# UPPER TUOLUMNE RIVER BASIN WATER TEMPERATURE MONITORING AND MODELING STUDY

## MODEL DEVELOPMENT REPORT

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

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

**Prepared by:**
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**September 2017**

# Upper Tuolumne River Basin
# Water Temperature Monitoring and Modeling Study

## Model Development Study Report

## TABLE OF CONTENTS

## List of Figures

## List of Tables

## List of Attachments

# List of Acronyms and Abbreviations

| | |
|---|---|
| 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 |
| 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

## 1.1 Background

The Turlock Irrigation District (TID) and Modesto Irrigation District (MID) (collectively, the Districts) jointly 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 headpond formed by the diversion dam. Under normal river flows, the headpond formed by the diversion dam extends for approximately two miles 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 headpond storage is estimated to be less than 100 acre-feet (ac-ft) 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 reservoirs: Hetch Hetchy, Lake Eleanor, Cherry Lake (also known as Lake Lloyd), 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) and operated by the San Francisco Public Utilities Commission. Inflow to the La Grange headpond is the sum of releases from the Don Pedro Project, located 2.3 miles upstream, and very minor contributions from two small intermittent drainageways 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 4.7 megawatts (MW). The La Grange Hydroelectric Project (Project; FERC No. 14581) operates in run-of-river mode. The LGDD provides no flood control benefits, and there are no existing recreation facilities associated with the Project or the La Grange headpond.

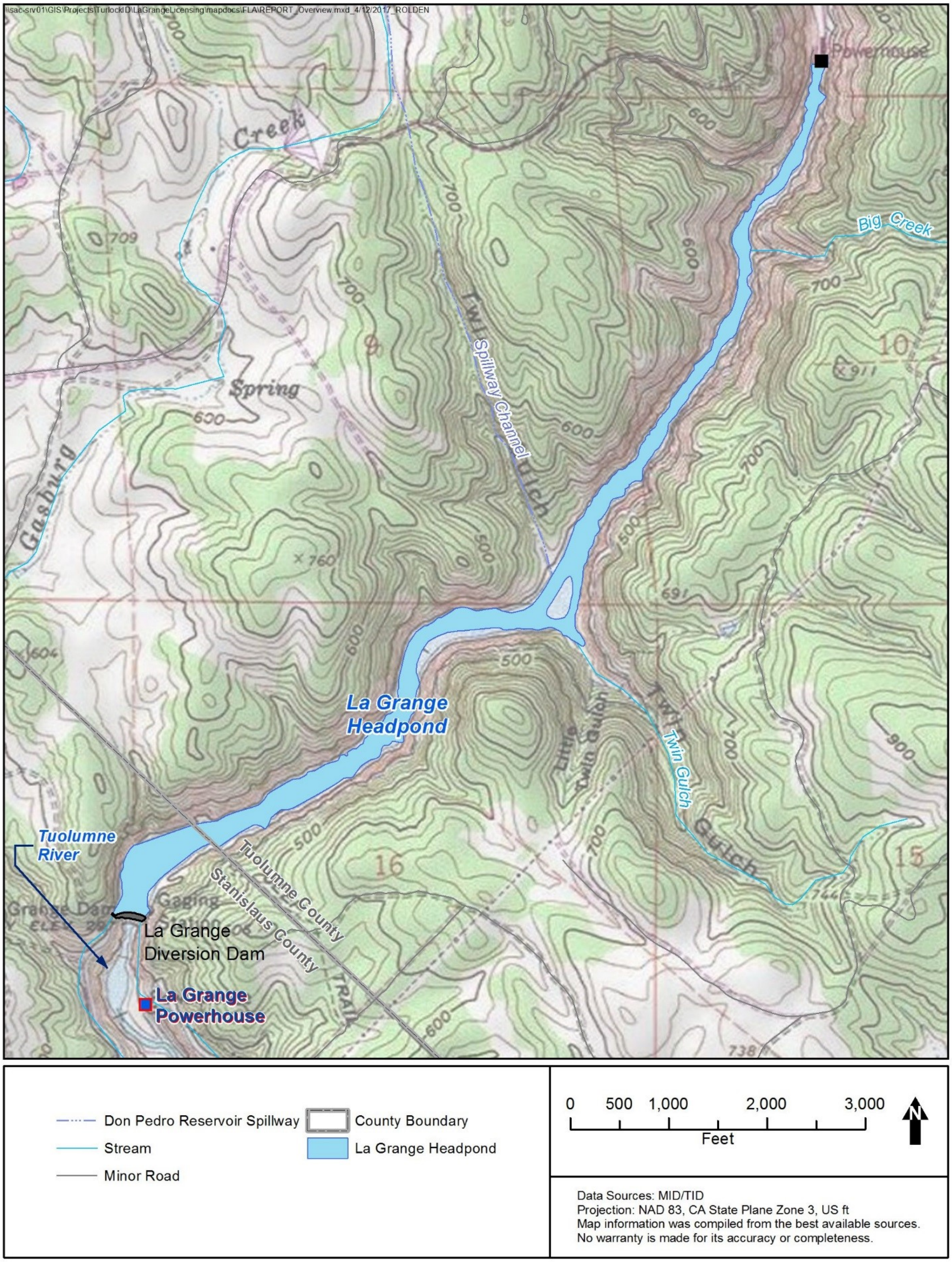
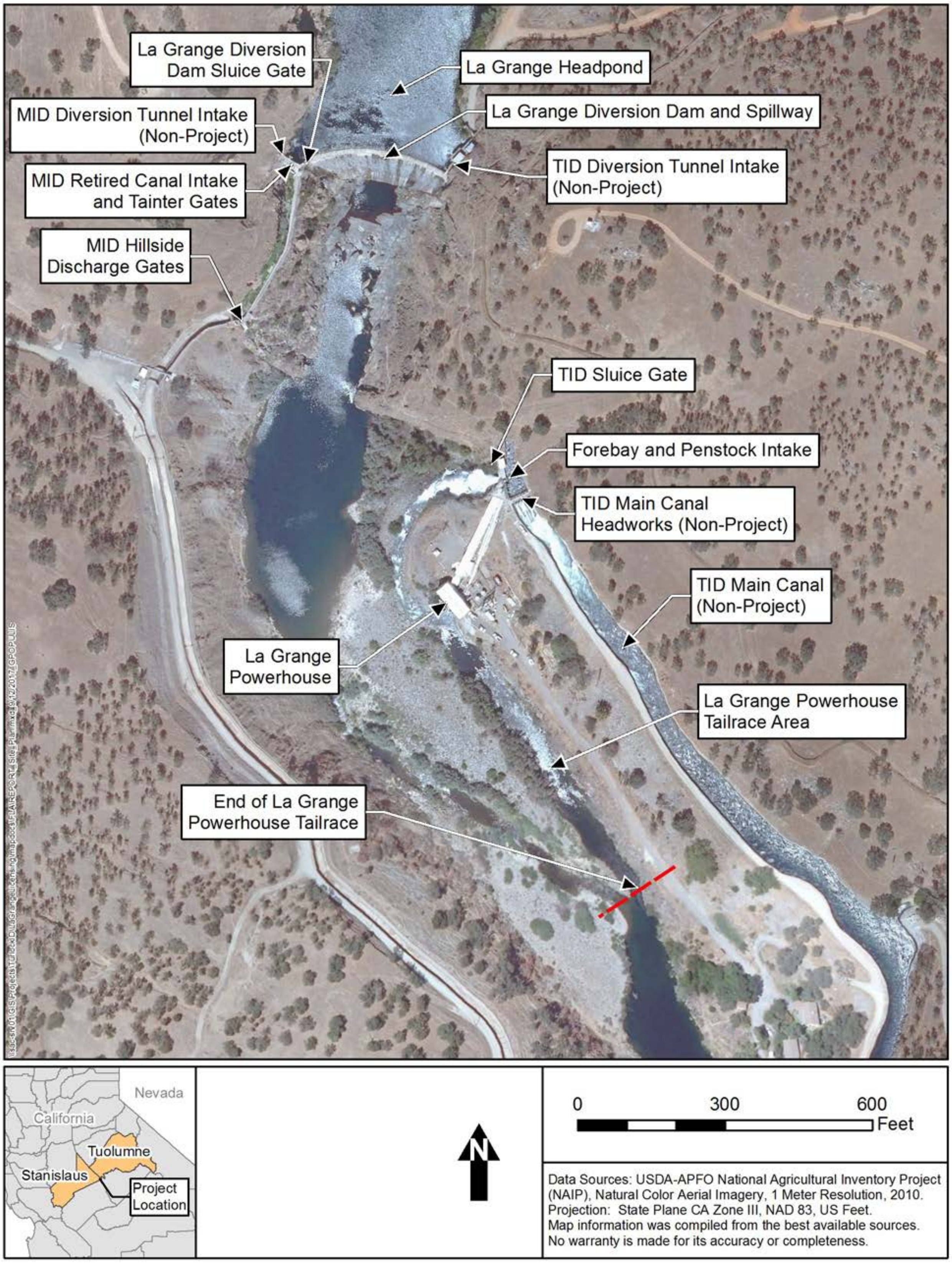


**Figure 1.1-1.** **La Grange Hydroelectric Project location map.**



Data Sources: USDA-APFO National Agricultural Inventory Project (NAIP), Natural Color Aerial Imagery, 1 Meter Resolution, 2010.
Projection: State Plane CA Zone III, NAD 83, US Feet.
Map information was compiled from the best available sources.
No warranty is made for its accuracy or completeness.

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

## 1.2 Licensing Process

In 2014, the Districts commenced the pre-filing process for the licensing of the La Grange Project by filing a Pre-Application Document with FERC[1]. On September 5, 2014, the Districts filed their Proposed Study Plan to assess Project effects on fish and aquatic resources, recreation, and cultural resources in support of their intent to license the Project. On January 5, 2015, in response to comments from licensing participants, 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[2].

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 the National Marine Fisheries Service (NMFS) in its July 22, 2014 comment letter.

**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[1] |
| 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[2] | |

[1] 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 "no modifications to the study plan are recommended."

[2] FERC directed the Districts to conduct the study plan as proposed by NMFS.

In the SPD, FERC recommended that, as part of the Fish Passage Facilities Alternatives Assessment, the Districts evaluate the technical and biological feasibility of the movement of anadromous salmonids through La Grange and Don Pedro project reservoirs if the results from Phase 1 of that study indicate that the most feasible concept for fish passage would involve fish

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[1] 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).

[2] The Fish Passage Assessment Study Plan contained a number of individual, but related, study elements.

passage through Don Pedro Reservoir or La Grange headpond. On September 16, 2016, the Districts filed the final study plan with FERC. On November 17, 2016, the Districts filed a letter with FERC after consulting with fish management agencies (i.e., NMFS and the California Department of Fish and Wildlife [CDFW; formerly known as the California Department of Fish and Game [CDFG]]) regarding the availability of test fish and a determination that no fish would be available to support conducting this study in 2017. On January 12, 2017, the Districts filed a letter with FERC stating that with FERC's approval, they intend to conduct the study in 2018 if the results from the Fish Passage Facilities Alternatives Assessment indicate that upstream or downstream fish passage at La Grange and Don Pedro projects would require anadromous fish transit through one or both reservoirs.

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 vicinity of the Project's powerhouse draft tubes to determine the potential for injury or mortality from contact with the turbine runners. 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.

On February 2, 2016, the Districts filed the Initial Study Report (ISR) for the La Grange Hydroelectric Project. The Districts held an ISR meeting on February 25, 2016, and on March 3, 2016, filed a meeting summary. Comments on the meeting summary and requests for new studies and study modifications were to be submitted to FERC by Monday, April 4, 2016. One new study request was submitted; NMFS requested a new study entitled Effects of La Grange Hydroelectric Project Under Changing Climate (Climate Change Study). On May 2, 2016, the Districts filed with FERC a response to comments received from licensing participants and proposed modifications to the Fish Passage Facilities Alternatives Assessment and the La Grange Project Fish Barrier Assessment, and a revised pre-filing schedule. On May 27, 2016, FERC filed a determination on requests for study modifications and new study. The May 27, 2016 determination approved the Districts' proposed modifications and did not approve the NMFS Climate Change Study, and accepted the Districts' revised pre-filing schedule.

On February 1, 2017, the Districts filed the Updated Study Report (USR) for the La Grange Hydroelectric Project. The Districts held a USR meeting on February 16, 2017, and on March 3, 2017, filed a meeting summary. Comments on the meeting summary and requests for new studies and study modifications were to be submitted to FERC by Monday, April 3, 2017. Comments on the USR were received from the Central Sierra Environmental Resource Center on February 27, 2017, from NMFS on April 3, 2017, and from CDFW on April 13, 2017. On May 2, 2017, the Districts filed with FERC a response to comments received from licensing participants.

On April 24, 2017, the Districts filed the Draft License Application for the La Grange Hydroelectric Project. Comments on the Draft License Application were received from NMFS on May 12, 2017, from FERC on July 18, 2017, and from CDFW on August 18, 2017. The Districts' response to these comments is included in the La Grange Hydroelectric Project Final License Application (FLA). The FLA was filed with FERC on October 11, 2017, in accordance with the Districts' Request for Extension of Time granted by FERC on September 1, 2017.

This study report describes the objectives, methods, and results of the Water Temperature Monitoring and Modeling Study, which is one of nine studies being implemented voluntarily by the Districts (see Section 1.3 for more information). Documents relating to the Project licensing are publicly available on the Districts' licensing website at www.lagrange-licensing.com/.

## 1.3 Voluntary Studies

To facilitate the Fish Passage Facilities Alternatives Assessment the Districts provided to licensing participants Technical Memorandum (TM) No. 1 in September 2015. Information provided in TM No. 1 included a summary of relevant site, hydrologic, and biological background data and suggested design criteria that were to be used as a basis for development of alternative fish passage facility concepts. The purpose of this initial submittal of potential design criteria was to obtain needed input and direction from fisheries resource agencies on essential design parameters necessary to undertake the study.

TM No. 1 identified a number of information gaps critical to informing the biological and associated engineering basis of conceptual designs. When agency input on design parameters was not forthcoming, the Districts proposed in November 2015 to address these critical information gaps through a collaborative process with all licensing participants. Licensing participants and the Districts formed a Plenary Group and adopted a plan to implement the Upper Tuolumne River Fish Reintroduction Assessment Framework (Assessment Framework) intended to develop information needed to complete fish passage conceptual studies and to assess the overall viability of developing and sustaining anadromous salmonid populations in the upper Tuolumne River (TID/MID 2016, 2017a). In support of the Assessment Framework, licensing participants agreed that site-specific studies of ecological, biological, and socioeconomic issues could help inform decision making regarding fish reintroduction and fish passage. In all, study plans were developed for the conduct of nine voluntary studies (see Table 1.3-1), two of which -- Fish Migration Barriers Study and Water Temperature Monitoring and Modeling Study -- had been proposed by the Districts previously in its RSP document, but not required in FERC's SPD. The remaining seven study plans were developed in collaboration with licensing participants in early 2016, and field data collection began in mid-2016.

**Table 1.3-1. Voluntary studies proposed by the Districts.**

| No. | Study | Completed | Not Completed |
|---|---|---|---|
| 1 | Upper Tuolumne River Basin Fish Migration Barriers Study | X | |
| 2 | Upper Tuolumne River Basin Water Temperature Monitoring and Modeling Study | X | |
| 3 | Upper Tuolumne River Chinook Salmon and Steelhead Spawning Gravel Mapping Study | | X |
| 4 | Upper Tuolumne River Habitat Mapping Assessment | | X |
| 5 | Upper Tuolumne River Macroinvertebrate Assessment | | X |
| 6 | Upper Tuolumne River Instream Flow Study | | X |
| 7 | Hatchery and Stocking Practices Review | X | |
| 8 | Socioeconomic Scoping Study | | X |
| 9 | Regulatory Context for Potential Anadromous Salmonid Reintroduction into the Upper Tuolumne River Basin | | X |

On May 2, 2016, the Districts filed with FERC an updated pre-filing licensing schedule to allow time for the Districts to complete ongoing FERC-approved studies, for NMFS to complete its Upper Tuolumne River Habitat and Carrying Capacity Study and study of Tuolumne River *O. mykiss* genetics, and for the conduct of a Fish Transit Study in parallel with the ongoing fish passage engineering study. On May 27, 2016, FERC filed a determination on requests for study modifications and new studies, and approved the revised schedule and Districts' study plan for the Fish Transit Study.

The Districts have since completed the Upper Tuolumne River Basin Fish Migration Barriers Study, the Upper Tuolumne River Basin Water Temperature Monitoring and Modeling Study, and the Hatchery and Stocking Practices Review Study. As explained in Exhibit E of the La Grange Hydroelectric Project FLA (TID/MID 2017b), based on the results of the Fish Passage Facilities Alternatives Assessment and other reintroduction studies and relevant information, the remaining voluntary studies do not require completion at this time.

## 1.4 Description of the Upper Tuolumne River Basin

The upper Tuolumne River originates from tributary streams located on Mount Lyell and Mount Dana in the Sierra Nevada. These tributaries join at Tuolumne Meadows (elevation 8,600 feet), and from this point the upper Tuolumne River descends rapidly through a deep canyon in wilderness areas of Yosemite National Park to Hetch Hetchy Reservoir (at an elevation of about 3,500 feet). Six miles below O'Shaughnessy Dam, which impounds Hetch Hetchy Reservoir, the Tuolumne River leaves Yosemite National Park and enters the Stanislaus National Forest. Except for a short reach at Early Intake Reservoir, the river flows unimpeded through a deep canyon for approximately 40 miles, from O'Shaughnessy Dam to the upstream end of Don Pedro Reservoir (Figure 1.4-1).

The mainstem Tuolumne River is joined by several tributaries–including (from upstream to downstream) Cherry Creek, the South Fork/Middle Fork Tuolumne River, the Clavey River, and the North Fork of the Tuolumne River–before entering the Don Pedro Project Boundary at approximately RM 80.8[3]. There are two dams in the Cherry Creek basin: Cherry Dam, which impounds Cherry Lake, located on Cherry Creek about 12 miles above its confluence with the Tuolumne River and Eleanor Dam, which impounds Lake Eleanor, located about 3.5 miles upstream of its confluence with Cherry Creek (SFPUC 2008).

### 1.4.1 Geomorphology of the Upper Tuolumne River Basin

The upper Tuolumne River and its tributaries flow through steep, narrow valleys that confine the river channel. In most areas, the channels have high gradients, and habitat consists mostly of bedrock chutes, boulder cascades, and pools (SFPUC 2008). From the Poopenaut Valley to Early Intake, channel morphology is diverse, ranging from low-gradient, sand-bedded areas and wetland meadows to steep, bedrock-confined reaches. Although hydraulic conditions in the upper Tuolumne River are controlled primarily by channel width constrictions or expansions and resistant bedrock outcrops, there are smaller geomorphic controls that give rise to a complex morphology, which provide a variety of aquatic and riparian habitats (McBain and Trush 2004).

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[3] At its normal maximum water surface elevation of 830 feet, Don Pedro Reservoir extends upstream to about RM 79.5.

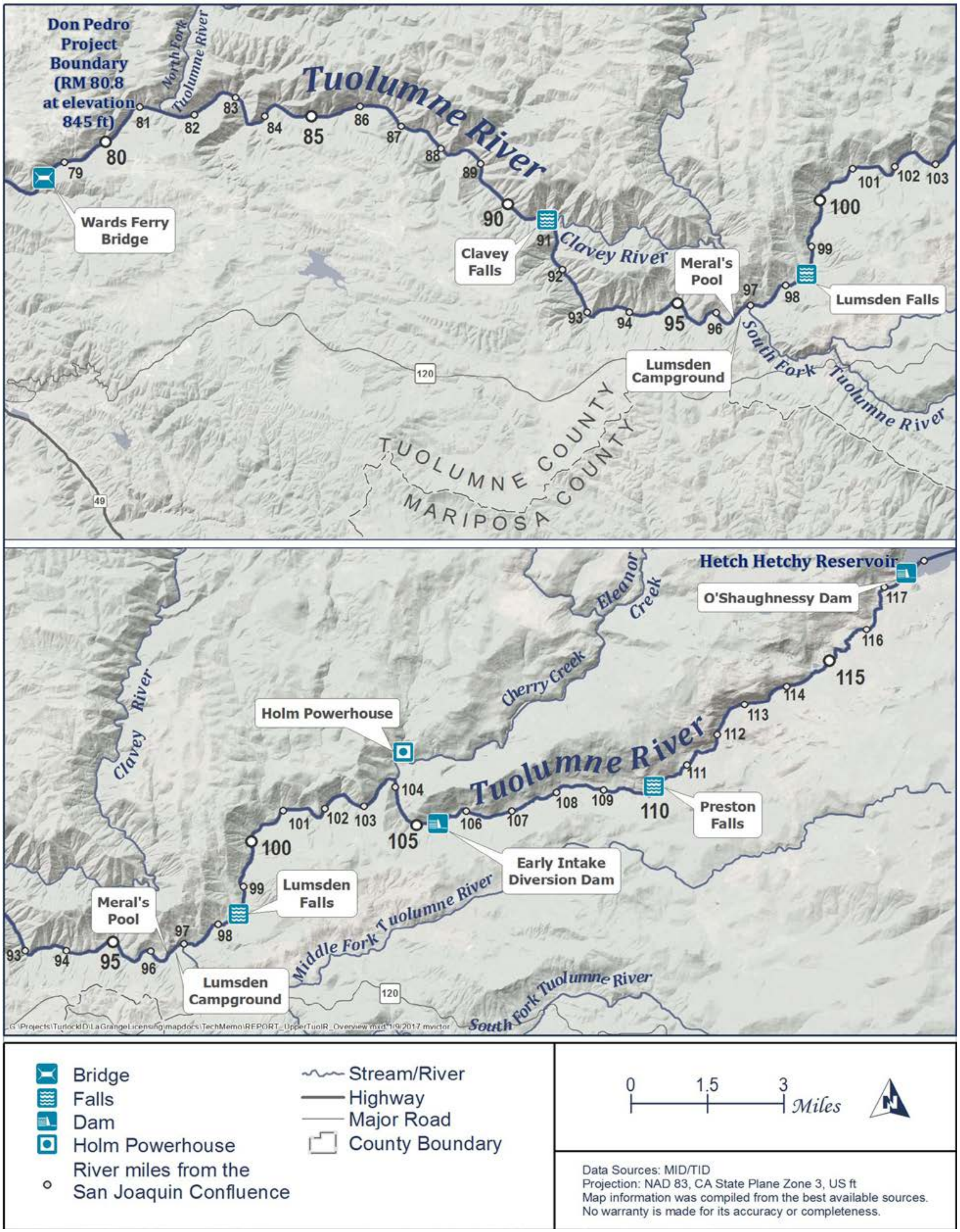

**Figure 1.4-1.** **The Tuolumne River basin upstream of Don Pedro Project. The top map depicts the river from Wards Ferry Bridge to RM 101, and the bottom map depicts the river from RM 94 to RM 118.**

From Early Intake to the confluence with the South Fork of the Tuolumne River, the channel is deeply incised with steep side slopes. Channel gradient in this reach is as high as four percent, and habitat consists mostly of pools separated by steep cascades, although alluvial bars and side-channels occur in places where the valley widens or bedrock controls reduce channel gradient. From the South Fork to the Clavey River, the channel consists of boulder cascades separated by pools. Downstream of the Clavey River, gradient decreases, and the channel becomes semi-alluvial. There are three waterfalls on the upper mainstem Tuolumne River: Clavey Falls (RM 91), Lumsden Falls (RM 98.25), and Preston Falls (RM 110).

Cherry Creek is a steep stream (≈ five percent gradient) confined within a narrow bedrock canyon (SFPUC 2008). Its bed consists mainly of boulders and bedrock, although much sand is stored in pools. Immediately downstream of Cherry Dam there are low gradient gravel-bedded sections interspersed with steep, bedrock chutes. In the upper reaches of Cherry Creek, riparian and upland vegetation have encroached onto formerly active alluvial bars due to flow regulation. For most of its length, Eleanor Creek, a tributary to Cherry Creek, flows through a bedrock canyon, with a steep channel (≈ six percent gradient) made up of a series of pools and waterfalls (SFPUC 2008).

The Clavey River is the longest unregulated river in the Sierra Nevada (McBain & Trush 2004). Research suggests that in the Clavey River (1) frequent small floods scour and deposit sand at pools and bars, (2) moderate-sized floods (every 12 to 17 years) move gravel and cobbles, reshape side channels, and may move large woody debris, and (3) large floods (every 70 to 100 years) erode large bars, remove and create side channels, and move large boulders over short distances (SFPUC 2008). Based on existing information, it is unclear to what extent channel-forming events in the other tributaries mirror those in the Clavey River.

### 1.4.2 Hydrology of the Upper Tuolumne River Basin

The Tuolumne River upstream of Don Pedro Dam has a watershed area of about 1,533 square miles. Above 5,000 feet, the flow regimes of the Tuolumne River and its tributaries are snowmelt-dominated. Smaller streams in this elevation range may have extremely low summer flows, although groundwater and interflow may provide small amounts of water in late summer. About 75 percent of the natural runoff above 5,000 feet occurs between April and July, with 20 percent or less occurring from December through March, and as little as 5 percent occurring from August through November (ACOE 1972). In the middle elevations, from 3,000 to 5,000 feet, more precipitation occurs as rainfall, and there can be multiple rain-on-snow events each year. Much of the runoff in these elevations occurs from December through March during winter rains, with most of the remaining runoff occurring from April through July (ACOE 1972).

In 1918, CCSF completed Lake Eleanor, a reservoir on Eleanor Creek, a tributary to Cherry Creek, which is in turn a tributary to the Tuolumne River (SFPUC 2008). Hetch Hetchy Reservoir was built on the mainstem Tuolumne River in 1923 and expanded in 1938. CCSF completed Cherry Lake (also known as Lake Lloyd) on Cherry Creek in 1955 (SFPUC 2008).

The SFPUC diverts water from Hetch Hetchy Reservoir and conveys it to the San Francisco Bay Area via the Hetch Hetchy water conveyance system, which consists of a series of facilities that extend to Crystal Springs Reservoir in San Mateo County (SFPUC 2008). Water from Hetch Hetchy Reservoir is delivered through the Canyon Power Tunnel to Kirkwood Powerhouse above Early Intake. Water exiting the powerhouse is returned either to the Tuolumne River or discharged into the Mountain Tunnel, which conveys water to Priest Reservoir and Moccasin Powerhouse. Water released from Moccasin Powerhouse is returned to the Tuolumne River via Moccasin Reservoir and Moccasin Creek or routed to the Foothill Tunnel for delivery to the Bay Area. Priest and Moccasin reservoirs are small waterbodies used to control flow into Moccasin Powerhouse and regulate discharge to Moccasin Creek, respectively (SFPUC 2008).

The SFPUC uses most of the water in Cherry Lake to generate hydroelectric power at Holm Powerhouse (SFPUC 2008). Water released from Holm Powerhouse returns to Cherry Creek and is used to satisfy the Districts' water rights (SFPUC 2008). Water impounded in Lake Eleanor is conveyed to Cherry Lake and subsequently to Holm Powerhouse. The SFPUC diverts an average of 244,000 ac-ft per year from the Tuolumne River at Hetch Hetchy Reservoir to supply water to about 2.4 million people in Tuolumne, Alameda, Santa Clara, San Mateo, and San Francisco counties (SFPUC 2008). Water diverted by the SFPUC for water supply represents about 32.6 percent of the average annual unimpaired runoff at Hetch Hetchy Reservoir, which is estimated to be 749,607 ac-ft (SFPUC 2008).

There are four locations of streamflow measurement (i.e., U.S. Geological Survey [USGS] stream gages) in the Tuolumne River basin upstream of Don Pedro Reservoir: (1) Tuolumne River below Early Intake near Mather, (2) Cherry Creek below Holm Powerhouse, (3) South Fork Tuolumne River near Oakland Recreation Camp, and (4) Middle Tuolumne River at Oakland Recreation Camp. The sum of flow measurements from these four gages accounts for the majority of flow in the Tuolumne River watershed. Based on USGS gage measurements, the annual unimpaired flow of the Tuolumne River just upstream of Don Pedro Reservoir has averaged about 1.97 million ac-ft since 1975. The maximum annual unimpaired runoff since 1975 was 4.6 million ac-ft (Water Year 1983), and the minimum was 0.38 million ac-ft (Water Year 1977)[4]. A substantial portion of the difference between historical and current unimpaired flows to Don Pedro Reservoir is accounted for by out-of-basin diversions by the SFPUC to provide water to residential, commercial, and industrial users in the Bay Area.

The hydrogeologic units underlying the Tuolumne River from Hetch Hetchy Reservoir to Don Pedro Reservoir exhibit low permeability (SFPUC 2008), and as a result there are no large groundwater bodies along this reach of the river. Significant groundwater storage in the basin occurs in the permeable terrain downstream of Don Pedro Reservoir, i.e., the San Joaquin Valley Groundwater Basin, which underlies the foothills and valley floor.

#### 1.4.2.1 Within-day Flow Variability in the Upper Tuolumne River

Due to hydropower peaking operations at Holm Powerhouse, hourly flows in the Tuolumne River upstream of Don Pedro Reservoir can vary greatly. Data summarized in Tables 1.4-1, 1.4-2, and 1.4-3 characterize how flows may vary within a single day in the Tuolumne River downstream of the Clavey River confluence during Critical, Below Normal, and Above Normal

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[4] The preliminary estimate on unimpaired runoff at La Grange gage for Water Year 2017 is 4.8 million ac-ft.

water years[5]. This hydraulic variability is further illustrated in three select water years: 2008, 2009, and 2013 in Figure 1.4-2, Figure 1.4-3, and Figure 1.4-4, respectively. Data illustrated in each year shows how flows downstream of Holm Powerhouse fluctuate from approximately 150 or 200 cubic feet per second (cfs) up to 1,000 or 1,200 cfs on a daily basis most clearly during the late summer months of July through September.

**Table 1.4-1. Within-day flow fluctuation (cfs) in Critical water years, by month, in the Tuolumne River below Clavey River confluence.**

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Minimum | 0 | 0 | 7 | 19 | 9 | 6 | 2 | 2 | 1 | 0 | 0 | 0 |
| Percentile (5th) | 1 | 1 | 39 | 55 | 28 | 38 | 397 | 286 | 49 | 3 | 1 | 4 |
| Median | 135 | 218 | 223 | 517 | 620 | 794 | 798 | 688 | 377 | 184 | 134 | 157 |
| Percentile (95th) | 721 | 736 | 783 | 1,033 | 1,021 | 1,209 | 1,142 | 1,071 | 805 | 478 | 582 | 746 |
| Maximum | 5,142 | 1,549 | 1,110 | 2,122 | 1,058 | 1,285 | 1,209 | 1,366 | 1,109 | 1,074 | 1,211 | 3,822 |

**Table 1.4-2. Within-day flow fluctuation (cfs) in Below Normal water years, by month, in the Tuolumne River below Clavey River confluence.**

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Minimum | 0 | 3 | 8 | 8 | 7 | 2 | 5 | 3 | 1 | 0 | 1 | 0 |
| Percentile (5th) | 4 | 110 | 34 | 55 | 23 | 18 | 48 | 10 | 2 | 3 | 14 | 11 |
| Median | 337 | 451 | 545 | 513 | 354 | 651 | 984 | 818 | 269 | 223 | 260 | 283 |
| Percentile (95th) | 1,245 | 756 | 964 | 950 | 1,163 | 1,293 | 1,021 | 1,016 | 619 | 638 | 826 | 796 |
| Maximum | 6,105 | 906 | 2,064 | 2,410 | 6,101 | 2,576 | 1,249 | 1,066 | 1,032 | 1,207 | 2,009 | 1,998 |

**Table 1.4-3. Within-day flow fluctuation (cfs) in Above Normal water years, by month, in the Tuolumne River below Clavey River confluence.**

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Minimum | 0 | 14 | 9 | 14 | 8 | 35 | 7 | 2 | 1 | 0 | 0 | 0 |
| Percentile (5th) | 35 | 36 | 36 | 45 | 74 | 129 | 63 | 50 | 6 | 2 | 1 | 2 |
| Median | 319 | 331 | 196 | 218 | 420 | 684 | 816 | 923 | 411 | 180 | 136 | 231 |
| Percentile (95th) | 1,162 | 1,243 | 1,364 | 1,002 | 2,562 | 2,341 | 1,599 | 1,152 | 977 | 688 | 828 | 1,320 |
| Maximum | 14,307 | 5,571 | 12,910 | 5,774 | 20,390 | 5,789 | 6,934 | 1,365 | 1,160 | 4,095 | 1,975 | 23,764 |

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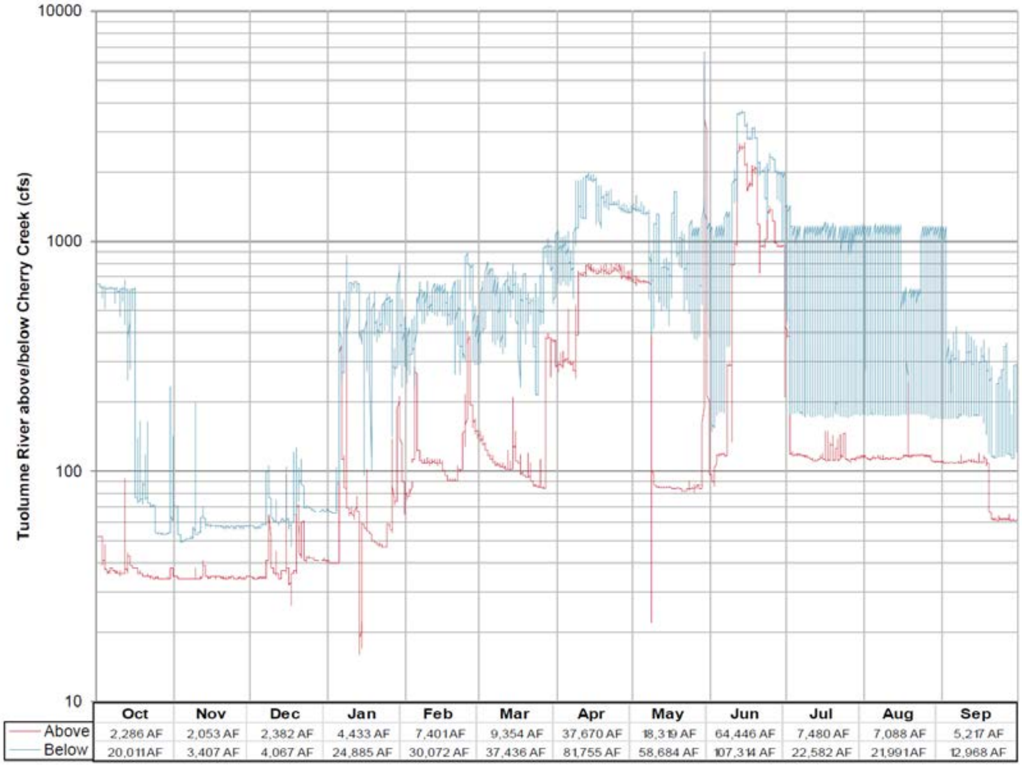
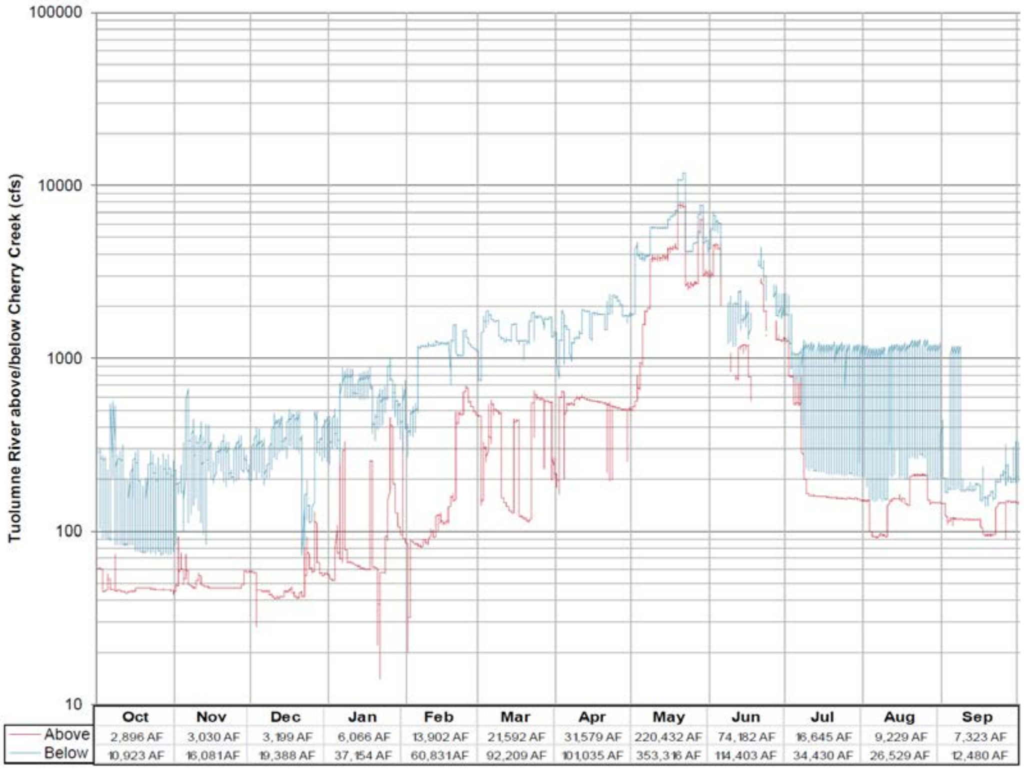
[5] California Department of Water Resources CDEC Historical Water Year Hydrologic Classification Indices.



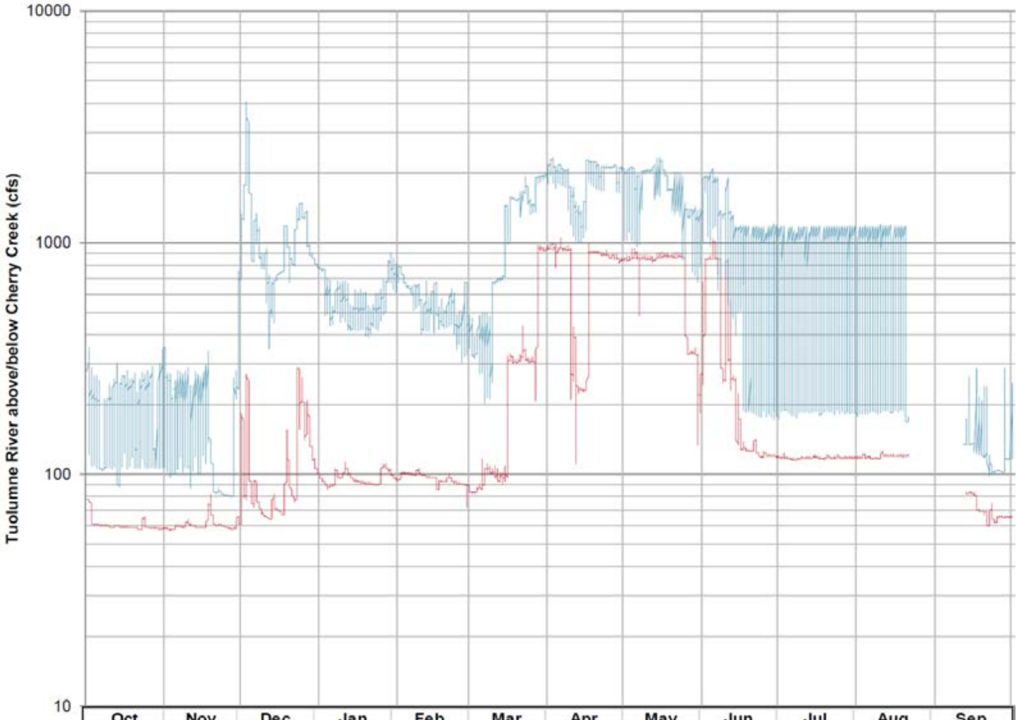
| | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Above | 2,286 AF | 2,053 AF | 2,382 AF | 4,433 AF | 7,401 AF | 9,354 AF | 37,670 AF | 18,319 AF | 64,446 AF | 7,480 AF | 7,088 AF | 5,217 AF |
| Below | 20,011 AF | 3,407 AF | 4,067 AF | 24,885 AF | 30,072 AF | 37,436 AF | 81,755 AF | 58,684 AF | 107,314 AF | 22,582 AF | 21,991 AF | 12,968 AF |

**Figure 1.4-2. Tuolumne River Flow above/below Cherry Creek for Water Year 2008.**



| | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Above | 2,896 AF | 3,030 AF | 3,199 AF | 6,066 AF | 13,902 AF | 21,592 AF | 31,579 AF | 220,432 AF | 74,182 AF | 16,645 AF | 9,229 AF | 7,323 AF |
| Below | 10,923 AF | 16,081 AF | 19,388 AF | 37,154 AF | 60,831 AF | 92,209 AF | 101,035 AF | 353,316 AF | 114,403 AF | 34,430 AF | 26,529 AF | 12,480 AF |

**Figure 1.4-3. Tuolumne River Flow above/below Cherry Creek for Water Year 2009.**



| | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Above | 3,704 AF | 3,673 AF | 6,515 AF | 5,917 AF | 5,319 AF | 19,418 AF | 44,957 AF | 45,125 AF | 19,793 AF | 7,279 AF | 4,743 AF | 2,612 AF |
| Below | 12,119 AF | 12,485 AF | 65,873 AF | 37,067 AF | 30,335 AF | 69,886 AF | 111,237 AF | 103,693 AF | 48,520 AF | 20,744 AF | 13,800 AF | 5,439 AF |

**Figure 1.4-4. Tuolumne River Flow above/below Cherry Creek for Water Year 2013.**

### 1.4.2.2 Flow Releases to Support Fisheries and Whitewater Boating

Minimum flow releases from Hetch Hetchy Reservoir, which were developed to support rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*) throughout their life histories, vary according to water-year type. Releases in normal, dry, and critically dry years total at least 59,235, 50,019, and 35,215 ac-ft, respectively (SFPUC 2008). SFPUC releases an additional 64 cfs into the river below Hetch Hetchy Reservoir when the diversion through Canyon Tunnel (which flows from Hetch Hetchy Reservoir to Kirkwood Powerhouse) exceeds 920 cfs. Once minimum flow releases are made at O'Shaughnessy Dam, they cannot be diverted at Early Intake, but instead remain in the Tuolumne River where they are supplemented by tributary flows and occasional releases at Kirkwood Powerhouse to the Tuolumne River.

The minimum stream flow maintained by SFPUC below Cherry Lake is 5 cfs from October through June and 15.5 cfs from July through September (RMC and McBain and Trush 2007, Revised 2016). In years when no pumping (i.e., water conveyance between Lake Eleanor and Cherry Lake) takes place between Lake Eleanor and Cherry Lake, the minimum flow downstream of Lake Eleanor is 5 cfs from October through June and 15.5 cfs from July through September (RMC and McBain and Trush 2007, Revised 2016). In years when pumping does occur, the minimum stream flow is 5 cfs from November through February, 10 cfs from March 1 through April 14, 20 cfs from April 15 through September 15, and 10 cfs from September 16 through September 30 (RMC and McBain and Trush 2007, Revised 2016). There are no specific, regulated minimum flow releases for October in years when pumping occurs, but the SFPUC operational practice in pumping years has been to continue the September 16-30 release of 10 cfs through October 31 (RMC and McBain and Trush 2007, Revised 2016). These minimum flows take into consideration the effects of seasonal water temperatures on habitat suitability.

SFPUC owns and operates the 170 MW Holm Powerhouse located near the mouth of Cherry Creek. The Holm Powerhouse generally operates in a peaking mode, except when Cherry Creek river flows are sufficient for the plant to operate at full capacity. Flows in the Tuolumne River downstream of its confluence with Cherry Creek may be significantly influenced by the peaking operation of Holm Powerhouse. The on-peak operation of Holm Powerhouse during summer provides flows for whitewater rafting in the Tuolumne River downstream of Cherry Creek, with most whitewater boating trips starting at the USFS Lumsden Campground near the South Fork confluence.

### 1.4.3 Water Quality in the Upper Tuolumne River Basin

The Tuolumne River watershed upstream of Hetch Hetchy Reservoir lies entirely within the less developed parts of Yosemite National Park, and as a result water quality in Hetch Hetchy Reservoir is excellent. Nitrogen and phosphorus concentrations are typically near or below detection limits, and dissolved oxygen concentrations are usually at or near saturation (SFPUC 2008).

Water quality in the Tuolumne River between O'Shaughnessy Dam and Don Pedro Reservoir is very good, but nutrient concentrations increase slightly with distance downstream. The Districts conducted a study during the summer of 2012 to characterize water quality in the Tuolumne River just upstream of Don Pedro Reservoir (TID/MID 2013). This sampling confirmed that water in the river just upstream of Don Pedro Reservoir was clear, dissolved oxygen was near saturation, alkalinity was low (<16 mg/L), pH was near neutral, fecal coliform bacteria were below detection limits, nitrogen and phosphorous occurred at concentrations generally less than 1 mg/L, and algae blooms were absent.

Maximum summer water temperatures (June through July) in the Tuolumne River between Hetch Hetchy and Don Pedro reservoirs at times can exceed 23°C (TID/MID 2016b). The Districts developed a Tuolumne River Flow and Water Temperature Model, Without Dams Assessment (Jayasundara et al. 2014) to simulate water temperatures in the Tuolumne River without the effects of the Hetch Hetchy (including Cherry Lake and Eleanor Lake), Don Pedro, and La Grange projects. Comparison of the seven-day average of daily maximum (7DADM) temperatures under with- and without-dams conditions indicates that summer and fall maximum water temperatures in the upper Tuolumne River would be substantially higher, up to 4.5°C, in the absence of the Hetch Hetchy impoundments than they are under existing conditions (Figures 1.4-5 and 1.4-6). During most of the year, 7DADM temperatures are generally similar to or slightly higher, up to 2.5°C, with the dams in place, and can be up to 4°C higher in winter (Figures 1.4-5 and 1.4-6). As noted in the figure captions, plots for RM 98 and RM 88 compare simulated without-dams temperatures to empirically derived with-dams temperatures. The without-dams simulation also reveals that 7DADM water temperatures in the Tuolumne River mainstem, in the absence of impoundments, would approach thermal equilibrium well upstream of the current location of the Don Pedro Project.

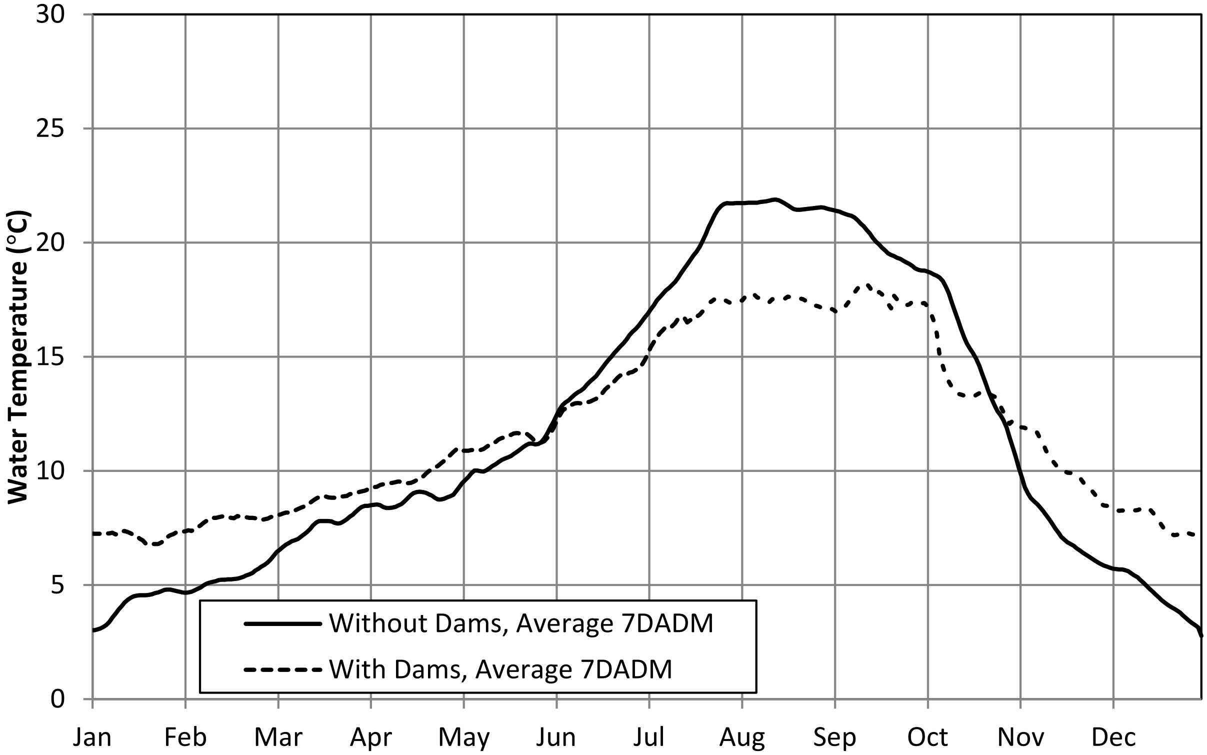


**Figure 1.4-5.** **Comparison of 7DADM water temperatures under with- and without-dams conditions in the Tuolumne River below the South Fork Tuolumne River (≈RM 98). Without-dams temperatures are simulated based on the period 1970–2012 (Jayasundara et al. 2014), and with-dams temperatures are based on data collected by temperature loggers from 2005 to 2012.**

### 1.4.4 Existing Fish Species in the Upper Tuolumne River Basin

The fish assemblage in the upper Tuolumne River and its tributaries consists mainly of rainbow trout, brown trout, Sacramento sucker (*Catostomus occidentalis*), Sacramento pikeminnow (*Ptychocheilus grandis*), California roach (*Hesperoleucus symmetricus*), and hardhead (*Mylopharodon conocephalus*) (SFPUC 2008).

During 2009, CDFW conducted a Heritage and Wild Trout Program Phase 1 assessment of the upper Tuolumne River near the USFS Lumsden Campground. During the survey, the following salmonid species were identified in an approximately 1,500-foot survey reach: coastal rainbow trout (*O. mykiss irideus*), Chinook salmon (*O. tshawytscha*), kokanee (*O. nerka*), and brown trout (Weaver and Mehalick 2009). Some of the coastal rainbow and brown trout exceeded 18 inches (457 mm) in length, and estimated average rainbow trout and brown trout densities were 1,122 and 128 fish per mile, respectively (Weaver and Mehalick 2009). Farther upstream, fish species observed during a 2014 survey in the Tuolumne River between Early Intake and Hetch Hetchy Dam included rainbow trout, brown trout, riffle sculpin (*Cottus gulosus*), California roach, and Sacramento sucker (Stillwater Sciences 2016). According to Weaver and Mehalick (2009), however, no trout species are native to the Tuolumne River upstream of Preston Falls, so "the

NPS [National Park Service] does not support Wild Trout designation in this portion of the river [i.e., above the falls].”

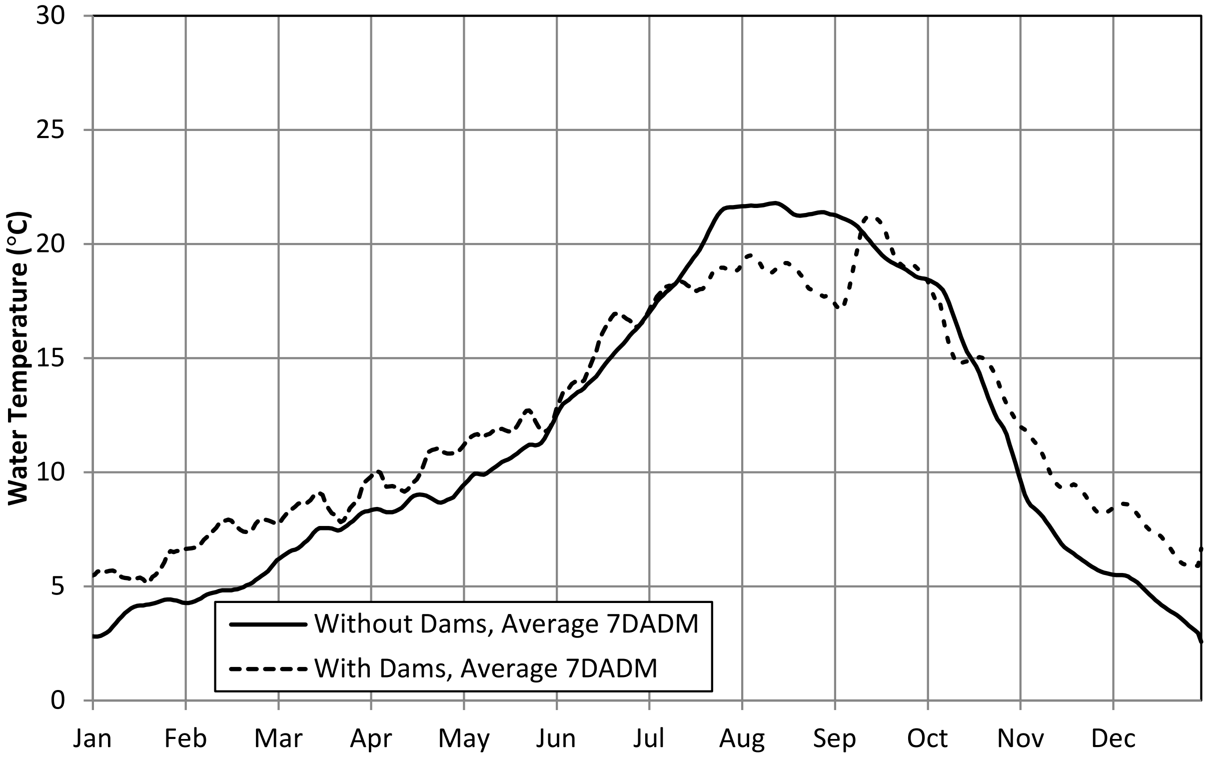


**Figure 1.4-6. Comparison of 7DADM water temperatures under with- and without-dams conditions in the Tuolumne River below Indian Creek (≈RM 88). Without-dams temperatures are simulated based on the period 1970–2012 (Jayasundara et al. 2014), and with-dams temperatures are based on data collected by temperature loggers from 2009 to 2012.**

Although some brook trout (*Salvelinus fontinalis*) reportedly still occur in headwater areas, they are not considered self-sustaining in the mainstem Tuolumne River (De Carion et al. 2010). Because of its relatively low spring flows and high spring and summer temperatures, the North Fork Tuolumne River supports smallmouth bass (*Micropterus dolomieu*) (De Carion et al. 2010). Brook trout, kokanee, brown trout, and smallmouth bass are nonnative to the basin, and brown trout and smallmouth bass can be highly piscivorous. Other non-native fish species that have been documented in the upper Tuolumne River basin include golden shiner (*Notemigonus crysoleucas*) and green sunfish (*Lepomis cyanellus*) in Cherry Lake (SFPUC 2008). There is also anecdotal evidence that kokanee and adfluvial Chinook salmon from the Don Pedro Reservoir spawn in the upper basin (SFPUC 2008; Bacher 2013; Perales 2015). Although in small numbers (i.e., two to eight), in 2012 juvenile Chinook salmon were collected in the upper Tuolumne River (Perales 2015).

CDFW stocks rainbow trout throughout the upper Tuolumne River watershed (CDFW 2016). CDFW has released, or continues to release, kokanee, brook trout, rainbow trout, coho salmon, Chinook salmon, brown trout, Eagle Lake trout (*Oncorhynchus mykiss aquilarum*), and largemouth bass (*Micropterus salmoides*) in Don Pedro Reservoir. Largemouth bass are also stocked in Don Pedro Reservoir by the Don Pedro Recreation Agency. Kokanee and adfluvial Chinook salmon reproducing in the upper Tuolumne River (see preceding paragraph) are the product of CDFW stocking programs conducted in Don Pedro Reservoir (Perales 2015). The planted Chinook salmon are “surplus” juveniles from Iron Gate Hatchery, located on the Klamath River, outside the Central Valley (Perales 2015).

### 1.4.5 Fish Habitat in the Upper Tuolumne River Basin

Twelve habitat types have been identified in the Tuolumne River reach between O’Shaughnessy Dam and Early Intake: deep pools, shallow pools, pocket waters, cascades, cascades/deep pools, cascades/pocket waters, chutes, riffles, runs, glides, side channels, and backwaters (SFPUC 2008).

Water temperatures may at times affect trout in the upper basin. Maximum summer (June–July) water temperatures in the Tuolumne River between Hetch Hetchy and Don Pedro reservoirs can exceed 23°C, which could adversely affect rainbow and brown trout (SFPUC 2008). Winter water temperatures are typically low and might limit the successful egg incubation and emergence of brown trout (SFPUC 2008).

SFPUC makes minimum releases from Hetch Hetchy Reservoir, Cherry Lake, and Lake Eleanor to support resident fisheries (see Section 1.4.2). Flows in the Tuolumne River downstream of its confluence with Cherry Creek are heavily influenced by the peaking operation of the Holm Powerhouse, which provides on-peak energy for SFPUC and supports whitewater rafting. The resulting flow fluctuations in the upper Tuolumne River (see Section 1.4.2) influence resident trout habitat and may affect habitat suitability for trout, other fish species, and macroinvertebrates. The resulting flow fluctuations in the upper Tuolumne River (see Section 1.4.2) influence resident trout habitat and may result in the stranding of trout, other fish species, and macroinvertebrates.

# 2.0 STUDY GOALS AND OBJECTIVES

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 the upper extent of the Don Pedro Project 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; and
- develop and test a computer model to simulate existing thermal conditions in the Tuolumne River from below Early Intake to above the Don Pedro Project Boundary. The model will serve as a tool for determining water temperature at any point in the study reach under historical conditions.

## 2.1 Species of Interest

Prior to implementation of this study, three anadromous salmonid species were considered for reintroduction to the upper Tuolumne River above the Don Pedro Project and two were chosen for evaluation -- Central Valley (CV) Spring-Run Salmon (*O. tshawytscha*) and California Central Valley (CCV) Steelhead (anadromous *O. mykiss*). The federal Endangered Species Act (ESA) listing status for both species and additional information on fall-run Chinook is described below.

### 2.1.1 Central Valley Spring-Run Chinook Salmon

The Central Valley spring-run Chinook salmon ESU was originally listed as a threatened species in 1999 (64 FR 50394). After the development of the NMFS hatchery listing policy, the status of the ESU was re-evaluated, and a final determination was made that reaffirmed the threatened species status for the ESU (70 FR 37204) (NMFS 2016a). NMFS proposed critical habitat for Central Valley spring-run Chinook salmon on December 10, 2004 (69 FR 71880) and published a final rule designating critical habitat for the ESU on September 2, 2005 (70 FR 52488) (NMFS 2016a). There is no CV spring-run Chinook salmon critical habitat in the Tuolumne River watershed. Per the Recovery Plan, both the Tuolumne River (below La Grange Diversion Dam) and the upper Tuolumne River (above the La Grange Diversion Dam) are considered candidate areas for reintroduction (NMFS 2014).

### 2.1.2 California Central Valley Steelhead

NMFS listed the CCV steelhead as a threatened species on March 19, 1998 (63 FR 13347), and on September 8, 2000, pursuant to a July 10, 2000 rule issued by NMFS under Section 4(d) of the ESA (16 USC § 1533(d)), statutory take restrictions that apply to listed species began to apply, with certain limitations, to CCV steelhead (65 FR 42422) (NMFS 2016b). On January 5, 2006, NMFS reaffirmed the threatened status of CCV steelhead and decided to apply the joint U.S. Fish and Wildlife Service-National Marine Fisheries Service DPS policy (61 FR 4722). NMFS proposed critical habitat for CCV steelhead on February 5, 1999 (64 FR 5740) in compliance with Section 4(a)(3)(A) of the ESA. In the Tuolumne River, critical habitat for CCV steelhead extends from the confluence with the San Joaquin River upstream to La Grange Diversion Dam. Per the Recovery Plan, the Tuolumne River (below La Grange Diversion Dam) is considered a Core 2 population (i.e., meeting or having the potential to meet, the biological recovery standard for moderate risk of extinction). The upper Tuolumne River (above La Grange Diversion Dam) is considered a candidate area for reintroduction (NMFS 2014).

### 2.1.3 Fall-run Chinook Salmon

At the January 2016 Workshop for the Framework Plenary Group (described in section 1.3 above), NMFS stated an interest in the evaluating the reintroduction of both spring-run and fall-run Chinook and steelhead to the upper Tuolumne River Reach (La Grange Hydroelectric Project Reintroduction Assessment Framework Plenary Group 2016). After evaluation of this request, the Districts did not agree that evaluating reintroduction of fall-run Chinook to the upper Tuolumne River was appropriate.[6] Concerns with fall-run Chinook included the fact that they are not listed and are not consistent with a reintroduction program to advance the Recovery Plan; concerns regarding stress of non-volitional passage; competition, interbreeding and genetic effects with spring-run Chinook, disease transmission given a large proportion of fall-run Chinook are out-of-basin hatchery strays, and adverse impacts to the source population if upper river activities were unsuccessful. Furthermore, the historical distribution of fall-run Chinook is believed to have been confined to lower elevations of the Sacramento and San Joaquin River tributaries (Yoshiyama et al. 2001). Since 1971, California Department of Fish and Wildlife has conducted annual salmon spawning surveys in the lower Tuolumne River. In addition to CDFW's work, the Districts have also studied fall-run Chinook salmon on the lower Tuolumne River through annual seine surveys conducted since 1986, annual snorkel surveys since 1982, adult fish weir counts since 2009, and more recently as part of the Don Pedro Hydroelectric Project relicensing. Historical data obtained through these efforts show that spawner estimates have ranged from 40,300 in 1985 to 77 in 1991 (TID/MID 2010, Report 2009-2). Variation in numbers have been attributed to water quality and water availability in the San Joaquin River system as well as changes in ocean conditions. Studies conducted through the FERC relicensing of Don Pedro Hydroelectric Project have demonstrated that under the current flow regime, there is sufficient spawning gravels available in the lower Tuolumne River to support a spawning population of over 50,000 fall-run Chinook salmon and over 700,000 *O. mykiss* (TID/MID 2013b). As such, fall-run Chinook were not evaluated as part of this study.

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[6] At the February 16, 2016 Reintroduction Assessment Framework Technical Committee conference call, the Districts questioned the prudency of including fall-run Chinook and presented their concerns.

# 3.0 STUDY AREA

The Water Temperature Monitoring and Modeling Study area includes the mainstem Tuolumne River from below Early Intake (RM 105.4) to above the upper extent of the Don Pedro Project Boundary (approximately RM 80.8) (Figure 1.4-1).

Through this study 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 several small tributaries (Table 3.0-1). A summary of physiographic information is provided in Table 3.0-2. 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 summarized in the Upper Tuolumne River Basin Fish Migration Barriers Study (TID/MID 2017d). In this final report, water temperature data and thermal conditions will be assessed in each of the listed tributaries to the first complete barrier to fish migration.

**Table 3.0-1. Tuolumne River mean annual flow at Modesto, La Grange, and Hetch Hetchy for the period 1971-2011 (USGS 2015).**

| 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 |

Source: http://waterdata.usgs.gov.

**Table 3.0-2. 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[1,2] | 42 | 234 | 10,800 |
| South Fork Tuolumne River[1,3] | 35 | 164 | 9,600 |
| Clavey River[1,4,5] | 36 | 157 | 9,250 |
| North Fork Tuolumne River[1] | 37 | 100 | 8,150 |

[1] http://streamstatsags.cr.usgs.gov.

[2] U.S. Geological Survey. 2013. Cherry Creek below Dion R. Holm Powerplant, near Mather, CA Water Data Report.

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

[4] 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.

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

# 4.0 METHODOLOGY

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.

## 4.1 Synthesis of Historical Data and Additional Monitoring

In 2015, existing geometric, flow and stage, water temperature and meteorological data were used to characterize the thermal regime and provide a general system description of the Tuolumne River below CCSF's Early Intake and upstream of the Don Pedro Project Boundary. Temperature data were identified for the mainstem Tuolumne River from Early Intake to above the Don Pedro Project Boundary, 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 (described below) was undertaken by the Districts and licensing participants to identify locations where additional temperature monitoring stations should be established. Locations for deploying temperature data loggers were selected to provide a general characterization of mainstem and tributary reaches. The Water Temperature Monitoring Sampling Plan is included as Attachment A. For an overview of the quality assurance/quality control (QA/QC) process developed for temperature monitoring, see Attachment B.

## 4.2 Collaboration with Licensing Participants

As defined in the FERC-approved RSP, the Districts held a Flow and Temperature Monitoring and Modeling Workshop with licensing participants 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 licensing participants proposed temperature and flow monitoring locations, and (3) review and confirm with licensing participants 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 C.

## 4.3 Model Development

In 2016, existing stream description (geometry), flow and stage, temperature, and meteorological data were used to develop a water temperature model to simulate the thermal regime in the Tuolumne River from below Early Intake to above the Don Pedro Project Boundary that has been identified as potentially accessible to reintroduced steelhead and Chinook salmon.

### 4.3.1 Previous Work

Previous water temperature modeling work in the study area included studies in the reach between O'Shaughnessy Dam and Early Intake (Jayasundara et al. 2017), studies of Don Pedro Reservoir and the lower Tuolumne River (TID/MID 2013c, Dotan et al. 2013, Stillwater 2011, AD Consultants 2009, RMA 2007) and the "without projects" condition model extending from the headwaters of Hetch Hetchy Reservoir to the San Joaquin River confluence (TID/MID 2017g). For stream reaches, all of these efforts have focused on one-dimensional model representations of longitudinal temperature gradients with laterally and depth-averaged conditions. However, spatial and temporal resolution varied by study. Jayasundara et al. (2017) modeled the stream on a 25-meter spatial resolution with hourly time steps. TID/MID (2017g) used a spatial resolution of approximately one-mile, with hourly time steps. Dotan et al. (2013), Stillwater (2011), AD Consultants (2009), and RMA (2007) all employed the U.S. Army Corps of Engineers HEC-5Q model with a 6-hour time step and a spatial resolution of one-half to one-mile.

The modeling effort for this study adopted a similar sub-daily time step (hourly) and directly built off of the previous effort by Jayasundara et al. (2017), using available field data, assumptions, and modeling parameters, as well as review and interpretation of previous findings and results.

### 4.3.2 Model Selection

Based on the project objective and fundamental attributes of the system, appropriate models were evaluated for use. The process of model selection for the Tuolumne River is addressed in Jayasundara et al. (2017). Key considerations included:

- 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 stream temperature gradients. These 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 minimum and maximum daily temperatures to develop metrics for thermal suitability assessment and regulatory considerations; and

- open-source code (i.e., code that is accessible for user review and modification).

The RMA models, RMA-2 for hydrodynamics (King 2014) and RMA-11 (King 2013) for water temperature, were used to represent the Tuolumne River in a one-dimensional, depth-averaged, finite element scheme. These models have been applied successfully to the Tuolumne River in simulations below Hetch Hetchy over a wide range of flows (Jayasundara et al. 2017). The utility application RMAGEN (v7.4) (King 2014) was used to create a geometry file of the Tuolumne River that was used by both the hydrodynamic and water temperature models. RMA-2 calculates velocity, water surface elevation, and depth at defined nodes of each grid element in the geometric network representing the river. In this project, the model was applied in one-dimensional, laterally and depth-averaged form. RMA-11 is a companion finite-element water quality model that uses depth and velocity results from RMA-2 to solve advection and diffusion equations of constituent transport. Details of each of these models are provided below. Additional model details are included in Jayasundara et al. 2017.

Model development included: data development, model implementation, and model calibration. These elements were, for the most part, carried out in that order to arrive at a complete, calibrated model.

### 4.3.3 Model Data Development

Data development included the process of aggregating all data necessary to implement a model. For a river temperature model, these data included geometric data, meteorological data, hydrologic data, and water temperature data. Geometric data were used to mathematically describe the river planform (e.g., UTM coordinates or latitude/longitude descriptions of the river), gradient, and local cross section information describing the "shape" or morphology of the river. Meteorological data included solar radiation, air temperature, wet bulb or dew point temperature, wind speed (and in certain instances direction), cloud cover, and barometric pressure. Hydrologic data included headwater inflows, tributary inflows, and diversions or known outflows. Water temperature data included water temperature at inflow locations noted previously. In addition, there was a need for flow and water temperature data at locations within the model domain. These data were not used to run the model, but rather to calibrate the model. The development of calibration and application period data sets are presented in subsequent sections.

### 4.3.4 Model Implementation

Model implementation consisted of acquiring and testing the selected model; using available data to construct the appropriate geometric representation of the river (including shading characteristics); formulating boundary conditions for flow and temperature; formatting necessary meteorological data; and selecting representative model parameters. The outcome of this effort was a functional, but uncalibrated model.

### 4.3.5 Model Calibration

Model calibration included modifying parameter values and appropriate information to ensure that the model replicated field observations over a range of hydrologic, thermal, and meteorological conditions. Therefore, this task required additional field data for flow and temperature in the study region (within the model domain) to sufficiently test the model. Appropriate statistical measures are included in this process to provide resource managers and decision makers the level of confidence necessary to make informed decisions based on model simulations. Model calibration results are provided in Attachment F to this study report.

# 5.0 GENERAL SYSTEM DESCRIPTION

To effectively develop and apply a water temperature model in the upper Tuolumne River watershed, a basic understanding of flow and thermal 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 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.

## 5.1 Flow

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 is regulated by reservoirs.

The Tuolumne River and Cherry Creek are both regulated streams and thus have modified flow regimes in response to hydropower, storage, and water management operations. An example of Cherry Creek flows below Cherry Valley Dam, contributions from Eleanor Creek, and flows below Holm Powerhouse are shown in Figure 5.1-1 for 2010. Releases to the upper section of Cherry Creek (above Holm Powerhouse) from Cherry Valley Dam are typically below 20 cfs unless associated with high flow conditions and reservoir spill or storage management operations. Releases from Eleanor Dam are likewise small except during spill; in 2010, for example, maximum release was less than 10 cfs. Releases to the lower section of Cherry Creek from Holm Powerhouse due to hydropower and other water management operations dominate the flow regime at the mouth of Cherry Creek.

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 overshadowed by the signature of dynamic peaking flows from Holm Powerhouse, and that these conditions persist some 26 miles downstream to Wards Ferry (Figure 5.1-2). Travel time, peak attenuation, and the contribution of other tributaries are all apparent in this figure.

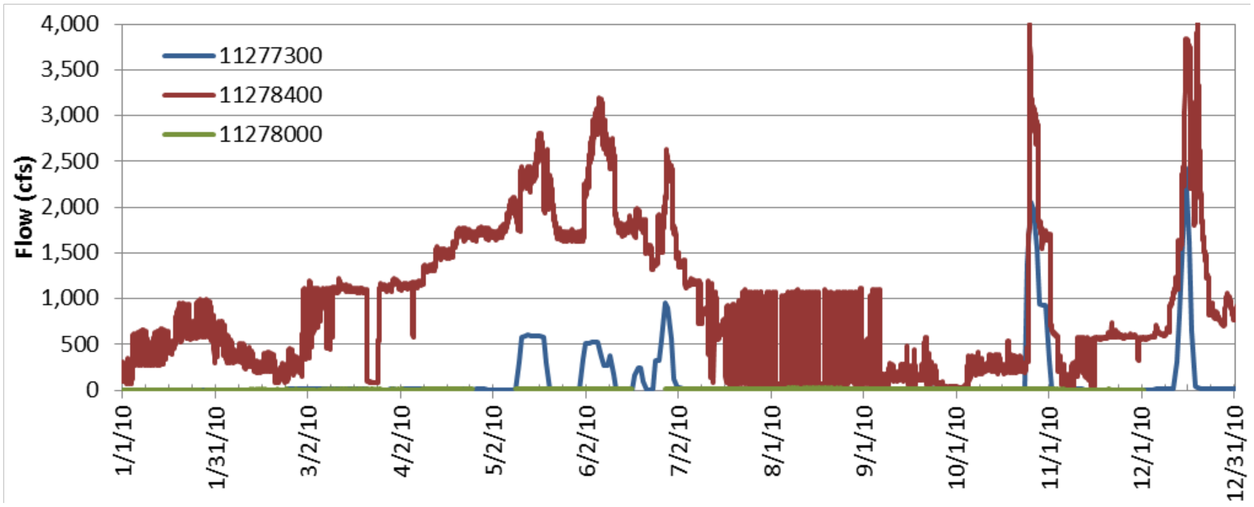

**Figure 5.1-1.** **Cherry Creek flow below Cherry Valley Dam (USGS Gage 11277300) and below Holm Powerhouse (USGS Gage 11278400), and Eleanor Creek flow below Eleanor Dam (USGS Gage 11278000), 2010.**

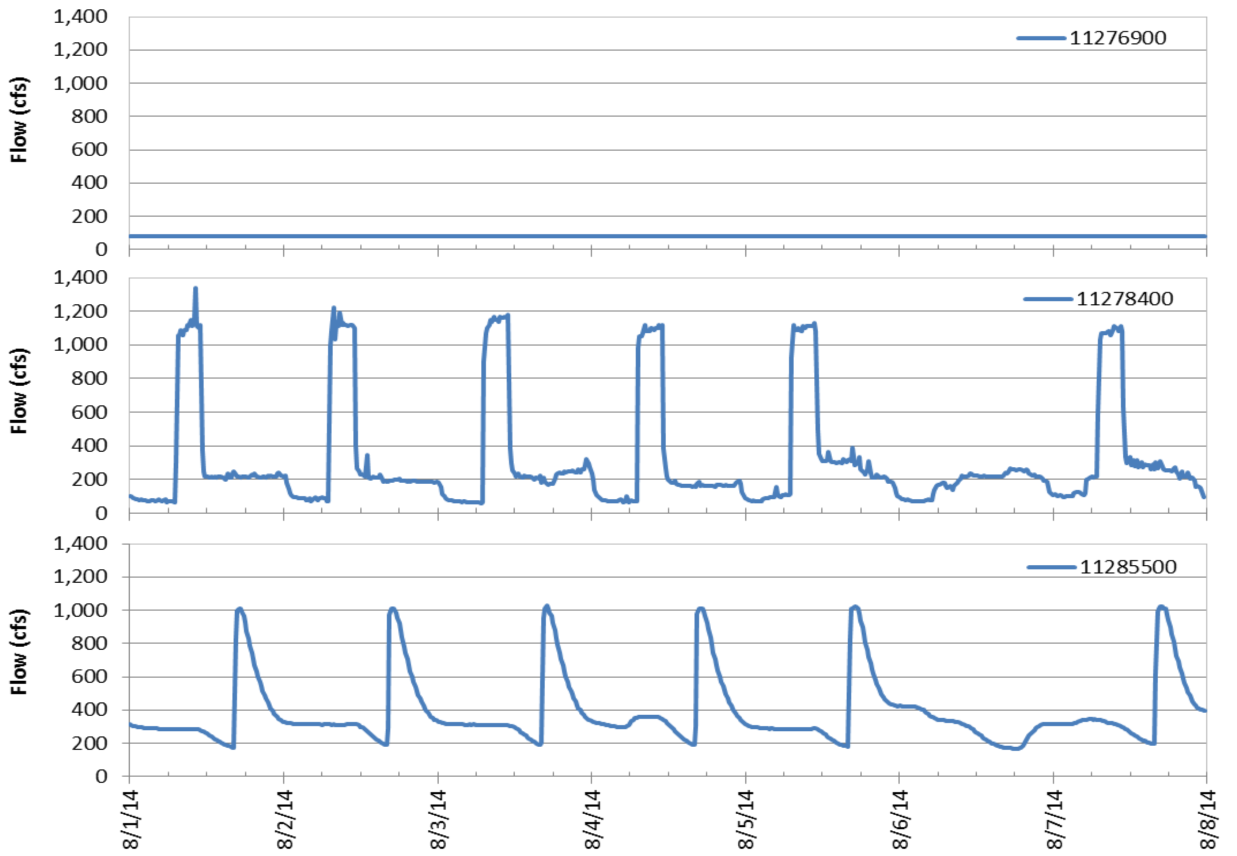

**Figure 5.1-2.** **Flow in the Tuolumne River below Early Intake (USGS Gage 11276900) - top, Cherry Creek below Holm Powerhouse (USGS Gage 11278400) - middle, and Tuolumne River near Wards Ferry (USGS Gage 11285500) – bottom, August 1-8, 2014.**

The tributaries downstream of Cherry Creek exhibit a largely unimpaired flow regime. Using the proration flows (TID/MID 2013) for the Clavey and North Fork Tuolumne rivers for water year 2011 (October 1, 2010 to September 30, 2011), the flow signatures of winter rainfall events are clearly indicated, as is the snowmelt signature of the winter's accumulation of snowpack (Figure 5.1-3). The North Fork Tuolumne River has both a smaller basin area and a lower headwater elevation than the Clavey River, resulting in 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.

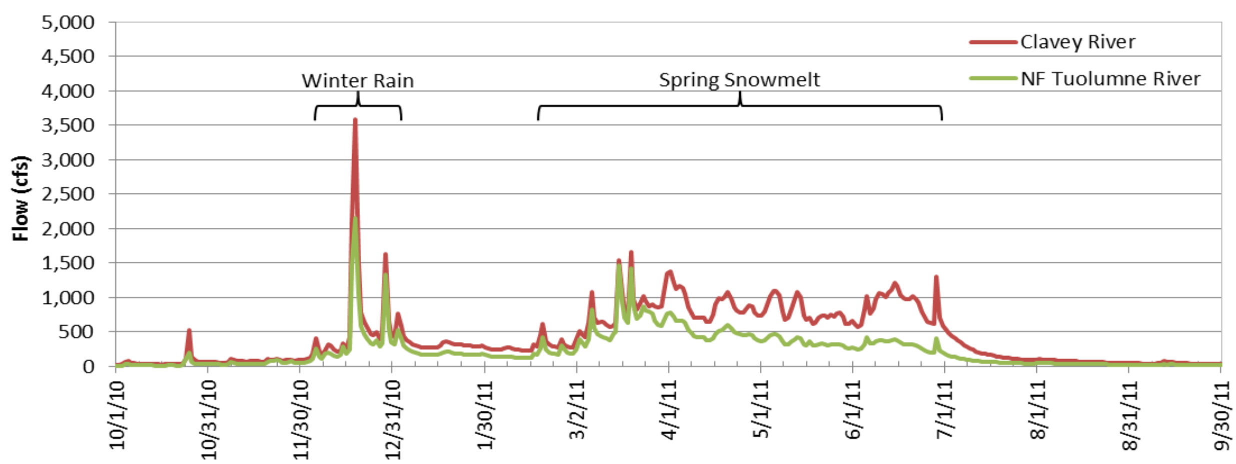

**Figure 5.1-3.** **Clavey and North Fork Tuolumne rivers near mouths, daily flows for water year 2011 (October 1, 2010 to September 30, 2011) (TID/MID 2013).**

Comparing flows at Cherry Creek above Holm Powerhouse with flows in the Clavey River illustrates that Cherry Creek flows are moderated during the winter rainfall events. The seasonal snowmelt signal is likewise moderated, as winter and spring runoff waters from above Cherry and Eleanor lakes are stored for summer hydropower production and downstream water supply (Figure 5.1-4).

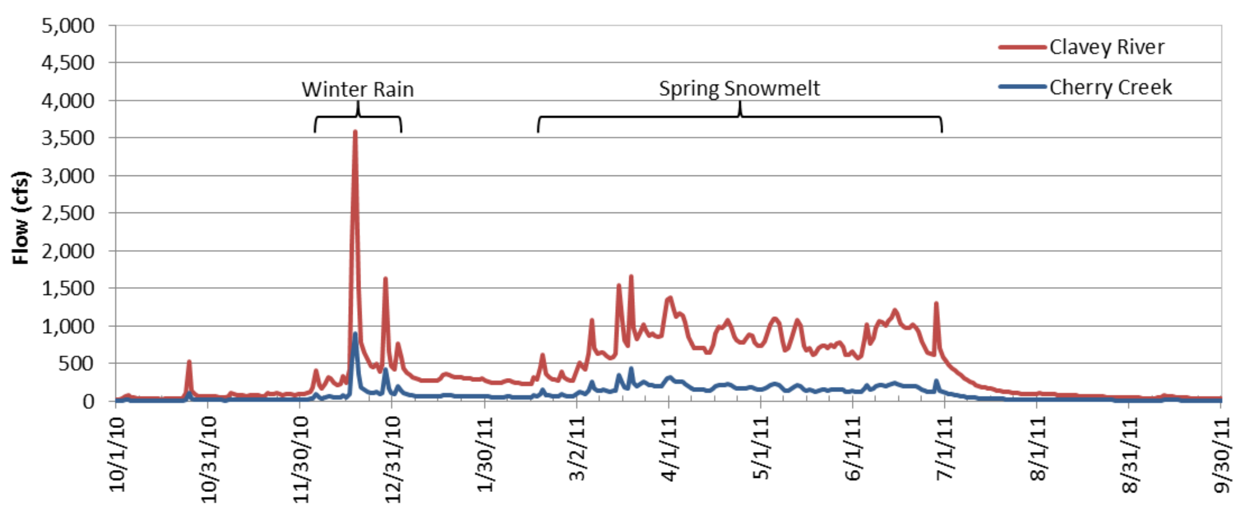

**Figure 5.1-4.** **Clavey River near mouth and Cherry Creek (above Holm Powerhouse): daily flows for water year 2011 (October 1, 2010 to September 30, 2011) (TID/MID 2013).**

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 (e.g., seasonal flow variability, snowmelt runoff, upstream reservoir operations (e.g., hydropower peaking operation)) are typically present in all year types. Further, these conditions have direct implications on water temperature regimes in the Tuolumne River and its tributaries.

## 5.2 Water Temperature

As with flow, water temperature exhibits a seasonal pattern in the study area. A useful concept to consider when 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 5.2-1. 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 runoff 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. These contributions are often markedly colder than the mainstem and can also be of considerable magnitude, and 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$^{o}$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.

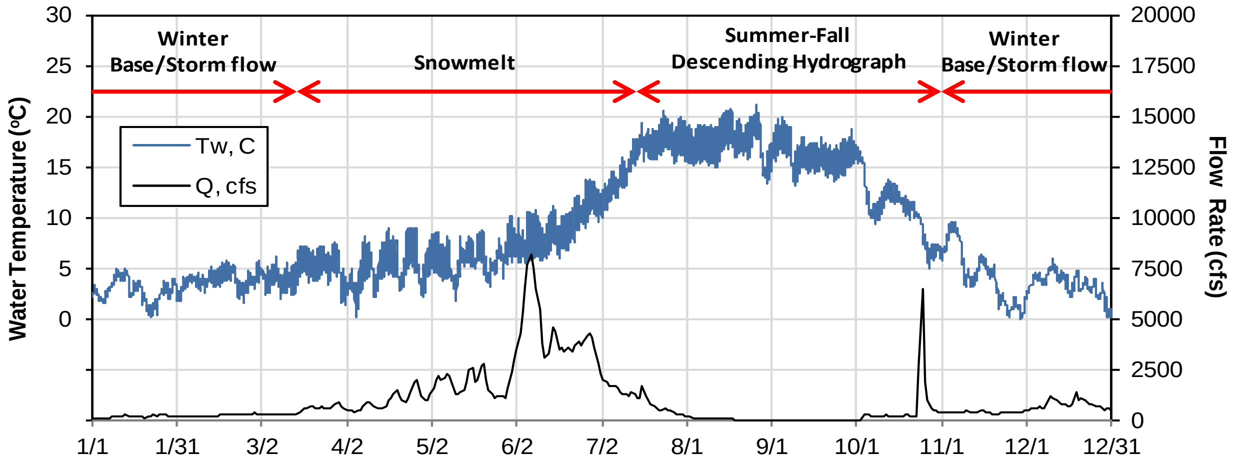

**Figure 5.2-1.** **Flow and water temperature, Tuolumne River above Hetch Hetchy (USGS Gage 11274790) showing representative seasonal hydrograph elements. Flow data from TID/MID (2017e) water temperature data from http://waterdata.usgs.gov/ca/nwis.**

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 Cherry Creek (including Eleanor Creek) and the 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 cooler water temperatures, compared to a natural stream in summer (e.g., tributary inflows from the South Fork Tuolumne River or Clavey River) in downstream river reaches throughout the year. For the Tuolumne River, these cooler waters emanate from O'Shaughnessy Dam, or occasionally from Kirkwood Tunnel releases to the Tuolumne River near Early Intake. 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 River, 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 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. Subsequently the streams with no appreciable storage (i.e., South Fork Tuolumne, Clavey, and North Fork Tuolumne rivers) are presented. 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.

### 5.2.1 Cherry Creek

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 5.2-1 and Figure 5.2-2).

**Table 5.2-1. Water temperature data sites on Eleanor Creek.**

| Site Name | Site Label[1] | RM | Agency | Location Description |
|---|---|---|---|---|
| USGS Gage #11278000 | 11278000 | 3.1 | USGS | Eleanor Creek near Hetch Hetchy, CA |
| EC1 | EC01.8 | 1.8[2] | CCSF | Eleanor Creek, upstream of Miguel Creek confluence |
| EC2 | EC01.7 | 1.7[2] | CCSF | Eleanor Creek, downstream of Miguel Creek confluence |
| EC5 | EC00.0 | 0[2] | CCSF | Eleanor Creek, upstream of Cherry Creek confluence |
| MC1 | MC00.0 | 0[3] | CCSF | Miguel Creek, upstream of Eleanor Creek confluence |

[1] Reporting format included in Attachment D.
[2] From confluence with Cherry Creek.
[3] From confluence with Eleanor Creek.

Water temperature conditions in Eleanor Creek exhibit the seasonal elements identified in Figure 5.2-1; cold winter temperatures, with cool conditions persisting through the snowmelt, followed by heating summer period maxima and cooling in fall (Figure 5.2-3). 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. Slightly cooler downstream water temperatures in winter and early spring are most likely due to the contributions of cooler water from Miguel Creek. Throughout spring, water temperatures are similar throughout Eleanor Creek, but starting in late summer, temperatures in lower Eleanor Creek begin to cool more rapidly than those upstream (Figure 5.2-3). This may be in response to channel form, tributary inflows, topographic shading, or releases from Eleanor Lake upstream, 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.

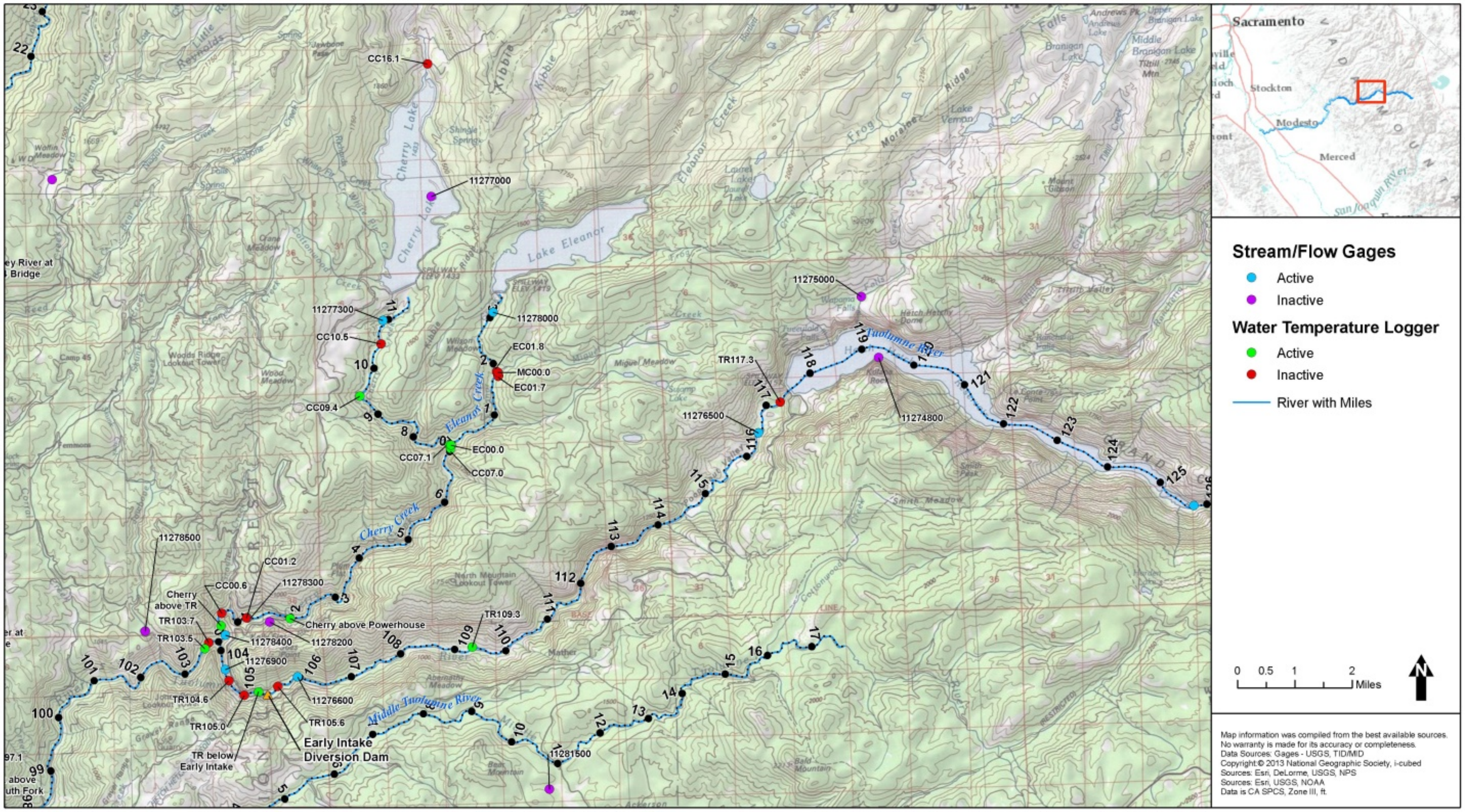

Figure 5.2-2. Water temperature data collection sites in Eleanor Creek, Cherry Creek, and upper Tuolumne River.

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.

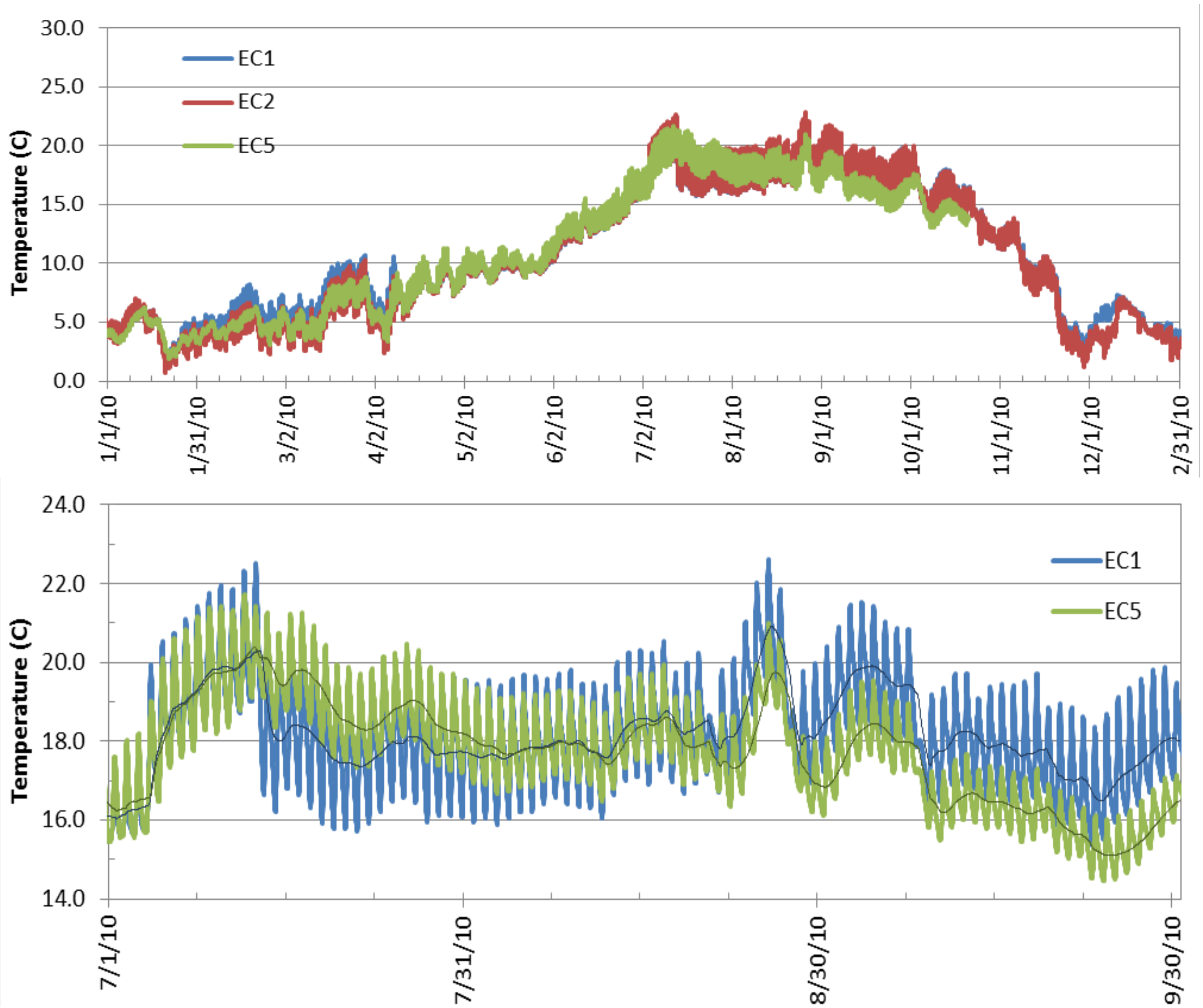

**Figure 5.2-3.** **Eleanor Creek water temperature (top) above Miguel Creek (EC1), below Miguel Creek (EC2), and above the confluence with Cherry Creek (EC5) for January-December 2010, and (bottom) above Miguel Creek (EC1) and above the confluence with Cherry Creek (EC5) for July-September 2010. 24-hour moving average trace for each time series included.**

Water temperature data is available at twelve sites on Cherry Creek, including two sites that were installed by the Districts for this project (Table 5.2-2 and Figure 5.2-2). As with Eleanor Creek, water temperature conditions in Cherry Creek exhibit the seasonal elements identified in Figure 5.2-1 (Figure 5.2-4). While winter temperatures are similar in the creek, water temperatures show a general increase in temperature downstream, starting in spring and persisting well into fall. Water temperatures at CC2, near the dam, are coolest and there is a 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 5.2-2. Water temperature data sites on Cherry Creek.**

| Site Name | Site Label[1] | RM[2] | 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 |
| Cherry Above Powerhouse | Cherry Above Powerhouse | 2.0 | TID/MID | Cherry Creek, upstream of Dion Holm Powerhouse |
| 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, near Mather, CA |
| Cherry Above TR | Cherry Above TR | 0.5 | TID/MID | Cherry Creek below Dion Holm Powerhouse |
| TCKPH | CC00.6 | 0.6 | CDFG | Cherry Creek below Dion Holm Powerhouse |
| USGS Gage 11278400 | 11278400 | 0.2 | USGS | Cherry Creek below Dion Holm Powerhouse, near Mather, CA |

[1] Reporting format included in Attachment D.

[2] From confluence with Tuolumne River.

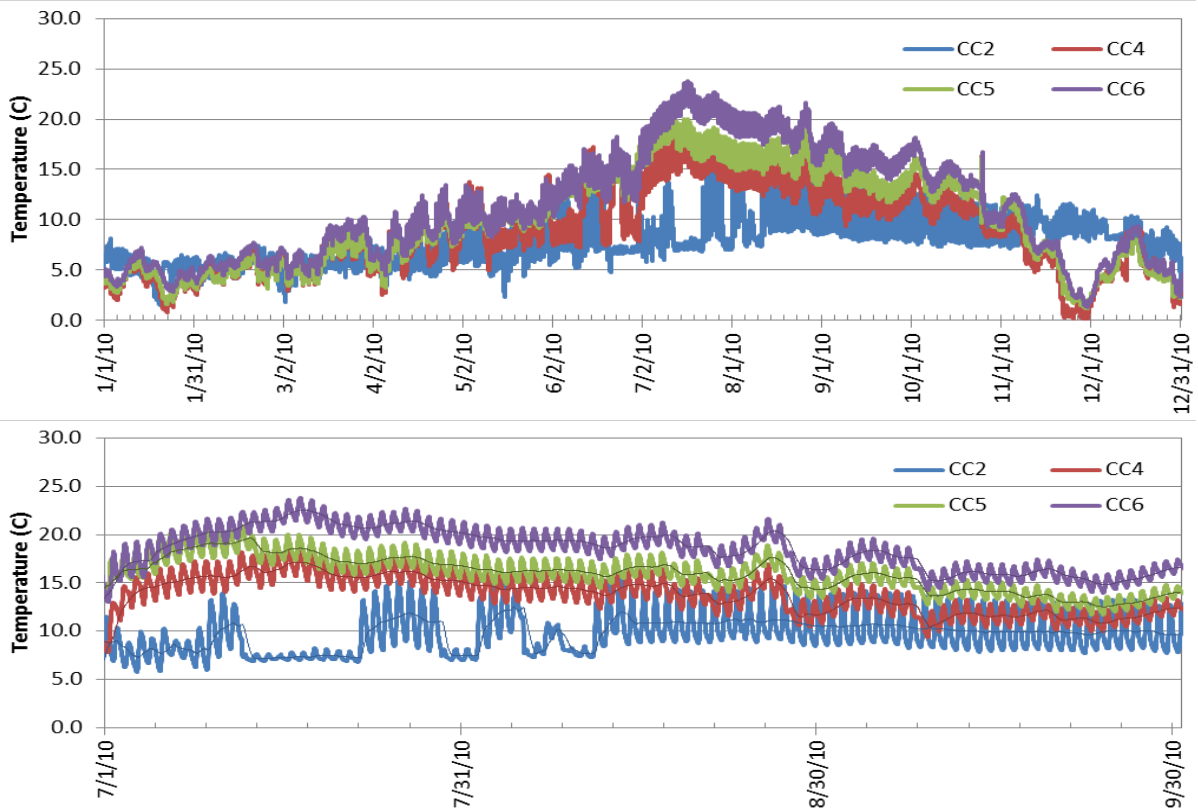

**Figure 5.2-4.** **Cherry Creek water temperature (top) downstream of Cherry Valley Dam (CC2), above Eleanor Creek (CC4), below Eleanor Creek (CC5), above Holm Powerhouse (CC6) for January-December 2010, and (bottom) July-September, 2010. 24-hour moving average trace for each time series included.**

Below Holm Powerhouse, the temperature regime of Cherry 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 releases, which originate from Cherry Lake, are warmer than the creek immediately upstream of the powerhouse. In the summer the inverse is true (Figure 5.2-5, top). Summer temperatures are notably cooler below the powerhouse because creek flows are at seasonal lows. Even though temperatures may exceed 20$^{o}$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 5.2-5, bottom). Flow and temperature conditions below the powerhouse are conveyed with little change to the nearby Tuolumne River.

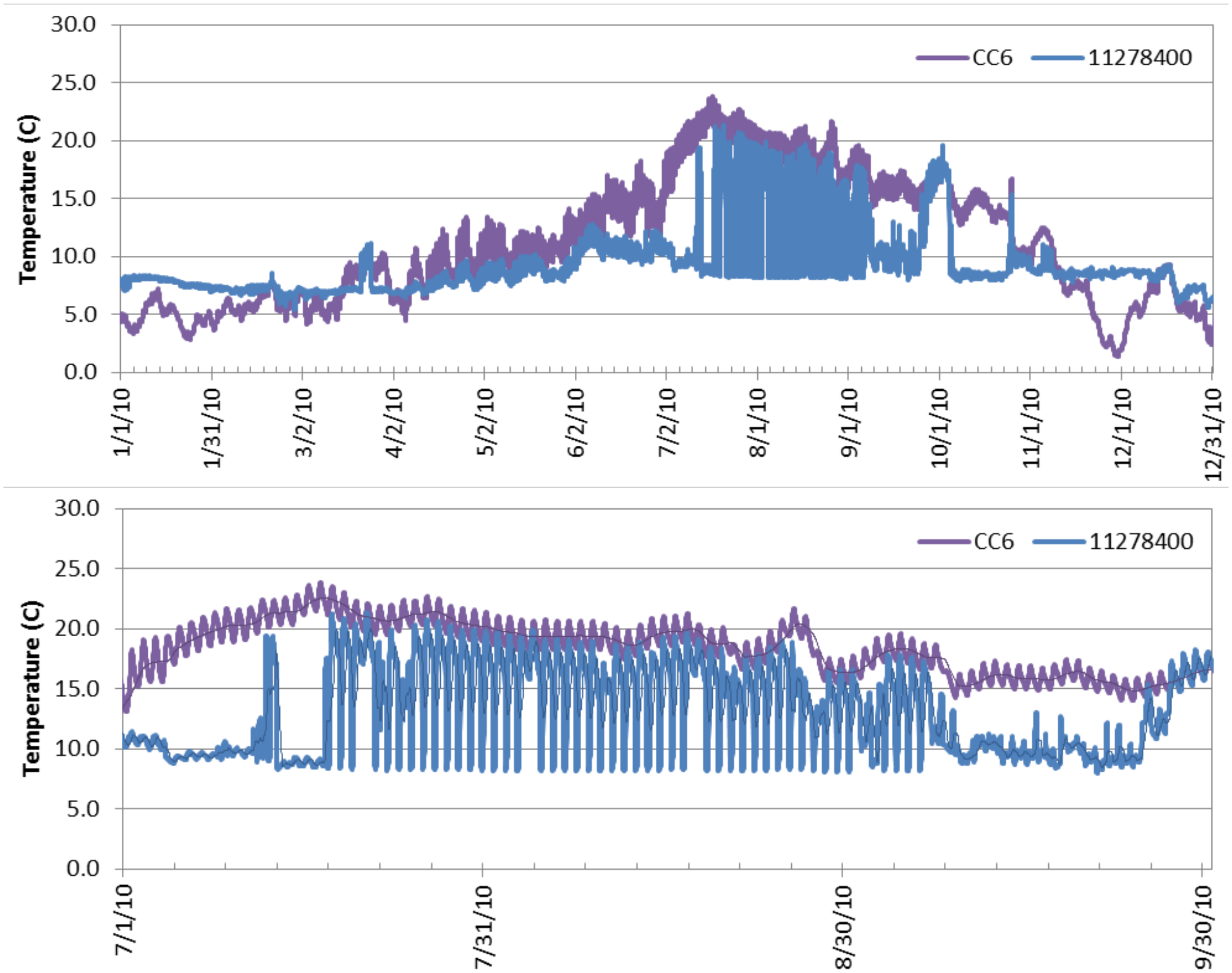

**Figure 5.2-5. Cherry Creek water temperature (top) above Holm Powerhouse (CC6) and below Holm Powerhouse (USGS 11278400) January-December 2010, and (bottom) July-September, 2010. 24-hour moving average trace for each time series included.**

### 5.2.2 South Fork Tuolumne River

The South Fork Tuolumne River enters the Tuolumne River at approximately RM 97. Three water temperature monitoring sites were located at approximately RM 0.1 to 0.2 (Figure 5.2-6 and Attachment D) that provided water temperature data into 2015. Site TSFRK was operated by CDFW, site TR6 was operated by CCSF, and site SF1 was operated by NMFS. An additional data collection site (South Fork above TR) was installed by the Districts in 2015 to collect data through 2016. 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$^{o}$C (Figure 5.2-7).

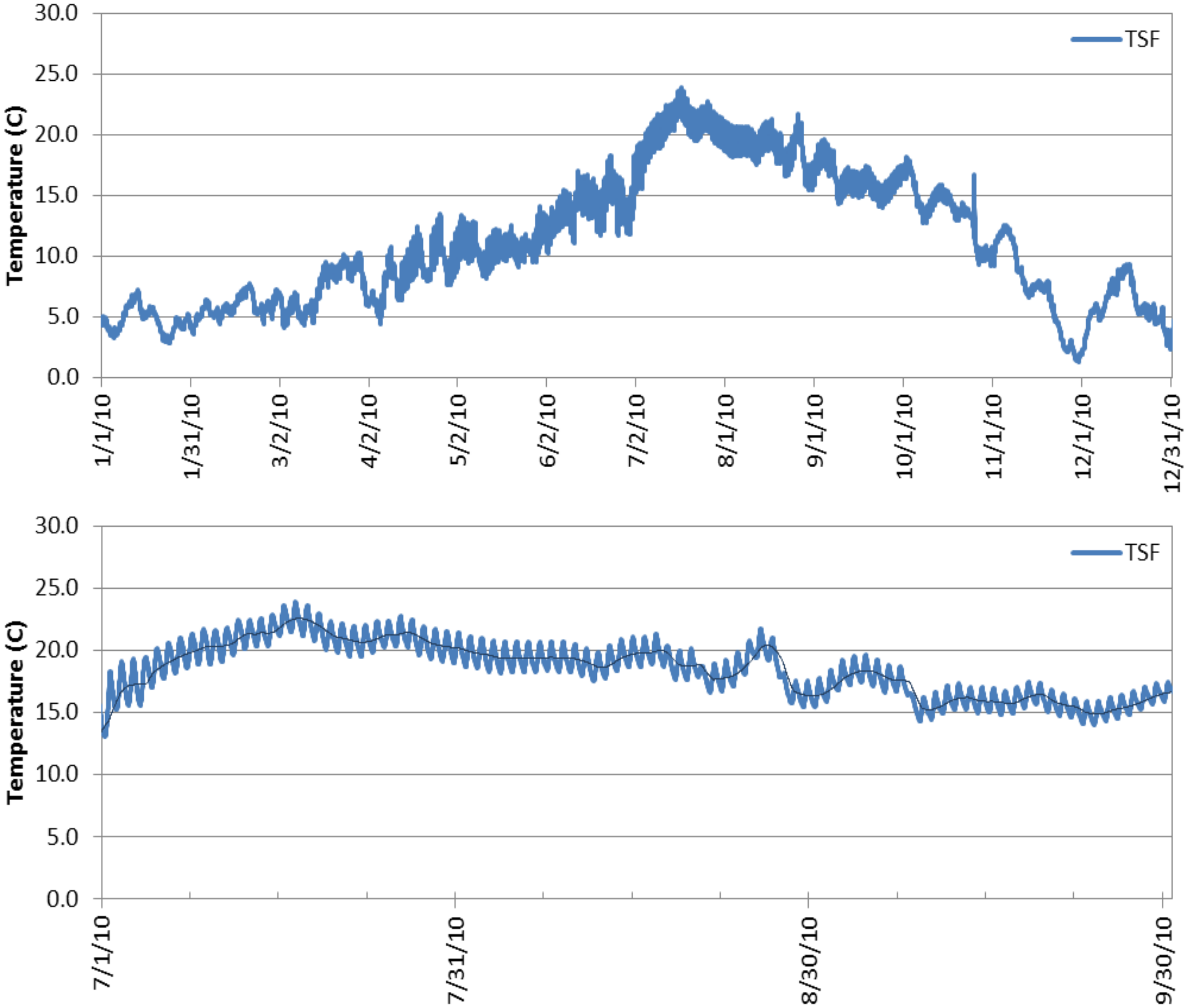

**Figure 5.2-6. South Fork Tuolumne River water temperature (top) above Tuolumne River (RM 0.2) (TSFRK) January-December 2010, and (bottom) July-September, 2010. 24-hour moving average trace for each time series included.**

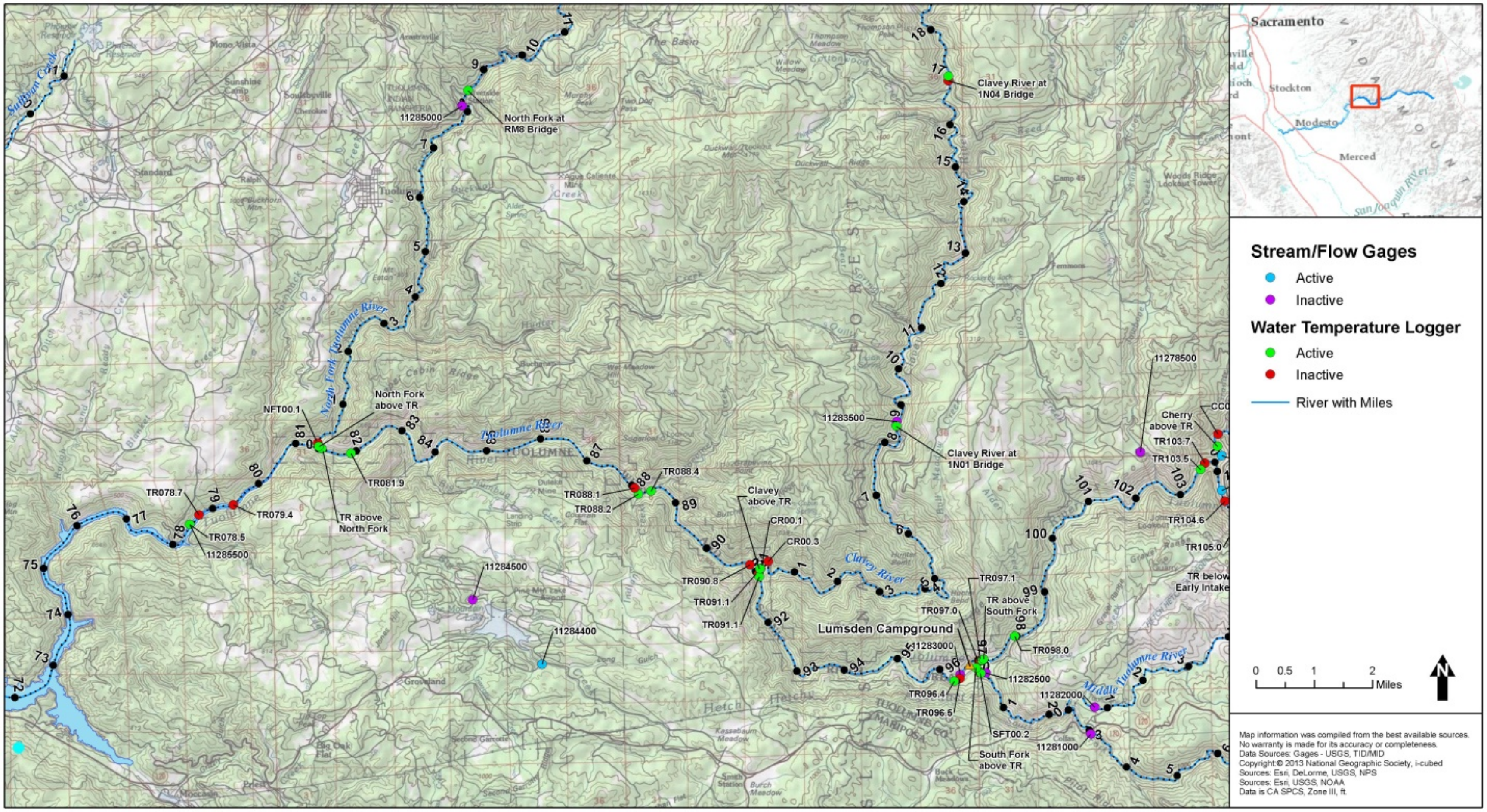

Figure 5.2-7. Water temperature data collection sites in the Tuolumne River and principal tributaries below Cherry Creek.

### 5.2.3 Clavey River

The Clavey River enters the Tuolumne River at approximately RM 91.0. Water temperature monitoring sites at three locations provided limited data prior to 2015 (Figure 5.2-6 and Attachment D). The Districts installed monitoring sites at each of the three locations along the Clavey River in 2015 to collect additional data for this study. Water temperature data collected for this project at RM 16.9 and RM 0.1 are shown in Figure 5.2-8. Daily maximum temperatures at these sites exceeded 20°C at RM 0.1 and 25°C at RM 16.9.

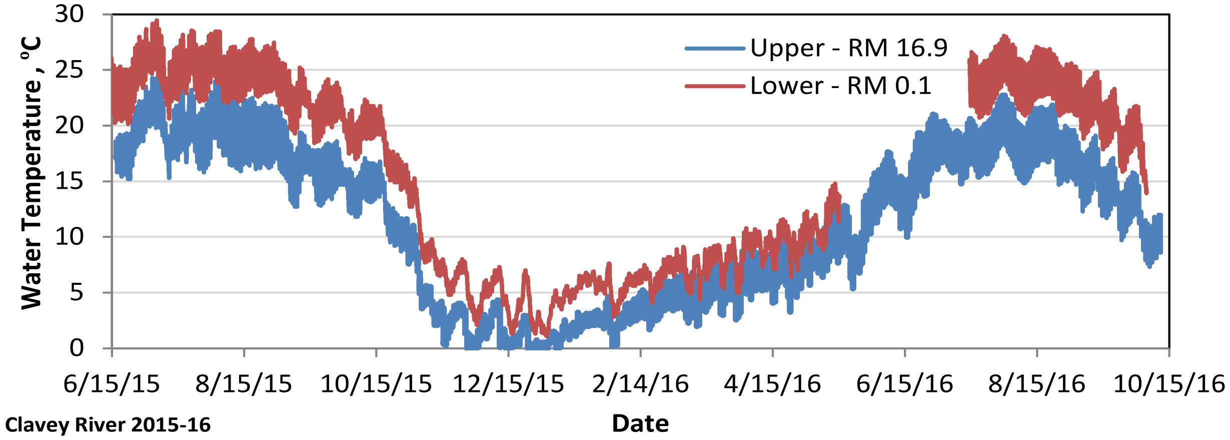

**Figure 5.2-8.** **Clavey River water temperature at RM 16.9 and above the confluence with the Tuolumne River (RM 0.1), June 2015 to October 2016.**

### 5.2.4 North Fork Tuolumne River

The North Fork Tuolumne River enters the Tuolumne River at approximately RM 81.3. One water temperature monitoring site (at RM 0.1) provided limited data prior to 2015 (Figure 5.2-6 and Attachment D). Two water temperature monitoring sites were installed for this study in 2015 at RM 0.1 and RM 8.0. During the summer months, the water temperature at both sites on the North Fork of the Tuolumne River were over 25°C, and temperatures at the mouth reached nearly 30°C (Figure 5.2-9).

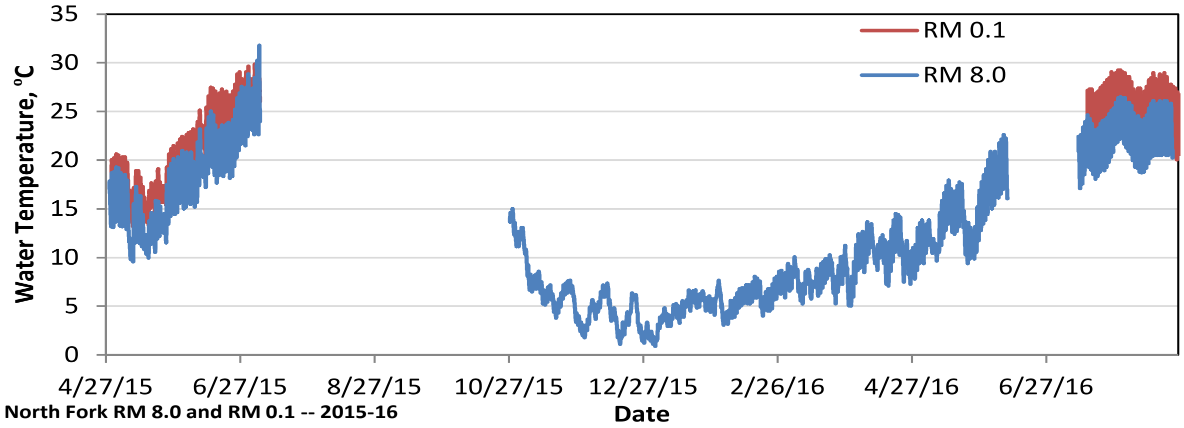

**Figure 5.2-9.** **North Fork Tuolumne River water temperature at RM 0.1 and RM 8.0, Aril 2015 to October 2016.**

### 5.2.5 Mainstem Tuolumne River

The study area includes the Tuolumne River from below Early Intake to the upper extent of the Don Pedro Project Boundary). 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. During the summer and fall months, both of these streams receive deep, cool reservoir releases from their respective upstream dams. In Cherry Creek, similarly cool waters are conveyed to and released from Holm Powerhouse to lower Cherry Creek during hydropower operations. These waters are notably cooler than downstream tributaries, which are largely unimpaired and as summer time flows diminish experience notable increases in water temperatures. While these downstream tributaries can experience very warm water temperatures, the relatively low flow in these streams reduces 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$^{o}$C through much of June throughout the study area (Figure 5.2-10, top). In July water temperatures begin to increase notably, and by mid-July temperatures at Wards Ferry may surpass 25$^{o}$C. Temperatures at Early Intake in 2009, though released from O'Shaughnessy Dam at roughly 15$^{o}$C, exceed 20$^{o}$C during this period due to the relatively low flow rates and adverse heating conditions.

All tributary flows are in excess of 20$^{o}$C and sometimes 25$^{o}$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 from daily hydropower peaking operations have temperatures of less than 10$^{o}$C during July and August (Figure 5.2-10, middle) and 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 5.2-10 (bottom). Early Intake experiences a basic diurnal signal with a late afternoon maximum and an early morning minimum. 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 are absent (e.g., mid-September) (Figure 5.2-10, 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 5.2-8 and Figure 5.2-9), and the lower gradient in this reach that leads to a longer transit time.

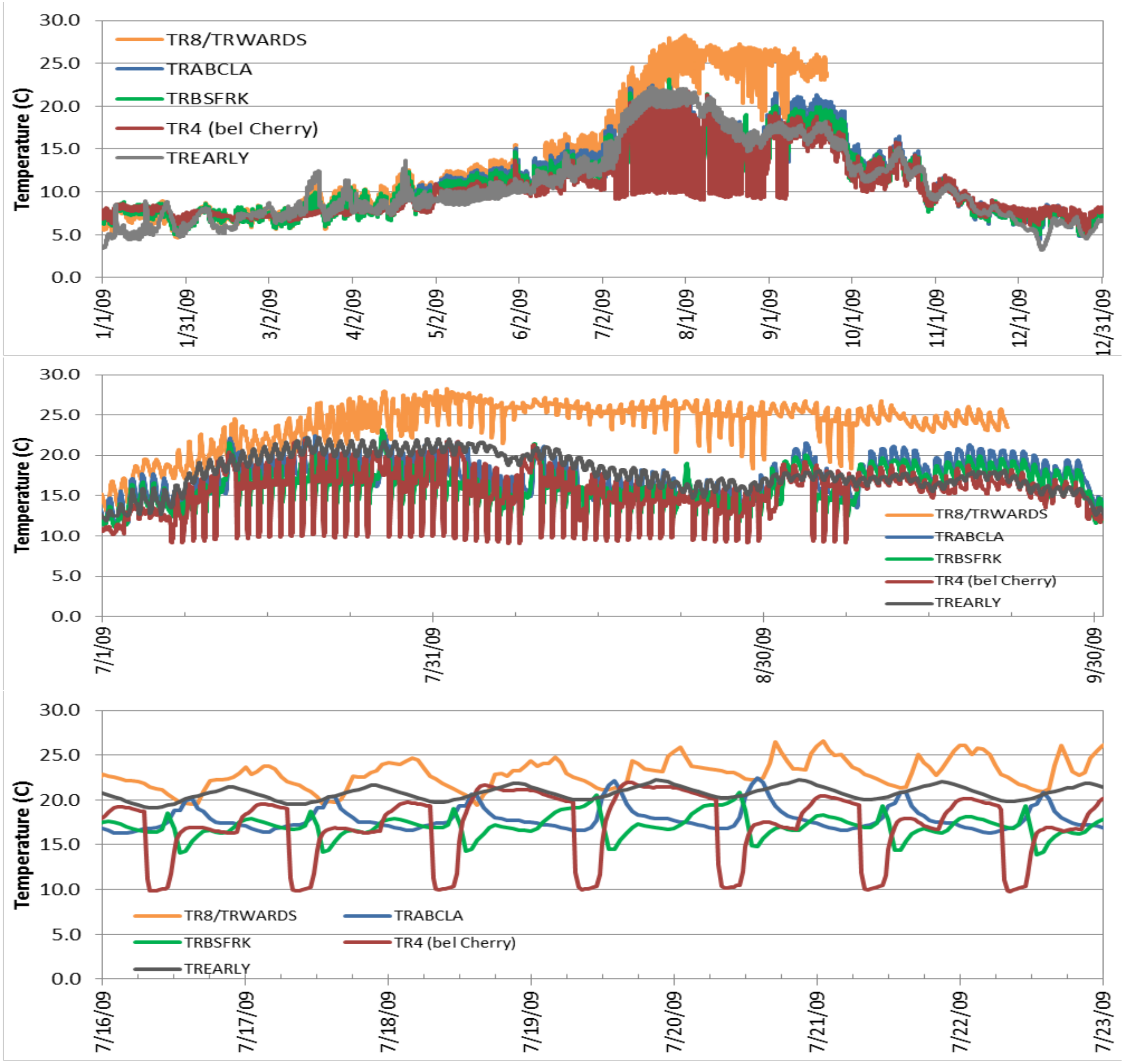

**Figure 5.2-10.** **Tuolumne River water temperatures below Early Intake (TREARLY), below Cherry Creek (TR4), below South Fork Tuolumne River (TRBSFRK), above Clavey River (TRABCLA), and at Wards Ferry (TR8/TRWARDS), from (top) January 1 – December 31, (middle) July 1 – September 30, and (bottom) July 16 – July 23, 2009.**

# 6.0 MODEL DATA DEVELOPMENT

Datasets were developed through gathering, synthesis, and review of existing data, and QA/QC of newly collected data. The following sections introduce each data type and the associated data identified, compiled, and developed for the study through the end of 2014. Subsequently, temperature data for 2015 and 2016 are 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.

## 6.1 Flow Data Requirements

Time-series flow data were required at all boundary condition locations (i.e., at the "edge" of the modeling domain) for modeling. Boundary conditions included inflows to the system (e.g., headwater and tributary contributions) and outflows from the system (e.g., diversions). A stage-flow relationship was 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 hydropower peaking operations. In this case, stage data were used to characterize travel time through river reaches and assist in model representation and calibration. In addition to boundary condition data, flow and stage information within the model domain (i.e., not at the boundaries) was useful for model calibration.

The study area included the mainstem Tuolumne River (from Early Intake downstream to above the Don Pedro Project Boundary) and the four principal tributaries. Boundaries for the flow and water temperature model are listed in Table 6.1-1. Flow data included natural flow regimes (typically reported as daily average flow rates in unimpaired tributaries) or from hydropower and water management operations (typically reported as hourly average to capture fluctuations in flow). Accretions and depletions to the system were calculated using a mass balance.

**Table 6.1-1. Boundary conditions for upper Tuolumne River flow and temperature model.**

| Location | RM | Boundary Type |
|---|---|---|
| Upstream extent of model (Tuolumne River above 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 below Don Pedro Project Boundary) | 77.0[1] | Outflow |

[1] Approximate river mile. The model will terminate at Wards Ferry, but under full pool this location may move upstream slightly.

### 6.1.1 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 6.1-2). Most of the listed gages include records from before 2005 through to the 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. Sub-daily data were available from USGS (typically fifteen-minute data) upon request for the stations listed; however, older sub-daily data series may not be complete.

**Table 6.1-2. Active USGS gages collecting flow and stage data in study area.**

| Gage Number | Name | RM | Data Type[1] |
|---|---|---|---|
| **Tuolumne River** | | | |
| 11276500 | Tuolumne River near Hetch Hetchy CA[2] | 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 |
| **Cherry Creek** | | | |
| 11277300 | Cherry Creek below Valley Dam near Hetch Hetchy CA | CC 10.9 | N/A |
| 11278300 | Cherry Creek near Early Intake CA | CC 1.2 | N/A |
| 11278400 | Cherry Creek below Dion R. Holm Powerhouse near Mather CA | CC 0.2 | BC |
| 11278000 | Eleanor Creek near Hetch Hetchy CA | EC 3.1 | N/A |
| **South Fork Tuolumne River** | | | |
| - | No active stations/long-term records | N/A | N/A |
| **Clavey River** | | | |
| - | No active stations/long-term records | N/A | N/A |
| **North Fork Tuolumne River** | | | |
| - | No active stations/long-term records | N/A | N/A |

[1] BC – boundary condition data, CAL – calibration data.

[2] The Tuolumne River near Hetch Hetchy and upper Cherry and Eleanor Creek are above the proposed study reach, but are included for completeness.

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 6.1-3). Velocity and discharge measurements were collected during field visits and these observations were used to formulate stage-discharge curves when feasible and create extended flow records for the major tributaries where flow data were 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 were useful for calibrating the hydrodynamic model by capturing stage change associated with hydropower peaking operations. These data augmented information at the downstream Wards Ferry gage to calibrate flow/stage in the study reach.

While additional characterization of tributary contributions occurred in 2015, there was still a lack of flow data for previous years. 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 2013). 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 6.1-1. Ultimately, flow conditions in all but Cherry Creek utilized these calculated flows. The mainstem Tuolumne River and the lowest portion of

Cherry Creek (below Dion R. Holm Powerhouse [Holm Powerhouse]) utilized sub-daily flow information from USGS and CCSF records to capture hydropower peaking conditions.

**Table 6.1-3. Additional stage monitoring locations in 2015 and 2016.**

| Logger Location[1] | RM | Data Type[2] |
|---|---|---|
| **Tuolumne River[3]** | | |
| 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 |
| **Cherry Creek** | | |
| None installed in 2015. | - | - |
| **South Fork Tuolumne River** | | |
| South Fork Tuolumne River upstream of Tuolumne River | SF 0.1 | BC |
| **Clavey River** | | |
| Clavey River at USFS Bridge (1N04 Bridge) | CR16.9 | N/A |
| Clavey River at USFS Bridge (1N01 Bridge) | CR 8.4 | N/A |
| Clavey River upstream of Tuolumne River | CR 0.1 | BC |
| **North Fork Tuolumne River** | | |
| North Fork Tuolumne River at USFS Bridge (1N01 Bridge) | NF 8.4 | N/A |
| North Fork Tuolumne River upstream of Tuolumne River | NF 0.1 | BC |

[1] USFS = U.S. Forest Service.
[2] CAL = calibration data; BC = Boundary condition data.
[3] Only stage data were collected in the mainstem Tuolumne River; no velocity measurements were collected.

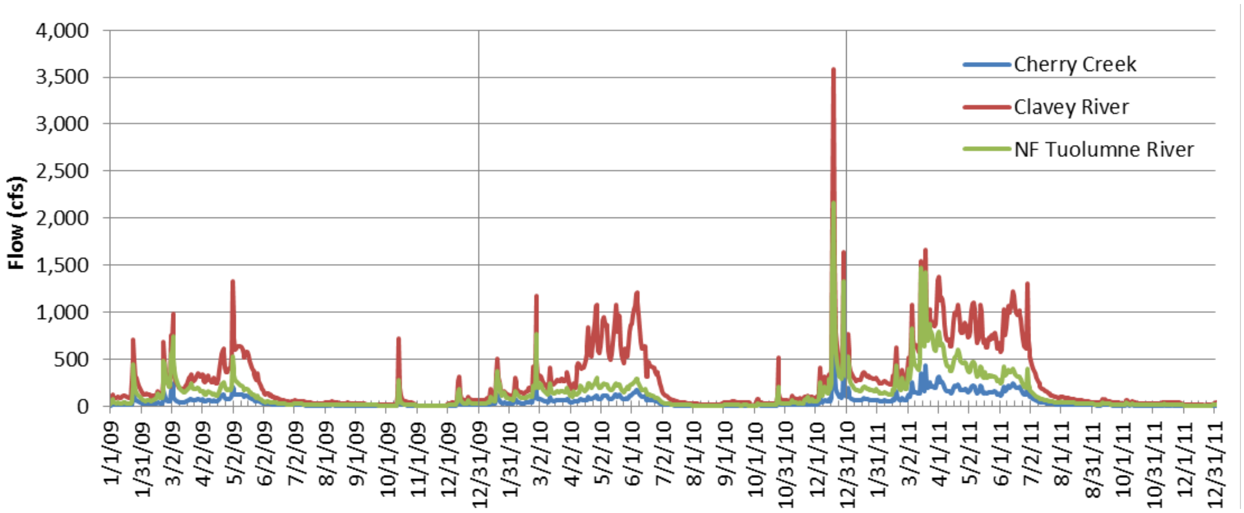

**Figure 6.1-1. Calculated daily flow for Cherry Creek, Clavey River, and North Fork Tuolumne River based on HDR proration analysis (TID/MID 2013), 2009-2011.**

### 6.1.2 Operations

Operations are an important element of mainstem Tuolumne River and Cherry Creek hydrology. Outlined below are the basic operations, by sub-reach, that were considered when assessing flow and temperature.

#### 6.1.2.1 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 6.1-4 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) (SFPUC 2007).

**Table 6.1-4. 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[1] (cfs) | Criteria[2,3] | Minimum Release[1] (cfs) | Criteria[2,3] | Minimum Release[1] (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 |

[1] Minimum average daily flow as measured at USGS Gage 11276500 (Tuolumne River near Hetch Hetchy).
[2] 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.
[3] Inflow criteria in ac-ft are the cumulative calculated inflow into Hetch Hetchy Reservoir commencing on the previous October 1 of each year.

#### 6.1.2.2 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 (SFPUC 2014) Table 6.1-5). 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 (SFPUC 2007).

**Table 6.1-5. Cherry Lake and Lake Eleanor information.**

<table>
<tr><th></th><th>Cherry Lake</th><th>Lake Eleanor</th></tr>
<tr><td>Dam</td><td>Cherry Valley Dam</td><td>Eleanor Dam</td></tr>
<tr><td>Reservoir Maximum Capacity (acre-ft)</td><td>274,300</td><td>27,100</td></tr>
<tr><td>Reservoir Maximum Water Surface Elevation (ft)</td><td>4703</td><td>4661</td></tr>
<tr><td>Drainage Area Upstream of Reservoir (square miles)</td><td>117</td><td>78.1</td></tr>
<tr><td rowspan="2">USGS Gages</td><td>USGS Gage 11277200 Cherry Lake near Hetch Hetchy, CA</td><td>USGS Gage 11277500 Lake Eleanor near Hetch Hetchy, CA</td></tr>
<tr><td colspan="2">USGS Gage 11277100 Lake Eleanor Diversion Tunnel to Cherry Lake near Hetch Hetchy, CA</td></tr>
<tr><td>Location of Dam (approximate RMs from mouth of creek)</td><td>11.5</td><td>3.5</td></tr>
<tr><td>Baseflow Compliance Point Downstream of Dam</td><td>USGS Gage 11277300 Cherry Creek downstream of Valley Dam near Hetch Hetchy, CA</td><td>USGS Gage 11278000 Eleanor Creek near Hetch Hetchy, CA</td></tr>
</table>

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 (Tables 6.1-6 and 6.1-7). 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 used to calculate flow through the powerhouse.

During periods of high runoff, Holm Powerhouse is operated approximately at capacity 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 6.1-6. 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 6.1-7. Minimum releases from Eleanor Dam for baseflows in Eleanor Creek.**

| Month | Minimum Flow (cfs)[1] | |
|---|---|---|
| | 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 | -[2] | 5 |
| November | 5 | 5 |
| December | 5 | 5 |

[1] "Pumping" is defined as when water is pumped from Cherry Lake to Lake Eleanor through the Cherry-Eleanor Tunnel.

[2] 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.

## 6.2 Water Temperature Data Requirements

Time-series water temperature data were required at all boundary condition locations (i.e., at the “edge” of the modeling domain) for modeling. Boundary conditions included 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) were used for model calibration. Measured river temperatures are assumed to represent thalweg temperatures.

### 6.2.1 Available Water Temperature Data

Historical water temperature data from the mainstem Tuolumne River and on the principal tributaries were assembled from 2005 through 2014. These data are summarized in Table 6.2-1. These data are assumed to have undergone some level of QA/QC; however, the metadata associated with these programs were 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.

**Table 6.2-1. Historical water temperature data in the study area (pre-2015).**

| Station #/Label | Agency | Active | Site Location/Name |
|---|---|---|---|
| **Tuolumne River** | | | |
| TR105.0 | CDFG | 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 Wards Ferry |
| TR078.7 | CDFG | No | Tuolumne River upstream of Wards Ferry Bridge |
| 11285500 | USGS | Yes | Tuolumne River at Wards Ferry Br near Groveland, CA |
| **Cherry Creek** | | | |
| 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 |
| **Eleanor Creek** | | | |
| 11278000 | USGS | Yes | Eleanor Creek near Hetch Hetchy, CA |
| EC01.8 | CCSF | No | Eleanor Creek, upstream of Miguel Creek confluence |
| EC01.7[2] | 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 |
| **South Fork Tuolumne** | | | |
| SFT00.2 | CCSF | Yes | South Fork Tuolumne River near 1N10 Bridge |
| SFT00.2 | CDFG | No | South Fork of the Tuolumne River near confluence |
| **Clavey River** | | | |
| CR16.9 | CCSF | No | Clavey River at 1N04 Bridge |
| CR00.3 | UC Davis | No | Clavey River, upstream of Tuolumne River confluence |
| **North Fork Tuolumne** | | | |
| NFT00.1 | UC Davis | No | North Fork Tuolumne River near confluence |

[1] CCSF had three loggers in this area.

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 6.2-2). 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.

**Table 6.2-2. Additional water temperature monitoring locations in 2015 and 2016.**

| Logger Location | RM | Water Temp. | Stream Stage[1] | Data Start | Data End | Continuous Data Set |
|---|---|---|---|---|---|---|
| TR above North Fork | TR 81.3 | X | X | 4/29/2015 | 10/4/2016 | Yes |
| TR above Clavey River | TR 91.1 | X | X | 6/17/2015 | 10/4/2016 | No |
| TR above South Fork | TR 97.0 | X | X | 4/30/2015 | 10/12/2016 | Yes |
| TR below Early Intake | TR 105.2 | X | - | 4/30/2015 | 10/12/2016 | Yes |
| North Fork above TR | NF 0.1 | X | X | 4/29/2015 | 10/4/2016 | No |
| North Fork at RM8 Bridge | NF 8.0 | X | X | 4/28/2015 | 8/23/2016 | No |
| Clavey River above TR | CR 0.1 | X | X | 4/29/2015 | 10/4/2016 | No |
| Clavey River at USFS Bridge (1N01) | CR 8.4 | X | X | 4/28/2015 | 10/11/2016 | Yes |
| Clavey River at USFS Bridge (1N04) | CR 16.9 | X | X | 6/16/2015 | 10/11/2016 | Yes |
| South Fork above TR | SF 0.1 | X | X | 4/30/2015 | 10/12/2016 | No |
| Cherry Creek above TR (bel PH) | CC 0.6 | X | - | 4/30/2015 | 10/12/2016 | Yes |
| Cherry Creek above HPH | CC 2.0 | X | - | 4/29/2015 | 10/12/2016 | Yes |

[1] "X" = Data collected; "-" = Data is not being collected at this location.

Where field observations were unavailable, water temperature values were calculated using the equilibrium temperature (Teq) model where temperature is a function of meteorology and flow. This is consistent with the approach taken in previous modeling efforts (Jayasundara et al. 2014). The previous equilibrium temperature model calibration, which had been calibrated for years 2008 through 2012 in the previous study, was updated with the new flow and meteorological data through 2016. During the updating process, model parameter values and the assumptions/corrections, i.e., snowmelt season correction and winter correction made in the previous study, were not changed.

In the previous study (Jayasundara et al. 2014), the assignment of the temperatures for Clavey River and North Fork Tuolumne River were based on regression equations between these tributaries and the South Fork Tuolumne River. The regression equations were based on the temperature data, which were available for each of those tributaries in 2009. In this study, the regression equations mentioned were updated with the additional data measured in 2015 (thereafter measured data were employed where available). For the minor tributaries that were represented in the RMA-2 model, no temperature data were assigned in the RMA-11 model: minor tributaries were assumed to enter the river at the temperature of the mainstem Tuolumne River. During warmer summer and fall periods the flow in these tributaries is very small and the impact on mainstem water temperature is negligible.

### 6.2.2 Available Temperature Calibration Data

For temperature calibration, non-continuous temperature data at various locations along the upper Tuolumne River reach from 2008 to 2016 were available. These data are summarized below (Figure 6.2-1).

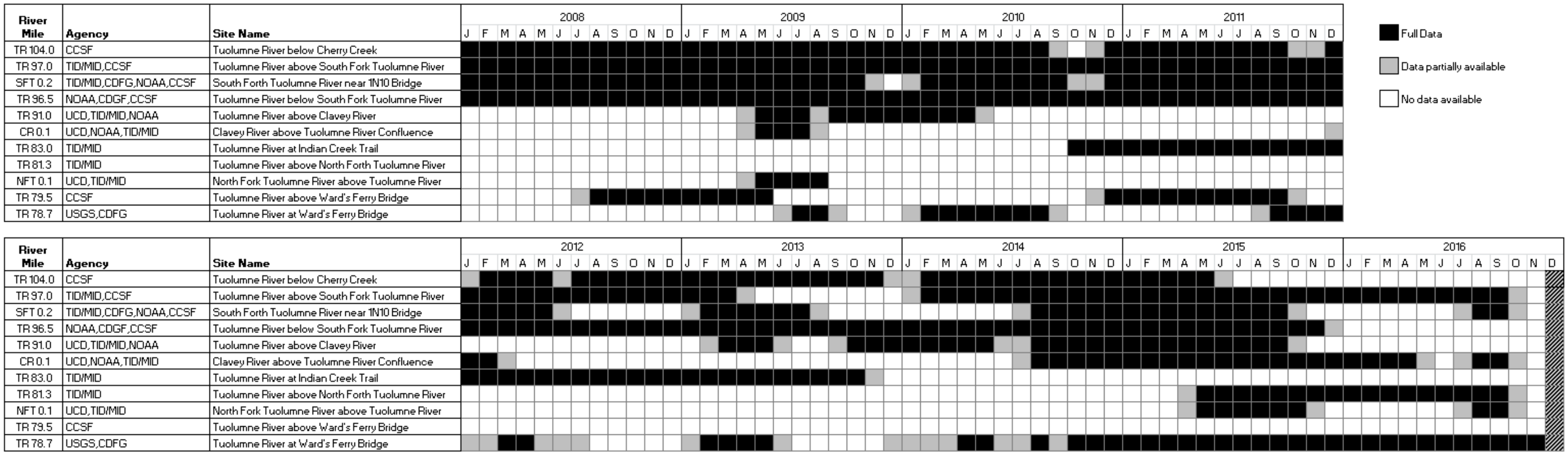

**Figure 6.2-1. Summary of water temperature calibration data from 2008 to 2016.**

## 6.3 Geometry Data Requirements for Modeling

The numerical models used in this study required a detailed description of the stream's physical characteristics: planform, gradient, and cross-section data. Geometric data, described below, were assumed "static" for the purpose of this modeling effort (i.e., sediment transport and associated changes in bed morphology are not assessed).

- (x-y): a plan view of the river, generally 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 consists 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 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 are:
  - 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.

### 6.3.1 Available Geometry Data

Planform, gradient, and cross section data were available for the mainstem Tuolumne River from previous modeling efforts (Jayasundara et al. 2017; TID/MID 2017f; Jayasundara et al. 2014; McBain and Trush unpublished data). Tributary data were developed from available sources. Specifics with regard to available planform, gradient, cross section, and topographic and riparian vegetation data are addressed below.

#### 6.3.1.1 Planform

Planform river course data were available throughout the study reach. Planform information from existing modeling efforts was used for the mainstem Tuolumne River. An example of planform data for the mainstem Tuolumne River in the study reach is shown in Figure 6.3-1.

Tributary representations were 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 were made to the Tuolumne River from Early Intake to above the Don Pedro Project Boundary.

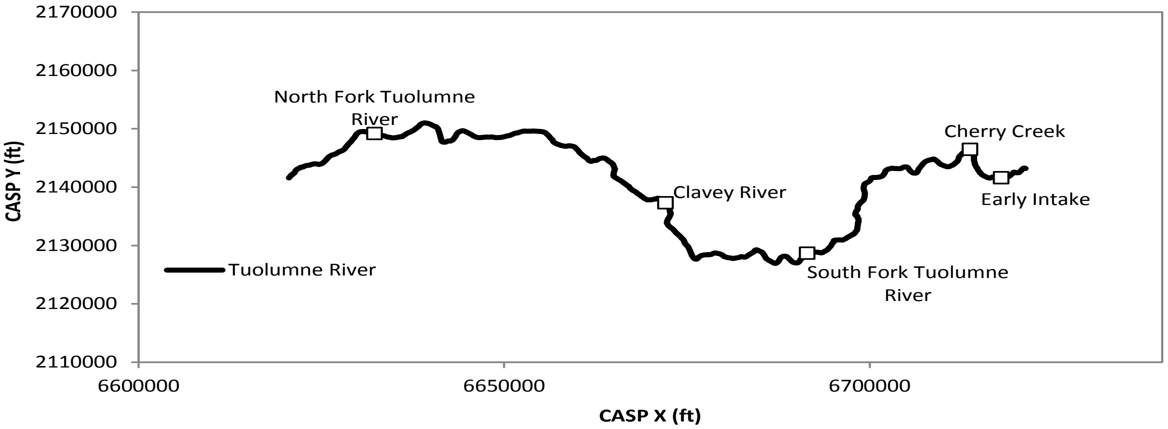

**Figure 6.3-1.** **Planform representation of the Tuolumne River from above Early Intake to above the Don Pedro Project Boundary, including the locations of major tributaries.**

### 6.3.1.2 Gradient

River profile data were available throughout the study reach and were 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 6.3-2. Information from existing modeling efforts was used for the mainstem Tuolumne River. To the extent these data provided additional information to the mainstem, appropriate refinements were made to the Tuolumne River from Early Intake to above the Don Pedro Project Boundary.

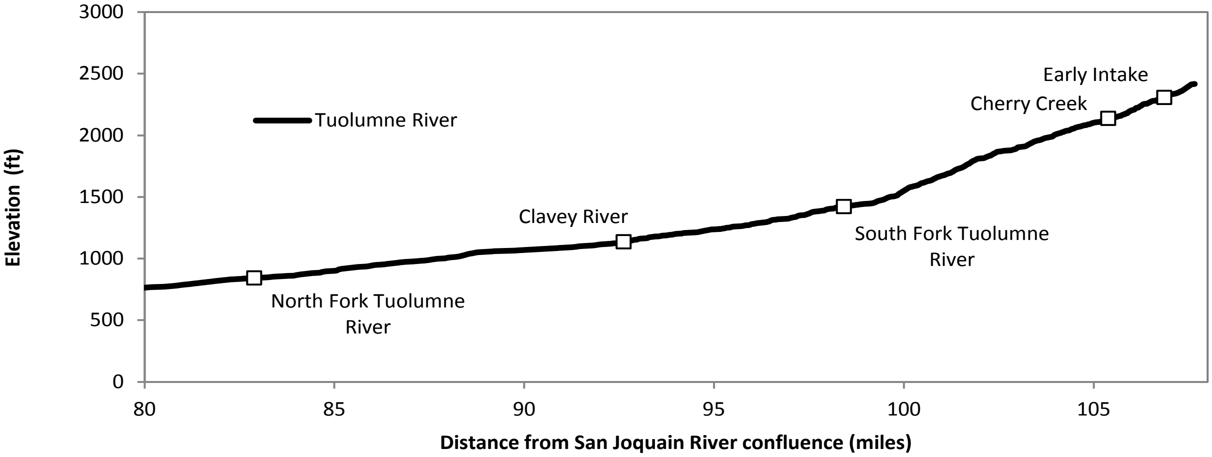

**Figure 6.3-2.** **Longitudinal elevation profile (gradient) of Tuolumne River from above Early Intake to above the Don Pedro Project Boundary, including the locations of major tributaries.**

### 6.3.1.3 Cross Sections

Cross section information from existing modeling efforts were used for the mainstem Tuolumne River. To the extent these data provided additional information to the mainstem, appropriate refinements were made to the Tuolumne River from Early Intake to above the Don Pedro Project Boundary. An example of cross section data represented in the model is shown in Figure 6.3-3.

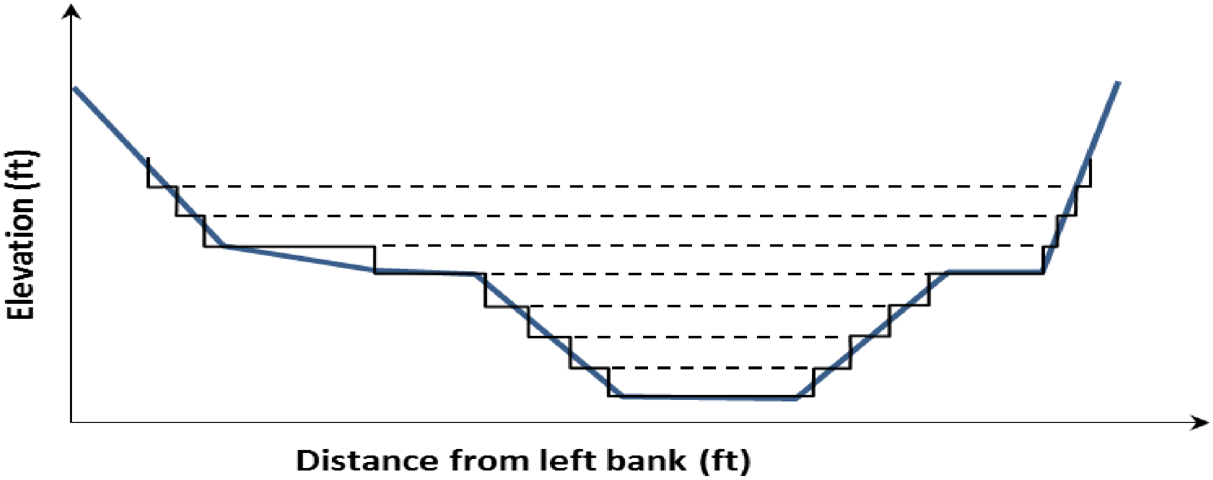

**Figure 6.3-3. Example of a cross-section representation in the RMA-2 and RMA-11 models (looking downstream).**

### 6.3.1.4 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 was minimal for several reasons. For example, 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 was discontinuous or sporadic, and did 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 would not represent a condition necessary for persistent reduction in water temperature during the warmer periods of the year. 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 winter high flow 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 6-.3-4). These attributes occur both on the mainstem and tributaries throughout the study reach.

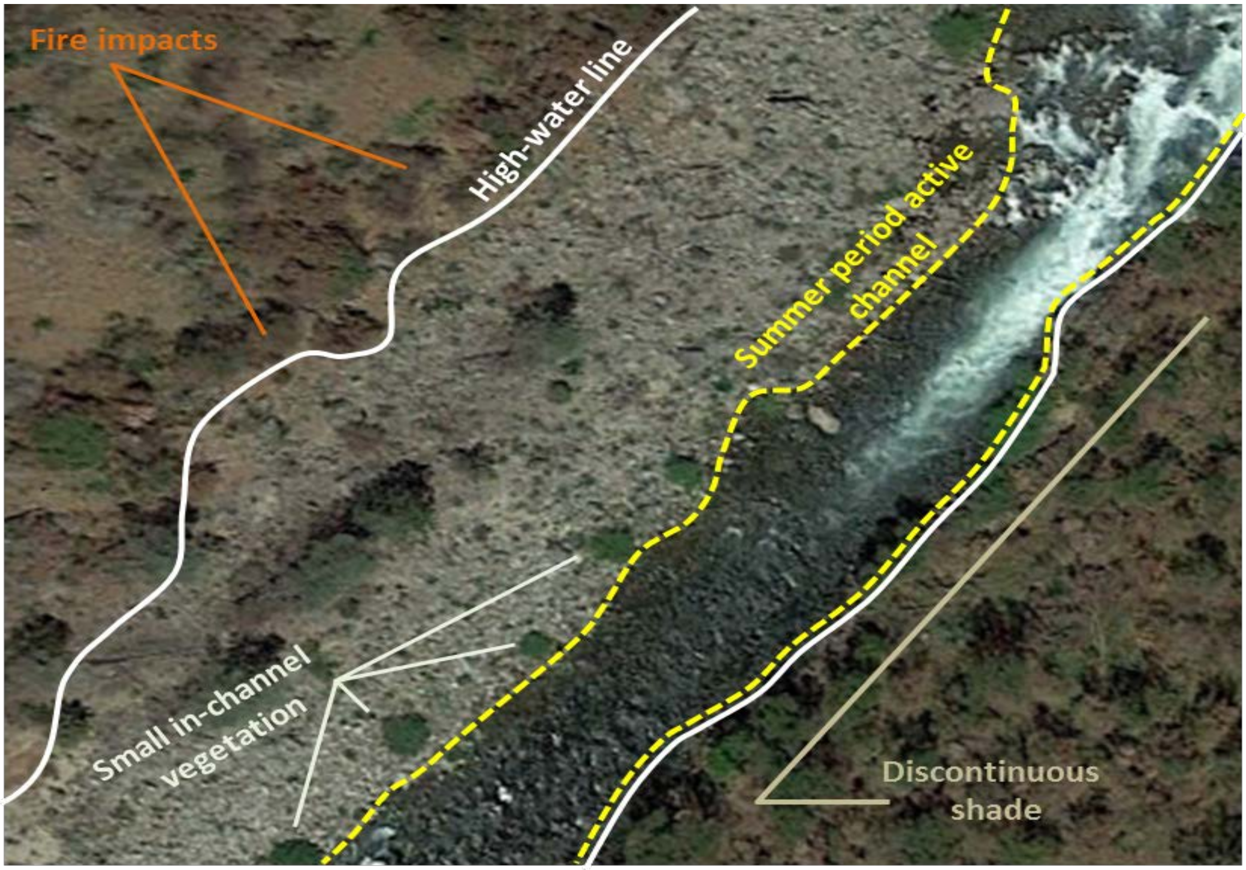

**Figure 6.3-4. Attributes limiting effects of riparian vegetation shading on water temperature conditions, Tuolumne River below Cherry Creek confluence.**

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 6.3-5). Using the U.S. Forest Service Remote Automated Weather Station (RAWS), solar radiation data were downloaded for a representative day (July 3, 2015) from the Smith Peak station. These data are plotted in Figure 6.3-6, 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.

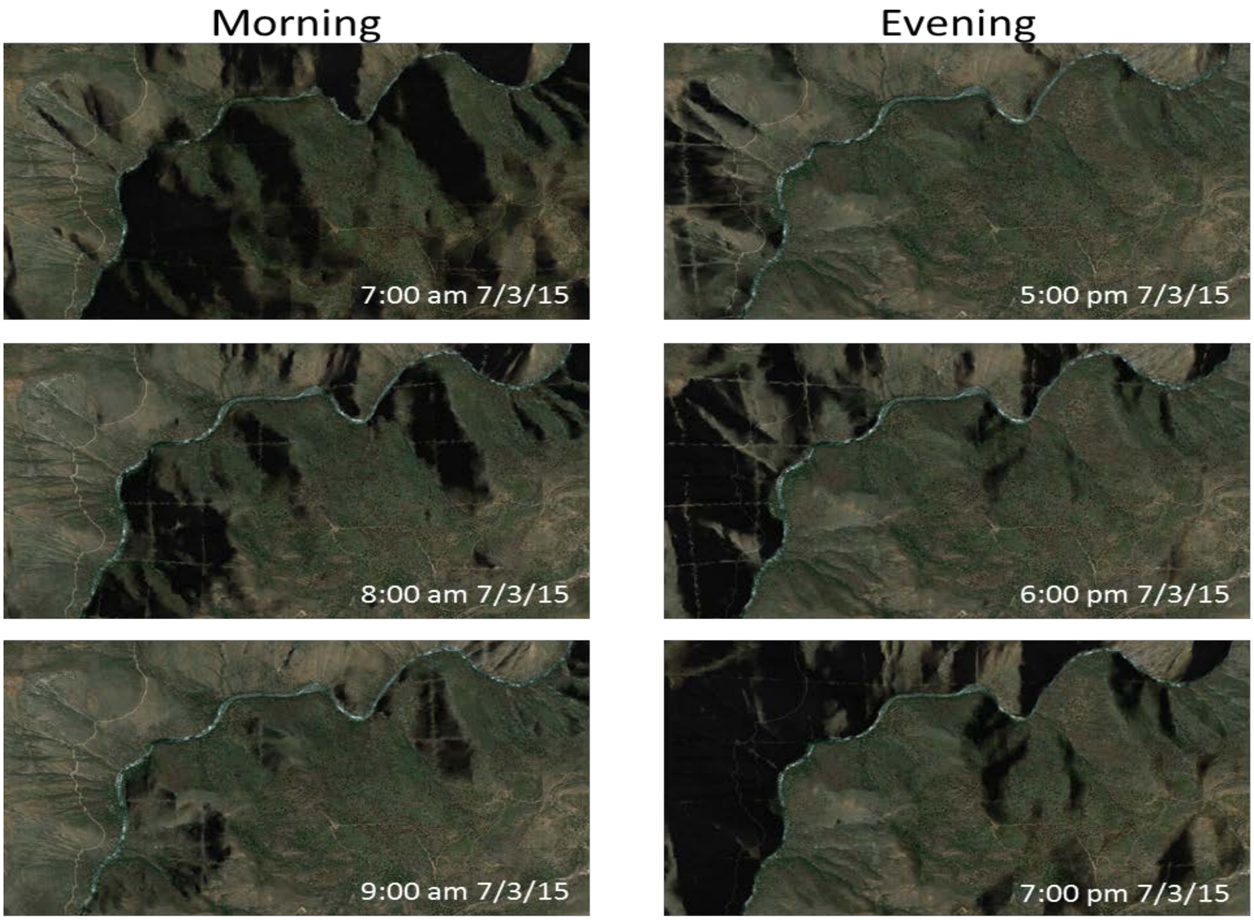

**Figure 6.3-5.** **Morning and evening on a representative reach of the Tuolumne River in the study area, July 3, 2015 (Source: Google Earth terrain-shade model).**

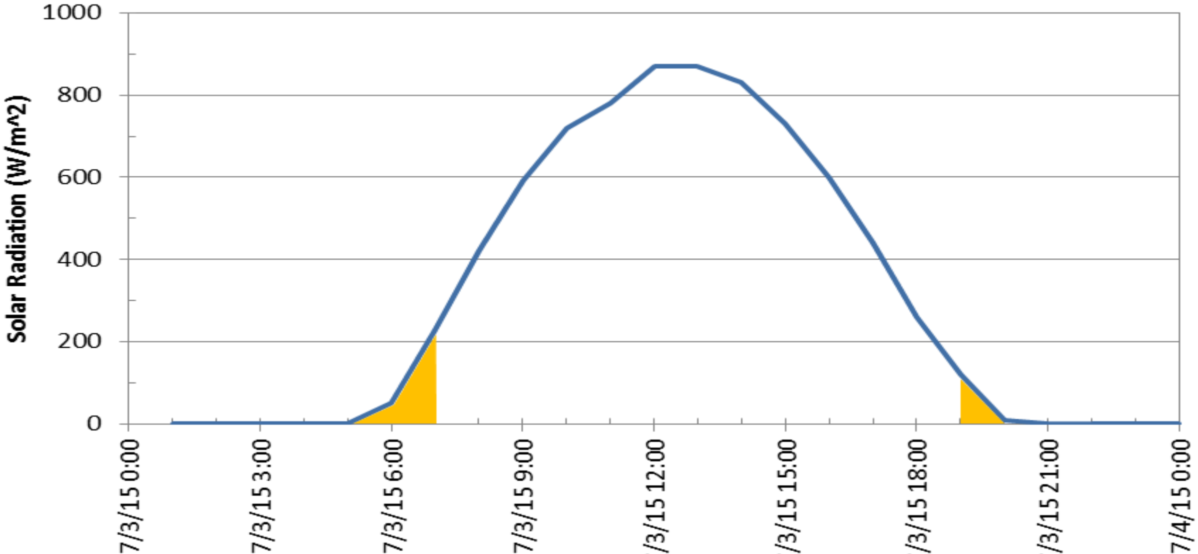

**Figure 6.3-6.** **Smith Peak solar radiation, July 3, 2015. (NWS ID#: 044115, http://www.raws.dri.edu). Orange ranges indicate approximate topographic-shaded periods of the day.**

### 6.3.2 Model Geometry Refinement

For this study, the upstream end of the previous upper Tuolumne River model reach (Jayasundara et al. 2014), between O'Shaughnessy Dam and Don Pedro Reservoir was changed such that the new model grid began just below Early Intake. The new model grid outline, embedded in Google Earth (GE) image showing the river reach between Early Intake and Wards Ferry Bridge, is included in Figure 6.3-7.

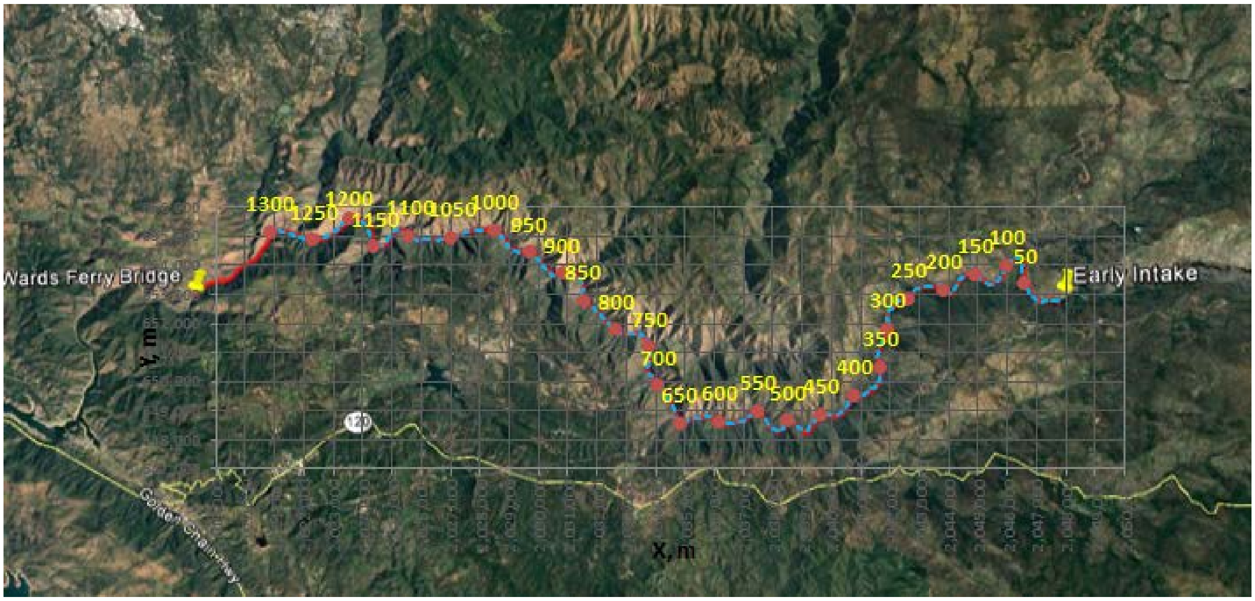

**Figure 6.3-7. Model grid (dashed blue line) and Google Earth path (red line) of the upper Tuolumne River between Early Intake and Wards Ferry Bridge. Node numbers are indicated in every 50 nodes.**

The elevations of the upstream end and the downstream end of the model grid were 2,323 ft and 832 ft, respectively. This grid was separated into two sub-reaches to represent different meteorology conditions over the appreciable elevation difference based on the average overall reach elevations (i.e., 1,578 ft). The upper sub-reach included model nodes 1 to 360 while the lower reach included model nodes from 361 to 1307. Five different element types based on the reach types in the previous model grid (Jayasundara et al. 2014) were assumed for the new model grid. Cross sections in the previous model grid (Jayasundara et al. 2014) were modified slightly to accommodate additional insight regarding the channel form from field visits and measurements. Widths at the two most bottom depths (bottom 0.5 meters) were increased 15 percent, and higher widths increased by 10 percent.

## 6.4 Meteorological Data Requirements

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

### 6.4.1 Available Meteorological Data

Meteorological data were applied throughout the model calibration phase. To represent sub-daily conditions, data were input as an hourly time series. These data sets were adjusted for reach-specific elevations. Two meteorological data “zones” were assumed in the model to represent local conditions over the longitudinal and vertical ranges of the model domains. One zone was applied for the upper sub-reach of the upper Tuolumne River reach and the other zone was employed for the lower sub-reach of the upper Tuolumne River reach. The upper sub-reach and the lower sub-reach meteorological zones had representative elevations of 1,951 feet and 1,205 feet, respectively. Both representative elevations were the average of the elevations of the upstream end(s) and the downstream end(s) of the sub-reaches. These meteorological zones were specified in the model input files to automatically apply the appropriate meteorological conditions on a reach specific basis. All data were formatted for RMA-11 and the appropriate input files constructed.

Hourly meteorological data for the project area were gathered from three meteorological stations. While data for years 2008 and 2009 were developed by McBain and Associates Ltd/SFPUC, the rest of the data for the model years from 2010 through 2016 were developed by Watercourse Engineering, Inc. Information on the meteorological stations are presented in Table 6.4-1.

**Table 6.4-1. Meteorological data stations, operating agency and parameters for each model year.**

| Year | Station Name (Agency)[1] | Parameters[2,3] |
|---|---|---|
| 2008 | Buck Meadows (WRCC) | Ta, WS(01/01 through 06/24) |
| | Modesto (CIMIS) | WS (06/25 through 12/31), SR |
| 2009 – 2011 (incl.) | Buck Meadows (WRCC) | Ta |
| | Modesto (CIMIS) | WS, SR |
| 2012[4] | Buck Meadows (WRCC) | Ta(01/01 through 06/11) |
| | Smith Peak (MesoWest) | Ta(06/28 through 12/31) |
| | Modesto (CIMIS) | WS, SR |
| 2013 -2016 (incl.) | Smith Peak (MesoWest) | Ta |
| | Modesto (CIMIS) | WS, SR |

[1] WRCC: Western Regional Climate center, CIMIS: California Irrigation Management Information System, MesoWest: University Of Utah, Department of Atmospheric Sciences.

[2] Ta: Air Temperature, WS: Wind Speed, SR: Solar Radiation. Wet bulb Temperature is calculated with the Ta data at the representative elevations of each meteorological zone. Cloudiness is calculated out of SR data. Atmospheric Dust Attenuation values are set to 0.06 for all meteorological zones.

[3] Unless it is noted in parentheses, data duration is whole year.

[4] Air Temperature gap between 06/11 and 06/28 were filled by the average of Air Temperature at “neighbor” hours, i.e., the hours with equal hour differences to the start and to the end of the gap.

Air temperature data gathered from two meteorological stations listed above (Buck Meadows and Smith Peak) were adjusted for the two meteorological zones based on the lapse rate, which is described in the section below. After the adjustment, wet bulb temperatures were calculated for each meteorological zone accordingly.

#### 6.4.1.1 Lapse Rate

Lapse rate describes air temperature changes with respect to elevation. The air temperature in higher elevations is generally lower than air temperature at lower elevations (Linacre 1992, Holman 1976). Elevations of Buck Meadows and Smith Peak meteorological stations are reported as 3,200 feet and 3,870 feet, respectively. Air temperature for each zone was estimated based on adjustments for the altitude change (lapse rate) between the stations' elevations and the representative elevations of the zones. A lapse rate of $6^{o}$C per 3,128 feet of elevation change was applied (Linacre 1992).

### 6.4.1.2 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 6-1. Wet bulb temperatures are calculated to accommodate changes in air temperature (based on the aforementioned lapse rates) and barometric pressure with elevation.

$$e\left(Twb,Ta,P\right)=\left(6.108\exp\left(\begin{cases}\dfrac{17.27Twb}{Twb+237.3} & Twb\geq 0\\ \dfrac{21.875Twb}{Twb+265.5} & Twb<0\end{cases}\right)\right)-0.00066\left(1+0.00115Twb\right)\left(T_a-Twb\right)P$$

**Equation 6-1.**

# 7.0 MODEL IMPLEMENTATION

Model implementation consisted of assembling the aforementioned data into the proper format for RMA-2 and RMA-11, and selecting default model coefficients and parameters. Specific tasks included:

- constructing the appropriate geometric representation of the river and creating a geometry input file with RMAGEN. Shading characteristics were also formulated for the river reaches;
- assigning representative meteorological data to the individual meteorological zones; and
- formulating boundary conditions for flow (Figure 7.0-1) and temperature (Figure 7.0-2) for appropriate model inflows.

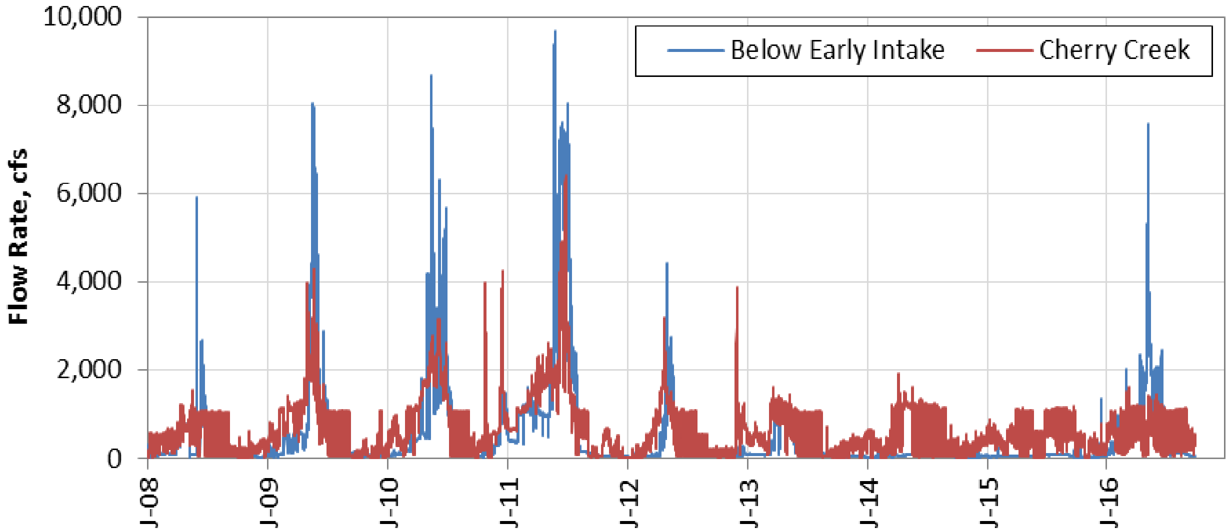

**Figure 7.0-1. Flow Boundary Conditions below Early Intake and at Cherry Creek Tributary**

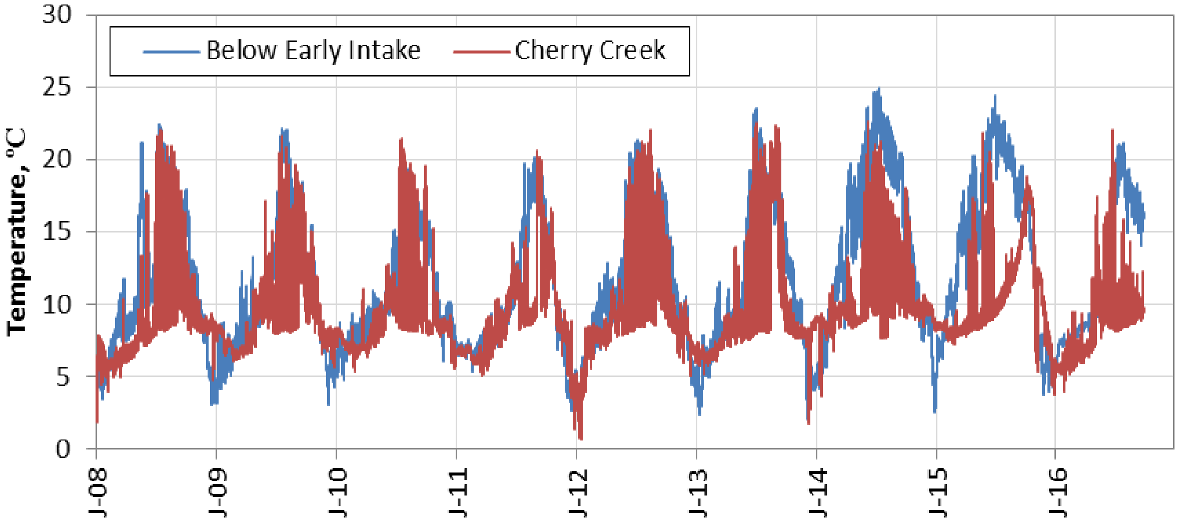

**Figure 7.0-2. Water Temperature Boundary Conditions below Early Intake and at Cherry Creek Tributary**

This process was completed with the outcome being a functional, but uncalibrated model. The next model implementation step is to test the model with theoretical parameter and available data. The accuracy of the model results are of secondary importance at this step. After the model implementation step, the model is ready to be calibrated.

Since this project adopted previous modeling efforts in the study reach (Jayasundara et al. 2017), model implementation consisted principally of grid refinement, wherein the model was applied only to the Early Intake to Wards Ferry reach of the Tuolumne River. All major tributaries were represented as inflow to the mainstem. While the monitoring program collected sufficient data to support tributary modeling, the barriers assessment (TID/MID 2017d) indicated that reintroduction efforts would likely be limited to the mainstem Tuolumne River between Early Intake to above Don Pedro Reservoir.

# 8.0 MODEL CALIBRATION

Following model implementation described above, adjustments were made to specific model coefficients and parameters to calibrate the model to observed data for the period 2008 to 2016. Seven calibration locations were assessed based on available/provided data: below Cherry Creek, above South Fork Tuolumne River confluence, below South Fork Tuolumne River confluence, above Clavey River, below Indian Creek, and above North Fork Tuolumne River confluence, and above Wards Ferry.

Model results were assessed graphically and with summary statistics. Graphical assessment included a visual comparison of simulated and observed time series to qualitatively examine temporal response of the model over a range of time scales ranging from seasonal to sub-daily. Summary statistics were calculated to quantitatively assess model performance, and included mean bias, mean absolute error (MAE), and root mean squared error (RMSE) (Deas and Lowney 2000). Mean bias yields insight on systematic error and ideal values are near zero. MAE indicates overall model performance as a deviation from zero. Finally, RMSE can assist in identifying large deviations from observed data.

Included herein is the graphical presentation of the calibration results for 2015, which are representative of the calibration process for the other years. The remaining calibration graphs for the other years are included in Attachment E.

## 8.1 Flow Calibration

Flow calibration was completed in the previous round of modeling (Jayasundara et al. 2014), but was updated herein to include additional simulation years. In this model, available pressure data from transducers installed by HDR were used to refine flow calibration of the model. In addition, flow data at Wards Ferry from 2013 to 2016, for periods when reservoir storage did not adversely impact the record, were used to verify the flow calibration.

### 8.1.1 Flow Calibration using Pressure Data

Flow calibration was performed for the 2015 through 2016 period at two locations where pressure transducer data (relative stage) were available: (1) above the South Fork Tuolumne River confluence and (2) the above North Fork Tuolumne River confluence.

Model parameters employed in the Tuolumne River flow calibration included reach slope factors and Manning's roughness coefficients. Eddy viscosity was generally insensitive to changes and was not used in flow calibration. Slope factors were employed to represent different stream morphology units, such as pools, runs, low and high gradient riffles, and steep rapids or cascades. These factors reduce the effective slope of the stream to more realistically represent water surface slopes in the hydrodynamic model, leading to more representative depths and travel times. In steep reaches, the slope factors play a larger role, while in low gradient reaches, they play a smaller role.

The final slope factor values for each reach type are presented in Table 8.1-1. In this modeling study, depth-variable logic for Manning coefficients was used. Depth versus Manning coefficient used in the model is included in Figure 8.1-1.

**Table 8.1-1. Model parameters used in the upper sub-reach and the lower upper-reach of upper Tuolumne flow calibration.**

| Cross Section Type | Element Type No. | Slope Factor |
|---|---|---|
| Pool | 1 & 6 | 0.850 |
| Run | 2 & 7 | 0.880 |
| Low Gradient Riffle | 3 & 8 | 0.910 |
| High Gradient Riffle | 4 & 9 | 0.940 |
| Rapids (Cascade) | 5 & 10 | 0.970 |

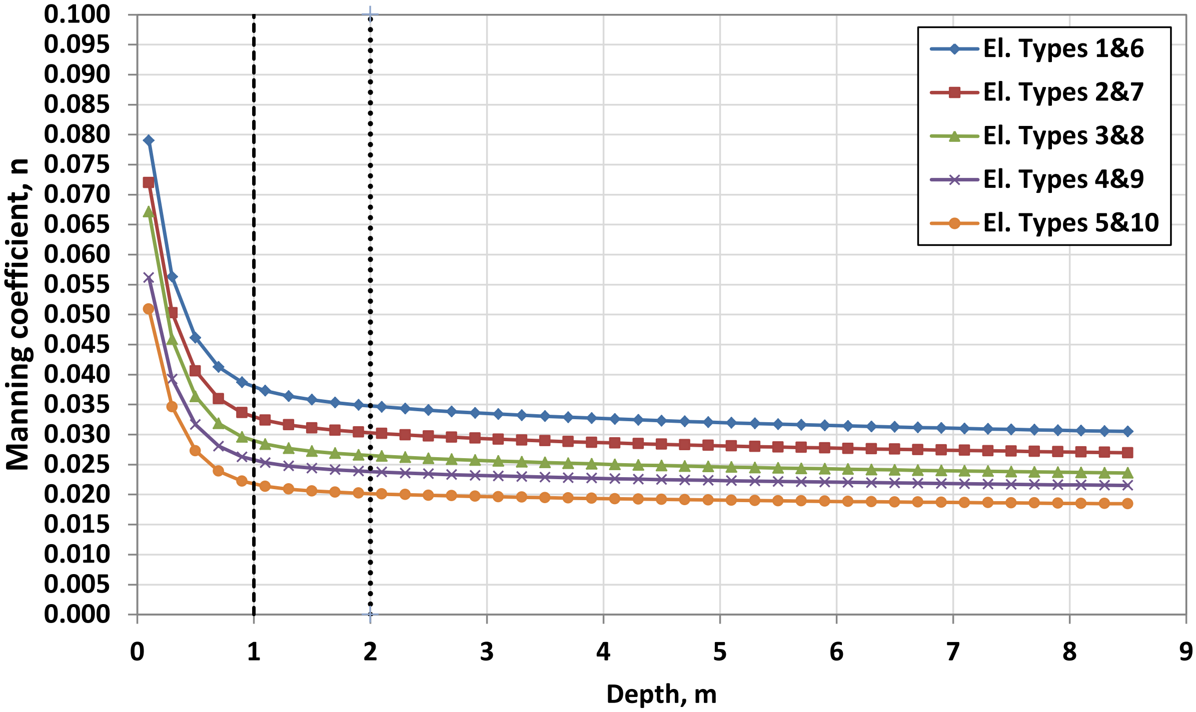

**Figure 8.1-1. Variable Manning coefficient versus depth representation.**

Model performance was assessed for stage at two intermediate locations (above the South and North Fork Tuolumne Rivers (2015-16). Graphical model performance for the Upper Tuolumne River calibrations are presented below (Figure 8.1-2 and Figure 8.1-4). The period between 7/25/2015 to 8/4/2015 are also presented to illustrate the replication of complex peaks (Figure 8.1-3 and Figure 8.1-5).

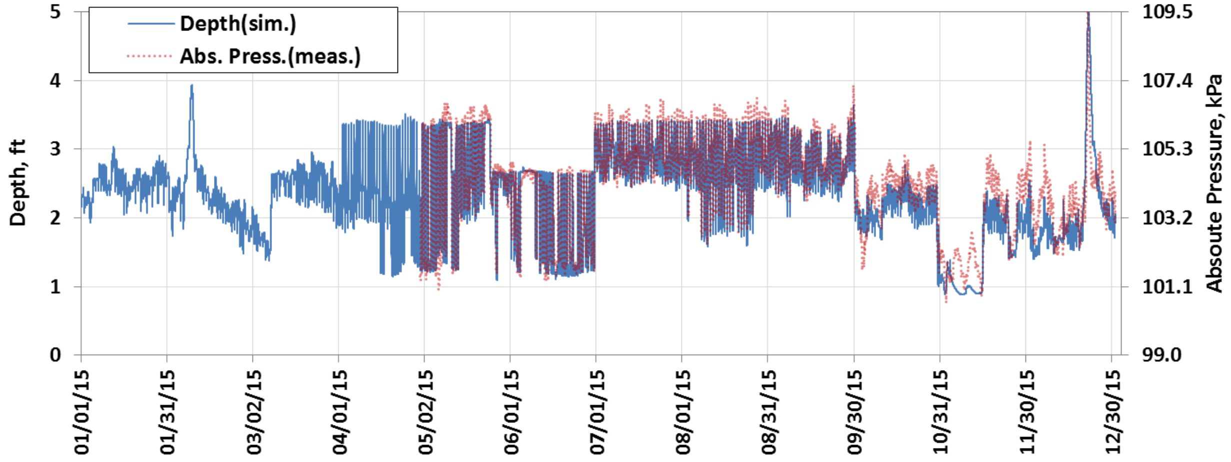

**Figure 8.1-2.** **Comparison of depth and absolute pressure above South Fork Tuolumne River confluence in 2015**

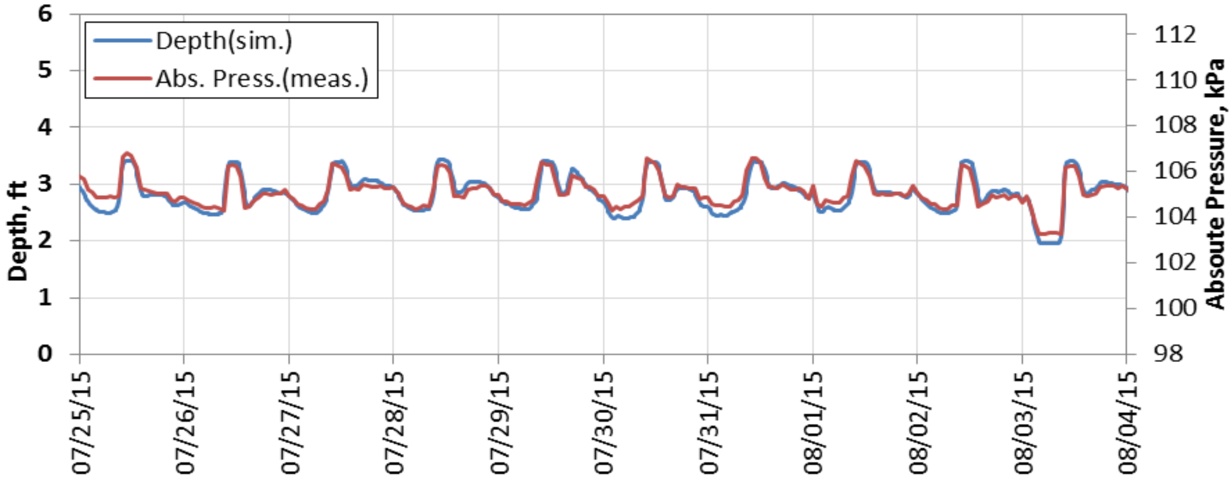

**Figure 8.1-3.** **Comparison of depth and absolute pressure above North Fork Tuolumne River confluence. 07/25 – 08/04, 2015.**

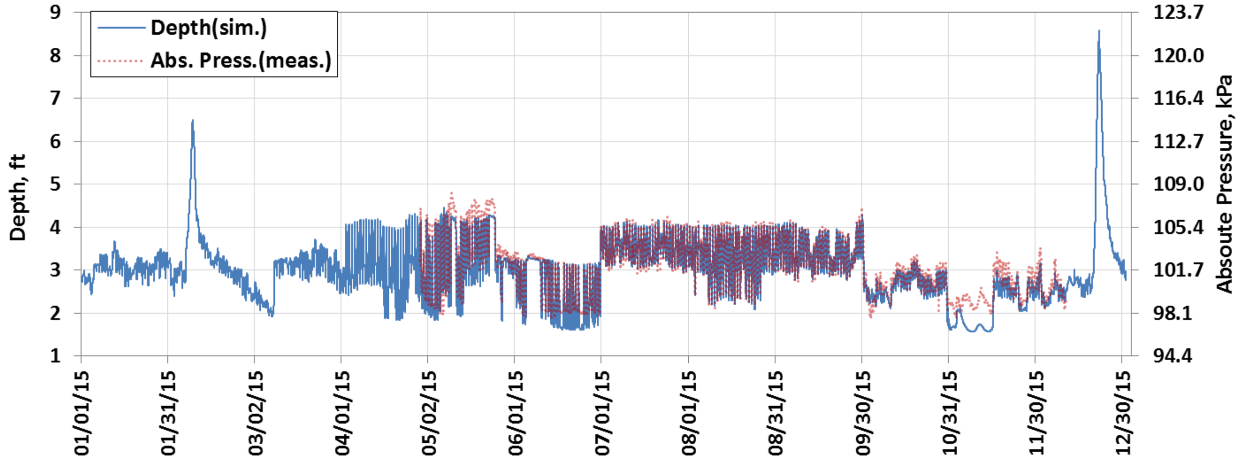

**Figure 8.1-4.** **Comparison of depth and absolute pressure above North Fork Tuolumne River confluence in 2015**

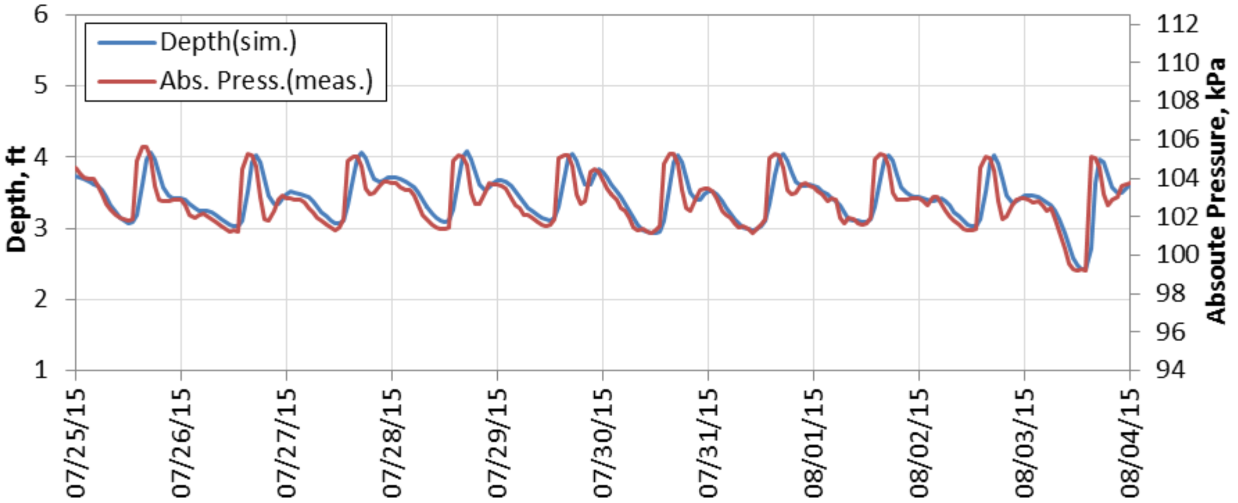

**Figure 8.1-5.** **Comparison of depth and absolute pressure above North Fork Tuolumne River confluence. 07/25 – 08/04, 2015.**

These visual comparisons suggest that the model performed well in replicating the flow conditions along upper Tuolumne River. These comparisons were made along the Tuolumne River above the South Fork Tuolumne River confluence and the North Fork Tuolumne River confluence, which were chosen because pressure transducer data were available. At both locations, the flow patterns that were captured in the measured pressure data closely match the pattern of the simulated depth measurements.

### 8.1.2 Flow Calibration at Wards Ferry

Model performance was also assessed for flow at Wards Ferry. The following comparisons of simulated and measured flow at Wards Ferry indicate that flow calibration allowed simulated flow to replicate actual flows (Table 8.1-2, and Figures 8.1-6 through 8.1-9).

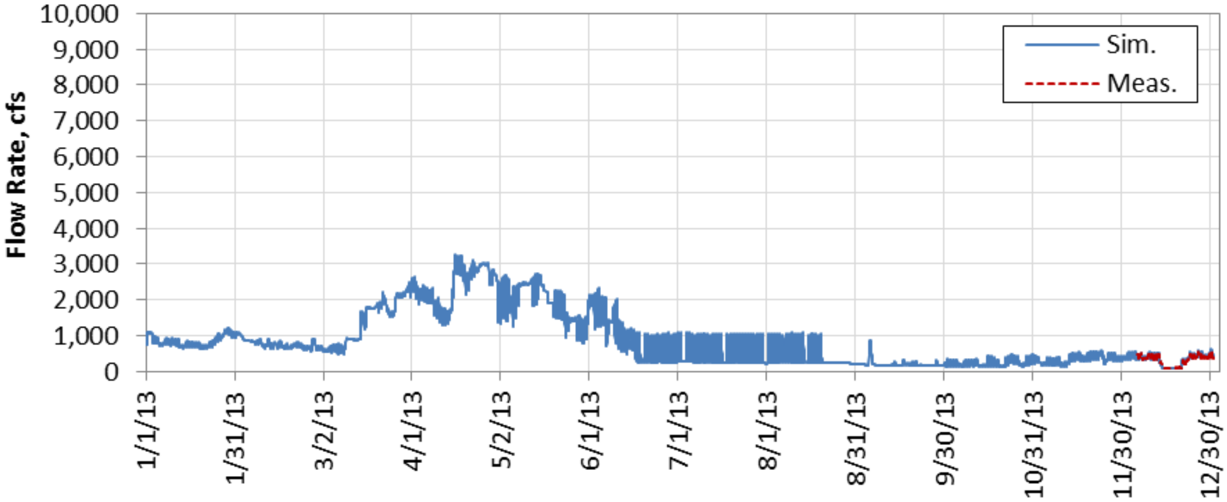

**Figure 8.1-6.** **Simulated flow versus measured flow in Tuolumne River at Wards Ferry Bridge. 2013.**

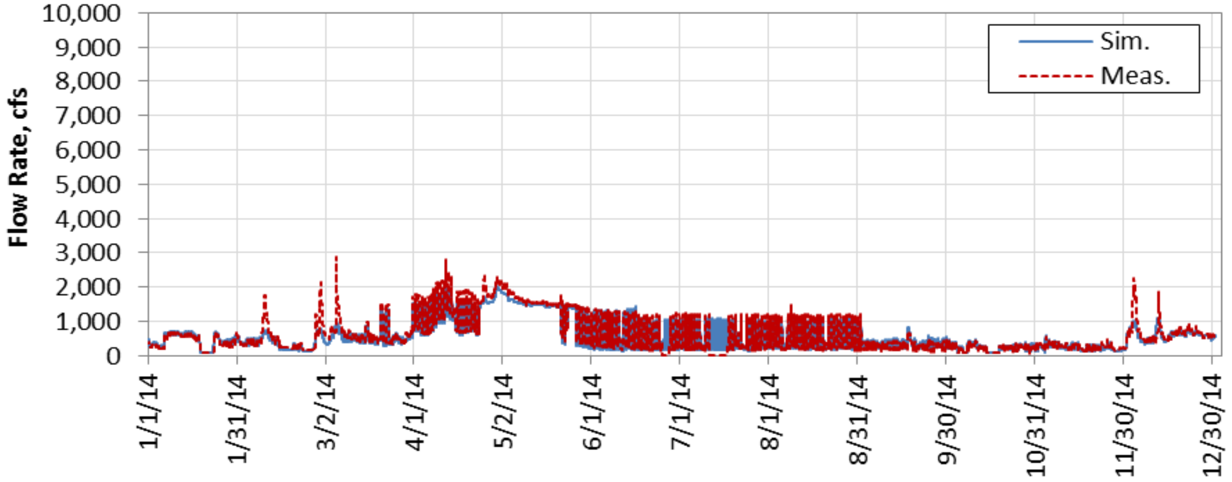

**Figure 8.1-7.** **Simulated flow versus measured flow in Tuolumne River at Wards Ferry Bridge. 2014.**

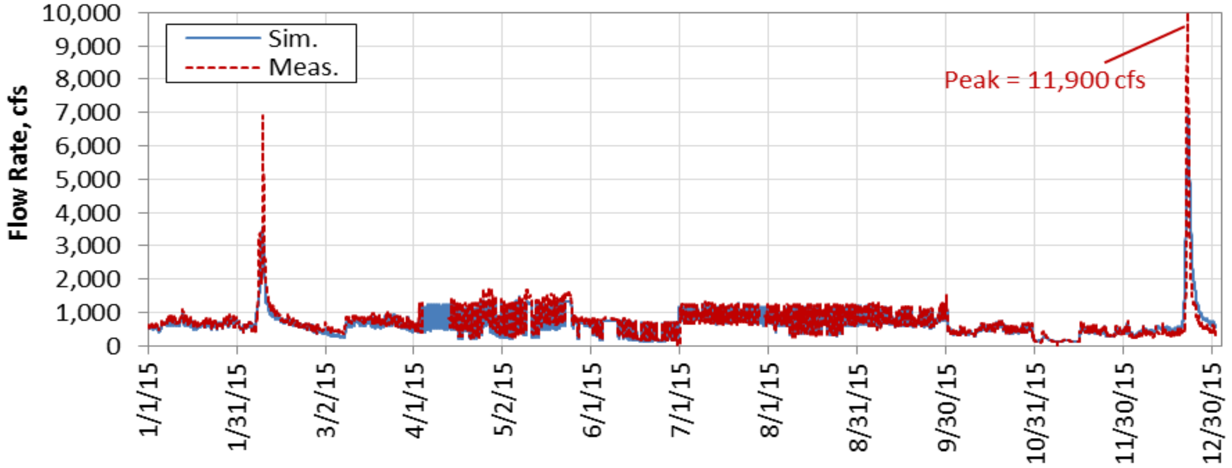

**Figure 8.1-8.** **Simulated flow versus measured flow in Tuolumne River at Wards Ferry Bridge. 2015.**

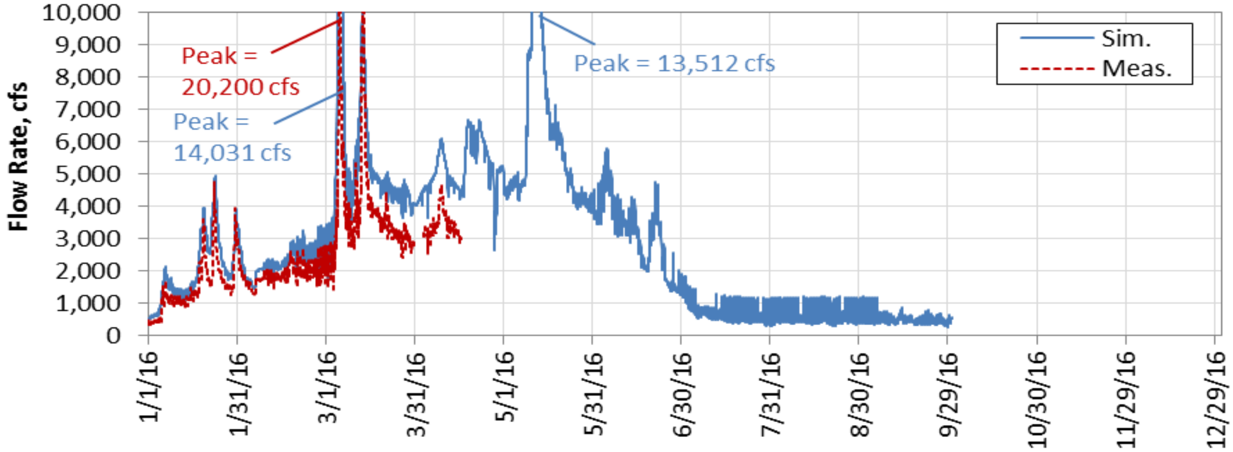

**Figure 8.1-9.** **Simulated flow versus measured flow in Tuolumne River at Wards Ferry Bridge. 2016.**

**Table 8.1-2. Flow Rate (cfs) statistics in Tuolumne River at Wards Ferry Bridge. 2013 – 2016.**

| Year | Mean Bias | Mean Absolute Error (MAE) | Root Mean Squared Error (RMSE) | Count |
|---|---|---|---|---|
| 2013 | 19.49 | 29.98 | 37.41 | 625 |
| 2014 | -41.26 | 77.17 | 153.94 | 8568 |
| 2015 | -36.61 | 92.60 | 259.04 | 8471 |
| 2016 | 628.69 | 690.09 | 1130.48 | 1751 |

Flow calibration performance was evaluated visually and statistically. Visual comparisons between simulated and measured flow data in Tuolumne River at Wards Ferry suggest that the model closely replicates the measured flow conditions in the river in 2013, 2014 and 2015. In these years, the statistical biases and errors were also low. However, the model seemed to have consistently over-predicted the flows in 2016. This is likely due to the high water surface elevation in Don Pedro Reservoir as a result of higher flows in 2016. The higher water level in the reservoir causes inundation at Wards Ferry. This may have caused inaccurate flow measurements at Wards Ferry.

## 8.2 Temperature Calibration

Temperature calibration involved simulating the models over the nine years when sufficient data were available to run the model and compare model output to measured data. Selected model parameters were adjusted to reduce the difference between simulated and observed data at these calibration locations. Model parameters that were adjusted included:

- Manning roughness or bed slope (to evaluate travel time, see above);
- evaporative heat flux coefficient *a* and *b*;
- dead pool area (area below zero flow); and
- bed conduction.

Evaporative heat flux coefficients, $a$ (pressure$^{-1}$ L t$^{-1}$) and $b$ (pressure$^{-1}$), were both set to 6.0x10$^{-5}$ for the both sub-reaches/meteorological zones. Dead pool area was applied in model cross-sections to represent the potential increased thermal mass associated with such features. Specifically, these features typically have storage below zero flow stage and these volumes can have a notable effect on water temperature (see PCWA 2010). Pools had higher volumes than riffles, while higher gradient reach types were assigned much smaller values. Dead pool volumes used in the modeling are listed in Table 8.2-1.

Bed conduction can affect water temperatures, particularly during low flow conditions (Jobson 1977). Because bed temperatures vary seasonally, a step-function was used to define bed temperatures in the model (Table 8.2-2), while the bed conduction coefficient was maintained constant at 28.7 (W·m$^{-2}$ °C$^{-1}$). The upper Tuolumne River is largely bedrock controlled, and the model is sensitive to bed conduction parameters.

**Table 8.2-1. Dead pool area used in upper Tuolumne River (upper and lower sub-reaches) water temperature calibration.**

| Cross Section Type | Dead Pool Area[1] |
|---|---|
| Pool | Width at 1 m depth x 2.0 $m^2$ |
| Run | Width at 1 m depth x 1.0 $m^2$ |
| Low Gradient Riffle | From Node 1 through 81: 0.01 $m^2$<br>From Node 82 through 1307: Width at 1 m depth x 0.25 $m^2$ |
| High Gradient Riffle | From Node 1 through 81: 0.01 $m^2$<br>From Node 82 through 1307: Width at 1 m depth x 0.25 $m^2$ |
| Cascade | From Node 1 through 81: 0.01 $m^2$<br>From Node 82 through 1307: Width at 1 m depth x 0.25 $m^2$ |

**Table 8.2-2. Step function defines assumed seasonal bed temperature in the model (°C).**

| Date[1] | Temperature, °C |
|---|---|
| 1-Jan | 14 |
| 1-Mar | 14 |
| 30-Apr | 17 |
| 30-May | 21 |
| 28-Aug | 21 |
| 17-Oct | 20 |
| 27-Oct | 17 |
| 31-Dec | 14 |

[1] Dates for normal years. For leap years, all dates except the first and the last days of the year, should be read as one day prior.

Data were available at seven calibration locations on the mainstem Tuolumne River: (1) below the Cherry Creek confluence, (2) above the South Fork Tuolumne River confluence, (3) below the South Fork Tuolumne River confluence, (4) above the Clavey River confluence, (5) below the Indian Creek confluence, (6) above the North Fork Tuolumne River confluence, and (7) at Wards Ferry (USGS).

Data were not available at all locations for all years, but where data were available, graphical and statistical analysis were completed. For the Tuolumne River at Wards Ferry only periods when the reservoir did not inundate the gage were used for statistical analysis. (When the reservoir inundated this monitoring location, the temperature signal represented Don Pedro Reservoir thermal conditions, which were not modeled in this effort.)

As with flow, temperature calibration results for the 2015 year are presented herein and the remaining results are presented in Attachment E. Model calibration results are presented graphically for all locations in 2015. Summary statistics for all years at all locations are presented thereafter to illustrate model performance for all calibration years.

Temperature calibration statistics were calculated to quantitatively assess model performance. These include mean bias, mean absolute error (MAE), and root mean squared error (RMSE) (Deas and Lowney 2000). Mean bias yields insight on systematic error and ideal values are near zero. It is the difference between the average of simulated temperature and measured temperature for each modeled time step. MAE indicates overall model performance as a deviation from zero. Finally, RMSE can assist in identifying large deviations from observed data.

As a general guideline, water temperature target model performance is the following: mean bias below 1.0°C, MAE below 1.5°C and RMSE below 2.0°C.

### 8.2.1 Calibration Performance

Overall, the model simulated seasonal variations in diel range and overall tracked observed data well. Comparison of model simulated and measured water temperatures for 2015 are presented below, with the graphical presentation of model simulated results and measured data for other years included in Attachment E. The corresponding flow rates are presented in the secondary axis.

In general, simulated temperatures tracked observed water temperatures well. All locations reproduced inter-annual, seasonal, short term (days) and sub-daily conditions (Figures 8.2-1 through 8.2-7). Simulated temperatures at locations closer to the headwater boundary (Early Intake) matched measured data more closely than locations further downstream. For the Tuolumne River above the South Fork Tuolumne River (Figure 8.2-2), simulations closely tracked observed data, but were slightly cooler early in the year. Model performance was similar for the Tuolumne River above the Clavey River location. The model was still cooler in January and February, and also in mid- to late-June during a particularly low flow period. A few factors may contribute to this under-prediction. Model cross section geometry was unavailable in the study reach for low flow conditions (flows less than approximately 87 cfs at Early Intake (see Jayasundara et al. 2017). Thus, these extremely low flow conditions may not be completely represented in the current model geometric representation. Another possible explanation is that the temperature logger data may not be representative at low flows (e.g., collecting data in shallow water). This is less likely because this same temperature under-prediction occurs above the Clavey River, North Fork Tuolumne River, and at Wards Ferry.

Simulated water temperature at the Clavey River, North Fork Tuolumne River, and Wards Ferry all indicate similar model performance: slightly cooler in January, February, and in mid-to late June (Figure 8.2-4, Figure 8.2-6 and Figure 8.2-7). Throughout the other periods of the year, response to seasonal conditions, snowmelt, short-term meteorological events, and diel range are well represented at each location. Simulated water temperatures at the other calibration locations – below Cherry Creek (Figure 8.2-1), below South Fork Tuolumne River (Figure 8.2-3), and below Indian Creek (Figure 8.2-5) – that lack measured data in 2015 are included for completeness.

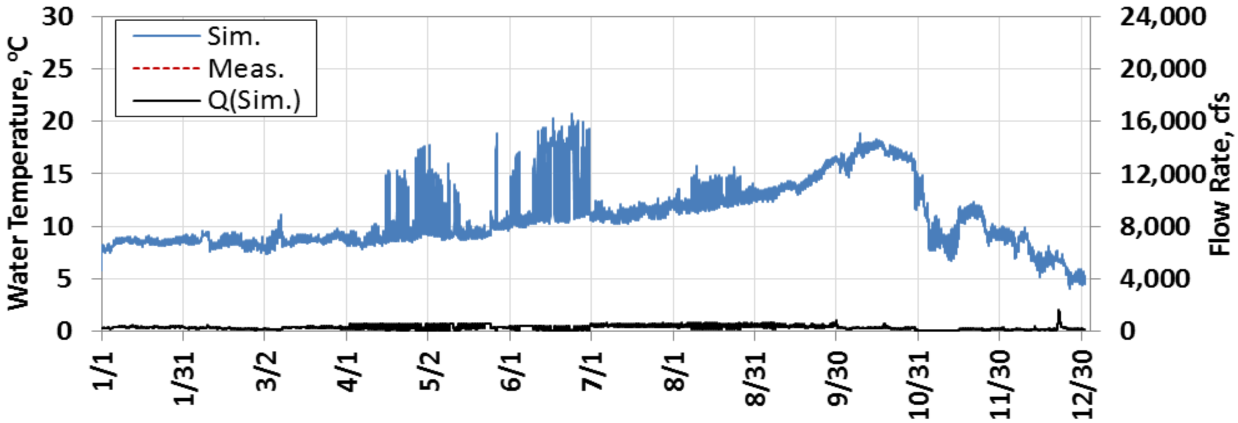

**Figure 8.2-1.** **Comparison of measured (Meas.) and simulated (Sim.) water temperature below Cherry Creek confluence for the calibration year 2015. Flow rate (in cfs) is presented in the secondary axis. (Note: Measured data for this location not available during this period.)**

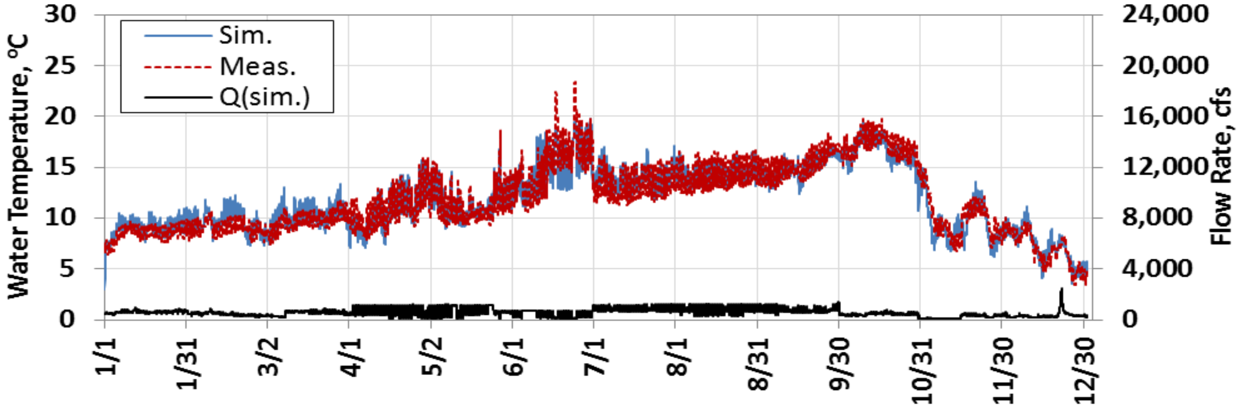

**Figure 8.2-2.** **Comparison of measured (Meas.) and simulated (Sim.) water temperature above South Fork Tuolumne River confluence for the calibration year 2015. Flow rate (in cfs) is presented in the secondary axis.**

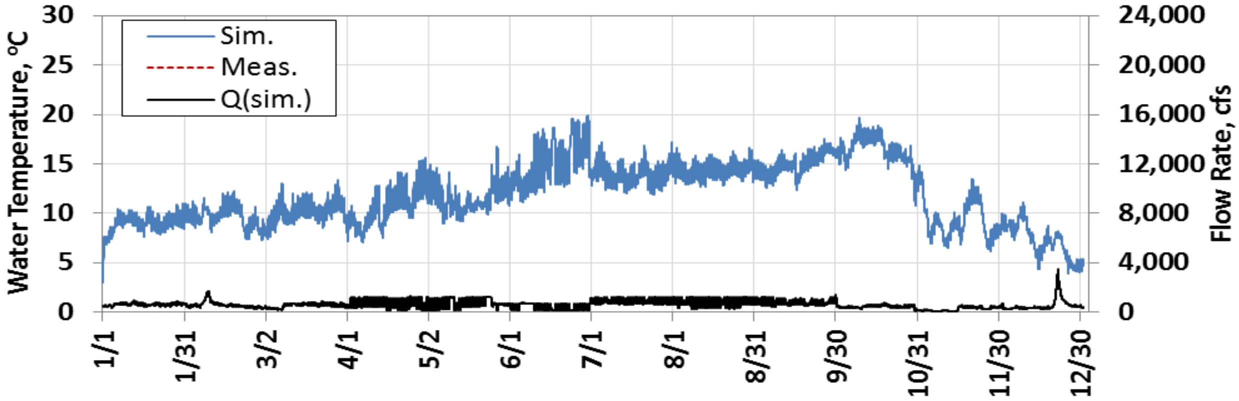

**Figure 8.2-3.** **Comparison of measured (Meas.) and simulated (Sim.) water temperature below South Fork Tuolumne River confluence for the calibration year 2015. Flow rate (in cfs) is presented in the secondary axis. (Note: Measured data for this location not available during this period.)**

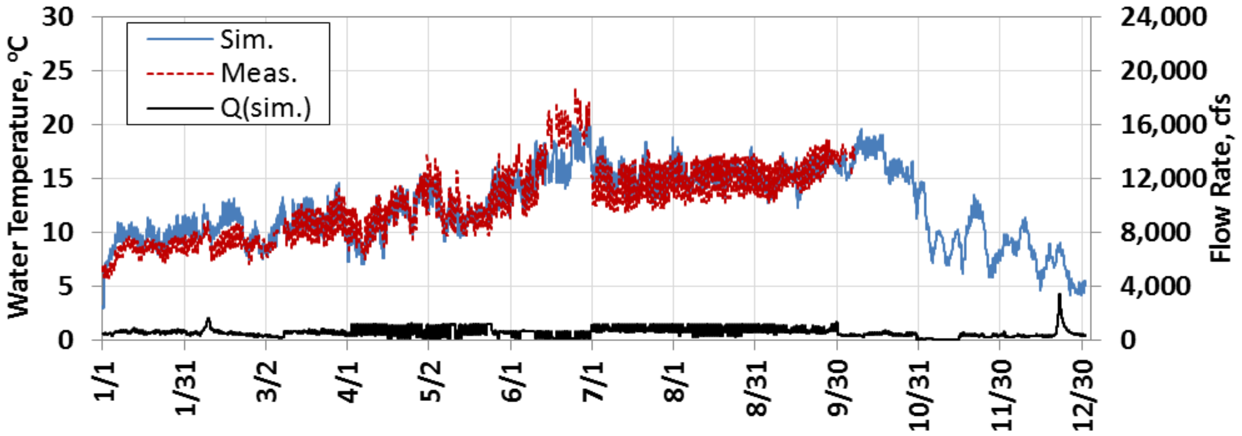

**Figure 8.2-4.** Comparison of measured (Meas.) and simulated (Sim.) water temperature above Clavey River confluence for the calibration year 2015. Flow rate (in cfs) is presented in the secondary axis.

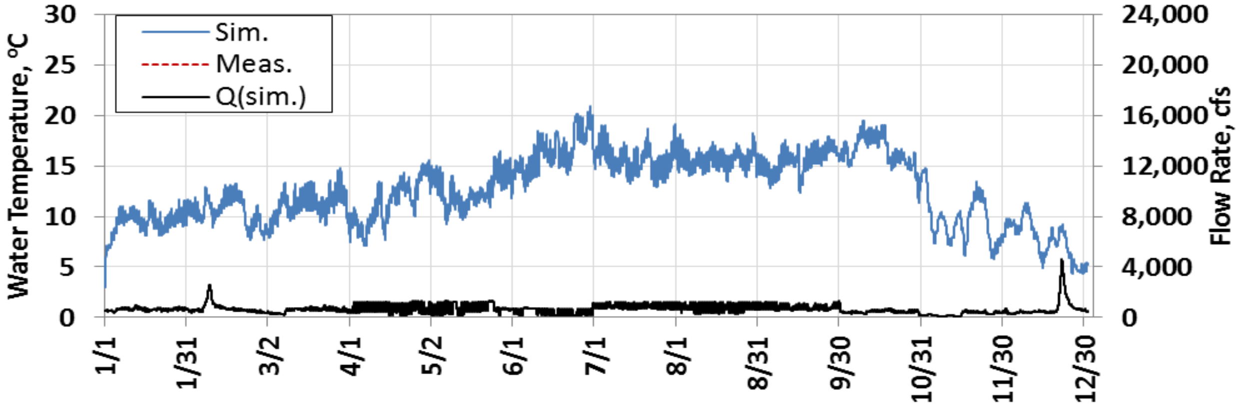

**Figure 8.2-5.** Comparison of measured (Meas.) and simulated (Sim.) water temperature below Indian Creek confluence for the calibration year 2015. Flow rate (in cfs) is presented in the secondary axis. (Note: Measured data for this location not available during this period.)

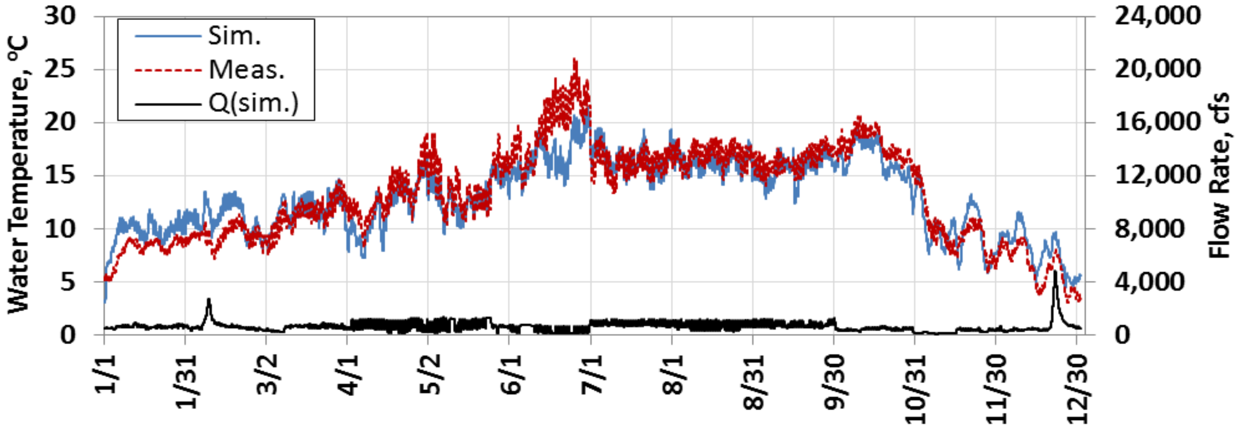

**Figure 8.2-6.** Comparison of measured (Meas.) and simulated (Sim.) water temperature above North Fork Tuolumne River confluence for the calibration year 2015. Flow rate (in cfs) is presented in the secondary axis.

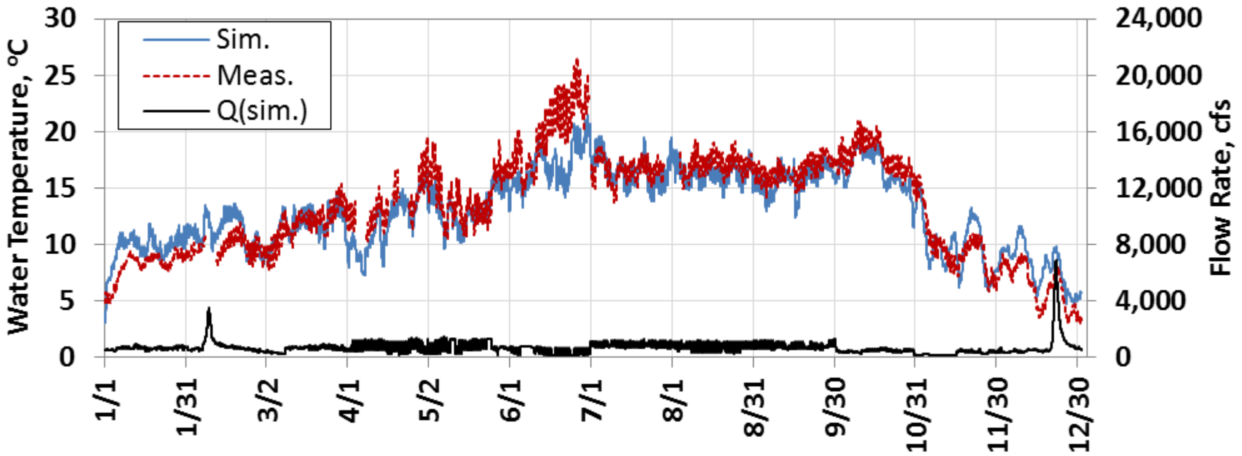

**Figure 8.2-7.** **Comparison of measured (Meas.) and simulated (Sim.) water temperature above Wards Ferry for the calibration year 2015. Flow rate (in cfs) is presented in the secondary axis.**

## 8.3 Summary Statistics

Calibration statistics are presented in Table 8.3-1. For all years, mean bias was typically low and near zero in several cases, MAE was generally under 1$^{o}$C, and RMSE was always less than 2$^{o}$C. Overall, given the level of available data, these results indicate that the model effectively captures a range of hydrologic and water temperature conditions in the upper Tuolumne River system.

**Table 8.3-1.** **Summary of Calibration Statistics from 2008 to 2016.**

| Year | Location Name (Node No.) | Mean Bias | Mean absolute error (MAE) | Root mean squared error (RMSE) | Count |
|---|---|---|---|---|---|
| 2008 | Bel. Cherry Cr.(82) | -0.22 | 0.34 | 0.56 | 8785 |
| | Abv. SF TR (442) | -0.15 | 0.85 | 1.21 | 8785 |
| | Bel. SF TR (448) | -0.22 | 0.79 | 1.13 | 8726 |
| | Abv. Clavey R. (754) | NA[1] | NA | NA | NA |
| | Bel. Indian Cr. (914) | NA | NA | NA | NA |
| | Abv. Wards Ferry Br. (1305)[2] | -1.16 | 1.74 | 2.19 | 3088 |
| 2009 | Bel. Cherry Cr.(82) | -0.09 | 0.35 | 0.49 | 8747 |
| | Abv. SF TR (442) | -0.05 | 0.85 | 1.16 | 8761 |
| | Bel. SF TR (448) | -0.05 | 0.86 | 1.20 | 8761 |
| | Abv. Clavey R. (754) | 0.10 | 1.26 | 1.65 | 5968 |
| | Bel. Indian Cr. (914) | 0.14 | 1.42 | 1.87 | 5966 |
| | Abv. Wards Ferry Br. (1305) | 0.57 | 1.12 | 1.36 | 1560 |
| 2010 | Bel. Cherry Cr.(82) | -0.04 | 0.27 | 0.64 | 7388 |
| | Abv. SF TR (442) | -0.13 | 0.72 | 0.98 | 8755 |
| | Bel. SF TR (448) | -0.12 | 0.65 | 0.90 | 8760 |
| | Abv. Clavey R. (754) | -0.35 | 0.57 | 0.70 | 3057 |
| | Bel. Indian Cr. (914) | 0.21 | 0.60 | 0.78 | 5103 |
| | Abv. Wards Ferry Br. (1305) | NA | NA | NA | NA |
| 2011 | Bel. Cherry Cr.(82) | 0.02 | 0.16 | 0.24 | 6635 |
| | Abv. SF TR (442) | -0.15 | 0.65 | 0.88 | 8761 |

| Year | Location Name (Node No.) | Mean Bias | Mean absolute error (MAE) | Root mean squared error (RMSE) | Count |
|---|---|---|---|---|---|
| | Bel. SF TR (448) | -0.03 | 0.60 | 0.84 | 8754 |
| | Abv. Clavey R. (754) | NA | NA | NA | NA |
| | Bel. Indian Cr. (914) | 0.08 | 0.80 | 1.08 | 8760 |
| | Abv. Wards Ferry Br. (1305) | NA | NA | NA | NA |
| 2012 | Bel. Cherry Cr.(82) | 0.06 | 0.46 | 0.93 | 4521 |
| | Abv. SF TR (442) | 0.25 | 1.10 | 1.45 | 8785 |
| | Bel. SF TR (448) | 0.12 | 1.06 | 1.37 | 8785 |
| | Abv. Clavey R. (754) | NA | NA | NA | NA |
| | Bel. Indian Cr. (914) | -0.03 | 1.37 | 1.75 | 8785 |
| | Abv. Wards Ferry Br. (1305) | NA | NA | NA | NA |
| 2013 | Bel. Cherry Cr.(82) | 0.18 | 0.21 | 0.24 | 2290 |
| | Abv. SF TR (442) | 0.46 | 0.85 | 1.22 | 5385 |
| | Bel. SF TR (448) | 0.40 | 0.85 | 1.24 | 5385 |
| | Abv. Clavey R. (754) | NA | NA | NA | NA |
| | Bel. Indian Cr. (914) | -0.02 | 1.33 | 1.75 | 8270 |
| | Abv. Wards Ferry Br. (1305) | NA | NA | NA | NA |
| 2014 | Bel. Cherry Cr.(82) | -0.08 | 0.57 | 0.88 | 4503 |
| | Abv. SF TR (442) | 0.13 | 1.01 | 1.39 | 8458 |
| | Bel. SF TR (448) | NA | NA | NA | NA |
| | Abv. Clavey R. (754) | 0.07 | 1.14 | 1.46 | 5082 |
| | Bel. Indian Cr. (914) | NA | NA | NA | NA |
| | Abv. NF TR (1270)[3] | -0.27 | 1.40 | 1.73 | 2784 |
| | Abv. Wards Ferry Br. (1305) | -0.80 | 1.68 | 2.15 | 7745 |
| 2015 | Bel. Cherry Cr.(82) | NA | NA | NA | NA |
| | Abv. SF TR (442) | 0.11 | 0.80 | 1.07 | 8760 |
| | Bel. SF TR (448) | NA | NA | NA | NA |
| | Abv. Clavey R. (754) | 0.25 | 0.95 | 1.23 | 5823 |
| | Bel. Indian Cr. (914) | NA | NA | NA | NA |
| | Abv. NF TR (1270) | -0.19 | 1.35 | 1.74 | 8760 |
| | Abv. Wards Ferry Br. (1305) | -0.28 | 1.40 | 1.81 | 8224 |
| 2016[4] | Bel. Cherry Cr.(82) | NA | NA | NA | NA |
| | Abv. SF TR (442) | 0.38 | 0.63 | 0.82 | 6576 |
| | Bel. SF TR (448) | NA | NA | NA | NA |
| | Abv. Clavey R. (754) | 0.27 | 0.85 | 1.08 | 1862 |
| | Bel. Indian Cr. (914) | NA | NA | NA | NA |
| | Abv. NF TR (1270) | 0.49 | 1.12 | 1.37 | 6577 |
| | Abv. Wards Ferry Br. (1305) | 1.27 | 1.29 | 1.47 | 2397 |

[1] No available measured data.

[2] Tuolumne River at Wards Ferry was inundated during the first 3 months of 2012.

[3] TR above North Fork data were unavailable until 2014.

[4] Unlike the other (full) model years, the model was run for the period between 01/01 and 09/30 (incl.) in year 2016.

# 9.0 CONCLUSION

This Upper Tuolumne River Temperature Model has produced a mathematical flow and water temperature model, calibrated and tested to represent the existing conditions from below Early Intake to above the upper extent of the Don Pedro Project Boundary for the period between 2008 and 2016.

The model update consisted of four major components: development of a conceptual framework, model selection, model development, and model application. The development of the conceptual framework provided focus and direction of the modeling study. In the model selection phase, a review of appropriate computer models occurred that resulted in the selection of RMA-2 and RMA-11 for analysis and comparison. Model development was further divided into several major processes: data development and implementation, and calibration. As part of the data development process, the flow, temperature, geometry, and meteorological data were reviewed and compiled in the format needed by the models. Model implementation included developing the initial model conditions, modifying the software as needed, and specifying the model parameters. Once the data were developed and the model set-up, the model was calibrated. During this phase, model parameters (e.g., Manning's channel roughness, evaporation coefficients) were adjusted to reduce the difference between simulated and observed data for both flow and temperature. Model performance at the calibration locations was assessed both graphically and statistically. The updated, calibrated model provides sub-daily flow and water temperature (15 minute) at a fine spatial scale (100 ft), through a range of inter-annual, seasonal, short duration, and diel conditions with overall low bias, mean absolute error, and root mean squared error.

The updated model can now be applied to the historic period to develop a continuous thermal record of the river throughout the study reach and to support an assessment of thermal suitability in the study area. By simulating historic conditions for nine years, the model also captures elements of everyday operations as well as conditions that are infrequent but nonetheless important events in the upper Tuolumne River, such as planned and unplanned operational outages. Further, these years span hydrologic conditions that span from above normal precipitation to critically dry, and a similarly diverse range of meteorological conditions.

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# UPPER TUOLUMNE RIVER BASIN WATER TEMPERATURE MONITORING AND MODELING STUDY

## MODEL DEVELOPMENT REPORT

## ATTACHMENT A

## 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 A-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 A-2).

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

| Logger Location | River Mile | Latitude | Longitude | Temperature | Stage |
|---|---|---|---|---|---|
| **Tuolumne River** | | | | | |
| 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 | |
| **Cherry Creek** | | | | | |
| Cherry above Holm PH | CC 1.2 | 37.89395 | -119.94917 | X | |
| Cherry above Tuolumne | CC 0.6 | 37.89253 | -119.97121 | X | |
| **South Fork Tuolumne River** | | | | | |
| South Fork above Tuolumne | SF 0.2 | 37.83870 | -120.04852 | X | X |
| **Clavey River** | | | | | |
| 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 |
| **North Fork Tuolumne River** | | | | | |
| 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 A-2).

**Table A-2. Proposed schedule of field visits for 2015 and 2016 including general access methods.**

| Month | Vehicle/Hike Access | WW Boat Access |
|---|---|---|
| **2015** | | |
| March/April (installation) | X | X |
| May | | |
| June | X | |
| July | | X |
| August | X | |
| September | | |
| October/November (removal | X | X |
| **2016** | | |
| 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 A-1) at identified tributary and mainstem locations (Table A-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 B (QA/QC Approach) were also collected at each location.

**Figure A-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 A-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 A-2). Additional information described in Attachment B (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 A-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, in addition to 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

## MODEL DEVELOPMENT REPORT

## ATTACHMENT B

## 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 assess the suitability of conditions for anadromous fish reintroduction to the upper reaches of the Tuolumne River and its tributaries above the Don Pedro Project Boundary.

To ensure the collected data are 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 they are representative of field conditions and are 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 +/–0.5$^{o}$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 +/–0.2$^{o}$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 included:

- 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 Retrieval 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 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 are 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-retrieval 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

## MODEL DEVELOPMENT REPORT

## ATTACHMENT C

## WORKSHOP MEETING NOTES AND MATERIALS

# 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

TID WATER & POWER
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MID Modesto Irrigation District
The Power to Grow

# 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/8DZ4VNVN

**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 | Temperature Study Introduction (Districts)<br>a. Study goal and objectives, scope, and study area<br>Review and Discussion of Existing Information<br>a. Parameters and sources<br>b. Review process summary<br>c. Results, findings and recommendations<br>Proposed Monitoring Program – Presentation and Discussion<br>a. Rationale<br>i. Space (locations)<br>ii. Time (periods of interest)<br>iii. Equipment<br>Temperature Modeling – Presentation and Discussion<br>a. Approach (including spatial and temporal resolution)<br>b. Data needs<br>c. Model information/output<br>Schedule and Reporting |
| 4:00 pm – 4:30 pm | Meeting Wrap-up (All)<br>a. Confirm study approach and methods<br>b. Agreements, action items and next steps |

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Modesto Irrigation District
The Power to Grow

# 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 | [redacted] |
| 2 | Jesse Deason | HDR | [redacted] |
| 3 | Bill Paris | MID | [redacted] |
| 4 | Art Godwin | TID | [redacted] |
| 5 | Mike Deas | Watercourse Engineering | [redacted] |
| 6 | John Devine | HDR | [redacted] |
| 7 | Steve Boyd | TID | [redacted] |
| 8 | Ron Yoshiyama | San Francisco | [redacted] |
| 9 | Peter Barnes | SWRCB | [redacted] |
| 10 | Chris Shutes | CSPA | [redacted] |
| 11 | Mark Gard | USFWS | [redacted] |
| 12 | Bob Hughes | CDFW | [redacted] |
| 13 | Bill Sears | SFPUC | [redacted] |
| 14 | Peter Drekmeier | TRT | [redacted] |

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 |

# 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

# 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.

# 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

# 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

# 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

# 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.)

# 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.)

# 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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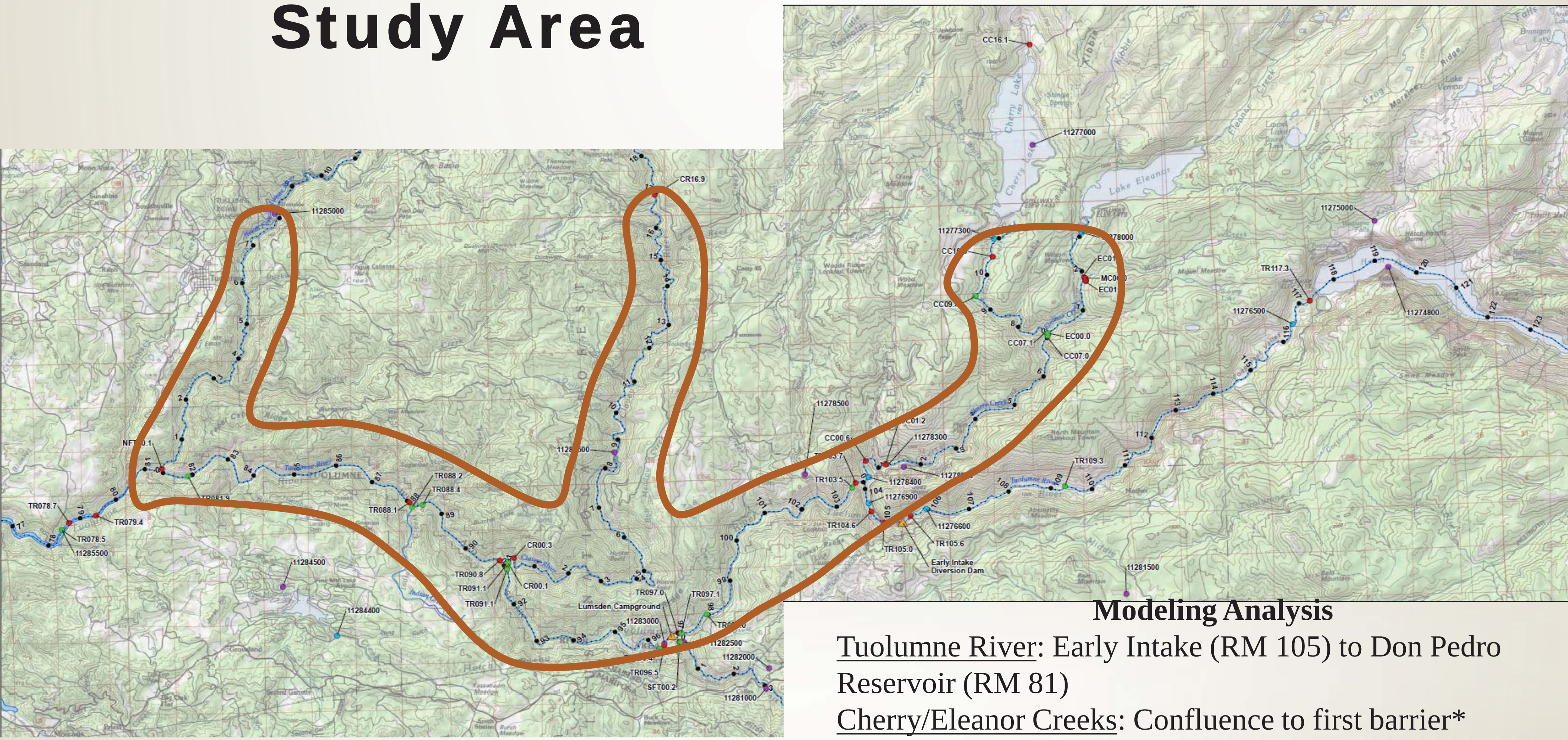
# Study Area



**Modeling Analysis**

Tuolumne River: Early Intake (RM 105) to Don Pedro Reservoir (RM 81)

Cherry/Eleanor Creeks: Confluence to first barrier*

SF Tuolumne River: Barrier near confluence (no model)

Clavey River: Confluence to first barrier*

NF Tuolumne River: Confluence to first barrier*

* TBD

# 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

# 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)

# 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
- <u>Monitoring Recommendations</u>
  - Additional seasonal flow data on Clavey and NF Tuolumne R.
  - Stage data on mainstem (travel time)

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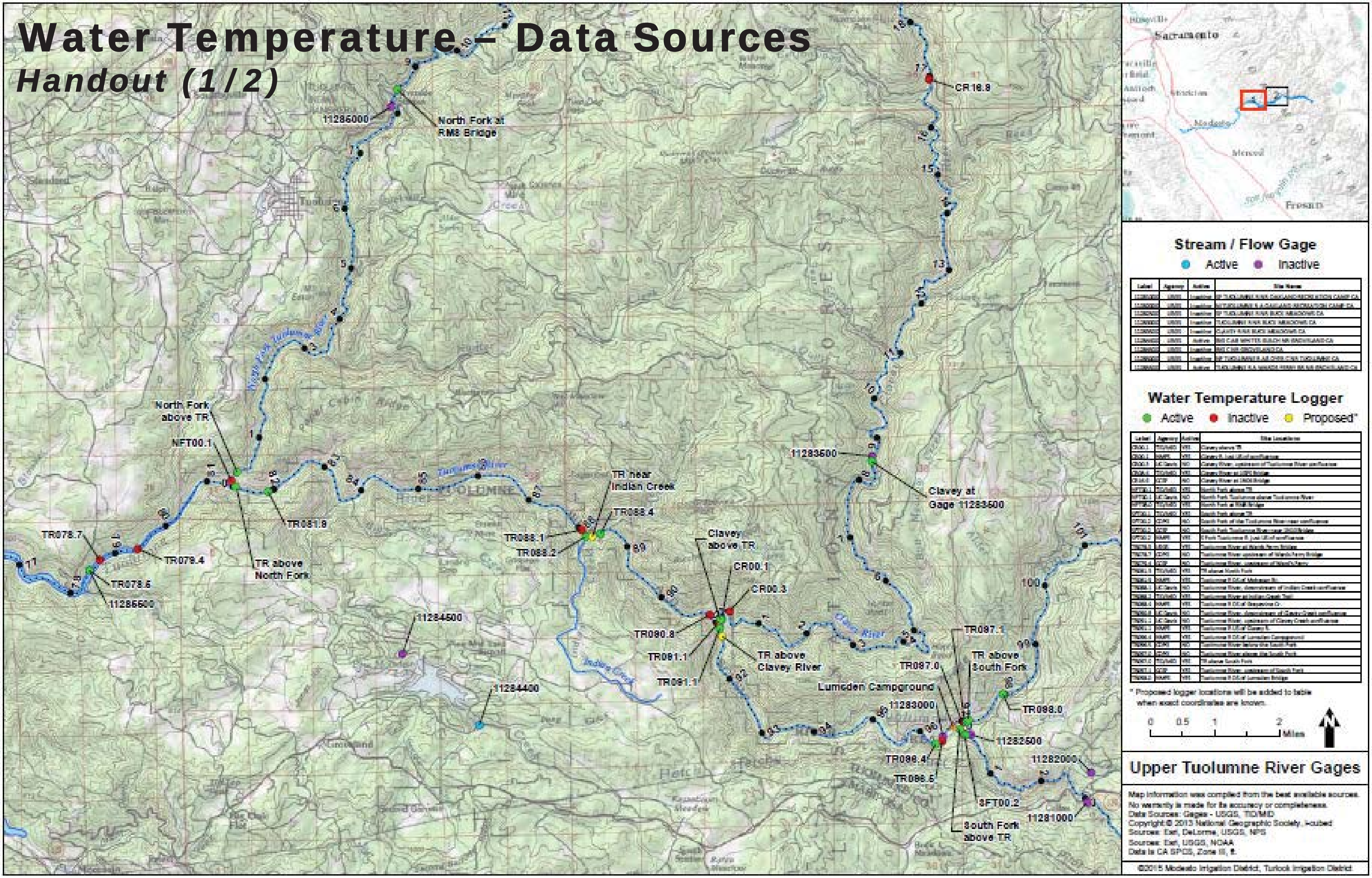
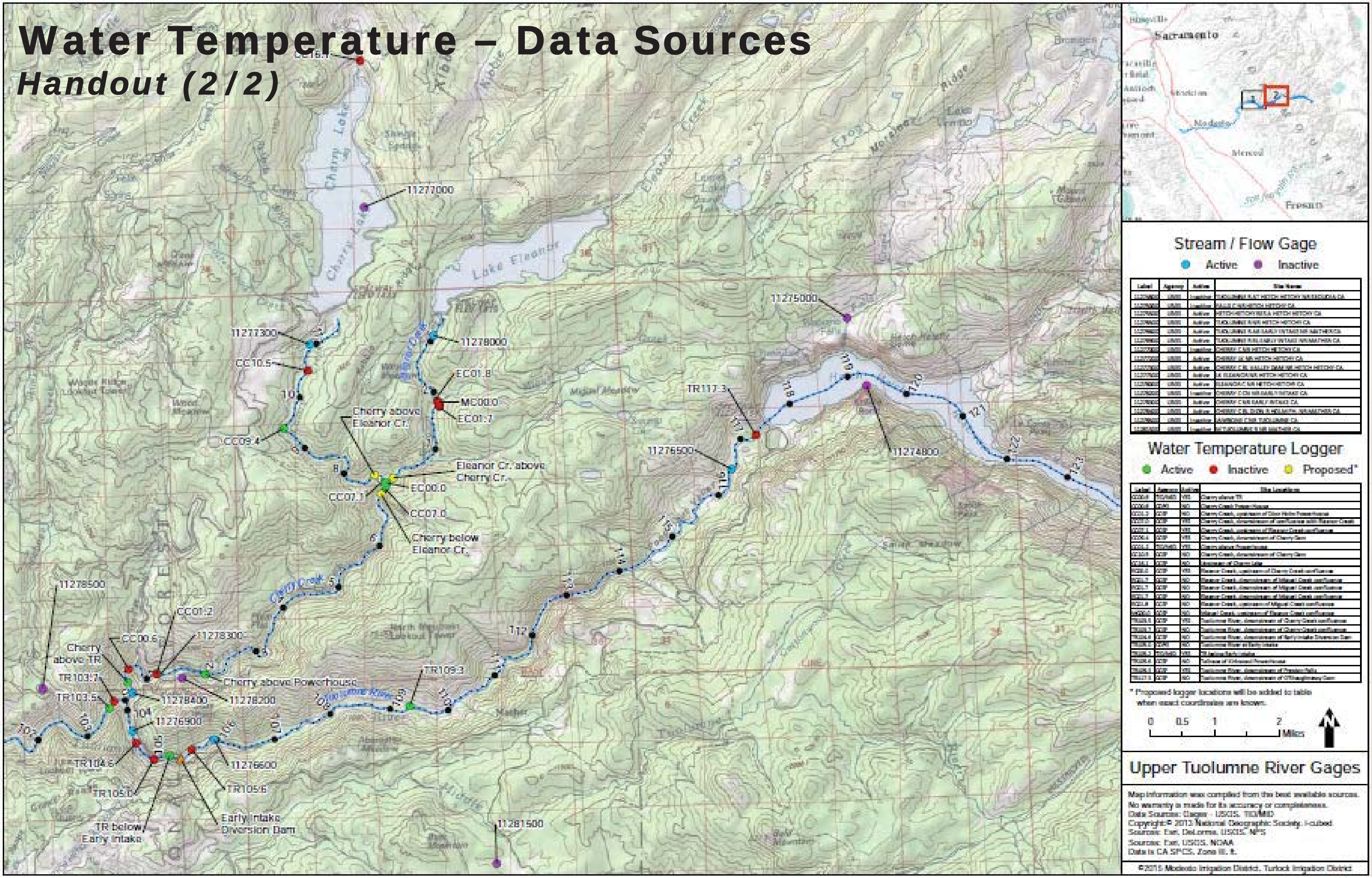
# Water Temperature – Data Sources

## *Handout (1/2)*



# Water Temperature – Data Sources

## *Handout (2/2)*



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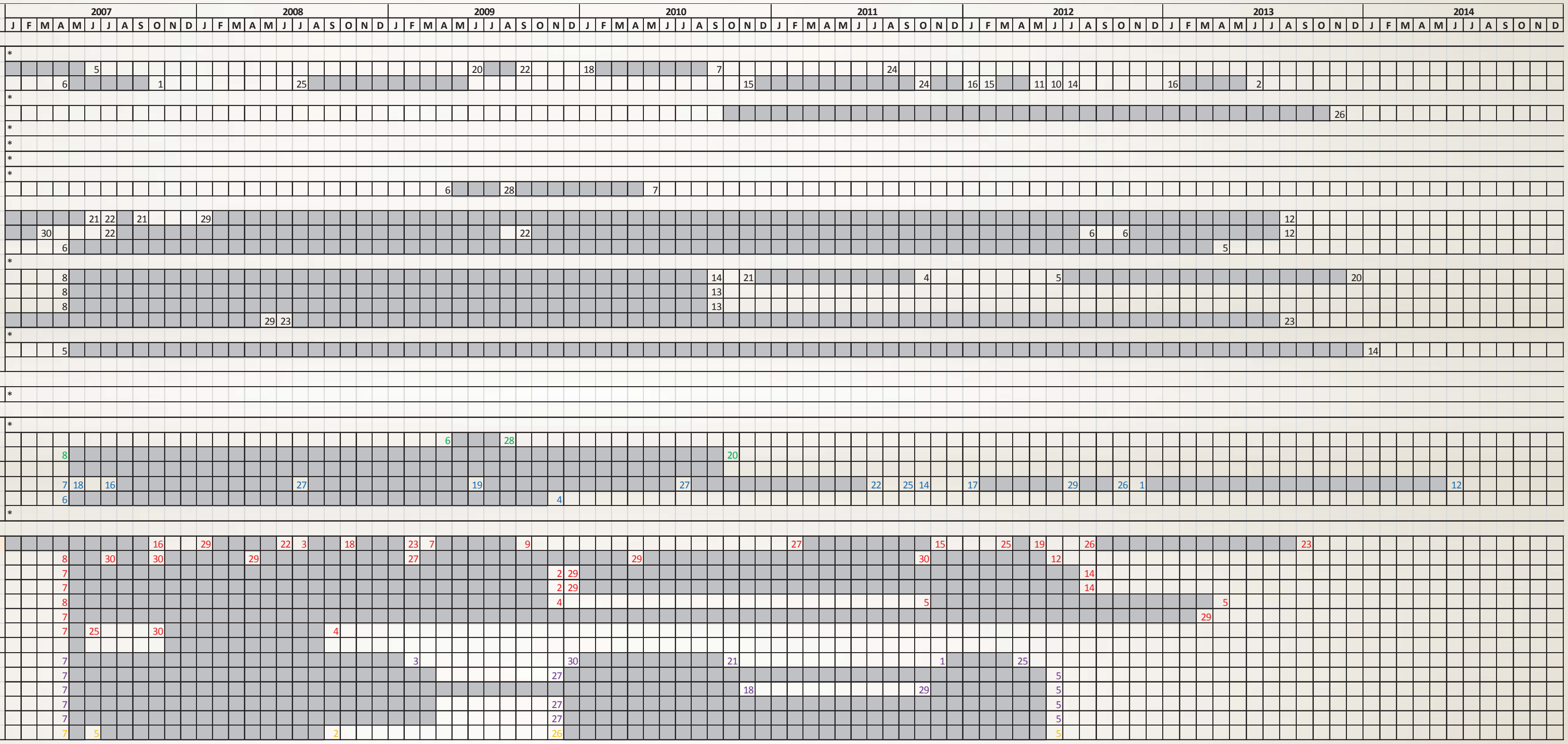
# Water Temperature Data - Availability

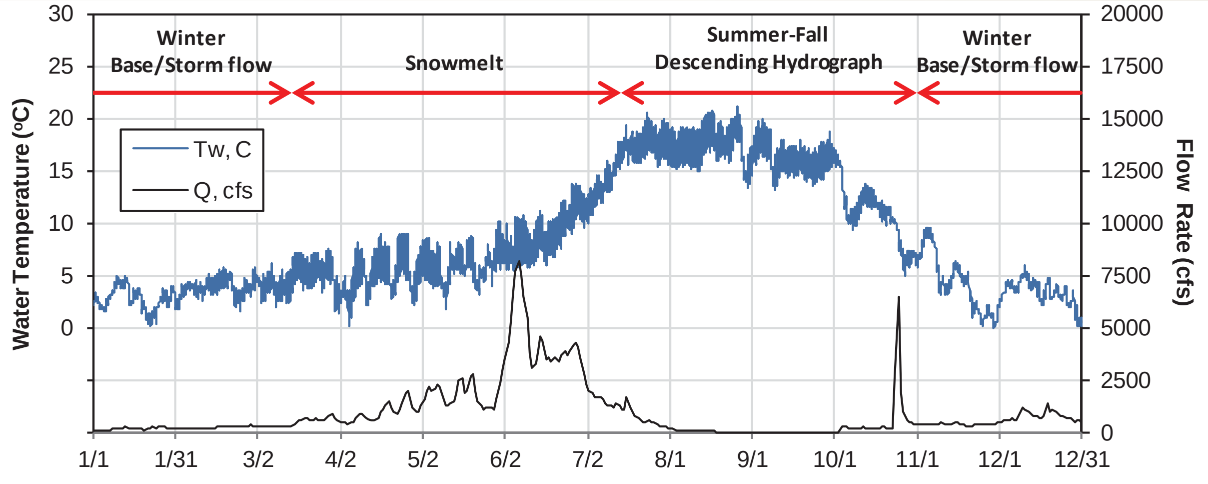
## *Handout*

| Map Label | Agency | Active | Site_Locations |
|---|---|---|---|
| **Tuolumne River - Mainstem** | | | |
| 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 |
| TR081.9 | NMFS | YES | Tuolumne R DS of Mohecan Br. |
| TR083.0 | TID/MID | YES | Tuolumne River at Indian Creek Trail |
| TR088.1 | UC Davis | NO | Tuolumne River, downstream of Indian Creek confluence |
| 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 |
| TR096.4 | NMFS | YES | Tuolumne R DS of Lumsden Campgorund |
| TR096.5 | CDFG | NO | Tuolmune River below the South Fork |
| TR097.0 | CDFG | NO | Tuolumne River above the South Fork |
| TR097.1 | CCSF | NO | Tuolumne River, upstream of South Fork |
| TR098.0 | NMFS | YES | Tuolumne R DS of Lumsden Bridge |
| TR103.5 | CCSF | NO | Tuolumne River, ds of Cherry Ck confluence (TR4) |
| TR103.7 | CCSF | NO | Tuolumne River, ds of Cherry Ck confluence (TR3) |
| TR104.6 | CCSF | NO | Tuolumne River, ds of Early Intake Diversion Dam |
| TR105.0 | CDFG | NO | Tuolumne River at Early Intake |
| TR105.6 | CCSF | NO | Tailrace of Kirkwood Powerhouse |
| TR109.3 | CCSF | NO | Tuolumne River, downstream of Preston Falls |
| TR117.3 | CCSF | NO | Tuolumne River, downstream of O'Shaughnessy |
| **NF Tuolumne River** | | | |
| NFT00.1 | UC Davis | NO | North Fork Tuolumne above Tuolumne River |
| **Clavey River** | | | |
| CR00.1 | NMFS | YES | Clavey R. just US of confluence |
| CR00.3 | UC Davis | NO | Clavey River, upstream of Tuolumne River confluence |
| CR16.9 | CCSF | NO | Clavey River at 1N04 Bridge |
| **SF Tuolumne River** | | | |
| 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 |
| **Cherry Creek** | | | |
| CC00.6 | CDFG | NO | Cherry Creek Power House |
| CC01.2 | CCSF | NO | Cherry Creek, upstream of Dion Holm Powerhouse |
| CC07.0 | CCSF | NO | Cherry Creek, ds of confluence with Eleanor Creek |
| CC07.1 | CCSF | NO | Cherry Creek, upstream of Eleanor Creek confluence |
| CC09.4 | CCSF | NO | Cherry Creek, downstream of Cherry Dam |
| CC10.5 | CCSF | NO | Cherry Creek, downstream of Cherry Dam |
| CC16.1 | CCSF | NO | Upstream of Cherry Lake |
| **Eleanor Creek** | | | |
| EC00.0 | CCSF | NO | Eleanor Creek, upstream of Cherry Creek confluence |
| EC01.7 | CCSF | NO | Eleanor Creek, downstream of Miguel Creek confluence |
| EC01.7 | CCSF | NO | Eleanor Creek, downstream of Miguel Creek confluence |
| EC01.7 | CCSF | NO | Eleanor Creek, downstream of Miguel Creek confluence |
| EC01.8 | CCSF | NO | Eleanor Creek, upstream of Miguel Creek confluence |
| MC00.0 | CCSF | NO | Miguel Creek, upstream of Eleanor Creek confluence |



# 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

# 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

# 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**[1] | n/a | Calculated |
| **Air Temperature**[2] | deg C | Adjusted Stockton |
| **Wet-Bulb Temperature**[3] | deg C | Calculated |
| **Barometric Pressure** | mmHg | Adjusted Stockton |
| **Wind Speed** | m/s | Adjusted Stockton |
| **Solar Radiation** | $w/m^2$ | Sacramento 1973-1990 and Modesto City AP 1991-2010 (both NREL Solar radiation data), 2010 to present – Oakdale CIMIS |

[1] **Cloud cover was estimated based on solar radiation.**

[2] **Air temperature was only available from the Stockton meteorological station. Air temperature to be adjusted to representative elevation using a lapse rate.**

[3] **Wet-bulb temperatures are calculated based on adjusted air temperature and relative humidity from Stockton.**

# Task 2: Monitoring

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

# 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)

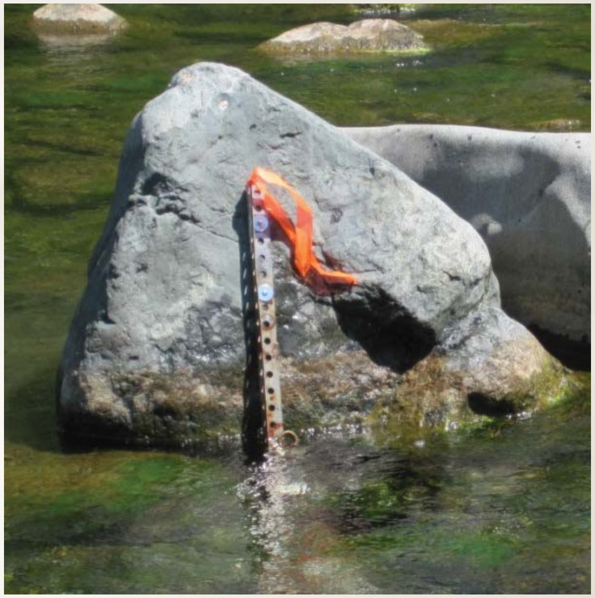
# Proposed Monitoring Locations

| | 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

# Monitoring Equipment

- Hobo Pro V2 or TidBit loggers (+/- 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.

# Site Access and Monitoring

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

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

# 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.

# 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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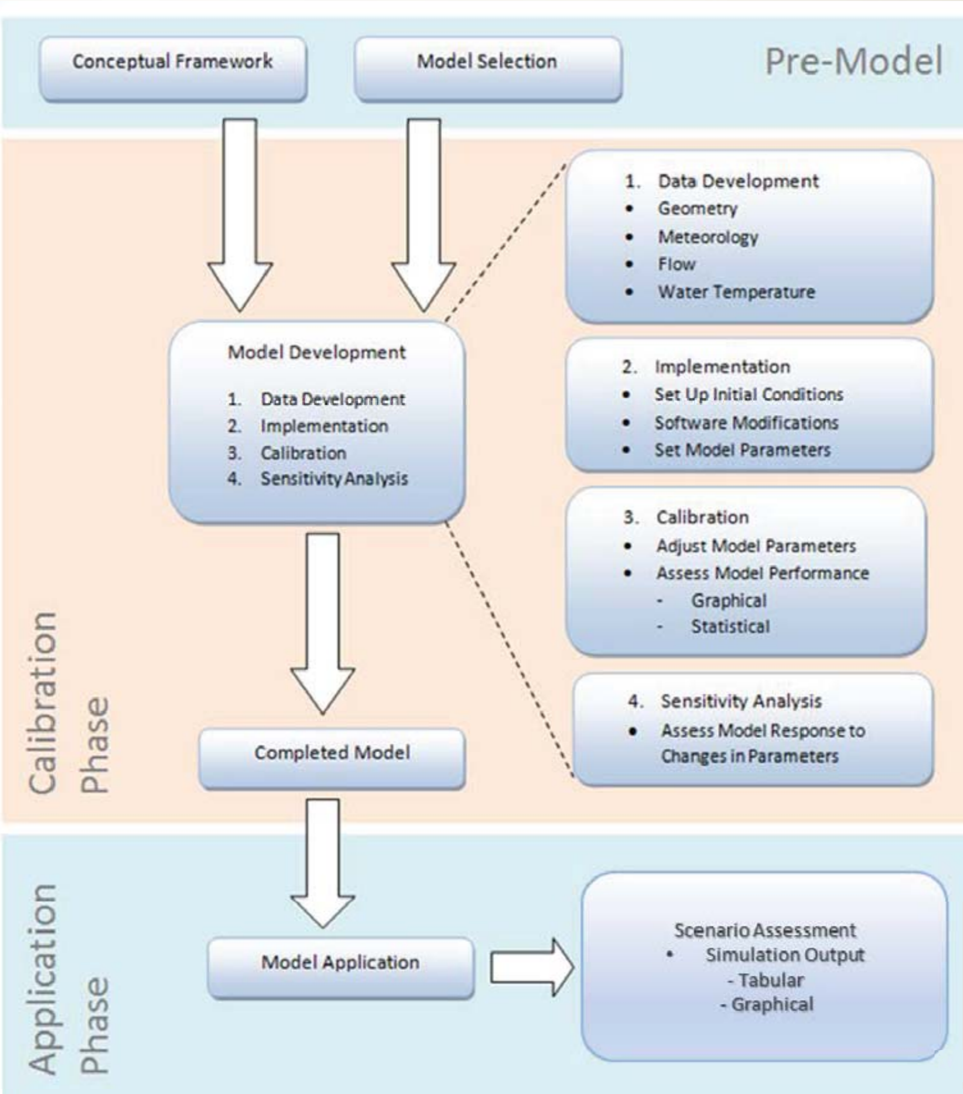
# Water Temperature Modeling

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



Pre-Model

Conceptual Framework

Model Selection

Calibration Phase

Model Development

1. Data Development
2. Implementation
3. Calibration
4. Sensitivity Analysis

1. Data Development
   - Geometry
   - Meteorology
   - Flow
   - Water Temperature

2. Implementation
   - Set Up Initial Conditions
   - Software Modifications
   - Set Model Parameters

3. Calibration
   - Adjust Model Parameters
   - Assess Model Performance
     - Graphical
     - Statistical

4. Sensitivity Analysis
   - Assess Model Response to Changes in Parameters

Completed Model

Application Phase

Model Application

Scenario Assessment
- Simulation Output
  - Tabular
  - Graphical

# Model Selection Considerations

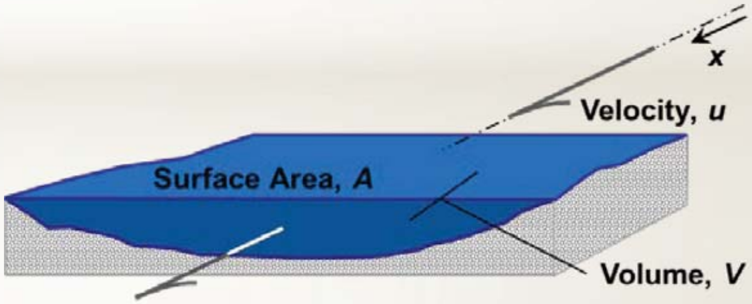
- System Characteristics
  - Steep channel gradient
  - Variable flow regime
  - Snowmelt hydrograph and thermal response
  - Low summer flows
  - Variable meteorology (spatial/temporal)
  - Topographic, riparian shade
- Previous model applications:
  - Upper Tuolumne River: Hetch Hetchy to Early Intake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

# 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.

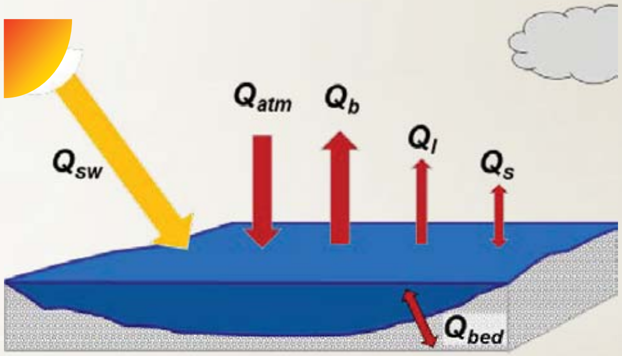
# RMA-2: Hydrodynamics

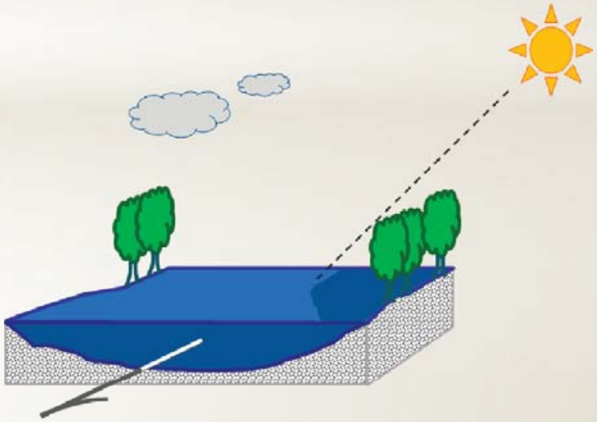
- Steady and unsteady (dynamic) flows can be analyzed (e.g., hydropower peaking) – solution of St Venant Equations
- Steep river reach capability
- Branching networks
- Low flow modeling ability
- $\Delta t = 1$ hr (maximum)
- $\Delta x = 25\text{-}50$ m (approximately)
- Open source code



# 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
- Δt = 1 hr (maximum)
- Δx = 25-50 m (approximately)
- Open source code





# 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]

# 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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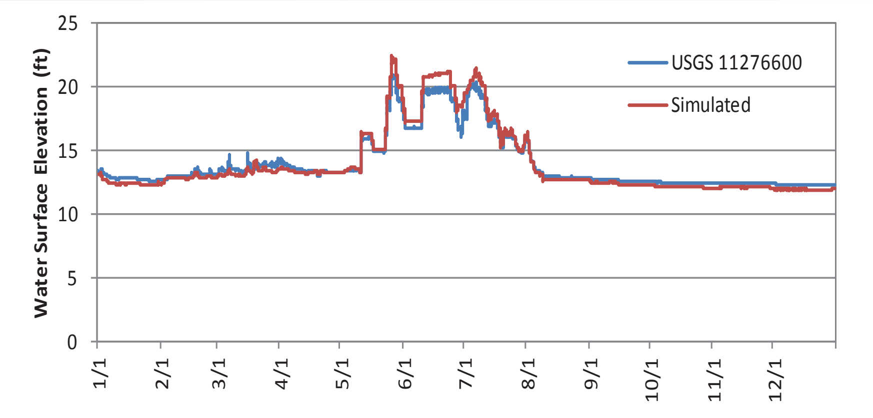
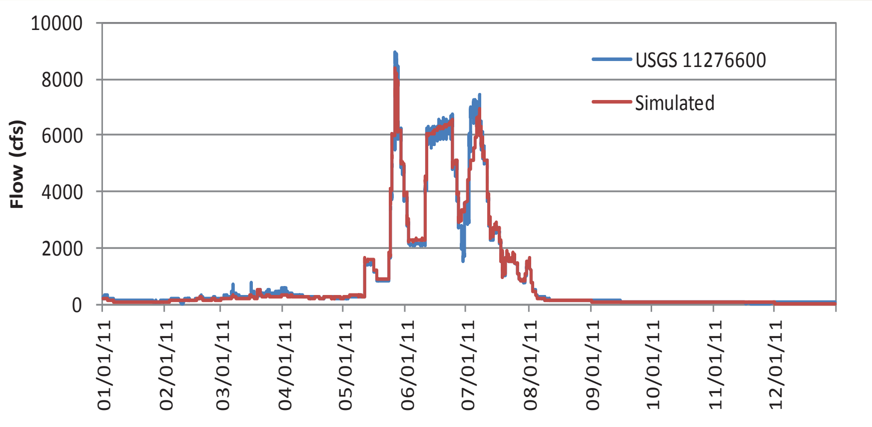
# Hydrology

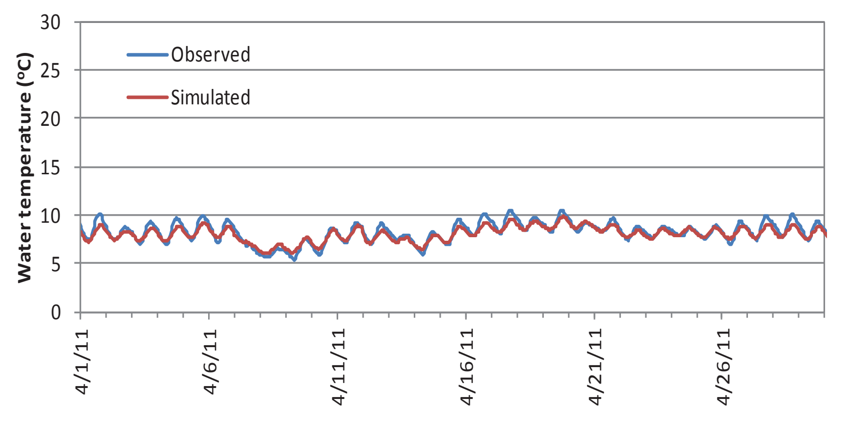
- Mainstem and tributary flows
  - Natural flow regimes (daily)
  - Hydropower peaking conditions (hourly)
- Accretions/depletions (calculated based on mass balance)
- Calibration data (within domain to test model)
  - Flow
  - Stage data (assess travel time (if multiple gages available))

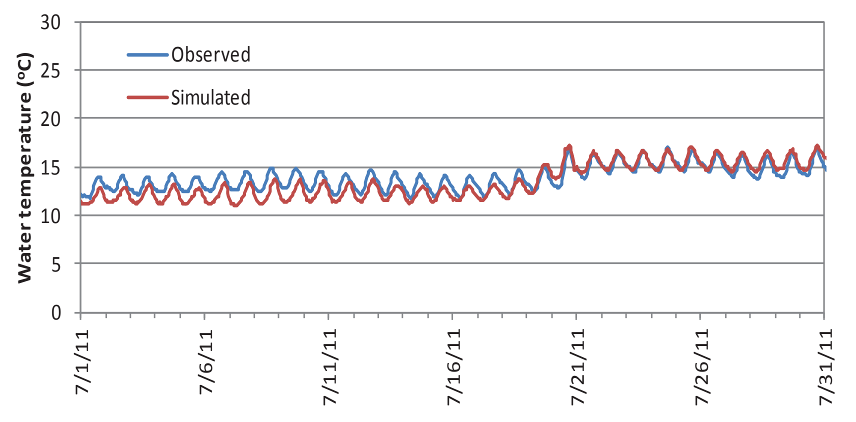




# Water Temperature

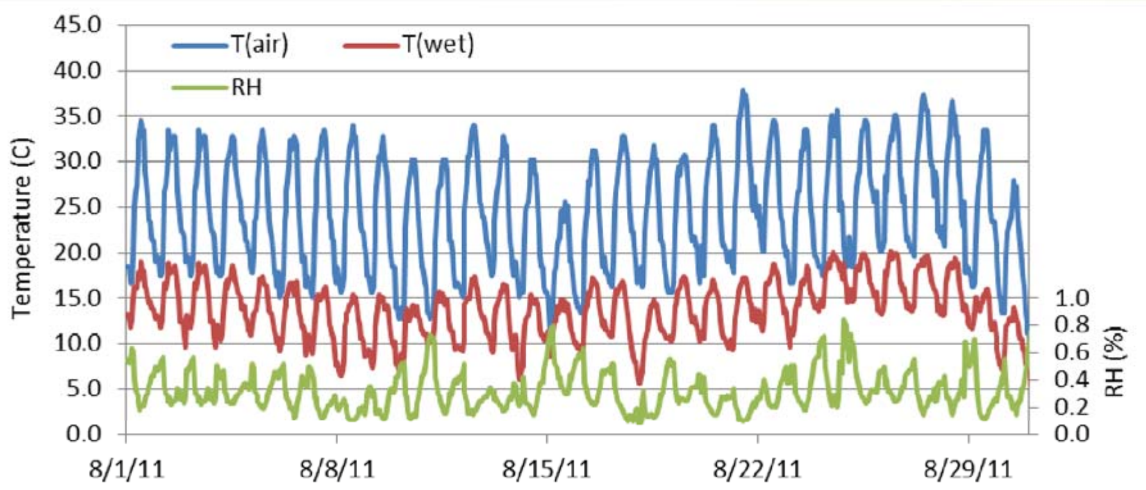
- Mainstem and tributary inflow temperatures
  - Natural flow regimes (daily or hourly)
  - Hydropower peaking conditions (hourly)
- Accretions/depletions (daily, weekly, or at river temperature)
- Calibration data (within domain to test model)





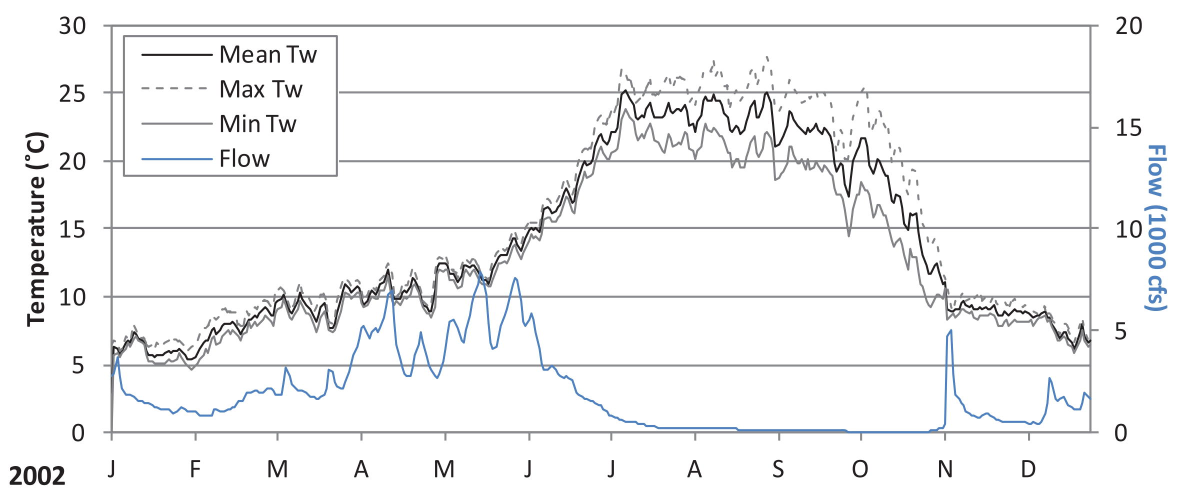
# Meteorology

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



# 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



# Next Steps

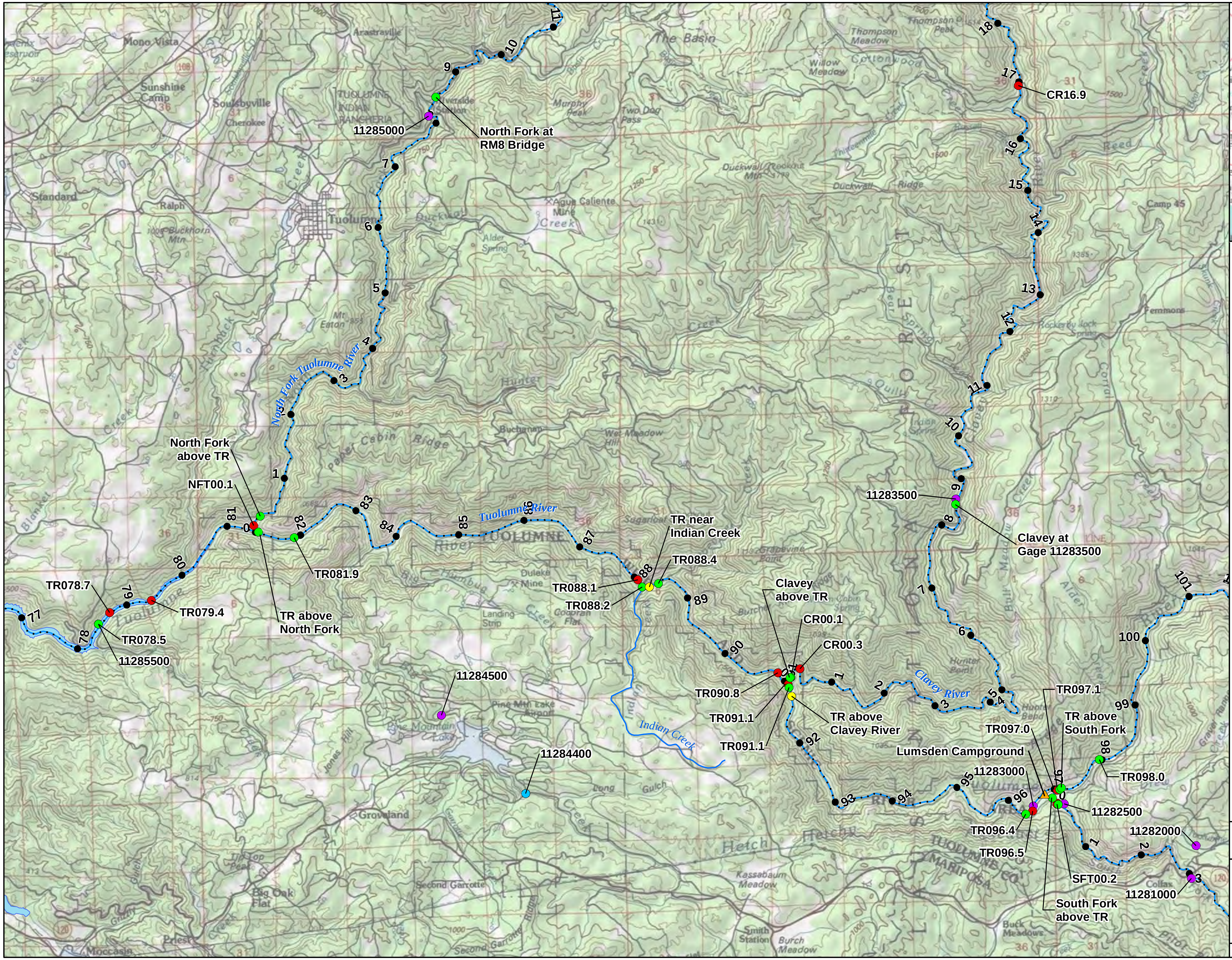
- 2015
  - Data synthesis and assessment (May)
  - Continue with field monitoring (through October 2016)
  - Ongoing coordination with project team on temperature assessment questions as they relate to barrier assessment
- 2016
  - Initial Study Report (February)
  - Develop temperature model based on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

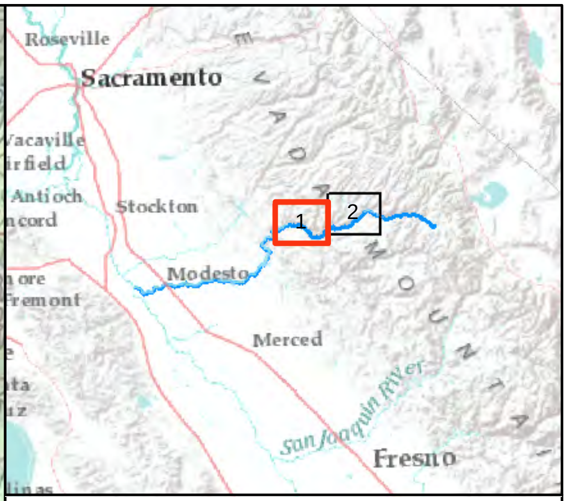
# Questions or Comments?

| Map Label | Agency | Active | Site_Locations | 2007 | | | | | | | | | | | | 2008 | | | | | | | | | | | | 2009 | | | | | | | | | | | | 2010 | | | | | | | | | | | | 2011 | | | | | | | | | | | | 2012 | | | | | | | | | | | | 2013 | | | | | | | | | | | | 2014 | | | | | | | | | | | | 2015 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 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 | J | F | M | A | M | J | J | A | S | O | N | D | J | F | M | A |
| **Tuolumne River - Mainstem** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| TR078.5 | USGS | YES | Tuolumne River at Wards Ferry Bridge | * | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| TR078.7 | CDFG | NO | Tuolumne River upstream of Wards Ferry Bridge | ▨ | ▨ | ▨ | ▨ | ▨ | 5 | | | | | | | | | | | | | | | | | | | | | | | | 20 | ▨ | ▨ | 22 | | | | 18 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | 7 | | | | | | | | | | | 24 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| TR079.4 | CCSF | NO | Tuolumne River, upstream of Ward's Ferry | | | | 6 | ▨ | ▨ | ▨ | ▨ | ▨ | 1 | | | | | | | | | 25 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | | | | | | | | | | | | | | | | | | | | 15 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | 24 | ▨ | ▨ | 16 | 15 | ▨ | ▨ | 11 | 10 | 14 | | | | | | 16 | ▨ | ▨ | ▨ | ▨ | 2 | | | | | | | | | | | | | | | | | | | | | | |
| TR081.9 | NMFS | YES | Tuolumne R DS of Mohecan Br. | * | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| TR083.0 | TID/MID | YES | Tuolumne River at Indian Creek Trail | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | 26 | | | | | | | | | | | | | | | | | |
| TR088.1 | UC Davis | NO | Tuolumne River, downstream of Indian Creek confluence | * | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 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 Campgorund | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| TR096.5 | CDFG | NO | Tuolmune River below the South Fork | ▨ | ▨ | ▨ | ▨ | ▨ | 21 | 22 | ▨ | 21 | | | | 29 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | 12 | | | | | | | | | | | | | | | | | | | | |
| TR097.0 | CDFG | NO | Tuolumne River above the South Fork | ▨ | ▨ | 30 | | | | 22 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | | 22 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | 6 | | 6 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | 12 | | | | | | | | | | | | | | | | | | | | |
| TR097.1 | CCSF | NO | Tuolumne River, upstream of South Fork | | | | 6 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | 5 | | | | | | | | | | | | | | | | | | | | | | | | |
| TR098.0 | NMFS | YES | Tuolumne R DS of Lumsden Bridge | * | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 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 | * | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| TR109.3 | CCSF | NO | Tuolumne River, downstream of Preston Falls | | | | 5 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | 14 | | | | | | | | | | | | | | | | |
| TR117.3 | CCSF | NO | Tuolumne River, downstream of O'Shaughnessy | * | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **NF Tuolumne River** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| NFT00.1 | UC Davis | NO | North Fork Tuolumne above Tuolumne River | * | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Clavey River** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| CR00.1 | NMFS | YES | Clavey R. just US of confluence | * | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| CR00.3 | UC Davis | NO | Clavey River, upstream of Tuolumne River confluence | | | | | | | | | | | | | | | | | | | | | | | | | | | | 6 | ▨ | ▨ | ▨ | 28 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| CR16.9 | CCSF | NO | Clavey River at 1N04 Bridge | | | | 8 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | 20 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **SF Tuolumne River** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| SFT00.2 | CDFG | NO | South Fork of the Tuolumne River near confluence | | | | 7 | 18 | | 16 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | 27 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | 19 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | 27 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | 22 | | 25 | 14 | | | 17 | ▨ | ▨ | ▨ | ▨ | ▨ | 29 | ▨ | ▨ | 26 | 1 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | 12 | | | | | | | | | | |
| SFT00.2 | CCSF | NO | South Fork Tuolumne River near 1N10 Bridge | | | | 6 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | 4 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| SFT00.2 | NMFS | YES | S Fork Tuolumne R. just US of confluence | * | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Cherry Creek** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| CC00.6 | CDFG | NO | Cherry Creek Power House | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | 16 | | | 29 | ▨ | ▨ | ▨ | ▨ | 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 | ▨ | ▨ | ▨ | ▨ | ▨ | 29 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | 27 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | 29 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | 30 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | 12 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| CC07.0 | CCSF | NO | Cherry Creek, ds of confluence with Eleanor Creek | | | | 7 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | 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 | | | | 8 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | 4 | | | | | | | | | | | | | | | | | | | | | | | | 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 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Eleanor Creek** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| EC00.0 | CCSF | NO | Eleanor Creek, upstream of Cherry Creek confluence | | | | 7 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | 3 | | | | | | | | | | 30 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | 21 | | | | | | | | | | | | | 1 | ▨ | ▨ | ▨ | ▨ | 25 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| EC01.7 | CCSF | NO | Eleanor Creek, downstream of Miguel Creek confluence | | | | 7 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | | | | | | | | 27 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | 5 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| EC01.7 | CCSF | NO | Eleanor Creek, downstream of Miguel Creek confluence | | | | 7 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | 18 | | | | | | | | | | | | 29 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | 5 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| EC01.7 | CCSF | NO | Eleanor Creek, downstream of Miguel Creek confluence | | | | 7 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | | | | | | | | 27 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | 5 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| EC01.8 | CCSF | NO | Eleanor Creek, upstream of Miguel Creek confluence | | | | 7 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | | | | | | | | 27 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | 5 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| MC00.0 | CCSF | NO | Miguel Creek, upstream of Eleanor Creek confluence | | | | 7 | ▨ | 5 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | 2 | | | | | | | | | | | | | | | | 26 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | 5 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

* These data sets have been identified, but data have not been obtained and placed in data base at this time

# Less than





## Stream / Flow Gage

● Active ● Inactive

| Label | Agency | Active | Site Name |
|---|---|---|---|
| 11281000 | USGS | Inactive | SF TUOLUMNE R NR OAKLAND RECREATION CAMP CA |
| 11282000 | USGS | Inactive | M 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 |
| 11284400 | 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 Campgorund |
| TR096.5 | CDFG | NO | Tuolmune 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.

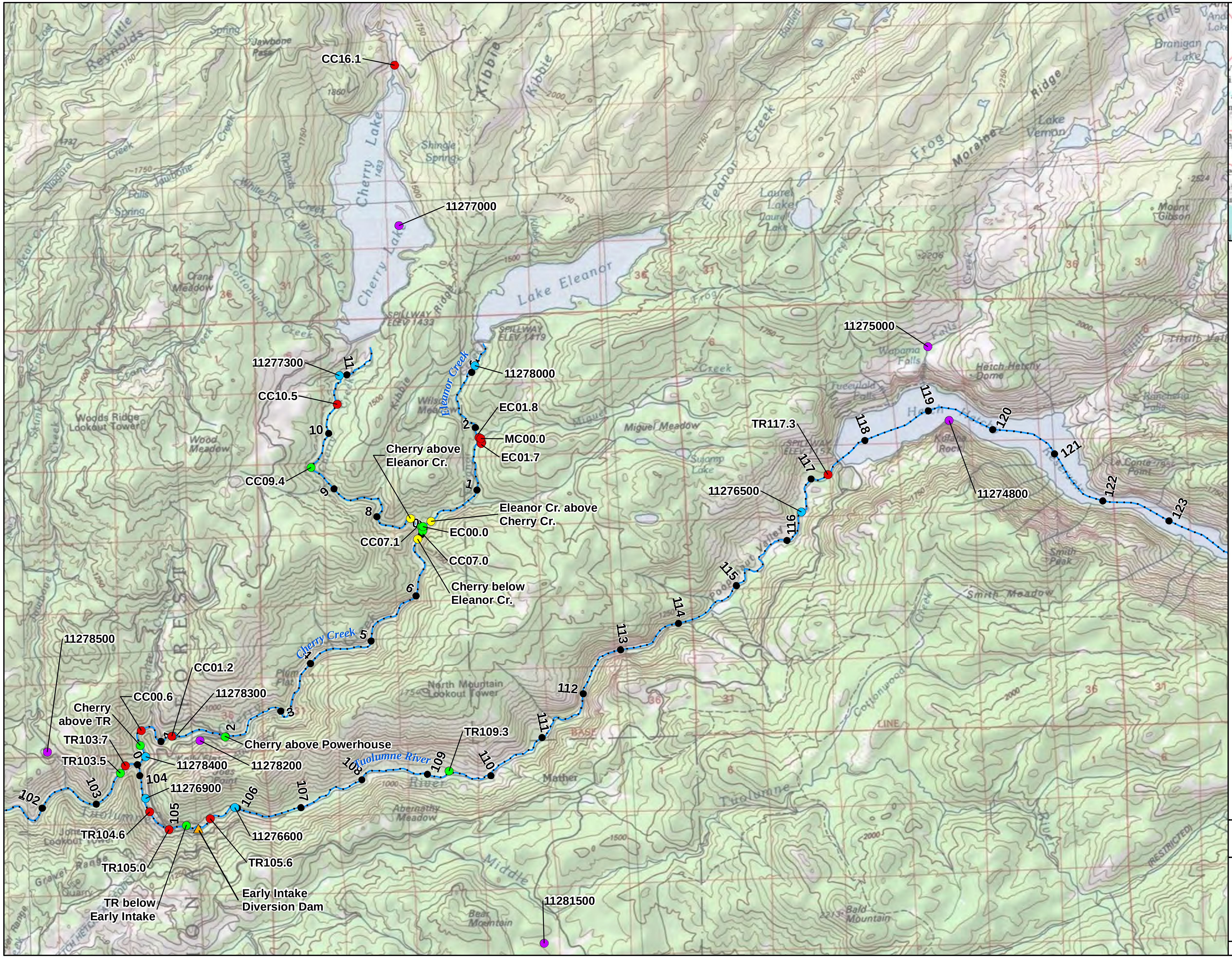
0 0.5 1 2
Miles

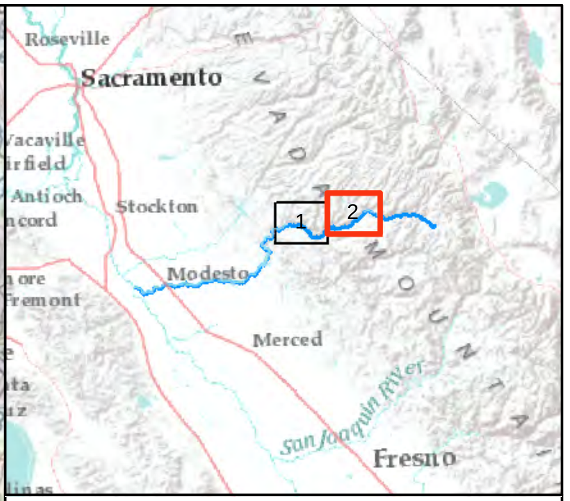
N

# 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

Sources: Esri, DeLorme, USGS, NPS
Sources: Esri, USGS, NOAA
Data is CA SPCS, Zone III, ft.





## Stream / Flow Gage

● Active ● Inactive

| Label | Agency | Active | Site Name |
|---|---|---|---|
| 11274800 | USGS | Inactive | TUOLUMNE R AT HETCH HETCHY NR SEQUOIA CA |
| 11275000 | USGS | Inactive | FALLS C NR HETCH HETCHY CA |
| 11275500 | USGS | Active | HETCH HETCHY RES A HETCH HETCHY CA |
| 11276500 | USGS | Active | TUOLUMNE R NR HETCH HETCHY CA |
| 11276600 | USGS | Active | TUOLUMNE R AB EARLY INTAKE NR MATHER CA |
| 11276900 | USGS | Active | TUOLUMNE R BL EARLY INTAKE NR MATHER CA |
| 11277000 | USGS | Inactive | CHERRY C NR HETCH HETCHY CA |
| 11277200 | USGS | Active | CHERRY LK NR HETCH HETCHY CA |
| 11277300 | USGS | Active | CHERRY C BL VALLEY DAM NR HETCH HETCHY CA |
| 11277500 | USGS | Active | LK ELEANOR NR HETCH HETCHY CA |
| 11278000 | USGS | Active | ELEANOR C NR HETCH HETCHY CA |
| 11278200 | USGS | Inactive | CHERRY C CN NR EARLY INTAKE CA |
| 11278300 | USGS | Active | CHERRY C NR EARLY INTAKE CA |
| 11278400 | USGS | Active | CHERRY C BL DION R HOLM PH, NR MATHER CA |
| 11278500 | USGS | Inactive | JAWBONE C NR TUOLUMNE CA |
| 11281500 | USGS | Inactive | M TUOLUMNE R NR MATHER CA |

## Water Temperature Logger

● Active ● Inactive ● Proposed*

| Label | Agency | Active | Site Locations |
|---|---|---|---|
| CC00.6 | TID/MID | YES | Cherry above TR |
| CC00.6 | CDFG | NO | Cherry Creek Power House |
| CC01.2 | CCSF | NO | Cherry Creek, upstream of Dion Holm Powerhouse |
| CC07.0 | CCSF | YES | Cherry Creek, downstream of confluence with Eleanor Creek |
| CC07.1 | CCSF | YES | Cherry Creek, upstream of Eleanor Creek confluence |
| CC09.4 | CCSF | YES | Cherry Creek, downstream of Cherry Dam |
| CC01.2 | TID/MID | YES | Cherry above Powerhouse |
| CC10.5 | CCSF | NO | Cherry Creek, downstream of Cherry Dam |
| CC16.1 | CCSF | NO | Upstream of Cherry Lake |
| EC00.0 | CCSF | YES | Eleanor Creek, upstream of Cherry Creek confluence |
| EC01.7 | CCSF | NO | Eleanor Creek, downstream of Miguel Creek confluence |
| EC01.7 | CCSF | NO | Eleanor Creek, downstream of Miguel Creek confluence |
| EC01.7 | CCSF | NO | Eleanor Creek, downstream of Miguel Creek confluence |
| EC01.8 | CCSF | NO | Eleanor Creek, upstream of Miguel Creek confluence |
| MC00.0 | CCSF | NO | Miguel Creek, upstream of Eleanor Creek confluence |
| TR103.5 | CCSF | YES | Tuolumne River, downstream of Cherry Creek confluence |
| TR103.7 | CCSF | NO | Tuolumne River, downstream of Cherry Creek confluence |
| TR104.6 | CCSF | NO | Tuolumne River, downstream of Early Intake Diversion Dam |
| TR105.0 | CDFG | NO | Tuolumne River at Early Intake |
| TR105.2 | TID/MID | YES | TR below Early Intake |
| TR105.6 | CCSF | NO | Tailrace of Kirkwood Powerhouse |
| TR109.3 | CCSF | YES | Tuolumne River, downstream of Preston Falls |
| TR117.3 | CCSF | NO | Tuolumne River, downstream of O'Shaughnessy Dam |

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

0 0.5 1 2 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.

# UPPER TUOLUMNE RIVER BASIN WATER TEMPERATURE MONITORING AND MODELING STUDY

## MODEL DEVELOPMENT REPORT

## ATTACHMENT D

## DATA INVENTORY

## Table D-1. Upper Tuolumne River and tributaries flow data inventory, 2005 - 2010.

■ daily median ▩ 1 hour data ▒ 30 minute data □ 15 minute data

Solid box indicates data is available for entire month. Otherwise, number in box indicates number of days in month for which data is available.

| | | | Land | | | 2005 | | | | | | | | | | | | 2006 | | | | | | | | | | | | 2007 | | | | | | | | | | | | 2008 | | | | | | | | | | | | 2009 | | | | | | | | | | | | 2010 | | | | | | | | | | | |
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| River Mile | Site Name | Agency | Owner | Active | Site_Locations | 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 |
| CC00.2 | 11278400 | USGS | USFS* | YES | Cherry Creek below Dion R Holm PH, near Mather CA | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | 30 | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ |
| CC01.2 | 11278300 | USGS | USFS* | YES | Cherry Creek near Early Intake CA | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | 25 | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | 24 | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ |
| CC10.9 | 11277300 | USGS | USFS | YES | Cherry Creek below Valley Dam near Hetch Hetchy CA | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | 29 | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ |
| EC03.1 | 11278000 | USGS | NPS | YES | Eleanor Creek near Hetch Hetchy CA | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | 30 | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | 27 | 30 | □ | □ | 25 | □ | □ | □ | □ | □ | □ | □ | 29 | □ | □ | □ | 29 | □ | □ | □ | □ | □ | □ | □ | □ |
| 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 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| NF08.0 | | 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 | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | 20 | □ | □ | □ | □ | □ | □ | □ | □ | □ | 20 | 22 | □ | □ | □ | □ | □ | □ | 28 |
| 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 | | | | | | | | | | | | | | | | | | | | | | 18 | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | 30 | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | 30 | □ | □ | 21 | □ | □ |

*managed under Wild and Scenic River designation

■ daily median ▩ 1 hour data ▒ 30 minute data □ 15 minute data

Solid box indicates data is available for entire month. Otherwise, number in box indicates number of days in month for which data is available.

## Table D-2. Upper Tuolumne River and tributaries flow data inventory, 2011 - 2016.

| | | | Land | | | 2011 | | | | | | | | | | | | 2012 | | | | | | | | | | | | 2013 | | | | | | | | | | | | 2014 | | | | | | | | | | | | 2015 | | | | | | | | | | | | 2016 | | | | | | | | | | | |
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| River Mile | Site Name | Agency | Owner | Active | Site_Locations | 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 |
| 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 | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | 20 | 17 | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | ▨ |
| CC10.9 | 11277300 | USGS | USFS | YES | Cherry Creek below Valley Dam near Hetch Hetchy CA | □ | □ | □ | □ | □ | 28 | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | ▨ |
| EC03.1 | 11278000 | USGS | NPS | YES | Eleanor Creek near Hetch Hetchy CA | 30 | 27 | □ | □ | □ | □ | □ | □ | □ | □ | □ | 28 | 29 | 28 | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | 28 | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | ▨ |
| SFT00.1 | | TID/MID | USFS* | YES | South Fork Tuolumne River above Tuolumne River confluence | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | | 1 | | 1 | | | | | | | | | | | 1 | | | 1 | | ▨ |
| CR00.1 | | TID/MID | USFS* | YES | Clavey River, upstream of Tuolumne River confluence | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | | 1 | | 1 | | | | | | | | | | 1 | | | 1 | | ▨ |
| CR08.4 | | TID/MID | USFS | YES | Clavey River at 1N01 Bridge | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | | 1 | | | | | | | | | | | | 1 | | | 1 | | ▨ |
| CR16.9 | | TID/MID | USFS | YES | Clavey River at 1N04 Bridge | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | | 1 | | | | | | | | | | | | 1 | | | 1 | | ▨ |
| NF00.1 | | TID/MID | BLM* | YES | NF Tuolumne River upstream of Tuolumne River confluence | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | | 1 | | | | | | | | | | | | 1 | | | | | ▨ |
| NF08.0 | | TID/MID | USFS | YES | NF Tuolumne River near 1N01 Bridge | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | | 1 | | | | | | | | | | | | 1 | | | | | ▨ |
| TR78.5 | 11285500 | USGS | BLM | YES | Tuolumne River at Wards Ferry Bridge nearr Groveland CA | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 25 | □ | □ | □ | □ | □ | 28 | 24 | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | 28 | 24 | □ | □ | □ | □ | □ | □ | □ | □ | 16 | □ | □ | □ | □ | □ | □ | 14 | ▨ |
| 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 | □ | □ | □ | □ | □ | □ | □ | 30 | □ | □ | □ | □ | □ | □ | 27 | □ | □ | □ | □ | □ | □ | □ | □ | 25 | 25 | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | ▨ |
| TR125.5 | 11274790 | USGS | NPS | YES | Tuolumne River at Grand Canyon of Tuolumne above Hetch Hetchy | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | 29 | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | ▨ |

*managed under Wild and Scenic River designation

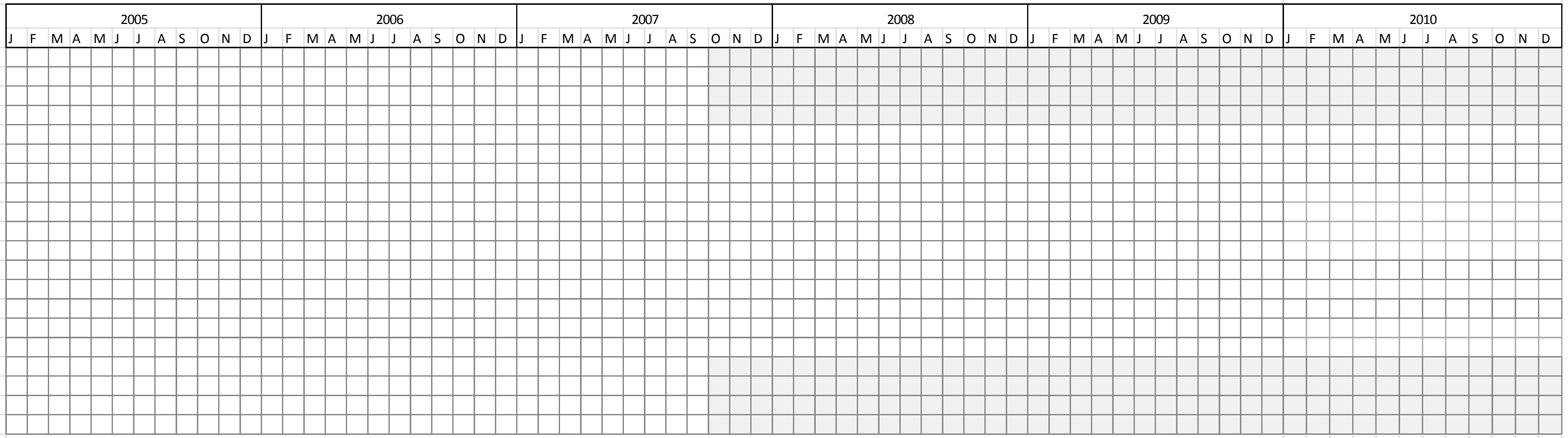
■ daily median ▩ 1 hour data ▒ 30 minute data □ 15 minute data

Solid box indicates data is available for entire month. Otherwise, number in box indicates number of days in month for which data is available.

## Table D-3. Upper Tuolumne River and tributaries stage data inventory, 2005 - 2010.

■ daily median ▓ 1 hour data ▒ 30 minute data ░ 15 minute data

Solid box indicates data is available for entire month. Otherwise, number in box indicates number of days in month for which data is available.



| 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 |
| CR00.3 | CRAT | UC Davis | USFS* | NO | 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 |
| NF08.0 | | TID/MID | USFS | YES | NF Tuolumne River near 1N01 Bridge |
| TR78.5 | 11285500 | USGS | BLM | YES | Tuloumne River at Wards Ferry Bridge nearr Groveland CA |
| TR81.3 | | TID/MID | USFS* | YES | Tuolumne River, upstream of NF Tuolumne confluence |
| TR091.1 | TRCL | UC Davis | USFS* | NO | Tuolumne River, upstream of Clavey Creek confluence |
| TR091.1 | | TID/MID | USFS* | YES | Tuolumne River, upstream of Clavey Creek confluence |
| TR097.0 | | TID/MID | USFS* | YES | Tuolumne River above the South Fork |
| 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

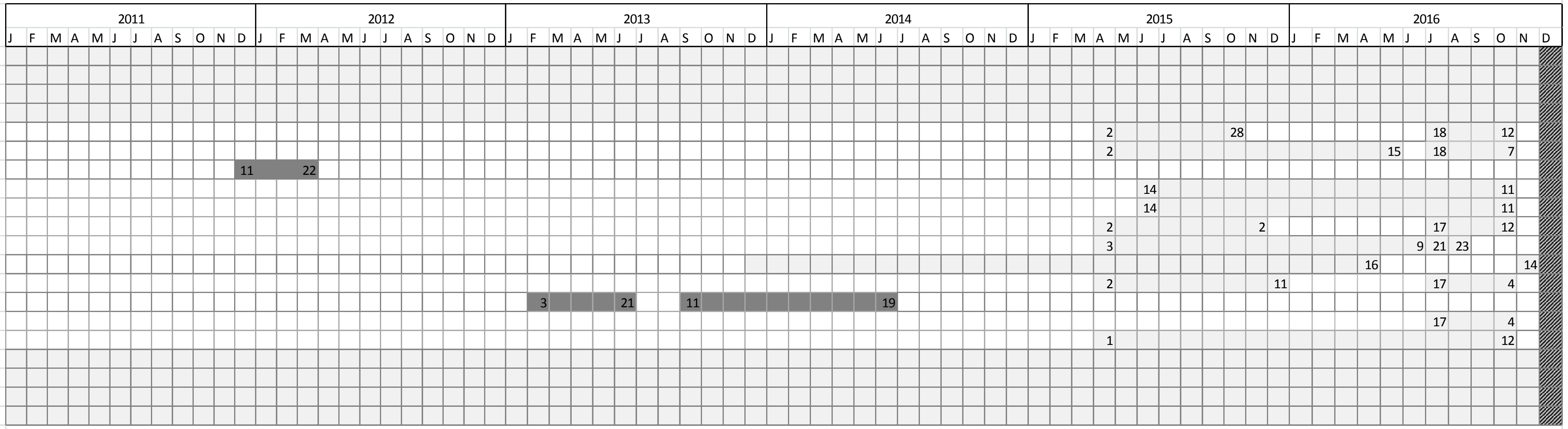
■ daily median ▓ 1 hour data ▒ 30 minute data ░ 15 minute data

Solid box indicates data is available for entire month. Otherwise, number in box indicates number of days in month for which data is available.

## Table D-4. Upper Tuolumne River and tributaries stage data inventory, 2011 - 2016.

■ daily median ▓ 1 hour data ▒ 30 minute data ░ 15 minute data

Solid box indicates data is available for entire month. Otherwise, number in box indicates number of days in month for which data is available.



| 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 |
| CR00.3 | CRAT | UC Davis | USFS* | NO | 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 |
| NF08.0 | | TID/MID | USFS | YES | NF Tuolumne River near 1N01 Bridge |
| TR78.5 | 11285500 | USGS | BLM | YES | Tuloumne River at Wards Ferry Bridge nearr Groveland CA |
| TR81.3 | | TID/MID | USFS* | YES | Tuolumne River, upstream of NF Tuolumne confluence |
| TR091.1 | TRCL | UC Davis | USFS* | NO | Tuolumne River, upstream of Clavey Creek confluence |
| TR091.1 | | TID/MID | USFS* | YES | Tuolumne River, upstream of Clavey Creek confluence |
| TR097.0 | | TID/MID | USFS* | YES | Tuolumne River above the South Fork |
| 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 |

| River Mile | 2011 D | 2012 M | 2013 F | 2013 J | 2013 S | 2014 J | 2015 A | 2015 J | 2015 O | 2015 N | 2015 D | 2016 A | 2016 M | 2016 J | 2016 J | 2016 A | 2016 O | 2016 N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SFT00.1 | | | | | | | 2 | | 28 | | | | | | 18 | | 12 | |
| CR00.1 | | | | | | | 2 | | | | | | 15 | | 18 | | 7 | |
| CR00.3 | 11 | 22 | | | | | | | | | | | | | | | | |
| CR08.4 | | | | | | | | 14 | | | | | | | | | 11 | |
| CR16.9 | | | | | | | | 14 | | | | | | | | | 11 | |
| NF00.1 | | | | | | | 2 | | | 2 | | | | | 17 | | 12 | |
| NF08.0 | | | | | | | 3 | | | | | | | 9 | 21 | 23 | | |
| TR78.5 | | | | | | | | | | | | 16 | | | | | | 14 |
| TR81.3 | | | | | | | 2 | | | | 11 | | | | 17 | | 4 | |
| TR091.1 (UC Davis) | | | 3 | 21 | 11 | 19 | | | | | | | | | | | | |
| TR091.1 (TID/MID) | | | | | | | | | | | | | | | 17 | | 4 | |
| TR097.0 | | | | | | | 1 | | | | | | | | | | 12 | |

*managed under Wild and Scenic River designation

■ daily median ▓ 1 hour data ▒ 30 minute data ░ 15 minute data

Solid box indicates data is available for entire month. Otherwise, number in box indicates number of days in month for which data is available.

## Table D-5. Water temperature data inventory, Upper Tuolumne River and tributaries, 2005 - 2010.

■ daily median ▓ 1 hour data ▒ 30 minute data ░ 15 minute data

Solid box indicates data is available for entire month. Otherwise, number in box indicates number of days in month for which data is available.

| River Mile | Site Name | Agency | Land Owner | Active | Site_Locations | 2005 | | | | | | | | | | | | 2006 | | | | | | | | | | | | 2007 | | | | | | | | | | | | 2008 | | | | | | | | | | | | 2009 | | | | | | | | | | | | 2010 | | | | | | | | | | | |
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| | | | | | | 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 |
| CC00.2 | 11278400 | USGS | USFS | YES | Cherry Creek below Dion R Holm PH, near Mather CA | | | | | | | | | | | | | | | | | 6 | 29 | 5 | 8 | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ |
| CC00.6 | TCKPH | CDFG | USFS | NO | Cherry Creek Power House | | | | 4 | ▓ | ▓ | 21 | 6 | ▓ | ▓ | ▓ | ▓ | 4 | | | | | 2 | 29 | 4 | 26 | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | 16 | | | 29 | ▓ | ▓ | ▓ | ▓ | 22 | 3 | ▓ | ▓ | 18 | ▓ | ▓ | ▓ | 23 | 7 | ▓ | ▓ | ▓ | ▓ | ▓ | 9 | | | | | | | | | | | | | | | |
| CC00.5 | | TID/MID | USFS | YES | Cherry Creek below Dion Holm Powerhouse | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| CC01.2 | CC6 | CCSF | USFS | NO | Cherry Creek, upstream of Dion Holm Powerhouse | | | | | | | | | | | | | | | | | | | | | | | | | | | | 8 | ▒ | ▒ | 30 | ▒ | ▒ | 30 | ▒ | ▒ | ▒ | ▒ | ▒ | 29 | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | 27 | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | 29 | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ |
| CC01.2 | 11278300 | USGS | USFS | YES | Cherry Creek near Early Intake CA | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 4 | 21 | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ |
| CC02.0 | | TID/MID | USFS | YES | Cherry Creek, upstream of Dion Holm Powerhouse | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| CC07.0 | CC5 | CCSF | USFS | YES | Cherry Creek, downstream of confluence with Eleanor Creek | | | | | | | | | | | | | | | | | | | | | | | | | | | | 7 | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | 2 | 29 | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ |
| CC07.1 | CC4 | CCSF | USFS | YES | Cherry Creek, upstream of Eleanor Creek confluence | | | | | | | | | | | | | | | | | | | | | | | | | | | | 7 | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | 2 | 29 | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ |
| CC09.4 | CC3 | CCSF | USFS | YES | Cherry Creek, downstream of Cherry Dam | | | | | | | | | | | | | | | | | | | | | | | | | | | | 8 | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | 4 | | | | | | | | | | | | | |
| CC10.5 | CC2 | CCSF | USFS | NO | Cherry Creek, downstream of Cherry Dam | | | | | | | | | | | | | | | | | | | | | | | | | | | | 7 | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ |
| CC10.9 | 11277300 | USGS | USFS | YES | Cherry Creek below Valley Dam near Hetch Hetchy CA | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 27 | 10 | 10 | 15 | ░ | 27 | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | 21 |
| CC16.1 | CC1 | CCSF | USFS | NO | Cherry Creek upstream of Cherry Lake | | | | | | | | | | | | | | | | | | | | | | | | | | | | 7 | ▒ | 25 | | | | 30 | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | 4 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| EC00.0 | EC5 | CCSF | USFS | YES | Eleanor Creek, upstream of Cherry Creek confluence | | | | | | | | | | | | | | | | | | | | | | | | | | | | 7 | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | 3 | | | | | | | | | | 30 | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | 21 | | |
| EC01.7 | EC4 | CCSF | NPS | NO | Eleanor Creek, downstream of Miguel Creek confluence | | | | | | | | | | | | | | | | | | | | | | | | | | | | 7 | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | | | | | | | | 27 | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ |
| EC01.7 | EC3 | CCSF | NPS | NO | Eleanor Creek, downstream of Miguel Creek confluence | | | | | | | | | | | | | | | | | | | | | | | | | | | | 7 | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | 18 | |
| EC01.7 | EC2 | CCSF | NPS | NO | Eleanor Creek, downstream of Miguel Creek confluence | | | | | | | | | | | | | | | | | | | | | | | | | | | | 7 | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | | | | | | | | 27 | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ |
| EC01.8 | EC1 | CCSF | NPS | NO | Eleanor Creek, upstream of Miguel Creek confluence | | | | | | | | | | | | | | | | | | | | | | | | | | | | 7 | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | | | | | | | | 27 | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ |
| EC03.1 | 11278000 | USGS | NPS | YES | Eleanor Creek near Hetch Hetchy CA | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | 11 | ░ | 20 | ░ | ░ | ░ | ░ | 18 |
| MC00.0 | MC1 | CCSF | NPS | NO | Miguel Creek, upstream of Eleanor Creek confluence | | | | | | | | | | | | | | | | | | | | | | | | | | | | 7 | ▒ | 5 | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | 2 | | | | | | | | | | | | | | | 26 | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ |
| SFT00.1 | | TID/MID | USFS* | YES | South Fork Tuolumne River above Tuolumne River confluence | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| SFT00.2 | TSFRK | CDFG | USFS* | NO | South Fork of the Tuolumne River near confluence | | | | 7 | 18 | | 16 | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | 27 | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | 19 | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | 27 | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | 22 | | 25 | 14 | | | 17 | ▓ | ▓ | ▓ | ▓ | ▓ | 29 | ▓ | ▓ | 26 | 1 | ▓ |
| SFT00.2 | SF1 | NMFS | USFS* | YES | South Fork of the Tuolumne River just upstream of confluence | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| SFT00.2 | TR6 | CCSF | USFS* | NO | South Fork Tuolumne River near 1N10 Bridge | | | | | | | | | | | | | | | | | | | | | | | | | | | | 6 | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | 4 | | | | | | | | | | | | | |
| CR00.1 | CLAVEY1 | NMFS | USFS* | YES | Clavey River, upstream of Tuolumne River confluence | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| CR00.1 | | TID/MID | USFS* | YES | Clavey River, upstream of Tuolumne River confluence | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| CR00.3 | CRAT | UC Davis | USFS* | NO | Clavey River, upstream of Tuolumne River confluence | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 6 | ▓ | ▓ | ▓ | 28 | | | | | | | | | | | | | | | | | |
| CR08.4 | CLAVEY2 | NMFS | USFS* | YES | Clavey River, middle bridge, RD1N01 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| CR08.4 | | TID/MID | USFS | YES | Clavey River  at 1N01 Bridge | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| CR08.4 | CR2 | CCSF | USFS | NO | Clavey River  at 1N01 Bridge | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| CR16.9 | CR1 | CCSF | USFS | NO | Clavey River at 1N04 Bridge | | | | | | | | | | | | | | | | | | | | | | | | | | | | 8 | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | 20 | | |
| CR16.9 | | TID/MID | USFS | YES | Clavey River at 1N04 Bridge | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| NFT00.1 | NFTUOL | UCD | BLM* | NO | North  Fork Tuolumne River above Tuolumne River | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 5 | ▓ | ▓ | ▓ | 30 | | | | | | | | | | | | | | | | | |
| NF00.1 | | TID/MID | BLM* | YES | NF Tuolumne River upstream of Tuolumne River confluence | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| NF08.0 | | TID/MID | USFS | YES | NF Tuolumne River near 1N01 Bridge | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| TR78.5 | 11285500 | USGS | BLM | YES | Tuloulmne River at Wards Ferry Bridge nearr Groveland CA | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| TR078.7 | TRWARDS | CDFG | BLM | YES | Tuolumne River upstream of Wards Ferry Bridge | | | | | 8 | ▓ | ▓ | ▓ | ▓ | 21 | | 23 | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | 5 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 20 | ▓ | ▓ | 22 | | | | 18 | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | 7 | | | |
| TR079.4 | TR8 | CCSF | BLM | NO | Tuolumne River, upstream of Ward's Ferry | | | | | | | | | | | | | | | | | | | | | | | | | | | | 6 | ▒ | ▒ | ▒ | ▒ | ▒ | 1 | | | | | | | | | | 25 | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | | | | | | | | | | | | | | | | | | | | | | 15 | ▒ |
| TR81.3 | | TID/MID | USFS* | YES | Tuolumne River, upstream of NF Tuolumne confluence | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| TR81.9 | UPPERT1 | NMFS | USFS* | YES | Tuolumne River, downstream of Mohecan Bridge | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| TR083.0 | TID1 | TID/MID | USFS* | NO | Tuolumne River at Indian Creek Trail | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | ▓ | ▓ | ▓ |
| TR88.4 | UPPERT2 | NMFS | USFS* | YES | Tuolumne River, downstream of Grapevine Creek | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| TR091.1 | TRCL | UC Davis | USFS* | NO | Tuolumne River, upstream of Clavey Creek confluence | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 6 | ▓ | ▓ | ▓ | 28 | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | 7 | | | | | | | |
| TR091.1 | | TID/MID | USFS* | YES | Tuolumne River, upstream of Clavey Creek confluence | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| TR91.1 | UPPERT3 | NMFS | USFS* | YES | Tuolumne River, upstream of Clavey River | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| TR96.4 | UPPERT4 | NMFS | USFS* | YES | Tuolumne River, downstream of Lumsden Campground | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| TR096.5 | TBSFRK | CDFG | USFS* | NO | Tuolmune River below the South Fork | | | | 4 | ▓ | ▓ | ▓ | ▓ | 17 | 30 | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | 2 | 7 | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | 21 | 22 | ▓ | 21 | | | | 29 | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ |
| TR096.6 | | CCSF | USFS* | NO | Tuolumne River, Lumsden | | | | | | | | | | | | | | | | | | | | | | | | | | | | 6 | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | 10 | | | | | | | | | | | | | |
| TR097.0 | | TID/MID | USFS* | YES | Tuolumne River above the South Fork | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| TR097.1 | TR7 | CCSF | USFS* | YES | Tuolumne River, upstream of South Fork | | | | | | | | | | | | | | | | | | | | | | | | | | | | 6 | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ |
| TR98.0 | UPPERT5 | NMFS | USFS* | YES | Tuolumne River, downstream of Lumsden Bridge | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| TR103.5 | TR4 | CCSF | USFS* | YES | Tuolumne River, downstream of Cherry Creek confluence (TR4) | | | | | | | | | | | | | | | | | | | | | | | | | | | | 8 | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | 14 | | 21 | ▒ |
| TR103.7 | TR3 | CCSF | USFS* | NO | Tuolumne River, downstream of Cherry Creek confluence (TR3) | | | | | | | | | | | | | | | | | | | | | | | | | | | | 8 | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | 13 | | | |
| TR104.4 | 11276900 | USGS | USFS* | YES | Tuolumne River below Early Intake near Mather CA | | | | | | | | | | | | | | | | | | 28 | 11 | 8 | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ |
| TR104.6 | TR2 | CCSF | USFS | NO | Tuolumne River, downstream of Early Intake Diversion Dam | | | | | | | | | | | | | | | | | | | | | | | | | | | | 8 | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | 13 | | | |
| TR105.0 | TREARLY | CDFG | USFS | NO | Tuolumne River at Early Intake | | | | | | | 7 | 6 | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | 30 | | | | | 16 | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | 29 | 23 | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ |
| TR105.2 | | TID/MID | USFS | YES | Tuolumne River below Early Intake | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| TR105.9 | 11276600 | USGS | USFS | YES | Tuolumne River abv Early Intake nr Mather CA | ■ | ■ | 19 | ■ | ■ | ■ | 28 | | 23 | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | 27 | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ |
| TR109.3 | TR1 | CCSF | USFS* | YES | Tuolumne River, downstream of Preston Falls | | | | | | | | | | | | | | | | | | | | | | | | | | | | 5 | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ |
| TR116.5 | 11276500 | USGS | NPS | YES | Tuolumne River near Hetch Hetchy CA | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | 16 | 16 | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | 26 | 5 | | 25 | 30 | 27 | 17 | 19 | ░ | 21 | 20 | 15 | 5 | | 24 | ░ | ░ | ░ | 30 | | | 13 | 8 | 15 | ░ | ░ |
| TR125.5 | 11274790 | USGS | NPS | YES | Tuolumne River at Grand Canyon of Tuolumne above Hetch Hetchy | | | | | | | | | | | | | | | | | | | | | | 11 | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | 20 | ■ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ |

*managed under Wild and Scenic River designation

■ daily median ▓ 1 hour data ▒ 30 minute data ░ 15 minute data

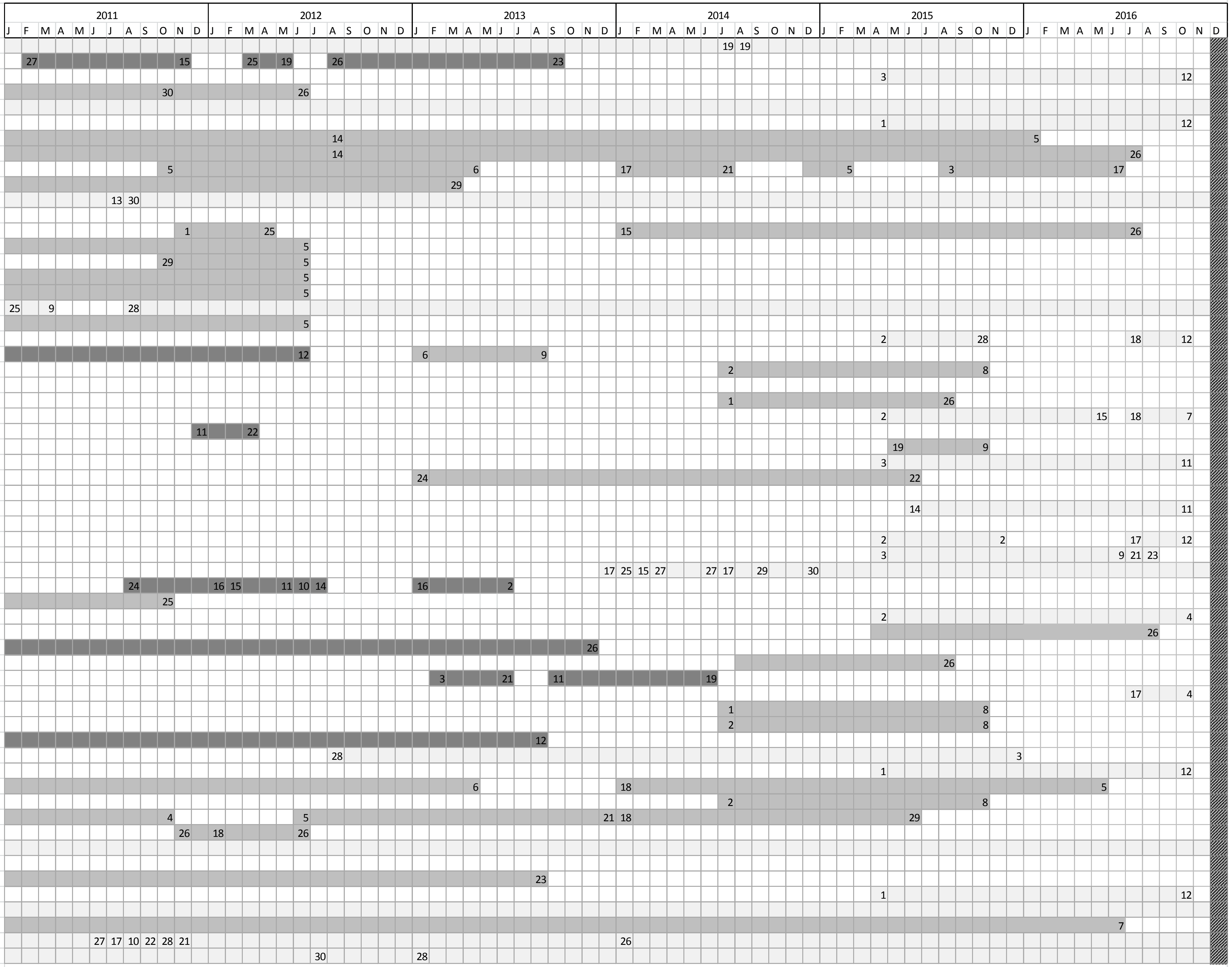
Solid box indicates data is available for entire month. Otherwise, number in box indicates number of days in month for which data is available.

## Table D-6. Water temperature data inventory, Upper Tuolumne River and tributaries, 2011 - 2016.

■ daily median ▓ 1 hour data ▒ 30 minute data □ 15 minute data

Solid box indicates data is available for entire month. Otherwise, number in box indicates number of days in month for which data is available.

| 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 |
| CC00.6 | TCKPH | CDFG | USFS | NO | Cherry Creek Power House |
| CC00.5 | | TID/MID | USFS | YES | Cherry Creek below Dion Holm Powerhouse |
| CC01.2 | CC6 | CCSF | USFS | NO | Cherry Creek, upstream of Dion Holm Powerhouse |
| CC01.2 | 11278300 | USGS | USFS | YES | Cherry Creek near Early Intake CA |
| CC02.0 | | TID/MID | USFS | YES | Cherry Creek, upstream of Dion Holm Powerhouse |
| CC07.0 | CC5 | CCSF | USFS | YES | Cherry Creek, downstream of confluence with Eleanor Creek |
| CC07.1 | CC4 | CCSF | USFS | YES | Cherry Creek, upstream of Eleanor Creek confluence |
| CC09.4 | CC3 | CCSF | USFS | YES | Cherry Creek, downstream of Cherry Dam |
| CC10.5 | CC2 | CCSF | USFS | NO | Cherry Creek, downstream of Cherry Dam |
| CC10.9 | 11277300 | USGS | USFS | YES | Cherry Creek below Valley Dam near Hetch Hetchy CA |
| CC16.1 | CC1 | CCSF | USFS | NO | Cherry Creek upstream of Cherry Lake |
| EC00.0 | EC5 | CCSF | USFS | YES | Eleanor Creek, upstream of Cherry Creek confluence |
| EC01.7 | EC4 | CCSF | NPS | NO | Eleanor Creek, downstream of Miguel Creek confluence |
| EC01.7 | EC3 | CCSF | NPS | NO | Eleanor Creek, downstream of Miguel Creek confluence |
| EC01.7 | EC2 | CCSF | NPS | NO | Eleanor Creek, downstream of Miguel Creek confluence |
| EC01.8 | EC1 | CCSF | NPS | NO | Eleanor Creek, upstream of Miguel Creek confluence |
| EC03.1 | 11278000 | USGS | NPS | YES | Eleanor Creek near Hetch Hetchy CA |
| MC00.0 | MC1 | CCSF | NPS | NO | Miguel Creek, upstream of Eleanor Creek confluence |
| SFT00.1 | | TID/MID | USFS* | YES | South Fork Tuolumne River above Tuolumne River confluence |
| SFT00.2 | TSFRK | CDFG | USFS* | NO | South Fork of the Tuolumne River near confluence |
| SFT00.2 | SF1 | NMFS | USFS* | YES | South Fork of the Tuolumne River just upstream of confluence |
| SFT00.2 | TR6 | CCSF | USFS* | NO | South Fork Tuolumne River near 1N10 Bridge |
| CR00.1 | CLAVEY1 | NMFS | USFS* | YES | Clavey River, upstream of Tuolumne River confluence |
| CR00.1 | | TID/MID | USFS* | YES | Clavey River, upstream of Tuolumne River confluence |
| CR00.3 | CRAT | UC Davis | USFS* | NO | Clavey River, upstream of Tuolumne River confluence |
| CR08.4 | CLAVEY2 | NMFS | USFS* | YES | Clavey River, middle bridge, RD1N01 |
| CR08.4 | | TID/MID | USFS | YES | Clavey River at 1N01 Bridge |
| CR08.4 | CR2 | CCSF | USFS | NO | Clavey River at 1N01 Bridge |
| CR16.9 | CR1 | CCSF | USFS | NO | Clavey River at 1N04 Bridge |
| CR16.9 | | TID/MID | USFS | YES | Clavey River at 1N04 Bridge |
| NFT00.1 | NFTUOL | UCD | BLM* | NO | North Fork Tuolumne River above Tuolumne River |
| NF00.1 | | TID/MID | BLM* | YES | NF Tuolumne River upstream of Tuolumne River confluence |
| NF08.0 | | TID/MID | USFS | YES | NF Tuolumne River near 1N01 Bridge |
| TR78.5 | 11285500 | USGS | BLM | YES | Tuloumne River at Wards Ferry Bridge near Groveland CA |
| TR078.7 | TRWARDS | CDFG | BLM | NO | Tuolumne River upstream of Wards Ferry Bridge |
| TR079.4 | TR8 | CCSF | BLM | NO | Tuolumne River, upstream of Ward's Ferry |
| TR81.3 | | TID/MID | USFS* | YES | Tuolumne River, upstream of NF Tuolumne confluence |
| TR81.9 | UPPERT1 | NMFS | USFS* | YES | Tuolumne River, downstream of Mohecan Bridge |
| TR083.0 | TID1 | TID/MID | USFS* | NO | Tuolumne River at Indian Creek Trail |
| TR88.4 | UPPERT2 | NMFS | USFS* | YES | Tuolumne River, downstream of Grapevine Creek |
| TR091.1 | TRCL | UC Davis | USFS* | NO | Tuolumne River, upstream of Clavey Creek confluence |
| TR091.1 | | TID/MID | USFS* | YES | Tuolumne River, upstream of Clavey Creek confluence |
| TR91.1 | UPPERT3 | NMFS | USFS* | YES | Tuolumne River, upstream of Clavey River |
| TR96.4 | UPPERT4 | NMFS | USFS* | YES | Tuolumne River, downstream of Lumsden Campground |
| TR096.5 | TBSFRK | CDFG | USFS* | NO | Tuolmune River below the South Fork |
| TR096.6 | | CCSF | USFS* | NO | Tuolumne River, Lumsden |
| TR097.0 | | TID/MID | USFS* | YES | Tuolumne River above the South Fork |
| TR097.1 | TR7 | CCSF | USFS* | YES | Tuolumne River, upstream of South Fork |
| TR98.0 | UPPERT5 | NMFS | USFS* | YES | Tuolumne River, downstream of Lumsden Bridge |
| TR103.5 | TR4 | CCSF | USFS* | YES | Tuolumne River, downstream of Cherry Creek confluence (TR4) |
| TR103.7 | TR3 | CCSF | USFS* | NO | Tuolumne River, downstream of Cherry Creek confluence (TR3) |
| TR104.4 | 11276900 | USGS | USFS* | YES | Tuolumne River below Early Intake near Mather CA |
| TR104.6 | TR2 | CCSF | USFS | NO | Tuolumne River, downstream of Early Intake Diversion Dam |
| TR105.0 | TREARLY | CDFG | USFS | NO | Tuolumne River at Early Intake |
| TR105.2 | | TID/MID | USFS | YES | Tuolumne River below Early Intake |
| TR105.9 | 11276600 | USGS | USFS | YES | Tuolumne River abv Early Intake nr Mather CA |
| TR109.3 | TR1 | CCSF | USFS* | YES | Tuolumne River, downstream of Preston Falls |
| 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

■ daily median ▓ 1 hour data ▒ 30 minute data □ 15 minute data

Solid box indicates data is available for entire month. Otherwise, number in box indicates number of days in month for which data is available.

# UPPER TUOLUMNE RIVER BASIN WATER TEMPERATURE MONITORING AND MODELING STUDY

## MODEL DEVELOPMENT REPORT

## ATTACHMENT E

## MAP OF STUDY AREA INCLUDING LOCATIONS OF DATA COLLECTION SITES

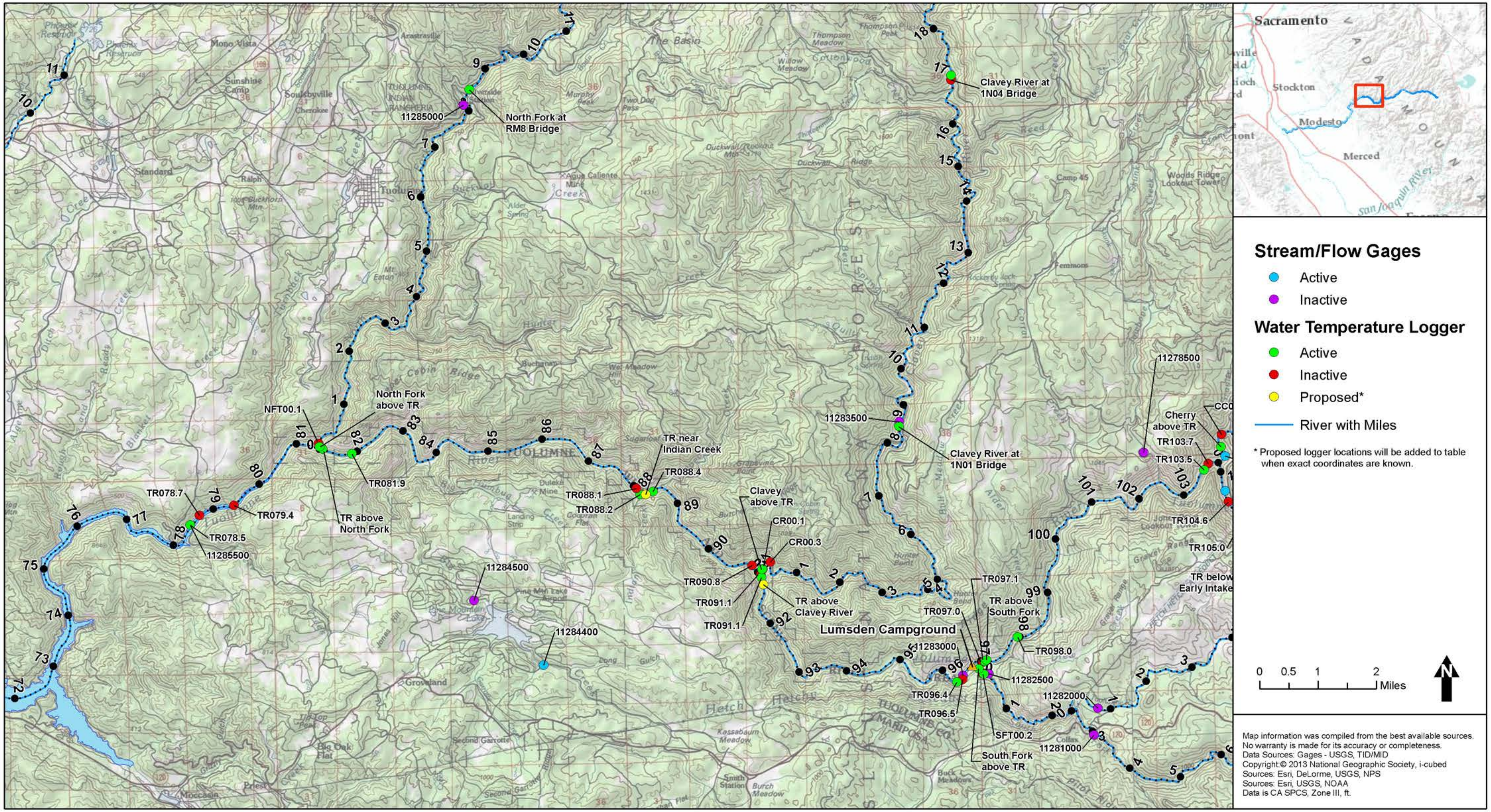
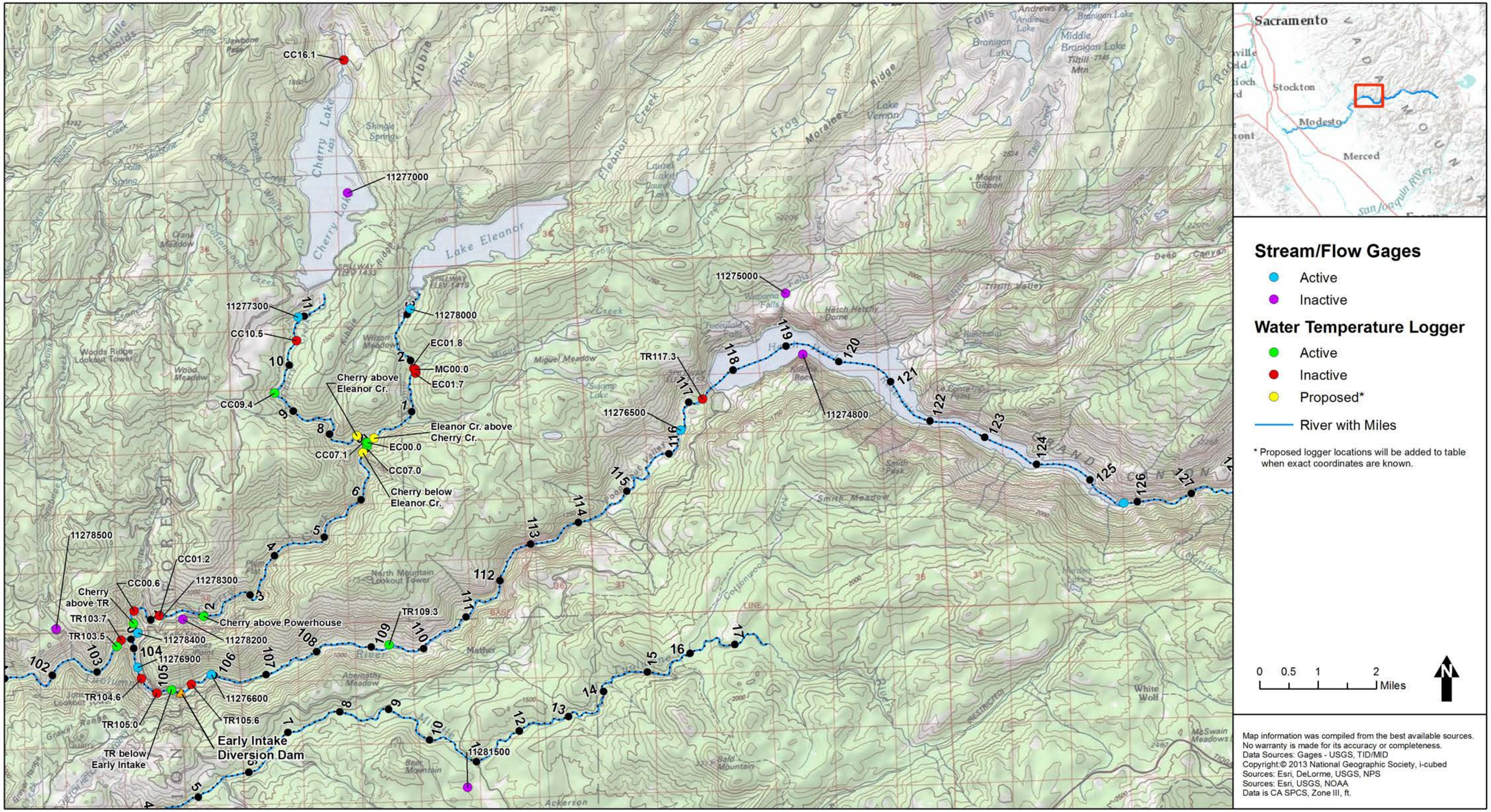


**Figure E-1.** Study area including locations of data collection sites, 1 of 2.



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.

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

# UPPER TUOLUMNE RIVER BASIN WATER TEMPERATURE MONITORING AND MODELING STUDY

## MODEL DEVELOPMENT REPORT

## ATTACHMENT F

## MODEL CALIBRATION RESULTS

The model simulated seasonal variations in diel range and overall tracked observed data well. Comparison of model simulated and measured water temperatures for 2008 to 2016 (excluding 2015) are presented below. The corresponding flow rates are presented in the secondary axis. In general, simulated temperatures tracked observed water temperatures well. All locations reproduced inter-annual, seasonal, short term (days) and sub-daily conditions.

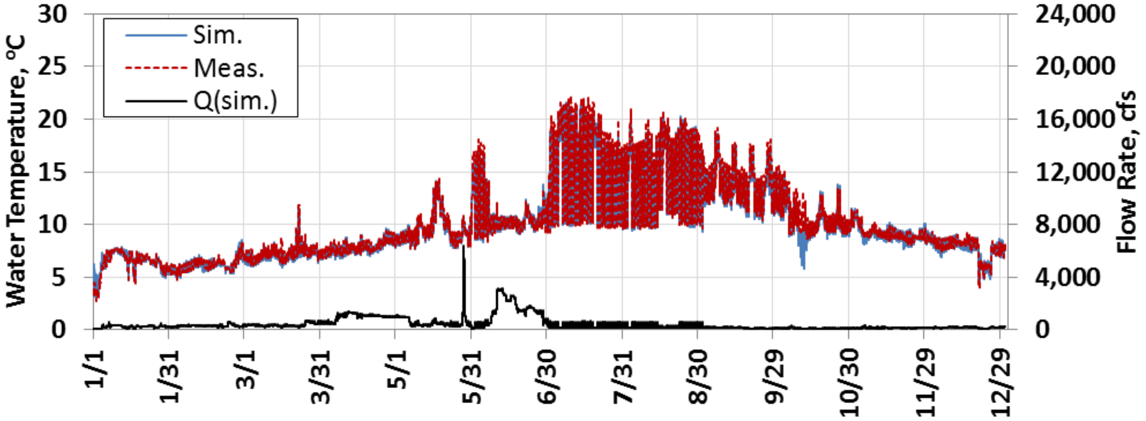


**Figure F-3.** Comparison of measured (Meas.) and simulated (Sim.) water temperature below Cherry Creek confluence for the calibration year 2008. Flow rate (in cfs) is presented in the secondary axis.

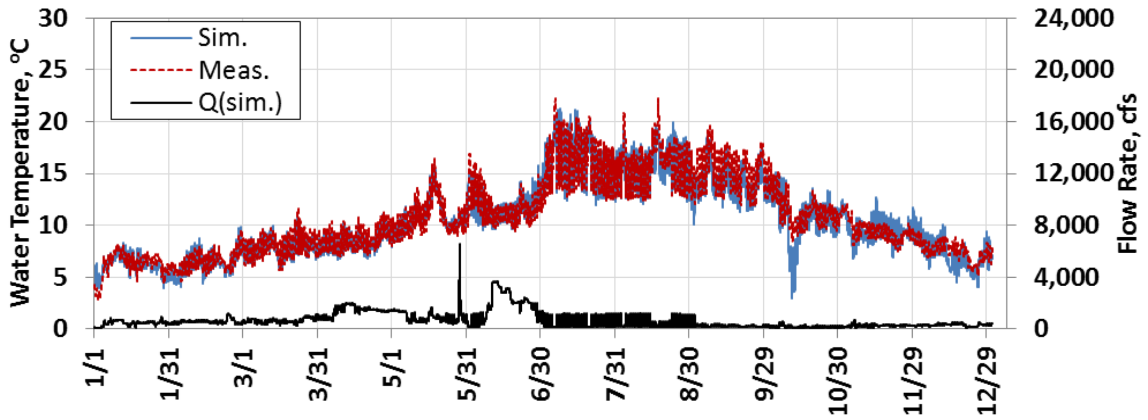


**Figure F-4.** Comparison of measured (Meas.) and simulated (Sim.) water temperature above South Fork Tuolumne River confluence for the calibration year 2008. Flow rate (in cfs) is presented in the secondary axis.

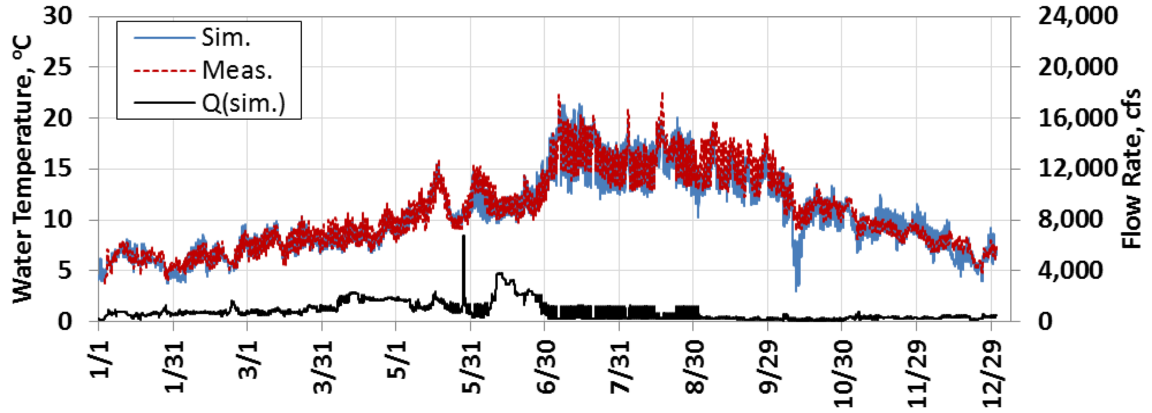


**Figure F-5.** Comparison of measured (Meas.) and simulated (Sim.) water temperature below South Fork Tuolumne River confluence for the calibration year 2008. Flow rate (in cfs) is presented in the secondary axis.

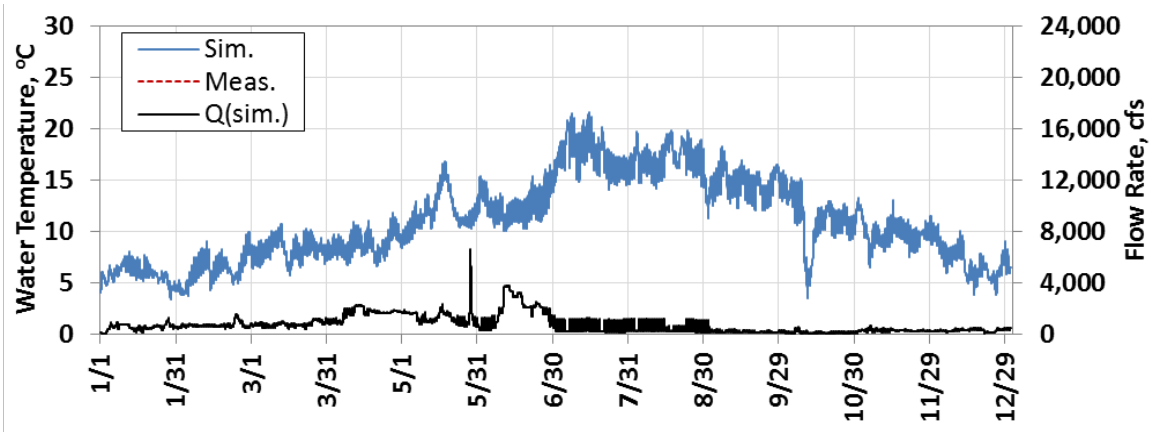


**Figure F-6.** Comparison of measured (Meas.) and simulated (Sim.) water temperature above Clavey River confluence for the calibration year 2008. Flow rate (in cfs) is presented in the secondary axis. (Note: Measured data for this location not available during this period.)

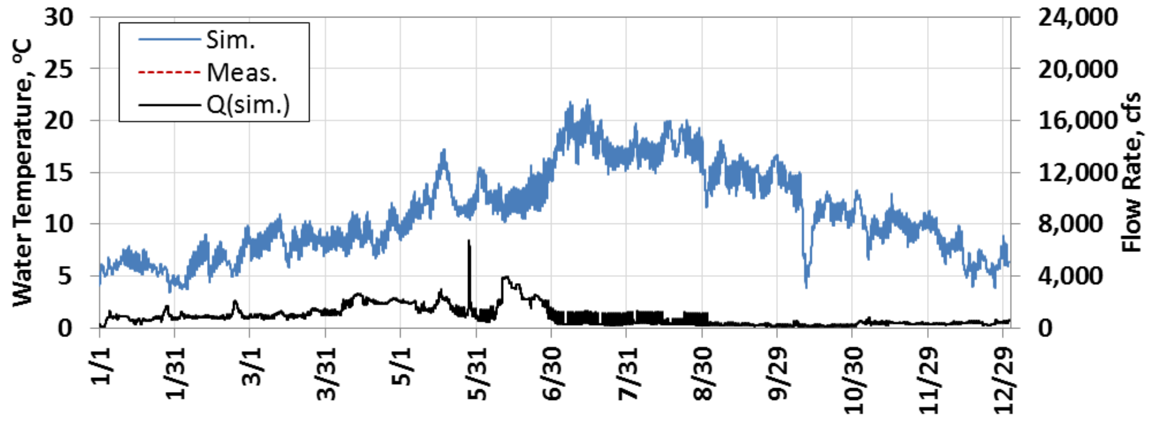


**Figure F-7.** Comparison of measured (Meas.) and simulated (Sim.) water temperature below Indian Creek confluence for the calibration year 2008. Flow rate (in cfs) is presented in the secondary axis. (Note: Measured data for this location not available during this period.)

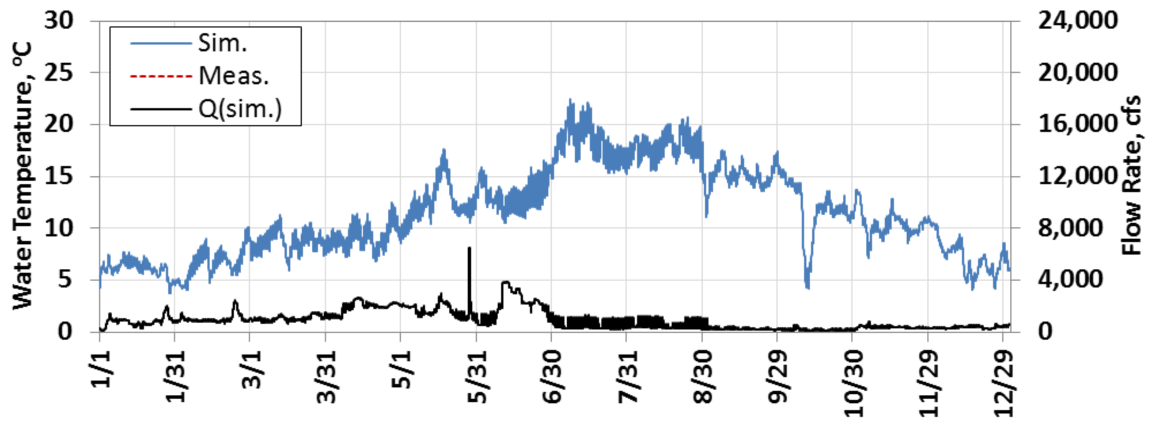


**Figure F-8.** Comparison of measured (Meas.) and simulated (Sim.) water temperature above North Fork Tuolumne River confluence for the calibration year 2008. Flow rate (in cfs) is presented in the secondary axis. (Note: Measured data for this location not available during this period.)

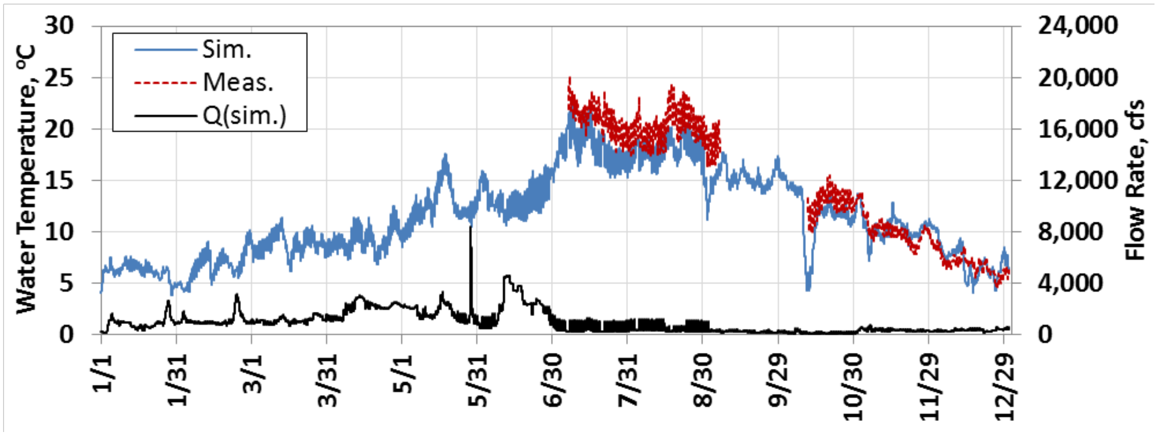


**Figure F-9.** Comparison of measured (Meas.) and simulated (Sim.) water temperature at Wards Ferry for the calibration year 2008. Flow rate (in cfs) is presented in the secondary axis.

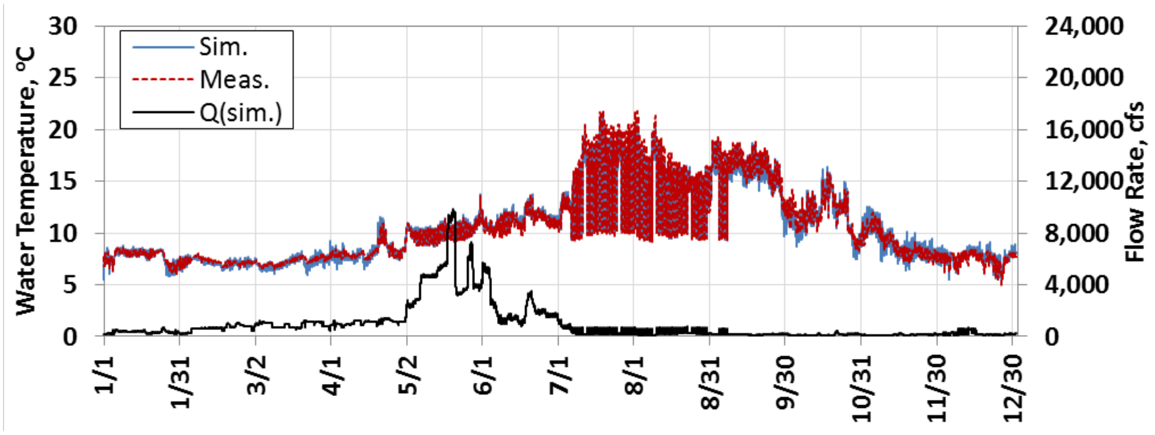


**Figure F-10.** Comparison of measured (Meas.) and simulated (Sim.) water temperature below Cherry Creek confluence for the calibration year 2009. Flow rate (in cfs) is presented in the secondary axis.

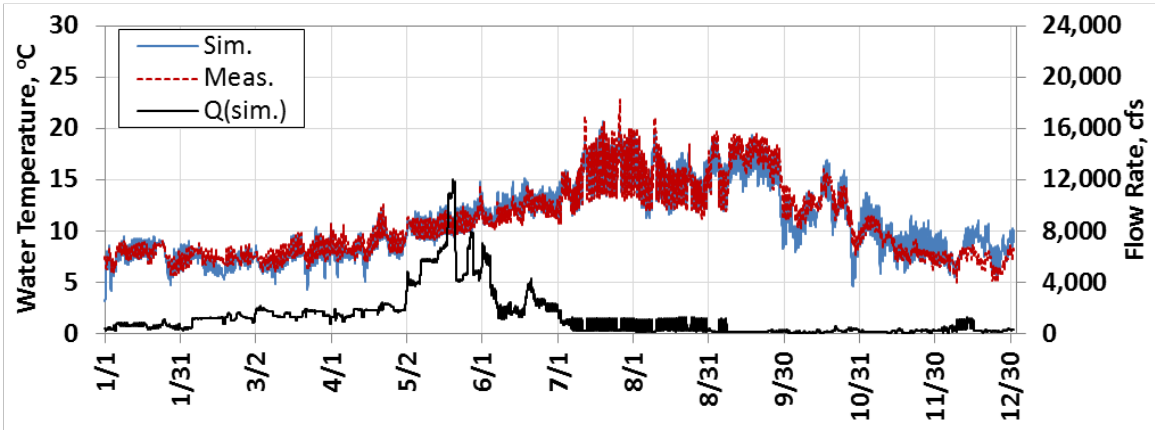


**Figure F-11.** Comparison of measured (Meas.) and simulated (Sim.) water temperature above South Fork Tuolumne River confluence for the calibration year 2009. Flow rate (in cfs) is presented in the secondary axis.

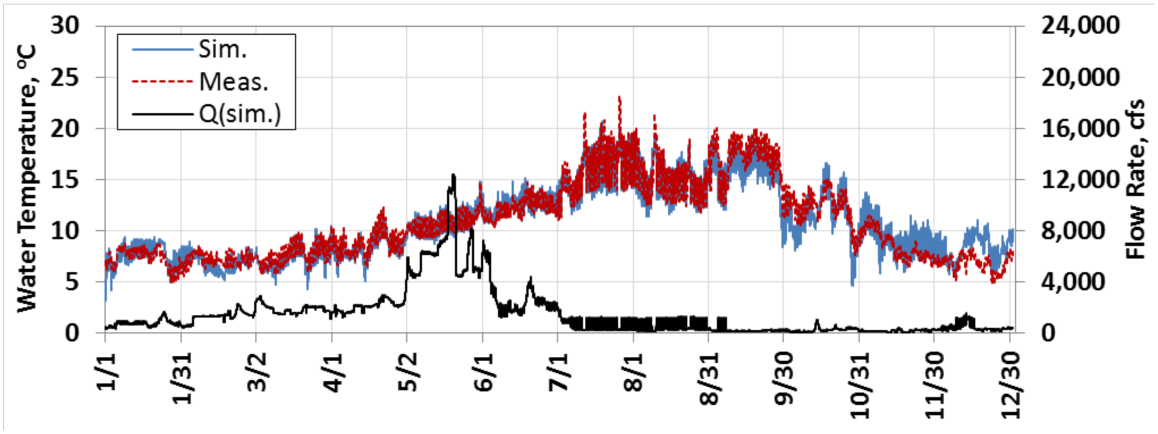


**Figure F-12.** Comparison of measured (Meas.) and simulated (Sim.) water temperature below South Fork Tuolumne River confluence for the calibration year 2009. Flow rate (in cfs) is presented in the secondary axis.

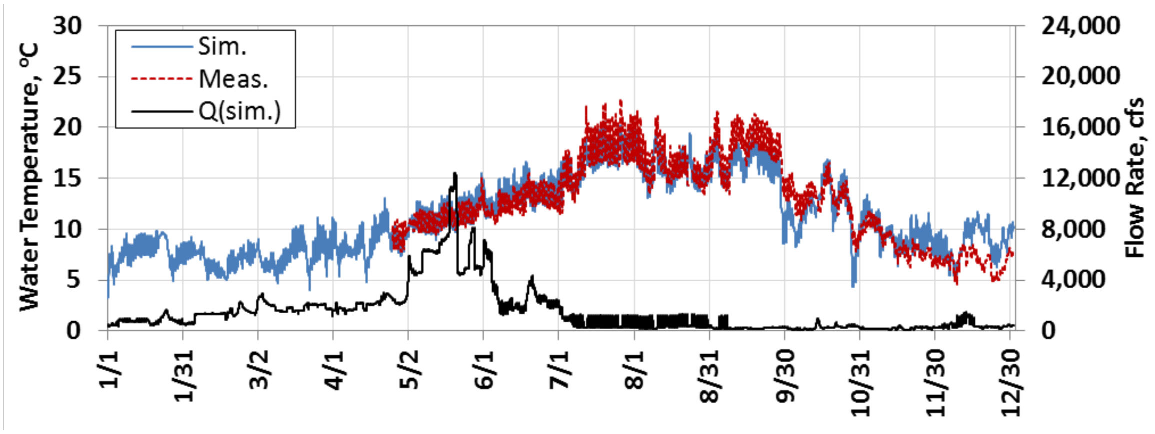


**Figure F-13.** Comparison of measured (Meas.) and simulated (Sim.) water temperature above Clavey River confluence for the calibration year 2009. Flow rate (in cfs) is presented in the secondary axis.

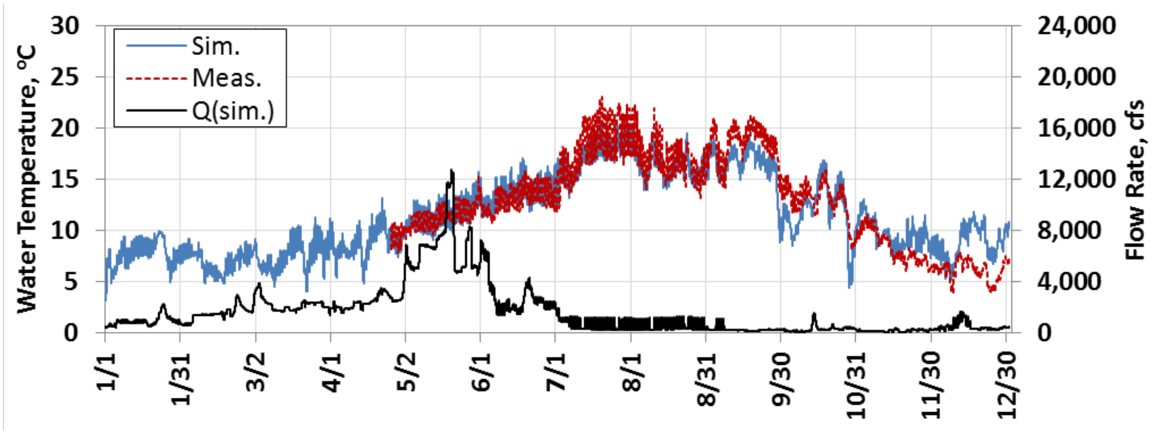


**Figure F-14.** Comparison of measured (Meas.) and simulated (Sim.) water temperature below Indian Creek confluence for the calibration year 2009. Flow rate (in cfs) is presented in the secondary axis.

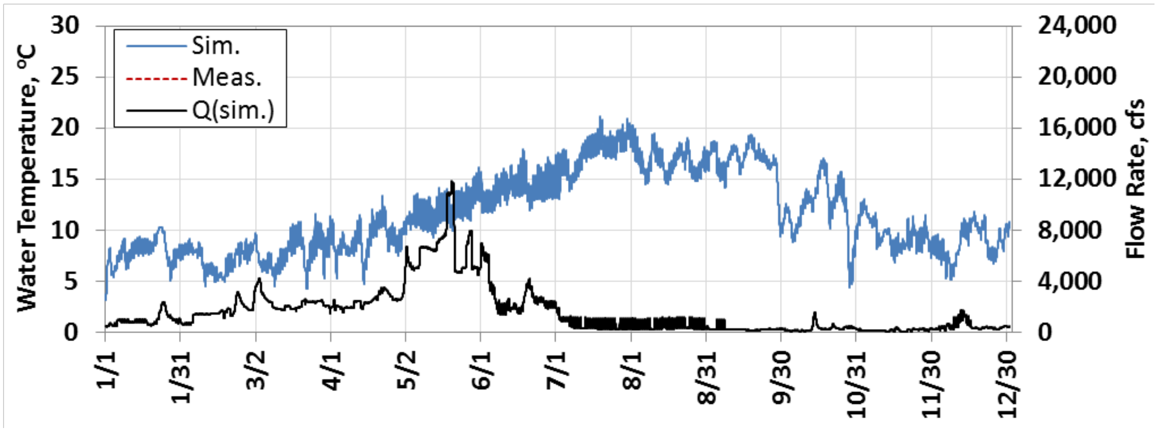


**Figure F-15.** Comparison of measured (Meas.) and simulated (Sim.) water temperature above North Fork Tuolumne River confluence for the calibration year 2009. Flow rate (in cfs) is presented in the secondary axis. (Note: Measured data for this location not available during this period.)

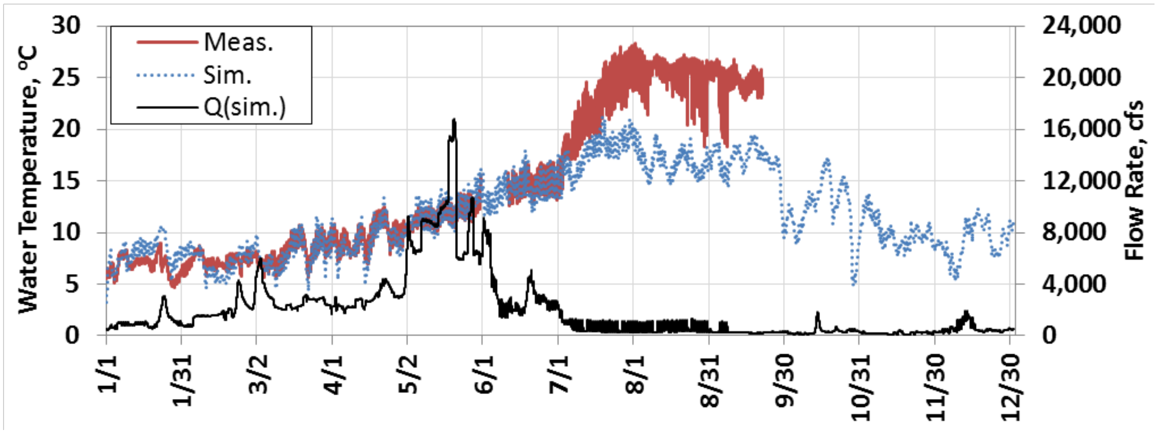
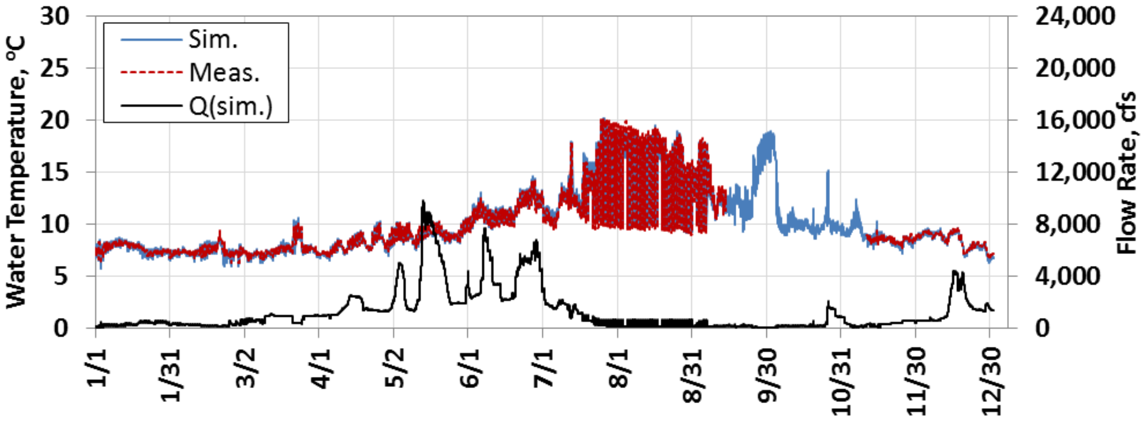


**Figure F-16.** Comparison of measured (Meas.) and simulated (Sim.) water temperature at Wards Ferry for the calibration year 2009. Flow rate (in cfs) is presented in the secondary axis.



**FigureG-17.** **Comparison of measured (Meas.) and simulated (Sim.) water temperature below Cherry Creek confluence for the calibration year 2010. Flow rate (in cfs) is presented in the secondary axis.**

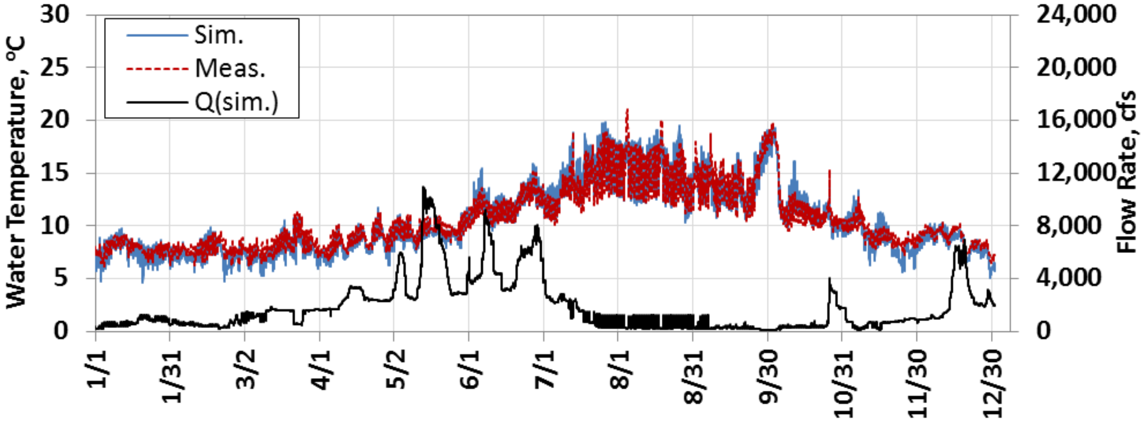


**Figure F-18.** **Comparison of measured (Meas.) and simulated (Sim.) water temperature above South Fork Tuolumne River confluence for the calibration year 2010. Flow rate (in cfs) is presented in the secondary axis.**

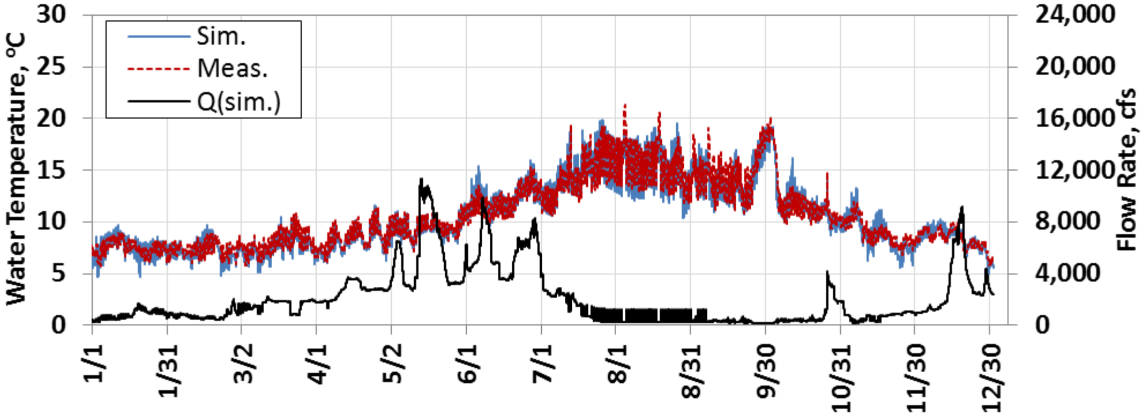


**Figure F-19.** **Comparison of measured (Meas.) and simulated (Sim.) water temperature below South Fork Tuolumne River confluence for the calibration year 2010. Flow rate (in cfs) is presented in the secondary axis.**

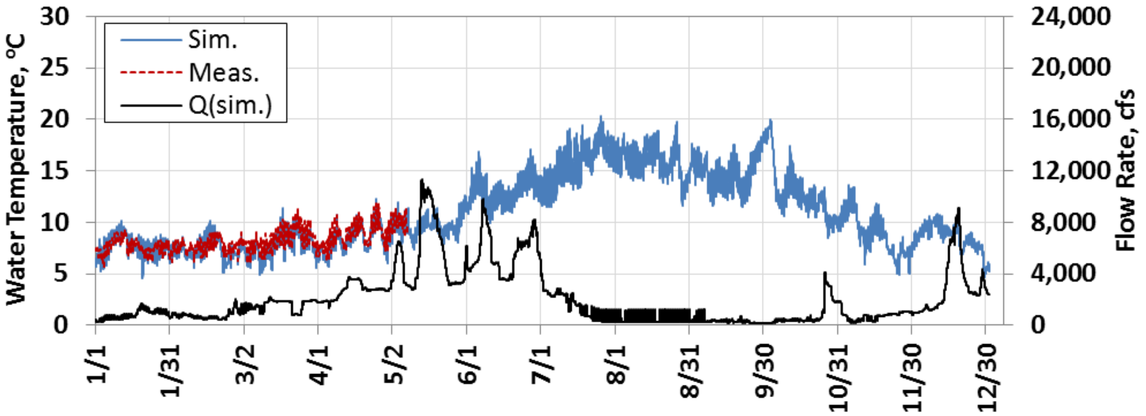


**Figure F-20.** **Comparison of measured (Meas.) and simulated (Sim.) water temperature above Clavey River confluence for the calibration year 2010. Flow rate (in cfs) is presented in the secondary axis.**

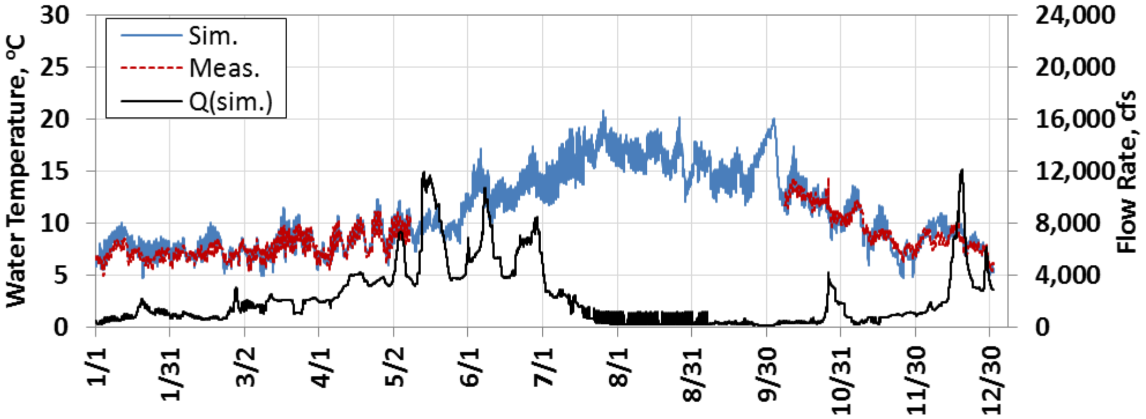


**Figure F-21.** **Comparison of measured (Meas.) and simulated (Sim.) water temperature below Indian Creek confluence for the calibration year 2010. Flow rate (in cfs) is presented in the secondary axis.**

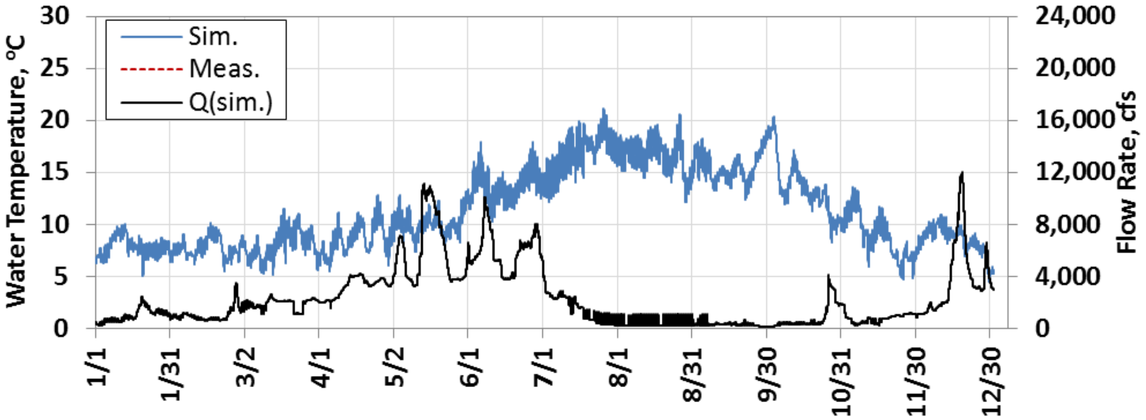


**Figure F-22.** **Comparison of measured (Meas.) and simulated (Sim.) water temperature above North Fork Tuolumne River confluence for the calibration year 2010. Flow rate (in cfs) is presented in the secondary axis. (Note: Measured data for this location not available during this period.)**

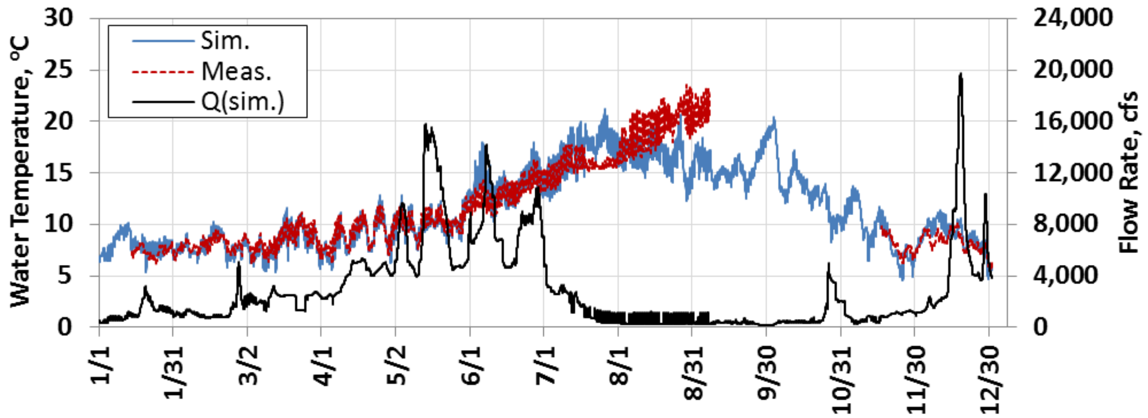


**Figure F-23.** Comparison of measured (Meas.) and simulated (Sim.) water temperature at Wards Ferry for the calibration year 2010. Flow rate (in cfs) is presented in the secondary axis.

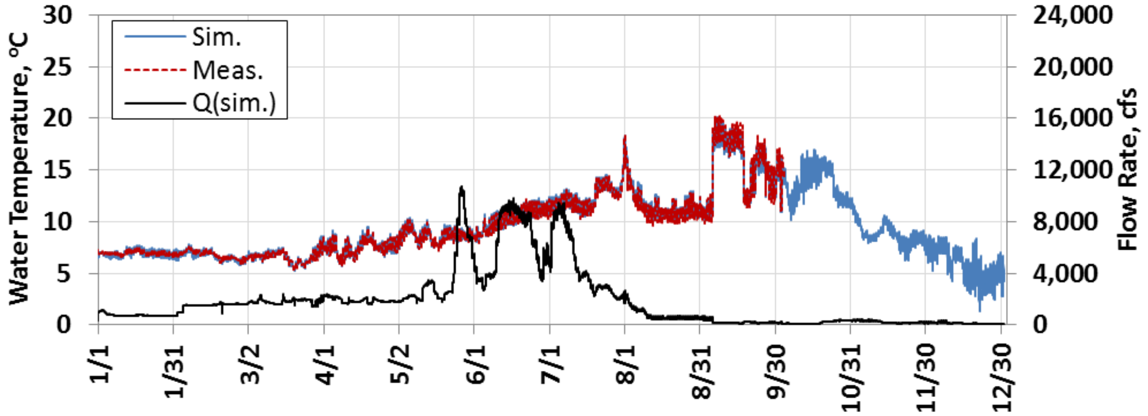


**Figure F-24.** Comparison of measured (Meas.) and simulated (Sim.) water temperature below Cherry Creek confluence for the calibration year 2011. Flow rate (in cfs) is presented in the secondary axis.

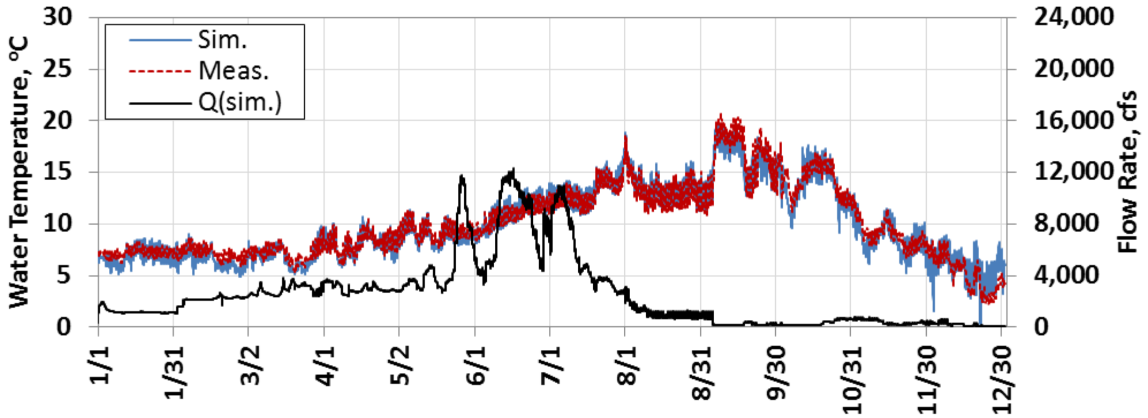


**Figure F-25.** Comparison of measured (Meas.) and simulated (Sim.) water temperature above South Fork Tuolumne River confluence for the calibration year 2011. Flow rate (in cfs) is presented in the secondary axis.

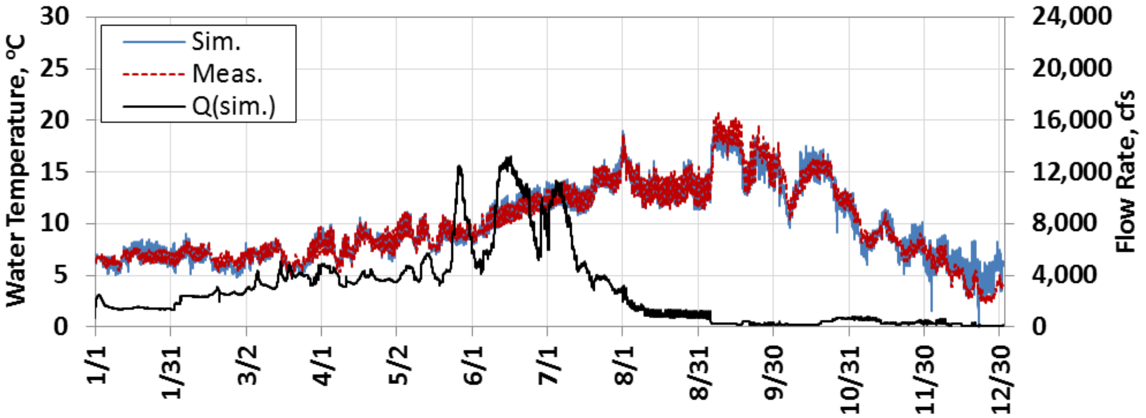


**Figure F-26.** Comparison of measured (Meas.) and simulated (Sim.) water temperature below South Fork Tuolumne River confluence for the calibration year 2011. Flow rate (in cfs) is presented in the secondary axis.

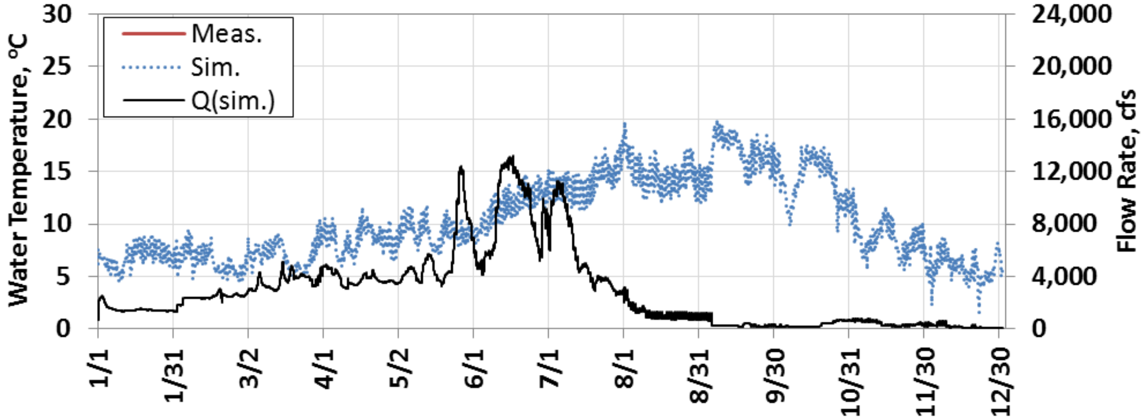


**Figure F-27.** Comparison of measured (Meas.) and simulated (Sim.) water temperature above Clavey River confluence for the calibration year 2011. Flow rate (in cfs) is presented in the secondary axis. (Note: Measured data for this location not available during this period.)

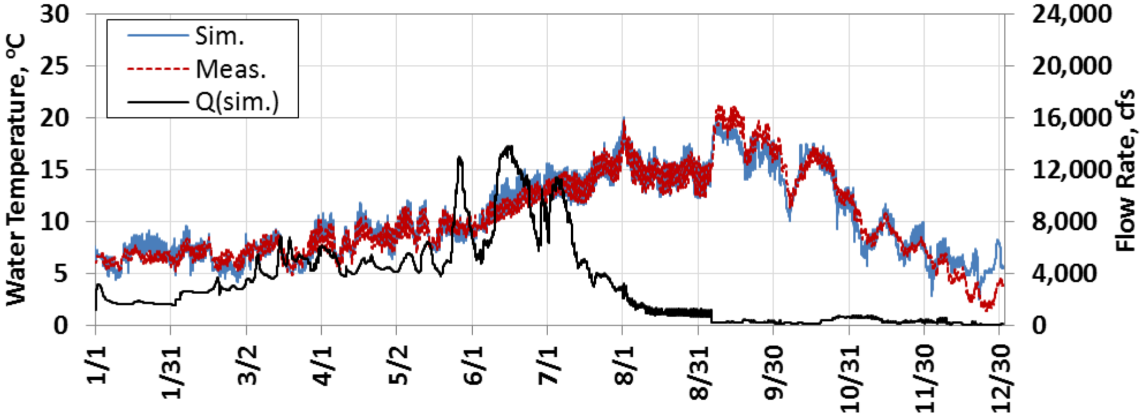


**Figure F-28.** Comparison of measured (Meas.) and simulated (Sim.) water temperature below Indian Creek confluence for the calibration year 2011. Flow rate (in cfs) is presented in the secondary axis.

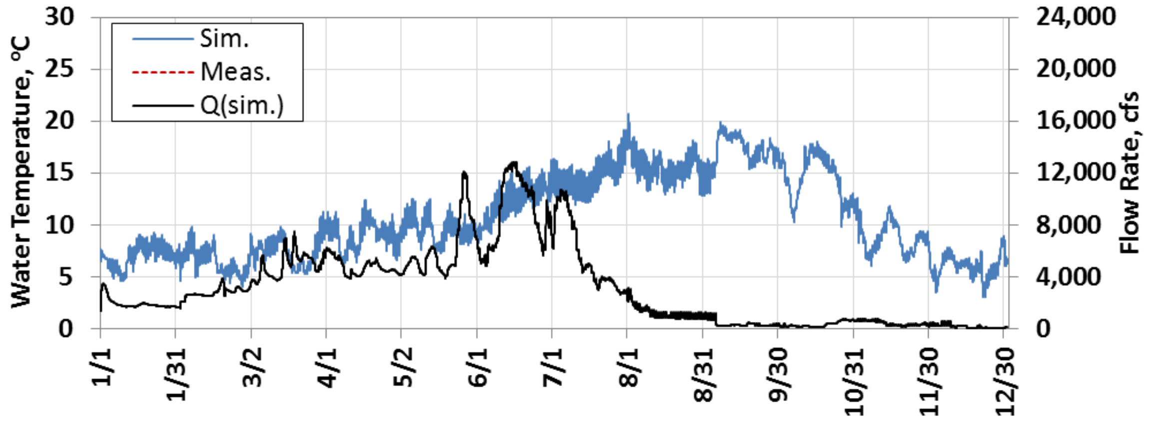


Figure F-29. Comparison of measured (Meas.) and simulated (Sim.) water temperature above North Fork Tuolumne River confluence for the calibration year 2011. Flow rate (in cfs) is presented in the secondary axis. (Note: Measured data for this location not available during this period.)

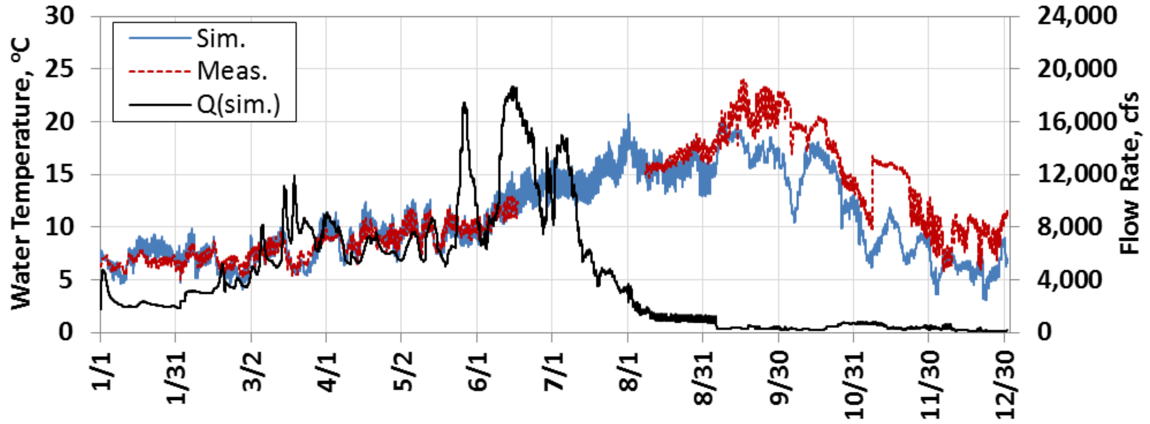


Figure F-30. Comparison of measured (Meas.) and simulated (Sim.) water temperature at Wards Ferry for the calibration year 2011. Flow rate (in cfs) is presented in the secondary axis.

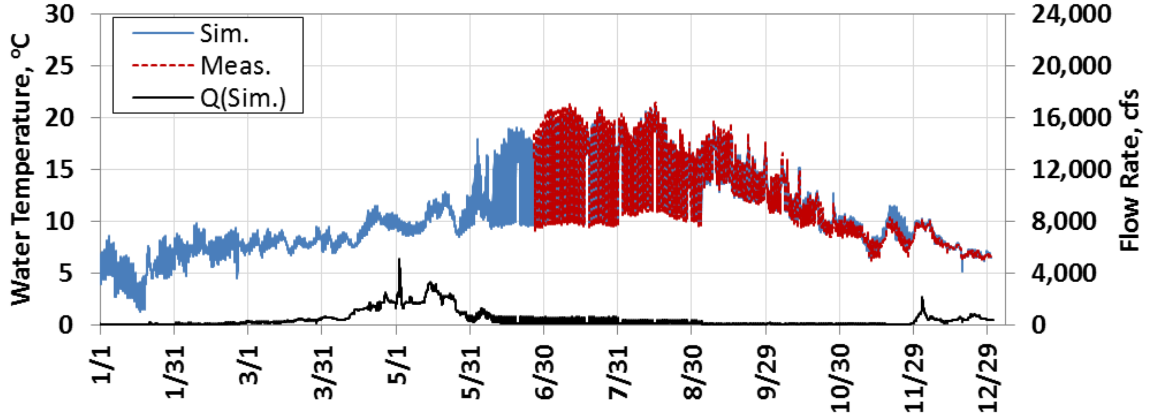


Figure F-31. Comparison of measured (Meas.) and simulated (Sim.) water temperature below Cherry Creek confluence for the calibration year 2012. Flow rate (in cfs) is presented in the secondary axis.

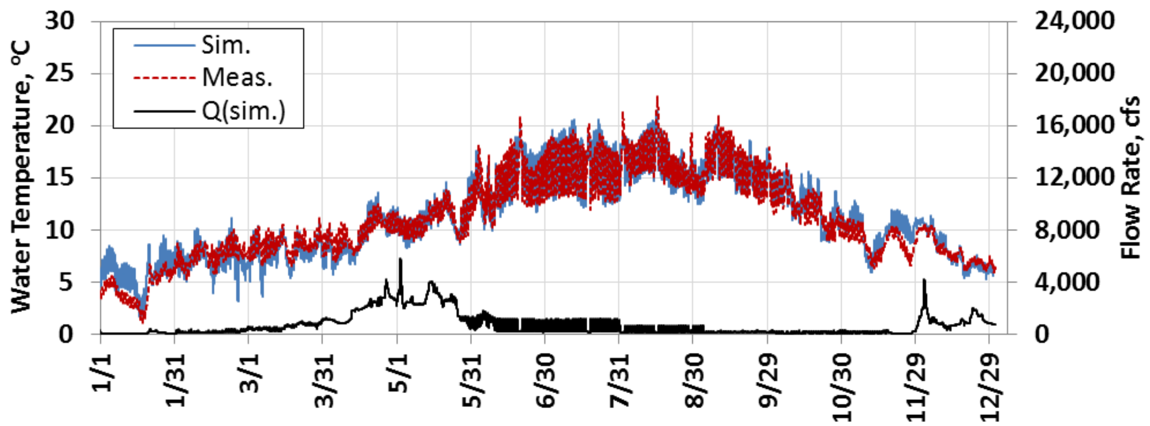


**Figure F-32.** Comparison of measured (Meas.) and simulated (Sim.) water temperature above South Fork Tuolumne River confluence for the calibration year 2012. Flow rate (in cfs) is presented in the secondary axis.

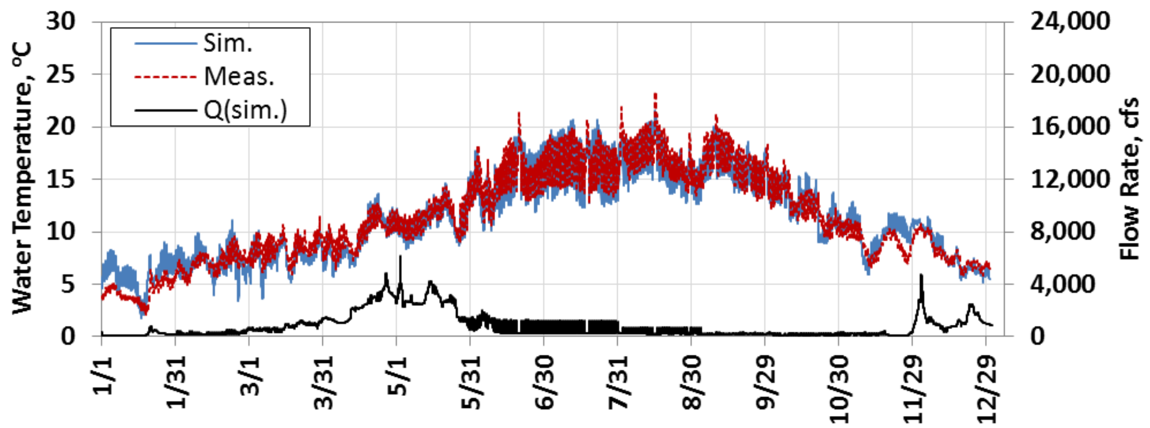


**Figure F-33.** Comparison of measured (Meas.) and simulated (Sim.) water temperature below South Fork Tuolumne River confluence for the calibration year 2012. Flow rate (in cfs) is presented in the secondary axis.

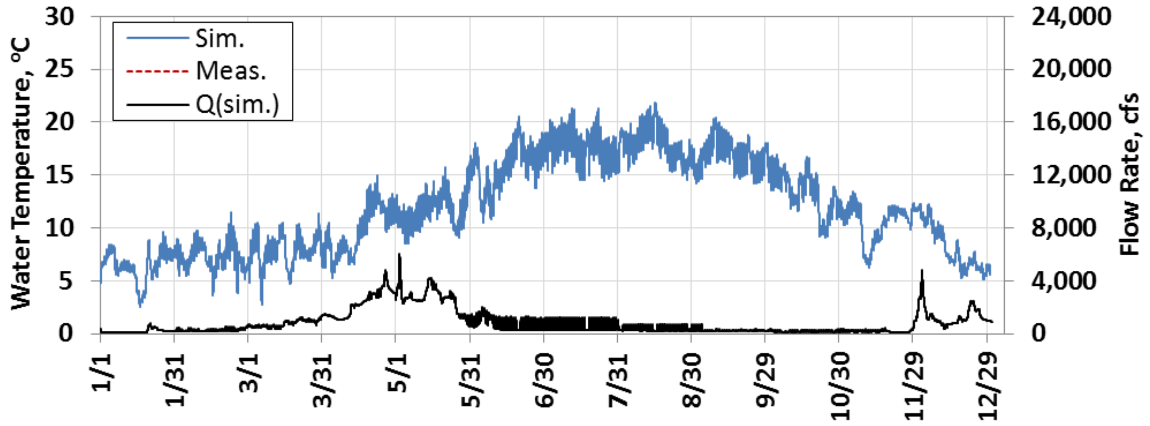


**Figure F-34.** Comparison of measured (Meas.) and simulated (Sim.) water temperature above Clavey River confluence for the calibration year 2012. Flow rate (in cfs) is presented in the secondary axis. (Note: Measured data for this location not available during this period.)

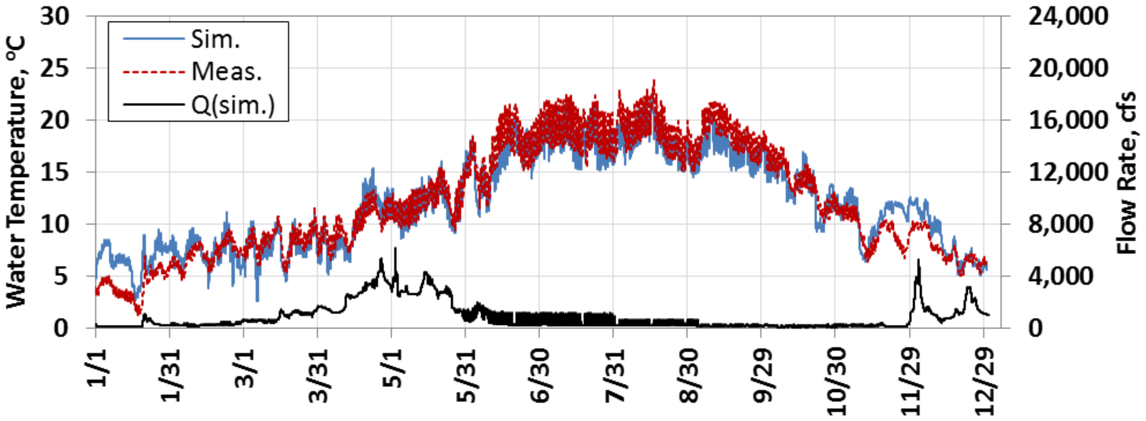


**Figure F-35.** Comparison of measured (Meas.) and simulated (Sim.) water temperature below Indian Creek confluence for the calibration year 2012. Flow rate (in cfs) is presented in the secondary axis.

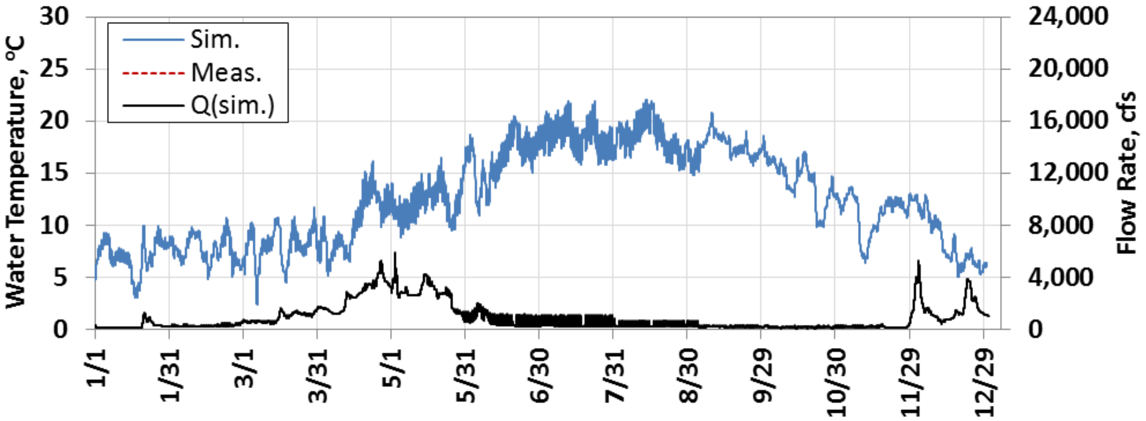


**Figure F-36.** Comparison of measured (Meas.) and simulated (Sim.) water temperature above North Fork Tuolumne River confluence for the calibration year 2012. Flow rate (in cfs) is presented in the secondary axis. (Note: Measured data for this location not available during this period.)

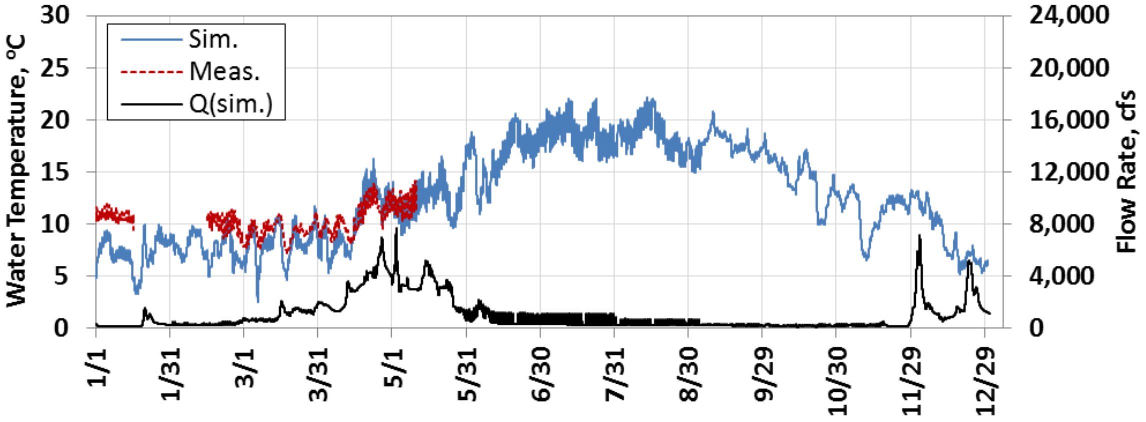


**Figure F-37.** Comparison of measured (Meas.) and simulated (Sim.) water temperature at Wards Ferry for the calibration year 2012. Flow rate (in cfs) is presented in the secondary axis.

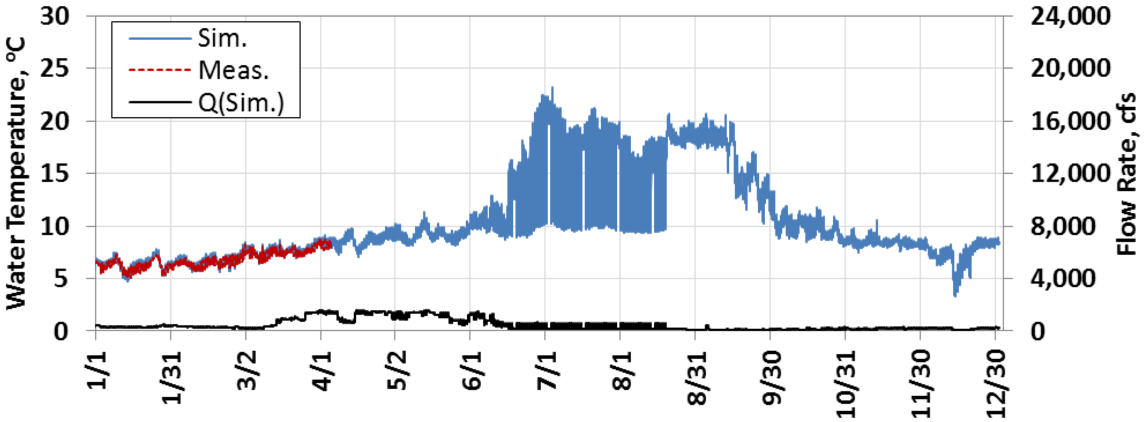


**Figure F-38.** Comparison of measured (Meas.) and simulated (Sim.) water temperature below Cherry Creek confluence for the calibration year 2013. Flow rate (in cfs) is presented in the secondary axis.

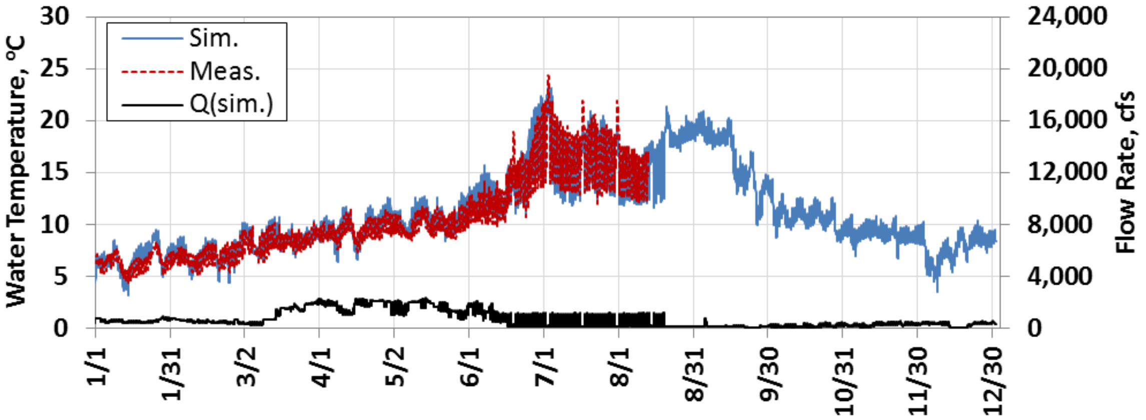


**Figure F-39.** Comparison of measured (Meas.) and simulated (Sim.) water temperature above South Fork Tuolumne River confluence for the calibration year 2013. Flow rate (in cfs) is presented in the secondary axis.

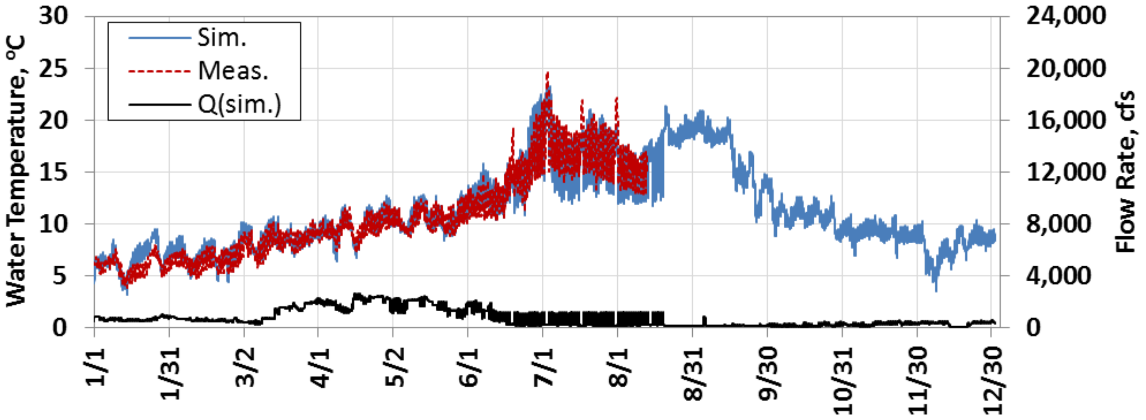


**Figure F-40.** Comparison of measured (Meas.) and simulated (Sim.) water temperature below South Fork Tuolumne River confluence for the calibration year 2013. Flow rate (in cfs) is presented in the secondary axis.

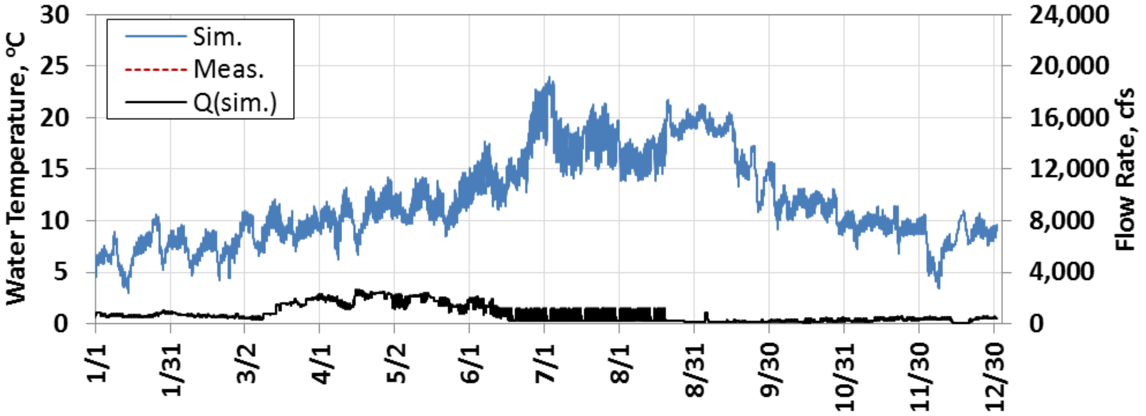


**Figure F-41.** Comparison of measured (Meas.) and simulated (Sim.) water temperature above Clavey River confluence for the calibration year 2013. Flow rate (in cfs) is presented in the secondary axis. (Note: Measured data for this location not available during this period.)

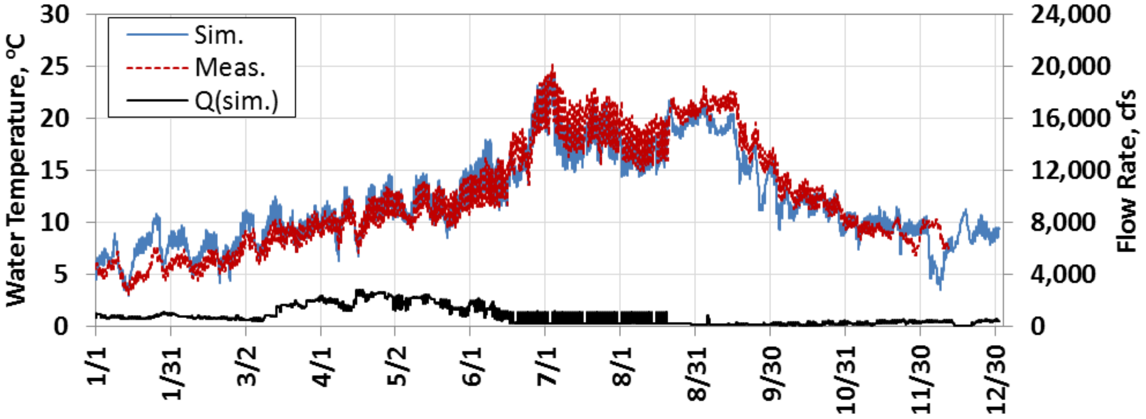


**Figure F-42.** Comparison of measured (Meas.) and simulated (Sim.) water temperature below Indian Creek confluence for the calibration year 2013. Flow rate (in cfs) is presented in the secondary axis.

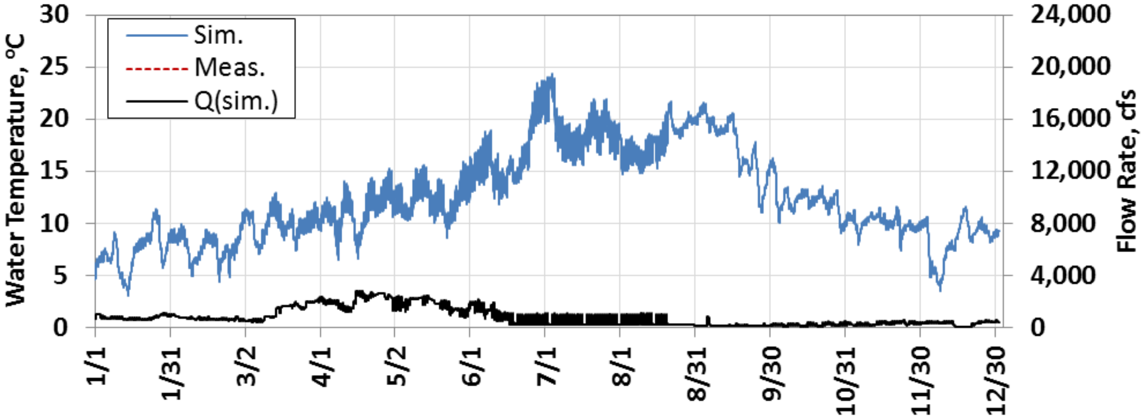


**Figure F-43.** Comparison of measured (Meas.) and simulated (Sim.) water temperature above North Fork Tuolumne River confluence for the calibration year 2013. Flow rate (in cfs) is presented in the secondary axis. (Note: Measured data for this location not available during this period.)

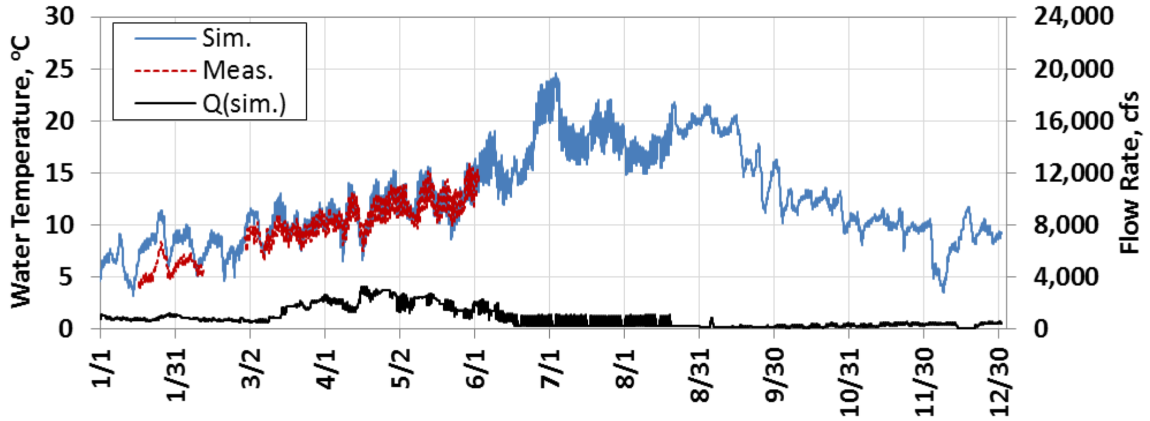


**Figure F-44.** Comparison of measured (Meas.) and simulated (Sim.) water temperature at Wards Ferry for the calibration year 2013. Flow rate (in cfs) is presented in the secondary axis.

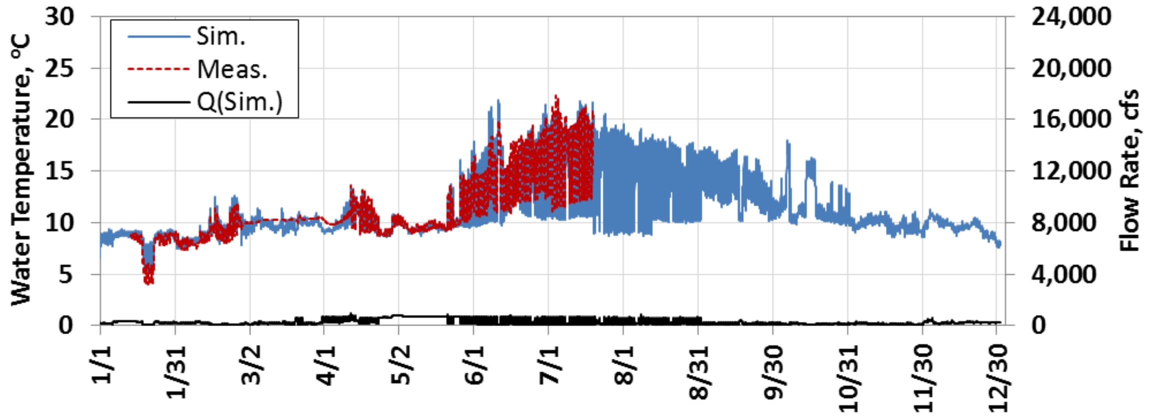


**Figure F-45.** Comparison of measured (Meas.) and simulated (Sim.) water temperature below Cherry Creek confluence for the calibration year 2014. Flow rate (in cfs) is presented in the secondary axis.

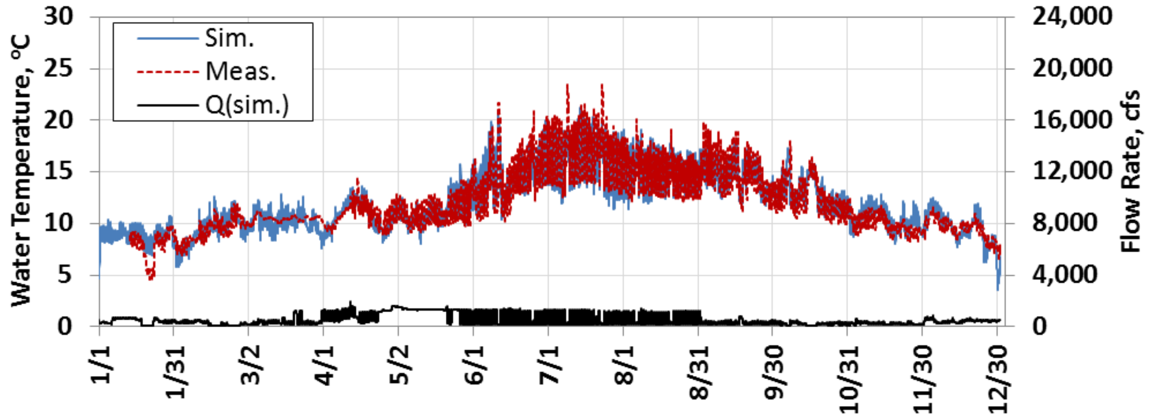


**Figure F-46.** Comparison of measured (Meas.) and simulated (Sim.) water temperature above South Fork Tuolumne River confluence for the calibration year 2014. Flow rate (in cfs) is presented in the secondary axis.

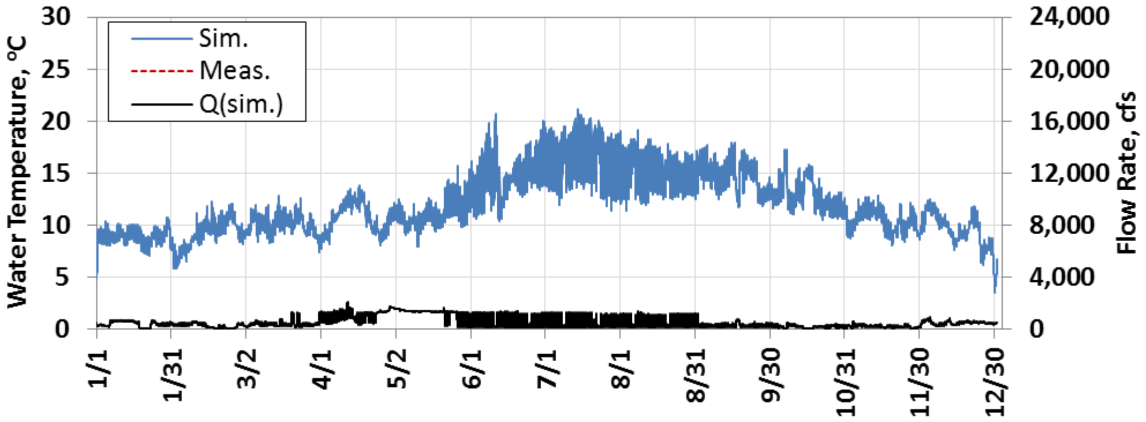


**Figure F-47.** Comparison of measured (Meas.) and simulated (Sim.) water temperature below South Fork Tuolumne River confluence for the calibration year 2014. Flow rate (in cfs) is presented in the secondary axis. (Note: Measured data for this location not available during this period.)

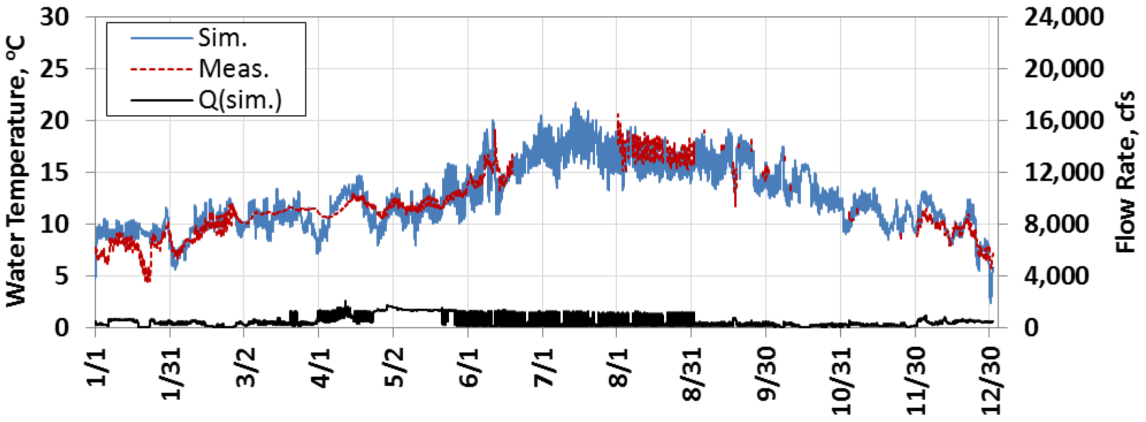


**Figure F-48.** Comparison of measured (Meas.) and simulated (Sim.) water temperature above Clavey River confluence for the calibration year 2014. Flow rate (in cfs) is presented in the secondary axis.

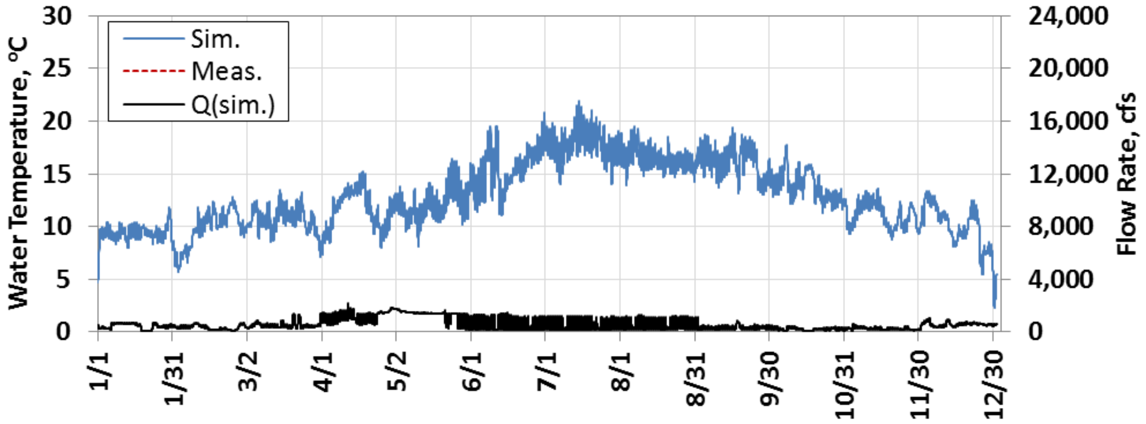


**Figure F-49.** Comparison of measured (Meas.) and simulated (Sim.) water temperature below Indian Creek confluence for the calibration year 2014. Flow rate (in cfs) is presented in the secondary axis. (Note: Measured data for this location not available during this period.)

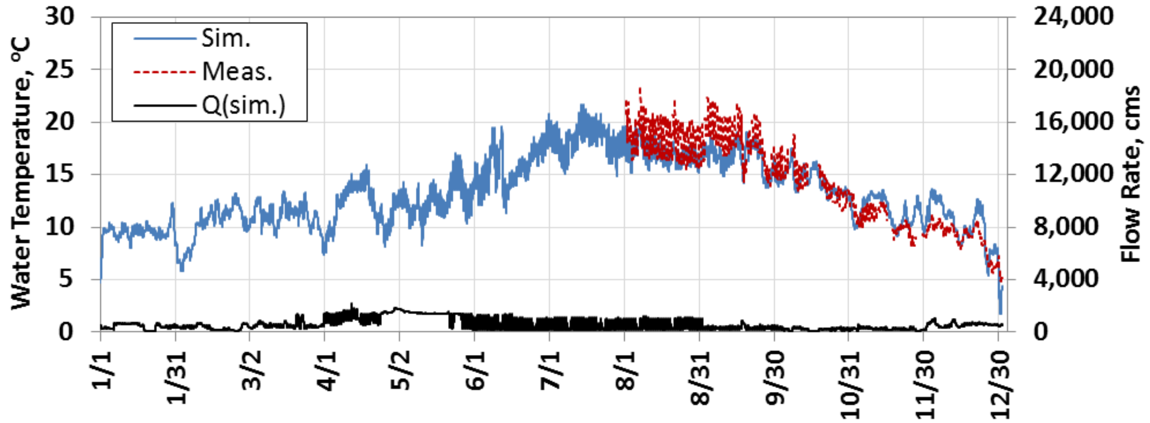


**Figure F-50.** Comparison of measured (Meas.) and simulated (Sim.) water temperature above North Fork Tuolumne River confluence for the calibration year 2014. Flow rate (in cfs) is presented in the secondary axis.

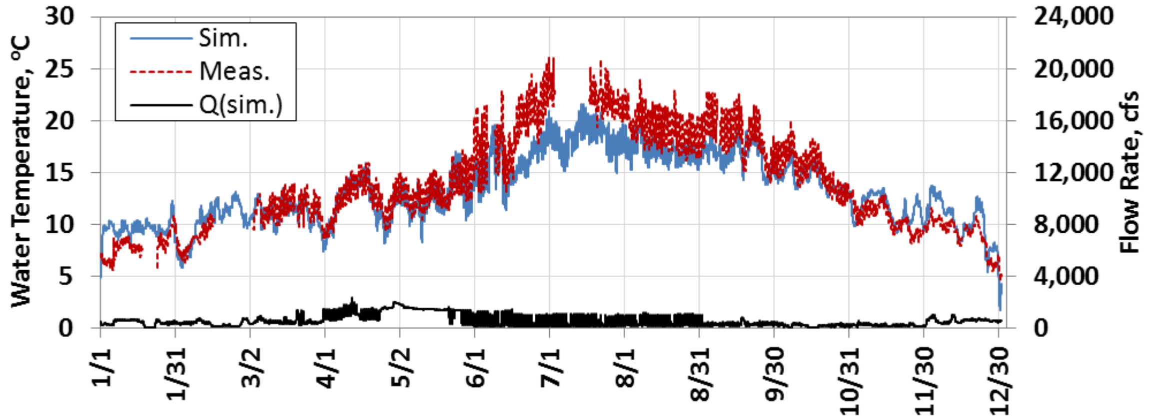


**Figure F-51.** Comparison of measured (Meas.) and simulated (Sim.) water temperature at Wards Ferry for the calibration year 2014. Flow rate (in cfs) is presented in the secondary axis.

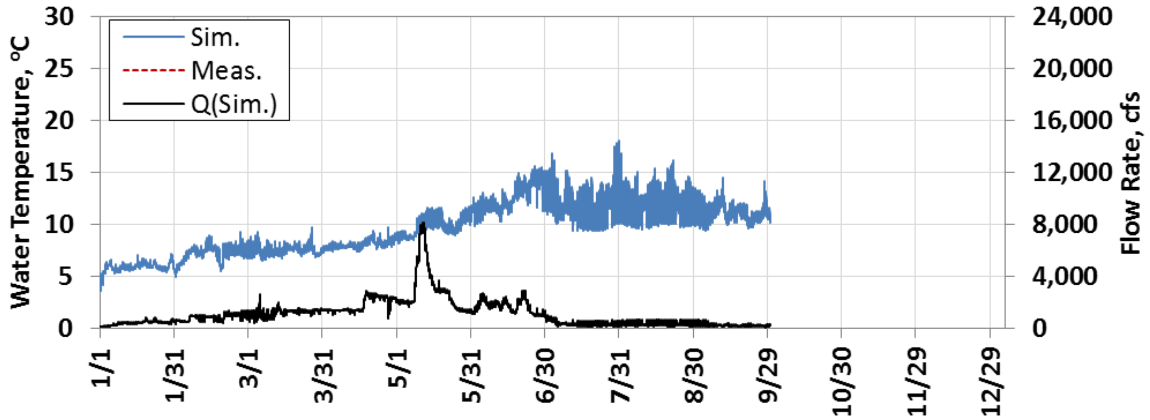


**Figure F-52.** Comparison of measured (Meas.) and simulated (Sim.) water temperature below Cherry Creek confluence for the calibration year 2016. Flow rate (in cfs) is presented in the secondary axis. (Note: Measured data for this location not available during this period.)

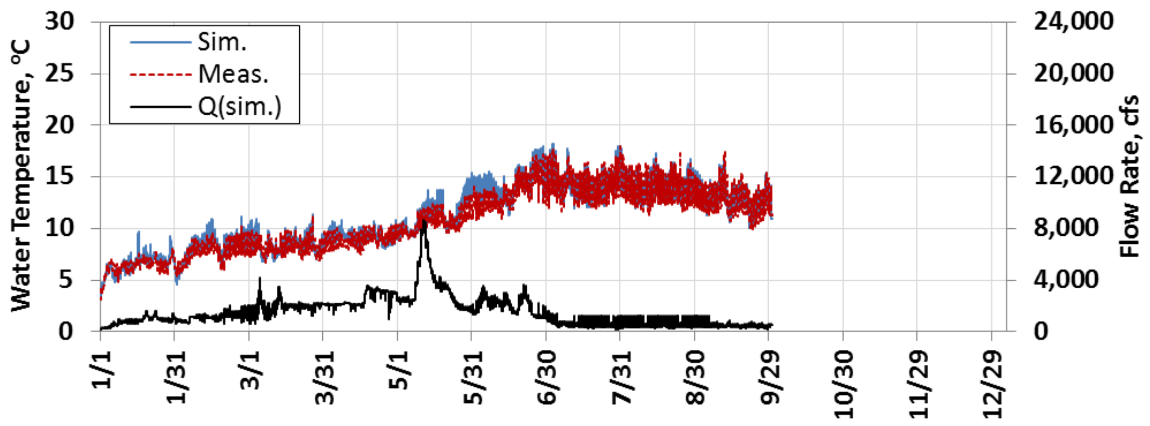


**Figure F-53.** Comparison of measured (Meas.) and simulated (Sim.) water temperature above South Fork Tuolumne River confluence for the calibration year 2016. Flow rate (in cfs) is presented in the secondary axis.

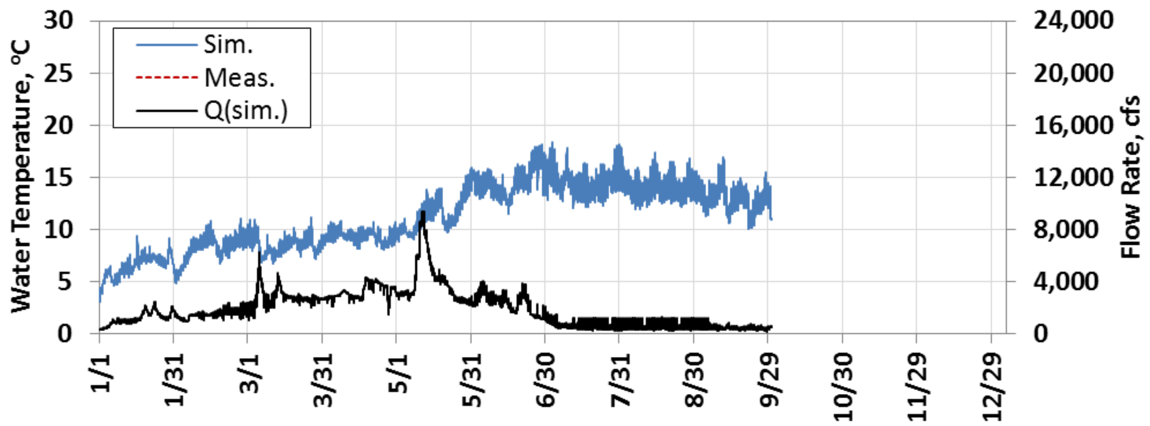


**Figure F-54.** Comparison of measured (Meas.) and simulated (Sim.) water temperature below South Fork Tuolumne River confluence for the calibration year 2016. Flow rate (in cfs) is presented in the secondary axis. (Note: Measured data for this location not available during this period.)

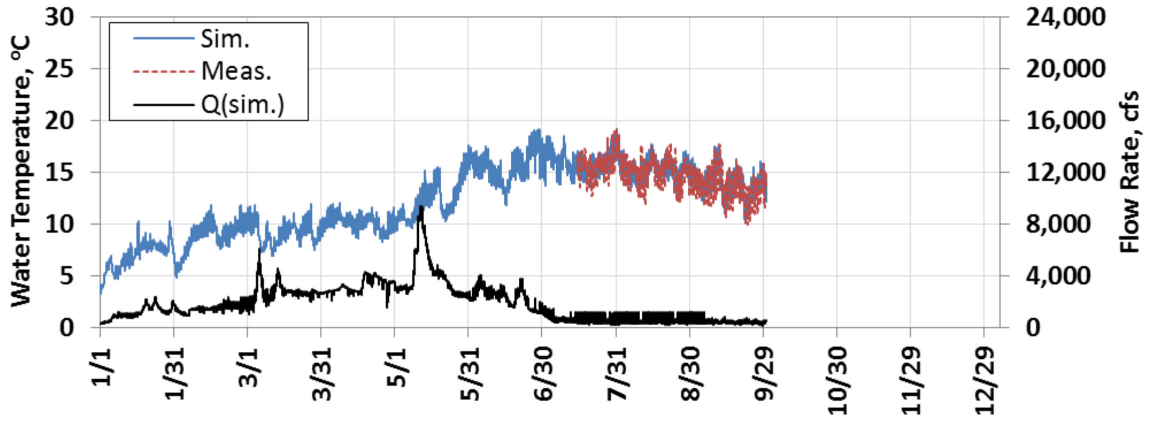


**Figure F-55.** Comparison of measured (Meas.) and simulated (Sim.) water temperature above Clavey River confluence for the calibration year 2016. Flow rate (in cfs) is presented in the secondary axis.

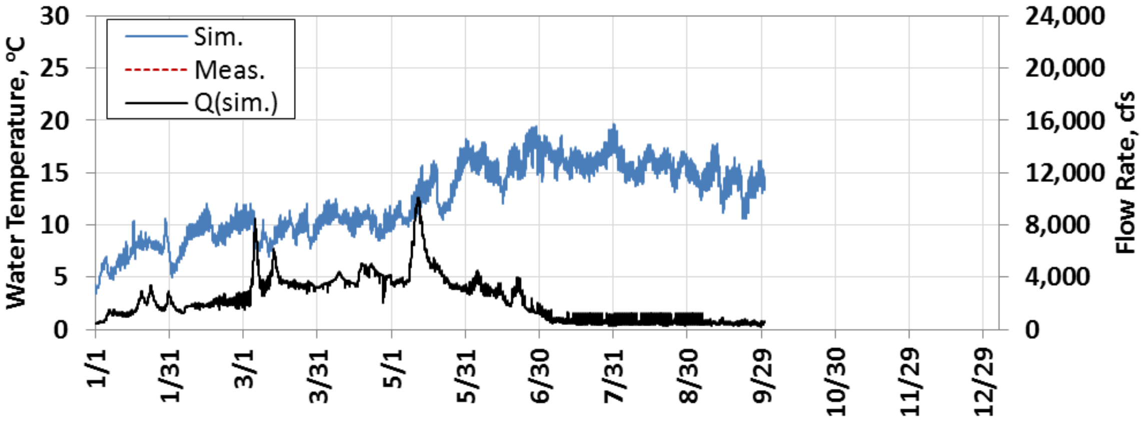


**Figure F-56.** Comparison of measured (Meas.) and simulated (Sim.) water temperature below Indian Creek confluence for the calibration year 2016. Flow rate (in cfs) is presented in the secondary axis. (Note: Measured data for this location not available during this period.)

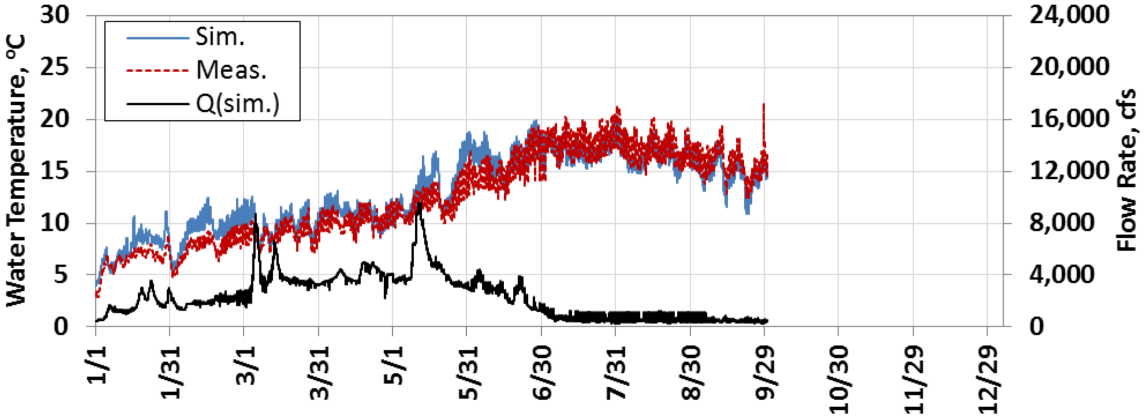


**Figure F-57.** Comparison of measured (Meas.) and simulated (Sim.) water temperature above North Fork Tuolumne River confluence for the calibration year 2016. Flow rate (in cfs) is presented in the secondary axis.

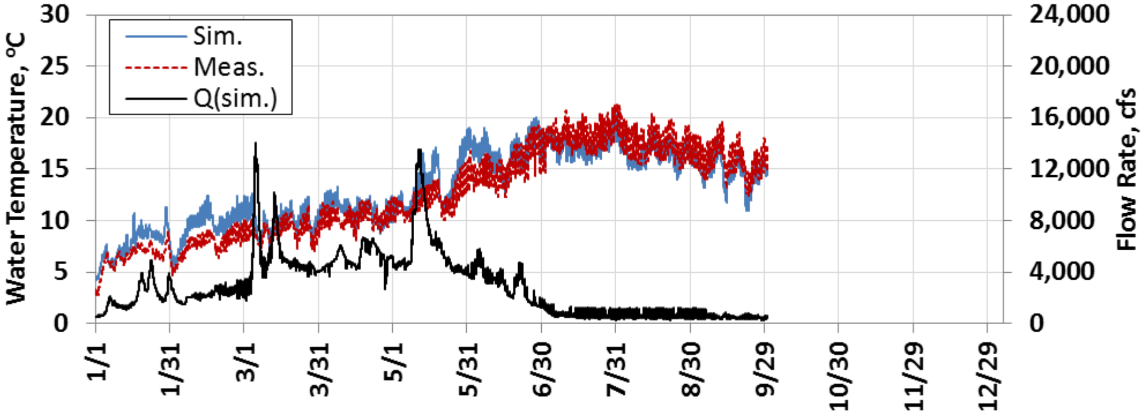


**Figure F-58.** Comparison of measured (Meas.) and simulated (Sim.) water temperature at Wards Ferry for the calibration year 2016. Flow rate (in cfs) is presented in the secondary axis