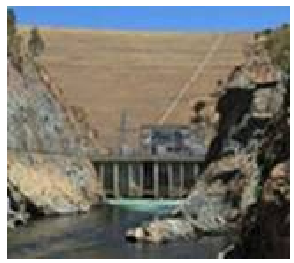
LOWER TUOLUMNE RIVER TEMPERATURE MODEL
AMENDED STUDY REPORT
DON PEDRO PROJECT
FERC NO. 2299


Prepared for:
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September 2017

Lower Tuolumne River Temperature Model
Amended Study Report

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List of Acronyms

ac ....acres
ACEC.........................Area of Critical Environmental Concern
AF ....acre-feet
ADCP.........................Acoustic Doppler Current Profiler
ACOE.........................U.S. Army Corps of Engineers
ADA...........................Americans with Disabilities Act
ALJ.............................Administrative Law Judge
APE............................Area of Potential Effect
ARMR........................Archaeological Resource Management Report
BA..............................Biological Assessment
BDCP.........................Bay-Delta Conservation Plan
BLM...........................U.S. Department of the Interior, Bureau of Land Management
BLM-S ....Bureau of Land Management – Sensitive Species
BMI............................Benthic macroinvertebrates
BMP...........................Best Management Practices
BO..............................Biological Opinion
CalEPPC ....California Exotic Pest Plant Council
CalSPA.......................California Sports Fisherman Association
CAS............................California Academy of Sciences
CCC............................Criterion Continuous Concentrations
CCIC..........................Central California Information Center
CCSF..........................City and County of San Francisco
CCVHJV....................California Central Valley Habitat Joint Venture
CD..............................Compact Disc
CDBW........................California Department of Boating and Waterways
CDEC.........................California Data Exchange Center
CDFA.........................California Department of Food and Agriculture
CDFW........................California Department of Fish and Wildlife
CDMG........................California Division of Mines and Geology
CDOF.........................California Department of Finance
CDPH.........................California Department of Public Health

CDPR.........................California Department of Parks and Recreation
CDSOD......................California Division of Safety of Dams
CDWR........................California Department of Water Resources
CE ....California Endangered Species
CEII............................Critical Energy Infrastructure Information
CEQA.........................California Environmental Quality Act
CESA ....California Endangered Species Act
CFR ....Code of Federal Regulations
cfs...............................cubic feet per second
CGS............................California Geological Survey
CMAP ....California Monitoring and Assessment Program
CMC...........................Criterion Maximum Concentrations
CNDDB......................California Natural Diversity Database
CNPS..........................California Native Plant Society
CORP ....California Outdoor Recreation Plan
CPUE ....Catch Per Unit Effort
CRAM........................California Rapid Assessment Method
CRLF..........................California Red-Legged Frog
CRRF ....California Rivers Restoration Fund
CSAS..........................Central Sierra Audubon Society
CSBP..........................California Stream Bioassessment Procedure
CT ....California Threatened Species
CTR............................California Toxics Rule
CTS ....California Tiger Salamander
CVRWQCB ....Central Valley Regional Water Quality Control Board
CWA ....Clean Water Act
CWHR........................California Wildlife Habitat Relationship
Districts......................Turlock Irrigation District and Modesto Irrigation District
DLA ....Draft License Application
DPRA.........................Don Pedro Recreation Agency
DPS ....Distinct Population Segment
EA ....Environmental Assessment
EC ....Electrical Conductivity

EFH............................Essential Fish Habitat
EIR.............................Environmental Impact Report
EIS..............................Environmental Impact Statement
EPA............................U.S. Environmental Protection Agency
ESA............................Federal Endangered Species Act
ESRCD.......................East Stanislaus Resource Conservation District
ESU............................Evolutionary Significant Unit
EWUA........................Effective Weighted Useable Area
FERC..........................Federal Energy Regulatory Commission
FFS.............................Foothills Fault System
FL...............................Fork length
FMU...........................Fire Management Unit
FOT............................Friends of the Tuolumne
FPC............................Federal Power Commission
ft/mi...........................feet per mile
FWCA........................Fish and Wildlife Coordination Act
FYLF..........................Foothill Yellow-Legged Frog
g.................................grams
GIS.............................Geographic Information System
GLO...........................General Land Office
GPS............................Global Positioning System
HCP............................Habitat Conservation Plan
HHWP........................Hetch Hetchy Water and Power
HORB........................Head of Old River Barrier
HPMP.........................Historic Properties Management Plan
ILP.............................Integrated Licensing Process
ISR.............................Initial Study Report
ITA.............................Indian Trust Assets
kV..............................kilovolt
m................................meters
M&I...........................Municipal and Industrial
MCL...........................Maximum Contaminant Level
mg/kg.........................milligrams/kilogram

mg/L..........................milligrams per liter
mgd ....million gallons per day
mi ....miles
mi^2 ....square miles
MID...........................Modesto Irrigation District
MOU ....Memorandum of Understanding
MSCS.........................Multi-Species Conservation Strategy
msl.............................mean sea level
MVA ....Megavolt Ampere
MW ....megawatt
MWh ....megawatt hour
mya............................million years ago
NAE ....National Academy of Engineering
NAHC ....Native American Heritage Commission
NAS...........................National Academy of Sciences
NAVD 88..................North American Vertical Datum of 1988
NAWQA ....National Water Quality Assessment
NCCP ....Natural Community Conservation Plan
NEPA ....National Environmental Policy Act
ng/g ....nanograms per gram
NGOs ....Non-Governmental Organizations
NHI ....Natural Heritage Institute
NHPA.........................National Historic Preservation Act
NISC ....National Invasive Species Council
NMFS.........................National Marine Fisheries Service
NOAA ....National Oceanic and Atmospheric Administration
NOI ....Notice of Intent
NPS ............................U.S. Department of the Interior, National Park Service
NRCS ....National Resource Conservation Service
NRHP.........................National Register of Historic Places
NRI............................Nationwide Rivers Inventory
NTU ....Nephelometric Turbidity Unit
NWI...........................National Wetland Inventory

NWIS ....National Water Information System
NWR ....National Wildlife Refuge
NGVD 29...................National Geodetic Vertical Datum of 1929
O&M..........................operation and maintenance
OEHHA......................Office of Environmental Health Hazard Assessment
ORV ....Outstanding Remarkable Value
PAD............................Pre-Application Document
PDO............................Pacific Decadal Oscillation
PEIR...........................Program Environmental Impact Report
PGA............................Peak Ground Acceleration
PHG............................Public Health Goal
PM&E ....Protection, Mitigation and Enhancement
PMF............................Probable Maximum Flood
POAOR......................Public Opinions and Attitudes in Outdoor Recreation
ppb.............................parts per billion
ppm ....parts per million
PSP.............................Proposed Study Plan
QA..............................Quality Assurance
QC..............................Quality Control
RA..............................Recreation Area
RBP............................Rapid Bioassessment Protocol
Reclamation ...............U.S. Department of the Interior, Bureau of Reclamation
RM ....River Mile
RMP...........................Resource Management Plan
RP...............................Relicensing Participant
RSP ....Revised Study Plan
RST ....Rotary Screw Trap
RTM ....Real Time Temperature Monitoring
RWF...........................Resource-Specific Work Groups
RWG..........................Resource Work Group
RWQCB.....................Regional Water Quality Control Board
SC...............................State candidate for listing under CESA
SCD............................State candidate for delisting under CESA

SCE ....State candidate for listing as endangered under CESA
SCT ....State candidate for listing as threatened under CESA
SD1 ....Scoping Document 1
SD2 ....Scoping Document 2
SE...............................State Endangered Species under the CESA
SFP.............................State Fully Protected Species under CESA
SFPUC ....San Francisco Public Utilities Commission
SHPO ....State Historic Preservation Office
SJRA ....San Joaquin River Agreement
SJRGA ....San Joaquin River Group Authority
SJTA ....San Joaquin River Tributaries Authority
SPD ....Study Plan Determination
SRA............................State Recreation Area
SRMA ....Special Recreation Management Area or Sierra Resource Management Area (as per use)
SRMP.........................Sierra Resource Management Plan
SRP ....Special Run Pools
SSC ....State species of special concern
ST...............................California Threatened Species under the CESA
STORET ....Storage and Retrieval
SWAMP.....................Surface Water Ambient Monitoring Program
SWE ....Snow-Water Equivalent
SWRCB......................State Water Resources Control Board
TAC............................Technical Advisory Committee
TAF ....thousand acre-feet
TCP ....Traditional Cultural Properties
TDS ....Total Dissolved Solids
TID.............................Turlock Irrigation District
TMDL ....Total Maximum Daily Load
TOC............................Total Organic Carbon
TRT ....Tuolumne River Trust
TRTAC ....Tuolumne River Technical Advisory Committee
UC ....University of California

USDA.........................U.S. Department of Agriculture
USDOC......................U.S. Department of Commerce
USDOI .......................U.S. Department of the Interior
USFS..........................U.S. Department of Agriculture, Forest Service
USFWS ......................U.S. Department of the Interior, Fish and Wildlife Service
USGS .........................U.S. Department of the Interior, Geological Survey
USR............................Updated Study Report
UTM...........................Universal Transverse Mercator
VAMP........................Vernalis Adaptive Management Plan
VELB.........................Valley Elderberry Longhorn Beetle
VRM ....Visual Resource Management
WPT...........................Western Pond Turtle
WSA...........................Wilderness Study Area
WSIP..........................Water System Improvement Program
WWTP ....Wastewater Treatment Plant
WY............................water year
µS/cm ....microSeimens per centimeter

1.0 INTRODUCTION

1.1 Background

Turlock Irrigation District (TID) and Modesto Irrigation District (MID) (collectively, the Districts) are the co-licensees of the 168-megawatt (MW) Don Pedro Project (Project) located on the Tuolumne River in western Tuolumne County in the Central Valley region of California. The Don Pedro Dam is located at river mile (RM) 54.8 and the Don Pedro Reservoir has a normal maximum water surface elevation of 830 ft above mean sea level (msl; NGVD 29). At elevation 830 ft, the reservoir stores over 2,000,000 acre-feet (AF) of water and has a surface area slightly less than 13,000 acres (ac). The watershed above Don Pedro Dam is approximately 1,533 square miles (mi^2). The Project is designated by the Federal Energy Regulatory Commission (FERC) as project no. 2299.

Both TID and MID are local public agencies authorized under the laws of the State of California to provide water supply for irrigation and municipal and industrial (M&I) uses and to provide retail electric service. The Project serves many purposes including providing water storage for the beneficial use of irrigation of over 200,000 ac of prime Central Valley farmland and for the use of M&I customers in the City of Modesto (population 210,000). Consistent with the requirements of the Raker Act passed by Congress in 1913 and agreements between the Districts and City and County of San Francisco (CCSF), the Project reservoir also includes a "water bank" of up to 570,000 AF of storage. CCSF may use the water bank to more efficiently manage the water supply from its Hetch Hetchy water system while meeting the senior water rights of the Districts. The "water bank" within Don Pedro Reservoir provides significant benefits for CCSF's 2.6 million customers in the San Francisco Bay Area.

The Project also provides storage for flood management purposes in the Tuolumne and San Joaquin rivers in coordination with the U.S. Army Corps of Engineers (ACOE). Other important uses supported by the Project are recreation, protection of aquatic resources in the lower Tuolumne River, and hydropower generation.

The Project Boundary extends from RM 53.2, which is one mile below the Don Pedro powerhouse, upstream to RM 80.8 at an elevation corresponding to the 845 ft contour (31 FPC 510 [1964]). The Project Boundary encompasses approximately 18,370 ac with 78 percent of the lands owned jointly by the Districts and the remaining 22 percent (approximately 4,000 ac) owned by the United States and managed as a part of the U.S. Bureau of Land Management (BLM) Sierra Resource Management Area.

The primary Project facilities include the 580-foot-high Don Pedro Dam and Reservoir completed in 1971; a four-unit powerhouse situated at the base of the dam; related facilities including the Project spillway, outlet works, and switchyard; four dikes (Gasburg Creek Dike and Dikes A, B, and C); and three developed recreational facilities (Fleming Meadows, Blue Oaks, and Moccasin Point Recreation Areas). The location of the Project and its primary facilities is shown in Figure 1.1-1.

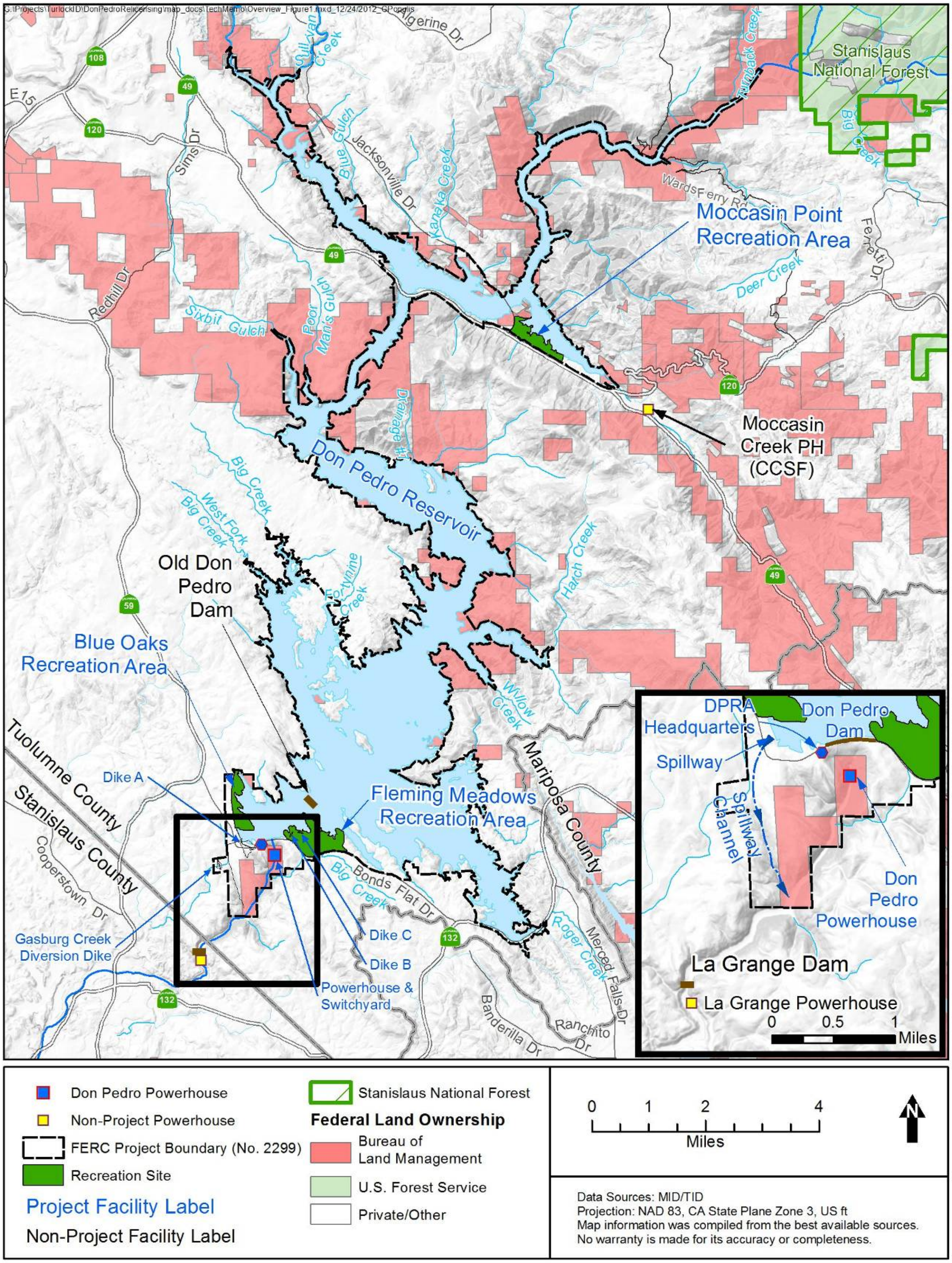


Figure 1.1-1. Don Pedro Project location.

1.2 Relicensing Process

The current FERC license for the Project expires on April 30, 2016, and the Districts will apply for a new license no later than April 30, 2014. The Districts began the relicensing process by filing a Notice of Intent and Pre-Application Document (PAD) with FERC on February 10, 2011, following the regulations governing the Integrated Licensing Process (ILP). The Districts' PAD included descriptions of the Project facilities, operations, license requirements, and Project lands as well as a summary of the extensive existing information available on Project area resources. The PAD also included ten draft study plans describing a subset of the Districts' proposed relicensing studies. The Districts then convened a series of Resource Work Group meetings, engaging agencies and other relicensing participants in a collaborative study plan development process culminating in the Districts' Proposed Study Plan (PSP) and Revised Study Plan (RSP) filings to FERC on July 25, 2011 and November 22, 2011, respectively.

On December 22, 2011, FERC issued its Study Plan Determination (SPD) for the Project, approving, or approving with modifications, 34 studies proposed in the RSP that addressed Cultural and Historical Resources, Recreational Resources, Terrestrial Resources, and Water and Aquatic Resources. In addition, as required by the SPD, the Districts filed three new study plans (W&AR-18, W&AR-19, and W&AR-20) on February 28, 2012 and one modified study plan (W&AR-12) on April 6, 2012. Prior to filing these plans with FERC, the Districts consulted with relicensing participants on drafts of the plans. FERC approved or approved with modifications these four studies on July 25, 2012.

Following the SPD, a total of seven studies (and associated study elements) that were either not adopted in the SPD, or were adopted with modifications, formed the basis of Study Dispute proceedings. In accordance with the ILP, FERC convened a Dispute Resolution Panel on April 17, 2012 and the Panel issued its findings on May 4, 2012. On May 24, 2012, the Director of FERC issued his Formal Study Dispute Determination, with additional clarifications related to the Formal Study Dispute Determination issued on August 17, 2012. The dispute did not involve *W&AR-16: Lower Tuolumne River Temperature Model*.

On January 17, 2013, the Districts issued the Initial Study Report (ISR) for the Project and held an ISR meeting on January 30 and 31, 2013. The ISR included a progress report for *W&AR-16: Reservoir Temperature Model Report*. The Districts filed a summary of the ISR meeting with FERC on February 8, 2013. Comments on the meeting summary and requests for new studies and study modifications were filed by relicensing participants on or before March 11, 2013 and the Districts filed reply comments on April 9, 2013. FERC issued the *Determination on Requests for Study Modifications and New Studies* on May 21, 2013.

Filed with FERC as part of the ISR, the Districts W&AR-16 progress report recommended that the river temperature modeling platform should be updated to the U.S. Army Corps of Engineers' (ACOE) Hydrologic Engineering Center's River Analysis System (HEC-RAS) model. Several relicensing participants commented on the Districts' plan to move the river temperature modeling to the HEC-RAS platform on or before March 11, 2013. In its May 21, 2013 Determination, FERC approved the Districts' proposal to adopt the HEC-RAS modeling platform. FERC also required the Districts to hold additional workshops on the HEC-RAS model. The Districts subsequently held workshops and model use training with relicensing participants on June 4 and June 5, 2013.

This study report describes the objectives, methods, and results of the Lower Tuolumne River Temperature Model Study (W&AR-16) as implemented by the Districts in accordance with FERC's May 21, 2013 Determination. Documents relating to the Project relicensing are publicly available on the Districts' relicensing website at www.donpedro-relicensing.com.

1.3 Study Plan

On July 16, 2009 FERC issued an Order on Rehearing regarding the Don Pedro Project (see 128 FERC: 61,035) requiring the Districts to determine the flows needed to maintain specified water temperatures at particular river locations and seasonal windows relevant to life history requirements of California Central Valley steelhead and fall–run Chinook salmon (TID/MID 2011a). This study made use of the existing CalFed San Joaquin River Basin model (SJR5Q) of the lower Tuolumne River (AD Consultants et al 2009). The TID/MID (2011a) study also made use of the most recent temperature data available from the CDFW at that time and, in addition, data collected by the Districts under their real time temperature monitoring (RTM) program, through which the Districts have been measuring temperatures in the lower Tuolumne River since 1986. The subsequent comparisons of model results and the most recent RTM data showed that the original SJR5Q model appeared to systematically over-predict water temperatures by up to 2 °C, and sometimes greater, at typical summer low flows. Although the original SJR5Q model calibration exceeded the model uncertainty identified in the study plan (1–2 °F) less than 10 percent of the time, 20–25 percent error exceedances were found in comparison to thermologgers not used in the original model calibration. These discrepancies resulted in the recommendation in the TID/MID (2011a) report, submitted to FERC as part of the Order on Rehearing, to recalibrate the river temperature model as part of relicensing using all of the most recent data available.

The Districts' proposed Lower Tuolumne River Temperature Model Study (W&AR-16) study plan was intended to complete the recalibration of the SJR5Q model performed under the 2009 FERC Order (TID/MID 2011b). FERC approved the relicensing study plan with modifications. The SPD required the Districts to (1) provide model output that could be used as input to the SJR5Q model; (2) model river temperatures by methods adequate to compute the 7-day average of the daily maximum temperature (7DADM) recommended by EPA (2003); (3) model river temperatures as needed to compare the results to maximum weekly average temperature (MWAT) standard presented in TID/MID (2011a), and (4) provide all data used in calibration.

Through 2012, the Districts attempted to recalibrate the original SJR5Q model. Prior to conducting a Consultation Workshop with RPs on October 26, 2012, the Districts issued a Lower Tuolumne River Temperature Model Status Report dated September 2012 providing a description of the work completed on the model up to that point (TID/MID 2012a). At the Consultation Workshop meeting with RPs, the Districts (1) presented the initial recalibration results; (2) discussed the status of the modeling efforts; (3) shared observations and insights gleaned during model development; (4) provided examples showing the considerable variation in diurnal variation observed from one data collection station to the next, even when the stations were in close proximity to each other; and (5) proposed two improvements to the study, to be performed in the second-year. First, the Districts would undertake an intensive water temperature field data collection effort in the summer of 2013 to further evaluate the summer diurnal temperature regimes along the lower Tuolumne (see Attachment A of TID/MID 2012a). Second, the Districts would move the modeling to the more transparent and flexible ACOE-supported HEC-RAS platform.

As pointed out in the ISR, the SJR5Q model is a proprietary model derived from the HEC-5Q model platform, a model that is no longer supported by the ACOE. When the Districts tried to calibrate the model, the SJR5Q model's 6 hour time-step did not adequately simulate the observed diurnal temperature ranges that were occurring primarily below about RM 37. Since the SJR5Q model's source code is proprietary, intermediate model steps were neither transparent nor able to be verified[1] and the model could not provide insight into the complexities of the observed data. Hence, after attempting to implement the model, the Districts concluded that migrating the model platform to HEC-RAS would better meet the goals and objectives of the study plan (TID/MID 2012a; 2012b; 2012c; 2013a; 2013b). FERC agreed with the Districts recommendation and approved the move to the HEC-RAS platform in its May 21, 2013 Determination.

The HEC-RAS version of the Lower Tuolumne River Temperature model is fully described in this study report. HEC-RAS is the ACOE's current one-dimensional river temperature model. Unlike SJR5Q or HEC-5Q, HEC-RAS is a supported ACOE program, and its computation methods and steps are transparent and readily distinguishable so the model's input and output can be fully understood. It is also readily usable by others and provides results in 1-hour time step, which is useful for determining daily maximum temperatures and calculating seven day average daily maximum values (7DADM).

The following sections describe the work completed in accordance with the FERC-approved study plan. The data obtained from the June through September 2013 intensive survey described in Attachment A to the progress report (TID/MID 2013a) are currently being compiled. These data will be analyzed and compared with model predictions with results provided as an addendum to this report in the first quarter of 2014.

This study was also conducted in accordance with the Consultation Workshop protocol required by FERC's December 21, 2011 SPD. A draft protocol was issued to relicensing participants on March 5, 2012, reviewed during a meeting with relicensing participants on March 20, 2012 and filed with FERC as final on May18, 2012 after a 30-day review and comment period following the March 20 meeting. No comments were received on the Workshop protocol.

The Districts conducted Workshops with relicensing participants related to the development and use of the lower Tuolumne River temperature model on April 10, 2012; October 26, 2012; January 24, 2013; and June 4/5, 2013. Meeting materials were circulated prior to each

[1] An example of SJR5Q's lack of transparency is that the SJR5Q model does not use reservoir inflow temperature data directly from the Tuolumne River and it is not apparent from model inspection or documentation how the reservoir inflow temperature data set is obtained. Without greater transparency of intermediate steps, a Lead Investigator using SJR5Q is not able to confirm, or attest to, the reliability of the model results.

Workshop, meeting notes were provided for review and comment, all comments were responded to, and final Workshop notes were filed with FERC.

On May 18, 2017, the Districts hosted a Modeling Tools Update Meeting with relicensing participants. At the meeting, the Districts announced that a version of the model previously distributed to relicensing participants contained an error. In particular, on February 12, 2014, a copy of the model was distributed to relicensing participants in which the Dry Creek and accretion input series were reversed in the 2013 Base Case, due to a labeling error. This error was corrected in all subsequent versions of the model distributed to relicensing participants. This error did not result in any impacts to the analysis in this report.

2.0 STUDY GOALS AND OBJECTIVES

The study goal is to develop a river temperature model that simulates current and potential future water temperature conditions in the lower Tuolumne River from below Don Pedro Dam (RM 54.8) to the confluence with the San Joaquin River (RM 0). The river temperature model includes simulation of the temperature regime of the lower Tuolumne River for the 1971 through 2012 period, consistent with the period of record of the Tuolumne River Operations Model. The following objectives apply to this study:

- reproduce observed river water temperatures, within reasonable calibration standards, over the expected range of hydrologic conditions;
- determine sensitivity of water temperatures to both flow and meteorological conditions;
- provide output to inform other studies, analyses and models; and
- predict potential changes in river temperature conditions under alternative future operating conditions.

In addition, output from the model should be:

- capable of being used as input to the SJR5Q and more recent HEC-5Q San Joaquin basin-wide model;
- able to calculate daily maximum temperatures; and,
- able to be compared to the maximum weekly average temperature (MWAT) standard presented in TID/MID (2011a).

The river temperature model is part of a suite of site-specific Tuolumne River models developed as part of the relicensing of the Don Pedro Project which also includes the Tuolumne River Operations Model (W&AR-02) and the Don Pedro Reservoir Temperature Model (W&AR-03) (TID/MID 2013c; TID/MID 2013d). These models form an integrated system of models for evaluating "base case" conditions and alternative Project operations scenarios. The Operations Model establishes reservoir inflows, outflows, and water levels. Output from the Operations Model acts as input to the reservoir temperature model, which in turn provides reservoir outflow temperatures as an input to the river temperature model described in this report. The Operations Model and the river temperature model provide input to the Tuolumne River Chinook (W&AR-06) and *Oncorhynchus Mykiss* (*O. Mykiss*) (W&AR-10) population models. This integrated system of models specific to the Tuolumne River watershed provides the necessary analytical tools for evaluating the effects of potential changes to the Don Pedro Project.

3.0 STUDY AREA

The study area for the lower Tuolumne River temperature model consists of the Tuolumne River from the outlet of Don Pedro Project at an elevation of approximately 300 ft to the Tuolumne River's confluence with the San Joaquin River at elevation 35 ft (Figure 3.0-1). The total drainage area and reach length of the study area are approximately 430 square miles over 54 river miles. There is one major tributary, Dry Creek, in this reach. Joining the lower Tuolumne River at RM 16, Dry Creek has a drainage area of approximately 204 square miles, nearly half of the total drainage area encompassed by the model.

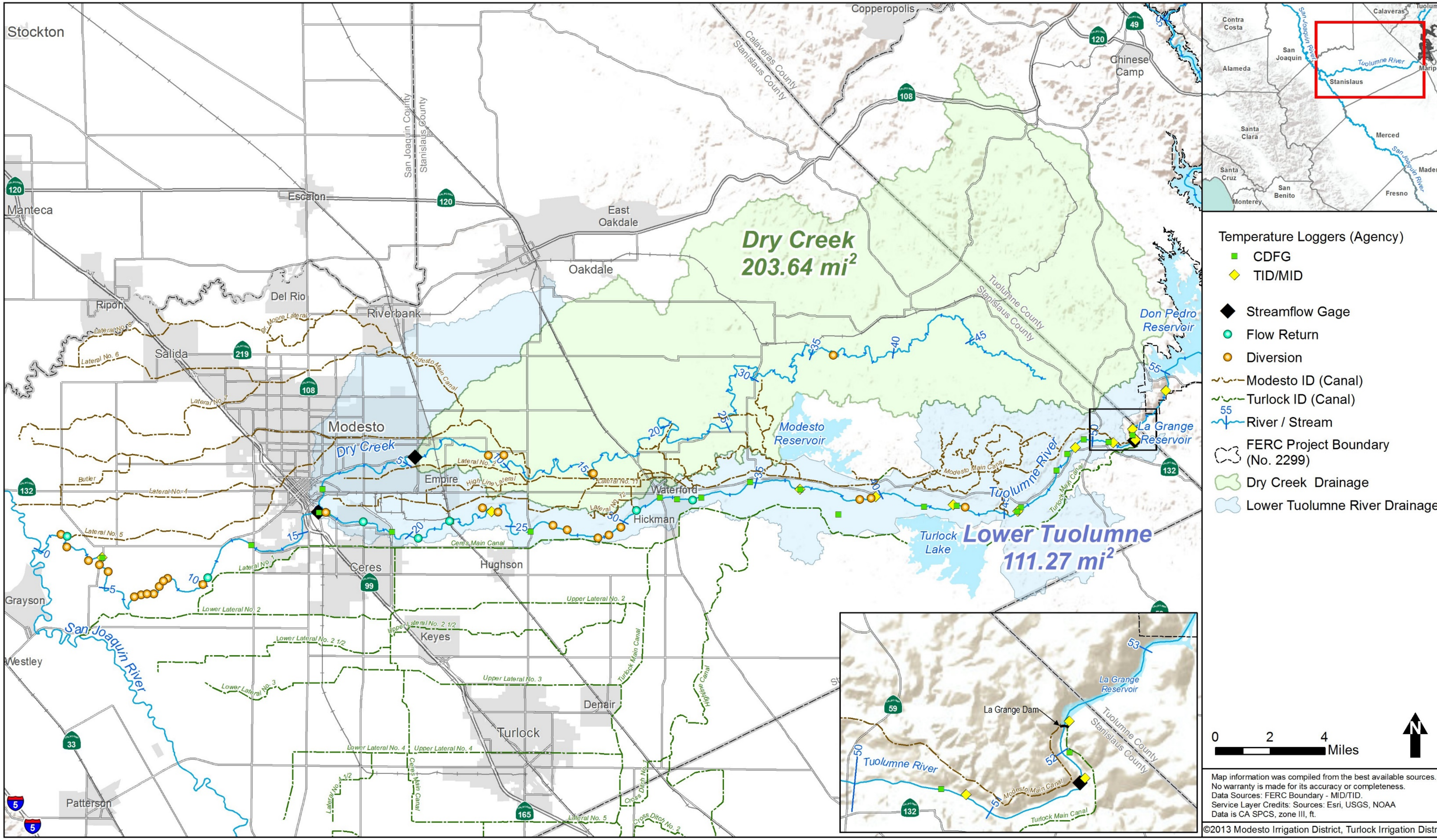


Figure 3.0-1. Lower Tuolumne River temperature model study area and temperature monitoring locations.

3.1 Climate and Hydrology

The semi-arid Mediterranean climate of the Sierra Nevada foothills is characterized by hot, dry summers, with precipitation generally occurring from October to April, with the majority of this occurring from December to March (Table 3.1-1). Over the study reach of the lower Tuolumne River, sunshine is abundant and less than 12 inches of precipitation are received in an average year. Snowmelt runoff from the upper Tuolumne basin occurs primarily between April and July.

Table 3.1-1. Monthly climatological data for the lower Tuolumne River area.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Downstream of Don Pedro Project												
MODESTO, CALIFORNIA (WRCC Station No. 045738)												
Period of Record : 1/ 1/1931 to 12/31/2005, Approx. Elevation: 90 ft												
Avg. High (°F)	54°	61°	67°	73°	81°	88°	94°	92°	88°	78°	64°	54°
Avg. Low (°F)	38°	41°	44°	47°	52°	56°	60°	59°	56°	50°	42°	38°
Mean (°F)	46°	51°	55°	60°	66°	72°	77°	75°	72°	64°	53°	46°
Avg. Rainfall (in)	2.4	2.1	2.0	1.1	0.5	0.1	0	0	0.2	0.6	1.3	2.1
Avg. snowfall (in)	0	0	0	0	0	0	0	0	0	0	0	0

Source: Western Regional Climate Center - http://www.wrcc.dri.edu/summary/climsmnca.html. (TID/MID 2011c)

Project area hydrology is detailed in Attachment 2 of the Districts' April 9, 2013, Response to ISR Comments. Outflows from Don Pedro Reservoir reflect real-time operations by the Districts to manage flows in accordance with Don Pedro Reservoir storage requirements, ACOE flood control guidelines, and downstream demand for water, including instream flow requirements contained in the current FERC license (TID/MID 2013c). After passing through the Project's powerhouse or outlet works (approximately RM 54.6), water eventually flows into the short reach of the Tuolumne River impounded by the La Grange Dam (RM 52.2). At La Grange Dam, water is diverted into MID's canal system to the north, diverted into TID's canal system to the south, or passes downstream to the lower Tuolumne River.

Currently, stream flows measured at the La Grange and Modesto gages (USGS Gage Nos. 11289650 and 11290000, respectively) record the vast majority of flow in the lower Tuolumne River at any time (TID/MID 2013c; Table 3.1-2). Some of the streamflow in this area appears to be derived from groundwater inflow and the lower Tuolumne River is generally considered to be a gaining stream[2,3] (California Department of Water Resources [CDWR] 2004). Some of the streamflow is also derived from natural tributary inflows (Figure 3.0-1). In addition to Dry Creek (CDWR gage DCM), which joins the Tuolumne River upstream of the USGS Modesto gage, minor and unmeasured natural surface inflows come from Peaslee Creek (RM 45.2) as well as McDonald Creek (via Turlock Lake). About 75 percent of the time these inflows occur between December and March, during and after winter rain storm events. Urban and agricultural

[2] A gaining stream is a stream whose flow rate increases in the downstream direction, generally as a result of groundwater inflows.

[3] As a component of this study, accretion/depletion estimates for the lower Tuolumne River were measured by the Districts through a series of three separate instream flow measurements along the lower Tuolumne River. The results of these measurements were provided to relicensing participants as the work was performed, then brought together in a separate report and provided to relicensing participants on April 25, 2013.

runoff, operational spills from irrigation canals, and riparian pumping withdrawals all affect the flows of the lower Tuolumne River (Figure 3.0-1).

Table 3.1-2. Lower Tuolumne River mean monthly flows (cfs) 1997-2012.

Month	Mean flow (cfs)[1,2]								
	USGS 11289651 - Don Pedro Project Outflow[3] = Tuolumne River + Modesto Canal + Turlock Canal			USGS 11289650 - Tuolumne River Below La Grange Dam Near La Grange, CA			USGS 11290000 - Tuolumne River at 9th Street Bridge, Modesto, CA		
	Mean	Highest	Lowest	Mean	Highest	Lowest	Mean	Highest	Lowest
January	2,012	13,630	203	1,729	13,070[4]	165	2,124	15,500	222
February	2,321	8,885	245	1,997	8,116[4]	168	2,308	8,782	262
March	3,090	5,983	989	2,022	5,407	165	2,299	5,665	285
April	3,705	8,922	1,168	2,232	7,436	271	2,430	8,264	428
May	3,806	9,902	2,155	1,926	7,847	385	2,064	7,964	560
June	3,656	7,134	2,049	1,399	5,027	54	1,526	5,153	201
July	3,361	5,448	2,414	655	2,845	88	829	2,985	192
August	2,846	5,074	2,205	467	2,498	86	623	2,415	184
September	1,732	2,882	1,130	365	1,423	68	547	1,637	181
October	1,141	1,587	604	367	628	141	538	1,153	243
November	443	862	224	292	399	161	388	520	215
December	1,043	4,752	223	904	4,625	164	1,036	4,996	220

Source: TID/MID 2011c, Table 5.2.2-9 and Table 5.2.2-11.

1 Values Calculated using USGS NWIS monthly statistics module:
http://waterdata.usgs.gov/nwis/nwisman/?site_no=11289650&agency_cd=USGS,
http://waterdata.usgs.gov/nwis/nwisman/?site_no=11289000&agency_cd=USGS,
http://waterdata.usgs.gov/nwis/nwisman/?site_no=11289500&agency_cd=USGS, and
http://waterdata.usgs.gov/nwis/nwisman/?site_no=11289651&agency_cd=USGS

2 Some values rounded by USGS - sum of individual gage monthly mean flows may not precisely equal combined gage monthly mean flows.

3 Don Pedro outflow is calculated from La Grange, Modesto canal, and Turlock canal gage measurements. See TID/MID 2011c, Table 5.2.2-9

4 The flood of record occurred in January, 1997, with high reservoir releases continuing on into February, 1997. These values skew the January and February mean monthly flow averages for the 1997 to 2009 period. Without 1997 values, the mean monthly flow in January is 827 cfs and February is 1,675, compared to 1,769 and 2,170 cfs, respectively.

3.2 Landform and Land Use

From upstream to downstream, the Tuolumne River leaves a steep and confined bedrock valley and enters the eastern Central Valley downstream of La Grange Dam near La Grange Regional Park (at Basso Bridge, RM 47.5), where hillslope gradients in the vicinity of the river corridor are typically less than five percent. From this point to the confluence with the San Joaquin River (RM 0), the Tuolumne River corridor lies in a broad alluvial valley. Within the alluvial valley, the river can be divided into two geomorphic reaches defined by channel slope and bed composition: a gravel-bedded reach that extends from TID's La Grange powerhouse (RM 52.0) to Geer Road Bridge (RM 24, adjacent to the City of Hughson); and a sand-bedded reach that extends from Geer Road Bridge to the confluence with the San Joaquin River (RM 0) (McBain & Trush 2000).

A number of large-scale anthropogenic changes have occurred to the lower Tuolumne River corridor since the California Gold Rush in 1848. Gold mining, grazing, and agriculture encroached on the lower Tuolumne River channel even before the first aerial photographs were taken by the Soil Conservation Service in 1937. In-river excavation of bed material for gold and aggregate to depths well below the river thalweg formed large ponds directly in the river and eliminated active floodplains and terraces and created large in-channel and off channel pits. Agricultural and urban encroachment in combination with in-channel excavation and reduction in coarse sediment supply and high flows has resulted in a relatively static channel within a narrow floodway confined by dikes and agricultural fields.

Downstream of the Don Pedro Dam, in the Central Valley area of the Tuolumne River watershed, land is primarily privately owned and used for agriculture, grazing and rural residential purposes, or for denser residential, municipal and industrial purposes in the communities of Waterford (RM 32), Modesto (RM 16), Hughson (RM 24) and Ceres (RM 19)(Stanislaus County 2006). A small portion of the land downstream of the Project is under state management; Turlock Lake State Recreation Area is a small state park extending along the southern bank of the Tuolumne River (approximately RM 42.4 to 41.6) to the north shore of Turlock Lake.

Although the tailing piles are primarily the legacy of gold mining abandoned in the early 20th century, gravel and aggregate mining continue alongside the river for a number of miles, particularly upstream of the town of Waterford (RM 34)(TID/MID 2011c). The areal extent and condition of the riparian resources and habitats along the lower Tuolumne River is the subject of the Lower Tuolumne River Riparian Information and Synthesis Study (W&AR-19; TID/MID 2013e). In general, primarily due to restoration efforts, riparian vegetation is increasing within the lower Tuolumne River corridor. However, shading is not uniform over the river's course and riparian vegetation height is generally much less than the river's width.

3.3 Historical Water Temperatures

CDFW and the Districts have been measuring temperature at approximately 30 sites located between the Don Pedro Dam and the confluence with the San Joaquin since the early 2000s, while some locations near the La Grange and Modesto USGS gages have been monitored for over two decades, since 1987.

Based on historical temperature data collected on the lower Tuolumne River[4], monthly seven day average daily maximum (7DADM) temperatures observed along the river are summarized below in Table 3.3-1 and Table 3.3-2. These data show:

- releases from Don Pedro Dam, reflecting hypolimnion temperatures, do not exceed 13ºC at any time of year and are often as low as 9ºC (Table 3.3-1),
- water temperatures downstream of Don Pedro Dam are influenced to a varying extent in the warmer months by releases from Don Pedro Reservoir's cold-water pool,
- upstream to downstream, year-round mean summertime 7DADM temperatures in the lower Tuolumne River vary from approximately 13.5ºC near La Grange diversion dam to approximately 25ºC at RM 3.5 just above the confluence with the San Joaquin River, and

[4] Temperature data collected from the Tuolumne river is provided in Attachment C of the Reservoir Temperature Model Report (TID/MID 2013f) provided as part of the Initial Study Report filing of January 2013.

- during the core Chinook outmigration period of April/May and irrigation season (March through October), the 7DADM temperatures range from 11ºC near La Grange to about 20ºC near the river's mouth.

Table 3.3-1. Don Pedro hypolimnion and Project outflow temperature comparisons.

Month	Average Temperature (°C)					
	Don Pedro Hypolimnion Upstream of Don Pedro Dam Elevation 535 ft msl[1]; approx. RM 55.1			Don Pedro Project Outflow RM 54.3		
	8/2004 – 11/2012 (most of 2009 missing)			1/1987 - 9/1988 and 5/2010 - 2/2013		
	Mean	Highest	Lowest	Mean	Highest	Lowest
January	10.8	11.4	10.2	10.5	11.7	8.9
February	10.1	11.0	9.5	9.7	11.4	8.5
March	10.1	10.7	9.3	9.3	11.1	7.8
April	10.2	11.4	9.3	9.4	10.9	8.3
May	10.4	10.8	9.8	9.8	11.1	8.6
June	10.7	11.6	10.0	10.2	11.7	9.0
July	11.0	12.1	10.4	10.6	11.7	9.4
August	11.3	12.2	10.6	10.9	12.2	9.4
September	11.4	11.9	10.8	11.1	12.2	10.0
October	11.5	11.9	11.0	11.3	12.2	10.0
November	11.4	12.0	10.7	11.3	13.3	9.3
December	11.5	12.3	11.1	11.2	12.2	10.1

[1] When profile did not extend down to 535 ft msl, the temperature measured at the bottom of the profile was used for calculating averages.

ft feet
msl mean sea level
RM River Mile

Table 3.3-2. Monthly 7DADM temperatures in the lower Tuolumne River (various dates)[1].

Month	Average			7-Day Average Daily Maximum Temperature																	
	Don Pedro Project Outflow			@ USGS 11289650 - Tuolumne River Below La Grange Dam			Tuolumne River at Riffle 13B			Tuolumne River at Roberts Ferry Bridge			Tuolumne River at Hughson			Tuolumne River at 9th St Bridge			Tuolumne River at Shiloh Bridge		
	RM 54.3			Near La Grange, CA												Near Modesto, CA			Near San Joaquin Confluence		
	1/1987 - 9/1988 and			RM 51.8			RM 45.5			RM 39.5			RM 23.6			RM 16.2			RM 3.5		
	May 2010 – Feb 2013			Nov 2001 – Oct 2012			Nov 2001 – Nov 2012			Aug 1998 – Jul 2010			Dec 1997 – Jan 2010			Jul 1968-Apr 1979 and Sep 1988-Jun 2013			Apr 1987 – Dec 2012		
	Mean	High	Low	Mean	High	Low	Mean	High	Low	Mean	High	Low	Mean	High	Low	Mean	High	Low	Mean	High	Low
January	10.46	11.7	8.9	10.9	11.6	10.4	11.0	11.8	10.6	10.9	11.9	10.1	11.1	12.4	9.9	10.7	12.7	9.2	10.7	12.6	8.4
February	9.68	11.4	8.5	10.8	11.2	10.1	11.6	12.2	10.6	11.9	13.0	10.9	12.3	13.9	10.9	12.5	15.9	8.4	12.5	14.6	10.1
March	9.33	11.1	7.8	10.8	11.6	9.7	12.4	13.5	10.5	13.4	15.5	11.0	14.3	17.4	11.1	15.4	19.7	10.5	15.3	18.5	10.5
April	9.38	10.9	8.3	10.8	11.7	9.9	12.8	14.6	10.9	13.5	15.2	11.4	15.1	17.2	11.7	17.8	22.0	11.4	16.7	21.5	11.3
May	9.8	11.1	8.6	11.3	12.0	10.4	14.0	15.6	11.7	15.5	18.1	12.7	18.0	20.9	12.9	20.8	24.6	12.9	19.6	27.4	12.9
June	10.15	11.7	9	12.0	12.9	11.1	16.9	20.6	12.6	20.3	26.0	13.8	23.8	27.9	14.1	25.0	31.3	13.9	23.4	28.7	15.1
July	10.56	11.7	9.4	12.4	13.3	11.7	18.3	21.9	14.1	21.4	26.3	15.3	25.7	28.9	16.0	27.2	31.4	17.4	25.8	29.6	18.0
August	10.87	12.2	9.4	12.7	13.4	12.1	18.0	20.7	13.8	20.8	24.7	16.0	25.0	28.3	19.0	26.1	29.9	16.1	25.0	28.1	17.3
September	11.1	12.2	10	12.7	13.3	12.2	16.9	19.1	15.0	18.8	22.1	14.6	22.3	25.3	16.4	23.1	27.1	18.5	22.2	25.7	16.8
October	11.31	12.2	10	12.3	12.8	12.0	14.0	14.6	13.4	14.8	16.1	13.9	17.0	18.9	15.2	18.1	22.1	14.9	17.7	20.3	14.9
November	11.26	13.3	9.25	11.5	12.0	10.9	12.2	12.6	11.5	12.4	13.3	11.7	13.4	14.6	12.0	13.8	18.6	11.6	13.2	14.7	9.6
December	11.24	12.22	10.1	11.2	11.6	10.7	11.2	11.7	10.3	11.0	11.5	10.0	10.9	12.0	10.1	10.6	12.5	8.5	10.4	11.8	7.5

[1] Monthly averages of the 7DADM over the period of record are summarized in this table. Mean, high, and low monthly 7DADM values over the period of record are indicative of the high temperatures in the river by month.

3.4 Local Irrigation

There are two diversions from La Grange Dam: TID's Turlock Canal to the south and MID's Modesto Canal to the north. The Modesto Canal diverts water through a tunnel into Modesto Reservoir; from there water is distributed into a system of surface canals for delivery to agricultural and municipal customers. The Turlock Canal diverts water through a surface canal into Turlock Lake, and from there it is distributed to primarily agricultural customers in a system of surface canals. Both Turlock Lake and Modesto Reservoir are used for temporary storage of water to balance the supply and demand of needed water.

Both canal systems provide operational spills to the Tuolumne River and Dry Creek. These are used for flow balancing and head maintenance and return unused water to the Tuolumne River (Table 3.4-1). These return flows are very sporadic and only recently some have been measured continuously.

Table 3.4-1. TID and MID operational spills.

Name	Owner	River Mile	Approximate Average Flow (cfs)
Hickman Spill	TID	32.7	unknown
Waterford Main	MID	30.6	3
Lateral No. 1 (Santa Fe Aggregate)	MID	21.6	2
Faith Home Spill	TID	20.3	9
Lateral No. 1 (airport)	MID	18.1	4
Lateral No. 2 (Dry Creek)	MID	16.2	2
Lateral No. 1	TID	10.3	unknown
Lateral No. 5	MID	1.7	unknown

In addition to these operational spills, there are claimed and licensed diversions on the Tuolumne River below La Grange diversion dam (Table 3.4-2). None of these diversions are measured on a daily basis, and only recently has the California State Water Resources Control Board (SWRCB) required reporting for riparian diversions. Due to the uncertainty involved, the lower Tuolumne temperature model accounts for these diversions as part of accretions/depletions, calculated using available stream gages (Section 4.3.3).

Table 3.4-2. Known Tuolumne River diversions.

Application Identification Number	Type	River Mile	Annual Diversion (AF)	Diversion Rate[1] (cfs)	Application Identification Number	Type	River Mile	Annual Diversion (AF)	Diversion Rate[1] (cfs)
A015371	Licensed	43.4	91	0.3	A009301	Licensed	8.4	1,066	2.5
S007652	Claimed	39.5	unknown	7.2	A011390	Licensed	8.2	818	1.5
A012262	Licensed	38.9	2,172	3.0	A009301	Licensed	8.0	1,066	2.5
S021736	Claimed	29.8	unknown	4.5	A011390	Licensed	7.6	818	1.5
S021739	Claimed	29.8	unknown	6.7	A011390	Licensed	7.3	818	1.5
S021738	Claimed	29.2	unknown	2.1	A005269	Licensed	7.2	635	2.1
S021737	Claimed	28.8	unknown	4.5	A012396	Licensed	6.9	488	1.0
S018705	Claimed	27.5	46	unknown	A001633	Licensed	4.4	1,518	3.2
S009161	Claimed	26.9	180	4.5	A004607	Licensed	4.4	357	1.5
S011191	Claimed	23.8	60	3.8	A013496	Licensed	4.0	84	0.2
S011103	Claimed	23.4	unknown	3.3	S017392	Claimed	3.2	767	unknown
S014004	Claimed	16.5	250	6.7	S017319	Claimed	2.1	2,474	unknown
A012674	Licensed	10.0	1,623	2.7	A009573	Licensed	1.4	4,782	9.8

Source: http://www.waterboards.ca.gov/waterrights/water_issues/programs/ewrims/index.shtml
[1] Maximum permitted diversion rate.
AF Acre Feet
cfs cubic feet per second

4.0 METHODOLOGY

4.1 Model Configuration

The model being used in this study is the ACOE HEC-RAS model. The HEC-RAS model of the Tuolumne River begins just below the Don Pedro Dam and extends 54 miles downstream to the confluence with the San Joaquin River, as shown in Figure 4.2-1. Figure 4.2-1 also shows the location of the Districts' irrigation diversions at La Grange diversion dam and the inflow at Dry Creek, as well as various landmarks for orientation along the river.

The model uses as its headwater input the flow and temperature released from the Don Pedro Project. At La Grange diversion dam the flows withdrawn by the Districts for irrigation and M&I purposes are accounted for and measured. Dry Creek flows are added at RM 16. Along the length of the river, additional accretions flows, presumed to be from groundwater, are also added. The effect of diversions or returns is also accounted for in the accretion/depletion estimates. The details of these flows are described further below. The model time step is one hour.

4.2 Temperature Monitoring Data

Model input includes Don Pedro Reservoir outflow temperatures. As pointed out above, , an extensive temperature data collection program has been undertaken over the last 10-plus years on the lower Tuolumne River. A complete inventory of historical data was previously provided to relicensing participants and filed with FERC as Attachment C of the Reservoir Temperature Model Report (TID/MID 2013f) provided as part of the January 2013 Initial Study Report. However, Don Pedro outflow temperatures have been measured only since mid-2010; therefore, calendar year 2011 was chosen as the calibration year and 2012 was used as the verification year for modeling purposes. For 2011 and 2012 there were 23 temperature monitoring locations along the river that had complete, or nearly complete, temperature records. These are shown in Figure 3.0-1. Of these 23 stations, 16 are monitored by CDFW, and seven are monitored by the Districts. These are listed below in Table 4.2-1 by river mile.

The meteorological data used in model development came from the Districts' MET station at Crocker Ranch (location noted on Figure 4.2-2), with the exception of the solar radiation data, which came from the Denair II station in Turlock. Equipment errors at the Crocker Ranch station prohibited use of the solar radiation data from this station for 2011 and 2012. The 2011-2012 data for air temperature, wind speed, pressure and relative humidity are shown in Figures 4.2-3 through 4.2-5.

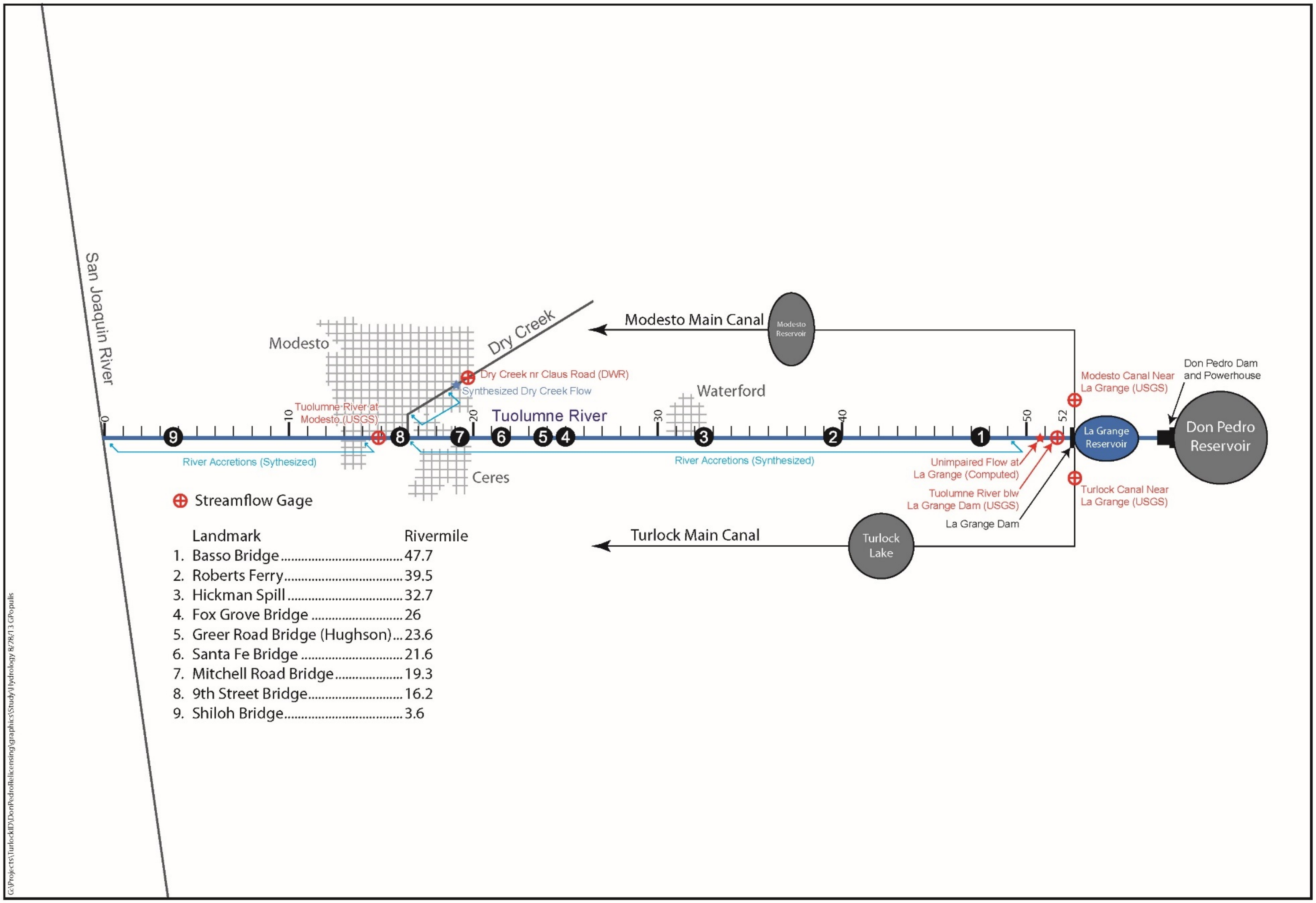


Figure 4.2-1. Schematic of lower Tuolumne River.

Table 4.2-1. River temperature monitoring locations.

Owner	Location	Tuolumne River Mile	Coordinates (Decimal °)		Period of Record[1]	
			Latitude	Longitude	Start Date	End Date
Boundary Condition Temperature Monitors						
TID/MID	Below Don Pedro Powerhouse	54.3	37.6929	-120.4216	5/19/10	2/13/13
CDFW	Dry Creek above Tuolumne River	N/A	37.6398	-120.9848	2/3/06	4/27/12
In-River Temperature Monitors						
TID/MID	Above La Grange Dam	52.2	37.6725	-120.4438	8/25/11	12/6/12
TID/MID	USGS La Grange Gage	51.8	37.6669	-120.4418	1/8/77	12/4/12
CDFW	Riffle A1	51.6	37.6694	-120.4438	6/18/01	1/15/13
TID/MID	Riffle A7	50.7	37.6652	-120.4567	11/14/01	12/4/12
CDFW	Riffle C1	49.7	37.6671	-120.4764	6/14/01	1/22/13
CDFW	Riffle D2	48.8	37.6595	-120.4874	6/14/01	1/22/13
CDFW	Basso Bridge	47.5	37.6507	-120.4946	7/29/03	1/22/13
TID/MID	Riffle 13B	45.5	37.6290	-120.5205	11/14/01	12/5/12
CDFW	Riffle G3	45.0	37.6289	-120.5208	6/15/01	1/22/13
CDFW	Riffle I2	43.2	37.6319	-120.5611	6/15/01	1/22/13
TID/MID	Riffle 21	42.9	37.6323	-120.5635	5/27/04	12/5/12
CDFW	Riffle K1	42.6	37.6315	-120.5829	6/16/01	1/23/13
TID/MID	Roberts Ferry Bridge	39.5	37.6366	-120.6153	8/11/98	12/5/12
CDFW	Riffle Q3	35.0	37.6444	-120.6991	5/31/02	1/23/13
CDFW	Above Hickman Spill	33.0	37.6361	-120.7317	3/9/05	1/23/13
CDFW	Below Hickman Spill	32.0	37.6352	-120.7478	3/9/05	1/23/13
CDFW	Fox Grove Bridge	26.0	37.6178	-120.84553	9/9/05	1/1/13
TID/MID	City of Hughson (Geer Rd)	23.6	37.6281	-120.8717	12/10/97	12/4/12
CDFW	Santa Fe Bridge	21.0	37.623	-120.8987	8/12/05	1/15/13
CDFW	Mitchell Road Bridge	19.0	37.6172	-120.9382	8/12/05	4/27/12
CDFW	Above Dry Creek	16.3	37.6271	-120.9811	7/25/06	1/15/13
CDFW	Ninth Street Bridge	16.2	37.6274	-120.987	8/12/05	8/22/12
CDFW	Shiloh Bridge	3.5	37.6027	-121.1313	2/16/05	1/6/13

Source: Attachment C of the Reservoir Temperature Model (TID/MID 2013f)

[1] In some cases, large gaps in the data occur so the 'Start' and 'End' dates provided in Table 4.2-1 simply represent the first and last day that data are available.

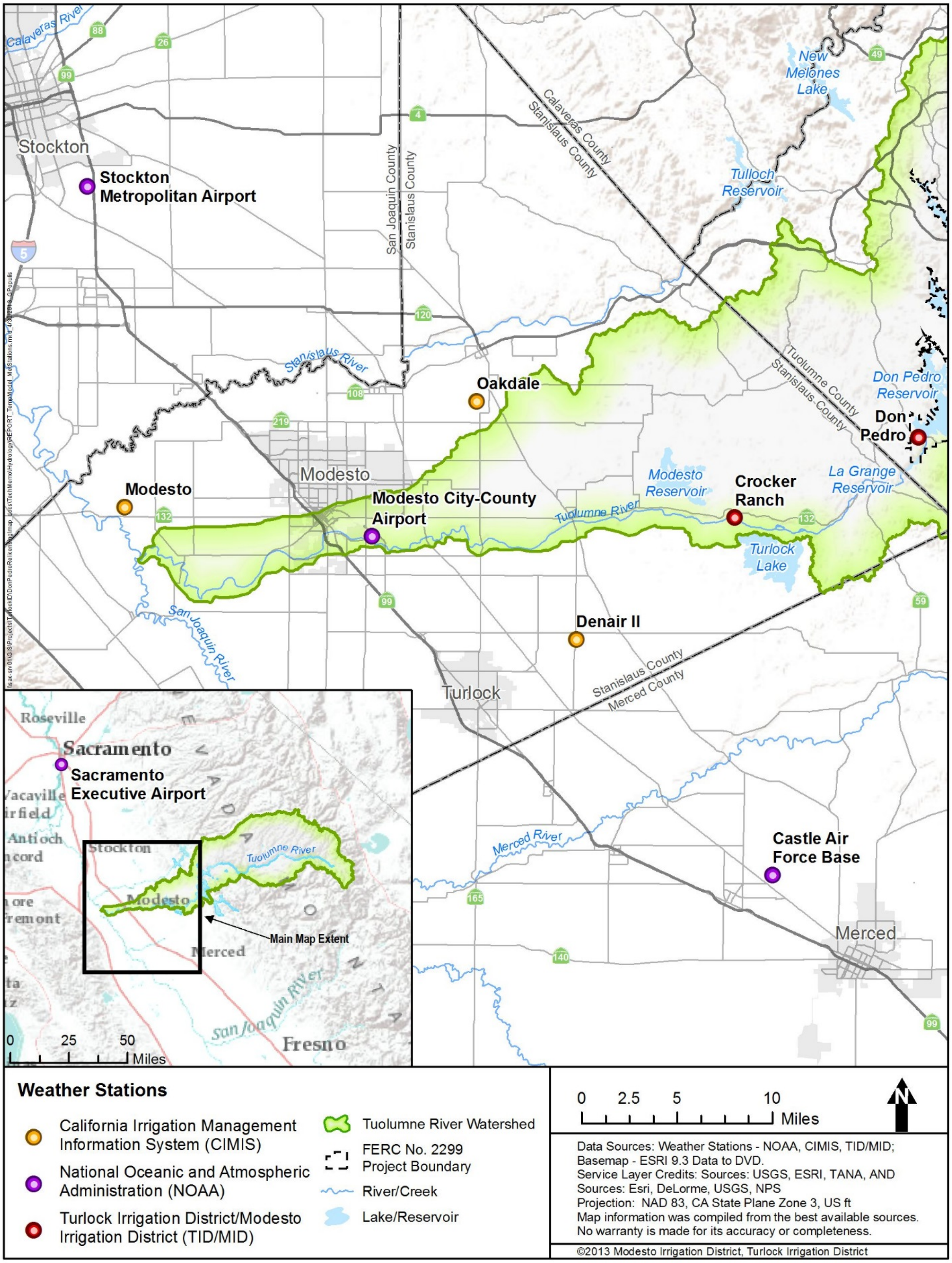


Figure 4.2-2. Location of meteorological stations.

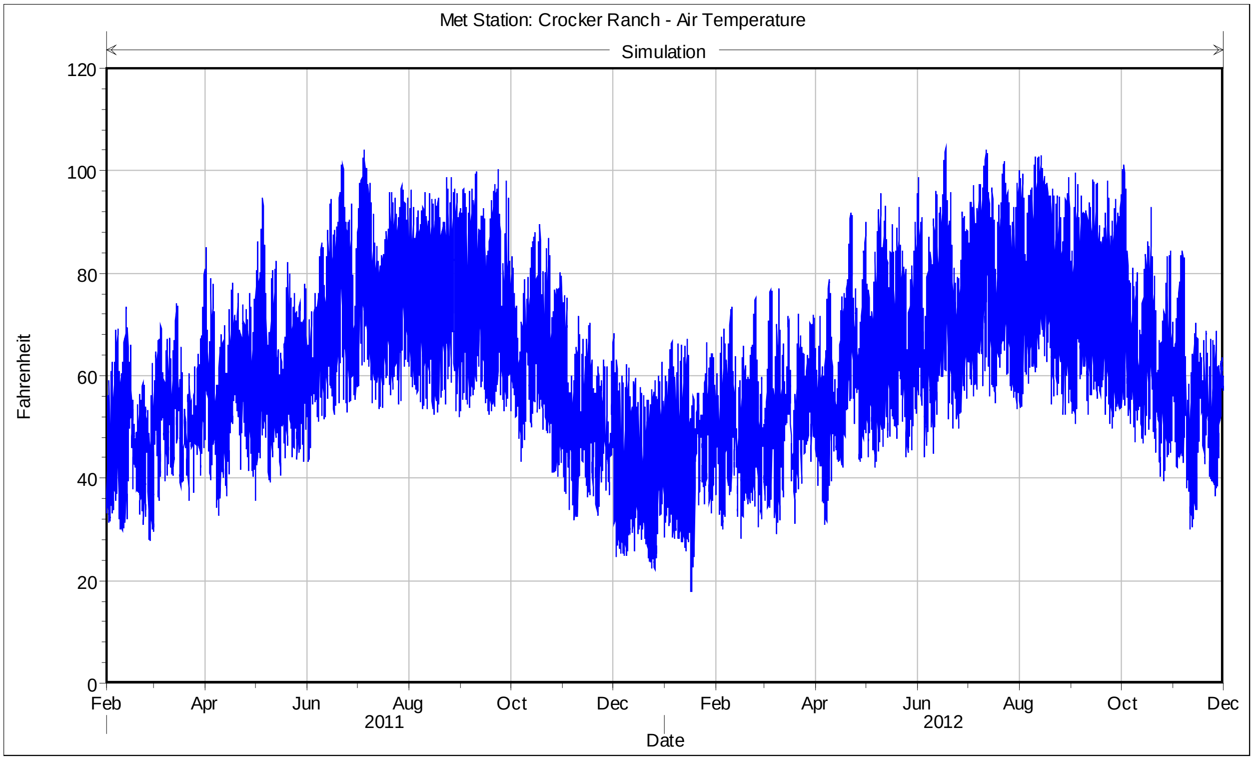


Figure 4.2-3. Crocker Ranch air temperature for 2011-2012.

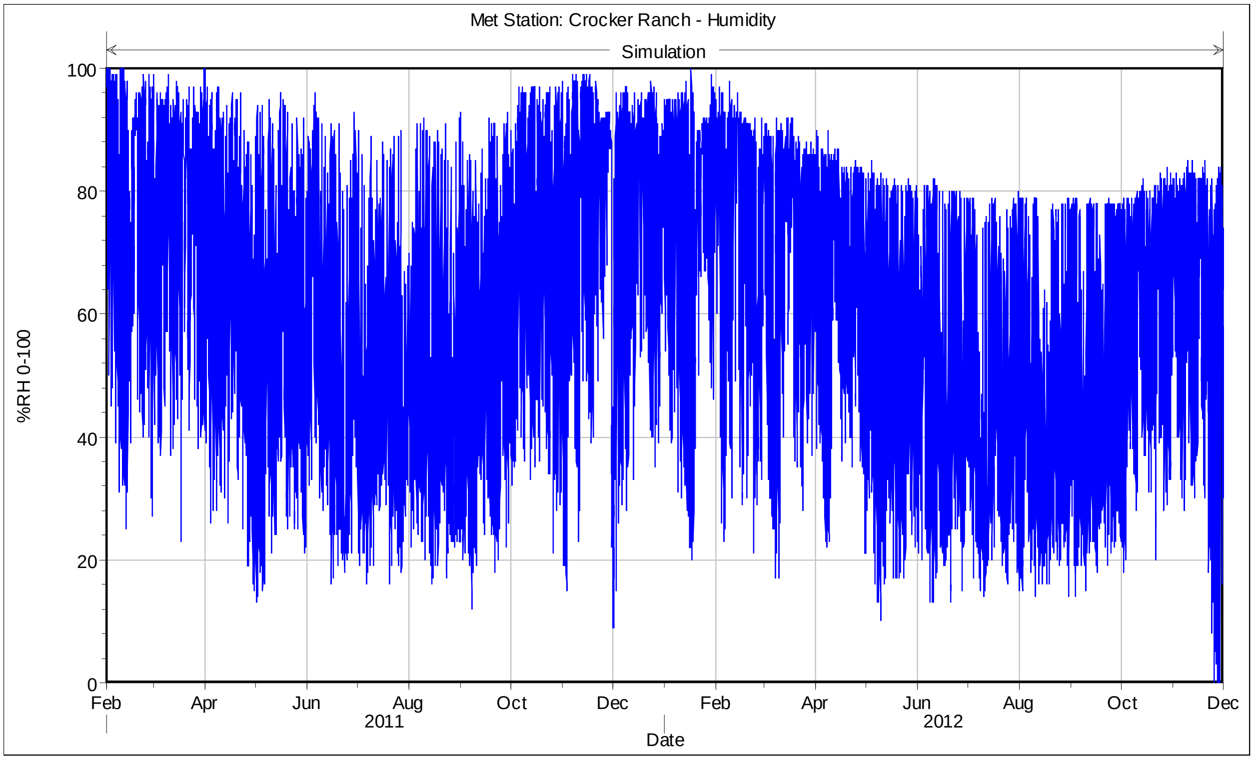


Figure 4.2-4. Crocker Ranch relative humidity for 2011-2012.

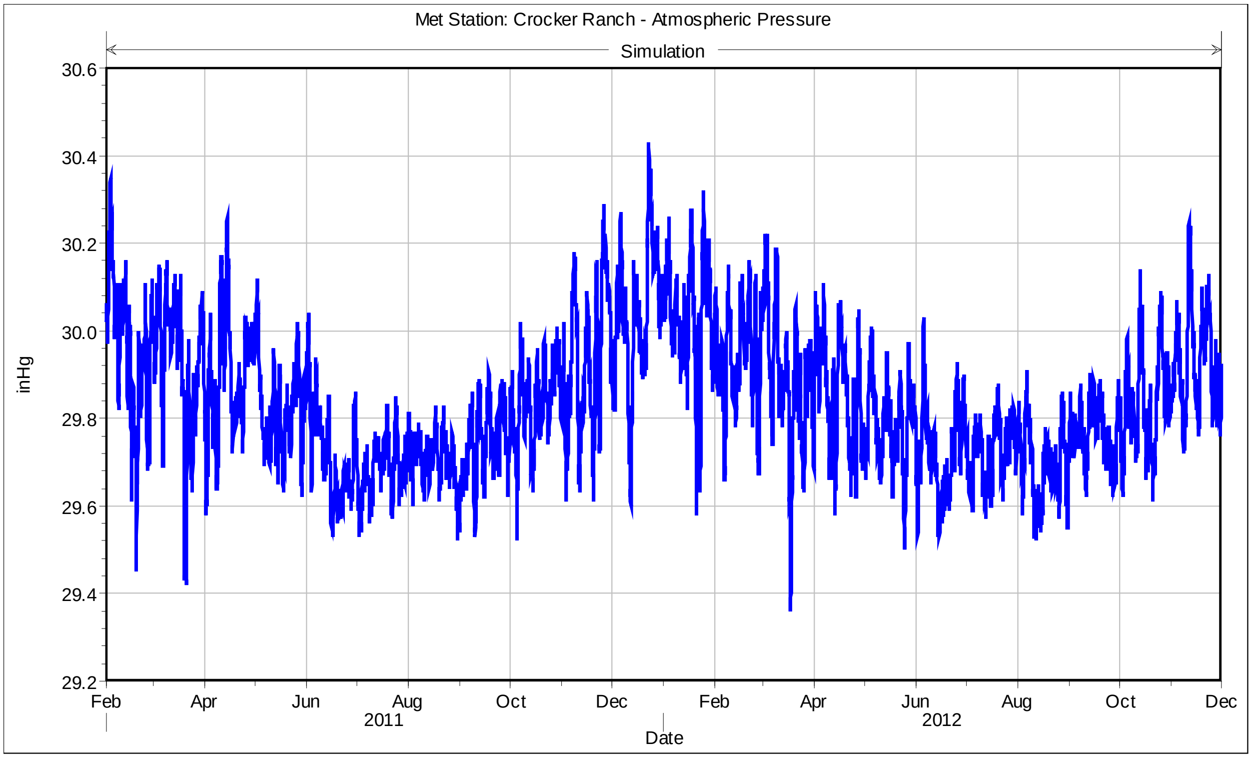


Figure 4.2-5. Crocker Ranch atmospheric pressure for 2011-2012.

4.3 Model Computations

4.3.1 River Hydraulic Characteristics

The HEC-RAS model allows inflows and outflows to be specified by the user. For the lower Tuolumne River model, inflows occur at the upstream boundary of the model at Don Pedro Dam and where Dry Creek enters the Tuolumne River at RM 16. Outflows occur at La Grange Dam as diversions by each of the Districts for irrigation and M&I water. These are discussed in detail in Section 4.3.3.

The main hydraulic computational procedure is based on the solution of the one-dimensional Bernoulli Equation. Energy losses due to friction are computed using the Manning Equation, and loss coefficients are estimated for expansion and contraction of the flow (USACE 2010). The model hydraulics are capable of handling mixed flow regimes of super and sub-critical flow. HEC-RAS has the ability to model structures such as bridges, dams, culverts, weirs and levees.

The lower Tuolumne River begins at the outlet of the Don Pedro Dam at elevation 300 ft at RM 54.3. The river flows for about a mile before it enters the impoundment of La Grange Dam at around RM 53.2. La Grange Dam is located at RM 52.2. The dam has a maximum height of approximately 125 ft and is 350 ft long. It has a crest elevation of 296.5 ft. The dam is included in the HEC-RAS model.

The roughness and slope of the river control the water velocity and travel time. The slope is computed directly from the elevation information contained in the cross section geometry, discussed in the next section. The length between each cross section is also specified. The river roughness is set via the Manning "n" value as detailed below and summarized in Table 4.3-1. The Mannings "n" values were set to reflect geomorphic conditions, as outlined in McBain and Trush (2000). In brief, McBain and Trush found that above RM 24 the river bed is predominantly gravel. Below RM 24 the bed is predominantly sand.

Mannings "n" values above La Grange Dam are 0.04 and 0.06 for the channel and banks, respectively. These are typical values suggested by Chow (1959) for main channels.

Water is diverted at La Grange Dam via canals on the north (MID) and south side (TID). Some water drawn off via the TID canal can be passed through penstocks to a small generation facility (La Grange powerhouse). The outflow from the powerhouse returns water back to the river at approximately RM 51.6. Additionally some water (~25 cfs) is released from the old MID canal headworks via a small valve at the end of now-unused portion of the old Main Canal. This water cascades down the rock bank until it enters the river just below La Grange Dam. In HEC-RAS there was no attempt made to match this flow routing scheme, and water was simulated as simply passing over the dam.

Travel times were adjusted in the model to reflect actual times of travel between the dam and the USGS La Grange gage. This was done by using an increased Manning value of 0.1 for the channel, for about one mile downstream of the dam (to RM 51.2). The river overbanks in this area are typically a mixture of steep embankments covered in rock, rock debris with some trees and brush. A Manning value of 0.1 was used for the overbanks in this reach to RM 47.8. From RM 51.2 to 50.5 the main channel Manning values were reduced to 0.08, representing a bottom with gravel, cobbles and boulders. From RM 50.3 to 47.8 the main channel Manning value was reduced to 0.05, representing a smoother version of the case above, with smaller boulders and a less tortuous flow path. Below RM 47.8 the main channel "n" value was reduced further to 0.04 representing a gravel/cobble channel with low sinuosity and both pools and shoals. This value was used for the remainder of the river. The overbank "n" values were reduced to 0.06, representing a decrease in the density of riparian vegetation, and the presence of open fields. This value was used to RM 31. Below this point the value was decreased slightly to 0.055 to represent even less vegetation and more open fields. This value was used for the remainder of the river.

The Mannings "n" values were adjusted during the calibration so that computed travel times matched the observed travel times. The travel time in the river was tracked through the river water temperature data, by the timing of the daily maximum and minimum temperatures under relatively constant flow conditions.

Table 4.3-1. Manning "n" values used in HEC-RAS model.

River Mile	Main Channel	Overbank	Notes
54.3 – 52.2	0.04	0.06	Above La Grange Dam
52.2 – 51.2	0.1	0.1	Below La Grange Dam to USGS La Grange gage – higher values used to slow flow below large drop in elevation
51.2 – 50.5	0.08	0.1	Very rocky bed, large boulders
50.5 – 47.8	0.05	0.1	Gravel, cobbles and a few boulders
47.8 – 31.0	0.04	0.06	Clean, slightly meandering main channel – transition from gravel to sand bed; less steep overbanks
31.0 – 0.0	0.04	0.055	Mainly sand bed; even less steep overbanks

4.3.2 River Channel Geometry

A number of data sources were available that provided river cross-sections and overbank topography. Table 4.3-2 lists the six sources used to describe the channel and overbanks for the temperature model. These data sources represented the most recent field measurements available.

Table 4.3-2. Lower Tuolumne River—river channel data sources.

River Mile	Source	Original Reason for Collection
0-12	USACE 2001	Floodplain survey performed in 1999 by ACOE; transects were 100 ft apart. Transect elevations used for model were 0.5 miles apart.
14-31.5	HDR 2012	Field survey in December 2012 at approximately 235 cfs in support of HEC-RAS temperature model; transects collected every 0.5 mile
33.6 to 39.9	HDR 2003-2006	Developed from the Ruddy Segment (RS 177300-21074) data developed by HDR for the Tuolumne River restoration program HEC-RAS model; survey files included stitched TIN surfaces originating from LiDAR and ground truthed bathymetric soundings. More than 100 transects were measured, anywhere from 50 to 100 feet apart. (AD Consultants et al 2009). Transect elevations created for model at 0.5 mile intervals.
40-45.5	Extrapolated	Channel geometry extrapolated from upstream and downstream transects; overbank developed from LiDAR (flown at about 300 cfs in March 2012). Transects developed for model 0.5 miles apart.
45.5-51.5	TID/MID 2013g. W&AR-4, Spawning Gravel in the Lower Tuolumne River.	ADCP performed at 2000 cfs in 2013. A combination of LiDAR and overbank surveys. Transects developed for model 0.5 miles apart.
52.3-54.3	Meridian Surveying Engineering 2012	Hydrographic Survey for TID. Transects developed for model 0.5 miles apart.

ADCP = Acoustic Doppler Current Profiler
cfs = cubic feet per second
ACOE = Corps of Engineers
ft = feet
LiDAR = Light Detection and Ranging
MID = Modesto Irrigation District
RM = River Mile
SJRB = San Joaquin River Basin
TID = Turlock Irrigation District

Based on the these data sources, river cross sections were generated approximately every 0.5 miles using GIS software. In HEC-RAS, additional cross sections are created by interpolating between these 0.5 mile sections. The calibrated model uses 1/6 mile cross section intervals below La Grange diversion dam.

A HEC-RAS generated profile of the river below Don Pedro is shown in Figure 4.3-1. The large drop in elevation at the downstream face of La Grange diversion dam is evident.

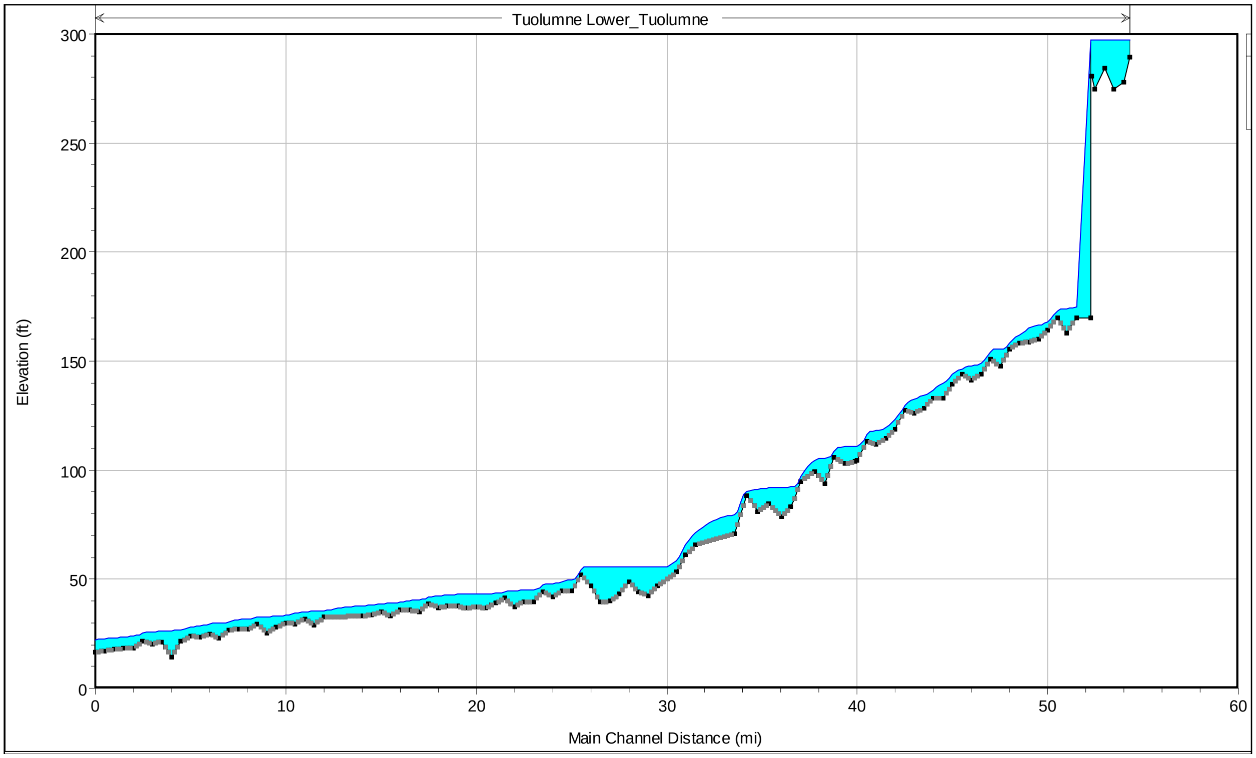


Figure 4.3-1. HEC-RAS profile of Tuolumne River.

4.3.3 Model Inflows and Outflows

The hydrology dataset developed for the Tuolumne River Operations Model (W&AR-02) was used as input to HEC-RAS. Inflow at the upstream limit of the HEC-RAS model is the computed releases from Don Pedro Reservoir provided by the output of the Operations Model. The powerhouse discharge and low level outlet works flow are summed in the calculation. For calibration and validation, inflow temperatures were measured in 2011 and 2012 just below Don Pedro Dam, reflecting the temperature of the combined flows from the powerhouse and low-level outlet works. The dam's outflow and temperature for 2011-2012 are shown in Figures 4.3-2 and 4.3-3.

An examination of Figures 4.3-2 and 4.3-3 show that 2011 and 2012 were substantially different hydrologically. The year 2011 was a very wet year with an average flow in the river of approximately 4,200 cfs. In comparison 2012 was a relatively dry year with an average flow of approximately 1,500 cfs. The average annual flow released from Don Pedro Dam is approximately 2,270 cfs for the period 1971 to 2012.

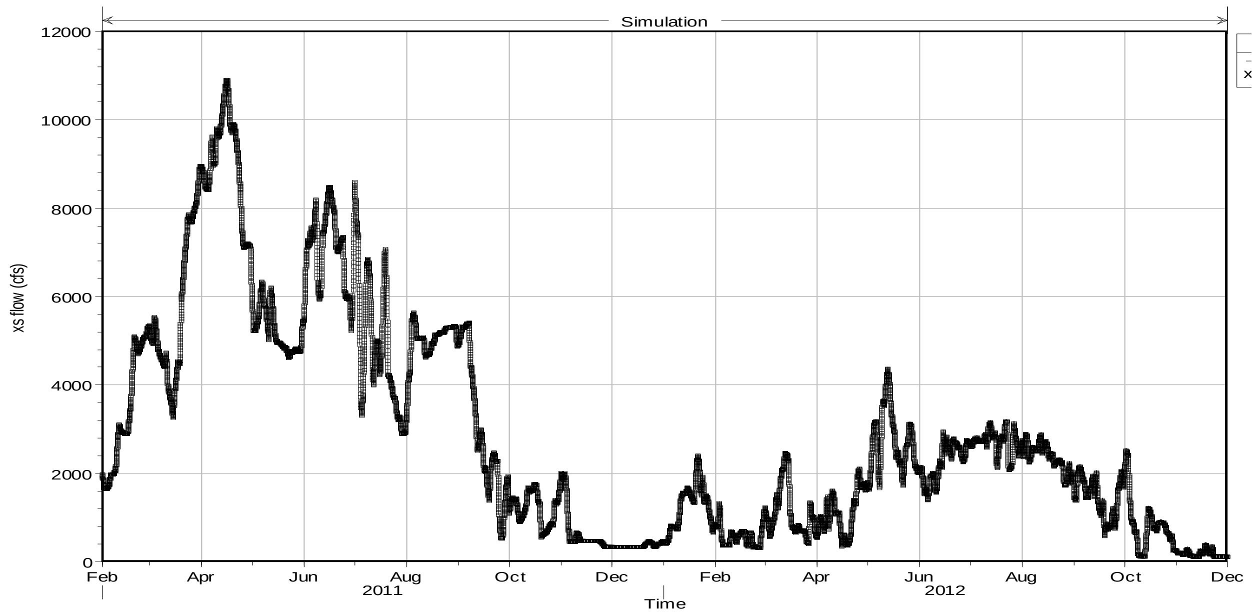


Figure 4.3-2. Don Pedro releases 2011-2012 (Source: Appendix B of TID/MID 2013c).

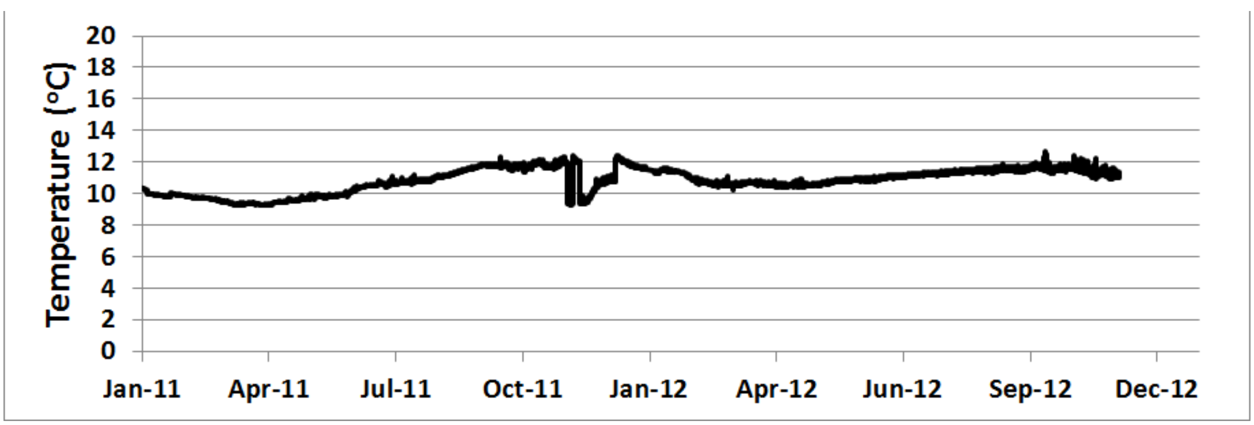


Figure 4.3-3. Don Pedro release temperature 2011-2012. (Source: Attachment C of TID/MID 2013d).

The flow diverted by the Districts at La Grange Dam for 2011-2012 is shown in Figure 4.3-4. The diversion flow in the model represents the combined diversion of both Districts.

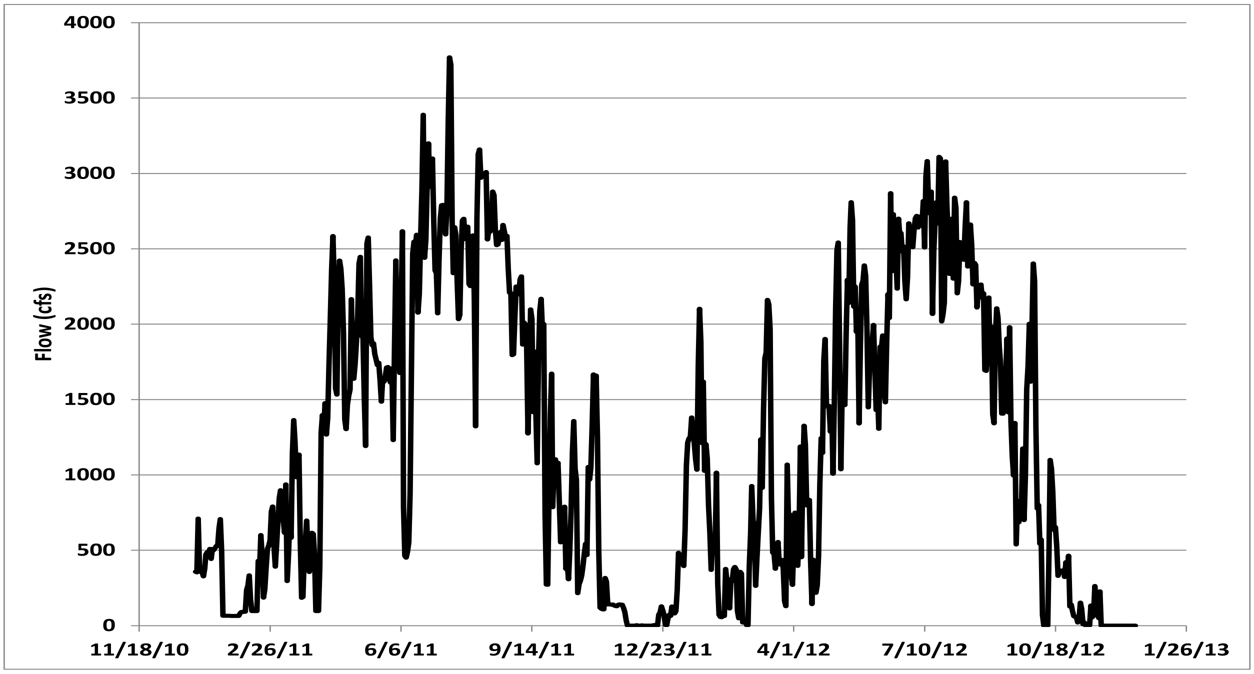


Figure 4.3-4. Total flow diverted at La Grange Diversion Dam 2011-2012 (Source: TID/MID).

Tributary accretions, riparian diversions, and operational spill contributions to the river were generally described in Section 3.1; the locations of operational spills are shown in Figure 3.0-1. Other than the Dry Creek gage flow data, no long-term records of accretions below La Grange diversion dam are available. Hence, a simple gage summation method was used to develop an estimate of inflows between the La Grange gage and the Modesto gage for the calibration and validation periods of 2011 and 2012). The resulting time variable accretion, or depletion, is shown in Figure 4.3-5. In HEC-RAS this flow was distributed uniformly over the reach between RM 51.8 and RM 16.2.

For accretion below the USGS Modesto gage, several discrete measurements taken by the Districts in 2012/2013 were averaged to yield a constant accretion of 32 cfs. These constitute the only available accretion flow measurements for this reach. This flow was distributed uniformly between RM 16 and RM 0.

There are no temperature measurements of the accretion flow. It is often assumed that groundwater temperature is equal to the annual average air temperature and varies little over the year (e.g. National Groundwater Association 1999). This equates to 15°C (TID/MID 2011c) for the Tuolumne River. This value was used in the model. This value is similar to that shown in Figure 4.3-6 (EPA 2013). Sensitivity analyses indicated no noticeable impact for groundwater temperature values ranging from 10 – 20°C.

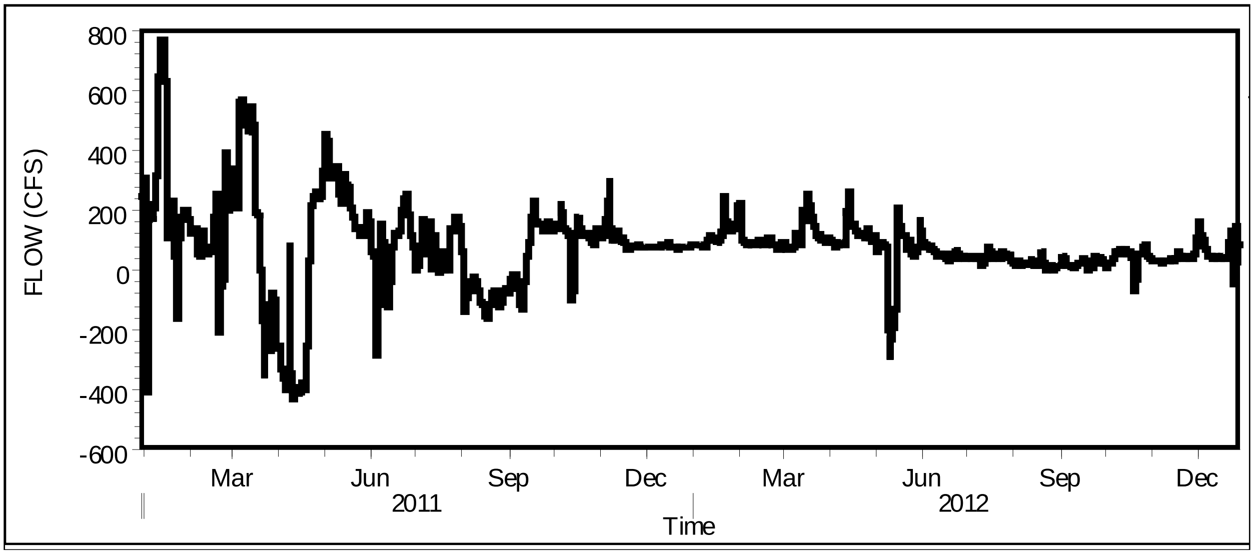


Figure 4.3-5. Computed accretion (positive flow)/depletion (negative flow) RM 51.8-RM 16.2 for calibration/validation years.

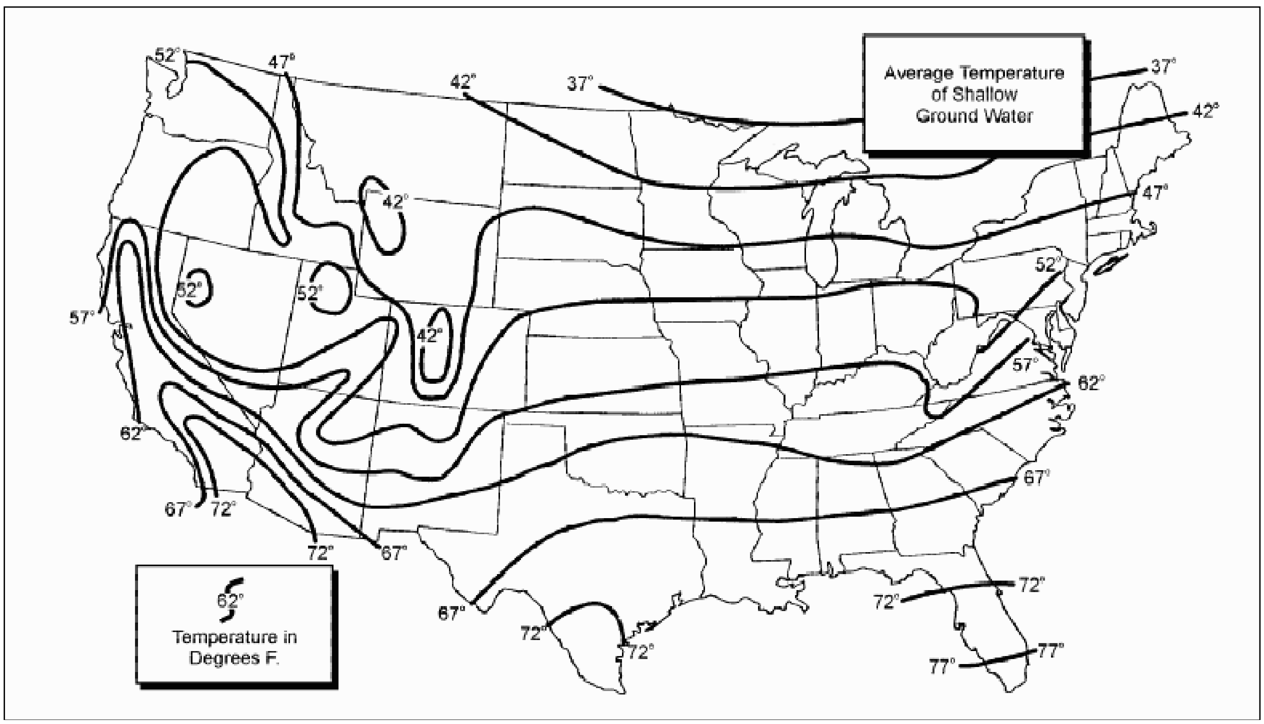


Figure 4.3-6. Shallow groundwater temperatures in the US (EPA 2013).

4.3.4 Temperature Computations

HEC-RAS computes a time variable heat balance in model cells that are defined by the cross-sections. In HEC-RAS the net heat flux is computed as (USACE 2010):

$$q_{net} = q_{sw} + q_{atm} - q_b + q_h - q_L$$

where:

q_{sw} is short wave solar radiation (W/m^2)

q_{atm} is incoming longwave radiation (W/m^2)

q_b is outgoing longwave radiation (W/m^2)

q_h is sensible heat (W/m^2)

q_L is latent heat (W/m^2)

Hourly short wave radiation, q_{sw}, was based on data collected at the Denair II station in Turlock (see Figure 4.3-1). The actual solar radiation impacting the water surface is typically less than the incoming solar radiation that is measured. This is due to effects of shading and reflection. The lower Tuolumne river is partially shaded along much of its length to some degree (see for example Figure 4.3-8). The short wave radiation was therefore adjusted as part of the calibration. The final values used were 80 percent of the measured Denair values. The final time series is shown in Figure 4.3-7.

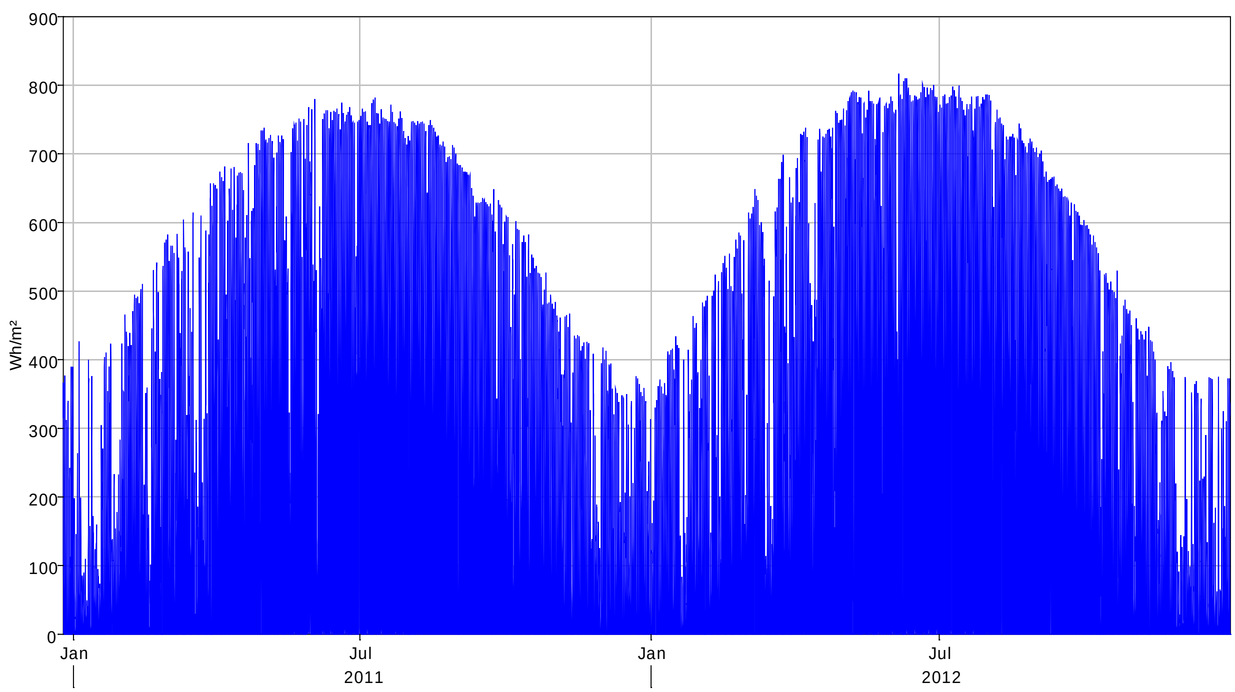


Figure 4.3-7. Denair short wave radiation used in HEC-RAS.

Figure 4.3-8. Lower Tuolumne River; various locations below La Grange diversion dam.

The incoming longwave radiation, q_{atm} , is computed as:

$$q_{atm} = \varepsilon \, \sigma \, T_{air}^{\;4}$$

where:

ε is the emissivity of air

σ is the Stefan Boltzmann constant (W/m^2-K)
T_{air} is the air temperature (^{o}C)

The outgoing longwave radiation, q_b is computed as:

$$q_b = \varepsilon_\omega \, \sigma \, T_{water}^{\;4}$$

where:

ε_ω is the emissivity of water
T_{water} is the water temperature (^{o}C)

The sensible heat flux, q_h , is computed as:

$$q_h = (K_h/K_w)\ C_p\ \rho_w\ (T_{air} - T_{water})\ U$$

Where:
K_h/K_w is the diffusivity ratio
C_p is the specific heat of air (J/kg-C)
ρ_w is the density of water (kg/m^3)
U is wind speed (m/s)

The latent heat flux, q_L , is computed as:

$$q_L = 0.622/P\ L\ \rho_w\ (es - ea)\ U$$

Where:
P is the atmospheric pressure (mb)
L is the latent heat of vaporization (J/kg)
ρ_w is the density of water (kg/m^3)
es is the saturated vapor pressure at the water temperature (mb)
ea is the saturated vapor pressure at the air temperature (mb)
U is wind speed (m/s)

5.0 MODEL CALIBRATION AND OPERATION

5.1 Model Calibration

As described above, 2011 was used for model calibration and 2012 for model validation. This is consistent with the Don Pedro Reservoir temperature model. Calendar year 2011 was chosen as it represented the first full year that contained a complete data set, including measured outflow temperatures from Don Pedro Reservoir; a full set of thermologger data along the river; and measured local meteorology.

The annual average temperatures for 2011 and 2012, measured at the 22 locations mentioned previously, are shown in Figure 5.1-1. River temperatures in 2011 were cooler than those in 2012 owing to the fact that 2011 was a very wet year with high releases extending through July and into August. In both years river temperatures appear to reach equilibrium temperature between RM 20 and RM 30. Although the overall trend in the river is consistent there are points that show marked deviations, particularly in 2012. These include below Hickman Spill (RM 32), Mitchell Rd Bridge (RM 19) and 9th St Bridge (RM 16.2).

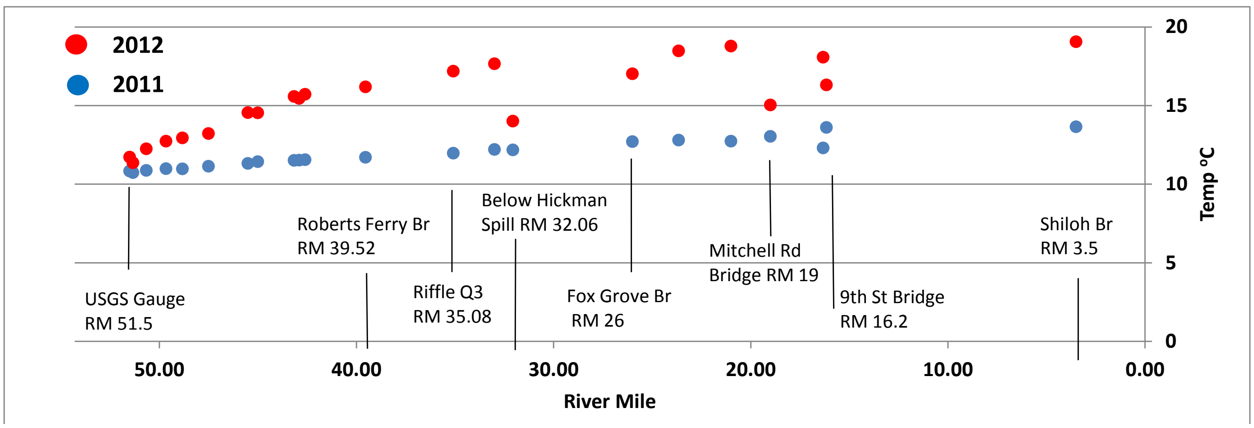


Figure 5.1-1. Annual average temperature in lower Tuolumne River 2011-2012.

Figure 5.1-1 is reproduced in Figure 5.1-2 showing the actual and modeled annual average temperatures at each station. Figure 5.1-2 shows that although the model was calibrated to a very cool water year (2011), it is able to reproduce temperature conditions during a warmer year (2012) with reasonable accuracy. This is discussed in more detail in section 5.3 below. However, it is worth noting that the model does not reproduce the localized cooling effects noted in the figure. In the summer of 2013, the Districts commenced an intensive investigation of river temperatures in the river reaches where the localized cooling had been observed. The results of this study are expected to be available in the first quarter of 2014 and will be shared with relicensing participants.

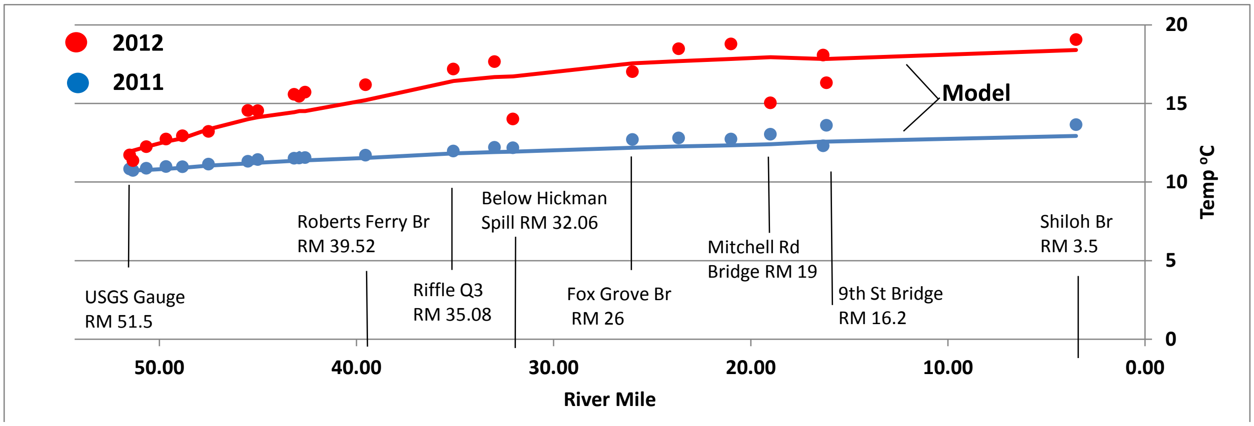


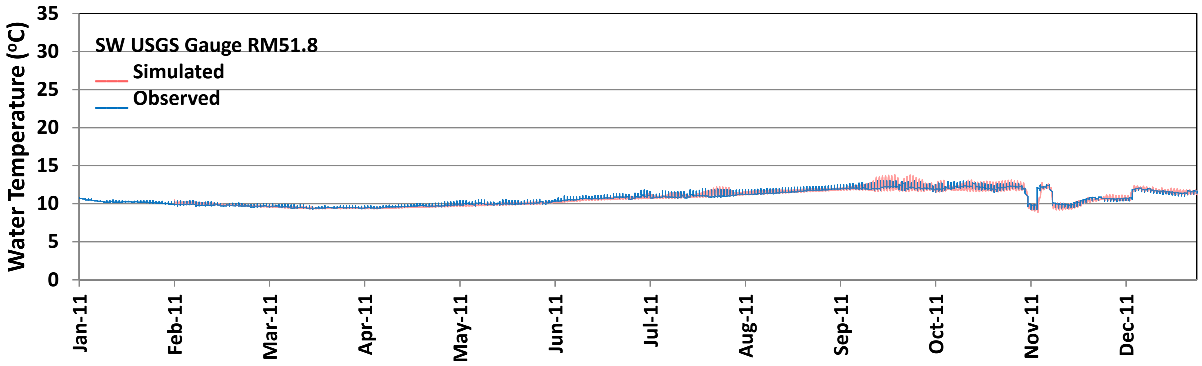
Figure 5.1-2. **Observed and computed annual average temperature in Lower Tuolumne River 2011-12.**

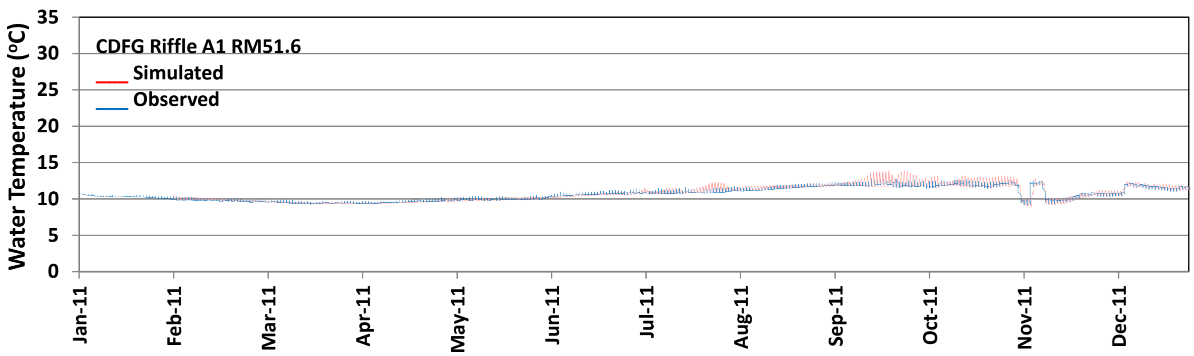
The various plots provided in Figure 5.1-3 show an hourly time series of the observed and computed temperatures at each of the 22 stations for the calibration year of 2011. Statistical comparisons of the calibration and validation results are summarized in Table 5.3-1.

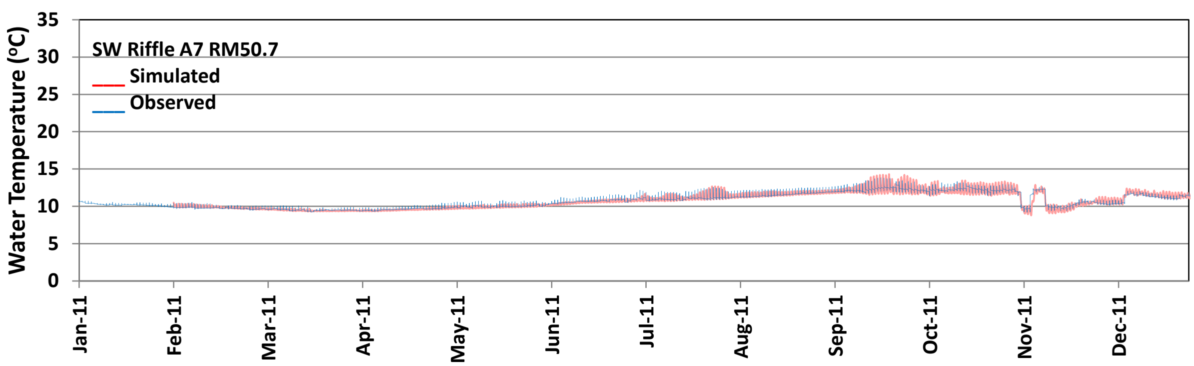
The plots in Figure 5.1-3 indicate that the model reproduces the measured data very well, although it tends to somewhat overestimate the diurnal range in the lower reach. The small annual and diurnal range seen closest to Don Pedro Reservoir reflects a large buffering effect that the reservoir volume and depth of release have on river temperatures at these locations. This is also reflected in the actual monitoring data collected at sites closest to the dam. Gradually the diurnal and annual ranges expand as the water moves further downstream due to increased time of exposure to local atmospheric conditions.

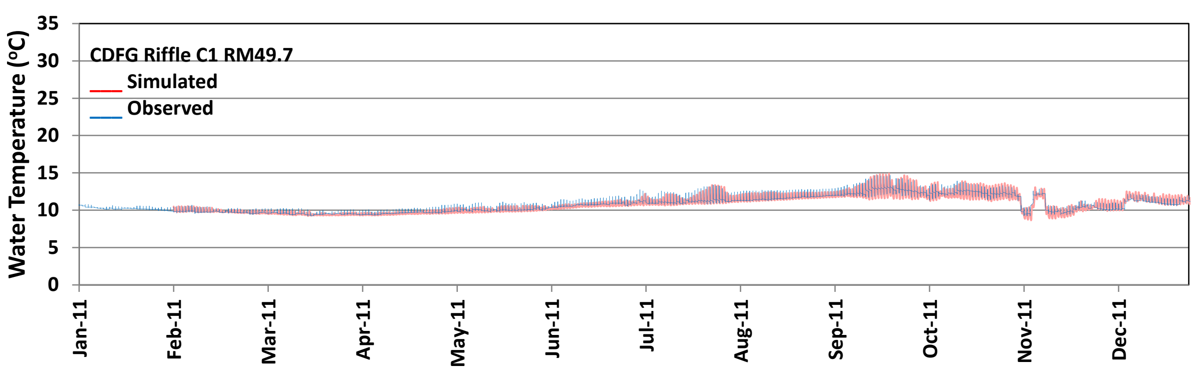
The model tracks the data reasonably well until about RM 39.5, Roberts Ferry Bridge, when the diurnal range in the data decreases noticeably. At the next station, Riffle Q3 at RM 35.0, the range expands again and the model fit is good. At RM 33.0, Above Hickman Spill, the diurnal range again compresses dramatically, only to expand at the next site less than a mile further downstream (Below Hickman Spill RM 32.0). At RM 26.0 through RM 16.2 the range substantially decreases and remains limited until the last station at Shiloh Bridge at RM 3.5. The model remains consistent in its response throughout the entire length of the river by predicting a relatively large diurnal range and does not fully reproduce these decreased diurnal fluctuations. The model is acting as expected, as there exists no additional model input that would result in significant variations in diurnal temperatures ranges over very short reaches of the river. This suggests that local factors are affecting water temperature other than variables included in the model.

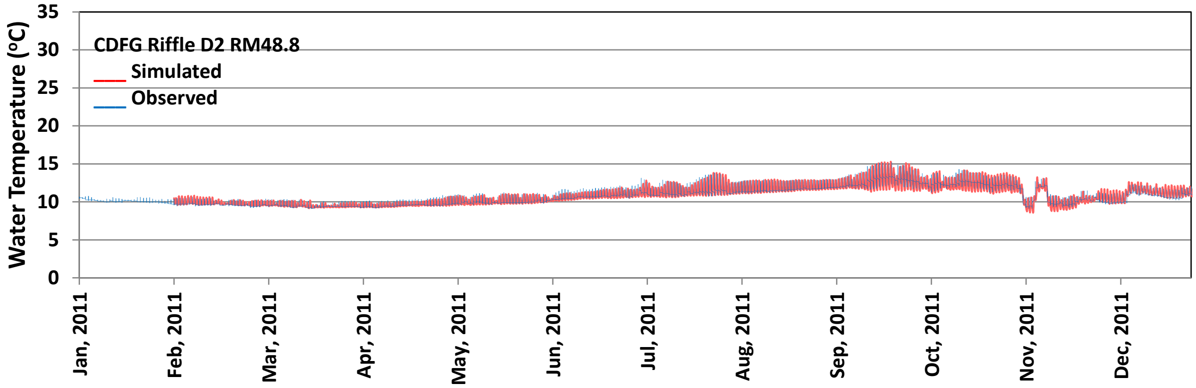
This phenomenon is explored in more detail in Section 5.4, which discusses the magnitude of the changes in diurnal range along the river, both annually and over the summer, as well as the historical record of this phenomena in the river over the last ten years.

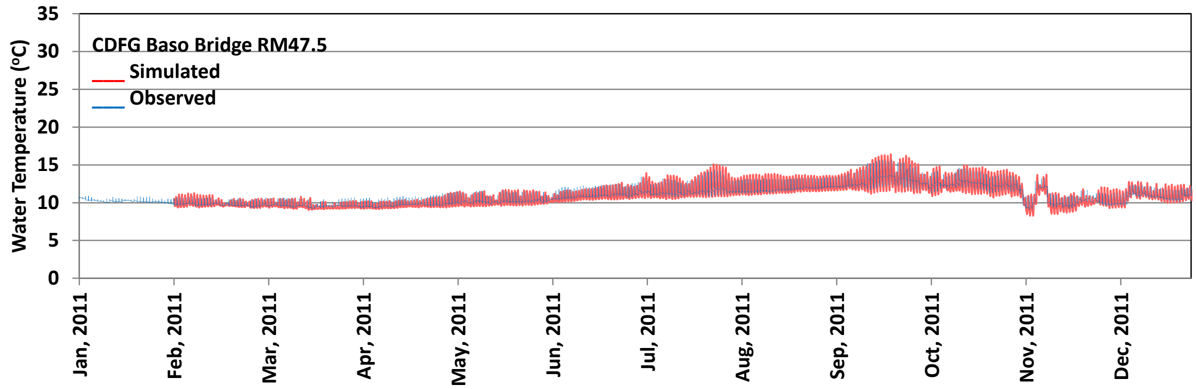

SW USGS Gauge RM51.8
Simulated
Observed
Water Temperature (ºC)
0
5
10
15
20
25
30
35
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Nov-11
Dec-11

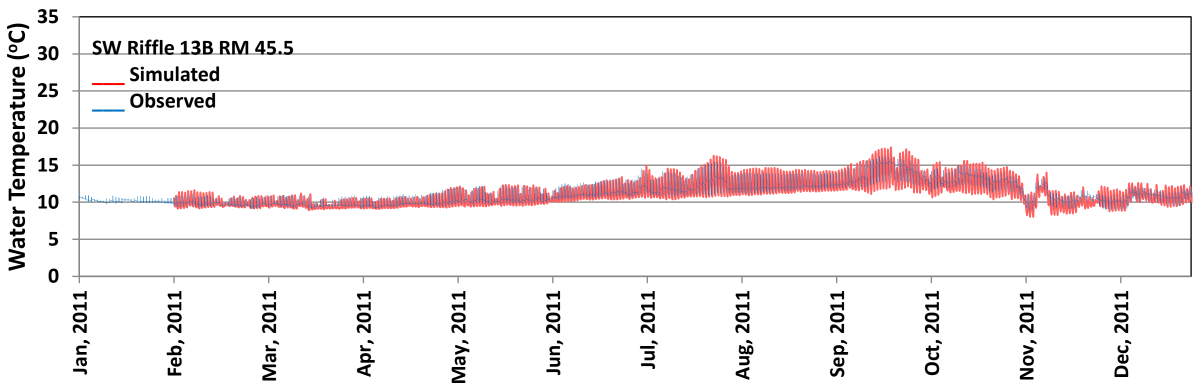

CDFG Riffle A1 RM51.6
Simulated
Observed
Water Temperature (ºC)
0
5
10
15
20
25
30
35
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Nov-11
Dec-11

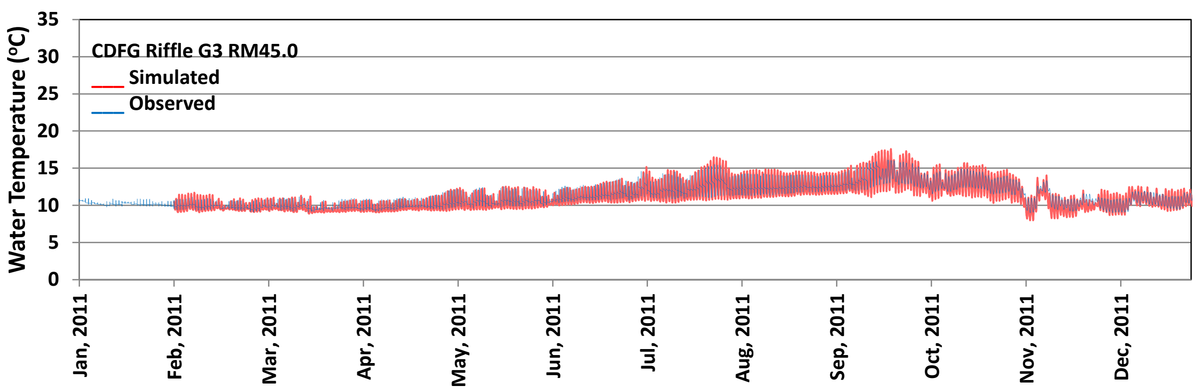

SW Riffle A7 RM50.7
Simulated
Observed
Water Temperature (ºC)
0
5
10
15
20
25
30
35
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Nov-11
Dec-11

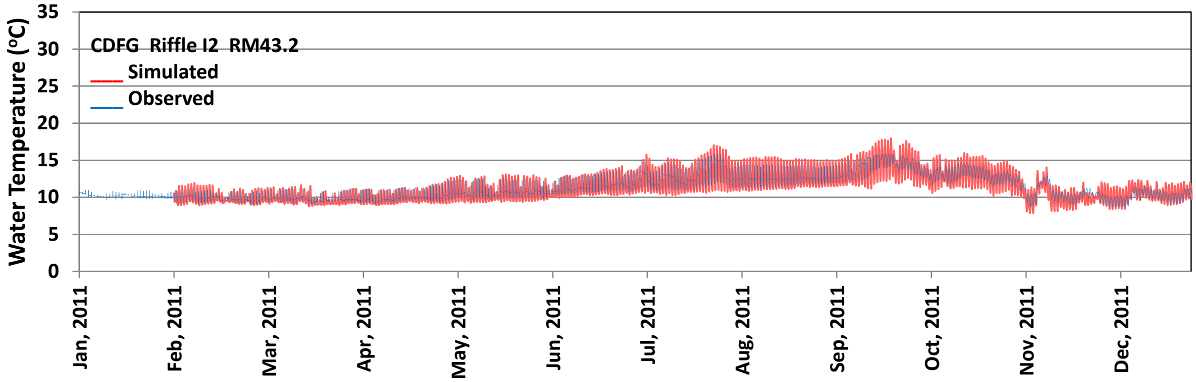

CDFG Riffle C1 RM49.7
Simulated
Observed
Water Temperature (ºC)
0
5
10
15
20
25
30
35
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Nov-11
Dec-11

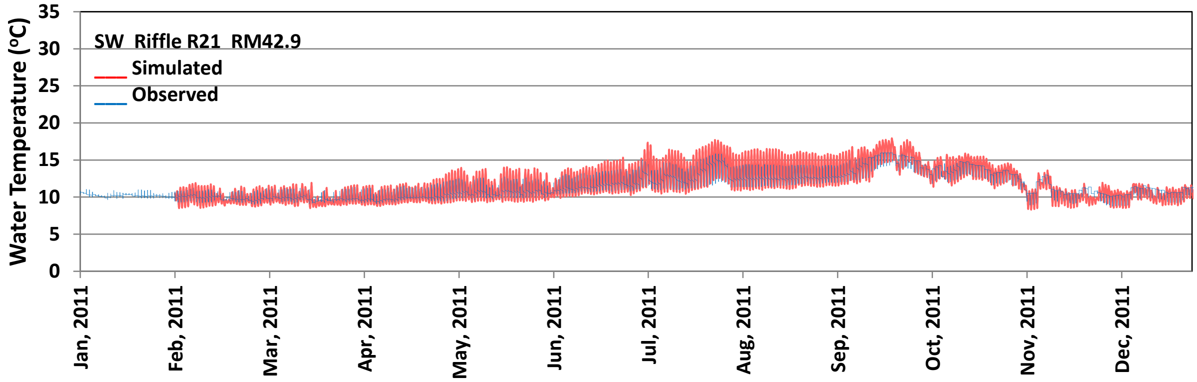

CDFG Riffle D2 RM48.8
Simulated
Observed
Water Temperature (ºC)
35
30
25
20
15
10
5
0
Jan, 2011
Feb, 2011
Mar, 2011
Apr, 2011
May, 2011
Jun, 2011
Jul, 2011
Aug, 2011
Sep, 2011
Oct, 2011
Nov, 2011
Dec, 2011

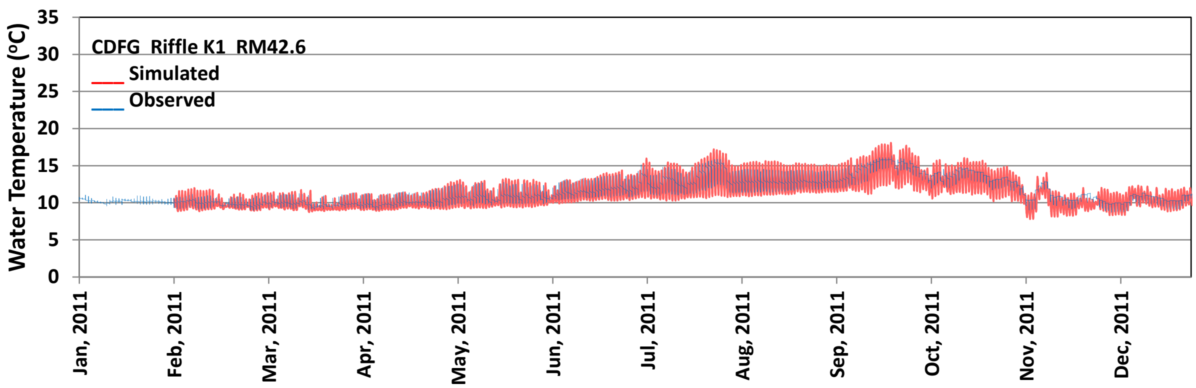

CDFG Baso Bridge RM47.5
Simulated
Observed
Water Temperature (ºC)
35
30
25
20
15
10
5
0
Jan, 2011
Feb, 2011
Mar, 2011
Apr, 2011
May, 2011
Jun, 2011
Jul, 2011
Aug, 2011
Sep, 2011
Oct, 2011
Nov, 2011
Dec, 2011

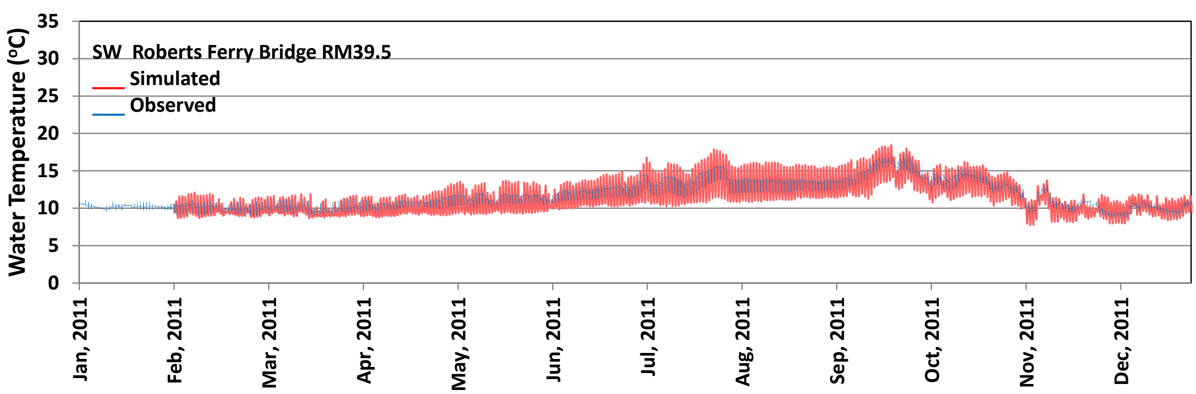

SW Riffle 13B RM 45.5
Simulated
Observed
Water Temperature (ºC)
35
30
25
20
15
10
5
0
Jan, 2011
Feb, 2011
Mar, 2011
Apr, 2011
May, 2011
Jun, 2011
Jul, 2011
Aug, 2011
Sep, 2011
Oct, 2011
Nov, 2011
Dec, 2011

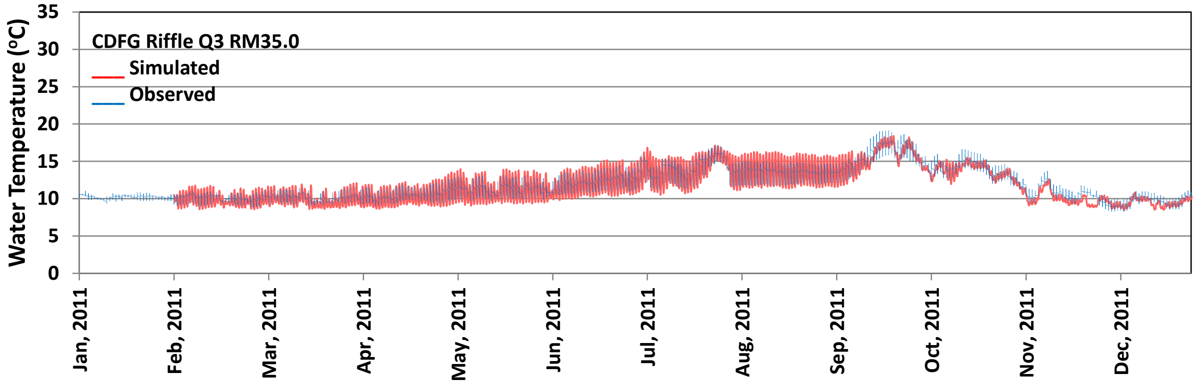

CDFG Riffle G3 RM45.0
Simulated
Observed
Water Temperature (ºC)
35
30
25
20
15
10
5
0
Jan, 2011
Feb, 2011
Mar, 2011
Apr, 2011
May, 2011
Jun, 2011
Jul, 2011
Aug, 2011
Sep, 2011
Oct, 2011
Nov, 2011
Dec, 2011

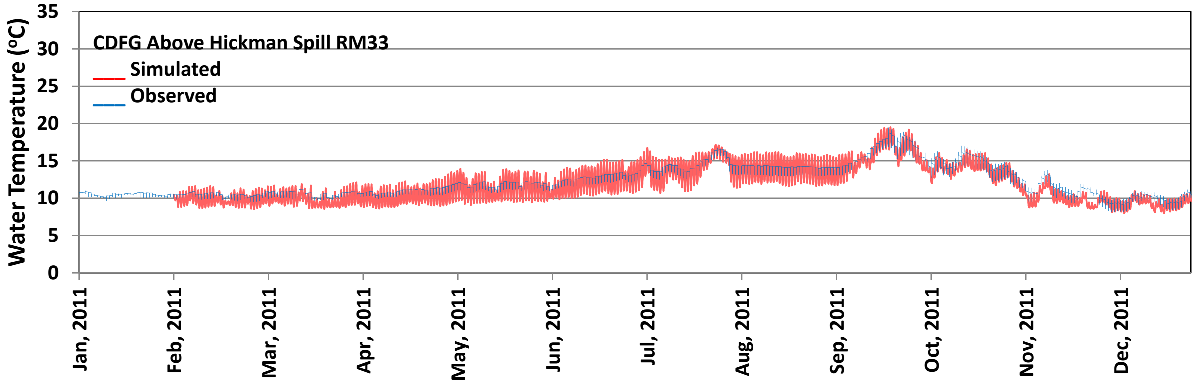

CDFG Riffle I2 RM43.2
Simulated
Observed
Water Temperature (ºC)
35
30
25
20
15
10
5
0
Jan, 2011
Feb, 2011
Mar, 2011
Apr, 2011
May, 2011
Jun, 2011
Jul, 2011
Aug, 2011
Sep, 2011
Oct, 2011
Nov, 2011
Dec, 2011

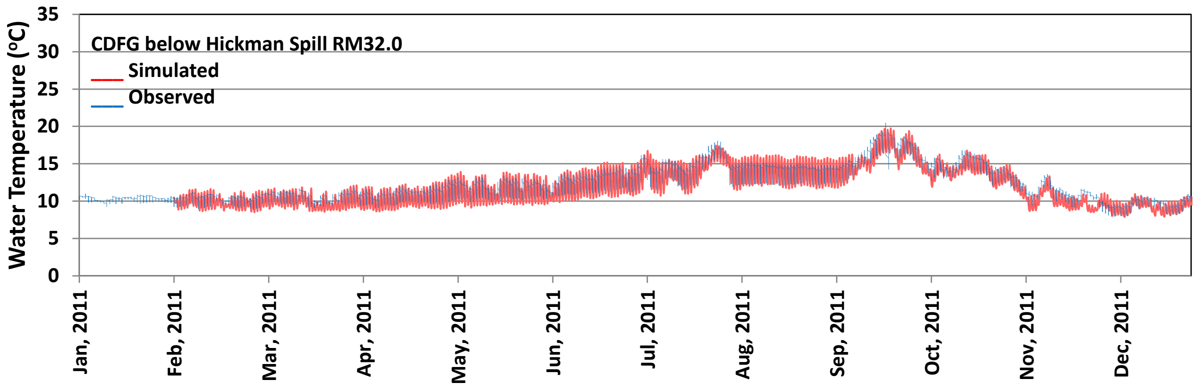

SW Riffle R21 RM42.9
Simulated
Observed
Water Temperature (ºC)
35
30
25
20
15
10
5
0
Jan, 2011
Feb, 2011
Mar, 2011
Apr, 2011
May, 2011
Jun, 2011
Jul, 2011
Aug, 2011
Sep, 2011
Oct, 2011
Nov, 2011
Dec, 2011

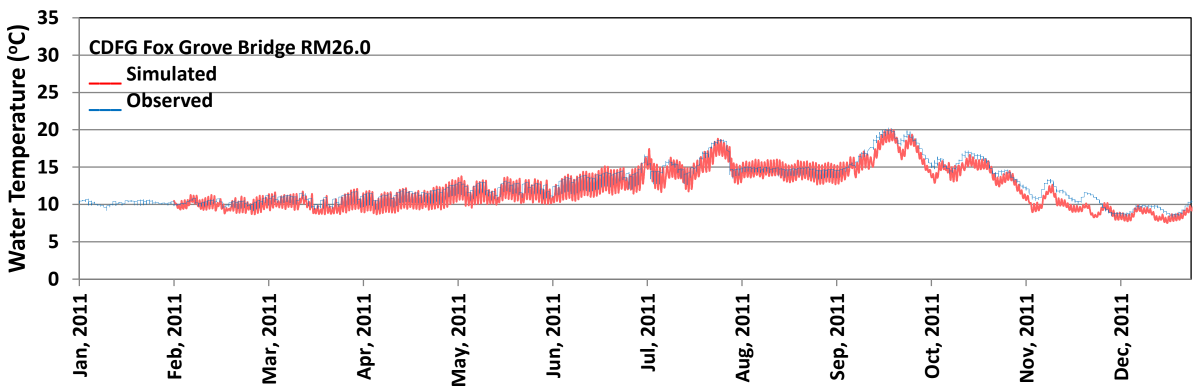

CDFG Riffle K1 RM42.6
Simulated
Observed
Water Temperature (ºC)
35
30
25
20
15
10
5
0
Jan, 2011
Feb, 2011
Mar, 2011
Apr, 2011
May, 2011
Jun, 2011
Jul, 2011
Aug, 2011
Sep, 2011
Oct, 2011
Nov, 2011
Dec, 2011

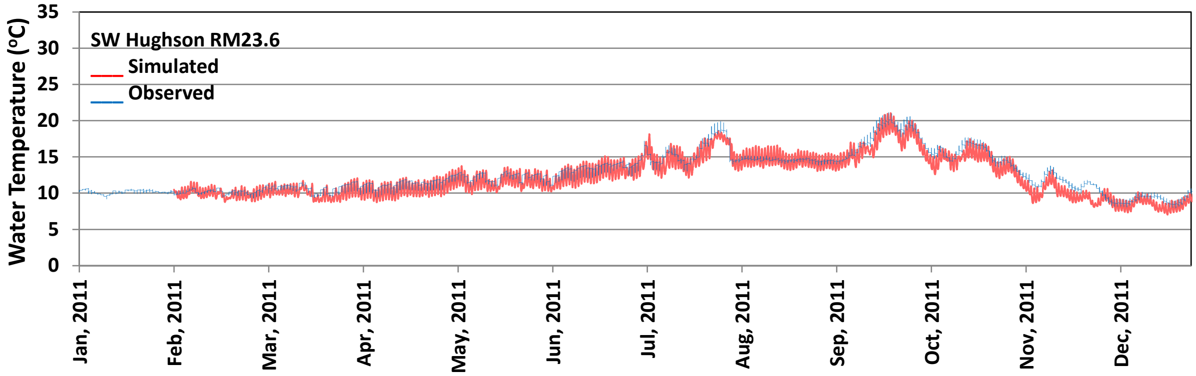

SW Roberts Ferry Bridge RM39.5
Simulated
Observed
Water Temperature (ºC)
35
30
25
20
15
10
5
0
Jan, 2011
Feb, 2011
Mar, 2011
Apr, 2011
May, 2011
Jun, 2011
Jul, 2011
Aug, 2011
Sep, 2011
Oct, 2011
Nov, 2011
Dec, 2011

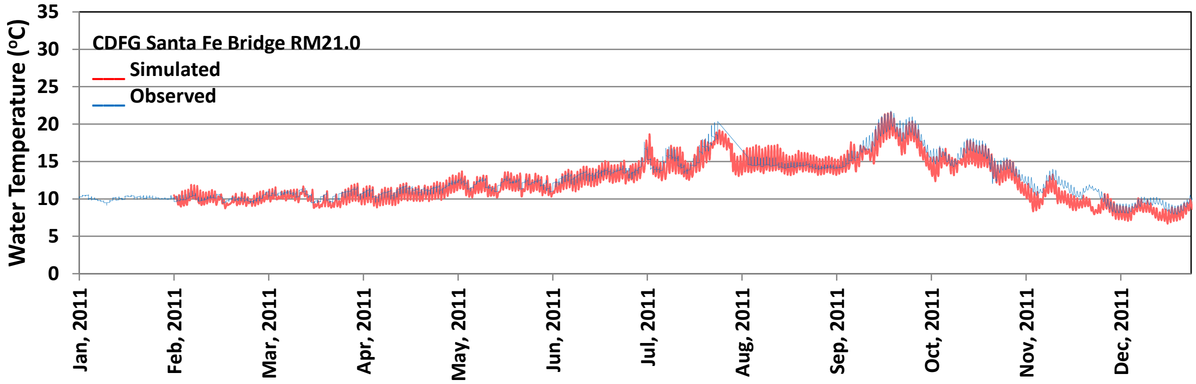

CDFG Riffle Q3 RM35.0
Simulated
Observed
Water Temperature (ºC)
35
30
25
20
15
10
5
0
Jan, 2011
Feb, 2011
Mar, 2011
Apr, 2011
May, 2011
Jun, 2011
Jul, 2011
Aug, 2011
Sep, 2011
Oct, 2011
Nov, 2011
Dec, 2011

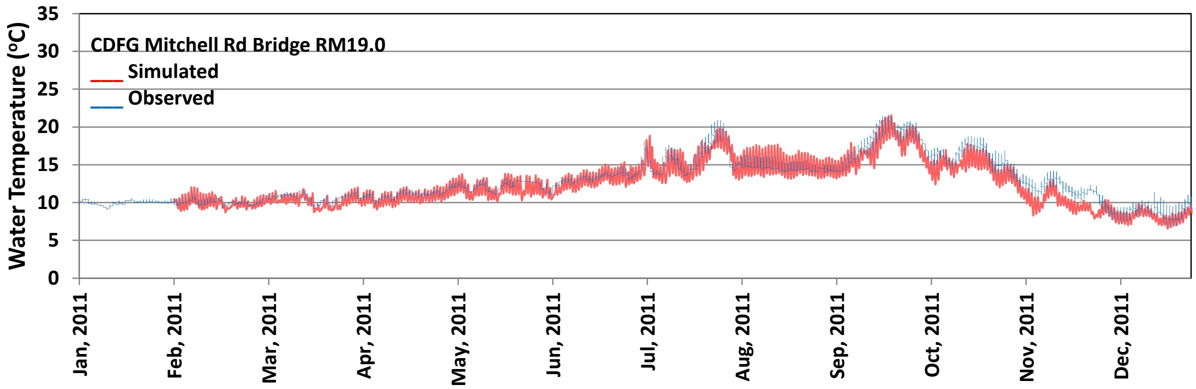

CDFG Above Hickman Spill RM33
Simulated
Observed
Water Temperature (ºC)
35
30
25
20
15
10
5
0
Jan, 2011
Feb, 2011
Mar, 2011
Apr, 2011
May, 2011
Jun, 2011
Jul, 2011
Aug, 2011
Sep, 2011
Oct, 2011
Nov, 2011
Dec, 2011

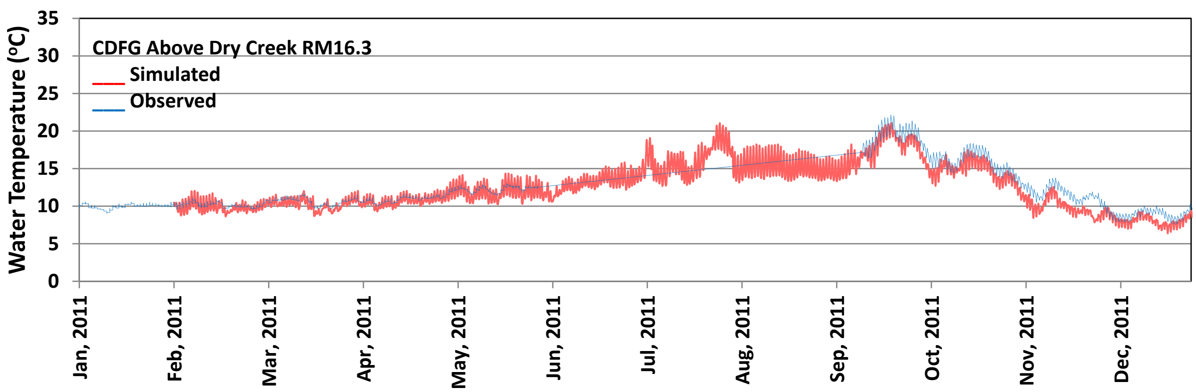

CDFG below Hickman Spill RM32.0
Simulated
Observed
Water Temperature (ºC)
35
30
25
20
15
10
5
0
Jan, 2011
Feb, 2011
Mar, 2011
Apr, 2011
May, 2011
Jun, 2011
Jul, 2011
Aug, 2011
Sep, 2011
Oct, 2011
Nov, 2011
Dec, 2011


CDFG Fox Grove Bridge RM26.0
Simulated
Observed
Water Temperature (ºC)
35
30
25
20
15
10
5
0
Jan, 2011
Feb, 2011
Mar, 2011
Apr, 2011
May, 2011
Jun, 2011
Jul, 2011
Aug, 2011
Sep, 2011
Oct, 2011
Nov, 2011
Dec, 2011


SW Hughson RM23.6
Simulated
Observed
Water Temperature (ºC)
0
5
10
15
20
25
30
35
Jan, 2011
Feb, 2011
Mar, 2011
Apr, 2011
May, 2011
Jun, 2011
Jul, 2011
Aug, 2011
Sep, 2011
Oct, 2011
Nov, 2011
Dec, 2011


CDFG Santa Fe Bridge RM21.0
Simulated
Observed
Water Temperature (ºC)
0
5
10
15
20
25
30
35
Jan, 2011
Feb, 2011
Mar, 2011
Apr, 2011
May, 2011
Jun, 2011
Jul, 2011
Aug, 2011
Sep, 2011
Oct, 2011
Nov, 2011
Dec, 2011


CDFG Mitchell Rd Bridge RM19.0
Simulated
Observed
Water Temperature (ºC)
0
5
10
15
20
25
30
35
Jan, 2011
Feb, 2011
Mar, 2011
Apr, 2011
May, 2011
Jun, 2011
Jul, 2011
Aug, 2011
Sep, 2011
Oct, 2011
Nov, 2011
Dec, 2011


CDFG Above Dry Creek RM16.3
Simulated
Observed
Water Temperature (ºC)
0
5
10
15
20
25
30
35
Jan, 2011
Feb, 2011
Mar, 2011
Apr, 2011
May, 2011
Jun, 2011
Jul, 2011
Aug, 2011
Sep, 2011
Oct, 2011
Nov, 2011
Dec, 2011

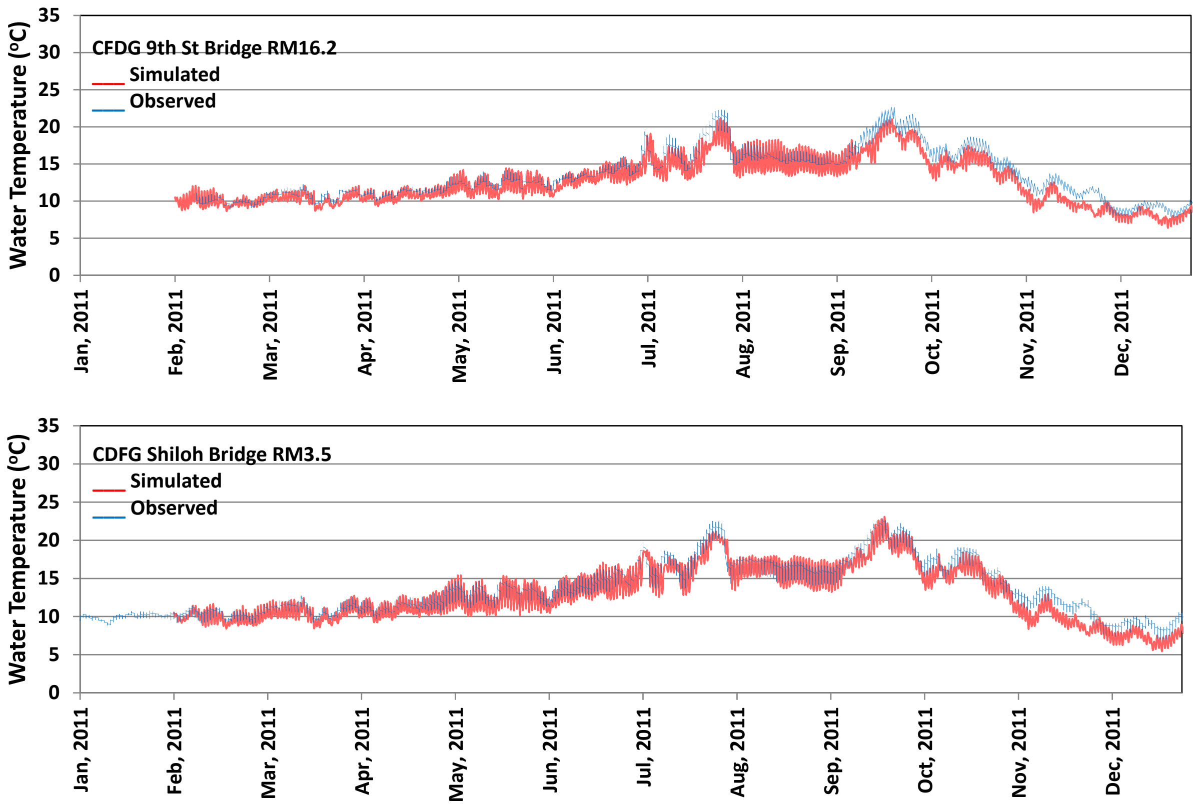


Figure 5.1-3. Calibration results for 2011.

5.2 Model Validation

The model was validated using 2012 data and applying the model parameters developed through the 2011 calibration. As noted previously, river conditions in 2012 were very different than conditions in 2011. In 2011, the total outflows from Don Pedro were almost three times greater than than the total outflows in 2012 (3.01 million AF versus 1.04 million AF; see Figure 5.2-1 for a comparison of June-Oct flows).

In 2012, the river temperature response was also markedly different than 2011. River temperatures are consistently higher in 2012 from February through December compared to 2011. During the warmest months the difference in year over year temperatures reaches 10^{o}C in the lower portions of the river. The results of the model validation are shown in the plots of Figure 5.2-2, using the same station sequence and temperature scales as the calibration figures.

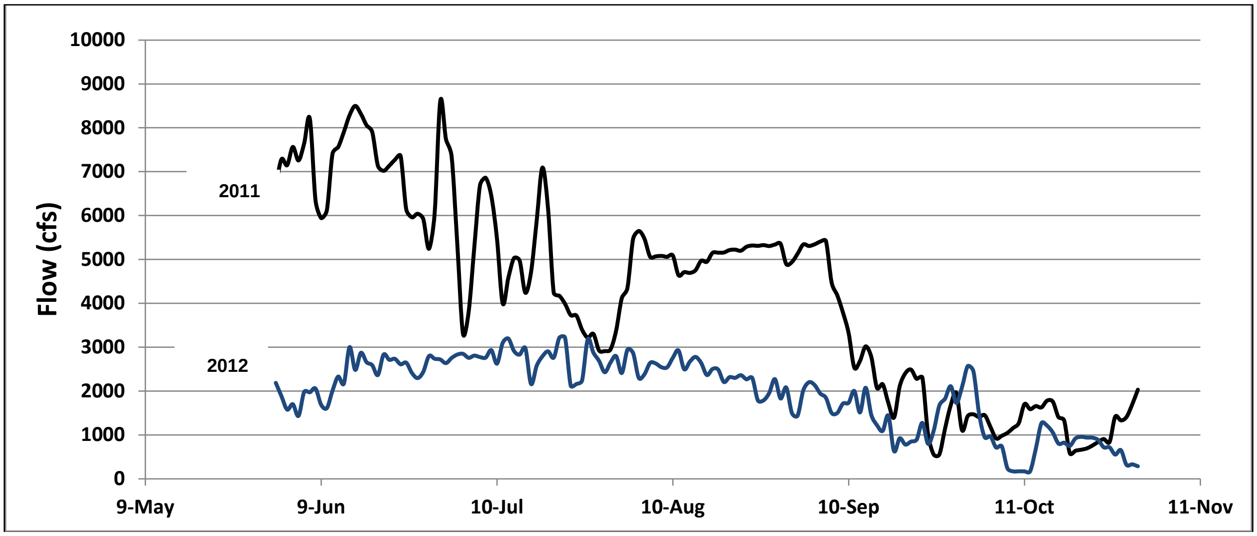
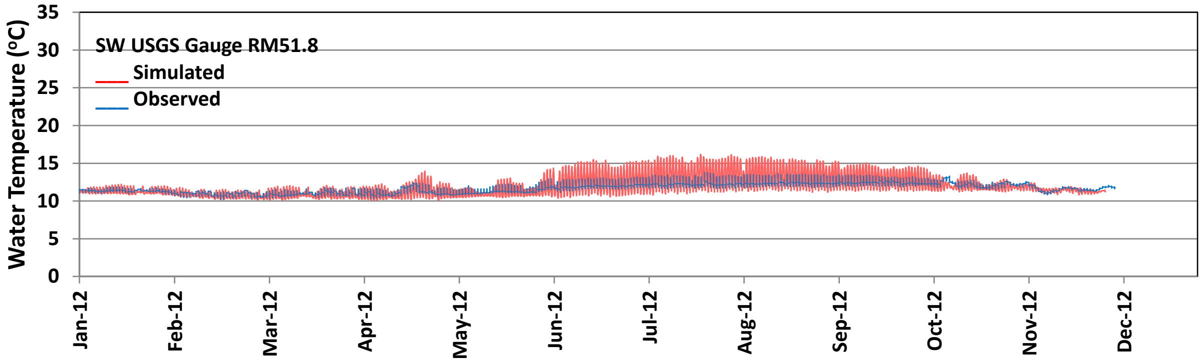


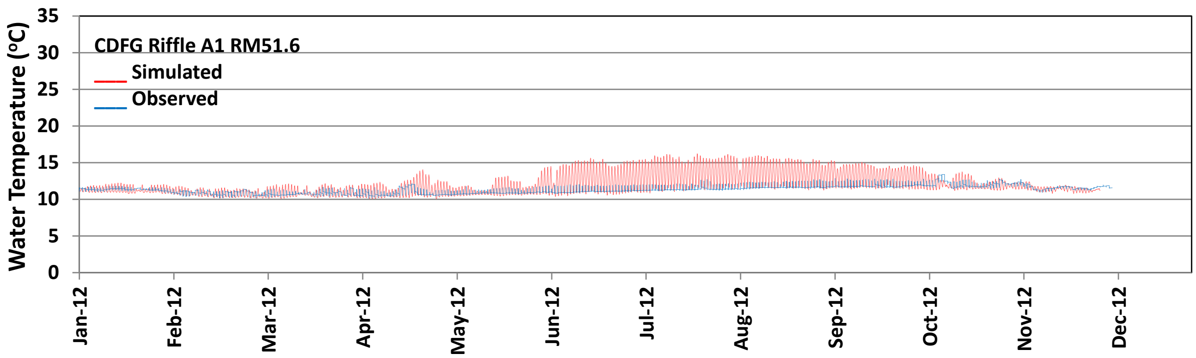
Figure 5.2-1. Comparison of Don Pedro releases, June-Oct for 2011 and 2012.

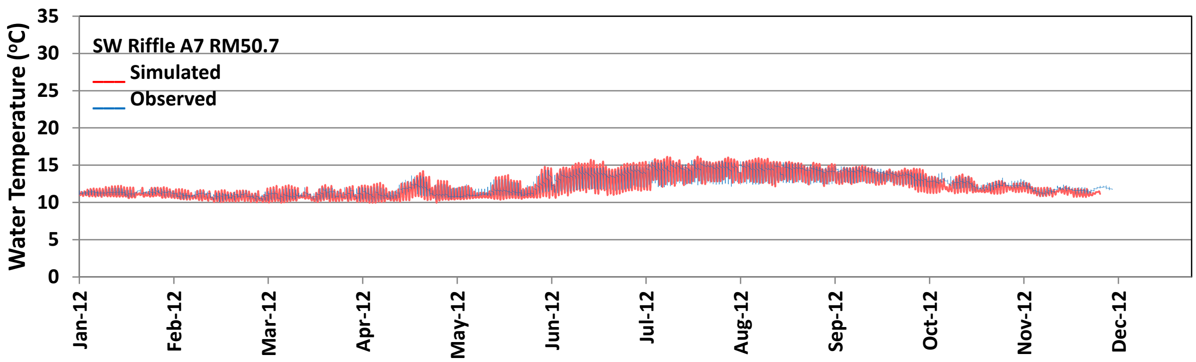
Despite the substantial differences in flow and temperature conditions between the two years the model is able to reproduce the observed temperatures to a high degree. It is interesting to note that model diurnal ranges match the observed data fairly consistently to RM 47.5, but then the observed diurnal ranges significantly contract at RM 45.5. The reason for this is not fully understood but some hypotheses are discussed in Section 5.4. By RM 39.5 the model and measured diurnal ranges are again similar. At RM 16.3 and below the model predicts slightly greater diurnal range than the observed data.

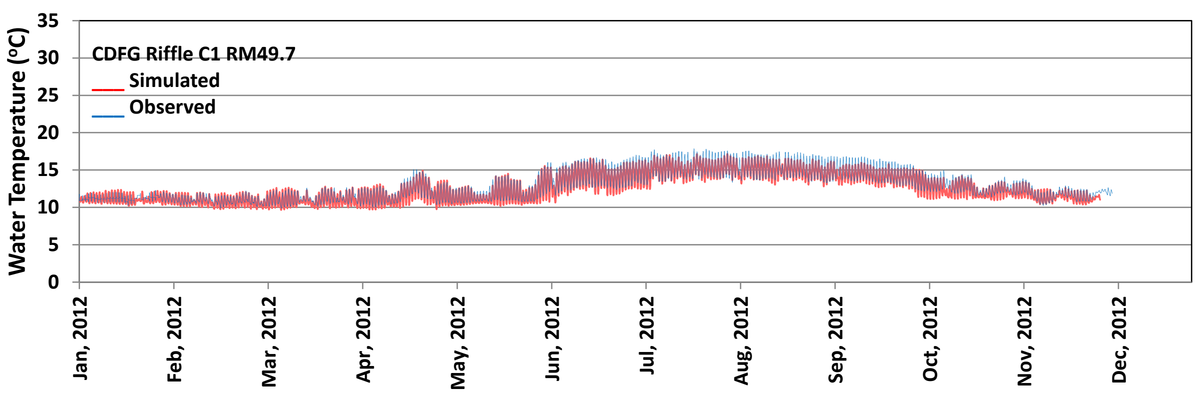
The model tends to over-predict maximum temperature in the summer at the first two sites directly below La Grange Dam (RM 51.8 and 51.6). Sensitivity analysis showed that this is an artifact produced by the model simulating spill over La Grange Dam, as opposed to the actual routes traveled (See Section 4.3.1). There is no simple fix to this issue, however by the next site at RM 50.7, the model and data match well.

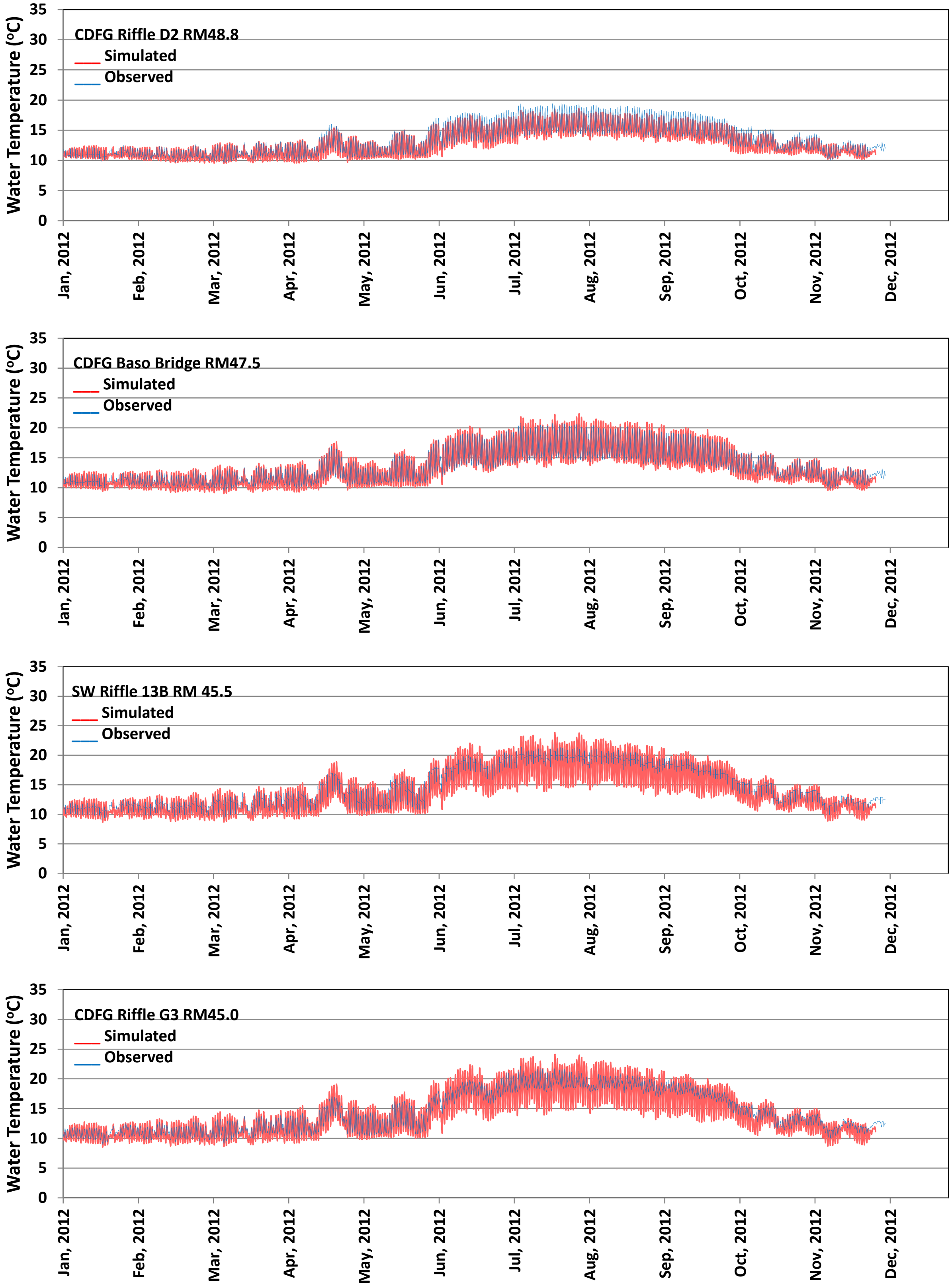
Below about RM 26 the model begins to predict slightly lower minimum daily temperatures in the winter months. This was also observed in 2011. This may be due to the occurrence of slightly greater groundwater flows than assumed in the model; groundwater inflow would be warmer than surface water during winter.

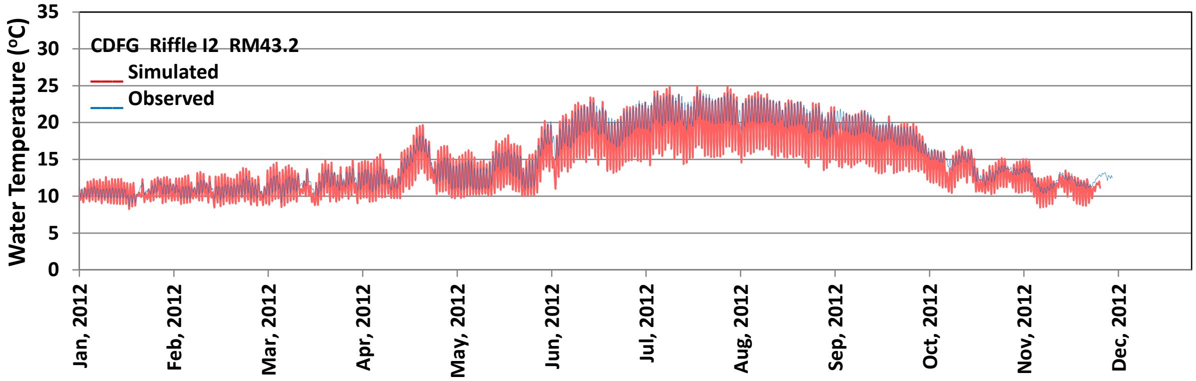

SW USGS Gauge RM51.8
Simulated
Observed
Water Temperature (ºC)
35
30
25
20
15
10
5
0
Jan-12
Feb-12
Mar-12
Apr-12
May-12
Jun-12
Jul-12
Aug-12
Sep-12
Oct-12
Nov-12
Dec-12

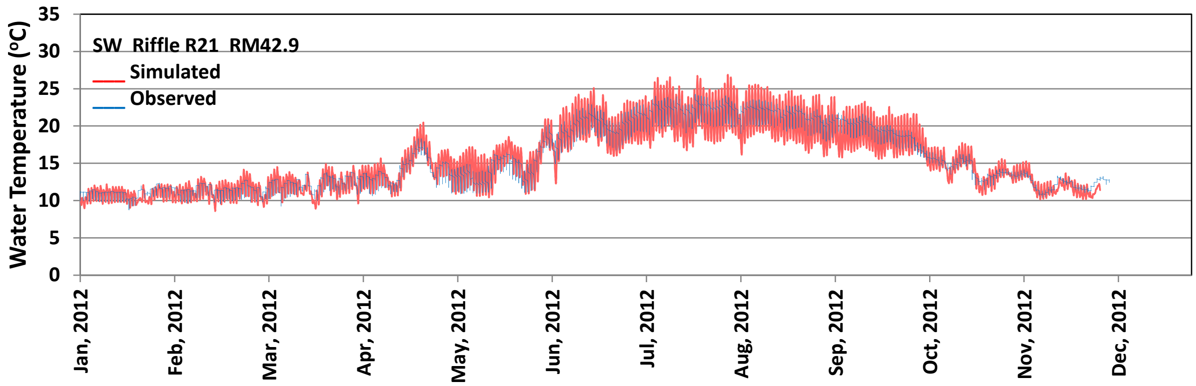

CDFG Riffle A1 RM51.6
Simulated
Observed
Water Temperature (ºC)
35
30
25
20
15
10
5
0
Jan-12
Feb-12
Mar-12
Apr-12
May-12
Jun-12
Jul-12
Aug-12
Sep-12
Oct-12
Nov-12
Dec-12

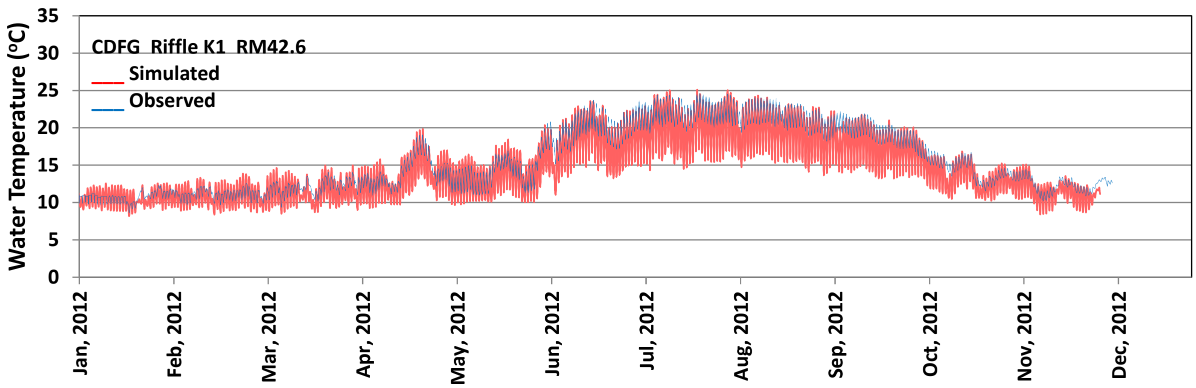

SW Riffle A7 RM50.7
Simulated
Observed
Water Temperature (ºC)
35
30
25
20
15
10
5
0
Jan-12
Feb-12
Mar-12
Apr-12
May-12
Jun-12
Jul-12
Aug-12
Sep-12
Oct-12
Nov-12
Dec-12

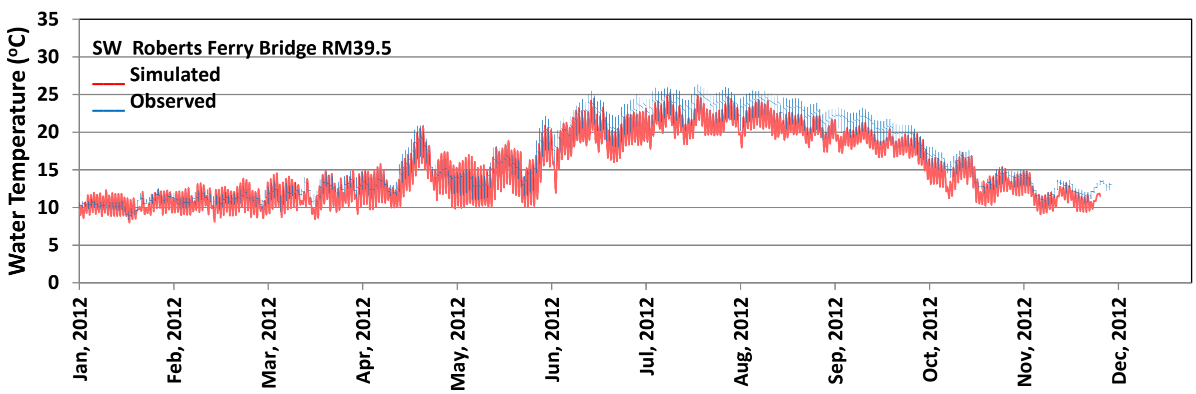

CDFG Riffle C1 RM49.7
Simulated
Observed
Water Temperature (ºC)
35
30
25
20
15
10
5
0
Jan, 2012
Feb, 2012
Mar, 2012
Apr, 2012
May, 2012
Jun, 2012
Jul, 2012
Aug, 2012
Sep, 2012
Oct, 2012
Nov, 2012
Dec, 2012

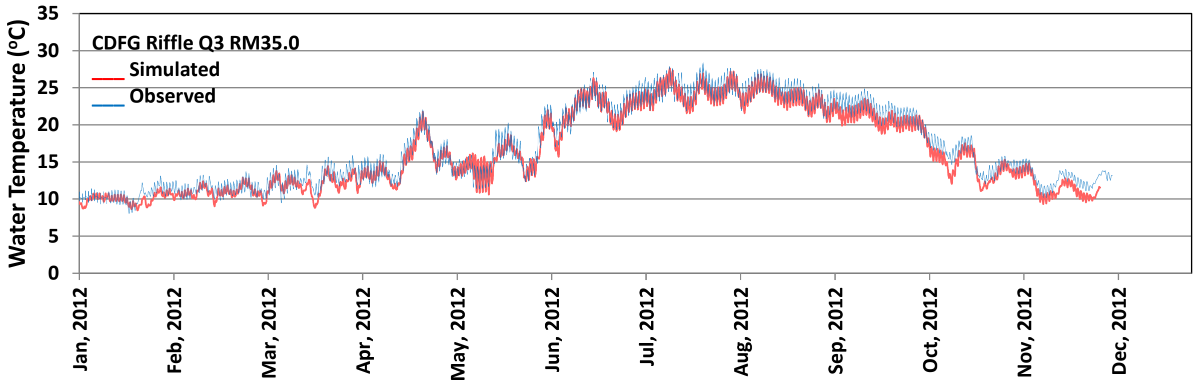

CDFG Riffle D2 RM48.8
Simulated
Observed
Water Temperature (°C)
0
5
10
15
20
25
30
35
Jan, 2012
Feb, 2012
Mar, 2012
Apr, 2012
May, 2012
Jun, 2012
Jul, 2012
Aug, 2012
Sep, 2012
Oct, 2012
Nov, 2012
Dec, 2012
CDFG Baso Bridge RM47.5
Simulated
Observed
SW Riffle 13B RM 45.5
Simulated
Observed
CDFG Riffle G3 RM45.0
Simulated
Observed

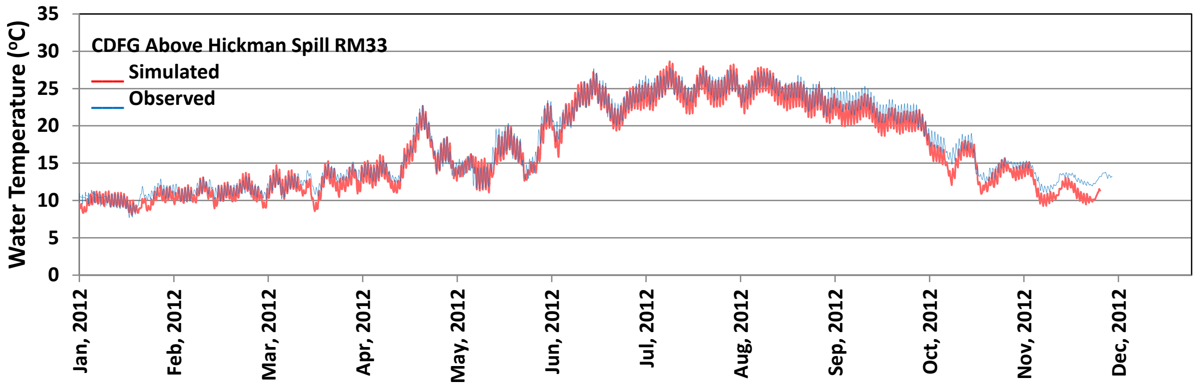

CDFG Riffle I2 RM43.2
Simulated
Observed
Water Temperature (°C)
35
30
25
20
15
10
5
0
Jan, 2012
Feb, 2012
Mar, 2012
Apr, 2012
May, 2012
Jun, 2012
Jul, 2012
Aug, 2012
Sep, 2012
Oct, 2012
Nov, 2012
Dec, 2012

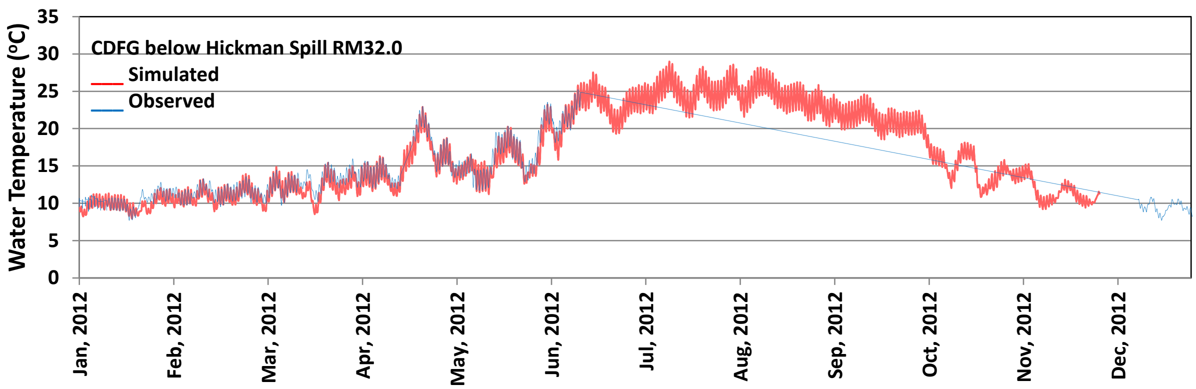

SW Riffle R21 RM42.9
Simulated
Observed
Water Temperature (°C)
35
30
25
20
15
10
5
0
Jan, 2012
Feb, 2012
Mar, 2012
Apr, 2012
May, 2012
Jun, 2012
Jul, 2012
Aug, 2012
Sep, 2012
Oct, 2012
Nov, 2012
Dec, 2012

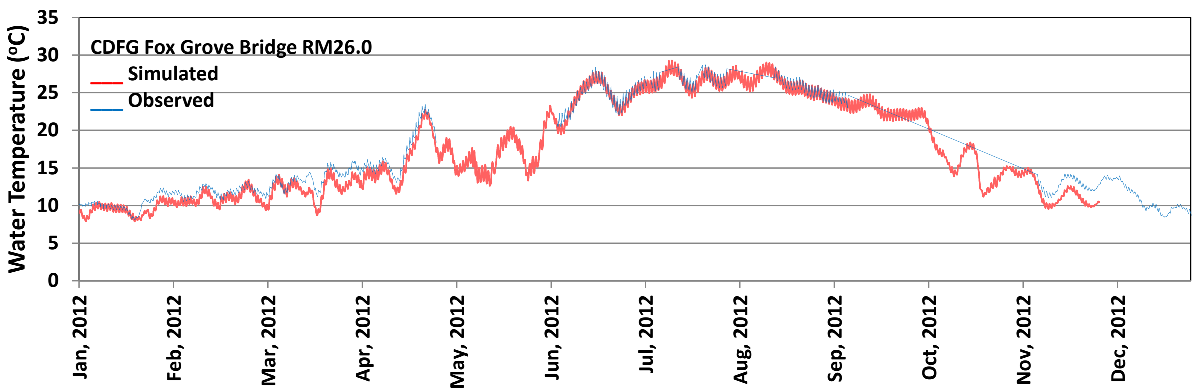

CDFG Riffle K1 RM42.6
Simulated
Observed
Water Temperature (°C)
35
30
25
20
15
10
5
0
Jan, 2012
Feb, 2012
Mar, 2012
Apr, 2012
May, 2012
Jun, 2012
Jul, 2012
Aug, 2012
Sep, 2012
Oct, 2012
Nov, 2012
Dec, 2012

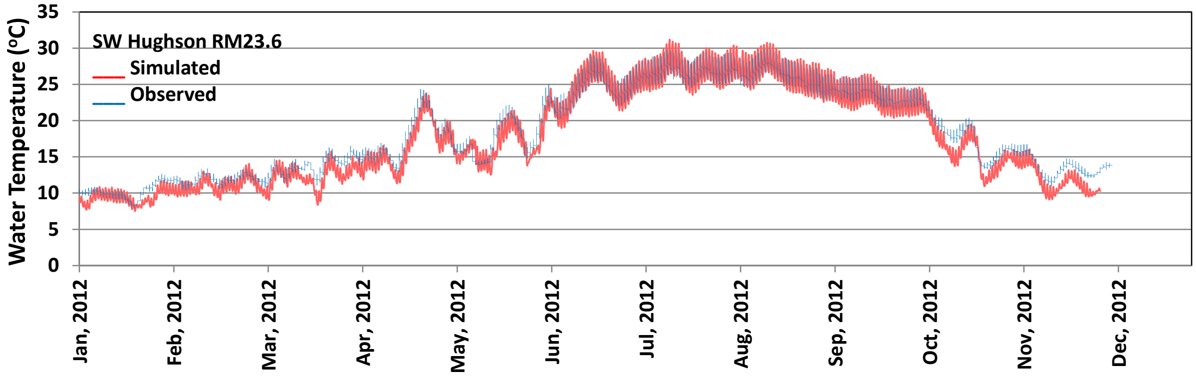

SW Roberts Ferry Bridge RM39.5
Simulated
Observed
Water Temperature (°C)
35
30
25
20
15
10
5
0
Jan, 2012
Feb, 2012
Mar, 2012
Apr, 2012
May, 2012
Jun, 2012
Jul, 2012
Aug, 2012
Sep, 2012
Oct, 2012
Nov, 2012
Dec, 2012

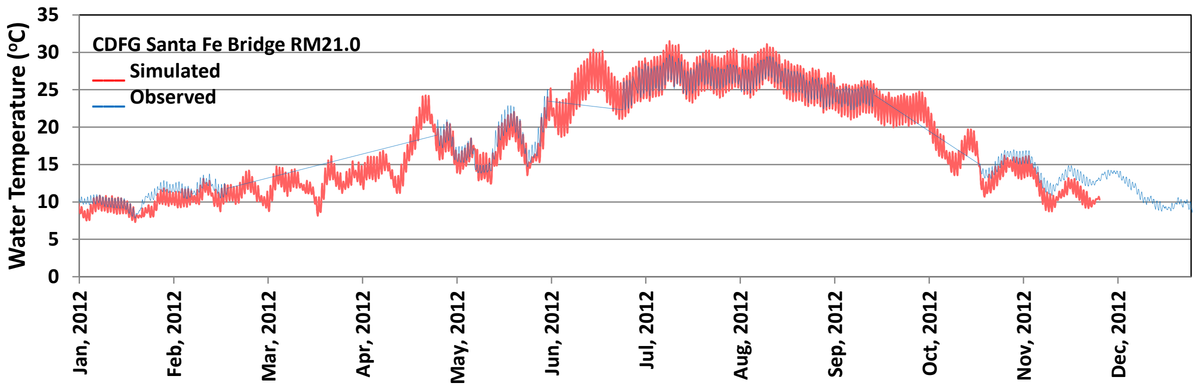

CDFG Riffle Q3 RM35.0
Simulated
Observed
Water Temperature (ºC)
35
30
25
20
15
10
5
0
Jan, 2012
Feb, 2012
Mar, 2012
Apr, 2012
May, 2012
Jun, 2012
Jul, 2012
Aug, 2012
Sep, 2012
Oct, 2012
Nov, 2012
Dec, 2012

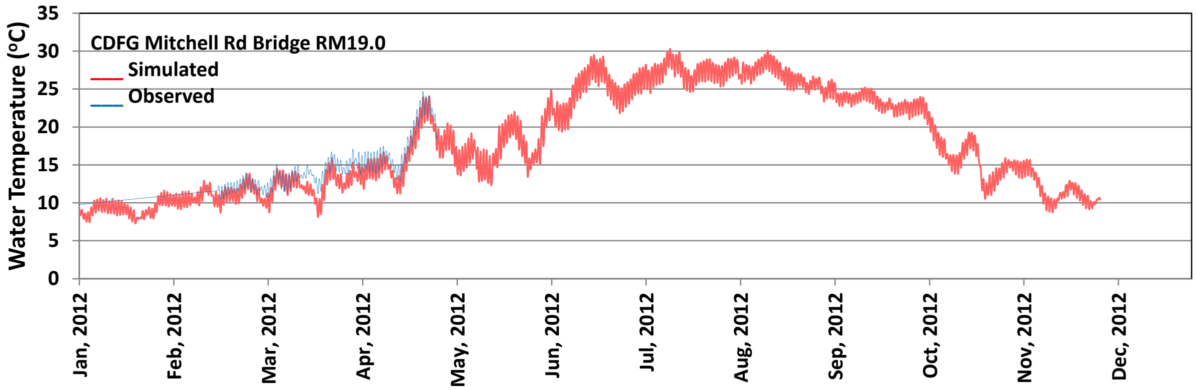

CDFG Above Hickman Spill RM33
Simulated
Observed
Water Temperature (ºC)
35
30
25
20
15
10
5
0
Jan, 2012
Feb, 2012
Mar, 2012
Apr, 2012
May, 2012
Jun, 2012
Jul, 2012
Aug, 2012
Sep, 2012
Oct, 2012
Nov, 2012
Dec, 2012

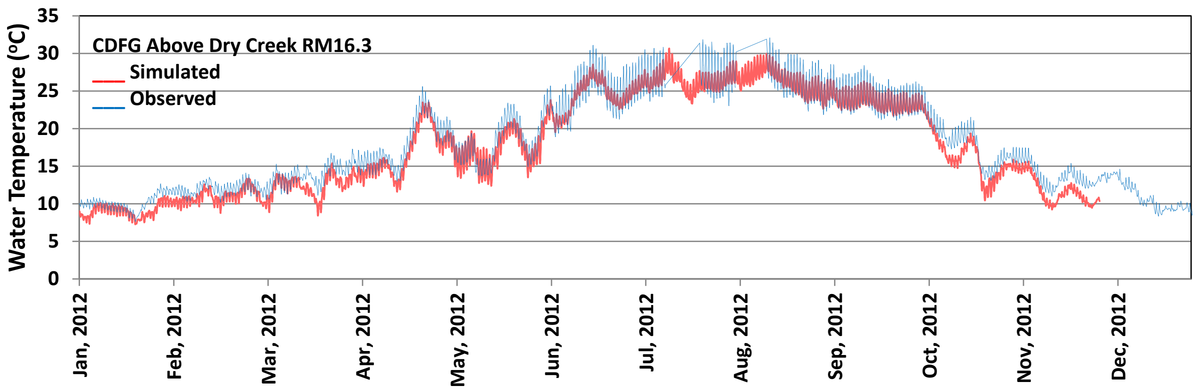

CDFG below Hickman Spill RM32.0
Simulated
Observed
Water Temperature (ºC)
35
30
25
20
15
10
5
0
Jan, 2012
Feb, 2012
Mar, 2012
Apr, 2012
May, 2012
Jun, 2012
Jul, 2012
Aug, 2012
Sep, 2012
Oct, 2012
Nov, 2012
Dec, 2012


CDFG Fox Grove Bridge RM26.0
Simulated
Observed
Water Temperature (ºC)
35
30
25
20
15
10
5
0
Jan, 2012
Feb, 2012
Mar, 2012
Apr, 2012
May, 2012
Jun, 2012
Jul, 2012
Aug, 2012
Sep, 2012
Oct, 2012
Nov, 2012
Dec, 2012


SW Hughson RM23.6
Simulated
Observed
Water Temperature (°C)
0
5
10
15
20
25
30
35
Jan, 2012
Feb, 2012
Mar, 2012
Apr, 2012
May, 2012
Jun, 2012
Jul, 2012
Aug, 2012
Sep, 2012
Oct, 2012
Nov, 2012
Dec, 2012


CDFG Santa Fe Bridge RM21.0
Simulated
Observed
Water Temperature (°C)
0
5
10
15
20
25
30
35
Jan, 2012
Feb, 2012
Mar, 2012
Apr, 2012
May, 2012
Jun, 2012
Jul, 2012
Aug, 2012
Sep, 2012
Oct, 2012
Nov, 2012
Dec, 2012


CDFG Mitchell Rd Bridge RM19.0
Simulated
Observed
Water Temperature (°C)
0
5
10
15
20
25
30
35
Jan, 2012
Feb, 2012
Mar, 2012
Apr, 2012
May, 2012
Jun, 2012
Jul, 2012
Aug, 2012
Sep, 2012
Oct, 2012
Nov, 2012
Dec, 2012


CDFG Above Dry Creek RM16.3
Simulated
Observed
Water Temperature (°C)
0
5
10
15
20
25
30
35
Jan, 2012
Feb, 2012
Mar, 2012
Apr, 2012
May, 2012
Jun, 2012
Jul, 2012
Aug, 2012
Sep, 2012
Oct, 2012
Nov, 2012
Dec, 2012

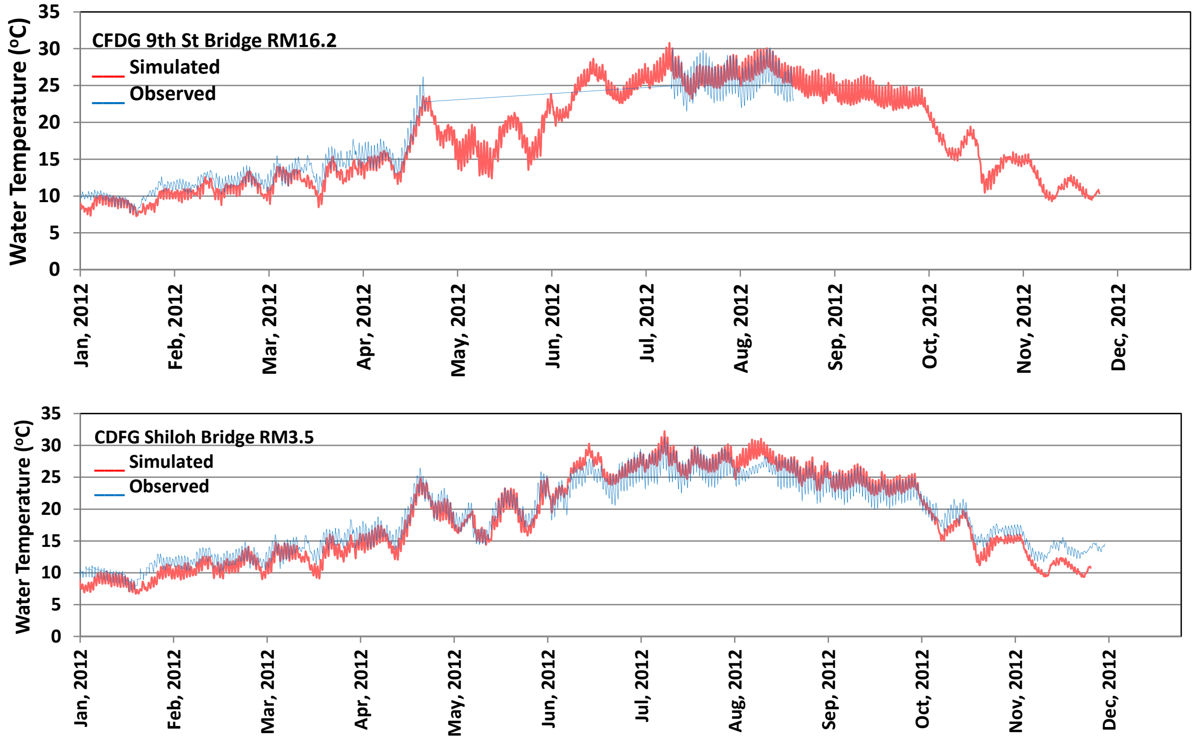


Figure 5.2-2. Model validation using calendar year 2012.

5.3 Fitness of Model Results

Several statistics may be used to provide a general indication of how well the model fits the observed data. These are discussed below.

Mean Bias

The mean bias is defined as the average difference between the measured and modeled temperatures. It is expressed as:

$$\text{Mean bias} = \frac{T_{meas} - T_{calc}}{n_{meas}}$$

where T_{meas} is the observed temperature
T_{calc} is the computed temperature
n_{meas} is the number of observations

The mean bias indicates the average magnitude of the difference between the measured and modeled temperature, as well as whether the model is generally under-predicting (a negative mean bias) or over-predicting (a positive mean bias). There is no generally accepted statistical standard for comparison of observed and predicted values. Past river temperature studies have tended to pick round numbers and use them as a comparison, e.g. 1°C or 2°C. This study will use the same approach. Apart from the magnitude of the mean bias it is also desirable that the mean bias should vary between positive and negative values from site to site, as this would indicate that the model does not have a system-wide bias.

Mean Absolute Error

The mean absolute error (MAE) is the absolute value of the mean bias. This is used so that positive and negative model differences (the difference between measured and computed temperature) do not cancel each other. This will result in larger values than the mean bias and gives another measure of model uncertainty.

Root Mean Square Error

The Root Mean Square Error (RMSE) is defined as:

$$RMSE = \sqrt{\frac{\sum (T_{meas} - T_{calc})^2}{X}}$$

Where X is the mean value of the measured data.

The RMSE is similar to the MAE, but is much more affected by the presence of outliers. As the differences are squared and summed before being subject to the radical, the values of RMSE will always be greater than the MAE.

Table 5.3-1 shows the resulting statistics for both 2011 and 2012 for daily maximum, daily minimum and daily average temperatures. The annual average value of the measured data is also given.

Table 5.3-1 shows that in general the model performed better in 2011 than 2012. This is expected as the model was calibrated to 2011 data. However, given how different the river conditions were in 2011 and 2012, the model results represent overall river temperature reasonably well. As the model calibration was focused more on daily maximum and daily averages, these statistics are reproduced more consistently in the modelthan the daily minimums.

As a simple comparison metric we can identify those monitoring sites that were above 1^{o}C for mean bias, above 1.5 ^{o}C for MAE and above 2 ^{o}C for RMSE for 2011. For 2012 we use 1.5^{o}C, 2^{o}C and 3^{o}C,respectively, which represents the same relative comparison as 2011, given that 2012 was 30-50 percent warmer. The number of sites that exceed the above described metrics are shown in Table 5.3-2. The model tracks the average river temperature well in both years. In 2012, the over-prediction of the diurnal range in certain stretches of the river is reflected in the results for daily minimum and maximums.

Overall the comparison plots shown in the previous two sections, in addition to the statistical comparisons presented in this section, indicate that the model can, with reasonable accuracy, predict water temperatures in the Lower Tuolumne River.

Table 5.3-1. Statistical fit of model to data.

TID/MID USGS Gauge RM 51.8		2011			2012		
Statistic	**Units**	**Daily Max**	**Daily Min**	**Daily Avg**	**Daily Max**	**Daily Min**	**Daily Avg**
Mean Bias	°C	0.1	0.1	0.1	-0.4	0.4	-0.2
Mean Absolute Error	°C	0.2	0.1	0.2	0.5	0.4	0.4
Root Mean Squared Error	°C	0.3	0.3	0.3	1.0	0.7	0.9
Number of Data Points	--	334	334	334	335	335	335
Average Annual Temp	°C	--	--	10.8	--	--	11.7
CDFW Riffle A1 RM 51.6		**2011**			**2012**		
Statistic	**Units**	**Daily Max**	**Daily Min**	**Daily Avg**	**Daily Max**	**Daily Min**	**Daily Avg**
Mean Bias	°C	0.0	0.1	0.0	-0.9	0.2	-0.6
Mean Absolute Error	°C	0.1	0.1	0.1	1.0	0.2	0.7
Root Mean Squared Error	°C	0.4	0.2	0.3	2.2	1.1	2.0
Number of Data Points	--	334	334	334	336	336	336
Average Annual Temp	°C	--	--	10.7	--	--	11.4
TID/MID Riffle A7 RM 50.7		**2011**			**2012**		
Statistic	**Units**	**Daily Max**	**Daily Min**	**Daily Avg**	**Daily Max**	**Daily Min**	**Daily Avg**
Mean Bias	°C	0.1	0.1	0.1	-0.3	0.7	0.0
Mean Absolute Error	°C	0.2	0.1	0.2	0.4	0.7	0.3
Root Mean Squared Error	°C	0.4	0.3	0.3	1.2	1.6	1.1
Number of Data Points	--	334	334	334	336	336	336
Average Annual Temp	°C	--	--	10.9	--	--	12.2
CDFW Riffle C1 RM 49.7		**2011**			**2012**		
Statistic	**Units**	**Daily Max**	**Daily Min**	**Daily Avg**	**Daily Max**	**Daily Min**	**Daily Avg**
Mean Bias	°C	0.1	0.2	0.2	-1.5	1.9	0.2
Mean Absolute Error	°C	0.2	0.2	0.2	1.6	1.9	0.3
Root Mean Squared Error	°C	0.4	0.4	0.4	2.7	3.6	1.1
Number of Data Points	--	334	334	334	336	336	336
Average Annual Temp	°C	--	--	11.0	--	--	12.7
CDFW Riffle D2 RM 48.8		**2011**			**2012**		
Statistic	**Units**	**Daily Max**	**Daily Min**	**Daily Avg**	**Daily Max**	**Daily Min**	**Daily Avg**
Mean Bias	°C	-0.2	0.1	0.1	-1.9	2.1	0.2
Mean Absolute Error	°C	0.2	0.2	0.1	2.0	2.1	0.4
Root Mean Squared Error	°C	0.4	0.4	0.3	3.3	3.9	1.1
Number of Data Points	--	334	334	334	336	336	336
Average Annual Temp	°C	--	--	11.0	--	--	13.0

CDFW Baso Bridge RM 47.5		**2011**			**2012**		
Statistic	**Units**	**Daily Max**	**Daily Min**	**Daily Avg**	**Daily Max**	**Daily Min**	**Daily Avg**
Mean Bias	°C	-0.5	0.4	0.1	-3.1	2.0	-0.1
Mean Absolute Error	°C	0.6	0.4	0.2	3.2	2.0	0.4
Root Mean Squared Error	°C	1.1	0.7	0.4	5.1	3.3	1.2
Number of Data Points	--	334	334	334	336	336	336
Average Annual Temp	°C	--	--	11.1	--	--	13.2
TID/MID - Riffle 13B - RM 45.5		**2011**			**2012**		
Statistic	**Units**	**Daily Max**	**Daily Min**	**Daily Avg**	**Daily Max**	**Daily Min**	**Daily Avg**
Mean Bias	°C	-0.7	0.4	0.1	-1.3	1.8	0.6
Mean Absolute Error	°C	0.7	0.4	0.2	1.4	1.8	0.6
Root Mean Squared Error	°C	1.3	0.9	0.4	2.0	3.0	1.3
Number of Data Points	--	334	334	334	336	336	336
Average Annual Temp	°C	--	--	11.3	--	--	14.6
CDFW Riffle G3 RM 45.0		**2011**			**2012**		
Statistic	**Units**	**Daily Max**	**Daily Min**	**Daily Avg**	**Daily Max**	**Daily Min**	**Daily Avg**
Mean Bias	°C	-0.8	0.6	0.2	-2.4	2.7	0.5
Mean Absolute Error	°C	0.9	0.6	0.2	2.5	2.7	0.6
Root Mean Squared Error	°C	1.5	1.6	0.5	3.6	3.8	1.3
Number of Data Points	--	334	334	334	336	336	336
Average Annual Temp	°C	--	--	11.4	--	--	14.5
CDFW - Riffle I2 - RM 43.2		**2011**			**2012**		
Statistic	**Units**	**Daily Max**	**Daily Min**	**Daily Avg**	**Daily Max**	**Daily Min**	**Daily Avg**
Mean Bias	°C	-1.1	0.7	0.2	-1.7	3.6	1.2
Mean Absolute Error	°C	1.1	0.7	0.2	1.9	3.6	1.2
Root Mean Squared Error	°C	1.8	1.8	0.6	2.7	4.7	1.9
Number of Data Points	--	334	334	334	336	336	336
Average Annual Temp	°C	--	--	11.5	--	--	15.6

TID/MID - Riffle R21 - RM 42.9	2011				2012		
Statistic	**Units**	**Daily Max**	**Daily Min**	**Daily Avg**	**Daily Max**	**Daily Min**	**Daily Avg**
Mean Bias	°C	-1.1	0.7	-0.3	-1.0	2.3	-0.1
Mean Absolute Error	°C	1.1	0.7	0.4	1.2	2.3	0.6
Root Mean Squared Error	°C	1.8	1.4	0.9	1.6	3.2	0.8
Number of Data Points	--	334	334	334	335	335	335
Average Annual Temp	°C	--	--	11.5	--	--	15.5
CDFW - Riffle K1 - RM 42.6	**2011**				**2012**		
Statistic	**Units**	**Daily Max**	**Daily Min**	**Daily Avg**	**Daily Max**	**Daily Min**	**Daily Avg**
Mean Bias	°C	-1.1	0.7	0.2	-1.8	3.6	1.2
Mean Absolute Error	°C	1.1	0.7	0.3	2.0	3.6	1.3
Root Mean Squared Error	°C	1.9	1.6	0.6	2.7	4.6	1.9
Number of Data Points	--	334	334	334	336	336	336
Average Annual Temp	°C	--	--	11.6	--	--	15.7
TID/MID Roberts Ferry Bridge RM 39.5	**2011**				**2012**		
Statistic	**Units**	**Daily Max**	**Daily Min**	**Daily Avg**	**Daily Max**	**Daily Min**	**Daily Avg**
Mean Bias	°C	-1.4	1.1	0.2	0.0	1.4	1.0
Mean Absolute Error	°C	1.5	1.1	0.3	1.1	1.4	1.1
Root Mean Squared Error	°C	2.5	2.0	0.6	1.5	2.0	1.6
Number of Data Points	--	334	334	334	336	336	336
Average Annual Temp	°C	--	--	11.7	--	--	16.2
CDFW Riffle Q3 RM 35.0	**2011**				**2012**		
Statistic	**Units**	**Daily Max**	**Daily Min**	**Daily Avg**	**Daily Max**	**Daily Min**	**Daily Avg**
Mean Bias	°C	-0.5	0.1	0.1	-0.5	1.1	0.8
Mean Absolute Error	°C	1.0	0.4	0.3	1.0	1.2	0.9
Root Mean Squared Error	°C	1.5	0.9	0.6	1.4	1.6	1.3
Number of Data Points	--	334	334	334	336	336	336
Average Annual Temp	°C	--	--	12.0	--	--	17.2
CDFW Above Hickman Spill RM 33	**2011**				**2012**		
Statistic	**Units**	**Daily Max**	**Daily Min**	**Daily Avg**	**Daily Max**	**Daily Min**	**Daily Avg**
Mean Bias	°C	-0.9	0.7	0.3	-0.7	1.6	1.0
Mean Absolute Error	°C	1.2	0.8	0.4	1.1	1.6	1.1
Root Mean Squared Error	°C	2.0	1.5	0.8	1.5	2.0	1.5
Number of Data Points	--	334	334	334	336	336	336
Average Annual Temp	°C	--	--	12.2	--	--	17.7

CDFW below Hickman Spill RM 32.0	2011				2012		
Statistic	**Units**	**Daily Max**	**Daily Min**	**Daily Avg**	**Daily Max**	**Daily Min**	**Daily Avg**
Mean Bias	°C	-0.5	0.2	0.3	-0.8	1.3	0.8
Mean Absolute Error	°C	0.8	0.5	0.3	1.1	1.4	0.8
Root Mean Squared Error	°C	1.3	0.9	0.7	1.1	1.5	0.9
Number of Data Points	--	334	334	334	161	161	161
Average Annual Temp	°C	--	--	12.2	--	--	14.0
CDFW Fox Grove Bridge RM 26.0	**2011**				**2012**		
Statistic	**Units**	**Daily Max**	**Daily Min**	**Daily Avg**	**Daily Max**	**Daily Min**	**Daily Avg**
Mean Bias	°C	-0.3	0.4	0.5	-0.4	1.1	0.8
Mean Absolute Error	°C	0.7	0.6	0.5	1.1	1.1	0.9
Root Mean Squared Error	°C	1.2	1.1	1.0	1.3	1.3	1.2
Number of Data Points	--	334	334	334	210	210	210
Average Annual Temp	°C	--	--	12.7	--	--	17.0
TID/MID Hughson RM 23.6	**2011**				**2012**		
Statistic	**Units**	**Daily Max**	**Daily Min**	**Daily Avg**	**Daily Max**	**Daily Min**	**Daily Avg**
Mean Bias	°C	-0.4	0.5	0.5	-0.3	0.7	0.8
Mean Absolute Error	°C	0.7	0.6	0.6	1.0	0.9	0.9
Root Mean Squared Error	°C	1.2	1.1	1.1	1.3	1.3	1.3
Number of Data Points	--	334	334	334	336	336	336
Average Annual Temp	°C	--	--	12.8	--	--	18.5
CDFW Santa Fe Bridge RM 21.0	**2011**				**2012**		
Statistic	**Units**	**Daily Max**	**Daily Min**	**Daily Avg**	**Daily Max**	**Daily Min**	**Daily Avg**
Mean Bias	°C	-0.6	0.6	0.5	-1.6	1.8	0.9
Mean Absolute Error	°C	0.8	0.7	0.5	2.0	1.9	0.9
Root Mean Squared Error	°C	1.4	1.3	1.0	1.9	1.7	1.1
Number of Data Points	--	325	325	325	207	207	207
Average Annual Temp	°C	--	--	12.7	--	--	18.8

CDFW Mitchell Rd Bridge RM 19.0	2011				2012		
Statistic	**Units**	**Daily Max**	**Daily Min**	**Daily Avg**	**Daily Max**	**Daily Min**	**Daily Avg**
Mean Bias	°C	-0.3	0.5	0.6	-0.7	2.2	1.4
Mean Absolute Error	°C	0.8	0.6	0.6	1.1	2.2	1.4
Root Mean Squared Error	°C	1.3	1.1	1.2	0.7	1.3	0.9
Number of Data Points	--	326	326	326	72	72	72
Average Annual Temp	°C	--	--	13.0	--	--	15.0
CDFW Above Dry Creek RM 16.3	**2011**				**2012**		
Statistic	**Units**	**Daily Max**	**Daily Min**	**Daily Avg**	**Daily Max**	**Daily Min**	**Daily Avg**
Mean Bias	°C	-0.1	0.9	0.8	-0.9	1.3	0.9
Mean Absolute Error	°C	0.7	1.0	0.8	1.5	1.3	1.1
Root Mean Squared Error	°C	1.0	1.6	1.3	1.9	1.7	1.5
Number of Data Points	--	228	228	228	315	315	315
Average Annual Temp	°C	--	--	12.3	--	--	18.1
CFDG 9th St Bridge RM 16.2	**2011**				**2012**		
Statistic	**Units**	**Daily Max**	**Daily Min**	**Daily Avg**	**Daily Max**	**Daily Min**	**Daily Avg**
Mean Bias	°C	-0.1	1.0	1.0	-1.1	1.2	0.6
Mean Absolute Error	°C	0.7	1.0	1.0	1.5	1.4	1.2
Root Mean Squared Error	°C	1.0	1.7	1.5	1.6	1.2	1.0
Number of Data Points	--	327	327	327	154	154	154
Average Annual Temp	°C	--	--	13.6	--	--	16.3
CDFW Shiloh Bridge RM 3.5	**2011**				**2012**		
Statistic	**Units**	**Daily Max**	**Daily Min**	**Daily Avg**	**Daily Max**	**Daily Min**	**Daily Avg**
Mean Bias	°C	0.3	0.9	0.7	-0.2	1.5	0.7
Mean Absolute Error	°C	0.7	1.0	0.7	1.6	1.7	1.4
Root Mean Squared Error	°C	1.1	1.6	1.3	1.9	2.1	1.7
Number of Data Points	--	334	334	334	336	336	336
Average Annual Temp	°C	--	--	13.6	--	--	19.1

avg average
CDFW California Department of Fish and Wildlife
max maximum
min minimum
RM River Mile
TID/MID Turlock Irrigation District and Modesto Irrigation District

Table 5.3-2. Number of monitoring sites that exceed the comparison metrics(total number of sites = 22).

Statistic	2011			2012		
	Daily Max	Daily Min	Daily Avg	Daily Max	Daily Min	Daily Avg
Mean Bias	4	1	0	6	12	0
Mean Absolute Error	0	0	0	3	6	0
Root Mean Squared Error	2	0	0	3	8	0

5.4 Observed Diurnal Variations

As described in Section 5.1, in 2011 the observed data at certain monitoring stations show some marked differences in the diurnal range when compared to other nearby monitoring stations. The annual average diurnal ranges for 2011 per monitoring site are plotted in Figure 5.4-1 in descending river mile order. Note that stations with incomplete data sets for 2011 are also included in Figure 5.4-1, e.g. Riffle I2, 7-11 Gravel, Santa Fe Gravel. The ranges for the summer months are plotted in Figure 5.4-2. Figures 5.4-3 and 5.4-4 show the average summer range plotted on a river mile scale for 2011 and 2012, respectively. Initially the diurnal range expands rapidly as the flow leaves the La Grange Dam and the smaller mass of water becomes exposed to local atmospheric conditions for longer periods of time. This part of the river response is perhaps the only consistent trend with regard to diurnal range. After this initial expansion of the range there follows a rapid contraction in both years, although at different locations. There then follows a fairly random sequence of diurnal range changes that differ from year to year.

The measured temperature data have been verified; there is no reason to believe that the data are in error. HDR and Districts' personnel visited each site over a two day period in August 2012 and recorded details of the site, looking for possible local field conditions that would explain the variations. No correlations between site characteristics or position of the thermologgers could be found.

As mentioned previously, an intensive, spatially focused thermal study was undertaken in summer/fall 2013 with results expected by the first quarter of 2014[5]. This study may provide further insight into this phenomena.

[5] Attachment A of TID/MID 2013a.

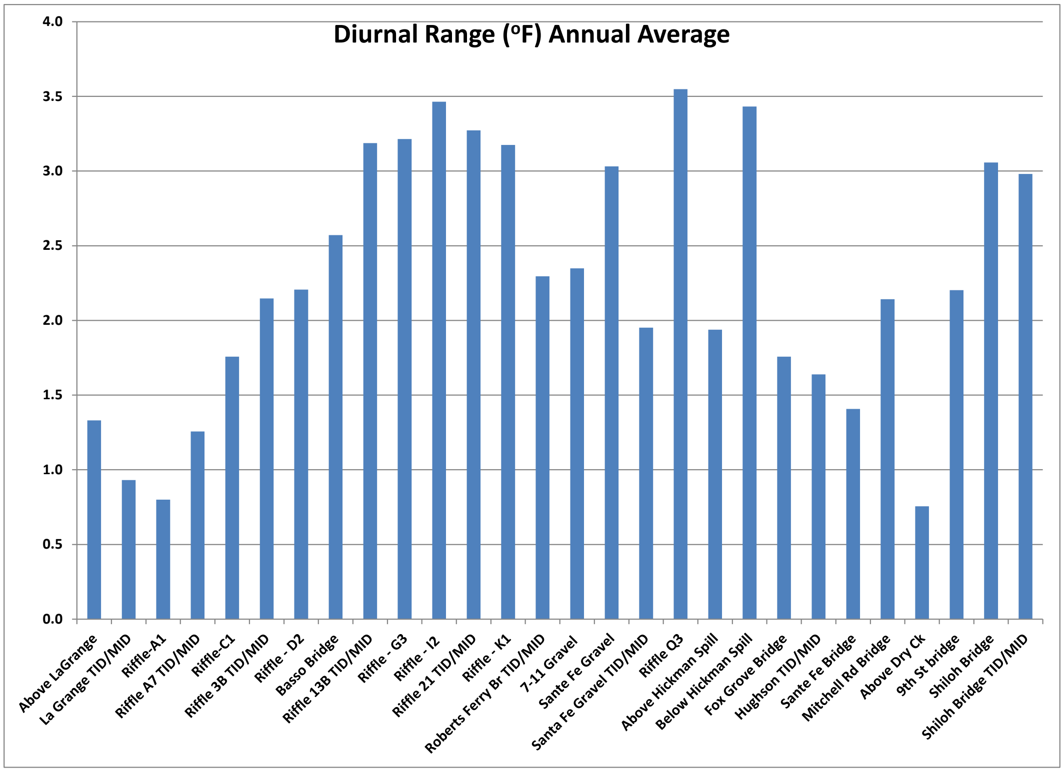


Figure 5.4-1. Annual average diurnal variation by site for 2011.

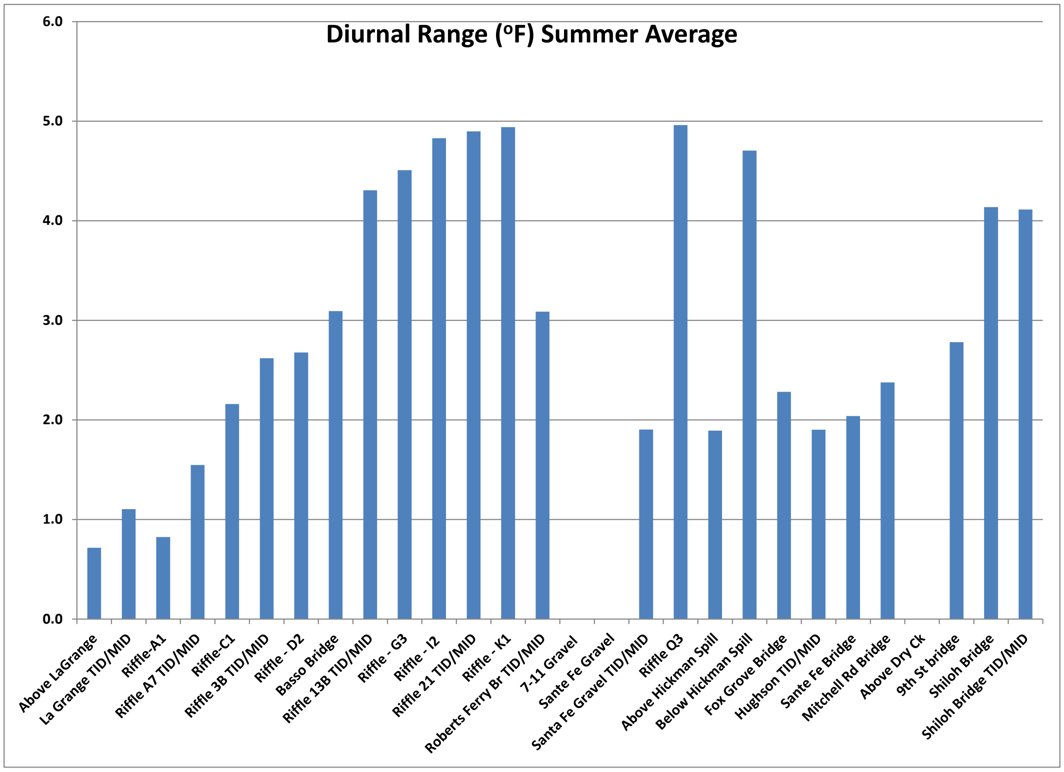


Figure 5.4-2. Summer average diurnal variation by site for 2011.

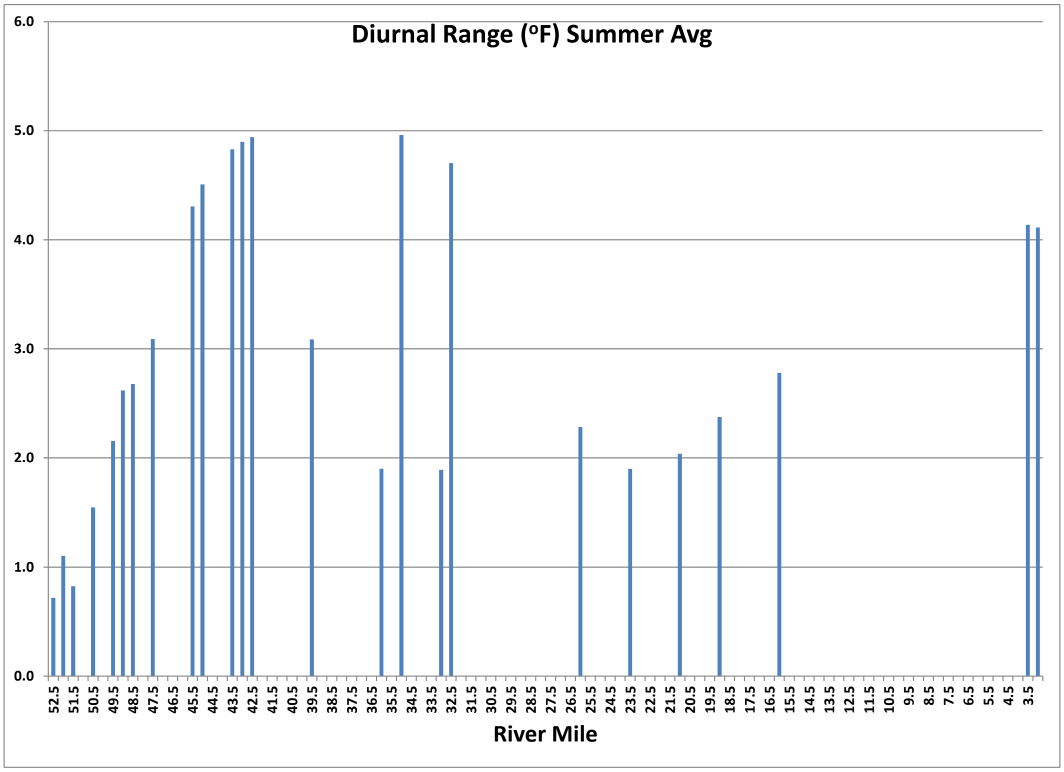


Figure 5.4-3. **Summer average diurnal range by river mile for 2011.**

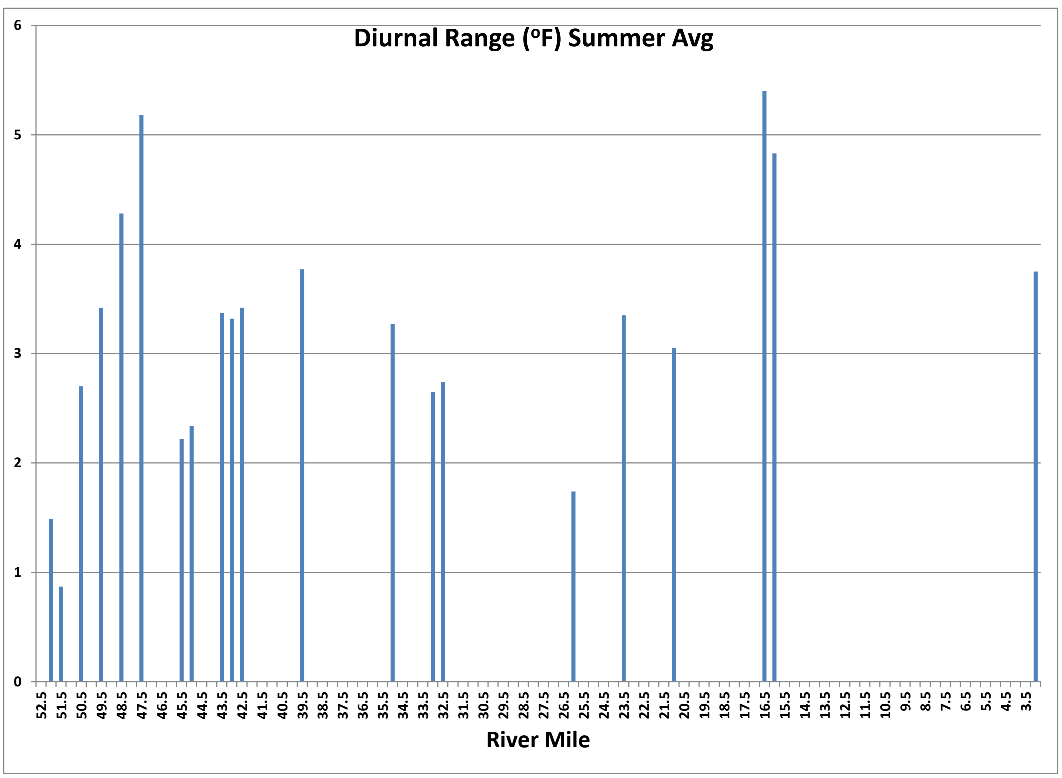


Figure 5.4-4. **Summer average diurnal range by river mile for 2012.**

Figure 5.4-3 was re-plotted in Figure 5.4-5 with annotations that show the various operational spill locations from the Districts' irrigation systems and approximate locations where potential groundwater inflow was detected during accretion flow measurements in late June 2012. As any groundwater inflow would have minimal diurnal variation it could be expected to suppress the range observed at river reaches influenced by groundwater inflows.

Figure 5.4-6 is the same as Figure 5.4-5 with the location of the special run pools highlighted. It is possible that the large thermal mass associated with these pools may also act to dampen the diurnal range.

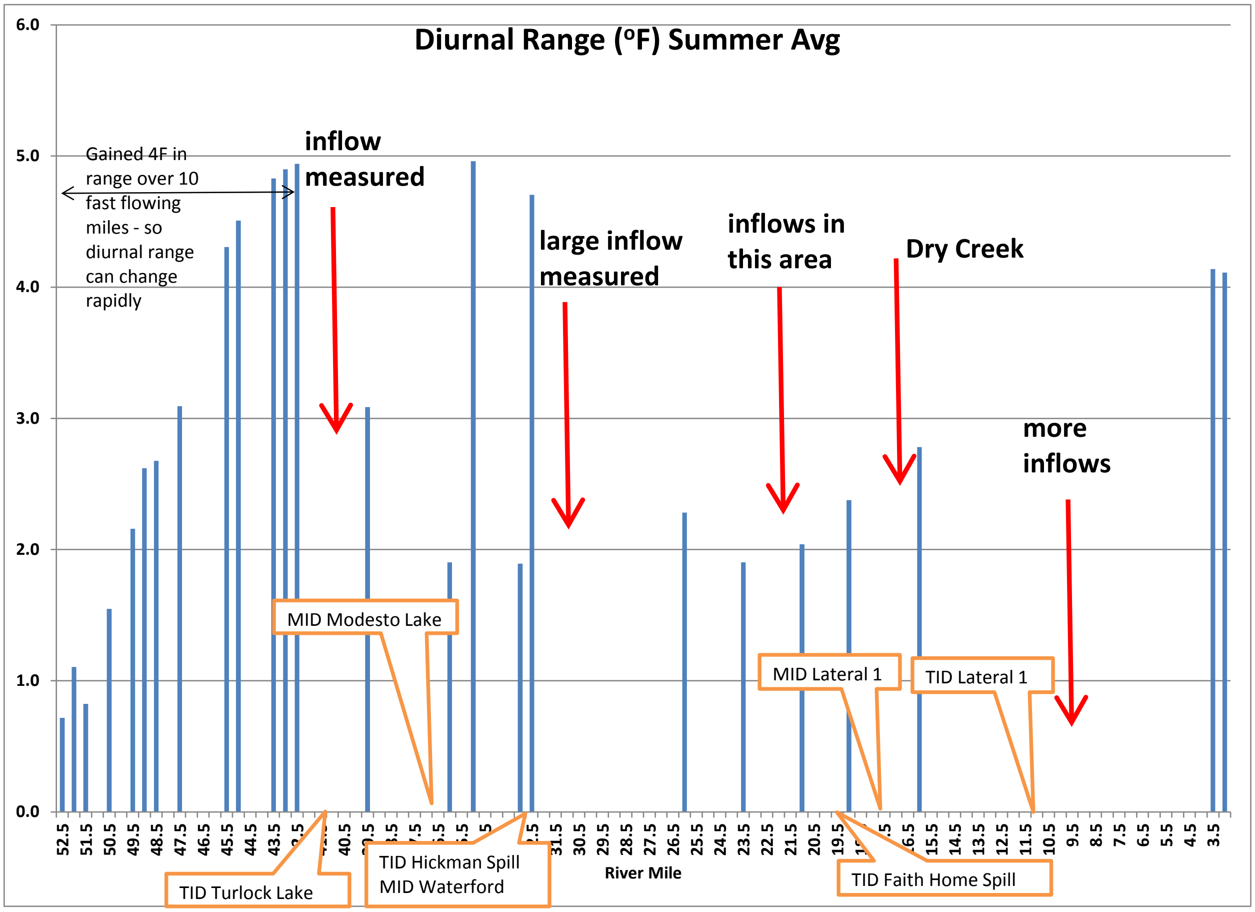


Figure 5.4-5. **Summer average diurnal range (2011) at actual river location – annotated with return flow locations.**

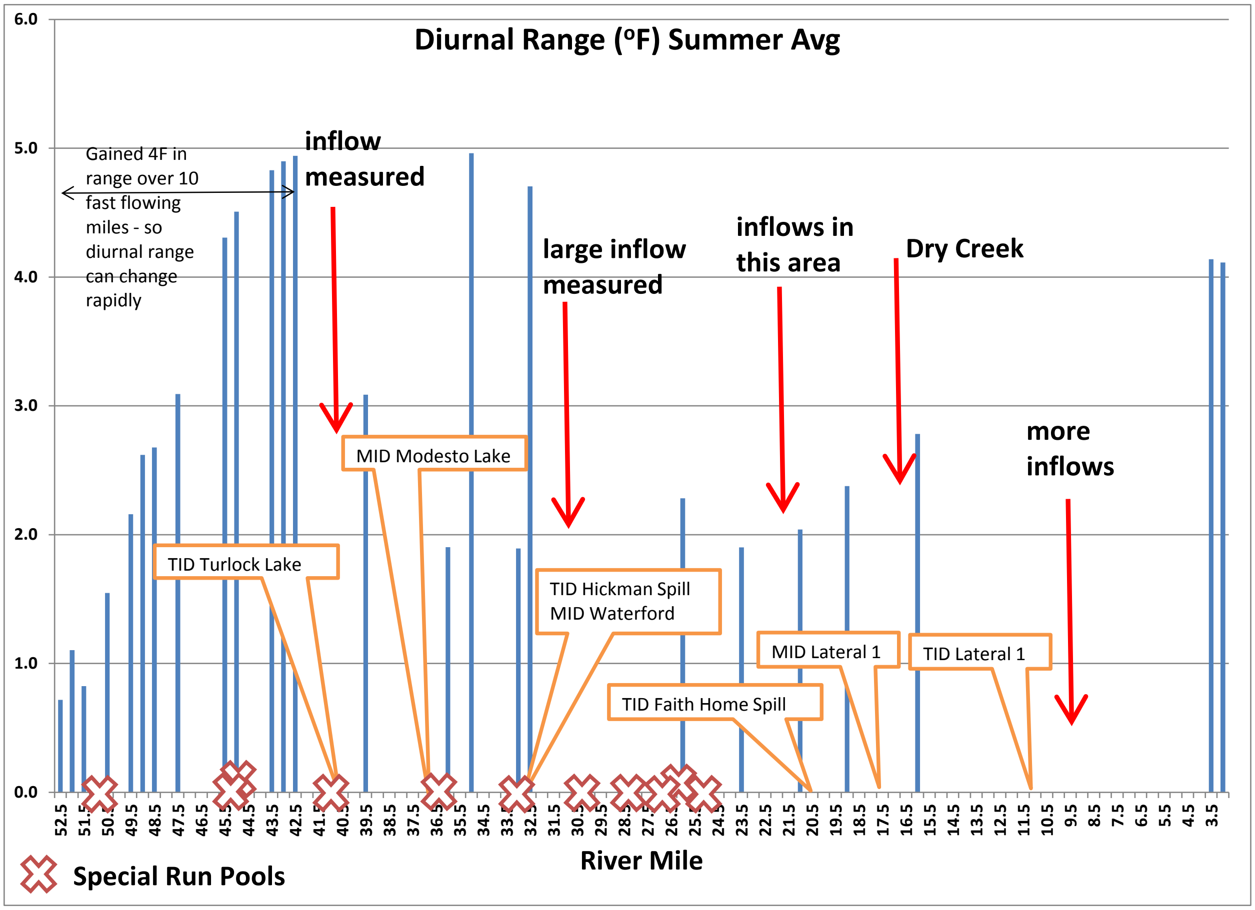
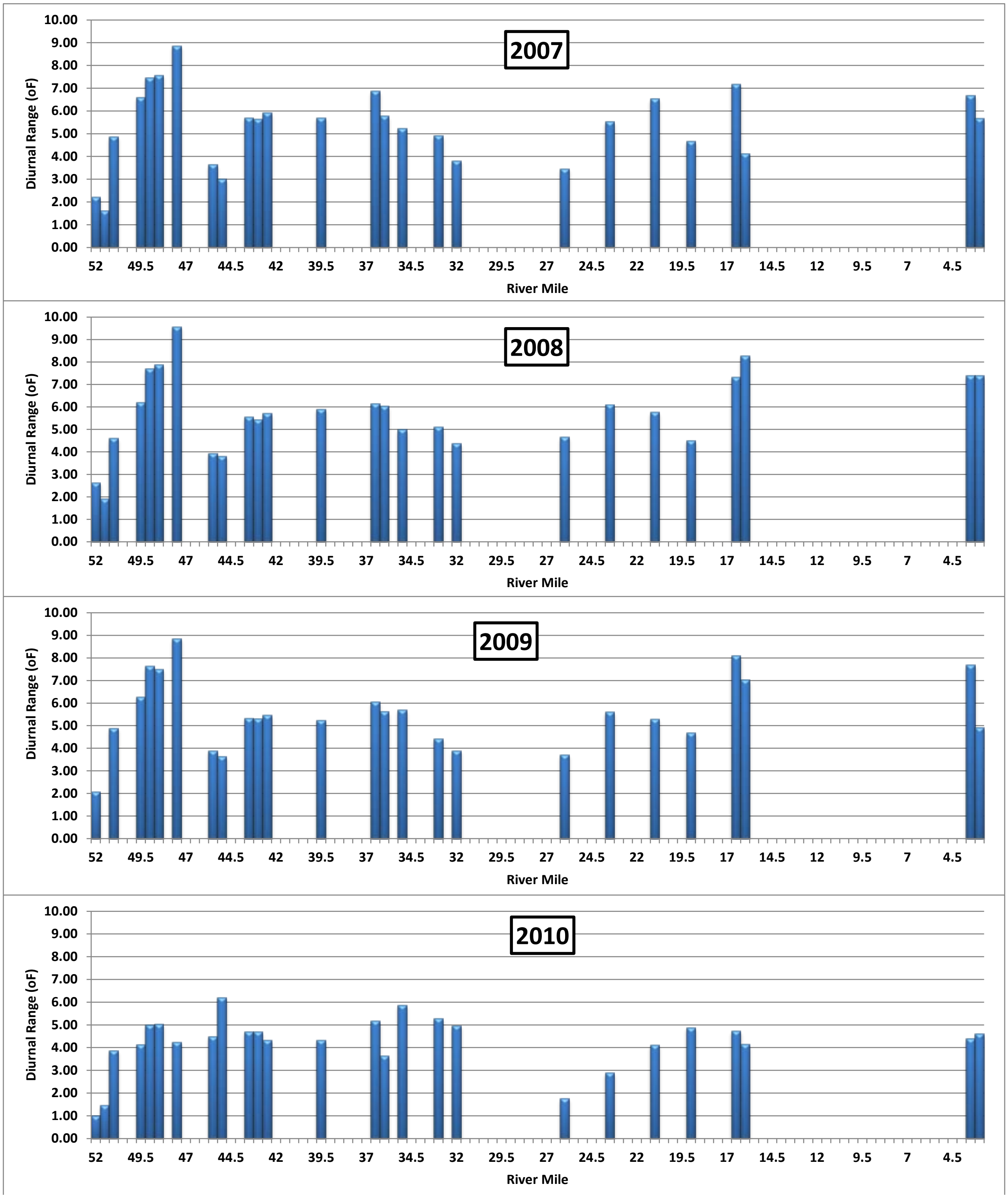


Figure 5.4-6. Summer average diurnal range (2011) – annotated with special run pool locations.

To put 2011 and 2012 into an historical perspective the summer ranges for 2007-2012 are shown in Figure 5.4-7. The figure indicates several points:

- the diurnal ranges are smaller in 2010-2012 than for 2007-2009
- a reproducible pattern appears to occur every year
- 2007-2009 are remarkably similar


2007
2008
2009
2010
Diurnal Range (oF)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
52
49.5
47
44.5
42
39.5
37
34.5
32
29.5
27
24.5
22
19.5
17
14.5
12
9.5
7
4.5
River Mile

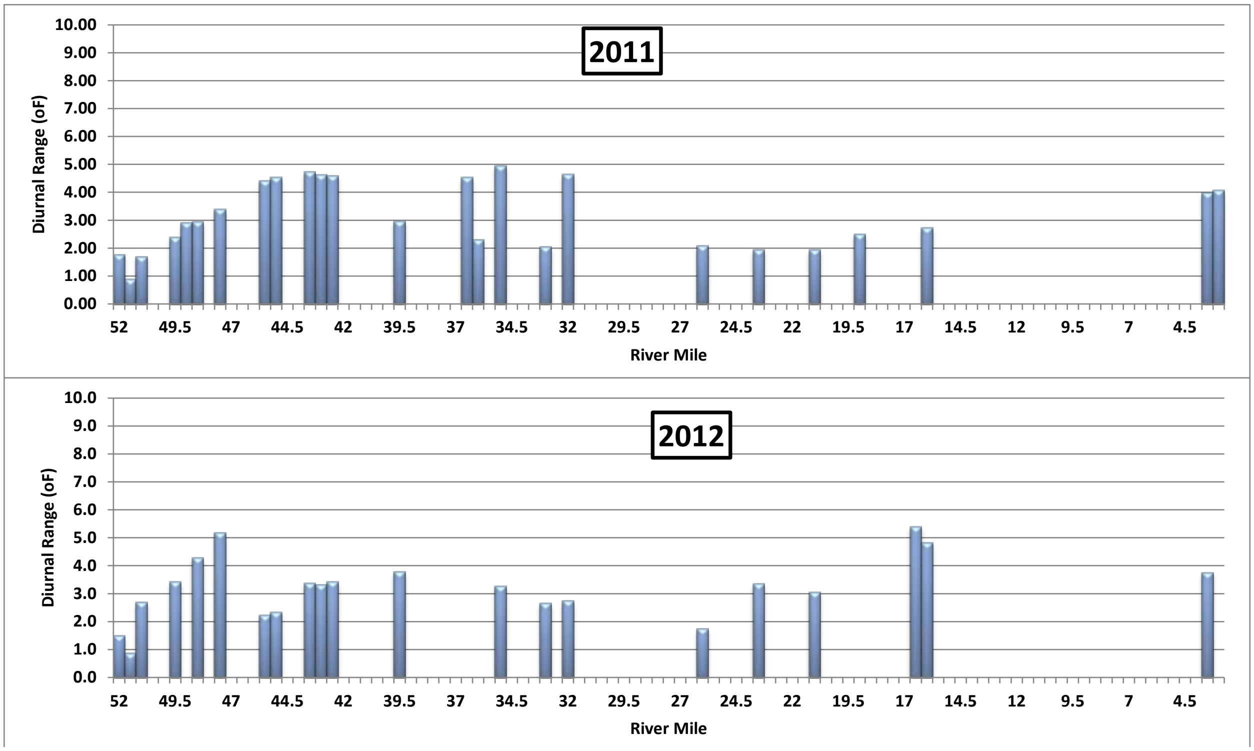


Figure 5.4-7. **Summer diurnal ranges 2007-12.**

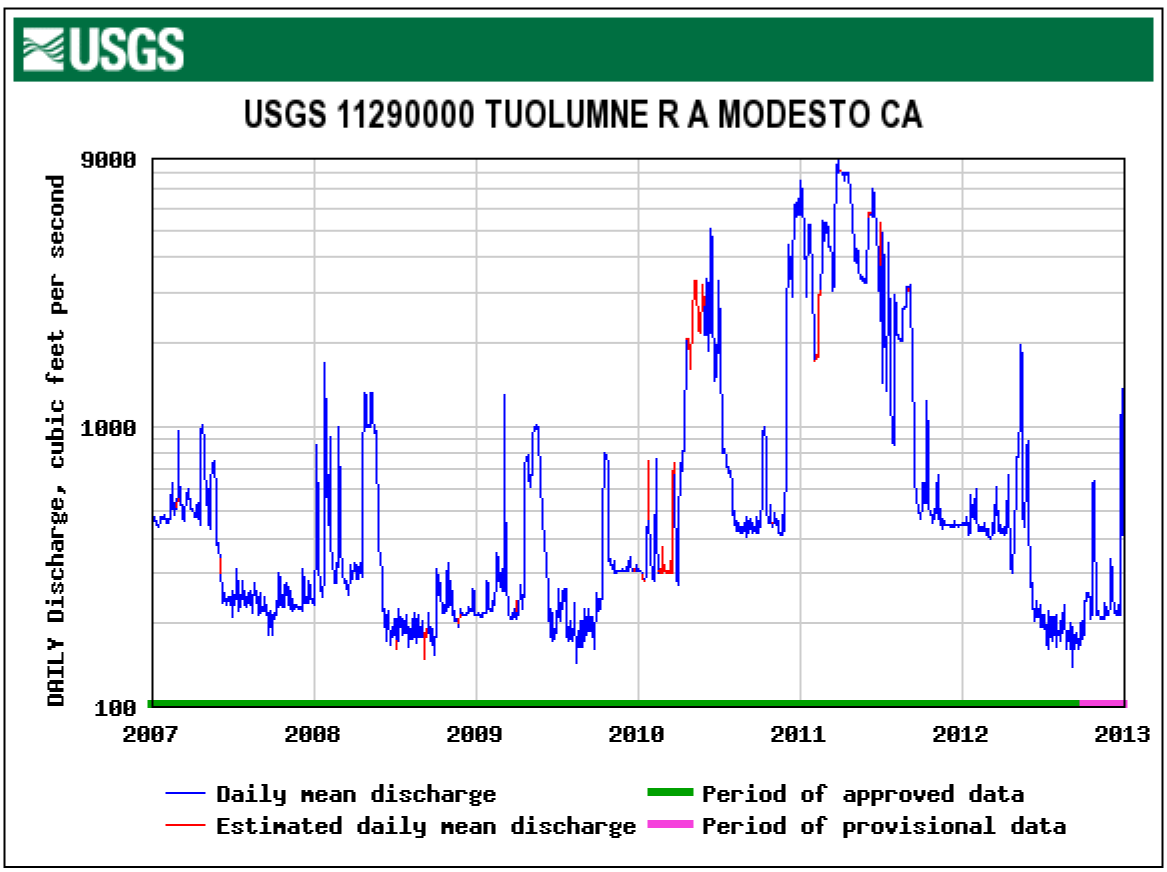


Figure 5.4-8. **USGS measured flow at Modesto 2007 – 2012.**

Flow rate is likely to affect the diurnal temperature ranges, with very high flows, such as occurred in 2011 tending to dampen the diurnal range. However, even with higher flows, the spatial pattern of rapid changes in diurnal flow range is still evident. Another possible explanation of the observed phenomena is given by Lowney (2000). In brief, Lowney states that maximum diurnal variations resulting from a relatively constant temperature release from a dam should occur about 12 hours after the release of this constant temperature water (i.e. 12 hours travel time downstream). Similarly, minimum diurnal variations should occur about 24 hours after release. The pattern is then repeated downstream in a diminishing pattern as other influences impact the water. The rationale is that water released in the morning gets warmed for 12 hours. Water released at dusk would get no solar warming. Thus a large diurnal variation might be expected at a travel time of 12 hours downstream. Conversely water that was released 24 hours previously will have the same solar exposure no matter when it exited the dam – so in theory a minimal diurnal variation might be observed at this point.

By observation of the plots provided in Figures 5.4-3 and 5.4-4, large changes in the diurnal temperature range occur over very short distances along the river, and do not appear to be related to travel time. Therefore, it appears that at some monitoring locations, local influences from either groundwater, other water inflows/outflows, or the occurrence of the deep special run pools may be more likely to affect observed temparatures.

6.0 DISCUSSION

The study goal was to develop a river temperature model that simulates current and potential future water temperature conditions in the lower Tuolumne River from below Don Pedro Dam (RM 54.8) to the confluence with the San Joaquin River (RM 0). The results presented show that the HEC-RAS model was able to reproduce the observed river water temperatures within a reasonable level of accuracy for both the calibration year of 2011 and the validation year of 2012.

Hydrologically, 2011 and 2012 were very different years, with 2011 having an average flow of ~4,200 cfs, and 2012 having an average river flow of ~1,500 cfs. The large 2011 flows kept the summer river temperatures low, while the lower 2012 flows produced warmer summer river temperatures. The outflow temperatures from Don Pedro Reservoir were similar for both years. A suite of statistical analyses used to evaluate the model showed that the model reproduced the observed data with reasonable reliability.

In summary, the objectives of the modeling study have been met, including:

- reasonably reproduce observed river water temperatures over the entire expected range of hydrologic conditions;
- predict sensitivity of water temperatures to changing flow and meteorological conditions;
- provide output to inform other studies, analyses and models; and
- predict potential changes in river temperature conditions under alternative future operating conditions.

Results from HEC-RAS can be output in DSS format which makes it compatible with the SJR5Q model, which was another requirement of the study.

7.0 STUDY VARIANCES AND PROPOSED MODIFICATIONS

The study was conducted in conformance to the FERC-approved Lower Tuolumne Temperature Model Study Plan (W&AR-16) approved in FERC's May 21, 2013 Determination. There are no variances.

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