LOWER TUOLUMNE RIVER TEMPERATURE MODEL

PROGRESS REPORT
DON PEDRO PROJECT
FERC NO. 2299

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

Prepared by:
HDR Engineering, Inc.

January 2013

Lower Tuolumne River Temperature Model
Progress Report

TABLE OF CONTENTS

List of Figures

List of Tables

List of Acronyms

ac ....acres

ACEC.........................Area of Critical Environmental Concern

AF ....acre-feet

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

CDFG.........................California Department of Fish and Game (as of January 2013, 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 General Description of the Don Pedro Project

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 formed by the dam extends 24-miles upstream at the 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).

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. CCSF's "water bank" within Don Pedro Reservoir provides significant benefits for its 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 the anadromous fisheries in the lower Tuolumne River, and hydropower generation.

The Project Boundary extends from approximately one mile downstream of the dam to approximately RM 79 upstream of the dam. Upstream of the dam, the Project Boundary runs generally along the 855 ft contour interval which corresponds to the top of the Don Pedro Dam. 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) is 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.

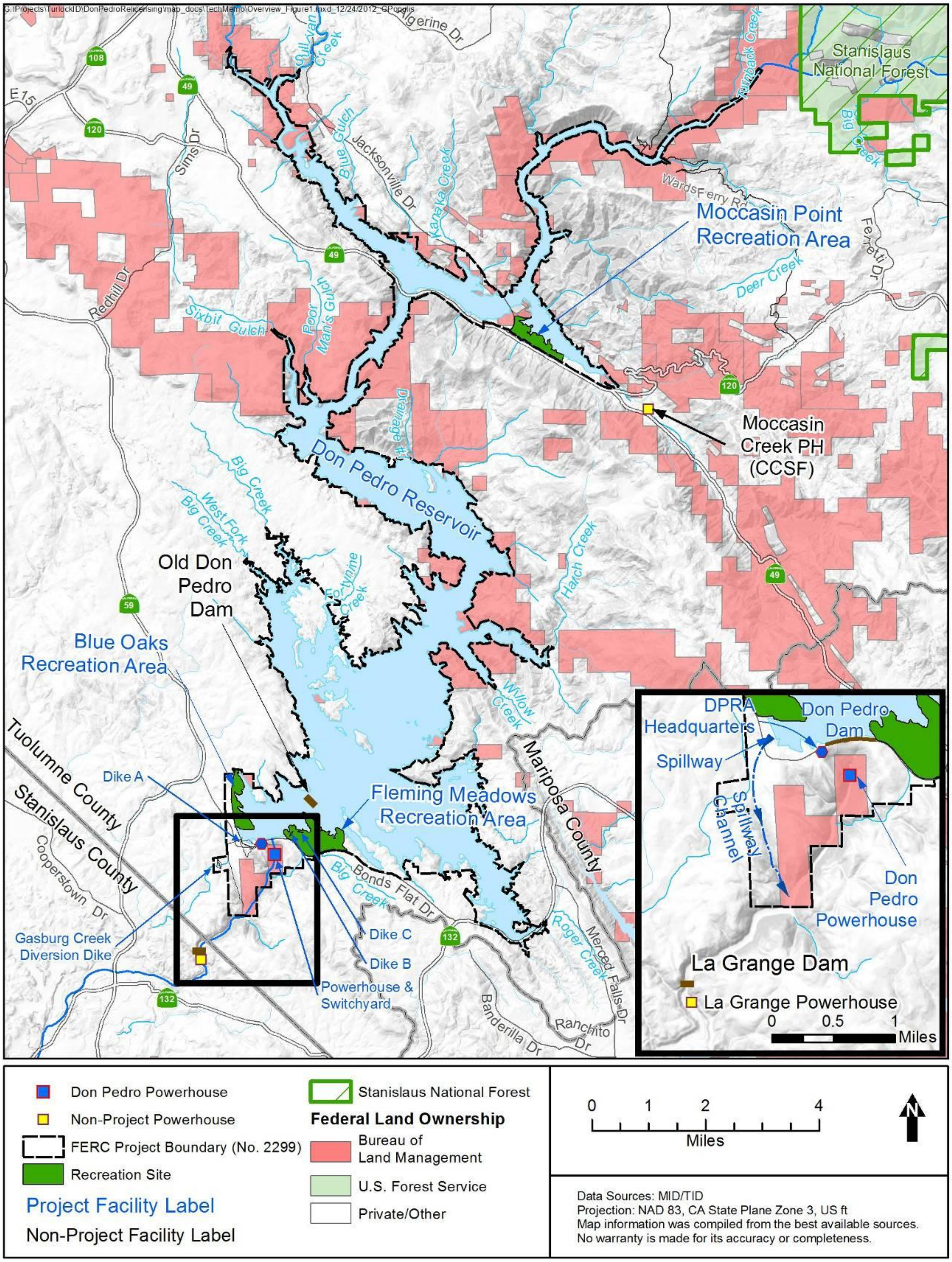


Figure 1.1-1. Don Pedro Project location.

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.

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

1.3 Study Plan

FERC approved the study plan for the Lower Tuolumne River Temperature Model (W&AR-16) with modifications. The SPD required the Districts to provide model output that could be used in the existing CalFed San Joaquin River Basin model, model river temperatures as needed to calculate daily maximum temperatures and compare the results to weekly average temperatures presented in TID/MID (2011), and provide all data used in calibration. The Lower Tuolumne River Temperature model is being developed consistent with the study plan as modified by the SPD.

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 to the confluence with the San Joaquin River. The river temperature model includes simulation of the lower Tuolumne River for a period of analysis that covers the range of hydrology of the Tuolumne River. The following objectives apply to this modeling study:

- reproduce observed river water temperatures, within acceptable calibration standards, over a 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.

The river temperature model interfaces with the Tuolumne River Operations Model (W&AR-02) and the Reservoir Temperature Model (W&AR-03). Output from the reservoir temperature model serves as input to the river temperature model. The river temperature model may also provide useful information to the Chinook (W&AR-06) and *Oncorhynchus Mykiss* (*O. Mykiss*) (W&AR-10) salmonid models.

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 2011). This study made use of the SJR5Q model of the lower Tuolumne River. The TID/MID (2011) study also made use of the most recent temperature data available from CDFG at that time and, in addition, data collected by the Districts under their real time temperature monitoring (RTM) program on 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°F, 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 thermographs not used in the original model calibration. These discrepancies resulted in the recommendation in the TID/MID (2011) report that the Tuolumne River portion of the SJR5Q model be recalibrated as part of relicensing.

The Districts' proposed *Lower Tuolumne River Temperature Model* (W&AR-16) was intended to complete this recalibration. The Districts have completed the recalibration of 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. At the Consultation Workshop meeting with RPs, the Districts presented the initial calibration results and discussed the status of the modeling efforts. The Districts had previously made available to

RPs by CD all of the input temperature and meteorological data used in the model. At the October 26 Workshop, the Districts indicated that the model calibration was generally strong with the exception that the diurnal range in actual river temperatures varies considerably from one data collection station to the next, with many stations downstream of RM 37 showing unexpected reduced levels of diurnal temperature ranges. The detailed recalibration efforts undertaken as part implementing study plan W&AR-16 has revealed that temperature conditions on the lower Tuolumne River are actually quite complex. The Districts are proposing additional investigations in 2013 to further evaluate the summer temperature regime of the lower Tuolumne as described in Section 6 below.

The following sections describe the work completed in accordance with the FERC-approved study plan, leading up to the current status of the lower Tuolumne river temperature model.

3.0 STUDY AREA

The study area includes the Tuolumne River from the outlet from Don Pedro Reservoir to the confluence with the San Joaquin River (Figure 3.0-1). This encompasses RM 0 to 54, as detailed below.

The lower Tuolumne River watershed, the subbasin from RM 0 to 54, covers approximately 430 square miles of drainage area, and contains one major tributary, Dry Creek, that confluences with the Tuolumne River at RM 16. Other contributions come from Peaslee Creek as well as McDonald Creek (via Turlock Lake) primarily during and after storm events. In this reach, the Tuolumne River extends from about elevation 35 feet at the confluence with the San Joaquin River to elevation 300 feet at the tailrace of the Don Pedro powerhouse. The lower Tuolumne River watershed is long and narrow and is dominated by irrigated farmland and the urban/suburban areas associated with the City of Modesto, Waterford, and Ceres.

This area of the watershed transitions from gently rolling hills near its easterly reaches to uniformly flat floodplain and terrace topography in the downstream direction. Soils are deep and fertile and irrigated agriculture and urban land use dominates the landscape. The Tuolumne River downstream of La Grange Dam flows 52 river miles to its confluence with the San Joaquin River. The Tuolumne River leaves its steep and confined bedrock valley and enters the eastern Central Valley downstream of La Grange Dam near La Grange Regional Park, 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, the Tuolumne River corridor lies in an 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 La Grange Dam (RM 52) to Geer Road Bridge (RM 24); and a sand-bedded reach that extends from Geer Road Bridge to the confluence with the San Joaquin River (McBain & Trush 2000).

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 before the first aerial photographs were taken by the Soil Conservation Service in 1937. Excavation of bed material for gold and aggregate to depths below the river thalweg eliminated active floodplains and terraces and created large in-channel and off channel pits. Agricultural and urban encroachment in combination with 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. 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 around RM 34 (Tuolumne River TAC 2000).

Downstream of Waterford, the Tuolumne River follows an increasingly sinuous path across the agricultural lands of the Central Valley and through the City of Modesto. The Tuolumne River finds its confluence with the San Joaquin River approximately 15 river miles beyond Modesto, along the axis of California’s Central Valley.

At Don Pedro Dam, water is discharged into the Tuolumne River from the powerhouse or outlet works, then enters the short reach of the Tuolumne River impounded by the La Grange Dam. At the La Grange Dam, water is diverted into MID's canal system to the north of the Tuolumne River, diverted into TID's canal system to the south of the Tuolumne River, or passes to the lower Tuolumne River downstream of La Grange Dam.

Downstream of the Project, the Tuolumne River becomes a lower gradient stream on its journey to the San Joaquin River. In this low-elevation area, the vast majority (around 75 percent) of local runoff occurs during winter rainstorms between December and March. Also contributing to flows within this region are natural inflows from Dry Creek and Peaslee Creek, as well as urban and agricultural runoff and operational spills from irrigation canals. Some of the streamflow in this area, however, is derived from groundwater inflow, and the lower Tuolumne River is generally considered to be a gaining stream (California Department of Water Resources [CDWR] 2004). This groundwater contribution to the lower Tuolumne is being evaluated by the Districts through a series of accretion flow measurements along the lower Tuolumne River.

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 such as Waterford and Modesto (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 spanning from the southern bank of the Tuolumne River to the north shore of Turlock Lake.

The lower Tuolumne River is heavily monitored for temperature with approximately 30 sites located between the Don Pedro Dam and the confluence with the San Joaquin. Monitoring is conducted by CDFG and the Districts. The locations of these sites is shown on Figure 3.0-1 and is discussed further in Section 4.3 below. Note that in Figure 3.0-1, sites labeled "TID" and "Stillwater" are referring to sites monitored by TID/MID; Stillwater Sciences has maintained several sites on TID/MID's behalf over time.

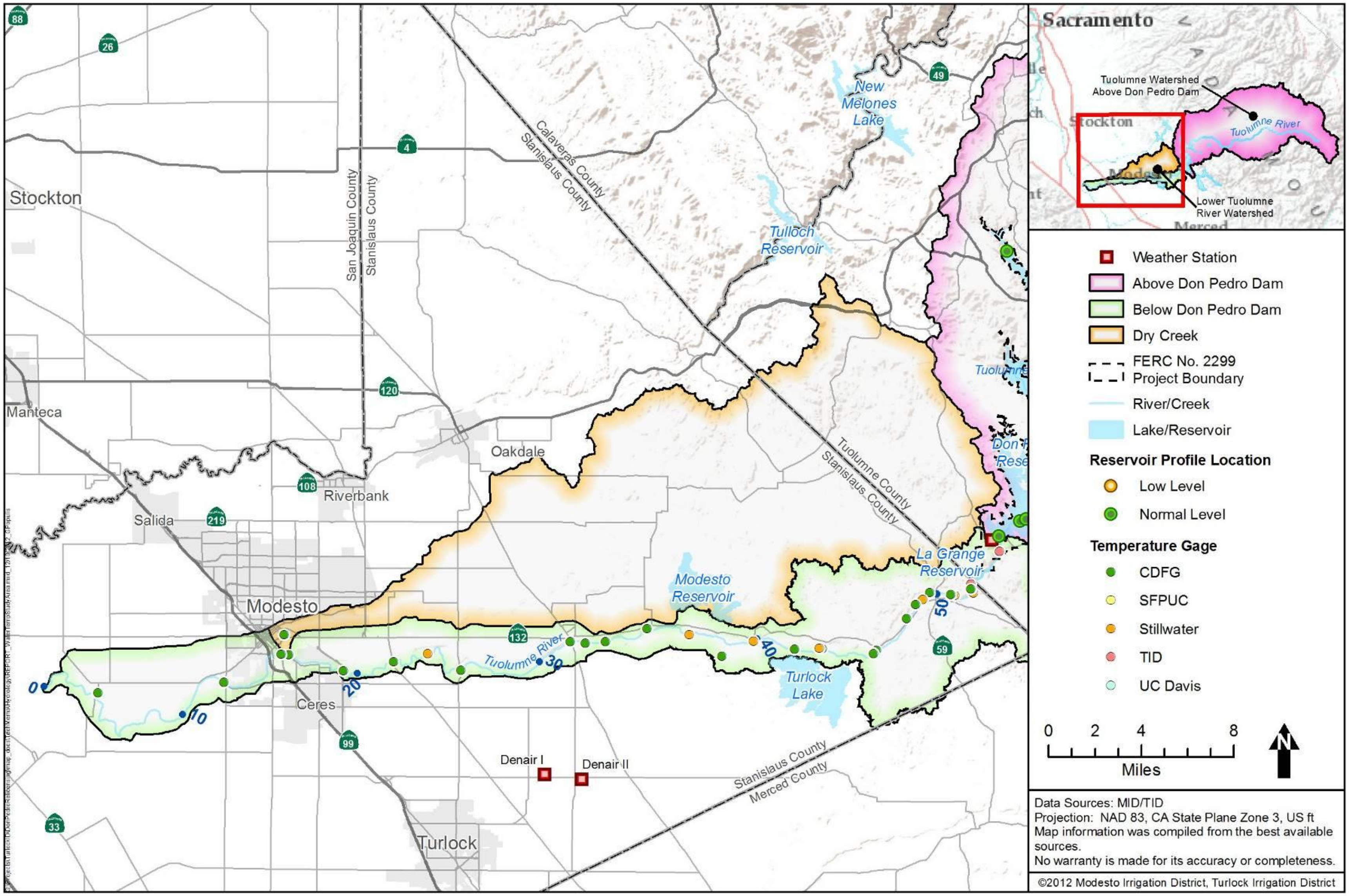


Figure 3.0-1. Study area.

4.0 METHODOLOGY

4.1 Model Set Up

An existing HEC5Q model that encompasses a four river system, as shown in Figure 4.1-1, was the starting point of this study. This model is known as the SJR5Q model and was developed by AD Consultants (AD Consultants 2009).

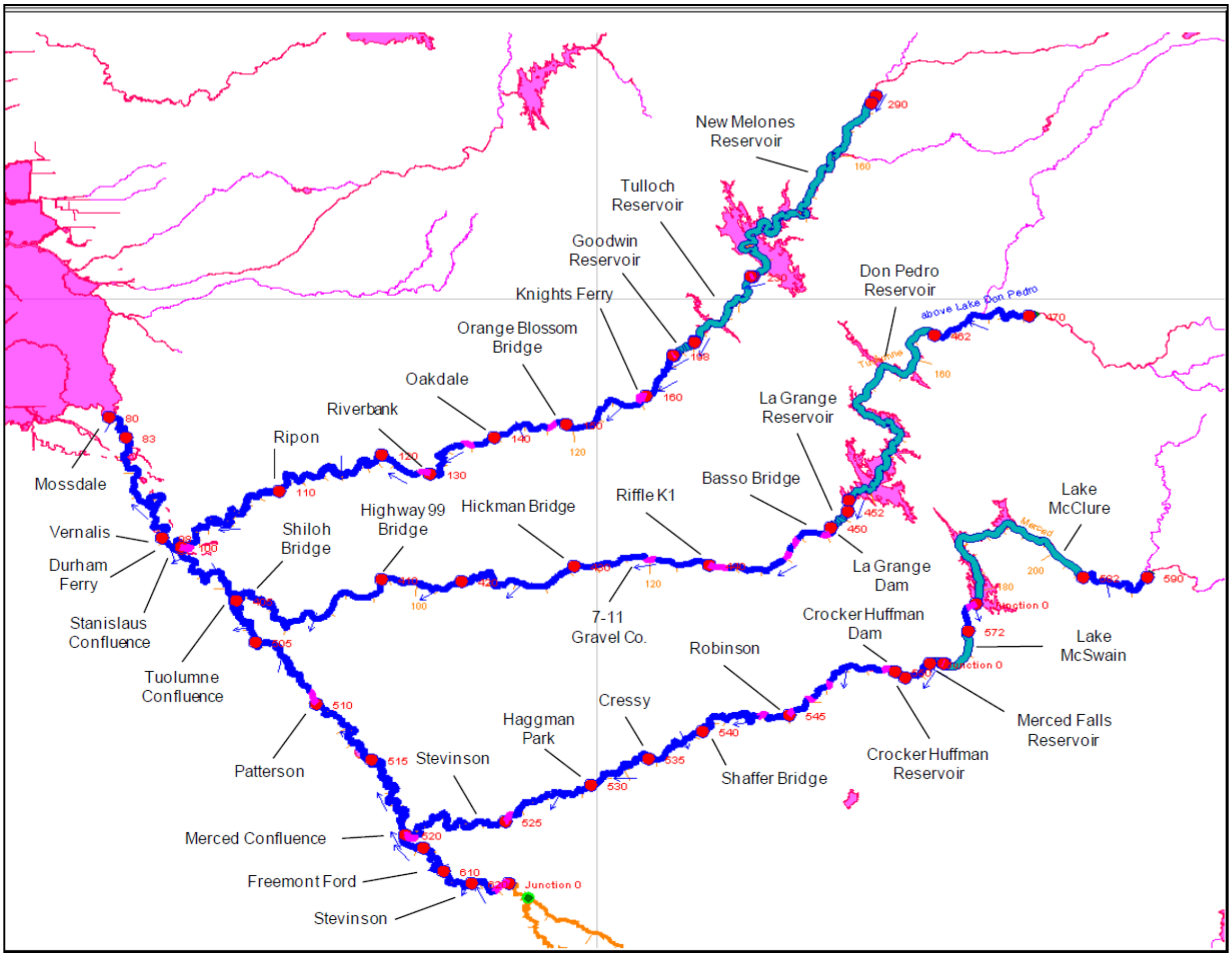


Figure 4.1-1. SJR5Q model coverage.

4.1.1 Model Refinements

The original SJR5Q model of the Tuolumne River began above the Don Pedro Dam and extended down to the confluence with the San Joaquin River, as shown in Figure 4.1-1. In accordance with the Study Plan, the river model was to only include the reach downstream of the Don Pedro Dam, with a separate reservoir model being used for the upstream reservoir. These changes were made and the new domain of the model is shown in Figure 4.1-2. Figure 4.1-2 also shows the irrigation diversion at La Grange Dam and the inflow at Dry Creek. These were part of the original model and were not changed as part of this study, i.e. no other inflows or diversions were added.

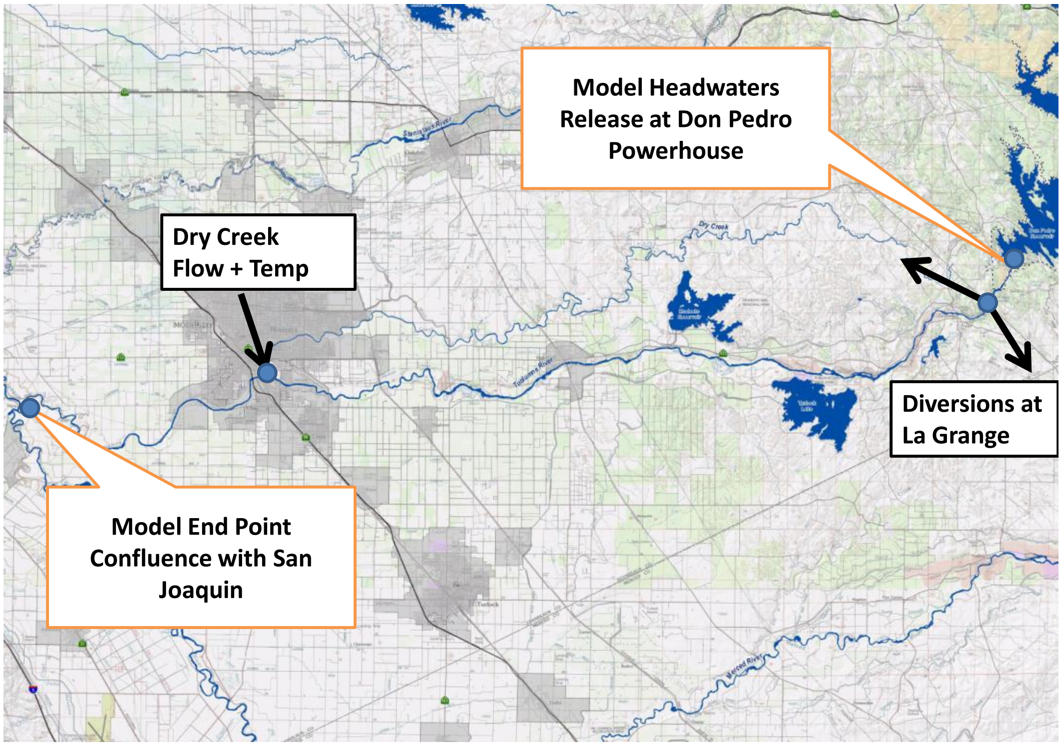


Figure 4.1-2. Modified lower Tuolumne River model domain.

4.2 Model Computations

4.2.1 Hydraulics

The SJR5Q model has inflows and outflows specified. Inflows occur at the upstream start of the model at Don Pedro Dam and Dry Creek where it enters the Tuolumne at RM 16. Outflows occur at La Grange Dam as diversions by each of the Districts for irrigation and M&I water. The model uses Manning's Equation, shown below, to determine the velocity in the river. The model hydraulics use a six hour time step at 12am, 6am, 12pm and 6pm.

Manning's Equation: $$V = 1.49/n\ R_H^{2/3}\ S^{1/2}$$

where:

V	river velocity	(ft/s)
n	riverbed roughness coefficient	
R_H	hydraulic radius	(ft)
S	slope of river	

The model uses a representation of the geometry of the river that includes the cross sectional areas, hydraulic radius, slope of the river at various points and varying Manning's n values. This information is in an input file called "S3_4R.dat".

The Don Pedro powerhouse outflows and temperature are read into the model in the binary file "4RIVERS_TEMP.DSS", where DSS stands for Data Storage System. This represents the starting flow rate and temperature for the river model. The diversions at La Grange Dam are also specified in this file. The diversion flow represents the combined diversion of both Districts.

The flow and temperature of the releases from Don Pedro Reservoir for 2011 are shown below in Figures 4.2-1 and 4.2-2. Dry Creek flows and temperature were recorded by the USGS and are shown in Figures 4.2-3 and 4.2-4. There is a data gap from 9/13/2011 to 2/15/2012 for Dry Creek temperatures. These were filled in using 2010 data.

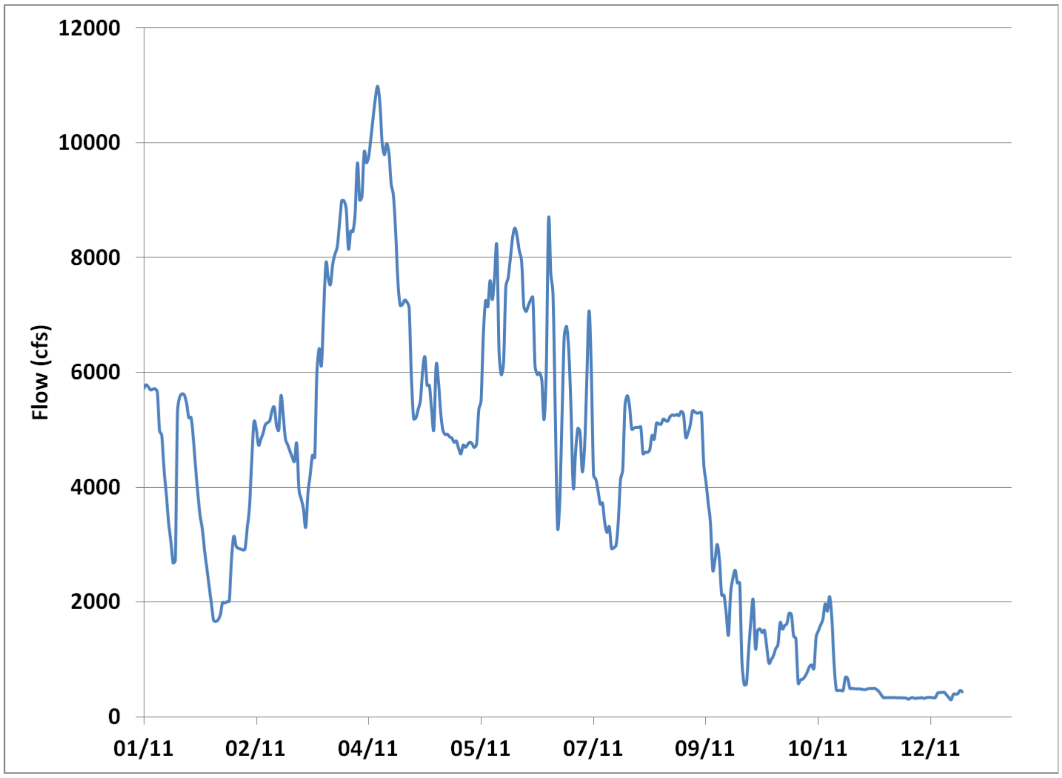


Figure 4.2-1. Don Pedro releases 2011.

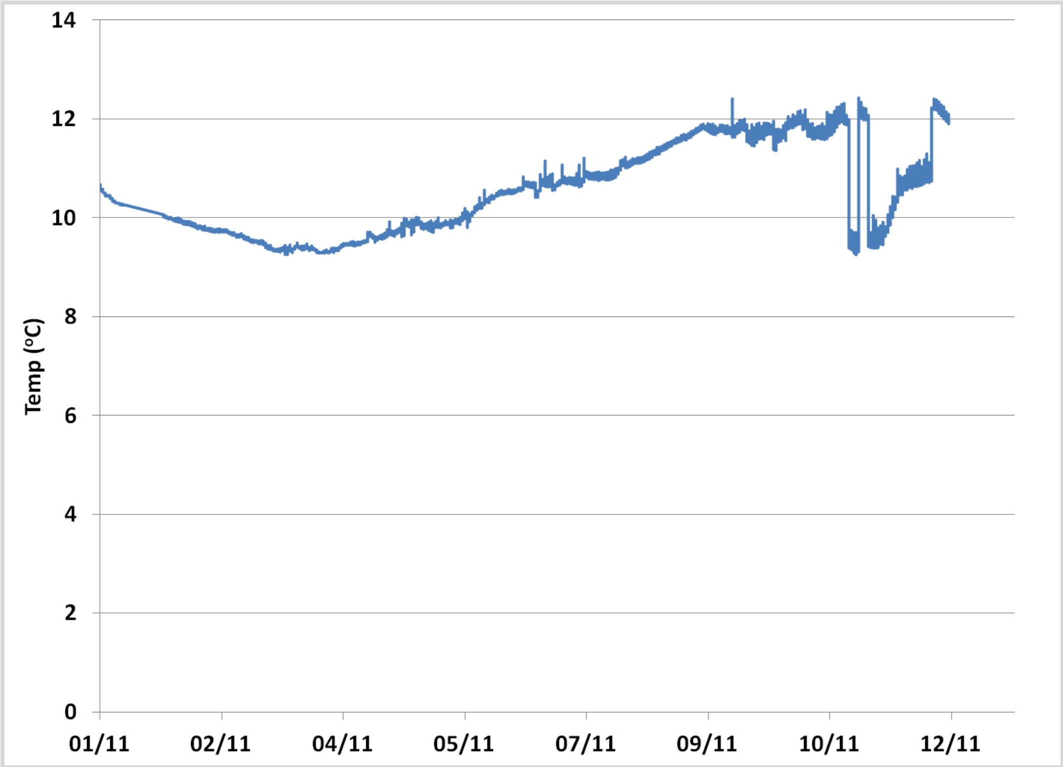


Figure 4.2-2. Don Pedro release temperature 2011.

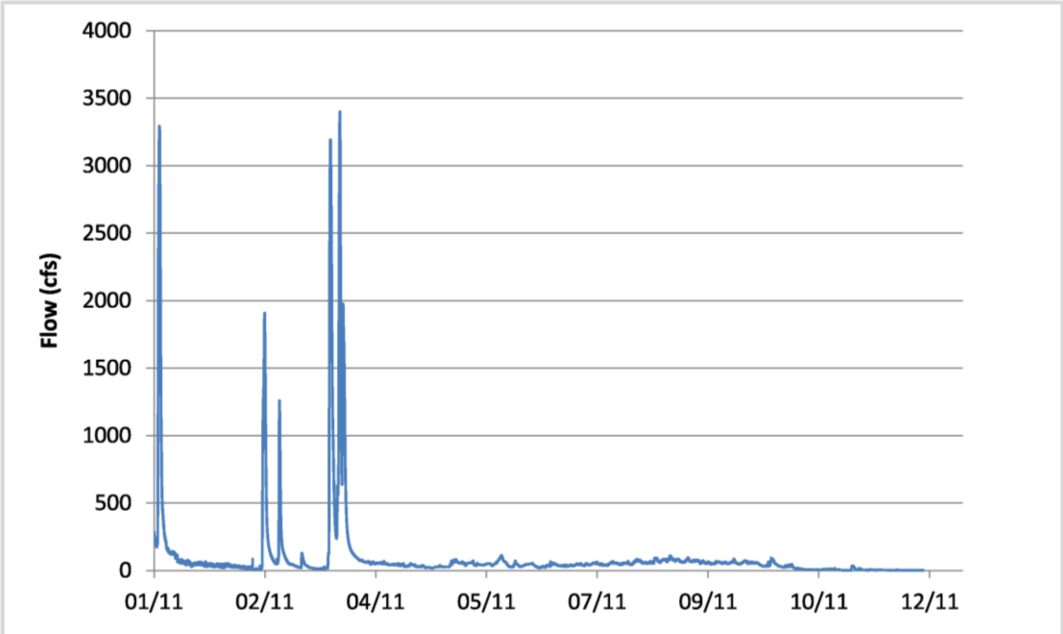


Figure 4.2-3. Dry Creek flow 2011.

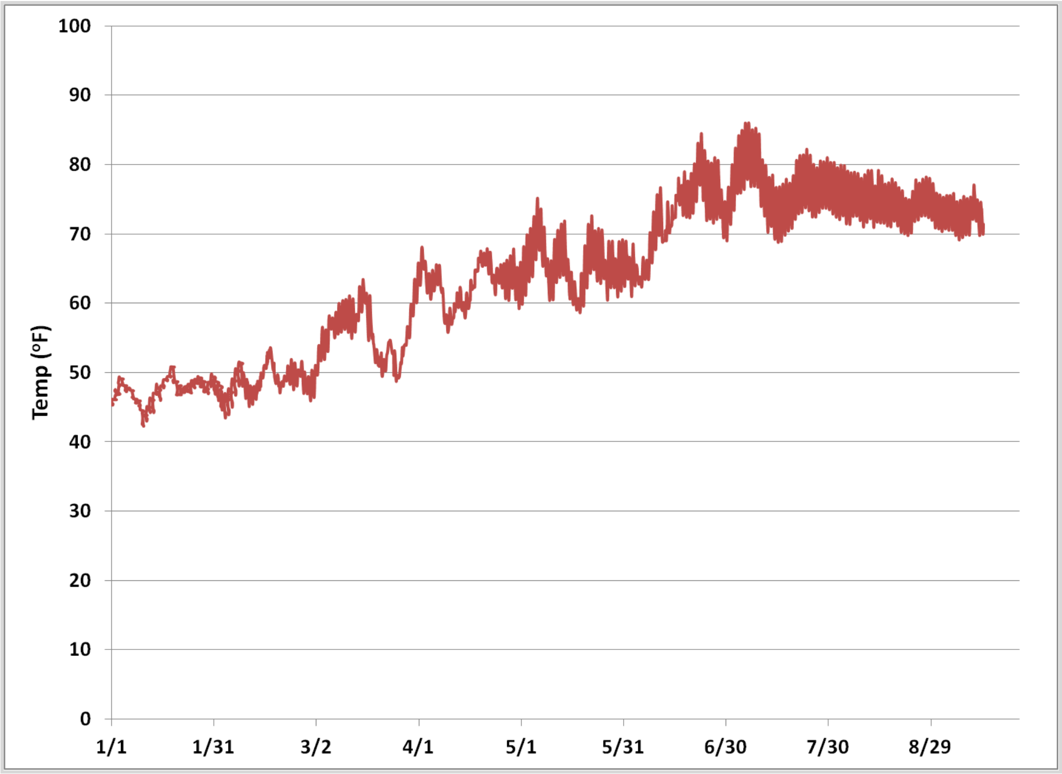


Figure 4.2-4. Dry Creek temperature 2011.

4.2.2 Temperature

The SJR5Q model calculates water temperature in six hour time steps at 12 am, 6 am, 12 pm and 6 pm. The model computes a heat balance on the water in the river by adding heat that enters across the water surface. If heat exits across the surface then the water cools. This is commonly known as heat exchange or heat transfer at the surface. In this model the heat transfer is expressed as:

$$H = K_{ex} (T_e - T_w)$$

where:

H	heat transfer at surface	(kcal/m^2/s)
K_{ex}	heat exchange coefficient	
T_e	equilibrium temperature	(^{o}F)
T_w	water temperature	(^{o}F)

The heat exchange coefficient, K_{ex}, is time variable. It is related to the air temperature and is usually lower at night and higher during the day. This is read into the model through the binary file “4RIVERS_TEMP.DSS”.

There are many formulations in practice to compute the equilibrium temperature, T_e. The most common expression is:

$$T_e = T_d + R/K$$

where:

T_d	dewpoint temperature	(^oC)
R	solar radiation	(W/m^2)
K	surface heat exchange coefficient	($W/m^2/^oC$)

This will give the equilibrium temperature in ^oC, which is then converted to ^oF before being used in the model. Solar radiation data was available from the Districts' station at Crocker Ranch, adjacent to Turlock Lake (see next section for details). The equilibrium temperature is read into the model through the binary "4RIVERS_TEMP.DSS" file.

4.3 Monitoring Data

Model input includes Don Pedro Reservoir outflows, and their temperatures, to the Tuolumne River. Temperature monitoring data used for this study, as well as a complete inventory of historical data, can be found in Attachment A of the Reservoir Temperature Model (TID/MID 2013). Don Pedro outflow temperatures have been measured since mid-2010, therefore, 2011 was chosen as the calibration year, as this would be the first full year with all the required information. For 2011 there were 20 temperature monitoring locations along the river that had complete, or nearly complete, temperature records. These are shown in Figure 4.3-1. Of these 20 stations, 12 are California Department of Fish and Game (CDFG) sites, and eight are the Districts' (TID/MID). These are listed below in Table 4.3-1 by river mile, in descending order.

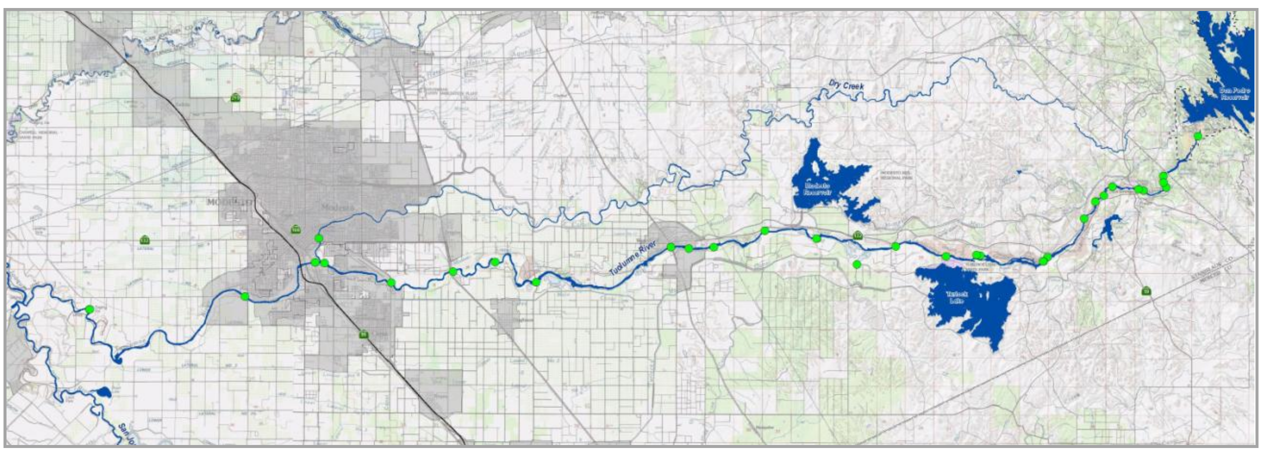


Figure 4.3-1. Temperature monitoring locations.

Table 4.3-1. Temperature monitoring locations.

Source	Location	
TID/MID	La Grange Dam USGS	RM 51.8
CDFG	Riffle A1	RM 51.6
TID/MID	Riffle A7	RM 50.7
CDFG	Riffle C1	RM 49.7
TID/MID	Riffle 3B	RM 49.1
CDFG	Riffle D2	RM 48.8
CDFG	Basso Bridge	RM 47.5

Source	Location	
TID/MID	Riffle 13B	RM 45.5
TID/MID	Riffle 21	RM 42.9
CDFG	Riffle K1	RM 42.6
TID/MID	Roberts Ferry Bridge	RM 39.5
CDFG	Riffle Q3	RM 35.0
CDFG	Above Hickman Spill	RM 33.0
CDFG	Below Hickman Spill	RM 32.0
CDFG	Fox Grove Bridge	RM 26.0
TID/MID	Hughson WWTP	RM 23.6
CDFG	Mitchell Road Bridge	RM 19.0
CDFG	Ninth Street Bridge	RM 16.1
TID/MID	Shiloh Bridge	RM 3.5
CDFG	Shiloh Bridge	RM 3.5

The meteorological data used in the model came from the Districts' MET station at Crocker Ranch, as shown in Figure 4.3-2. The 2011 data for air temperature, solar radiation and dewpoint temperature are shown in Figures 4.3-3 through 4.3-5.

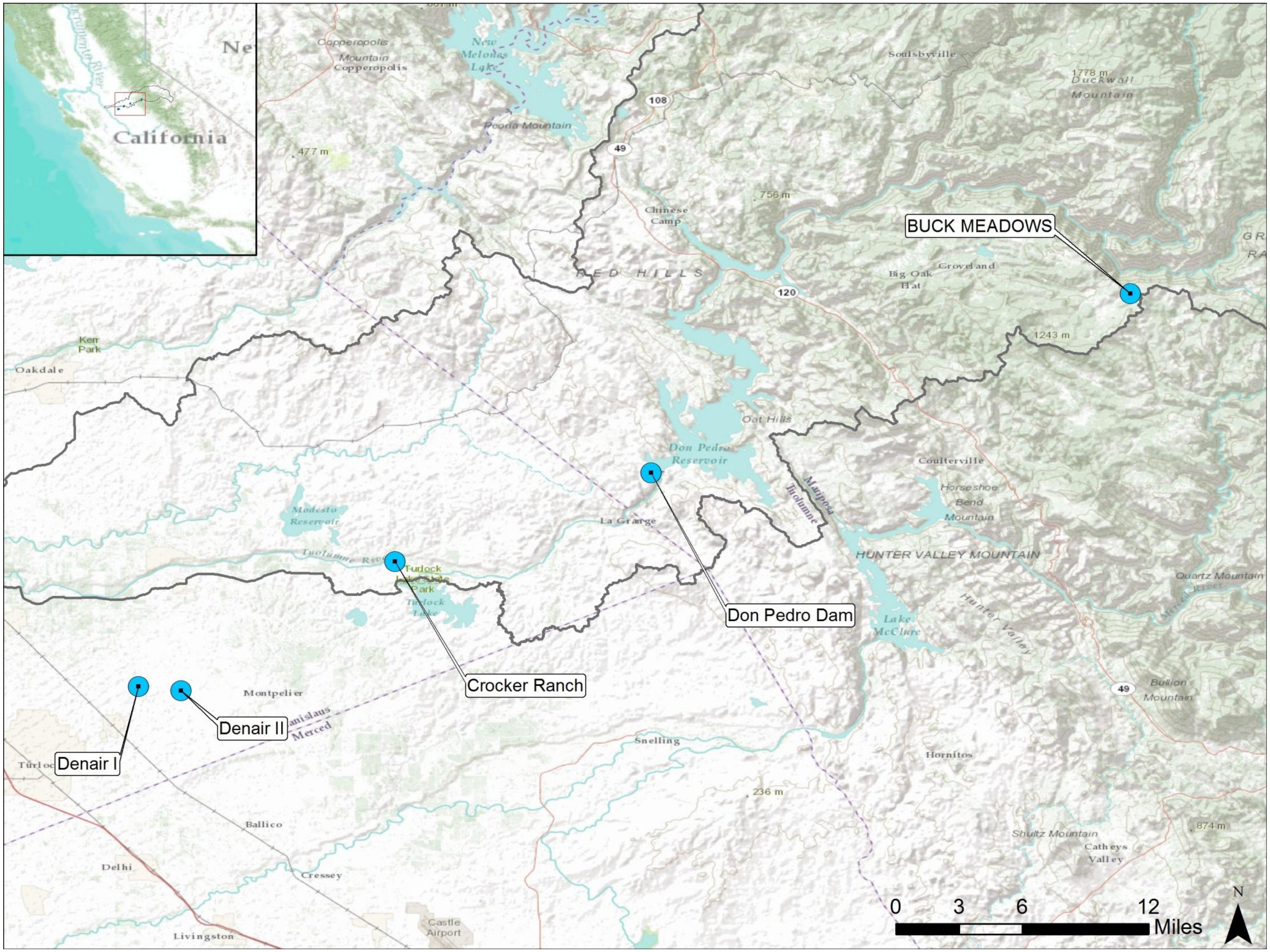


Figure 4.3-2. Location of meteorological stations.

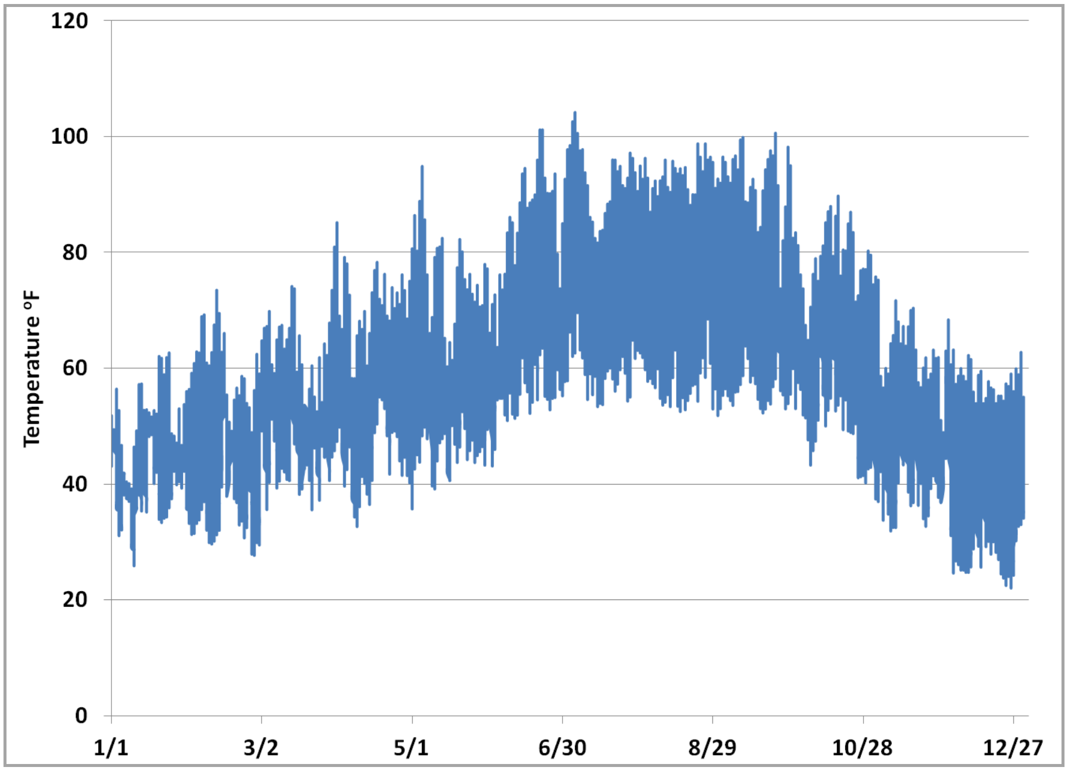


Figure 4.3-3. Crocker Ranch air temperature for 2011.

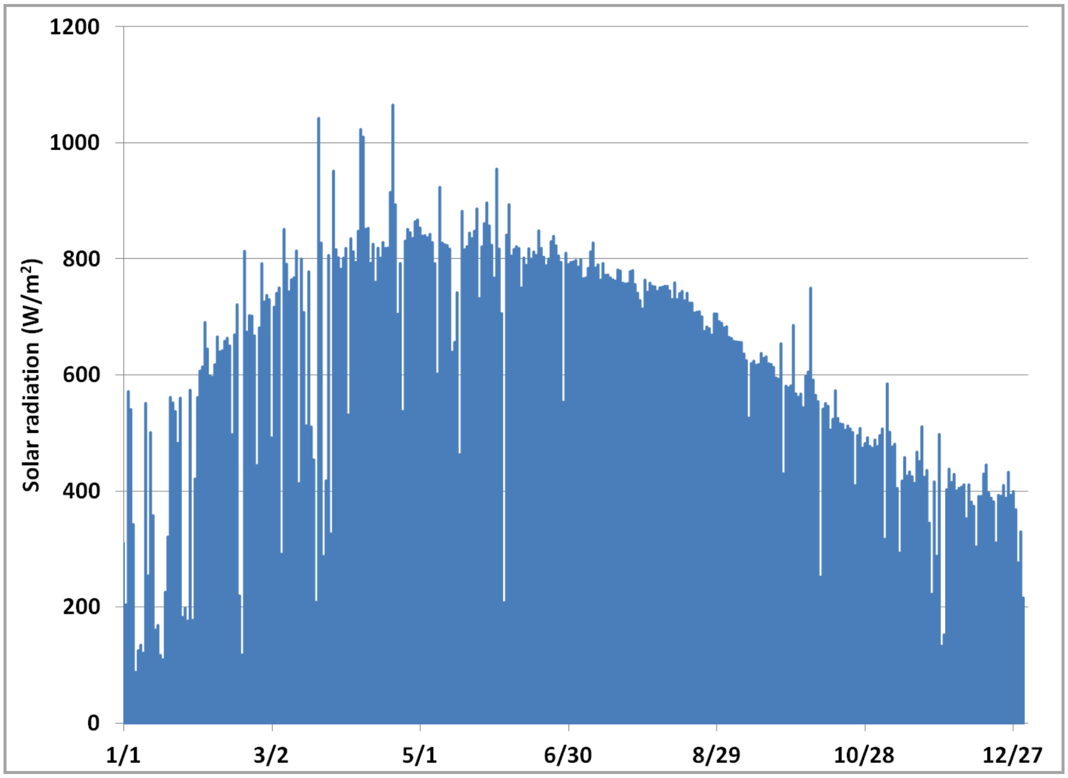


Figure 4.3-4. Crocker Ranch solar radiation for 2011.

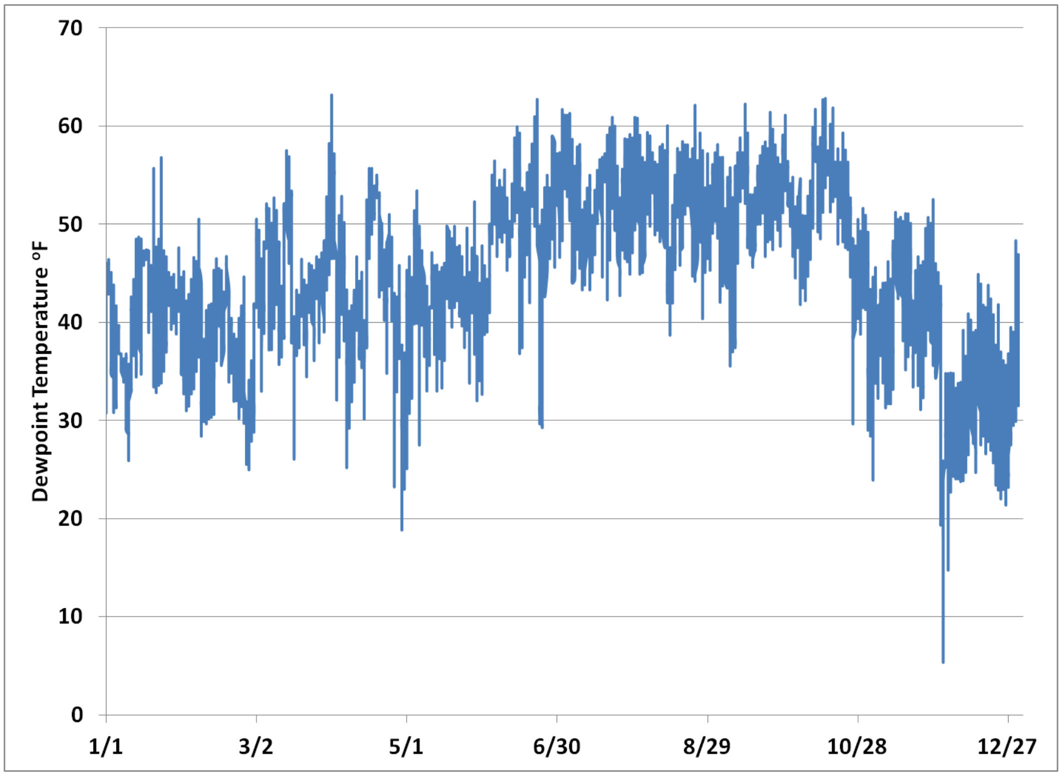


Figure 4.3-5. Crocker Ranch dewpoint temperature for 2011.

5.0 RESULTS

5.1 Calibration Results

The calibration results applying the SJR5Q model to 2011 conditions are shown in Figures 5.1-1 through 5.1-5. The monitoring data are hourly, and are shown in black. The model output is every six hours and is shown in red. Overall it can be seen that the model does a reasonable job of reproducing the measured data. The small annual and diurnal range seen closest to Don Pedro Reservoir reflects 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.

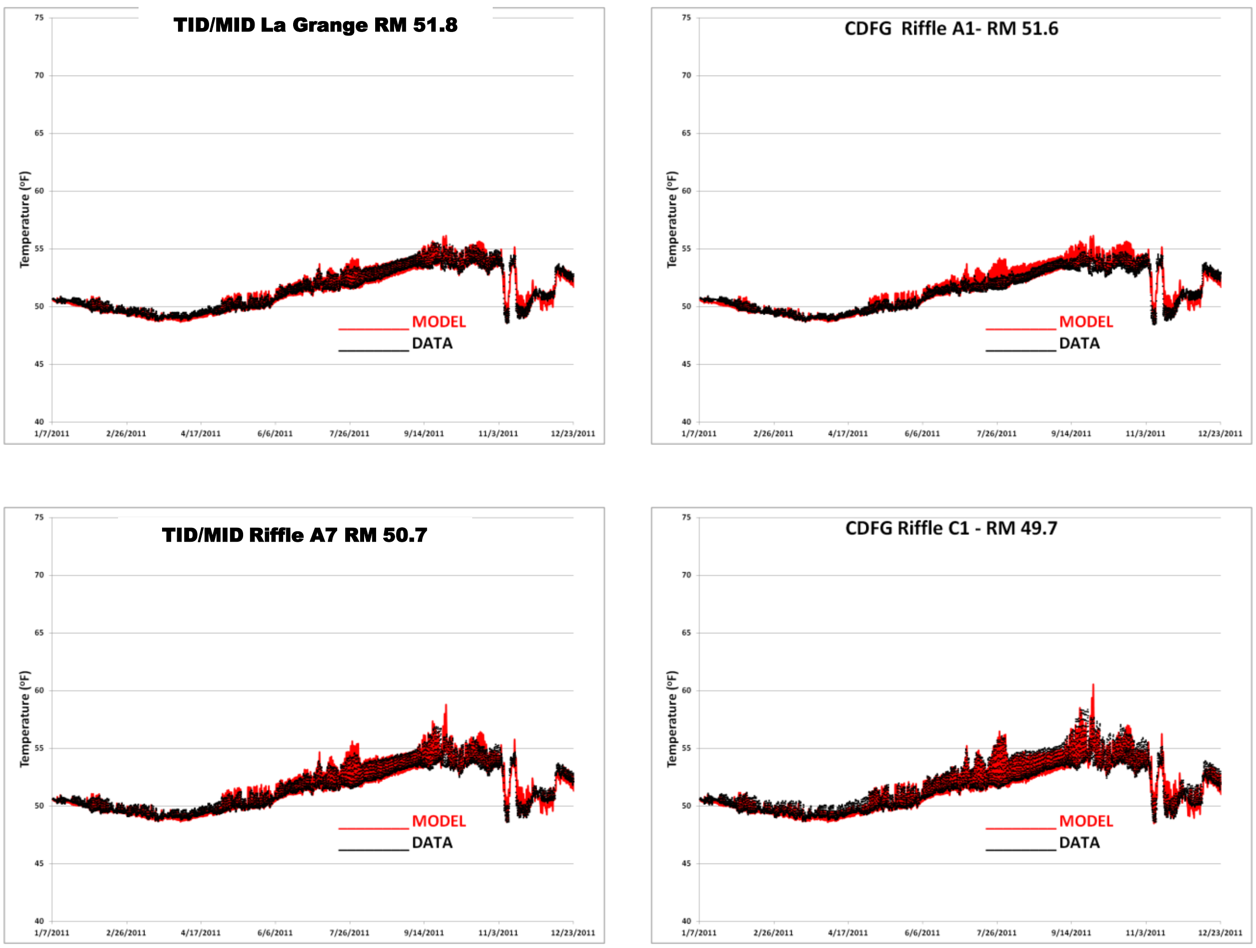


Figure 5.1-1. Calibration results for 2011, RM 51.8 to 49.7.

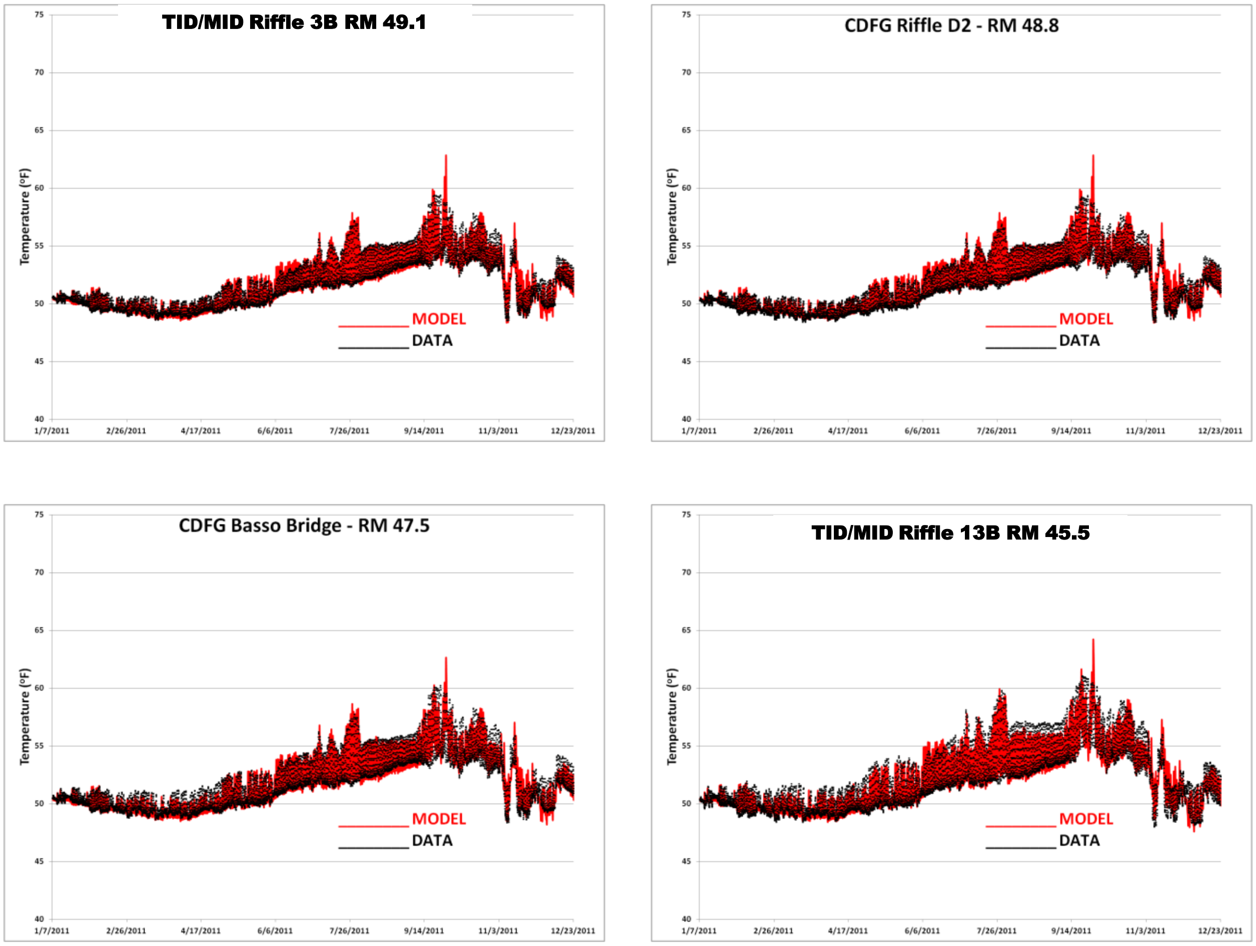


Figure 5.1-2. Calibration results for 2011, RM 49.1 to 45.5.

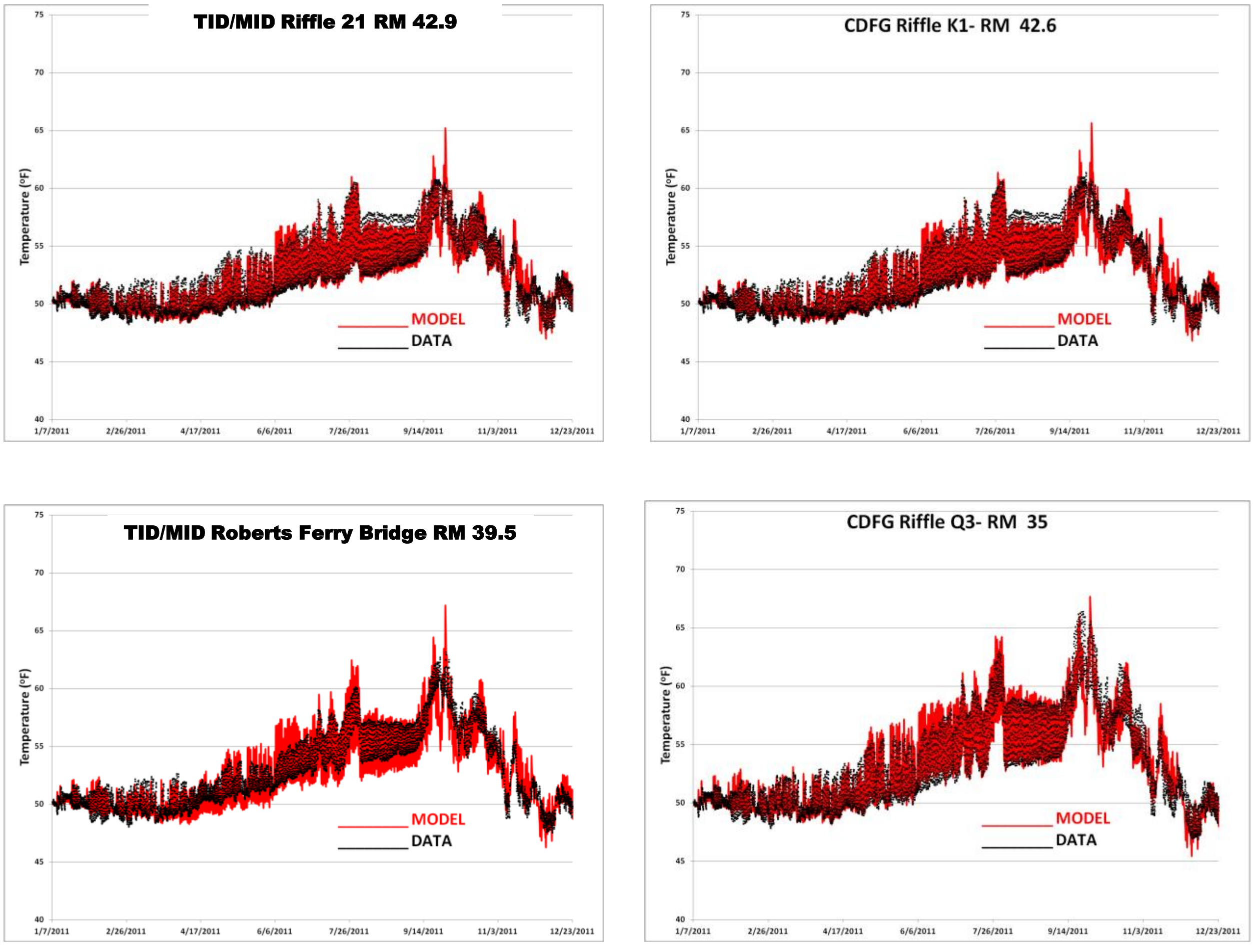


Figure 5.1-3. Calibration results for 2011, RM 42.9 to 35.

The model tracks the data reasonably well until about RM 33 when the diurnal range in the data decreases noticeably and unexpectedly. At the next station, less than a mile downstream, the range expands, before substantially decreasing again at RM 26 through 16.1. The model remains consistent in its response throughout the entire length of the river by predicting a relatively large diurnal range and does not pick up these smaller diurnal fluctuations. The model is acting as expected as the model is not receiving any changes in input data that might cause it to predict significant variations in temperatures over short reaches of the river. This is evidence that other factors are affecting water temperature than just those variables included in the model.

This phenomenon is explored later, in Section 5.2.

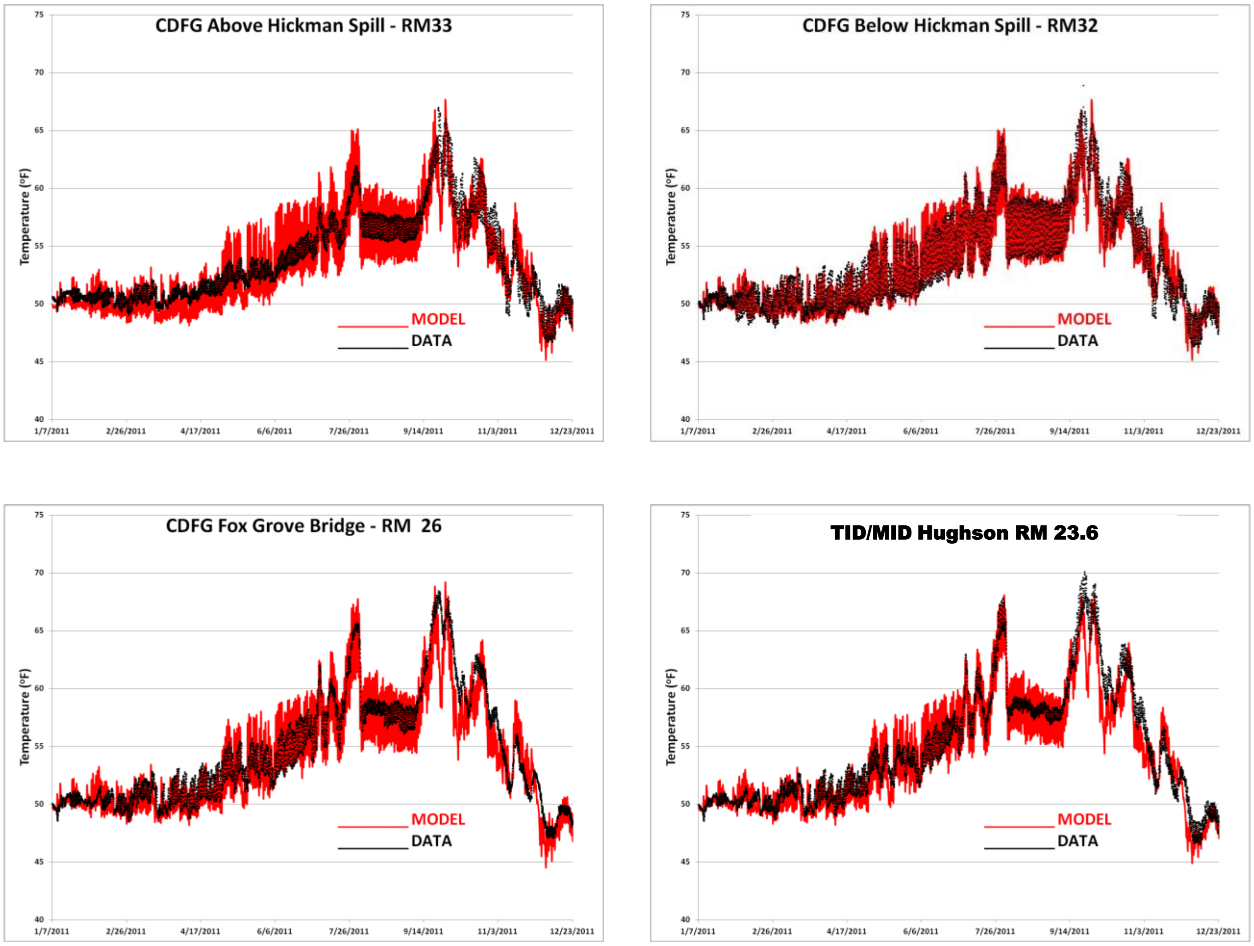


Figure 5.1-4. Calibration results for 2011, RM 33 to 23.6.

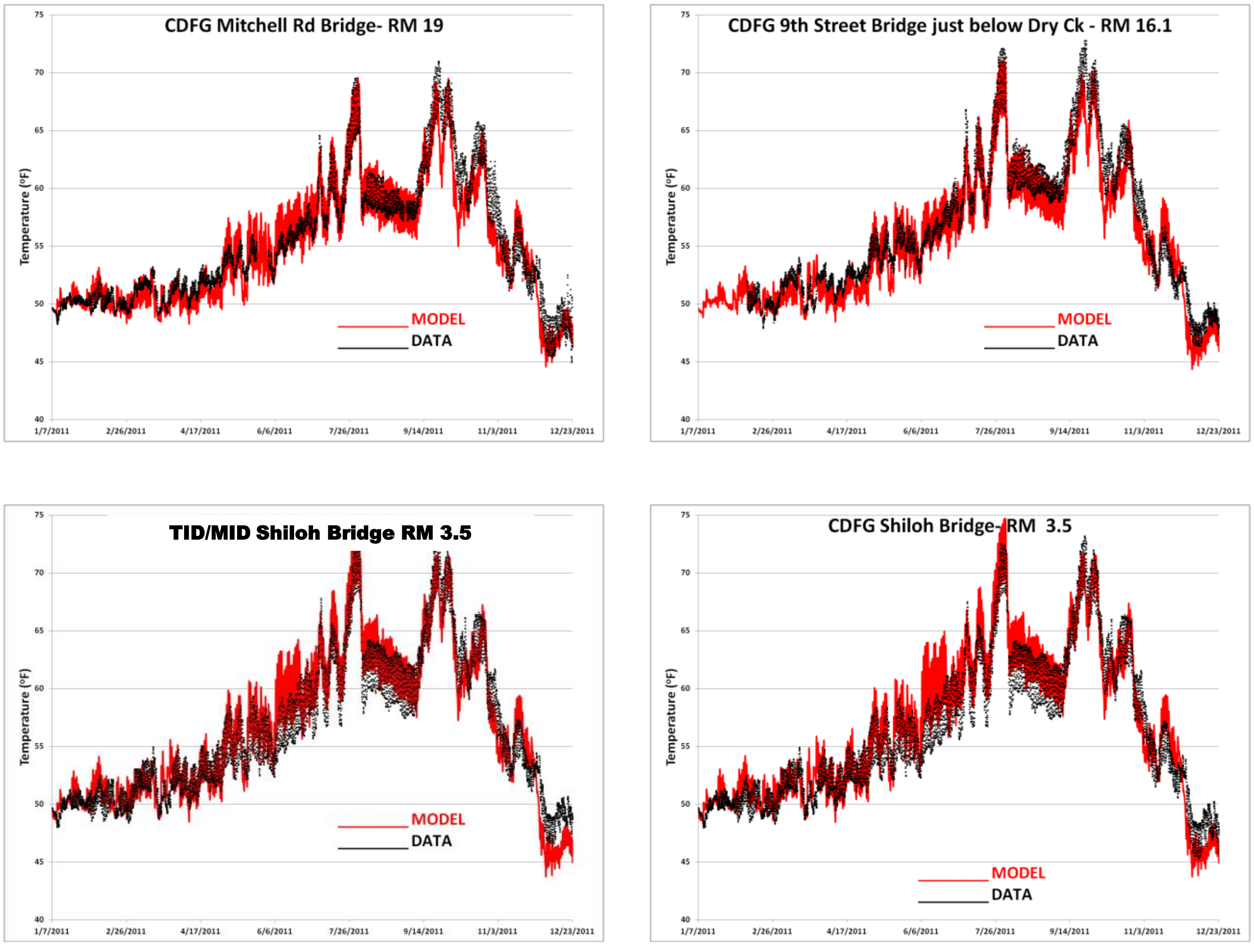


Figure 5.1-5. Calibration results for 2011, RM 19 to 3.5.

5.1.1 Calibration Statistics

The model calibration statistics are presented below in Table 5.1-1. The results are tabulated for each site and includes the coefficient of determination (r^2); and the percent of data within 0.9 ^oF, 1.8 ^oF and 2.7 ^oF (0.5 ^oC, 1 ^oC and 1.5^oC) of the computed model temperature. Only sites with complete, or nearly complete, data for the full year were considered. Table 5.1-1 shows the model has a strong correlation to the data, with most sites having an r^2 of more than 0.9, and an average for all sites of more than 0.9. The coverage results show that on average 58 percent, 80 percent and 93 percent of the model results are with 0.5 ^oC, 1 ^oC and 1.5^oC. The comparison is made using the model computed temperature every six hours with the recorded temperature at that time, e.g. model computed temperature at 6am is compared to the measured temperature at 6am.

The last column reports what percentage of the model values at each site were above the measured values. This is a method to evaluate if the model is systematically biased, i.e. is either consistently above or below the measured data. A value of 50 percent would mean that half the model values were above the data and half the model values were below the data. This would indicate no bias. The results show a mix of sites both above and below the data, with an average of all sites of 47 percent. This is an indication that the model is not systematically biased.

Table 5.1-1. Model calibration statistics 2011.

		Percent Coverage			percent above
Site	**r^2**	**+/-0.9F**	**+/-1.8F**	**+/-2.7F**	**observed**
TID/MID La Grange	0.97	94%	99%	100%	28%
CDFG Riffle-A1 (to 12/22)	0.89	81%	96%	99%	52%
TID/MID Riffle A7	0.95	91%	98%	100%	32%
CDFG Riffle-C1	0.95	88%	98%	100%	37%
TID/MID Riffle 3B	0.94	85%	97%	99%	36%
CDFG Riffle - D2	0.95	85%	96%	99%	64%
CDFG Basso Bridge	0.94	82%	95%	99%	46%
TID/MID Riffle 13B	0.89	61%	84%	96%	39%
CDFG Riffle - K1	0.88	51%	77%	92%	49%
TID/MID Riffle 21	0.87	51%	76%	93%	35%
TID/MID Roberts Ferry Br	0.85	37%	69%	88%	36%
CDFG Riffle Q3	0.92	54%	75%	88%	60%
CDFG Above Hickman Spill	0.87	25%	58%	84%	52%
CDFG Below Hickman Spill	0.90	44%	66%	83%	49%
CDFG Fox Grove Bridge	0.91	28%	58%	81%	52%
TID/MID Hughson	0.93	36%	65%	87%	41%
CDFG Mitchell Rd Bridge	0.95	40%	71%	89%	58%
CDFG 9th St bridge - just below Dry Ck (from 2/8)	0.96	46%	77%	94%	44%
CDFG Shiloh Bridge	0.96	41%	67%	87%	66%
TID/MID Shiloh Bridge	0.96	44%	66%	83%	41%
average	**0.92**	**58%**	**80%**	**93%**	**47%**

5.2 Observed Diurnal Variations

As mentioned previously in Section 5.1, the observed data shows some marked differences in the diurnal range from monitoring site to monitoring site. The annual average diurnal ranges per monitoring site are plotted in Figure 5.2-1 in descending river mile order. Note that even stations with incomplete data for 2011 are included here, e.g. Riffle I2, 7-11 Gravel, Santa Fe Gravel. The ranges for the summer months are plotted in Figure 5.2-2. Figure 5.2-3 shows the average summer range plotted on a river mile scale. 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. However, as the water passes Riffle I2 (RM 43.2) the range stops expanding and actually begins to decrease. From this point on the range fluctuates in a seemingly random manner for the rest of the river reach.

The data have been checked and there is no reason to believe that the data are in error. HDR and Districts' personnel visited every 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.

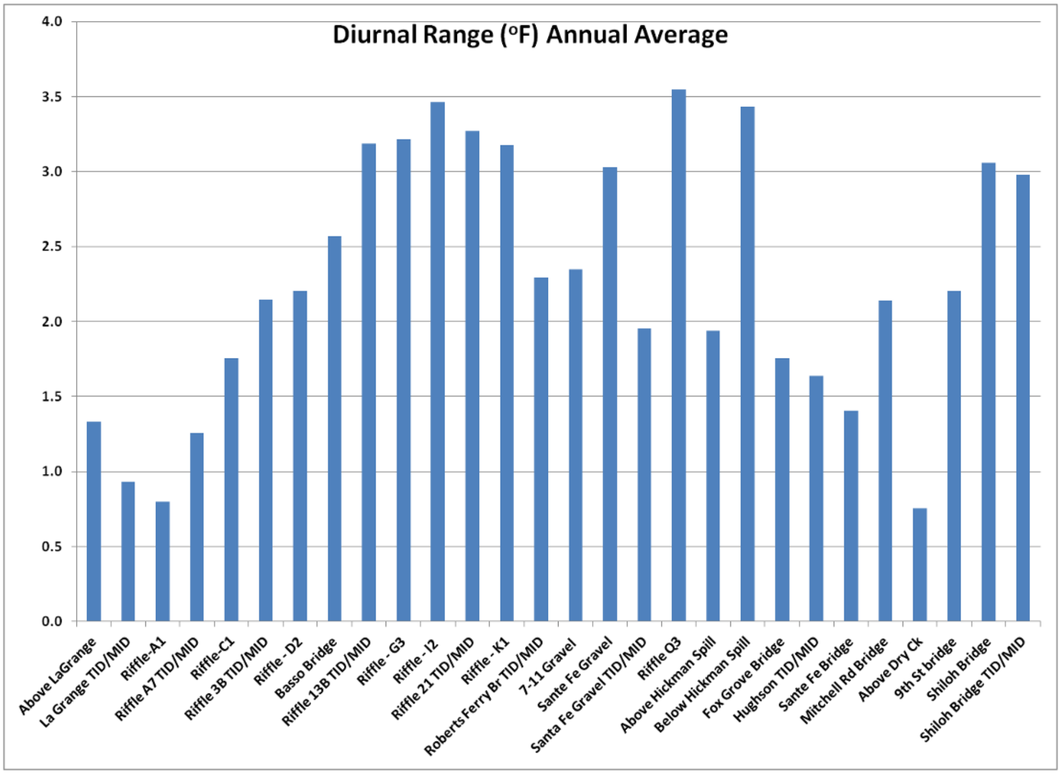


Figure 5.2-1. Annual average diurnal variation by site.

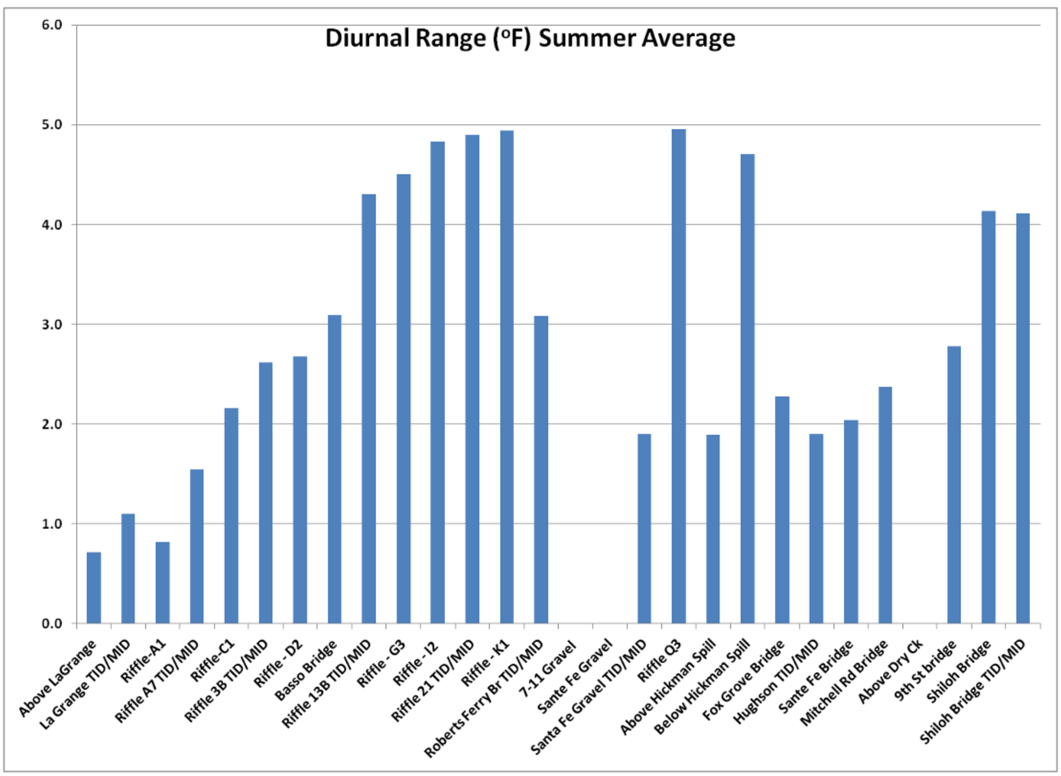


Figure 5.2-2. Summer average diurnal variation by site.

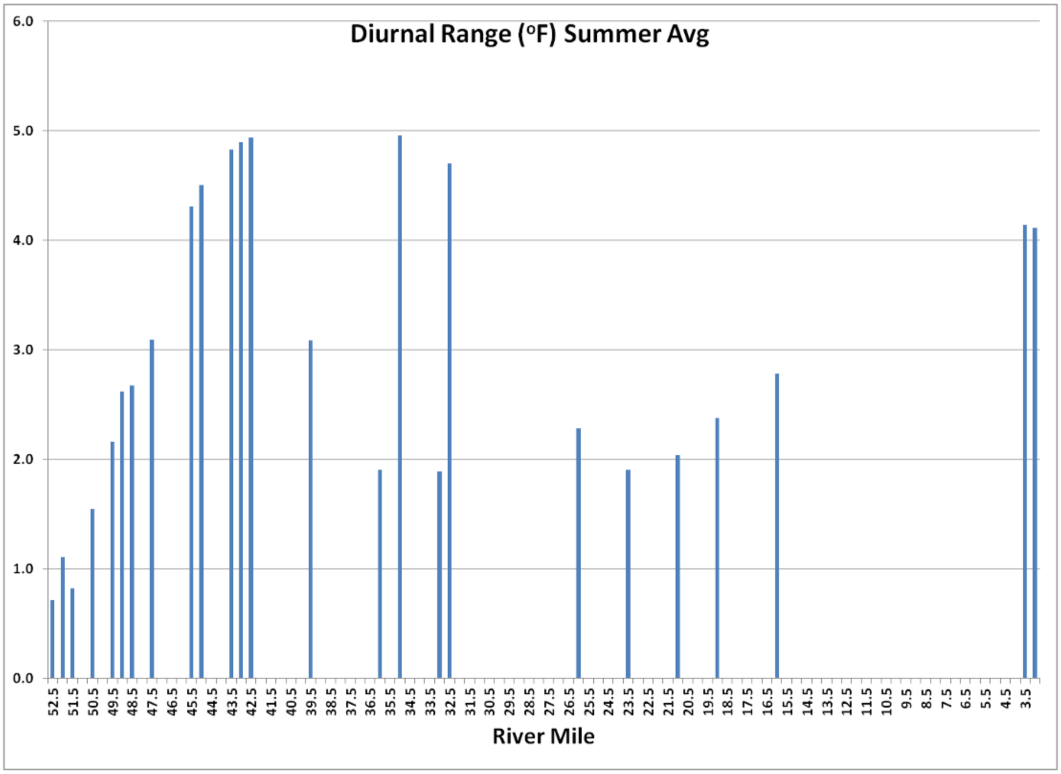


Figure 5.2-3. Summer average diurnal range at actual river location.

Figure 5.2-3 was replotted in Figure 5.2-4 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 5.2-5 is the same as Figure 5.2-4 with the location of the special run pools highlighted. It was speculated that the large thermal mass associated with these pools may also act to dampen the diurnal range.

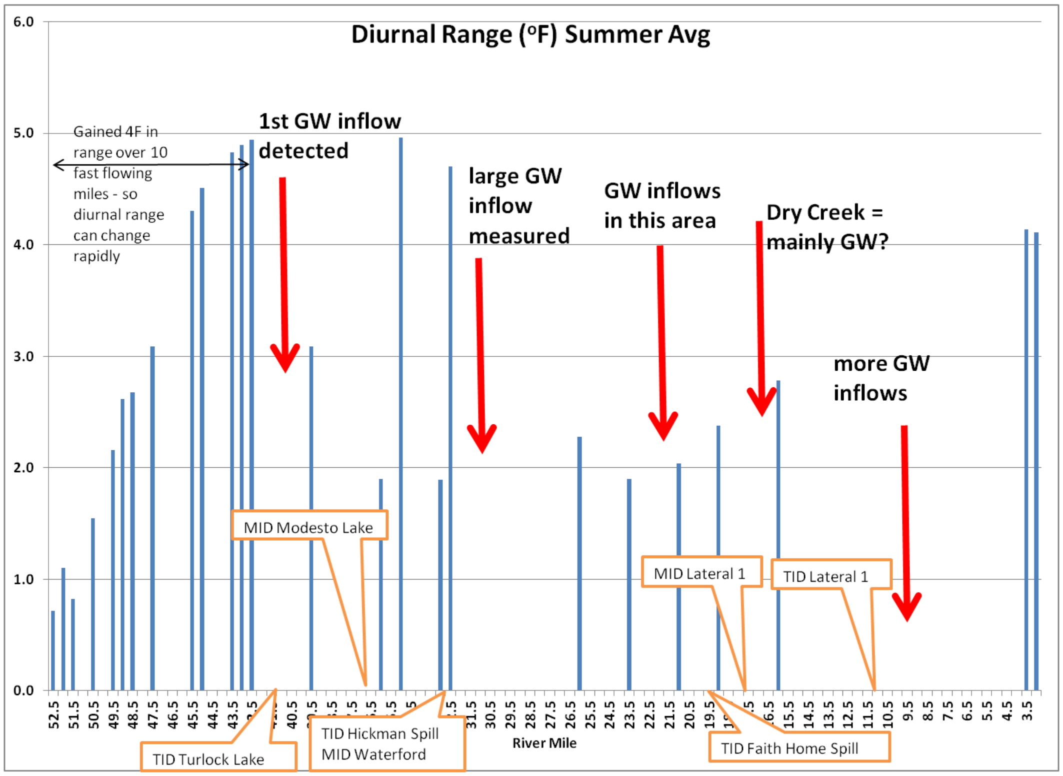


Figure 5.2-4. Summer average diurnal range at actual river location – annotated with return flow locations.

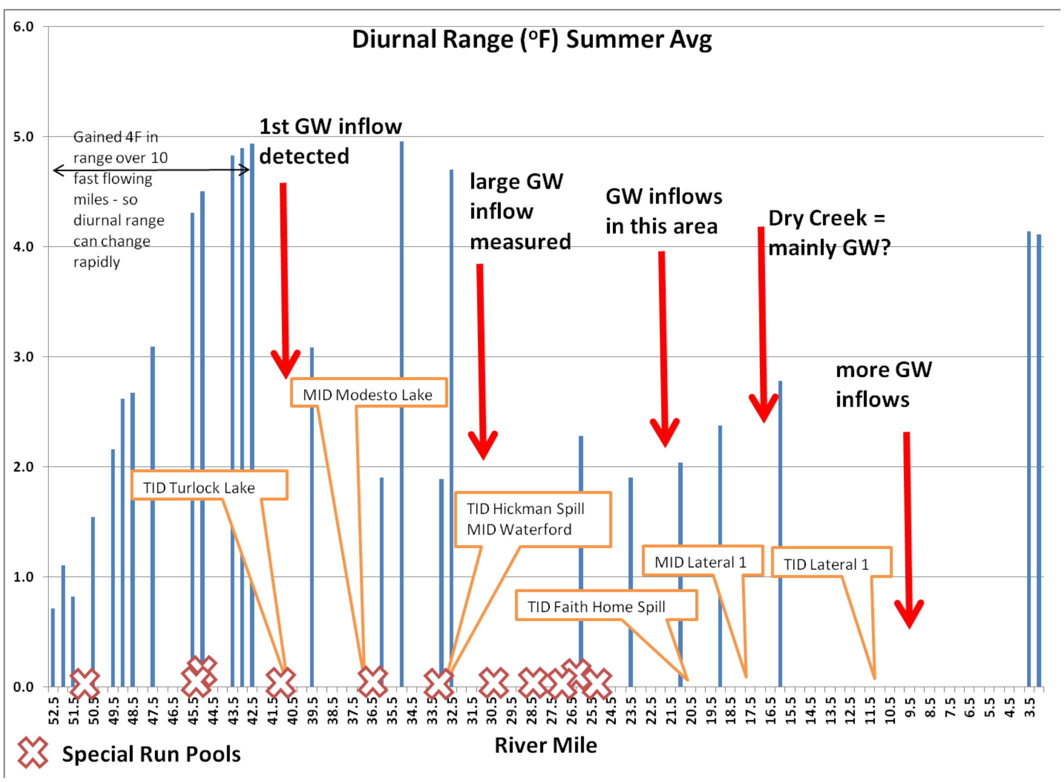
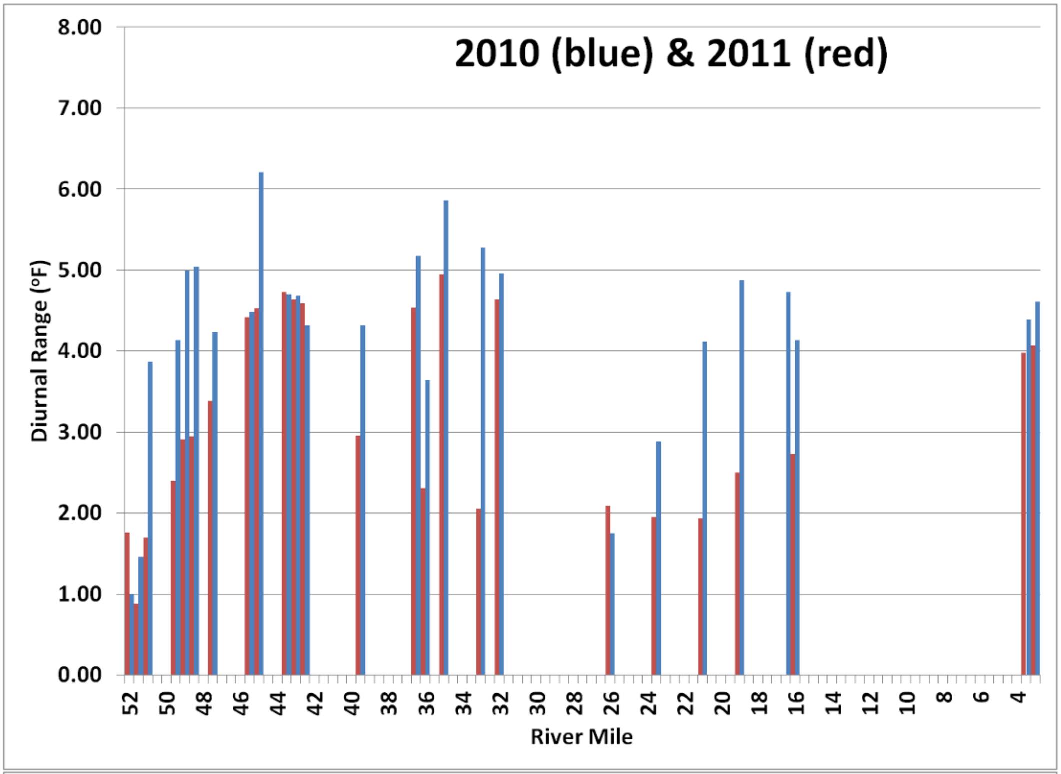


Figure 5.2-5. Summer average diurnal range– annotated with special run pools locations.

In an effort to examine whether the data for 2011 were an unusual case the annual and summer diurnal ranges for the last 10 years were compared to 2011. These are shown in Figures 5.2-6 to 5.2-15 in reverse chronological order. These data indicate that the smaller diurnal temperature fluctuations occurring in the downstream direction are observed each year, with considerable variation from one year to the next.



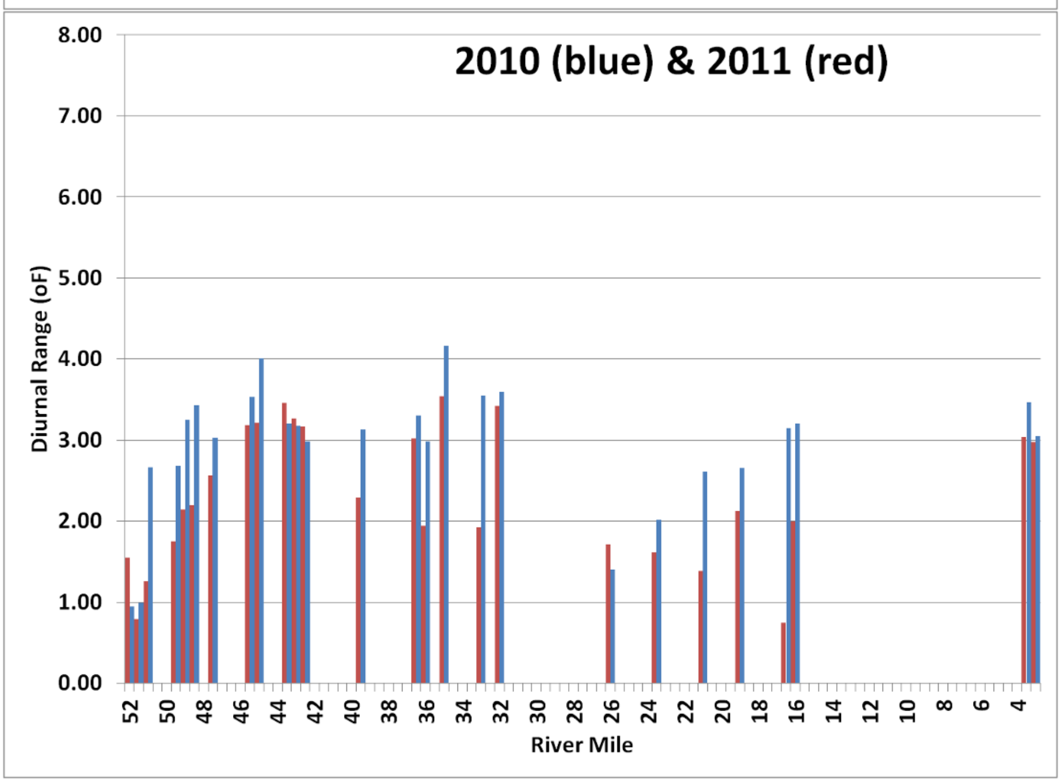


Figure 5.2-6. Comparison of 2011 and 2010 ranges (top=summer, lower=annual).

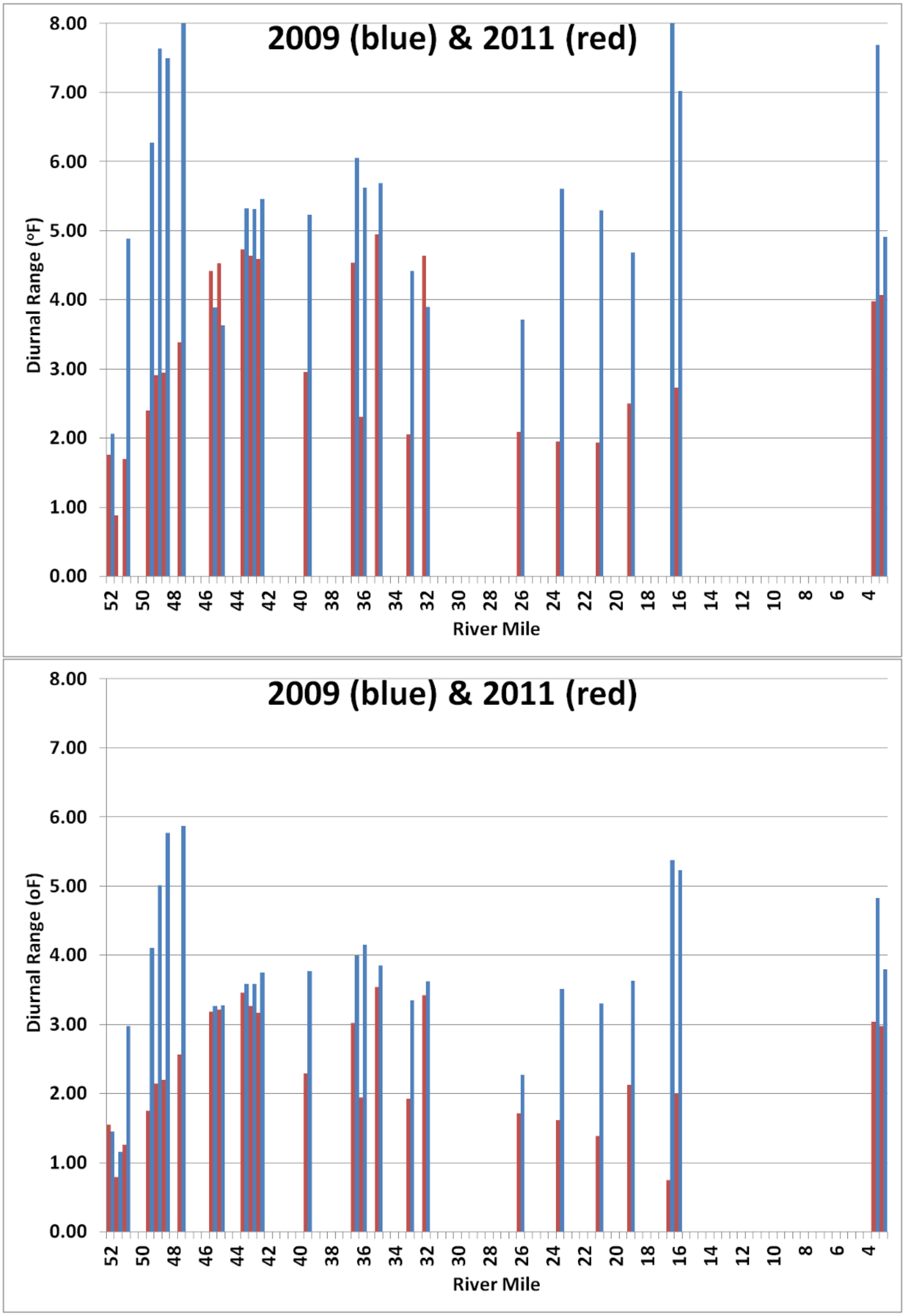


Figure 5.2-7. Comparison of 2011 and 2009 ranges (top=summer, lower=annual).

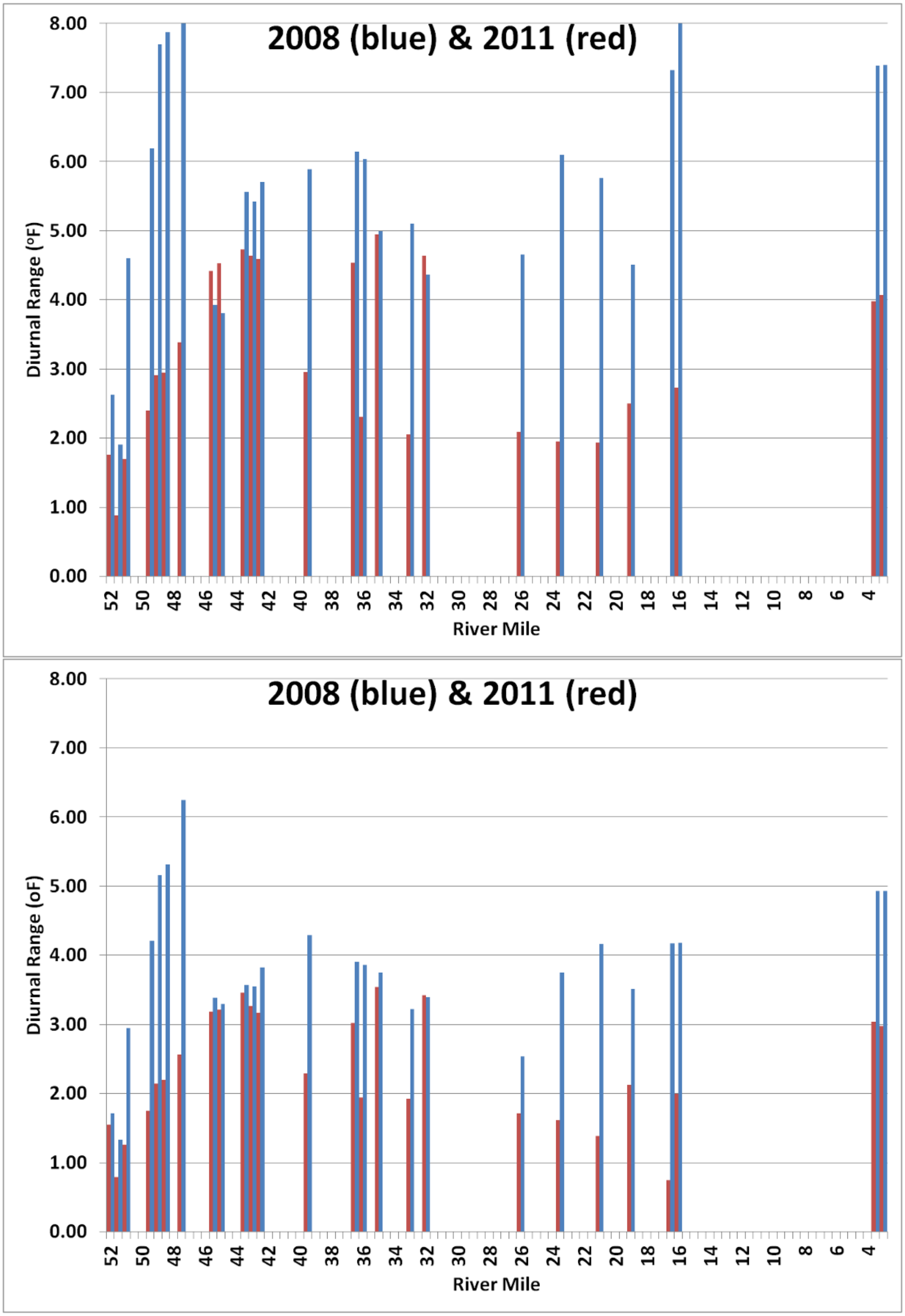
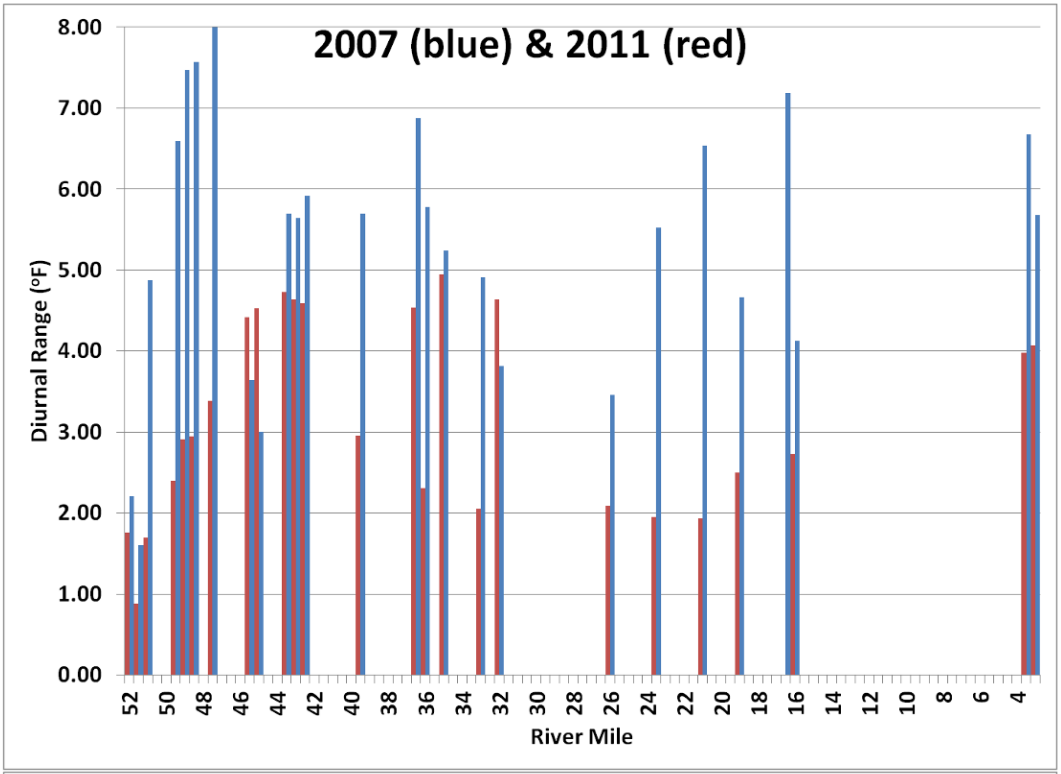


Figure 5.2-8. Comparison of 2011 and 2008 ranges (top=summer, lower=annual).



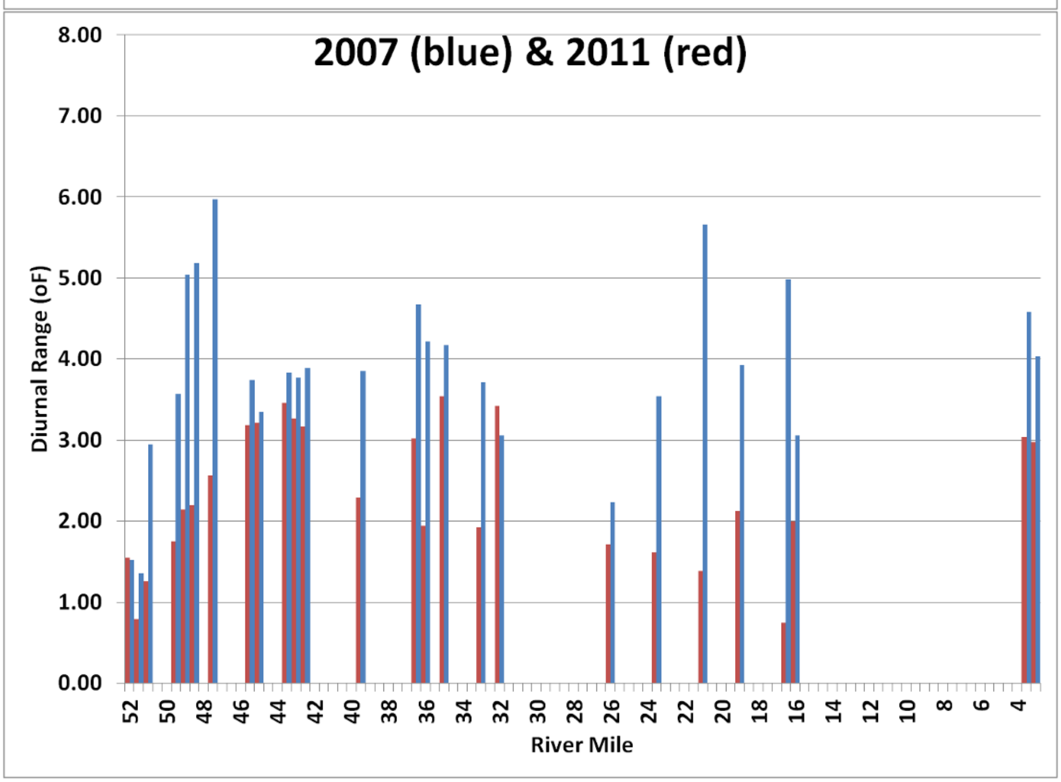


Figure 5.2-9. Comparison of 2011 and 2007 ranges (top=summer, lower=annual).

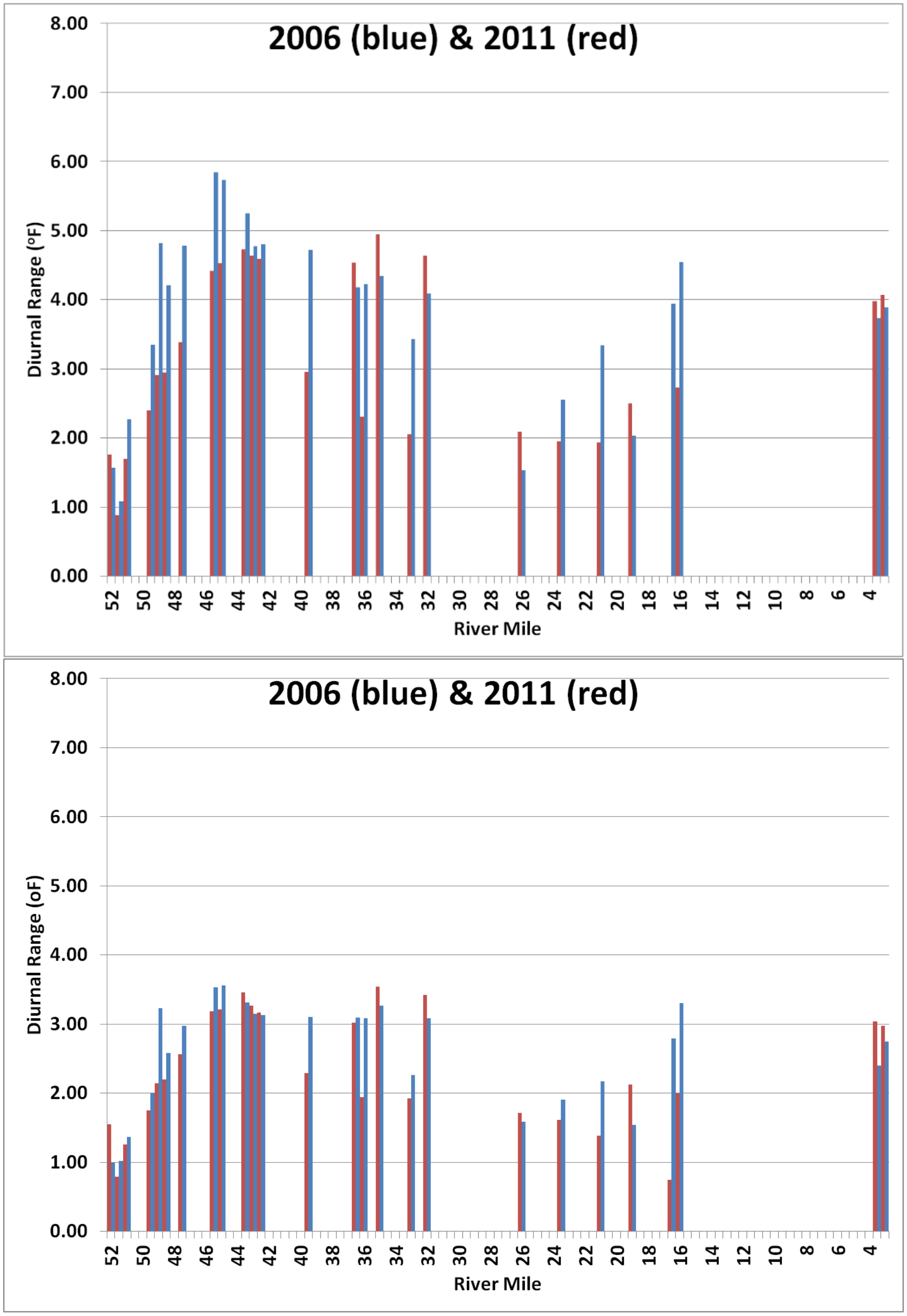


Figure 5.2-10. Comparison of 2011 and 2006 ranges (top=summer, lower=annual).

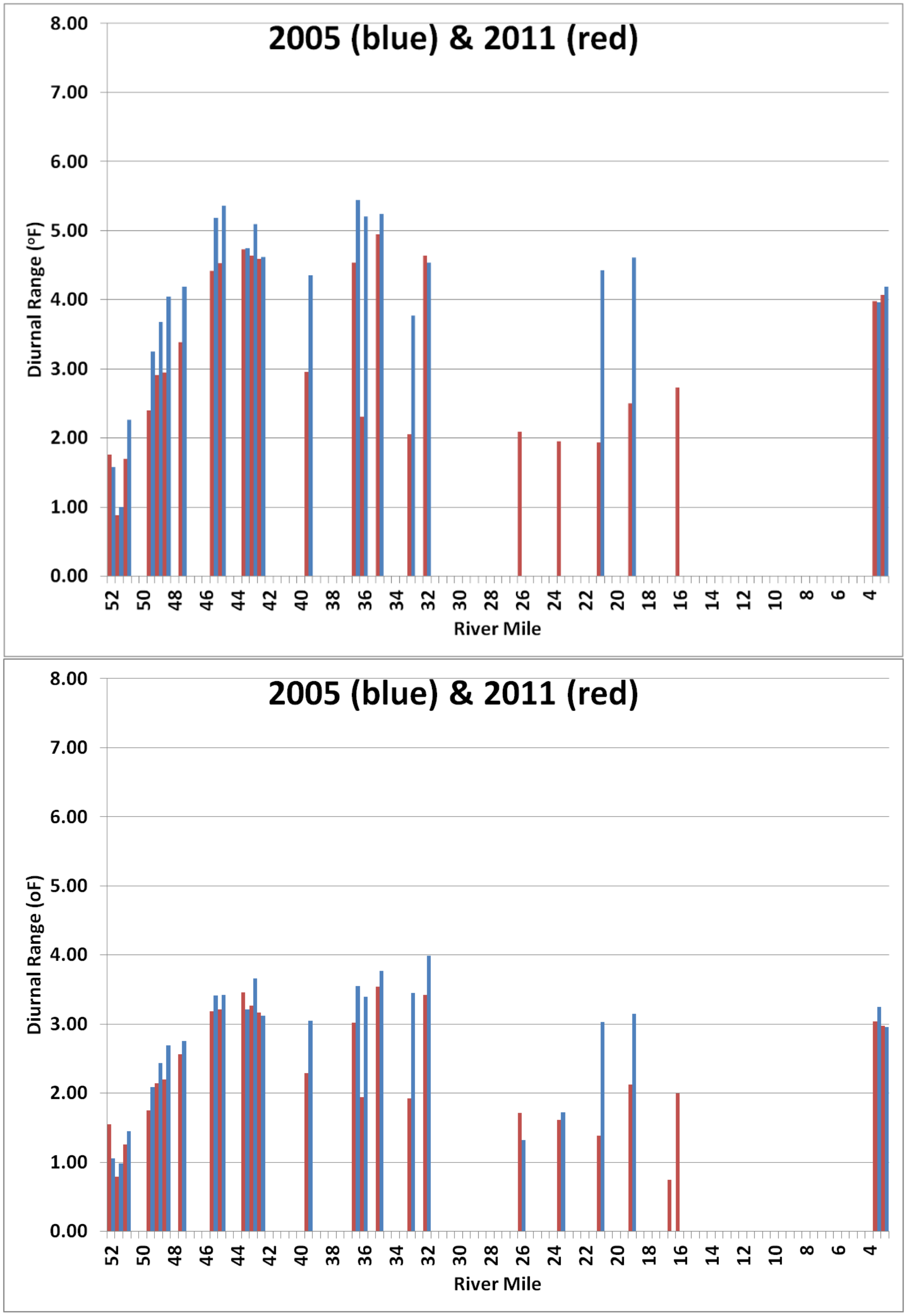


Figure 5.2-11. Comparison of 2011 and 2005 ranges (top=summer, lower=annual).

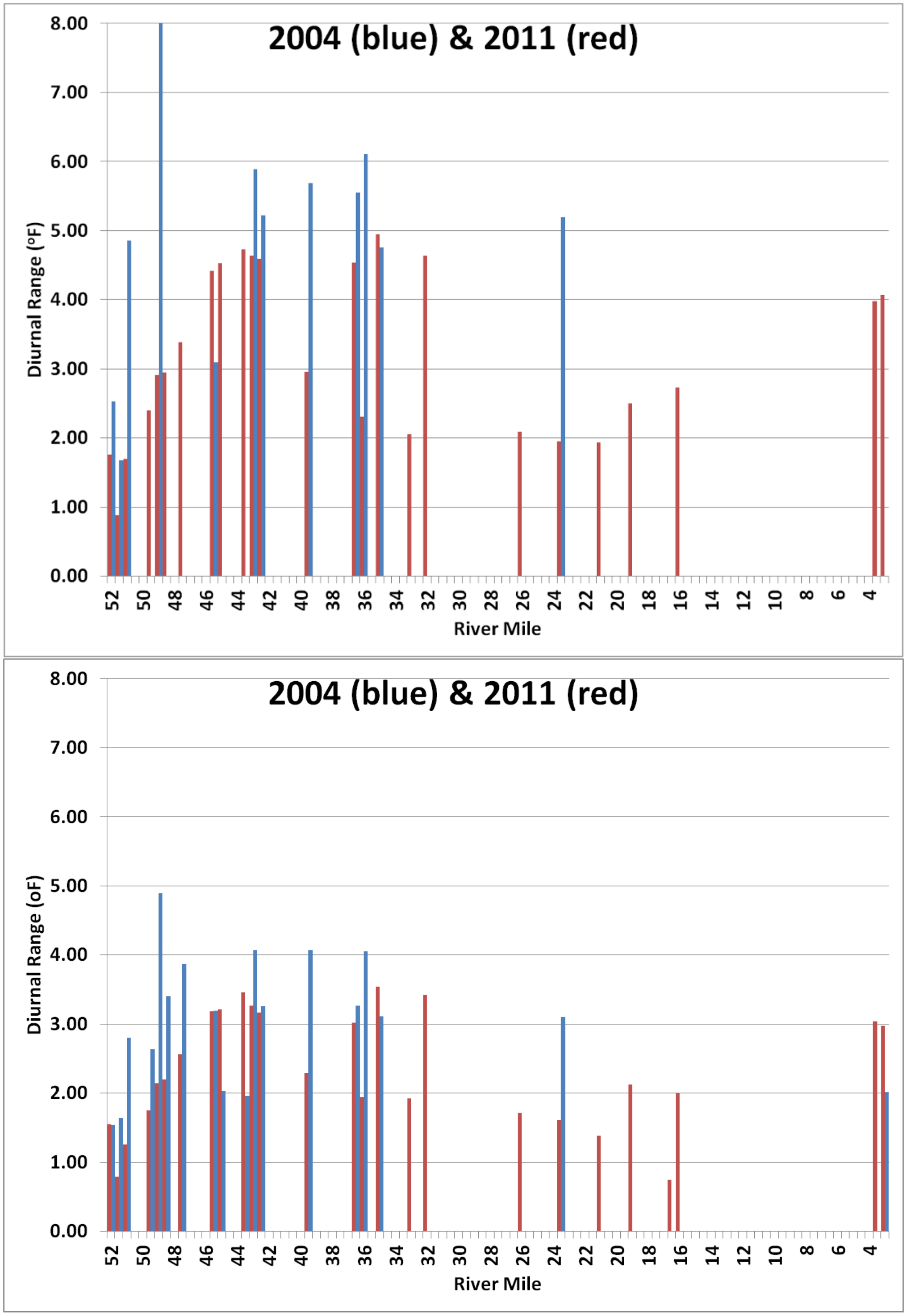


Figure 5.2-12. Comparison of 2011 and 2004 ranges (top=summer, lower=annual).

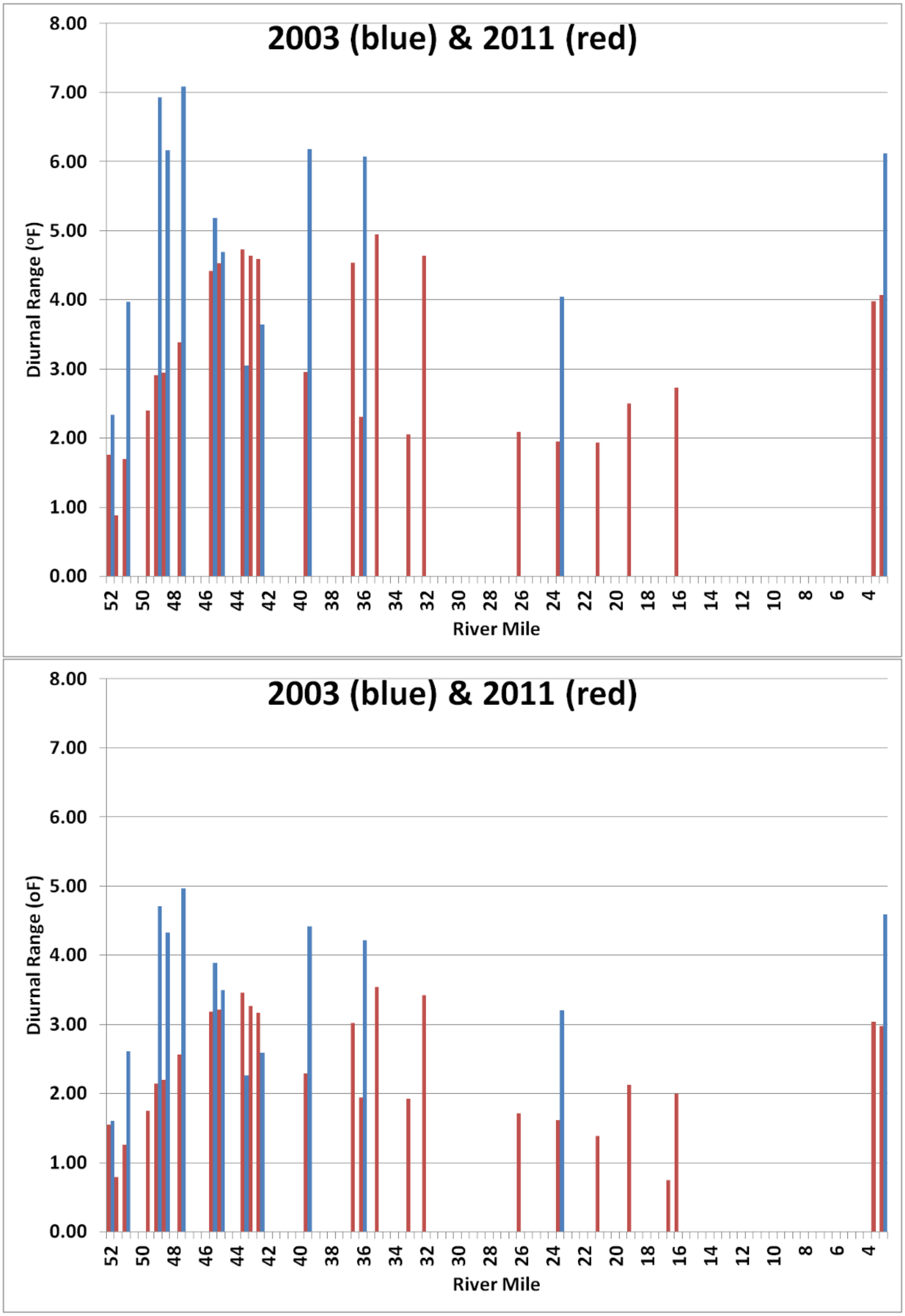


Figure 5.2-13. Comparison of 2011 and 2003 ranges (top=summer, lower=annual).

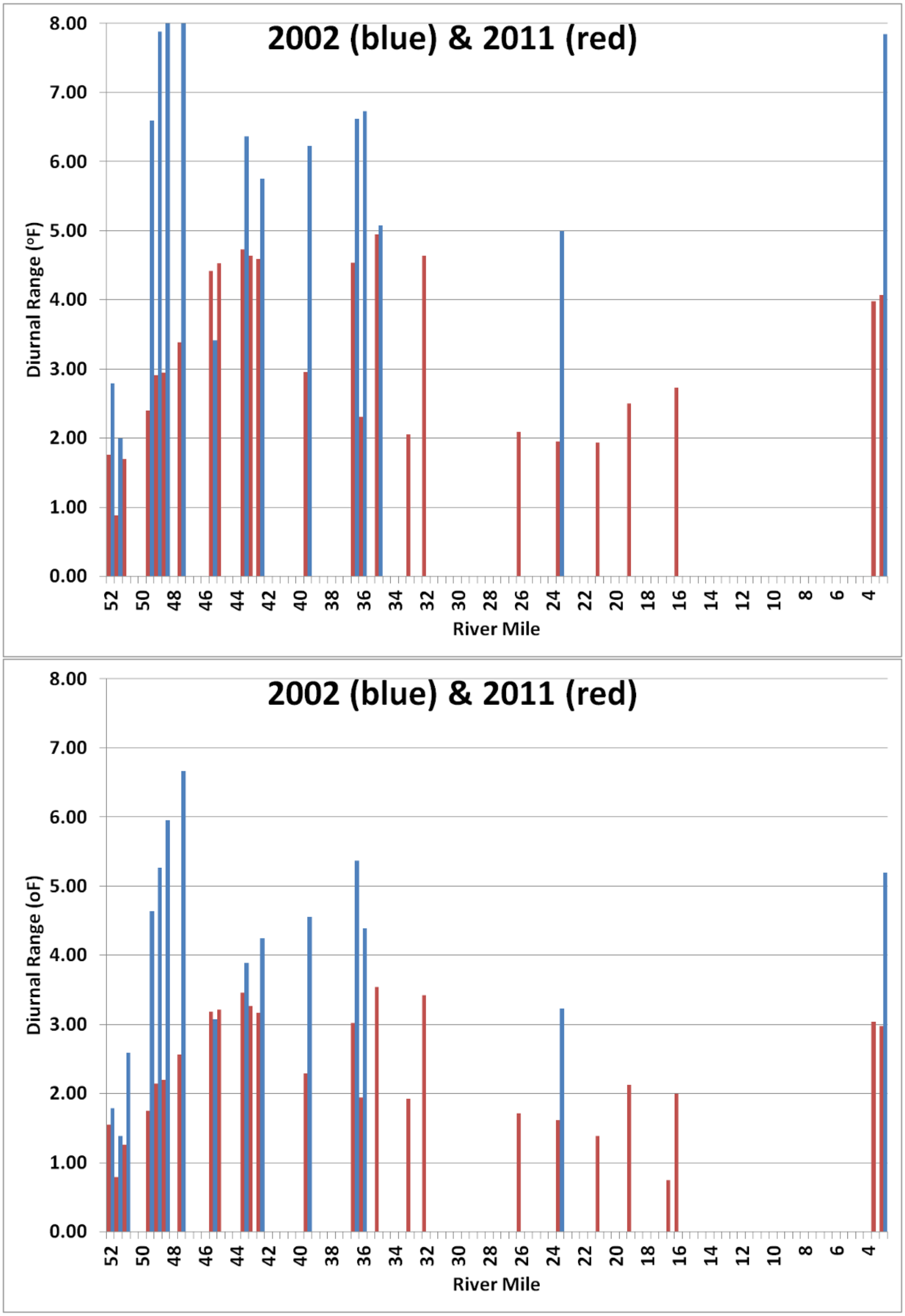


Figure 5.2-14. Comparison of 2002 and 2010 ranges (top=summer, lower=annual).

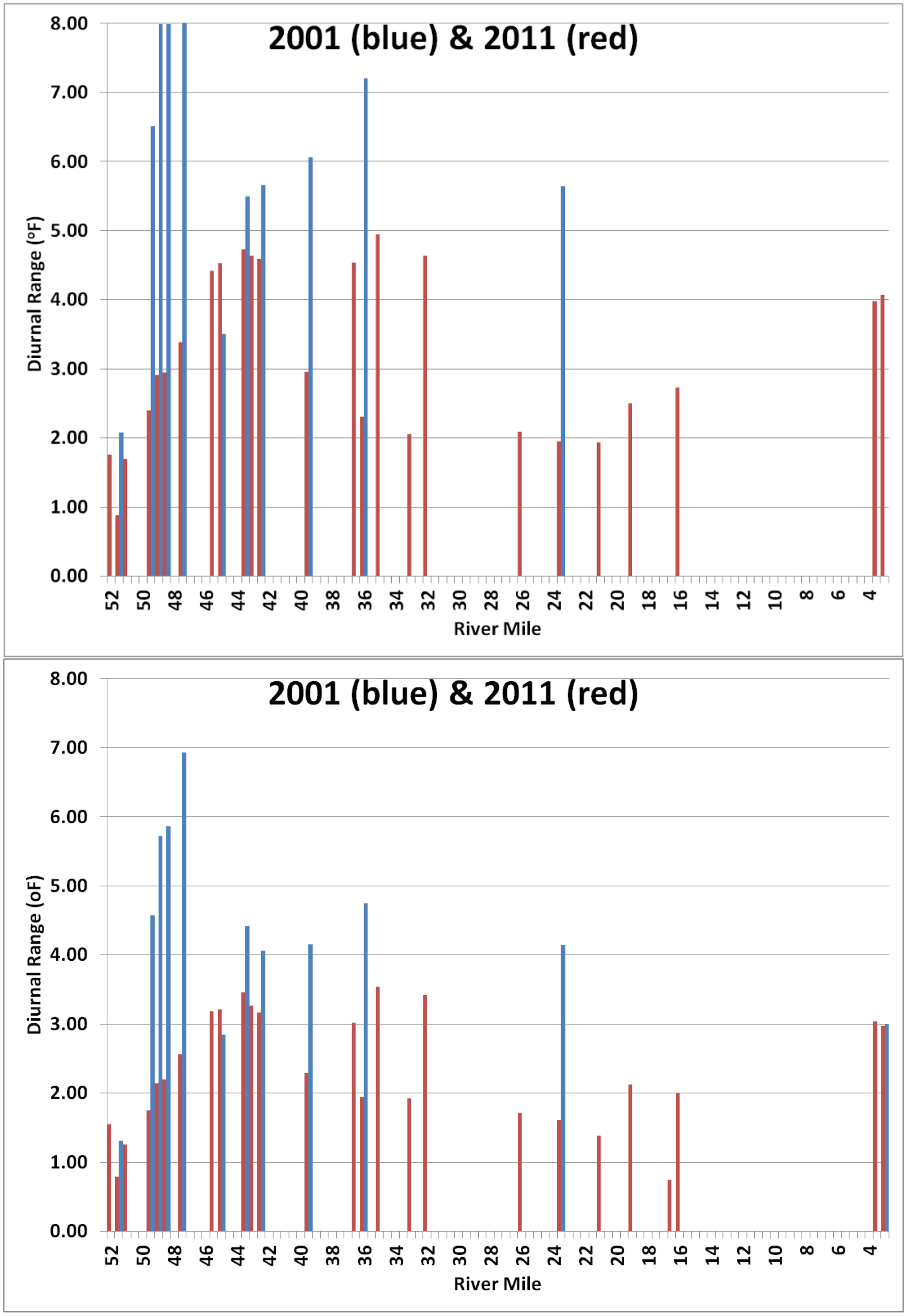


Figure 5.2-15. Comparison of 2011 and 2001 ranges (top=summer, lower=annual).

6.0 DISCUSSION AND RECOMMENDATIONS

The SJR5Q model reasonably simulated temperature conditions in the lower Tuolumne River, except where unexpected changes in diurnal temperature ranges were observed below about RM 40. These limited diurnal temperature variations are currently unexplained. However, groundwater inflows or possibly reemergence of hyporrheic flows may be possible causes. The Districts are proposing to undertake in the summer of 2013 an intensive river temperature investigation at two sites where rapid changes in these diurnal variations occur over short longitudinal distances in an effort to pinpoint the longitudinal extent, and potentially the cause, of the rapid changes.

Regarding the SJR5Q model, the Districts have shifted to a different ACOE platform, HEC-RAS, for future river modeling efforts. This model will be completed by mid-January 2013. There are several reasons for this shift, not the least of which is that the SJR5Q's six hour time step will have difficulty in capturing the diurnal variations. At the October 26, 2012 Workshop held with relicensing participants, the Districts informed RPs of their intent to shift the lower Tuolumne River temperature model to the ACOE's HEC-RAS modeling platform.

As explained, the increasing complexity of the lower river's temperature regime calls for a more advanced modeling platform. Additionally, it is expected that by migrating to the HEC-RAS model, a more robust model will be available to all RPs. Further, FERC's Study Plan Determination required the Districts to "model the flows necessary to meet the 7-day average of the daily maximum temperature (7DADM) as recommended by EPA (2003)." The 7DADM criteria are dependent upon hourly data; therefore, a model with an hourly time-step will be better suited to the task. The ACOE HEC-RAS model platform has an hourly time-step and, because HEC-RAS is the next generation of the ACOE HEC-5Q river temperature model, adopting the HEC-RAS model will be consistent with FERC's requirement that the Districts' model be able to be used in conjunction with the San Joaquin River Basin water temperature model.

In addition to the reasons mentioned above, the change to the HEC-RAS platform will have the following benefits:

- more detailed temperature calculations, including hourly and even sub-hourly if needed;
- a more user-friendly graphical interface;
- availability of more detailed hydraulic analyses and simulations;
- transparent and intuitive input/graphical output; it will be very easy to train those who want to use the model on how to use the input/output functions;
- HEC-RAS is a highly used river model (large user community, therefore, easy to find someone to peer review, for example);
- written and fully supported by ACOE – it is the ACOE's standard river model at present, replacing HEC-5Q;
- the model is fully documented and fully transparent;

- the model will run on all versions of Windows (including new versions as they appear); and
- the model is able to be downloaded from the ACOE website and the code is available for inspection.

Thus, HEC-RAS will better support the FERC relicensing, as it better meets the FERC-directed study modifications and it is readily usable by (and teachable to) all relicensing participants and users.

7.0 STUDY VARIANCES AND MODIFICATIONS

This study was conducted following the methods in Study W&AR-16 that was included in the Districts' Revised Study Plan filed with FERC on November 11, 2011, and approved by FERC in its Study Determination on December 22, 2011. The study was performed in conformance with the FERC-approved study with the exception that it may not be able to produce adequate output to determine the 7DADM. The Districts intend to migrate to the HEC-RAS model platform and complete an intensive river temperature investigation as a second-year study in 2013. The HEC-RAS model will be calibrated and ready for use in mid-January 2013.

8.0 REFERENCES

AD Consultants, Resources Management Associates Inc., Watercourse Engineering, Inc. 2009. San Joaquin River Basin Water Temperature Modeling and Analysis. Prepared for: CALFED ERP-06D-S20. Moraga, CA.

California Department of Water Resources, 2004. California's Groundwater Bulleting 118: San Joaquin Valley Groundwater Basin, Modesto Subbasin. Sacramento, California.

Environmental Protection Agency (EPA). 2003. *EPA Region 10 Guidance For Pacific Northwest State and Tribal Temperature Water Quality Standards,* EPA 910-B-03-002, EPA Region 10 Office of Water, Seattle, WA.

McBain & Trush, Inc. 2000. Habitat Restoration Plan for the Lower Tuolumne River Corridor. Arcata, California. Prepared for The Tuolumne River Technical Advisory Committee. March 2000.

Stanislaus County. 2006. Stanislaus County General Plan. Stanislaus County Board of Supervisors, Modesto, California.

Tuolumne River Technical Advisory Committee. 2000. Habitat Restoration Plan for the Lower Tuolumne River. McBain and Trush, Inc. Available online at: http://Tuolumne rivertac.com/documents.htm.

Turlock Irrigation District and Modesto Irrigation District (TID/MID). 2011. Tuolumne River water temperature modeling study. Final Report. Prepared by Stillwater Sciences, Berkeley, California for Turlock Irrigation District and Modesto Irrigation District, California, March 2011.

_____. 2013. Reservoir Temperature Model Progress Report (W&AR-03), Attachment A: Water Temperature Dataset. Attachment to Don Pedro Hydroelectric Project Initial Study Report. January 2013.