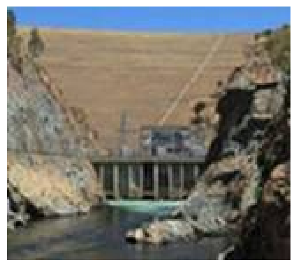
IN-RIVER DIURNAL TEMPERATURE VARIATION
STUDY REPORT
DON PEDRO PROJECT
FERC NO. 2299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Modesto Irrigation District

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

Prepared by:
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April 2014

In-River Diurnal Temperature Variation
Study Report

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List of Acronyms

ac................................acres
ACEC.........................Area of Critical Environmental Concern
ACHP.........................Advisory Council for Historic Preservation
ACOE.........................U.S. Army Corps of Engineers
ADA...........................Americans with Disabilities Act (ADA/ABAAG)
AF ....acre-feet
AGS............................Annual Grasslands
ALJ.............................Administrative Law Judge
APE............................Area of Potential Effect
APEA.........................Applicant-Prepared Environmental Assessment
ARMR........................Archaeological Resource Management Report
AWQC ....Ambient Water Quality Criteria
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
BOW..........................Blue Oak Woodland
ºC................................celsius
CalCOFI.....................California Cooperative Oceanic Fisheries Investigations
CalEPPC ....California Exotic Pest Plant Council
CalSPA.......................California Sportfishing Protection Alliance
CAS............................California Academy of Sciences
CBDA ....California Bay-Delta Authority
CCC............................Criterion Continuous Concentrations
CCIC..........................Central California Information Center
CCSF..........................City and County of San Francisco
CD..............................Compact Disc
CDBW........................California Department of Boating and Waterways

CDEC.........................California Data Exchange Center
CESA ....California Endangered Species Act
CDFA.........................California Department of Food and Agriculture
CDFG.........................California Department of Fish and Game (as of January 2013, CDFW)
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
CEC............................California Energy Commission
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
cm...............................centimeters
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
CPUC ....California Public Utilities Commission
CPUE ....Catch Per Unit Effort
CRAM........................California Rapid Assessment Method
CRC............................Chamise-Redshank Chaparral
CRLF..........................California Red-Legged Frog
CRRF ....California Rivers Restoration Fund
CSAS..........................Central Sierra Audubon Society
CSBP..........................California Stream Bioassessment Procedure

CSU............................California State University
CT ....California Threatened Species
CTR............................California Toxics Rule
CTS ....California Tiger Salamander
CVP............................Central Valley Project
CVRWQCB ....Central Valley Regional Water Quality Control Board
CWA ....Clean Water Act
CWD ....Chowchilla Water District
CWHR........................California Wildlife Habitat Relationship
CZMA ....Coastal Zone Management Act
DDT ....dichlorodiphenyltrichloroethane
Districts......................Turlock Irrigation District and Modesto Irrigation District
DLA ....Draft License Application
DO..............................Dissolved Oxygen
DOI ....Department of Interior
DPRA.........................Don Pedro Recreation Agency
DPS ....Distinct Population Segment
DSE............................Chief Dam Safety Engineer
EA ....Environmental Assessment
EBMUD ....East Bay Municipal Utilities District
EC ....Electrical Conductivity
EFH............................Essential Fish Habitat
EIR ....Environmental Impact Report
EIS..............................Environmental Impact Statement
Elev or el ....Elevation
ENSO ....El Niño Southern Oscillation
EPA............................U.S. Environmental Protection Agency
ESA ....Federal Endangered Species Act
ESRCD.......................East Stanislaus Resource Conservation District
ESU ....Evolutionary Significant Unit
EVC............................Existing Visual Condition
EWUA........................Effective Weighted Useable Area
°F................................fahrenheit

FERC..........................Federal Energy Regulatory Commission
FFS.............................Foothills Fault System
FL...............................Fork length
FLA............................Final License Application
FMP...........................Fishery Management Plan
FMU...........................Fire Management Unit
FOT............................Friends of the Tuolumne
FPA............................Federal Power Act
FPC............................Federal Power Commission
FPPA..........................Federal Plant Protection Act
ft.................................feet
ft/mi............................feet per mile
FWCA........................Fish and Wildlife Coordination Act
FWUA........................Friant Water Users Authority
FYLF..........................Foothill Yellow-Legged Frog
g..................................grams
GIS.............................Geographic Information System
GLO...........................General Land Office
GORP.........................Great Outdoor Recreation Pages
GPS............................Global Positioning System
HCP............................Habitat Conservation Plan
HSC............................Habitat Suitability Criteria
HHWP........................Hetch Hetchy Water and Power
HORB........................Head of Old River Barrier
hp...............................horsepower
HPMP.........................Historic Properties Management Plan
IFIM...........................Instream Flow Incremental Methodology
ILP.............................Integrated Licensing Process
in................................inches
ISR.............................Initial Study Report
ITA.............................Indian Trust Assets
IUCN..........................International Union for the Conservation of Nature
KOPs..........................Key Observation Points

kV............................kilovolt

kVA..........................kilovolt-amperes

kW...........................kilowatt

LWD ....large woody debris

m ....meters

mm ....millimeter

M&I..........................Municipal and Industrial

MCL.........................Maximum Contaminant Level

mg/kg ....milligrams/kilogram

mg/L.........................milligrams per liter

mgd ....million gallons per day

MGR ....Migration of Aquatic Organisms

MHW ....Montane Hardwood

mi ....miles

mi^2 ....square miles

MID..........................Modesto Irrigation District

MOA ....Memorandum of Agreement

MOU ....Memorandum of Understanding

MPN.........................Most Probable Number

MPR.........................market price referents

MSCS.......................Multi-Species Conservation Strategy

msl............................mean sea level

MUN ....municipal and domestic supply

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

NGVD29....................National Geodetic Vertical Datum of 1929
NEPA..........................National Environmental Policy Act
NERC..........................North American Electric Reliability Corporation
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
O&M..........................operation and maintenance
OEHHA......................Office of Environmental Health Hazard Assessment
OID............................Oakdale Irrigation District
ORV...........................Outstanding Remarkable Value
OSHA.........................Occupational Safety and Health Administration
PA..............................Programmatic Agreement
PAD............................Pre-Application Document
PDAW........................Project Demand of Applied Water
PDO............................Pacific Decadal Oscillation
PEIR...........................Program Environmental Impact Report
PGA............................Peak Ground Acceleration
PG&E.........................Pacific Gas and Electric
PHABSIM..................Physical Habitat Simulation System
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
PWA...........................Public Works Administration
QA..............................Quality Assurance
QC..............................Quality Control
RA..............................Recreation Area
RBP............................Rapid Bioassessment Protocol
REC-1 ....water contact recreation
REC-2 ....water non-contact recreation
Reclamation ...............U.S. Department of the Interior, Bureau of Reclamation
RM ....River Mile
RMP...........................Resource Management Plan
RP...............................Relicensing Participant
rpm.............................Rotations per minute
RPS ....Renewable Portfolio Standard
RSP ....Revised Study Plan
RST ....Rotary Screw Trap
RWG ....Resource Work Group
RWQCB.....................Regional Water Quality Control Board
SC...............................State candidate for listing under CESA
SCADA......................Supervisory Control and Data Acquisition
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
SEED..........................U.S. Bureau of Reclamation’s Safety Evaluation of Existing Dams
SFP.............................State Fully Protected Species under CESA
SFPUC ....San Francisco Public Utilities Commission

SHPO ....State Historic Preservation Officer
SJRA ....San Joaquin River Agreement
SJRGA ....San Joaquin River Group Authority
SJTA ....San Joaquin River Tributaries Authority
SM..............................Standard Method
SMUD ....Sacramento Municipal Utility District
SPAWN......................spawning, reproduction and/or early development
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
SWP ....State Water Project
SWRCB......................State Water Resources Control Board
TAC.............................Technical Advisory Committee
TAF ....thousand acre-feet
TCP ....Traditional Cultural Properties
TCWC ....Tuolumne County Water Company
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
USBR ..........................U.S. Bureau of Reclamation
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

VES............................visual encounter surveys

VRM ....Visual Resource Management

VRO...........................Visual Resource Objective

WBWG ....Western Bat Working Group

WECC........................Western Electricity Coordinating Council

WPA...........................Works Progress Administration

WPT...........................Western Pond Turtle

WQCP........................Water Quality Control Plan

WSA...........................Wilderness Study Area

WSIP..........................Water System Improvement Program

WSNMB ....Western Sierra Nevada Metamorphic Belt

WUA..........................weighted usable area

WWTP ....Wastewater Treatment Plant

WY.............................water year

yd^3 ....cubic yard

yr ....year

µS/cm ....microSeimens per centimeter

µg/L............................micrograms per liter

µmhos.........................micromhos

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 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 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 which CCSF uses 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 a water surface elevation of 845 ft (31 FPC 510 [1964]). The Project Boundary encompasses approximately 18,370 ac with 74 percent of the lands owned jointly by the Districts and the remaining 26 percent (approximately 4,800 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.

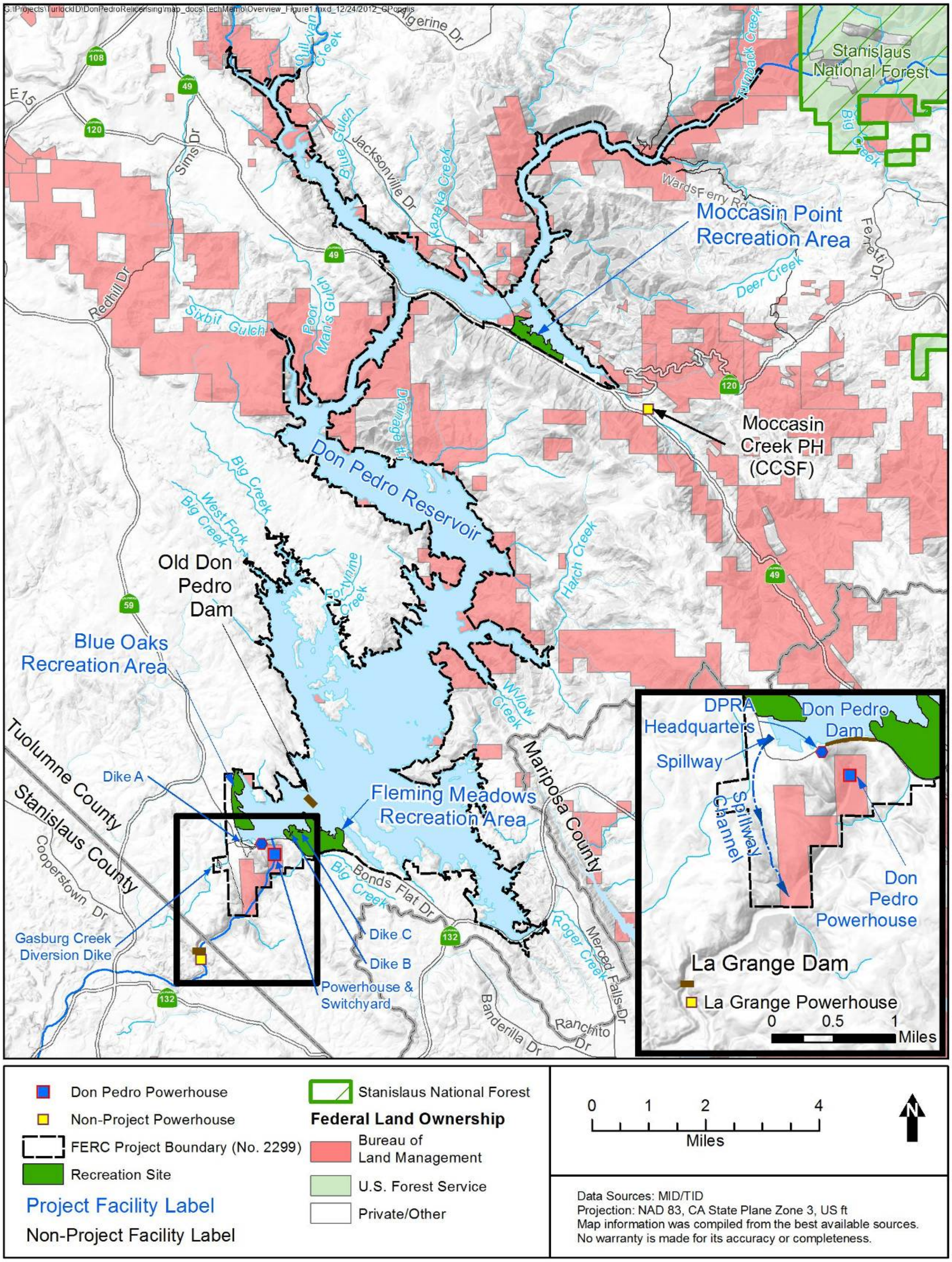


Figure 1.1-1. **Don Pedro Project location.**

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, in accordance with the regulations governing the Integrated Licensing Process (ILP). The Districts' PAD included descriptions of the Don Pedro 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, 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 issued on August 17, 2012. The dispute did not involve *W&AR-16: Lower Tuolumne River Temperature Model* or its related second year study, *In-River Diurnal Temperature Variation* Study.

On January 17, 2013, the Districts issued the Initial Study Report (ISR) and held an ISR meeting on January 30 and 31, 2013. The ISR included a progress report for *W&AR-16: Lower Tuolumne River Temperature Model.* 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 (RPs) 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 (1) 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 and (2) a second year field study be performed to more intensively examine in-river diurnal temperature variation. Several relicensing participants commented on the Districts' plan to move the river temperature modeling to the HEC-RAS platform, but no comments were received on the diurnal temperature variation study plan. In its May 21, 2013 Determination, FERC approved the Districts' proposal to adopt the HEC-RAS modeling platform and the diurnal variation study plan. FERC also required the Districts to hold additional workshops on the HEC-RAS model.

The Districts filed their Updated Study Report (USR) on January 6, 2014; held a USR meeting on January 16, 2014; and filed a summary of the meeting on January 27, 2014. The Districts filed a response to USR comments on February 28, 2014.

The Districts filed the Draft License Application (DLA) on November 26, 2013 and will file a Final License Application (FLA) no later than April 30, 2014. This study report, an attachment to the FLA, describes the objectives, methods, and results of the In-River Diurnal Temperature Variation Study 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 Hydroelectric 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. Additionally, 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). In its December 2011 SPD, 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.

In 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 2012). 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 2012). Second, the Districts would move the modeling to the more transparent and flexible ACOE-supported HEC-RAS platform. FERC agreed with the Districts' recommendations and approved the two recommendations in its May 21, 2013 Determination.

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, as well as its associated second year study, on April 10, 2012; October 26, 2012; January 24, 2013; and June 4, 2013. Meeting materials were circulated prior to each Workshop, meeting notes were provided for review and comment, all comments were responded to, and final Workshop notes were filed with FERC.

2.0 STUDY GOALS AND OBJECTIVES

The goals of this study are to (1) more precisely identify and define the occurrence of and, if possible, the reasons for moderated diurnal temperature fluctuations observed in monitoring data collected in 2011 at specific river sub-reaches of the lower Tuolumne River (2) identify and define some of the apparent local in-river temperature complexities that may not be predictable by a one-dimensional temperature model, and (3) refine the HEC-RAS temperature model, if warranted by the findings of this study.

The objective of this study was to install intensive thermologger grids at key locations in the river, namely those locations where actual diurnal temperature variations from observed data were significantly different than those predicted by the model. Loggers were installed at different depths, within different parts of the channel, and reflect the differences in channel geometry over the river's course. Loggers were also sited within and adjacent to special run pools and areas where groundwater accretion may be occurring.

3.0 METHODOLOGY

The lower Tuolumne River extends 54 miles from below Don Pedro Dam and powerhouse to the confluence with the San Joaquin River and has a drainage area approximately 430 square miles (Figure 3.1-1). There is one major tributary, Dry Creek, which joins the lower Tuolumne River at RM 16 and has a drainage area of approximately 204 square miles, nearly half of the total drainage area.

3.1 Study Area

The study area consists of specific reaches in the lower Tuolumne River between the outlet of Don Pedro powerhouse at an elevation of approximately 300 ft to the Tuolumne River's confluence with the San Joaquin River at an elevation of approximately 35 ft (Table 3.1-1; Figure 3.1-1). The reasoning behind each reach's selection as well as the specific installation locations are provided in Table 3.1-1. A general overview of the study area, including locations of operational outflows, return flows, riparian diversions, and flow and temperature monitoring locations, is provided in Figure 3.1-1.

Table 3.1-1. High density water temperature monitoring locations.

Location	Reason	Installed Location			
		River Mile	River Channel Orientation		
			Left	Middle	Right
RM 36.5 to RM 34.5	Within Gravel Mining Reach. Area of suspected groundwater inflow due to seepage from Turlock Lake and Modesto Reservoir. Special Run Pool (SRP) 11 in study area. Riffle Q3 in Study Area. Upstream of where reduction in diurnal temperature variation first observed. Downstream of both Turlock and Modesto lakes.	36.5	X	X	X
		36.25	X	--	X
		36	X	X	--
		35	--	X	X
		35.25	X	X	X
		35	X	X	--
		34.75	--	X	--
		34.5	X	X	X
RM 33.5 to RM 32	Within the In-Channel Gravel Mining Reach. Area of suspected groundwater inflow. SRP 5 in study area. Diurnal temperature range low in this area; normalizes downstream of this study site. Hickman spill is located in this study area.	33.5	X	--	X
		33.2	X	X	X
		32.8	X	X[1]	X
		32.5	--	X	X
RM 24 to RM 23	Within Upper Sand Bedded Reach. Located in area of suspected groundwater inflow, based on accretion measurements in 2012 and 2013. Diurnal temperature variation reduced in this area.	24	X	X[1]	X
		23.75	X	X	X[1]
		23.5	X	X	--
		23.25	X	--	X
		23	X	X	X[1]
RM 10 to RM 9	Within Lower Sand Bedded Reach. Area of suspected groundwater inflow, based on accretion measurements in 2012 and 2013.	10	X	X[1]	X[1]
		9.75	X	X	X
		9.5US	X	X	X
		9.5DS	X	X	X
		9.2	X	X	X

-- = Narrow channel at this location; no logger installed
RM = River Mile, SRP = Special Run Pool, X = a logger was installed at this location, US = upstream of water diversion
DS = downstream of water diversion
[1] Logger installed. However, due to local sediment conditions or invasive aquatic vegetation, no data obtained (See Section 6.0)

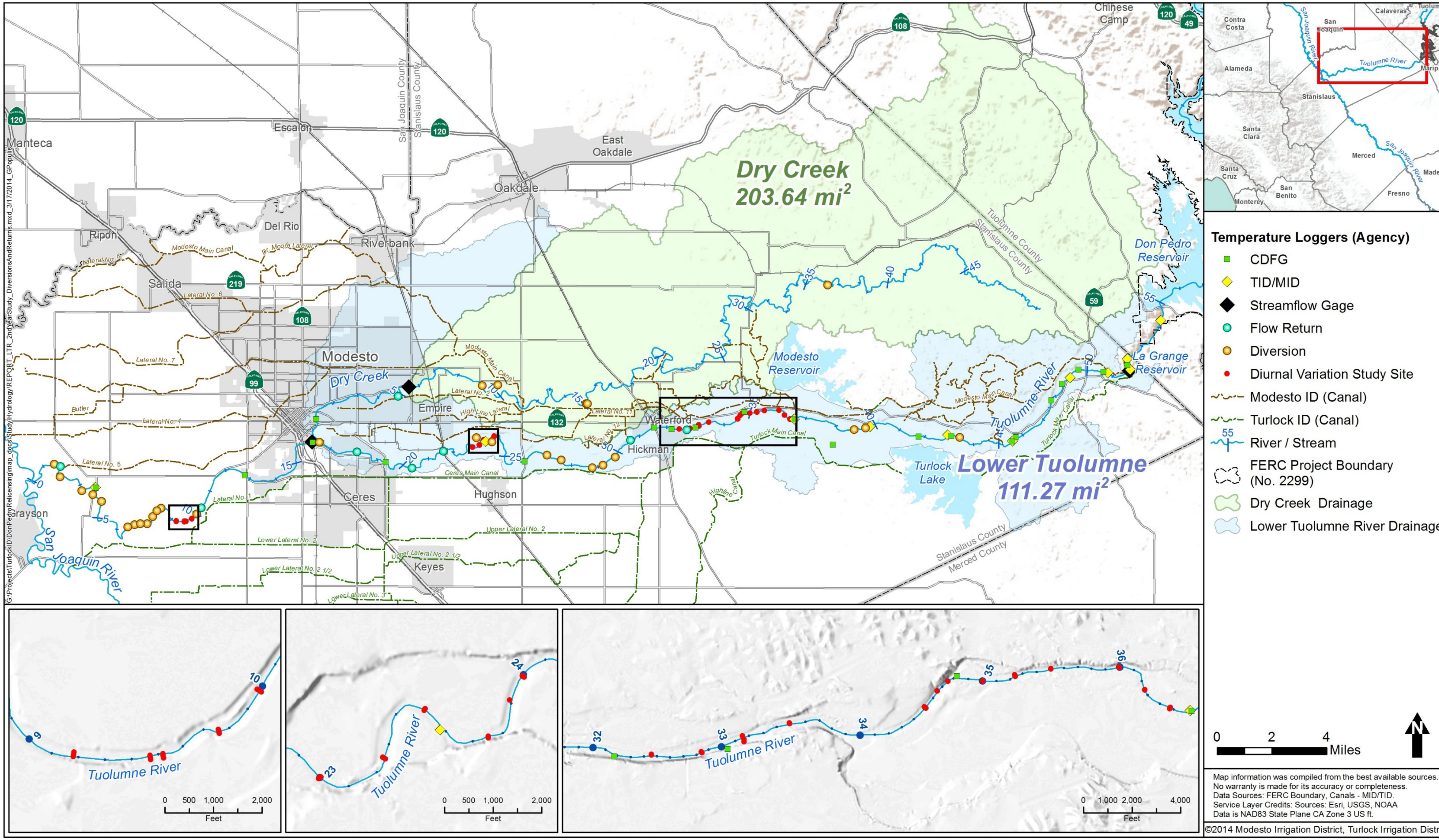


Figure 3.1-1. **Location of thermologgers to support intensive water temperature investigation in the lower Tuolumne River.**

3.2 Install High Density Grid of Continuous Thermologgers

Continuous thermologgers at selected in-river locations were installed no later than July 1, 2013 and removed after September 30, 2013 (Table 3.1-1; Figure 3.1-1). Water temperatures were recorded once per hour. Loggers were placed in a variety of in-river settings and locations including at multiple depths in one special run pool (SRP) [SRP 5], habitats of interest, large eddies, and/or suspected points of groundwater inflow. The targeted density of temperature loggers was one transect per quarter mile unless a SRP spanned a greater distance than one-quarter mile in which case the loggers were located above and below the SRP. In general, loggers were placed on both sides of the river and in the thalweg unless field conditions warranted a change (See Attachment A).

The thermologgers have 12-bit resolution with a minimum accuracy of +/- 0.2^{o} C (i.e., Onset or equivalent). Each thermologger was contained in a durable protective housing that permits the active flow of water in and around the unit. Each thermologger was secured in channel either by a weight or metal angle-iron such that the thermologger would remain in place during high flows (Figure 3.2-1). The thermologgers were installed in the identified locations of interest, and the were disguised as much as possible while ensuring the ability to retrieve the units for future downloads. A professional-grade GPS was used to record the installation coordinates of each logger along with an associated data dictionary to record the logger's serial number, water depth at installation, and photo. In addition, any waypoints or photographs that were valuable for future retrieval, especially where there was not an obvious monument, were recorded. Thermologgers were downloaded monthly.

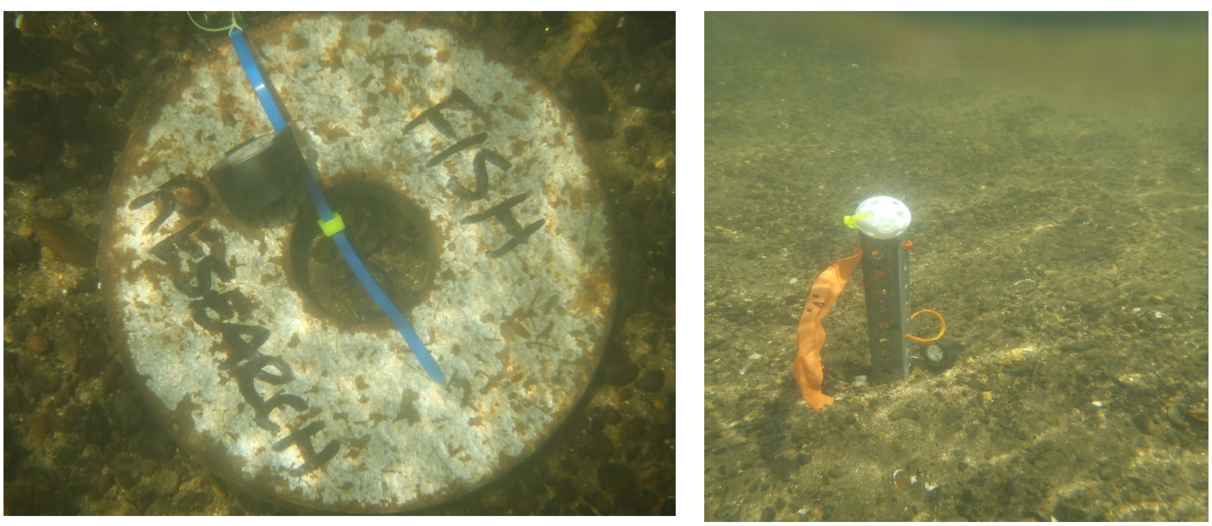


Figure 3.2-1. Examples of typical logger installation

Prior to installation, each thermologger was numbered and calibrated to manufacturer's recommended specifications. During each visit, data were downloaded into an optic shuttle or directly to a personal computer. Qualified staff reviewed the data in the field to look for obvious flaws and identify, if possible, the cause. After the thermologger was removed from the water, it was cleaned and visually inspected. A record of all thermologger installations and data downloads was maintained. During the study's implementation, loggers were routinely checked. Loggers were replaced in the field if they were found to be malfunctioning or lost.

3.3 Collect Water Temperature Profiles in SRP 11 and SRP 5

Once in early August and once in early September, temperature profiles were collected to examine the temperature conditions occurring in SRP 11 (RM 36. 5 to RM 36.25) and SRP 5 (RM 33.4 to RM 32.9). Generally, measurements were taken at three (3) foot vertical increments where the change in temperature with respect to depth is small (< 0.5°C). Where the temperature gradient was greater or where measuring an apparent zone of interflow or an underflow, one (1) foot or smaller vertical increments were used. At each sample depth, the temperature readings were allowed to stabilize before water temperature was recorded. The profile location in each SRP were taken at what was believed to be the deepest point of the pool, using existing bathymetry data and a hand held depth sounder. A GPS receiver was used during each successive sampling occasion to locate the geographical coordinates of each sample site. Care will be taken to identify the same site for successive profiles where water conditions and GPS accuracy allow.

3.4 Data Quality Assurance and Processing

In addition to the field quality assurance procedures, the Districts subjected all collected data to quality assurance/quality control (QA/QC) procedures including, but not limited to (1) spot-checking data, and (2) reviewing thermologger readings and electronic data for completeness. The datasets were also reviewed graphically to check for errors. If any datum seemed inconsistent during the QA/QC procedure, the problem was further investigated. Values that are determined to be anomalous were removed from the database and the reasoning documented. For example, at the end of August, temperatures cooled and dropped unexpectedly at logger RM 10LB. Following review of the all available information, it was determined that the unexpected observations were due to sediment build-up around the logger (Figure 3.4-1). By examining the middle channel and left bank logger measurements, RM 10LB provides a good example of how shifting sediment at some locations complicated implementation of the study and confounded some temperature measurements, particularly in the lower river (Figure 3.4-1). Late-season water hyacinth mats covering portions of the river also confounded data collection; a metal detector couldn’t find some loggers buried under the water hyacinth (Figure 3.4-2).

If data were unavailable for brief periods of the record (i.e. less than 6 consecutive hours), the missing data was synthesized into the record using a straight line interpolation method, and the data were indicated as “synthesized” in the record and all subsequent summaries. Data gaps greater than six consecutive hours were not synthesized and appear in the data set and related graphs as a gap.

The raw data files will be retained in their unaltered state for future QA/QC reference. Any data modified in the final record will be so indicated in the record.

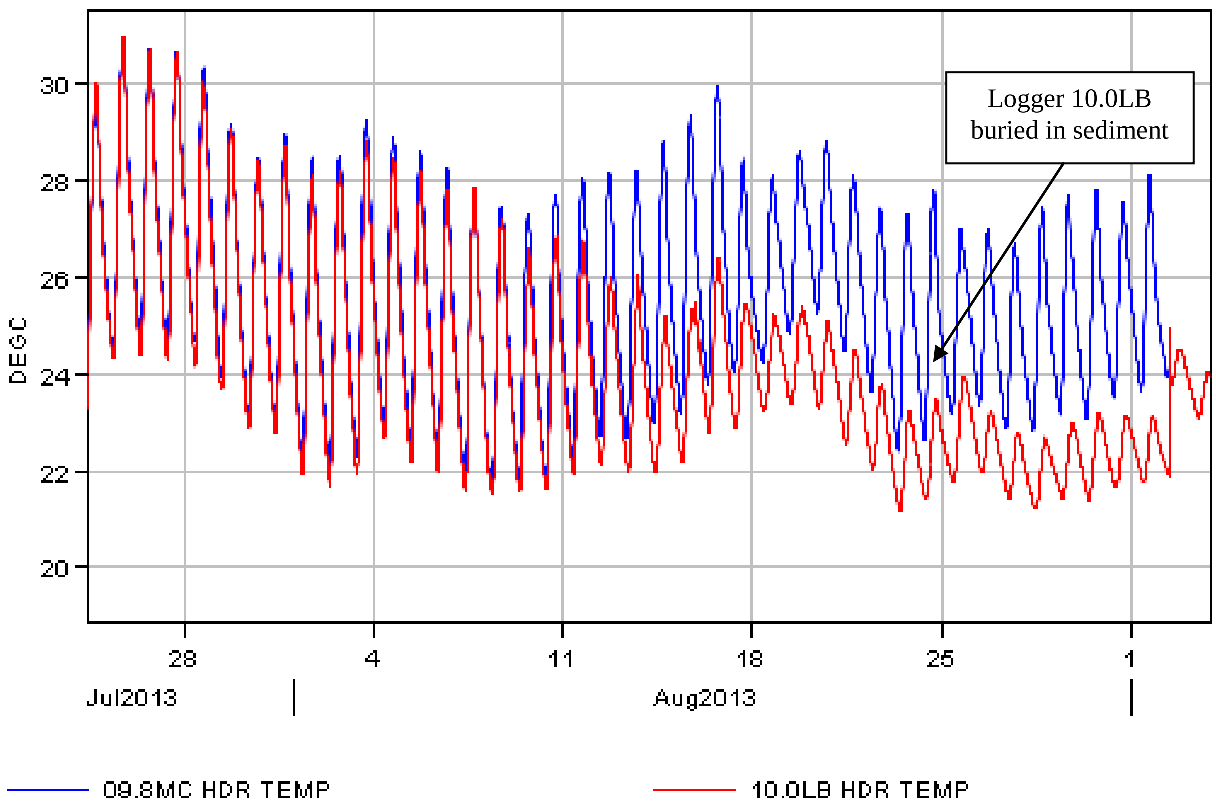


Figure 3.4-1. Diurnal temperature variation during the study period—effect of sediment on temperature measurements.

Figure 3.4-2. Photos of water hyacinth blocakges at RM 23.3 and RM 21.5 (Santa Fe Bridge).

4.0 RESULTS

The following subsections present (1) temperature, flow, and meteorological boundary conditions during the study period; (2) a summary of each site's diurnal temperature variation during the study period; (3) temperature profiles measured in (RM 36.5 to RM 36.25) and SRP 5 (RM 33.4 to RM 32.9); and (4) longitudinal profiles when the upstream temperatures were at their highest, lowest, and average.

4.1 Flow and Meteorological Conditions

Don Pedro powerhouse outflow temperatures have been measured hourly since the fall of 2010. Outflow temperatures were essentially constant throughout the study period, July 1 through September 30, 2013, ranging between 10.7 ºC and 11.2 ºC and fluctuating no more than 0.25°C on any given day (Attachment B).

In addition to collecting water temperature data, the Districts also compiled available flow and meteorological data during the study period. Flow data are provided in Figure 4.1-1 for two locations, La Grange (USGS 11289650) and Modesto (USGS 11290000). Flows were predominantly about 100 cfs, but did go up to 250 cfs during a test flow for the relicensing's Lowest Boatable Flow study (TID/MID 2013a).

Air temperatures measured at the Districts' Crocker Ranch meteorological station are provided in Figure 4.1-2, as is the number of daylight hours. The study started soon after the longest day of the year and daylight decreased over the study period.

Below RM 16, Dry Creek's inflows also influence flow and temperature in the lower Tuolumne River. Dry Creek's flows and temperatures during the study period are shown in Figure 4.1-3. Dry Creek flows ranged between 25 and 75 cfs, introducing water temperatures that ranged between 16 and 30 ºC into the lower Tuolumne River. Since the Tuolumne River flows at the Modesto gage (RM 16.2) ranged from approximately 150 to 250 cfs (Figure 4.1-1), the flows from Dry Creek accounted for anywhere from 10 percent to 50 percent of the total river flows, potentially influencing downstream temperatures.

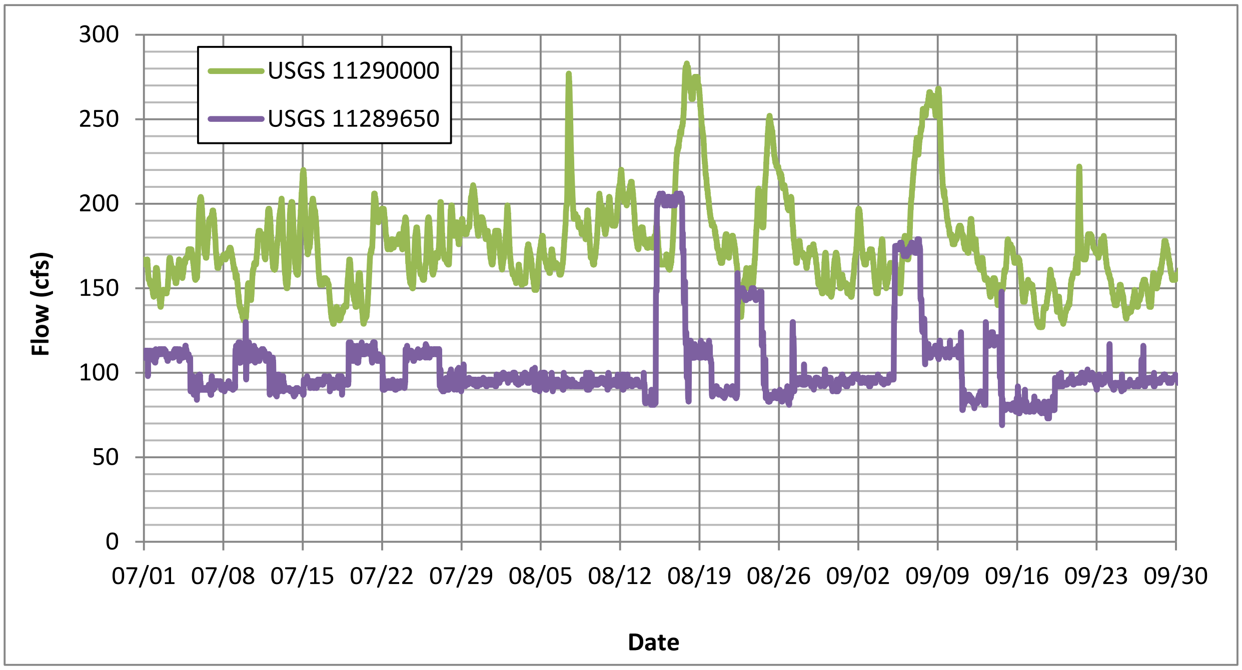


Figure 4.1-1. Flow at La Grange (11289650) and Modesto (11290000) gage locations, 7/1/13—9/30/13.

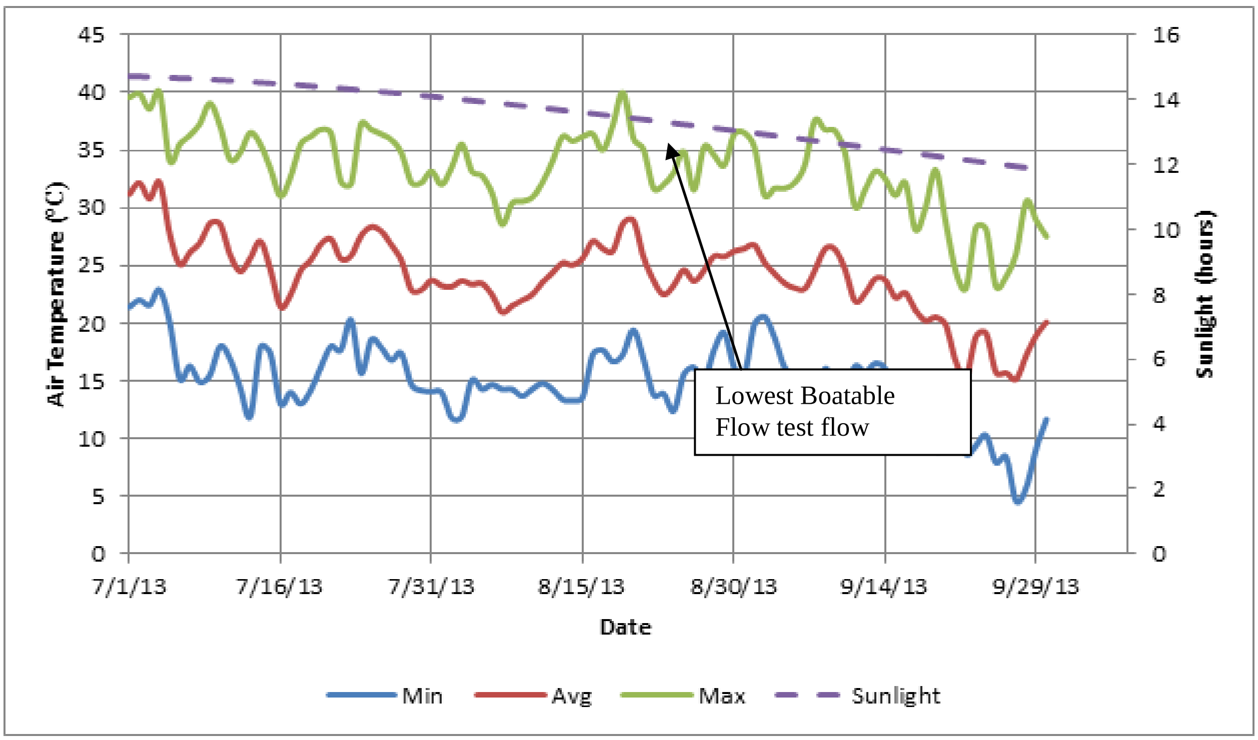


Figure 4.1-2. Daily maximum, average, and minimum air temperatures at Crocker Ranch and hours of daylight, 7/1/13—9/30/13.

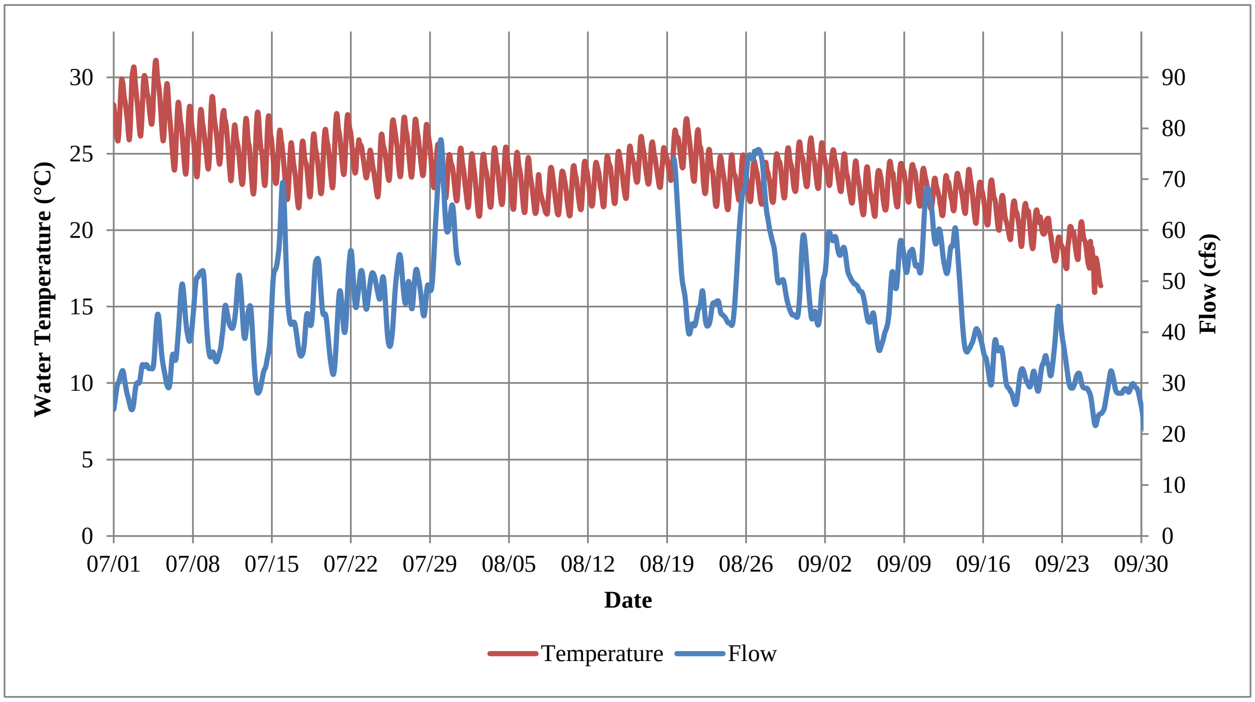


Figure 4.1-3. Dry Creek flow and temperature, 7/1/13—9/30/13.

4.2 Diurnal Temperature Variation By Investigated Reach

Study results are summarized below. Due to the large number of loggers and quantity of data collected during this study, photos and plotted temperatures of each monitored site are provided in Attachment A and the complete temperature data set is provided in Attachment B.

4.2.1 Gravel Mining Reach and In-Channel Gravel Mining Reach

The Gravel Mining (RM 34.2-40.3) and In-Channel Gravel Mining (RM 24.0-34.2) reaches are characterized by gravel bed and banks with some confinement by bluffs. Both reaches run through areas of off-channel aggregate extraction, e.g. “gravel pits,” as well as orchard or row crops (McBain and Trush 2000) (Figure 4.2-1 through Figure 4.2-3). There is also history of in-channel aggregate mining in each reach.

CDFW and/or the Districts maintain temperature loggers at RM 38, RM 36.5, RM 35, RM 33, RM 32, RM 31 and RM 26. During calibration of the lower Tuolumne River temperature model, summer river temperatures were not consistently reproducible around RM 33, and actual diurnal temperature ranges were significantly smaller downstream of RM 33 than predicted by the model (TID/MID 2013b). For this study, 18 loggers were installed along eight transects upstream of RM 33 in the Gravel Mining Reach and 10 loggers were installed along four transects downstream of RM 33 in the In-Channel Gravel Mining Reach (Figure 4.2-1 through Figure 4.2-3).

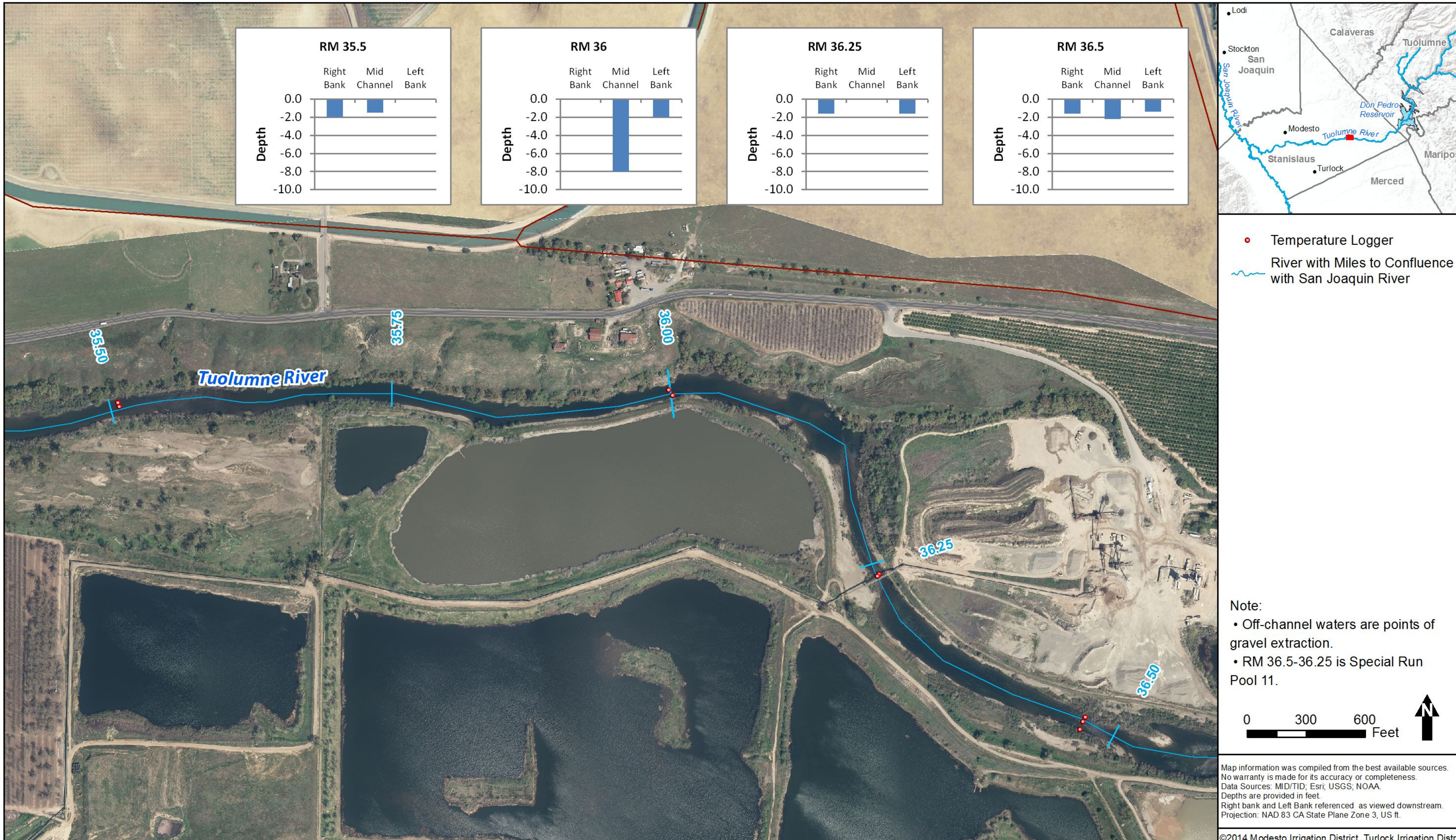


Figure 4.2-1. **Water temperature thermologgers from river mile 36.5 to 35.5.**

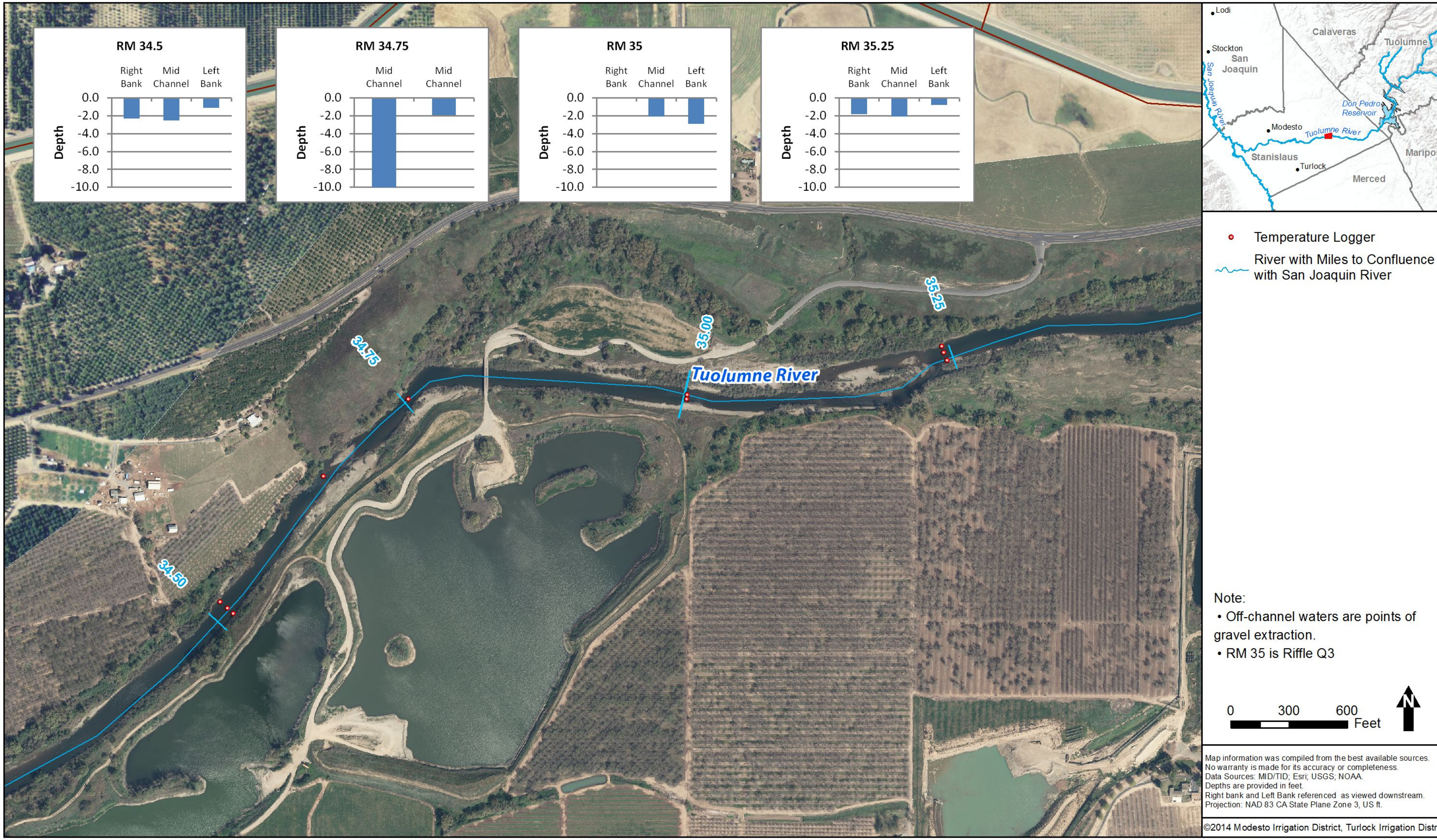


Figure 4.2-2. Water temperature thermologgers from river mile 35.25 to 34.5.

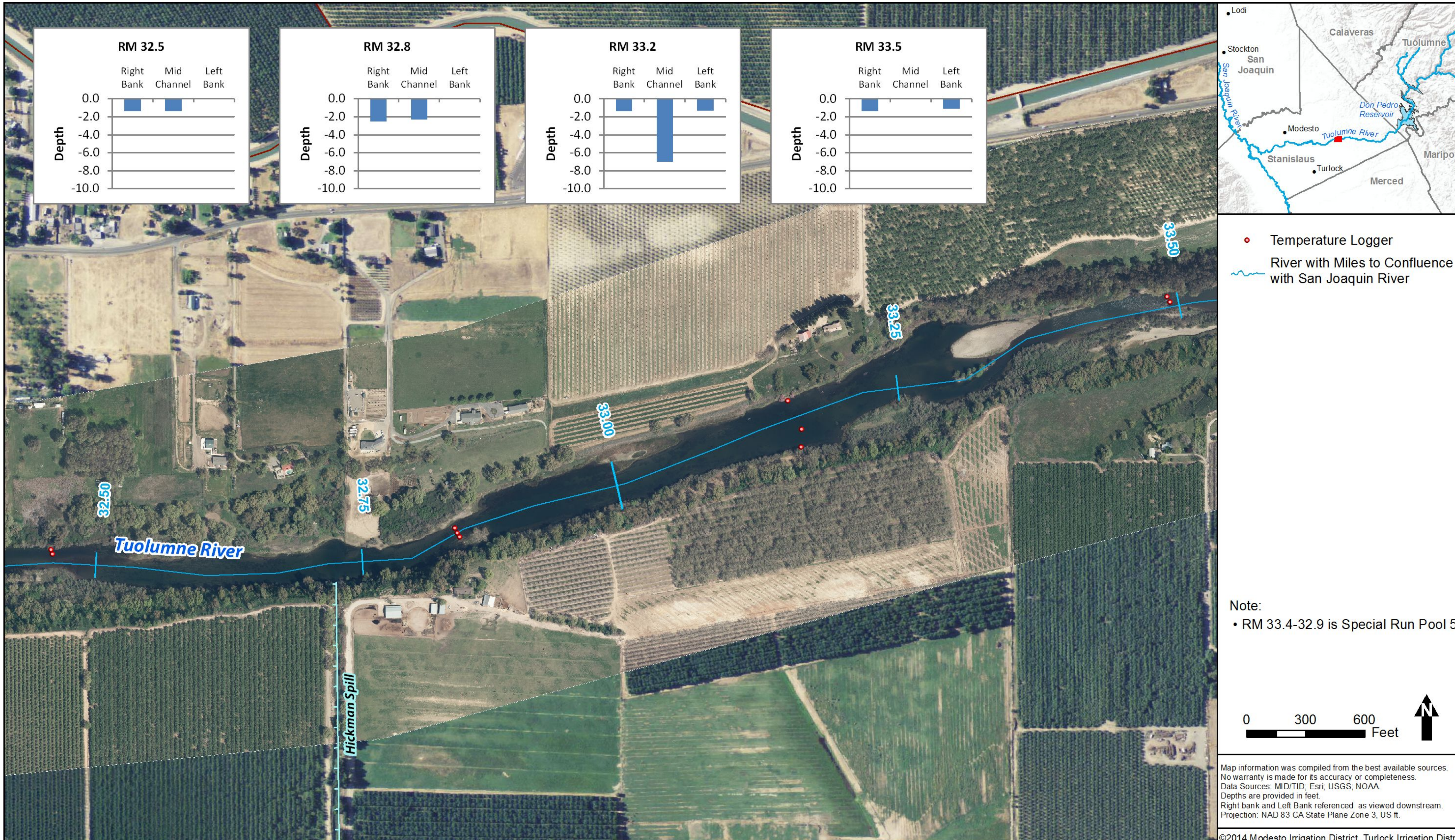


Figure 4.2-3. **Water temperature thermologgers from river mile 33.5 to 32.5.**

Temperature data collected from each logger are plotted in Figure 1 through Figure 13 of Attachment A: *Representative Photographs and Daily Minimum and Maximum Water Temperatures*. Despite being installed at different depths and parts of the channel, the diurnal variation within each transect was essentially the same during the study period and differences between adjacent transects' diurnal variation were small. As shown in Table 4.2-1 and Figure 4.2-4, all of the transects exhibited average diurnal temperature variations between about 2.5 ºC and 3.5ºC. Special Run Pool 11 (RM 36. 5 to RM 36.25) and SRP 5 (RM 33.4 to RM 32.9) are discussed further below in Section 4.3.

Table 4.2-1. Diurnal temperature variation during the study period.

River Mile/ Selected logger[1]	Number of Observations	Daily Temperature Variation (Δ ºC)			Date of Minimum Variation	Date of Maximum Variation
		Min	Average	Max		
GRAVEL MINING REACH						
36.5MC	92	1.75	3.73	5.26	9/21/2013	7/8/2013
36.25RB	92	1.68	3.53	4.59	7/23/2013	7/24/2013
36LB	92	1.63	3.25	4.19	7/23/2013	7/17/2013
35.5MC	92	1.58	2.50	3.68	9/22/2013	8/19/2013
35.25MC	92	1.6	2.41	3.6	7/23/2013	8/19/2013
35MC	92	1.37	2.62	3.43	7/23/2013	7/24/2013
34.75MC	92	1.53	2.76	3.58	7/23/2013	7/24/2013
34.5MC	92	1.54	2.88	3.71	7/23/2013	8/15/2013
Standard Deviation		0.11	0.49	0.63	--	--
IN-CHANNEL GRAVEL MINING REACH						
33.5LB	92	1.57	3.71	4.97	7/23/2013	7/24/2013
33.2MC Surface[2]	92	1.54	3.54	4.68	7/23/2013	7/24/2013
33.2MC Bottom[2]	92	1.46	2.66	3.57	7/23/2013	8/18/2013
32.8RB	92	1.69	2.60	3.5	9/22/2013	8/19/2013
32.5RB	92	1.33	2.44	3.83	7/23/2013	7/13/2013
Standard Deviation		0.13	0.59	0.67	--	--
UPPER SAND-BEDDED REACH						
24RB	45[3]	1.56	2.73	3.68	9/21/2013	8/15/2013
23.8	45[3]	1.56	3.03	4.12	9/21/2013	8/15/2013
23.5MC	92	1.39	3.36	4.53	9/21/2013	7/8/2013
23.25RB	45[3]	1.29	3.00	4.41	9/22/2013	8/11/2013
23MC	92	1.35	3.61	4.82	9/21/2013	7/8/2013
Standard Deviation		0.12	0.34	0.43	--	--
LOWER SAND-BEDDED REACH						
10LB	92	0.95	3.94	8.14	9/5/2013	7/18/2013
9.75 (9.8MC)	63[4]	3.38	5.62	7.69	7/22/2013	7/18/2013
9.5US (9.6MC)	92	1.45	5.17	7.64	9/21/2013	7/18/2013
9.5DS (9.4MC)	92	1.62	5.11	7.57	9/21/2013	7/18/2013
9.2RB	92	1.6	5.07	7.47	9/21/2013	7/18/2013
Standard Deviation		0.92	0.62	0.26	--	--

-- Not applicable
Δ change or difference
MC Middle Channel
RB Right Bank
LB Left Bank
[1] Most complete dataset from this transect; representative of transect temperatures.
[2] Loggers were placed at the surface and at the bottom of SRP 5.
[3] Data collected from 8/5/2013 to 9/30/2013.
[4] Data collected from 7/1/2013 to 9/1/2013.

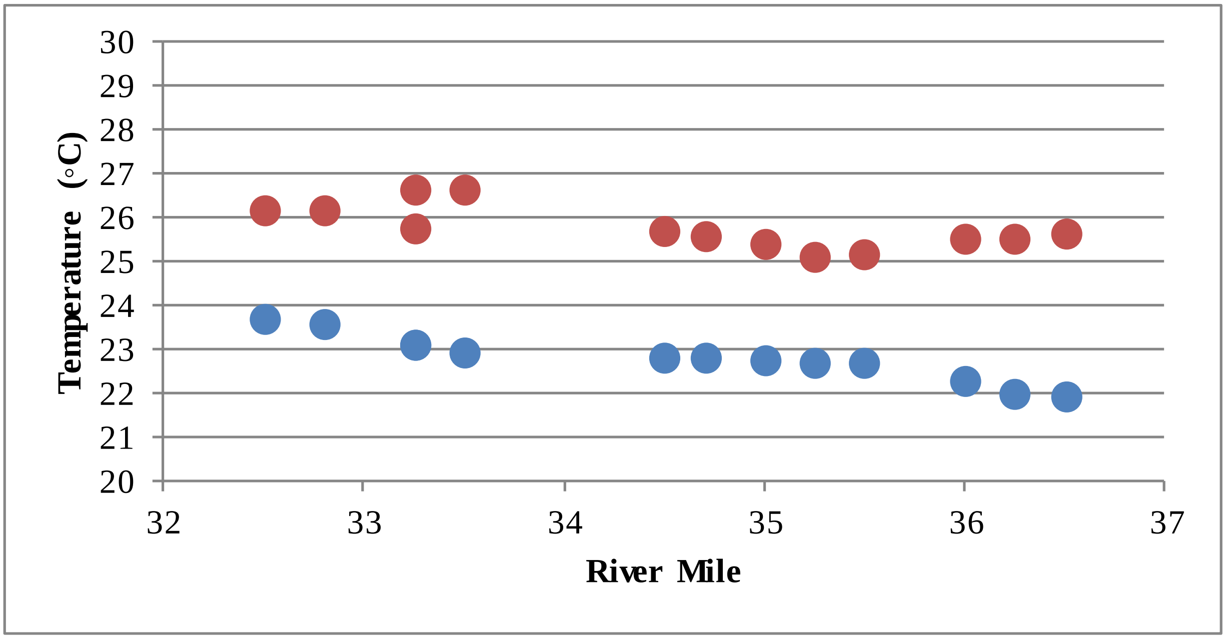


Figure 4.2-4. Average daily maximum and minimum temperatures —upstream and downstream of RM 33.

4.2.2 Upper Sand-Bedded Reach

The Upper Sand-Bedded Reach encompasses the river from approximately RM 19.3 to RM 24.0. The reach is characterized by sand bed and banks with little confinement by bluffs. The reach runs through mostly agricultural areas with some rural encroachment (McBain and Trush 2000) (Figure 4.2-5).

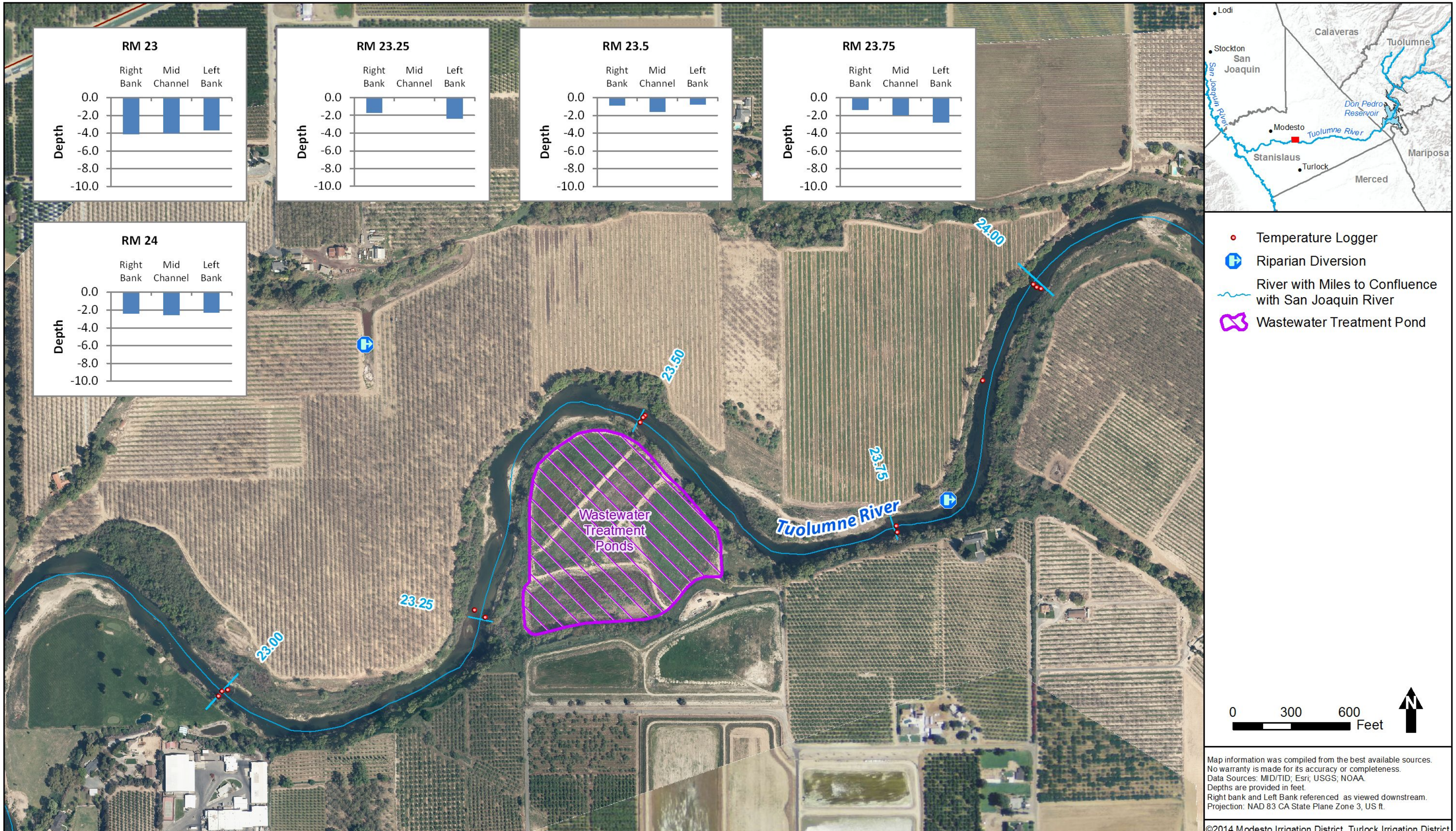


Figure 4.2-5. Water temperature thermologgers from river mile 24 to 23.

CDFW and/or the Districts maintain temperature loggers at RM 24 and RM 21 and the closest logger maintained upstream of the reach is at RM 26. During calibration of the lower Tuolumne River temperature model, observed summer river diurnal temperatures were not consistently reproducible by the model. Observed diurnal temperature ranges were significantly smaller at, and downstream of, RM 24 than predicted by the Model (TID/MID 2013b).

For this study, 14 loggers were installed along five transects downstream of RM 24, an area of suspected groundwater inflow (Figure 4.2-5). Transects were a little more than a mile downstream of SRP 9 (RM 25.9) and SRP 10 (RM 25.2). Two of the transects were located adjacent the City of Hughson's Wastewater Treatment ponds, which are located inland, south and adjacent to the river, at approximately RM 23.6 to RM 23.25.

Temperature data collected from each logger are graphed plotted in Attachment A, Figure 14 through Figure 18. Despite being installed at different depths and parts of the channel, the average diurnal temperature variation within and between transects in each reach was essentially the same during the study period, at 3ºC (Table 4.1-1; Figure 4.2-6).

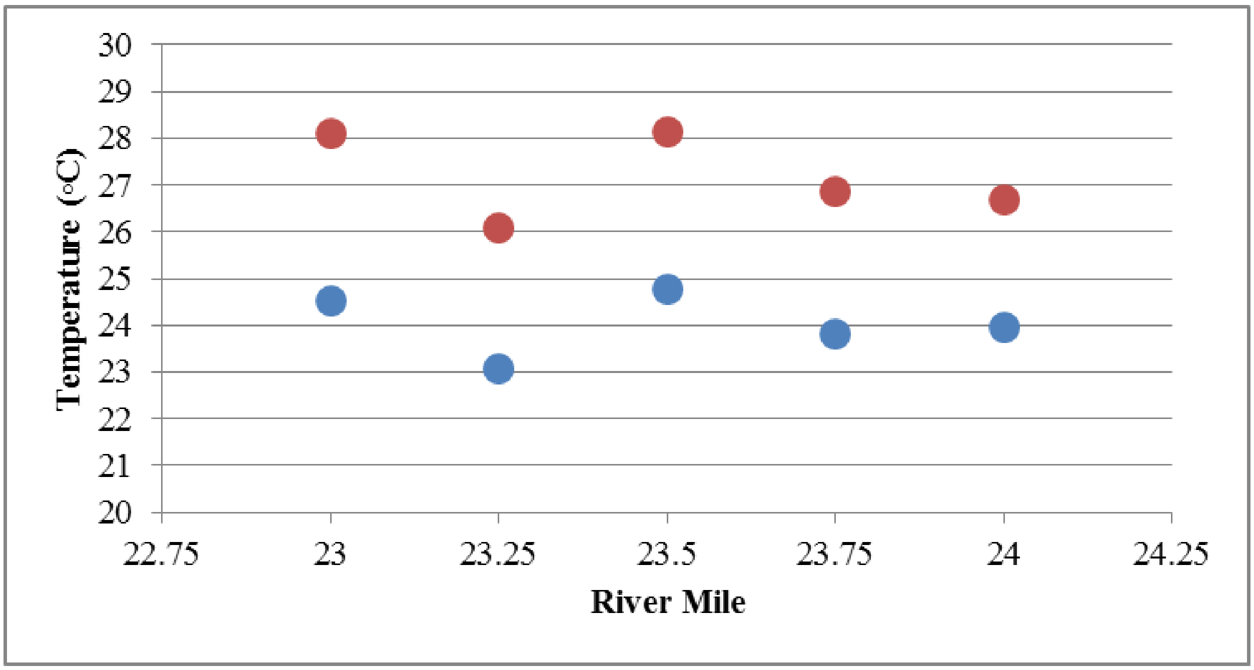


Figure 4.2-6. Average daily maximum and minimum temperatures —Upper Sand-Bedded Reach.

4.2.3 Lower Sand-Bedded Reach

The Lower Sand-Bedded Reach encompasses the river from approximately RM 10.5 to RM 0.0. The river slows and widens in this reach starting just downstream of the City of Modesto and ends at the San Joaquin River confluence. The reach is characterized by sand bed and banks with little to no confinement by bluffs and runs predominantly through agricultural areas (McBain and Trush 2000) (Figure 4.2-7).

For this study, 15 loggers were installed along five transects downstream of RM 10 (Figure 4.2-7). The locations are downstream of the Dry Creek confluence (RM 16) and TID's Lateral 1 operational outflow (RM 11). During logger installation for this study, at least five riparian diversions were observed in this reach.

Temperature data collected from each logger are graphed in Attachment A, Figure 19 through Figure 23. Despite being installed at different depths and parts of the channel, the average diurnal temperature variation within and between transects in each reach was essentially the same during the study period, at 5ºC (Table 4.1-1; Figure 4.2-8).

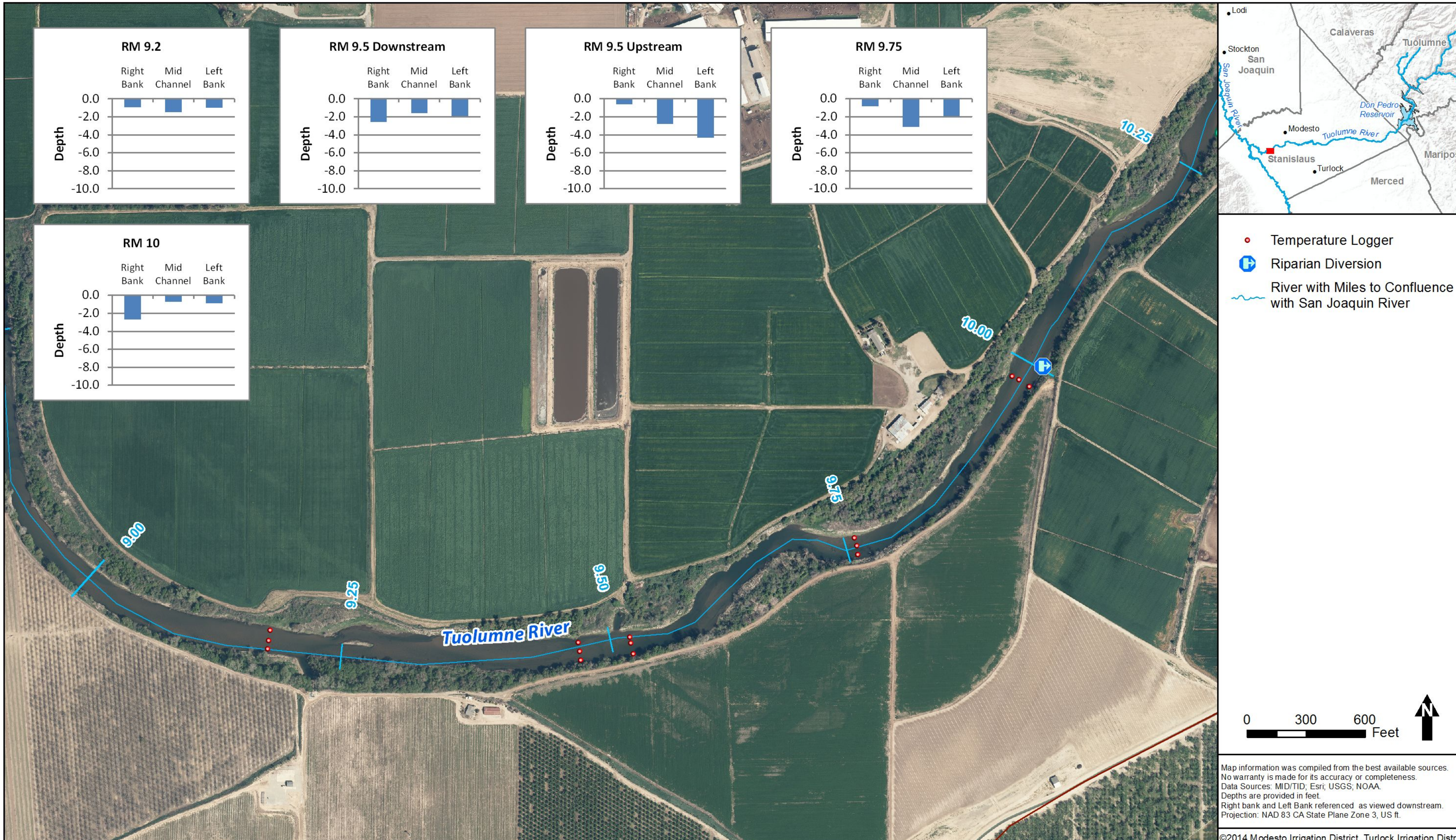


Figure 4.2-7. Water temperature thermologgers from river mile 10 to 9.2.

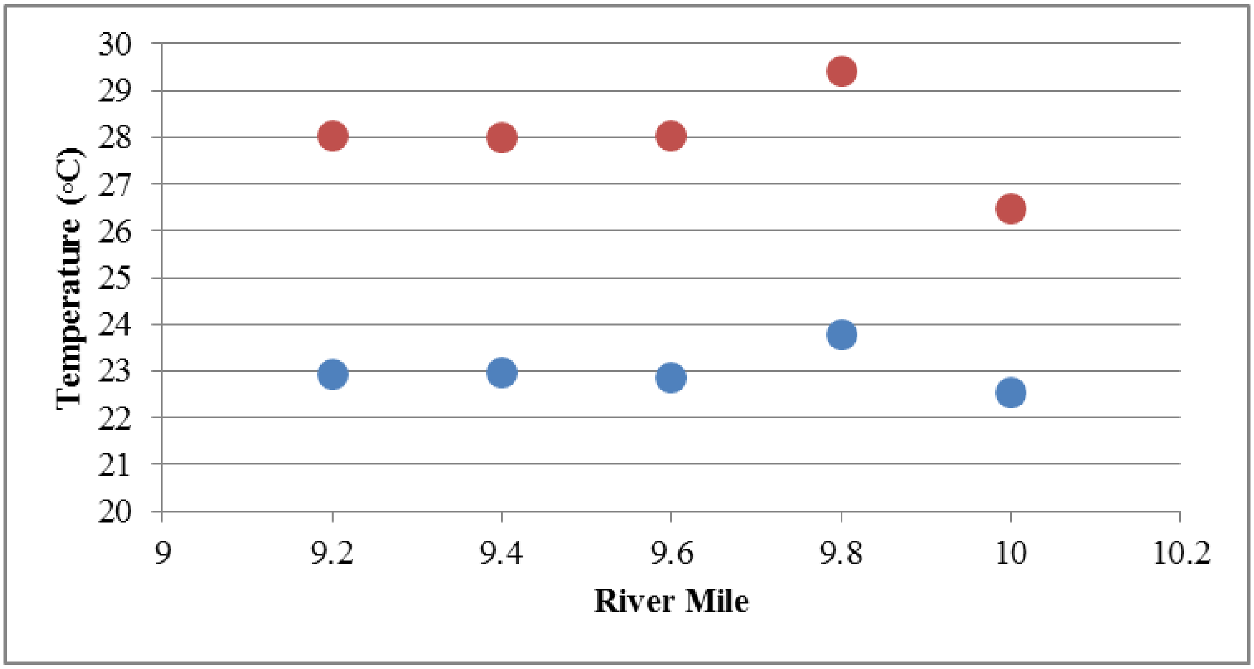


Figure 4.2-8. **Average daily maximum and minimum temperatures during the study period – Lower Sand Bedded Reach.**

4.3 Special Run Pools

Since the 1930s, aggregate mining companies have excavated sand and gravel directly from the active river channel, creating large, in-channel pits now referred to as "Special Run Pools". These SRPs are as much as 400 feet wide and 35 feet deep, occupying 32 percent of the channel length in the gravel-bedded reach.

4.3.1 Special Run Pool 11

Extending from approximately RM 36.5 to 36.25, SRP 11 is a remnant area of instream aggregate mining. Once in early August and once in early September, temperature profiles were collected at the deepest point of the pool (approximately RM 36.3). The pool was approximately 6 feet deep. From surface to bottom there was a two degree difference in August and a one degree difference in September (Figure 4.3-1).

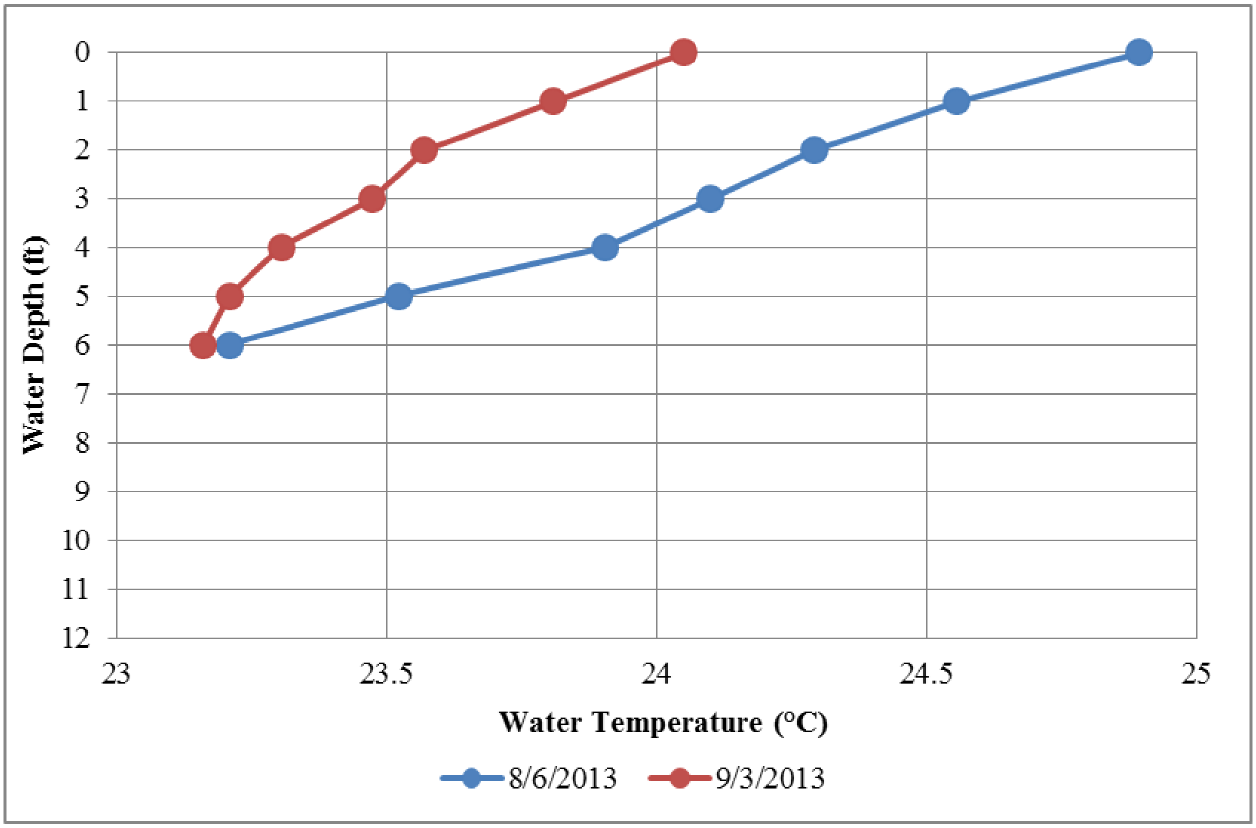


Figure 4.3-1. Temperature profile—SRP 11.

4.3.2 Special Run Pool 5

Extending from RM 32.9 to 33.4, SRP 5 is a remnant area of instream aggregate extraction. Once in early August and once in early September, temperature profiles were collected from the deepest point of the pool (at approximately RM 33.2). The pool was approximately 11 feet deep. From surface to bottom there was a two degree difference in August and an almost four degree difference in September and the thermocline was more pronounced in September than in August (Figure 4.3-2).

In addition to the temperature profiles, for the duration of the study period, continuous temperature loggers were deployed within a meter of the surface and within a meter of the bottom, e.g. described as “33.2MC Surface” and “33.2MC Bottom” in Table 4.1-1. Comparing data plotted in Figure 4.3-3, Figure 4.3-4, and Figure 4.3-5, indicates that the stratification within SRP 5 is affecting the downstream temperature’s diurnal variation. Each day, SRP 5 stratifies for a short period and then turns over. By the time the water reaches the next downstream location, the water is completely mixed. Figure 4.3-3 shows the daily cycle around August 6, the date of the first temperature profile, and Figure 4.3-4 shows the daily cycle around September 3, the date of the section temperature profile. Figure 4.3-5 shows the daily cycle over the whole month of July.

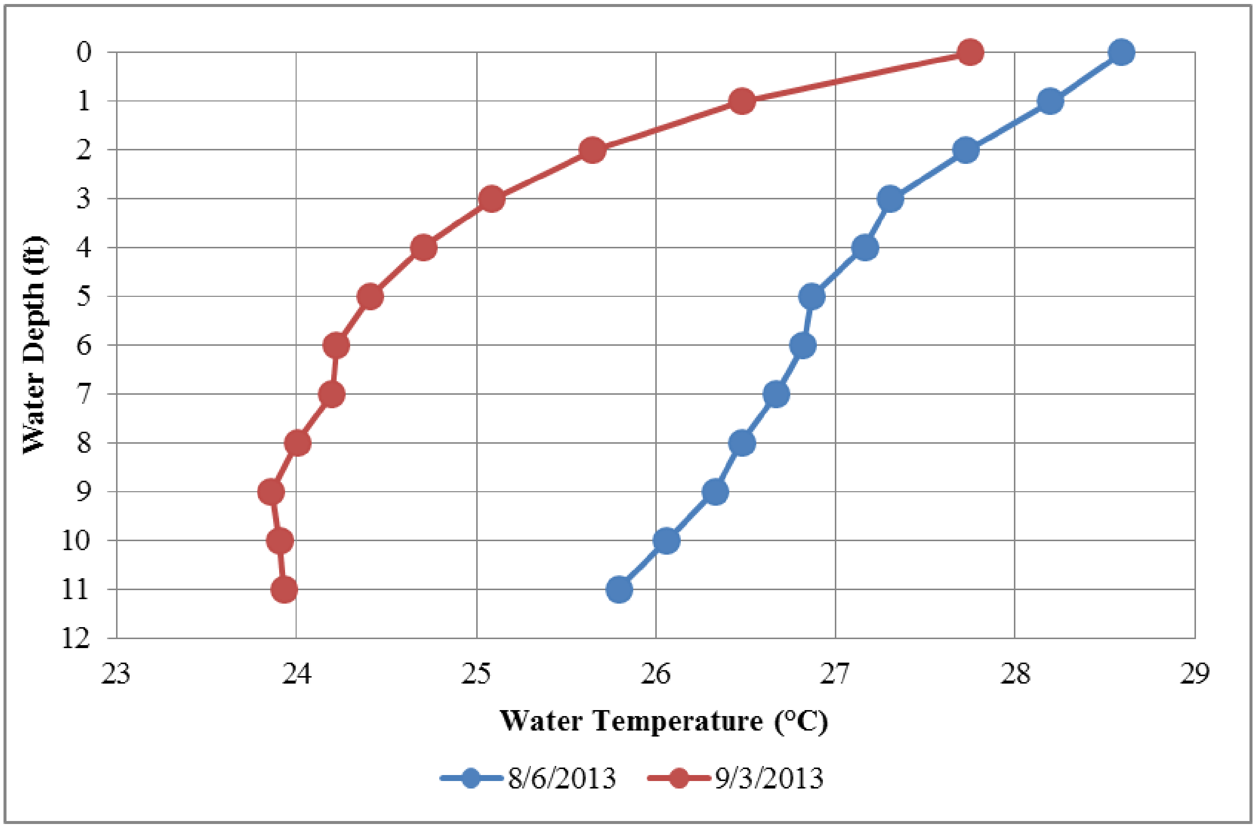


Figure 4.3-2. Temperature profiles—SRP 05.

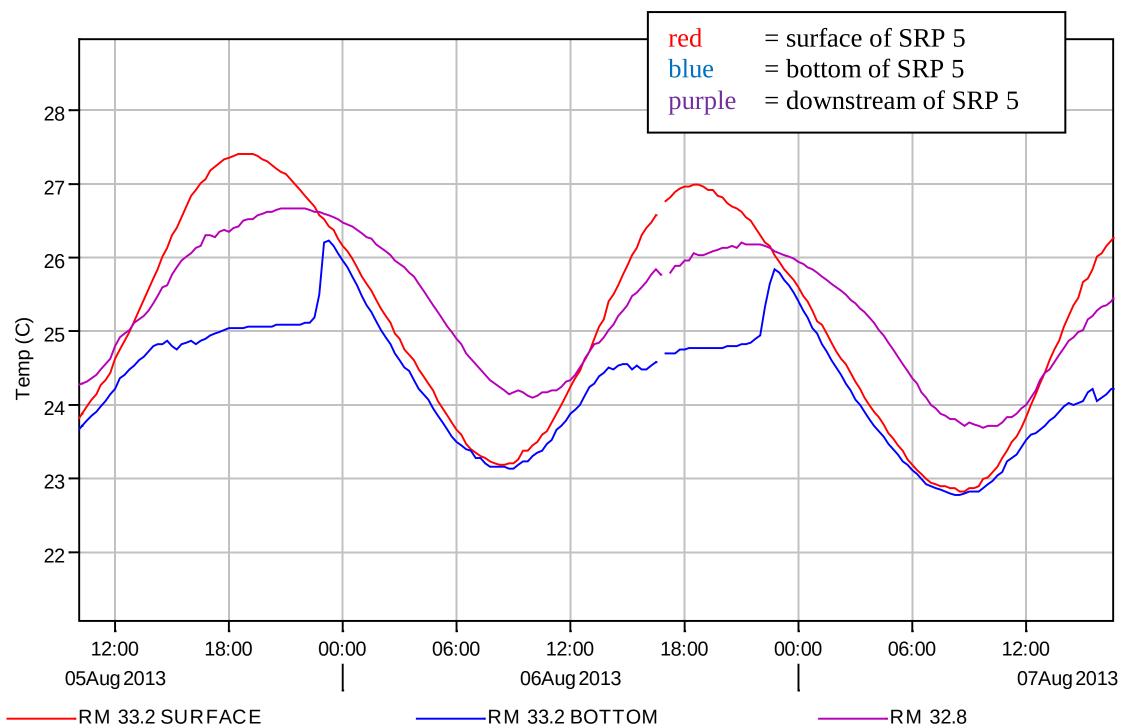


Figure 4.3-3. Effect of SRP5 stratification on temperatures—8/6/13.

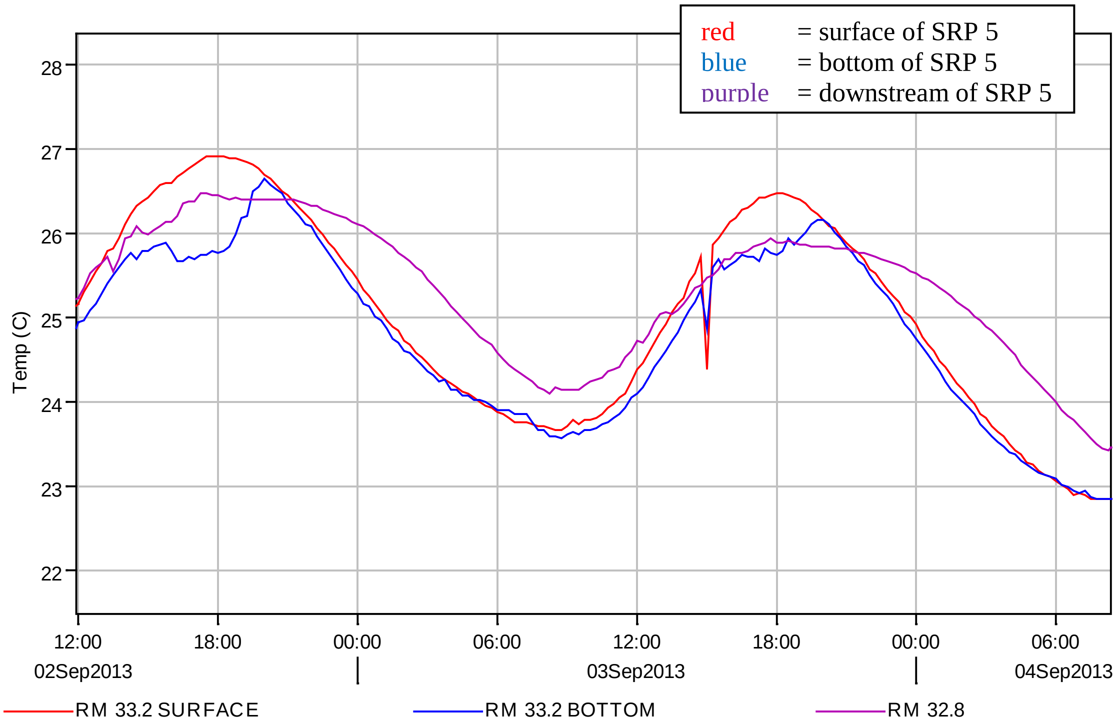


Figure 4.3-4. Effect of SRP5 stratification on temperatures—9/3/13.

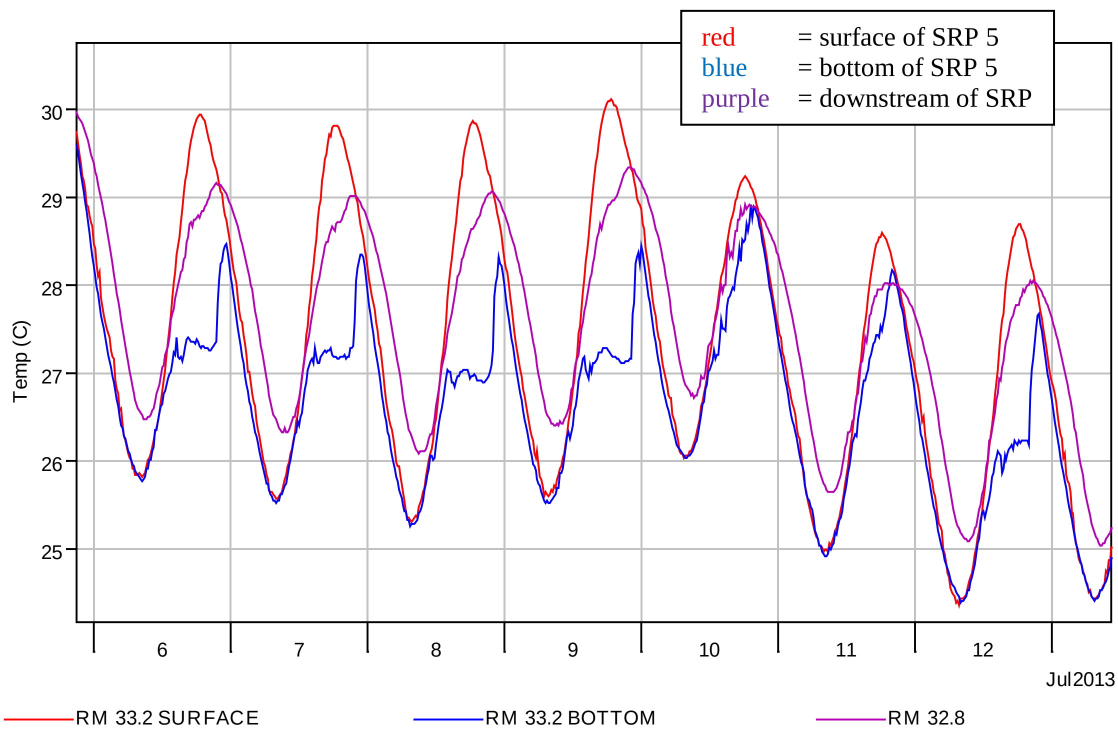


Figure 4.3-5. Effect of SRP5 stratification on temperatures—July, 2013.

4.4 Longitudinal Profiles

To examine longitudinal temperatures, four representative dates were selected for establishing longitudinal profiles (Figure 4.4-1). Since RM 36.5 is the most upstream location monitored in this study and is, on a daily basis, expected to have the lowest temperatures of any of the sites monitored during the summer, dates where RM 36.5 exhibited its maximum, minimum, and average maximum temperatures were selected (Table 4.4-1). During this period average daily flow was approximately 100 cfs (measured at La Grange), with few exceptions. One notable exception occurred when flows were increased to approximately 200 cfs for a few days around August 17th, for the Lowest Boatable Flow Study (TID/MID 2013a). Hence, a fourth date, August 17th, was examined in Figure 4.4-1, as well.

Table 4.4-1. Distribution of maximum temperatures at RM 36.5, 7/1/13—9/30/13.

Maximum Temperature (ºC)	Number of Days	Notes
29	9	Highest maximum 29.8 ºC on July 4
28	5	
27	13	
26	22	
25	12	Average maximum 25.2 ºC on August 23
24	8	
23	11	Maximum 23.5 ºC on August 17, when flows were 200 cfs.
22	2	
21	2	
20	5	
19	2	Lowest maximum 20.3 on September 25

All data collected by CDFW and TID/MID[1] during the study period are shown in Figure 4.4-1. The average maximum and average minimum temperatures on the selected dates are provided in Figure 4.4-2 through Figure 4.4-5. Taken together with the longitudinal profiles in Figure 4.4-1, these figures illustrate the following:

- the general increase of temperatures from upstream to downstream, up to about RM 30,
- equilibrium temperatures generally appear to be attained by roughly RM 30,
- an increase in variation between some transects as inflow temperatures are reduced, and
- a reduction of diurnal temperature variation with increased flow.

These observations are discussed further in Section 5.0.

[1] Collectively, CDFW and TID/MID currently maintain 29 continuous loggers in the lower Tuolumne River. The most upstream logger is located at RM 51.8 and the most downstream logger is located at RM 3.4 (TID/MID 2013c). The sites monitored for this this study were in addition to the established continuous sites.

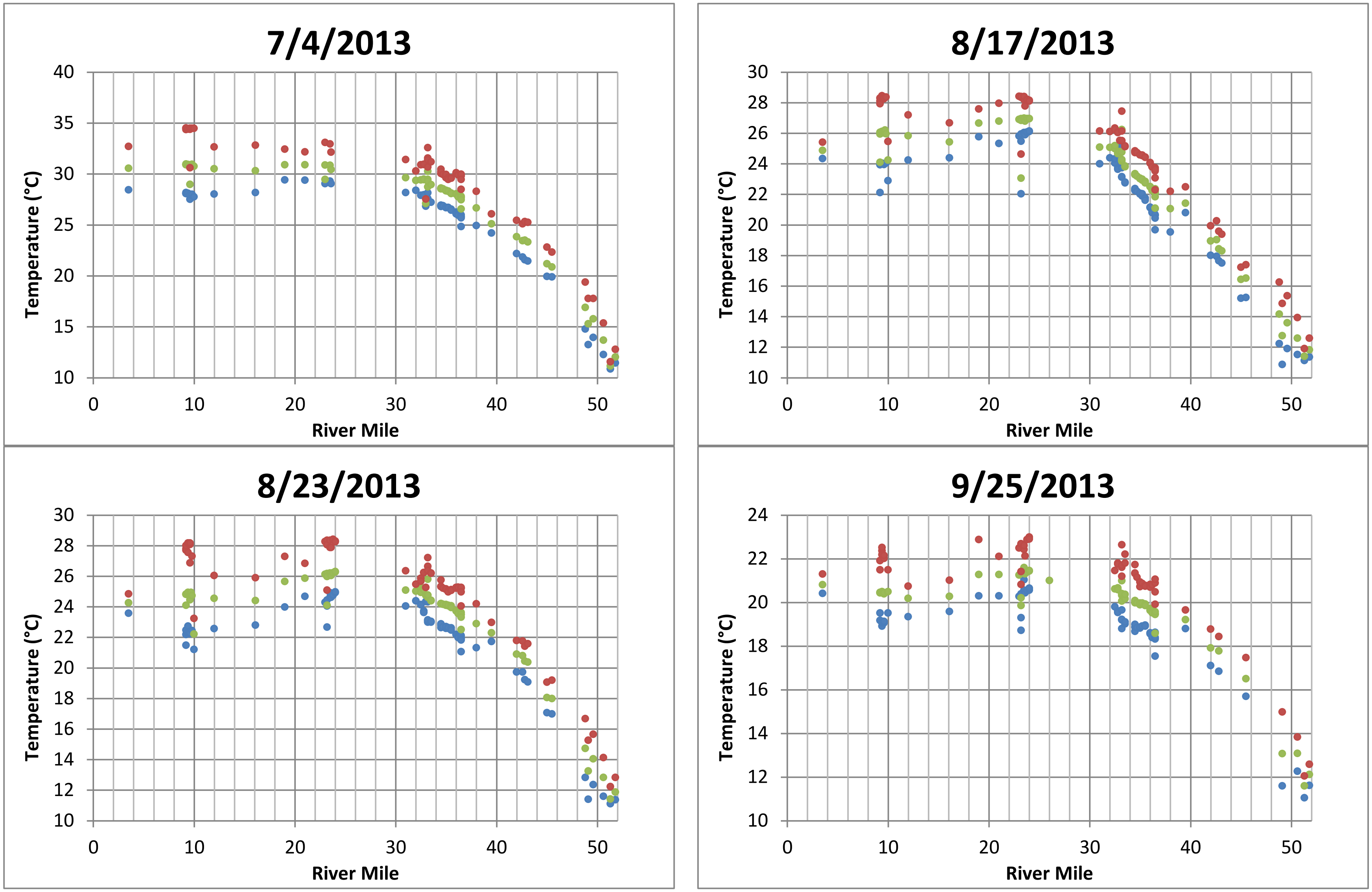


Figure 4.4-1. Maximum, average, and minimum temperatures from selected dates. [Red=maximum; Green=average; Blue=minimum].

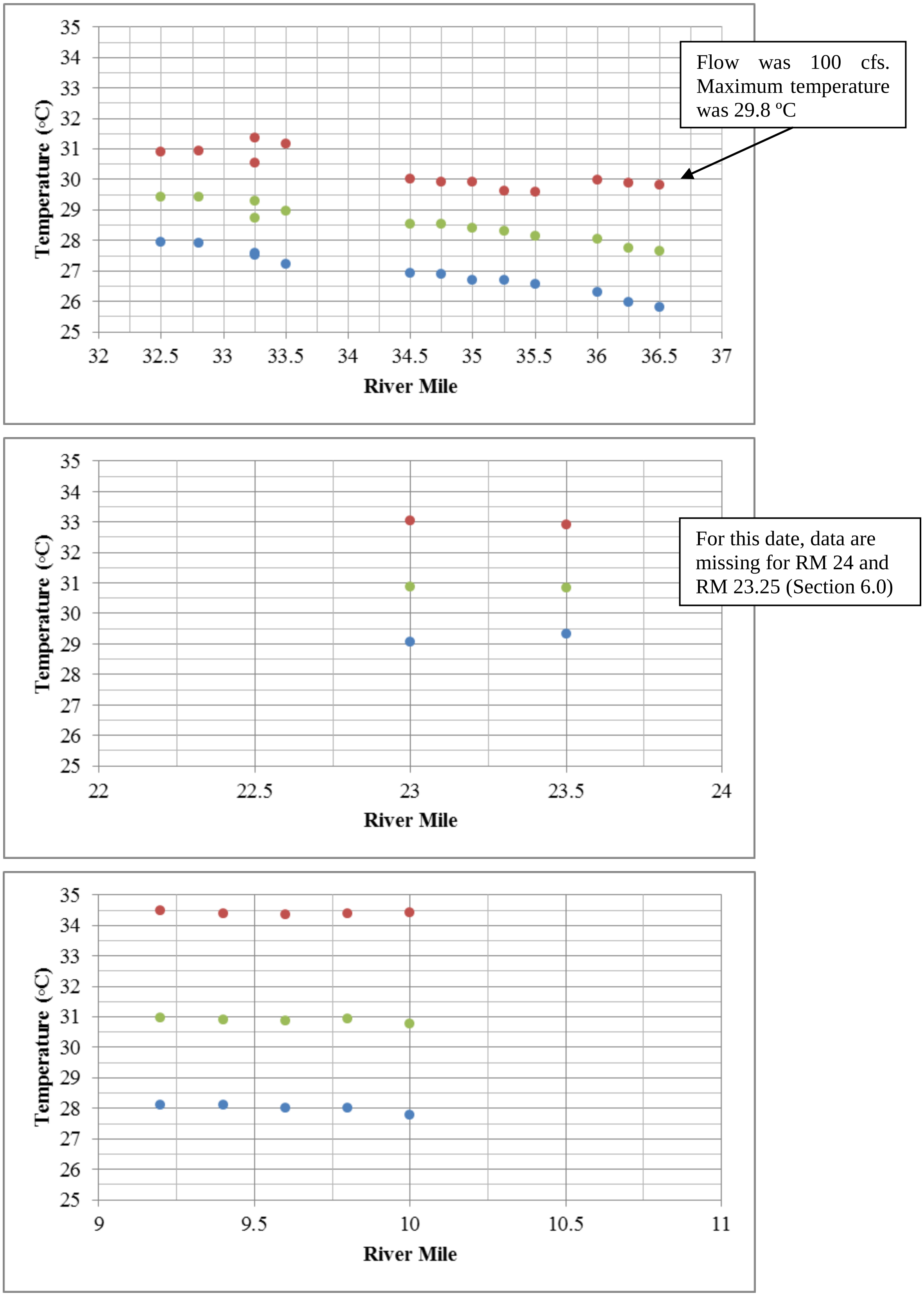


Figure 4.4-2. July 4, 2013. [Red=maximum; Green=average; Blue=minimum].

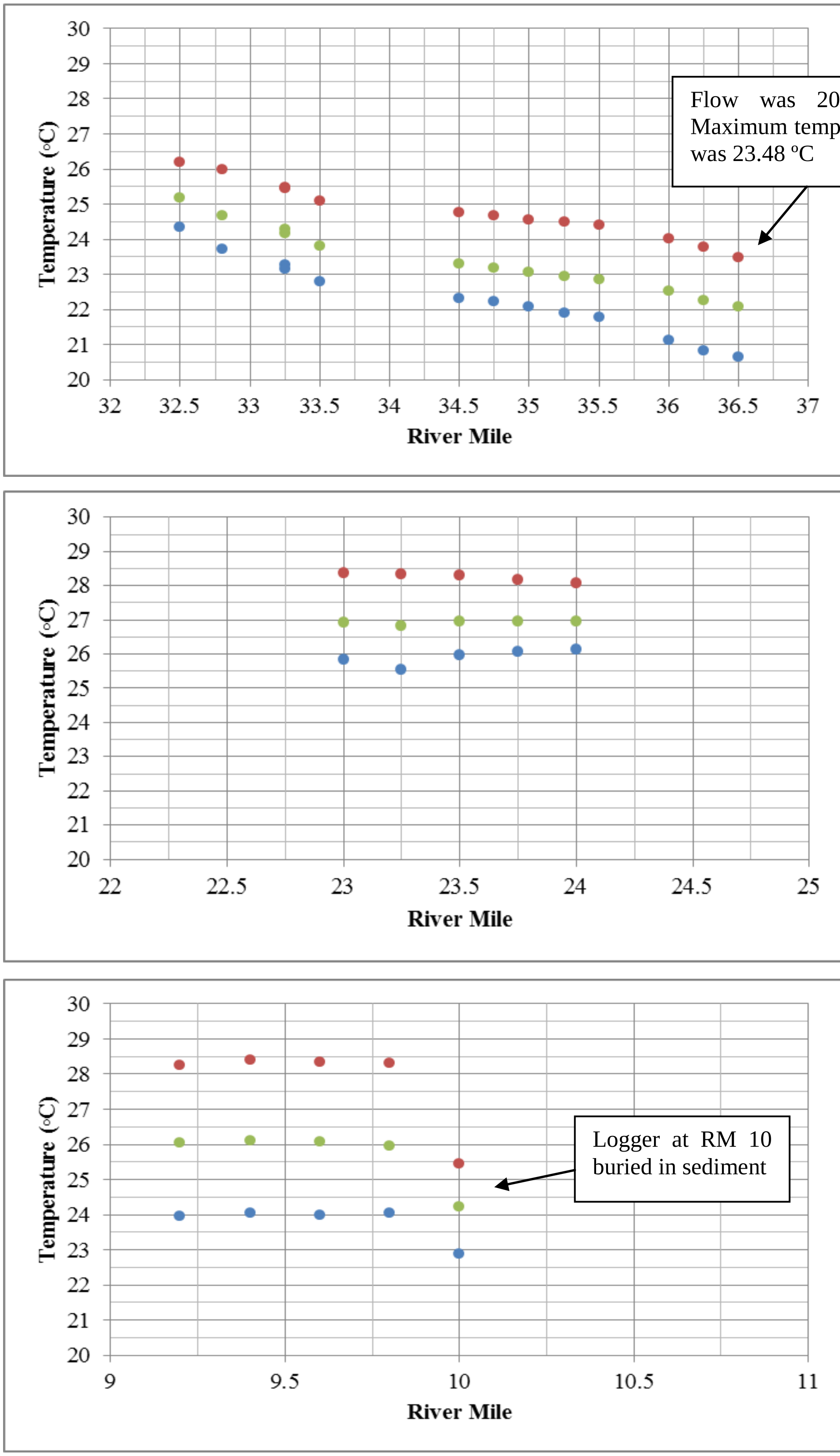
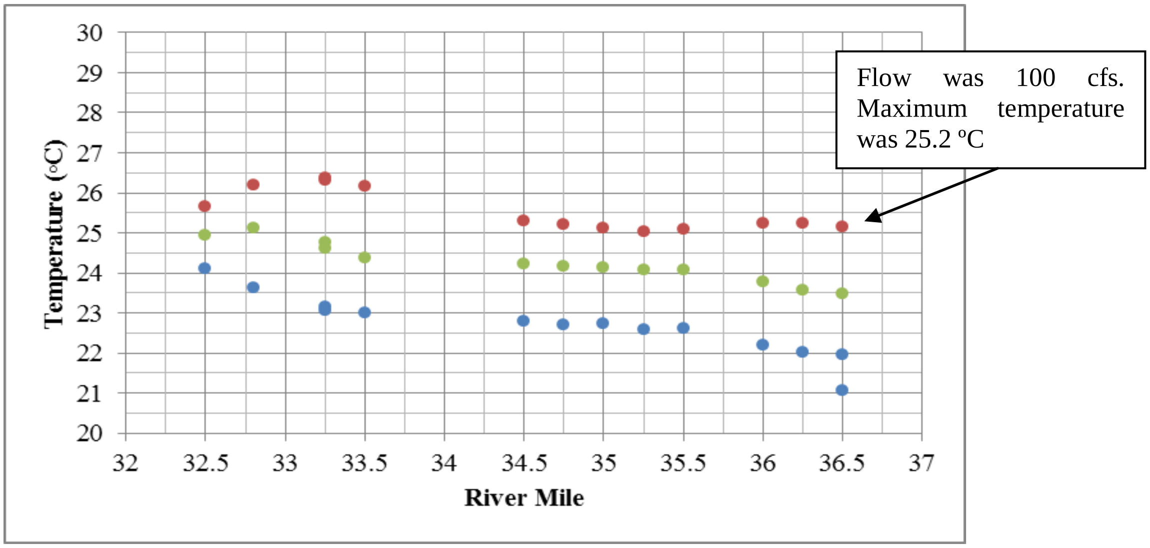
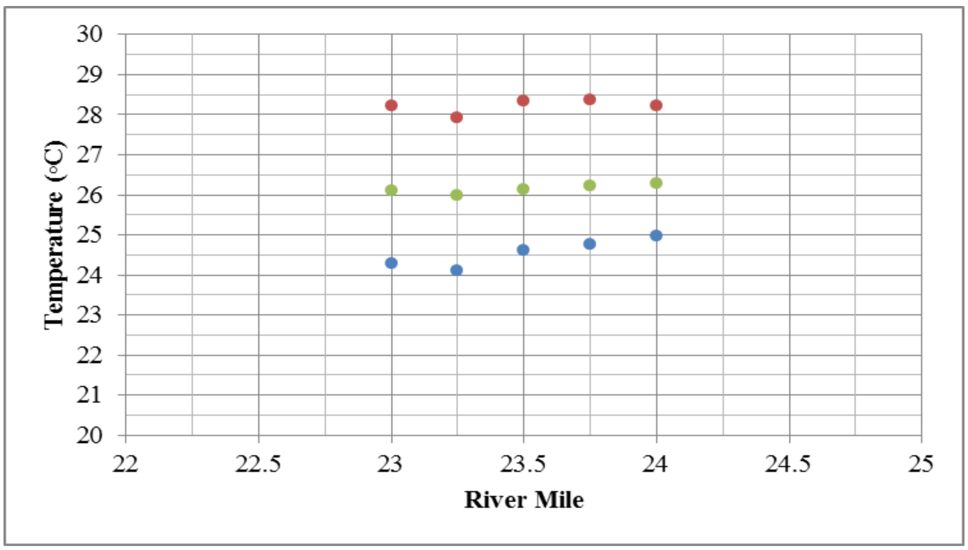


Figure 4.4-3. August 17, 2013. [Red=maximum; Green=average; Blue=minimum].





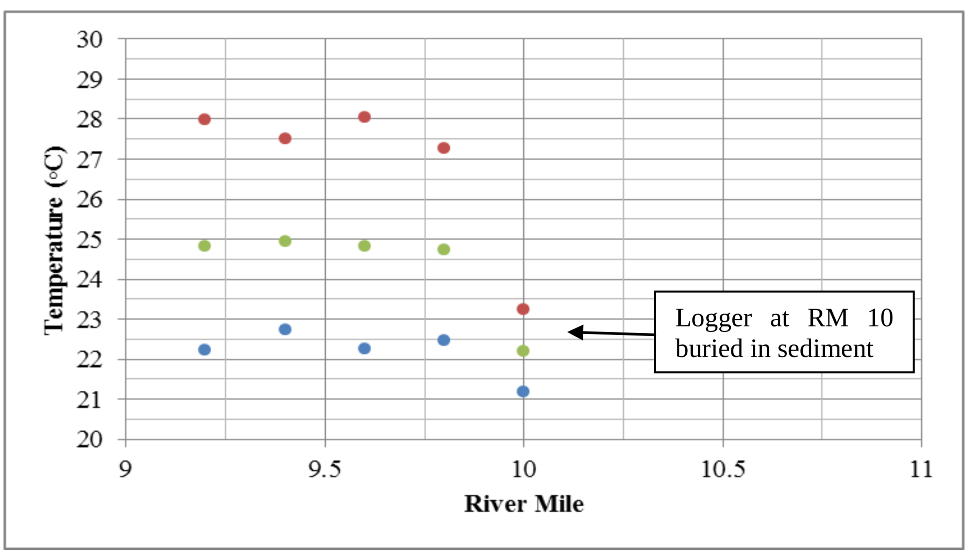
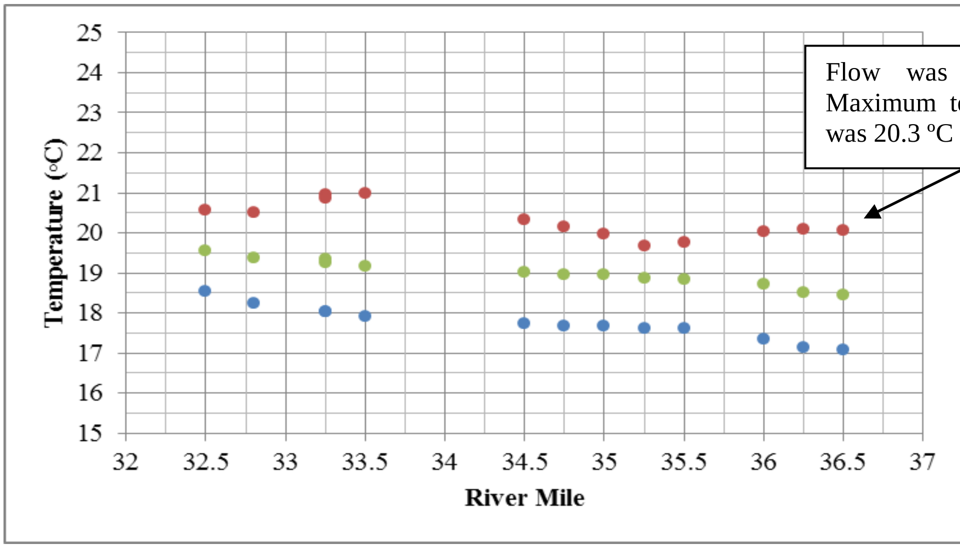
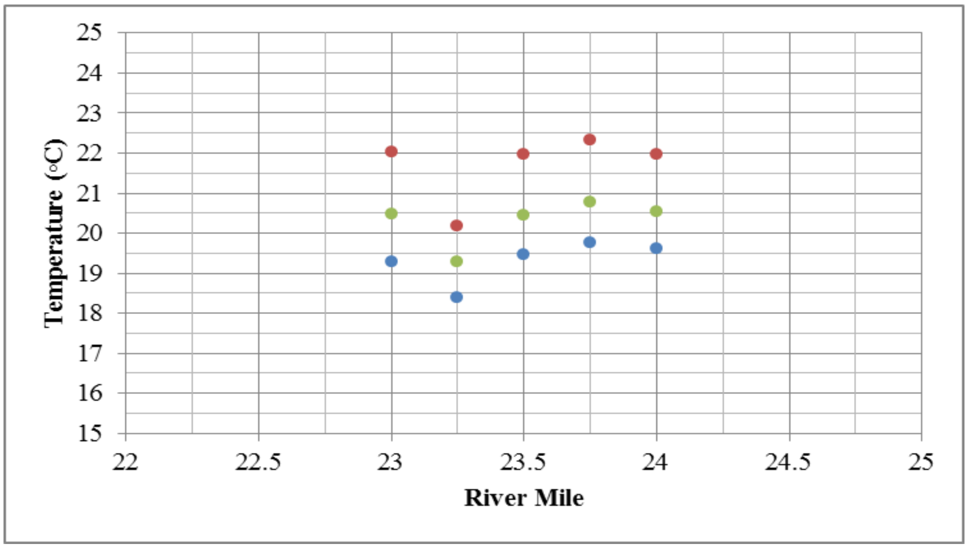


Figure 4.4-4. August 23, 2013. [Red=maximum; Green=average; Blue=minimum].





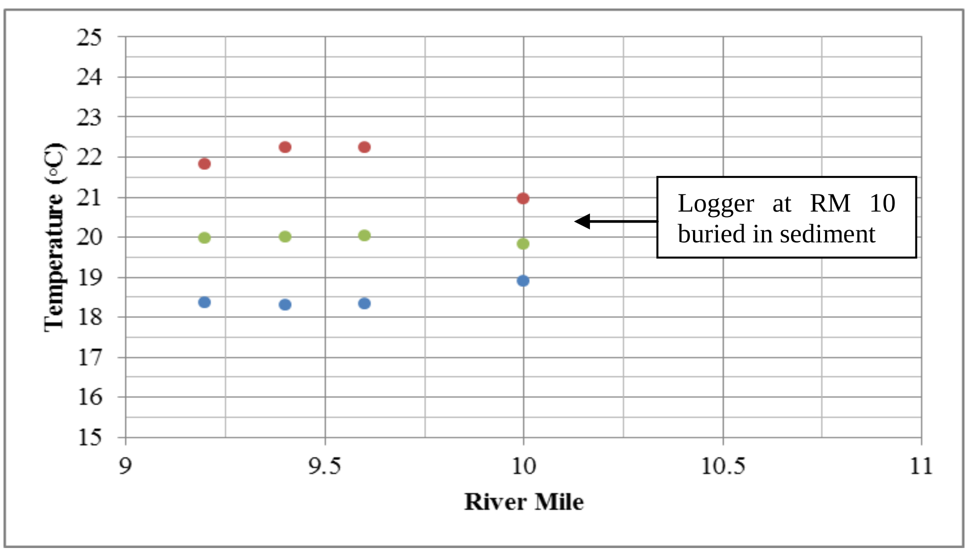


Figure 4.4-5. September 25, 2013. [Red=maximum; Green=average; Blue=minimum].

5.0 DISCUSSION AND FINDINGS

This intensive spatially-focused thermal study was undertaken in summer 2013 to further study the potential for local influences, such as groundwater, operational spills and special run pools, to influence diurnal temperature variation occurring over short distances in sub-reaches of the lower Tuolumne River (Figure 5.0-1). In Section 5.1, the diurnal variation observed in 2013 is compared to the diurnal variation observed in 2011 and 2012. Temperature data collected in the years 2011 and 2012 were used to calibrate and validate the lower Tuolumne River temperature model. In Section 5.2, representative loggers used for calibration and validation of the lower Tuolumne temperature model are examined to evaluate consistency with loggers located just upstream and downstream. Conclusions from this study are provided in Section 5.3.

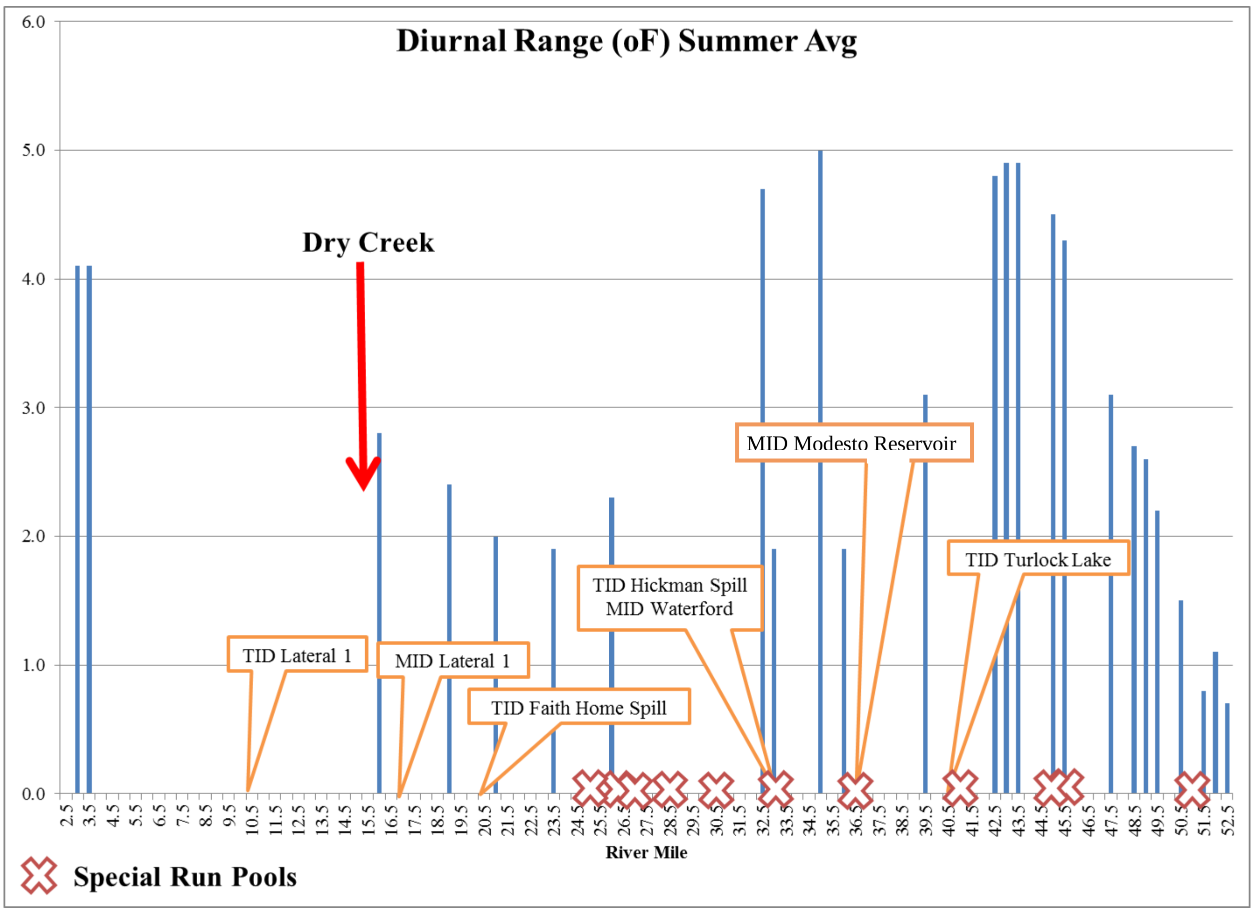


Figure 5.0-1. Summer average diurnal range (2011) at actual river location [ºF; Source TID/MID 2013b].

5.1 Comparison to Historical Information (2011 – 2012)

Diurnal temperature variation observed between July 1 and September 30 are plotted for the years 2013, 2012, and 2011 in Figure 5.1-1, Figure 5.1-2, and Figure 5.1-3. Presented in degrees Celsius, the diurnal variation observed in in 2013 is more similar to 2012 than 2011, but is generally consistent at locations measured in all three years.

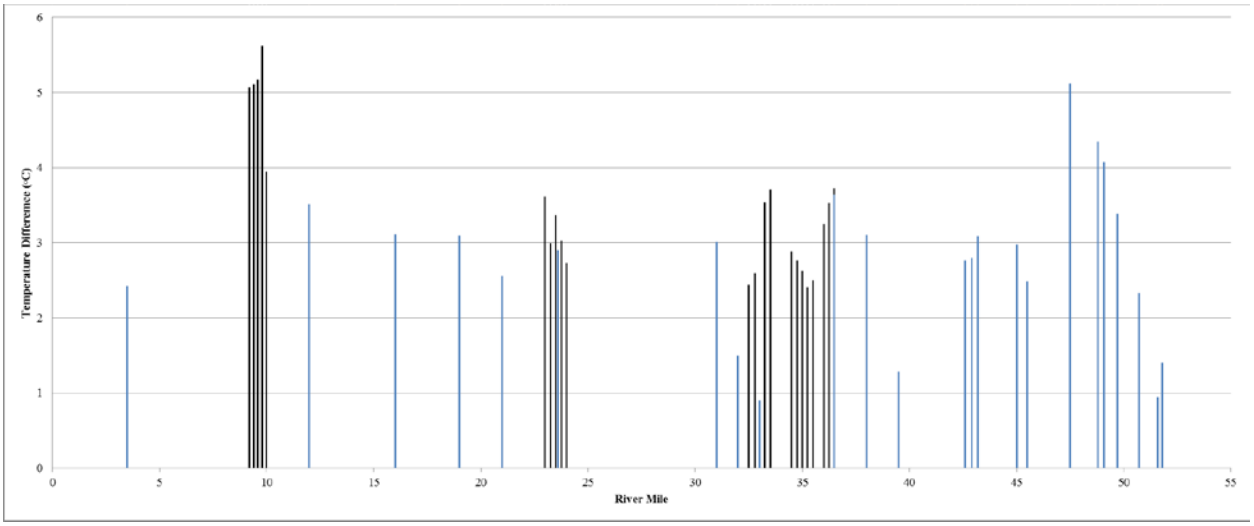


Figure 5.1-1. Average daily diurnal variation, 7/1/13—9/30/13 [ºC; blue = data collected from TID/MID and CDFW loggers; black = data collected for this study].

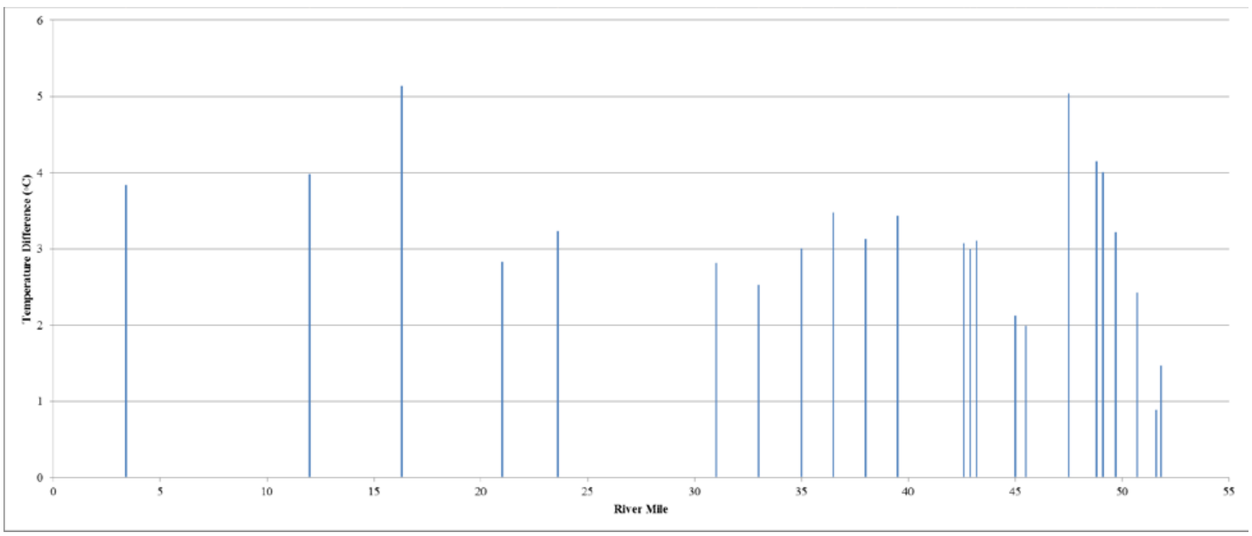


Figure 5.1-2. Average daily diurnal variation, 7/1/2012—9/30/2012 [ºC; blue = data collected from TID/MID and CDFW loggers].

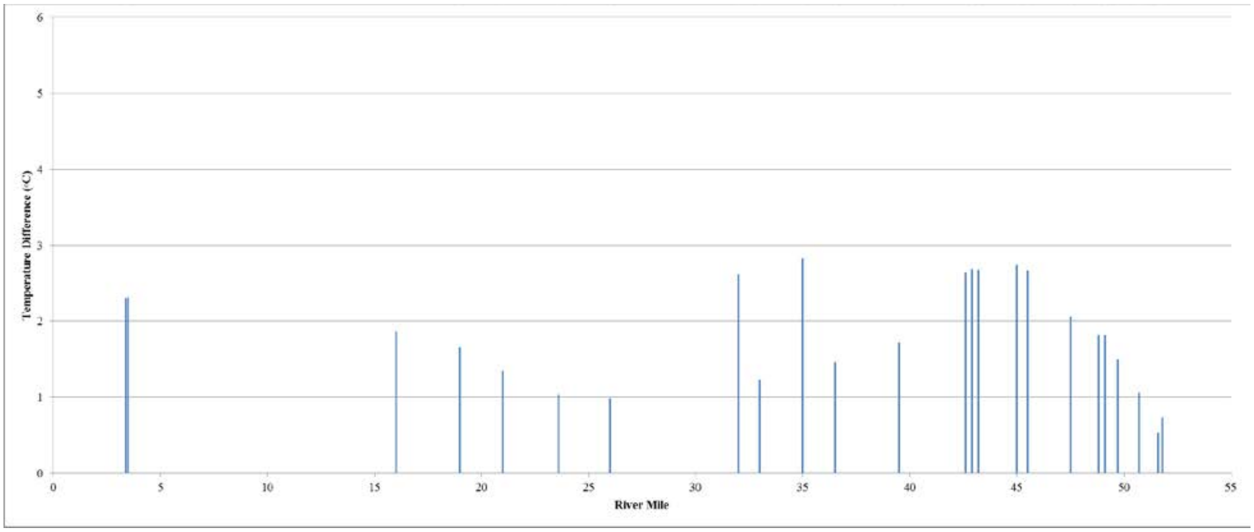


Figure 5.1-3. Average daily diurnal variation, 7/1/2011—9/30/2011. [ºC; blue = data collected from TID/MID and CDFW loggers].

Groundwater inflow would be expected to have a near constant temperature, which would be expected to suppress the in-river diurnal temperature range within its influence. However, no apparent effect was observed in the 2013 data. In 2013, the reach most expected to be influenced by groundwater inflows was RM 10.0 to RM 9.2 but no influence was observed. In fact, in 2013 diurnal variation downstream of RM 10 was actually higher than anywhere else on the river.

When Dry Creek inflows and temperatures are considered, it is likely that any groundwater influence was masked by Dry Creek, which confluences with the Tuolumne River at RM 16, just upstream of the study site. As shown in Figure 4.1-3, during the 2013 study period, Dry Creek flows ranged between 25 and 75 cfs, introducing water temperatures that ranged between 16 and 30 ºC. Since the Tuolumne River flows at the Modesto gage (RM 16.2) ranged from approximately 150 to 250 cfs (Figure 4.1-1), the flows and temperatures from Dry Creek accounted for anywhere from 10 percent to 50 percent of the total river flows.

Special run pools, on the other hand, do appear to have a measureable, very localized, effect on diurnal temperatures, at least on occasion. As shown in Section 4.3.2, SRP 11 and SRP 5 were both stratified in during the study period (Figure 4.3-3; Figure 4.3-4). In addition, when loggers were placed at both the surface and at the bottom of SRP 5, a visible local effect on downstream diurnal temperatures was observed for a short time each day (See Figure 4.3-3, Figure 4.3-4, and Figure 4.3-5). In 2013, the reach expected to be affected by SRPs most would be RM 24 to RM 23, as there are a number of upstream SRPs. The diurnal variation was consistent in 2013 and 2012; however, in 2011 the difference in diurnal variation from upstream to downstream is more pronounced.

5.2 Comparison to On-going Monitoring Logger Data

At some locations, temperatures recorded by this study are inconsistent with temperatures recorded by CDFW's and TID/MID's on-going long term monitoring loggers. As shown in Figure 5.2-1 and Figure 5.2-2, in these cases, the CDFW or TID/MID measured diurnal variation

- is one or two degrees Celsius smaller than the logger's installed upstream and downstream,
- shows delayed maximum and minimum temperature timing, compared to both upstream *and* downstream loggers, and
- tracks closely with daily average temperature, but not maximum and minimum temperatures.

In these cases, the closely placed, even redundant, loggers would suggest that the source of the dampened diurnal variation is logger-specific, either in its calibration or placement, rather than groundwater, flow, or proximity to a SRP. Established loggers near Roberts Ferry Bridge, exhibit the same phenomenon (Figure 5.2-3).

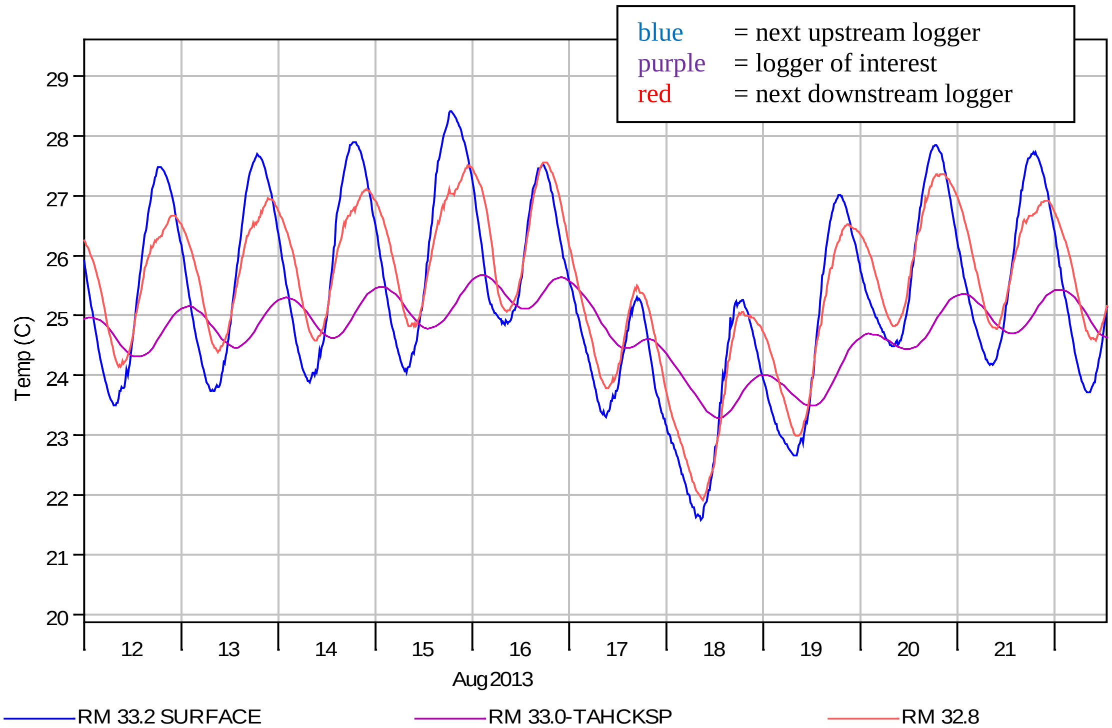


Figure 5.2-1. Temperature observed in 2013 above Hickman Spill (RM 33), 0.2 miles upstream (blue) to 0.2 miles downstream (red).

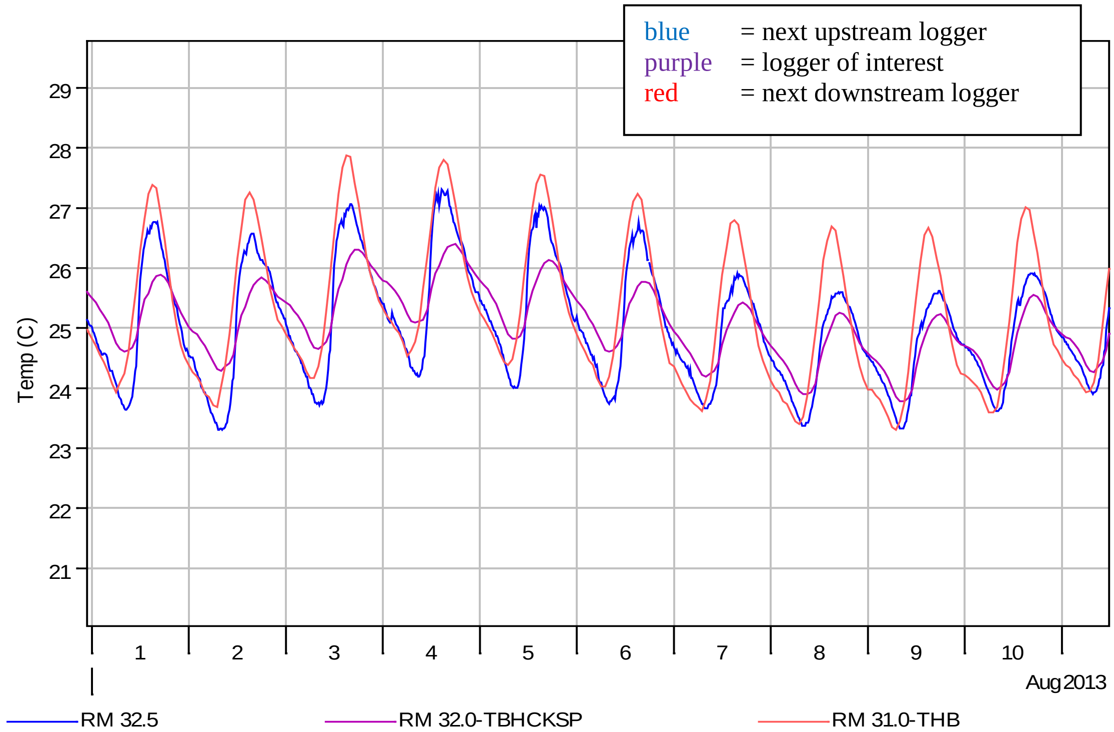


Figure 5.2-2. **Temperature observed in 2013 below Hickman Spill, 0.5 miles upstream upstream (blue) to one mile downstream (red).**

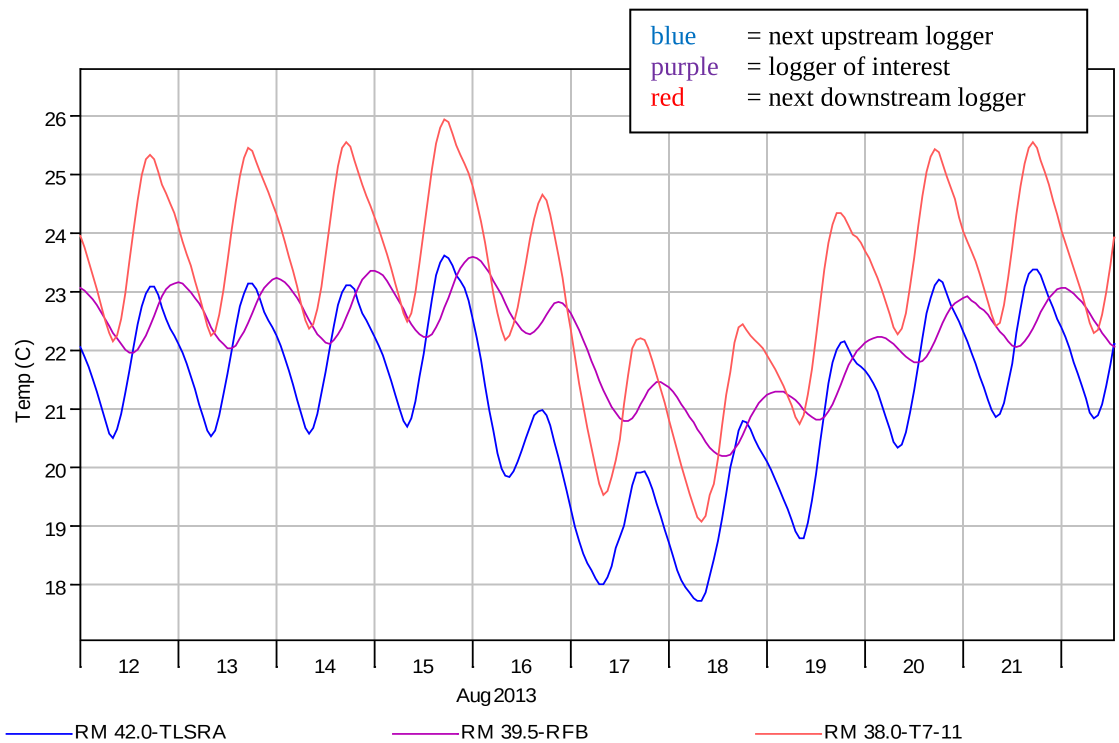


Figure 5.2-3. **Temperature observed in 2013 near Roberts Ferry Bridge, 2.5 miles upstream (blue) to 1.5 miles downstream (red).**

5.3 Conclusions

In-river diurnal variation observed in 2011 and 2012 exhibited a general pattern that was repeated in 2013. Summertime water releases from Don Pedro Reservoir initially experience a rapid increase in diurnal temperature range from essentially 0°C to 5°C, over the first 5 to 10 miles. Then, downstream of about RM 42 to 47, perhaps depending on summertime river flow, the summertime diurnal temperature range is generally limited to about 2.5°C to 3.5°C until about RM 10 to 15 where once again a 5°C diurnal range may be observed. Within this general pattern, summertime data recorded since 2011 have also displayed some rapid changes in the diurnal temperature range over very short longitudinal distances. Elucidating local influence on diurnal variation was an objective of this study.

To gain further insight into the diurnal temperature patterns observed in 2011 and 2012, the Districts undertook an intensive survey of river temperatures in the summer of 2013 consisting of installing forty-eight thermologgers along 22 transects and within two SRPs of the lower Tuolumne River. All the thermologgers employed in 2013 were new and manufactured by the same company, and considerable attention was given to precise and consistent calibration, checking, and data download. As was observed in 2011 and 2012, diurnal variation observed in this study exhibited an initial rapid expansion downstream of Don Pedro Reservoir and was dampened at higher summertime flows. However, no other patterns were persistent. The influence of groundwater originally suspected of occurring in the vicinity of RM 23, 32, and 36 could not be corroborated in 2013 data. The influence of SRPs was modest and local, i.e. diurnal variation was dampened just downstream of SRP 5 but did not extend significantly downstream. Some minor thermal stratification was observed in the SRPs at the lowest summer flows experienced (about 100 cfs), but mixing appeared to occur at flows of around 200 cfs.

The high density of loggers installed for this study allowed for an additional exploration to be performed. Some of the loggers installed for this study were intentionally located in close proximity to CDFW and TID/MID’s long-term temperature monitoring stations for the purpose of testing data consistency. It was reasonable to expect temperature and diurnal variation collected at adjacent locations to yield the same temperatures and ranges. This was not the case. In at least three areas, the long-term stations’ loggers did not duplicate diurnal ranges of multiple study loggers located over very short distances upstream and downstream, and the lack of duplication could not be explained by site characteristics or position of the thermologgers. Results of this study, therefore, suggest that the heterogeneity observed in diurnal variation could be attributed to the measurement devices installed at the long-term stations themselves. Differences in age, manufacturer, calibration protocols and unobserved local site variability could easily produce the observed inconsistencies in the raw data. Over the long term record, the temperature data attributed to a single RM may be comprised of multiple loggers, loggers that might be calibrated differently or replaced several times.

Concerns that the lower Tuolumne temperature model (TID/MID 2013b) would not be able to predict certain summertime temperature variations led to the 2013 intensive survey. However, nothing found by the 2013 survey leads the Districts to recommend recalibration of the river temperature model. The lower Tuolumne River model calibration and validation statistics for average and maximum temperatures indicate that modeled temperatures are a good fit to the observed temperature trends in the river.

6.0 STUDY VARIANCES AND MODIFICATIONS

The study was conducted in conformance to the FERC-approved In - River Diurnal Temperature Variation Study Plan approved in FERC's May 21, 2013, Determination. There were two general variances; (1) the placement of loggers and (2) data loss, resulting in incomplete data sets for some locations.

The FERC-approved study states that "Loggers shall be placed on both sides of the river and in the thalweg. The loggers shall be operational from July 1 to September 30 and record temperatures at one hour intervals." As discussed above, loggers were generally installed at three locations along a given river mile, the left bank, right bank and thalwag. In some instances less than three loggers were installed due to the river geometry at a given location (Attachment B). For example, at RM 36.25 the channel narrows significantly as it moves through a short riffle section so only two loggers were installed here; however, any changes in temperature across the channel would be noted. Other example of where less than three loggers were installed included areas were installing a logger was not possible due to extremely steep banks or some other access issue. Overall, this variance did not affect the overall data quality and analysis required by this study.

The FERC-approved study states that temperature data would be collected hourly "…for a continuous two months of monitoring during summertime flow conditions." Data loss occurred during the study period due to logger or computer malfunction, vandalism of the installation equipment, and/or equipment loss as a consequence of changing sediment or intensive aquatic vegetation growth (i.e. water hyacinth). Time intervals and locations of specific data losses are described in Attachment A. This variance is not significant when compared to the total amount of data collected during the study period and did not limit the analysis required by the study plan.

7.0 REFERENCES

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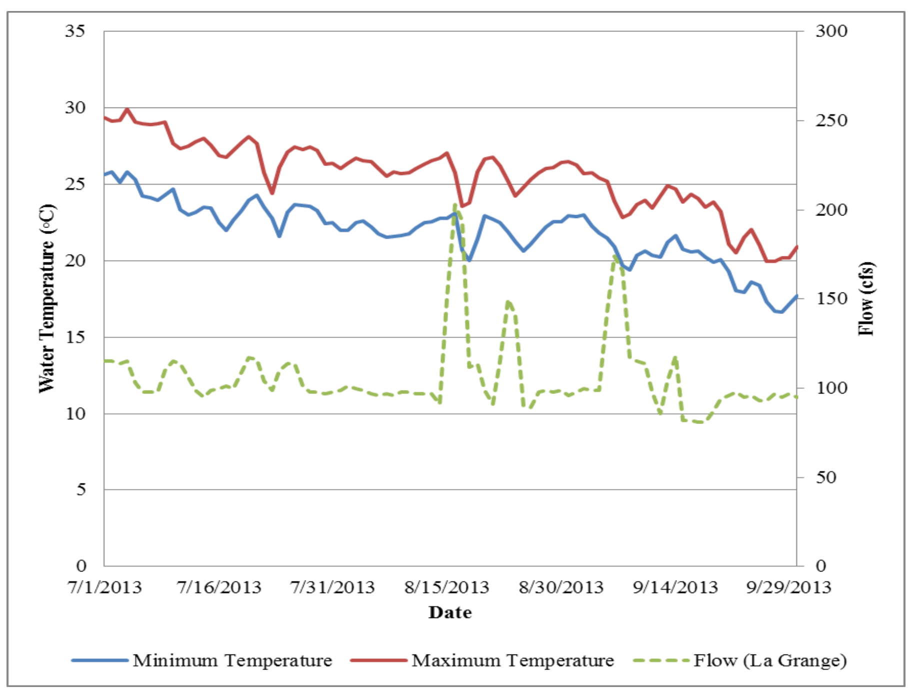
IN-RIVER DIURNAL TEMPERATURE VARIATION

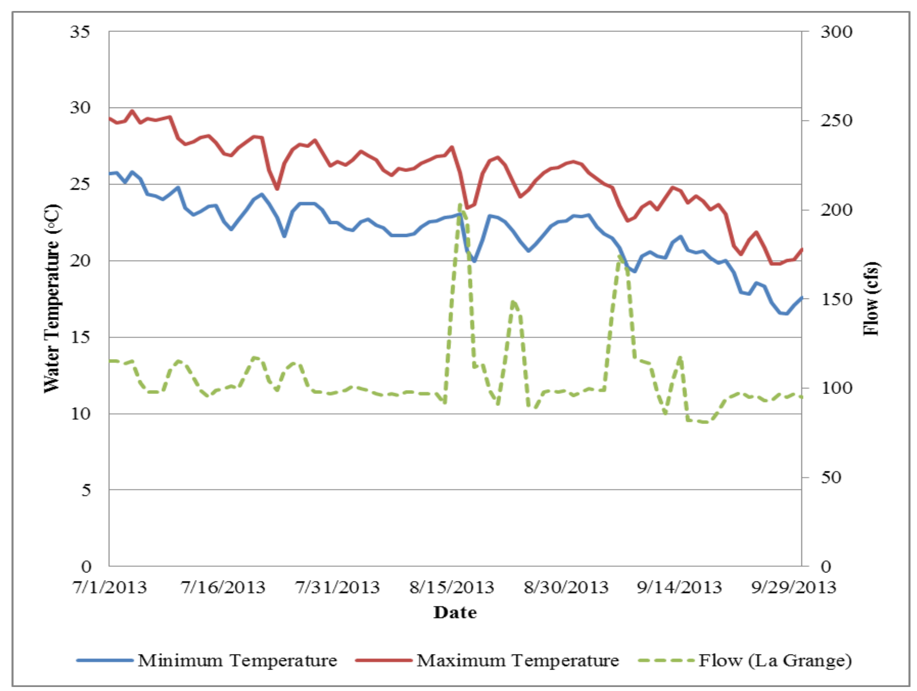
ATTACHMENT A

REPRESENTATIVE PHOTOGRAPHS AND DAILY MINIMUM AND MAXIMUM WATER TEMPERATURES

List of Figures

Left Bank | **Mid Channel** | **Right Bank**





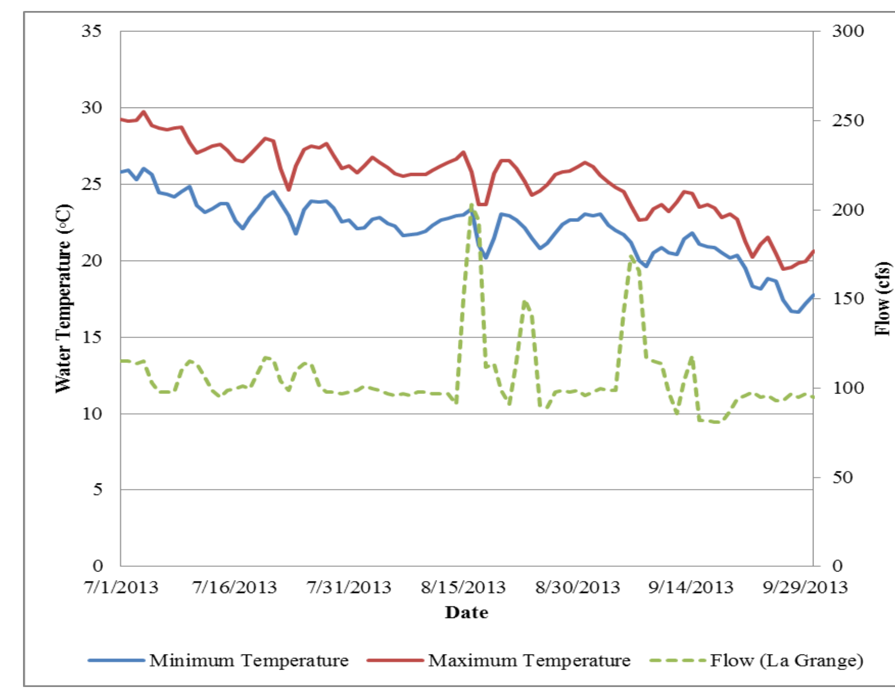
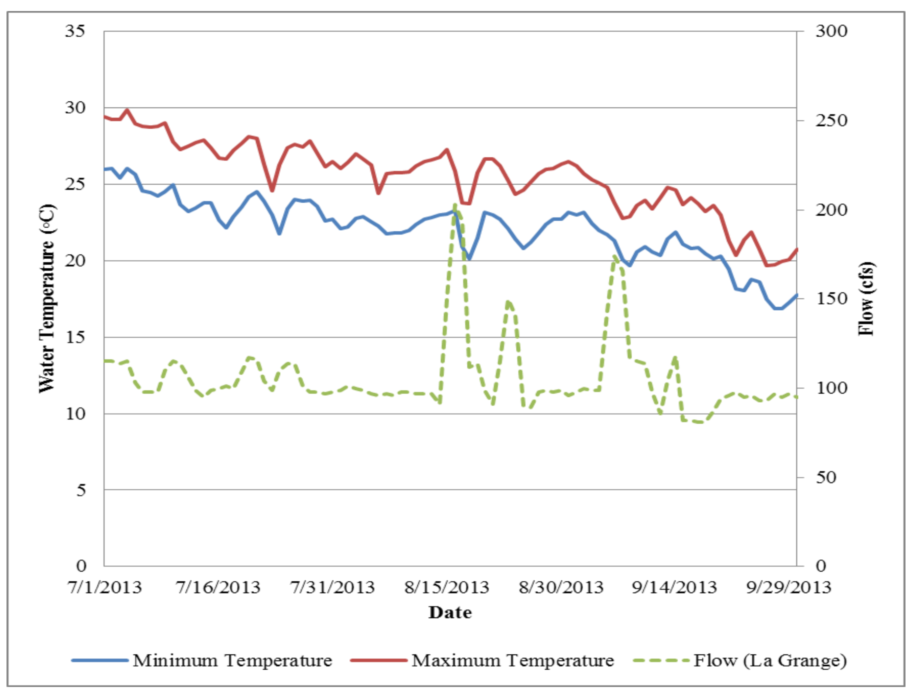


Figure 1. River Mile 36.5.

No mid channel logger was installed
because the channel was narrow and uniform

Left Bank | **Mid Channel** | **Right Bank**



No mid channel logger was installed
because the channel was narrow and uniform

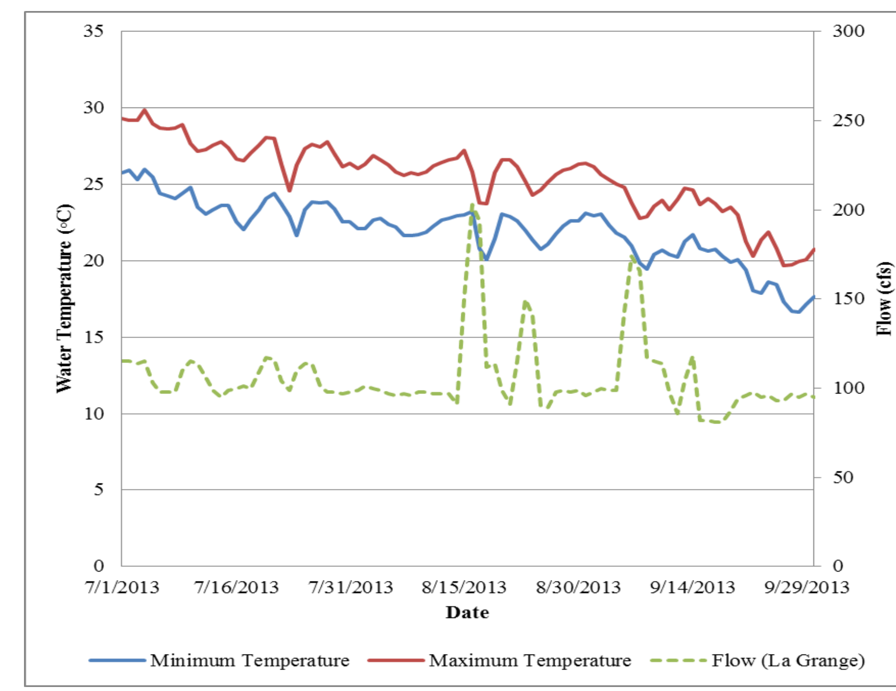
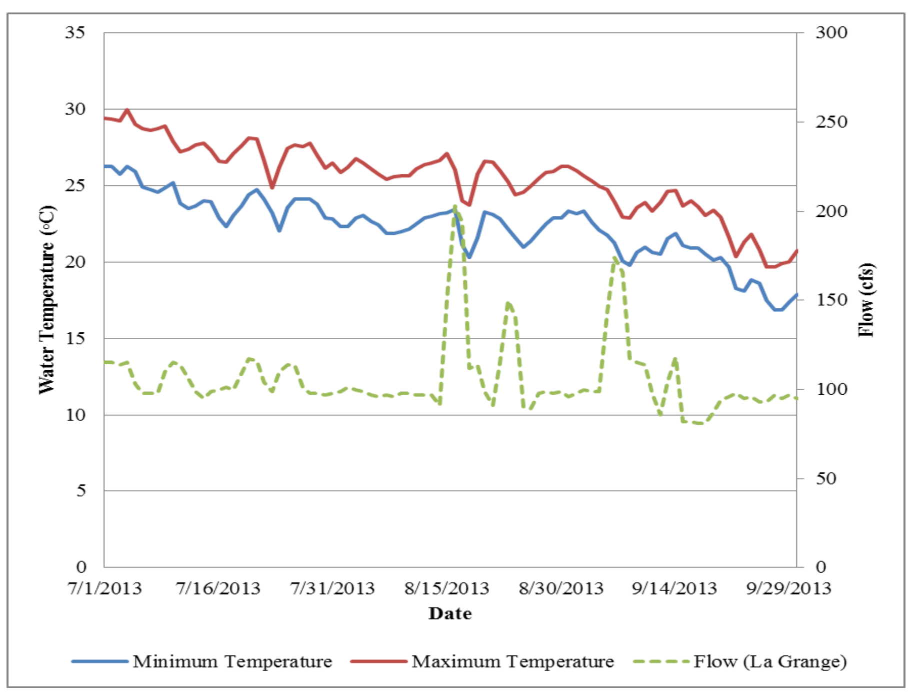
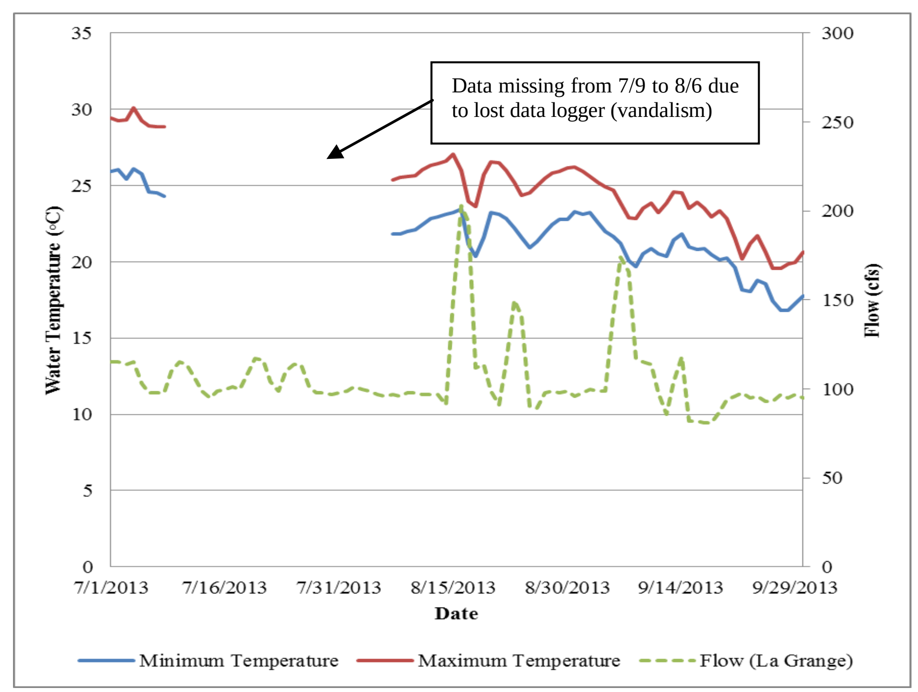


Figure 2. River Mile 36.25.

No right bank logger was installed
because the channel was narrow and uniform

Left Bank | **Mid Channel** | **Right Bank**

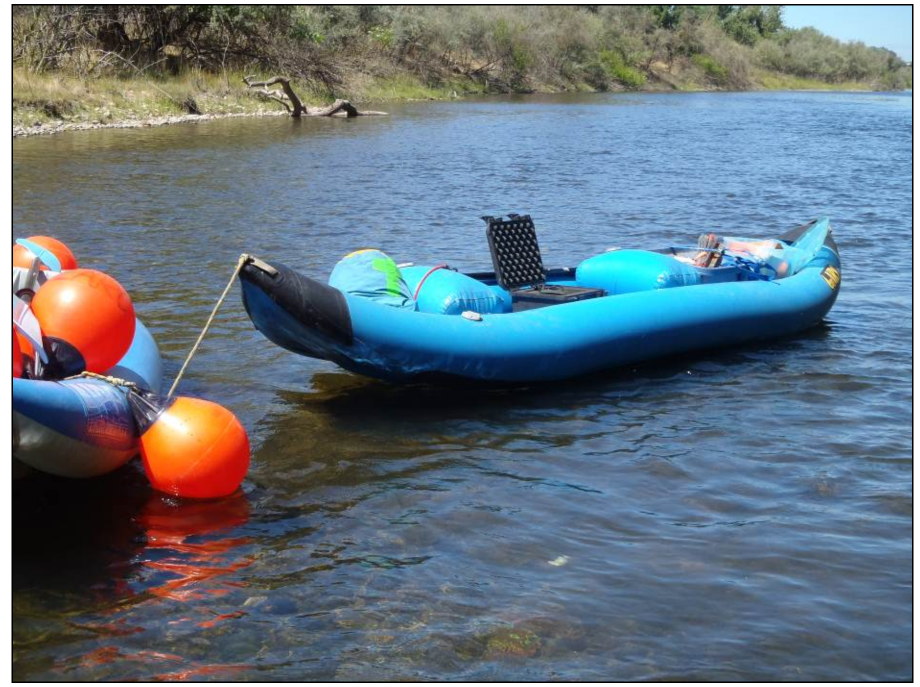




No right bank logger was installed
because the channel was narrow and uniform

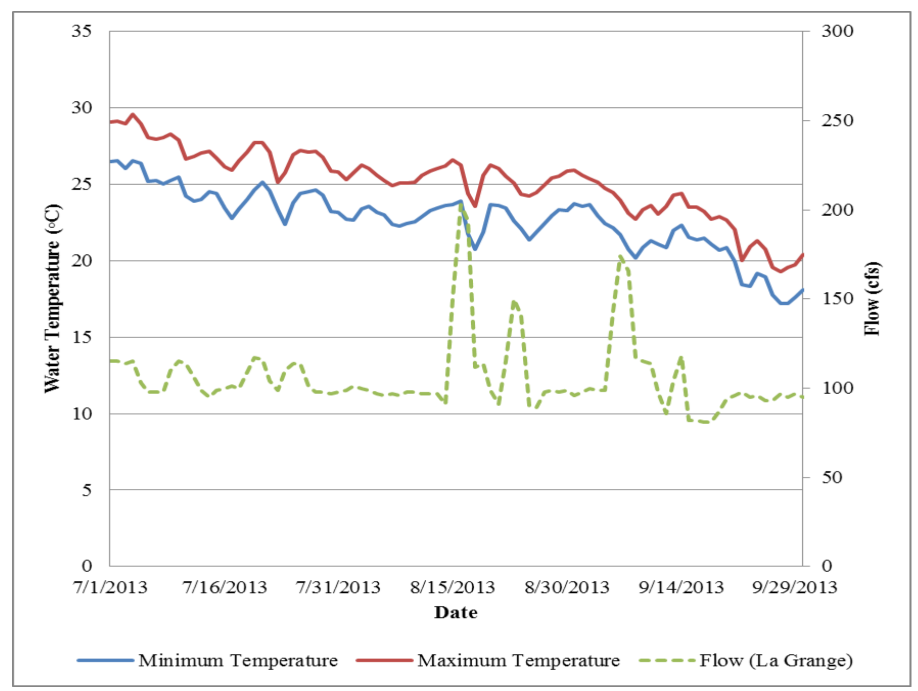
Figure 3. River Mile 36.

No left bank logger was installed
because the channel was narrow and uniform



Left Bank **Mid Channel** **Right Bank**

No leftt bank logger was installed
because the channel was narrow and uniform



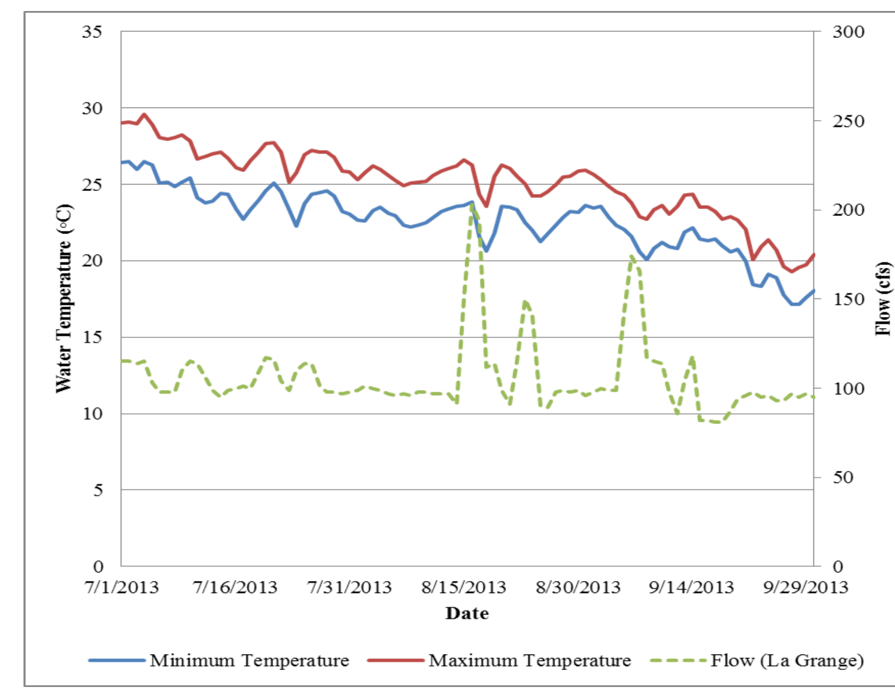
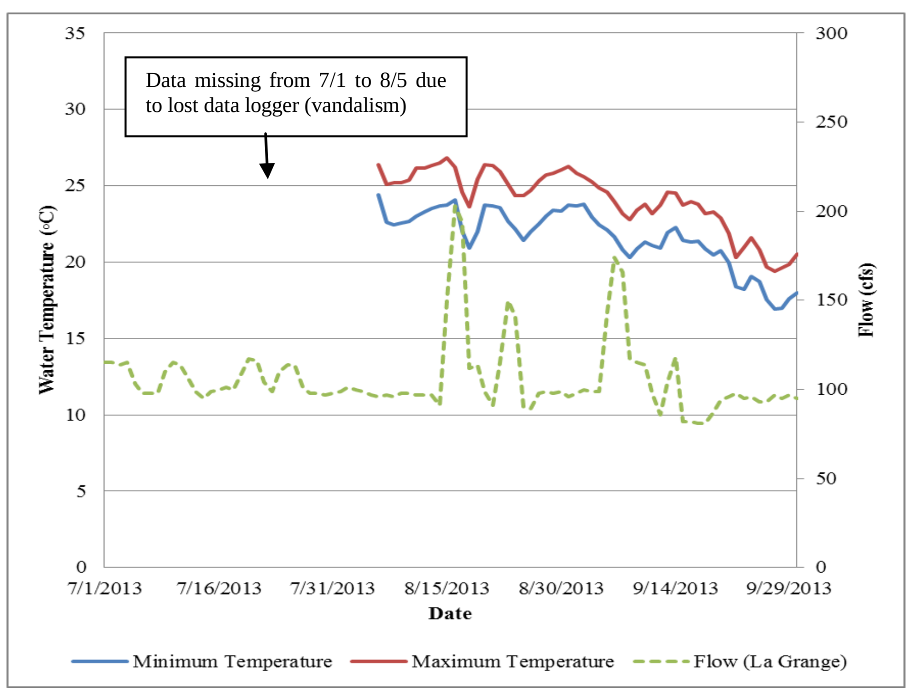


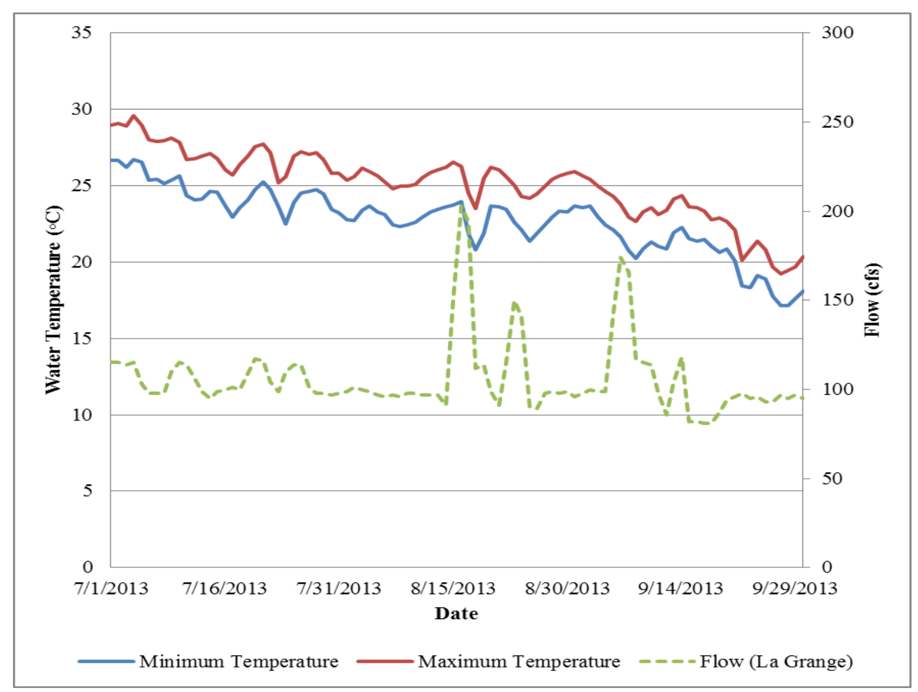
Figure 4. **River Mile 35.5.**

Left Bank

Mid Channel

Right Bank





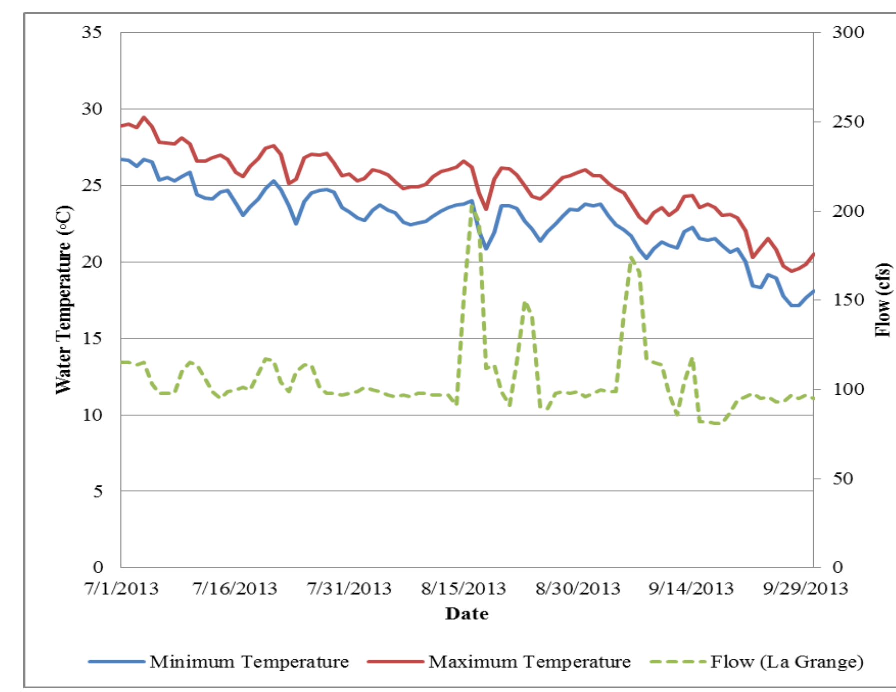
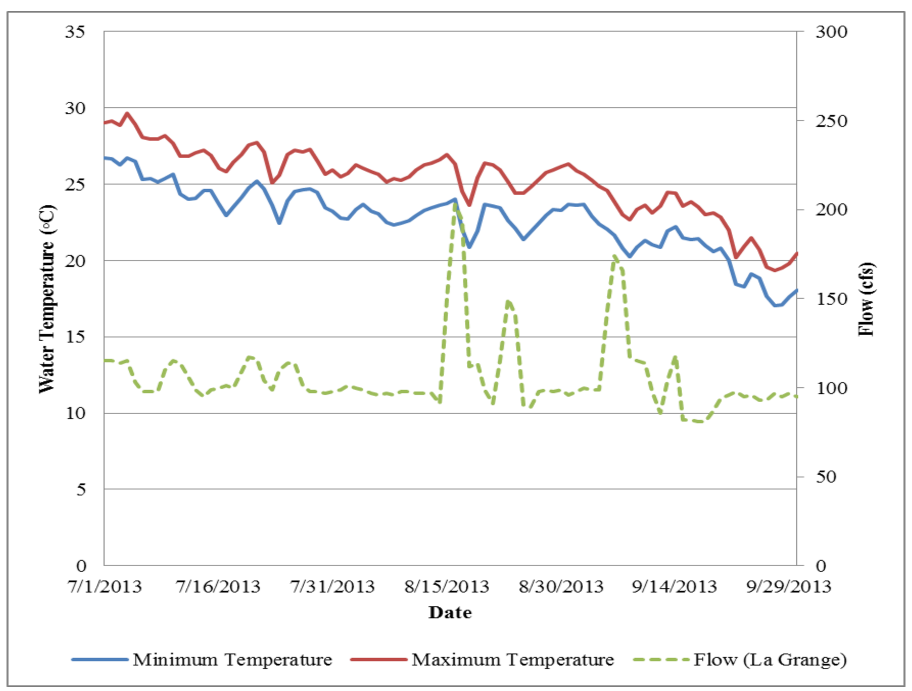
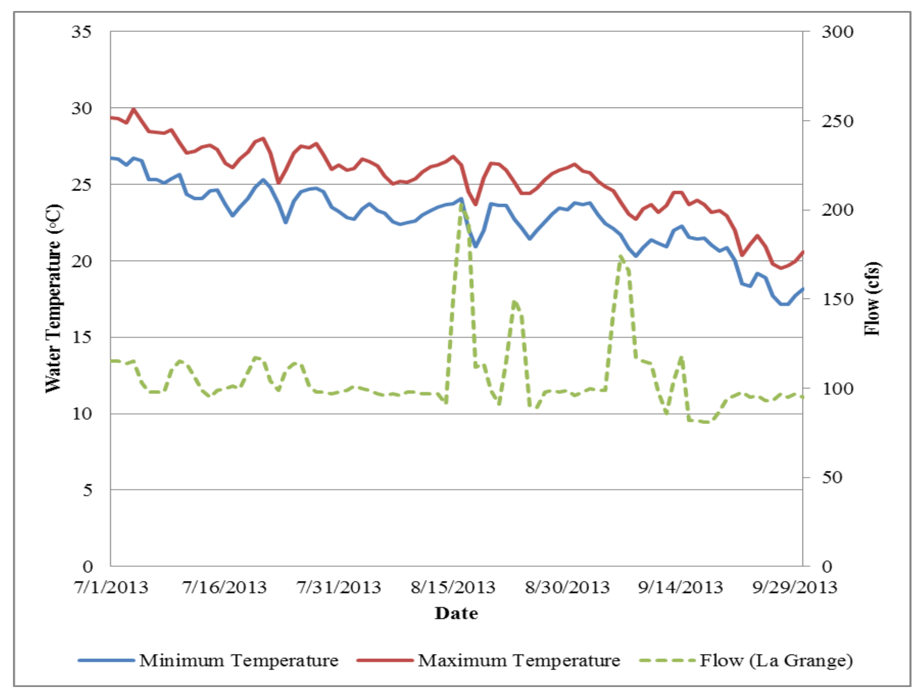


Figure 5. **River Mile 35.25.**

No right bank logger was installed
because the channel was narrow and uniform

Left Bank | **Mid Channel** | **Right Bank**





No right bank logger was installed
because the channel was narrow and uniform

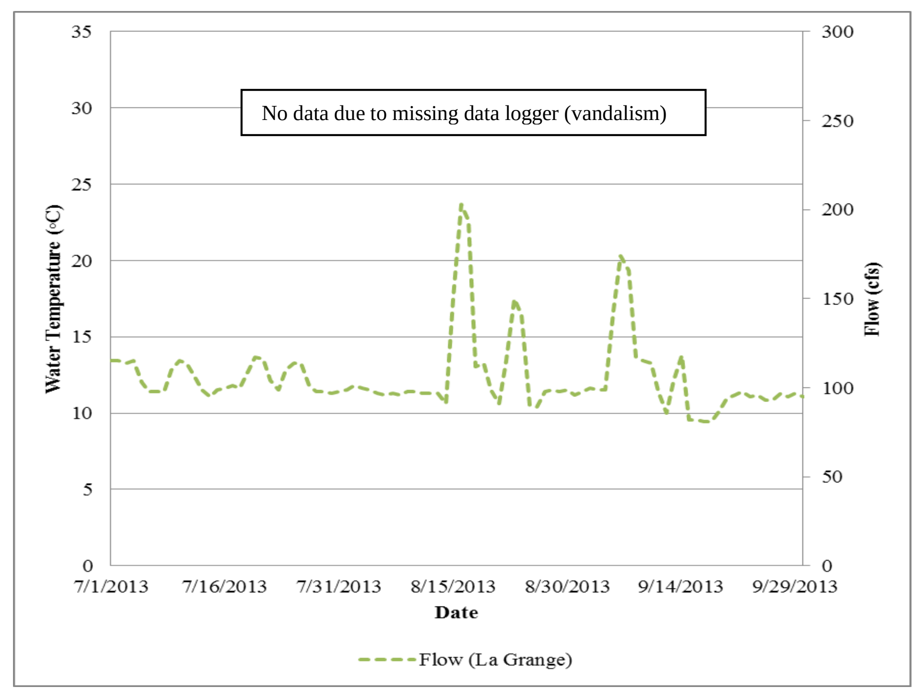
Figure 6. River Mile 35.

No left bank logger was installed
due to a steep bank and an uniform channel.

No right bank logger was installed
due to a steep bank and an uniform channel.

Left Bank | **Mid Channel** | **Right Bank**

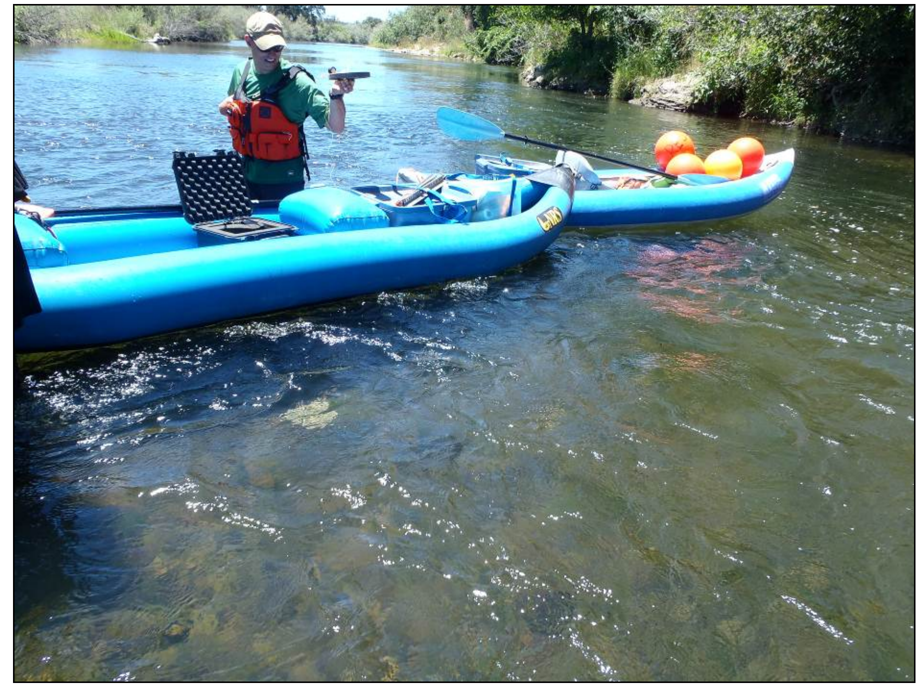
No left bank logger was installed
due to a steep bank and an uniform channel.



No right bank logger was installed
due to a steep bank and an uniform channel.

Figure 7. River Mile 34.75.

No left bank logger was installed
because the channel funneled through a single narrow run



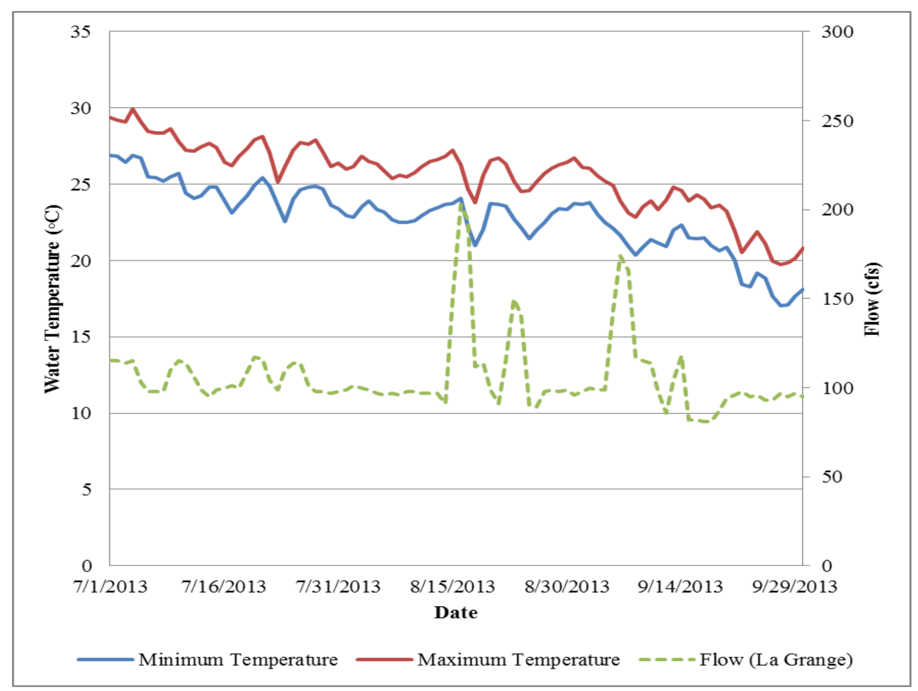
No right bank logger was installed
because the channel funneled through a single narrow run

Left Bank

Mid Channel

Right Bank

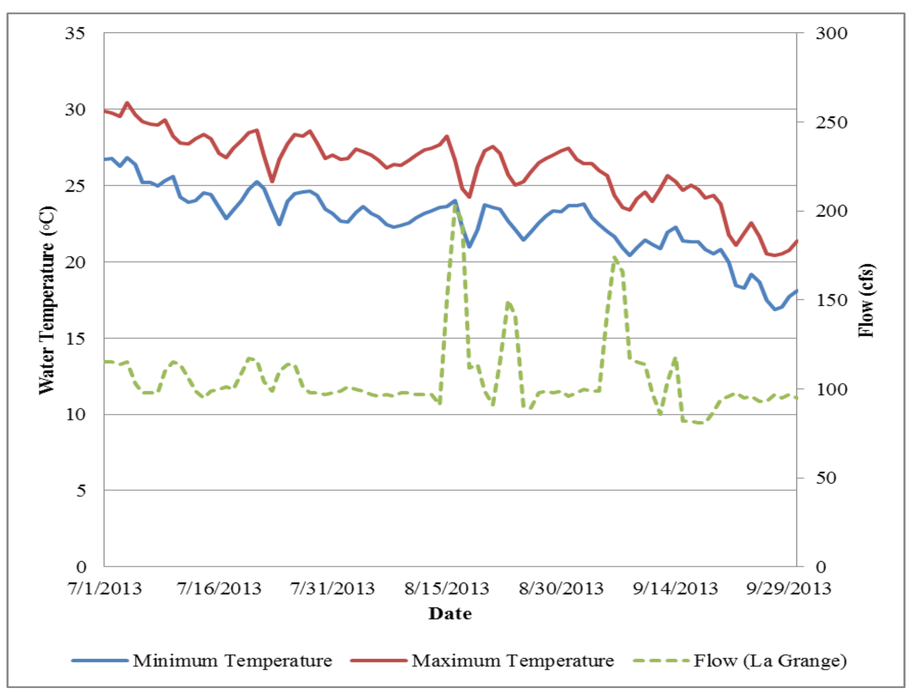
No left bank logger was installed
because the channel funneled through a single narrow run

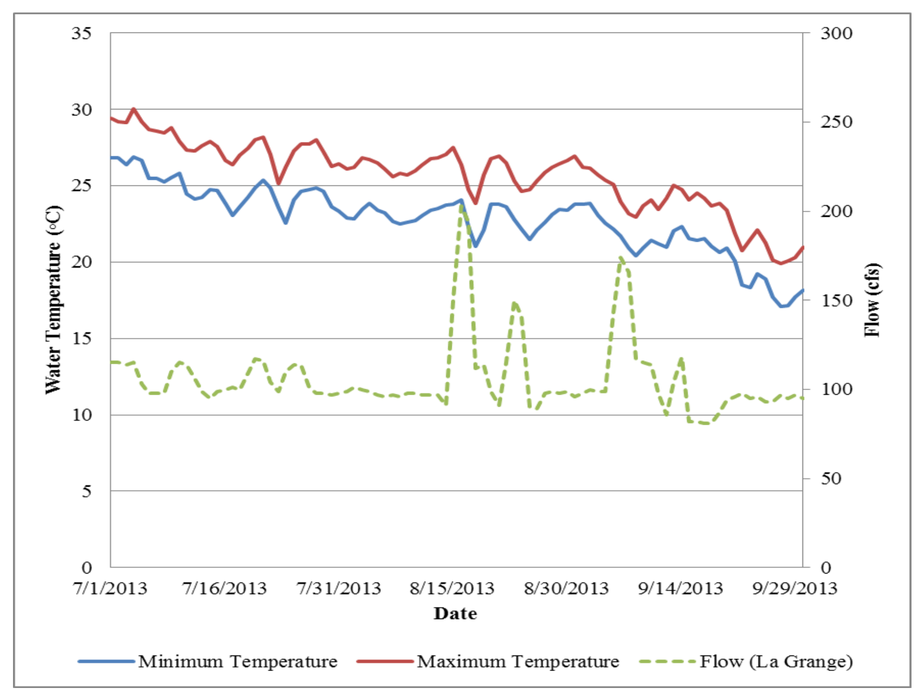


No right bank logger was installed
because the channel funneled through a single narrow run

Figure 8. River Mile 34.7.

Left Bank | **Mid Channel** | **Right Bank**





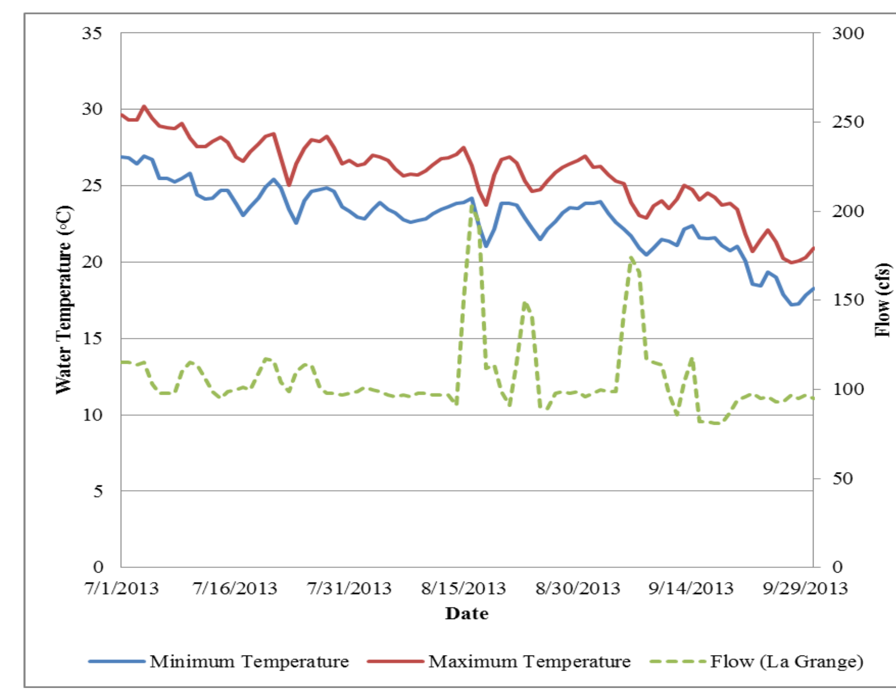
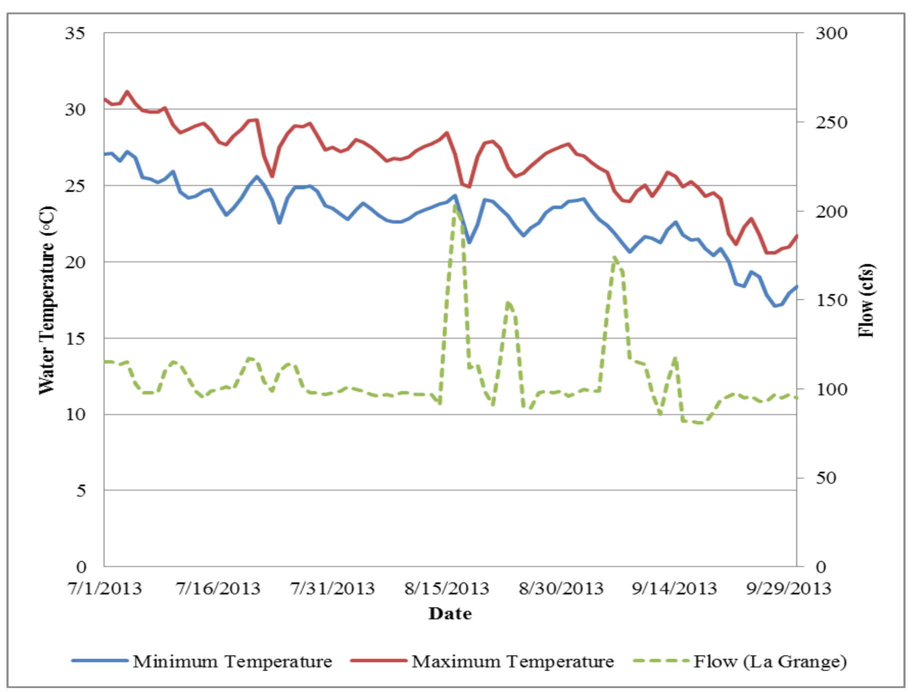


Figure 9. River Mile 34.5.

No mid channel logger was installed
because the channel was narrow and uniform

Left Bank | **Mid Channel** | **Right Bank**



No mid channel logger was installed
because the channel was narrow and uniform

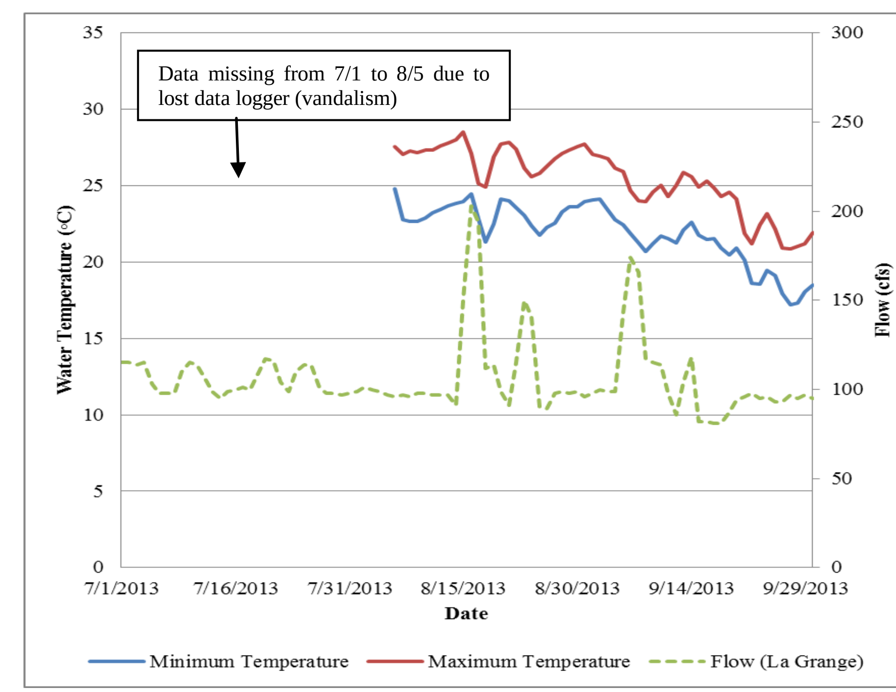
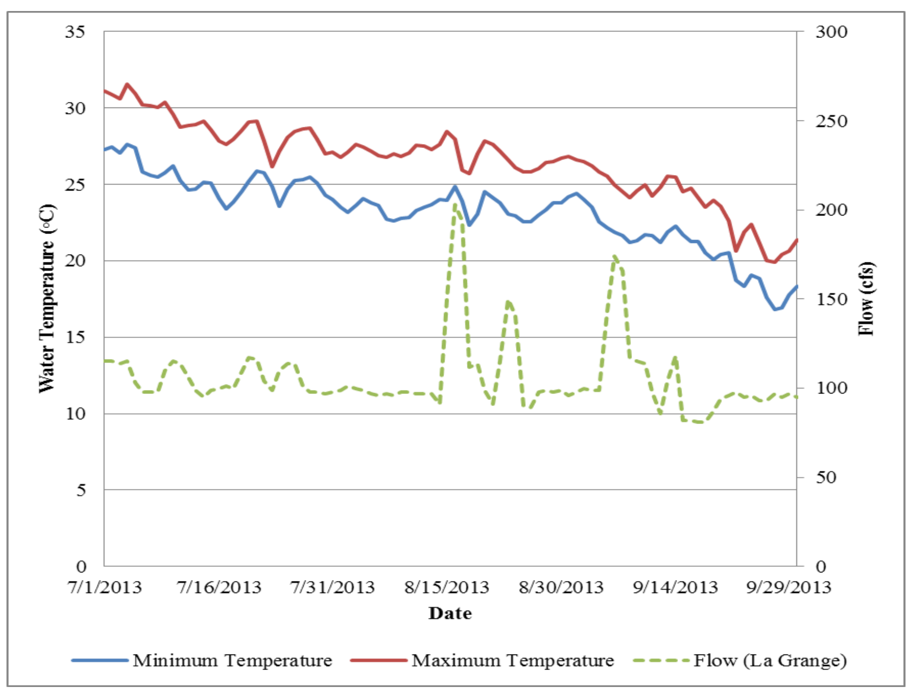
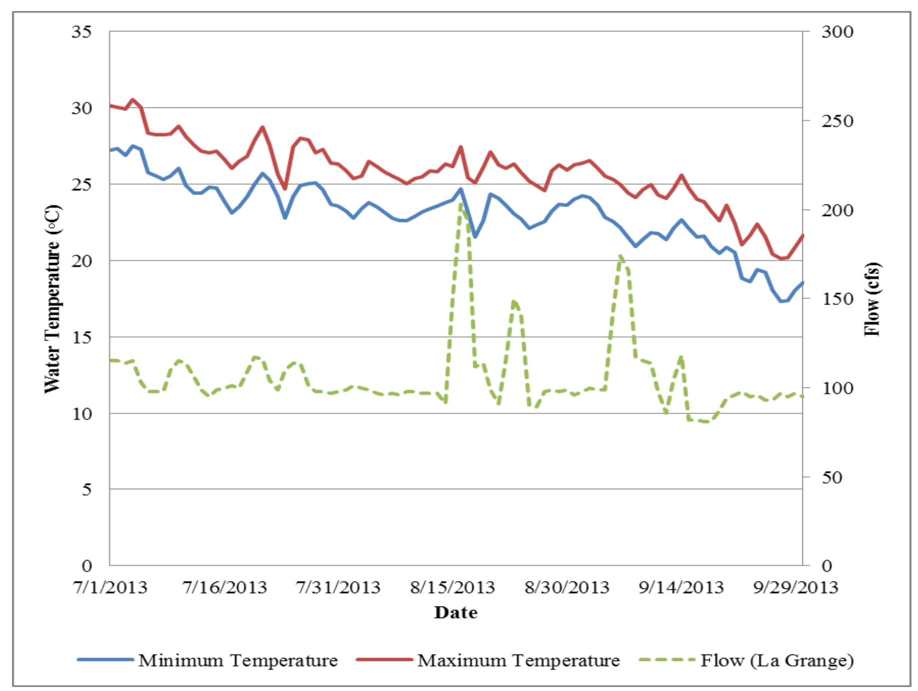


Figure 10. River Mile 33.5.

Left Bank | **Mid Channel** | **Right Bank**





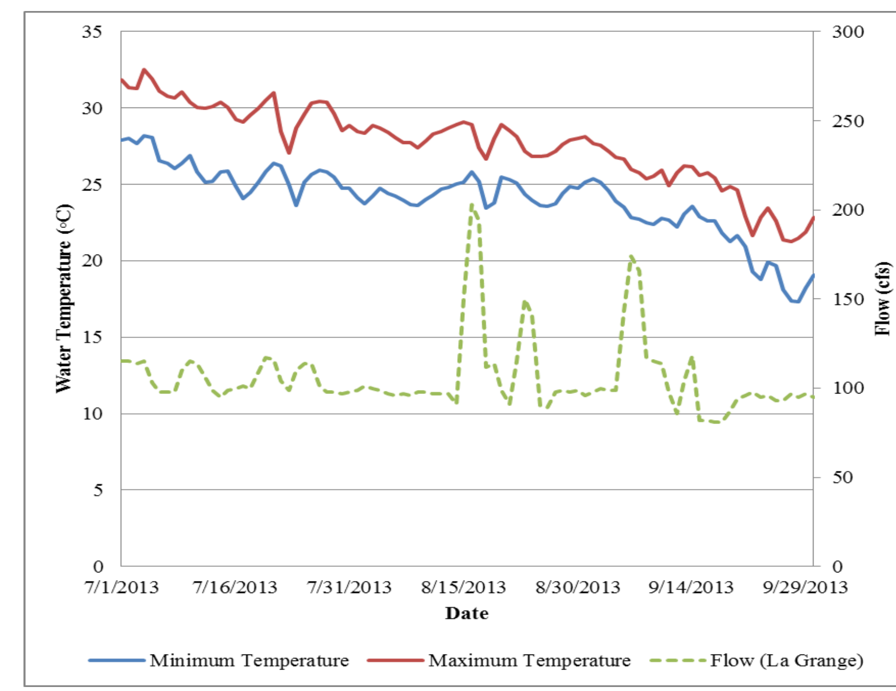
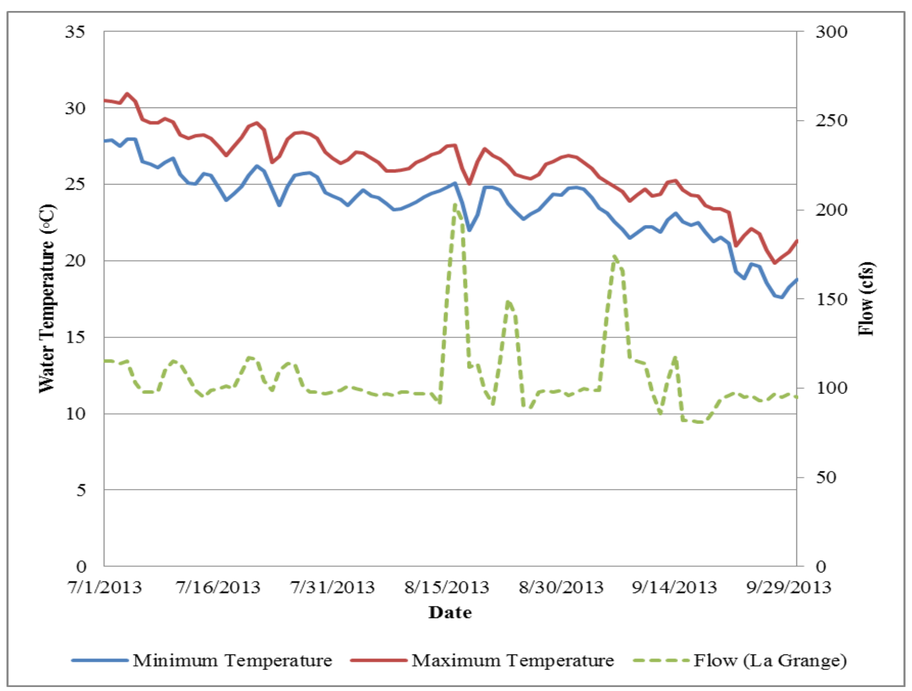
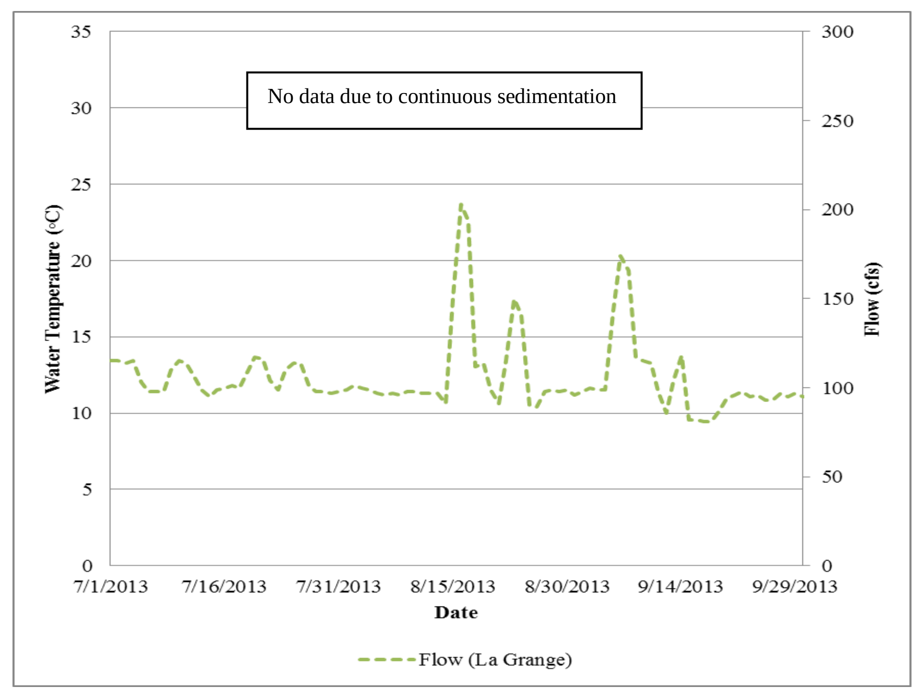


Figure 11. **River Mile 33.2.**

Left Bank | **Mid Channel** | **Right Bank**





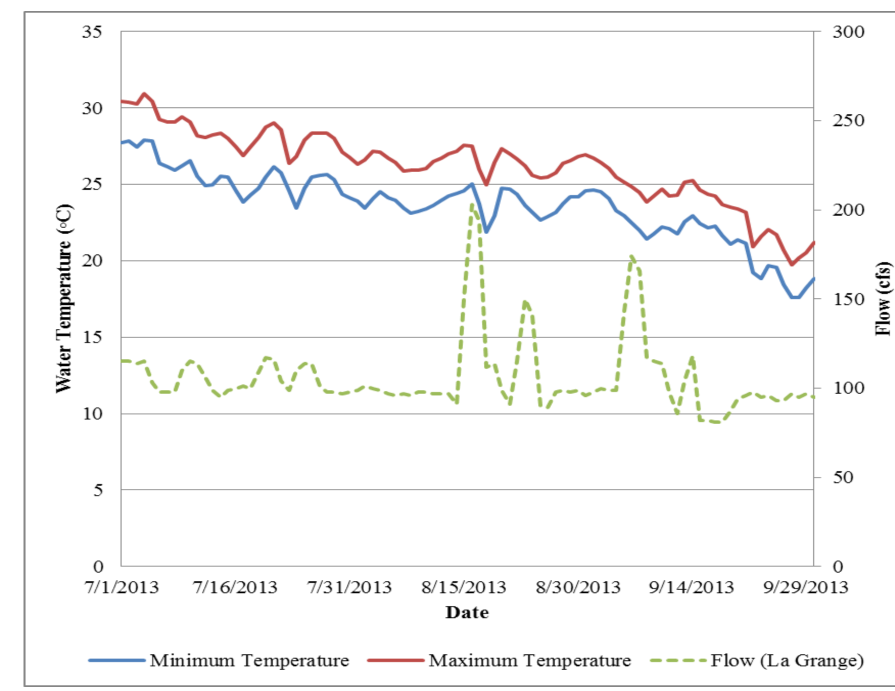


Figure 12. River Mile 32.8.

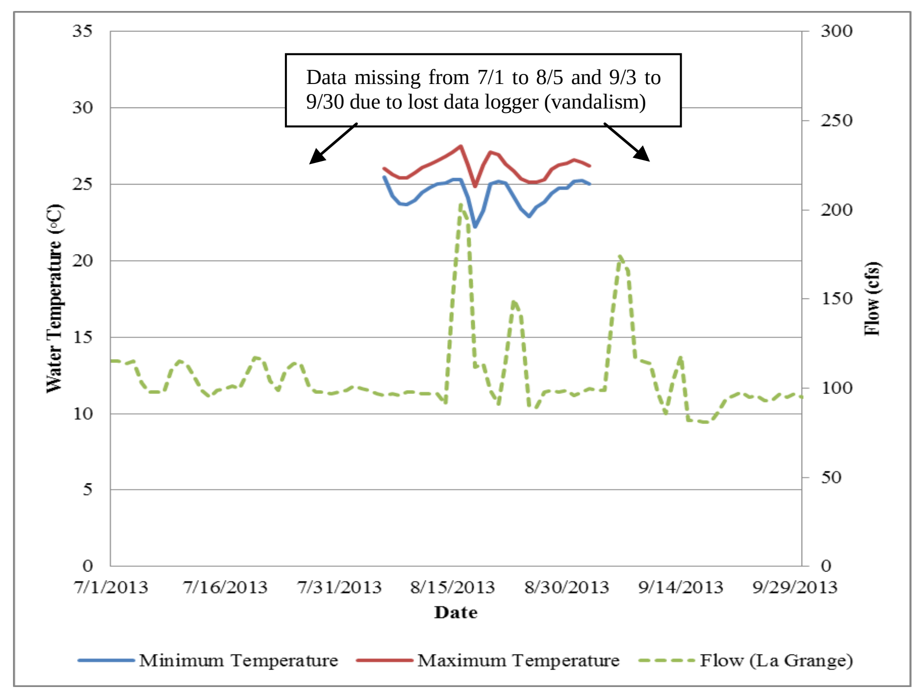
No left bank logger was installed because the channel was narrow and the left bank was a very shallow backwater that eventually became dry as flows reduced.

Left Bank

Mid Channel

Right Bank

No left bank logger was installed because the channel was narrow and the left bank was a very shallow backwater that eventually became dry as flows reduced.



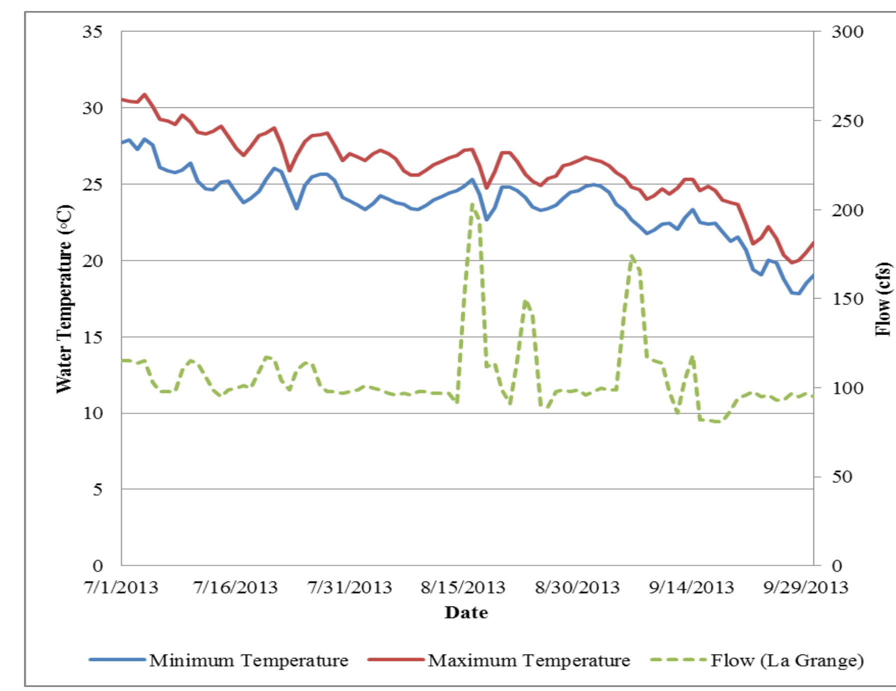
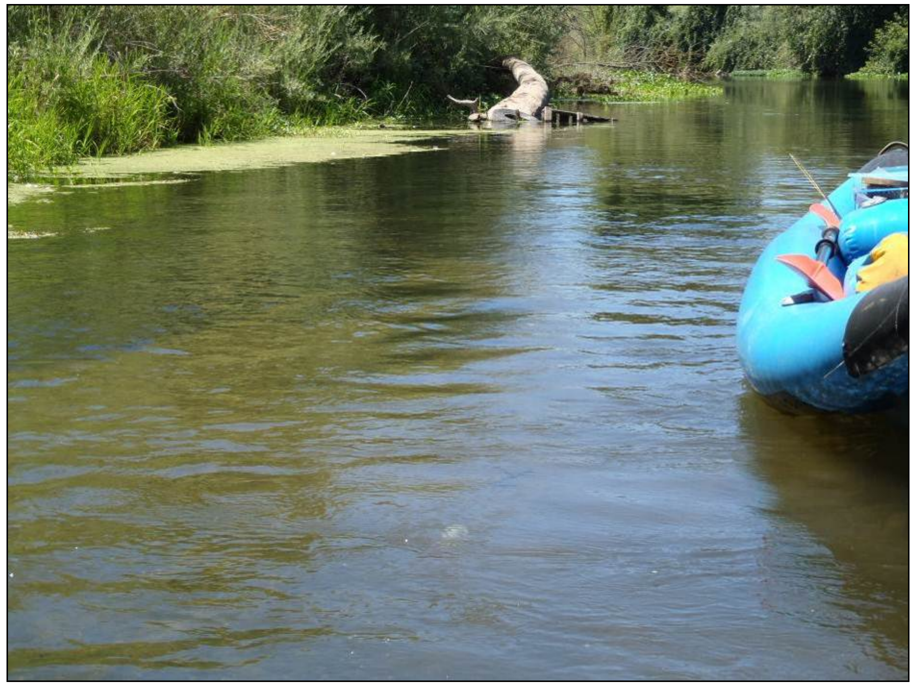


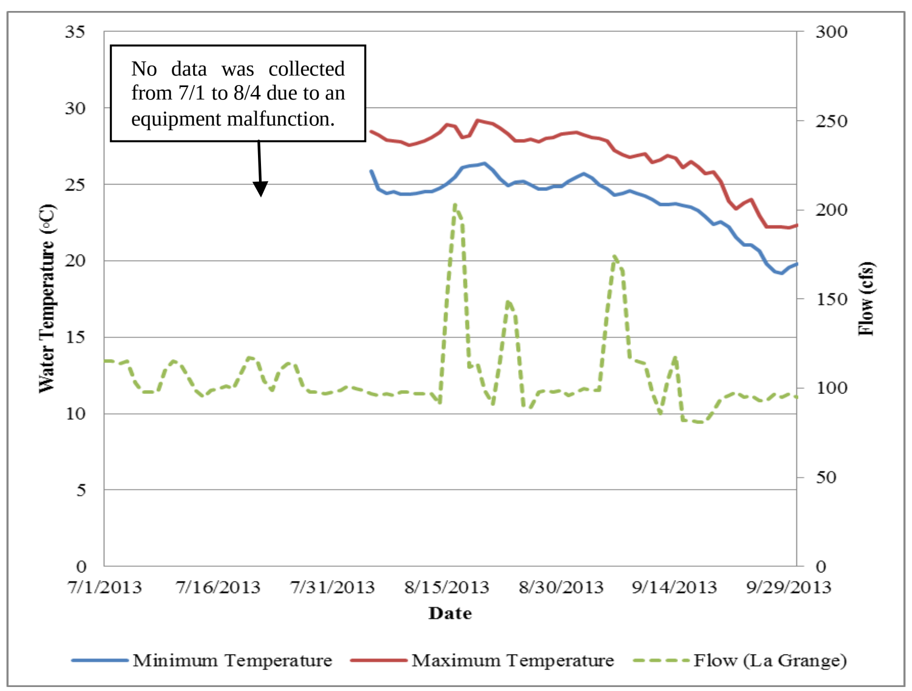
Figure 13. River Mile 32.5.

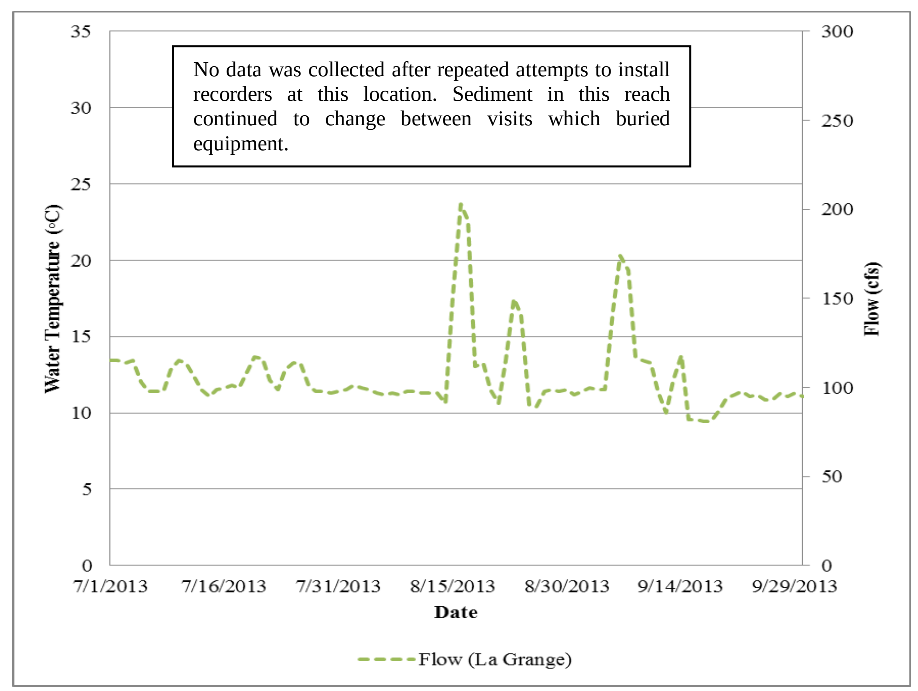


Left Bank

Mid Channel

Right Bank





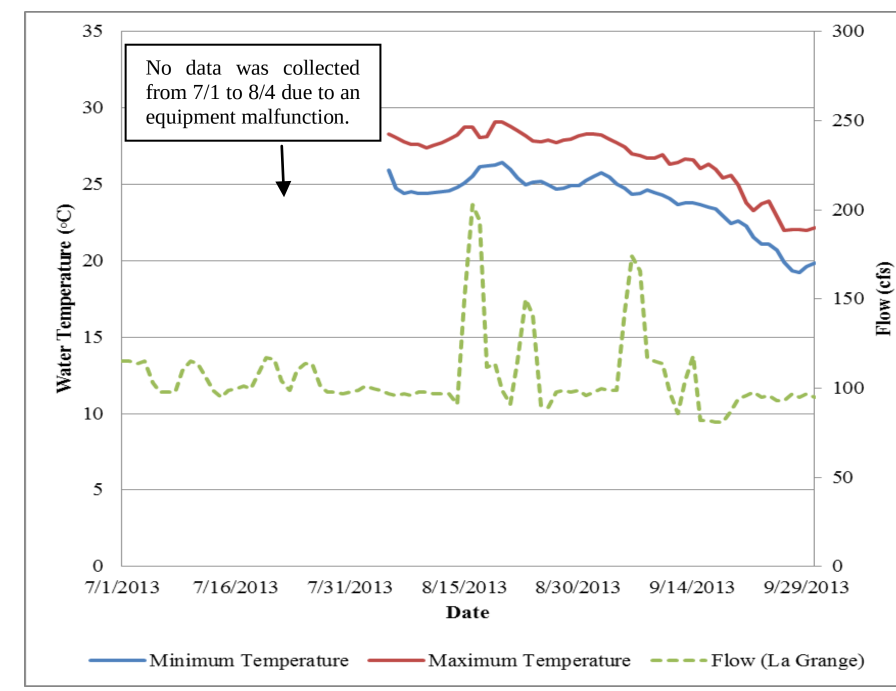
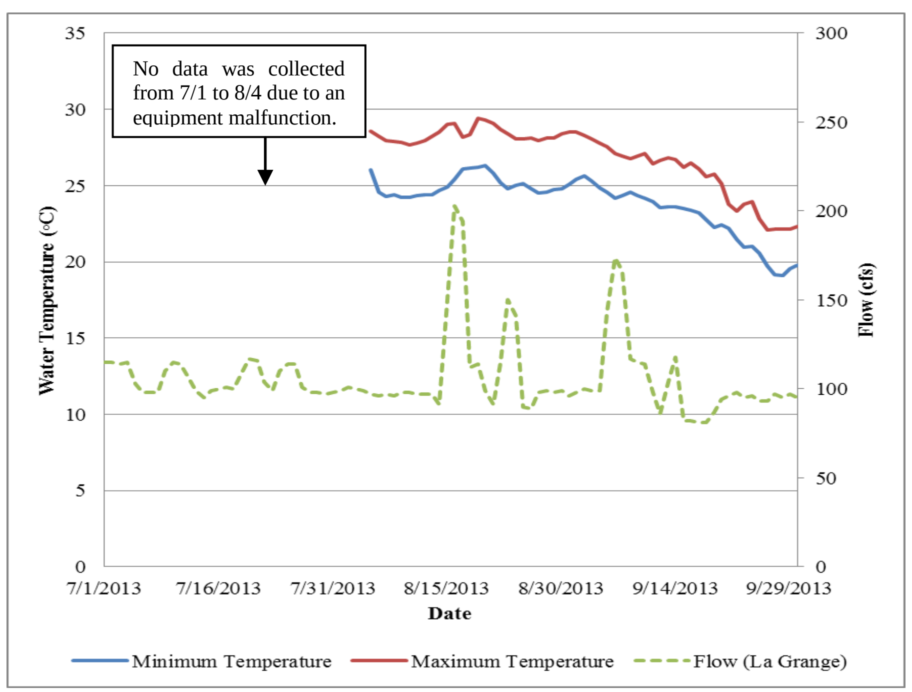


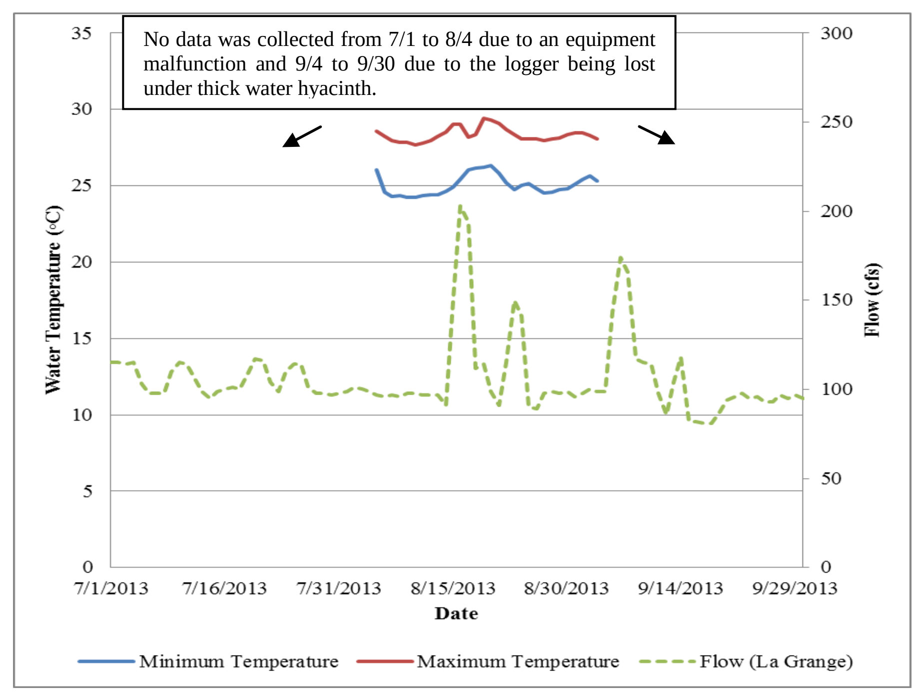
Figure 14. River Mile 24.

Left Bank

Mid Channel

Right Bank





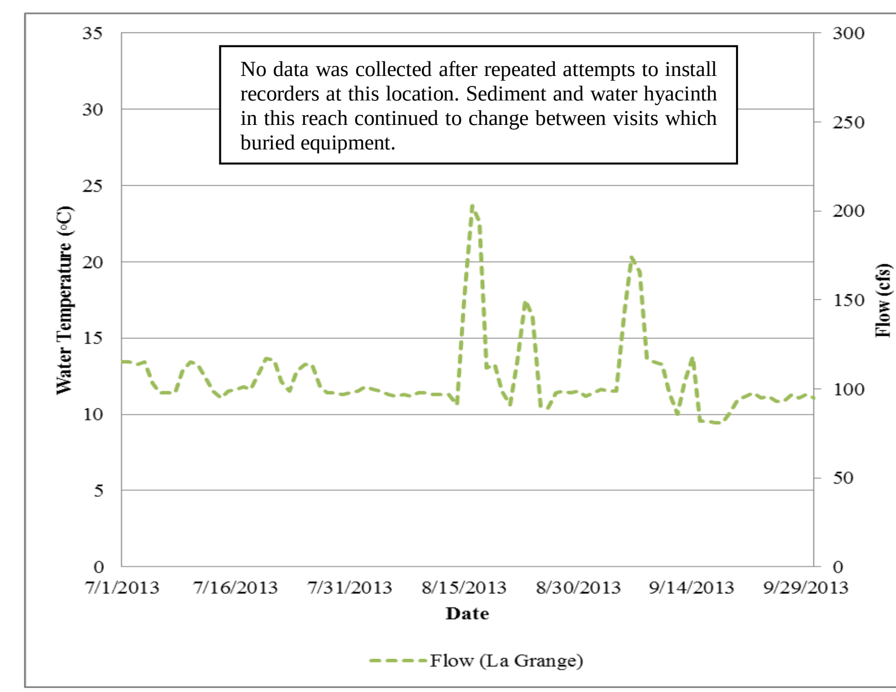
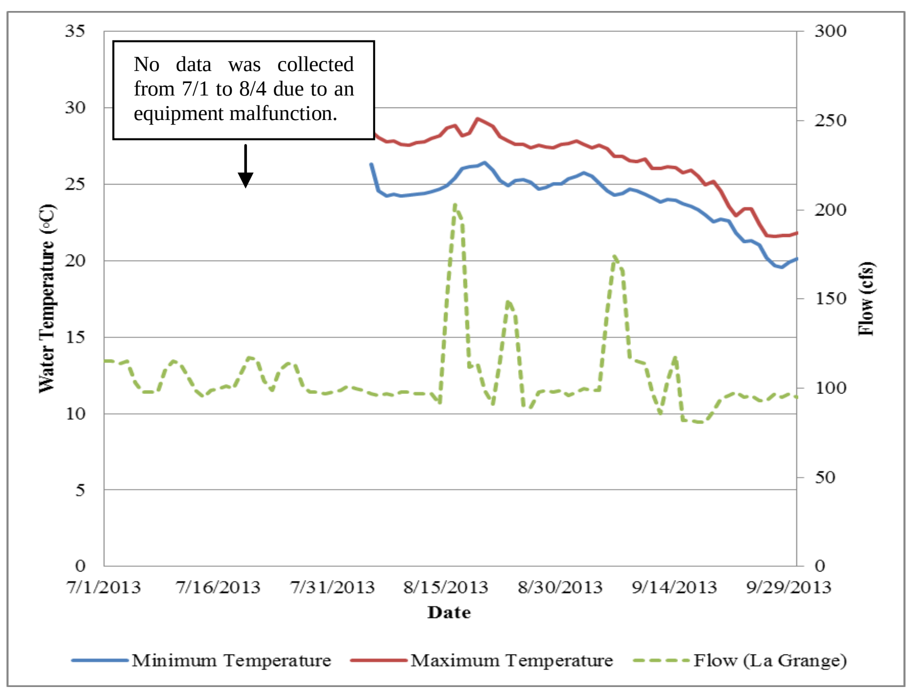


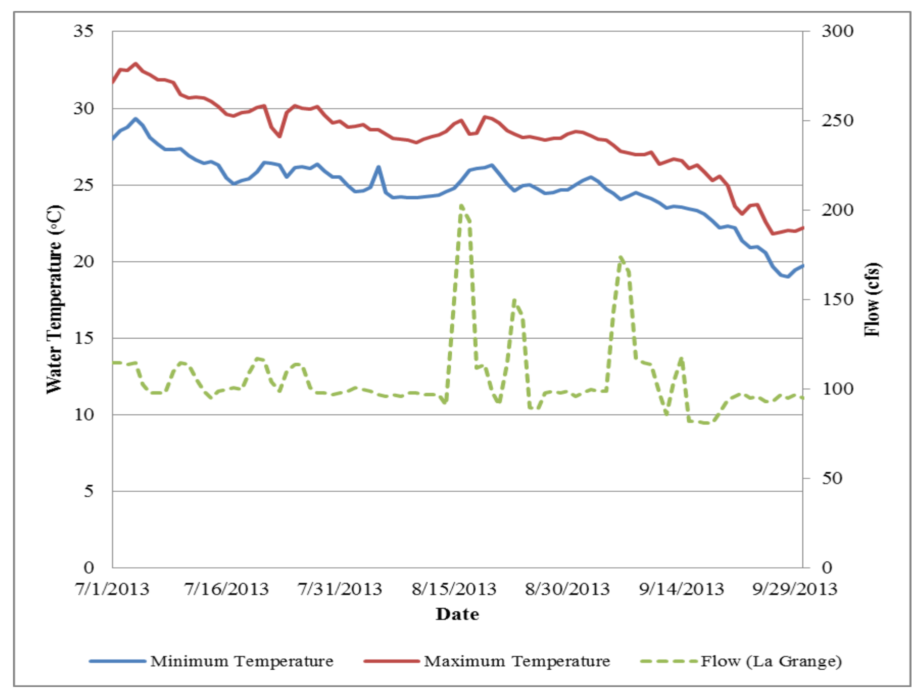
Figure 15. River Mile 23.75.

Left Bank

Mid Channel

Right Bank





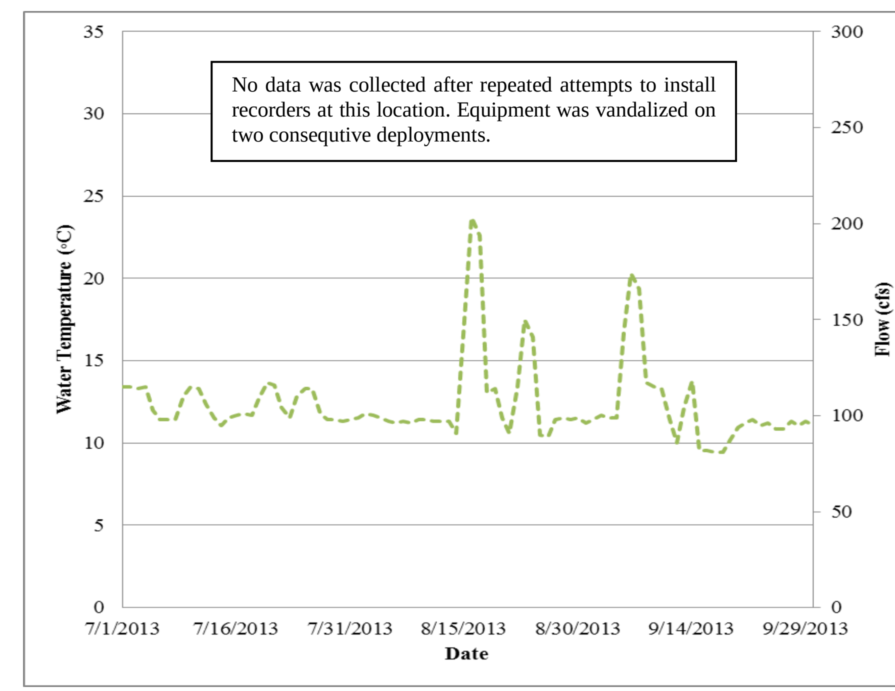
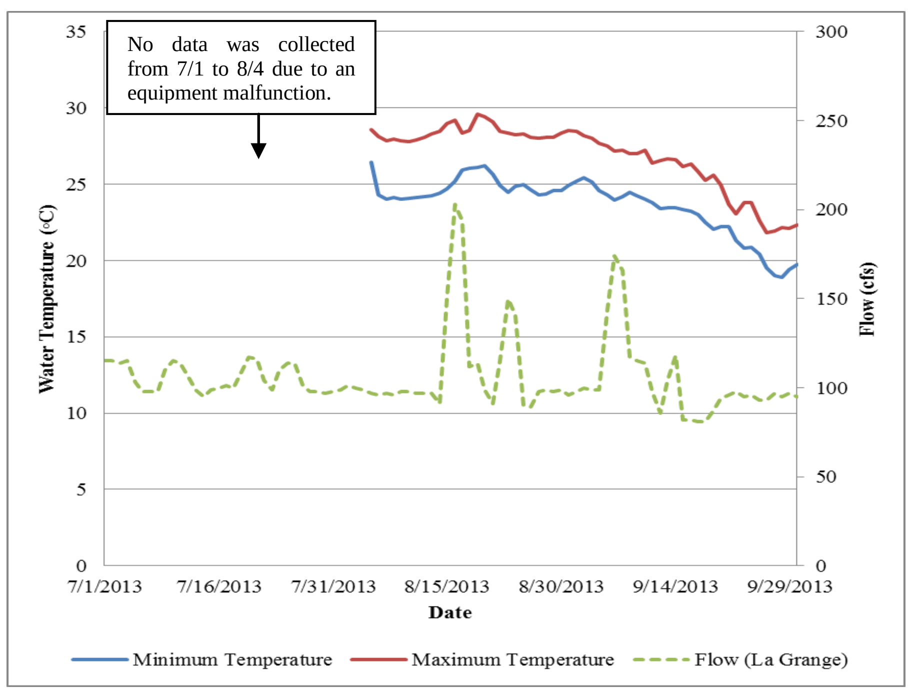


Figure 16. **River Mile 23.5.**

No mid-channel logger was installed because the channel was narrow and uniform at this location.

Left Bank **Mid Channel** **Right Bank**



No mid-channel logger was installed because the channel was narrow and uniform at this location.

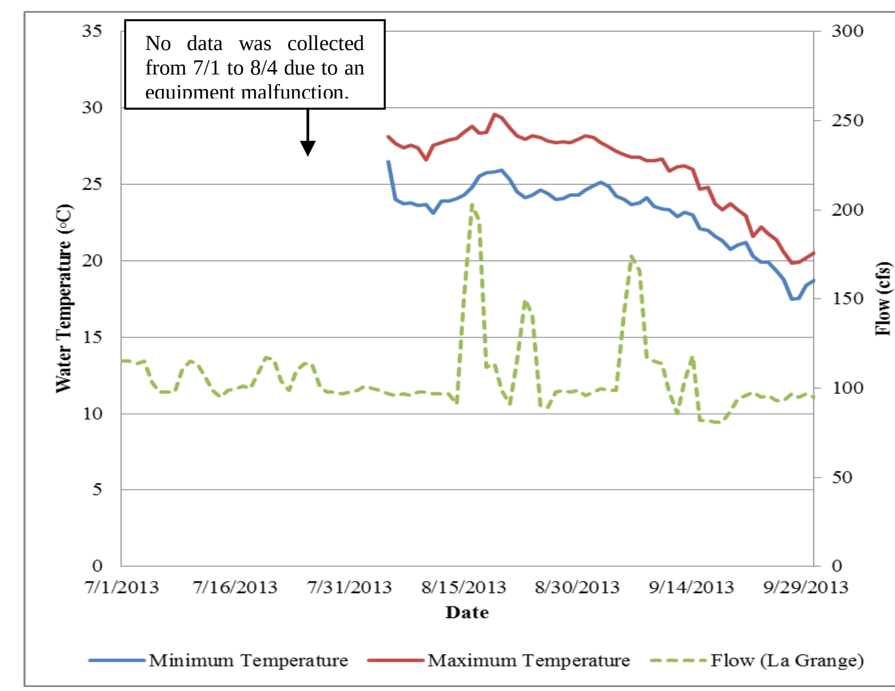
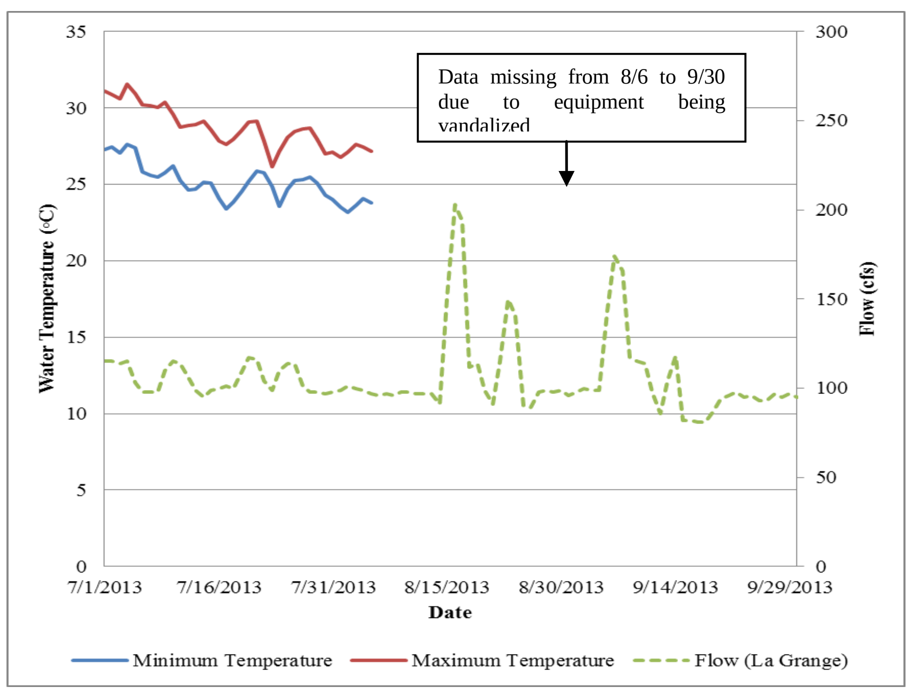


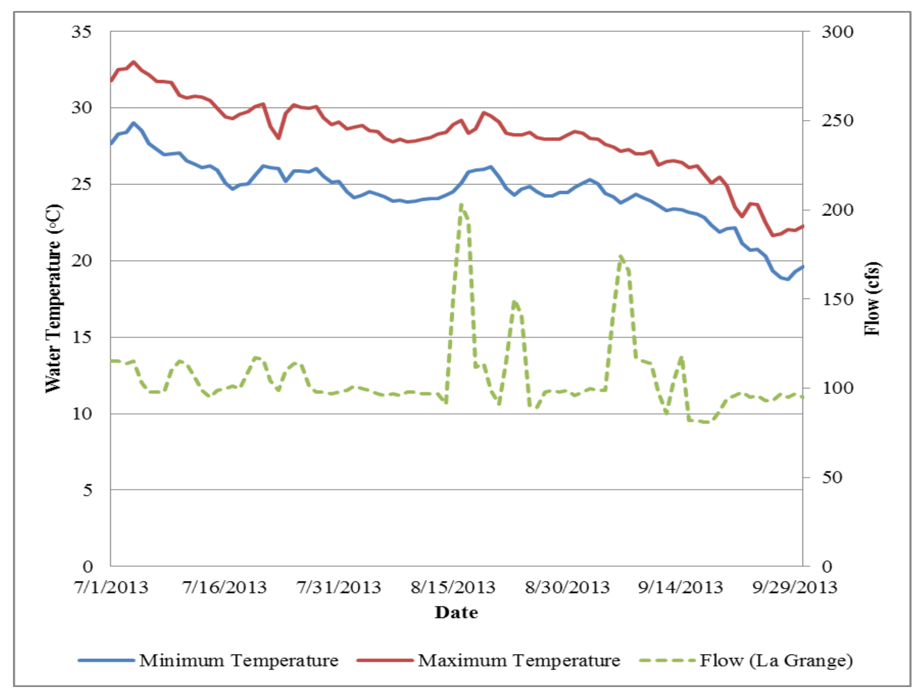
Figure 17. River Mile 23.25.

Left Bank

Mid Channel

Right Bank





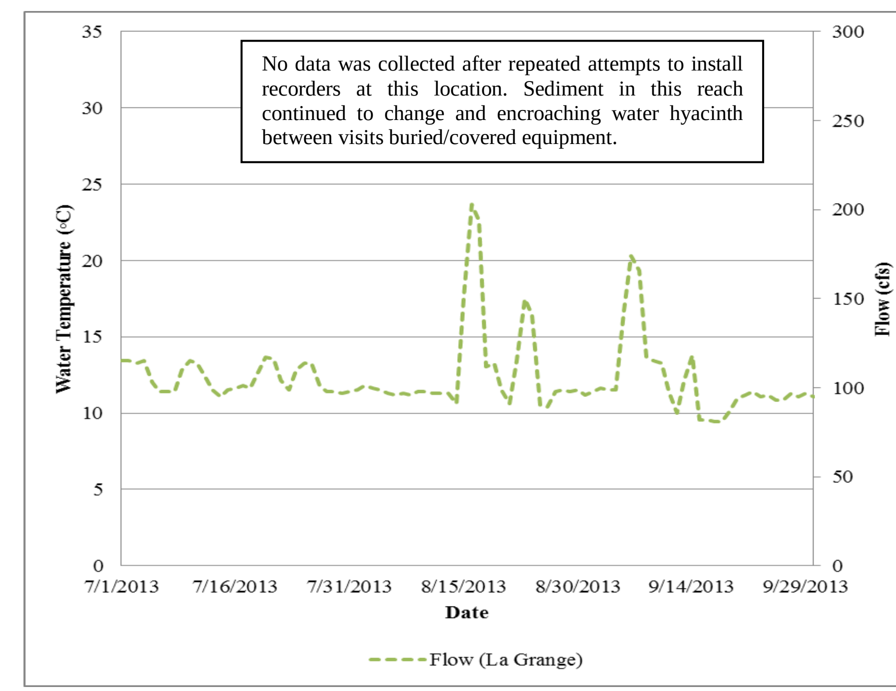
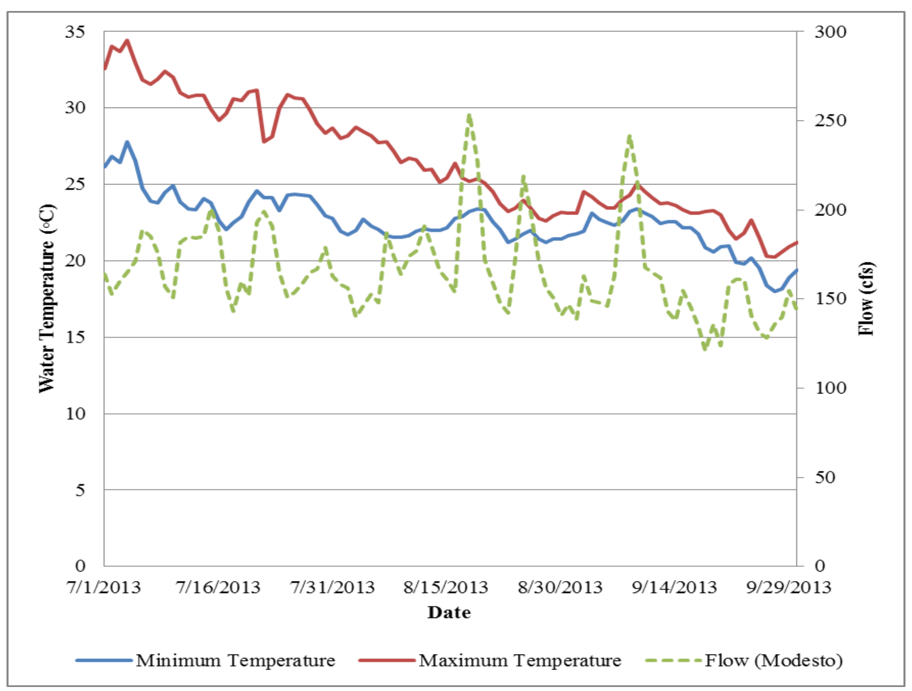
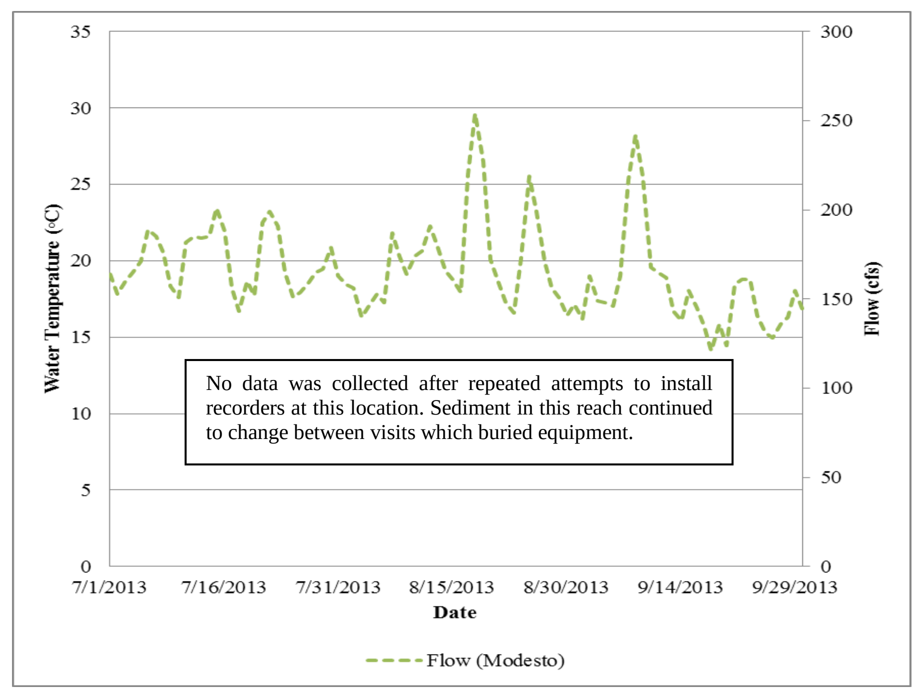


Figure 18. **River Mile 23.**

Left Bank **Mid Channel** **Right Bank**





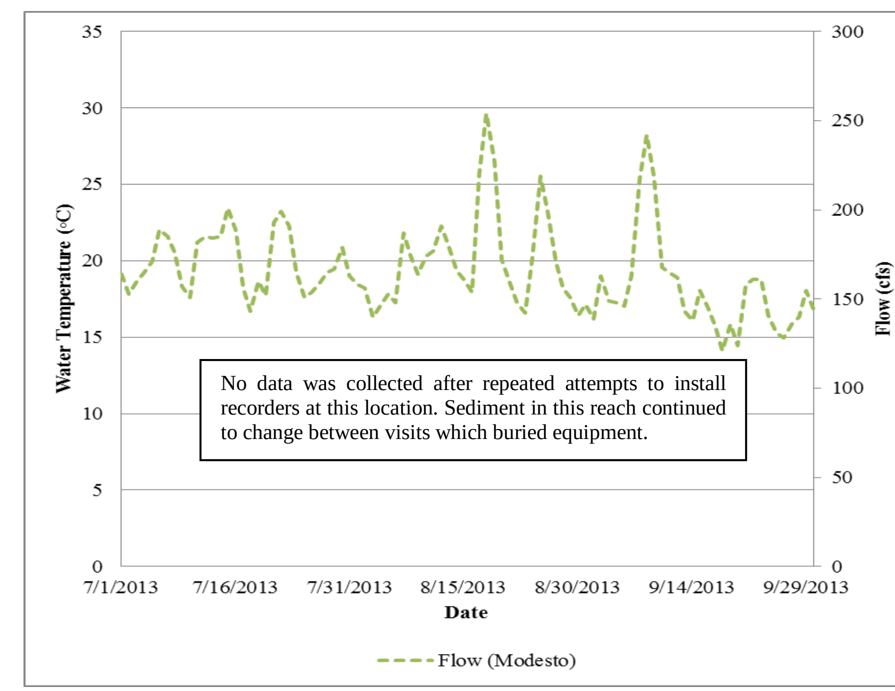
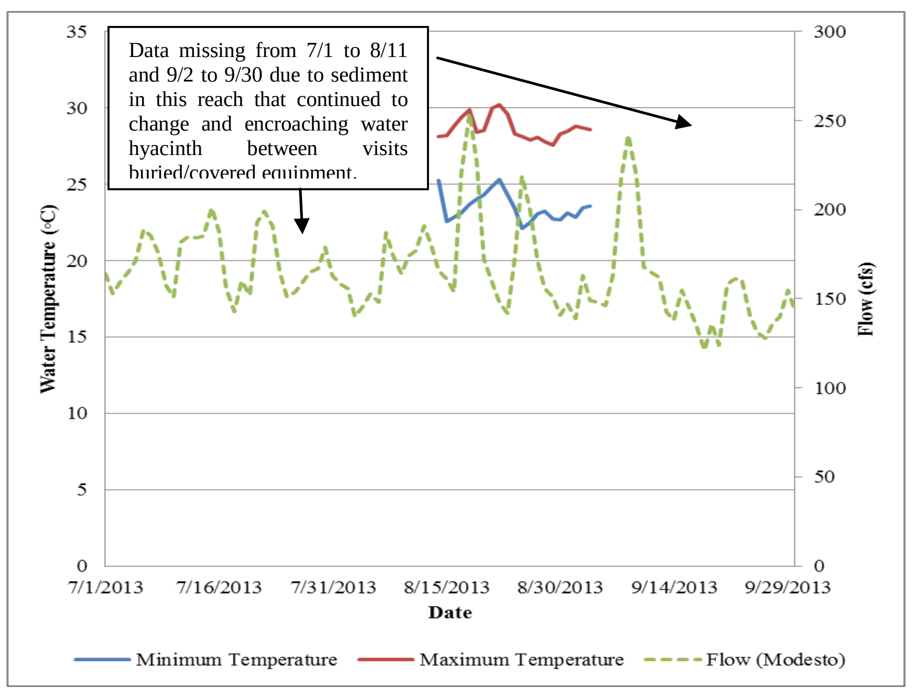
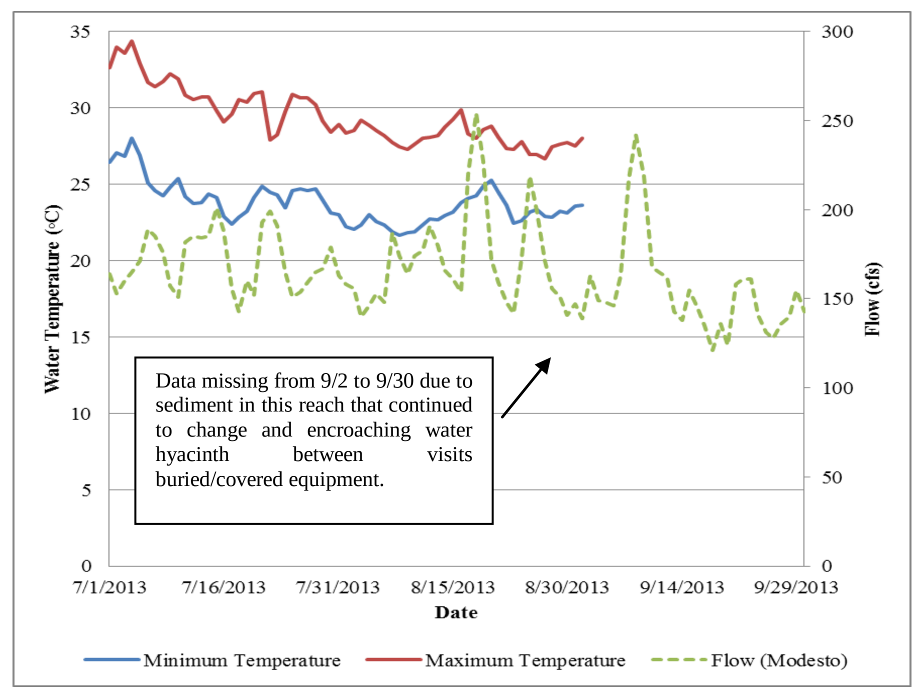


Figure 19. River Mile 10.

Left Bank **Mid Channel** **Right Bank**





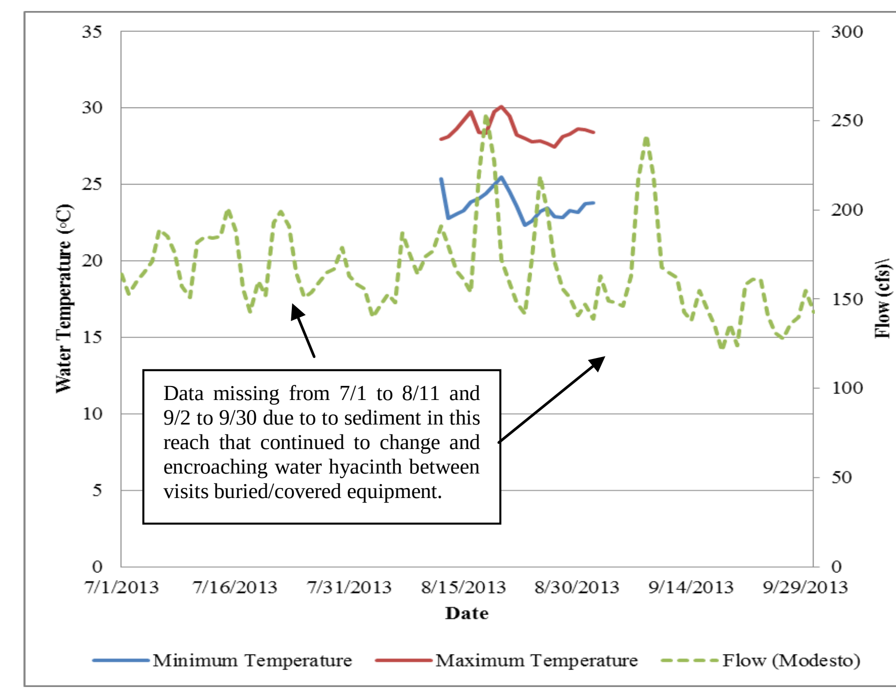
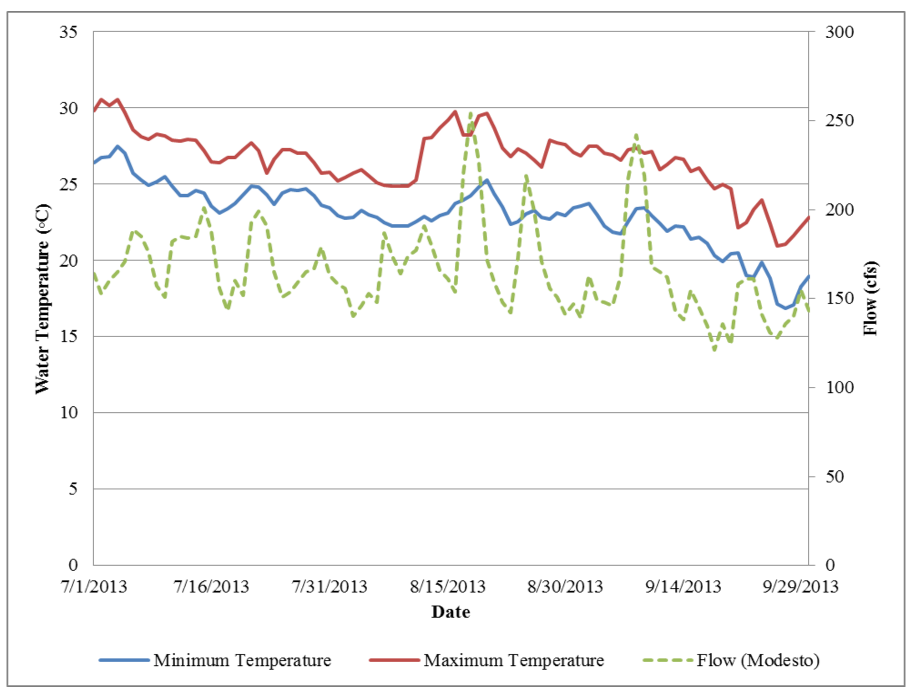


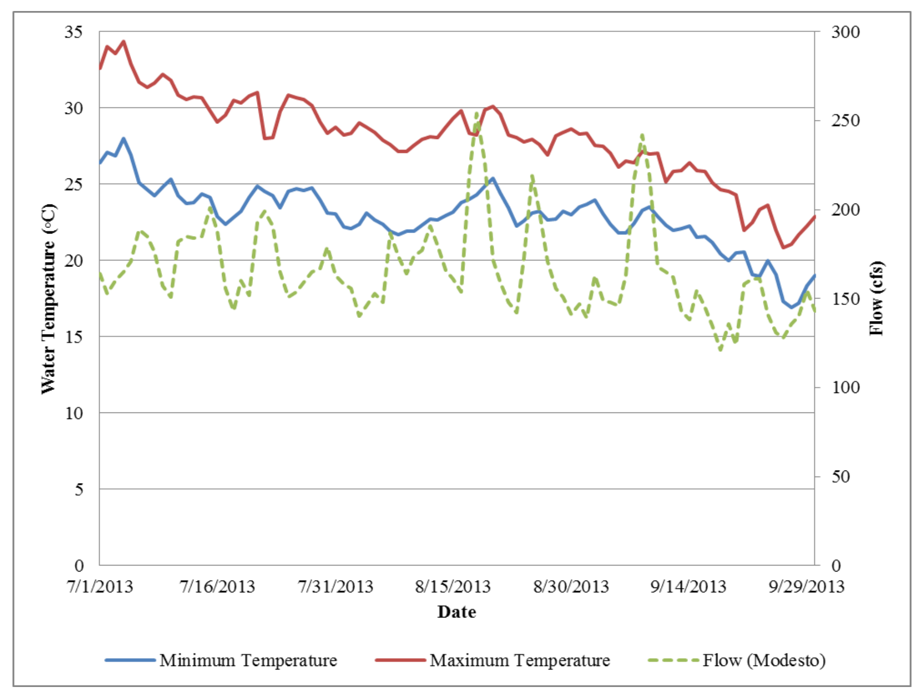
Figure 20. River Mile 9.75.

Left Bank

Mid Channel

Right Bank





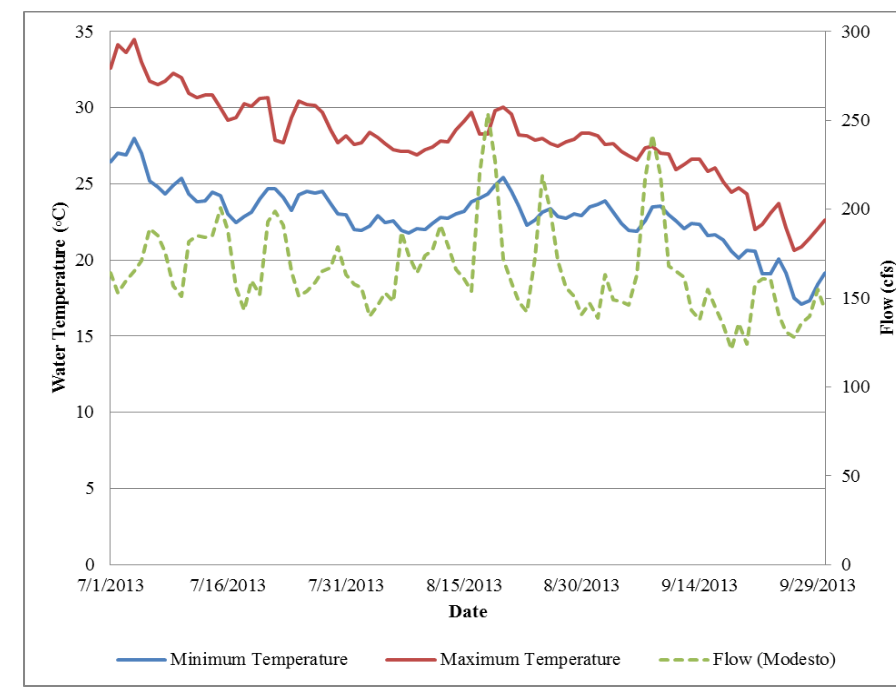
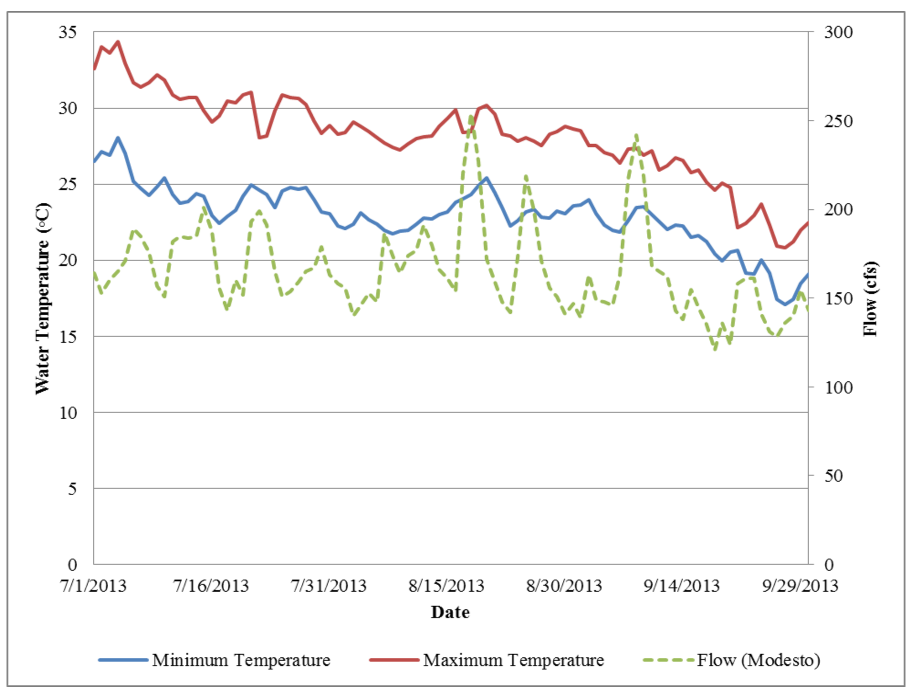
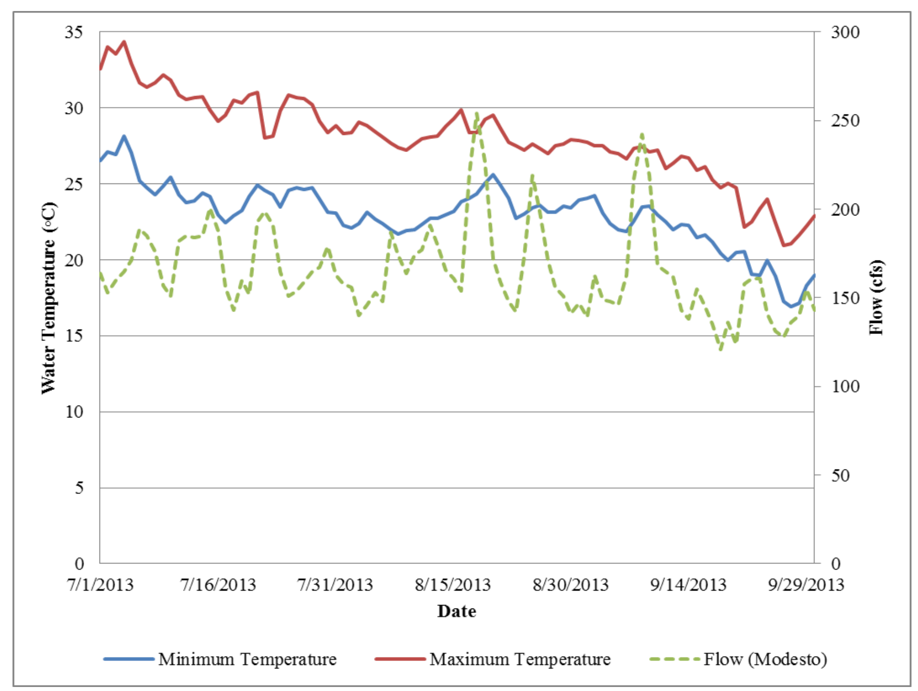


Figure 21. River Mile 9.5US.

Left Bank | **Mid Channel** | **Right Bank**





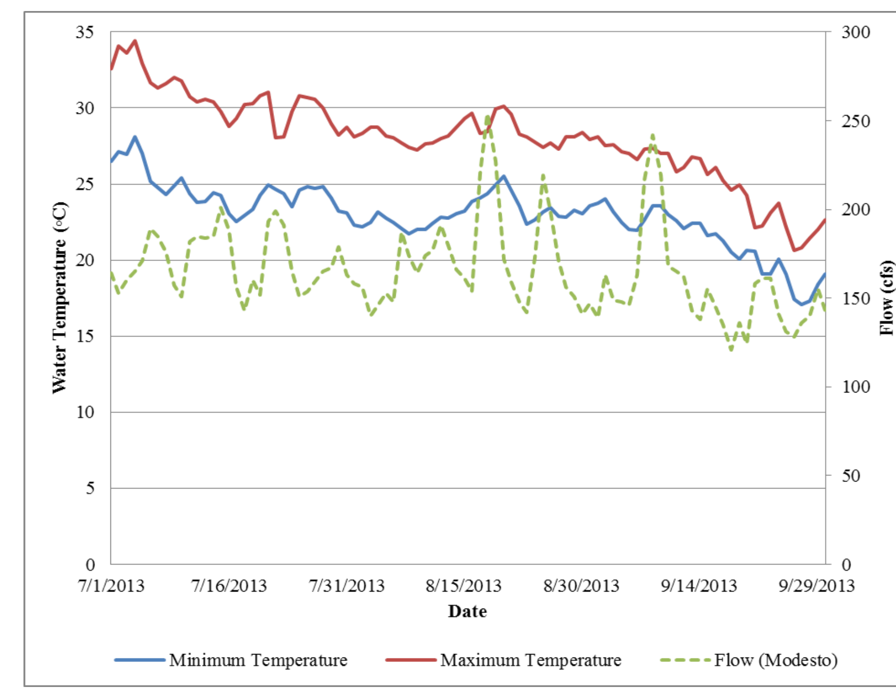
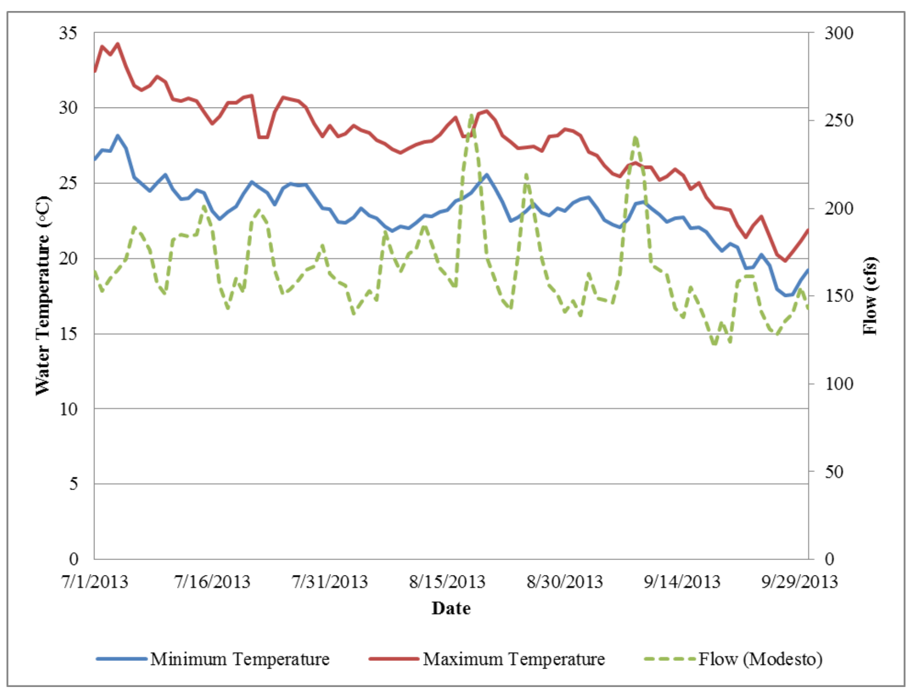


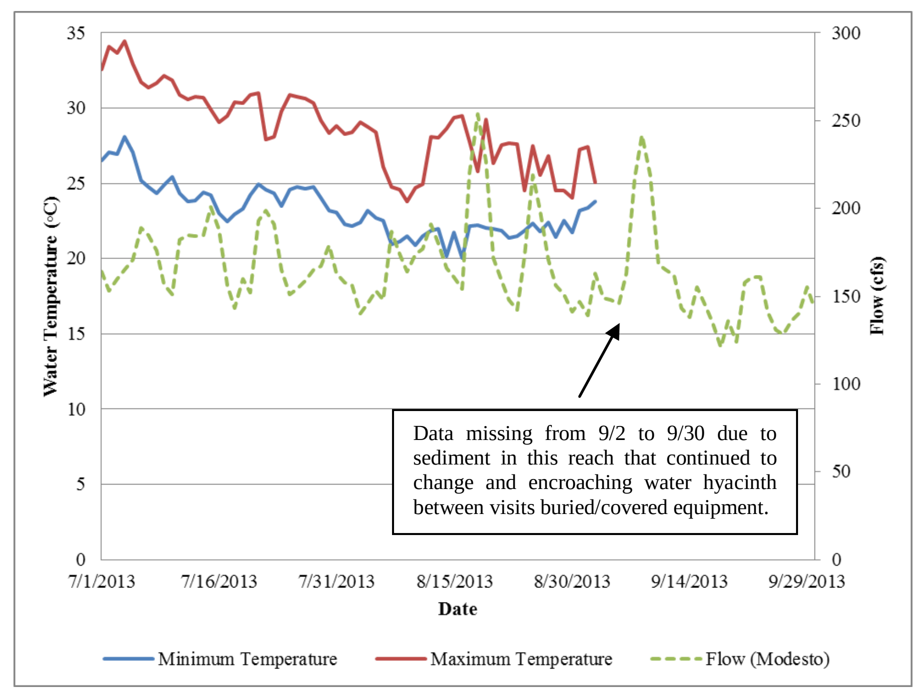
Figure 22. River Mile 9.5DS.

Left Bank

Mid Channel

Right Bank





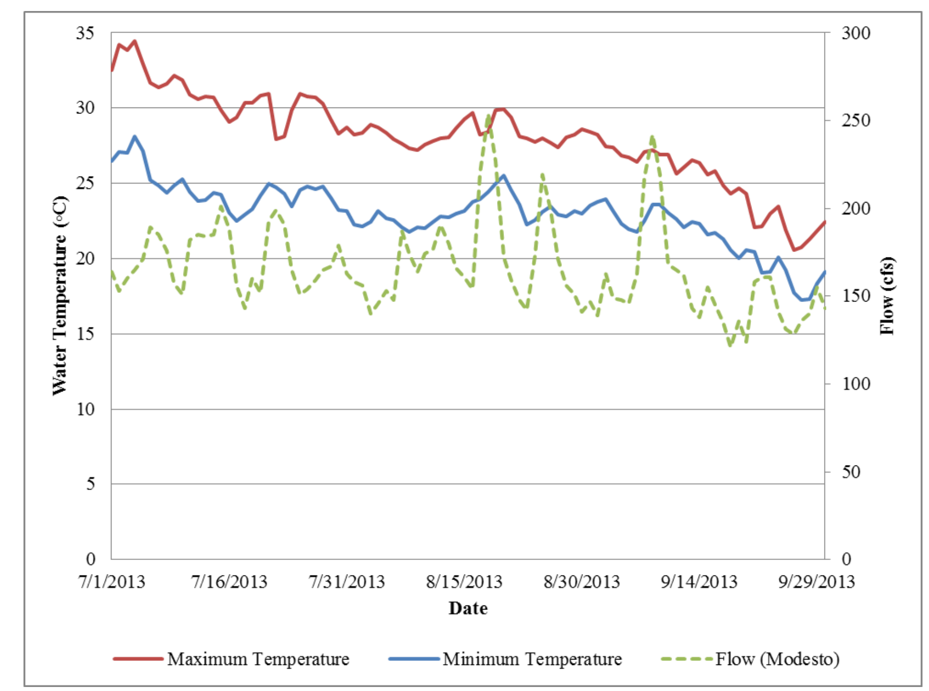


Figure 23. River Mile 9.2.

IN-RIVER DIURNAL TEMPERATURE VARIATION

ATTACHMENT B

WATER TEMPERATURE DATA SET
(February 2014)

Due to the size and format of the material in the In-River Diurnal Temperature Variation Study Attachment B, copies of the material may be obtained upon request to the Districts. Please contact John Devine, Relicensing Project Manager, at 207.775.4495 or by e-mail at john.devine@hdrinc.com.