W&AR-03 and W&AR-16

Temperature Model Meetings No. 3

June 4, 2013

From: Staples, Rose
Sent: Wednesday, May 29, 2013 5:27 PM
To: 'Alves, Jim'; 'Amerine, Bill'; 'Asay, Lynette'; 'Barnes, James'; 'Barnes, Peter'; 'Barrera, Linda'; 'Blake, Martin'; 'Bond, Jack'; Borovansky, Jenna; 'Boucher, Allison'; 'Bowes, Stephen'; 'Bowman, Art'; 'Brenneman, Beth'; 'Buckley, John'; 'Buckley, Mark'; 'Burke, Steve'; 'Burt, Charles'; 'Byrd, Tim'; 'Cadagan, Jerry'; 'Carlin, Michael'; 'Charles, Cindy'; 'Colvin, Tim'; 'Costa, Jan'; 'Cowan, Jeffrey'; 'Cox, Stanley Rob'; 'Cranston, Peggy'; 'Cremeen, Rebecca'; 'Damin Nicole'; 'Day, Kevin'; 'Day, P'; 'Denean'; 'Derwin, Maryann Moise'; Devine, John; 'Donaldson, Milford Wayne'; 'Dowd, Maggie'; 'Drake, Emerson'; 'Drekmeier, Peter'; 'Edmondson, Steve'; 'Eicher, James'; 'Fargo, James'; 'Ferranti, Annee'; 'Ferrari, Chandra'; 'Findley, Timothy'; 'Fleming, Mike'; 'Fuller, Reba'; 'Furman, Donn W'; 'Ganteinbein, Julie'; 'Giglio, Deborah'; 'Gorman, Elaine'; 'Grader, Zeke'; 'Gutierrez, Monica'; 'Hackamack, Robert'; 'Hastreiter, James'; 'Hatch, Jenny'; 'Hayat, Zahra'; 'Hayden, Ann'; 'Hellam, Anita'; 'Heyne, Tim'; 'Holley, Thomas'; 'Holm, Lisa'; 'Horn, Jeff'; 'Horn, Timi'; 'Hudelson, Bill'; 'Hughes, Noah'; 'Hughes, Robert'; 'Hume, Noah'; 'Jackson, Zac'; 'Jauregui, Julia'; 'Jennings, William'; 'Jensen, Art'; 'Jensen, Laura'; 'Johannis, Mary'; 'Johnson, Brian'; 'Jones, Christy'; 'Jsansley'; 'Justin'; 'Keating, Janice'; 'Kempton, Kathryn'; 'Kinney, Teresa'; 'Koepele, Patrick'; 'Kordella, Lesley'; Le, Bao; 'Levin, Ellen'; 'Lewis, Reggie'; 'Linkard, David'; Loy, Carin; 'Lwenya, Roselynn'; 'Lyons, Bill'; 'Madden, Dan'; 'Manji, Annie'; 'Marko, Paul'; 'Marshall, Mike'; 'Martin, Michael'; 'Martin, Ramon'; 'Mathiesen, Lloyd'; 'McDaniel, Dan'; 'McDevitt, Ray'; 'McDonnell, Marty'; 'Mein Janis'; 'Mills, John'; 'Monheit, Susan'; 'Morningstar Pope, Rhonda'; 'Motola, Mary'; 'Murphey, Gretchen'; 'Murray, Shana'; 'O'Brien, Jennifer'; 'Orvis, Tom'; 'Ott, Bob'; 'Ott, Chris'; 'Paul, Duane'; 'Pavich, Steve'; 'Pool, Richard'; 'Porter, Ruth'; 'Powell, Melissa'; 'Puccini, Stephen'; 'Raeder, Jessie'; 'Ramirez, Tim'; 'Rea, Maria'; 'Reed, Rhonda'; 'Richardson, Daniel'; 'Richardson, Kevin'; 'Ridenour, Jim'; 'Riggs T'; 'Robbins, Royal'; 'Romano, David O'; 'Roos-Collins, Richard'; Rosekrans, Spreck; 'Roseman, Jesse'; 'Rothert, Steve'; 'Sandkulla, Nicole'; 'Saunders, Jenan'; 'Schutte, Allison'; 'Sears, William'; 'Shakal, Sarah'; 'Shipley, Robert'; 'Shumway, Vern'; 'Shutes, Chris'; 'Sill, Todd'; 'Slay, Ron'; 'Smith, Jim'; Staples, Rose; 'Stapley, Garth'; 'Steindorf, Dave'; 'Steiner, Dan'; 'Stender, John'; 'Stone, Vicki'; 'Stork, Ron'; 'Stratton, Susan'; 'Taylor, Mary Jane'; 'Terpstra, Thomas'; 'TeVelde, George'; 'Thompson, Larry'; 'Tmberliner'; 'Ulibarri, Nicola'; 'Ulm, Richard'; 'Vasquez, Sandy'; 'Verkuil, Colette'; 'Vierra, Chris'; 'Wantuck, Richard'; 'Welch, Steve'; 'Wenger, Jack'; 'Wesselman, Eric'; 'Wheeler, Dan'; 'Wheeler, Dave'; 'Wheeler, Douglas'; 'White, David K'; 'Wilcox, Scott'; 'Williamson, Harry'; 'Willy, Allison'; 'Wilson, Bryan'; 'Winchell, Frank'; 'Wooster, John'; 'Workman, Michelle'; 'Yoshiyama, Ron'; 'Zipser, Wayne'
Subject: Don Pedro June 4 Reservoir - River Temperature Model Workshop AGENDA and ADVANCE MATERIALS
Attachments: DonPedroJune4Workshp_Agenda_130528.pdf

Please find attached the AGENDA for the upcoming June 4, 2013 Reservoir and River Temperature Model Training Workshop, to be held at the HDR Offices in Sacramento (2379 Gateway Oaks Drive Suite 200) from 9:00 a.m. to 4:00 p.m. Please bring your computer with HEC-RAS loaded—though there will be a few laptops there available for participant use as well.

Updated calibration and validation reports for each model are also being uploaded to the www.donpedro-relicensing.com website (in the calendar under JUNE 4 and also in the ANNOUNCEMENTS section). Please note that a study plan to investigate diurnal temperature variation in the lower Tuolumne is provided as an attachment to the river temperature model report. If you have any difficulty accessing and/or opening these documents, please let me know.

These two reports are also being provided to you for a 30-day comment period. Please forward all comments to me by Friday, June 28, 2013. Thank you.

ROSE STAPLES
CAP-OM
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Executive Assistant, Hydropower Services

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Don Pedro Reservoir &
Lower Tuolumne River Model Workshop & Training

June 4, 2013
9:00 am – 4:00 pm
HDR Offices, 2379 Gateway Oaks Drive, Sacramento

Agenda

Introductions
Workshop Purpose and Study Background

HECRAS River Temperature Model

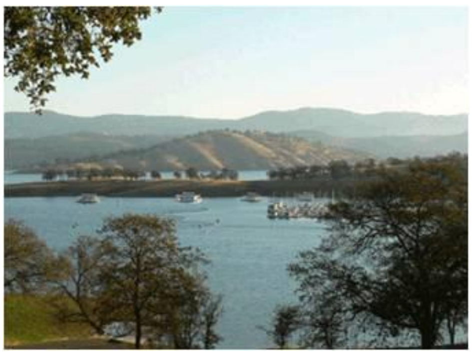
- Model overview
- River geometry
- Model hydraulic calculations
  - Inflows and outflows
  - Importing outflows Don Pedro Reservoir
  - Running a hydraulic calculation
  - Examining the results
- Model temperature calculations
  - Input data
  - Importing Don Pedro release temperature
  - Running a temperature calculation
  - Looking at results
- Base Case
- Extracting output for use in SJR5Q model

Lunch Break- Lunch to Be Provided

MIKE3 FM Don Pedro Temperature Model

- Model overview
- Model inputs
  - Inflows and outflows
  - Met data
  - Geometry
  - Parameters
- Running the model
  - Setting up a model run
  - Setting up output files
  - Batch mode for long runs
- Visualizing model output
  - Creating a time series at a given point
  - Creating vertical slices
  - Looking at results at a certain depth
- Base Case

RESERVOIR TEMPERATURE MODEL
STUDY REPORT
DON PEDRO PROJECT
FERC NO. 2299



TID WATER & POWER
Serving Central California since 1887

MID Modesto Irrigation District

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

Prepared by:
HDR Engineering, Inc.

May 2013

Reservoir Temperature Model
Study Report

TABLEOF CONTENTS

List of Figures

List of Tables

Table No. **Description** **Page No.**

List of Attachments

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)

CDFW ....California Department of Fish and Wildlife

CDMG........................California Division of Mines and Geology

CDOF.........................California Department of Finance

CDPH........................California Department of Public Health
CDPR........................California Department of Parks and Recreation
CDSOD......................California Division of Safety of Dams
CDWR........................California Department of Water Resources
CE ....California Endangered Species
CEII...........................Critical Energy Infrastructure Information
CEQA.........................California Environmental Quality Act
CESA ....California Endangered Species Act
CFR...........................Code of Federal Regulations
cfs..............................cubic feet per second
CGS...........................California Geological Survey
cm..............................centimeter
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
deg.............................degrees
DHI ....Danish Hydraulic Institute
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
FM.............................Flexible Mesh
FMU..........................Fire Management Unit
FOT...........................Friends of the Tuolumne
FPC ....Federal Power Commission
ft ....feet or foot
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
µSiemans...................microSiemans
m ....meters
m/s.............................meters per second
m^3/s ....cubic meters per second
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
PSU…………………Practical Salinity Units
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
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
SI .... International System
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 feet (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.

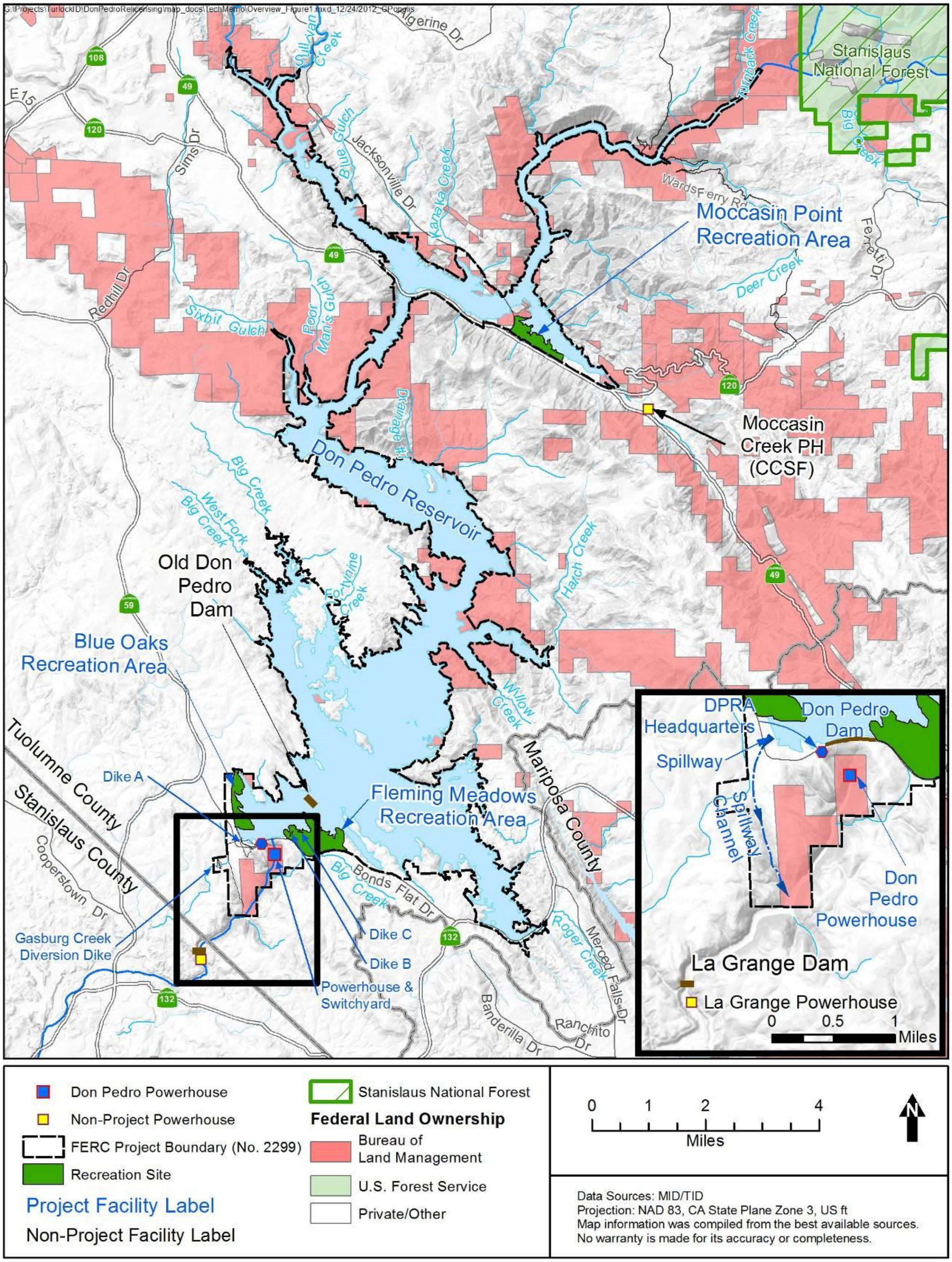


Figure 1.1-1. Don Pedro Project location.

1.2 Relicensing Process

The current Federal Energy Regulatory Commission (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) (TID/MID 2011a). 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 study report describes the objectives, methods, and results of the Reservoir Temperature Model Study (W&AR-03) 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

The Districts' continued operation and maintenance (O&M) of the Project will affect the temperature regime of waters in the Don Pedro Reservoir. Similarly, flow releases from Don Pedro Reservoir will affect the temperature of waters downstream of Don Pedro Dam and may contribute to cumulative effects to the aquatic resources of the lower Tuolumne River.

The FERC-approved Reservoir Temperature Model Study Plan (W&AR-03) described the procedures applied herein to develop a three dimensional (3-D) model characterizing the thermal structure and dynamics of the Don Pedro Reservoir (TID/MID 2011b). Through this model, water temperatures in the reservoir have been simulated using historical meteorology, hydrology and water temperatures, along with current Project operations. In the relicensing process, the reservoir temperature model presented herein is a tool that will be used to evaluate the effects to the reservoir's thermal structure under potential future operating scenarios.

2.0 GOALS AND OBJECTIVES

The goal of this study is to develop a reservoir temperature model that accurately simulates and characterizes the seasonal water temperature dynamics experienced in Don Pedro Reservoir under current and potential future conditions. The model will be able to:

- reproduce observed reservoir temperatures, within acceptable calibration standards, over a range of hydrologic conditions;
- provide output that can inform other studies, analyses, and models; and
- predict potential changes in reservoir thermal conditions under alternative future operating scenarios.

The reservoir temperature model interfaces with the Project Operations Model (Study W&AR-02) and the Lower Tuolumne River Temperature Model (Study W&AR-16) (TID/MID 2013a; TID/MID 2013b). Output from the reservoir temperature model serves as input to the river temperature model. The reservoir and river temperature models, working together, will also support the Chinook and *O. mykiss* population models being developed under studies W&AR-06 and W&AR-10, respectively.

3.0 STUDY AREA

The study area consists of the Don Pedro Reservoir, extending from about elevation 300 feet (ft) to about elevation 850 ft, or from the tailwater of Don Pedro powerhouse to about 20 ft above the Don Pedro Reservoir normal maximum reservoir elevation of 830 ft. The study area is shown in Figure 3.0-1.

The Don Pedro Reservoir extends upstream from the Don Pedro Dam (RM 54.8) for approximately 24 miles at the normal maximum water surface elevation of 830 ft. The surface area of the reservoir at the 830-ft elevation is approximately 12,960 ac and the gross storage capacity is 2,030,000 AF. The Don Pedro Reservoir shoreline, including the numerous islands within the reservoir, is approximately 160 miles long.

Inflows to Don Pedro Reservoir consist predominantly of flows from the main stem of the Tuolumne River. The flow in the main stem of the Tuolumne River consists of regulated releases from the Hetch Hetchy Reservoir system, located above RM 117, and unregulated flows from several significant tributaries, including the South Fork, Middle Fork, Clavey River, and the North Fork. The North Fork of the Tuolumne River joins the main stem at RM 81.5, just upstream of the Don Pedro Project Boundary.

The upper Tuolumne River watershed, defined for purposes of this report as the subbasin above about RM 80, covers approximately 1,300 mi^2 of drainage area and contains all the major tributaries of the Tuolumne River, including the North Fork, South Fork, Middle Tuolumne, Clavey River, Cherry Creek, and Eleanor Creek. The upper Tuolumne River extends from the confluence of the Dana and Lyell Forks to just below the confluence of the North Fork at approximate elevation 850 ft. The average gradient of the river is roughly 110 feet/mile (ft/mi), but local gradients vary greatly. Flows in the upper Tuolumne River are regulated and controlled by the CCSF's Hetch Hetchy Water and Power system, including Hetch Hetchy Reservoir, Lake Eleanor and Cherry Lake, and CCSF's extensive infrastructure of water conveyance and water power facilities.

The foothills reach of the Tuolumne River extends from RM 54 to RM 80 and is dominated by the Don Pedro Project. This portion of the watershed includes several smaller tributaries including Woods Creek, Moccasin Creek, Hatch Creek and Rogers Creek that flow into Don Pedro Reservoir. The dendritic shape of the reservoir is indicative of the topographic influence of these tributaries. The resulting bathymetry of Don Pedro Reservoir is therefore complex and torturous in nature. Added to the natural terrain complexity is the presence of the Old Don Pedro Dam at RM 56.5, which was submerged in 1971 with the filling of Don Pedro Reservoir. Old Don Pedro Dam had a crest elevation of approximately 600 ft and is approximately 1000 ft long.

Outflows from Don Pedro Reservoir are provided by the powerhouse intake tunnel with a centerline elevation of 534 ft. The hydraulic capacity of the powerhouse tunnel is 6300 cubic feet per second (cfs). Outflows can also be provided by the outlet works control gates which were installed in the original diversion tunnel used for new Don Pedro construction. The invert elevation of the intake to the outlet works is at approximate elevation 342 ft and the hydraulic capacity of the outlet works and tunnel is approximately 7500 cfs. Outflows can also be provided at the gated and ungated spillways located to the north of the main dam.

The primary purpose of the Don Pedro Reservoir is to provide water storage to meet the needs of the Districts' irrigation and M&I water supply customers. As a storage reservoir, Don Pedro can experience significant variations in water levels in a given year. Historically, the highest water level reached was approximately 831 ft (1997) and the lowest level was approximately 630 ft (1977). The minimum operating level for Don Pedro Reservoir is 600 ft.

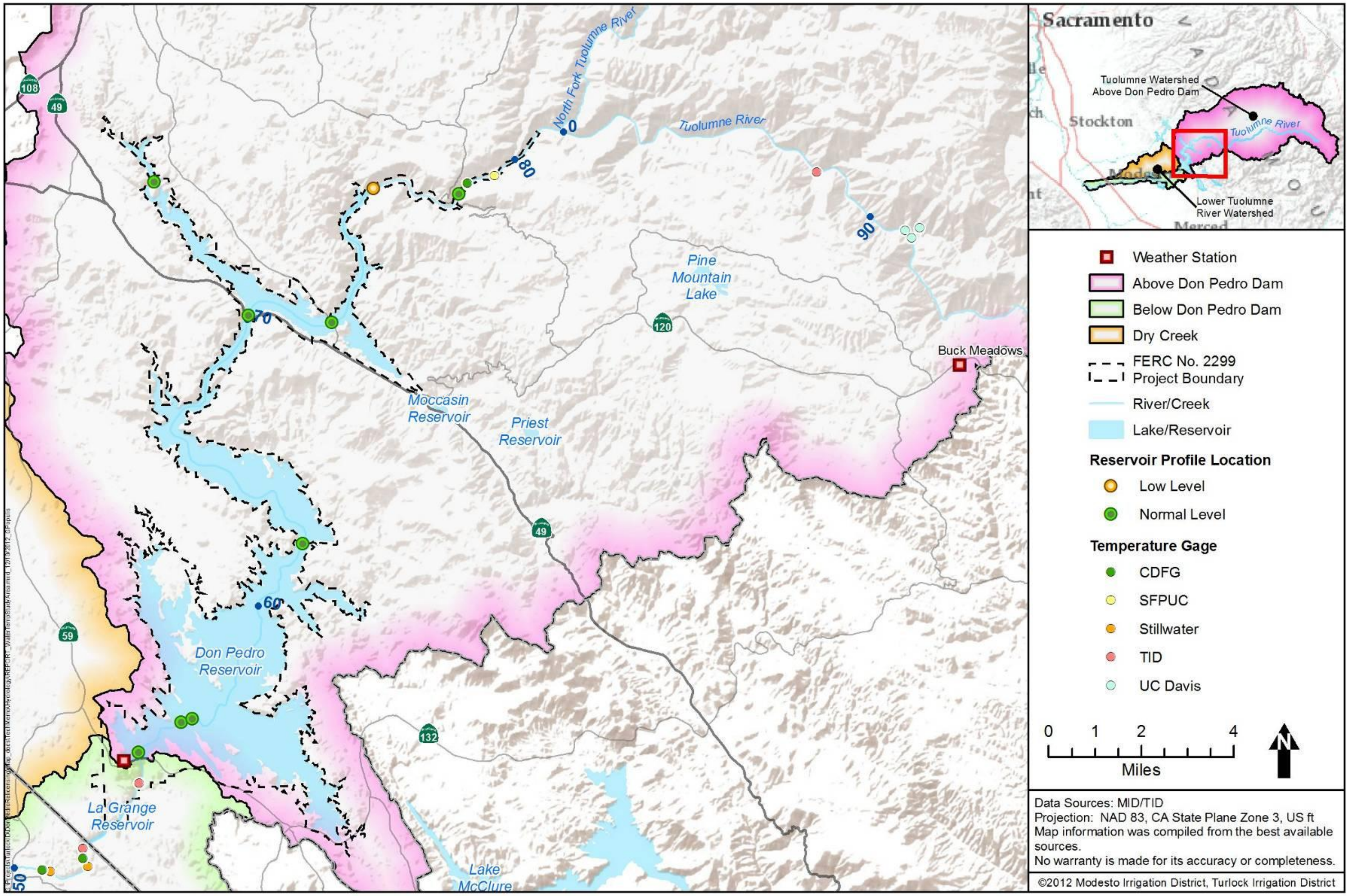


Figure 3.0-1. Study area.

4.0 METHODOLOGY

4.1 Model Platform Selection

To select the appropriate reservoir temperature model, the Districts developed a list of required water temperature model capabilities necessary to meet the study goals and objectives. The primary model requirements are to:

- simulate water temperatures on an appropriate time-step to capture water temperature variability on a temporal scale which is biologically meaningful;
- simulate water temperatures over a range of historical hydrology and meteorology experienced in the Project area;
- account for the effect of major physical in-reservoir complexities on reservoir temperatures, including the Old Don Pedro Dam and the reservoir's geometry; and
- simulate the effects of changes in storage, climatological factors, inflow temperatures and discharge elevation on the temperature of Don Pedro releases.

The following water temperature model platforms were originally considered for use[1]:

- HEC-5Q, one-dimensional (1-D), longitudinally- and laterally-averaged (AD Consultants et. al. 2009)
- CE-QUAL-W2, two-dimensional (2-D), laterally averaged (Cole and Wells 2003)
- RMA-10, three-dimensional (3-D) (King 1993)
- MIKE3-FM, three-dimensional (3-D) (DHI 2009a)

The 1-D model, HEC-5Q, has been widely used across many relicensing and water resource processes[2] and has been found to provide consistent and reliable results where appropriately applied. HEC-5Q is empirical in design and reservoir behavior is estimated by equations and algorithms developed from long and narrow (highly longitudinal) or short and wide (highly transverse) reservoirs. The one dimensional (1-D) structure of the model does not determine the horizontal variation in temperatures that would be observed in the 24 mile long, highly dendritic Don Pedro Reservoir, nor does it have the ability to adequately model the effects on reservoir temperature variability of the now submerged Old Don Pedro Dam, especially at lower reservoir levels. Temperature data obtained from actual vertical profiles in the reservoir and upstream and downstream temperature data describe a more complex temperature regime. Hence, model results from the 1-D model would be of limited value.

[1] For additional detail, see W&AR-03 Reservoir Temperature Model Study Plan (TID/MID 2011b).
[2] The San Joaquin River Basin Water Temperature Model (SJR5Q) is an application of the HEC-5Q modeling platform that represents the Don Pedro Reservoir as a one-dimensional vertically-segmented reservoir (AD Consultants 2009).

The 2-D model, CE-QUAL-W2, has been widely used and is recognized as a reliable model. However, like the HEC-5Q model, CE-QUAL assumes complete lateral mixing and averages lateral temperatures. The CE-QUAL-W2 model would require multiple branches to accurately represent the complex geometry of the Don Pedro Reservoir and result in the loss of detail where branches overlap. Segment widths in the middle, south and north Bays of the 2-D model would exceed two miles at certain locations; the 2-D model assumes uniform parameters (i.e., velocity, temperature) throughout the width of the segment. Hence, the model results would also be of somewhat limited value.

Two 3-D model platforms were considered, the RMA-10 and MIKE3 models. Both models account for environmental variability, providing results that are more biologically relevant, and provide greater flexibility when evaluating outflow temperature dynamics than the 1-D or 2-D models. However, the MIKE3 documentation, graphical user interface, and technical support were considered to be more suitable for purposes of relicensing where many parties need to understand and potentially use the model. Hence, based on review of the two 3-D modeling platforms, MIKE3-FM was selected for the temperature modeling of the Don Pedro Reservoir.

The selected modeling approach allows the Districts to develop a model that meets the full needs of the relicensing process. MIKE3 was developed by the Danish Hydraulic Institute (DHI) as a professional engineering software package for 3-D free-surface flows (DHI 2009a, 2009b, 2009c). MIKE3 is fully integrated with GIS enabling the user to efficiently set up model geometry given geo-referenced bathymetric data. The Graphical User Interface enables the modeler to efficiently prepare input and graphically present output. The flexible mesh version of the model (MIKE3-FM) (DHI 2011) allows variable-spacing of computational grid points to obtain high spatial resolution in areas of prime interest while saving on model run time through a coarse mesh in other areas. It simulates unsteady three-dimensional flows taking into account density variations, bathymetry, and external forcing such as meteorology, water levels, currents and other hydrographic conditions.

4.2 Selection of Model Time Step

The reservoir temperature model interfaces with the Project Operations Model (Study W&AR-02) and the lower Tuolumne River temperature model (Study W&AR-16) (TID/MID, 2013a; TID/MID 2013b). Output from the reservoir temperature model serves as input to the river temperature model. Flow releases from Don Pedro and reservoir levels are provided by the Operations Model on a mean daily basis. Therefore, a daily time step was chosen for the reservoir model.

4.3 Input Data, Calibration and Validation Data

The two broad categories of data required by the model are (1) input data on reservoir characteristics and (2) data used for model calibration/verification. Input data pertain to the detailed physical characteristics of the reservoir being modeled, including bathymetry and boundary conditions. The boundary conditions include inflows, withdrawals/releases, temperature of inflows, and local meteorological data (air temperature, wind speed and direction, relative humidity). Mechanistic response parameters such as heat exchange coefficients were also input along with reservoir operation rules to create the outflow data set that served as an input to this model (see Project Operations Model, W&AR-02). Data for model calibration/verification are primarily measurements of the metrics that are calculated by the model, which in this case are temperature measurements in the reservoir (i.e., vertical profiles). The specific data required for the MIKE3-FM model are listed in Table 4.3-1 under four headings: (1) physical and geomorphological, (2) flow and operation parameters (3) inflow temperatures, and (4) meteorology. Additional detail regarding each type of data is provided below.

Table 4.3-1. MIKE3-FM model data sources.

Required Data	Source		
Physical and Geomorphological—Don Pedro Reservoir and Dam			
Bathymetry	Field survey	Attachment B	
Normal maximum water level	Design drawings	830 ft	
Minimum water level	Design drawings	600 ft	
Dam spillway, ungated (elevation)	Design drawings	830 ft	
Dam spillway, ungated (length, type)	Design drawings	995 ft long; ogee crest	
Powerhouse intake (invert elevation)	Design drawings	525 ft	
Powerhouse intake (lat/long)	Design drawings	37.70342	120.419095
Diversion Tunnel/Outlet works (invert elevation)	Design drawings	342 ft	
Diversion Tunnel Intake/Outlet works (lat/long)	Design drawings	37.70402	120.420002
Physical and Geomorphological—Old Don Pedro Dam			
Old Don Pedro Dam (lat/long above/below)	TID and MID 2011	729134 E	4177175 N
		728741 E	4177044 N
Old Don Pedro normal maximum water level	Design drawings	600 ft	
Old Don Pedro Dam top of gates elevation	Design drawings; TID and MID 2011	605.5 ft (NGVD 29)	
Old Don Pedro Dam crest (length, type)	Design drawings	1000 ft	
Old Don Pedro outlet (elevation)	TID	multiple[1]	
Flow and Operations			
Tuolumne River upstream of reservoir (regulated)	CCSF, TID[2]	See W&AR-02 Project Operations Model (TID/MID 2013a)	
Tuolumne River upstream of reservoir (total flow)	TID		
Storage (daily)	TID		
Releases through powerhouse and outlets (daily)	TID		
Temperature			
Tuolumne River upstream of reservoir (Tuolumne River at Indian Creek Trail, Tuolumne River at Ward's Ferry, and other upstream locations)	Districts CCSF CDFW	See Attachment A	
Tributaries: Rough & Ready, Moccasin, Sullivan and Woods Creeks	Districts		
Reservoir Profiles	Districts CDFW		
Tuolumne River downstream of reservoir (below Don Pedro Powerhouse)	Districts		
Meteorology			
Air temperature, wind speed/direction relative humidity	Don Pedro Weather Station	See Attachment A and Attachment D	
Cloud cover (measured at Modesto)	National Oceanic and Atmospheric Administration	weatherspark.com	

[1] The Old Don Pedro Dam had 12 gated outlets arranged in two rows of six gates. Each outlet was 52-inches in diameter; the lower row of six have a centerline at elevation 421 ft and the upper row of six has a centerline of elevation 511 ft. All of these gates were left in the open position when Old Don Pedro Dam was inundated by the new Don Pedro Dam. There are also three 5-ft diameter sluiceway gates, each with a centerline at 355 ft; these gates are believed to be closed.

[2] CCSF's site, TR-8, and CDFG's site, TRWARDS, are located within the reservoir at approximately 785 msl and 763 msl, respectively. The Districts' site Tuolumne River at Indian Creek Trail is upstream of the reservoir's influence.

4.3.1 Physical and Geomorphological

Construction of the reservoir's topographic surface for modeling is documented in the Districts' Don Pedro Reservoir Bathymetric Study Report provided as Attachment B. In brief, the reservoir ground surface below the full pool elevation of 830 ft was determined by two techniques: underwater surfaces were surveyed using field measurements collected from May 1 to June 5, 2011, and dry surfaces topography was obtained using radar technology collected in August 2004. Data obtained by the two techniques were then synthesized into one surface using geographic information system (GIS) software. The data above elevation 760 ft and below 792 ft overlapped; topographic measurements in the overlapping interval showed a good correlation. The Bathymetric Report was submitted to Relicensing Participants for review October 18, 2012 and was discussed at the Workshop held on October 26, 2012.

4.3.2 Inflows, Outflows, and Operations

Daily flows developed as part of the Tuolumne River Operations Model (W&AR 02) (TID/MID 2013a) were used as input to the reservoir temperature model calibration and verification procedures. Daily inflows to the reservoir were estimated based on the flow recorded at the U.S. Department of the Interior, Geological Survey (USGS) La Grange gaging station, located approximately 0.5 miles downstream of the La Grange Dam, and the change in storage volume of Don Pedro Reservoir. Regulated flows from the operation of CCSF's Hetch Hetchy system and unimpaired flows from the unregulated portions of the drainage are accounted for in the Operations Model. This estimated daily inflow also includes flow from local tributaries to the reservoir (e.g., Moccasin, Sullivan, Woods Creeks). These are small, low elevation tributaries, all of which are intermittent streams except for Moccasin Creek which has a minimum flow provided by CCSF's upstream facilities of about 20 cfs.

The combined total inflow to the reservoir is calculated by using a mass balance equation that derives inflow from the record of reservoir releases, change in storage and estimated reservoir losses. This computed value is then disaggregated between regulated and unregulated components by recognizing the unregulated component of inflow which has been separately computed as the difference between the estimated unimpaired flow at the La Grange gage less the estimated unimpaired flow at the Hetch Hetchy system. The unimpaired flow record was developed within a series of Workshops held as part of the W&AR-02: Operations Modeling Study with relicensing participants, culminating in a consensus approach finalized in Workshop No. 4 on March 27, 2013.[3]

[3] The method of developing the unimpaired flow is described in Attachment 2 of the Districts April 9, 2013 filing with FERC entitled "Response to Relicensing Participants Comments on Initial Study Report."

4.3.3 Temperature

Temperature data have been collected at a number of locations in the Tuolumne River watershed and the Don Pedro Reservoir (Table 4.3-2; Figure 3.0-1) and available data are provided in Attachment A. Obtaining a complete inflow temperature data set was particularly challenging, as CCSF's site TR-8, and CDFW's site TRWARDS, are located within the reservoir at approximate elevation 785 ft msl and 763 ft respectively, and are often inundated. Hence, the Districts' temperature station "Tuolumne River at Indian Creek Trail" installed in October 2010 was located above the influence of the Don Pedro Reservoir. Located near the North Fork Tuolumne River confluence, this temperature gage was used to represent the inflow temperature in the model.

CDFW has collected monthly temperature profiles at six stations in Don Pedro Reservoir since 2004. This data set has been augmented by the Districts since 2010. Since October 2010, the Districts have collected temperature profiles at CDFW's six established stations plus stations above and below the Old Don Pedro dam. Monthly profiles were collected using a Hydrolab MS5 multi-parameter water quality sonde (temperature sensor +/- 0.2°C).

Table 4.3-2. Reservoir Model water temperature measurement locations with period of record.

Site Location	Approximate River Mile	Latitude	Longitude	Period of Record
Tuolumne River at Indian Creek Trail	83.0	37.88383	-120.15361	10/2010 - 11/2012
Near New Don Pedro Dam	55.1	37.702638	-120.421722	8/2004 – 11/2012
Below Old Don Pedro Dam	56.3	37.712083	-120.405	7/2011 – 11/2012
Above Old Don Pedro Dam	56.4	37.71316	-120.4005	7/2011 – 11/2012
At Middle Bay	62.0	37.76794	-120.357	8/2004 – 11/2012
At Highway 49 Bridge	70.1	37.83955	-120.378305	8/2004 – 11/2012
At Woods Creek Arm	--	37.88127	-120.415361	8/2004 – 11/2012
At Jacksonville Bridge	72.3	37.83733	-120.34525	8/2004 – 11/2012
At Ward's Ferry	78.4	37.87744	-120.295	8/2004 – 11/2012
Tuolumne River below Don Pedro Powerhouse	54.3	37.6929	-120.421616	10/2010 - 11/2012

4.3.4 Meteorology

Air temperature, wind speed and direction, and relative humidity are required inputs for the model. To provide data on local weather conditions, the Districts installed a weather station near the Blue Oaks area of the reservoir on November 30, 2010 (Figure 3.0-1; Attachment A). For comparison purposes, data from other local meteorological stations were also compiled (Figure 4.3-1). Data collected from these stations were used for calibration and validation of the model herein. Development of the meteorological data set for the full period of record, that is Water Year 1971 through 2012, is described and provided in Attachment D.

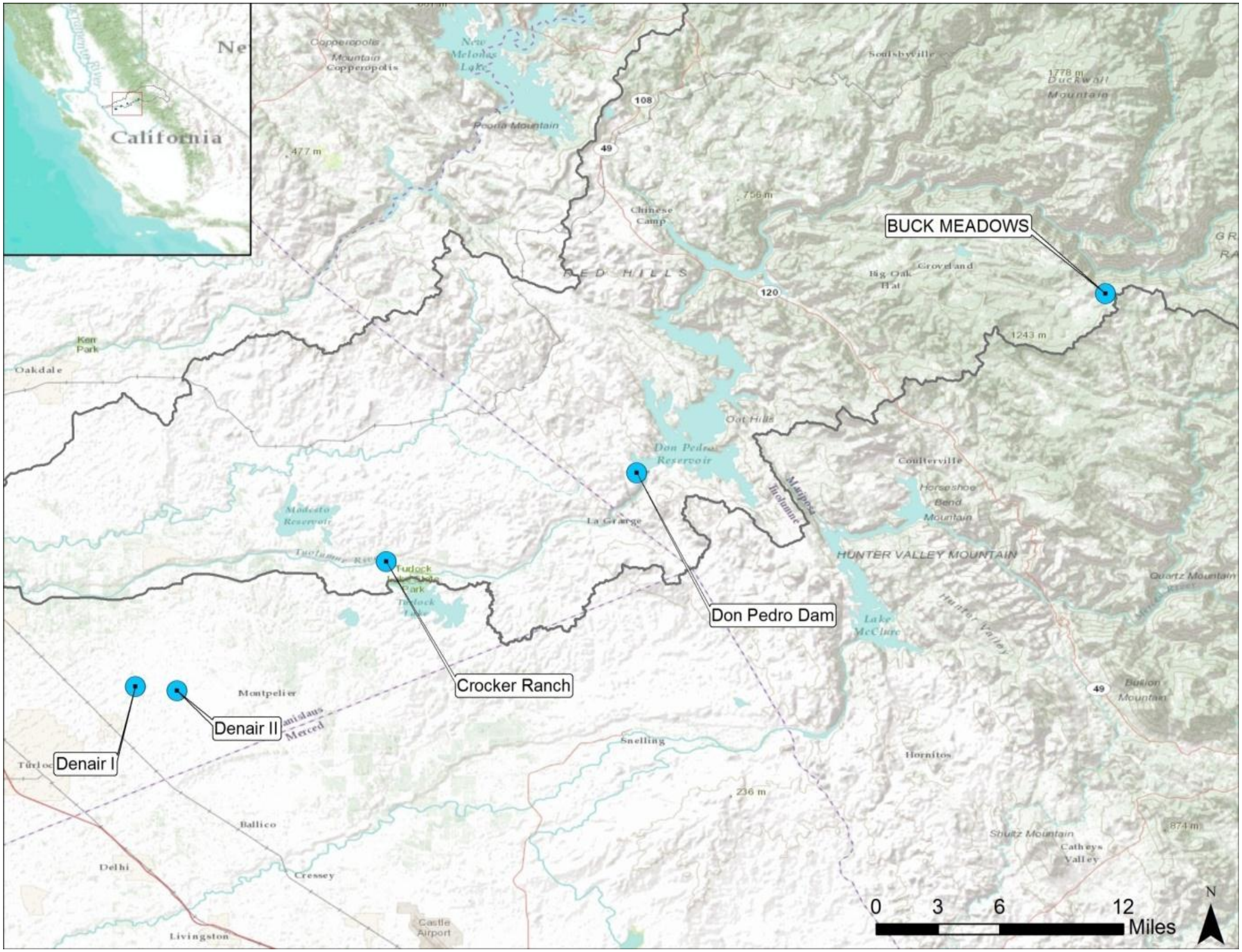


Figure 4.3-1. Meteorological station locations

4.4 Model Development

4.4.1 Model Structure and Interface

The MIKE3-FM model uses a master file called an "m3fm" file that controls all aspects of the simulation. The "m3" refers to the 3D model and the "fm" refers to the Flexible Mesh (FM) version that is being used for the Don Pedro Reservoir temperature model.

As shown in Figure 4.4-1, the "m3fm" file uses a graphical interface and a folder format that is similar to Windows Explorer[4] . The Don Pedro MIKE3-FM model and its components are best described by following the structure of the "m3fm" file itself (Figure 4.4-1):

- Domain (Section 4.4.2)
- Time (Section 4.4.3)
- Module Selection (Section 4.4.4)
- Hydrodynamic Module (Section 4.4.5)
- Temperature Module (Section 4.4.6)
- Output (Section 4.4.7)

The bulk of the Don Pedro Reservoir temperature model is contained within the Hydrodynamic Module. As shown in Figure 4.4-1, the Hydrodynamic Module consists of 18 parts. Each of the components, and associated parts, is discussed below.

[4] By clicking on the "+" icon the underlying directories can be expanded and similarly collapsed using the "-" icon.

Figure 4.4-1. MIKE3-FM master interface in "m3fm" file.

4.4.1.1 Units

The version of the MIKE3 model referred to in this report works only in International System (SI) units. A newly released version, which arrived in December 2012, will allow use of English and/or SI units, or mixing of either. The Districts anticipate using English units for many of the model inputs and outputs, as appropriate.

4.4.2 Domain

The model domain details are described individually in this section.

4.4.2.1 Bathymetry

The first tab under the Domain folder will show the model bathymetry (Figure 4.4-2). As mentioned above, the bathymetry data are detailed in a separate report, which is provided herein as Attachment B. The model bathymetry data were measured as elevations above mean sea level; elevations are converted to meters for the model.

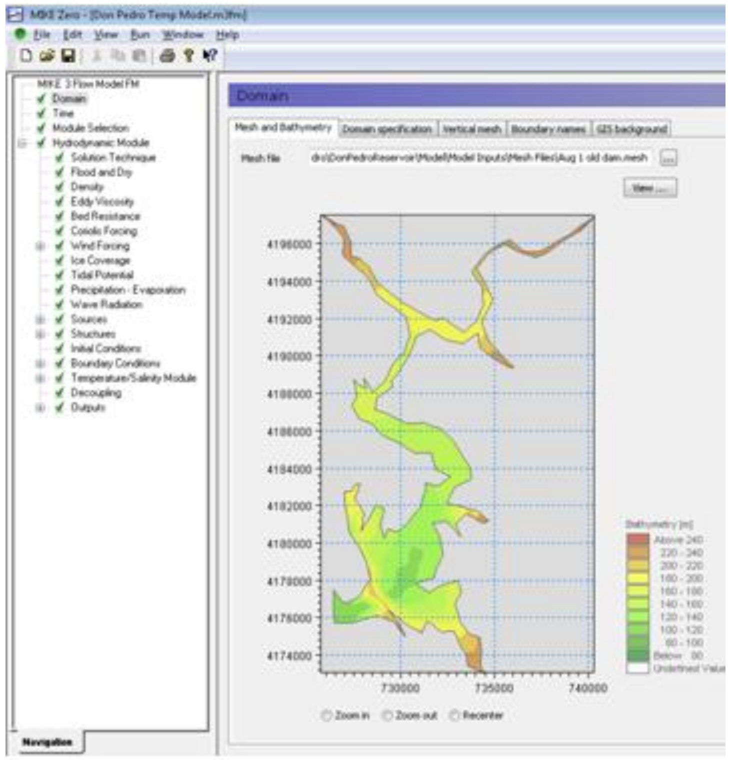


Figure 4.4-2. Model bathymetry screen.

4.4.2.2 Model Mesh

The second tab under the Domain folder displays mesh information and is not shown. The third tab will show the model vertical mesh options (Figure 4.4-3). The model mesh is created using DHI mesh creation tools and then imported into the "m3fm" run file. For the horizontal plane, the mesh uses unstructured triangular elements (Figure 4.4-4). For the vertical structure, the model has two options and within each option there are refinement choices (Figures 4.4-5 through 4.4-7). The options for the vertical structure are:

- Sigma Level. Under this option, a sigma level grid is a terrain following coordinate system. The model vertical mesh expands and contracts as the water depth changes, but keeps the number of vertical layers the same. An example of a transect along Don Pedro Reservoir is shown in Figure 4.4-5.
- Sigma and Z-level Combination. The sigma and z-level option allows the use of a fixed depth grid in deep water with the sigma grid used in shallower water. A schematic of this option is shown in Figure 4.4-6.

Both schemes work well for the Don Pedro Reservoir but the combined scheme is preferred as it reduces the model run times.

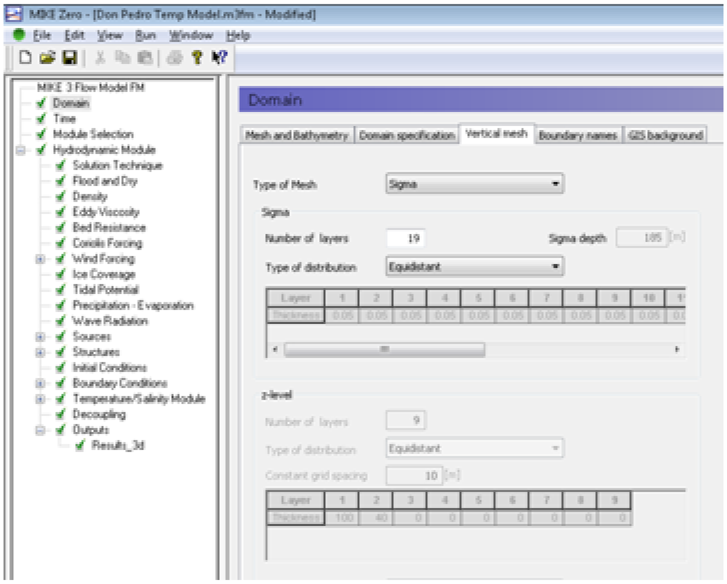


Figure 4.4-3. Vertical mesh option screen.

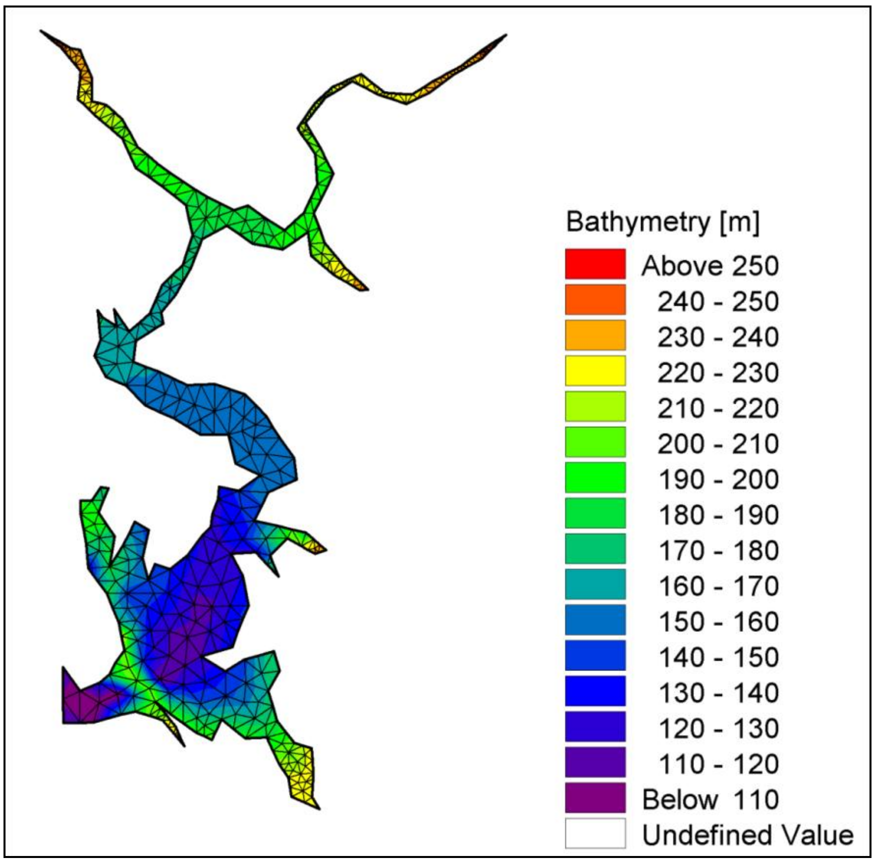


Figure 4.4-4. Model mesh horizontal layout.

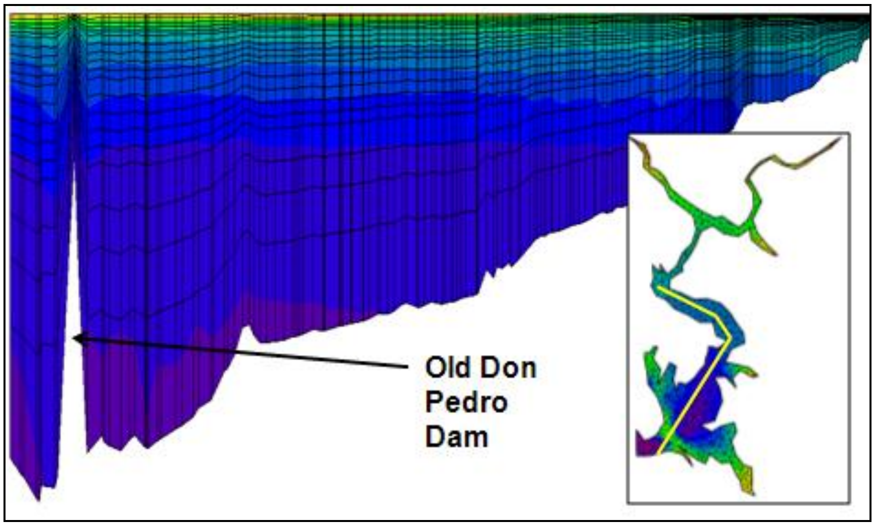


Figure 4.4-5. Example of sigma mesh reservoir longitudinal section

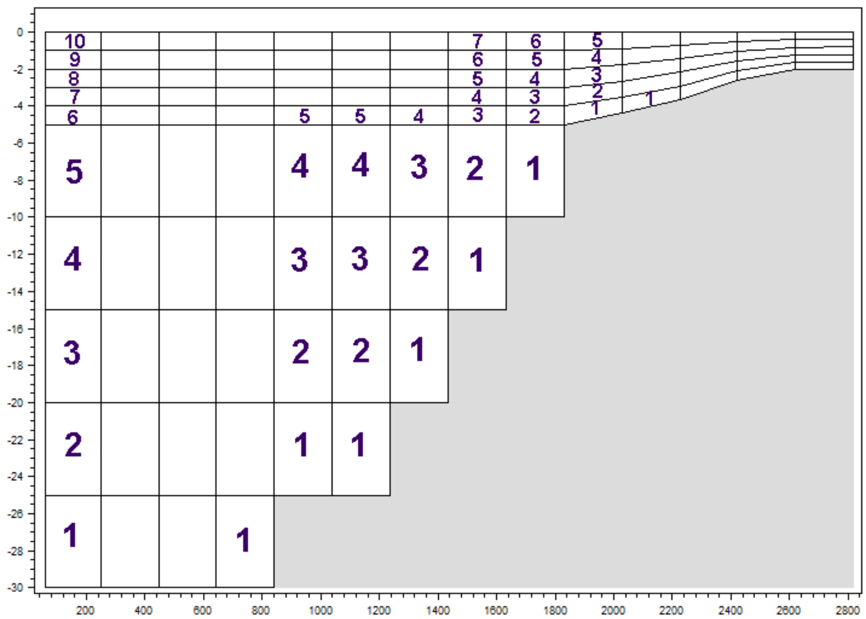


Figure 4.4-6. Example of sigma and z-level vertical mesh scheme.

4.4.3 Simulation Time

The model's time step is detailed in this section. The length of a model run is set using the "Time" tab, as shown in Figure 4.4-1. The user specifies the start date, the time step interval, and the number of time steps. The model will then compute the end date. The time step interval is only of relevance for the output of results, as results cannot be saved at less than the time step interval. For example, if the time step interval is set to 86,400 seconds, i.e. one day, then only daily output can be specified later on the Output tab. For Don Pedro Reservoir the time step is almost always kept at 1 hour. The actual computational time step used by the model is calculated internally and continually varies, usually limited by computational stability considerations.

4.4.4 Module Selection

Reservoir temperatures, the focus of this study, are contained within the Hydrodynamic Module, which is the base module and is by default always included (Section 4.4.5).

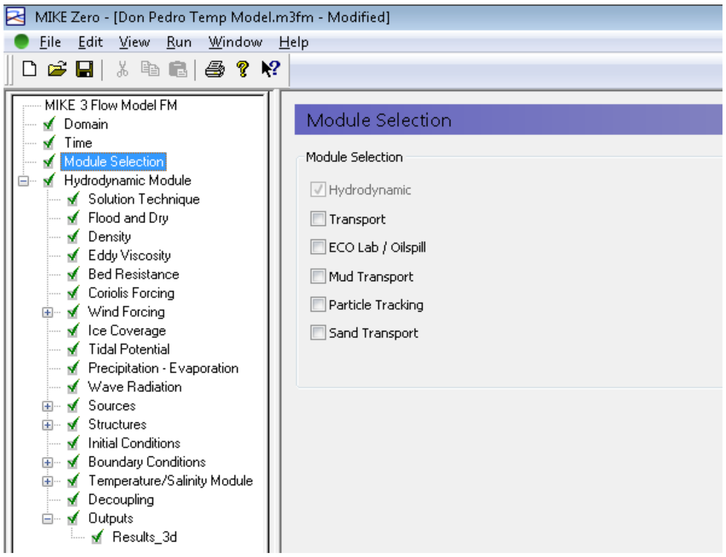


Figure 4.4-7. Module selection

4.4.5 Hydrodynamic Module

The model's hydrodynamic module details are contained in this section. As was mentioned above in Figure 4.4-7, the hydrodynamic module is selected for the Don Pedro Reservoir temperature model. Each of the 18 components of the Hydrodynamic Module is discussed below.

4.4.5.1 Solution technique

The first tab shows the solution technique parameters (Figure 4.5-8 below). In general the default values for these tend to produce good results. Most of the parameters here address the constraints around the internal time step calculation.

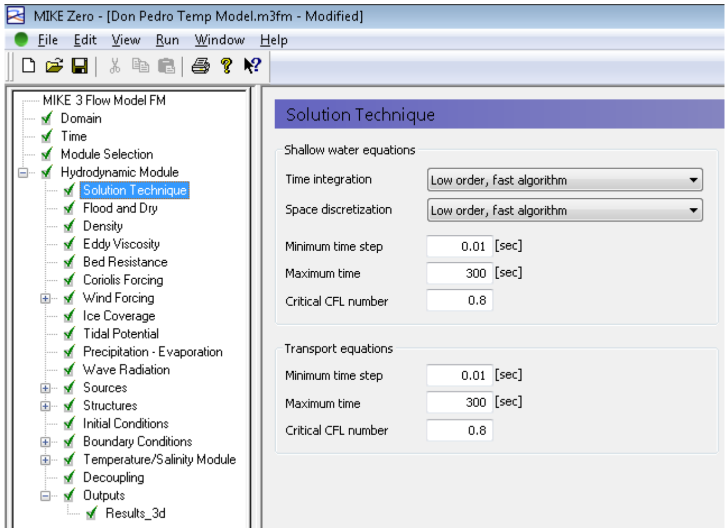


Figure 4.4-8. Solution Technique parameters.

4.4.5.2 "Flood" and "Dry" Cells

The MIKE3 model has the option to allow model cells to go dry if the water level decreases or fill ("flood") if the water level rises. This feature is important for a system like Don Pedro where reservoir level variations are significant. This "flood" and "dry" mechanism allows the same model mesh to be used for all current and future operating scenarios. When the water level decreases the model will stop including dry cells in the hydrodynamic calculation. As shown in Figure 4.4-9, three parameters determine when a model cell is removed from the calculation (i.e. "dry"), when it is re-entered into the calculation ("wet"), or when the hydrodynamic solution is adapted because of a very shallow water depth ("flooding depth").

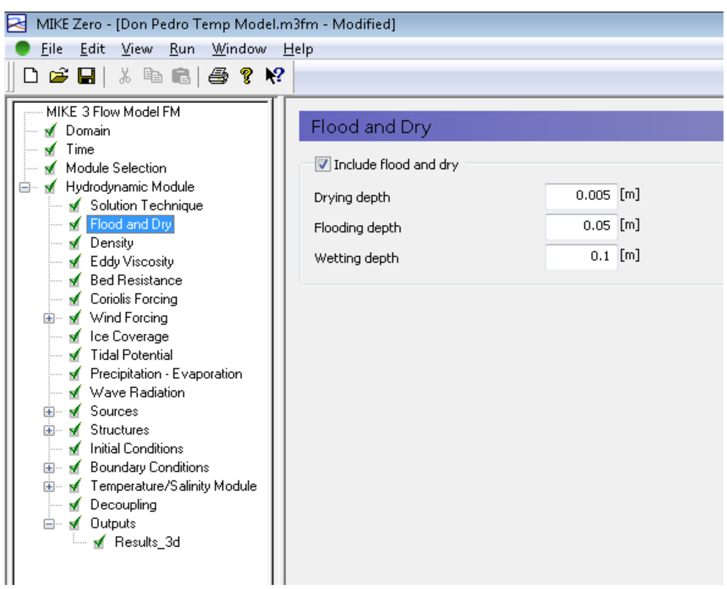


Figure 4.4-9. Flood and dry settings.

4.4.5.3 Density

As shown in Figure 4.4-10, the density of the water at any point is modeled as a function of temperature. Entered into the model in Practical Salinity Units (PSU), salinity is not relevant in this application. Reservoir water is of snow-melt origin and specific conductivity of the reservoir water reportedly ranges between 2 and 100 microSiemans per centimeter (µSiemans/cm) (TID/MID 2011a; TID/MID 2013e). A reference temperature would be used if adjustments to the basic density-temperature relationship are needed. However, they are not used in the Don Pedro Reservoir model.

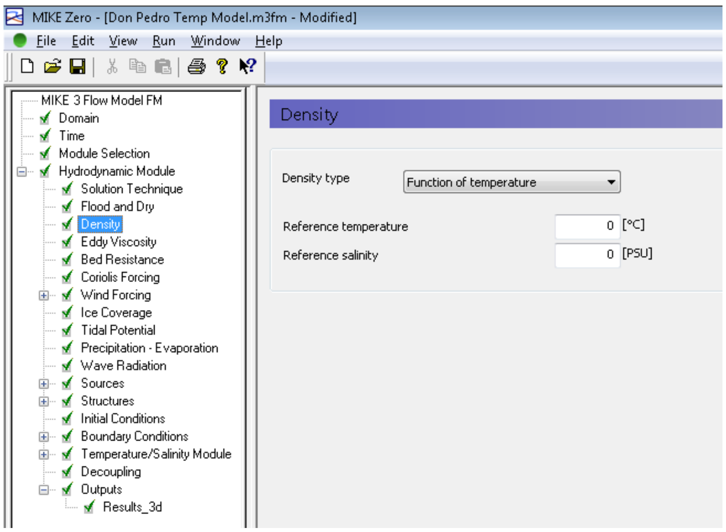


Figure 4.4-10. Density as a function of temperature is selected.

4.4.5.4 Eddy Viscosity

The eddy viscosity panel describes how the model will set the horizontal and vertical dispersion. Figure 4.4-11 shows that the option used for the Don Pedro Reservoir temperature model's horizontal dispersion is the Smagorinksy Formulation (Smagorinky 1963). There are two other options in the horizontal: (a) no dispersion or (b) constant dispersion. It was found that the Smagorinksy Formulation worked well, although the model results for Don Pedro Reservoir were found to be relatively insensitive to horizontal dispersion.

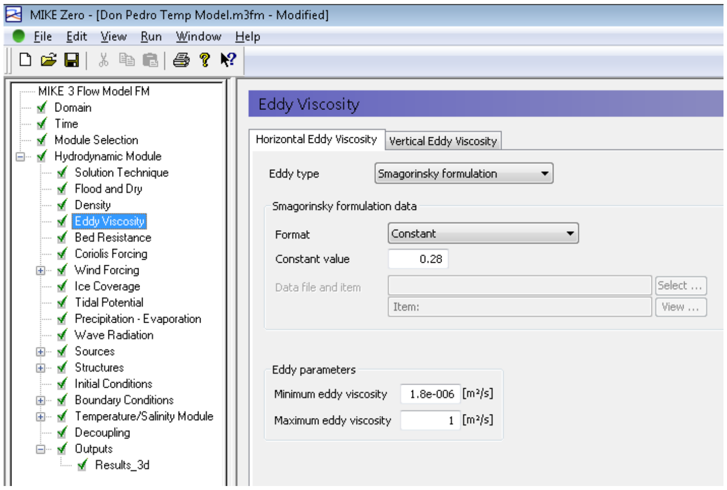


Figure 4.4-11. Horizontal dispersion.

Vertical dispersion is a necessary parameter in stratified systems such as Don Pedro Reservoir. There are four main options available (Rodi 1984):

- no dispersion;
- constant dispersion;
- log law; or
- k – epsilon.

Figure 4.4-12 shows that the option used for the Don Pedro Reservoir temperature model's vertical dispersion is the log law. Using both log law and k-epsilon resulted in the modeled temperatures matching favorably with the calibration and verification year measurements. However, the log law parameter was preferred as the run times are shorter. There is a further option to include damping terms but this did not improve the results and increased run times, so it was not incorporated into the model.

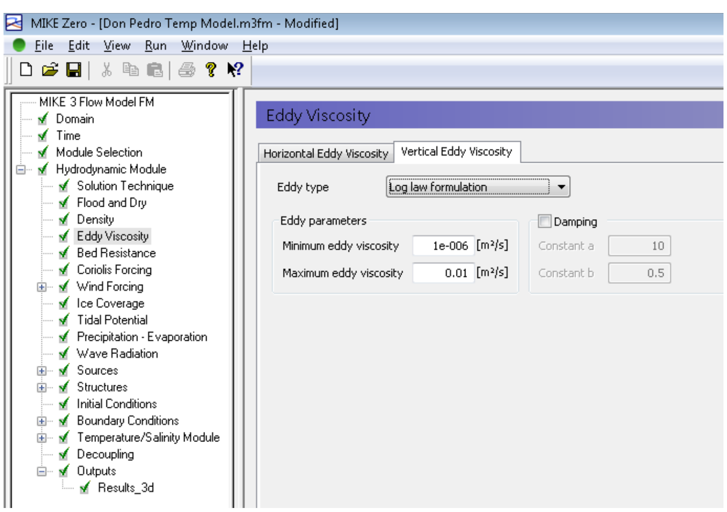


Figure 4.4-12. Vertical dispersion.

4.4.5.5 Bed Resistance

As water flows over a solid surface, like the bed of the reservoir or river, there are friction losses that occur. The rougher the surface, the greater the losses. In the bed resistance tab the height of the surface indentations is specified (Figure 4.4-13). In a slow moving system like a reservoir, the calculation is very insensitive to this parameter. A value of 5 cm (0.05m) was used.

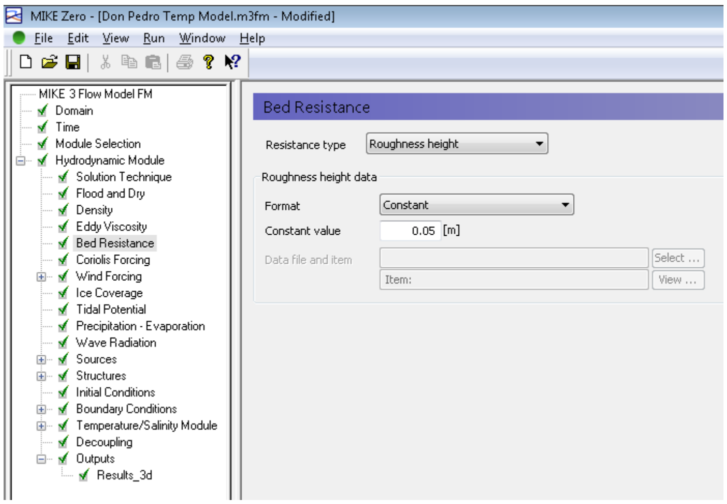


Figure 4.4-13. Bed resistance.

4.4.5.6 Coriolis Force

In large water masses the rotation of the earth can affect the circulation pattern and the MIKE3 model accounts for this (Figure 4.4-14). For the Don Pedro Reservoir temperature model, no noticeable change in calibration or verification results occurred when the model was tested for sensitivity to this parameter. Hence, because model computation time could be decreased without it, the Don Pedro Reservoir model does not include Coriolis force.

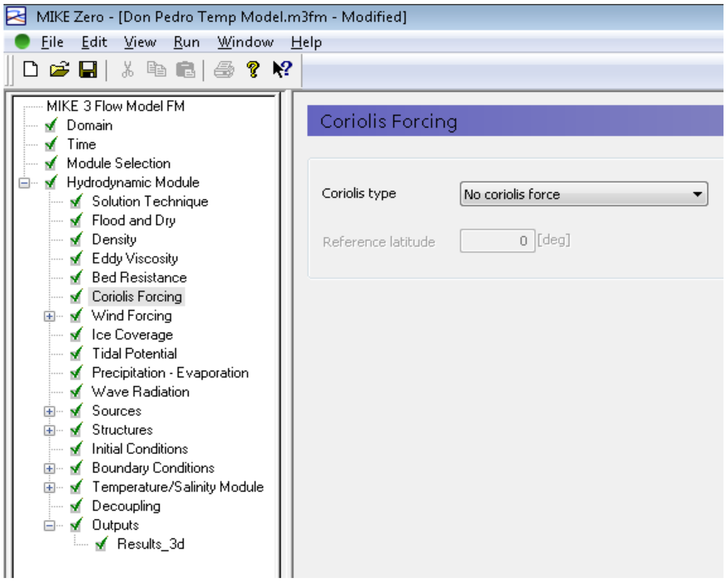


Figure 4.4-14. Coriolis force.

4.4.5.7 Wind Forcing

In lakes and reservoirs the circulation can be effected by wind (Figure 4.4-15) and this effect was included in the Don Pedro Reservoir model. The wind data reside in a data file that is called by the "m3fm" file. The wind speed and direction data was collected by the Districts' meteorological station located at Don Pedro Reservoir (See Section 4.3.3).

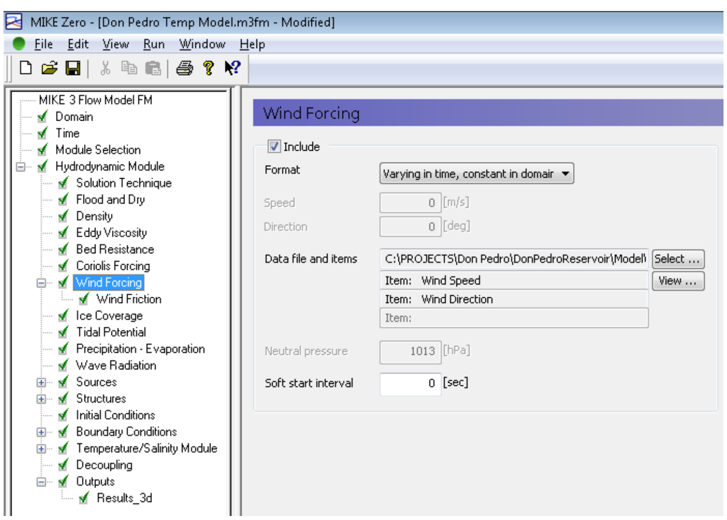


Figure 4.4-15. Wind forcing.

By selecting the "View" button on the tab the wind speed and direction can be viewed. Figure 4.4-16 shows the data for 2011, where wind speed is provided in meters per second (m/s) and direction is provided in degrees (deg). Also specified in the wind forcing folder is the wind friction constant. This is the conversion factor that relates the wind speed to the force that will drag on the water surface. For Don Pedro Reservoir the default value was used (Figure 4.4-17) (DHI 2011).

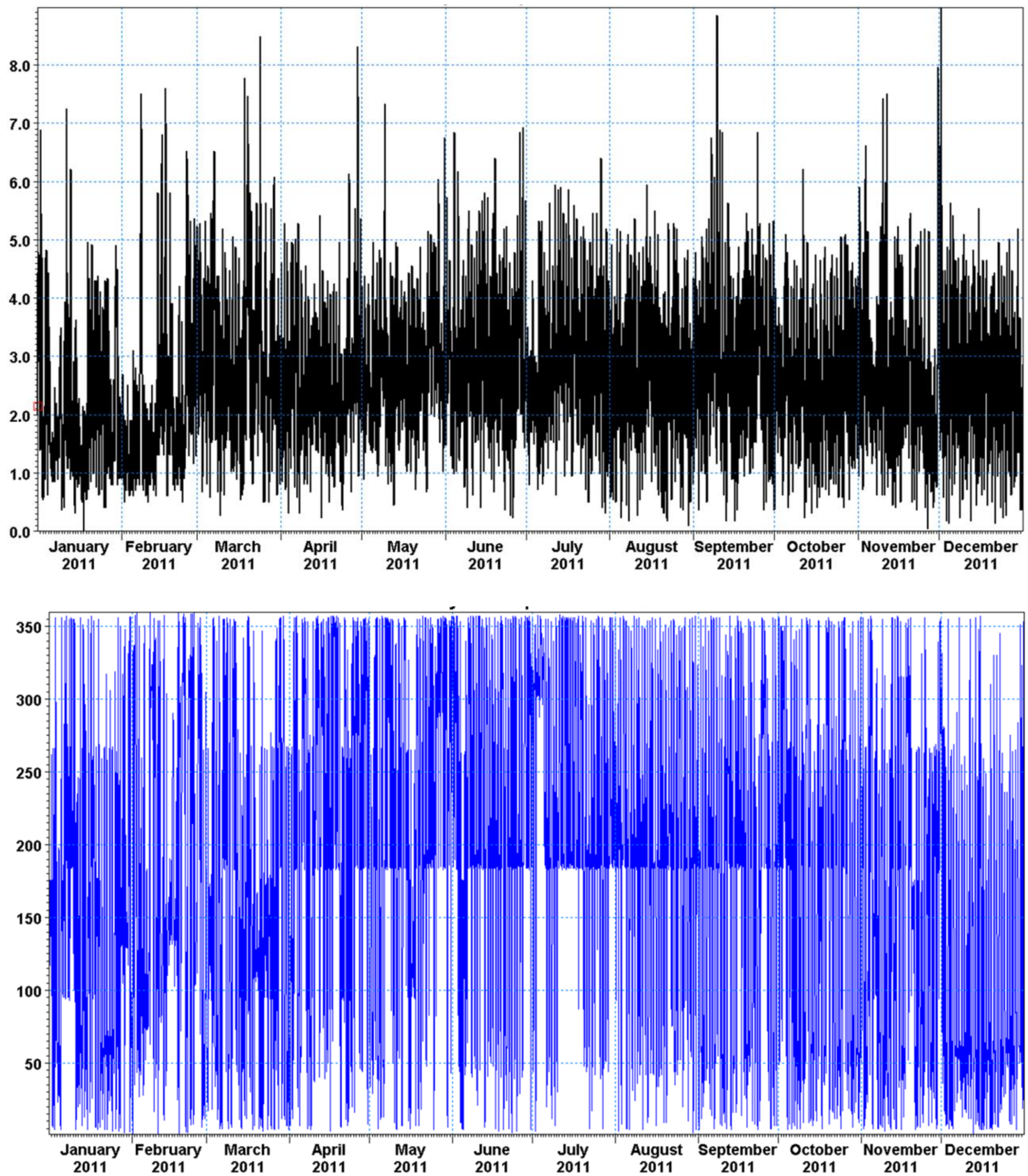


Figure 4.4-16. Wind data collected at Don Pedro Met Station 2011. Top plot is wind speed (m/s); bottom plot is wind direction (deg).

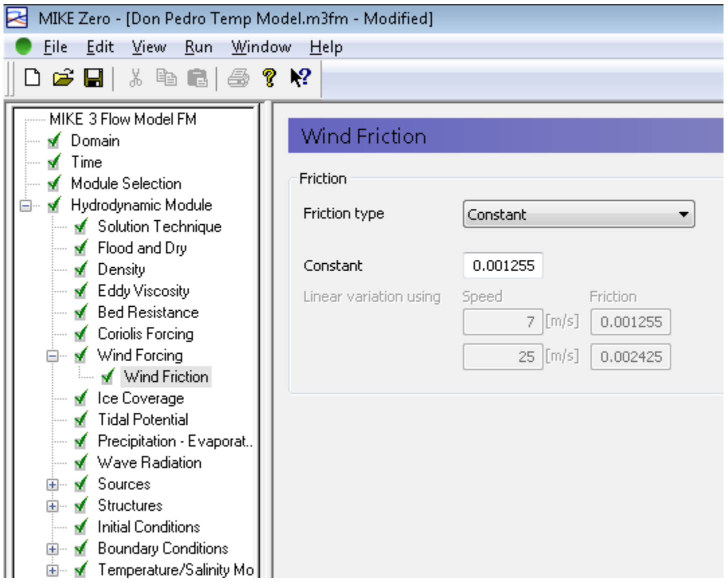


Figure 4.4-17. Wind friction factor.

4.4.5.8 Ice Coverage

Located in a Mediterranean climate, ice coverage is not applicable to the Don Pedro Reservoir and was not included (Figure 4.4-18).

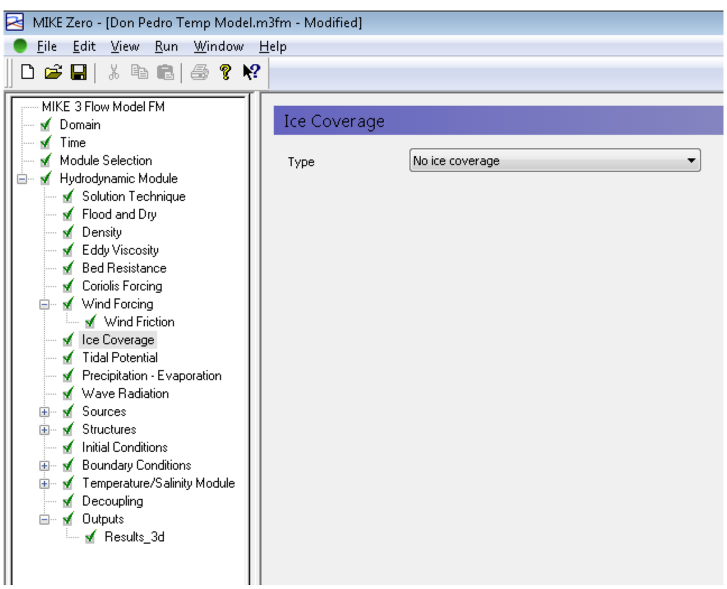


Figure 4.4-18. Ice coverage.

4.4.5.9 Tidal Potential

Located in California's Central Valley, upstream of the Sacramento-San Joaquin Delta, tidal influence is not applicable to the Don Pedro Reservoir and was not included (Figure 4.4-19).

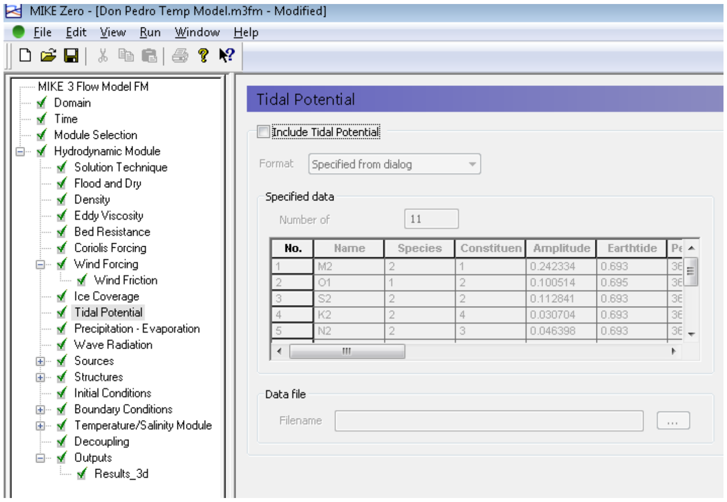


Figure 4.4-19. Tidal potential.

4.4.5.10 Precipitation and Evaporation

The MIKE3 model will allow measured precipitation and evaporation to be input, if not accounted for elsewhere (Section 4.4.2). For Don Pedro Reservoir the model inflow and outflows were excerpted from the hydrology appendix of Tuolumne River Operations Model (W&AR-02), which accounted for precipitation directly on the reservoir surface and evaporation (TID/MID 2013a). Because precipitation and evaporation are accounted for in the hydrology data set, it is not duplicated in the hydrodynamic module (Figure 4.4-20).

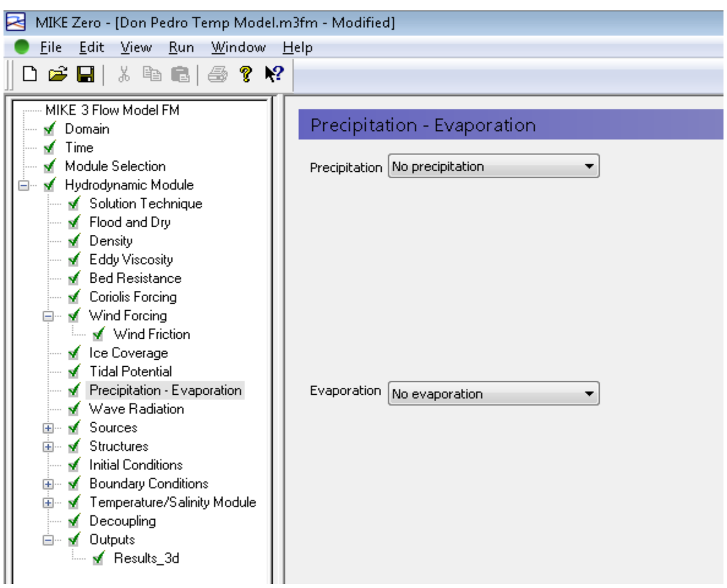


Figure 4.4-20. Precipitation and evaporation.

4.4.5.11 Wave Radiation

The effect of breaking shoreline waves is not an issue in Don Pedro Reservoir and is not included (Figure 4.4-21).

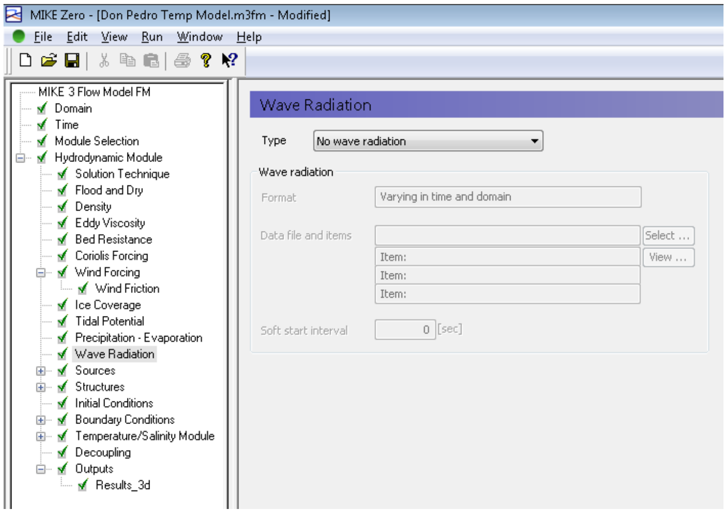


Figure 4.4-21. Wave Radiation.

4.4.5.12 Sources

Reservoir model inflows and outflows are specified by placing “sources” in the model through the hydrodynamic module. For the purpose of modeling, outflows are specified as a source with negative flow values.

The main inflow into the model is the flow in the Tuolumne River and the outflow is the release at Don Pedro Dam either through the powerhouse units 1 through 4, the powerhouse hollow jet valve, the outlet works, or the spillway. To ensure consistency between study findings, inflows to and outflows from the Don Pedro Reservoir were taken from the hydrology data set provided in the Tuolumne River Daily Operations Model (W&AR-02) (TID/MID 2013a). Inflows and outflows are provided as average daily flows.

To better reflect physical conditions, it is desirable to spread the total reservoir inflow over more than one source point. This prevents placing all the flow into one model cell which may cause stability problems in the model. Additionally there are a number of smaller tributaries that contribute flow to the reservoir, and although their flows are not directly measured, they are accounted for in the hydrology data set. Hence, the total inflow from the Water Operations Model was split into 10 source points, each contributing 10 percent of the total inflow. The locations of these inflow points, and the single outflow point at Don Pedro Dam, are shown in Figure 4.4-22, which shows the “geographic view” tab under “sources,” while the list of source points is shown in Figure 4.4-23. The names of the various sources are listed by selecting the “list view” tab, as shown in Figure 4.4-23. The sources considered are:

(a) Tuolumne River

(b) Woods Creek

(c) Hatch Creek

(d) North Bay

(e) Rogers Creek

(f) Moccasin Creek

(g) Unknown creek at Six-bit and Poor Mans Gulch

Note that the two larger tributaries, the Tuolumne River and Woods Creek have multiple source points, with the overwhelming majority of the inflow coming from the main stem Tuolumne River.

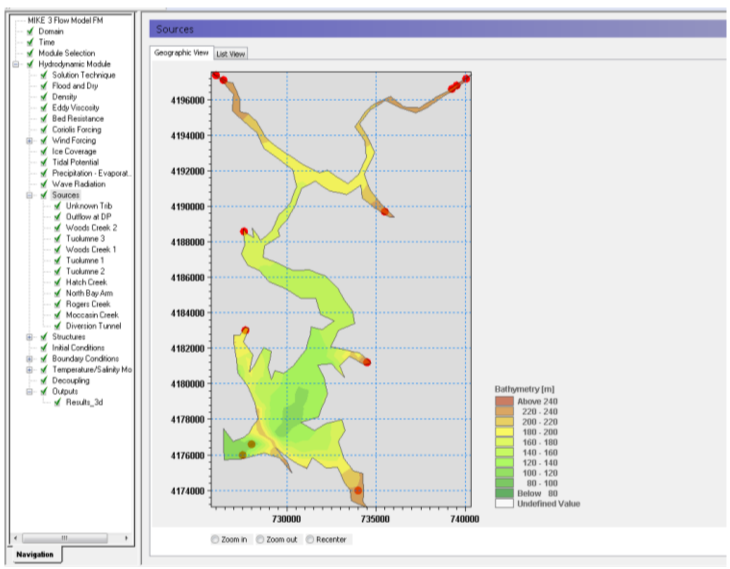


Figure 4.4-22. Location of model inflow and outflow sources.

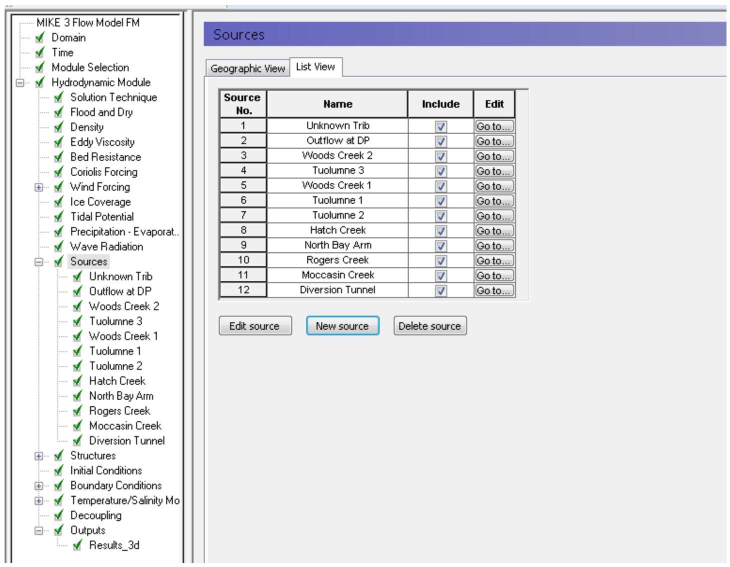


Figure 4.4-23. Listing of inflow and outflow sources.

When in the list view, the details of an individual source can be shown by using the "go to" button. The details for the source "Tuolumne 3", one of three sources located near the head of the Tuolumne River inlet to the reservoir, are shown in Figure 4.4-24. This includes the Easting and Northing in Universal Transverse Mercator (UTM) coordinates and the model layer where the flow, provided as cubic meters per second (m^3/s) is input. The data file that contains the time-variable flows is also specified; by selecting the "view" button this data can be displayed, as shown in Figure 4.4-25.

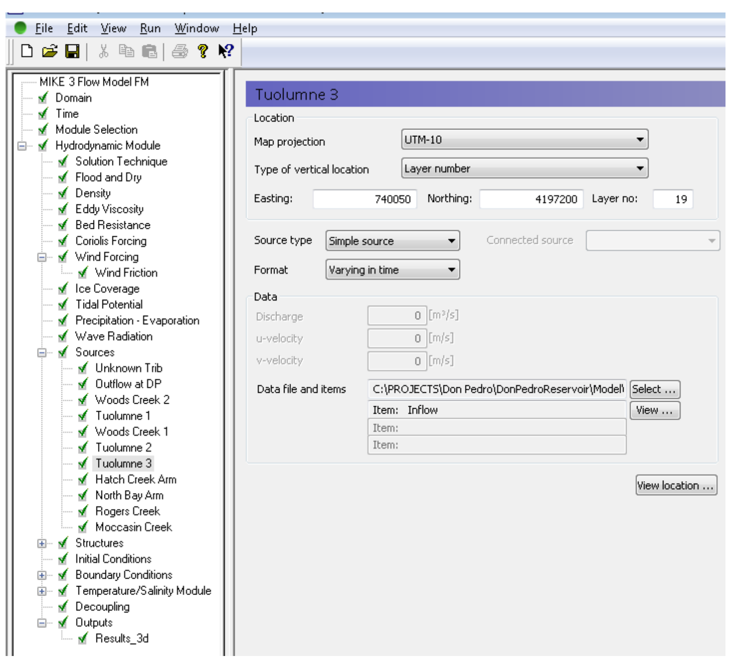


Figure 4.4-24. "Tuolumne 3" source details.

Figure 4.4-25. "Tuolumne 3" inflow for 2011 in cubic-meters per second (m^3/s).

Likewise, the details of the outflow at the Don Pedro powerhouse are shown in Figure 4.4-26. In this case, the source point's specific elevation of 535 ft or 163 m is specified in Figure 4.4-26, while the outflow data for 2011 is shown in Figure 4.4-27. When outflow exceeds the hydraulic capacity of the powerhouse tunnel of 6300 cfs (178.4 m^3/s), the excess flow exits via the diversion tunnel at elevation 345 ft (105.2 m). In 2011 the flow did exceed 6300 cfs, as shown by the flat portions of Figure 4.4-27. The flow never exceeded the hydraulic capacity of the combined powerhouse and diversion tunnels and the reservoir did not spill in 2011. In 2012 the flow never exceeded 6300 cfs and so all flow passed through the powerhouse tunnel.

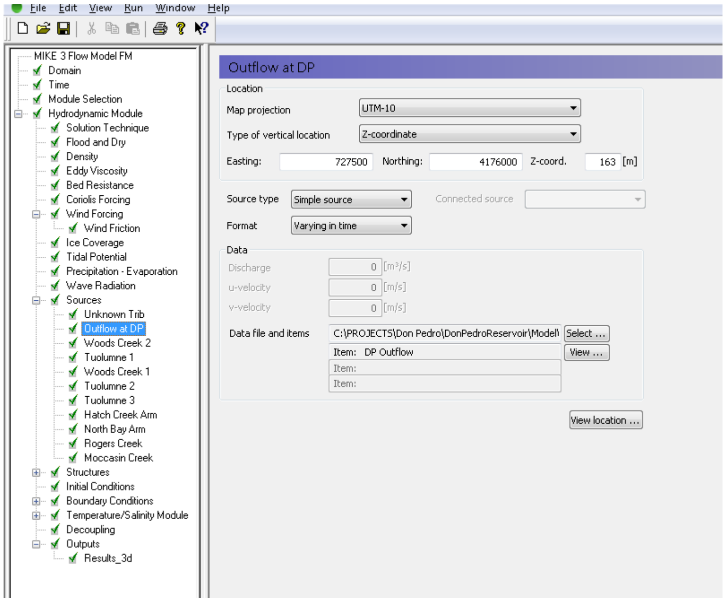


Figure 4.4-26. "Outflow at Don Pedro powerhouse" source details.

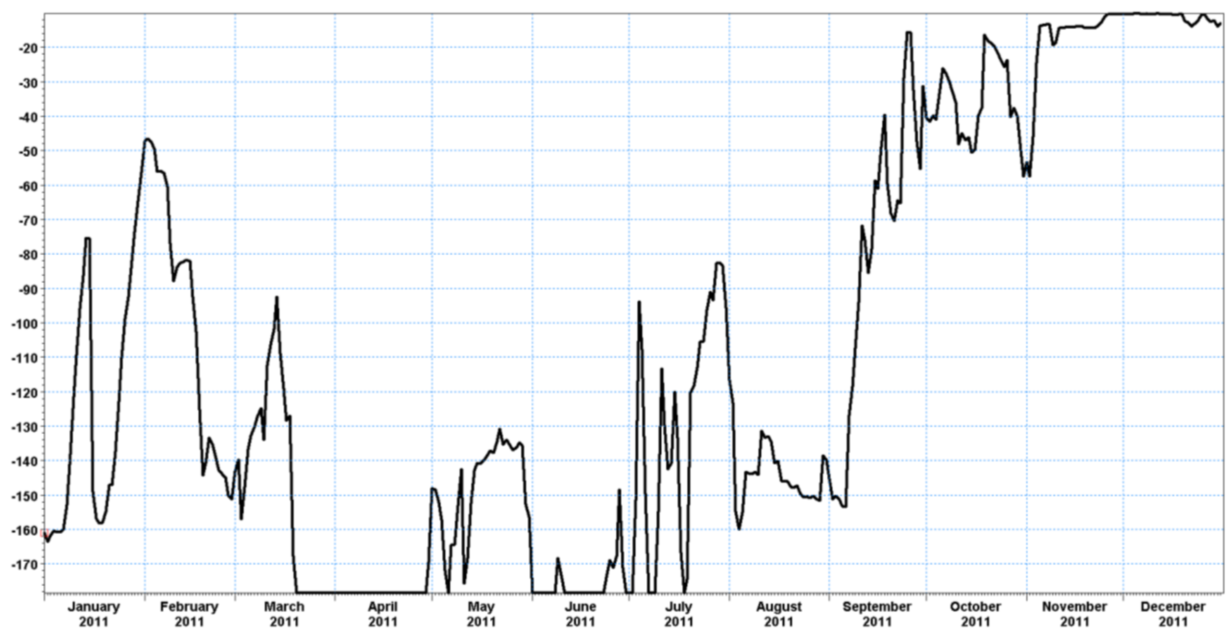


Figure 4.4-27. "Outflow at Don Pedro powerhouse" outflow for 2011 in cubic-meters per second (m^3/s). Note outflows are assigned a negative value.

4.4.5.13 Structures

The model allows certain structures to be defined, as listed in Figure 4.4-28. Within the Don Pedro Reservoir, the only internal structure is Old Don Pedro Dam. During calibration and validation, the water depth above the Old Don Pedro Dam was so large that it does not act as a weir, rather just a deep bathymetric feature. However, it is anticipated that under certain extended drought conditions or under different future operating scenarios, Old Don Pedro Dam will act as a weir, and if water levels drop lower than the crest of Old Don Pedro, the open outlets will act as submerged orifices.

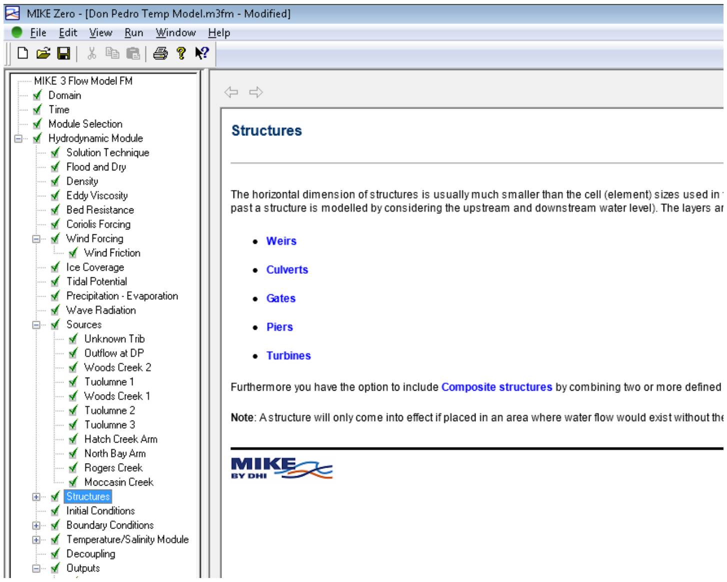


Figure 4.4-28. Structure options.

4.4.5.14 Hydrodynamic Initial Conditions

The initial condition option used in the Don Pedro Reservoir model is to specify the observed water surface elevation on the start date of the model run, in this case January 10, 2011. This is shown in Figure 4.4-29. Other options include specifying initial velocities and varying surface elevations, where these are usually generated from previous model runs. The initial conditions referred to here do not include the initial temperatures, which are listed below in Section 4.4.6.

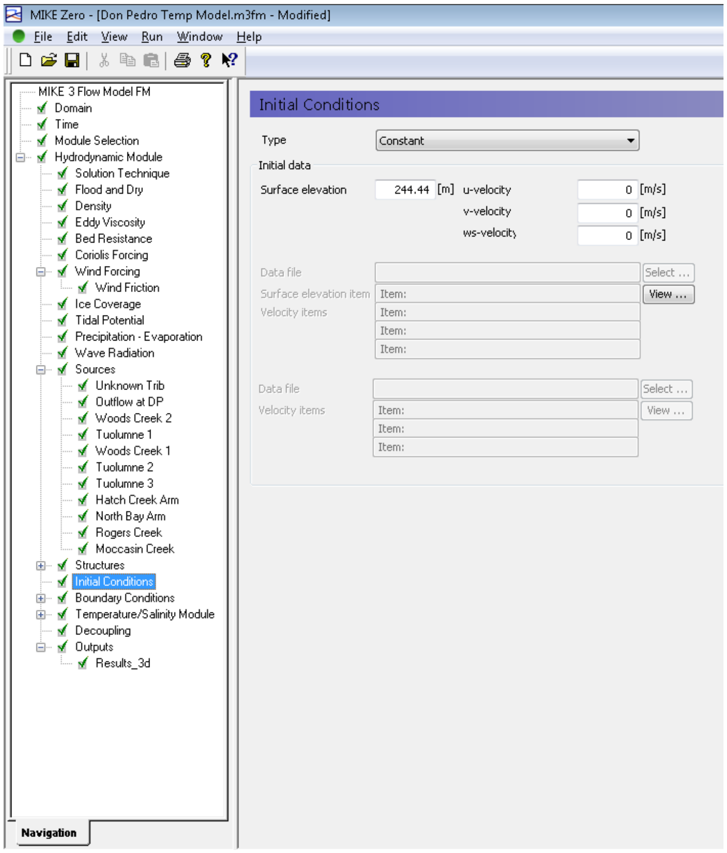


Figure 4.4-29. Hydrodynamic initial conditions.

4.4.5.15 Model Boundary Conditions

In the Don Pedro Reservoir model the inflow and outflow are specified using sources. There are no open water boundaries, so the model domain looks like a closed system with land boundaries on all sides (Figure 4.4-30). There are no additional boundary conditions to be set.

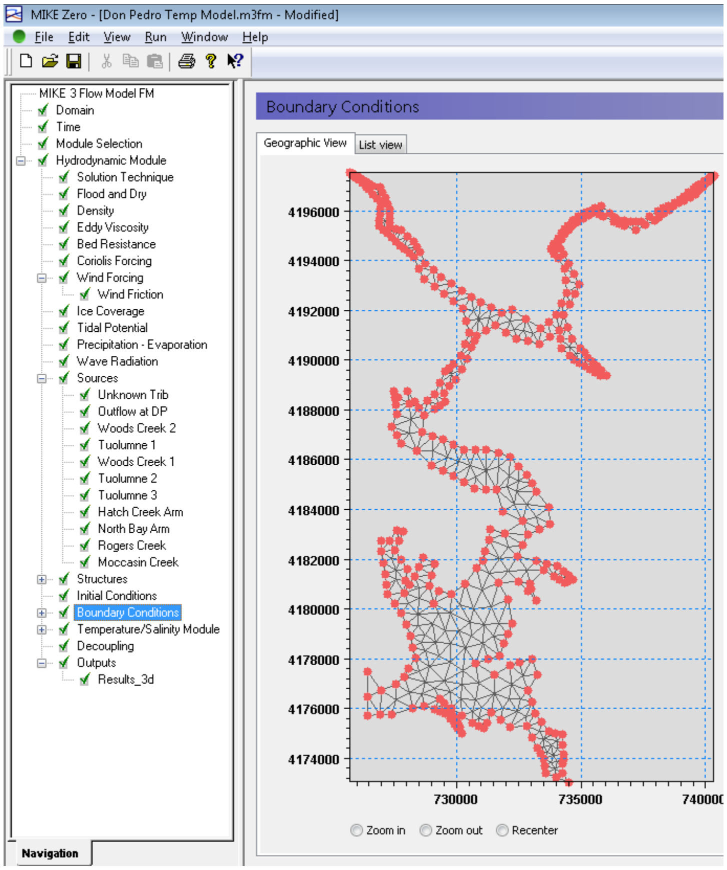


Figure 4.4-30. Boundary conditions: model domain showing all land boundaries.

4.4.6 Temperature Module

When density is set as a function of temperature in the density tab, as is the case for the Don Pedro Reservoir model (Section 4.4.5.3), then the temperature module is available. Figure 4.4-31 shows the temperature module's main tab. It is possible to require the model to operate within a specified temperature range. Any temperatures above or below the limits set by the user will be automatically capped at these values. As this was not a desired feature for the Don Pedro Reservoir model the limits were set beyond the range of any expected temperatures, i.e. -5^{o} C minimum and 40^{o} C maximum, as shown in Figure 4.4-32.

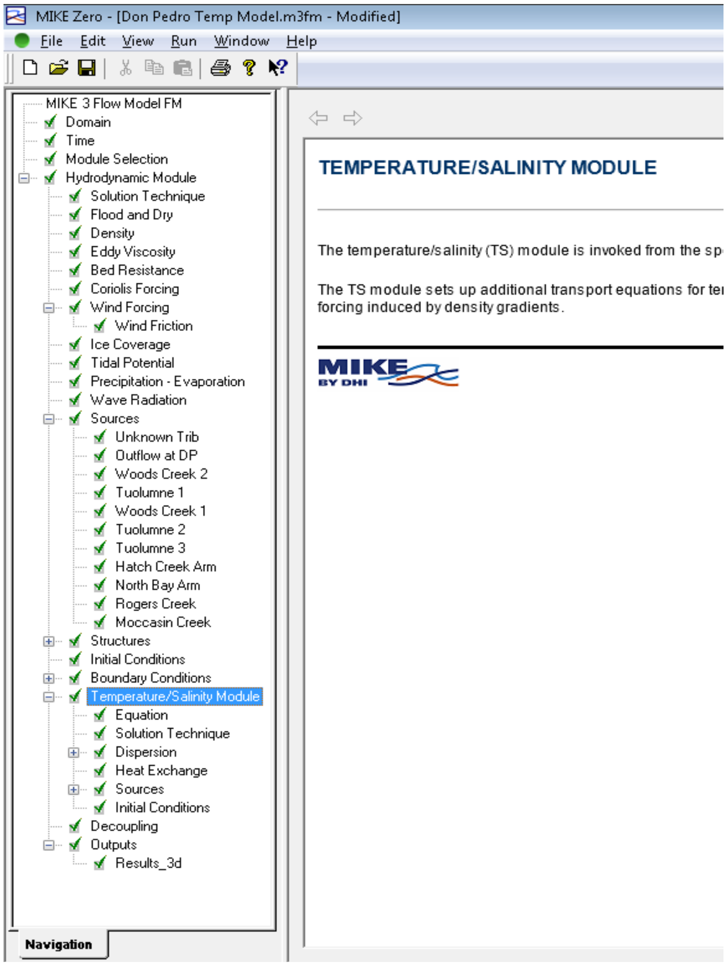


Figure 4.4-31. Temperature module.

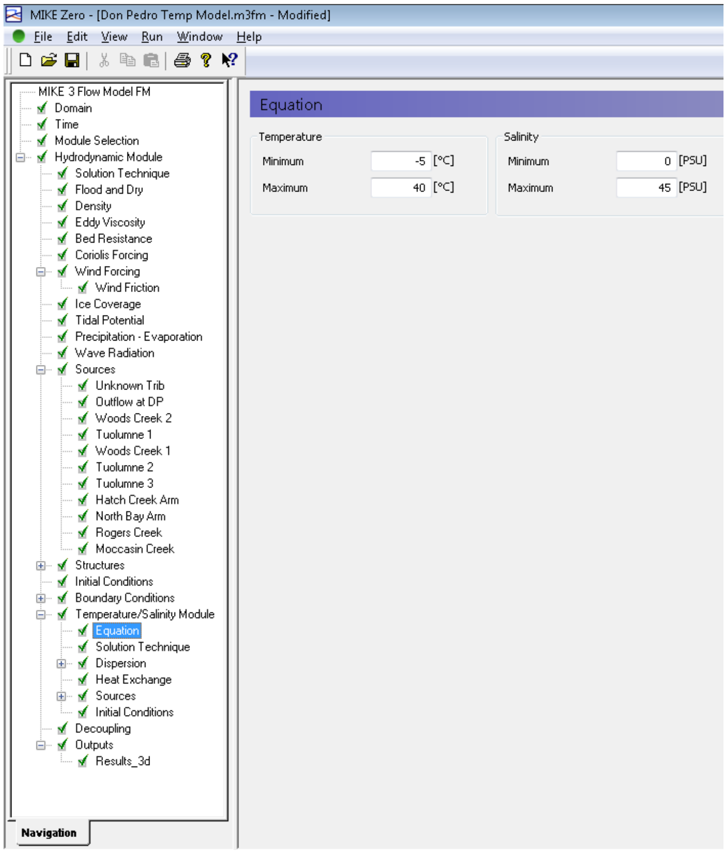


Figure 4.4-32. Temperature limits.

Internal control on the solution for the temperature equations can be set as well for the practical purpose of using model run times effective and efficiently (Figure 4.4-33). Generally unless there is a run time issue, such as a model blowup, the default low order solutions are used, as higher order solutions take significantly longer to run.

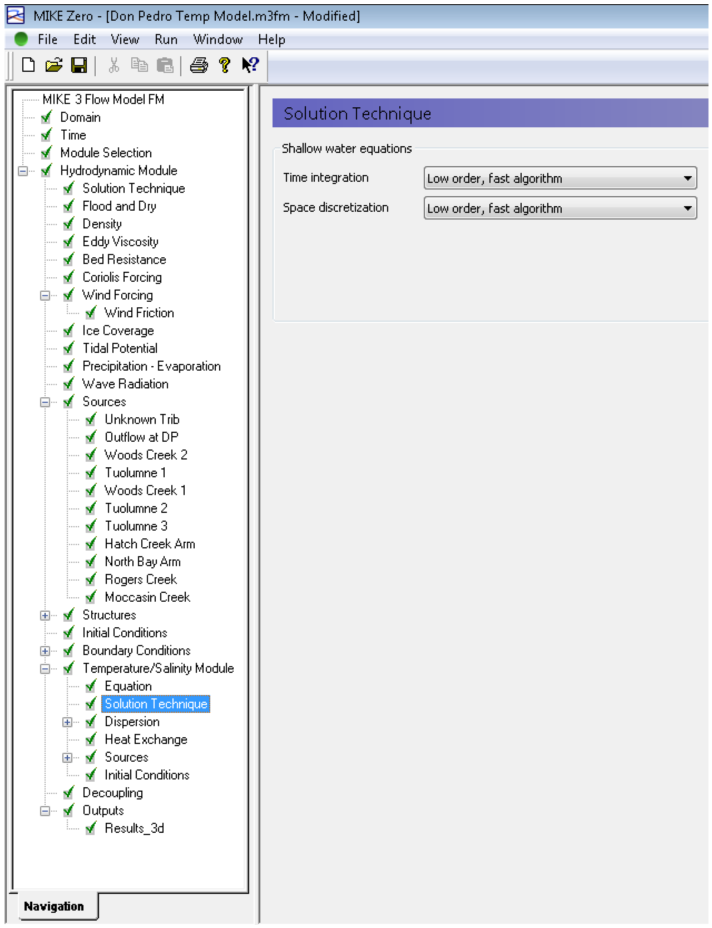


Figure 4.4-33. Solution settings.

As with the other components of the hydrodynamic module, the user can specify the horizontal and vertical temperature dispersion through the dispersion tab, as shown in Figure 4.4-34.

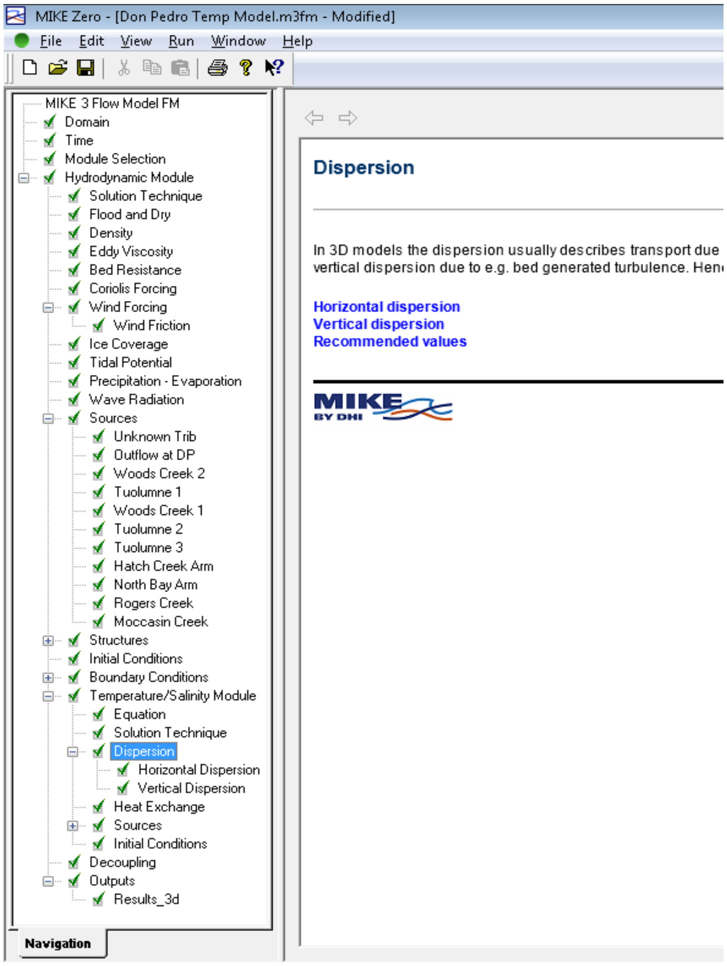


Figure 4.4-34. Temperature dispersion main tab.

4.4.6.1 Horizontal Dispersion

There are three options available for the horizontal temperature dispersion: (1) no dispersion; (2) scaled eddy viscosity and (3) a constant dispersion. For the Don Pedro Reservoir temperature model, a constant dispersion of 1 m^2/s was used (Figure 4.4-35). This is a typical value used for reservoirs e.g. Maiss et al (1994).

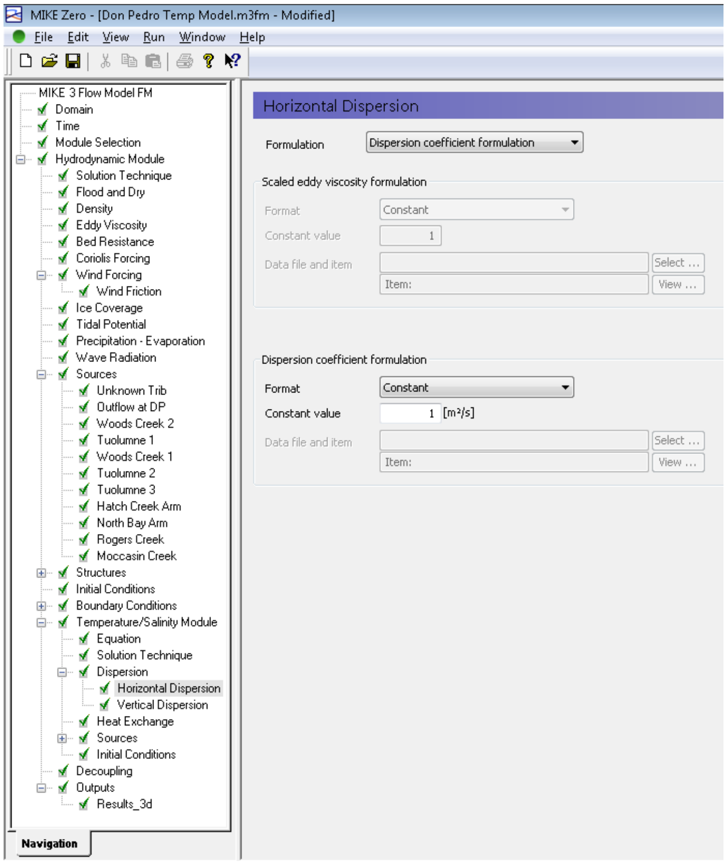


Figure 4.4-35. Temperature horizontal dispersion.

4.4.6.2 Vertical Dispersion

The same three vertical temperature dispersion options are available as for the horizontal dispersion discussed above. Again constant dispersion was used, with a value of 1 x 10^{-6} m^2/s (Figure 4.4-36). This value is typical of those used in deep, stratified systems (e.g. Fischer, 1979; Bonnet et al. 2000).

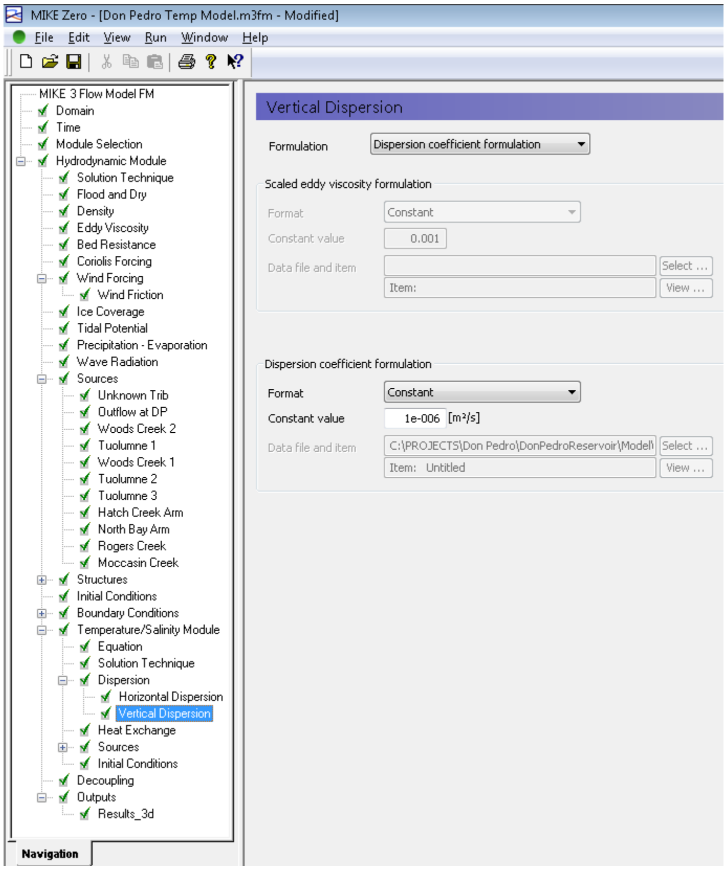


Figure 4.4-36. Temperature vertical dispersion.

4.4.6.3 Heat Exchange

The model computes a heat balance in the water based on the four physical controlling processes:

- heat loss due to vaporization (also called latent heat flux);
- heat transfer between the air and water due to temperature differences (also called sensible heat exchange);
- short wave radiation; and
- long wave radiation.

These processes and how they are formulated in the MIKE model are described in detail in the "MIKE 21 and MIKE 3, FLOW MODULE FM, Hydrodynamic and Transport Module, Scientific Documentation" (DHI 2009a). The discussion is condensed here to the final equations and how they relate to the parameters shown in the main heat exchange tab, as shown in Figure 4.4-37.

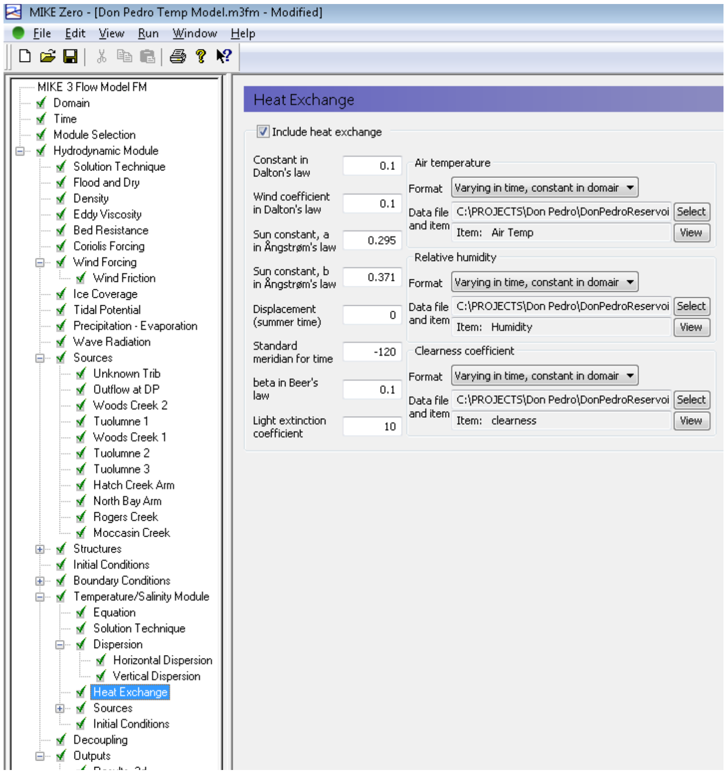


Figure 4.4-37. Heat exchange parameters.

4.4.6.4 Vaporization

The heat loss due to vaporization (evaporation) is computed in the model using Dalton's Law:

$$q_v = LC_e(a_1 + b_1W_{2m})(Q_{water} - Q_{air})$$

where:

q_v	heat loss	(W/m^2)
L	latent heat constant	(J/kg)
C_e	moisture transfer coefficient	(unitless)
W_{2m}	wind speed 2 meters above the water surface	(m/s)
Q_{water}	vapor pressure of water	(Pa)
Q_{air}	vapor pressure in atmosphere	(Pa)

a_1 and b_1 are user specified constants and show up as the first two constants highlighted in Figure 4.4-38, below.

The value used for a_1 and b_1 was 0.1 for both. These were adjusted during the 2011 calibration.

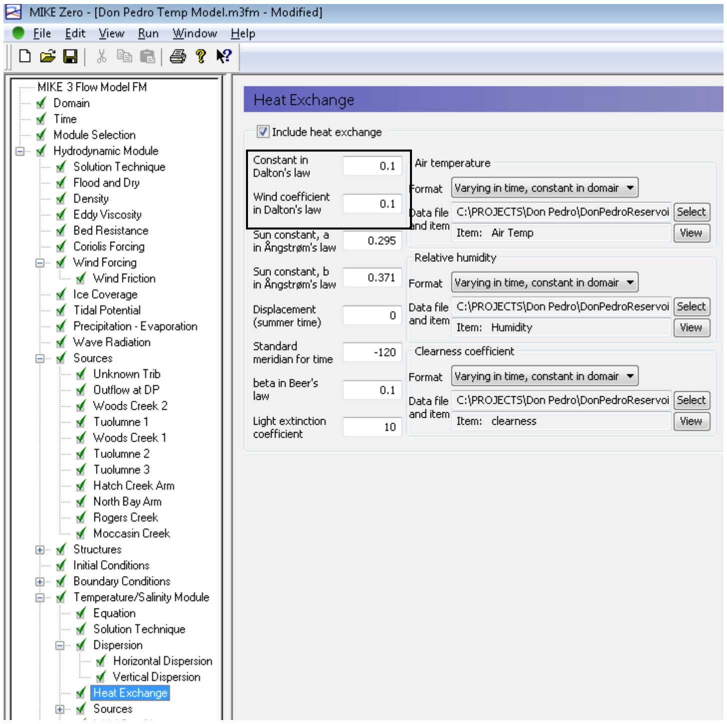


Figure 4.4-38. Daltons law constants.

The vapor pressure in the atmosphere is a function of the humidity. Humidity data were collected by the Districts' station at Don Pedro Dam (Figure 3.0-1; Section 4.3.4). The data file can be viewed by selecting the "view" button of the heat exchange panel. The humidity for 2011 is shown in Figure 4.4-39.

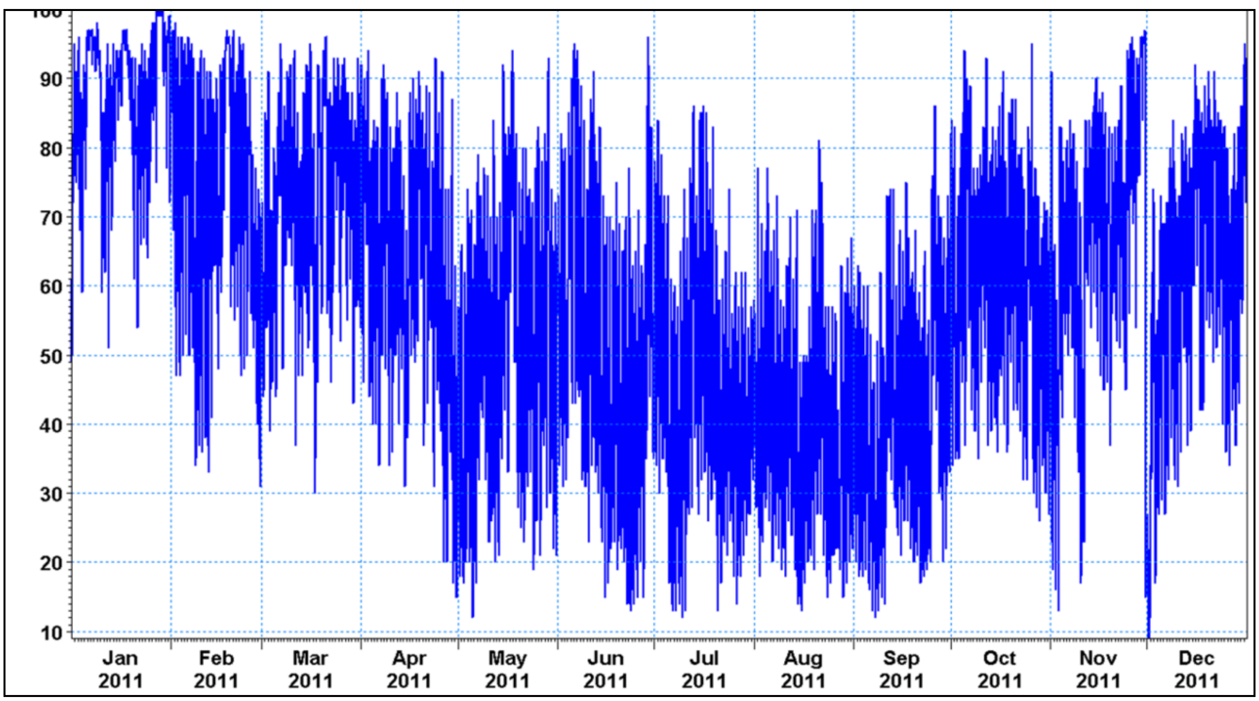


Figure 4.4-39. Relative humidity (%) for 2011.

4.4.6.5 Sensible Heat Exchange

Heat exchange due to temperature differences between the air and water surface are called sensible heat exchange. These can result in either a heat gain or loss to the water. They are described as:

$$q_c = \begin{cases} \rho_{air} c_{air} c_{heating} W_{10} (T_{air} - T_{water}) & T_{air} \geq T \\ \rho_{air} c_{air} c_{cooling} W_{10} (T_{air} - T_{water}) & T_{air} < T \end{cases}$$

where:

q_v	heat loss or gain	(W/m^2)
ρ_{air}	air density	(kg/m^3)
c_{air}	specific heat of air	($J/kg/^oC$)
$c_{heating}$	heat transfer constant	(unitless)
$c_{cooling}$	heat transfer constant	(unitless)
q_c	heat loss or gain	(W/m^2)
ρ_{air}	air density	(kg/m^3)
W_{10}	wind speed 10 meters above the water surface	(m/s)
T_{air}	air temperature	(^oC)
T_{water}	water temperature	(^oC)

All of the above constants are known and so do not appear in the heat exchange panel. The air temperatures are based on data collected at the Districts' station at Don Pedro Dam. By selecting the "view" button on the heat exchange panel the data file can be accessed. The air temperature for 2011 is shown in Figure 4.4-40.

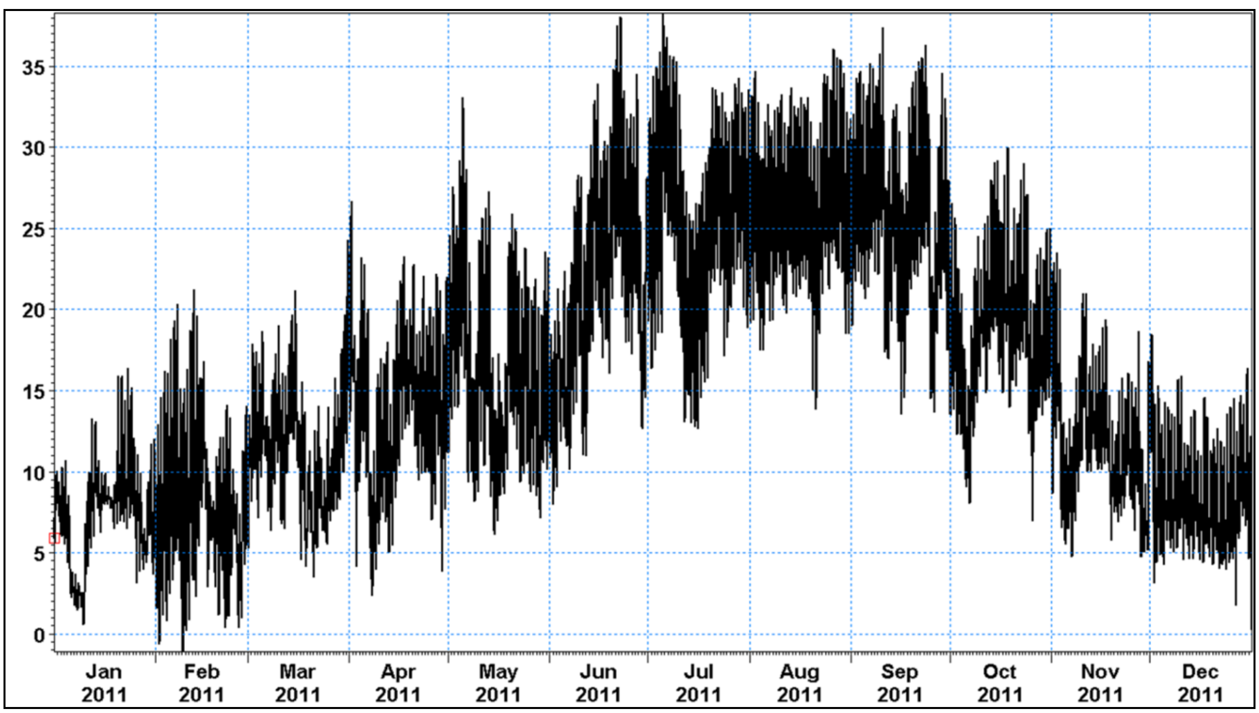


Figure 4.4-40. Air temperature in degree Celsius (^oC) for 2011.

4.4.6.6 Short Wave Radiation

Short wave radiation reaching the surface of the water is a complicated series of calculations based on many functions. In the model the final computation is expressed as:

$$H = (a + bX) H_0$$

where:

H	Heat gain; short wave radiation reaching the water surface	(W/m^2)
X	clearness of the sky	(%)
H_0	incoming solar radiation	(W/m^2)

and a and b are user defined constants and show up in the heat exchange panel as highlighted in Figure 4.4-41.

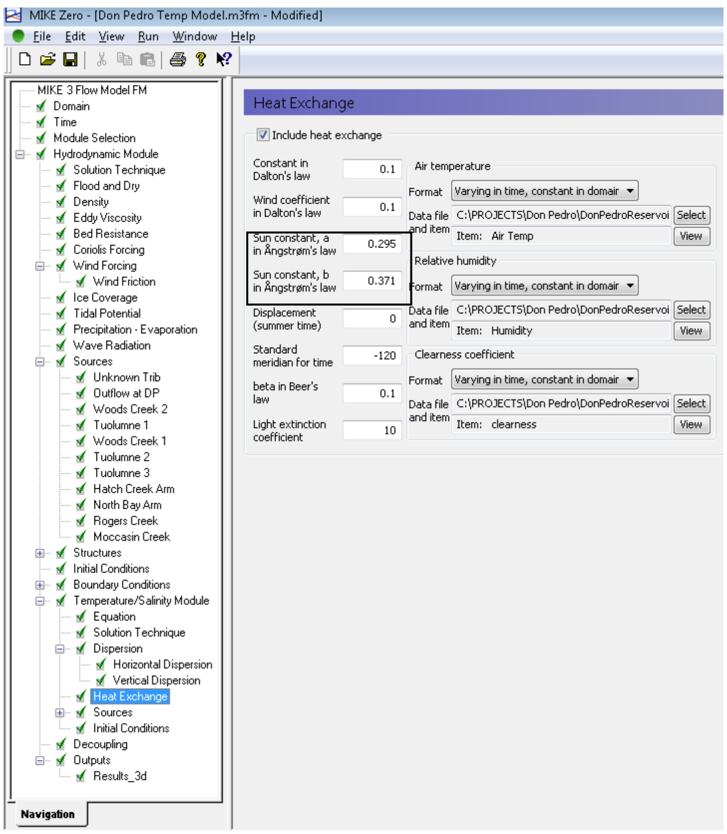


Figure 4.4-41. Short wave radiation parameters.

The clearness of the sky is related to the cloud cover. Daily cloud cover data for either Don Pedro Reservoir or Modesto is not available; however, monthly data are. Monthly average clearness was obtained from weatherspark.com which compiles data from NOAA's National Weather Service - Aviation Weather Center, which includes Modesto Airport. This is shown in Figure 4.4-42.

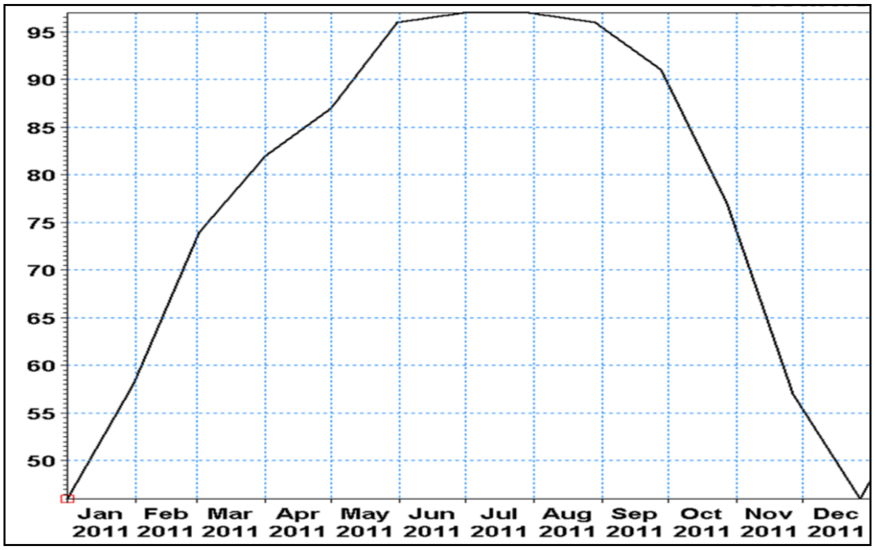


Figure 4.4-42. Modesto clearness (%).

The model-computed incoming solar radiation, H_0, is a function of latitude and longitude. It is not a routinely available input variable. However by custom coding some print flags in the text version of the "m3fm" file it was saved as output. A comparison of the model-computed radiation for 2011-12 and the data collected at the Don Pedro Dam meteorological station is shown in Figure 4.4-43. It became apparent that there were anomalies in the measured data, as observed by decreases in solar radiation during the summer. Recently the station was taken offline to service the solar detector. As a further comparison the model is compared to two long term meteorological stations, Denair I and Denair II, both located in Turlock. These results, as seen in Figure 4.4-44, show that the model compares well to the observed data.

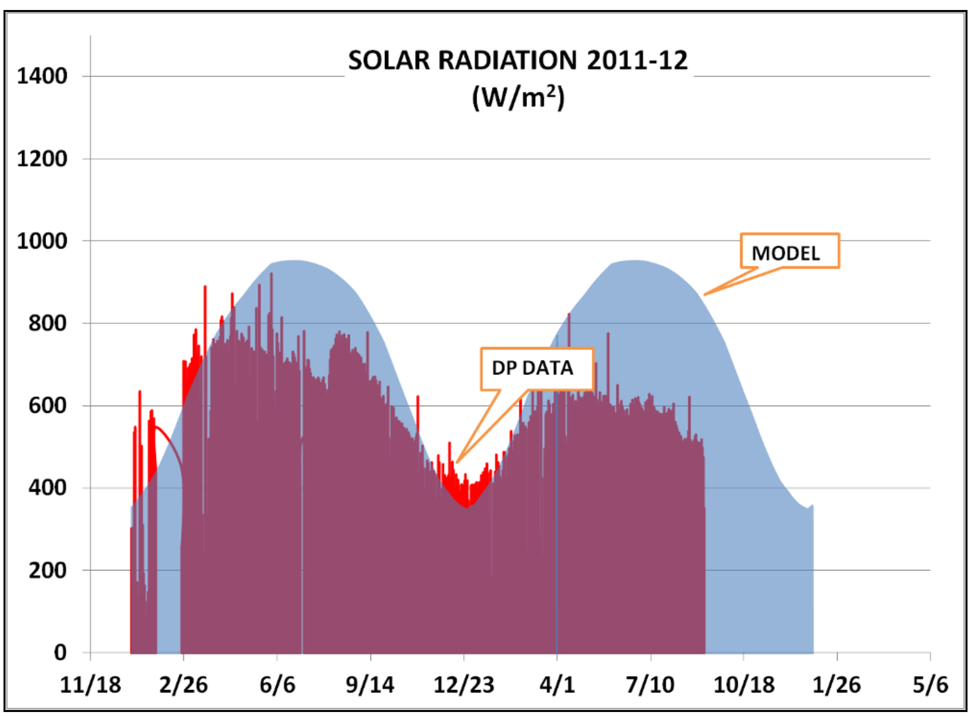


Figure 4.4-43. Computed and observed solar radiation at Don Pedro 2011-12.

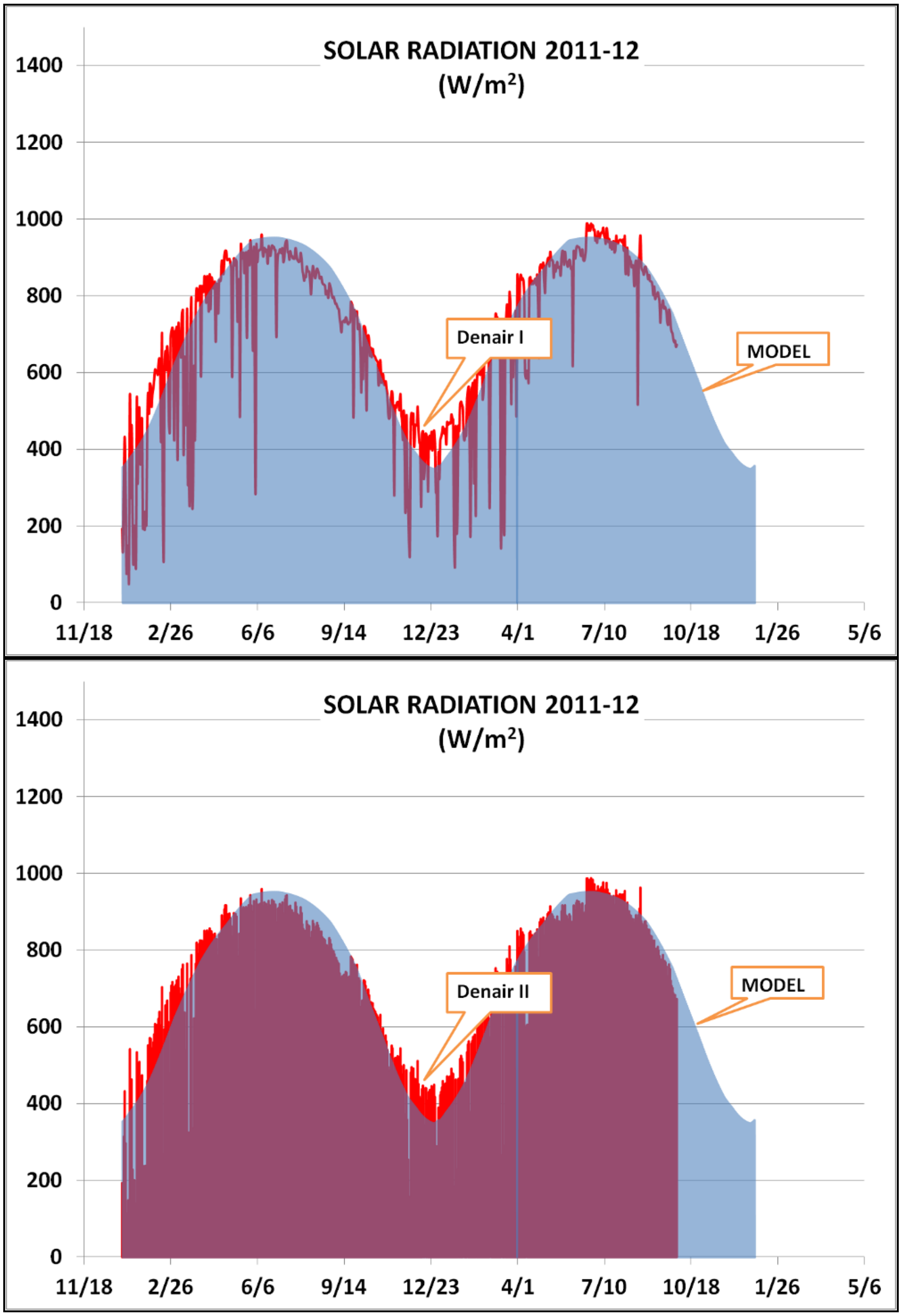


Figure 4.4-44. Computed and observed solar radiation at Denair 1 (top) and II (bottom), 2011-12.

4.4.6.7 Long Wave Radiation

Long wave radiation is heat that escapes from the water in the infrared range. It is computed using Brunts equation:

$$q_{lr,net} = -\sigma_{sb}(T_{air} + T_K)^4 \left(a - b\sqrt{e_d}\right)\left(c + d\frac{n}{n_d}\right)$$

where:

$q_{lr,net}$	heat loss; outgoing long wave radiation	(W/m^2)
σ_{sb}	Stefan-Boltzman constant	($W/m^2/^oC^4$)
T_{air}	surface air temperature	(^oC)
T_k	equilibrium temperature	(^oC)
e_d	vapor pressure of air	(Pa)
n	number of sunshine hours	(hrs)
n_d	max number of sunshine hours	(hrs)

a, b, c, d are well known coefficients and are not variable by the user.

4.4.6.8 Light Penetration

The above calculations basically describe the amount of radiation present at the water surface. Some of the short wave radiation in the visible spectrum (i.e. light) has the ability to penetrate the surface of the water. This radiation is rapidly absorbed by the water, warming it. The rate of light absorption, or attentuation, is described by Beer's Law:

$$I(d) = (1 - \beta) I_0 e^{-\lambda d}$$

where:

I(d)	short wave radiation intensity, I, at depth, d, below the surface	(W/m^2)
β	amount of radiation absorbed at the surface	
I_o	light intensity just below the surface	(W/m^2)
λ	first order light absorption rate	(m^{-1})
d	depth	(m)

The β and λ terms are adjustable on the the exchange panel as highlighted below in 4.4-45.

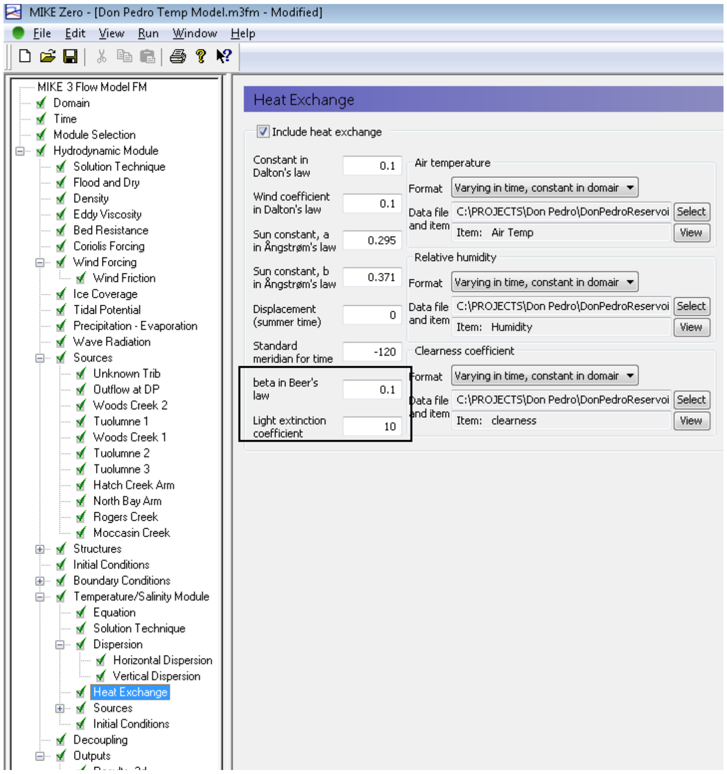


Figure 4.4-45. Light penetration constants.

4.4.6.9 Temperature Sources

Water inflows and outflows were previously defined in terms of flow rate. In this section they are assigned time variable temperatures through the source temperature tab (Figure 4.4-45). The format is similar to the source tab described previously, except that now a time variable temperature time series will be read from a data file. In the Don Pedro Reservoir model the inflow temperature is taken from measured data from the Tuolumne River at Indian Creek Trail (See Figure 3.0-1 Study Area). The Indian Creek Trail data for 2011 are shown in Figure 4.4-46. In the absence of other measured tributary temperatures, these values are assigned to all the sources. The outflow temperature is computed by the model.

In order to run the reservoir model over a longer historical timeframe a long term inflow temperature data set has been developed. The approaches to developing the long term data set are given as Attachment E "Full period of record inflow temperature data set".

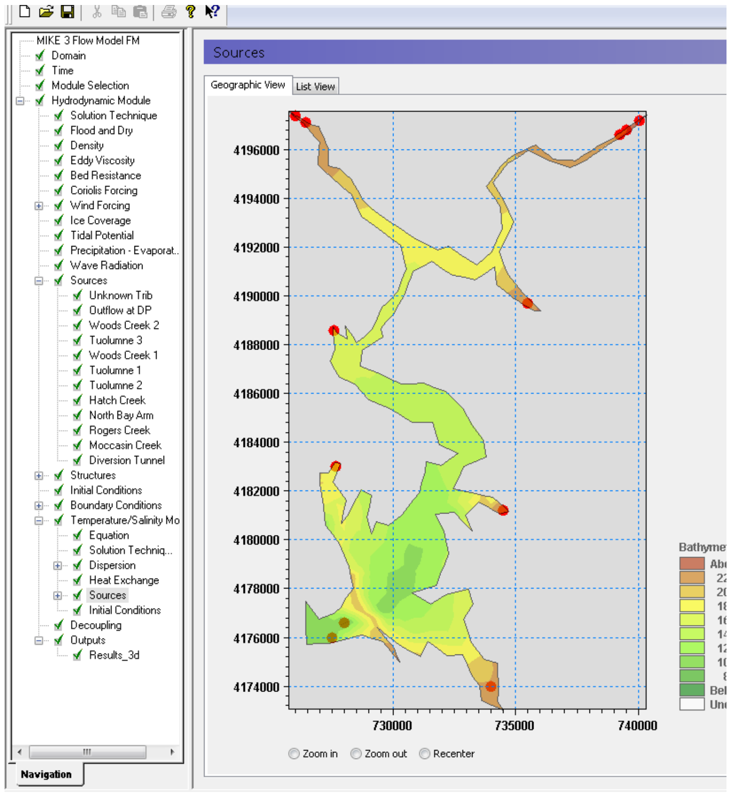


Figure 4.4-46. Source temperature tab.

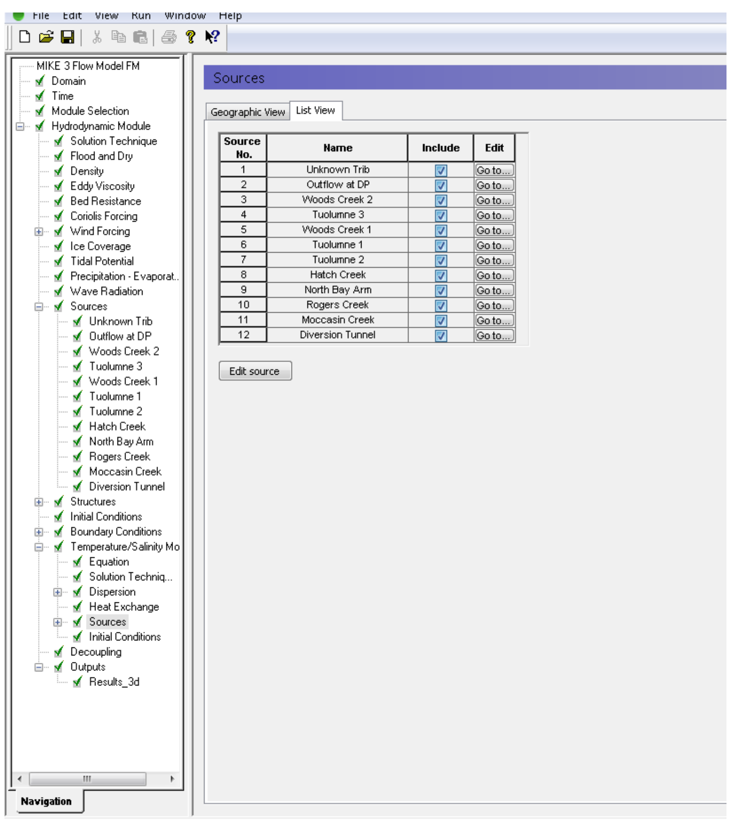


Figure 4.4-47. Temperature sources.

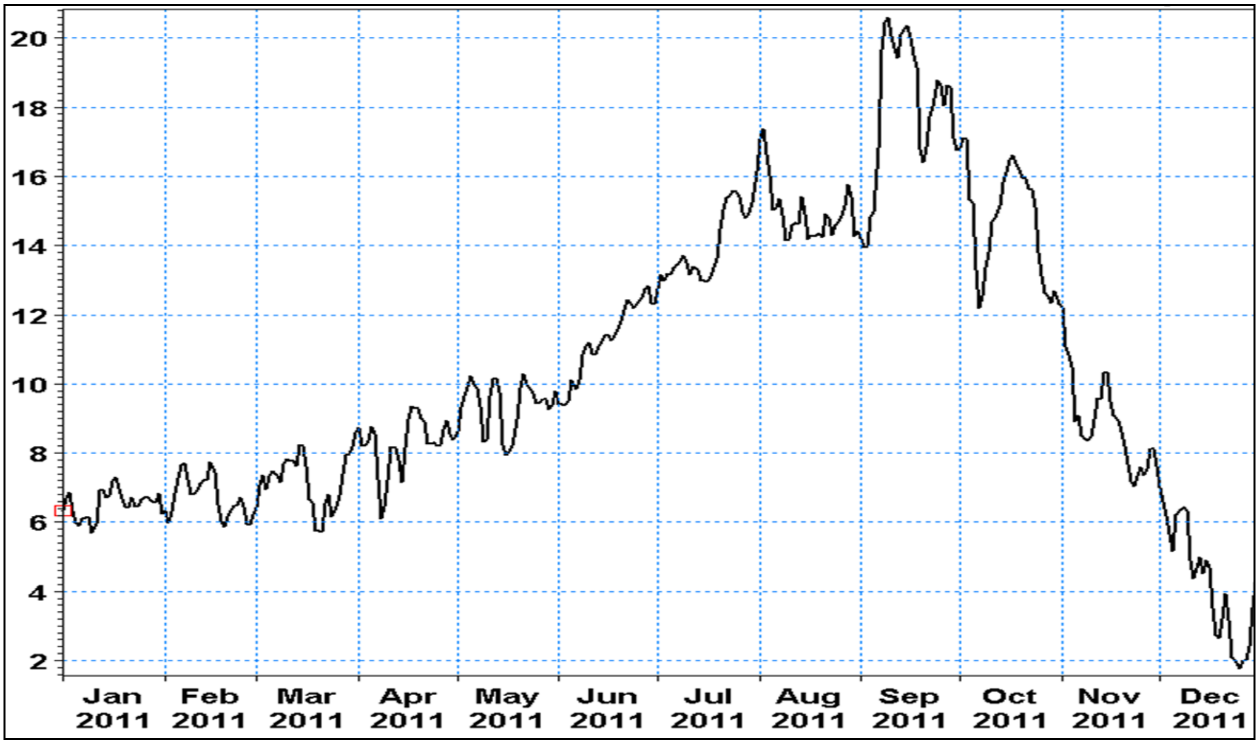


Figure 4.4-48. Measured inflow temperature at Indian Creek Trail (^oC) for 2011.

4.4.6.10 Initial Temperatures

Initial reservoir temperatures can either be specified as constant, as shown in Figure 4.4-49, or varying throughout the model. For Don Pedro Reservoir a value of 10^o C was used. This value is representative of the reservoir's wintertime, non-stratified, equilibrium temperature. (See Attachment A).

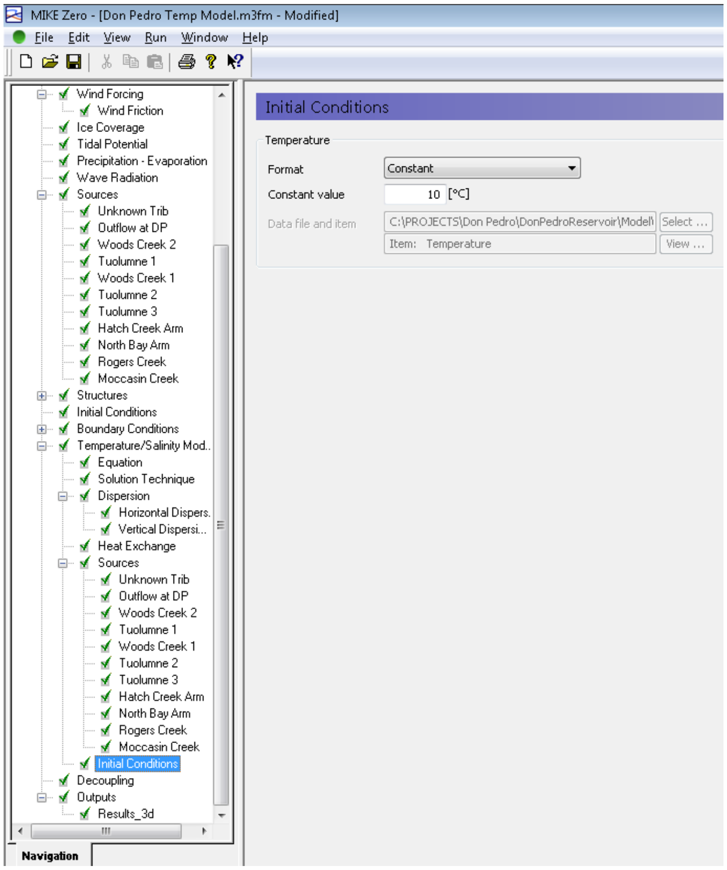


Figure 4.4-49. Temperature initial condition.

4.4.6.11 Decoupling

In some cases where water quality is being simulated, the water quality calculation does not need to be updated every hydrodynamic time step. This is aimed at increasing run times. It is not relevant in this case. The input tab is shown below in Figure 4.4-50.

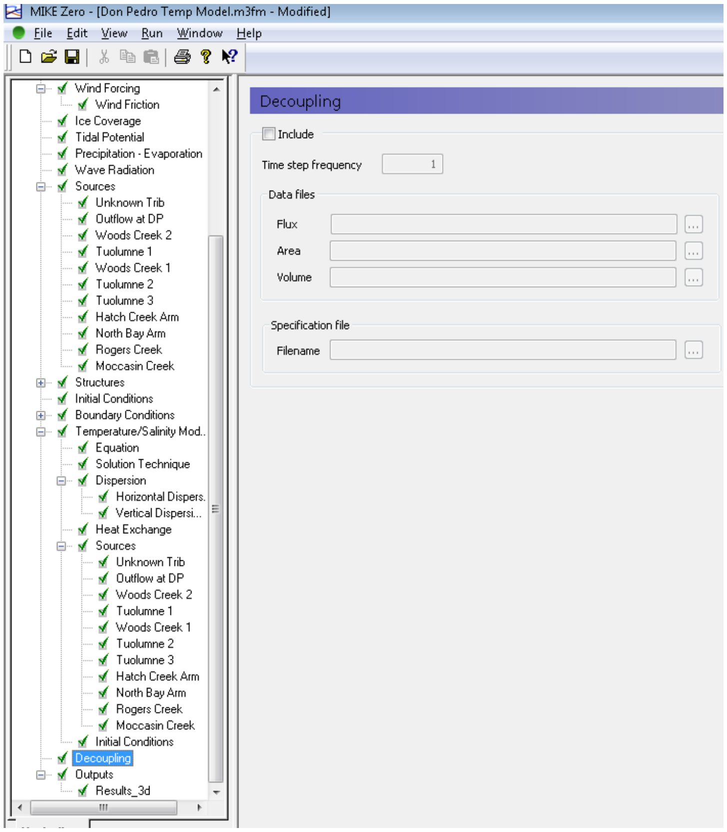


Figure 4.4-50. Decoupling tab.

4.4.7 Model Output

The model allows results to be written to data files with many options. The main output tab displays the various data files the user has set up, as shown in Figure 4.4-51. The files can also be deselected, so not every file needs to be written for every model run.

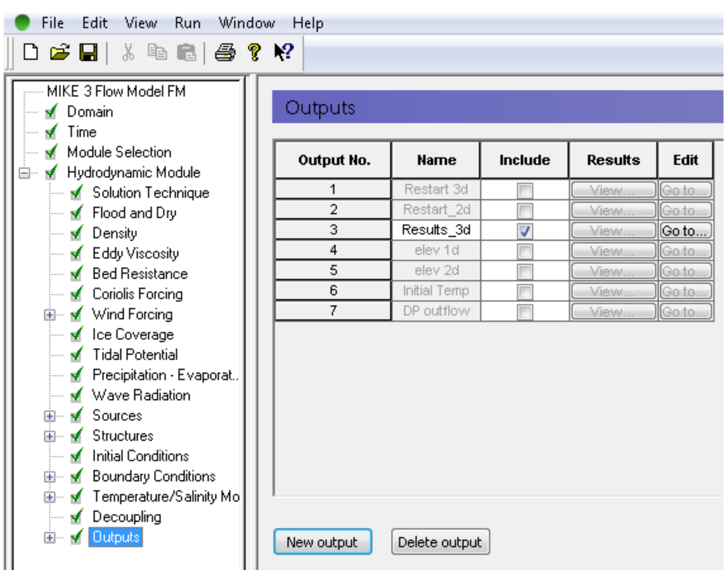


Figure 4.4-51. Output selection screen.

The model output folder (Figure 4.4-52) contains three tabs:

- geographic view
- output specification
- output Items

The geographic view displays the extent of where data will be output, as described in the output specification tab. As shown in Figure 4.4-52, all of the Don Pedro Reservoir model domain is selected.

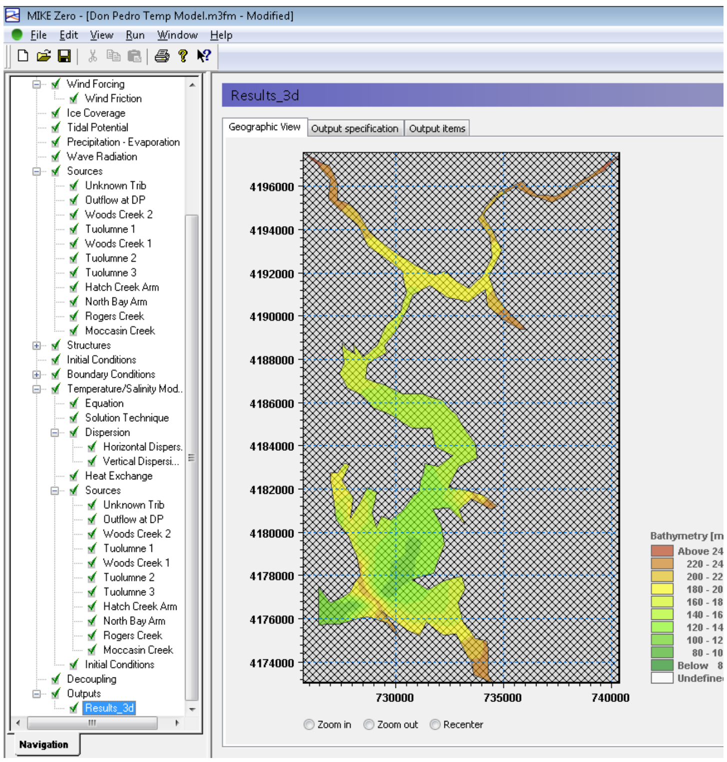


Figure 4.4-52. Geographic view of output area.

In the output specification tab there are options to select the geographic extent of the data; whether the output will contain 1D, 2D or 3D data; the time steps that will be output; and which vertical layers in the model will be output. The path and filename of the output file is specified. These are shown in Figure 4.4-53.

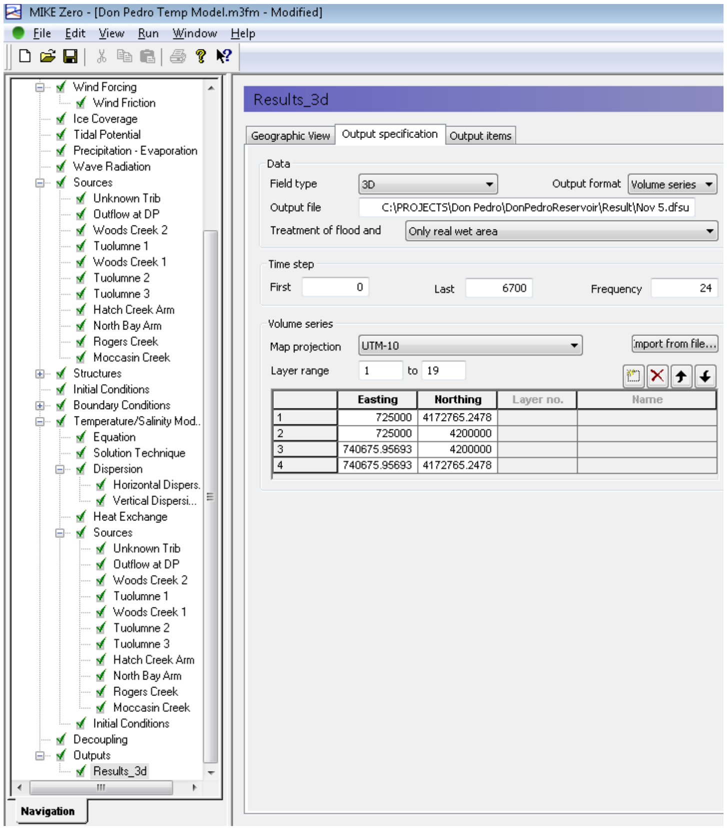


Figure 4.4-53. Output specifications.

The final output tab contains the variables that can be selected for output. Different file types have different variable options. For example “surface elevation” is available for a 2D horizontal output file but not for a 3D file, as shown below in Figure 4.4-54.

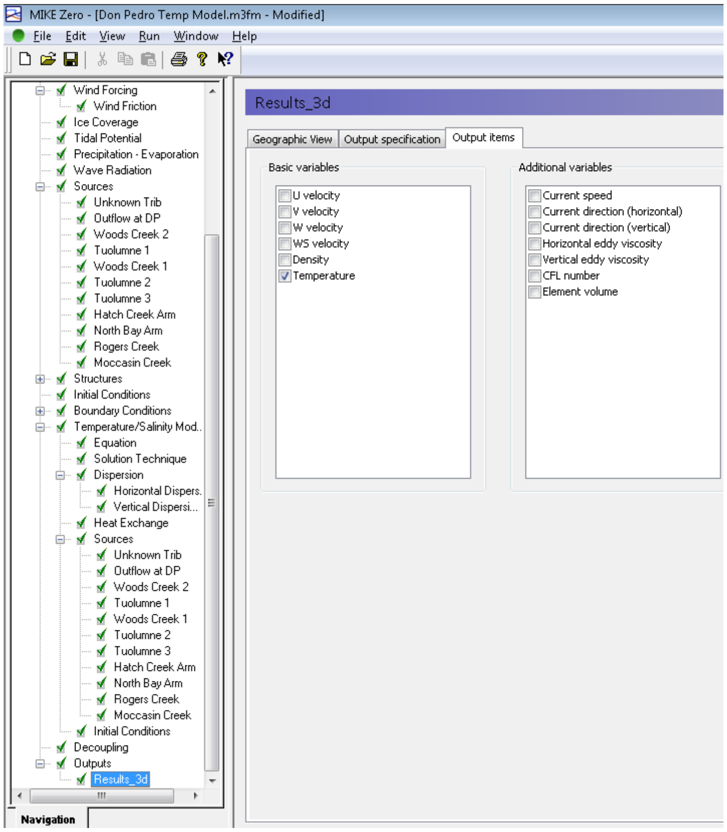


Figure 4.4-54. Example of available output variables for 3D output.

5.0 RESULTS AND DISCUSSION

The FERC-approved Study Plan lists the following requirements:

- the model will be calibrated and verified using field data that cover continuously the periods of stratification (April through September) and de-stratification (October and November) of the Don Pedro Reservoir; the data used for the calibration are discussed in Section 5.1;
- model-computed temperatures will be compared to monthly temperature profiles (see Sections 5.2 and 5.3 below);
- model–computed temperature of the Don Pedro releases will be compared to the temperature data collected at the powerhouse; temperature measurements at the powerhouse (1978 through 1988, 2010 through present) will also be used for the model calibration/verification (see Section 5.4 below);
- surface water temperature recorded concurrently with the bathymetric data in May and June 2011 will also be used in the model calibration; and
- performance of a QA/QC review of the modeling following the calibration and verification.

5.1 Temperature Profile Data

Vertical temperature profiles collected in the Don Pedro impoundment were used to calibrate and validate the reservoir model. The calibration year is 2011 and the validation year is 2012. As discussed previously these years were chosen as they were the years with complete data sets. The temperature profiles are measured approximately monthly for most of the year, typically February through October/November. The profile data are collected by both CDFW and the Districts. The profile locations are listed above in Table 4.3-2 and are shown on Figure 5.1-1. The locations of the temperature profiles are:

- Highway 49 Bridge (CDFW and Districts)
- Above Old Don Pedro Dam (Districts)
- Below Old Don Pedro Dam (Districts)
- Don Pedro Dam (CDFW and Districts)
- Jacksonville Bridge (CDFW and Districts)
- Middle Bay (CDFW and Districts)
- Woods Creek (CDFW and Districts)
- Ward's Ferry (CDFW and Districts)

Plots of reservoir profiles are provided in Attachment A. The vertical temperature profiles show that in the early portion of the year, January through March, the reservoir is not stratified and equilibrium temperatures are around 10^{o} C. In April the data indicate significant warming at the surface with temperatures around 18^{o} C observed, and initial reservoir stratification is beginning to occur. The data for May and June look similar to April, but with the surface heat penetrating to some depth. By July the surface temperatures have risen above 25^{o} C and the reservoir temperature stratification is well-defined. The profiles show a decrease in temperature with depth that extends some 200 ft until the temperature stabilizes around 10-12^{o} C. The temperature stratification remains strong through July, August, and September. At the end of September the reservoir is still strongly stratified, but surface temperatures have dropped by a couple of degrees and are usually just below 25^{o} C. When the last profiles were measured in 2011 on October 13 the reservoir remained stratified. Surface temperatures continued to drop and were around 20^{o} C.

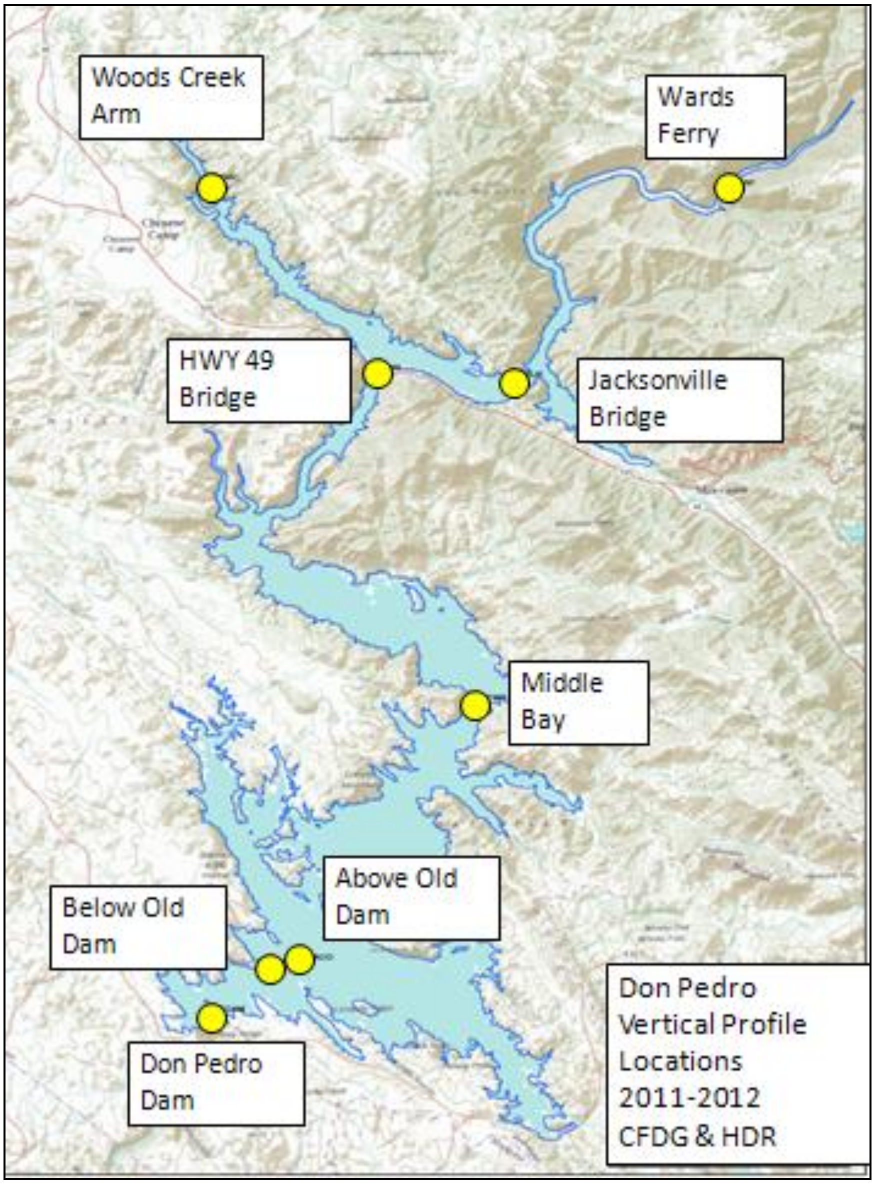


Figure 5.1-1. Vertical temperature profile locations.

5.2 Model Results – 2011 Calibration Year

Figures 5.2-1 through 5.2-11 show the calibration results for 2011. Vertical temperature profiles for 2011 were measured on the following days (Attachment A):

January 12	July 11
February 7	July 26
March 22	August 30
April 20	September 27
May 18	October 13
June 6	--

As mentioned in Section 1, the current version of the model works in SI units; therefore, the temperatures are in Celsius and depth is in meters. The y-axis represents depth as measured from an elevation of 260m (853 ft). This benchmark elevation was chosen as water will never be above this height so no data would ever be excluded from the plots. For reference the normal maximum pool elevation of 830 ft and the minimum operating pool of 600 ft are also shown. As noted on the plot captions, the observed data are shown by open blue circles with model results given by open red triangles.

The model temperature was initially set at 10^{o} C when the model run started on January 10, and it takes until April to see the heat transferring through the deeper model surface layers. The model profiles in January, February and March show the slow progression of temperature from the surface. The shallower areas of the reservoir respond quicker and so the model profiles in Ward's Ferry and Woods Creek show a better fit in the early months.

From April the reservoir begins to show noticeable stratification and this remains through October when the last profiles were measured for 2011. The model reproduces the strong reservoir stratification and is a good fit in to the measured data throughout the year at the various stations.

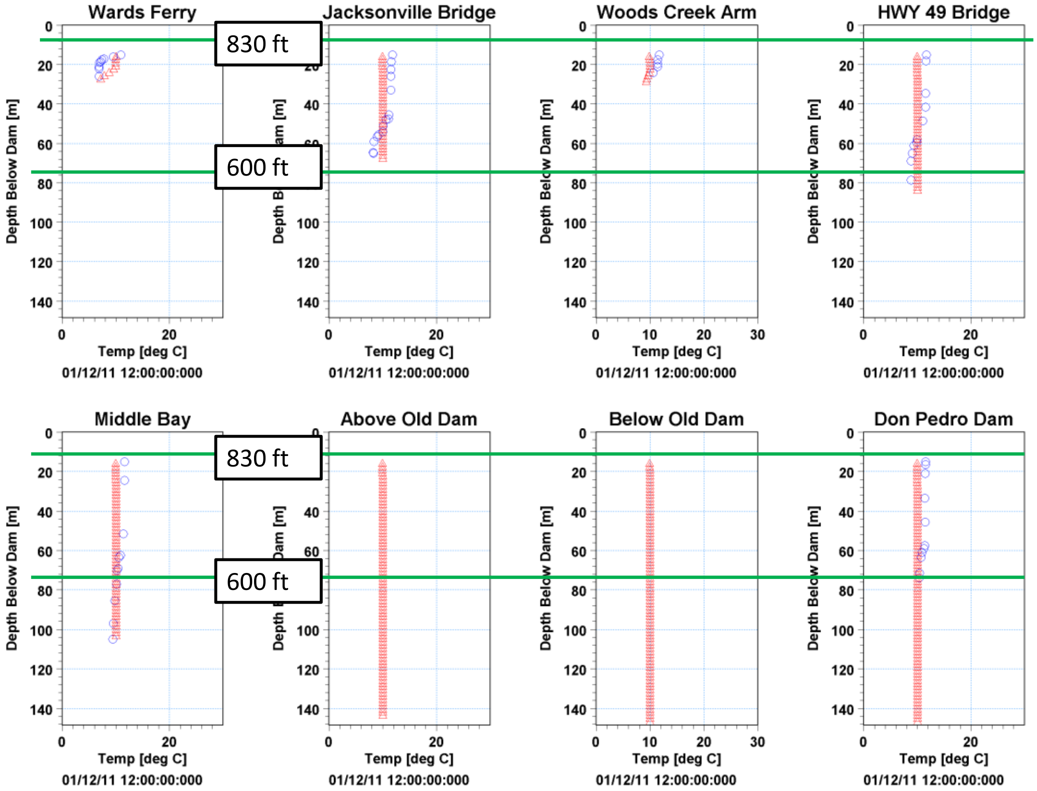


Figure 5.2-1. January 12, 2011 calibration. (Observed = blue circles; Model = red triangles)

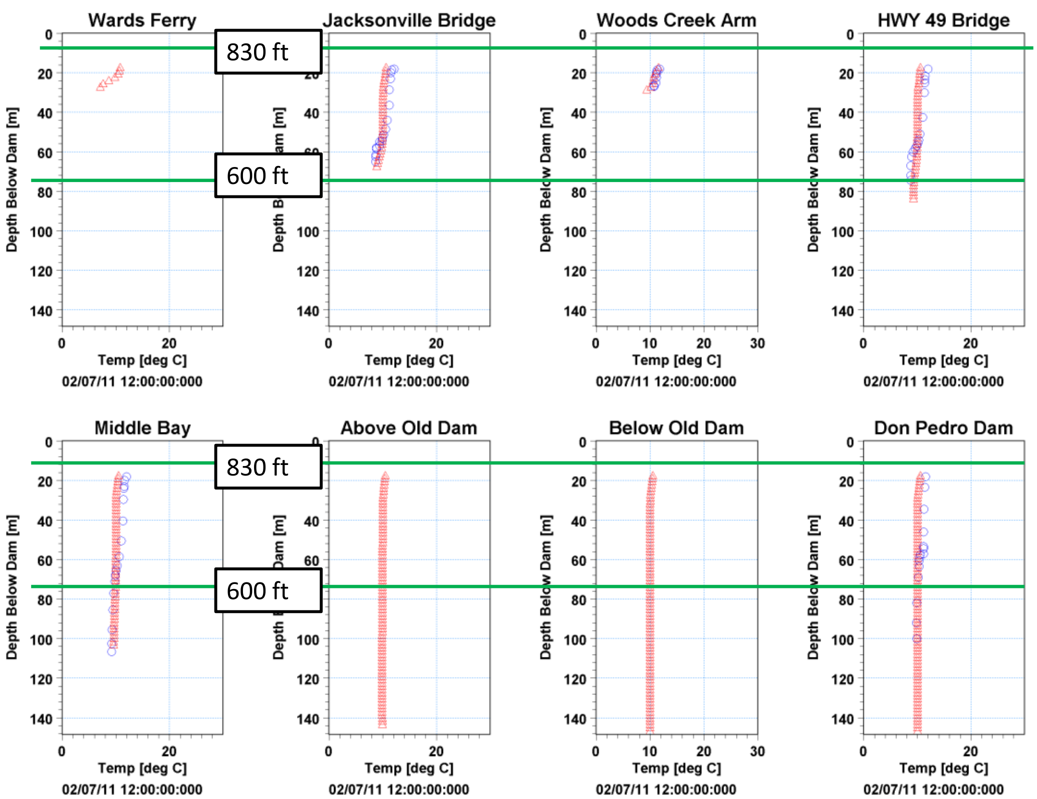


Figure 5.2-2. February 7, 2011 calibration. (Observed = blue circles; Model = red triangles)

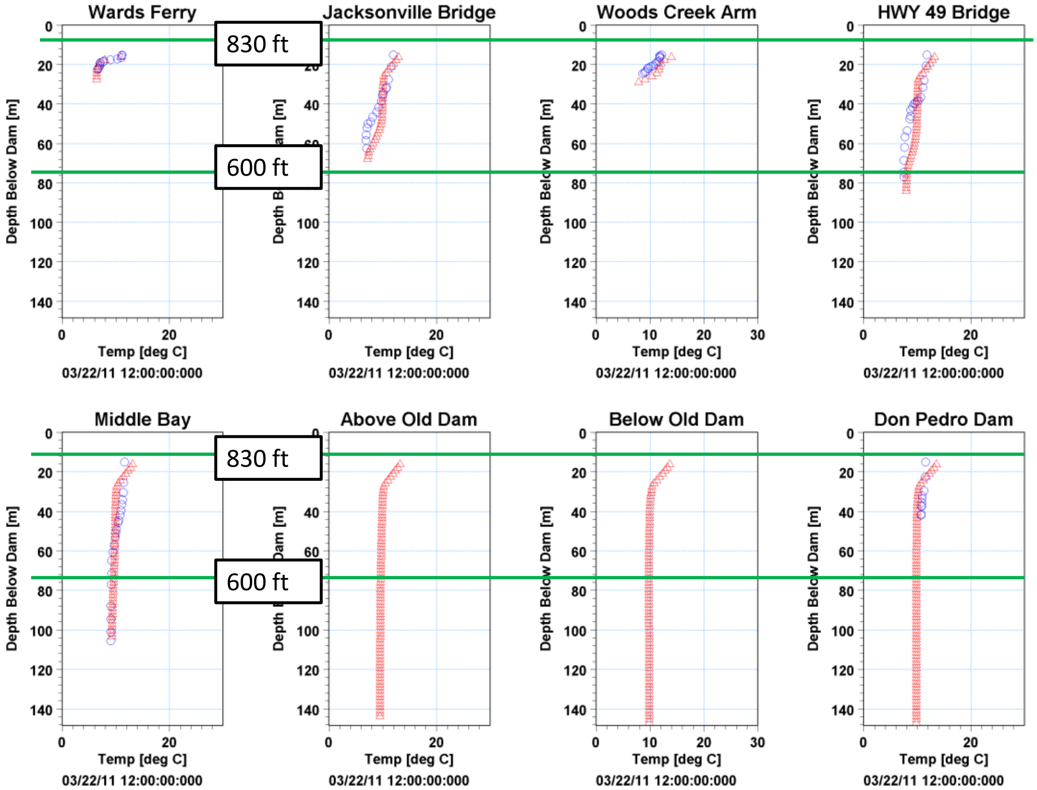


Figure 5.2-3. March 22, 2011 calibration. (Observed = blue circles; Model = red triangles)

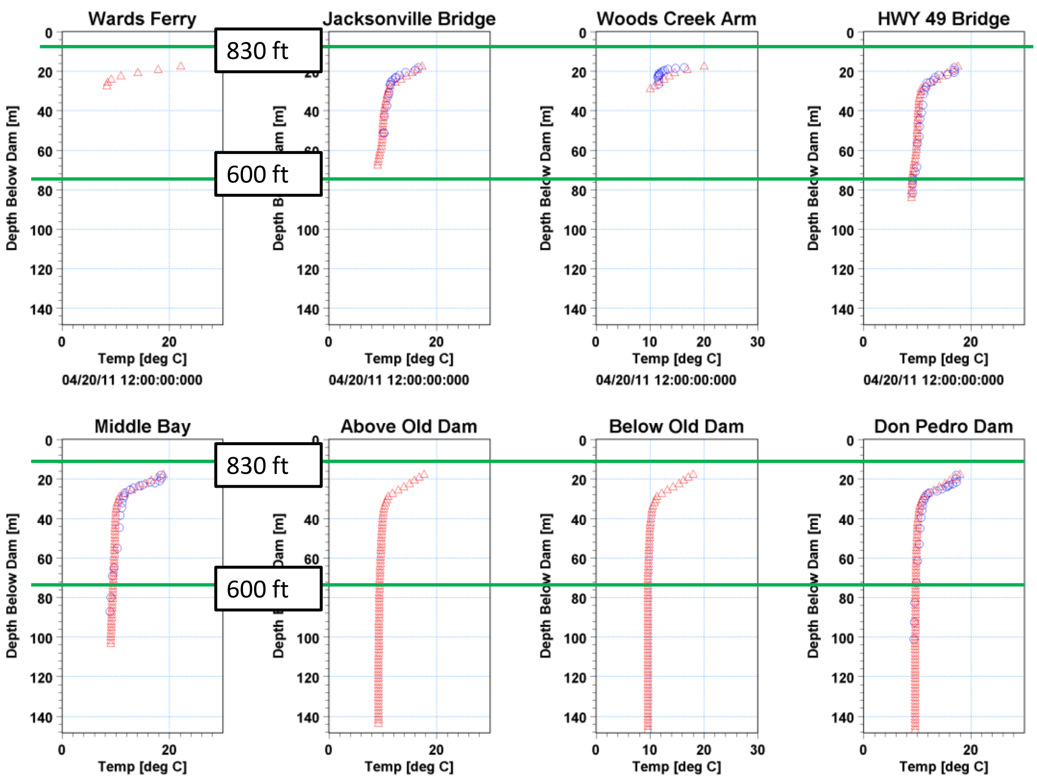


Figure 5.2-4. April 20, 2011 calibration. (Observed = blue circles; Model = red triangles)

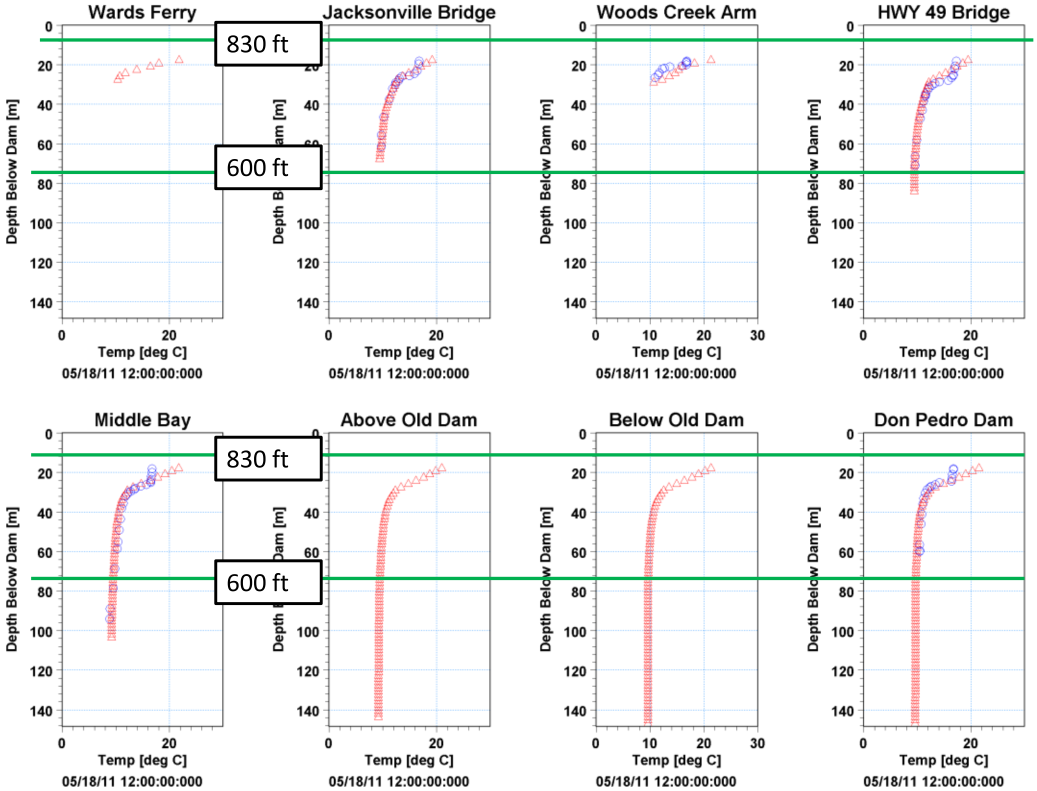


Figure 5.2-5. May 18, 2011 calibration. (Observed = blue circles; Model = red triangles)

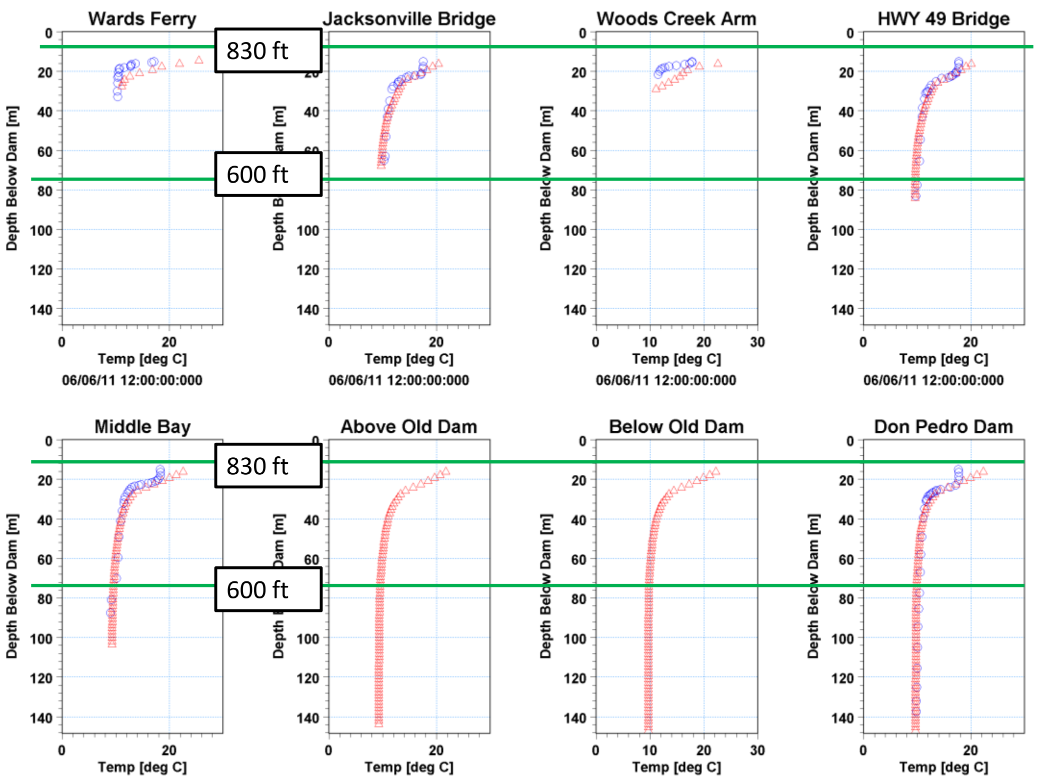


Figure 5.2-6. June 6, 2011 calibration. (Observed = blue circles; Model = red triangles)

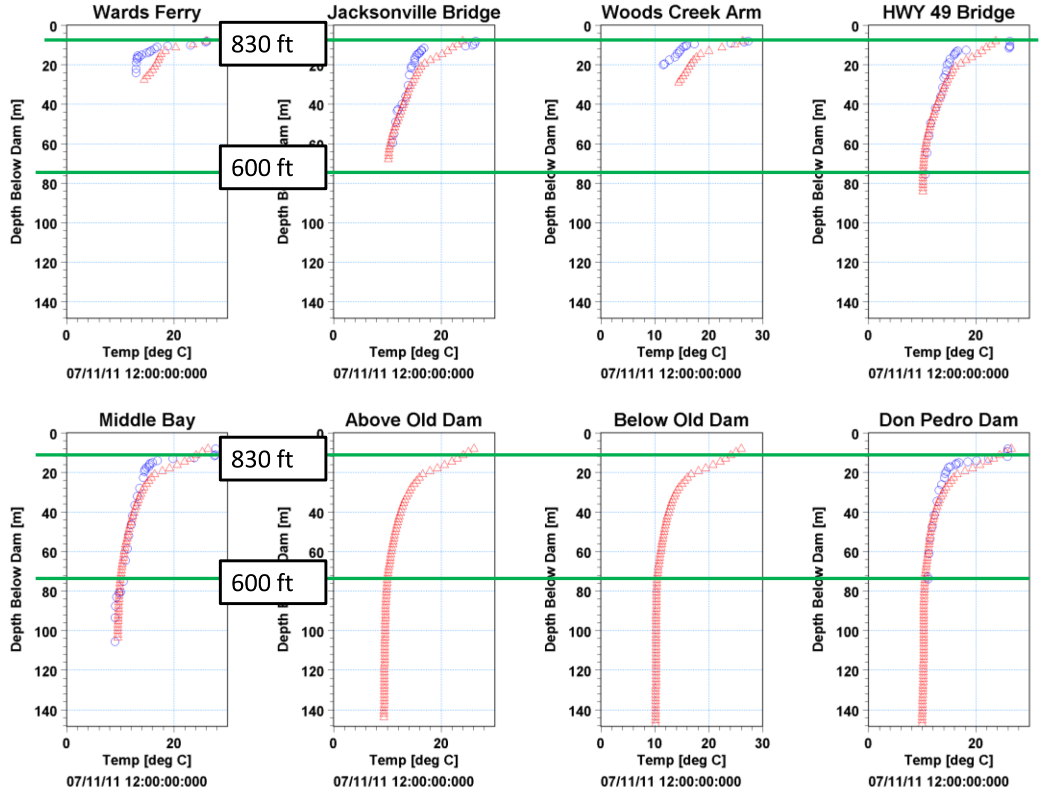


Figure 5.2-7. July 11, 2011 calibration. (Observed = blue circles; Model = red triangles)

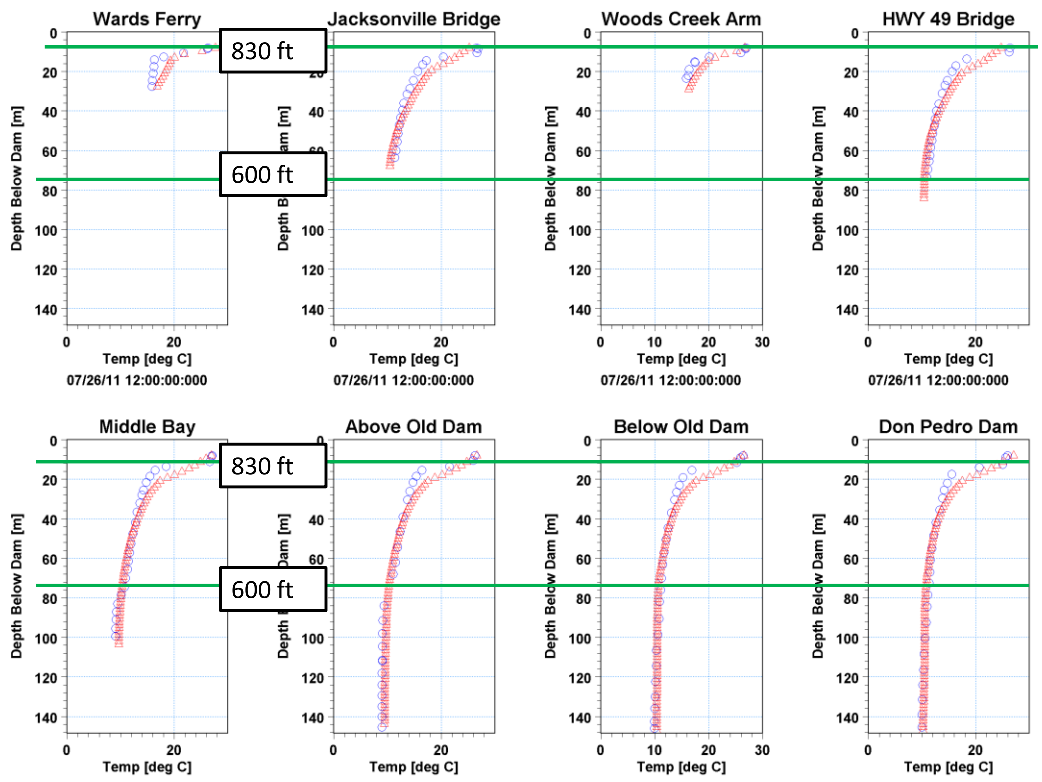


Figure 5.2-8. July 26, 2011 calibration. (Observed = blue circles; Model = red triangles)

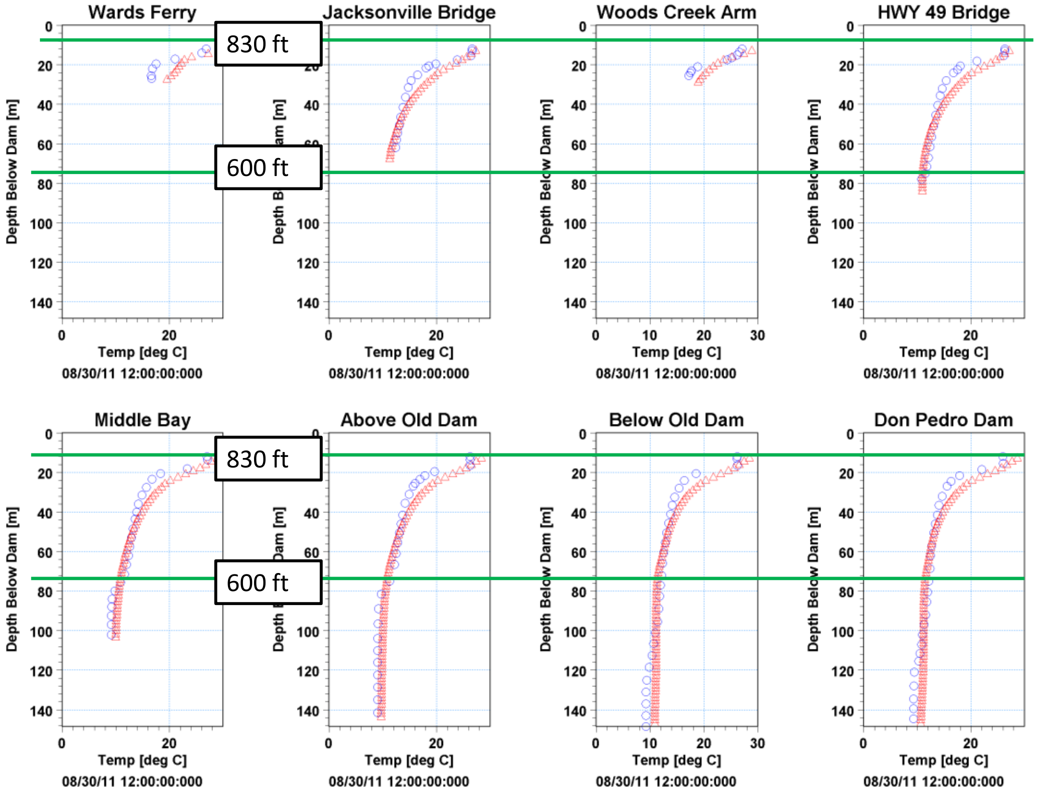


Figure 5.2-9. Aug 30, 2011 calibration. (Observed = blue circles; Model = red triangles)

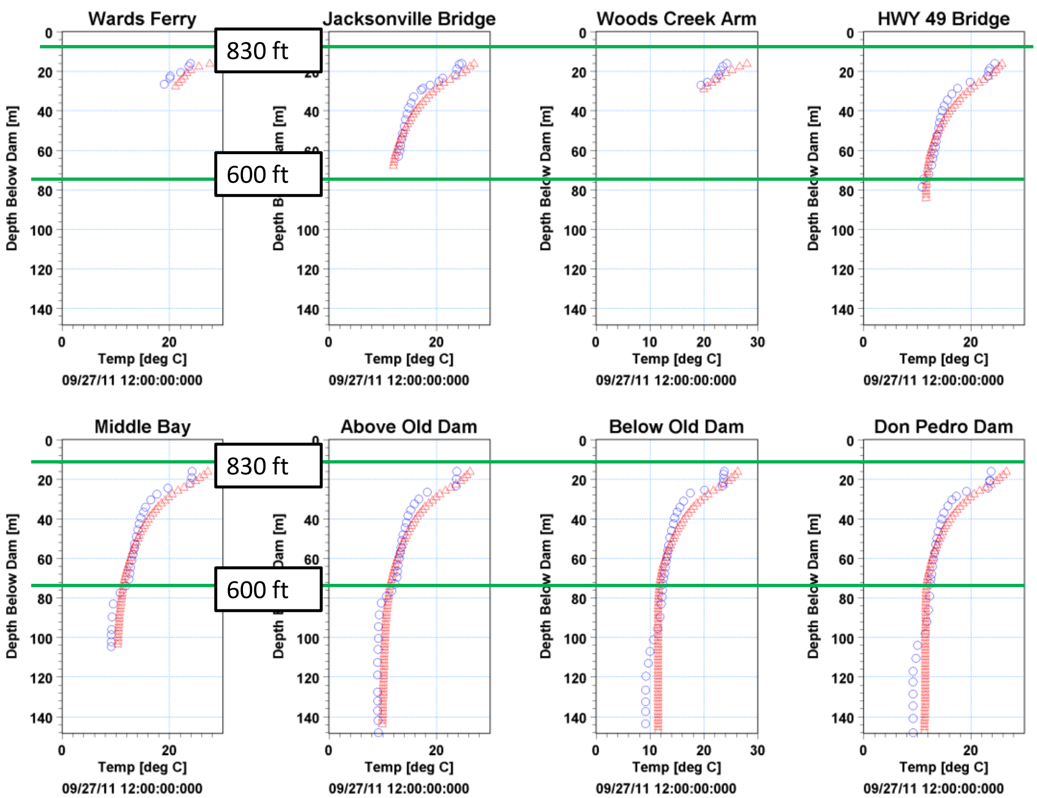


Figure 5.2-10. September 27, 2011 calibration. (Observed = blue circles; Model = red triangles)

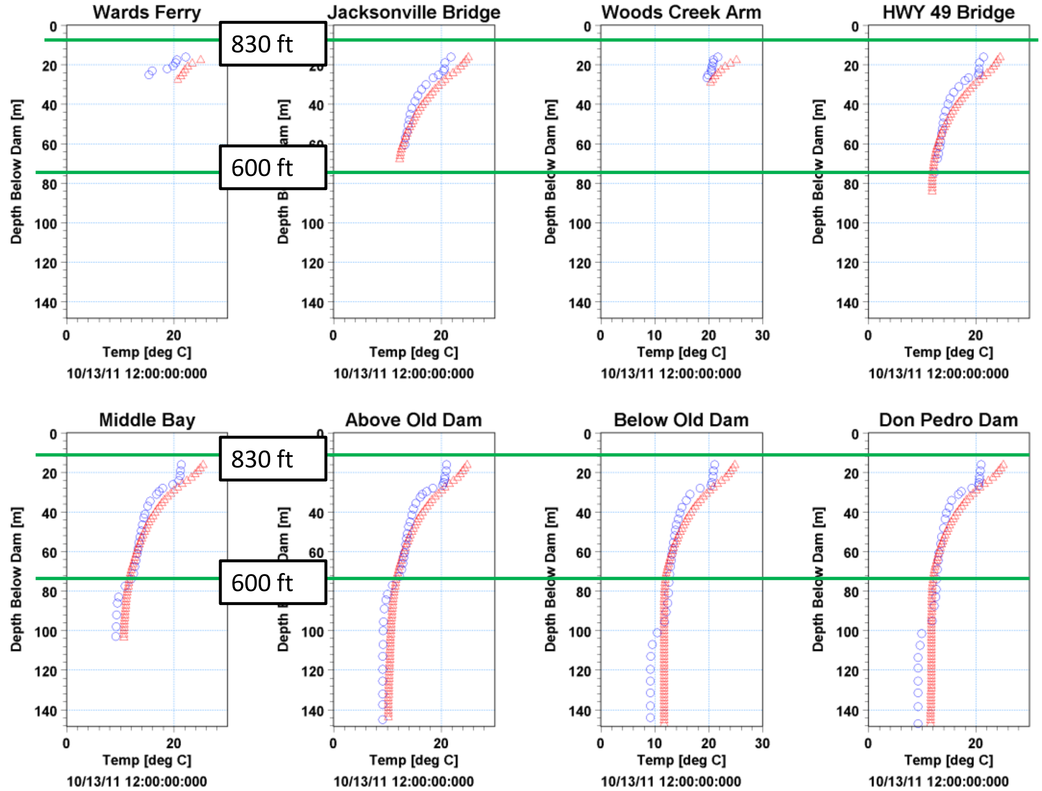


Figure 5.2-11. Oct 13, 2011 calibration. (Observed = blue circles; Model = red triangles)

5.3 Model Results – 2012 Validation Year

Figures 5.3-1 through 5.3-12 show the validation results for 2012 using data collected by the Districts. Vertical temperature profiles for 2012 were measured on the following days:

January 19	June 13
February 14	July 3
March 14	August 22
April 23	September 19
May 8	October 9
May 17	November 19

The model was run continuously from January 10, 2011 to December 5, 2012, when the available data ended. The figures show that the model compares well with the measured data throughout 2012. The measured data for 2012 are very similar to 2011 with the same trends in the timing, and amount of stratification occurring.

In March 2013 the CDFW data set was provided to the Districts. Figures 5.3-13 through 5.3-22 show the comparison to this data set. The plots are virtually identical to the previous plots using data collected by the Districts, as the two measured datasets are in excellent agreement. The days that CDFW collected vertical temperature profiles in 2012 were:

January 19	July 10
February 14	August 10
March 14	September 12
April 23	October 25
May 8	December 26
June 14	--

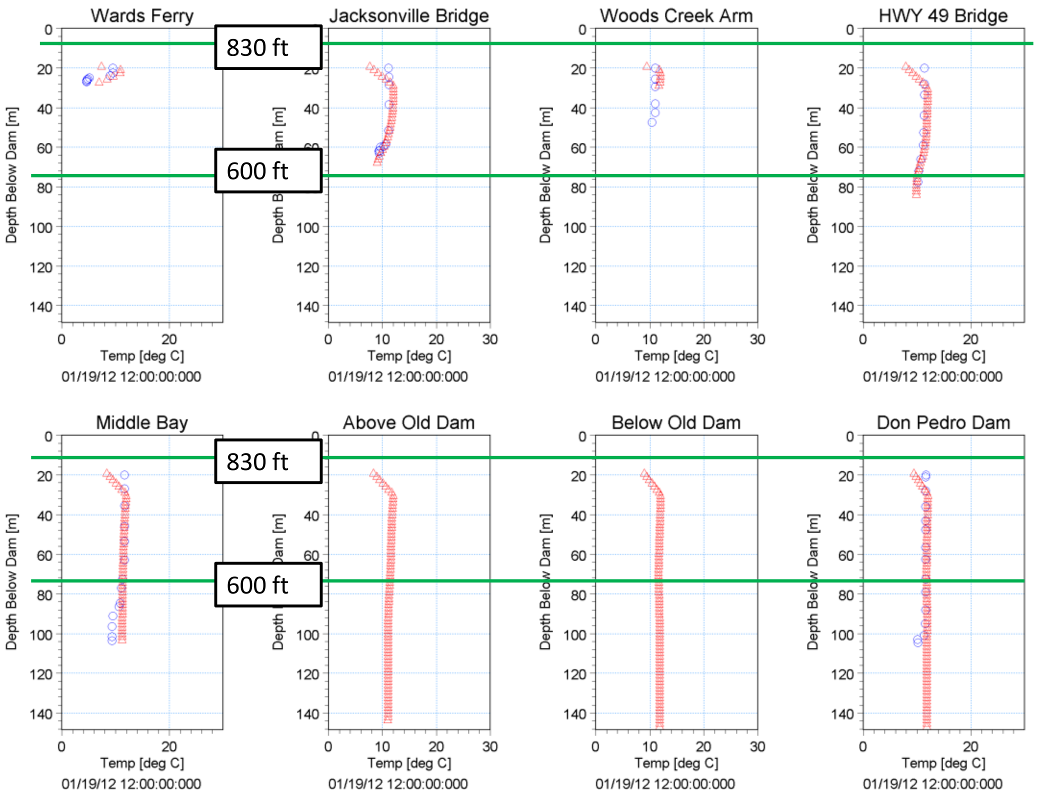


Figure 5.3-1. Jan 19, 2012 validation. (Observed = blue circles; Model = red triangles)

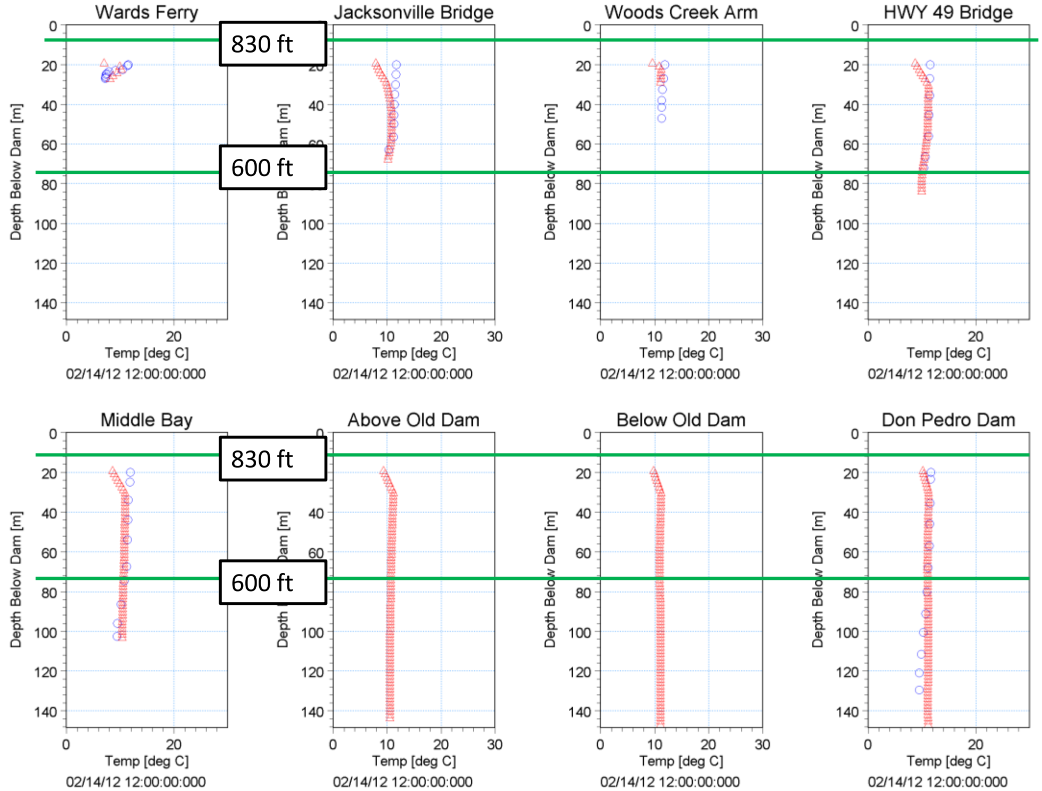


Figure 5.3-2. Feb 14, 2012 validation. (Observed = blue circles; Model = red triangles)

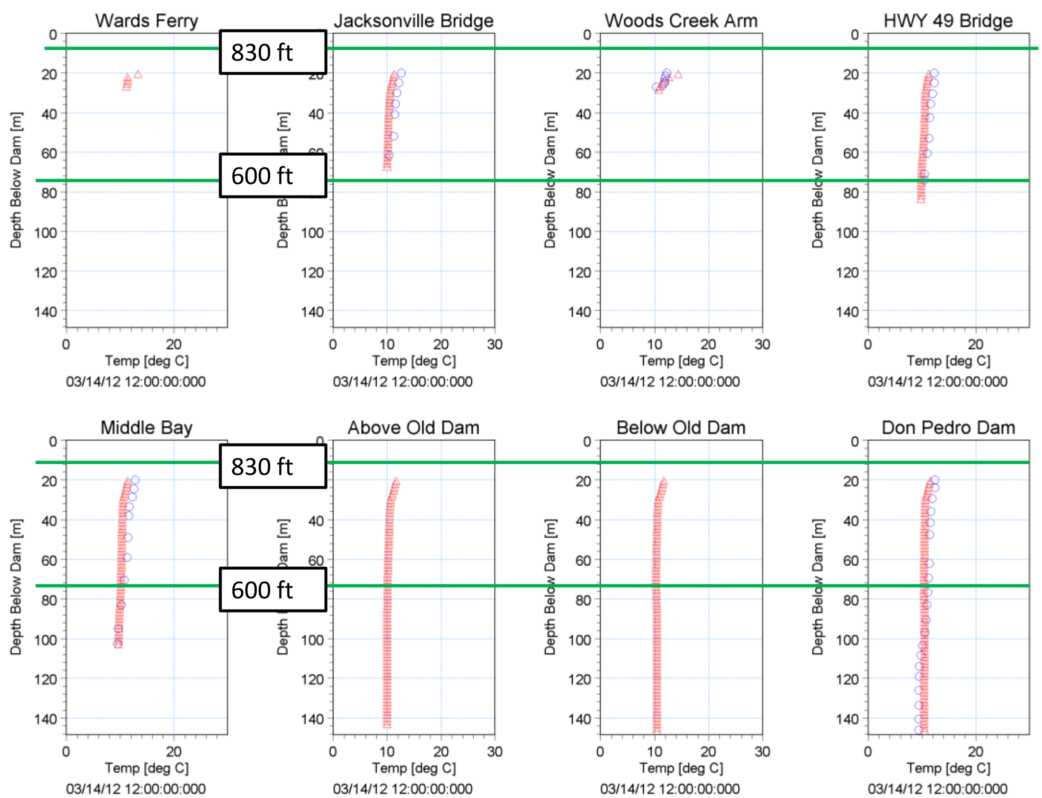


Figure 5.3-3. Mar 14, 2012 validation. (Observed = blue circles; Model = red triangles)

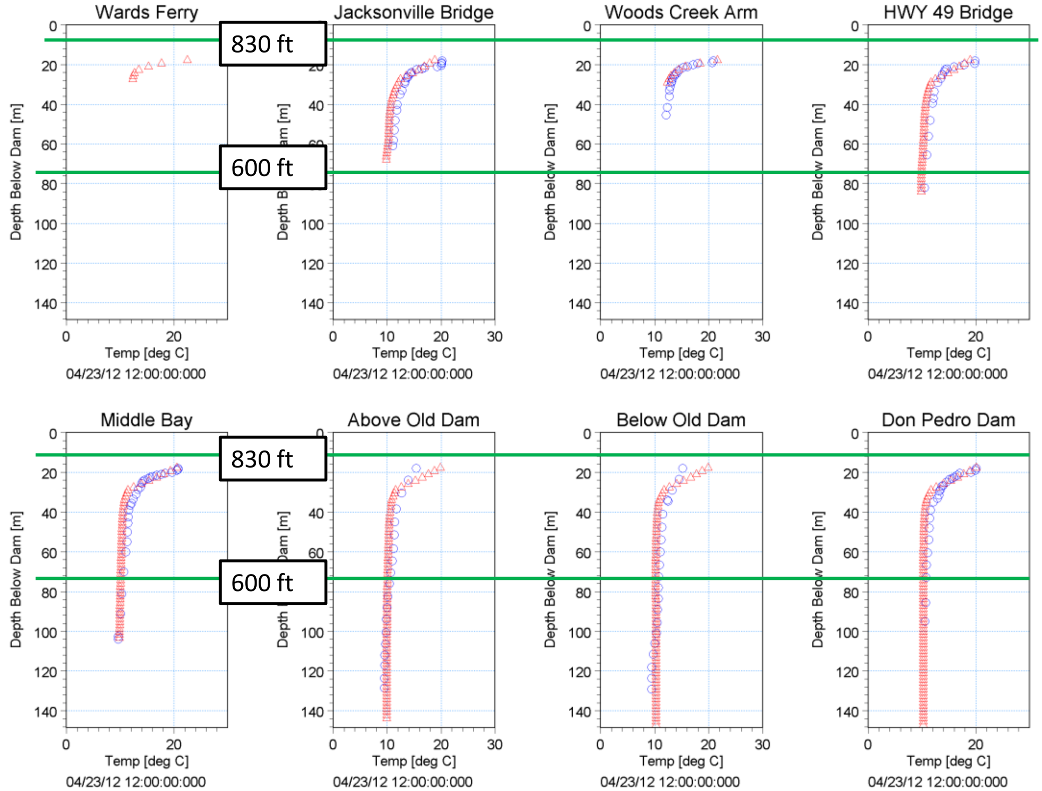


Figure 5.3-4. April 23, 2012 validation. (Observed = blue circles; Model = red triangles)

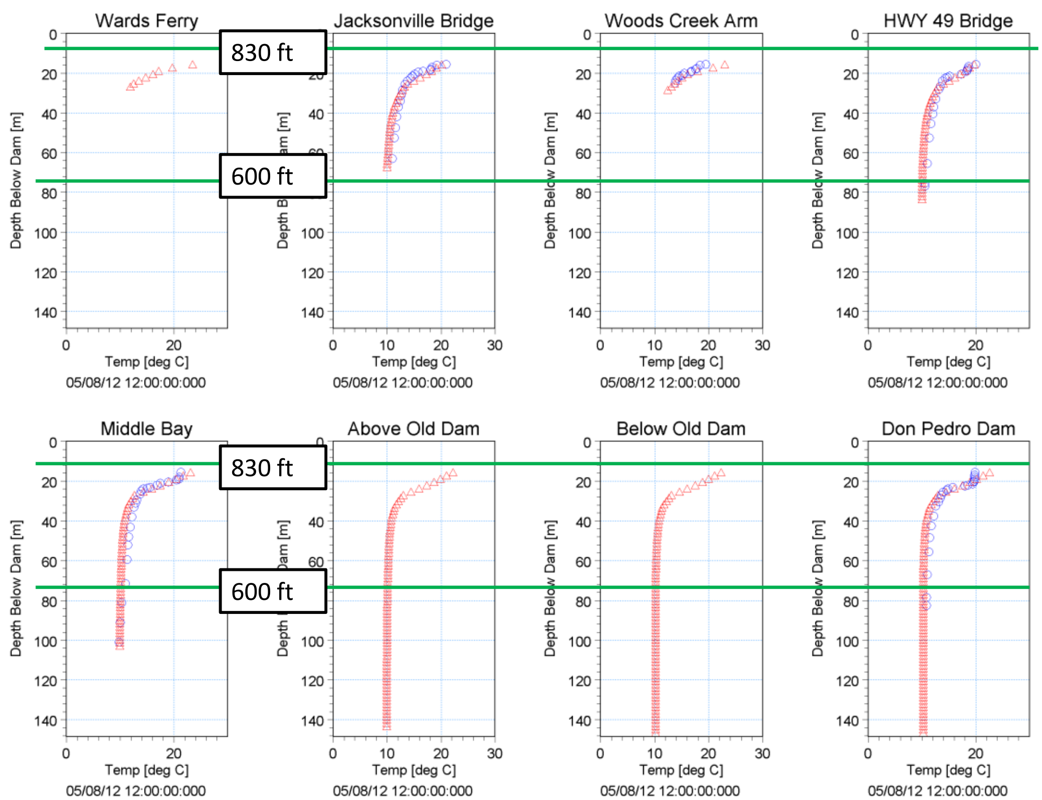


Figure 5.3-5. May 8, 2012 validation. (Observed = blue circles; Model = red triangles)

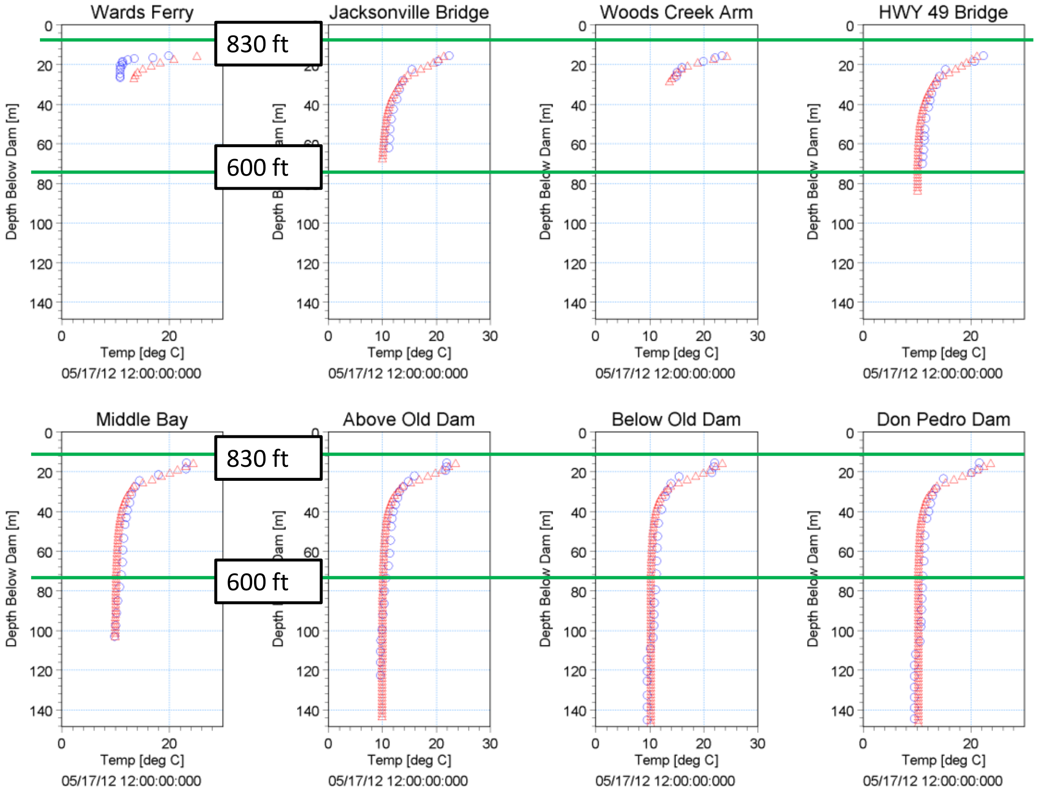


Figure 5.3-6. May 17, 2012 validation. (Observed = blue circles; Model = red triangles)

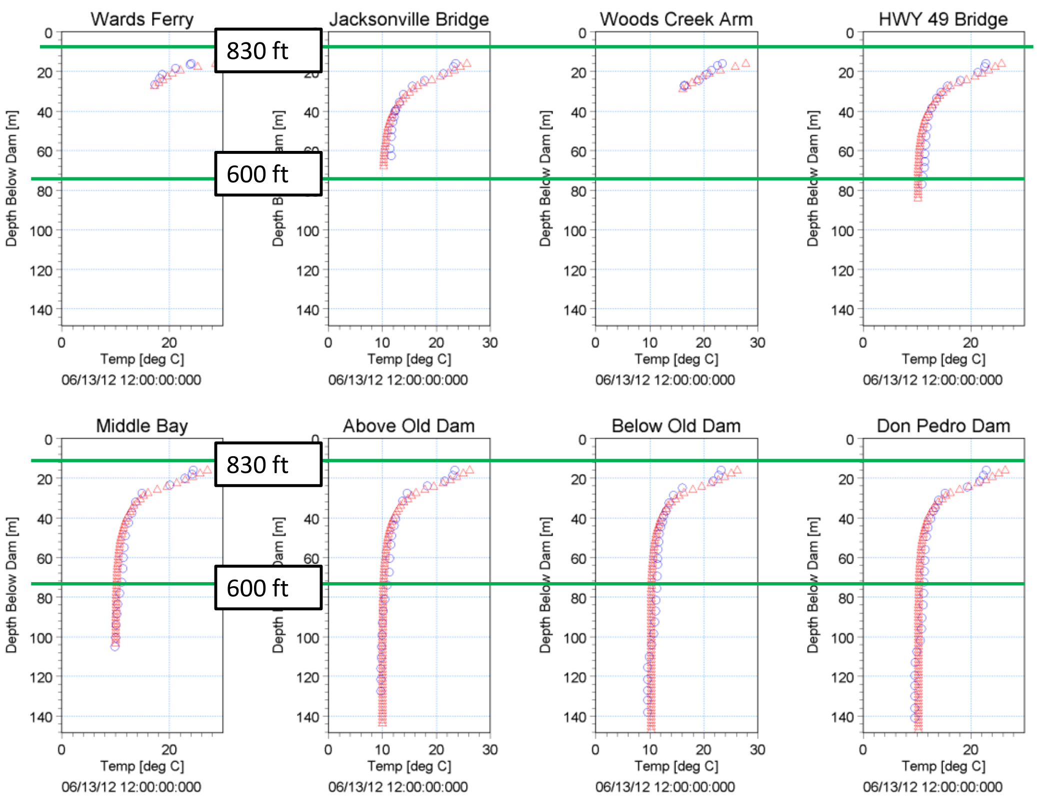


Figure 5.3-7. June 13, 2012 validation. (Observed = blue circles; Model = red triangles)

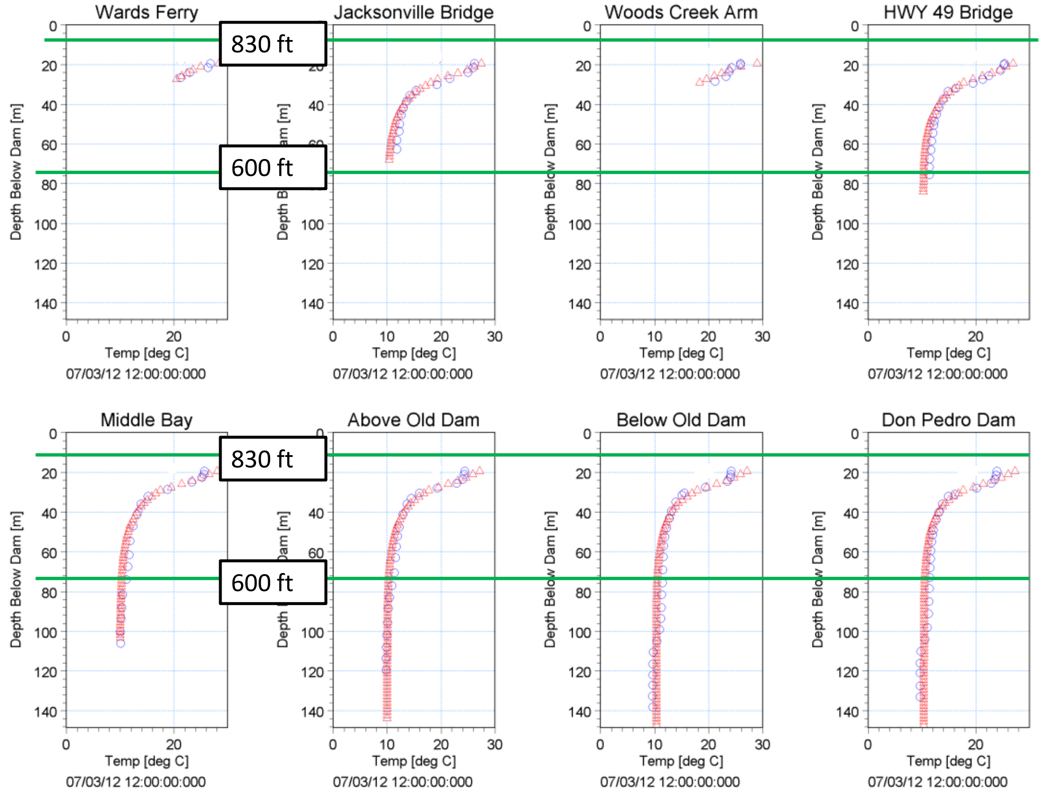


Figure 5.3-8. July 3, 2012 validation. (Observed = blue circles; Model = red triangles)

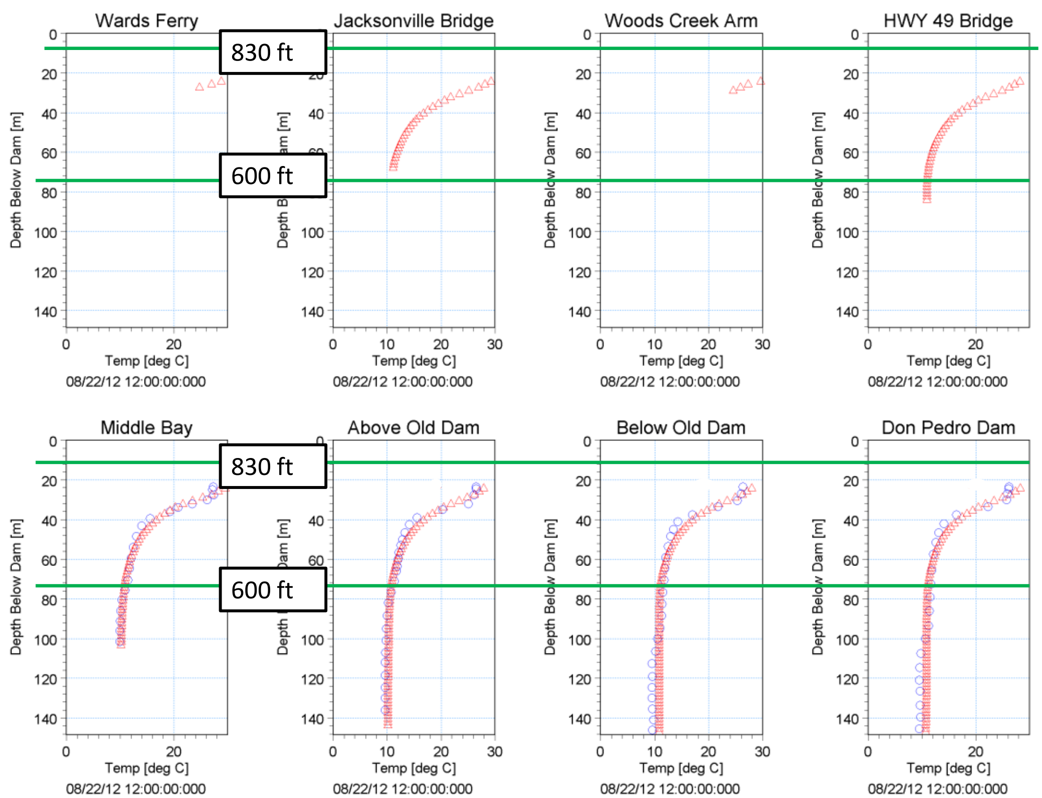


Figure 5.3-9. Aug 22, 2012 validation. (Observed = blue circles; Model = red triangles)

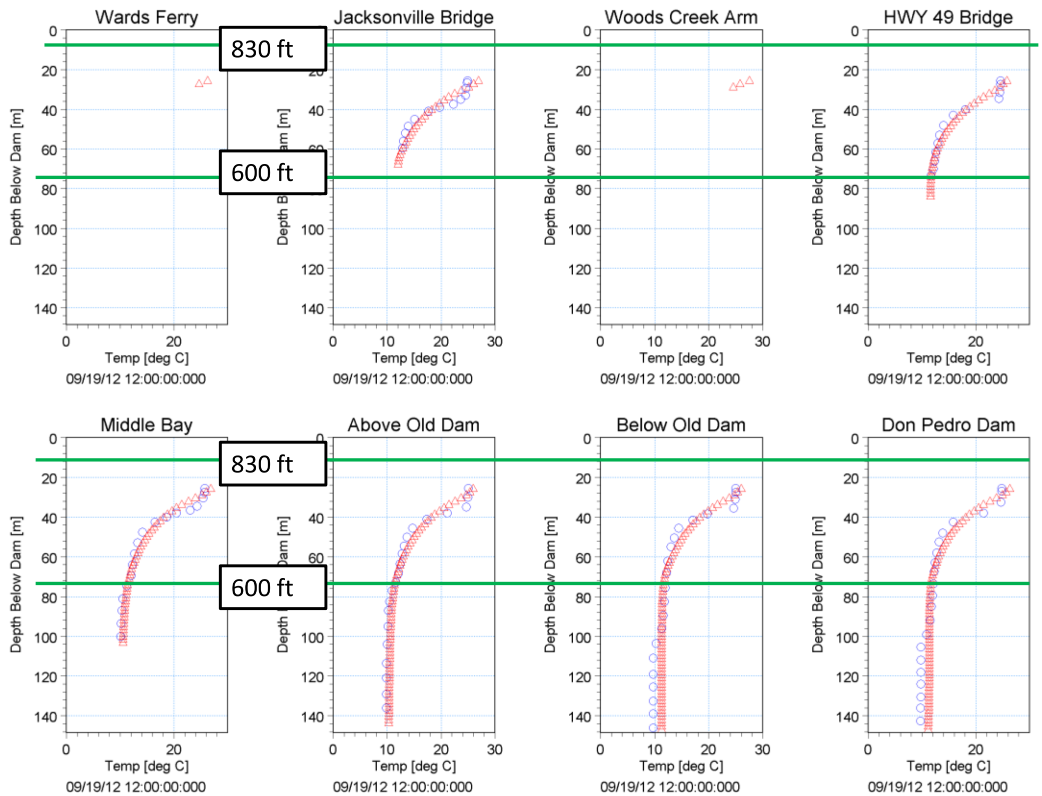


Figure 5.3-10. Sept 19, 2012 validation. (Observed = blue circles; Model = red triangles)

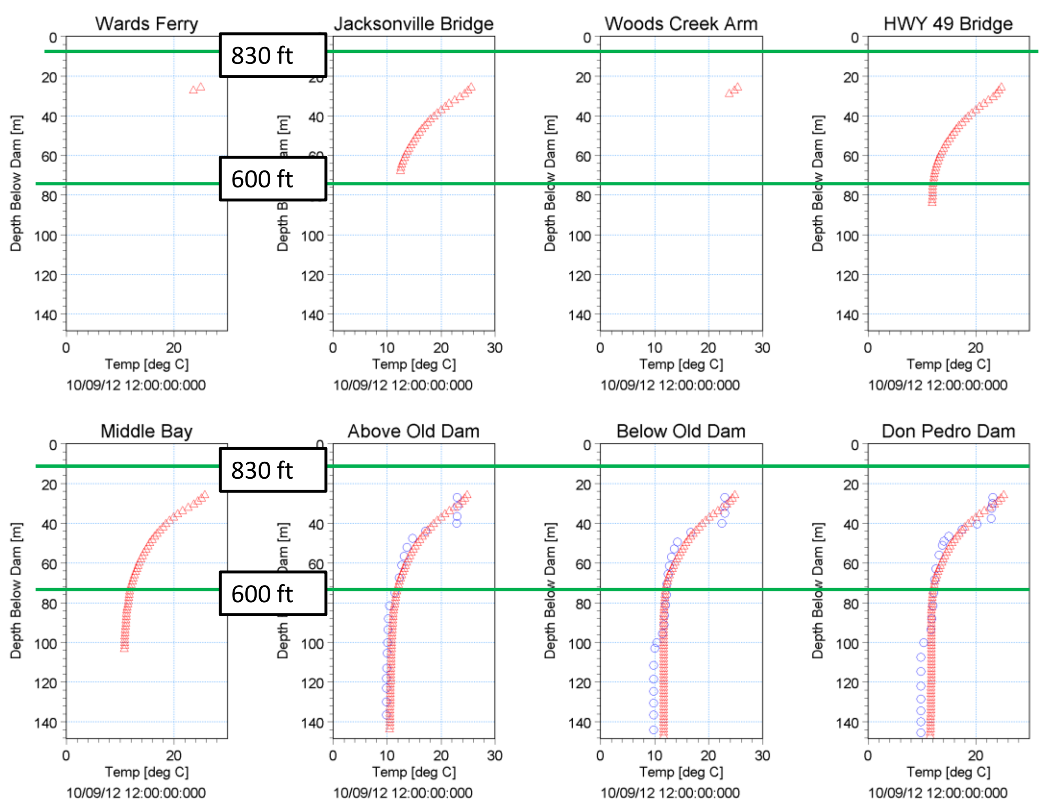


Figure 5.3-11. Oct 9, 2012 validation. (Observed = blue circles; Model = red triangles)

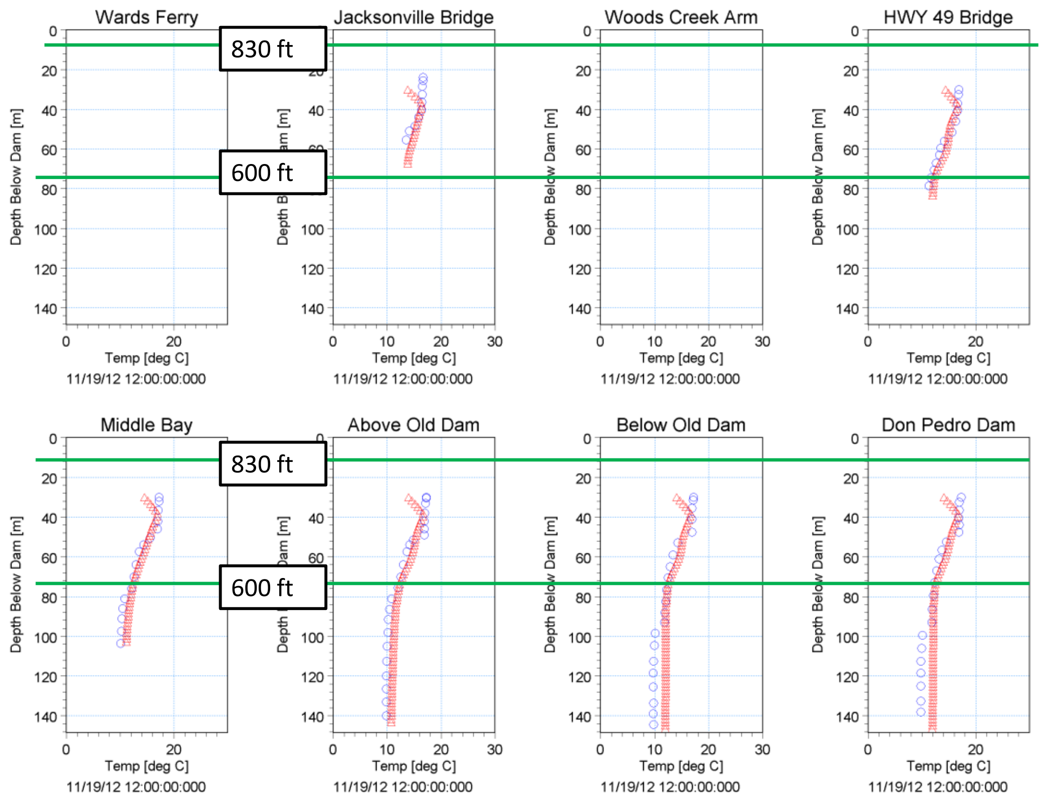


Figure 5.3-12. Nov 19, 2012 validation. (Observed = blue circles; Model = red triangles)

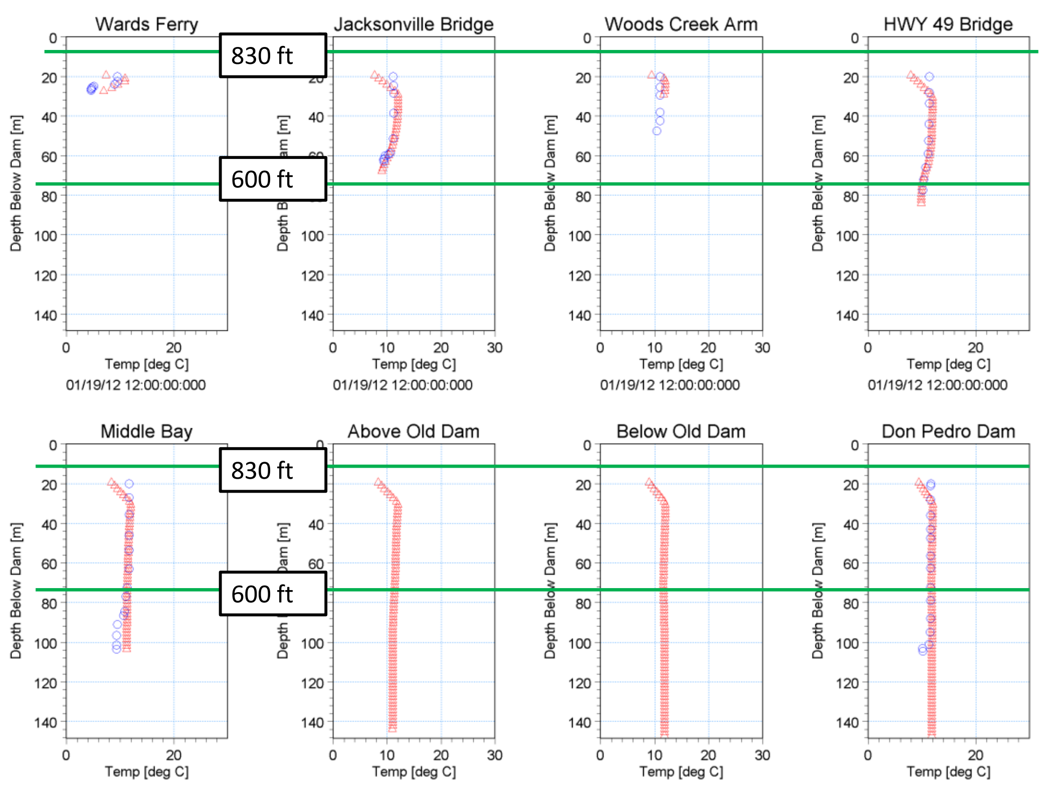


Figure 5.3-13. Jan 19, 2012 validation. (CDFW data only)

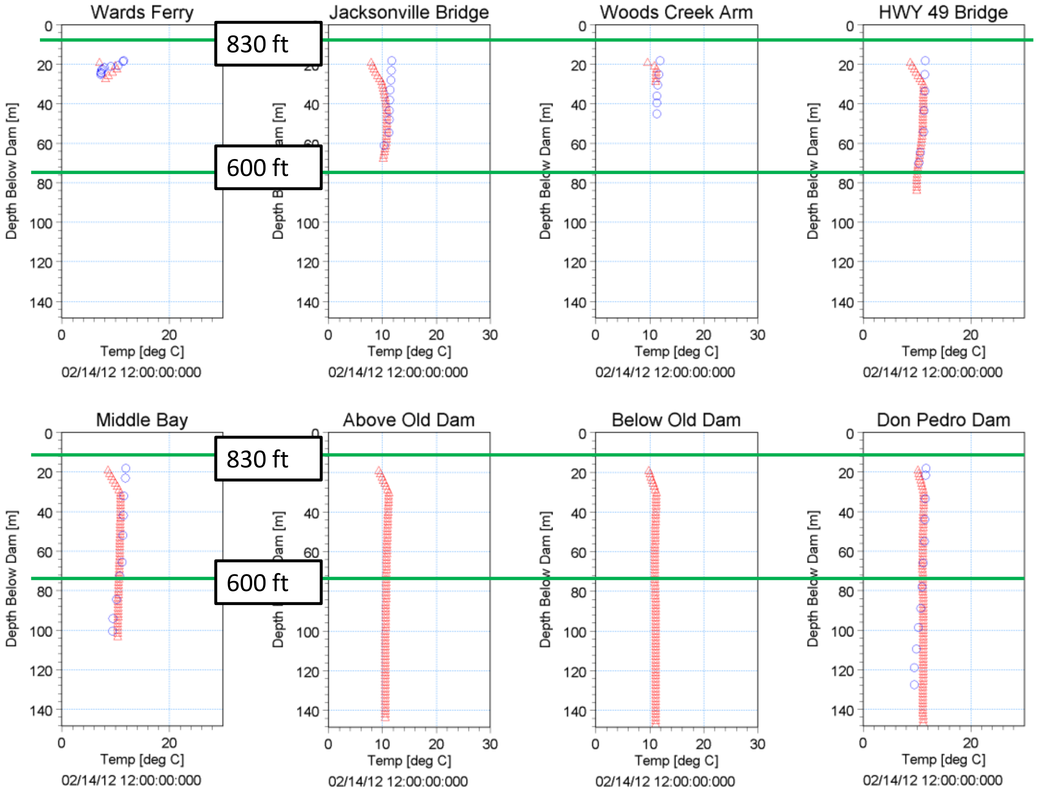


Figure 5.3-14. Feb 14, 2012 validation. (CDFW data only)

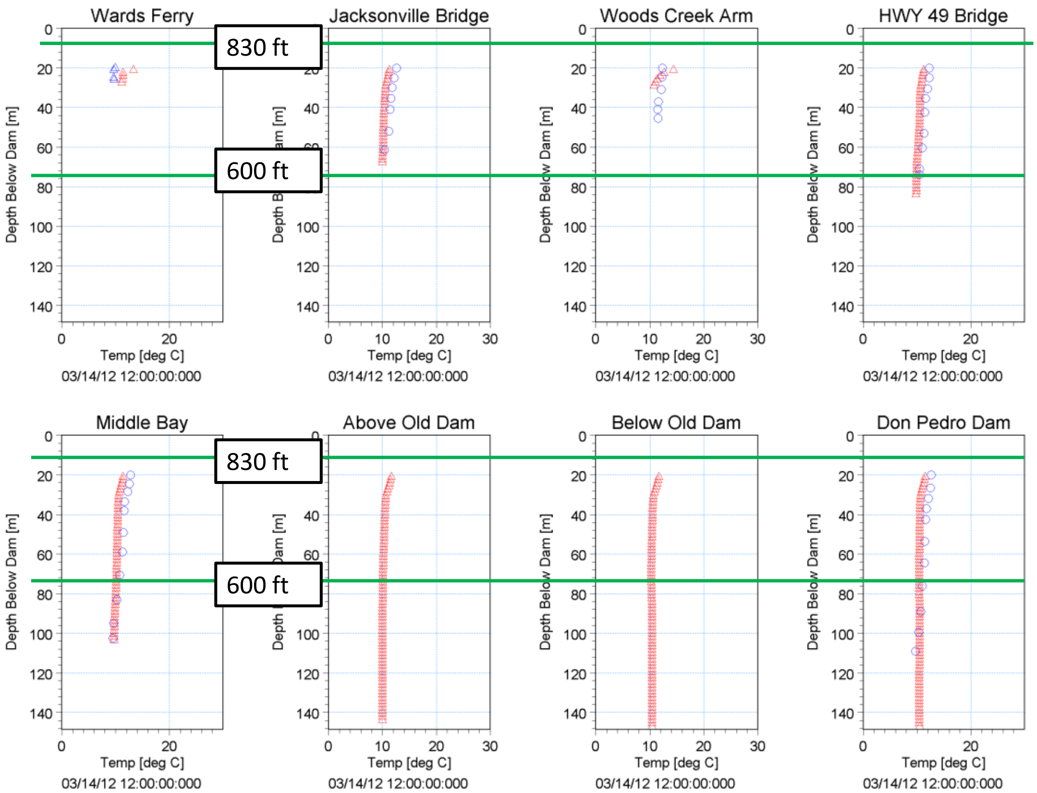


Figure 5.3-15. Mar 14, 2012 validation. (CDFW data only)

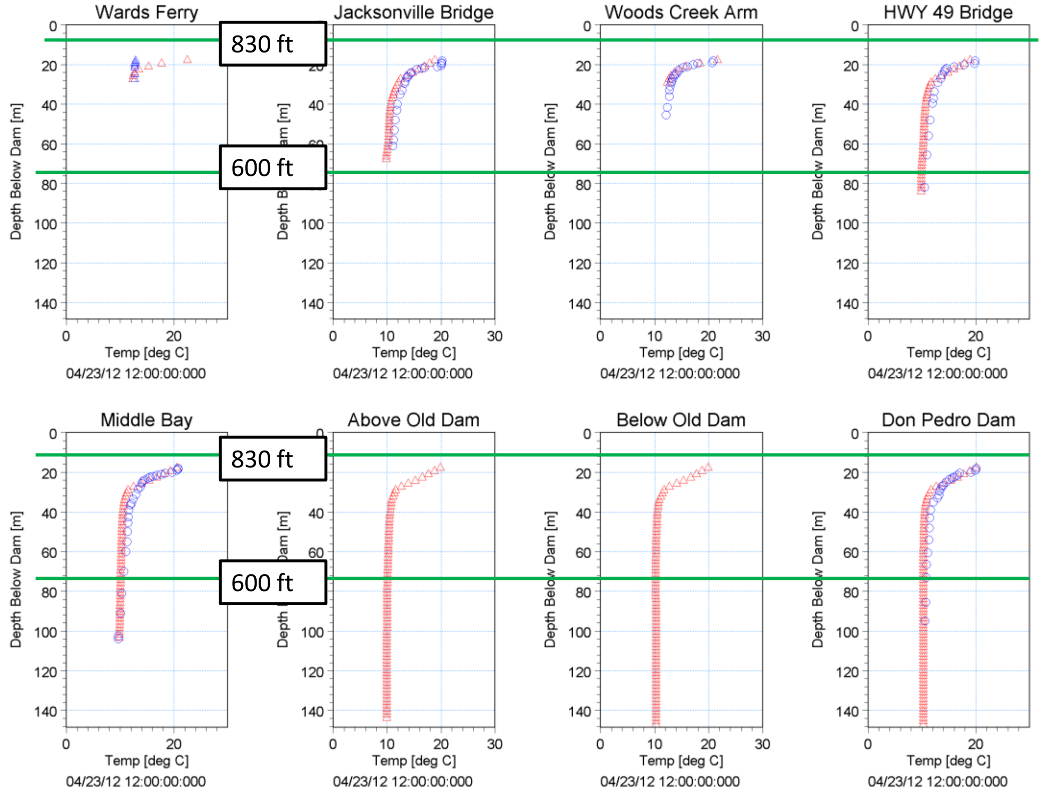


Figure 5.3-16. Apr 23, 2012 validation. (CDFW data only)

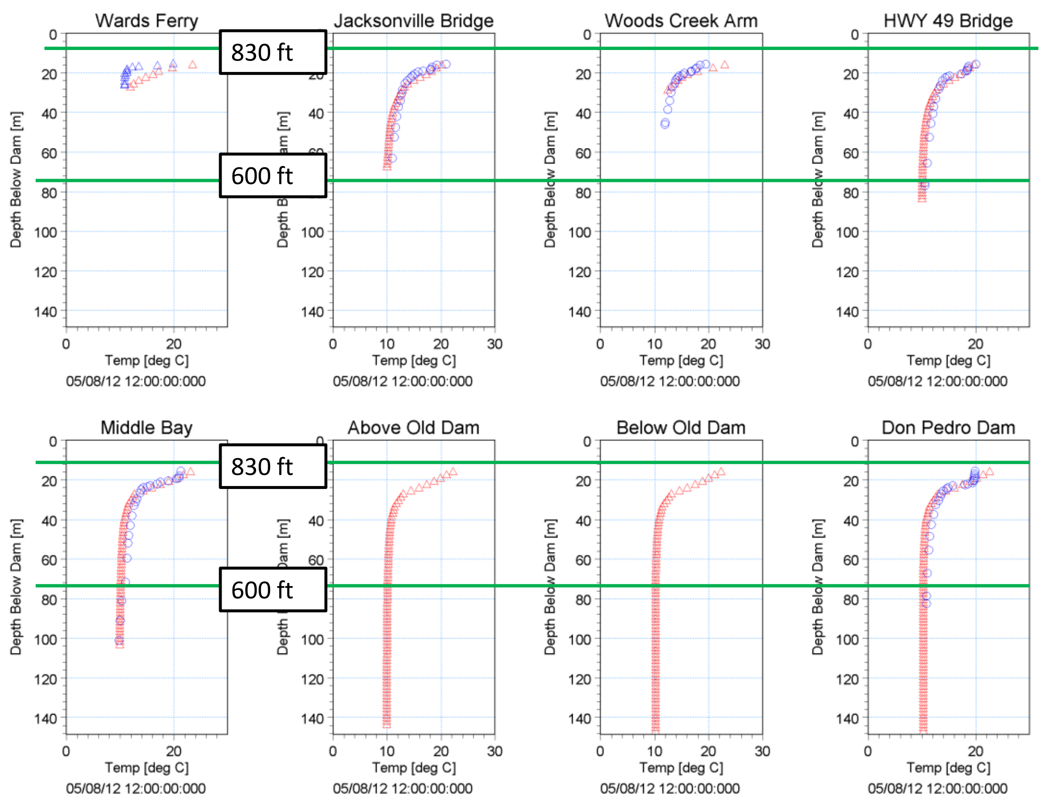


Figure 5.3-17. May 8, 2012 validation. (CDFW data only)

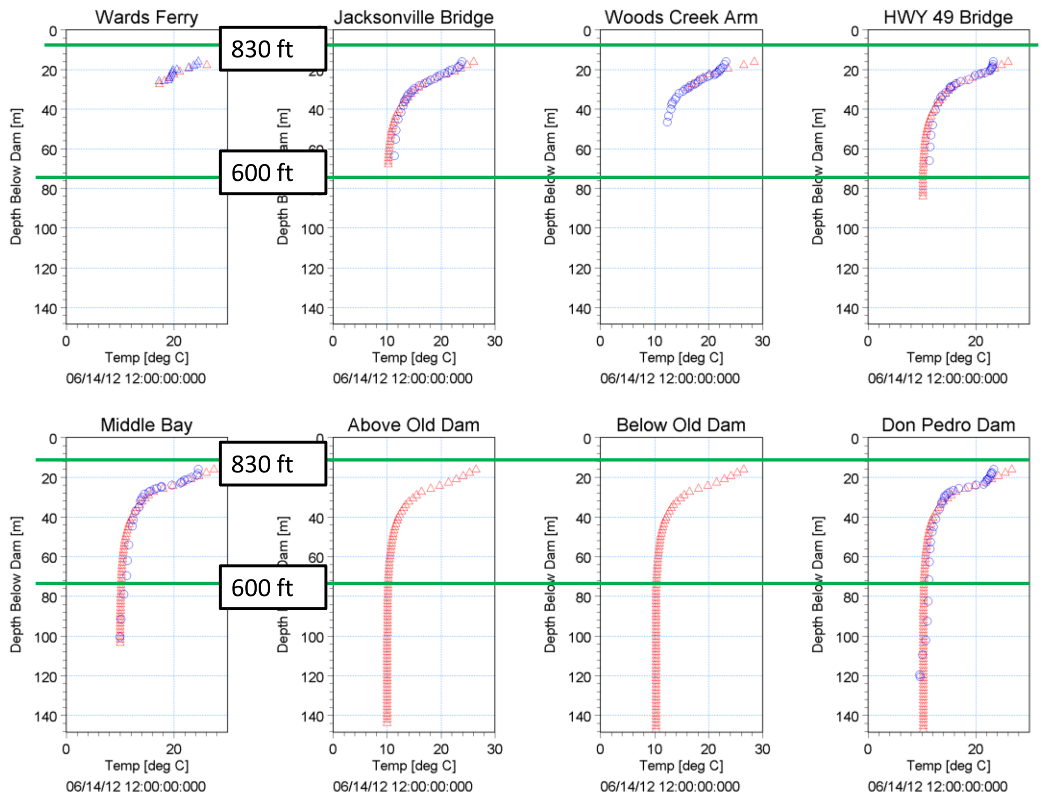


Figure 5.3-18. June 14, 2012 validation. (CDFW data only)

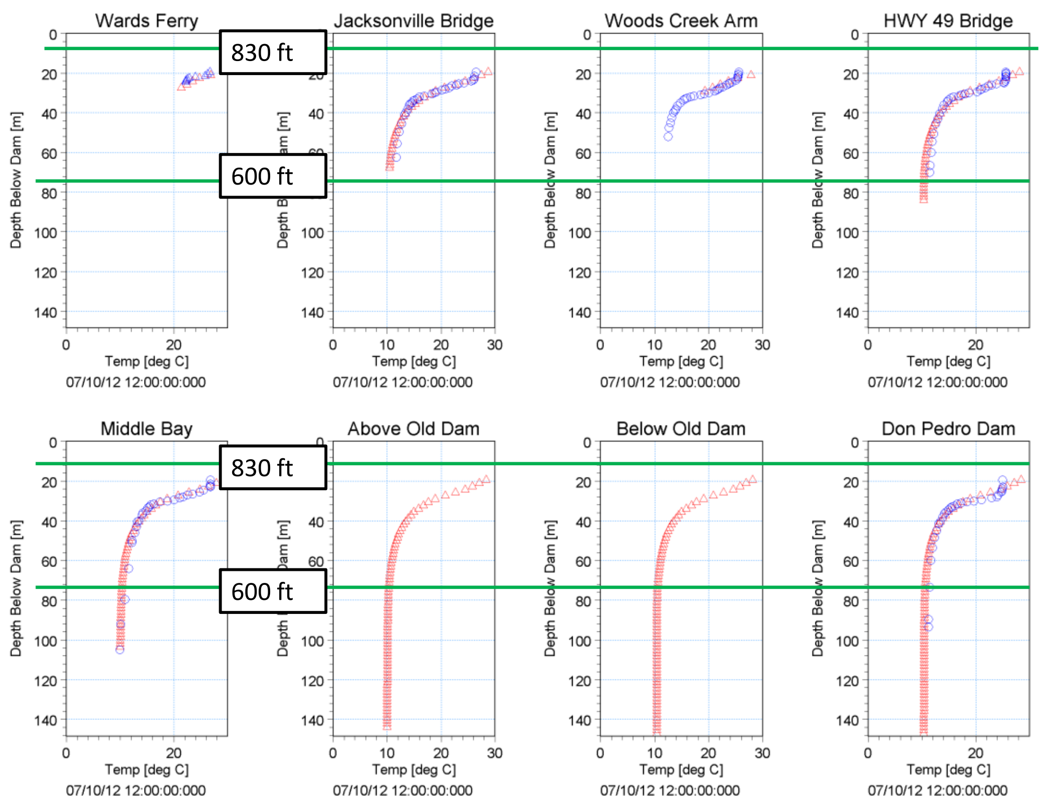


Figure 5.3-19. July 10, 2012 validation. (CDFW data only)

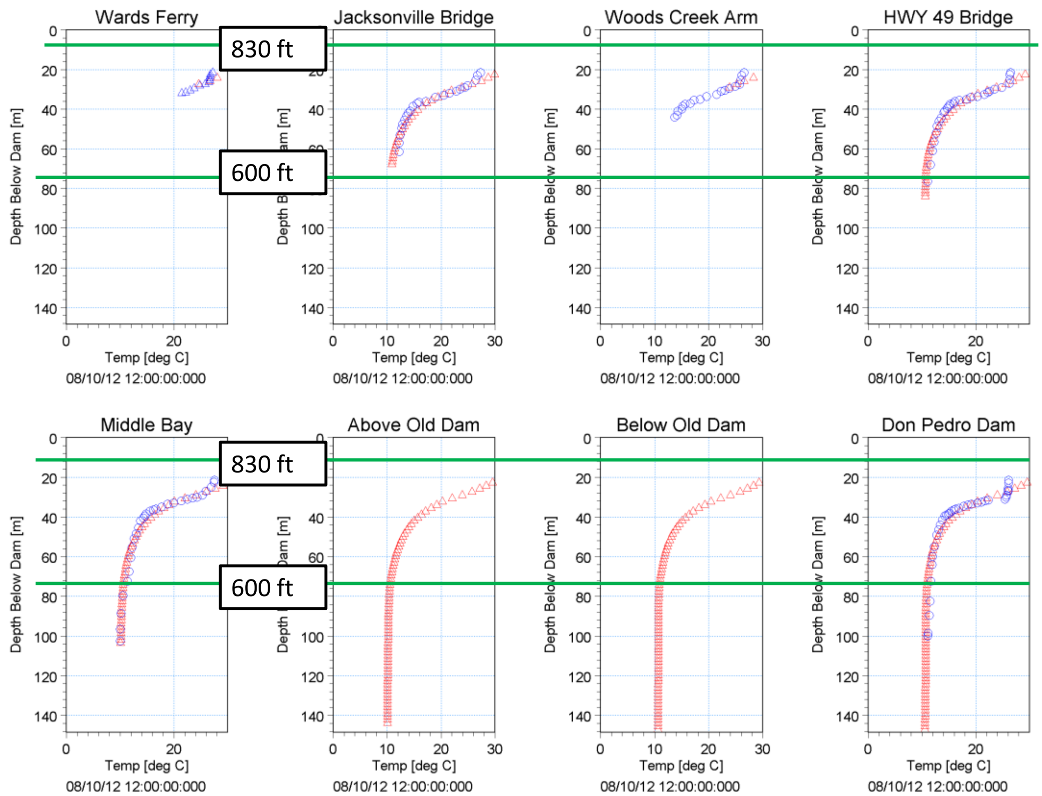


Figure 5.3-20. Aug 10, 2012 validation. (CDFW data only)

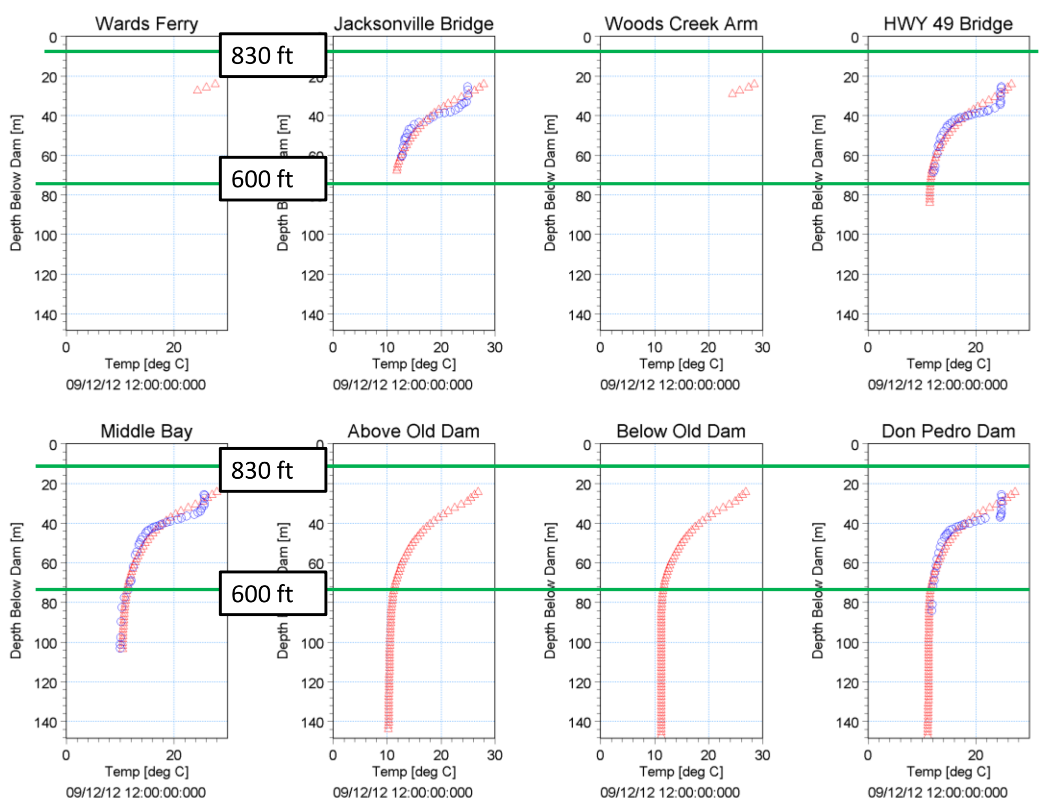


Figure 5.3-21. Sept 12, 2012 validation. (CDFW data only)

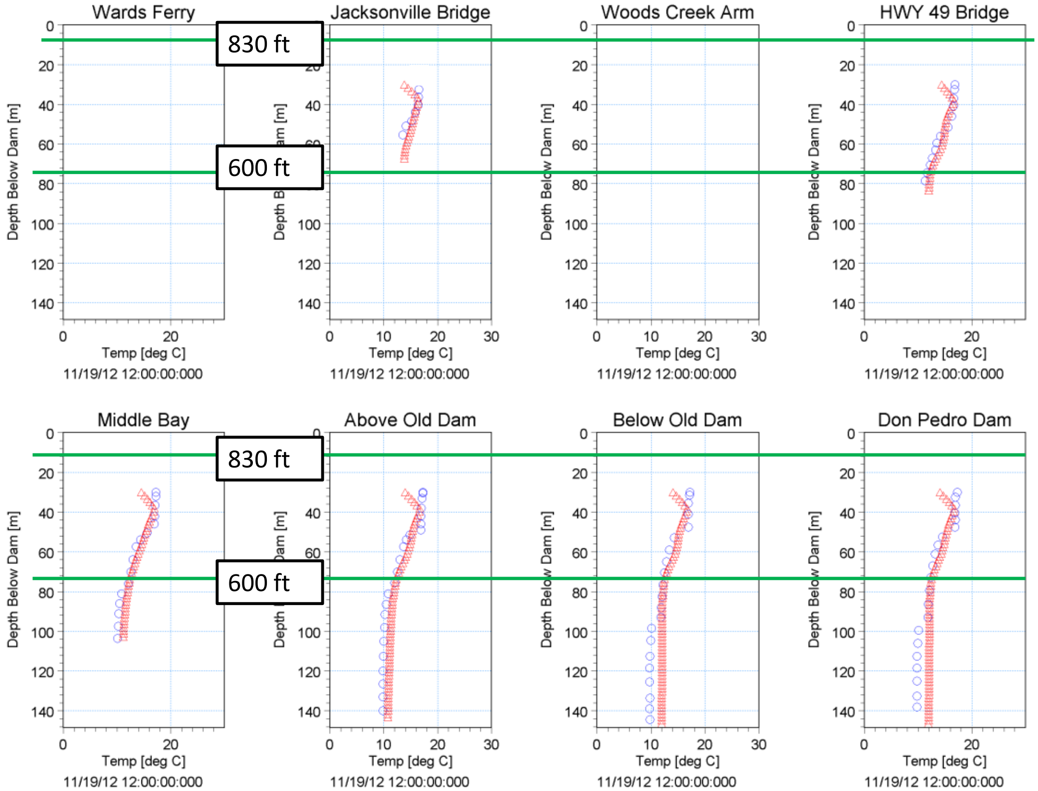


Figure 5.3-22. Oct 25, 2012 validation. (CDFW data only)

5.4 Comparison of Outflow Temperatures

The model was run continuously from January 10, 2011 to December 6, 2012. The computed and measured outflow temperatures over this period are shown in Figure 5.4-1. The model shows good agreement with the measured data, except for a brief period in November 2011 when the powerhouse experienced a forced outage and the outlet gates were used to release flows. The release from the outlet works appeared to be about 2 to 3 degrees Celsius cooler than the power tunnel at this time.

Figure 5.4-1. Measured and modeled outflow temperatures, 2011-12. (Measured = black; Modeled = red)

5.5 Comparison to Observed Surface Temperature Data

During the bathymetric surveys conducted in May and June 2011, surface temperature was recorded. This is shown in Figure 5.5-1. The data is hard to compare directly to the model output as it was collected piecemeal over a five week period (May 2 to June 2). As such the model surface temperatures are shown at the beginning, middle and end of the survey time span – May 2, May 18 and June 2, 2011 (Figure 5.5-2). The figures show the model is predicting temperatures that are in the same range as those measured over the same period.

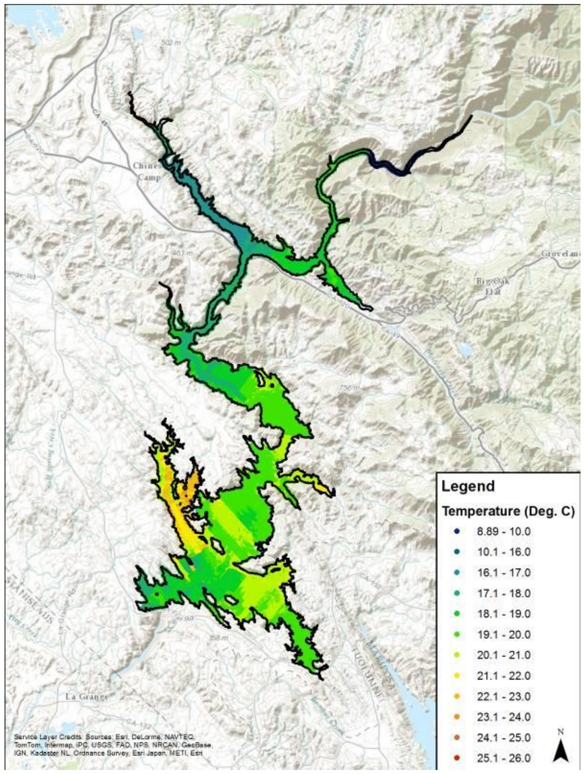


Figure 5.5-1. Measured surface temperatures May 2 – June 2, 2011.

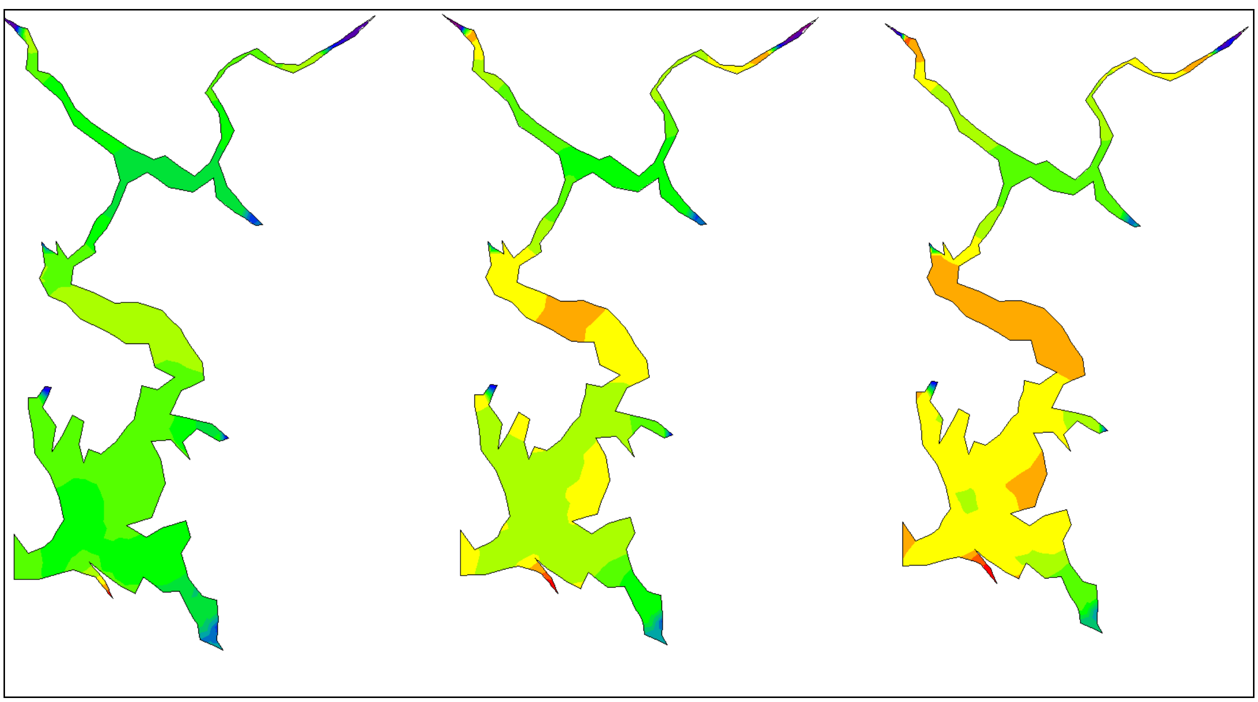


Figure 5.5-2. Modeled surface temperatures May 2, May 18 and June 2, 2011.

5.6 QA/QC Review

A review of all the model input data was performed by an HDR engineer who had not worked on the project and was not involved in the development of the reservoir model, but who is familiar with the DHI MIKE3-FM platform. Each model input time series was compared to the original data that resided in an excel file. These were:

- Inflow
- Reservoir releases
- Inflow temperatures
- Air temperature
- Relative humidity
- Evaporation rates
- Precipitation
- Wind speed
- Wind direction
- Sky clearness

The model bathymetry was compared to the bathymetric survey data. The model parameters that are included in the master run file for the model, the m3fm file, were also checked for consistency with the values reported here. As an inherent check the parameter ranges in the MIKE model are constrained to within reasonable limits set by DHI, and will result in an error if a value outside the range is entered.

6.0 STUDY VARIANCES AND MODIFICATIONS

This study was conducted following the methods described in Study Plan W&AR-03 included in the Districts' Revised Study Plan filed with FERC on November 11, 2011, and approved by FERC in its Study Plan Determination on December 22, 2011. The study was performed in accordance with the FERC-approved study with three exceptions.

The FERC-approved study states that "….January to December 2008 is proposed as one of the model calibration periods." Instead of using 2008 for the calibration period, the Districts used 2011 because the modeling data set for 2008 required synthesizing several input parameters that the Districts were able to directly measure in 2011 and 2012. Hence, the Districts determined that having direct measurements during 2011and 2012 was superior to using estimated values for purposes of model calibration/validation.

The FERC-approved study calls for including the four tributary creeks where water temperature has been measured continuously by the Districts since late April 2011 (Rough and Ready, Woods, Moccasin and Sullivan Creeks; data provided in Attachment A). Both temperature and flow information are required to incorporate the tributaries. During some monitoring periods, all three of these streams were dry. In addition, because hydrology information for the Don Pedro Reservoir Temperature Model was adopted from Tuolumne River Operations Model, (W&AR-02) tributaries could not be directly inserted into the model. The water balance approach developed for the Operations Model accounted for all flow into/out of reservoir, but did not distinguish between the main stem Tuolumne and local tributaries. Adding in the tributary sources would have resulted in double counting. In recognition that not all of the flow into the reservoir enters via the Tuolumne River, the model includes sources that correspond to some of the major tributaries. As observed, these streams contribute only minor amounts of flow, and for many periods no flow, to the reservoir.

The FERC-approved study states that "….a final report will be produced by November 30, 2012" and "the model will be available by December 2012 to evaluate alternative future reservoir operation scenarios." The selection of 2012 as the validation year impacted this schedule, as the final hydrology data set, reservoir profiles, and input temperature data were not all available until the end of February 2013. To stay reasonably on schedule, the Districts conducted an initial training session for relicensing participants in the structure, function, and use of the model on January 24, 2013.

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STUDY REPORT W&AR-03
RESERVOIR TEMPERATURE MODEL

ATTACHMENT A

WATER TEMPERATURE DATA SET
(May 2013)

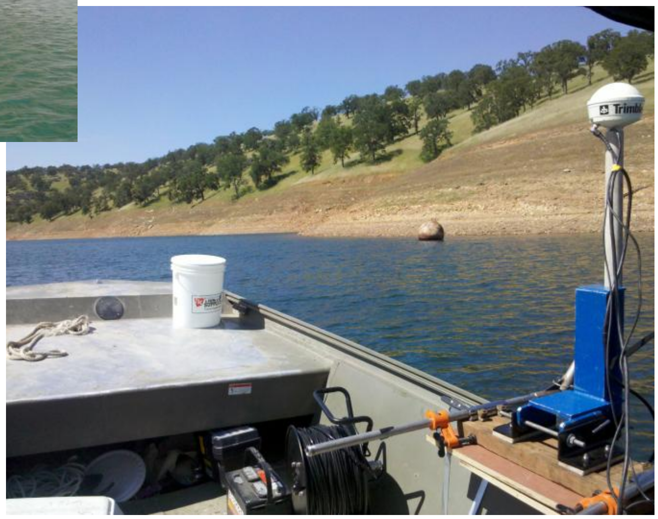
Due to the size and format of the material in Study W&AR-03 Attachment A, copies of the material may be obtained upon request to the Districts. Please contact John Devine, Relicensing Project Manager, at 207.775.4495 or by e-mail at john.devine@hdrinc.com.

STUDY REPORT W&AR-03
RESERVOIR TEMPERATURE MODEL

ATTACHMENT B

DON PEDRO RESERVOIR BATHYMETRIC STUDY REPORT

DON PEDRO RESERVOIR BATHYMETRIC STUDY REPORT



Prepared for:
TURLOCK IRRIGATION DISTRICT
MODESTO IRRIGATION DISTRICT AND
Turlock and Modesto, California

Prepared by:
HDR ENGINEERING, INC.
Sacramento, California

October 2012

Don Pedro Project
FERC No. 2299

TABLE OF CONTENTS

Section No.	Description	Page No.

List of Tables

Table No.	Description	Page No.

List of Figures

Figure No.	Description	Page No.

Attachments

Attachment	Description
A	Quality Assurance Documentation
B	Don Pedro Reservoir Bathymetric Contours (Sheets 1-15) Map Figures: 27 inches x 36 inches (Scaleable to 11 inches x 17 inches and 36 inches x 48inches)

BATHYMETRIC STUDY REPORT

1.0 Objectives

The objective of this study was to develop an accurate reservoir geometry for the Turlock Irrigation District and Modesto Irrigation District (collectively, the "Districts") Don Pedro Reservoir (FERC No. 2299). The resulting reservoir geometry is also used to update the reservoir's elevation-storage curve and provide data on existing conditions for inclusion in the three-dimensional ("3-D") reservoir temperature model under development in support of the FERC relicensing of the Don Pedro Project ("Project").

2.0 Study Area

The study area consists of Don Pedro Reservoir located in Tuolumne County, California, on the Tuolumne River (Figure 2.0-1). Based on Engineer's estimates developed prior to the construction of the Project, at the normal maximum pool elevation of 830 feet (ft) (NGVD 29), Don Pedro Reservoir has a surface area of 12,960 acres and stores 2,030,000 acre-feet of water (ACOE 1972).

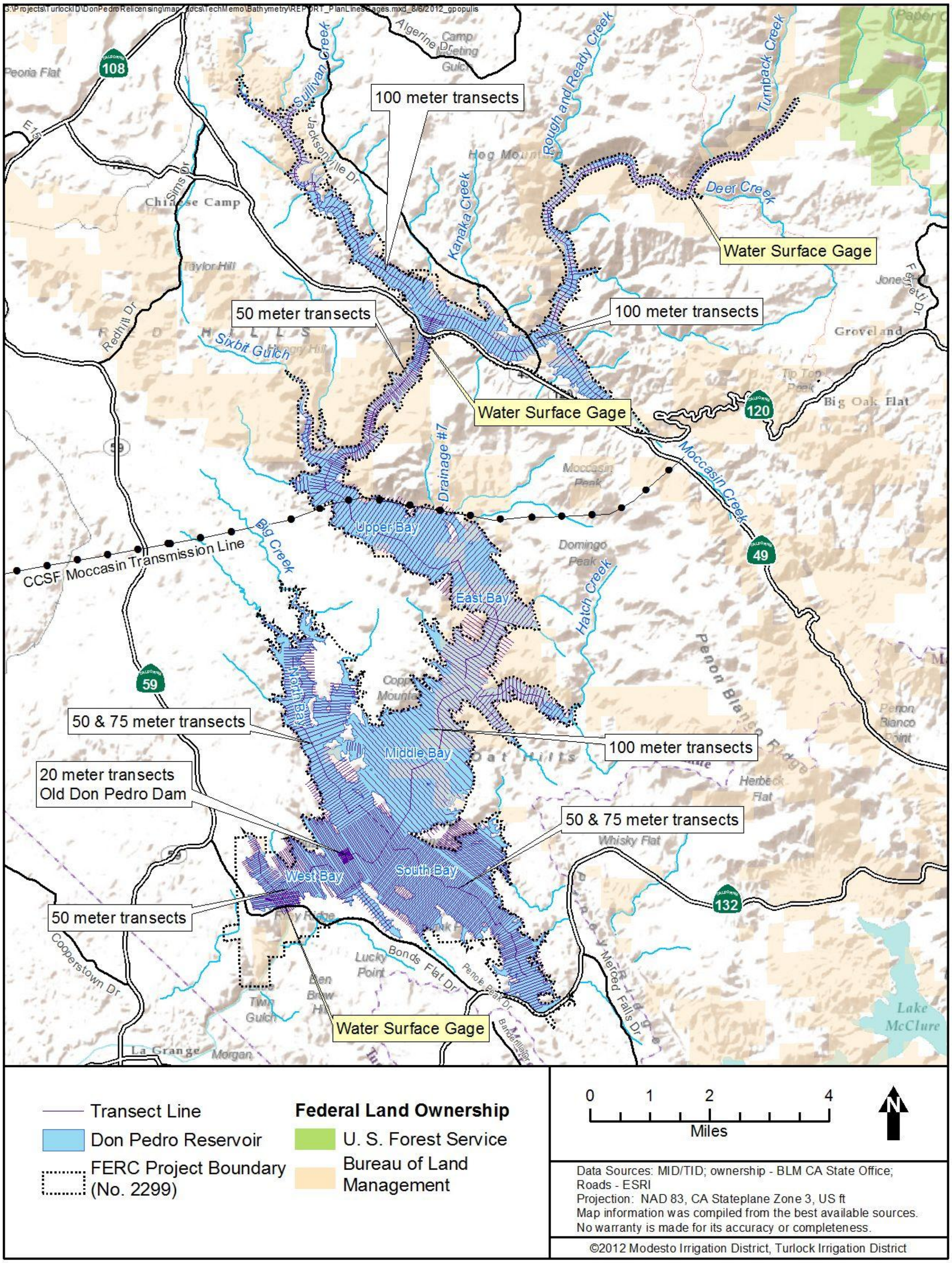


Figure 2.0-1. Don Pedro bathymetry survey plan transects and water surface gages.

3.0 Methods

Bathymetry below the full pool elevation of 830 ft was determined by two techniques: underwater surfaces were surveyed using field measurements (Section 3.1) and topographic information for surfaces above the water were obtained using radar technology (Section 3.2). Data obtained by the two techniques were synthesized into one surface using geographic information system (GIS) software (Section 3.3). Quality assurance and quality control practices are described in Section 3.4.

3.1 Field Survey

The field survey was performed over 16 days between May 1 and June 5, 2011, from a flat-bottom aluminum Johnboat with an outboard motor. This time period was selected due to the relatively high water levels, relatively calm weather, and low amount of recreational boater activity.

During the bathymetric data collection, Don Pedro Reservoir's water surface elevation ranged from approximately 792 ft to 805 ft. Depth data for Don Pedro Reservoir was collected using an Airmar B258 1-kW dual frequency transducer and a Foruno FCV-585 digital depth sounder (with real-time depth profile display) connected to a Trimble PRO-XR GPS and TSC1 Data Collector, capable of providing a real time differential Global Positioning System ("DGPS") data stream. The depth sounder's transducer was mounted onto the side of the boat and lowered 0.3 ft below the surface of the water. The GPS dome antenna was mounted on a platform above the level of the boat. The accuracy of the B258 transducer was ± 0.1 foot of depth (for depths roughly 4 ft or greater) and the accuracy of the PRO-XR GPS receiver was less than one meter of linear distance (with optimal satellite coverage).

Soundings were taken at approximately 1-second intervals and the boat speed was set to ensure that bottom features were appropriately sampled. The boat was navigated along the transect lines using the DGPS, and the position of each sounding was determined using the DGPS system. All depth and horizontal positioning data were recorded digitally in the field as a series of points with x-y-z coordinates, using a rugged field notebook personal computer, running Hypack Hydrographic Survey software.

A total of 1152 transects, spaced at 50, 75, 100 meter intervals and oriented approximately perpendicular to the longitudinal axis of the reservoir, were pre-located and created using Hypack. Areas of topographical concern, such as the Old Don Pedro Dam, were surveyed with greater density for added resolution. In addition to the standard transects, perpendicular "tie lines", oriented approximately parallel to the longitudinal axis of the reservoir and its tributary arms, were established to ensure inter-transect data consistency. A Furuno real-time depth profile display was deployed to identify and navigate areas of topographical concern including confined coves and bars that were found while performing routine grid transects. Transects covered the entire reservoir at the water surface elevation during the time of the field data collection (Figure 2.0-1).

Once all the data were collected, the sounder depth records were edited in Microsoft Excel to remove all but the necessary data to be matched up with a DGPS location and depths were corrected for submergence of the transducer, i.e. the “draft” or the depth from the water surface to the face of the transducer.

Reservoir water level elevations were measured throughout the study from three gages. Water surface elevations near the dam of the reservoir are routinely measured and recorded hourly by TID.[1] For this study, water surface elevation gages were also installed at two other locations, where existing benchmarks provided vertical control for combining all elevation data to a common datum: (1) the Highway 120/49 Bridge across Railroad Canyon (NGS E1389),[2] and (2) the Wards Ferry Bridge (NGS HS4439).[3] All vertical control measurements were then converted to match the vertical datum of the gage at Don Pedro Dam. These reservoir elevations were incorporated into the bathymetric model to adjust each reservoir depth measurement across the reservoir for changes in water surface elevation between the beginning and end of each survey period to the reservoir datum.

The potential existed for an energy slope to form on the surface of Don Pedro Reservoir, as relatively large rates of inflow were observed at the time of the survey.[4] (When an energy slope is present, a reservoir’s water surface elevation increases from downstream to upstream.) Hence, on May 5, 2011, a water surface elevation logger (WSEL) was surveyed near the upper end of the reservoir using the monuments at the Highway 120/49 Bridge and at Wards Ferry Bridge. Water surface elevations as detected by the new logger were then compared to the water level as detected by the gage at Don Pedro Dam. After analyzing the collected water level information, it was determined that there was not a measurable energy gradient during the period of survey. Hence, for the purpose of this data collection effort, the water surface of Don Pedro Reservoir was assumed to be flat.

3.2 IFSAR

Topographic information above 792 ft was obtained by interferometric synthetic aperture radar (IFSAR), which was collected by the vendor Intermap during August 2004. The water surface of the reservoir at the time the IFSAR data were collected was 760 ft and the resulting Digital Terrain Model (DTM) extends upwards to well above the reservoir’s full pool elevation of 830 ft.

3.3 Surface Model Generation

A contour line at the normal maximum water surface elevation of 830 ft was generated using a GIS contouring tool with the IFSAR DTM. It was visually checked and modified as needed using a horizontally more accurate hi-resolution aerial image.

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1 http://www.tid.org/water/hydrological-data

2 http://www.ngs.noaa.gov/cgi-bin/ds_mark.prl?PidBox=HS1389

3 http://www.ngs.noaa.gov/cgi-bin/ds_mark.prl?PidBox=HS4439

4 Inflows to Don Pedro Reservoir ranged from 5,192 cfs to 12,652 cfs during this study (http://cdec.water.ca.gov/).

The bathymetric survey point data were imported into ESRI ArcGIS Desktop software where the point data was integrated with the IFSAR DTM data to make a continuous network of points below the normal maximum water surface contour. That network of points was used develop a network of bottom lines or thalwegs. The points, the bottom lines and the normal maximum water surface contour were then used as input for the ESRI surface interpolation tool "Topo to Raster". The Old Don Pedro Dam was located during the survey and construction drawings of that dam[5] were useful to integrate that feature into the interpolated surface. Contours at 10 ft intervals were then inferred using ESRI contouring tools. The result of this analysis was a continuous surface model that will be used as input to the 3-D reservoir temperature model.

3.4 Quality Assurance and Quality Control

Data quality was assured by following manufacturer's instructions and periodically verifying data values through an alternative measurement (in the field) and third-party review (in the office). Throughout the field survey, the depths measured by the sounder were periodically compared to the actual depth. The actual depth was measured by either lowering a "bar" beneath the sounder or by direct measurement of the bottom with a lead line or pole. Measurement of the "draft" or the depth from the water surface to the face of the transducer was also periodically recorded.

Quality Assurance of the bathymetric surface was performed by an independent reviewer following three steps. The first step consisted of a review of the field methods and materials. The second step consisted of checking the edited raw data. Finally, the third step consisted of verifying the methods used in the production of the final deliverable.

Review of field methods included a review of the "bar checks" performed in the field and described above. In addition, specifications of the sounder and DGPS used in the survey were reviewed to confirm the accuracy of the data as reported. The water surface elevation data at the three gages were also checked for consistency.

Next the processing of the raw data was checked. Any data with DGPS errors or sounding errors that had been flagged by the modeler were checked to confirm that the deletion was appropriate prior to interpolation. Soundings were spot checked for consistency. The crossing of transects and tie-lines was reviewed to ensure that the sounder recorded similar depths at the intersection of survey lines. If any sharp differences in depth at adjacent points were present, they were identified as either an error or a real feature.

The last step was check of the final bathymetric surface (Attachment A). Once the field methods and raw data were reviewed, the production of contours from a bathymetric surface was checked. Calculation of the bottom elevation from sounding depths was reviewed to ensure corrections for the draft and varying water surface elevation were properly accounted for. The method of interpolation and settings used in the interpolation was reviewed to ensure that reasonable contours were generated. Contours created using interpolation were checked against actual soundings to verify that the interpolated surface is reasonable. Finally, contours were checked

[5] TID and MID 1920

against the original elevation-storage curve, as well as historical United States Geological Survey (USGS) maps.

4.0 Results and Analysis

Don Pedro Reservoir contours at 10-ft intervals are displayed along with a shaded relief of the surface in a series of maps at the end of this report (Figures 1 through 15 in Attachment B).

Using the survey data, reservoir volume was calculated in one-foot contour intervals from the bottom of the reservoir to the normal full pool elevation. The calculated storage using the new bathymetry data is compared to the original storage capacity information in Table 4.0-1 and Figure 4.0-1. The original elevation-storage curve indicated that Don Pedro Reservoir at the time of its construction had a total storage capacity of 2,030,000 acre-feet of water at elevation 830 ft (ACOE 1972), while the new bathymetric surface indicates the reservoir holds 2,014,306 acre-feet at that elevation—a difference of less than 1 percent.

Table 4.0-1. Don Pedro Reservoir volume comparison between original elevation storage curve and 2011 bathymetry survey data.

	Cumulative Volume (ac-ft)				Incremental	
Elevation (ft)	Original Storage Curve[1]	2011 Bathymetry Survey	Gain (Loss) in Total Storage[2]	Percent Gain/Loss of Total Storage	Gain (Loss) in Total Storage[2]	Percent
550	158731	158578	(153)	-0.01%	(153)	-0.10%
570	212870	211023	(1,847)	-0.09%	(1,694)	-0.80%
590	274760	272508	(2,252)	-0.11%	(405)	-0.15%
620	384060	382330	(1,730)	-0.09%	523	0.14%
650	517450	516849	(601)	-0.03%	1,129	0.22%
680	678950	677807	(1,143)	-0.06%	(542)	-0.08%
710	869700	867442	(2,258)	-0.11%	(1,116)	-0.13%
740	1094900	1090096	(4,804)	-0.24%	(2,545)	-0.23%
770	1359200	1350810	(8,390)	-0.41%	(3,586)	-0.26%
800	1669000	1657028	(11,972)	-0.59%	(3,582)	-0.21%
830	2030000	2014306	(15,694)	-0.77%	(3,722)	-0.18%

[1]ACOE 1972 Flood Control Manual
[2] Original Survey Volume at Elevation – 2011 Survey Volume at Same Elevation

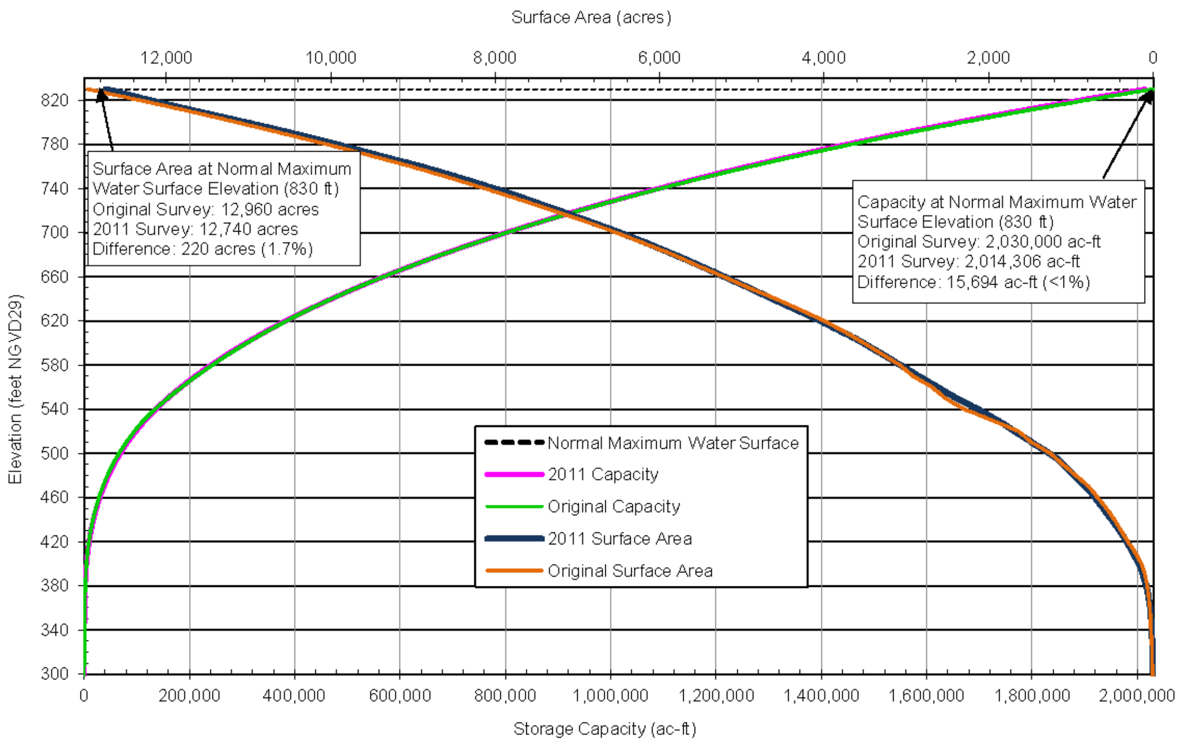

Figure 4.0-1. Don Pedro Reservoir area-capacity curves (reference data: ACOE 1972; 2011 bathymetry study).

5.0 Discussion

As demonstrated in Section 4.0, the storage volumes provided by the original elevation-storage curve and the new bathymetric surface differ by less than 1%. It is recognized that the two estimates were developed based on different survey methods and bathymetric surface calculation methodologies. Other than the elevation-storage curve itself, the input data used to generate the ACOE 1972 curve were not available. However, both methods relied on engineering standards for computations in use at the time of survey, indicating an appropriate level of computational rigor was applied to both estimates. Therefore, it is reasonable to conclude that, for all intents and purposes, the 2011 survey substantially confirms the 1972 elevation-storage information and that any loss of storage in the Don Pedro Reservoir since Project construction can be considered to be minimal.

6.0 References

ACOE. 1972. Report on Reservoir Regulation for Flood Control. Appendix A Flood Control Regulations. Don Pedro Dam and Lake, Tuolumne River, California. Department of the Army. Sacramento District, Corps of Engineers. Sacramento, California. August.

Barnes, D.H. 1987. The Greening of Paradise Valley. The first 100 years (1887-1987) of the Modesto Irrigation District. Commissioned by the Modesto Irrigation District in recognition of its centennial year. 233 pp. Available on line at: http://www.mid.org/about/history/default.html

Environmental Science Research Institute ArcGIS 10. Available online at: <http://help.arcgis.com/en/ arcgisdesktop/10.0/help/index.html>.

Intermap. Available online at: <http://www.intermap.com/>.

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