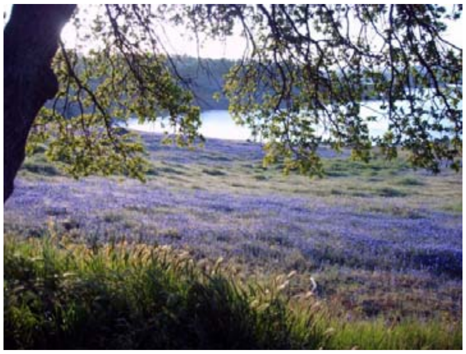
RESERVOIR TEMPERATURE MODEL
PROGRESS REPORT
DON PEDRO PROJECT
FERC NO. 2299





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

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Reservoir Temperature Model
Progress Report

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List of Acronyms

ac	acres
ACEC	Area of Critical Environmental Concern
AF	acre-feet
ACOE	U.S. Army Corps of Engineers
ADA	Americans with Disabilities Act
ALJ	Administrative Law Judge
APE	Area of Potential Effect
ARMR	Archaeological Resource Management Report
BA	Biological Assessment
BDCP	Bay-Delta Conservation Plan
BLM	U.S. Department of the Interior, Bureau of Land Management
BLM-S	Bureau of Land Management – Sensitive Species
BMI	Benthic macroinvertebrates
BMP	Best Management Practices
BO	Biological Opinion
CalEPPC	California Exotic Pest Plant Council
CalSPA	California Sports Fisherman Association
CAS	California Academy of Sciences
CCC	Criterion Continuous Concentrations
CCIC	Central California Information Center
CCSF	City and County of San Francisco
CCVHJV	California Central Valley Habitat Joint Venture
CD	Compact Disc
CDBW	California Department of Boating and Waterways
CDEC	California Data Exchange Center
CDFA	California Department of Food and Agriculture
CDFG	California Department of Fish and Game (as of January 2013, Department of Fish and Wildlife)
CDMG	California Division of Mines and Geology
CDOF	California Department of Finance
CDPH	California Department of Public Health

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

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

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

NWI............................National Wetland Inventory
NWIS ....National Water Information System
NWR ....National Wildlife Refuge
NGVD 29 ....National Geodetic Vertical Datum of 1929
O&M ....operation and maintenance
OEHHA......................Office of Environmental Health Hazard Assessment
ORV ....Outstanding Remarkable Value
PAD.............................Pre-Application Document
PDO.............................Pacific Decadal Oscillation
PEIR ....Program Environmental Impact Report
PGA.............................Peak Ground Acceleration
PHG.............................Public Health Goal
PM&E ....Protection, Mitigation and Enhancement
PMF.............................Probable Maximum Flood
POAOR ....Public Opinions and Attitudes in Outdoor Recreation
ppb..............................parts per billion
ppm ....parts per million
PSP ....Proposed Study Plan
QA ....Quality Assurance
QC ....Quality Control
RA ....Recreation Area
RBP ....Rapid Bioassessment Protocol
Reclamation ...............U.S. Department of the Interior, Bureau of Reclamation
RM ....River Mile
RMP ....Resource Management Plan
RP...............................Relicensing Participant
RSP ....Revised Study Plan
RST ....Rotary Screw Trap
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 ft above mean sea level (msl; NGVD 29). At elevation 830 ft, the reservoir stores over 2,000,000 acre-feet (AF) of water and has a surface area slightly less than 13,000 acres (ac). The watershed above Don Pedro Dam is approximately 1,533 square miles (mi^2).

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

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

The Project Boundary extends from approximately one mile downstream of the dam to approximately RM 79 upstream of the dam. Upstream of the dam, the Project Boundary runs generally along the 855 ft contour interval which corresponds to the top of the Don Pedro Dam. The Project Boundary encompasses approximately 18,370 ac with 78 percent of the lands owned jointly by the Districts and the remaining 22 percent (approximately 4,000 ac) is owned by the United States and managed as a part of the U.S. Bureau of Land Management (BLM) Sierra Resource Management Area.

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

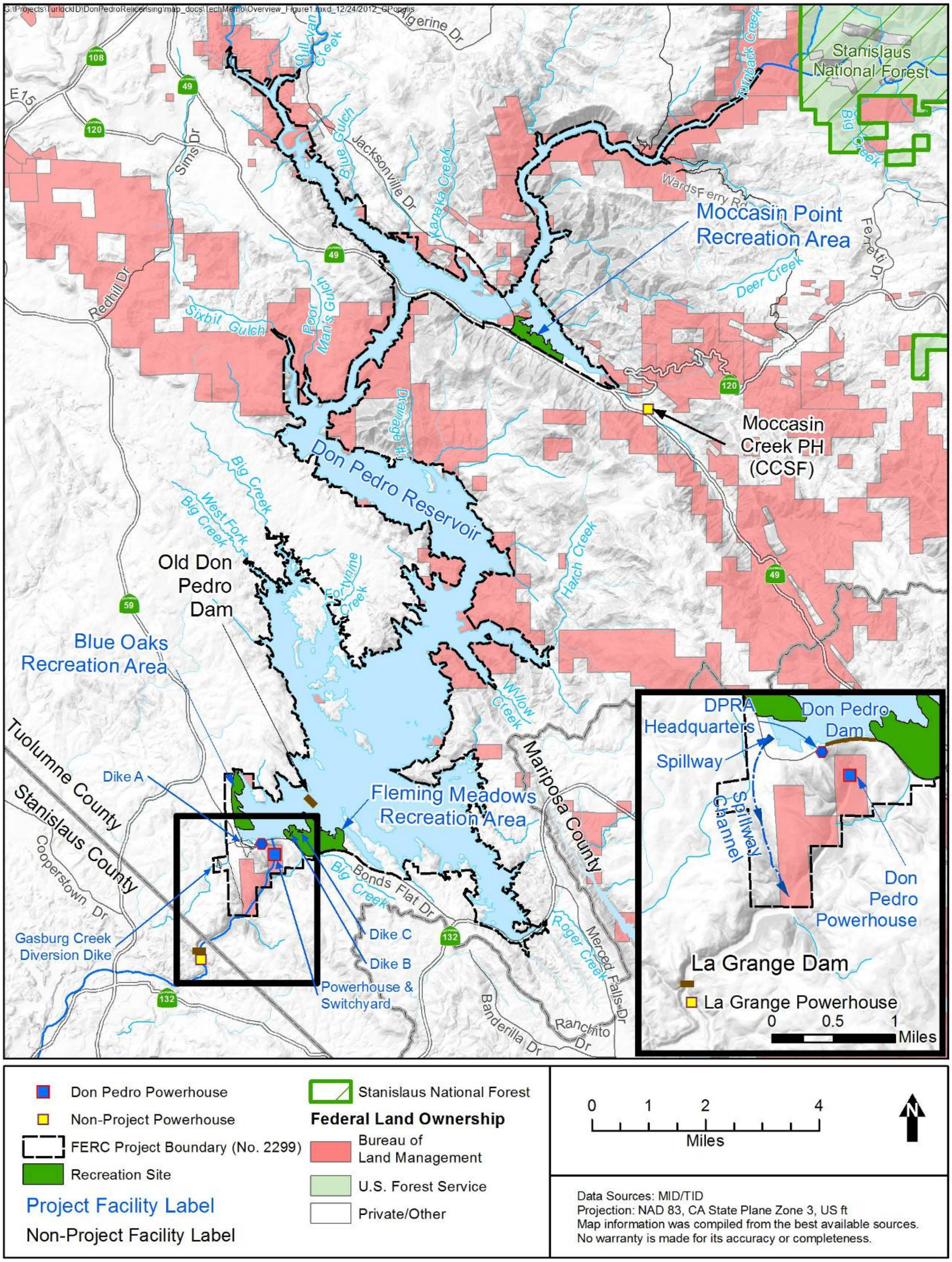

Figure 1.1-1. Don Pedro Project location.

1.2 Relicensing Process

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

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

Following the SPD, a total of seven studies (and associated study elements) that were either not adopted in the SPD, or were adopted with modifications, formed the basis of Study Dispute proceedings. In accordance with the ILP, FERC convened a Dispute Resolution Panel on April 17, 2012 and the Panel issued its findings on May 4, 2012. On May 24, 2012, the Director of FERC issued his Formal Study Dispute Determination, with additional clarifications related to the Formal Study Dispute Determination issued on August 17, 2012.

This progress report describes the objectives, methods, and results of the 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. Through this model, water temperatures in the reservoir were 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 may be used to evaluate the effects on reservoir thermal structure and dynamics resulting from the current and 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's objectives are 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 conditions.

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). Output from the reservoir temperature model serves as input to the river temperature model. Reservoir and river temperatures may also inform 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 extends from about elevation 300 feet to about elevation 850 feet, or from the tailwater of Don Pedro powerhouse to about 20 feet above the Don Pedro Reservoir normal maximum reservoir elevation of 830 feet. The study area is shown in Figure 3.0-1.

The Don Pedro Reservoir extends upstream from the Don Pedro Dam (RM54.8) for approximately 24 miles at the normal maximum water surface elevation of 830 feet. The surface area of the reservoir at the 830-foot elevation is approximately 12,960 acres 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.

The inflows to Don Pedro Reservoir are dominated by the main stem of the Tuolumne River. The flow in the main stem of the Tuolumne River are primarily the release from the Hetch Hetchy Reservoir system, located above river mile 117. The North Fork of the Tuolumne river joins the main stem at river mile 81.5.

The upper Tuolumne River watershed, the subbasin above about RM 80, covers approximately 1,300 square miles 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 feet. 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 City and County of San Francisco's (CCSF) Hetch Hetchy Water and Power system, including Hetch Hetchy Reservoir, Lake Eleanor and Cherry Lake, and CCSF's extensive infrastructure of water transmission and water power facilities.

The foothills reach of the Tuolumne River can be considered to extend from RM 54 to RM 80 and this reach is dominated by the Don Pedro Project. This portion of the watershed includes many 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 which was inundated in 1971 at river mile 56.5. Old Don Pedro Dam had a crest height of 600 ft and was approximately 1000 ft long.

Outflows from Don Pedro Reservoir mainly come from withdrawals through the powerhouse intake tunnel at elevation 535. At flows above 6,300 cfs, flow can be diverted through the diversion tunnel at elevation 345 ft up to approximately 7,500 cfs. Above these flow rates the flow must pass over the spillway at elevation 830 ft.

The reservoir can experience extreme variations in water levels, ranging from a normal maximum operating elevation of 830 ft to below 700 ft in dry years. In dry years it is not uncommon for the reservoir elevations to change by 100 ft or more.

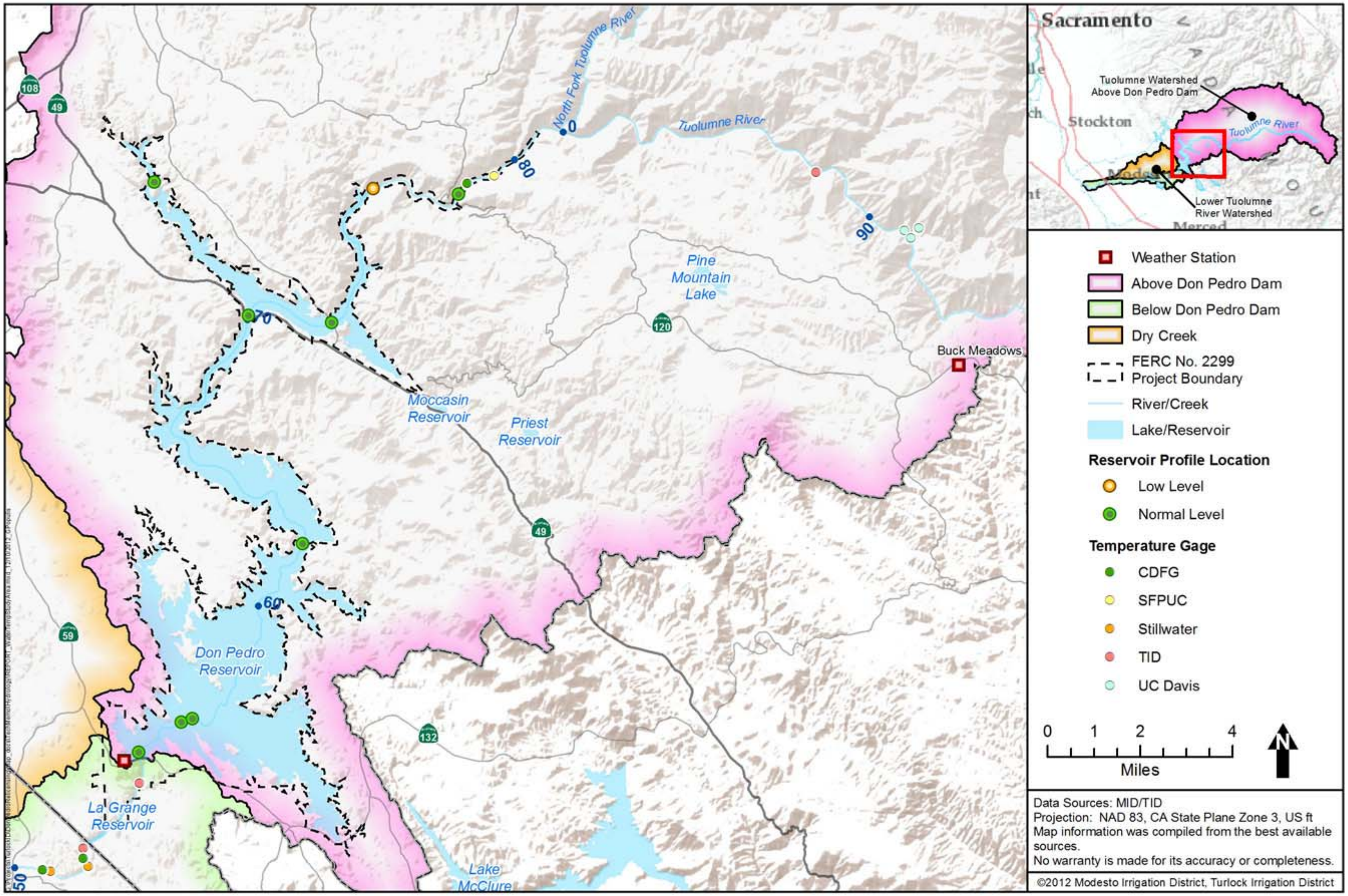

Figure 3.0-1. Study area.

4.0 METHODOLOGY

4.1 Model Platform Selection

To select the water temperature model or model platform, the Districts developed a list of required water temperature model platform attributes necessary to meet the study's goals and objectives. The attributes were:

- simulate water temperatures on an appropriate time-step to capture biologically-appropriate water temperature variability;
- simulate water temperatures over the full range of historical hydrology and meteorology experienced by Project-affected streams (i.e., the hydrology period of record from Water Year (WY) 1971 through WY 2012);
- Account for the effect of major physical in-reservoir complexities on reservoir temperatures, including the Old Don Pedro Dam and the reservoir's dendritic shape; and
- simulate the effects of Don Pedro Reservoir releases on downstream water temperatures due to storage changes, climatological effects, flow changes and outlet used (i.e., the Don Pedro power intake and tunnel, the outlet works/original construction bypass tunnel)

Based on the selection attributes, the following water temperature model platforms were considered[1]:

- HEC-5Q, one-dimensional (1-D), longitudinally- and laterally-averaged
- CE-QUAL-W2, two-dimensional (2-D), laterally averaged
- RMA-10, three-dimensional (3-D)
- MIKE3-FM, three-dimensional (3-D)

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 it has been applicable. 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. These assumptions do not allow the horizontal variation in temperatures observed in the 24 mile long dendritic Don Pedro Reservoir to be incorporated into the model, nor do they account for the effect of Old Don Pedro Dam on reservoir temperatures at depth. Reservoir profiles and upstream and downstream temperature data describe a more complex temperature regime. Hence, the model results are limited in their biological relevance.

The 2-D model, CE-QUAL-W2, has been widely used in many relicensing processes and is recognized as a reliable model. However, like the HEC-5Q model, CE-QUAL assumes complete

[1] For additional detail, see W&AR-03 Reservoir Temperature Model Study Plan (TID/MID 2011).
[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).

lateral mixing and averages lateral temperatures. The CE-QUAL-W2 model would require multiple branches to accurately represent the dendritic shape 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 are also somewhat limited in their biological relevance.

Two 3-D model platforms were considered, the RMA-10 and MIKE 3. Both models provide results that are more biologically relevant and provide more flexibility for outlet withdrawal dynamics than the 1-D or 2-D models. However, the MIKE3 documentation, graphical user interface, and technical support are considered superior to RMA-10. 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 has allowed the Districts to develop a model that meets the 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). Output from the reservoir temperature model serves as input to the river temperature model. Flow releases from Don Pedro and reservoir levels will be provided by the Operations Model on a mean daily basis.

4.3 Compilation of Input, Calibration, and Verification 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 and 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 rule data to create the outflow dataset 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 five 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.

<table>
<tr><th>Required Data</th><th colspan="3">Source</th></tr>
<tr><td colspan="4">Physical and Geomorphological—Don Pedro Reservoir and Dam</td></tr>
<tr><td>Bathymetry</td><td>Field survey</td><td colspan="2">TID and MID 2011</td></tr>
<tr><td>Normal maximum water level</td><td>Design drawings</td><td colspan="2">830 ft</td></tr>
<tr><td>Normal minimum water level</td><td>Design drawings</td><td colspan="2">600 ft</td></tr>
<tr><td>Dam spillway, ungated (elevation)</td><td>Design drawings</td><td colspan="2">830 ft</td></tr>
<tr><td>Dam spillway (length, type)</td><td>Design drawings</td><td colspan="2">335 ft long; ogee crest</td></tr>
<tr><td>Powerhouse intake (invert elevation)</td><td>Design drawings</td><td colspan="2">535 ft</td></tr>
<tr><td>Powerhouse intake (lat/long)</td><td>Design drawings</td><td>37.70342</td><td>120.419095</td></tr>
<tr><td>Diversion Tunnel/Outlet works (invert elevation)</td><td>Design drawings</td><td colspan="2">342 ft</td></tr>
<tr><td>Diversion Tunnel Intake/Outlet works (lat/long)</td><td>Design drawings</td><td>37.70402</td><td>120.420002</td></tr>
<tr><td colspan="4">Physical and Geomorphological—Old Don Pedro Dam</td></tr>
<tr><td rowspan="2">Old Don Pedro Dam (lat/long above/below)</td><td rowspan="2">TID and MID 2011</td><td>729134 E</td><td>4177175 N</td></tr>
<tr><td>728741 E</td><td>4177044 N</td></tr>
<tr><td>Old Don Pedro normal maximum water level</td><td>Design drawings</td><td colspan="2">600 ft</td></tr>
<tr><td>Old Don Pedro Dam top of gates elevation</td><td>Design drawings;
TID and MID 2011</td><td colspan="2">605.5 ft (NGVD 29)</td></tr>
<tr><td>Old Don Pedro Dam crest (length, type)</td><td>Design drawings</td><td colspan="2">1000 ft</td></tr>
<tr><td>Old Don Pedro outlet (elevation)</td><td>TID</td><td colspan="2">multiple[1]</td></tr>
<tr><td colspan="4">Flow and Operations</td></tr>
<tr><td>Tuolumne River upstream of reservoir (regulated)</td><td>CCSF, TID[2]</td><td colspan="2" rowspan="4">See W&AR-02 Project Operations Model (TID/MID 2013, in progress)</td></tr>
<tr><td>Tuolumne River upstream of reservoir (total flow)</td><td>TID</td></tr>
<tr><td>Storage (daily)</td><td>TID</td></tr>
<tr><td>Releases through powerhouse and outlets (daily)</td><td>TID</td></tr>
<tr><td colspan="4">Temperature</td></tr>
<tr><td>Tuolumne River upstream of reservoir (Tuolumne River at Indian Creek Trail, Tuolumne River at Ward's Ferry, and other upstream locations)

Tributaries: Rough & Ready, Moccasin, Sullivan and Woods Creeks</td><td>Districts
CCSF

Districts</td><td colspan="2" rowspan="3">See Attachment A</td></tr>
<tr><td>Reservoir Profiles</td><td>Districts
CDFG</td></tr>
<tr><td>Tuolumne River downstream of reservoir (below Don Pedro Powerhouse)</td><td>Districts</td></tr>
<tr><td colspan="4">Meteorology</td></tr>
<tr><td>Air temperature, wind speed/direction relative humidity</td><td>TID Don Pedro Station</td><td colspan="2">See Attachment A</td></tr>
<tr><td>Cloud cover (measured at Modesto)</td><td>National Oceanic and Atmospheric Administration</td><td colspan="2">weatherspark.com</td></tr>
</table>

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 SFPUC'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.

CCSF City and County of San Francisco
CDEC California Data Exchange Center

CDFG	California Department of Fish and Game
ft	feet
MID	Modesto Irrigation District
msl	Mean Sea Level
TID	Turlock Irrigation District
USGS	U.S. Geological Survey

4.3.1 Physical and Geomorphological

Construction of the reservoir's topographic surface for modeling is documented in the Districts (TID/MID 2012) Don Pedro Reservoir Bathymetric Study Report (Attachment B). In brief, as described in the Bathymetry Study Plan[3], 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 Flow and Operations

Daily flows developed as part of the Tuolumne River Operations Model (Ops Model) (W&AR 02) were used as input to the reservoir temperature model calibration and verification procedures. Daily flow into the reservoir is estimated by the Districts and the City and County of San Francisco (CCSF) based on the flow recorded at the 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 Ops Model. This estimated daily inflow also includes flow in local tributaries to the reservoir (e.g., Moccasin, Sullivan, Woods Creeks).

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 contents 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 daily inflow to Don Pedro Reservoir from the unregulated portion of the drainage area has been smoothed to remove any negative flow values resulting from the computational process. The flow releases from Don Pedro Reservoir will be provided on a mean daily basis.

[3] The Bathymetry Study Plan was provided as an attachment to W&AR-03 Reservoir Temperature Model Study Plan (TID/MID 2011).

4.3.3 Temperature

Historical and recent temperature data collected in the Tuolumne River watershed are provided in Attachment A. Locations of water temperature data collection used in this study are shown in Figure 3.0-1 and listed in Table 4.3-2. Obtaining a complete inflow temperature dataset was particularly challenging, as the CCSF (also referred to SFPUC) site, TR-8, and CDFG'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 upstream of the North Fork Tuolumne River confluence. This temperature gage was used to represent the inflow temperature in the model. Within the reservoir, CDFG has collected monthly temperature profiles at six stations in Don Pedro Reservoir since 2004. This dataset has been augmented by the Districts since 2010. Since October 2010, the Districts have collected temperature profiles at CDFG's six established stations plus a station immediately above the Old Don Pedro dam and a station below the old dam. Monthly profiles were collected using a Hydrolab MS5 multi-parameter water quality sonde (temperature sensor +/- 0.2°C).

Table 4.3-2. Don Pedro 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).

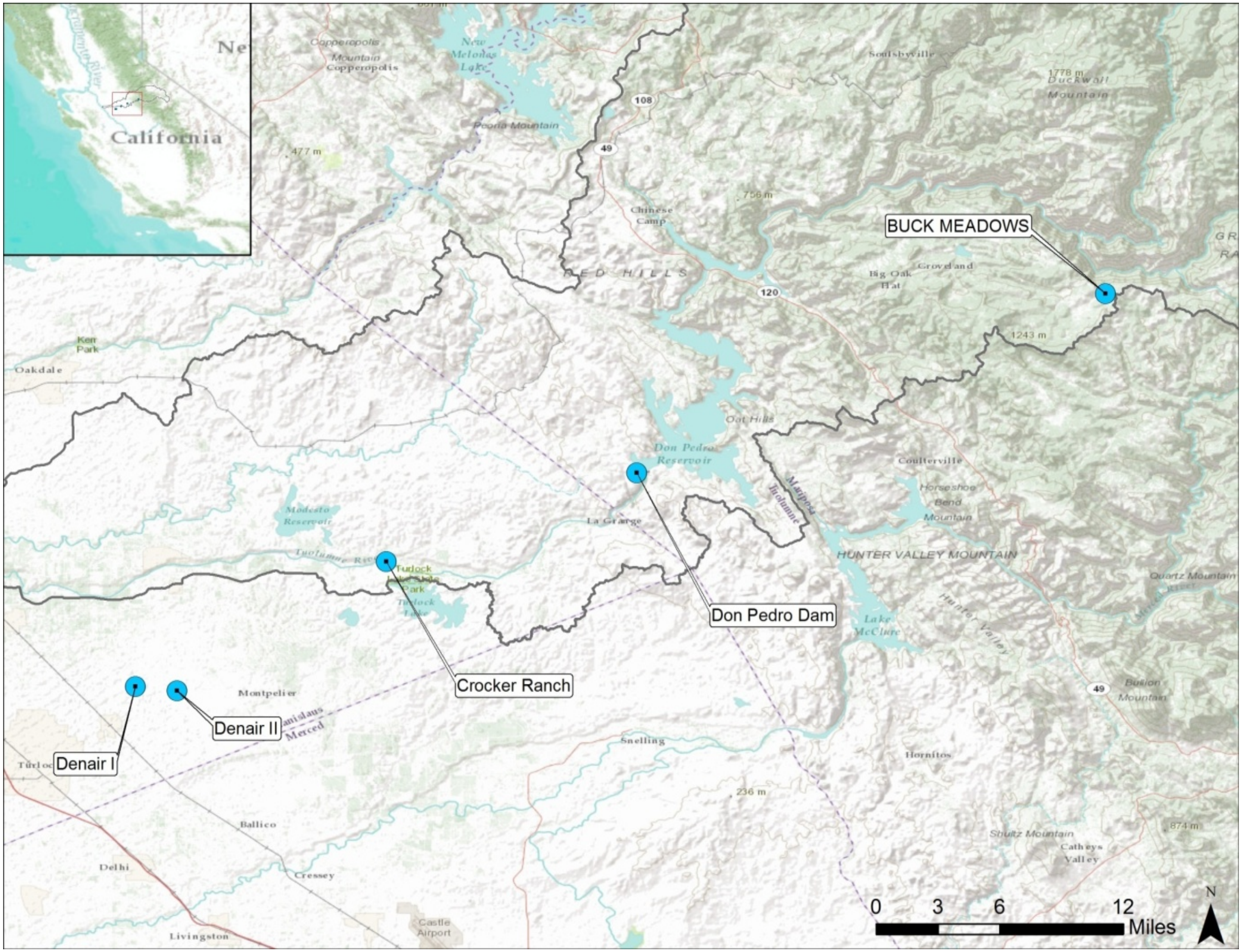

Figure 4.3-1. Meteorological station locations

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.

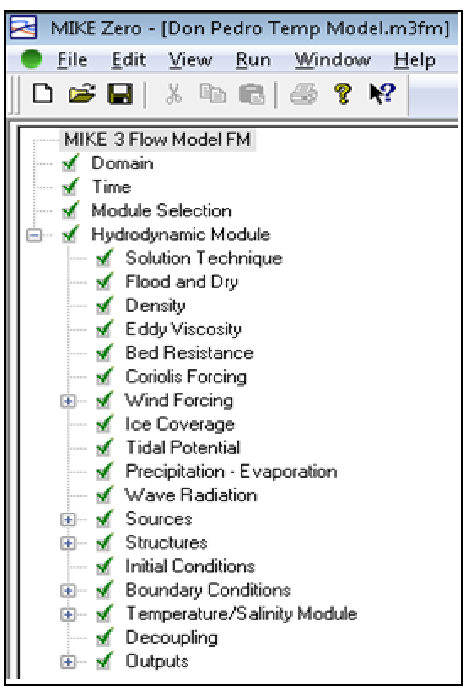

Figure 4.4-1. MIKE3-FM master interface in "m3fm" file.

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

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 is detailed in a separate report and is provided as Attachment B. The model bathymetry data were measured as elevations above mean sea level; elevations are converted to meters for the model.

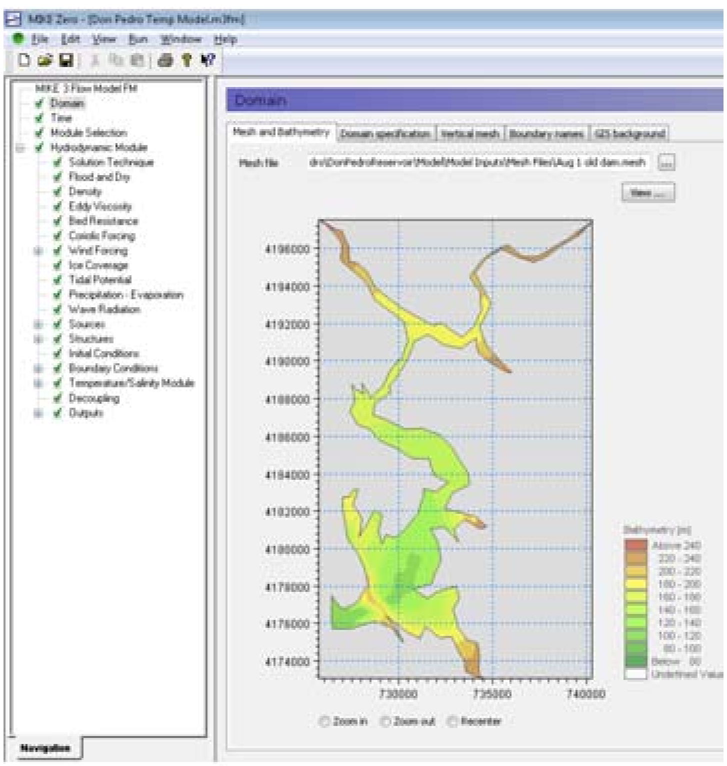

Figure 4.4-2. Model bathymetry screen.

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:

- <u>Sigma Level.</u> 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 for a transect along Don Pedro Reservoir is shown in Figure 4.4-5.
- <u>Sigma and Z-level Combination</u>. 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.

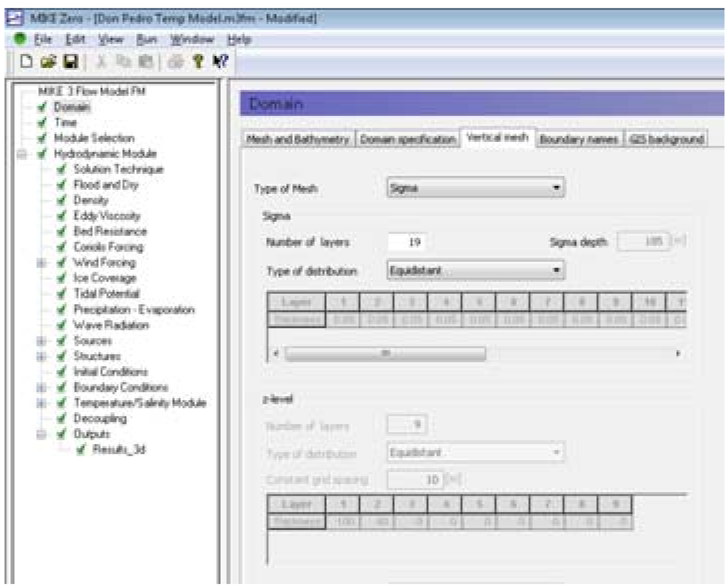

Figure 4.4-3. Vertical mesh option screen.

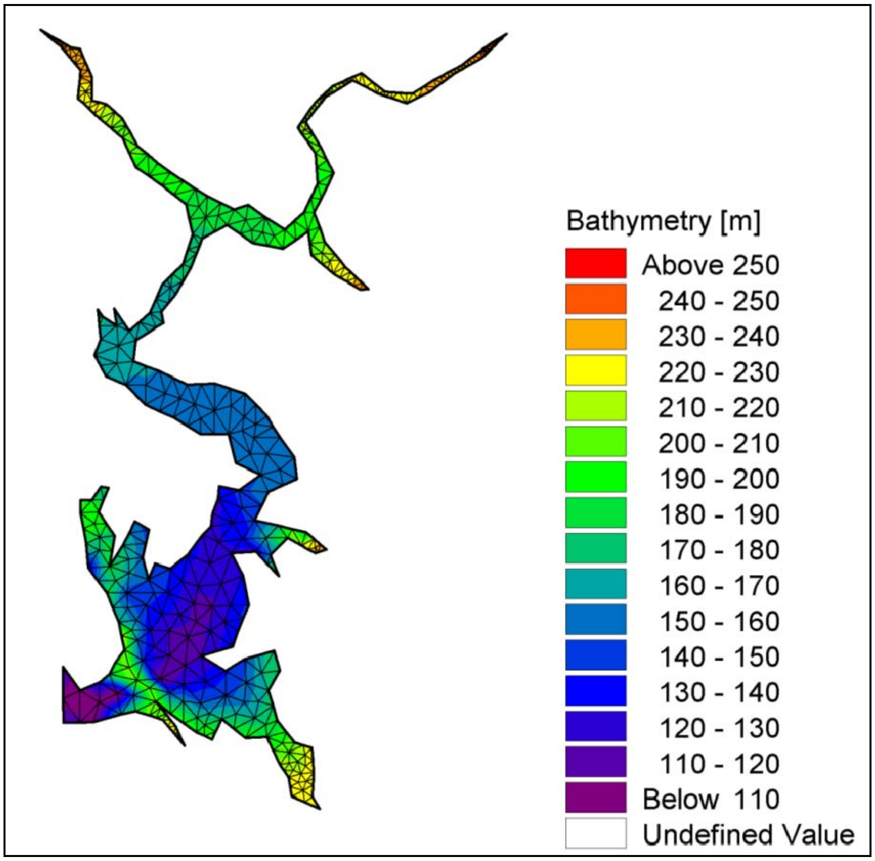

Figure 4.4-4. Model mesh horizontal layout.

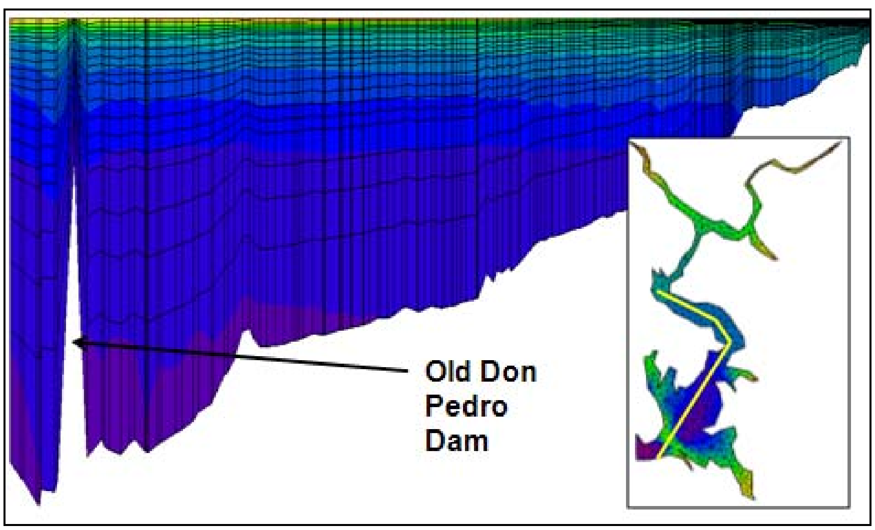

Figure 4.4-5. Example of sigma mesh reservoir longitudinal section

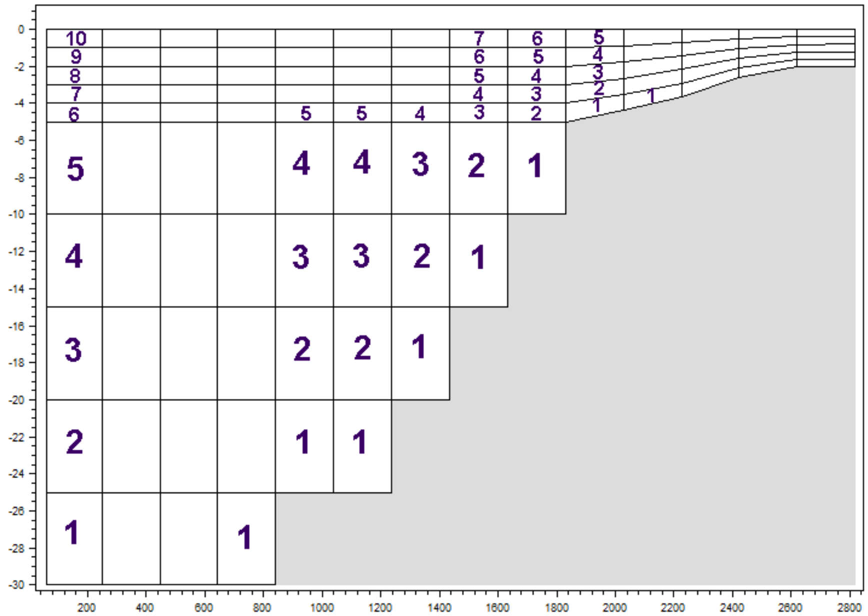

Figure 4.4-6. Example of sigma and z-level vertical mesh scheme.

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 generally 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

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

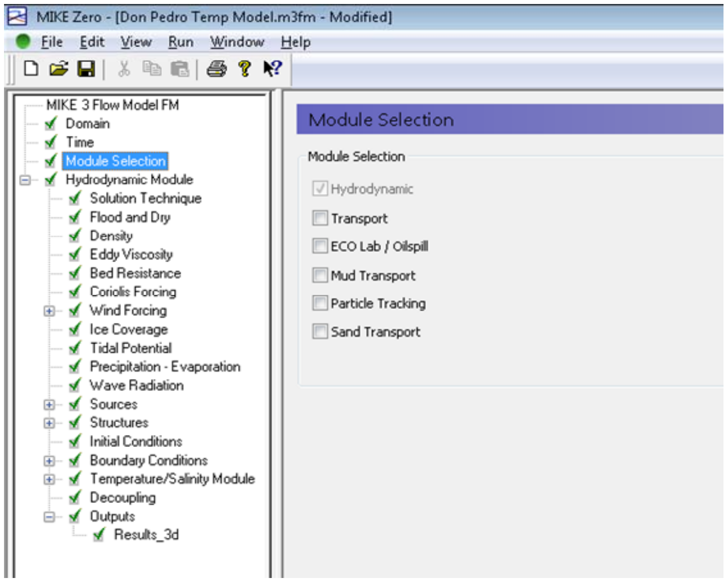

Figure 4.4-7. Module selection

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 are 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 deal with the constraints around the internal time step calculation.

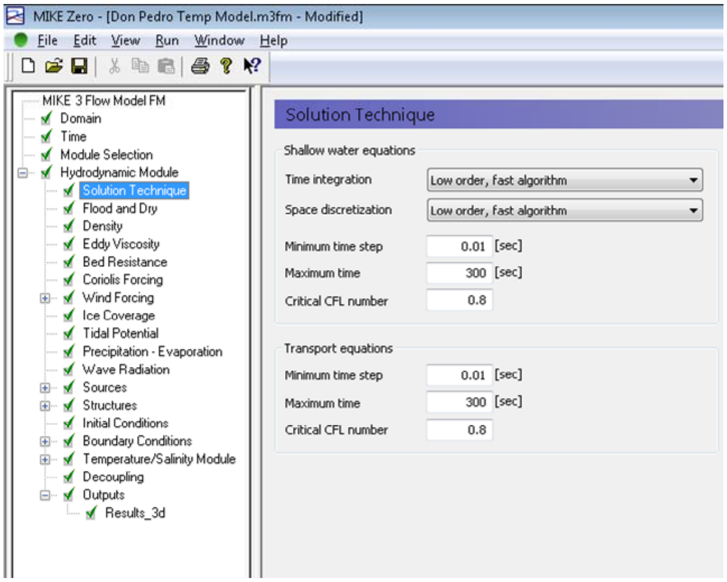

Figure 4.4-8. Solution Technique parameters.

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 "wet" if the water level rises. This feature is important for a system like Don Pedro where reservoir variations are significant. "Flood" and "dry" 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").

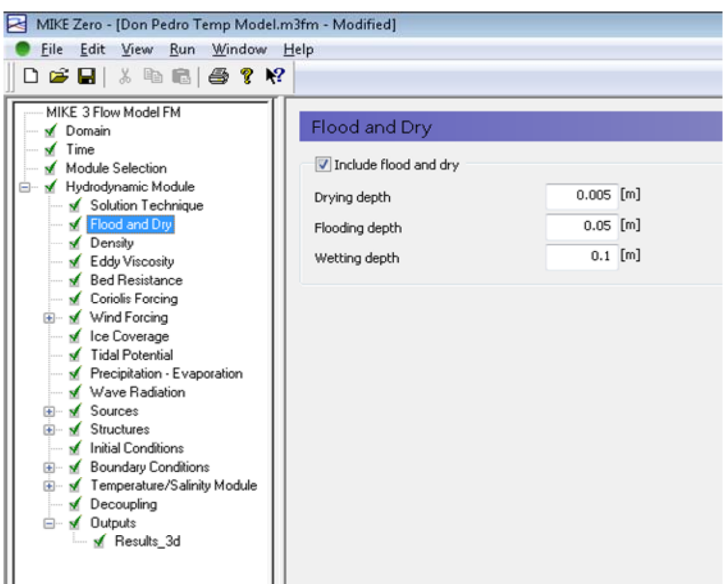

Figure 4.4-9. Flood and dry settings.

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. Salinity is not relevant in this application; i.e. water of snow-melt origin, specific conductivity of the reservoir water reportedly ranges between 2 and 100 µSiemans/cm (TID/MID 2011; TID/MID 2013). 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.

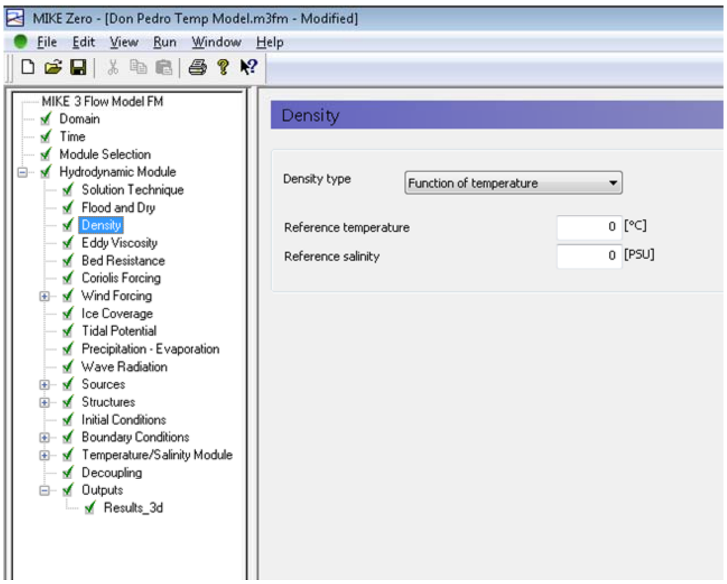

Figure 4.4-10. Density as a function of temperature is selected.

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 Smagorinksy Formulation. worked well, although the model results for Don Pedro Reservoir were found to be relatively insensitive to horizontal dispersion.

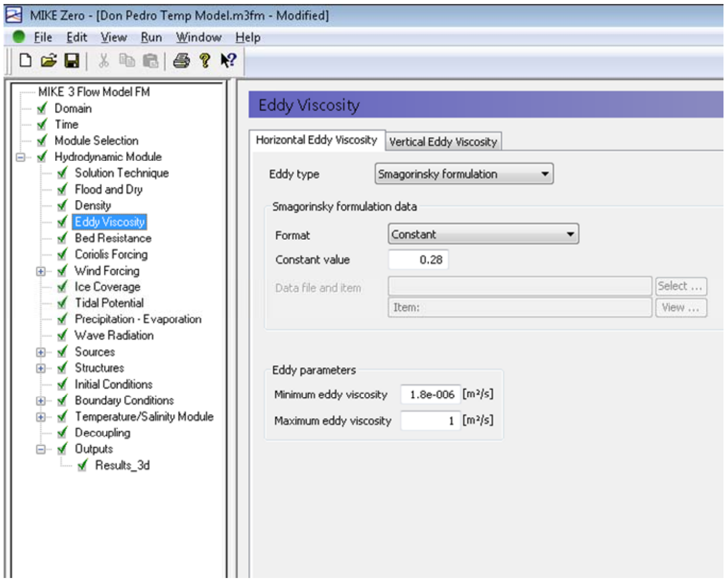

Figure 4.4-11. Horizontal dispersion.

Vertical dispersion is always a key 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.

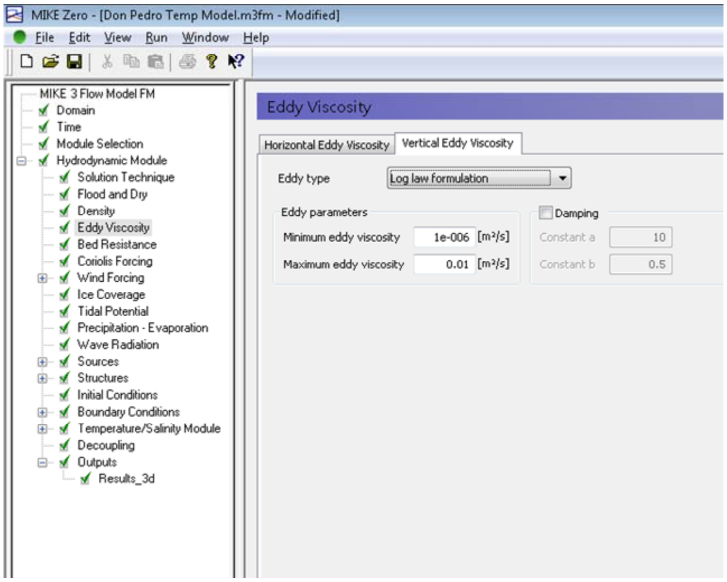

Figure 4.4-12. Vertical dispersion.

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.

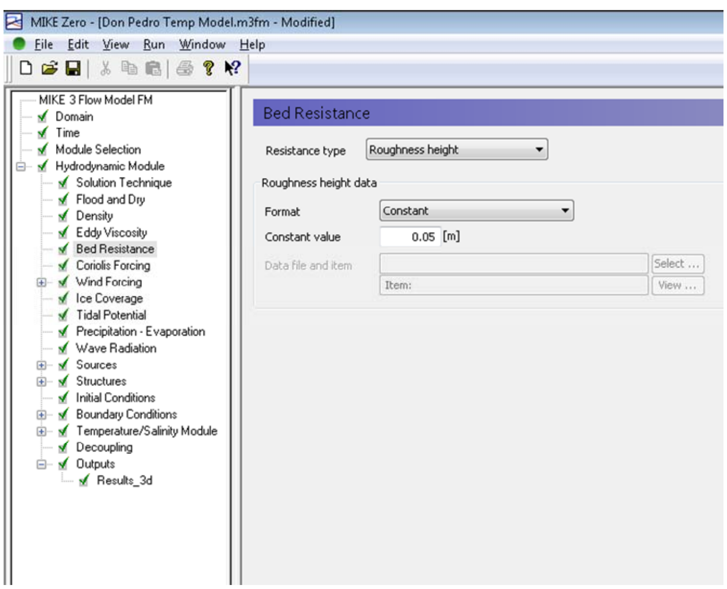

Figure 4.4-13. Bed resistance.

4.4.5.6 Coriolis Force

In large water masses the rotation of the earth can effect 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 sensitivity analysis was performed. Hence, because model computation time could be decreased without it, to save computation time the Don Pedro Reservoir model does not include Coriolis force.

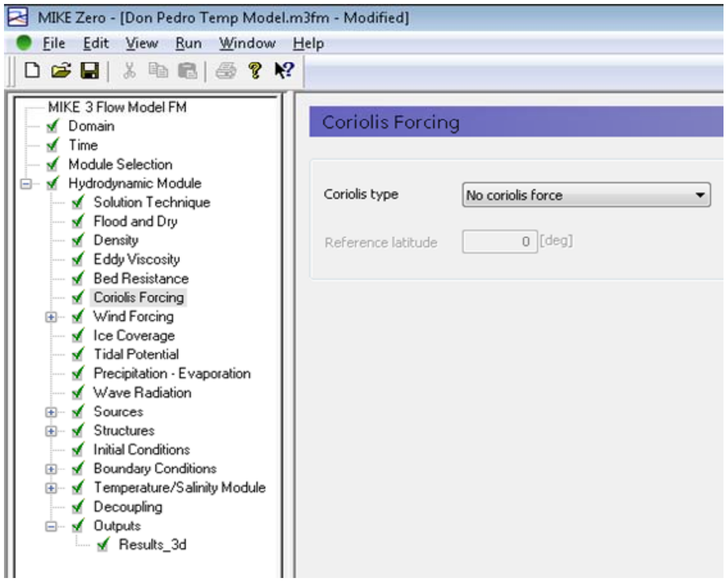

Figure 4.4-14. Coriolis force.

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).

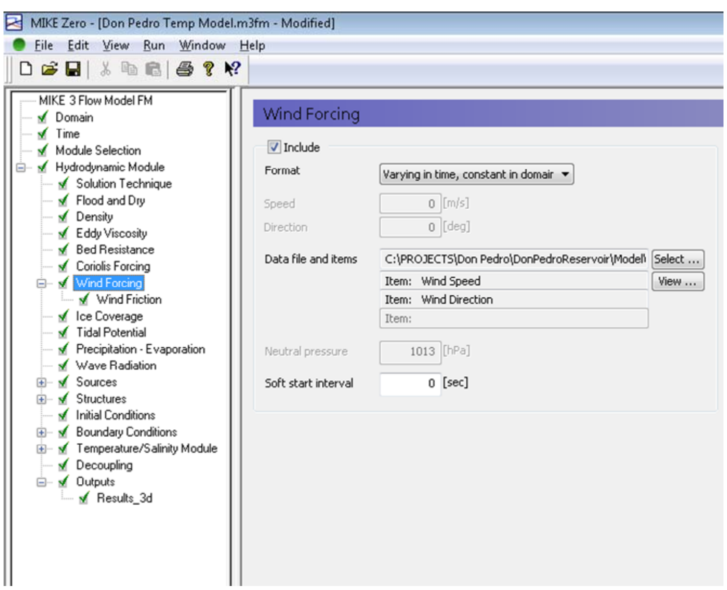

Figure 4.4-15. Wind forcing.

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. 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).

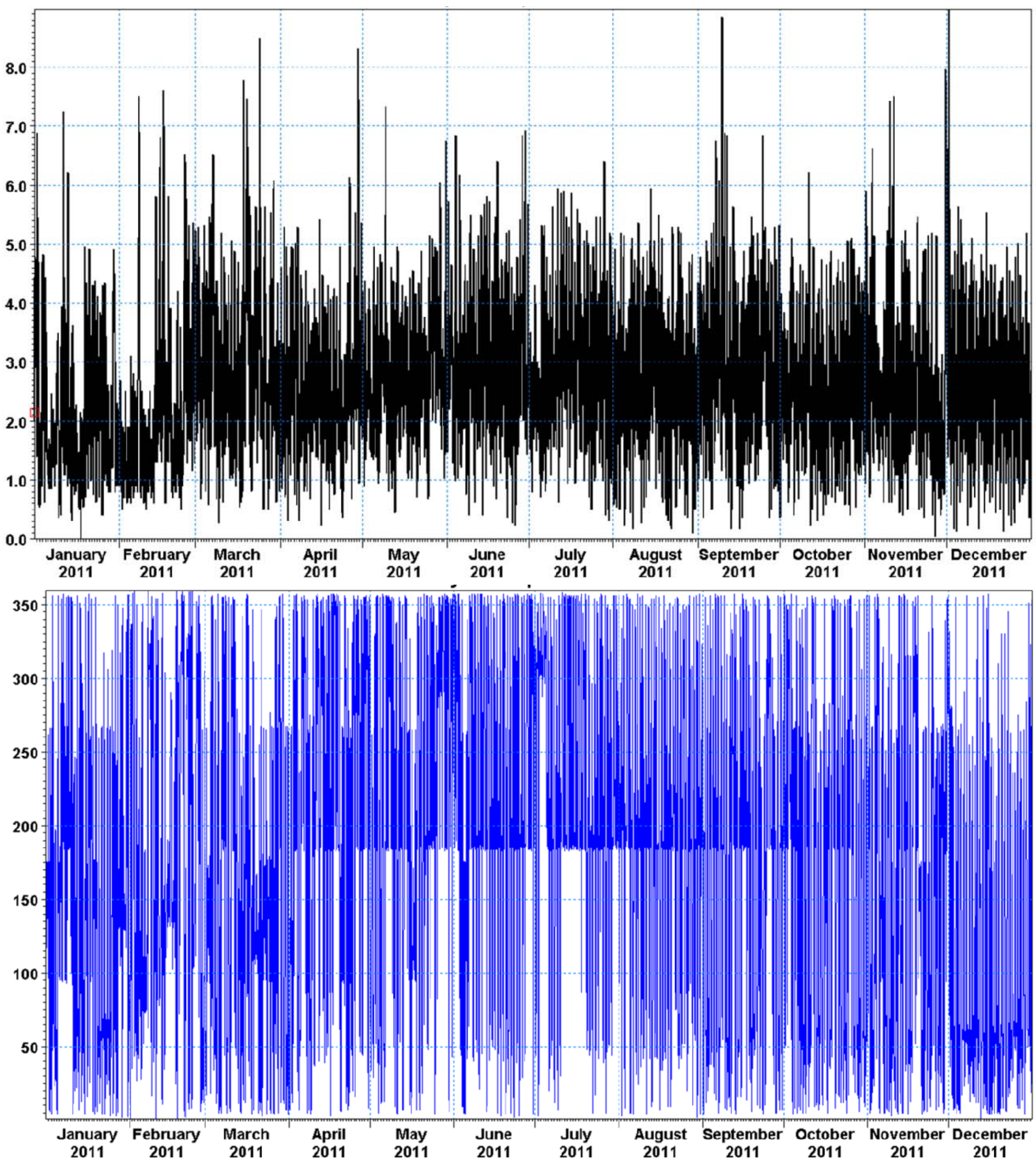

Figure 4.4-16. Wind data collected at Don Pedro Met Station 2011. Top plot is wind speed (m/s); bottom plot is wind direction (deg).

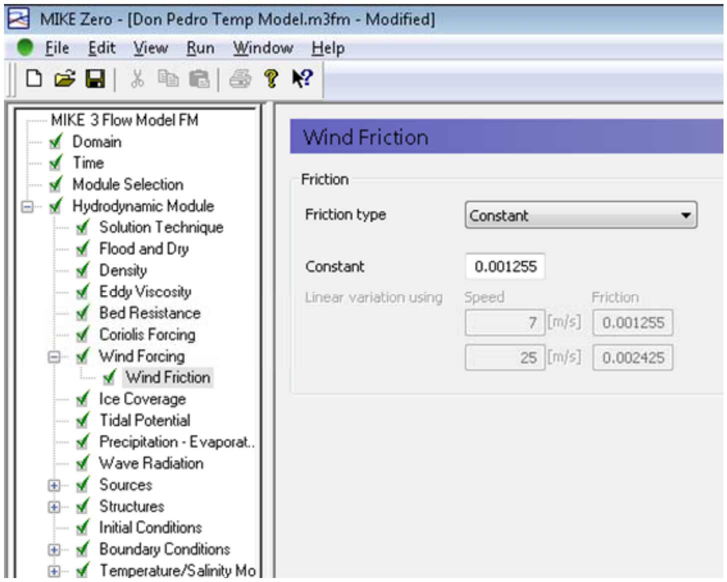

Figure 4.4-17. Wind friction factor.

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).

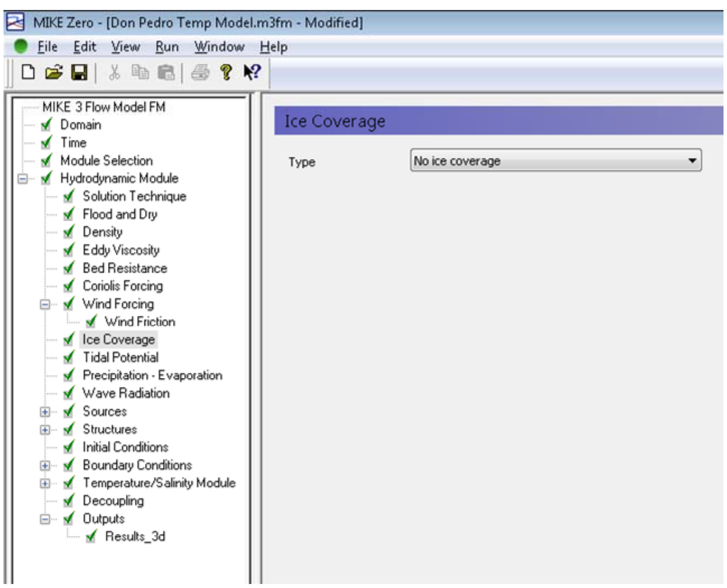

Figure 4.4-18. Ice coverage.

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).

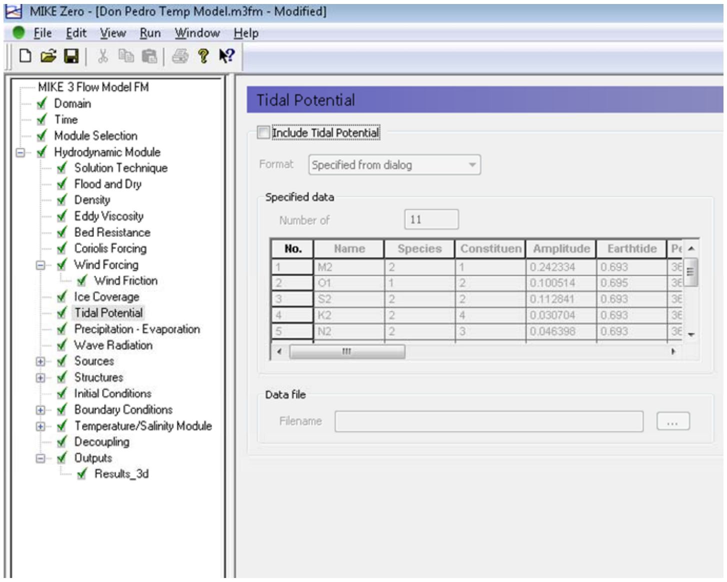

Figure 4.4-19. Tidal potential.

4.4.5.10 Precipitation and Evaporation

The MIKE 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 2013). Because precipitation and evaporation are accounted for in the hydrology data set, it is not duplicated in the hydrodynamic module (Figure 4.4-20).

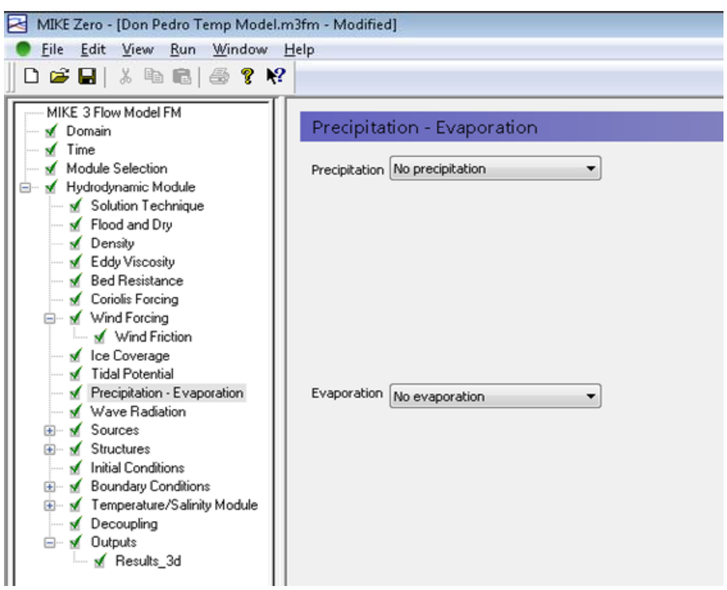

Figure 4.4-20. Precipitation and evaporation.

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).

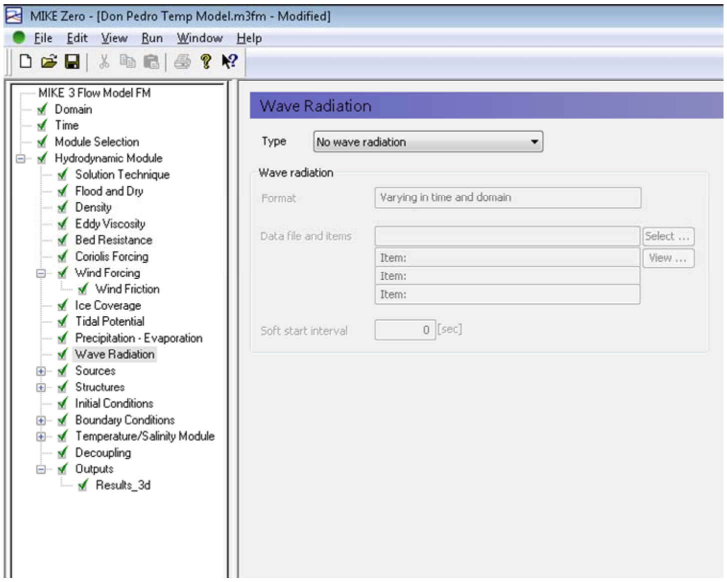

Figure 4.4-21. Wave Radiation.

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, inflow and outflow into the Don Pedro Reservoir was taken from the hydrology dataset provided in the Tuolumne River Operations Model (W&AR-02).

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 will 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 flow coming down the Tuolumne River.

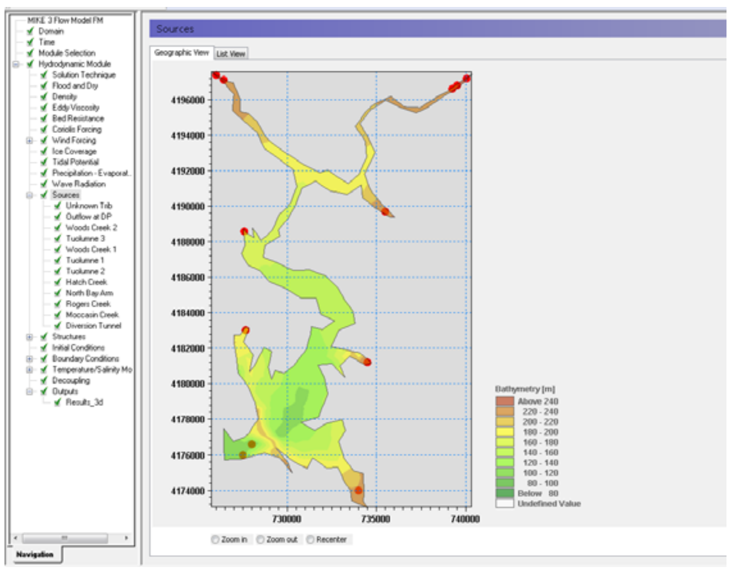

Figure 4.4-22. Location of model inflow and outflow sources.

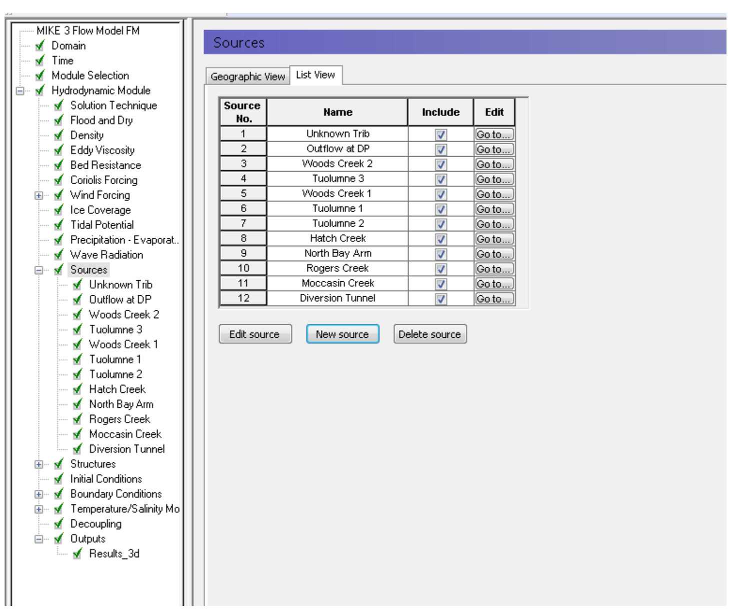

Figure 4.4-23. Listing of inflow and outflow sources.

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 is being 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.

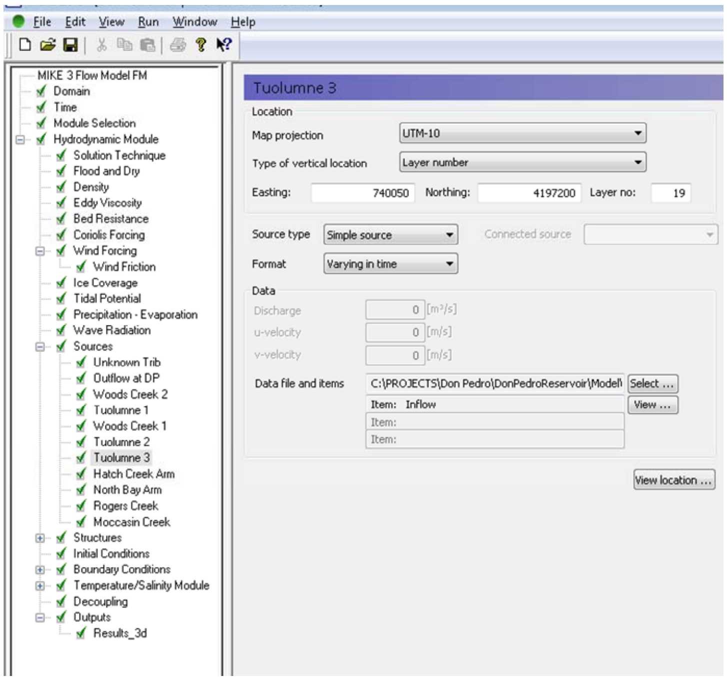

Figure 4.4-24. "Tuolumne 3" source details.

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.

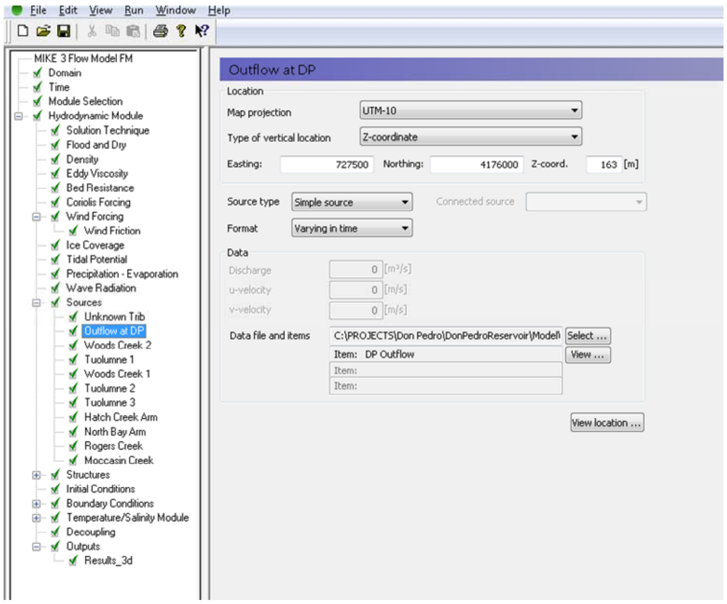

Figure 4.4-26. "Outflow at Don Pedro powerhouse" source details.

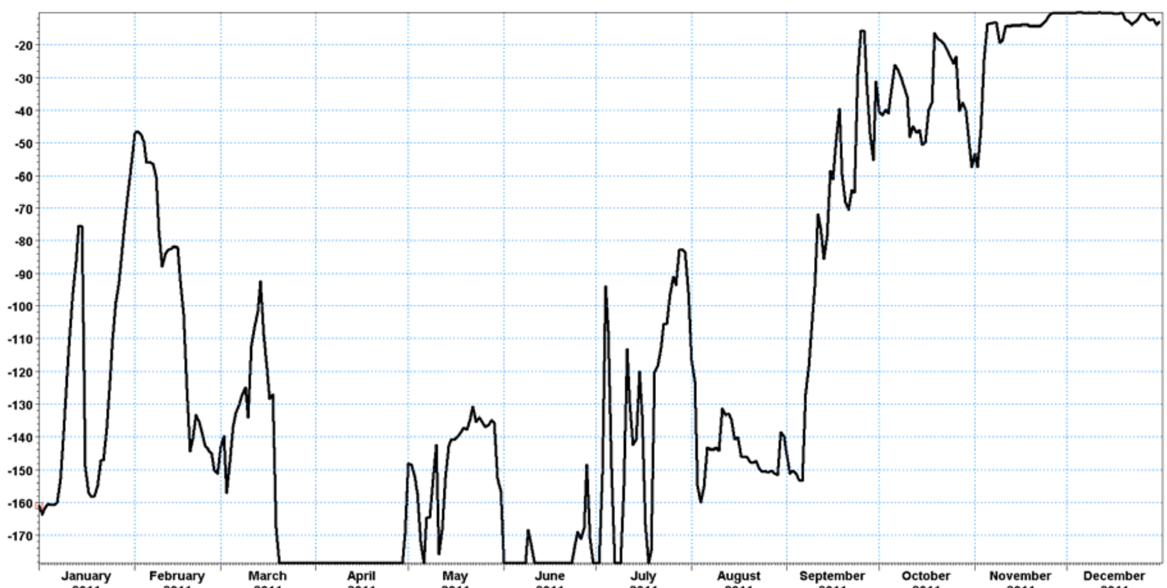

Figure 4.4-27. "Outflow at Don Pedro powerhouse" outflow for 2011 in cubic-meters per second (m^3/s). Note outflows are assigned a negative value.

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 barrier to flow and will be treated as a weir.

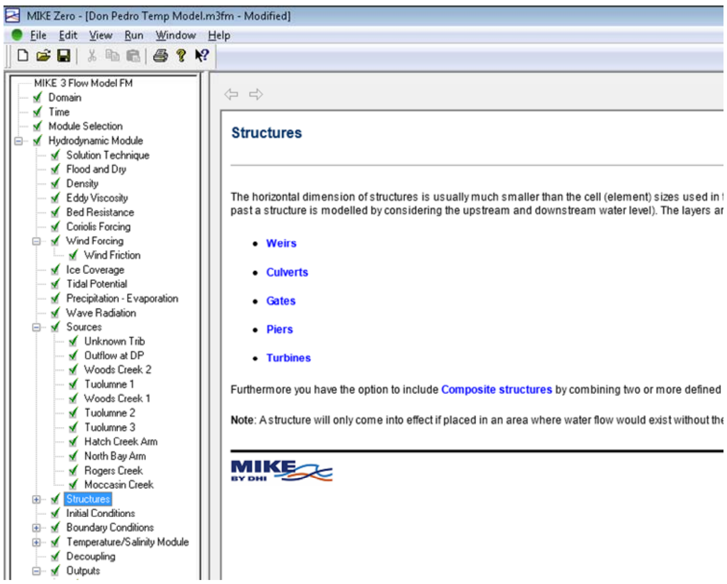

Figure 4.4-28. Structure options.

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.

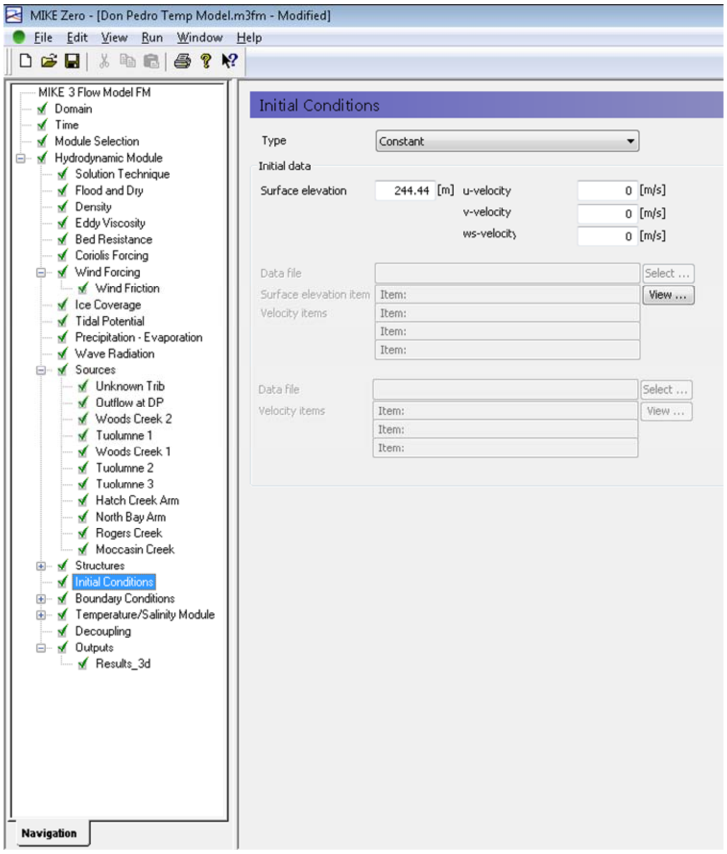

Figure 4.4-29. Hydrodynamic initial conditions.

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.

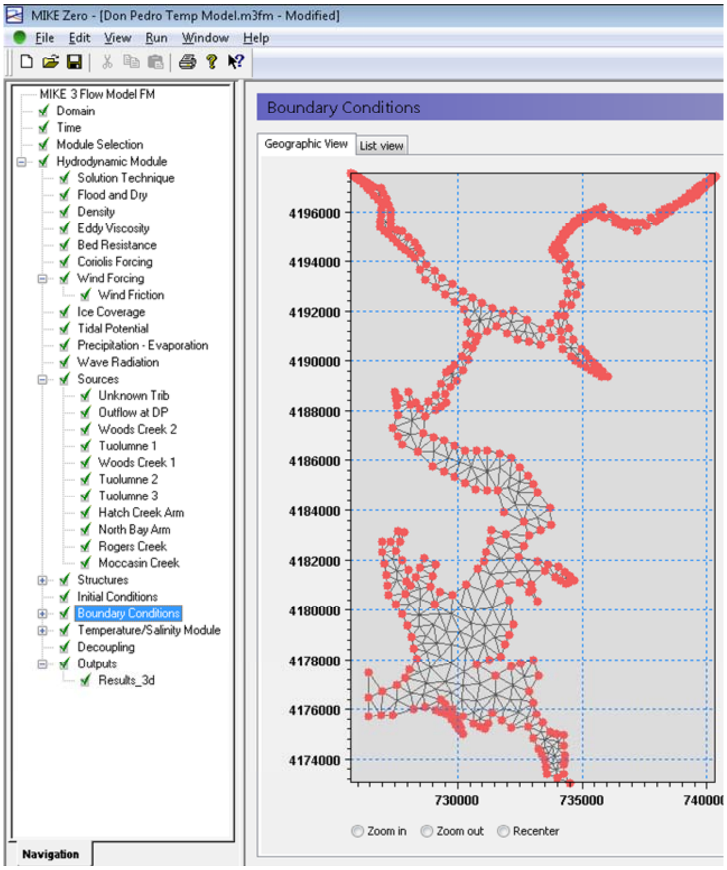

Figure 4.4-30. Boundary conditions: model domain showing all land boundaries.

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.

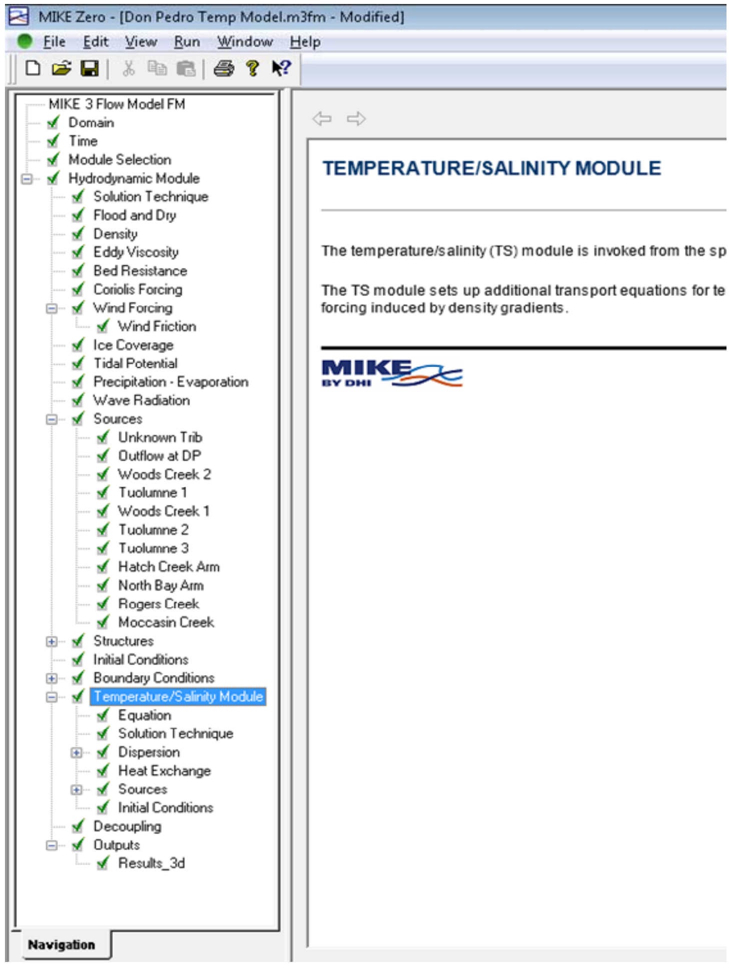

Figure 4.4-31. Temperature module.

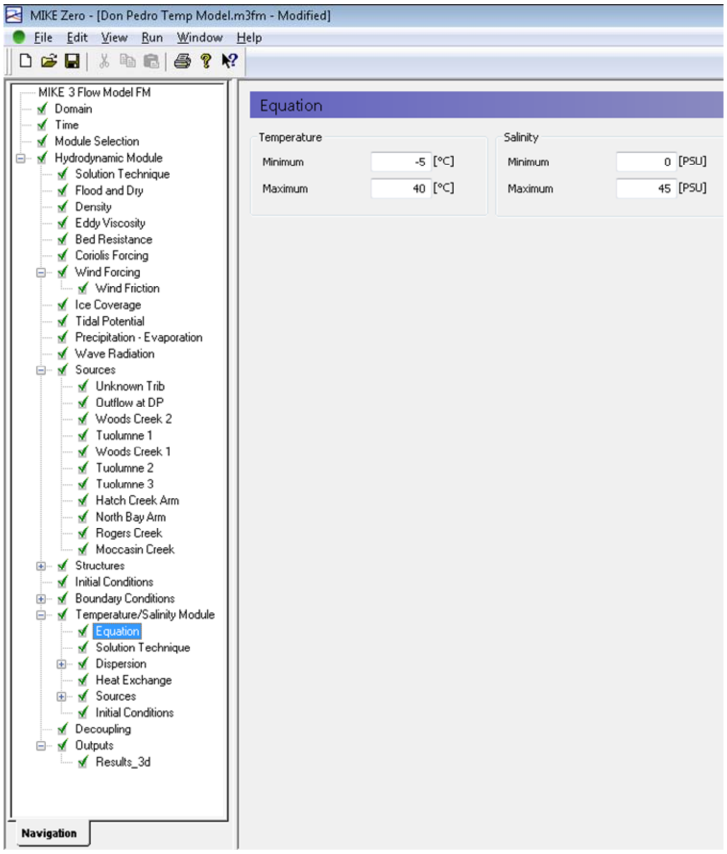

Figure 4.4-32. Temperature limits.

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.

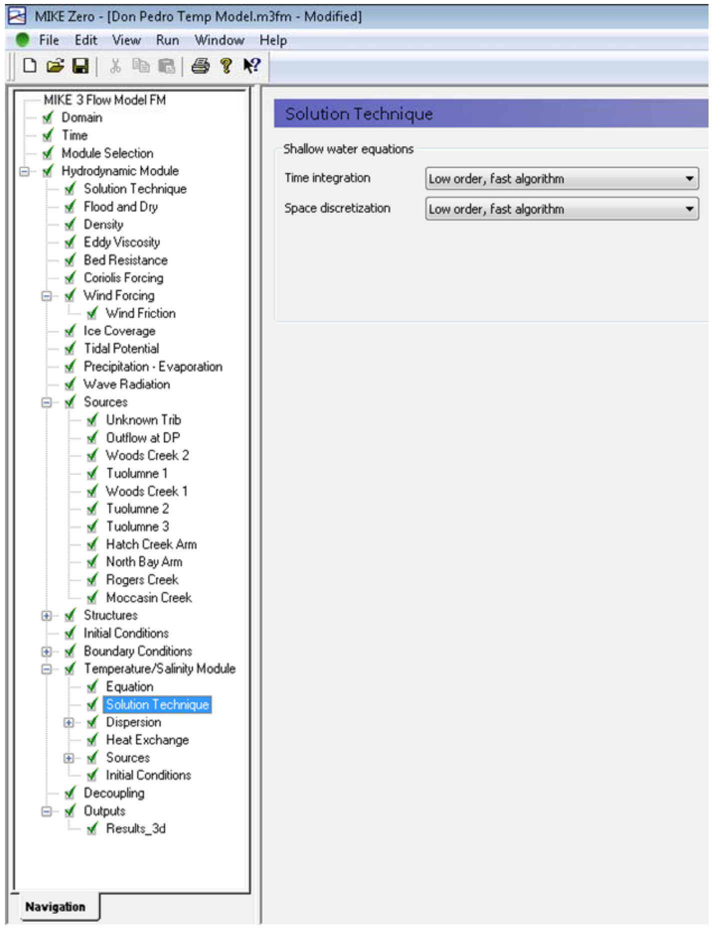

Figure 4.4-33. Solution settings.

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.

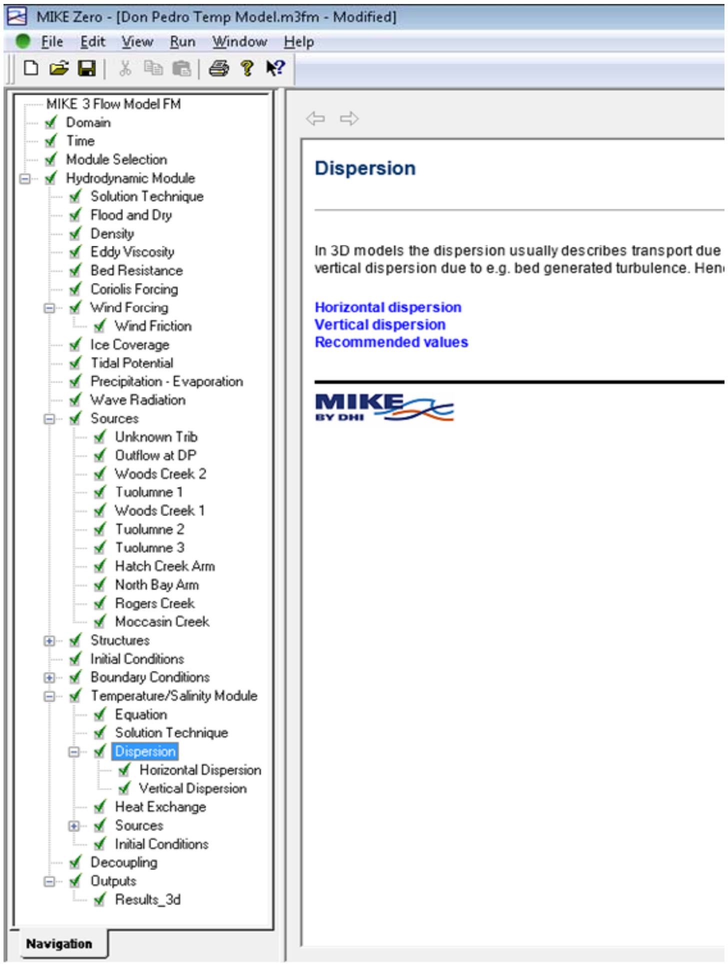

Figure 4.4-34. Temperature dispersion main tab.

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 meter squared per second (m^2/s) was used (Figure 4.4-35). This is a typical value used for reservoirs e.g. Maiss et al (1994).

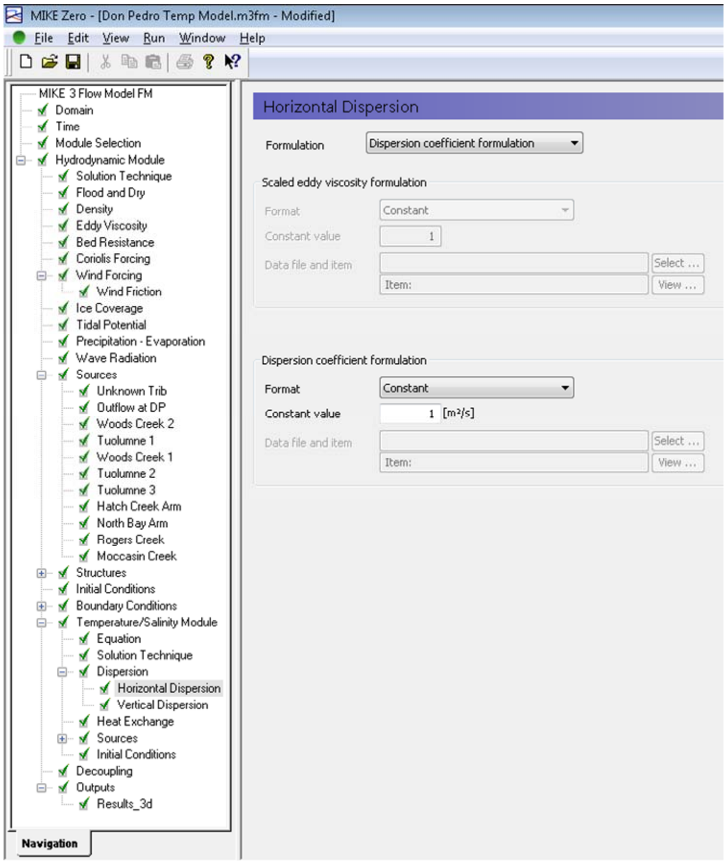

Figure 4.4-35. Temperature horizontal dispersion.

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).

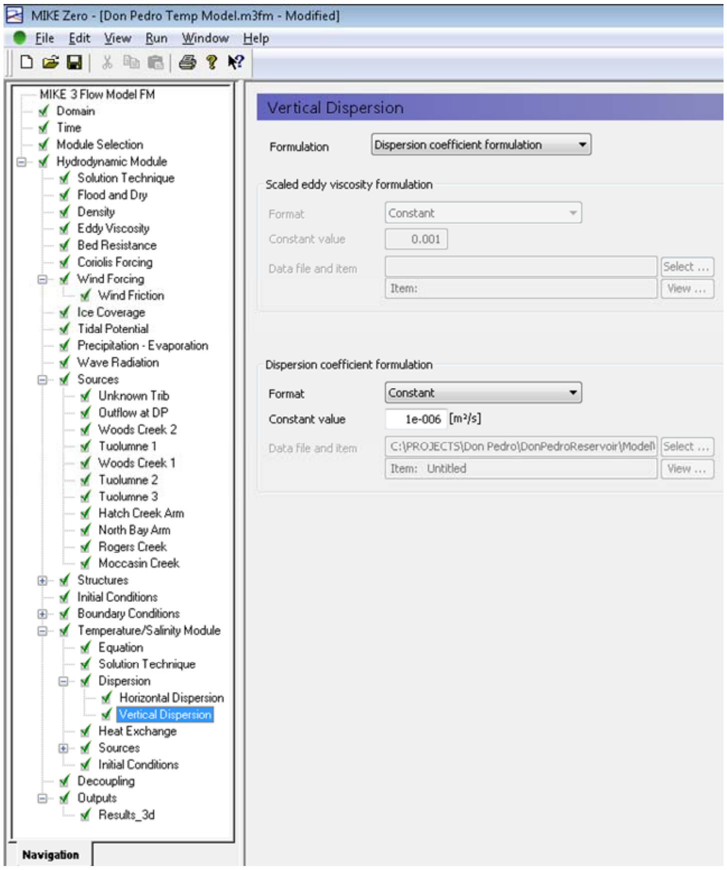

Figure 4.4-36. Temperature vertical dispersion.

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.

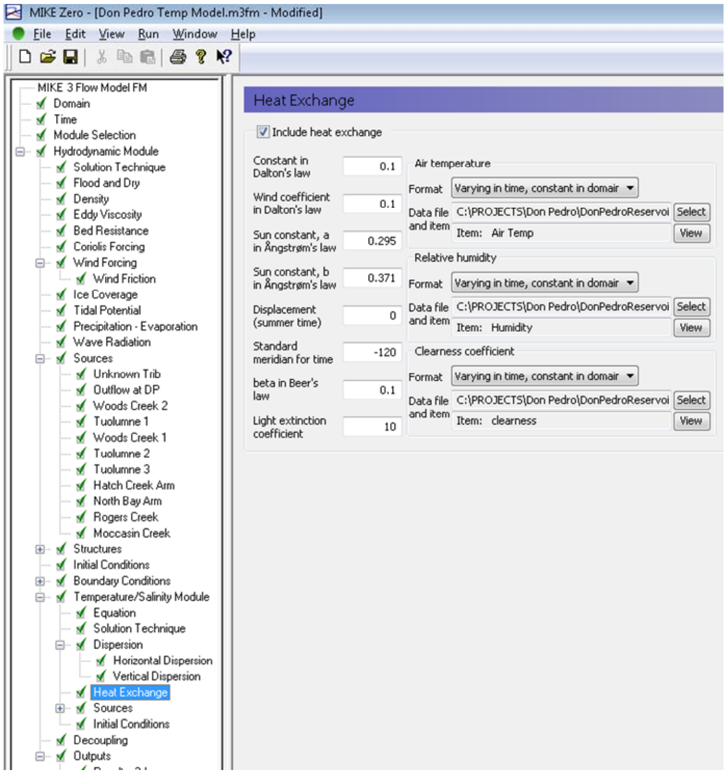

Figure 4.4-37. Heat exchange parameters.

4.4.6.4 Vaporization

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

$$q_v = LC_e(a_1 + b_1 W_{2m})(Q_{water} - Q_{air})$$

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.

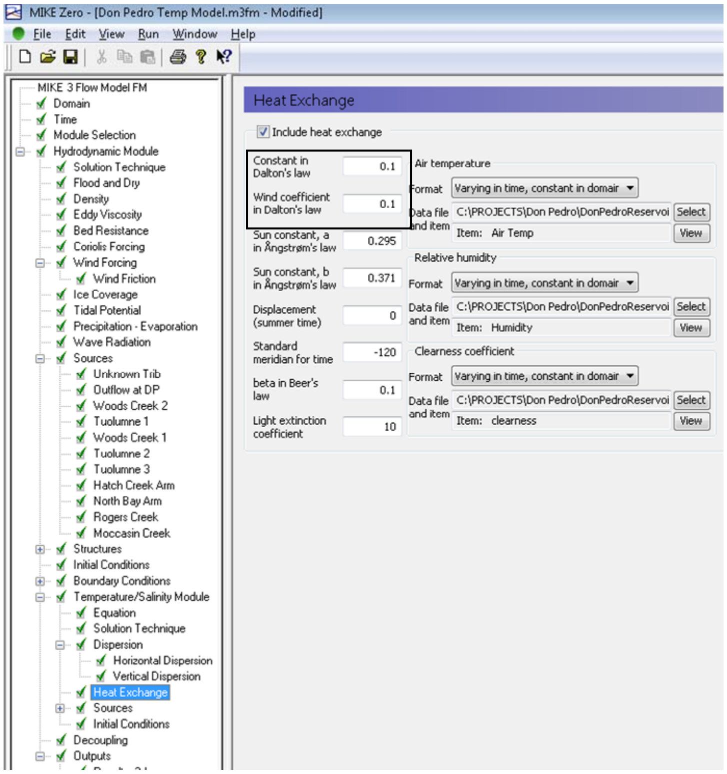

Figure 4.4-38. Daltons law constants.

The vapor pressure in the atmosphere is a function of the humidity. Humidity data were collected by the Districts' station at Don Pedro Dam (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.

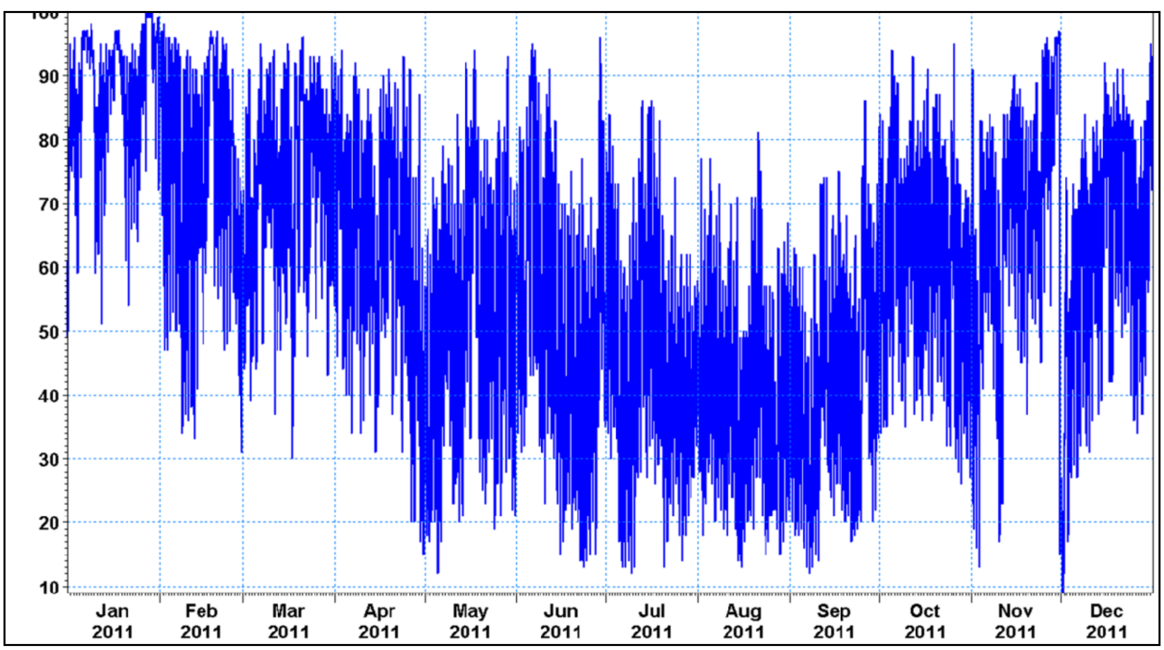

Figure 4.4-39. Relative humidity (%) for 2011.

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.

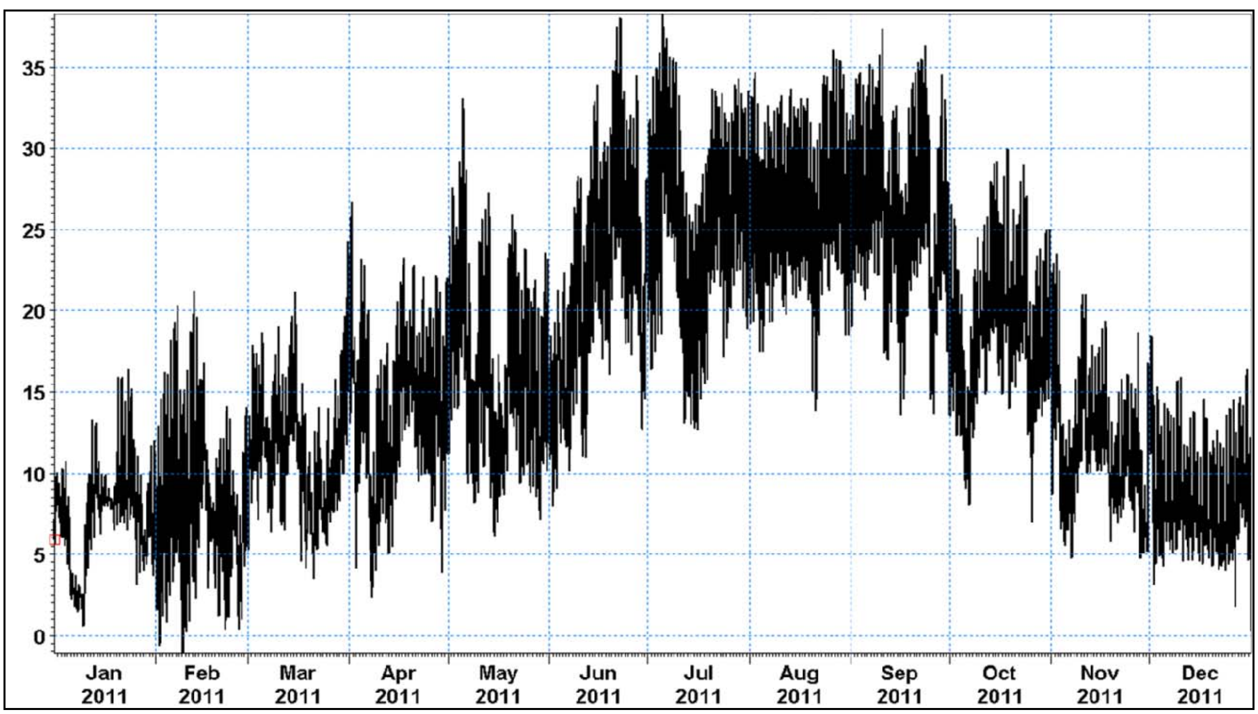

Figure 4.4-40. Air temperature in degree celsius (^oC) for 2011.

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.

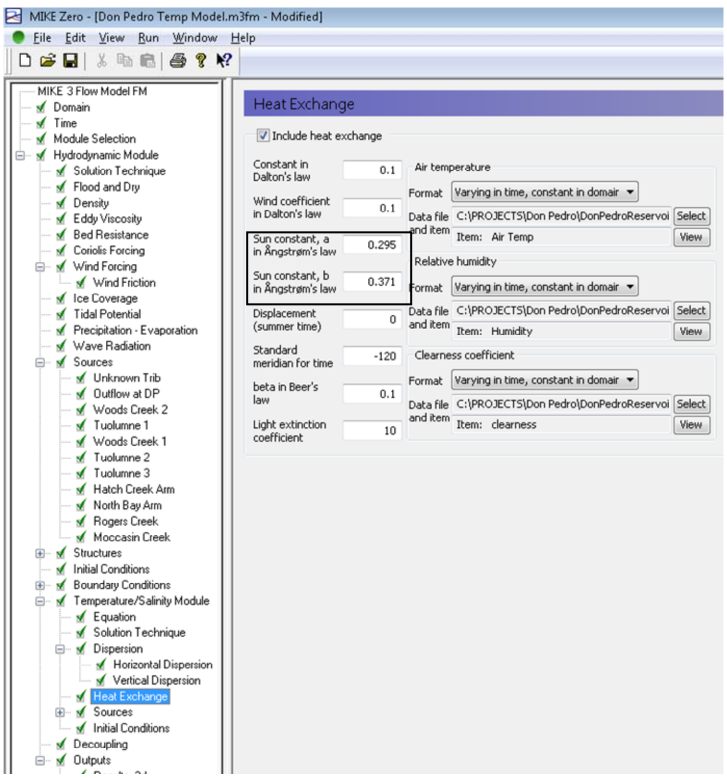

Figure 4.4-41. Short wave radiation parameters.

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.

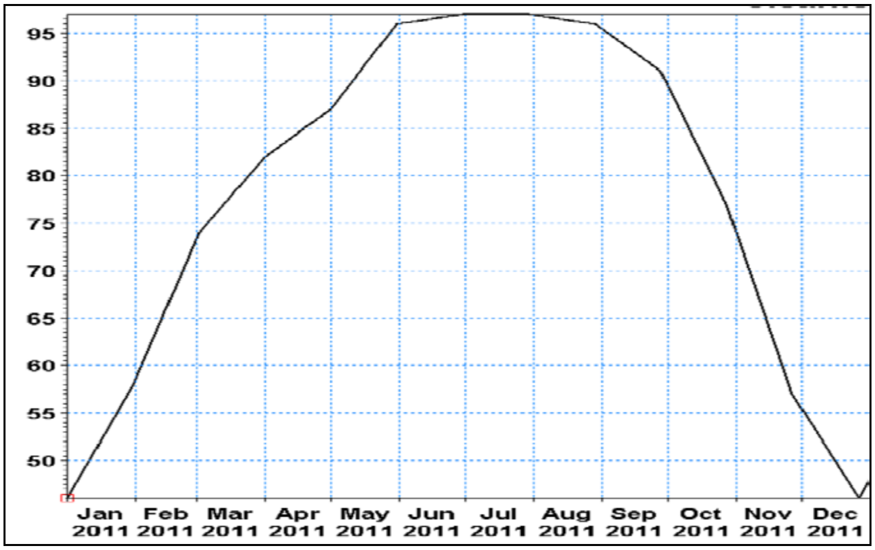

Figure 4.4-42. Modesto clearness (%).

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.

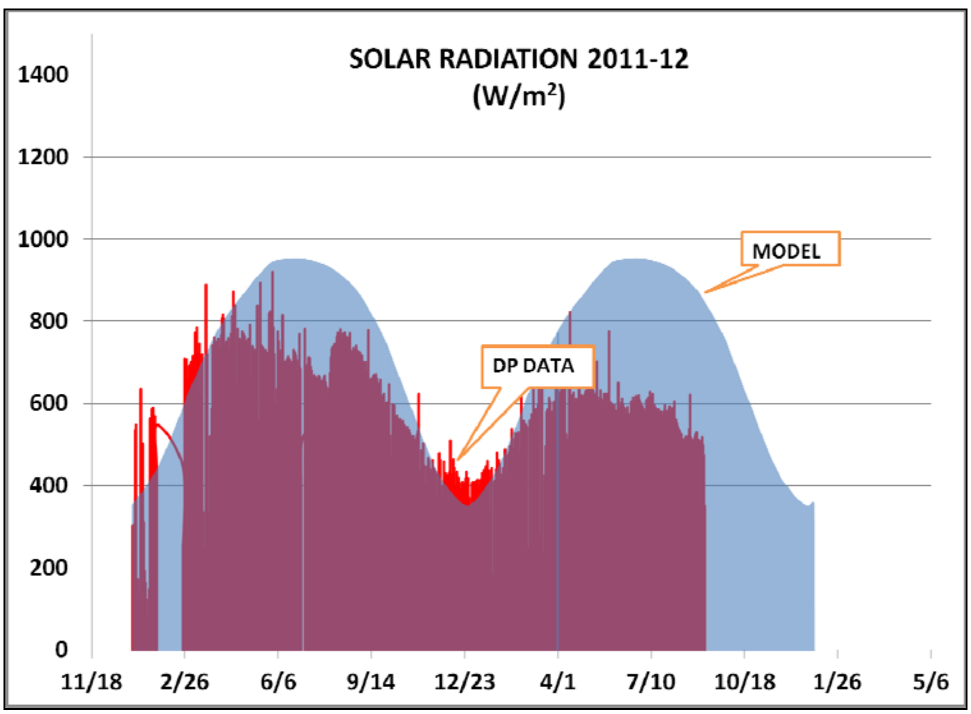

Figure 4.4-43. Computed and observed solar radiation at Don Pedro 2011-12.

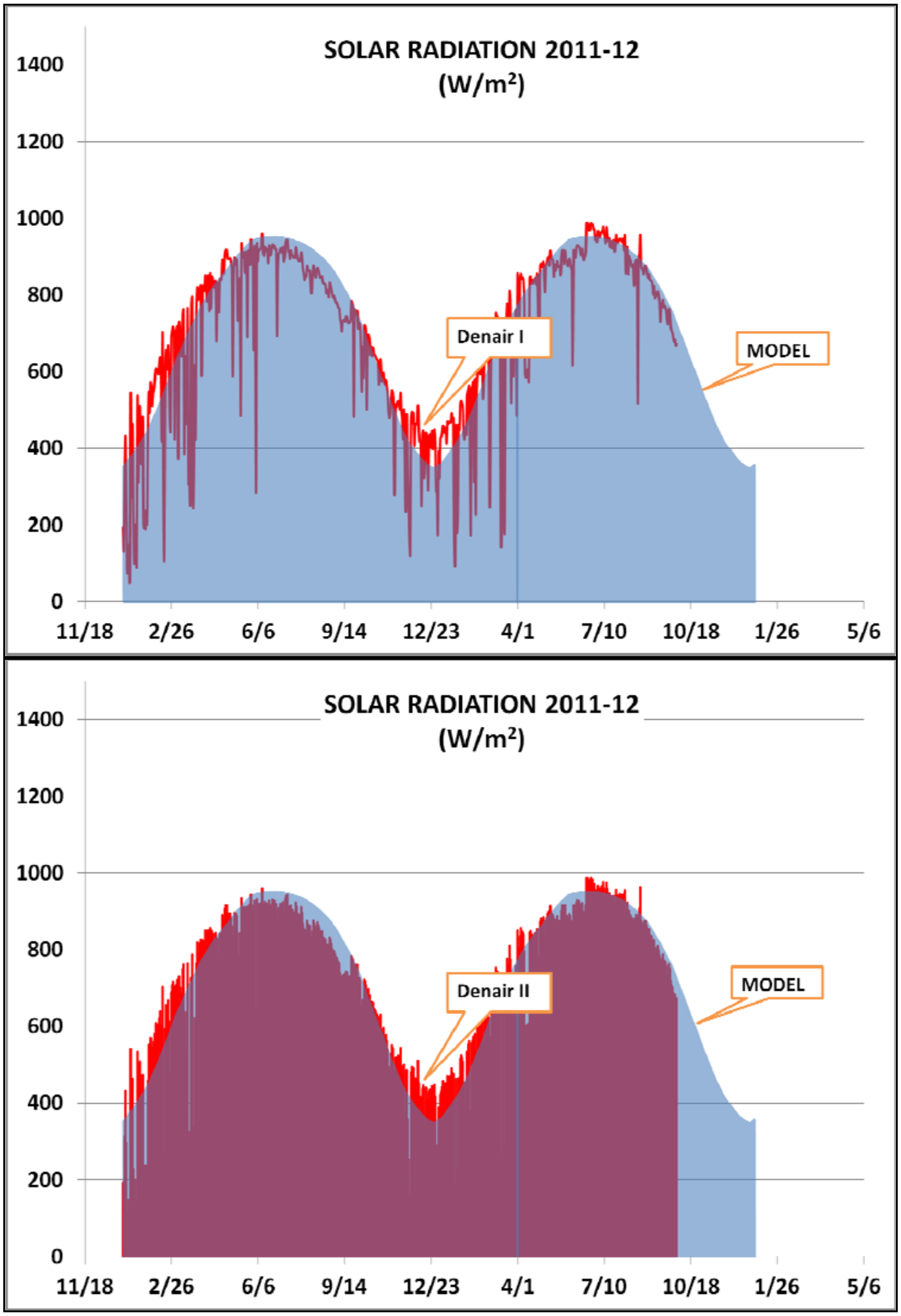

Figure 4.4-44. Computed and observed solar radiation at Denair 1 (top) and II (bottom), 2011-12.

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:

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

where:

$q_{lr,net}$	heat loss; outgoing long wave radiation	(W/m^2)
σ_{sb}	Stefan-Boltzman constant	(W/m^2/^{o}C^4)
T_{air}	surface air temperature	(^{o}C)
T_k	equilibrium temperature	(^{o}C)
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, which remains popular:

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

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.

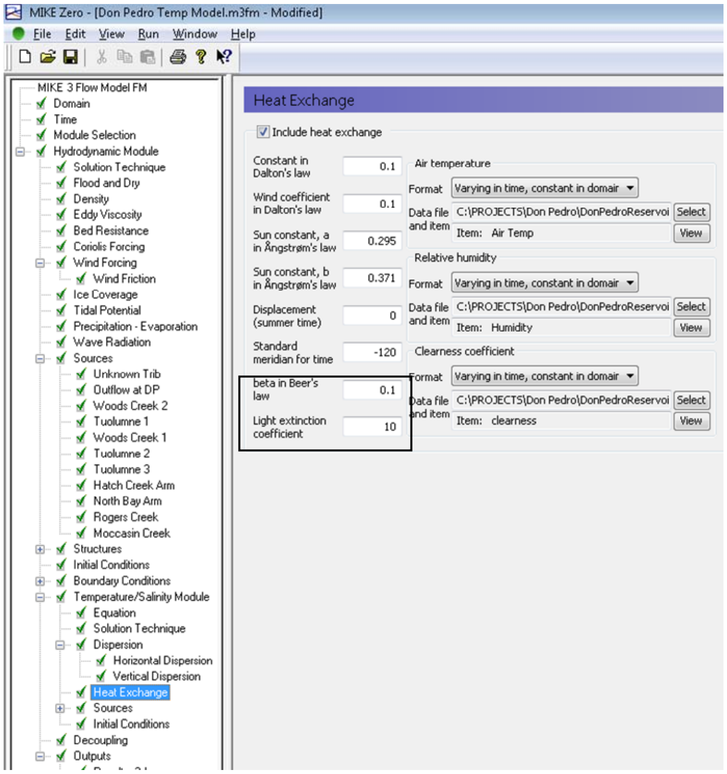

Figure 4.4-45. Light penetration constants.

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 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.

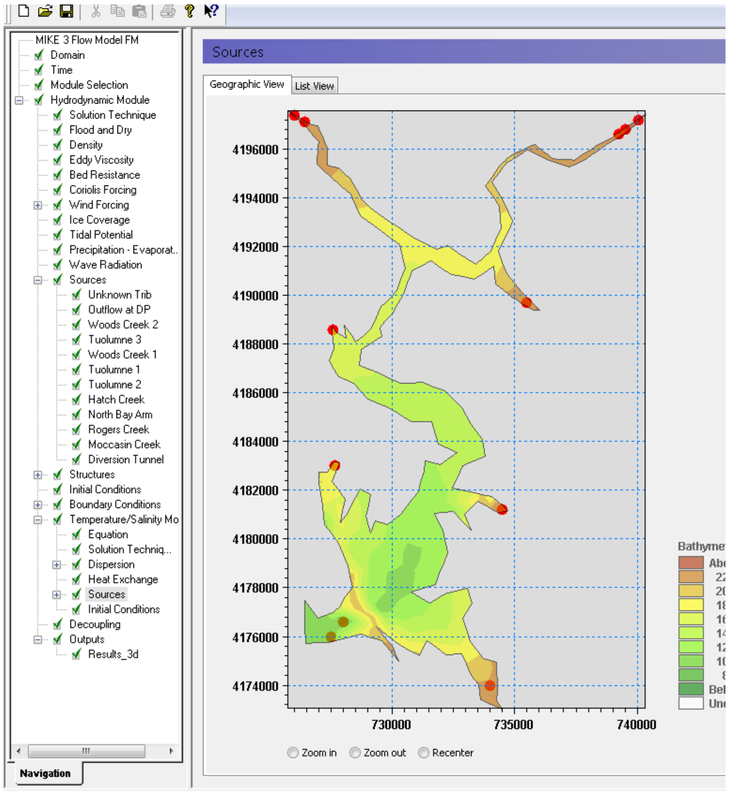

Figure 4.4-46. Source temperature tab.

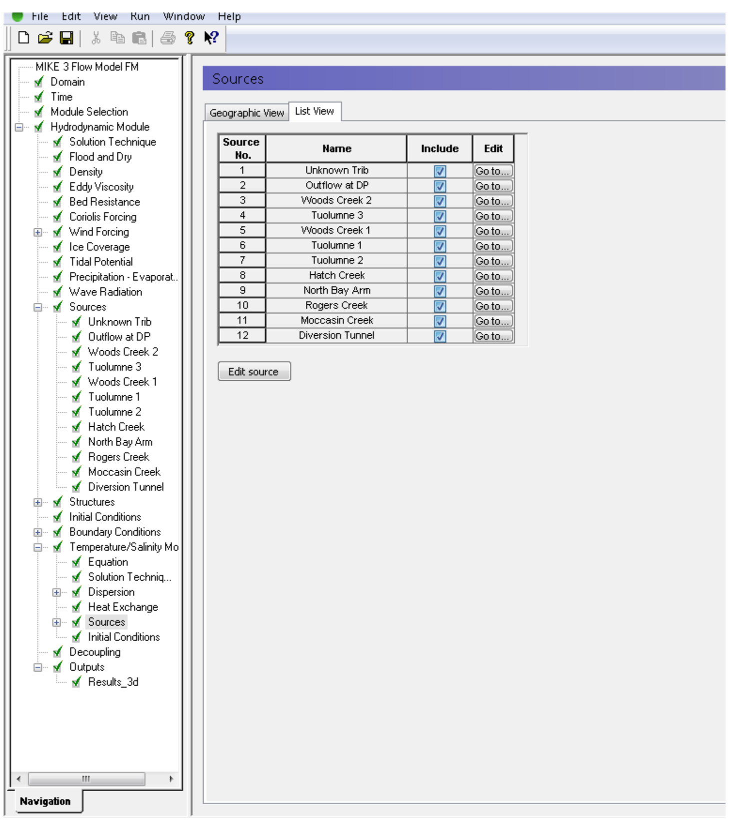

Figure 4.4-47. Temperature sources.

Figure 4.4-48. Measured inflow temperature at Indian Creek Trail (°C) 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°C was used.

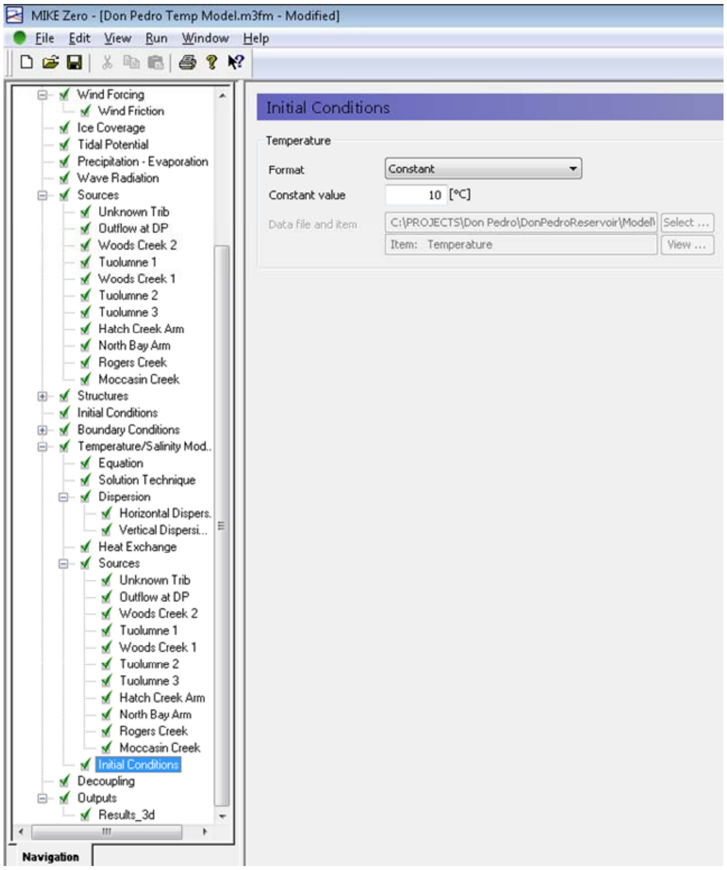

Figure 4.4-49. Temperature initial condition.

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.

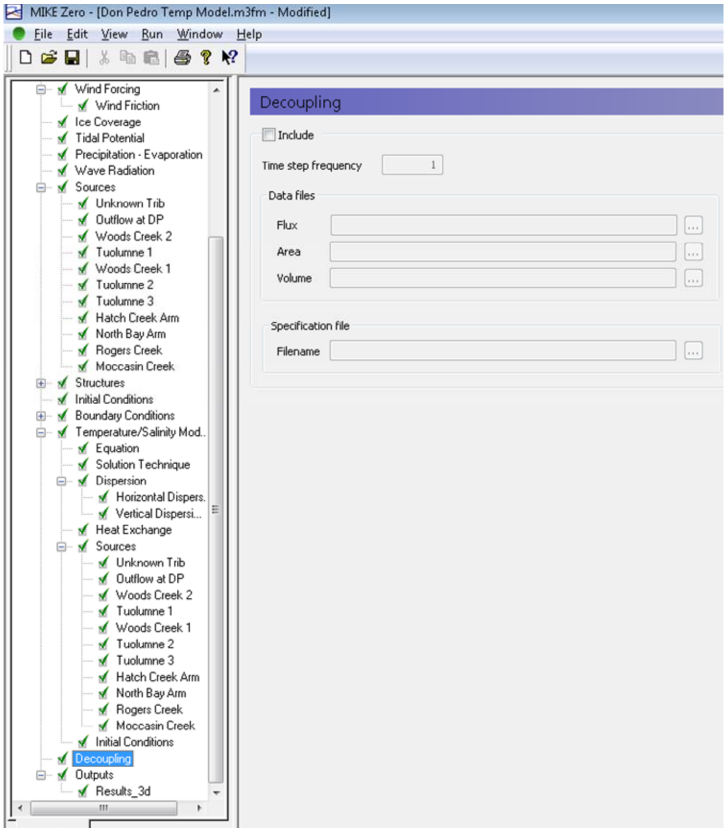

Figure 4.4-50. Decoupling tab.

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.

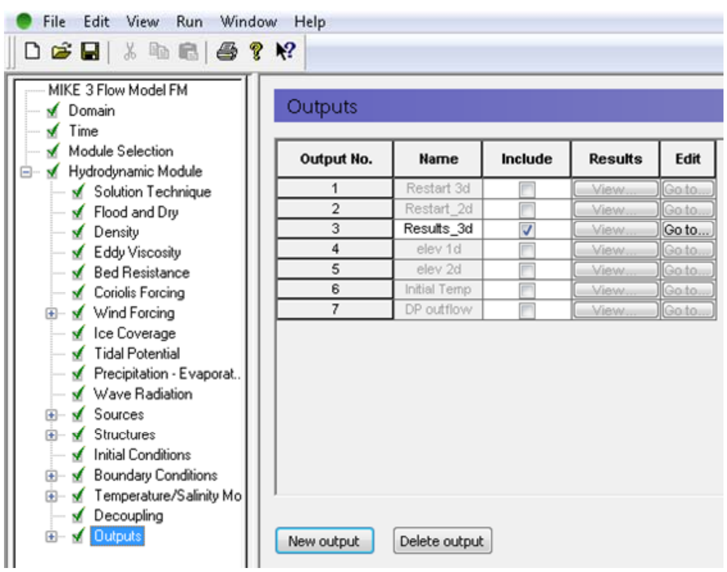

Figure 4.4-51. Output selection screen.

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.

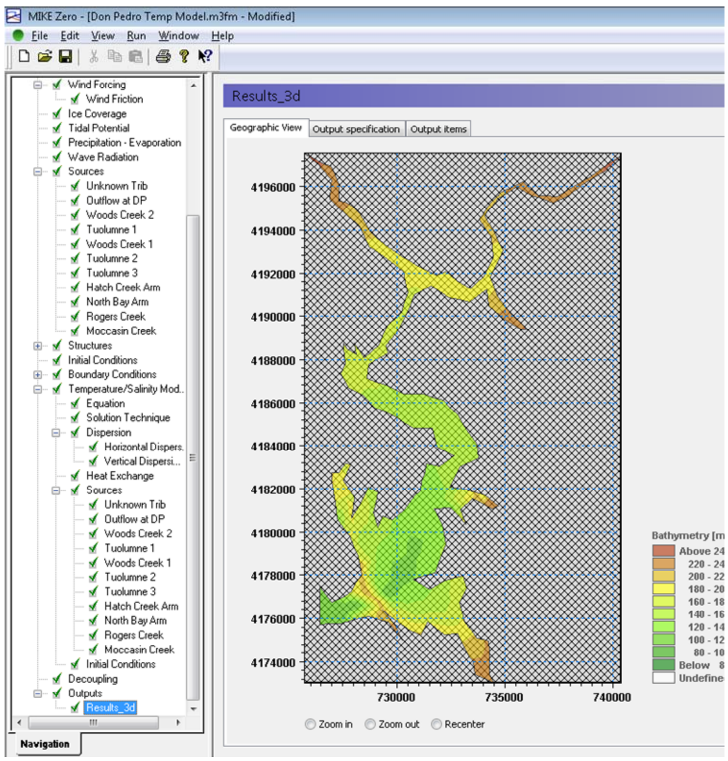

Figure 4.4-52. Geographic view of output area.

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.

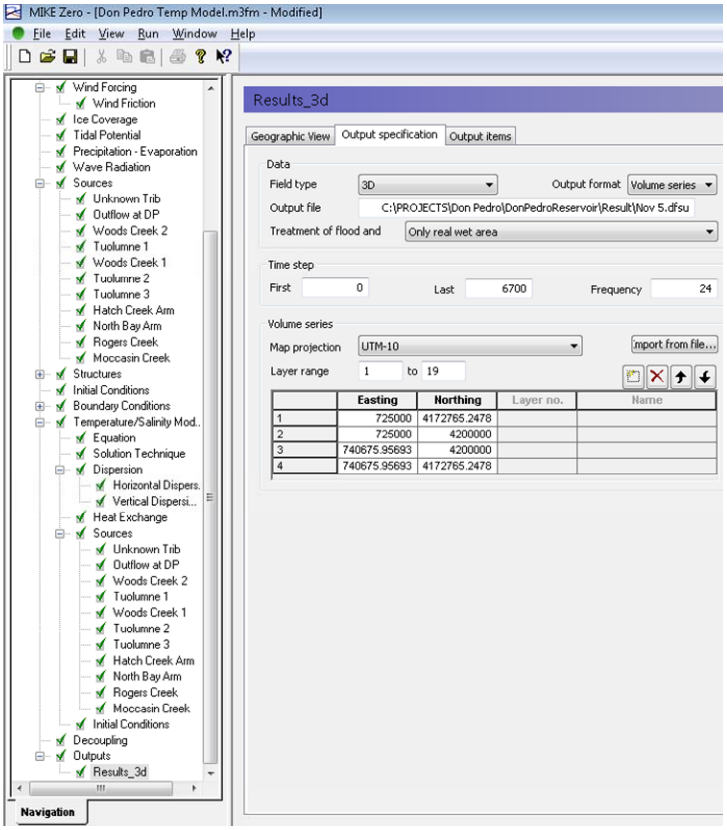

Figure 4.4-53. Output specifications.

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.

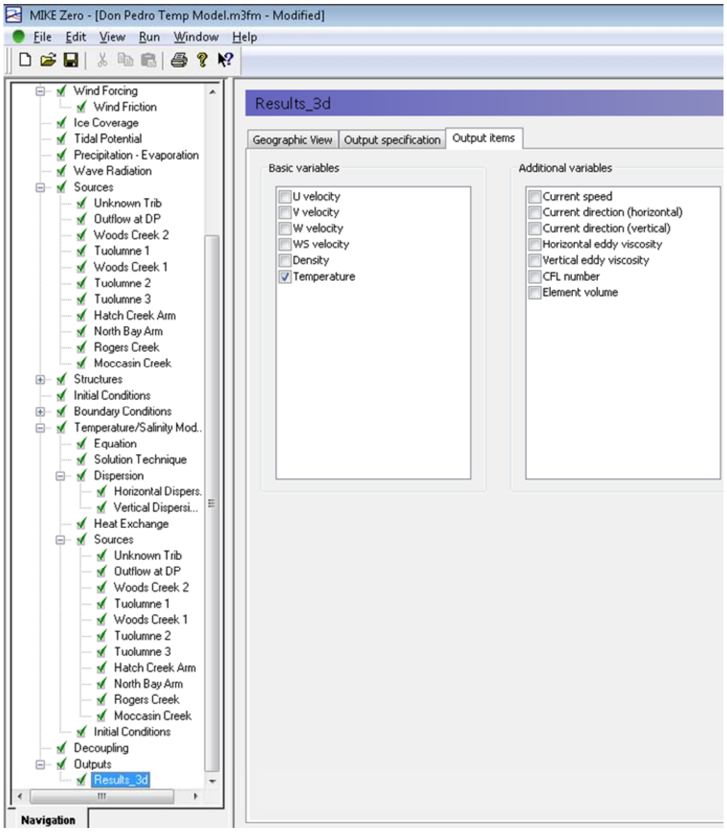

Figure 4.4-54. Example of available output variables for 3D output.

5.0 RESULTS AND DISCUSSION

The FERC Approved Study Plan lists the following items:

- The model will be calibrated and verified using field data that cover continuously the 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. The comparison is discussed in Sections 5.2 and 5.3.
- In addition, model –computed temperature of the withdrawal will be compared to the temperature data collected at the powerhouse. Temperature measurements at the powerhouse (1978 - 1988, 2010 - 2011) will also be used for the model calibration/verification. This is discussed in Section 5.4.
- Surface water temperature recorded concurrently with the bathymetric data in May and June 2011 will also be used in the model calibration. This is discussed in Section 5.5.
- The Districts will conduct a QA/QC review of the modeling following the calibration and verification to confirm its validity for evaluating future conditions. Following this review, the Districts will meet with the Relicensing Participants, per Section 6.0. This is discussed in Section 5.6.

5.1 Temperature Profile Data

Vertical temperature profiles are 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 only years with complete data sets to use as inputs to the model. The temperature profiles are measured approximately monthly for most of the year, typically January through October/November. The profiles are measured by CFDG and the Districts. The profile locations were listed above in Table 4.3-2 are shown in Figure 5.1-1. The profiles collected are:

- Highway 49 Bridge (CDFG and TID/MID)
- Above Old Don Pedro Dam (TID/MID only)
- Below Old Don Pedro Dam (TID/MID only)
- Don Pedro Dam (CDFG and TID/MID)
- Jacksonville Bridge (CDFG and TID/MID)
- Middle Bay (CDFG and TID/MID)
- Woods Creek (CDFG and TID/MID)
- Ward’s Ferry (CDFG and TID/MID)

Plots of reservoir profiles are provided in Attachment A. The vertical temperature profiles show that in the early portion of the year, January – March, the reservoir is not stratified and equilibrium temperatures are around 10 ^{o}C. In April the data begin to show significant warming at the surface with temperatures around 18 ^{o}C observed, and initial stratified conditions are becoming apparent. The data for May and June look similar to April, but with the surface heat penetrating a little deeper. By July the surface temperatures have risen above 25 ^{o}C and there is a well defined temperature profile. The profiles shows a decrease in temperature with depth that extends some 200 ft until the temperature stabilizes around 10-12 ^{o}C. The profiles basically remain the same through July and August. At the end of September the reservoir is still significantly stratified and the profiles look similar to July and August, except that the surface temperatures have dropped by a couple of degrees and are just below 25 ^{o}C. When the last profiles for 2011 were measured on October 13 the reservoir was still stratified. Surface temperatures continued to drop and were around 20 ^{o}C.

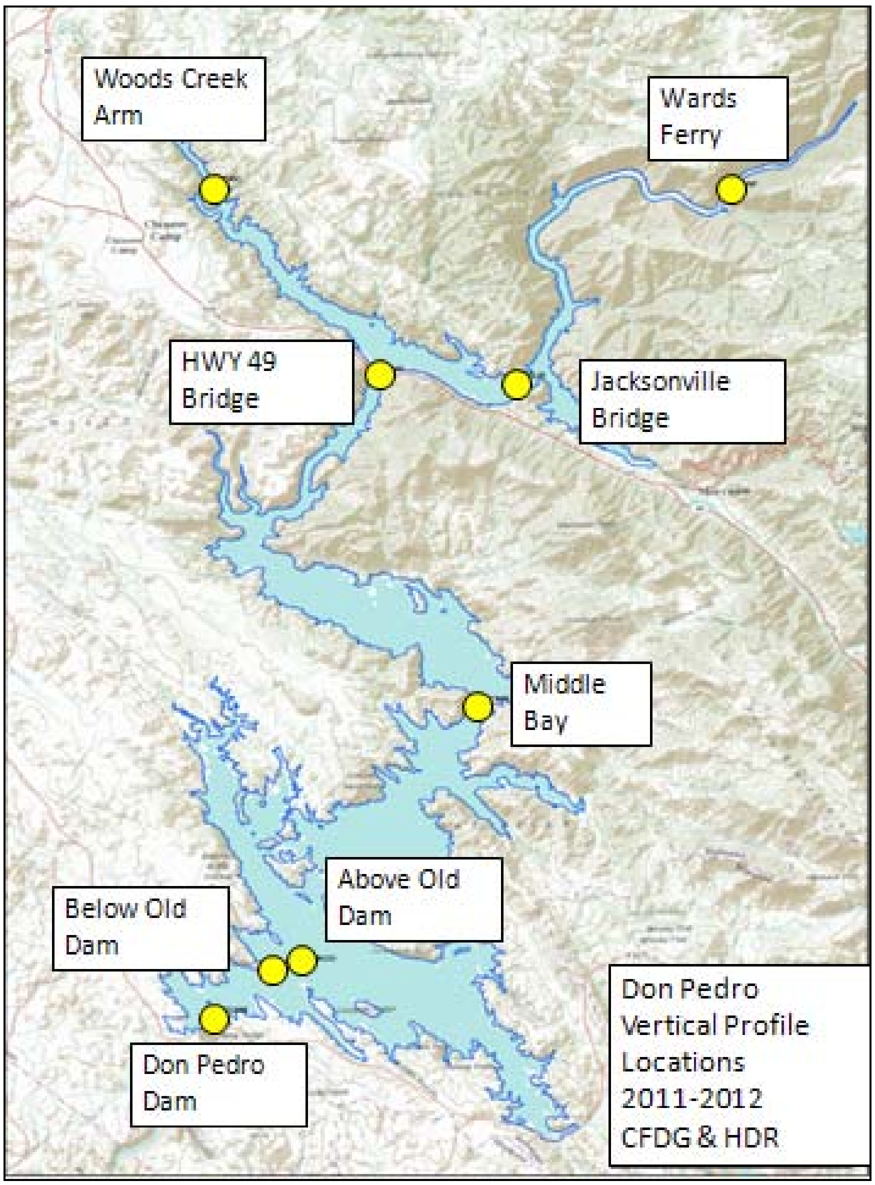

Figure 5.1-1. Vertical temperature profile locations.

5.2 Model Results – 2011 Calibration Year

Figures 5.2-1 – 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 and so the plots are in Celsius and depth 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.

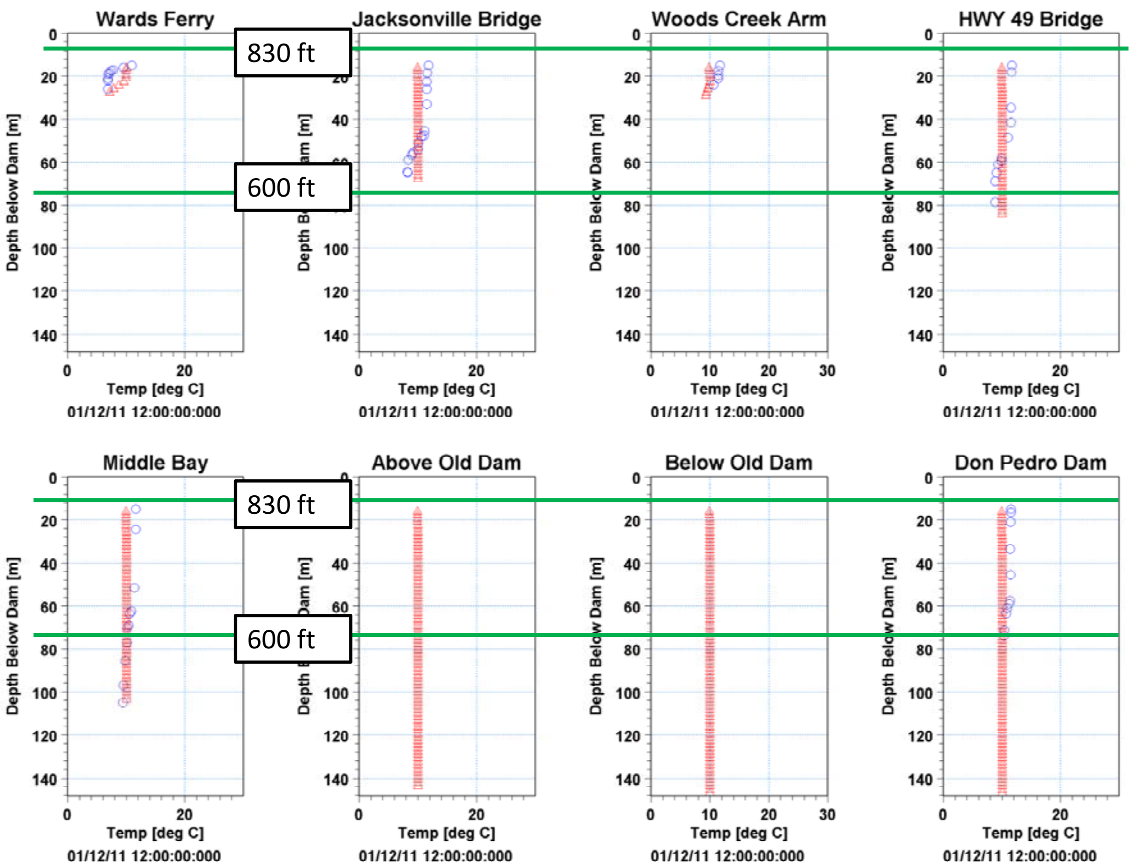

Figure 5.2-1. January 12, 2011 calibration. (Observed = blue circles; Model = red triangles)

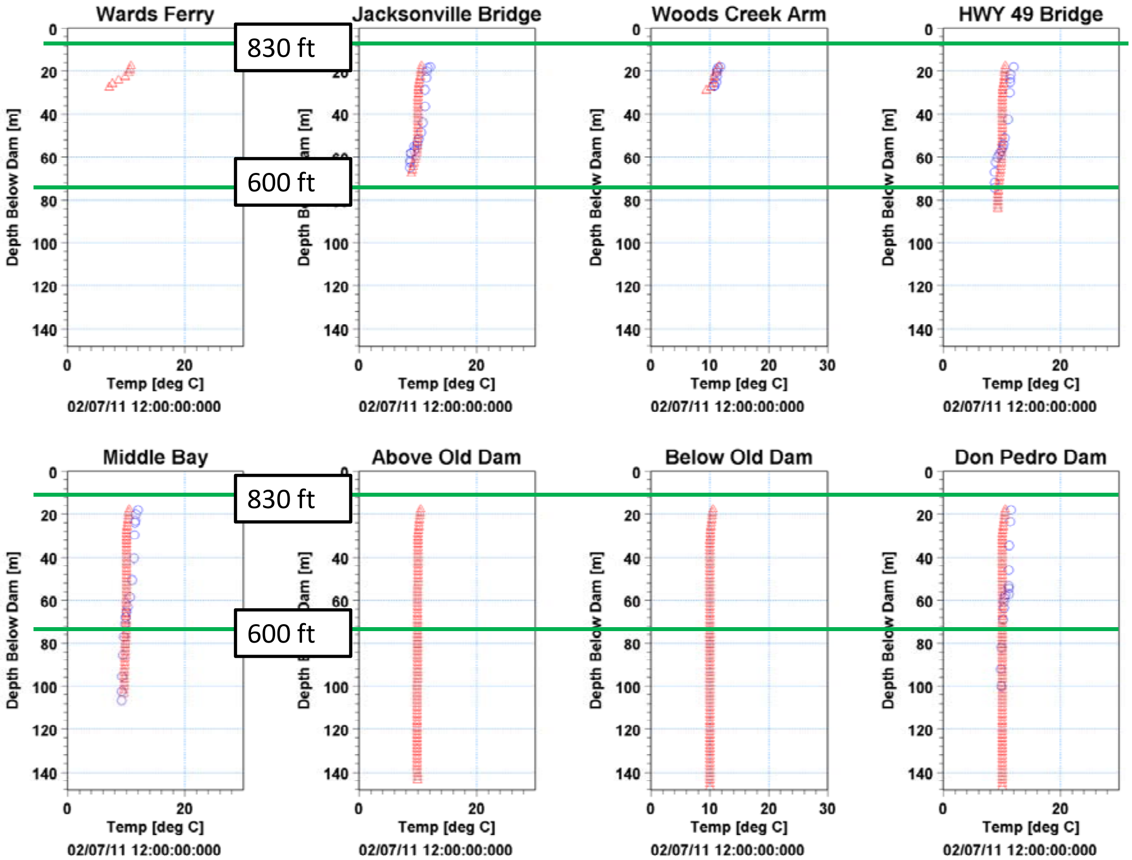

Figure 5.2-2. February 7, 2011 calibration. (Observed = blue circles; Model = red triangles)

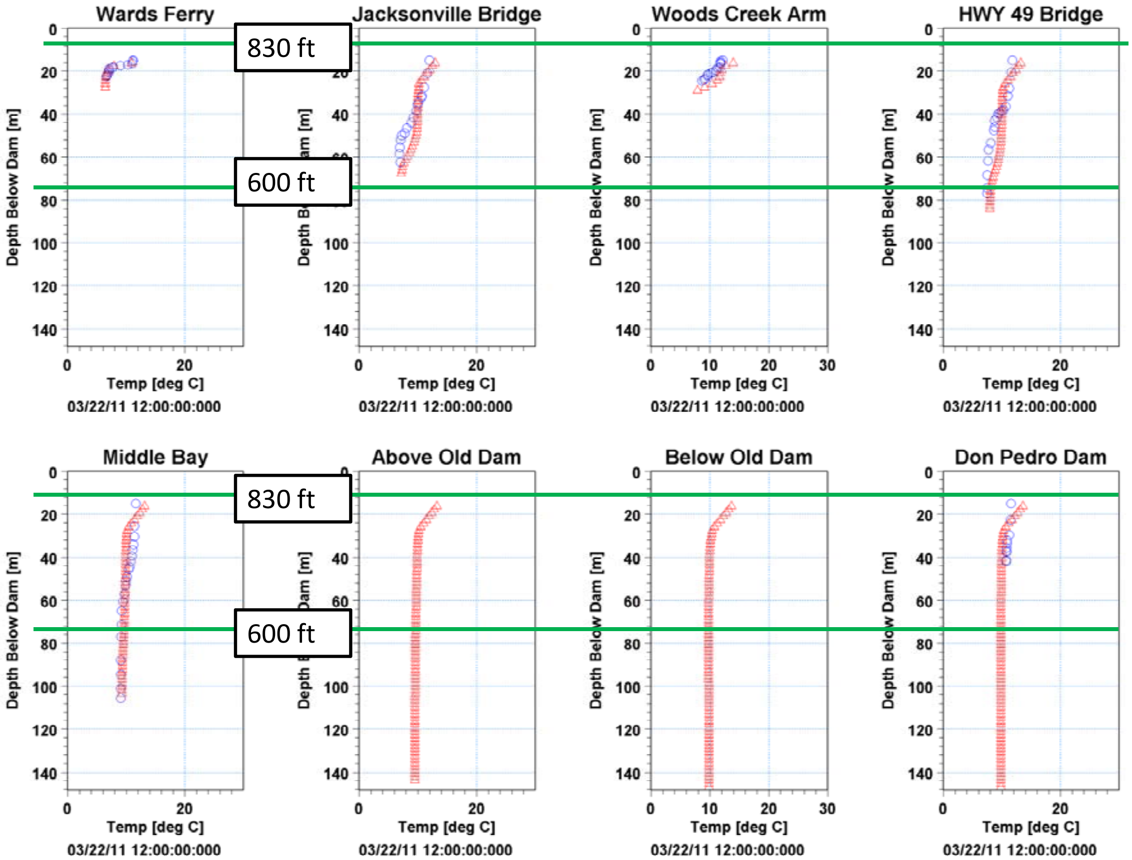

Figure 5.2-3. March 22, 2011 calibration. (Observed = blue circles; Model = red triangles)

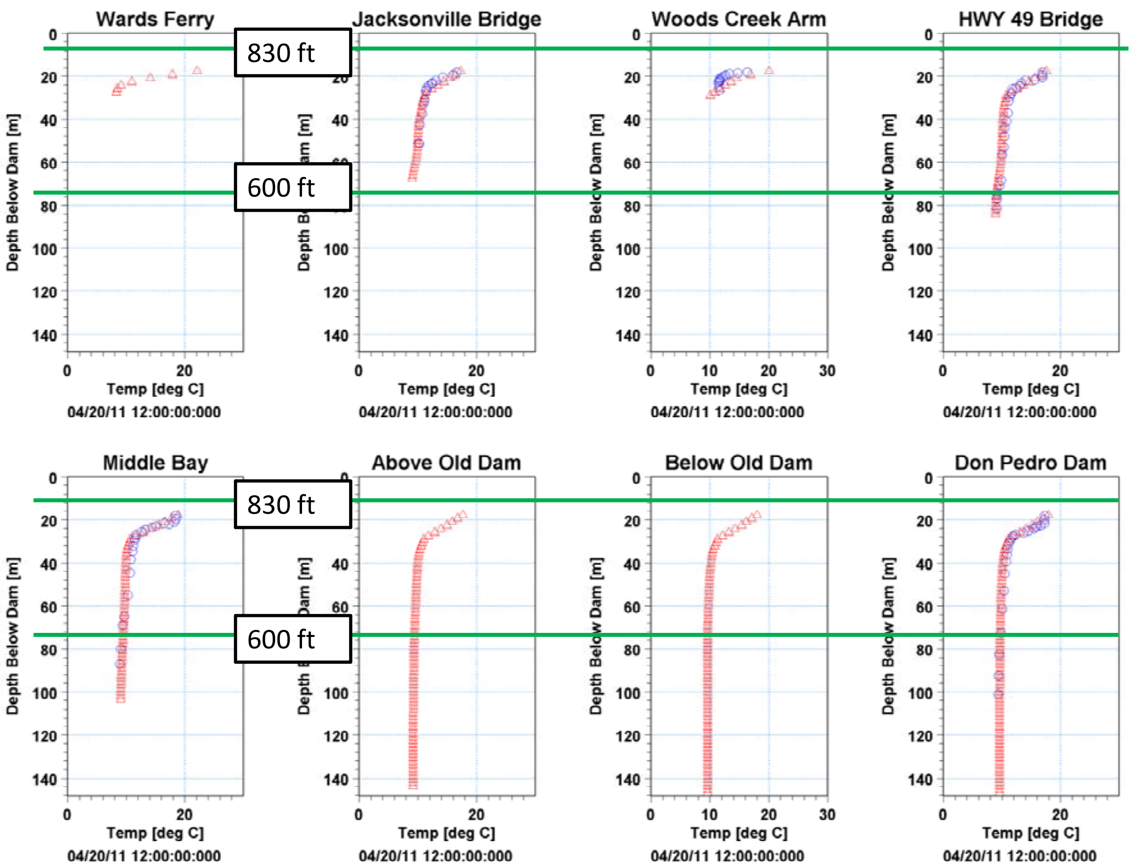

Figure 5.2-4. April 20, 2011 calibration. (Observed = blue circles; Model = red triangles)

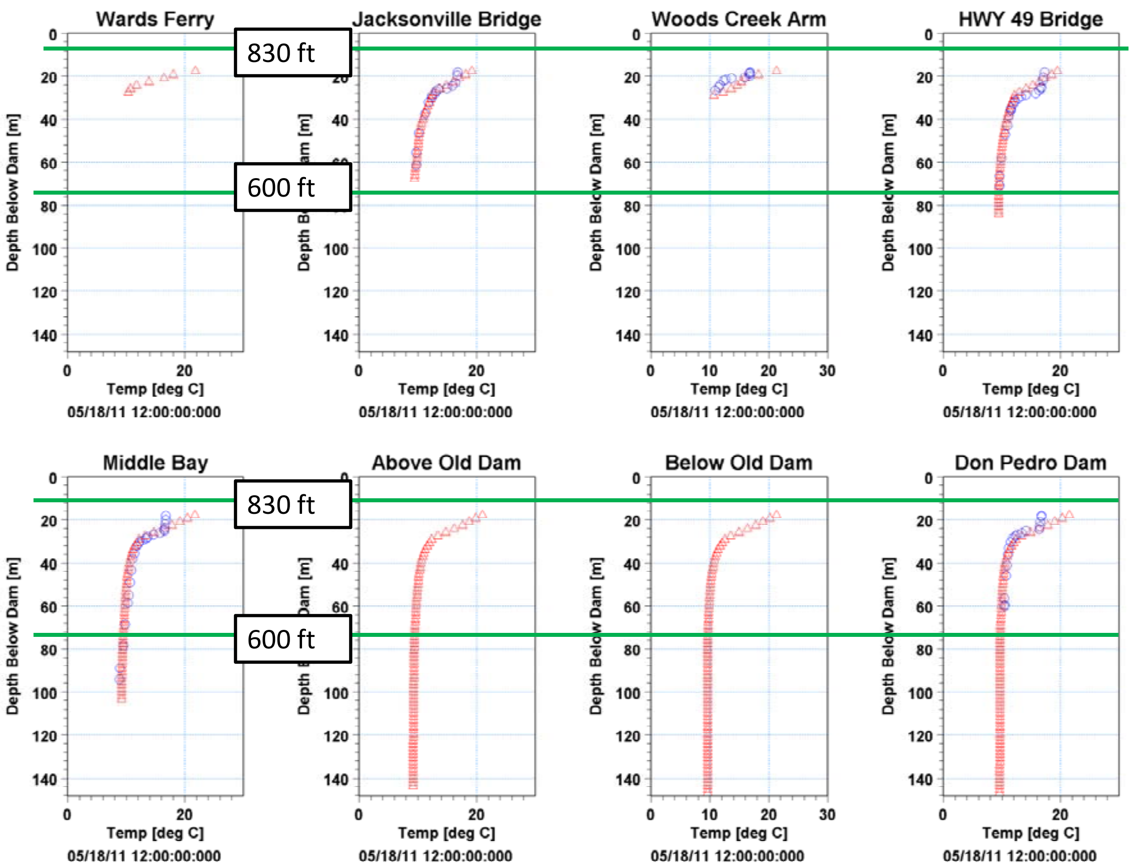

Figure 5.2-5. May 18, 2011 calibration. (Observed = blue circles; Model = red triangles)

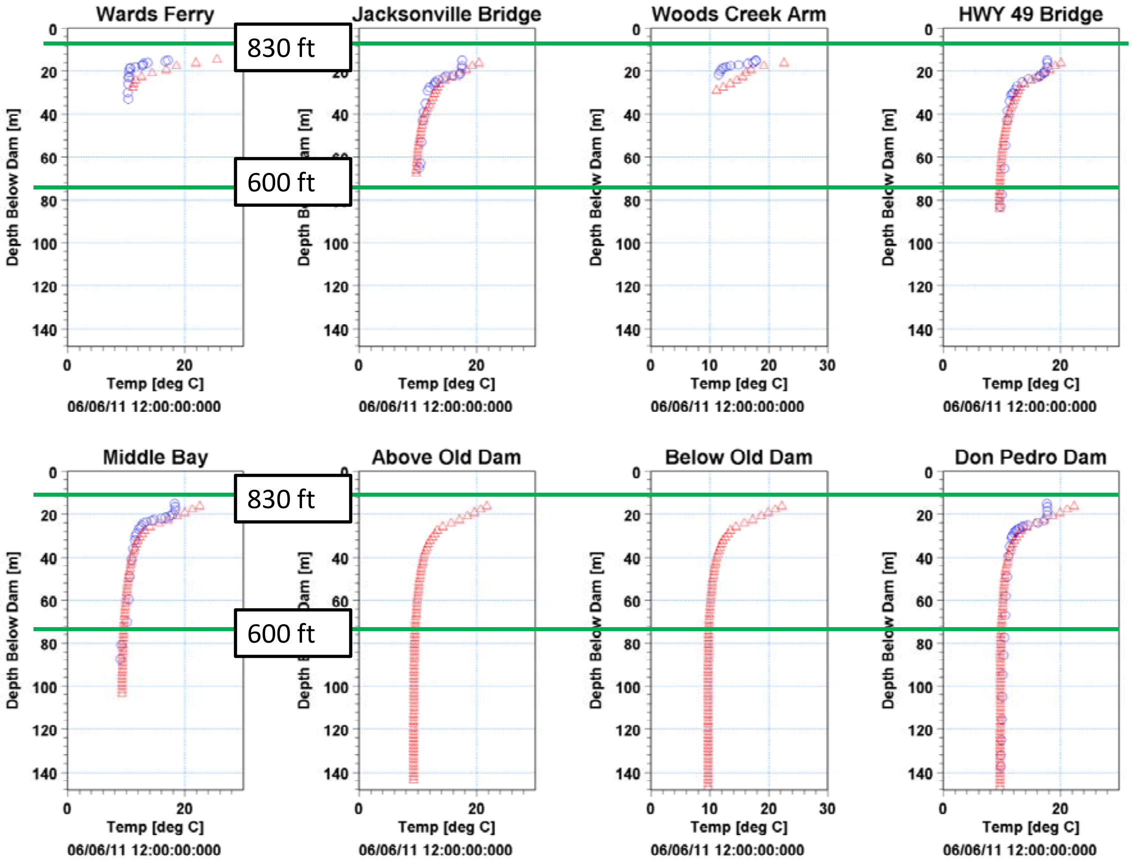

Figure 5.2-6. June 6, 2011 calibration. (Observed = blue circles; Model = red triangles)

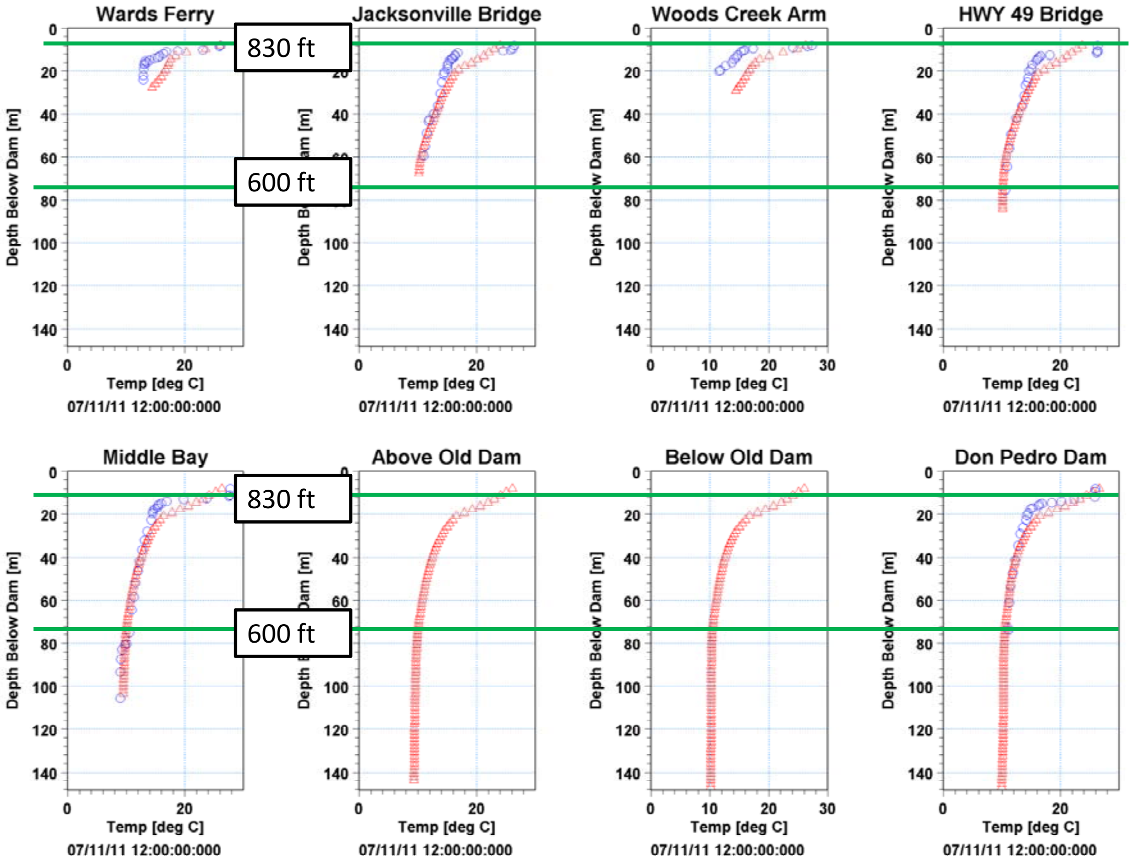

Figure 5.2-7. July 11, 2011 calibration. (Observed = blue circles; Model = red triangles)

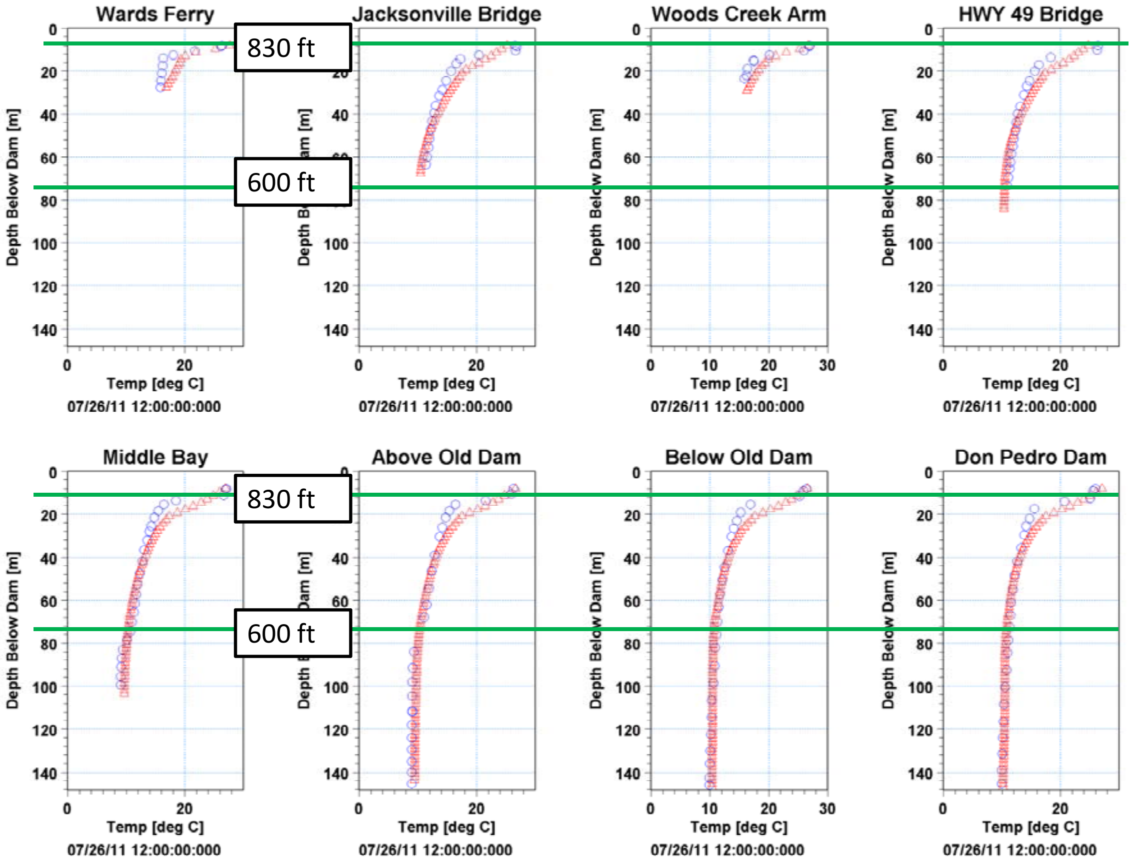

Figure 5.2-8. July 26, 2011 calibration. (Observed = blue circles; Model = red triangles)

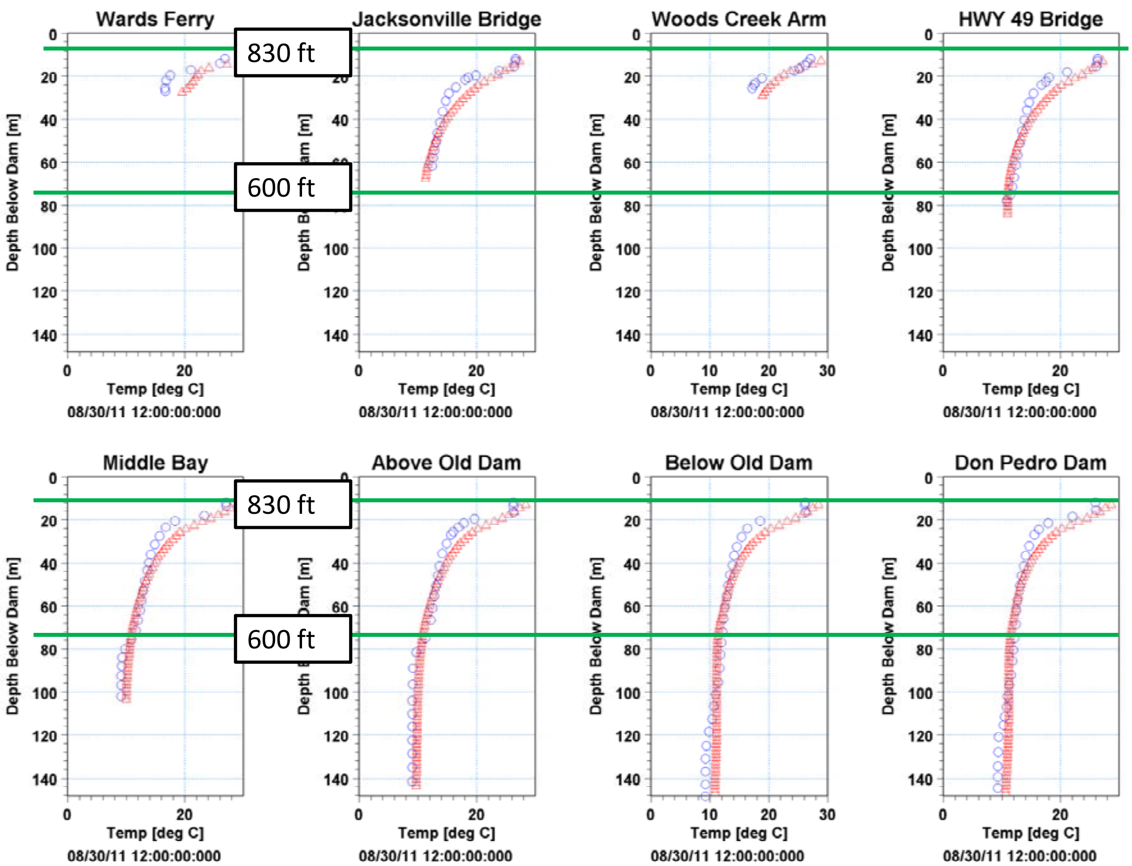

Figure 5.2-9. Aug 30, 2011 calibration. (Observed = blue circles; Model = red triangles)

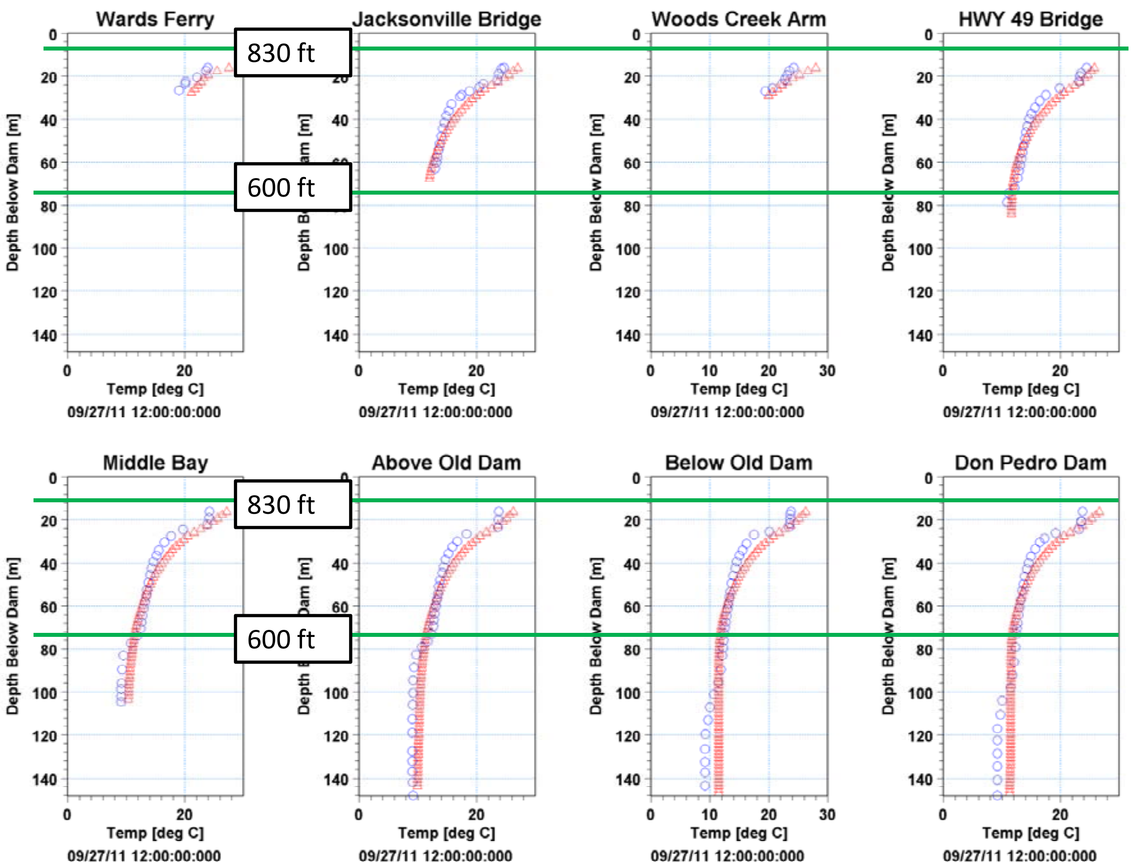

Figure 5.2-10. September 27, 2011 calibration. (Observed = blue circles; Model = red triangles)

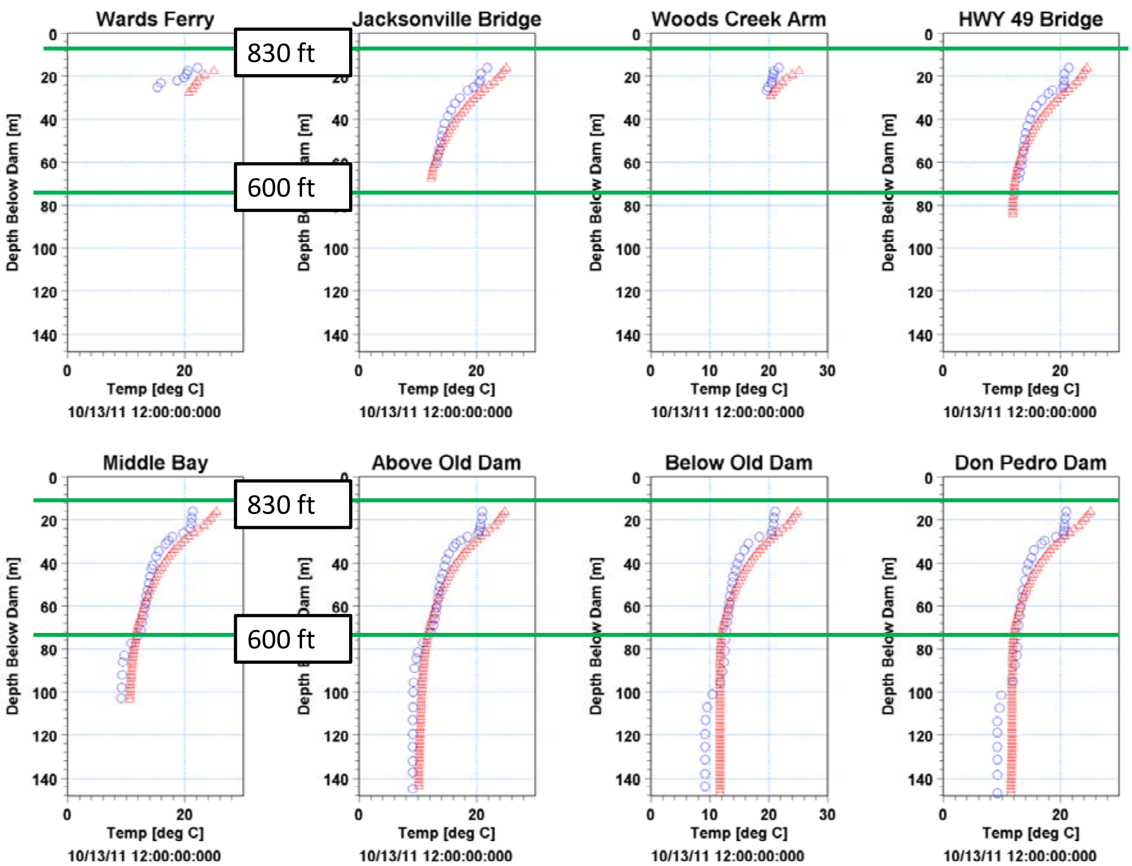

Figure 5.2.11. Oct 13, 2011 calibration. (Observed = blue circles; Model = red triangles)

5.3 Model Results – 2012 Validation Year

As of the writing of this report only limited profile data for 2012 was available from CDFG. A complete 2012 data set is expected to be available by mid-January 2013. At this time the model validation can be completed. Assuming the CDFG data is available by mid-January, model validation will be completed by mid-February. Validation results will be shared with Relicensing Participants.

5.4 Comparison of Outflow Temperatures

A comparison between the measured temperatures recorded below the Don Pedro Dam in 2011 and the model computed outflow temperatures are shown in Figure 5.4.1. Note that the model run ended on October 13, 2011 as there were no more vertical reservoir profiles after this date. The model shows a strong correlation with the measured outflow temperature.

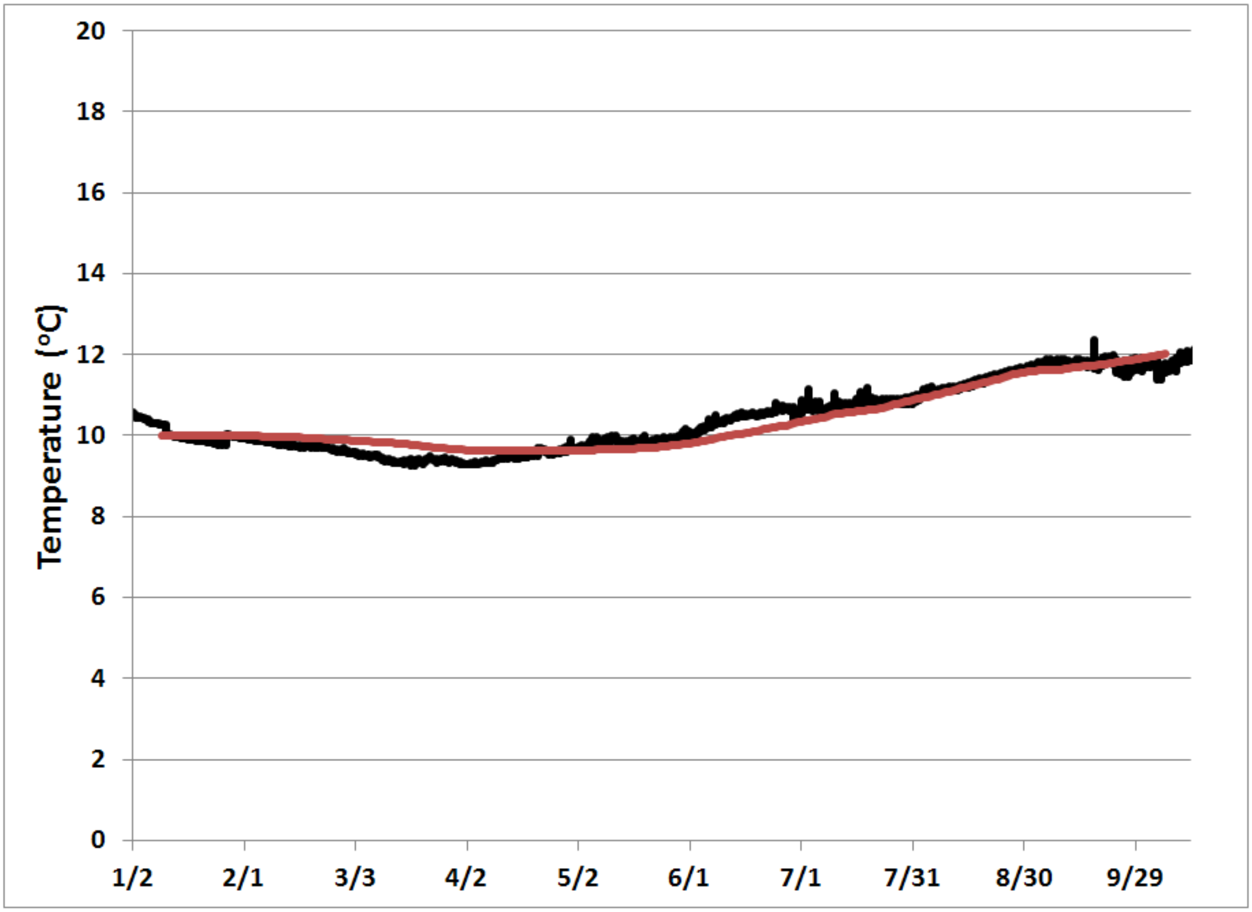

Figure 5.4.1. Measured and modeled outflow temperatures, 2011. (Measured = black; Modeled = red)

5.5 Comparison to Observed Surface Temperature Data

This will done concurrently with the validation to the 2012 data and will be completed by mid-February 2013.

5.6 QA/QC Review

This review will take place after the model validation has been completed and will be completed by mid-February 2013.

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 now able to directly measure in 2011 and 2012. Hence, the Districts determined that the direct measurements from 2011 would be used for model calibration and the direct measurements from 2012 would be used for validation.

The FERC-approved study calls for including the four tributary creeks where water temperature has been measured continuously by HDR since late April 2011 (Rough and Ready, Woods, Mocassin and Sullivan Creeks; data provided in Attachment A). Both temperature and flow information are required to incorporate the tributaries. 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. However, these contribute only minor amounts of 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 alternate future reservoir operation scenarios." The selection of 2012 as the validation year impacted the schedule, as the final hydrology data set, reservoir profiles, and input temperature data were not all available until early December 2012. Vertical temperature profile data for 2012 from CDFG is expected in mid-January. To stay reasonably on schedule, the Districts intend to conduct an initial training session for RPs in the use of the model on January 24, 2013. Full model validation results should be available by mid-February and these will be provided to RPs for review and comment.

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