BUREAU OF RECLAMATION

Technical Memorandum

# Water Temperature Modeling Platform: Data Development – Sacramento, Trinity, and American Rivers Systems (INTERIM DRAFT)

**Central Valley Project Water Temperature Modeling Platform**

California-Great Basin Region

**U.S. Department of the Interior** **June 2022**

# Mission Statements

The U.S. Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated Island Communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

# Water Temperature Modeling Platform: Data Development – Sacramento, Trinity, and American Rivers Systems (INTERIM DRAFT)

## Central Valley Project Water Temperature Modeling Platform

California-Great Basin Region

*prepared by*

**United States Department of the Interior, Bureau of Reclamation**

**California-Great Basin**

*With Technical Support by:*

**Watercourse Engineering, Inc.**

Cover Photo: Keswick Dam on the Sacramento River by John Hannon

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# Abbreviations and Acronyms

| | |
|---|---|
| API | Application Programming Interface |
| CC | Cloud Cover |
| CVP | Central Valley Project |
| GUI | Graphical User Interface |
| I/O | Input/Output |
| IT | Information Technology |
| Pr | Precipitation |
| QA/QC | Quality Assurance/Quality Control |
| Reclamation | U.S. Department of the Interior, Bureau of Reclamation |
| RH | Relative Humidity |
| SR | Solar Radiation |
| Tair | Air Temperature |
| TCD | Temperature Control Device |
| Tdp | Dew Point Temperature |
| TMDL | Total Maximum Daily Load |
| TMP | Temperature Management Plan |
| Tw | Water Temperature |
| Twb | Wet Bulb Temperature |
| Wdir | Wind Direction |
| WS | Wind Speed |
| WTMP | Water Temperature Modeling Platform |

# Chapter 1 Introduction

Flow and water temperature simulation models are useful and necessary tools to support resource managers in their understanding of temperature dynamics in Central Valley Project (CVP) reservoirs managed by US Department of the Interior, Bureau of Reclamation (Reclamation), and downstream river reaches. Such tools support evaluation of how operational decisions and various influencing factors could affect water temperature in reservoirs and rivers, and the resulting potential impacts to fishery species that are sensitive to water temperature. The improvement of models, modeling approach, and associated tools to support operational decision making is considered a necessary adaptation strategy in a changing climate and regulatory environment that takes advantage of technological advancements and all available information and data. One of Reclamation's objectives for the development of the Water Temperature Modeling Platform (WTMP) is to improve the effective and efficient management of resources for downstream regulatory and environmental requirements within the context of an uncertain environment. The WTMP is to provide realistic predictions of reservoir and downstream river water temperatures with sufficient confidence to carry out the necessary planning for seasonal and real-time applications while also describing situational risk and uncertainty.

## Needs for Data Development

Data development is an important component of the WTMP, comprising the identification of data needs, the acquisition of necessary data, and the development of datasets for use with models. A data management system (DMS) was also developed to provide a data base, a process for data retrieval, data review and quality assurance/quality control (QA/QC), and providing data to the WTMP in model-ready format. In addition, the DMS develops and stores metadata and documentation for all data sources. Development of the DMS is discussed in *Technical Memorandum: Data Management System (DRAFT)* (Reclamation 2022). Available data information is limited for most data sets (e.g., specific QA/QC procedures/notes, sensor information/accuracy, field conditions and station maintenance). Data are drawn from a wide range of sources that have a range of quality control measures. Data are reviewed prior to use in the WTMP, but the level of review is largely an assessment of clearly erroneous data, missing data, or similar circumstances. Phase II of the project will assess potential sources of uncertainty and methods to incorporate and assess uncertainty into model simulations and assessments.

Model development is the process of acquiring historical data to develop, calibrate and validate, and apply models. The development of the historical data includes the acquisition, review, data gap filling, formatting data for model input, and documentation. The scope of this technical memorandum includes:

- Sacramento River system, including Shasta Lake, Keswick Reservoir, and Sacramento River from Keswick Reservoir to Red Bluff Diversion Dam.

- Trinity River system, including Trinity Lake, Trinity River from Lewiston Dam to North Fork Trinity River, Lewiston Lake, Whiskeytown Lake, Spring Creek Tunnel, and Clear Creek.
- American River system, including Folsom Lake, Lake Natoma, and American River from Nimbus Dam to the mouth.

Data development for the Stanislaus River will occur in the summer of 2022. Findings will be included in a subsequent draft of this technical memorandum.

# Document Organization

The implementation of WTMP includes many components; each with its own technical challenges and considerations. The documentation of the WTMP includes a series of technical memoranda that document the development of, and recommendations for, certain components. The information in the technical memoranda are incorporated by reference, where appropriate, to avoid duplication of information.

This document describes data types used in modeling reservoirs and streams, WTMP and model data requirements for currently selected WTMP models.  Subsequently, data for each system is presented.  An electronic-format inventory of flow and water temperature data collected to date and other technical information are included in the appendices.

# Chapter 2 Data Types

Three general types of data are used in the WTMP: time series data, physical data, and operational data. These data types are defined herein and their role in modeling presented.

## Time Series Data

Time series data represent a sequence of data points in chronological order. These data points are usually successive measurements at a location made by an entity, often at set time intervals over a period, and are used to track changes in conditions over time. Time series data are used for three principal purposes in the WTMP: as boundary conditions that represent information flow into the models, as field observations used for model calibration and validation, and to support model application and analyses.

Time series data include system inflows and outflows, reservoir stage (storage), vertical water temperature profiles, and meteorology data. System inflows include headwater inflows as well as tributary inflows. Water temperature and flow data is needed from inflow locations in reservoirs and river reaches. Some time series data are collected at variable periods of time, such as reservoir thermal profiles; spot measurements of temperature, flow, or stage; and historic reservoir operations (see operational data, below).

## Physical Data

Physical data define physical aspects of the system that are not time dependent for the purposes of this temperature modeling project. Physical data include reservoir and river geometry (e.g., latitude/longitude, morphology/bathymetry, location of tributaries/withdrawals), reservoir outflow descriptions (e.g., elevation, diameter, capacity) and conveyance capacities, and similar information. River stage-discharge relationships and reservoir stage-volume-surface area tables or curves also represent physical data. Stage-discharge and stage-area-volume information are often used to translate one parameter in a time series to another. For example, a time series of stage measurements can be converted to stream flow using a stage-discharge relationship.

Physical data, while not time dependent in the same manner of time series data, can change through time. A modification to the outlet works of a dam is an example of an infrastructure modification that may occur during the life of a project. The model selection process for the WTMP (*Technical Memorandum: Model Selection (DRAFT)* (Reclamation 2021)) included specific metrics for considering models that could accommodate a wide range of system configurations, and thus accommodate potential infrastructure modifications. These basic physical attributes (data) of reservoirs and rivers (e.g., dams, diversions) are characterized in the model development documentation, and can include historic changes through time. An example of a physical data change is the addition of the additional spillway capacity at Folsom Dam completed in 2017, and action that resulted in new time series data for reservoir releases.

## Operations Data

Operations data include reservoir operating rules, management protocols, minimum instream flows, downstream target temperatures, and similar information. Operational data may be static for longer periods of time and without fixed frequency. However, some operations data change at regular intervals or exert control over other time series data. For example, historic TCD operations change slowly and at uneven intervals over the spring through fall, and have a critical relationship to flow and temperature time series data.

# Chapter 3 WTMP Model Data Requirements

Required information for WTMP models includes geometric information that describes the physical systems (i.e., physical data); flow information; water temperature data; and meteorological observations that act as forcing functions in temperature models. Other model values, coefficients, and constants -- such as start date, simulation duration, time step control, calibration parameters, and other model control parameters -- will be addressed in model development documentation. Data development for WTMP models is outlined below.

## Geometry Data

Geometry data are required for both reservoir and river models to describe the physical system. For reservoir models, geometric data describe the reservoir morphology (bathymetry), the reservoir stage-volume relationship, locations of inflow and outflow points, elevations and capacities of outlet works, and provide information regarding topographic shading (Table 3-1). Geometric data for river models describe channel morphology, locations of inflow and outflow, facilities locations, and information regarding topographic and riparian shading (Table 3-2).

Table 3-1. Geometry data for reservoirs, description, and sources of information.

| Geometry Data | Description | Sources |
|---|---|---|
| Bathymetry | Contour map of lake or reservoir below water surface and surrounding upland area | Digitized topographic maps/aerial photos; Digital Elevation Map (DEM); Bathymetric Survey |
| Stage-Volume Curve | Description of the relationship between a reservoir stage and its volume | Bathymetry or topographic maps (pre-project) |
| Facilities Description | Temperature Control Device (TCD), dam outlets, diversion intakes, spill elevations, temperature shutter elevations and operations, temperature control curtains, submerged dams, etc. | Operators, diagrams/schematics |
| Inflow/Outflow Locations | Location of inflow and outflow points | Maps, aerial photos, field surveys |

Table 3-2. Geometry data for rivers, description, and sources of information.

| Geometry Data | Description | Sources |
|---|---|---|
| Channel Morphology | Cross section of channel below water surface and surrounding upland area; channel gradient | LiDAR, Field measurements |
| Stage-Discharge Curve | Description of the relationship between a river stage and its discharge | USGS observations, measured stage and flow |
| Facilities Description | Diversion dam elevation and installation schedule | Operators, diagrams/schematics |
| Inflow/Outflow Locations | Location of inflow and outflow points | Maps, aerial photos, field surveys |

## Hydrologic Data

Hydrologic data used for implementation of WTMP models includes inflow, stage (or water surface elevation), and operations (or outflow) data. For a river model, flow data are necessary to represent the river volume, surface area, depth, and current velocities at different flow rates given the geometric description of the river system. Hydrologic data at daily (e.g., daily average) and sub-daily (e.g., hourly) increments are required. To represent highly transient events, such as hydropower peaking, pulse flows, and flow ramping rates, sub-daily data are required. Hydrologic data represent boundary conditions, as well as calibration/validation information to assess model performance at locations within the modeling domain. Hydrologic data are collected in a variety of methods, but typically includes direct measurements (discharge through a penstock or similar conduit), tracking stage and relating stage to flow through a known equation (e.g., meter or weir) or a stage-discharge curve (stream). These flows vary in their accuracy depending on method, equipment used, quality and maintenance of equipment, technical expertise, and other factors. Some guidance can be obtained by reviewing an explanation of USGS stage and discharge records. USGS states:

“The accuracy of streamflow data depends primarily on (1) the stability of the stage-discharge relation or, if the control is unstable, the frequency of discharge measurements, and (2) the accuracy of observations of stage, measurements of discharge, and interpretations of records. The degree of accuracy of the records is stated in the REMARKS in the station description. "Excellent" indicates that about 95 percent of the daily discharges are within 5 percent of the true value; "good" within 10 percent; and "fair," within 15 percent. "Poor" indicates that daily discharges have less than "fair" accuracy. Different accuracies may be attributed to different parts of a given record.”

Brief review of stream flow measurements at various USGS stations in the project area over the 2000-2021 period indicates that few locations (and times) registered “excellent” ratings, with the majority in the “good,” “fair,” and “poor” categories. Some sites and certain times of years or flow conditions provide different levels of quality.

## Temperature Data

Water temperature data are required in a similar manner as flow data in model applications: as boundary conditions at headwaters and tributaries and as calibration points within the model domain. Time series and vertical profile water (reservoirs only) temperature data are required to implement and calibrate the models. For reservoir modeling, water temperature data describes water temperatures at reservoir inflow locations, which mainly come from upstream sources, as well as from tributaries and surface runoff. Water temperature vertical profiles describe vertical variations (or lack of variation) in water temperature at locations of interest, e.g., near the TCD. For river modeling, water temperature data are required at headwater and tributary inflows as well as at intermediate monitoring sites for model calibration. For sub-daily modeling applications, such as those explored herein, data frequency is generally on the order of one hour, but lower frequencies can be used if the diurnal signal of water temperatures is effectively represented.

Water temperature data are collected by a wide variety of agencies and entities using a range of equipment and methods. USGS provides guidance on this topic (USGS Surface-water-quality records), identifying that water temperature measurements with accuracy of less than or equal or less than ±0.2℃ are “Excellent,” between ±0.2℃ and less than or equal to 0.5℃ are “Good,” between ±0.5℃ and less than or equal to 0.8℃ are “Fair,” and >±0.2℃ are “Poor.” Review of available records suggests that commonly used water quality probes or remote sensing loggers (e.g., Hobo temperature loggers) fall into the “Excellent” or “Good” categories, but older data sets may not be of the same level of accuracy. While the level of accuracy of the instrumentation is generally good, deployment methods play an important role in water temperature monitoring. Data may not be collected an appropriate frequency (e.g., hourly), duration (seasonal versus year-round), or location (thalweg versus near-shore). Further, temperature monitoring equipment is subject to drift, and QA/QC information is not always provided to ascertain if the monitoring equipment was verified to be within the factory specifications prior to and following deployment. The development of the WTMP assumed data are representative of lake and stream conditions; however, model developers, analysts, and technicians should be aware of these data conditions.

## Meteorology Data

Hourly time series meteorology data is a boundary condition for WTMP models. The necessary meteorology data includes solar radiation, cloud cover, air temperature, dew point or wet bulb temperature, relative humidity, atmospheric pressure, wind speed, and wind direction. Some meteorology data is commonly measured at data collection stations (e.g., air temperature, relative humidity, wind speed and direction), while other types of data are less commonly collected directly and may be developed from measured data (e.g., cloud cover). Principal data sources for the WTMP project include NWS, CIMIS, and the RAWS networks. Stations in these networks typically are standardized, providing a defined level of accuracy and standardized reporting. While these stations include accurate components, a larger challenge with meteorological data is representation of local conditions. Long term, lake or riverside meteorological stations are absent in the project area. Nearby meteorological stations are used as representative conditions for the various systems modeled in the WTMP.

The WTMP uses local, long-term meteorological data sets for each region. That is, each system - the Sacramento, Trinity, American, and Stanislaus– has a discrete, region-specific long-term meteorology for modeling. Meteorology for each region may include data from other stations (nearby station), estimated data (cloud cover), and adjusted data (air temperature and wet bulb temperature at different elevations) to fill data gaps in the development of the long-term record for use in the WTMP. A single representative meteorology for each region provides a single data set and method of data development to model historical conditions as well as to develop forecasting approaches.

## Solar Radiation

Solar radiation is reported hourly or daily. Hourly data follow a daily normal curve that peaks at solar noon. This cycle is imposed on a seasonal signal with an annual maximum on the summer solstice and minimum on the winter solstice. For local latitude (approximately 41° north) and the range of elevations in the project area, the annual maximum solar signal is approximately 1,000 $W/m^2$. Topographic shading on system reservoirs and streams can reduce incoming solar radiation early in the morning and late in the afternoon. This shading is short lived and occurs when incoming solar radiation is low and has a minimal impact on water temperature, particularly during the late spring through early fall when solar altitude is higher. Thus, topographic shading is not included in the WTMP.

Riparian vegetation shading, if sufficient in density, spatial extent, and height can be seasonally important in smaller river systems. In general, stream systems in the project area do not experience extensive riparian vegetation shade. Certain reaches will be explored during model development to ascertain the role shading may play on water temperature.

## Cloud Cover

Cloud Cover information can be obtained in various ways. Some meteorology observations report sub-hourly, hourly, or daily cloud cover data directly. That data is often reported as a percent of sky cover value. Airport-based meteorology stations may report cloud cover at various levels or ceilings. Cloud cover values may also be developed from solar radiation data (see Data Gaps, below) wherein daily average solar radiation data is used to estimate a daily value for cloud cover.

## Air Temperature

Air temperature data is typically reported sub-hourly or hourly. Air temperature decreases with elevation. A lapse rate of -6°C per 1,000 m (Linacre 1992) increase in elevation is applied to air temperature data sets to correct for the difference in elevation between the meteorology station and the project area. If there is a large elevation difference between the highest and lowest elevations of the model domain, the meteorology data can be divided into multiple zones within the model domain to reflect the elevation-based air temperature variations.

## Dew Point and Wet Bulb Air Temperatures

WTMP models can use either dew point or wet bulb air temperature data. One or both of these parameters are reported at most weather stations, typically sub-hourly or hourly. Dew point and wet bulb air temperature can be computed using air temperature (corrected for elevation), relative humidity, and air pressure (either measured time series values or a constant value based on elevation). If air temperatures are modified for elevation (lapse rate), dew point and/or wet bulb temperatures are also modified accordingly.

## Wind Speed and Direction

Wind speed and direction are measured sub-hourly or hourly by an anemometer installed at an established height above ground. Wind speed and direction can be affected by terrain or obstacles. Wind speed increases with altitude. To normalize wind speed data collected at different stations, values are adjusted to an elevation of 2 meters above ground level.

## Atmospheric Pressure

Sub-hourly or hourly atmospheric pressure is typically available from meteorological stations.

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# Chapter 4 Data Gaps

Generally, a data gap refers to a portion of a data set that is missing. This section focuses on time series data gaps and approaches to fill these missing data that can range from short (hours, days) to long (weeks, months, years) periods. There can be data gaps in other information necessary to implement a model, such as system geometry and facility operations, and development of this information is (or will be) documented in multiple WTMP technical memoranda and modeling reports.

As noted above, time series data are used for model boundary conditions, for model calibration and validation, and model application. Data gap filling focuses on boundary conditions because these are necessary data for model simulation, while calibration data, which are not are missing extensive periods, are sufficient to test model performance.

Gap filling depends on several factors, including the relative size of the gap, the time of year during which the gap occurs, and how the data is used in the model, and other factors. The size of a data gap is relative; whether a gap is considered "large" or "small" depends on the type and interval of the data and the inherent variability in the data. Data gaps that fall during a period of particular interest or gaps in data that have a large impact on model performance require more careful consideration. Important in all gap filling exercises is clear documentation that outlines available data, other data sources, approach, limitations to the final data set, and recommendations to support future modeling efforts.

## Methods for Filling Gaps in Boundary Condition Data

Different types of data may use different approaches or methods to address data gaps. Outlined below are approaches for flow and stage data, water temperature data, and meteorological data.

### Flow and Stage Data

Time series flow data is applied as model boundary conditions for headwater inflow, tributary inflows, and system outflows. Flow data is often reported as 15-minute, hourly or daily average values. The resolution of flow data (i.e., interval) is process dependent. A daily time step for flow data may be sufficient for WTMP modeling efforts for tributary inflows or stage in large reservoirs. However, to represent highly transient events, such as hydropower peaking and pulse flows, sub-daily data provide important variability.

In relatively stable systems, short-term data gaps -- on the order of hours for sub-daily data or days for daily data – can be filled using linear interpolation or similar averaging approach. Data gaps that are a few weeks long can be filled with data with a similar linear interpolation of averaging approach. Data from a previous or following time period can be employed if the system remains stable, or neighboring watersheds with the flow scaled relative to basin area. Regression relationships are often an effective means to fill longer data based on information from nearby stations or neighboring watersheds with the flow scaled relative to basin area. When applying flow data from another watershed, other factors affecting flow, such as watershed elevation, aspect, and timing of snowmelt, are also considered. Data from a longer time step (e.g., monthly average) can often be used to develop a daily distribution of flows.

Spatial gaps in flow data (no data for an inflow or outflow location) can be filled by some of the same methods used to fill gaps in a time series. Specifically, flow can be estimated from flow measured in a similar watershed with similar elevation, aspect, and snowmelt timing, scaled to basin size. Precipitation data can be used to inform flow patterns. Mass balance of known flows can also be used to estimate flows for intermediate locations with missing data.  When developing flow data, both distribution (timing) and magnitude of flow are important characteristics to represent in the data set.

## Water Temperature Data

Water temperature data is often reported as hourly or sub-hourly values, and at times daily average. WTMP modeling aims to employ water temperature data at an hourly time step to effectively simulate sub-daily water temperatures. In relatively stable systems, short-term data gaps – on the order of hours for sub-daily data or days for daily data – can be filled using linear interpolation or similar averaging approach. Data gaps that are a few weeks long can be filled with data with a similar linear interpolation of averaging approach.  Data from a previous or following time period can be employed if the system remains stable, or neighboring watersheds with the flow scaled relative to basin area. Regression relationships are often an effective means to fill longer data gaps based on information from nearby stations or neighboring watersheds with the flow scaled relative to basin area. Data can also be calculated flow-weighted average temperature. Flow-weighted average water temperature requires temperature and flow data at each sample time. An example of a flow-weighted average water temperature is the calculation of Shasta Dam outflow temperature using flow and temperature data for each of the five powerhouse penstocks:

$$\text{Flow weighted average temperature } = \frac{\sum_i^5 T_i Q_i}{\sum_i^5 T_i}$$

where $T_i$ and $Q_i$ are temperature and flow of penstock $i$ (1 to 5).

Spatial gaps in water temperature data (no data for an inflow location) can be filled by some of the same methods used to fill gaps in a time series. Specifically, temperature can be estimated from data measured in a nearby watershed with similar characteristics (e.g., elevation, aspect, and snowmelt timing), or using a regression with data from an adjacent watershed or stations. For streams that are at or near equilibrium temperature (i.e., with atmospheric conditions), and equilibrium temperature approach can be used to develop time series on daily or sub-daily frequency.

The equilibrium temperature approach employed herein uses the dynamic equilibrium equation

$$\frac{dT_w}{dt} = S = \frac{q_n A}{C_p \rho V}$$

Where:

| | |
|---|---|
| $T_w$= | water temperature (°C) |
| $t$= | time step (s) |
| $S$= | sources and sinks (°C $s^{-1}$) |

$q_n$= net heat flux (W $m^{-2}$)
$A$= unit area water body ($m^2$)
$C_p$= specific heat of water (J $kg^{-1}$ °$C^{-1}$)
$\rho$= density of water, temperature dependent (kg $m^{-3}$)
$V$= unit volume water body ($m^3$)

Net het flux is calculated using meteorological data at the appropriate time step (e.g., hourly) and a rating curve can be used to develop a relationship for A/V to reflect heat loading differences seasonally or for different stream morphologies (e.g., low flow versus high flow seasons, or wide shallow versus deep narrow streams, respectively). This approach is not valid during periods when streams are not at or near equilibrium, for example, during snowmelt runoff when streams may be well below equilibrium.

A singular spectrum analysis (SSA) has been explored to fill gaps in periodic data. This method has been applied to stage, flow, and salinity in Sacramento-San Joaquin Delta modeling applications, using data from nearby observations. The approach has not been applied, but is being considered for filling data gaps in the WTMP project.

## Meteorology Data

Meteorology time series information represent boundary conditions data to calculate heat exchange at the air-water interface, and for the WTMP are required at an hourly frequency. Short gaps in meteorology data (several hours) can usually be filled by linear interpolation. Longer gaps and gaps of days to several days several weeks can usually be filled with data from the previous and/or following time period during times of relatively stable conditions. Gaps with short term variability or longer gaps in meteorology data, several weeks to months or years long, can be filled with data from a similar year or with data from a nearby station (with appropriate adjustments for elevation, wind sheltering, etc.). Methods for developing data and filling gaps in specific types of meteorology data are presented in the following sections.

There are lengthy historical data sets available, such as PRISM, NARM, CONUS and others, that include meteorological values for air temperature, vapor pressure terms, and solar radiation. However, these data sets are typically based on a daily frequency or longer, and though they can provide useful insight, they are not sufficient for sub-daily boundary conditions necessary to model temperature.

### *Solar Radiation*

Short gaps (up to several hours) in solar radiation data can be filled using linear interpolation, with care taken to represent the typical daily distribution of data. Daily maximum data is sufficient for model applications. Gaps up to a couple of weeks long can be filled with data from the previous or following week, data from a nearby station, with consideration to local conditions that may result in differences between stations (e.g., a coastal area with daily fog, an area that experienced smokey conditions from wildfire activity, etc.). Data from a similar year can be used to fill data gaps if the gaps occur during seasons of stable meteorology. Solar radiation can also be calculated based on theoretical principals (Deas and Lowney 2000, Martin and McCutcheon 1999); however, such values do not accommodate atmospheric extinction, or the aforementioned (local conditions of smoke, fog).

A common quality control issue with solar radiation data is low reported values due to a fouled sensor. Solar radiation data can be checked for quality by applying an annual sinusoidal curve to the annual solar signal (approximately 1,000 $W/m^2$ at local latitude based on local meteorological station observations) and comparing those theoretical daily maximum values to the measured data. A fouled sensor will produce a reduced solar signal that follows the curve but with a lower annual maximum. Cleaning a fouled sensor produces an immediate increase in solar radiation data to values closely mimicking the theoretical data curve.

### *Cloud Cover*

Gaps in cloud cover data can be filled with data from a nearby station, with consideration to local conditions that may result in differences between stations (e.g., a coastal area with daily fog, an area that experienced smokey conditions due to wildfire activity, etc.). Daily average cloud cover data can be used to estimate hourly data. North American Reanalysis Model (NARM) results provide information on cloud cover with a spatial resolution of four to five kilometers. Percent cloud cover can also be estimated by applying an annual sinusoidal curve to the annual solar signal and comparing the theoretical daily maximum values from that curve to the measured data. The difference between the curve and the measured data is an estimate of daily cloud cover.

### *Air Temperature*

When using air temperature data from an alternate nearby station to fill a data gap, a lapse rate adjustment for differences in elevation between the primary and alternate stations may be applied (6°C /1,000 m). In addition, comparing periods when both the original meteorology station and the alternate nearby station have recorded data can establish a relationship between data sets. That relationship can be used to inform adjustments that should be made to the alternate data set to be more representative of local conditions in the study area.

### *Dew Point Temperature, and Wet Bulb Air Temperatures*

Because dew point and wet bulb are required to be consistent with air temperature and atmospheric pressure these parameters are typically calculated. Snyder and Shaw (1984), as well as others, provide such relationships. Therefore, when filling such data gaps, any missing air temperature data needs to be filled first. Also, if atmospheric data are absent, values can be calculated based on elevation (see below).

### *Wind Speed and Direction*

Gaps in wind speed and direction data can be a challenging exercise. Ideally, data from an alternate nearby station in a similar setting can be compared and used, or a relationship developed. Statistical relationships (e.g., regression) relating wind speed and/or direction to other stations may not be as robust as for other date types. A comparison of data from the primary station with data from other nearby stations provides information regarding which alternate station experiences wind patterns most similar to the primary station. If there is a consistent difference in magnitudes and directions of wind speed between two stations with similar wind patterns, a factor can be applied to the alternate data set to fill gaps in the primary data set.

### *Atmospheric Pressure*

Where atmospheric pressure is missing, this parameter can readily be calculated based on elevation (Bowie et al. 1985, Snyder and Shaw 1984). Because the heat budget terms are largely insensitive to changes in atmospheric pressure, filling data gaps with an elevation-based calculation is appropriate.

# Chapter 5 WTMP Model Data Development

Data development for WTMP modeling efforts are described in the following sections. Model domains addressed in this technical memorandum are:

- Shasta Lake
- Keswick Reservoir
- Sacramento River from Keswick Dam to Red Bluff Diversion Dam (RBDD)
- Trinity Lake
- Lewiston Lake
- Trinity River
- Whiskeytown Lake
- Clear Creek
- Folsom Lake
- Lake Natoma
- American River from Nimbus Dam to confluence

## Data Development: Shasta Lake

Data development for Shasta Lake includes geometry, hydrologic, water temperature, and meteorology data. Information includes locations of data collection, temporal range of data, gaps in data sets, and methods used to fill data gaps.

### Geometry Data

Geometric data for Shasta Lake and dam include bathymetry and the stage-volume relationship, physical attributes of the Shasta Dam temperature control device (TCD) and dam outlet works, and TCD operations.

#### *Bathymetry*

A geometric representation of Shasta Lake was created by digitizing historic maps of the area currently inundated by Shasta Lake and of the surrounding upland areas. Spatial data used to create Shasta Lake bathymetry came from three principal sources:

- USGS 1:24,000-scale digital elevation models (DEM) (twelve discrete models, 32.8 feet x 32.8 feet (ft) (10 meter x 10 meter (m)) resolution were combined for a total of 17,556,005

XYZ data points used to map the area surrounding Shasta Lake at 1,064.9 ft (324.6 m) elevation.

- Google Earth (GE) images were used to trace reservoir and island shorelines when the Shasta Lake water surface elevation was approximately 1,000 ft (304.8 m) and 940 ft (286.5 m) on 02/21/2014.
- USGS historical topographic map published in 1901, before construction of Shasta Dam (1:125,000-scale quadrangle for Redding, California, with a 20 ft (6.1 m) contour interval) was used to define XYZ data for elevations below 940 ft (286.5 m).

Detailed information regarding the data sources listed above and project methodology is outlined in (Deas and Sogutlugil 2017a). The final bathymetric map is shown in Figure 4-1.

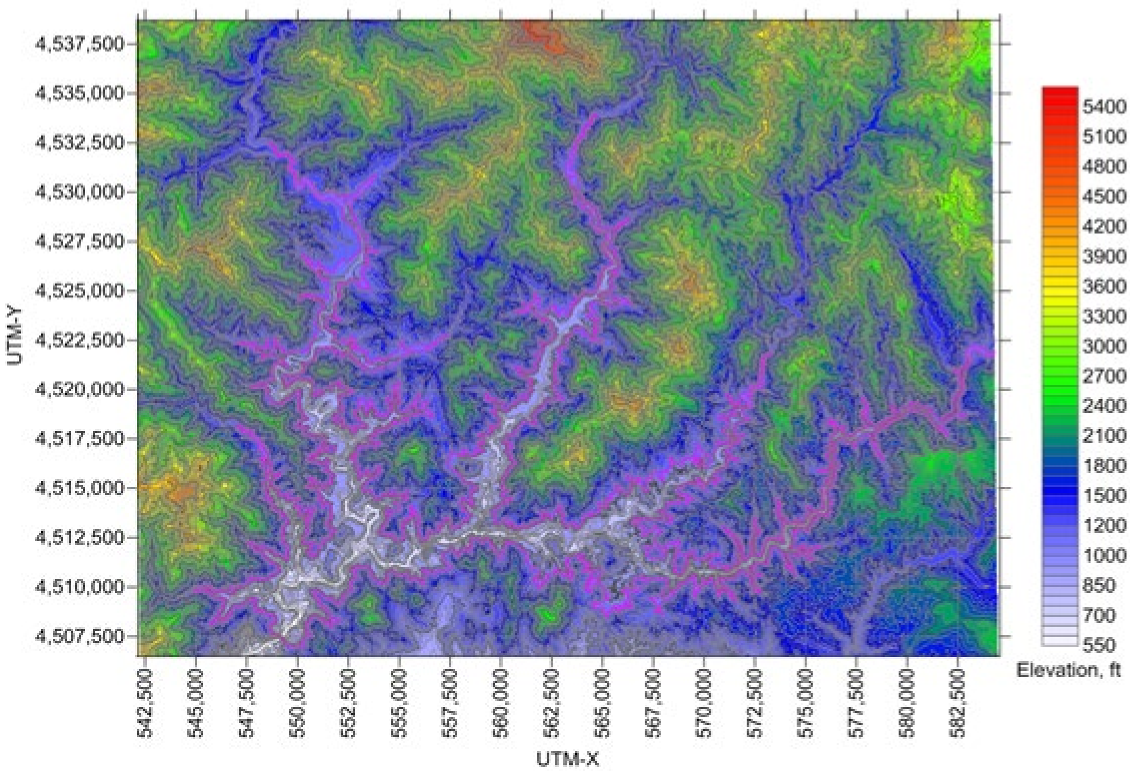



Figure 5-1. Shasta Lake digital topography and bathymetry map. The 1,100 ft (335.3 m) contour around the lake is shown with magenta line.

### *Stage – Volume Relationship*

The stage–volume relationship (depicted as a storage versus elevation curve) of the measured hourly data from Shasta Dam (USBR-SHA) station from 2000 through 2017 (https://cdec.water.ca.gov/) is shown in Figure 4-2. At full pool, Shasta Lake has an elevation of 1,067 ft. (325.2 m), storage of 4,552,000 AF (~5,615x$10^9$ $m^3$), and a surface area of 30,000 acres (12,150 hectares). The green dashed lined shows the bathymetric stage-volume relationship produced using Surfer® software, based on the bathymetric map shown in Figure 4-1. The relationship developed using the Surfer® software closely approximates the curves developed from measured data and from the model grid (discussed in the accompanying *Technical Memorandum: Water Temperature Modeling Platform: Model Development*).

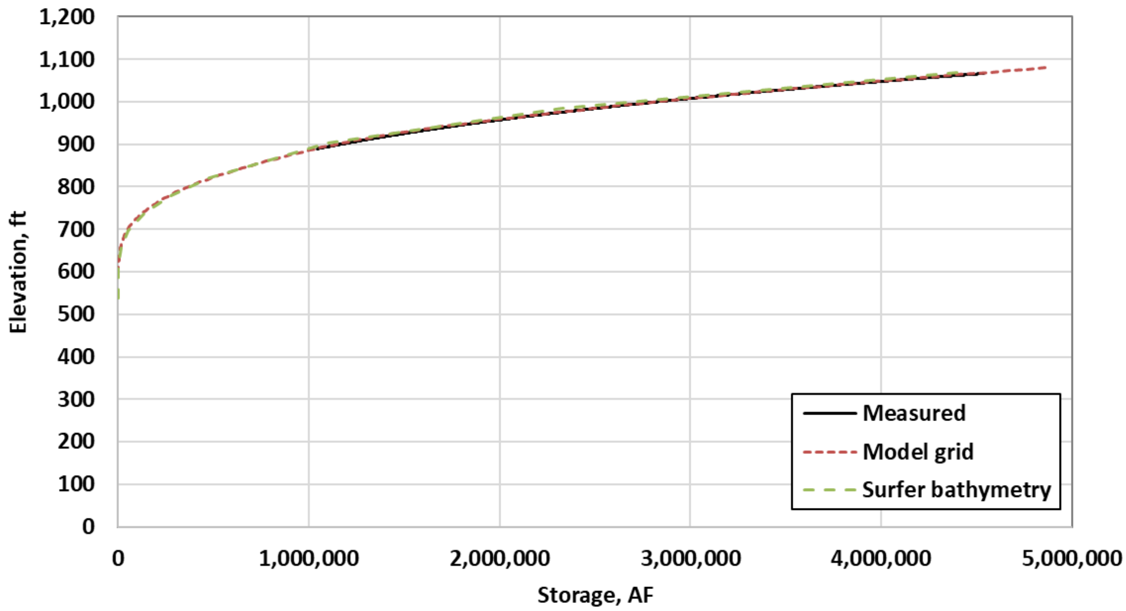



Figure 5-2. Storage versus elevation curves for Shasta Lake.

### ***Shasta Dam TCD and Dam Outlet Geometry***

The Shasta Dam TCD consists of a series of fixed panels attached to the dam, with adjustable gates that feed water to the penstocks that lead to the powerhouse (Figure 5-3). The 250 ft (76.2 m) wide by 300 ft (91.4 m) high TCD structure has five gate openings, each 50 ft (15.2 m) wide, on each of three levels (upper, middle, lower). These TCD levels allow water to be drawn into the TCD from different elevations (and different temperatures) within Shasta Lake.  The TCD extends 40 ft (15.2 m) upstream from the face of the dam. Flow can enter any open gate at any level in the TCD and be conveyed to any operating powerhouse intake, i.e., there are no internal structures to impede flow once waters enter the TCD (Reclamation 1999). In addition to the intake structures mentioned above, a low-level intake structure is attached to the side of the TCD. The 150 ft (45.7 m) wide by 160 ft (48.5 m) tall low-level intake structure, also referred to as the side gate structure, is made of three elements that were individually assembled and attached to the dam. The side gate structure has bottom openings at elevation 720 ft (219.5 m). Two slide gates, mounted on the side of the TCD, control the flow from the low-level intake structure to the main TCD structure (Reclamation 1999).

Each set of gates on the TCD requires a minimum 35 ft (10.7 m) of freeboard for hydropower production to take place (Personal Communication R. Field, April 12, 2018) and to protect the structural integrity of the infrastructure.  For example, if the upper gate level is to be used without any other gate level in use, there must be 35 ft (10.7 m) of water depth above that gate invert.  If water levels fall below this level, at a minimum one gate at the middle gate level must be opened. The TCD structure is not watertight and "leakage" refers to water that enters the TCD through areas other than the operable gates.

The dam has 18 outlets used for water release directly to the river (via Keswick Reservoir), known as the upper (six 8 ft (2.4 m) outlets), middle (eight 8 ft (2.4 m) outlets), and lower (four 8.5 ft (2.6 m) outlets) River Release gates. The spillway invert is 1,037 ft (316.1 m) and has a capacity of 186,000 cfs (5,267 cms) at water surface elevation of 1,065 ft (324.6 m), and is controlled by three drum gates, each 28 ft (8.5 m) tall and 110 ft (33.5 m) wide. The elevation information for the river release outlets, TCD levels, and other Shasta Dam facilities are presented in Table 5-1.

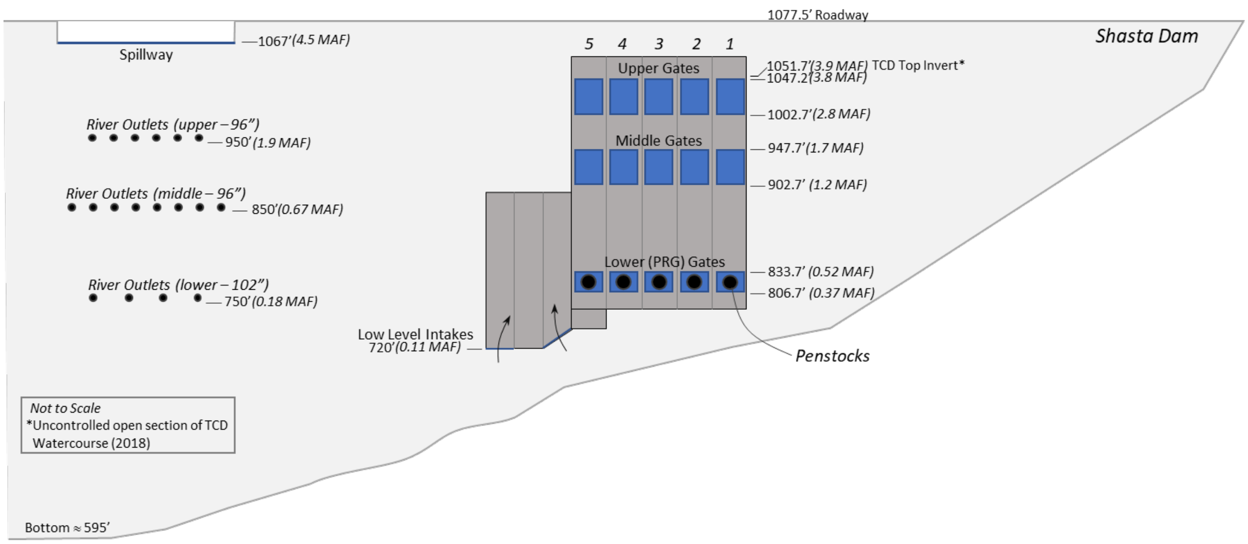



Figure 5-3. Shasta Dam outlet works and Temperature Control Device, view looking downstream at upstream face of dam. Powerhouse units 1 through 5 are shown for reference.

Table 5-1. Shasta Dam facilities and elevations.

| Outlet Name | Outlet Location | Elevation (ft) | Elevation (m) |
|---|---|---|---|
| Spillway | Crest | 1,037 | 316.08 |
| TCD upper level | Top | 1,042 | 317.60 |
| TCD upper level | Centerline | 1,021 | 311.20 |
| TCD upper level | Bottom | 1,000 | 304.80 |
| TCD middle level | Top | 942 | 287.12 |
| TCD middle level | Centerline | 921 | 280.72 |
| TCD middle level | Bottom | 900 | 274.32 |
| TCD lower level (PRG) | Top | 830 | 252.98 |
| TCD lower level (PRG) | Centerline | 816 | 248.72 |
| TCD lower level (PRG) | Bottom | 802 | 244.45 |
| TCD low-level intake (side gates) | Intake at Bottom | 720 | 219.46 |
| TCD leakage | Various[1] | Various | Various |
| River release upper outlets | Center | 942 | 287.12 |
| River release middle outlets | Center | 842 | 256.64 |
| River release lower outlets | Center | 742 | 226.16 |

[1]TCD leakage occurs between elevations 720 ft (219.5 m) and 1000 ft (304.8 m).

### *Shasta Dam Temperature Control Device Operations*

Reclamation provided historic gate schedule information that documented the timing for the opening and closing of each TCD gate from 1997 through 2021. The TCD schedule provides insight to blending and non-blending periods between different levels of the TCD. An example from the TCD schedule record is presented in Table 5-2. In the table, active gates and closed gates are coded as “1” and “0”, respectively. Operational changes for gates in any one level or between levels are noted with an asterisk.

Table 5-2. Shasta Dam Temperature Control Device schedule for 2016. "U" indicates upper level gate, "M" indicates middle level gate, "L" indicates lower level gate, and "S" indicates side gate. A "1" indicates a gate is active, "0" indicates a gate is inactive, and an asterisk indicates a gate's status has changed (from active to inactive, or vice versa).

| Date and time of gate change | Julian Day | U1 | U2 | U3 | U4 | U5 | M1 | M2 | M3 | M4 | M5 | L1 | L2 | L3 | L4 | L5 | S1 | S2 | Number of gates open |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1/1/16 0:00 | 1.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 5 |
| 2/16/16 12:00 | 47.5 | 0 | 0 | 0 | 0 | 0 | 1* | 1* | 1* | 1* | 1* | 0* | 0* | 0* | 0* | 0* | 0 | 0 | 5 |
| 3/8/16 12:00 | 68.5 | 1* | 1* | 1* | 1* | 1* | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 |
| 3/15/16 12:00 | 75.5 | 1 | 1 | 1 | 1 | 1 | 0* | 0* | 0* | 0* | 0* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| 5/9/16 12:00 | 130.5 | 1 | 1 | 1 | 1 | 1 | 1* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 |
| 5/12/16 12:00 | 133.5 | 0* | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| 5/16/16 12:00 | 137.5 | 0 | 1 | 1 | 1 | 1 | 1 | 1* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 |
| 5/31/16 12:00 | 152.5 | 0 | 0* | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| 6/3/16 12:00 | 155.5 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 |
| 6/21/16 12:00 | 173.5 | 0 | 0 | 0* | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| 6/26/16 12:00 | 178.5 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 |
| 7/5/16 12:00 | 187.5 | 0 | 0 | 1* | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 |
| 7/8/16 12:00 | 190.5 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 |
| 7/10/16 12:00 | 192.5 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 |
| 7/14/16 12:00 | 196.5 | 0 | 1* | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 |
| 7/26/16 12:00 | 208.5 | 0 | 0* | 0* | 1 | 1 | 1 | 1 | 1 | 1 | 1* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 |
| 8/6/16 12:00 | 219.5 | 0 | 0 | 0 | 0* | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 |
| 8/9/16 12:00 | 222.5 | 0 | 0 | 0 | 0 | 0* | 1 | 1 | 1 | 1 | 1 | 1* | 0 | 0 | 0 | 0 | 0 | 0 | 6 |
| 8/12/16 12:00 | 225.5 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0* | 0 | 0 | 1* | 1* | 0 | 0 | 7 |

| Date and time of gate change | Julian Day | U1 | U2 | U3 | U4 | U5 | M1 | M2 | M3 | M4 | M5 | L1 | L2 | L3 | L4 | L5 | S1 | S2 | Number of gates open |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8/15/16 12:00 | 228.5 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0* | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 6 |
| 8/16/16 12:00 | 229.5 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0* | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 5 |
| 8/17/16 12:00 | 230.5 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0* | 0 | 0 | 0 | 0 | 1* | 1 | 1 | 0 | 0 | 5 |
| 8/19/16 12:00 | 232.5 | 0 | 0 | 0 | 0 | 0 | 1 | 0* | 0 | 0 | 0 | 0 | 1* | 1 | 1 | 1 | 0 | 0 | 5 |
| 9/5/16 12:00 | 249.5 | 0 | 0 | 0 | 0 | 0 | 0* | 0 | 0 | 0 | 0 | 1* | 1 | 1 | 1 | 1 | 0 | 0 | 5 |
| 9/7/16 12:00 | 251.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1* | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 6 |
| 9/16/16 12:00 | 260.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0* | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 5 |
| 1/1/17 0:00 | 367.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 5 |

## Hydrologic Data

Hydrologic data used for model implementation of a reservoir includes inflow, stage (or water surface elevation) and operations (or outflow) data. Inflows to Shasta Lake come primarily from the Sacramento River, McCloud River, and Pit River and were recorded by USGS gages. Inflow for Squaw Creek was unavailable for the period of simulation and data were estimated using a regression relationship (see below). Inflow coming from Big Backbone Creek was assumed to be negligible. Stage data has been recorded as water surface elevation by Reclamation during the operation of the dam. Outflow rates to the powerhouse, river (via Keswick Reservoir), and through the spillway have also been recorded by Reclamation during the operation of the dam. A summary of sources for flow data used in the Shasta Lake models are listed in Table 5-3.

Squaw Creek data (USGS gage 11365500) were available from 1944 to 1966. Sacramento River data (USGS gage 11342000) were available for the same period and were used to develop the following regression equations relating Sacramento River daily flow (Qsac) to Squaw Creek daily flow (Qsquaw) for dry, normal, and wet years:

- $Qsquaw(dry) = 0.022912*Qsac^{1.266539}$ ($r^2 = 0.879650$)
- $Qsquaw(normal) = 0.018757*Qsac^{1.287450}$ ($r^2 = 0.877481$)
- $Qsquaw(wet) = 0.024284*Qsac^{1.238937}$ ($r^2 = 0.850436$)

Hydrologic year type was based on the Squaw Creek long term mean flow, with the dry, normal, and wet years represented by the lower, middle, and upper thirds of the ranked data, respectively.

Table 5-3. Sources of flow data (Q) used for Shasta Lake models, 2000-2021.

| Site Number/ Abbreviation | Agency | Site Active | Site Name | Data Types | Data Frequency | Application of Data |
|---|---|---|---|---|---|---|
| 11342000 | USGS | YES | Sacramento River at Delta CA | Q | 15-minute | Branch Inflow (Boundary Condition) |
| 11368000 | USGS | YES | McCloud River above Shasta Lake CA | Q | Daily | Branch Inflow (Boundary Condition) |
| 11365500 | USGS | NO | Squaw C ab Shasta Lake CA | Q | NA | Branch Inflow (Boundary Condition) |
| 11365000 | USGS | YES | Pit River near Montgomery Creek CA | Q | Daily | Branch Inflow (Boundary Condition) |
| SHA[1] | CDEC-Reclamation | YES | Shasta Dam | Elevation, storage, $Q_{ph}$[2], spill, $Q_{control}$[3] | Hourly[4] | Boundary Condition and Calibration |
| DLT | CDEC-Reclamation | YES | Sacramento River at Delta | Q | 15-minute | Branch Inflow (Boundary Condition) |
| MSS | CDEC-PG&E | YES | McCloud River above Shasta Lake | Q | Hourly | Branch Inflow (Boundary Condition) |
| PMN | CDEC-Reclamation | YES | Pit River near Montgomery Creek | Q | Daily | Branch Inflow (Boundary Condition) |

[1] Data from this station are used in the model for calibration and selective withdrawal operations.

[2] Powerhouse flow ($Q_{ph}$) -- includes flow data for each of five penstocks.

[3] $Q_{control}$ flows consist of releases through the River Release gates.

[4] While elevation and storage data are available in CDEC web page, hourly $Q_{ph}$, Spill, and $Q_{control}$ data were supplied exclusively by Reclamation to Watercourse Engineering, Inc.

## Water Temperature Data

Time series and vertical profile water temperature data are required to implement and calibrate the Shasta Lake models. Water temperature data describes water temperatures at reservoir inflow locations, which mainly come from upstream sources, as well as from tributaries and surface runoff. Water temperature vertical profiles describe vertical variations (or lack of variation) in water temperature near the TCD and other dam outflow locations.

### *System Inflow Temperatures*

Inflows to Shasta Lake are primarily from the Sacramento River, McCloud River, Pit River, and Squaw Creek. Water temperature data were not available for Squaw Creek during the modeled period, so data from the Sacramento River site at Delta, CA was used to represent water temperatures in Squaw Creek. Water temperature data were also not available for Big Backbone Creek, but because its flow was assumed to be negligible for the purposes of this model, its impact on water temperature in Shasta Lake is also assumed to be negligible. A summary of sources for water temperature time series data used in the Shasta Lake model are presented in Table 5-4.

Table 5-4. Shasta Lake water temperature (Tw) data sources, 2000-2021.

| Site Number/ Abbreviation | Agency | Site Active | Site Name | Data Types | Data Frequency | Application of Data |
|---|---|---|---|---|---|---|
| DLT | CDEC-Reclamation | YES | Sacramento R at Delta | Tw | Hourly | Branch Inflow (Boundary Condition) |
| MSS | CDEC-PG&E | YES | McCloud R above Shasta Lk | Tw | Hourly | Branch Inflow (Boundary Condition) |
| PMN | CDEC-Reclamation | YES | Pit R near Montgomery Cr | Tw | Hourly | Branch Inflow (Boundary Condition) |
| SHD | CDEC-Reclamation | YES | Shasta Dam Water Quality | Tw | Hourly | Calibration Selective Withdrawal Operations |
| SP1 | CDEC-Reclamation | YES | Shasta Penstock #1 | Tw | Hourly | Selective Withdrawal Operations |
| SP2 | CDEC-Reclamation | YES | Shasta Penstock #2 | Tw | Hourly | Selective Withdrawal Operations |
| SP3 | CDEC-Reclamation | YES | Shasta Penstock #3 | Tw | Hourly | Selective Withdrawal Operations |
| SP4 | CDEC-Reclamation | YES | Shasta Penstock #4 | Tw | Hourly | Selective Withdrawal Operations |
| SP5 | CDEC-Reclamation | YES | Shasta Penstock #5 | Tw | Hourly | Selective Withdrawal Operations |

### *Water Temperature Vertical Profiles*

Temperature profiles measured above Shasta Dam in the model years 2000–2021 were supplied by Reclamation. These manual vertical profiles, using high quality instrumentation, are collected (by boat) approximately monthly, with more frequent measurements taken during summer and under certain conditions. The number of profiles available for each month from 2000 to 2021 are listed in Table 5-5. Additional water temperature profile data were collected from 2000 through 2021 using a temperature logger string, installed in the reservoir, that collected temperature data at multiple depths (approximately 20 ft intervals) at 15-minute intervals. The logger string was deployed upstream of the dam in the vicinity of the location where the monthly (or more frequent) thermal profiles are collected. Additional water temperature profiles were collected in the Sacramento River, McCloud River, and Pit River arms of Shasta Lake using manual sampling techniques in summer 2019 (Figure 5-4).

Table 5-5. Number of water temperature profiles above Shasta Dam, by month, 2000 through 2021.

| Year | Jan. | Feb. | March | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Total for Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2000 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 19 |
| 2001 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 19 |
| 2002 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 0 | 18 |
| 2003 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 1 | 2 | 2 | 1 | 18 |
| 2004 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 19 |
| 2005 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 18 |
| 2006 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 17 |
| 2007 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 18 |
| 2008 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 19 |
| 2009 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 3 | 1 | 2 | 1 | 20 |
| 2010 | 1 | 1 | 1 | 0 | 2 | 3 | 2 | 2 | 2 | 2 | 2 | 1 | 19 |
| 2011 | 1 | 1 | 1 | 1 | 2 | 3 | 2 | 2 | 2 | 2 | 2 | 1 | 20 |
| 2012 | 1 | 1 | 1 | 0 | 3 | 2 | 2 | 2 | 2 | 3 | 2 | 0 | 19 |
| 2013 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 1 | 2 | 1 | 18 |
| 2014 | 1 | 1 | 1 | 1 | 2 | 3 | 1 | 2 | 3 | 4 | 2 | 1 | 22 |
| 2015 | 1 | 1 | 1 | 2 | 3 | 2 | 2 | 4 | 4 | 3 | 1 | 1 | 25 |
| 2016 | 1 | 1 | 2 | 2 | 1 | 2 | 4 | 5 | 4 | 4 | 3 | 0 | 29 |
| 2017 | 1 | 1 | 0 | 2 | 3 | 4 | 4 | 5 | 4 | 5 | 3 | 1 | 33 |
| 2018 | 1 | 1 | 2 | 2 | 5 | 4 | 4 | 4 | 4 | 5 | 3 | 1 | 36 |
| 2019 | 1 | 1 | 2 | 2 | 4 | 4 | 5 | 4 | 4 | 5 | 3 | 1 | 36 |
| 2020 | 1 | 1 | 2 | 4 | 4 | 4 | 5 | 4 | 4 | 5 | 3 | 1 | 38 |
| 2021 | 1 | 1 | 3 | 4 | 4 | 5 | 4 | 5 | 6 | 3 | 2 | 1 | 39 |

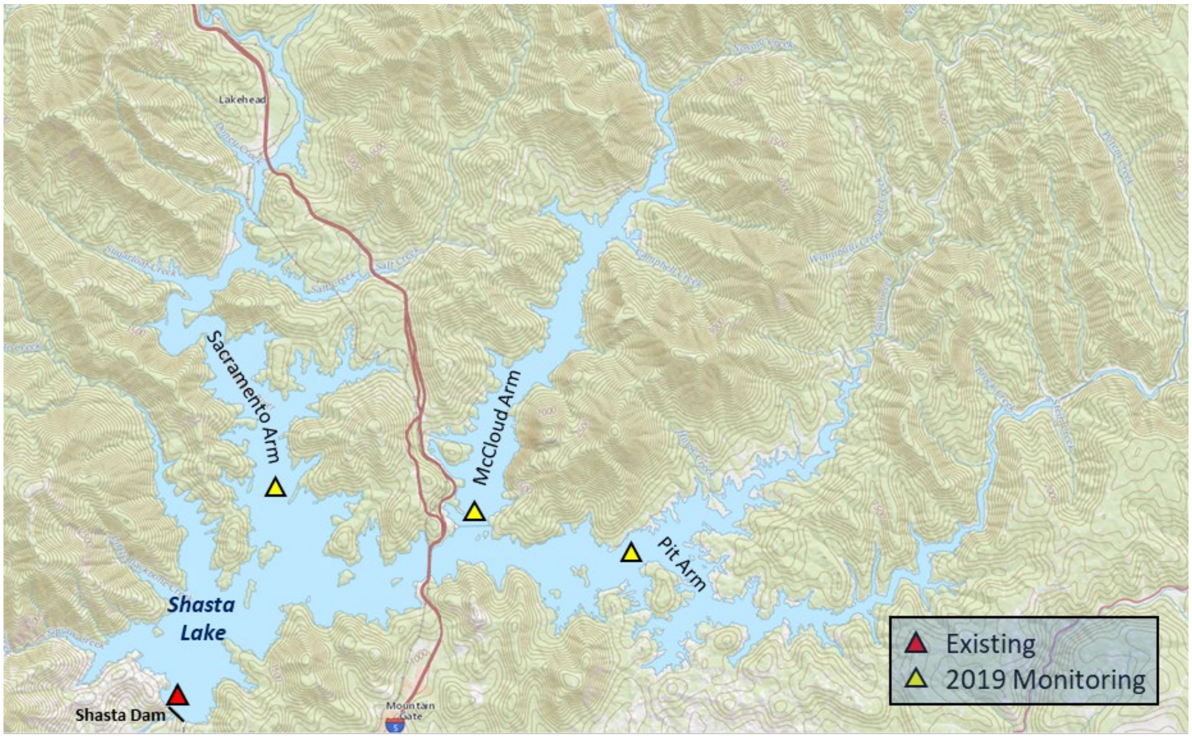



Figure 5-4. Location of thermal profile measurements for 2000 through 2021 (“existing”) and additional thermal profile measurements for 2019.

## Meteorology Data

Meteorology data were available from multiple sources in the vicinity of Shasta Lake (Table 5-6). Meteorology data, used to calculate heat flux and light intensity in the model, include air temperature (°C), dew point temperature (°C), wet bulb temperature (°C), wind speed (m/s), wind direction (degrees), solar radiation ($W/m^2$) and cloud cover (scale 0.0-1.0). Cloud cover and wet bulb temperature were derived from observed data. Stations KRDD and RRAC1 are located close to each other. Station KRDD supplied air temperature, dew point temperature, and wind speed and direction data. Solar radiation data were collected by station RRAC1 and was used to estimate cloud cover. One meteorology data set was developed for use in the Shasta Lake, Keswick Reservoir, Sacramento River, and Whiskeytown Lake models. The large spatial extent of the model domains, coupled with the mountainous topography, may lead to variable meteorology conditions, particularly local wind field conditions.

Table 5-6. Available meteorology data and data sources for the Shasta Lake-Keswick Reservoir area.

| Site No. / Abbreviation | Agency | Active | Site Name | Data Types | Data Frequency |
|---|---|---|---|---|---|
| DLT | CDEC-USGS | YES | Sacramento R at Delta | Tair | Hourly |
| HRZ | CDEC-Reclamation | YES | HIRZ | Tair, Pr[1] | Hourly |
| LKS | CDEC-Reclamation | YES | Lakeshore | Tair, Pr[1] | Hourly |
| SHS | CDEC-Reclamation | YES | Above Shasta Dam | Tair, Pr[1] | Hourly |
| SHD | CDEC-Reclamation | YES | Below Shasta Dam | Tair, Pr[1] | Hourly |
| KRDD[2] | MesoWest-WRCC(RAWS) | YES | Redding Municipal (Airport) | Tair, Tdw, Pr, WS, Wdir, RH, SR | Hourly |
| RRAC1[3] | MesoWest | YES | Redding CA | Tair, Tdw, Twb, WS, Wdir, RH, SR | Hourly |
| CW5599 | MesoWest | YES | C5599 Redding | Tair, Tdw, Pr, WS, Wdir, RH, SR | Hourly |
| WDLCA | MesoWest | YES | Wonderland (P349) CA | Tair, Tdw, WS, Wdir, RH | Hourly |
| STDCA | MesoWest | YES | Shasta Dam CA | Tair, Tdw, WS, Wdir, RH | Hourly |
| SLFC1 | MesoWest-WRCC(RAWS) | YES | Sugarloaf (SFC) | Tair, Tdw, Pr, WS, Wdir, RH, SR | Hourly |
| CTANT | MesoWest | YES | Antlers | Tair, Tdw, Pr, WS, Wdir, RH | Hourly |

[1] Precipitation is event (15-min) data.

[2] All meteorology data except SR from this station were used in both models.

[3] SR data from this station were used in both models.

Abbreviations:

Tair: Air temperature, Pr: Precipitation, Tdw: Dewpoint temperature, WS: Wind Speed, Wdir: Wind Direction, RH: Relative Humidity, SR: Solar Radiation

# Data Development: Keswick Reservoir

The following sections describe the data development for Keswick Reservoir models. Geometry data development is discussed first, followed by hydrologic data development, water temperature data development, and last, meteorology data development. Information provided includes locations of data collection, temporal range of data, gaps in data sets, and methods used to fill gaps in data.

## Geometry Data

Development of geometric data for Keswick Reservoir is discussed in the following sections. Bathymetry data is discussed first, followed by development of the stage-volume relationship for Keswick Reservoir. Last, a description of the Keswick Dam outlet facilities is provided.

### *Bathymetry*

Bathymetry data for Keswick Reservoir was collected in 2016 through a collaborative effort between Glen-Colusa Irrigation District (GCID), Watercourse Engineering (Watercourse), and Reclamation. Details of the methodology used to develop Keswick Reservoir bathymetry are outlined in (Deas and Sogutlugil 2017b). The final bathymetric map is presented in Figure 5-5.

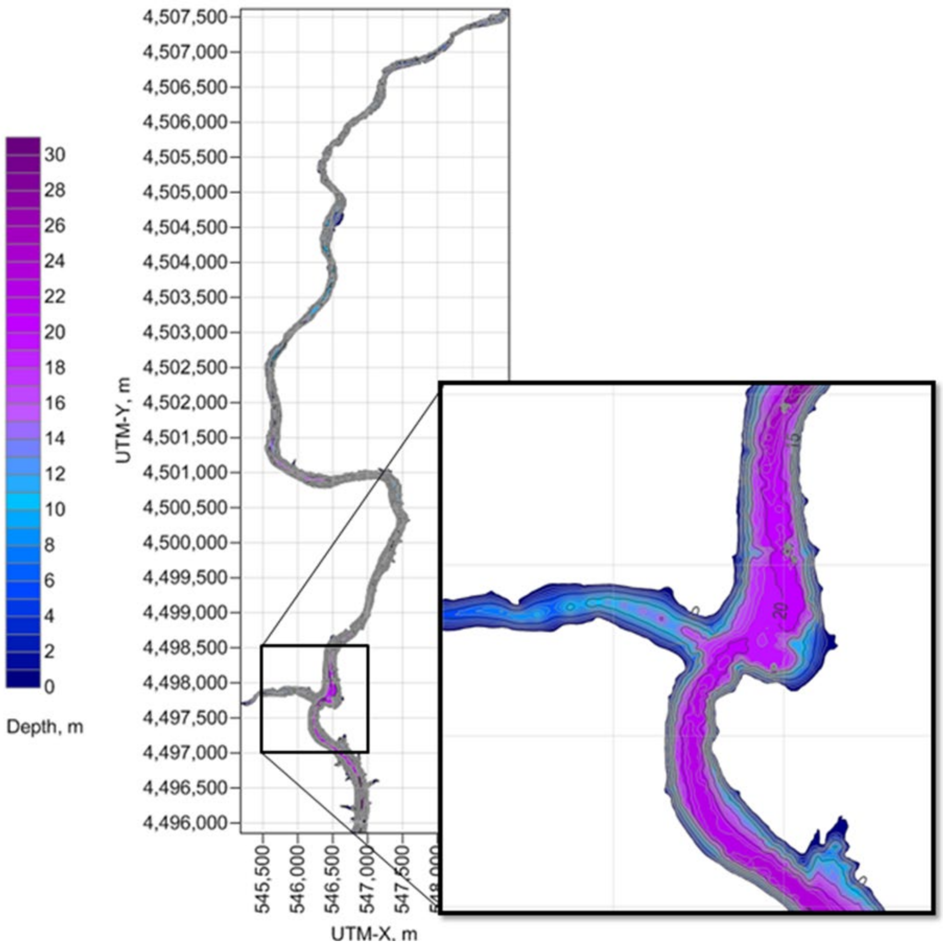



Figure 5-5. Keswick Reservoir bathymetry. Enlargement provided to show depth contour lines in meters.

### *Stage-Volume Relationship*

Stage–volume relationships (depicted as a storage versus elevation curve) developed from three sources of information are compared in Figure 5-6. The stage-volume relationships developed from the bathymetric survey data and from the model grid (discussed in the accompanying *Technical Memorandum: Water Temperature Modeling Platform: Model Development*) closely approximate measured hourly data from Keswick Reservoir station (KES-Reclamation) for 2000 through 2017 (Source: California Data Exchange Center).

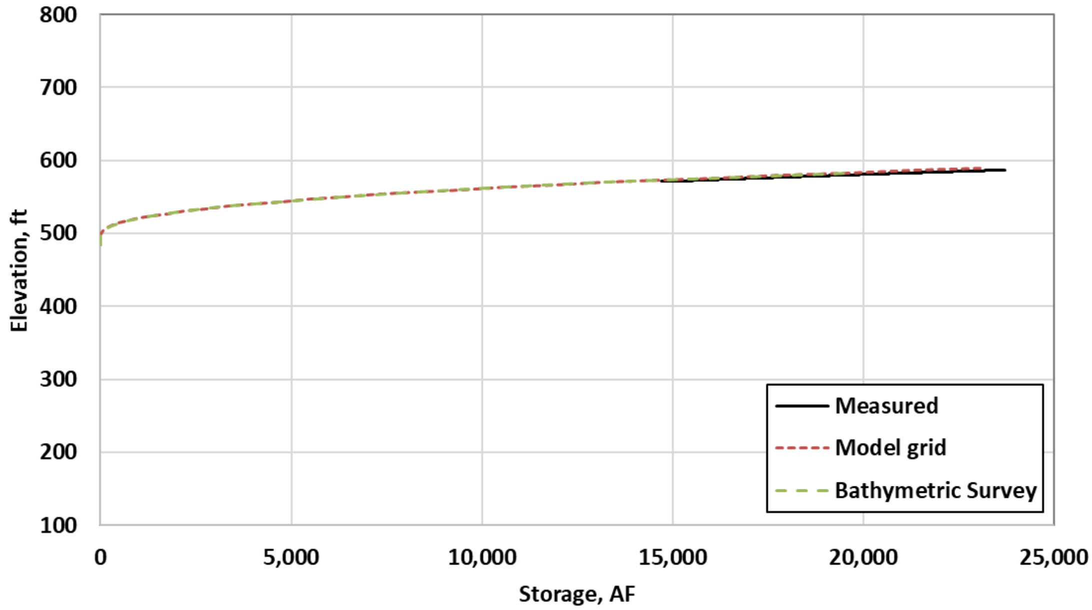



Figure 5-6. Storage versus elevation curves for Keswick Dam derived from measured data, the bathymetric survey, and the model grid.

***Keswick Dam Facilities***

Keswick Dam is a concrete gravity dam that impounds Keswick Reservoir, which has a capacity of 23,800 AF ($2.936 \times 10^7$ $m^3$) at full pool elevation of 587 ft (178.92 m) (Reclamation 2018). The dam is 157 ft. (47.85 m) high, with crest elevation of 595.5 ft (181.51 m) and has four 50 ft (15.2 m) wide by 50 ft (15.2 m) high spillways (fixed wheel gates) at crest elevation of 537 ft (163.68 m). Keswick power plant has three turbines, with the total capacity of 16,000 cfs (453 cms) at full pool elevation. Top and bottom elevations of powerhouse intakes are 547.25 ft (166.8 m) and 525 ft (160 m), respectively.

## Hydrologic Data

Time series flow data are required to implement and test the Keswick Reservoir models. Flow data describes inflows to and outflows from the reservoir. Outflow from Shasta Lake is controlled by Shasta Dam and is the primary source of inflow to Keswick Reservoir. Keswick Reservoir also receives flow from Trinity, Lewiston and Whiskeytown reservoirs via Spring Creek Tunnel. Outflows from Keswick Reservoir are from dam releases and spills. Inflows from precipitation and outflows from evaporation are, however, negligible and omitted, along with any losses or gains to and from the groundwater around the area of interest. In addition, flow data provides information regarding reservoir storage and water surface elevation. Sources for flow data used in the Keswick Reservoir models are listed in Table 9.

Table 5-7. Sources of flow data (Q) used for Keswick Reservoir model, 2001-2021.

| Site Number/ Abbreviation | Agency | Site Active | Site Name | Data Types | Data Frequency | Application of Data |
|---|---|---|---|---|---|---|
| SHA | CDEC-Reclamation | YES | Shasta Dam | $Q_{out}$[1] | Hourly | Headwater Boundary Condition |
| SPC | CDEC-Reclamation | YES | Spring Creek Debris Dam | Q | Hourly | Tributary Inflow Boundary Condition |
| 11371600 | USGS | YES | Spring C PH A Keswick CA | Q | Daily – Hourly[2] | Tributary Inflow Boundary Condition |
| KES | CDEC-Reclamation | YES | Keswick Reservoir | Elevation, storage, $Q_{out}$[1], spill, $Q_{ph}$[3] | Hourly | Boundary Condition and Calibration |

[1] $Q_{out}$ consists of the total flow leaving a structure, as opposed to Q, which represents measured flow at a gage site.

[2] Only daily average Q data are available in the related USGS web page. Hourly Q data were supplied exclusively by Reclamation to Watercourse Engineering, Inc.

[3] $Q_{ph}$ indicates flow from Keswick Reservoir to the powerhouse.

## Water Temperature Data

Water temperature data including time series at system inflow and outflow locations, as well as vertical profile data, are required to implement and test the model. Data are used for boundary conditions, initial conditions and for model calibration.

### *System Inflows*

During the water temperature management season, the temperature of the water released from Shasta Lake into Keswick Reservoir is controlled by the Shasta Dam TCD. Keswick Reservoir also receives flow from Trinity, Lewiston and Whiskeytown reservoirs via Spring Creek Tunnel and Powerhouse. Sources of time series water temperature data for Keswick Reservoir are presented in Table 10.

Table 5-8. Keswick Reservoir water temperature (Tw) data sources, 2000-2021.

| Site Number/ Abbreviation | Agency | Site Active | Site Name | Data Types | Data Frequency | Application of Data |
|---|---|---|---|---|---|---|
| SHD | CDEC-Reclamation | YES | Shasta Dam Water Quality | Tw | Hourly | Headwater Boundary Condition |
| SPP | CDEC-Reclamation | YES | Spring Creek Powerhouse | Tw | Hourly | Tributary Inflow |
| KWK | CDEC-Reclamation | YES | Keswick Water Quality | Tw | Hourly | Calibration |

***Water Temperature Vertical Profiles***

In contrast to Shasta Lake, historic measured temperature profiles in Keswick Reservoir for the model years were limited. Only four measurements (one in January, one in March, one in April and one in May) in year 2010, at two different locations in the reservoir, were available for calibration purposes. One measurement location is approximately 0.3 miles downstream of the Spring Creek confluence, and the other location is approximately 0.2 miles upstream of the same confluence point.

Additional temperature profile monitoring was implemented in Keswick Reservoir on September 6, 2017 and was deployed seasonally through December, 2020. Water temperature profile information was collected in the reservoir using remote logging thermistors (temperature loggers) attached to a cable system suspended from the log boom upstream of the dam (Figure 5-7). Loggers were typically spaced at depth intervals of 10 feet.

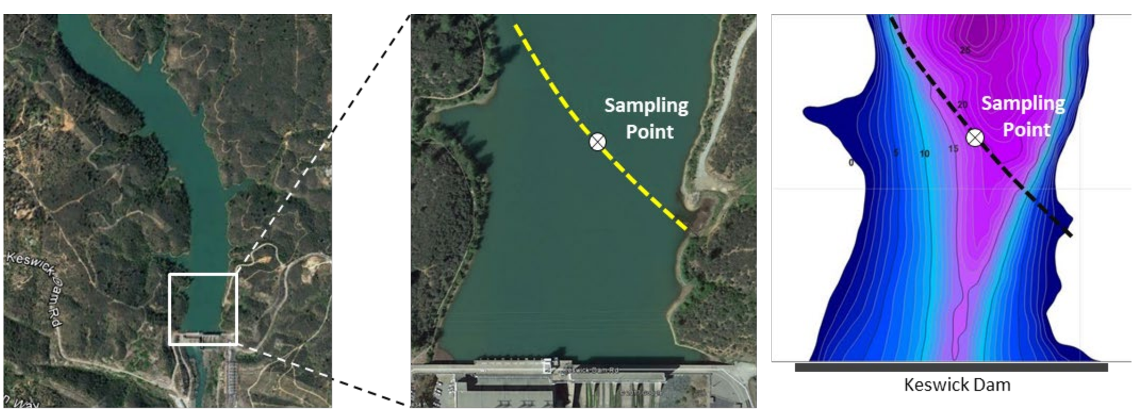



Figure 5-7. Keswick Reservoir - plan view. Project area (left); sampling point along log boom (middle); sampling point along log boom with bathymetry (right).

### Meteorology Data

Due to the proximity of Shasta Lake to Keswick Reservoir, the same meteorology data set can be used for both models. Refer to the discussion of meteorology data development for Shasta Lake for a description of the types and sources of meteorology data used to construct the meteorology input file.

## Data Development: Sacramento River from Keswick Dam to Red Bluff Diversion Dam

The following sections describe the data developed for the Sacramento River from Keswick Dam to Red Bluff Diversion Dam. Geometry data are described first, followed by hydrologic data, water temperature data, and meteorology data. Data sources, data gaps, methods for filling data gaps, as well as other pertinent information, are provided for each type of data.

### Geometry Data

Development of geometric data for the Sacramento River model reach is discussed in the following sections. Bed elevation and slope information is discussed first, followed by cross section information, and the locations of inflows and outflows. A description of  Anderson-Cottonwood Irrigation District (ACID)  Diversion Dam facilities and operations are provided.

#### *Channel Cross Sections*

Cross-section geometry and roughness coefficients were extracted from the hydraulically representative cross sections in the existing HEC-5Q model (RMA 2003). These cross sections were imported to a new HEC-RAS geometry (as part of ResSim model development, discussed in *Technical Memorandum: Model Development, Calibration, Validation, and Sensitivity Analysis*) where the cross sections were placed along the centerline of the ResSim stream alignment corresponding to their stationing in the HEC-5Q data set. Figure 5-8 shows a typical cross section on the Sacramento River, as presented in the HEC-RAS interface.

New bathymetric data is scheduled to be collected for the Sacramento River from Keswick to Red Bluff in 2023.  If that data is made available before the end of this project, cross-section information for the HEC-RAS model will be updated.

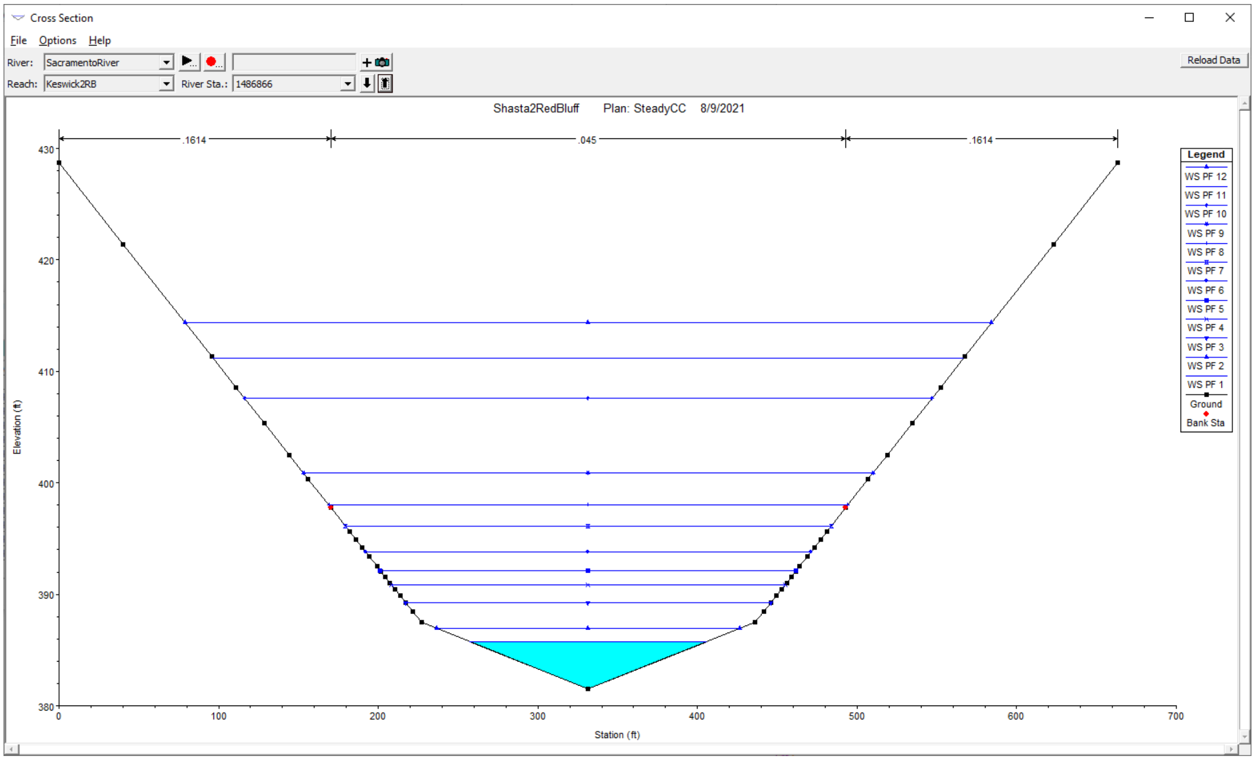



Figure 5-8. Exported HEC-5Q cross section shown in HEC-RAS.

### ***Locations of Inflows and Outflows Represented in WTMP Models***

The WTMP model representation for the Sacramento River from Keswick Dam to Red Bluff Diversion Dam has one outflow and four inflow locations. The locations of the outflow and inflows are listed below with their approximate distance from Keswick Dam:

- ACID Diversion Dam (outflow), approximately 3.5 miles downstream of Keswick Dam
- Clear Creek (inflow), approximately 12.4 miles downstream of Keswick Dam
- Cow Creek (inflow), approximately 21.5 miles downstream of Keswick Dam
- Cottonwood Creek (inflow), approximately 28.0 miles downstream of Keswick Dam
- Battle Creek (inflow), approximately 30.2 miles downstream of Keswick Dam

### ***ACID Diversion Dam***

The ACID diversion dam is located upstream of the South Market Street bridge in Redding, California. When operating, the diversion dam raises the water surface elevation of Sacramento River, impounding Lake Redding, and providing flow to the ACID irrigation canal while maintaining functionality of fish ladders. A description of the diversion dam and its operations are provided in the following sections.

### Facilities Description

The ACID diversion dam comprises a 450 ft. long weir, fish ladders on the north and south banks, and a diversion structure (diverts flow to the ACID canal) on the south bank (Figure 5-8).


Figure 5-9. Sacramento River and ACID Diversion Dam.

Minimum and maximum fish ladder operational water surface elevations in the upstream pool are approximately 484 ft and 487 ft, respectively (CH2MHill 1999a, 1999b). The diversion dam has a concrete foundation structure invert elevation of approximately 472 ft and top elevation of approximately 481 ft (CH2MHill 1999b). "Boards" are placed on a steel structure installed on the diversion dam during diversion season, up to an elevation of approximately 487.5 ft, to enable flow diversion into the ACID canal while ensuring proper functioning of fish ladders.

**Facilities Operations** The historic schedule of board installation and removal from 2000 through 2021 is listed in Table 5-9.

Table 5-9. ACID board installation and removal date ranges for calendar years 2000 through 2021.

| Calendar Year | Installation Dates | Removal Dates |
|---|---|---|
| 2021 | 3/22-4/3 | 11/1-11/12 |
| 2020 | 3/16-3/27 | 11/2-11/13 |
| 2019 | 4/15-4/30 | 11/4-11/15 |
| 2018 | 2/20-2/28 (3/19, 3/20)[1] | 10/24-11/2 |
| 2017 | 4/12-4/15 (5/16) | 11/6-11/17 |
| 2016 | 3/21-3/30 | 11/1-11/8 |
| 2015 | 3/17-3/24 | 10/19-10/27 |
| 2014 | 2/11-2/21 | 11/3-11/10 |
| 2013 | 3/25-3/29 | 11/4-11/12 |
| 2012 | 3/26-4/10 | Unknown[2] |
| 2011 | 4/11-4/15 | 10/17-10/21 |
| 2010 | 3/22-4/8 | 11/1-11/9 |
| 2009 | 3/23-3/27 | 10/26-11/2 |
| 2008 | 3/24-3/28 | Unknown[2] |
| 2007 | 3/26-3/31 | 11/1[3]-Unknown[2] |
| 2006 | 5/1-5/6 | 11/1-11/6[3] |
| 2005 | 3/28-4/1 | 10/31-11/4 |
| 2004 | Unknown[2] | 11/8-11/12[3] |
| 2003 | 3/24-4/4 | 11/10-11/14[3] |
| 2002 | 4/1-4/5 | 11/11-11/19[3] |
| 2001 | 4/2-4/6 | 10/30-11/8[3] |
| 2000 | 4/3-4/7[3] | Unknown[2] |

[1]Dates in parenthesis (dates) indicate significant adjustment to the boards

[2]"Unknown" indicates that there is no mention in Board meeting minutes or general manager board report. For all "unknown" date ranges, assume installation occurs 4/1 to 4/7 and removal occurs 11/1 to 11/7.

[3]Estimated date range for installation or removal.

## Hydrologic Data

Time series flow data are required to implement and test the Sacramento River model. Flow data describes inflows to and outflows from the river. The headwater boundary condition for the Sacramento River model is the outflow from Keswick Reservoir, which is controlled by Keswick Dam. Data for outflow at ACID was available from a USGS gage in the ACID canal in Redding. Additional outflows for irrigation diversion were relatively small and were accounted for in reach accretions and depletions. Primary inflows to the Sacramento River between Keswick Dam and Red Bluff Diversion Dam are from Clear Creek, Cow Creek, Cottonwood Creek, and Battle Creek. Flows measured at USGS gages at Keswick (11370500) and above Bend Bridge at Red Bluff (11377100) provide data for model calibration. Sources for flow data, and how that data were applied in the Sacramento River model, are listed in Table 5-10.

Table 5-10. Sources of flow data (Q) for Sacramento River from Keswick Dam to Red Bluff Diversion Dam.

| Site Number/ Abbreviation | Agency | Site Active | Site Name | Data Types | Data Frequency | Application of Data |
|---|---|---|---|---|---|---|
| KES | CDEC-Reclamation | YES | Keswick Reservoir | $Q_{out}$[1] | Hourly | Headwater Boundary Condition |
| 11370500 | USGS | YES | Sacramento R A Keswick CA | Q | Hourly | Model Calibration |
| 11370700 | USGS | YES | Anderson-Cottonwood ID CN AT Redding CA | Q | Hourly | Outflow Boundary Condition |
| 11372000 | USGS | YES | Clear Creek near Igo CA | Q | Hourly/ Daily | Boundary Condition |
| CCP4 | Graham Mathew and Assc. | No | Clear Creek at Phase 4 Site | Q | Hourly | Inflow Boundary Condition |
| 11374000 | USGS | YES | Cow Cr NR Millville CA | Q | Hourly | Inflow Boundary Condition |
| 11376000 | USGS | YES | Cottonwood Cr NR Cottonwood CA | Q | Hourly | Inflow Boundary Condition |
| 11376550 | USGS | YES | Battle Cr Fish Hatchery NR Cottonwood CA | Q | Hourly | Inflow Boundary Condition |
| 11377100 | USGS | YES | Sacramento R AB Bend Bridge NR Red Bluff CA | Q | Hourly | Model Calibration |

[1] $Q_{out}$ consists of the total flow leaving a structure, as opposed to Q, which represents measured flow at a gage site.

## Temperature Data

Water temperature data are used for boundary conditions, initial conditions and for model calibration. Sources of water temperature data for the Sacramento River model are listed in Table 5-11. Inflow boundary condition data are applied at the reach headwater and at each of the aforementioned tributaries. Temperature data from the Sacramento River at Balls Ferry Bridge, Jellys Ferry and Bend Bridge, available from CDEC, are used for model calibration.

Headwater temperature boundary condition data is measured at Keswick Dam outflow. Significant gaps exist in the tributary data sets (months to years long). Clear Creek and Cow Creek had more than one site for temperature data. For those tributaries, the site closest to confluence was used as the primary data source and data from the other site was used to fill gaps in the primary data. Remaining gaps in data were filled using equilibrium temperature analysis (Appendix A). Cottonwood Creek and Battle Creek had one data collection site each. Gaps in those data sets were filled using equilibrium temperature analysis.

Table 5-11. Sources of water temperature data (Tw) for Sacramento River from Keswick Dam to Red Bluff Diversion Dam.

| Site Number/ Abbreviation | Agency | Site Active | Site Name | Data Types | Data Frequency | Application of Data |
|---|---|---|---|---|---|---|
| Upstream model | Upstream model | Upstream model | Keswick Reservoir Outflow | Tw | Hourly | Headwater Boundary Condition |
| 11372000 | USGS | YES | Clear Creek near Igo CA | Tw | Hourly/ Daily | Boundary Condition |
| CCVW Confluence | USFWS | | Clear Creek video weir RM0.1<br>Clear Creek confluence RM0.5 | Tw | Hourly | Boundary Condition |
| NA | CDFW | YES | Cow Cr near mouth (old video station at RM1)<br>Cow Cr near mouth (new video station at RM3.8) | Tw | Hourly | Boundary Condition |
| BSF | CDEC | | Sacramento River at Balls Ferry Bridge | Tw | Hourly | Model Calibration |
| NA | CDFW | YES | Cottonwood Cr | Tw | Hourly | Boundary Condition |
| NA | CDFW | YES | Battle Cr | Tw | Hourly | Boundary Condition |
| JLF | CDEC | | Sacramento River at Jellys Ferry | Tw | Hourly | Model Calibration |
| BND | CDEC | YES | Sacramento River at Bend Bridge | Tw | Hourly | Model Calibration |

### Meteorology Data

Due to the proximity to Shasta Lake, the Sacramento River model can apply the same meteorology data set that was developed for the Shasta Lake models. Refer to the discussion of meteorology data development for Shasta Lake for a description of the types and sources of meteorology data used to construct the meteorology input file.

## Data Development: Trinity Lake

The following sections describe the data developed for the Trinity Lake CEQUAL-W2 model. Geometry data are described first, followed by hydrologic data, water temperature data, and meteorology data. Data sources, as well as other pertinent information, are provided for each type of data.

## Geometry Data

Development of geometry data for Trinity Lake is discussed in the following sections. Bathymetry data is discussed first, followed by the stage-volume relationship for Trinity Lake. Lastly, a description of the Trinity Dam outlet facilities is provided.

### *Bathymetry*

Spatial data used to create the Trinity Lake bathymetry were gathered from three principal sources (Table 5-12). Development of bathymetry for Trinity Lake, including identifying and filling gaps in spatial data, is described in detail in Appendix B. The final digital bathymetric map, covering the entirety of Trinity Lake and the surrounding shore area, is shown in Figure 5-10.

Table 5-12. Spatial data used to create Trinity Lake bathymetry, including sources and horizontal and vertical datums.

| Title | Source | Datum | Units |
|---|---|---|---|
| USGS 1 arc second n41w123 20210624 (data set/map) | USGS 2021 | NAD83; NAVD88 | Geographic coordinates; decimal degrees |
| USGS Topographic Quadrangle Map: Trinity Dam, California | USGS 1982 | NAD27; NGVD29 | UTM Coordinate (Zone 19): Meters |
| ESRI World Imagery (satellite imagery) | ESRI | WGS84 | Meters |

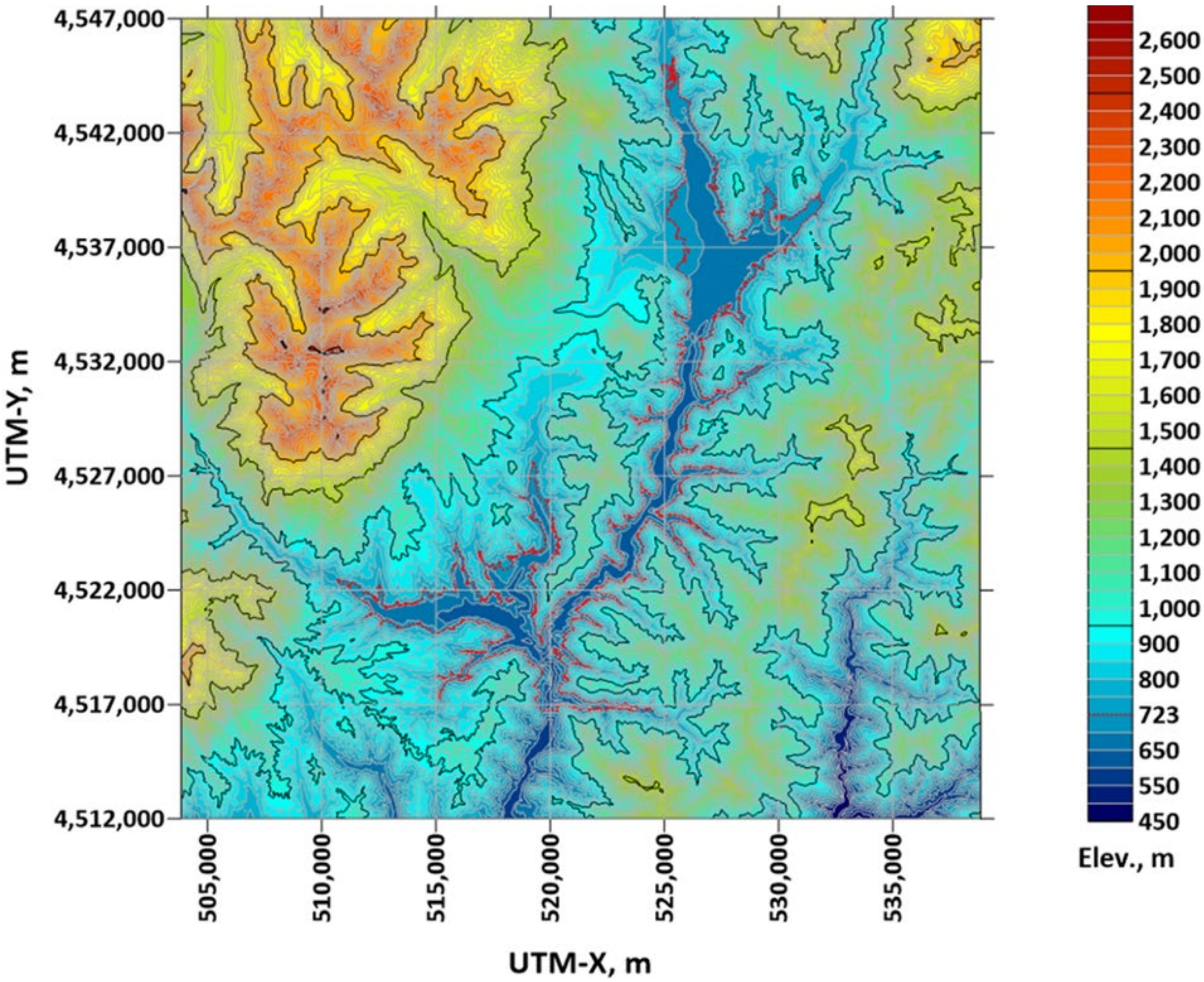



Figure 5-10. Trinity Lake bathymetry and surrounding topography. Full pool elevation is indicated by dotted red line.

### *Stage-Volume Relationship*

The digitized bathymetry was used to develop a Trinity Lake stage-storage curve that was compared to information included in the existing stage-storage table supplied by Reclamation (1962). The stage-volume curves for the two independent sources are in close agreement (Figure 5-11), indicating the bathymetric map is representative of Trinity Lake.

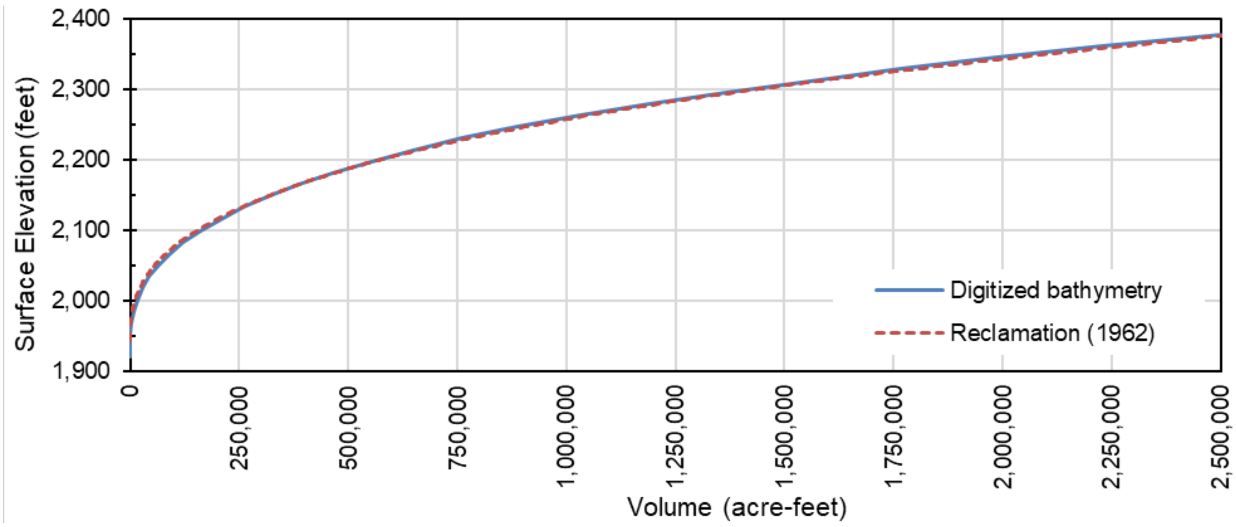



Figure 5-11. Trinity Lake stage-storage (volume) curve based on the digitized bathymetry and from the existing Reclamation stage-storage table (Reclamation 1962).

### *Trinity Dam Facilities*

Trinity Dam impounds Trinity Lake, which has a full pool elevation of 2,370.0 ft (722.4 m) and 2,448 thousand acre-feet (TAF) storage capacity. The dam is 538.0 ft. (164.0 m) high, with crest elevation of 2,395.0 ft (730.0 m). The main spillway has a 22,400 cfs capacity and the auxiliary spillway has a 2,250 cfs capacity. Dam outlet works have a 24,000 cfs capacity and supply flow to two generators in Trinity Powerplant with a total capacity of 105,556 kilowatts. Intake structures at Trinity Dam include a 28 ft diameter intake (invert elevation 2,100 ft) that feeds the main outlet and powerplant, and a 7 ft diameter auxiliary intake (invert elevation 1,995.5) that has a maximum capacity of 2,500 cfs.

## Hydrologic Data

Time series hydrologic data are required for the Trinity Lake model inflows and outflows. Sources of available flow data for Trinity Lake are listed in Table 5-12. Development of inflow data is explained first followed by a description of Trinity Lake outflow data. In addition to describing reservoir inflows and outflows, flow data provides information regarding reservoir storage and water surface elevation.

### *Trinity Lake Inflows*

Main inflows to Trinity Lake include Trinity River, East Fork Trinity River, Coffee Creek, Swift Creek, and Stuart Fork. Inflow data for Trinity Lake is limited to USGS gage 11523200 (Trinity River near Coffee Creek) 15-minute data and computed total daily reservoir inflow values provided by Reclamation. In addition, daily flow data for Coffee Creek near Trinity Center (USGS gage 11523700) is available for 1910 through 1966.

Total daily inflow values were disaggregated and distributed among the main inflow sources using a flow proration method (to be discussed in detail in the final draft of this technical memorandum). The flow proration method involves disaggregating and distributing total flow among the tributaries, based on the size of their drainage areas. The USGS StreamStats tool was used to determine drainage area for each of the main inflow locations.

The flow proration method also applies other basin characteristics to inform flow distribution and seasonal flow patterns. In addition, daily flow data for Trinity River near Coffee Creek and Coffee Creek near Trinity Center were used to characterize seasonal flow patterns. Headwater and mean basin elevations for Trinity River, Coffee Creek, Swift Creek, and Stuart Fork drainages lie at approximately the same elevations and are assumed to have similar seasonal flow patterns characteristic of snowmelt dominated systems. Seasonal flow patterns for Trinity River and Coffee Creek were used to inform seasonal flow patterns for Swift Creek and Stuart Fork. Headwater and mean basin elevation for East Fork Trinity River are similar to North Fork Trinity River, a system with mixed snowmelt/rainfall runoff characteristics. North Fork Trinity River flow data were used to inform flow patterns for East Fork Trinity River. Numerous smaller inflows were considered negligible and were aggregated with main inflows.

#### *Trinity Lake Outflows*

Outflows from Trinity Lake are from Trinity Dam releases and spills. Hourly flow data are available for powerhouse generation releases from powerhouse units 1 and 2, as well as total powerhouse release. Hourly flow data for dam releases from gates 1, 2, and 3, and their total releases, as well as spill release data are also available. Outflows were disaggregated and assigned to the main (2100 ft elevation) and auxiliary (1995.5 t elevation) intakes, such that releases in excess of those diverted for power generation were assigned to the auxiliary intake. Excess releases greater than the auxiliary intake capacity were assigned to the main outlet (Deas 1998).

Table 5-13. Sources of flow data (Q) for Trinity Lake.

| Site Number/ Abbreviation | Agency | Site Active | Site Name | Data Types | Data Frequency | Application of Data |
|---|---|---|---|---|---|---|
| QG1, QG2, QG | USBR | YES | Generation Release from Trinity Dam Powerhouse Units 1 and2, and total release (QG=QG1+QG2), CFS | Q | Hourly | Boundary Condition |
| QS | USBR | YES | Trinity Dam spill release, CFS | Q | Hourly | Boundary Condition |
| QU1, QU2, QU3, QU | USBR | YES | Outlet release from gates 1,2, and 3, and total outlet release (QU=QU1+QU2+QU3), CFS | Q | Hourly | Boundary Condition |
| QT | USBR | YES | Total Dam Release (QT=QG+QS+QU), CFS | Q | Hourly | Boundary Condition |
| HL | USBR | YES | RESERVOIR ELEVATION, FT | Stage | Hourly | Boundary Condition |
| LS | USBR | YES | RESERVOIR STORAGE, AF | Storage | Hourly | Boundary Condition |

| Site Number/ Abbreviation | Agency | Site Active | Site Name | Data Types | Data Frequency | Application of Data |
|---|---|---|---|---|---|---|
| ES | USBR | YES | EVAPORATION, CFS | Q | Daily | Depletion (outflow) |
| EV | USBR | YES | EVAPORATION, INCH | Inch | Daily | Depletion (outflow) |
| PP | USBR | YES | PRECIPITATION, INCH | Inch | Daily | Accretion (inflow) |
| QI | USBR | YES | COMPUTED INFLOW, CFS | Flow | Daily | Headwater Boundary Condition |

## Temperature Data

Temperature data is used for model boundary conditions at inflow locations and for model calibration (Table 5-12). The Trinity Lake models have one calibration location – Trinity Dam. Limited hourly temperature data is available for Coffee Creek, Swift Creek, Stuart Fork, and for Trinity Lake outflows. In addition, temperature profile data is available for one location in Trinity Lake. Temperature boundary condition development is in progress and will require more time to complete.

Table 5-14. Sources of temperature data (Tw) for Trinity Lake. “NA” indicates information is not available.

| Site Number/ Abbreviation | Agency | Site Active | Site Name | Data Types | Data Frequency | Application of Data |
|---|---|---|---|---|---|---|
| NA | USFWS | No | Coffee Creek | Tw | Hourly | Boundary Condition |
| NA | USFWS | No | Swift Creek | Tw | Hourly | Boundary Condition |
| NA | USFS | No | Stuart Fork | Tw | Hourly | Boundary Condition |
| NA | USBR | Yes | Trinity Dam Release | Tw | Hourly | Model Calibration |
| TP1 | USBR | Yes | Trinity Lake Vertical Profile | Tw | Week/ Month | Model Calibration |

## Meteorology Data

Meteorology data, used to calculate heat flux and light intensity in the models, includes air temperature (°C), dew point temperature (°C), wet bulb temperature (°C), wind speed (m/s), wind direction (degrees), solar radiation (W/m$^2$) and cloud cover (scale 0.0-1.0). Cloud cover and wet bulb temperature are derived from observed data. Meteorology data were available from multiple sources in the Trinity basin (Table 8). Trinity Camp remote automated weather station (RAWS) has a relatively complete data set and is close to Trinity Lake, Lewiston Lake, and Trinity River below

Lewiston Dam, so was selected to be the primary source of meteorology data for the Trinity basin models. However, the Trinity Camp RAWS data set has significant gaps prior to 2007. Smaller data gaps (less than a day) were filled using linear regression, but the larger data gaps were filled using data from neighboring stations. Refer to Appendix C for a detailed description of meteorology data development for Trinity basin models.

Table 5-15. Data sources and available meteorology data for the Trinity basin.

| Station ID | Agency | Active | Site Name | Latitude | Longitude | Elevation | Parameters Measured | Data Frequency |
|---|---|---|---|---|---|---|---|---|
| TCAC1 | Bureau of Land Management | YES | Trinity Camp | 40.786° | -122.804° | 3308 | Tair, RH, Wdir, WS, SR | Hourly |
| LFH | CDEC-Reclamation | YES | Lewiston Fish Hatchery | 40.727° | -122.793° | 1870 | Tair, RH, Wdir, WS, SR | Hourly |
| LWD | CDEC-Land Management | NO | Lowden | 40.69° | -122.831° | 3120 | Tair, RH, Wdir, WS | Hourly |
| WVR | CDEC-US Forest Service | NO | Weaverville RS | 40.733° | -122.95° | 2136 | Tair, RH, Wdir, WS, SR | Hourly |
| OKB | CDEC-National Park Service | NO | Oak Bottom | 40.651° | -122.606° | 1326 | Tair, RH, Wdir, WS, SR | Hourly |
| RRAC1 | MesoWest | YES | Redding CA | 40.516° | -122.292° | 500 | Tair, RH, Wdir, WS, SR | Hourly |

Abbreviations:
Tair: Air temperature, RH: Relative Humidity, WS: Wind Speed, Wdir: Wind Direction, SR: Solar Radiation

# Data Development: Lewiston Lake

The following sections describe the data developed for Lewiston Lake. Geometry data are described first, followed by hydrologic data, water temperature data, and meteorology data. Data sources, as well as other pertinent information, are provided for each type of data.

## Geometry Data

Development of geometric data for Lewiston Lake is discussed in the following sections. Bathymetry development is discussed first, followed by the stage-volume relationship for Lewiston Lake. A description of the Lewiston Dam outlet facilities is then provided, followed by descriptions of temperature control curtains installed in Lewiston Lake.

### *Bathymetry*

Detailed bathymetry data in 50 m intervals were received from Reclamation. To balance computational time and model accuracy, 100 m interval cross sections were used. Development of Lewiston Lake bathymetry (Figure 5-12) is addressed in Jayasundara and Deas (2013).

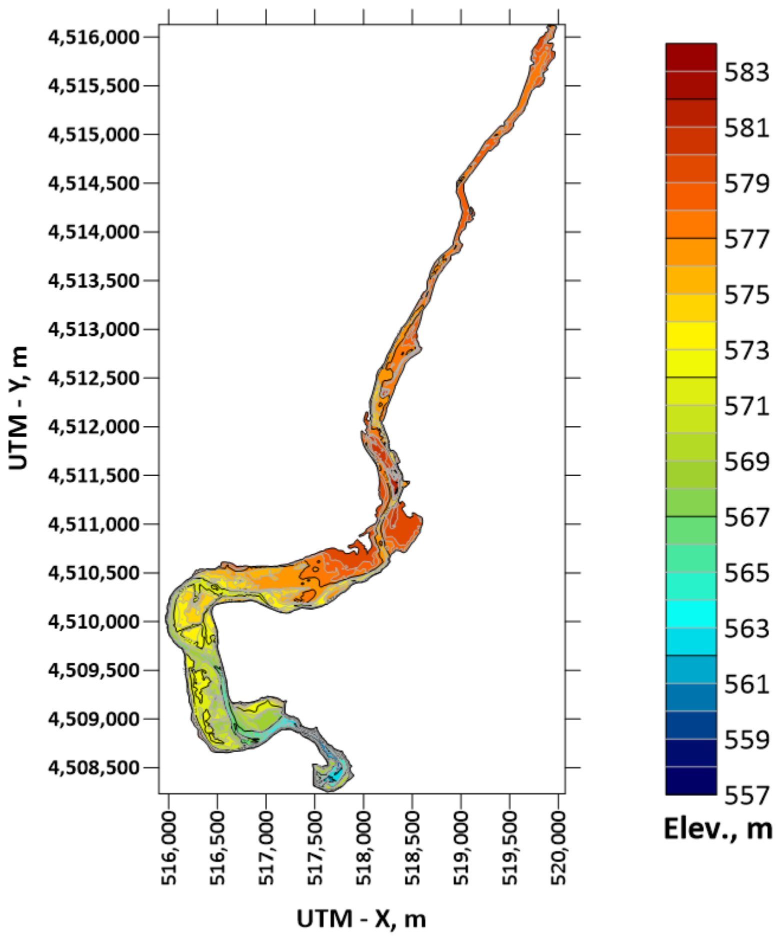



Figure 5-12. Lewiston Lake bathymetry.

### *Stage-Volume Relationship*

The stage–volume relationship (depicted as a storage volume versus elevation curve) of stage and storage data provided by Reclamation is shown in Figure 5-13. The bathymetric stage-volume relationship produced using Surfer® software, based on the bathymetric map shown in Figure 5-12 is also shown for comparison. The relationship developed using the Surfer® software closely approximates the curve developed from measured data.

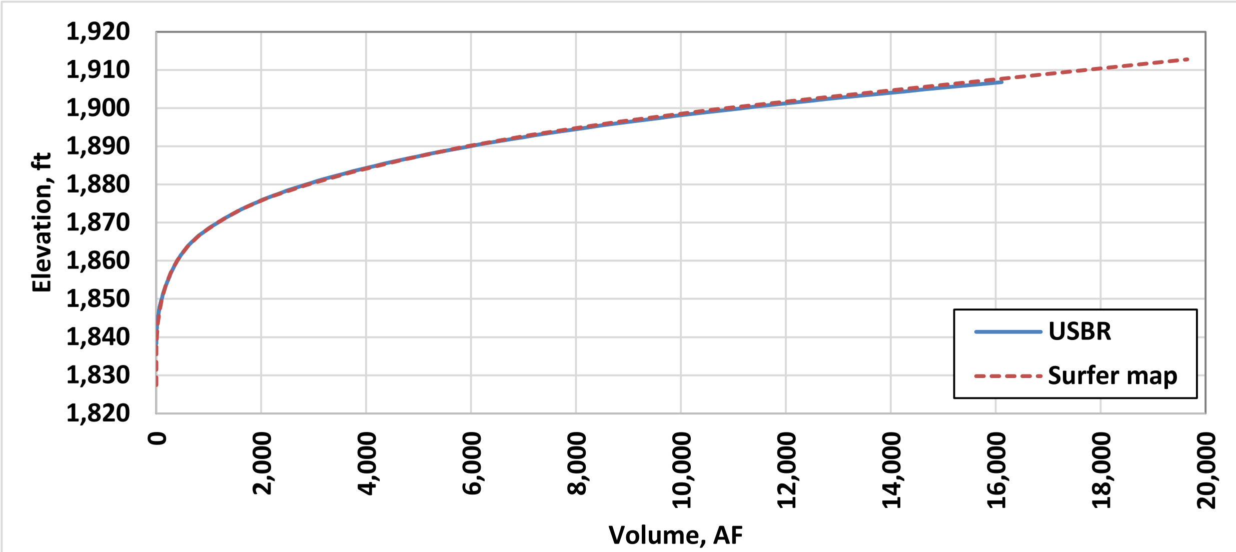



Figure 5-13. Stage vs Elevation curve for Lewiston Lake.

***Lewiston Lake Facilities***

Lewiston Dam impounds Lewiston Lake, which has a capacity of 14,660 AF ($1.808x10^7$ $m^3$) at full pool elevation of 1,902.0 ft (579.7 m) (Reclamation 2021). The dam is 91.0 ft. (27.7 m) high, with crest elevation of 1,910.0 ft (582.2 m) and has a spillway at 1,874.5 ft (571.3 m) elevation with a 30,000 cfs capacity. Dam outlet works at 1,902.0 ft (579.7 m). elevation have 325 cfs capacity. Lewiston Power Plant and river flow release from a common conduit that extends upstream (through the dam) in Lewiston Lake. Lewiston Dam outlet structure specifications are listed in Table 5-14.

Table 5-16. Lewiston Dam outlet structures specifications.

| Structure | Centerline, ft (m) | Width/diameter (ft) | Reference[1] |
|---|---|---|---|
| River/Power Plant | 1,845.0 (562.36) | 4.0 | 416-D-1064 |
| Spillway | 1,874.5 (571.35) | 60.0 | 416-D-1059 |
| Hatchery outlet | 1,885.0 (574.55) | 4.0 | 416-D-1067 |
| Clear Creek Tunnel | 1,887.0 (575.16) | 17.4 | 416-D-104 |

([1]Source: Reclamation drawings)

***Temperature Control Curtains***

A temperature control curtain was constructed by Reclamation in 1992, just upstream of ‘narrows’ of Lewiston Lake, to allow cooler flows to enter Clear Creek Tunnel. The curtain is 835 ft long, 35 ft deep, and extends across the entire width of the reservoir. There is also a smaller, 35 ft deep curtain immediately upstream of the fish hatchery intake at the south end of Lewiston Dam to draw deeper, cooler water for the fish hatchery (Vermeyen, 1997).

## Hydrologic Data

Hydrologic data used for implementation of Lewiston Lake models includes inflow, stage (or water surface elevation) and outflow data (Table 5-15). Inflows to Lewiston Lake will be discussed first, followed by outflows.

Table 5-17. Sources of flow data (Q) for Lewiston Lake.

| Site Number/ Abbreviation | Agency | Site Active | Site Name | Data Types | Data Frequency | Application of Data |
|---|---|---|---|---|---|---|
| QT (TRN) | USBR | YES | Total Release from Trinity Dam (QG+QS+QU), CFS | Q | Hourly | Inflow Boundary Condition |
| QG | USBR | YES | Generation Release from Lewiston Dam Powerhouse, CFS | Q | Hourly | Outflow Boundary Condition |
| QS1, QS2, QS | USBR | YES | Lewiston Dam Spill Release, Gate #1, Gate #2, Total, CFS | Q | Hourly | Outflow Boundary Condition |
| QF | USBR | YES | Diversion to Lewiston Fish Hatchery, CFS | Q | Hourly | Outflow Boundary Condition |
| QR | USBR | YES | Lewiston Dam Release to Trinity River, CFS | Q | Hourly | Outflow Boundary Condition |
| QU | USBR | YES | Lewiston Dam Outlet Release, CFS | Q | Hourly | Outflow Boundary Condition |
| QG (JCR) | USBR | YES | Judge Francis Carr PH (representing Clear Creek Tunnel Flow), CFS | Q | Hourly | Outflow Boundary Condition |
| HL | USBR | YES | RESERVOIR ELEVATION, FT | Stage | Hourly | Boundary Condition |
| LS | USBR | YES | RESERVOIR STORAGE, AF | Storage | Hourly | Boundary Condition |

### *Lewiston Lake Inflows*

Inflow to Lewiston Lake comes primarily from the Trinity Powerhouse releases and is recorded hourly by Reclamation. Due to peaking operations, when the powerhouse is offline, there is no inflow to Lewiston Lake. Stage data were recorded as water surface elevation by Reclamation during the operation of the dam.

The total outflow of Lewiston Lake is about 6 percent more than the total inflow (Trinity Dam release). About 6 percent of the total annual flow to Lewiston is estimated to be contributed by runoff from the watershed and rainfall from November to May period (R. Wittler, personal communication, 10/15/2012).

### *Lewiston Lake Outflows*

There are five outflows from Lewiston Lake: Judge Francis Carr Powerplant (via Clear Creek Tunnel), Lewiston fish hatchery, spillway, Lewiston Powerplant, and release to Trinity River. Hourly flow rates for each outflow are recorded by Reclamation.

## Temperature Data

Temperature data necessary for Lewiston Lake models includes inflow temperature boundary condition data and temperature data for model calibration. In addition, water temperature profile data is available for four locations in Lewiston Lake. All four profile sampling locations are in the vicinity of Lewiston Dam: near the spillway, log boom, Clear Creek outlet, and upstream of the temperature control curtain (Figure 5-10). Available water temperature data for Lewiston Lake are summarized in Table 5-16.

Trinity Dam outflow temperature data is applied as headwater boundary condition temperature to Lewiston Lake. There are significant gaps in the Lewiston Lake inflow temperature data (a.k.a, Trinity Dam outflow). Those gaps will be filled using modeled output from the Trinity Lake model. Water temperature of rainfall and associated runoff can be assumed to be approximately in equilibrium with air temperature, so the rainfall/runoff inflow boundary condition is assumed to be equal to air temperature as measured at Trinity Camp RAWS, adjusted for elevation. The Lewiston Lake model is calibrated for temperature at two locations: near the Clear Creek tunnel outflow and Lewiston Dam release.

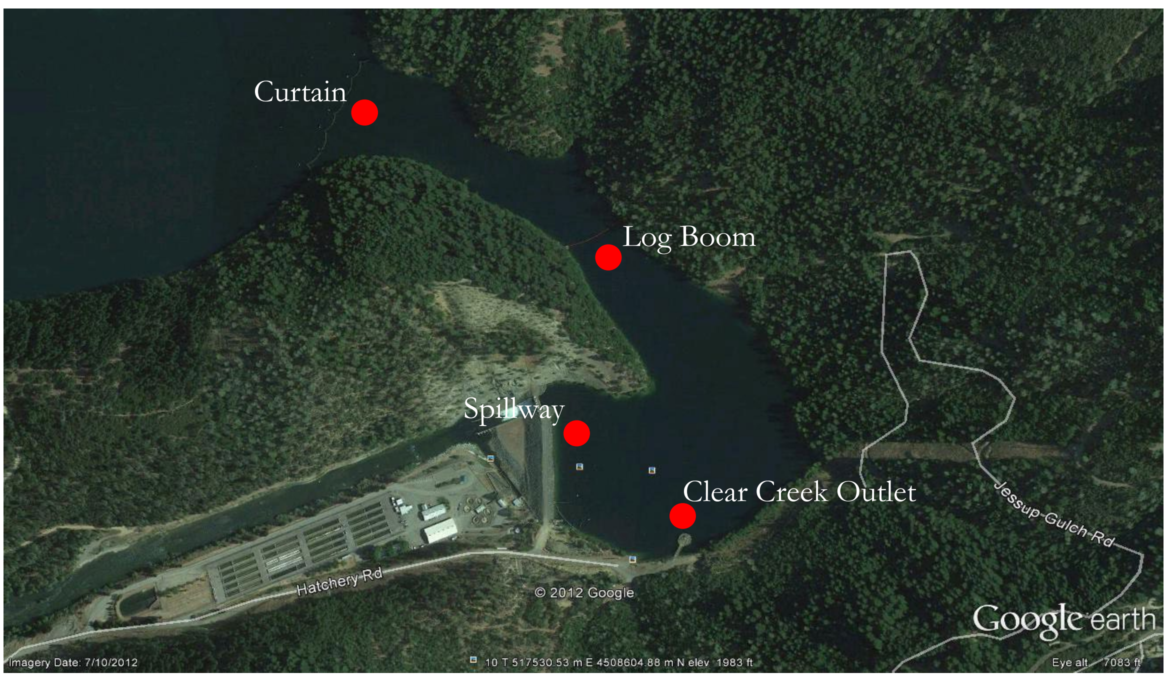



Figure 5-14. Locations of water temperature profiles for Lewiston Lake.

Table 5-18. Sources of water temperature data (Tw) for Lewiston Lake.

| Site Number/ Abbreviation | Agency | Site Active | Site Name | Data Types | Data Frequency | Application of Data |
|---|---|---|---|---|---|---|
| Upstream model | Upstream model | Upstream model | Trinity Dam Release | Tw | Hourly | Headwater Boundary Condition |
| 11525500 | USGS | YES | Trinity R AT Lewiston CA | Tw | Hourly | Model Calibration |
| LFH | CDEC | YES | Lewiston Fish Hatchery | Tw | Hourly | Model Calibration |
| TP1 | USBR | | Temperature Profile: Log Boom | Tw | Weekly or Monthly | Reservoir Characterization |
| TP2 | USBR | | Temperature Profile: Fish Hatchery Intake | Tw | Weekly or Monthly | Reservoir Characterization |
| TP3 | USBR | | Temperature Profile: Clear Creek Intake | Tw | Weekly or Monthly | Model Calibration |
| TP4 | USBR | | Temperature Profile: Upper Curtain | Tw | Weekly or Monthly | Reservoir Characterization |

### Meteorology Data
Due to their close proximity, Lewiston Lake and Trinity Lake models use the same meteorology data set. Refer to the Meteorology Data section for Trinity Lake for a description of the types and sources of meteorology data used to develop the meteorology input file.

## Data Development: Trinity River

The following sections describe the data developed for Trinity River, from Lewiston Dam to the water temperature compliance point at river mile 72.5, near the mouth of North Fork Trinity River. Geometry data are described first, followed by hydrologic data, water temperature data, and meteorology data. Data sources, as well as other pertinent information, are provided for each type of data.

### Geometry Data
Development of geometric data for the Trinity River model reach is discussed in the following sections. Alignment, bed elevation and slope information are discussed first, followed by cross section information, and the locations of inflows and outflows.

### *Alignment, Bed Elevation, and Slope*

Data used to establish stream alignment, bed elevation, and slope were available online through the USGS National Hydrologic Dataset (NHD) (flowline layer). The NHD data, georeferenced to unprojected latitude and longitude on the NAD38 datum, were projected to UTM zone 10N to produce lengths (reaches, cross-sections) in US survey feet. The vertical datum is NGVD29.

### *Channel Cross Sections*

A HEC-RAS model was used to develop channel cross sections for use in the Trinity River ResSim model. Data used to develop cross sections for a HEC-RAS model are available through the TRRP dataport.

### *Locations of Inflows*

The WTMP model representation for the Trinity River from Lewiston Dam to North Fork Trinity River has four inflow locations. The locations of the inflows are listed below with their approximate distance from Lewiston Dam:

- Indian Creek, approximately 15.7 miles downstream of Lewiston Dam
- Weaver Creek, approximately 17.3 miles downstream of Lewiston Dam
- Browns Creek, approximately 23.2 miles downstream of Lewiston Dam
- Canyon Creek, approximately 31.7 miles downstream of Lewiston Dam

## Hydrologic Data

Time series flow data are required to implement and test the Trinity River model. Flow data describes inflows to and outflows from the river reach. The headwater boundary condition for the Trinity River model is the total outflow from Lewiston Lake, which is controlled by Lewiston Dam. Total outflow from Lewiston Dam includes powerplant releases, dam releases, fish hatchery flows, and spills. Primary inflows to the Trinity River between Lewiston Dam and North Fork Trinity River are Indian Creek, Weaver Creek, Browns Creek, and Canyon Creek. A USGS gage in Indian Creek near Douglas Creek (gage 11525670) provides tributary boundary condition data. Inflows from the ungaged tributaries, Weaver Creek, Browns Creek, and Canyon Creek, were developed using flow balance in Trinity River (utilizing flow data from three USGS gages in Trinity River), tributary drainage area, and information provided by USGS gages in Indian Creek and North Fork Trinity River. Flows measured at USGS gage above North Fork Trinity River near Helena (11526400) provide data for the model outflow boundary condition. Sources for flow data and how that data were applied in the Trinity River model are listed in Table 5-10.

Table 5-19. Sources of flow data (Q) for Trinity River from Lewiston Dam to North Fork Trinity River.

| Site Number/ Abbreviation | Agency | Site Active | Site Name | Data Types | Data Frequency | Application of Data |
|---|---|---|---|---|---|---|
| QG | USBR | YES | Lewiston Dam Powerhouse | Q | Hourly/ Daily | Inflow Boundary Condition |
| QS | USBR | YES | Lewiston Dam Spill Total | Q | Hourly/ Daily | Inflow Boundary Condition |
| QF | USBR | YES | Lewiston Dam Hatchery Release | Q | Hourly | Inflow Boundary Condition |
| QR | USBR | YES | Lewiston Dam River Release | Q | Hourly/ Daily | Inflow Boundary Condition |
| QU | USBR | YES | Lewiston Dam Outlet Release | Q | Hourly | Inflow Boundary Condition |
| QT | USBR | YES | Lewiston Dam Total Release (QT=QG+QS+QF+QR+QU) | Q | Hourly | Inflow Boundary Condition |
| 11525500 | USGS | YES | Trinity River at Lewiston CA | Q | Hourly/ Daily | Inflow Boundary Condition |
| 11526250 | USGS | YES | Trinity R at Junction City CA | Q | Hourly/ Daily | Model Calibration |
| 11525854 | USGS | YES | Trinity River at Douglas City CA | Q | Hourly/ Daily | Model Calibration |
| 11525670 | USGS | YES | Indian Creek near Douglas City CA | Q | Hourly/ Daily | Inflow Boundary Condition |
| 11525655 | USGS | YES | Trinity River below Lime Kiln Gulch near Douglas City CA | Q | Hourly | Model Calibration |
| 11526400 | USGS | YES | Trinity River above North Fork Trinity River near Helena CA | Q | Hourly | Outflow Boundary Condition |

## Temperature Data

Water temperature data are used for boundary conditions, initial conditions and for model calibration. Sources of water temperature data for the Trinity River model are listed in Table 5-10. Inflow boundary condition data are applied at the reach headwater and at each of the aforementioned tributaries.

Headwater temperature boundary condition data is measured at Lewiston Dam outflow by USGS gage 11525500. Incomplete data sets are available for tributary inflow temperatures. Large gaps in data for individual tributaries may be filled with measured data from neighboring tributaries with similar watershed characteristics. Surrogate temperature data may be adjusted for different watershed attributes, headwater elevation, or other factors. North Fork Trinity River joins Trinity River just below the model downstream boundary but temperature data from the USGS gage 11526500

(North Fork Trinity River above Helena, CA) may also be used to fill gaps in data sets from nearby tributaries.

Table 5-20. Sources of temperature data (Tw) for Trinity River from Lewiston Dam to North Fork Trinity River.

| Site Number/ Abbreviation | Agency | Site Active | Site Name | Data Types | Data Frequency | Application of Data |
|---|---|---|---|---|---|---|
| 11525500 | USGS | YES | Trinity River at Lewiston CA | Tw | Hourly/ Daily | Headwater Boundary Condition |
| LFH | CDEC | YES | Lewiston Fish Hatchery | Tw | Hourly | Headwater Boundary Condition |
| 11525854 | USGS | YES | Trinity River at Douglas City CA | Tw | Hourly | Model Calibration |
| NA | Various | NO | Indian Creek | Tw | Hourly | Boundary Condition |
| NA | Various | NO | Weaver Creek | Tw | Hourly | Boundary Condition |
| NA | Various | NO | Browns Creek | Tw | Hourly | Boundary Condition |
| NA | Various | NO | Canyon Creek | Tw | Hourly | Boundary Condition |

### Meteorology Data

Due to its close proximity to Lewiston Lake and Trinity Lake, the Trinity River model uses the same meteorology data set, adjusted for elevation. Refer to the Meteorology Data section for Trinity Lake for a description of the types and sources of meteorology data used to construct the meteorology input file. From the base of Lewiston Dam (elevation 1,870 ft) to the confluence of the North Fork Trinity River (elevation 1,370 ft), the Trinity River drops approximately 500 feet. Air temperatures were adjusted to an average reach elevation of 1,620 ft.

## Data Development: Whiskeytown Lake

The following sections describe the data collected for Whiskeytown Lake. Geometry data are described first, followed by hydrologic data, water temperature data, and meteorology data. Data sources, as well as other pertinent information, are provided for each type of data.

### Geometry Data

Development of geometric data for Whiskeytown Lake is discussed in the following sections. Bathymetry development is discussed first, followed by the stage-volume relationship for

Whiskeytown Lake. Last, a description of the Whiskeytown outlet facilities is provided, including a description of Spring Creek Tunnel.

***Bathymetry***

Spatial data used to create the Whiskeytown Reservoir bathymetry were gathered from three principal sources (Table 5-19). Development of bathymetry for Whiskeytown Lake, including identifying and filling gaps in spatial data, is described in detail in Appendix D. The final digital bathymetric map, covering the entirety of Whiskeytown Reservoir and the surrounding shore area, is shown in Figure 5-11. Detailed representations of the regions upstream of the Oak Bottom curtain and downstream of the Spring Creek curtain are shown in Figure 5-12.

Table 5-21. Spatial data used to create Whiskeytown bathymetry, including sources and horizontal and vertical datums.

| Title | Source | Datum | Units |
|---|---|---|---|
| USGS 1 arc second n41w123 20210624 (data set/map) | USGS 2021 | NAD83<br>NAVD88 | Geographic Coordinates: decimal degrees |
| The U.S. Geological Survey (USGS) Bathymetry, Topography and Orthomosaic imagery for Whiskeytown Lake, northern California | Logan et al. 2020 | NAD83<br>NAVD88 | UTM Coordinate (Zone 10): Meter |
| Historic 1956 US Department of Interior topographic maps of the Whiskeytown Reservoir Area | Alster 1956 | NAD27 (Calif. State Plan, zone 0401)<br>NGVD29 | UTM Coordinate (Zone 10): Feet |

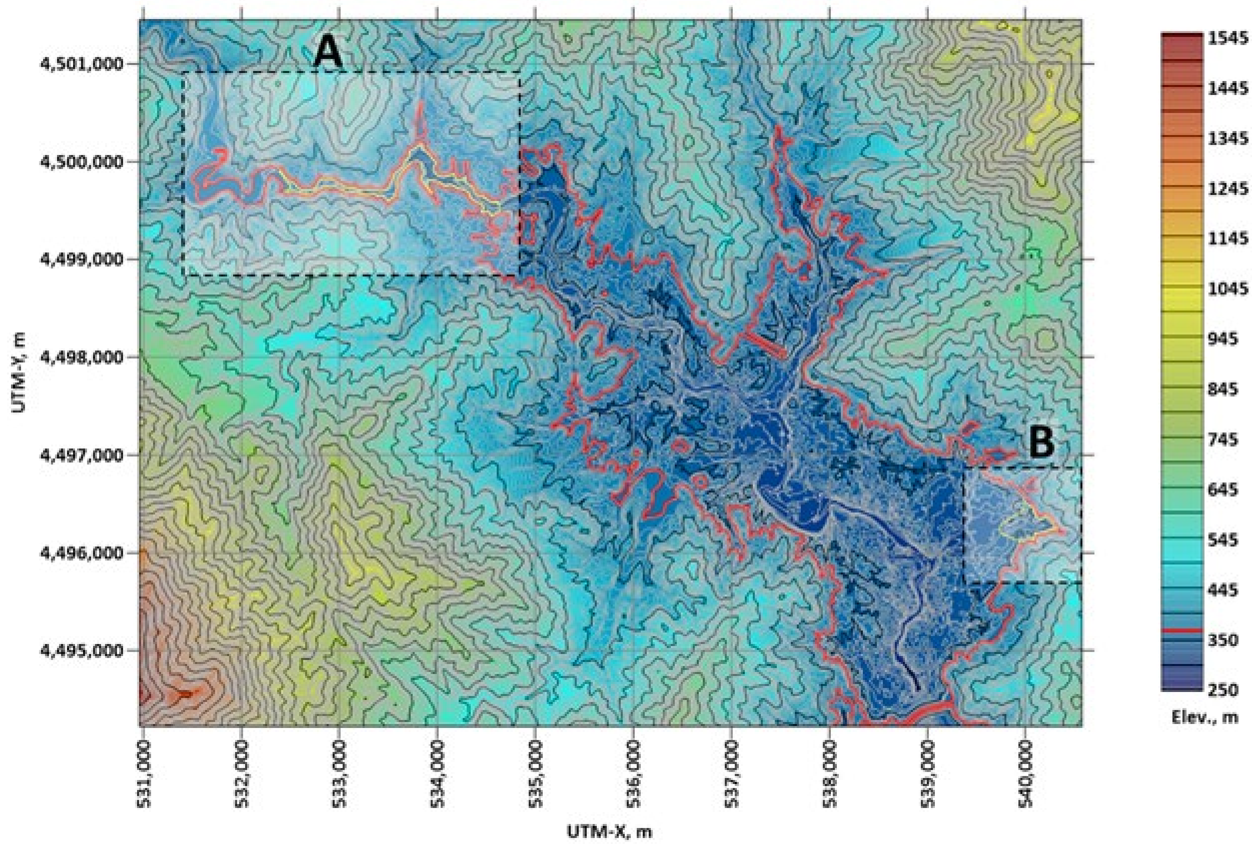
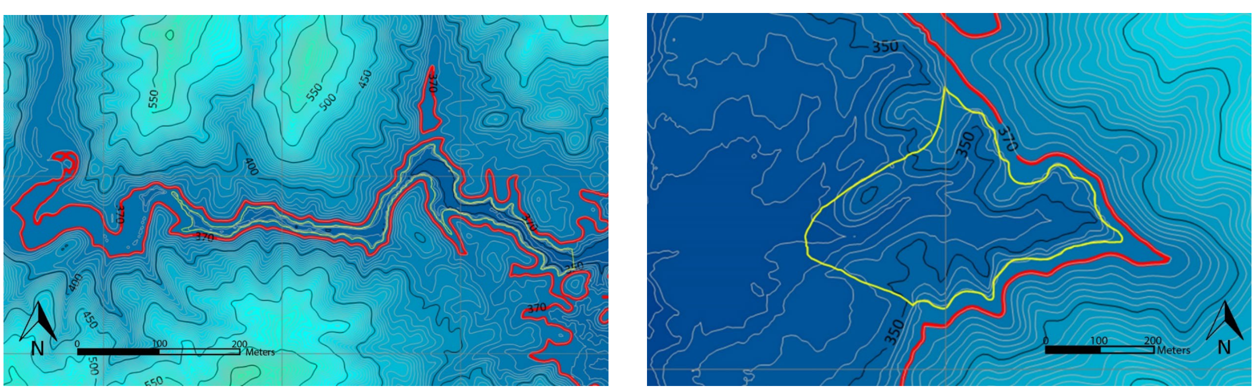



Figure 5-15. Whiskeytown Lake bathymetry and topography with upstream (A) and downstream (B) curtain additions. Full pool elevation (1210 ft in NGVD29) is indicated by red line.




(A) (B)

Figure 5-16. Bathymetric map of area upstream of Oak Bottom curtain (A) and downstream of Spring Creek curtain (B). Areas correspond to highlighted areas in FIGURE.

### *Stage-Volume Relationship*

The stage–volume relationship (depicted as a storage volume versus elevation curve) of stage and storage data provided by Reclamation is shown in Figure 5-13. The bathymetric stage-volume relationship produced using Surfer® software, based on the bathymetric map shown in Figure 5-11, is also shown for comparison. The relationship developed using the Surfer® software closely approximates the curve developed from measured data.

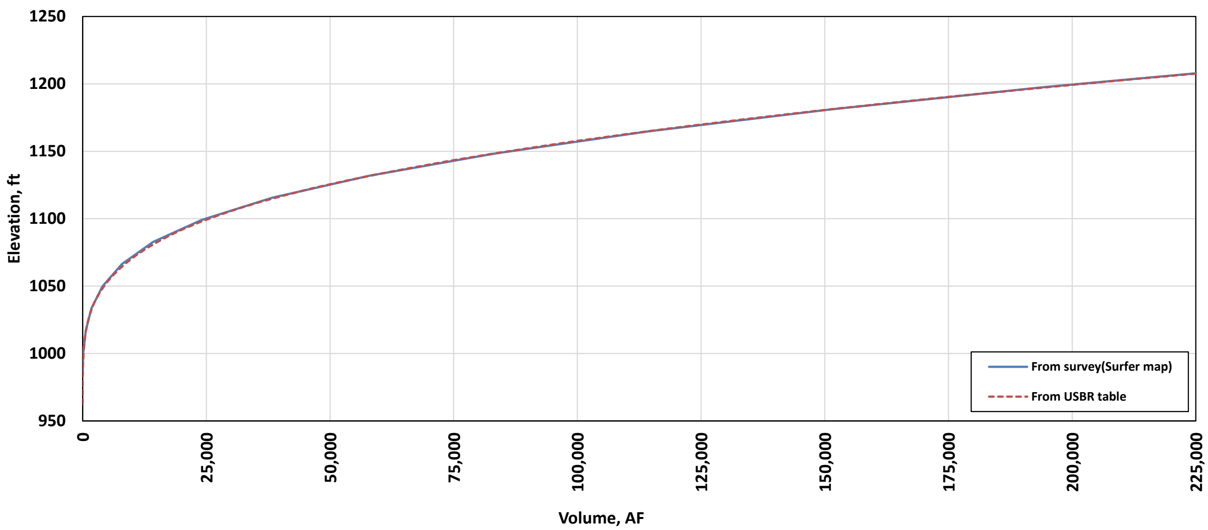



Figure 5-17. Stage-volume relationship for Whiskeytown Lake from bathymetric map and from USBR data.

### *Whiskeytown Lake Outlet Facilities*

Outflows from Whiskeytown Lake are from dam outlets, a spillway, and outflows to Spring Creek Powerplant via Spring Creek Tunnel (Figure 5-14). Whiskeytown Dam is 282 ft. high, with a crest length of 4,000 ft. and crest elevation of 1,228 ft. Whiskeytown Dam outlet works are located on the eastern abutment of the dam.

Whiskeytown Dam outlet works consist of two intakes (upper-level and lower-level) and a glory hole spillway (Figure 5-14). The upper-level intake structure is 8’6” wide and 11’4” tall, with screened openings on each of the four sides (Figure 5-14). The lower-level intake structure consists of two, stacked, box-like structures. The upper portion is 21 ft. wide, 10.5 ft. deep, and 14 ft. tall, with screened openings on each of the four sides and the top. The lower portion is 21 ft. wide, 10.5 ft. deep, and 15.5 ft. tall, with screened openings on three sides (no opening on the downstream side, facing the dam). The flood spillway is a 19 ft. diameter glory hole with an invert elevation of 1,210 ft. (NGVD29) and 28,780 cfs capacity at 1220.5 (NGVD29) elevation. Additional information regarding the dam outlets is provided in Table 5-20.

The invert for the Spring Creek Tunnel is at 1075 ft elevation, which is below the minimum operating water surface elevation of 1100 ft. The approximate location of the Spring Creek Tunnel intake is shown in Figure 5-17.

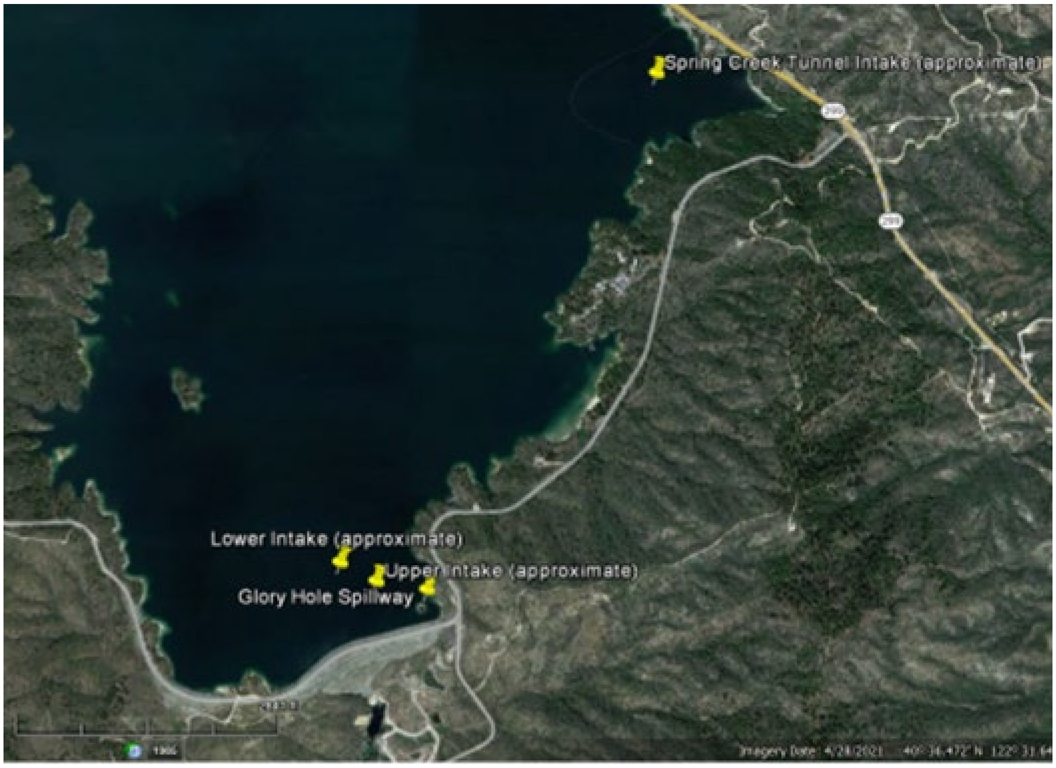



Figure 5-18. Whiskeytown Dam with approximate locations of lower and upper intakes, glory hole spillway, and Spring Creek Tunnel intake, marked with yellow pins.

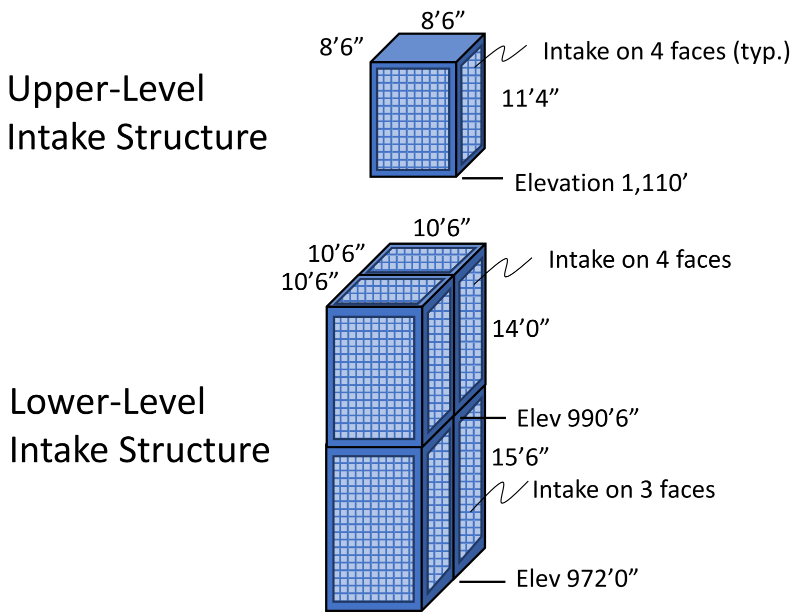



Figure 5-19. Schematic of upper-level (top) and lower-level (bottom) Whiskeytown Dam intake structures.

Table 5-22. Whiskeytown Dam intake structures specification and location information. "NA" indicates not applicable.

| | Upper-level Intake | Lower-level Intake (top structure) | Lower-level Intake (bottom structure) | Datum |
|---|---|---|---|---|
| Invert Elevation (ft) | 1,110 | 990.5 | 972 | NGVD29 |
| Latitude | 40.6010° | 40.60152° | 40.60152° | NAD83 |
| Longitude | -122.5386° | -122.54005° | -122.54005° | NAD83 |
| Intake Structure Width (ft) | 8′6″ | 10′6″ | 10′6″ | NA |
| Intake Structure Depth (ft) | 8′6″ | 10′6″ | 10′6″ | NA |
| Intake Structure Hight (ft) | 11′4″ | 14′ | 15′6″ | NA |
| Intake Pipe Diameter (ft) | 19′ | 6′ | 6′ | NA |

## Hydrologic Data

Hydrologic data used for model implementation of a reservoir includes inflow, stage (or water surface elevation) and outflow (or operations) data. Available flow data for Whiskeytown models is listed in Table 5-15. Inflows to Whiskeytown Lake are discussed in the next section, followed by a discussion of outflows.

Table 5-23. Sources of flow (Q) data for Whiskeytown Lake.

| Site Number/ Abbreviation | Agency | Site Active | Site Name | Data Types | Data Frequency | Application of Data |
|---|---|---|---|---|---|---|
| QG1 (WHI) | USBR | YES | Release to Spring Creek Powerhouse Unit 1, CFS | Q | Hourly | Outflow Boundary Condition |
| QG2 (WHI) | USBR | YES | Release to Spring Creek Powerhouse Unit 2, CFS | Q | Hourly | Outflow Boundary Condition |
| QG (WHI) | USBR | YES | Release to Spring Creek Powerhouse Total, CFS | Q | Hourly | Outflow Boundary Condition |
| QU1 | USBR | YES | Regulating Gate 1 Release, CFS | Q | Hourly | Outflow Boundary Condition |
| QU2 | USBR | YES | Regulating Gate 2 Release, CFS | Q | Hourly | Outflow Boundary Condition |
| QU3 | USBR | YES | City of Redding Generation Release, CFS | Q | Hourly | Outflow Boundary Condition |
| QU4 | USBR | YES | Jet Valve Release, CFS | Q | Hourly | Outflow Boundary Condition |
| QU | USBR | YES | Whiskeytown Dam Outlet Release Total (QU1+QU2+QU3+QU4), CFS | Q | Hourly | Outflow Boundary Condition |
| QS | USBR | YES | Whiskeytown Dam Spill Release, CFS | Q | Hourly | Outflow Boundary Condition |
| QT | USBR | YES | Whiskeytown Dam Release Total (QU+QS), CFS | Q | Hourly | Outflow Boundary Condition |
| HL | USBR | YES | Reservoir Elevation, ft. | Stage | Hourly | Model Calibration |
| LS | USBR | YES | Reservoir Storage, AF | Storage | Hourly | Model Calibration |
| QG1 (JCR) | USBR | YES | Judge Francis Carr PH Unit 1 Generation Release, CFS | Q | Hourly | Inflow Boundary Condition |

| Site Number/ Abbreviation | Agency | Site Active | Site Name | Data Types | Data Frequency | Application of Data |
|---|---|---|---|---|---|---|
| QG2 (JCR) | USBR | YES | Judge Francis Carr PH Unit 2 Generation Release, CFS | Q | Hourly | Inflow Boundary Condition |
| QG (JCR) | USBR | YES | Judge Francis Carr PH Generation Release Total (QG1+QG2), CFS | Q | Hourly | Inflow Boundary Condition |
| QB (LEW) | USBR | YES | Clear Creek Tunnel Release to Crystal Creek (tributary to Clear Creek), CFS | Q | Hourly | Inflow Boundary Condition |

***Inflows***

Inflows to Whiskeytown Lake come primarily from Lewiston Lake via Clear Creek Tunnel and Judge Francis Carr (Carr) Powerplant. Clear Creek provides additional inflow to Whiskeytown Lake. Inflows from Carr Powerplant are well documented but data for Clear Creek inflows are only available from 1950 to 1993. Data were developed to represent Clear Creek inflows by establishing a linear regression relationship between historical Clear Creek data and data from nearby, similar watersheds with gaged flows. The method applied for developing data to represent inflows from Clear Creek is explained in greater detail in Appendix E.

***Outflows***

There are four outflow locations from Whiskeytown Lake: Spring Creek Tunnel, Whiskeytown Dam upper and lower intakes, and a glory hole spillway. Outflows through the upper-level and lower-level intakes are diverted through two regulating gates, a City of Redding powerplant, and a jet-valve release. Hourly flow rates for each outflow are recorded by Reclamation.

## Temperature Data

Temperature data necessary for Whiskeytown Lake models includes inflow temperature boundary condition data as well as temperature data for model calibration. Water temperature profile data is available for three locations in Whiskeytown Lake (Figure 5-20). Available water temperature data for Whiskeytown Lake are summarized in Table 5-16.


Figure 5-20. Locations of water temperature profiles in Whiskeytown Lake.

Table 5-24. Sources of water temperature data for Whiskeytown Lake.

| Site Number/ Abbreviation | Agency | Site Active | Site Name | Data Types | Data Frequency | Application of Data |
|---|---|---|---|---|---|---|
| QG1 (JCR) | USBR | YES | Judge Francis Carr PH Unit 1 Generation Release, CFS | Tw | Hourly | Boundary Condition |
| QG2 (JCR) | USBR | YES | Judge Francis Carr PH Unit 2 Generation Release, CFS | Tw | Hourly | Boundary Condition |
| QG (JCR) | USBR | YES | Judge Francis Carr PH Generation Release Total (QG1+QG2), CFS | Tw | Hourly | Boundary Condition |
| Whiskeytown Dam Release | USFWS | YES | Whiskeytown Dam pool (Clear Creek below Whisketown Dam) | Tw | Hourly | Model Calibration |
| TP1 | USBR | YES | Temperature Profile Location 1: 2 miles upstream of Whiskeytown Dam | Tw | Monthly | Model Calibration |
| TP2 | USBR | YES | Temperature Profile Location 2: 1000 ft upstream of Whiskeytown Dam | Tw | Monthly | Model Calibration |
| TP3 | USBR | YES | Temperature Profile Location 3: upstream of Spring Creek Tunnel | Tw | Monthly | Model Calibration |
| OBDS | USBR | NO | Temperature Profile: downstream of Oak Bottom Curtain (string) | Tw | Hourly | Reservoir Characterization |
| OBUS | USBR | NO | Temperature Profile: upstream of Oak Bottom Curtain (string) | Tw | Hourly | Model Calibration |
| SCIN | USBR | NO | Temperature Profile: inside Spring Creek Curtain (string) | Tw | Hourly | Reservoir Characterization |
| SCOUT | USBR | NO | Temperature Profile: outside Spring Creek Curtain (string) | Tw | Hourly | Model Calibration |

Carr Powerplant release temperature data is applied as a headwater boundary condition. A tributary inflow boundary condition is assigned at the mouth of Clear Creek. The Whiskeytown Lake model is calibrated at two locations: near Whiskeytown Dam and near Spring Creek Tunnel intake.

Significant gaps are present in inflow temperature boundary condition data for Carr Powerplant and Clear Creek. Because flow into Clear Creek Tunnel is conveyed through Carr Powerplant, Clear Creek Tunnel intake temperature data can be used to fill gaps in the Carr Powerplant outflow temperature data set. However, data analysis indicated temperatures at Carr Powerplant differ from temperatures at Clear Creek Tunnel intake. A model was developed to adjust the Clear Creek intake temperature data for in-tunnel heating (Appendix F). After filling gaps in Carr Powerplant data with data from Clear Creek Tunnel intake, adjusted for in-tunnel heating, gaps are still present in the headwater temperature boundary condition. Methods for filling those remaining gaps in the data are currently under development. Temperature boundary condition at Clear Creek was developed using an equilibrium temperature approach, discussed in Appendix E.

### Meteorology Data

Due to the proximity of Whiskeytown Lake to Shasta Lake, the same meteorology data set was used for both models. Refer to the discussion of meteorology data development for Shasta Lake for a description of the types and sources of data used to construct the meteorology input file.

## Data Development: Clear Creek

The following sections describe the data developed for an 18-mile reach of Clear Creek, from Whiskeytown Dam to Sacramento. Geometry data are described first, followed by hydrologic data, water temperature data, and meteorology data. Data sources, as well as other pertinent information, are provided for each type of data.

### Geometry Data

Development of geometric data for the Clear Creek model reach is discussed in the following sections. Alignment, bed elevation and slope information is discussed first, followed by cross section information, and the locations of inflows and outflows.

#### *Alignment, Bed Elevation, and Slope*

Data representing channel alignment, bed elevation, and channel slope are being developed and will be available for review late summer 2022.

#### *Channel Cross Sections*

Cross section data are being developed and will be available for review late summer 2022.

#### *Locations of Inflows*

Clear Creek receives inflow from several small tributaries. The WTMP model representation for Clear Creek will have one inflow location – Paige Boulder Creek.

## Hydrologic Data

Time series flow data are required to implement and test the Clear Creek model. Flow data describes inflows to the reach. The headwater boundary condition for the Clear Creek model is the outflow from Whiskeytown Lake, which is controlled by Whiskeytown Dam. Limited inflow data are available from Paige Boulder Creek, an intermittently-flowing tributary to Clear Creek. Flow gains and losses due to rainfall runoff, evaporation, and additional ungaged inflows and outflows are determined by flow balance. Sources for flow data and how that data will be applied in the Clear Creek model are listed in Table 5-10.

Table 5-25. Sources of flow data (Q) for Clear Creek from Whiskeytown Dam to Sacramento River.

| Site Number/ Abbreviation | Agency | Site Active | Site Name | Data Types | Data Frequency | Application of Data |
|---|---|---|---|---|---|---|
| QU1 | USBR | YES | Regulating Gate 1 Release, CFS | Q | Hourly | Inflow Boundary Condition |
| QU2 | USBR | YES | Regulating Gate 2 Release, CFS | Q | Hourly | Inflow Boundary Condition |
| QU3 | USBR | YES | City of Redding Generation Release, CFS | Q | Hourly | Inflow Boundary Condition |
| QU4 | USBR | YES | Jet Valve Release, CFS | Q | Hourly | Inflow Boundary Condition |
| QU | USBR | YES | Whiskeytown Dam Outlet Release Total (QU1+QU2+QU3+QU4), CFS | Q | Hourly | Inflow Boundary Condition |
| QS | USBR | YES | Whiskeytown Dam Spill Release, CFS | Q | Hourly | Inflow Boundary Condition |
| QT | USBR | YES | Whiskeytown Dam Release Total (QU+QS), CFS | Q | Hourly | Inflow Boundary Condition |
| Paige Boulder | NPS | NO | Paige Boulder Creek | Q | Hourly | Inflow Boundary Condition |
| 11372000 | USGS | YES | Clear Creek near Igo CA | Q | Hourly/ Daily | Model Calibration |

## Temperature Data

Water temperature data are used for boundary conditions, initial conditions and for model calibration. Sources of water temperature data for the Clear Creek model are listed in Table 5-10. Inflow boundary condition data are input at the reach headwater and at tributary inflows.

Whiskeytown Dam outflow temperature is input as the headwater boundary condition for Clear Creek below Whiskeytown Dam. A comparison of temperature data from the various dam outlets and the tailwater pool indicate the temperatures measured in the tailwater pool are representative of dam outflow temperatures.  Limited data is available for inflow boundary condition at Paige Boulder

Creek. Incomplete sets of temperature data are available from USFWS for seventeen locations in Clear Creek for model calibration (not listed in table).

Table 5-26. Sources of temperature data (Tw) for Clear Creek from Whiskeytown Dam to Sacramento River.

| Site Number/ Abbreviation | Agency | Site Active | Site Name | Data Types | Data Frequency | Application of Data |
|---|---|---|---|---|---|---|
| QU1 | USBR | YES | Regulating Gate 1 Release, CFS | Tw | Hourly | Boundary Condition |
| QU2 | USBR | YES | Regulating Gate 2 Release, CFS | Tw | Hourly | Boundary Condition |
| QU3 | USBR | YES | City of Redding Generation Release, CFS | Tw | Hourly | Boundary Condition |
| QU4 | USBR | YES | Jet Valve Release, CFS | Tw | Hourly | Boundary Condition |
| QU | USBR | YES | Whiskeytown Dam Outlet Release Total (QU1+QU2+QU3+QU4), CFS | Tw | Hourly | Boundary Condition |
| QS | USBR | YES | Whiskeytown Dam Spill Release, CFS | Tw | Hourly | Boundary Condition |
| QT | USBR | YES | Whiskeytown Dam Release Total (QU+QS), CFS | Tw | Hourly | Boundary Condition |
| Whiskeytown | USFWS | YES | Whiskeytown Dam Pool (RM18.3) | Tw | Hourly | Boundary Condition |
| Paige Boulder | NPS | NO | Paige Boulder Creek | Tw | Hourly | Boundary Condition |
| 11372000 | USGS | YES | Clear Creek near Igo CA | Tw | Hourly/ Daily | Model Calibration |

### Meteorology Data

Due to the proximity of Clear Creek to Shasta Lake, the same meteorology data set was used for both models. Refer to the discussion of meteorology data development for Shasta Lake for a description of the types and sources of data used to construct the meteorology input file.

## Data Development: Folsom Lake

Data development for Folsom Lake models is presented in the following sections: geometry data, hydrologic data, water temperature data and meteorology data. Information provided includes locations and sources of data collection, temporal range of data, and gaps in data sets.

## Geometry Data

Geometric data developed for the Folsom Lake water temperature models are described in the following sections: bathymetry, stage-volume relationship, and Folsom Dam facilities (TCDs, outlets, and operations).

### *Bathymetry*

Folsom Lake bathymetric data were provided by Reclamation as GIS shape files. The bathymetry data were collected using two different methods: (1) multi-beam sonar with real-time kinematic (RTK) GPS positioning and (2) photogrammetry, in September and October of 2005, respectively, as part of a sedimentation survey conducted by Reclamation (Ferrari, 2007). The survey used the California State Plane, zone 2, North American Datum of 1983 (NAD83) horizontal datum and National Geodetic Vertical Datum of 1929 (NGVD29) vertical datum (same as the Folsom Dam Project vertical datum).

The data were converted in GIS to Universal Transverse Mercator (UTM) Zone 10 and the vertical units were converted from feet to meters (vertical datum used was NGVD29). These data were then converted to an x, y, z text file that was imported into SURFER (Golden Software). A 3-D grid file was created from these points using the kriging gridding method. A detailed description of Folsom Lake bathymetry development is included in Cardno (2017). The final SURFER-generated elevation contour map of Folsom Lake is shown in Figure 5-21 along with a detail of the contours at Folsom Dam.

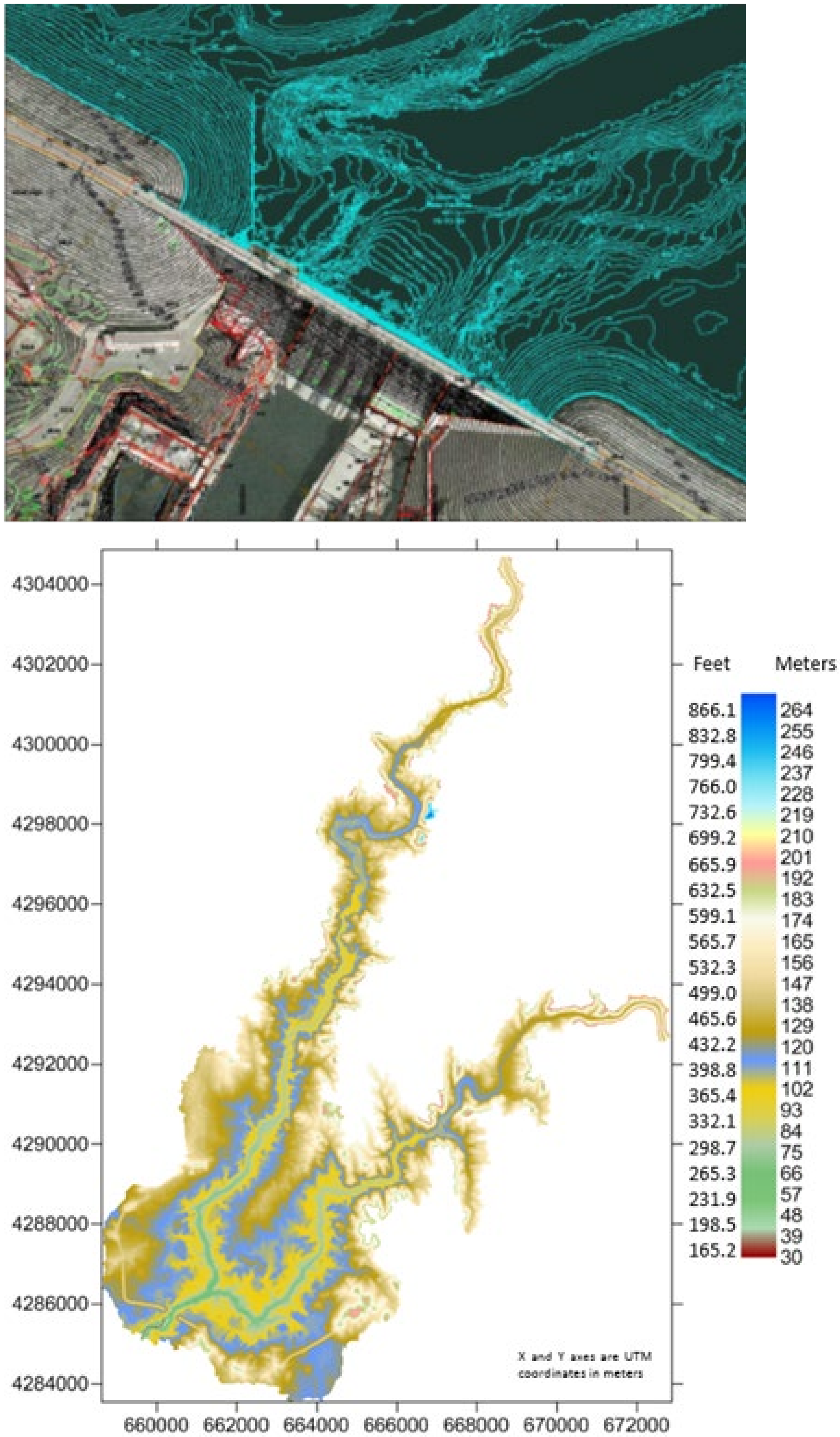



Figure 5-21. Elevation contour map of Folsom Lake (bottom) and detailed elevation contours at Folsom Dam (top).

### *Stage-Volume Relationship*

The final bathymetry of the computational grid was tested by calculating the stage-volume curve for the model grid and comparing it to the stage-volume curve previously developed for the Folsom Lake system (Ferrari 2007). A comparison of the stage-volume curves from the two sources is shown in Figure 5-22.

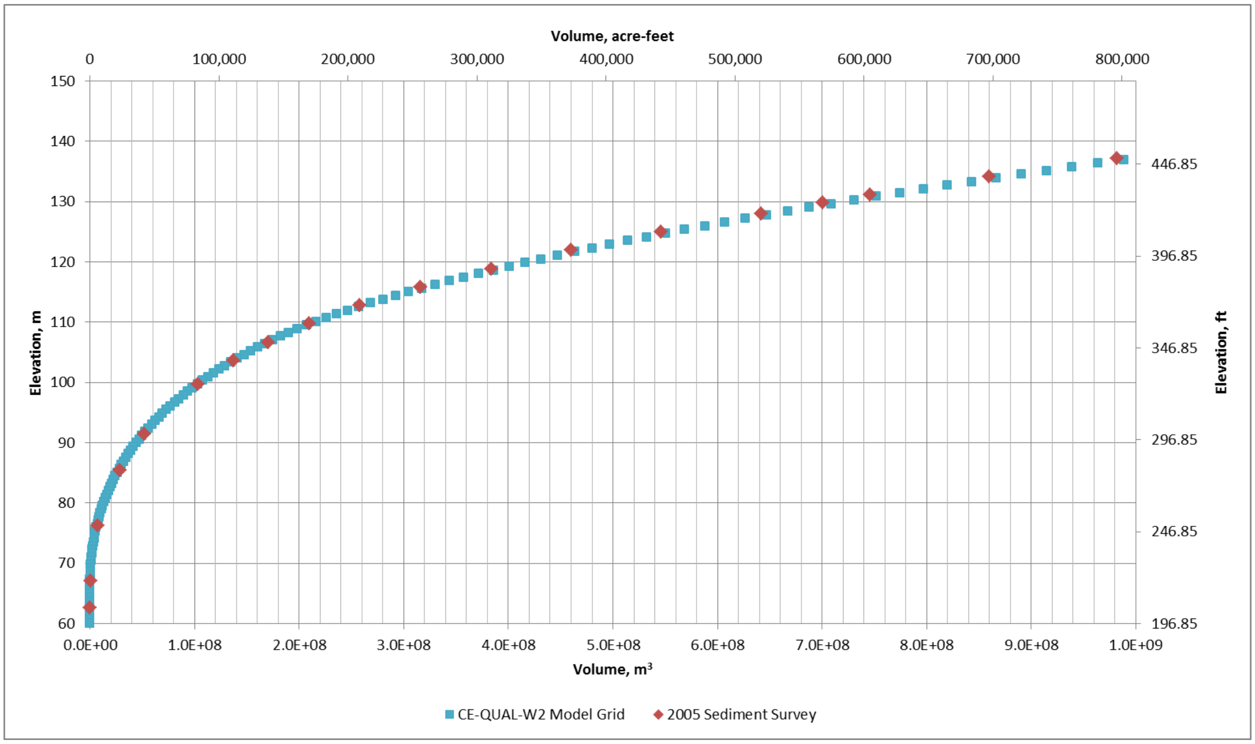



Figure 5-22. CE-QUAL-W2 model stage-volume curve versus the 2005 sediment survey (Ferrari 2007).

### *Folsom Dam Facilities*

Folsom Dam and the auxiliary spill gages have a total of twenty-six different controllable outlet structures (Figure 5-23, Table 5-28). These structures, their locations, size, and shape are described in Table 1AMER. The twenty-six outlet structures can be divided into four subsets: (1) municipal intake; (2) power generation penstock outlets; (3) river outlet gates; (4) spillway gates, and (5) auxiliary spillway gates. Water is also diverted by El Dorado Irrigation District (EID) from Folsom Lake upstream of the dam. The following sections discuss each outlet type in detail.


Figure 5-23. Folsom Dam and Auxiliary Spillway (top) and Folsom Dam (bottom).

Table 5-27. Description of Folsom Dam Outlets.

| Outlet Description | Shape | Dimension (ft) (d=diameter, w=width,) | Dimension (ft) (h=height) | Mono-lith | Horizontal Centerline Coordinates (m) X/Y | Centerline Elev (ft) | Invert Elev (ft) | Shuttered Configuration (ft) A = All Lowered | Shuttered Configuration U = Upper Raised | Shuttered Configuration M = Middle Raised | Shuttered Configuration L = Lower Raised |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Power Penstock #1 | Circle | d=15.5 | N/A | 8 | 660290/4285811 | 307 | 299.25 | 401.0 | 362.0 | 336.0 | 284.0 |
| Power Penstock #2 | Circle | d=15.5 | N/A | 9 | 660304/4285804 | 307 | 299.25 | 401.0 | 362.0 | 336.0 | 284.0 |
| Power Penstock #3 | Circle | d=15.5 | N/A | 10 | 660317/4285796 | 307 | 299.25 | 401.0 | 362.0 | 336.0 | 284.0 |
| Municipal | Circle | d=7.0 | N/A | 7 | 660264/4285826 | 317 | 313.5 | Max 401 ft - Min 331.5 ft | N/A | N/A | N/A |
| Rectangular River #1-4 (Upper) | Rectangle | w=5.0 | h=9.0 | 13-16 | 660358/4285771 | 280 | 275.5 | N/A | N/A | N/A | N/A |
| Rectangular River #1-4 (Lower) | Rectangle | w=5.0 | h=9.0 | 13-16 | 660358/4285771 | 210 | 205.5 | N/A | N/A | N/A | N/A |
| Spillway Gates 1-8 | Radial Gate | w=42.0 | h=50.0 | 12-20 | 660351/4285774 | N/A | 418.0 | N/A | N/A | N/A | N/A |
| Auxiliary Spillway Gages 1-6 | Radial Gate | w=23.75 | h=39.083 | N/A | 661002/4285420 | N/A | 367.02 | N/A | N/A | N/A | N/A |
| EID Pump | N/A | N/A | N/A | N/A | N/A | N/A | 320.0 | N/A | N/A | N/A | N/A |

**Municipal Intake** The Municipal Intake is a single, circular inlet built into the concrete structure of the dam on the north side of the power generation penstock intake structures. The TCD is installed in front of the intake. An aerial view of the structure is shown in Figure 5-24. The TCD can be raised or lowered to control the elevation of water withdrawal. Under normal conditions, the TCD is operated between 401 ft. (122.2 m) and 331.5 ft. (101 m); however, under extreme conditions, when the water level is lower, water can be withdrawn from intake pipe (centerline 317 ft.; 96.62 m). Figure 5-24 and Figure 5-25, include illustrations of the outlet structure and elevations. The water that enters the Municipal Intake is used to supply water to various communities (City of Folsom, Folsom Prison, the City of Roseville, Sacramento Suburban Water District and San Juan Water District). Please refer to Table 5-28 for a full description of the outlet characteristics.

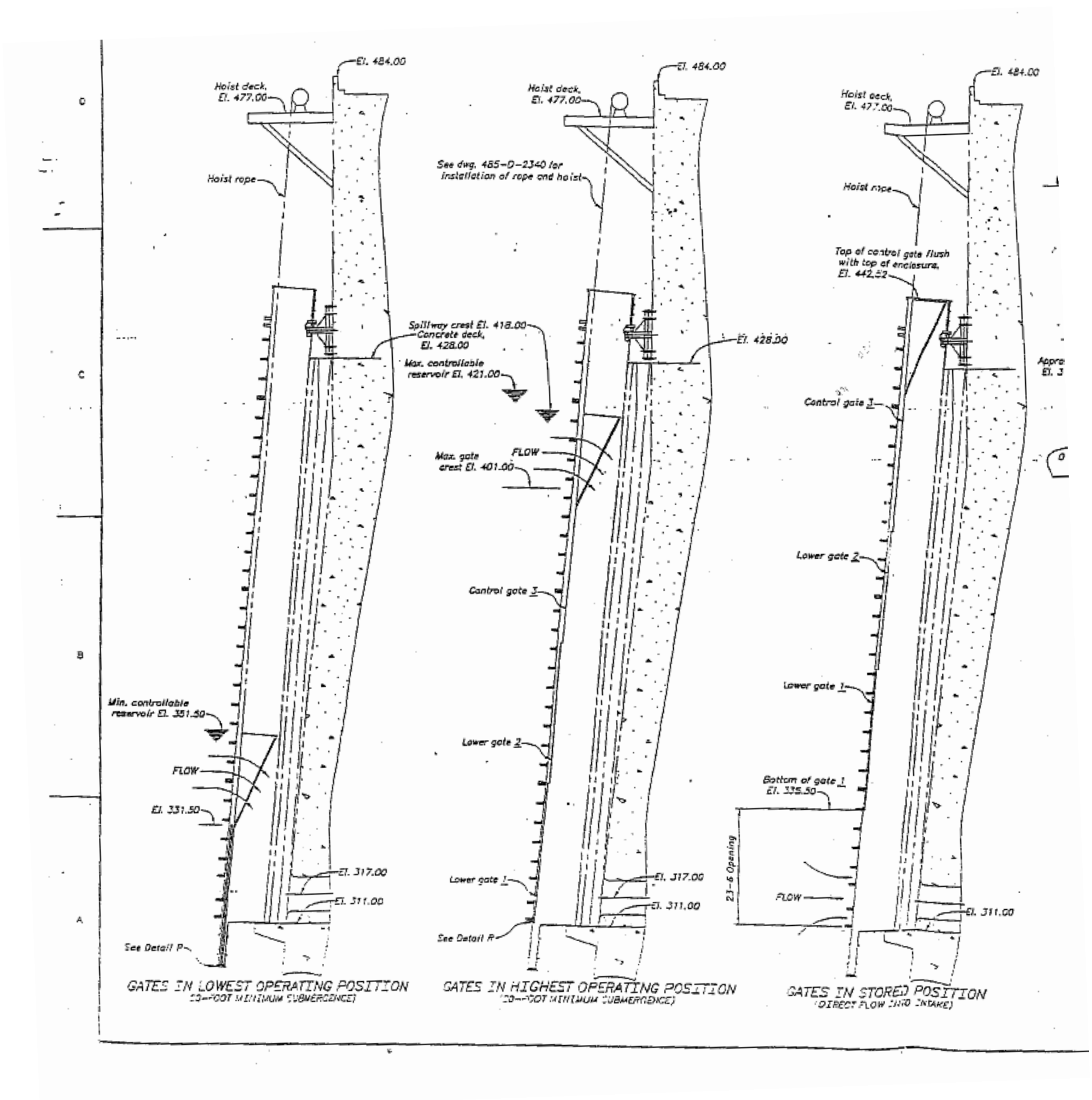



Figure 5-24. Municipal Water Supply Intake Illustration.

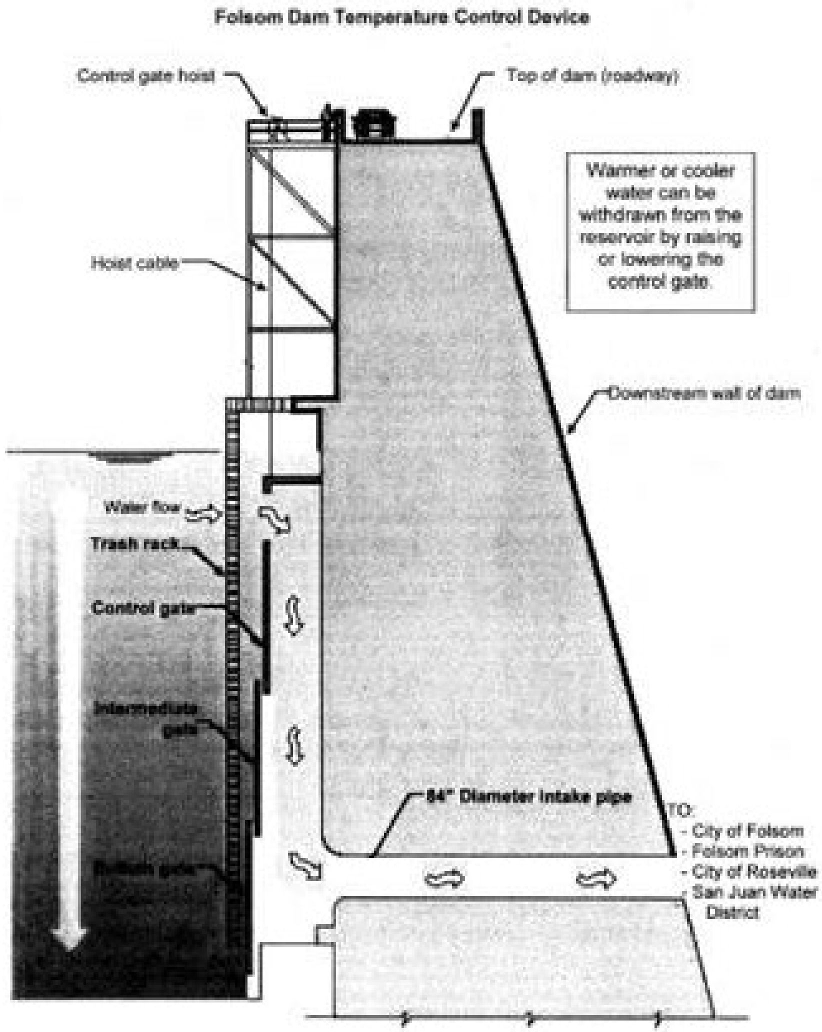



Figure 5-25. Folsom Dam side-view with Municipal Water Supply Intake Structure Illustration.

**Power Generation Penstock Outlets** There are three separate power penstock outlets incorporated into the structure of the dam. Figure 5-26 and Figure 5-27 show the power generation outlet structures, TCDs, and elevations. A separate TCD is installed in front of each of the power outlets. The TCDs can be raised (removed) or lowered (installed) to control the elevation of the withdrawal, but only with a relatively coarse step adjustment when the shutters are in their typical "ganged" configuration (top three, middle two, and bottom four 13-foot-tall shutter segments ganged together). During unique circumstances (drought conditions) the "ganged" shutter segments can be "de-ganged" to allow for individual 13 feet tall shutter adjustability, however, this is not easily accomplished. The amount of water entering each power penstock can be controlled individually and varies depending on the amount of water being released for power generation demand and the mix of temperature needed to meet downstream temperature requirements. Please refer to Table 5-28 for a full description of the outlet characteristics.

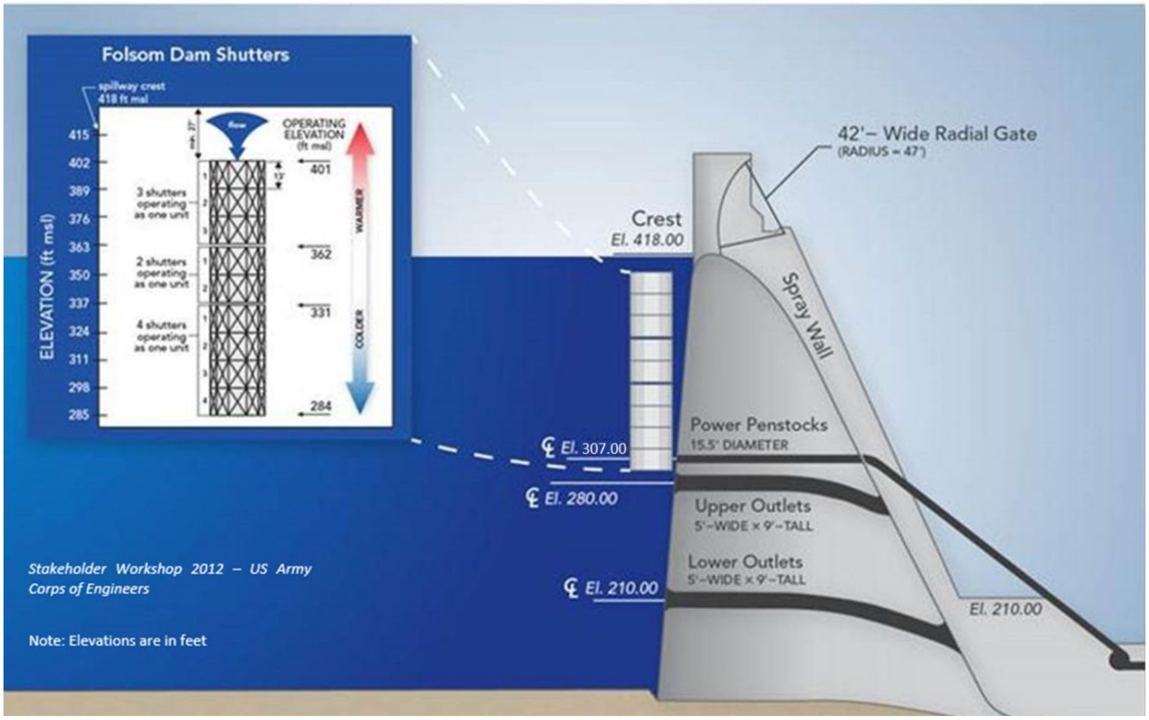



Figure 5-26. Side View Schematic of Folsom Dam Outlets and Shutters.

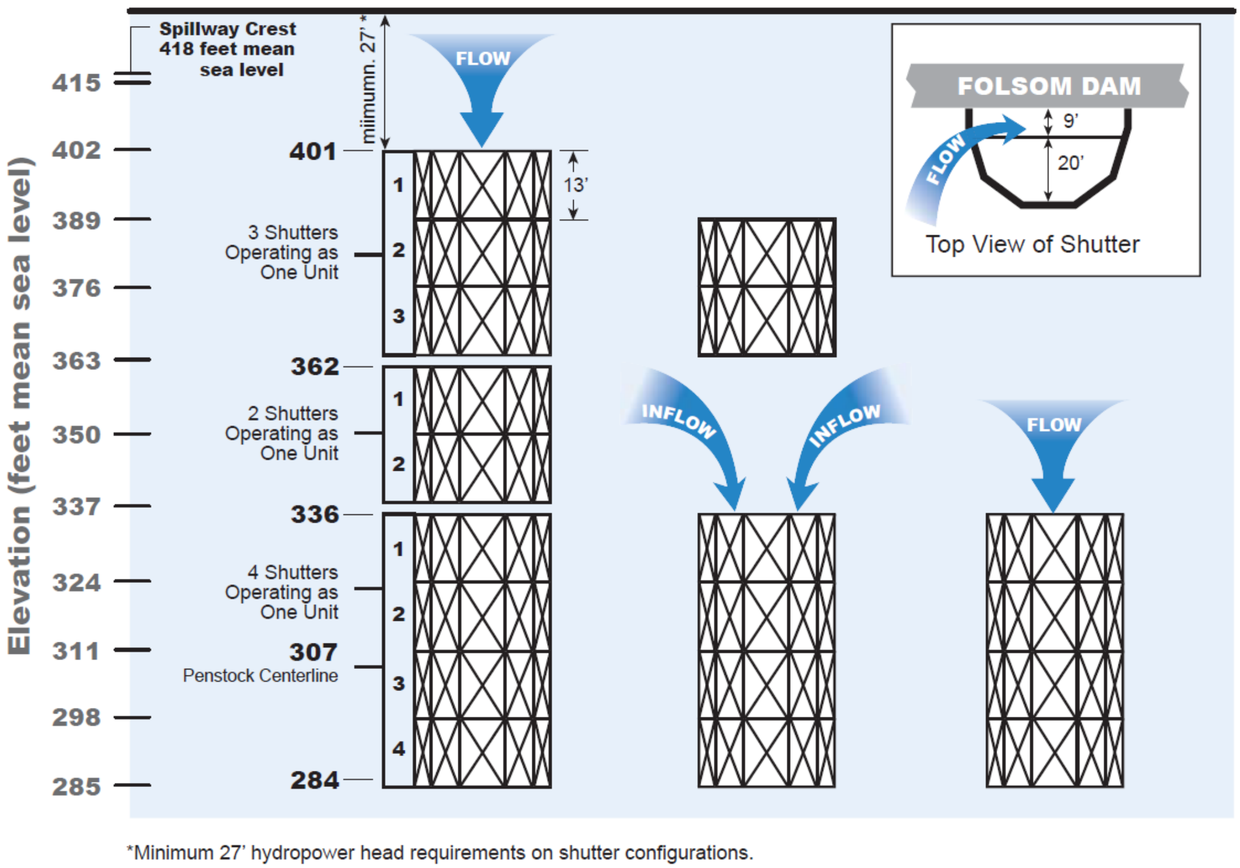



Figure 5-27. Powerhouse Shutter Schematic.

The TCD shutters on the penstocks do not fit together in a watertight manner and some leakage of water occurs through the shutters. The exact amount is unknown and potentially variable depending on shutter fit during installation and shutter configuration. The leakage is typically cold hypolimnion water, which can affect cold water management.

**River Outlet Gates** Eight rectangular river outlets are incorporated into the concrete structure of the dam (Table 5-28). These outlets are organized into two rows of four, with one set of four directly above the other set. The river outlets do not have TCDs. These outlets are used when water needs to be drawn down rapidly from the reservoir pool or the low-level outlets have been used under specific conditions in the fall to access cold water stored in the reservoir below the powerhouse intakes. There is also some leakage from these outlets. Water released from the river outlets is discharged into the river channel/spillway area on the downstream side of the dam and bypasses the powerhouses. Please refer to Table 5-28 for a full description of the outlet characteristics.

**Spillway Gates** Eight spillway gates are located along the top of Folsom Dam at an elevation of 418 feet (127.4 m) (Figure 5-23). Each spillway is controlled by a 42-foot (12.8 m) wide radial gate with a radius of 47 feet (14.3 m). These gates are used for flood control when the reservoir elevation exceeds 418 feet (127.4 m). All water released over the spillways is discharged into the river on the downstream side of the dam. Please refer to Table 5-28 for a full description of the outlet characteristics.

**Auxiliary Spill Gates** In 2017 a new auxiliary spillway was constructed adjacent to the existing main dam as shown in Figure 5-28. This new spillway includes 6 bulkhead and radial gates and a 3,100-foot-long spillway chute. Each gate is approximately 23.75 feet wide and 39.083 feet high, with invert elevations of 367.02 ft (NGVD29). Please refer to Table 5-28 for a full description of the outlet characteristics.

Figure 5-28. 2017 Folsom Auxiliary Spill Gates.

**EL Dorado Irrigation District (EID) Diversion in Folsom Lake** In addition to water diverted for municipal water supply at the dam, water is also diverted by EID at a location approximately 3.5 miles to the northeast of Folsom Dam. Historically, the fixed elevation intake structure has been set at an elevation of 320 feet (97.5 m). The structure is currently being modified to include variable elevation intakes.

## Hydrologic Data

Hydrologic data used for model implementation of a reservoir includes inflow, stage (or water surface elevation) and operations (or outflow) data. A summary of sources for flow data used in the Folsom Lake model is listed in Table 5-29 and discussed below in sections, Folsom Lake Inflows and Dam Operations and Folsom Lake Outflows.

Table 5-28. Folsom Lake hydrologic data sources, 2000-2021.

| Site Number/ Abbreviation | Agency | Site Active | Site Name | Data Types | Data Frequency | Application of Data |
|---|---|---|---|---|---|---|
| 11427000 | USGS | YES | North Fork American River at North Fork Dam CA | Q | Hourly | Branch Inflow |
| 11433300 | USGS | YES | Middle Fork American River near Foresthill CA | Q | Daily | Branch Inflow |
| 11444500/ CDEC-CBR | USGS/PG&E | YES | South Fork American River near Pilot Hill CA | Q | Daily | Branch Inflow |
| 11425416 | USGS | YES | Newcastle PP near Newcastle CA | Q | Daily | Tributary Inflow |
| 11433930 | USGS | YES | Mormon Ravine near Newcastle CA | Q | Daily | Tributary Inflow |
| EID | El Dorado Irrigation | YES | El Dorado Irrigation District Diversion | Q | Monthly/Daily | Folsom Diversion |
| FOL[1] | CDEC-Reclamation | YES | Folsom Dam | Elevation, storage, $Q_{ph}$[2], spill, $Q_{control}$[3] | Hourly[4] | Boundary Condition and Calibration |

[1] Data from this station are used in the model for calibration and selective withdrawal operations.

[2] Powerhouse flow ($Q_{ph}$) -- includes generation release data for each of 3 penstocks.

[3] $Q_{control}$ flows consist of releases through the 8 River Outlet Release gates.

[4] While elevation and storage data are available in CDEC web page, hourly $Q_{ph}$, Spill, and $Q_{control}$ data were supplied exclusively by Reclamation to Watercourse Engineering, Inc.

### *Folsom Lake Inflows*

Folsom Lake is fed by three main inflows: the North Fork American River (NFAR), the South Fork American River (SFAR), and Newcastle Powerhouse/South Canal (i.e., Yuba-Bear River water). In addition, some local accretion occurs in the watershed immediately surrounding the reservoir. NFAR inflow to Folsom Lake (2000 – 2021) was obtained by combining the United States Geological Survey (USGS) gage on the NFAR at North Fork Dam, CA (USGS gage no. 11427000) and the Middle Fork American River (MFAR) near Foresthill gage (USGS gage no. 11433300). This is only an estimate of NFAR inflow into Folsom. The gages are upstream of the confluence of the two rivers and some local accretion inflows occur downstream of the gages. SFAR inflow to Folsom Lake (2000 – 2021) was based on the USGS/CDEC gaging station near Placerville, CA (USGS gage no. 11444500/ CDEC station CBR). This gage does not account for local accretion inflows in between the gage site and Folsom Lake. Data (2000-2021) from the USGS Newcastle Power Plant near Newcastle, CA gage (USGS gage no. 11425416) and Mormon Ravine near Newcastle, CA gage

(USGS gage no. 11433930) were used to quantify the South Canal import water inflow to Folsom Lake from the Yuba-Bear / Drum-Spaulding projects.

### *Dam Operations and Folsom Lake Outflows*

Details of Folsom dam outflows and TCD operations for the Municipal Intake, middle/low level river outlets gates, spillway gates, power generation penstocks, and El Dorado Irrigation Diversion are provided below.

**Municipal Intake** The Municipal Intake hourly flows were obtained from USBR for the complete calibration period (2000-2021) (Table 5-29). The Municipal Intake reservoir withdrawal TCD elevation data were obtained from daily operation logs available from May 2004 through December 2021. The logs contained a daily recording of the Municipal Intake TCD gate elevation, measured intake temperature, and reservoir WSE. To estimate the elevation of the Municipal Intake TCD during 2000-2004, the general operation pattern observed in the 2004-2021 data were used. In 2004-2021, the Municipal Intake TCD was generally operated about 50 feet below the reservoir WSE (approximately the 65°F temperature withdrawal zone in the summer) or at the maximum or minimum TCD elevation when the preferred withdrawal zone was out of range of the Municipal Intake TCD.

**River Outlet Gates** Hourly middle and low-level river outlet flows were obtained from USBR for the complete calibration period (2000-2021) (Table 5-29).

**Spillways** Hourly spillway flows were obtained from USBR for the complete calibration period (2000-2021) for the original spillways (on Folsom Dam) and for the auxiliary spillways added in 2017 (Table 5-29).

**Power Generation Penstock and Shutter Elevations** Hourly flows for each power generation penstock were obtained for the years 2000 – 2021 from USBR. Daily TCD configuration records were available for the period of 2001-2021 (Table 5-29). No records of TCD elevations were available for 2000.

**El Dorado Irrigation District Diversion** Monthly EID diversion volumes (acre-feet per month) from Folsom Lake were available for 2000-2021. The data were obtained from EID. The monthly volumes were converted into cubic meters per second for modeling purposes. Additionally, daily diversion flows were available for 1/1/2016 through 12/31/2021 from EID. The higher resolution data were used when available.

## Temperature Data

Water Temperature data sources for Lake Folsom and vicinity are provided in Table 5-30 and discussed in sections Folsom Lake Inflow Temperatures, Folsom In-Lake Temperatures, and Folsom Dam Outflow Temperatures below.

Table 5-29. Folsom Lake water temperature data sources, 2000-2021.

| Site Number/ Abbreviation | Agency | Site Active | Site Name | Data Frequency | Application of Data |
|---|---|---|---|---|---|
| USGS 11433790 | USGS | YES | North Fork American River at Auburn Dam Site | Hourly | Branch Inflow |
| USGS 11446030 | USGS | YES | South Fork American River near Pilot Hill, CA | Hourly | Branch Inflow |
| Various | Various | No | Mormon Ravine/Newcastle PP | Daily | Tributary Inflow |
| TP1-6 | Reclamation | YES | Folsom Lake Profiles (6 Locations) | Biweekly (Varies) | Calibration |
| FOL-TW1 | Reclamation | YES | Folsom Powerhouse Penstock Unit #1 | Hourly | Calibration / Selective Withdrawal Operations |
| FOL-TW2 | Reclamation | YES | Folsom Powerhouse Penstock Unit #2 | Hourly | Calibration / Selective Withdrawal Operations |
| FOL-TW3 | Reclamation | YES | Folsom Powerhouse Penstock Unit #3 | Hourly | Calibration / Selective Withdrawal Operations |
| M&I Intake | Reclamation | YES | M&I Intake Temperature | Daily (Varies) | Calibration / Selective Withdrawal Operations |
| USGS 11446220 | USGS | YES | American R bl Folsom Dam near Folsom CA | 15-min | Calibration |

### *Folsom Lake Inflow Temperatures*

The historical water temperature data (2000 – 2021) for the NFAR were obtained from the USGS gaging station/California Data Exchange Center (CDEC) station on the NFAR at Auburn Dam Site near Auburn, CA (USGS gage no. 11433790/ CDEC station NFA) (Table 5-30). The temperature gage is very close to the inflow of the NFAR into Folsom Lake.

The historical water temperature data (2000 – 2021) for the SFAR were obtained from USGS gaging station on the SFAR near Pilot Hill, CA (11446030) (Table 5-30).

No single continuous water temperature data set was available for the period of calibration (2000-2021) for Newcastle Powerhouse/Mormon Ravine inflows. Instead, data from seven different sources from the South Canal spanning various time periods were compiled and combined into a single average monthly water temperature estimate for the Newcastle Powerhouse.

### *Folsom Lake In-Lake Temperatures*

A total of 185 in-reservoir temperature profiles were collected between January 1st, 2001, and December 31st, 2021, in roughly two to four week intervals. A map of the location of the temperature profile sites is shown in Figure 5-29, with additional site details summarized in Table 5-31.

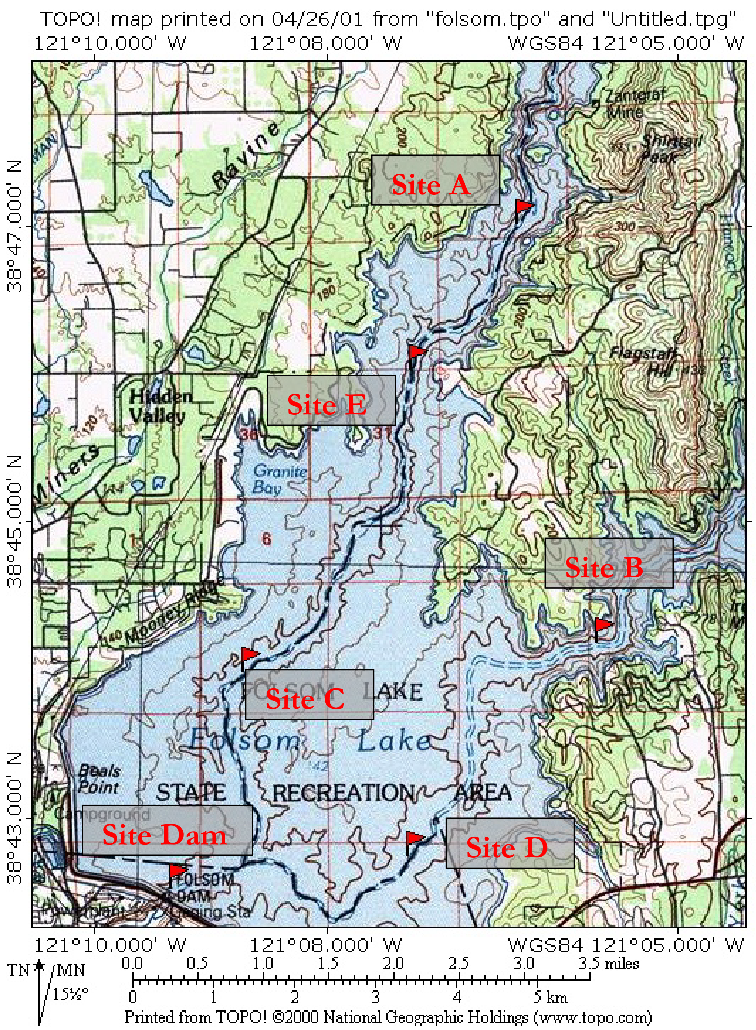



Figure 5-29. Locations of Folsom Lake Temperature Profile Stations.

Table 5-30. Folsom Lake Temperature Profile Locations.

| Site Name | Latitude | Longitude | Description |
|---|---|---|---|
| Site A | 38°47.01' N | 121°06.39' W | North Fork arm near Anderson Creek |
| Site B | 38°44.19' N | 121°05.63' W | Red Buoy in front of EID's intake, South Fork arm |
| Site C | 38°44.00' N | 121°08.69' W | North Fork arm off Mooney Ridge |
| Site D | 38°42.76' N | 121°07.31' W | South Fork arm off Mormon Island Dam |
| Site E | 38°46.02' N | 121°07.31' W | North Fork arm |

| Site Name | Latitude | Longitude | Description |
|---|---|---|---|
| Site Dam | 38°42.54' N | 121°09.32' W | White buoy in front of dam |

***Folsom Dam Outflow Temperatures***

USGS 11446220 American River below Folsom Dam near Folsom CA is the nearest location for historical water temperature data below Folsom Lake (Table 5-30). This station is located approximately half a mile downstream of Folsom Lake on the American River. Data from this location was used to compare the composite temperature of all outflows from Folsom Lake that enter the Lower American River.

Hourly water temperature data for each of the three Folsom Powerhouse penstocks is available from 2012 through 2021. These data were provided by USBR (Table 5-30).

Daily water temperature data were also recorded for the M&I intake. Data from this source are available from 2004 through 2021 (Table 5-30).

## Meteorology Data

The meteorology (MET) data required for Folsom Lake water temperature modeling included: air temperature; dew point temperature; wind speed and direction; cloud cover; and solar radiation. These data were obtained from three MET stations: CIMIS 131 - Fair Oaks; CDEC Station Folsom/Dyke 8; and Mather Air Force Base (Mather AFB) (Table 5-32). The locations of the stations are shown in Figure 5-30.

Table 5-31. Summary of Meteorological Stations Used to for Folsom Calibration Period.

| Site No. / Abbreviation | Agency | Active | Site Name | Data Types[1] | Data Frequency |
|---|---|---|---|---|---|
| CIMIS 131 | CIMIS | YES | Fair Oaks CA | Tair, Tdw, WS, Wdir, RH, SR | Hourly |
| FLD | CDEC | YES | Folsom/Dyke 8 | Tair, Tdw, WS, Wdir | Hourly |
| KMHR | NOAA | YES | Mather Air Force Base | CC | Hourly |

[1]Tair: Air temperature, Pr: Precipitation, Tdw: Dewpoint temperature, WS: Wind Speed, Wdir: Wind Direction, RH: Relative Humidity, SR: Solar Radiation, CC: Cloud Cover.

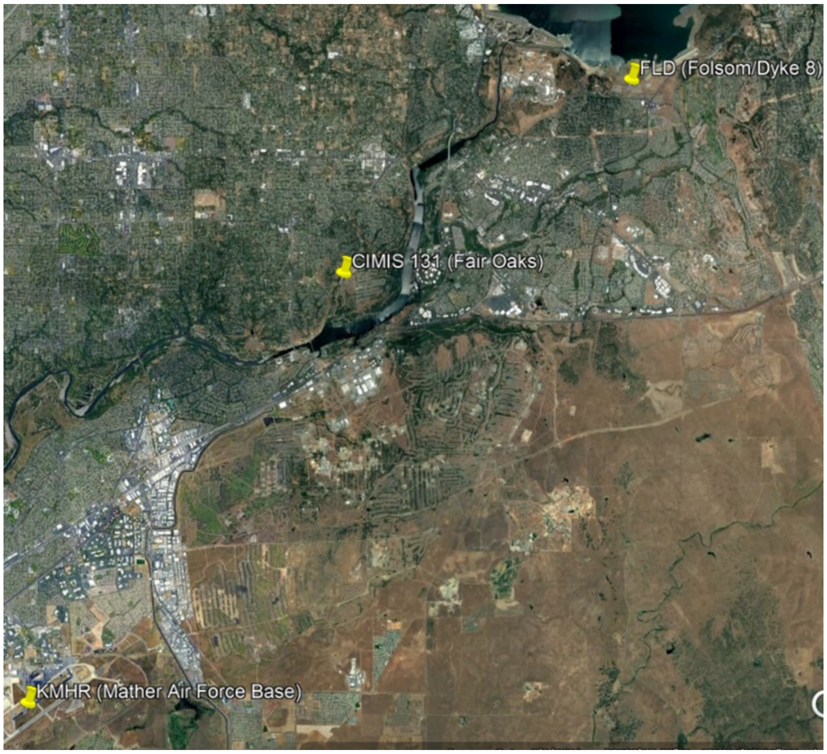



Figure 5-30. Meteorology station locations for American River models.

Air temperature, dew point temperature, and solar radiation data were used from the Fair Oaks weather station (Table 5-32). This was the most complete and reliable dataset for these three parameters in the vicinity of Folsom Lake. Wind speed and direction data were collected from Fair Oaks and Folsom/Dyke 8. The Fair Oaks MET station consistently reported a substantially lower wind speed than the other sites. This indicated that the wind gage for the station was in a sheltered location. For this reason, the Fair Oaks MET station wind data were only used to fill gaps in the Folsom/Dyke 8 wind data. A relationship between wind speed at the Fair Oaks MET station and Folsom/Dyke 8 was developed and applied to the Fair Oaks data when it was used. Cloud cover data were obtained from the Mather AFB MET station (Table 5-32).

# Data Development: Lake Natoma

The following sections describe the data development for the Lake Natoma hydrodynamic and temperature models. Geometry data development is discussed first, followed by hydrologic data development, water temperature data development, and last, meteorology data development. Information provided includes locations of data collection and temporal range of data.

## Geometry Data

Development of geometric data for Lake Natoma is discussed in the following sections. Bathymetry data is discussed first, followed by development of the stage-volume relationship for Lake Natoma. Last, a description of the Nimbus Dam outlet facilities is provided.

### *Bathymetry*

Topographic transect data for Lake Natoma were collected by CBEC, Inc.[1] A total of 34 transects were collected. The locations of the transects ranged from 1,700 feet downstream of Folsom Dam to within a few feet of Nimbus Dam. Figure 5-30 shows the location of each of the collected transects in dark blue superimposed on a DEM of the surrounding topography. Each of the 34 transects were made the center of a model grid segment for the Lake Natoma CE-QUAL-W2 model.

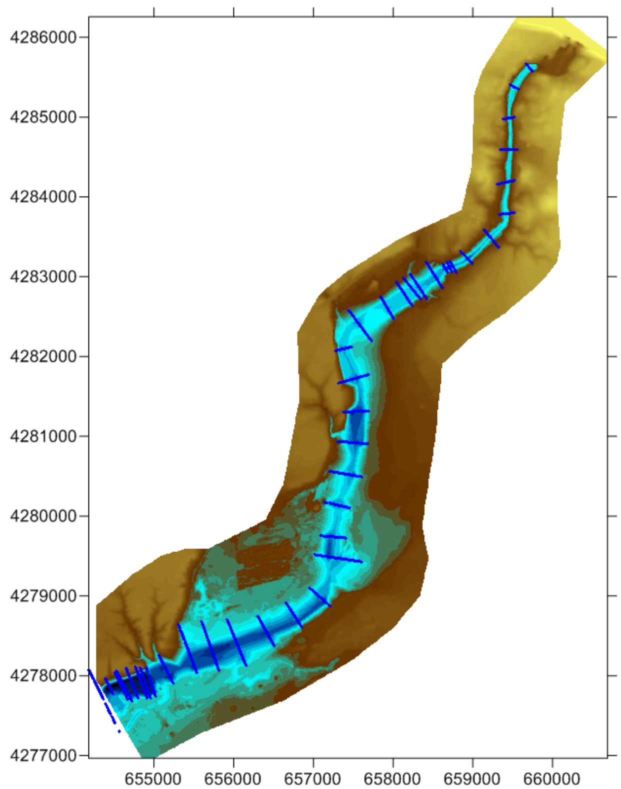



Figure 5-31. Lake Natoma bathymetry and transect data.

### *Stage-Volume Relationship*

The stage-volume curve of the updated CE-QUAL-W2 model grid was compared to the stage-volume curve derived from CDEC (reported stage and volume data). A plot of these curves is shown in Figure 5-31.

[1] Data provided by Chris Hammersmark (cbec, Inc.) to Craig Addley (Cardno)

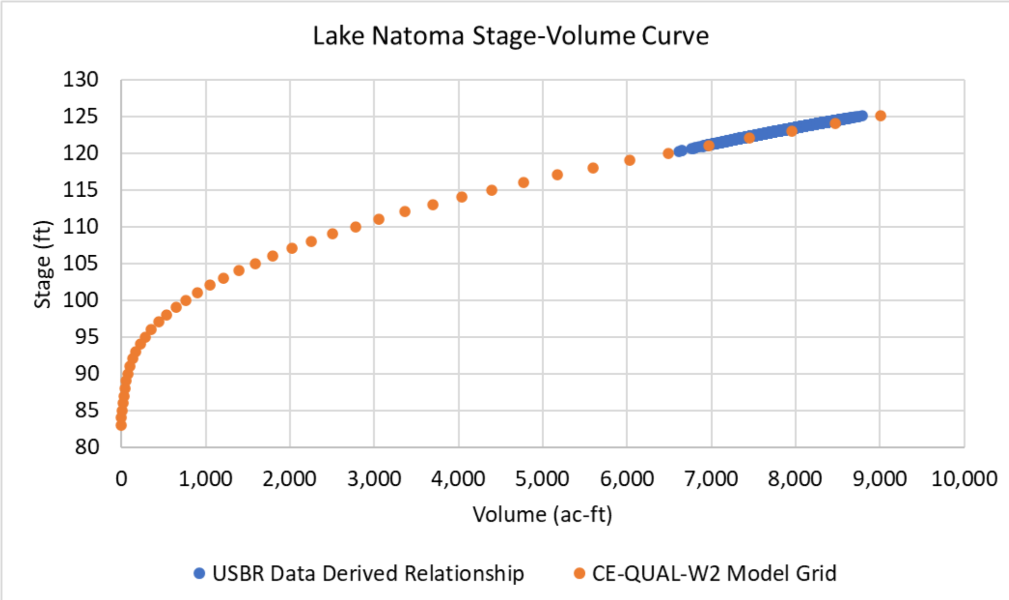



Figure 5-32. Stage-volume curves for Lake Natoma derived from Reclamation data and the updated CE-QUAL-W2 model grid.

### *Nimbus Dam Facilities*

Nimbus Dam is a concrete gravity dam that impounds Lake Natoma, which has a capacity of 8,760 AF at full pool elevation. A photo of the dam is provided in Figure 5-32. The dam is 87 ft. (26.8 m) high, with crest elevation of 132.0 ft (40.2 m). Flows are regulated by 18 radial spill gates, each 40-feet by 24-feet. Nimbus power plant has two generators, with the total capacity of 7,763 kilowatts each. Nimbus dam also provides fish hatchery flow. A summary of the Nimbus dam facilities is provided in Table 5-33.

Figure 5-33. View of Nimbus Dam from downstream side.

Table 5-32. Summary of Nimbus Dam Facilities.

| Structure Name | Structure Type | Elevation | Width/Diameter |
|---|---|---|---|
| Power Generation Intake (Powers 2 generators) | Weir | 107 ft. (32.61m) | 82 ft. (25 m) |

| Structure Name | Structure Type | Elevation | Width/Diameter |
|---|---|---|---|
| Spillways (18 gates) | Weir | 103.4 ft. (31.52m) | 656 ft. (200m) |
| Hatchery Withdrawal | Pipe | 109.5 ft. (33.38m) | 5 ft. (1.52m) |

## Hydrologic Data

Time series flow and elevation data for Lake Natoma are shown in Table 5-34. Outflow from Folsom Lake is controlled by Folsom Dam and is the primary source of inflow to Lake Natoma. Water is diverted from Lake Natoma at Folsom South Canal

Table 5-33. Sources of flow data used for Lake Natoma model, 2000-2021.

| Site Number/ Abbreviation | Agency | Site Active | Site Name | Data Types | Data Frequency | Application of Data |
|---|---|---|---|---|---|---|
| FOL | CDEC-Reclamation | YES | Folsom Dam | Qout[1] | Hourly | Headwater Boundary Condition |
| NAT | CDEC-Reclamation | YES | Nimbus Dam | Elevation, storage, spill Qph[3], Qhatchery | Hourly | Boundary Condition and Calibration |
| FSC | CDEC-Reclamation | YES | South Canal | Q | Hourly | Withdrawal |
| 11446500 | USGS | YES | American River at Fair Oaks | Q | Daily – Hourly[2] | Downstream Flow Check |

1 Qout consists of the total flow leaving a structure, as opposed to Q, which represents measured flow at a gage site.

2 Only daily average Q data are available in the related USGS web page. Hourly Q data were supplied exclusively by Reclamation to Watercourse Engineering, Inc.

3 Qph indicates flow from Lake Natoma to the powerhouse.

## Temperature Data

Water temperature data including time series at Lake Natoma inflow and outflow locations, as well as vertical profile data are shown in Table 5-35.

### *Lake Natoma Inflows*

The temperature of the water released from Folsom Lake into Lake Natoma is controlled by the Folsom Dam TCD and river outlet releases or spill flows during the high flow season. Sources of time series water temperature data for Lake Natoma are presented in Table 5-35.

Table 5-34. Lake Natoma water temperature data sources, 2000-2021.

| Site Number/ Abbreviation | Agency | Site Active | Site Name | Data Types | Data Frequency | Application of Data |
|---|---|---|---|---|---|---|
| 11446220 | USGS | YES | American River below Folsom Dam near Folsom CA | Tw | Hourly | Headwater Boundary Condition |
| 11446500 | USGS | YES | American River at Fair Oaks | Tw | Hourly | Calibration |
| Lake Natoma Temperature Profiles | Reclamation | NO | Lake Natoma Near Nimbus Dam | Tw | 354 Profiles (July-Oct 2001; Mar-Jun 2002; Mar-May 2003; Jul-Nov 2003) | Calibration |

***Water Temperature Vertical Profiles***

In contrast to Folsom Lake, historic measured temperature profiles in Lake Natoma for the model years were limited. Daily water temperature profiles from Lake Natoma near Nimbus Dam were collected for four periods during the calibration period: 7/18/2001 – 10/08/2001, 3/29/2002 - 6/19/2002, 3/28/2003 – 5/28/2003, and 7/10/2003-11/13/2003. These data profiles were obtained from a previous modeling effort by Reclamation (Bender et al. 2007). The details of the source of these data were not indicated in the Reclamation documentation.

### Meteorology Data

Due to the proximity of Folsom Lake to Lake Natoma, the same meteorology data set can be used for both models, with the exception of wind speed. Lake Natoma's more sheltered location corresponds better with the wind data collected from Fair Oaks (CIMIS #131), rather than Folsom/Dyke 8. Refer to the discussion of meteorology data development for Folsom Lake for a description of the types and sources of meteorology data used to construct the meteorology input file (e.g., Table 5-32).

## Data Development: Lower American River

The following sections describe the data development for the Lower American River below Nimbus Dam hydrodynamic and temperature models. Geometry data development is discussed first, followed by hydrologic data development, water temperature data development, and last, meteorology data development. Information provided includes locations of data collection and temporal range of data.

## Geometry Data

Development of geometric data for the Lower American River is discussed in the following sections.

### *Bathymetry*

Topographic data for the Lower American River discussed in detail in cbec, Inc (2019).[2] The data are based on October 2017 topo-bathymetric LiDAR (often called "Green LiDAR" that can penetrate water to varying depths) and 2017 single-beam sonar and RTK-GPS survey points collected in December 2017 through February 2018 to augment deeper bathymetry not collected by the Green LiDAR. An example image of the bathymetry is shown in Figure 5-33

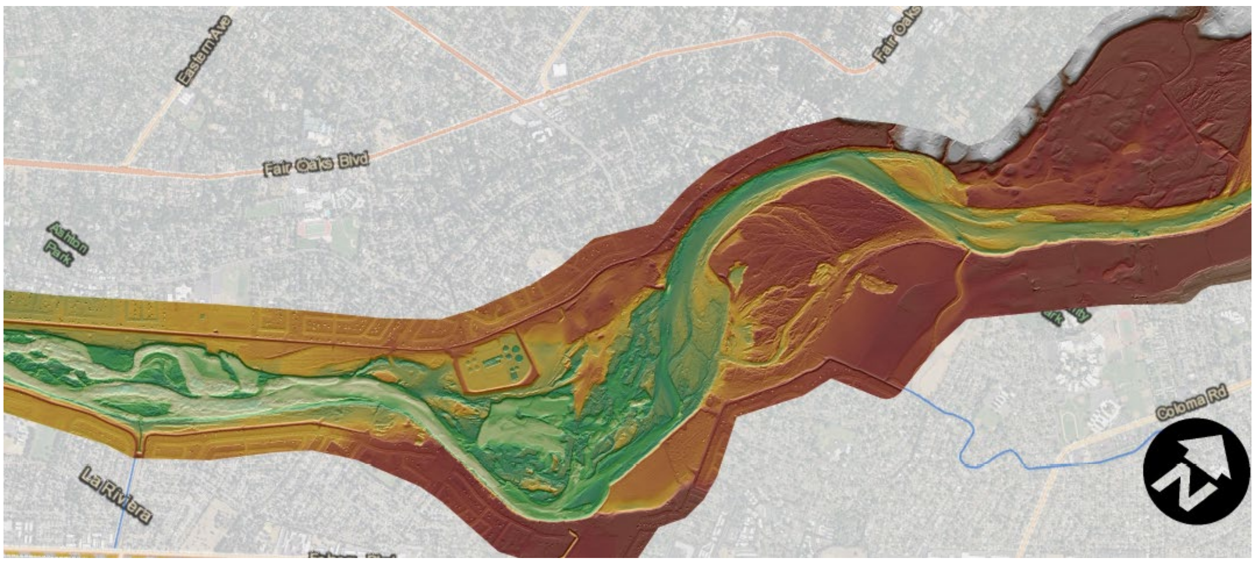



Figure 5-34. Example Lower American River Topography from cbec, Inc (2019).

River linework showing the approximate center of the river (thalweg) and river miles from the confluence with the Sacramento River were developed by Cardno GIS staff. An example of these data is shown in Figure 5-34.

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[2] Data provided by Chris Hammersmark (cbec, Inc.) to Craig Addley (Cardno)


Figure 5-35. Example of River Linework on the Lower American River.

## Hydrologic Data

Time series flow and stage data sources for the Lower American River are shown in Table 5-35. Outflow from Lake Natoma is controlled by Nimbus Dam and is the primary source of inflow to the Lower American River. Two water diversions exist along the length of the river – Carmichael Water District Bajamont Diversion, and City Sacramento E. A. Fairbairn Diversion.

Table 5-35. Sources of flow data used for Lower American River model, 2000-2021.

| Site Number/ Abbreviation | Agency | Site Active | Site Name | Data Types | Data Frequency | Application of Data |
|---|---|---|---|---|---|---|
| 11446500 | USGS | YES | American River at Fair Oaks | Q | Daily – Hourly[2] | Headwater Boundary Condition |
| HST | CDEC | YES | American River a H Street Bridge | Stage | Hourly | Calibration |
| Bajamont | Carmichael Water District | YES | Carmichael Water District Bajamont Diversion | Q | Daily | Diversion |
| Fairbairn | City of Sacramento | YES | City Sacramento E. A. Fairbairn Diversion | Q | Daily | Diversion |

## Temperature Data

The primary sources of long-term time series water temperature data for the Lower American River are presented in Table 5-36.

Table 5-36. Lake Natoma water temperature data sources, 2000-2021.

| Site Number/ Abbreviation | Agency | Site Active | Site Name | Data Types | Data Frequency | Application of Data |
|---|---|---|---|---|---|---|
| 11446220 | USGS | YES | American River below Folsom Dam near Folsom CA | Tw | Hourly | Headwater Boundary Condition |
| 11446700 | USGS | YES | American River at William B Pond Park at Carmichael, CA | Tw | Hourly | Calibration |
| 11446980 | USGS | YES | American River below Watt Avenue Bridge near Carmichael, CA | Tw | Hourly | Calibration |

## Meteorology Data

Due to the proximity of Lower American River to Lake Natoma, the same meteorology data set is used for both models (Table 5-32). Refer to the discussion of meteorology data development for Lake Natoma for a description of the types and sources of meteorology.

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# Chapter 6 Summary

Developing and applying the models for the WTMP requires acquiring and organizing a considerable amount of information and data. This document defines geometric hydrology, water temperature, and meteorology data needs for the Sacramento River, Trinity River, and American River systems. These data are currently being developed for the Stanislaus River system. Geometric data for the reservoirs (bathymetry, stage-volume table, facilities descriptions, and similar data) are generally well defined, available, or can readily be developed. Geometric data for stream reaches is largely sufficient. There are areas where additional information would be useful (e.g., deeper portions of the Sacramento River downstream of Clear Creek); however, there are sufficient data to proceed with model development, calibration/validation, and application.

The time series hydrology, water temperature, and meteorology data focus on the 2000-2021 period. Available data are summarized by location in Table 6-1. For each location, the number of data stations for each parameter are listed as well as how many of those stations data sets have large gaps in data. Information provided for each of those data sets with large gaps includes a brief description of the data gap and how it was filled, as well as the relative importance of that data set to the model. In all, 263 data sets are used for the Sacramento and Trinity River basin models. Of those data sets, 25 have gaps of sufficient duration that required additional efforts to fill.

Hydrology data are widely available throughout the project areas. Exceptions include Squaw Creek flows into Shasta Lake and Clear Creek flows into Whiskeytown Lake, which were developed based on relationships with other nearby streams. There are regions with limited tributary flow data (temporally and spatially) in the Trinity Basin, and efforts to relate gaged tributaries to ungagged tributaries are underway.

Water temperature data are also widely available throughout the project areas. Squaw Creek flows into Shasta Lake were based on Sacramento River water temperatures as a proxy, and Clear Creek flows into Whiskeytown Lake were developed based off an equilibrium temperature calculation considering historic water temperatures in the creek. Data gaps in Sacramento River tributary temperatures (mostly seasonally limited data) were likewise filled with an equilibrium temperature calculation considering historic water temperatures in the creeks. There are regions with limited tributary temperature data (temporally and spatially) in the Trinity Basin, and efforts to relate monitored tributaries to unmonitored tributaries are underway. Hourly temperatures of North Fork and South Fork American River inflows into Folsom Lake were estimated using a regression analysis of daily temperatures.

Comprehensive meteorological data sets (solar radiation, cloud cover, air temperature, dew point or wet bulb temperature, relative humidity, atmospheric pressure, wind speed, and wind direction) are developed for each basin. The Sacramento River (Shasta Lake, Keswick Reservoir and Sacramento River) and Clear Creek (Whiskeytown Lake and Clear Creek) basins utilize Redding Airport meteorological data (RAWS), the Trinity River system (Trinity Lake, Lewiston Lake, and Trinity River) utilize Trinity Camp meteorological data (RAWS), and the American River system (Folsom Lake, Lake Natoma, and the American River) utilize the Fair Oaks gage (CIMIS). Each of these records relies on other stations or calculations to fill data gaps to arrive at a final, model ready data set; however, the bulk of the data at each station originates from the long-term record available at each station.

A data management system (DMS) was developed to provide a data base, a process for data retrieval, data review and quality assurance/quality control (QA/QC), and providing data to the WTMP in model-ready format. In addition, the DMS develops and stores metadata and documentation for all data sources. All data includes a level of uncertainty due to monitoring equipment, location, method of collection, level of QA/QC, and other factors. Phase II of the project will assess potential sources of uncertainty and methods to incorporate and assess uncertainty into model simulations and assessments.

Table 6-1. Available data for Sacramento and Trinity River basin models, 2000 – 2021.

| Location | Station ( no.) | Parameter | Tw Profiles (no.) | Filled Stations (no.) | Filled Stations | Importance | Data Gap Description | Gap Filling Method |
|---|---|---|---|---|---|---|---|---|
| Shasta Lake | 31 | Hourly Flow | n/a | 0 | n/a | n/a | n/a | n/a |
| Shasta Lake | 7 | Daily Flow | n/a | 1 | 1. Daily Squaw Creek Flow | Low | 1. No Data | 1. Linear regression with USGS 11342000 (SACRAMENTO RA DELTA CA) |
| Shasta Lake | 1 | Stage | n/a | 0 | n/a | n/a | n/a | n/a |
| Shasta Lake | 1 | Volume | n/a | 0 | n/a | n/a | n/a | n/a |
| Shasta Lake | 12 | Temp | 2 | 1 | 1. Hourly Squaw Creek Temp | Low | 1. No Data | 1. Use the same temp as USGS 11342000 (SACRAMENTO RA DELTA CA) |
| Keswick Lake | 13 | Hourly Flow | n/a | 0 | n/a | n/a | n/a | n/a |
| Keswick Lake | 2 | Daily Flow | n/a | 0 | n/a | n/a | n/a | n/a |
| Keswick Lake | 1 | Stage | n/a | 0 | n/a | n/a | n/a | n/a |
| Keswick Lake | 1 | Volume | n/a | 0 | n/a | n/a | n/a | n/a |
| Keswick Lake | 3 | Temp | 1 | 0 | n/a | n/a | n/a | n/a |
| Whiskeytown Lake | 10 | Hourly Flow | n/a | 0 | n/a | n/a | n/a | n/a |
| Whiskeytown Lake | 1 | Daily Flow | n/a | 1 | 1. Daily Clear Creek Flow | Medium | 1. No Data | 1.Linear regression with USGS 11342000 (SACRAMENTO RA DELTA CA) and USGS 11376000 (COTTONWOOD C NR COTTONWOOD CA) |
| Whiskeytown Lake | 1 | Stage | n/a | 0 | n/a | n/a | n/a | n/a |
| Whiskeytown Lake | 1 | Volume | n/a | 0 | n/a | n/a | n/a | n/a |
| Whiskeytown Lake | 10 | Temp | 7 | 2 | 1. Hourly Carr PH Release Temp<br>2. Hourly Clear Creek Inflow Temp | 1. High<br>2. Medium | 1. Multiple data gaps; typically greater than a year<br>2. No data | 1. Linear regression with Clear Creek Tunnel intake temp and flow rate at Carr PH<br>2. Equilibrium Temperature Model |
| Sacramento River | 8 | Hourly Flow | n/a | 0 | n/a | n/a | n/a | n/a |

**Chapter 6 Summary**

| Location | Station ( no.) | Parameter | Tw Profiles (no.) | Filled Stations (no.) | Filled Stations | Importance | Data Gap Description | Gap Filling Method |
|---|---|---|---|---|---|---|---|---|
| Sacramento River | 4 | Daily Flow | n/a | 0 | n/a | n/a | n/a | n/a |
| Sacramento River | 9 | Temp | 0 | 4 | 1. Hourly Temp at Clear Creek (RM 288)<br>2. Hourly Temp at Cow Creek (RM 277)<br>3. Hourly Temp at Cottonwood Creek (RM 272)<br>4. Hourly Temp at Battle Creek (RM 270) | 1. Medium<br>2. Medium<br>3. Medium<br>4. Medium | 1.Multiple data gaps; typically less than a year<br>2. Multiple data gaps; typically less than a year<br>3.Multiple data gaps; typically less than a year<br>4. Multiple data gaps; typically less than a year | 1. Equilibrium Temperature Model |
| Trinity Lake | 1 | 15-min Flow | n/a | 0 | n/a | n/a | n/a | n/a |
| Trinity Lake | 6 | Hourly Flow | n/a | 0 | n/a | n/a | n/a | n/a |
| Trinity Lake | 1 | Daily Flow | n/a | 0 | n/a | n/a | n/a | n/a |
| Trinity Lake | 1 | Inch | n/a | 0 | n/a | n/a | n/a | n/a |
| Trinity Lake | 1 | Stage | n/a | 0 | n/a | n/a | n/a | n/a |
| Trinity Lake | 1 | Volume | n/a | 0 | n/a | n/a | n/a | n/a |
| Trinity Lake | 5 | Temp | 1 | 3 | 1. Hourly/Daily Temp at Trinity River<br>2. Hourly/Daily Temp at Principal Tributaries<br>3. Trinity Lake Dam Release | 1. High<br>2. High<br>3. High | 1.Multiple data gaps; typically less than a year<br>2. Multiple data gaps; typically less than a year<br>3.Multiple data gaps; typically less than a year | 1. in Progress<br>2. in Progress<br>3. Fill with W2 model |
| Lewiston Lake | 8 | Hourly Flow | n/a | 0 | n/a | n/a | n/a | n/a |
| Lewiston Lake | 2 | Daily Flow | n/a | 0 | n/a | n/a | n/a | n/a |
| Lewiston Lake | 1 | Stage | n/a | 0 | n/a | n/a | n/a | n/a |
| Lewiston Lake | 1 | Volume | n/a | 0 | n/a | n/a | n/a | n/a |
| Lewiston Lake | 7 | Temp | 4 | 0 | n/a | n/a | n/a | n/a |

| Location | Station ( no.) | Parameter | Tw Profiles (no.) | Filled Stations (no.) | Filled Stations | Importance | Data Gap Description | Gap Filling Method |
|---|---|---|---|---|---|---|---|---|
| Trinity River | 8 | Hourly Flow | n/a | 3 | 1. Hourly/Daily Temp Weaver Creek<br>2. Hourly/Daily Temp Browns Creek<br>3. Hourly/Daily Temp Canyon Creek | 1. Medium<br>2. Medium<br>3. Medium | 1. Typically greater than a year<br>2. Typically greater than a year<br>3. Typically greater than a year | 1. Flow Balance<br>2. Flow Balance<br>3. Flow Balance |
| Trinity River | 4 | Daily Flow | n/a | 0 | n/a | n/a | n/a | n/a |
| Trinity River | 4 | Stage | n/a | 0 | n/a | n/a | n/a | n/a |
| Trinity River | 5 | Temp | 0 | 3 | 1. Daily Flow Weaver Creek<br>2. Daily Flow Browns Creek<br>3. Daily Flow Canyon Creek | 1. Medium<br>2. Medium<br>3. Medium | 1. Typically greater than a year<br>2. Typically greater than a year<br>3. Typically greater than a year | 1. in Progress<br>2. in Progress<br>3. in Progress |
| Folsom Lake | 2 | 15min Flow | n/a | 0 | n/a | n/a | n/a | n/a |
| Folsom Lake | 30 | Hourly Flow | n/a | 0 | n/a | n/a | n/a | n/a |
| Folsom Lake | 5 | Daily Flow | n/a | 1 | 1. USGS 11433930 Mormon Ravine | Low | 1. Numerous gaps, very small flow rates | 1. Last good value |
| Folsom Lake | 3 | Stage | n/a | 2 | 1. M&I Gate Elevation<br>2. Powerhouse Shutter Positions | High | 1. No data 2000-2004. Larger periods of erroneous data in later record.<br>2. No data for year 2000 | 1. Comparison to previous operations, known WSE, available temperature profiles.<br>2. Estimated using observed changes in water temperature, water surface elevation |
| Folsom Lake | 1 | Volume | n/a | 0 | n/a | n/a | n/a | n/a |
| Folsom Lake | 15 | Temp | n/a | 3 | 1. USGS 11433790 - North Fork American River at Auburn Dam<br>2. USGS 11446030 - South Fork American River near Pilot Hill<br>3. Mormon Ravine/Newcastle Powerhouse (no USGS #) | High | 1. Multiple Data Gaps, one 2-year period;<br>2. Multiple data gaps<br>3. No data available for most years | 1. Daily temperature regression for shorter periods, 2-year gap filled with daily USGS data;<br>2. Daily temperature regression;<br>3. Monthly average of available data. |
| Lake Natoma | 23 | Hourly Flow | n/a | 0 | n/a | n/a | n/a | n/a |
| Lake Natoma | 1 | Stage | n/a | 0 | n/a | n/a | n/a | n/a |
| Lake Natoma | 1 | Volume | n/a | 0 | n/a | n/a | n/a | n/a |
| Lake Natoma | 2 | Temp | n/a | 0 | n/a | n/a | n/a | n/a |

## Chapter 6 Summary

| Location | Station ( no.) | Parameter | Tw Profiles (no.) | Filled Stations (no.) | Filled Stations | Importance | Data Gap Description | Gap Filling Method |
|---|---|---|---|---|---|---|---|---|
| American River | 3 | Flow | n/a | 0 | n/a | n/a | n/a | n/a |
| American River | 2 | Stage | n/a | 0 | n/a | n/a | n/a | n/a |
| American River | 3 | Temp | n/a | 1 | 1. USGS 11446220 - American River below Folsom Dam | High | 1. Multiple gaps of several months at a time | 1. Final calibration result from Folsom CE-QUAL-W2 model. |

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Personal Communications:

Currey, J. Anderson-Cottonwood Irrigation District

Field, Randi, U.S. Bureau of Reclamation

Patton, Tom, U.S. Bureau of Reclamation

# Appendix A: Sacramento River Tributary Temperatures

N
W Watercourse Engineering Inc.
S

# Technical Memorandum

Date: May 16, 2022

To: Randi Field, U.S. Bureau of Reclamation
Donna Garcia, U.S. Bureau of Reclamation

From: Michael Deas, Watercourse Engineering, Inc.

Re: Sacramento River Tributary Temperatures

## Purpose

Tributary flows and water temperature contributions to the Sacramento River form important boundary conditions for the HEC ResSim model in the WTMP. Tributary flows are typically small compared to mainstem flows, particularly in summer and fall. However, during winter and spring, storm events can yield high tributary inflows when Shasta (and Keswick) Dam releases are low. Reclamation occasionally experiences temperature management concerns in spring when tributary inflows are relatively high in relation to Keswick Dam releases when atmospheric conditions can lead to elevated temperatures in tributary contributions (Reclamation 2017). These conditions are infrequent and typically short-lived (e.g., several days to a week), but may require that Reclamation modify operations to offset tributary inflow temperatures.

Key tributaries (and river mile (RM) where these tributaries enter the Sacramento River) include Clear Creek (RM 288), Cow Creek (RM 277), Cottonwood Creek (RM 272), and Battle Creek (RM 270). For all tributary contributions daily flows and hourly water temperatures are used in the WTMP. Flow data are complete for these tributaries. Sub-daily water temperatures are available, in part, for these tributaries. Outlined herein are available data and sources, and the approach to filling water temperature data at an hourly time step.

## Available Data

Flow data for the tributaries is available at several U.S. Geological Survey (USGS) gages (Table A-1).

**Table A-1. USGS flow stations for Sacramento River Tributaries at Clear Creek, Cow Creek, Cottonwood Creek, and Battle Creek.**

| Name | Station # | River Mile | Owner |
|---|---|---|---|
| Clear Creek nr Igo, CA | 11372000 | 10.9 | USGS |
| Cow Creek nr Millville, CA | 11374000 | 3.0 | USGS |
| Cottonwood C nr Cottonwood, CA | 11376000 | 2.7 | USGS |
| Battle Creek bl Coleman Fish Hatchery nr Cottonwood, CA | 11376550 | 5.6 | USGS |

Water temperature data were available from the California Department of Fish and Wildlife (CDFW). These data were collected largely to monitor fish trapping/counting facilities in the tributaries. Early in the modeling period (2000-2021), temperature data were collected seasonally, or not at all in certain tributaries. Further, the location of monitoring changed through time in response to CDFW monitoring location and local program needs; however, review of available observations suggest that these changes did not materially impact water temperatures.

**Table A-2. CDFW temperature monitoring locations for Sacramento River Tributaries at Clear Creek, Cow Creek, Cottonwood Creek, and Battle Creek.**

| Name | Station #/River Mile | Owner |
|---|---|---|
| Clear Creek | RM 0.5 | CDFW |
| Clear Creek | RM 0.1 | CDFW |
| Cow Creek | RM 3.8 | CDFW |
| Cow Creek | RM 1.0 | CDFW |
| Cottonwood Creek | RM 0.6 | CDFW |
| Battle Creek | BC 5.1 | CDFW |
| Battle Creek | BC0.1 | CDFW |
| Battle Creek | BC0.2 | CDFW |

All flows and temperatures are applied as boundary conditions at the confluence of the tributary and Sacramento River without modification (e.g., flow gains and losses between the gage and the river are assume negligible, as are changes in water temperature).

## Data Processing and Analysis

Missing water temperatures for Sacramento River tributaries was filled using two methods:

- Short gaps (up to a few hours) were filled by simple linear interpolations.
- Long gaps (up to several years for certain tributaries) were filled using an equilibrium temperature approach

The equilibrium temperature approach used hourly meteorological data, and daily flow and stage data are used to produce hourly water temperature data (NFWF 2013). The approach assumes that water temperatures are in equilibrium with meteorological conditions: a reasonable assumption given the long distance from headwaters to the Sacramento River for each of the tributaries in question (e.g., these tributaries did not illustrate a snowmelt signature). Meteorological data from Redding Airport (station RRAC1, elevation 505 ft) were used.

Stage-discharge were developed from USGS data at each gaging location listed in Table A-1 and are shown in Figure A-1. A stage-discharge curve developed in 2004 was available for Clear Creek (Pers comm S Pittman, March 22, 2022). The station was approximately 2 miles upstream from the Sacramento River. Flows from the USGS gage at IGO were used to determine stage.

Available measured temperature was used to calibrate the equilibrium calculation prior to gap filling. Parameters modified in the calculation included evaporative heat flux coefficients in the heat budget and a depth factor associated with the rating curve proxy. Examples of calculated equilibrium temperature versus measured temperatures for Clear Creek and Cow Creek are shown in Figure A-2.

Final water temperature data sets for each tributary are shown for Clear Creek, Cow Creek, Cottonwood Creek, and Battle Creek in Figure A-3 through Figure A-6, respectively. Measured data were used when available, with equilibrium temperature used to fill in gaps (exceptions include gaps of short duration (a few hours)).

## Recommendations

These boundary conditions estimates will be reviewed during model calibration. If assumptions on gains/losses in flow and changes in water temperature between the monitoring location and the Sacramento River are of concern, additional water temperature monitoring is recommended to quantify potential differences in conditions between the monitoring location and the Sacramento River.

## References

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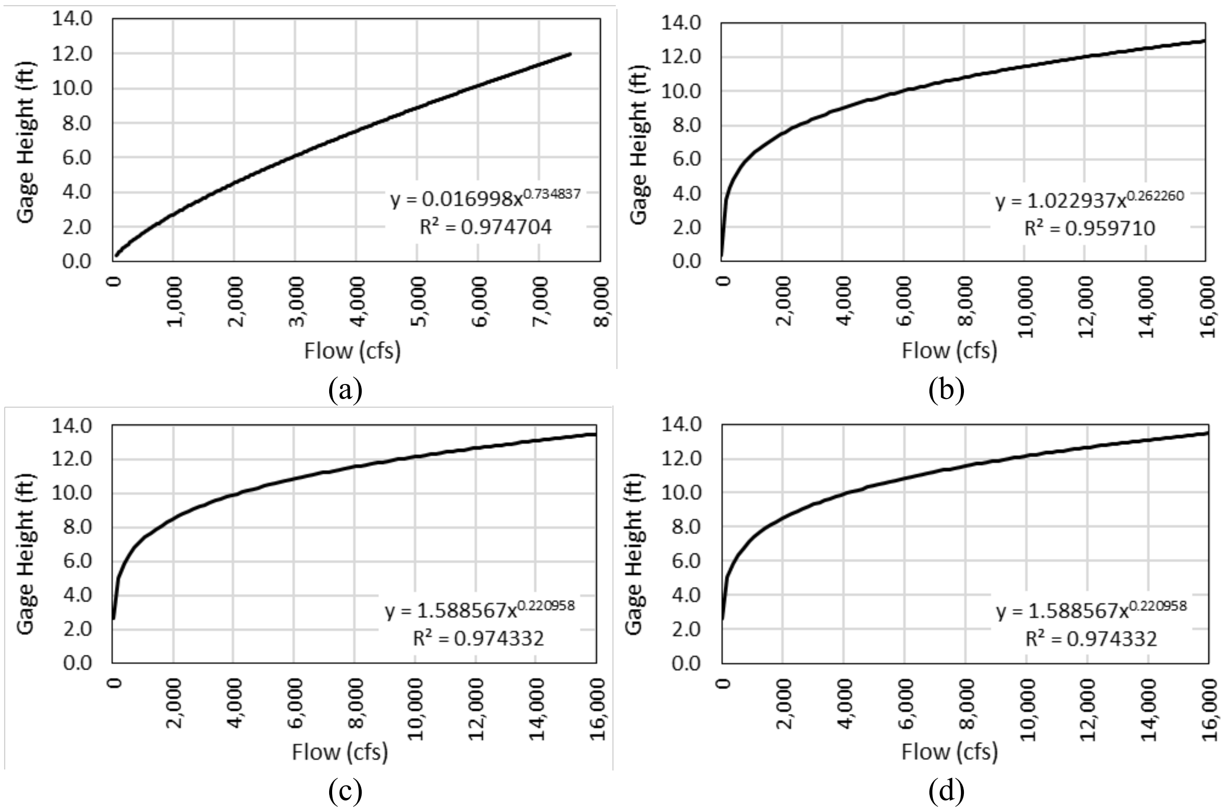
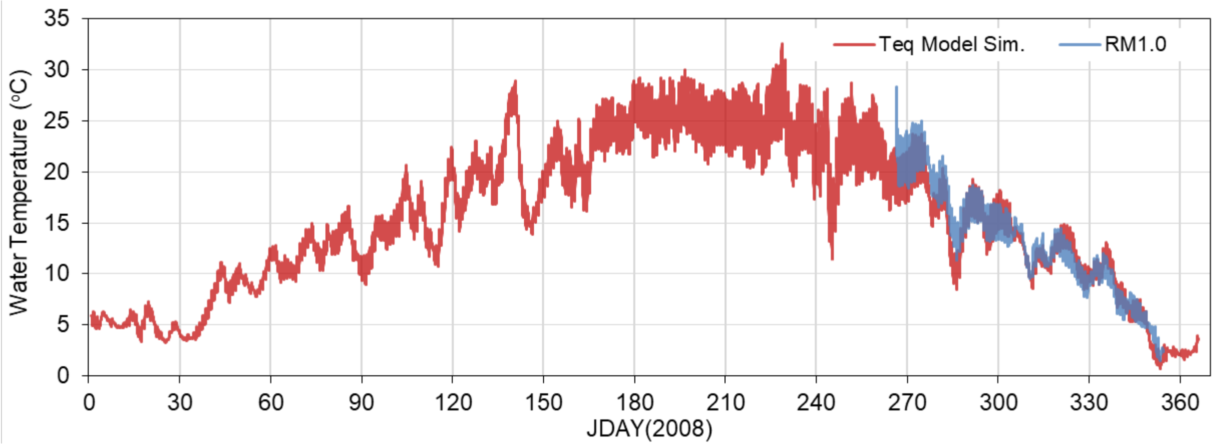
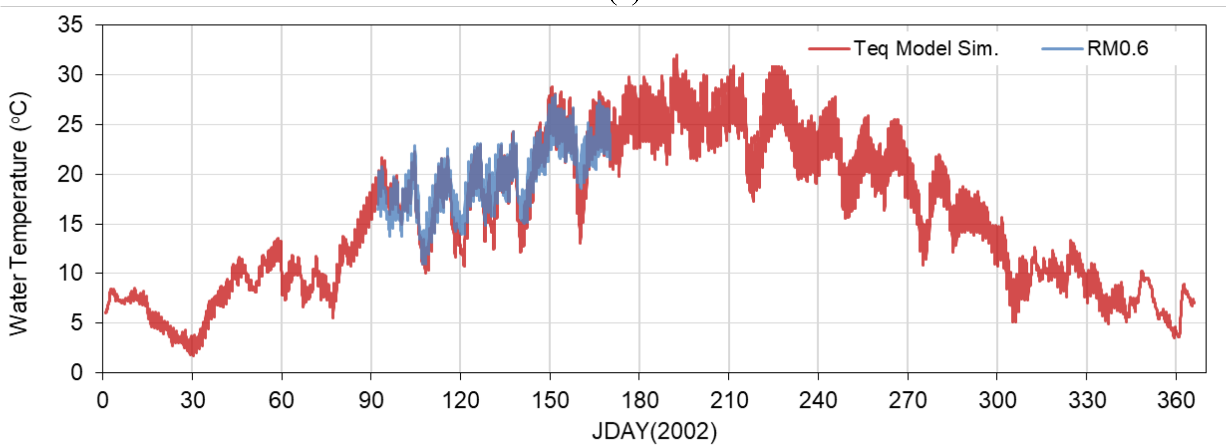



**Figure A-1. Stage-discharge curves for (a) Clear Creek, (b) Cow Creek, (c) Cottonwood Creek, (d) Battle Creek.**




(a)




(b)

**Figure A-2. Measured and calculated equilibrium temperature for (a) Cottonwood Creek (2002) and (b) Cow Creek (2008).**

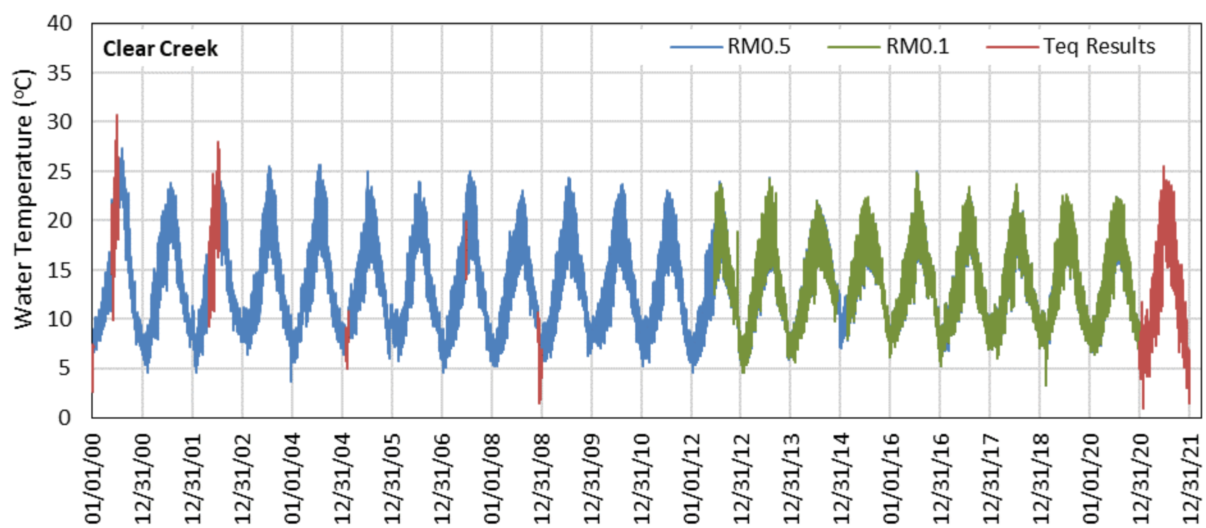



**Figure A-3. Measured and gap filled time series hourly water temperature data for Clear Creek (2000-2021).**

**0 Appendix A: Sacramento River Tributary Temperatures**

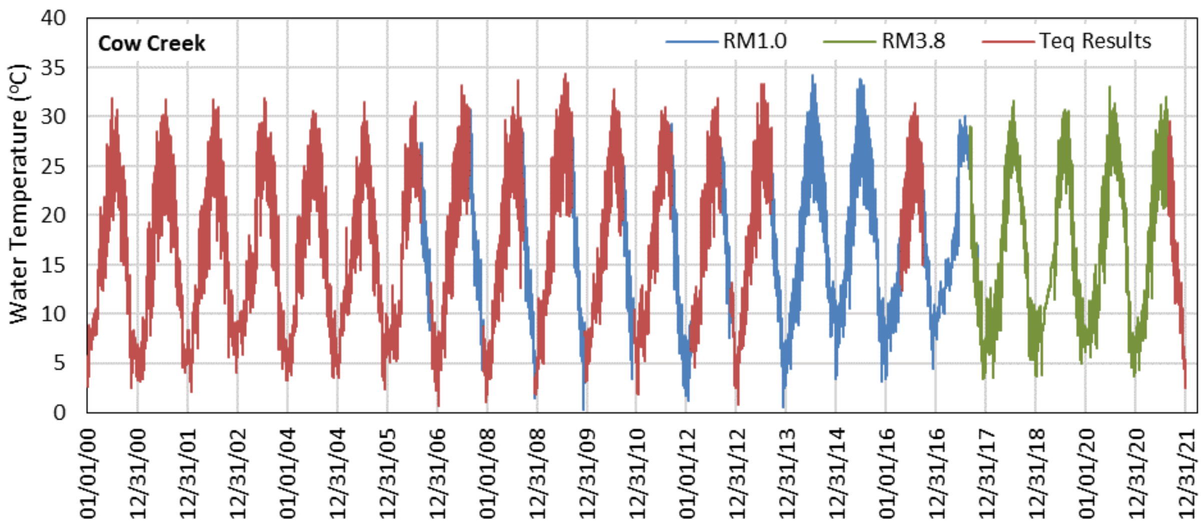



**Figure A-4. Measured and gap filled time series hourly water temperature data for Cow Creek (2000-2021).**

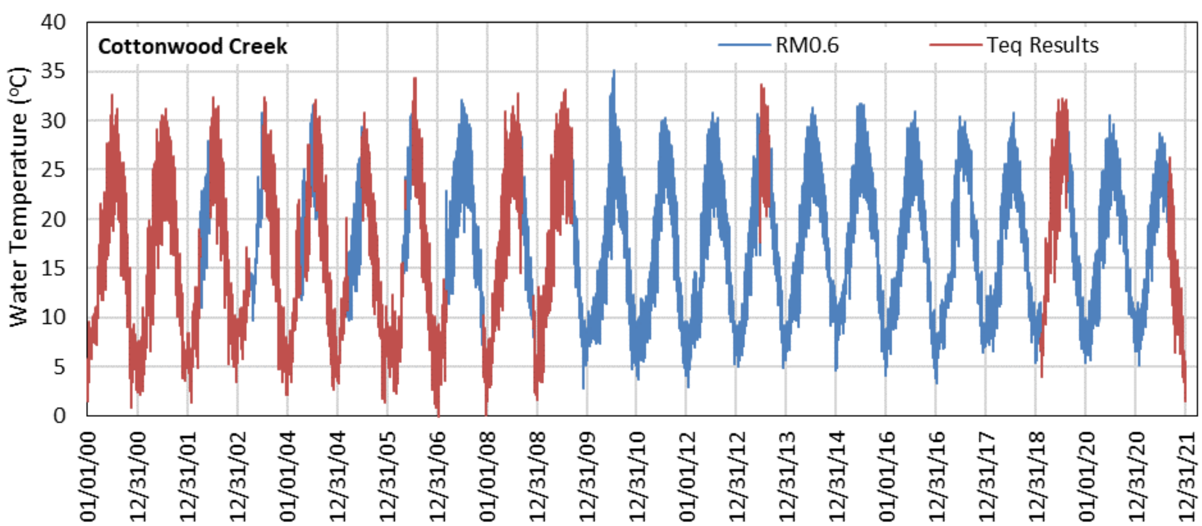



**Figure A-5. Measured and gap filled time series hourly water temperature data for Cottonwood Creek (2000-2021).**

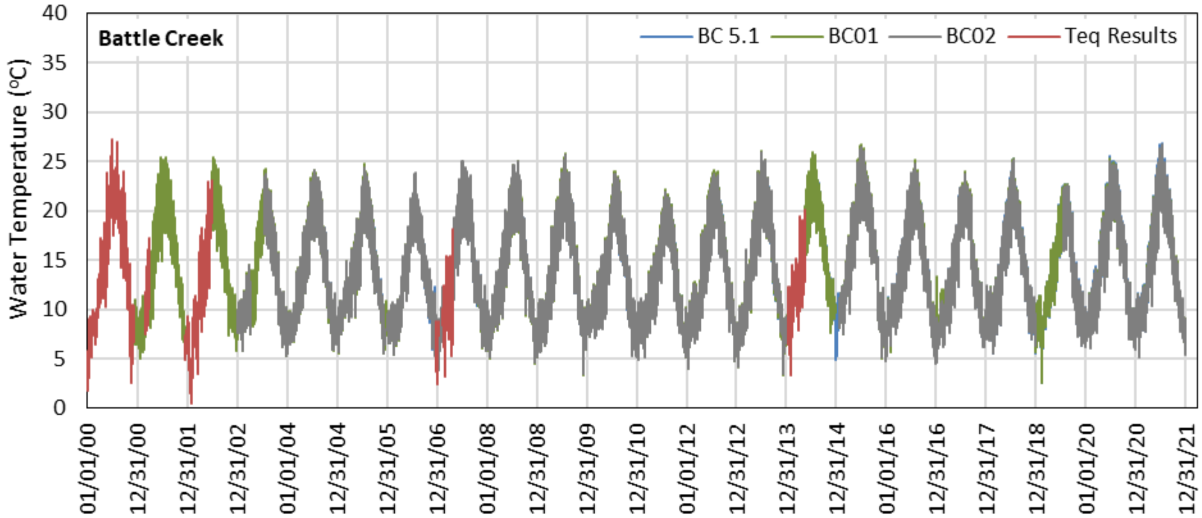



**Figure A-6. Measured and gap filled time series hourly water temperature data for Battle Creek (2000-2021).**

# Appendix B: Trinity Lake Bathymetry Development

Technical Memorandum

Date: May 16, 2022

To: Randi Field, U.S. Bureau of Reclamation
Donna Garcia, U.S. Bureau of Reclamation

From: Michael Deas, Watercourse Engineering, Inc.
Brendan Deas, Watercourse Engineering, Inc.
I. Ertugrul Sogutlugil, Watercourse Engineering, Inc.

Re: Trinity Lake Bathymetry Development

## Objective

The purpose of this digital bathymetry is to develop a geospatial database that will be utilized to develop a geometric representation of Trinity Lake in the CE-QUAL-W2 model currently under development and support HEC-ResSim modeling. This technical memorandum outlines the methodology used to create a digital bathymetry of Trinity Reservoir. The effort, completed using available data sources, generated an electronic version that can be shared among agencies and interested parties to minimize different interpretations of developing model geometric representations from traditional topographic map forms.

## Spatial Data and Methodology

Spatial data used to create the Trinity Reservoir bathymetry were gathered from two principal sources (Table B-3).

**Table B-1. Spatial data used to create the Trinity Reservoir bathymetry, including source and horizontal and vertical datums.**

| Title | Source | Datum | Units |
|---|---|---|---|
| USGS 1 arc second n41w123 20210624 (data set/map) | USGS 2021 | NAD83<br>NAVD88 | Geographic Coordinates: decimal degrees |
| U.S. Geological Survey (USGS) Topographic Quadrangle maps of Trinity Reservoir, northern California | USGS 1982 | NAD27<br>NGVD29 | UTM Coordinate (Zone 10): Meter |
| ESRI World Imagery (satellite imagery) | ESRI | WGS84 | Meter |

While there have been additional mapping efforts of the Trinity Lake area after 1982, many were topographically focused on the surrounding terrestrial areas, and the 1982 USGS maps are assumed to best represent a complete bathymetric dataset from pre-lake topographic surveys (e.g., USGS Trinity Dam CA, 1:62,500 1950, https://ngmdb.usgs.gov/topoview). However, the USGS maps cut off a small portion of the reservoir near the inlet of the East Fork of the Trinity River, and this region will be discussed in more detail below.

Necessary data conversions and reprojections were completed using Surfer® (Golden Software, Inc.) and ArcMap (ESRI). All data were ultimately resolved to metric units with plan view (XY) data in UTM coordinates and vertical (Z) information in feet and meters3. Detailed information regarding the data sources listed above and project methodology is presented in the following sub-sections.

To develop a comprehensive digital map for construction of a CE-QUAL-W2 model grid, the lakeshore and surrounding topography were developed from the USGS 1 arc second data set. Subsequently, relevant elevation contour data from the 1982 USGS maps was digitized to create a bathymetric representation of the reservoir. Finally, the bathymetric data were embedded in the regional topography and lake shoreline. Each step is outlined below.

## *Regional Topography and Lake Shoreline Reservoir*

To develop the regional topography and lake shoreline a Digital Elevation Model (DEM) was downloaded from the USGS dataset (USGS 2021). The DEM covers a large area of the Trinity River and Sacramento River system in the project area: between the coordinates 40.0° and 41.0°

[3] USGS digital elevation models (DEM) for the project area were available in UTM coordinates representing XYZ information in metric units (meters). In two different final data sets, Z information was represented in English units (feet) and in metric units. While both versions are available, this document uses the Z-in-English-units version.

N, and 122.0º and 123.0º W. Surfer® (Golden Software, Inc.) was used to develop the digital information through the following steps:

- Gridded data and a topographic map (main map) were created from the *.tif files available from USGS (2021).
- The Trinity Reservoir vicinity was cropped from the main map.
- Gridded data from the cropped area was converted to text files (.dat files), then these geographic coordinates were converted to UTM coordinates.
- An updated grid file was created by interpolating the UTM data mentioned via a Kriging method in Surfer® (10-m (~33-feet) by 10-m resolution).
- The final topographic map was created using the above grid data. Water surface elevation in the map (Figure B-1) was set at 714.0 m (~2342.5 ft), which was the approximate elevation of Trinity Reservoir at the time of the survey used to develop the DEM. Normal full pool elevation of Trinity Reservoir is 722.4 m (~2370.08 ft) (Reclamation 1966).
- The final extent of Trinity Reservoir, set within the regional topography is shown in Figure B-1.

## *Historic USGS Maps*

Construction of Trinity Dam began in 1957 and completed in 1962, and the reservoir and surrounding area was mapped (including lake bathymetry) in 1982 as part of the United States Geological Survey. The major contour of these maps is 100-meters, minor contour intervals are 20-meters, and the horizontal and vertical datum are the 1927 North American Datum and the National Geodetic Vertical Datum of 1929, respectively. Scale is 1:24000 (Figure B-2).

These maps were downloaded from the National Geologic Map Database Project (NGMDB) as part of USGS's online topoView service (https://ngmdb.usgs.gov/topoview). The latest post-dam maps with reliable bathymetric data were a collection of five 1982 USGS quadrangle maps. These individual maps were individually georeferenced to ensure fit then aligned and combined into one composite map document that displayed the entire reach of Trinity Reservoir. The data were then georeferenced again using Surfer® (Golden Software, Inc) and each bathymetric elevation was digitized to create a set of bathymetric contours for Trinity Reservoir. Contours were digitized for the elevations listed below:

- 722 m
- 720 m
- 700 m
- 680 m
- 660 m
- 640 m
- 620 m
- 600 m

## 0 Appendix B: Trinity Lake Bathymetry Development

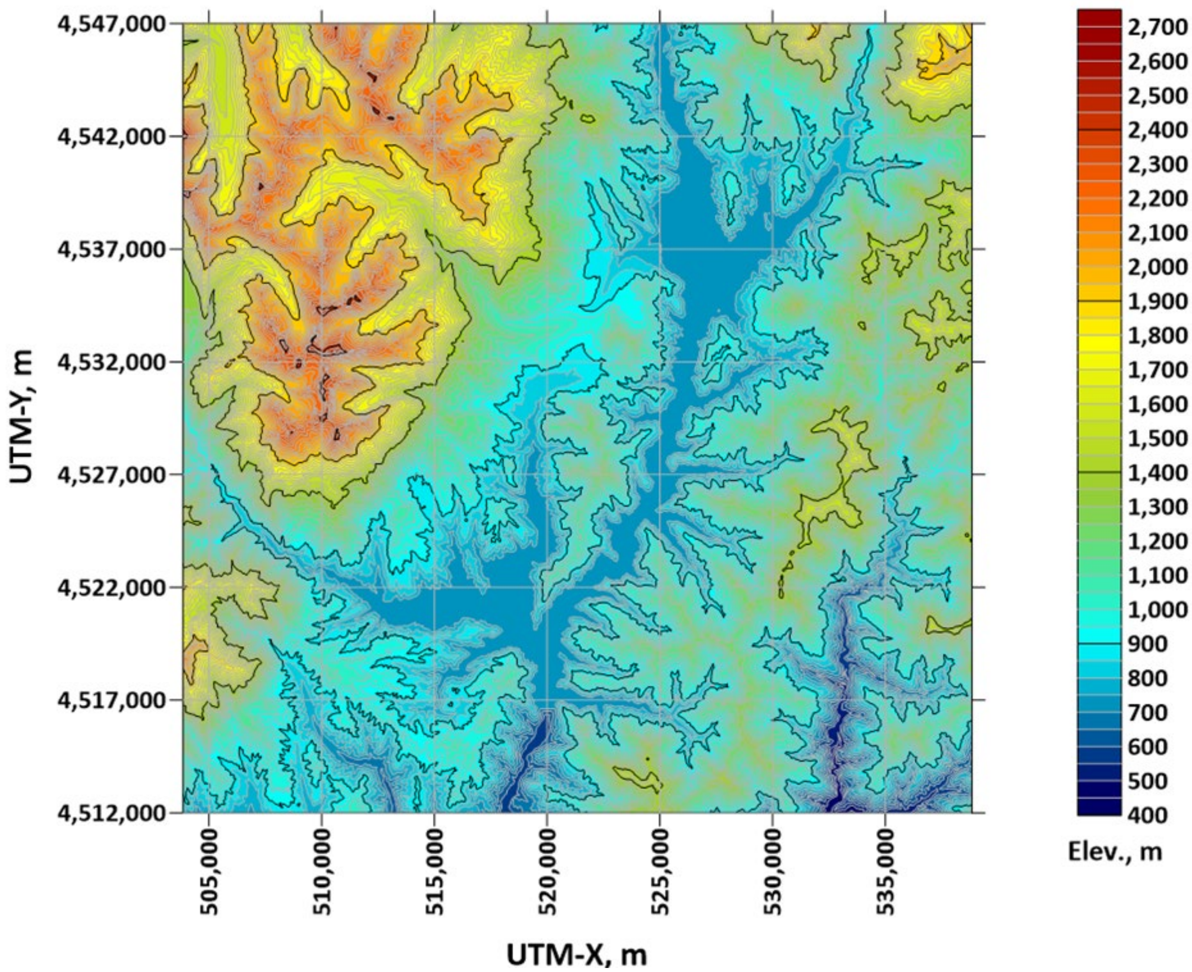



**Figure B-1. Trinity Lake (at elevation 714.0 m) and topography around the lake extracted from the combined data set of U.S. Geological Survey, 20210624, USGS 1 Arc Second n41w12320210624 map and U.S. Geological Survey, 20210624, USGS 1 Arc Second n42w12320210.**

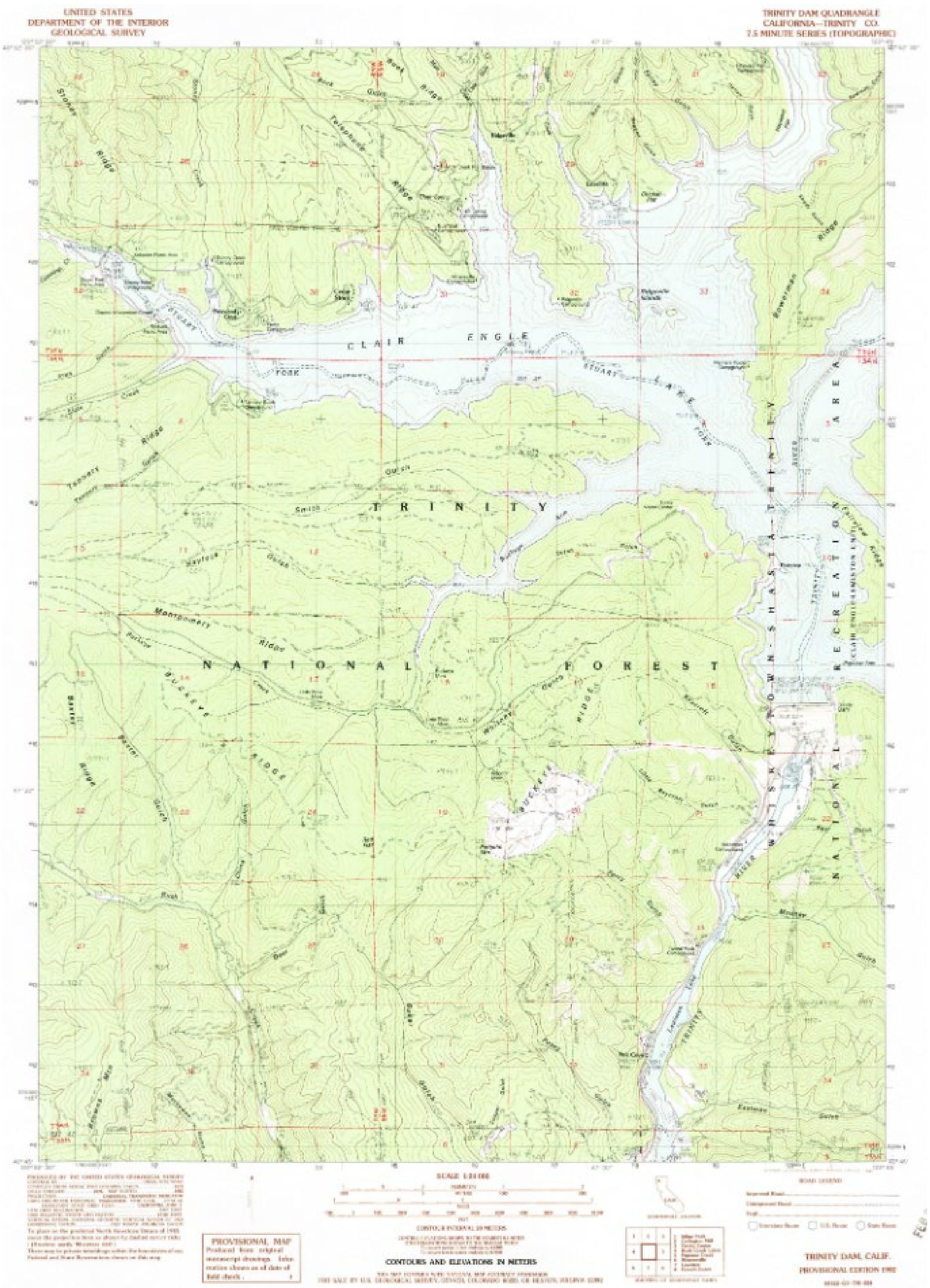



**Figure B-2. Historical topographic map of Trinity Dam area (USGS: Trinity Dam Calif, 1982).**

In addition to the contours, three thalwegs were also digitized (Figure B-3). The thalwegs had no assigned elevation on the original 1982 maps and represented the Stuart Fork, East Fork, and mainstem Trinity River prior to dam construction. To assign elevations to the thalwegs, corresponding elevations were assigned to the points crossing the contours listed above. For all other points in between, elevations were assigned by linear interpolation based on their distances from the most upstream points. Finally, the horizontal and vertical datum for all contours and thalwegs were converted to NAD83(2011) (UTM coordinates) and NAVD88(meters), respectively.

Data gathered from the USGS maps covers the entirety of the reservoir except for a small shallow stretch (affecting the 720 and 722 m elevation contours) along the inlet of the East fork of the Trinity River. This gap was filled using available satellite imagery, discussed below.

### *Satellite Imagery*

This aforementioned approach covered the entirety of the lake except for a small shallow stretch along the inlet of the East Fork Trinity River. To fill this gap, satellite imagery of the missing area was acquired from ESRI ArcGIS basemap layers and fitted to match the projection of the digitized USGS maps. By overlaying the fitted and georeferenced satellite imagery with the bathymetric map, the missing shoreline and shallow area missing from the USGS data were able to be accurately mapped and added to complete the existing digitized bathymetric contours.

### *Final Map*

The complete bathymetric contours and thalwegs were interpolated via Kriging method (with a 5m by 5m resolution) to create a grid file and map in Surfer (Figure B-4). The bathymetric grid created by the contours and thalwegs was embedded in the grid created by the USGS DEM (Figure B-1) to create the final grid and combine the two maps. The final digital bathymetric map covers the entirety of Trinity Reservoir and the surrounding region and is shown in Figure B-5.

The digitized bathymetry was used to develop a Trinity Lake stage-storage curve, and this was compared to information included in the existing Reclamation stage-storage table to confirm the bathymetric map was representative of Trinity Lake. The stage-volume curves for the two independent sources are in close agreement (Figure B-6).

## Electronic Data

The final bathymetry and upland topography data are available in electronic form.

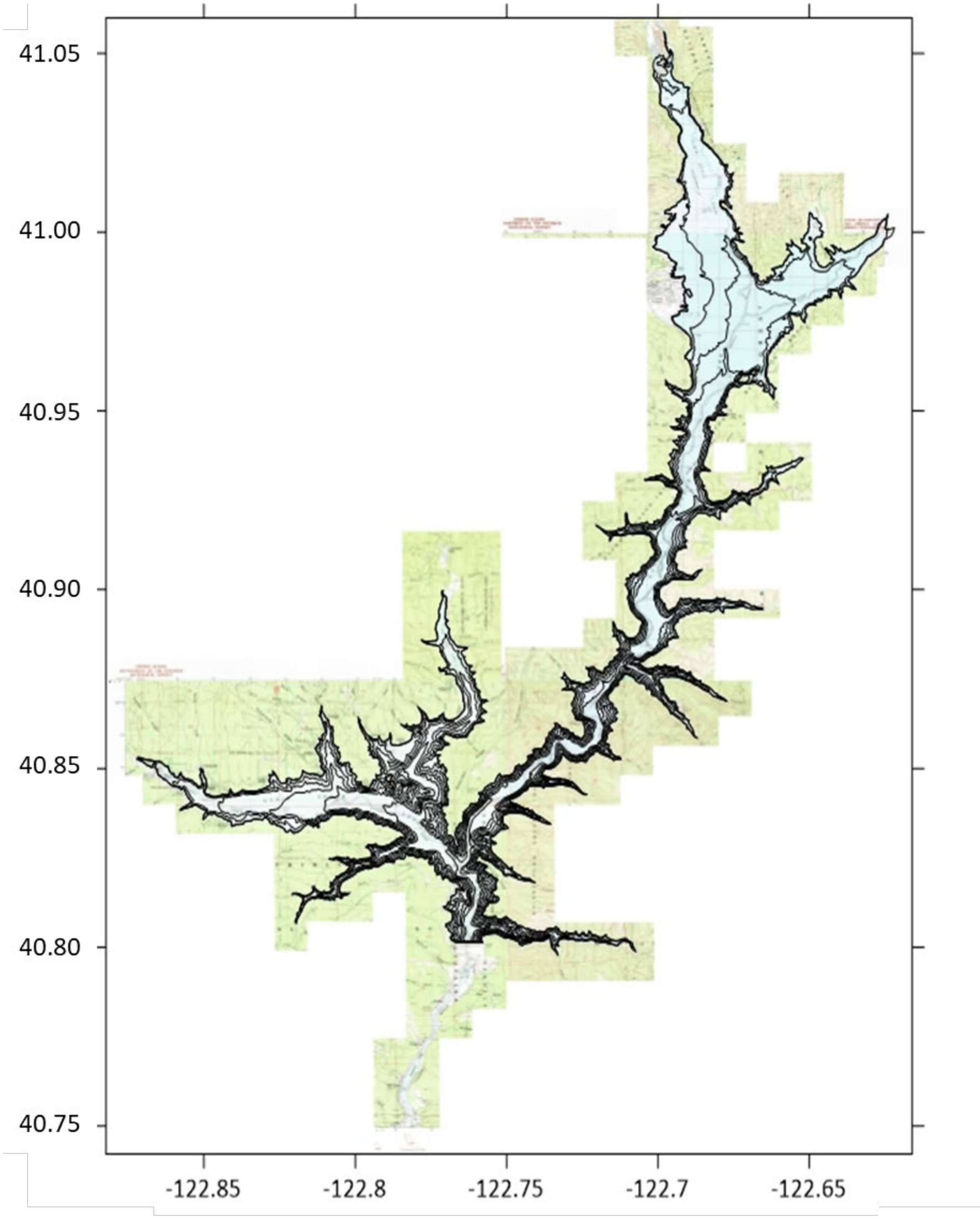



**Figure B-3. Composite USGS map (latitude/longitude) of Trinity Lake with overlayed digitized 20m contours.**

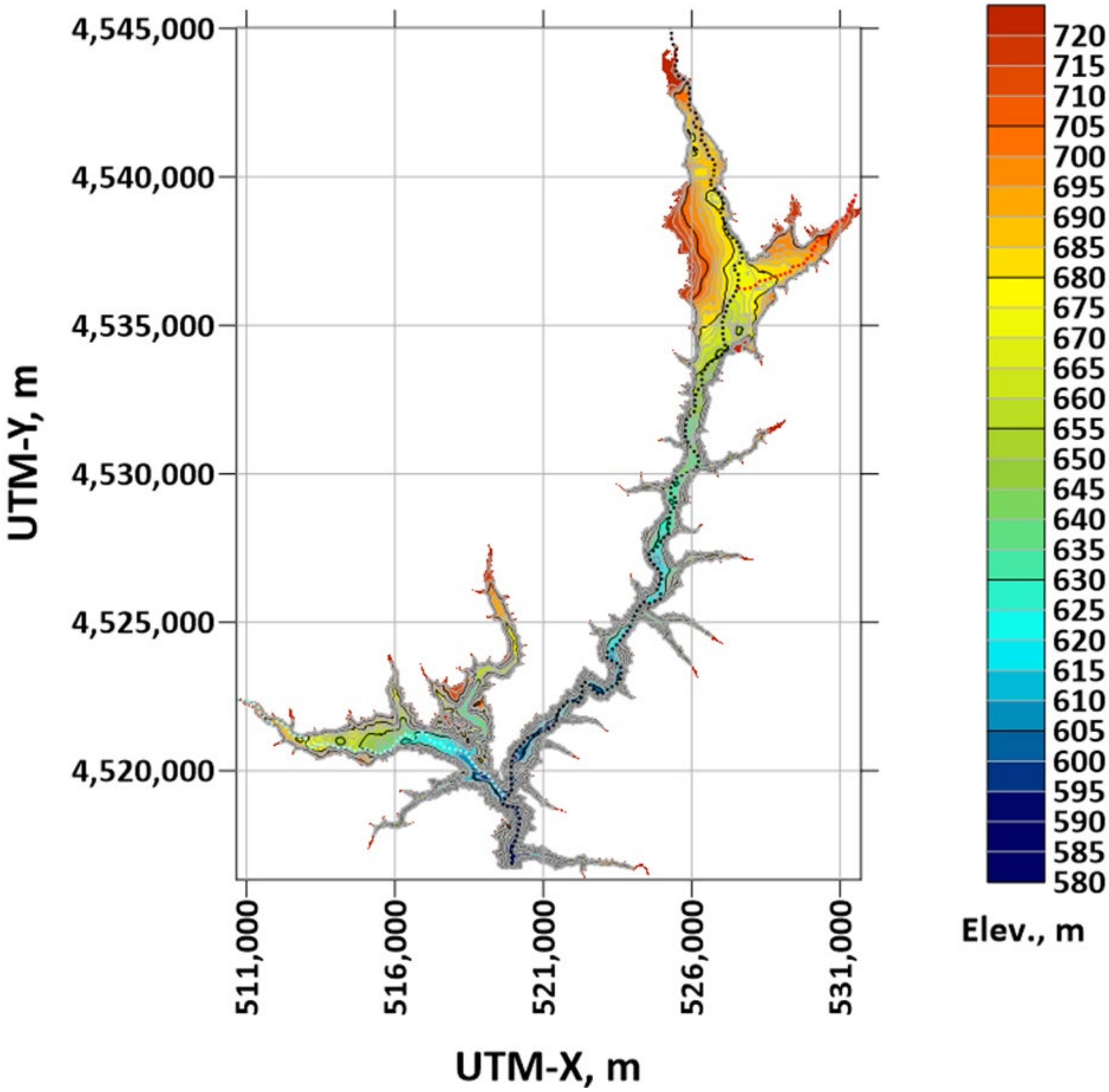



**Figure B-4. Trinity Lake bathymetry. Contours are represented by black lines. Thalwegs are indicated by black (Trinity River), red (East Fork Trinity River), cyan (Stuart Fork) lines.**

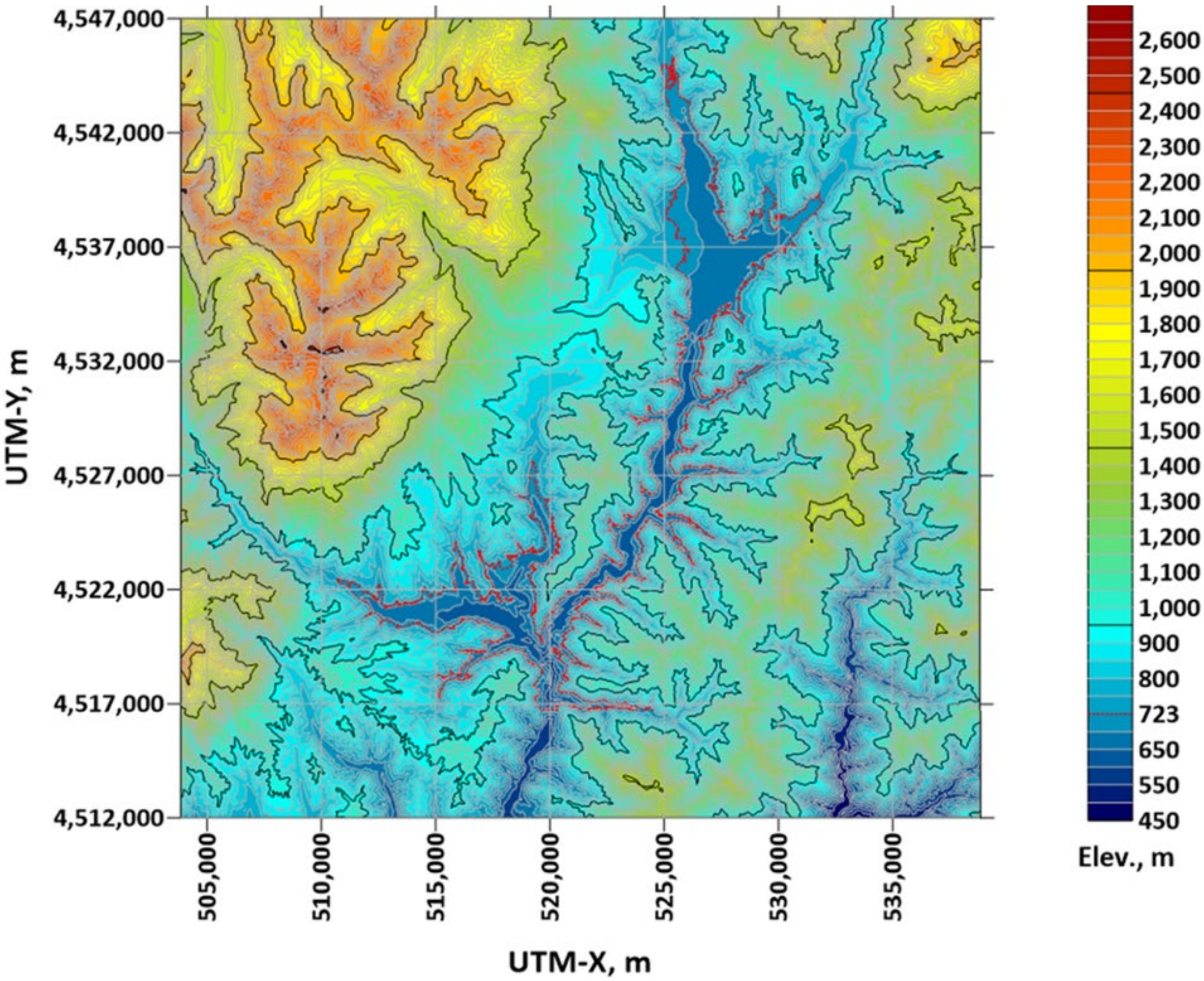



**Figure B-5. Trinity Lake bathymetry and topography around the lake. Full pool elevation is indicated by dotted red line.**

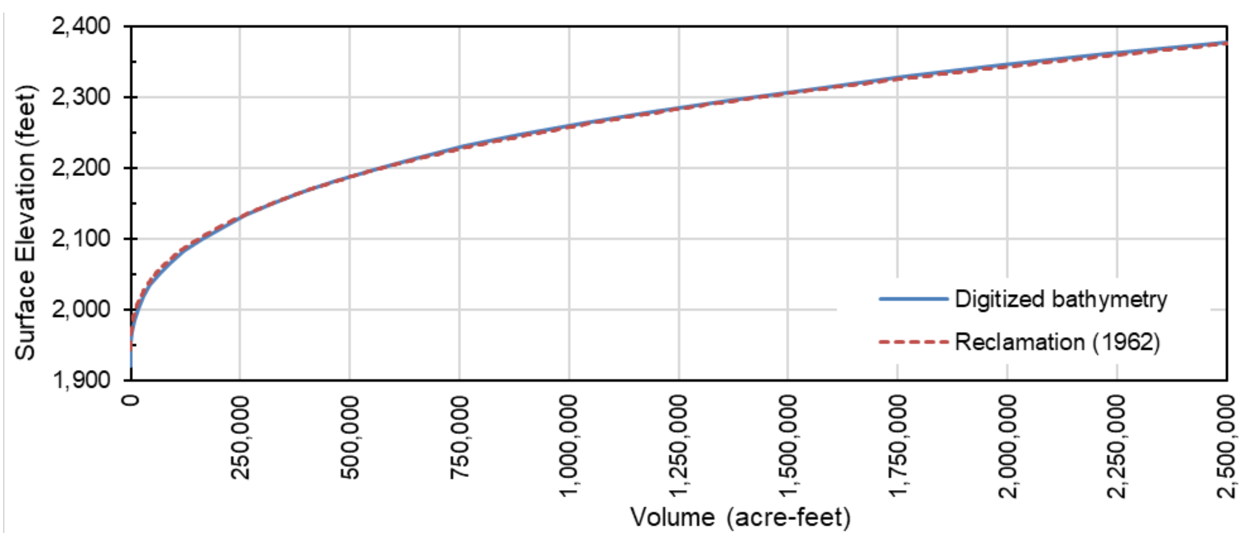



**Figure B-6. Trinity Lake stage-storage curve based on the digitized bathymetry and the existing Reclamation stage-storage table (Reclamation 1962).**

## References

Esri. 2022. World Imagery. Basemap. Scale not specified. Esri, DigitalGlobe, GeoEye, i-cubed, USDA FSA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. 2022.

U.S. Bureau of Reclamation (Reclamation). 1966. Trinity River Division Features of the Central Valley Project, Technical Record of Design and Construction: Volume II – Construction. Denver, CO. April.

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US Geological Survey. (USGS). 1982. California – Trinity Co. 7.5 Minute Series (Topographic). Map. 1:24000. Maps: Trinity Center, Trinity Dam, Covington Mill, Carrville, Papoose Creek quadrangles. United States Department of Interior, USGS. Print. 1982.

U.S. Geological Survey. (USGS). 2021. 20211116, USGS 1 Arc Second n41w123 20210624: U.S. Geological Survey (https://www.sciencebase.gov/catalog/item/60d562e7d34ef0ccfc0c82ad).

# Appendix C: Trinity Basin Meteorology Data Development

**Technical Memorandum**

Date: May 23, 2022

To: Randi Field, U.S. Bureau of Reclamation
Donna Garcia, U.S. Bureau of Reclamation

From: Michael Deas, Watercourse Engineering, Inc
Yujia Cai, Watercourse Engineering, Inc.

Re: Trinity Basin Meteorological Data Development

## Introduction

The CE-QUAL-W2 model developed for Lewiston Lake requires sub-daily meteorological data for years 2000 to 2021 as a model boundary condition. Data necessary to implement the model are presented below followed by discussion of development of the meteorology data set for application in the model.

## Meteorology Data Development

Meteorology data necessary for implementing the Lewiston Lake CE-QUAL-W2 model includes air temperature (°C), dew point (or wet bulb) air temperature (°C), wind speed (m/s), wind direction (radians), solar radiation (W/m$^2$), and cloud cover (0-10 scale). A lapse rate (-0.6 °C per 100 m elevation increase) is be applied to air temperature data to adjust for the elevation differences between the weather station and Lewiston reservoir spillway height (1902 ft). Cloud cover is calculated from solar radiation. Dew point and wet bulb temperature are calculated from relative humidity and air temperature (adjusted for elevation) and atmospheric pressure.

### *Available Meteorology Data*

Meteorological data was available from several stations in the upper Trinity River basin (Figure C-1 and Table C-1). Trinity Camp remote automated weather station (RAWS) is in close proximity to the project area, provided data for all necessary meteorology data types, and provided the most complete set of data for the model period.

## 0 Appendix C: Trinity Basin Meteorology Data Development

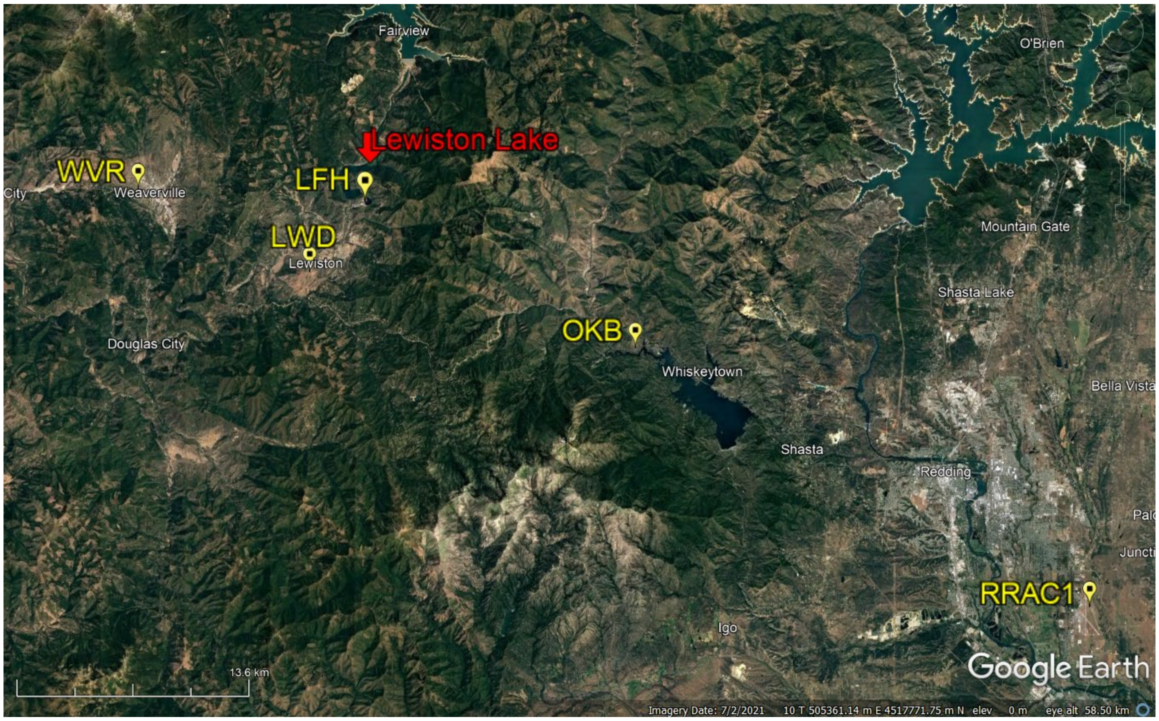


**Figure C-1. Locations of five meteorological stations near Lewiston Lake (designated by red arrow).**

**Table C-1. Metadata for six meteorological stations near Lewiston Lake.**

| Station ID | Agency | Site Name | Latitude | Longitude | Elevation, ft | Parameters Measured[1] | Data Frequency |
|---|---|---|---|---|---|---|---|
| TCAC1 | RAWS-Bureau of Land Management | Trinity Camp | 40.786° | 122.804° | 3308 | Tair, RH, Wdir, WS, SR | Hourly |
| LFH | CDEC-Reclamation | Lewiston Fish Hatchery | 40.727° | -122.793° | 1870 | Tair, RH, Wdir, WS, SR | Hourly |
| LWD | CDEC-Bureau of Land Management | Lowden | 40.69° | -122.831° | 3120 | Tair, RH, Wdir, WS | Hourly |
| WVR | CDEC-US Forest Service | Weaverville Ranger Station | 40.733° | -122.95° | 2136 | Tair, RH, Wdir, WS, SR | Hourly |
| OKB | RAWS-National Park Service | Oak Bottom | 40.651° | -122.606° | 1326 | Tair, RH, Wdir, WS, SR | Hourly |
| RRAC1 | RAWS-Bureau of Land Management | Redding CA | 40.516° | -122.292° | 500 | Tair, RH, Wdir, WS, SR | Hourly |

[1]Abbreviations:
Tair: Air temperature, RH: Relative Humidity, WS: Wind Speed, Wdir: Wind Direction, SR: Solar Radiation

## Data Gaps

To be applied as a boundary condition in the Lewiston Lake CE-QUAL-W2 model, the meteorology data set must be a continuous time series. There are short data gaps in the Trinity Camp data set between 2007 and 2021 (on the order of a few hours) that were filled by linear interpolation. However, between 2000 and 2006, there are larger gaps in the data set -- within each year there are multiple gaps on the order of several continuous days. The total number of hours of missing data in years 2000 through 2006 are shown in Table C-2. Data from the other five nearby meteorological stations were used to fill these larger gaps in the Trinity Camp data set.

**Table C-2. Meteorological data gaps of Trinity Camp RAWS station – total number of hours of missing data, by data type and year, from 2000 through 2006.**

| Data type | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
|---|---|---|---|---|---|---|---|
| Air temperature | 212 | 1016 | 2124 | 578 | 80 | 330 | 588 |
| Relative humidity | 218 | 1035 | 1837 | 579 | 80 | 331 | 593 |
| Wind speed | 198 | 1463 | 1837 | 599 | 109 | 345 | 602 |
| Wind direction | 207 | 1471 | 1837 | 578 | 81 | 330 | 587 |
| Solar radiation | 232 | 1053 | 2064 | 585 | 82 | 352 | 747 |

## Filling Gaps in Data

None of the other meteorology stations collected all of the data necessary to fill the gaps in the Trinity Camp data set. Data from the other five meteorology stations in the vicinity were analyzed for data quality, data integrity, and similarity to Trinity Camp RAWS data. Based on this analysis, and considering the stations' proximity to Lewiston Lake, these "alternate" stations were ranked and assigned a priority for filling gaps in each of the data types (Table C-3).

**Table C-3. Summary of selected stations to fill meteorological parameter gaps and priority.**

| Meteorological Parameters | Station ID and Priority |
|---|---|
| Air Temperature | LFH, priority 1<br>LWD, priority 2 |
| Relative Humidity | LFH, priority 1<br>LWD, priority 2 |
| Wind Speed | LWD, priority 1<br>OKB, priority 2 |
| Wind Direction | WVR, priority 1 |
| Solar Radiation | RRAC1, priority 1 |

### Air Temperature, Relative Humidity, and Wind Speed

Air temperature and relative humidity data from Trinity Camp were compared to data collected at two alternate nearby stations, Lewiston Fish Hatchery (LFH) and Lowden (LWD), for years 2000 to 2006. The comparison of air temperature data is shown in Figure C-2. The lapse rate was applied to data from each station to adjust for difference in elevation between the meteorology station and Lewiston Dam spillway (1902  ft). Relative humidity data from Trinity Camp is compared to data from stations LFH and LWD in Figure C-3.

Wind speed data from Trinity Camp were compared to data from station LWD and Oak Bottom(OKB) (Figure C-4). Anemometer height information was not available for those stations, so no height adjustment was made to wind speed data (anemometer height is assumed to be at 2 meters).

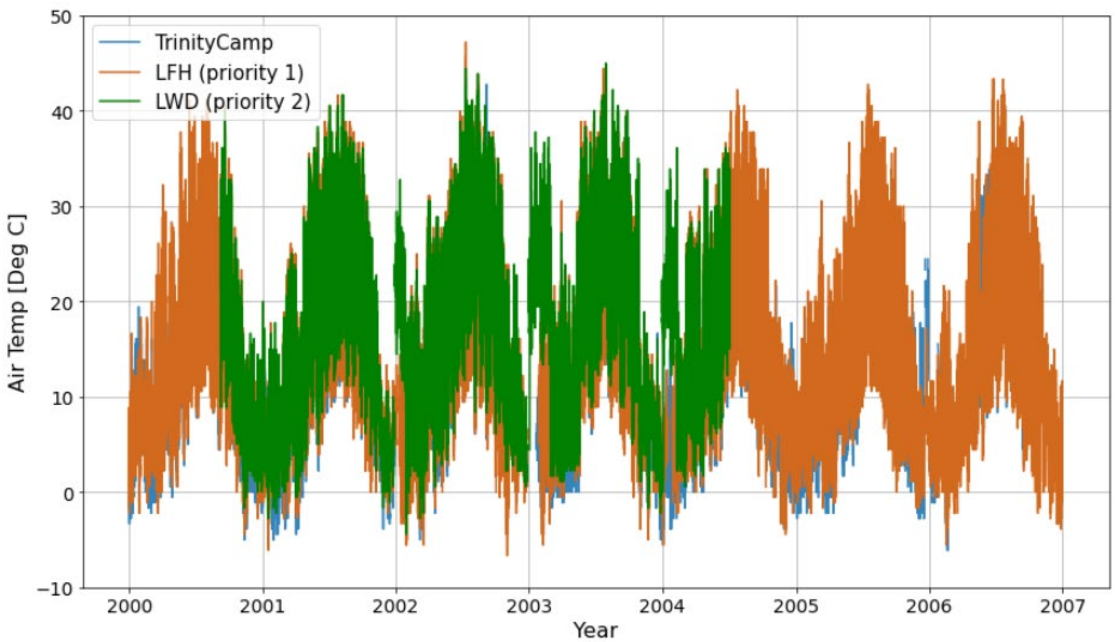


**Figure C-2. Air temperature comparison at Trinity Camp RAWS (blue line), Lewiston Fish Hatchery (LFH, orange line), and Lowden (LWD, blue line).**

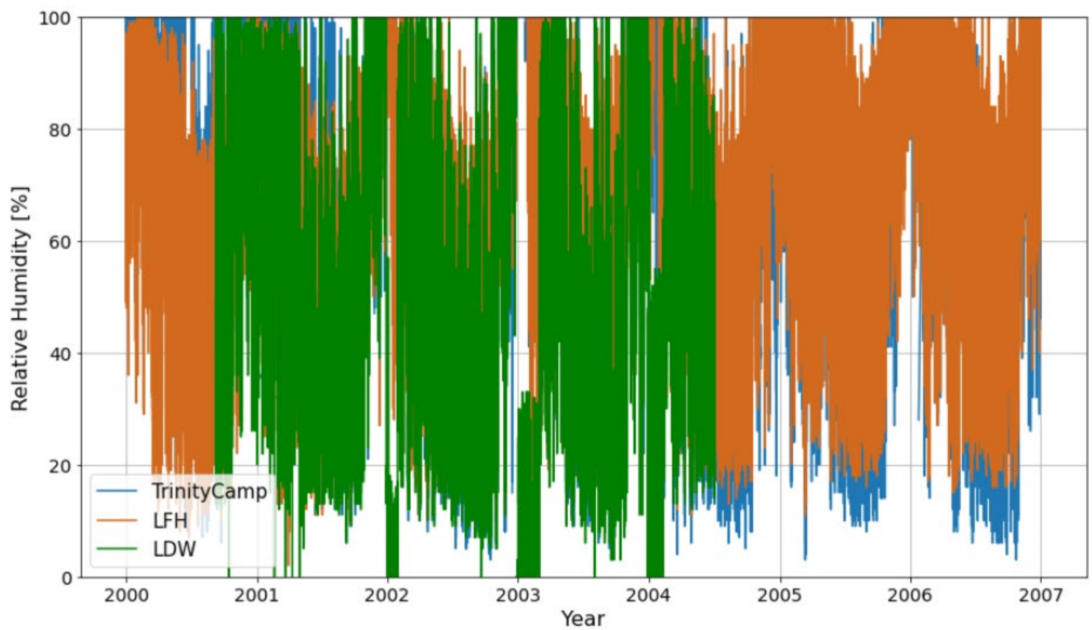


**Figure C-3. Relative humidity comparison at Trinity Camp RAWS (blue line), Lewiston Fish Hatchery (LFH, orange line), and Lowden (LWD, blue line).**

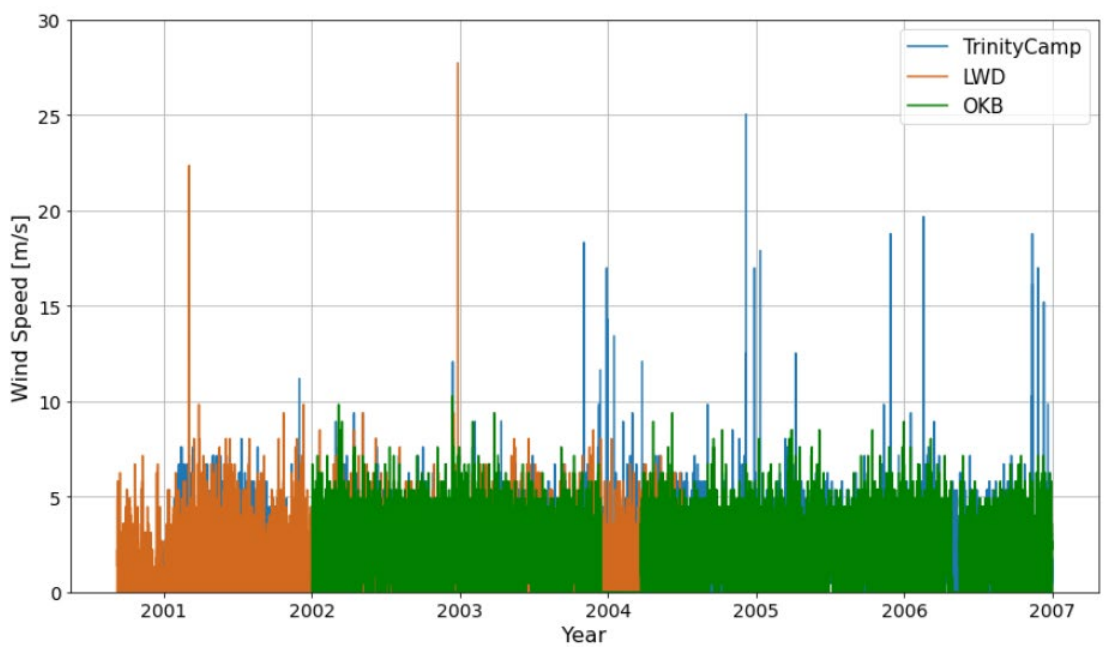


**Figure C-4. Wind Speed comparison at Trinity Camp RAWS (blue line), Lowden (LWD, orange line), and Oak Bottom (OKB, green line).**

### Wind Direction

Wind direction is controlled by local conditions such that two stations near each other may not report the same data. To use data from an alternate nearby station to fill a gap in the Trinity Camp wind direction data, characterization of wind direction trend, based on dominant wind direction, was established. Wind direction data collected at each station was sorted into 10° increments, and the percent of data in each increment was plotted. Among the available wind direction data, only the data from Weaverville Ranger Station (WVR) station has similar dominant wind direction as Trinity Camp RAWS station (Figure C-5).

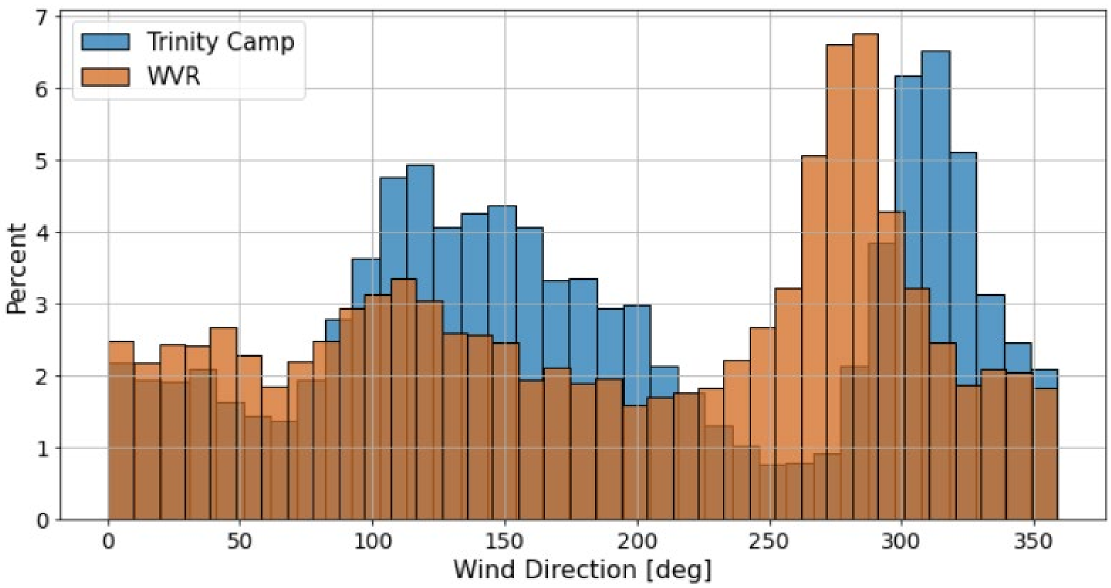


**Figure C-5. Wind Direction comparison (year 2000 to 2006) at Trinity Camp RAWS (blue line) and Weaverville (WVR, orange line).**

After using nearby stations to fill wind direction data gaps, there were still big continuous gaps from November 2005 to February 2006. Those gaps were filled using the median values of all other year's data at the same date and hour. The distribution of filled wind direction data were compared to the original data to ensure a similar dominant wind direction (Figure C-6).

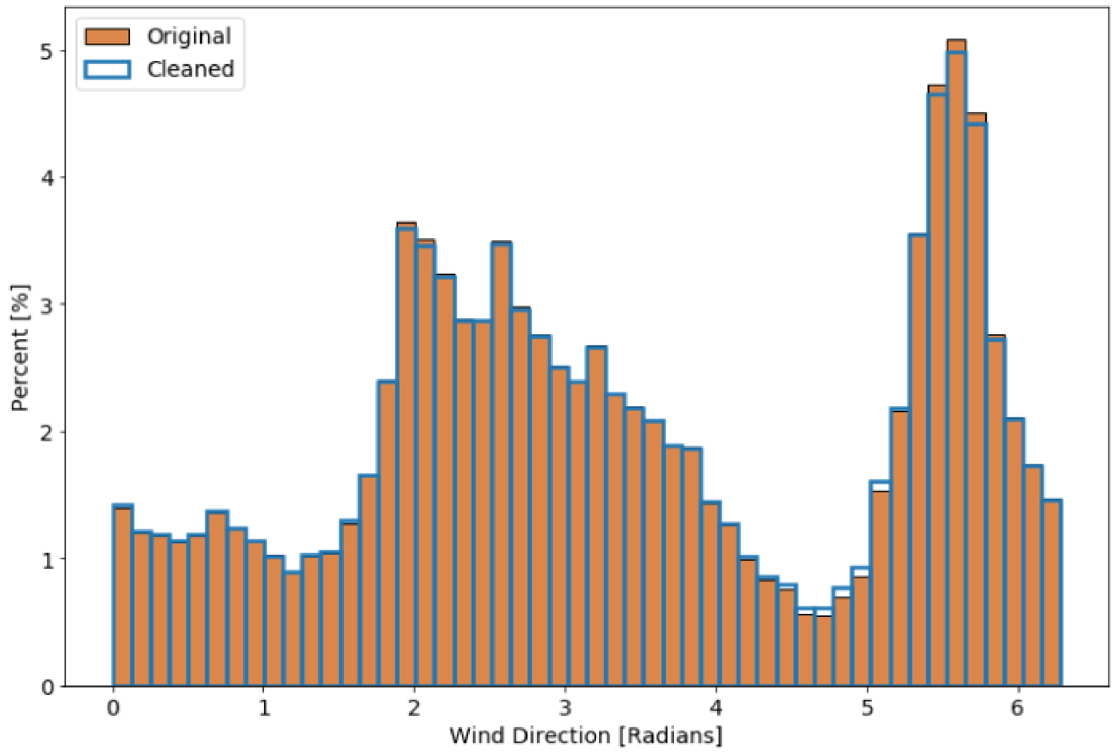


**Figure C-6. Wind direction distribution of Trinity Camp before (orange) and after (blue) gap filling from the year 2000 to 2021.**

### Solar Radiation

Although meteorology station RRAC1 in Reading is relatively far from Lewiston Lake, it is used to fill gaps in Trinity Camp solar radiation data. Routine maintenance of solar radiation sensors is critical to collecting accurate data. Meteorology station RRAC1 is known to be well maintained and to supply high quality data.

## Summary

Trinity Camp RAWS data was used as the primary source for meteorology data for the Lewiston Lake CE-QUAL-W2 model because of its proximity to Lewiston Lake and its high quality data. Significant gaps in data from 2000 through 2006 were filled with data from alternate nearby stations. When gaps in the Trinity Camp data set were filled, data were reviewed and intuitively incorrect data points were adjusted (e.g., relative humidity above 100% or below 0%, wind direction greater than 360°, etc.).

# Appendix D: Whiskeytown Lake Bathymetry Development

# Technical Memorandum

Date: April 17, 2022

To: Randi Field, U.S. Bureau of Reclamation
Donna Garcia, U.S. Bureau of Reclamation

From: Michael Deas, Watercourse Engineering, Inc.
Brendan Deas, Watercourse Engineering, Inc.
I. Ertugrul Sogutlugil, Watercourse Engineering, Inc.

Re: Whiskeytown Lake Bathymetry Development

## Objective

The purpose of this digital bathymetry is to develop a geospatial database that will be utilized to develop a geometric representation of Whiskeytown Lake in the CE-QUAL-W2 model currently under development and support HEC-ResSim modeling. This technical memorandum outlines the methodology used to create a digital bathymetry of Whiskeytown Reservoir. The effort, completed using available data sources, generated an electronic version that can be shared among agencies and interested parties to minimize different interpretations of developing model geometric representations from traditional topographic map forms.

## Spatial Data and Methodology

Spatial data used to create the Whiskeytown Reservoir bathymetry were gathered from three principal sources (Table D-1).

**Table D-1. Spatial Data used to create Whiskeytown Bathymetry, including source and horizontal and vertical datums.**

| Title | Source | Datum | Units |
|---|---|---|---|
| USGS 1 arc second n41w123 20210624 (data set/map) | USGS 2021 | NAD83<br>NAVD88 | Geographic Coordinates: decimal degrees |
| The U.S. Geological Survey (USGS) Bathymetry, Topography and Orthomosaic imagery for Whiskeytown Lake, northern California | Logan et al. 2020 | NAD83<br>NAVD88 | UTM Coordinate (Zone 10): Meter |
| Historic 1956 US Department of Interior topographic maps of the Whiskeytown Reservoir Area | Alster 1956 | NAD27 (Calif. State Plan, zone 0401)<br>NGVD29 | UTM Coordinate (Zone 10): Feet |

There was reference to bathymetry in Jensen et al. (1999) that identified additional work for a modeling effort completed in 1999. This survey work was to accommodate potential changes to the reservoir that occurred during construction (i.e., after the 1956 maps were completed). However, the comprehensive and detailed USGS bathymetry (Logan et al. 2020) is assumed to best represent the current day reservoir bathymetry in this region of the reservoir. Logan et al. (2020) did not include areas upstream of the Oak Bottom curtain and downstream of the Spring Creek curtain, and these two regions are discussed in more detail below.

Necessary data conversions and reprojections were completed using the National Oceanic and Atmospheric Administration's VDatum tool (NOAA 2021). All data were ultimately resolved to metric units with XY data in UTM coordinates and vertical (Z) information in meters. Horizontal and vertical datums of the final map, which includes the bathymetry and the topography around the reservoir, are NAD83(2011) and NAVD88, respectively. Detailed information regarding the data sources listed above and project methodology is presented below.

To develop a comprehensive digital map for construction of a CE-QUAL-W2 model grid the lakeshore and surrounding bathymetry were developed from the USGS 1 arc second data set. Subsequently, the detailed bathymetric survey by Logan et al. (2020) was embedded in the regional topography and lake shoreline to identify missing regions. Finally, the missing regions were filled by digitizing the 1956 maps (Alster et al. 1956). Each step is outlined below.

## *Regional Topography and Lake Shoreline Reservoir*

To develop the regional topography and lake shoreline a Digital Elevation Model (DEM) was downloaded from the USGS dataset (USGS 2021). The DEM covers a large area of the Trinity River and Sacramento River system in the project area: between the coordinates 40.0o and 41.0o N, and 122.0o and 123.0o W. Surfer® (Golden Software, Inc.) (Surfer) was used to develop the digital information through the following steps:

- Gridded data and topographic map (main map) were created out of the *.tif file available at USGS (2021).
- The Whiskeytown Lake vicinity was cropped from the large, main map.
- Gridded data from the cropped area were converted to text file (.dat file), then these geographic coordinates were converted to UTM coordinates.
- An updated grid file was created by interpolating the UTM data mentioned via a Kriging method in Surfer (10-m (~33-feet) by 10-m resolution).
- Final topographic map was created using the aforementioend grid data. Water surface elevation in the map (**Error! Reference source not found.**) was set at 366.45 m (~1,202 ft), which was the approximate elevation of Whiskeytown Lake at the time of the survey used to deveop the DEM. Normal operating level of Whiskeytown Lake is 368.8 m (1,210 ft) (Reclamation 1966).

The final extent of Whiskeytown Lake, set within the regional topography is shown in Figure D-1.

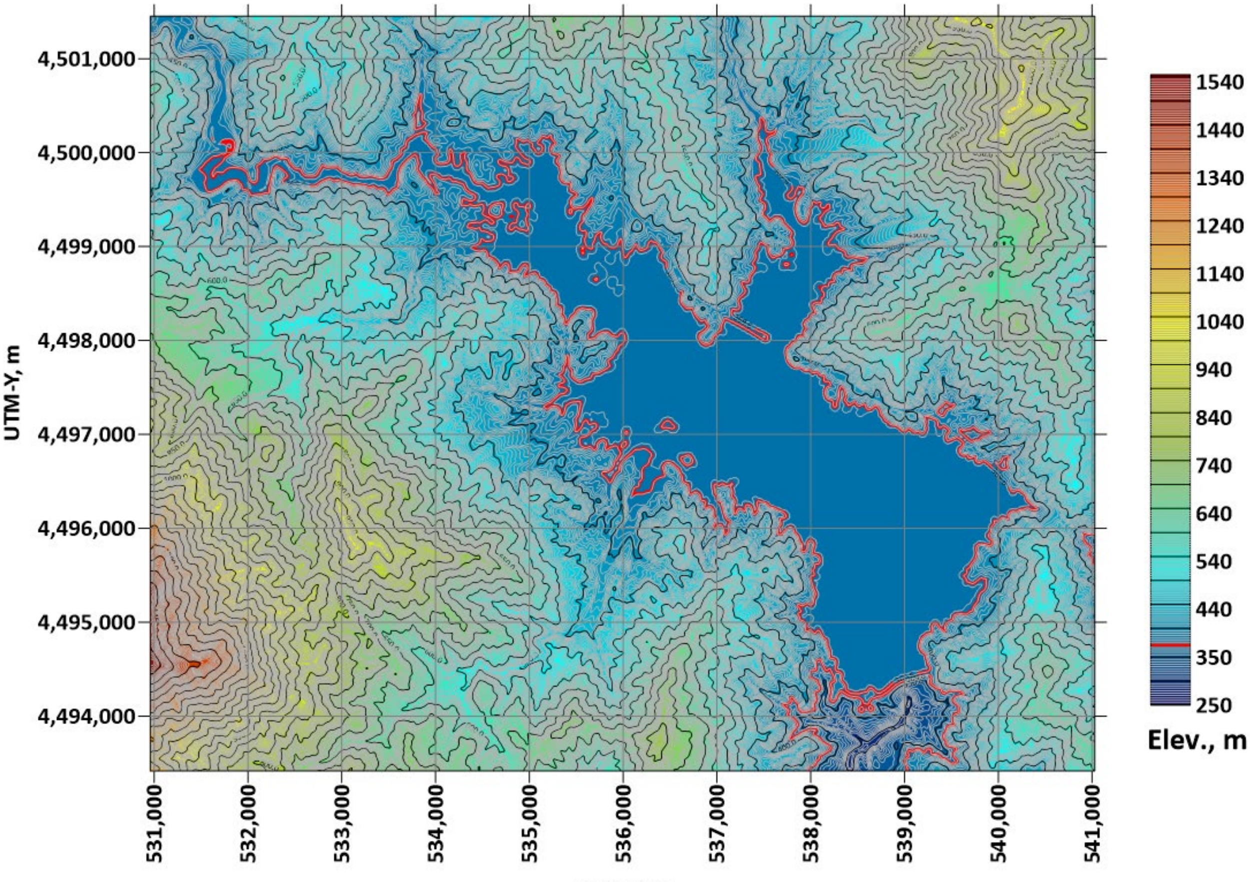


**Figure D-1. Whiskeytown Lake bathymetry and topography around the lake. Extracted from the data set included in U.S. Geological Survey, 20210624, USGS 1 Arc Second n41w12320210624. Full pool elevation (1210 ft in NGVD29) is indicated by red line.**

## *USGS Topography and Orthomosaic Imagery for Whiskeytown Lake*

Bathymetric data of Whiskeytown Lake proper was downloaded from the USGS Science Base catalog (see Logan et al. 2020). XY data at 2-meter (6.56-feet) resolution was selected for this project, which is consistent with developing a CE-QUAL-W2 model grid that will have longitudinal resolution ranging from 65 meters (213 feet) to 700 meters (2,297 feet) and a vertical resolution on the order of 1m. A grid (file) was created using Surfer® (Golden Software, Inc.) (Surfer). Based on the provided *.tif file, and a subsequent bathymetric map of the Whiskeytown Reservoir created (Figure D-2).

This bathymetric map does not include areas of Whiskeytown Lake that were not surveyed by Logan et al. (2020), including:

- Areas upstream of the Oak Bottom temperature control curtain, near upper end of the reservoir.
- Downstream of the Spring Creek temperature control curtain where waters are diverted via the Spring Creek tunnel to Keswick Reservoir.

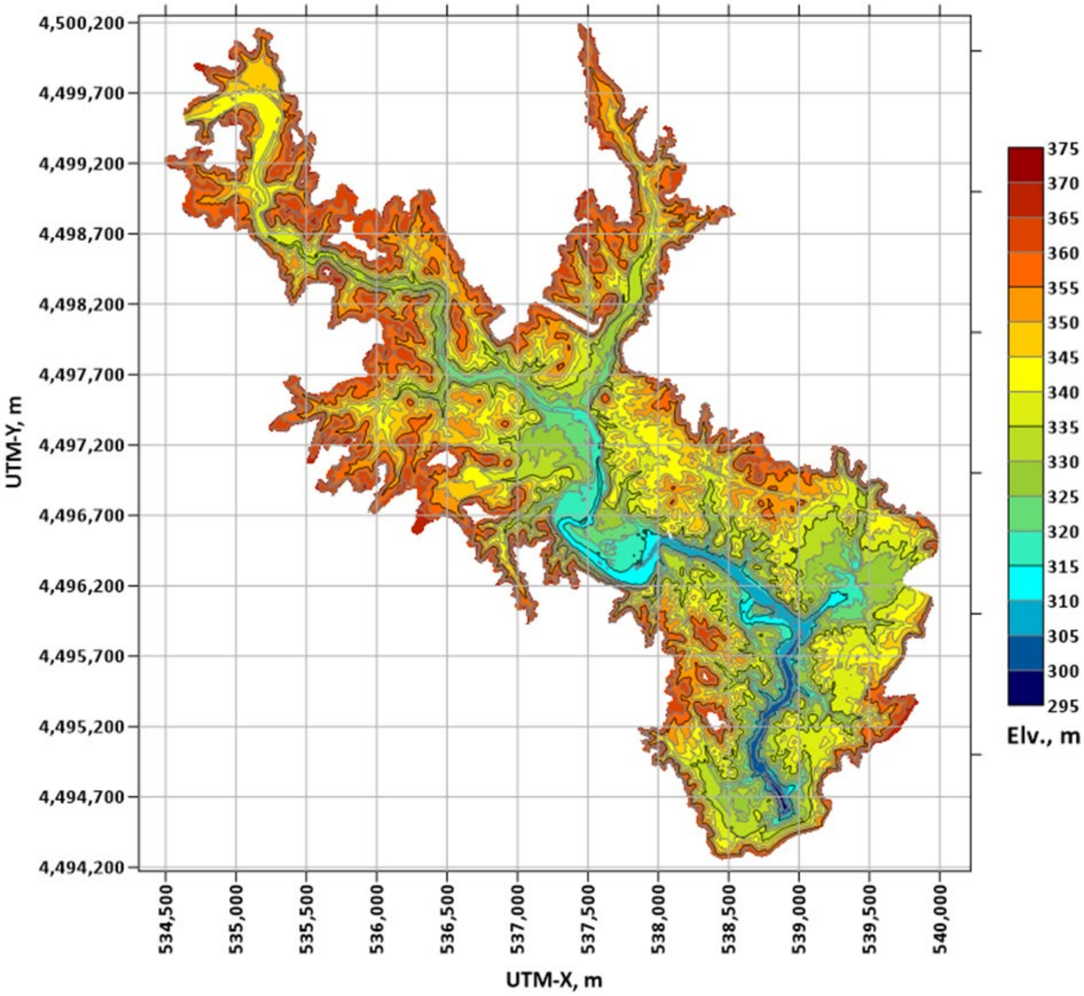


**Figure D-2. Whiskeytown Lake bathymetry map with the data collected during May 2019 SWATHPlus survey of Whiskeytown Lake, California. 2-meter (6.56-feet) resolution.**

The Whiskeytown Lake bathymetry associated with the Logan et al (2020) survey was subsequently embedded in the regional DEM and shoreline representation shown in Figure D-1. This map, shown in Figure D-3, illustrates the regions of the lake upstream of the Oak Bottom curtain and downstream of the Spring Creek Curtain that were not surveyed by Logan et al. (2020). Bathymetry for these missing regions were derived from historical topographic maps, discussed below.

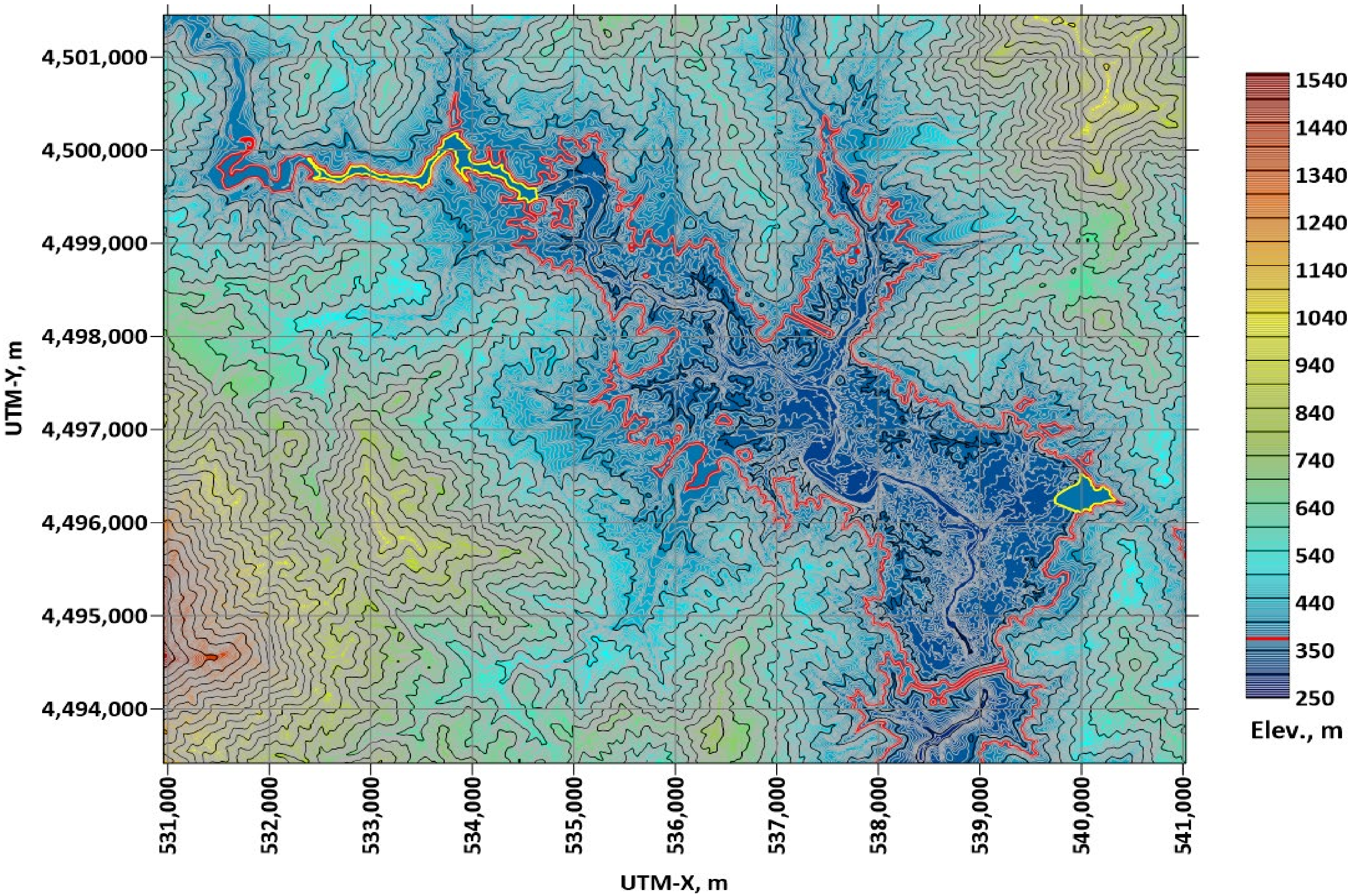


**Figure D-3. Whiskeytown Lake bathymetry and topography around the lake with the two non-covered/gap areas included in the polygons indicated by yellow lines. Full pool elevation (1210 ft in NGVD29) is indicated by red line.**

## *Historical Whiskeytown Reservoir Maps*

Construction of Whiskeytown Dam began in 1960, and the latest pre-dam maps readily available were a set of 17 topographic 1956 US Department of Interior Maps, based on 1:12,000 aerial photography. These maps were scanned and digitized to create new elevation contour data to fill in the existing gaps in Whiskeytown Lake bathymetry upstream of the Oak Bottom curtain and downstream of the Spring Creek curtain. The major contour of these maps was 30.48meters (100.0-feet), minor contour intervals are 3.05-meter (10.0-feet) (Figure D-4).

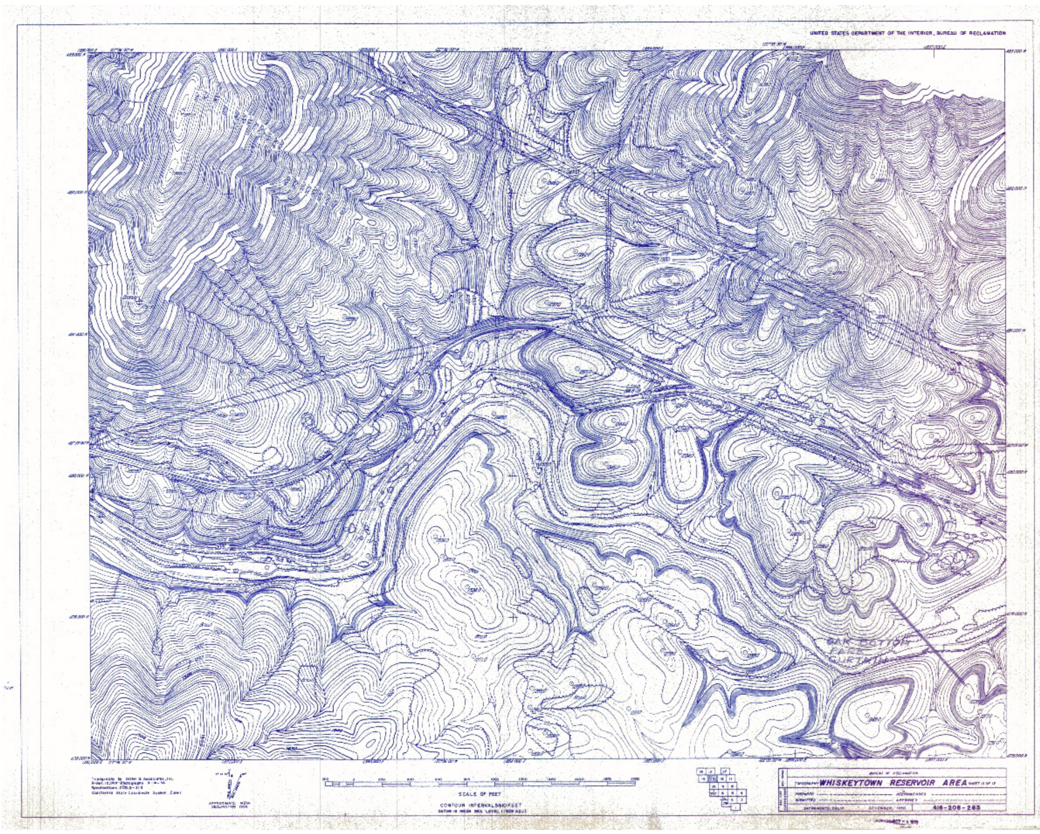


**Figure D-4. Historical topographic map of Whiskeytown area. Published in 1956.**

The existing gaps in the Whiskeytown bathymetry were found to fall within five historical map panels. These maps were scanned, and all relevant elevation contours, metadata, and thalwegs (below the waterline) were digitized on 9.14-meter (30.0-feet) intervals. The data were converted to UTM coordinates (zone 10), with the horizontal and the vertical datum as NAD83(2011) and NAVD88, respectively, using VDatum in preparation for integration into the final map. Each map panel's contours and associated data were then combined to create a complete bathymetric map of each preexisting gap in the USGS data (Figure D-3).

The final digital bathymetric map covers the entirety of Whiskeytown Reservoir and the surrounding shore area is shown in Figure D-5, with detailed representation of the region upstream of the Oak Bottom curtain and downstream of the Spring Creek curtain in Figure D-6 and Figure D-7, respectively.

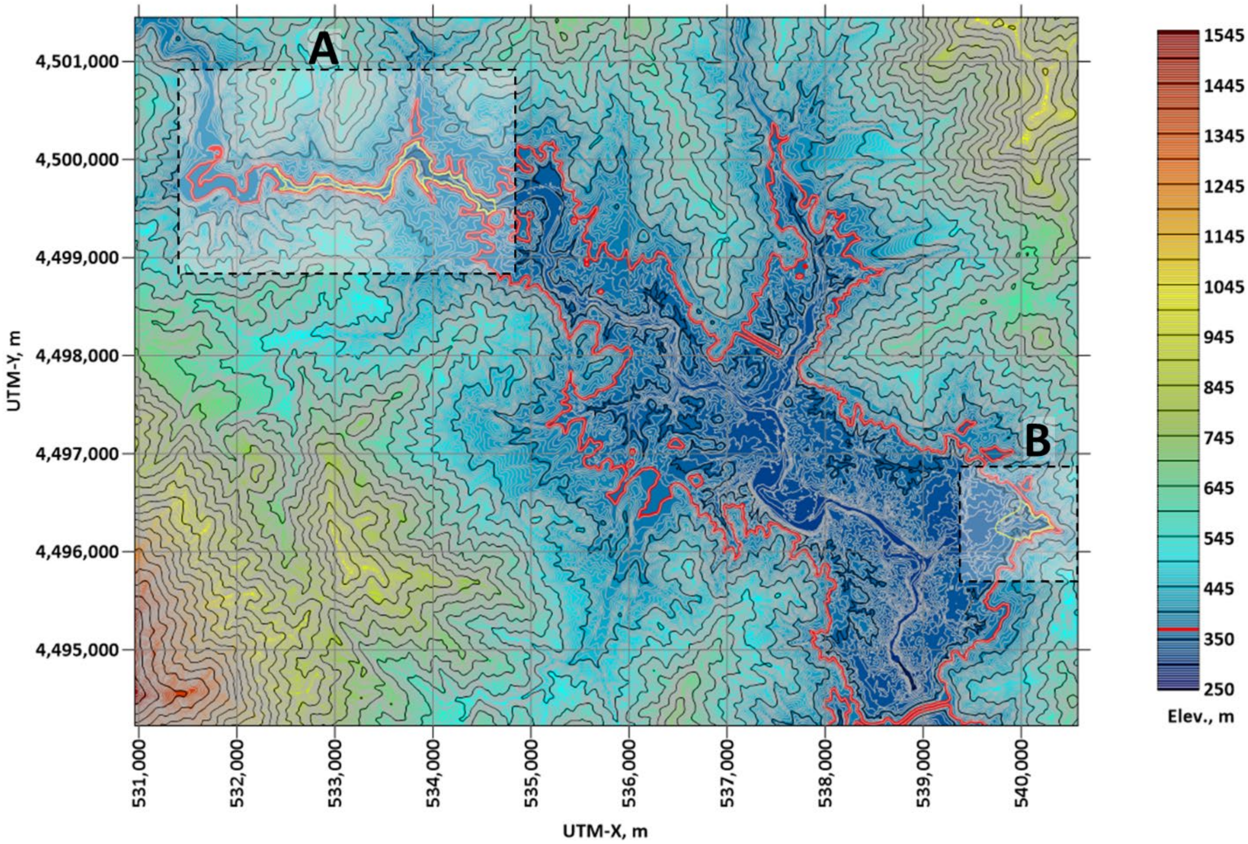


**Figure D-5. Whiskeytown Lake bathymetry and topography with upstream (A) and downstream (B) curtain additions. Full pool elevation (1210 ft in NGVD29) is indicated by red line.**

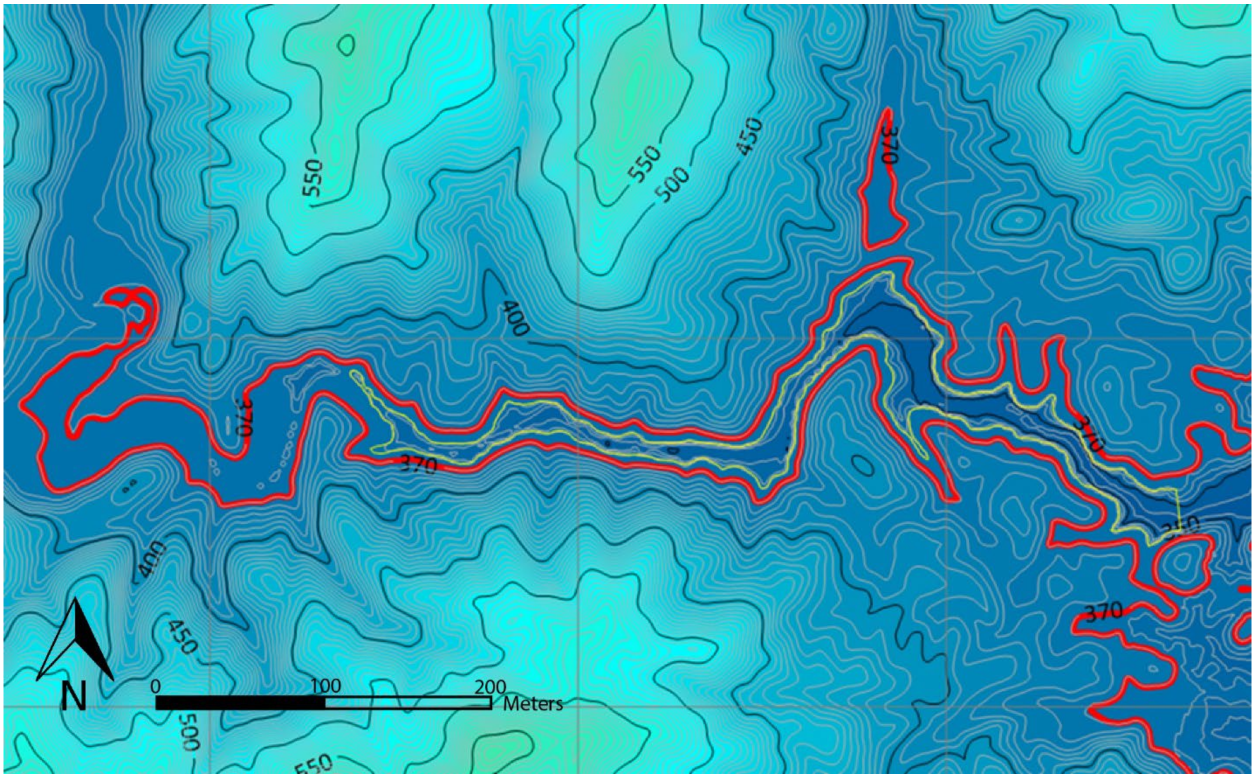


**Figure D-6. Filled upper gap upstream of the Oak Bottom temperature control curtain. (Rectangle "A" in Figure 5).**

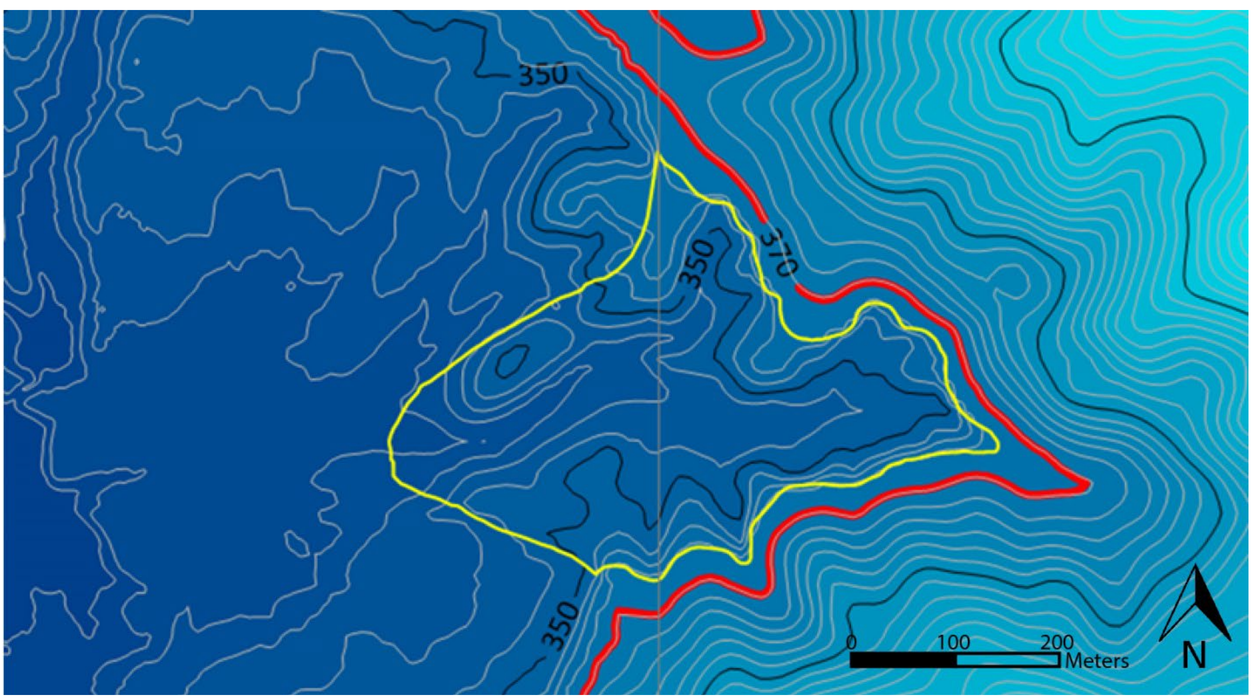


**Figure D-7. Filled lower gap downstream from the Spring Creek temperature control curtain. (Rectangle "B" in Figure 5).**

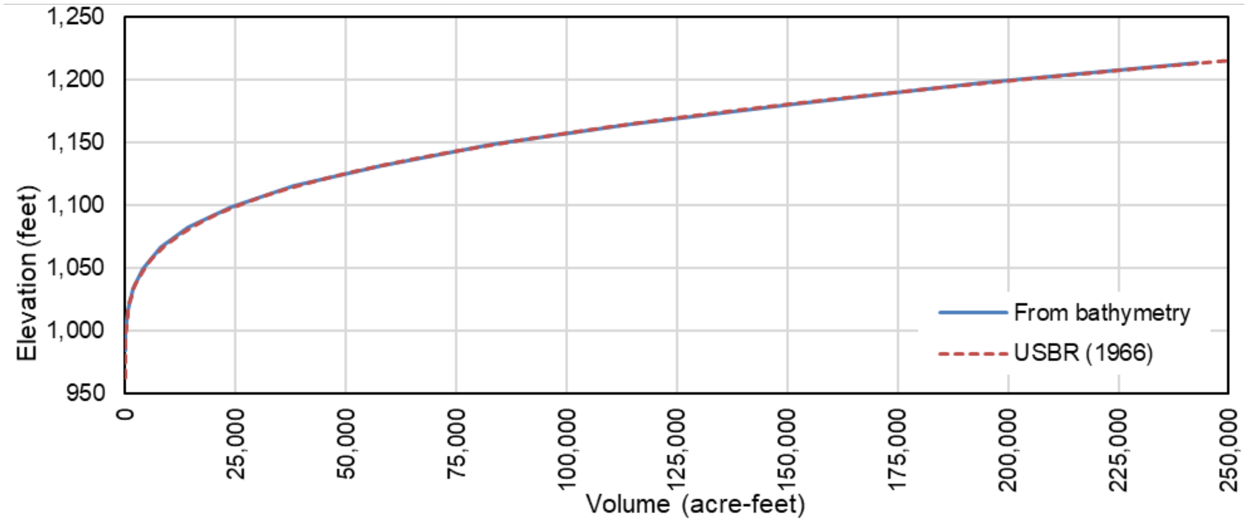


**Figure D-8. Whiskeytown Lake stage-storage curve based on the digitized bathymetry and the existing Reclamation stage-storage table (Reclamation 1966).**

# Electronic Data

Bathymetry data are available in electronic form, in Surfer's grid (.grd file) and map (.srf file) formats or converted to text format.

# References

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U.S. Geological Survey. (USGS). 2021. 20211116, USGS 1 Arc Second n41w123 20210624: U.S. Geological Survey (https://www.sciencebase.gov/catalog/item/60d562e7d34ef0ccfc0c82ad).

# Appendix E: Clear Creek Flow and Water Temperature Data Development

# Technical Memorandum

Date: May 12, 2022

To: Randi Field, U.S. Bureau of Reclamation
Donna Garcia, U.S. Bureau of Reclamation

From: Michael Deas, Watercourse Engineering, Inc.
Yujia Cai, Watercourse Engineering, Inc.

Re: Clear Creek Flow and Water Temperature Data Development

## Introduction

Clear Creek originates in the mountains east of Trinity Lake and flows generally southward for approximately 50 miles to the confluence with the Sacramento River. Whiskeytown Lake is impounded by Whiskeytown Dam approximately 18 miles upstream from the confluence with the Sacramento River. Inflows to Whiskeytown Lake include Clear Creek, other local watershed inflow, and diversions from the Trinity River basin via the Clear Creek tunnel. The Clear Creek watershed area above Whiskeytown Dam is 200 square miles and the Clear Creek watershed area upstream of Whiskeytown Lake 154 square miles (https://streamstats.usgs.gov/). Approximately 80 percent of the inflow to Whiskeytown Lake consists of Trinity River basin diversions (https://sacriver.org/) that enter the headwaters of the lake at Judge Francis Carr Powerhouse.

A USGS flow gage was maintained on Clear Creek at French Gulch CA from 1950 to 1993 (USGS 11371000), and limited water temperature observations were available at this station from 1957 to 1967. No flow or water temperature records of Clear Creek are available after year 1993.

Historic data were used to develop a representative Clear Creek flow and water temperature boundary condition for the Whiskeytown Lake model as part of Water Temperature Modeling Platform (WTMP), and the methodology is described herein.

## Flow Development

To estimate inflows to Whiskeytown Lake from Clear Creek for the 2000-2021 WTMP modeling period, monthly linear regression relationships were developed based on flow data at two USGS gauge stations in adjacent watersheds: the SACRAMENTO R A DELTA CA (USGS

11342000) and COTTONWOOD C NR COTTONWOOD CA (USGS 11376000). The stations, shown in Figure E-1, were selected due to:

- Proximity or similar features to Clear Creek Basin
- Complete flow records available for the same 1950 to 1993 period as historic Clear Creek flows were available (USGS 11371000) and for the WTMP modeling period for years 2000 to 2021
- High statistical correlation with monthly flow at Clear Creek.

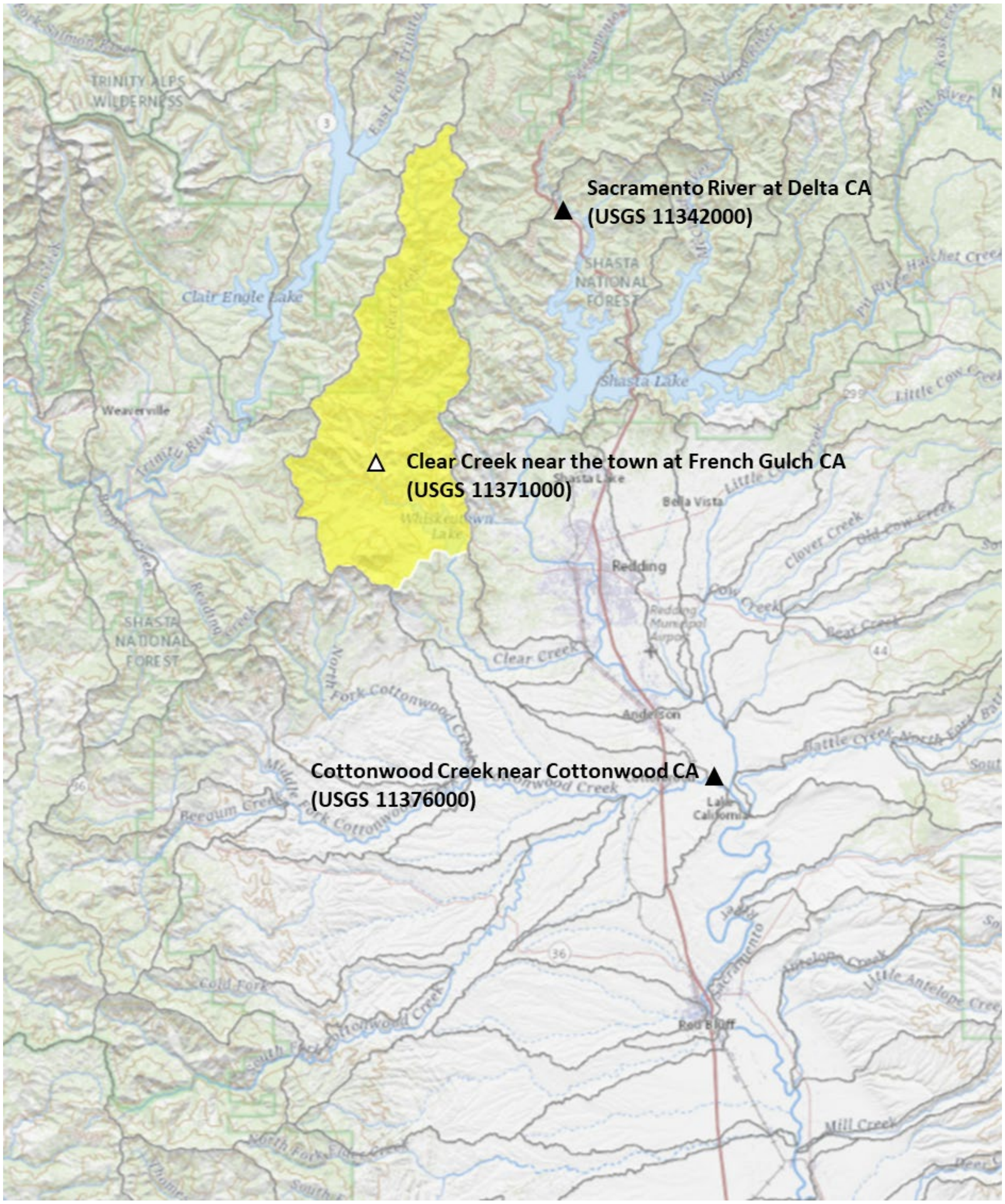


**Figure E-1. Clear Creek watershed above Whiskeytown dam and location of USGS gages used to develop regression relationships for Clear Creek inflow to Whiskeytown Lake (map source: https://streamstats.usgs.gov/).**

Daily flow records from 1950 to 1993 at Clear Creek (USGS 11371000) were compared to flow for the same period for the Sacramento River at Delta (11342000) and Cottonwood Creek (USGS 11376000), and watershed information of the three stations were examined (https://streamstats.usgs.gov/). The upstream watershed for the Sacramento River at Delta is approximately 425 square miles, nearly four times larger than Clear Creek watershed. While flow in the Sacramento River at Delta has a larger magnitude, flow patterns were similar to Clear

Creek from late fall to early Spring (the Sacramento River typically has a snowmelt signature in late spring into to early summer (April – July). Cottonwood Creek watershed area is approximately 922 square miles, while several times larger than the Clear Creek watershed, flow patterns were similar to Clear Creek during March through July.

Monthly linear regression relationships between flow at Clear Creek and the two aforementioned stations were developed using flow records from year 1950 – 1993. The statistical performance and linear regression coefficients were represented in Table E-1. Those relationships were used to produce daily flow data at Clear Creek near French Gulch from year 2000 – 2021 (Figure E-2).

**Table E-1. Statistical performance and coefficients for linear regressions.**

| Month | $R^2$ | RMSE (cfs) | Coefficient a | Std error Coef a | Coefficient C | Std error Coef C | Station Used |
|---|---|---|---|---|---|---|---|
| Jan | 0.92 | 203 | 0.23 | 0.002 | 7.87 | 6.49 | Delta |
| Feb | 0.90 | 211 | 0.23 | 0.002 | 7.81 | 7.95 | Delta |
| Mar | 0.83 | 251 | 0.20 | 0.003 | 111 | 8.37 | Cottonwood |
| Apr | 0.80 | 146 | 0.24 | 0.003 | 52.9 | 5.66 | Cottonwood |
| May | 0.68 | 89.9 | 0.27 | 0.005 | -5.58 | 3.97 | Cottonwood |
| Jun | 0.82 | 27.7 | 024 | 0.003 | 3.97 | 1.21 | Cottonwood |
| Jul | 0.73 | 9.91 | 0.21 | 0.004 | 5.07 | 0.49 | Cottonwood |
| Aug | 0.69 | 4.58 | 0.10 | 0.002 | -8.00 | 0.46 | Delta |
| Sept | 0.80 | 7.66 | 0.07 | 0.001 | -1.24 | 0.32 | Delta |
| Oct | 0.94 | 21.7 | 0.10 | 0.001 | -4.55 | 0.65 | Delta |
| Nov | 0.80 | 113 | 0.13 | 0.002 | 12.7 | 3.50 | Delta |
| Dec | 0.91 | 136 | 0.19 | 0.002 | 3.66 | 4.33 | Delta |

*$Q_{clear\ creek} = a^*Q_{Delta\ or\ Cottonwood} + C$

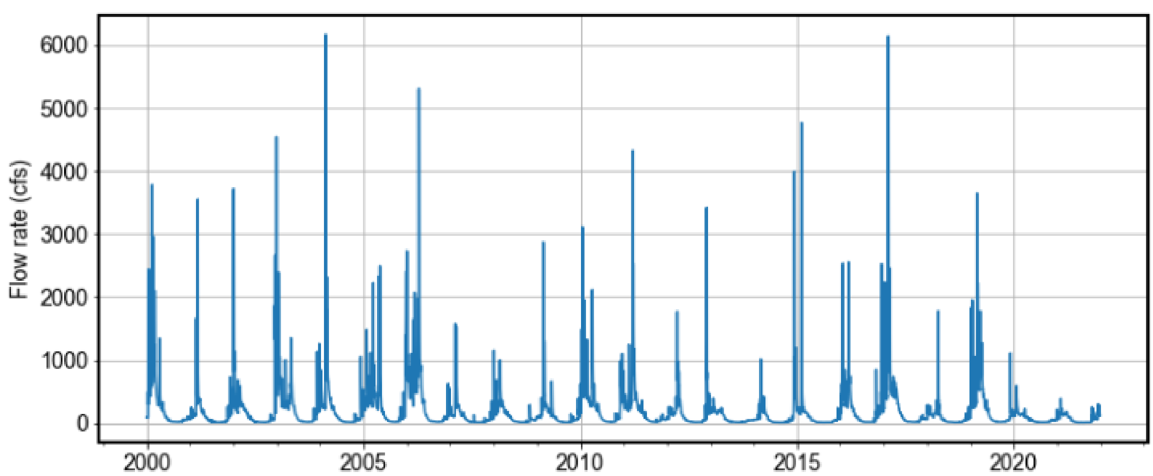

**Figure E-2. Synthetic daily flow at Clear Creek near French Gulch from year 2000 – 2021.**

The USGS gage at Clear Creek near French Gulch is located approximately 4.25 miles upstream of Whiskeytown Lake, and upstream basin area is approximately 115 square miles (https://streamstats.usgs.gov/). While Clear Creek watershed area upstream of Whiskeytown is

154 square miles, to estimate total Clear Creek inflow to Whiskeytown a factor 1.339 (154 square miles / 115 square miles) was applied to Clear Creek flow at USGS gage to account for ungagged inflow downstream of the gage.

Subsequently, a water balance was computed for Whiskeytown Lake to assess the calculated Clear Creek inflow was a representative estimate. The daily water balance used calculated Clear Creek inflow, Judge Francis Carr Powerhouse inflows, Spring Creek Tunnel outflows, Whiskeytown Dam outflows, and Whiskeytown Lake storage change. To smooth out transient events through the lake, a weekly averaged accretion/depletion term was calculated (Figure E-3). Most of the time the accretion/depletion term was close to zero, with large values occurring when notable rainfall events occurred (e.g., daily precipitation in excess of 2 inches). The period average flow for the calculated Clear Creek flow was over 200 cfs. Thus, explicitly characterizing Clear Creek inflow resulted in a near zero accretion/depletion, which will improve Whiskeytown Lake model representations.

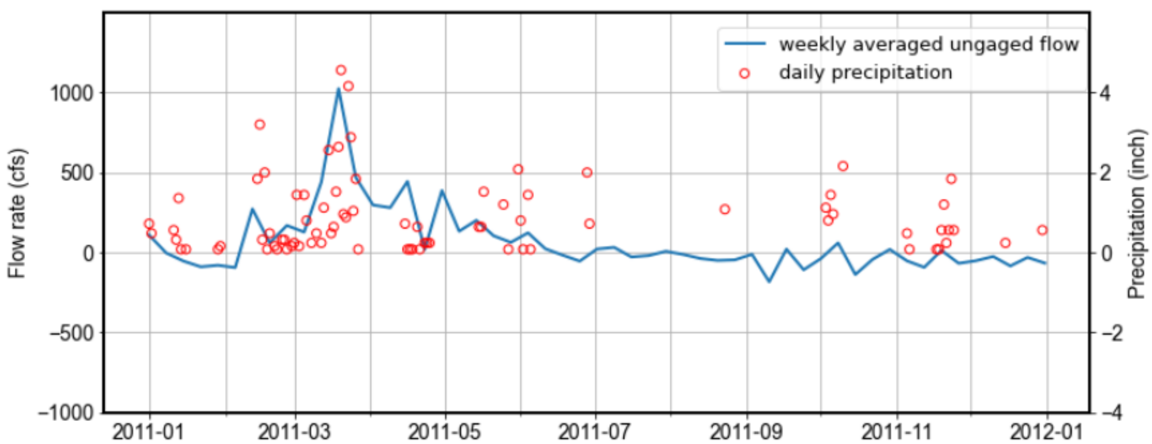


**Figure E-3. Computed weekly averaged net ungaged flow at Whiskeytown Lake using synthetic Clear Creek flow in year 2011.**

# Water Temperature Development

Water temperatures for Clear Creek inflows to Whiskeytown Lake were developed using an equilibrium temperature approach, wherein hourly meteorological data, and daily flow and stage data are used to produce hourly water temperature data (NFWF 2013). The approach assumes that water temperatures are in equilibrium with meteorological conditions. The relationship is dynamic and though a useful proxy for estimating water temperature boundary conditions. The approach has limitations. For example, in certain basins where spring and early summer snowmelt creates high flow conditions, water temperatures may remain well below equilibrium for notable distances downstream. In this case, historic Clear Creek flow records at the USGS gage near French Creek did not indicate a strong snowmelt signature, and the equilibrium approach was deemed appropriate. When the calculated equilibrium water temperature fell below 0°C, an infrequent condition, the value was set to 0°C.

Meteorological data from Redding Airport (station RRAC1, elevation 505 ft) were used, with air temperature, dew point, and wet bulb temperature adjusted to the elevation of Clear Creek (elevation 1,345 ft) using a lapse rate of 10.2oF per 3,280 ft (Linacre, E. 1992) elevation change.

Stage data with two Clear Creek rating curves to represent high and low flow conditions were developed using measured flow and stage data from 1955 to 1993 (Figure E-4).

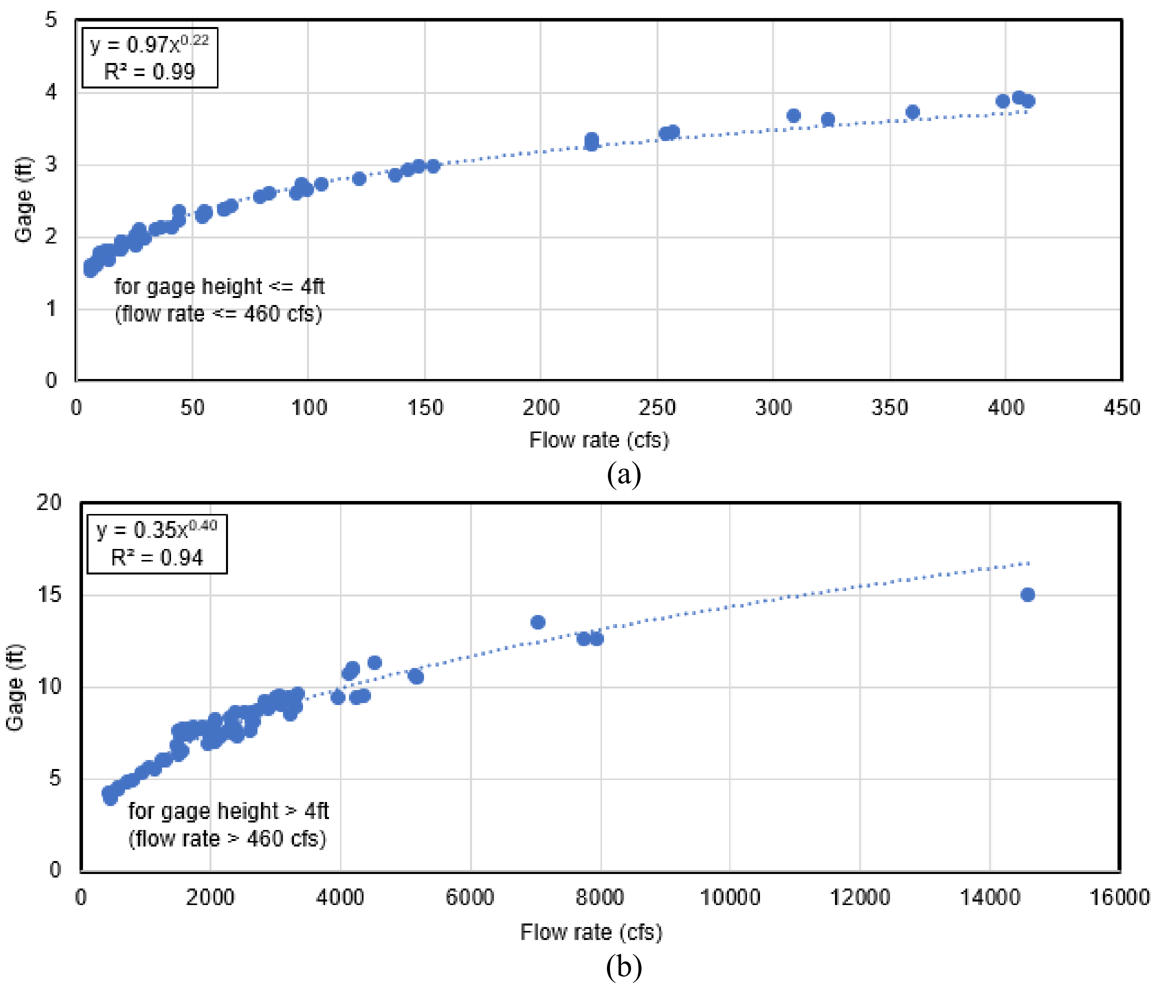


**Figure E-4. Rating curves developed for Clear Creek using 1955-1993 data (USGS 11371000) for (a) low flow (≤460 cfs) and (b) high flow (>460 cfs).**

Grab sample temperature data were available at Clear Creek (USGS 11371000) from 1957 to 1967 (Table E-2). Though there are few records in summer months (July-September), the entire data set was examined based on Julian Day to develop an envelope of maximum and minimum temperatures for an annual period based on a 14-day moving average. This envelop provided a "guide" in the development of an equilibrium temperature model application to develop time series of water to develop a representative temperature range at Clear Creek throughout the year and was used for the 2000 to 2021 period (Figure E-5).

**Table E-2. Number of water temperature data points in each month for Clear Creek at French Gulch: 1957-1967.**

| Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of data | 31 | 28 | 43 | 36 | 17 | 10 | 4 | 0 | 3 | 9 | 29 | 52 |

## Summary

No available flow or water temperature data were available for Clear Creek inflows to Whiskeytown Lake for the WTMP modeling period (2000-2021). Clear Creek daily inflows were developed using monthly regression equations using information from adjacent basins: Sacramento River at Delta and Cottonwood Creek near Cottonwood.  A water balance was completed on Whiskeytown Lake to verify the estimated flows were representative. Water temperature data were developed using an equilibrium temperature approach based on the estimated flow data and meteorology from Redding Airport. The range of historic water temperature data were used as a guide to develop equilibrium water temperatures for inflows to Whiskeytown Lake. These data and assumptions can be reassessed during model calibration (e.g., CE-QUAL-W2 and HEC-ResSim).

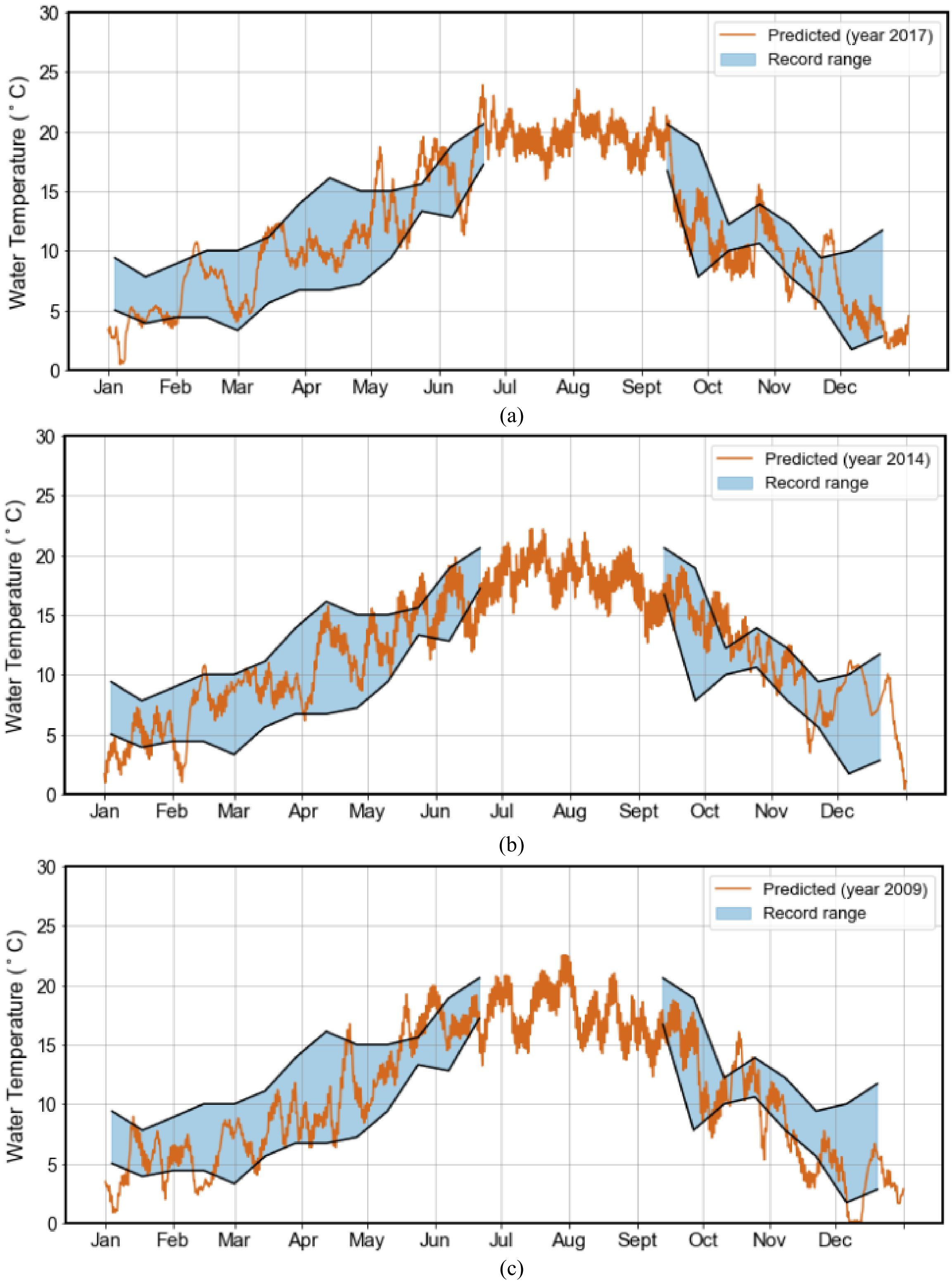


**Figure E-5. Calculated hourly equilibrium temperature for Clear Creek and range of historic water temperature data (1957-67) for (a) 2017, (b) 2014, and (c) 2009.**

# References

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# Appendix F: Clear Creek Tunnel Heating Model

Watercourse Engineering Inc.

# Technical Memorandum

Date: May 12, 2022

To: Randi Field, U.S. Bureau of Reclamation
Donna Garcia, U.S. Bureau of Reclamation

From: Michael Deas, Watercourse Engineering, Inc.
Yujia Cai, Watercourse Engineering, Inc.

Re: Clear Creek Tunnel Heating Model

## Purpose

The Clear Creek Tunnel conveys water from Lewiston Lake in the Trinity River basin to Judge Francis Carr Powerhouse at Whiskeytown Lake in the Clear Creek watershed (and Sacramento River basin). The tunnel is 10.7 miles long and 17.5 feet in diameter throughout its length (except the last 385 feet, which has a diameter 15.67 feet). Water from the Clear Creek Tunnel is conveyed through two penstocks to the Judge Francis Carr Powerhouse. Models included in the Water Temperature Modeling Platform (WTMP) require that heat gain or loss through the Clear Creek Tunnel be effectively represented. This document describes the calculation of heat gain (°F) in the Clear Creek Tunnel on a monthly basis and the application of the results.

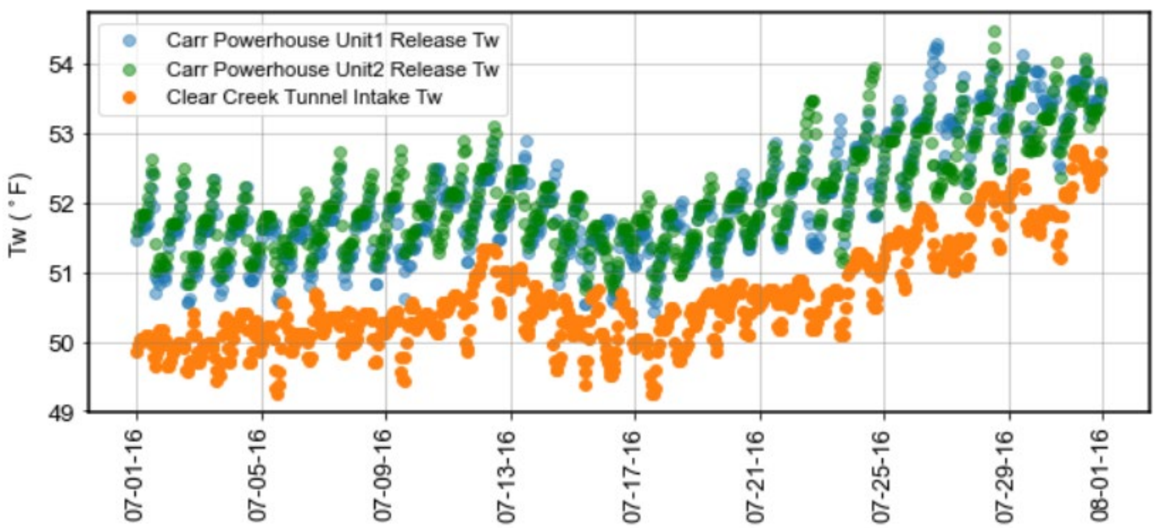
## Available Data

Available field observations include hourly Clear Creek Intake water temperature data at Lewiston Lake, hourly flow rate data in Clear Creek Tunnel (both total flow, and separate flows in each of the two penstocks), and hourly release water temperature at Judge Francis Carr Powerhouse. Flow and water temperature data are available from the year 2000 to 2020, but multiple data gaps exist in water temperature data. Specifically,

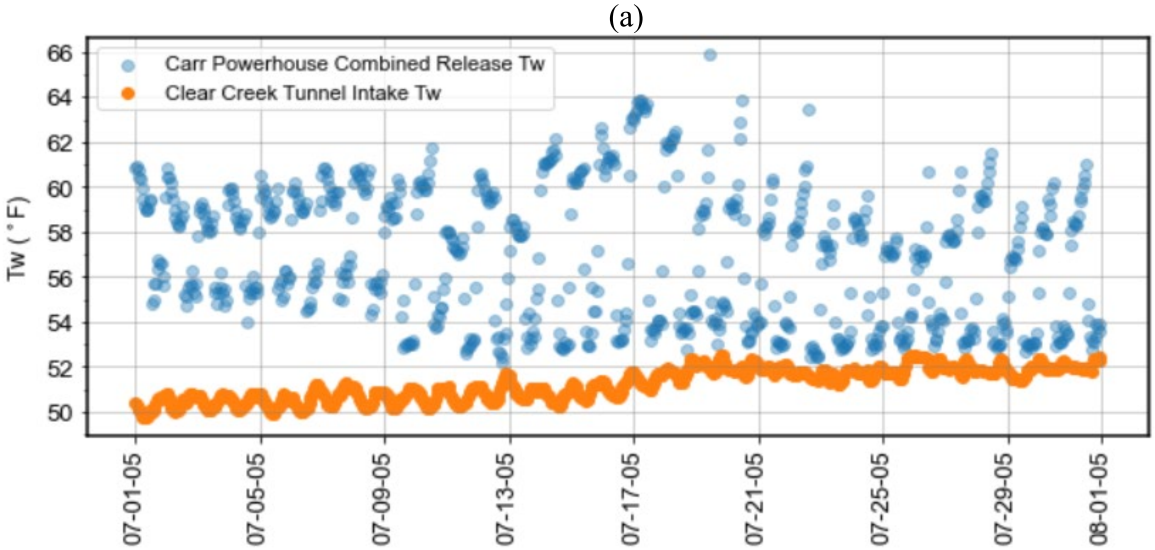
- At Judge Francis Carr Powerhouse reliable water temperature data prior to 2006 were unreliable (see below), and there are no water temperature data between the years 2006 and 2011 (temperature loggers missing according to field records).
- Judge Francis Carr Powerhouse outflow water temperature data are available at both penstocks after the year 2012; however, Judge Francis Carr Powerhouse and at the Clear Creek Tunnel intake water temperature data gaps ranging from days to months exist in the 2012 to 2021 period.

- Water temperature data at Judge Francis Carr Powerhouse from year 2012 to present typically reflects the short-, medium-, and long-term temperature signature at the Clear Creek Tunnel intake, albeit consistently warmer (Figure F-1(a)). Prior to year 2006 the relationship between water temperature at Judge Francis Carr Powerhouse and Clear Creek Tunnel intake is unclear, with little similarity between the two temperatures (Figure F-1(b)). The lack of consistent temperature trends between the two locations suggests that the monitoring approach prior to 2006 did not effectively capture water temperatures released from Judge Francis Carr Powerhouse. These differences suggest that the water temperature monitoring location, equipment, or method at Judge Francis Carr Powerhouse was changed to a more effective approach post-2012.

Based on the above information, Clear Creek Tunnel heating relationships were based on available data from 2012 to 2021.




(a)




(b)

**Figure F-1. Clear Creek Tunnel intake and Judge Francis Carr Powerhouse (Carr Powerhouse) water temperatures in (a) July 2016 and (b) July 2005).**

# Data Processing and Analysis

Initial assessment of available data indicated that water temperatures consistently increased through the tunnel year-round. Conduction, the principal heating mechanism in the tunnel (X. Lu. et al.2005), is a function temperature difference between water and tunnel wall. Temperature increases through Clear Creek Tunnel are closely related to inflow temperature, flow rate, and season. Generally,

- When flow rate is low, conveyance time through the tunnel increases, which translates to increased heat gain. The converse is true when flow rate is high.
- When inflow temperature is low, heat gain is greater compared to when inflow temperature is high.

Analyzing the flow distribution from the year 2012 to 2021 identified several flow regimes that were considered in the development of heating relationships: two units at operating at capacity (approximately 3,200 cfs), one (either) unit at operating at capacity (approximately 1,600 cfs), or a low flow condition (neither unit operating at or near capacity) (Figure F-2).

When the two units were not operating at full capacity, flowrates were typically lower than 250 cfs (per unit) and often considerably lower (Figure F-2). Under this condition, the residence time increases, which can lead to greater heat gains than under high flow conditions. The impact of increased residence time is more pronounced during the warmer periods of the year. However, the thermal energy contribution to Whiskeytown Lake is not necessarily large under these conditions because the flow rate is only a fraction of typical operations (one- or two-unit flows, approximately 1,600 cfs or 3,200 cfs, respectively).

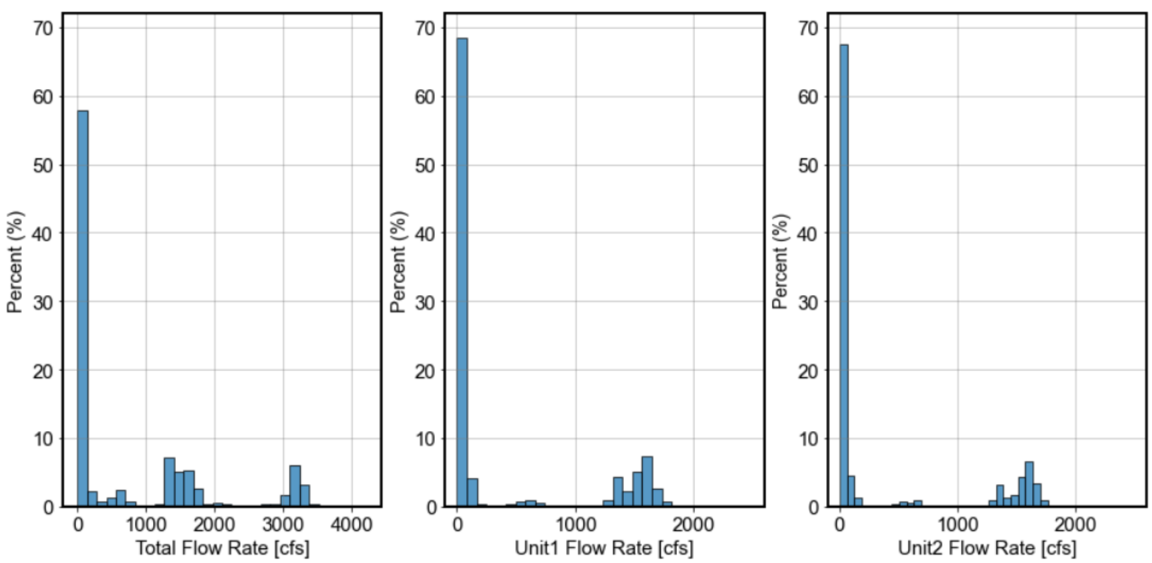



**Figure F-2. Flow Rate Distributions in Judge Francis Carr Powerhouse from the Year 2012 – 2021. (left) total flow rate; (middle) Unit 1 flow rate; (right) Unit 2 flow rate.**

Flow weighted outflow water temperature at Judge Francis Carr Powerhouse was estimated using multiple linear regression relationships where powerhouse flow rate and Clear Creek Tunnel intake temperature were independent variables (Equation 1). Two sets of monthly heat gain relationships were developed: for total flows ≤500 cfs and for total flows >500 cfs. The cutoff point of 500 cfs was arrived at assuming each of the two units had a flow of <250 cfs (for a total of ≤500 cfs). For the period May through October the two sets of equations were employed to capture the range of operations. For the period November through April a low flow condition was unnecessary.

$$T_{release,t=i} = \frac{Q_{1,t=i}*T_{1,t=i} + Q_{2,t=i}*T_{2,t=i}}{Q_{1,t=i}+Q_{2,t=i}} = \mathrm{AQ}_{\mathrm{total,t=i}} + BT_{in,t=i} + C \qquad \text{(Equation 1)}$$

Where

- $T_{release,t=i}$ is flow weighted average release temperature at time *i*;
- $Q_{1,t=i}$ is flow rate of Unit 1 at time *i*;
- $Q_{2,t=i}$ is flow rate of Unit 2 at time *i*;
- $Q_{Total,t=i}$ is the total release flow rate of Unit 1 and Unit 2 at time *i*;
- $T_{1,t=i}$ is release water temperature of Unit 1 at time *i*;
- $T_{2,t=i}$ is release water temperature of Unit 2 at time *i*;
- $T_{in,t=i}$ is the intake water temperature at Lewiston at time *i*;
- *A*, *B*, and *C* are regression coefficients.

Available data were filtered to remove spikes in temperature due to powerhouse flows increasing from (near) zero to full load, inconsistencies between loggers in Unit 1 and/or Unit 2, transit time between the Clear Creek Tunnel intake and Judge Francis Carr Powerhouse, loggers collecting erroneous temperatures (e.g., air temperature), and other factors. Similarly, erroneous readings in Clear Creek Tunnel Intake temperature data (e.g., air temperature) were removed.

# Model Performance and Results

Summary statistics representing linear regression performance are summarized in Table F-1 through Table F-3. The coefficients of fitted linear regression and standard error are summarized in Table F-4 through Table F-6. Analyses were performed using the statistical analysis package statsmodels in Python, V0.13.2.

**Table F-1. Summary of statistics of predicted and measured outflow temperature when flow rate> 500 cfs: May - October.**

| Statistics | May | June | July | August | September | October |
|---|---|---|---|---|---|---|
| Mean Square Error (deg F)$^2$ | 0.073 | 0.15 | 0.03 | 0.12 | 0.064 | 0.15 |
| $R^2$ | 0.98 | 0.94 | 0.91 | 0.94 | 0.96 | 0.93 |
| Count | 785 | 1091 | 773 | 851 | 730 | 1114 |

**Table F-2. Summary of statistics of predicted and measured outflow temperature when flowrate ≤ 500 cfs: May - October.**

| Statistics | May | Jun | Jul | Aug | Sept | Oct |
|---|---|---|---|---|---|---|
| Mean Square Error (deg F)$^2$ | 0.50 | 0.20 | 0.22 | 0.42 | 0.13 | 0.085 |
| $R^2$ | 0.80 | 0.90 | 0.59 | 0.51 | 0.86 | 0.95 |

| Statistics | May | Jun | Jul | Aug | Sept | Oct |
|---|---|---|---|---|---|---|
| Count | 1447 | 1065 | 715 | 1046 | 1070 | 1758 |

**Table F-3. Summary of statistics of predicted and measured outflow temperature: November-April.**

| Statistics | Nov | Dec | Jan | Feb | Mar | Apr |
|---|---|---|---|---|---|---|
| Mean Square Error (deg F)$^2$ | 0.24 | 0.26 | 0.11 | 0.11 | 0.32 | 0.45 |
| $R^2$ | 0.93 | 0.88 | 0.88 | 0.83 | 0.87 | 0.84 |
| Count | 2477 | 3468 | 2704 | 1422 | 2227 | 2100 |

**Table F-4. Coefficients of linear regression (flowrate > 500) cfs: May-October.**

| Coefficients | May | Jun | Jul | Aug | Sept | Oct |
|---|---|---|---|---|---|---|
| A | -0.0002 | -0.0002 | -0.0001 | -0.000052 | -0.000055 | -0.00008 |
| Std. error A | 0.000018 | 0.000015 | 0.0000069 | 0.000014 | 0.000014 | 0.000015 |
| B | 0.92 | 0.87 | 0.92 | 0.90 | 0.91 | 1.04 |
| Std. error B | 0.0080 | 0.0060 | 0.01 | 0.0080 | 0.0070 | 0.009 |
| C | 4.99 | 7.84 | 5.61 | 6.31 | 6.06 | -0.55 |
| Std. error C | 0.39 | 0.31 | 0.53 | 0.40 | 0.35 | 0.43 |

*$T_{release,\ t=i} = A{*}Q_{total,\ t=i} + B{*}T_{in,\ t=I} + C$

**Table F-5. Coefficients of linear regression (flowrate ≤ 500 cfs): May-October.**

| Coefficients | May | June | July | August | September | October |
|---|---|---|---|---|---|---|
| A | -0.0040 | -0.0017 | -0.0018 | -0.0019 | 0.00030 | 0.00040 |
| Std. error A | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| B | 0.74 | 0.77 | 0.82 | 0.59 | 0.88 | 0.91 |
| Std. error B | 0.010 | 0.0080 | 0.027 | 0.020 | 0.011 | 0.0050 |
| C | 14.88 | 13.06 | 10.87 | 22.63 | 7.30 | 6.00 |
| Std. error C | 0.48 | 0.40 | 1.37 | 1.07 | 0.57 | 0.26 |

*$T_{release,\ t=i} = A{*}Q_{total,\ t=i} + B{*}T_{in,\ t=I} + C$

**Table F-6. Coefficients of linear regression: November - April.**

| Coefficients | Nov | Dec | Jan | Feb | Mar | Apr |
|---|---|---|---|---|---|---|
| A | -0.00020 | -0.00020 | -0.00030 | -0.000041 | -0.00010 | -0.00020 |
| Std. error A | 0.000016 | 0.000016 | 0.000015 | 0.00002 | 0.000034 | 0.000026 |
| B | 0.933 | 1.06 | 0.84 | 0.73 | 0.87 | 4.86 |
| Std. error B | 0.005 | 0.007 | 0.006 | 0.009 | 0.007 | 0.45 |
| C | 4.67 | -1.03 | 8.83 | 13.45 | 7.52 | 4.86 |
| Std. error C | 0.25 | 0.30 | 0.26 | 0.41 | 0.34 | 0.45 |

*$T_{release,\ t=i} = A{*}Q_{total,\ t=i} + B{*}T_{in,\ t=I} + C$

A comparison between predicted and measured hourly flow-weighted release water temperature at Judge Francis Carr Powerhouse is shown in Figure F-3. Predicted release water temperature is calculated by substituting measured intake water temperature and total flowrates in Clear Creek Tunnel to the linear regression equations. Gaps in the figure are periods when inflow water temperature data are missing.

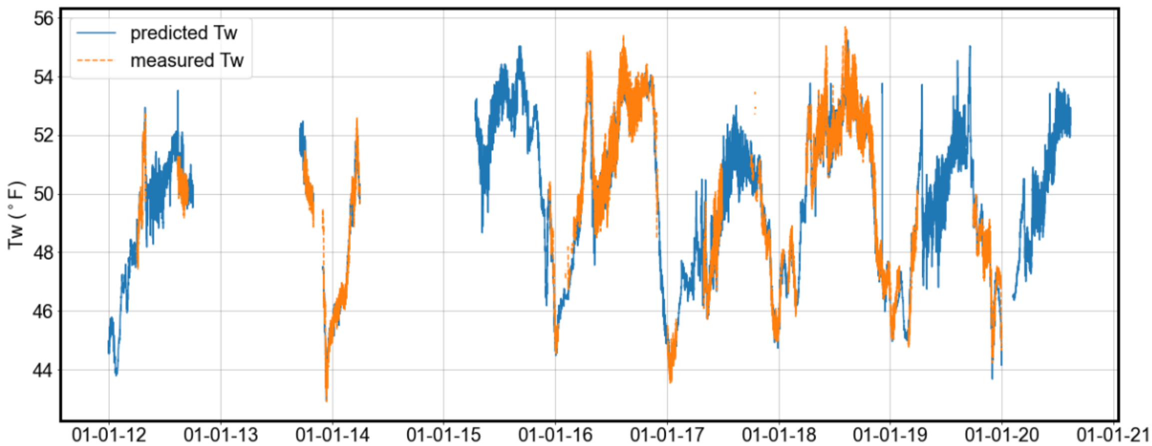


**Figure F-3. Predicted and measured flow weighted outflow temperature at Judge Francis Carr Powerhouse.**

Heat gains of water in Clear Creek Tunnel were calculated as the temperature difference between temperature at the Lewiston Lake intake and flow weighted release temperature at Judge Francis Carr Powerhouse at the same date and hour. Predicted and observed heat gains in each month are shown in Table F-7 and Table F-8.

**Table F-7. Predicted heat gains in Clear Creek Tunnel.**

| Heat Gains | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean (deg F) | 1.46 | 1.27 | 1.33 | 1.31 | 1.67 | 1.28 | 1.35 | 1.33 | 1.37 | 1.22 | 1.39 | 1.48 |
| Std. Deviation (deg F) | 0.24 | 0.31 | 0.22 | 0.22 | 0.64 | 0.49 | 0.28 | 0.37 | 0.15 | 0.13 | 0.16 | 0.14 |

**Table F-8. Observed heat gains in Clear Creek Tunnel.**

| Heat Gains | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean (deg F) | 1.44 | 1.09 | 1.29 | 1.28 | 1.66 | 1.40 | 1.38 | 1.27 | 1.35 | 1.18 | 1.44 | 1.48 |
| Std. Deviation (deg F) | 0.40 | 0.42 | 0.61 | 0.68 | 0.88 | 0.70 | 0.46 | 0.50 | 0.34 | 0.35 | 0.51 | 0.53 |

## Recommendation

Examining both the predicted and observed data, the average heat gains of water in Clear Creek Tunnel are between 1ºF to 2ºF throughout the year. The linear regression relationships used to predict increases in waters conveyed through Clear Creek Tunnel utilize inflow temperature and flow. The relationships for May through October perform better when the flowrate is high (e.g., flows >500 cfs). For the November to April relationships a single set of relationships is used

These regressions will be used to represent temperature increases in waters conveyed from Lewiston Lake to Whiskeytown Lake via the Clear Creek Tunnel in the WTMP.

## References

Lu, X., P. Tervola, M. Viljanen. 2005. “Transient analytical solution to heat conduction in composite circular cylinder.” International Journal of Heat and Mass Transfer. 49. 341–348.