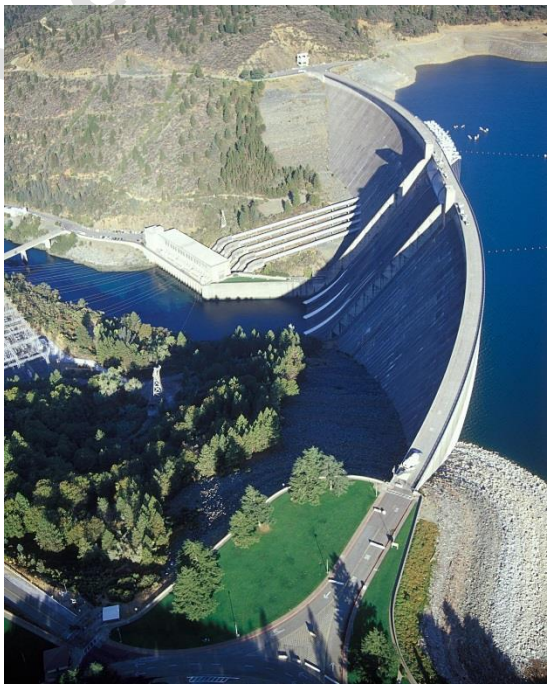
RECLAMATION

Managing Water in the West

DRAFT Workplan for Shasta and Trinity Division Seasonal Operational Water Temperature Modeling

Central Valley Project, California
Mid-Pacific Region



U.S. Department of the Interior
Bureau of Reclamation

October 2016

Mission Statements

The mission of the Department of the Interior is to protect and manage the Nation's natural resources and cultural heritage; provide scientific and other information about those resources; and honor 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.

Contents

Page

Introduction and Objectives

Recent drought and associated impacts to fish species have increased attention on water temperature management in the Sacramento River below Keswick Dam. Specifically, Winter-Run chinook salmon, a listed species under the Endangered Species Act (ESA), has been one of the species impacted by water temperature management challenges associated with the limited supply of water on the Sacramento River during the drought. Water temperature models have been developed to assist resource managers to plan, forecast, and operate storage and conveyance systems such as the Shasta and Trinity Divisions of the Central Valley Project (CVP) to meet a wide range of water supply demands. A useful element in ongoing resource management is a periodic assessment of existing tools and opportunities for improvement.

Background

Currently, the Bureau of Reclamation (Reclamation) utilizes a water temperature modeling framework to forecast water temperature conditions in the Sacramento River for seasonal operations planning. The base model, HEC-5Q, simulates water temperature in response to specified hydrology on a 6-hour time step at approximately 1 mile increments. The sub-daily time step of this model provides insight into daily minimum and maximum water temperatures (6 a.m. and 6 p.m., respectively). The model domain includes the Trinity and Shasta Divisions of the CVP, and models:

- Trinity Lake (one-dimensional: laterally and longitudinally averaged)
- Lewiston Reservoir and Carr Diversion (two-dimensional*: laterally averaged)
- Whiskeytown Lake and Spring Creek Diversion (one-dimensional: laterally and longitudinally averaged)
- Shasta Lake (one-dimensional: laterally and longitudinally averaged)
- Keswick Reservoir (two-dimensional*: laterally averaged)
- Sacramento River from Keswick Dam to below the American River, along with Clear Creek from Whiskeytown to the Sacramento River (one-dimensional: laterally and vertically averaged)

** Pseudo two-dimensional model presentation, laterally averaged.*

This large-scale network model is a valuable tool to analyze the inter-connected elements of the Trinity and Shasta Divisions, representing Trinity Lake, diversions from the Trinity River system to the Sacramento River, releases from Whiskeytown to Clear Creek, and inter-basin diversions into Keswick, as well as Shasta Lake, and downstream Sacramento River conditions, as shown in Figure 1. This configuration provides a powerful network model that can simulate all the

facilities and operations for extended periods. The model is computationally efficient, with relatively short simulation times (tens of minutes) for simulation periods of decades.

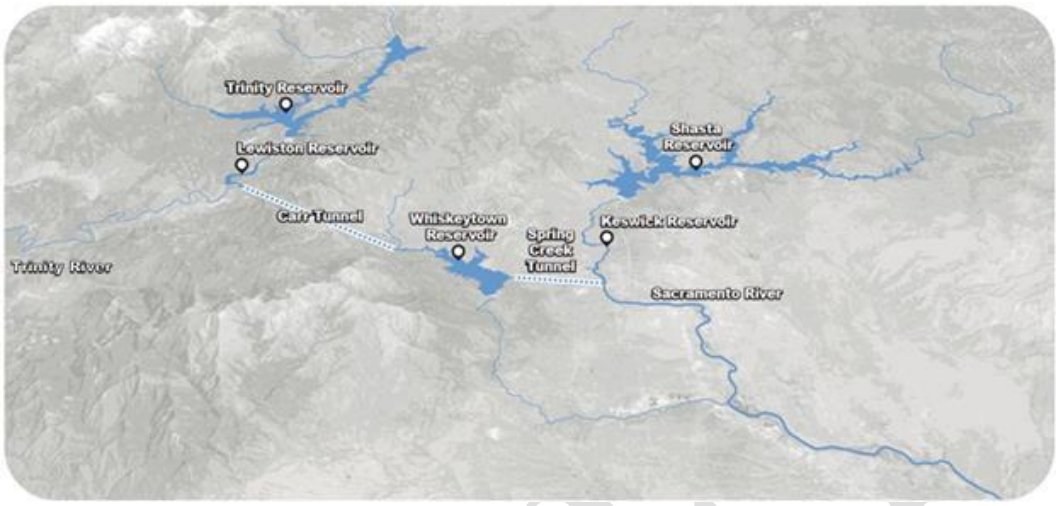


Figure 1. Trinity and Sacramento River reservoirs, conveyance facilities, and stream reaches.

Project Description

Though the current HEC-5Q modeling framework for the Shasta and Trinity Divisions remains a valuable and effective tool for operations planning, opportunities may exist for improvement and refinement. As Reclamation proceeds into the future, models that are broadly accepted, frequently updated, well documented, and are actively supported will become increasingly important. In addition, models capable of finer scale spatial and temporal analysis are expected to provide benefits to operations. With those goals for model development and refinement into the future, this project is intended to result in the following outcomes:

1) Development of a revised/new framework for seasonal Shasta and Trinity Division planning/operations modeling.
2) Evaluation and selection of appropriate models/interface mechanisms for the framework.
3) Revision/development of models, interface mechanisms (input and output), and linkages within the framework.
4) Review and potential revision/update/development of input data for models.
5) Calibration, validation, and peer review of new/revised data, models and other products.
6) Implementation of the new/revised framework, including a transition process to full operational use.
7) Partner and stakeholder involvement and outreach during all phases of the project.

Modeling Objectives

Similar to the existing HEC-5Q tool, a revised/new framework for the Shasta and Trinity Divisions of the CVP is expected to meet the following general objectives:

1) Identify initial cold water pool volumes
2) Based on the initial cold water pool volume, forecast the impacts of potential operational strategies on water temperatures through the temperature control period (late spring into fall)
3) Assist in the development of a cold water management plan, with incorporation of uncertainty in model representation and future conditions (e.g., inflow quantity and temperature, meteorology, etc.)

In order to meet these objectives, the models and framework will need to have the following capabilities:

1) Prediction of reservoir* inflow volume, temperature, and timing, with associated uncertainty estimates.
2) Prediction of reservoir* water temperature stratification, with associated uncertainty estimates.
3) Reservoir** and river*** temperature modeling capabilities.
4) In an operations planning mode; automated selective reservoir withdrawl to meet a temperature target at a specified downstream point, given a reservoir release schedule.
5) Estimation of uncertainty associated with predicted water temperatures and/or ability to meet downstream temperature target.
6) Capability to translate uncertainty in individual inputs and modeling estimates throughout framework.

* Reservoir modeling identified will likely need to be completed at appropriate scales/resolution for Shasta Lake, and potentially Trinity Lake.
** Reservoir modeling identified will potentially need to be completed at appropriate scales/resolution for Shasta, Keswick, Trinity, Lewiston, Whiskeytown, and Spring Creek Reservoirs.
*** For river temperature modeling, forecast/prediction of water temperature on an appropriate timestep at locations in the Sacramento River downstream of Keswick dam for a given seasonal reservoir release schedule.

DRAFT Project Plan

This project is intended to develop a collection of data, long-term monitoring stations, and a set of tools within a modeling framework to assist resource managers with balancing water releases from Shasta Lake and downstream needs and water temperatures. Because there are several parties that are actively involved in operations and water temperature management in the Sacramento River system that also bringing considerable expertise to the process, a collaborative approach is envisioned. Initial outreach will identify interest, experience, and resources. Subsequently, as model framework elements are developed, interim products will be shared with involved parties to solicit feedback. There are likely to be data and information limitations, and assumptions will be required at certain steps in the process.

The proposed approach aims to utilize existing models, update/refine existing models, and develop, as necessary, new models to be used to assist operators managing Shasta Lake, as well as other facilities, for water temperature control in downstream Sacramento River reaches. The project would be phased to accommodate higher priorities sooner, with future phases to be implemented as needed. It is currently envisioned that the initial phase will focus on the Shasta Lake and Keswick Reservoir components of the framework, since they represent the most significant factors influencing temperatures on the Sacramento River downstream of Keswick Dam. This phasing will also allow for the selection and development of modeling tools and linkages between models that can inform development of the remaining elements of the overall framework.

Stakeholder Involvement and Outreach

Objective:
Maintain transparency and interaction with stakeholders through outreach activities.

Tasks:

- Convene Technical Advisory Group consisting of Reclamation and other identified agencies (i.e., NMFS, State Water Resources Control Board, CVP contractors, etc.) - through this group model development activities will be shared to maintain transparency
- Conduct training as appropriate

Deliverables:
Meetings, calls, and other communications and project administrator activities. Collaboration with other agencies during model development and application.

Framework Design/Refinement

Objective:
Develop a system-wide framework that illustrates the spatial and temporal representation of each model used in the Trinity and Sacramento River basins, how the different elements (reservoirs and rivers) relate to one another, how information is shared among the models (data and does the output from one model provide input to another model), status of the models (latest calibration, version, etc.)

Tasks:
- Gather information on existing tools
- Design a framework,
    - Define spatial and temporal scale
    - Identify the "path" of information through the model(s) and data sharing from model inputs to model outputs
    - Identify the status of the models and any potential development and data needs

This framework will provide insight into model refinement/development and ensure that tasks and phases can be prioritized based on need and ability to efficiently implement each task upon completion (i.e. place into direct use in current or refined framework).

Deliverable:
Technical memorandum outlining a modeling framework.

Additional Description/Initial Concepts:
The framework will likely be highly similar to that of the current HEC-5Q operational framework, and is anticipated to ultimately include the following key elements:
1) Inflow volume, timing, and temperature forecasting/modeling to Shasta Lake.
2) Temperature and stratification forecasting/modeling of Shasta Lake based on forecasted inflow, meteorologic conditions, and a forecasted release schedule.
3) Inflow volume, timing, and temperature forecasting/modeling to Trinity Lake.
4) Temperature forecasting/modeling of Trinity Lake based on forecasted inflow, meteorologic conditions, and a forecasted release schedule.
5) Temperature forecasting/modeling of Lewiston Reservoir based on a forecasted release schedule from Trinity Lake, meteorologic conditions, and a forecasted Carr Tunnel diversion schedule.
6) Temperature forecasting/modeling of Whiskeytown Lake based on forecasted inflow, a forecasted diversion schedule through Carr Tunnel,

meteorologic conditions, and a forecasted release and diversion schedule to Clear Creek and Spring Creek Tunnel.

7) Temperature forecasting/modeling of Keswick Reservoir based on a forecasted release schedule from Shasta Dam, meteorologic conditions, a forecasted diversion schedule from Spring Creek Diversion Dam, and a forecasted release schedule.
8) Temperature forecasting/modeling of the Sacramento River based on a forecasted release schedule from Keswick Dam, forecasted meteorologic conditions, and a forecasted release schedule from Whiskeytown Dam/Clear Creek.
9) Data linkages between each of the model elements outlined above.
10) Simulated operation of the Shasta Dam Temperature Control Device (TCD) for automated selective withdrawal from Shasta Lake given a downstream temperature target and specified forecasted release schedule.

Model Selection/Design

Objective:
Select models for each of the elements of the framework based on objectives and selection criteria. Determine the appropriate spatial and temporal resolution of the selected models, and conduct any additional necessary design specification for the models.

Tasks:
For each model in the framework (and at appropriate timing in the overall project plan):

- Identify specific selection criteria and requirements for model
- Identify existing models and potential modeling packages for new model development
- Evaluate identified models based on selection criteria and select one
- Complete initial model design and/or identify necessary refinements (if selected modeling approach is to refine an existing one)

Deliverables:
Model selection and initial design/refinement identification for each model in framework (to be completed at appropriate timing in overall project plan).

Additional Description/Initial Concepts:
Model elements and capabilities for consideration in selection will likely include (but not be limited to):

- Contribution of model if different from an existing one (value added)
- Model capabilities (such as flexibility to represent selective withdrawal or temperature control curtains for reservoir components)
- Model spatial and temporal scales
- Model data needs
- Model performance

- Interface of new model with other models in framework
- Resources required to develop and maintain a model
- Actively supported
- Access to the principal code author and/or open source code (allowing review and modification)
- No cost (no initial cost or annual maintenance fee)
- Comprehensive documentation and training available
- User interface for input file quality control
- Post processors (both public and proprietary) available
- Wide range of applications

The Trinity and Sacramento River basins have a long history of temperature modeling. A partial list of currently available models that simulate temperature for the systems is listed in Table 1. While other models exist, these models represent those that are, or have been, used for major studies in the project area. These models would be among those evaluated for use as part of the selection process.

Table 1. Partial list of currently available models

System	Thermal Conditions/ Attributes	Model	Dimension	Sponsor
Trinity Lake	Seasonal Stratification	HEC-5Q	1-D (vert.)	USBR
Lewiston Reservoir	Seasonally weak stratification and longitudinal gradient, curtains	HEC-5Q	2-D (vert./long, pseudo)	USBR
		CE-QUAL-W2	2-D (vert./long)	USBR
Whiskeytown Lake	Seasonal Stratification, curtains	HEC-5Q	1-D (vert.)	USBR
Shasta Lake	Seasonal Stratification, TCD	HEC-5Q	1-D (vert.)	USBR
		CE-QUAL-W2	2-D (vert./long)	USGS/UNR/NOAA
Keswick Reservoir	Seasonally weak stratification and longitudinal gradient,	HEC-5Q	2-D (vert./long, pseudo)	USBR

Sacramento R.	Well mixed vertically, and generally well mixed laterally	HEC-5Q	1-D (long.)	USBR
		RMA-2/11	1-D (long.)	USBR
		RAFT	1-D (long.)	NOAA

Abbreviations:
- Long. = longitudinal representation
- Vert. = vertical representation
- Pseudo = reservoir segmented vertically & longitudinal in a simple two-dimensional representation (no hydrodynamics).

Data Development

Objective:
Identify necessary input data to models, and obtain or develop datasets for use with models.

Tasks:
- Identify necessary data and sources for use with models
- For input requirements which will use historic data, obtain datasets from appropriate sources
    - Perform quality analysis and potentially quality control on data
- For input requirements which will use current or very recent historic data sources as initialization information for a modeling simulation, determine data sources
    - Develop automated mechanisms for data retrieval and/or quality analysis/quality control as necessary
- For input requirements which will use forecast data, identify and/or develop data sources
- Develop metadata and documentation for all data sources

Deliverables:
For each model; a description of the model input requirements. For each model input requirement; datasets, data sources, data retrieval mechanisms, and metadata/documentation.

Additional Description/Initial Concepts:
Model input data requirements will vary by model, but in general, there will be three types of data necessary; time series data, physical data, and operational data.

Time series data include, but are not limited to:
- Reservoir stage (storage)
- Reservoir inflow (tributaries, diversions to)
- Precipitation

- Reservoir outflow (diversions from, dam releases and spill)
- Reservoir inflow temperature (tributaries, diversions)
- Reservoir temperature profiles
- Local meteorological data (solar radiation, cloud cover, air temperature, dew point temperature, wind speed and direction, atmospheric pressure, etc.)

Time series data for applications such as the one identified herein is typically hourly (for locations or processes that change considerably over a day, e.g., hydropower peaking flows) or daily (for processes that change more slowly, e.g., reservoir storage change)

Physical data include, but are not limited to:

- Reservoir morphology (bathymetry)
- Reservoir stage-volume-surface area curve
- Topographic shading information
- Location of diversion to and diversions from the reservoir
- Outlet works elevations and capacities (including TCD/selective withdrawal facilities)

Operations data include, but are not limited to:

- Storage rules and limits
- Operating rules
- TCD guidance
- Ramping rates (rate of change criteria)
- Temperature targets or criteria
- Hydropower memoranda of agreement/understanding
- Legal obligations on storage and releases

Note that while this information may not be formally input into the model, operations information is often implicitly incorporated into analyses through pre-processing of hydrology and water temperature data and post-processing of model results to ensure operations are realistic and representative.

To the extent that information is not readily available for components of the river/reservoir system, new data may need to be collected as part of this process (i.e. bathymetric data, etc.).

Model Development

Objective:

For each of the model components in the framework, the model selected for use may need to be revised, refined, or developed.

Tasks:

- Obtain existing models (if modeling effort is a revision or refinement of existing model)

- Refine existing model or develop new model depending on approach determined through selection process

Deliverables:
For each model component in the framework, revised or new model.

Additional Description/Initial Concepts:
As outlined in the "Task Management and Timeline" segment of this document, the first three modeling components of the revised system will be temperature modeling of Shasta Lake, Keswick Reservoir, and the Sacramento River downstream of Keswick due to the priority in developing these components of the overall framework. A model selection evaluation will be completed as part of this process.

Based on initial work completed independently by the Sacramento River Settlement Contractors (SRSC) and NMFS, one model that will be considered is the CE-QUAL-W2 model for Shasta Lake temperature modeling. This model has been previously developed by the University of Nevada - Reno. Based on initial review completed by the SRSC, the model has most of the qualifications identified in the "Model Selection" section of this document. In addition, refinements have already been developed simultaneously by the SRSC and NMFS that may accelerate the timeframe for completion of the Shasta Lake model component of the framework if this model is selected.

Model Linkage

Objective:
Development/refinement of automated data management processes/linkages between models within the framework.

Tasks:
- Identify datasets that will be passed from one component of the framework to another
- Identify automated data management mechanisms that can be used to provide for the flow of data between components of the framework
- Develop and implement automated data management mechanisms as each modeling component of the framework is developed/revised

Deliverables:
Automated data management mechanisms between modeling components of the framework.

Additional Description/Initial Concepts:
Initial implementation of new/refined modeling components may necessitate using appropriate model linkages to connect the new/refined modeling components to the original HEC-5Q framework. This may allow for the

new/refined modeling components to be tested and potentially implemented operationally in advance of complete refinement of the overall framework.

Estimation of Uncertainty

Objective:
Develop and communicate uncertainty bounds in estimates of water temperature downstream of Keswick Dam, as well as ability to achieve temperature targets throughout a complete season. This potentially includes intermediate estimates of uncertainty on particular components of system, such as predictions of lake stratification early in the season.

Tasks:

- Determine data/components within system that contribute to significant uncertainty in specified model results
- Develop estimates/estimation procedures for uncertainty in those datasets
- Develop estimates/estimation procedures for translating uncertainty through modeling system to model results (may include determinations of joint uncertainty of several input/modeling components)

Deliverables:
Estimates/mechanisms for estimating uncertainty in individual datasets/modeling components, and mechanisms for translating uncertainty to model results.

Additional Description/Initial Concepts:
For all their complexity, models are still only mathematical representations of the world and represent simplifications of real world processes. Model performance metrics will be developed as an integral part of this project to provide insight into model uncertainty, from all sources.

Further, when a model is used as a forecasting tool, uncertainty can be introduced into the analysis because of unknown future conditions. While models can provide remarkable insight, even in data poor environments, data limitations can reduce the effectiveness of models to fulfill their principal objective. An element of the proposed modeling framework would allow quantified sources of uncertainty (e.g., data uncertainty, forecast uncertainty) to be assessed and the impacts on modeled flow and water temperature defined for resource managers to consider in decision making.

Output Communication

Objective:
Develop output communication/visualization tools and data presentation approaches to assist resource managers in conveying results.

Tasks:

- Identify key modeling results and uncertainty estimates that provide value to resource managers and other stakeholders
- Identify communication/visualization tools for those results
- Develop communication/visualization tools

Deliverables:
Communication/visualization tools and presentation methods/venues.

Calibration & Validation

Objective:
Calibrate and validate model components as they are refined/developed.

Tasks:

- Complete calibration and validation of modeling components

Deliverables:
Documentation of results of calibration and validation tasks; potential inclusion of results of tasks into uncertainty estimation procedures for framework.

Documentation

Objective:
Documentation of model assumptions, calibration, performance, procedures for operation, and recommendations for next steps.

Tasks:

- Development of documentation for each modeling component

Deliverables:
Documentation, in a consistent format, of each component of system, to be included in overall documentation of the framework.

Peer Review

Objective:
Provide for peer review of model components and overall framework.

Tasks:

- Upon completion of new/refined model components and/or data development, conduct peer review

Deliverables:
Summary/documentation of peer review on model components/datasets.

Implementation

Objective:
Complete implementation of new/refined modeling components in a way that provides for operational use as early as possible, given the need to ensure that the new/refined modeling component is functioning properly and a fully operational system remains in place to prevent adverse outcomes as new modeling components are brought on-line.

Tasks:
- Implement model components in a parallel process
- Define model performance metrics for comparing different modeling approaches
- Develop performance information and complete comparison

Deliverables:
Technical memorandum outlining procedures for model comparison, data utilized, linkage of models (modeling framework), results of comparison among models, and recommendations for future activities.

Additional Description/Initial Concepts:
Upon completion of each of the framework's model components, the models will be applied to planning and management activities in parallel with the existing modeling and management approach. This process will provide a means for assessing model performance, identifying data gaps, and determining if continued model development or refinement of new or existing models may be desired. The process may also be used to determine if existing components of the framework are adequate and/or the most efficient means for continued operational modeling. To accomplish this task, data and similar forecasting information currently used in the temperature modeling planning and management process will be assumed.

Task Management and Timeline

As previously described, a collaborative approach is envisioned that involves several parties that are actively involved in operations and water temperature management in the Sacramento River system. Initial outreach will identify interest, experience, and resources. The proposed approach aims to utilize existing models, update/refine existing models, and develop, as necessary, new models. The project would be phased to accommodate higher priorities sooner, with future phases to be implemented as needed.

Implementation of Tasks

In order to leverage the expertise and resources of the stakeholders involved in Sacramento River temperature issues, implementation of tasks will likely be conducted by multiple parties and, at times, in parallel. Reclamation will serve as the coordinator of activities. Specific activities and the associated timelines for completion will be determined based on interest and resource availability. Based on initial discussions and interactions, it is anticipated that the SRSC will provide significant resources to the effort, and will assist with the completion of the "Framework Design/Refinement" task described previously, and the other activities outlined in the "DRAFT Project Plan" portion of this document specifically for the Shasta Lake and Keswick Reservoir components of the framework. Implementation of the tasks associated with other components of the framework and involvement by other entities will be determined through outreach activities, and this document will be updated to reflect the entities involved with the development of each of the components of a revised/new framework.

Timeline/Phasing of Tasks

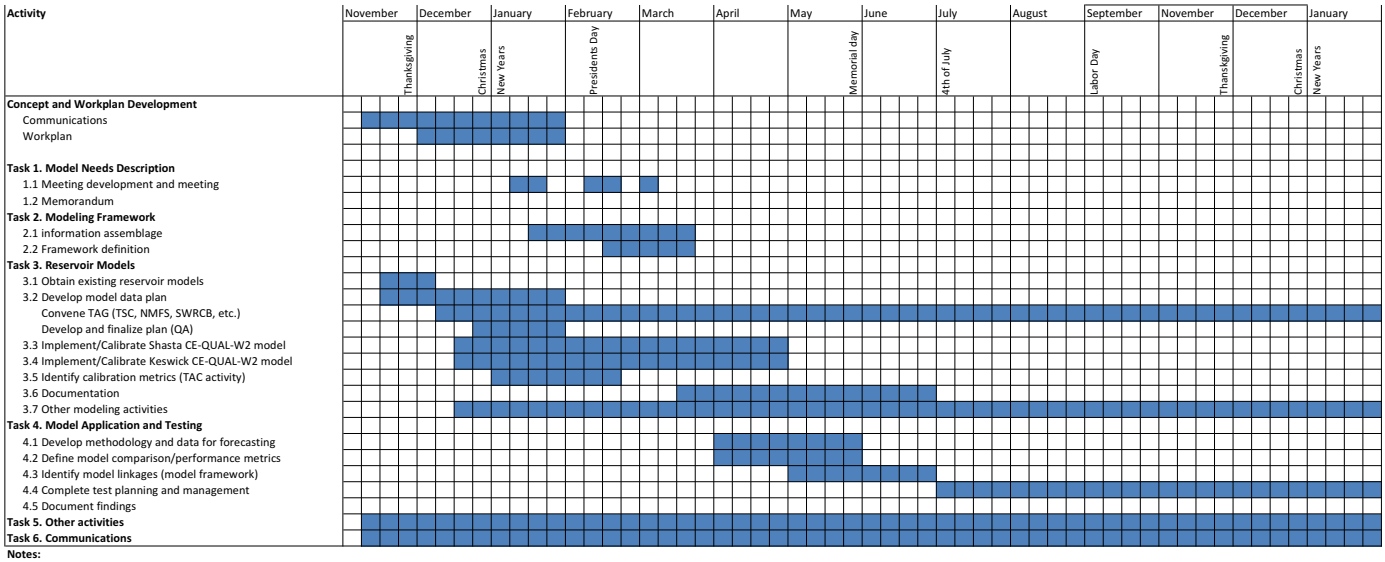
High priority elements of the system that have been identified include revisiting the temperature modeling tools for Shasta Lake and Keswick Reservoir, particularly under lower storage conditions. It is anticipated that activities to select and develop new/revised tools for these components of the framework will be undertaken and completed first, and initial work has already been independently pursued by the SRSC as well as the NMFS Southwest Fisheries Science Center, as discussed in the "Model Development" section above. This initial development is expected to inform an accelerated model selection process for these model components. In addition, development of a revised overall framework design/plan will be conducted as a parallel process. Modification, refinement, or development of models for other system elements (e.g., Trinity Lake, Whiskeytown Lake, Lewiston Reservoir, and downstream Sacramento River reaches), if deemed necessary through the model selection/design process outlined in this document, would occur as a later phase, and are expected to benefit from information gained through the development of the Shasta Lake and

Keswick Reservoir components of the framework. In general, for each model component of the framework, the tasks in the "DRAFT Project Plan" portion of this document will be carried out for that particular model component. It is likely these tasks will be conducted in parallel for different components of the framework as resources allow.

The initial timeline for the first phase of the project is shown in Appendix A.

Appendix A – DRAFT Timeline

The draft timeline on the next page (provided by the SRSC) remains under development, and will be further informed by initial outreach activities.



Notes:

1. Task 3.1: HEC5Q and CE-QUAL-W2 models have already been obtained