Appendix J Feather River Water Temperature Model

This appendix documents the Feather River Water Temperature model development, calibration, and internal computation procedures.

Purpose

The Feather River water temperature model was developed to support of the Federal Energy Regulatory Commission (Commission) hydropower licensing of the Oroville Facilities. The model was simulated water temperature within the complex and in the Feather River to the confluence with the Sacramento River for use in analysis of the Oroville Facilities' temperature management capabilities, and to support fishery impact analysis.

Oroville Facilities Description

The Oroville Facilities are a physically and operationally complicated system. Oroville Reservoir releases water through a main intake structure with adjustable stop logs or shutters; allowing release from different elevations within the reservoir through the Hyatt Pumping-Generating Plant where the water is used to generate electricity. Because of power operations, releases are made on a peaking basis: up to 17,500 cubic feet per second (cfs) when power is in high demand (on-peak) with little or no release the remainder of the day (off-peak). The water that flows through the Hyatt Pumping-Generating Plant is discharged into the Thermalito Diversion Pool where the flows are diverted into either theThermalito Forebay, the Feather River Fish Hatchery, or the Low Flow Channel. From the Thermalito Forebay, flows can be diverted into either several canals or released through the Thermalito Pumping–Generating Plant to the Thermalito Afterbay. From the Thermalito Afterbay, flows can be diverted into several canals or released to the Feather River. Both the Thermalito Pumping-Generating Plant and the Hyatt Pumping-Generating Plant can operate in a pumpback mode, moving water from the Thermalito Afterbay into the Thermalito Forebay through the Thermalito Pumping-Generating Plant, Thermalito Diversion Pool, and finally back into Oroville Reservoir through the Hyatt Pumping-Generating Plant. Pumpback operations are determined by the power price differential between the on-peak and off-peak periods.

The Oroville Facilities are currently operated by the California Department of Water Resources (DWR) to meet water temperature objectives at two locations, the intake to the Feather River Fish Hatchery and at Robinson Riffle in the Low Flow Channel, about 5 miles below the Thermalito Diversion Dam. Water temperatures at these two locations are managed by DWR using various operational measures to control water temperatures of the release from Oroville Reservoir and the heating that takes place in the Low Flow Channel to Robinson Riffle. These temperature control actions (TCA) include the following:

- Eliminate Pumpback/Peaking Operations – During the day, Oroville peaking power releases are stored in the Thermalito Afterbay, where the water is warms. During pumpback operations this warmer water is pumped back through the Thermalito Forebay into the Thermalito Diversion Pool and from there into Oroville Reservoir. The warm water mixes with the water in the Diversion Pool and can increase the temperature of the Thermalito Diversion Pool release to the Feather River. Peaking produces a similar effect as the warmer water flows back into the Thermalito Diversion Pool for release down the Feather River when the release from Oroville drops during nonpeaking hours. Eliminating these operations in favor of a constant release in turn eliminates the return flow of warm water from the Thermalito Afterbay and Thermalito Forebay into the Thermalito Diversion Pool.
- Pull Shutters – The main intake structure at Oroville Reservoir has a number of shutters, or stoplogs, that can be added or removed to control the elevation and temperature of water released from Oroville Reservoir. Adjusting the withdrawal elevation is a large task because of the size of the shutters, and cannot be done as quickly as modifications to the power operations. Typically, once a shutter is removed, it is not re-installed until the following year.
- River Valve - A Hyatt Pumping-Generating Plant bypass valve can be used to release water from a very low elevation in the reservoir. This valve can access virtually all the cold water in Oroville Reservoir.
- Increase Low Flow Channel Flow – Most of the release from Oroville Reservoir is diverted through the Thermalito Forebay to the Thermalito Pumping–Generating Plant and into the Thermalito Afterbay for power generation. The Low Flow Channel usually only conveys the minimum required fishery flows for the reach. Increasing this flow can reduce the heating in this reach of the Feather River and help meet the temperature targets at Robinson Riffle. This TCA does not help meet the fish hatchery temperature targets.

General Feather River Temperature Model Description

The Feather River Temperature Model is an hourly temperature simulation model of the Oroville Facilities and the Feather River downstream to the confluence with the Sacramento River. The model accepts all water operations as inputs and computes the resulting temperature profiles in the reservoirs, reservoir release temperatures, diversion temperatures, and temperatures in the Feather River. Using an iterative process, the model implements the TCA's to meet temperature targets at the Feather River Fish Hatchery and Robinson Riffle.

The Feather River Temperature model is not a single model; rather it is a system of six individual temperature models of the various reservoir and river portions of the system and a number of utility programs that handle data setup, data translation between models, and implementation of the TCA's. The specific temperature models are as follows:

- Oroville Reservoir Temperature Model
- Thermalito Diversion Pool Temperature Model
- Thermalito Forebay Temperature Model
- Thermalito Afterbay Temperature Model
- Feather River Hydraulic Model
- Feather River Temperature Model

These individual models and utility programs are linked via a central database system used to manage the data flow between the models. This database system uses the United States Army Corp of Engineers (USACE) Data Storage System (HEC-DSS) (www.hec.usace.army.mil)

Figure 1 is a schematic of the Feather River Temperature Model.

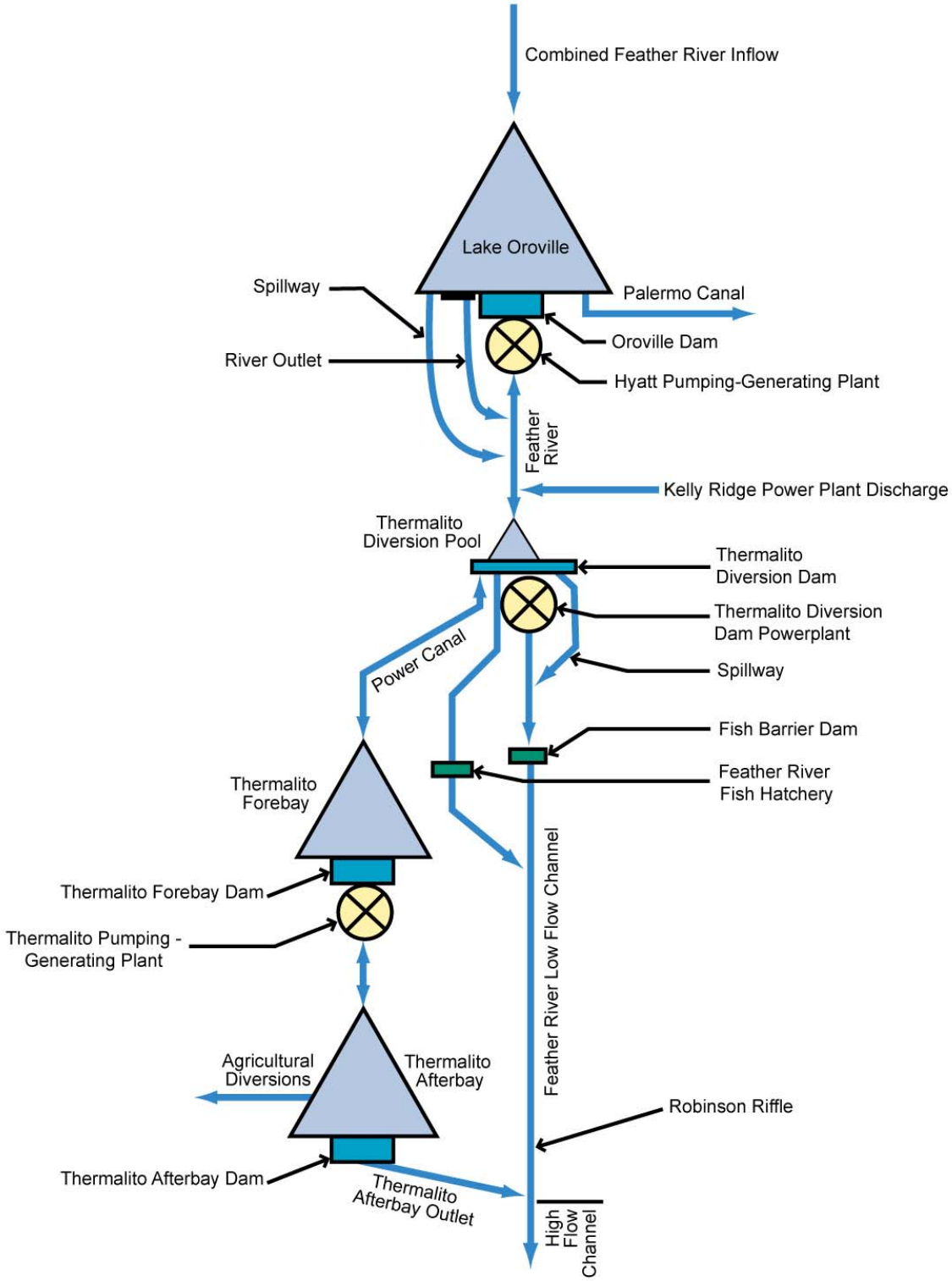

Figure 1 Feather River Temperature Model Schematic

Selected Modeling Tool

The Water Quality for River-Reservoir Systems Software Package (WQRRS) was selected as the modeling tool used to build the individual temperature models. WQRRS is a one-dimensional, deterministic model that performs water balance and heat budget calculations to determine water temperatures. In lakes or reservoirs the model assumes vertical temperature stratification, and provides vertical temperature profiles without spatial distribution of water temperature conditions. In river networks the model assumes vertical mixing and provides longitudinal temperatures in branching channels and/or around islands.

The package includes three separate modules that can be integrated into a system analysis or be used as separate programs.

The reservoir module of WQRRS, WORRSR, is suitable for simulation of stratified reservoirs. The reservoir is divided into control volumes, consisting of a stack of horizontal water layers. During the model simulation water layers are added when the water level rises or removed when the water level drops as required.

Stream or river temperature simulation is performed by two additional modules, SHP a stream network hydraulics module, and WQRRSO, a stream water quality module. SHP computes flow conditions using one of four different methods (1) input of stage-flow relationships, (2) backwater equations, (3) hydrologic routing (i.e., Muskingum or modffled Puls), or (4) hydraulic routing (i.e., kinematic wave or St Venant equations). The stream water quality module (WQRRSO) must be provided with binary input from SHP to describe the internal stream hydraulics. The modules communicate with each other via binary files for effective linkage.

The WQRRS one-dimensional reservoir model was selected for several reasons:

- Oroville Reservoir becomes strongly vertically stratified during the summer
- The temperature profile in the reservoir is critical because of the selective elevation intake structure at Lake Oroville.
- Only the release temperature, not the spatial distribution of temperature within Oroville Reservoir is of interest
- WQRRS is a public domain modeling tool that has been applied to similar reservoirs
- Experience indicates that WQRRS can be calibrated to the temperature profiles at Oroville Dam.
- WQRRS includes both a reservoir and a river module for easy compatibility between the two model types

System Model Development

The Feather River Temperature Model represents a complex system of reservoirs, pumping-generating plants, diversions, and stream channels subject to complicated operational rules. In order to adequately represent the physical system a set of individual temperature models were linked to operate as a single integrated system.

Individual Temperature Model Development

Independent reservoir models were developed for Oroville Reservoir, Thermalito Diversion Pool, Thermalito Forebay, Thermalito Afterbay and the Feather River. To set up the models, bathymetric data were used to divide the lakes into 1-meter thick stacked layers of water for Oroville Reservoir, and 1-foot thick stacked layers of water for the other three reservoirs. The Feather River model was developed using cross section data spaced 0.25 miles apart in the Low Flow Channel and 1 mile apart from the Thermalito Afterbay Return to the Sacramento River.

A number of modifications were made to the original WQRRS source code:

- Code was updated to be Y2K-compatible
- Measured short radiation and estimated long wave radiation read in for heat budget calculations
- All input/output fixed to hourly time interval
- Oroville Reservoir model modified to include trace of sinking or rising plume from pump-storage pumping operations
- Oroville Reservoir model modified to include variable elevation intake structure
- Capability to read/write selected time-series data to HEC-DSS format database

The individual models were then calibrated using data from August 11, 2002 to December 30, 2003, and verified with data from March 28 through July 15, 2002.

These code changes and the calibration/verification process are more completely documented in *Calibration and Verification of Oroville Temperature Model* (DWR 2005).

System Model Development

The individual temperature models were then linked to create a single integrated temperature simulation model of the system.

Simulation Sequence

The Feather River Temperature Model simulates temperatures throughout the system in downstream order. Simulated temperatures from the upstream reservoirs are used as input to the next downstream reservoir. The simulation sequence is as follows:

- Oroville Reservoir Temperature Model is run to simulate the temperature of releases to the Thermalito Diversion Pool.
- Thermalito Diversion Pool Temperature Model is run to simulate the temperature of the Power Canal Diversion to the Thermalito Forebay and the release to the Low Flow Channel.
- Thermalito Forebay Temperature Model is run to simulate the temperature of the release to the Thermalito Afterbay.
- Thermalito Afterbay Temperature Model is run to simulate the temperature of the release to the Feather River.
- Feather River Hydraulic and Temperature Models are run to simulate the temperatures in the Feather River.

In the simulation sequence each model is run for the full simulation period before the next model is run. During pump-back operations the upstream reservoir needs to know the flow and temperature of the water being pumped for each hour of the simulation period. Under the imposed simulation scheme this is not always the case. For example the Thermalito Forebay is simulated before the Thermalito Afterbay. During the Thermalito Forebay simulation the pump-back flow and temperature must be know to perform the temperature simulation; however, since the Thermalito Afterbay has not been simulated yet the temperature of the water being pumped back is unknown. This is addressed by simulating the reservoirs twice, steps 1 to 4 above, the first time assuming a temperature of for all 12 °C for all pump-back water, and the second time using the temperatures from the first iteration.

TCAs are implemented on a weekly basis; that is they can only change once a week; because of constraints imposed by the power operations. The TCAs are implemented in a predefined sequence to meet the temperature targets. A number of utility programs were developed, one for each TCA, that can read the results of a single simulation, compare these results to the temperature targets, and implement the TCA by modifications to the input data for the individual temperature models for the next simulation. The system simulation is then repeated with the new TCAs in place. This process is repeated until the temperature targets are met or all available TCA's have been implemented.

The final simulation order then becomes as follows:

1. No TCAs
2. For Feather River Fish Hatchery targets
    a. No pumpback or peaking operations (NOPUMP utility)
    b. Adjust shutters at Oroville intake (SHUTTER utility)
    c. Use river valve (RIVVALE utility)
3. For Robinson Riffle targets
    a. Pull Shutters (SHUTTER utility)
    b. Increase flow in Low Flow Channel (LFC200 utility)

Data Flow

The modeling sequence described above requires careful data management to ensure the correct data is passed between the individual models for each simple sequence and between sequences for each TCA. This data management is handled by using a central database scheme. Each of the models reads time series input and writes time series output to the central database. Each of the utility programs developed for the TCAs then can read model output from the central database, evaluate it against the temperature targets, generate the revised time series input required to implement the next TCA, and write the new time series input to the central database for use as input by the individual models in the next simulation sequence.

The central database system is made up of three HEC-DSS format databases. These are as follows:

- Metdata.dss – Contains constant meteorology data that does not change from simulation to simulation
- Opsdata.dss – Contains the system operations data, including tributary inflows, reservoir releases, releases, etc.
- Tempdata.dss –Mmain temperature results database, used to pass temperature results between the individual models and utility programs

Note that no model or utility program ever directly passes data to another individual model or utility program, all data passing is handled through the central database system. Figure 2 shows the data flow for the Feather River Temperature Model.

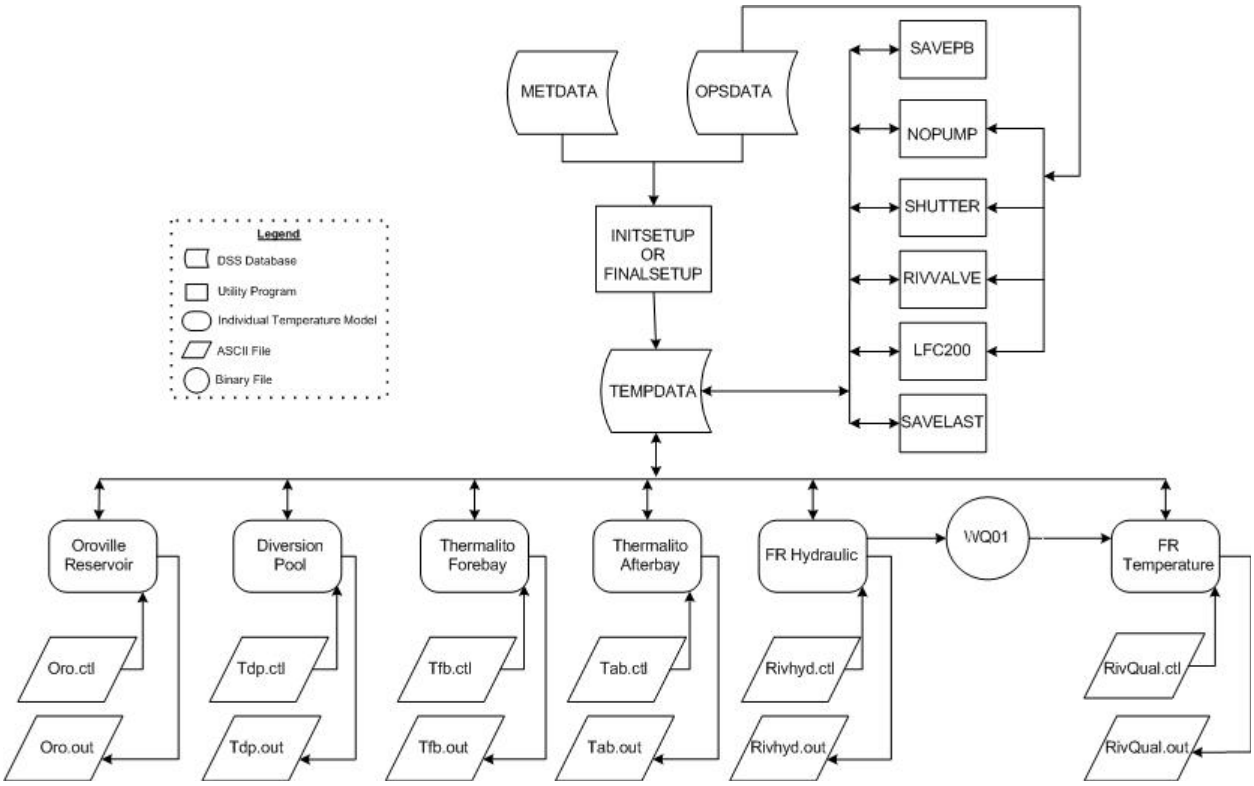

Figure 2 Feather River Temperature Model Data Flow

Input Data Requirements

Hourly input data required to run the Feather River Temperature Model includes the following:

Flow Data

This includes the tributary flows, accretion/depletion, and constant diversions that are not modified under any TCA

- Oroville Reservoir
  - Pacific Gas & Electric inflow and temperature
  - Feather River inflow and temperature

- Thermalito Diversion Pool
  - Kelley Ridge inflow and temperature

- Thermalito Forebay
  - Agricultural diversion flow

- Thermalito Afterbay Afterbay
    - Agricultural diversions flow

- Feather River
    - Accretion/depletions flow and temperature

Operations Data

Facility operations data with for all possible combinations of TCAs from no TCAs to all to all possible TCA in place. (no pumpback/peaking, increase Low Flow Channel flow, use river valve, and all available combinations)

- Oroville Reservoir
    - Spillway release
    - Power release
    - River valve release
    - Shutter pos
    - Palermo Canal release
    - Pump-back from Thermalito Diversion Pool

- Thermalito Diversion Pool
    - Power Canal diversion
    - Hatchery Diversion
    - Feather River Release
    - Pump back from Thermalito Forebay
    - Pump back to Oroville

- Thermalito Forebay
    - Power Canal inflow
    - Release to Thermalito Afterbay flow
    - Pumpback to TPD flow

- Thermalito Afterbay
    - Thermalito Forebay inflow
    - Pumpback to Thermalito Forebay
    - Release to Feather River

- Feather River
    - Thermalito Diversion Pool inflow
    - Feather River Fish Hatchery return flow
    - Thermalito Afterbay inflow

Meteorological Data

Meteorological data required for heat balance computations

- Daily dry-bulb temperature
- Dew point temperature
- Atmospheric temperature
- Solar radiation
- Wind speed

Hourly historic meteorological and flow data and was developed for the period of September 1921 through September 1994 to support the Oroville Facilities Relicensing modeling. The majority of the meteorology data came from two stations near the Oroville Facilities: Durham station near the Thermalito Afterbay and Nicolaus station near the confluence of the Feather River with the Sacramento River. The Durham station was used for the reservoirs and the portion of the Feather River above the Yuba River. The Nicolaus weather station was used for the portion of Feather River below the Yuba River.

Hourly operations data for the Oroville Facility Relicensing were developed using CALSIM simulation data to set monthly operation targets, creating weekly targets from these monthly targets, and using an hourly time interval water and power operations model to simulate the hourly operations within each week. This process was repeated fro each potential combination of TCAs that could occur in the simulation modeling. These values are not historical; they are unique to each alternative being simulated. The hourly operation data can be generated by any desired means, the temperature model operates independently of the source of the data.

Documentation

The Feather River Temperature Model and the WQRRS model used in the Oroville Relicensing are extensively documented in the following:

May 2005, Oroville Facilities Relicensing Report, Calibration and Verification of Oroville Temperature Model, California Department of Water Resources

May 2005, Oroville Temperature Model User's Manual, California Department of Water Resources

October 1978, Water Quality for River-Reservoir Systems User's Manual, October 1978 US Army Corps of Engineers Hydrology Engineering Center

Reliability and Acceptability of Model

The Feather River Temperature Model was developed for use in the Oroville Facility relicensing. The model was calibrated and verified and showed good ability to simulate the temperature operations of the Oroville Facilities and the Feather River. During the

relicensing process, the model, its development, assumptions, methods and results were presented to the regulatory agencies and the general public. Modifications were made to the model based on comments received.

The final model was used to simulate potential temperatures under the re-licensing scenarios. These temperatures were accepted and used in the fishery, power, economic evaluations performed. The results were also used to assist in setting new temperature targets that could be implemented in the new Commission license when it is issued, in support of a settlement agreement between all interested parties, and in the implementation of the settlement agreement.

Potential Model Improvements

While modeling to support the Oroville Relicensing was completed in March 2006, the potential for future improvements to the Oroville temperature model exist:

- Since the conclusion of modeling for the relicensing, DWR has been conducting data collection. This data could be used to perform a more refined calibration and verification of the temperature model.
- The period of record for CALSIM modeling, which served as the operational basis for the Oroville temperature modeling, has been extended to 2003. The flow and meteorological input data could be extended to cover this period.
- As part of the Oroville Relicensing Settlement Agreement, DWR will be conducting a feasibility study to evaluate potential structural improvements to increase access to the cold water pool in Oroville Reservoir to improve temperature conditions for anadromous fish in the Feather River. It is likely that some additional temperature modeling will be required to support this effort, including the possible development of a two-dimensional model of the Thermalito Afterbay.
- The California State Water Project Operations Control Office (OCO) is investigating the possibility of adapting the current model for use in real-time temperature modeling to aid in operation planning to meet temperature targets.