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Mid-Pacific Region
Managing Water in the West

Report to State Water Resources Control Board

Initial *Hindcast* of Temperature Performance Sacramento River 2014

March 2015

By US Bureau of Reclamation
Mid-Pacific Region
Central Valley Operations Office

Introduction

This document was developed pursuant to the February 3, 2015 Order by the Executive Director of the State Water Resources Control Board (SWRCB) responding to the temporary, urgency change petition filed by the California Department of Water Resources (DWR) and the Bureau of Reclamation. Specifically, section 6.a of the Order directed Reclamation to perform *hindcast* temperature modeling of the water year 2014 temperature control season to verify the accuracy and validity of Reclamation's temperature model.

Temperature management on the Sacramento River was challenging in 2014 given the low reservoir levels, less than average runoff, and limited cold water pool. Management efforts were further complicated in August 2014 when the temperature profile in Shasta Lake developed a very step thermal gradient at an elevation near the lowest level outlets.

Although the temperature model results consistently suggested that river temperatures could be maintained near 56 degrees into September, Reclamation cautioned that this result was Highly dependent on successful use of the side gate on the Shasta Temperature Control Device (TCD) to access the remaining cold water in Shasta Lake. The actual performance of the TCD at this point in the season resulted in elevated water temperatures prior to the end of the egg incubation life stage. As a result, the 2014 wild winter-run brood year experienced high levels of mortality.

To help assess the model accuracy and improve decision making at various steps through the temperature season, the model inputs were adjusted to reflect observed water year 2014 conditions, including lake temperatures profiles, reservoir inflows, inter-basin transfers, and temperature control device operations. The results help identify the source of any significant discrepancies between modeled and observed temperatures, and hopefully serve to help inform improved planning efforts for 2015 and beyond.

Background

Water Temperature Operations in the Upper Sacramento River

Management of water temperature in the upper Sacramento River is governed by current water right permit requirements and biological opinion requirements. Water temperature on the Sacramento River system is influenced by several factors, including the relative water temperatures and ratios of releases from Shasta Dam and from the Spring Creek Powerplant into Keswick Reservoir. The temperature of water released from Shasta Dam and the Spring Creek Powerplant is a function of the reservoir temperature profiles at the discharge points at

Shasta and Whiskeytown, the depths from which releases are made, the seasonal management of the deep cold water reserves, ambient seasonal air temperatures and other climatic conditions, tributary accretions and water temperatures, and residence time in Keswick, Whiskeytown and Lewiston Reservoirs, and in the Sacramento River.

SWRCB Water Rights Order 90-05 and Water Rights Order 91-01

In 1990 and 1991, the SWRCB issued Water Rights Orders 90-05 and 91-01 modifying Reclamation's water rights for the Sacramento River. The orders stated Reclamation shall operate Keswick and Shasta Dams and the Spring Creek Powerplant to meet a daily average water temperature of 56°F as far downstream in the Sacramento River as practicable during periods when higher temperature would be harmful to fisheries.

Under the orders, the water temperature compliance point may be modified on a seasonal basis. In addition, Order 90-05 modified the minimum flow requirements initially established in 1960 for the Sacramento River below Keswick Dam. The water right orders also recommended the construction of a Shasta Temperature Control Device (TCD) to improve the management of the limited cold water resources.

Pursuant to Orders 90-05 and 91-01, Reclamation configured and implemented the Sacramento-Trinity Water Quality Monitoring Network to monitor temperature and other parameters at key locations in the Sacramento and Trinity Rivers. The SWRCB orders also required Reclamation to establish the Sacramento River Temperature Task Group (SRTTG) to formulate, monitor, and coordinate temperature control plans for the upper Sacramento and Trinity Rivers.

Each year, with finite cold water resources and competing demands usually an issue, the SRTTG will devise operation plans with the flexibility to provide the best protection consistent with the CVP's temperature control capabilities and considering the annual needs and seasonal spawning distribution monitoring information for winter-run and fall-run Chinook salmon. In every year since the SWRCB issued the orders, these plans have included a unique compliance point to make best use of the available cold water resources based on the location of spawning Chinook salmon. Reports are submitted periodically to the SWRCB over the temperature control season defining the temperature operation plans.

Computer modeling and a thorough discussion of analytical results are critical components of managing the cold water resources of Shasta Lake and developing the annual water temperature goals for the upper Sacramento River to protect winter-run Chinook salmon. The

SRTTG has used temperature modeling and a multi-disciplinary evaluation of results to coordinate seasonal water temperature strategies for over 20 years.

Shasta Temperature Control Device

Construction of the Temperature Control Device (TCD) at Shasta Dam was completed in 1997. This device is designed to provide for greater flexibility in managing the cold water reserves in Shasta Lake while enabling hydroelectric power generation to occur and to improve salmon habitat conditions in the upper Sacramento River. The TCD is also designed to enable selective release of water from varying lake levels through the power plant in order to manage and maintain adequate water temperatures in the Sacramento River downstream of Keswick Dam.

Prior to construction of the Shasta TCD, Reclamation released water from Shasta Dam's river outlets to alleviate high water temperatures during critical periods of the spawning and incubation life stages of the winter-run Chinook stock. Releases through the low-level outlets bypass the power plant and result in a loss of hydroelectric generation at the Shasta Powerplant. The release of water through the low-level river outlets was a major facet of Reclamation's efforts to control upper Sacramento River temperatures from 1987 through 1996.

The seasonal operation of the TCD is generally as follows: during mid-winter and early spring the highest elevation gates possible are utilized to draw from the upper portions of the lake to conserve deeper colder resources. During late spring and summer, the operators begin the seasonal progression of opening deeper gates as Shasta Lake elevation decreases and cold water resources are utilized. In late summer and fall, the TCD side gates are opened to utilize the remaining cold water resource below the Shasta Powerplant elevation in Shasta Lake.

The seasonal progression of the Shasta TCD operation is designed to maximize the conservation of cold water resources deep in Shasta Lake, until the time the resource is of greatest management value to fishery management purposes.

The Sacramento River Temperature Task Group (SRTTG)

The SRTTG is a multiagency group formed pursuant to Water Rights Orders 90-5 and 91-1, to assist with improving temperature conditions in the Sacramento River. Annually, Reclamation develops temperature operation plans for the Shasta and Trinity systems. These plans consider impacts on winter-run and other races of Chinook salmon, and associated project operations. The SRTTG meets initially in the spring to discuss biological, hydrologic, and operational information, objectives, and alternative operations plans for temperature control. Once the SRTTG has recommended an operation plan for temperature control, Reclamation then submits a report to the SWRCB, generally on or before June 1st each year. After implementation of the operation plan, the SRTTG may perform additional studies and commonly holds meetings as needed through the summer and into fall to develop any needed revisions based on updated biological data, reservoir temperature profiles and operations data. Updated plans may be needed for summer operations to protect winter-run, or in fall for fall-run spawning season.

Generic Cold Water Pool Management

Summer water temperature stratification in large reservoirs is common throughout the western United States, and efficient management of the cold water resource is critical in protecting species like winter-run Chinook salmon.

Figure 1 represents a generic large reservoir system with specific infrastructure to help manage seasonal cold water resources. Large reservoir systems with river temperature goals generally have a structural device that allows for selective elevation withdrawal as the lake stratifies. These devices are typically in the form of gate structures or shutters that allow better manage of the limited cold water resource. By changing the elevation of water withdrawal through the season, reservoir operators can target a downstream water temperature goal over a period of time that corresponds to the life stages of various fisheries.

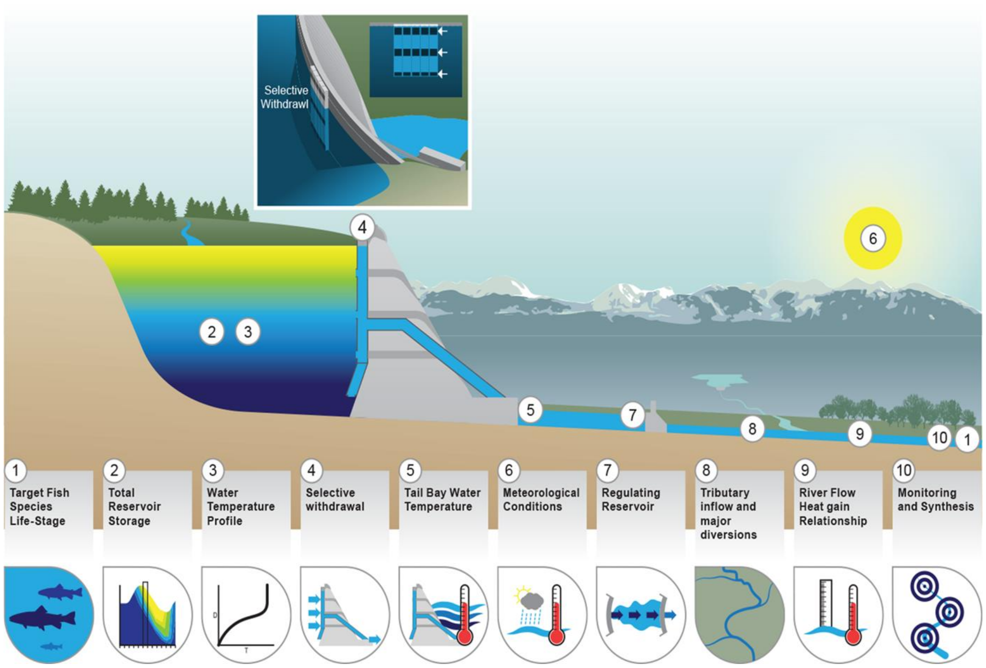

Figure 1

In a system with a selective withdrawal device such as the Shasta TCD, three key water temperature goals are analyzed simultaneously;

1) The seasonal utilization of a finite cold water resources available in reservoir storage,
2) The ability to blend the ever changing cold water pool through selective withdrawal and powerplant operations to provide a desired target temperature immediately downstream,
3) Consideration of the flows needed to provide the desired water river temperatures to a geographical compliance location in the riverine environment.

As we have seen in 2014, it is critical that the temperature manage strategy be sustainable throughout the targeted life stage to be successful. The process utilizes modeling results, a thorough understanding of physical infrastructure, and other system-wide operational constraints to formulate a sound seasonal plan and to make adjustments to that plan as the year progresses.

The goal of the resource team is to make the fullest use of cold water resource without running out of that resource before the critical life-stage has been achieved. When that cold water resource is limited, or uncertainty is high, difficult choices can become necessary to help extend the availability of the resource through the entire period of concern. These could include delaying the start of the management action, changing a compliance point, or targeting a slightly higher river temperature.

Systematic cold water utilization models such as depicted in Figure 1, are useful for annual or seasonal strategic planning and coordination by task group members. Models can provide estimates of overall cold water resource availability, selective withdrawal blending (TCD) performance, and ultimate river water temperature estimates, and strategic compliance point locations.

Reclamation's HEC-5Q model for our CVP Sacramento River system is such a cold water utilization and strategic planning model. The model is designed to provide seasonal information and analysis of available cold water, projected Shasta TCD blending, and estimated river temperatures. Each of these management components are used to produce an overall estimate of the system capabilities to sustain a river water temperature goal over a seasonal timeframe.

These temperature models have numerous input and output requirements needed to represent the complex thermodynamic processes and inherent natural variability that can significantly influence water temperatures over a seasonal period. (See Figure 1 boxes.)

The items in boxes 2 through 9 can all have significant natural variability during the spring and summer months and therefore can only be "forecasted" from information datasets. These data are updated with each model update. Box 4 – Selective withdrawal strategies – is the operational forecast "variable" that is adjusted through the season to account for the then-current information sets (new lake temperature profiles, release schedules, TCD performance, river water temperature objective).

Model output is typically presented in a seasonal timeline depicting temperatures at various locations in the system. These charts also display the progress of TCD operations to help assess the pace and utilization of the cold water resources. These charts are used to help communicate and share temperature information in the SRTTG and are useful to assess overall system cold water management (reservoir stratification, TCD operation, and river temperatures). It is through this exchange of information that adjustments to can be effectively discussed, evaluated and implemented.

Natural variability and operational challenges occur most every year. The periodic analysis as updated information comes available is intended to inform the SRTTG of the strategic implications and risks associated with various fishery management options. As useful as the modeling information can be, not all the variability and uncertainty of TCD performance can be predicted by a computer model. There will always be an element of real-time operational adjustment needed to react to unforeseen conditions.

<u>Review of 2014 Temperature Modeling Efforts</u>

Hindcast of 2014 Shasta TCD performance

Reclamation was conducted a "*hindcast*" modeling analysis of 2014 Shasta temperature management using Reclamation's HEC-5Q model. This the same model used to help develop the annual temperature plan and to produce periodic information sets for the SRTTG.

The hindcast modeling effort uses observed 2014 datasets where possible to assess the forecasted 2014 cold water management outcomes as produced by Reclamation's model. In this sense, the analysis described below is informative and can generate valuable "lessons learned" and strategic planning insights for future consideration in years similar to drought years like 2014.

In the time allowed, Reclamation was not able to assemble all the actual 2014 meteorological data in the format needed to run the model, but Reclamation was able to develop most of the necessary hindcast information required to recreate a reasonable representation of the 2014 temperature management season. Though slightly limited in scope, this assessment does shed some light on the challenges of cold water management with selective withdrawal capabilities in conditions like 2014.

In 2014, the temperature compliance location was set at the *near Clear Creek* gage on the Upper Sacramento River. This location was selected early in the year based, in part, on low storage levels in Shasta Lake and, in part, on the modeling data produced in May of 2014.

For this hindcast effort, Reclamation has used as a base the initial modeling information set from the May 2014 "forecast" and re-run the HEC-5Q model with key datasets adjusted to observed 2014 information. We have used these data to assess the model output related to TCD performance, projection of Shasta Lake stratification, and river temperature projections.

Hindcast Version #1 – Hindcast of TCD performance adjustment only

For the first hindcast analysis, Reclamation reran the May 2014 model to reproduce the actual weighted TCD temperatures that occurred in 2014. This is the only model parameter changed, forcing the target tailbay temperatures to track with actual records. By changing the target tailbay temperature to actual records, the model will produce new results for river temperatures at the Clear Creek location.

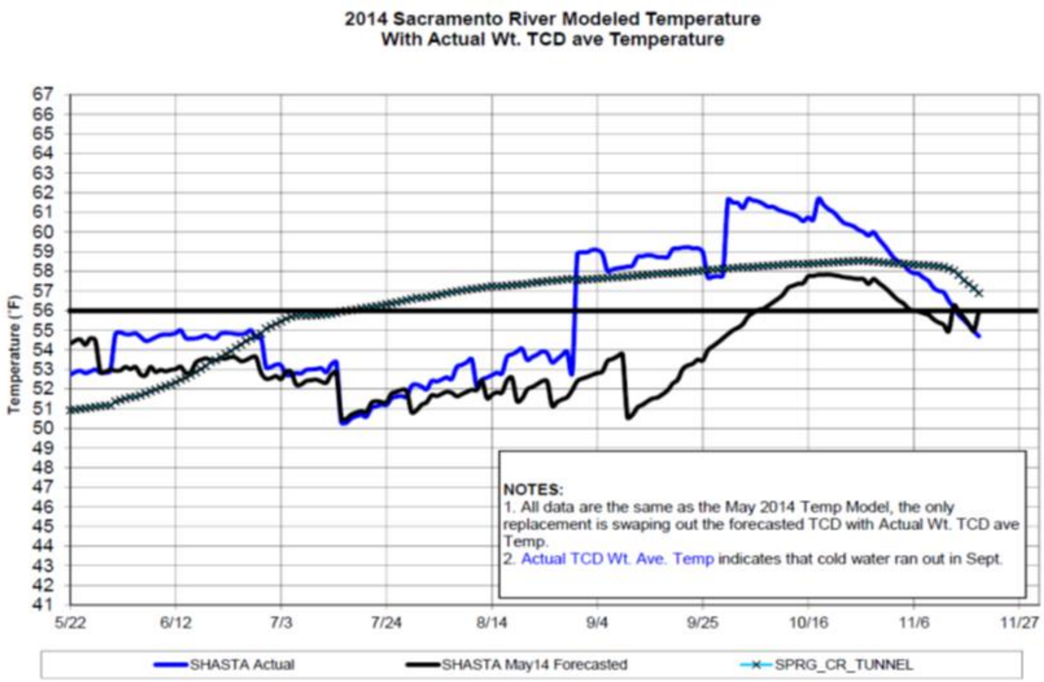

Figure 2

Figure 2 illustrates the difference in timing of actual the TCD performance versus the projection of the May 2014 planning analysis presented to the SRTTG. In general, this chart illustrates that the actual TCD performance at the tailbay was slightly warmer in the June timeframe than modeled estimation (representing a general conservation of cold water), while still producing the same general timeline of modeled TCD operations actions until late August. In late August, the sharp increase in modeled tailbay temperatures coincides with the actual timing when the TCD side gates could not adequately draw cold water and produce results as compared to the original May 2014 TCD side gate projections.

The original May 2014 model run (black line) had projected the start of TCD side gate operations occurring around the September 7, while the actual TCD operations began in late August. This is a difference of approximately 10 days earlier than forecasted. In addition, the actual TCD side gate operations were significantly warmer than the original May 2014 projections.

General Conclusion #1: The model represented well the pre-side gate performance progression of the TCD, but did a poor job of characterizing the TCD performance once the TCD side gate operation went into real-time effect.

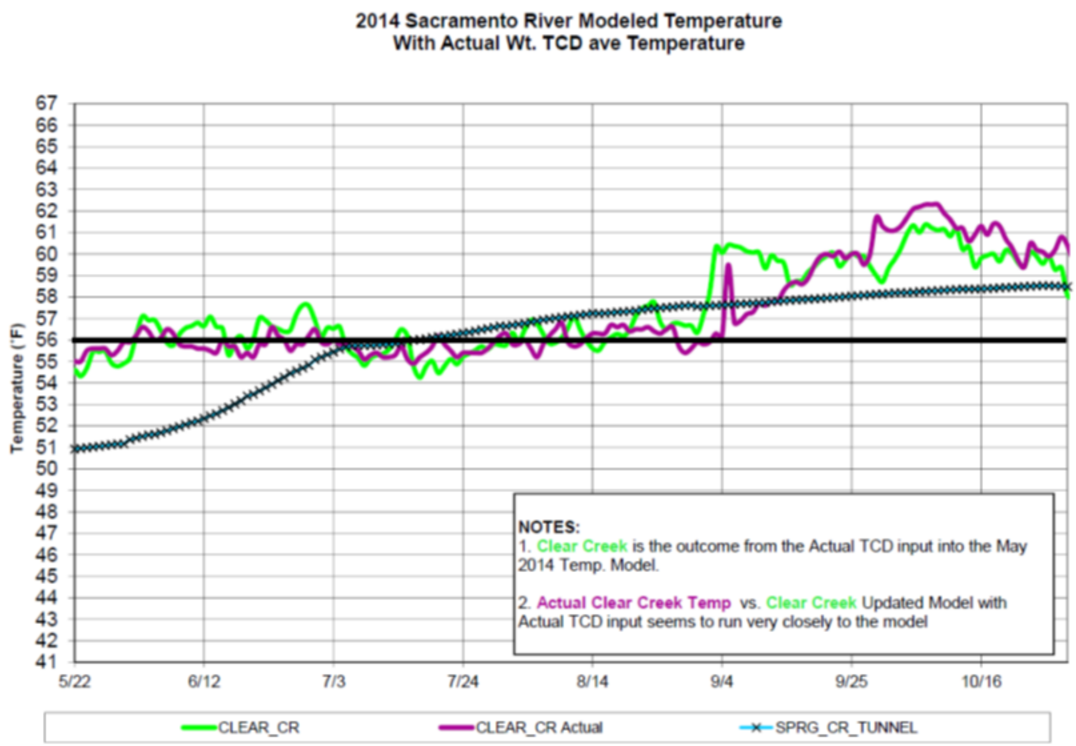

Figure 3

Figure 3 illustrates the modeled river performance in routing the actual tailbay water temperatures downstream to the Clear Creek compliance location. This plot illustrates a strong modeling match through August until there is some minor timing mismatch of actual Clear Creek temperatures in early September when compared to the modeled Clear Creek temperatures. This mismatch appears to coincide with the onset of TCD side gate operations at Shasta Dam.

General Conclusion #2: The estimates of Sacramento River temperature from the tailbay downstream to Clear Creek appear to correlate well if the TCD side gate timing and performance are well identified.

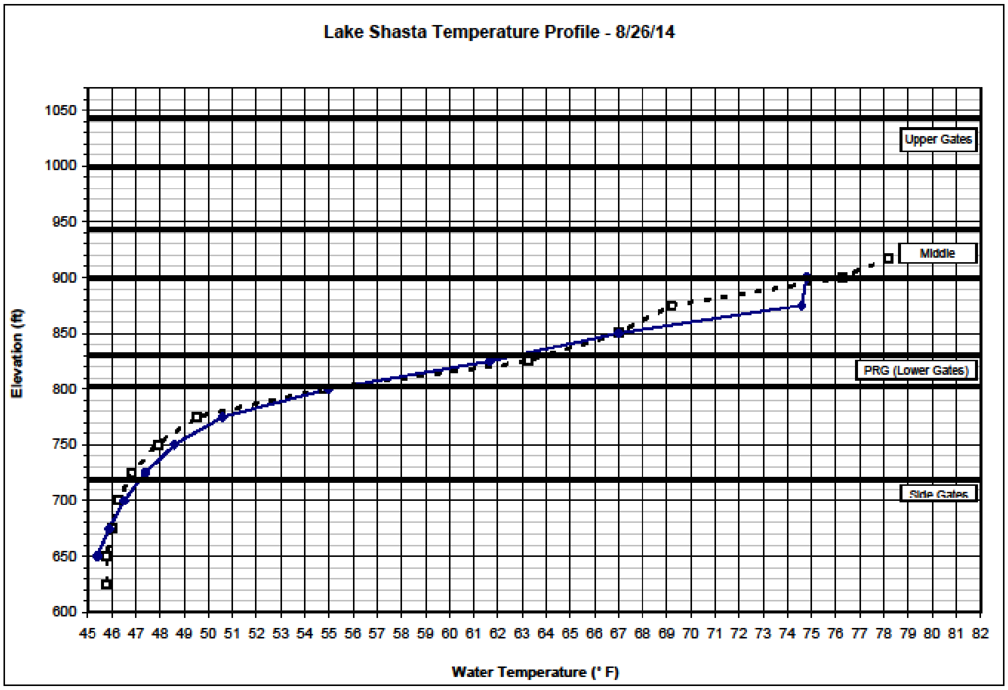

Figure 4

Figure 4 compares the May 2014 model projection of lake temperature profile in late August 2014 (the black line) versus the actual profile on that date (the blue line). Again this plot illustrates a good modeling match to the actual measured data.

General Conclusion #3: The HEC-Q5 model appears to estimate the lake stratification and Shasta Lake temperature profiles fairly well, even several months in advance.

Figure 5 below compares the original May 2014 modeling input for Keswick flows and actual Keswick releases. In general there is good conformance of the May 2014 Keswick forecasted monthly average flows to the actual Keswick releases through the late August timeframe. The chart does illustrate a fairly significant flow difference in September 2014, with actual flow having a slower ramp down rate than assumed in the original May 2014 study. In September of 2014, stranding was a concern for emerging winter-run fry and river monitoring and assessment was conducted to help guide flow release decisions during this period.

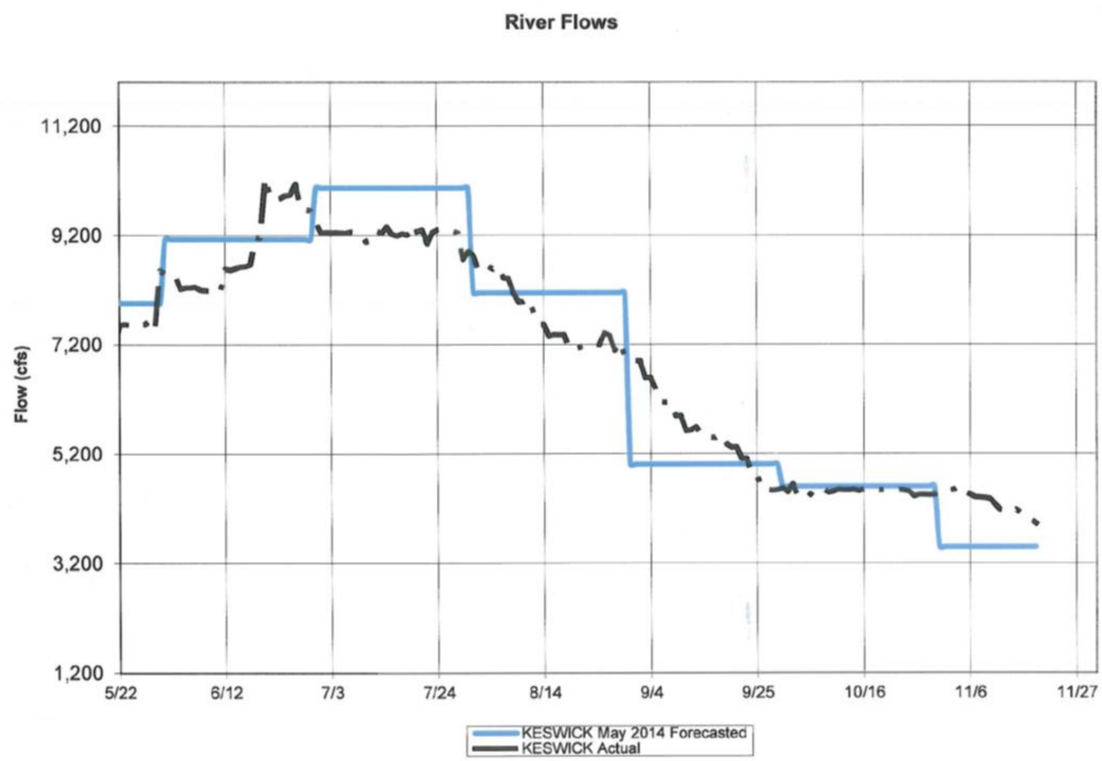

Figure 5

General Conclusion #4: A review of the actual Keswick releases versus the estimated monthly flows from the May 2014 forecast do indicate some short-term differences, but this variation in flow does not explain difference in TCD side gate performance.

Hindcast Version #2 – Introduction of actual flows and releases at Shasta, Spring Creek Powerplant, and Keswick.

As the next step in the analysis, Reclamation introduced the 2014 observed flow records for Shasta, Spring Creek Powerplant, and Keswick to the May 2014 model run. For this simulation, the actual TCD weighted averages were slightly smoothed to bi-monthly values to provide the model an added degree of freedom to make TCD adjustments while keeping the thermal loading properties observed in 2014. Figure 6 illustrates the results of this step in the analysis.

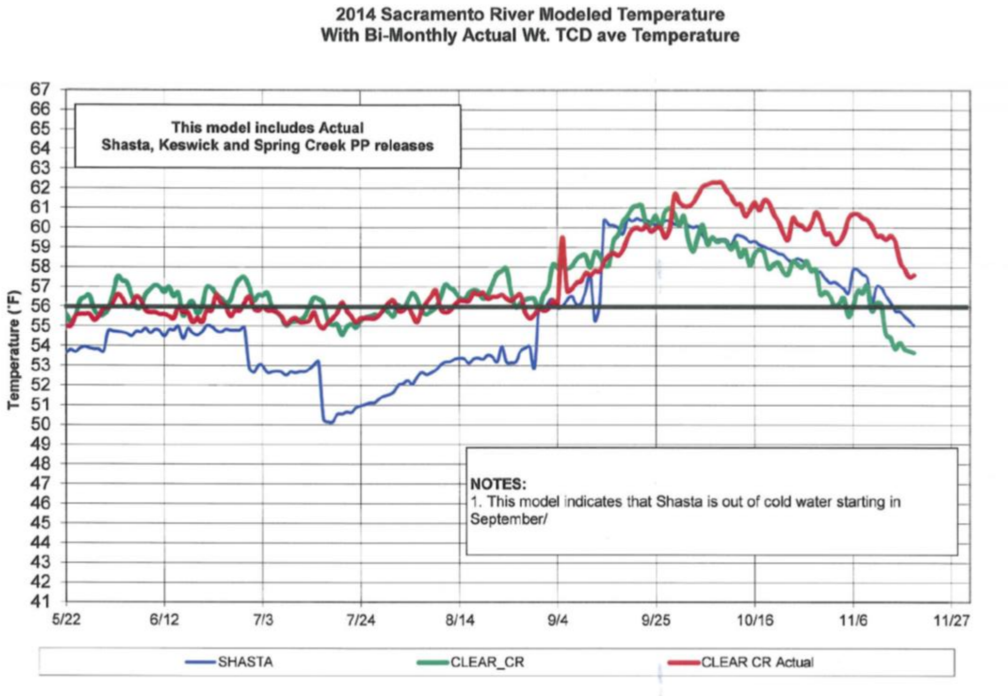

Figure 6

This simulation step shows very similar TCD operations as the actual record. Significant TCD gates elevation changes occur on roughly the same dates, late June, mid-July, and late August. The observed Sacramento River water temperature (at Clear Creek) and modeled temperatures show very good conformance until late September once adjusted for actual TCD side gate performance. Some deviation occurs in October and November, likely due to warmer than average air temperatures, more than modeling discrepancy.

General Conclusion #5: The HEC-5Q model appears to simulate well the anticipated timing of the TCD gate operations. If the TCD side gate had performed as expected, the forecasted river temperatures and overall seasonal strategic temperature plan would have likely been realized.

Seasonal Forecast Updates presented to SRTTG

Reclamation's model is updated monthly through the temperature management season. New water temperature profiles for Shasta Lake and Trinity Lake are incorporated into the model as they come available to ensure the best estimate of the available remaining cold water. This is a quasi-self-calibration which allows for strategic discussion by the SRTTG and adjustments to the seasonal management plan, as necessary. In 2014, all updates of the HEC-5Q model gave the same general conclusion, to expect TCD Side Gate operation in early September. The table below summarizes dates of the SRTTG meetings and the estimated timing of side gate operations associated with the modeling available at that time. At each meeting, Reclamation expressed uncertainty about how well the TCD side gate might perform under the developing conditions.

2014 SRTTG Meetings & Estimated TCD side gate Start Dates

SRTTG meeting	Projected TCD Side Gate Timing
May 22	Early September
June 26	September 1
July 24	September 1
August 26	Concurrent

Summary of 2014 TCD Performance

2014 Early Season TCD Operations

In the late spring and early summer of 2014, the TCD appears to have performed as designed given the steep temperature gradient of the Shasta Lake profiles. Figure 7 below shows the water temperature profile for Shasta Lake relative to TCD gate elevations on June 18 2014.

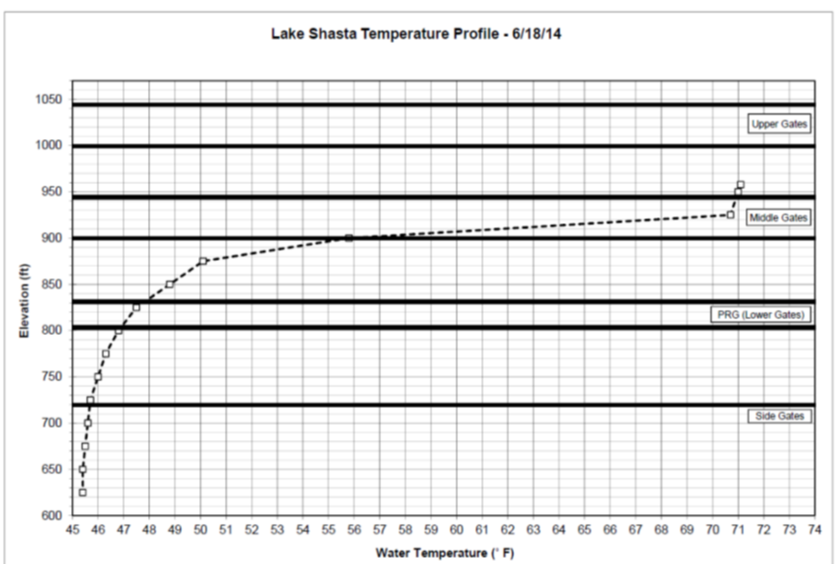

Figure 7

The chart illustrates the operational challenges inherent in TCD operations under these conditions. In order to conserve the coldest water near the bottom of the lake, while concurrently managing Sacramento River water temperatures at the Clear Creek gage location, Reclamation had to maintain a Shasta tailbay temperature between 53 to 54 degrees. Figure 7 shows that the 53 to 54 degree water in Shasta Lake was contained in a rather narrow elevation band within the lake at that time.

Operating the TCD to blend water from such a narrow band represented a real-time challenge for Reclamation operators – especially given that these high gradient temperature zones are the least stable from day to day as Shasta Lake conditions change. The good news is that in future years similar to 2014, indications are that the TCD can efficiently be managed in this high gradient zone prior to the TCD side gate operations provided a high level of attention is given to the potential of daily temperature fluctuations.

2014 Challenges with TCD Side Gate Operations

The TCD side gates are designed to draw water up from deep in Shasta Lake near the original river bottom and force that water up to the penstock elevations. In order to accomplish this, the TCD side gate are opened and the PRG gates are progressively closed in create the draw necessary to bring the colder, denser water from the bottom of lake up to penstock inlet elevation. The side gate operation of the TCD has been used in almost all years to effectively access and blend the last remaining cold water pool in late summer and fall.

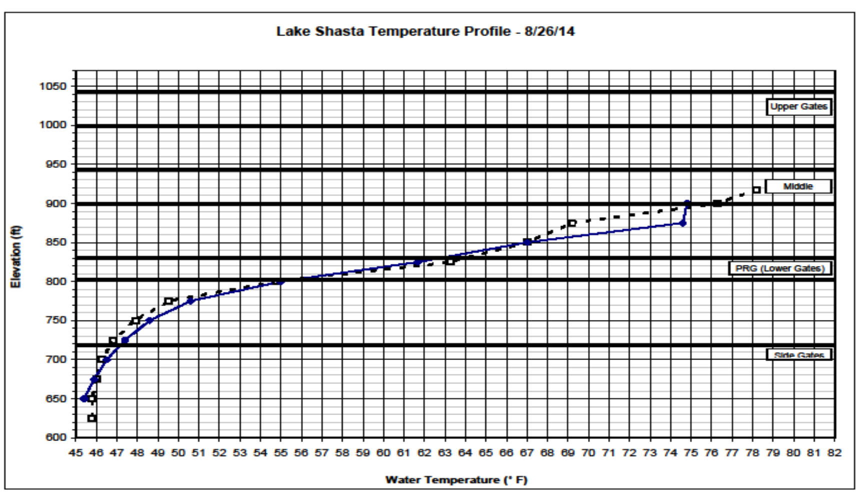

Figure 8

The Shasta Lake profile of August 26, 2014 (Figure 8 – Black Line) shows the cold water pool conditions at the time that Reclamation was transitioning to the TCD side gate operations. The profile indicates that 47 to 48 degree water was available near the invert of the side gate. The profile also shows that 56 to 60 degree water was located near the invert of the PRG gates, which is also the elevation of the penstock tubes that feed the Shasta Powerplant. The profile also shows that immediately above the penstock elevations and towards the middle gate level the lake water warmed substantially from 64 degrees to 70 degrees.

The Shasta Lake profile of late summer in 2014, as confirmed by the August 26 profile, presents a lake condition where very warm, less dense water was positioned immediately above the penstock elevations and cold, dense water had settled at the invert of the TCD side gates. We had no previous experience with the side gate under this degree of water temperature difference and density gradients.

Although previous experience with the TCD side gate suggested that much of this deep colder water could be blended as it has in past years, there were some concerns that the density difference in the Shasta Lake water column could be too great for the TCD side gate to effectively draw colder water up to the penstock level, and that the less dense water above the penstock elevations would begin to leak through and feed the penstock elevation despite the settings of gates at TCD. It is clear from the experience of 2014 that the TCD side gate operations did not perform to design or modeling expectation. The exact dynamic leading to the failure of the TCD side gate to draw properly is unknown, but should be investigated further.

Once it became clear that the TCD side gate was not drawing properly, Reclamation conducted ad hoc operations using the 750 ft elevation river outlet in an attempt to access some of the remaining cold water. Eventually, the full profile of Shasta Lake became too warm to fully control the water temperatures feeding the Sacramento River.

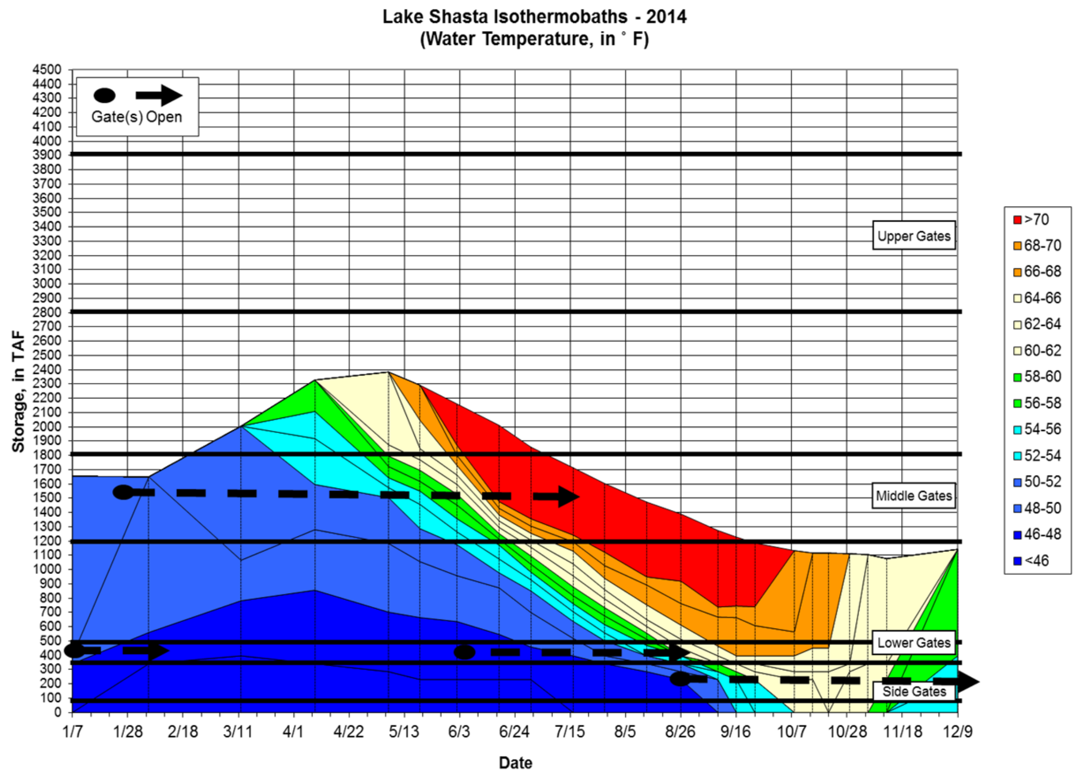

Figure 9

Figure 9 illustrates the full season cold water usage in Shasta Lake for 2014. Reclamation generally targeted the 52 to 54 degree thermal layer with TCD blending most of the summer to manage to the 56 degree objective at the river compliance point. This chart illustrates a rather normal progression of this thermal layer through the middle gates and PRG gates of the TCD as the temperature season progressed. In late August, when the TCD side gate operations begin, the chart shows a fairly rapid dipping of the upper warm layers, indicating the source of water entering Shasta Powerplant is from the warmer pool levels. During mid-September and into October, the reduction in the 52 to 54 degree layer indicates the ad hoc use of the 750 ft. outlet and the eventual exhaustion of the cold water to that level.

Summary of Findings

- During prolonged drought conditions, there will certainly be years when Shasta Lake will not fill enough to allow for full use of the Shasta TCD Upper Gates for blending purposes. In these years when only the middle gates and below are available to manage the cold water pool, annual water temperature planning will be extremely challenging.

- In more extreme conditions similar to 2014, the TCD side gates operations will likely need to be strategized to occur later in September to avoid outcomes similar to 2014. This may necessitate incrementally warmer river temperature objectives earlier in the temperature control season and/or delayed TCD operations to conserve cold water.
- The current HEC-5Q model seems to have been adequate in representing lake stratification, in-river temperature gains, and TCD performance prior to use of the TCD side gate, but did a poor job of characterizing the TCD performance once the TCD side gate operation went into real-time effect.