UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
West Coast Region
7600 Sand Point Way NE, Bldg. 1
Seattle, Washington 98115

June 28, 2016

Mr. David Murillo
Regional Director
Mid-Pacific Region
U.S. Bureau of Reclamation
2800 Cottage Way
Sacramento, California 95825

Re: Sacramento River Temperature Management Plan

Dear Mr. Murillo:

Thank you for your June 27, 2016, letter and enclosed Sacramento River Temperature Management Plan. For purposes of compliance with the reasonable and prudent alternative (RPA) Action I.2.4[1], described in NOAA's National Marine Fisheries Service's (NMFS) biological opinion (issued June 4, 2009) on the long-term operations of the Central Valley Project (CVP) and State Water Project (CVP/SWP Opinion), the U.S. Bureau of Reclamation (Reclamation) is required to submit a Sacramento River temperature management plan to NMFS for concurrence. The Plan is required to meet a water temperature not in excess of 56°F at compliance locations between Balls Ferry and Bend Bridge from May 15 through September 30 for protection of Sacramento River winter-run Chinook salmon (*Oncorhynchus tshawytscha*), and not in excess of 56°F at the same compliance locations between Balls Ferry and Bend Bridge from October 1 through October 31 for protection of Central Valley spring-run Chinook salmon (*O. tshawytscha*) in the river mainstem (whenever possible). The objective of Action I.2.4 is to manage the cold water storage within Shasta Reservoir and make cold water releases from Shasta Reservoir to provide suitable habitat temperatures for winter-run Chinook salmon, spring-run Chinook salmon, California Central Valley steelhead (*O. mykiss*), and the Southern distinct population segment of North American green sturgeon (*Acipenser medirostris*) in the Sacramento River between Keswick Dam and Bend Bridge, while retaining sufficient carryover storage to manage for next year's cohorts.

Winter-run in brood years 2014 and 2015 had very poor survivals due to drought and temperature effects. Because of this low survival in two of three cohorts, the overall risk to the survival and recovery of winter-run is much higher this year than in the past. In order to stay within the anticipated effects of implementing the 2009 RPA, risk of mortality from temperature related effects must be reduced to the maximum extent this year, which necessitates a less flexible approach than has been employed in the past.

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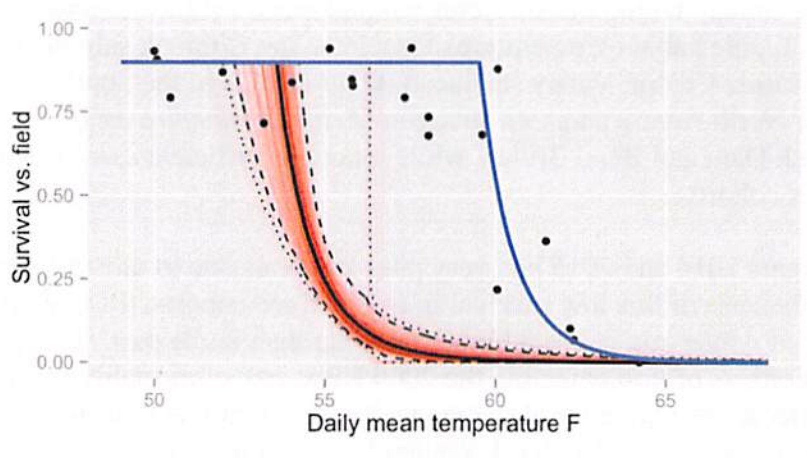
1 http://www.westcoast.fisheries.noaa.gov/publications/Central_Valley/Water%20Operations/Operations,%20Criteria%20and%20Plan/040711_ocap_opinion_2011_amendments.pdf

As a result of poor survivals in 2014 and 2015, NMFS evaluated the scientific literature of temperature effects on salmon, and the fish agencies (NMFS, U.S. Fish and Wildlife Service, and the California Department of Fish and Wildlife), along with Reclamation and the California Department of Water Resources (DWR), reexamined the Sacramento River Water Quality Model used for temperature management in the upper Sacramento River. Collectively, NMFS arrived at three main findings:

1. Best available scientific data indicate that water temperatures up to 50°F (6-10°C constant) are optimal for winter-run egg and fry survival and development [U.S. Environmental Protection Agency (EPA) 2003[2]]. To avoid high mortality of winter-run eggs and fry and staying within the effects anticipated from implementation of the RPA, best available science further points to using EPA's (2003) temperature maximum of 55°F for the 7-Day Average of the Daily Maxima (7DADM). By calculating a running average of the maximum water temperatures each day for 7 days, the 7DADM metric captures conditions that winter-run eggs and fry are exposed to on a daily basis while reducing the potential that one extremely high daily maximum temperature would result in exceeding the temperature criterion. This is a significant finding. The previous approach of managing to 56°F daily average temperature (DAT) at the location of the redds was not supported, as it is not sensitive to extreme high or low water temperatures within a given day.

2. NMFS' Southwest Fisheries Science Center's (SWFSC) new temperature-dependent mortality model (the "Martin model," which uses field data to calibrate temperature effects on salmon) identified 53.7°F as the critical temperature at which temperature- related winter-run egg and fry mortality increases significantly with increasing water temperatures (as shown in the below figure). This model, in general, corroborates the EPA temperature criteria recommendations (see #1, above).

Mortality increases rapidly past the critical temperature



[2] https://www3.epa.gov/region10/pdf/water/final_temperature_guidance_2003.pdf

3. Inputs to Reclamation's temperature model are not conservative, and the model generally assumes that operations can achieve temperature targets that are either not realistic or not supported in the historical record. The CVP/SWP Opinion, RPA Action I.2.4(3), required Reclamation to fix this and other major flaws of this model; however, that RPA action has not been implemented.

NMFS shared these findings with Reclamation starting in December 2015, and with other agencies and stakeholders throughout the winter and early spring of this year. We also discussed 2016 temperature management with Reclamation extensively at this time both to explain and set expectations that because of two years of poor winter-run survivals, we needed to recalibrate our risk tolerance toward greater protection of the species. Reclamation and DWR's 2016 Drought Contingency Plan (DCP; submitted to the State Water Board on January 15, 2016[3]), Attachment 4 (NOAA/NMFS Considerations for 2016 Shasta Operations Potential Temperature Criteria Adjustments and Suggested Model Inputs), describes various metrics to achieve temperature criteria that could meet the needs of winter-run this year, and suggested modeling scenarios, based on the interagency team's evaluation of best available science.

Consultation History

On March 15, 2016, Reclamation provided NMFS with a set of preliminary Sacramento River temperature modeling results in response to the requirements in the CVP/SWP Opinion and RPA Action I.2.3. Reclamation acknowledged that the model results were being provided only as information at that point, and that temperature analyses would be updated in the near future based on recent storm events and new estimates of hydrology. On March 18, 2016, NMFS issued a letter responding to Reclamation (enclosure 1). Within that letter, NMFS enclosed a "Shasta Operations Temperature Compliance Memo" that provided a review of the preliminary February forecasts and temperature modeling scenarios, including information supporting the use of a 56°F DAT at Jelly's Ferry as the temperature compliance point this year.[4] In addition, given the poor performance and uncertainties associated with Reclamation's model and the extreme importance to manage for higher juvenile winter-run survival during the temperature management season this year, NMFS proposed some buffers to help address the unavoidable uncertainty in temperature model and potential adjustments to the Sacramento River temperature criteria. These buffers included:

1. continued use of the more conservative (*i.e.*, warmer) Local 3-Month Temperature Outlook meteorological forecast input using an average of 2014 and 2015 meteorological data;
2. use of 75% and 99% hydrological forecasts (in addition to the 50% and 90%) with additional weight to El Niño hydrological years to more accurately reflect the current hydrology;

[3] http://www.water.ca.gov/waterconditions/docs/2016-DroughtContingencyPlan-CVP-SWPOperations-Feb-Nov_1.19.16-FINAL.pdf
[4] This is roughly equivalent to a 55°F 7-day average of the daily maximums (55°F 7DADM) temperature at Bonneyview Bridge ["CCR" California Data Exchange Center (CDEC) temperature gauge station].

3. application of a Shasta Reservoir temperature profile stratification scenario from the historical record that shows a steep cold water decline in the spring (*e.g.*, what happened in 2015);
4. meeting an end of May Shasta Reservoir storage of at least 4.0 million acre-feet (MAF); and
5. use of EPA's (2003) recommendation of 55°F 7DADM metric at the CCR temperature compliance point.

On March 25, 2016, Reclamation sent NMFS results of the 50% and 90% exceedance forecasts, water temperature modeling, and the initial water supply allocations for 2016. At that time, Reclamation's plan for seasonal temperature management looked very positive, and met the temperature criteria included in the 2016 DCP (in addition to targeting a Keswick Dam release temperature of 52°F DAT in order to meet a 55°F 7DADM at CCR), and therefore, on March 31, 2016, NMFS concurred on the package (enclosure 2).

On May 2, 2016, Reclamation distributed a set of handouts[5] in preparation for the May 3, 2016, Sacramento River Temperature Task Group (SRTTG) meeting. Within the handouts, and during the SRTTG meeting, Reclamation shared new information that Shasta Reservoir, while nearly full, was much warmer than expected and previously modeled. As a result, Reclamation indicated that it would not be able to meet a Keswick Dam release of 52°F DAT that was included in its March 25, 2015, Reservoir Operations Forecasts letter. NMFS relayed to Reclamation that the previous temperature management plan no longer met the provisions in NMFS' March 31, 2016, concurrence and that it was no longer supportable. NMFS and Reclamation agreed to work together to develop a new plan.

Over this past month, the Shasta Water Interagency Managers (SWIM) Team[6] developed multiple Keswick Dam release scenarios for Reclamation to model. In addition to using Reclamation's standard temperature model, the Zeug *et al.* (2012) mortality model, the NMFS- SWFSC's River Assessment for Forecasting Temperature (RAFT) model, and the Martin model were also used to examine release scenarios and their effects on estimated egg and fry mortality rates. Unfortunately, following multiple iterations, teamwork, and technical discussions to look at all options, the SWIM Team acknowledged that given the smaller cold water pool in Shasta Reservoir, the criterion of 55°F 7DADM at CCR and full side gate access no earlier than October 15 would not be able to be met this year. Therefore, the SWIM Team turned to working continuously to find a scenario that would optimize operations with a given Keswick Dam release schedule. Enclosure 3 provides a chronology and progression of the Keswick Dam release schedule scenarios and associated temperature, RAFT, and mortality modeling results.

[5] http://www.westcoast.fisheries.noaa.gov/publications/Central_Valley/Water%20Operations/Sacramento%20River%20Temperature%20Task%20Group/sacramento_river_temperature_task_group_may_3_2016_meeting_agenda_and_handouts.pdf

[6] Interagency managers from Reclamation, NMFS, DWR, U.S. Fish and Wildlife Service, California Department of Fish and Wildlife, and State Water Resources Control Board

On June 7, 2016, Reclamation shared its draft Sacramento River Temperature Management Plan with NMFS. The plan had a similar Keswick Dam release schedule as proposed in Reclamation's March forecast; however, Reclamation proposed to meet a 56°F DAT at Balls Ferry rather than 55°F 7DADM at CCR. On June 14, 2016, NMFS provided Reclamation with comments on the draft Sacramento River Temperature Management Plan (enclosure 4), in addition to a more general consultation history, and comments associated with the historical record, modeling, and uncertainty.

During a June 8, 2016, Federal agency meeting, NMFS distributed a NMFS-California Department of Fish and Wildlife (CDFW) Shasta temperature plan (enclosure 5). In consideration of the current status of winter-run Chinook salmon, and uncertainties related to Reclamation's model, the plan, in general, outlined conservative operations in June and July. Following this conservative start, the plan allowed NMFS the ability to make a subsequent determination to allow releases up to 9,000 cfs for mid-August through mid-October based on the results of a late July/early August SWIM team "true up" meeting to examine actual Shasta cold water expenditure against the model projections (provided the new modeling illustrated that temperature compliance can be maintained throughout October at higher releases). Reclamation, however, indicated that the NMFS-CDFW plan would not meet the Bureau's other obligations of providing water supply.

Reclamation's June 27, 2016, Sacramento River Temperature Management Plan

On June 27, 2016, Reclamation submitted its Sacramento River Temperature Management Plan to NMFS and requested concurrence that it was consistent with RPA Action I.2.4 in NMFS' CVP/SWP Opinion. In summary, Reclamation's plan consists of:

- monthly average Keswick Dam releases of 9,000 cfs in June, 10,500 cfs in July, 10,000 cfs in August, 9,000 cfs in September, and 6,500 cfs in October.
    - The 10,500 cfs Keswick Dam release in July is a cap (rather than a monthly average) and would be ramped up in two 750 cfs increments, each based on (and following the review of) weekly Shasta Lake temperature profiles and temperature model runs to ensure that all metrics (*e.g.*, full side gate operation, 56.0°F DAT at Balls Ferry, cold water pool volume at <49°F) continue to be attainable.
    - The timing for reductions in flows in September and October would be scheduled in coordination with the fish agencies to reduce risk of redd dewatering. Fall flow reductions would occur once all winter-run Chinook salmon fry are estimated to have emerged from their redds, but as early as possible to reduce stranding of fall- run Chinook redds in the upper Sacramento reach.
- a temperature compliance point and metric that will not exceed 56.0°F DAT at Balls Ferry.
    - Reclamation will operate in a manner to avoid any exceedance of 56.0°F DAT at Balls Ferry, and Reclamation will promptly implement steps to reduce the temperature to the compliance criterion to deal with any unforeseen transitions to periods of very high air temperatures and to assure that any exceedance is minimized.

  - In addition, during any exceedance, Reclamation will take immediate action to lower the daily maximum water temperatures to at or below 55.0°F through the area of the most downstream redd and will maintain the 55.0°F daily maximum water temperature through the period where water temperatures at Balls Ferry may exceed 56.0°F.
- full side gate operation of the Shasta Dam Temperature Control Device (TCD) on or after October 9, 2016.
- weekly monitoring of temperature profiles at Shasta Reservoir, temperature performance, TCD operations, and temperature model runs.
  - In addition, Reclamation will monitor the 7DADM temperatures at the SAC (Sunset Pumps) and CCR CDEC gauging stations. Data will be distributed to the SWIM team prior to its weekly update calls. The SWIM team will review the above data, and consider the location of redds, the weather forecasts, the volume of available cold water, inflows, the integrated operations with the Trinity River Division, and other real-time considerations.
  - The SWIM team will also provide advice on minimizing potential effects of redd de-watering and stranding, based on any flow changes resulting from implementation of the Plan.
  - If SWIM Team consensus cannot be reached, Reclamation will formulate an action consistent with the Plan, which can be implemented pending Reclamation consultation with NMFS and NMFS concurrence.
- verifying on a weekly basis that the volume of water in Shasta Reservoir < 49°F is not less than 95% of the forecasted volume as predicted by the June 7, 2016, temperature model run (*i.e.*, the basis for the Plan).
  - If this volume is less than 95% of the forecasted amount, Reclamation will reduce Keswick Dam releases by 1,000 cfs for one week in an effort to allow the volume of water < 49° F to make progress back to at least 100% of the June 7 projection.
  - If, after one week the volume of water < 49°F is not equal to or greater than 100% of the June 7 projection, Reclamation will further reduce Keswick Dam releases by another 1,000 cfs (but not less than 8,000 cfs), and Reclamation will immediately call a special Directors-level meeting to assess whether the variation in overall cold water pool is significant enough to require a reformulation of the Plan.
- revising the Plan through the SWIM team with the goal to create a modified temperature compliance metric and location of 55.0°F 7DADM through the spawning area if overall conditions are better than forecasted (*e.g.*, greater than anticipated cold water volume).

Summary and Expectations

The following are NMFS' summary conclusions and expectations based on Reclamation's proposed Sacramento River temperature management plan:

- NMFS has reviewed Reclamation's proposed Sacramento River temperature management plan and supporting biological review. The Plan will likely provide temperature needs for incubating winter-run Chinook salmon eggs and fry in brood year 2016, although some temperature-dependent mortality is expected.

- Reclamation shall monitor temperature profiles at Shasta Reservoir on a weekly basis, and distribute all associated data and model run results to the SWIM team as soon as possible and prior to the weekly SWIM team meetings. The SWIM team shall confirm that all metrics (*e.g.*, full side gate access on or after October 9, 2016, >95% of modeled volume of Shasta Reservoir water <49°F, 56.0°F DAT at Balls Ferry, no winter-run Chinook salmon redd dewatering, *etc.*) can still be met through the remainder of the temperature control season.
- The timing for reductions in flows in September and October shall be scheduled in coordination with the fish agencies to reduce risk of winter-run redd dewatering.
- In the event of a temperature exceedance of 56.0°F DAT at Balls Ferry, Reclamation shall immediately operate to a water temperature not to exceed a daily maximum of 55.0°F at the downstream-most winter-run Chinook salmon redd identified.
- If the volume of Shasta Reservoir water <49°F is less than 95% of the modeled volume from the June 7 model run, Reclamation shall reduce Keswick Dam releases by 1,000 cfs. If, after a week, the volume of Shasta Reservoir water <49°F is less than 100% of the June 7 projection, Reclamation shall reduce the Keswick Dam release by another 1,000 cfs (but not to a release less than 8,000 cfs) and Reclamation shall immediately call a special Directors- level meeting to assess whether the variation in overall cold water pool is significant enough to require a reformulation of the Plan.
- If overall conditions are better than forecasted (*e.g.,* greater than anticipated cold water volume), then the plan may be revised through the SWIM team process with the goal to create a modified temperature compliance metric and location of 55.0°F 7DADM through the winter-run spawning area.

In conclusion, NMFS concurs that Reclamation's proposed Sacramento River temperature management plan is consistent with RPA Action I.2.4. We are making this finding based on both the Biological Review attached to Reclamation's June 27, 2016, letter, our understanding of the water temperature needs of winter-run Chinook salmon, and our conclusion that the potential effects of implementing the Sacramento River temperature management plan in water year 2016 were considered in the underlying analysis of the CVP/SWP Opinion. Furthermore, the best available scientific and commercial data indicate that implementation of the Sacramento River temperature management plan will not exceed levels of take anticipated for implementation of the RPA specified in the CVP/SWP Opinion.

We look forward to continued close coordination with you and your staff throughout this water year.

If you have any questions regarding this letter, please contact me at barry.thom@noaa.gov or (503) 231-6266, or Maria Rea at maria.rea@noaa.gov or (916) 930-3600.

Sincerely,

Barry A. Thom

for William W. Stelle, Jr.
Regional Administrator

Enclosures:

1. NMFS' March 18, 2016, letter to Reclamation in response to a set of preliminary Sacramento River temperature model results
2. NMFS' March 31, 2016, letter to Reclamation in response to Reclamation's March forecast and water supply allocation for water year 2016
3. NMFS' June 28, 2016, memorandum to the administrative record
4. NMFS' June 14, 2016, Comments on Reclamation's proposed draft Sacramento River TMP
5. NMFS-CDFW draft Shasta temperature plan

cc: Copy to file – ARN 151422SWR2006SA00268

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Literature cited:

Martin, B., S. John, A. Pike, J. Roberts, E. Danner. 2016. Modeling temperature dependent mortality of winter-run Sacramento River Chinook Salmon. See Enclosure 1.

Zeug, S.C., P.S. Bergman, B.J. Cavallo, and K.S. Jones. 2012. Application of a life cycle simulation model to evaluate impacts of water management and conservation actions on an endangered population of Chinook salmon. Environmental Modeling & Assessment 17: 455- 467.

Enclosure 1

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
West Coast Region
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MAR 18 2016

Mr. Ron Milligan
Operations Manager, Central Valley Project
U.S. Bureau of Reclamation
3310 El Camino Avenue, Suite 300
Sacramento, California 95821

Dear Mr. Milligan:

Thank you for your March 15, 2016, letter and the set of preliminary Sacramento River temperature modeling results, in response to the requirements in NOAA's National Marine Fisheries Service's (NMFS) 2009 biological opinion and reasonable and prudent alternative (RPA) Action I.2.3.

Especially over the course of the last 2 years, there has also been an unprecedented level of coordination between NMFS and Reclamation, in addition to the U.S. Fish and Wildlife Service, DWR, California Department of Fish and Wildlife, and California State Water Resources Control Board, on the development and implementation of Sacramento River temperature management plans. We appreciate the ongoing close coordination over the last several months as we continue to work through the changing hydrology and development of drought contingency plans, forecasts, and temperature model run scenarios that meet the needs of Sacramento River winter-run Chinook salmon and system-wide operations. We also appreciate the regularly scheduled meetings with the Sacramento River Settlement Contractors to coordinate Shasta operations, forecasts, winter-run needs, and projects to improve and restore Central Valley salmon habitat.

The scenarios attached to your letter contained a suite of options and difficult choices which are most likely no longer necessary or, at a minimum, mitigated significantly by the substantial increase in Shasta storage during the first two weeks of March. For example, from March 1-16, Shasta Reservoir gained over 1 million acre-feet (MAF) in storage, and is currently conducting flood control releases. With some snow pack in the Shasta Reservoir catchment basin, inflows will continue, and snowmelt with augment the cold water pool.

We look forward to receiving a March 90% exceedance forecast with updated hydrology and temperature evaluation with a request for review and concurrence next week. Given the loss of two out of three cohorts of winter-run Chinook salmon, we will review the revised forecast carefully to ensure the Keswick release schedule and water temperatures will provide adequate habitat for winter-run spawning and egg and alevin incubation. We will continue to use the maintenance of 52°F daily average temperature (DAT) at Keswick Dam (as an indicator of the ability to meet a 55°F 7-day average of the daily maximum (7DADM) temperatures at the

Bonneyview Bridge temperature compliance point (CCR CDEC station location) throughout the temperature management season as the metric to evaluate your forecasted operations, and will also review end of season storage and dewatering effects.

For your information, we are attaching a review of your February forecasts and temperature modeling scenarios, including information supporting the use of a 56°F DAT at Jelly's Ferry as the temperature compliance point this year, which is roughly equivalent to a 55°F 7DADM at CCR. We especially appreciate the hard work of your staff to adjust and verify the temperature model. The hind cast temperature profiles were informative, and helped to support a planning target of 4.2 MAF for spring storage, when feasible, as a proxy for an adequate cold water pool. We especially look forward to creating good technical venues to discuss the NMFS-Southwest Fisheries Science Center survival model over the next year, and to continued work on the reservoir model.

Again, we look forward to receiving your revised forecast package and temperature effects analysis next week. If you have any questions regarding this letter, please feel free to contact me, or have your staff contact Brycen Swart at (916) 930-3712, or via e-mail at brycen.swart@noaa.gov.

Sincerely,

FOR
Maria C. Rea
Assistant Regional Administrator
California Central Valley Office

cc: Copy to file – ARN 151422SWR2006SA00268

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UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
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Date: March 18, 2016

Memorandum to: CVP/SWP Operations Opinion
Administrative Record Number 151422SWR2006SA00268

From: Brycen Swart, Fisheries Biologist Brycen Swart

Subject: Shasta Operations Temperature Compliance Memo

Introduction

California has just ended its fourth consecutive year of below-average rainfall and snowpack, resulting in significant adverse effects to juvenile winter-run Chinook salmon populations. Due to a lack of sufficient inflow and cold water pool in Shasta Reservoir and competing water demands in 2014 and 2015, Sacramento River water temperatures rose to sub-lethal and lethal levels contributing to very low egg-to-fry survival of juvenile winter-run Chinook salmon estimated to pass Red Bluff Diversion Dam (RBDD) in brood years 2014 (5.6%) and 2015 (4.2%), well below the 18-year average of 23.6% survival. In addition, egg-to-fry survival of juvenile winter-run Chinook salmon in brood year 2013 was estimated to be 15.1%, approximately 36% below the 18-year average of 23.6% survival (Figure 1). Adults returning in 2016 are largely the progeny from brood year 2013. Using a newly developed temperature-dependent mortality model, NMFS Southwest Fisheries Science Center (SWFSC) found that in 2014 and 2015, temperature dependent mortality alone resulted in a loss of approximately 77% and 85% of the population, respectively (B. Martin, personal communication, February 23, 2016; attachment).

Since winter-run Chinook salmon spawn every three years, there is a need to conservatively manage for protection of the 2016 winter-run cohort given the year class failures observed in the last two years. The U.S. Bureau of Reclamation (Reclamation) typically uses the 2016 February forecast to provide initial allocations. To the extent that the February forecast is used to determine whether the predicted water delivery schedule is likely to leave sufficient water for temperature management to meet Endangered Species Act requirements, NMFS proposes model inputs to the Sacramento River Water Quality Model and adjustments to the temperature criteria to minimize adverse thermal effects to winter-run eggs and alevin.

Thermal Needs for Incubation and Early Fry Development

Water temperatures significantly affect the distribution, health, and survival of native salmonids in the California Central Valley. Since salmonids are ectothermic (cold-blooded), their survival is dependent on external water temperatures and they will experience adverse health effects when exposed to temperatures outside their optimal range. Salmonids have evolved and thrived under the water temperature patterns that historically existed (*i.e.*, prior to significant anthropogenic impacts that altered temperature patterns) in California Central Valley streams and rivers. Although evidence suggests that historical water temperatures exceeded optimal conditions for salmonids at times during the summer months on some rivers, the temperature diversity in these unaltered rivers provided enough cold water during the summer to allow salmonid populations as a whole to thrive [United States Environmental Protection Agency (EPA) 2003].

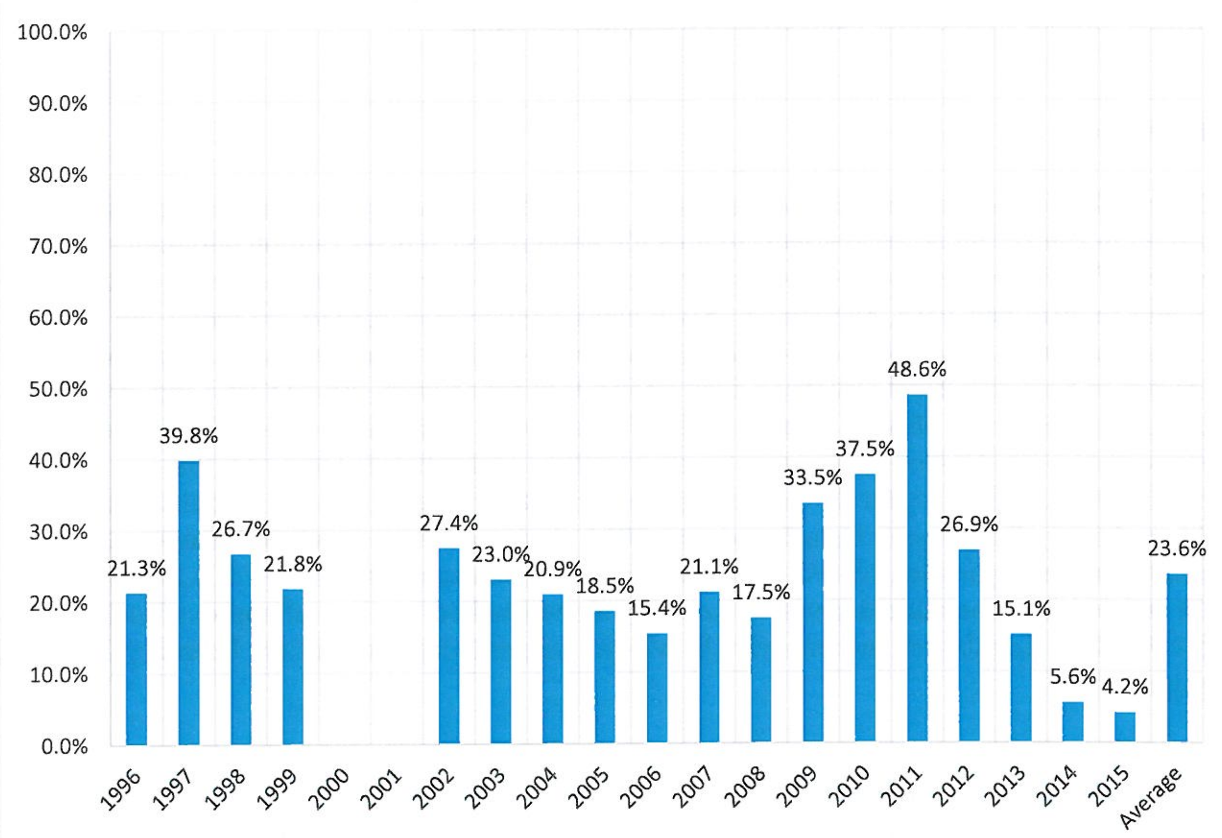

Figure 1. Estimated egg-to-fry survival from passage at Red Bluff Diversion Dam

Pacific salmon populations have historically fluctuated dramatically due to climatic conditions, ocean conditions, and other disturbances. High water temperatures during drought conditions likely affected the historical abundance of salmon. In general, the increased exposure to stressful water temperatures and the reduction of suitable habitat caused by drought conditions reduce the abundance of salmon. Human-caused elevated water temperatures significantly increase the magnitude, duration, and extent of thermal conditions unsuitable for salmonids (EPA 2003).

The effects of water temperature in regulating developmental rates of incubating eggs are well documented (*e.g.*, Hicks 2000, McCullough 1999). During incubation, water temperature affects the rate of embryo and alevin development, the amount of dissolved oxygen in the water, and, to a significant extent, the survival of early fry (Bjornn and Reiser 1991). Within an acceptable range, the higher the temperature is, the faster the rate of development will be, and the shorter the incubation period and time to emergence (Beacham and Murray 1990). Temperatures from 39.2 to 53.6°F (4-12°C) tend to produce relatively high survival to hatching and emergence, with approximately 42.8-50°F (6-10°C) being optimum. Exposure to temperatures above the optimal range results in sub-lethal or chronic effects (*e.g.*, decreased juvenile growth, which results in smaller, more vulnerable fish; increased susceptibility to disease which can lead to mortality; and decreased ability to compete and avoid predation), as temperatures rise until at some point they become lethal.

United States Environmental Protection Agency Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards

Temperature water quality standards are an important tool for the protection and recovery of threatened and endangered salmonid species through maintaining and improving their habitat. In 1999, the EPA Region 10 started a project to develop regional temperature criteria guidance that would be protective of salmonids. States and tribes in the Pacific Northwest could then use this guidance when developing their temperature standards, as required by the Clean Water Act. The criteria guidance was jointly developed by EPA, U.S. Fish and Wildlife Service, National Marine Fisheries Service, States, and Tribes in the Pacific Northwest. They examined the most recent science on how temperature affects salmonid physiology and behavior, the combined effects of temperature and other stressors on threatened fish stocks, the pattern of temperature fluctuations in the natural environment, and other relevant issues. The project culminated in 2003 with the EPA publication of guidance recommendations to States and Tribes on how they can designate uses and establish temperature numeric criteria for waterbodies to protect coldwater salmonid species in the Pacific Northwest.

EPA (2003) recommends a 13°C (55.4°F) maximum 7 day average of the daily maxima (7DADM) criterion for the protection of waterbodies used or potentially used for salmon and trout spawning, egg incubation, and fry emergence and recommends that this use apply from the average date that spawning begins to the average date incubation ends (the first 7DADM is calculated 1 week after the average date that spawning begins). The 7DADM metric is recommended because it describes the maximum temperatures in a stream, but is not overly influenced by the maximum temperature of a single day. Thus, it reflects an average of maximum temperatures that fish are exposed to over a weeklong period. Since this metric is oriented to daily maximum temperatures, it can be used to protect against acute effects, such as lethality, and can also be used to protect against sub-lethal or chronic effects.

EPA (2003) also recommends that water quality standard should apply to all the river miles including the lowest point downstream for egg incubation and fry emergence. Because streams generally warm progressively in the downstream direction, waters upstream of that point will generally need to be cooler in order to ensure that the criterion is met downstream. Thus, a waterbody that meets a criterion at the furthest downstream extent of use will in many cases provide water cooler than the criterion at the upstream extent of the use.

Sacramento River Temperature Compliance Regulatory Requirements

In order to protect salmon egg incubation and fry emergence from adverse thermal effects, the State Water Resources Control Board Orders 90-5 and 91-1 require Reclamation to operate Keswick and Shasta dams to meet a daily average temperature of 56°F at RBDD or at a temperature compliance point (TCP) modified when the objective cannot be met at RBDD based on Reclamation's other operational commitments, including those to water contractors, D-1641 regulations and criteria, and Shasta Reservoir projected end of September (EOS) storage volume.

The 2009 biological and conference opinion on the long-term operation of the Central Valley Project and State Water Project (CVP/SWP operations Opinion) highlights the challenging nature of maintaining an adequate cold water pool in critically dry years, extended dry periods, and under future conditions, which will be affected by increased downstream water demands and climate change. Despite Reclamation's best efforts, severe temperature-related effects cannot be avoided in some years. Reasonable and Prudent Alternative (RPA) Action Suite I.2 includes exception procedures to deal with this reality. Specifically, RPA Action I.2.4 states that Reclamation shall manage Shasta Division operations to achieve a temperature compliance of not in excess of 56°F daily average temperature (DAT) between Balls Ferry and Bend Bridge from May 15 through October 31. In addition, there is a 10-year average performance measure and for temperature compliance points on the Sacramento River during the summer season:

- Meet Clear Creek compliance point 95% of time
- Meet Balls Ferry compliance point 85% of time
- Meet Jelly's Ferry compliance point 40% of time
- Meet Bend Bridge compliance point 15% of time

So far the current 6-year average (2010-2015) since issuance of the CVP/SWP operations Opinion is below this performance metric (see Table 1):

- Clear Creek was met 66% of the time
- Balls Ferry was met 50% of the time
- Jellys Ferry was met 50% of the time
- Bend Bridge was met 0% of the time

Also there is a 10-year average performance measures associated with meeting EOS carryover storage at Shasta Reservoir in order to maintain the potential to meet the various temperature compliance points:

- 87% of years: Minimum EOS storage of 2.2 million acre-feet (MAF)
- 82% of years: Minimum EOS storage of 2.2 MAF and End of April (EOA) storage of 3.8 MAF in following year (to maintain potential to meet Balls Ferry compliance point)
- 40% of years: Minimum EOS storage of 3.2 MAF (to maintain potential to meet Jelly's Ferry compliance point in following year)

The current 6-year average also falls short of this performance metric:

- 50% of Years: Minimum 2.2 MAF
- 50% of Years: Minimum 2.2 MAF and EOA 3.8 MAF
- 33% of Years: Minimum 3.2 MAF

Table 1. Yearly Shasta Reservoir Storages, Water Year Types, Temperature Compliance Points (TCP), Egg-to-Fry Survival, and Various TCP Temperatures.

WY	Beginning of October Storage	End of April Storage	WY Type	TCP	Egg to Fry Survival	SHD DAT	KWK DAT	CCR DAT	CCR 7DADM	BSF DAT	JLF DAT	BND DAT	RBDD DAT
1996	3136	4308	W	BSF	21.3%	51.6	52.3			55.0	55.9	56.0	57.5
1997	3098	3937	W	JLF	39.8%	50.8	51.8			54.5	55.5	56.3	57.1
1998	2308	4061	W	JLF	26.7%	50.7	51.6	52.2	53.3	54.0	55.2	55.4	56.6
1999	3441	4256	W	BND	21.8%	48.9	50.5	51.6	53.3	53.4	54.6	55.1	56.4
2000	3327	4153	AN	BSF		50.3	51.8	52.7	54.3	54.3	55.4	55.8	57.2
2001	2985	4020	D	JLF		50.8	52.0	53.0	54.6	54.4	55.6	56.0	57.6
2002	2200	4297	D	JLF	27.4%	50.1	51.5	52.6	54.3	54.1	55.2	55.7	57.2
2003	2558	4537	AN	BSF	23.0%	50.1	51.6	52.6	54.2	54.2	55.4	55.9	57.3
2004	3159	4060	BN	BSF	20.9%	51.8	52.5	53.5	55.1	54.8	55.9	56.4	57.7
2005	2183	4207	AN	BSF	18.5%	51.2	52.3	53.2	54.7	54.8	56.0	56.4	57.7
2006	3035	4057	W	BND	15.4%	49.6	50.9	51.7	53.1	53.3	54.7	55.0	56.3
2007	3205	3901	D	BSF	21.1%	51.5	52.5	53.3	55.0	54.8	55.7	56.2	57.4
2008	1879	2954	C	CCR	17.5%	53.1	53.8	54.6	56.6	55.9	56.9	57.4	58.8
2009	1384	2998	D	CCR	33.5%	51.9	53.0	54.1	55.9	55.6	56.8	57.2	58.8
2010	1774	4391	BN	JLF	37.5%	49.5	51.2	52.2	54.0	54.0	55.2	55.6	57.1
2011	3319	4266	W	JLF	48.6%	49.7	51.0	52.1	53.8	53.8	55.0	55.5	56.7
2012	3341	4440	BN	JLF	26.9%	49.7	51.3	52.4	54.3	53.9	55.0	55.5	56.9
2013	2592	3788	D	AND	15.1%	52.0	53.0	54.0	55.8	55.4	56.3	56.6	58.4
2014	1906	2409	C	CCR	5.6%	54.3	55.7	56.9	58.8	58.0	59.4	59.8	61.8
2015	1157	2662	C	CCR	4.2%	52.9	55.2	56.7	58.8	58.1	59.5	60.1	61.6
Avg	2407	3783			23.6%	51.0	52.3	53.3	55.0	54.8	56.0	56.4	57.9
Difference from CCR7DADM						-4.0	-2.7	-1.7		-0.2	1.0	1.4	2.9

Sacramento River Water Quality Model

Drought conditions over the last four years have highlighted the uncertainties in Reclamation's Sacramento River Water Quality Model (SRWQM) and its inability to meet the regulatory requirements outlined in the CVP/SWP operations Opinion. The SRWQM has a difficult time reflecting actual release temperature and conditions when the critical reservoir thermocline of about 52°F approaches the elevation of the temperature control device (TCD) side gates and/or reservoir outlet works. Given the significant simplification of the input data (which is derived from a 12-month operations outlook), the unknowns regarding future meteorological conditions, and the fact that the actual TCD does not have infinite adjustability, the model can only realistically provide a broad brush picture of future operations, but cannot provide sufficient precision to determine future operations.

However, model improvements have been made over time using lessons learned from previous years. For example, due to the higher ambient air temperature in the past few years, in 2015 Reclamation began using more conservative (*i.e.*, warmer) meteorological forecasts from the local 3-month temperature outlook (L3MTO) rather than continuing to use average temperature as an input to the Sacramento River water temperature profile. Additionally, in 2014, the upper 5 to 6 miles of the Sacramento River read 0.6°F warmer than the model, so in 2015 Reclamation adjusted the model 0.6°F for better accuracy.

NMFS 2016 Sacramento River Suggested Model Inputs and Temperature Criteria Adjustments

Given the poor performance and uncertainties associated with Reclamation's model and the extreme importance to manage for higher juvenile winter-run survival during the temperature management season this year, NMFS proposes some buffers to help address the unavoidable uncertainty in temperature model and potential adjustments to the Sacramento River temperature criteria: (1) continue to use the more conservative (*i.e.*, warmer) L3MTO meteorological forecast input using an average of 2014 and 2015 meteorological data; (2) use 75% and 99% hydrological forecasts (in addition to the 50% and 90%) with additional weight to El Niño hydrological years to more accurately reflect the current hydrology; (3) apply a Shasta Reservoir temperature profile stratification scenario from the historical record that shows a steep cold water decline in the spring (*e.g.*, what happened in 2015); (4) meet an end of May Shasta Reservoir storage of at least 4.0 MAF; and (5) use the EPA (2003) recommendation of 55°F 7DADM metric and applying it to the Bonneyview Bridge (CCR) TCP.

Recognizing the difficulty of changing the regulatory compliance from a DAT to a 7DADM, NMFS analyzed to see what the downstream TCP equivalency would be. Over an 18-year period (1998-2015), CCR 7DADM tracked pretty closely to Balls Ferry (BSF) DAT [BSF DAT was 0.2°F cooler than the CCR 7DADM and the JSF DAT was 1.0°F warmer than the CCR 7DADM (Table 1)] during the temperature management season, except for 2008, 2009, and 2012 to 2015 (*i.e.*, dry and critically dry years), where CCR 7DADM tracked somewhere between BSF DAT and Jellys Ferry (JLF) DAT (Figure 2). Therefore a 55°F CCR 7DADM would be equivalent to a 56°F JLF DAT. Based upon this information, NMFS recommends a TCP of not in excess of 56°F DAT at JLF.

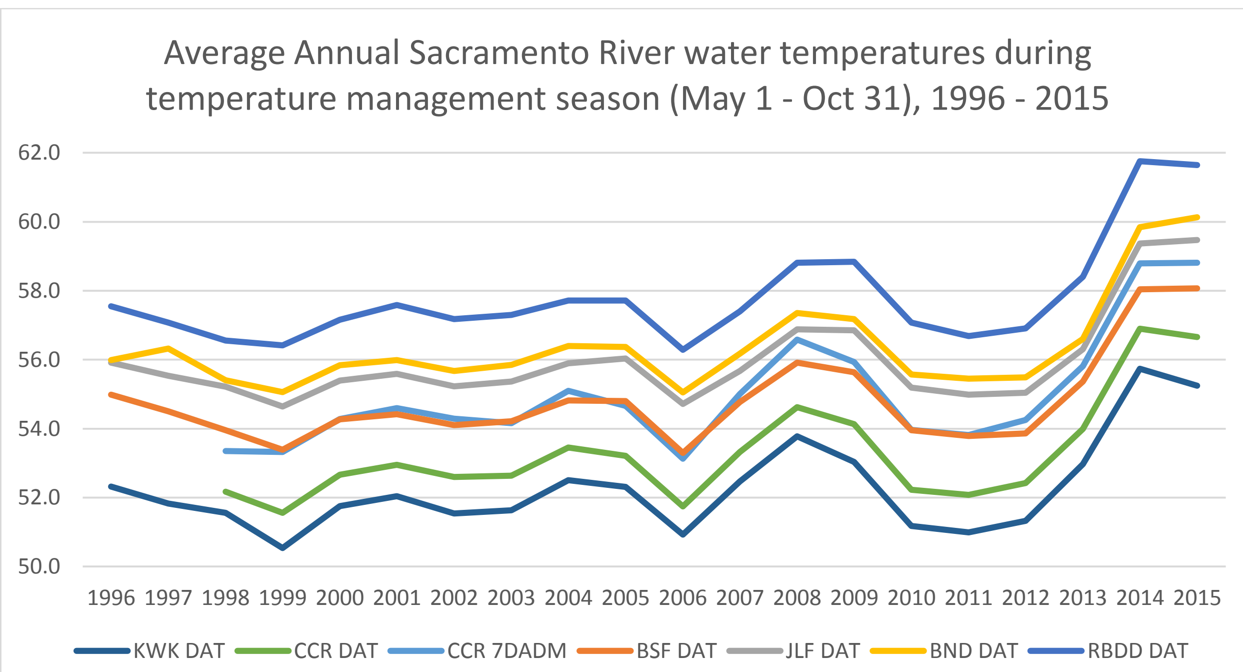

Figure 2. Average annual Sacramento River water temperature during the temperature management season (May 1 – Oct 31), 1996-2015.

2016 February Forecast from the February Update to the Central Valley Project and State Water Project 2016 Drought Contingency Plan[1]

On February 19, 2016, Reclamation released its updated operational forecasts using 50%, 90%, and 99% exceedance runoff forecasts based on the hydrological conditions as they existed on February 1, 2016. The base assumptions include utilizing existing storage conditions; actual precipitation and runoff occurring to date; future precipitation, accretions, depletions, and projected water supply deliveries based on historical statistics; meeting existing water quality standards; and current biological opinion reasonable and prudent alternatives. For these forecasts, the supplies available to the Sacramento River Settlement Contractors, San Joaquin River Exchange Contractors, and Central Valley Project Improvement Act Level 2 Refuge supplies would be consistent with a "Shasta Normal" supply for the 50% and 90% forecasts, and consistent with a "Shasta Critical" supply in the 99% forecast. In addition, the timing of diversion patterns for the Sacramento River Settlement Contractors was assumed to be adjusted (similar to last year's operations) and allow for lower Keswick releases in April and May.

According to Reclamation's 90% hydrological exceedance 2016 February Forecast (Table 2), the forecasted EOA storage for Shasta Reservoir is approximately 3.45 MAF. According to Reclamation's potential for meeting a Sacramento River water temperature compliance point target[2] of 56^{o}F DAT at Jellys Ferry, there needs to be an EOA storage of at least 4.0 MAF (Figure 3). According to the 1996 to 2015 historical record (Table 1), an EOA storage of at least 4.2 MAF was necessary in order to meet the Jelly's Ferry TCP in 4 out of 7 years. Therefore, based on the currently proposed monthly average releases from Keswick Dam, Reclamation will not be able to meet a TCP of not in excess of 56°F DAT at JLF.

[1] http://www.waterboards.ca.gov/waterrights/water_issues/programs/drought/tucp/docs/2016dcpfebnovadd1.pdf, addendum 1

[2] Note: The CVP/SWP operations Opinion states that Reclamation shall meet a temperature compliance point *not in excess* (emphasis added) of 56^{o}F, not a target of 56^{o}F.

Table 2. 2016 February Forecast

February 1 - 90% HYDROLOGY

END OF MONTH STORAGES (TAF)

RESERVOIRS	2016								
	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER
Trinity	810	906	1031	1025	1027	930	847	771	755
Shasta	2767	3187	3452	3563	3270	2884	2467	2238	2188
Folsom	579	626	653	615	507	394	326	289	236
Oroville	1831	2127	2295	2239	2062	1753	1469	1300	1160
New Melones	425	459	456	447	406	351	302	259	244

MONTHLY AVERAGE RELEASES (CFS)

RESERVOIRS	2016								
	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER
Trinity	300	300	540	2920	780	450	730	740	370
Sacramento	3000	3250	3250	4300	9850	10150	9800	7000	4200
American	2450	3000	3500	4050	3500	3000	2300	1750	1500
Feather	950	800	2200	1750	2100	3450	3800	3800	1950
Stanislaus	210	200	460	400	150	150	150	150	580

DELTA SUMMARY (CFS)

	2016								
	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER
Rio Vista Flows	15700	14050	8650	6500	6100	4450	5650	6300	3000
Sac River at Freeport	18600	16850	11150	9400	11550	11100	12700	13000	7250
SJ River at Vernalis	1250	1400	1300	1250	600	600	550	650	1550
Computed Outflow	16100	16500	10250	7400	7250	4150	4250	4100	5000
Combined Project Pumping	5050	2600	1500	1500	1500	3300	5350	7300	2700

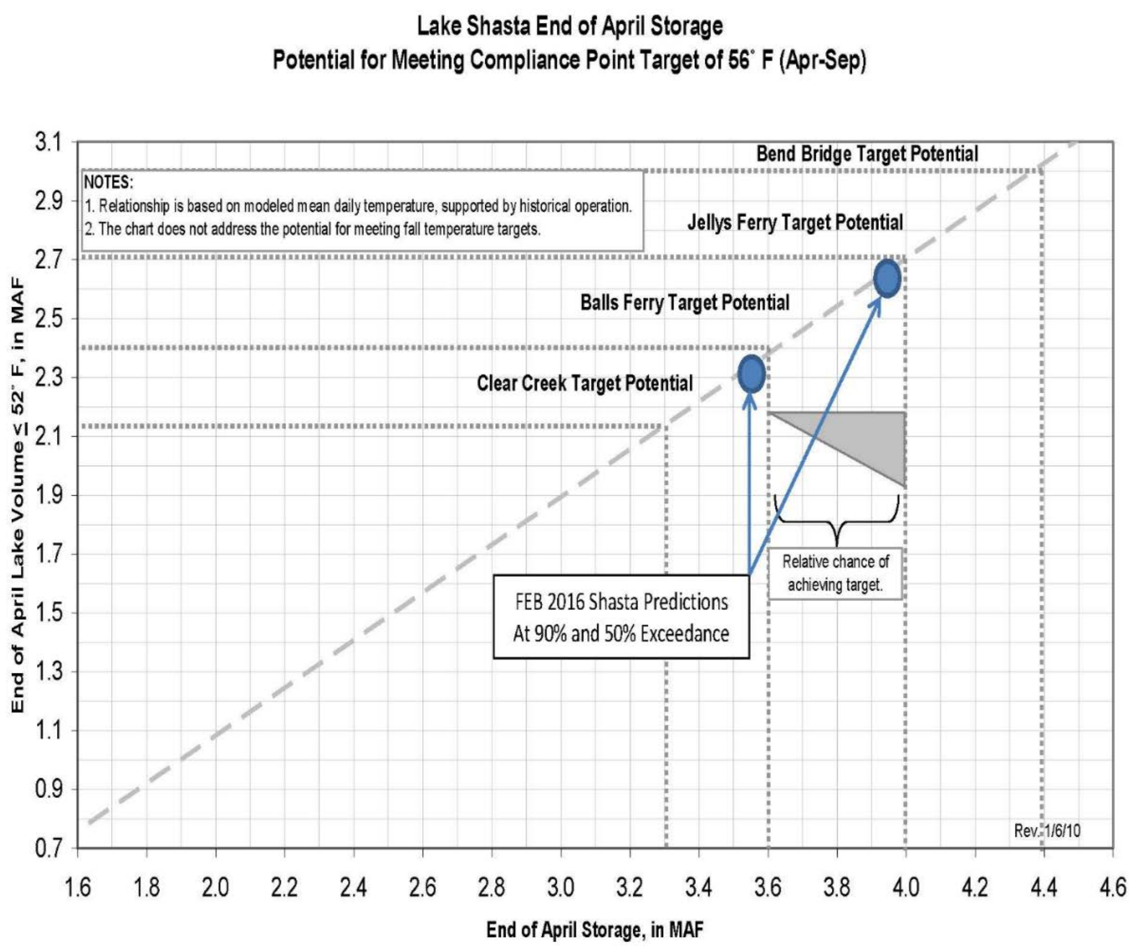

Figure 3. Lake Shasta End of April Storage Potential for Meeting Compliance Point Target.

On March 15, 2016, NMFS received from Reclamation a preliminary set of Sacramento temperature model results targeting water temperatures at Keswick Dam release point and CCR based on the February 1, 2016, hydrologic conditions and forecasted river inflow. According to the 90% exceedance hydrology, Reclamation's proposed Keswick Dam monthly average releases for May through November (Table 2), and targeting 52ºF DAT at the Keswick release point[3] (KWK), Reclamation would only be able to meet 52ºF DAT at KWK until a couple of days before August 23rd (Figure 4). After that date, the cold water pool in Shasta Reservoir would be depleted and/or inaccessible and the DAT at KWK would increase to more than 56ºF for the rest of the temperature management season.

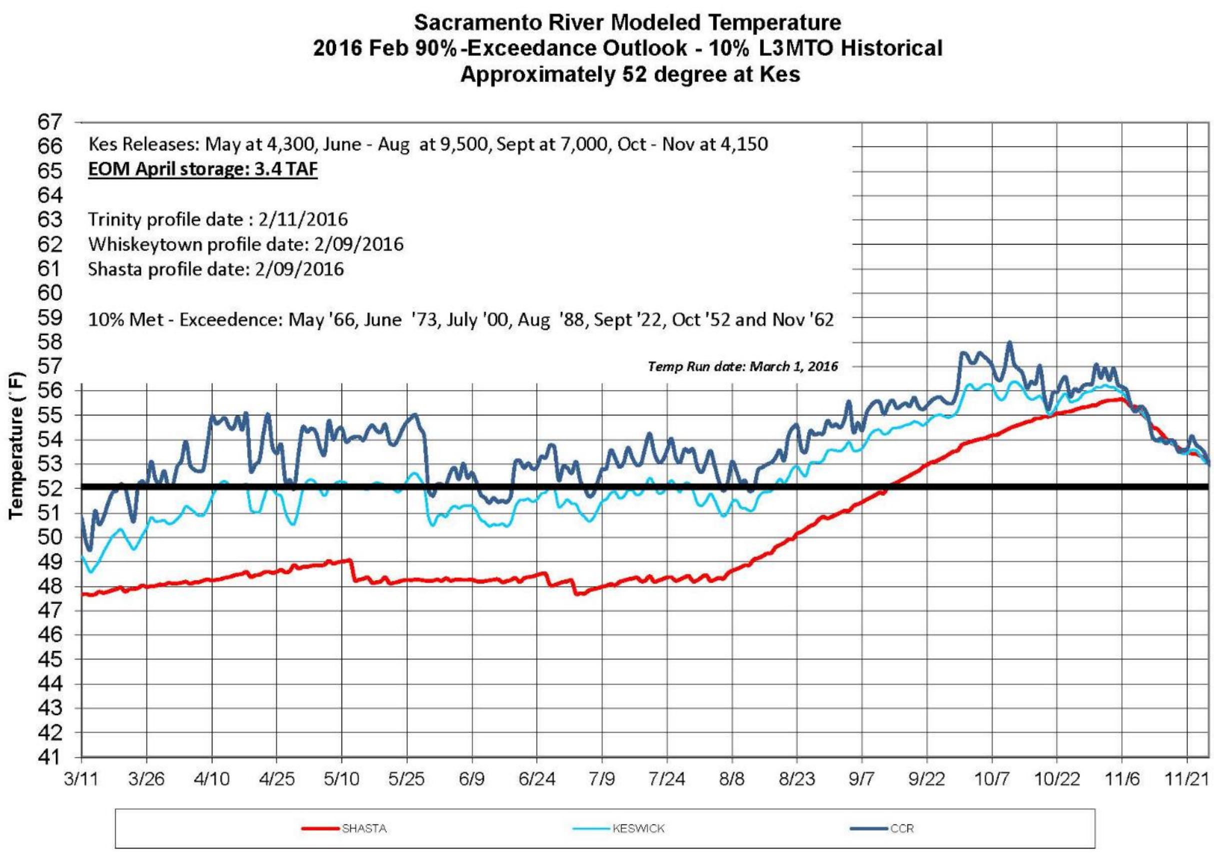

Figure 4. Reclamation's Sacramento River Modeled Temperature Results using the 2016 February 90% exceedance outlook, historical 10% local 3-month temperature outlook meteorology, Reclamation's proposed Keswick Dam monthly average releases for May through November, and targeting approximately 52ºF DAT at KWK.

NMFS-SWFSC modeled the same operational scenario using their River Assessment for Forecasting Temperatures (RAFT) model. Their results were similar to Reclamation's temperature model results in that Reclamation would only be able to meet a 52ºF DAT at KWK until then end of August (Figure 5). Again, after that, the cold water pool in Shasta Reservoir

[3] NMFS and Reclamation agreed to a surrogate of 52ºF DAT at KWK in lieu of 56°F DAT at JLF. See Table 1 for the correlation of KWK DAT to JLF DAT over the last 20 years.

would be depleted and/or inaccessible and DAT at KWK would increase to more than 56°F for the rest of the temperature management season.

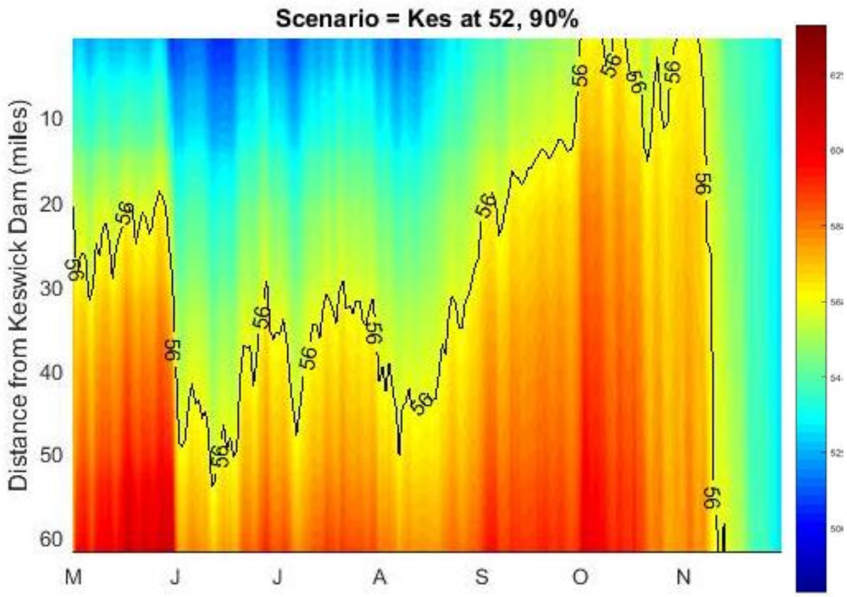

Figure 5. NMFS-SWFSC RAFT model results using the 2016 February 90% exceedance outlook, historical 10% local 3-month temperature outlook meteorology, Reclamation's proposed Keswick Dam monthly average releases for May through November, and targeting approximately 52°F DAT at KWK.

Additionally, the NMFS-SWFSC ran their temperature mortality model under this operational scenario (Figure 6). Egg-to-fry survival values start to decline for those redds that were constructed in mid-June. The survival values continue to decline further throughout the temperature management season as suitable temperatures are not able to be maintained throughout the egg incubation and fry emergence periods for the later spawners. The mean cumulative temperature dependent mortality based on this scenario is 30.5% (95% CI 0.157-53.63%).

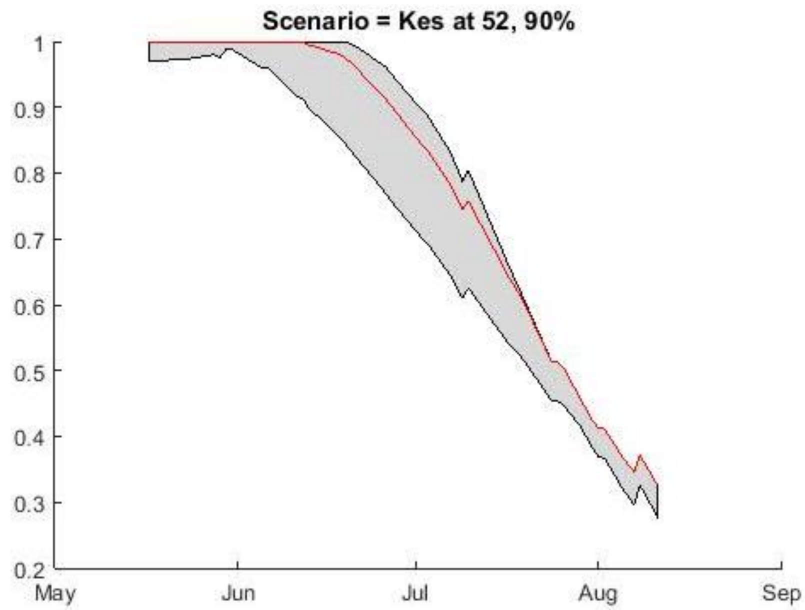

Figure 6. NMFS-SWFSC temperature mortality model results using the 2012-2015 redd distribution to calculate survival values (mean in red, 10% and 90% confidence intervals shaded grey)

In order to meet a TCP of not in excess of 56°F DAT at JLF (or alternatively, 52°F DAT at KWK), NMFS recommended that Reclamation model the following operational scenario and Keswick Dam release schedule for the February forecast (Table 3):

- Target an end of May Shasta storage of 4 MAF.
- Minimum Keswick Dam release of 3,250 cfs through May.
- Stable Keswick Dam release of 7,000 cfs from June through mid-October (or complete winter-run emergence).
- Immediately after complete winter-run emergence, reduce Keswick Dam releases, per ramping rates, to 4,000 cfs through January 2017 or through complete fall-run emergence.
- Use meteorological data from 2015.

Table 3. NMFS Scenario Flow Schedule

End of the Month Storage										
		Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Shasta		2766	3186	3451	3627	3503	3311	3066	2837	2707
Monthly River Releases (TAF/cfs)										
		Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Sacramento	TAF	187	200	193	200	417	430	430	417	338
	cfs	3250	3250	3250	3250	7000	7000	7000	7000	5500

NMFS calculated that this new Keswick Dam release schedule scenario would equate to a savings of 506 TAF (Table 4), ensuring that there is enough cold water storage to last throughout the temperature management season and resulting in EOS storage at 2.84 MAF.

Table 4. Reclamation's Proposed Keswick Dam Release Schedule Compared to NMFS Scenario for Keswick Dam Release Schedule

		Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Total
Reclamation	End of Month Storage (TAF)	2767	3187	3452	3563	3270	2884	2467	2238	2188	
	Monthly Releases Average (CFS)	3000	3250	3250	4300	9850	10150	9800	7000	4200	
	Monthly Releases (TAF)	173	200	193	264	586	624	603	417	258	
NMFS	End of Month Storage (TAF)	2766	3186	3451	3627	3503	3311	3066	2837	2707	
	Monthly Average Releases (CFS)	3250	3250	3250	3250	7000	7000	7000	7000	5500	
	Monthly Releases (TAF)	187	200	193	200	417	430	430	417	338	
Savings	Monthly Releases (TAF)	-14	0	0	65	170	194	172	0	-80	506

Reclamation ran their Sacramento River Water Quality Model based on the NMFS scenario for Keswick Dam release schedule (Figure 7). The results show that 52°F DAT target at KWK can be achieved throughout the temperature management season with some occasional exceedances.

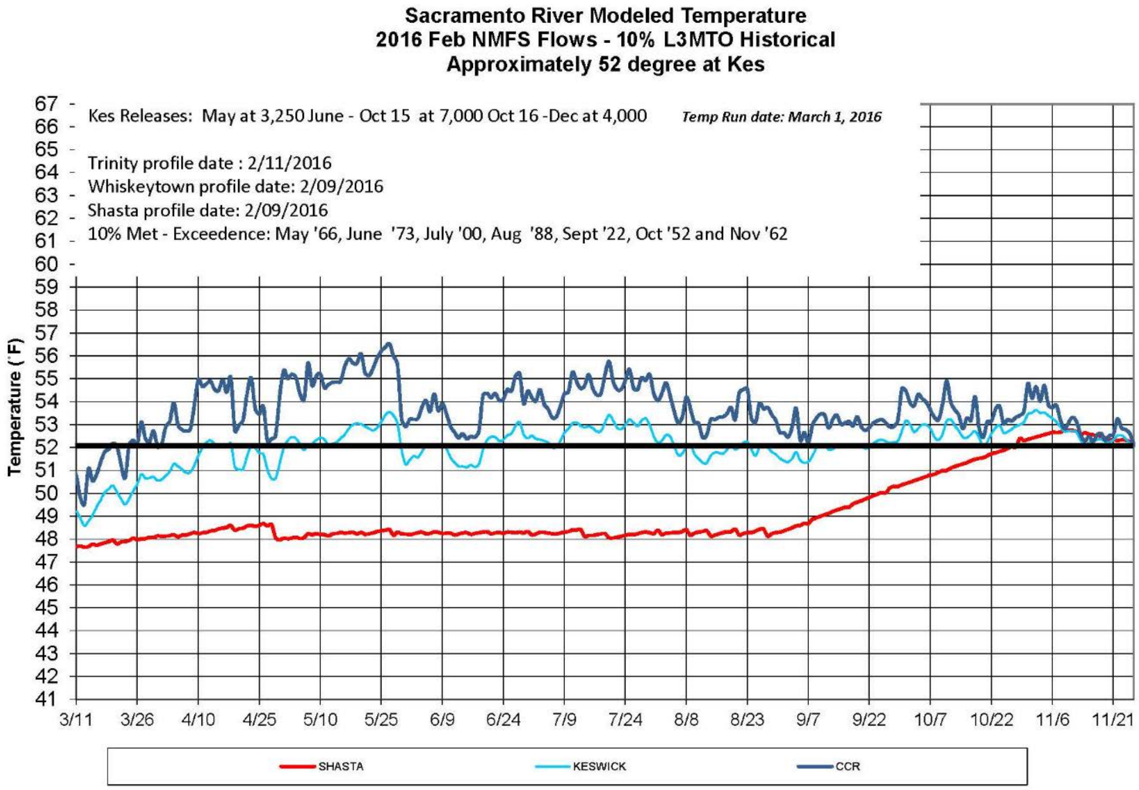

Figure 7. Reclamation's Sacramento River Modeled Temperature Results using the 2016 February 90% exceedance outlook, historical 10% local 3-month temperature outlook meteorology, NMFS-scenario for Keswick Dam monthly average releases for May through November, and targeting approximately 52ºF DAT at KWK.

The NMFS-SWFSC RAFT model presented similar results, that a 52ºF DAT target at KWK can be achieved throughout the temperature management season with some occasional exceedances. (Figure 8).

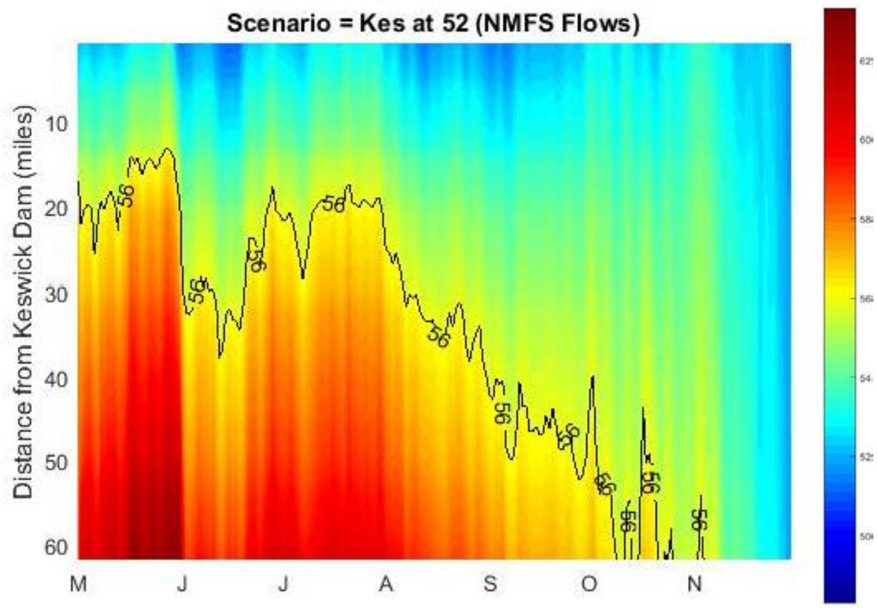

Figure 8. NMFS-SWFSC RAFT model results using the 2016 February 90% exceedance outlook, historical 10% local 3-month temperature outlook meteorology, NMFS scenario for Keswick Dam monthly average releases for May through November, and targeting approximately 52°F DAT at KWK.

The NMFS-SWFSC temperature mortality model under this operational scenario (Figure 9) shows a much improved egg-to-fry survival compared to Reclamation's proposed Keswick Dam monthly average release schedule, as temperature has relatively little effect on mortality. The mean cumulative temperature dependent mortality based on this scenario is 5.4% (95% CI 0.88-37.93%).

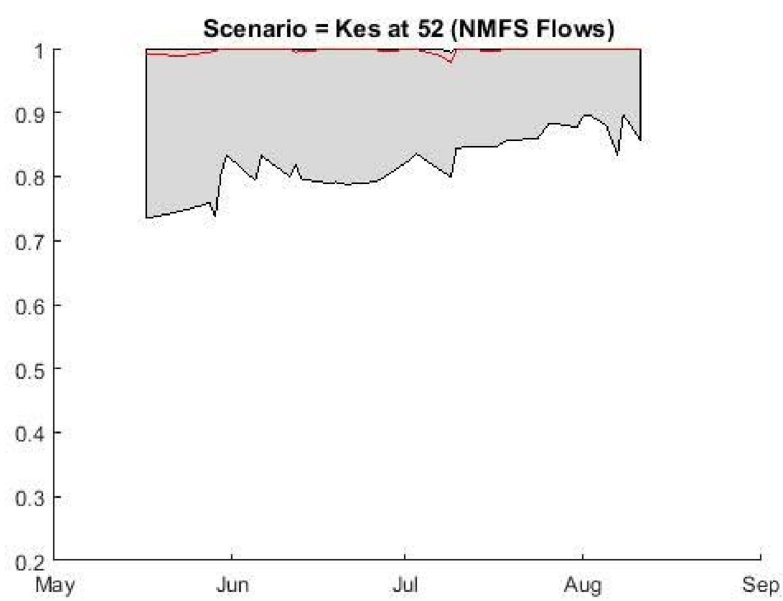

Figure 9. NMFS-SWFSC temperature mortality model results using the 2012-2015 redd distribution to calculate survival values (mean in red, 10% and 90% confidence intervals shaded grey)

Reclamation also ran their Sacramento River Water Quality Model using the 75% exceedance outlook and their proposed Keswick Dam monthly average release schedule. Similar to the 90% hydrological exceedance, Reclamation would only be able to meet 52ºF DAT at KWK until about the end of August (Figure 9). After that, KWK DAT would rise to a peak of about 54ºF through the end September and October.

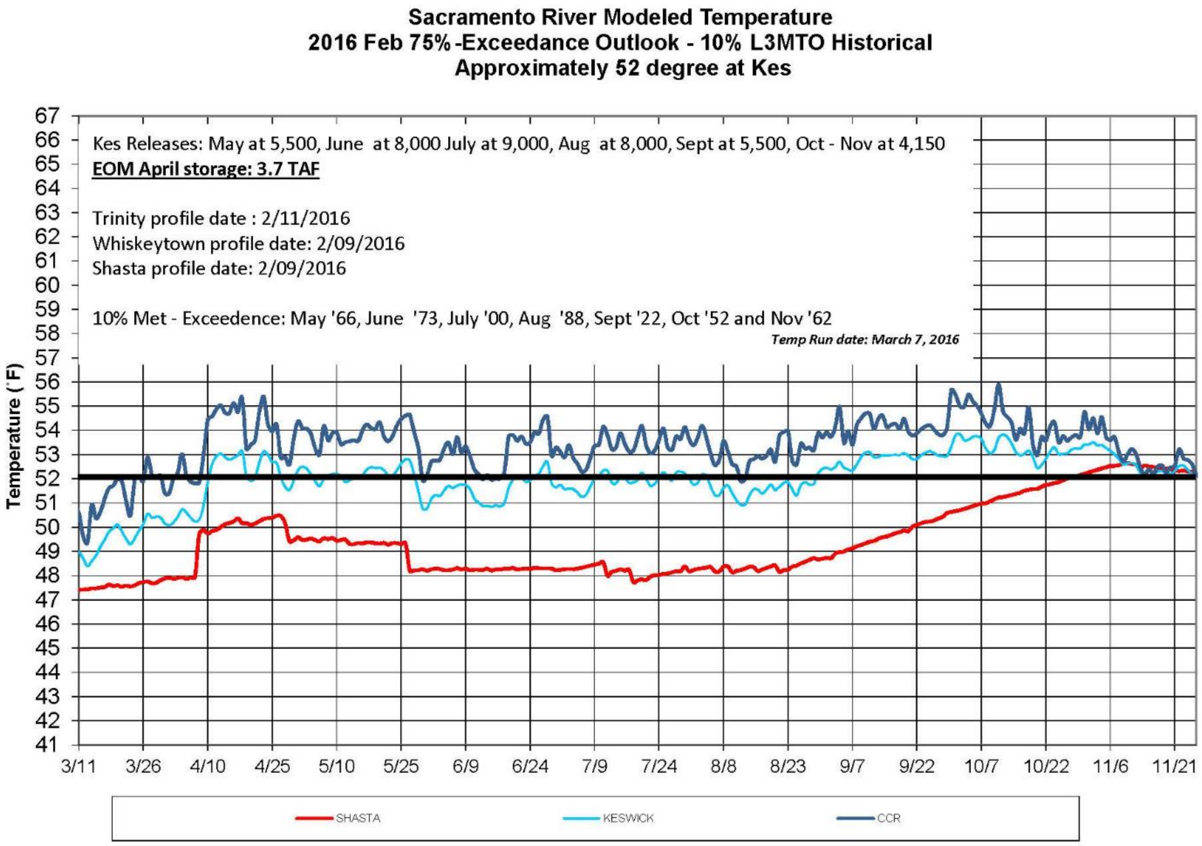

Figure 9. Reclamation's Sacramento River Modeled Temperature Results using the 2016 February 75% exceedance outlook, historical 10% local 3-month temperature outlook meteorology, Reclamation's proposed Keswick Dam monthly average releases for May through November, and targeting approximately 52ºF DAT at KWK.

Results of NMFS-SWFSC RAFT under this scenario were similar to that of the SRWQM (Figure 10), showing that a 52ºF DAT target at KWK can be achieved throughout most of the temperature management season with warmer water at KWK at the end of September and beginning of October.

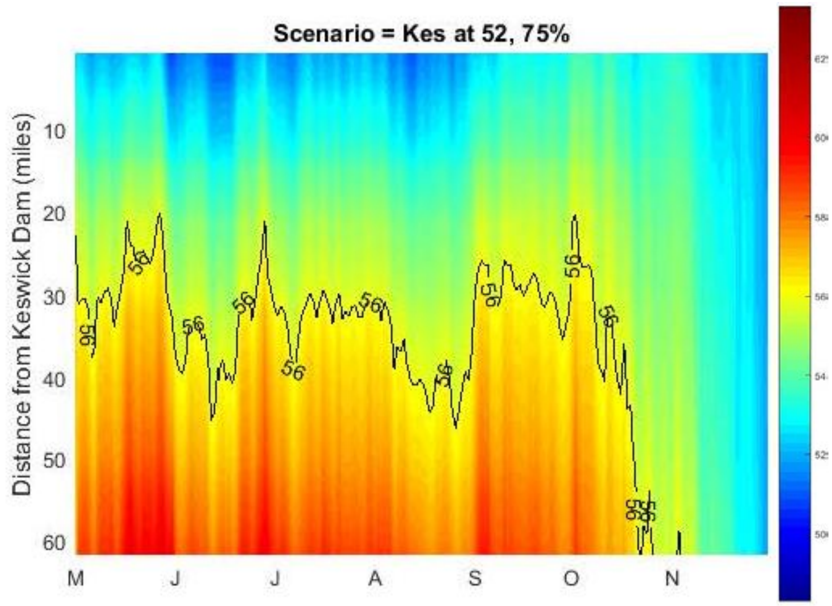

Figure 10. NMFS-SWFSC RAFT model results using the 2016 February 75% exceedance outlook, historical 10% local 3-month temperature outlook meteorology, Reclamation's proposed Keswick Dam monthly average releases for May through November, and targeting approximately 52ºF DAT at KWK.

Results of NMFS-SWFSC temperature mortality model under the 75% exceedance outlook (Figure 11) shows a decreased egg-to-fry survival compared to the NMFS scenario for those spawners after early July, but much better egg-to-fry survival compared to the 90% exceedance outlook. The mean cumulative temperature dependent mortality based on this scenario is 6.3% (95% CI 0.84-36.82%).

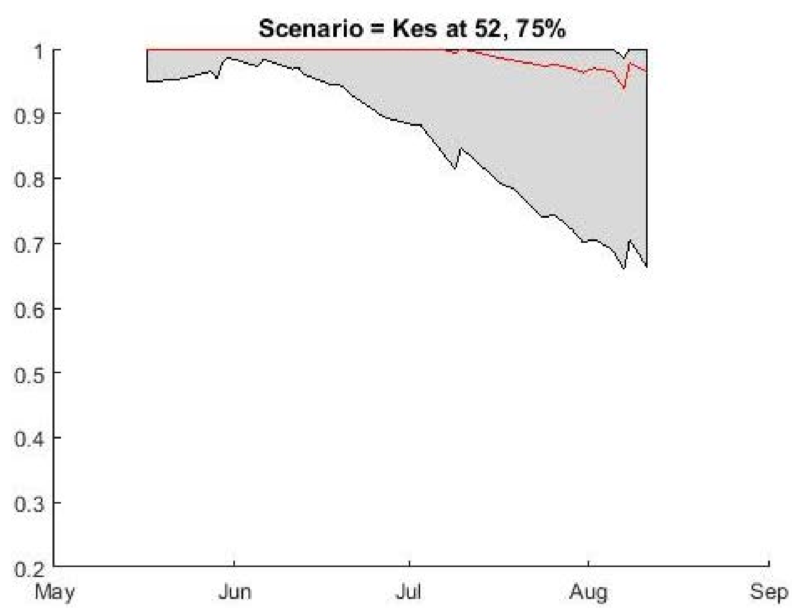

Figure 11. NMFS-SWFSC temperature mortality model results using the 2012-2015 redd distribution to calculate survival values (mean in red, 10% and 90% confidence intervals shaded grey)

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Attachment

Modeling temperature dependent mortality of winter-run Sacramento River Chinook salmon.

Benjamin Martin, Sara John, Andrew Pike, Jason Roberts, Eric Danner

Model development

Overview

We developed a semi-mechanistic/statistical model of temperature-dependent survival of winter-run Chinook in the Sacramento River. Our modeling approach makes use of information on the timing and distribution of redd locations taken from aerial surveys from 1996-2015. For each known redd we extract a temperature exposure profile that redd would have experienced from fertilization to emergence using RAFT, a spatially explicitly hydraulic model of the Sacramento River (Pike et al. 2013). For each known redd, we then apply a temperature-dependent mortality model with daily time steps to calculate the probability of survival from fertilization to emergence. We then calculated predicted survival within a year by aggregating the survival of all redds within a year, and compare the predicted survival in a year to observed yearly survival from egg-to-fry (ETF) estimated by the US Fish and Wildlife serve from 1996-2015. Finally we estimate the parameters of our daily temperature-dependent mortality model by minimizing the deviations between predicted and observed survival across years.

Redd location and timing

The timing and location of WR redds was determined from aerial helicopter surveys conducted by CDFW on a semi-weekly basis. During each aerial survey the location and estimated number of newly formed redds was recorded.

RAFT temperature model

We extracted temperature exposure profiles for all redds located in CDFW aerial surveys using RAFT, River Assessment for Forecasting Temperatures (RAFT). RAFT is a 1-dimensional stream temperature model that predicts thermal impacts of reservoir releases on the downstream environment (Pike et al. 2013). RAFT uses a process-based approach by computing heat transfer due to advection, longitudinal dispersion, atmospheric and subsurface heat-exchange, and tributary inputs to simulate temperatures and flow at a spatiotemporal resolution of 1km and sub-hourly timesteps. The CDFW aerial survey redd location data were converted to RAFT river kilometer. For each redd, a daily temperature exposure profile was complied from the date the redd was first sighted (fertilization), through to emergence. The number of days from fertilization to emergence was calculated using a temperature-dependent development model (Zueg et al. 2009), where the rate of development in day i is given by:

$$D_{i+1} = D_i + (0.00058 \times T - 0.018)$$

where T is the mean daily RAFT temperature in Fahrenheit. At fertilization D=0, and Chinook emerge on the day D exceeds 1.

Temperature-dependent mortality model

We applied a daily temperature dependent mortality model to all redds based on the mean daily temperature exposure profiles calculated from RAFT (Figure 1). The temperature-dependence of survival in our model is determined by two parameters. T_{crit}, the temperature below which there is no mortality due to temperature. Above T_{crit}, we assume the instantaneous mortality rate increases linearly with increasing temperature with a slope equal to b_T, the second parameter:

$$h_i = b_T \max(T_i - T_{crit}, 0)$$

T_i is the mean daily temperature experienced by a given redd on the ith day of its development. The survival probability during the ith day of:

$$s_i = e^{-h_i}$$

Survival throughout the entire embryonic period is given by the product of the daily temperature dependent survival probabilities from hatching to emergence, multiplied by the temperature-independent survival rate, μ.

$$S = \mu \prod_{i=1}^{n} s_i$$

The value of μ represents the expected winter-run survival to RBDD in the absence of adverse temperature effects. We hypothesized that due to limited optimal habitat for spawning, mean redd quality decreases with increasing female spawner density. Thus we evaluated whether female spawner density affected ETF survival by evaluating a models including a density dependence term in the background survival rate:

$$\mu = \mu_0 + \mu_1 N$$

where N is the number of winter run spawning females determined from carcass surveys. Annual estimates for ETF survival were calculated by taking the average of the redd-specific survival rates of all redds within a year.

The major assumptions of our model are that WR Chinook are equally sensitive to temperature throughout their development from fertilization to emergence. In other words, the survival of pre-eyed embryos, eyed embryos, and alevin are all equally affected by temperature (T_{crit} and b_T parameters are constant throughout development). Additionally we assume that temperature-dependent mortality in day *i* depends only on the mean daily temperature on that day, and is independent of the temperature on preceding days. For example, if T_{crit} is exceeded on 7 days during development by 1 degree, the survival rate predicted by our model is independent of whether the 7 days above T_{crit} are consecutive or spread evenly throughout the development period. These assumptions are made because insufficient data are available to specify more complex, parameter rich, models that allow temperature-dependent survival to vary with time or development stage. Chinook fry are much less sensitive to elevated temperatures than pre-emergence stages. For example Chinook fry can be reared successfully at 68F (Fangue unpublished), while rearing embryos at 64F results in nearly 100% mortality. We therefore only included the effect of temperature on survival from fertilization to emergence. Post-emergence mortality is figured into the background survival rate (μ).

Parameter estimation

Model parameters were estimated via non-linear least squares. We searched parameter space for the parameter set that minimized the squared deviation between model predicted winter-run ETF survival to RBDD, and estimates from USFWS from 1996-2015. Because the dependent variable are proportions (fraction survival), and thus bounded between 0 and 1, we logit transformed the dependent variable (Warton and Hui 2011). This ensured predictions cannot exceed possible values (e.g. negative survival), and normalized residual error. Thus data were transformed such that:

$$p_i^* = \log\left(\frac{p_i}{1-p_i}\right)$$

$$x_i^* = \log\left(\frac{x_i}{1-x_i}\right)$$

where p_i and x_i are the predicted and observed fractional survival in year i.

We used a numerical optimization routine in Matlab (fminsearch) to search parameter space for the parameter set (θ) that minimized the sum of squares between predicted and observed winter-run survival:

$$SSQ(\theta) = \sum_{i=1}^{n}\left(p_i^*(\theta) - x_i^*\right)^2$$

Uncertainty analysis

To evaluate how uncertainty in ETF survival estimates affected our parameter estimates and model predictions we preformed an uncertainty analysis. Using the logit transformed yearly survival estimates we resampled yearly survival estimates from a Gaussian distribution with a mean equal to the estimated value (from the USFWS report) and a standard deviation equal to the standard error of the yearly survival estimates (calculated from the reported confidence intervals in the USFWS report). We used this method to generate 1000 randomized datasets, and then used the same model fitting techniques to estimate model parameters. We calculated 95% uncertainty intervals by using the 97.5 and 2.5% quantiles for the 1000 simulated datasets. Furthermore we used parameter estimates from the 1000 simulated data sets to construct prediction confidence intervals for mortality as a function of temperature. For each parameter set we calculated survival as a function of temperature for different exposure times (e.g. one day, one week, one month).

Comparison to laboratory data

To compare thermal tolerance estimated in laboratory studies with thermal tolerance in the field, we fit the same temperature dependent mortality model to laboratory data. Data on survival throughout the embryonic period as a function of temperature were taken from data sources compiled in Myrick and Cech (2001). We use non-linear least squares to estimate T_{crit} and b_T from laboratory data and compared the resulting predictions for survival as a function of temperature to those estimated using ETF survival data in the field.

RESULTS

The model including temperature-dependent mortality out-performed the model assuming a constant temperature independent survival probability (Table 1), rejecting the null hypothesis that yearly survival was independent of temperature (p=0.0005). Furthermore the null hypothesis that survival was independent of female spawner density was rejected (p=0.029). Altogether the full model including temperature and density dependent effects explained most of the variance in annual ETF survival (R^2= 0.77).

Our analysis indicates substantial year-to-year variation in temperature dependent mortality. In most years temperature contributes negligibly to predicted ETF survival (Figure 2). In these cases, such as 2002-2003, 2007, and 2010-2012, redds were rarely if ever exposed to temperatures above T_{crit}, and survival was high. Among years with low temperature-dependent mortality, those with a high number of female spawners (2002-2007) had lower ETF survival than years with few female spawners (2010-2012). Overall we estimate that starting from a background survival rate of ~35% at very low spawner density, every additional 1000 returning females reduces survival by a little less than 2% (1.88%). As a result, the predicted background survival rate is cut in half as we move from the low (~400) to high (~9000) end of observed variation in female spawner density (Figure 3).

Although in many years temperature had little influence on ETF survival, in the years it did affect survival, the impact was substantial. Most notably, in 2014 and 2015 temperature dependent mortality alone resulted in a loss of ~77% and 85% of the population. When combined with background survival, this resulted in the extremely low ETF survival both predicted and observed in these years (~5%). These high levels of temperature dependent mortality are driven by the high value of b_T, the slope by which instantaneous mortality rate increases above T_{crit}. As a result of a high value of b_T, mortality rate increases rapidly above T_{crit}. For example there is no predicted mortality due to temperature up to around 54F (Figure 4). However above this critical temperature mortality rate increased rapidly; a week at 56F resulted in a loss of approximately 20% of the population, and a loss of 60% after a month (Figure 4).

Uncertainty analysis

Parameter estimates of T_{crit} varied between 52 and 56F (Table 2). However there was significant co-variation between T_{crit} and b_T (Figure 3). The roughly 5% of simulated datasets with high T_{crit} estimates were associated with extremely high values of b_T (the slope by which mortality increases above T_{crit}). As a result, parameter sets with a high T_{crit} predicted that mortality increased extremely rapidly above T_{crit}, such that exposure to water temperatures exceeding T_{crit} by only a fraction of a degree over short period of time, result in high mortality rates.

The model predictions for 90% of the resampled parameter values fell within a well-defined range, especially within the range of temperatures typically encountered in the upper Sacramento (50-58F) (Figure 4).

Lab vs. Field

Thermal tolerance of winter-run Chinook estimated in the field was substantially reduced relative to thermal tolerance estimated from laboratory data (Figure 6). While the estimated values for b_T were roughly similar in the lab and field, T_{crit} estimated from field data was more than 6 degrees lower in the field in the lab. Thus using lab data, our model predicts no mortality at 56F, while in the field this results in a loss 80% of the population.

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Cook, D. and S. Weisburg. 1990. Confidence intervals in nonlinear regression. Journal of the American Statistical Association 85: 544-551

Myrick, C. A., & Cech, J. J. 2001. Temperature effects on Chinook salmon and steelhead: a review focusing on California's Central Valley populations. Bay-Delta Modeling Forum.

Pike, A. et al. 2013. Forecasting river temperatures in real time using a stochastic dynamics approach. - Water Resour. Res. 49: 5168–5182.

Warton, D.I. and Hui, F.K., 2011. The arcsine is asinine: the analysis of proportions in ecology. *Ecology*, *92*(1), pp.3-10.

Table 1. Model comparison

Model	SSQ	df	F value	P value	R^2
Constant mortality	9.47	1			
Temperature dependent mortality	3.18	3	13.52	0.0005	0.66
Temperature and density dependent mortality	2.17	4	6.05	0.029	0.77

Table 2. The least squares estimate for the parameters in the full model are given in table 2.

Parameter	Least Squares Estimate	Resampling 95% CI
T_{crit}	53.72	52.09 – 56.25
b_T	0.0133	0.0059 - 0.557
μ_0	0.3467	0.276- 0.44
μ_1	-1.88E-05	-6.18E-6 - -3.275E-5

Figure 1. Schematic diagram of the temperature-dependent mortality model. The instantaneous daily mortality rate (h) is 0 when the mean daily temperature is below T_{crit}. Above Tcrit, h increases linearly with temperature with a slope, b_T.

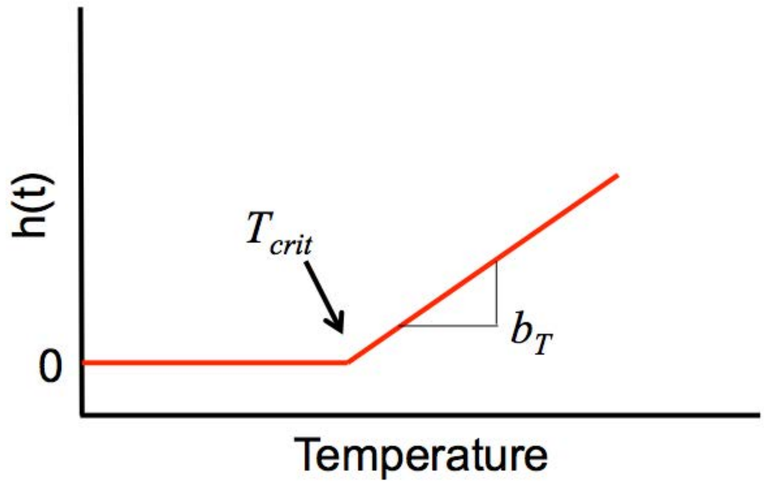


Figure 2. Observed vs. predicted survival in the full model (top and middle panels) and the predicted mortality due to temperature

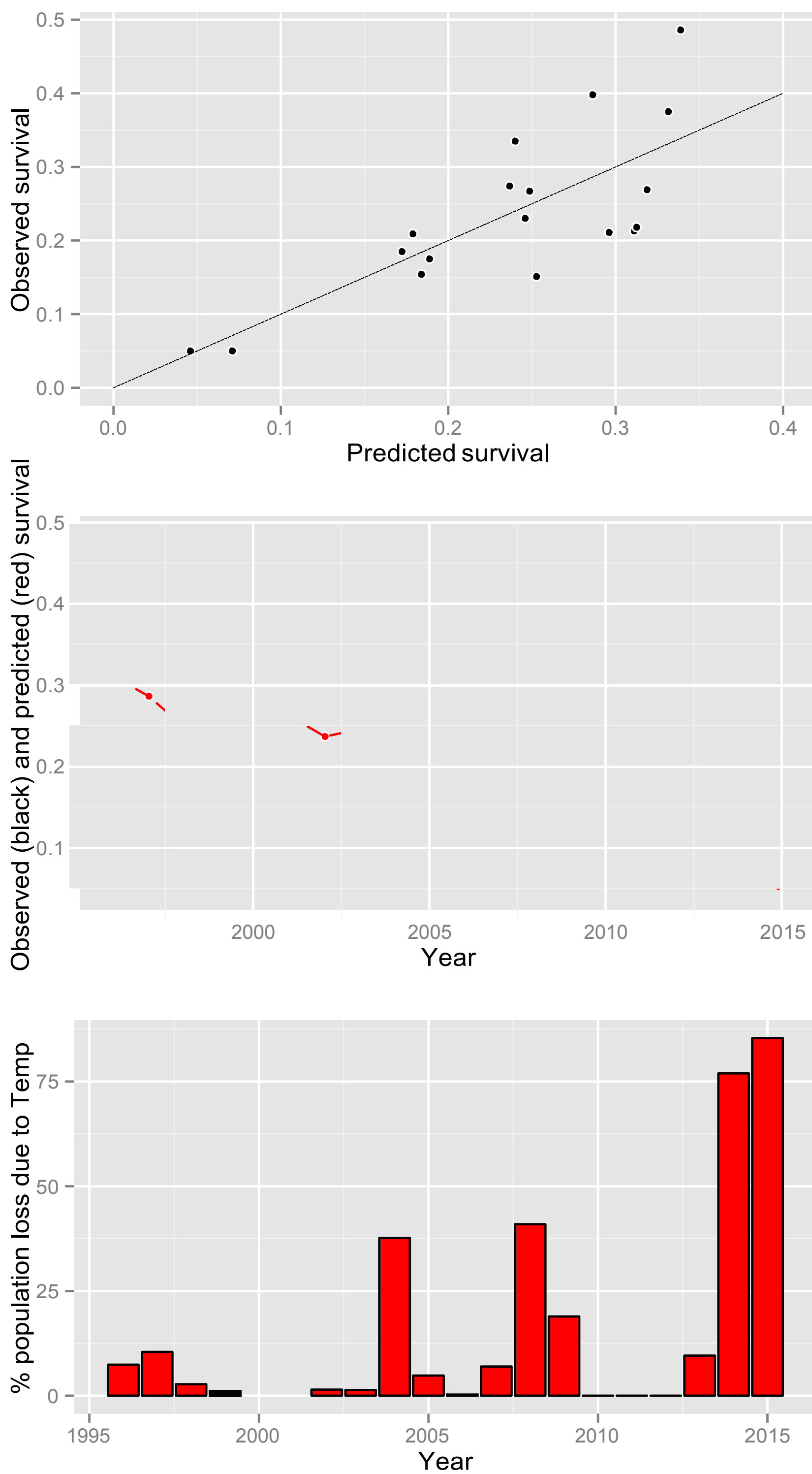


Figure 3. Influence of female spawner density on background survival rate. Panel A show the time series of the number of returning female spawners. Panel B shows the relationship between observed and predicted (red line) ETF survival and female spawner density. Panel C shows this seem relationship but with observed ETF corrected to exclude mortality due to temperature (corrected ETF = Observed ETF / (1 – fractional population loss due to temperature alone).

A.

B.

C.

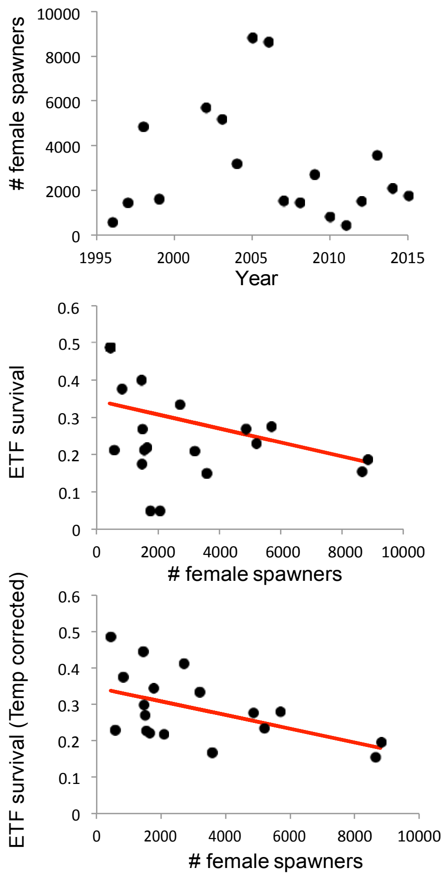


Figure 4. Predictions for mortality due to temperature exposure for 1 day, 1 week, and 1 month in the redd model. Each red line represents one of a 1000 parameter sets estimated from the resampled yearly survival dataset. The thick black line represent the median predicted value and the dashed black lines the 90 confidence intervals and the dotted lines the 95% confidence intervals.

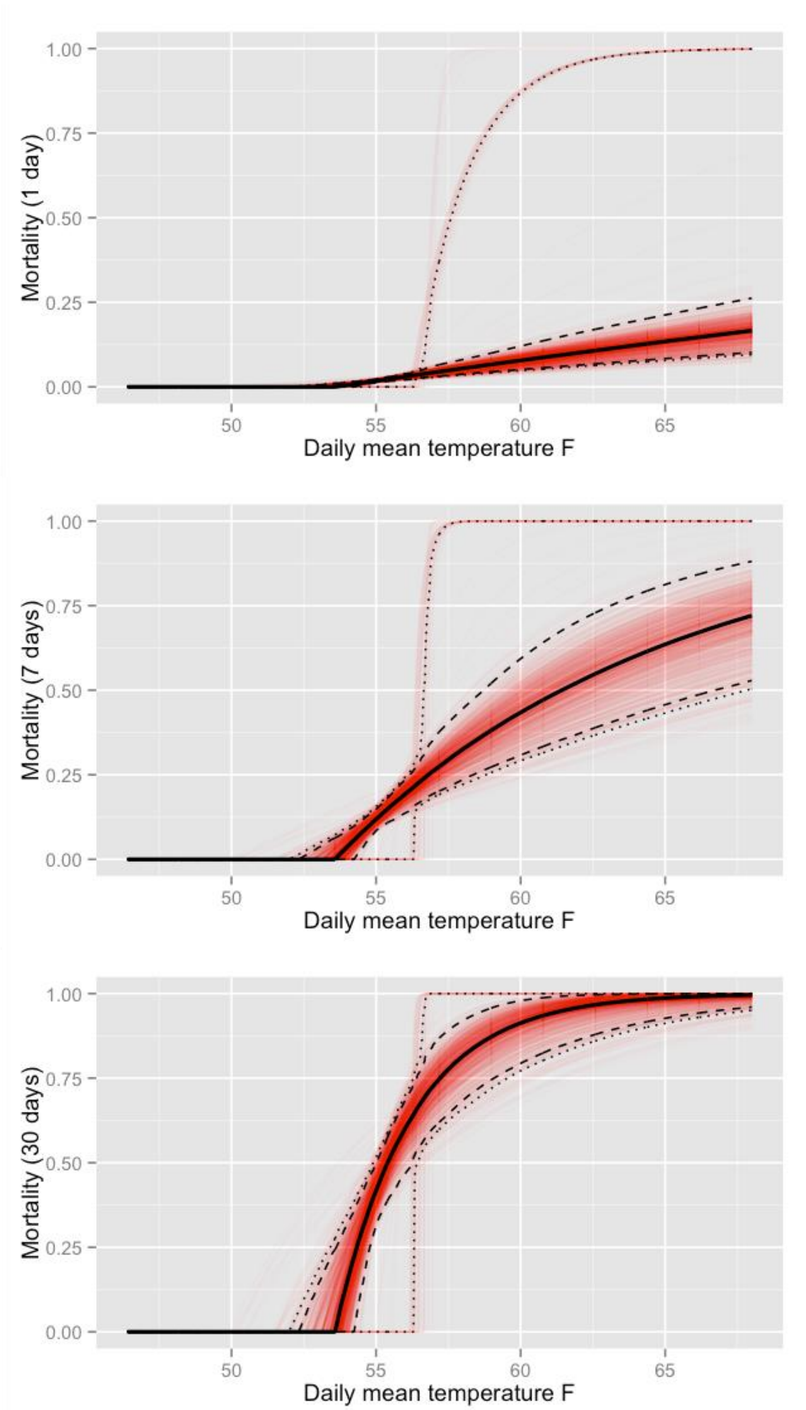


Figure 5. Parameter estimate frequency charts (diagonal) and covariance matrix in the redd temperature model.

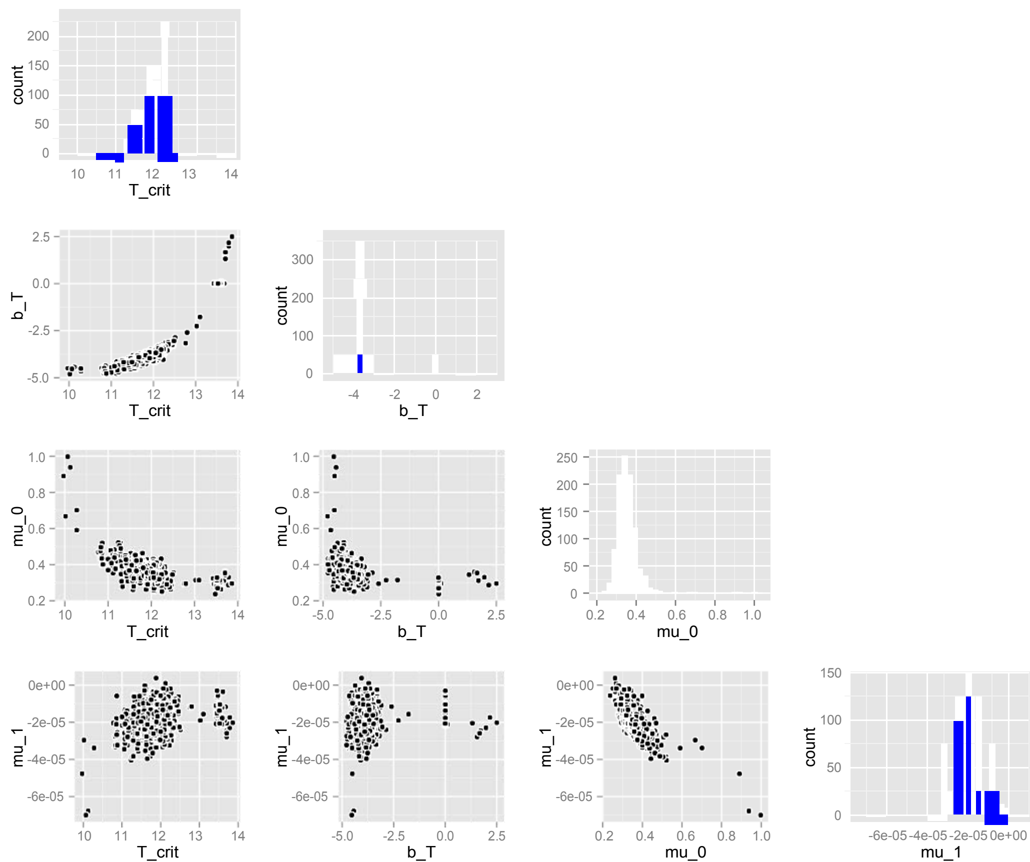
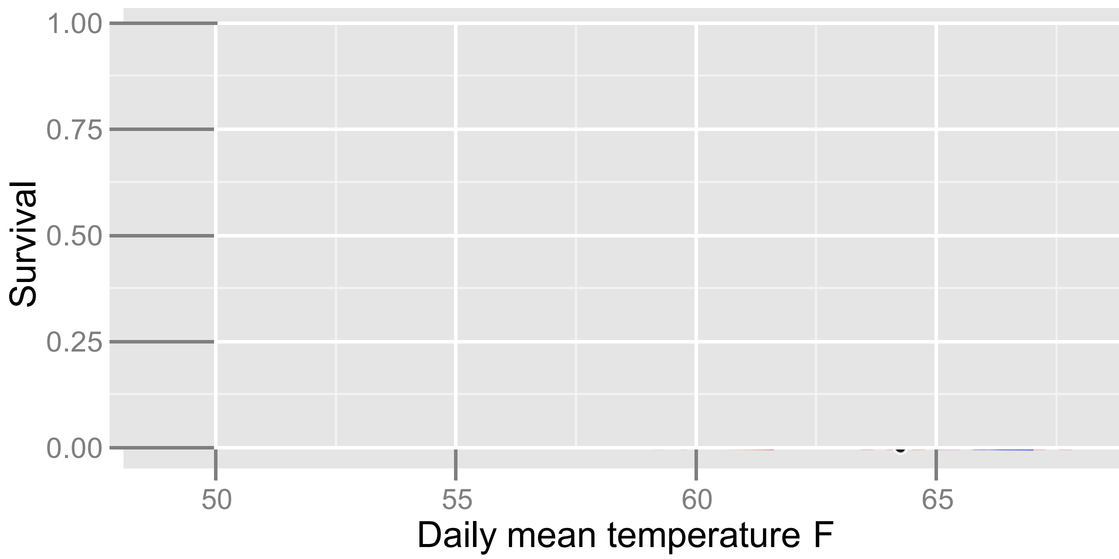


Figure 6. Temperature dependent survival estimated in the laboratory vs. field. Observed survival (black points) through the embryonic period in laboratory studies as a function temperature. The blue line represents the least-squares model fit to laboratory data. The black and red lines represents the same model but with parameters estimated from field ETF survival data (solid, median; dashed, 90% CI).



Enclosure 2

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
West Coast Region
650 Capitol Mall, Suite 5-100
Sacramento, California 95814-4700

MAR 3 1 2016

Mr. Ron Milligan
Operations Manager, Central Valley Project
U.S. Bureau of Reclamation
3310 El Camino Avenue, Suite 300
Sacramento, California 95821

Dear Mr. Milligan:

Thank you for the opportunity to review the U.S. Bureau of Reclamation's (Reclamation) March forecast and water supply allocation for water year 2016. Your March 25, 2016, letter included the results of the 90 and 50 percent exceedance forecasts, water temperature modeling, and this year's initial water supply allocation. In addition, after a discussion with NMFS on March 28, 2016, Reclamation adjusted the 50 percent exceedance forecast, reran the water temperature model, and submitted the results to NOAA's National Marine Fisheries Service via electronic mail on March 29, 2016. For purposes of compliance with the reasonable and prudent alternative (RPA) Action I.2.3, described in NOAA's National Marine Fisheries Service's (NMFS) biological opinion (issued June 4, 2009) on the long-term operations of the Central Valley Project (CVP) and State Water Project (CVP/SWP Opinion), NMFS' concurrence is required prior to the initial water supply allocation of the year. The objective is to use a conservative forecast as early as possible to protect the cold water pool in Shasta Reservoir so that suitable spawning and egg/alevin incubation habitat can be maintained in the Sacramento River during the summer and fall season for federally listed endangered Sacramento River winter-run Chinook salmon (*Oncorhynchus tshawytscha*), and threatened Central Valley spring-run Chinook salmon (*O. tshawytscha*).

Winter-run in brood years 2014 and 2015 experienced very low egg-to-fry survival to Red Bluff as a result of high water temperatures during their egg and alevin incubation stages. As brood year 2016 is the third of three winter-run cohorts, it is very important to operate Shasta Reservoirs conservatively to provide and maintain adequate water temperatures throughout the winter-run early life stages. As such, as part of Reclamation's and the California Department of Water Resources' January 19, 2016, "Central Valley Project and State Water Project 2016 Drought Contingency Plan For Water Project Operations, February – November 2016,[1]" NMFS requested inclusion of attachment 4 that provides a list of suggested model inputs towards Reclamation's temperature modeling scenario. NMFS has reviewed its suggested model inputs and compared it with Reclamation's 50% and 90% exceedance forecasts and associated temperature model runs, and have determined that Reclamation has met NMFS' expectations for model inputs. For example:

[1] http://www.waterboards.ca.gov/waterrights/water_issues/programs/drought/docs/plans/2016dcpfebnov.pdf

- Meeting an end of September (EOS) Shasta storage of at least 2.2 million acre-feet (MAF);
- Targeting a daily average Keswick release temperature of 52°F (which will likely meet a 56°F daily average temperature downstream of Balls Ferry) as a surrogate for the 55°F 7-day average of the daily maximum (7DADM) temperatures at the Bonneview Bridge temperature compliance point (CCR CDEC gage station);
- Utilizing a 10% long-term 3-month temperature outlook (L3MTO) that reflects meteorological conditions in 2014; and
- Comparing the quantity and quality of the Shasta cold water pool at the beginning of March and end of May between historically similar years and the temperature model run.

On March 15, 2016, Reclamation submitted[2] to NMFS a preliminary set of Sacramento River temperature model results based on the February 1, 2016, hydrologic conditions and forecasted reservoir inflow. Because the forecasts were outdated and did not reflect the dry February or the considerable precipitation in the first half of March, Reclamation indicated that it would update the temperature analyses based on the early March storms and new estimates of hydrology. On March 18, 2016, NMFS issued a response letter[3] to Reclamation. In addition to looking forward to receiving Reclamation's March 90 percent exceedance forecast with updated hydrology and temperature model runs, NMFS enclosed a memorandum that supports the use of a 56°F daily average temperature at Jellys Ferry as the temperature compliance point this year, which is roughly equivalent to a 55°F 7DADM at CCR.

The March 2016 reservoir operations forecast is based on estimated runoff within the Sacramento River basin as of March 15, 2016. The estimated annual inflow into Shasta Reservoir is 5.56 MAF (100% of mean) in the 90 percent exceedance forecast and 6.11 MAF (110% of mean) in the 50 percent exceedance forecast. The projected storage in Shasta Reservoir is forecast to be at 4.33 MAF at the end of May 2016 and 3.03 MAF at the EOS in the 90 percent exceedance forecast (*i.e.*, more conservative forecast), and the projected storage in Shasta Reservoir is forecast to be at 4.552 MAF at the end of May 2016 and 3.18 MAF at the EOS in the revised 50 percent exceedance forecast. The following table provides Reclamation's initial water supply allocations based on the 90 percent exceedance forecast:

March 90% Exceedance Municipal & Industrial Water Service Contracts – Agricultural Water Service Contracts And Refuge Level 2 Contracts					
	North of Delta M&I	North of Delta Agricultural	South of Delta M&I	South of Delta Agricultural	Level 2 Refuge Supply
Allocation	100%	100%	55%	5%	100%

2
http://www.westcoast.fisheries.noaa.gov/publications/Central_Valley/Water%20Operations/Operations,%20Criteria%20and%20Plan/bureau_of_reclamation_s_february_forecast_-_march_15__2016.pdf

3
http://www.westcoast.fisheries.noaa.gov/publications/Central_Valley/Water%20Operations/Operations,%20Criteria%20and%20Plan/nmfs__march_18__2016__response_to_the_bureau_of_reclamation_s_february_forecast.pdf

NMFS has reviewed Reclamation's March CVP operations 90 percent and 50 percent exceedance forecasts (enclosure 1) and corresponding water temperature model runs (enclosure 2), and a revised 50 percent exceedance forecast and associated water temperature model run (enclosure 3). In addition, the NMFS-Southwest Fisheries Science Center utilized the Keswick release and temperature data as input into its River Assessment for Forecasting Temperature (RAFT) and survival models. Enclosure 4 provides RAFT and survival model results for the March CVP operations 90 percent and 50 percent exceedance forecasts, and enclosure 5 provides RAFT and survival model results for the revised 50 percent exceedance forecast. Finally, NMFS reviewed Reclamation's graph comparing the quantity and quality of the Shasta cold water pool at the beginning of March and end of May between historically similar years and the temperature model run (enclosure 6).

The resulting water temperature model runs based on the 90 percent exceedance forecast indicate that a Keswick release daily average temperature of 52°F, or 56°F daily average temperature compliance point between Balls Ferry and Jellys Ferry (which is comparable and a surrogate for the 55°F 7DADM temperatures at CCR) will be achievable throughout the winter-run and spring-run Chinook salmon spawning and incubation period (*i.e.*, May 15 through October 31). Based on the projected EOS storage in Shasta Reservoir (at least 2.2 MAF) and temperature model runs (meeting a Balls Ferry temperature compliance point), Reclamation and NMFS agree that RPA Action I.2.3.A should be implemented this year. Results from the survival model indicate that the annual mean temperature-dependent related mortality utilizing the Keswick release flows and temperatures from the:

- 90 percent exceedance forecast is 2.17% [median = 0.77%; 95% confidence intervals (CI) = 0 - 25.49%],
- 50 percent exceedance forecast is 3.59% (median = 0.079%; 95% CI = 0 - 34.42%), and
- revised 50 percent exceedance forecasts 2.67% (median = 0.078; 95% CI = 0 - 31.13%).

In addition, Reclamation's graph comparing the quantity and quality of the Shasta cold water pool at the beginning of March and end of May between historically similar years and the temperature model run (enclosure 6) indicates that although the model is relatively accurate in estimating the quantity of cold water at the end of May, it underestimates the quality of cold water available (*i.e.*, there is more of the coldest water than the model predicts). This hindcast comparison provides a buffer of conservatism during the development of the Sacramento River temperature management plan.

In reviewing the monthly Keswick release schedules, NMFS is concerned about the potential for winter-run Chinook salmon redd dewatering prior to complete fry emergence in the fall, and also fall-run Chinook salmon redd dewatering in the late fall and into the winter. The level of concern is based on the uncertainty of the timing and distribution of redd locations and the monthly Keswick release schedule time step. To reduce this concern, NMFS will work with Reclamation in real-time to adjust Keswick releases, as needed, to provide stable flows throughout the winter-run Chinook salmon egg and alevin incubation stages until complete emergence, and also to stabilize flows for fall-run Chinook salmon spawning and egg incubation.

In summary, NMFS concurs with Reclamation's forecasts based on March 15, 2016, hydrologic conditions, and initial water supply allocation, that RPA Action I.2.3.A should be implemented this year, and that a 55°F 7DADM temperature will be attainable at CCR. In addition, NMFS will work with Reclamation to adjust the Keswick release schedules in order to minimize the potential for winter-run and fall-run Chinook salmon redd dewatering. Our concurrence is based on Reclamation implementing the following monthly average Keswick release schedule (in cubic feet per second):

Exceedance	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
90%	5000	6500	9000	10500	10000	9000	6500	6500	6500	4150	4150
Revised 50%	5200	8500	9000	10500	10000	9000	7500	7500	7500	5000	4000

Should Reclamation need to change the monthly average release schedule, NMFS expects close coordination between our agencies to ensure that the habitat needs (*i.e.*, cold water, stable flows) of winter-run Chinook salmon continue to be met. In addition, NMFS will work with Reclamation on real-time management during the temperature management season. It will be critically important this year to target a 55°F 7DADM temperature at CCR as the compliance criterion and location.

Thank you for the recent discussions with your staff in meeting the requirements in the CVP/SWP Opinion and RPA Action I.2.3. I look forward to further communication between our agencies to fully meet the requirements provided in RPA Action I.2.3.A of the CVP/SWP Opinion. If you have any questions regarding this letter, please feel free to contact me, or have your staff contact Mr. Brycen Swart at (916) 930-3712, or via e-mail at brycen.swart@noaa.gov.

Sincerely,

Maria C Rea

Maria C. Rea
Assistant Regional Administrator

Enclosures:

1. 90 and 50 percent exceedance forecasts (2 pages)
2. Temperature model runs (2 pages)
3. Revised 50 percent exceedance forecast and associated water temperature model run (2 pages)
4. RAFT and survival model results for the 90 and 50 percent exceedance forecasts (5 pages)
5. RAFT and survival model results for the revised 50 percent exceedance forecast (5 pages)
6. Shasta Reservoir cold water storage in the March 15, 2016, model run vs. historic data (3 pages)

cc: Copy to file – ARN 151422SWR2006SA00268

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Estimated CVP Operations BASE 90% Exceedance

Storages

Federal End of the Month Storage/Elevation (TAF/Feet)

			Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Trinity		854	1171	1350	1315	1242	1114	1035	964	950	939	942	971	1053
	Elev.		2273	2290	2287	2280	2267	2259	2251	2249	2248	2248	2252	2261
Whiskeytown		207	206	238	238	238	238	238	230	206	206	206	206	206
	Elev.		1199	1209	1209	1209	1209	1209	1207	1199	1199	1199	1199	1199
Shasta		2766	4044	4289	4330	4128	3756	3352	3032	2858	2723	2654	2788	3072
	Elev.		1049	1058	1059	1052	1039	1023	1009	1001	995	992	998	1011
Folsom		606	667	797	964	908	711	553	522	436	358	313	332	410
	Elev.		436	449	465	460	440	423	419	408	397	389	393	405
New Melones		459	567	568	572	548	494	445	402	392	410	427	444	462
	Elev.		871	872	872	868	856	846	835	833	837	841	845	849
San Luis		312	426	367	202	91	34	34	111	259	470	687	835	897
	Elev.		459	444	409	377	335	331	353	373	407	443	476	491
Total			7081	7609	7620	7155	6346	5659	5262	5102	5106	5228	5576	6099

State End of the Month Reservoir Storage (TAF)

Oroville		
	Elev.	
San Luis Total San Luis (TAF)		

Monthly River Releases (TAF/cfs)

		Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Trinity	TAF	18	32	260	150	68	45	44	23	18	18	18	17
	cfs	300	540	4,225	2,526	1,102	734	744	373	300	300	300	300
Clear Creek	TAF	11	13	13	9	7	5	9	14	10	11	11	10
	cfs	175	218	216	150	120	85	150	225	175	175	175	175
Sacramento	TAF	246	297	400	535	645	615	535	400	387	400	255	230
	cfs	4000	5000	6500	9000	10500	10000	9000	6500	6500	6500	4150	4150
American	TAF	599	208	215	274	289	245	115	121	118	108	92	83
	cfs	9750	3500	3500	4602	4702	3989	1928	1971	1981	1750	1500	1500
Stanislaus	TAF	12	27	25	9	9	9	9	35	12	12	12	12
	cfs	200	460	400	150	150	150	150	577	200	200	200	213
Feather	TAF												
	cfs												

Trinity Diversions (TAF)

	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Carr PP	13	38	37	77	83	37	32	0	14	19	6	5
Spring Crk. PP	28	8	30	70	75	30	30	12	5	12	3	7

Delta Summary (TAF)

		Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Tracy		210	71	50	184	282	282	272	282	272	258	195	145
USBR Banks		0	0	0	0	0	0	0	0	0	0	0	0
Contra Costa		12.7	12.7	12.7	9.8	11.1	12.7	14.0	16.8	18.4	18.3	14.0	14.0
Total USBR		223	84	63	194	293	295	286	299	290	276	209	159
State Export													
Total Export													
COA Balance		0	0	0	1	1	125	301	374	433	433	433	433
Old/Middle River Std.													
Old/Middle R. calc.		-5,102	-1,271	-1,285	-4,453	-5,267	-6,902	-7,591	-6,510	-7,388	-7,257	-5,099	-4,224
Computed DOI		47435	18171	12965	7816	4994	3497	3009	4002	4505	7109	11403	12499
Excess Outflow		36032	6774	2814	0	0	0	0	0	0	2603	5401	1099
% Export/Inflow		12%	7%	9%	32%	40%	52%	60%	59%	63%	56%	37%	30%
% Export/Inflow std.		35%	35%	35%	35%	65%	65%	65%	65%	65%	65%	65%	45%

Hydrology

	Trinity	Shasta	Folsom	New Melones
Water Year Inflow (TAF)	1536	5,563	2,787	854
Year to Date + Forecasted % of mean	127%	100%	102%	81%

CVP actual operations do not follow any forecasted operation or outlook; actual operations are based on real-time conditions.
CVP operational forecasts or outlooks represent general system-wide dynamics and do not necessarily address specific watershed/tributary details.
CVP releases or export values represent monthly averages.
CVP Operations are updated monthly as new hydrology information is made available December through May.

3/24/2016

Estimated CVP Operations BASE 50% Exceedance

Storages

Federal End of the Month Storage/Elevation (TAF/Feet)

			Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Trinity		854	1173	1376	1366	1379	1286	1169	1061	1009	1002	1040	1105	1212
	Elev.		2273	2293	2292	2293	2284	2273	2262	2256	2255	2260	2267	2277
Whiskeytown		207	206	238	238	238	238	238	230	230	225	206	206	206
	Elev.		1199	1209	1209	1209	1209	1209	1207	1207	1205	1199	1199	1199
Shasta		2766	3875	4328	4508	4369	4006	3654	3381	3183	3052	2994	3297	3842
	Elev.		1043	1059	1066	1061	1048	1035	1024	1016	1010	1007	1020	1042
Folsom		606	667	800	957	933	780	610	507	460	430	419	448	515
	Elev.		436	449	464	462	447	430	417	411	407	406	410	418
New Melones		459	567	589	645	686	644	598	557	552	574	602	638	696
	Elev.		871	876	886	894	886	877	869	868	873	878	885	895
San Luis		312	441	376	201	154	83	73	149	294	501	657	807	929
	Elev.		463	447	411	391	393	410	434	449	481	494	523	547
Total			6930	7707	7917	7758	7038	6342	5886	5727	5785	5918	6500	7399

State End of the Month Reservoir Storage (TAF)

Oroville	
San Luis Total San Luis (TAF)	

Monthly River Releases (TAF/cfs)

		Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Trinity	TAF	18	27	260	150	68	53	52	23	18	18	18	17
	cfs	300	460	4,225	2,526	1,102	855	870	373	300	300	300	300
Clear Creek	TAF	11	13	13	9	7	7	9	12	12	11	11	10
	cfs	175	218	216	150	120	120	150	200	200	175	175	175
Sacramento	TAF	473	297	400	535	645	615	535	461	446	461	307	222
	cfs	7700	5000	6500	9000	10500	10000	9000	7500	7500	7500	5000	4000
American	TAF	599	327	338	350	290	277	208	123	119	123	123	194
	cfs	9750	5500	5500	5881	4714	4500	3500	2000	2000	2000	2000	3500
Stanislaus	TAF	12	27	25	9	9	9	9	35	12	12	12	12
	cfs	200	460	400	150	150	150	150	577	200	200	200	213
Feather													

Trinity Diversions (TAF)

	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Carr PP	0	21	24	71	67	68	61	40	19	1	0	5
Spring Crk. PP	28	0	25	68	60	60	60	30	19	25	24	40

Delta Summary (TAF)

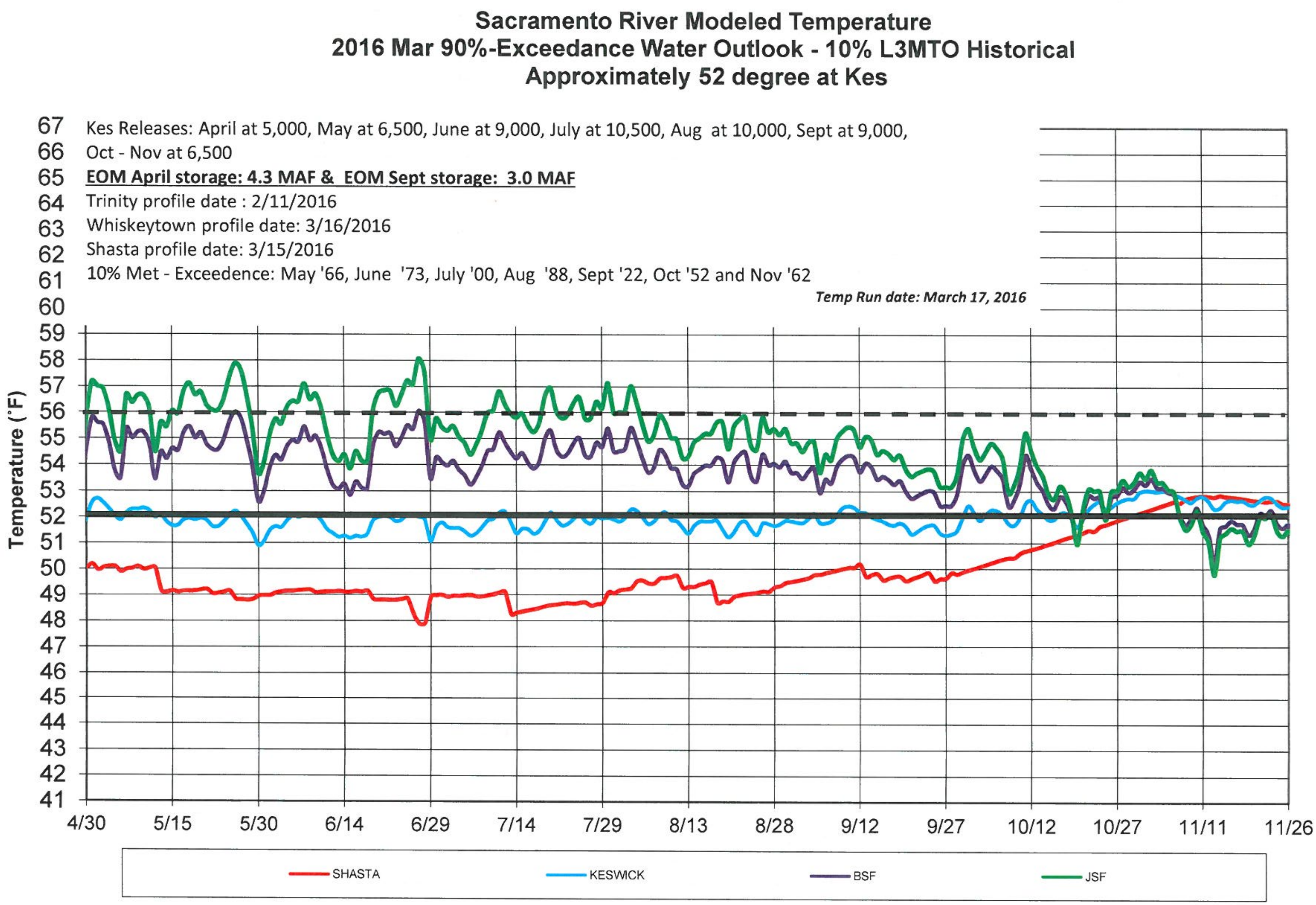
		Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Tracy		230	71	50	272	282	282	272	282	272	200	200	210
USBR Banks		0	0	0	0	7	7	7	0	0	0	0	0
Contra Costa		12.7	12.7	12.7	9.8	11.1	12.7	14	16.8	18.4	18.3	14	14
Total USBR		243	84	63	282	300	302	293	299	290	218	214	224
State Export													
Total Export													
COA Balance		0	0	0	-27	-27	-27	-27	-27	-27	-27	-27	-27
Old/Middle R. std.													
Old/Middle R. calc.		-5,118	-705	-612	-5,890	-8,770	-9,130	-9,159	-7,073	-8,427	-5,242	-5,107	-5,151
Computed DOI		69852	27937	21522	10254	6507	4783	4404	4376	5514	14055	17048	22405
Excess Outflow		58448	16541	10265	0	0	781	1395	374	1009	9549	11045	11004
% Export/Inflow		10%	5%	6%	36%	51%	57%	62%	60%	62%	32%	29%	26%
% Export/Inflow std.		35%	35%	35%	35%	65%	65%	65%	65%	65%	65%	65%	35%

Hydrology

	Trinity		Shasta		Folsom		New Melones	
Water Year Inflow (TAF)	1642.6		6,112		3,216		1011	
Year to Date + Forecasted % of mean	136%		110%		118%		96%	

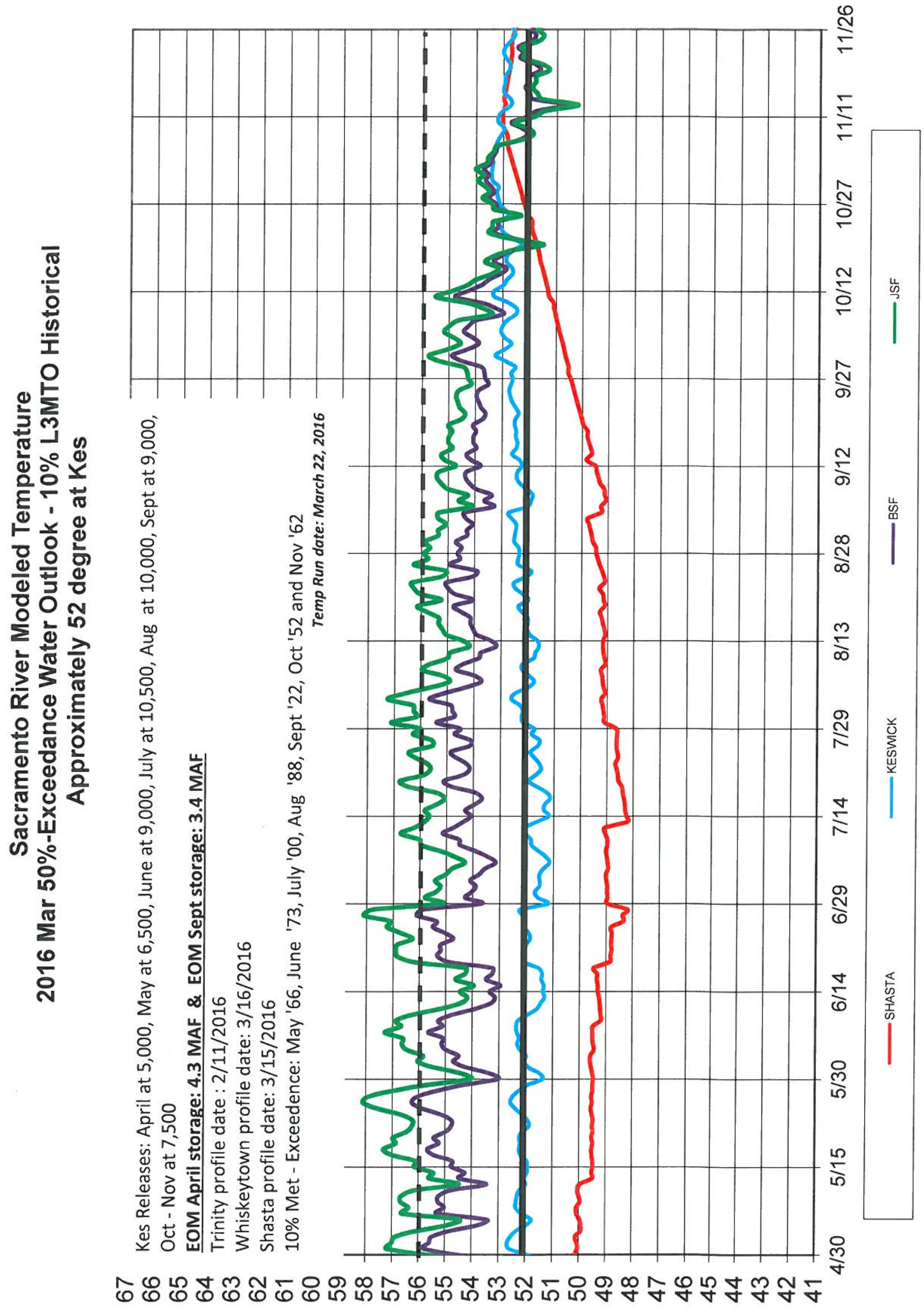
CVP actual operations do not follow any forecasted operation or outlook; actual operations are based on real-time conditions.
CVP operational forecasts or outlooks represent general system-wide dynamics and do not necessarily address specific watershed/tributary details.
CVP releases or export values represent monthly averages.
CVP Operations are updated monthly as new hydrology information is made available December through May.

3/25/2016



Sacramento River Modeled Temperature
2016 Mar 90%-Exceedance Water Outlook - 10% L3MTO Historical
Approximately 52 degree at Kes
Kes Releases: April at 5,000, May at 6,500, June at 9,000, July at 10,500, Aug at 10,000, Sept at 9,000, Oct - Nov at 6,500
EOM April storage: 4.3 MAF & EOM Sept storage: 3.0 MAF
Trinity profile date : 2/11/2016
Whiskeytown profile date: 3/16/2016
Shasta profile date: 3/15/2016
10% Met - Exceedence: May '66, June '73, July '00, Aug '88, Sept '22, Oct '52 and Nov '62
Temp Run date: March 17, 2016
Temperature (°F)
67 66 65 64 63 62 61 60 59 58 57 56 55 54 53 52 51 50 49 48 47 46 45 44 43 42 41
4/30 5/15 5/30 6/14 6/29 7/14 7/29 8/13 8/28 9/12 9/27 10/12 10/27 11/11 11/26
SHASTA
KESWICK
BSF
JSF

Enclosure 2


Sacramento River Modeled Temperature
2016 Mar 50%-Exceedance Water Outlook - 10% L3MTO Historical
Approximately 52 degree at Kes
Kes Releases: April at 5,000, May at 6,500, June at 9,000, July at 10,500, Aug at 10,000, Sept at 9,000, Oct - Nov at 7,500
EOM April storage: 4.3 MAF & EOM Sept storage: 3.4 MAF
Trinity profile date : 2/11/2016
Whiskeytown profile date: 3/16/2016
Shasta profile date: 3/15/2016
10% Met - Exceedence: May '66, June '73, July '00, Aug '88, Sept '22, Oct '52 and Nov '62
Temp Run date: March 22, 2016
Temperature (°F)
67
66
65
64
63
62
61
60
59
58
57
56
55
54
53
52
51
50
49
48
47
46
45
44
43
42
41
4/30
5/15
5/30
6/14
6/29
7/14
7/29
8/13
8/28
9/12
9/27
10/12
10/27
11/11
11/26
SHASTA
KESWICK
BSF
JSF

Estimated CVP Operations BASE 50% Exceedance

Storages

Federal End of the Month Storage/Elevation (TAF/Feet)

			Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Trinity		**854**	**1173**	**1368**	**1354**	**1364**	**1257**	**1169**	**1091**	**1057**	**1064**	**1115**	**1180**	**1287**
	Elev.		2273	2292	2291	2292	2282	2273	2265	2261	2262	2268	2274	2285
Whiskeytown		**207**	**206**	**238**	**238**	**238**	**238**	**238**	**230**	**230**	**225**	**206**	**206**	**206**
	Elev.		1199	1209	1209	1209	1209	1209	1207	1207	1205	1199	1199	1199
Shasta		**2766**	**4041**	**4489**	**4552**	**4414**	**4066**	**3684**	**3381**	**3165**	**3020**	**2949**	**3252**	**3797**
	Elev.		1049	1065	1067	1062	1050	1036	1024	1015	1009	1005	1019	1040
Folsom		**606**	**667**	**800**	**957**	**933**	**780**	**610**	**507**	**460**	**430**	**419**	**448**	**515**
	Elev.		436	449	464	462	447	430	417	411	407	406	410	418
New Melones		**459**	**567**	**589**	**645**	**686**	**644**	**598**	**557**	**552**	**574**	**602**	**638**	**696**
	Elev.		871	876	886	894	886	877	869	868	873	878	885	895
San Luis		**312**	**441**	**376**	**201**	**154**	**83**	**73**	**149**	**294**	**501**	**657**	**807**	**929**
	Elev.		463	447	411	391	393	410	434	449	481	494	523	547
Total			7095	7861	7947	7789	7068	6372	5916	5757	5815	5948	6531	7430

State End of the Month Reservoir Storage (TAF)

Oroville	
San Luis **Total San Luis (TAF)**	

Monthly River Releases (TAF/cfs)

		Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Trinity	TAF	18	27	260	150	68	53	52	23	18	18	18	17
	cfs	**300**	**460**	**4,225**	**2,526**	**1,102**	**855**	**870**	**373**	**300**	**300**	**300**	**300**
Clear Creek	TAF	11	13	13	9	7	7	9	12	12	11	11	10
	cfs	**175**	**218**	**216**	**150**	**120**	**120**	**150**	**200**	**200**	**175**	**175**	**175**
Sacramento	TAF	307	309	523	535	645	615	535	461	446	461	307	222
	cfs	**5000**	**5200**	**8500**	**9000**	**10500**	**10000**	**9000**	**7500**	**7500**	**7500**	**5000**	**4000**
American	TAF	599	327	338	350	290	277	208	123	119	123	123	194
	cfs	**9750**	**5500**	**5500**	**5881**	**4714**	**4500**	**3500**	**2000**	**2000**	**2000**	**2000**	**3500**
Stanislaus	TAF	12	27	25	9	9	9	9	35	12	12	12	12
	cfs	**200**	**460**	**400**	**150**	**150**	**150**	**150**	**577**	**200**	**200**	**200**	**213**
Feather													

Trinity Diversions (TAF)

	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Carr PP	0	29	29	73	82	38	31	22	5	-12	0	5
Spring Crk. PP	**28**	**8**	**30**	**70**	**75**	**30**	**30**	**12**	**5**	**12**	**24**	**40**

Delta Summary (TAF)

		Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Tracy		230	71	50	272	282	282	272	282	272	200	200	210
USBR Banks		0	0	0	0	7	7	7	0	0	0	0	0
Contra Costa		12.7	12.7	12.7	9.8	11.1	12.7	14	16.8	18.4	18.3	14	14
Total USBR		243	84	63	282	300	302	293	299	290	218	214	224
State Export													
Total Export													
COA Balance		0	0	0	-27	-27	-27	-27	-27	-27	-27	-27	-27
Old/Middle R. std.													
Old/Middle R. calc.		-5,118	-705	-612	-5,890	-8,770	-9,130	-9,159	-7,073	-8,427	-5,242	-5,107	-5,151
Computed DOI		67151	28139	23523	10254	6507	4783	4404	4376	5514	14055	17048	22405
Excess Outflow		55748	16742	12266	0	0	781	1395	374	1009	9549	11045	11004
% Export/Inflow		10%	5%	6%	36%	51%	57%	62%	60%	62%	32%	29%	26%
% Export/Inflow std.		35%	35%	35%	35%	65%	65%	65%	65%	65%	65%	65%	35%

Hydrology

	Trinity		Shasta		Folsom		New Melones	
Water Year Inflow (TAF)	1642.6		6,112		3,216		1011	
Year to Date + Forecasted % of mean	136%		110%		118%		96%	

CVP actual operations do not follow any forecasted operation or outlook; actual operations are based on real-time conditions.
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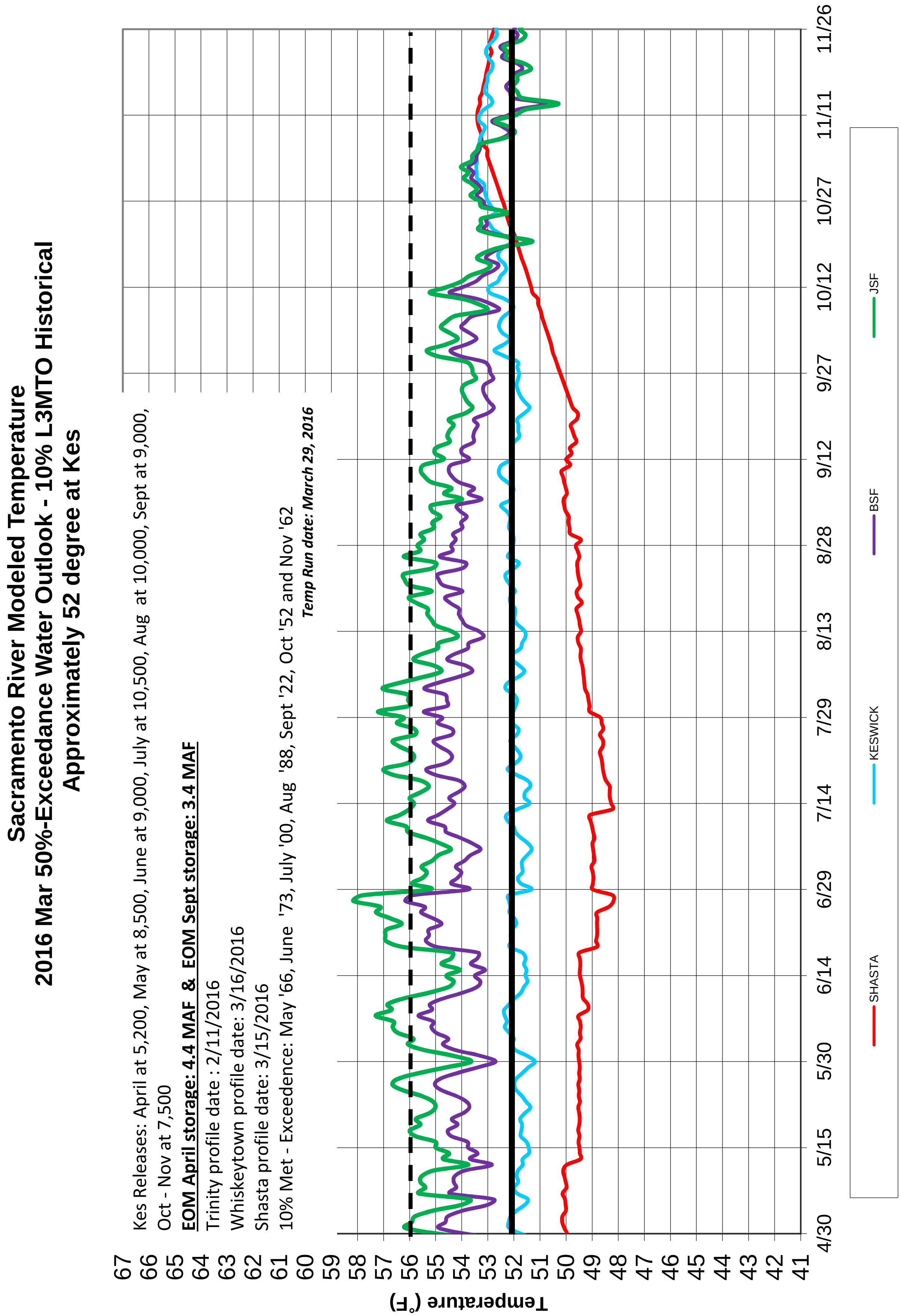
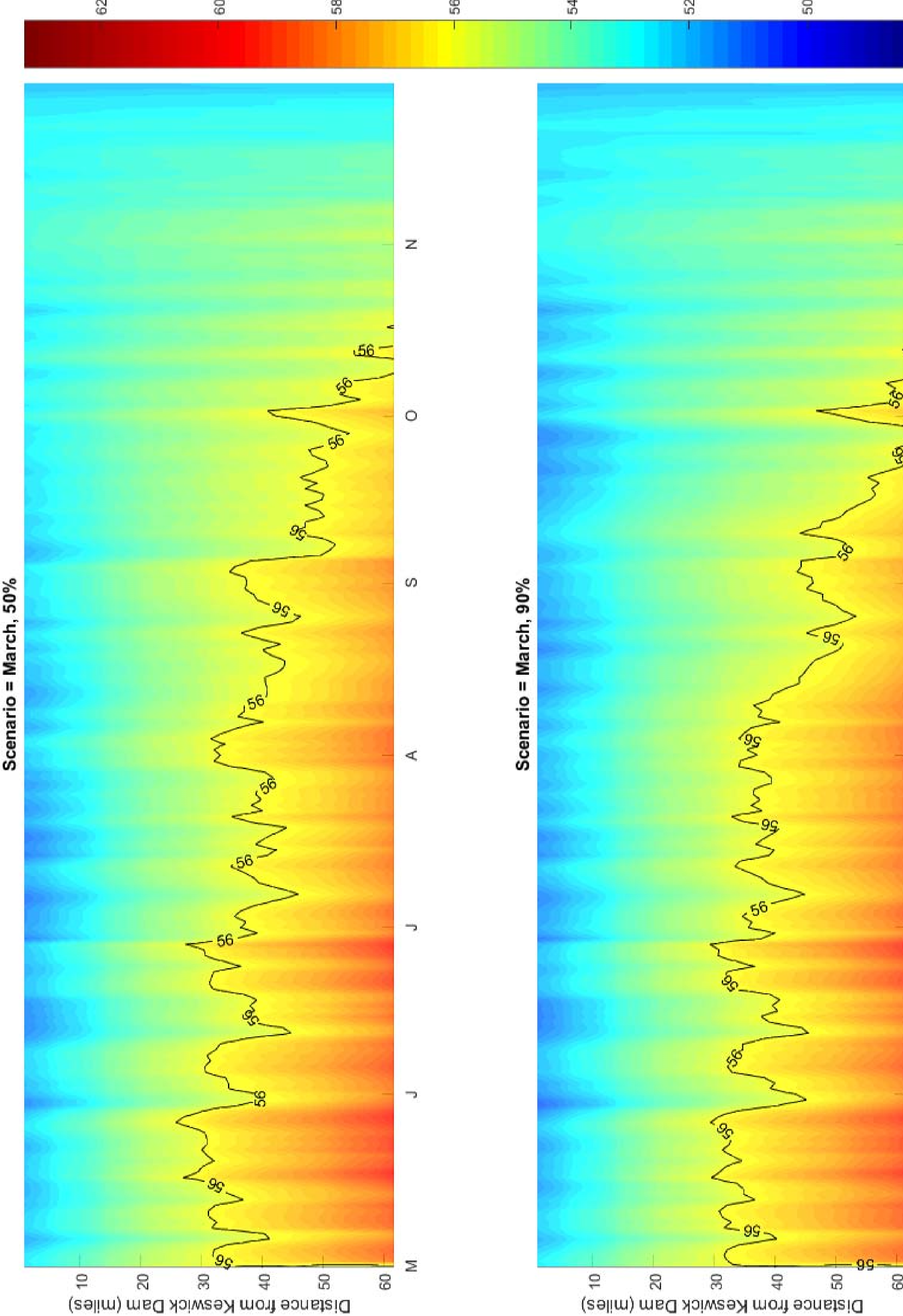
CVP releases or export values represent monthly averages.
CVP Operations are updated monthly as new hydrology information is made available December through May.

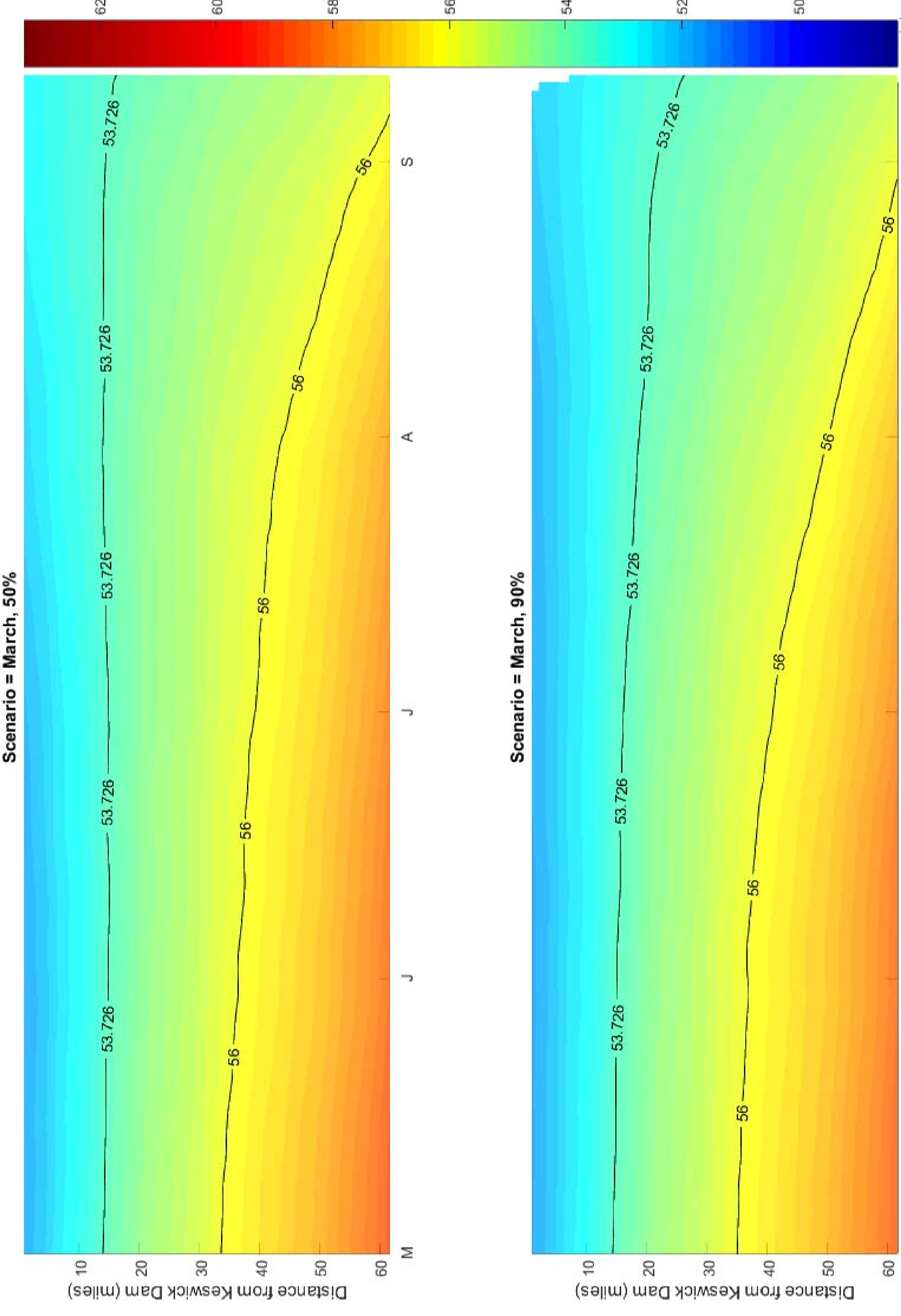
Revised 3/29/2016


Sacramento River Modeled Temperature
2016 Mar 50%-Exceedance Water Outlook - 10% L3MTO Historical
Approximately 52 degree at Kes
Kes Releases: April at 5,200, May at 8,500, June at 9,000, July at 10,500, Aug at 10,000, Sept at 9,000, Oct - Nov at 7,500
EOM April storage: 4.4 MAF & EOM Sept storage: 3.4 MAF
Trinity profile date : 2/11/2016
Whiskeytown profile date: 3/16/2016
Shasta profile date: 3/15/2016
10% Met - Exceedence: May '66, June '73, July '00, Aug '88, Sept '22, Oct '52 and Nov '62
Temp Run date: March 29, 2016
Temperature (°F)
67
66
65
64
63
62
61
60
59
58
57
56
55
54
53
52
51
50
49
48
47
46
45
44
43
42
41
4/30
5/15
5/30
6/14
6/29
7/14
7/29
8/13
8/28
9/12
9/27
10/12
10/27
11/11
11/26
SHASTA
KESWICK
BSF
JSF

Enclosure 4

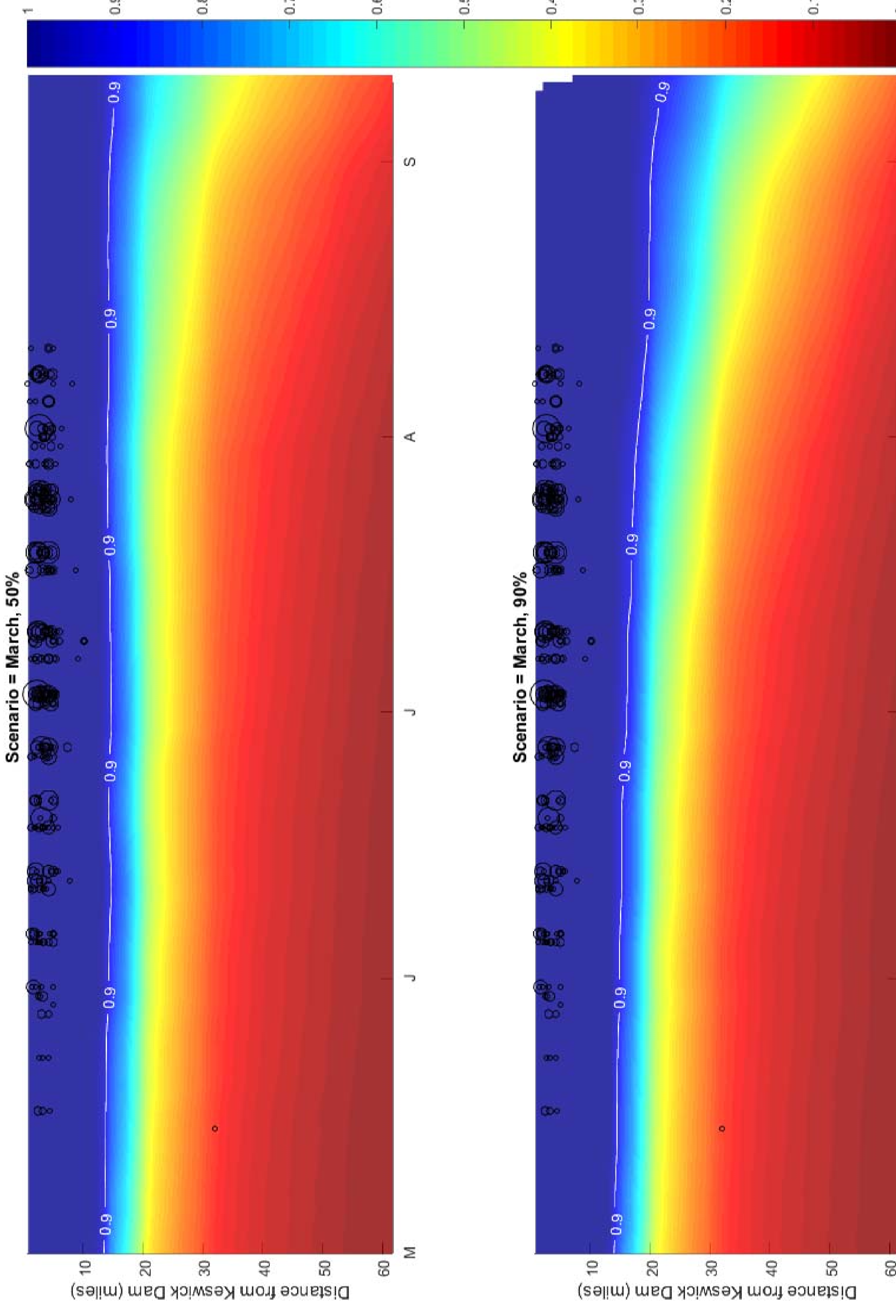


ARWA-209

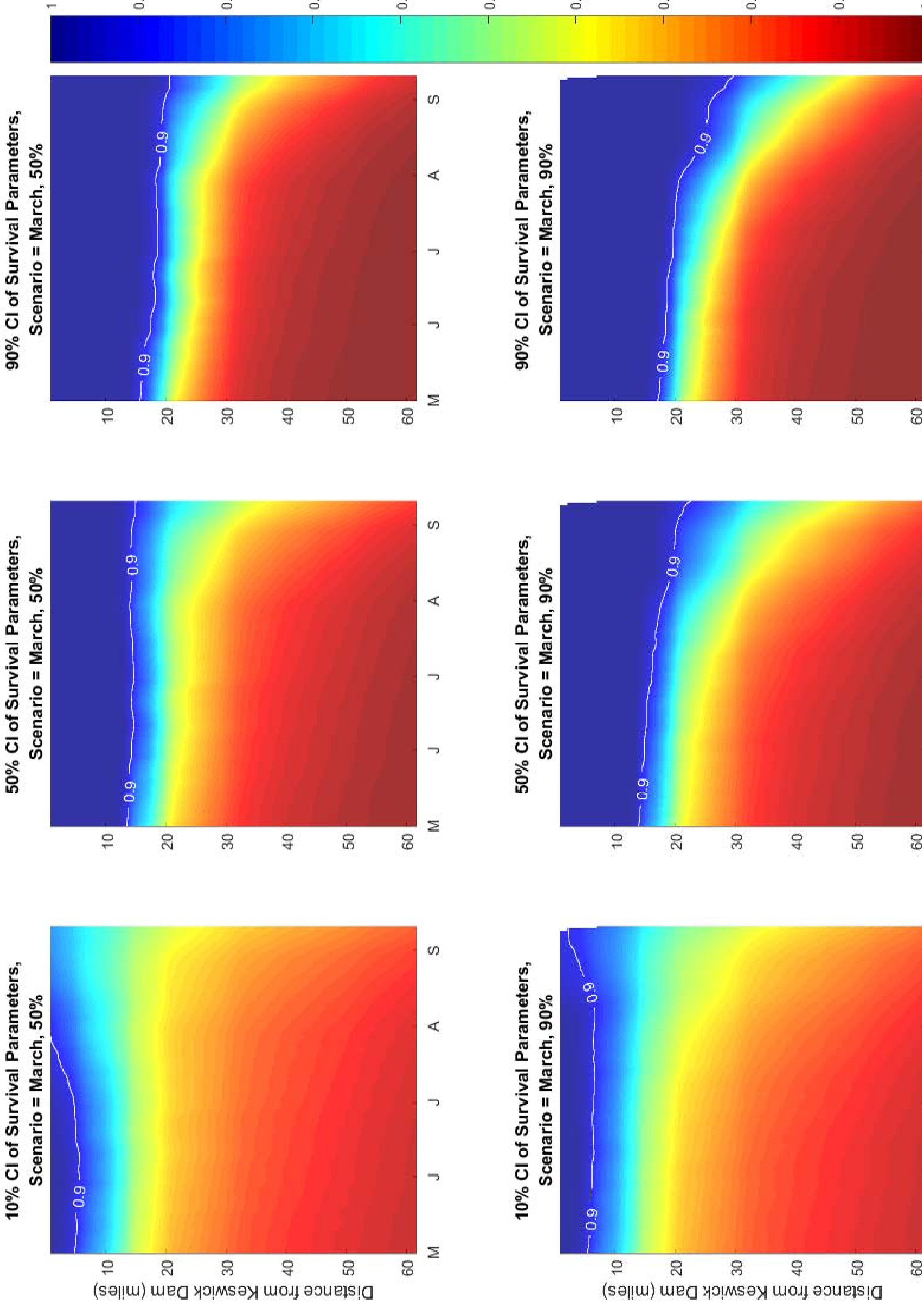


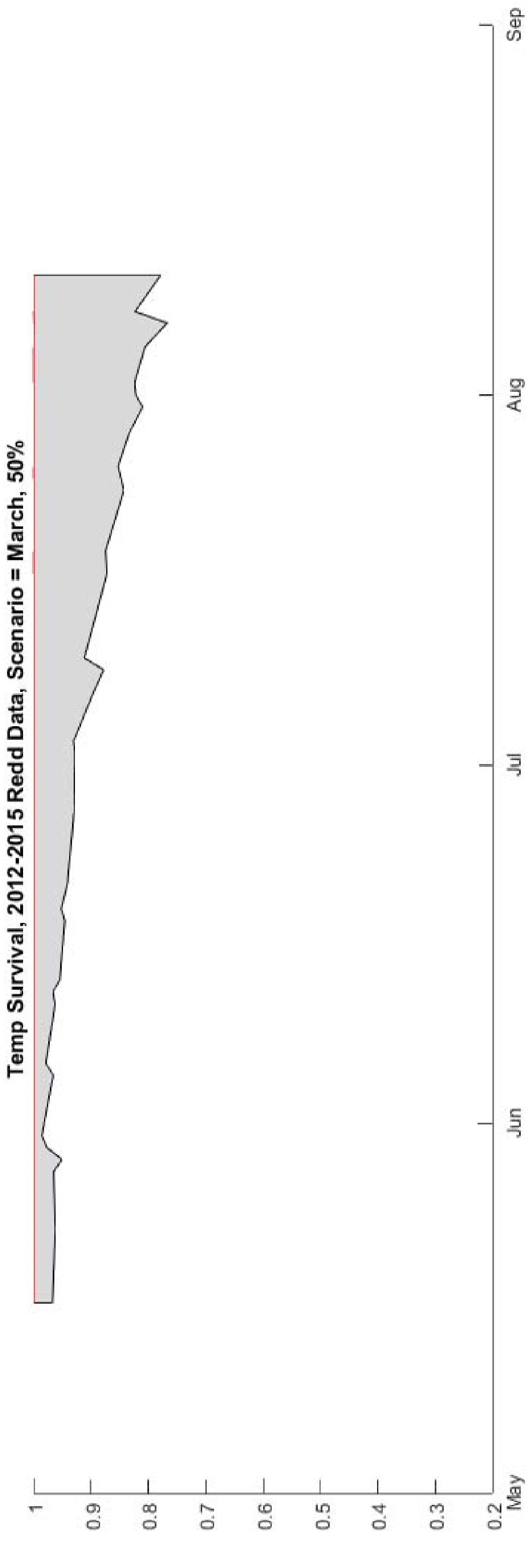
Scenario = March, 50%
Scenario = March, 90%
Distance from Keswick Dam (miles)
10
20
30
40
50
60
M
J
J
A
S
53.726
56
62
60
58
56
54
52
50

Enclosure 4

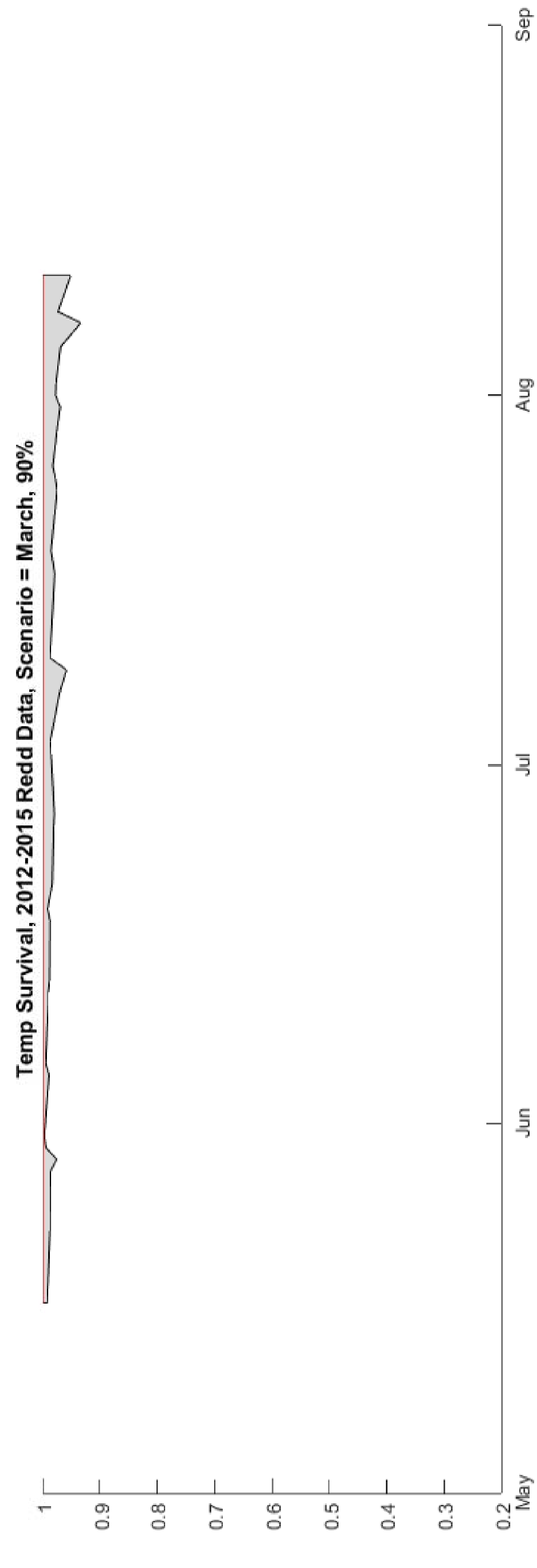

Scenario = March, 50%
Distance from Keswick Dam (miles)
10
20
30
40
50
60
0.9
M
J
J
A
S
Scenario = March, 90%
Distance from Keswick Dam (miles)
10
20
30
40
50
60
0.9
M
J
J
A
S
1
0

Enclosure 4


10% CI of Survival Parameters, Scenario = March, 50%
50% CI of Survival Parameters, Scenario = March, 50%
90% CI of Survival Parameters, Scenario = March, 50%
10% CI of Survival Parameters, Scenario = March, 90%
50% CI of Survival Parameters, Scenario = March, 90%
90% CI of Survival Parameters, Scenario = March, 90%
Distance from Keswick Dam (miles)
M J J A S
0.9

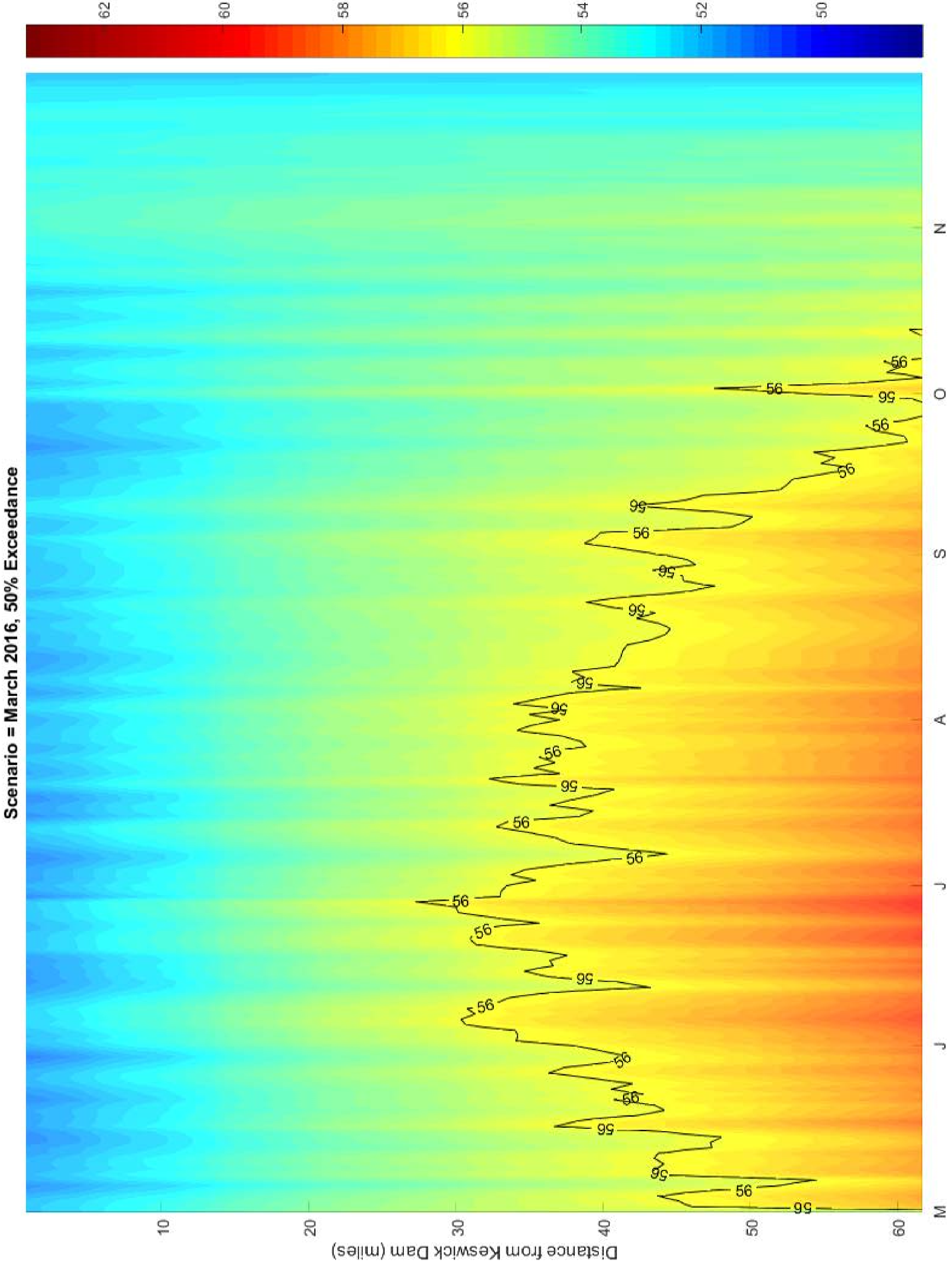


Temp Survival, 2012-2015 Redd Data, Scenario = March, 50%
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
May
Jun
Jul
Aug
Sep



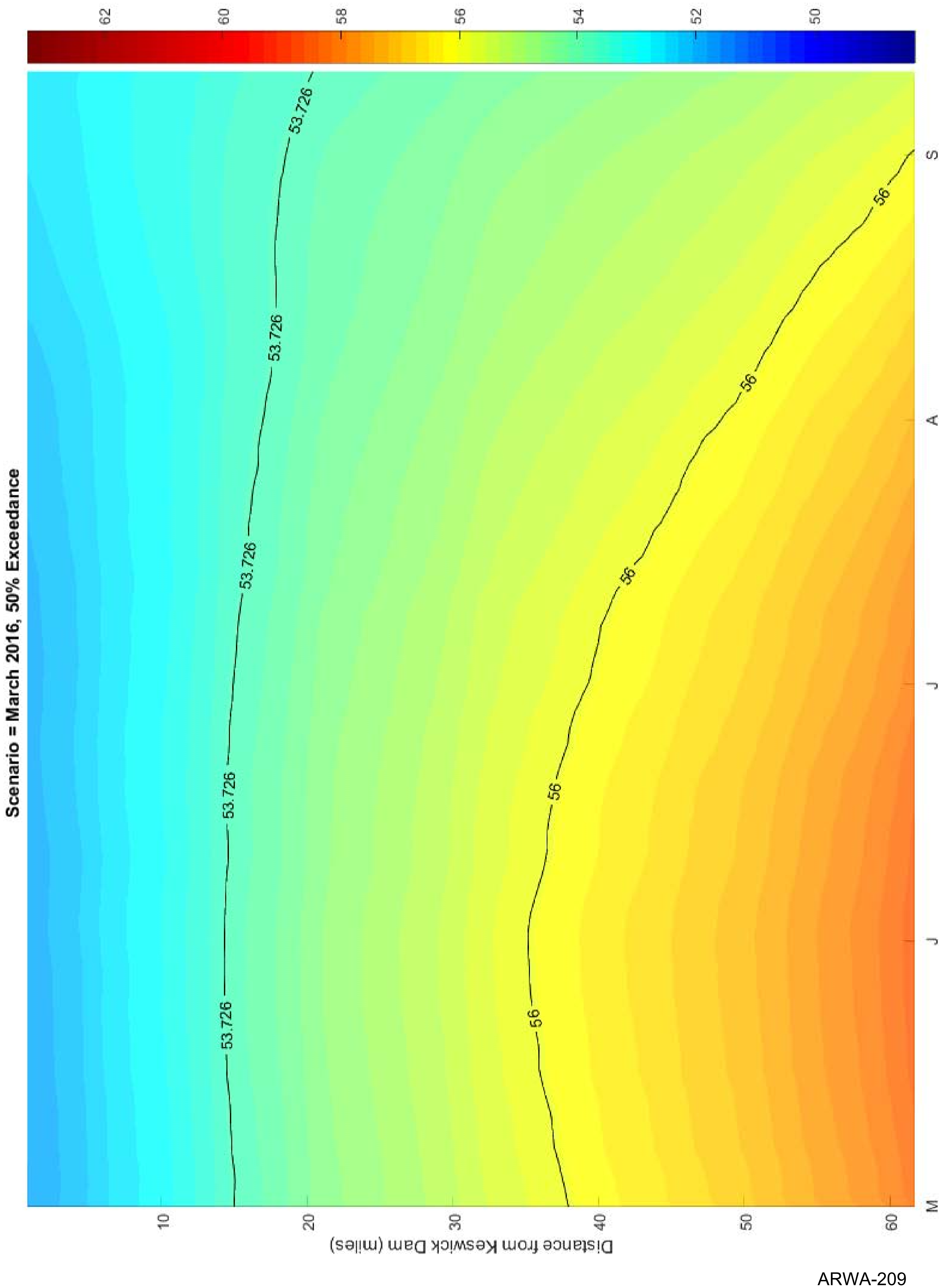
Temp Survival, 2012-2015 Redd Data, Scenario = March, 90%
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
May
Jun
Jul
Aug
Sep

Enclosure 5

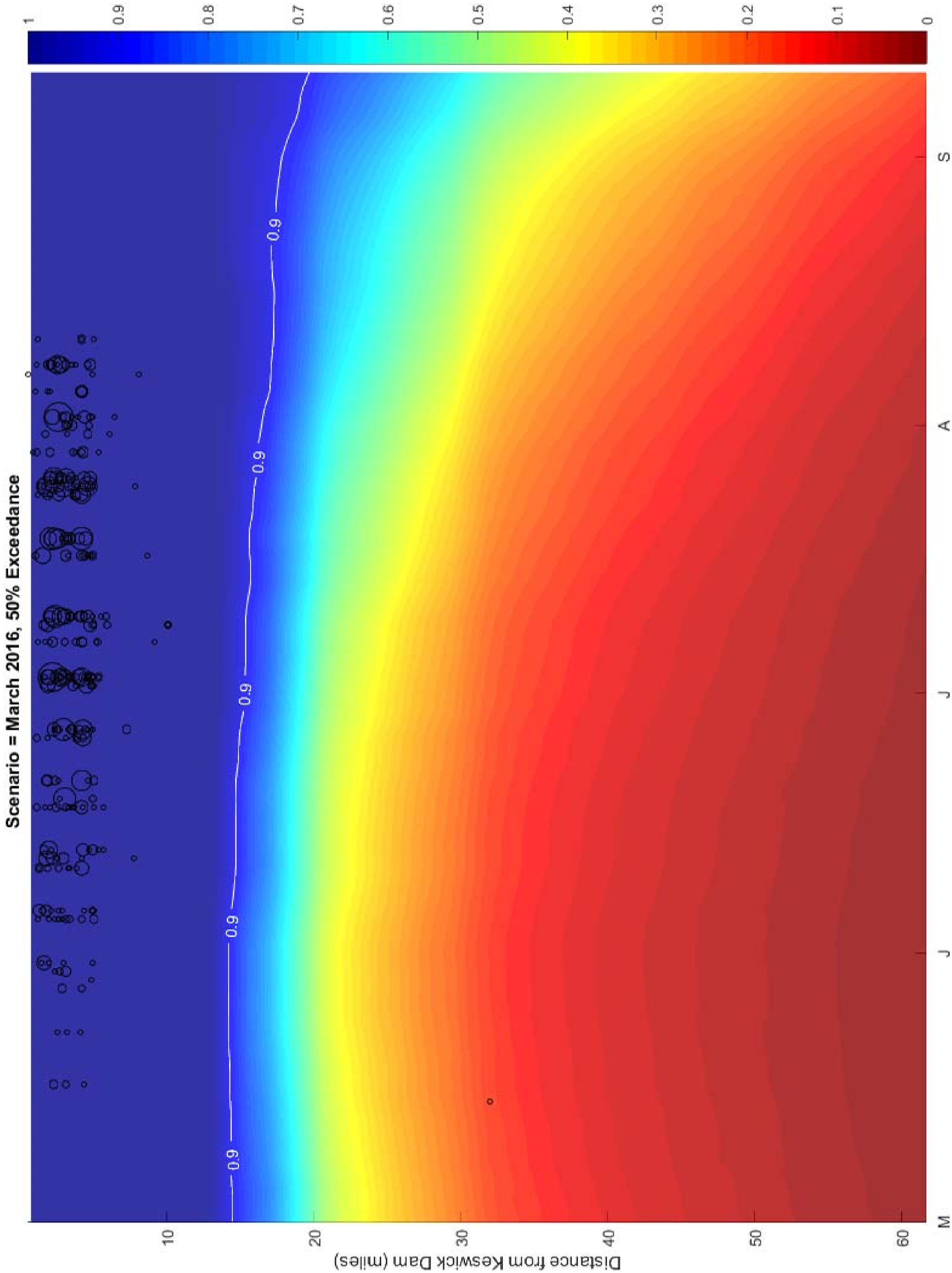


Scenario = March 2016, 50% Exceedance
Distance from Keswick Dam (miles)
10
20
30
40
50
60
M
J
J
A
S
O
N
56
62
60
58
56
54
52
50

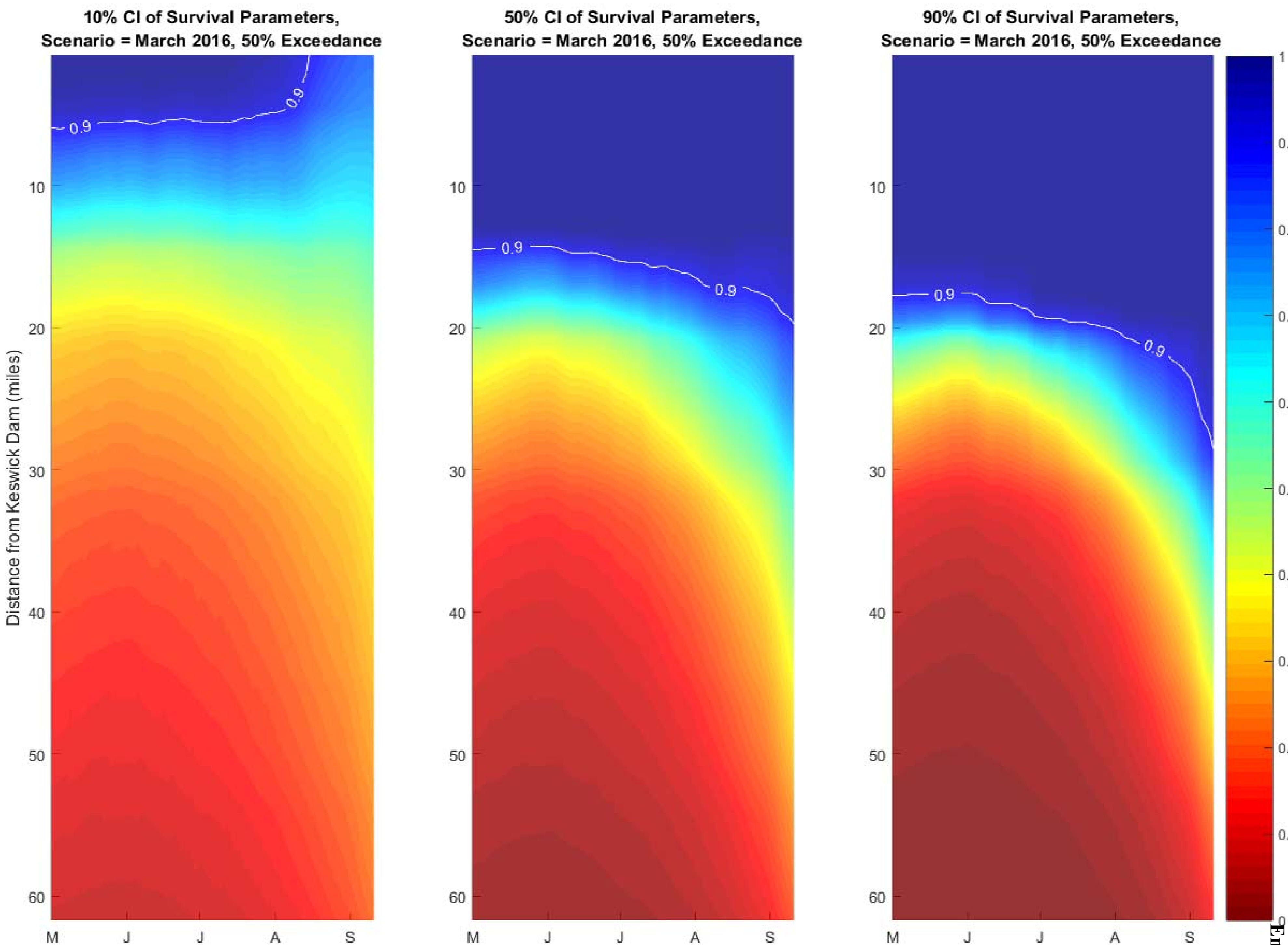
Enclosure 5

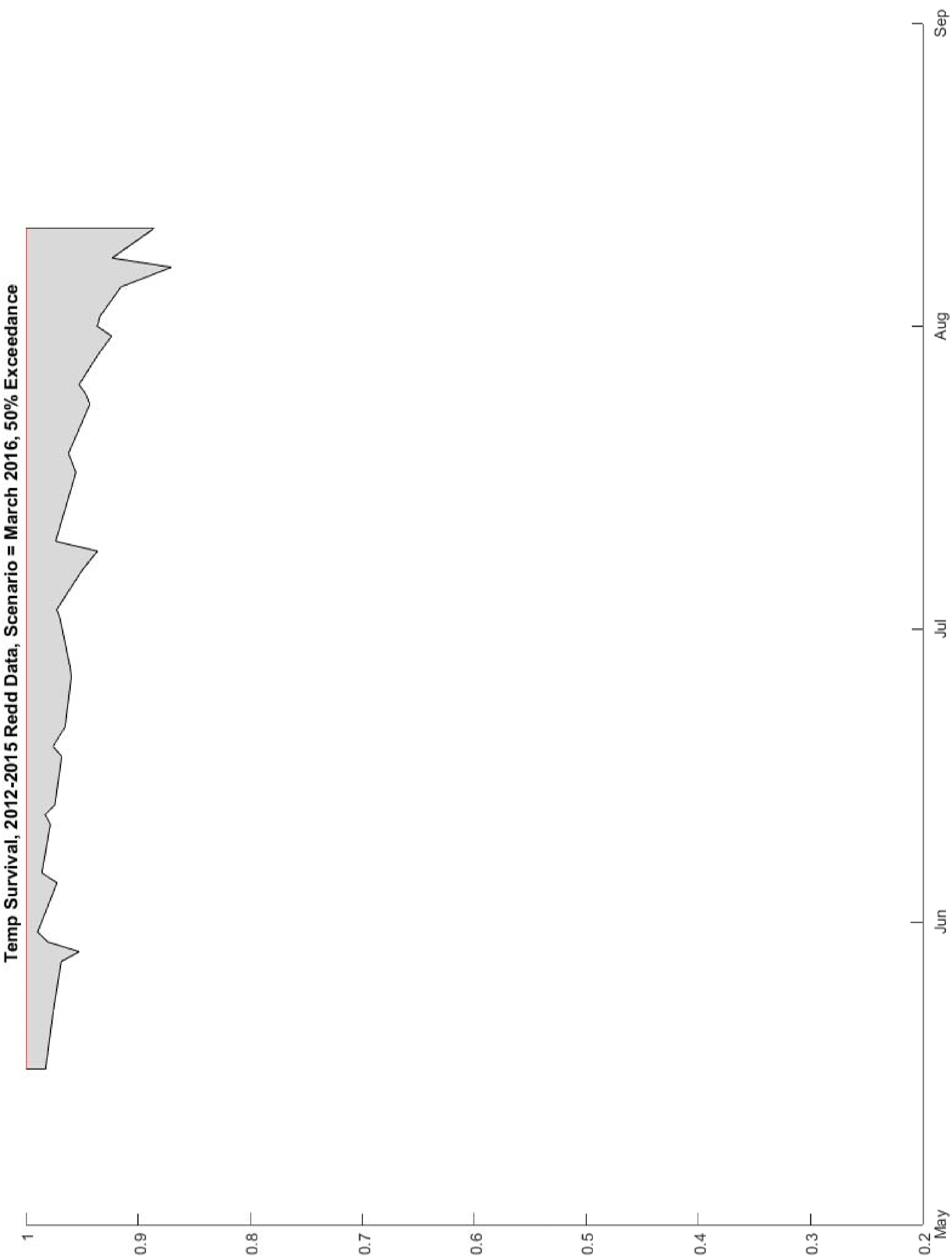


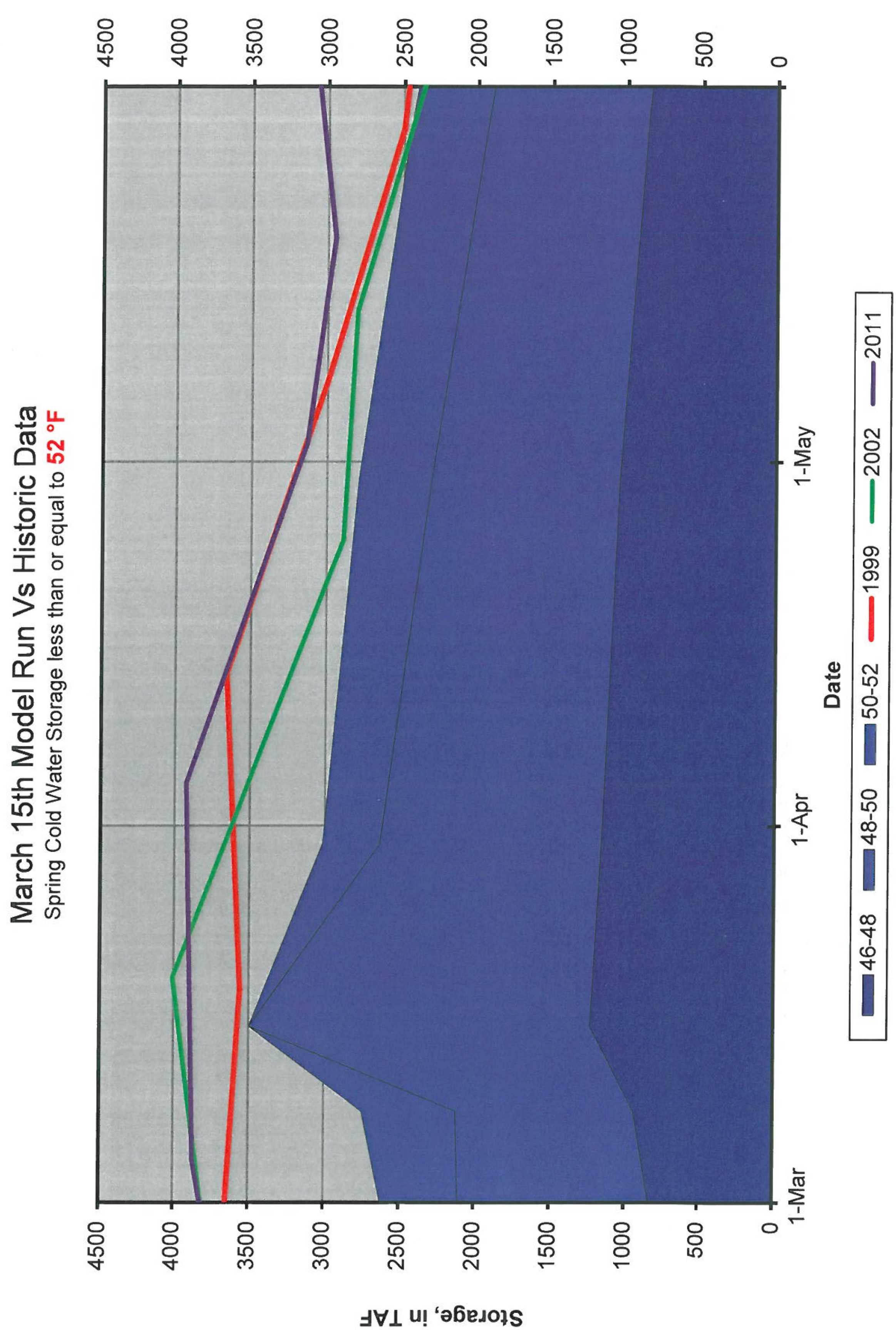
ARWA-209


Scenario = March 2016, 50% Exceedance
Distance from Keswick Dam (miles)
10
20
30
40
50
60
M
J
J
A
S
0.9
0.9
0.9
0.9
0.9
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

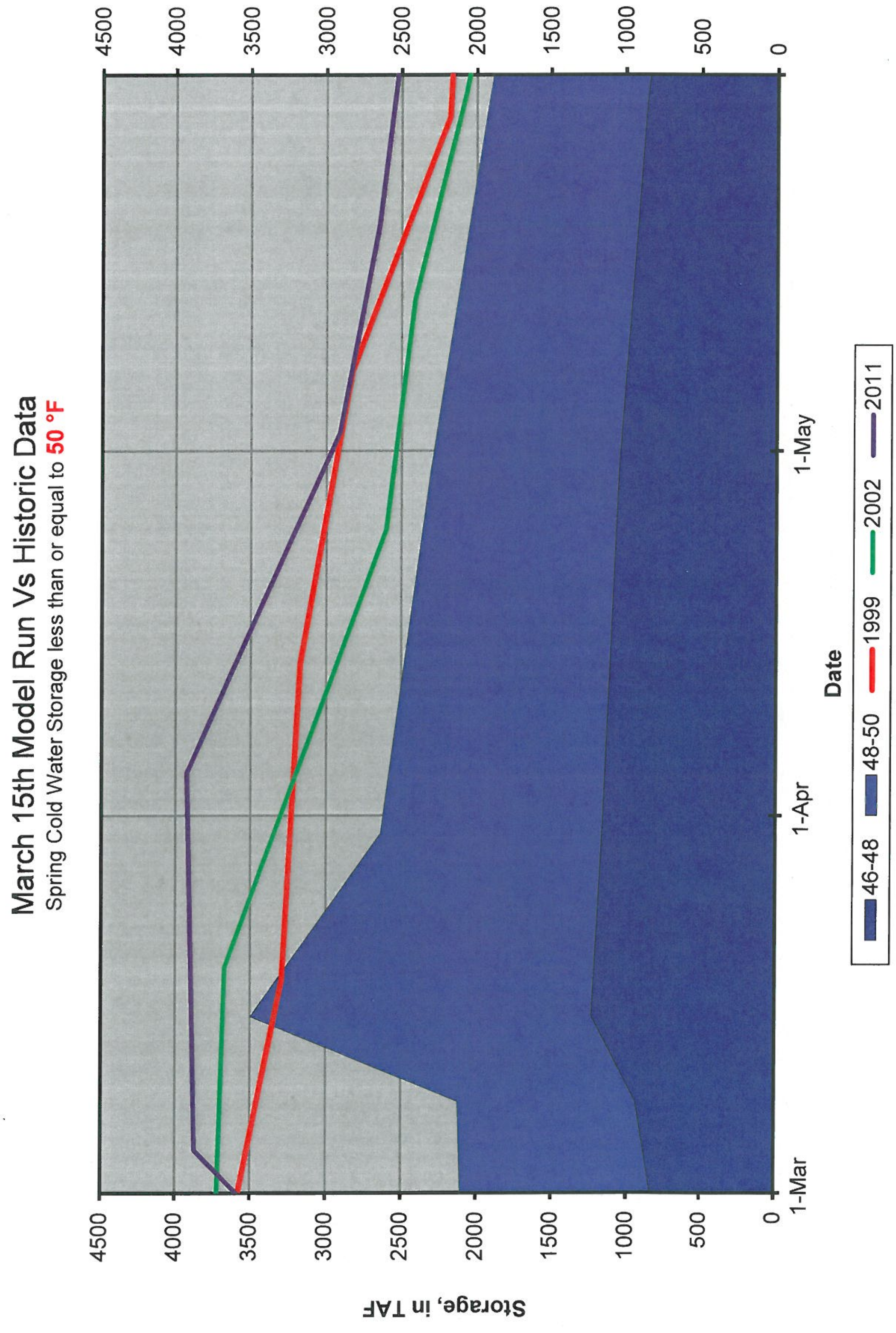
ARWA-209


10% CI of Survival Parameters,
Scenario = March 2016, 50% Exceedance
50% CI of Survival Parameters,
Scenario = March 2016, 50% Exceedance
90% CI of Survival Parameters,
Scenario = March 2016, 50% Exceedance
Distance from Keswick Dam (miles)
10
20
30
40
50
60
M
J
J
A
S
0.9
1
0

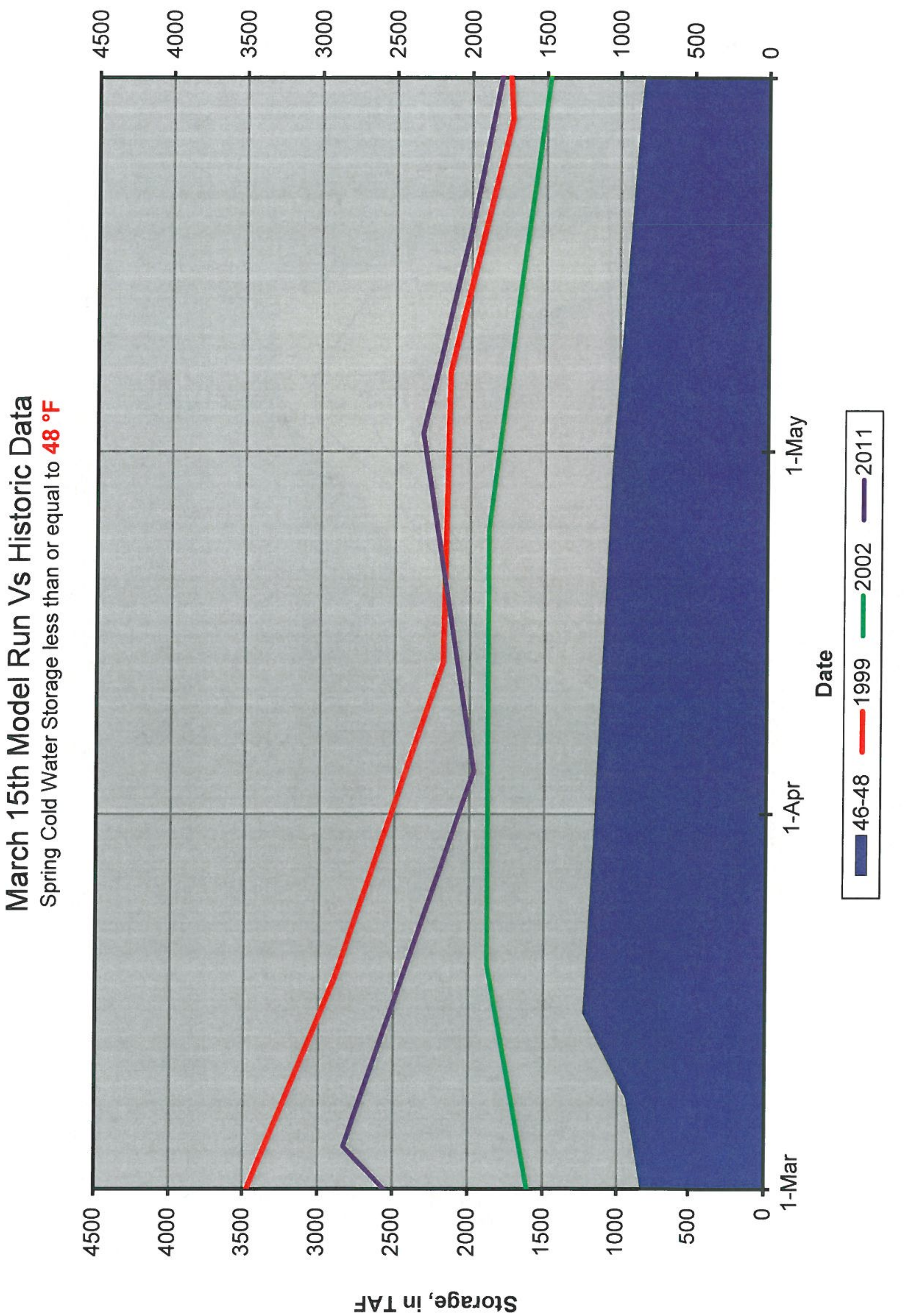

Temp Survival, 2012-2015 Redd Data, Scenario = March 2016, 50% Exceedance
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
May
Jun
Jul
Aug
Sep



March 15th Model Run Vs Historic Data
Spring Cold Water Storage less than or equal to 52 °F
Storage, in TAF
0
500
1000
1500
2000
2500
3000
3500
4000
4500
1-Mar
1-Apr
1-May
Date
46-48
48-50
50-52
1999
2002
2011


March 15th Model Run Vs Historic Data
Spring Cold Water Storage less than or equal to 50 °F
Storage, in TAF
0
500
1000
1500
2000
2500
3000
3500
4000
4500
1-Mar
1-Apr
1-May
Date
46-48
48-50
1999
2002
2011

Enclosure 6



March 15th Model Run Vs Historic Data
Spring Cold Water Storage less than or equal to 48 °F
Storage, in TAF
Date
1-Mar
1-Apr
1-May
0
500
1000
1500
2000
2500
3000
3500
4000
4500
46-48
1999
2002
2011

Enclosure 3

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
West Coast Region
650 Capitol Mall, Suite 5-100
Sacramento, California 95814-4700

Date: June 28, 2016

Memorandum to: CVP/SWP operations administrative record, number 151422SWR2006SA00268

From: Brycen Swart, Fisheries Biologist

Subject: Chronology of the Development of the Sacramento River Temperature Management Plan for the 2016 Temperature Management Season Part II

Table 1. Sacramento River Temperature Management Model Scenarios Summary Table

Date Scenario Run	Scenario		May	June	July	Aug	Sept	Oct	Nov	Full Side Gates	Zeug et al. (2012) Temperature dependent mortality estimates (w/ 0.5–1.0ºF sensitivity analysis)	Martin et al. (2016) Temperature dependent mortality estimates (95% Confidence Interval)	Martin et al. (2016) Temperature dependent mortality estimates w/ 0.5–1.0ºF sensitivity analysis (95% CI)
25-Mar	March 90% Exceedance Forecast	KES monthly avg flow (cfs)	6500	9500	10500	10000	9000	6500	6500	~25-Sep	N/A	2.2% (0 – 25.49)	
		KES monthly avg temp (ºF)	~52	~52	~52	~52	~52	~52	~52				
3-May	April 90% Exceedance Forecast	KES flow	6500	9000	11500	10000	8500	6500	5500	24-Sep	N/A	5.0% (0.08 – 43.33)	
		KES temp		52.5	52.5	52.5	52.5	53.5					
		CCR temp		52.9	52.8	52.9	52.8	52.9					
9-May	Run 1 March Flows	KES flow	6500	9000	10500	1000	9000	6500	6500	8-Sep	N/A	8.0% (0.09 – 43.36)	
		KES temp	52.4	52.3	52.1	52.2	52.6	54.2					
	Run 1a 9000 cfs	KES flow	6500	9000	9000	9000	8500	6500	5500	14-Sep	N/A	N/A	
		KES temp	52.3	52.2	52.1	52.3	52.5	53.3					
	Run 1b 8500 cfs	KES flow	6500	8500	8500	8500	8500	6500	5500	16-Sep	N/A	5.2% (0.08 – 44.90)	
		KES temp	52.3	52.3	52.3	52.5	52.4	52.8					
	Run 2 May 7000 cfs	KES flow	7000	8500	10000	9500	8500	6500	5500	6-Sep	N/A	7.0% (0.08 – 43.48)	
		KES temp	52.4	52.0	52.0	52.1	52.9	53.8					
	Run 3 May 7000 cfs (b)	KES flow	7000	8500	9500	9500	8500	6500	5500	9-Sep	N/A	6.0% (0.08 – 43.55)	
		KES temp	52.4	52.0	52.1	52.1	52.8	53.6					
12-May	7500 cfs	KES flow	6500	7500	7500	7500	7500	6500	5500	31-Jul	N/A	5.7% (0.08 – 45.89)	
		KES temp (no change)	52.06	52.38	52.46	52.24	52.51	52.51					
		KES temp	52.06	52.09	52.04	52.39	52.82	52.67					
	8000 cfs	KES flow	6500	8000	8000	8000	8000	6500	5500	8-Aug	N/A	5.3% (0.08 – 43.12)	
		KES temp (no change)	52.06	52.20	52.26	52.11	52.64	52.92					
		KES temp	52.06	52.08	52.07	52.12	52.81	53.00					
	8500 cfs	KES flow	6500	8500	8500	8500	8500	6500	5500	14-Aug	N/A	5.8% (0.06 – 42.45)	
		KES temp	52.06	52.07	52.05	52.04	52.83	53.40					
	9000 cfs	KES flow	6500	9000	9000	9000	9000	6500	5500	14-Sep 16-Aug	N/A	7.6% (0.03 – 43.62)	
		KES temp (52.3 to 52.4)	52.3	52.2	52.1	52.3	52.5	53.3					
		KES temp (52.0)	51.91	51.96	51.94	52.05	53.08	53.77					
17-May	7500 cfs	KES flow	6500	7500	7500	7500	7500	6500	5500	29-Aug	4.5%	4.9% (0.08 – 44.53)	
		KES temp	52.42	52.40	52.38	52.40	52.38	52.41					
	8000 cfs	KES flow	6500	8000	8000	8000	8000	6500	5500	8-Sep	4.6%	4.6% (0.08 – 43.44)	7.9 – 15.3% (0.08 – 61.02)
		KES temp	52.31	52.31	52.35	52.34	52.35	52.70					
	8500 cfs	KES flow	6500	8500	8500	8500	8500	6500	5500	19-Sep	4.8%	4.8% (0.08 – 44.36)	
		KES temp	52.35	52.32	52.38	52.37	52.40	52.84					
	9000 cfs	KES flow	6500	9000	9000	9000	8500	6500		10-Sep	5.0%	7.6% (0.03 – 43.62)	
		KES temp	52.34	52.32	52.35	52.33	52.37	53.22					
	9500 cfs	KES flow	6500	9500	9500	9500	8500	6500	5500	10-Sep	5.5%	9.9% (0.02 – 43.54)	
		KES temp	52.33	52.30	52.31	52.30	52.44	53.88					
	10,000 cfs	KES flow	6500	8500	10000	10000	9250	8000	5500	8-Sep	5.7%	10.7% (0.07 – 43.05)	
		KES temp	52.34	52.36	52.31	52.31	52.42	53.99					
18-May	9500 cfs	KES flow	6500	9500	9500	9500	8500	6500	5500	1-Oct	6.5%	6.6% (0.08 – 50.16)	11.5 – 21.8% (0.09 – 65.27)
		KES temp	52.5	52.65	52.65	52.63	52.62	52.78					
	10,000 cfs	KES flow	6500	8500	10000	10000	9250	8000	5500	6-Oct	6.8%	12.2% (0.09 – 58.84)	21.5 – 35.3% (0.09 – 71.46)
		KES temp	52.77	52.73	52.76	52.87	52.73	52.57					
	10,000 cfs	KES flow	6500	8500	10000	10000	9250	8000	5500	18-Oct	N/A	N/A	N/A
		KES temp	53.00	52.94	52.98	53.13	52.94	52.28					
20-May	Proposal 1 (10,000 cfs)	KES flow	6500	8500	10000	10000	9250	8000	5500	6-Oct	6.8% (8.4 – 10.4)	12.2% (0.09 – 58.84)	21.5 – 35.3% (0.09 – 71.46)
		KES temp	52.77	52.73	52.76	52.87	52.73	52.57					
		CCR temp	54.27	54.23	54.26	54.37	54.23	54.07					
	Proposal 2 (9500 cfs)	KES flow	6500	9500	9500	9500	8500	6500	5500	1-Oct	6.5% (8.0 – 9.9)	6.6% (0.08 – 50.16)	11.5 – 21.8% (0.09 – 65.27)
		KES temp	52.5	52.65	52.65	52.63	52.62	52.78					
		CCR temp	54.00	54.15	54.15	54.13	54.12	54.28					

Date Scenario Run	Scenario		May	June	July	Aug	Sept	Oct	Nov	Full Side Gates	Zeug et al (2012) Temperature dependent mortality estimates (w/ 0.5–1.0ºF sensitivity analysis)	Martin et al (2016) Temperature dependent mortality estimates (95% Confidence Interval)	Martin et al (2016) Temperature dependent mortality estimates w/ 0.5–1.0ºF sensitivity analysis (95% CI)
26-May	May 90% Exceedance Forecast	KES flow		9000	10000	10000	8500	6800	5500	14-Oct	5.8%	7.1% (0.08 – 51.52)	12.8 – 24.5% (0.09 – 66.21)
		KES temp	52.55	52.63	52.71	52.68	52.75	52.29					
		CCR temp	53.42	53.91	53.96	53.81	53.61	52.98					
		BLF temp	55.73	56.18	56.17	55.70	55.13	54.07					
31-May	Scenario 1 (8000 cfs)	KES flow		8000	8000	8000	8000	6500	5500	23-Oct	5.6%	4.0% (0.08 – 39.47)	6.8 – 13.4% (0.08 – 58.52)
		KES temp		52.11	52.34	52.30	52.25	51.38					
		BLF temp		55.09	55.62	54.99	53.84	52.27					
		JLF temp		56.63	57.34	56.44	54.92	52.80					
	Scenario 2 (10,000 cfs)	KES flow		9000	10000	10000	8500	6800	5500	26-Sep	4.9%	3.0% (0.03 – 31.90)	5.3 – 10.5% (0.03 – 51.48)
		KES temp		51.88	51.84	51.82	52.31	52.69					
		BLF temp		54.58	54.58	54.08	53.89	53.28					
		JLF temp		56.02	56.07	55.35	54.83	53.70					
	Scenario 3 (11,500 cfs)	KES flow		10000	11500	10000	8500	6800	5500	25-Sep	N/A	3.6% (0.03 – 36.89)	6.5 – 12.8% (0.03 – 55.84)
		KES temp		52.06	51.89	52.11	52.33	52.98					
		BLF temp		54.48	54.39	54.34	53.91	53.51					
		JLF temp		55.81	55.74	55.59	54.83	53.91					
2-Jun	Scenario 1A (8000 cfs)	KES flow		8000	8000	8000	8000	6500	5500	1-Oct	5.0%	3.1% (0.03 – 33.93)	5.6 – 11.3% (0.03 – 53.70)
		KES temp		51.88	51.87	51.90	52.43	51.98					
		BLF temp		54.91	55.24	54.65	54.07	52.75					
		JLF temp		56.47	56.98	56.13	55.04	53.23					
	Scenario 2A (8,500 cfs)	KES flow		8500	8500	8500	8500	6500	5500	2-Sep	N/A	2.9% (0.03 – 30.77)	5.3 – 10.3% (0.03 – 50.36)
		KES temp		51.75	51.63	51.78	52.27	52.79					
		BLF temp		54.64	54.77	54.40	53.85	53.41					
		JLF temp		56.15	56.43	55.82	54.78	53.84					
	Scenario 3A (9,000 cfs)	KES flow		9000	9000	9000	8500	6800	5500	10-Sep	5.0%	2.9% (0.03 – 32.51)	5.0 – 9.9% (0.03 – 52.19)
		KES temp		51.88	51.83	51.95	52.14	52.97					
		BLF temp		54.61	54.84	54.43	53.83	53.27					
		JLF temp		56.05	56.45	55.79	54.81	53.70					
	Scenario 4A (9,500 cfs)	KES flow		9500	9500	9500	8500	6500	5500	17-Sep	N/A	3.3% (0.03 – 34.40)	6.0 - 11.9% (0.03 – 53.60)
		KES temp		51.86	51.87	52.02	52.26	52.94					
		BLF temp		54.46	54.74	54.36	53.85	53.51					
		JLF temp		55.85	56.29	55.66	54.78	53.93					
	Scenario 5A (10,000 cfs)	KES flow		9000	10000	10000	8500	6800	5500	16-Sep	5.1%	3.4% (0.03 – 34.16)	6.1 – 11.7% (0.03 – 53.22)
		KES temp		51.85	51.91	51.94	52.28	53.13					
		BLF temp		54.56	54.64	54.19	53.86	53.64					
		JLF temp		56.02	56.13	55.45	54.80	54.03					
	Scenario 6A (11,500 cfs)	KES flow		10000	11500	10000	8500	6800	5500	9-Sep	5.2%	5.0% (0.03 – 35.98)	8.7 – 15.2% (0.03 – 54.40)
		KES temp		52.03	51.88	51.83	52.54	53.83					
		BLF temp		54.46	54.31	53.13	54.07	54.22					
		JLF temp		55.78	55.66	55.36	54.99	54.57					
7-June	Draft Plan	KES flow		9000	10500	10000	9000	6500		9-Oct	6.0% (7.4 – 9.2)	4.6% (0.08 – 43.01)	8.0 – 15.7% (0.08 – 61.00)
		KES temp		52.42	52.41	52.39	52.35	52.30					
		BLF temp		55.03	54.96	54.58	53.85	53.01					
		JLF temp		56.42	56.37	55.82	54.75	53.47					

Brief Background and Temperature Model Explanation

The U.S. Bureau of Reclamation (Reclamation) has a coupled river/reservoir model they use to target some temperature at some compliance point along the Sacramento River based their most recent Shasta Reservoir profile, some set of operating conditions [made up of temperature control device (TCD) gate configurations and Keswick release flows], and a medium range weather forecast. From this they generate scenarios (discharge flows at Keswick and temperatures at various points) for the entire summer and fall salmon temperature management season (Figures 1 and 2).

On March 31, 2016, NOAA's National Marine Fisheries Service (NMFS) concurred with Reclamation's forecasts based on the March 15, 2016, hydrological conditions and initial water supply allocation that RPA Action I.2.3.A should be implemented this year, and that a 55^{o}F 7-day daily average of the daily maxima (7DADM) would be attainable to the CCR CDEC gauge location [or a surrogate of a Keswick release daily average temperature (DAT) of 52^{o}F or 56^{o}F DAT between Balls Ferry and Jellys Ferry][1] based on the following flow schedule:

Exceedance	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
90%	5000	6500	9000	10500	10000	9000	6500	6500	6500	4150	4150
Revised 50%	5200	8500	9000	10500	10000	9000	7500	7500	7500	5000	4000

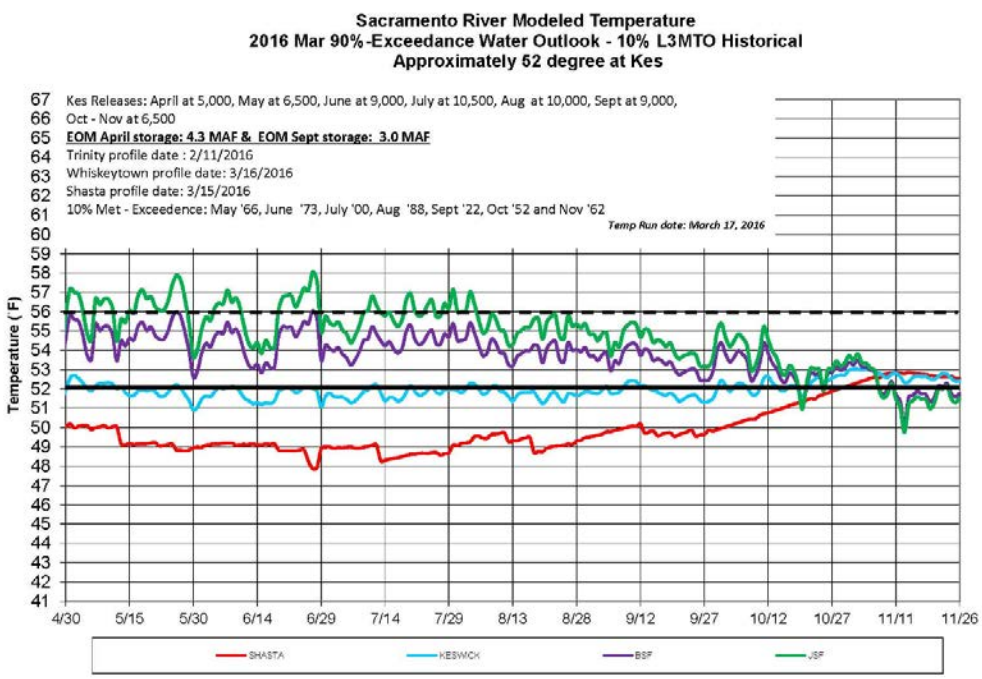


Figure 1. Reclamation's Sacramento River Water Quality Model (SRWQM) Temperature Results for May through November using the 2016 March 90% exceedance outlook, historical 10% local 3-month temperature outlook meteorology, Reclamation's proposed Keswick Dam monthly average releases, and targeting approximately 52^{o}F DAT at KWK.

[1] http://www.westcoast.fisheries.noaa.gov/publications/Central_Valley/Water%20Operations/nmfs__march_31__2016__response_to_the_bureau_of_reclamation_s_march_forecast.pdf

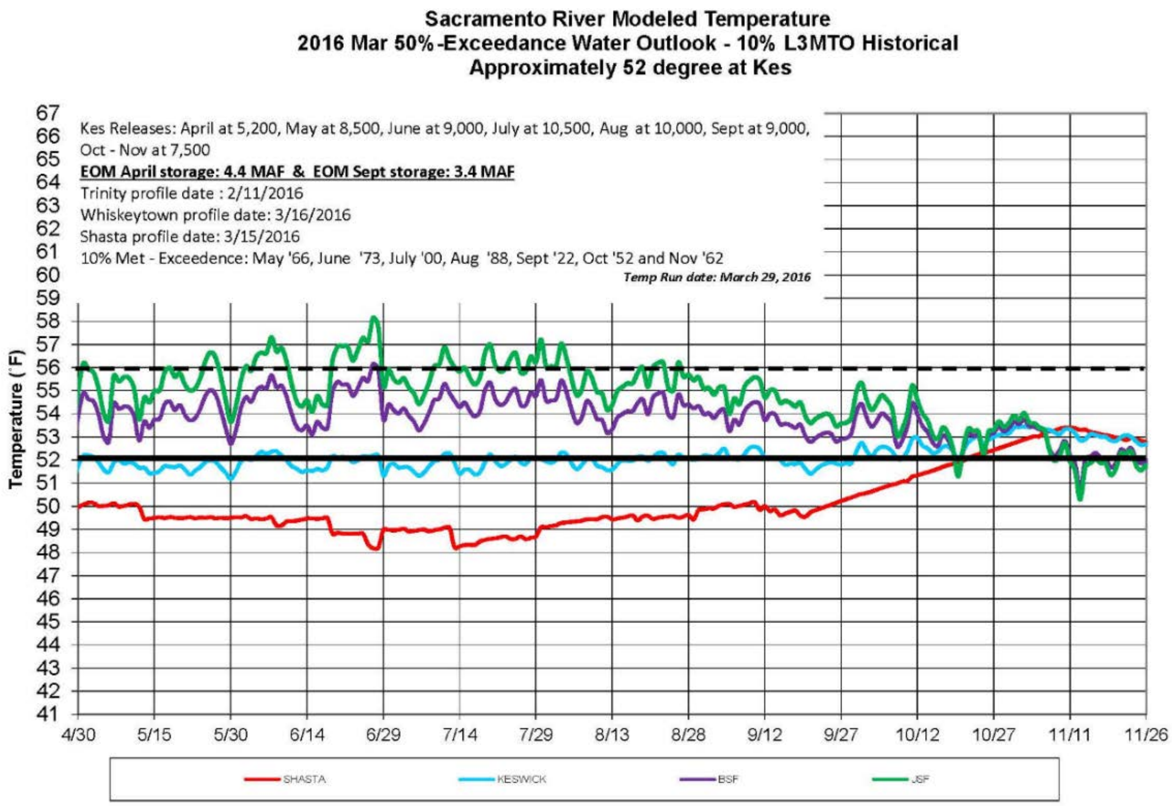


Figure 2. SRWQM Results for May through November using the 2016 March 50% exceedance outlook, historical 10% local 3-month temperature outlook meteorology, Reclamation's proposed Keswick Dam monthly average releases, and targeting approximately 52°F DAT at KWK.

The NMFS Southwest Fisheries Science Center (NMFS-SWFSC) used the flow and temperature at Keswick from these scenarios as boundary conditions for their River Assessment for Forecasting Temperatures (RAFT), which provides the spatiotemporal resolution needed to estimate the exposure of the full distribution of redds (based on the average of the past three years). They then apply those exposures to their temperature dependent mortality model[2], which provides a "survival landscape" (Figure 3) and annual temperature-dependent mortality statistics (Table 2).

[2] Martin, B., S. John, A. Pike, J. Roberts, and E. Danner. 2016. Modeling temperature dependent mortality of winter-run Sacramento River Chinook salmon. National Marine Fisheries Service, Southwest Fisheries Science Center. Santa Cruz, California.

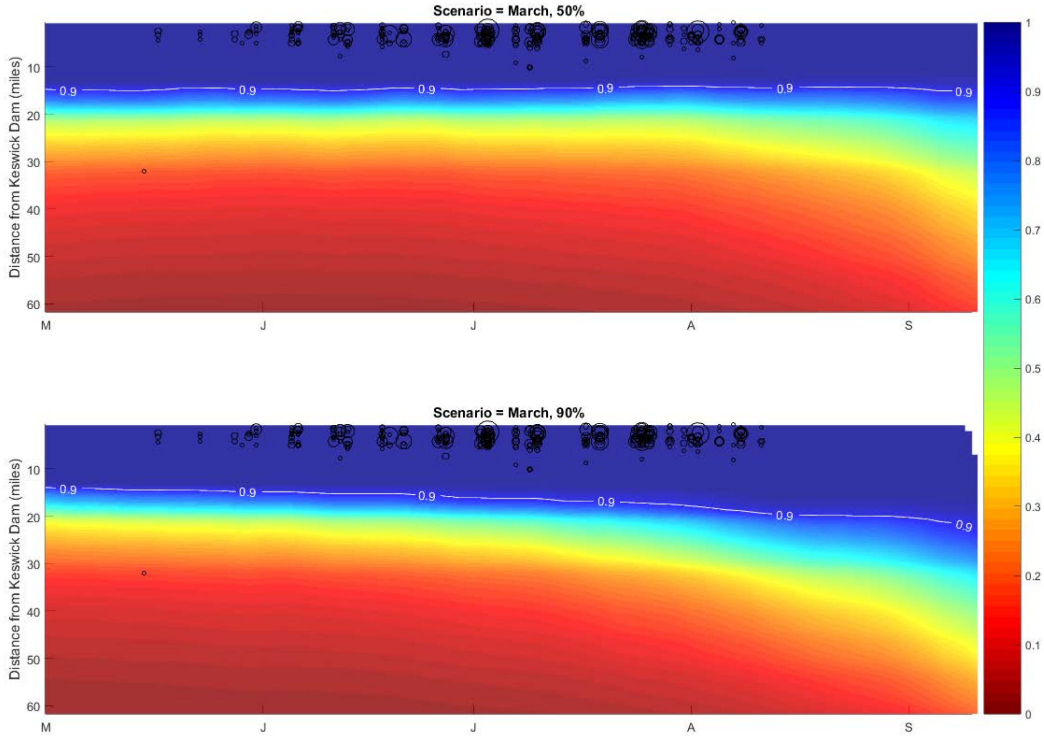


Figure 3. March 2016 Forecast NMFS-SWFSC RAFT survival landscape

Table 2. March 2016 Forecast Percent Temperature-Dependent Mortality

Percent Temperature-dependent Mortality			
Run	Mean	Median	2.5 - 97.5 Percentiles
March 2016 water outlook forecast 90%	2.17	0.77	0 - 25.49
March 2016 water outlook forecast Revised 50%	2.67	0.078	0 - 31.13

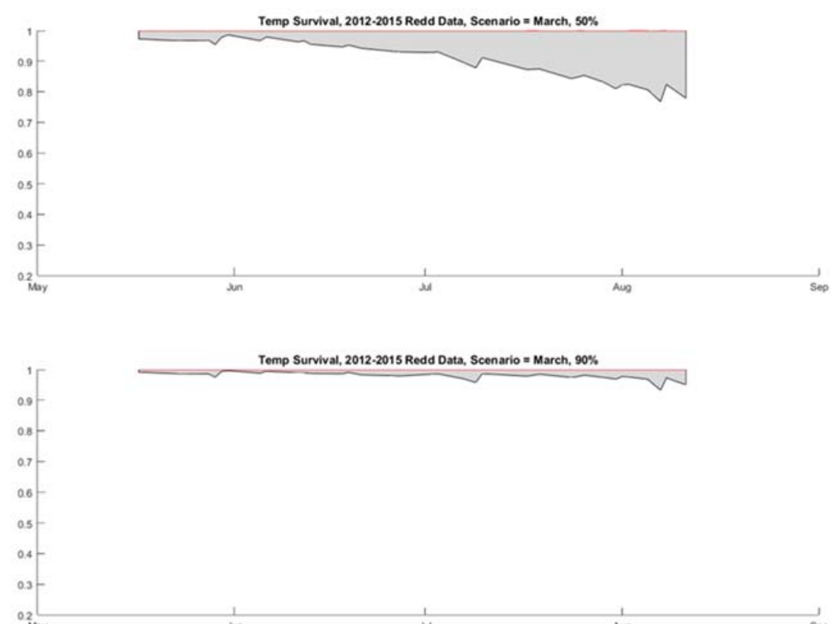


Figure 4. March 2016 Forecast Temperature-Dependent Survival Histogram

There is uncertainty associated with each of the model steps above. The uncertainty with the survival model is provided graphically in the histograms in Figure 4. This is driven by not knowing the exact values of the two temperature dependent parameters in the model: T_{crit}, the temperature below which there is no mortality due to temperature, and b_T, the slope at which instantaneous mortality rate increases with temperature above T_{crit}.

$$h_i = b_T \max (T_i - T_{crit}, 0)$$

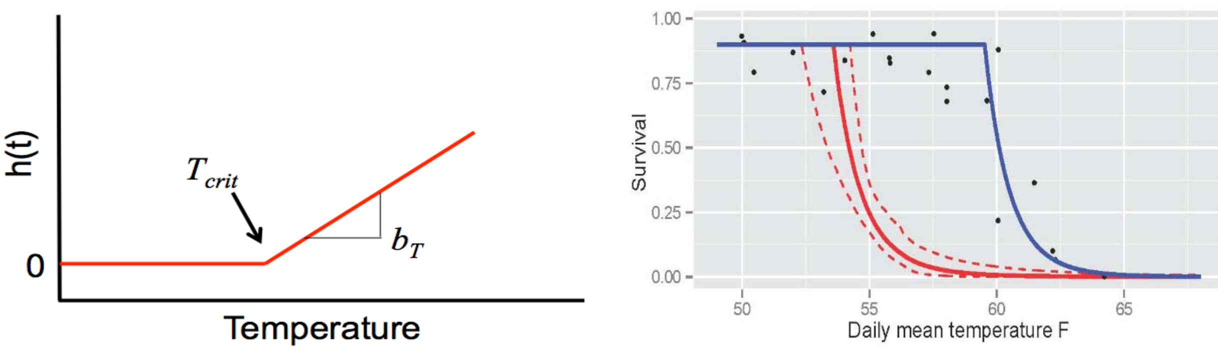


Figure 5. Equation and schematics of the temperature-dependent mortality model

The basic pattern is the higher the T_{crit}, the steeper b_T. This means the model might predict a low T_{crit} with slowly increasing mortality as temps exceed T_{crit}. Or, a high T_{crit}, meaning no mortality until some point, then mortality occurs very rapidly (Figure 5). Based on laboratory data, field data, and a least squares estimate, the T_{crit} value was found to be 53.7°F (Figure 5). This is a much lower temperature than the 56°F DAT that has been the focus in the past for winter-run Chinook salmon temperature management in Water Rights Order 90-5. For more detail, please see attachment in:

http://www.westcoast.fisheries.noaa.gov/publications/Central_Valley/Water%20Operations/Operations,%20Criteria%20and%20Plan/nmfs__march_18__2016__response_to_the_bureau_of_reclamation_s_february_forecast.pdf

The uncertainty with RAFT is minimal. The only significant source of error would be the local weather conditions over the course of the season. These would have to be extreme to substantially alter the temperature in such a short amount of river below the dam where the spawning habitat is (<14 river miles); the water just doesn't have the time to heat up that quickly. So if the NMFS-SWFSC has the correct discharge flows and temperatures, the RAFT model should be very accurate.

This leaves the uncertainty with the Reclamation model scenarios. These analyses only use the discharge temperature and flow at Keswick predicted by the SRWQM, but to get those values correct for the entire season for all of the scenarios, Reclamation needs to get all of the environmental input variables accurate: the reservoir inflows, weather, operations (gate changes, *etc.*), reservoir dynamics, over a 6-month period. Historically, Reclamation has overestimated their ability to meet the temperature compliance points (Figure 6). Over the past 10 years, the, 56°F DAT at a temperature compliance point specified at the beginning of the season was exceeded ~33% of the time (11% in May, 20% in June, 29% in July, 41% in Aug, 54% in Sept, and 44% in Oct). The compliance points can change over the course of a season which does minimize the frequency and magnitude of exceeding the 56°F DAT, but the bottom line is that Reclamation exceeds the 56°F DAT at any temperature compliance point a significant amount of the time, and often by a significant temperature differential (Figure 7). The higher that differential, the higher the likelihood of egg mortality, especially when temperatures exceed the T_{crit} values.

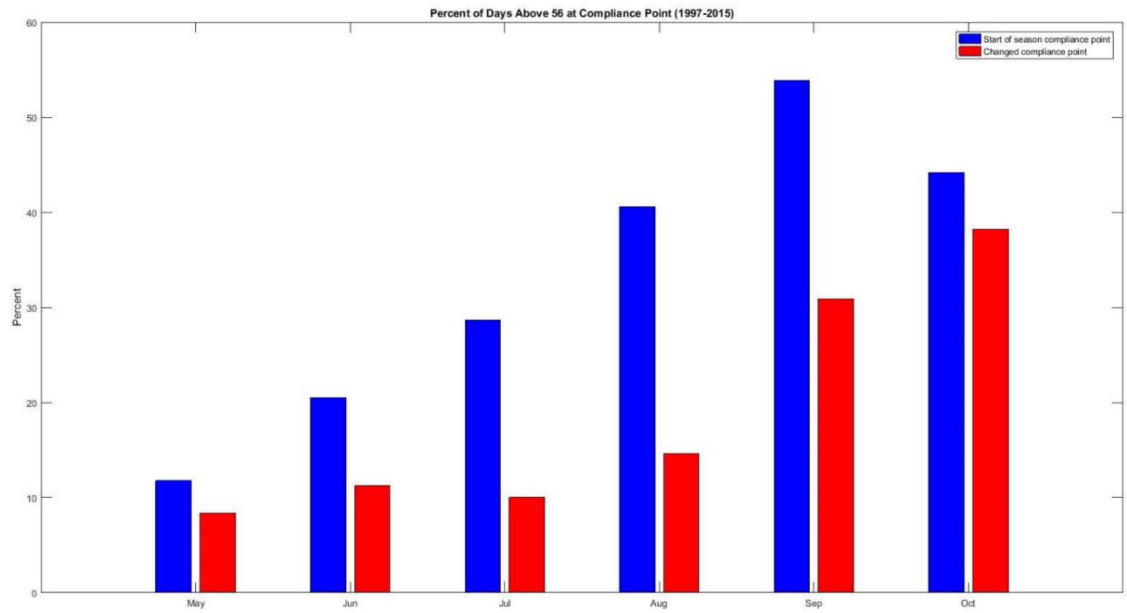


Figure 6. Percent of Days Above 56ºF DAT at Compliance Point (1997-2015). Blue bars indicate start of the season compliance location. Red bars indicate a changed temperature compliance location.

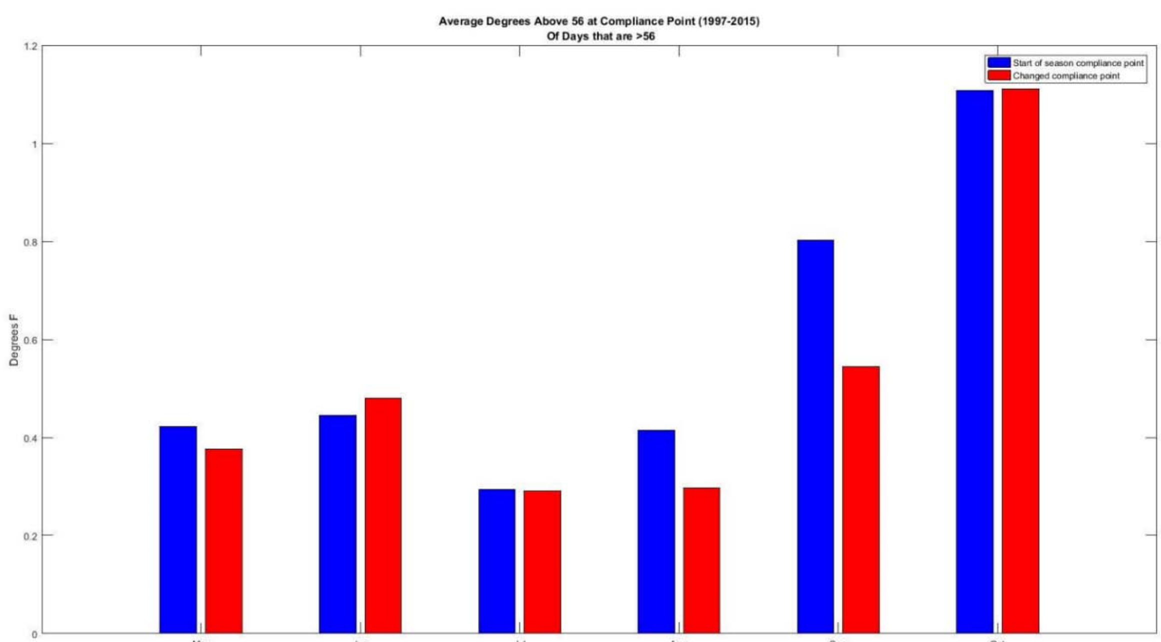


Figure 7. Average Degrees Above 56ºF DAT at Compliance Point (1997-2015).

Based on RAFT runs using a constant flow and temperature at Keswick, under average meteorological conditions, the NMFS-SWFSC generated contour plots of the 55°F 7DADM at CCR in relation to the flow and temperature at Keswick for each month (*i.e.*, the release temperatures at Keswick that would be needed to meet 7DADM at CCR for each month) (Figure 8). In general, there is a small difference in general between 5,000 and 7,500 cfs, but above that, small increases in flow (*e.g.*, 500 cfs) do not make much of a difference in the Keswick release temperature.

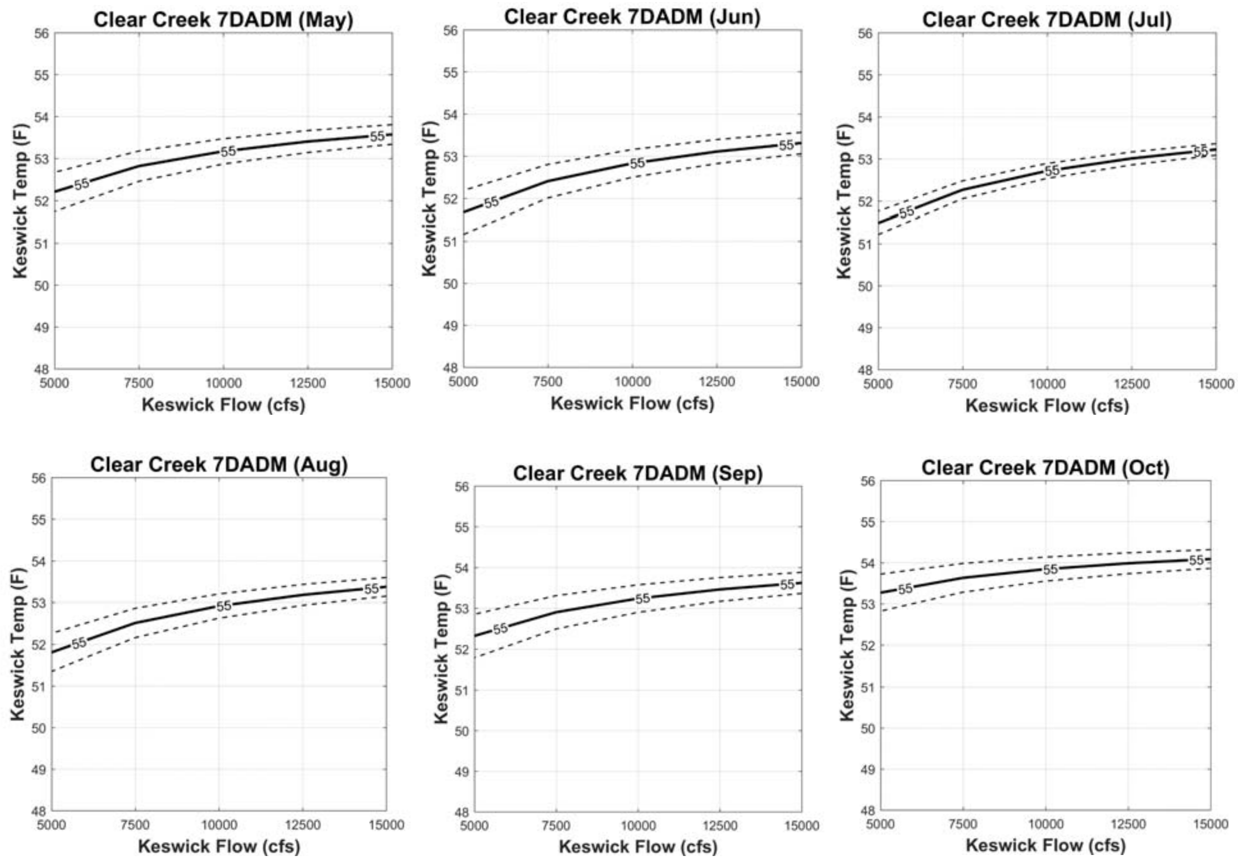


Figure 8. 55°F 7DADM at Clear Creek (CCR) in relation to the flow and temperature at Keswick by month. Dotted lines are 95% contour intervals.

The NMFS-SWFSC also ran an analysis relating 55^{o}F 7DADM at CCR to a 56^{o}F DAT downstream, divided up by month, based on historical data (Figure 9). Each point represents a day from 1997-2015. A curve was plotted through these points that calculated where the 56^{o}F DAT would be the same as the 55 ^{o}F 7DADM at CCR. Within an individual month there is lots of scatter and this is mainly related to meteorology. However, between months, the location of 56^{o}F DAT equal to 55^{o}F 7DADM at CCR moves downstream as the summer progresses. It ranges from 28 miles below Keswick in June to almost 38 miles in September.

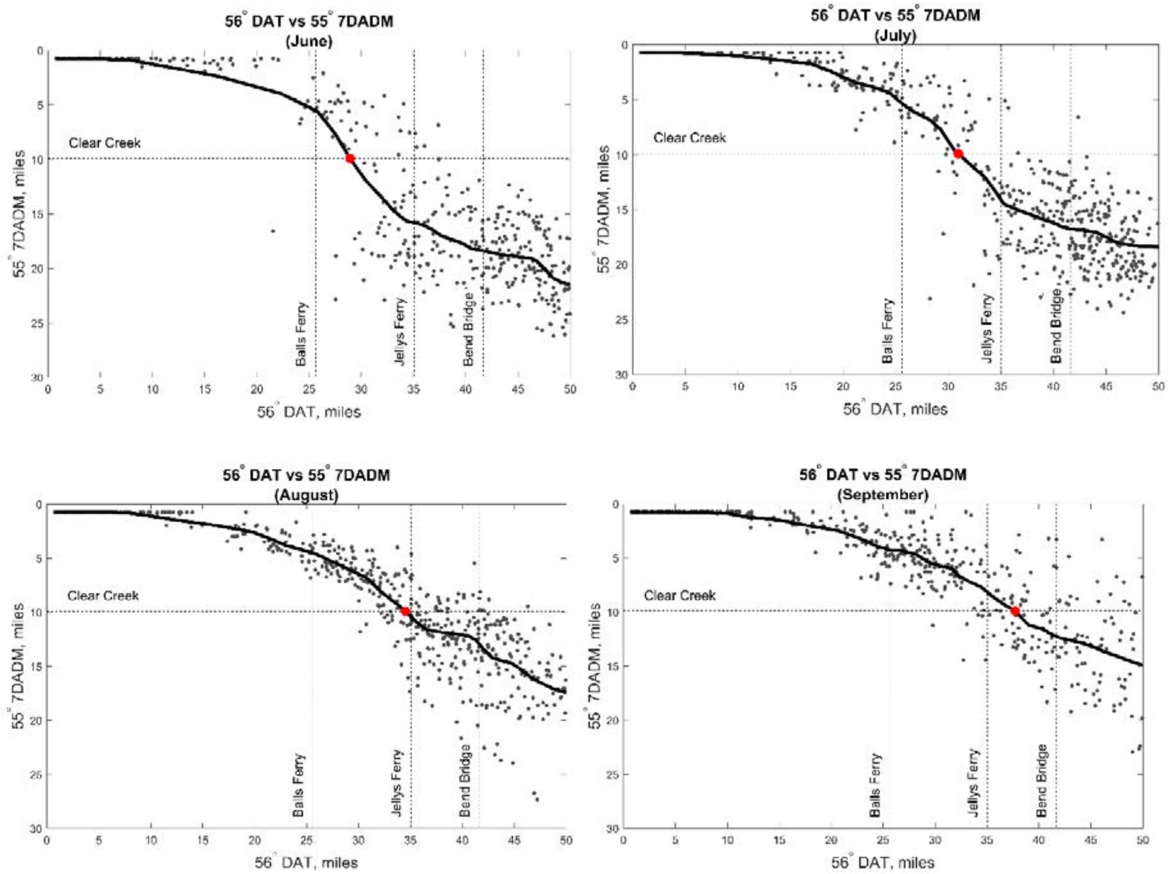


Figure 9. 55^{o}F 7DADM at Clear Creek (CCR) in relation to a 56^{o}F DAT downstream by month

In addition they ran an inverse of the above analysis, relating 56ºF DAT at Balls Ferry (BSF) to 7DADM downstream using data from 1997-2015 (Figure 10). The figure shows the 7 DADM for those days, at all locations. The mean is shown with the blue line, +/- 2 standard deviations is shaded grey, and the mean at CCR is shown with the red dot. Figure 11 shows just the 7 DADM at CCR on days when the DAT is 56ºF at BSF. It is plotted as a histogram to see the distribution of the data.

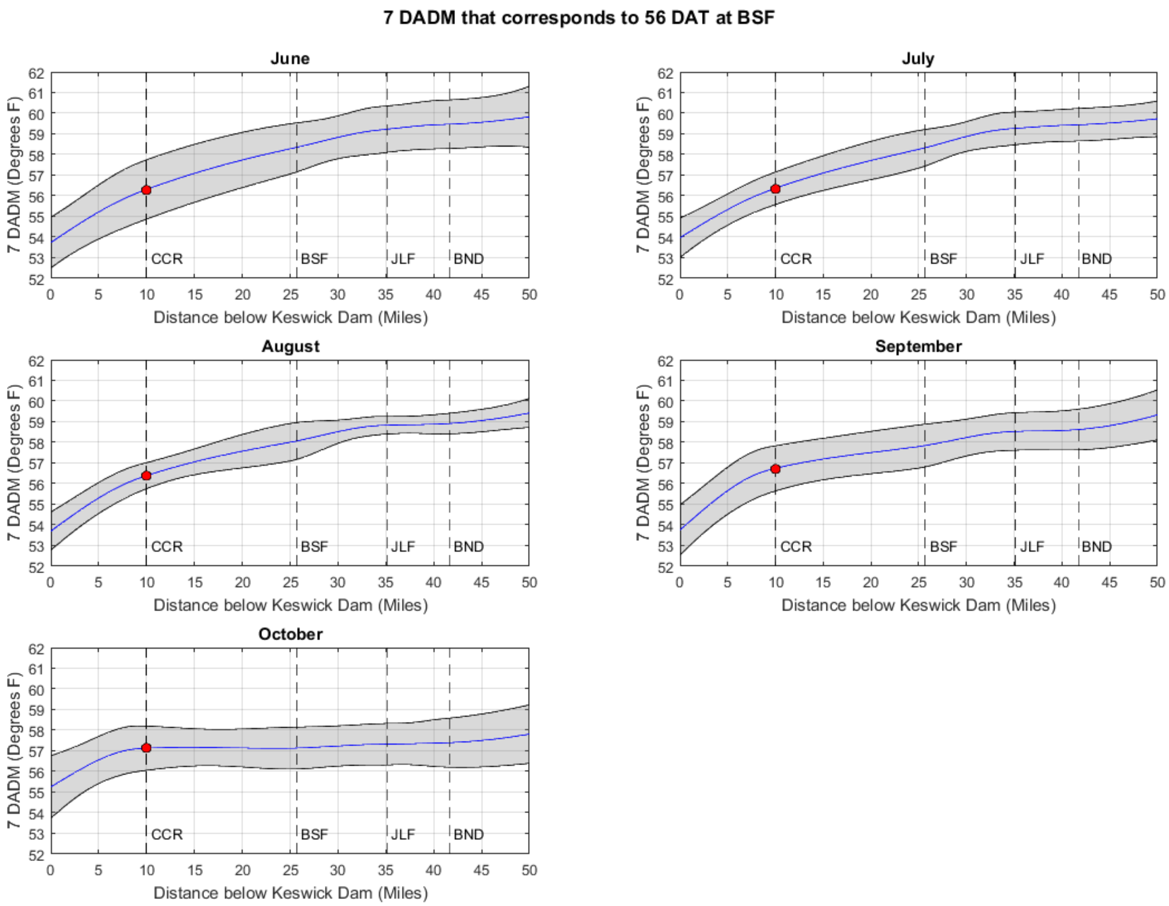


Figure 10. 56ºF DAT at Balls Ferry in relation to a 7DADM downstream by month.

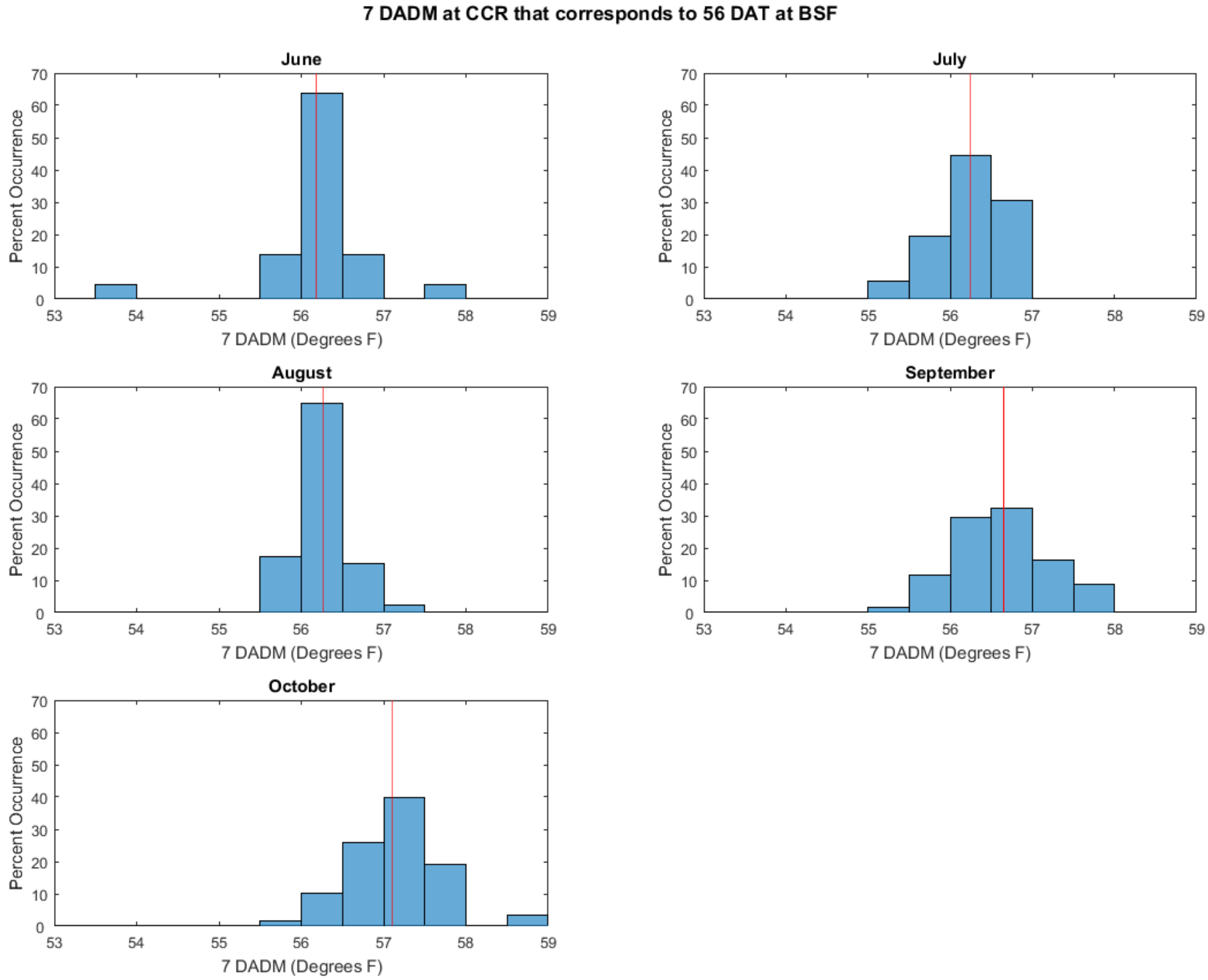


Figure 11. Monthly distribution of 7DADM at CCR that corresposnds to a 56ºF DAT at Balls Ferry. The mean is shown with the red line.

May 3, 2016 –Sacramento River Temperature Task Group meeting: April Forecast
Based on the lastest Shasta Reservoir temperature profile, Reclamation shared that there was 167 thousand acre-feet (TAF) less cold water (<48ºF) at the beginning of May than there was according to the March forecast (Figure 12). Due to the decrease in cold water pool, Reclamation determined that targeting 52ºF DAT out of Keswick reservoir was not achievable throughout the Sacramento River winter-run Chinook salmon spawning and egg incubation temperature mangaement season (*i.e*., approximately May 8 – October 15). Using the same Keswick flow releases proposed in March, Reclamation instead ran the April Sacramento River temperature model for the 90% and 50% exceedance hydrology (based on April 1, 2016, hydrologic conditions and forecasted river inflow) targeting a Keswick release DAT of 52.5ºF (Figures 13 and 14).

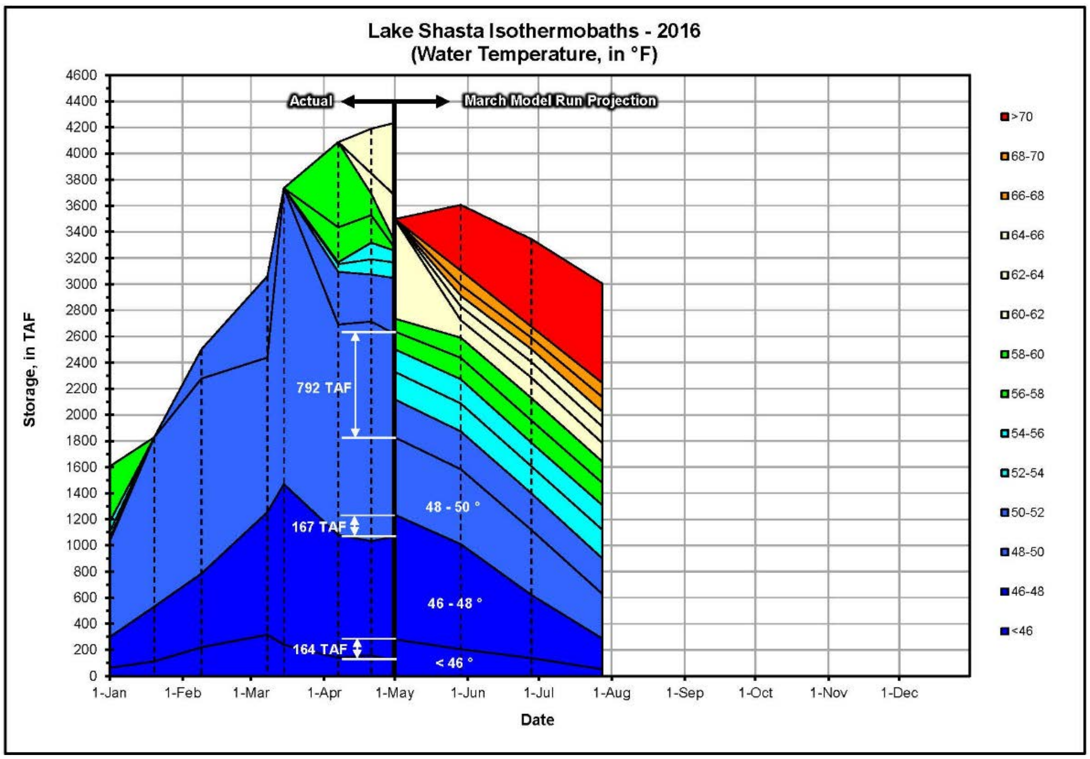


Figure 12. May 1, 2016 Shasta Reservoir Isothermobath

This was not the Kewsick release temperature that NMFS had concurred on in their March 31, 2016, forecast response letter. Furthermore, the Martin *et al*. (2016) temperature-dependent mortality model predicted more than double the annual mean temperature-dependent mortality under the April 90% and 50% hydrological exceedance forecast (5.0% and 5.5% respectively) compared to the March forecast (2.2% and 2.7% respectively).

Table 3. April 2016 Forecast Percent Temperature-Dependent Mortality

Percent Temperature-dependent Mortality			
	Mean	Median	2.5 - 97.5 Percentiles
April 2016 90% Forecast	5.02	0.193	0.077 - 43.33
April 2016 50% Forecast	5.50	0.172	0.078 - 44.86

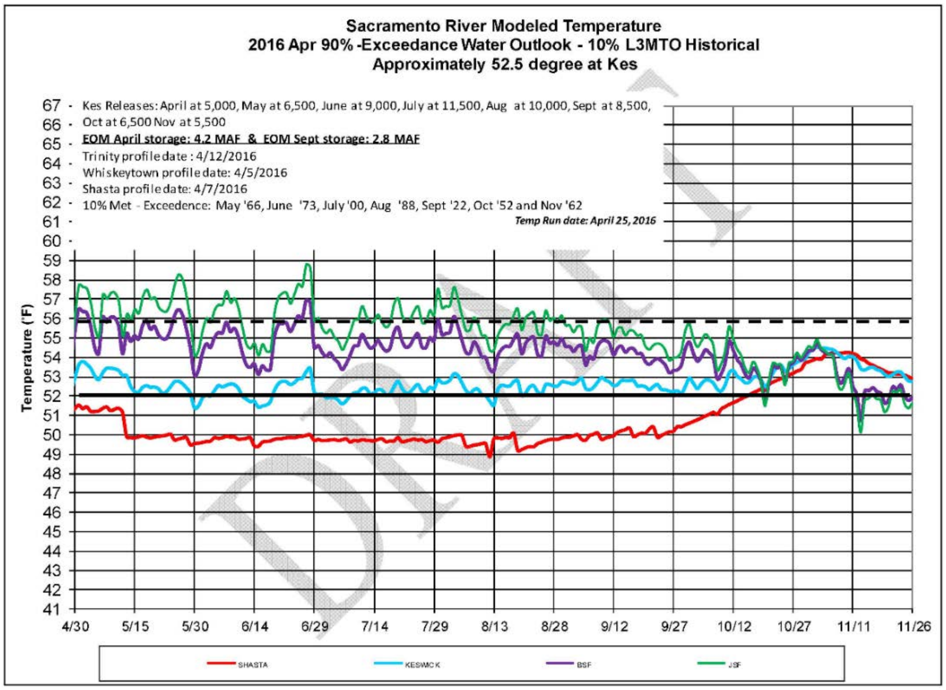


Figure 13. SRWQM results using the 2016 April 90% exceedance outlook, historical 10% local 3-month temperature outlook meteorology, Reclamation's proposed Keswick Dam monthly average releases for May through November, and targeting approximately 52.5°F DAT at KWK.

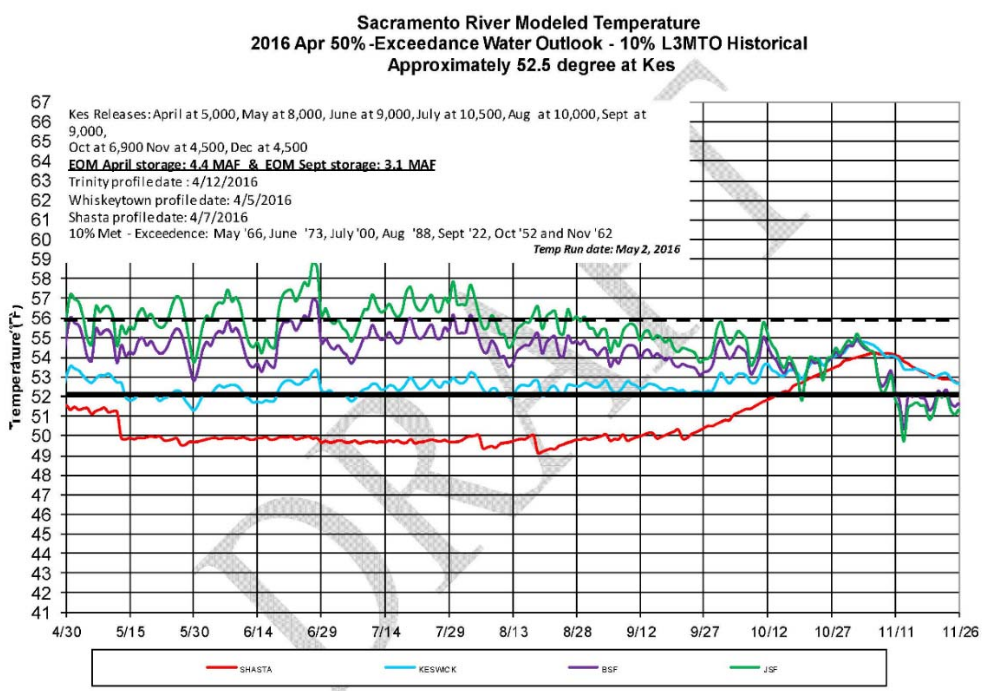


Figure 14. SRWQM results using the 2016 April 50% exceedance outlook, historical 10% local 3-month temperature outlook meteorology, Reclamation's proposed Keswick Dam monthly average releases for May through November, and targeting approximately 52.5°F DAT at KWK.

May 9, 2016

At the request of the fish agencies through the Shasta Water Interagency Managers Team (SWIM team), Reclamation re-ran a number of river temperature plots with the latest Shasta temperature profile using different flow scenarios in order to target an average initial Keswick release temperature at 52°F (Table 4):

- Run 1 – The monthly releases outlined in the March exchange with NMFS. Runs 1a and 1b assume lower summer releases (9000 cfs and 8500 cfs, respectively) to try and lower fall temperatures.

Reclamation also looked at two runs to explore the sensitivity of May releases under these conditions:

- Run 2 – Modifies May to 7,000 cfs, but includes lower summer releases to improve fall temperatures
- Run 3 – Modifies May to 7,000 cfs, but includes still lower monthly flows to improve fall temperatures

Table 4. Summary of May 9, 2016 SRWQM scenario results based on the May 3, 2016 Shasta Reservoir temperature profile

May 3rd profile								
Keswick May 6500 -- March flows								
Run 1								
	May	June	July	Aug	Sep	Oct	Nov	Side Gates
Keswick	6500	9000	10500	10000	9000	6500	6500	8-Sep
temp	52.4	52.3	52.1	52.2	52.6	54.2		
May 3rd profile								
Keswick May 6500 -- Keswick 9000								
Run 1a								
	May	June	July	Aug	Sep	Oct	Nov	Side Gates
Keswick	6500	9000	9000	9000	8500	6500	5500	14-Sep
temp	52.3	52.2	52.1	52.3	52.5	53.3		
May 3rd profile								
Run 1b								
3Kes May 6500 June to Aug 8500								
	May	June	July	Aug	Sep	Oct	Nov	Side Gates
Keswick	6500	8500	8500	8500	8500	6500	5500	16-Sep
temp	52.3	52.3	52.3	52.5	52.4	52.8		
May 3rd profile								
Keswick May 7000								
Run 2								
	May	June	July	Aug	Sep	Oct	Nov	Side Gates
Keswick	7000	8500	10000	9500	8500	6500	5500	6-Sep
	52.4	52.0	52.0	52.1	52.9	53.8		
May 3rd profile								
Keswick May 7000 (b)								
Run 3								
	May	June	July	Aug	Sep	Oct	Nov	Side Gates
Keswick	7000	8500	9500	9500	8500	6500	5500	9-Sep
	52.4	52.0	52.1	52.1	52.8	53.6		

All of the runs showed Jellys Ferry at 56ºF DAT or less in the fall, but drifted above the 52ºF DAT at Keswick in September (Figures 15-18). This is the product of the mixing of the coldest water (< 48ºF water) in both the late March and early April temperature profiles. Although the volume of water at or below 50ºF in Shasta Reservoir was 2.8 to 3.0 million acre-feet (MAF), these runs need that coldest water to carry the 52ºF DAT Keswick release through September.

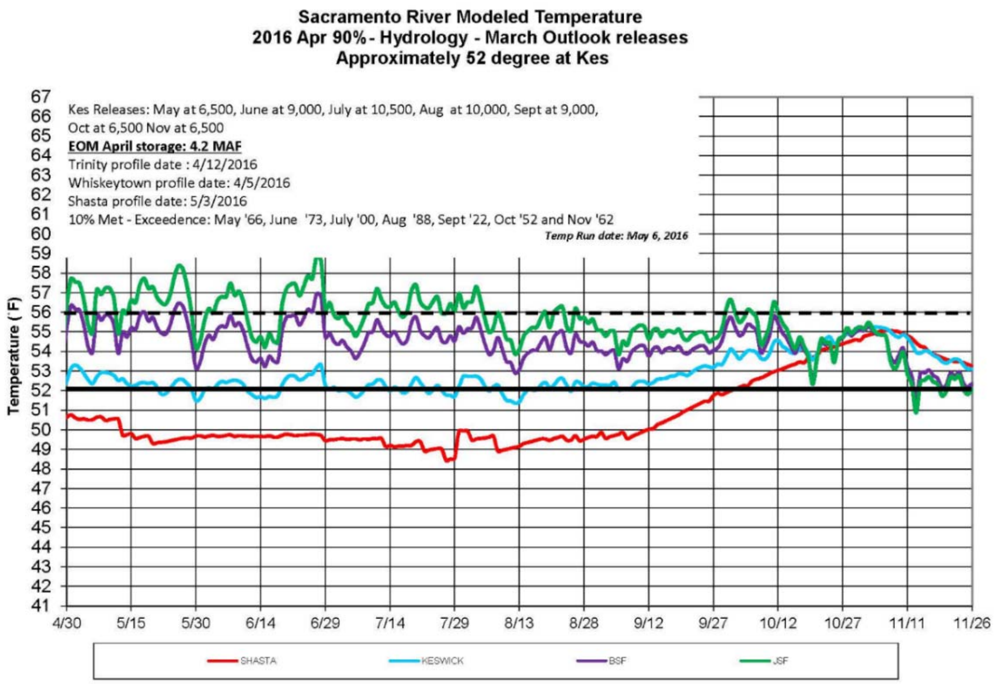


Figure 15. Run 1, May 9, 2016

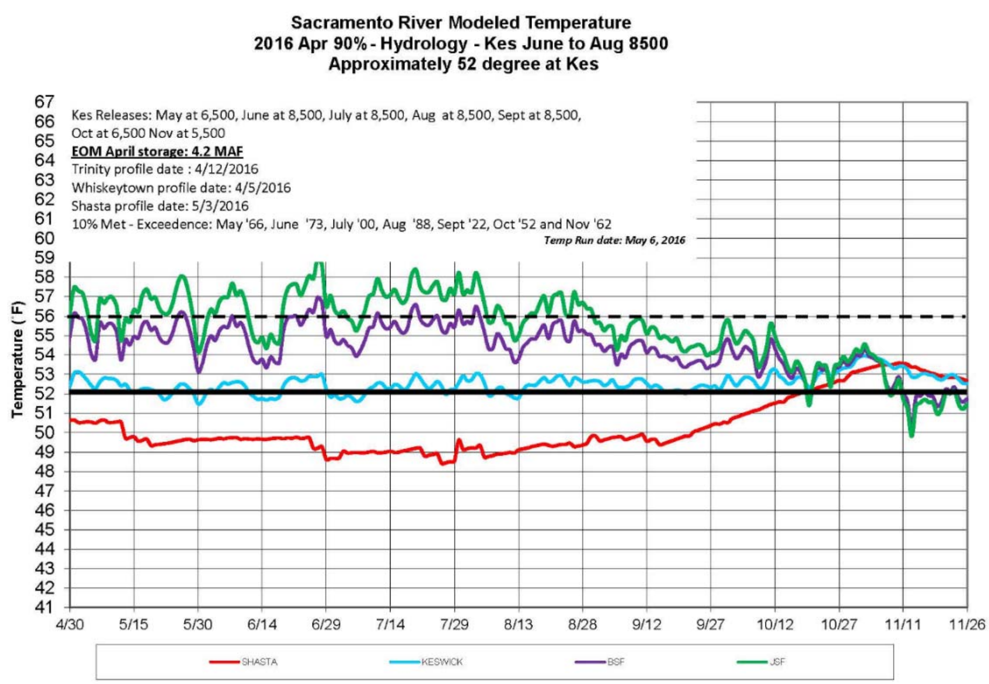


Figure 16. Run 1b, May 9, 2016

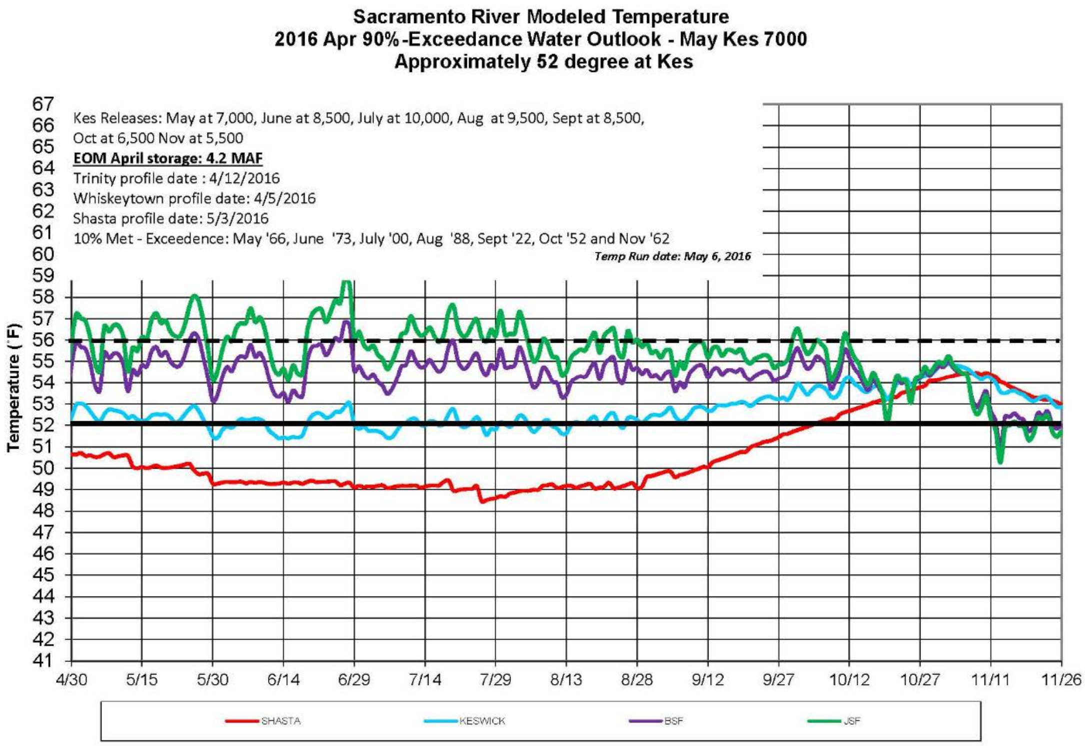


Figure 17. Run 2, May 9, 2016

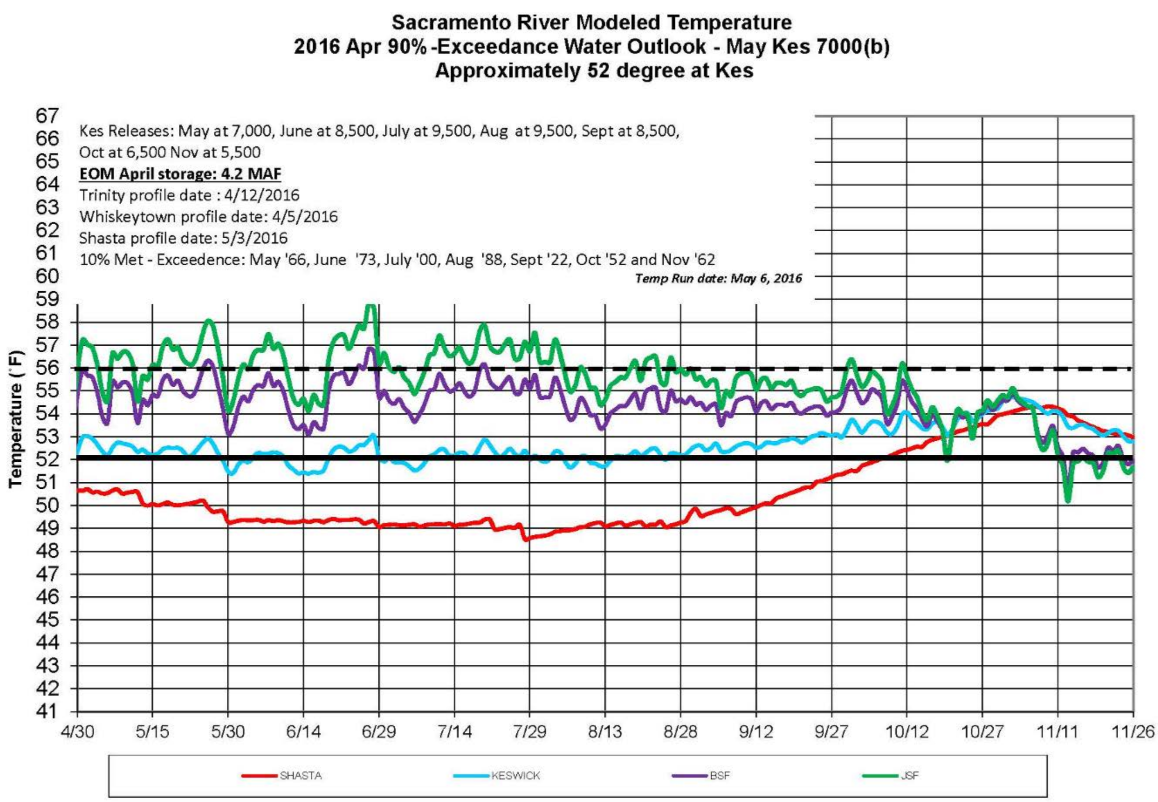


Figure 18. Run 3, May 9, 2016

Figure 19 shows the temperature-dependent survival histogram and annual temperature-dependent mortality model results from each of the scenarios, with scenario 1b (*i.e.*, Keswick release flows for June through September of 8,500 cfs) having the least amount of mortality with a mean 5.2% (Table 5). Run 1b also pushed out the full side gate operations to the latest date of September 16.

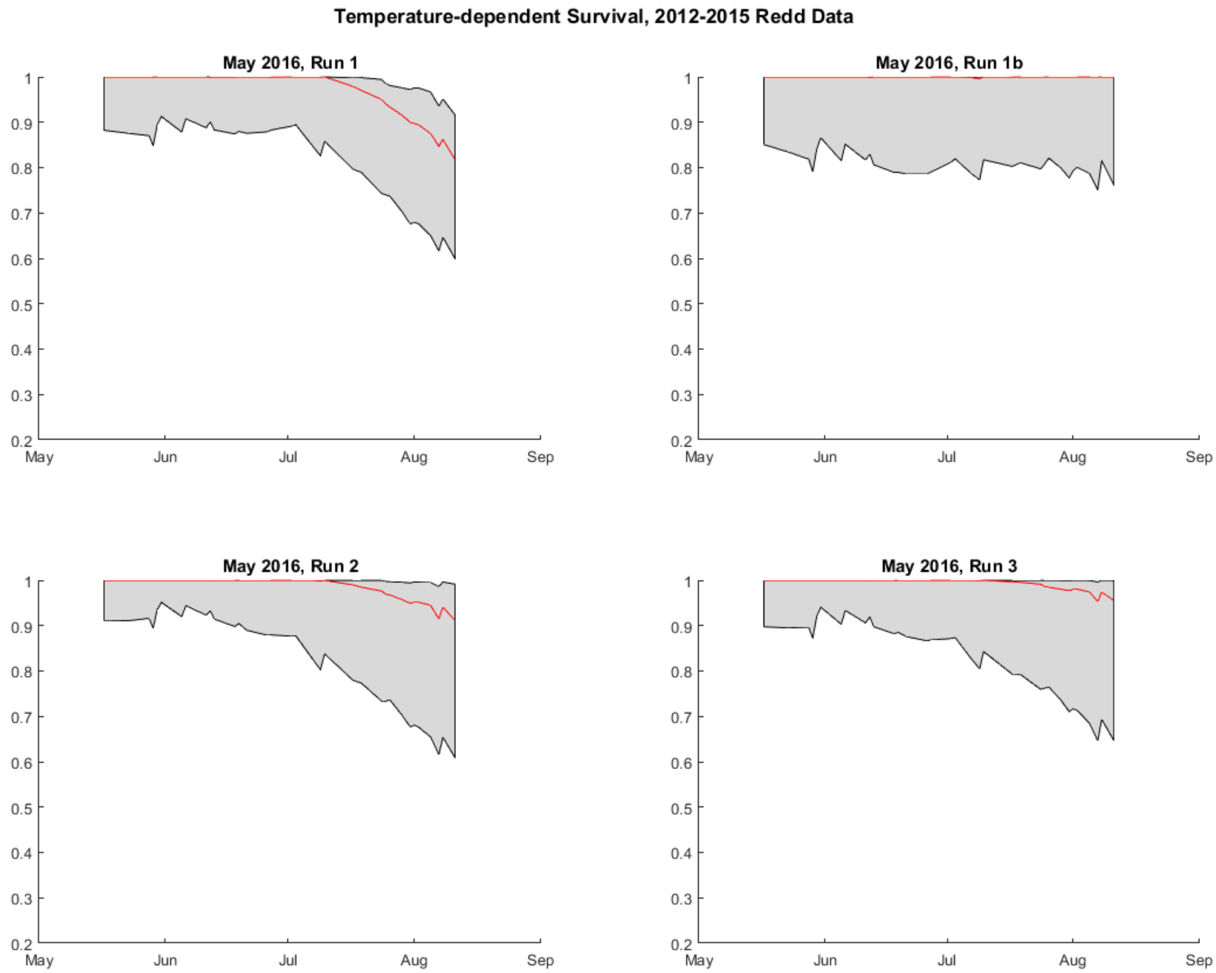


Figure 19. May 9, 2016 scenarios temperature-dependent survival:
Run 1 Keswick releases: May at 6,500 cfs, June at 9,000 cfs, July at 10,500 cfs, August at 10,000 cfs, September at 9,000 cfs, October at 6,500 cfs, and November at 6,500 cfs;
Run 1b Keswick releases: May at 6,500 cfs, June at 8,500 cfs, July at 8,500 cfs, August at 8,500 cfs, September at 8,500 cfs, October at 6,500 cfs, and November at 5,500 cfs;
Run 2 Keswick releases: May at 7,000 cfs, June at 8,500 cfs, July at 9,500 cfs, August at 9,500 cfs, September at 8,500 cfs, October at 6,500 cfs, and November at 5,500 cfs; and
Run 3 Keswick releases: May at 6,500 cfs, June at 8,500 cfs, July at 8,500 cfs, August at 8,500 cfs, September at 8,500 cfs, October at 6,500 cfs, and November at 5,500 cfs

Table 5. May 9, 2016 scenarios temperature-dependent mortality

Percent Temperature-dependent Mortality			
	Mean	Median	2.5 - 97.5 Percentiles
May 2016, Run 1	7.96	4.34	0.085 - 43.36
May 2016, Run 1b	5.18	0.13	0.079 - 44.90
May 2016, Run 2	7.04	2.55	0.075 - 43.48
May 2016, Run 3	6.01	1.38	0.075 - 43.55

May 12, 2016

Reclamation ran some more scenarios of 7500, 8000, 8500, and 9000 cfs July through September Keswick release schedule targeting 52ºF DAT at Keswick (*i.e*., lower target than the May 9, 2016 scenarios, Figures 20-23). The temperature-dependent mortality model showed that Keswick release flows of 8,000 cfs resulted in the least amount of mortality with a mean of 5.3% (Table 7). However, full side were accessed approximately a month earlier for these scenarios compared to the May 9, 2016, scenarios.

Table 6. Summary of May 12, 2016 Runs

Summary of May 12th Runs									
May 3 profile									
Keswick May 6500 -- Keswick 52 and 9000 J-S									
2Kes May 6500 June to Aug 9000									
	May	June	July	Aug	Sep	Oct	Nov	Side Gates	
Keswick	6500	9000	9000	9000	8500	6500	5500	14-Sep	
temp 52.3 to 52.4	52.3	52.2	52.1	52.3	52.5	53.3			
temp (52.0 degree	51.91	51.96	51.94	52.05	53.08	53.77		16-Aug	
May 3 profile									Sept Shasta storage
Keswick May 6500 -- Keswick 52 degree and 8500 J-S									3.1 MAF
may3profile_Kes52n8500									
	May	June	July	Aug	Sep	Oct	Nov	Full Side Gates	
Keswick	6500	8500	8500	8500	8500	6500	5500	14-Aug	
temp	52.06	52.07	52.05	52.04	52.83	53.40			
May 3 profile									Sept Shasta storage
Keswick May 6500 -- Keswick 52 degree and 8000 J-S									3.2 MAF
may3profile_Kes52n8000									
	May	June	July	Aug	Sep	Oct	Nov	Full Side Gates	
Keswick	6500	8000	8000	8000	8000	6500	5500	8-Aug	
temp (no change)	52.06	52.2	52.26	52.11	52.64	52.92			
temp	52.06	52.08	52.07	52.12	52.81	53.00			
	****Wilkins had to be cut by 600 cfs in July*								
May 3 profile									Sept Shasta storage
Keswick May 6500 -- Keswick 52 degree and 7500 J-S									3.3 MAF
may3profile_Kes52n8000									
	May	June	July	Aug	Sep	Oct	Nov	Full Side Gates	
Keswick	6500	7500	7500	7500	7500	6500	5500	31-Jul	
temp (no change)	52.06	52.38	52.46	52.24	52.51	52.51			
temp	52.06	52.09	52.04	52.39	52.82	52.67			
	****Wilkins had to be cut by 1200 cfs in July*								

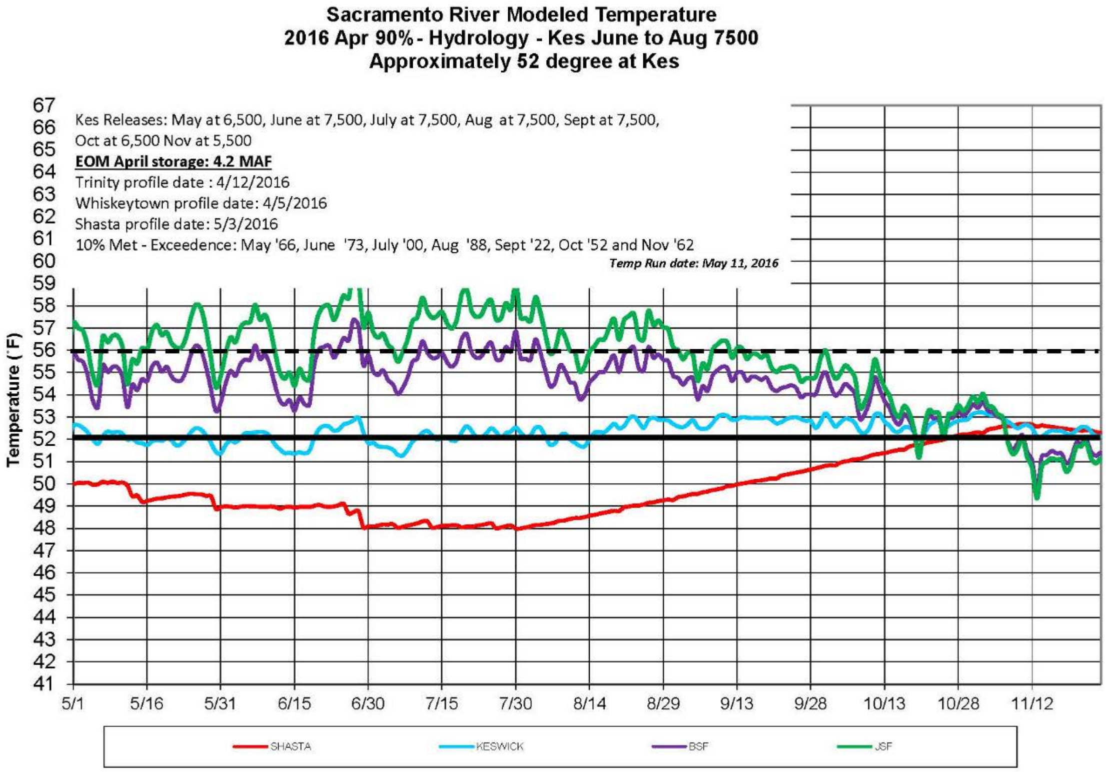


Figure 20. May 12, 2016, Keswick release scenario 7,500 cfs

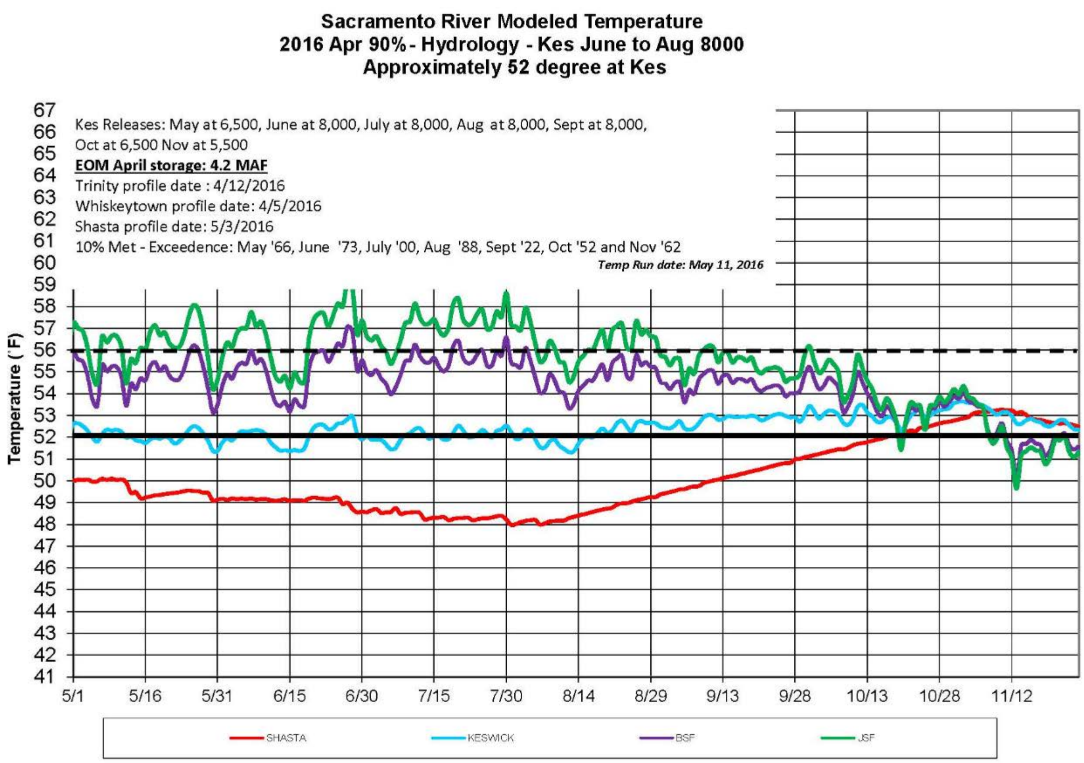


Figure 21. May 12, 2016, Keswick release scenario 8,000 cfs

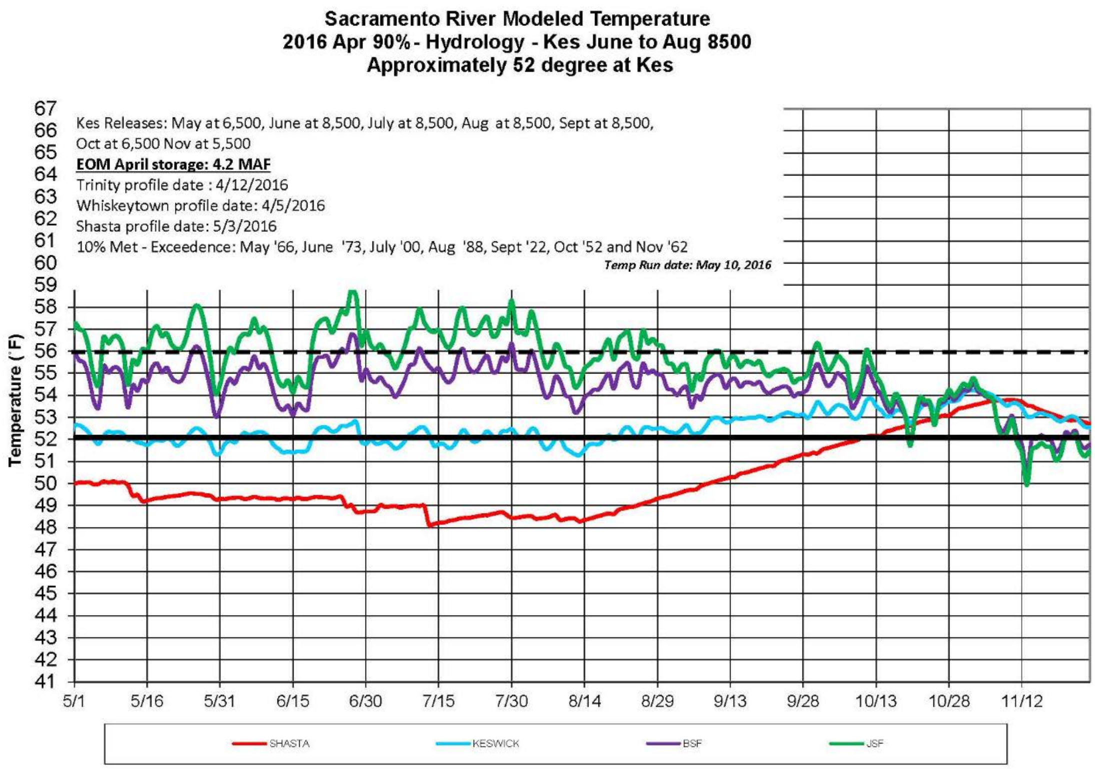


Figure 22. May 12, 2016, Keswick release scenario 8,500 cfs

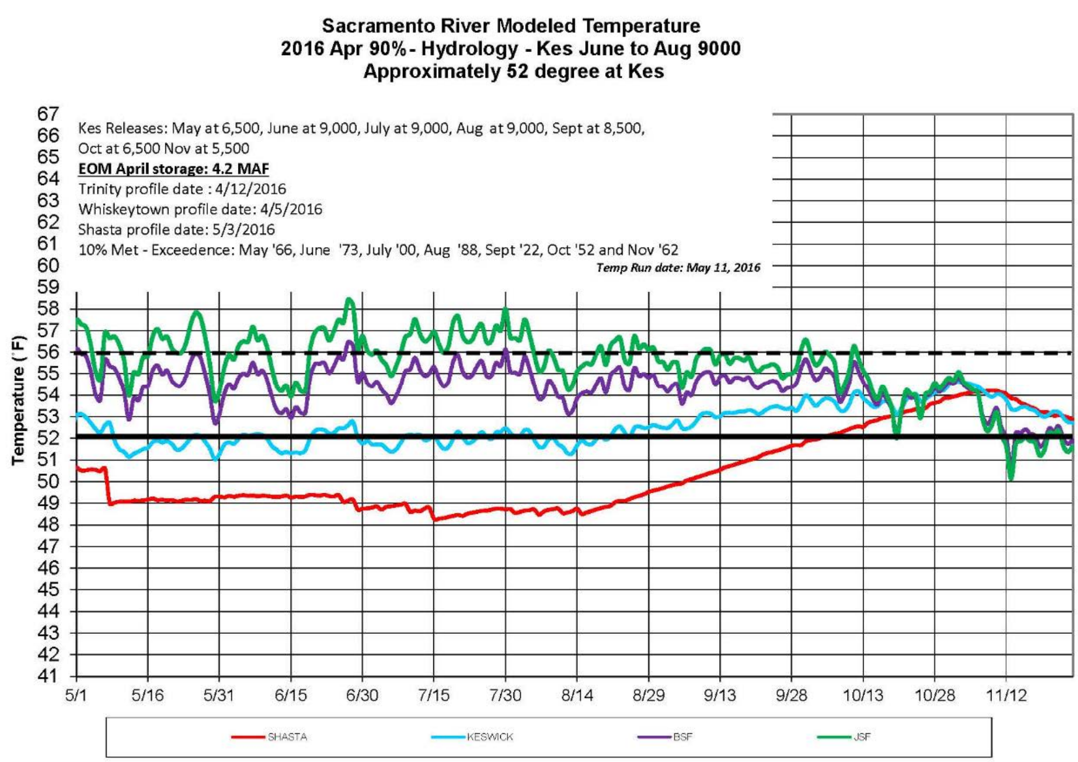


Figure 23. May 12, 2016, Keswick release scenario 9,000 cfs

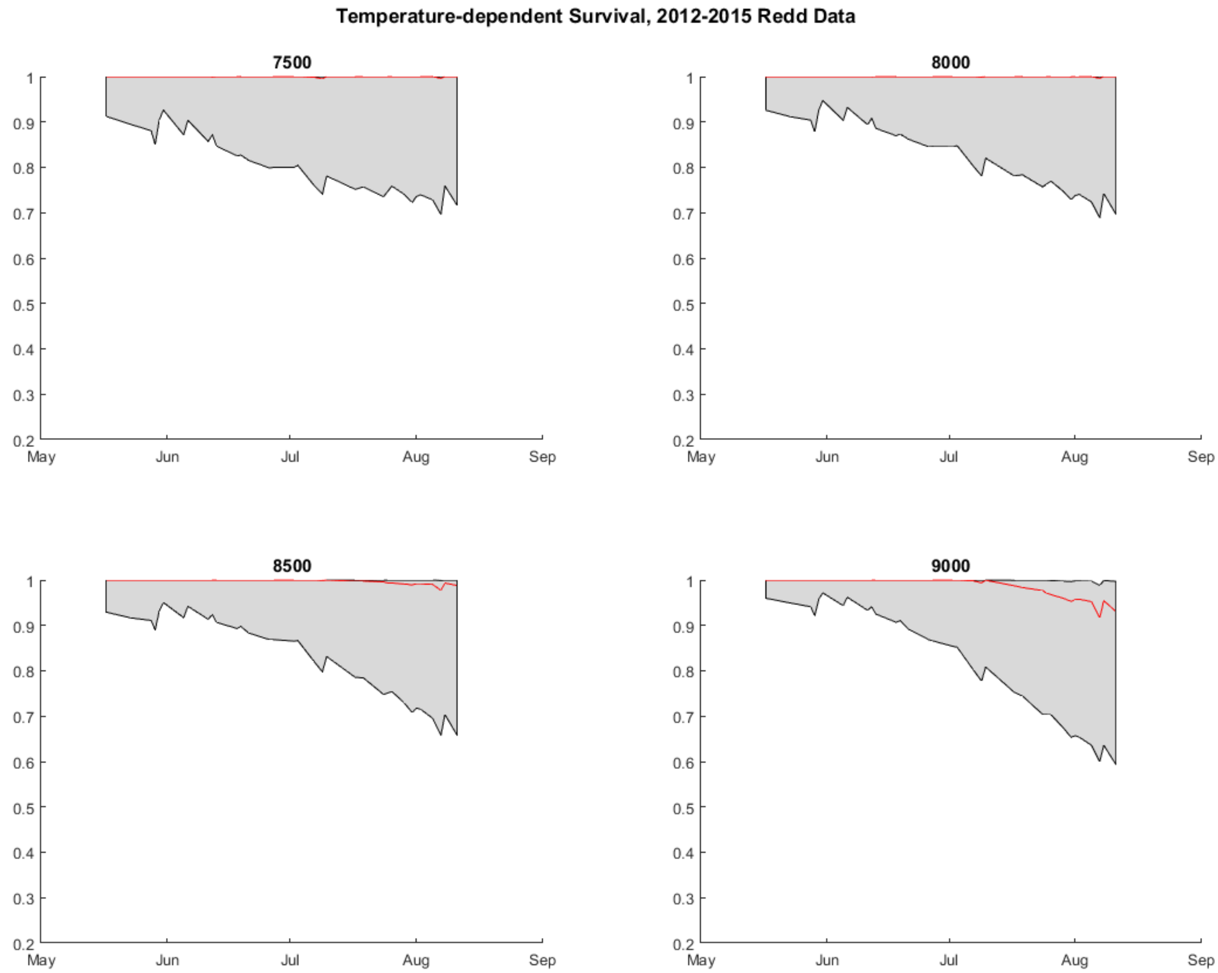


Figure 24. May 12, 2016 scenarios temperature-dependent survival forecast histogram.

Table 7. May 12, 2016 scenarios temperature-dependent mortality

Percent Temperature-dependent Mortality			
Run	Mean	Median	2.5 - 97.5 Percentiles
7500	5.74	0.15	0.079 - 45.89
8000	5.29	0.16	0.077 - 43.12
8500	5.76	0.77	0.062 - 42.45
9000	7.61	2.60	0.028 - 43.62

May 17, 2016

Reclamation ran scenarios for 7,500 through 10,000 cfs Keswick release flows at 500 cfs increments. Comparing and contrasting the monthly average Keswick temperatures from the summary table (Table 8), and the blue Keswick temperature lines on each of the scenario runs (Figures 25 – 30), the 7,500 through 9,000 cfs scenarios are all relatively similar. However, the temperature-dependent mortality model results showed the 8,000 cfs scenario with the least amount of mortality, with a mean of 4.6% (Table 9). The fish agencies decided the 8,000 cfs scenario is the preferred scenario based on the low temperature-dependent mortality, later side gate operations, and less likely to dewater redds.

Table 8. Summary of May 17, 2016 scenario runs

May 3 profile
Keswick May 6500 -- Keswick Max degree and 7500 J-S
may3profile_Kes_MAXn7500

Folsom Release patterns are identical for all scenarios

	May	June	July	Aug	Sep	Oct	Nov
Keswick	6500	7500	7500	7500	7500	6500	5500
Monthly Ave Temp	52.42	52.4	52.38	52.4	52.38	52.41	

Full Side Gates	Sept Shasta Storage	June-Aug CVP Export	CVP Export Reduction (June - Aug)	Folsom EOM Sept Storage	American River Temperature Target (oF)	Egg to Emergence temp dependent mortality above Clear Creek (Zeug et al 2012)
29-Aug	3.3 MAF	222 TAF	288 TAF	374		4.5%

***Wilkins had to be cut by 1200 cfs in July

May 3 profile
Keswick May 6500 -- Keswick Max degree and 8000 J-S
may3profile_Kes_MAXn8000

	May	June	July	Aug	Sep	Oct	Nov
Keswick	6500	8000	8000	8000	8000	6500	5500
Monthly Ave Temp	52.31	52.31	52.35	52.34	52.35	52.7	

Full Side Gates	Sept Shasta Storage	June-Aug CVP Export	CVP Export Reduction (June - Aug)	Folsom EOM Sept Storage	American River Temperature Target (oF)	Egg to Emergence temp dependent mortality above Clear Creek (Zeug et al 2012)
8-Sep	3.2	314 TAF	196 TAF	344		4.6%

***Wilkins had to be cut by 600 cfs in July

May 3 profile
Keswick May 6500 -- Keswick MAX degree and 8500 J-S
may3profile_Kes_MAXn8500

	May	June	July	Aug	Sep	Oct	Nov
Keswick	6500	8500	8500	8500	8500	6500	5500
Monthly Ave Temp	52.35	52.32	52.38	52.37	52.4	52.84	

Full Side Gates	Sept Shasta Storage	June-Aug CVP Export	CVP Export Reduction (June - Aug)	Folsom EOM Sept Storage	American River Temperature Target (oF)	Egg to Emergence temp dependent mortality above Clear Creek (Zeug et al 2012)
19-Sep	3.1 MAF	373 TAF	137 TAF	345		4.8%

May 3 profile
Keswick May 6500 -- Keswick MAX degree and 9000 J-S
may3profile_Kes_MAXn9000

	May	June	July	Aug	Sep	Oct	Nov
Keswick	6500	9000	9000	9000	8500	6500	5500
Monthly Ave Temp	52.34	52.32	52.35	52.33	52.37	53.22	

Full Side Gates	Sept Shasta Storage	June-Aug CVP Export	CVP Export Reduction (June - Aug)	Folsom EOM Sept Storage	American River Temperature Target (oF)	Egg to Emergence temp dependent mortality above Clear Creek (Zeug et al 2012)
10-Sep	3.0 MAF	455 TAF	55 TAF	342	~68	5.0%

May 3 profile
Keswick May 6500 -- Keswick MAX degree and 9500 J-S
may3profile_Kes_MAXn9500

	May	June	July	Aug	Sep	Oct	Nov
Keswick	6500	9500	9500	9500	8500	6500	5500
Monthly Ave Temp	52.33	52.3	52.31	52.3	52.44	53.88	

Full Side Gates	Sept Shasta Storage	June-Aug CVP Export	CVP Export Reduction (June - Aug)	Folsom EOM Sept Storage	American River Temperature Target (oF)	Egg to Emergence temp dependent mortality above Clear Creek (Zeug et al 2012)
10-Sep	2.9 MAF	509 TAF	1 TAF	379	~68	5.5%

May 3 profile
Keswick May 6500 -- Keswick MAX degree and 10000 J-S
may3profile_Kes_MAXn10000

	May	June	July	Aug	Sep	Oct	Nov
Keswick	6500	8500	10000	10000	9250	8000	5500
Monthly Ave Temp	52.34	52.36	52.31	52.31	52.42	53.99	

Full Side Gates	Sept Shasta Storage	June-Aug CVP Export	CVP Export Reduction (June - Aug)	Folsom EOM Sept Storage	American River Temperature Target (oF)	Egg to Emergence temp dependent mortality above Clear Creek (Zeug et al 2012)
8-Sep	2.8 MAF	510 TAF	0	386	~68	5.7%

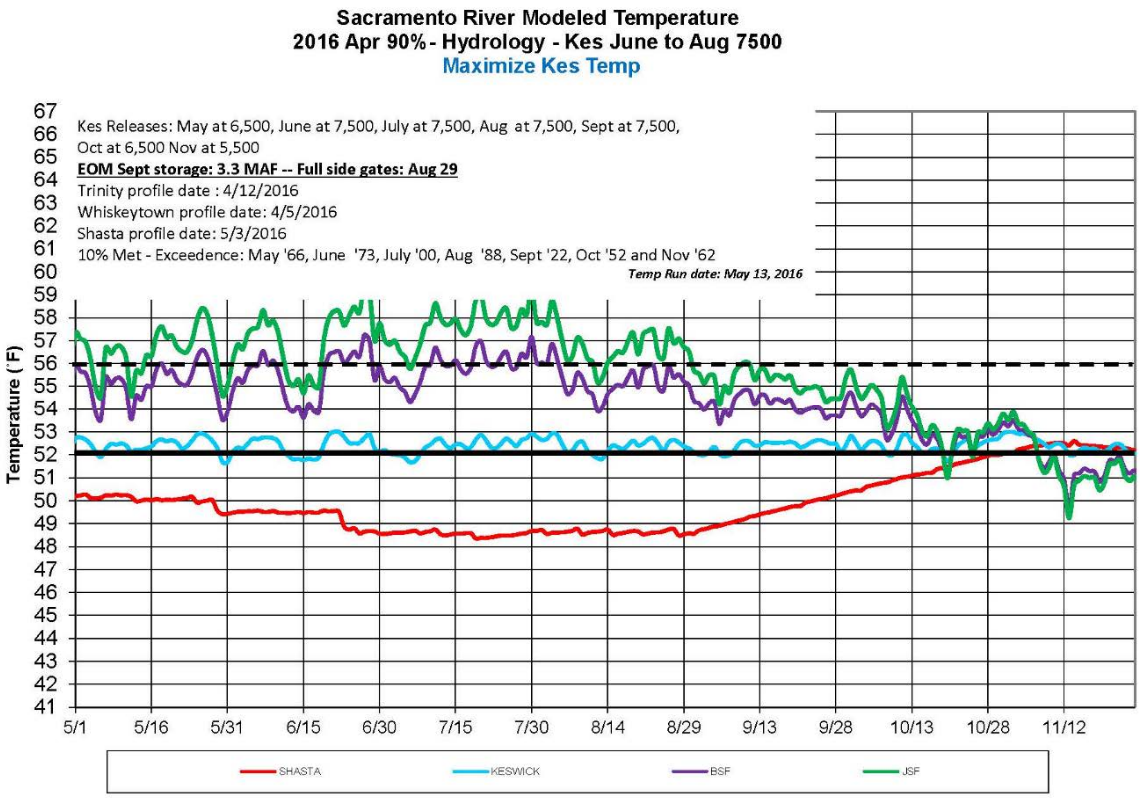


Figure 25. May 17, 2016, Keswick release scenario 7,500 cfs

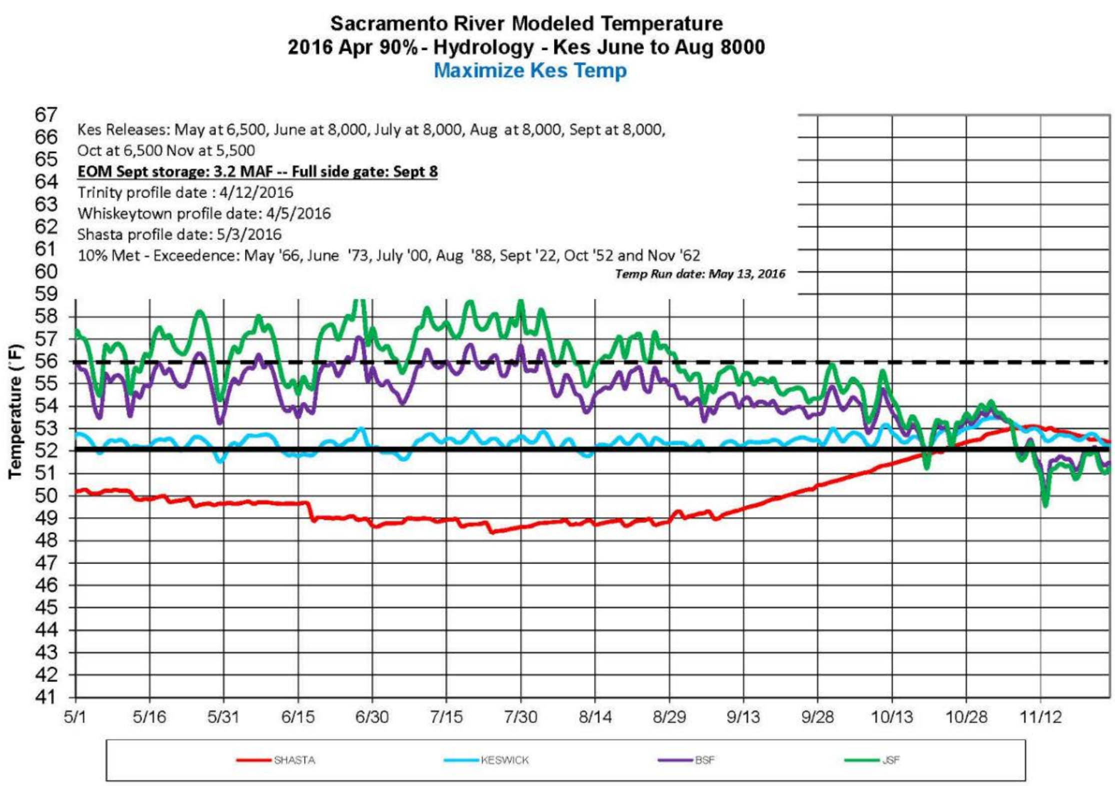


Figure 26. May 17, 2016, Keswick release scenario 8,000 cfs

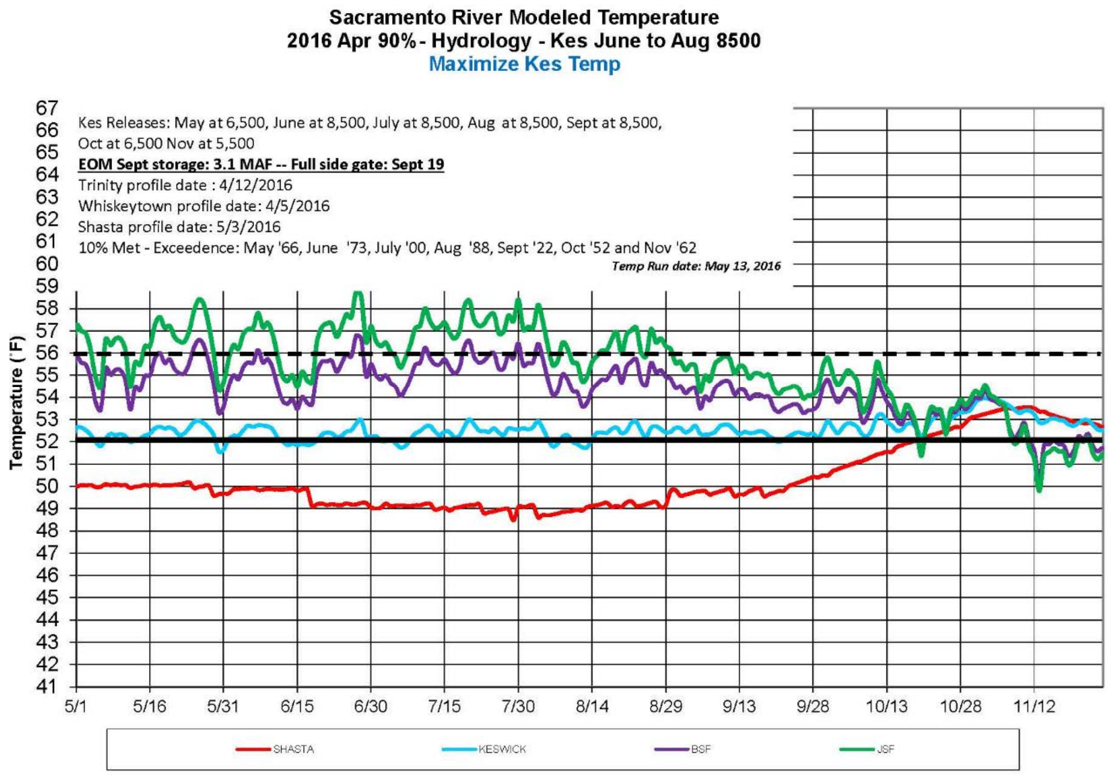


Figure 27. May 17, 2016, Keswick release scenario 8,500 cfs

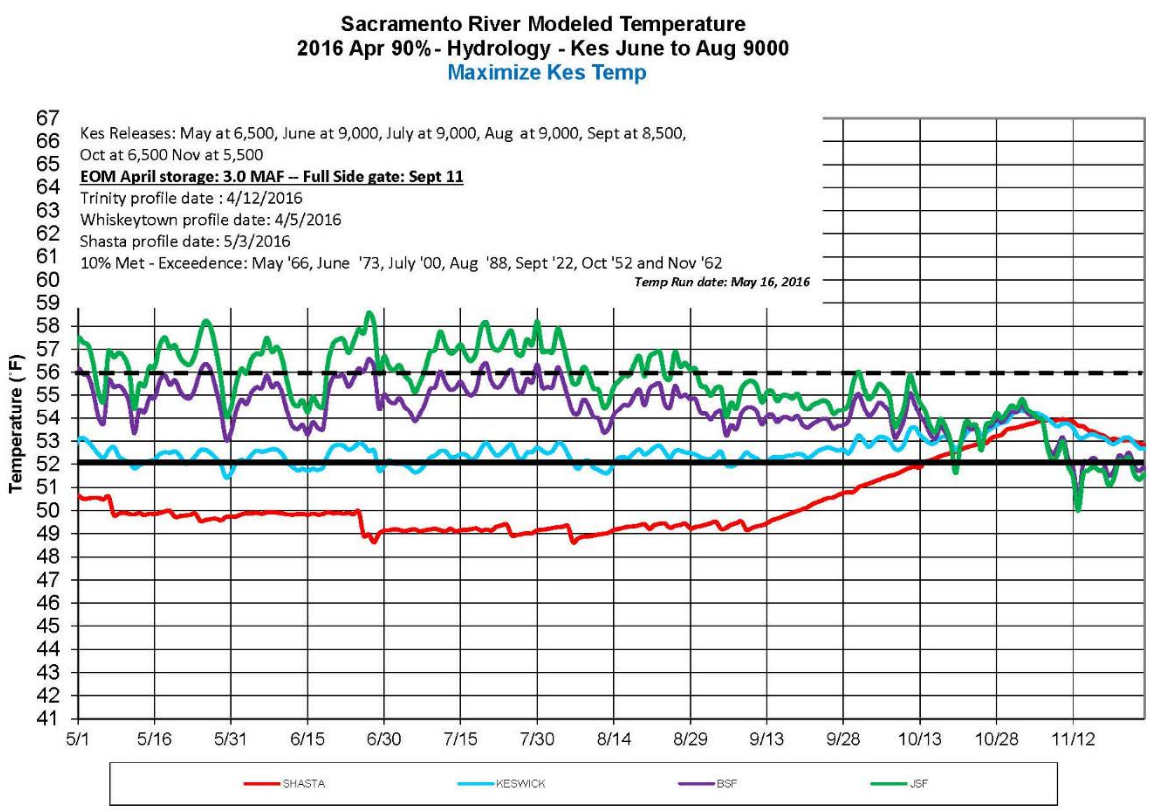


Figure 28. May 17, 2016, Keswick release scenario 9,000 cfs

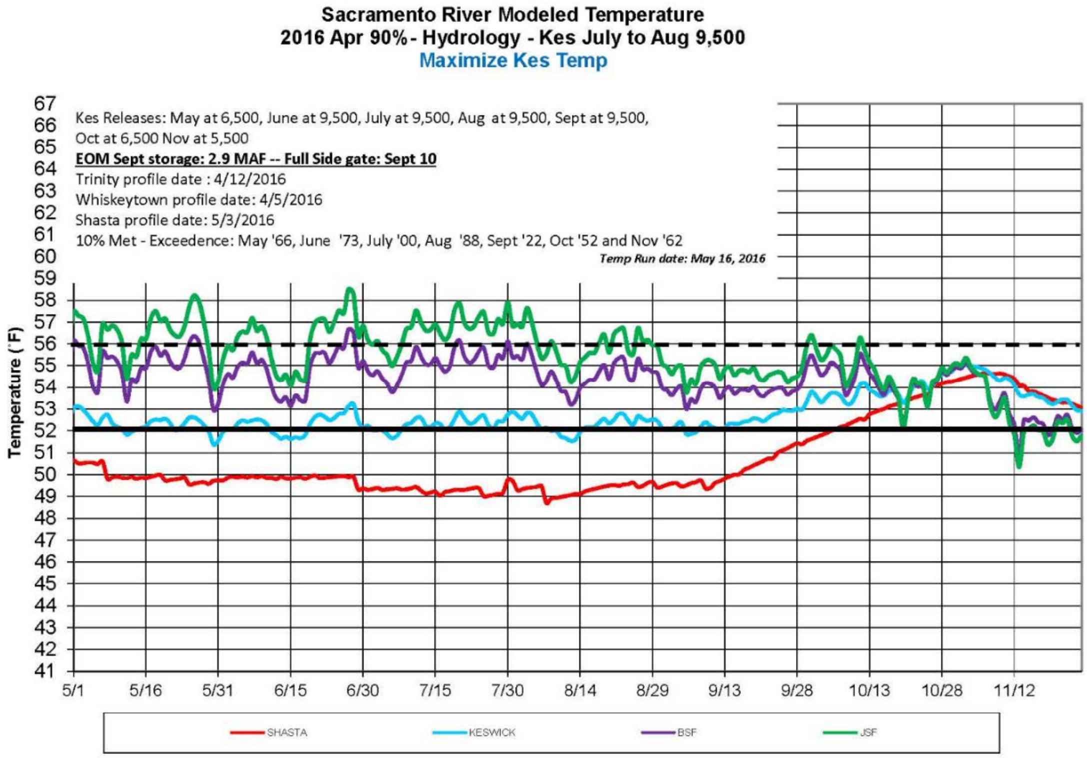


Figure 29. May 17, 2016, Keswick release scenario 9,500 cfs

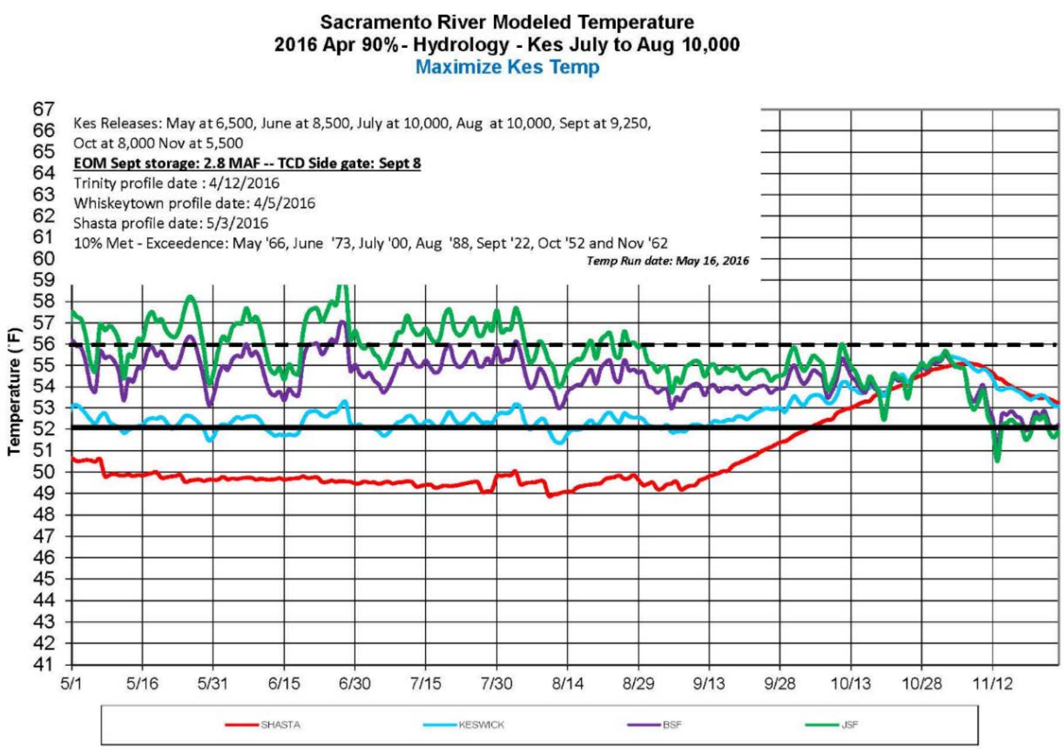


Figure 30. May 17, 2016, Keswick release scenario 10,000 cfs

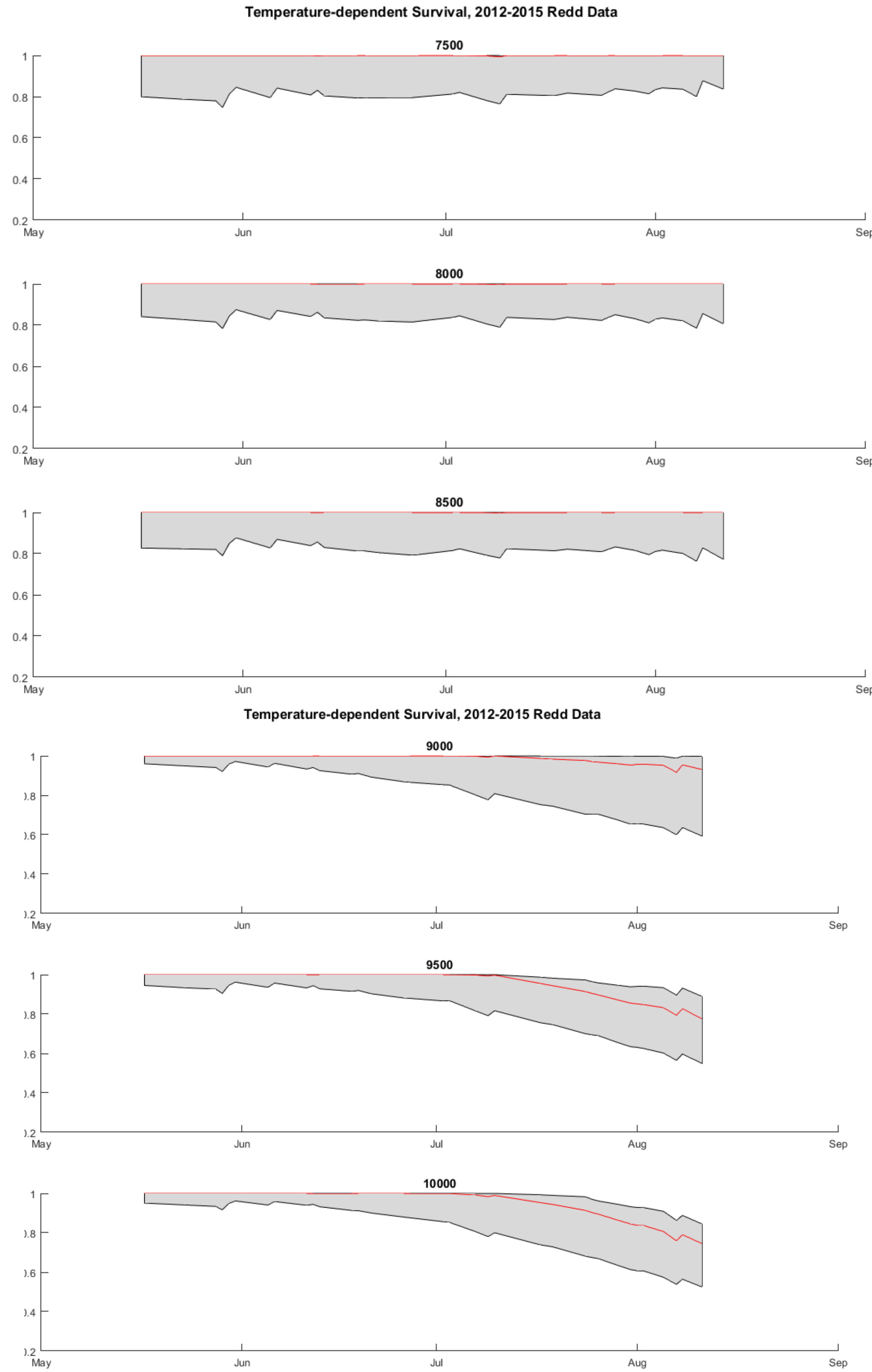


Figure 31. May 17, 2016, scenarios temperature-dependent survival forecast histogram.

Table 9. May 17, 2016 scenarios temperature-dependent mortality

Percent Temperature-dependent Mortality			
Run	Mean	Median	2.5 - 97.5 Percentiles
7500	4.93	0.14	0.083 - 44.53
8000	4.56	0.11	0.080 - 43.44
8500	4.84	0.11	0.078 - 44.36
9000	7.61	2.6	0.028 - 43.62
9500	9.87	6.41	0.020 - 43.54
10000	10.68	7.2	0.070 - 43.05

<u>May 18, 2016</u>

Reclamation ran model scenarios (Table 10) that adjusted some TCD targets to stretch out the cold water throughout summer (Figures 32-34). The third model run increased the Keswick monthly average temp to 53°F. By doing so the temperature further improves in the fall and had later full side gate operations.

Table 10. Summary of May 18, 2016 scenario runs

**Running these two model run, the TCD temperature target was slightly warmer to preserve cold water for the fall*

May 3 profile
Keswick May 6500 -- Keswick MAX degree and 9500 J-S
may3profile_Kes_EvenM-O_9500

	May	June	July	Aug	Sep	Oct	Nov	Full Side Gates	Sept Shasta Storage	June-Aug CVP Export	CVP Export Reduction (June - Aug)	Folsom EOM Sept Storage	American River Temperature Target (oF)	Egg to Emergence temp dependent mortality above Clear Creek (Zeug et al 2012)
Keswick	6500	9500	9500	9500	8500	6500	5500		2.9 MAF	509 TAF	1 TAF	379	~68	4.3%
Monthly Ave Temp	52.5	52.65	52.65	52.63	52.62	52.78		1-Oct						

May 3 profile
Keswick May 6500 -- Keswick MAX degree and 10000 J-S
may3profile_Kes_EvenM-O_10000

	May	June	July	Aug	Sep	Oct	Nov	Full Side Gates	Sept Shasta Storage	June-Aug CVP Export	CVP Export Reduction (June - Aug)	Folsom EOM Sept Storage	American River Temperature Target (oF)	Egg to Emergence temp dependent mortality above Clear Creek (Zeug et al 2012)
Keswick	6500	8500	10000	10000	9250	8000	5500		2.8 MAF	510 TAF	0	386		4.3%
Monthly Ave Temp	52.77	52.73	52.76	52.87	52.73	52.57		6-Oct					~68	

May 3 profile
Keswick May 6500 -- Keswick MAX degree and 10000 J-S
may3profile_Kes_53deg_M-O_10000

	May	June	July	Aug	Sep	Oct	Nov	Full Side Gates	Sept Shasta Storage	June-Aug CVP Export	CVP Export Reduction (June - Aug)	Folsom EOM Sept Storage	American River Temperature Target (oF)
Keswick	6500	8500	10000	10000	9250	8000	5500		2.8 MAF	510 TAF	0	386	
Monthly Ave Temp	53.00	52.94	52.98	53.13	52.94	52.28		18-Oct					~68

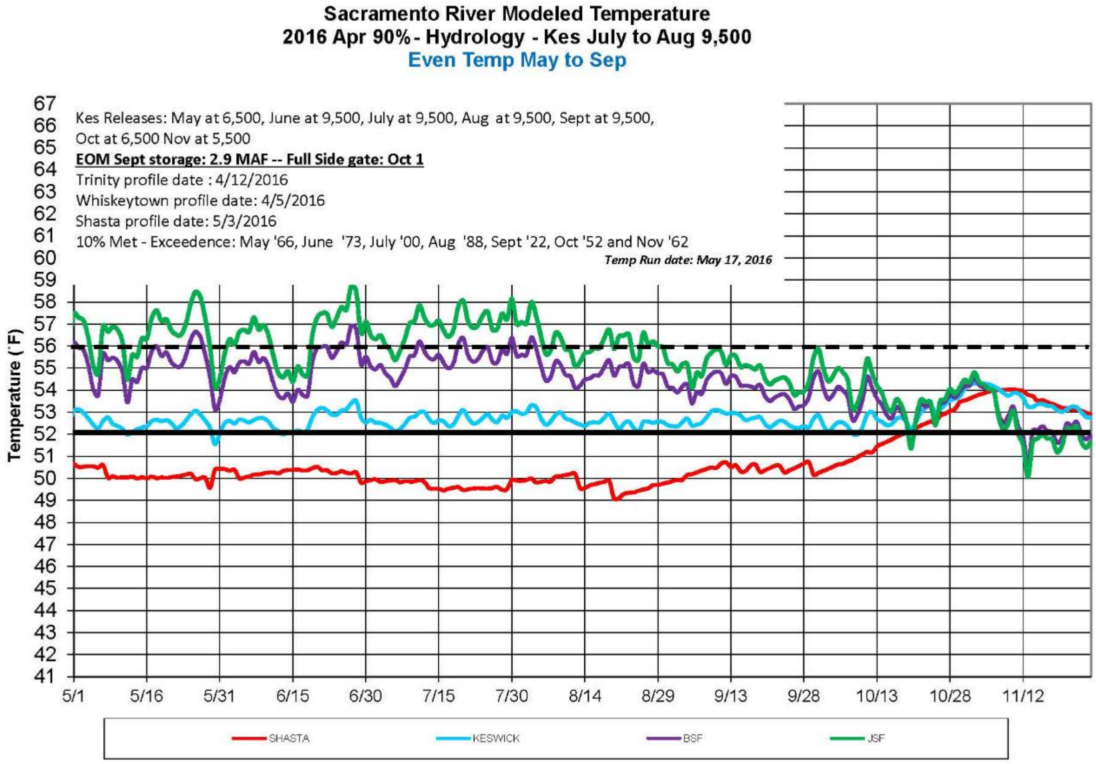


Figure 32. May 18, 2016, Keswick release scenario 9,500 cfs

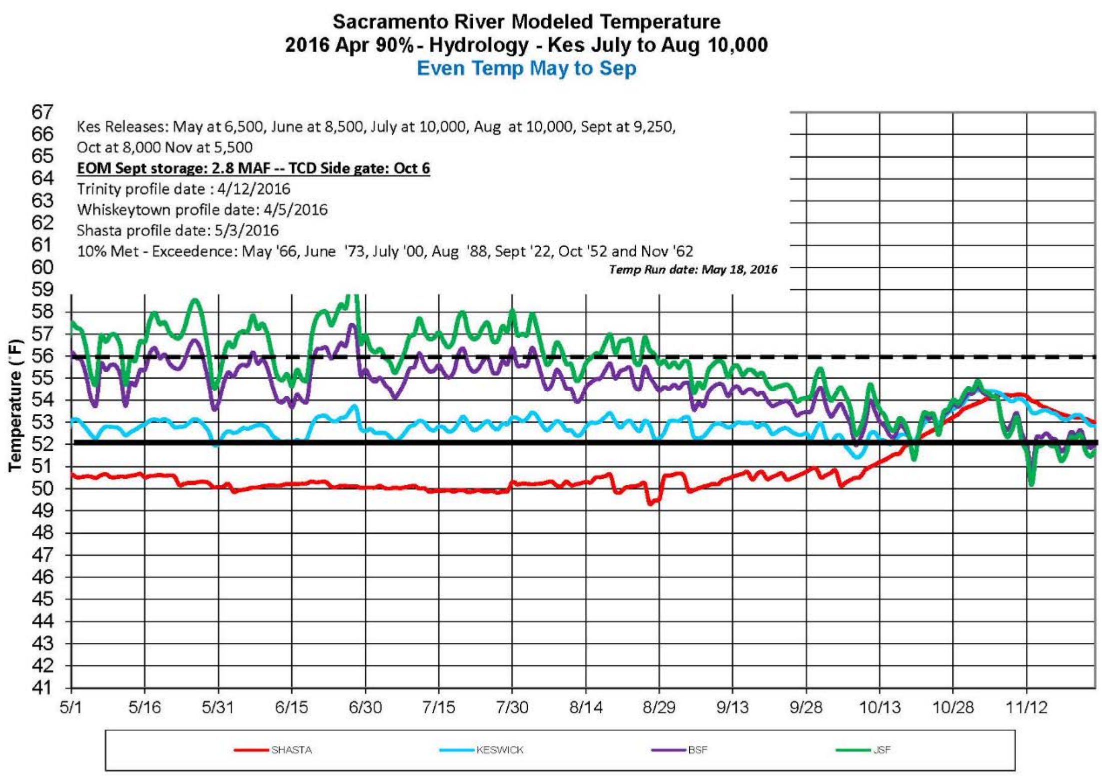


Figure 33. May 18, 2016, Keswick release scenario 10,000 cfs @ KES 52.5ºF DAT

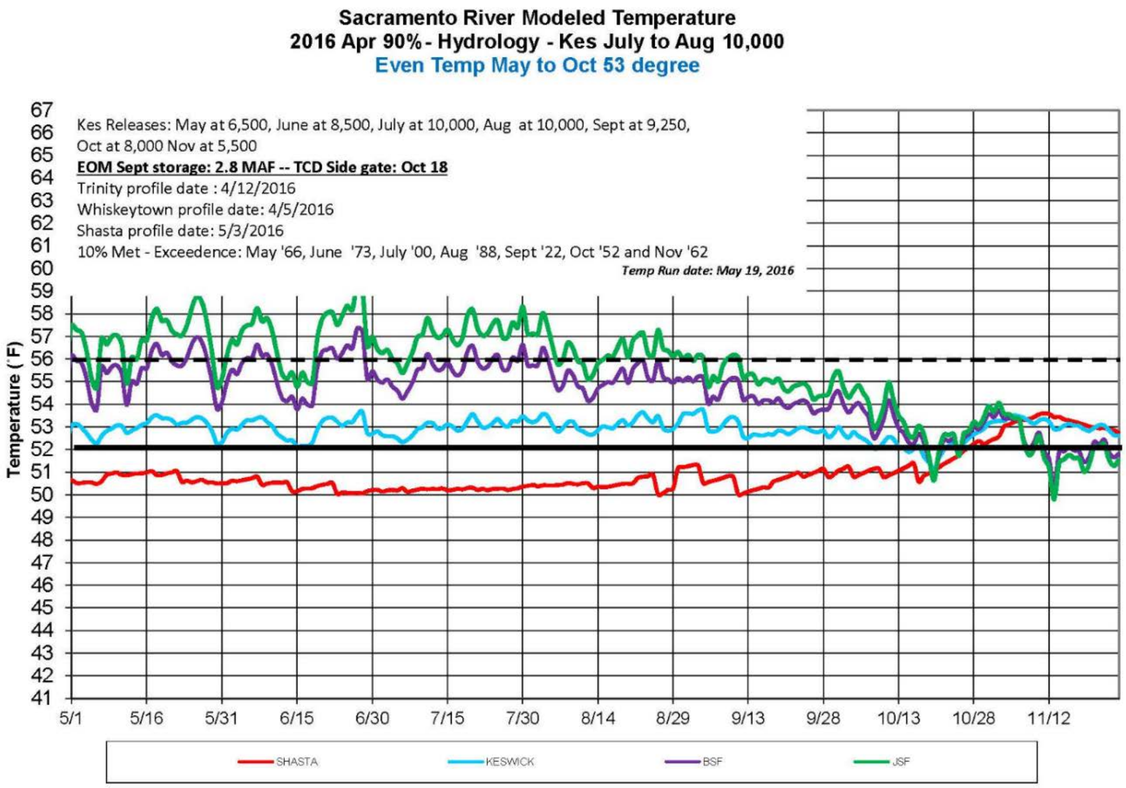


Figure 34. May 18, 2016, Keswick release scenario 10,000 cfs @ KES 53ºF DAT

<u>May 19, 2016, RAFT Temperature Sensitivity Analysis</u>
The NMFS-SWFSC ran temperature-dependent survival model results for the 8000, 9500 Even M-O, and 10000 Even M-O scenarios and added increased Keswick temperature increments (before going into RAFT) to get an idea of how this might impact the survival numbers. Specifically, they added constant temperature increases to the SRWQM scenarios in increments of 0.5ºF (0.5, 1.0, 1.5ºF) for the months of August through October (the period when temperatures historically most often exceed compliance), and only for the Keswick temp (flow was not altered), ran those data through RAFT and then ran those temperatures through the Martin temperature-dependent mortality model. According to the results in Figures 35 – 37, even missing the target temperature at Keswick by 0.5ºF results in a substantial increase in mortality and that the increase is greater under the higher flow scenarios (Table 11). The confidence intervals for the higher releases are also higher/broader.

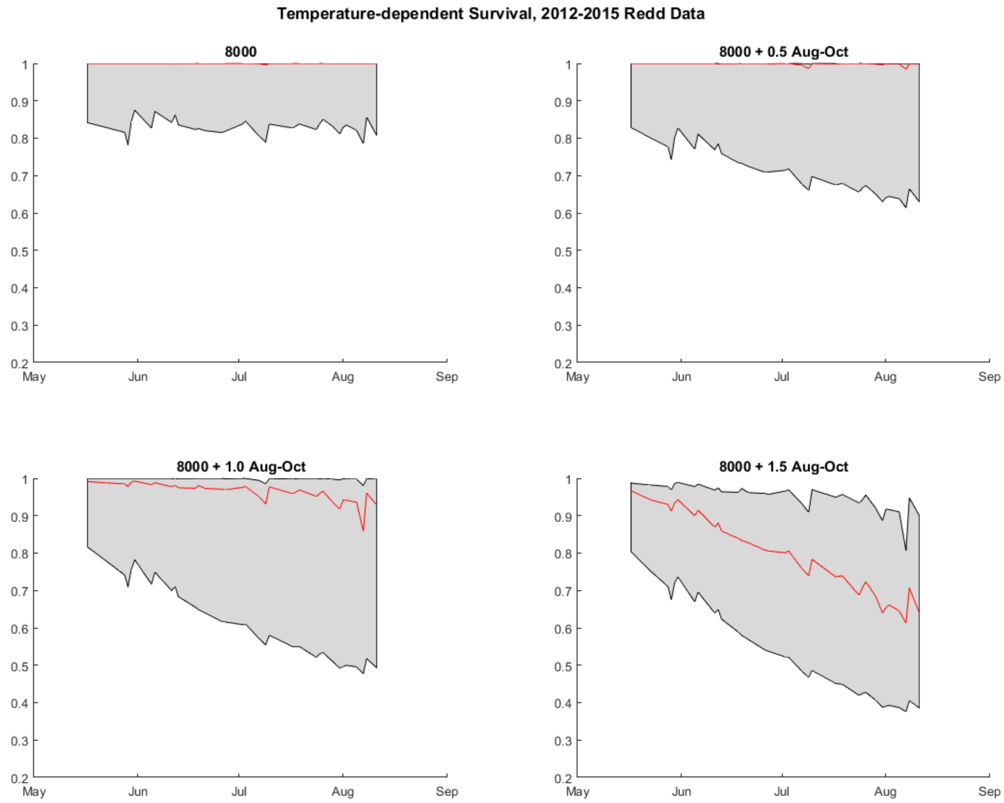


Figure 35. May 19, 2016, RAFT Temperature Sensitivity Analysis Results 8,000 cfs

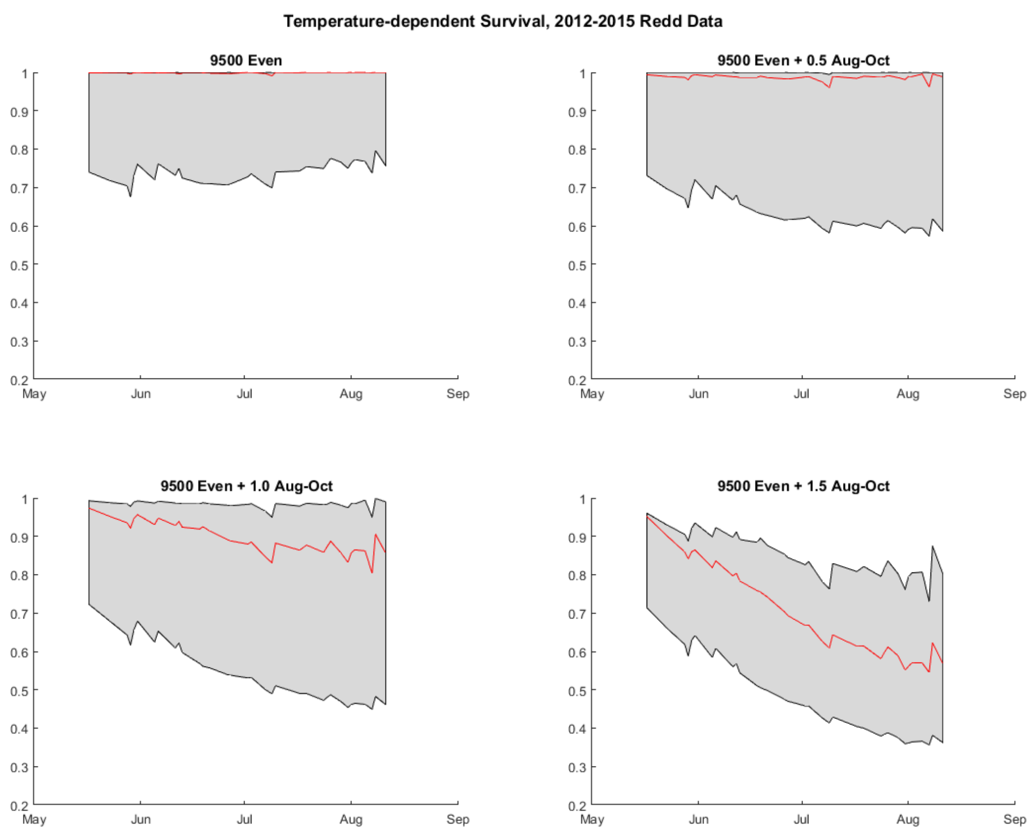


Figure 36. May 19, 2016, RAFT Temperature Sensitivity Analysis Results 9,500 cfs

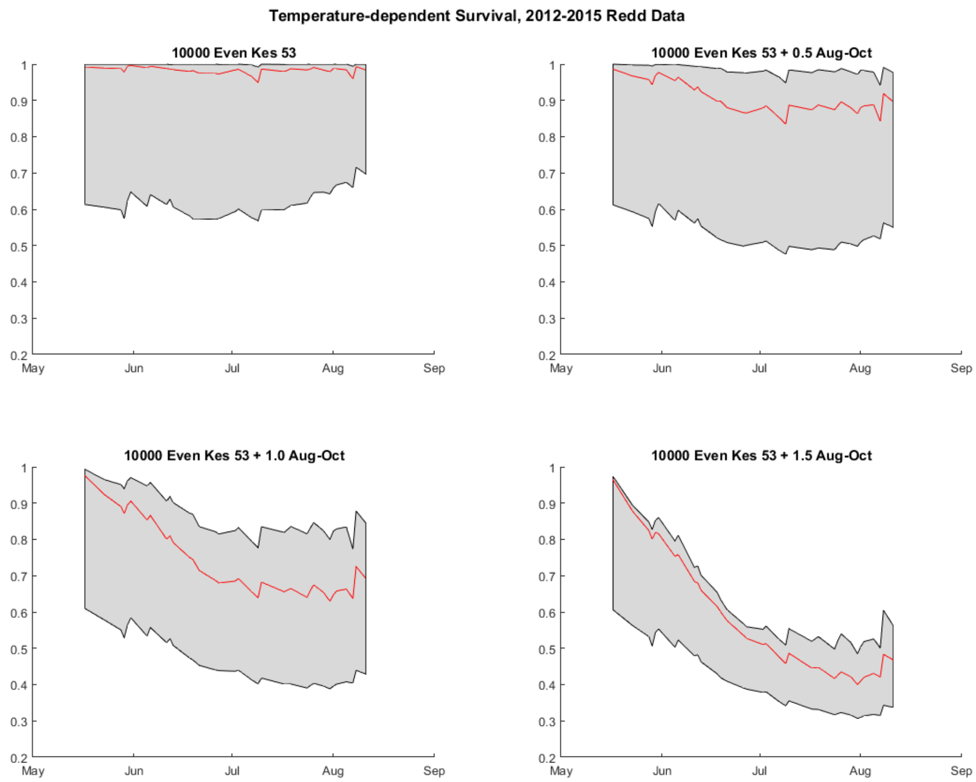


Figure 37. May 19, 2016, RAFT Temperature Sensitivity Analysis Results 10,000 cfs

Table 11. May 19, 2016, scenarios Martin temperature-dependent mortality model results

Percent Temperature-dependent Mortality			
Run	Mean	Median	2.5 - 97.5 Percentiles
8000	4.56	0.11	0.08 - 43.44
8000 + 0.5 Aug-Oct	7.86	0.52	0.084 - 53.17
8000 + 1.0 Aug-Oct	15.28	7.69	0.088 - 61.02
8000 + 1.5 Aug-Oct	28.95	29.32	0.088 - 66.79
9500 Even	6.59	0.35	0.084 - 50.16
9500 Even + 0.5 Aug-Oct	11.52	3.04	0.088 - 58.81
9500 Even + 1.0 Aug-Oct	21.84	17.36	0.088 - 65.27
9500 Even + 1.5 Aug-Oct	36.88	39.23	0.088 - 70.9
10000 Even Kes 53	12.19	4.05	0.088 - 58.84
10000 Even Kes 53 + 0.5 Aug-Oct	21.46	16.18	0.088 - 65.61
10000 Even Kes 53 + 1.0 Aug-Oct	35.25	35.95	0.088 - 71.46
10000 Even Kes 53 + 1.5 Aug-Oct	48.8	53.36	0.088 - 75.99

May 20, 2016, Reclamation's Draft Sacramento River Temperature Management Proposal

Reclamation proposes a temperature compliance point of 56°F DAT at CDEC gauge station CCR through two alternate flow proposals of 10,000 cfs and 9,500 cfs. Temperatures would be managed in real-time to meet a 53°F DAT at Keswick Dam (KES). According to the Martin *et al*. (2016) temperature-dependent mortality model, the 10,000 cfs alternative would result in almost double the mortality compared to the 9,500 cfs alternative (Table 13). In addition, substantially more mortality (almost double to triple) would occur with a 0.5 – 1.0°F increase out of Keswick releases for each alternative.

Table 12. Summary of May 20, 2016 Draft Sacramento River Temperature Management Proposals

Sacramento River Temperature Management Proposal May 19, 2016													
Proposal 1	May	June	July	Aug	Sep	Oct	Nov	*Full Side Gates*	*Sept Shasta Storage*	*June-Aug CVP Export*	*CVP Export Reduction (June - Aug)*	*Folsom EOM Sept Storage*	*American River Temperature Target (oF)*
Keswick	6500	8500	10000	10000	9250	8000	5500		2.8 MAF	510 TAF	0	386	~68
KES Monthly Ave Temp	52.77	52.73	52.76	52.87	52.73	52.57		6-Oct					
CCR Monthly Ave Temp *-- Modification of 1.6 degree*	54.27	54.23	54.26	54.37	54.23	54.07							
Proposal 2	May	June	July	Aug	Sep	Oct	Nov	*Full Side Gates*	*Sept Shasta Storage*	*June-Aug CVP Export*	*CVP Export Reduction (June - Aug)*	*Folsom EOM Sept Storage*	*American River Temperature Target (oF)*
Keswick	6500	9500	9500	9500	8500	6500	5500		2.9 MAF	509 TAF	1 TAF	379	~68
KES Monthly Ave Temp	52.5	52.65	52.65	52.63	52.62	52.78		1-Oct					
CCR Monthly Ave Temp *-- Modification of 1.6 degree*	54.00	54.15	54.15	54.13	54.12	54.28							

Table 13. May 20, 2016, Draft Sacramento River Temperature Management Proposal Biological Analysis

Metric	9,500 cfs alternative	10,000 cfs alternative
Temperature dependent mortality above CCR (Zeug et al 2012; based on modified KWK predicted temperatures)	6.5%	6.8%
Temperature dependent mortality (Martin et al 2016)	6.6%	12.2%
Full Side Gate Use	October 1	October 6
Temperature dependent mortality above CCR with 0.5-1.0 F increase (Zeug et al 2012)	8.0-9.9%	8.4-10.4%
Temperature dependent mortality above CCR with 0.5-1.0 F increase (Martin et al 2016)	11.5-21.8%	21.5%-35.3%
WRCS redd dewatering risk	Plan avoids reducing flows until WRCS emerged from gravel	
FRCS redd dewatering risk	16%	18.5%

However, of greater importance is that Reclamation's proposed draft plan does not meet the requirements found in RPA Action 1.2.4 of not in excess of 56°F DAT at a compliance location between Balls Ferry and Bend Bridge from May 15 through September 30 (and through October 31 for spring-run, whenever possible). In addition, it does not meet the NMFS March 31, 3016, concurrence letter of 55°F 7DADM at CCR (nor the surrogate of 52°F DAT at Keswick or 56°F DAT between Balls Ferry and Jellys Ferry). Reclamation's proposal to target 53°F DAT at Keswick (approximately 55°F to 56°F at CCR) is at the upper thermal physiological limit for egg incubation and fry emergence. It does not provide a buffer if daily average temperatures exceed this level. As noted above, even missing the target temperature at Keswick by 0.5°F results in an increase in mortality by almost double (Table 13). In addition, the proposal did not model the fish agency preferred scenario (52.5°F DAT at Keswick with flows of 8,000 cfs June through September) that was discussed at the May 17, 2016 SWIM team meeting. The fish agency preferred scenario results in less temperature-dependent mortality and less potential to dewater redds than Reclamation's proposal.

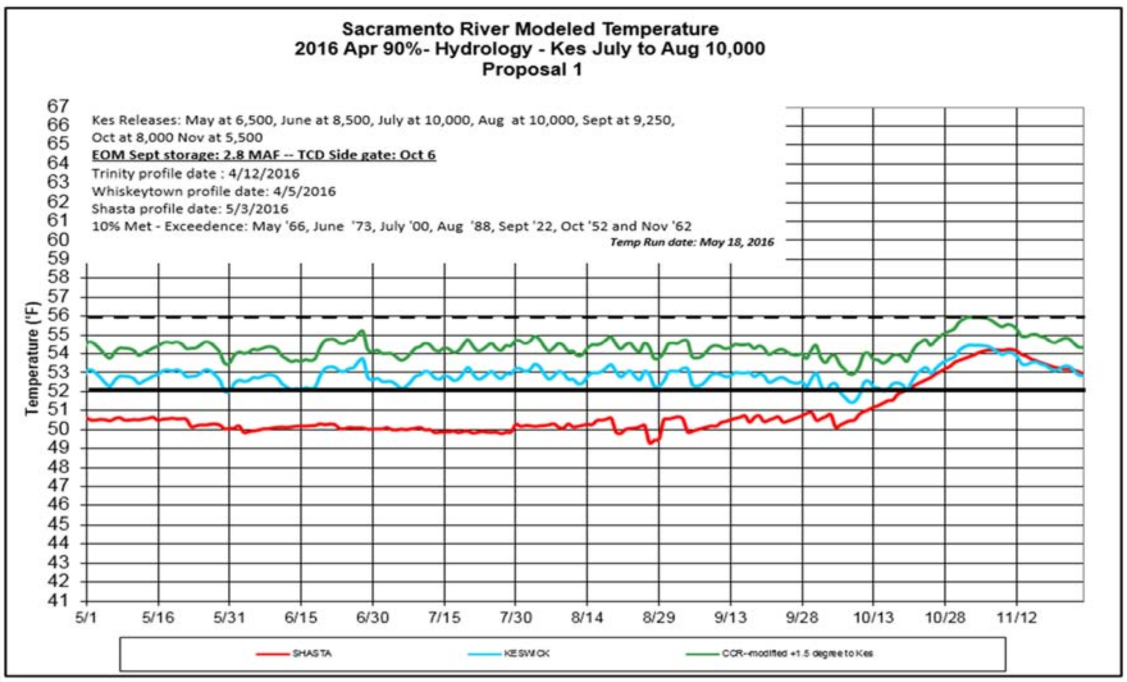


Figure 38. May 20, 2016, Draft Sacramento River Temperature Management Proposal 10,000 cfs Alternative

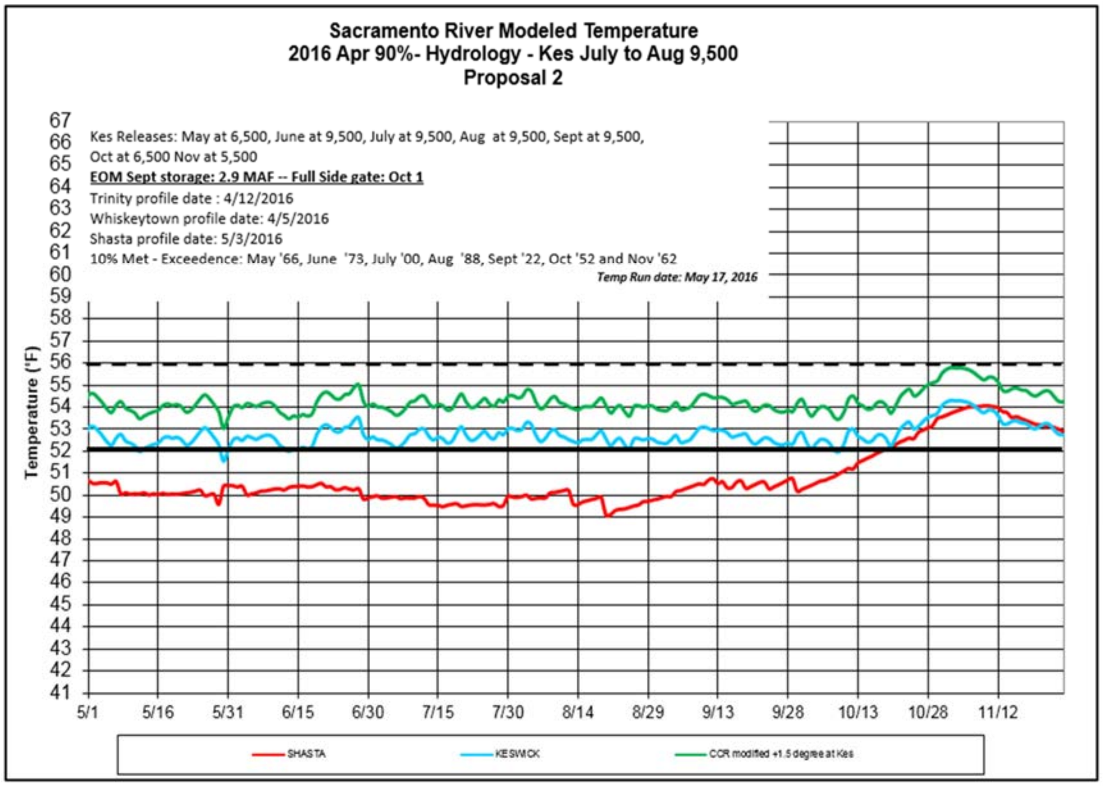


Figure 39. May 20, 2016, Draft Sacramento River Temperature Management Proposal 9,500 cfs Alternative

Note that there are a couple of differences between the Zeug *et al*. (2012) and Martin *et al*. (2016) temperature-dependent egg-to-fry mortality models. Zeug *et al*. (2012) model uses data from laboratory studies to construct the relationship between temperature, egg mortality, development time, fry mortality and fry rearing time. Meanwhile, the Martin *et al*. (2016) model compares laboratory study data to egg-to-fry survival data from USFWS Red Bluff Diversion Dam rotary screw trap to construct the relationship between temperature, time, and egg-to-fry mortality. Thermal tolerance of winter-run Chinook estimated in the field is substantially reduced relative to thermal tolerance estimated from laboratory data, by more than 6ºF. Using lab data, models predict no mortality at 56ºF, while in the field this results in a loss of 80% of the population (43% of which is temperature-dependent mortality). The Martin *et al*. (2016) model captures this observed field data.

May 26, 2016 – SRTTG Meeting

Shasta Reservoir isothermobath profile from May 16 (Figure 40) showed that the volume of 48°F and colder water is stabilizing, indicating the lake has stratified. Reclamation ran the Sacramento River temperature model using the May 90% exceedance hydrology (based on May 1, 2016, hydrologic conditions and forecasted river inflow), with an estimated monthly Keswick release of 9,000 cfs for June and 10,000 cfs in July and August, and 10% L3MTO parameters. Keswick was modeled to target 53°F DAT and included a 1.3°F increase from Keswick to CCR (Figure 41). Results of this run indicated opening of full side gates was delayed to October 14.

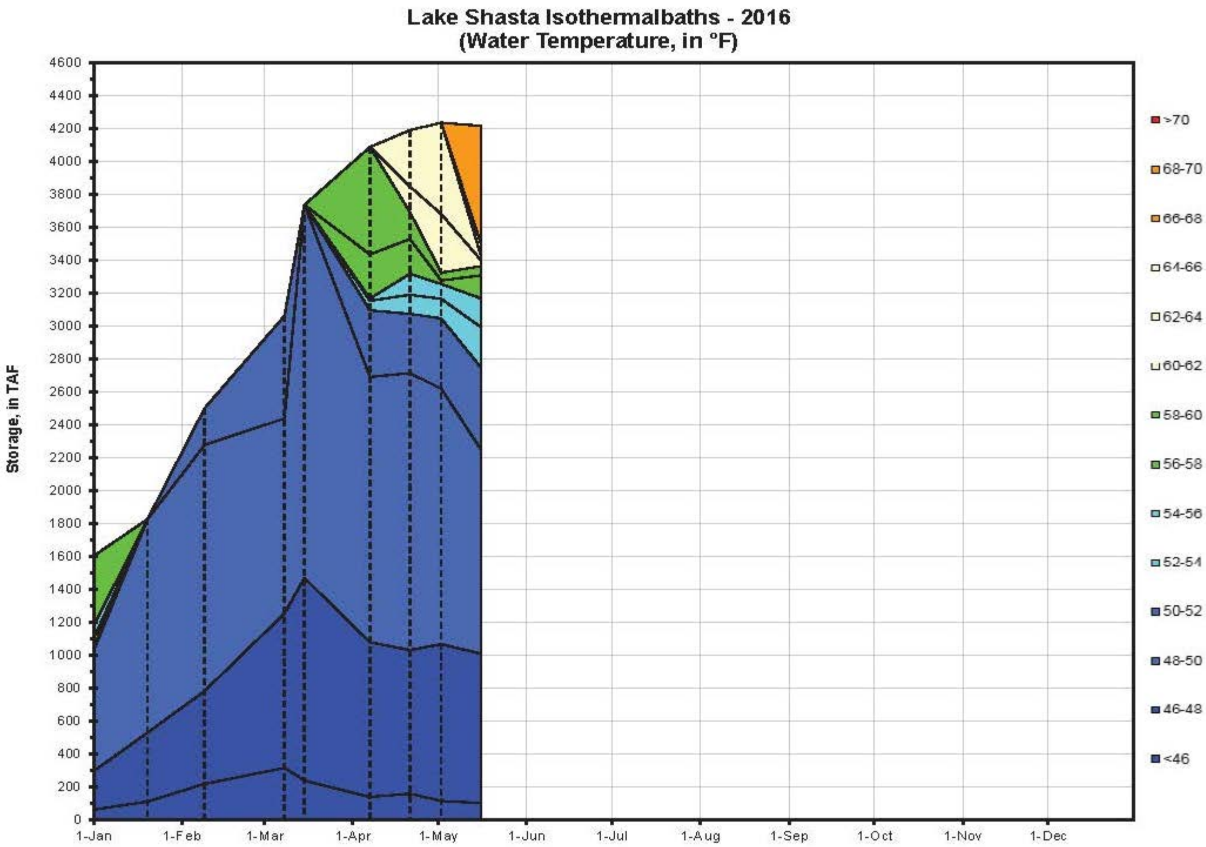
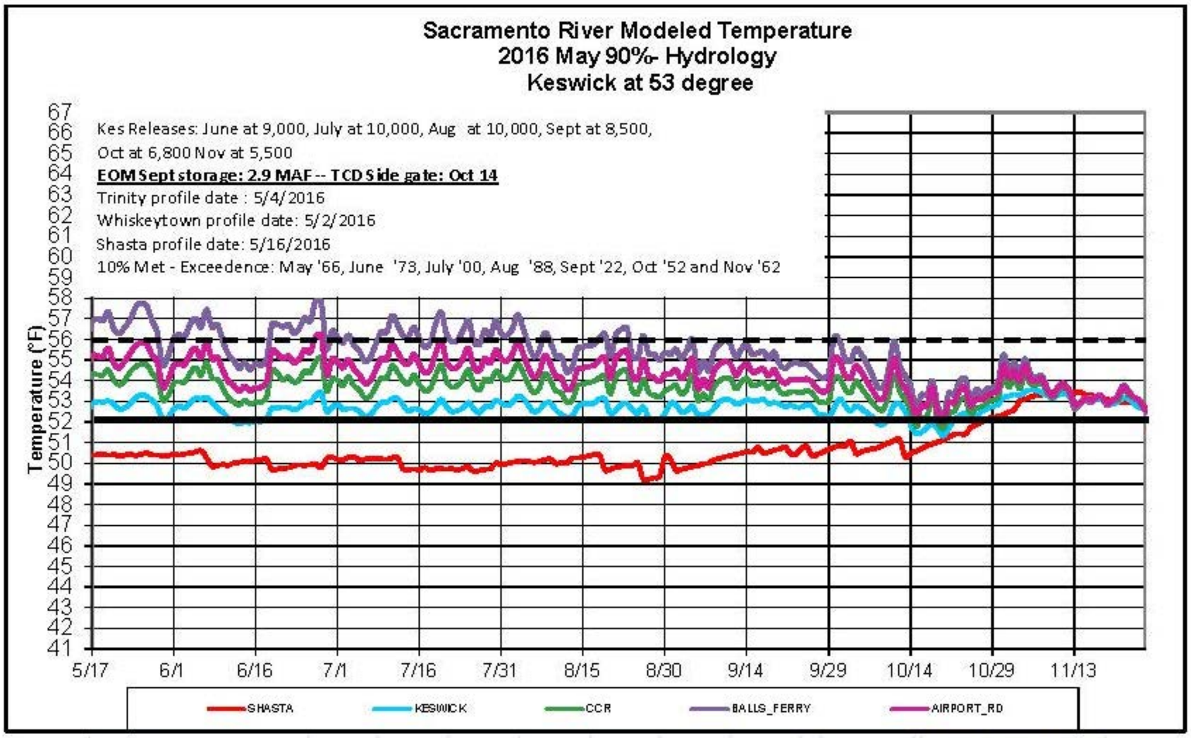


Figure 40. May 16, 2016, Shasta Reservoir Isothermobath



May 90% Temp Model Run	May	June	July	Aug	Sep	Oct	Nov	Full Side Gates	Egg to Emergence temp dependent mortality above Clear Creek (Zeug et al 2012)
Keswick		9000	10000	10000	8500	6800	5500		5.8%
KES Monthly Ave Temp	52.55	52.63	52.71	52.68	52.75	52.29		14-Oct	
CCR Monthly Ave Temp -- *Modification model* -- *1.3 degree from Kes to CCR*	53.42	53.91	53.96	53.81	53.61	52.98			
Balls Ferry	55.73	56.18	56.17	55.70	55.13	54.07			

Figure 41. May 26, 2016, SRTTG Temperature Model Run

The Zeug *et al*. (2012) egg to emergence temperature-dependent mortality was estimated to be 5.8% and while the Martin *et al*. (2016) estimate was 7.1%. NMFS ran the Martin temperature-dependent mortality model with an additional 0.5°F, 1.0°F, and 1.5°F added to the August through October Keswick temperatures. Model sensitivities showed that a 0.5°F increase in temperature can increase mortality by more than 50% (to 12.8%) and a 1.0°F increase, more than three-fold (24.5%, Table 14).

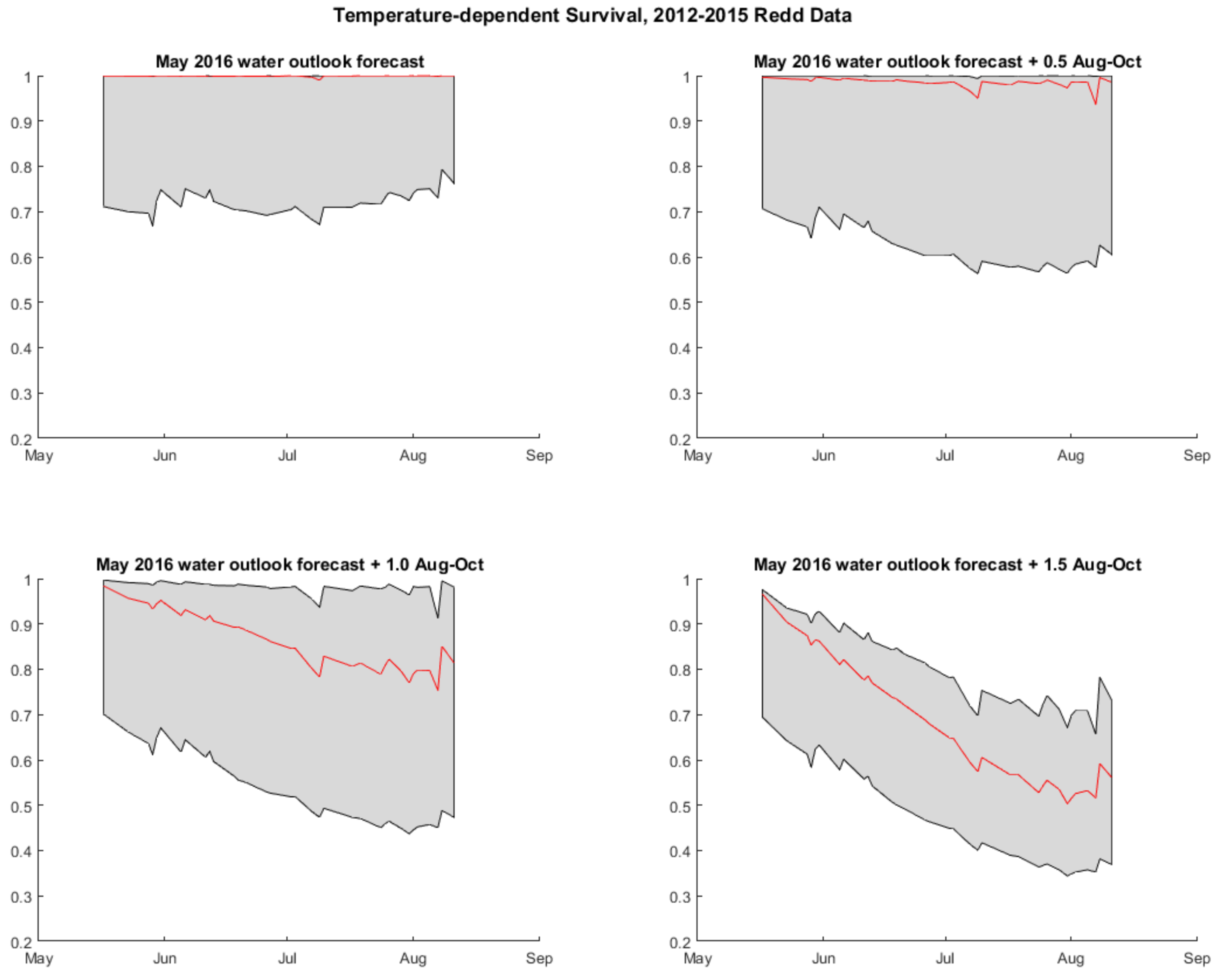


Figure 42. May 26, 2016, SRTTG temperature-dependent survival histogram results

Table 14. May 26, 2016, SRTTG temperature-dependent mortality

Percent Temperature-dependent Mortality			
Run	Mean	Median	2.5 - 97.5 Percentiles
May 2016 water outlook forecast	7.11	0.28	0.084 - 51.52
May 2016 water outlook forecast + 0.5 Aug-Oct	12.8	4.31	0.088 - 59.84
May 2016 water outlook forecast + 1.0 Aug-Oct	24.45	21.84	0.088 - 66.21
May 2016 water outlook forecast + 1.5 Aug-Oct	39.34	42.17	0.088 - 71.65

May 31, 2016
Reclamation ran three scenario model runs – 8000 cfs, 10,000 cfs, and 11,500 cfs – based on the latest hydrology from May 24, 2016, plus it included inputs to Keswick release temperatures and flows from Spring Creek (Table 15, Figures 43-45).

Table 15. Summary of May 31, 2016 scenario runs

June 1 study

Scenario 1 8,000	June	July	Aug	Sep	Oct	Nov	Full Side Gates	Sept Shasta Storage	July-Sep CVP Export	Folsom EOM Sept Storage	Egg to Emergence temp dependent mortality above Clear Creek (Zeug et al 2012)	Martin et al (2015) Temperature dependent mortality estimates
Keswick	8000	8000	8000	8000	6500	5500		2.9	480 TAF	265	5.6%	xx
Keswick	52.11	52.34	52.30	52.25	51.38		23-Oct					
Balls Ferry	55.09	55.62	54.99	53.84	52.27							
Jellys Ferry	56.63	57.34	56.44	54.92	52.80							

****Wilkins had to be cut by 600 cfs in July*

Scenario 2 10,000	June	July	Aug	Sep	Oct	Nov	Full Side Gates	Sept Shasta Storage	July-Sep CVP Export	Folsom EOM Sept Storage	Egg to Emergence temp dependent mortality above Clear Creek (Zeug et al 2012)	Martin et al (2015) Temperature dependent mortality estimates
Keswick	9000	10000	10000	8500	6800	5500		2.7	660 TAF	363	4.9%	xx
Keswick	51.88	51.84	51.82	52.31	52.69		26-Sep					
Balls Ferry	54.58	54.58	54.08	53.89	53.28							
Jellys Ferry	56.02	56.07	55.35	54.83	53.70							

Scenario 3 11,500	June	July	Aug	Sep	Oct	Nov	Full Side Gates	Sept Shasta Storage	July-Sep CVP Export	Folsom EOM Sept Storage	Egg to Emergence temp dependent mortality above Clear Creek (Zeug et al 2012)	Martin et al (2015) Temperature dependent mortality estimates
Keswick	10000	11500	10000	8500	6800	5500		2.5	758 TAF	403	xx	xx
Keswick	52.06	51.89	52.11	52.33	52.98		25-Sep					
Balls Ferry	54.48	54.39	54.34	53.91	53.51							
Jellys Ferry	55.81	55.74	55.59	54.83	53.91							

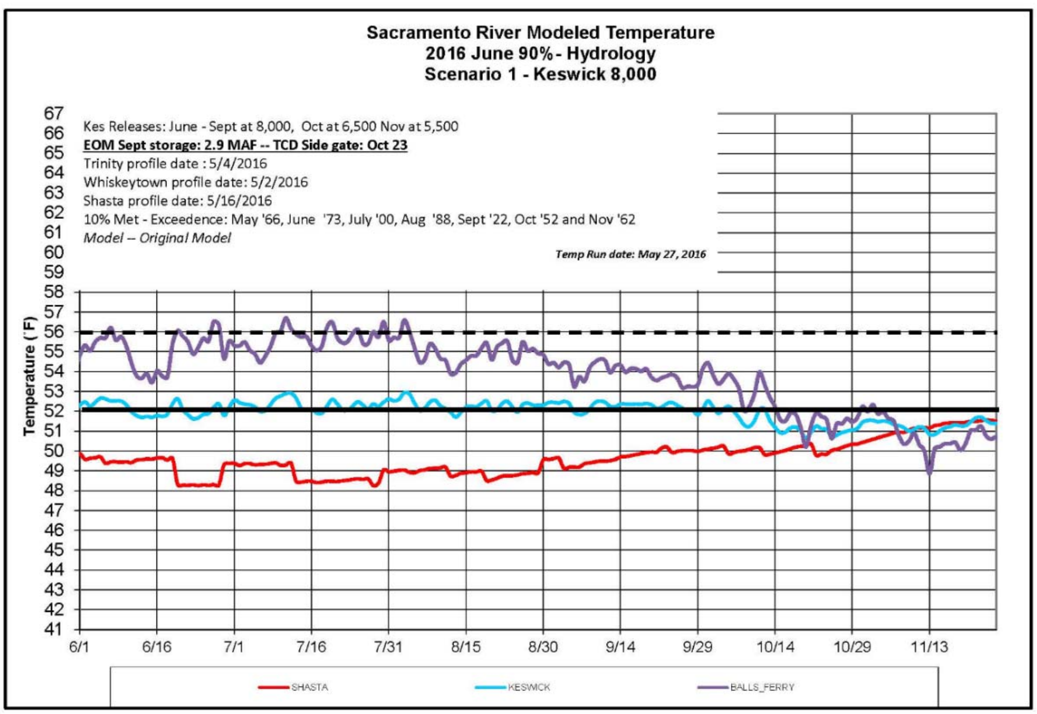


Figure 43. May 31, 2016, Keswick release scenario 8,000 cfs.

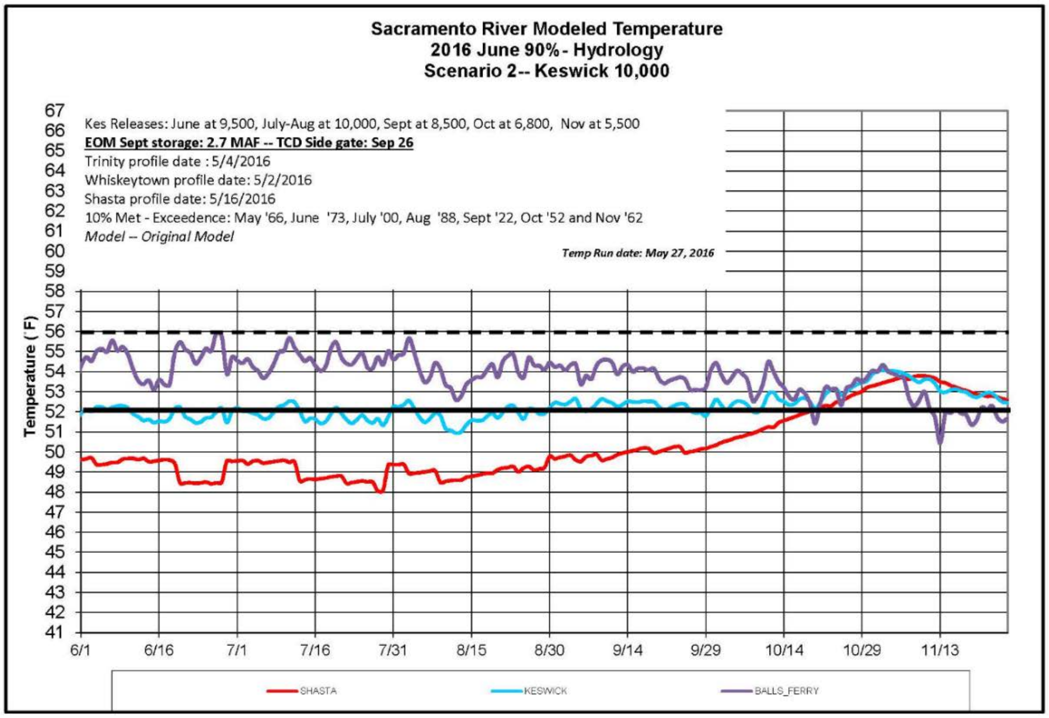


Figure 44. May 31, 2016, Keswick release scenario 10,000 cfs.

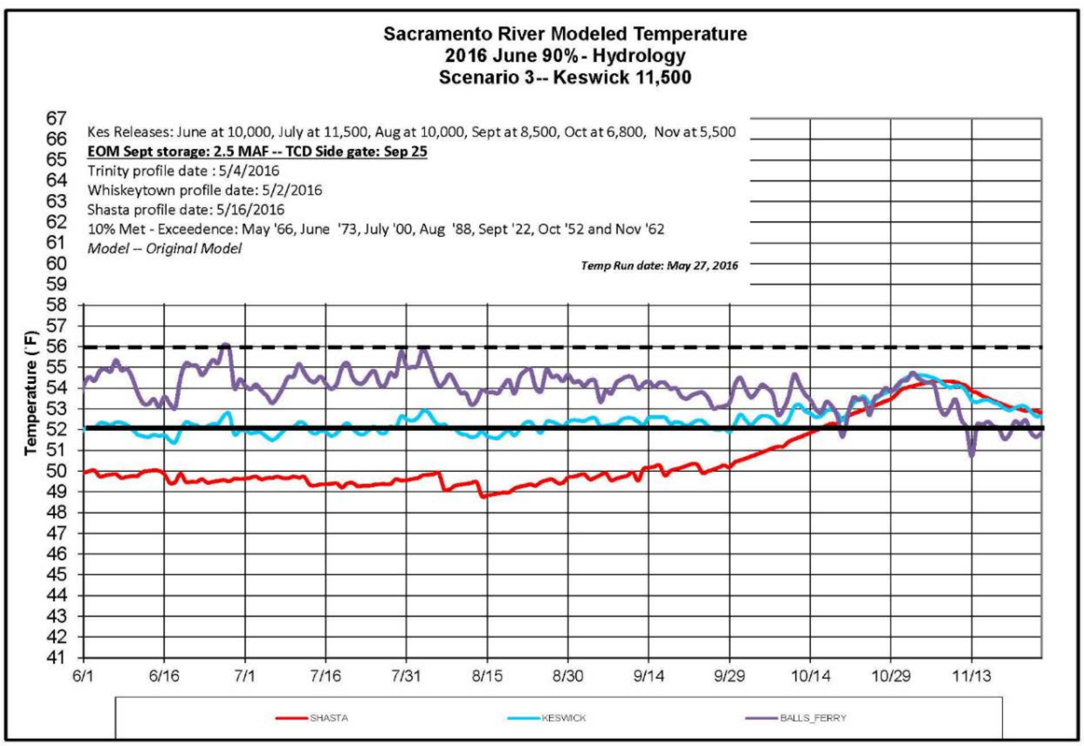


Figure 45. May 31, 2016, Keswick release scenario 11,500 cfs.

Table 16. Martin temperature-dependent mortality model results from the May 31, 2016, scenarios

Percent Temperature-dependent Mortality			
Run	Mean	Median	2.5 - 97.5 Percentiles
June1_8000	3.95	0.11	0.075 - 39.47
June1_8000 + 0.5 Aug-Oct	6.83	0.49	0.08 - 49.79
June1_8000 + 1.0 Aug-Oct	13.35	5.4	0.083 - 58.52
June1_8000 + 1.5 Aug-Oct	26.02	25.32	0.083 - 64.88
June1_10000	2.95	0.082	0.03 - 31.91
June1_10000 + 0.5 Aug-Oct	5.29	0.15	0.03 - 41.88
June1_10000 + 1.0 Aug-Oct	10.51	3.37	0.03 - 51.48
June1_10000 + 1.5 Aug-Oct	20.97	18.29	0.03 - 59.3
June1_11500	3.59	0.1	0.03 - 36.89
June1_11500 + 0.5 Aug-Oct	6.5	0.53	0.03 - 46.97
June1_11500 + 1.0 Aug-Oct	12.82	5.72	0.03 - 55.84
June1_11500 + 1.5 Aug-Oct	24.9	23.74	0.03 - 62.61

The NMFS-SWFSC plotted the three scenarios with all three levels of exceedance against each other in order to illustrate the tradeoffs with increasing flow (Figures 46 and 47). For example, in Figure 47, second row, if the Keswick release temperatures are off by 0.5°F, there is a ~70% chance of no mortality in the 8,000 and 10,000 cfs runs, but it drops to 40% for the 11,500 cfs scenario. While the 8,000 and 10,000 cfs runs are pretty much indistinguishable, the likelihood of exceedance goes up dramatically under higher flow scenarios. The upper left of the graphs, at stable Keswick release of 8,000 cfs, is most favorable for winter-run Chinook, and most achievable. As stable Keswick release increases, the likelihood of release temperatures increasing through the temperature management season increases as well.

Figure 47 also illustrates the differences in the Keswick release temperatures in August through October and the resulting temperature-dependent mortality. For example, in the first column, the 11,500 cfs runs start showing the effect of late season temp increases; the difference between the 8,000 and 10,000 cfs run are not large enough to be distinguishable in the temperature-dependent mortality model. Then as you move down each row (assuming higher exceedances), the magnitude of the late season effect becomes greater. There is still no difference between the 8,000 cfs and 10,000 cfs runs but, the likelihood of exceedance goes up with increasing flows. Therefore, it would be appropriate to compare the risk of temperature-dependent mortality in one Keswick release scenario with that of another release scenario one row down, that is, with higher likelihood of temperature exceedances.

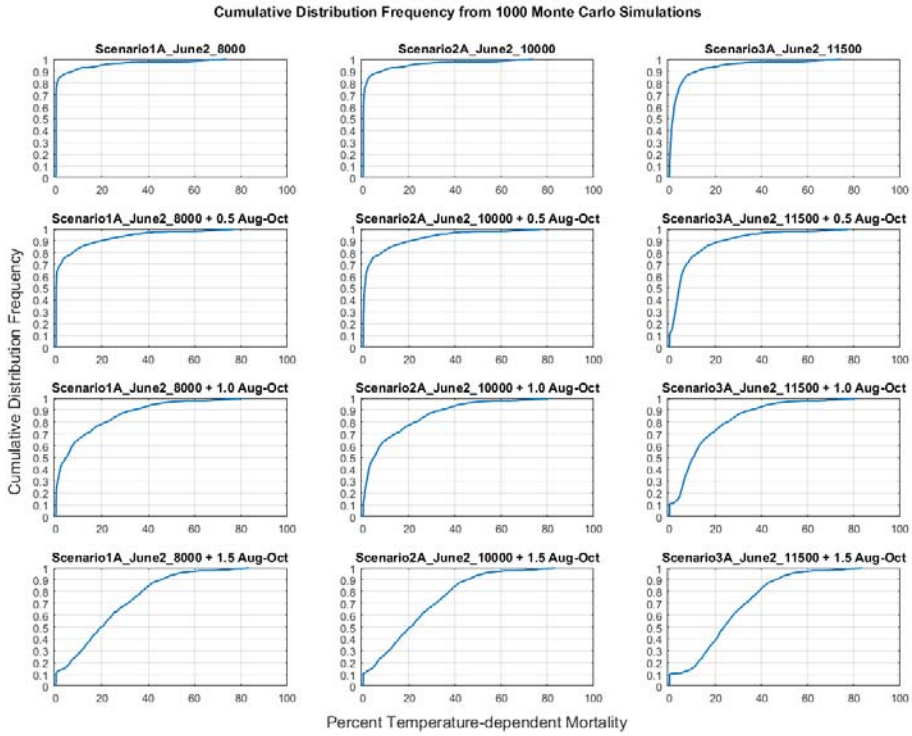


Figure 46. May 31, 2016, Keswick release scenarios temperature-dependent survival distribution frequency.

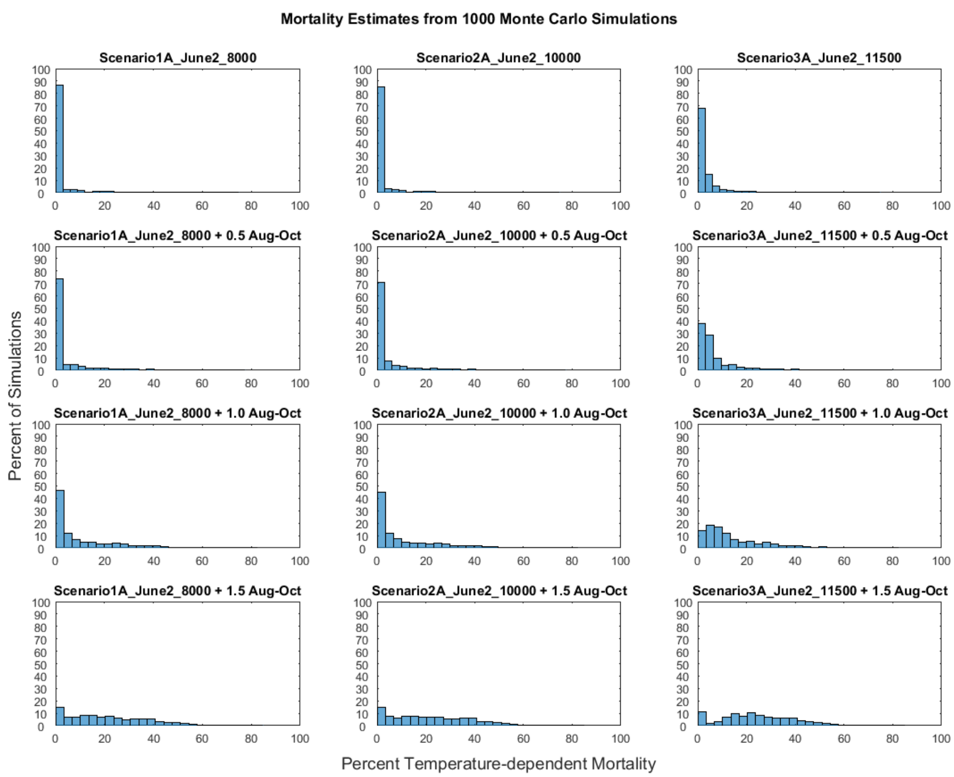
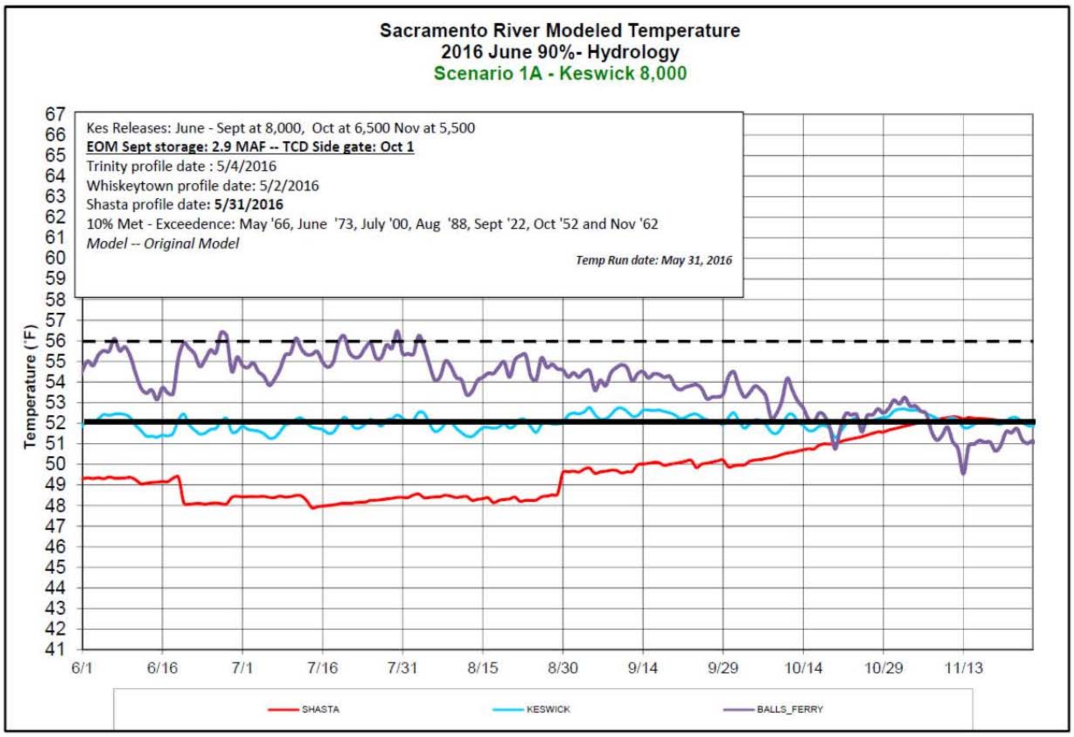


Figure 47. May 31, 2016, Keswick release scenarios temperature-dependent survival histogram.

June 2, 2016

Over the course of multiple days, Reclamation submitted six Keswick release flow scenarios – 8000 cfs, 8500 cfs, 9000 cfs, 9500 cfs, 10,000 cfs, and 11,500 cfs – that all targeted a Keswick release temperature of 52ºF DAT. Figures 48 through 53 are the SRWQM results. Table 16 is the temperature-dependent mortality results. Figure 54 shows the Shasta Reservoir (SHD) release temperatures. Temperatures increase rapidly after full side gate operations. At 8,000 cfs, temperatures remain the coolest and full side gate operations are pushed out to the latest date to October 1.



Scenario 1A 8,000	June	July	Aug	Sep	Oct	Nov	Full Side Gates	Sept Shasta Storage	July Export	Aug Export	Sep Export	Folsom EOM Sept Storage	Major Consequences/Choices	Egg to Emergence temp dependent mortality above Clear Creek (Zeug et al 2012)	Martin et al (2015) Temperature dependent mortality estimates
Keswick	8000	8000	8000	8000	6500	5500	Aug 23/ Aug 31/ Oct 1	2.9	60	150	270	305	* No 5% SOD allocation * Friant releases needed for Exchange Contractors * Delta Outflow - difficult to meet * American River 68 degree * Off Ramp year at Folsom	5%	3.1%
Keswick	51.88	51.87	51.90	52.43	51.98										
Balls Ferry	54.91	55.24	54.65	54.07	52.75										
Jellys Ferry	56.47	56.98	56.13	55.04	53.23										

Figure 48. June 2, 2016, Keswick release scenario 8,000 cfs.

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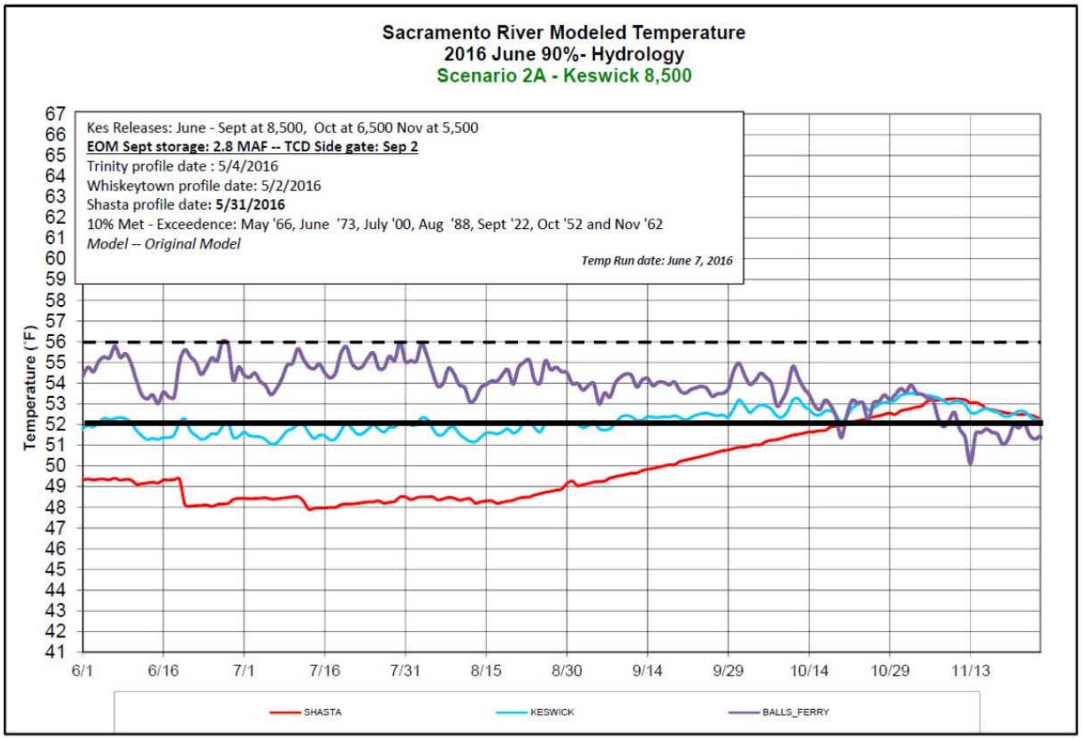
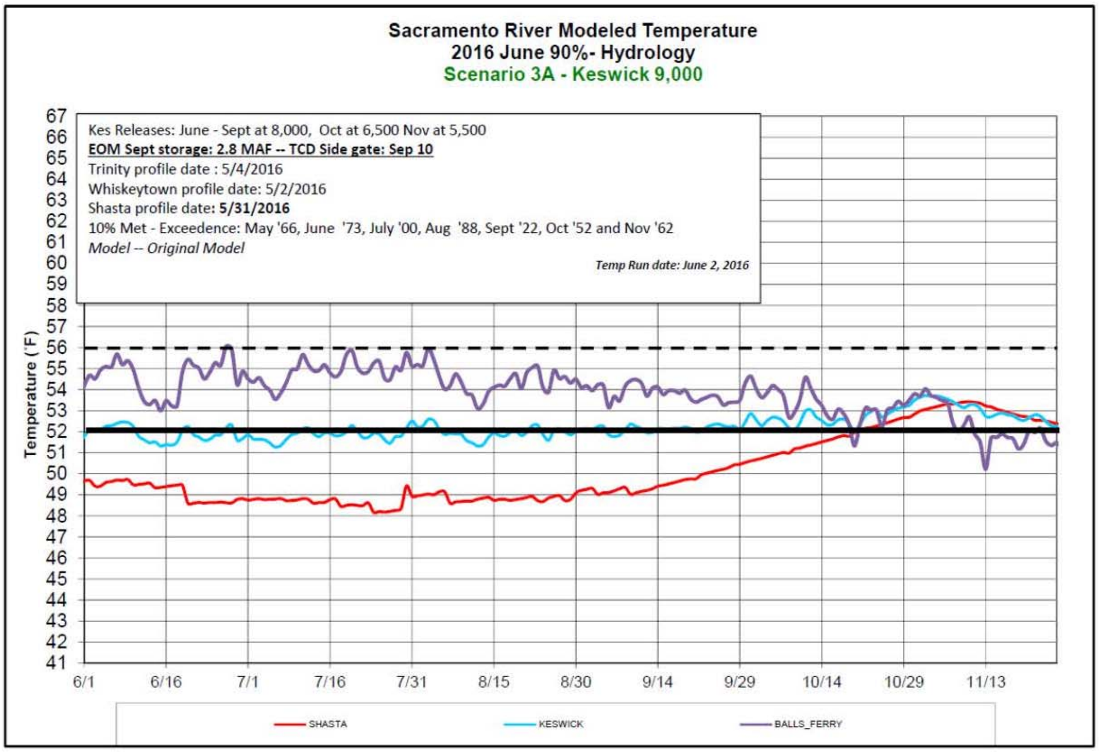


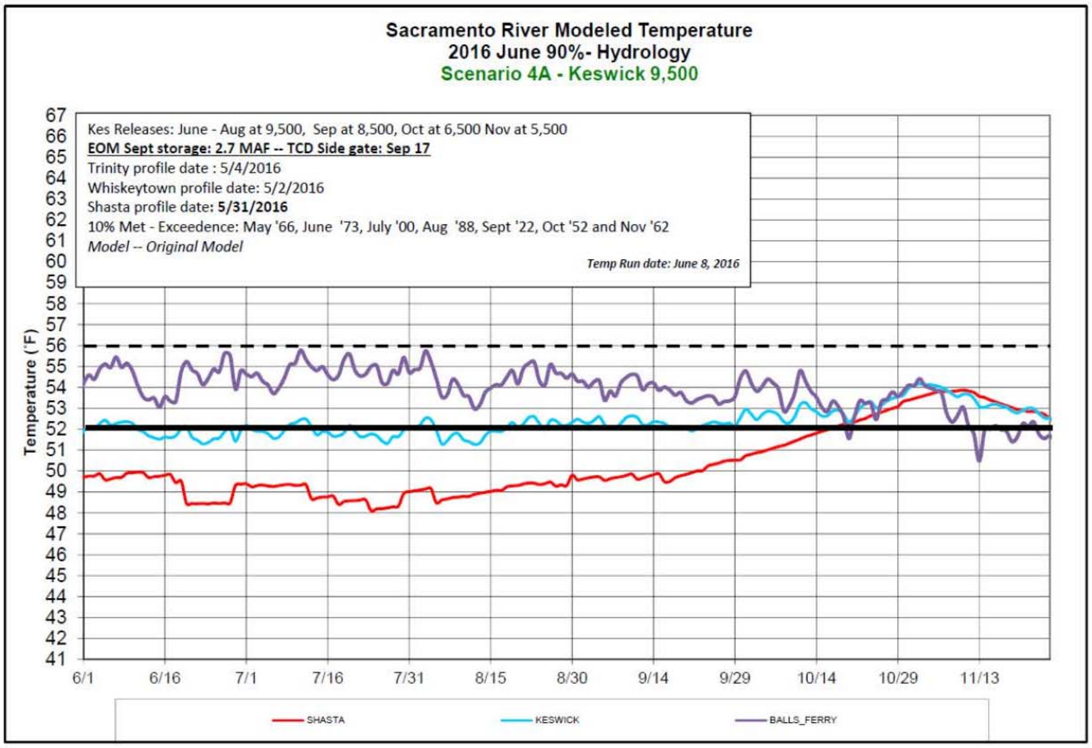
Scenario 2A 8,500	June	July	Aug	Sep	Oct	Nov	Full Side Gates	Sept Shasta Storage	July Export	Aug Export	Sep Export	Folsom EOM Sept Storage	Major Consequences/Choices	Egg to Emergence temp dependent mortality above Clear Creek (Zeug et al 2012)	Martin et al (2015) Temperature dependent mortality estimates
Keswick	8500	8500	8500	8500	6500	5500	Aug 18/ Aug 31/ Sep 2	2.8	60	180	270	336	* No 5% SOD allocation * Friant releases needed for Exchange Contractors * Delta Outflow - difficult to meet * American River 68 degree * Off Ramp year at Folsom		
Keswick	51.75	51.63	51.78	52.27	52.79										
Balls Ferry	54.64	54.77	54.4	53.85	53.41										
Jellys Ferry	56.15	56.43	55.82	54.78	53.84										

Figure 49. June 2, 2016, Keswick release scenario 8,500 cfs.



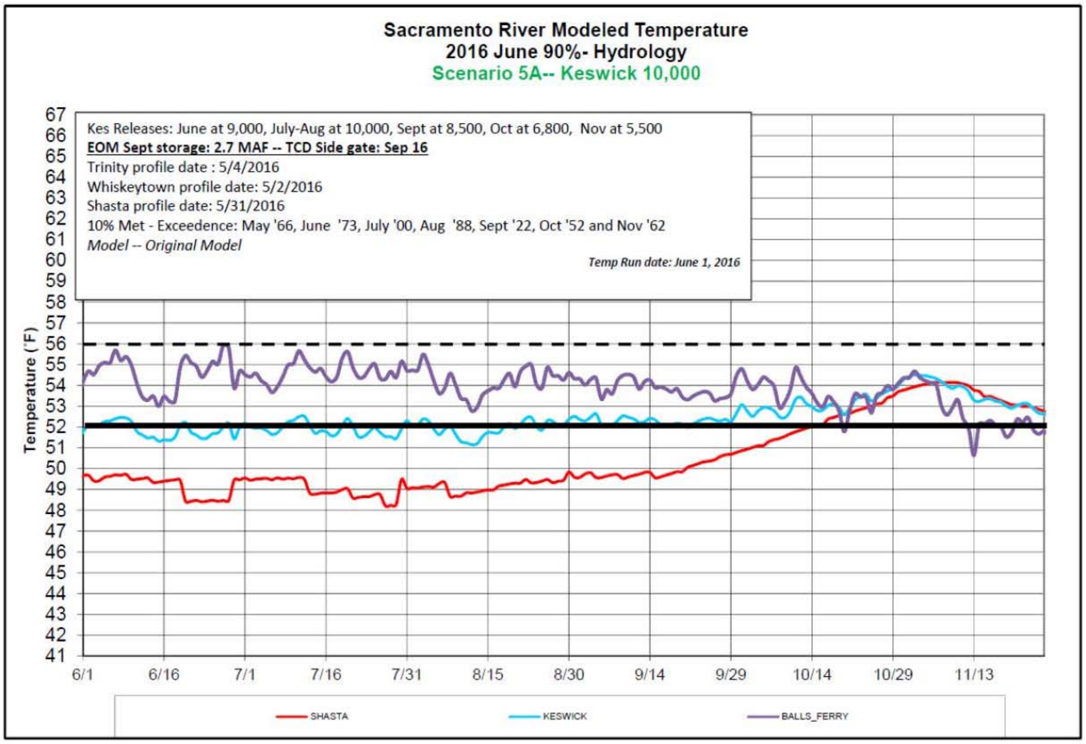
Scenario 3A 9,000	June	July	Aug	Sep	Oct	Nov	Full Side Gates	Sept Shasta Storage	July Export	Aug Export	Sep Export	Folsom EOM Sept Storage	Major Consequences	Egg to Emergence temp dependent mortality above Clear Creek (Zeug et al 2012)	Martin et al (2015) Temperature dependent mortality estimates
Keswick	9000	9000	9000	8500	6800	5500	10-Sep	2.8	75	160	270	361	* No 5% SOD allocation * Friant releases needed for Exchange Contractors * Delta Outflow - difficult to meet * American River 68 degree * Off Ramp year at Folsom		
Keswick	51.88	51.83	51.95	52.14	52.97										
Balls Ferry	54.61	54.84	54.43	53.83	53.27										
Jellys Ferry	56.05	56.45	55.79	54.81	53.70										

Figure 50. June 2, 2016, Keswick release scenario 9,000 cfs.



Scenario 4A 9,500	June	July	Aug	Sep	Oct	Nov	Full Side Gates	Sept Shasta Storage	July Export	Aug Export	Sep Export	Folsom EOM Sept Storage	Major Consequences/Choices	Egg to Emergence temp dependent mortality above Clear Creek (Zeug et al 2012)	Martin et al (2015) Temperature dependent mortality estimates
Keswick	9500	9500	9500	8500	6500	5500	17-Sep	2.7	91	160	270	400	* 5% SOD allocation preserved * Friant releases not needed * Delta Outflow is difficult to met * American River 67 degree * Folsom storage target met		
Keswick	51.86	51.87	52.02	52.26	52.94										
Balls Ferry	54.46	54.74	54.36	53.85	53.51										
Jellys Ferry	55.85	56.29	55.66	54.78	53.93										

Figure 51. June 2, 2016, Keswick release scenario 9,500 cfs.



Scenario 5A 10,000	June	July	Aug	Sep	Oct	Nov	Full Side Gates	Sept Shasta Storage	July Export	Aug Export	Sep Export	Folsom EOM Sept Storage	Major Consequences	Egg to Emergence temp dependent mortality above Clear Creek (Zeug et al 2012)	Martin et al (2015) Temperature dependent mortality estimates
Keswick	9000	10000	10000	8500	6800	5500	16-Sep	2.7	140	250	270	403	* 5% SOD allocation preserved * Friant releases not needed * Delta Outflow is met * American River 67 degree * Folsom storage target met	5.1%	3.36%
Keswick	51.85	51.91	51.94	52.28	53.13										
Balls Ferry	54.56	54.64	54.19	53.86	53.64										
Jellys Ferry	56.02	56.13	55.45	54.80	54.03										

Figure 52. June 2, 2016, Keswick release scenario 10,000 cfs.

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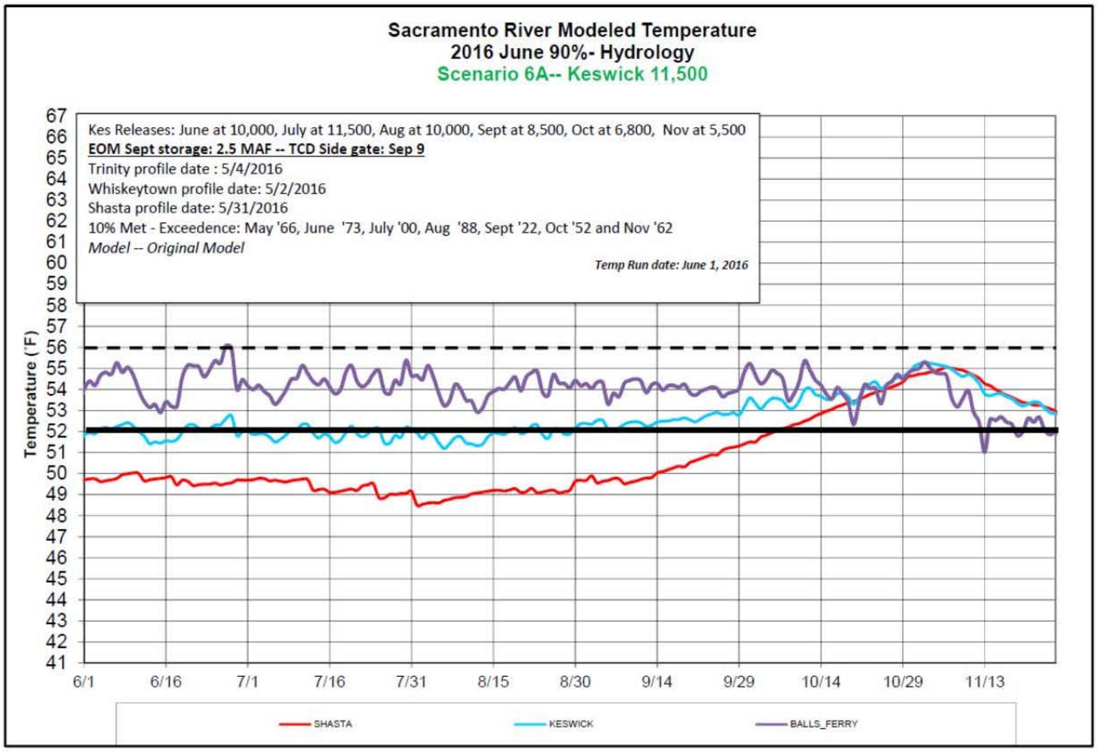

Scenario 6A 11,500	June	July	Aug	Sep	Oct	Nov	Full Side Gates	Sept Shasta Storage	July Export	Aug Export	Sep Export	Folsom EOM Sept Storage	Major Consequences	Egg to Emergence temp dependent mortality above Clear Creek (Zeug et al 2012)	Martin et al (2015) Temperature dependent mortality estimates
Keswick	10000	11500	10000	8500	6800	5500	9-Sep	2.5	230	258	270	403	* 5% SOD allocation preserved * Friant releases not needed * Delta Outflow met * American River 67 degree * Folsom storage met	5.2%	4.95%
Keswick	52.03	51.88	51.83	52.54	53.83										
Balls Ferry	54.46	54.31	53.13	54.07	54.22										
Jellys Ferry	55.78	55.66	55.36	54.99	54.57										

Figure 53. June 2, 2016, Keswick release scenario 11,500 cfs.

Table 17. June 2, 2016, scenarios temperature-dependent mortality

Percent Temperature-dependent Mortality			
Run	Mean	Median	2.5 - 97.5 Percentiles
June2_8000	3.12	0.084	0.033 - 33.93
June2_8000 + 0.5 Aug-Oct	5.61	0.17	0.033 - 44.18
June2_8000 + 1.0 Aug-Oct	11.25	4.46	0.033 - 53.7
June2_8000 + 1.5 Aug-Oct	22.32	19.56	0.033 - 61.16
June2_8500	2.92	0.083	0.03 - 30.77
June2_8500 + 0.5 Aug-Oct	5.29	0.54	0.03 - 40.8
June2_8500 + 1.0 Aug-Oct	10.34	3.65	0.03 - 50.36
June2_8500 + 1.5 Aug-Oct	20.09	16.77	0.03 - 58.51
June2_9000	2.85	0.082	0.03 - 32.51
June2_9000 + 0.5 Aug-Oct	5.02	0.16	0.03 - 42.66
June2_9000 + 1.0 Aug-Oct	9.85	2.29	0.03 - 52.19
June2_9000 + 1.5 Aug-Oct	19.77	15.92	0.031 - 59.91
June2_9500	3.3	0.083	0.03 - 34.4
June2_9500 + 0.5 Aug-Oct	6.02	0.44	0.03 - 44.34
June2_9500 + 1.0 Aug-Oct	11.93	4.89	0.03 - 53.6
June2_9500 + 1.5 Aug-Oct	23.39	21.79	0.03 - 60.98
June2_10000	3.36	0.1	0.03 - 34.16
June2_10000 + 0.5 Aug-Oct	6.05	0.77	0.03 - 44.01
June2_10000 + 1.0 Aug-Oct	11.69	4.66	0.03 - 53.22
June2_10000 + 1.5 Aug-Oct	22.57	20.36	0.032 - 60.7
June2_11500	4.95	1.45	0.03 - 35.98
June2_11500 + 0.5 Aug-Oct	8.7	4.23	0.03 - 45.49
June2_11500 + 1.0 Aug-Oct	15.16	10.17	0.032 - 54.4
June2_11500 + 1.5 Aug-Oct	25.36	23.61	0.032 - 61.36

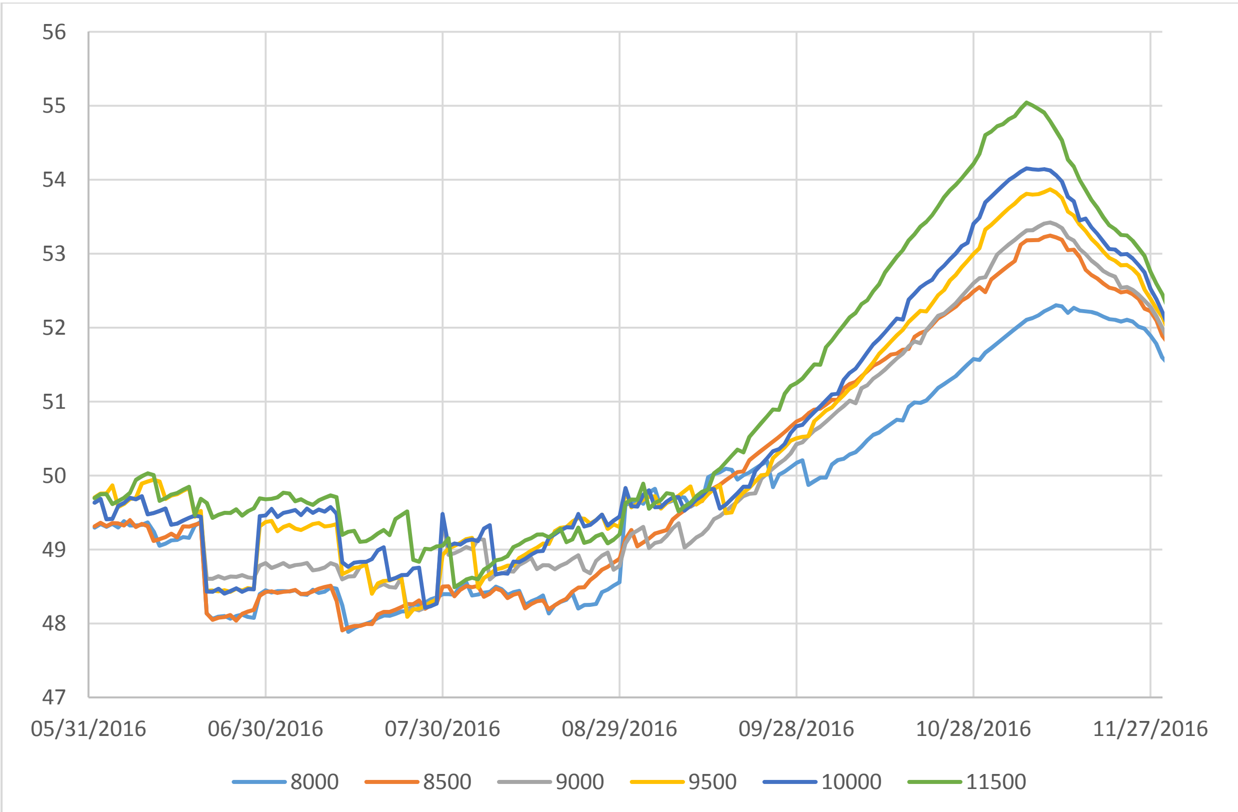

Figure 54. June 2, 2016, Keswick release scenarios, Shasta Reservoir release temperatures

June 7, 2016 – Draft Sacramento River Temperature Management Plan

Reclamation submitted a draft Sacramento River Temperature Management Plan proposing the following flows in Table 18. These flows are consistent with those in the Mach 31, 2016, concurrence letter from NMFS. The compliance point and metric would be 56ºF DAT at Balls Ferry with the average Keswick release temperature of 52.5ºF. Fall flow reductions would occur once all winter-run Chinook salmon eggs are estimated to have emerged, but as early as possible to reduce stranding of fall-run Chinook redds in the upper Sacramento River reach. Full side gate operations of the Shasta Dam TCD is projected to occur on October 9, 2016. Mean temperature-dependent mortality according to the Martin model is 4.6% (Table 20). This is a higher temperature dependent mortality than in the June 2, 2016, 8000 cfs modeled scenario (3.1%) and more than double than in the March 31, 2016 modeled scenario (2.2%).

Table 18. June 7, 2016 Updated March Plan flow schedule and monthly average temperatures

	June	July	August	September	October
Keswick Average Flow (cfs)	9,000	10,500	10,000	9,000	6,500
Keswick Average Temperature (deg F)	52.42	52.41	52.39	52.35	52.3
Balls Ferry Average Temperature (deg F)	55.03	54.96	54.58	53.85	53.01
Jellys Ferry Average Temperature (deg F)	56.42	56.37	55.82	54.75	53.47

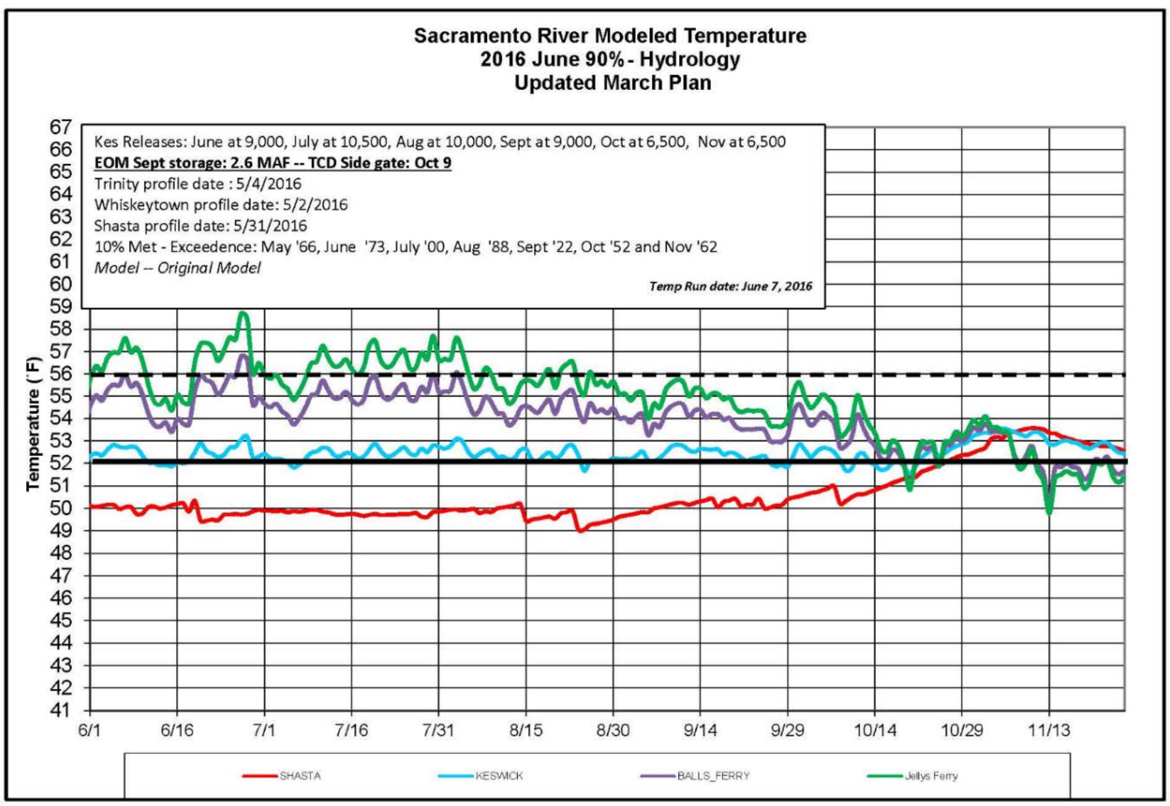

Figure 55. June 7, 2016, Update March Plan SRQWM model results

Table 19. June 7, 2016 Updated March Plan Biological Analysis

Metric	Temperature Management Plan Scenario
Full Side Gate	October 9
Egg to Emergence temp dependent mortality above Clear Creek (Zeug et al 2012)	6.0%
Temperature dependent mortality above CCR with 0.5-1.0°F increase	7.4-9.2%
Fall-run Chinook Redd dewatering (FWS 2006)	Percent of FCS redd dewatering based on 10500 cfs spawning flows is 13.3%.

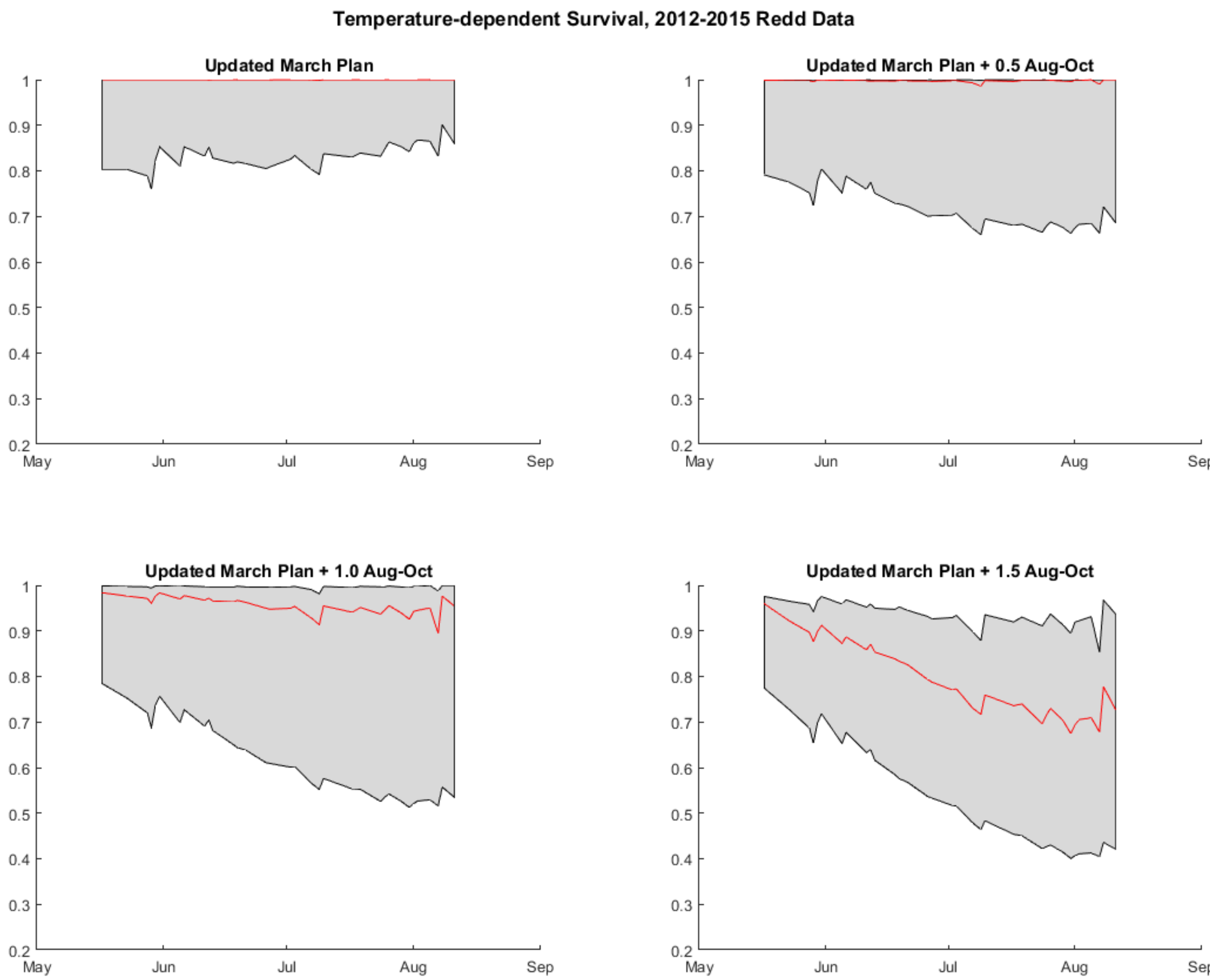

Figure 56. June 7, 2016 Updated March Plan temperature-dependent survival histogram results

Table 20. June 7, 2016, Updated March Plan temperature-dependent mortality

Percent Temperature-dependent Mortality			
Run	Mean	Median	2.5 - 97.5 Percentiles
Updated March Plan	4.58	0.11	0.077 - 43.01
Updated March Plan + 0.5 Aug-Oct	8.01	0.75	0.081 - 53.02
Updated March Plan + 1.0 Aug-Oct	15.68	8.93	0.083 - 60.98
Updated March Plan + 1.5 Aug-Oct	29.25	29.4	0.083 - 66.87

Enclosure 4

Sacramento River Temperature Management Plan
Consultation History and NMFS Comments on Reclamation's proposed plan of operations
DRAFT
06/14/16

Main point:
There are two decisions, one on flow, which affects the overall amount of cold water, and the second on how to target temperatures throughout the temperature management season and in order to delay last side gate operation of the Shasta Dam Temperature Control Device, once flows are selected. The second decision is a choice between how cool to target temperatures versus how long to extend the likely availability of cold water. The 2 issues and decisions should not be conflated. The first decision is policy elevation, second decision is not and is best made at the Shasta Water Interagency Managers Team (SWIM team) level, once a monthly flow schedule has been established.

What scenarios have been run and why? What do they tell us?
Reclamation informed the Sacramento River Temperature Task Group at its May 3 meeting that Shasta Reservoir was warmer than projected and, despite assurances that a very conservative approach was used to estimate the future availability of cold water, the model results that were the basis for NMFS' March 31, 2016, concurrence were no longer valid.

The SWIM team met to review the current profile and information, and constructed additional scenarios for Reclamation to evaluate.

In the first set of scenarios looked at in May, we asked the question: could the metrics we had established in the drought contingency plan be met? Specifically, could Reclamation meet a 55°F 7-day average of the daily maximum temperatures (7DADM) at the CCR CDEC gaging station, and delay full side gates to mid- to late-October? The answer was no. There was consensus at the SWIM team level that no scenario would meet both metrics.

Next, the SWIM team decided to evaluate the effect of flow on cold water storage by holding the temperatures constant, at 51.9°F daily average release temperature at Keswick Dam, and varying Keswick flow releases at 500 cfs increments from 7,500 cfs to 10,000 cfs. This allowed us to compare runs to examine both the timing of side gates, and running out of cold water, and the relative projected rate of increase, and amplitude of increase in temperatures, once cold water is expended.

A comparison of Keswick release temperature (figure 1) shows a very clear relative effect of flow on late season temperatures, with 8,000 cfs being significantly more likely to result in protective cold water temperatures than 9,000 cfs or higher.

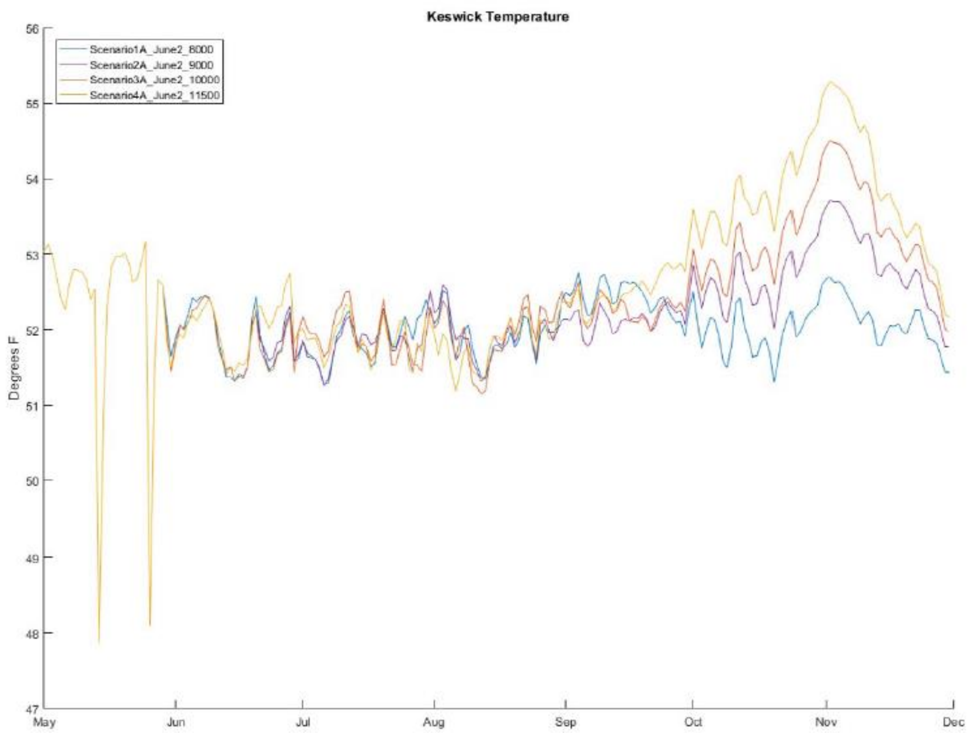

Figure 1.

Then NMFS-Southwest Fisheries Science Center (SWFSC) conducted an exceedance analysis using RAFT data for a historic estimate of how often (and to what magnitude) the 56°F daily average temperature was exceeded from 1997-2015 based on compliance targets. Daily mean temperature data were analyzed for the period May 15 - Oct 31 for each year 1997-2015. The data were analyzed using the compliance point that was set at the beginning of the season as well as with changed compliance points from later in the season. If a compliance point was changed multiple times during the season, the furthest upstream point was used for the analysis. Figure 2 shows that from May through October, daily average water temperatures were exceeded from approximately 8-38 percent of the time (when the temperature compliance location changed, with more frequent exceedances as the summer progressed. In addition, figure 3 shows that from May through October, daily average water temperature exceedances ranged in magnitude from approximately 0.3-1.1°F (when the temperature compliance location changed, with more frequent exceedances as the summer progressed.

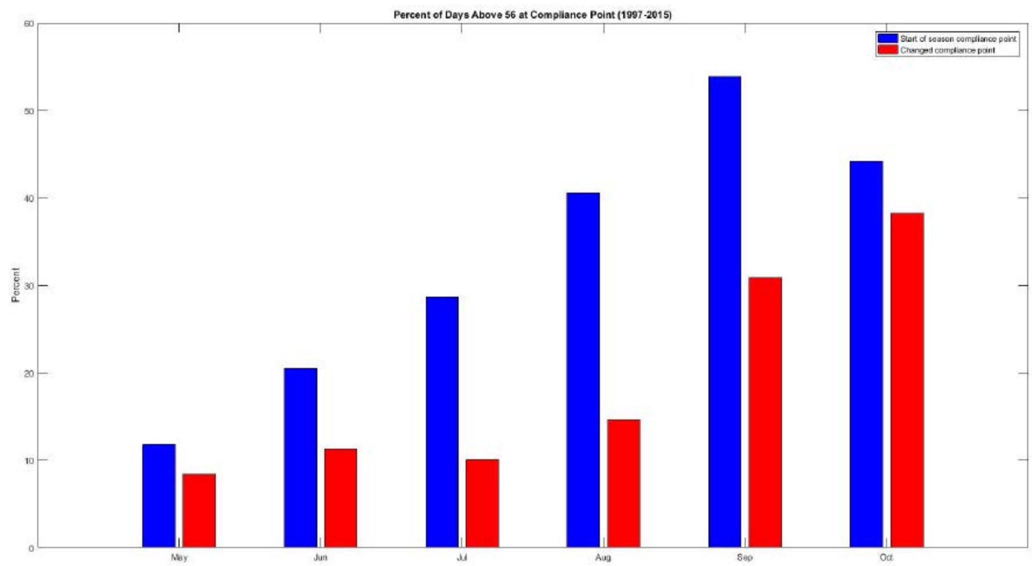

Figure 2. Percent exceedance of the 56°F daily average temperature, from 1997-2015.

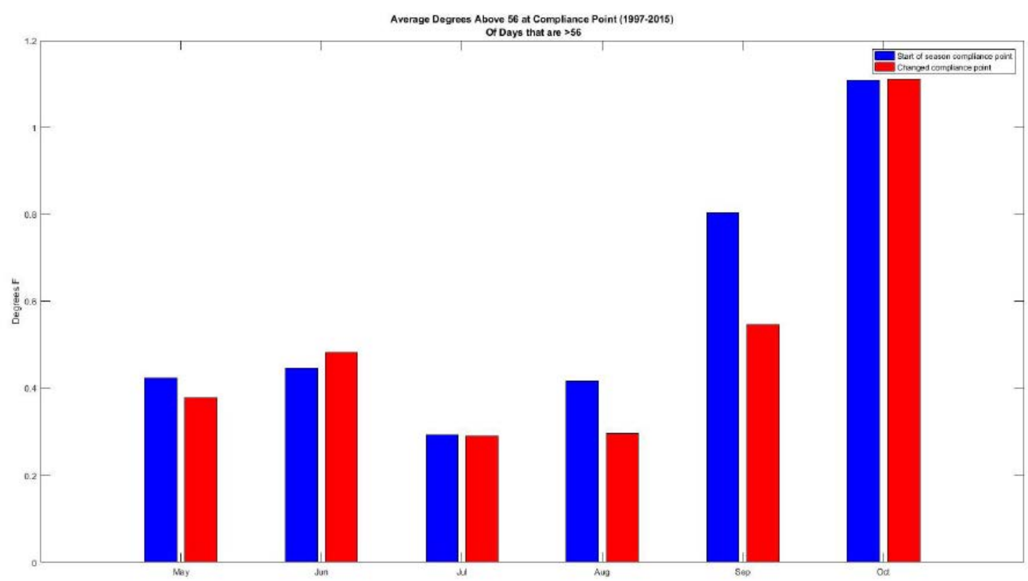

Figure 3. Magnitude of exceedance of the 56°F daily average temperature, from 1997-2015.

Each of the Keswick release schedules and temperature management scenarios included mortality estimates. Reclamation utilized Zeug *et al*. (2012), with inputs based on Reclamation's temperature model. The NMFS-SWFSC utilized the Martin temperature dependent mortality model, utilizing inputs based on its RAFT model. There are differences in mortality estimates between the 2 models, and NMFS believes the Martin model utilizes best available science, as the inputs are based on the RAFT model, and temperature dependent mortality is based on field measurements rather than laboratory tests. Regardless, without state-of-the-art Shasta and Keswick reservoir models based on best available science, winter-run Chinook salmon egg and fry mortality using input Keswick releases and temperatures is likely underestimated, as the timing and amplitude of temperature effects are likely underestimated.

NMFS and CDFW technical advice:
In light of the historical analysis and the model series a comparative analyses, the NMFS and California Department of Fish and Wildlife (CDFW) biologists concluded that the 8,000 cfs scenario was the most reasonably protective of the cold water pool. The biologists concluded that a stable Keswick release lower than 8,000 cfs might be more protective of winter-run eggs and alevin, but was not reasonable considering Reclamation's operations plan. NMFS and CDFW provided this advice to Reclamation.

On June 7, 2016, Reclamation submitted to NMFS a draft Sacramento River Temperature Management Plan that was different from NMFS and CDFW advice. As Reclamation indicated, the proposed Keswick releases were consistent with those in NMFS' March 31, 2016, concurrence letter, however, the plan also targets warmer water temperatures throughout season.

Reclamation continues to raise concerns about the low 55°F 7DADM metric and the possibility that targeting this metric may run out of cold water earlier. As stated in the "Main Point" section, above, targeting a temperature compliance point or metric potentially above 55°F 7DADM is a second step, and should not the conflated with the decision on flows. After a flow release schedule is selected, then a suboptimal temperature can be selected by the SWIM team, in order to stretch the cold water pool and delay full side gate operations.

NMFS' Comments on Reclamation's June 7, 2016, Draft Sacramento River Temperature Management Plan:
NMFS has reviewed Reclamation's proposed plan, and offer the following observations and concerns:

- NMFS' March 31, 2016, initial concurrence:
  - included a Keswick release schedule and temperature criterion. Reclamation's draft plan reiterates the agreed upon Keswick release schedule, but does not appear to meet the temperature criterion.
  - acknowledges the need to modify the flow schedule to minimize redd dewatering. We still need Reclamation to propose a release schedule that minimizes winter-run redd dewatering potential, rather than defer to real-time operations to manage this risk (such a schedule was not included in the June 7, draft).
- Temperature-dependent mortality:
  - Reclamation's estimate of temperature dependent mortality (using Zeug et al. 2012) is 6.0%; however, this is a 20% relative increase in mortality compared to what is estimated using stable Keswick monthly release schedules of 8,000-11,500 cfs (~5% mortality for each scenario).
  - NMFS-SWFSC estimates 4.58% temperature dependent mortality (using the Martin model), compared to 3.1% mortality for a stable release schedule of 8,000 cfs. This represents a 48% increase in temperature dependent mortality based on Reclamation's draft plan.
  - The Martin model is able to estimate confidence intervals. The Reclamation proposal has confidence intervals of .08 to 43% temperature related mortality, whereas the 8,000 cfs release intervals are .03 to 34%.
- Capturing uncertainty:

- A key limitation of both the Zeug and the Martin models is that they use the Reclamation temperature model outputs as inputs. Concerns about the accuracy and lack of calibration of the Reclamation model will lead to underestimates of temperature-related mortality in the Zeug and Martin model outputs. Therefore, while the confidence intervals surrounding mortality estimates from both the Zeug and Martin models explain uncertainty in the model predictions, they do not capture the even wider, underlying uncertainty in our ability to manage coupled reservoir and temperature control device operations with a high degree of specificity.
    - In order to evaluate the likelihood of exceeding suitable temperatures, NMFS considered the historic analysis (Figures 2 and 3). Considering the historic analysis, the last side gate operation may occur earlier in time, and the rate of increase and over amplitude of increase of temperatures is significantly likely to be greater than what was modeled.
    - NMFS considered a sensitivity analysis conducted by the SWFSC which added 0.5 and 1°F to consider the relative differences in mortalities between model runs associated with different proposals.
    - The results of this analysis are that the Reclamation proposal would have temperature related mortalities of 8 to 15.7 %, with new confidence intervals of .08 to 61 %, as compared to the 8,000 cfs flow run of 5.6 to 11.3 %, with new confidence intervals of .03 to 53.7%.
- Temperature compliance operations to CCR in 2015 provided a buffer for redds in the system. Redd distribution last year was further upstream relative to this year, so temperature compliance at CCR would not provide the same buffer this year.
- The timing of full side gate operation is projected to be October 9. However, it seems counterintuitive that the plan results in later full side gate access relative to that achieved by lower release schedules (*e.g.*, 8000, 8500, and 9000 cfs)

Enclosure 5

NMFS – DFW Shasta temp plan – for discussion

6/3/16

- Keswick releases no greater than 8000 cfs, daily average, for June and July
- If Reclamation wants different averaging period to assist with managing for tides in Delta – we can have that discussion
- Per earlier determinations by NMFS, temperature compliance point is 55 7DADM at CCR; This will be monitored on weekly, or bi-weekly as needed SWIM team meetings. NMFS SWFSC will use RAFT model in real-time to translate that to a downstream specific location for 56 DAT; that location will likely be between Balls Ferry and Jelly's ferry.
- In late July/early August, the SWIM team will true up the actual cold water expenditure against the model projections. If the temperature compliance point has been consistently maintained and the actual profile of the volume of cold water is better than projected/modeled, and new modeling shows that temperature compliance can be maintained throughout October at higher releases, then NMFS may make a subsequent determination to allow releases up to 9000 cfs for mid-August through mid-Oct.
- If positive findings cannot be made regarding cold water, then releases will be held at no greater than 8,000 cfs.
- NMFS is interested in providing flexible operations in other areas of the CVP/SWP system to mitigate effects of this operation for winter-run Chinook.
- Per Reclamation/FWS discussions on additional outflow, contingent on the status of the cold water pool, Shasta releases may assist in outflow in the mid-August through mid-October period.