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

February 19, 2019

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

Re: Transmittal of February Reservoir Operations Forecast Per RPA Action I.2.3

Thank you for the opportunity to review the U.S. Bureau of Reclamation's (Reclamation) Central Valley Project (CVP) reservoir operations February forecast of hydrology and projection of temperature management options for water year 2019 and the opportunity to provide Reclamation with technical assistance regarding implementation of reasonable and prudent alternative (RPA) Action I.2.3. Your February 15, 2019 letter included results of the 90 and 50 percent exceedance CVP reservoir operations forecasts, and water temperature modeling using 50 and 10 percent long-term 3-month temperature outlooks (L3MTO).

For purposes of compliance with RPA Action I.2.3 described in NOAA's National Marine Fisheries Service's (NMFS) June 4, 2009, conference and biological opinion on the long-term operation of the CVP and State Water Project (SWP), NMFS shall review the February forecast to determine whether the predicted delivery schedule is likely to leave sufficient water for temperature management to meet Endangered Species Act (ESA) requirements, and provide a written evaluation to Reclamation prior to Reclamation making the first allocation announcements. The objective of this RPA action is to use a conservative forecast as early as possible to protect the cold water pool in Shasta Reservoir so that suitable habitat can be maintained downstream during the summer and fall for federally listed endangered Sacramento River winter-run Chinook salmon *(Oncorhynchus tshawytscha)*, and threatened Central Valley spring-run Chinook salmon (*O. tshawytscha).*

NMFS has reviewed Reclamation's February 2019 CVP reservoir operations forecasts (Enclosure 1) and corresponding water temperature model runs for the Sacramento River (Enclosure 2). In addition, the NMFS-Southwest Fisheries Science Center (SWFSC) has provided model run results for the River Assessment for Forecasting Temperature (RAFT), and temperature-dependent mortality estimates using Reclamation's HEC-5Q model and the NOAA CE-QUAL-W2 reservoir model (Enclosure 3).

The CVP reservoir operations February forecast is based on estimated runoff within the Sacramento River Basin as of February 1, 2019, and forecasted inflow and projected storage are shown in (Table 1). As of February 1, 2019, the Sacramento Valley Water Year Type Index (SVI) was 6.9 (50 percent exceedance) and classified as below normal (*http://cdec.water.ca.gov/cgi-progs/iodir_ss/wsi*).

Table 1. Bureau of Reclamation's February CVP reservoir operations percent exceedance forecast for estimated annual inflow, and projected end of April and September storages into Shasta Reservoir in million acre-feet (MAF) for 2019.

Exceedance forecast (percent)	Estimated annual inflow (MAF)	End of April projected storage (MAF)	End of September projected storage (MAF)
90	4.46	4.05	2.65
50	4.99	4.40	3.12

The resulting HEC-5Q water temperature model runs based on the 90 percent exceedance hydrological and average historic meteorological conditions forecast (50% L3MTO) indicate that 56°F daily average temperature (DAT) at the Balls Ferry compliance point may not be met throughout the entire temperature management season (Figures 1 and 4 of Enclosure 2). Because past analyses have shown that the temperature model does not perform well in late September and October, Reclamation used the relationship between end-of-September (EOS) Shasta Reservoir volume below 56°F and projected water temperature at Balls Ferry in order to better predict fall water temperatures (Figure 4 of Enclosure 2). Results indicated that between September 20 and October 31, the historical maximum mean 3-day water temperature would be approximately 56.3°F.

Reclamation expressed concern regarding the use of a 10 percent exceedance meteorology coupled with a 90 percent exceedance hydrology in modeling runs, which may have a compounding effect, resulting in projected temperature performance well in excess of a 90 percent overall exceedance. However, NMFS thinks that hydrology and meteorology, although somewhat related, are relatively independent, and therefore, both should be considered in any modeled projections of temperature management. For example, long-range average temperature data from NOAA's National Climatic Data Center from May through October in the Sacramento region show increasing average temperatures through time (Figure 1).

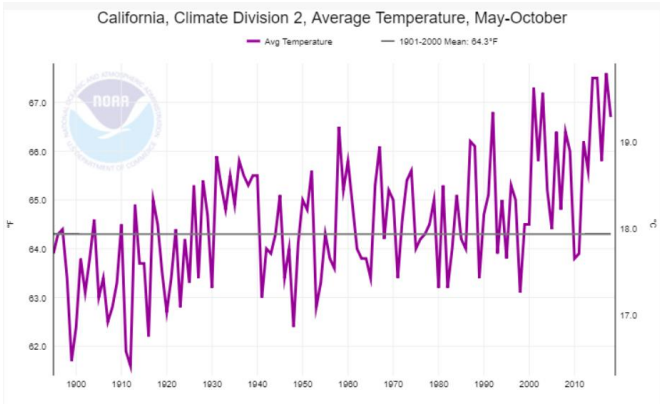

Figure 1. NOAA's National Climatic Data Center long-range data set showing an increasing trend in average temperatures from May through October (https://www.ncdc.noaa.gov/cag/divisional/time-series/0402/tavg/6/10/1895-2019?base_prd=true&firstbaseyear=1985&lastbaseyear=2017)

In addition, NOAA's National Weather Service (NWS) Climate Prediction Center (CPC) predicts a higher probability of above normal temperatures (1981-2000 average) across the western states in July, August, and September, 2019 (Figure 2).

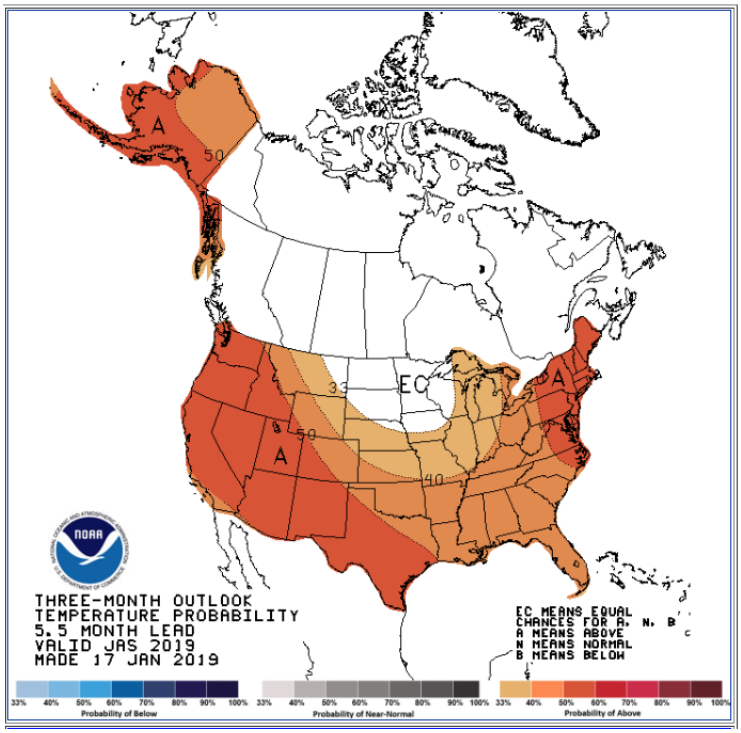

Figure 2. NOAA's National Weather Service's Climate Prediction Center's forecast of temperatures in July, August, and September, 2019 (https://www.cpc.ncep.noaa.gov/products/predictions/long_range/seasonal.php?lead=6)

Finally, NOAA-NWS CPS projects above average air temperatures (≈ 1°F warmer than the 1981-2010 average) in July, August, and September 2019, indicating that the use of 50% L3MTO is not conservative (Figure 3).

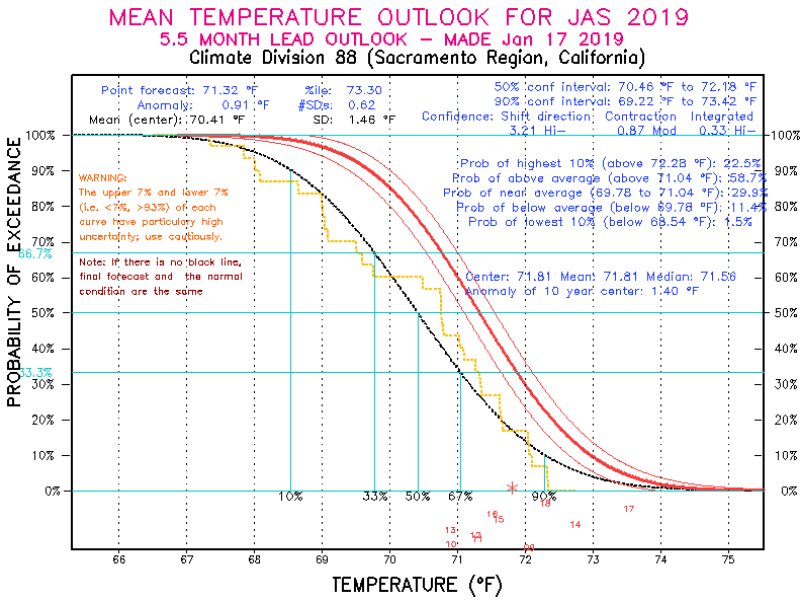

Figure 3. NOAA's National Weather Service Climate Prediction Center mean temperature outlook for July, August, and September 2019 for the Sacramento Region, California. Probability of exceedance curves give the forecast probability that a temperature, shown on the horizontal axis, will be exceeded for the given season at the given lead time (https://www.cpc.ncep.noaa.gov/products/predictions/long_range/poe_graph_index.php?lead=6&climdiv=88&var=t).

Finally, regarding the 90% exceedance forecast with 50% L3MTO projects full side gate access on September 22, 2019, whereas full side gate access is forecasted to occur on September 1, 2019 with either of the 10% L3MTO scenarios. A 3-week difference in full side gate access using more conservative meteorological conditions indicates sensitivity to ambient temperatures and further uncertainty in attaining 56°F at Balls Ferry reliably throughout September and October.

In addition to examining the ability to meet 56°F at Balls Ferry, NMFS analyzed predicted temperature dependent mortality. Tables 2 and 3 (summarized from Enclosure 3), provide results from the temperature-dependent egg mortality model using the NMFS-SWFSC CE-QUAL-W2 and Reclamation's HEC-5Q reservoir models, respectively. While the model uses a historical set of redd distribution and does not project actual mortality, results provide relative comparisons across scenarios. Note that the temperature-dependent mortality model estimates using NMFS-SWFSC's CE-QUAL-W2 reservoir model are 2.11-3.61 percent higher than those using Reclamation's HEC-5Q reservoir model.

Table 2. Estimated temperature-dependent egg mortality for 2019 under different hydrological and meteorological percent exceedance forecast scenarios, using NMFS-SWFSC's CE-QUAL-W2 reservoir model, and assuming 2012-17 spatial and temporal redd distribution.

Hydrology	Meteorology	Percent temperature-dependent egg mortality		
		Mean	Median	95% CI
50%	10%	40.78	42.89	0.08-74.02
50%	50%	13.64	4.07	0.08-61.16
90%	10%	37.07	38.8	0.08-73.7
90%	50%	20.6	16.56	0.08-63.79

Table 3. Estimated temperature-dependent egg mortality for 2019 under different hydrological and meteorological percent exceedance forecast scenarios, using Reclamation's HEC-5Q reservoir model, and assuming 2012-17 spatial and temporal redd distribution.

Hydrology	Meteorology	Percent temperature-dependent egg mortality		
		Mean	Median	95% CI
50%	10%	37.37	38.32	0.08-72.63
50%	50%	11.53	1.83	0.08-58.6
90%	10%	33.46	33.59	0.08-72.2
90%	50%	17.55	12.07	0.08-61.75

Under the 90% exceedance hydrology, the projected storage in Shasta Reservoir at the end of September is approximately 2.65 million acre feet, indicating that the metric is met for RPA Action I.2.3.A.

In summary, NMFS concludes that February conditions, forecasted operations, and modeling based on 90 percent hydrology and best available information on predicted meteorology do not show that a 56°F temperature at Balls Ferry can be attained throughout the temperature management season. Therefore, at this time, NMFS recommends the implementation of RPA Action I.2.3.B. We understand that the hydrology (including Shasta storage and snow pack) has improved since the California Department of Water Resources provided information based on February 1 hydrologic conditions, and you may be making initial allocations based on this information. NMFS would like to review the final March forecast and associated modeling before making a final determination on whether the proposed operations reliably show an ability to meet 56°F at Balls Ferry throughout the temperature management season. We are also willing to have further discussions between now and the March forecast about the most likely meteorology based on NOAA's National Weather Service and Climate Prediction Service CPC outputs, and how to integrate these forecasts with your model. Our intent is to get the most reliable air temperature predictions for the summer of 2019, while not being overly conservative. NMFS looks forward to receiving the updated hydrology, updated forecast and associated Keswick release schedule in March and is willing to share technical information in the interim to align approaches.

If you have any questions regarding this letter, please contact me at maria.rea@noaa.gov or at (916) 930-3600, or have your staff contact Garwin Yip at (916) 930-3611 or via e-mail at garwin.yip@noaa.gov.

Sincerely,

Maria C. Rea
Assistant Regional Administrator

Enclosures:

1. Reclamation's CVP Operations February 90 and 50 percent exceedance forecasts (2 pages)
2. Reclamations preliminary water temperature analysis based on four scenarios cross-factoring 90 and 50 percent exceedance hydrology with 10 and 50 percent exceedance meteorology (18 pages)
3. NMFS-SWFSC RAFT and temperature-dependent mortality model results for the four forecast and meteorology scenarios (6 pages)

cc: ARN File: 151422SWR2006SA00268

Enclosure 1

Estimated CVP Operations 90% Exceedance

Storages

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

		Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
Trinity	**1587**	**1657**	**1664**	**1715**	**1756**	**1663**	**1511**	**1328**	**1225**	**1194**	**1163**	**1145**	**1144**
	Elev.	2316	2316	2320	2323	2316	2304	2288	2279	2276	2273	2271	2271
Whiskeytown	**207**	**206**	**206**	**238**	**238**	**238**	**238**	**238**	**238**	**206**	**206**	**206**	**206**
	Elev.	1199	1199	1209	1209	1209	1209	1209	1209	1199	1199	1199	1199
Shasta	**2912**	**3517**	**3996**	**4045**	**3863**	**3583**	**3199**	**2887**	**2650**	**2451**	**2398**	**2422**	**2503**
	Elev.	1029	1048	1049	1043	1032	1016	1003	992	982	979	980	984
Folsom	**523**	**609**	**656**	**798**	**911**	**917**	**761**	**669**	**618**	**542**	**474**	**415**	**384**
	Elev.	430	435	449	460	461	446	436	430	422	413	405	401
New Melones	**1871**	**1975**	**1940**	**1882**	**1821**	**1740**	**1670**	**1606**	**1558**	**1507**	**1509**	**1513**	**1515**
	Elev.	1050	1047	1041	1036	1028	1021	1014	1009	1004	1004	1005	1005
San Luis	**813**	**897**	**924**	**799**	**579**	**292**	**95**	**4**	**36**	**157**	**340**	**553**	**682**
	Elev.	537	540	523	498	465	438	424	437	452	468	507	528
Total		8860	9386	9477	9168	8433	7474	6731	6325	6057	6090	6254	6434

Monthly River Releases (TAF/cfs)

Trinity	TAF	17	18	32	180	47	28	53	52	23	18	18	18
	cfs	**300**	**300**	**540**	**2,924**	**783**	**450**	**857**	**870**	**373**	**300**	**300**	**300**
Clear Creek	TAF	11	12	13	13	17	9	9	9	12	12	12	12
	cfs	**200**	**200**	**218**	**216**	**288**	**150**	**150**	**150**	**200**	**200**	**200**	**200**
Sacramento	TAF	180	200	447	528	625	669	591	436	428	296	246	246
	cfs	**3250**	**3250**	**7517**	**8593**	**10500**	**10885**	**9610**	**7334**	**6955**	**4968**	**4000**	**4000**
American	TAF	555	184	89	92	89	219	154	113	111	108	111	92
	cfs	**10000**	**3000**	**1500**	**1500**	**1500**	**3570**	**2505**	**1896**	**1800**	**1807**	**1800**	**1500**
Stanislaus	TAF	83	93	83	92	56	18	18	18	49	12	12	14
	cfs	**1500**	**1521**	**1400**	**1500**	**940**	**300**	**300**	**300**	**797**	**200**	**200**	**232**

Trinity Diversions (TAF)

	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
Carr PP	8	92	72	7	135	130	131	50	14	25	21	15
Spring Crk. PP	**10**	**99**	**42**	**0**	**120**	**120**	**120**	**40**	**35**	**15**	**12**	**10**

Delta Summary (TAF)

	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
Tracy	200	170	54	55	89	231	265	260	260	250	258	180
USBR Banks	0	0	0	0	0	18	18	18	0	0	0	0
Contra Costa	14.0	12.7	12.7	12.7	9.8	11.1	12.7	14.0	16.8	18.4	18.3	14.0
Total USBR	214	183	66	68	99	260	296	292	277	268	276	194
Total Export	396	295	102	105	159	318	377	447	391	327	534	374
COA Balance	0	0	0	0	0	0	0	82	94	0	0	0
Old/Middle River Std.												
Old/Middle R. calc.	-4,839	-2,967	-848	-790	-1,988	-4,198	-4,969	-5,983	-4,782	-4,375	-6,731	-4,709
Computed DOI	29807	21099	12355	9500	7699	4490	3156	2807	3611	4202	7499	9988
Excess Outflow	18406	10801	2252	2635	840	0	0	0	0	0	3432	4571
% Export/Inflow	19%	18%	10%	12%	19%	36%	46%	57%	53%	50%	52%	39%
% Export/Inflow std.	45%	35%	35%	35%	35%	65%	65%	65%	65%	65%	65%	65%

Hydrology

	Trinity	Shasta	Folsom	New Melones
Water Year Inflow (TAF)	948	4,460	2,281	956
Year to Date + Forecasted % of mean	78%	81%	84%	90%

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.

2/14/2019

Estimated CVP Operations 50% Exceedance

Storages

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

		Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
Trinity	**1587**	**1703**	**1850**	**2014**	**2024**	**1929**	**1822**	**1691**	**1553**	**1528**	**1515**	**1542**	**1606**
	Elev.	2319	2330	2342	2343	2336	2328	2318	2308	2305	2304	2307	2312
Whiskeytown	**207**	**206**	**206**	**238**	**238**	**238**	**238**	**238**	**238**	**206**	**206**	**206**	**206**
	Elev.	1199	1199	1209	1209	1209	1209	1209	1209	1199	1199	1199	1199
Shasta	**2912**	**3542**	**4127**	**4404**	**4359**	**4108**	**3684**	**3336**	**3124**	**2964**	**2925**	**3011**	**3371**
	Elev.	1030	1052	1062	1060	1052	1036	1022	1013	1006	1004	1008	1023
Folsom	**523**	**609**	**676**	**788**	**932**	**877**	**745**	**665**	**618**	**569**	**540**	**529**	**526**
	Elev.	430	437	448	462	457	444	436	430	425	421	420	420
New Melones	**1871**	**1975**	**1966**	**1926**	**1893**	**1866**	**1803**	**1739**	**1695**	**1654**	**1670**	**1694**	**1726**
	Elev.	1050	1049	1046	1042	1040	1034	1028	1023	1019	1021	1023	1026
San Luis	**813**	**888**	**947**	**801**	**564**	**420**	**219**	**94**	**114**	**235**	**411**	**621**	**780**
	Elev.	535	542	519	485	458	440	438	453	467	493	527	546
Total		8923	9772	10171	10011	9437	8512	7763	7341	7156	7267	7602	8215

Monthly River Releases (TAF/cfs)

Trinity	TAF	17	18	28	258	126	68	53	52	23	18	18	18
	cfs	**300**	**300**	**477**	**4,189**	**2,120**	**1,102**	**857**	**870**	**373**	**300**	**300**	**300**
Clear Creek	TAF	11	12	13	13	17	9	9	9	12	12	12	15
	cfs	**200**	**200**	**218**	**216**	**288**	**150**	**150**	**150**	**200**	**200**	**200**	**240**
Sacramento	TAF	180	200	327	492	595	707	615	476	428	355	307	246
	cfs	**3250**	**3250**	**5500**	**8000**	**10000**	**11500**	**10000**	**8000**	**6955**	**5975**	**5000**	**4000**
American	TAF	555	307	208	184	208	222	161	126	123	119	123	154
	cfs	**10000**	**5000**	**3500**	**3000**	**3500**	**3612**	**2611**	**2113**	**2000**	**2002**	**2000**	**2500**
Stanislaus	TAF	83	93	83	96	56	18	18	18	49	12	12	14
	cfs	**1500**	**1521**	**1400**	**1555**	**940**	**300**	**300**	**300**	**797**	**200**	**200**	**232**

Trinity Diversions (TAF)

	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
Carr PP	0	5	51	1	91	89	90	89	13	25	12	0
Spring Crk. PP	**35**	**30**	**30**	**2**	**80**	**80**	**80**	**80**	**35**	**20**	**15**	**20**

Delta Summary (TAF)

		Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
Tracy		200	208	54	55	259	270	265	265	265	246	260	215
USBR Banks		0	0	0	0	0	22	22	22	0	0	0	0
Contra Costa		14.0	12.7	12.7	12.7	9.8	11.1	12.7	14.0	16.8	18.4	18.3	14.0
Total USBR		214	221	66	68	269	303	300	301	282	264	278	229
Total Export		414	421	102	105	356	560	612	605	436	472	538	424
COA Balance		0	0	0	0	0	3	77	215	240	239	239	239
Old/Middle River Std.													
Old/Middle R. calc.		-3,841	-3,440	-46	281	-4,212	-6,995	-7,707	-7,839	-5,119	-5,956	-6,577	-5,028
Computed DOI		39623	29167	18575	16414	7833	5872	3611	2807	3611	4202	9760	29102
Excess Outflow		28222	18870	8069	6865	0	0	0	0	0	0	5694	23685
% Export/Inflow		16%	19%	7%	8%	35%	47%	56%	64%	56%	60%	46%	19%
% Export/Inflow std.		45%	35%	35%	35%	35%	65%	65%	65%	65%	65%	65%	65%

Hydrology

		Trinity		Shasta		Folsom		New Melones	
Water Year Inflow (TAF)		1266		4,990		2,755		1097	
Year to Date + Forecasted	% of mean	105%		90%		101%		104%	

CVP actual operations do not follow any forecasted operation or outlook; actual operations are based on real-time conditions.
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2/14/2019

Enclosure 2

February 14, 2019

Upper Sacramento River – February 2019 Preliminary Temperature Analysis

Location (°F DAT)	APR	MAY	JUN	JUL	AUG	SEP*	OCT*
February 90%-Exceedance Outlook – 50% Historical Meteorology							
Keswick Dam KWK	52.8	52.3	52.8	53.6	53.6	See Figures 1 and 2	See Figures 1 and 2
Sac. R. abv Clear Creek CCR	53.1	52.8	53.3	54.0	54.0	See Figures 1 and 3	See Figures 1 and 3
Balls Ferry BSF	55.3	55.7	55.5	55.8	55.8	See Figures 1 and 4	See Figures 1 and 4

Model Run	End of September Cold Water Pool <56°F (TAF)	First Side Gate	Full Side Gates
90% Hydro, 50% Met	580	8/25	9/22

Model Run Date February 14, 2019

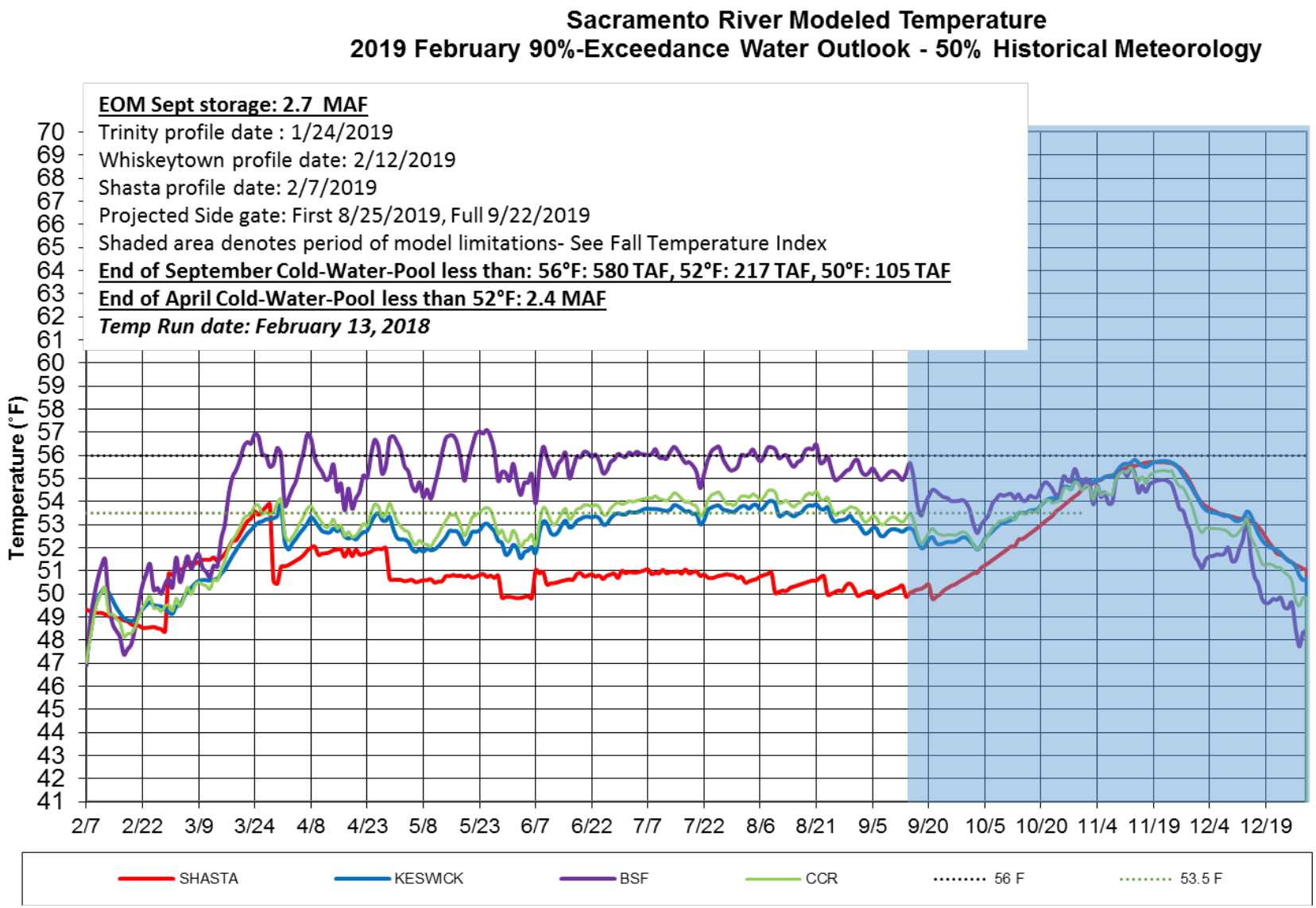

Figure 1. February 2019 simulated Sacramento River temperatures 90% runoff exceedance hydrology and 50% historical meteorology.

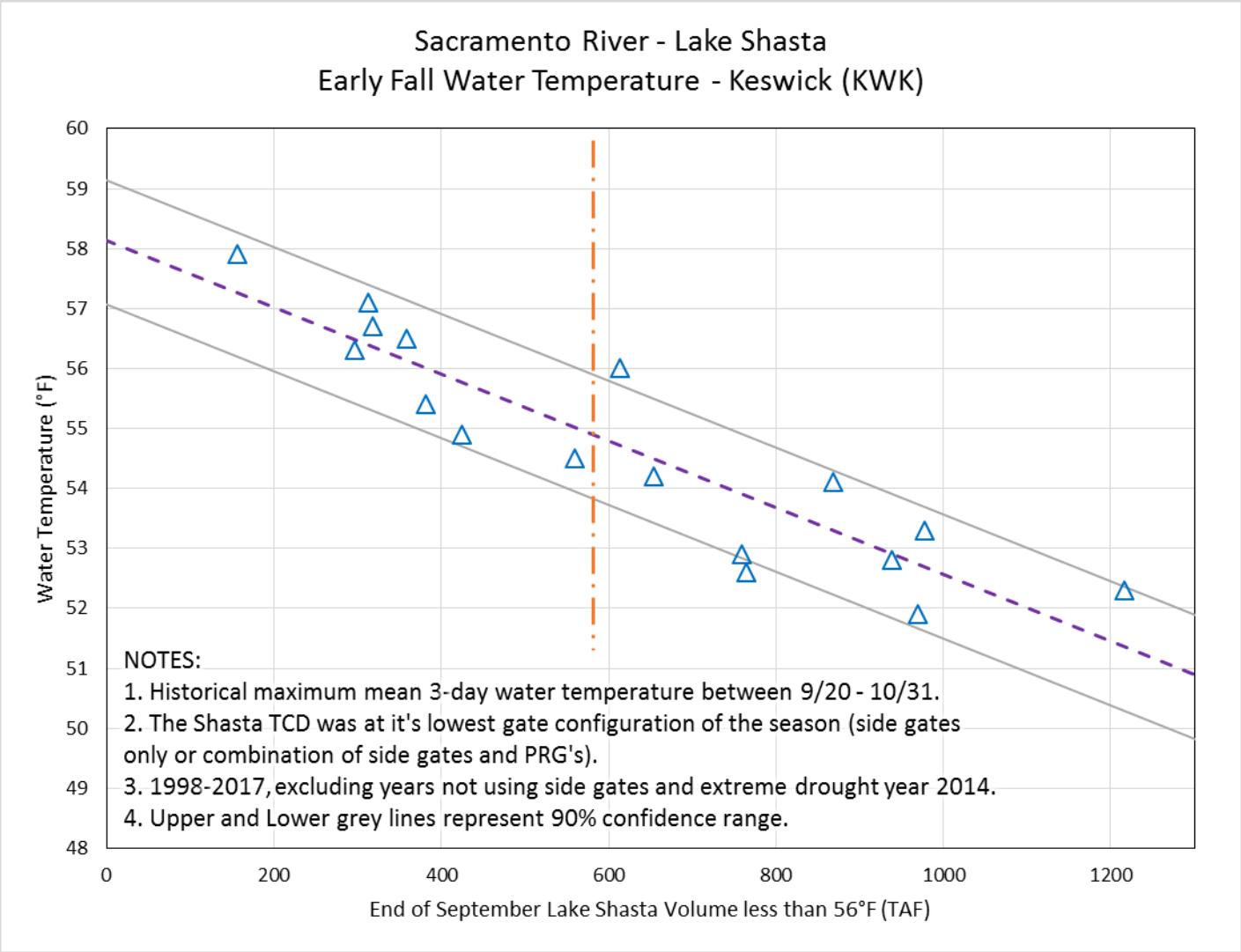

Figure 2. Historical relationship between Lake Shasta cold-water-pool characteristics and early fall Keswick water temperature and identifying relationship with 580 TAF end of September of cold-water-pool.

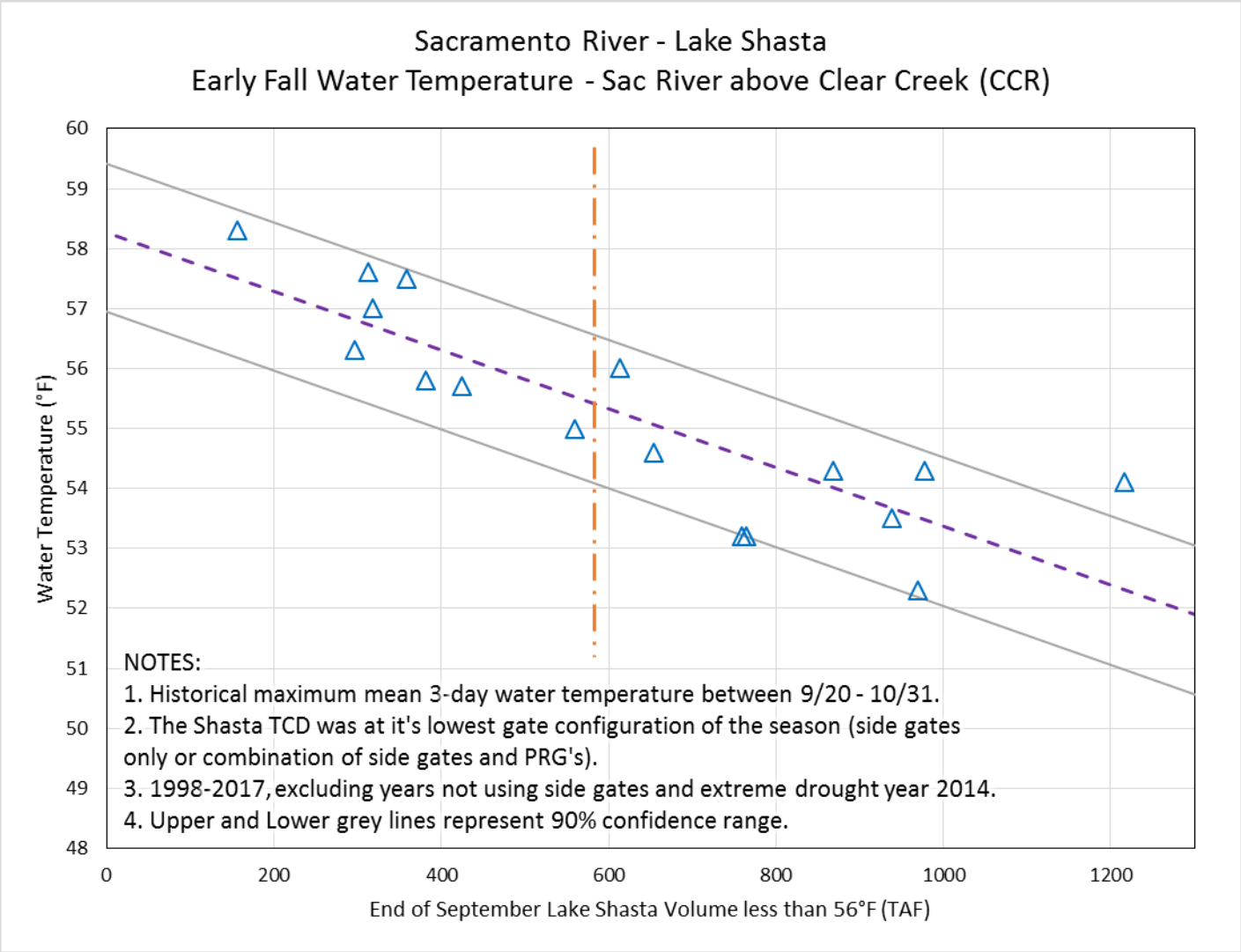

Figure 3. Historical relationship between Lake Shasta cold-water-pool characteristics and early fall Sacramento River above Clear Creek confluence water temperature and identifying relationship with 580 TAF end of September of cold-water-pool.

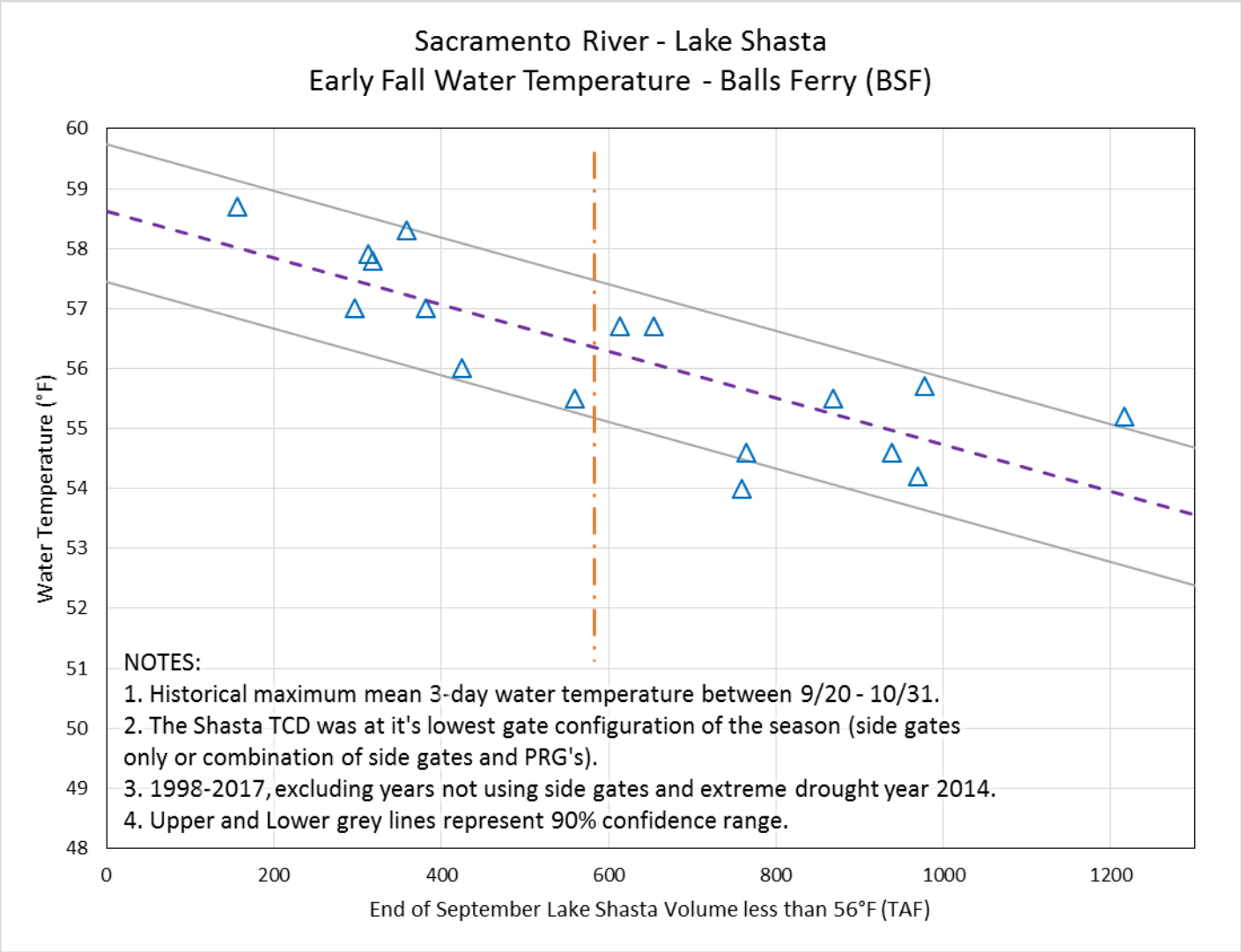

Figure 4. Historical relationship between Lake Shasta cold-water-pool characteristics and early fall Balls Ferry water temperature and identifying relationship with 580 TAF end of September of cold-water-pool.

* The HEC5Q model output is displayed above for the months April through August. Based on past analysis, the temperature model does not perform well in late September and October. One factor is that the modeled release temperatures are cooler than has historically been achieved when all release is through the side gates (lowest gates), especially when there's a large temperature gradient between the pressure relief gates (PRG) and the side gates. For the months of September and October, ranges in possible outcomes are illustrated with the Fall Temperature Index (graphics above Figures 2-4). This relationship is an end of September Lake Shasta Volume less than 56°F and likely downstream temperature performance for the early fall months.

Temperature Model Inputs, Assumptions, Limitations and Uncertainty:

1. The latest available profiles for Shasta, Trinity, and Whiskeytown were taken on February 7, January 24, and February 12, respectively. Model results are sensitive to initial reservoir temperature conditions and the model performs best under highly stratified conditions. The February 2018 temperature profile does not yet exhibit conditions for ideal model computations (still nearly isothermal conditions). The model performs well after the reservoir stratifies, typically in late spring (i.e. end of April). The concern this year is assuming over or under estimations with variable hydrologic and meteorological conditions and not capturing the stratification with sufficient detail to project into the future with confidence.
2. Guidance on forecasted flows from the creeks (e.g., Cow, Cottonwood, Battle, etc.) between Keswick Dam and Bend Bridge are not available beyond 5 days. Creek flows developed from the historical record that most closely reflects current conditions were used for all model runs. The resulting low creek flows cause significant additional warming in the upper Sacramento River during spring.
3. Operation is based on the February 2019 Operation Outlooks (monthly flows, reservoir release, and end-of-month reservoir storage) for the 90%- and 50%-exceedances. Trinity Lake inflows are updated with the CNRFC 90% runoff exceedance for both the 90% and 50% runoff exceedance studies.
4. Although mean daily flows and releases are temperature model inputs, they are based on the mean monthly values from the operation outlooks. Mean daily flow patterns are user defined and are generalized representations. It is important to note that these outlooks do not suggest a certain actual future outcome, but rather the statistical likelihood of an event occurring, including, but not limited to, projected storage and releases. Thus, the outlooks do not provide exact end of month storages or flow rates but general projections that will likely fall within the range of uncertainty based on the different hydrologic runoff conditions between the 90% and 50% runoff exceedance hydrology.
5. Cottonwood Creek flows, Keswick to Bend Bridge local flows, and ACID diversions are mean daily synthesized flows based on the available historical record for a 1922-2002 study period. Inflows were adjusted to a 50% historical exceedance for both the 90% and 50% runoff exceedance studies.
6. Meteorological inputs represent historical (1985 – 2017) monthly mean equilibrium temperature exceedance at 50% patterned after like months on a 6-hour time-step. Assumed inflows temperature remain static inputs and do not vary with the assumed meteorology. Tools to use long-term three-month-temperature outlooks, driven by the NOAA NWS Climate Prediction Center (CPC) are available beginning April, prior to April historical meteorology is used.

7. Meteorology, as well as the flow volume and pattern, significantly influences reservoir inflow temperatures and downstream tributary temperatures; and consequently, the development of the cold-water pool during winter and early spring, still uncertain prior to the end of April.
8. Modified model coefficients more closely represent actual Keswick Dam temperatures. As a result, temperature predictions downstream of Keswick Dam are likely to be warmer than actual.
9. The model is specifically being applied to generate the most accurate results at the Sacramento River above Clear Creek confluence location.

Supplemental Modeling Information

Summary of Temperature Results by Month (Monthly Average Temperature °F)

Location (°F DAT)	APR	MAY	JUN	JUL	AUG	SEP*	OCT*
February 90%-Exceedance Outlook – 10% Historical Meteorology							
Keswick Dam KWK	53.1	52.3	53.1	53.9	53.8	See Figures 5 and 8	See Figures 5 and 8
Sac. R. abv Clear Creek CCR	53.5	52.9	53.7	54.4	54.3	See Figures 5 and 9	See Figures 5 and 9
Balls Ferry BSF	55.9	56.1	56.0	56.4	56.2	See Figures 5 and 10	See Figures 5 and 10
February 50%-Exceedance Outlook – 50% Historical Meteorology							
Keswick Dam KWK	52.8	52.4	52.7	53.2	53.3	See Figures 6 and 8	See Figures 6 and 8
Sac. R. abv Clear Creek CCR	53.3	53.0	53.2	53.6	53.7	See Figures 6 and 9	See Figures 6 and 9
Balls Ferry BSF	55.9	56.0	55.6	55.3	55.5	See Figures 6 and 10	See Figures 6 and 10

Location (°F DAT)	APR	MAY	JUN	JUL	AUG	SEP*	OCT*
February 50%-Exceedance Outlook – 10% Historical Meteorology							
Keswick Dam KWK	52.3	51.9	53.0	53.5	53.8	See Figures 7 and 8	See Figures 7 and 8
Sac. R. abv Clear Creek CCR	53.0	52.6	53.5	54.0	54.2	See Figures 7 and 9	See Figures 7 and 9
Balls Ferry BSF	56.1	56.0	56.0	55.9	56.0	See Figures 7 and 10	See Figures 7 and 10

Model Run	End of September Cold Water Pool <56°F (TAF)	First Side Gate	Full Side Gates
90% Hydro, 10% Met	403	7/31	9/1
50% Hydro, 50% Met	674	8/27	9/25
50% Hydro, 10% Met	444	7/30	9/1

Model Run Date February 14, 2019

* The HEC5Q model output is displayed above for the months April through August. Based on past analysis, the temperature model does not perform well in late September and October. One factor is that the modeled release temperatures are cooler than has historically been achieved when all release is through the side gates (lowest gates), especially when there's a large temperature gradient between the pressure relief gates (PRG) and the side gates. For the months of September and October, ranges in possible outcomes are illustrated with the Fall Temperature Index (graphics below Figures 8-10). This relationship is an end of September Lake Shasta Volume less than 56°F and likely downstream temperature performance for the early fall months.

Temperature Analysis Results:
Modeling runs explore Sacramento River compliance performance above Clear Creek confluence and Balls Ferry locations by varying hydrology and meteorology. The temperature results for the Sacramento River between Keswick Dam and Balls Ferry are shown in Figures 5 through 7. The relationship between end-of-September lake volume below 56°F and a Balls Ferry compliance through fall is based on the Figures 8-10.

Temperature Model Inputs, Assumptions, Limitations and Uncertainty:
1. The latest available profiles for Shasta, Trinity, and Whiskeytown were taken on February 7, January 24, and February 12, respectively. Model results are sensitive to initial reservoir temperature conditions and the model performs best under highly stratified conditions. The February 2018 temperature profile does not yet exhibit conditions for ideal model computations (still nearly isothermal conditions). The model performs well after the reservoir stratifies, typically in late spring (i.e. end of April). The concern this year is assuming over or under estimations with variable hydrologic and meteorological conditions and not capturing the stratification with sufficient detail to project into the future with confidence.
2. Guidance on forecasted flows from the creeks (e.g., Cow, Cottonwood, Battle, etc.) between Keswick Dam and Bend Bridge are not available beyond 5 days. Creek flows developed from the historical record that most closely reflects current conditions were used for all model runs. The resulting low creek flows cause significant additional warming in the upper Sacramento River during spring.
3. Operation is based on the February 2019 Operation Outlooks (monthly flows, reservoir release, and end-of-month reservoir storage) for the 90%- and 50%-exceedances. Trinity Lake inflows are updated with the CNRFC 90% runoff exceedance for both the 90% and 50% runoff exceedance studies.
4. Although mean daily flows and releases are temperature model inputs, they are based on the mean monthly values from the operation outlooks. Mean daily flow patterns are user defined and are generalized representations. It is important to note that these outlooks do not suggest a certain actual future outcome, but rather the statistical likelihood of an event occurring, including, but not limited to, projected storage and releases. Thus, the outlooks do not provide exact end of month storages or flow rates but general projections that will likely fall within the range of uncertainty based on the different hydrologic runoff conditions between the 90% and 50% runoff exceedance hydrology.
5. Cottonwood Creek flows, Keswick to Bend Bridge local flows, and ACID diversions are mean daily synthesized flows based on the available historical record for a 1922-2002 study period. Inflows were adjusted to a 50% historical exceedance for both the 90% and 50% runoff exceedance studies.
6. Meteorological inputs represent historical (1985 – 2017) monthly mean equilibrium temperature exceedance at 10% and 50% patterned after like months on a 6-hour time-step. Assumed inflows temperature remain static inputs and do not vary with the assumed meteorology. Tools to use long-term three-month-temperature outlooks, driven by the NOAA NWS Climate Prediction Center (CPC) are available beginning April, prior to April historical meteorology is used.
7. Meteorology, as well as the flow volume and pattern, significantly influences reservoir inflow temperatures and downstream

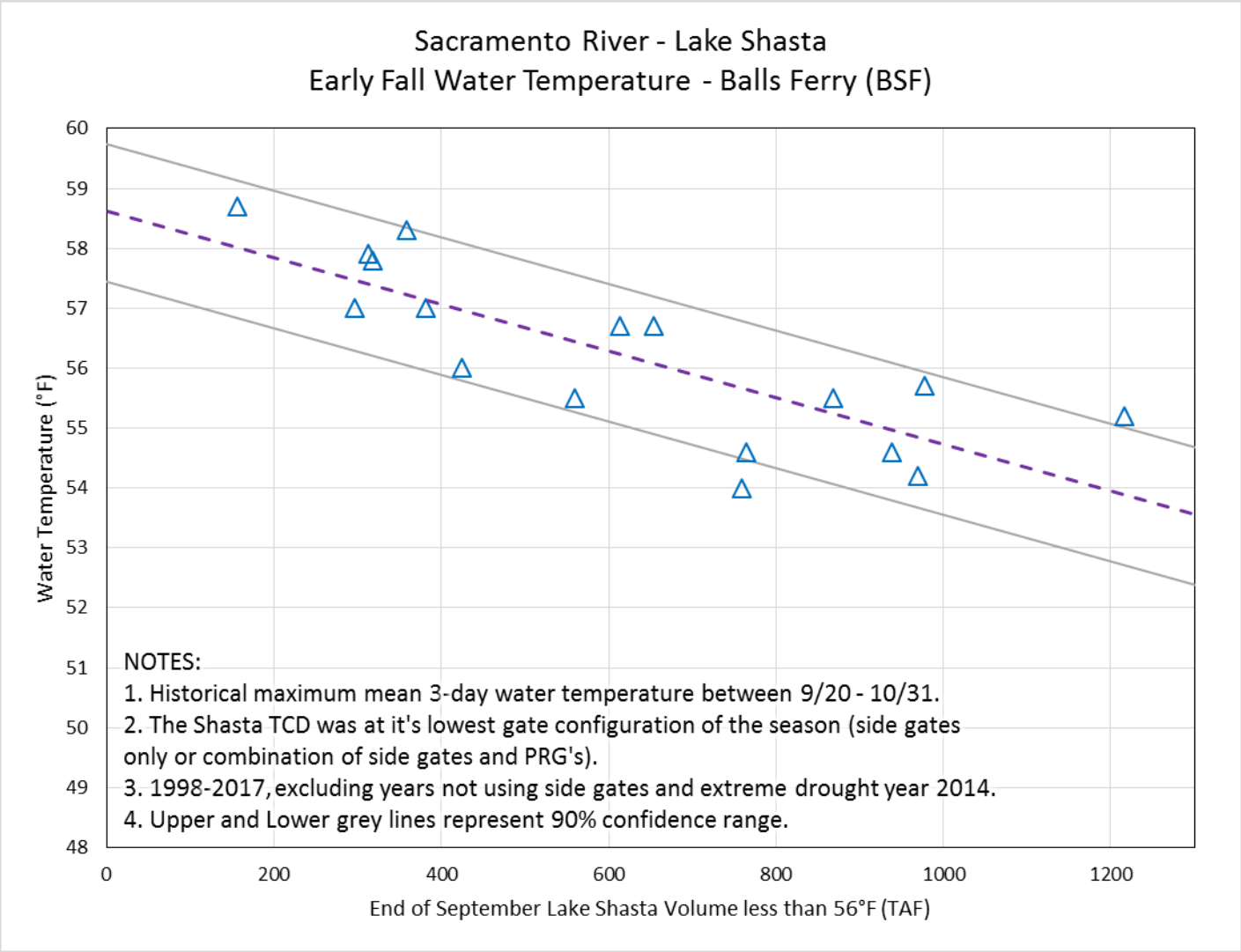

Figure 10. Historical relationship between Lake Shasta cold-water-pool characteristics and early fall Balls Ferry water temperature.

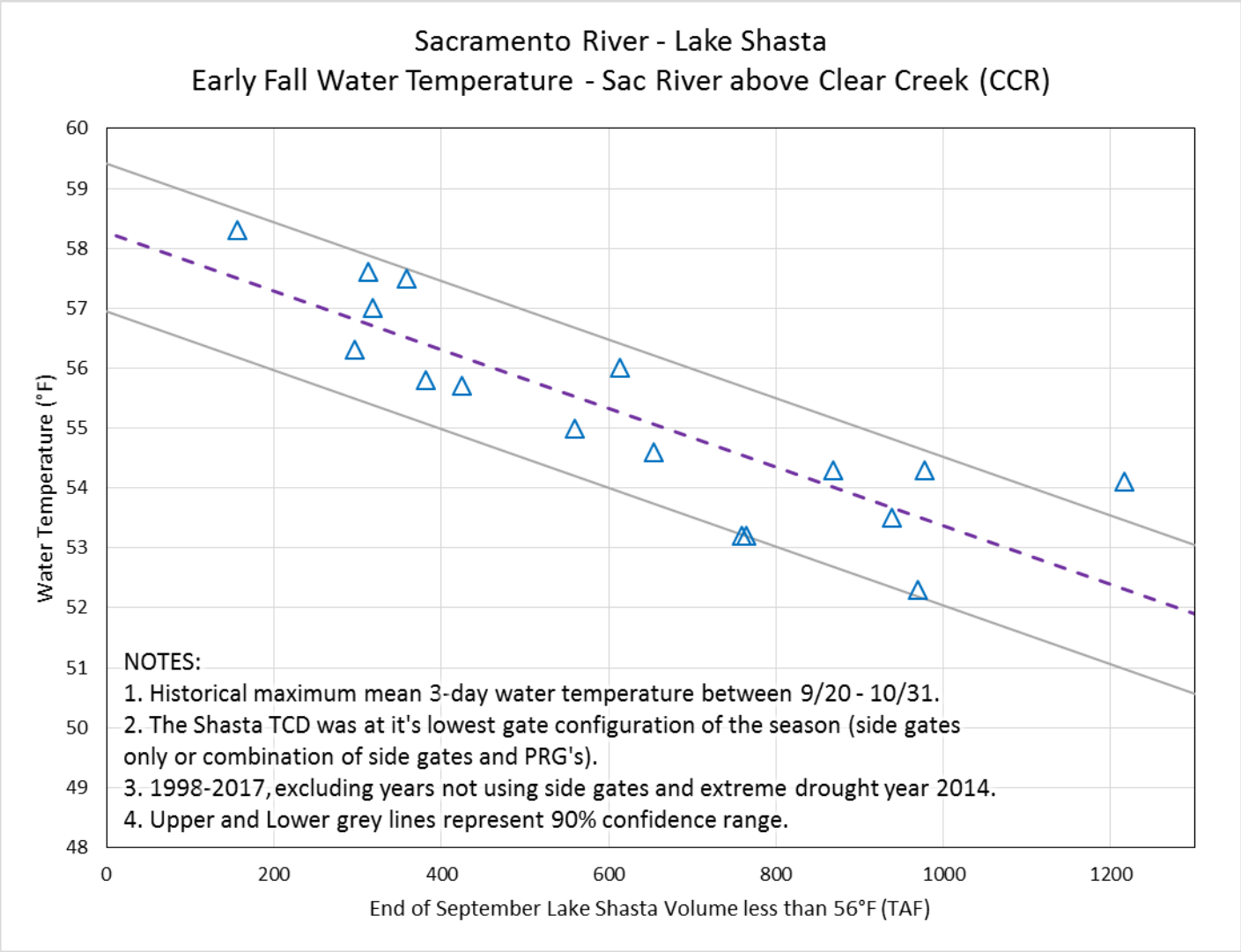

Figure 9. Historical relationship between Lake Shasta cold-water-pool characteristics and early fall Sacramento River above Clear Creek confluence water temperature.

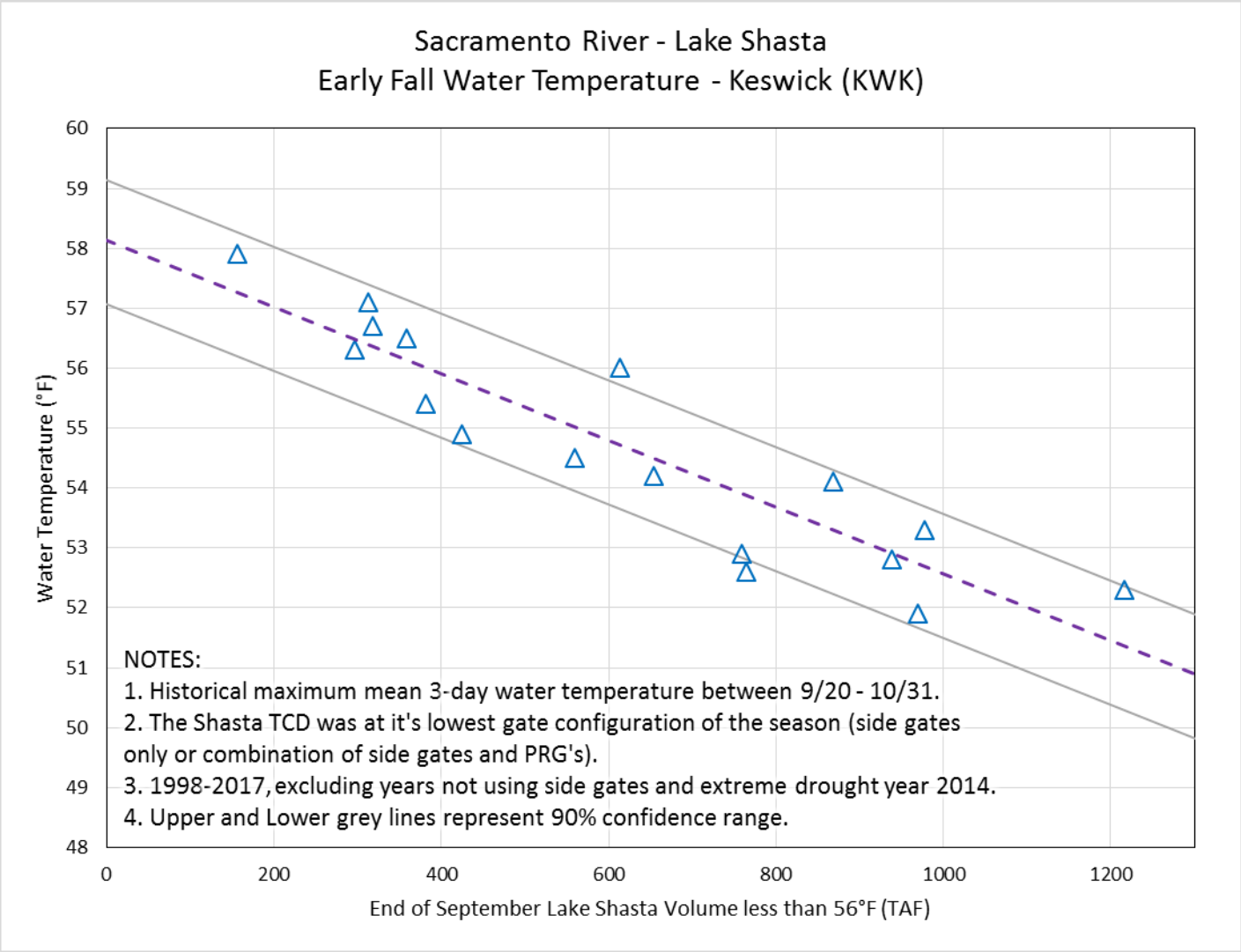

Figure 8. Historical relationship between Lake Shasta cold-water-pool characteristics and early fall Keswick water temperature.

Figure 8-10 <u>Model Performance and Fall Temperature Index</u>:

1. Based on past analyses, the temperature model does not perform well in late September and October. One factor is that the modeled release temperatures are cooler than has historically been achieved when all release is through the side gates (lowest gates), especially when there's a large temperature gradient between the pressure relief gates (PRG) and the side gates.
2. Based on historical records, the end-of-September Lake Shasta volume below 56˚F is a good indicator of fall water temperature in the river reach to Balls Ferry.
3. Based on these records and estimates, the charts below illustrates a range of uncertainty in the expected river temperatures based on the end-of-September lake volume less than 56˚F.

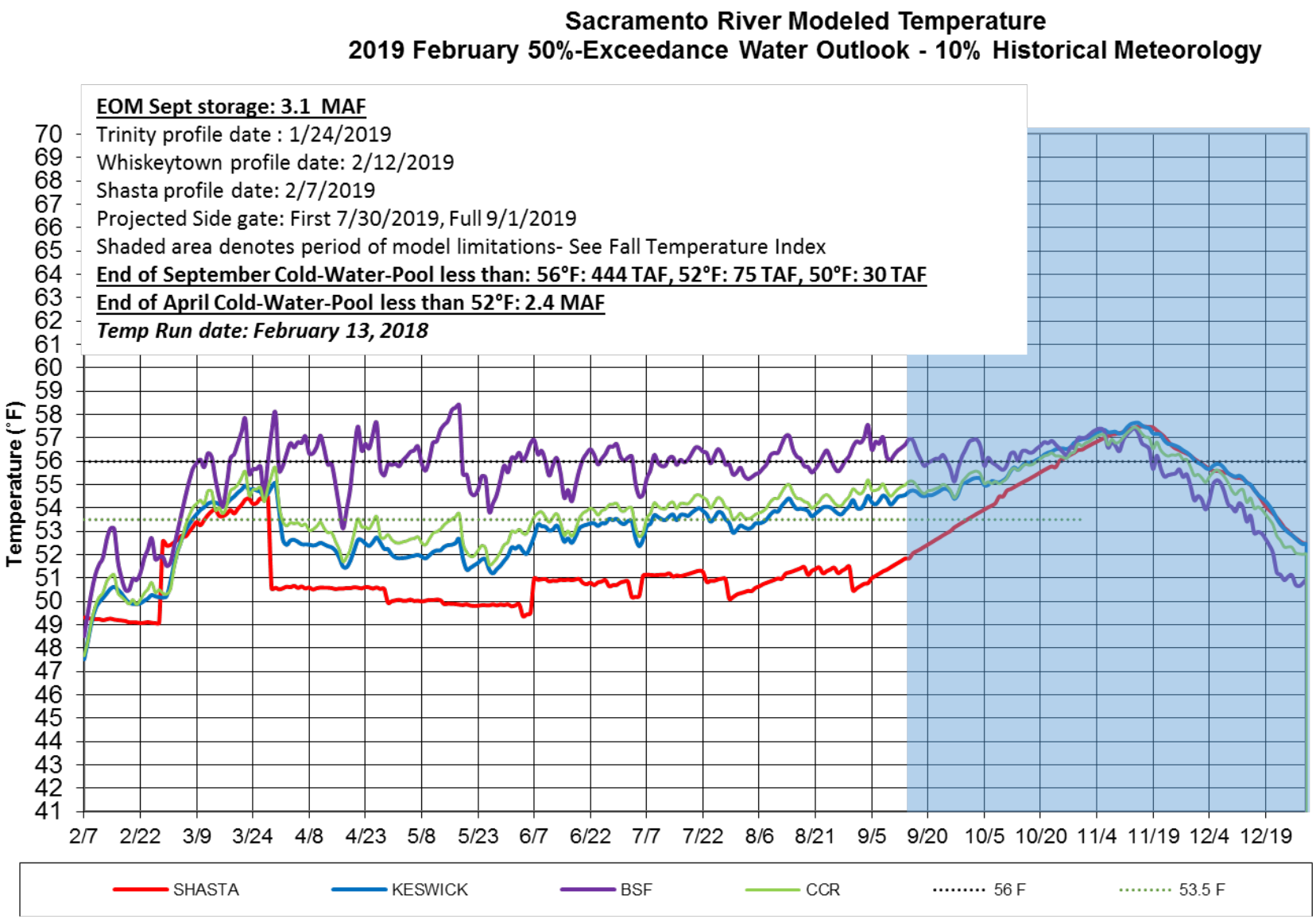

Figure 7. February 2019 simulated Sacramento River temperatures 50% runoff exceedance hydrology and 10% historical meteorology.

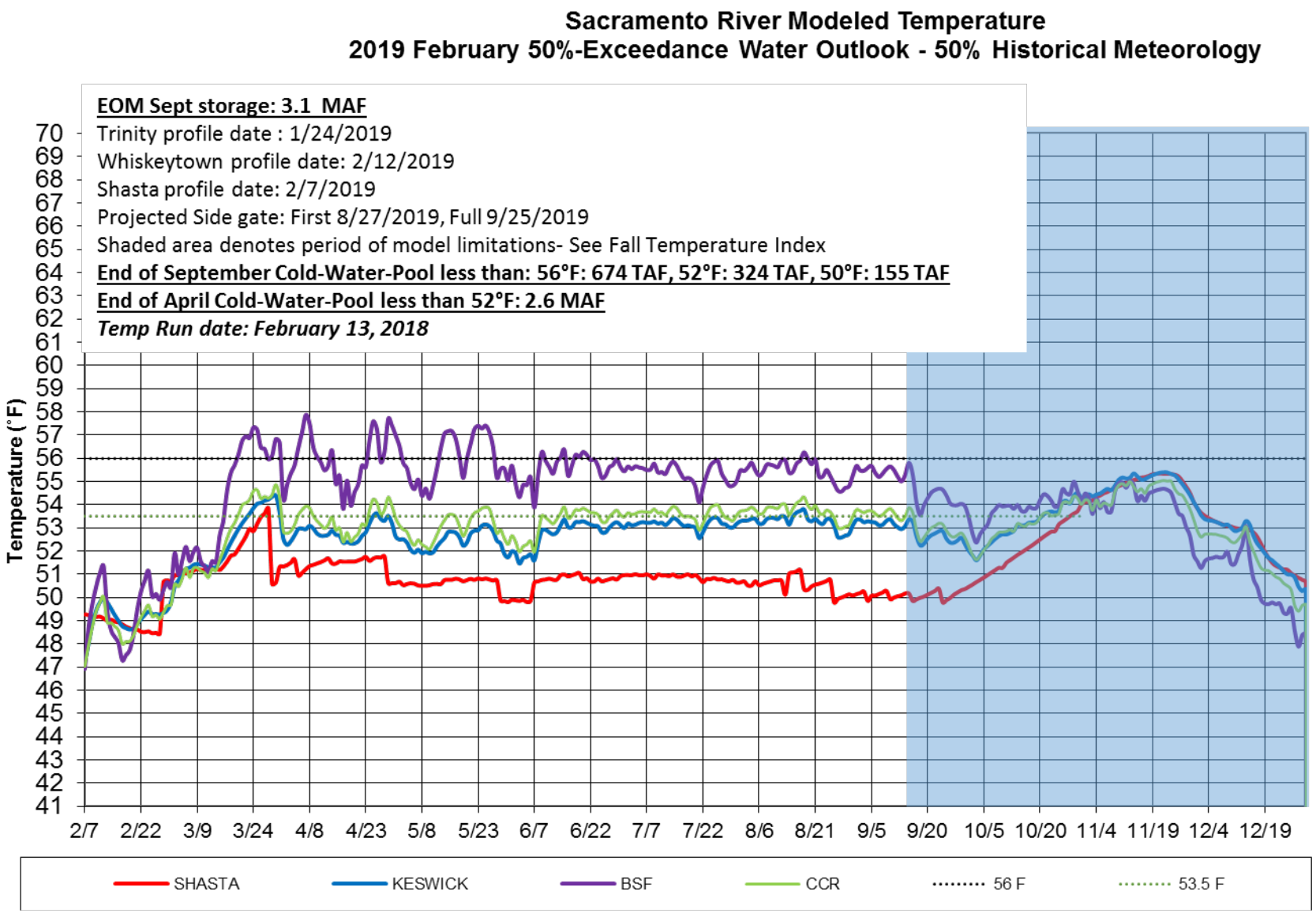

Figure 6. February 2019 simulated Sacramento River temperatures 50% runoff exceedance hydrology and 50% historical meteorology.

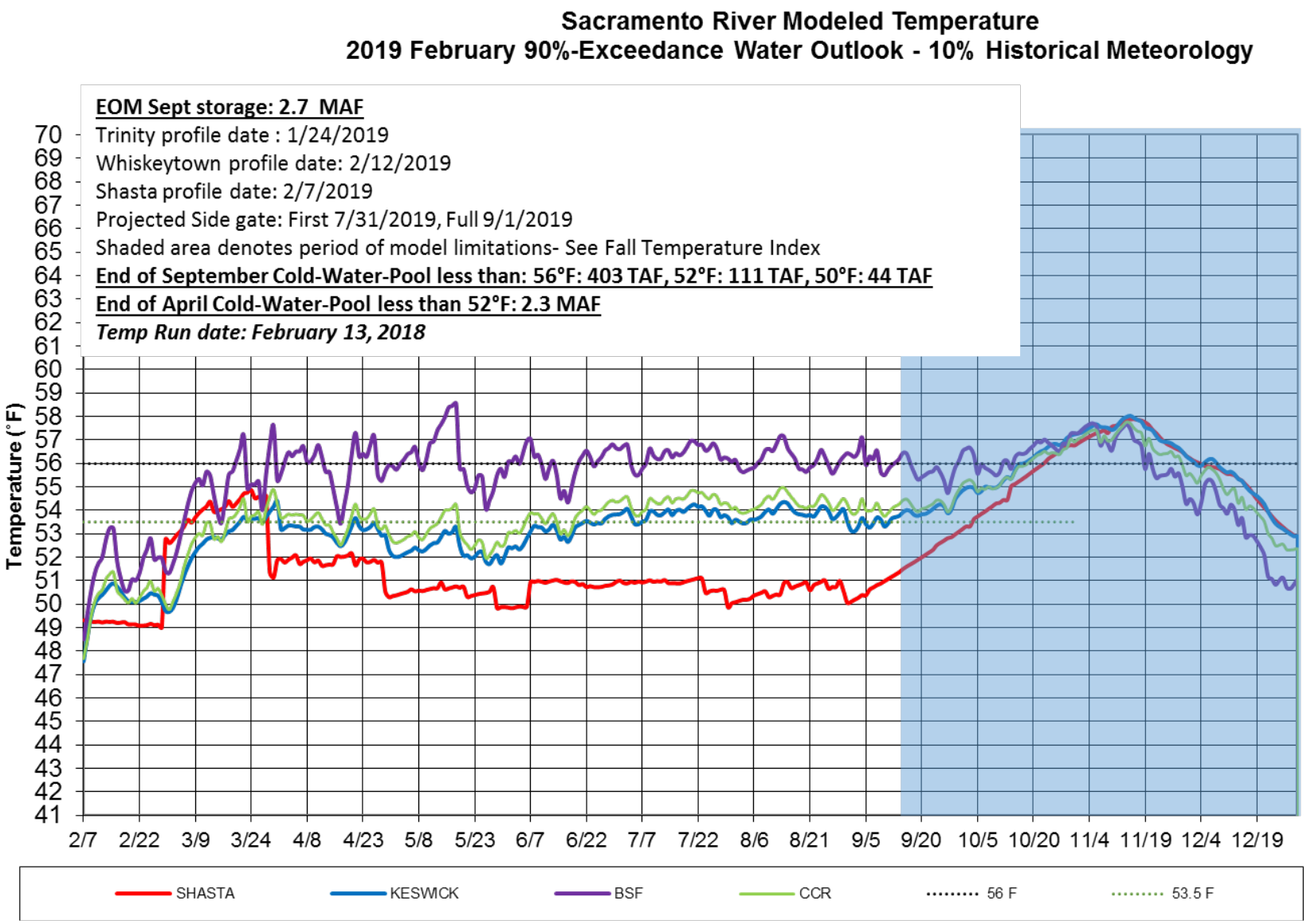

Figure 5. February 2019 simulated Sacramento River temperatures 90% runoff exceedance hydrology and 10% historical meteorology.

tributary temperatures; and consequently, the development of the cold-water pool during winter and early spring, still uncertain prior to the end of April.

8. Modified model coefficients more closely represent actual Keswick Dam temperatures. As a result, temperature predictions downstream of Keswick Dam are likely to be warmer than actual.

9. The model is specifically being applied to generate the most accurate results at the Sacramento River above Clear Creek confluence location.

Enclosure 3

Summary Document for Shasta/Keswick Operational Scenarios
Prepared by the Southwest Fisheries Science Center on February 17th, 2019

Below are results comparing four USBR scenarios ran Feb 15th 2019. Scenarios differ by hydrology (Input 50 or 90 percent exceedance) and air temperature (10 or 50 exceedance of L3MTO). Inputs from scenarios are used to generate daily average Sacramento River water temperatures using the RAFT model and associated temperature-dependent egg mortality and survival estimates using the NMFS temperature mortality model (Martin et al. 2017) for the 2019 temperature management season (Table 1 and Figures 2-3). Additionally, a set of mortality model runs were generated using USBR's HEC-5Q model output (Table 2 and Figures 4-5) for comparison purposes, where the RAFT model was not used, but temperatures from the HEC-5Q nodes were linearly interpolated in space.

Further details of modeling methods are at: http://oceanview.pfeg.noaa.gov/CVTEMP/

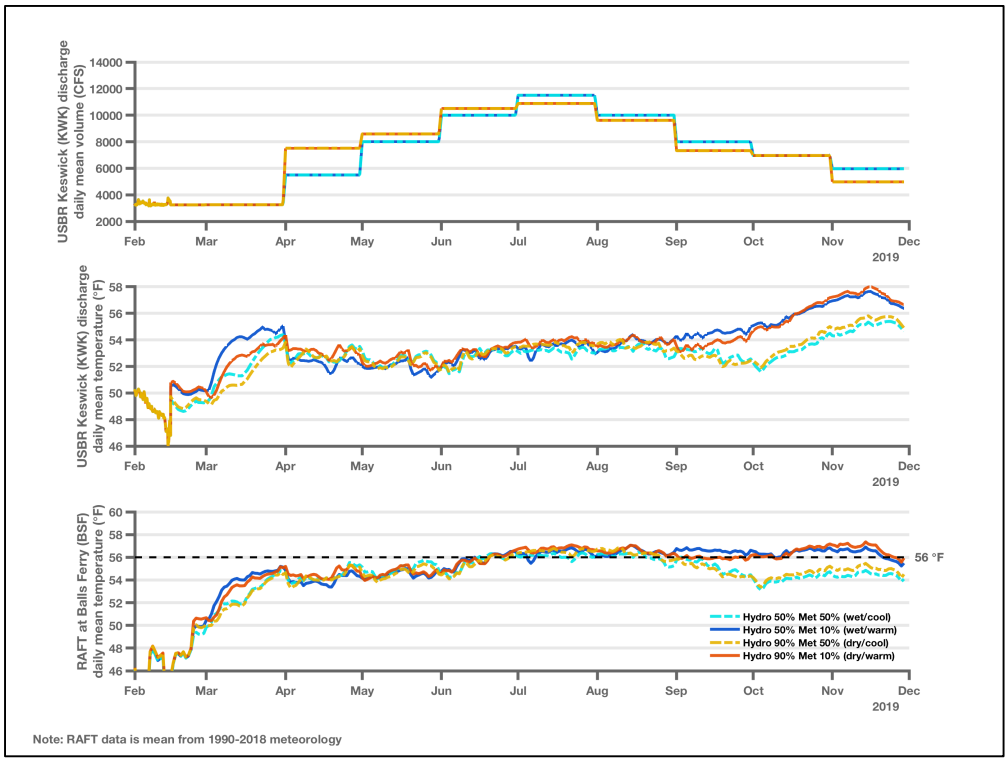

Figure 1: Summary plots showing differences in Keswick discharge volume and temperature, and Balls Ferry RAFT predicted temperature for four scenarios assessed.

Table 1: Estimated temperature-dependent egg mortality under different scenarios assuming a 2012-2017 spatial and temporal redd distribution.

Scenario	Mean (%)	Median (%)	Lower (%)	Upper (%)
FEB_14_2019_INPUT_50_OUTPUT_50_10L3MTO (Wet/Warm)	40.78	42.89	0.08	74.02
FEB_14_2019_INPUT_50_OUTPUT_50_50L3MTO (Wet/Cool)	13.64	4.07	0.08	61.16
FEB_14_2019_INPUT_90_OUTPUT_90_10L3MTO (Dry/Warm)	37.07	38.8	0.08	73.7
FEB_14_2019_INPUT_90_OUTPUT_90_50L3MTO (Dry/Cool)	20.6	16.56	0.08	63.79

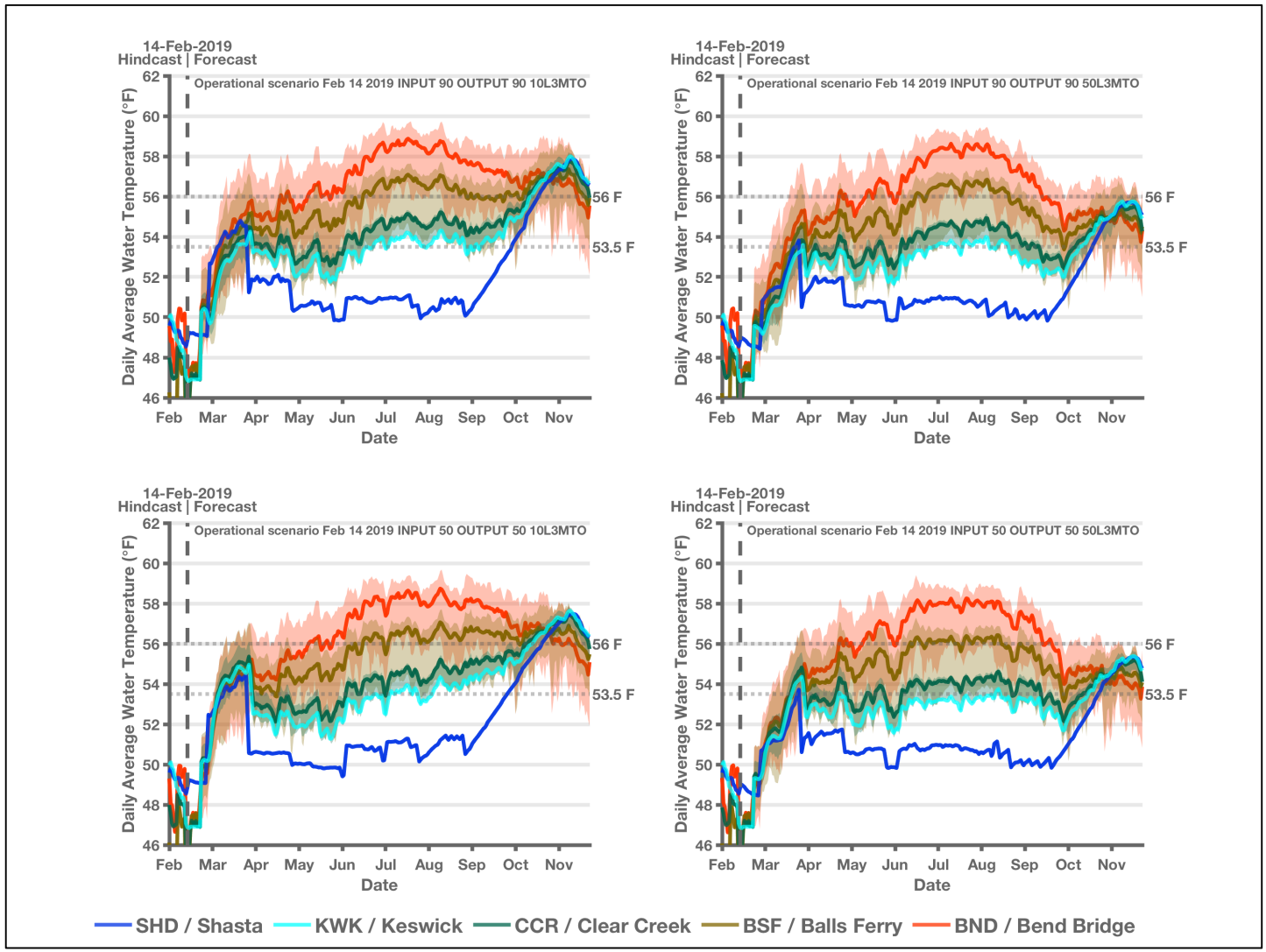

Figure 2: Estimated daily average water temperature produced by scenario input (Shasta and Keswick) and the RAFT model (Clear Creek, Balls Ferry, and Bend Bridge) under the four February 14th 2019 scenarios.

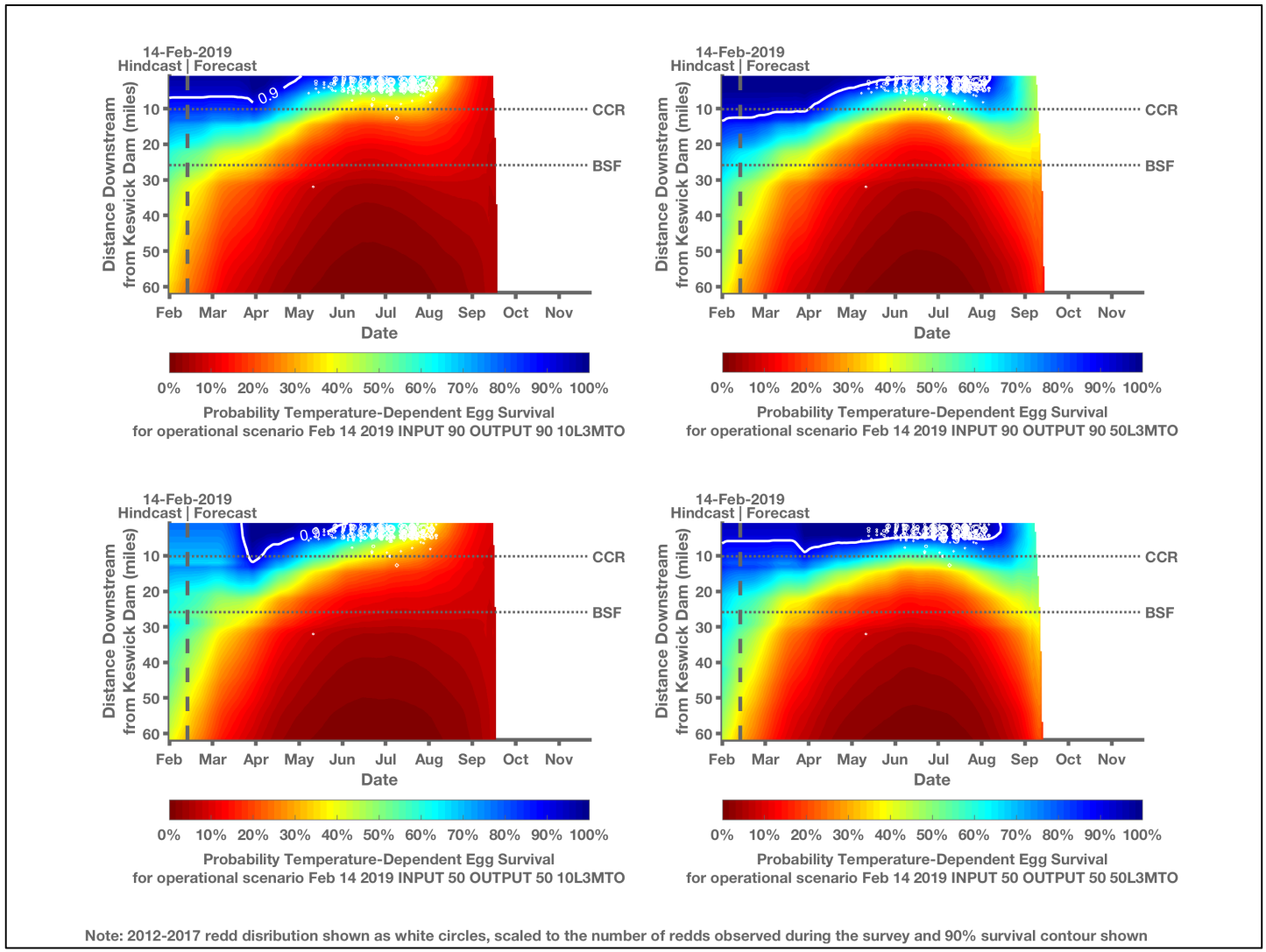

Figure 3: Estimated temperature-dependent egg survival produced by the NMFS temperature mortality model under the four February 14th 2019 scenarios

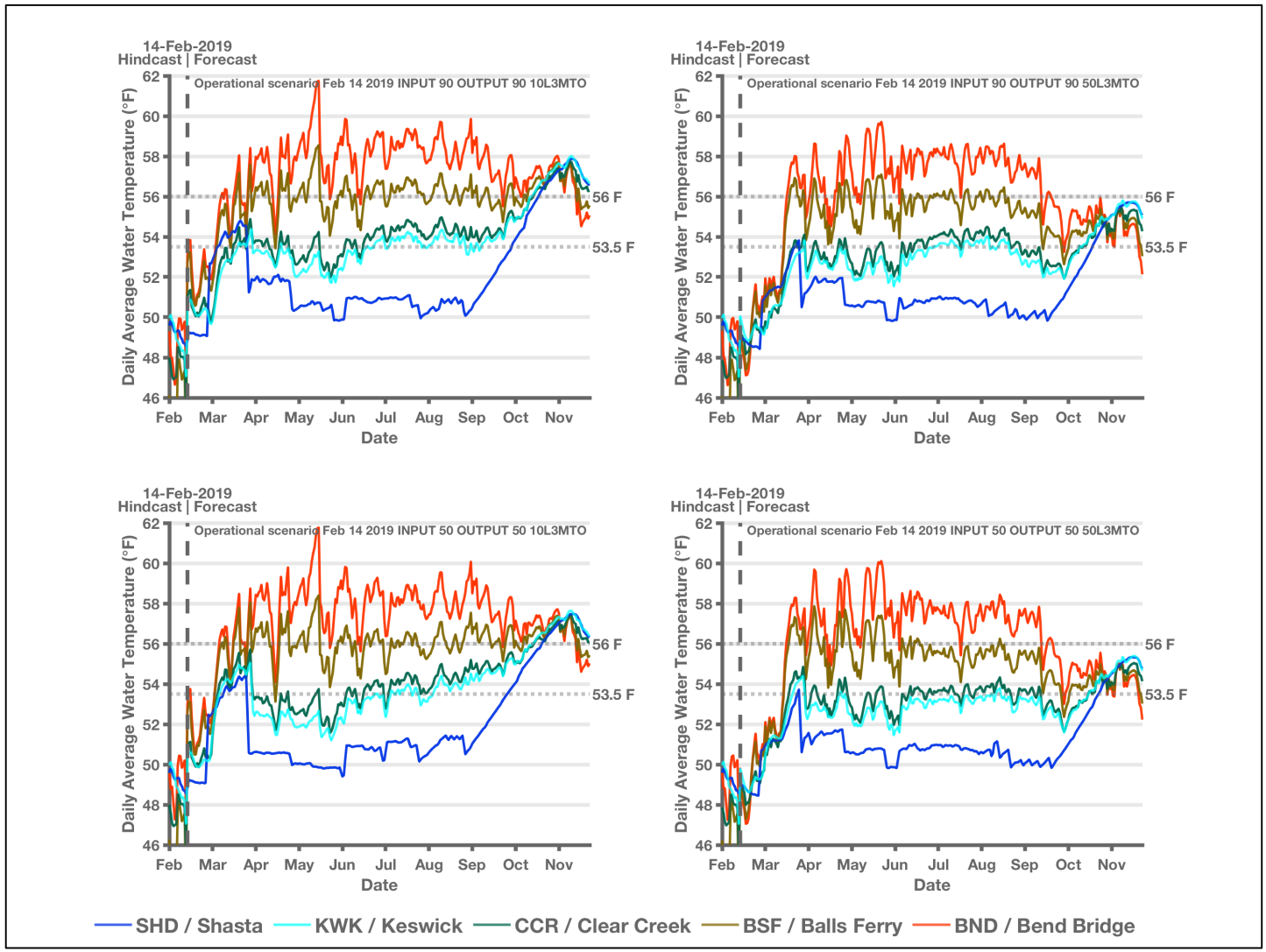

Figure 4: Estimated daily average water temperature produced by scenario input (Shasta, Keswick, Clear Creek, Balls Ferry, and Bend Bridge) under the four February 14th 2019 scenarios using HEC-5Q output.

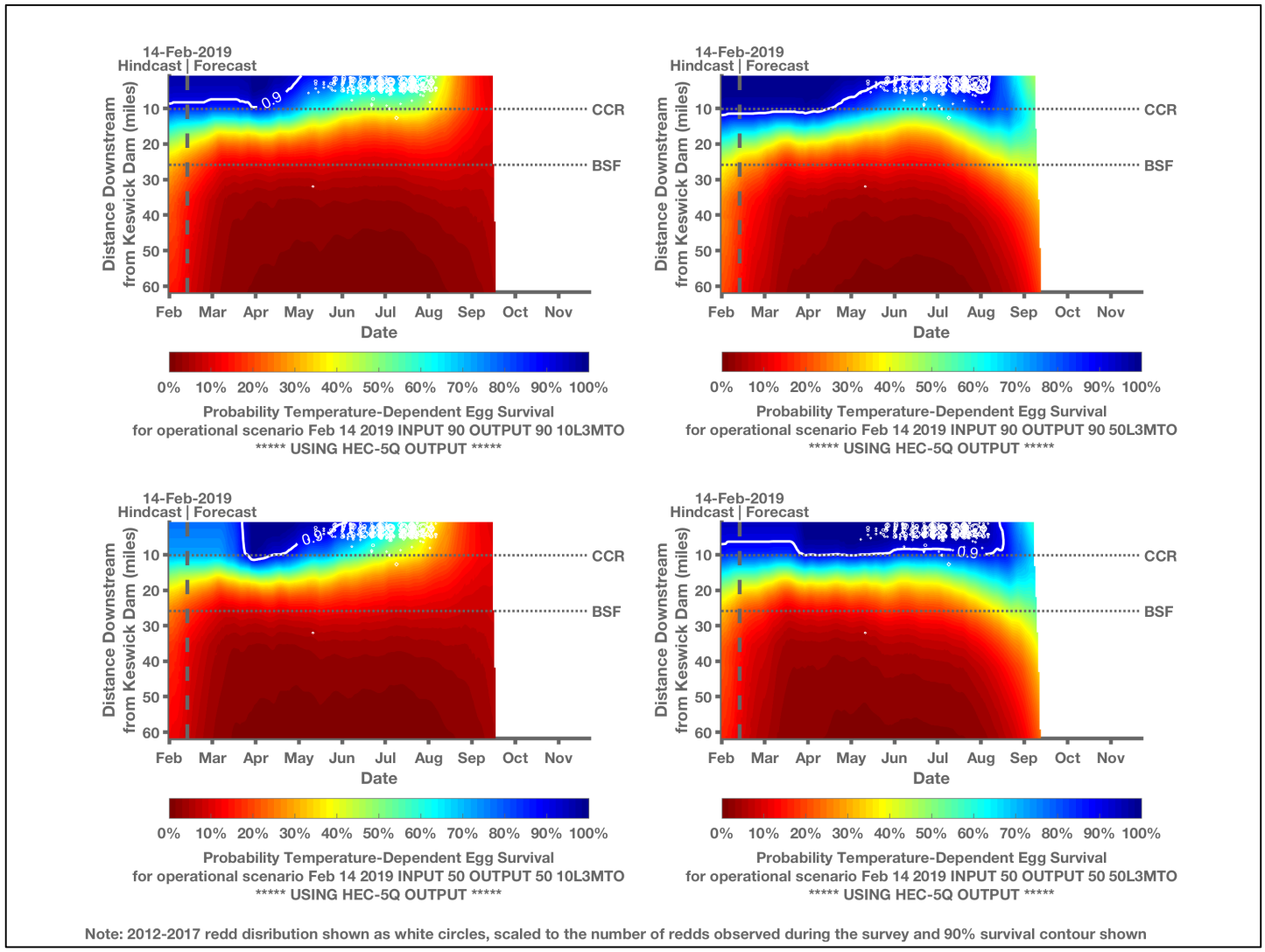

Figure 4: Estimated temperature-dependent egg survival produced by the NMFS temperature mortality model under the four February 14th 2019 scenarios using HEC-5Q output. To generate temperatures between HEC-5Q model nodes (KESWICK, CLEAR_CR, BALL_FERRY, JELLYS_FERRY, BEND_BR, and RED_BLIFF) linear interpolation was used.

Table 2: Estimated temperature-dependent egg mortality under different scenarios assuming a 2012-2017 spatial and temporal redd distribution using HEC-5Q output.

Scenario	Mean (%)	Median (%)	Lower (%)	Upper (%)
FEB_14_2019_INPUT_50_OUTPUT_50_10L3MTO (Wet/Warm)	37.37	38.32	0.08	72.63
FEB_14_2019_INPUT_50_OUTPUT_50_50L3MTO (Wet/Cool)	11.53	1.83	0.08	58.6
FEB_14_2019_INPUT_90_OUTPUT_90_10L3MTO (Dry/Warm)	33.46	33.59	0.08	72.2
FEB_14_2019_INPUT_90_OUTPUT_90_50L3MTO (Dry/Cool)	17.55	12.07	0.08	61.75

Reference:

Martin, B. T., Pike, A., John, S. N., Hamda, N., Roberts, J., Lindley, S. T. and Danner, E. M. (2017), Phenomenological vs. biophysical models of thermal stress in aquatic eggs. Ecology Letters 20: 50–59. doi:10.1111/ele.12705