Appendix D:

Technical Memorandum

2015 Placer County Water Agency and East Bay Municipal Utility District Transfer

Effects on Folsom Reservoir and the Lower American River

Placer County Water Agency

July 2015

Table of Contents

Executive Summary 1
1.0 Introduction **2**
2.0 Water Transfer Operations **3**
2.1. Water Transfer Overview 3
2.2. PCWA Operations Forecast 4
2.3. Reclamation Operations Forecast 5
2.4. Middle Fork American River Project Refill Agreement 8
3.0 EBMUD Water Supply Effects **8**
4.0 Folsom Reservoir Storage and Lower American River Flow Effects **9**
5.0 Water Temperature Effects **9**
5.1. Folsom Reservoir Inflow Water Temperature 9
5.1.1 North Fork American River 10
5.1.2. South Fork American River 10
5.2. Folsom Reservoir and Lower American River Water Temperature Modeling Approach 11
5.3. Folsom Reservoir and Lower American River Water Temperature Modeling Results 14
5.3.1 Forecasted Reclamation Operations 14
5.3.2 Forecasted Transfer Operations 14
6.0 Additional Drier Year Water Transfer Effects **20**
7.0 Conclusion **20**
8.1 References **21**

List of Tables

Table 1. Proposed Schedule of PCWA's MFP Water Transfer Releases into Folsom Reservoir.

Table 2. Forecasted PCWA Operations of the MFP at the North Fork American River below the American River Pump Station With and Without the EBMUD Transfer.

Table 3. Reclamation Draft May 2015 90% Runoff Exceedance Operations Forecasts.

Table 4. Watt Avenue Water Temperature Maximum Water Temperature and ATSP Schedules for the Base Case and Water Transfer Scenarios Options 1 and 2 for 2008 and 2014 MET data (Note: Lower ATSP Schedules Equal Colder Water Temperature).

List of Figures

Figure 1. PCWA Middle Fork American River Project, Folsom Reservoir, and Lower American River.

Figure 2. Folsom Reservoir Storage and Lower American River Flow for the Base Case (Reclamation High and Low Release Forecasts) and for the Alternative Water Transfer Release Options 1 and 2.

Figure 3. Water Temperature in the North Fork American River upstream of Folsom Reservoir for the Base Case and with the 12,000 AF Water Transfer based on 2008 (top) and 2014 (bottom) Air Temperature.

Figure 4. Example of 2008 and 2014 Monthly Meteorological (MET) Data (Air Temperature) Compared to Recent (2001-2015) MET Data (top) and Daily 2008 and 2014 Data (bottom).

Figure 5. Model Results for Water Temperature in the Lower American River at Watt Avenue using 2008 (top) and 2014 (bottom) Meteorological Data for High and Low Release Scenarios.

Figure 6. Model Results for Water Temperature below Folsom Reservoir using 2008 (top) and 2014 (bottom) Meteorological Data for High and Low Release Scenarios.

Figure 7. Model Results for Water Temperature in the Lower American River at Watt Avenue using 2008 Meteorological Data for the High and Low Release No Transfer, Option 1, and Option 2 Scenarios.

Figure 8. Model Results for Water Temperature in the Lower American River at Watt Avenue using 2014 Meteorological Data for the High and Low Release No Transfer, Option 1 and Option 2 Scenarios.

List of Attachments

Attachment A. PCWA Historical Water Transfers (1990-2015).

Attachment B. Folsom Reservoir Inflow Water Temperature Modeling.

Attachment C. North Fork, South Fork, and Lower American River Regression Performance for 2014.

Attachment D. Folsom Reservoir CE-QUAL-W2 Modeling.

Attachment E. Lower American River Water Temperature at Watt Avenue.

List of Acronyms

AF	acre-feet
ATSP	Automated Temperature Selection Procedure
cfs	cubic feet per second
California ISO	California Independent System Operator
CVP	Central Valley Project
Delta	Sacramento-San Joaquin Delta
EBMUD	East Bay Municipal Utility District
F	Fahrenheit
Freeport	Freeport Regional Water Project
LAR	Lower American River
MET	Meteorological
MFP	Middle Fork American River Project
MFAR	Middle Fork American River
NFAR	North Fork American River
PCWA	Placer County Water Agency
Reclamation	U.S. Bureau of Reclamation
SFAR	South Fork American River
SWRCB	State Water Resources Control Board
TCD	Temperature Control Device
WWD	Westlands Water District

EXECUTIVE SUMMARY

Placer County Water Agency (PCWA) and East Bay Municipal Utility District (EBMUD) propose a transfer of 12,000 acre-feet (AF) of surplus PCWA water to EBMUD in 2015 (Transfer). The Transfer water is currently stored in PCWA's Middle Fork American River Project (MFP) reservoirs and would not otherwise be released absent the Transfer. A standard 5% carriage loss (600 AF) of the Transfer water through Folsom Reservoir would result in EBMUD receiving 11,400 AF at the Freeport Regional Water Project (Freeport) Intake. PCWA will enter into a MFP Refill Agreement with the United States Bureau of Reclamation (Reclamation) to ensure non-injury to any downstream legal water users as a result of the Transfer, similar to refill agreements for previous PCWA transfers.

Transfer water would be released July through September from the MFP into the Middle Fork American River (MFAR) and then into the North Fork American River (NFAR) and Folsom Reservoir. Inflow from the NFAR to Folsom Reservoir during the July through September Transfer period would increase 33% (36,369 to 48,369 AF) as a result of the Transfer. Reclamation would provide the Transfer water to EBMUD on a schedule that is mutually agreeable and/or beneficial to Reclamation, EBMUD, and the environment. The Transfer release schedule would be bracketed by a combination of two release options:

- Option 1 (primary): Transfer water released late-August through November from Folsom Reservoir into the Lower American River (LAR) on top of (in addition to) Reclamation's forecasted 2015 LAR releases.

- Option 2 (secondary): Transfer water released from Folsom Reservoir as part of Reclamation's forecasted 2015 LAR releases.

The exact timing of the PCWA transfer into Folsom Reservoir and the release of the water from Folsom Reservoir to EBMUD may change slightly based on the transfer approval process and coordination with Reclamation. Preliminary modeling indicated that the effects of the transfer were relatively insensitive to the exact timing of the transfer window. Modeling of Option 1 and Option 2 based on a PCWA release to Folsom Reservoir in July and August of 6,000 TAF each month and releases from Folsom Reservoir to EBMUD in late-August and September is representative of conditions that would occur if either the PCWA release to Folsom Reservoir or the release of water from Folsom Reservoir to EBMUD were delayed a month or more. Therefore, the schedule outlined above was used to represent the transfer for the broader transfer window.

If Reclamation released the Transfer water in addition to their forecasted releases (Option 1), the Transfer would increase average LAR flows in August by approximately 2% (2,001 to 2040 or 1,641 to 1680 cubic feet per second [cfs], depending on the Reclamation modeling scenario) and average LAR flows in September by 30% (500 to 651 cfs). The increase in Folsom Reservoir outflows would benefit salmonid rearing habitat in the LAR. Alternatively, if Reclamation incorporated the Transfer water into their forecasted LAR releases (Option 2), the Transfer would increase end-of-September storage in Folsom Reservoir by 12,000 AF and could benefit carryover storage, water supply, and/or future flow-related fish habitat in the LAR.

Detailed CE-QUAL-W2 water temperature modeling indicates that the Transfer would decrease the water temperature of the NFAR inflow into Folsom Reservoir by 1.6 – 2.2˚F and aid LAR temperature management to meet downstream temperature targets at Watt Avenue. Depending on the release pattern implemented, modeling results indicate that an approximate 1˚ Fahrenheit (F) reduction of water temperature in the LAR could be achieved during the warmest part of the year. Because of the extreme drought conditions, the Reclamation forecasted Folsom Reservoir storage and LAR flow scenarios result in temperature regimes above the highest Automated Temperature Selection Procedure (ATSP)[1] schedule (78 ATSP schedule; 72˚F summer) at Watt Avenue. The Transfer slightly reduces the temperature, but not enough to meet an existing ATSP schedule.

The Transfer helps meet Water Forum Agreement[2] drier year objectives for the LAR, increases drier year hydropower generation/grid regulation, and enhances MFP white-water rafting opportunities.

1.0 INTRODUCTION

The proposed 12,000 AF Transfer between Placer County Water Agency (PCWA) and East Bay Municipal Utility District (EBMUD) is in response to California's exceptional drought conditions and will assist EBMUD in meeting their consumptive demand consistent with a Stage 4 critical drought declaration pursuant to the EBMUD Drought Management Program.

The Transfer water released to EBMUD under this proposal is surplus to the needs of PCWA's customer base under a Stage 2 Water Warning enacted under PCWA's Water Shortage Contingency Plan and would not otherwise be released this year absent the Transfer. Additionally, all Transfer water was diverted to storage prior to State Water Resources Control Board (SWRCB) May 1, 2015

[1] Automated Temperature Selection Procedure (ATSP) water temperature schedules identified in the Lower American River Flow Management Standard.

[2] The Water Forum Agreement, negotiated by a diverse group of businesses, agricultural leaders, citizens groups, conservation interests, water managers and local governments in Sacramento, Placer, and El Dorado counties, has two coequal objectives: (1) provide a reliable and safe water supply for the region's economic and planned development; and (2) preserve the fish, wildlife, recreational, and aesthetic values of the Lower American River.

Curtailment Notice. For the purposes of this Transfer, PCWA will be solely exercising Water Right Permit 13856 (Application 18085). PCWA will enter into a Middle Fork American River Project (MFP) Refill Agreement with the United States Bureau of Reclamation (Reclamation) to ensure non-injury to any downstream legal water users.

PCWA has periodically implemented temporary water transfers in drier water years over the past 25 years (Attachment A; Table 1). Drier year water transfers into Folsom Reservoir and the Lower American River (LAR) are part of the environmental release/enhancement objectives in PCWA's purveyor-specific Water Forum Agreement.

This technical memorandum describes the effects of the proposed 12,000 AF Transfer on the American River watershed downstream of the MFP based on the timing, duration, and volume of the proposed Transfer releases described herein. The technical memorandum includes an analysis of the effects of the proposed Transfer on Folsom Reservoir storage, and LAR hydrology and water temperature. Additional effects from the Transfer such as meeting Water Forum Agreement drier year objectives, greater hydropower generation, improved CAISO grid regulation, increased whitewater rafting opportunities, and providing EBMUD supplemental water supplies are also discussed.

2.0 WATER TRANSFER OPERATIONS

2.1. Water Transfer Overview

Under the proposed Transfer, PCWA would release an additional 12,000 AF of stored MFP water July through September of 2015 through MFP hydroelectric facilities into the MFAR then into the NFAR and Folsom Reservoir (Figure 1). Transfer water would be temporarily stored in Folsom Reservoir pursuant to a Warren Act Contract between EBMUD and Reclamation. A carriage loss of 5% is assumed through Folsom Reservoir providing 11,400 AF of Transfer water to EBMUD for re-diversion at the Freeport Regional Water Project (Freeport) Intake. Reclamation would provide the Transfer water to EBMUD on a schedule that is mutually agreeable and/or beneficial to Reclamation, EBMUD, and the environment. The release of Transfer water from Folsom Reservoir could occur on top of (in addition to), as part of Reclamation's forecasted operations (see Section 2.3 Reclamation Operations Forecast), or as a combination of these two options:

Option 1 (primary): Late-August through November up to 155 cubic feet per second (cfs) of water is released from Folsom Reservoir into the LAR on top of (in addition to) Reclamation's forecasted operation releases of water from Folsom Reservoir (total release of 11,400 AF).

Option 2 (secondary): A total of 11,400 AF of water is transferred to EBMUD as part of Reclamation's forecasted operational releases effectively increasing the end-of-September storage in Folsom Reservoir by 12,000 AF.

Following release of the Transfer water by Reclamation, the water would enter the Sacramento River and then the FPWP Facility Intake on the Sacramento River near Clarksburg.

The exact timing of the PCWA transfer into Folsom Reservoir and the release of the water from Folsom Reservoir to EBMUD may change slightly based on the transfer approval process and coordination with Reclamation. Preliminary modeling indicated that the effects of the transfer were relatively insensitive to the exact timing of the transfer window. Modeling of Option 1 and Option 2 based on a PCWA release to Folsom Reservoir in July and August of 6,000 TAF each month and releases from Folsom Reservoir to EBMUD in late-August and September is representative of conditions that would occur if either the PCWA release to Folsom Reservoir or the release of water from Folsom Reservoir to EBMUD were delayed a month or more. Therefore, the schedule outlined above was used to represent the transfer for the broader transfer window.

Table 1. Proposed Schedule of PCWAs MFP Water Transfer Releases into Folsom Reservoir

Month	Volume (AF)
July	2,000
August	7,000
September	3,000
Total	12,000

2.2. PCWA Operations Forecast

PCWA's operations forecast3 for the MFP with and without the Transfer are provided in Table 2. PCWA's forecast indicates that the Transfer would increase average July inflows to Folsom Reservoir by approximately 30% (19,914 to 25,914 AF) and average August inflows by 36% (16,455 to 22,455 AF).

[3] The operations forecast is a model run that incorporates various assumptions (e.g., hydrology, meteorological conditions, water demand, electrical demand, etc.) and is not an exact representation of future MFP operations.

Table 2. Forecasted PCWA Operations of the MFP[1] at the North Fork American River Below the American River Pump Station With and Without the EBMUD Transfer

Operations Scenario	Jun (AF)	Jul (AF)	Aug (AF)	Sep (AF)	Oct (AF)	Nov (AF)	Dec (AF)
NFAR Flow below ARPS[2] / Without Transfer	27,982	19,914	16,455	10,437	9,371	15,653	46,678
NFAR Flow below ARPS / With 12,000 AF Transfer[3]	27,982	25,914	22,455	10,437	9,371	15,653	46,678

[1] June 2015 Inflow projections through September are based on a 90% probability of exceedance of future precipitation. October through December projections are based on a 90% historical inflow exceedance.
[2] ARPS is American River Pump Station.
[3] Transfer water includes PCWA Water Forum release obligations.

2.3. Reclamation Operations Forecast

Reclamation operations forecasts for Folsom Reservoir and the LAR have been in dynamic flux due to exceptional drought conditions and SWRCB's suspension of the temperature management plan for Shasta Reservoir and the Sacramento River. PCWA used the most recently updated Folsom Reservoir operations forecasts as the Base Case conditions (baseline) to model hydrology and water temperature effects of the Transfer. The latest Reclamation operations forecasts are shown below in Table 34. Both the high release and low release options were used to model Transfer effects (Base Case or no transfer).

[4] The most recent Reclamation forecast of Folsom Reservoir/LAR operations and the basis for the modeling described in the Technical Memorandum was provided by Reclamation to the American River Operations Group on June 9, 2015.

Table 3. Reclamation Draft June 2015 90% Runoff Exceedance Operations Forecasts

DRAFT June 2015

Low Release Bookend - 90% Historical Inflow Oct-Dec
90% Runoff Exceedance Outlook:

90% Inflow based on PCWA/SMUD adjusted inflow Jun-Sep, 90% Histroical inflow Oct-Dec, Keswick releases at 8000 cfs Jun-Aug, minimal Delta project pumping Jun-Aug

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

		Jun	Jul	Aug	Sep	Oct	Nov	Dec
Folsom	535	422	265	187	171	177	189	211
Elev.		406	381	364	360	361	364	370

Monthly River Releases (cfs)

	Jun	Jul	Aug	Sep	Oct	Nov	Dec
American	2435	2997	1641	500	500	504	500

High Release Bookend - 90% Historical Inflow Oct-Dec
90% Runoff Exceedance Outlook:

90% Inflow based on PCWA/SMUD adjusted inflow Jun-Sep, 90% Histroical inflow Oct-Dec, Keswick releases at 7000 cfs Jun-Aug, minimal Delta project pumping Jun-Aug

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

		Jun	Jul	Aug	Sep	Oct	Nov	Dec
Folsom	535	397	196	98	83	89	101	123
Elev.		403	366	334	327	330	336	344

Monthly River Releases (cfs)

	Jun	Jul	Aug	Sep	Oct	Nov	Dec
American	2864	3702	2001	500	500	504	503

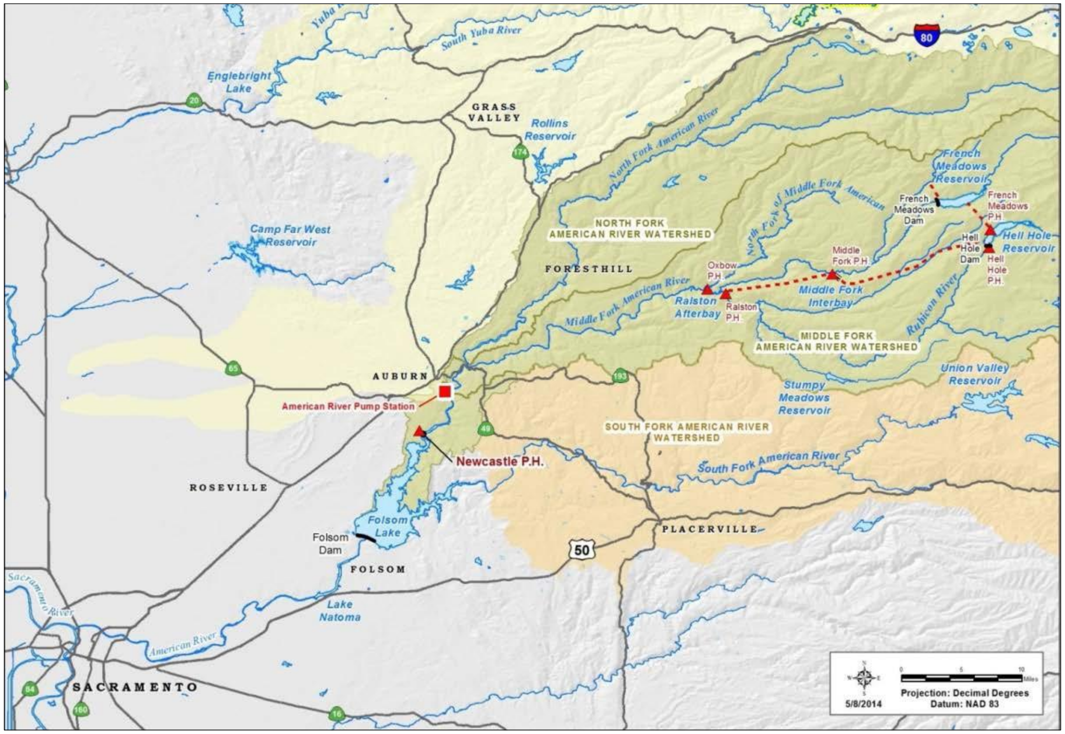


Figure 1. PCWA Middle Fork American River Project, Folsom Reservoir, and Lower American River

2.4. Middle Fork American River Project Refill Agreement

In order to refill MFP reservoirs following the release of the Transfer water without injury to downstream water right holders, PCWA would enter into a MFP Refill Agreement with Reclamation. The Refill Agreement minimizes the potential for refill of MFP reservoirs to affect Folsom Reservoir annual storage after a transfer. PCWA has a typical end-of-the-year (December-February) combined carryover target (storage low point) of 150,000 AF in its MFP reservoirs (French Meadows and Hell Hole). As a result of the Refill Agreement associated with PCWA water transfers implemented in 2013 and 2014, PCWA's current MFP carryover target for 2015-2016 is 94,500 AF5 (PCWA 2015). Following the proposed Transfer, PCWA would carry an additional 12,000 AF deficit in its carryover target forward in time until conditions identified in the Refill Agreement relieve the deficit (e.g., Folsom Reservoir reaches flood control levels or fills completely). Therefore, the assumed 2015-2016 carryover target would be 82,500 AF instead of the typical 150,000 AF.

3.0 EBMUD WATER SUPPLY EFFECTS

The Transfer would provide EBMUD with water in a year of very critical need6. EBMUD provides water supply to over 1.34 million people plus industrial, commercial, institutional, and irrigation water users in the East Bay region of San Francisco Bay Area. EBMUD's long-term source of water supply is the Mokelumne River in the Sierra Nevada with a diversion point at Pardee Reservoir in Calaveras and Amador Counties. In dry years, EBMUD supplements its water

[5] The Water Year (WY) 2015 carryover target was 90,000 AF per the 2014 Refill Agreement for the 35,000 AF WWD Transfer, however, with record rainfall occurring in December 2014, PCWA was only able to release enough water to evacuate the MFP reservoirs to 94,500 AF (see June 3, 2015 Memorandum to Ron Milligan, Reclamation).

[6] California is now in its fourth year of drought and the dry conditions are so extreme that water years 2012-2014 now rank as the driest consecutive three-year period on record in terms of statewide precipitation. The continuing drought has severely affected EBMUD's water supply with January 2015 constituting the driest January on record and March 2015 constituting the second driest March on record in the Mokelumne River Basin. Given these conditions, on April 14, 2015, EBMUD's Board of Directors declared a continuing water shortage emergency within EBMUD's service area, declared a Stage 4 critical drought (EBMUD's highest level), adopted a mandatory District-wide water use reduction goal of 20%, declared the need to use the Freeport Facility to deliver supplemental supplies to EBMUD's service area, and increased mandatory restrictions on potable water use.

supplies with water from the Central Valley Project (CVP) under its long-term renewal contract and transfers water from willing sellers if water is available.

CVP supplies are at unprecedented low levels this year and EBMUD's allocation will be just 25%, or 33,250 AF, of the water to which it is entitled under its CVP contract and, in addition, uncertainty exists regarding 2016 water supply conditions. EBMUD is pursuing water transfers in order to prevent or mitigate its existing water supply emergency and ensure its continued ability to provide essential public services. The proposed Transfer is necessary for EBMUD to provide essential public services.

4.0 FOLSOM RESERVOIR STORAGE AND LOWER AMERICAN RIVER FLOW EFFECTS

Depending on how Reclamation releases the Transfer water from Folsom Reservoir, Option 1 or Option 2 (see Section 2.1), the Transfer would increase flows in the LAR and/or storage in Folsom Reservoir. The Option 1 transfer water would increase average August LAR flows by approximately 2% (1,641 to 1,680 cfs or 2,001 to 2,040 cfs, depending on the Reclamation modeling scenario) and average September LAR flows by 30% (500 to 651 cfs) and benefit salmonid rearing habitat in the LAR. The Option 2 transfer would increase September 30th storage in Folsom Reservoir by 12,000 AF and could benefit carryover storage, water supply, or future flow-related habitat in the LAR (Figure 2). Alternatively, some combination of Options 1 and 2 could occur based on system wide operational constraints for the CVP or other factors such as Delta water quality control.

5.0 WATER TEMPERATURE EFFECTS

5.1. Folsom Reservoir Inflow Water Temperature

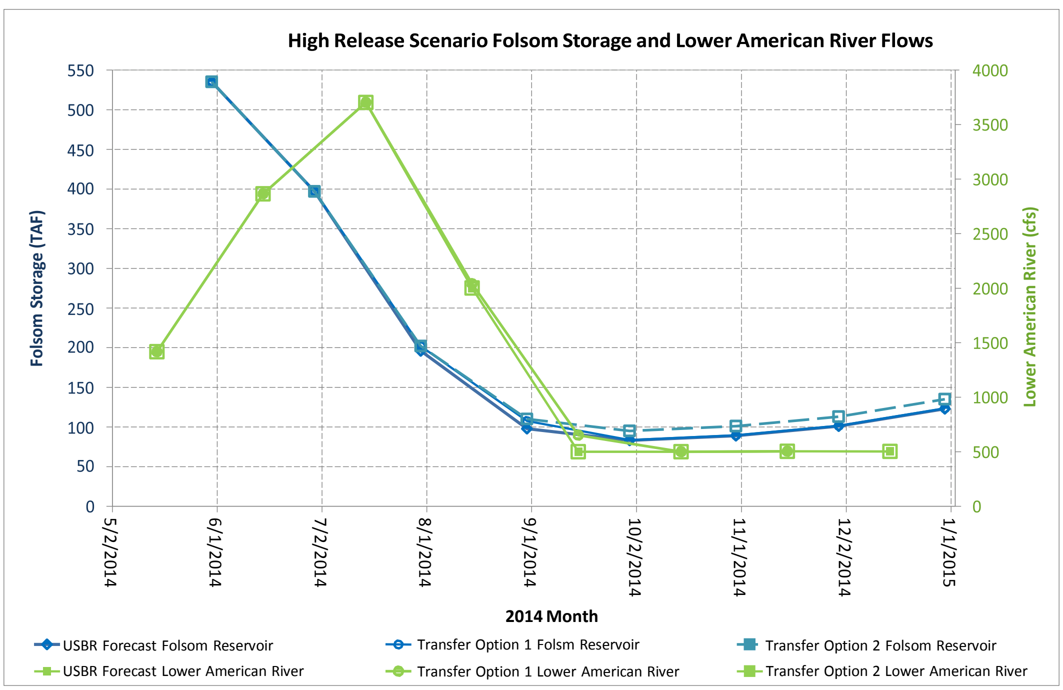
Summer water temperature in the NFAR and South Fork American River (SFAR) decreases with increased flow releases from the upstream hydropower facilities/deep water reservoirs. Inflow water temperature to Folsom Reservoir was determined by using regression models of the inflow water temperature versus flow and air temperature for the two rivers. Details of the regression models are provided in Attachment B of this document. The Base Case (no transfer) amount of inflow in each river was determined by back calculating inflow using the Reclamation 90% exceedance operations forecast for Folsom Reservoir and the LAR (both the High and Low Release options). In the NFAR, the effect of the Transfer water would be to increase NFAR flows into Folsom Reservoir. The Transfer would not affect SFAR inflow to Folsom Reservoir (PCWA does not own or operate any facilities in the SFAR watershed).

5.1.1. North Fork American River

Temperature modeling results for the NFAR just upstream of Folsom Reservoir show a reduction of 1.6 – 2.2˚F in water temperature for July – August as a result of the Transfer (Figure 3). This is a conservative estimate for modeling purposes as the Transfer water was spread evenly over the entire two month inflow period (July – August). It is possible that the water will enter Folsom Reservoir in a more concentrated pattern resulting in cooler inflow temperature than modeled. Attachment C illustrates the accuracy of the temperature modeling based on measured and predicted 2014 inflow temperatures. Also, if the transfer was shifted into September the same type of inflow water temperature cooling would occur.

5.1.2. South Fork American River

SFAR inflow water temperature to Folsom Reservoir is unaffected by the Transfer. The inflow water temperature used for the Folsom Reservoir water temperature modeling is provided in Attachment B. Attachment C illustrates the accuracy of the temperature modeling based on measured and predicted 2014 inflow temperatures.



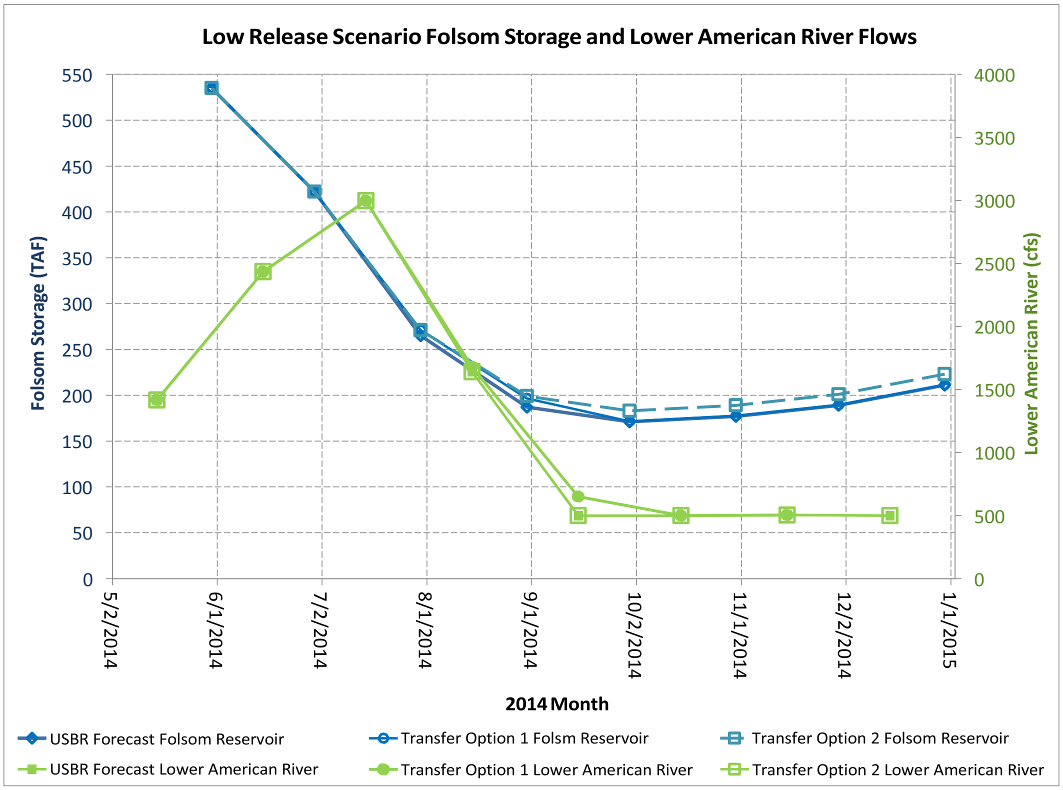
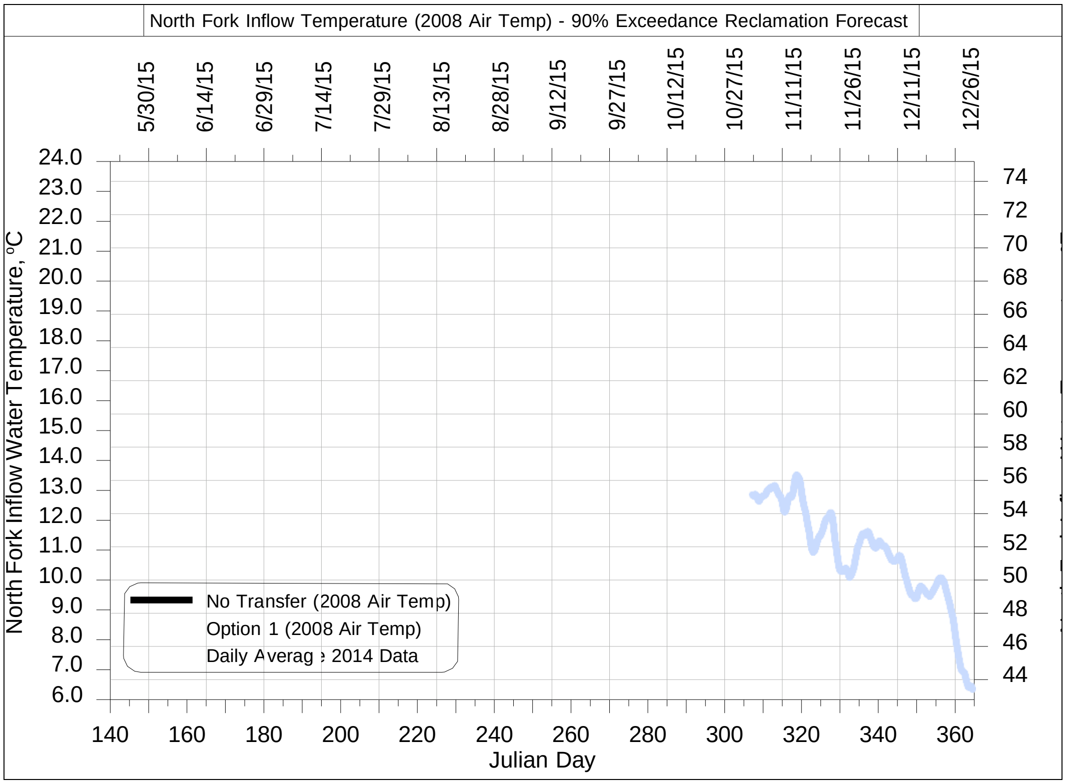


Figure 2. Folsom Reservoir Storage and Lower American River Flow for the Base Case (Reclamation High and Low Release Forecasts) and for the Alternative Water Transfer Release Options 1 and 2.

5.2. Folsom Reservoir and Lower American River Water Temperature Modeling Approach

To model the hydrologic and environmental effects of the Transfer, Reclamation's June 90% exceedance forecast operations scenarios for Folsom Reservoir and the LAR were used as the Base Case. The modeling of the Transfer water releases from Folsom Reservoir was then bracketed using the Option 1 and 2 Folsom Reservoir release scenarios identified above (Section 2.1 Water Transfer Overview).

Water temperature modeling was accomplished with a well-calibrated, state-of-the-art, two-dimensional CE-QUAL-W2 model of Folsom Reservoir (Attachment D) coupled with an accurate regression model of the LAR at Watt Avenue (Attachment E). Meteorological (MET) data from 2008 and 2014, example dry years, was used for the modeling. The 2008 MET data is reasonably representative of average meteorological conditions in recent years (e.g., 2001-2014) and 2014 is representative of a long relatively hot summer (Figure 4).



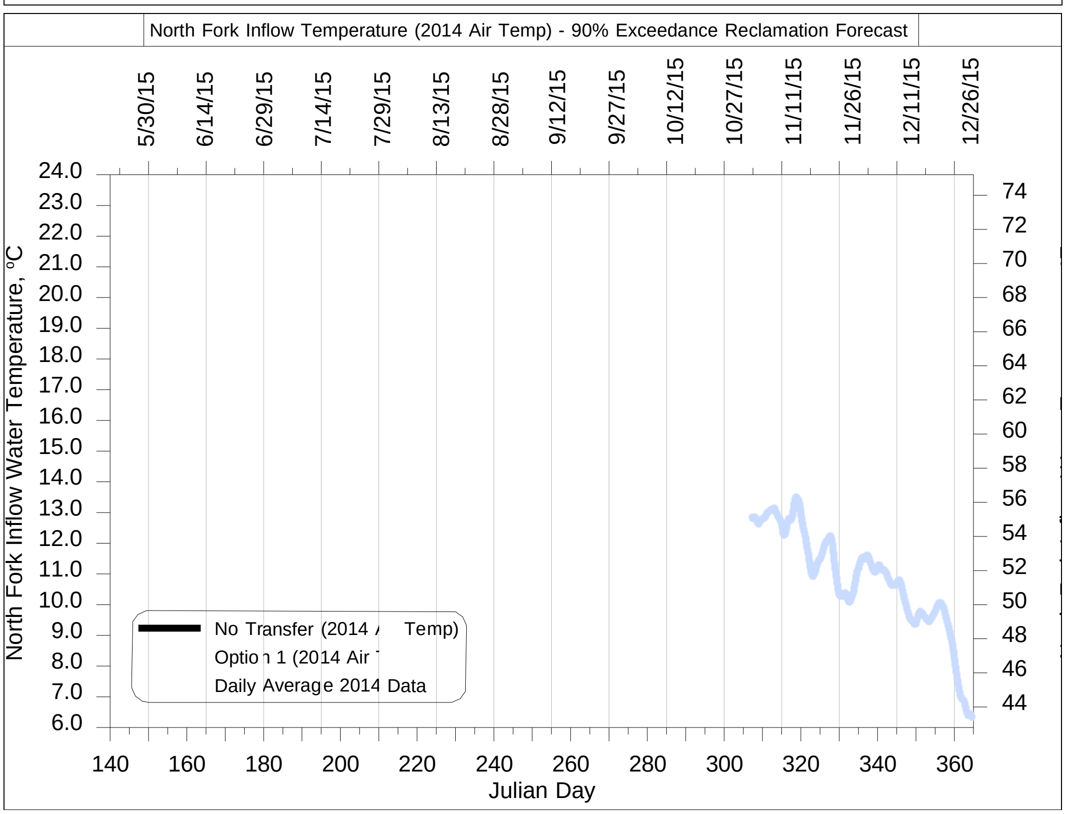
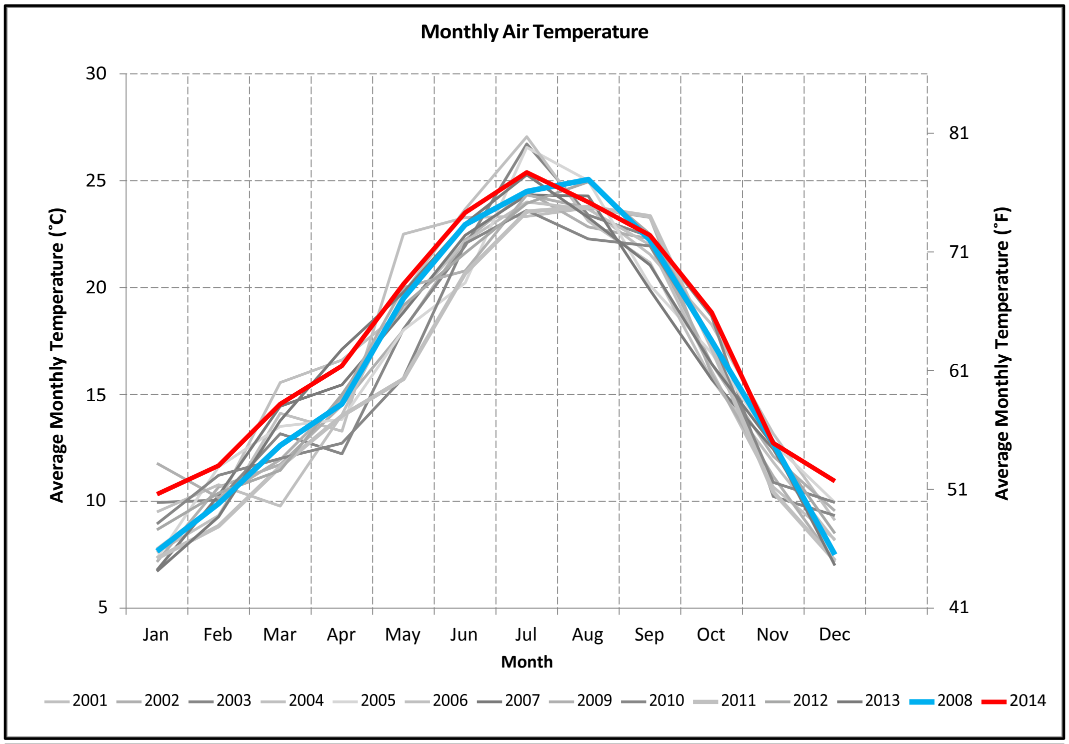


Figure 3. Water Temperature in the North Fork American River upstream of Folsom Reservoir for the Base Case and with the 12,000 AF Water Transfer based on 2008 (top) and 2014 (bottom) Air Temperature



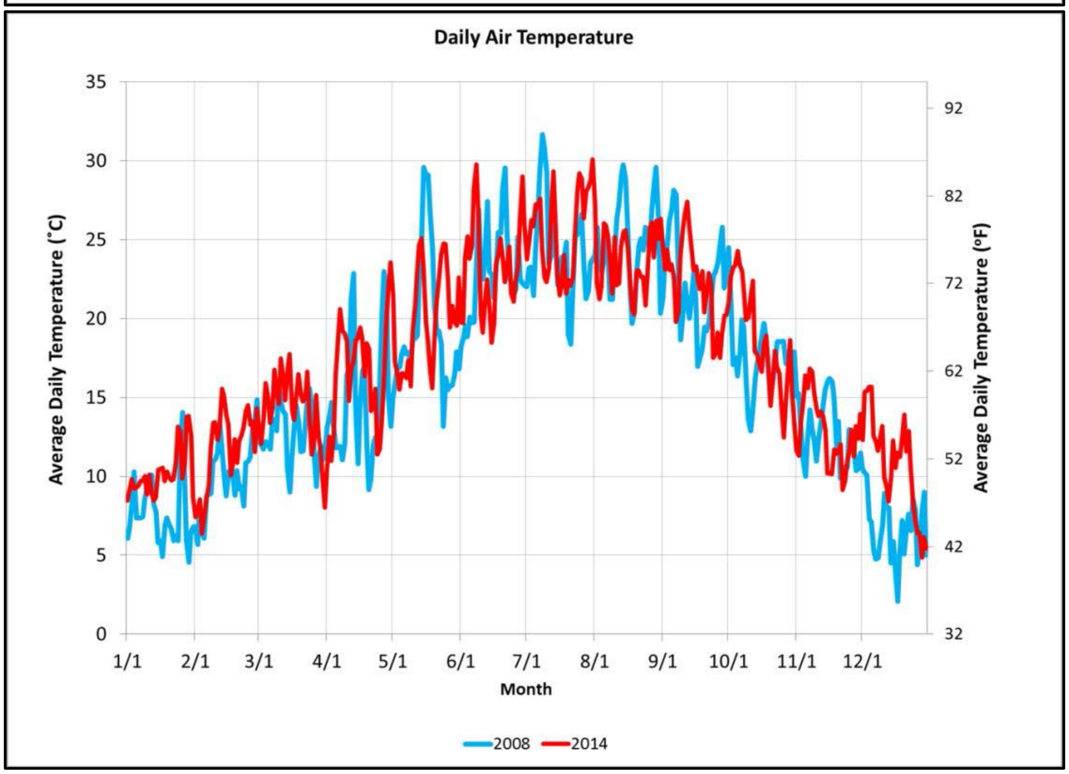


Figure 4. Example of 2008 and 2014 Monthly Meteorolgical (MET) Data (Air Temperature) Compared to Recent (2001-2015) MET Data (top) and Daily 2008 and 2014 Data (bottom).

5.3. Folsom Reservoir and Lower American River Water Temperature Modeling Results

5.3.1. Forecasted Reclamation Operations

Modeling indicates that due to the severe drought the Reclamation forecasted operations in 2015 result in very high water temperature conditions in the LAR for both the High Release and Low Release scenarios. The High Release scenario cannot meet the highest ATSP schedule (Schedule 78), which has a summer temperature target of 72˚F at Watt Avenue (Figure 5). Maximum temperatures at Watt Avenue would be above 78˚F in late August/early September (release temperatures below Folsom Reservoir would be above 72˚F; Figure 6). The low reservoir storage results in the temperature control device (TCD) middle shutters being removed in July and all of the shutters being removed in late August, which limits the opportunity to blend reservoir hypolimnion and metalimnion temperatures to effectively manage the cool water resources.

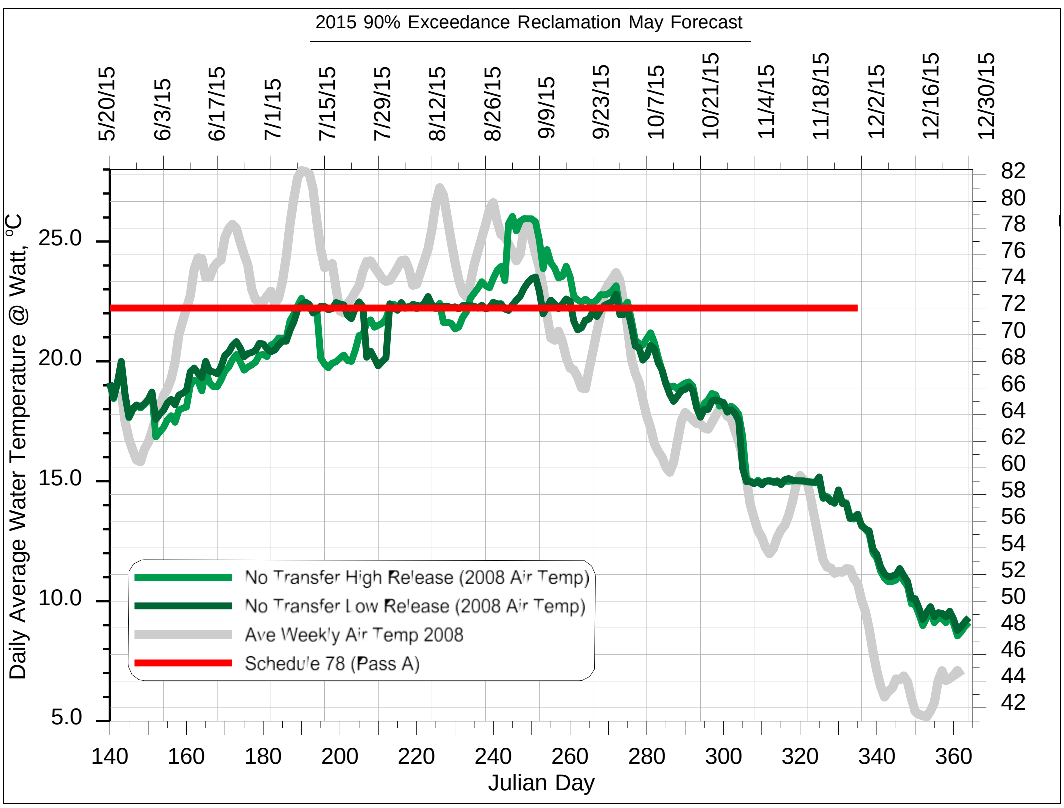
The Reclamation forecasted Low Release scenario results in approximately 2˚F cooler maximum temperatures than the High Release scenario. The Low Release scenario does not meet the highest ATSP schedule using 2014 and 2008 MET data (Figure 5) (release temperatures below Folsom Reservoir would be above 72˚F; Figure 6). The higher reservoir elevations under the Low Release scenario allow the TCDs to remain in place slightly longer and result in slightly better management of temperature than occurs with the High Release scenario.

5.3.2. Forecasted Transfer Operations

Modeling results indicate that the 12,000 AF Transfer Options 1 and 2 would result in a slightly cooler water temperature regime in the LAR for each of the Base Case scenarios (High and Low Release scenarios). For both the High and Low Release scenarios water temperature decreases up to 1˚F during the highest temperature time period (Figures 7 and 8). Option 2 provides less temperature benefit than Option 1, however, it does perform slightly better than the Base Case (No Transfer) Scenarios. Under the Low Release Scenario cool water is managed more effectively because the TCDs can be used slightly longer due to slightly higher water elevations in Folsom Reservoir.

Table 4. Watt Avenue Water Temperature Maximum Water Temperature and ATSP Schedules for the Base Case and Water Transfer Scenarios Options 1 and 2 for 2008 and 2014 MET data (Note: Lower ATSP Schedules Equal Colder Water Temperature).

Model Scenario	Maximum Water Temperature (˚F) 2008 MET	Maximum Water Temperature (˚F) 2014 MET	ATSP Temperature Schedule 2008 MET	ATSP Temperature Schedule 2014 MET
High Release Option				
Base Case	**78.8**	**79.5**	**78+**	**78+**
Transfer Option 1	**78.0**	**78.3**	**78+**	**78+**
Transfer Option 2	**78.6**	**79.2**	**78+**	**78+**
Low Release Option				
Base Case	**74.3**	**74.0**	**78+**	**78+**
Transfer Option 1	**73.0**	**73.2**	**65**	**78+**
Transfer Option 2	**73.2**	**73.5**	**78+**	**78+**



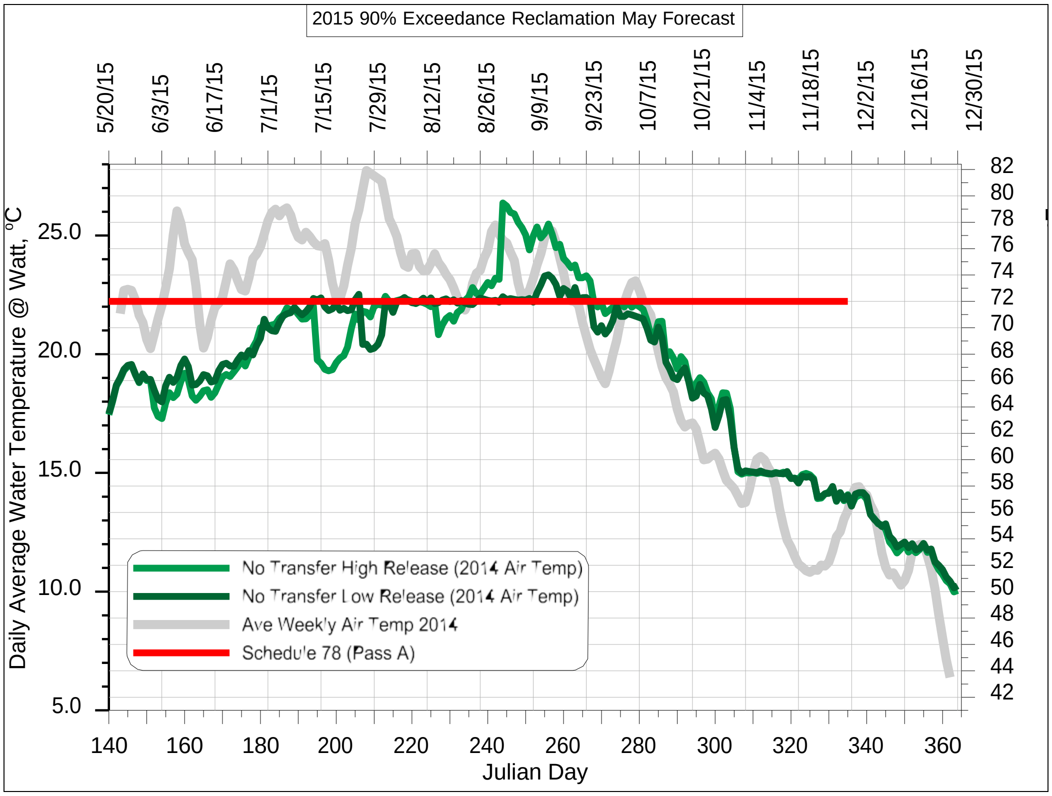
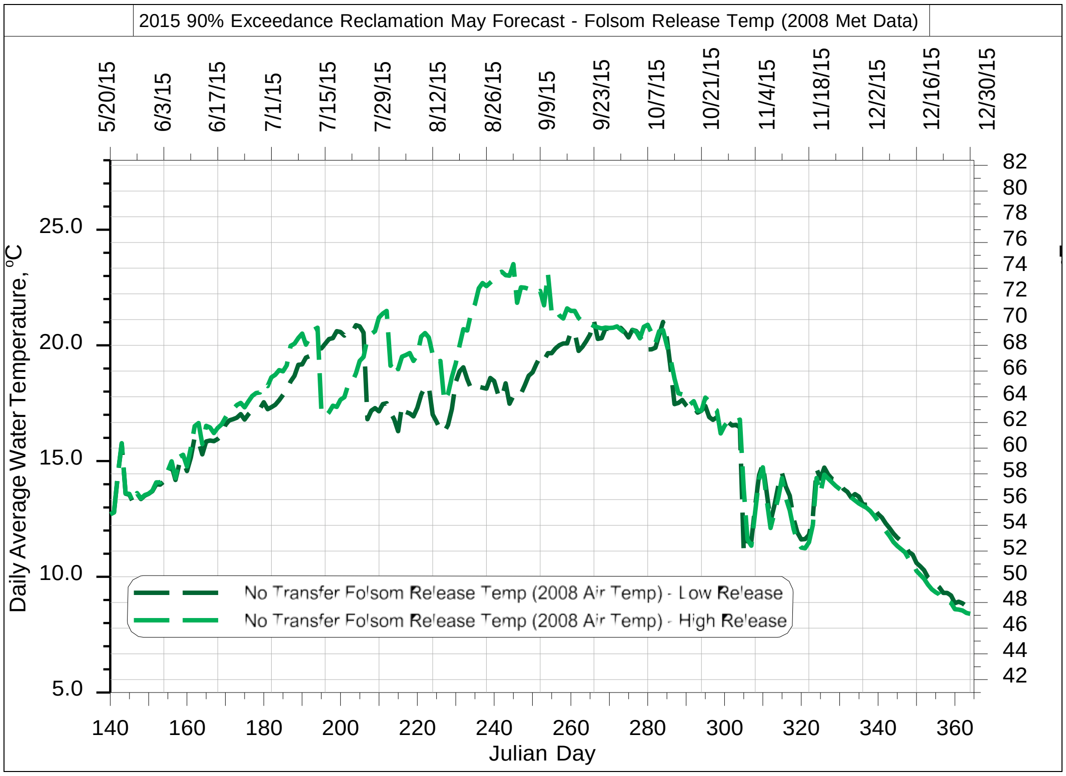


Figure 5. Model Results for Water Temperature in the Lower American River at Watt Avenue using 2008 (top) and 2014 (bottom) Meteorological Data for High and Low Release Scenarios.



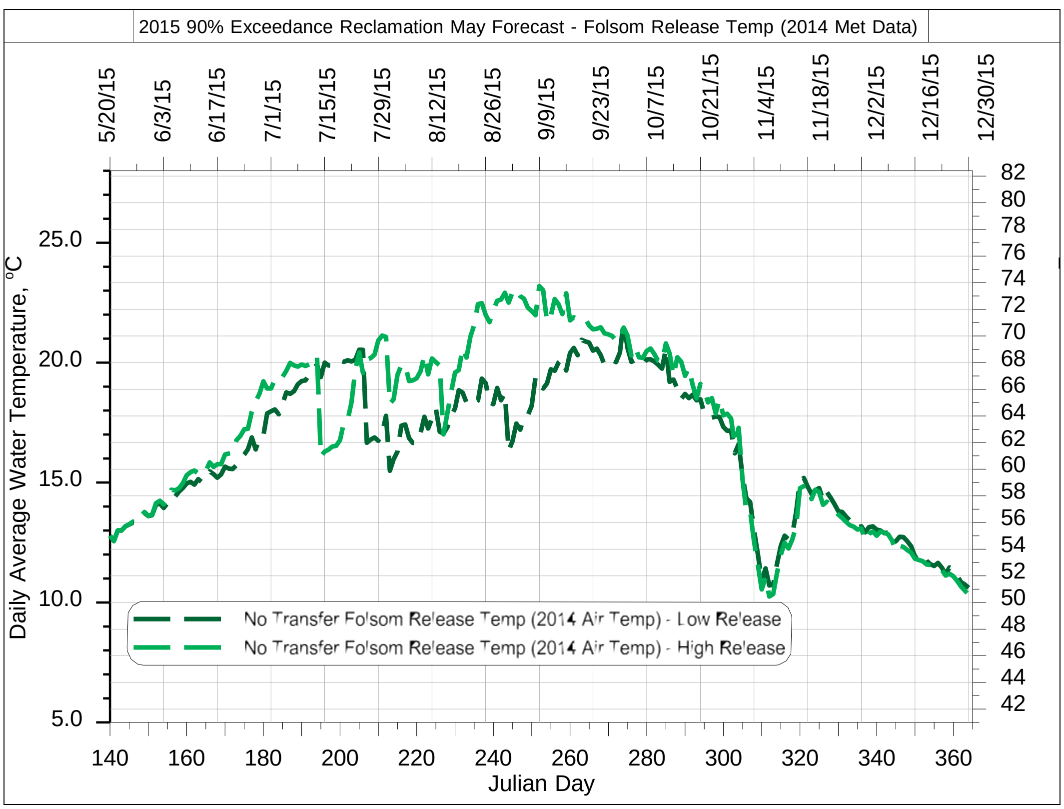
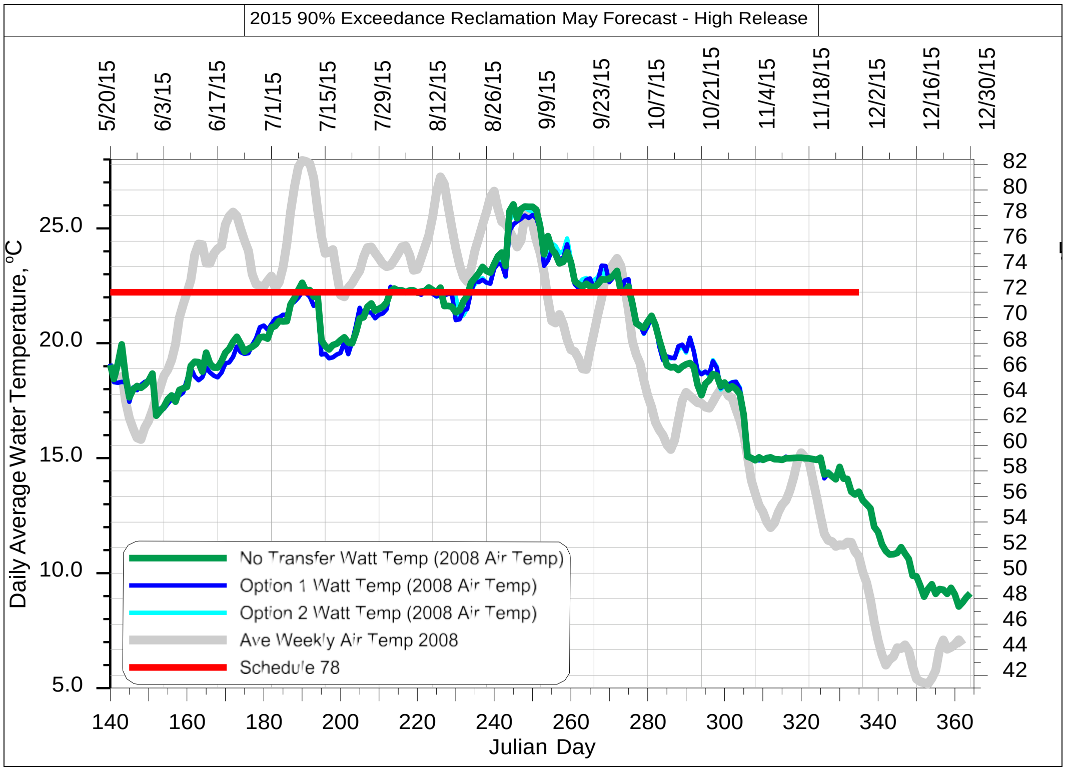


Figure 6. Model Results for Water Temperature below Folsom Reservoir using 2008 (top) and 2014 (bottom) Meteorological Data for High and Low Release Scenarios



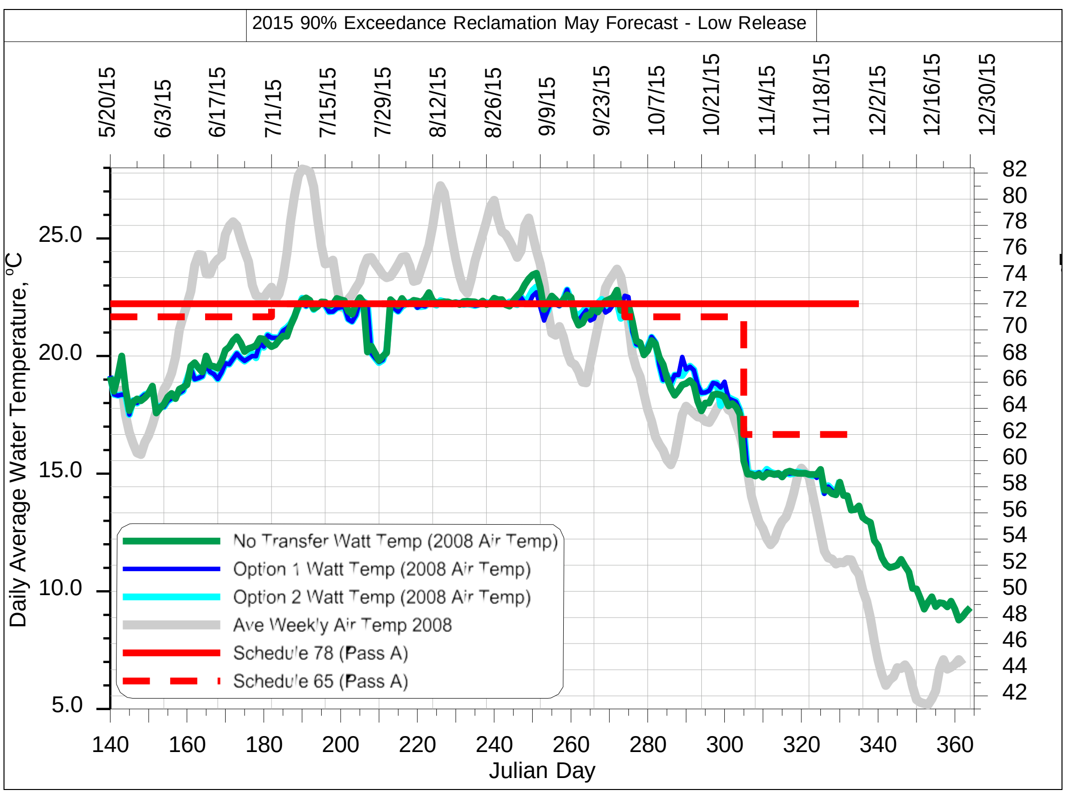
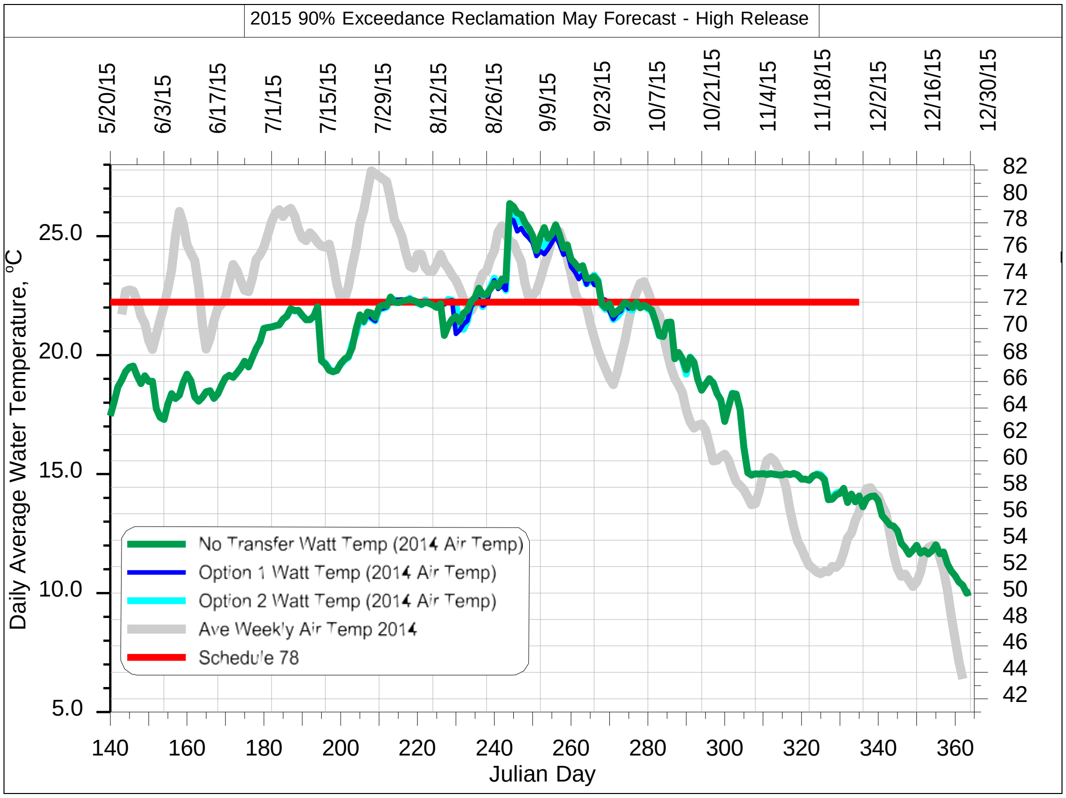


Figure 7. Model Results for Water Temperature in the Lower American River at Watt Avenue using 2008 Meteorological Data for the High (top) and Low Release (bottom) No Transfer, Option 1 and Option 2 Scenarios.



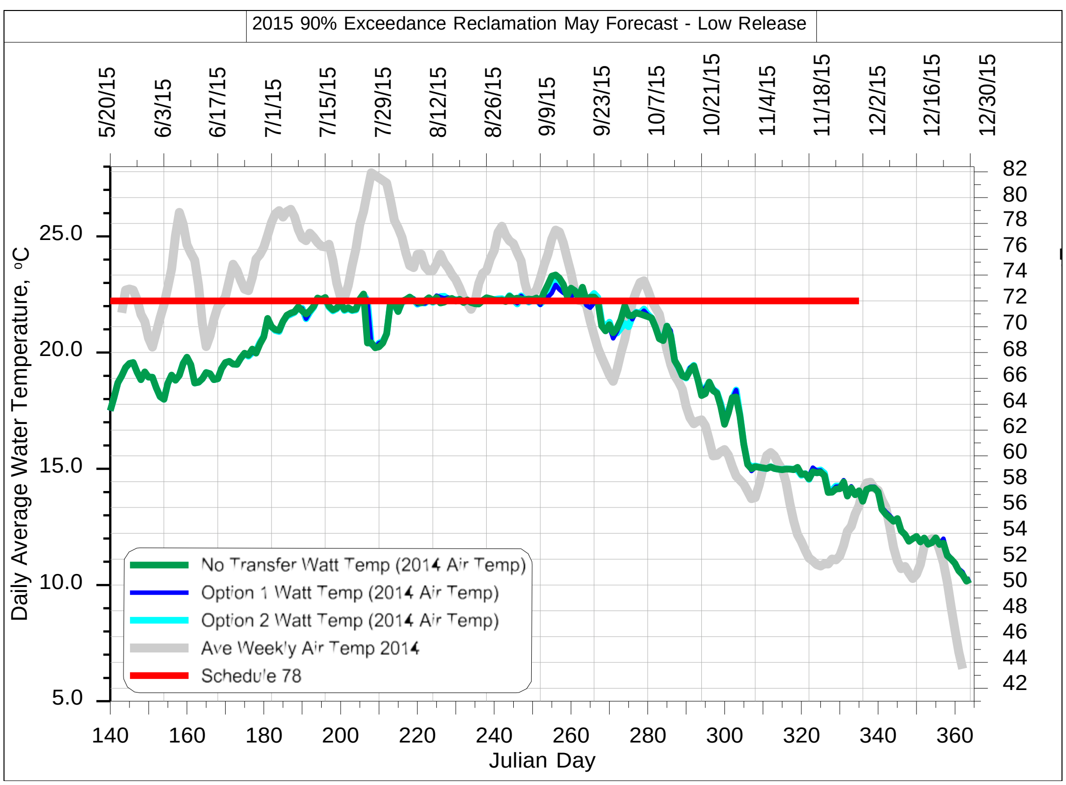


Figure 8. Model Results for Water Temperature in the Lower American River at Watt Avenue using 2014 Meteorological Data for the High (top) and Low Release (bottom) No Transfer Option 1, and Option 2 Scenarios.

6.0 ADDITIONAL DRIER YEAR WATER TRANSFER EFFECTS

Releasing 12,000 AF of transfer water in a drier year has additional beneficial effects, including achieving drier year flow augmentation objectives in the Water Forum Agreement, increasing hydropower generation and CAISO grid regulation capacity, and increasing commercial and recreational rafting opportunities in the MFAR.

PCWA's purveyor-specific Water Forum Agreement includes a commitment to release additional water from the MFP in dry years to preserve and protect the natural resources of the LAR. These environmental releases are conditioned upon PCWA's ability to find a willing buyer to purchase the water downstream of the confluence of the Sacramento and American rivers. The 2015 Transfer to EBMUD provides certainty that releases will be made into the LAR or will bolster critically low storage in Folsom Reservoir.

Making additional water available to PCWA's and Reclamation's powerhouses during the peak summer power load period of a drier year is important for grid regulation in California. Hydroelectric power generation is the primary source of flexible generation used by the California Independent System Operator (California ISO) to regulate the fluctuations of the electric grid in California. As a consequence of the drought, there currently is and will continue to be a significant reduction in hydroelectric generation capacity throughout the state until hydrologic conditions stabilize. The MFP is regularly called upon by California ISO to provide critical grid support services when abrupt changes in load occur.

PCWA's summer power generation releases support the regional whitewater economy and a whitewater rafting industry of 20,000 user-days on the MFAR. The prime rafting season starts on Memorial Day weekend (May 24-26) and extends through the summer to Labor Day (September 1). PCWA likely could provide an additional rafting day per week during the peak boating season (July and August) with the Transfer.

7.0 CONCLUSION

The proposed PCWA and EBMUD Transfer would release surplus water from PCWA's MFP reservoirs that would not otherwise be released from the MFP this year and would remain in storage absent the Transfer. The Transfer would not injure any legal user of the water and would benefit fish, wildlife, recreation, and/or other instream beneficial uses.

Specifically, the drier year transfer would provide the following beneficial effects:

Increased water supply for EBMUD;

Increased drier year flow in the Lower American River and/or storage in Folsom Reservoir;

Decreased water temperature in the Lower American River; and

Additional benefits, including meeting Water Forum Agreement drier year objectives, increasing drier year hydropower generation/grid regulation capacity, and enhancing MFAR whitewater rafting opportunities.

8.0 REFERENCES

Placer County Water Agency. 2015. PCWA's Carryover Storage and Refill Reporting for Dry Year Water Transfers Occurring in 2013 and 2014. Memorandum sent Ron Milligan, Reclamation June 3, 2015.

Attachment A

PCWA Historical Water TRANSFERS (1990-2015)

Attachment A Table 1. PCWA Historical Water Transfers (1990-2015).

Calendar Year	Water Transfer (ac-ft)	MRA* Jan	MRA* Feb	MRA* Mar	MRA* Apr	MRA* May	MRA* Jun	MRA* Jul	MRA* Aug	MRA* Sep	MRA* Oct	MRA* Nov	MRA* Dec	Total Release[1] (ac-ft)	Transfer Recipient
1990	38,597												38,597	38,597	Westlands Water District, San Luis, San Francisco
1991	40,000												40,000	40,000	San Francisco, Santa Clara
1992	10,000												10,000	10,000	State Water Bank
1993															
1994	20,000												20,000	20,000	State Water Bank
1995														0	
1996														0	
1997	12,000							17,000	18,000					12,000	Sac Area Flood Control
1998														0	
1999														0	
2000														0	
2001	20,000									21,800	400			22,200	Environmental Water Account
2002														0	
2003														0	
2004	18,700									7,900	7,900	2,900		18,700	Environmental Water Account
2005														0	
2006														0	
2007														0	
2008	20,000									29	8,139	139	21,268	29,575	Westlands Water District (WWD)
2009	20,000								5,209	15,415				20,624	San Diego
2010														0	
2011														0	
2012														0	
2013	20,000					20,000								20,000	WWD
2014	40,000				5,000		8,750	8,750	8,750	8,750					East Bay Municipal District & WWD

[1] In some years, release volumes were greater than the transfer amount.
*** MRA - Monthly Release Amounts (ac-ft)**

Attachment B

Folsom Reservoir Inflow Water Temperature

INTRODUCTION

This attachment documents inflow water temperature into Folsom Reservoir and the relationship between water temperature and flow for both the North Fork and South Fork American rivers (NFAR and SFAR). The sources for flow and temperature data, monthly regression relationships between flow and water temperatures, and comparisons of empirical versus modelled water temperatures (regression-based) are provided below.

DATA SOURCES

The nearest NFAR and SFAR flow and temperature gages with recent historical data were used to characterize Folsom Reservoir inflow water temperature. Descriptions of the gaging and temperature stations are provided in Attachment B Table 1, and the locations are shown on Attachment B Map 1. All data were quality controlled prior to use in the analyses.

North Fork/Middle Fork American Rivers

Flow
The nearest active upstream gaging stations to Folsom Reservoir are located on the NFAR at North Fork Dam, CA (USGS gage no. 11427000) and on the MFAR near Foresthill, CA (USGS gage no. 11433300). The MFAR flows into the NFAR downstream of both of these gages. Daily average flows from the MFAR gage were combined with the daily average flows measured on the NFAR gage to produce an estimate of flow at the inlet to Folsom Reservoir (July 1999 – June 2014).

Water Temperature
Historical daily water temperature data were obtained from the USGS gaging station/California Data Exchange Center (CDEC) on the NFAR at Auburn Dam Site near Auburn, CA (USGS gage no. 11433790/station NFA) (July 1999 – June 2014). This location is just upstream of Folsom Reservoir.

South Fork American River

Flow
The nearest active upstream gaging station to Folsom Reservoir located on the SFAR is the USGS gaging station near Placerville, CA (USGS gage no. 11444500). This gage does not account for local inflows between the gage site and the inlet to Folsom Reservoir; however very little inflow occurs below this gage during the drier months and in drier years (time period when water temperature is a function of flow).

Water Temperature
Historical water temperature data for the SFAR were obtained from USGS gaging station on the SFAR near Pilot Hill, CA (USGS gage no. 11446030).

FLOW AND WATER TEMPERATURE RELATIONSHIPS

North Fork/Middle Fork American River and SFAR water temperatures were strongly correlated with flow in the May – September time period and weakly correlated with flow in other months. Monthly regression relationships were developed from the empirical flow and water temperature data. In instances where the regressions needed to be applied on a daily basis throughout the year, the monthly regression coefficients were interpolated from the center of the month.

North Fork American River

For the NFAR water temperature into Folsom Reservoir a multiple regression equation that relates mean monthly North Fork American River flows (USGS gage near North Fork Dam) and mean monthly MFAR inflow (USGS gage near Foresthill) was developed to predict mean monthly water temperatures (November 1999 – June 2014) (Attachment B Table 2). Comparisons of the NFAR empirical and modeled water temperature for the inflows into Folsom Reservoir is provided in Attachment B Figure 1 and a time series plot showing the empirical and modeled water temperature is shown in Attachment B Figure 2.

South Fork American River

For the SFAR water temperature into Folsom Reservoir, a monthly regression relationship was developed from empirical flow and water temperature data from the SFAR average monthly water temperatures (USGS gage near Pilot Hill approximately 0.1 mile downstream of Weber Creek) and SFAR average monthly flows (SFAR USGS gage near Placerville) (August 1999 – June 2014) (Attachment B Table 3). Comparison of the SFAR measured and modeled water temperature for the inflows into Folsom Reservoir (November 1999 – June 2014) is provided in Attachment B Figure 3 and a time series plot showing the measured and modeled water temperature is shown in Attachment B Figure 4.

The SFAR water temperature into Folsom Reservoir that was used for the water transfer temperature modeling is shown in Attachment B Figure 5.

ATTACHMENT B

TABLES

Attachment B Table 1. Data Sources for Folsom Reservoir Inflow Water Temperature Regression Analyses.

River Reach and Attribute	Data Sources					
	Operator	Name	Identification Number	Location (lat/long)	Period of Record Available	Period of Record Used in Regression Analyses
North Fork/ Middle Fork American River Watersheds						
North Fork American River Daily Average Flow	USGS	NF American R a North Fork Dam CA	11427000	38.93611°N/121.0228°W	10/1/1941-present; hourly	7/1/1999-6/30/2014
Middle Fork American River Daily Average Flow	USGS	MF American R nr Foresthill CA	11433300	39.00611°N/120.7597°W	10/1/1958-9/30/2012; daily	
Daily Average Water Temperature	USGS/ CDEC	NF American River at Auburn Dam	11433790/ NFA	38.852000°N/121.057000°W	7/21/1999-present; hourly	
South Fork American River Watershed						
Daily Average Flow	USGS	South Fork American River near Placerville	11444500	38.77111°N/120.8153°W	10/1/1911-9/30/2012; daily	8/1/1999-6/30/2014
Daily Average Water Temperature	USGS	South Fork American River near Pilot Hill	11446030	38.76306°N/121.0072°W	8/4/1999-present; hourly	

Abbreviations:

USGS: United States Geological Survey

CDEC: California Data Exchange Center

Attachment B Table 2. Monthly Regression Equations to Model North Fork American River Folsom Reservoir Inflow Water Temperatures based on Monthly Average North Fork and Middle Fork American River Flows and Monthly Average Local Air Temperature (based on July 1999-June 2014 data).

Month	Regression Equation	R^2
x_{UNFA} = Upper North Fork American River Mean Monthly Flow (cfs) x_{MFA}= Middle Fork American River Mean Monthly Flow (cfs) X_{AIR} = Mean Monthly Air Temperature (°F) y = North Fork American River Mean Monthly Temperature (°F) upstream of Folsom Reservoir		
Jan	y=27.04771 + 2.81189*LOGXUNFA - 0.47640*LOGXMFA + 0.22371*XAIR	0.41[1]
Feb	y=5.75243 - 0.19558*LOGXUNFA - 0.60664*LOGXMFA + 0.83013*XAIR	0.84
Mar	y=26.99404 + 1.05901*LOGXUNFA - 4.49126*LOGXMFA + 0.58994*XAIR	0.94
Apr	y=60.67131 - 5.84327*LOGXUNFA - 4.03140*LOGXMFA + 0.37980*XAIR	0.95
May	y=54.68841 - 8.46923*LOGXUNFA - 2.37403*LOGXMFA + 0.55234*XAIR	0.95
Jun	y=102.01746 - 1.00915*LOGXUNFA - 13.59212*LOGXMFA + 0.05733*XAIR	0.94
Jul	y=128.91632 + 5.08863*LOGXUNFA - 24.95334*LOGXMFA - 0.03006*XAIR	0.85
Aug	y=113.54756 - 1.68439*LOGXUNFA - 10.14214*LOGXMFA - 0.23823*XAIR	0.44[1]
Sep	y=112.39111 - 5.79512*LOGXUNFA - 9.37626*LOGXMFA - 0.20727*XAIR	0.51[1]
Oct	y=39.95207 - 1.73580*LOGXUNFA - 2.56164*LOGXMFA + 0.46824*XAIR	0.61[1]
Nov	y=31.38417 + 0.24565*LOGXUNFA - 0.46914*LOGXMFA +0.40474*XAIR	0.41[1]
Dec	y=21.28772 - 0.64300*LOGXUNFA + 2.63127*LOGXMFA + 0.40135*XAIR	0.48[1]

Regression Variables:

x_{UNFA} = Upper North Fork American River Mean Monthly Flow (cfs) at the North Fork Dam, CA (USGS gage no. 11427000)

x_{MFA}= Middle Fork American River Mean Monthly Flow (cfs) near Foresthill, CA (USGS Gage 11433300 until Sept 20 2014)(CDEC OXB starting Oct 1, 2014)

X_{AIR} = Air Temperature (°F) at Fair Oaks (CIMIS-131)

y = North Fork American River Mean Monthly Temperature (°F) upstream of Folsom Reservoir

[1]Low r-squared values are the result of a narrow range in temperatures in these months. These regressions represent the average water temperature.

Attachment B Table 3. Monthly Regression Equations to Model South Fork American River Folsom Reservoir Inflow Water Temperatures based on Monthly Average South Fork American River Flows and Local Air Temperature (based on August 1999-June 2014 data).

Month	Regression Equation	R^2
y = Predicted water temperature (°F) x = South Fork American River mean monthly flow (cfs) Air = Mean monthly air temperature (°F)		
Jan	$y = 20.69984 + 2.91534*Log\ X_{SFA} + 0.28960*X_{AIR}$	0.45
Feb	$y = 5.75472 - 0.48212*Log\ X_{SFA} + 0.79575*X_{AIR}$	0.75
Mar	$y = 47.13000 - 4.35076*Log\ X_{SFA} + 0.26830*X_{AIR}$	0.78
Apr	$y = 65.08803 - 7.54184*Log\ X_{SFA} + 0.18307*X_{AIR}$	0.75
May	$y = 62.42750 - 11.48169*Log\ X_{SFA} + 0.46790*X_{AIR}$	0.96
Jun	$y = 79.92108 - 12.88612*Log\ X_{SFA} + 0.30343*X_{AIR}$	0.94
Jul	$y = 77.94852 - 11.71646*Log\ X_{SFA} + 0.28672*X_{AIR}$	0.79
Aug	$y = 105.01906 - 16.61535*Log\ X_{SFA} + 0.08482*X_{AIR}$	0.79
Sep	$y = 88.16222 - 10.85794*Log\ X_{SFA} + 0.04886*X_{AIR}$	0.56
Oct	$y = 59.29323 - 7.31408*Log\ X_{SFA} + 0.28409*X_{AIR}$	0.61
Nov	$y = 30.69185 - 0.47584*Log\ X_{SFA} + 0.40891*X_{AIR}$	0.31[1]
Dec	$y = 9.20239 - 0.14844*Log\ X_{SFA} + 0.77211*X_{AIR}$	0.65

Regression Variables:

x = South Fork American River mean monthly flow (cfs) near Placerville, CA (USGS Gage 11444500 through Sept 30 2014) (CDEC CBR from Oct 1 2015)

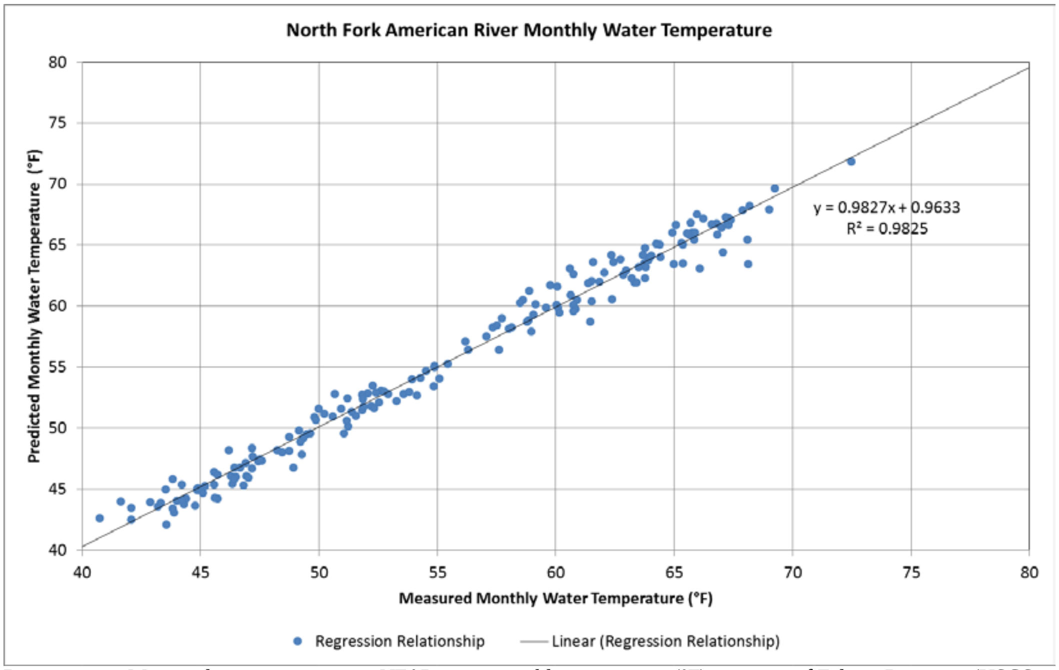
y =South Fork American River Mean Monthly Temperature (°F) near Pilot Hill, CA (USGS gage no. 11446030)

Air = Mean monthly air temperature at Fair Oaks (CIMIS-131) (°F)

[1] Low r-squared values are the result of a narrow range in temperatures in these months. These regressions represent the average water temperature.

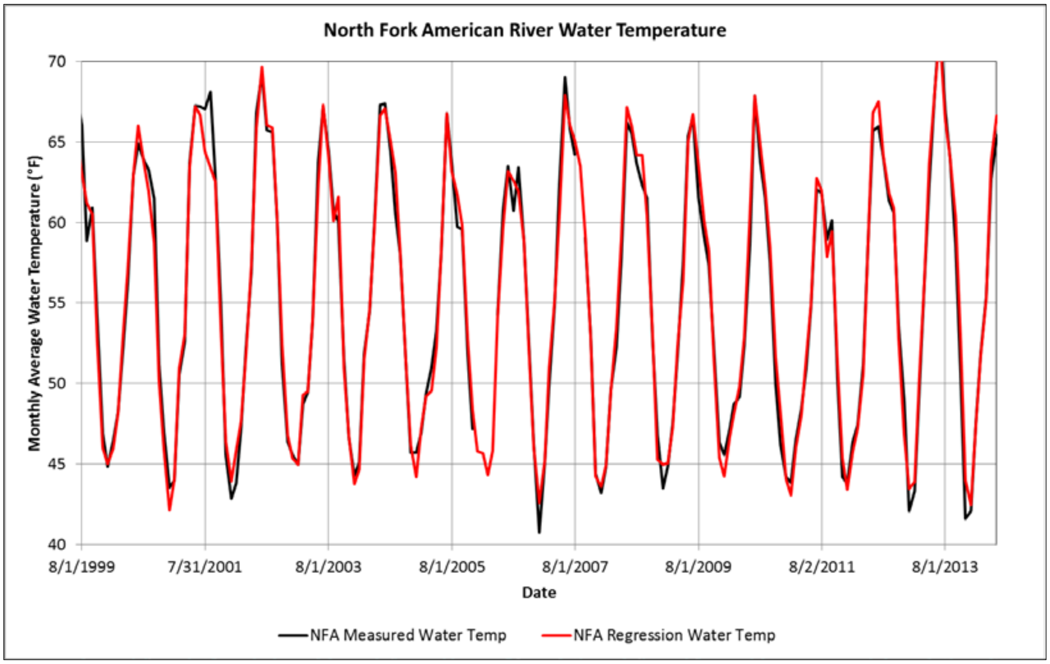
ATTACHMENT B

FIGURES



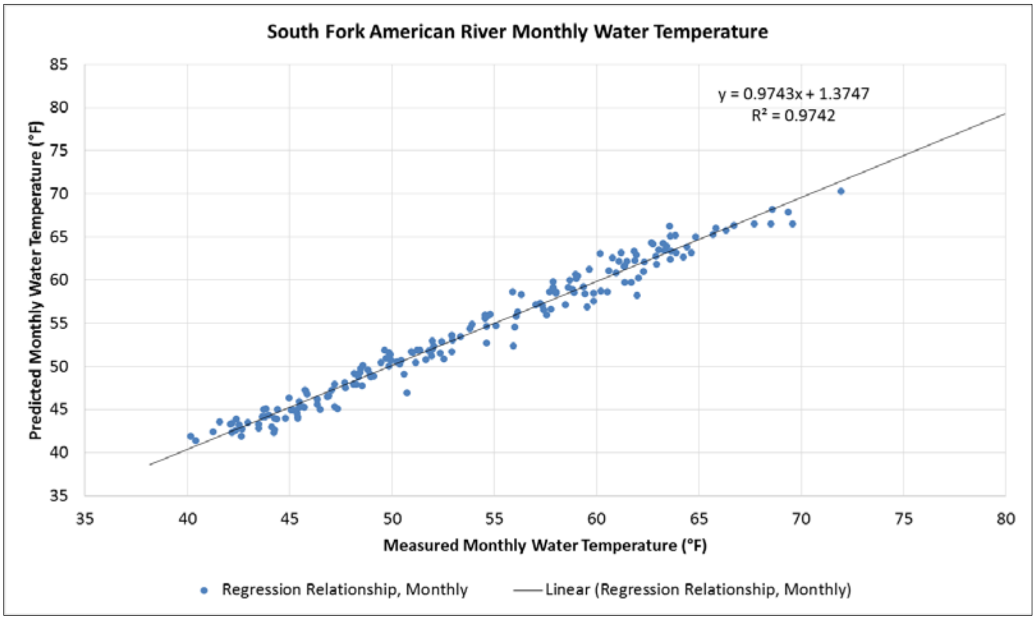
Data sources: Measured water temperature: NFAR mean monthly temperature (°F) upstream of Folsom Reservoir (USGS gage no. 11433790/CDEC station CDEC-NFA); Modeled (regression) water temperature: NFAR monthly flow (cfs) (USGS gage no. 11427000), MFAR mean monthly flow (cfs) (USGS Gage 11433300 until Sept 20 2014)(CDEC OXB starting Oct 1, 2014), and monthly average local air temperature (°F) (CIMIS-131).

Attachment B Figure 1. Measured versus Modeled (Regression) North Fork American River Temperature into Folsom Reservoir (July 1999-June 2014).



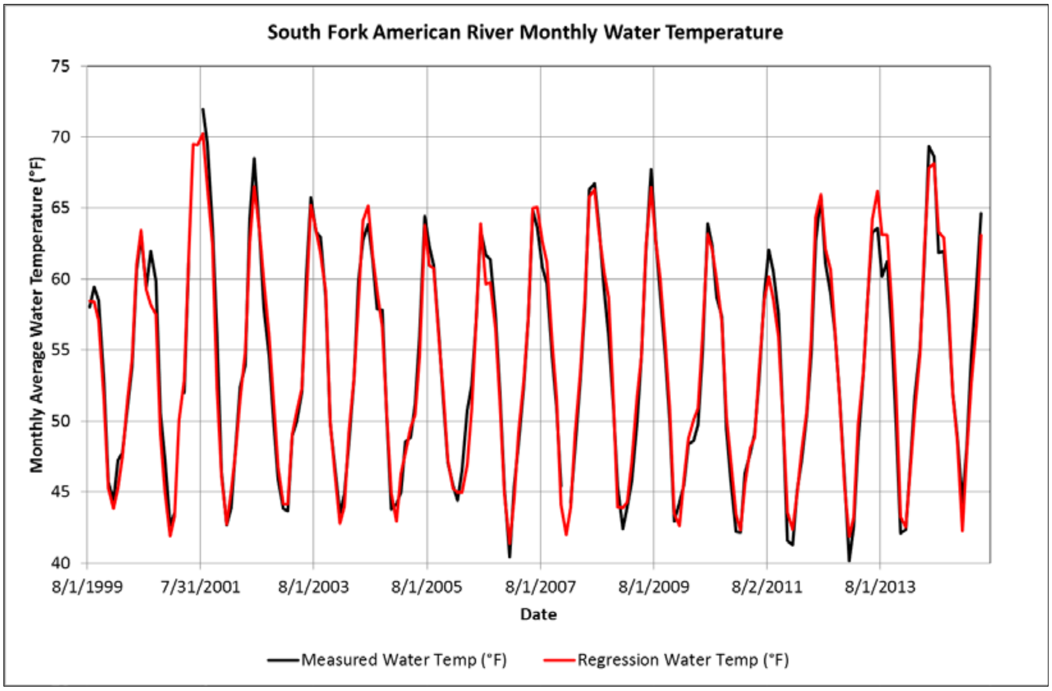
Data sources: Measured water temperature: North Fork American River mean monthly water temperature (°F) upstream of Folsom Reservoir (USGS gage no. 11433790/CDEC station NFA); Modeled (regression) water temperature: NFAR mean monthly flow (cfs) ((USGS gage no. 11427000), MFAR mean monthly flow (cfs) (USGS Gage 11433300 until Sept 20 2014)(CDEC OXB starting Oct 1, 2014), and monthly average local air temperature (°F) (CIMIS-131).

Attachment B Figure 2. Time Series of Measured and Modeled North Fork American River Temperature into Folsom Reservoir (July 1999-June 2014).



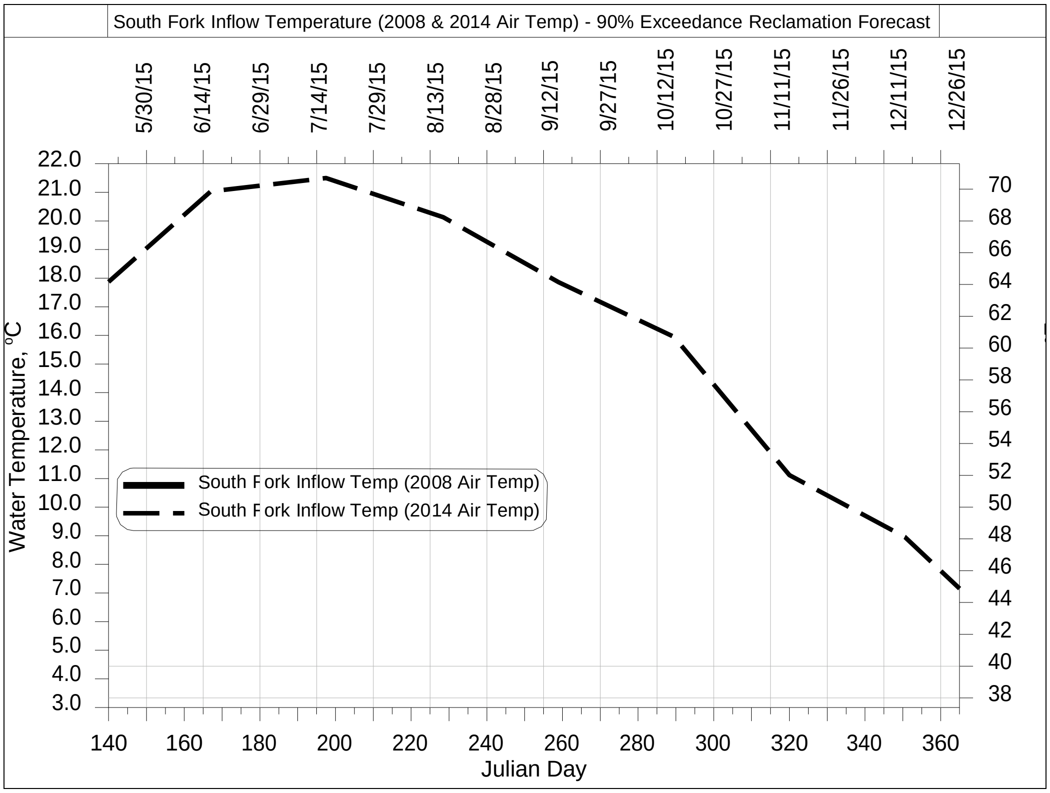
Data sources: Measured water temperature: Monthly average water temperature (°F) (USGS gage no. 11446030). Modeled (regression) water temperature: Monthly average air temperature (°F) (CIMIS-131) and monthly average flow at Chili Bar (cfs) (USGS gage no. USGS/CDEC gage no. 11444500/CDEC-CBR).

Attachment B Figure 3. Measured versus Modeled (Regression) South Fork American River Temperature into Folsom Reservoir (August 1999-June 2014).



Data sources: Measured Temperatures: South Fork American River monthly average water temperature (°F) (USGS gage no. 11446030). Modeled (regression) water temperature: Monthly average air temperature (°F) (CIMIS-131) and monthly average flow at Chili Bar (cfs) (USGS gage no. 11444500).

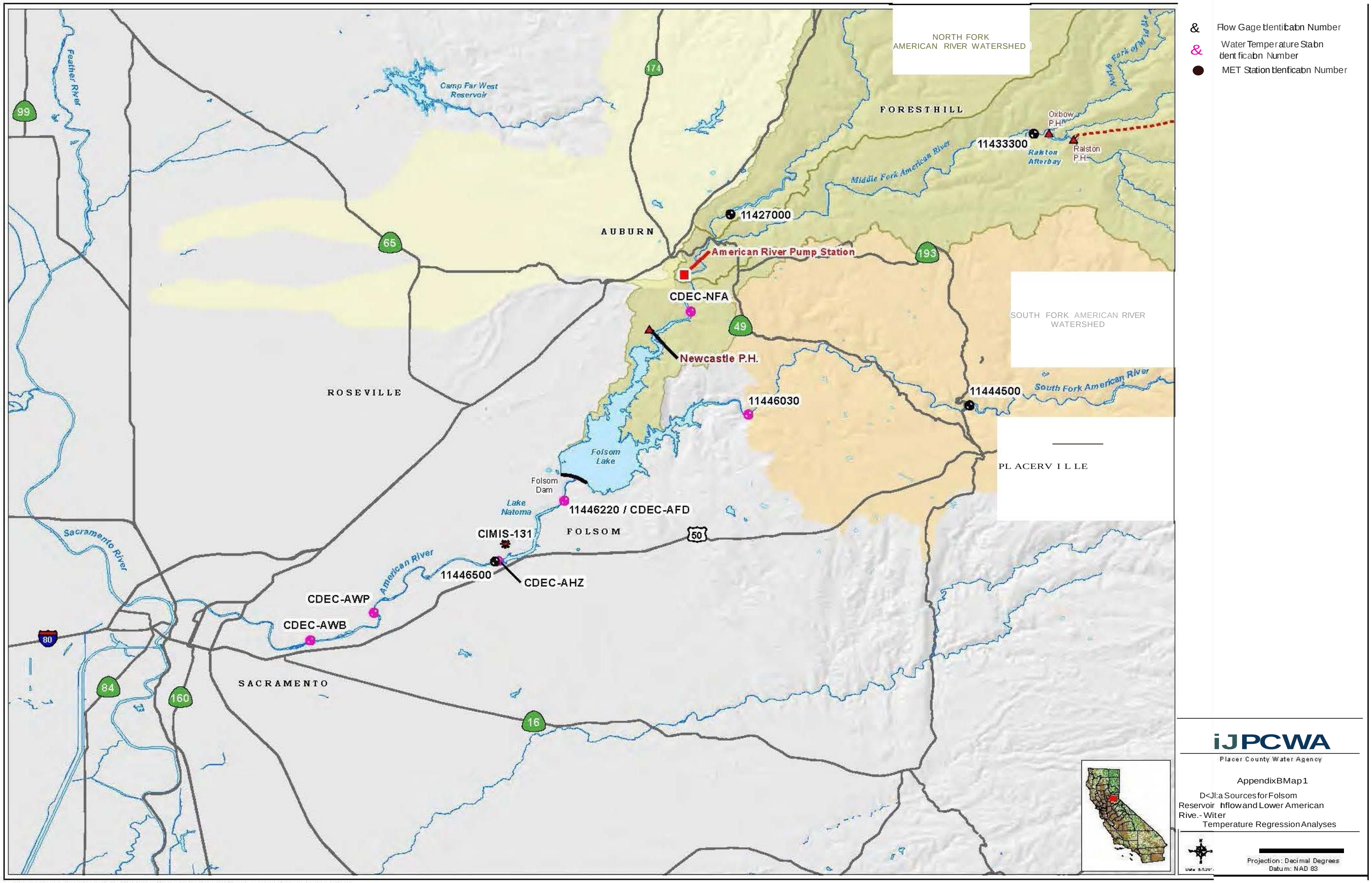
Attachment B Figure 4. Time Series of Measured and Modeled South Fork American River Temperature (August 1999-June 2014).



Attachment B Figure 5. Water Temperature in the South Fork American River upstream of Folsom Reservoir for use in Water Transfer Modeling.

ATTACHMENT B

MAP



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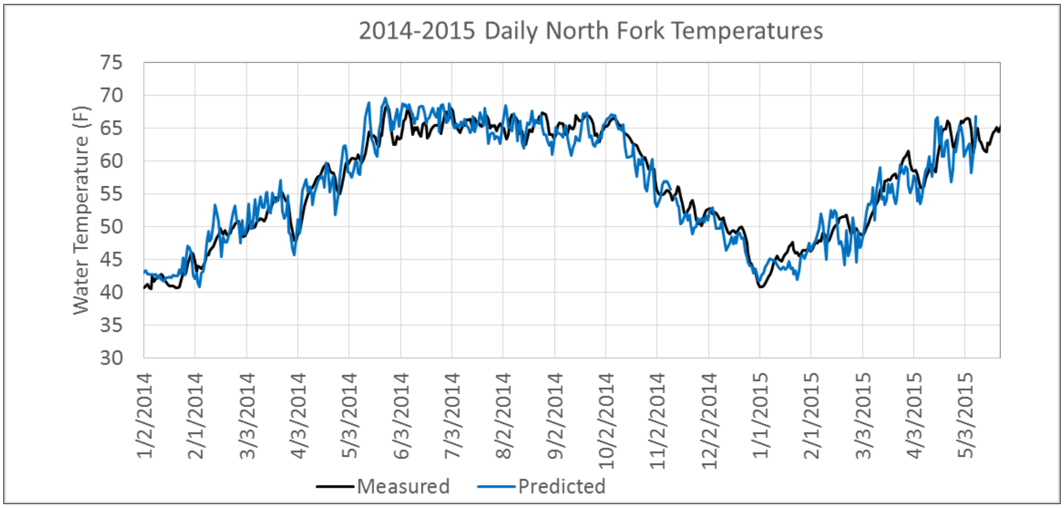
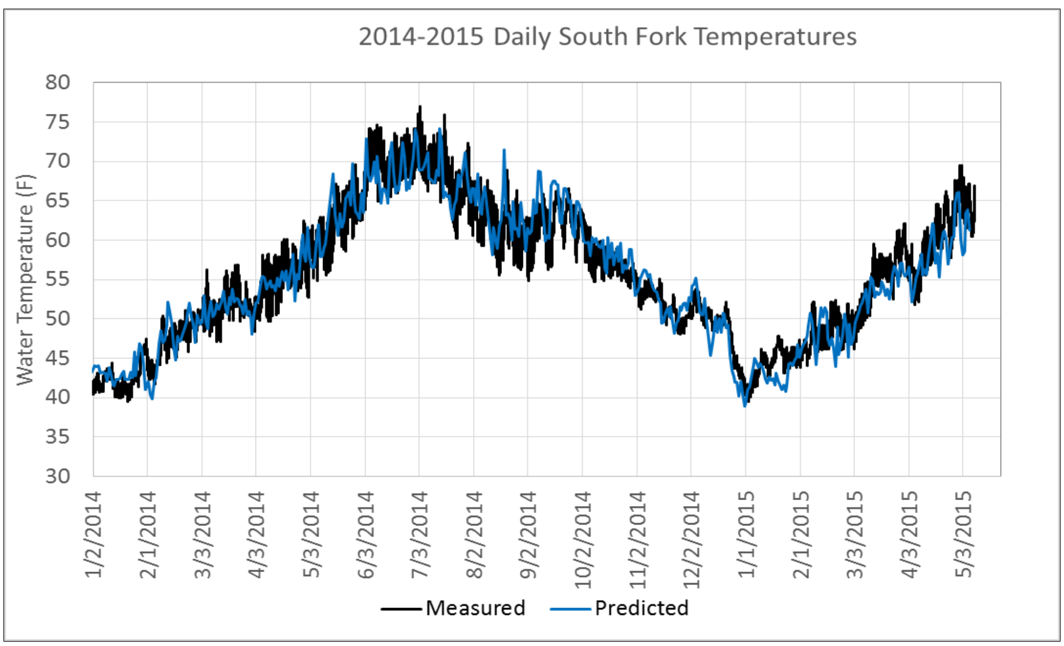
ATTACHMENT C

NORTH FORK, SOUTH FORK, AND LOWER AMERICAN RIVER REGRESSION

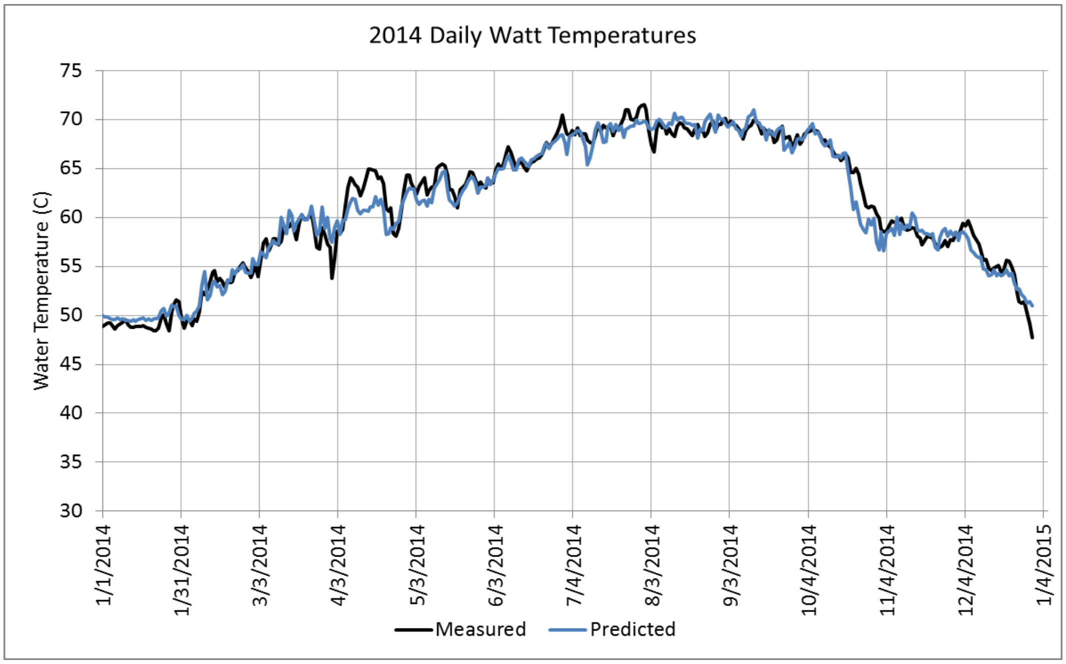
PERFORMANCE FOR 2014



Attachment C Figure 1. Measured and Predicted (Regression) North Fork American River Temperature into Folsom Reservoir (January 2014-May 2015).



Attachment C Figure 2. Measured and Predicted (Regression) South Fork American River Temperature into Folsom Reservoir (January 2014-May 2015).



Attachment C Figure 3. Measured and Predicted (Regression) Lower American River Temperature at Watt Avenue (January 2014 - Jan 2014).

ATTACHMENT D

FOLSOM RESERVOIR WATER TEMPERATURE MODEL

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ABSTRACT

Folsom Reservoir, located near Sacramento, California USA, is a deep-storage reservoir that provides municipal water, power generation, and cold water releases for salmonid fish in the lower American River. The dam has discrete temperature control shutters on the three powerhouse intakes. The shutters can be installed or removed in sections and they allow the dam operator to choose different water levels from each intake to blend outflow water temperature to accommodate downstream temperature requirements. The dam also has a municipal water outlet with a continuously adjustable temperature control device and a set of low level outlets that are used for water temperature control.

A complex model of the reservoir was developed using the CE-QUAL-W2 model (Cole and Wells, 2013) and calibrated to historical operations over a 10-year time period. Absolute mean temperature errors in model profiles and in downstream temperature were 0.56^{o}C and 0.58^{o}C, respectively, well less than the target of <1^{o}C. Leakage through the temperature control shutters at the dam was identified during model calibration.

A customized operational model tool was developed using the CE-QUAL-W2 model to automatically determine how best to select outlet shutter positions to maximize efficient use of the limited cold water available within the reservoir to meet the downstream temperature regulatory targets for fish in the lower American River. The model proved successful in running long-term simulations that can be used to evaluate reservoir operations based on modified or forecasted hydrological and meteorological inputs.

INTRODUCTION

A Folsom Reservoir water temperature modeling tool was developed to evaluate alternative inflow hydrology and reservoir operations scenarios and shutter operations for Folsom Dam to meet regulatory temperature targets in the lower American River (i.e., Automated Temperature Selection Procedure [ATSP] schedules identified in the Water Forum Flow Management Standard [Water Forum 2004, Water Forum 2006]). The primary objective of the temperature schedules are to maintain suitable temperatures for Central Valley steelhead during the summer rearing period and Chinook salmon spawning/incubation during the fall months given inflows, available reservoir volume, and outflows.

Folsom Dam was designed to be able to release water from various elevations within the reservoir simultaneously. Dam operators install or remove discrete temperature shutters on the three powerhouse intakes to take water from different depths to blend outflows to meet downstream regulatory temperature objectives. Operators also adjust the elevation of the municipal water supply outlet and operate the low level outlets on the dam to modify outflow water temperatures/preserve cold water resources in the reservoir.

The water temperature modeling tool was developed to automatically determine the best shutter settings and flow rates through each of the three powerhouse intakes to meet the coldest ATSP outflow temperature schedule possible and to utilize cold water in the reservoir most effectively. This includes a user specified target temperature for the municipal outlet and use of the low level outlets in late fall to access cold water that remains in the reservoir below the powerhouse outlets.

The modeling tool uses CE-QUAL-W2 (Cole and Wells, 2013), a 2-D hydrodynamic and temperature model, modified with new model code to enhance and automate temperature shutter modeling capability (including low-level outlets) and ATSP temperature schedule selection capability. The completed modeling tool allows modelers to run scenarios in which the model itself determines the optimal operation of powerhouse shutters, municipal outtake, and low-level outlets to meet downstream temperature targets.

BACKGROUND INFORMATION

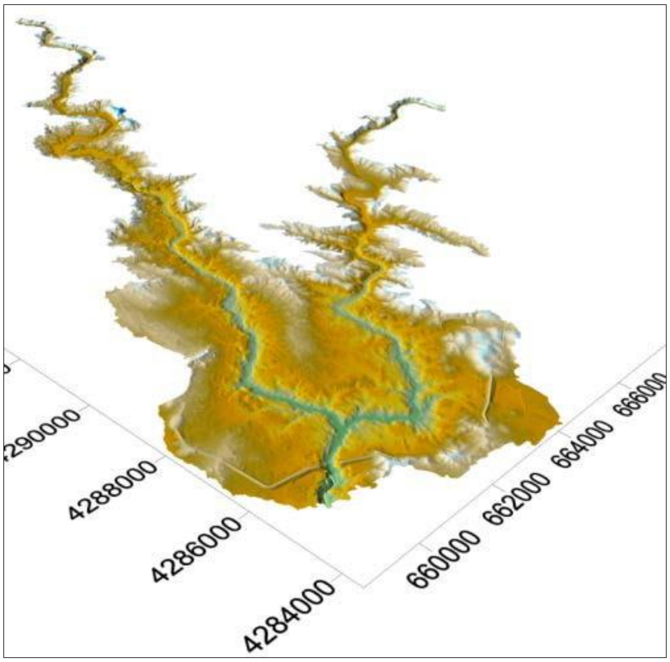
Folsom Dam and reservoir are located approximately 20 miles northeast of the city of Sacramento, California, on the American River. This reservoir has a capacity of 976,000 acre-feet (1,203,878,290 cubic meters) and drains an area of approximately 1,875 square miles (4,856 square kilometers). The dam was built by the U.S. Army Corps of Engineers between 1948 and 1956, at which point operation of the dam was transferred to the Bureau of Reclamation (U.S. Dept. of Interior, 2013). Downstream of Folsom Dam, the American River provides important habitat for Central Valley steelhead and Chinook salmon. Water temperatures in this section of the river play a critical role in determining the health of these, as well as other aquatic species.

Folsom Dam was constructed with a total of 20 different outlets and outlet structures. Three power generation penstocks are each fitted with discrete, removable/installable shutters that allow for 4 different configurations (discrete inflow elevations). These configurations allow the operator to pull water from different depths depending on water level and desired outflow temperature. In addition to the powerhouse shutters, a variable elevation temperature control device is used to divert water for municipal use. The remaining structures are all at fixed locations and include 8 rectangular river outlets and 8 spillway gates. These are generally used only for flood control and occasionally for temperature control in the late fall (low level outlets). The use of the low level outlets in the fall results in water bypassing the power generators. The locations of the main features on Folsom Dam are shown in Attachment D Figure 1. An earlier model study of Folsom Reservoir by the Bureau of Reclamation (Bender et al. 2007) was conducted in 2007. In that study, the CE-QUAL-W2 model was also used but with a coarser bathymetric grid than what was used in this study (described below).

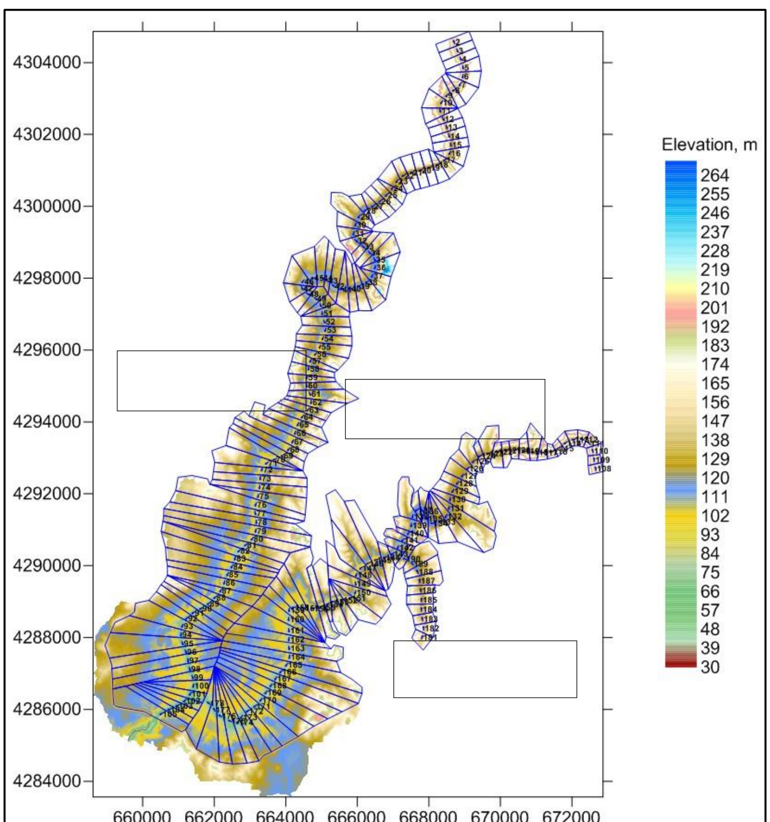
Attachment D Figure 9. Folsom Dam Outlet Structures (Google Maps, 2013)

MODEL BATHYMETRY

Bathymetric data for Folsom Reservoir were collected by means of multi-beam sonar and photogrammetry during the fall of 2005 as part of a sedimentation study conducted by the Bureau of Reclamation (Ferrari, 2007). These data were used to develop a 3-D bathometric representation of Folsom Reservoir as seen in Attachment D Figure 10. This grid was in turn used to develop the CE-QUAL-W2 model grid, shown in Attachment D Figure 11. The grid was divided up into a total of 3 branches with 191 segments each having an average length of 250 meters. The vertical model resolution was 0.61 m or 2 ft. The model grid matched the 2005 Sediment Survey volume elevation and surface area elevation curves (Ferrari, 2007).



Attachment D Figure 10. Folsom Reservoir Bathymetry Showing the North Fork and South Fork of the American River Channels (dimensions are in meters).



Attachment D Figure 11. Model Grid Segment Layout for the Three Model Branches (dimensions are in meters).

HISTORICAL MODEL CALIBRATION

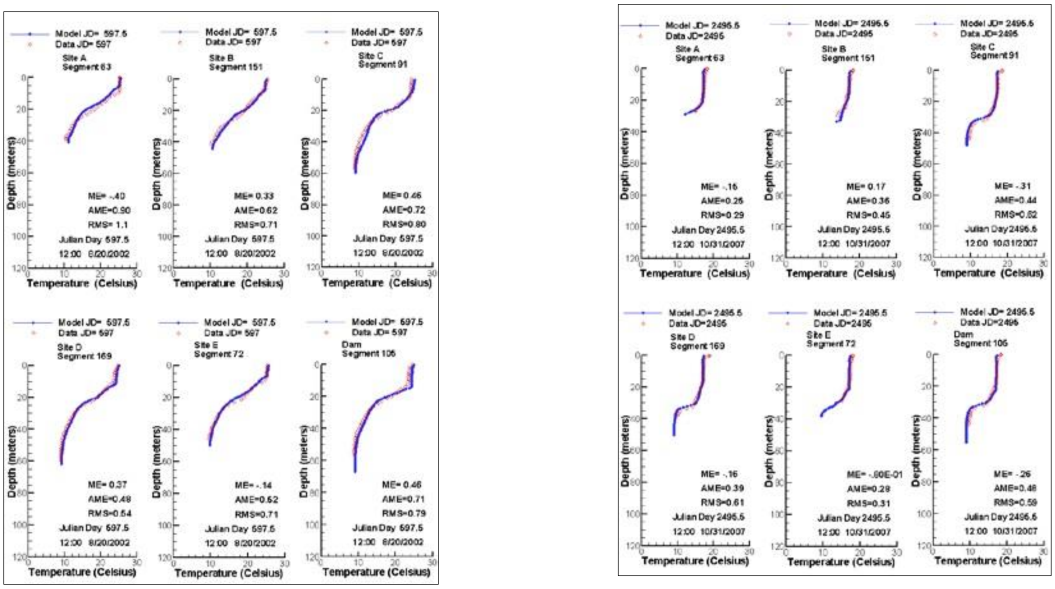
The model was calibrated for a 10-year period between January 1, 2001 and December 31, 2011. Boundary conditions for inflow, meteorological data, and outflow during this period were developed. A very detailed approach for filling in data gaps was undertaken to provide a good set of boundary conditions for the 10-year period.

Secchi disk data from 1979 were used to estimate the average light extinction coefficient. Calculations show that the light extinction coefficient varied from 0.3 to 0.7 m^{-1} with an average value close to the CE-QUAL-W2 default value of 0.45 m^{-1}.

Inflows included the North and Middle Forks of the American River, the SFAR, Mormon Ravine, and Newcastle Powerplant. Outflows included three penstocks with discrete shutter settings, municipal water withdrawals with variable shutter settings, low-level outlet releases, spills, and evaporation.

Air temperature, dew point temperature, wind speed and direction, cloud cover, and solar radiation were collected from various meteorological stations in the vicinity of Folsom Reservoir for this time period. Most of the model development uncertainty was in filling meteorological data gaps (e.g., wind data) and in estimating the amount of leakage into the lower level powerhouse outlets from the shutters.

Almost one thousand temperature profiles were taken over this 10-year period at 6 stations in Folsom Reservoir with a profile frequency of about once per month (data were collected by Bureau of Reclamation). Attachment D Figure 12 compares two representative model predictions with field data for temperature profiles taken in August 2002 and October 2007. Error statistics for the 10-year model period versus measured profiles are shown in Attachment D Table 5.

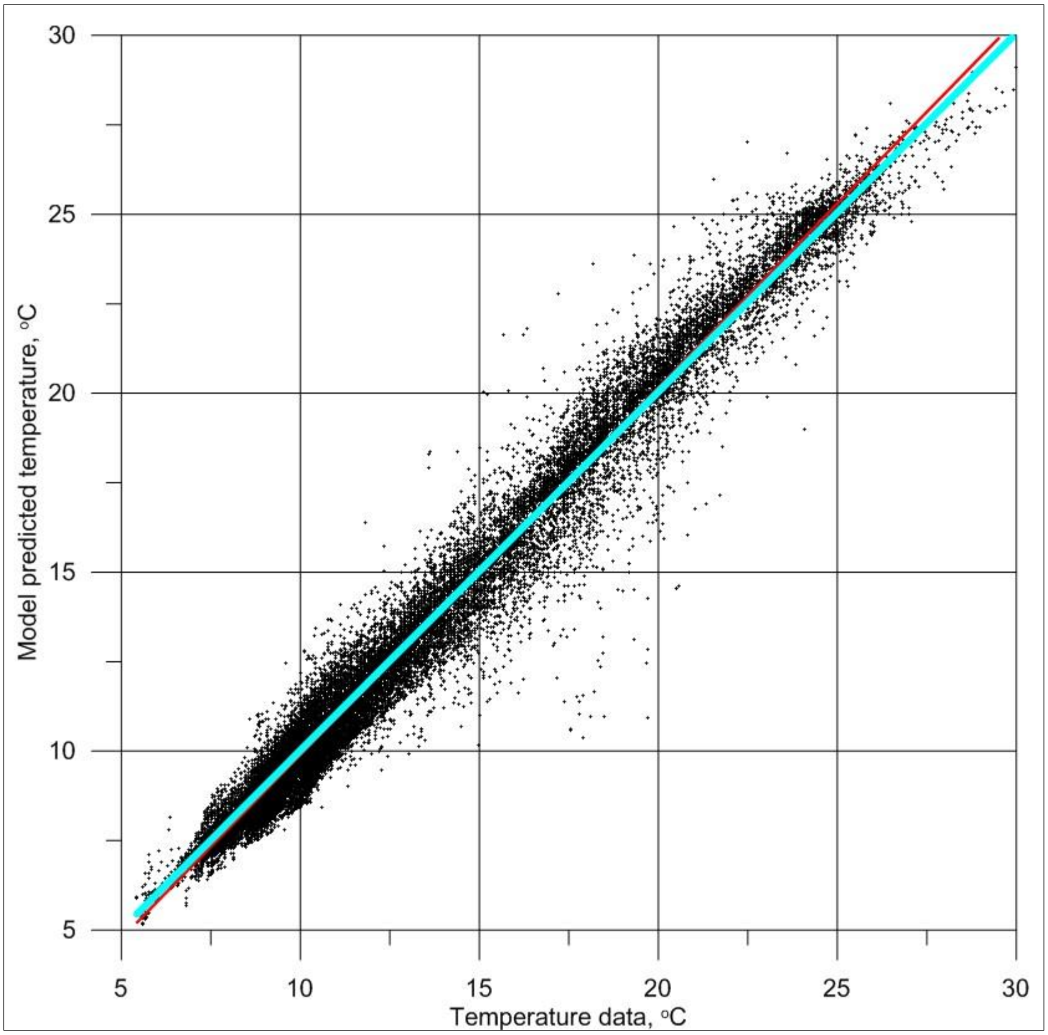


Attachment D Figure 12. Model Temperature Profiles Compared to Measured Temperature Profiles on August 20, 2002 (left) and October 31, 2007 (right) at Six Different Stations in Folsom Reservoir.

Attachment D Table 5. Modeled Versus Measured Temperature Profile Error Statistics.

Temperature Profile Model Segment (USBR Site)	# of profiles	# of individual temperature observations	Mean Error ^{o}C	Absolute Mean Error ^{o}C	Root Mean Squared Error ^{o}C
63 (Site A)	**169**	**4421**	**-0.050**	**0.607**	**0.772**
72 (Site E)	**154**	**4681**	**-0.093**	**0.589**	**0.769**
91 (Site C)	**154**	**4861**	**0.032**	**0.520**	**0.669**
105 (Dam)	**178**	**7190**	**-0.049**	**0.530**	**0.689**
151 (Site B)	**154**	**4283**	**0.175**	**0.585**	**0.726**
169 (Site D)	**171**	**5943**	**0.011**	**0.506**	**0.648**
Average overall statistics:			**0.004**	**0.556**	**0.712**

A comparison of all measured profile data to model profiles over the 10-year period is shown in Attachment D Figure 13.



Attachment D Figure 13. Comparison of Model Predicted Temperature Profile and Measured Temperature Profile Data Between 2001 and 2011. (Slope of the linear regression through the origin is 1.002 with an R^2 of 0.996 [red line]; blue line is a 1:1 slope).

Model predicted water temperatures and measured water temperatures immediately downstream of Folsom Dam were also compared (Attachment D Figure 14). Absolute mean errors for downstream temperatures were less than 0.6°C.

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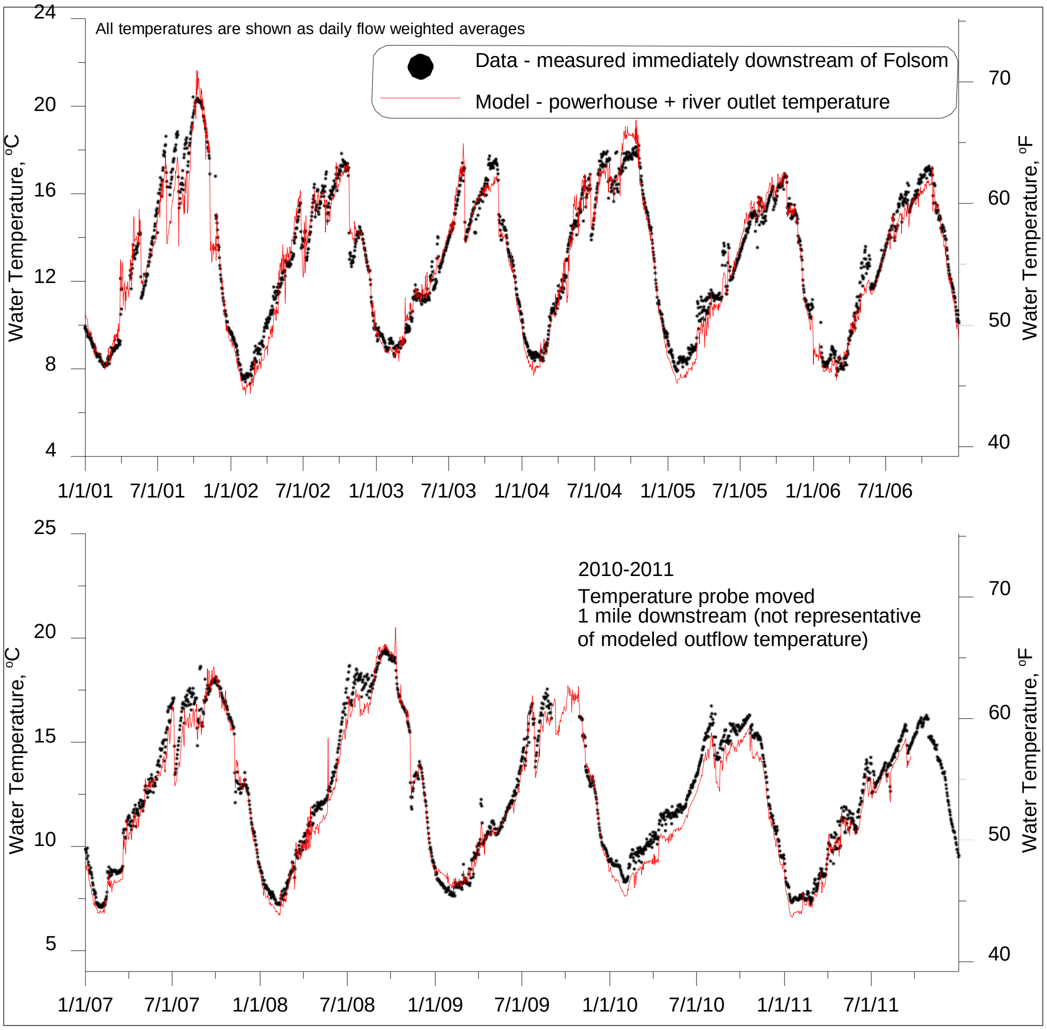


Attachment D Figure 14. Model Predicted Temperatures below Folsom Dam Compared to Measured Temperatures Immediately Downstream of Folsom Dam between 2001 and 2009. For 2010 and 2011, Model Predictions and Observed Data are Shown, but Not Completely Comparable because the Observed Data were Collected 1 mile Downstream of Folsom Dam.

AUTOMATIC MODEL SIMULATION TOOLS

Three individual model tools were developed and verified using boundary condition and meteorological data from the same time period to fully automate shutter operation. The three tools are as follows:

Automatic Municipal Water Intake Elevation

Based on the available historical data, 2006 and 2011, operators of the municipal water intake structure generally tried to extract water at approximately 18°C (65°F) or cooler during most time periods, given operational constraints (e.g., reservoir water surface elevation, minimum and maximum inlet elevations). This capability was built into the model, allowing the modeler to specify the municipal intake constraints: (1) target temperature; (2) maximum and minimum inlet elevations; and (3) minimum inlet elevation below the water surface elevation (WSE).

In addition to these constraints, operation rules were set including the following:

On March 1st of each model year, the elevation of the intake was raised as high as possible given the WSE constraint;

If not raised to maximum on March 1st, the model continued checking on a daily basis until the intake could be raised to a maximum elevation;

If intake temperature criteria were violated, the intake was lowered in one meter increments until water temperature met criteria; and

The model continued lowering intake elevation as dictated by the temperature criteria until Dec 1st of each model year, or until the minimum water intake elevation was reached.

Automatic Shutter Operations

The automatic shutter operation algorithm was developed to divide flow through each of the three powerhouse penstocks and to determine when to change the shutter configuration to pull water from the appropriate location in the reservoir to achieve target outflow temperatures. Each of the Folsom Dam powerhouse penstock shutters operate independently and have a total of 4 different elevation settings. The overall flow rate was specified as well as a daily water temperature target that the model was trying to match. A code was developed to calculate the percent flow to be directed through each penstock and the shutter elevations given the following constraints:

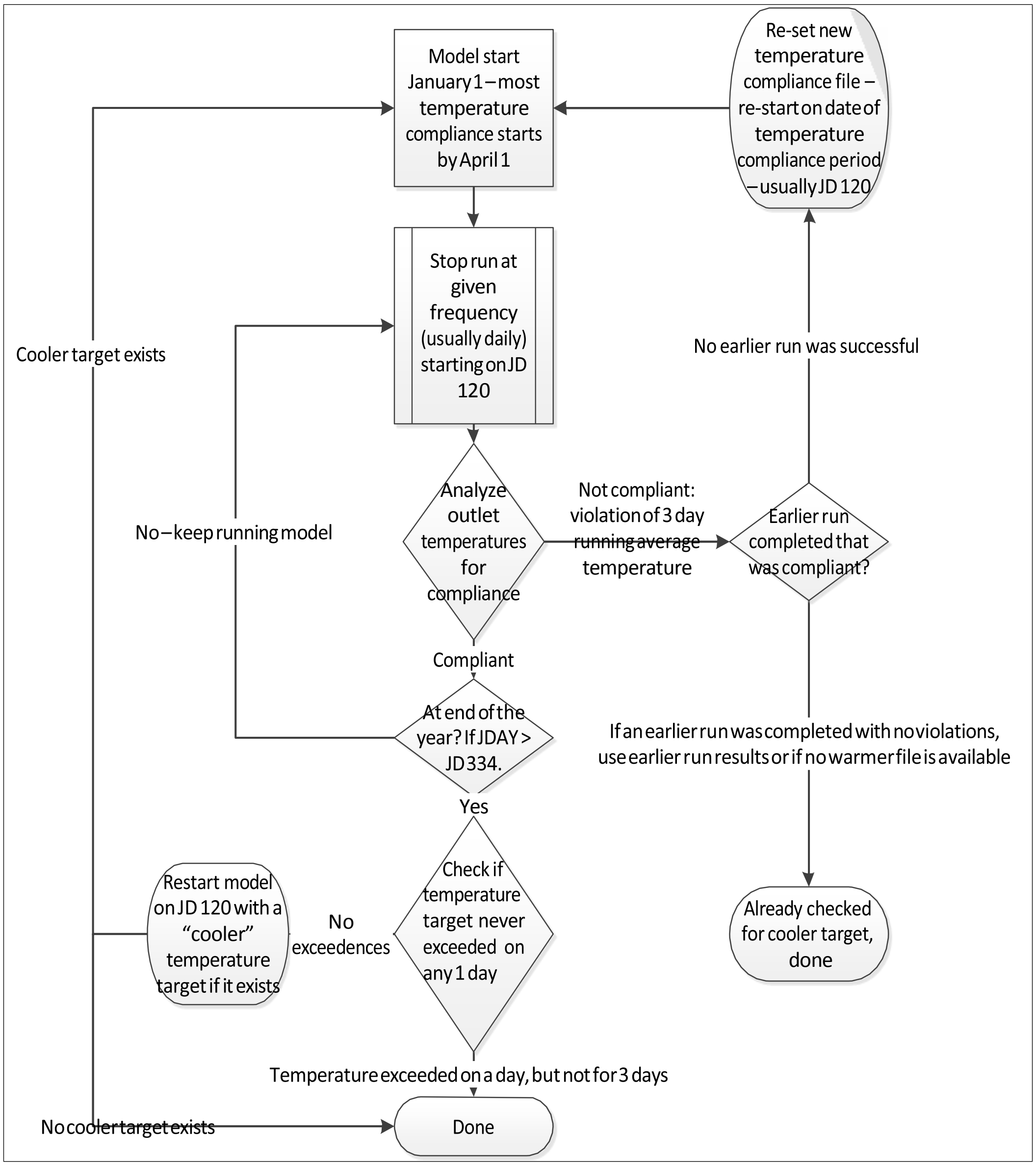
- Minimum and maximum flow through each powerhouse; and
- Shutter minimum elevation below WSE at any time (8.23 meters); otherwise the shutter opening would be lowered to the next lowest level.

An extensive set of operational rules were set up to apportion flow through each of the powerhouse penstocks and determine when the shutter opening needed to be lowered in order to meet temperature criteria. When all shutter openings were at their lowest level and temperature criteria were still not being met, the model was set up to allow a portion of the outflow water to pass through the lower level river outlets at the bottom of the dam – completely by-passing the powerhouse (a date range can be set in the input data to constrain when this operation can occur).

Automatic Temperature Schedule Choice

An algorithm was developed that allowed the model to run and to converge on the coldest ATSP temperature schedule that could be met. The model user provides

10 temperature target “schedules” or daily average temperature time-series files, ranging from coolest (#1) to warmest (#10). The model starts with schedule #5 and runs until it violates a temperature criterion more than 3 times in a season (either consecutively or cumulatively), at which point it restarts to an earlier time and chooses a warmer target schedule. Conversely if the starting temperature target file was too warm and the outflow temperatures never violate the temperature target, the model restarts to an earlier time and reruns using a cooler temperature target file. This logic for running the model is shown in Attachment D Figure 15.

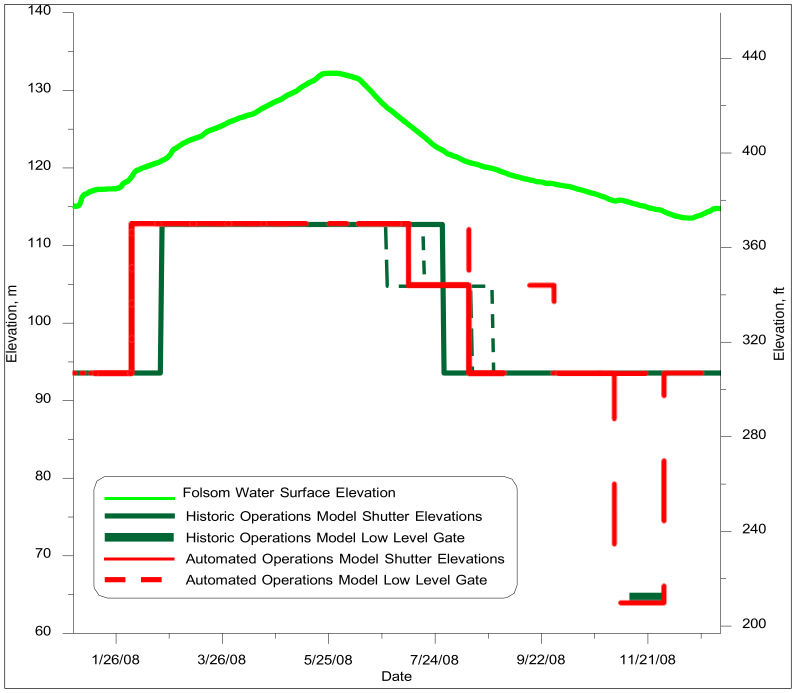


Attachment D Figure 15. Flow Chart for Automatic Model Selection of Optimal Temperature Schedule.

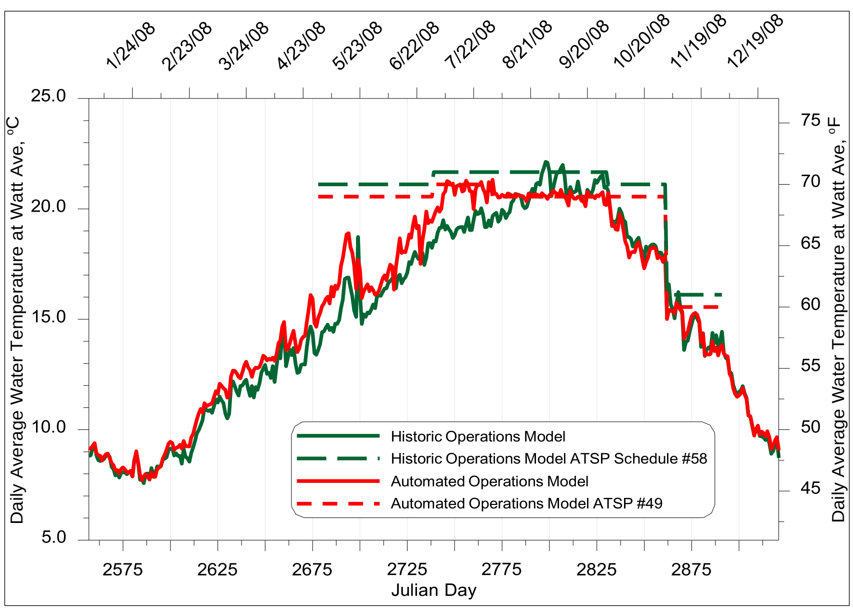
EXAMPLE RESULTS of AUTOMATIC SHUTTER and MUNICIPAL OUTLET SCENARIO

An example of the combined outflow temperature results of the automated temperature model for 2008 is shown compared to an historical operations calibration model in Attachment D Figure 8. Compared to actual operations, the model code optimized lower American River water temperature by releasing warmer water earlier in the summer and maintaining significantly cooler temperatures later into the fall spawning season. Resulting water temperatures approximately 32 km (20 miles) downstream at Watt **Avenue are shown in**

Attachment D Figure 9.



Attachment D Figure 16. **Comparison of Historical Versus Automated Water Temperature Model Shutter Operations below Folsom Dam, 2008.**



Attachment D Figure 17. **Comparison of Historical Versus Automated Model Operations for Watt Avenue Water Temperature, 2008. (Note: These results were obtained by using a combination of the CE-QUAL-W2 model and an American River water temperature regression between Folsom Dam and Watt Avenue).**

CONCLUSIONS

Using extensive flow, water temperature, and meteorological empirical data from 2001 to 2011, a fully calibrated CE-QUAL-W2 model of Folsom Reservoir was developed. The model performed very well when compared to in-lake temperature profile and downstream temperature data, with absolute mean errors of less than 0.6°C for both metrics. This calibrated model was then run using a series of tools developed to allow complete automation of the municipal outlet and powerhouse penstock shutters.

ACKNOWLEDGEMENTS

Calibration data sets were provided by the U.S. Bureau of Reclamation. We benefitted greatly by learning from previous modeling efforts by Chris Hammersmark, CBEC Inc., who has used the 1D Iterative Coldwater Pool Management Model extensively to model Folsom Reservoir.

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ATTACHMENT E

Lower American River Water Temperature at Watt Avenue

INTRODUCTION

This attachment documents the regression approach for predicting water temperatures at Watt Avenue.

DATA SOURCES

The sources for flow, water temperature, and other meteorological (MET) data are provided in Attachment E Table 1, and the locations are shown on Attachment E Map 1. The time period used for the regression analyses was 2001-2011. All data were quality controlled prior to use in the analyses.

WATER TEMPERATURE AT WATT AVENUE

Monthly multiple regression relationships were developed to predict water temperatures on the Lower American River at Watt Avenue. The multiple regressions were developed for each month using daily water temperature below Folsom Dam (California Data Exchange Center (CDEC) gage), daily-averaged Folsom Dam outflows (CDEC gage) minus the Folsom South Canal Diversion flows (CDEC gage), and daily air temperature measured near Fair Oaks. Inclusion of solar radiation resulted in minimal improvement to model performance, and was not included in the final regression used. Historical data, 2001-2011, did not include time periods with low summer flows (<1,400 cfs). To add low flow information to the regression, the Lower American River (LAR) HEC-5Q Model was used to develop temperatures at 500 and 1,000 cfs based on MET data from 2008.

The regression relationships (monthly constants and regression coefficients) were then used to predict daily water temperatures at Watt Avenue based on daily flow and air temperature measurements (Attachment E Table 2). The regression coefficients were linearly interpolated between the center of the month values to obtain daily regression coefficients. A comparison of the predicted and measured water temperatures from 2001-2011 at Watt Avenue is shown in Attachment E Figure 1.

ATTACHMENT E

TABLES

Attachment E Table 1. Data Sources for the Lower American River Water Temperature Regression Analyses.

River Reach and Attribute	Data Sources					
	Operator	Name	Identification Number	Location (lat/long)	Period of Record Available	Period of Record Used in Regression Analyses
Lower American River						
Daily Average Flow American River below Folsom Dam	US Bureau of Reclamation / CDEC	Folsom Lake outflows	FOL	38.683000°N / 121.183000°W	2/1/1995-present, hourly	1/1/2001-9/23/2011
Folsom South Canal	US Bureau of Reclamation/ CDEC	Folsom South Canal	FSC	38.650000°N/121.183000°W	7/11/2001-present, monthly	7/11/2001-9/23/2011
Daily Water Temperature below Folsom Dam	USGS/ CDEC	American R below Folsom Dam	11446220/ AFD	38.688300°N/121.166700°W	10/24/1998-present, daily	1/1/2001-9/23/2011
Daily Average Air Temperature – Lower American River	CIMIS	CIMIS at Fair Oaks	131	38.65056°N/121.2181°W	4/18/1997-present, daily	1/1/2001-9/23/2011

Abbreviations:

CIMIS: California Irrigation Management Information System
USGS: United States Geological Survey
CDEC: California Data Exchange Center

Attachment D Table 2. Coefficients Used for the Multiple Regression for Predicting Lower American River Water Temperature at Watt Avenue (2001-2011).

Month	Constant	A	B	C	D	R^2
Predicted Temp = Constant + A(Ave Air Temp) + B(Ave Water Temp below Folsom) + C(Ave Flow) + D(Ave Flow^2)						
Jan	1.9303	0.1141	0.7390	-0.0046	1.438E-05	0.64
Feb	1.6880	0.1771	0.7851	-0.0100	1.470E-05	0.63
Mar	5.9400	0.1291	0.5856	-0.0210	2.656E-05	0.75
Apr	6.5729	0.1232	0.6679	-0.0242	2.413E-05	0.80
May	8.5043	0.1935	0.5898	-0.0462	6.614E-05	0.88
Jun	11.0982	0.0948	0.6151	-0.0603	1.212E-04	0.94
Jul	13.4974	0.0858	0.5903	-0.0938	2.736E-04	0.93
Aug	15.4759	0.1222	0.4923	-0.1611	7.790E-04	0.88
Sep	10.2659	0.1721	0.5021	-0.0825	3.492E-04	0.82
Oct	6.0404	0.2428	0.4855	-0.0041	-1.707E-04	0.70
Nov	5.2172	0.3116	0.4541	-0.0237	1.151E-04	0.65
Dec	1.9128	0.1722	0.6747	0.0012	-1.579E-06	0.89

Regression Variables:

Ave Air Temp = Daily average air temperature at CIMIS at Fair Oaks (station no. 131) (°C)

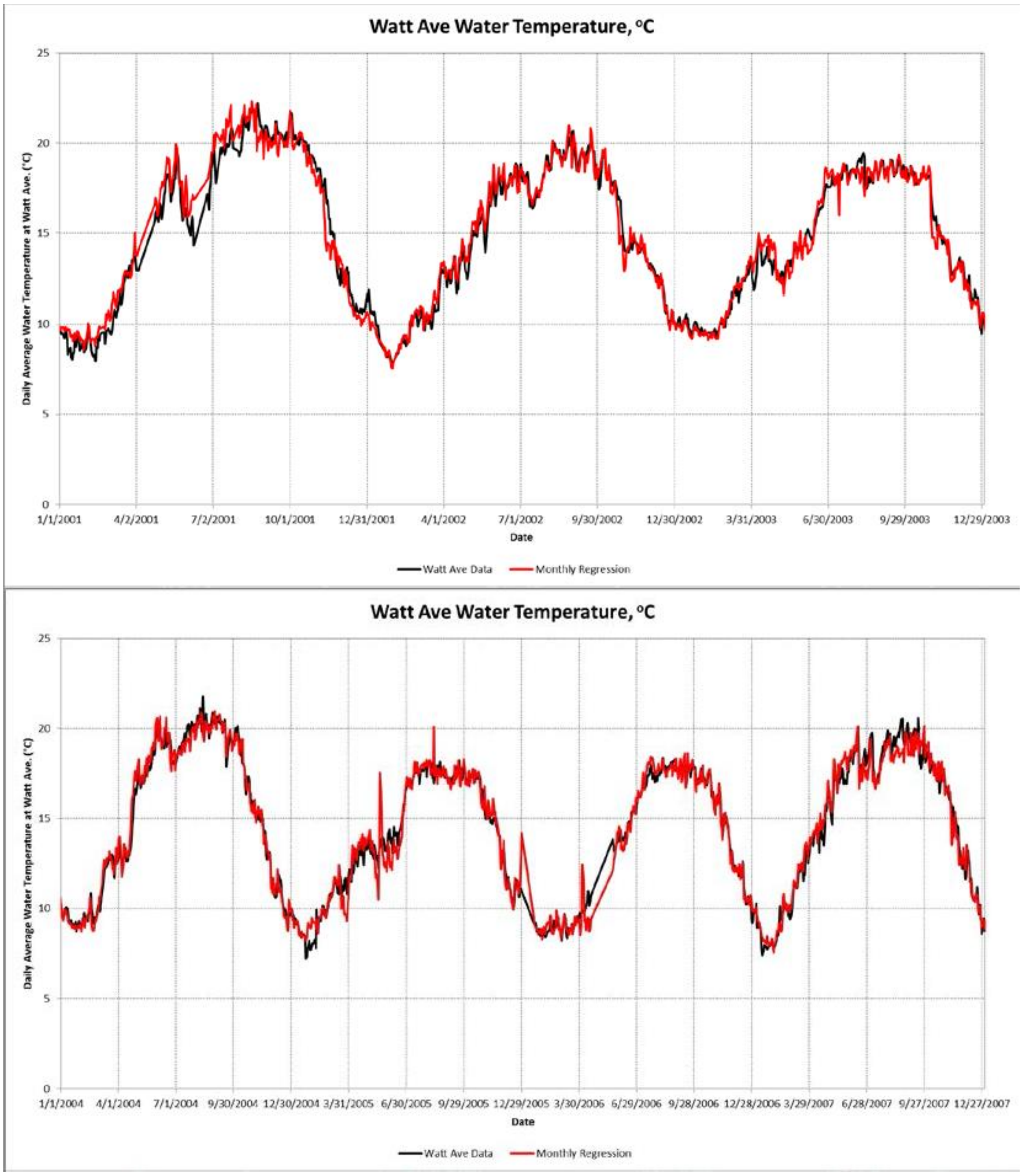
Ave Water Temp below Folsom = Daily water temperature below Folsom Data at USGS/CDEC station (station no. 11446220/AFD) (°C)

Ave Flow = Daily-averaged hourly flow below Folsom Reservoir (CDEC station FOL) – South Canal Diversion (CDEC station FSC) (cfs)

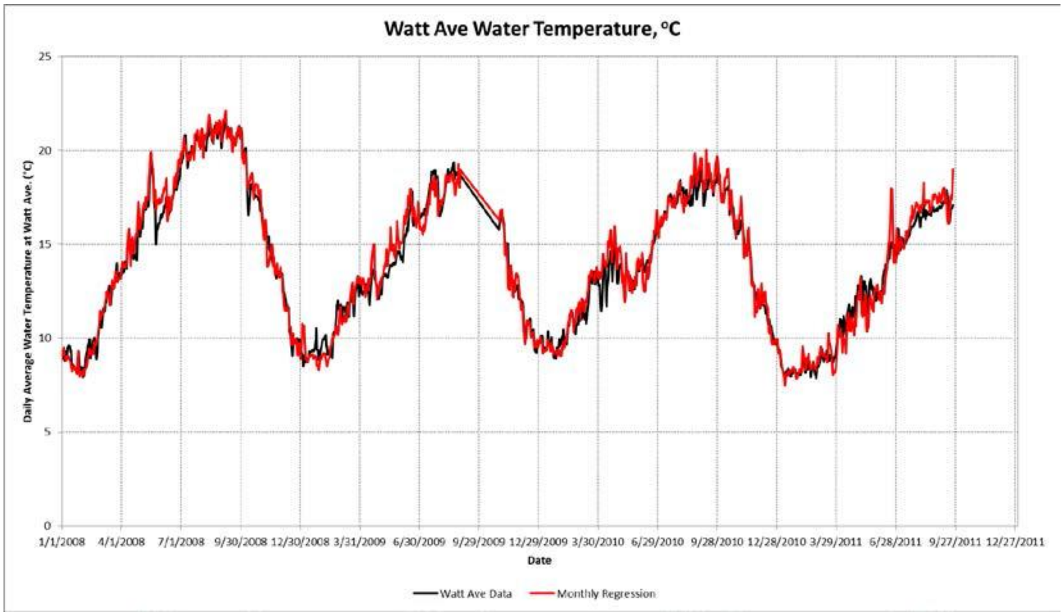
Predicted Temp = Lower American River at Watt Avenue (°C)

ATTACHMENT E

FIGURES



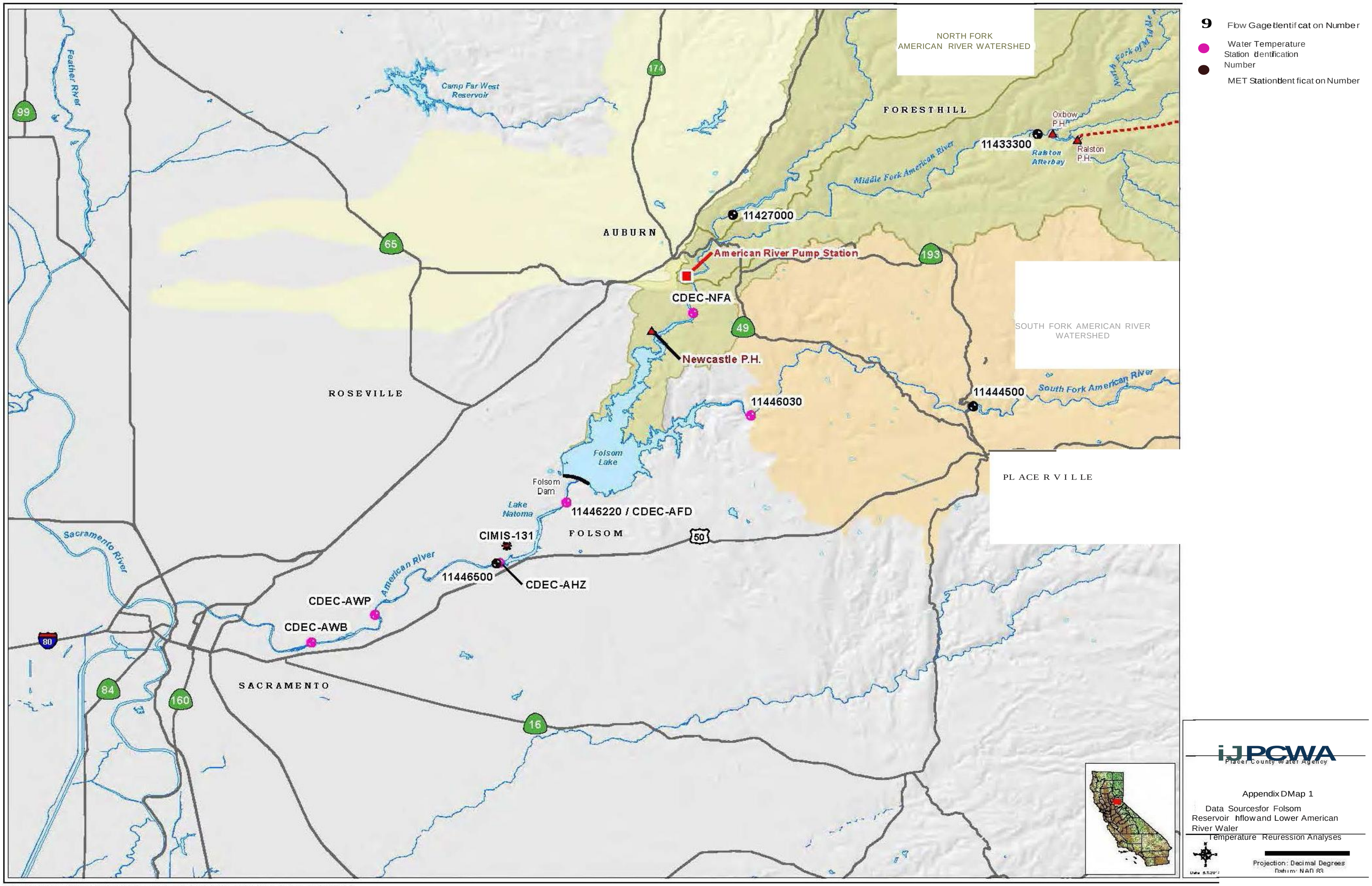
Attachment E Figure 1. Comparison of Measured and Modeled (Regression) Water Temperature on the Lower American River at Watt Avenue (2001-2011): 2001-2004 (top), 2004-2008 (middle), and 2008-2011 (bottom).



Attachment E Figure 1. Comparison of Measured and Modeled (Regression) Water Temperature on the Lower American River at Watt Avenue (2001-2011): 2001-2004 (top), 2004-2008 (middle), and 2008-2011 (bottom) (continued).

ATTACHMENT E

MAP



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