# Attachment G

## PCWA & WWD 2014 35,000 AF Transfer
## Folsom Reservoir Temperature Modeling
## Technical Memorandum

Technical Memorandum

# 2014 Placer County Water Agency and Westlands Water District Water Transfer Benefits to Folsom Reservoir and the Lower American River

Placer County Water Agency

May 20, 2014

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## List of Acronyms

| | |
|---|---|
| AF | acre-feet |
| ATSP | Automated Temperature Selection Procedure |
| cfs | cubic feet per second |
| California ISO | California Independent System Operator |
| Delta | Sacramento-San Joaquin Delta |
| EBMUD | East Bay Municipal Utility District |
| 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 |
| WWD | Westlands Water District |

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## EXECUTIVE SUMMARY

Placer County Water Agency (PCWA) and Westlands Water District (WWD) propose a transfer of 35,000 acre-feet (AF) of water to WWD in 2014 (Transfer). The Transfer water is stored in PCWA's Middle Fork Project (MFP) reservoirs and would not otherwise be released absent the Transfer. 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.

The Transfer would be released mid-June through September from the MFP into the Middle Fork American River (MFAR) and thence the North Fork American River (NFAR) and Folsom Reservoir. Inflow from the NFAR to Folsom Reservoir during June through September would increase 40% (88,058 to 123,058 AF) as a result of the Transfer. Reclamation would release the Transfer water from Folsom Reservoir to WWD on a schedule that is mutually beneficial to Reclamation, WWD, and the environment. The Transfer release schedule would be bracketed by a combination of two release alternatives:

- Option 1: Transfer water released July – September from Folsom Reservoir into the Lower American River (LAR) on top of (in addition to) Reclamation's forecasted 2014 LAR releases.
- Option 2: Transfer water released from Folsom Reservoir as part of Reclamation's forecasted 2014 LAR releases.

If Reclamation released the Transfer water in addition to their forecasted releases, the Transfer would increase average July – September LAR flows by approximately 11% (1,703 cfs to 1,895 cfs) and benefit salmonid rearing habitat in the LAR. Alternatively, if Reclamation incorporated the Transfer water into their forecasted LAR releases, the Transfer would increase end-of-September storage in Folsom Reservoir by 35,000 AF and could benefit carryover storage, water supply, and/or future flow-related fish habitat in the LAR.

The Transfer would decrease the water temperature of the NFAR inflow into Folsom Reservoir, increase the volume of cool metalimnion water in the reservoir, and aid LAR temperature management (blending of Folsom Reservoir metalimnion and hypolimnion water releases to meet downstream temperature targets at Watt Avenue). Depending on the release pattern, detailed CE-QUAL-W2 water temperature modeling indicates that a one schedule cooler Automated Temperature Selection Procedure (ATSP)[1] (temperature regime) could be achieved in the LAR at Watt Avenue as a result of the Transfer.

Additional benefits of the Transfer include meeting Water Forum Agreement drier year LAR objectives, increasing drier year hydropower generation / grid regulation, and enhancing MFP white-water rafting opportunities.

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

## 1.0 INTRODUCTION

By way of State Water Resources Control Board (SWRCB) Change Petition submitted to the Division of Water Rights (Division), Placer County Water Agency (PCWA) and Westlands Water District (WWD) propose a temporary transfer of 35,000 acre-feet (AF) of PCWA water to WWD in 2014 (Transfer). The Transfer is a response to the current drought conditions and will assist WWD in meeting their service area water supply needs.

The Transfer water is currently stored in PCWA's Middle Fork Project (MFP) reservoirs (French Meadows and Hell Hole) and would not otherwise be released this year absent the Transfer. For the purposes of this Transfer, PCWA will be solely exercising Water Right Permit 13856. 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, similar to refill agreements for other PCWA transfers.

PCWA has periodically implemented temporary water transfers in drier years over the past 25 years (Appendix A Table 1). Drier year water transfers into Folsom Reservoir and the lower American River (LAR) are consistent with environmental release/enhancement objectives in PCWA's purveyor-specific Water Forum Agreement. In 2013 PCWA transferred 20,000 AF to WWD. In April 2014, PCWA transferred 5,000 AF to East Bay Municipal Utility District (EBMUD). A 20,000 AF EBMUD water transfer was approved by the SWRCB this year (2014), but only the 5,000 AF will be transferred to EBMUD. The remaining 15,000 AF is available to be included as a part of the proposed Transfer to WWD.

The Transfer water would be released from the MFP from mid-June through September into the Middle Fork American River (MFAR) and thence the North Fork American River (NFAR) and Folsom Reservoir. Reclamation has indicated that it would provide the Transfer water from Folsom Reservoir into the LAR and to WWD either on top of (in addition to) Reclamation's forecasted operations schedule or as part of its forecasted operations (or some combination of the two). Reclamation and WWD would mutually agree on a Transfer schedule. The range of most likely transfer schedules was modeled in this technical memorandum to identify the environmental benefits of the Transfer.

This technical memorandum describes the benefits/effects of the 35,000 AF water transfer on the American River watershed MFAR, NFAR, Folsom Reservoir, and the LAR. Details of the water transfer operations (release pattern and amounts) are provided along with specific benefits/effects of the water transfer on WWD water supply, Folsom Reservoir storage / LAR flows (hydrology), and water temperature. Additional benefits of the transfer related to Water Forum Agreement drier year objectives, hydropower generation, and whitewater rafting are also discussed.

## 2.0 WATER TRANSFER OPERATIONS

### 2.1. Water Transfer Overview

Under the proposed transfer, PCWA would release an additional 35,000 AF of stored MFP water mid-June – September 2014 through MFP hydrogeneration facilities into the MFAR thence the NFAR and Folsom Reservoir (Figure 1; Table 1). Transfer water would be temporarily stored in Folsom Reservoir. Reclamation would provide the Transfer water to WWD on a schedule that is mutually agreeable and/or beneficial to Reclamation, WWD, and the environment. Typically this would entail release of the water from Folsom Reservoir in July – September. The release of transfer water 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:

1. Option 1: Each month, July - September, 11,667 AF (190 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.

2. Option 2: A total of 35,000 AF is transferred to WWD as part of Reclamation's forecasted operational releases. No increase in forecasted operational releases from Folsom Reservoir into the LAR would occur and the 35,000 AF of PCWA water would effectively increase the end-of-September storage in Folsom Reservoir.

Following release of the transfer water by Reclamation to the LAR, the water would enter the Sacramento River and thence the Sacramento-San Joaquin Delta and would be delivered to WWD through either the Banks or Jones pumping plants (accounting for appropriate carriage losses).

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

| Month | Volume, AF |
|---|---|
| June | 8,750 |
| July | 8,750 |
| August | 8,750 |
| September | 8,750 |
| Total | 35,000 |

### 2.2. PCWA Operations Forecast

PCWA's operations forecast[2] for the MFP with and without the Transfer are provided in Table 2. PCWA's forecast modeling indicates that the June – September North Fork/Middle Fork American

[2] 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.

River inflow to Folsom Reservoir would increase from 88,058 to 123,058 AF (40% increase) with the Transfer.

**Table 2. Forecasted PCWA Operations of the MFP[1] at the North Fork American River below the American River Pump Stations With and Without the WWD Transfer.**

| Operations Scenario | Month (Acre-feet) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
| NFAR Flow below ARPS[2] / Without Transfer | 51,390 | 22,707 | 23,876 | 21,409 | 20,066 | 6,830 | 24,706 | 51,211 |
| NFAR Flow below ARPS / With 35 TAF Transfer[3] | 51,390 | 31,457 | 32,626 | 30,159 | 28,816 | 6,830 | 24,706 | 51,211 |

[1] May 15, 2014 Inflow projections through September are based on a 75% 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 changing water year conditions. PCWA has used the most recently updated Folsom Reservoir operations forecast as Base Case conditions (baseline) to model hydrology and water temperature effects of the Transfer. The latest Reclamation operations forecast is shown below in Table 3[3]. The 90% runoff exceedance forecast was used to model transfer effects (Base Case).

**Table 3. Reclamation Draft May 15, 2014 90% Runoff Exceedance Operations Forecast.**

**DRAFT May 2014**

**90%-Runoff Exceedance Outlook**
**Federal End of the Month Storage/Elevation (TAF/Feet)**

| | | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Folsom | 547 | 539 | 498 | 407 | 339 | 294 | 254 | 219 | 200 | 190 | 202 | 256 | 316 |
| Elev. | | 421 | 416 | 404 | 394 | 386 | 379 | 371 | 367 | 365 | 367 | 379 | 390 |
| **Monthly River Releases (cfs)** | | | | | | | | | | | | | |
| American | | 1513 | 1417 | 2109 | 1759 | 1240 | 805 | 800 | 706 | 700 | 759 | 800 | 800 |

[3] 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 May 15, 2014.

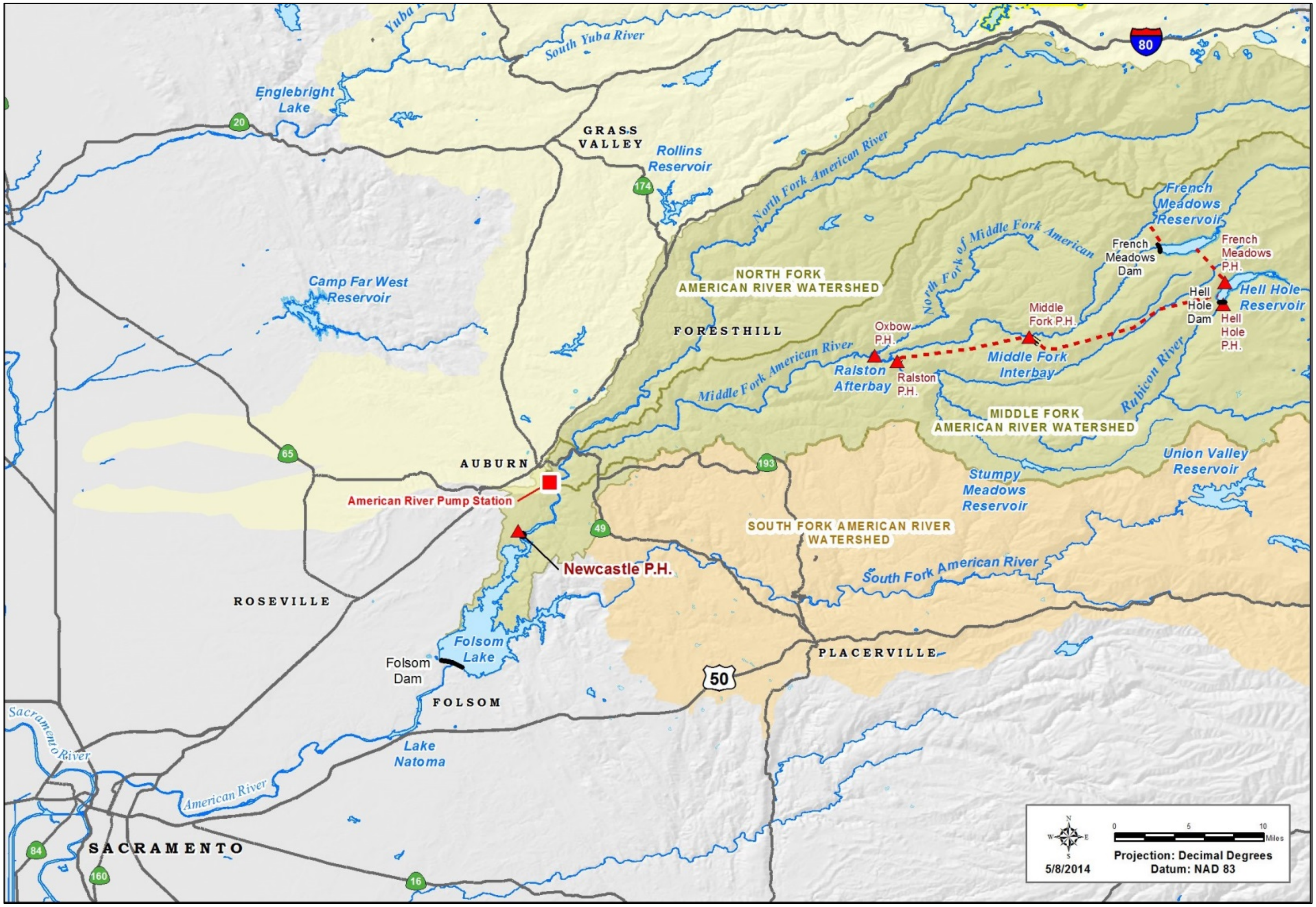



**Figure 1. PCWA Middle Fork Project, Folsom Reservoir, and Lower American River.**

### 2.4. Middle Fork 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, similar to refill agreements that PCWA and Reclamation have entered into for other PCWA transfers. The refill agreement minimizes the potential for refill of MFP reservoirs, after a temporary transfer, to affect Folsom Reservoir annual storage. 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 the 20,000 AF 2013 WWD transfer and the 5,000 AF 2014 EBMUD transfer, PCWA's MFP current carryover target for 2014/2015 is 125,000 AF. Following the proposed Transfer, PCWA would carry an additional 35,000 AF deficit in its carryover target forward in time until conditions identified in the refill agreement allow refill of the deficit (e.g., Folsom Reservoir reaches flood control levels or fills completely). This 35,000 AF carryover deficit would be in addition to the refill reservation currently being carried by PCWA as a result of the 2013 and 2014 transfers noted above. In total, the 2014 carryover deficit for the MFP would be 60,000 AF resulting in a 2014/2015 carryover target of 90,000 AF (instead of the typical 150,000 AF), if the 35,000 AF transfer is carried out.

## 3.0 WESTLANDS WATER SUPPLY BENEFITS

The 35,000 AF transfer would provide WWD with water in a year of critical need. WWD provides water supply to over 600,000 acres of farmland within Fresno and Kings counties. WWD's long-term source of water supply is the Central Valley Project (CVP), operated by Reclamation. Reclamation's 2014 allocation to WWD is zero percent of their annual contract amount. This zero percent allocation exacerbates the dry conditions experienced in 2013, which resulted in a 20 percent CVP allocation to WWD.

## 4.0 FOLSOM RESERVOIR STORAGE AND LOWER AMERICAN RIVER FLOW BENEFITS

Depending on how Reclamation releases the Transfer water from Folsom Reservoir, Option 1 or Option 2 (see Section 2.1 Water Transfer Overview), the Transfer would increase flows in the LAR and/or storage in Folsom Reservoir. The Option 1 transfer water would increase average July – August LAR flows from 1,703 cfs to 1,895 cfs (11% increase) and benefit salmonid rearing habitat in the LAR. The Option 2 transfer would increase September 30$^{th}$ storage in Folsom Reservoir by 35,000 AF and could benefit carryover storage, water supply, or future flow-related habitat in the LAR (Figure 2) (note: pursuant to the Flow Management Standard, fall spawning flows are dependent on September 30 Folsom Reservoir storage). Also, note that some combination of Options 1 and 2 could occur.

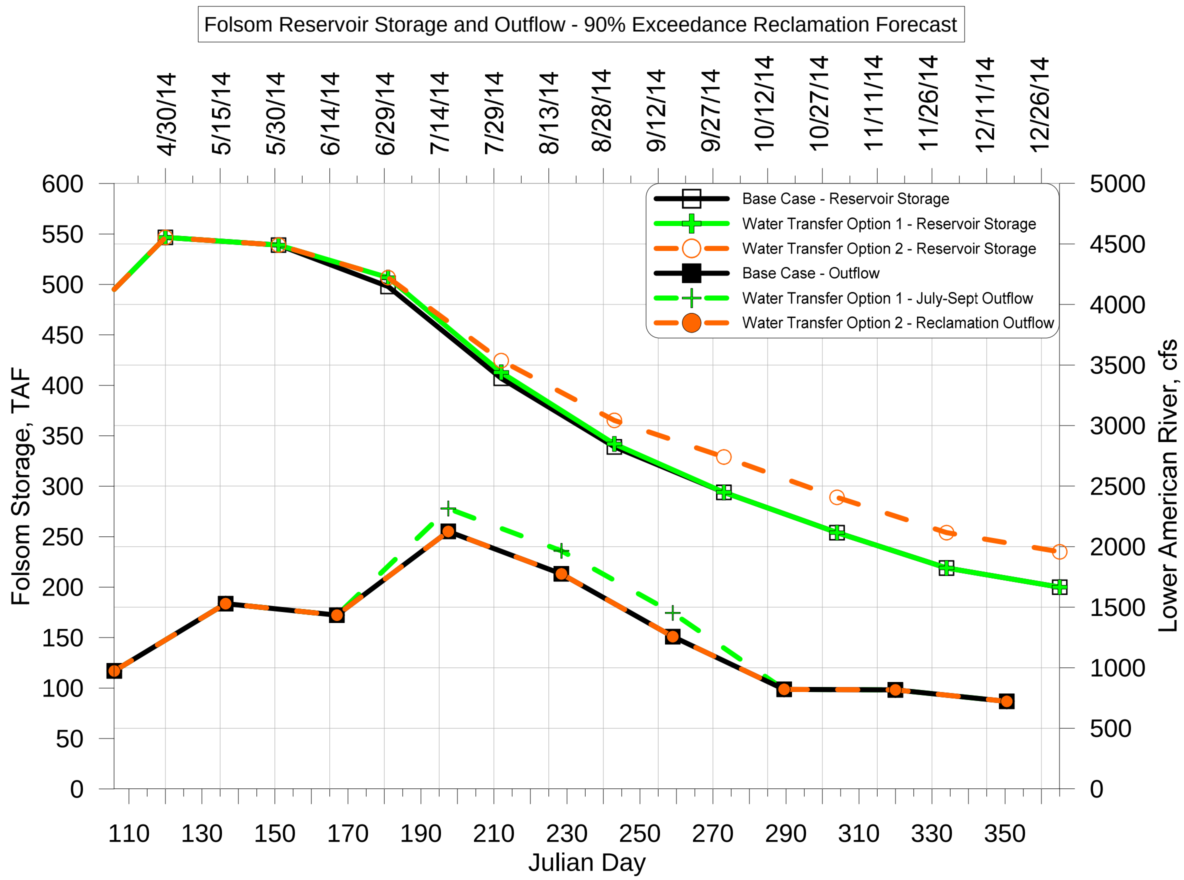



**Figure 2. Folsom Reservoir Storage and Lower American River Flow for the Base Case and for the Alternative Water Transfer Release Options 1 and 2.**

## 5.0 WATER TEMPERATURE BENEFITS

### 5.1. Folsom Reservoir Inflow Water Temperature

Summer water temperature in the NFAR (including the MFAR) and SFAR decreases with increased flow releases from the upstream hydropower facilities / deep water reservoirs. Inflow water temperature for Folsom Reservoir was determined based on regression models of the inflow water temperature versus flow for the two rivers. Details of the regression models are provided in Appendix B of this document. The Base Case 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. 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 0.5 – 1.5 ˚F in water temperature for June – September 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 four month inflow period (June—September). It is likely that the water will enter Folsom Reservoir in a more concentrated pattern resulting in cooler inflow temperature than modeled.

### 5.1.2. South Fork American River

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 Appendix B.

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

To model the hydrologic and environmental effects of the transfer, Reclamation's 90% exceedance forecasted operation of Folsom Reservoir and the LAR was 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 (Appendix C) coupled with an accurate regression model of the LAR at Watt Avenue (Appendix D). Meteorological (MET) data from 2008, another dry year, was used for the modeling. The 2008 MET data is also representative of average meteorological conditions in recent years (e.g., 2001-2014) (Figure 4).

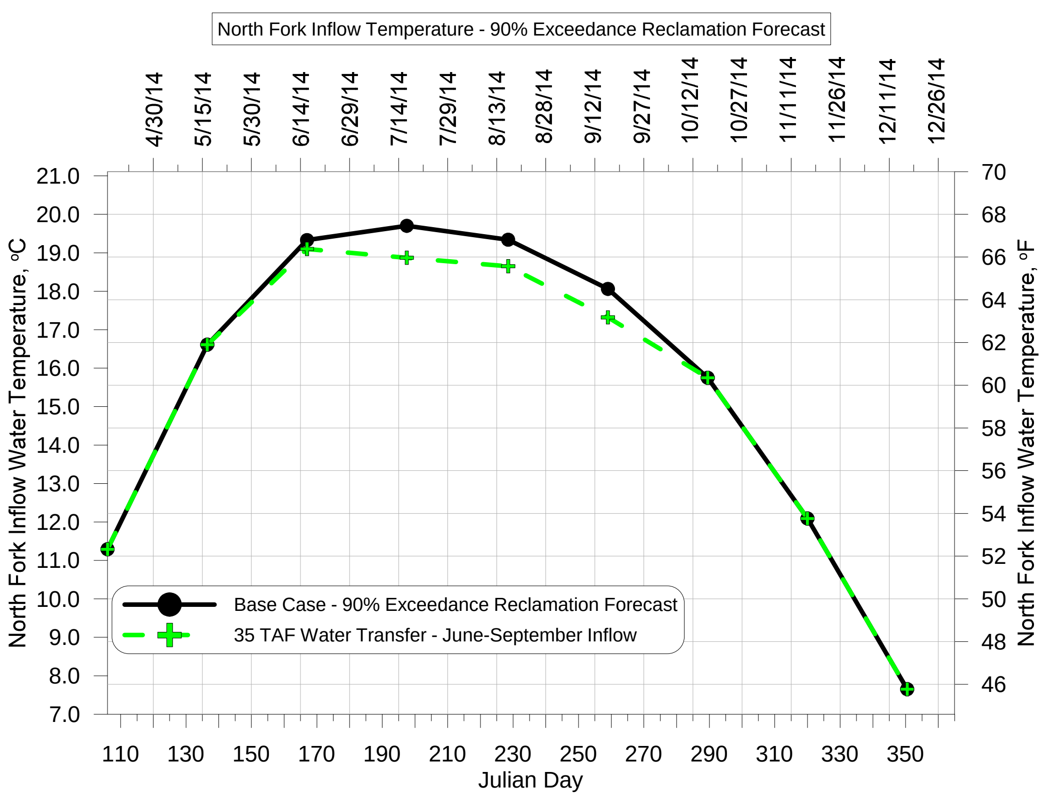



**Figure 3. Water Temperature in the North Fork American River upstream of Folsom Reservoir for the Base Case and with the 35,000 AF Water Transfer**

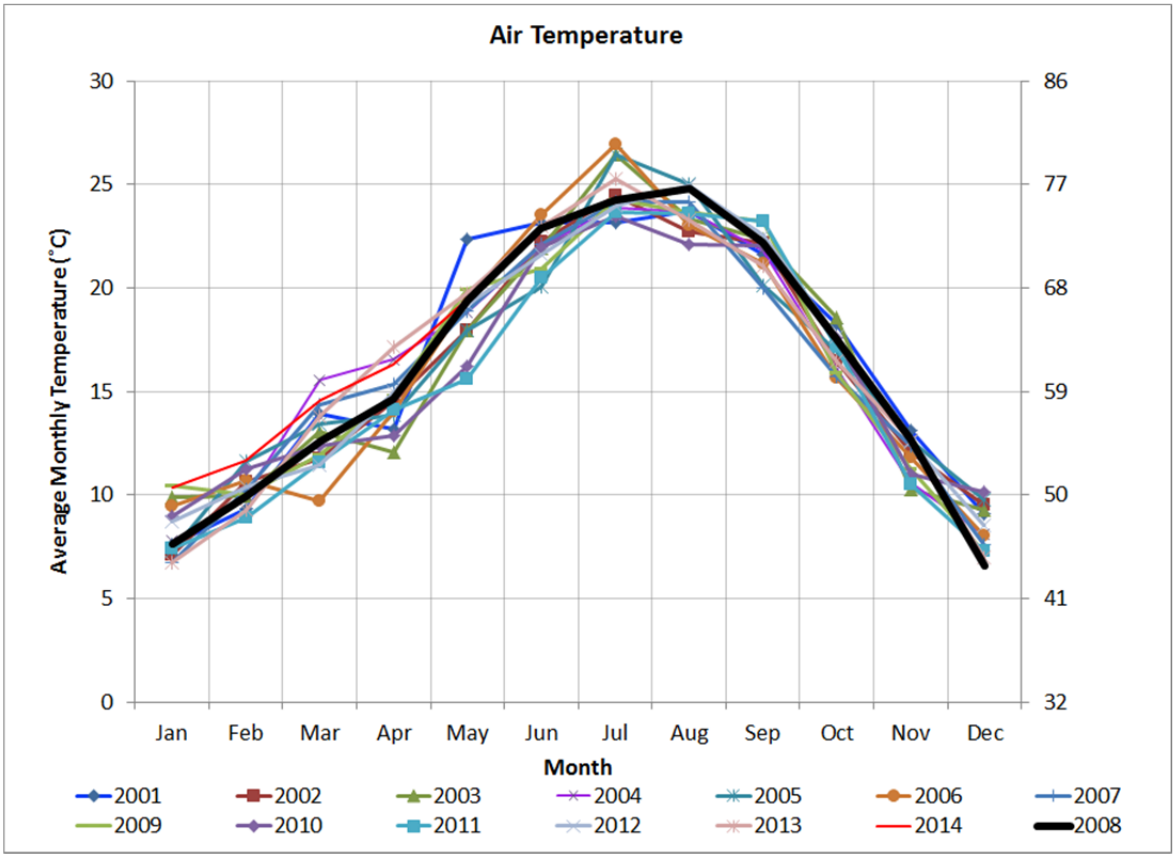



**Figure 4. Example of 2008 Meteorological (MET) Data (Air Temperature) Compared to Recent (2001-2014) MET Data.**

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

Modeling results indicate that the 35,000 AF Transfer resulted in a slightly cooler water temperature regime in the LAR. Water temperature at Watt Avenue decreased approximately one ATSP schedule depending on the Transfer scenario (Table 4; Figure 5).

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

| Model Scenario | CE-QUAL-W2 ATSP Temperature Schedule |
|---|---|
| **90% Exceedance Forecasted Operations** | |
| **Base Case** | 51 |
| **Transfer Option 1 (JJAS Inflow, JAS Outflow)** | 50 |
| **Transfer Option 2 (JJAS Inflow, Reclam. Forecast Outflow)** | 50+ |

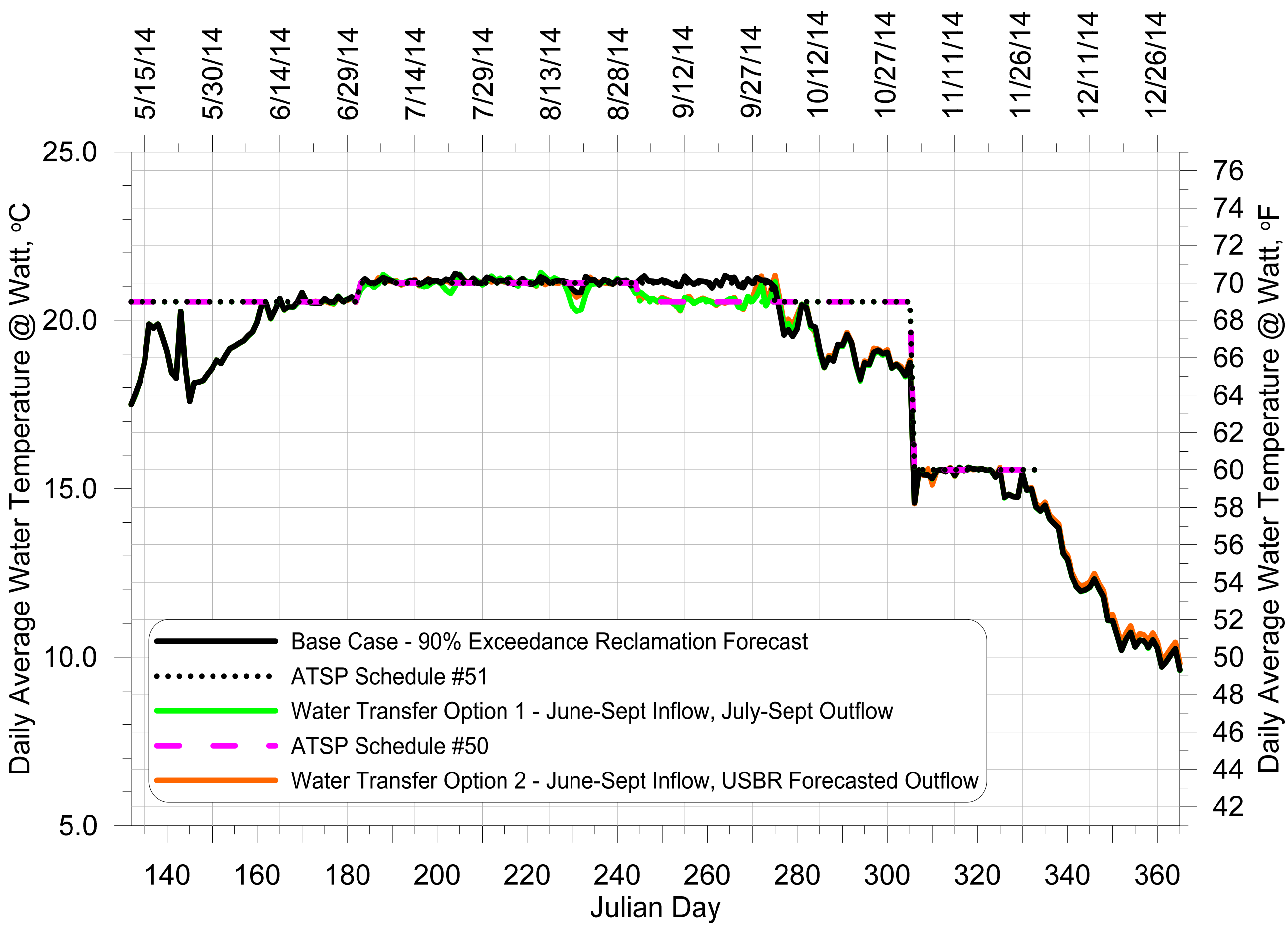



**Figure 5. Watt Avenue Water Temperature and ATSP Schedule Results for the Base Case and Water Transfer Options 1 and 2.**

## 6.0 ADDITIONAL DRIER YEAR WATER TRANSFER BENEFITS

Releasing 35,000 AF of transfer water in a drier year provides additional benefits including, achieving drier year flow augmentation objectives in the Water Forum Agreement, enhancing drier year hydropower generation, and enhancing commercial and recreational rafting in the MFAR.

PCWA's purveyor-specific Water Forum Agreement calls for replacement of water by PCWA into the LAR in drier years to benefit the LAR. This is contingent on PCWA's ability to find a willing buyer for the water. The Transfer to WWD provides an avenue to release this water into the LAR. The Water Forum Agreement was developed by a diverse group of American River stakeholders to provide a reliable water supply for the region's economic health and development and to preserve the environmental values of the LAR.

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 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). Without the Transfer in the 2014 summer period this recreational resource will be limited.

## 7.0 CONCLUSION

The proposed PCWA and WWD Transfer would release 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, and/or other instream beneficial uses.

Specifically, the drier year transfer would provide the following benefits/effects:

- Increased water supply for WWD;
- 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.

# APPENDIX A

# PCWA HISTORICAL WATER TRANSFERS (1990-2014)

## Appendix A Table 1. PCWA Historical Water Transfers (1990-2014).

| Calendar Year | Water Transfer (ac-ft) | Monthly Release Amounts (ac-ft) | | | | | | | | | | | | | Transfer Recipient |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total Release[1] (ac-ft) | |
| 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 | 35,000 | | | | | | | 17,000 | 18,000 | | | | | 35,000 | 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 |
| 2009 | 20,000 | | | | | | | | 5,209 | 15,415 | | | | 20,624 | San Diego |
| 2010 | | | | | | | | | | | | | | 0 | |
| 2011 | | | | | | | | | | | | | | 0 | |
| 2012 | | | | | | | | | | | | | | 0 | |
| 2013 | 20,000 | | | | | 20,000 | | | | | | | | 20,000 | Westlands Water District |
| 2014 | 5,000 | | | | 5,000 | | | | | | | | | | East Bay Municipal District |

[1] In some years, release volumes were greater than the transfer amount.

# APPENDIX B

# FOLSOM RESERVOIR INFLOW WATER TEMPERATURE

## INTRODUCTION

This appendix 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 Appendix B Table 1, and the locations are shown on Appendix 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 – September 2011).

#### 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 – September 2011). 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 – November 2011) (Appendix B Table 2). Comparisons of the NFAR empirical and modeled water temperature for the inflows into Folsom Reservoir is provided in Appendix B Figure 1 and a time series plot showing the empirical and modeled water temperature is shown in Appendix 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 – September 2011) (Appendix B Table 3). Comparison of the SFAR measured and modeled water temperature for the inflows into Folsom Reservoir (November 1999 – November 2011) is provided in Appendix B Figure 3 and a time series plot showing the measured and modeled water temperature is shown in Appendix B Figure 4.

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

# APPENDIX B

# TABLES

**Appendix 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 | 1/1/2000-12/31/2010 |
| 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 | 8/1999-9/2011 |
| 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

**Appendix B Table 2. Monthly Regression Equations to Predict North Fork American River Folsom Reservoir Inflow Water Temperatures based on Monthly Mean North Fork American River and Middle Fork American River Flows (July 1999-September 2011).**

| Month | Regression Equation | $R^2$ |
|---|---|---|
| $x_{UNFA}$ = Upper North Fork American River Mean Monthly Flow (cfs)<br>$x_{MFA}$= Middle Fork American River Mean Monthly Flow (cfs)<br>y = North Fork American River Mean Monthly Temperature (°F) upstream of Folsom Reservoir | | |
| Jan | $y=3.94190E\text{-}03x_{UNFA} - 1.46705E\text{-}03x_{MFA} + 4.25430E{+}01$ | 0.41[1] |
| Feb | $y=2.12881E\text{-}03x_{UNFA} - 1.46402E\text{-}04x_{MFA} + 4.44966E01$ | 0.30[1] |
| Mar | $y=6.08294E\text{-}04x_{UNFA} - 1.77799E\text{-}03x_{MFA} + 5.06600E01$ | 0.38[1] |
| Apr | $y=1.15676E\text{-}03x_{UNFA} - 3.02240E\text{-}03x_{MFA} + 5.40980E01$ | 0.69 |
| May | $y= -4.17902\text{-}03x_{UNFA} + 5.50159E\text{-}04x_{MFA} + 6.29616E01$ | 0.60 |
| Jun | $y=-2.61578E\text{-}03x_{UNFA} - 2.87062E\text{-}03x_{MFA} + 6.86189E01$ | 0.90 |
| Jul | $y=6.68709E\text{-}03x_{UNFA} - 1.13722E\text{-}02x_{MFA} + 7.34989E01$ | 0.69 |
| Aug | $y=-5.58064E\text{-}03x_{UNFA} - 6.18571E\text{-}03x_{MFA} + 6.86451E01$ | 0.30[2] |
| Sep | $y=-3.03734E\text{-}02x_{UNFA} - 8.52254E\text{-}03x_{MFA} + 6.84695E01$ | 0.44[2] |
| Oct | $y=-1.00756E\text{-}02x_{UNFA} - 3.65714E\text{-}03x_{MFA} + 6.17779E01$ | 0.39[2] |
| Nov | $y=-5.03434E\text{-}03x_{UNFA} - 2.91983E\text{-}03x_{MFA} + 5.43898E01$ | 0.37[1] |
| Dec | $y=-1.45678E\text{-}03x_{UNFA} + 1.81647E\text{-}03x_{MFA} + 4.55486E01$ | 0.26[1] |

Regression Variables:

$x_{UNFA}$ = Upper North Fork American River Mean Monthly Flow (cfs) at the North Fork Dam, CA (USGS Gage 11427000)
$x_{MFA}$= Middle Fork American River Mean Monthly Flow (cfs) near Foresthill, CA (USGS Gage 11433300)
y = North Fork American River Mean Monthly Temperature (°F) upstream of Folsom Reservoir

[1]Low r-squared values indicate weak relationship between water temperature and flow in the month. During these months, there was little variability in temperature. These regressions represent the average water temperature.

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

**Appendix B Table 3. Monthly Regression Equations to Predict South Fork American River Folsom Reservoir Inflow Water Temperatures based on Monthly Mean South Fork American River Flows (August 1999 – September 2011).**

| Month | Regression Equation | $R^2$ |
|---|---|---|
| y = Predicted water temperature (°F)<br>x = South Fork American River monthly average flow (cfs) | | |
| Jan | y = 8.36810E-04x + 4.22441E+01 | 0.29[1] |
| Feb | y = 4.04200E-04x + 4.39562E+01 | 0.04[1] |
| Mar | y = 1.34656E-08x2 - 6.94458E-04x + 4.89563E+01 | 0.47[1] |
| Apr | y = 6.87655E+01x-4.03224E-02 | 0.44[1] |
| May | y = 1.22937E+02x-1.05238E-01 | 0.77 |
| Jun | y = -2.92656E-03x + 6.63973E+01 | 0.93 |
| Jul | y = 1.14218E+02x-8.18265E-02 | 0.76 |
| Aug | y = 1.37458E+02x-1.15634E-01 | 0.89 |
| Sep | y = 1.05224E+02x-8.30803E-02 | 0.61 |
| Oct | y = 8.94277E+01x-7.14624E-02 | 0.67 |
| Nov | y = 6.16850E+01x-2.97174E-02 | 0.14[1] |
| Dec | y = 5.95860E-04x + 4.50261E+01 | 0.19[1] |

Regression Variables:

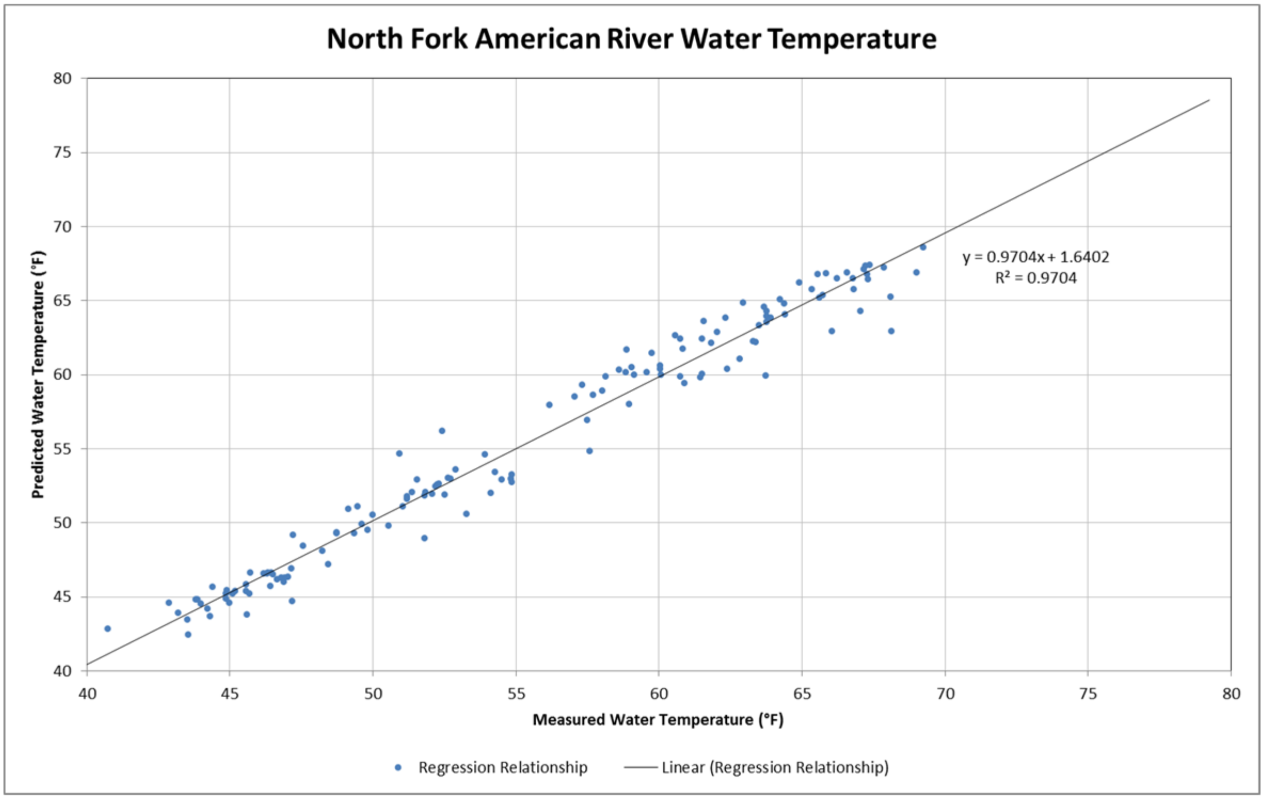
x = South Fork American River monthly averaged flow (cfs) near Placerville, CA (USGS Gage 11444500)

y =South Fork American River Mean Monthly Temperature (°F) near Pilot Hill, CA (USGS Gage 11446030)

[1] Low $r^2$ values indicate weak relationship between water temperature and flow in the month. During these months, there was little variability in temperature. These regressions represent the average water temperature.

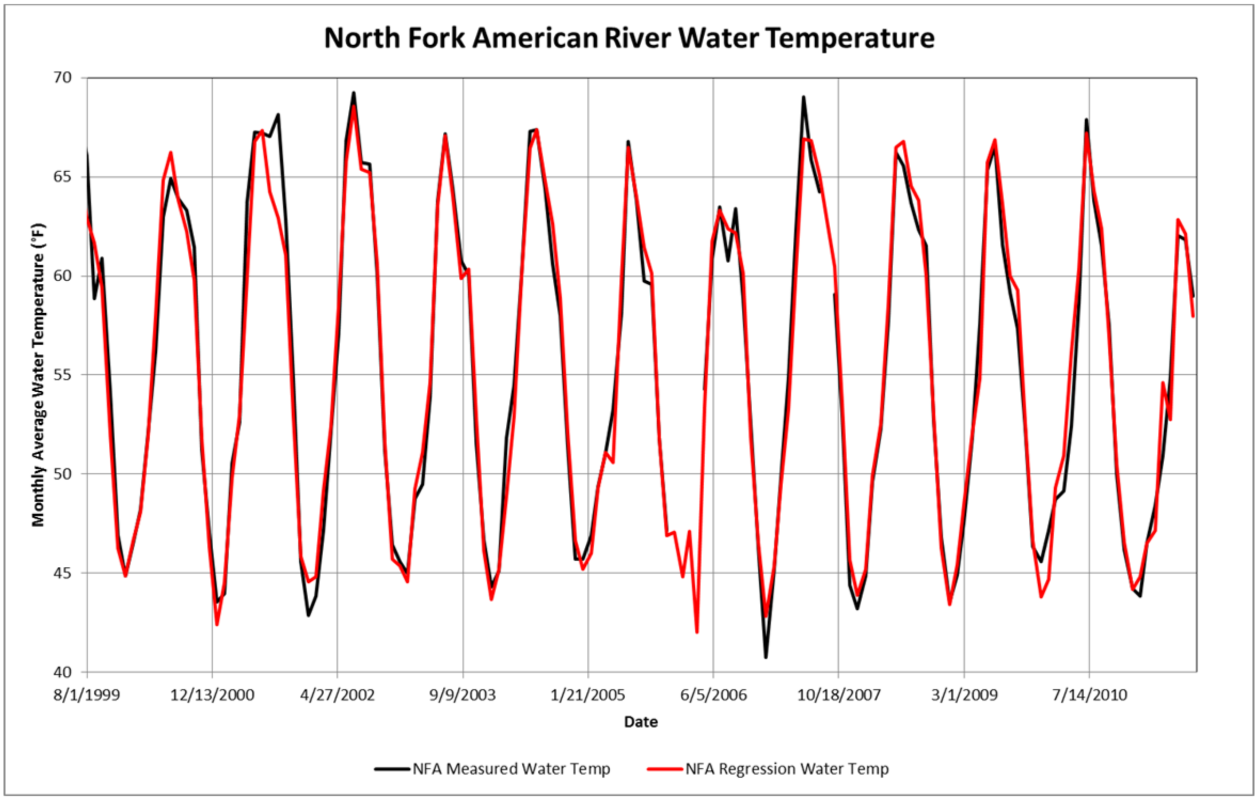
**APPENDIX B**

**FIGURES**



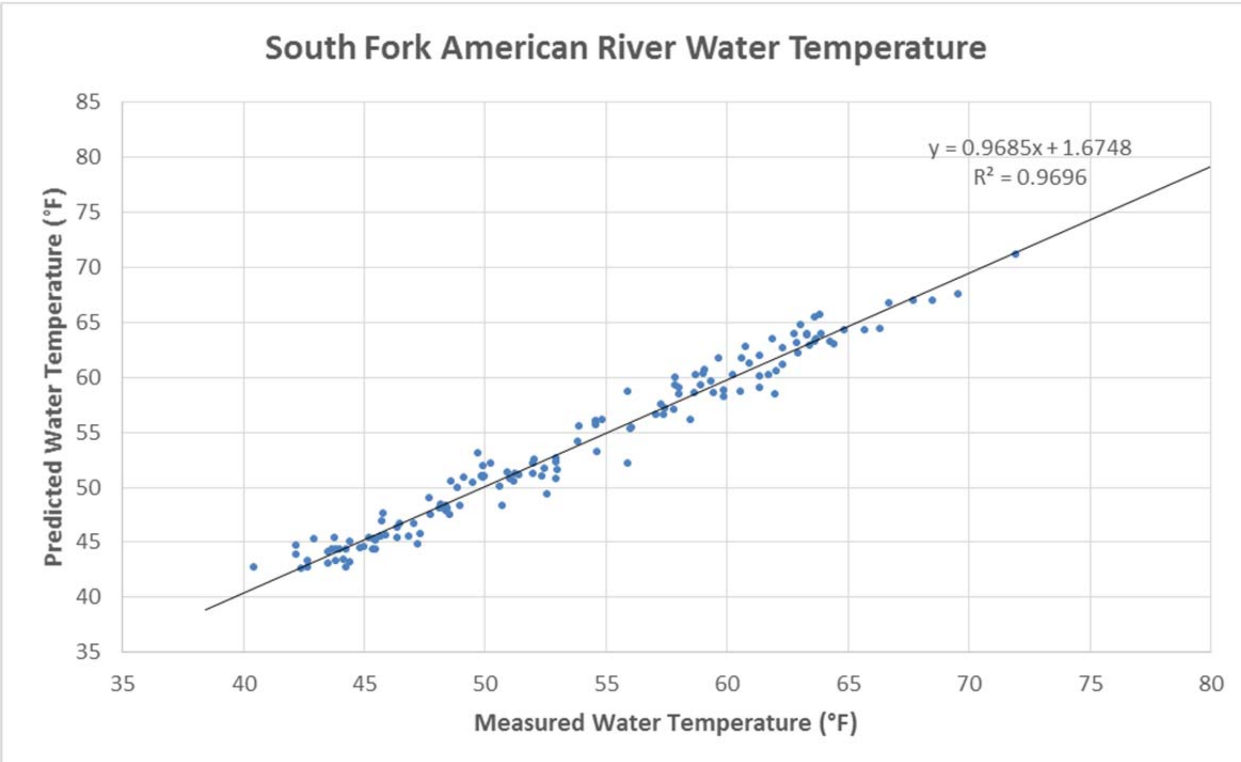

Data Sources: Water Temperature (Measured): North Fork American River Mean Monthly Temperature (°F) upstream of Folsom Reservoir (USGS gage no. 11433790/CDEC station NFA)

**Appendix B Figure 1. Measured versus Modeled (Regression) North Fork American River Temperature into Folsom Reservoir (July 1999-September 2011).**



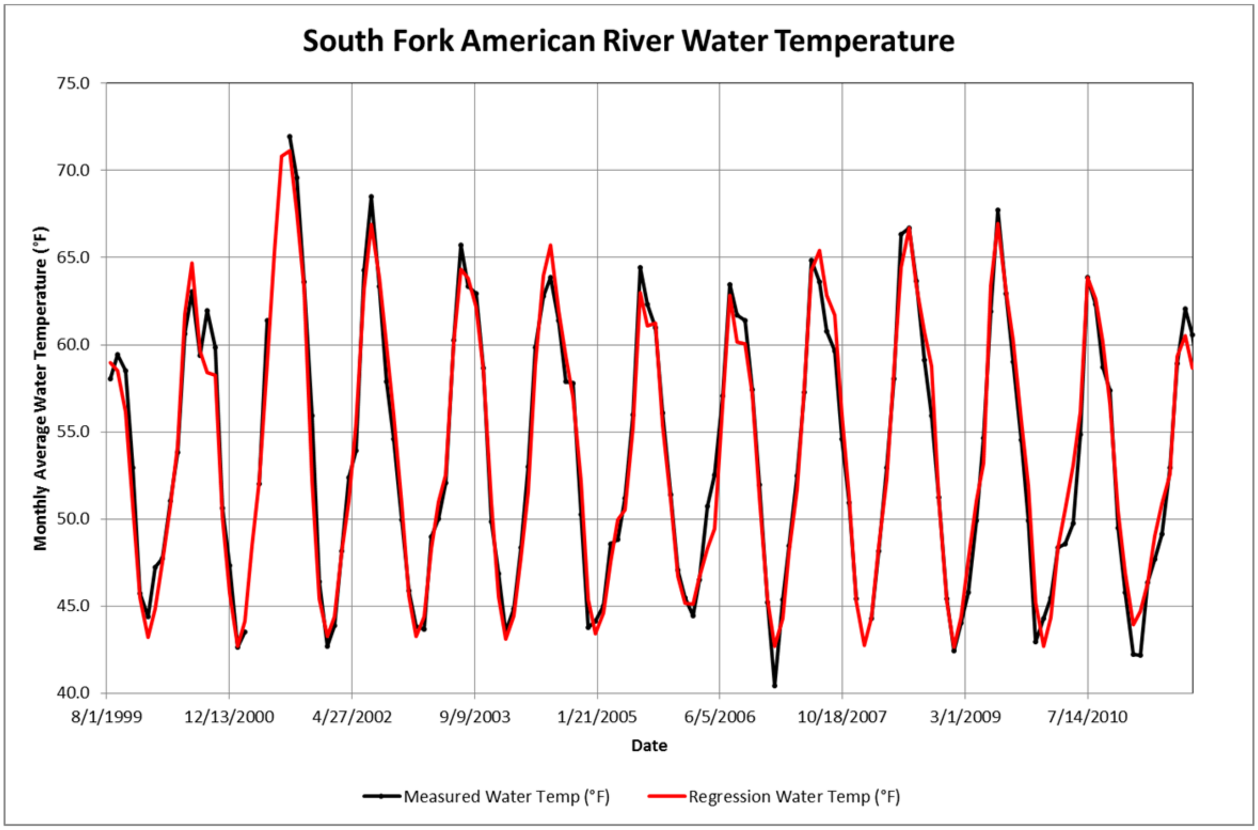

Data Sources: Water Temperature: North Fork American River Mean Monthly Temperature (°F) upstream of Folsom Reservoir (USGS gage no. 11433790/CDEC station NFA)

**Appendix B Figure 2. Time Series of Measured and Modeled North Fork American River Temperature into Folsom Reservoir (July 1999-September 2011).**



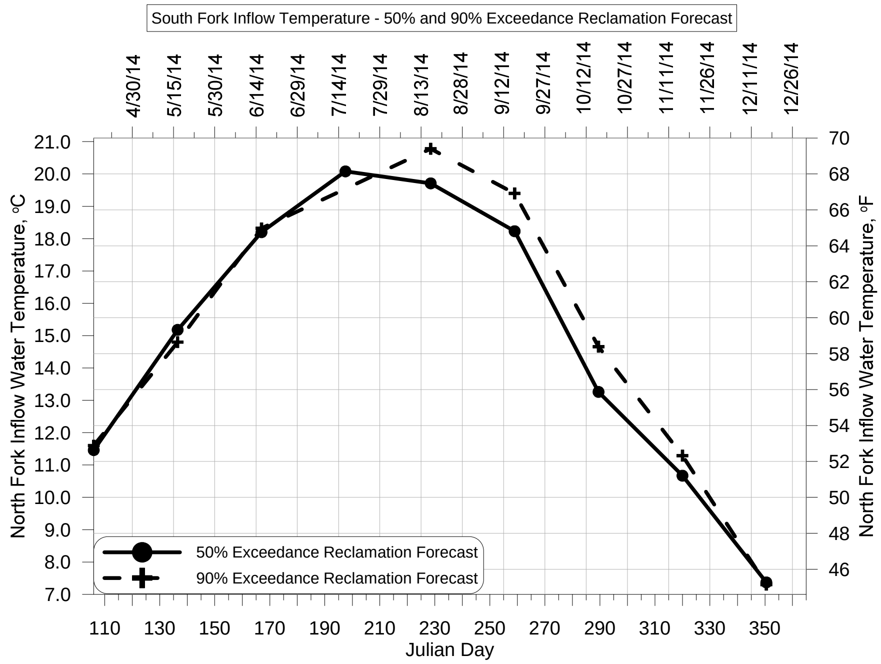

Data Source: Water Temperature (Measured): South Fork American River near Pilot Hill, CA (USGS gage no. 11446030)

**Appendix B Figure 3. Measured versus Modeled (Regression) South Fork American River Temperature into Folsom Reservoir (August 1999-September 2011).**




Data Source: Empirical Temperatures: South Fork American River near Pilot Hill, CA (USGS gage no. 11446030)

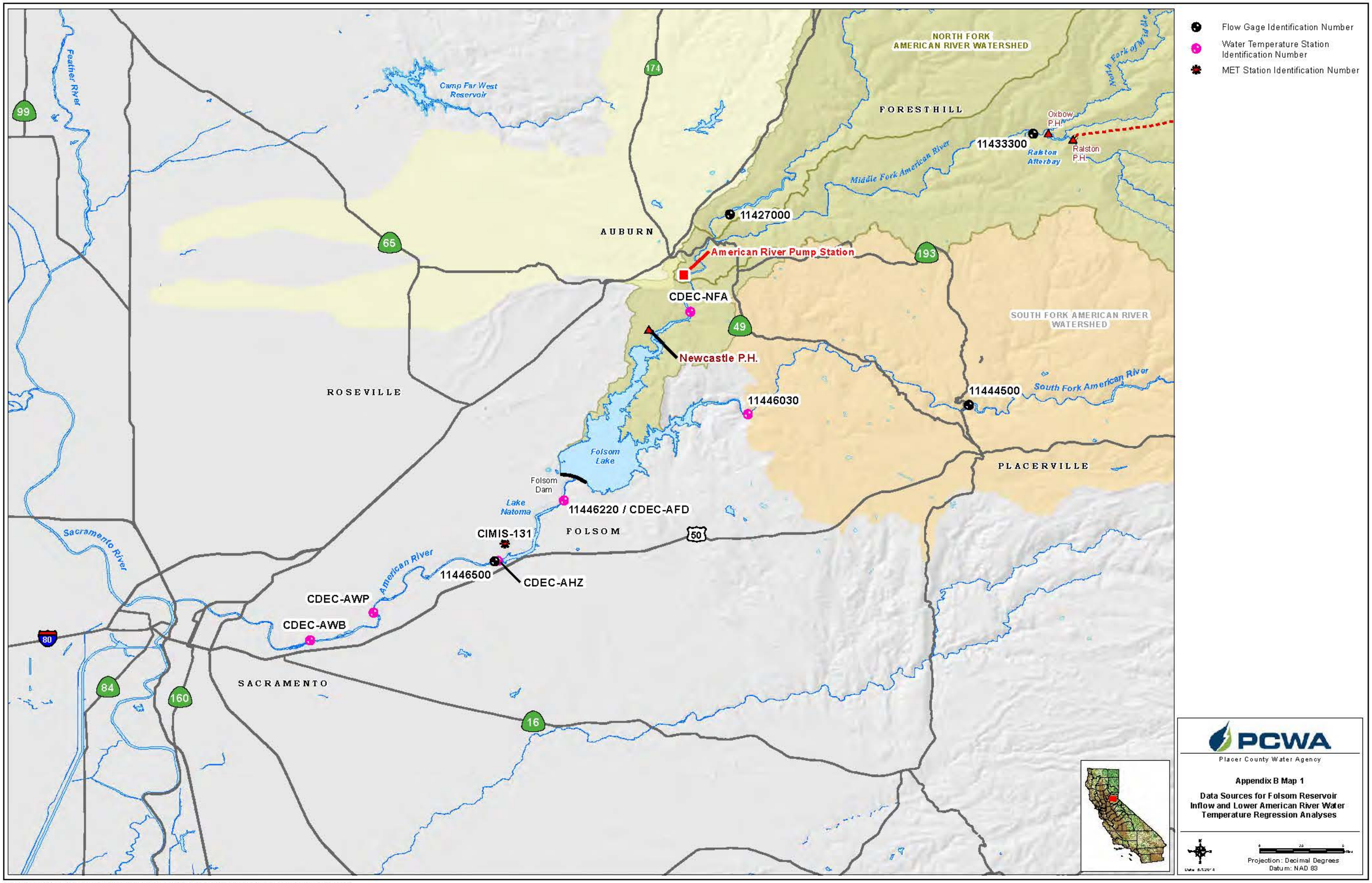
**Appendix B Figure 4. Time Series of Measured and Modeled South Fork American River Temperature (August 1999-September 2011).**




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

**APPENDIX B**

**MAP**

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# APPENDIX C

# 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°C and 0.58°C, respectively, well less than the target of <1°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

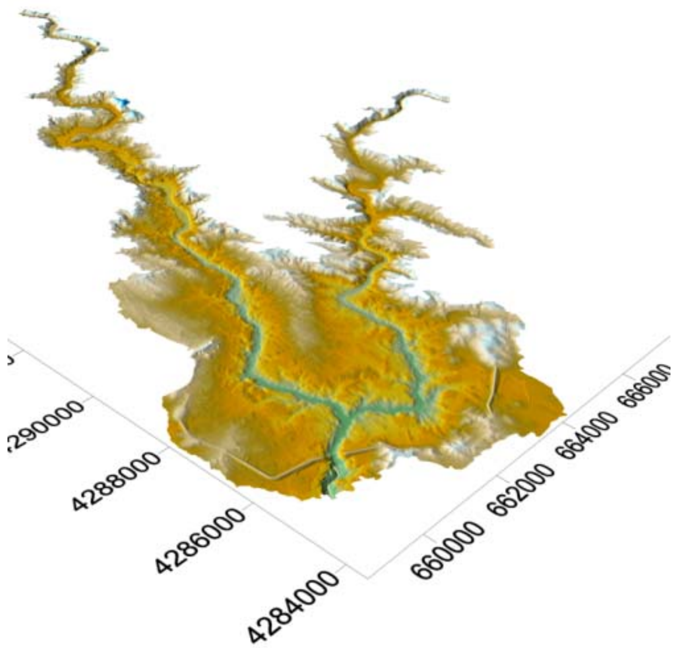
Folsom Dam and reservoir are located approximately 20 miles northeast of the city of Sacramento, California, on the American River. This reservoir has a capacity of 976,000 acre-feet (1,203,878,290 cubic meters) and drains an area of approximately 1,875 square miles (4,856 square kilometers). The dam 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 Appendix C 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).

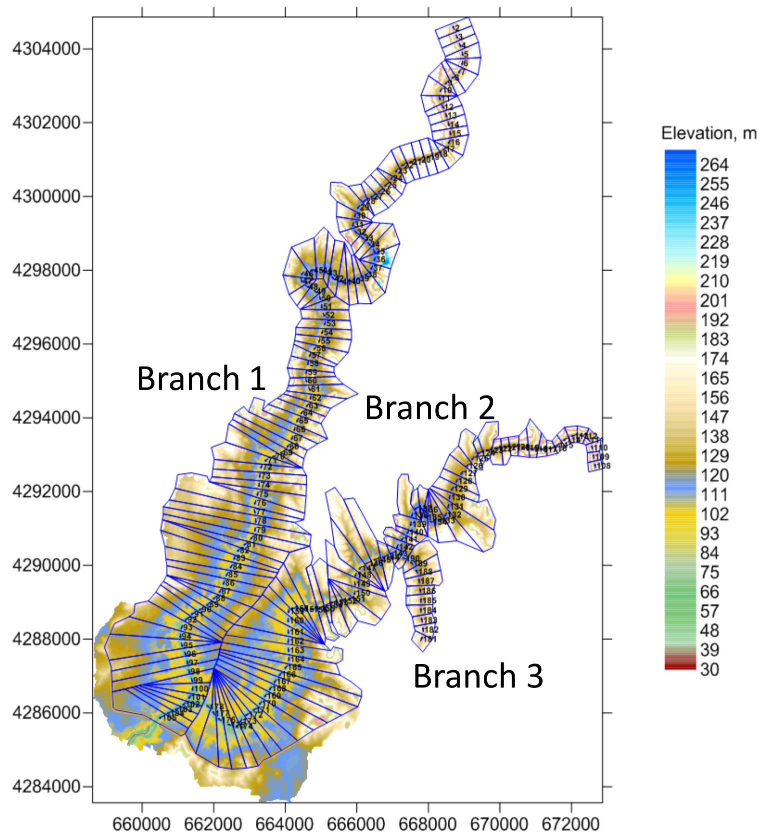

**Appendix C Figure 1. Folsom Dam Outlet Structures (Google Maps, 2013)**

## 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 Appendix C Figure 2. This grid was in turn used to develop the CE-QUAL-W2 model grid, shown in Appendix C Figure 3. 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).




**Appendix C Figure 2. Folsom Reservoir Bathymetry Showing the North Fork and South Fork of the American River Channels (dimensions are in meters).**




**Appendix C Figure 3. Model Grid Segment Layout for the Three Model Branches (dimensions are in meters).**

## HISTORICAL MODEL CALIBRATION

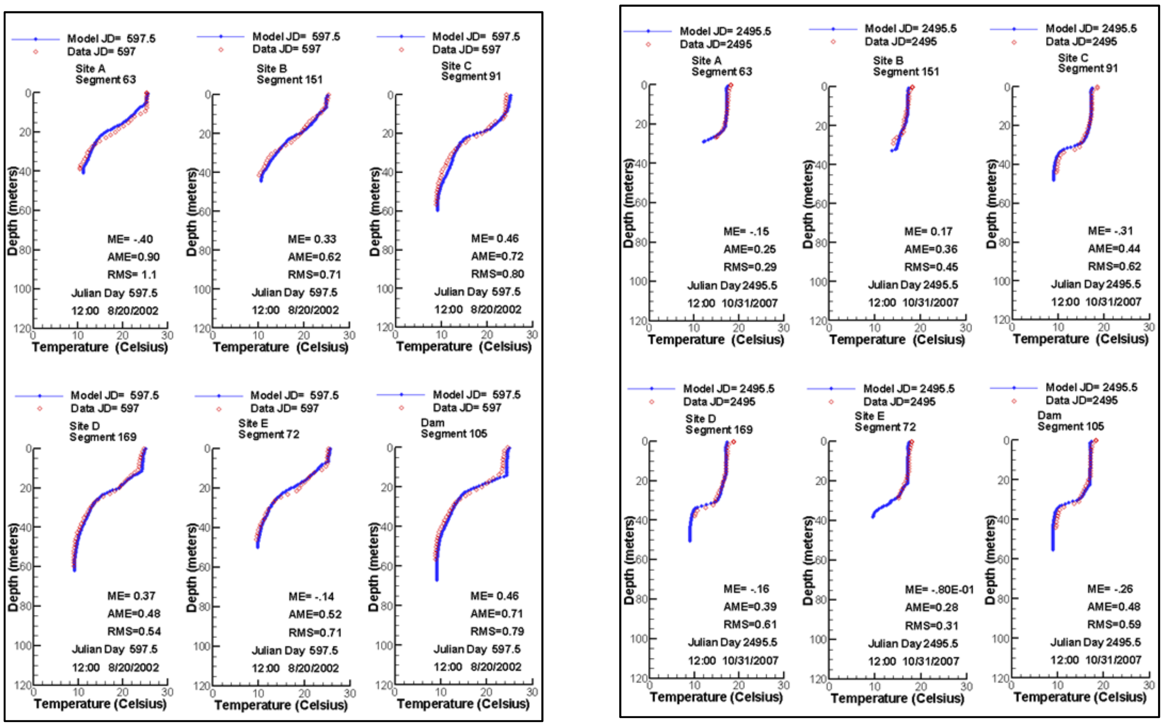
The model was calibrated for a 10-year period between January 1, 2001 and December 31, 2011. Boundary conditions for inflow, meteorological data, and outflow during this period were developed. A very detailed approach for filling in data gaps was undertaken to provide a good set of boundary conditions 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). Appendix C Figure 4 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 Appendix C Table 1.

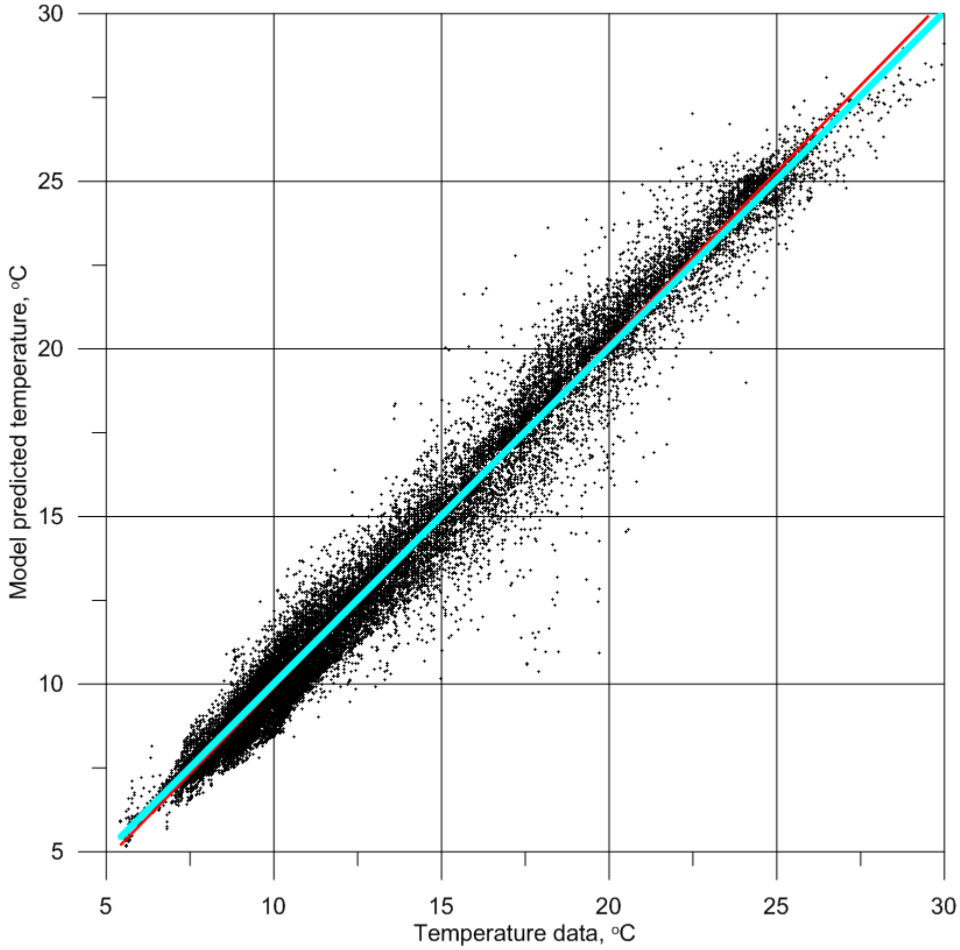



**Appendix C Figure 4. Model Temperature Profiles Compared to Measured Temperature Profiles on August 20, 2002 (left) and October 31, 2007 (right) at Six Different Stations in Folsom Reservoir.**

**Appendix C Table 1. Modeled Versus Measured Temperature Profile Error Statistics.**

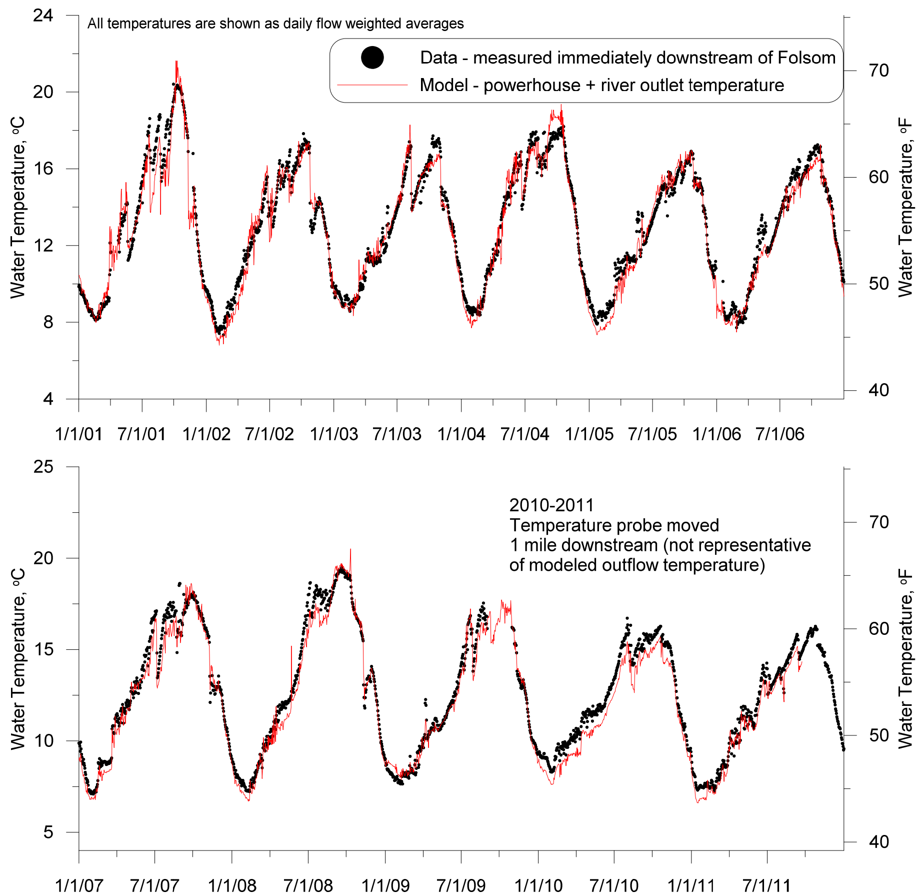
| Temperature Profile Model Segment (USBR Site) | # of profiles | # of individual temperature observations | Mean Error °C | Absolute Mean Error °C | Root Mean Squared Error °C |
|---|---|---|---|---|---|
| **63 (Site A)** | 169 | 4421 | -0.050 | 0.607 | 0.772 |
| **72 (Site E)** | 154 | 4681 | -0.093 | 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 Appendix C Figure 5.




**Appendix C Figure 5. 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 (Appendix C Figure 6). Absolute mean errors for downstream temperatures were less than 0.6°C.




**Appendix C Figure 6. 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$^{o}$C (65$^{o}$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:

1. On March 1st of each model year, the elevation of the intake was raised as high as possible given the WSE constraint;
2. 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;
3. If intake temperature criteria were violated, the intake was lowered in one meter increments until water temperature met criteria; and
4. 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

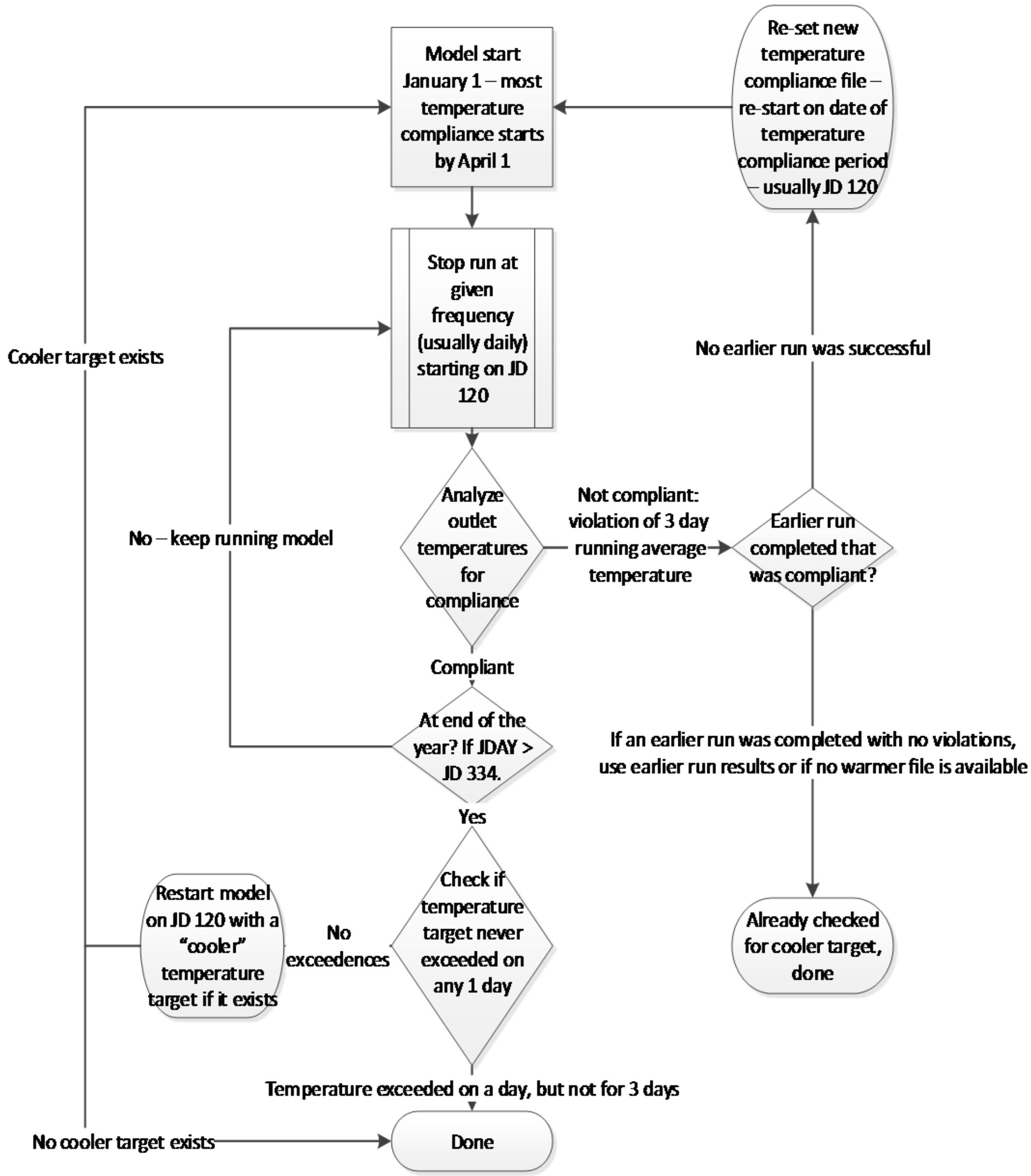
The automatic shutter operation algorithm was developed to divide flow through each of the three powerhouse penstocks and to determine when to change the shutter configuration to pull water from the appropriate location in the reservoir to achieve target outflow temperatures. Each of the Folsom Dam powerhouse 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:

1. Minimum and maximum flow through each powerhouse; and
2. 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

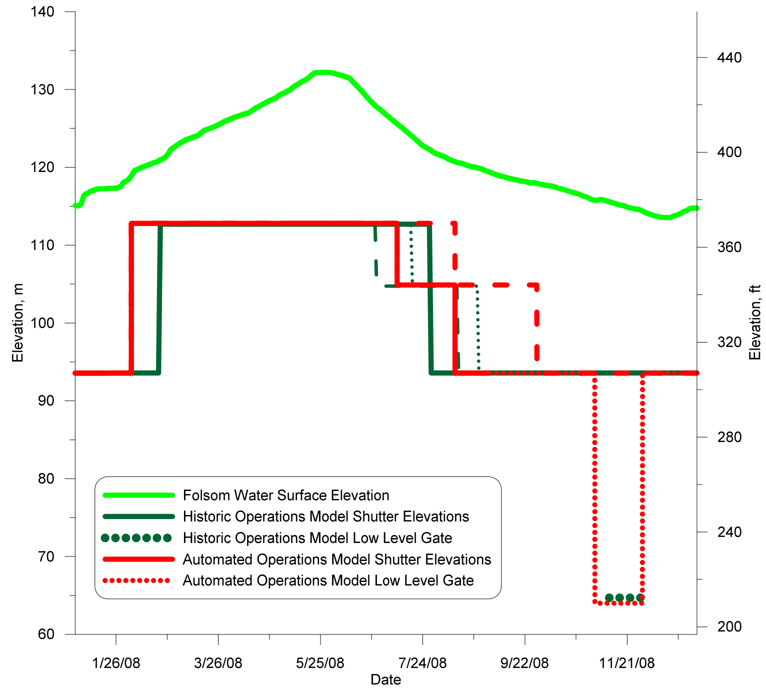
An algorithm was developed that allowed the model to run and to converge on the coldest ATSP temperature schedule that could be met. The model user provides 10 temperature target “schedules” or daily average temperature time-series files, ranging from coolest (#1) to warmest (#10). The model starts with 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 Appendix C Figure 7.



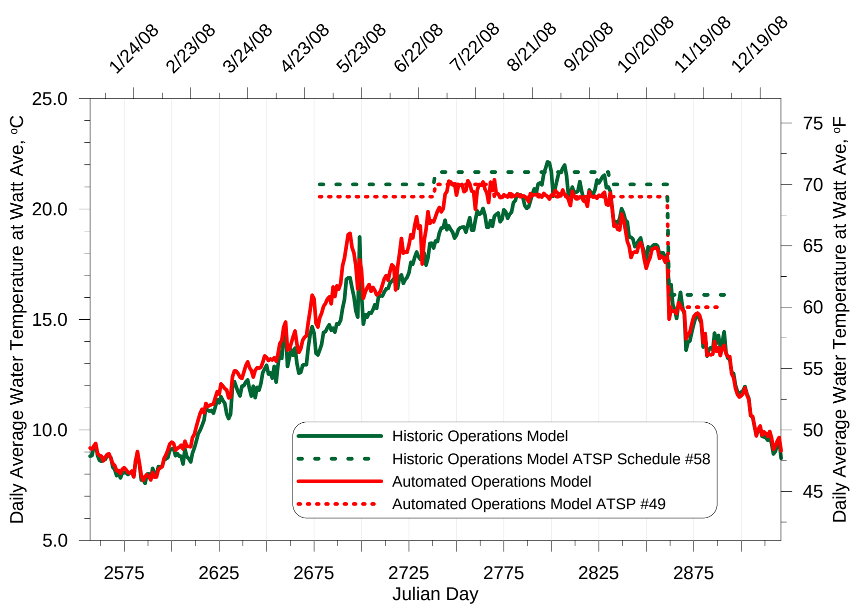

**Appendix C Figure 7. Flow Chart for Automatic Model Selection of Optimal Temperature Schedule.**

## 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 Appendix C 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 Appendix C Figure 9.




**Appendix C Figure 8. Comparison of Historical Versus Automated Water Temperature Model Shutter Operations below Folsom Dam, 2008.**




**Appendix C Figure 9. 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$^{o}$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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# APPENDIX D

# LOWER AMERICAN RIVER WATER TEMPERATURE AT WATT AVENUE

## INTRODUCTION

This appendix 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 Appendix D Table 1, and the locations are shown on Appendix D 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 (Appendix D 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 Appendix D Figure 1.

**APPENDIX D**

**TABLES**

**Appendix D 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

**Appendix 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**)

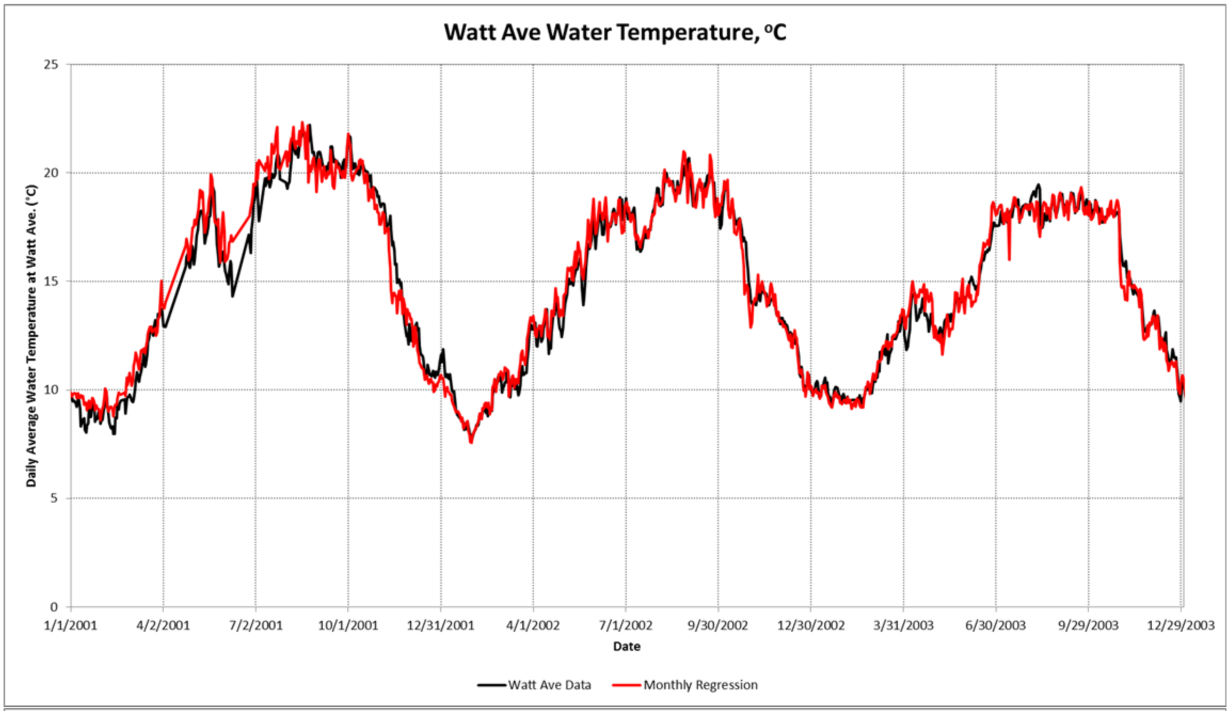
Ave Water Temp below Folsom = Daily water temperature below Folsom Data at USGS/CDEC station (station no. 11446220/AFD) (°C)

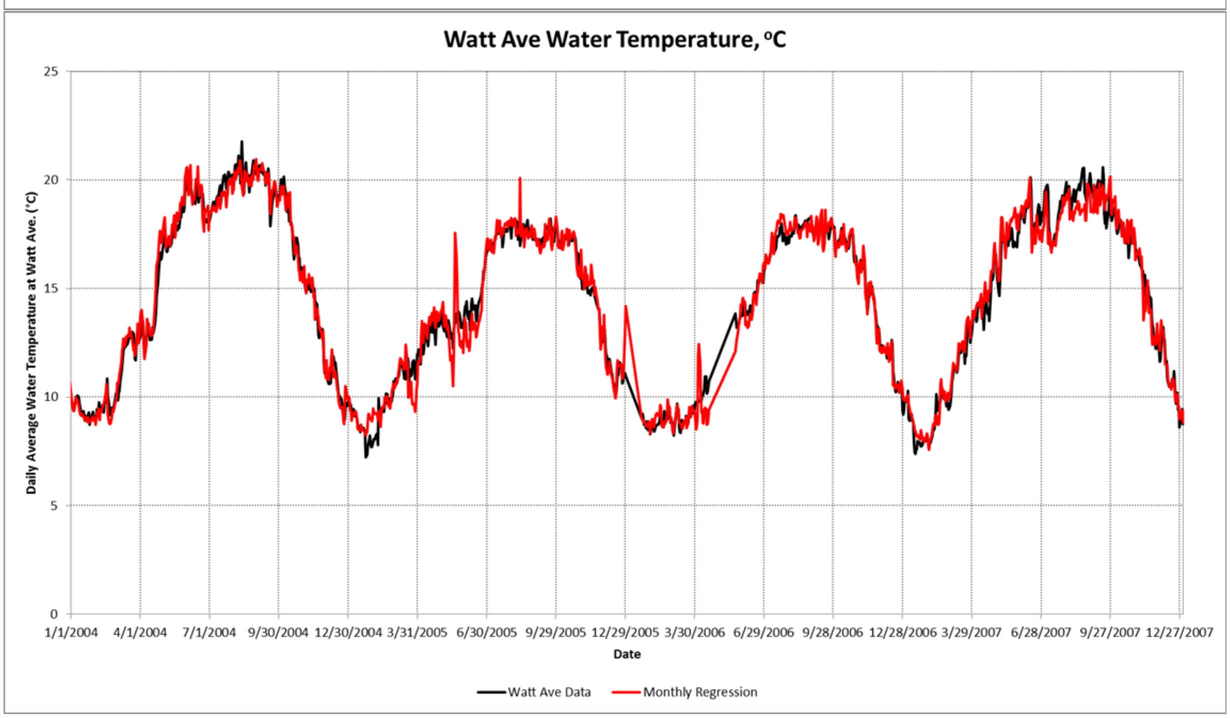
Ave Flow = Daily-averaged hourly flow below Folsom Reservoir (CDEC station FOL) – South Canal Diversion (CDEC station FSC) (cfs)

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

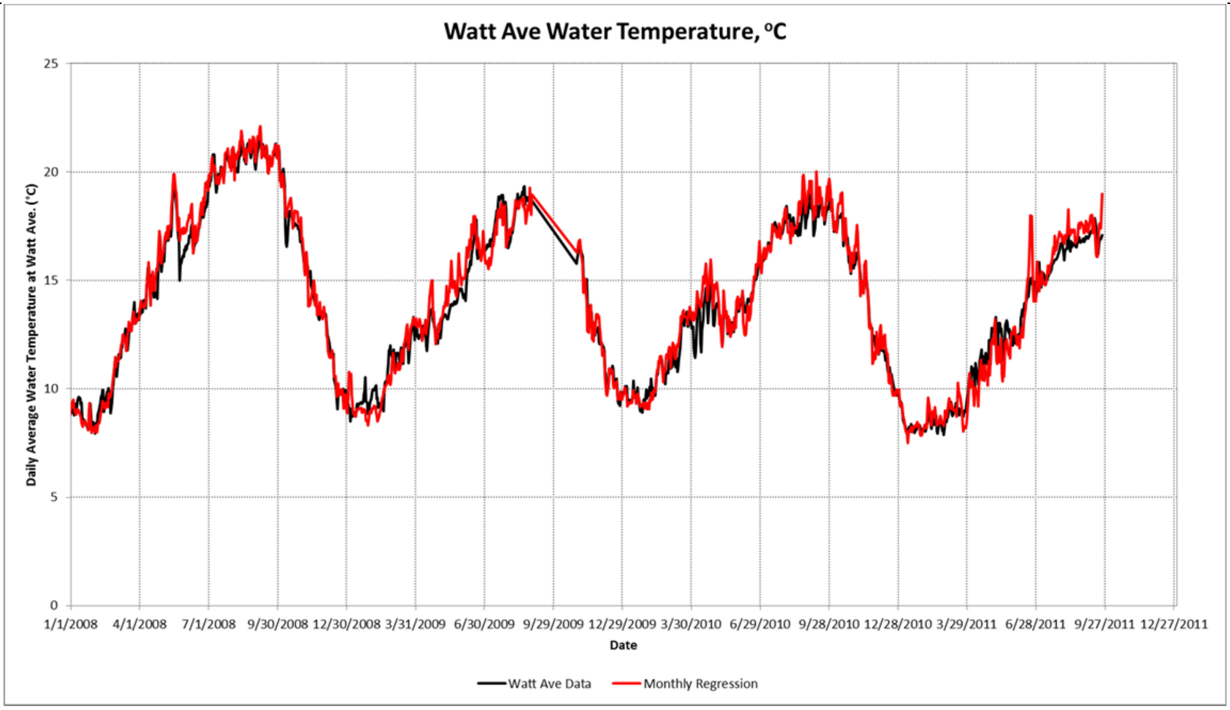
**APPENDIX D**

**FIGURES**



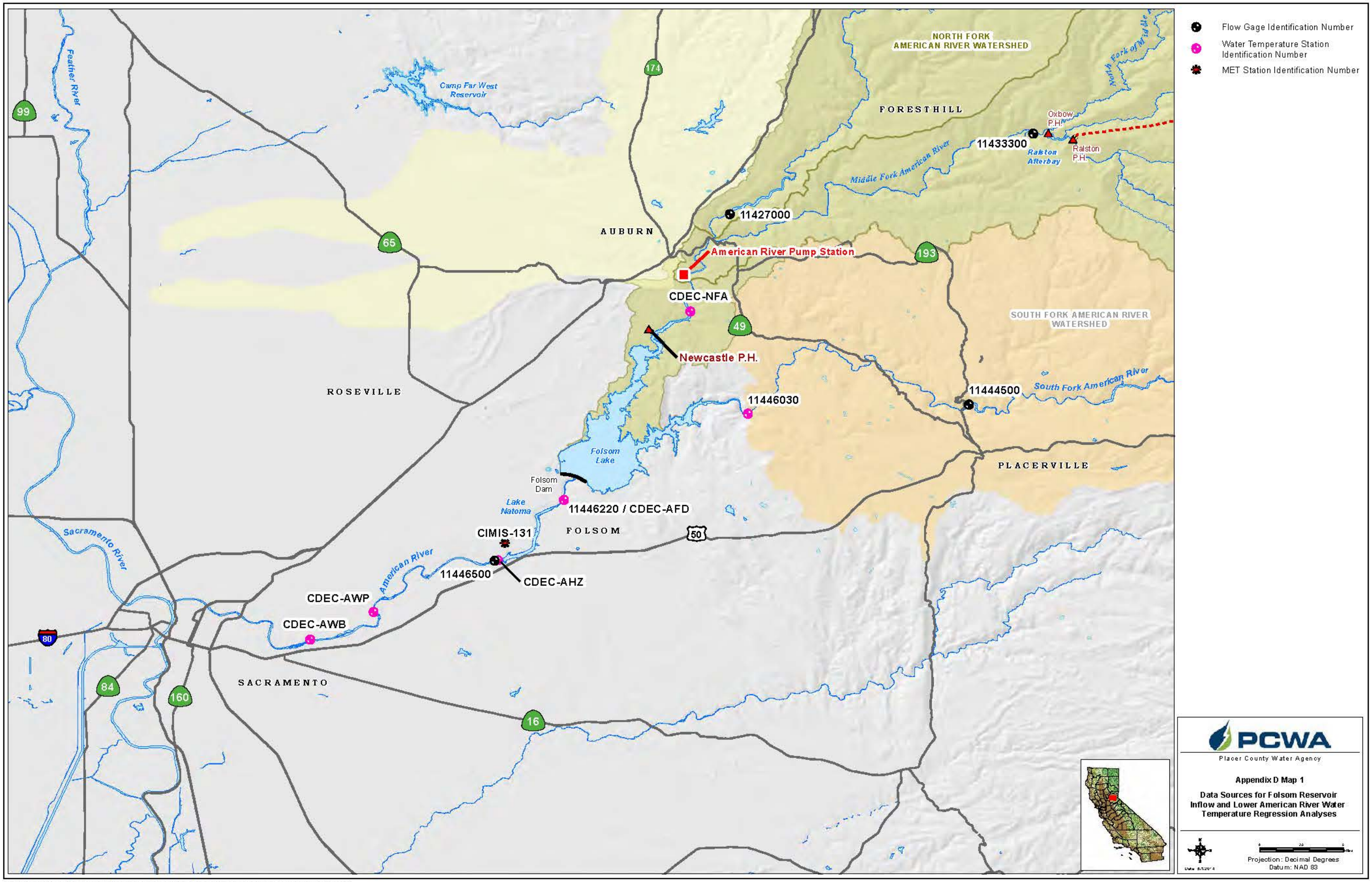

**Appendix D Figure 1. Comparison of Measured and Modeled (Regression) Water Temperature on the Lower American River at Watt Avenue (2001-2011): 2001-2004 (top), 2004-2008 (middle), and 2008-2011 (bottom).**




**Appendix D 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).**

**APPENDIX D**

**MAP**

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