EXHIBIT B

Temperature Modeling and Analysis for the San Joaquin River

Requested by the San Joaquin River Group Authority
in Connection with the 303(d) Proceedings

Prepared by

AD Consultants
RMA, Inc.

November 19, 2007

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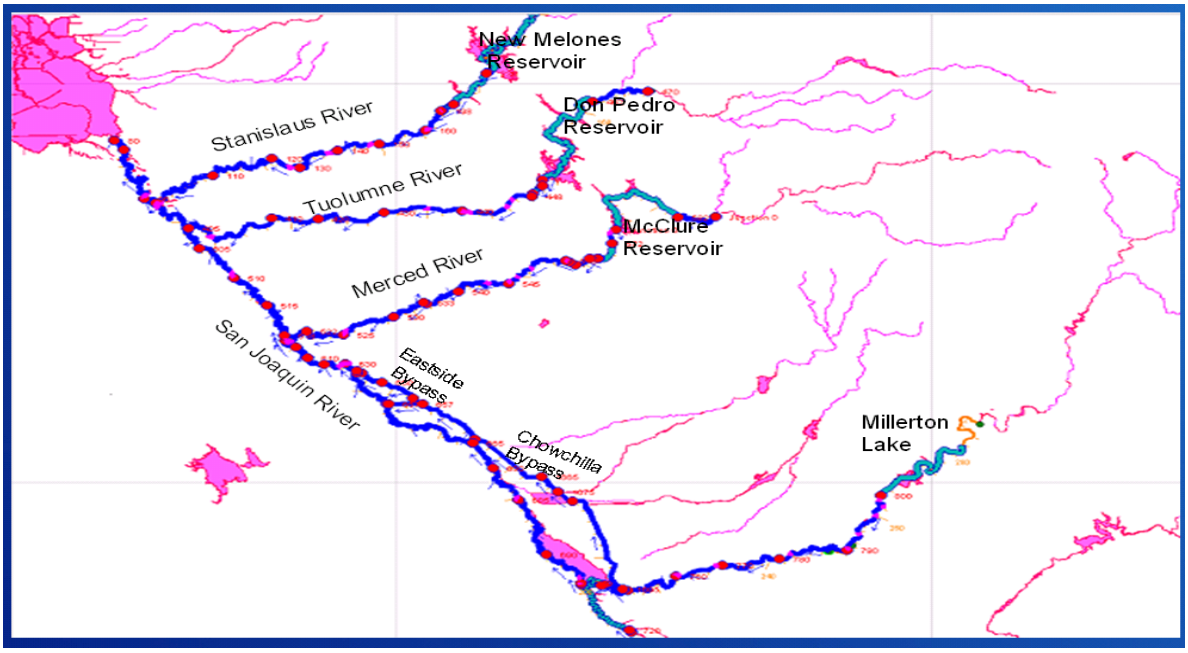
I. General

This report presents the results of water temperature modeling and analysis for the San Joaquin River (SJR) performed by AD Consultants and Resources Management Associates, Inc (RMA) as requested by the San Joaquin River Group Authority (SJRGA). The work was done to address issues in connection with the 303(d) Proceedings.

Most of the modeling results were presented to the Regional Water Quality Control Board (RWQCB) in the September 25 Temperature Workshop in Sacramento, California. Nevertheless, the report provides a more in-depth review of the results, as well as follow up analyses, specifically for the potential impact of the Friant Restoration on temperatures in the SJR in relation to the temperature objectives recommended by the CDFG and a broad view about the possibility to achieve these objectives given all the water physically available in the basin.

The modeling was performed using the CALFED sponsored San Joaquin River Basin-Wide Water Temperature Model. This HEC-5Q model encompasses the Stanislaus, Tuolumne, Merced and the main-stem and upper San Joaquin rivers, including Friant (Millerton Lake), as shown in Figure 1.

Figure 1 - HEC-5Q Model Representation of the San Joaquin Basin



The model has the capabilities to simulate various scenarios of system operation and then compute temperature response at any location throughout the system on a sub-daily basis (6-hour time increments). Using the model, it is possible to assess whether or not certain temperature objectives can be achieved given a prescribed operation scenario and what is the ramification of such operation on system storage.

II. Objective:

The objective of this analysis was to perform simulations with the HEC-5Q model and evaluate thermal conditions in the Stanislaus, main-stem SJR and lower SJR at Vernalis for different operation scenarios in connection with the Impaired Waters and Surface Water Quality Assessment 303(d) initiated by CDFG.

In the letter to the RWQCB on February 28, 2007, the CDFG proposed certain objectives (criteria) for temperatures at discrete locations on the Stanislaus, Tuolumne, Merced and the main-stem SJR at Vernalis. These objectives are summarized in Figure 2 below:

Figure 2 – Table 1 from CDFG letter to Regional Water Quality Control Board, February 28, 2007.

CDFG Proposed Temperature Criteria

River	Location	River Mile	Season	Life Phase	Threshold (ºF)	Affected River Miles	Threshold (ºC)
San Joaquin	Vernalis	72	9/1 - 10/31	Adult/Egg	64.4	118	18
	Vernalis	72	3/15 - 6/15	Smolt	59.0	118	15
Stanislaus	Mouth	0	9/1 - 10/31	Adult/Egg	64.4	58	18
	Riverbank	33	10/1 - 12/15	Egg	55.4	33	13
	Mouth	0	3/15 - 6/15	Smolt	59.0	58	15
Tuolumne	Mouth	0	9/1 - 10/31	Adult/Egg	64.4	52	18
	Waterford	28	10/1 - 12/15	Egg	55.4	24	13
	Mouth	0	3/15 - 6/15	Smolt	59.0	52	15
Merced	Mouth	0	9/1 - 10/31	Adult/Egg	64.4	52	18
	River Mile 28	28	10/1 - 12/15	Egg	55.4	24	13
	Mouth	0	3/15 - 6/15	Smolt	59.0	52	15

As such, all the results for the modeling runs (labeled "tasks" in this report) were evaluated with respect to the above objectives.

III. Tasks:

The following tasks were prepared for the September 25 staff workshop on temperature:

1. How "Actual" Temperatures Compare with "Historic" Conditions?

Model the "Historic" and "Actual" (1967-1982) temperatures for the following locations and times:

- Confluence of the Stanislaus River 9/1 – 10/31
- Vernalis 9/1 – 10/31
- Riverbank 10/1 – 12/15
- Confluence of the Stanislaus River 3/15 – 6/15
- Vernalis 3/15 – 6/15

For the purpose of this analysis, "Historic" temperatures were defined as pre-new storage development and "Actual" as post-new storage development on the Stanislaus River.

Concepts and assumptions:

The existing Stanislaus component of the Temperature Model was modified as follows:

- Removed New Melones and replaced with Old Melones.
- Extended stream section between Old Melones and Tulloch.
- Assumed same river cross sections above Old Melones to Stanislaus PH

- Removed Collierville PH
- Meteorology – extended based on Modesto max/min temperatures
- Hydrology – assumed historical flow and operation for Old Melones and Tulloch

Assess the following:

1) What were the "Historic" temperatures at the above mentioned locations and periods?
2) What were the "Actual" temperatures at the above mentioned locations and periods?
3) How do the "Historic" and "Actual" temperatures compare?
4) Did "Historic" temperatures meet the temperature objectives proposed by CDFG?

2. Can the IPO and Augmented IPO Meet CDFG Criteria?

Model temperatures in the Stanislaus and Lower SJR at Vernalis for the period 1980-2003 under the current IPO. Then, increase New Melones releases (Augmented IPO) and check if CDFG recommended criteria can be met.

Concepts and Assumptions:

Convert the IPO flows to daily time steps. Then run the IPO with the 5Q and track temperatures on a sub-daily basis at three locations: Riverbank, Confluence and Vernalis. Assume historical flows and temperature inflows for the main-stem SJR at the confluence. Increase releases from Goodwin for two periods: Spring and Fall as follows:

$Q_{Goodwin} = \max(Q_{IPO}, Q_{Schedule})$

Where:

Q_{IPO} = minimum flow per the IPO for fish, water quality, etc. (not including spills), and

$Q_{Schedule}$ varies (linearly) as follows:

Period	From	To	Flow Rate (cfs)
Spring	3/15	4/15	500
Spring	4/16	5/15	1000
Spring	5/16	6/15	1500
Fall	9/1	9/31	1500
Fall	10/1	10/15	1000
Fall	10/16	10/31	500

Assess the following:

1) Can the CDFG recommended criteria be met at all times and under all conditions?
2) If not, when and how often does New Melones Reservoir run out of water?

3. Can CDFG Criteria at Vernalis Be Met by Increasing Flows from the Tributaries?

Assume that the CDFG recommended temperatures at the confluences of all three tributaries are met for the time periods 9/1 – 10/31 and 3/15 – 6/15. Then, increase releases from the tributaries and check if CDFG criteria are met at Vernalis.

Concepts and Assumptions:

Use 1995-2006 for an example. First, assume historical flows from the Stanislaus, Tuolumne and Merced for the above periods. Assume temperatures are met (per CDFG criteria) at the confluence of each river with the SJR. Then:

- Route historical flows from the three rivers and check temperatures at Vernalis.
- Set Tuolumne and Merced flows (to equal historical) and increase Stanislaus. Compute temperatures at Vernalis.

- Set Stanislaus flows (to equal historical) and increase Tuolumne and Merced flows (50/50 split between the two rivers). Compute temperatures at Vernalis.

Assess the following:

1) Will the attainment of temperatures at the confluences have any improvement to temperatures at Vernalis?
2) If so, will it be enough to meet the Vernalis temperature criteria recommended by CDFG for those two time periods?

The following tasks were prepared as a follow up to the September 25 staff workshop on temperature:

4. What is the Impact of Friant Restoration on Temperature in the SJR?

Analyze the potential impact of Friant Restoration on temperatures in the SJR with respect to CDFG objectives per the 303(d) proceedings.

Concepts and Assumptions:

- 1980 - 2005 hydrology as defined in the USBR report.
- Restoration flows (minimum flow requirement below Friant Dam) defined by year type (Settlement Decision Tables 1A - 1F of 9/13/2006).
- Historical Friant diversions (Madera and Friant-Kern Canals) with physical operation constraints (maximum diversion rate computed as a function of reservoir elevation).
- Bypass operation and diversion to historical river channel at Sand Slough defined as a function of flow.
- Simulate the 26-year period to compute the flow and temperature in the San Joaquin River at Stevinson to provide upstream boundary of the CalFed Model.
- All subsequent simulations will use the CalFed model with the computed or historical data based Stevinson boundary flow and temperature.
- Simulate historical conditions with Stanislaus operating under IPO and historical boundary conditions.
- Simulate IPO-historical conditions with computed Friant restoration boundary conditions.
- Develop minimum flow relationships at Exchequer to examine feasibility of countering effects of Friant restoration. The minimum flow requirements will also need to be based on hydrologic year type). Simulate various Merced River minimum flow assumptions.

Assess the following:

1) What would be the temperature conditions at the confluence with the Merced River as a result of Friant Restoration?
2) To what extent can the Merced River reduce temperatures at the confluence given the new flow regime?

5. Is the SJR Temperature Impaired Even if All the Water the Basin is allocated for Fish?

Assume that all the water in the basin is allocated for fish release (no diversions). Compute the temperature response at the confluence of each river and at Vernalis. Check if the new computed temperature frequencies will still pass the temperature impairment test defined by RWQCB.

Concepts and Assumptions:

- Use the historical 1995 - 2005 hydrology as a case study.
- Maintain the same storage levels as historically occurred.
- Reroute all the historical diversions back the rivers.
- Reshape the rerouted diversions around the spring and fall to maximize temperature reductions in these seasons.

Assess the following:

1) Would the temperatures in confluences of the Stanislaus, Tuolumne and Merced and at Vernalis pass the temperature impairment test, as defined by the RWQCB?

IV. Modeling Results

All modeling results are saved in HEC-DSS (Data Storage System) files and are provided in the CD attached as Exhibit E to the SJRGA's November 19, 2007 comments. The HEC-DSS is a database developed the U.S. Army Corps of Engineers' Hydrologic Engineering Center designed to efficiently store and retrieve scientific data that is typically sequential. The database was designed to make it easy for users and application programs to retrieve and store data. HEC-DSS is incorporated into most of HEC's major application programs, including the HEC-5Q.

To view the content of the model results in the HEC-DSS files requires a special software called DSS-Vue. This is public domain software and is available for download from the following link:

http://www.hec.usace.army.mil/software/hec-dss/hecdssvue-download.htm

Also included in the CD are Excel and other supporting files used for post processing and analyzing of the results.

The following are summaries of the results for the above-mentioned Tasks.

1. How "Actual" Temperatures Compare with "Historic" Conditions?

Assessment of results:

1) "Historic" water temperatures in the Stanislaus River and the Lower San Joaquin River at Vernalis are higher than "Actual" water temperatures majority of the time.

2) "Historic" water temperatures do not meet the temperature objective set forth by CDFG for the proposed locations in the Stanislaus River and the Lower San Joaquin River at Vernalis majority of the time.

The first assessment is supported by Figure 3 to Figure 7:

Average daily temperatures at Riverbank, Confluence (of the Stanislaus with SJR) and Vernalis – the three reference points identified by CDFG for temperature objective, are presented in Figure 3. The line labeled "IPO_67" represents "Actual" and the line labeled "Hist1" represents "Historic". The Y-axis on the left shows the absolute values of these lines. The line labeled "Hist-IPO_67 difference" represents the difference between "Actual" and "Historic" (i.e., "Historic" minus "Actual"). The Y-axis on the right shows the values for this line. Whenever this line is above zero, it means that "Historic" temperatures are higher than "Actual".

Figure 4 shows similar results except for maximum daily temperatures (assumed to be at hour 18:00 in the model). Since CDFG proposed to use the average of 7-days maximum temperatures for defining temperature criteria at their proposed reference points, this graph might be more relevant than average temperatures, as far as the 303(d) is concerned.

Table 1 is a summary of Figure 4 and Figure 4 showing the numbers of days, on average, that "Historic" temperatures were higher than "Actual". The table also shows day-count for other locations on the Stanislaus River. This information can be obtained from the attached HEC-DSS file.

Table 1 – Number of days and % of time "Historic" temperatures are higher than "Actual"

Location	Average Temperatures # of days Historic > Actual	Average Temperatures % of Time Historic > Actual	Maximum Temperatures # of days Historic > Actual	Maximum Temperatures % of Time Historic > Actual
GOODWIN	248	68%	340	93%
KNIGHTS FERRY	241	66%	287	79%
ORANGE BLOSSOM	243	67%	278	76%
RIVERBANK	247	68%	318	87%
RIPON	251	69%	328	90%
CONFLUENCE	221	61%	303	83%
VERNALIS	205	56%	279	76%

The primary reason for the cooling effect under the "Actual" conditions is the increased storage in New Melones. Old Melones Reservoir had a storage capacity of approximately 110 thousand acre-ft while New Melones Reservoir storage capacity is approximately 2.4 million acre-ft. Old Melones Reservoir would cycle from full to empty on a yearly basis thus either spilling large quantities of water during the flood control season or passing through low flows when the reservoir is empty. New Melones Reservoir, on the other hand, has significantly larger capacity for carry-over storage that allows regulating releases as well providing cool water supply. This observation is demonstrated in Figure 5 which shows reservoirs storages for Old and New Melones, Goodwin release and water temperatures downstream to Goodwin Dam.

Another observation is the blending effect of Stanislaus River water with the water in the main-stem SJR the at confluence which is often already at ambient temperature (due to the long travel time from the upstream reservoirs, as will be discussed later in the report). As such, the differences between "Historic" and "Actual" temperatures diminish by the time the water reaches Vernalis.

It should be noted that for quality control purposes, model results for the "Historic" temperatures at Vernalis were compared with observed data. As shown in Figure 6, the comparison indicates that the model under-predicts the observed temperatures slightly, indicating that the model results are conservative from a temperature increment standpoint. Nevertheless, model results have a high degree of reliability with a coefficient of determination R^2=0.945, as shown in Figure 7.

The second assessment is supported by Figure 8 to Figure 10. These figures show the temperature objectives proposed by CDFG at Riverbank, the confluence (of the Stanislaus with SJR) and Vernalis and the computed "Historic" temperatures at these locations. The results show that systematically, the temperatures "shave" the beginning and ending periods specified for the objectives. Examples for an above-normal year (1970) and for dry year (1968) are provided in Figure 9 and Figure 10, respectively.

Figure 3 - Average Daily Temperatures at Riverbank, Confluence and Vernalis (1967-1982)

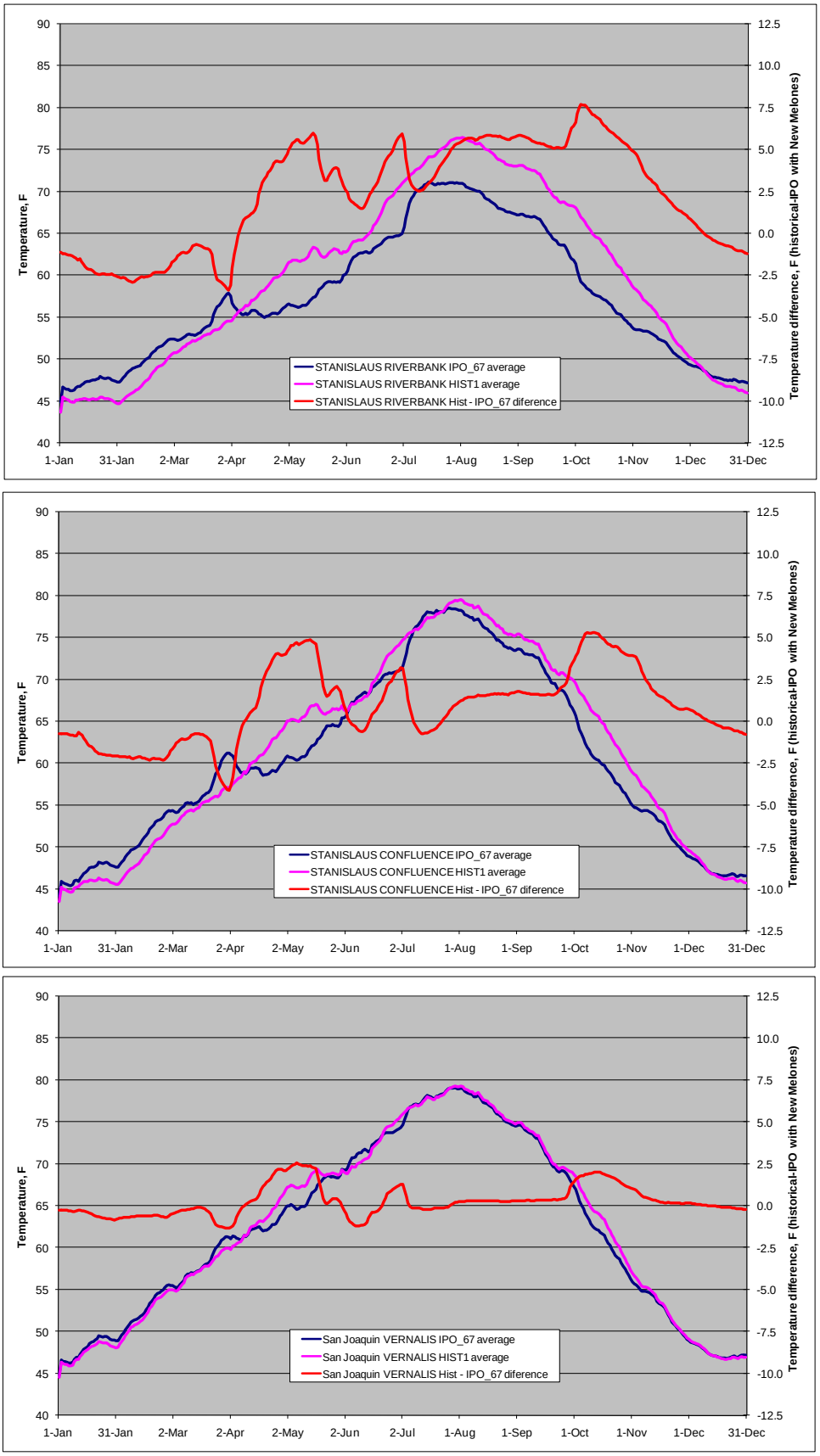


Figure 4 - Maximum Daily Temperatures at Riverbank, Confluence and Vernalis (1967-1982)

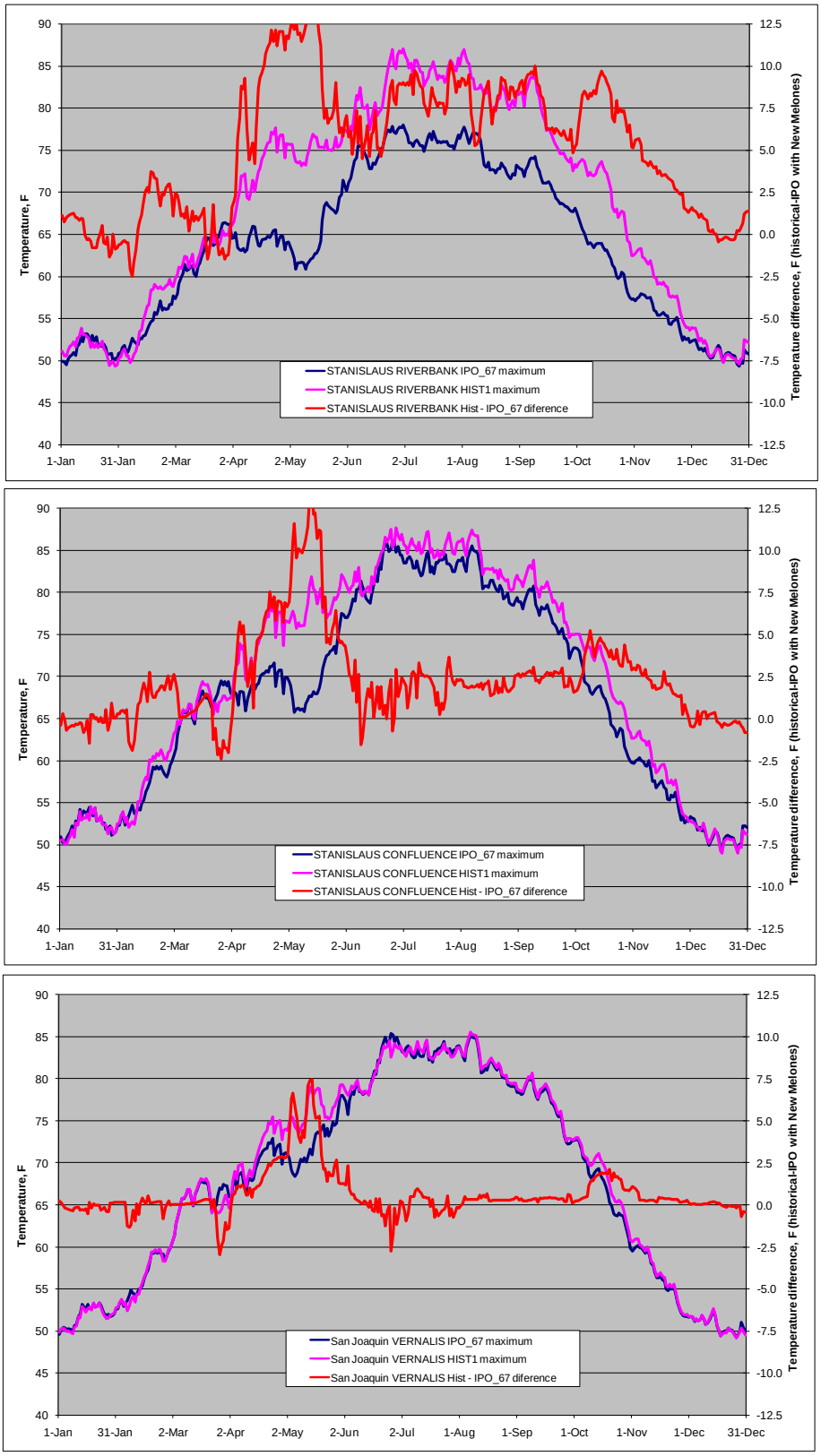


Figure 5 – New and Old Melones Storage, Goodwin Releases and Goodwin Temperatures under "Historic" (HIST1) and "Actual" (IPO_67) Operations.

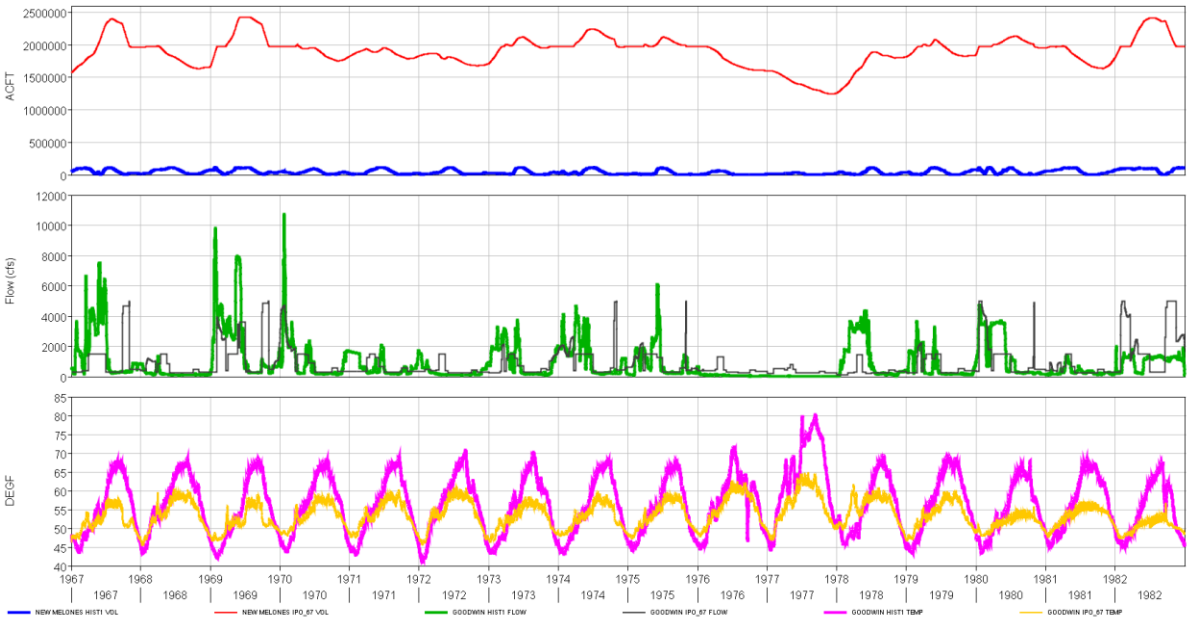


Figure 6 – Computed vs. Observed Temperatures at Vernalis for the "Historic" Conditions

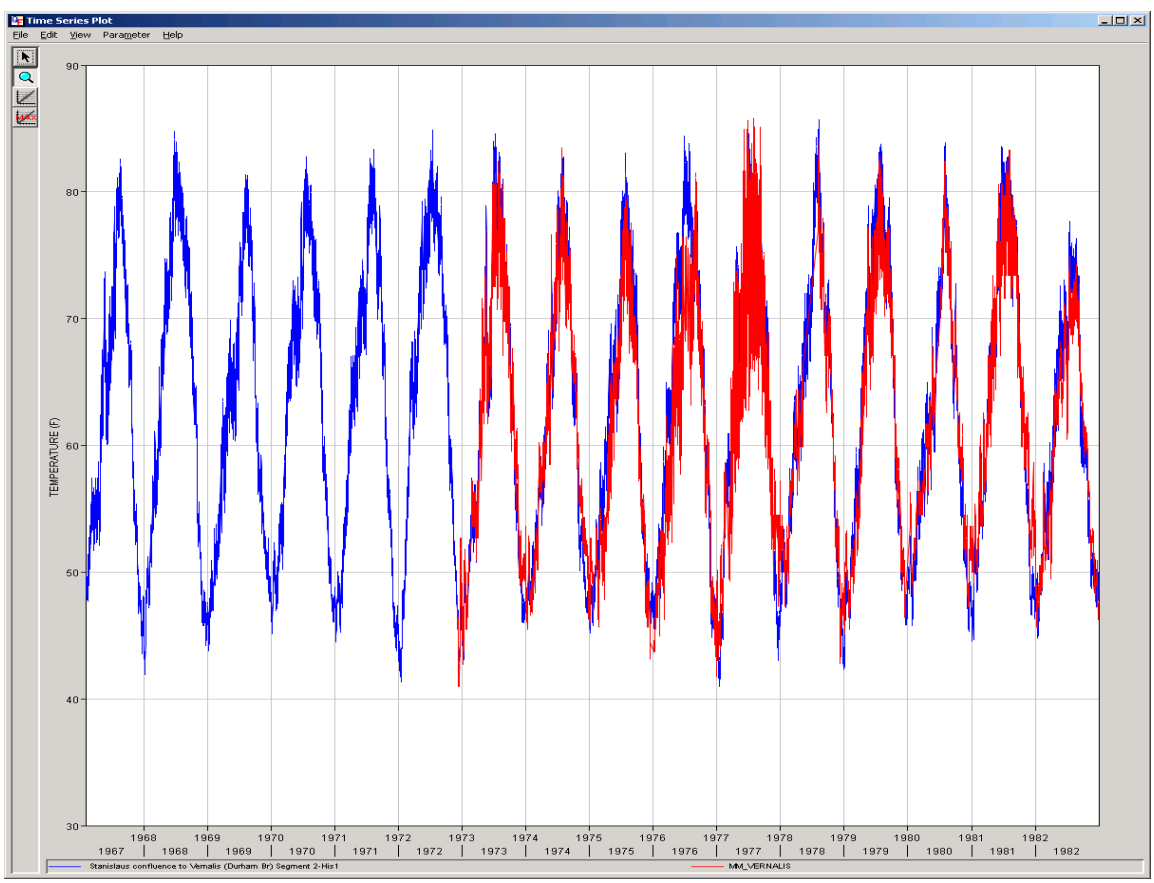


Figure 7 – Correlation between Computed vs. Observed Temperatures at Vernalis for the "Historic" Conditions

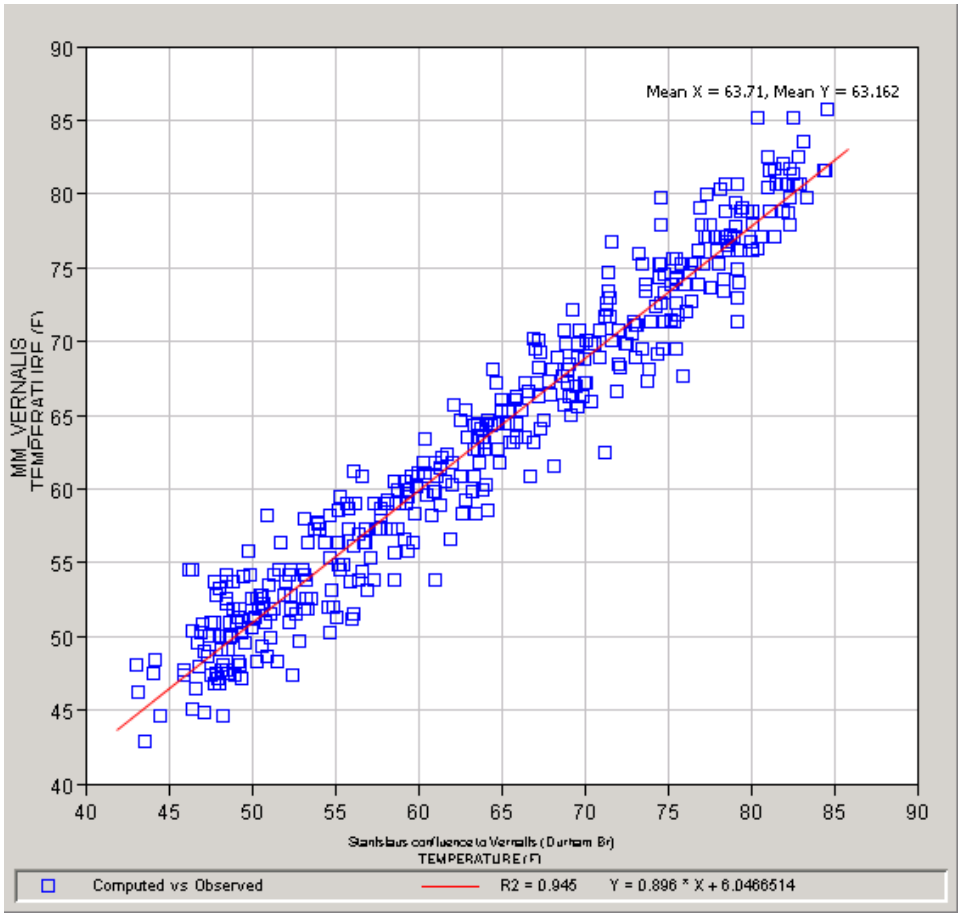


Figure 8 – "Historic" Temperature with respect to CDFG Proposed Temperature Objectives at Riverbank, Confluence (Stanislaus with SJR) and Vernalis.

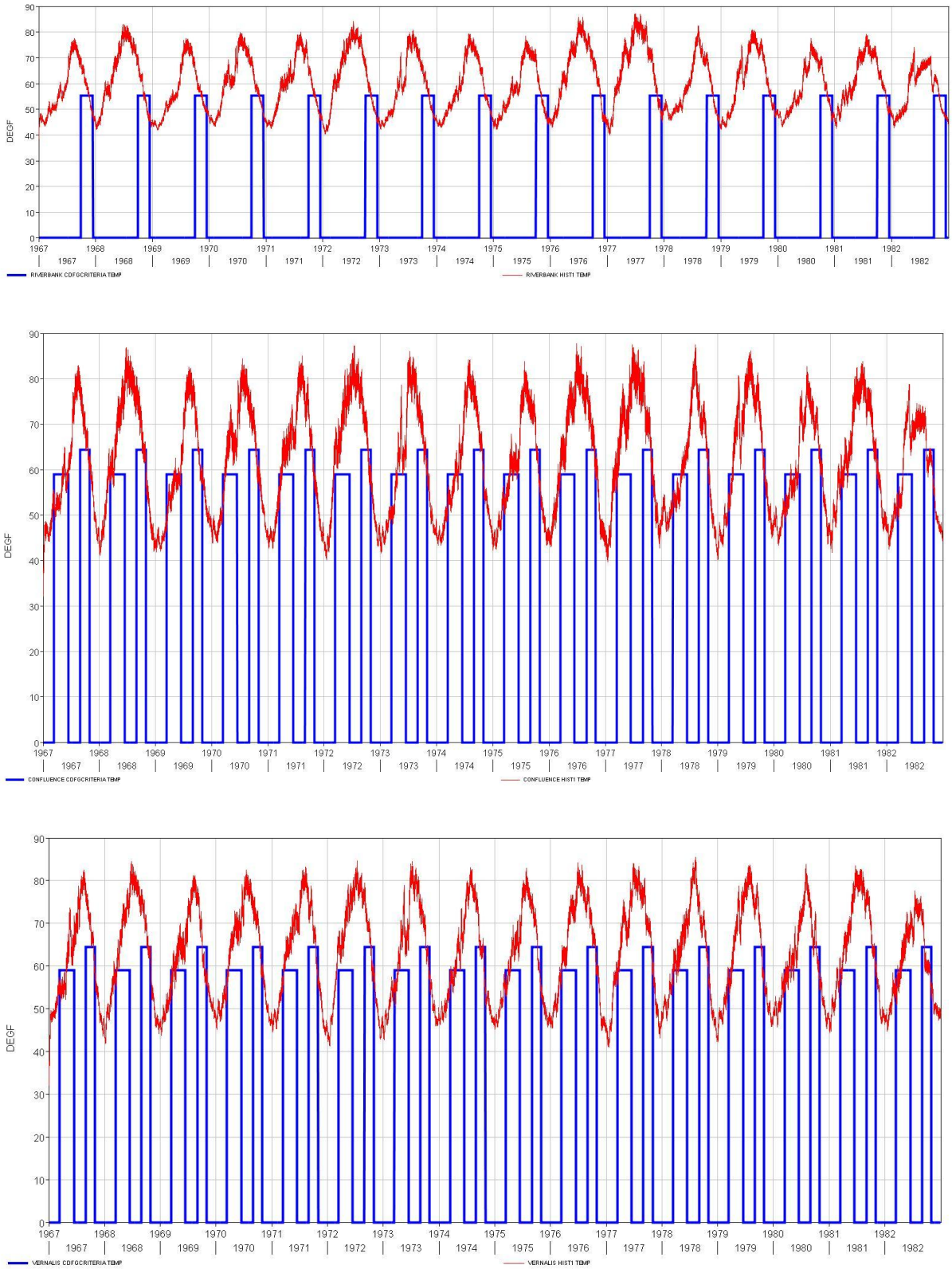


Figure 9 – "Historic" Temperatures vs. CDFG Objectives at the Confluence in Above-Normal Year (1970)

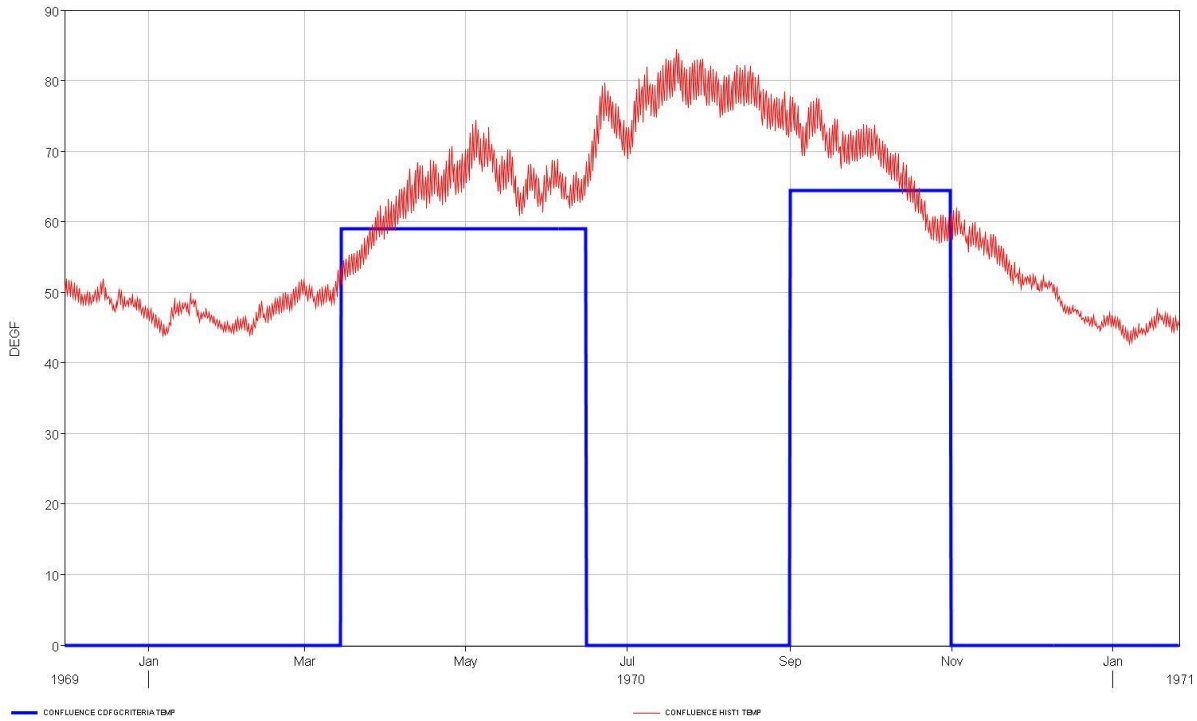
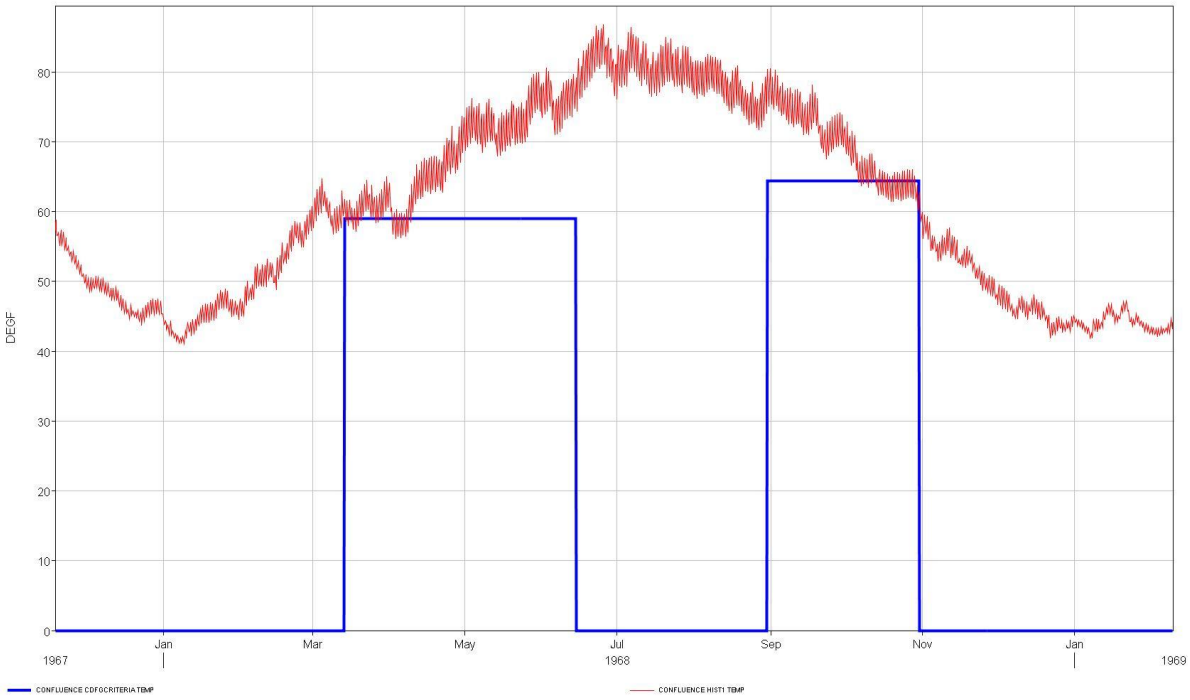


Figure 10- "Historic" Temperatures vs. CDFG Objectives at the Confluence in Dry Year (1968)



2. Can the IPO[1] or Augmented IPO Meet CDFG Criteria?

Assessment of results:

1) *The CDFG recommended criteria cannot be met most of the time under the current IPO or Augmented IPO.*

2) *Using New Melones as a surrogate to reduce water temperatures at Vernalis, through an Augmented IPO, could result in prolonged periods of an empty New Melones Reservoir, yet with minimal ability to meet CDFG recommended criteria.*

The above assessments are supported by the following figures:

Figure 11 and Figure 12 show the percent of the time, during the period 1980-2003, that maximum water temperature conditions at Vernalis equaled to or exceeded CDFG objectives (criteria), for the following cases:

- Historic flows[2].
- IPO flows.
- Augmented IPO flows.

Also shown in the figures are CDFG temperature objectives for the fall (in Figure 11) and spring (in Figure 12). A summary of these figures is presented in Table 2. It shows that although temperatures at Vernalis can be reduced somewhat by augmenting IPO releases from New Melones, the CDFG objectives still cannot be met the majority of the time.

Like in Task 1 above, the results show that systematically, the temperatures "shave" the beginning and ending periods specified for the objectives.

An example for the extent of the thermal improvement at Vernalis due to the Augmented IPO in relation to CDFG objectives is presented in Figure 13. The figure shows computed temperatures at Vernalis for a sequence of 4 years: 2000 to 2003. During this time frame, IPO releases were increased by a total of approximately 600, 000 AF or 155,000 AF annually. At the same time, the number of days during the fall and spring when the increased releases lowered water temperatures to the compliance level, as defined by CDFG objectives, is 17 or approximately 4 days per year.

The ramification of the increased releases (under the Augmented IPO) from New Melones storage is depicted in Figure 14. The figure shows that for the analysis period 1980-2003, New Melones Reservoir would have been dry for solid two and a half years during 1990 to 1993 and again in late 1994 with limited ability to recover in between. New Melones storage would also drop below 500,000 AF in 2003.

[1] The flow regime downstream of New Melones Reservoir is primarily characterized by the current Interim Plan of Operation (IPO) between the USBR and the California Department of Fish and Game that was signed in 1987. The IPO defines allocation of water from New Melones for fishery, Vernalis water quality, Bay-Delta and Central Valley Project contractors as function of New Melones storage and projected inflow. A more complete description of the IPO is attached as Exhibit G to the SJRGA's November 19, 2007 comments.

[2] Historic flows in this context are daily releases based on actual operation.

Table 2 – Percent of the Time Maximum Temperatures at Vernalis are Equal to or Greater Than CDFG Objectives.

	Fall	Spring
	(9/1 to 10/31)	(3/15 to 6/15)
	% of Time	% of Time
Case	Max Temp >= 59 F	Max Temp >= 64.4 F
Historic Flows	73.4%	93.3%
IPO Flows	71.7%	94.1%
Augmented IPO Flows	67.0%	94.2%

Figure 11 – Duration Curves for Maximum Water Temperatures at Vernalis in the fall (9/10 to 10/31)

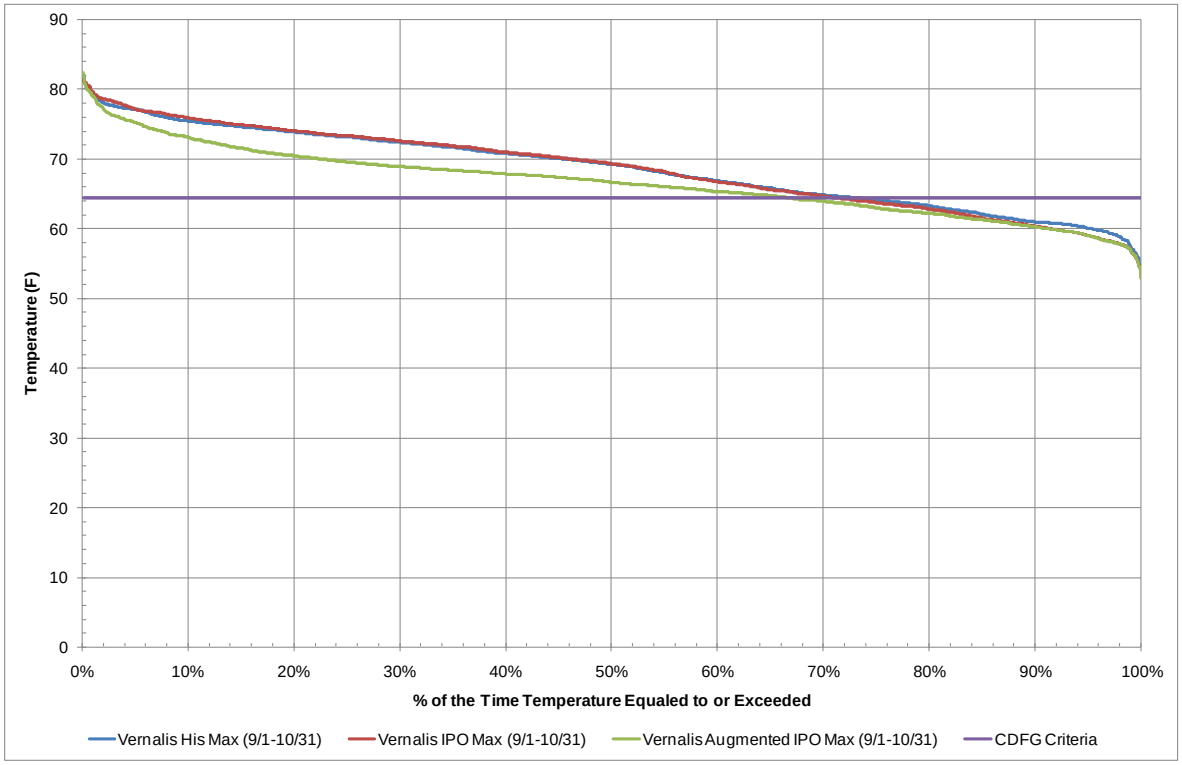


Figure 12 - Duration Curves for Maximum Water Temperatures at Vernalis in the Spring (3/15 to 6/15)

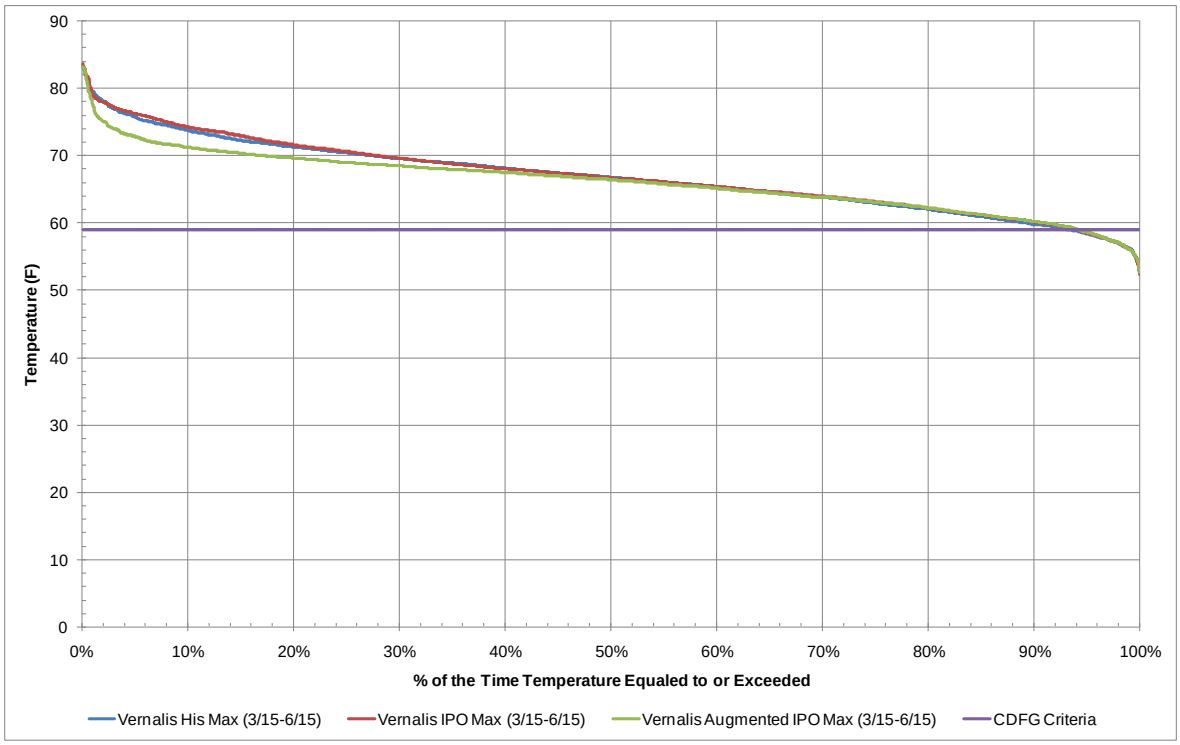


Figure 13 – Potential Thermal Improvements at Vernalis by Augmenting IPO releases and the Effect on New Melones Storage.

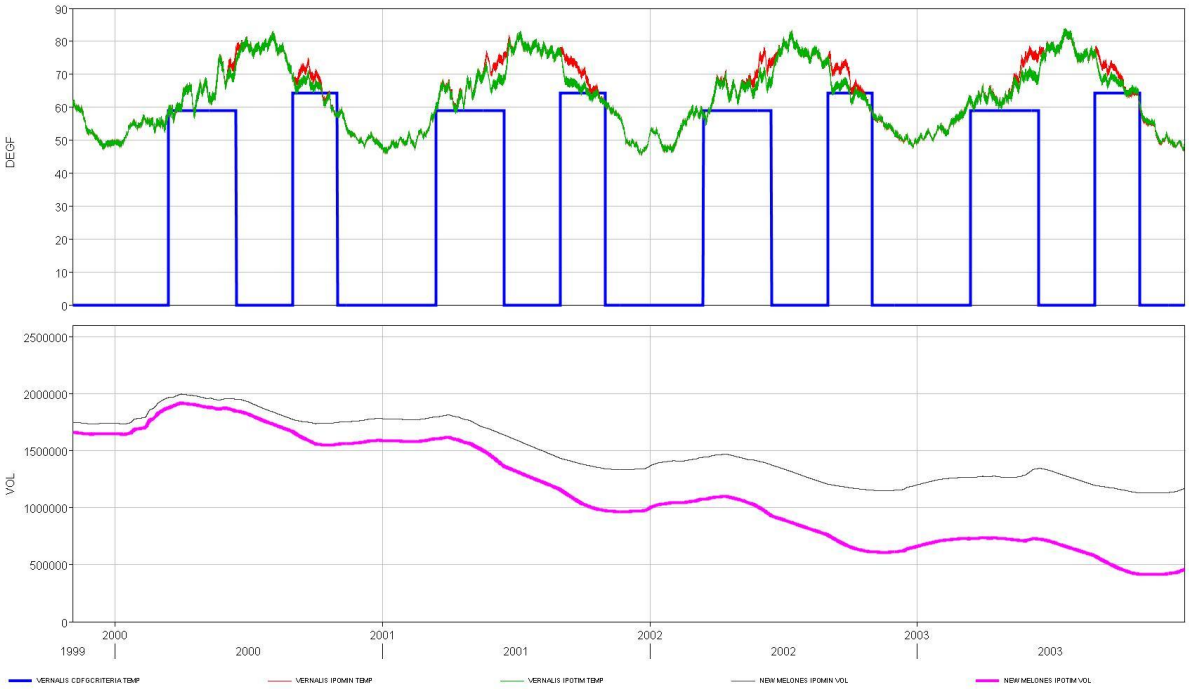
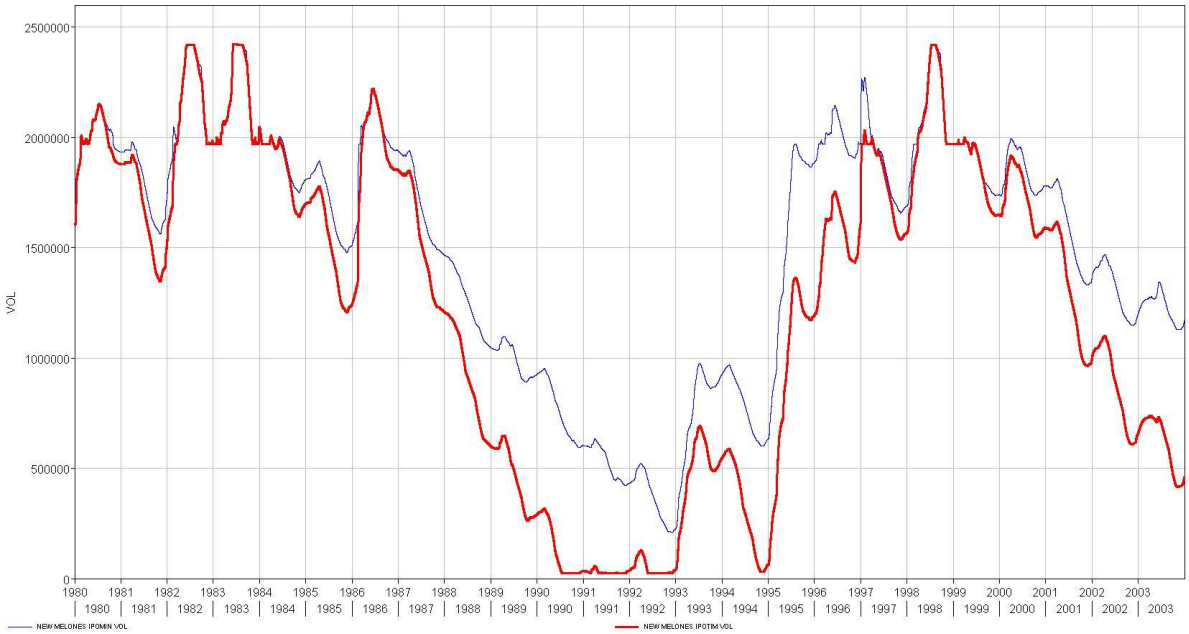


Figure 14 – New Melones Storage under the IPO and Augmented IPO



3. **Can CDFG Criteria at Vernalis Be Met by Increasing Flows from the Tributaries?**

Assessment of results:

1) *Attainment of temperatures at the confluences may have improvement to temperatures at Vernalis depending on the portion of the flow from each tributary and the time of the year.*

2) *However, attainment of temperatures at the confluences will not be enough to meet the Vernalis temperature criteria recommended by CDFG.*

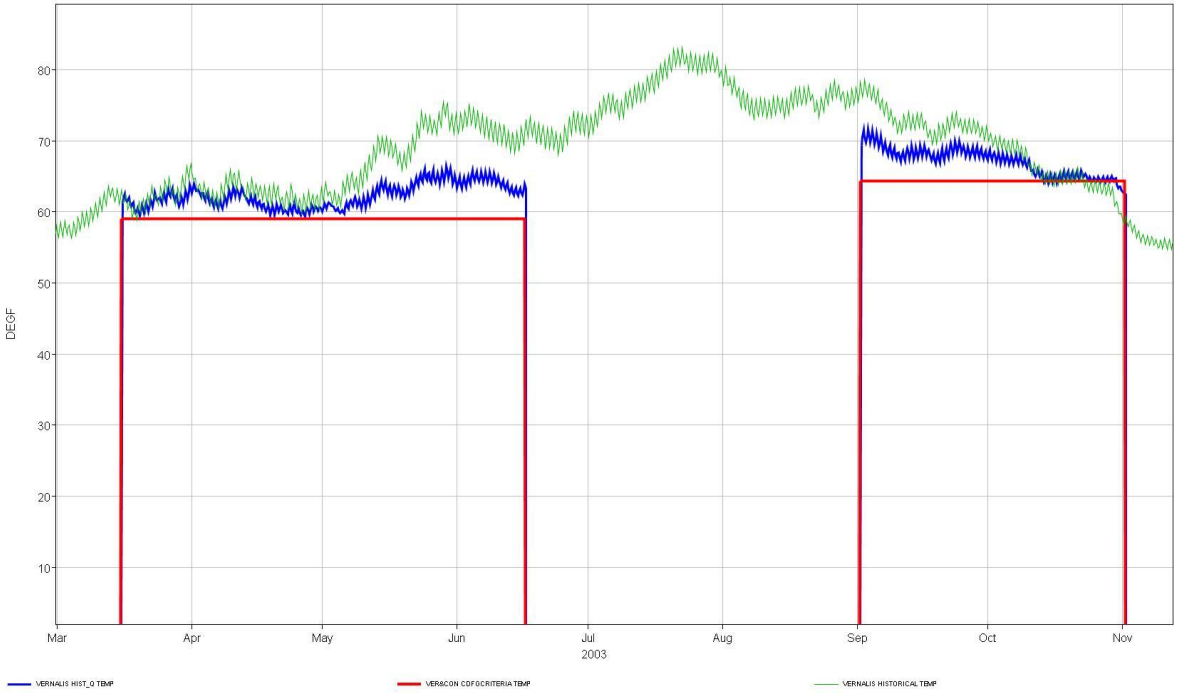
The first assessment is supported by a typical example in Figure 15. This figure shows two lines that represent computed temperatures at Vernalis for historical flows:

1) HISTORICAL – This is the computed temperatures at Vernalis for the historical conditions.

2) HIST_Q – This is a hypothetical case in which water temperatures at the confluence of each tributary were artificially set to equal CDFG's proposed temperature criteria (59 F for the spring and 64.4 F for the fall).

The graph shows that if, theoretically, water would leave the three tributaries at temperatures equal to CDFG criteria, it could reduce temperatures at Vernalis in late spring and early fall. The graph also shows less temperature improvements in early spring and late fall since in both cases the water approaches ambient temperatures.

Figure 15 – Vernalis Historical Vs. Modified Historical Temperatures Assuming Attainment of CDFG Temperature Criteria at the Three Confluences (Stanislaus, Tuolumne and Merced).



The second assessment is supported by series of runs that were built on top of the Hist_Q case above.

Summary of these runs are given in Table 3. The table shows that, on average, maximum temperatures at Vernalis cannot be met regardless of the amount released from each tributary, even if the initial temperature conditions are artificially set to equal CDFG criteria.

Table 3 – Vernalis average maximum temperatures given different release cases from the tributaries with initial water temperatures set to equal CDFG criteria.

	Minimum Flow (cfs)	Minimum Flow (cfs)	Minimum Flow (cfs)	Vernalis Average Max Temperatures (F)	
				Period	Period
Case	Stanislaus	Tuolumne	Merced	Spring	fall
CDFG CRITERIA	na	na	na	59.0	64.4
HIST_Q	Historic	Historic	Historic	62.8	66.7
SR_M2000	2000	Historic	Historic	62.1	65.3
TR_M1000	Historic	1000	Historic	62.5	65.8
MR_M1000	Historic	Historic	1000	62.8	66.1
TRMR_M1000	Historic	1000	1000	62.5	65.7
S2000_MT1000	2000	1000	1000	62.1	65.1

4. What is the Impact of Friant Restoration on Temperature in the SJR?

Assessment of results:

1) *Friant Restoration will have a minimal effect on temperatures in the SJR at the confluence with the Merced River.*

2) *However, since the Friant Restoration will introduce more water at the confluence, it will require larger releases from the Merced to reduce temperatures. This type of operation can be sustained for only a short period of time because of storage limitation on the Merced River and will not achieve the CDFG recommended criteria at the confluence.*

The above assessments are supported by the following figures:

Figure 16 shows the computed Historical and Settlement (Restoration) flows and temperatures in the SJR upstream to the confluence with the Merced for the period 1998-2001. The figure shows that although the Settlement flows are higher than the Historical, the temperatures are about the same. This phenomenon can be explained by the fact that due to the long travel time, the Friant water approaches equilibrium with ambient temperature by the time it arrives at the Merced confluence.

Figure 17 shows the extent of temperature reduction in the SJR at the confluence and the ramification of on Lake McClure storage when historical releases are augmented. The figure shows that in the first two years (1999 and 2000) that follow a wet year (1998) increased releases from Lake McClure could reduce temperatures at the confluence. However, due to the limited storage capacity of the reservoir, this type of operation will result in depletion of all the water by the third year (2001) and as such will not yield any temperature benefits thereafter.

Figure 16 – Flow and Temperature in the SJR Upstream to the Confluence with the Merced River

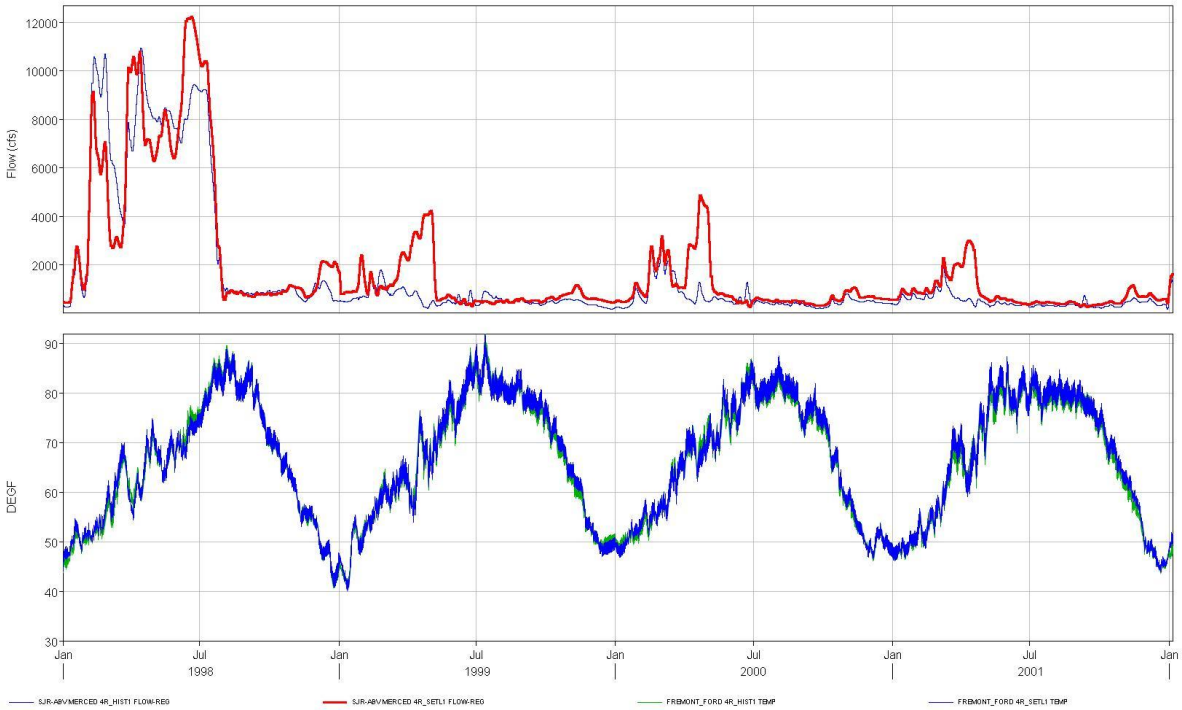
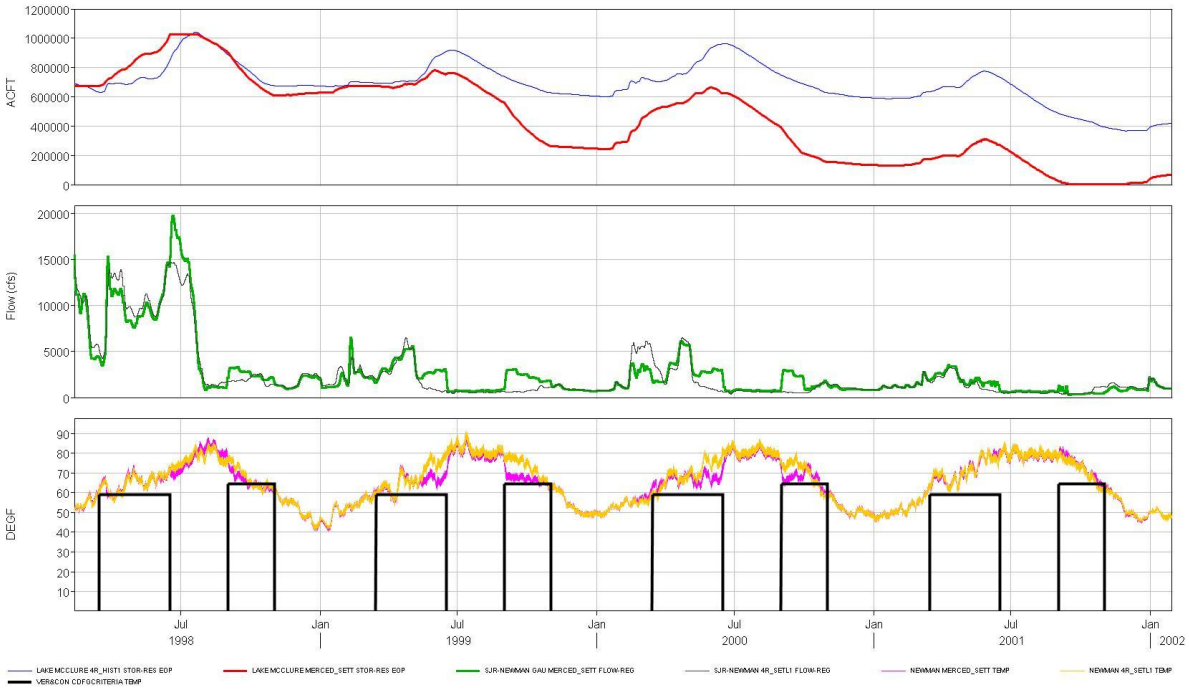


Figure 17 – Lake McClure Storage and Temperature Response at the Merced Confluence for Augmented Releases from the Merced River



5. **Is the SJR Temperature Impaired Even if All the Water in the Basin is Allocated for Fish Release ("All for Fish" case)?**

Assessment of results:

1) *If all the water in the SJR Basin would be allocated for fish release, most the SJR will still be considered temperature impaired, given CDFG temperature criteria and RWQCB impairment threshold.*

The above assessment is supported by the following:

Figure 18 is an example for the Stanislaus River that illustrates the concepts employed for "All for Fish" case: all the diversions are rerouted back to the river and reshaped in accordance with the spring and fall objectives periods, while maintaining the historical storage volumes in New Melones. This concepts was implemented as to all three the tributaries.

Table 4 shows summary results for Case 5. The table shows the RWQCP threshold of exceedances that defines temperature impairment, a number that varies depending on the number of samples. The count of exceedances is then tested against this threshold. If the number of exccedances is greater than the threshold, then by definition, there is temperature impairment.

As shown in the table, except for the Tuolumne and Stanislaus in the fall, in all other locations and periods there is temperature impairment, even if all the water in the SJR basin is allocated for fish release.

Figure 18 – Example of Concepts Employed in the "All for Fish" Case.

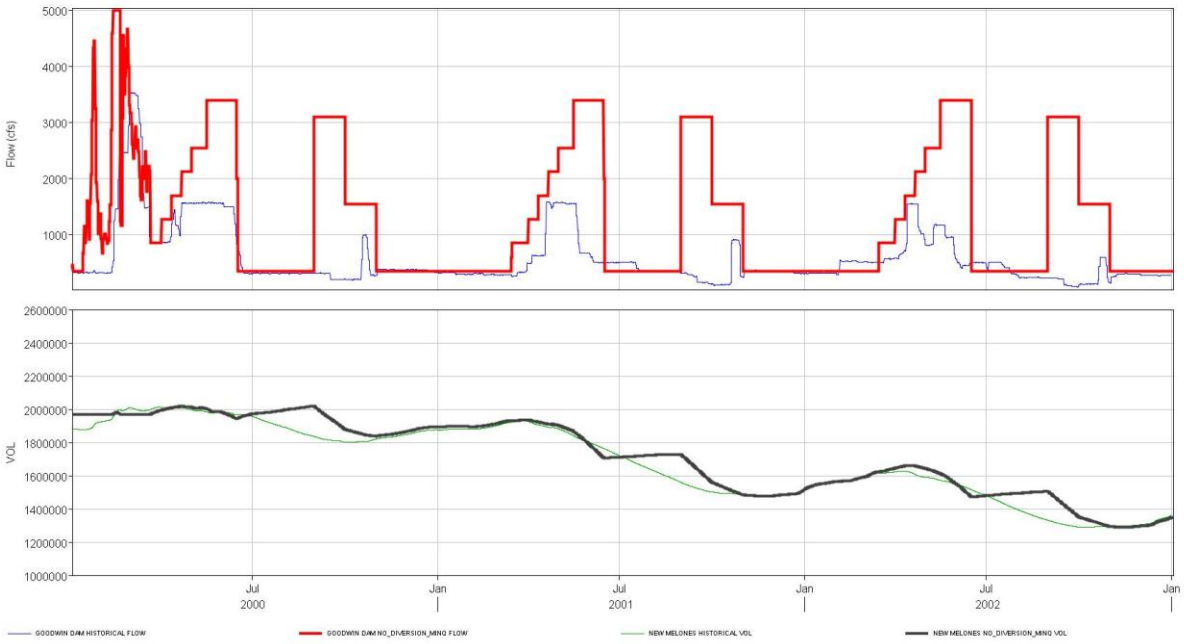


Table 4 – Summary of "All for Fish" case.

Number of samples >>	837	549
Threshold of exceedances for impairment >>	139	92
Counts of Exceedances		
Location	59 F Spring Criteria	64.4 F Fall Criteria
Merced River confluence	729	280
Tuolumne River confluence	410	7
Stanislaus River confluence	523	37
San Joaquin River at Vernalis	743	125

Note:

	Exceeds the threshold that defines impairment