UPPER COLORADO RIVER
DYNAMIC TEMPERATURE MODEL REPORT

WINDY GAP FIRMING PROJECT

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September 2, 2011

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ACRONYMS AND ABBREVIATIONS

AF	Acre-feet
Alt2	Alternative 2 (Windy Gap Firming Project Preferred Alternative)
Alt5	Alternative 5
BOR	Bureau of Reclamation
C-BT	Colorado - Big Thompson
CDOW	Colorado Division of Wildlife
CE	Cumulative Effects
COLSULCO	Colorado River at Hot Sulphur Springs Gage
CWQCD	Colorado Water Quality Control Division
DE	Direct Effects
DEIS	Draft Environmental Impact Statement
DM	Daily Maximum Temperature
DOI	Department of the Interior
EA	Environmental Assessment
EC	Existing Conditions
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
GCWIN	Grand County Water Information Network
HSSRAS	Hot Sulphur Springs Resort and Spa
MAE	Mean Absolute Error
MPWCD	Middle Park Water Conservancy District
MWAT	Maximum Weekly Average Temperature
NA	No Action
NCWCD	Northern Colorado Water Conservancy District
PHABSIM	Physical Habitat Simulation
RMS	River Modeling System
RMSE	Root Mean Square Error
UPCO Study	Upper Colorado River Study

USGS	U.S. Geological Survey
WAT	Weekly Average Temperature
WGFP	Windy Gap Firming Project
WQCD	Water Quality Control Division
WWTP	Wastewater Treatment Plant
WY	Water Year

EXECUTIVE SUMMARY

The Windy Gap Firming Project (WGFP) is a proposed water supply project that would provide more reliable water deliveries to Front Range and West Slope communities and industries to meet current and projected future water demands[1]. Because the WGFP would result in increased diversions and reduced flow in the Colorado River below Windy Gap Reservoir at certain times of the year (primarily in wetter years), an evaluation of the potential effects on river temperature was conducted. This executive summary presents a brief overview of the modeling objects, model development, calibration/validation, and model application findings.

INTRODUCTION AND OBJECTIVES

An analysis of historical river temperature data indicates that the most vulnerable locations, in terms of high water temperatures, in the upper Colorado River that could be affected by the WGFP lie between Windy Gap Reservoir and the Williams Fork confluence; therefore, this is the focus reach for the dynamic temperature model. Figure ES1 shows the Colorado River focus area for the dynamic temperature model.

Figure ES1. Colorado River from Granby Reservoir to Williams Fork.

[1] Extensive discussions of Windy Gap Firming Project objectives and alternatives are presented in the Windy Gap Firming Project Draft Environmental Impact Statement (DEIS; U.S, Department of Interior Bureau of Reclamation [BOR], 2008) and are not duplicated here.

The objective of this modeling effort is to evaluate the potential effects of changes to Windy Gap pumping under the WGFP on river temperatures in the Upper Colorado River. To achieve this, a dynamic temperature model was developed to simulate hourly river temperatures for the period of June through September for a variety of scenarios. This analysis was developed in response to EPA comments on the WGFP DEIS (Draft Envrionmental Impact Statement; BOR, 2008) requesting a dynamic temperature model to replace the DEIS steady-state QUAL2K temperature analysis.

MODEL DEVELOPMENT

River Modeling System (RMS), version 4.5 (Hauser et al., 2008), was used to simulate flow and river temperature in the upper Colorado River. As diagrammed in Figure ES2, RMS integrates two finite difference models. The first is a hydrodynamic model (ADYN) that relies on conservation of mass and momentum equations. ADYN inputs include user-specified cross-section geometry, initial conditions, inflows and other boundary conditions. The second (RQUAL) is a water-quality model that simulates water temperature using hydrodynamic output from ADYN and a physically-based heat budget. Inputs to RQUAL include meteorology, inflow temperatures, and various parameters and coefficients.

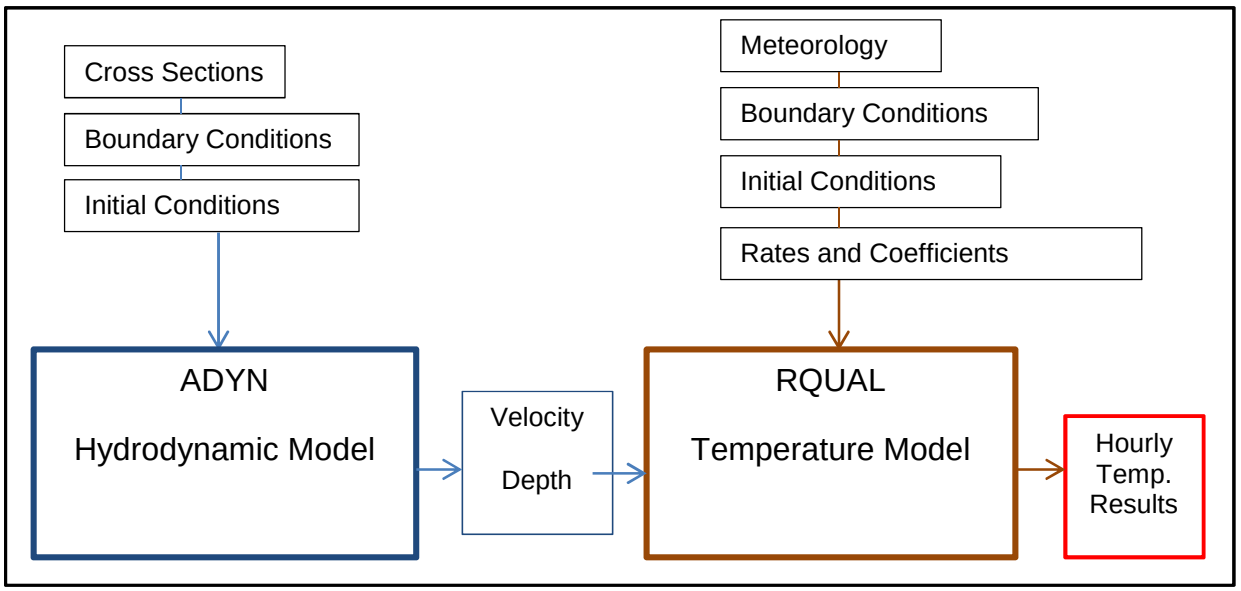

Figure ES2. Diagram of RMS Modeling System.

In choosing the specific year for calibration, several criteria were reviewed, including:

1) Availability of adequate meteorological, flow rate, and river temperature data,
2) Existence of elevated river temperatures including standard exceedances, and
3) Variation in observed water temperatures to test the model's ability to capture changes.

Based on this information, the calibration year was chosen to be 2007. Average temperatures in July and August were very warm relative to the other 62 years of record in the area. Specifically, July and August average temperatures were in the 95th and 98th percentile of the

distribution, with August 2007 being the hottest August on record. In consultation with the EPA, 2008 was selected as the validation year to test the model under a different range of flow rates and meteorological conditions.

CALIBRATION AND VALIDATION

The model was calibrated to observed data for the period of June 1, 2007 through September 30, 2007, and the model was validated against observed data for the period of June 1, 2008 to September 30, 2008.

Calibration targets were developed in consultation with EPA. These calibration targets were set in advance of model development to provide a predetermined framework with which to evaluate whether the model adequately simulates the system for the intended application. Simulated temperature data are assessed graphically against observed data to visually compare overall patterns of seasonal trends, diurnal shapes, and amplitudes. Residuals were also plotted to evaluate any bias or trending in simulated results. Additionally, daily mean, maximum, and minimum temperatures were evaluated for root mean square error (RMSE) values and mean average (MAE) errors.

The model met all calibration targets. Simulated hourly temperatures capture overall seasonal temperature patterns and amplitudes, including meteorologically-driven shifts. Diurnal ranges and patterns are also well simulated. RMSE and MAE values for daily averages, daily maximums, and daily minimums were below the target maximum error values at all five evaluation gages. Additionally, R^2 values for the correlation between observed and simulated temperatures were between 0.85 and 0.98 for the gages between Windy Gap Reservoir and Williams Fork. Finally, plots of residuals show no trends with space, time, or temperature-values, suggesting no major progressive or systematic errors. An example of one month of the hourly calibration results compared to observe results is shown in Figure ES3 (August 2007 values at CR-HSU, the thermistor location just upstream of Hot Sulphur Springs, which is a little more than half-way downstream from Windy Gap to Williams Fork on Figure ES1). Based on these good calibration results the model was further tested through a validation run.

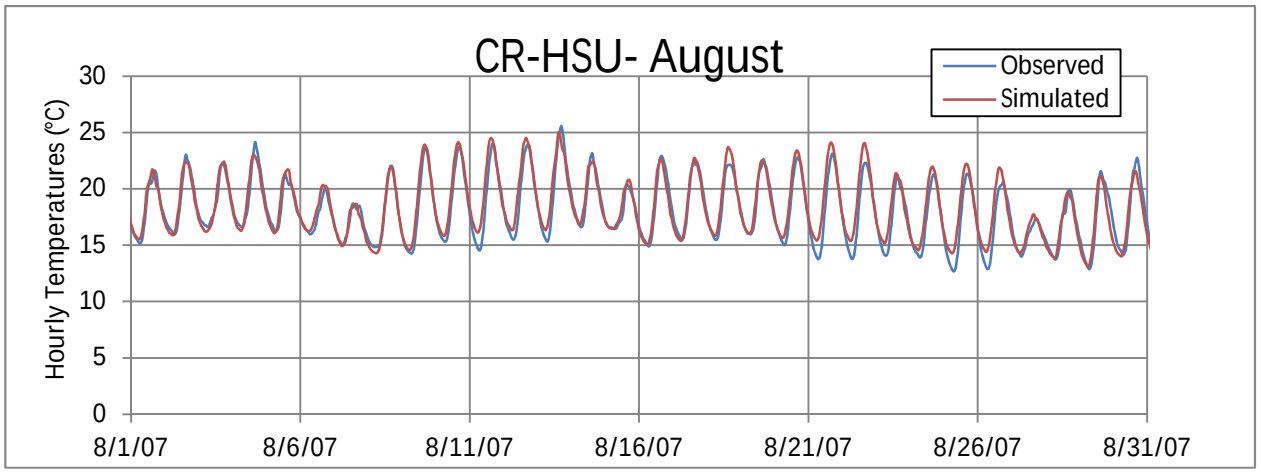

Figure ES3. Observed Data and Calibration-Simulated Results at CR-HSU in August.

The 2008 validation run of the model also met all calibration targets. Simulated hourly temperatures capture overall seasonal temperature patterns and amplitudes, including meteorologically-driven shifts. Diurnal ranges and patterns are also well simulated. RMSE and MAE values for daily averages, daily maximums, and daily minimums were below the target maximum error values at all six evaluation gages[2]. Additionally, R^2 values for observed and simulated temperatures were between 0.81 and 0.97 for gages between Windy Gap Reservoir and Williams Fork. Finally, plots of residuals show no trends with space, time, or temperature-values, suggesting no major progressive or systematic errors. An example month of the hourly validation results compared to observe results is shown in Figure ES4 (August 2008 values at the CR-HSU). Based on these good validation results, the model was used to simulate hourly river temperatures for this reach of the upper Colorado River from June through September for comparison of the alternatives.

[2] There were six review gages for validation, but only five for calibration. CR-HRU was available for evaluation of 2008 validation data; however, no data were available at this location for 2007 calibration review.

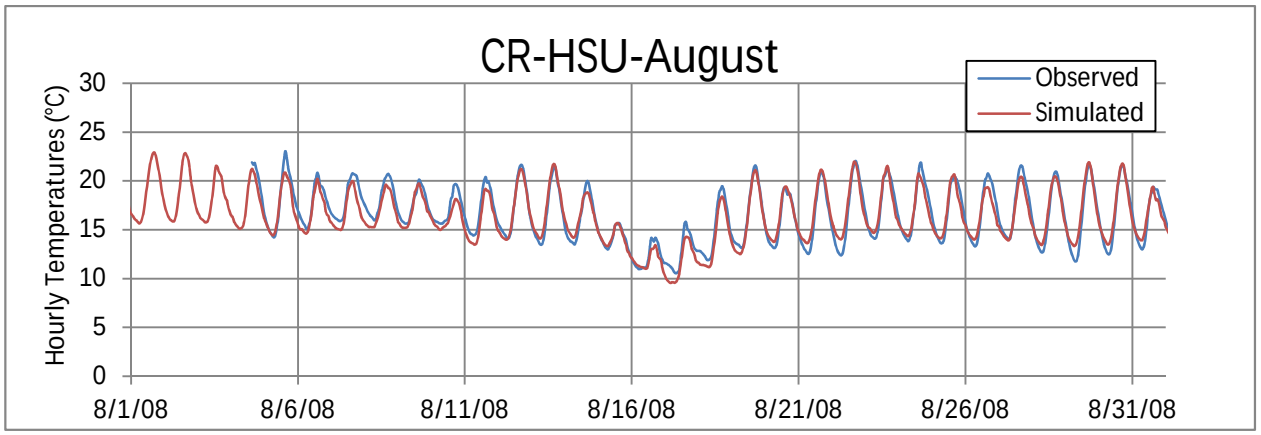

Figure ES4. Observed Data and Validation-Simulated Results at CR-HSU in August.

MODEL APPLICATION

The calibrated and validated dynamic temperature model for the upper Colorado River was applied to evaluate the potential effects on river temperatures of the proposed action alternative (Alt2) relative to no action and existing conditions. Alternative 5 (Alt5) was also evaluated to provide some insight on the potential temperature effects of the other WGFP DEIS alternatives. In agreement with EPA, the analysis focused on five key years of simulated daily hydrology (1975, 1979, 1986, 1987, and 1988), applying 2007 meteorology to all simulations. These five years represent the only years in the 15-year simulated daily hydrology that are expected to exhibit possible river temperature increases due to the proposed alternative. Other years in the five year period either exhibit no differences in pumping from Windy Gap or have very high flow rates during critical months and would not be expected to have temperature concerns. Daily hydrologic model results from the Windy Gap Firming Project Hydrologic Model, including diversions and gains/losses, provided the input hydrology. The 2007 meteorology was selected because it was one of the warmest years in the 63 years of temperature record. Specifically, July was the 6th hottest in the 62 years of record for that month (1949-2010), and August 2007 was the hottest in the 63 years of record for that month (1948-2010).

Both direct effects and cumulative effects were simulated. Direct effects and cumulative effects alternatives and assumptions are described in detail in the WGFP DEIS (BOR, 2008). In addition to cumulative effects detailed in the DEIS, cumulative effects also include '5412 Releases' as described in the 10825 Environmental Assessment (BOR, 2011). The matrix of the 30 model application simulations for the dynamic temperature model is shown in Table ES1. In addition to these 30 simulations, an additional set of cumulative effects simulations was performed for 1975 conditions of no action and Alt2, applying a different schedule for 5412 releases from that presented in the 10825 Environmental Assessment. The purpose of these additional simulations was to provide insight into the possible temperature benefits of an earlier start to 5412 releases.

Table ES1. Matrix of Model Application Runs with 2007 Meteorology.

		1975	1979	1986	1987	1988
Existing Conditions		✓	✓	✓	✓	✓
Direct Effects	Proposed Action (Alt2)	✓	✓	✓	✓	✓
	No Action	✓	✓	✓	✓	✓
	Alt 5	✓	✓	✓	✓	✓
Cumulative Effects	Proposed Action (Alt2)	✓	✓	✓	✓	✓
	No Action	✓	✓	✓	✓	✓

FINDINGS

In general, as expected, the largest simulated temperature increases are associated with the largest pumping differences at times of relatively lower river flow rates in the warmest months of the year (July and August). Further, hourly temperature simulation results show that the reduction in flow rates (and corresponding river stage) result in greater relative increase in the upper range of daily temperatures (during daylight hours), with only small changes in evening temperatures. This pattern is apparent across all simulation results, reflecting the strong influence of water depth on heating by solar radiation, which only occurs during daylight hours.

Overall, direct effects model results indicate that increased pumping for Alt2 would increase regulatory exceedances of chronic and acute temperature standards in July and/or August for four years out of the fifteen year period considered in the water quality DEIS evaluations (1975-1989). For cumulative effects, the increase in regulatory exceedances is limited to three years out of the fifteen year period. No exceedances were simulated for any scenario or year in June or September. It should be noted that the applicationof 2007 meteorology to all simulations would produce higher river temperatures and more exceedances than would be simulated with application of a more average year of meteorology, since July 2007 and August 2007 were among the hottest in the 63 years of air temperature record in the area.

For direct effects, simulated annual increases in chronic exceedances for Alt2 were as high as three additional weeks above the WAT standard relative to existing conditions and two additional weeks relative to no action. Simulated annual increases in acute exceedances for Alt2 were as high as seven additional days above the DM standard relative to existing conditions and three additional days relative to no action. Results for Alt5 were nearly identical to those for Alt2 due to very similar Windy Gap pumping patterns in the simulated years.

For cumulative effects, simulated annual increases in chronic exceedances were as high as three additional weeks above the WAT standard relative to existing conditions and two additional week relative to no action. Simulated annual increases in acute exceedances were as high as four additional days above the DM standard relative to existing conditions and four additional days relative to no action. The 10825 Project which would release 5412 acre-ft (AF) from Granby

Reservoir, starting on August 1 for cumulative effects simulations sharply reduced river temperatures and exceedances in August. The 1975 simulation of an earlier release schedule for 5412 releases from Granby Reservoir (July 15 start instead of Aug1 start) produced noteworthy results. July river temperatures were cooler under the earlier release data, resulting in fewer exceedances in July. A July start date for 5412 releases would also be expected to reduce exceedances in other simulated years.

1 INTRODUCTION

The Windy Gap Firming Project (WGFP) is a proposed water supply project that would provide more reliable water deliveries to Front Range and West Slope communities and industries to meet current and projected future water demands[3]. Because the WGFP would result in increased diversions and reduced flow in the Colorado River below Windy Gap Reservoir (primarily in wetter years), an evaluation of the potential effects on river temperature was conducted. This report presents the development and findings of a dynamic temperature model[4] developed to assess the potential effects of the WGFP on river temperatures in the upper Colorado River. This report presents model development, calibration, validation, and model application results.

1.1 SETTING

Map 1 shows the focus area for the dynamic temperature model. The Windy Gap Project currently diverts water from the Colorado River just downstream of the confluence of the Colorado and Fraser Rivers at Windy Gap Reservoir, and proposed additional WGFP diversions would occur at the same location. Above Windy Gap, the Colorado River flows out of Granby Reservoir and receives flow from Willow Creek. Below Windy Gap Reservoir, flows from Williams Fork reservoir serve to cool river temperatures (discussed in greater detail in Section 2.2.2). The reach also contains irrigation and municipal water rights diversions. The Hot Sulphur Springs wastewater treatment plant (WWTP) discharges to the river in this reach, as does the Hot Sulphur Springs Resort. The river runs along local alluvial aquifers and receives groundwater gains and return flows during portions of the year. Daily river and tributary flow records are available at the locations shown on Map 2.

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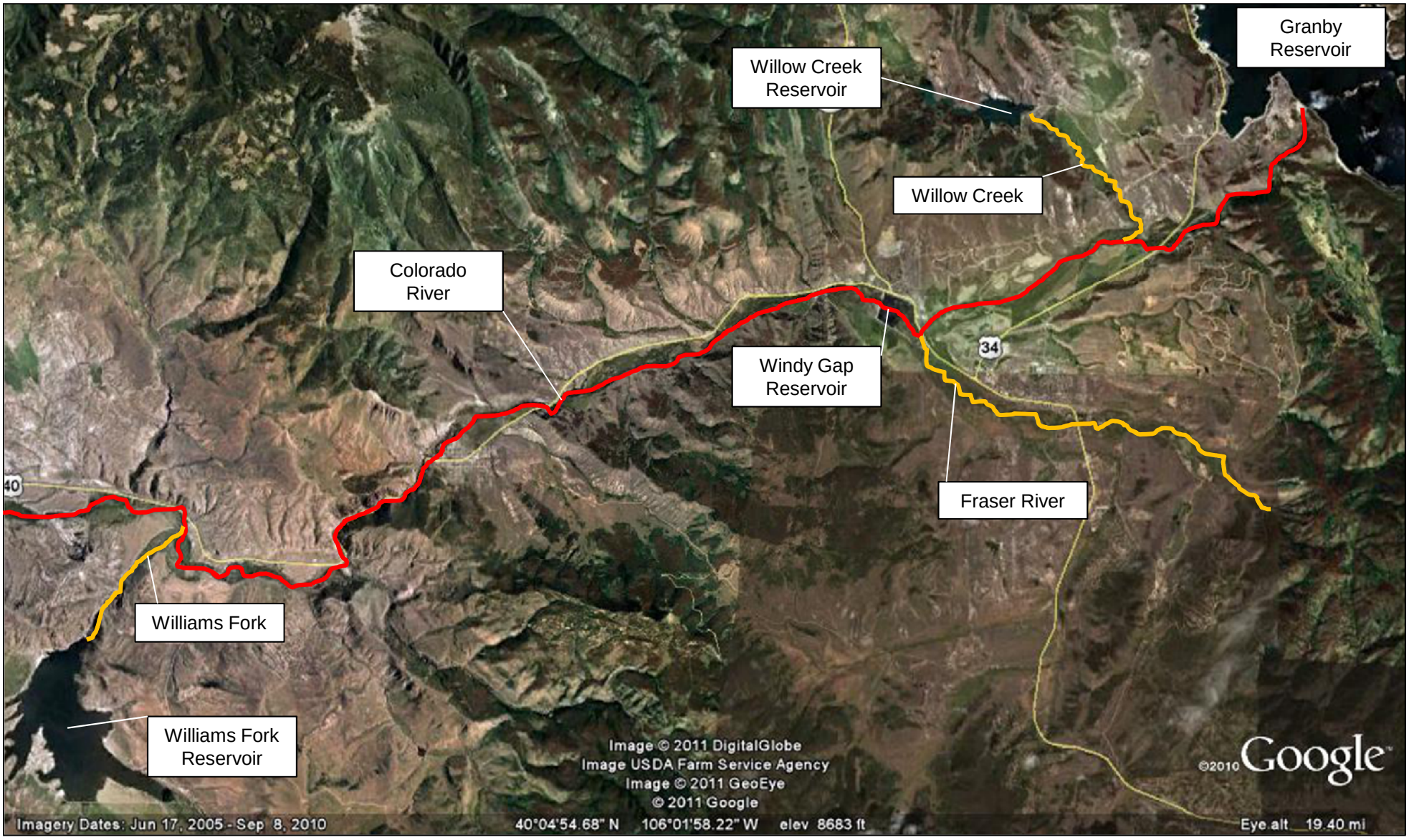
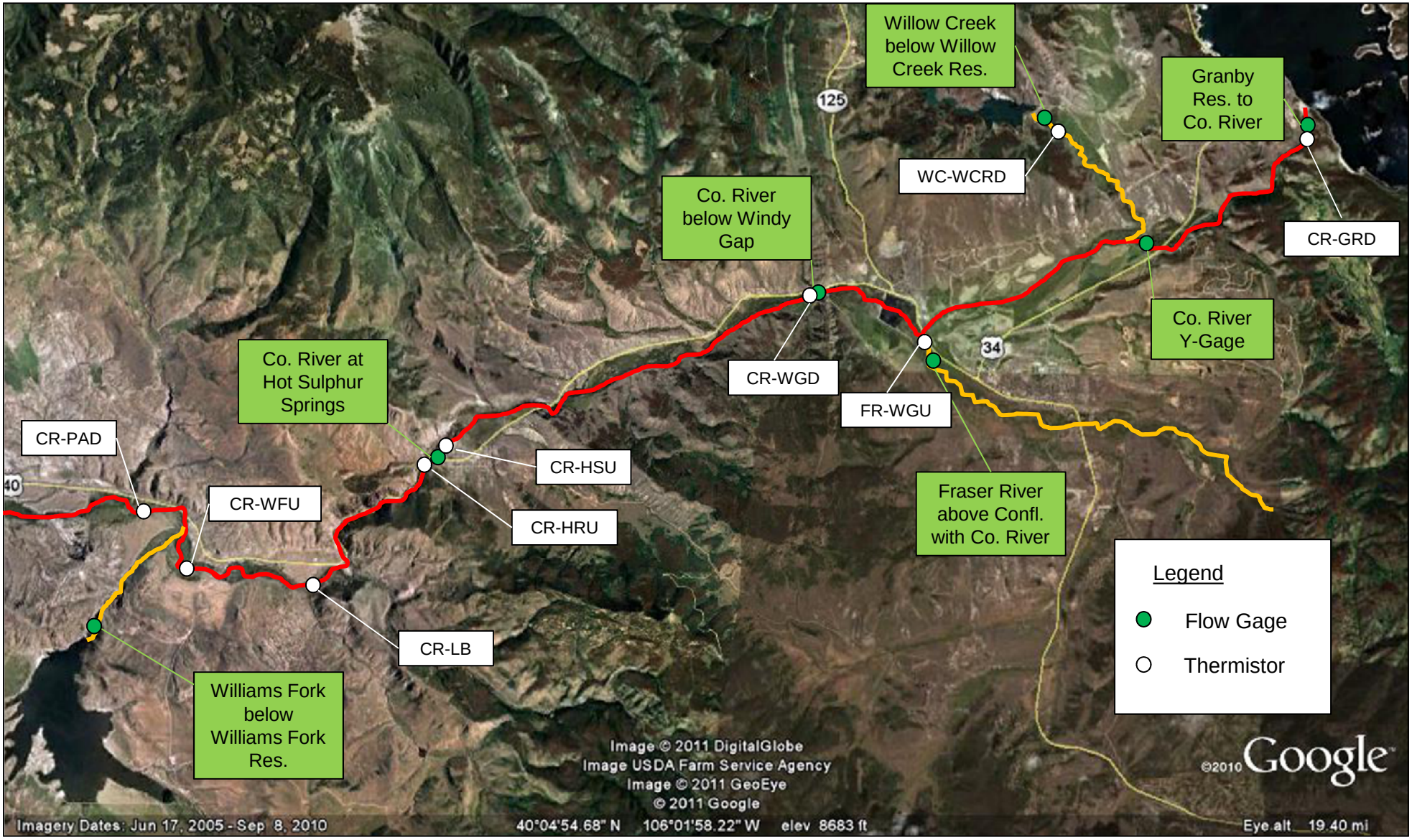
[3] Extensive discussions of Windy Gap Firming Project objectives and alternatives are presented in the Windy Gap Firming Project Draft Environmental Impact Statement (DEIS; U.S, Department of Interior Bureau of Reclamation [BOR], 2008) and are not duplicated here.

[4] Previously, to evaluate temperature mitigation strategies, a single day temperature analysis, applying QUAL2K (AMEC and ERO Resources, 2008) was developed to evaluate the temperature effects of the alternatives. This dynamic temperature model was developed to more thoroughly evaluate the effects of WGFP EIS alternatives on river temperatures.



Map 1
Dynamic Temperature Model Site Map



Map 2
Dynamic Temperature Model Flow Gages and Thermistors

Along this reach, the Colorado River is generally fairly wide (approximately 80 to >130 ft during spring and summer, excluding Byer's Canyon) and meandering, with some areas of braiding (below Windy Gap Reservoir) and occasional small islands. Google Earth® imagery from 2005 and 2007 shows riparian vegetation along the reach, varying in density. Below Hot Sulphur Springs, the river enters Byer's Canyon, a granitic formation that covers more than two river miles, where the river width narrows.

The river temperatures have been fairly consistently monitored in summer months across this reach since 2007 at the locations indicated on Map 2. These thermistors are operated by Grand County Water Information Network (GCWIN) and/or Northern Colorado Water Conservancy District (NCWCD). Thermistor data are collected at intervals ranging from 20 minutes to hourly. River temperature records show relatively large diurnal ranges in the summer (e.g., >10°C at CR-HSU in 2007). Generally, river temperatures steadily increase below Windy Gap Reservoir, with the highest daily maximum temperatures (DMs) often observed at CR-HSU and the highest weekly average temperatures (WATs) observed above Williams Fork (at CR-WFU) before temperatures are cooled by Williams Fork inflows. Observed data used in the model are discussed in detail in Section 2.2.

1.2 MODELING OBJECTIVES

The objective of this modeling effort is to evaluate the potential effects of changes to Windy Gap pumping protocols on river temperatures in the Upper Colorado River. To achieve this, the model must be able to simulate hourly river temperatures below the Windy Gap Reservoir in response to meteorological inputs and varying inflow rates and temperatures. The modeling should focus on the most temperature-sensitive reach of the upper Colorado River that could be affected by the proposed alternative. Further, the modeling should simulate the most sensitive season in terms of river temperatures.

The model will be used to assess differences in river temperatures for the following hydrologic scenarios, which are discussed later in this report (Section 4) and described in detail in the WGFP DEIS (U.S. DOI BOR, 2008):

- Existing Conditions.
- Direct Effects
    - No Action,
    - Alternative 2 (also referred to as Alt2 and the proposed alternative), and
    - Alternative 5.

- Cumulative Effects
  - No Action, and
  - Alternative 2.

For both direct effects and cumulative effects, simulation results for the alternatives will be assessed relative to the no action alternative and existing conditions. Results will be evaluated in terms of WATs and DMs in accordance with the applicable regulatory protocols for assessing river temperatures described in Colorado Water Quality Control Commission Regulations 31 and 33 (WQCD, 2010a and 2010b).

1.3 REPORT ORGANIZATION

This report is organized into six main text sections, with two appendices presenting supporting figures. The main report is organized as follows:

- Section 1 is the introductory section.
- Section 2 presents the modeling software and model development, including data sources.
- Section 3 presents the calibration and validation of the model.
- Section 4 presents the results of application of the model to assess the potential effects of WGFP on river temperatures.
- Section 5 summarizes the findings.
- Section 6 provides references cited.

The supporting appendices are organized as follows:

- Appendix A presents monthly plots of observed and simulated hourly temperatures plots for the 2007 calibration simulation. Only plots not presented in Section 3 are included in this appendix, and only months with observed data are included.
- Appendix B presents monthly plots of observed and simulated hourly temperatures plots for the 2008 validation simulation. Only plots not presented in Section 3 are included in this appendix, and only months with observed data are included.

2 MODEL DEVELOPMENT

To meet the modeling objectives described in Section 1.2, a water-quality model linked to a hydrodynamic model was developed. The following subsections describe the modeling software applied and the general modeling approach, including the geographic extent, the periods of simulation, and the input data sources.

2.1 MODELING SOFTWARE

River Modeling System (RMS), version 4.5 (Hauser et al., 2008), was used to simulate flow and river temperature in the upper Colorado River. RMS integrates two one-dimensional, longitudinal, dynamic, finite difference models. The first is a hydrodynamic model (ADYN) that simulates the hydrodynamics of free-surface water flow in open channels using conservation of mass and momentum equations. ADYN inputs include user-specified cross-section geometry, inflows and other boundary conditions. The second (RQUAL) is a water-quality model that simulates water temperature and uses the simulated hydrodynamics from the ADYN model. Water temperature is modeled in RQUAL with a physically-based heat budget representation, including net heat exchange at the air-water and bed-water interfaces. Inputs to RQUAL include meteorology, inflow temperatures, and various parameters and coefficients. Both ADYN and RQUAL were developed by staff at the Tennessee Valley Authority and have been used for numerous applications around the country (e.g., Bender et al., 2007; Null et al., 2010; FTN Associates, 2009; and Deas, 2005). Governing equations, model formulation, and applications are described in Hauser et al. (2007).

2.2 MODELING APPROACH

The first step to develop a tool to meet the modeling objectives described in Section 1.2 was to review available flow and river temperature data on the upper Colorado River and major tributaries to develop a conceptual understanding of system. From this conceptual understanding, the appropriate seasonal period of the modeling and geographic extent were defined. The model was then constructed using all available and relevant input data and calibrated to the chosen period of record. Validation was completed by running the calibrated model for a different period of observed record and comparing simulated and observed results. Following calibration and validation, the model was applied to evaluate the potential effects on river temperatures of select alternatives in the WGFP DEIS (U.S. DOI BOR, 2008).

The basis for selection of the periods of simulation and the geographic extent covered by the model is outlined in the following subsections. Model data input sources are also presented. Calibration and validation results are presented in Section 3, and model application results are presented in Section 4.

2.2.1 Period of Simulation

Gage records indicate that the warmest temperatures occur in the focus reach of the upper Colorado River during the months of July and August. In order to fully encompass this period, all simulations start one month before (June 1) and end one month after (September 30) this critical period. Thus, the portion of the year simulated in each model run is June 1 – September 30.

In choosing the specific year for calibration, several criteria were reviewed, including:

1) Availability of adequate meteorological, flow rate, and river temperature data,
2) Existence of elevated river temperatures including standard exceedances, and
3) Variation in observed water temperatures to test the model's ability to capture changes.

The dynamic temperature model requires meteorological data on an hourly basis. These data exist for the area starting in 2005. Therefore, the years 2005-2010 were considered in selection of the model calibration year. In this period, the year with the highest number of river temperature standard exceedances (acute and chronic) is 2007. This makes sense given that the warmest air temperatures (Figure 1 and Figure 2) and lowest flow rates (Figure 3) also occurred in that year. In addition, there is some variability in water temperatures during the summer of 2007 (Figure 4) to test the predictive capabilities of the model. Based on this information, the calibration year was chosen to be 2007.

For perspective, 2007 July and August temperatures were assessed against the long term temperature record using the data from the Grand Lake Weather Station 6SSW[5] (full record covers 1948-2010). Minimum and maximum daily temperatures were used to calculate average monthly values for July and August of each year. Results show that July 2007 was the 6th hottest in the 62 years of record for that month (1949-2010), corresponding to the 95th percentile based

[5] The Grand Lake Weather station was used for this analysis because it had the most complete long-term records in the vicinity. The station is located just north of Granby Reservoir, between Shadow Mountain Reservoir and Granby Reservoir. Data from the Grand Lake Weather Station track well with data from the Kremmling airport, with an R^2 value 0.94 in a linear correlation. As such, patterns in this data set are expected to be applicable to the focus area from Windy Gap to Williams Fork.

on the statistical analysis[6]. The 2007 average July temperature was 1.6°C warmer than the 62 year average. August 2007 was the hottest in the 63 years of record for that month (1948-2010), corresponding to the 98th percentile based on the statistical analysis. The 2007 average August temperature was 2.0°C warmer than the 63 year average.

In consultation with the EPA, 2008 was selected as the validation year to test the model under a different range of flow rates and meteorological conditions.

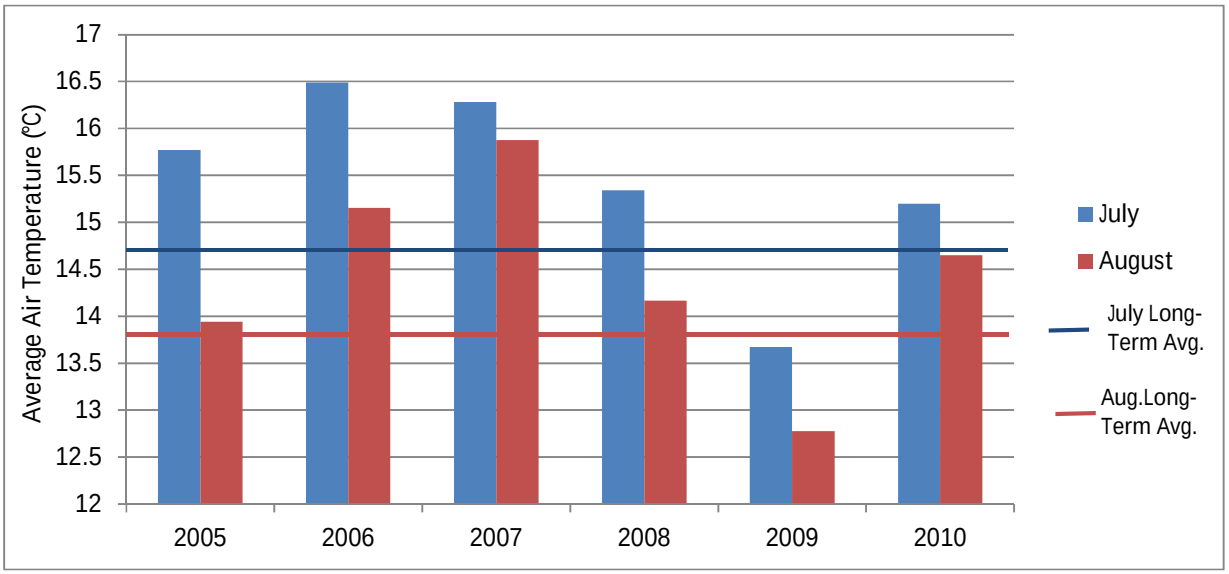


Figure 1. Mean Monthly Air Temperature at Grand Lake Weather Station.

[6] Quantile-quantile plots were developed to determine that the data fit a normal distribution, and percentile values are based on assessment of the calculated standard deviations.

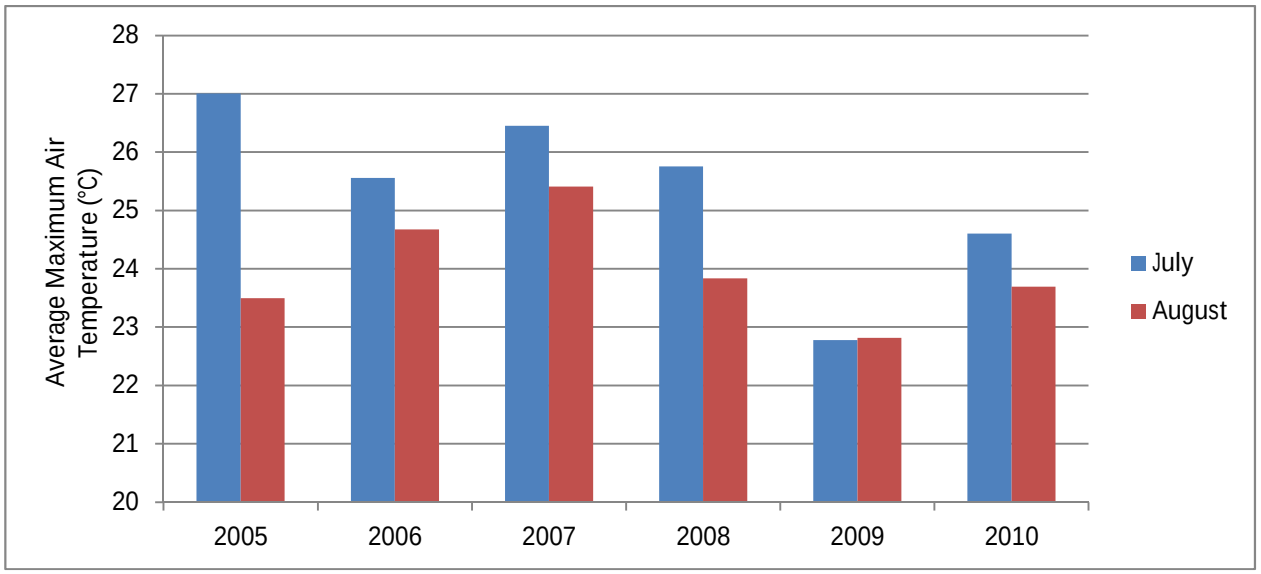


Figure 2. Average Maximum Air Temperatures at Grand Lake Weather Station.

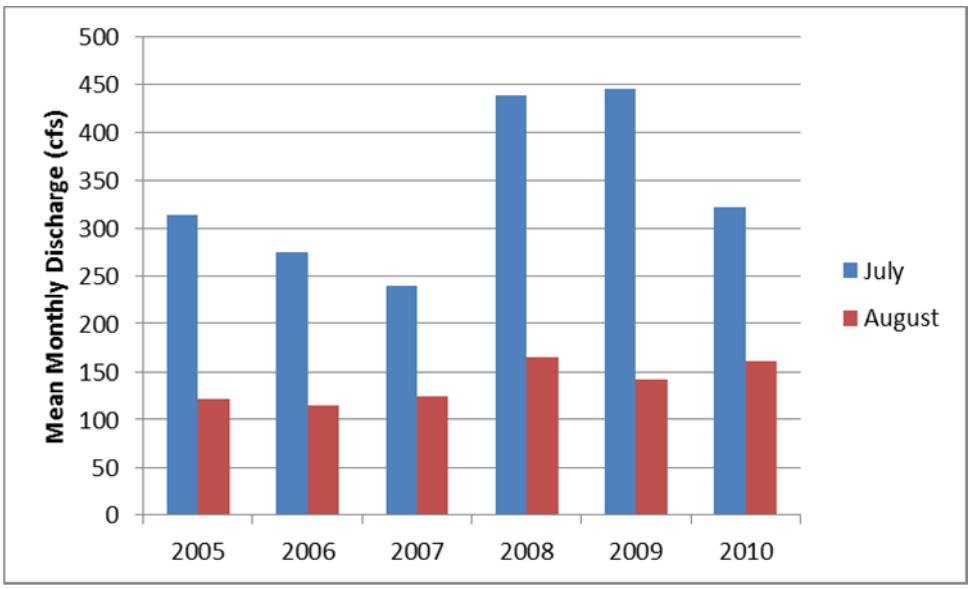


Figure 3. Mean Monthly Discharge at USGS Site 09034250.
Source: USGS NWIS Database

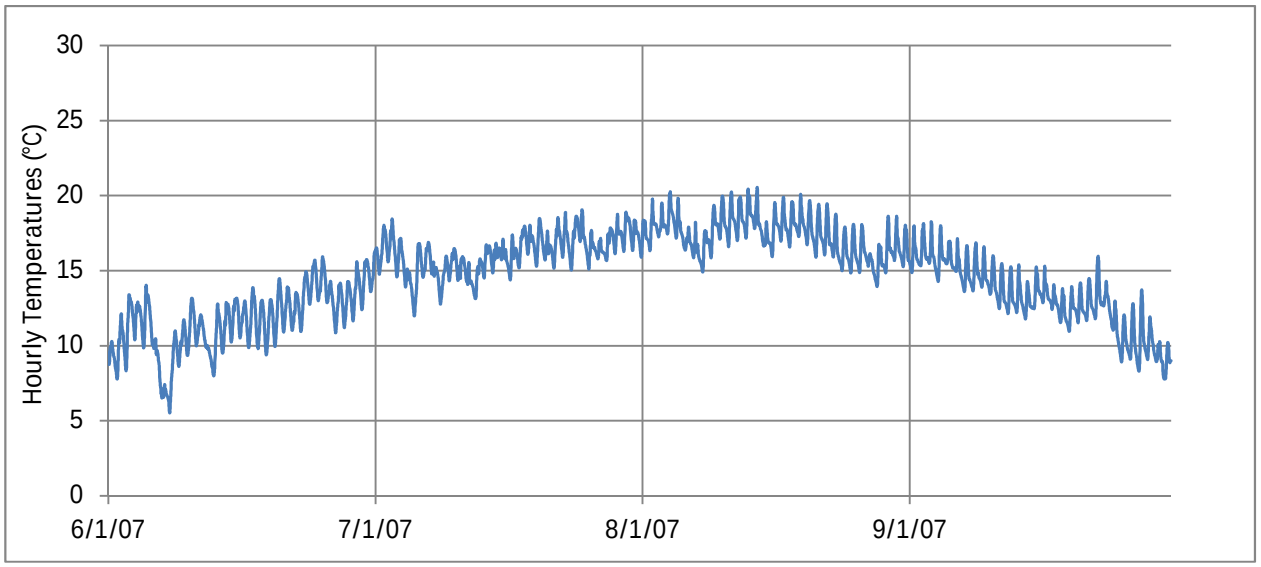


Figure 4. Water Temperatures in the Colorado River, 1-Mile Downstream from Windy Gap at the USGS Flow Gage.

Source: GCWIN Database; http://wilbur.gcwin.org/

2.2.2 Geographic Extent

An analysis of historical river temperature data indicates that the most vulnerable locations, in terms of high water temperatures, in the upper Colorado River that could be affected by the WGFP lie between Windy Gap Reservoir and the Williams Fork confluence. Figure 5 presents ranges of observed average daily temperatures from Granby Reservoir (~RM 44) to Kremmling (RM 0) for the hottest period of thermistor record, June through September of 2007. Flows from Williams Fork (~RM 20), originating from Williams Fork Reservoir, serve to cool the river. Although there is some temperature increase in the Colorado River between the Williams Fork confluence and the Blue River confluence (~RM 17), temperatures are generally lower below the Williams Fork confluence. In addition, due to the lack of adequate data in the reach below the Williams Fork confluence, hydrologic inputs are more uncertain in that reach (H. Thompson, personal communication). Thus, the model focuses on the approximately 24 miles of the Colorado River from Granby Reservoir to just downstream of the confluence with the Williams Fork. Map 1 presents this reach of the upper Colorado River, as well as major tributaries included in the model: Willow Creek, Fraser River, and Williams Fork.

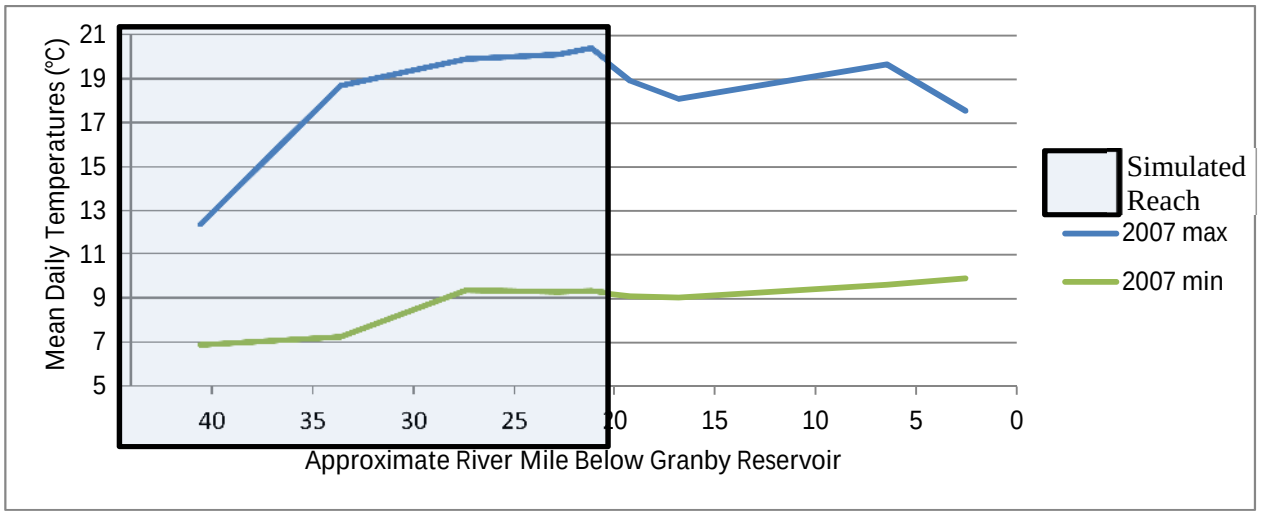


Figure 5. 2007 Range of Observed Daily Average Temperatures from Granby Reservoir to Kremmling.

2.2.3 Model Input Data Sources

Input data required by the model includes hydrology (inflows and outflows), river structure (cross-sections and thalweg elevations), meteorology, and temperature boundary conditions (temperatures of inflows). The following sections present the sources of these inputs.

2.2.3.1 Hydrologic Data

Hydrologic input data to the model for calibration and validation included flows from Granby Reservoir, three major tributary inflows (Willow Creek, Fraser River, and Williams Fork), 29 diversions, Windy Gap pumping, Hot Sulphur Springs wastewater treatment plant discharge, Hot Sulphur Springs Resort flows, and gains/losses across four sub-reaches. These data were obtained from the following sources:

- Granby Reservoir discharge - United States Bureau of Reclamation, Western Division Water and Power System, Water and Power Control Division, Loveland, Colorado
- Willow Creek below Willow Creek Reservoir – USGS gage 09021000
- Fraser River near Granby – Northern Colorado Water Conservancy District (NCWCD; http://www.ncwcd.org/datareports/westflow.asp)
- Williams Fork below Williams Fork Reservoir- USGS Gage 9038500
- Diversion data – NCWCD (provided by K. Rademacher, 4/8/2011)
- Windy Gap pumping records - United States Bureau of Reclamation, Western Division Water and Power System, Water and Power Control Division, Loveland, Colorado

- Hot Sulphur Springs WWTP monthly discharge —Windy Gap Firming Project Hydrologic Model (monthly average estimates generated by Denver water and provided by H. Thompson from the Upper Colorado River [UPCO] Study)
- Hot Sulphur Springs Resort flows (8,000 gal/day) - HSSRAS (2007)
- Gains/Losses – Mass balance across sub-reaches.

The following hydrology data were not direct inputs into the model but were used in conceptual model development and model performance evaluation:

- Colorado River Near Granby (Y-Gage)– USGS Gage 09019500
- Colorado River at Windy Gap– USGS Gage 09034250
- Colorado River near Parshall – NCWCD (http://www.ncwcd.org/datareports/westflow.asp)

Gages used in model development and evaluation are shown on Map 2.

For model application runs; observed hydrology data do not exist. The source of all daily hydrologic inputs for the model application runs was the Windy Gap Firming Project Hydrologic Model (described in Thompson, 2011). Model application run inputs and assumptions are discussed in greater detail in Section 4.

2.2.3.2 Cross-Section Geometry

User-specified cross-section geometry input provides the river slopes and structure to the ADYN model. A total of 50 Colorado River cross-sections were input into the ADYN model from Granby Reservoir to just below Williams Fork. These cross-sections came from the following sources:

- 44 cross-sections were obtained from ERO Resources. These cross-sections contained thalweg elevations, bottom widths, and side slopes. The cross-sections were evenly distributed over the full study reach.
- Three cross sections for the Windy Gap Reservoir were estimated from the Dam Reservoir Area Plan bathymetry.
- Two cross-sections, located ~1.25 miles downstream of the CR-WGD thermistor location, were provided by Tetra Tech. These detailed cross-sections were collected in 2008 for a PHABSIM (Physical Habitat Simulation) study by Walsh Aquatic Consultants under contract to Tetra Tech for Grand County.
- One detailed cross-section, located near the CR-LB thermistor, was taken from the Grand County Stream Management Plan, April 2008, Stream Reach Summary CR4-7.

The Windy Gap dam was simulated as a weir in the ADYN model, matching dimension of the spillway block flow structure. Additionally, USGS stage-discharge relationships from the following gages were used for model performance assessment:

- USGS gage Colorado at Windy Gap (9034250), and
- USGS gage Colorado at Hot Sulphur Springs (9034500).

2.2.3.3 Meteorology

The model uses hourly air temperature, dew point temperature, wind speed, cloud cover, and solar radiation data. Hourly meteorological data were obtained from the Northern Colorado Water Conservancy District Irrigation Management Service weather station near Windy Gap, Colorado. Data were available for all input parameters except cloud cover, which was taken from the weather station at the Kremmling airport (MesoWest station K20V, Kremmling, Colorado). Dew point was calculated from observed dry bulb air temperatures and relative humidity (see http://en.wikipedia.org/wiki/Dew_point for method details). Meteorologic input data sets were developed from these data sources for the periods of June 2007 through September 2007 and June 2008 through September 2008 to support calibration, validation, and model simulations.

For June 2007 through September 2007, air temperatures range from -6.26°C to 30.69°C. Dew point temperatures ranged from -10.02°C to 18.57°C. Wind speed varied between 0.04 and 6.7 m/s. Cloud cover ranged from 0 to 100%, and solar radiation values ranged from 0 to 939 Kcal/m^2/hr. For June 2008 through September 2008, air temperatures ranged from -4.75°C to 30.12°C. Dew point temperatures ranged from -13.53°C to 13.12°C. Wind speed varied between 0.02 and 7.2 m/s. Cloud cover ranged from 0 to 100%, and solar radiation values ranges from 0 to 975 Kcal/m^2/hr.

2.2.3.4 Temperature Boundary Conditions

The RQUAL model requires time series temperature inputs as boundary conditions for all inflows to the model. For this model, temperature inputs are needed for the upstream inflow boundary (Granby Reservoir discharge), the three inflow tributaries (Willow Creek, Fraser River, and Williams Fork), the HSS WWTP discharge, the HSS Resort discharge, and gains.

For the calibration and validation simulations, observed hourly or sub-hourly temperature records from the following locations were used as model input:

- Discharge from Granby Reservoir – NCWCD thermistor CR-GRD, location: Colorado River downstream of Granby Reservoir at flume
- Fraser River – Grand County water Information Network (GCWIN) thermistor FR-WGU (aka FR-abvCOR), location: Fraser River above confluence with Colorado River

Though not direct input, gage data from the following thermistors were also used in conceptual model development and model performance evaluation:

- CR-YGAGE – NCWCD, location: Colorado River downstream of YMCS flow gage
- WC-WCRD – NCWCD, location: Willow Creek downstream of Willow Creek Reservoir
- CR-WGD – NCWCD, location: Colorado River 1 mi downstream of Windy Gap at USGS flow gage
- CR-HSU – GCWIN (aka COR-abvHSS), location: Colorado River above Hot Sulphur Springs Water Treatment Plant
- CR-HRU – GCWIN (aka COR-abvHSR), location: Colorado River above Hot Sulphur Springs Resort
- CR-LB – GCWIN (aka COR-LoneBuck), location: Colorado River at Lone Buck below Colorado Division of Wildlife (CDOW) Office
- CR-WFU – NCWCD, location: Colorado River upstream of confluence with Williams Fork
- CR-PAD – GCWIN (aka COR-abvKidPond), location: Colorado River above Kids Pond below Parshall CO
- CR-CON – GCWIN (aka COR-ConRitschard), location: Colorado River at Public Access East of Con Ritschard Ranch, 3 mi downstream of Parshall
- CR-BLU - GCWIN (aka COR-Hwy9), location: Colorado River above Hwy 9 Bridge at Kremmling CO, 2.3 miles upstream of Blue River
- CR-BLD – USGS gage 9058000, location: Colorado River downstream of the Blue River near Kremmling

Willow Creek temperatures were available from a thermistor located just below the Willow Creek Reservoir (WC-WCRD); however, these temperatures were not considered good estimates of Willow Creek temperatures ~3.5 miles downstream where Willow Creek joins the Colorado River. Because the upstream Willow Creek temperatures closely trace temperatures of flows from Granby reservoir, temperatures from the GCWIN Y-gage thermistor were applied to Willow Creek tributary inflow temperatures. Y-gage is ~3.1 miles downstream from the Granby Reservoir dam.

There is no thermistor on Williams Fork. A two-step approach was taken to develop hourly temperature data input for Williams Fork. First, a heat-balance solution was developed by applying known flows from Williams Fork and known flows and temperatures upstream (CR-WFU) and downstream (CR-PAD) of Williams Fork on the Colorado River. This heat balance was used to solve for Williams Fork inflow temperatures for dates with temperature records at both CR-WFU and CR-PAD. This approach assumes all heating/cooling between CR-WFU and CR-PAD (~ 1.8 river miles) is due to Williams Fork inflows. While this is an uncertain assumption, the ability of the model to simulate temperatures in the key reach above Williams Fork is not expected to be affected. The heat balance produced hourly temperature estimates for portions of June through September for 2007- 2010, where observed temperature data on the

Colorado River were available. In the second step of the analysis, a correlation between heat balance results[7], observed meteorology (solar radiation and air temperatures), and Williams Fork flow rates was developed to allow for development of a complete input record of hourly temperatures. This multiple regression was applied to develop hourly Williams Fork temperatures for calibration, validation, and model application runs.

To generate hourly inflow temperatures for Fraser River inflow for model application runs (no observed temperature data exist for these hypothetical scenarios), the same multiple regression approach was applied. The regression was generated using observed FR-WGU data from 2007 through 2010 (available data from June – September each year). The regression considered solar radiation, air temperatures, and Fraser River flow rates. The best regression results were achieved when three separate regressions were generated – one for June, one for July and August, and one for September. This grouping of data recognizes the seasonality of different sources and temperatures of water to the Fraser River during the summer months (e.g., snowmelt, return flows, etc.). For calibration and validation simulations, observed FR-WGU data were used in the model, but the regression results were used for model application simulations. Regression results are plotted with observed data for 2007 through 2009 in Figure 6.

Temperatures for Hot Sulphur Springs WWTP discharges were set to 15.6°C per typical WWTP effluent temperatures, as reported in Metcalf and Eddy (1991). Based on data from Barrett and Pearl (1978) indicating that Hot Sulphur Springs temperatures ranged from 40 - 44°C, Hot Sulphur Springs discharge temperature was set to a constant 42 °C. The combined flow rate from these two discharges represents a fraction of a percent of the lowest flow rate observed at Hot Sulphur Springs across all simulations; therefore, any errors in these assumed temperatures are not expected to have significant effects on the simulated results. Temperature settings for gains across the reach were set in the calibration process and are therefore discussed in Section 3.2.1.

[7] 2010 Williams Fork heat balance results were not included in the regression, due to different reservoir discharge operations that year. During repairs to the outlet works, water was discharged from the upper level of the reservoir. Consequently, the 2010 discharge produced heat balance results that are not considered representative of current typical and expected future Williams Fork discharge temperatures.

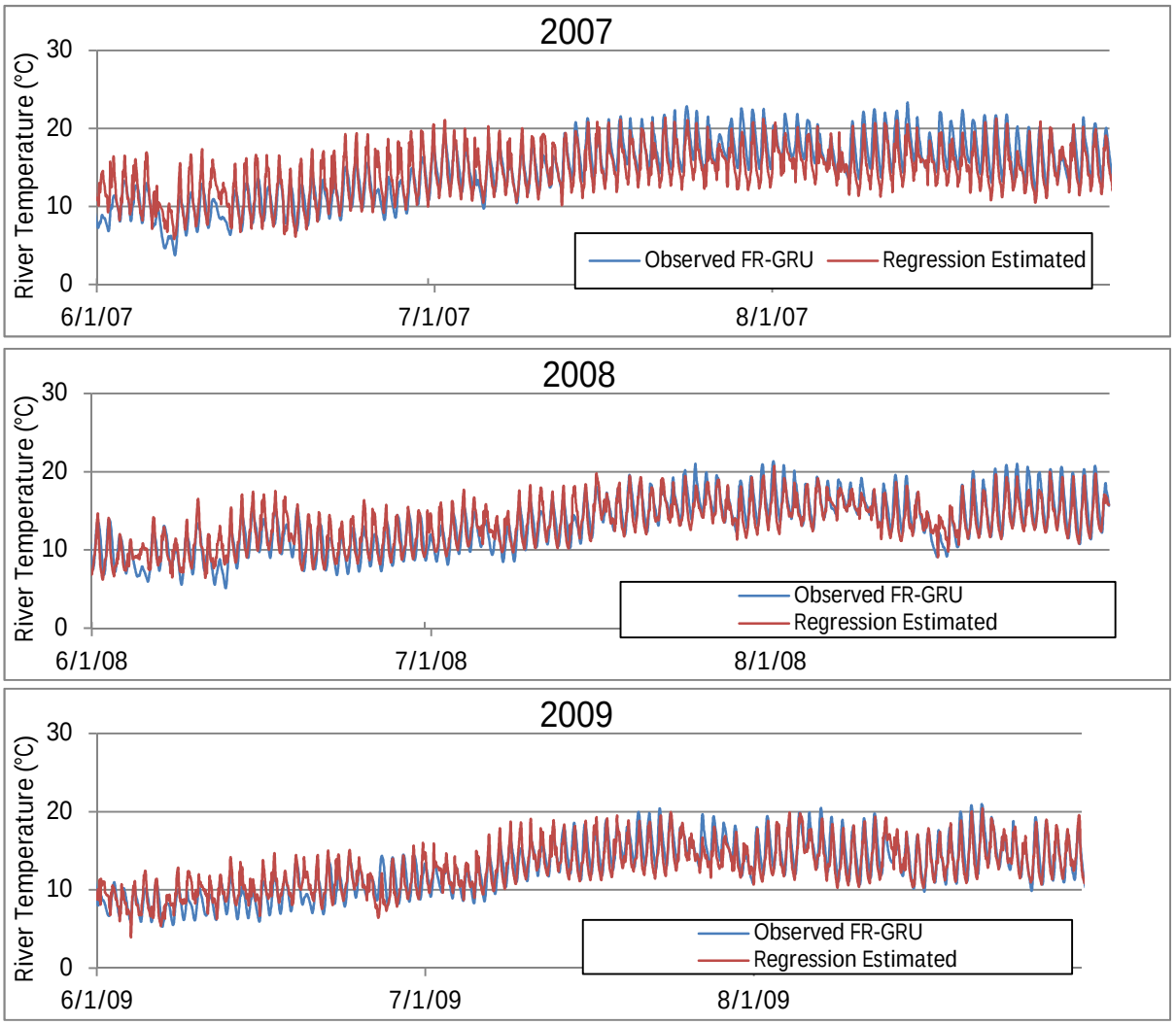


Figure 6. Multiple Regression Temperatures for the Fraser River.

2.2.4 Uncertainties

Every numerical model simulating environmental conditions has challenges and uncertainties. It is useful to list and track uncertainties to appropriately review and interpret calibration, validation, and application results.

This modeling effort endeavors to simulate a four month period of river temperatures on an hourly basis across a complex system with observed wide ranging daily and seasonal temperatures swings. Key uncertainties affecting calibration and validation include:

- Meteorology - A single meteorological input file must be used to describe the full 24 mile reach. Meteorological conditions of cloud cover, wind speed, solar radiation, and even air temperature can differ between Granby Reservoir and Williams Fork along the

Colorado River. Comparison of Kremmling Airport meteorological data to the Granby data shows differences from year to year and on smaller scales (e.g., from hour to hour). The meteorological data set applied is expected to be the best available representation of weather for the reach; however, it is important to acknowledge the uncertainty in this critical forcing data set in the model.

- Observed Flow Measurements – Field flow measurements are estimates of actual flow rates. In general, it is typical to assume that open channel flow measurements are accurate to within 10% of actual flow rates. Additionally, diversion data are recognized to often be unmeasured approximations of diversion volumes. All input hydrology errors can affect the model accuracy of simulated volumes and depths as well as gains and losses across reaches.

- Ungaged Tributaries – There are several un-gaged tributaries that enter this reach of the upper Colorado River that are not directly included in this model due to lack of information. These include Beaver Creek, Smith Creek, Drowsy Water Creek, and Kinney Creek. The site conceptual understanding anticipates that these tributaries are not important controls on river temperature; however, they are identified as uncertainties in the analysis.

- Observed River Temperature Measurements – Thermistors used to collect hourly or sub-hourly river temperature data are subject to potential errors. First, the reported accuracy of the thermistors used in this system is ±0.2 °C (Personal Communication with Jane Tollett, GCWIN, 2/21/2011). Additionally, there are potential issues with thermistor location placement that can increase errors/comparability to model results. Any placement in the river that results in temperature measurements that are not good estimates of the full cross-sectional average temperature at any time of the day will results in comparability issues, given the 1-dimensional nature of the modeling tool. For instance, placement in a deep pool or the "sunny side" of a cross-section can results in a bias toward cooler or warmer values than the cross-sectional average value.

- River Geometry – All available and applicable cross-section data from the reach were used in model development; however, this is a complex reach with complex geometry. If the model were unable to simulate observed temperatures, inadequate geometry information could be at fault.

- Estimated Williams Fork Temperatures – Simulated river temperatures below Williams Fork are limited by the accuracy of estimated temperatures of Williams Fork flows. As described in the previous section, Williams Fork temperatures were estimated based on a multiple regression of meteorological inputs and a simplified heat balance on limited observed data. While this does introduce uncertainty, it does not affect the predictions

in the most critical reach of the simulation (below Windy Gap Reservoir to above Williams Fork).

- Gains – Gains to the river are solved for based on observed hydrology. The breakdown of the origin of those gains (irrigation return flows, groundwater, ungaged tributaries, overland runoff, bank storage, etc.) is unknown. These ratios likely vary spatially and temporally, and each of these sources of gains might be expected to have a different temperature signal. Gains are applied to the model as a distributed lateral inflow and assigned a temperature, which is considered a calibration parameter (discussed further in Section 3).

- Algorithms – A numerical model attempts to recreate/predict environmental behavior with equations and relationships. The model implements these equations using input data by following prescribed solution steps which define the model algorithms. There is an unquantified uncertainty in the completeness and accuracy of the equations and relationships as well as the way in which the algorithms apply them.

As stated previously, all numerical models of environmental conditions are simplifications of natural systems. As simplified representations, all models therefore have associated uncertainties. It is good practice to identify and consider uncertainties in review of results and consideration of model applicability to future uses. Additionally, if the model is incapable of adequately simulating the observed system to meet calibration targets, an understanding of uncertainties is a good starting place to revisit the conceptual site understanding.

3 MODEL CALIBRATION AND VALIDATION

This section presents the model calibration approach and results as well as the validation run results for the Upper Colorado River dynamic temperature model developed for the WGFP. As described in Section 2.2.1, the model was calibrated for the period of June 1, 2007 through September 30, 2007, and the model was validated for the period of June 1, 2008 to September 30, 2008.

3.1 CALIBRATION TARGETS

Calibration targets were developed in consultation with EPA. These calibration targets were set in advance of model development to provide a predetermined framework with which to evaluate whether the model adequately simulates the system for the intended application.

Calibration targets focus largely on comparisons of observed and simulated temperatures; however, the calibration of the flow portion of the model (ADYN) was also assessed to provide checks on the underlying flow simulation. First, the target maximum overall mass balance error of the full ADYN simulation was one percent. This value was based on guidance in the ADYN model documentation (Hauser et al., 2007). Next, simulated flow and stage were compared to the observed flow and stage at two key locations in the system: Colorado River at Windy Gap Near Granby CO (USGS 09034250), and Colorado River at Hot Sulphur Springs, CO (Operated by Northern Water – COLSULCO; former USGS 09034500). These are the only two locations in the reach between Windy Gap and Williams Fork that had available USGS flow-stage rating curves. This evaluation of the hydrographs serves to check upstream inputs, tributary inputs, and gain/loss inputs as well as river dynamics in the model. The stage comparisons allow for review of whether the input geometry and roughness values capture the flow-stage relationship. Ultimately, however, the temperature simulation will provide the final check as to the adequacy of the simulated geometry.

Calibration targets for simulated river temperatures focus on observed water temperature measurement in the Colorado River collected by GCWIN and Northern Water at the following locations[8], which are shown on Map 2:

- CR-WGD (Colorado River 1 mile downstream of Windy Gap at USGS flow gage),
- CR-HSU (Colorado River above the town of Hot Sulphur Springs),
- CR-LB (Colorado River at Lone Buck -below CDOW Office, more than 3 miles downstream of Hot Sulphur Springs),
- CR-WFU (Colorado River upstream of the confluence with Williams Fork), and
- CR-PAD (Colorado River above Kid's Pond below Parshall).

Simulated temperature data are assessed graphically against observed data to visually compare overall patterns of seasonal trends, diurnal shapes, and amplitudes. Additionally, the following metrics are evaluated:

- Daily Mean Temperature,
- Daily Maximum Temperature, and
- Daily Minimum Temperature.

The following statistics are calculated for each of these metrics:

- Root-mean-square-error (RMSE), and
- Mean absolute error (MAE).

Each of these metric-statistic pairs was compared to the following calibration targets:

For daily mean temperature:

- RMSE < 1.5 °C
- MAE < 1.5 °C

For daily maximum temperature:

- RMSE < 1.5 °C

[8] CR-HRU, located at Hot Sulphur Springs- approximately 0.9 river miles downstream of CR-HSU, was evaluated in the validation simulation (2008); however, there were no data available at this location for the calibration (2007).

- MAE < 1.5 °C

For daily minimum temperature:

- RMSE < 1.5 °C
- MAE < 1.5 °C

Additionally, following the recommendations of Bartholow (1989), the observed-simulated R^2 was calculated, and model residuals were evaluated for any trends with space, time, or temperature.

3.2 CALIBRATION

This section presents the calibration findings and results, including comparison of simulated results to the calibration targets.

3.2.1 Calibration Approach

Following model development, described in Section 2, the model calibration was performed in two steps. First, the ADYN flow model was run and stabilized. Model stabilization was achieved by varying the number of interpolated cross sections in areas of the model with rapidly changing flow rates and/or slope. Manning's n values were also modified within reasonable ranges to improve the river dynamics, hydrograph matches, and stage matches. Additionally, the simple five-point cross-sections were modified (generally widened) to improve river top width simulation, as compared to top-width measurements from available Google Earth® imagery from June 2005 and August 2007. These cross-section modifications were performed recognizing the critical importance of capturing the river geometry in simulating river temperatures. Surveyed river thalweg elevations were honored across the reach. Likewise, detailed cross-sections from detailed surveys above Hot Sulphur Springs and near Lone Buck were not modified.

Second, the temperature (RQUAL) model was calibrated. The first step in this calibration was to run the model with recommended settings from the model documentation (Hauser et al., 2007). Next values were varied within reasonable ranges (per Hauser et al., 2007). From these initial runs, it is clear that the system temperature response is very strongly controlled by the input meteorology. Among the variable input parameters in the temperature model, shallow bed thickness and bed albedo settings showed temperature sensitivity, with lesser sensitivity observed for shading parameters within a reasonable range of values. Table 1 presents calibration values applied in the model.

Table 1. Calibration Value Settings.

Parameter	Brief Definition	Value(s) Applied	Comment
Bank Width	Bank width to effective barrier for shading	2 – 20 (ft)	Based on review of shading vegetation location adjacent to river in Google Earth® images from June 2005 and August 2006
Barrier Height	Effective barrier height for shading	2 – 20 (ft)	Based on review of vegetation density and general type apparent in Google Earth® images from June 2005 and August 2006; for Buyer's Canyon, barrier heights were set high (200 ft) to simulate the shading effects of the canyon walls
AA	Coefficient for wind speed function (evap. cooling term)	0.5E-9 m^3/mb/s	Recommended value (Hauser et al., 2007)
BB	Exponent for wind speed function (evap. cooling term)	1.5E-9 m^2/mb	Recommended value (Hauser et al., 2007)
XL	Effective channel bed thickness for upper heat conductive layer	8 – 13 (cm)	Within recommended range of 5 to 50cm, per Hauser et al. (2007)
XL2	Effective channel bed thickness for lower heat conductive layer	20 – 50 (cm)	Within recommended range of 10 to 200cm, per Hauser et al. (2007)
DIF	Thermal diffusivity of bed material	27.7 (cm^2/hr)	Recommended value (Hauser et al., 2007)

Parameter	Brief Definition	Value(s) Applied	Comment
CV	Bed heat storage capacity	0.68 (cal/cm3°C)	Recommended value (Hauser et al., 2007)
BETW	Fraction solar rad. absorbed by 0.6m water	0.4 (cal/cm3°C)	Recommended value (Hauser et al., 2007)
BEDALB	Albedo of bed material	0.2	Per Hauser et al.(2007): 0.05-0.1=dark, algae-covered bed; 0.25=average channel bed; 0.5=light-colored sandy beds
SHSOL	Fraction of solar radiation absorbed by shaded water	0.2	Recommended value (Hauser et al., 2007)
SHDBT	Ratio by which drybulb is cooler over shaded water	0.5	Recommended value (Hauser et al., 2007)
Manning's n	Roughness coefficient	0.025 to 0.040	Within reasonable range for river (Chow, 1959)

Another variable temperature input to the model was the boundary condition of distributed gains to the river. Given the seasonal patterns and magnitudes of the gains, they are expected to be largely return flows from irrigation diversions with some groundwater advective flow from the local alluvial aquifers[9]. Temperatures for these gains were initially applied at constant, low values in the range of the limited observations of deeper groundwater temperatures in the area (6 to 12°C from USGS individual observations at five near-river wells between Granby Reservoir and Kremmling, ranging from 14ft to 2000ft deep). These low constant values were found to be too cool, and tended to lead to under predictions of river temperatures. These low values did not capture the warming expected to be occurring due to return flows. Flood-type irrigation exposes water to warm surface soils and can be responsible for river warming via return flows. As noted in Bartholow (1989), and still valid, there is little literature information available on observed return flow temperatures. For perspective, Sylvester (1963) indicates that irrigation return flows from open drains can be 1.8°C warmer than receiving waters. Hewlett and Fortson (1982) observed that seepage from shallow groundwater varied at their study site from 6.1°C in January to 21.1°C in July, due to warming of shallow groundwater in areas of gentle land relief and minimal tree coverage.

Based on all of this, it is expected that the temperature of return flows is related to surface soil temperatures, which would be expected to vary with the meteorology, among other factors. A variety of return flow temperature patterns tracking observed meteorology (solar radiation and air temperatures) were tested. The best results were achieved in calibration by setting the return flow temperatures equal to the average daily air temperature. During the period of greatest return flows (June and July), the daily average air temperatures in 2007 averaged 14.4°C, ranging from 7.4 to 18.4°C, with one cold day averaging 4.1°C in early June. As a caution, while this approach worked for the reach of the river being evaluated and the target simulation season (Jun-Sept), this assumption may not be appropriate for other parts of the river or other seasons, where irrigation patterns and groundwater contributions vary.

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[9] Note: Bounding analyses were developed separately from this effort to bound the potential temperature effects of changes to surface water-groundater interaction cooling effects of bank storage and advective gains. These analyses (Hydros, 2011a and Hydros, 2011b) indicate that changes to these cooling mechanisms due to WGFP proposed pumping would be minimal. To be clear, the flows associated with these mechanisms are inherently included in this modeling effort in the balances developed to include gains. However, these mechansims are not explicitly modeled, as gains are assigned temperatures as described in this section. Based on the successful calibration and validation of this model as well as the findigns of the bounding analyses, this approach is valid.

3.2.2 Calibration Results

Flow (ADYN) and temperature (RQUAL) calibration results for the calibration period of June 1, 2007 through September 30, 2007 are presented in the following subsections.

3.2.2.1 Flow Model Calibration Results

As discussed in Section 3.1, the flow simulation was evaluated against observed flow rate and stage at the gage below the Windy Gap reservoir (USGS 09034250) and at the gage at Hot Sulphur Springs (Operated by Northern Water – COLSULCO; former USGS 09034500). The mass balance error for the entire ADYN flow simulation was 0.617%, which was below the target maximum of 1%. Further, detailed review of the output file showed no system warnings or supercritical flow.

3.2.2.1.1 Flow Rates

The simulated and observed hydrographs at both gages (below Windy Gap Reservoir and at Hot Sulphur Springs) match well, with R^2 values of 0.99+. The time series results are presented in Figure 7and Figure 8.

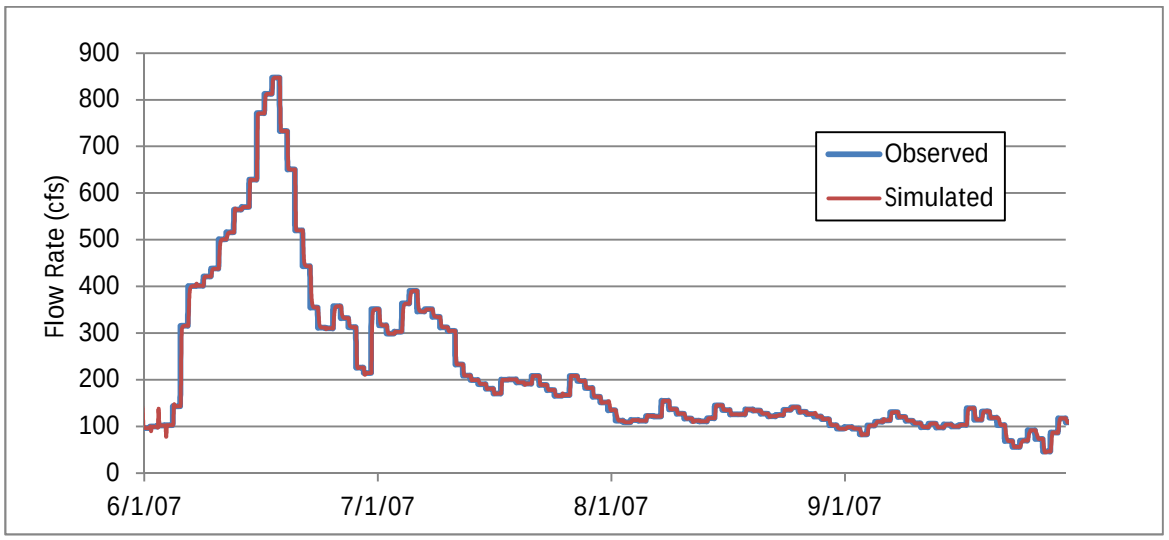

Figure 7. Observed and Simulated Hourly Flow Rates below Windy Gap - Calibration Run.

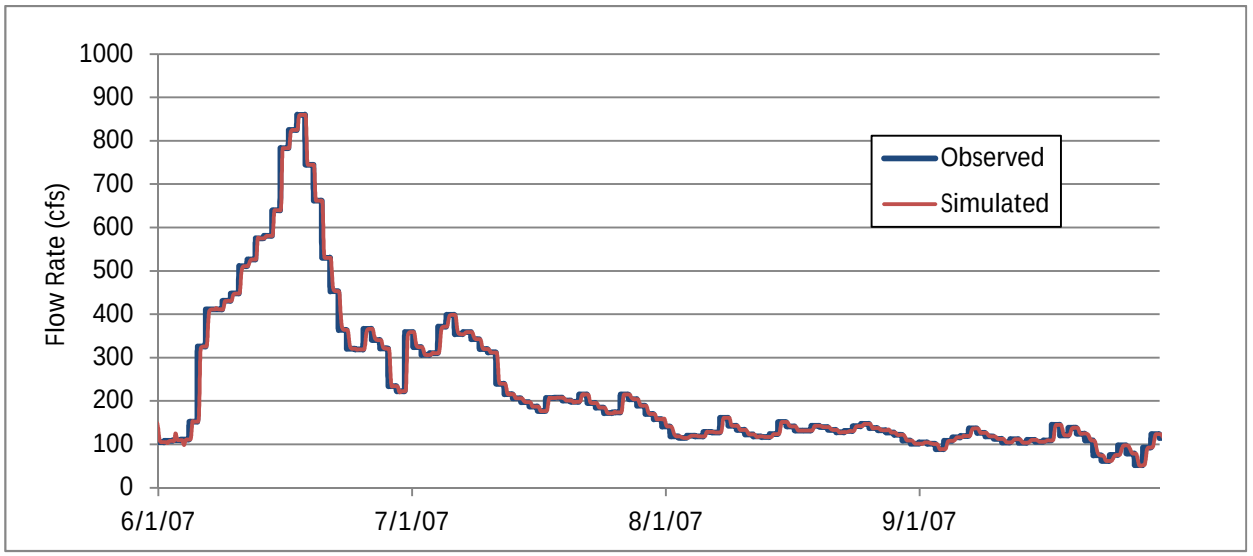

Figure 8. Observed and Simulated Hourly Flow Rates at Hot Sulphur Springs - Calibration Run.

3.2.2.1.2 Stage

The simulated and observed stages below Windy Gap Reservoir and at Hot Sulphur Springs show good overall shape matches. For the gage below Windy Gap Reservoir, the average difference in observed and simulated hourly stage was -0.15ft, ranging from -0.19 ft to +0.32 ft. For the gage at Hot Sulphur Springs, the average difference in observed and simulated hourly stage was -0.04ft, ranging from -0.37ft to +0.46ft. Observed and simulated time series stage values are shown in Figure 9.

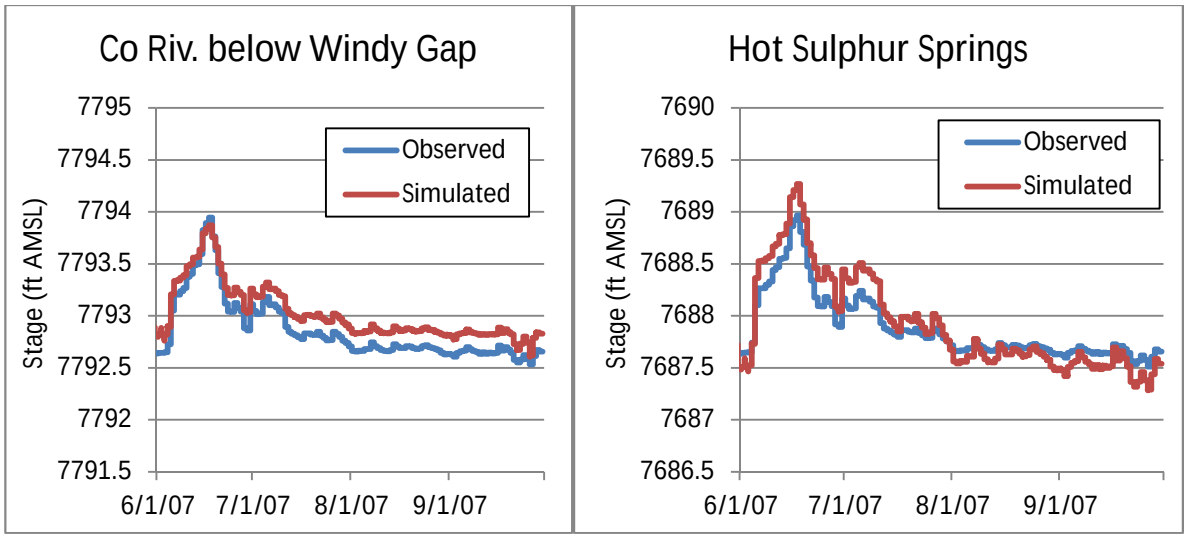

Figure 9. Observed and Simulated Stage - Calibration Run.

3.2.2.2 Temperature Model Calibration Results

As discussed in Section 3.1 calibration of the temperature model was assessed against observed temperature data in the Colorado River at the following five locations, which are shown on Map 2:

- CR-WGD (Colorado River 1 mi downstream of Windy Gap at USGS flow gage),
- CR-HSU (Colorado River above the town of Hot Sulphur Springs),
- CR-LB (Colorado River at Lone Buck -below CDOW Office, more than 3 miles downstream of Hot Sulphur Springs),
- CR-WFU (Colorado River upstream of the confluence with Williams Fork), and
- CR-PAD (Colorado River above Kid's Pond below Parshall).

The following subsections present tabular summaries followed by hourly temperature plots for the full simulation period as well as monthly plots for the key locations of CR-HSU and CR-WFU. CR-HSU and CR-WFU were selected as key locations because, among the stations evaluated, they exhibit the highest daily maximum temperatures and weekly average temperatures, respectively. These locations are also key locations because they will be focus locations for evaluation of model application results. Plots of residuals are also presented to support trending reviews.

3.2.2.2.1 Calibration Statistics

The calibration statistics of RMSE and MAE were calculated for each station for daily average, daily minimum, and daily maximum temperatures. These results, presented in Table 2, were all below the calibration max target value of 1.5°C. Table 2 also presents R^2 values for the same metrics. R^2 values were greater than 0.9 for daily averages (ranging between 0.92 and 0.98), greater than 0.9 for daily minimums (0.91 to 0.97), and greater than 0.8 for daily maximums (0.81 to 0.97).

Table 2. 2007 Calibration Summary Table

		CR-WGD	CR-HSU	CR-LB	CR-WFU	CR-PAD
Daily Average Temperature	R^2	0.98	0.96	0.94	0.93	0.92
	RMSE (°C)	0.46	0.55	0.59	0.72	0.75
	MAE (°C)	0.37	0.44	0.48	0.60	0.64
Daily Minimum Hourly Temperature	R^2	0.97	0.95	0.91	0.91	0.95
	RMSE (°C)	0.74	0.69	0.75	0.87	0.49
	MAE (°C)	0.58	0.54	0.63	0.73	0.33
Daily Maximum Hourly Temperature	R^2	0.97	0.91	0.85	0.85	0.81
	RMSE (°C)	0.64	0.90	1.38	1.19	1.28
	MAE (°C)	0.51	0.71	1.11	0.95	0.97

3.2.2.2.2 Hourly Temperature Plots

Figure 10 through Figure 14 show observed and simulated temperature results for the entire calibration simulation period at the five target locations. These plots show that the model captures overall seasonal temperature patterns and amplitudes, including meteorologically-driven shifts (e.g., the temperature dip observed across the system in early June).

To support a more detailed review of diurnal patterns in simulated and observed temperatures, monthly plots are presented for the two key locations of CR-HSU and CR-WFU (Figure 15 through Figure 20). Monthly plots are presented for each month for which observed data were available. The remaining monthly plots are presented in an Appendix A.

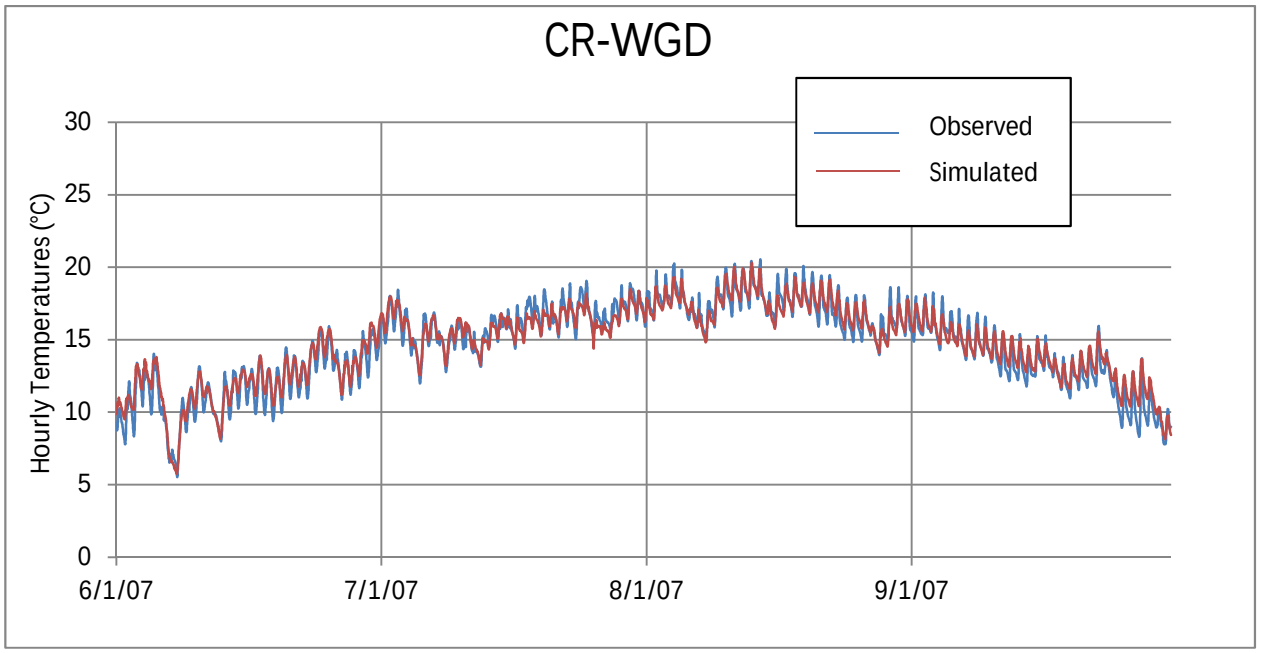

Figure 10. Observed and Simulated Hourly Temperatures at CR-WGD - Calibration Run.

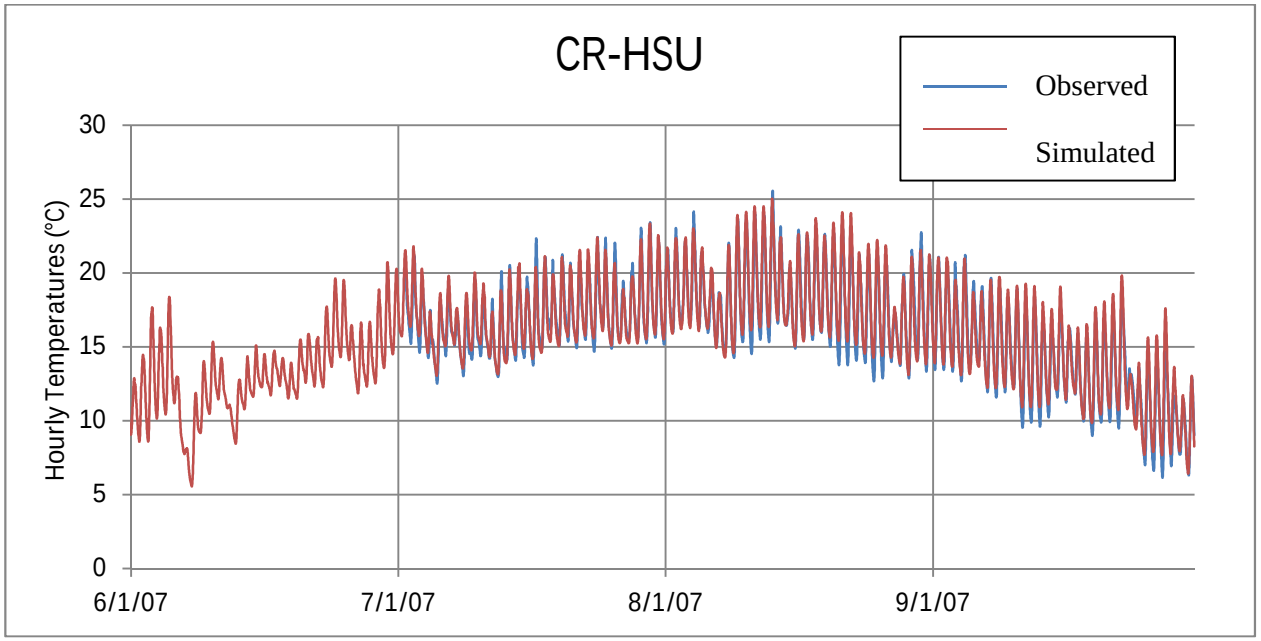

Figure 11. Observed and Simulated Hourly Temperatures at CR-HSU - Calibration Run.

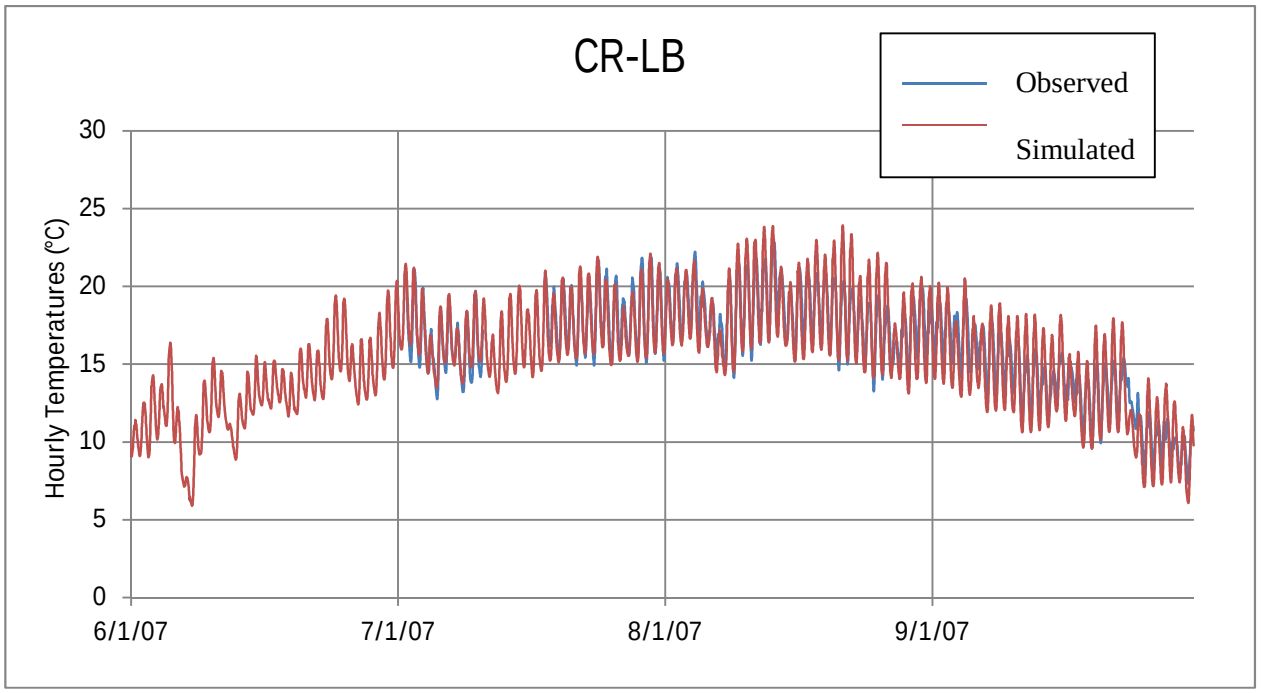

Figure 12. Observed and Simulated Hourly Temperatures at CR-LB - Calibration Run.

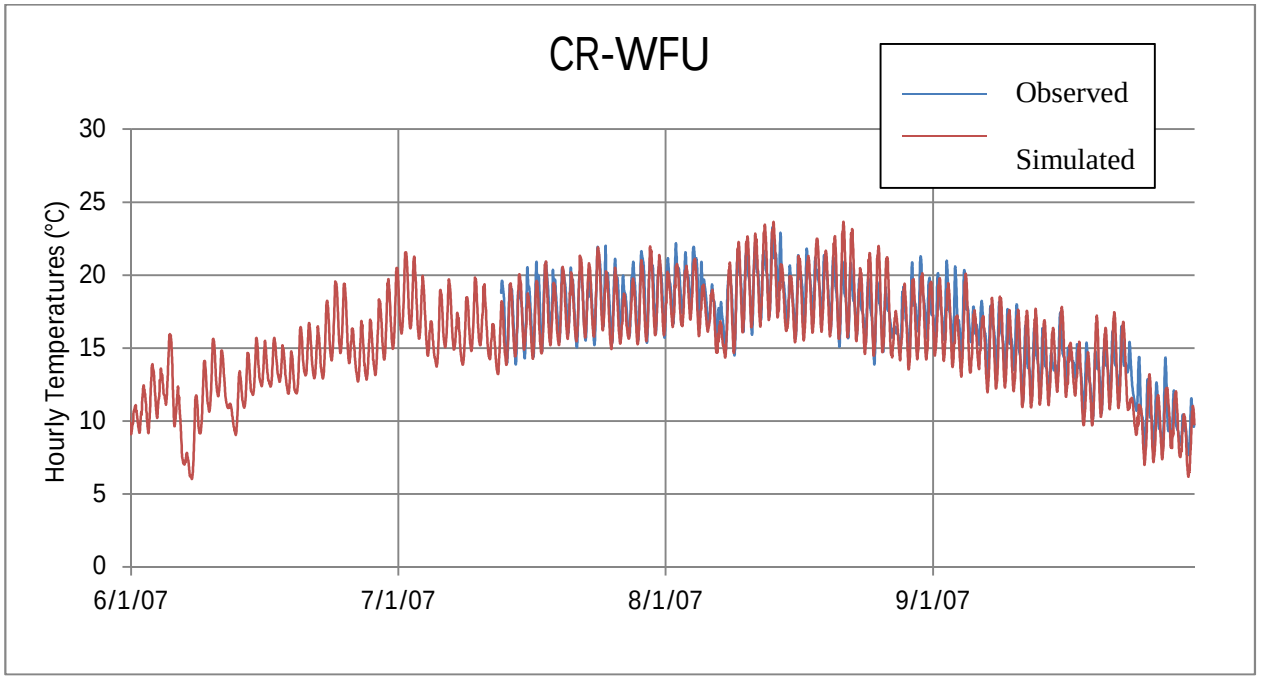

Figure 13. Observed and Simulated Hourly Temperatures at CR-WFU - Calibration Run.

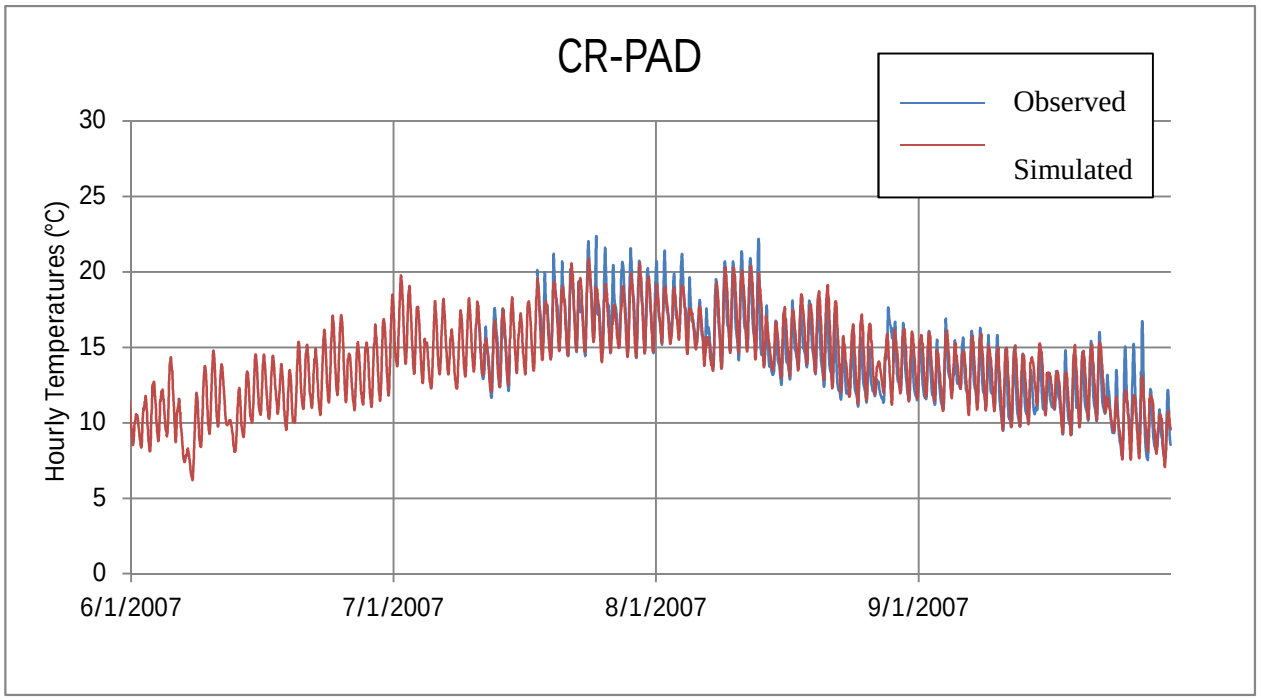

Figure 14. Observed and Simulated Hourly Temperatures at CR-PAD - Calibration Run.

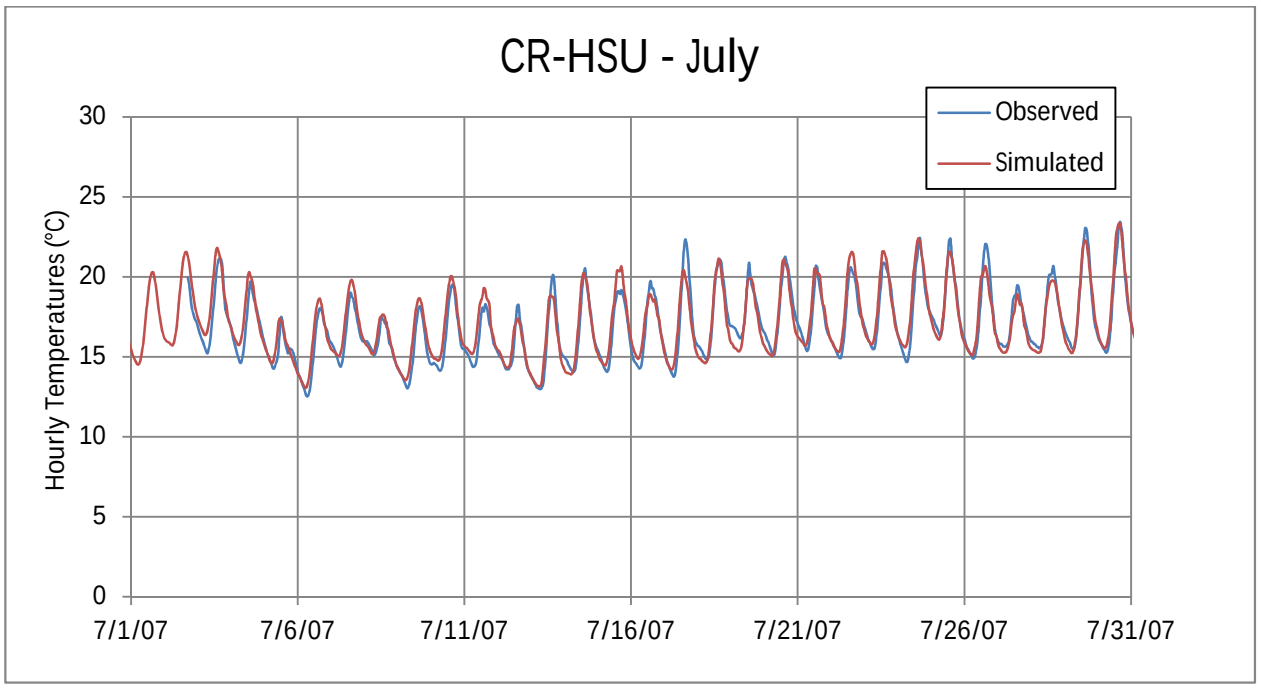

Figure 15. Observed and Simulated Hourly Temperatures at CR-HSU, July - Calibration Run.

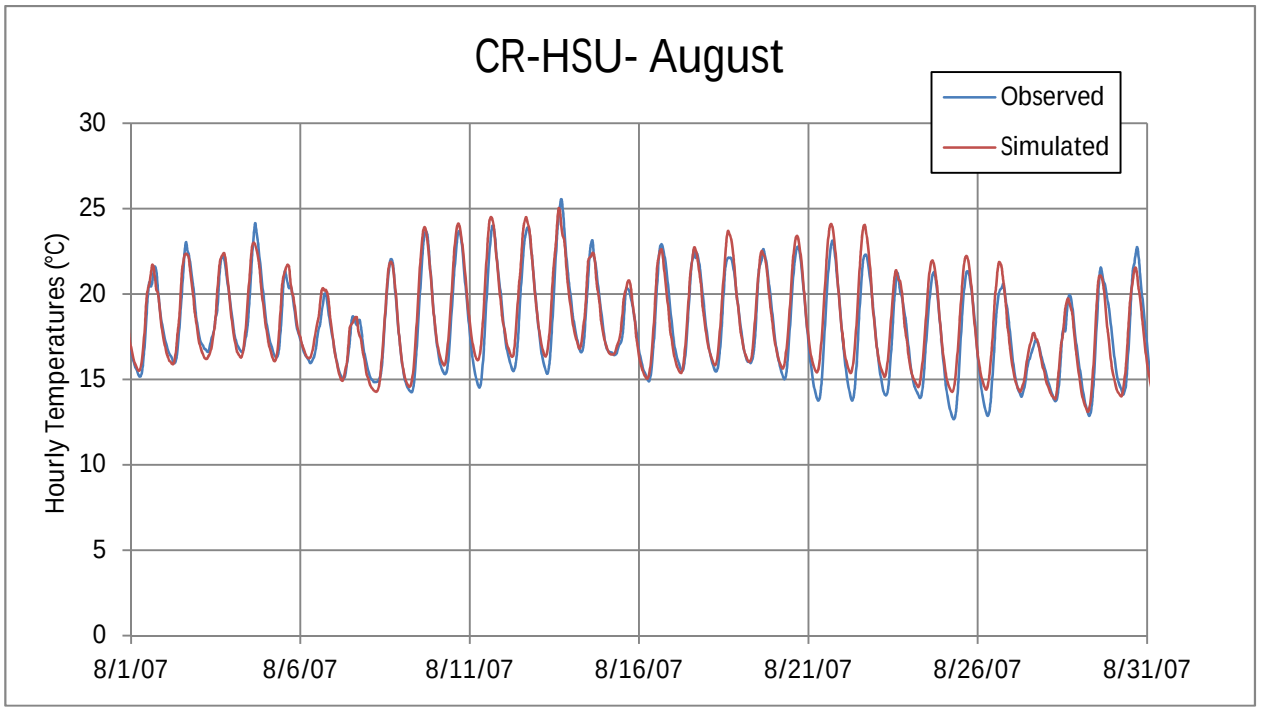

Figure 16. Observed and Simulated Hourly Temperatures at CR-HSU, August - Calibration Run.

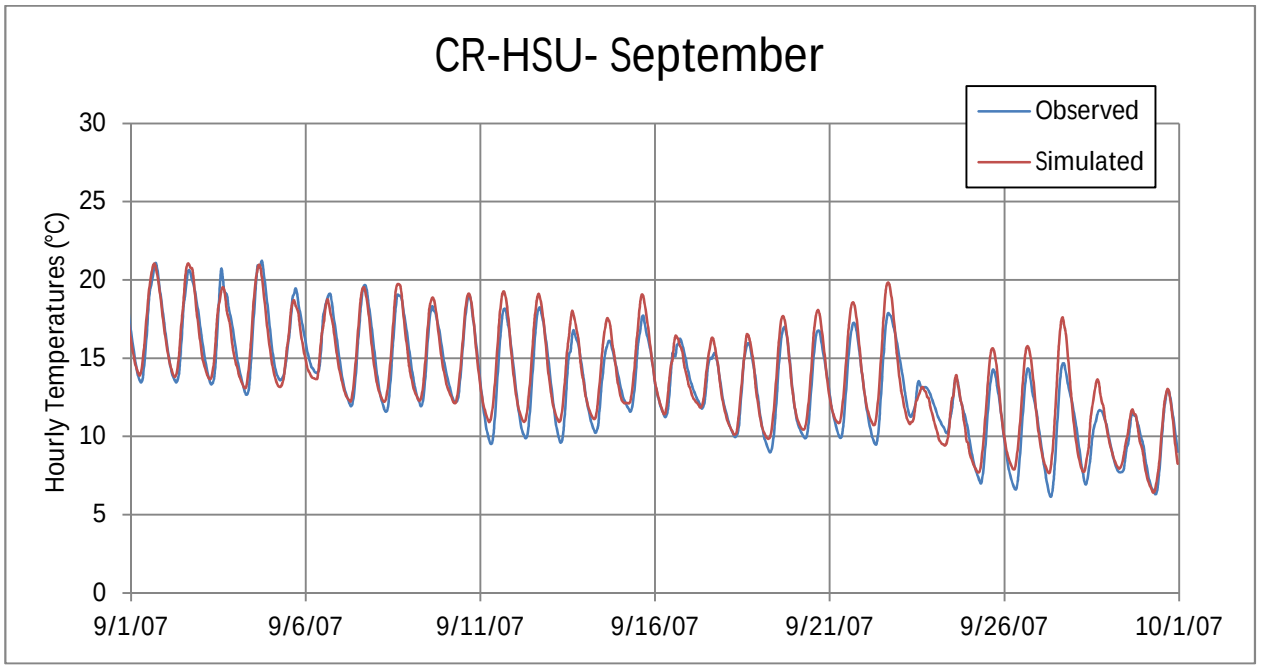

Figure 17. Observed and Simulated Hourly Temperatures at CR-HSU, September - Calibration Run.

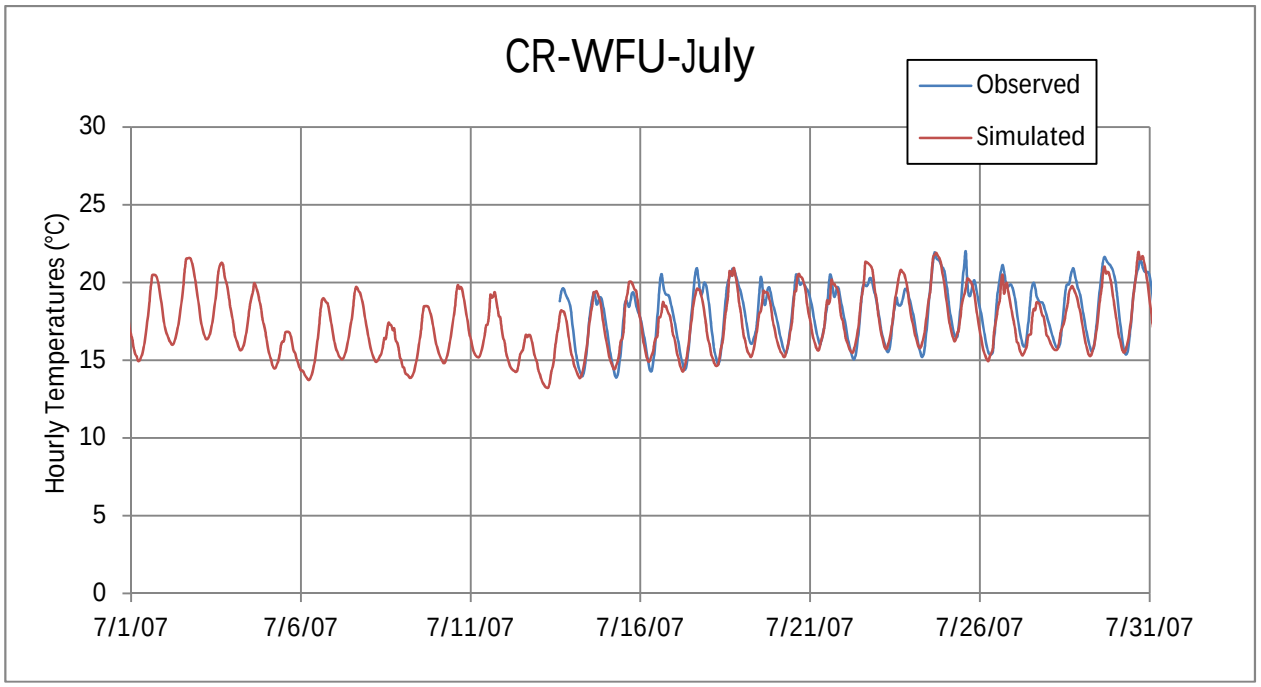

Figure 18. Observed and Simulated Hourly Temperatures at CR-WFU, July - Calibration Run.

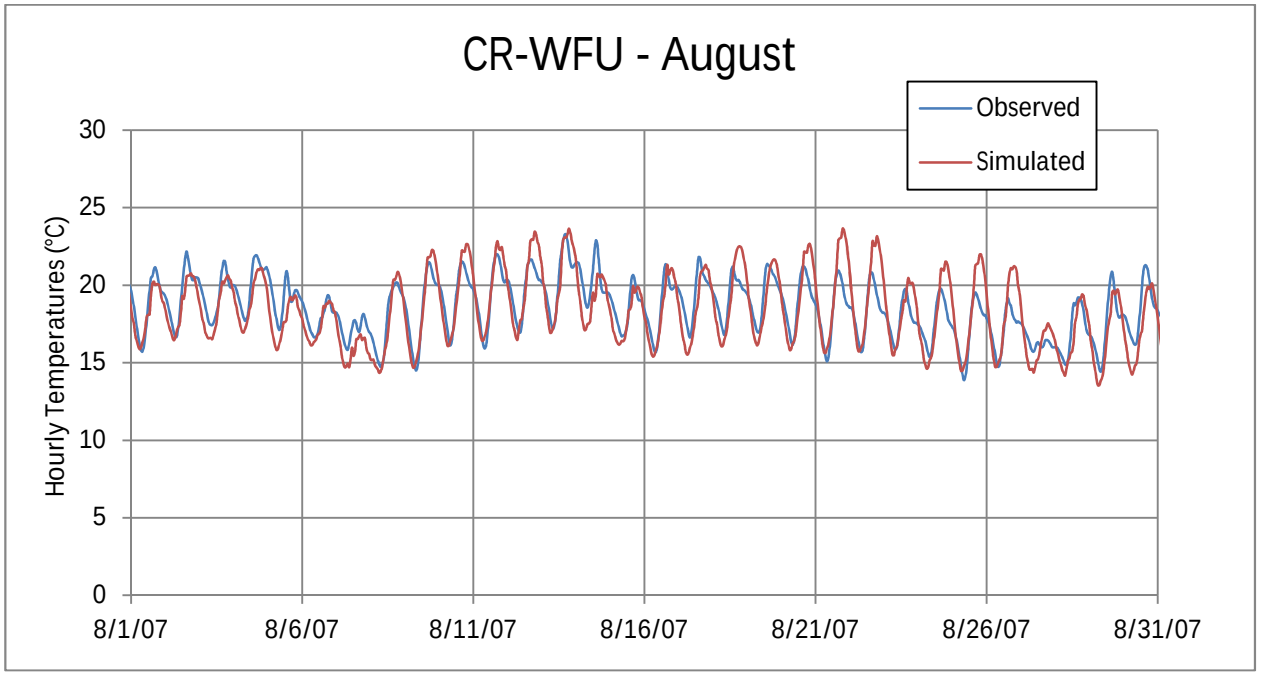

Figure 19. Observed and Simulated Hourly Temperatures at CR-WFU, August - Calibration Run.

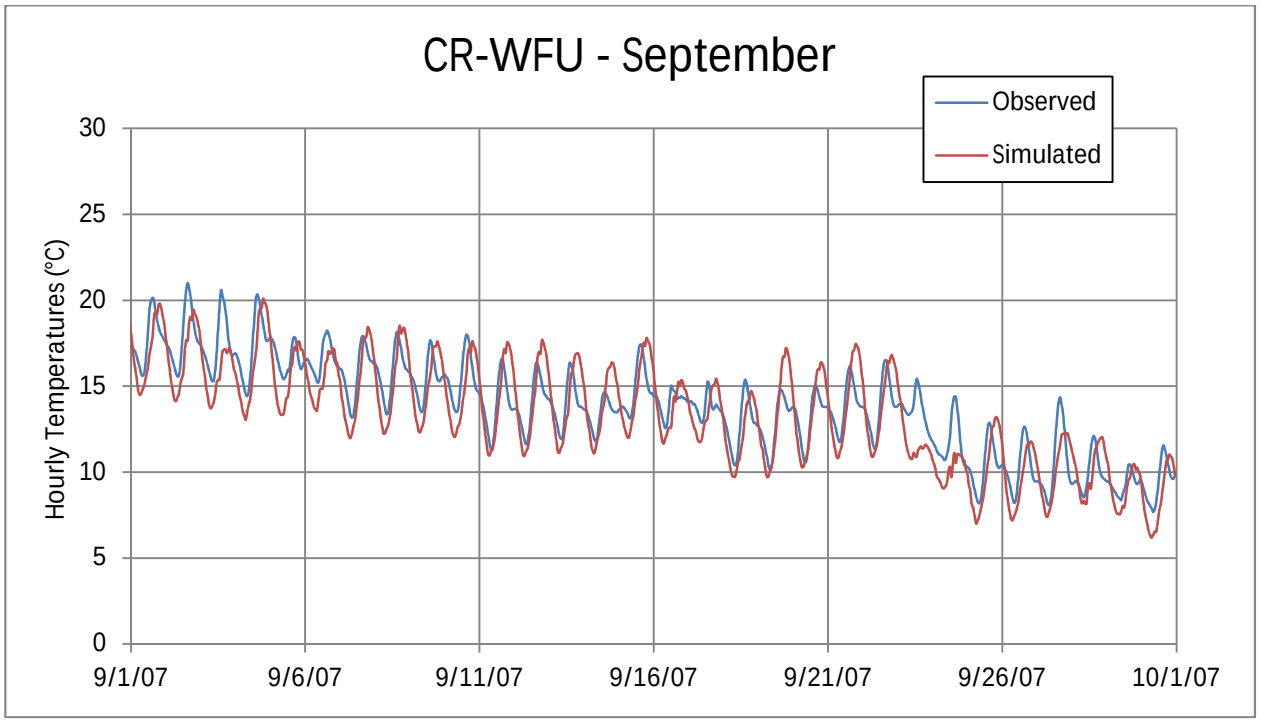

Figure 20. Observed and Simulated Hourly Temperatures at CR-WFU, September - Calibration Run.

3.2.2.2.3 Trends and Bias

Daily temperature residuals were plotted over time for each calibration gage to look for any issues of bias or trending (temporally or spatially). Such bias or trending could suggest progressive errors or other issues with the model. Figure 21 through Figure 25 present the plots of residuals for the calibration gages. Gages are presented in order of upstream to downstream locations. Each gage shows no temporal trends in residuals. Further, the mean error values for the gages do not show any trending spatially (e.g., consistent increasing or decreasing error moving downstream).

To evaluate whether there are any trends in the modeling calibration results with temperature (i.e., whether errors increase at higher or lower temperatures), daily residuals from all of the calibration gages were plotted against the corresponding observed temperatures. As shown in Figure 26, there is no clear error trending with temperature.

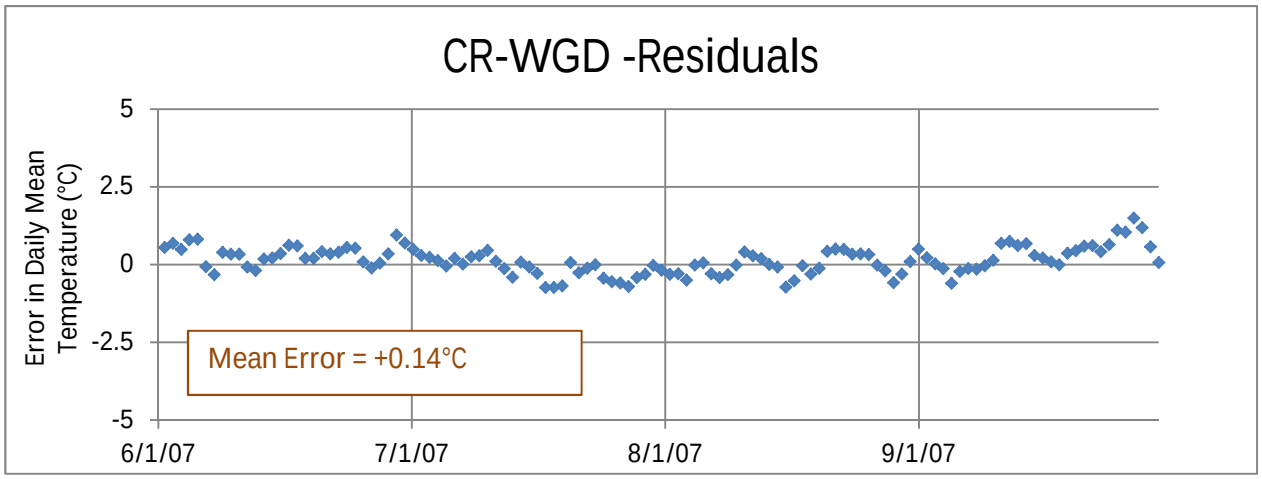

Figure 21. Daily Mean Residuals for Calibration - CR-WGD.

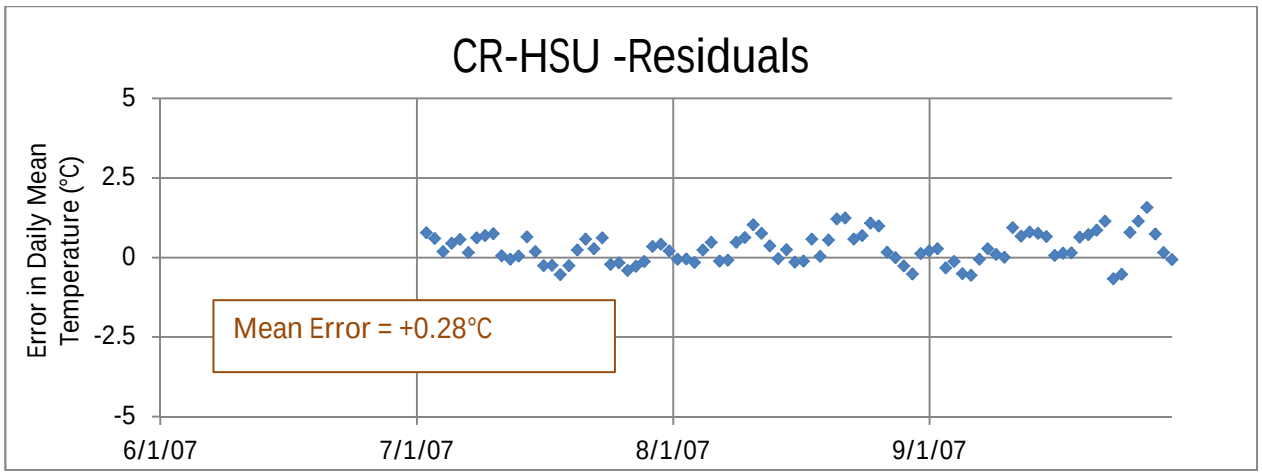

Figure 22. Daily Mean Residuals for Calibration - CR-HSU.

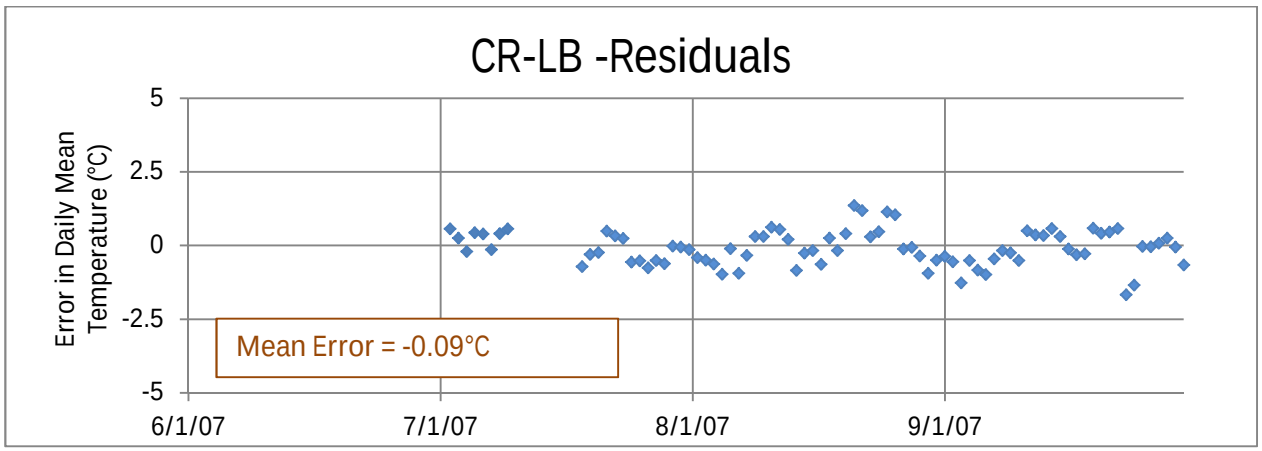

Figure 23. Daily Mean Residuals for Calibration - CR-LB.

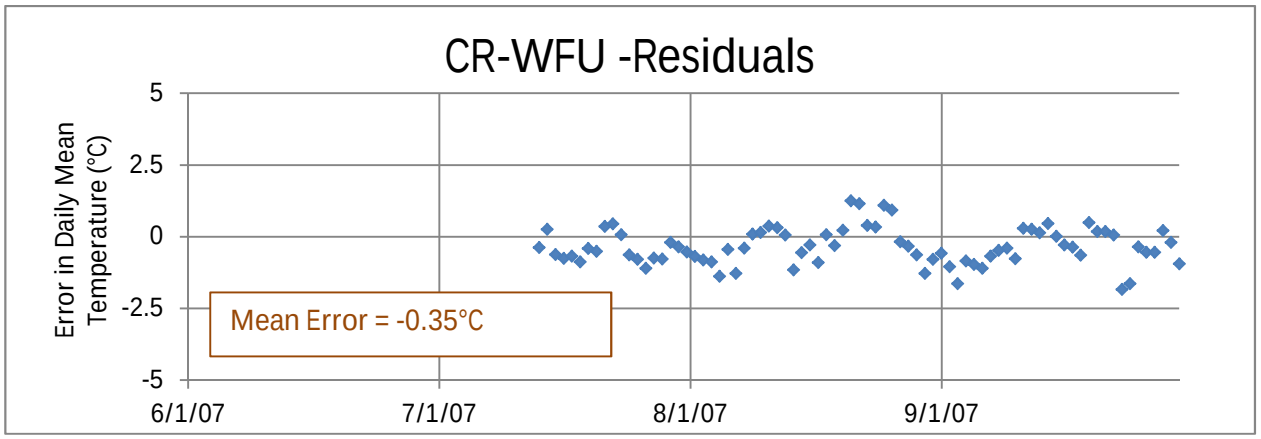

Figure 24. Daily Mean Residuals for Calibration - CR-WFU.

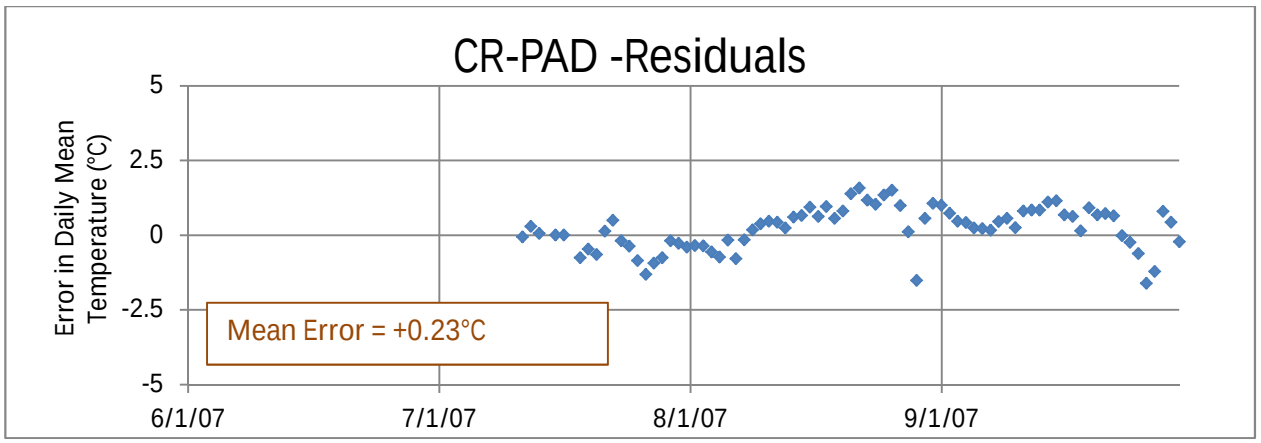

Figure 25. Daily Mean Residuals for Calibration - CR-PAD.

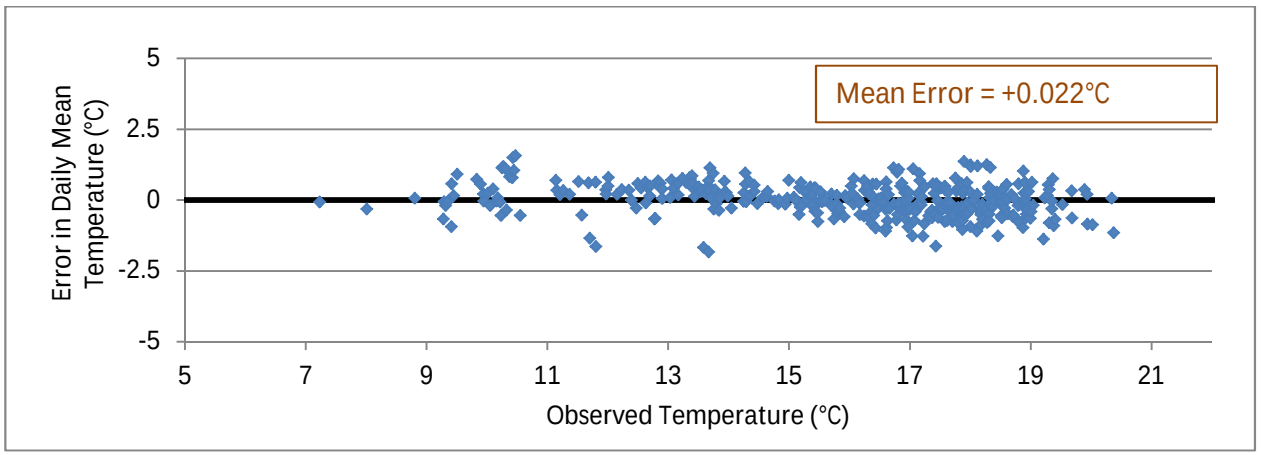

Figure 26. Calibration Residuals as a Function of Observed Temperature.

3.2.3 Calibration Summary

The model met all calibration targets. The flow simulation reproduced observed hydrographs and stages well, with a low mass balance error. The temperature model also produced good results. Simulated hourly temperatures capture overall seasonal temperature patterns and amplitudes, including meteorologically-driven shifts. Diurnal ranges and patterns are also well simulated. RMSE and MAE values for daily averages, daily maximums, and daily minimums were all below the target value of 1.5°C at all five evaluation gages. Additionally, R^2 values for the correlation between observed and simulated temperatures were between 0.85 and 0.98 for gages between Windy Gap Reservoir and Williams Fork. Finally, plots of residuals show no trends with space, time, or temperature-values, suggesting no major progressive or systematic errors. Based on these results the model was further tested through a validation run.

3.3 VALIDATION

Model validation is a testing process for a calibrated model. Typically, validation consists of running a calibrated model for a period of observed record other than the calibration period. Comparison of validation simulation results to observed results for the validation period allows for assessment of the model's ability to predict system response beyond the calibration period. Good model performance in validation offers confidence for model application. The following subsections present the validation simulation approach and results.

3.3.1 Validation Approach

The calibrated model was validated by simulating the temperature response for June through September of 2008. The only changes made to the model for the validation run were the following required inputs:

- 2008 Meteorological Data – These data were compiled from the same met station used for the 2007 data.
- Flow Inputs in the ADYN Model – All inflow tributaries, diversion, and gain/loss values were worked up from 2008 records in the same way they were developed for 2007 and applied to the flow model.
- Initial Conditions in the ADYN Model – Initial condition upstream and downstream heads and flow rates were set to match first time step flows and heads at these locations.
- Boundary Condition Temperatures in the RQUAL Model – Tributary temperatures were updated to 2008 values. 2008 average daily air temperatures were applied to gains. For Williams Fork, where temperature values are not available, the same multiple regression equation[10] applied for 2007 values was applied for 2008. 2008 air temperatures, solar radiation, and Williams Fork flow rates were used in the regression equation.

[10] As described in the Model Development discussion (to be provided with the final modeling report), Williams Fork temperatures were developed using a heat balance from the CR-WFU and CR-PAD gages which were then applied to develop a multi-regression. Hourly air temperature, solar radiation, and Williams Fork flow rates were correlated with the heat balance-generated Williams Fork temperatures. For consistency, the regression equation was applied to estimate Williams Fork temperatures for 2007 and 2008 as well as the model application runs.

3.3.2 Validation Results

Flow (ADYN) and temperature (RQUAL) validation results for the validation period of June 1, 2008 through September 30, 2008 are presented in the following subsections. Validation results were evaluated against the same criteria as the calibration run.

3.3.2.1 Flow Model Validation Run

As discussed in Section 3.1, the flow simulation was evaluated against observed flow rates and stages at the gage below the Windy Gap reservoir (USGS 09034250) and at the gage at Hot Sulphur Springs (Operated by Northern Water – COLSULCO; former USGS 09034500). The mass balance error for the entire ADYN flow simulation was 0.359%, which was below the target maximum of 1%.

3.3.2.1.1 Flow Rates

As seen in the calibration run, the simulated and observed hydrographs at the gage below Windy Gap Reservoir and the gage near Hot Sulphur Springs match well in the validation run, with R^2 values of 0.99+. The time series results are presented in Figure 27and Figure 28.

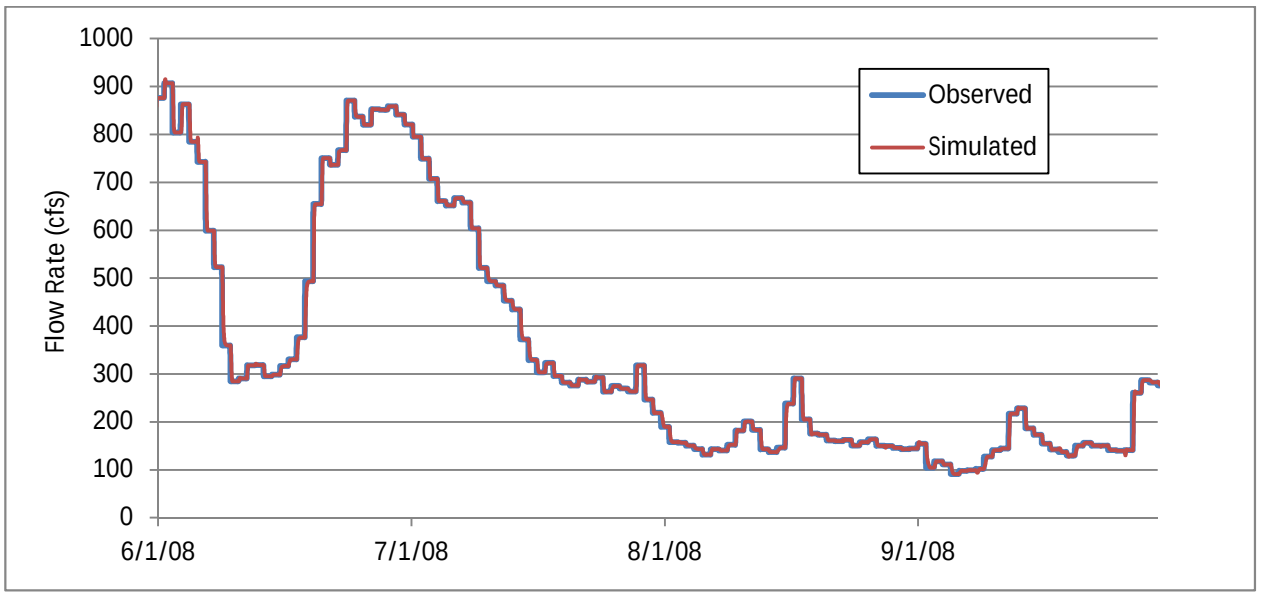

Figure 27. Observed and Simulated Hourly Flow Rates below Windy Gap - Validation Run.

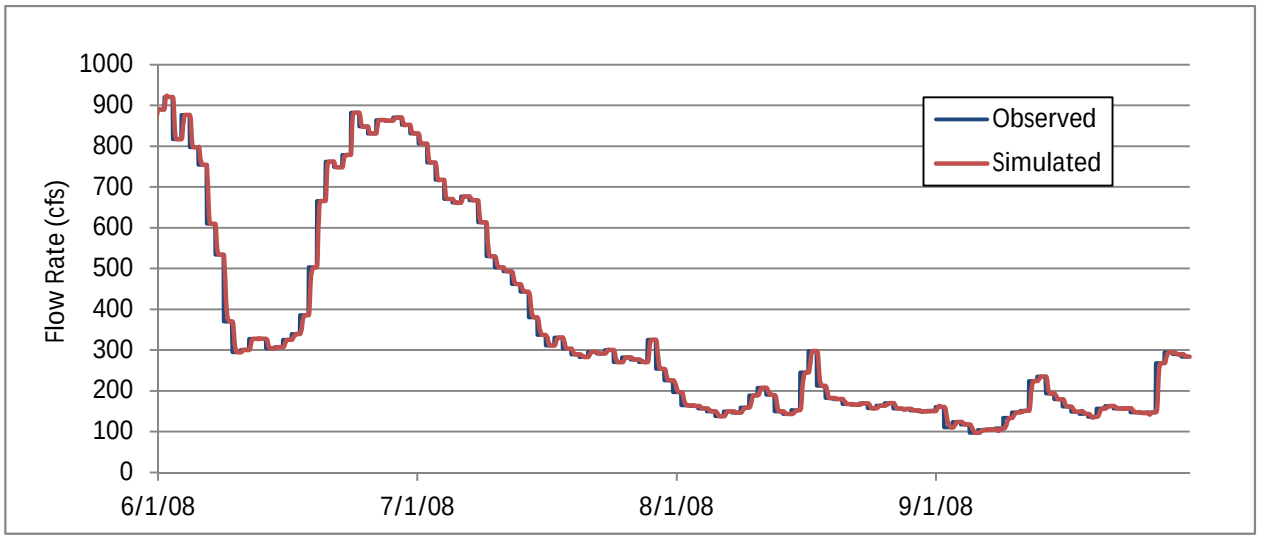

Figure 28. Observed and Simulated Hourly Flow Rates near Hot Sulphur Springs - Validation Run.

3.3.2.1.2 Stage

As seen in the calibration run, the validation run simulated and observed stages below Windy Gap Reservoir and at Hot Sulphur Springs show good overall shape matches and peak matches. For the gage below Windy Gap Reservoir, the average difference in observed and simulated hourly stage was +0.14ft, ranging from -0.17 ft to +0.39 ft. For the gage at Hot Sulphur Springs, the average difference in observed and simulated hourly stage was -0.07ft, ranging from -0.21ft to +0.39ft. Observed and simulated time series stage values are shown in Figure 29.

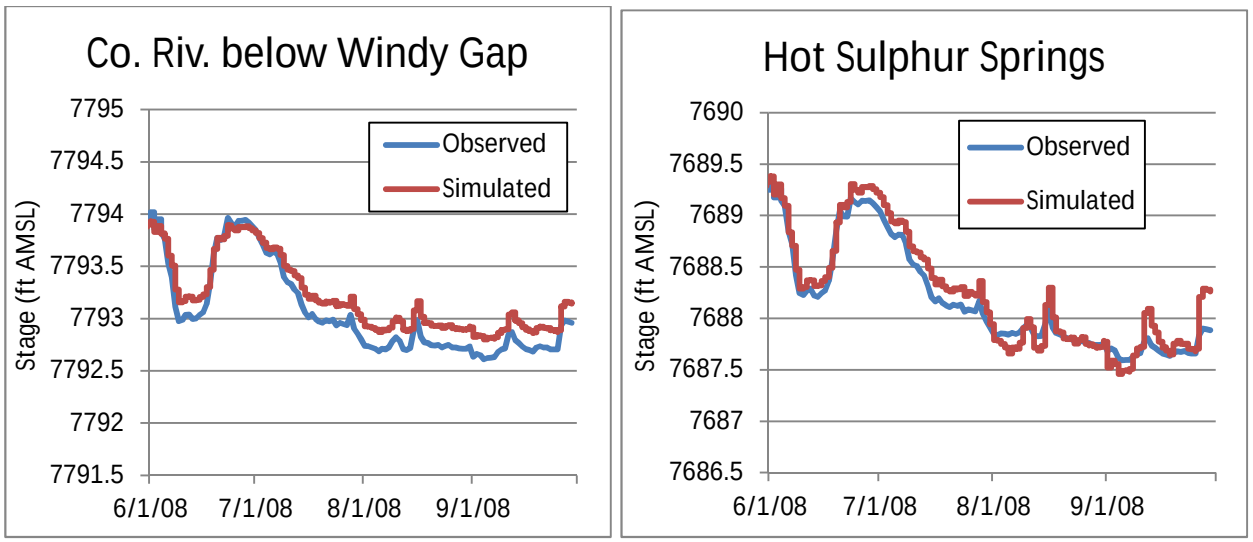

Figure 29. Observed and Simulated Stage - Validation Run.

3.3.2.2 Temperature Model Validation Results

To parallel the analysis completed for calibration, the validation run results were compared to the observed temperature data in the Colorado River at the same five locations (CR-WGD, CR-HSU, CR-LB, CR-WFU, and CR-PAD). Additionally, because thermistor data were available for 2008 for CR-HRU (located just downstream of the Hot Sulphur Springs Resort and ~0.9 river miles downstream of the CR-HSU location), CR-HRU was also included in the evaluation of validation results. All of these thermistor locations are shown on Map 2.

The following subsections present tabular summaries followed hourly temperature plots for the full validation simulation period as well as monthly plots for the key locations of CR-HSU and CR-WFU. Plots of residuals to support trending reviews are also presented.

3.3.2.3 Validation Statistics

The validation statistics of RMSE and MAE were calculated for each station for daily average, daily minimum, and daily maximum temperatures. These results, presented in Table 3, were all below the calibration max target value of 1.5°C. Table 3 also presents R^2 values for the same metrics. R^2 values were greater than 0.89 for daily averages (ranging between 0.89 and 0.97), greater than 0.8 for daily minimums (0.81 to 0.96), and greater than 0.8 for daily maximums (0.82 to 0.95).

Table 3. 2008 Validation Summary Table

		CR-WGD	CR-HSU	CR-HRU	CR-LB	CR-WFU	CR-PAD
Daily Average Temperature	R^2	0.97	0.93	0.94	0.94	0.89	0.91
	RMSE (°C)	0.46	0.66	0.53	0.56	0.91	0.51
	MAE (°C)	0.37	0.51	0.40	0.43	0.76	0.39
Daily Minimum Hourly Temperature	R^2	0.96	0.89	0.89	0.90	0.81	0.87
	RMSE (°C)	0.49	0.75	0.80	0.93	1.16	0.85
	MAE (°C)	0.40	0.63	0.63	0.78	1.00	0.78
Daily Maximum Hourly Temperature	R^2	0.92	0.91	0.95	0.83	0.82	0.85
	RMSE (°C)	0.87	0.94	0.78	1.10	1.04	0.77
	MAE (°C)	0.67	0.76	0.59	0.93	0.92	0.62

3.3.2.3.1 Hourly Temperature Plots- Validation

Figure 30 through Figure 35 show observed and simulated temperature results for the entire validation simulation period at the six target locations. These plots show that the model

captures overall seasonal temperature patterns and amplitudes, including meteorologically-driven shifts (e.g., the temperature dip observed across the system in mid-August).

To support a more detailed review of diurnal patterns in simulated and observed temperatures, monthly plots are presented for the two key locations of CR-HSU and CR-WFU (Figure 36 through Figure 40). Monthly plots are presented for each month for which observed data were available. The remaining monthly plots are presented in Appendix B.

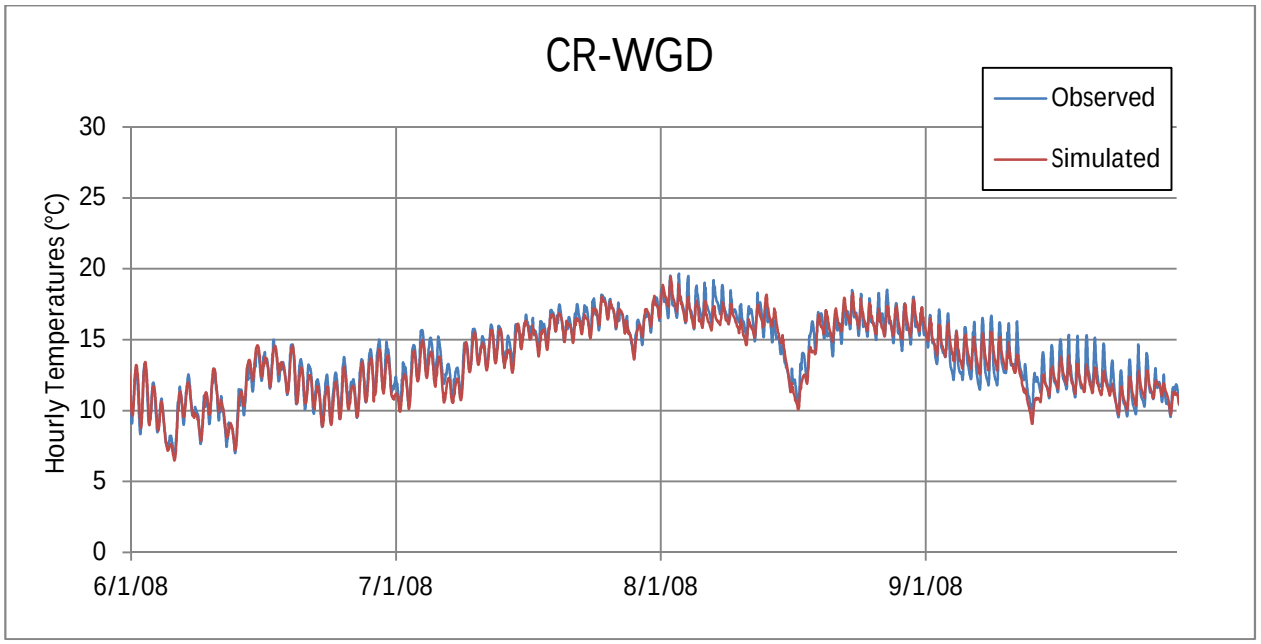

Figure 30. Observed and Simulated Hourly Temperatures at CR-WGD - Validation Run.

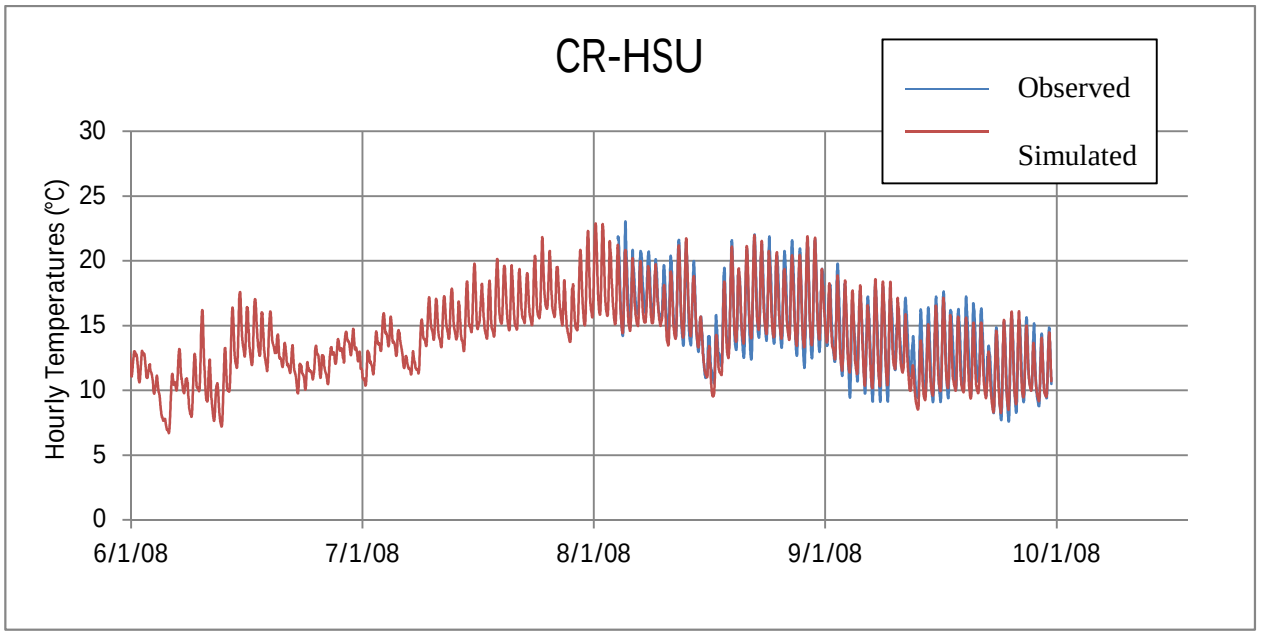

Figure 31. Observed and Simulated Hourly Temperatures at CR-HSU - Validation Run.

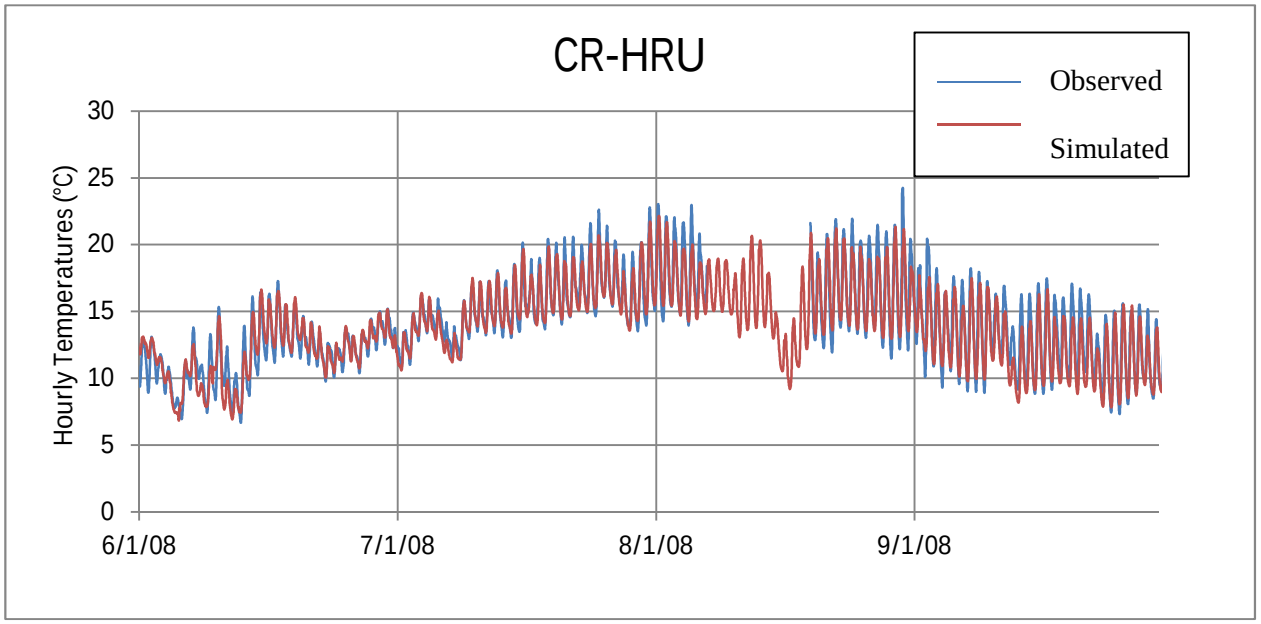

Figure 32. Observed and Simulated Hourly Temperatures at CR-HRU - Validation Run.

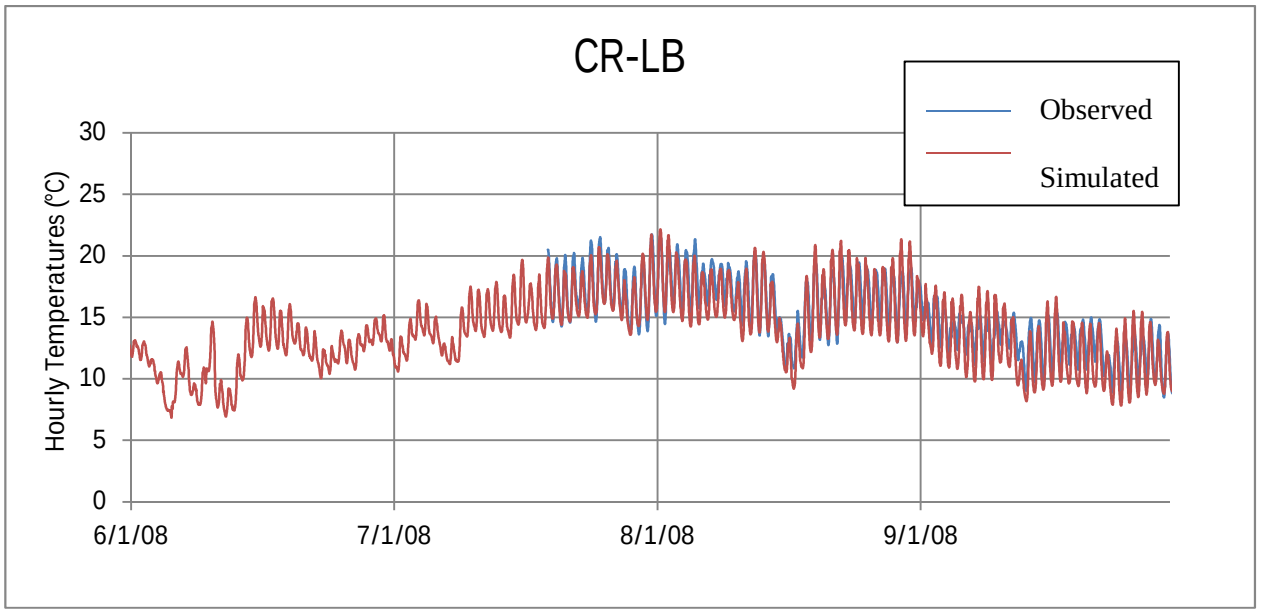

Figure 33. Observed and Simulated Hourly Temperatures at CR-LB - Validation Run.

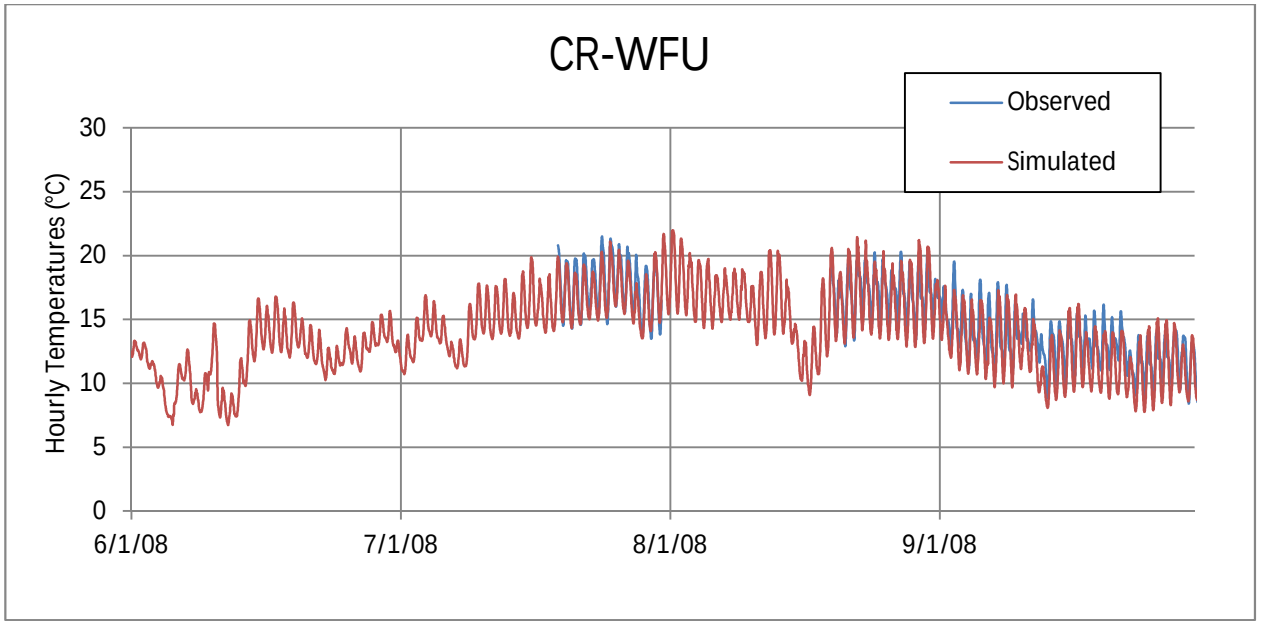

Figure 34. Observed and Simulated Hourly Temperatures at CR-WFU - Validation Run.

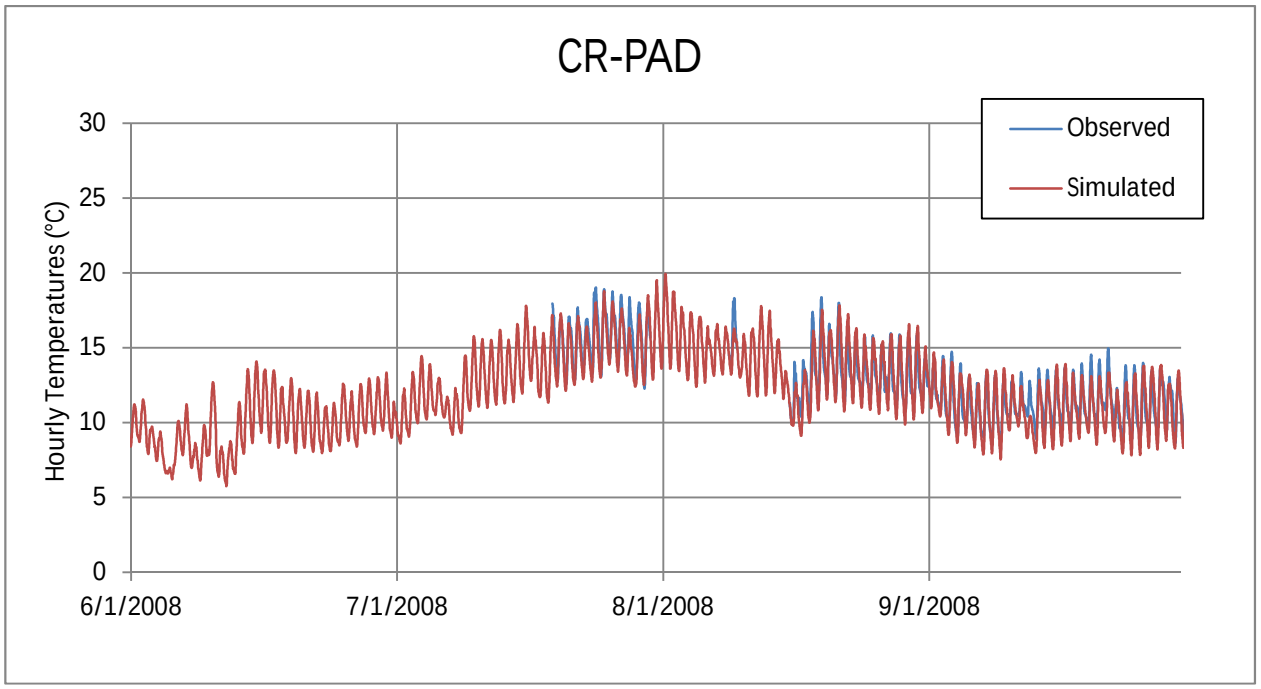

Figure 35. Observed and Simulated Hourly Temperatures at CR-PAD - Validation Run.

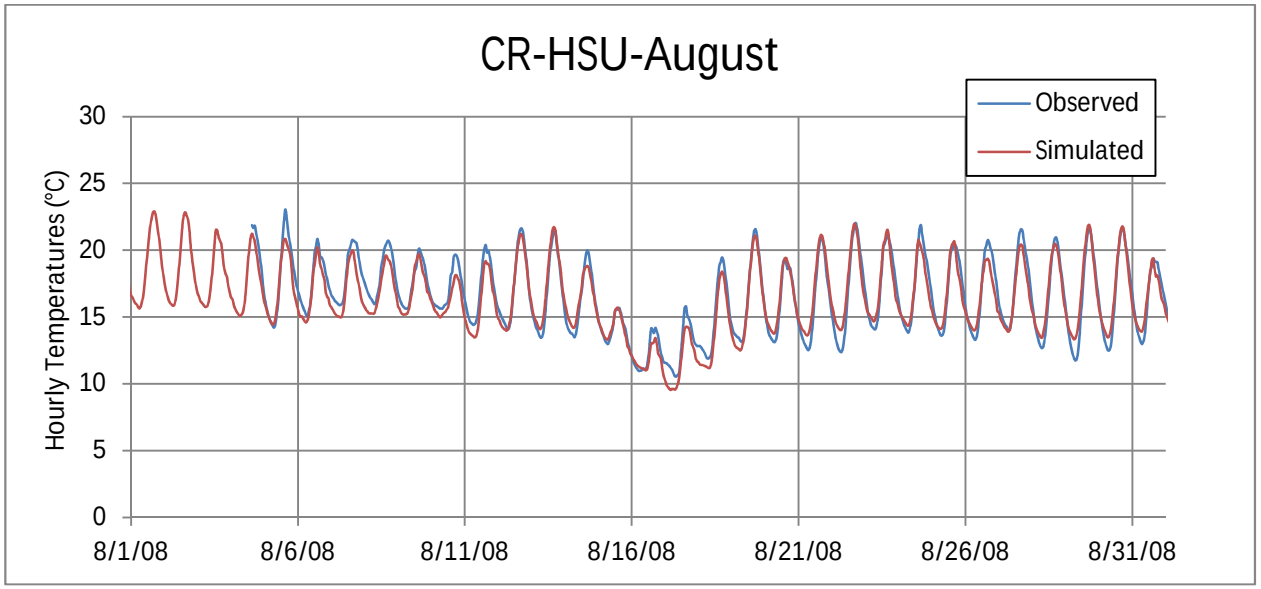

Figure 36. Observed and Simulated Hourly Temperatures at CR-HSU, August - Validation Run.

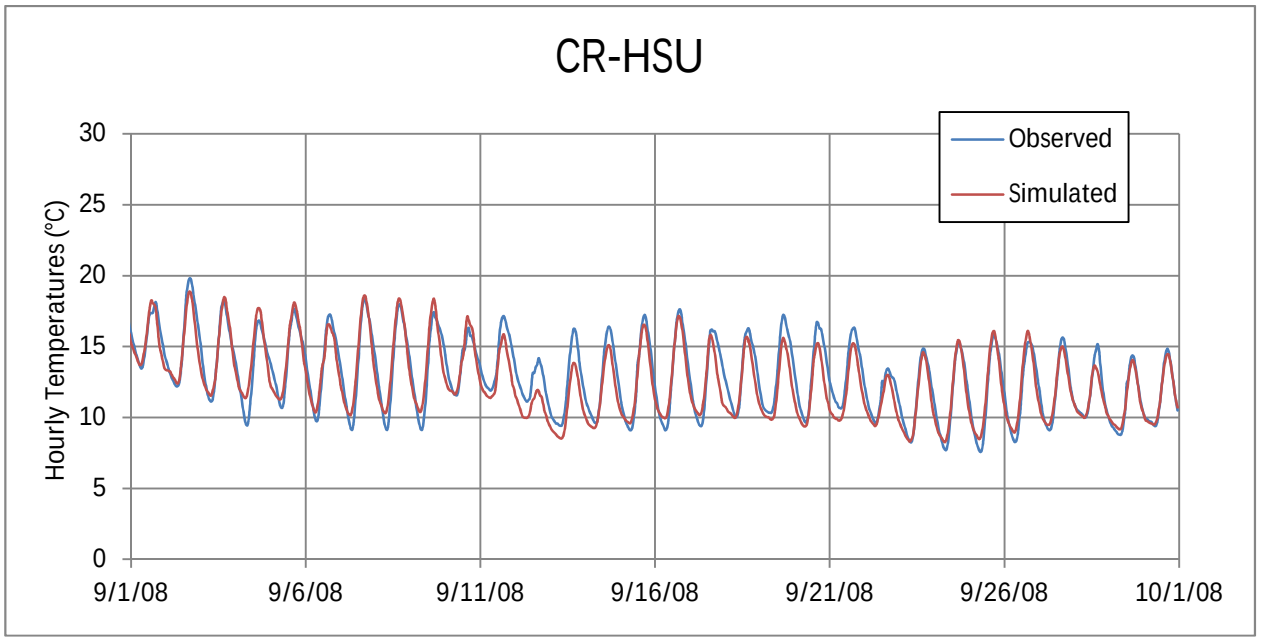

Figure 37. Observed and Simulated Hourly Temperatures at CR-HSU, September - Validation Run.

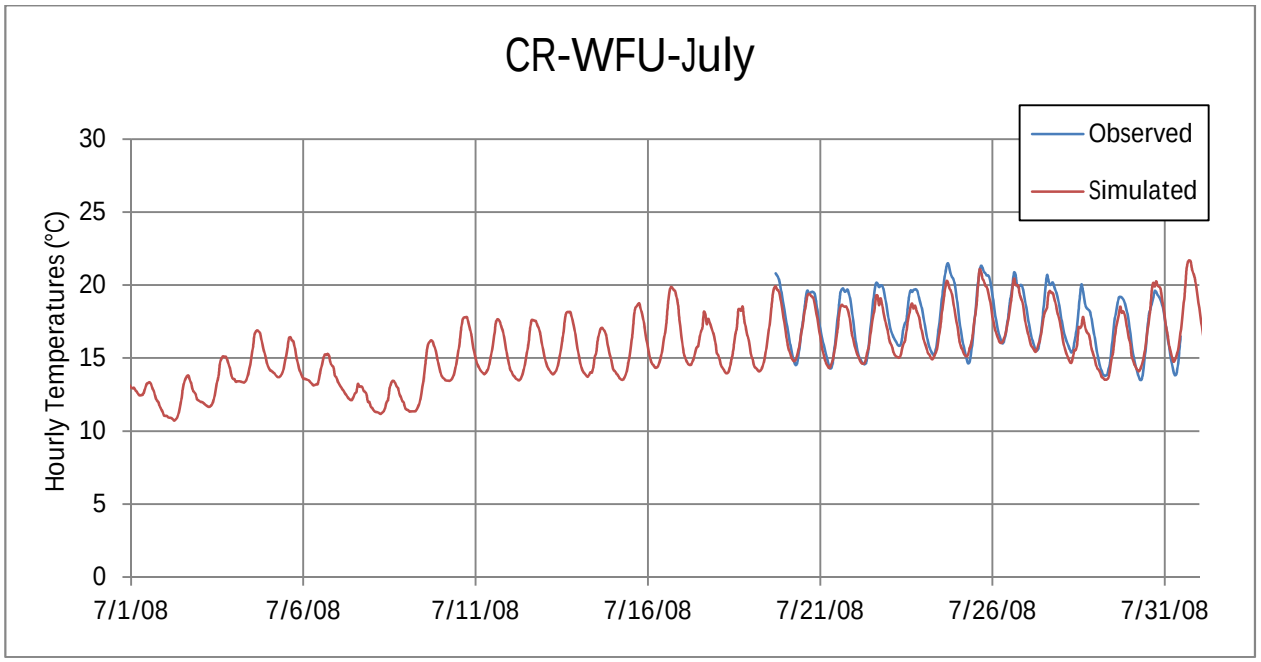

Figure 38. Observed and Simulated Hourly Temperatures at CR-WFU, July - Validation Run.

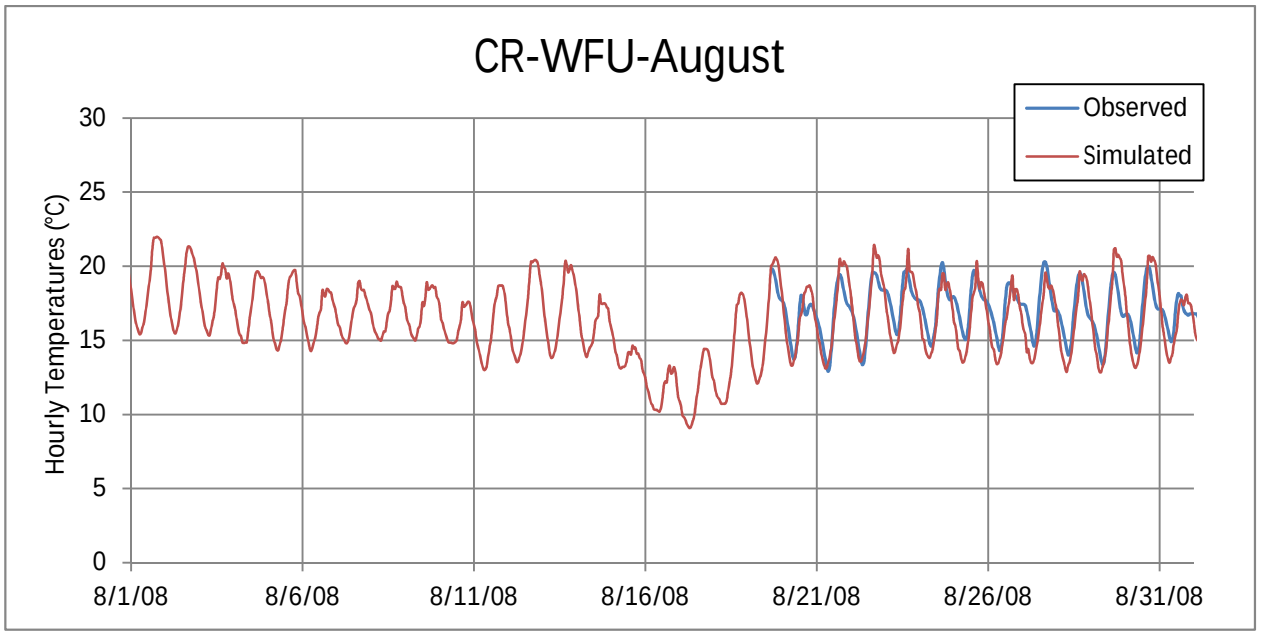

Figure 39. Observed and Simulated Hourly Temperatures at CR-WFU, August - Validation Run.

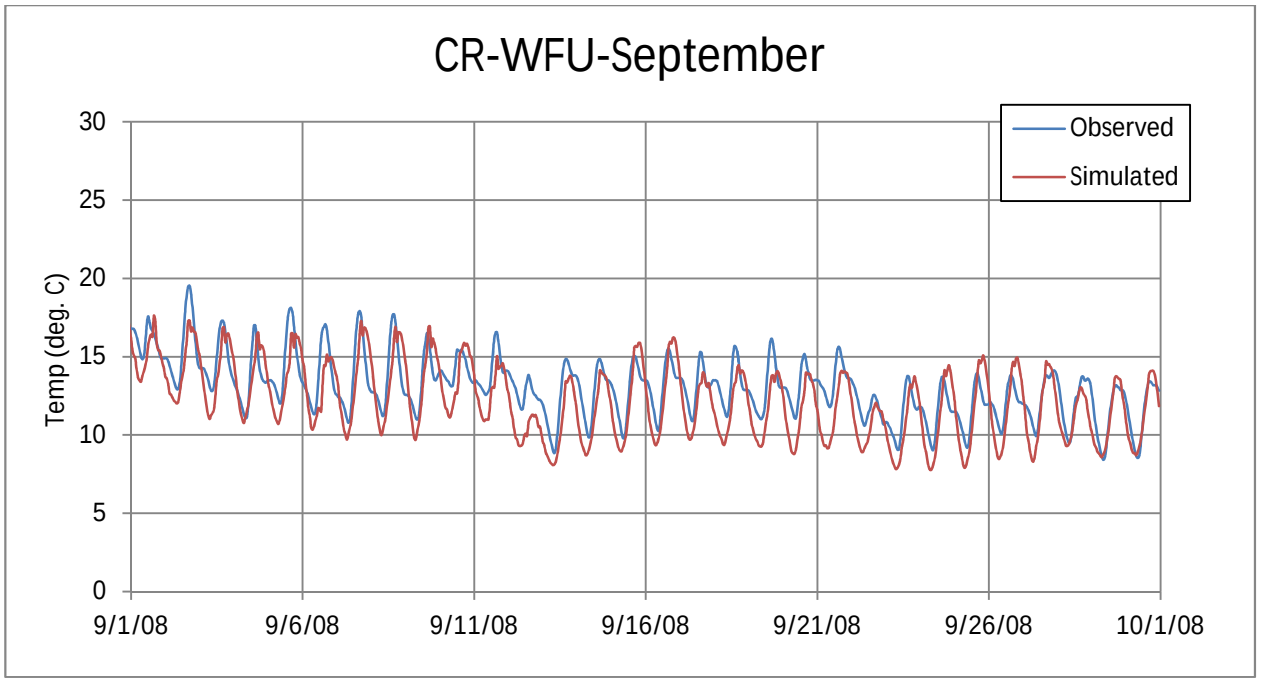

Figure 40. Observed and Simulated Hourly Temperatures at CR-WFU, September - Validation Run.

3.3.2.3.2 Trends and Bias

Daily temperature residuals were plotted over time for each gage to look for any issues of bias or trending (temporally or spatially). Such bias or trending could suggest progressive errors or other issues with model. Figure 41 through Figure 46 present the plots of residuals for the calibration gages plus CR-HRU. Gages are presented in order of upstream to downstream locations. Each gage shows no temporal trends in residuals. Further, the mean error values for the gages do not show any trending spatially (e.g., consistent increasing or decreasing moving downstream).

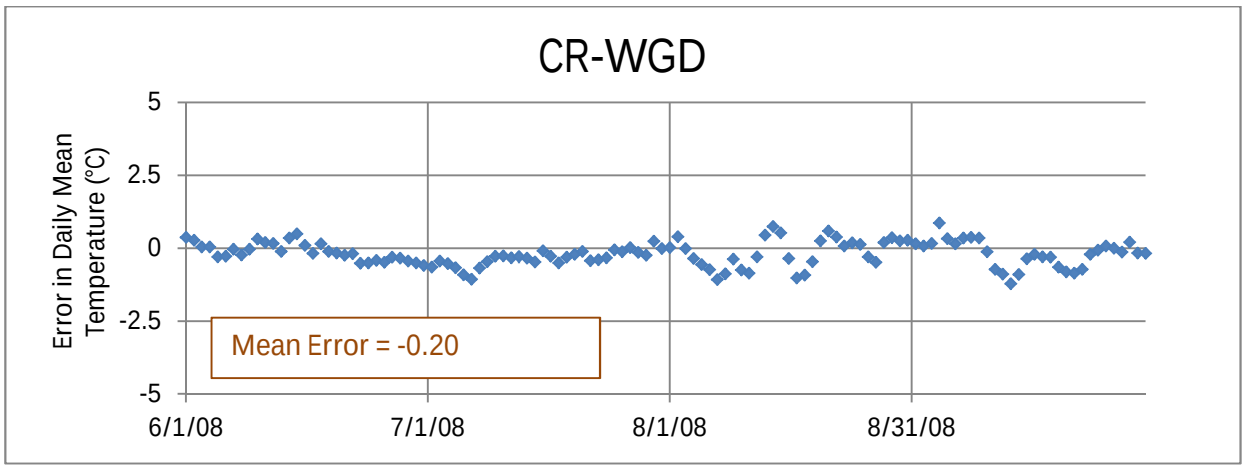

Figure 41. Daily Mean Residuals for Validation - CR-WGD.

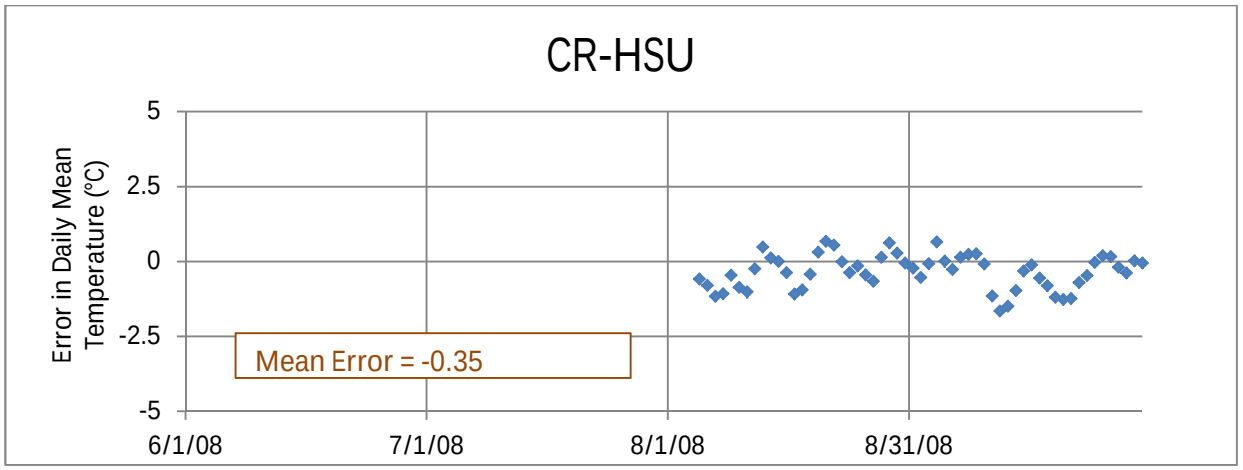

Figure 42. Daily Mean Residuals for Validation - CR-HSU.

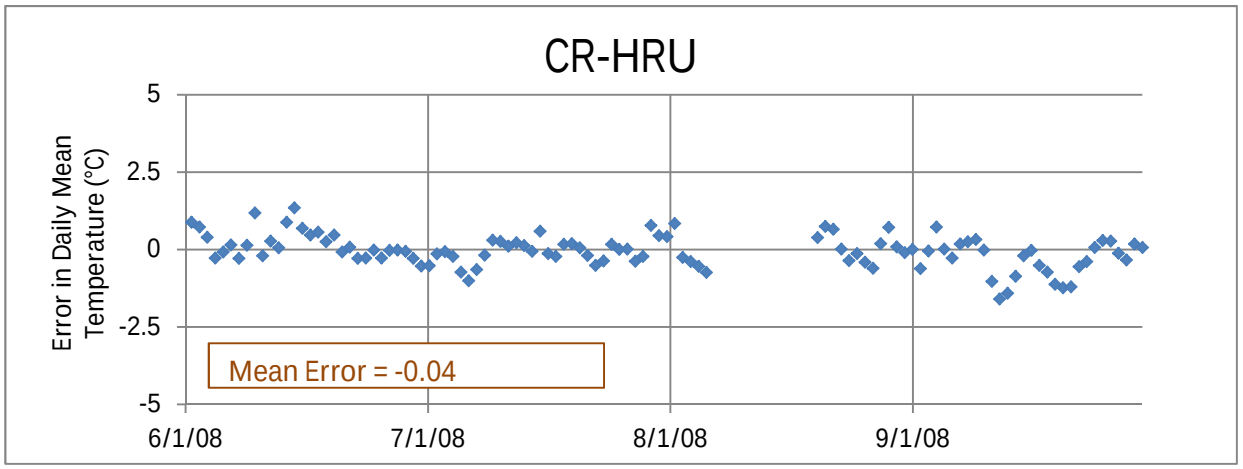

Figure 43. Daily Mean Residuals for Validation - CR-HRU.

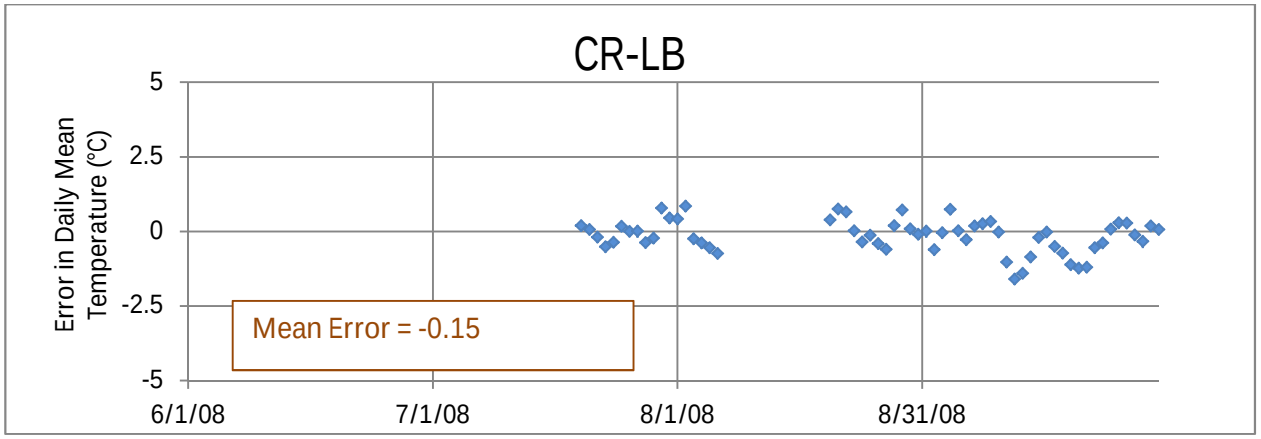

Figure 44. Daily Mean Residuals for Validation - CR-LB.

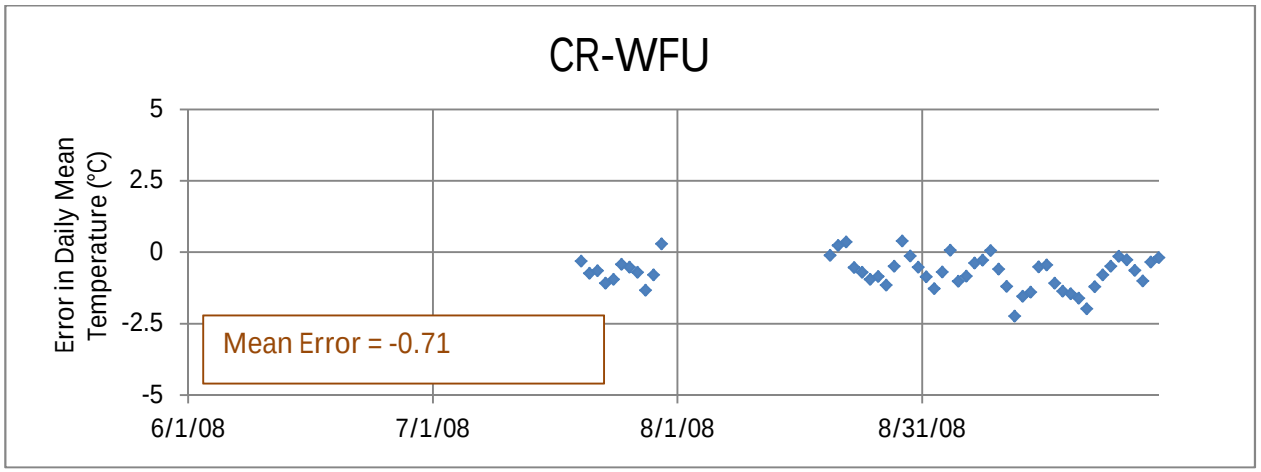

Figure 45. Daily Mean Residuals for Validation - CR-WFU.

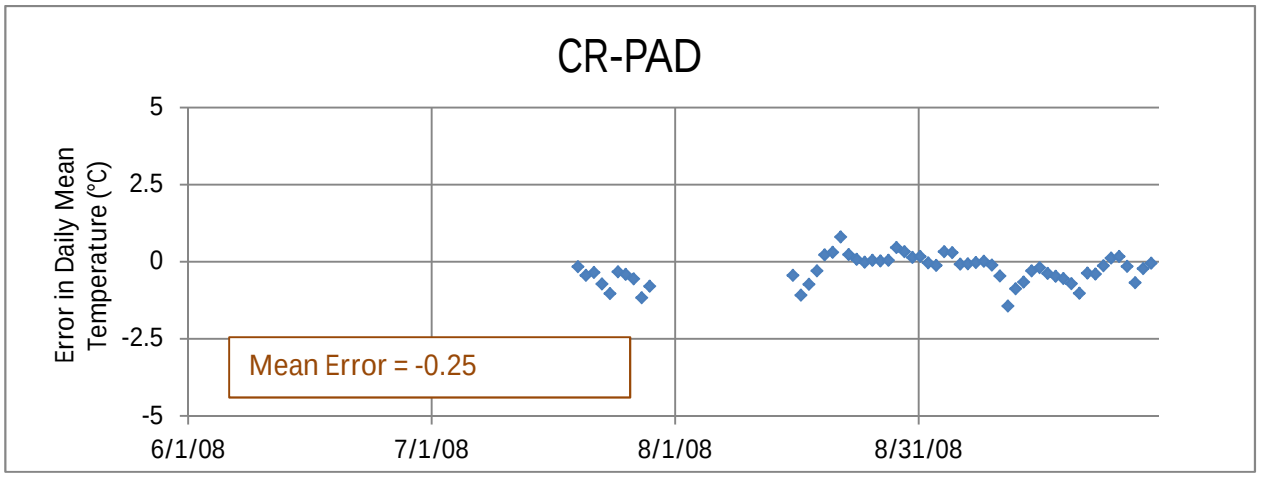

Figure 46. Daily Mean Residuals for Validation - CR-PAD.

To evaluate whether there are any trends in the modeling validation results with temperature (i.e., whether errors increase a higher or lower temperatures), daily residuals from all of the gages were plotted against the corresponding observed temperatures. As shown in Figure 47, there is no clear error trending with temperature.

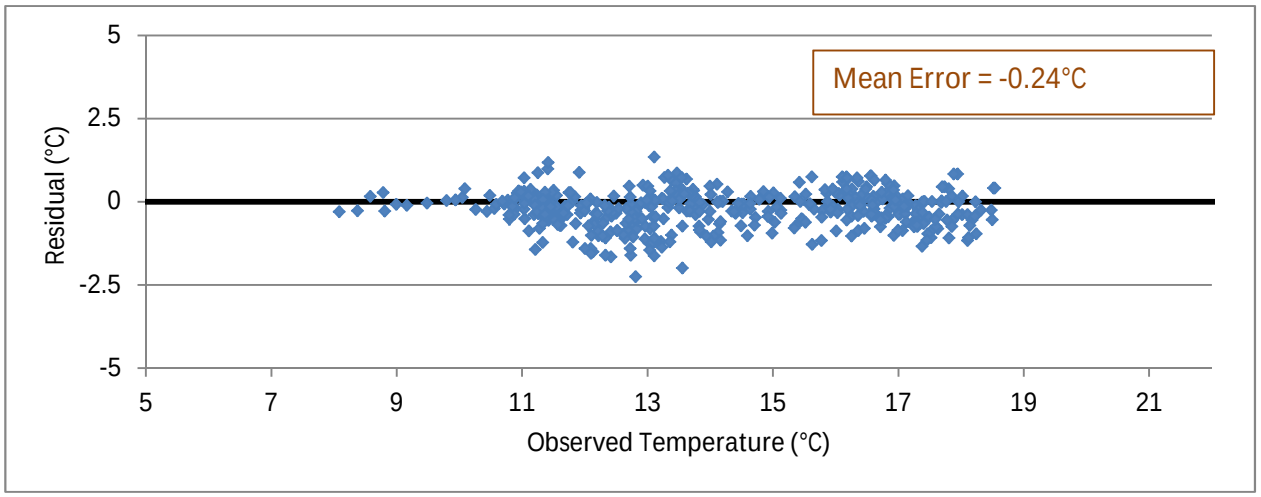

Figure 47. Validation Residuals as a Function of Observed Temperature.

3.3.3 Validation Summary

The 2008 validation run of the model met all calibration targets. The flow simulation reproduced observed hydrographs and stages well, with a low mass balance error. The

temperature model also produced good results. Simulated hourly temperatures capture overall seasonal temperature patterns and amplitudes, including meteorologically-driven shifts. Diurnal ranges and patterns are also well simulated. RMSE and MAE values for daily averages, daily maximums, and daily minimums were all below the target value of 1.5°C at all six evaluation gages. Additionally, R^2 values for observed and simulated temperatures were between 0.81 and 0.97 for gages between Windy Gap Reservoir and Williams Fork. Finally, plots of residuals show no trends with space, time, or temperature-values, suggesting no major progressive or systematic errors. Based on these results, the model will be used to simulate hourly river temperatures for this reach of the upper Colorado River from June through September for comparison of the alternatives.

4 MODEL APPLICATION

The calibrated and validated dynamic temperature model for the upper Colorado River was applied to evaluate the potential effects on river temperatures of the proposed action alternative (Alt2) relative to no action and existing conditions. Alternative 5 (Alt5) was also evaluated to provide some insight on the potential temperature effects of the other WGFP DEIS alternatives. In agreement with the EPA, the analysis focused on five key years of simulated hydrology (1975, 1979, 1986, 1987, and 1988)[11], applying 2007 meteorology to all simulations. These five years represent the only years in the 15-year simulated daily hydrology[12] that are expected to exhibit possible river temperature increases due to the proposed alternative. Other years in the fifteen year period either exhibit no differences in pumping from Windy Gap or have very high flow rates during critical months and would not be expected to have temperature concerns. Daily hydrologic model results from the Windy Gap Firming Project Hydrologic Model (provided by H. Thompson), including diversions and gains/losses, provided the input hydrology. The 2007 meteorology was selected because it was the warmest of the five years of complete record available (see Figure 1 and Figure 2).

Both direct effects and cumulative effects were simulated. Direct effects and cumulative effects alternatives and assumptions are described in detail in the WGFP DEIS (U.S. DOI BOR, 2008), and only discussed generally in Sections 4.1 and 4.2. The matrix of the 30 model application simulations for the dynamic temperature model is shown in Table 4.

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[11] The water-quality analyses completed for the WGFP have focused on a 15-year period (WY1975-WY1989). These 15 years contain dry, wet, and average conditions. The dynamic temperature model focuses on five of the 15 years (1975, 1979, 1986, 1987, and 1988). The other years are not included because they were either (1) years where Windy Gap pumping is the same for Existing Conditions, the Preferred Alternative, and Alternative 5 or (2) years where the flows in the Colorado River for the alternatives are very high and should not be problematic from a temperature standpoint.

[12] The 15-year period (WY1975 – WY1989) was selected as a focus period for WGFP water quality assessments from the overall study period of 47 years (1950-1996). The shorter period was selected because it coincides with a period during which more historic gage data are available for disaggregating monthly data to daily data, resulting in more accurate disaggregation. The period was selected to reflect the range of conditions observed over the full record. .

Table 4. Matrix of Model Application Simulations

		1975	1979	1986	1987	1988
Existing Conditions		✓	✓	✓	✓	✓
Direct Effects	Proposed Action	✓	✓	✓	✓	✓
	No Action	✓	✓	✓	✓	✓
	Alt 5	✓	✓	✓	✓	✓
Cumulative Effects	Proposed Action	✓	✓	✓	✓	✓
	No Action	✓	✓	✓	✓	✓

Modeling results focus on three locations in the river (shown on the modeled 2007 peak temperature profile in Figure 48 and on Map 2):

1. CR-WGD (located ~1 river mile below Windy Gap Reservoir)
2. CR-HSU (located above Hot Sulphur Springs)
3. CR-WFU (located upstream of the confluence with Williams Fork).

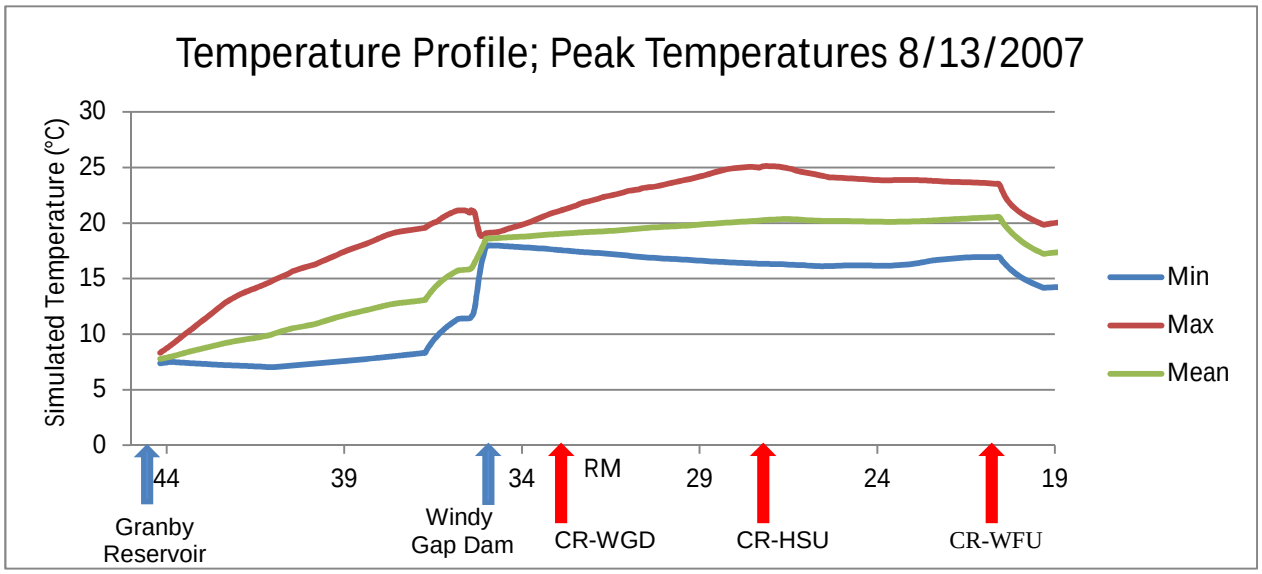

Figure 48. Simulated Temperature Profile on the Upper Colorado River for the Peak Temperatures in 2007 (8/13/2007).

The following subsections present the modeling results by simulation hydrology year. Direct effects and cumulative effects are presented separately, and both include existing conditions and the relevant no action simulation for comparisons. Each presentation of results includes hydrographs of hydrology below Windy Gap Reservoir and hydrographs of Windy Gap pumping. Simulated temperature results are presented in hourly plots. Regulatory reviews of weekly average temperatures (WATs) and daily maximums (DMs) are presented graphically and tabularly. All WATs and DMs were calculated using the appropriate Colorado Water Quality Control Division tool (CWQCD Temp-program-V4.2; personal communication, Robert Hillegas, May 24, 2011). In accordance with Regulation 31 (WQCD, 2010a), DMs are the highest two-hour average water temperature recorded during a given 24-hour period. In accordance with CWQCD tool output units, WAT exceedance results are presented in terms of weeks. As such, a one week WAT exceeedance is indicated if even one day in a given week has a seven day rolling average WAT exceedance.

4.1 DIRECT EFFECTS

The following subsections present the results for direct effects simulations of 1975, 1979, 1986, 1987, and 1988 hydrology scenarios under conditions of 2007 meteorology. Direct effects simulations assess river temperature effects attributable to project alternatives. Alternatives simulated with the dynamic temperature model to evaluate direct effects include:

- Existing Conditions – River temperatures are simulated for the hydrology of the key years, overlaying current water use demands and operations.
- No Action - Direct Effects (DE-NA) – River temperatures are simulated for the hydrology of the key years, overlaying actions that will be taken by the Participants if Reclamation does not approve a new connection of WGFP facilities to Colorado Big Thompson (C-BT) facilities. Specifically, no action includes continuation of operations under existing agreements for conveyance of Windy Gap water through C-BT facilities, as well as the enlargement of Ralph Price Reservoir by the City of Longmont.
- Alternative 2 - Direct Effects (DE-Alt2) - River temperatures are simulated for the hydrology of the key years, overlaying actions and operations of the proposed action alternative. Specifically, the proposed action includes increased diversions from Windy Gap and construction of a 90,000 AF Chimney Hollow Reservoir with prepositioning to allow storage of C-BT water in Chimney Hollow.
- Alternative 5 - Direct Effects (DE-Alt5) - River temperatures are simulated for the hydrology of the key years, overlaying actions and operations of the WGFP DEIS alternative 5. Specifically, the alternative 5 includes increased diversions from Windy Gap and a 60,000 AF Dry Creek Reservoir and a 30,000 AF Rockwell Reservoir.

For each simulation year, graphics are presented for input hydrology, hourly temperature output, WATs, and DMs. Tabular summaries of simulated temperature differences for alternatives relative to existing conditions and no action simulations are also presented.

4.1.1 1975 Direct Effects

The results of direct effects simulations applying 1975 hydrology scenarios under conditions of 2007 meteorology are presented in the following subsections. Direct effects simulations for 1975 included existing conditions, no action, Alt2, and Alt5.

4.1.1.1 1975 Direct Effects Hydrographs

Figure 49 and Figure 50 present the differences in pumping at Windy Gap and the corresponding flow below Windy Gap Reservoir for the direct effects alternatives simulated – existing conditions, no action, alternative 2, and alternative 5. Windy Gap pumping volumes (June through September) are summarized for each simulation in Table 5.

Overall, 1975 was an average year, with virgin annual flows[13] ranking 23rd out of the 47 years of hydrology simulated for the WGFP. For the 1975 Direct Effects simulations, Windy Gap pumping and river flows are nearly identical in June, August, and September for existing conditions, no action, Alt2, and Alt5. In July, no action, Alt2, and Alt5 show higher levels of pumping (7,000 AF, 18,000 AF, and 18,000 AF more pumping than existing conditions, respectively). Correspondingly, flows below Windy Gap Reservoir are lower in July for no action, Alt2, and Alt5, as compared to existing conditions (Figure 50).

[13] Virgin annual flows refer to flows at the USGS gage below Granby Reservoir. Virgin flows are defined as gaged flows plus adjustments for reservoir releases and filling, diversions, gaged inflows, trans-basin imports, and irrigation or other returns to the river. It reflects the hydrology that existed prior to the development of water supply systems, or the hydrology that would exist if the impacts of water diversions, reservoirs, and return flows were removed.

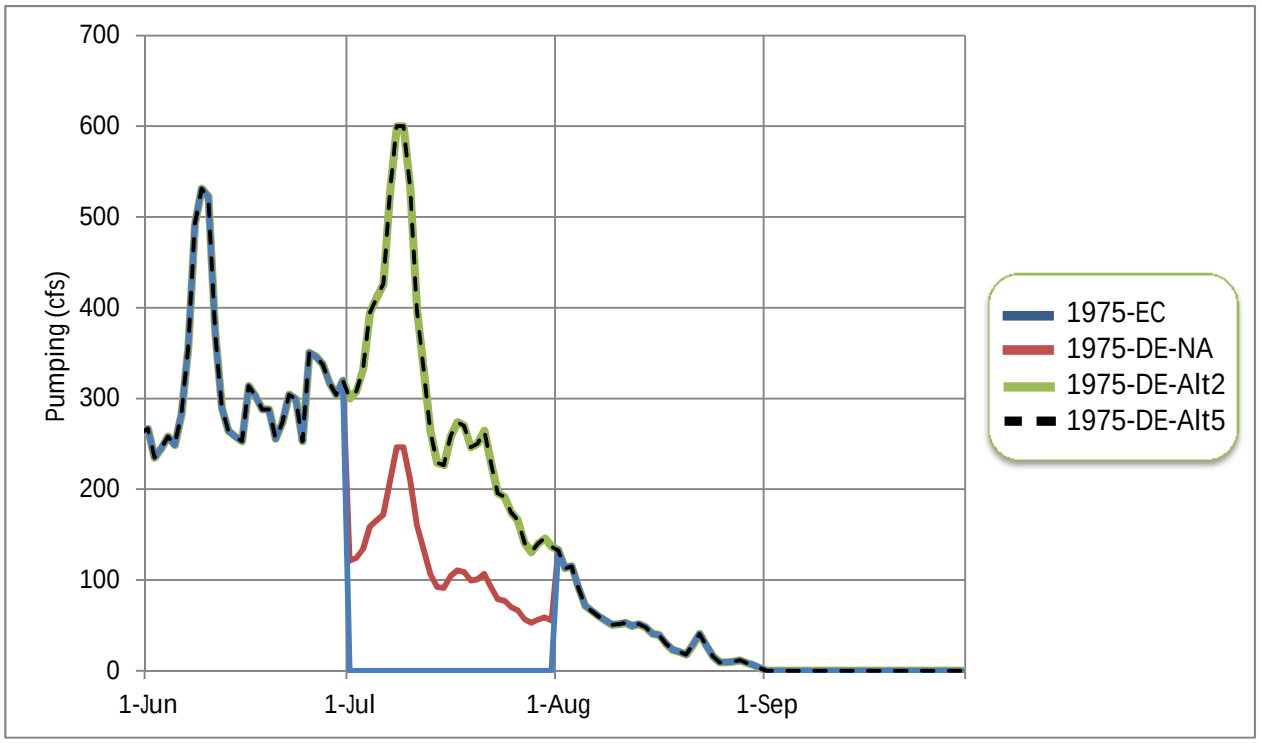

Figure 49. 1975 Direct Effects Windy Gap Pumping.

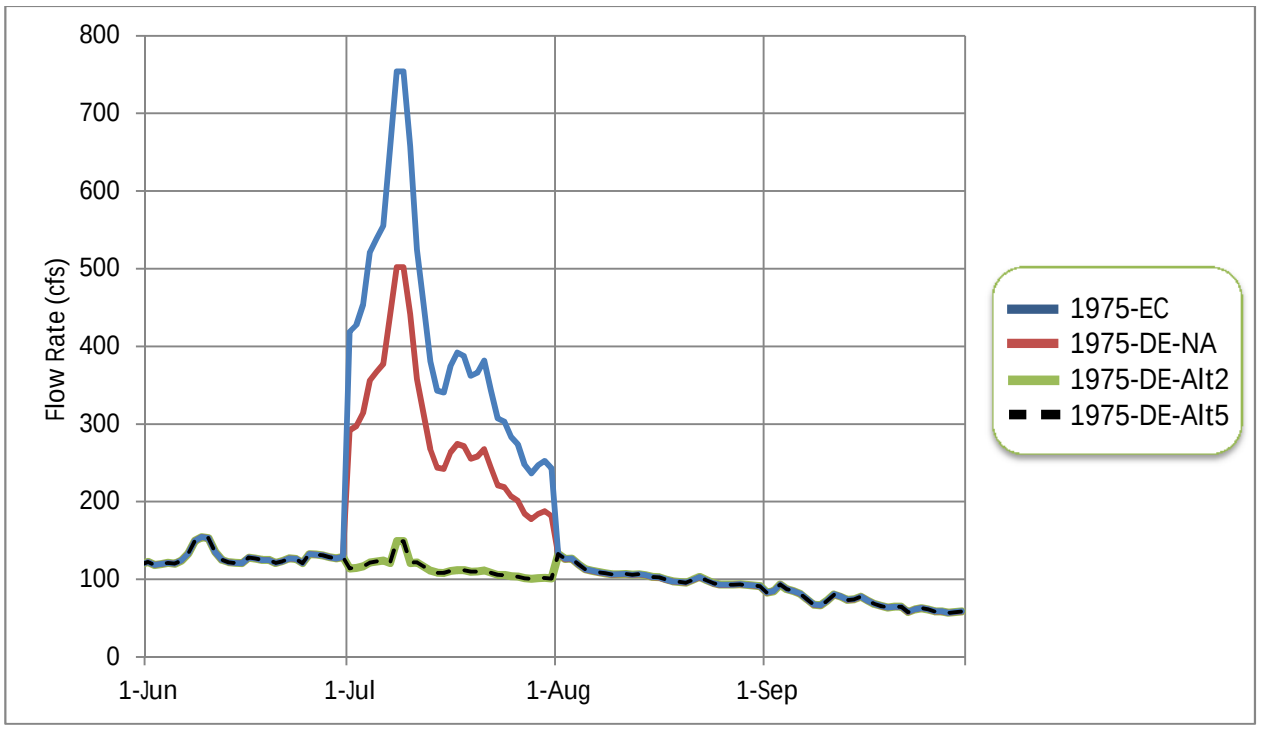

Figure 50. 1975 Direct Effects Flow Rates Below Windy Gap.

Table 5. 1975 Direct Effects Windy Gap Pumping Volumes.

	1975-DE Monthly Pumping Totals (AF/month)			
	June	July	August	September
Existing Conditions	18,700	0	2,693	0
No Action	18,700	7,271	2,693	0
Alternative 2	18,700	18,032	2,670	0
Alternative 5	18,700	18,032	2,670	0

4.1.1.2 1975 Direct Effects Hourly Temperature Plots

Figure 51 through Figure 56 present the hourly temperature plots produced by the model for thermistor locations CR-WGD, CR-HSU, and CR-WFU. Hourly temperature plots for the full simulation period are shown, as well as plots focusing on the period of the simulation with notable differences in predicted temperatures. For 1975 direct effects simulations, that period is July, which corresponds to the period of greater pumping for no action and the alternatives relative to existing conditions.

At all three locations, temperature patterns for Alt2 and Alt5 are the same due to matching Windy Gap pumping. The no action simulation shows higher daily peak temperatures than existing conditions, but lower daily maximum temperatures than Alt2 and Alt 5, corresponding to the relative pattern of flow below Windy Gap Reservoir (Figure 50). In general, it is apparent from review of the "July Zoom" figures that the reduction of flow rates (in the range simulated) causes a greater relative increase on the upper range of daily temperatures (during daylight hours), with only small changes in evening temperatures. This pattern is apparent across all simulation results, reflecting the strong influence of water depth on heating by solar radiation, which only occurs during daylight hours. In contrast, small changes to water depth do not have as much of an effect on temperatures at night, when river temperatures are more strongly a function of bed heat capacity and transfer characteristics and air temperatures. The 1975 direct effects temperature simulation results are summarized and discussed quantitatively in Section 4.1.1.3.

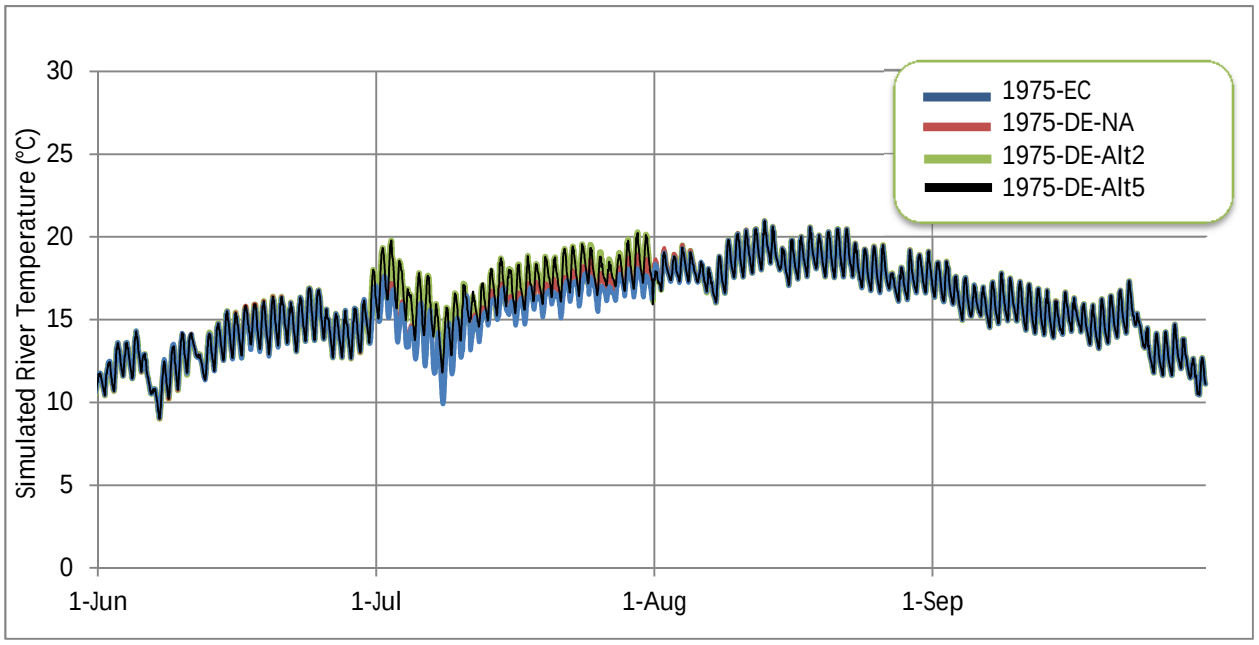

Figure 51. 1975 Direct Effects Hourly Temperature at CR-WGD.

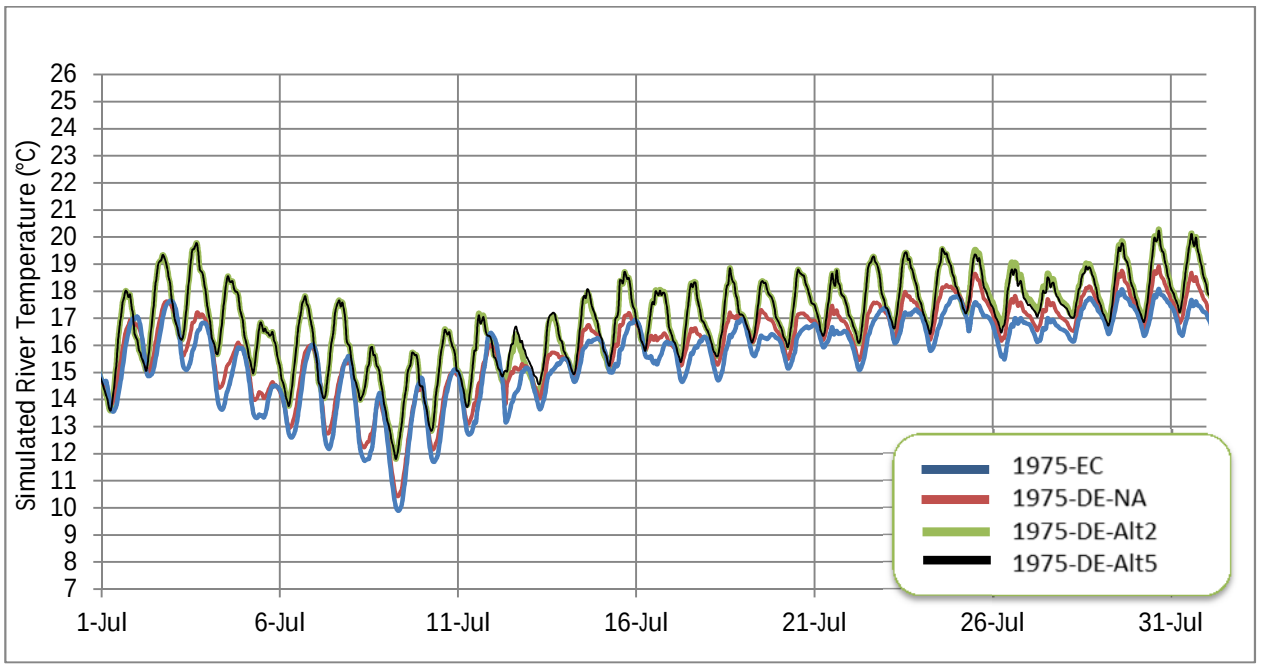

Figure 52. 1975 Direct Effects Hourly Temperature at CR-WGD- July Zoom.

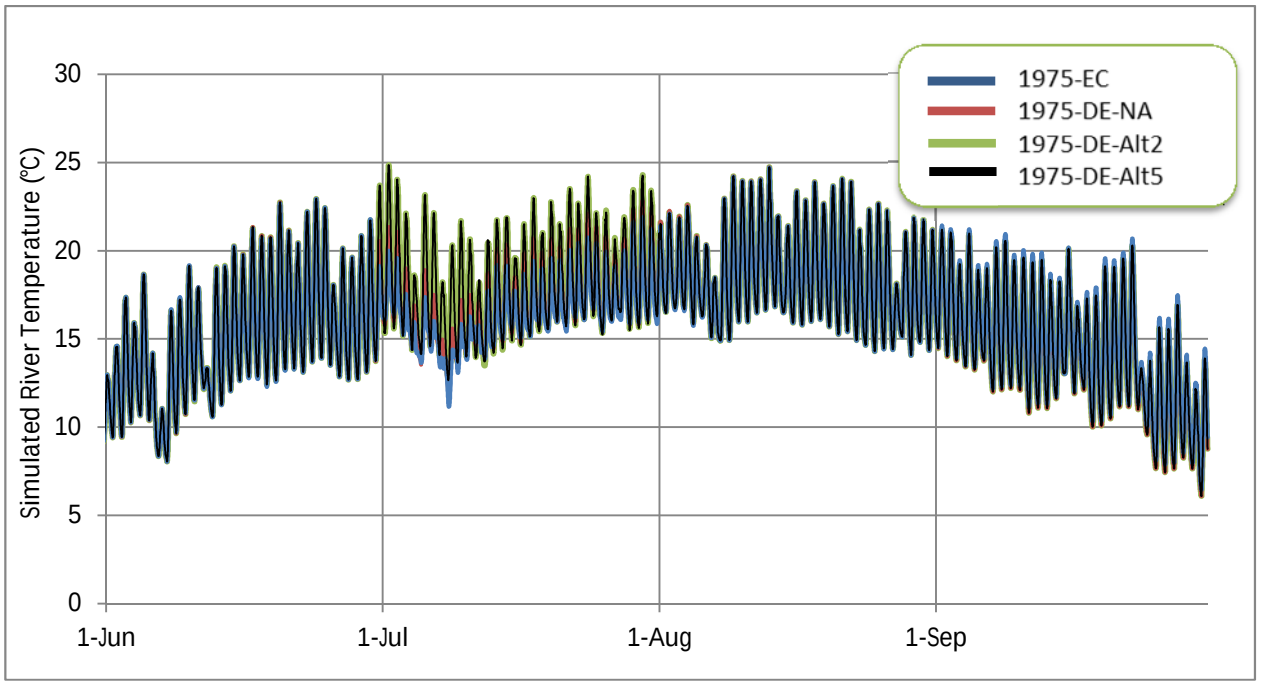

Figure 53. 1975 Direct Effects Hourly Temperature at CR-HSU.

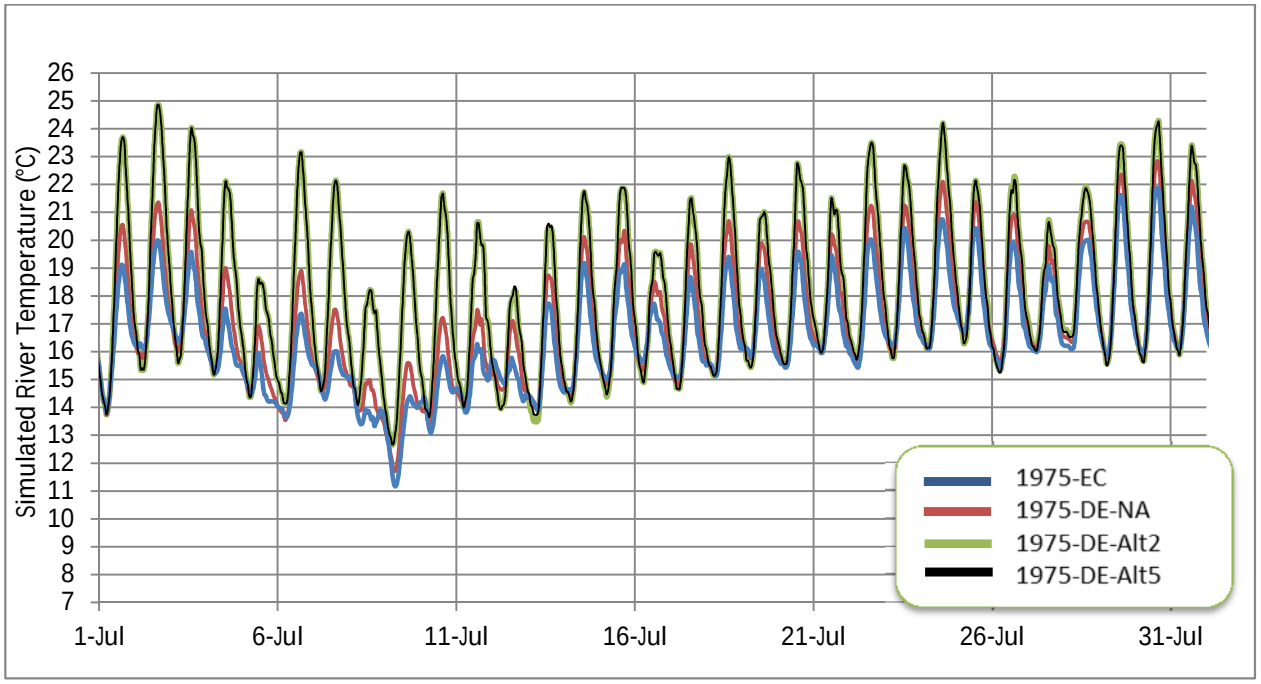

Figure 54. 1975 Direct Effects Hourly Temperature at CR-HSU – July Zoom.

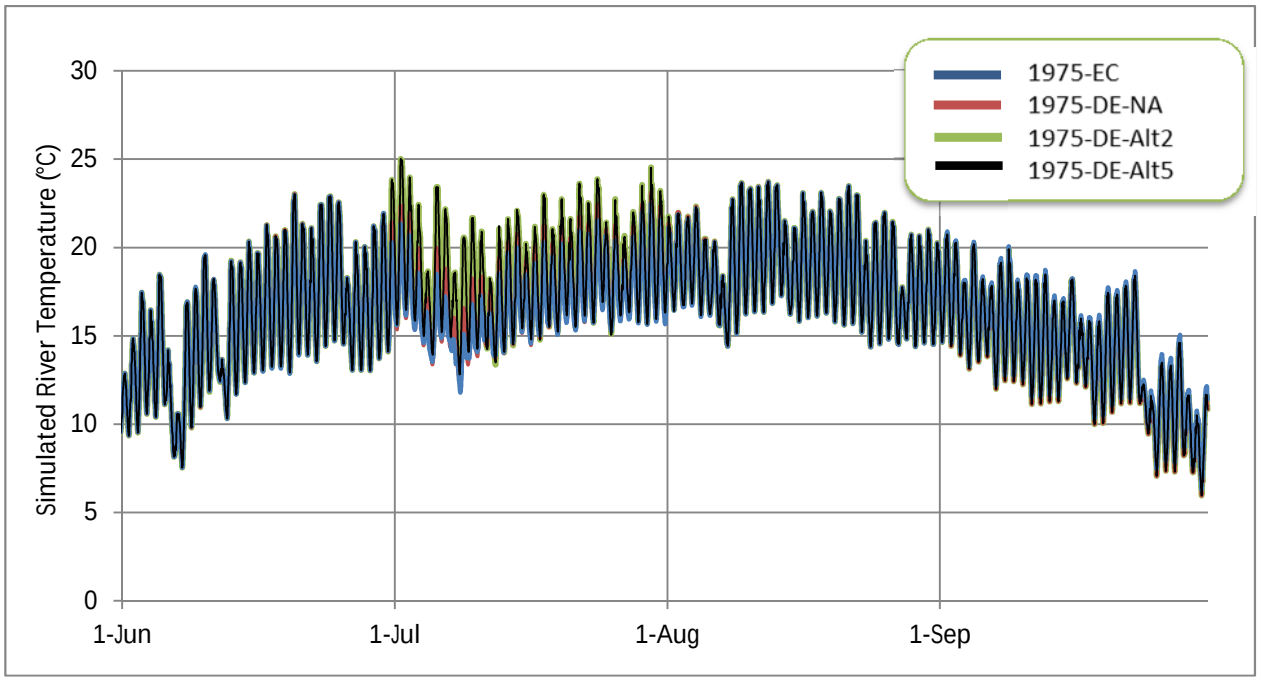

Figure 55. 1975 Direct Effects Hourly Temperature at CR-WFU.

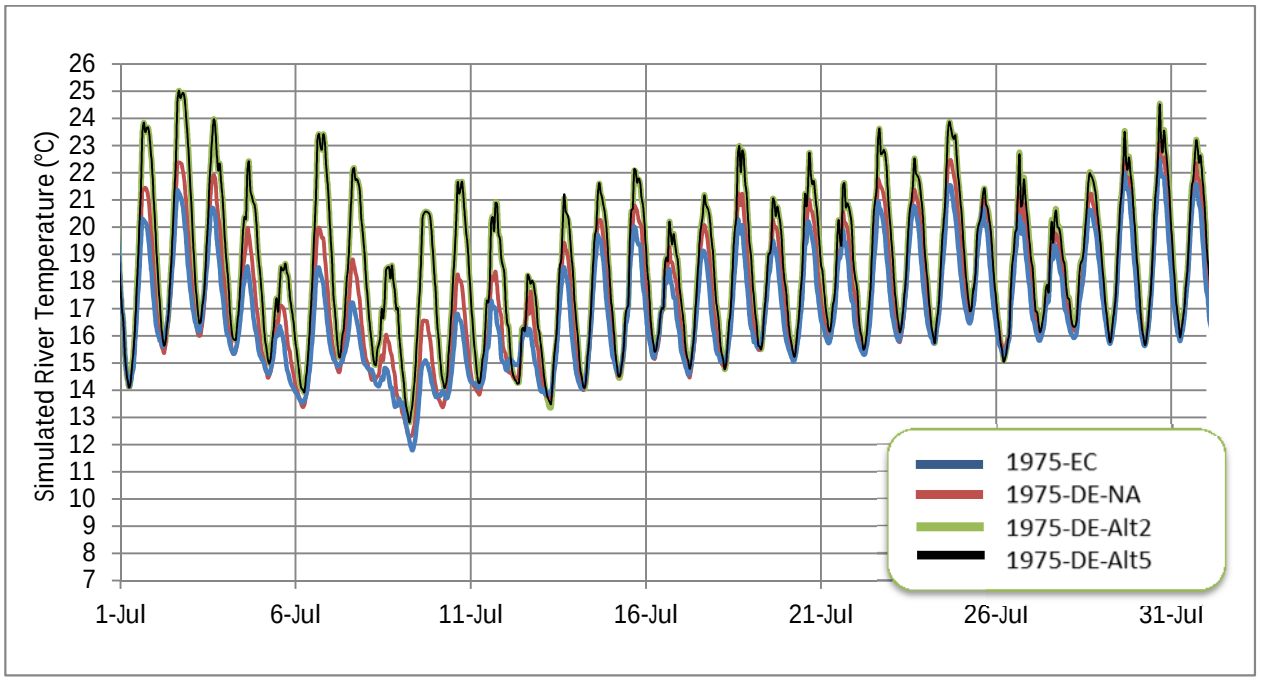

Figure 56. 1975 Direct Effects Hourly Temperature at CR-WFU- July Zoom.

4.1.1.3 1975 Direct Effects Weekly Average and Daily Maximum Temperatures

WATs and DMs were all calculated using the appropriate Colorado Water Quality Control Division tool (Temp-program-V4.2; personal communication, Robert Hillegas, May 24, 2011) for this segment of the upper Colorado River. Figure 57 through Figure 59 present WATs for each simulated day, following the first week of simulation. DMs are presented for each simulated day in Figure 60 through Figure 62. These figure sets show results for thermistor locations CR-WGD, CR-HSU, and CR-WFU.

Direct effects WATs and DMs show similar patterns. Alt2 and Alt5 results are nearly identical, due to matching pumping patterns from Windy Gap for the simulation period in 1975. In July, WATs and DMs for Alt2 and Alt5 are greater than those for no action and existing conditions, corresponding to the increased pumping at Windy Gap at that time for these alternatives. Likewise, the WATs and DMs for no action are slightly greater than those for existing conditions in July, due to slightly greater pumping from Windy Gap. Though the pumping differences end in July, the effect on WATs extends into the first week of August due to the rolling average calculation of WATs.

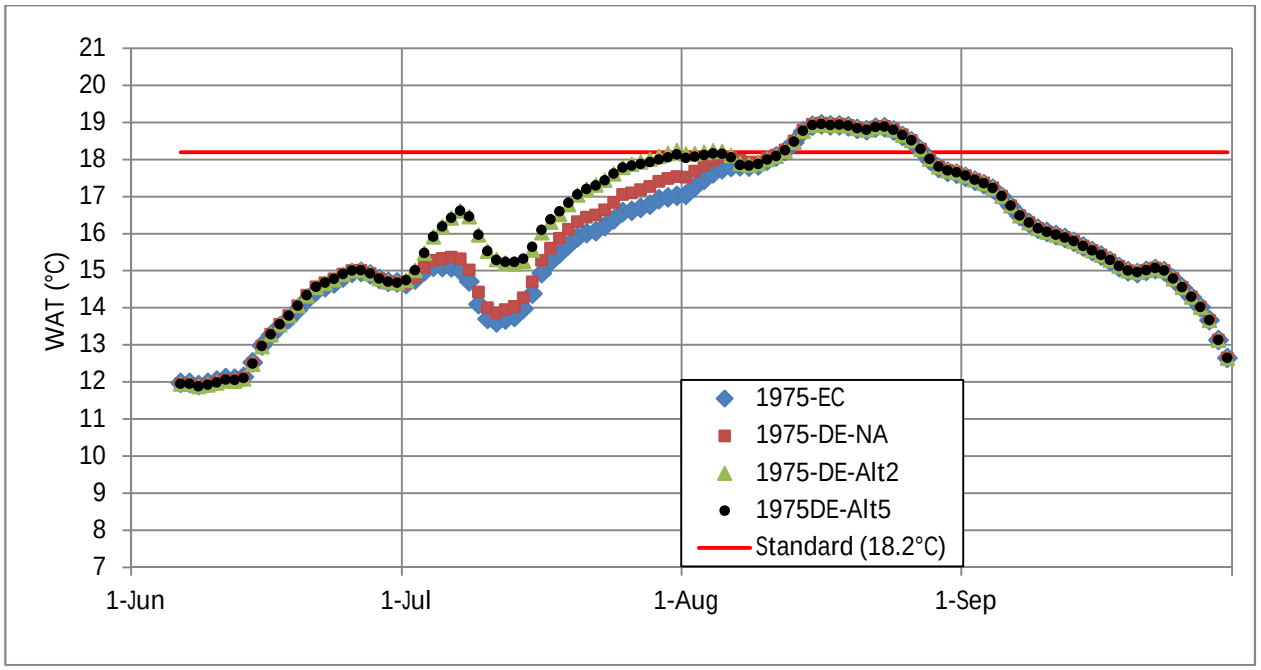

Figure 57. 1975 Direct Effects WATs at CR-WGD.

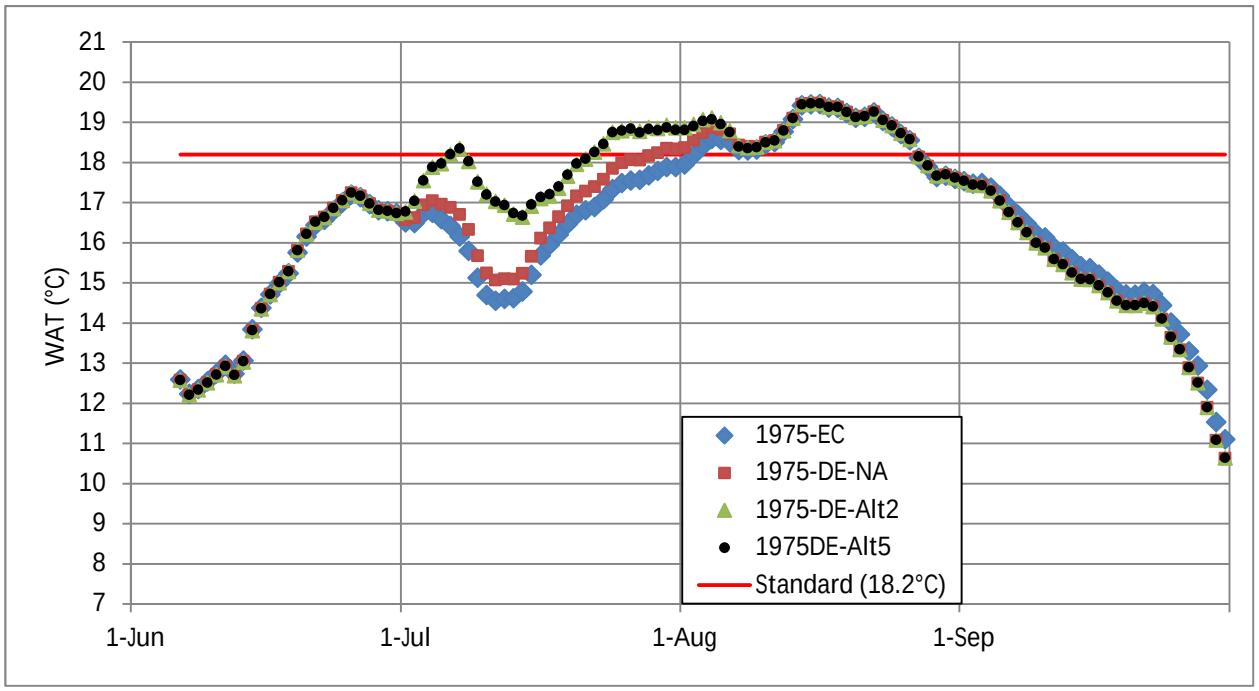

Figure 58. 1975 Direct Effects WATs at CR-HSU.

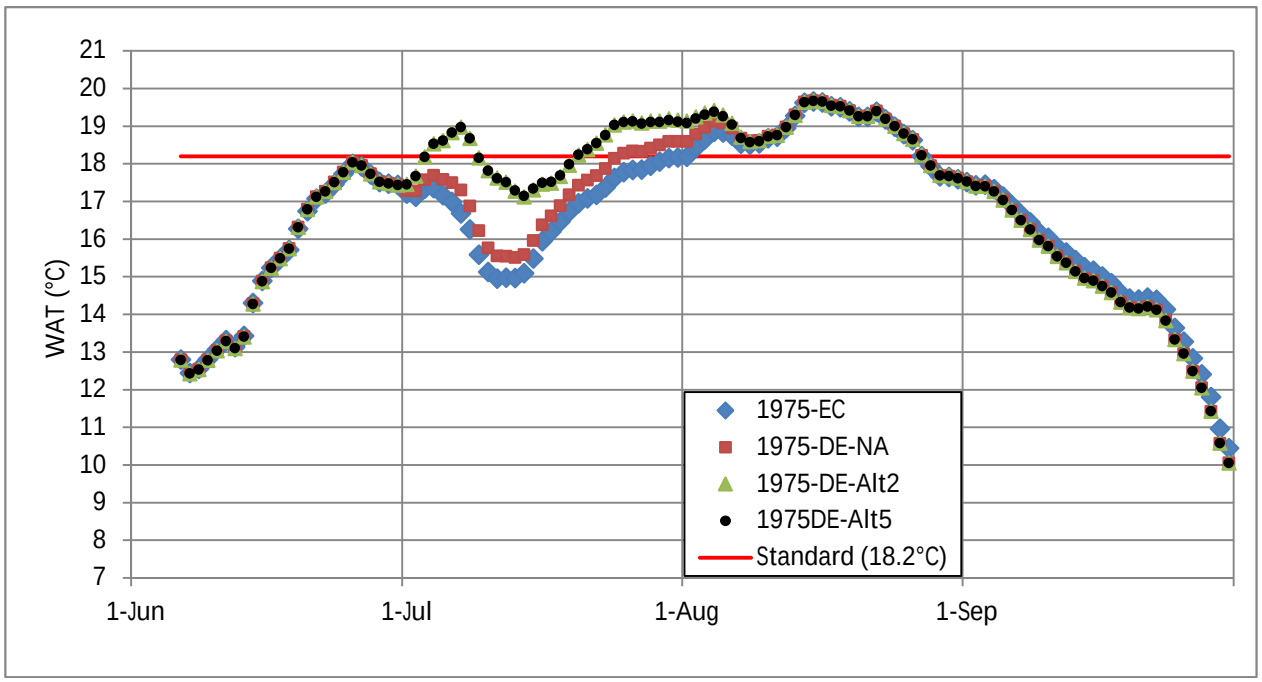

Figure 59. 1975 Direct Effects WATs at CR-WFU.

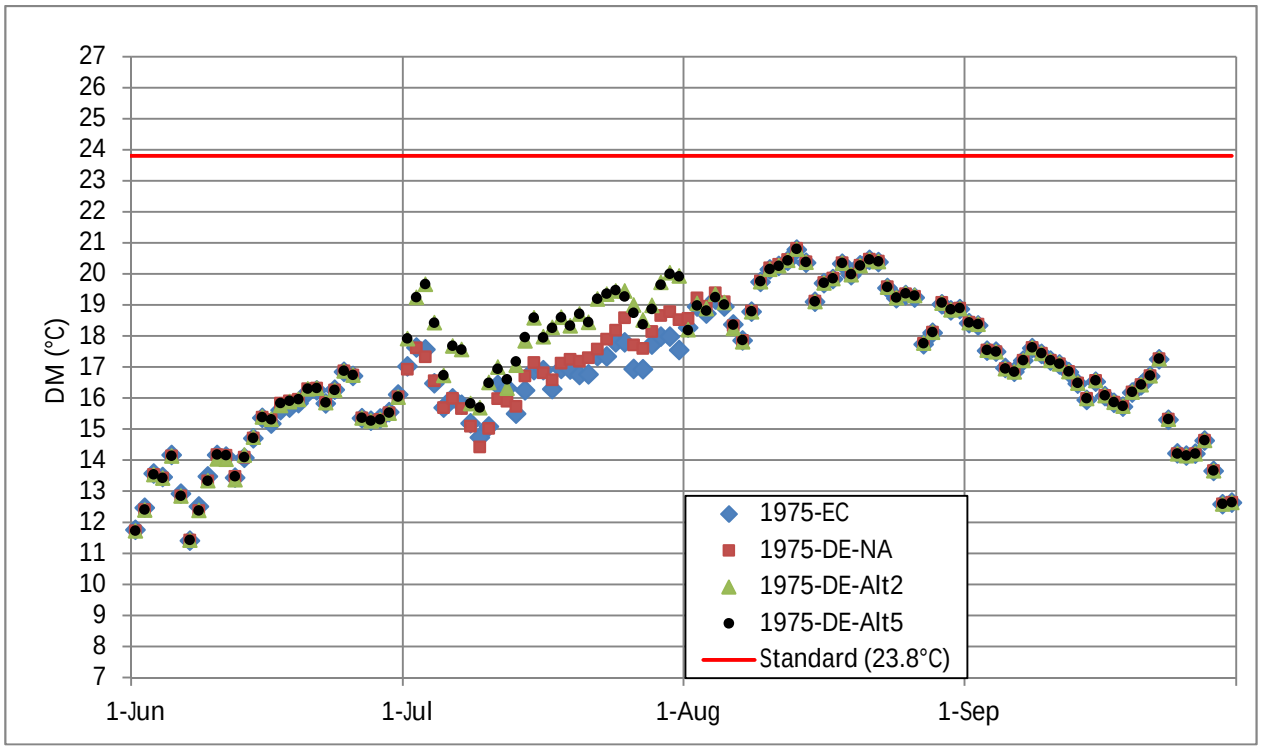

Figure 60. 1975 Direct Effects DMs at CR-WGD.

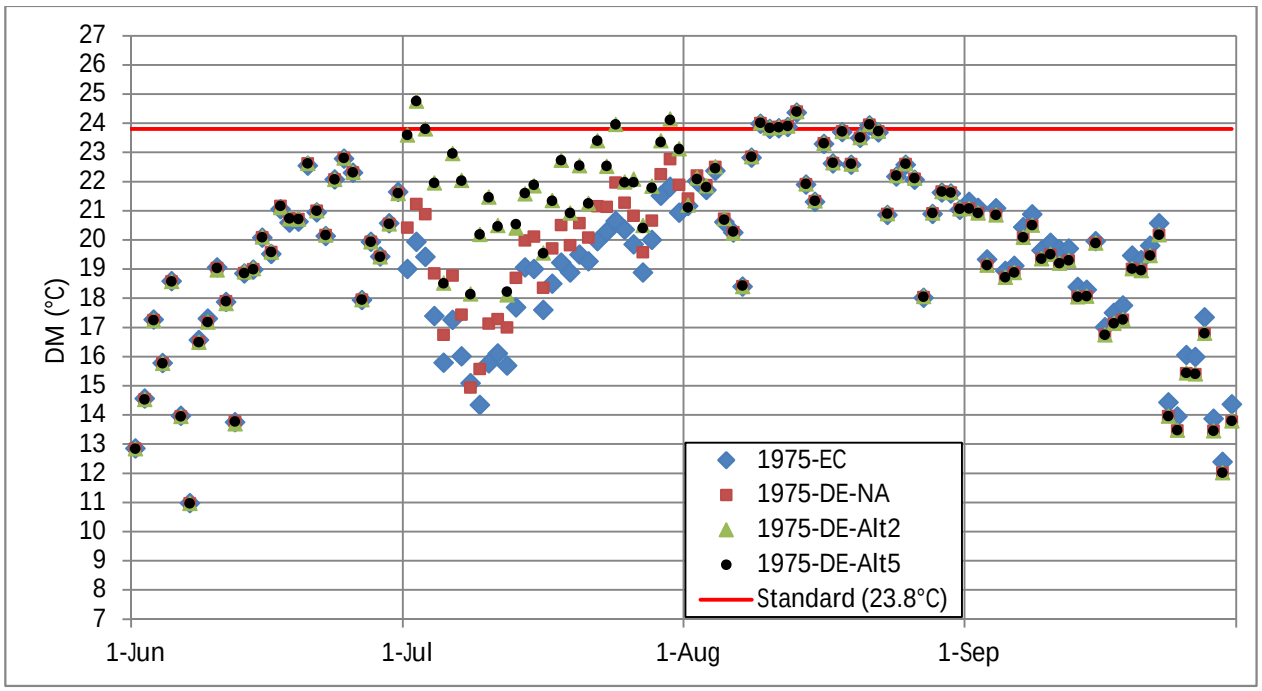

Figure 61. 1975 Direct Effects DMs at CR-HSU.

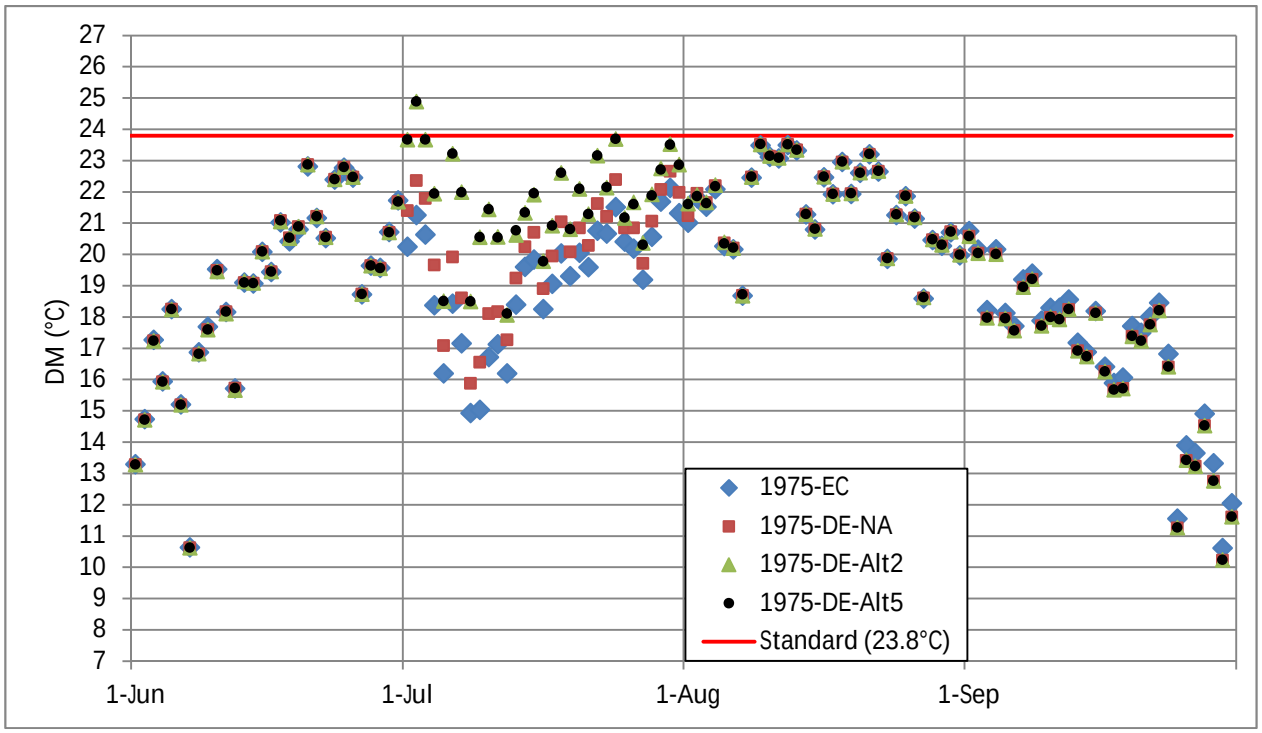

Figure 62. 1975 Direct Effects DMs at CR-WFU.

For 1975 direct effects, Table 6 summarizes the results of a regulatory analysis of the simulation results at the three thermistor locations, CR-WGD, CR-HSU, and CR-WFU. The maximum WAT for the full period did not change much (≤0.1°C) across alternatives at any of the stations; however, the number of weeks exceeding 18.2°C increased in July at HSU and WFU, relative to both no action and existing conditions. The number of weeks exceeding 18.2°C at WGD also increased in July for Alt2 by the addition of one day with a weekly average of 18.2°C (Alt5 simulation had a WAT of 18.1°C for that day). The maximum DM increased at HSU and WFU, with an increase in DM values exceeding 23.8°C in July at both HSU and WFU, and an increase in DM exceedances in August at HSU for NA, Alt2, and Alt5 relative to existing conditions. There were no acute exceedances simulated at WGD for any of the simulations, and there were no chronic or acute exceedances simulated at any location in June or September.

Table 6. 1975 Direct Effects Simulated Regulatory Results.

	1975- WGD				1975- HSU				1975- WFU			
	EC	NA	Alt2	Alt5	EC	NA	Alt2	Alt5	EC	NA	Alt2	Alt5
Chronic												
MWAT (°C)	18.9	19.0	19.0	19.0	19.5	19.5	19.5	19.5	19.7	19.7	19.7	19.7
June # weeks > 18.2 °C	0	0	0	0	0	0	0	0	0	0	0	0
July # weeks > 18.2 °C	0	0	1	0	0	1	3	3	0	1	3	3
August # weeks > 18.2 °C	3	3	3	3	4	4	4	4	4	4	4	4
Sept. # weeks > 18.2 °C	0	0	0	0	0	0	0	0	0	0	0	0
Acute												
Max DM (°C)	20.8	20.8	20.8	20.8	24.4	24.4	24.8	24.8	23.5	23.5	24.9	24.9
June # days > 23.8 °C	0	0	0	0	0	0	0	0	0	0	0	0
July # days > 23.8 °C	0	0	0	0	0	0	3	3	0	0	1	1
August # days > 23.8 °C	0	0	0	0	5	6	6	6	0	0	0	0
Sept. # days > 23.8 °C	0	0	0	0	0	0	0	0	0	0	0	0

Looking more closely at the 1975 direct effects simulations, Table 7 and

Table 8 present the simulated WAT and DM temperature effects of Alt2 and Alt5 relative to existing conditions and no action, respectively. For these 1975 simulations applying 2007 meteorology, the largest individual WAT increase due to Alt2, relative to existing conditions, was 2.7 °C in early July at WFU. Relative to no action, the largest WAT increase was 2.1°C, also in early July at WFU. The largest simulated DM increases were also in early July, with the largest one-day increase relative to existing conditions, 6.0°C, occurring at HSU for Alt2, and with a 4.6°C increase relative to the no action alternative (also at HSU). Results for Alt5 closely parallel results for Alt2, due to similar simulated pumping at Windy Gap Reservoir.

For Alt2 and Alt5 relative to existing conditions, the average July WAT increase ranged from 1.2°C to 1.5°C. For Alt2 and Alt5 relative to no action, the average July WAT increase ranged from 0.9°C to 1.1°C. For Alt2 and Alt5 relative to existing conditions, the average July DM increase ranged from 1.5°C to 3.2°C. For Alt2 and Alt5 relative to no action, the average July DM increase ranged from 1.3°C to 2.2°C.

Table 7. 1975 Direct Effects Simulated WAT and DM Increases Relative to Existing Conditions.

	1975-WGD		1975-HSU		1975-WFU	
	Increase Relative to Existing Conditions (°C)		Increase Relative to Existing Conditions (°C)		Increase Relative to Existing Conditions (°C)	
	Alt2	Alt5	Alt2	Alt5	Alt2	Alt5
Chronic						
Largest WAT Increase in July and August (°C)	1.9	1.9	2.5	2.5	2.7	2.7
Avg. July WAT Increase (°C)	1.2	1.2	1.5	1.5	1.5	1.5
Avg. Aug. WAT Increase (°C)	0.2	0.1	0.1	0.1	0.2	0.1
Acute						
Largest DM Increase in July and August (°C)	2.4	2.4	6.0	6.0	5.5	5.5
Avg. July DM Increase (°C)	1.5	1.5	3.2	3.2	2.5	2.5
Avg. Aug. DM Increase (°C)	0.0	0.0	0.0	0.0	0.1	0.0

Table 8. 1975 Direct Effects Simulated WAT and DM Increases Relative to No Action.

	1975-WGD		1975-HSU		1975-WFU	
	Increase Relative to No Action (°C)		Increase Relative to No Action (°C)		Increase Relative to No Action (°C)	
	Alt2	Alt5	Alt2	Alt5	Alt2	Alt5
Chronic						
Largest WAT Increase in July and August (°C)	1.5	1.5	2.0	2.0	2.1	2.1
Avg. July WAT Increase (°C)	0.9	0.9	1.0	1.0	1.1	1.1
Avg. Aug. WAT Increase (°C)	0.0	0.0	0.1	0.0	0.1	0.1
Acute						
Largest DM Increase in July and August (°C)	2.3	2.3	4.6	4.6	4.0	4.0
Avg. July DM Increase (°C)	1.3	1.3	2.2	2.2	1.6	1.6
Avg. Aug. DM Increase (°C)	0.0	0.0	0.0	0.0	0.0	0.0

4.1.1.4 1975 Direct Effects Summary

For the simulated 1975 direct effects hydrology with 2007 meteorology, Windy Gap pumping differences were limited to July, and correspondingly, changes to simulated river temperatures occurred primarily in July. Simulated hydrology was essentially the same for Alt2 and Alt5, giving similar results for the alternatives. Temperature increases were simulated at WGD, HSU, and WFU for Alt2 and Alt5 relative to existing conditions and no action. Larger temperature differences for alternatives were seen relative to existing conditions (versus no action), due to greater pumping differences. Increased exceedances were simulated at all three locations for Alt2 and at HSU and WFU for Alt5. The largest WAT increase simulated for Alt2 was at WFU in July (2.7°C as compared to existing conditions and 2.1°C as compared to no action). The largest DM increase was simulated for Alt2 at HSU in July (6.0°C as compared to existing conditions and 4.6°C as compared to no action).

4.1.2 1979 Direct Effects

The results of direct effects simulations applying 1979 hydrology scenarios under conditions of 2007 meteorology are presented in the following subsections. Direct effects simulations for 1979 included existing conditions, no action, Alt2, and Alt5.

4.1.2.1 1979 Direct Effects Hydrographs

Figure 63 and Figure 64 present the differences in pumping at Windy Gap and the corresponding flow below Windy Gap Reservoir for the direct effects alternatives simulated – existing conditions, no action, alternative 2, and alternative 5. Windy Gap pumping volumes (June through September) are summarized for each simulation in Table 9.

Overall, 1979 was an average to wetter year (classified as neither a dry or wet year in the WGFP analysis), with virgin annual flows ranking 14th out of the 47 years of hydrology simulated for the WGFP. For the 1979 direct effects simulations, Windy Gap pumping and river flows are nearly identical in June and September for existing conditions, no action, Alt2, and Alt5. In July and August, pumping and flows for no action, Alt2, and Alt5 are the same. In July and August, no action, Alt2, and Alt5 show higher levels of pumping as compared to existing conditions (13,000 AF more in July and 1,600 AF more in August). Correspondingly, flows below Windy Gap Reservoir are lower in July and August for no action, Alt2, and Alt5, as compared to existing conditions (Figure 64).

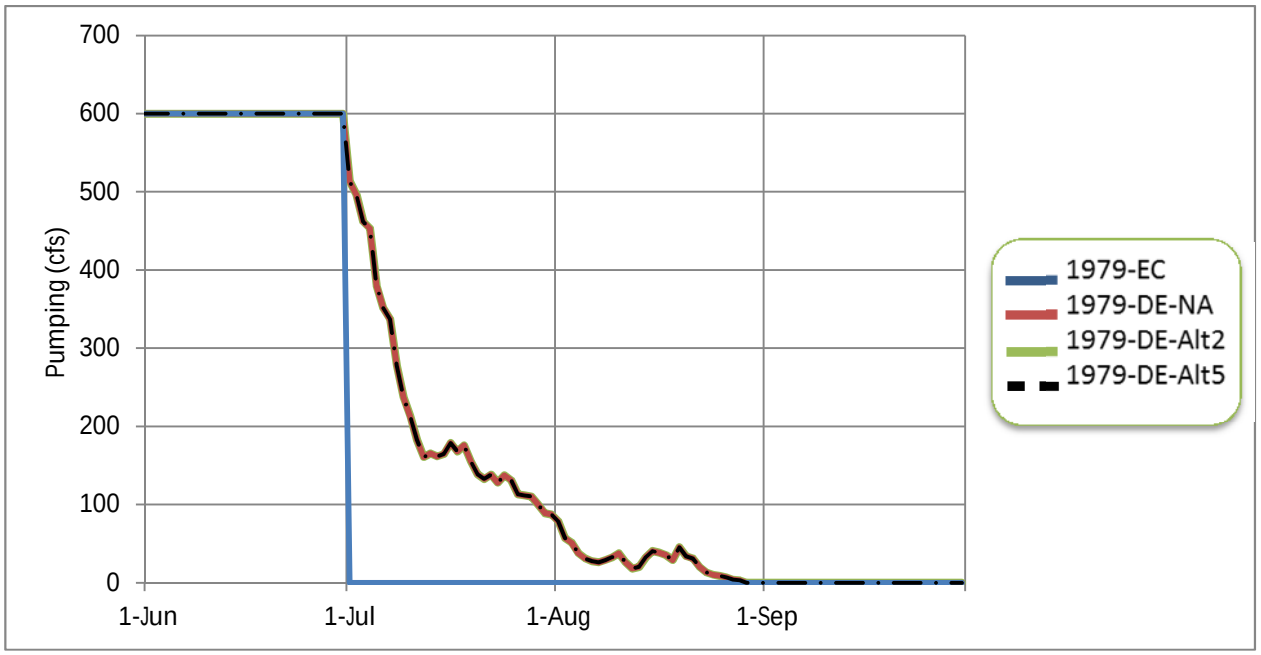

Figure 63. 1979 Direct Effects Windy Gap Pumping.

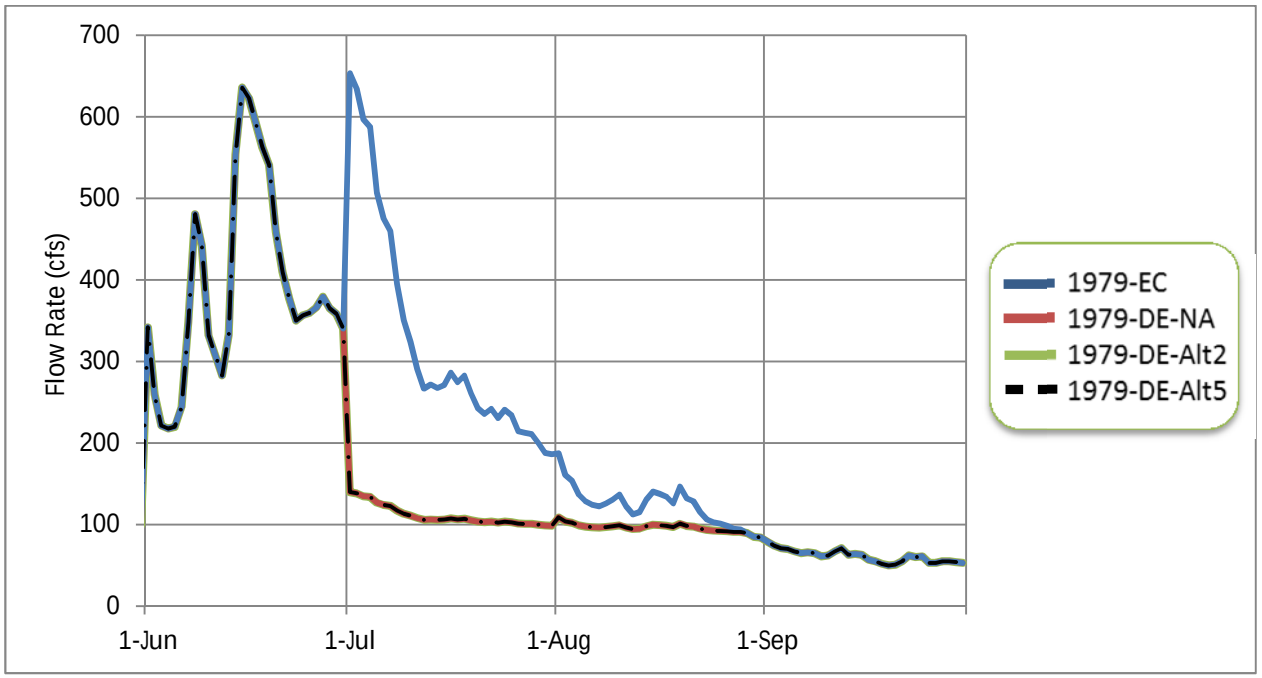

Figure 64. 1979 Direct Effect Flow Rates Below Windy Gap.

Table 9. 1979 Direct Effects Windy Gap Pumping Volumes.

	1979-DE Monthly Pumping Totals (AF/month)			
	June	July	August	September
Existing Conditions	35,700	0	0	0
No Action	35,700	13,196	1,638	0
Alternative 2	35,700	13,196	1,638	0
Alternative 5	35,700	13,196	1,638	0

4.1.2.2 1979 Direct Effects Hourly Temperature Plots

Figure 65 through Figure 70 present the hourly temperature plots produced by the model for thermistor locations CR-WGD, CR-HSU, and CR-WFU. Hourly temperature plots for the full simulation period are shown, as well as plots focusing on the period of the simulation with notable differences in predicted temperatures. For 1979 direct effects simulations, that period is July and August, which corresponds to the period of greater pumping for no action, Alt2, and Alt5, relative to existing conditions.

At all three locations, temperature patterns for no action, Alt2, and Alt5 are the same due to matching Windy Gap pumping. In general, it is apparent from review of the "July-August Zoom" figures for WGD and HSU that a greater increase in daily temperatures (relative to existing conditions) is simulated in July, though the highest simulated temperatures occur in August across scenarios due to the meteorology. The 1979 direct effects temperature simulation results are summarized and discussed quantitatively in Section 4.1.2.3.

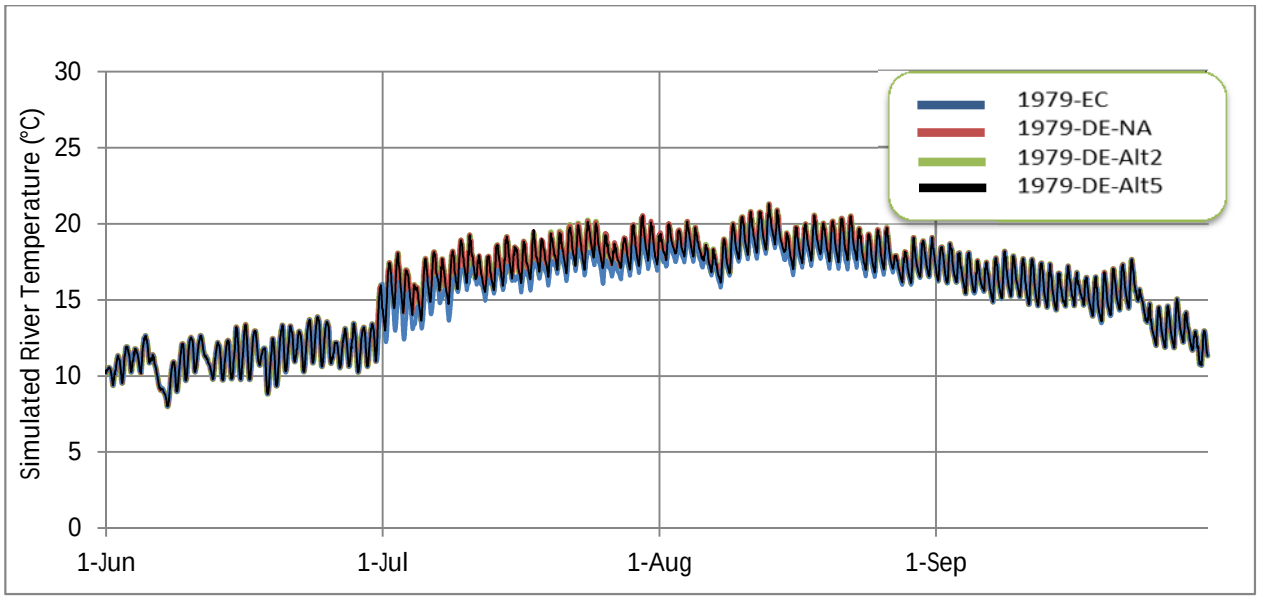

Figure 65. 1979 Direct Effects Hourly Temperature at CR-WGD.

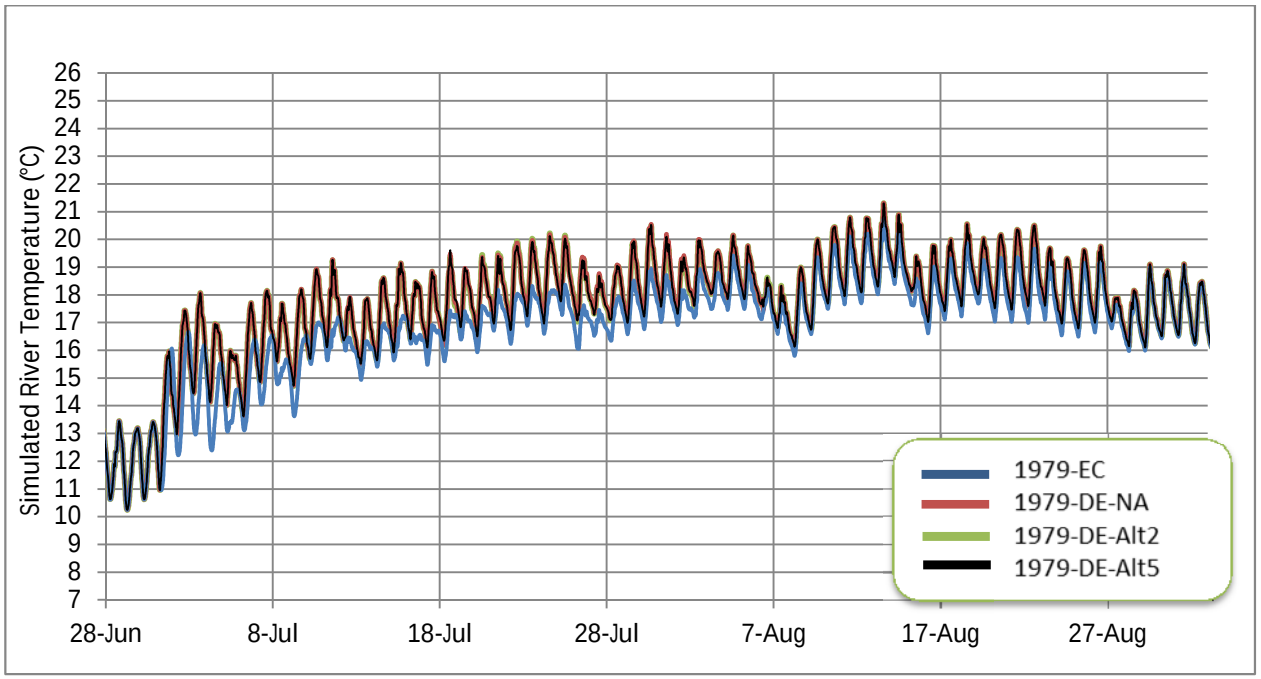

Figure 66. 1979 Direct Effects Hourly Temperature at CR-WGD – July-August Zoom.

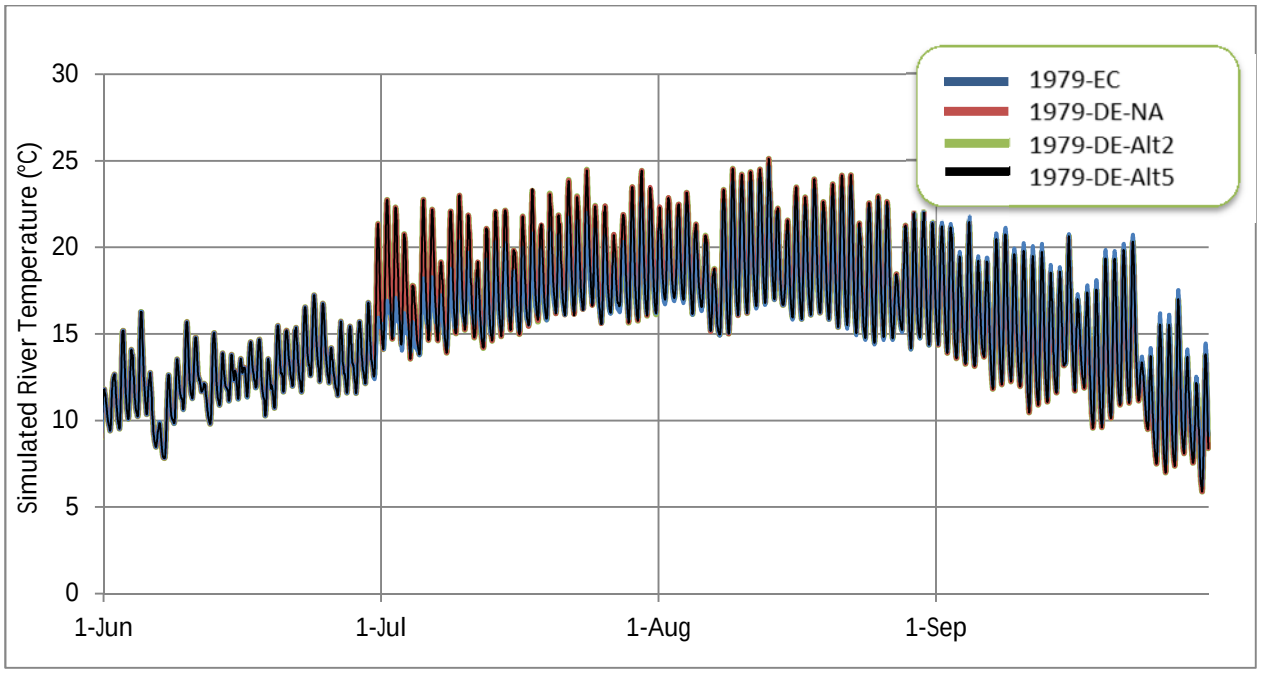

Figure 67. 1979 Direct Effects Hourly Temperature at CR-HSU.

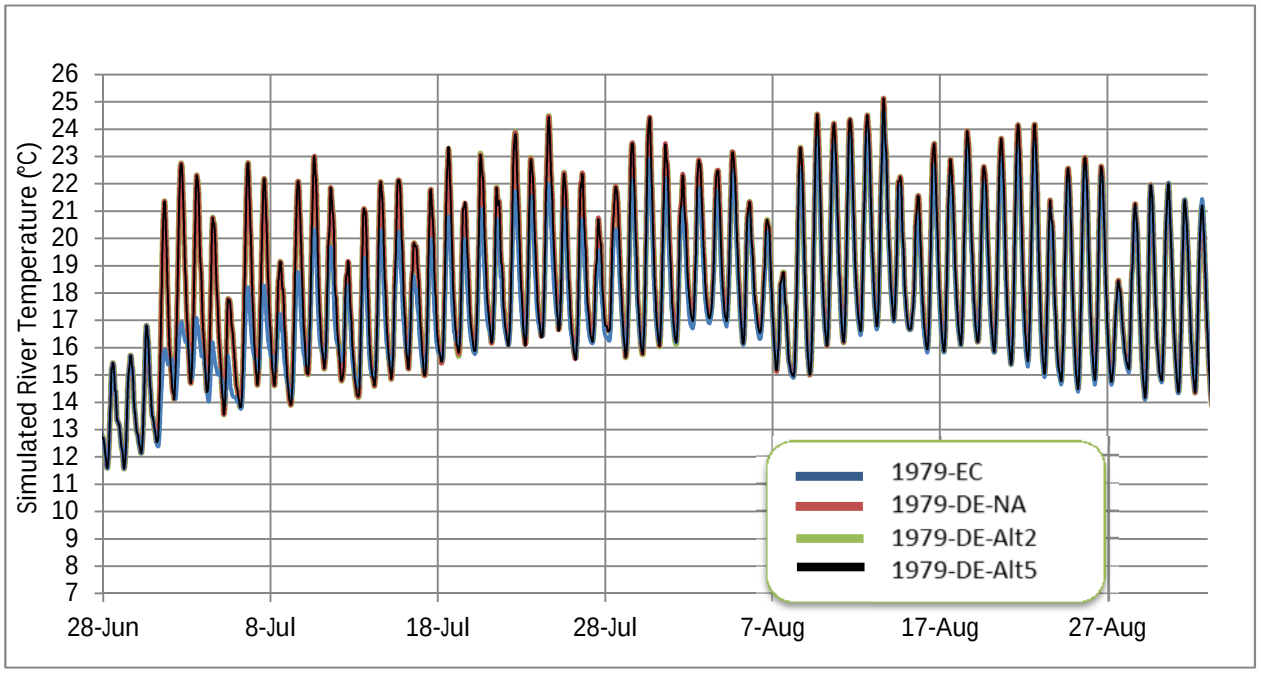

Figure 68. 1979 Direct Effects Hourly Temperature at CR-HSU – July-August Zoom.

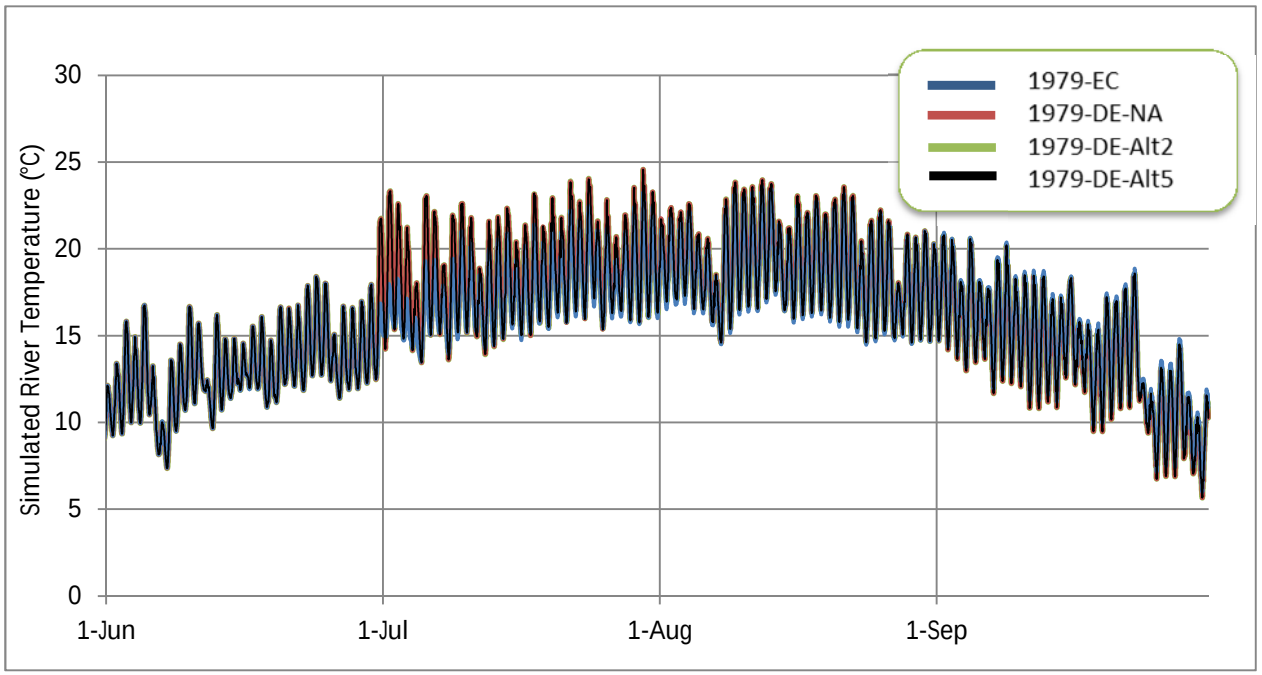

Figure 69. 1979 Direct Effects Hourly Temperature at CR-WFU.

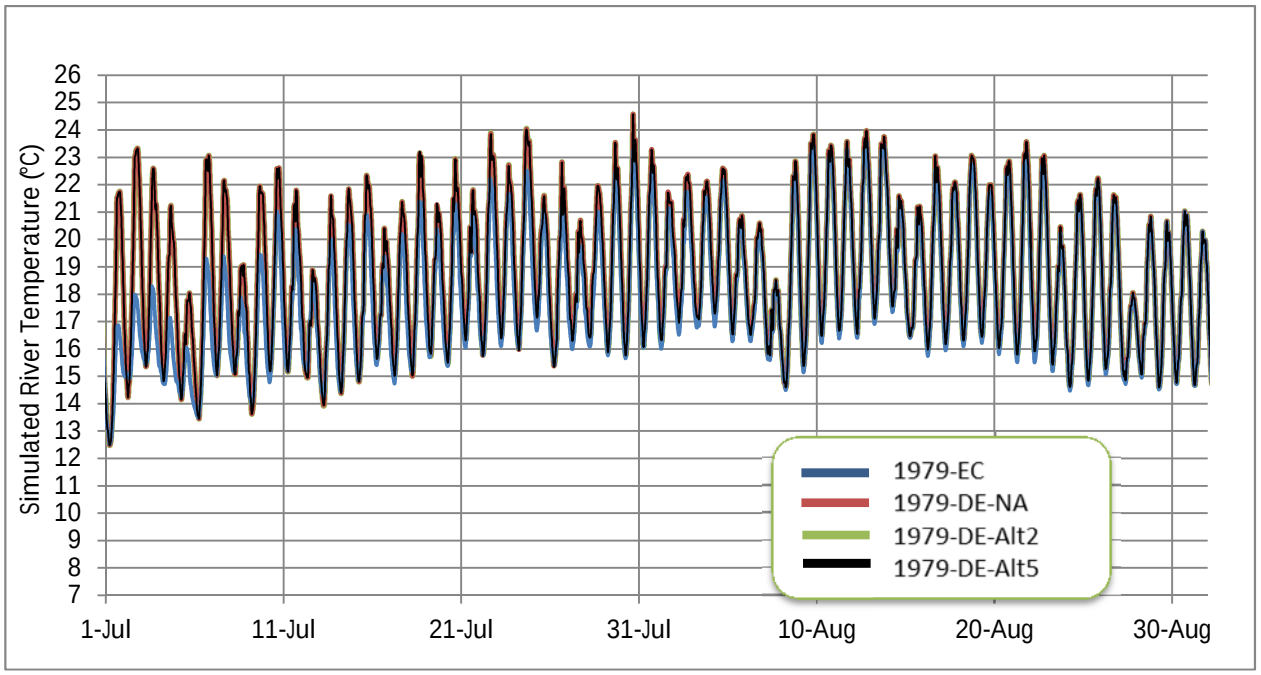

Figure 70. 1979 Direct Effects Hourly Temperature at CR-WFU – July-August Zoom.

4.1.2.3 1979 Direct Effects Weekly Average and Daily Maximum Temperatures

WATs and DMs were all calculated using the appropriate Colorado Water Quality Control Division tool (Temp-program-V4.2; personal communication, Robert Hillegas, May 24, 2011) for this segment of the upper Colorado River. Figure 71 through Figure 73 present WATs for each simulated day, following the first week of simulation. DMs are presented for each simulated day in Figure 74 through Figure 76. These figure sets show results for thermistor locations CR-WGD, CR-HSU, and CR-WFU.

Direct effects WATs and DMs show similar patterns. No action, Alt2, and Alt5 show matching results, due to matching pumping patterns from Windy Gap for the simulation period in 1975. The increase in WATs and DMs, relative to existing condtions, is greatest in July, corresponding to the greatest pumping differences.

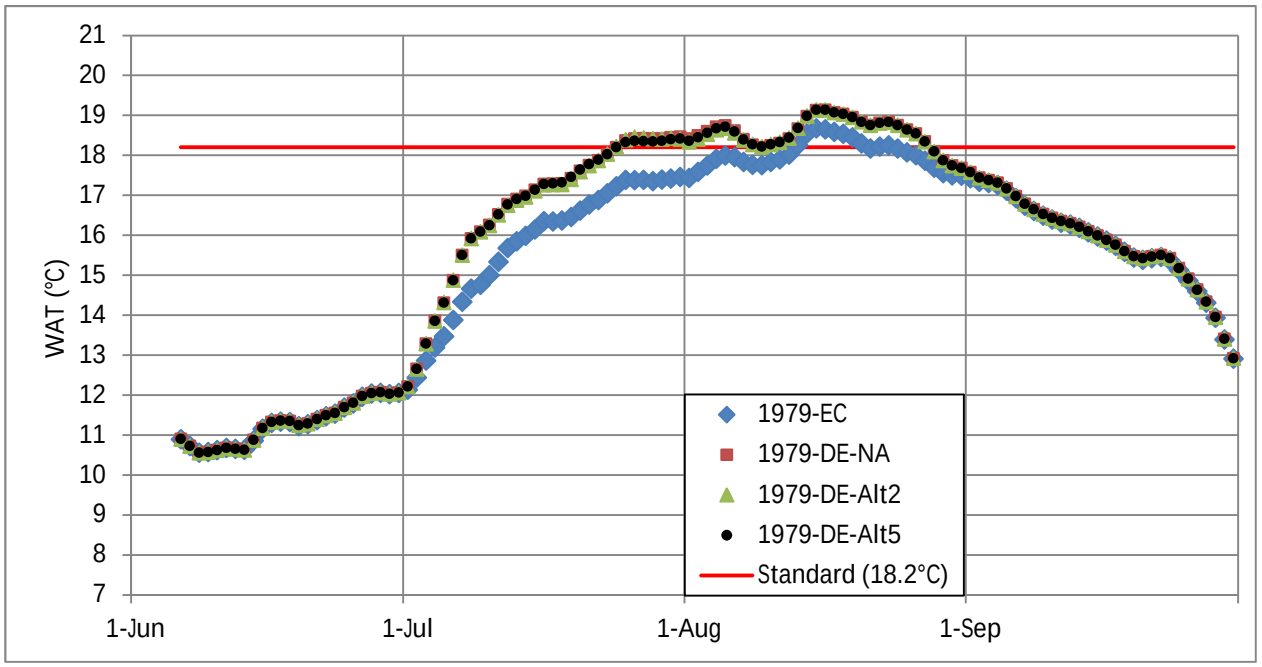

Figure 71. 1979 Direct Effects WATs at CR-WGD.

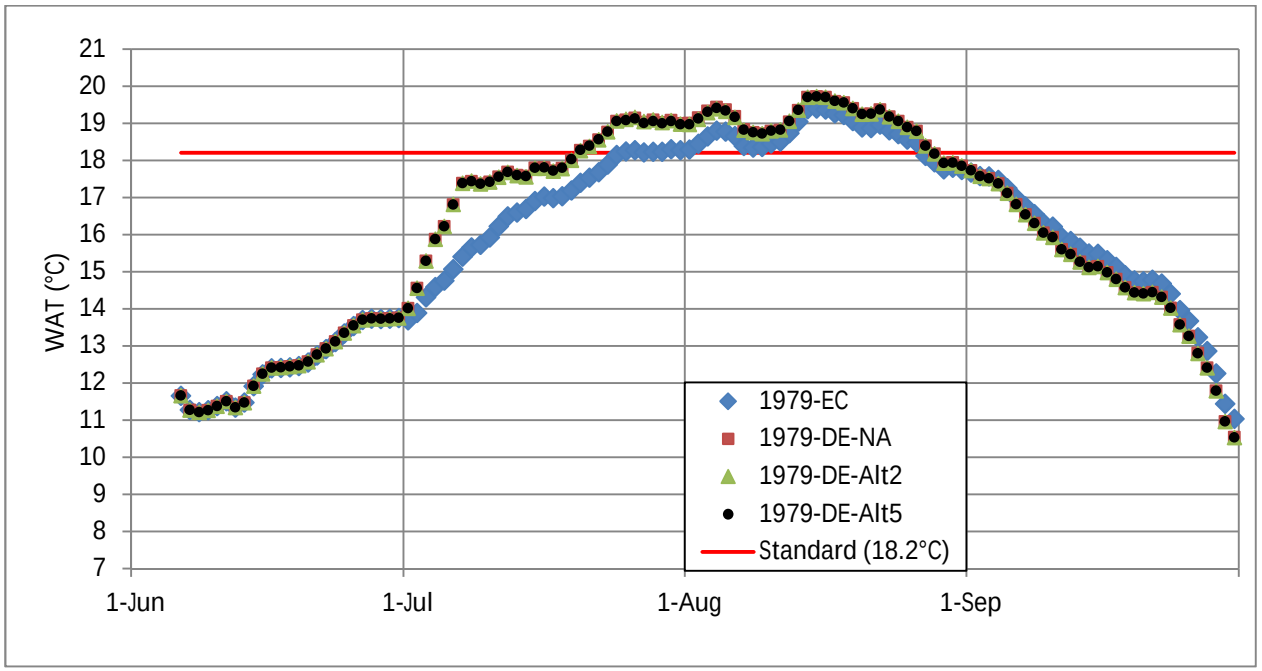

Figure 72. 1979 Direct Effects WATs at CR-HSU.

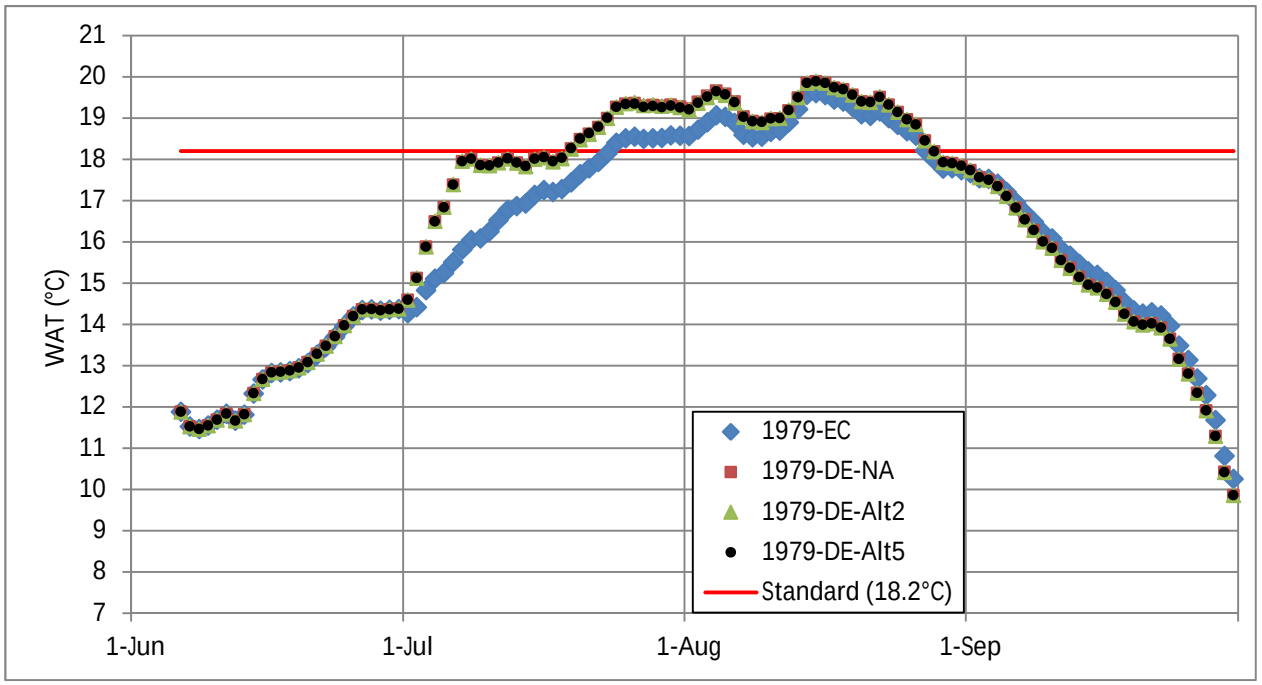

Figure 73. 1979 Direct Effects WATs at CR-WFU.

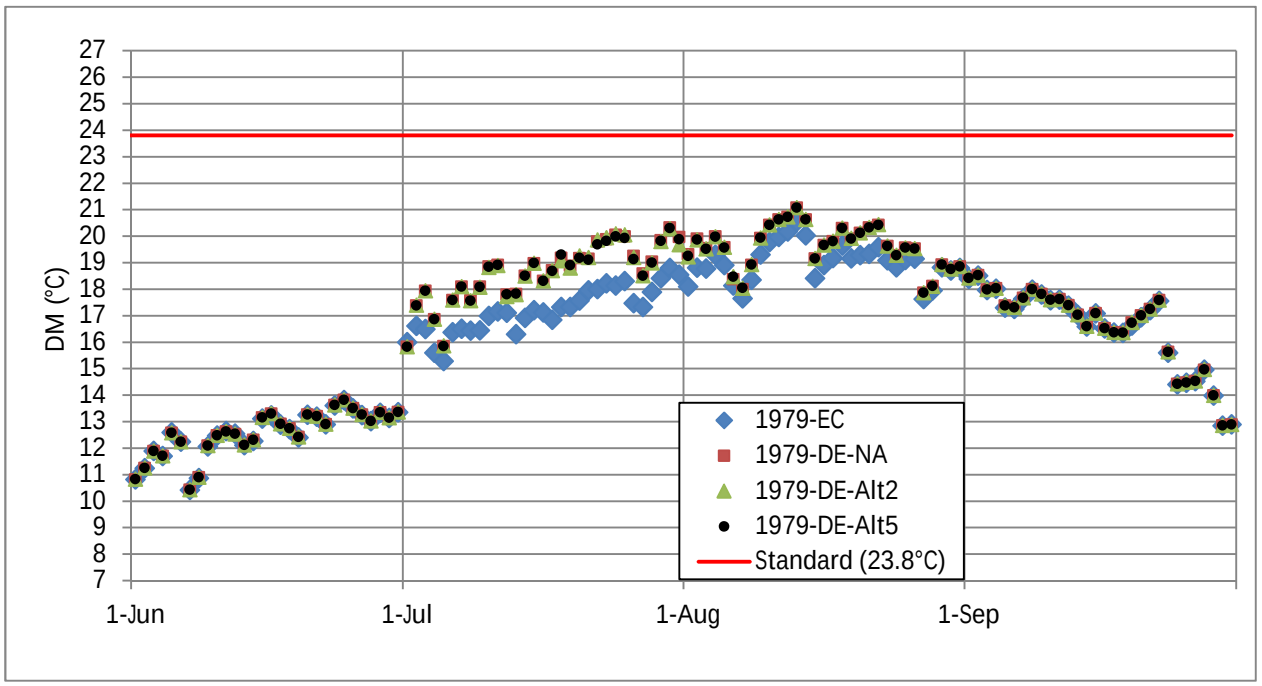

Figure 74. 1979 Direct Effects DMs at CR-WGD.

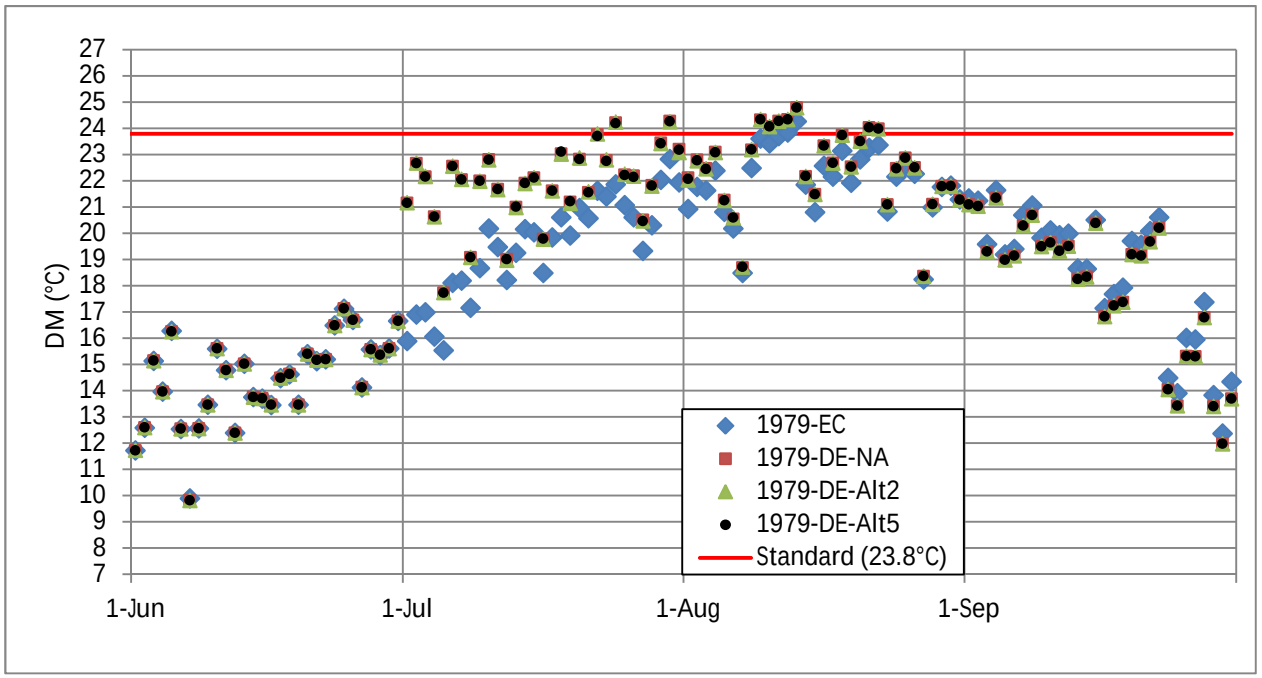

Figure 75. 1979 Direct Effects DMs at CR-HSU.

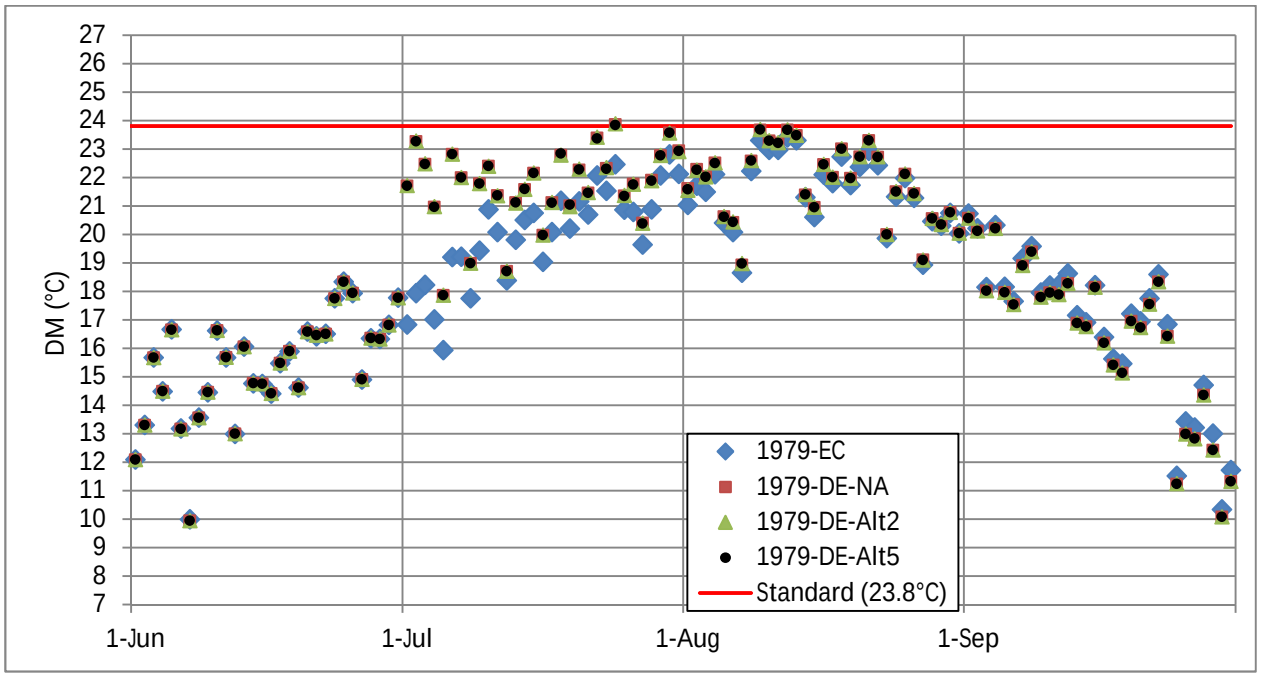

Figure 76. 1979 Direct Effects DMs at CR-WFU.

For 1979 direct effects, Table 10 summarizes the results of a regulatory analysis of the simulation results at the three thermistor locations, CR-WGD, CR-HSU, and CR-WFU. The maximum WATs were a little higher for Alt2 and Alt5 across the reach, relative to existing conditions (+0.3 to 0.4°C). Also, three additional weeks of WAT exceedances were simulated for Alt2 and Alt5 at WGD, relative to existing conditions. There were no increases in exceedances of MWAT for Alt2 or Alt5 relative to no action.

DMs followed the same general pattern as that seen for WATs, with increases in maximum DMs at all locations relative to existing conditions, but no increases relative to no action. The largest simulated maximum DM increase was at WFU (2.1°C for Alt2, as compared to existing conditions). The largest increase in the number of DM values exceeding 23.8°C (relative to existing conditions) was simulated at HSU, +2 days in July and +5 days in August. There were no acute exceedances simulated at WGD for any of the simulations, and there were no chronic or acute exceedances simulated at any location in June or September.

Table 10. 1979 Direct Effects Simulated Regulatory Results.

	1979- WGD				1979- HSU				1979- WFU			
	EC	NA	Alt2	Alt5	EC	NA	Alt2	Alt5	EC	NA	Alt2	Alt5
Chronic												
MWAT (°C)	18.7	19.1	19.1	19.1	19.4	19.7	19.7	19.7	19.6	19.9	19.9	19.9
June # weeks > 18.2 °C	0	0	0	0	0	0	0	0	0	0	0	0
July # weeks > 18.2 °C	0	2	2	1	1	2	2	2	2	2	2	2
August # weeks > 18.2 °C	2	3	3	4	4	4	4	4	3	4	4	4
Sept. # weeks > 18.2 °C	0	0	0	0	0	0	0	0	0	0	0	0
Acute												
Max DM (°C)	20.6	21.1	21.1	21.1	24.3	24.8	24.8	24.8	23.4	23.9	23.9	23.8
June # days > 23.8 °C	0	0	0	0	0	0	0	0	0	0	0	0
July # days > 23.8 °C	0	0	0	0	0	2	2	2	0	1	1	1
August # days > 23.8 °C	0	0	0	0	2	7	7	7	0	0	0	0
Sept. # days > 23.8 °C	0	0	0	0	0	0	0	0	0	0	0	0

Looking more closely at the 1979 direct effects simulations, Table 11 and Table 12 present the simulated WAT and DM temperature effects of Alt2 and Alt5 relative to existing conditions and no action, respectively. For these 1979 simulations applying 2007 meteorology, the largest individual WAT increase due to Alt2, relative to existing conditions, was 2.1 °C at WFU (July 7). For Alt2 and Alt5 relative to existing conditions, the average monthly WAT increases in July

and August ranged from 0.3°C to 1.1°C. Relative to no action, there were no WAT increases, due to the lack of differences in Windy Gap pumping.

The largest simulated DM increase relative to existing conditions was 5.8°C, occurring at HSU (July 2). For Alt2 and Alt5 relative to existing conditions, the average monthly DM increase in July and August ranged from 0.3°C to 2.3°C. Relative to no action, there were no large DM increases due to the lack of differences in Windy Gap pumping.

Table 11. 1979 Direct Effects Simulated WAT and DM Increases Relative to Existing Conditions.

	1979-WGD		1979-HSU		1979-WFU	
	Increase Relative to Existing Conditions (°C)		Increase Relative to Existing Conditions (°C)		Increase Relative to Existing Conditions (°C)	
	Alt2	Alt5	Alt2	Alt5	Alt2	Alt5
Chronic						
Largest WAT Increase in July and August (°C)	1.3	1.3	2.0	2.0	2.1	2.1
Avg. July WAT Increase (°C)	0.9	0.9	1.0	1.0	1.1	1.1
Avg. Aug. WAT Increase (°C)	0.5	0.5	0.4	0.4	0.3	0.3
Acute						
Largest DM Increase in July and August (°C)	2.0	2.0	5.8	5.8	5.3	5.3
Avg. July DM Increase (°C)	1.4	1.4	2.3	2.3	1.7	1.7
Avg. Aug. DM Increase (°C)	0.6	0.6	0.5	0.5	0.3	0.3

Table 12. 1979 Direct Effects Simulated WAT and DM Increases Relative to No Action.

	1979-WGD		1979-HSU		1979-WFU	
	Increase Relative to No Action (°C)		Increase Relative to No Action (°C)		Increase Relative to No Action (°C)	
	Alt2	Alt5	Alt2	Alt5	Alt2	Alt5
Chronic						
Largest WAT Increase in July and August (°C)	0.0	0.0	0.0	0.0	0.0	0.0
Avg. July WAT Increase (°C)	0.0	0.0	0.0	0.0	0.0	0.0
Avg. Aug. WAT Increase (°C)	0.0	0.0	0.0	0.0	0.0	0.0
Acute						
Largest DM Increase in July and August (°C)	0.1	0.1	0.0	0.1	0.0	0.1
Avg. July DM Increase (°C)	0.0	0.0	0.0	0.0	0.0	0.0
Avg. Aug. DM Increase (°C)	0.0	0.0	0.0	0.0	0.0	0.0

4.1.2.4 1979 Direct Effects Summary

For the simulated 1979 direct effects hydrology with 2007 meteorology, Windy Gap pumping differences occurred in July and August. Simulated hydrology was the same for no action, Alt2 and Alt5; therefore, there were no differences in simulated results for the alternatives relative to no action. Temperature increases were simulated at WGD, HSU, and WFU for Alt2 and Alt5 relative to existing conditions. Increased exceedances were simulated at all three locations for Alt2 and Alt5 relative to existing conditions. The largest WAT increase was simulated at WFU in July (+2.1°C). The largest DM increase was simulated HSU in July (+5.8°).

4.1.3 1986 Direct Effects

The results of direct effects simulations applying 1986 hydrology scenarios under conditions of 2007 meteorology are presented in the following subsections. Direct effects simulations for 1986 included existing conditions, no action, Alt2, and Alt5.

4.1.3.1 1986 Direct Effects Hydrographs

Figure 77 and Figure 78 present the differences in pumping at Windy Gap and the corresponding flow below Windy Gap Reservoir for the direct effects alternatives simulated – existing conditions, no action, alternative 2, and alternative 5. Windy Gap pumping volumes (June through September) are summarized for each simulation in Table 13.

1986 was a wet year, with virgin annual flows ranking 4th out of the 47 years of hydrology simulated for the WGFP. For the 1986 direct effects simulations, Windy Gap pumping and river flows are nearly identical in June and September for existing conditions, no action, Alt2, and Alt5. In July and August, pumping and flows vary across all scenarios. Overall, no action shows the most pumping, followed by Alt5, then Alt2; however, the resulting hydrograph, Figure 78, does not vary much across the scenarios because the pumping is a relatively small fraction of the flows. The 1986 simulated flows are the highest flow rates of the five years simulated.

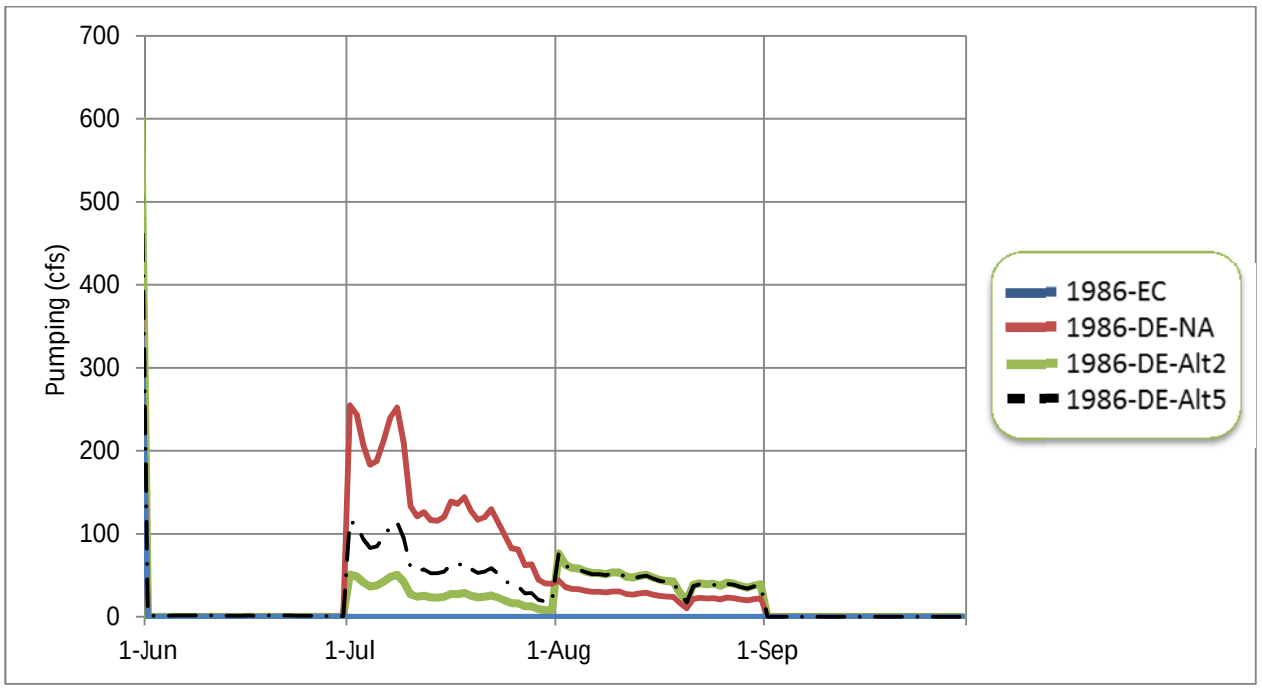

Figure 77. 1986 Direct Effects Windy Gap Pumping

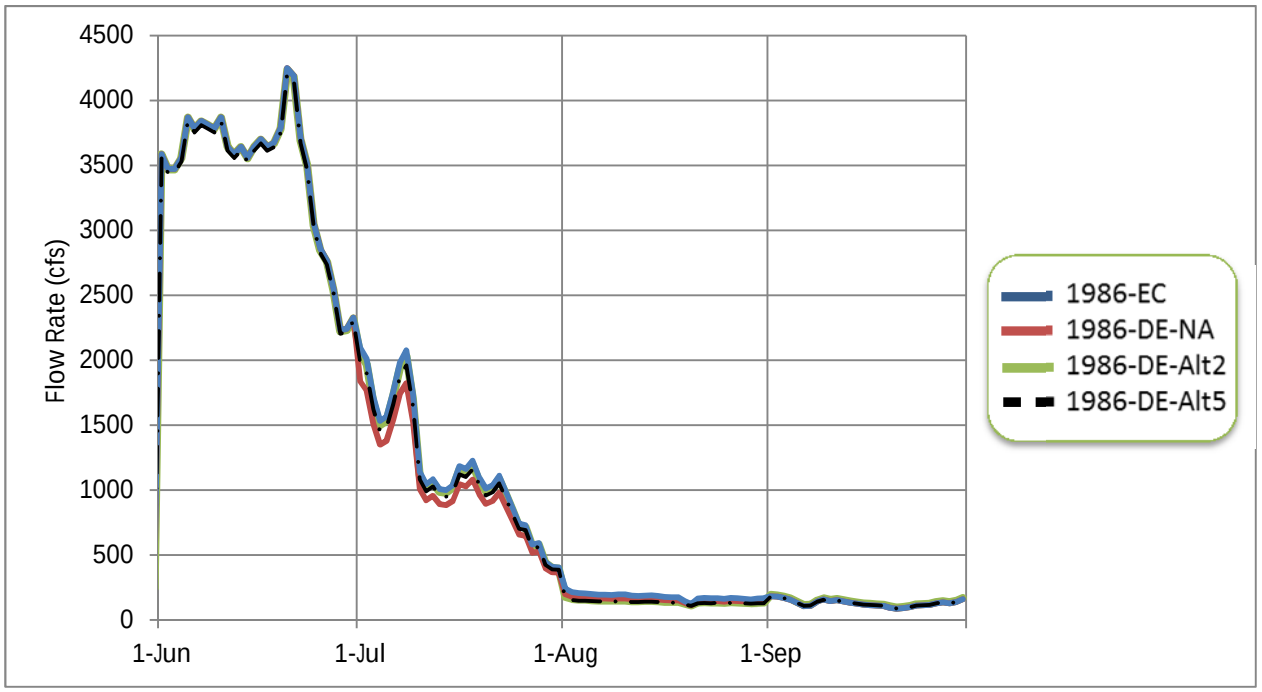

Figure 78. 1986 Direct Effects Flow Rates Below Windy Gap

Table 13. 1986 Direct Effects Windy Gap Pumping Volumes

	1986-DE Monthly Pumping Totals (AF/month)			
	June	July	August	September
Existing Conditions	0	0	0	0
No Action	0	8,451	1,597	0
Alternative 2	0	1,689	2,816	0
Alternative 5	79	3,822	2,742	0

4.1.3.2 1986 Direct Effects Hourly Temperature Plots

Figure 79 through Figure 84 present the hourly temperature plots produced by the model for thermistor locations CR-WGD, CR-HSU, and CR-WFU. Hourly temperature plots for the full simulation period are shown, as well as plots focusing on the period of the simulation with notable differences in predicted temperatures. For 1986 direct effects simulations, major differences in simulated temperatures were limited to the month of August. While pumping differences occurred in both July and August, overall flow rates in this reach of the river were

much higher in July as compared to August (Figure 78), resulting in only minor temperature differences.

In spite of pumping differences comparable to those simulated for 1975 and 1979 direct effects, temperature patterns for no action, Alt2, Alt5, and existing conditions showed only small differences. The limited effect can be attributed to the higher flow rates in the river in the 1986 simulation. A closer look at the "August Zoom" figures shows the highest peak daily temperatures simulated for Alt5, followed by Alt2, then no action, then existing conditions. These 1986 direct effects temperature simulation results are summarized and discussed quantitatively in Section 4.1.3.3.

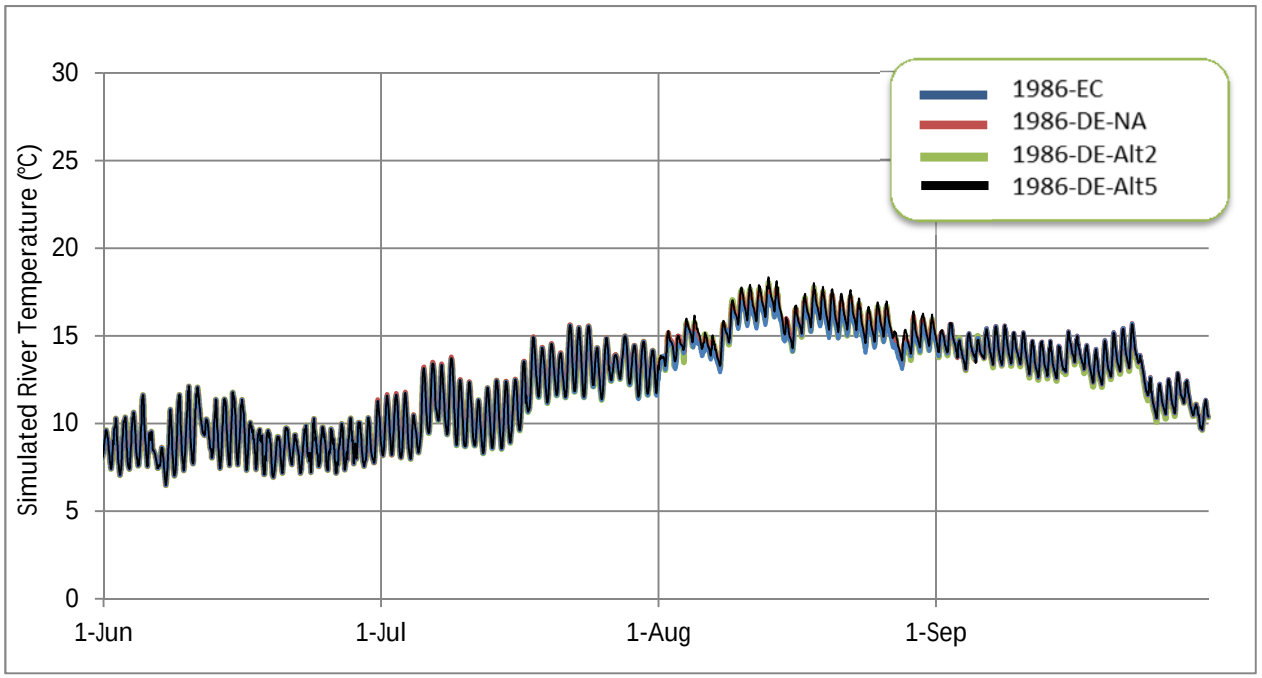

Figure 79. 1986 Direct Effects Hourly Temperature at CR-WGD

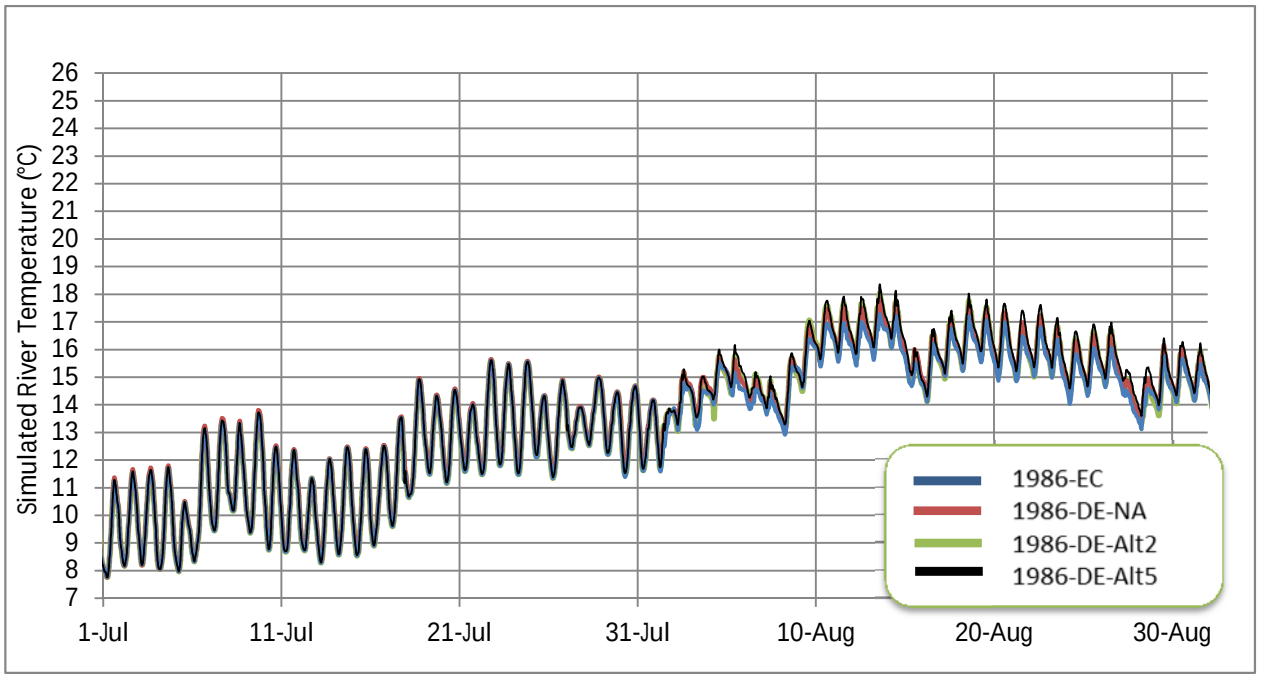

Figure 80. 1986 Direct Effects Hourly Temperature at CR-WGD July-August Zoom

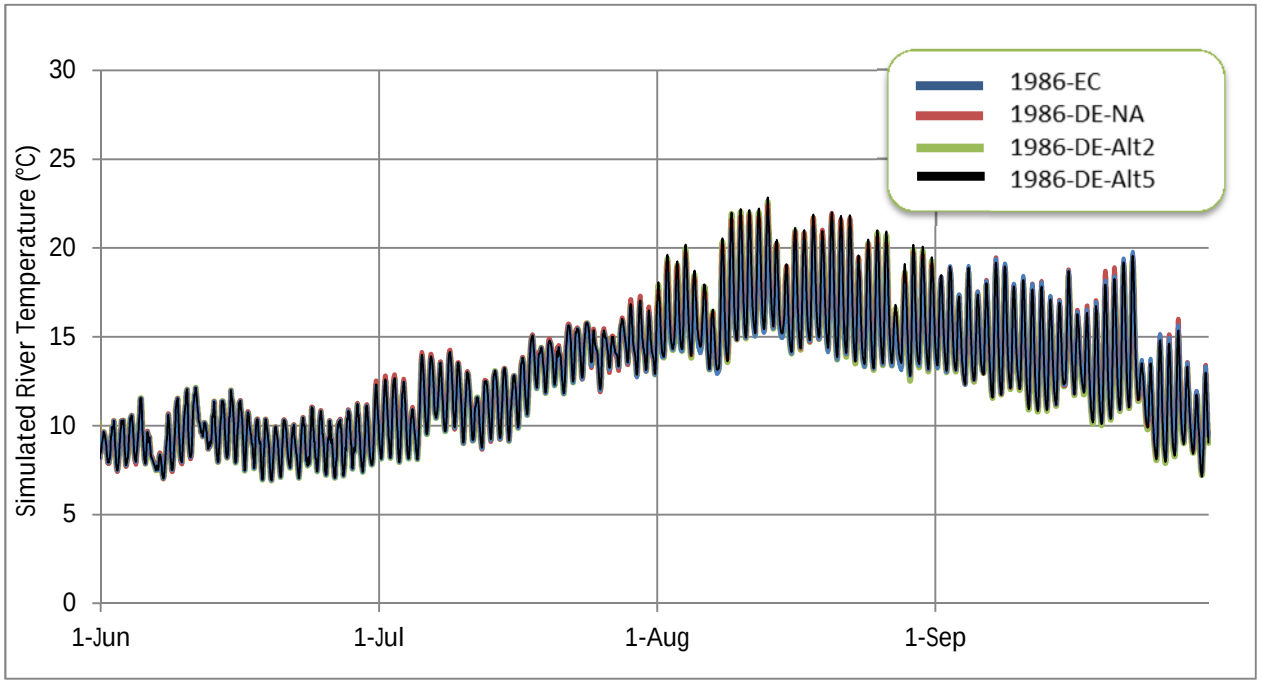

Figure 81. 1986 Direct Effects Hourly Temperature at CR-HSU

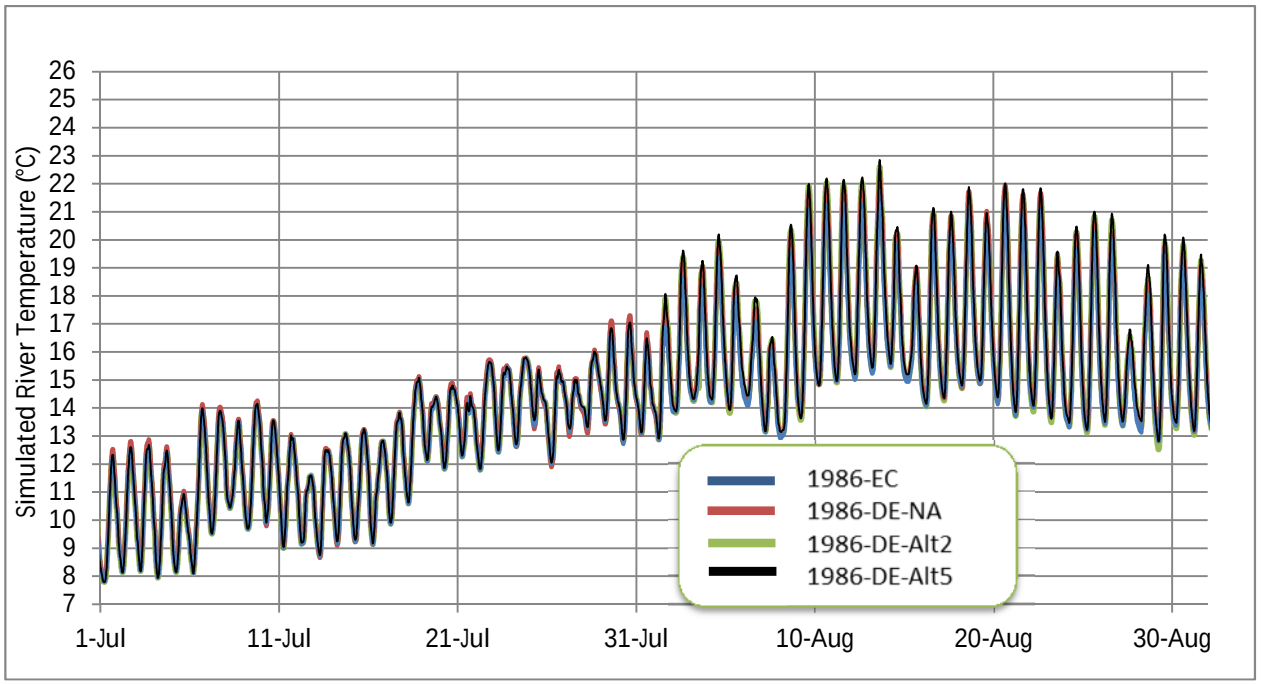

Figure 82. 1986 Direct Effects Hourly Temperature at CR-HSU July-August Zoom

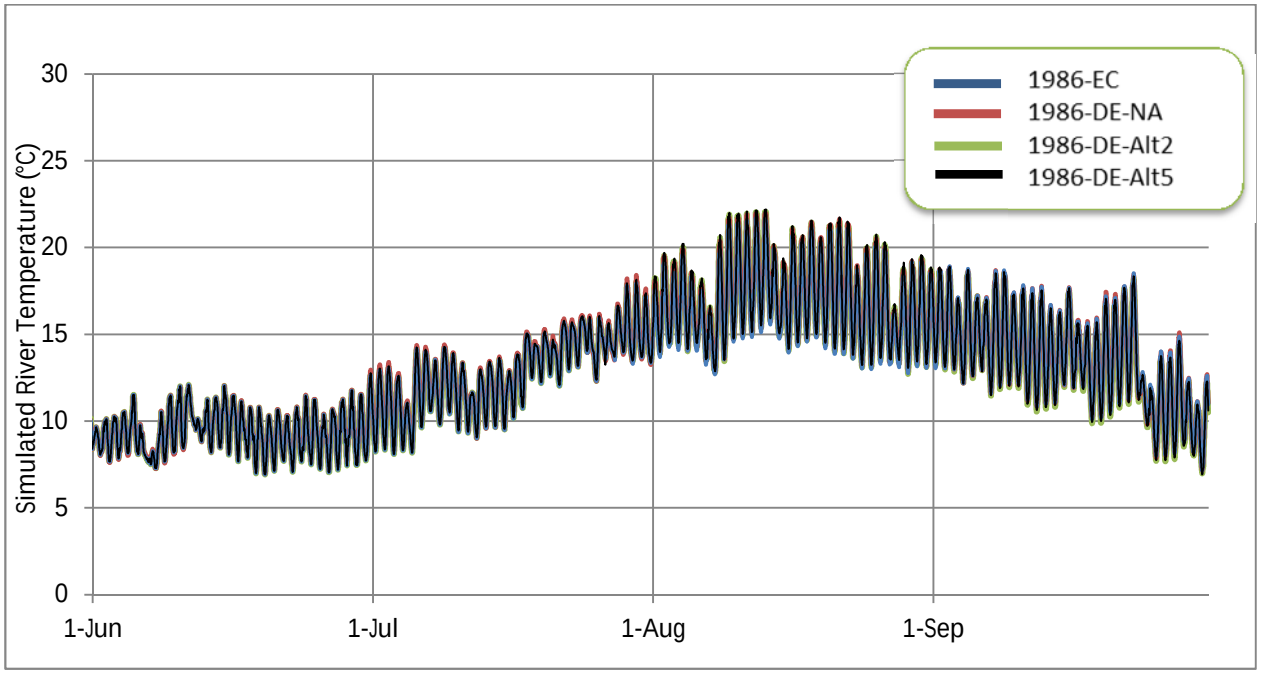

Figure 83. 1986 Direct Effects Hourly Temperature at CR-WFU

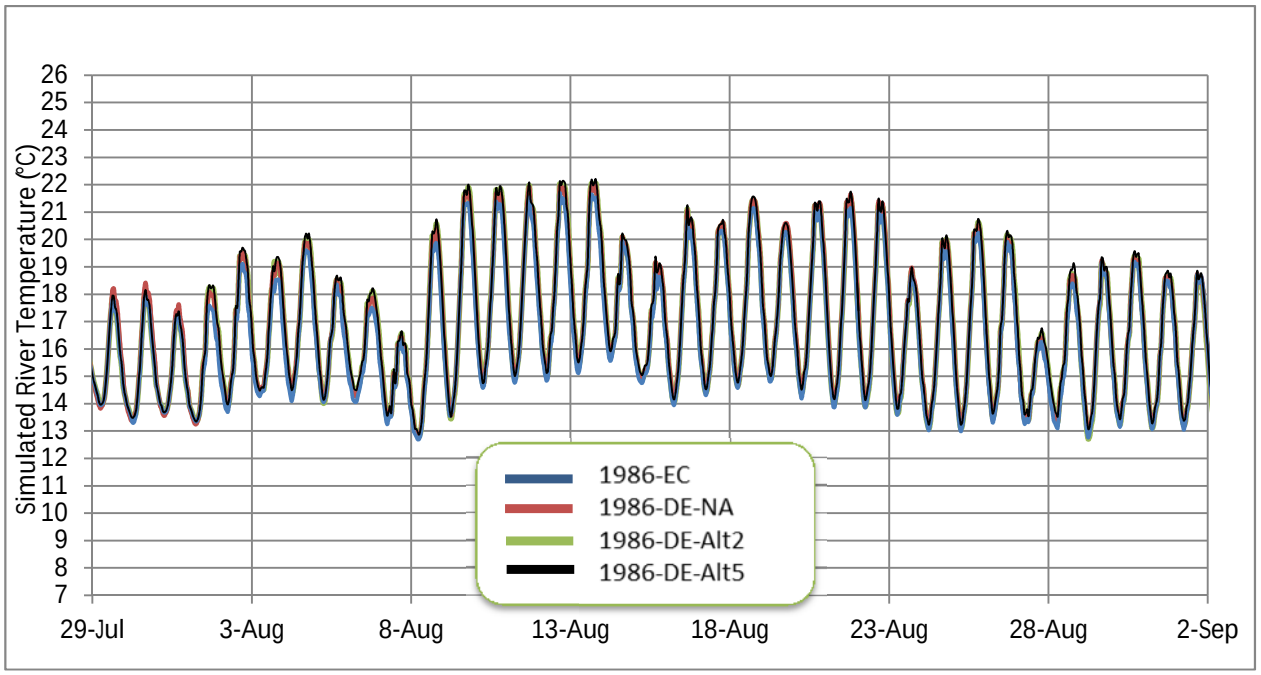

Figure 84. 1986 Direct Effects Hourly Temperature at CR-WFU July-August Zoom

4.1.3.3 1986 Direct Effects Weekly Average and Daily Maximum Temperatures

WATs and DMs were all calculated using the appropriate Colorado Water Quality Control Division tool (Temp-program-V4.2; personal communication, Robert Hillegas, May 24, 2011) for this segment of the upper Colorado River. Figure 85 through Figure 87 present WATs for each simulated day, following the first week of simulation. DMs are presented for each simulated day in Figure 88 through Figure 90. These figure sets show results for thermistor locations CR-WGD, CR-HSU, and CR-WFU.

In agreement with the minimal temperature differences presented in the previous subsection, the WAT and DM results show only very small differences, and differences are largely limited to August. Further, there are no WAT or DM exceedances simulated for any of the alternatives. This limited response to pumping differences is due to the relatively high flow rates in the river for the 1986 hydrology.

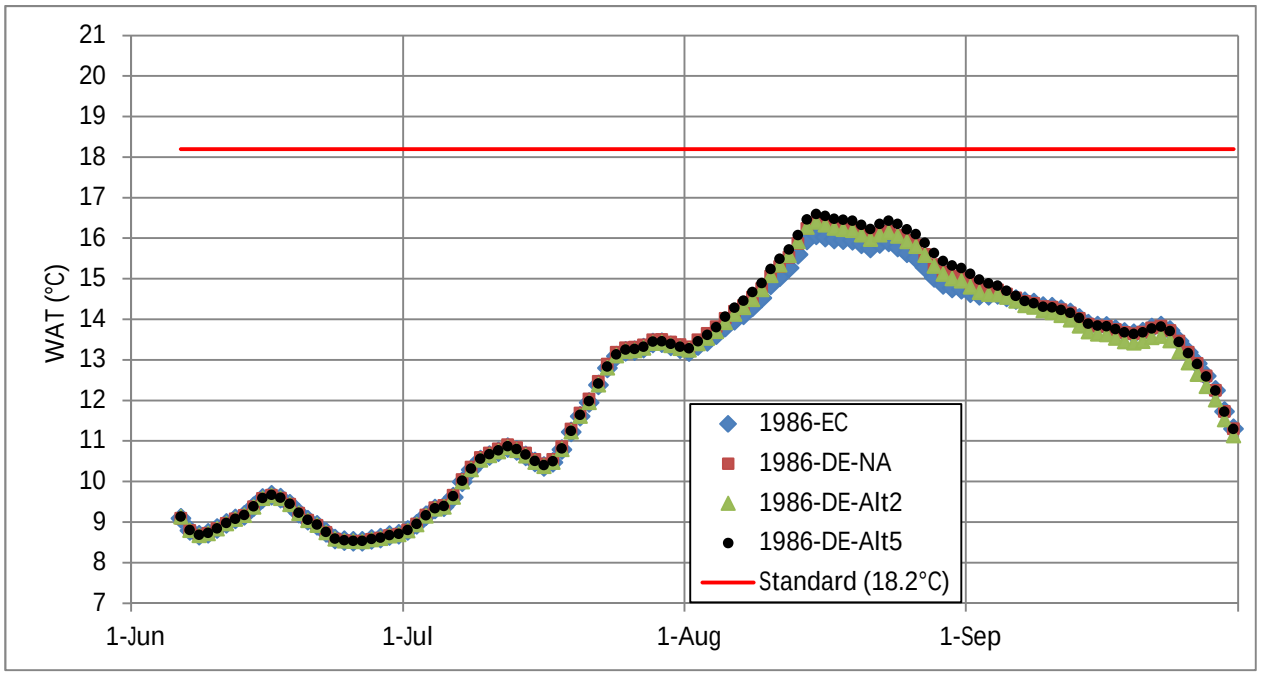

Figure 85. 1986 Direct Effects WATs at CR-WGD

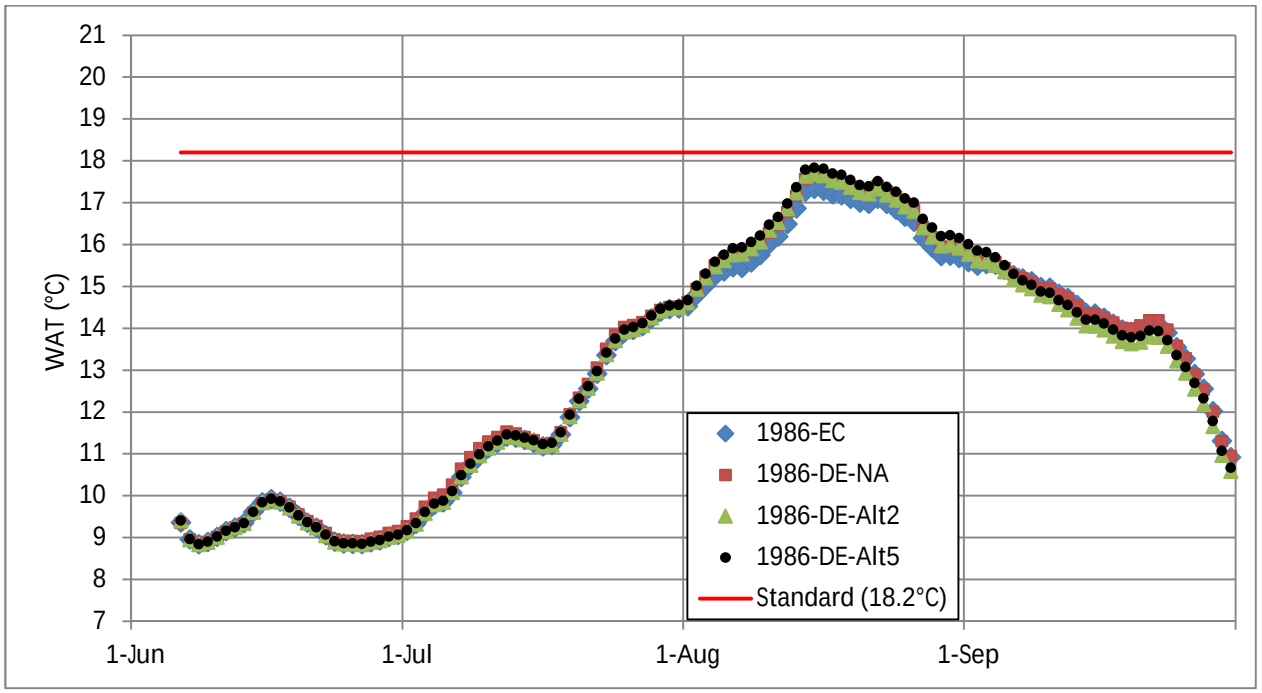

Figure 86. 1986 Direct Effects WATs at CR-HSU

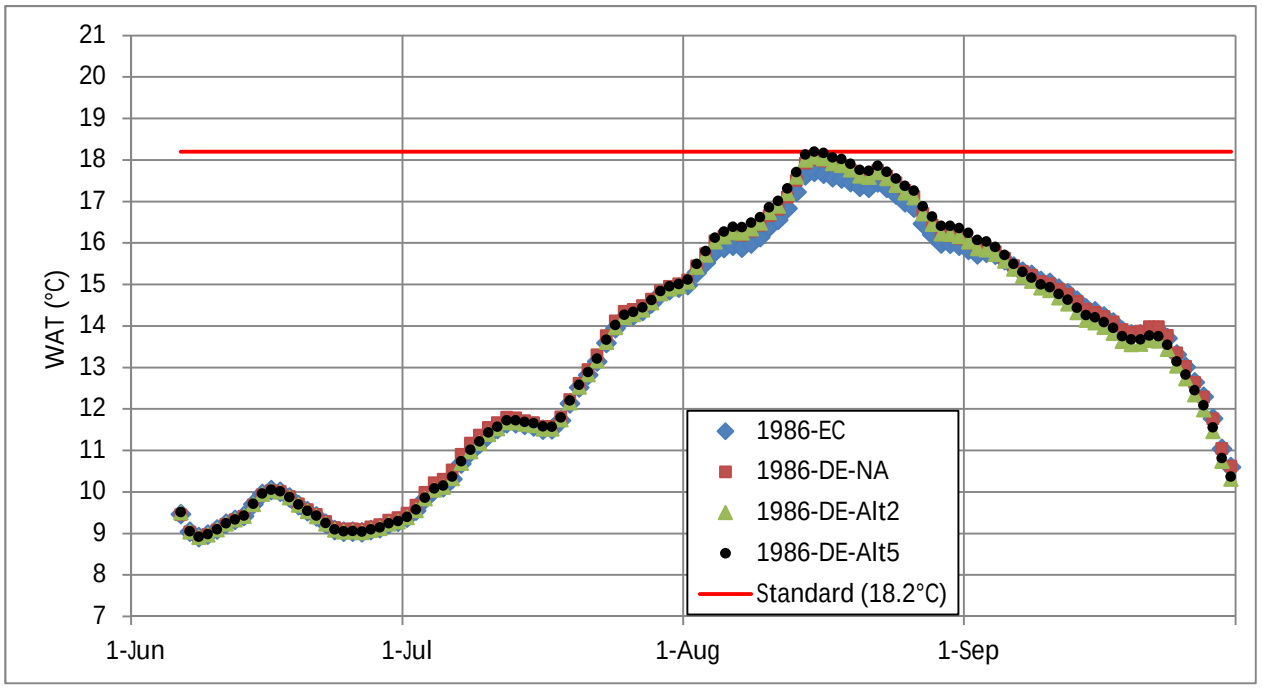

Figure 87. 1986 Direct Effects WATs at CR-WFU

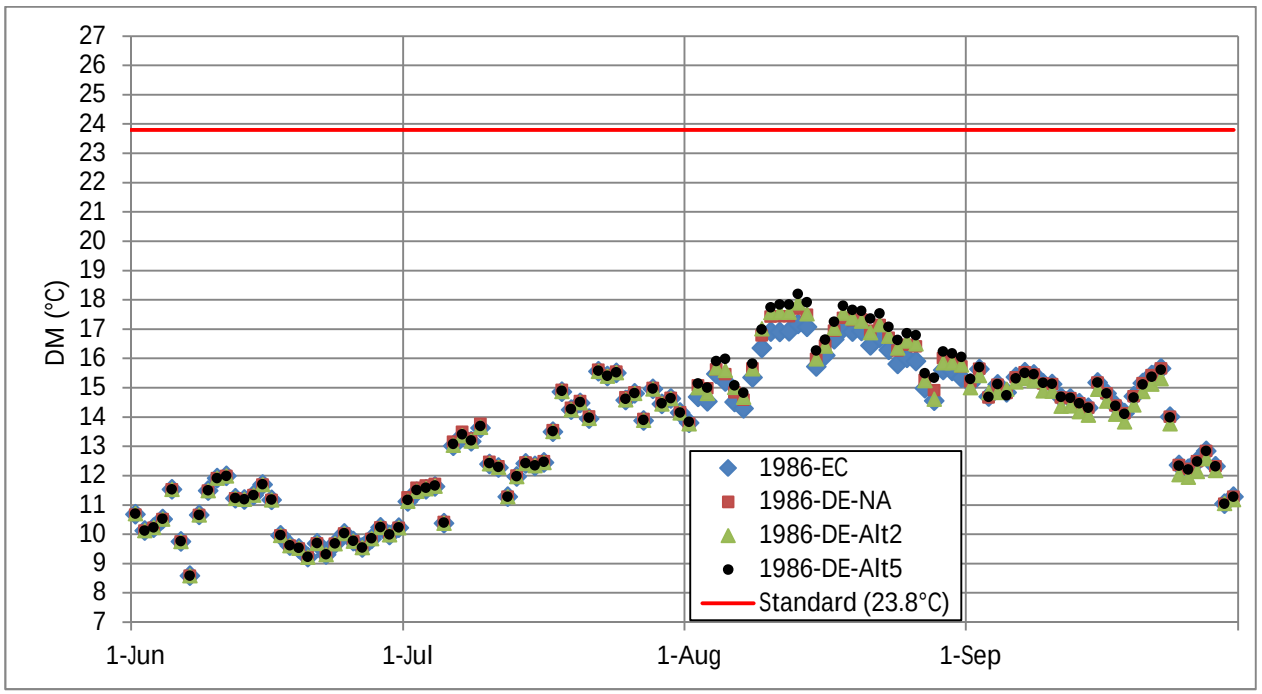

Figure 88. 1986 Direct Effects DMs at CR-WGD

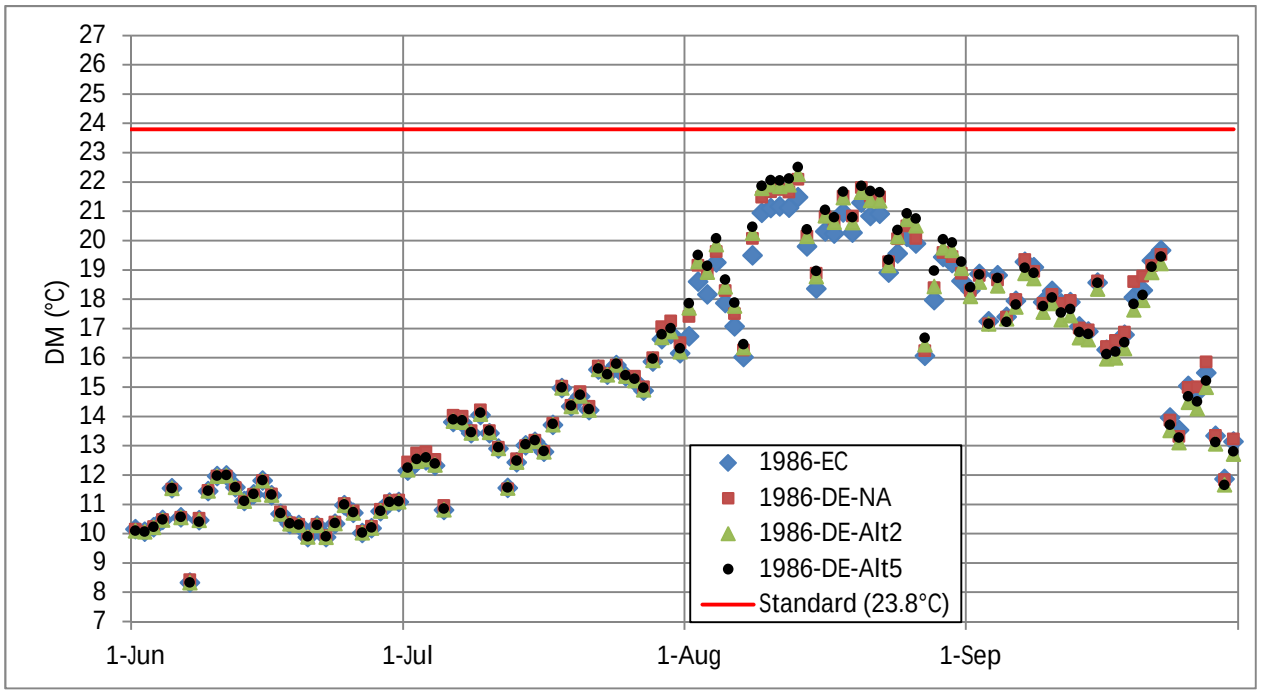

Figure 89. 1986 Direct Effects DMs at CR-HSU

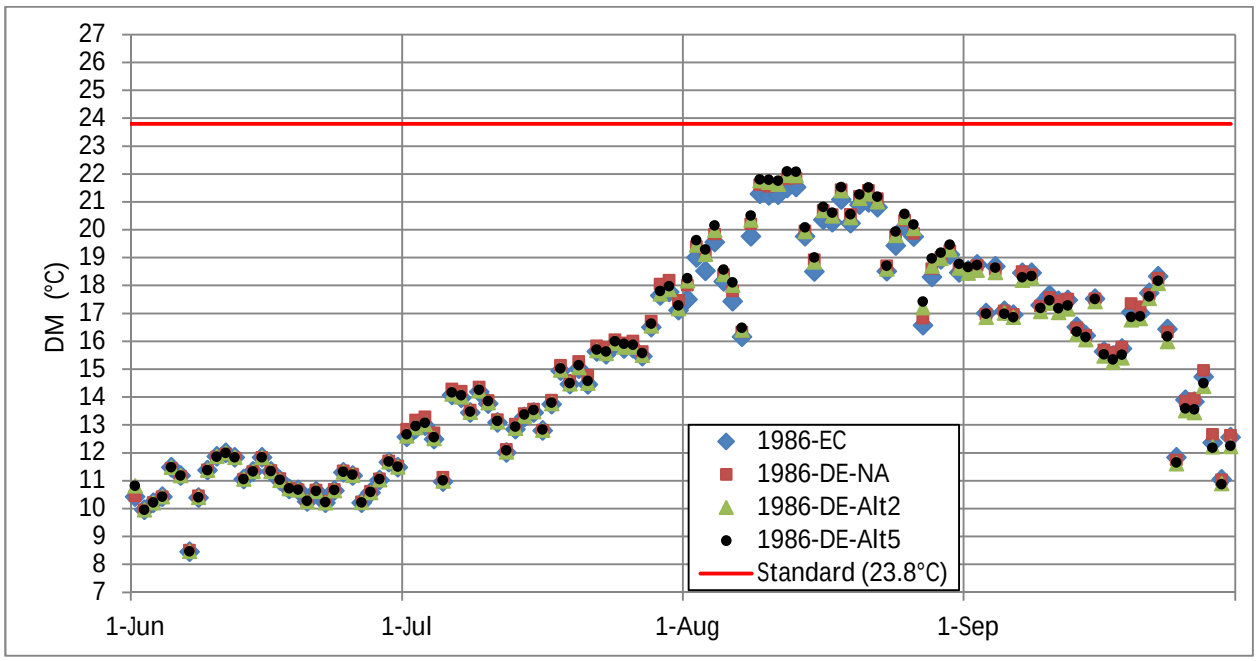

Figure 90. 1986 Direct Effects DMs at CR-WFU

For 1986 direct effects, Table 14 summarizes the results of a regulatory analysis of the simulation results at the three thermistor locations, CR-WGD, CR-HSU, and CR-WFU. The maximum WAT for the full period increased only slightly for Alt2 (0°C to 0.1°C relative to no action, and 0.3°C to 0.4°C relative to existing conditions). A similar pattern was simulated for maximum DMs, with only slight increases for Alt2 relative to no action (0.1°C to 0.2°C) and existing conditions (0.5°C to 0.8°C). There were no exceedances of chronic or acute standards for any of the simulations for the 1986 hydrology.

Table 14. 1986 Direct Effects Simulated Regulatory Results

	1986- WGD				1986- HSU				1986- WFU			
	EC	NA	Alt2	Alt5	EC	NA	Alt2	Alt5	EC	NA	Alt2	Alt5
Chronic												
MWAT (°C)	16.1	16.4	16.4	16.6	17.3	17.6	17.7	17.8	17.7	18.0	18.1	18.2
June # weeks > 18.2 °C	0	0	0	0	0	0	0	0	0	0	0	0
July # weeks > 18.2 °C	0	0	0	0	0	0	0	0	0	0	0	0
August # weeks > 18.2 °C	0	0	0	0	0	0	0	0	0	0	0	0
Sept. # weeks > 18.2 °C	0	0	0	0	0	0	0	0	0	0	0	0
Acute												
Max DM (°C)	17.2	17.7	17.9	18.2	21.5	22.1	22.3	22.5	21.5	21.9	22.0	22.1
June # days > 23.8 °C	0	0	0	0	0	0	0	0	0	0	0	0
July # days > 23.8 °C	0	0	0	0	0	0	0	0	0	0	0	0
August # days > 23.8 °C	0	0	0	0	0	0	0	0	0	0	0	0
Sept. # days > 23.8 °C	0	0	0	0	0	0	0	0	0	0	0	0

Looking more closely at the 1986 direct effects simulations, Table 15 and Table 16 present the simulated WAT and DM temperature effects of Alt2 and Alt5 relative to existing conditions and no action, respectively. For these 1986 simulations applying 2007 meteorology, the largest individual WAT increase due to Alt2, relative to existing conditions, was 0.4 °C at WFU (August 14). The value was only slightly higher for Alt5 (0.6°C) at WGD (August 27) due to greater pumping. For Alt2 and Alt5 relative to existing conditions, the average July and August WAT increase ranged from 0°C to 0.4°C. Relative to no action, WAT increases were even smaller, and in some cases negative due to greater pumping for no action as compared to Alt2 and Alt5 in July.

The largest simulated Alt2 DM increase relative to existing conditions was 1.0°C, occurring at HSU (August 1). The largest simulated Alt5 DM increase relative to existing conditions was similar at 1.1°C on August 1. For Alt2 and Alt5 relative to existing conditions, the average monthly DM increases for July and August ranged from 0°C to 0.8°C. Relative to no action, DM

increases were even smaller, and in some cases negative due to greater pumping for no action as compared to the Alt2 and Alt5 in July.

Table 15. 1986 Direct Effects Simulated WAT and DM increases Relative to Existing Conditions.

	1986-WGD		1986-HSU		1986-WFU	
	Increase Relative to Existing Conditions (°C)		Increase Relative to Existing Conditions (°C)		Increase Relative to Existing Conditions (°C)	
	Alt2	Alt5	Alt2	Alt5	Alt2	Alt5
Chronic						
Largest WAT Increase in July and August (°C)	0.3	0.6	0.4	0.5	0.4	0.5
Avg. July WAT Increase (°C)	0.0	0.0	0.0	0.1	0.0	0.1
Avg. Aug. WAT Increase (°C)	0.2	0.4	0.3	0.4	0.3	0.4
Acute						
Largest DM Increase in July and August (°C)	0.7	1.0	1.0	1.1	0.7	0.8
Avg. July DM Increase (°C)	0.0	0.0	0.0	0.1	0.0	0.1
Avg. Aug. DM Increase (°C)	0.4	0.7	0.6	0.8	0.3	0.5

Table 16. 1986 Direct Effects Simulated WAT and DM increases Relative to No Action.

	1986-WGD		1986-HSU		1986-WFU	
	Increase Relative to No Action (°C)		Increase Relative to No Action (°C)		Increase Relative to No Action (°C)	
	Alt2	Alt5	Alt2	Alt5	Alt2	Alt5
Chronic						
Largest WAT Increase in July and August (°C)	0.1	0.3	0.1	0.3	0.1	0.2
Avg. July WAT Increase (°C)	-0.1	0.0	-0.1	-0.1	-0.1	-0.1
Avg. Aug. WAT Increase (°C)	0.0	0.2	0.0	0.2	0.0	0.2
Acute						
Largest DM Increase in July and August (°C)	0.2	0.5	0.4	0.7	0.4	0.6
Avg. July DM Increase (°C)	-0.1	0.0	-0.1	-0.1	-0.2	-0.1
Avg. Aug. DM Increase (°C)	0.0	0.3	0.1	0.3	0.0	0.2

4.1.3.4 1986 Direct Effects Summary

For the simulated 1986 direct effects hydrology with 2007 meteorology, Windy Gap pumping differences occurred in July and August; however, due to relatively high flow rates in the river, temperature differences were minimal across scenarios. Small temperature increases were simulated at WGD, HSU, and WFU for Alt2 and Alt5 relative to existing conditions. The largest WAT increase for Alt2 relative to existing conditions was simulated at WFU in August (+0.4°C). The largest WAT increase for Alt2 relative to no action was also simulated at WFU in August (+0.1°C). The largest DM increase for Alt2 relative to existing conditions was simulated at HSU in August (+1.0°C). The largest DM increase for Alt2 relative to no action was also simulated at HSU in August (+0.4°C). There were no exceedances of WAT or DM standards for any of the simulations.

4.1.4 1987 Direct Effects

The results of direct effects simulations applying 1987 hydrology scenarios under conditions of 2007 meteorology are presented in the following subsections. Direct effects simulations for 1987 included existing conditions, no action, Alt2, and Alt5.

4.1.4.1 1987 Direct Effects Hydrographs

Figure 91 and Figure 92 present the differences in pumping at Windy Gap and the corresponding flow below Windy Gap Reservoir for the direct effects alternatives simulated – existing conditions, no action, alternative 2, and alternative 5. Windy Gap pumping volumes (June through September) are summarized for each simulation in Table 17.

Overall, 1987 was an average to drier year, with virgin annual flows ranking 42nd out of the 47 years of hydrology simulated for the WGFP. For the 1987 direct effects simulations, Windy Gap pumping and river flows are nearly identical in July, August, and September for existing conditions, no action, Alt2, and Alt5. In June, pumping is greatest for Alt2 and Alt5. No action shows slightly greater pumping than existing conditions, but the resulting hydrographs (Figure 92) are very similar.

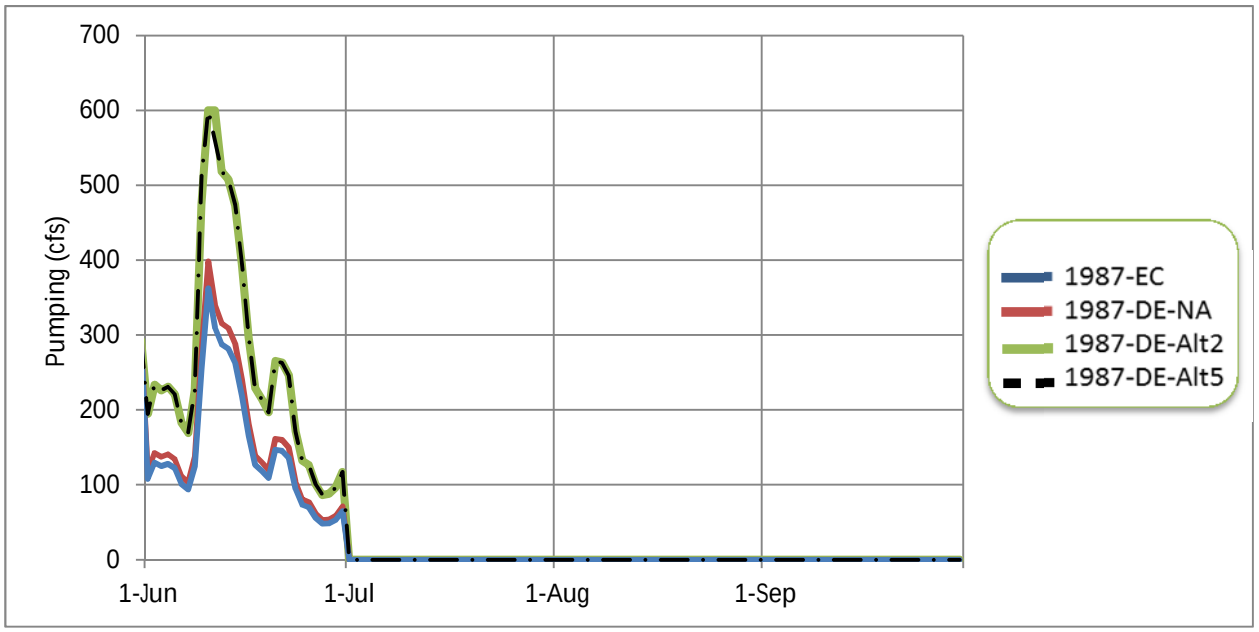

Figure 91. 1987 Direct Effects Windy Gap Pumping

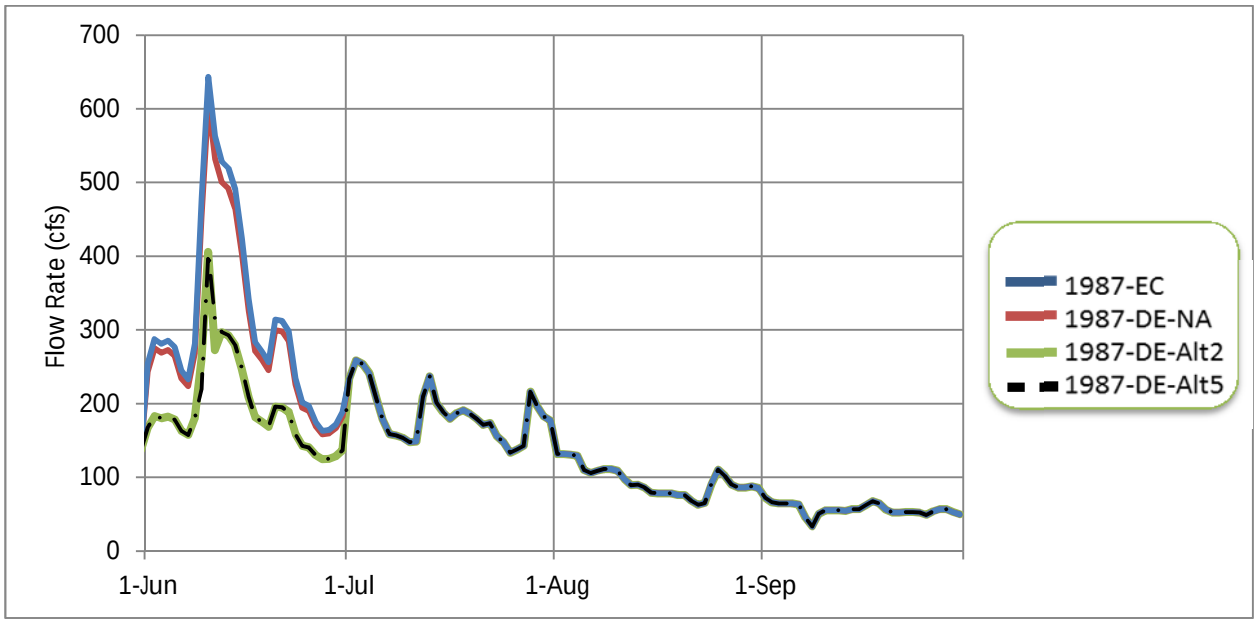

Figure 92. 1987 Direct Effects Flow Rates Below Windy Gap

Table 17. 1987 Direct Effects Windy Gap Pumping Volumes

	1987-DE Monthly Pumping Totals (AF/month)			
	June	July	August	September
Existing Conditions	8,659	0	0	0
No Action	9,515	0	0	0
Alternative 2	15,636	0	0	0
Alternative 5	15,635	0	0	0

4.1.4.2 1987 Direct Effects Hourly Temperature Plots

Figure 93 through Figure 98 present the hourly temperature plots produced by the model for thermistor locations CR-WGD, CR-HSU, and CR-WFU. Hourly temperature plots for the full simulation period are shown, as well as plots focusing on the period of the simulation with notable differences in predicted temperatures. For 1987 direct effects simulations, major differences in simulated temperatures were limited to the month of June, in agreement with the period of Windy Gap pumping differences.

Relatively small differences in hourly temperatures are simulated across the scenarios during the time of pumping differences in June. A closer look at the "June Zoom" figures shows Alt2 and Alt5 temperatures track together and show higher daily peaks than no action, which are in turn higher than existing conditions. This matches the expected relative pattern based on pumping differences. These 1987 direct effects temperature simulation results are summarized and discussed quantitatively in Section 4.1.4.3.

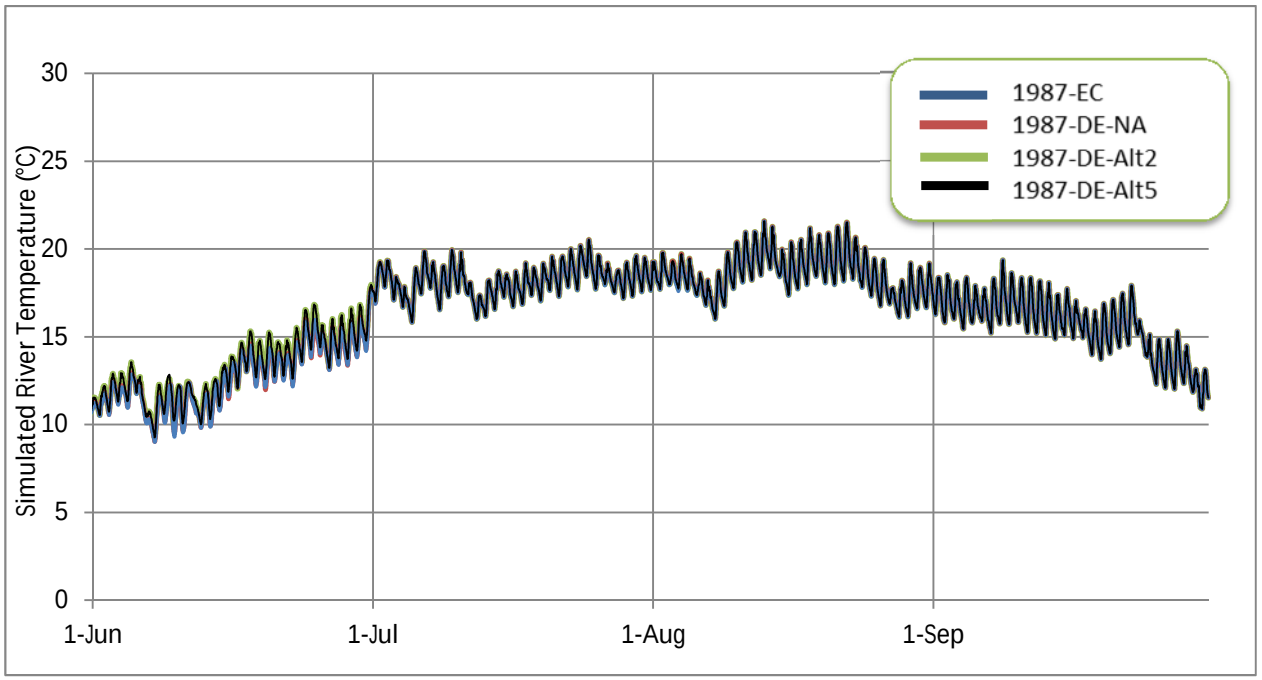

Figure 93. 1987 Direct Effects Hourly Temperature at CR-WGD

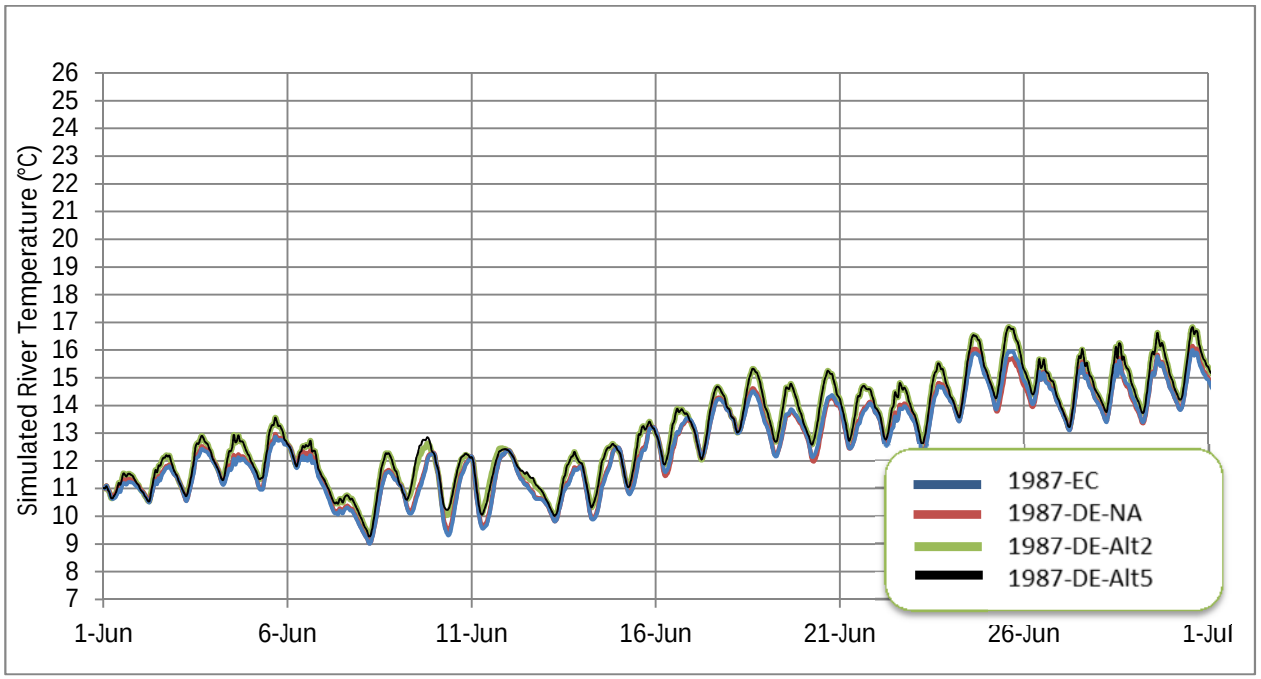

Figure 94. 1987 Direct Effects Hourly Temperature at CR-WGD June Zoom

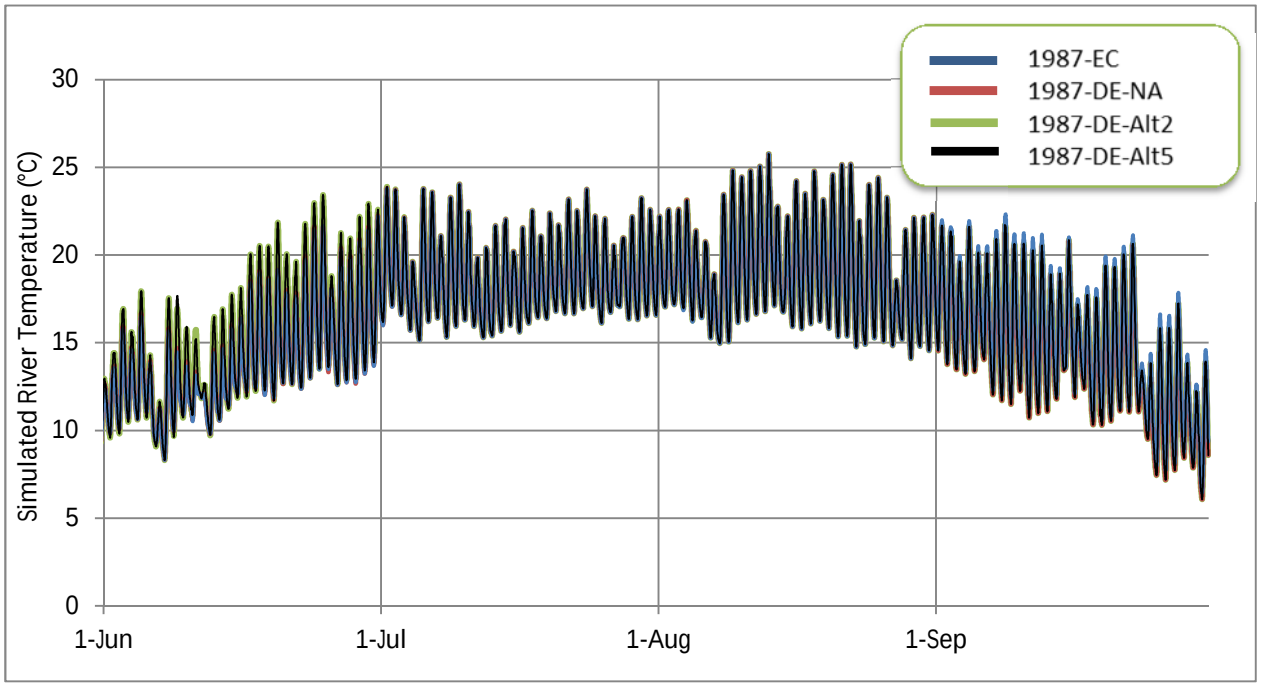

Figure 95. 1987 Direct Effects Hourly Temperature at CR-HSU

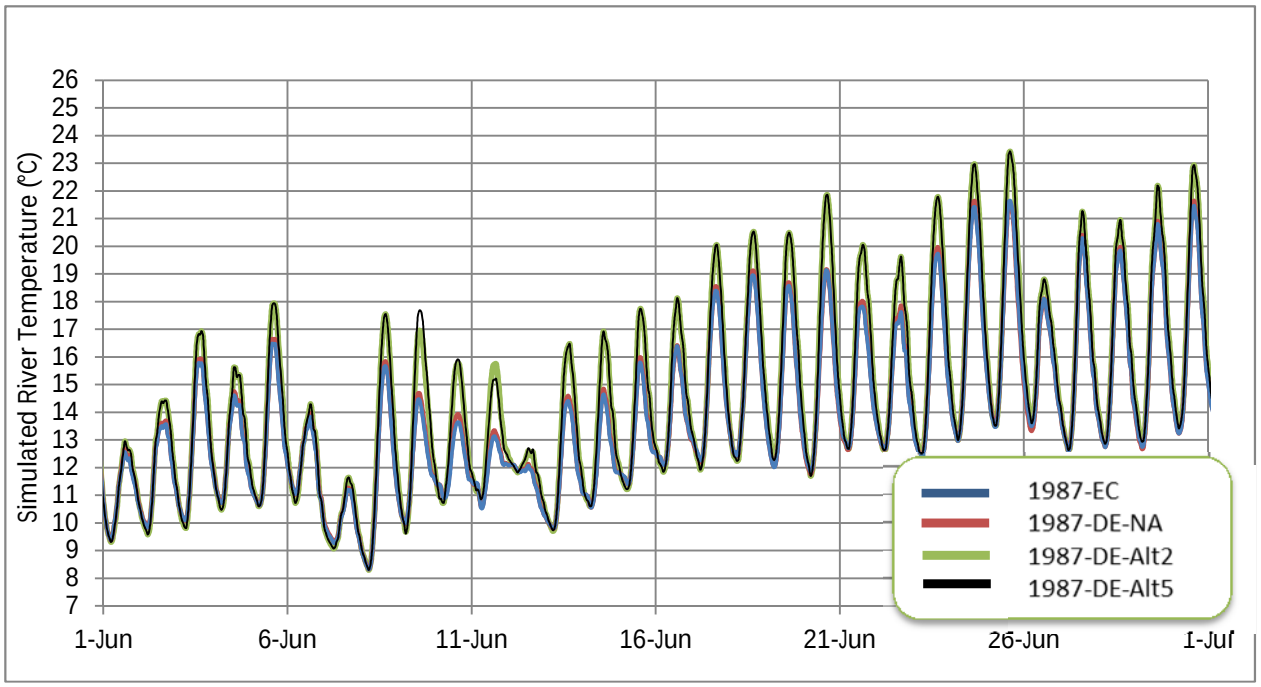

Figure 96. 1987 Direct Effects Hourly Temperature at CR-HSU June Zoom

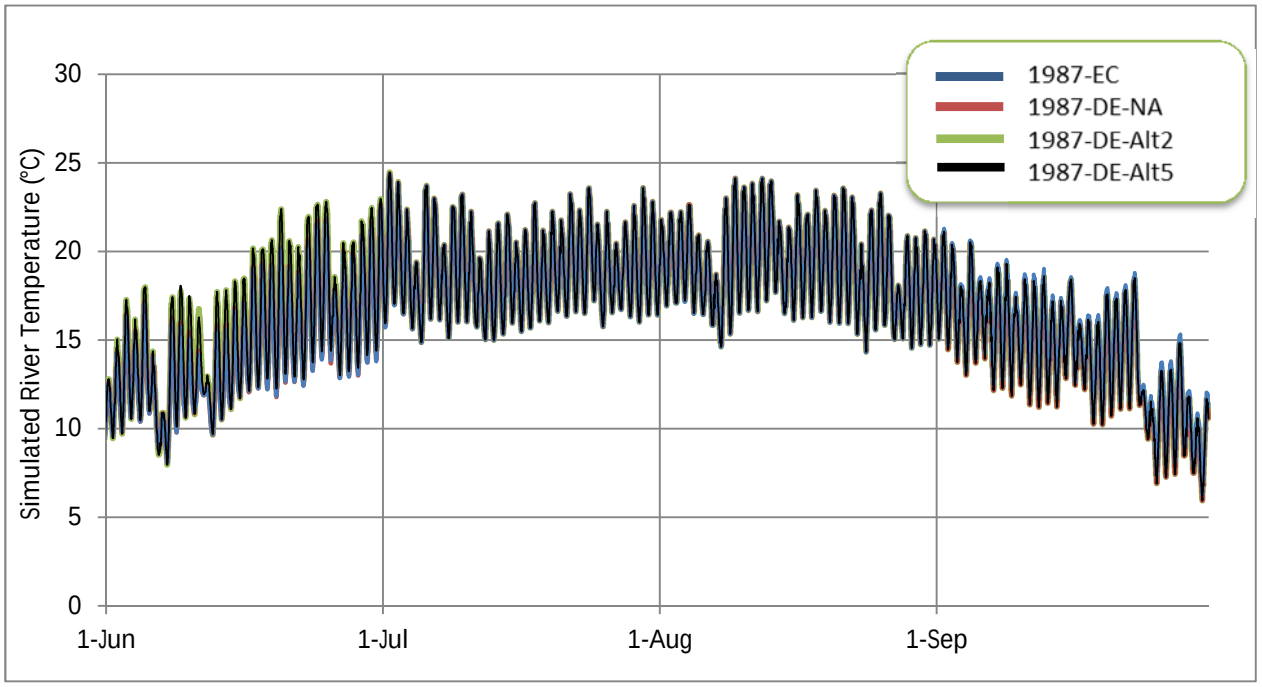

Figure 97. 1987 Direct Effects Hourly Temperature at CR-WFU

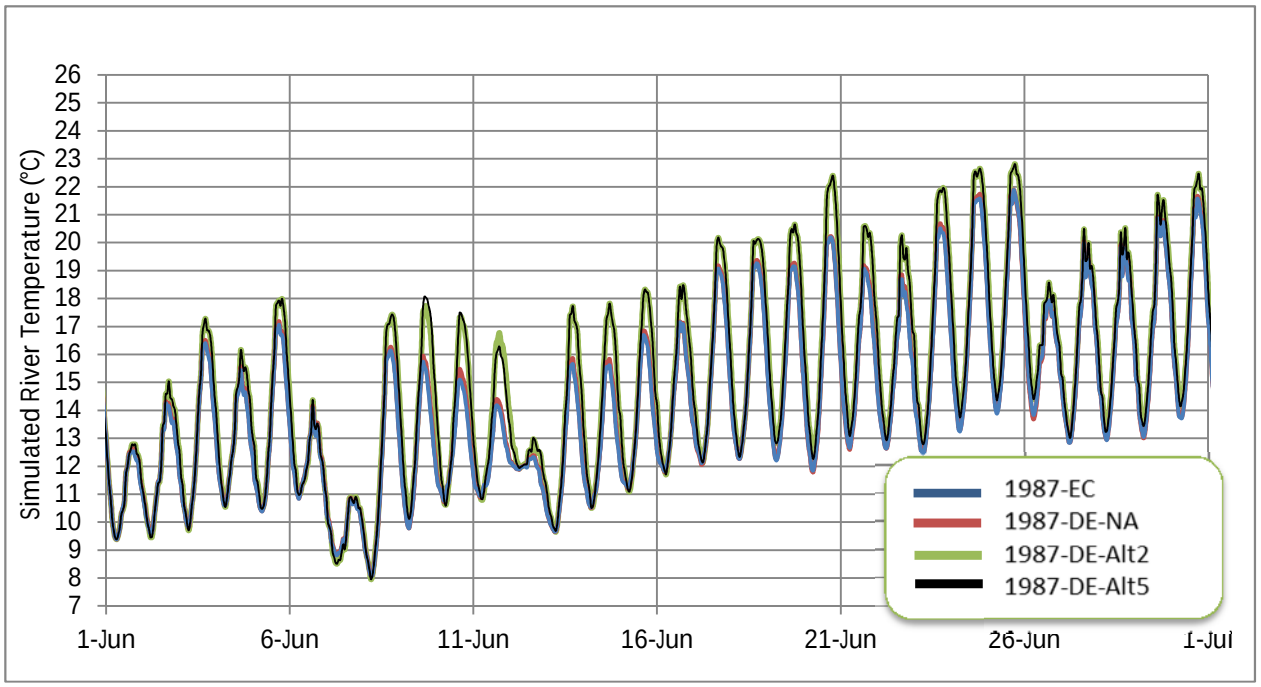

Figure 98. 1987 Direct Effects Hourly Temperature at CR-WFU June Zoom

4.1.4.3 1987 Direct Effects Weekly Average and Daily Maximum Temperatures

WATs and DMs were all calculated using the appropriate Colorado Water Quality Control Division tool (Temp-program-V4.2; personal communication, Robert Hillegas, May 24, 2011) for this segment of the upper Colorado River. Figure 99 through Figure 101 present WATs for each simulated day, following the first week of simulation. DMs are presented for each simulated day in Figure 102 through Figure 104. These figure sets show results for thermistor locations CR-WGD, CR-HSU, and CR-WFU.

In agreement with the minimal temperature differences presented in the previous subsection, the WAT and DM results show only very small differences in June (and extending one week into July due to the rolling average nature of the WAT calculation). This limited response to pumping differences is due to the relatively high flow rates in the river during the time of the pumping differences (June). At HSU and WFU, there is also a relative increase in WATs and DMs in September for Alt2, Alt5 and no action, as compared to existing conditions. This is the result of increased assumed withdrawals by Middle Park Water Conservancy District (MPWCD) in Alt2, Alt5, and no action, relative to existing conditions. This assumed increase in withdrawals reflects anticipated demands associated with growth at the time of likely implementation of the WGFP. This increase in MPWCD withdrawals is limited to September and occurs in all simulation years. The effects are most apparent in the WATs and DMs for 1987 due to low river flows in September. The effects are also apparent in September in the direct effects simulations for 1975 and 1979, where flows are also relatively low in September. None of the September simulation results show DM or WAT exceedances for any of the scenarios or simulation years.

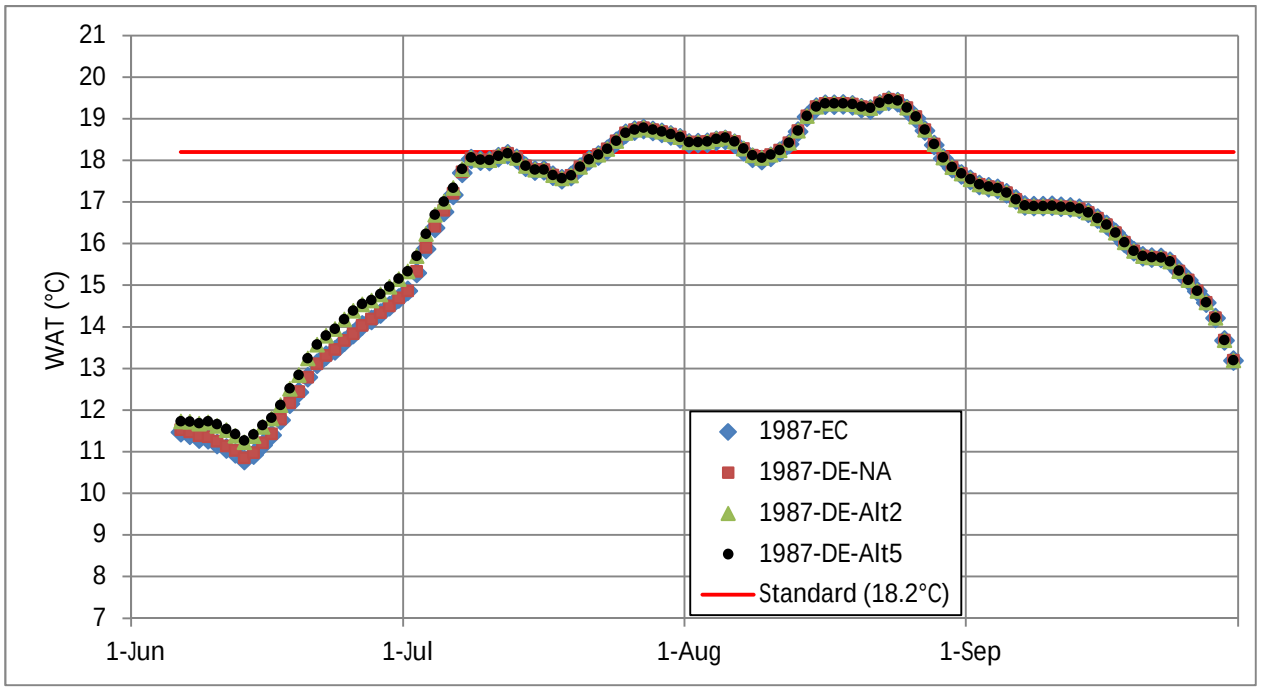

Figure 99. 1987 Direct Effects WATs at CR-WGD

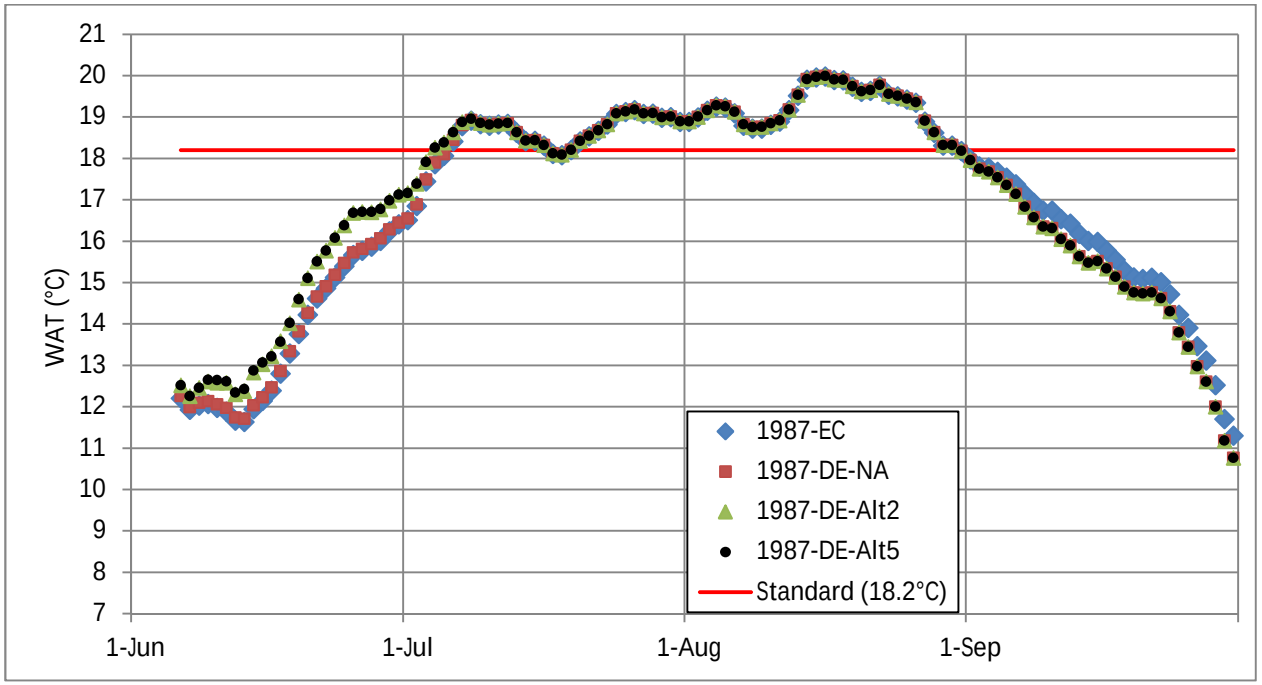

Figure 100. 1987 Direct Effects WATs at CR-HSU

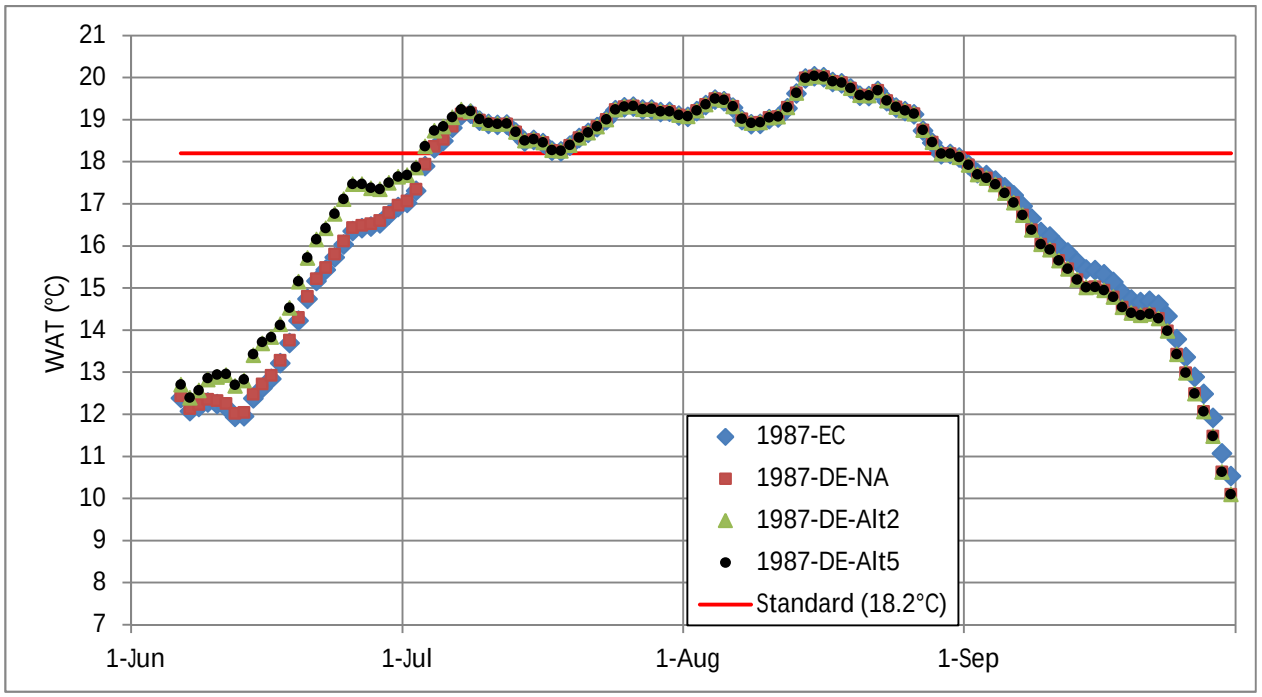

Figure 101. 1987 Direct Effects WATs at CR-WFU

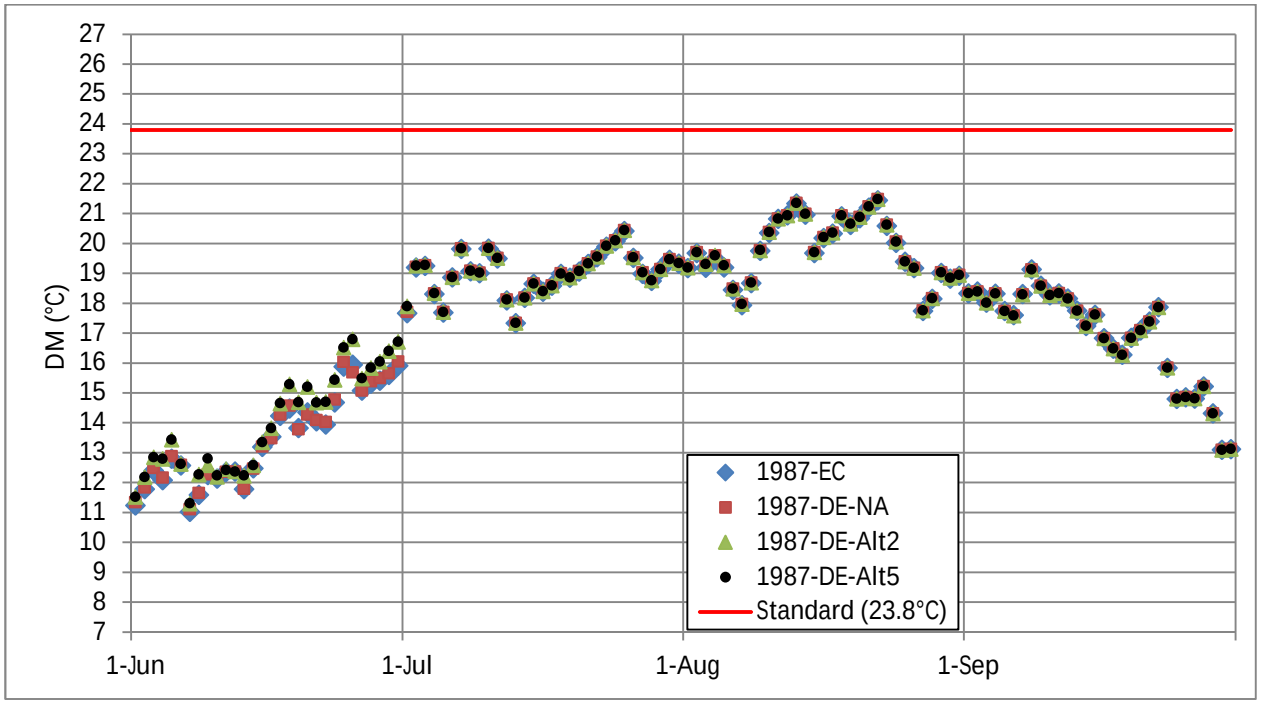

Figure 102. 1987 Direct Effects DMs at CR-WGD

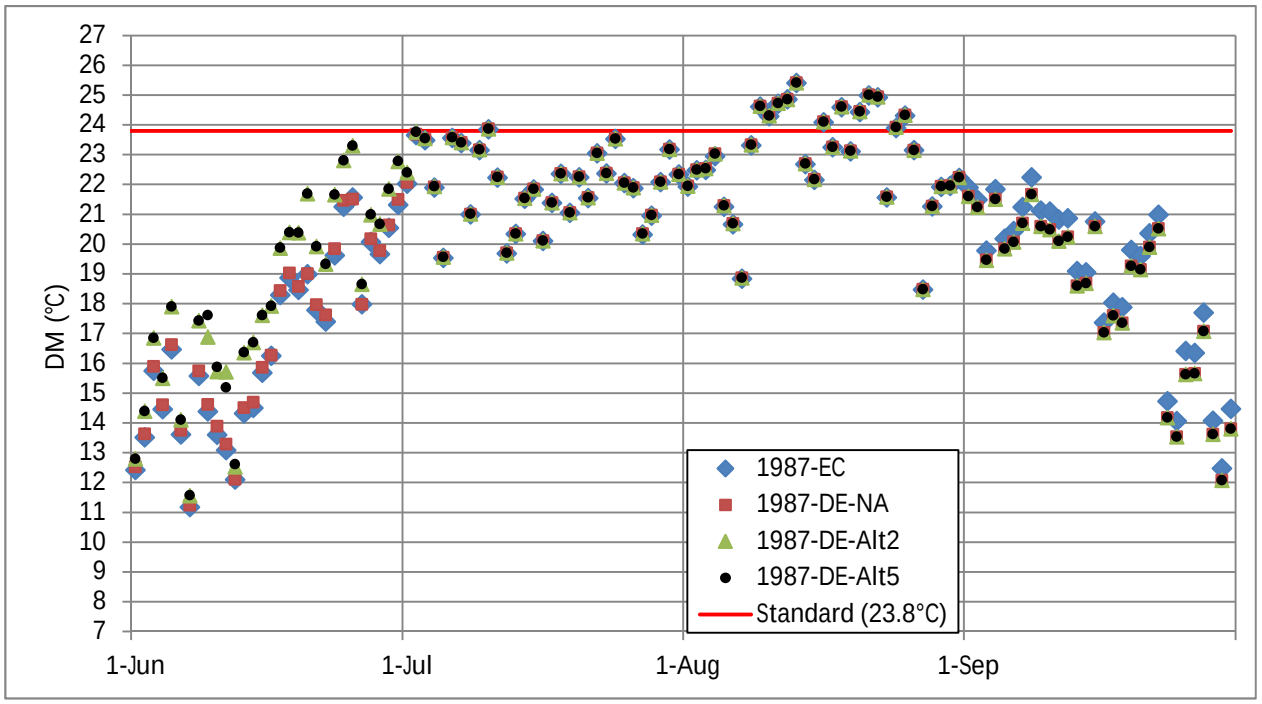

Figure 103. 1987 Direct Effects DMs at CR-HSU

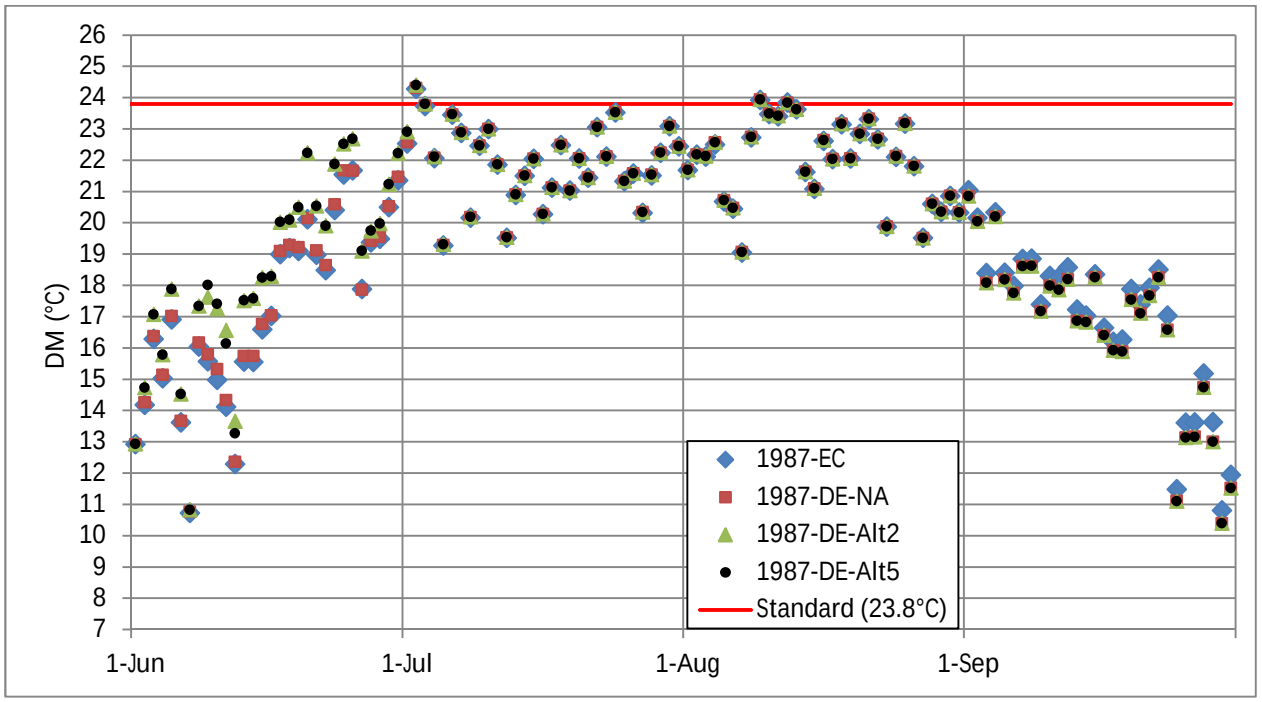

Figure 104. 1987 Direct Effects DMs at CR-WFU

For 1987 direct effects, Table 18 summarizes the results of a regulatory analysis of the simulation results at the three thermistor locations, CR-WGD, CR-HSU, and CR-WFU. The maximum WAT for the full period did not increase much for Alt2 (0.0°C relative to no action, and 0.0 to 0.1°C relative to existing conditions). A similar pattern was seen for maximum DMs, with only slight increases for Alt2 relative to no action (0.0 to 0.1°C) and existing conditions (0.0 to 0.1°C). These very small increases in maximum WATs and DMs occur because the differences in Windy Gap pumping do not occur during the times of the maximum WATs and DMs for the 1987 simulated hydrology with 2007 meteorology. Correspondingly, the only increase in exceedances (one additional week above the chronic WAT standard in July) is simulated to occur for Alt2 and Alt5, relative to both no action and existing conditions in July, during the first week of WAT calculations when the rolling average is accounting for increased temperatures in June.

Table 18. 1987 Direct Effects Simulated Regulatory Results

	1987- WGD				1987- HSU				1987- WFU			
	EC	NA	Alt2	Alt5	EC	NA	Alt2	Alt5	EC	NA	Alt2	Alt5
Chronic												
MWAT (°C)	19.4	19.5	19.5	19.5	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
June # weeks > 18.2 °C	0	0	0	0	0	0	0	0	0	0	0	0
July # weeks > 18.2 °C	2	2	2	2	4	4	4	4	4	4	5	5
August # weeks > 18.2 °C	4	4	4	4	5	5	5	5	4	4	4	4
Sept. # weeks > 18.2 °C	0	0	0	0	0	0	0	0	0	0	0	0
Acute												
Max DM (°C)	21.4	21.5	21.5	21.5	25.4	25.4	25.4	25.4	24.3	24.3	24.4	24.4
June # days > 23.8 °C	0	0	0	0	0	0	0	0	0	0	0	0
July # days > 23.8 °C	0	0	0	0	1	1	1	1	1	1	1	1
August # days > 23.8 °C	0	0	0	0	12	12	12	12	2	2	2	2
Sept. # days > 23.8 °C	0	0	0	0	0	0	0	0	0	0	0	0

Looking more closely at the 1987 direct effects simulations, Table 19 and Table 20 present the simulated WAT and DM temperature effects of Alt2 and Alt5 relative to existing conditions and no action, respectively. For these 1987 simulations applying 2007 meteorology, the largest individual WAT increase in July and August due to Alt2, relative to existing conditions, was 0.7°C at WFU (July 1). The largest increase relative to existing conditions was in June, also at WFU (1.1°C on June 25). (Reminder: Table 19 and Table 20 show only the July and August results, as no exceedances were simulated for any scenario in June or September.) Results were the same for Alt5. For Alt2 and Alt5 relative to existing conditions, the monthly average WAT increase in July and August was minimal, as pumping differences occurred in June. Relative to

no action, WAT increases were similar though slightly smaller. The largest individual WAT increase in July and August due to Alt2, relative to no action, was 0.6 °C at WFU (July 1). The largest increase relative to existing conditions was in June, also at WFU (1.0°C on June 25). Results were the same for Alt5.

As shown in Table 20, the largest individual DM increase in July and August due to Alt2, relative to existing conditions, was 0.4 °C at HSU (July 1). The largest increase relative to existing conditions was in June, also at HSU (2.7°C on June 20). Results were comparable for Alt5. Relative to no action, DM increases were similar though slightly smaller. The largest DM increase relative to existing conditions was in June, at WFU (2.7°C on June 20). The largest individual DM increase in July and August due to Alt2, relative to no action, was 0.3 °C at WFU (July 1). Results were comparable for Alt5.

Table 19. 1987 Direct Effects Simulated WAT and DM Increases Relative to Existing Conditions.

	1987-WGD		1987-HSU		1987-WFU	
	Increase Relative to Existing Conditions (°C)		Increase Relative to Existing Conditions (°C)		Increase Relative to Existing Conditions (°C)	
	Alt2	Alt5	Alt2	Alt5	Alt2	Alt5
Chronic						
Largest WAT Increase in July and August (°C)	0.5	0.5	0.6	0.7	0.7	0.7
Avg. July WAT Increase (°C)	0.1	0.1	0.1	0.1	0.1	0.1
Avg. Aug. WAT Increase (°C)	0.0	0.0	0.0	0.0	0.0	0.0
Acute						
Largest DM Increase in July and August (°C)	0.2	0.2	0.4	0.4	0.4	0.4
Avg. July DM Increase (°C)	0.0	0.0	0.0	0.0	0.0	0.0
Avg. Aug. DM Increase (°C)	0.0	0.0	0.0	0.0	0.0	0.0

Table 20. 1987 Direct Effects Simulated WAT and DM Increases Relative to No Action.

	1987-WGD		1987-HSU		1987-WFU	
	Increase Relative to No Action (°C)		Increase Relative to No Action (°C)		Increase Relative to No Action (°C)	
	Alt2	Alt5	Alt2	Alt5	Alt2	Alt5
Chronic						
Largest WAT Increase in July and August (°C)	0.5	0.5	0.6	0.6	0.6	0.6
Avg. July WAT Increase (°C)	0.1	0.1	0.1	0.1	0.1	0.1
Avg. Aug. WAT Increase (°C)	0.0	0.0	0.0	0.0	0.0	0.0
Acute						
Largest DM Increase in July and August (°C)	0.2	0.2	0.3	0.3	0.3	0.3
Avg. July DM Increase (°C)	0.0	0.0	0.0	0.0	0.0	0.0
Avg. Aug. DM Increase (°C)	0.0	0.0	0.0	0.0	0.0	0.0

4.1.4.4 1987 Direct Effects Summary

For the simulated 1987 direct effects hydrology with 2007 meteorology, Windy Gap pumping differences occurred in June, when flow rates in the river are typically high, minimizing temperature increase effects. In June, temperature increases were simulated at WGD, HSU, and WFU for Alt2 and Alt5 relative to existing conditions and no action. There were no exceedances of WAT or DM standards for any of the simulations in June when pumping rates varied across scenarios; however, due to rolling averages, there was an increase in WAT exceedances (by 1) in July at WFU. The largest WAT increase for Alt2 relative to existing conditions was simulated at WFU in June (+1.1°C). The largest WAT increase for Alt2 relative to no action was also simulated at WFU in June (+1.0°C). The largest DM increase for Alt2 relative to existing conditions was simulated at HSU in June (+2.7°C). The largest DM increase for Alt2 relative to no action was also simulated at HSU in June (+2.7°C).

4.1.5 1988 Direct Effects

The results of direct effects simulations applying 1988 hydrology scenarios under conditions of 2007 meteorology are presented in the following subsections. Direct effects simulations for 1988 included existing conditions, no action, Alt2, and Alt5.

4.1.5.1 1988 Direct Effects Hydrographs

Figure 105 and Figure 106 present the differences in pumping at Windy Gap and the corresponding flow below Windy Gap Reservoir for the direct effects alternatives simulated – existing conditions, no action, alternative 2, and alternative 5. Windy Gap pumping volumes (June through September) are summarized for each simulation in Table 21.

Overall, 1988 was an average year, with virgin annual flows ranking 34th out of the 47 years of hydrology simulated for the WGFP. For the 1988 direct effects simulations, Windy Gap pumping and river flows are nearly identical in August and September for existing conditions, no action, Alt2, and Alt5. In June, pumping is greatest for Alt2 and Alt5, and in July, pumping is greatest for no action. No action shows slightly greater pumping than existing conditions, but the resulting hydrographs (Figure 92) are very similar. Differences in flow below Windy Gap Reservoir between no action and existing conditions in June (Figure 106) are due to differences in Willow Creek spills and operations between the two scenarios. Willow Creek flows to the Colorado River are much lower under the existing conditions simulation.

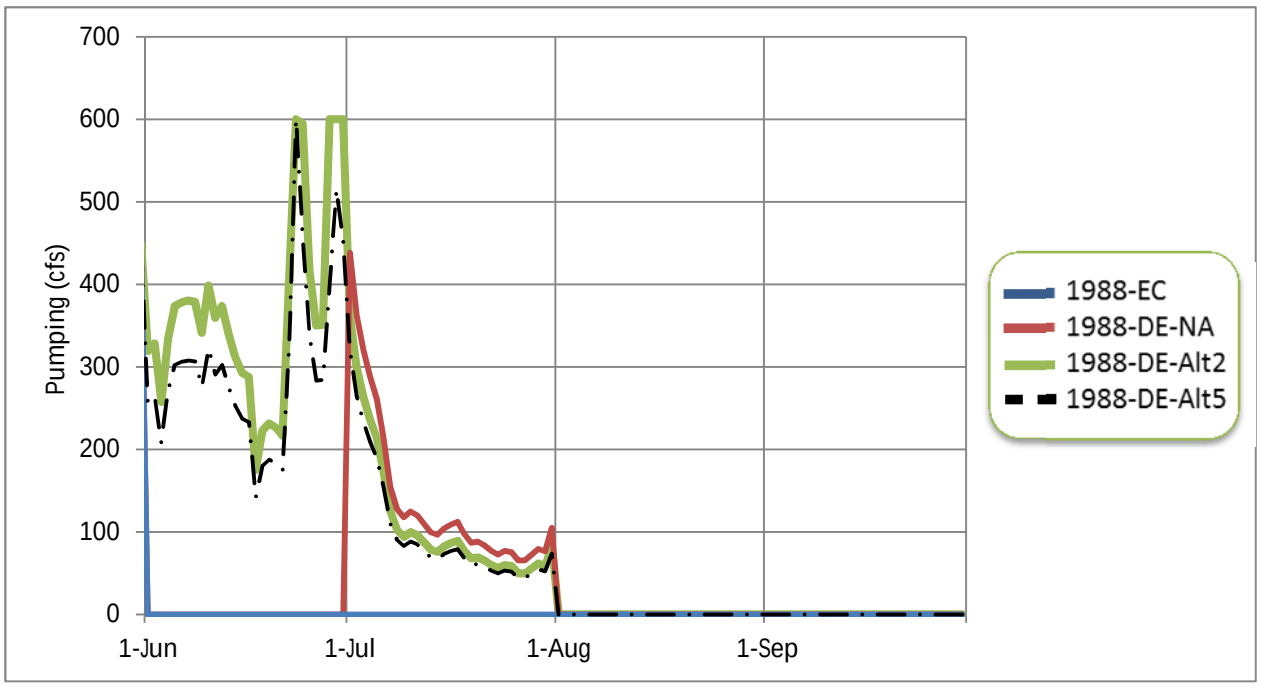

Figure 105. 1988 Direct Effects Windy Gap Pumping

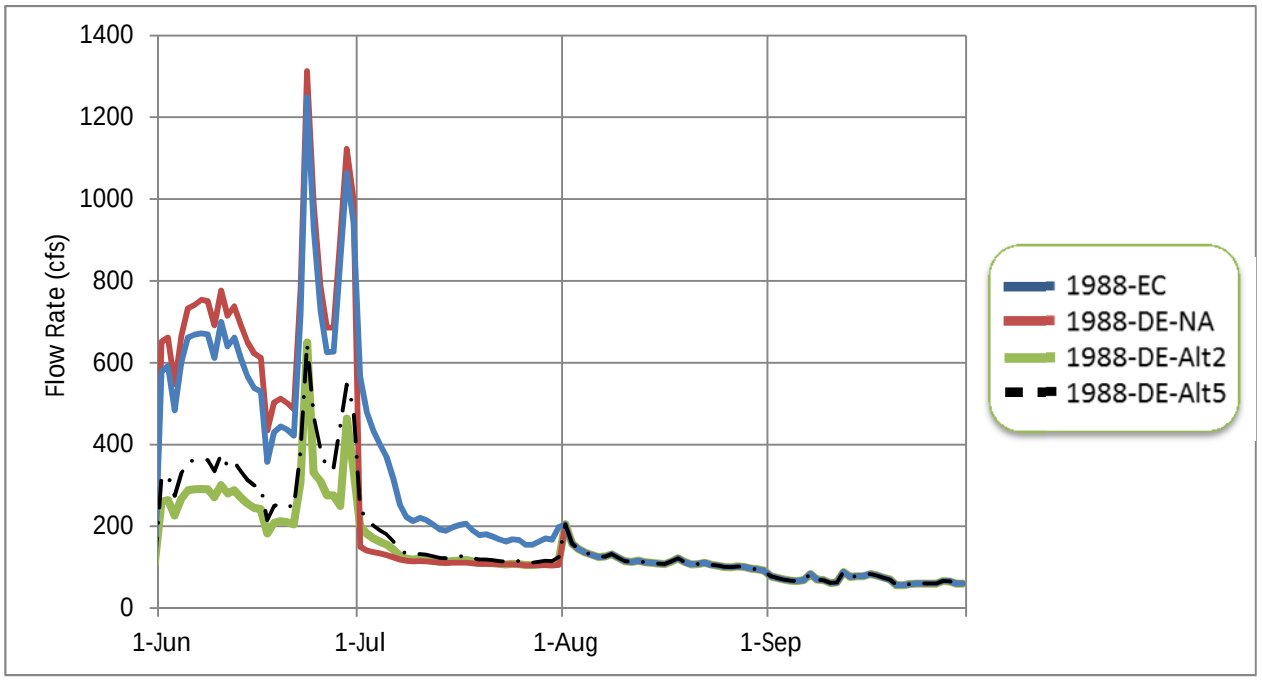

Figure 106. 1988 Direct Effects Flow Rates Below Windy Gap

Table 21. 1988 Direct Effects Windy Gap Pumping Volumes

	1988-DE Monthly Pumping Totals (AF/month)			
	June	July	August	September
Existing Conditions	0	0	0	0
No Action	0	8,488	0	0
Alternative 2	21,915	6,822	0	0
Alternative 5	17,735	6,031	0	0

4.1.5.2 1988 Direct Effects Hourly Temperature Plots

Figure 107 through Figure 112 present the hourly temperature plots produced by the model for thermistor locations CR-WGD, CR-HSU, and CR-WFU. Hourly temperature plots for the full simulation period are shown, as well as plots focusing on the period of the simulation with notable differences in predicted temperatures. For 1988 direct effects simulations, major differences in simulated temperatures were limited to the months of June and July, in agreement with the period of Windy Gap pumping differences.

Across scenarios, simulated temperatures rise sharply in the beginning of July, due to the drop in flow rates. Across the reach, Alt2 and Alt5 show temperatures higher than existing conditions and no action in June. In July, Alt2, Alt5, and no action show similar patterns at all three thermistor locations, with temperatures greater than existing conditions. Simulated temperatures for all scenarios are similar in August and September, when pumping and flow rates below Windy Gap are the same. These 1988 direct effects temperature simulation results are summarized and discussed quantitatively in Section 4.1.5.3.

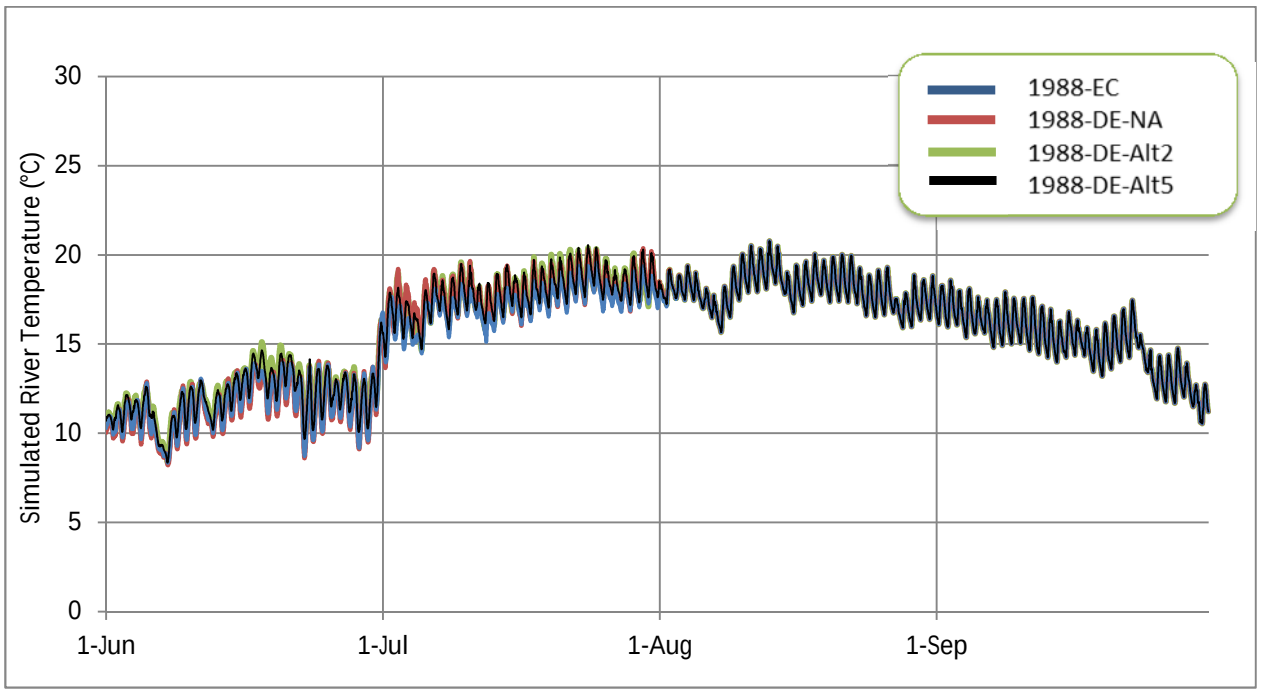

Figure 107. 1988 Direct Effects Hourly Temperature at CR-WGD

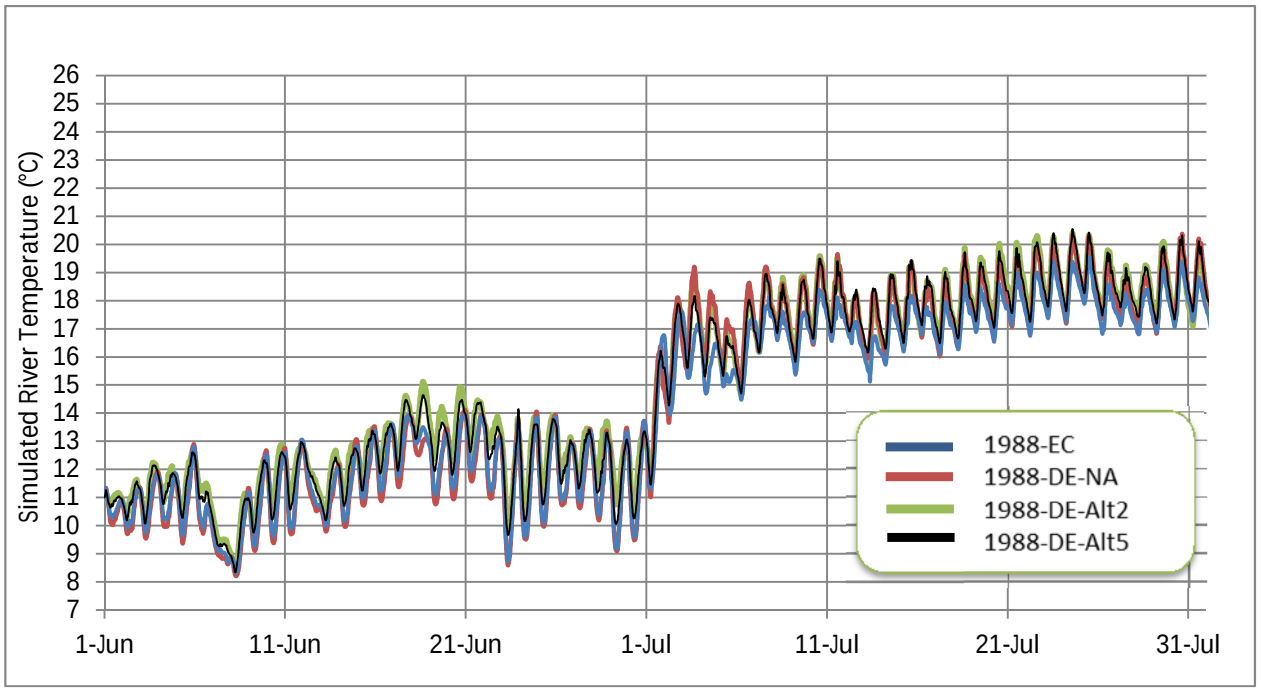

Figure 108. 1988 Direct Effects Hourly Temperature at CR-WGD June-July Zoom

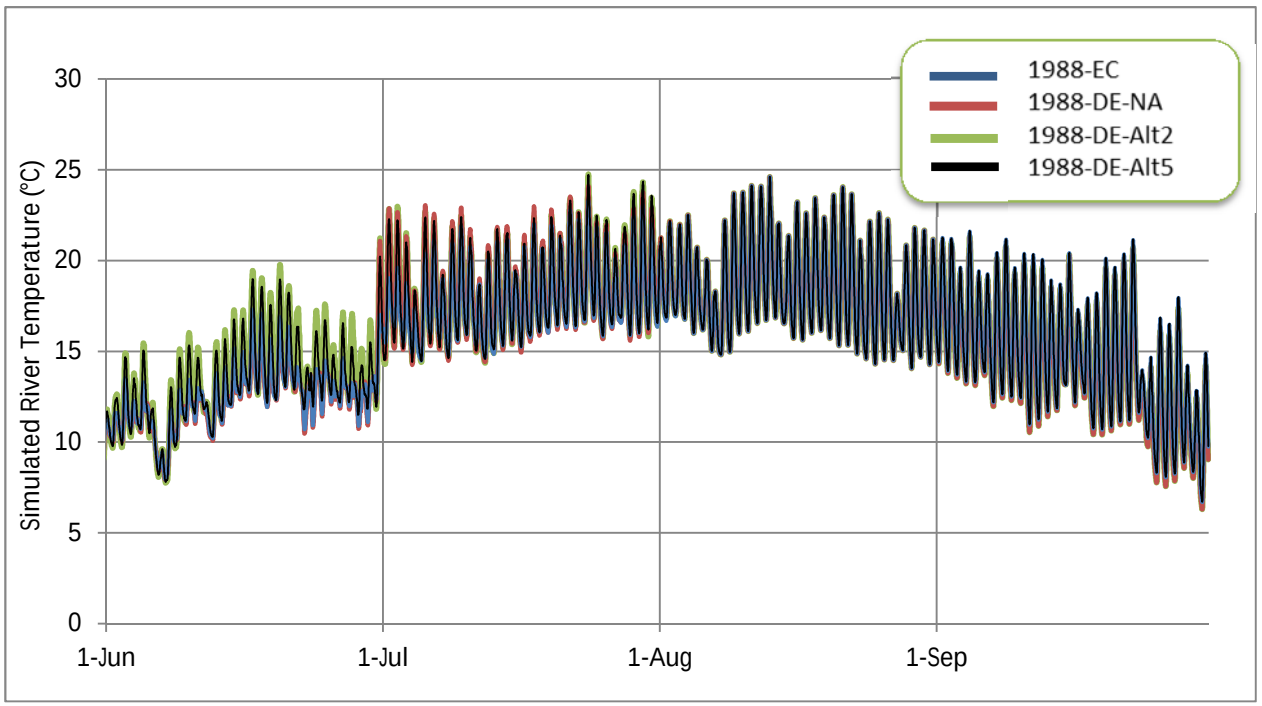

Figure 109. 1988 Direct Effects Hourly Temperature at CR-HSU

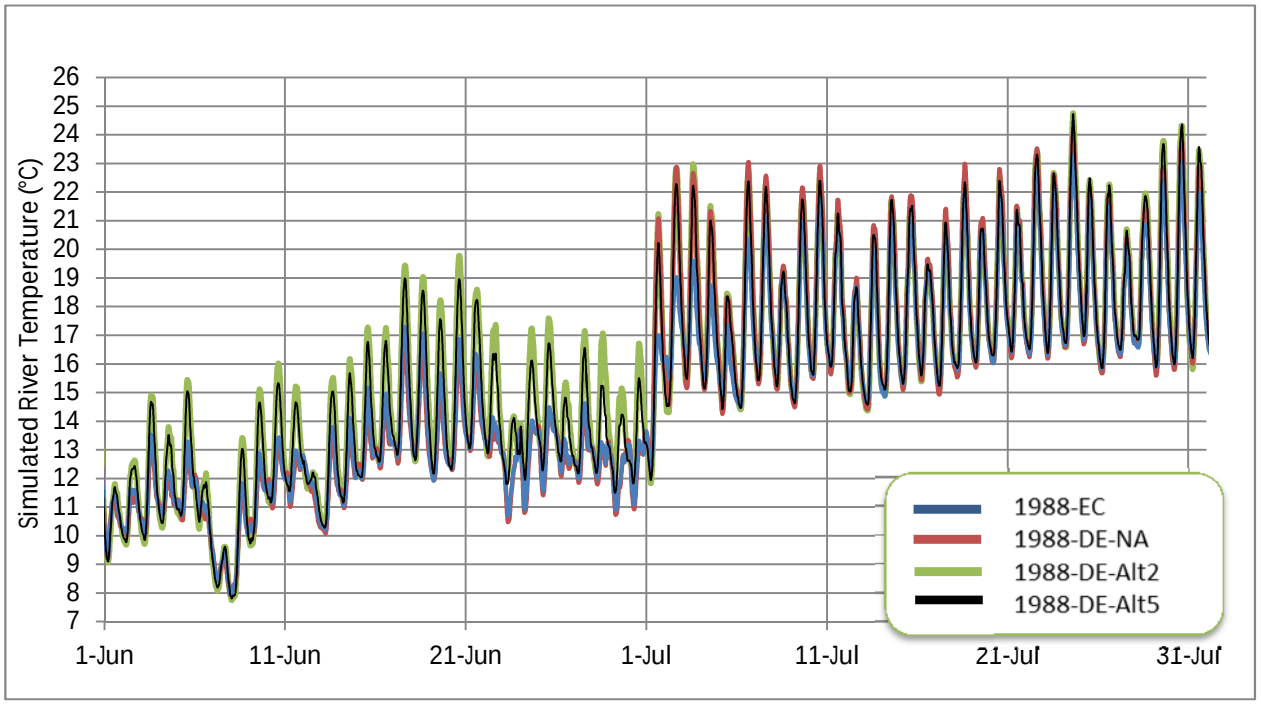

Figure 110. 1988 Direct Effects Hourly Temperature at CR-HSU June-July Zoom

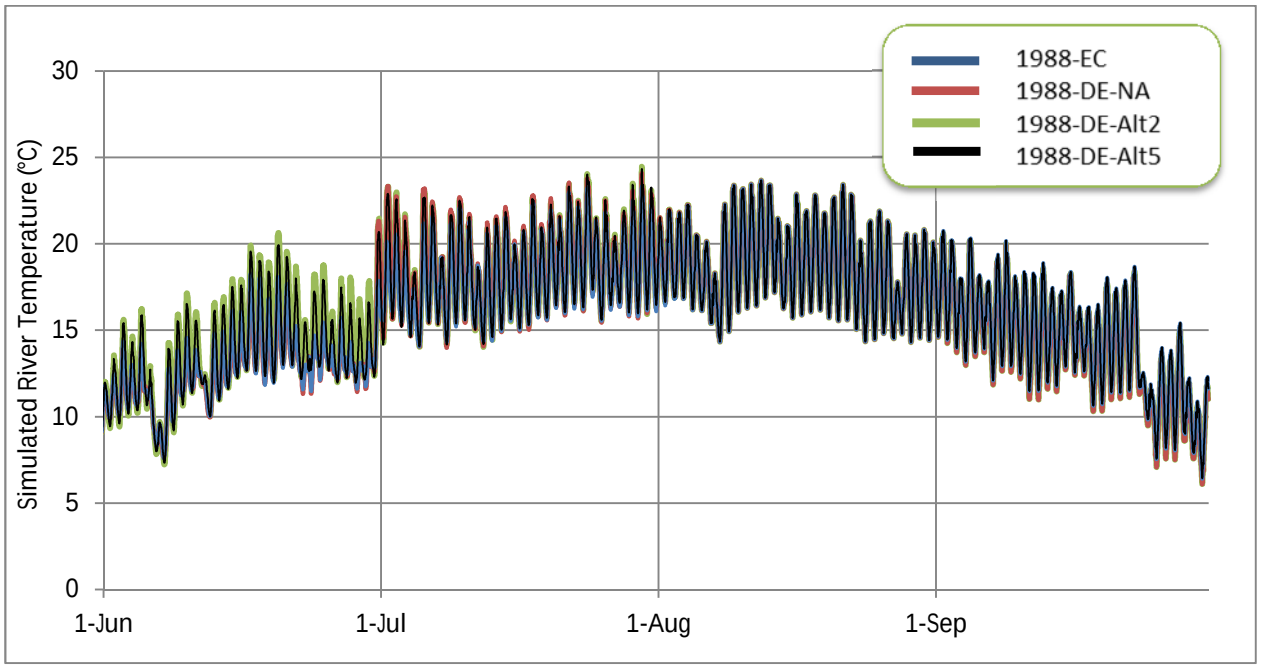

Figure 111. 1988 Direct Effects Hourly Temperature at CR-WFU

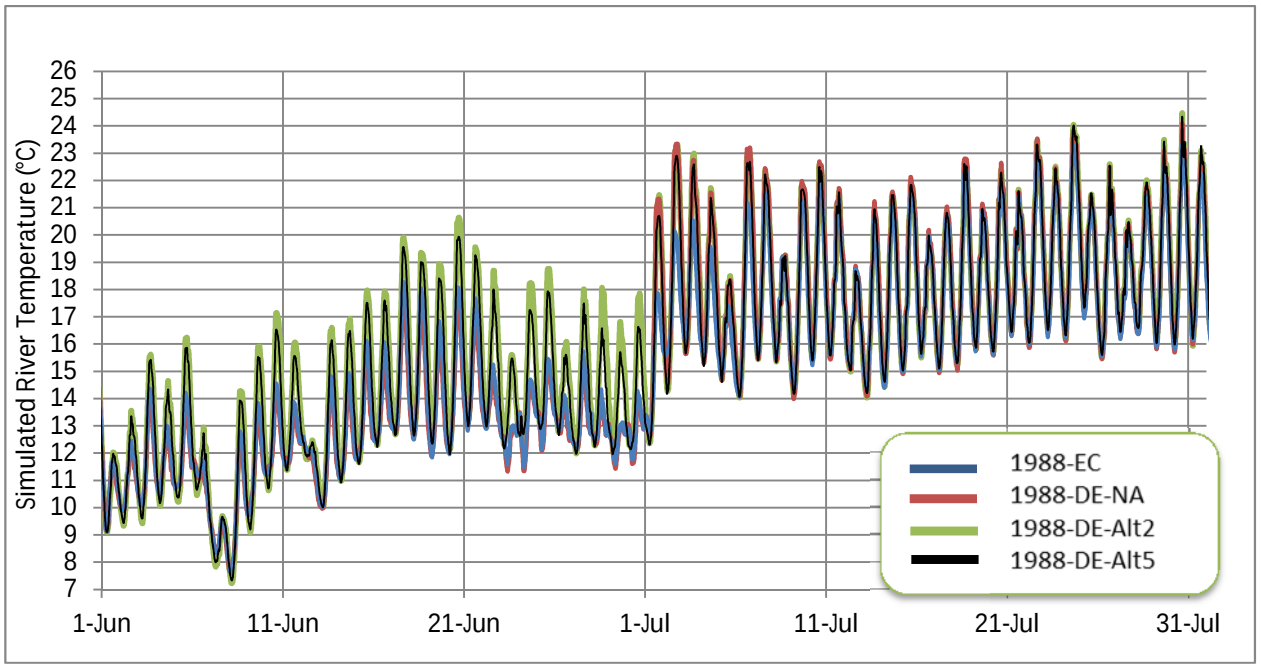

Figure 112. 1988 Direct Effects Hourly Temperature at CR-WFU June-July Zoom

4.1.5.3 1988 Direct Effects Weekly Average and Daily Maximum Temperatures

WATs and DMs were all calculated using the appropriate Colorado Water Quality Control Division tool (Temp-program-V4.2; personal communication, Robert Hillegas, May 24, 2011) for this segment of the upper Colorado River. Figure 113 through Figure 115 present WATs for each simulated day, following the first week of simulation. DMs are presented for each simulated day in Figure 116 through Figure 118. These figure sets show results for thermistor locations CR-WGD, CR-HSU, and CR-WFU.

WAT and DM differences relative to existing conditions occur primaily in June and July, when there are pumping differnces at Windy Gap. In June, Alt2 and Alt5 WATs and DMs are higher than those of existing conditions and no action; however, there are no exceedances of standards for any of the scenarios in June. In July, WAT and DM values for Alt2 and Alt5 are similar to no action values, and all three are higher than existing conditions values.

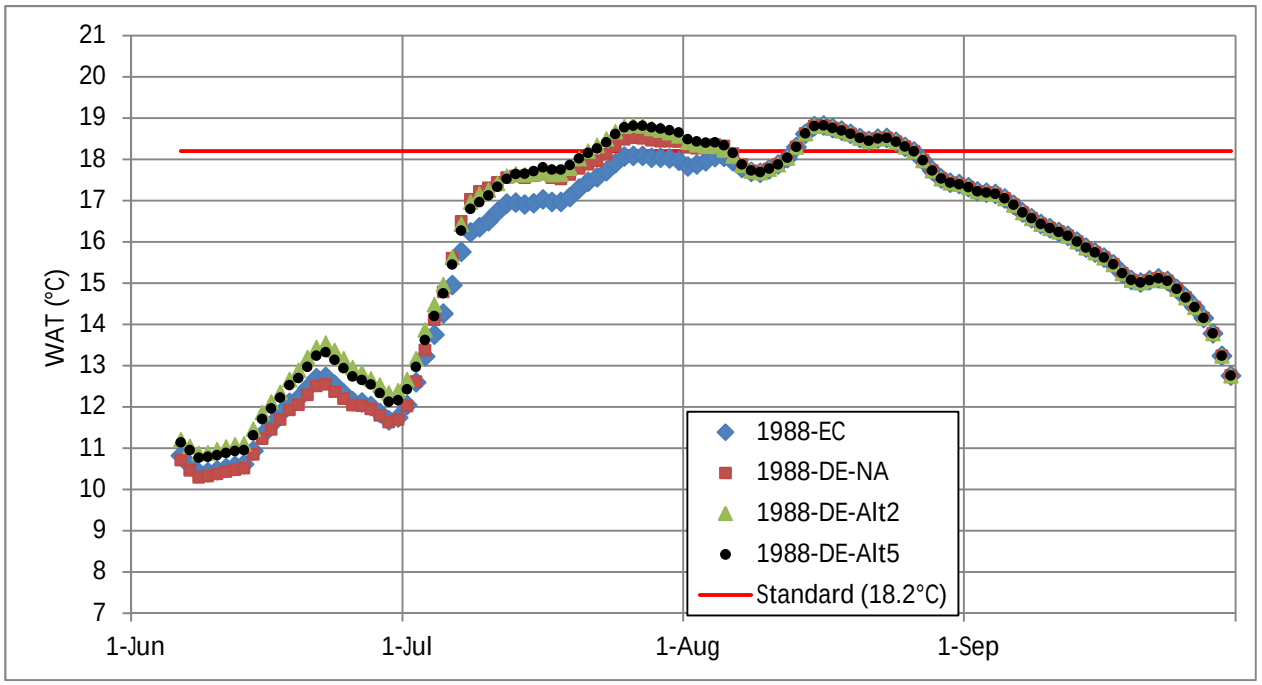

Figure 113. 1988 Direct Effects WATs at CR-WGD

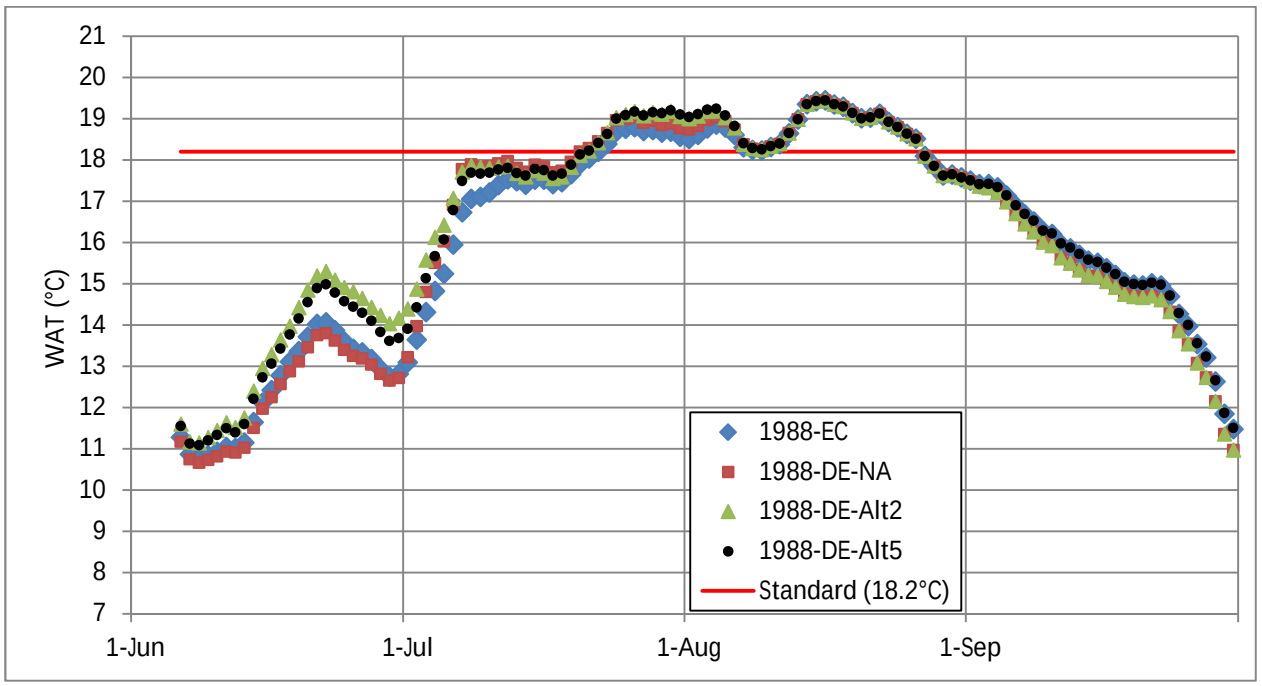

Figure 114. 1988 Direct Effects WATs at CR-HSU

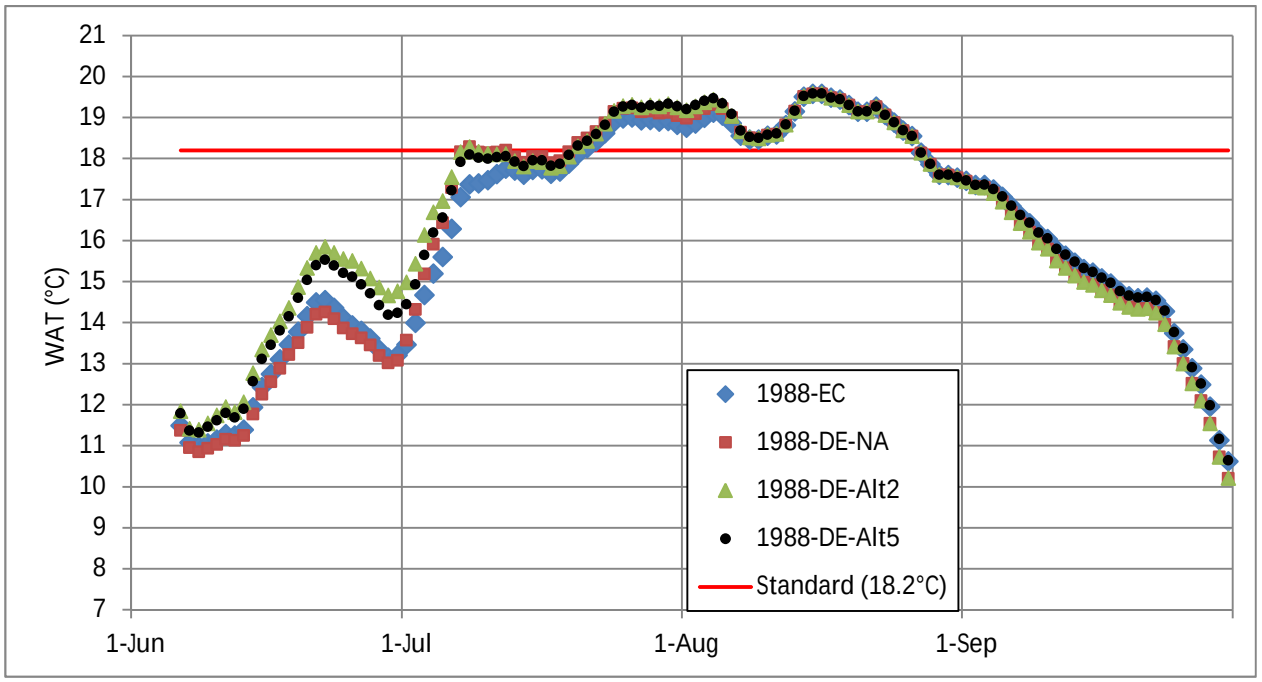

Figure 115. 1988 Direct Effects WATs at CR-WFU

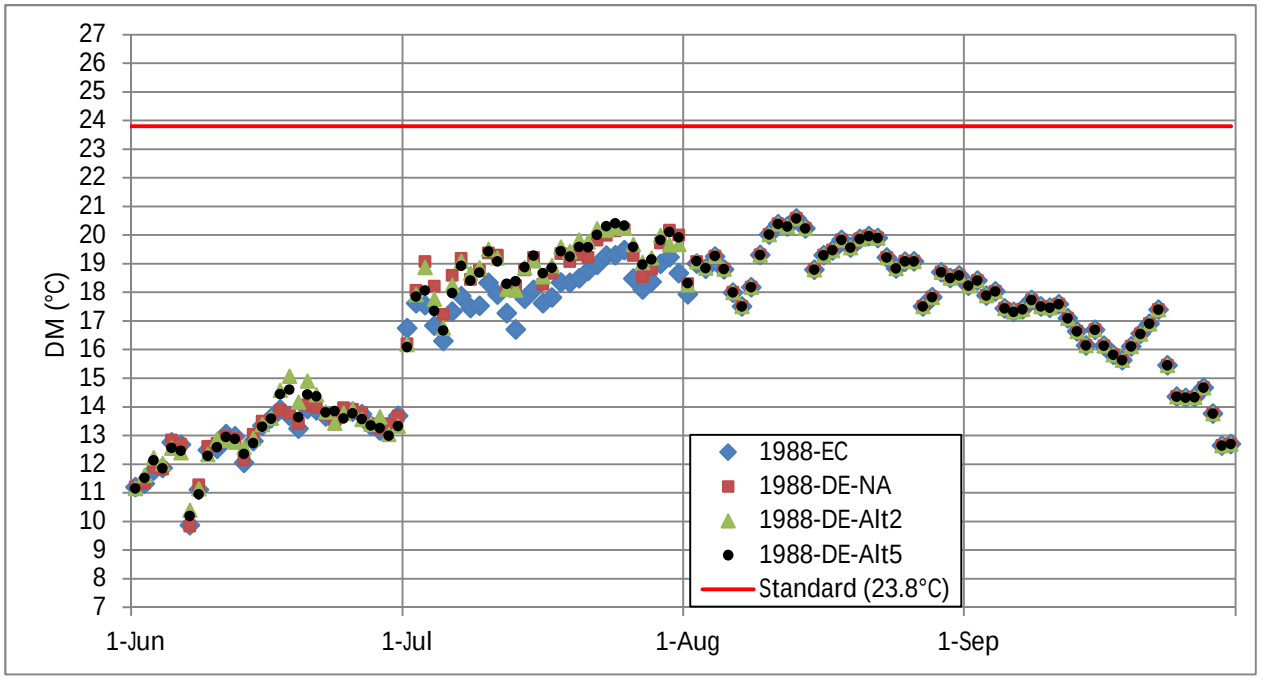

Figure 116. 1988 Direct Effects DMs at CR-WGD

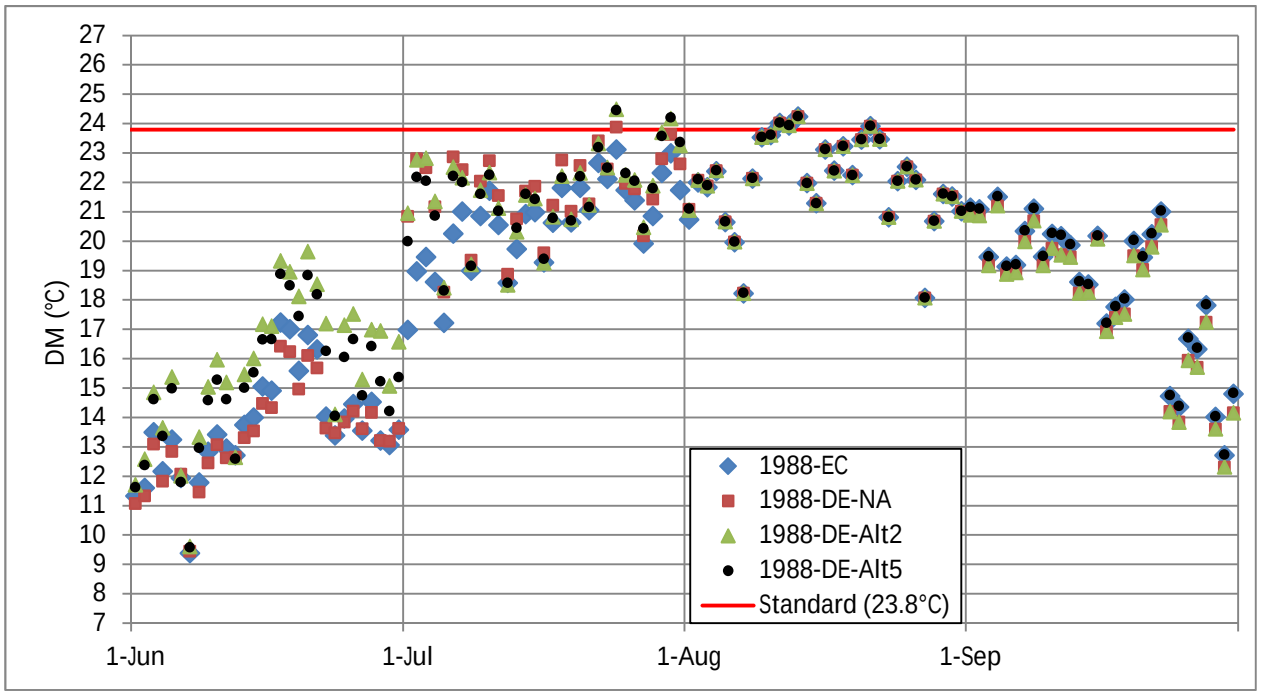

Figure 117. 1988 Direct Effects DMs at CR-HSU

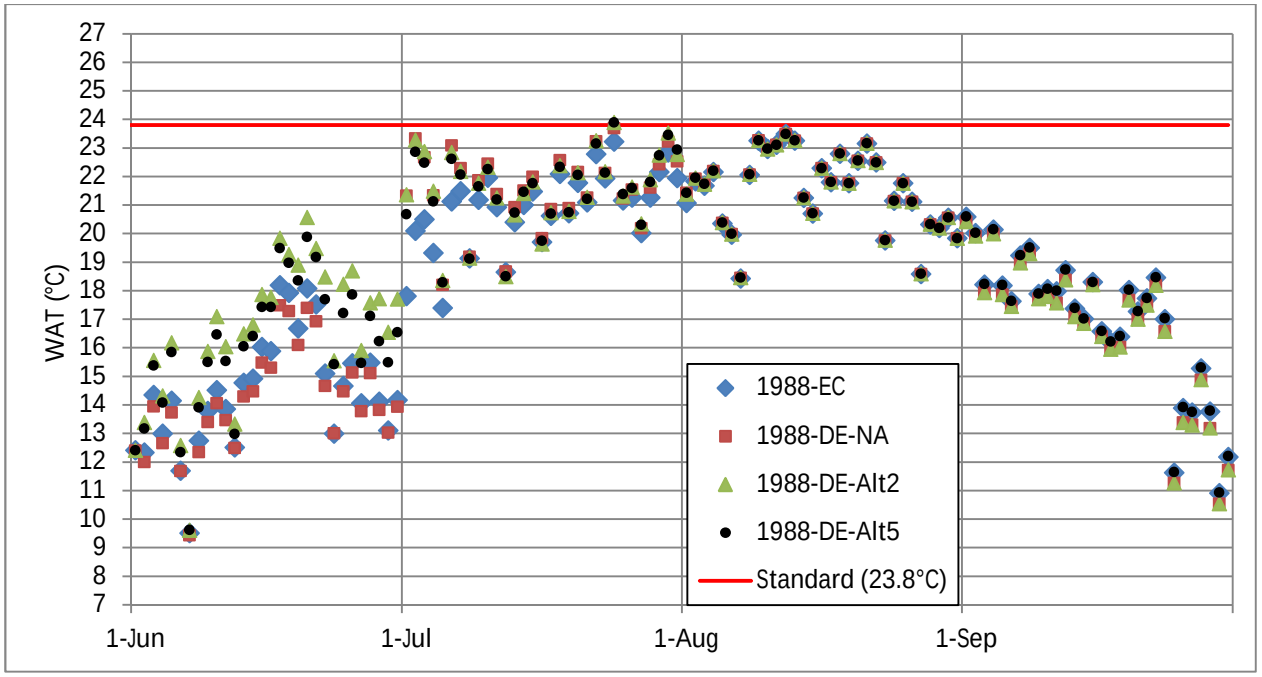

Figure 118. 1988 Direct Effects DMs at CR-WFU

For 1988 direct effects, Table 22 summarizes the results of a regulatory analysis of the simulation results at the three thermistor locations, CR-WGD, CR-HSU, and CR-WFU. The maximum WAT for the full period did not change for Alt2 or Alt5 relative to no action or existing conditions because of the timing of pumping differences. There was a simulated increase of 3 additional weeks of chronic exceedances (MWAT exceedances) for Alt2 and Alt5 relative to existing conditions in July and August at WGD.

The maximum DM increased slightly for Alt2 relative to existing conditions, with the maximum DM increase simulated as +0.4°C at WFU. The maximum DM also increased slightly for Alt2 relative to no action (+0.3°C at HSU). Small increases in the number of exceedances of DM standards are simulated to occur for Alt2 and Alt5 at HSU and WFU in July (+2 days relative to existing conditions, and +1 day relative to no action).

Table 22. 1988 Direct Effects Simulated Regulatory Results

	1988- WGD				1988- HSU				1988- WFU			
	EC	NA	Alt2	Alt5	EC	NA	Alt2	Alt5	EC	NA	Alt2	Alt5
Chronic												
MWAT (°C)	18.8	18.8	18.8	18.8	19.4	19.4	19.4	19.4	19.6	19.6	19.6	19.6
June # weeks > 18.2 °C	0	0	0	0	0	0	0	0	0	0	0	0
July # weeks > 18.2 °C	0	2	2	2	2	2	2	2	2	3	3	2
August # weeks > 18.2 °C	2	2	3	3	3	4	4	4	4	4	4	4
Sept. # weeks > 18.2 °C	0	0	0	0	0	0	0	0	0	0	0	0
Acute												
Max DM (°C)	20.6	20.6	20.6	20.6	24.2	24.2	24.5	24.5	23.5	23.7	23.9	23.9
June # days > 23.8 °C	0	0	0	0	0	0	0	0	0	0	0	0
July # days > 23.8 °C	0	0	0	0	0	1	2	2	0	0	1	1
August # days > 23.8 °C	0	0	0	0	4	4	4	4	0	0	0	0
Sept. # days > 23.8 °C	0	0	0	0	0	0	0	0	0	0	0	0

Looking more closely at the 1988 direct effects simulations, Table 23 and Table 24 present the simulated WAT and DM temperature effects of Alt2 and Alt5 relative to existing conditions and no action, respectively. For these 1988 simulations applying 2007 meteorology, the largest individual WAT increases were simulated to occur on June 25 (1.6°C and 1.8°C for Alt2 relative to existing conditions and no action, respectively). In July and August, as shown in Table 23, WATs increased as much as 1.5°C at WFU (July 1), due to Alt2, relative to existing conditions. The same statistic for Alt5 was 1.0°C at WFU (July 4). Relative to no action, the largest individual WAT increases in July and August for Alt2 and Alt5 were similar to the existing conditions comparison (1.4°C [WFU on July1] and 0.9°C [WFU on July 1], respectively). All of

these early July WAT values are influenced by the June numbers due to the rolling average calculation of WATs.

The largest individual DM increase due to Alt2, relative to existing conditions, was 4.0 °C at HSU (July 1). The largest individual DM increase in July and August due to Alt5, relative to existing conditions, was 3.2 °C, also at HSU on July 1. Relative to no action, the largest DM increases were in June (3.7°C and 2.7°C for Alt2 and Alt5, respectively). DM increases relative to no action were smaller in July and August (Table 24). The largest individual DM increase in July and August due to Alt2, relative to no action, was 0.9 °C at HSU (July 29). The largest individual DM increase in July and August due to Alt5, relative to no action, was 0.8 °C also at HSU on July 29.

Table 23. 1988 Direct Effects Simulated WAT and DM Increases Relative to Existing Conditions.

	1988-WGD		1988-HSU		1988-WFU	
	Increase Relative to Existing Conditions (°C)		Increase Relative to Existing Conditions (°C)		Increase Relative to Existing Conditions (°C)	
	Alt2	Alt5	Alt2	Alt5	Alt2	Alt5
Chronic						
Largest WAT Increase in July and August (°C)	0.8	0.8	1.3	0.8	1.5	1.0
Avg. July WAT Increase (°C)	0.7	0.6	0.5	0.4	0.6	0.5
Avg. Aug. WAT Increase (°C)	0.1	0.1	0.1	0.1	0.1	0.1
Acute						
Largest DM Increase in July and August (°C)	1.4	1.7	4.0	3.2	3.6	2.9
Avg. July DM Increase (°C)	1.0	0.9	1.1	0.9	0.7	0.6
Avg. Aug. DM Increase (°C)	0.0	0.0	0.0	0.0	0.0	0.0

Table 24. 1988 Direct Effects Simulated WAT and DM Increases Relative to No Action.

	1988-WGD		1988-HSU		1988-WFU	
	Increase Relative to No Action (°C)		Increase Relative to No Action (°C)		Increase Relative to No Action (°C)	
	Alt2	Alt5	Alt2	Alt5	Alt2	Alt5
Chronic						
Largest WAT Increase in July and August (°C)	0.6	0.4	1.2	0.7	1.4	0.9
Avg. July WAT Increase (°C)	0.2	0.1	0.1	0.0	0.2	0.0
Avg. Aug. WAT Increase (°C)	0.0	0.0	0.0	0.0	0.0	0.0
Acute						
Largest DM Increase in July and August (°C)	0.5	0.4	0.9	0.8	0.3	0.4
Avg. July DM Increase (°C)	0.1	0.0	0.0	-0.1	0.0	-0.1
Avg. Aug. DM Increase (°C)	0.0	0.0	0.0	0.0	0.0	0.0

4.1.5.4 1988 Direct Effects Summary

For the simulated 1988 direct effects hydrology with 2007 meteorology, Windy Gap pumping differences occurred in June and July. In June, temperature increases were simulated for Alt2 and Alt5 relative to existing conditions and no action; however, there were no exceedances of WAT or DM standards in June. In July, no action pumping increased relative to existing conditions, resulting in greater differences between the alternatives and existing conditions as compared to the alternatives and no action.

The largest WAT increase for Alt2 relative to existing conditions was in June (1.6°C). The largest WAT increase for Alt2 relative to no action was 1.8°C , also simulated in June. The largest individual DM increase due to Alt2, relative to existing conditions, was 4.0 °C at HSU. Relative to no action, the largest DM increase was 3.7°C, simulated in June.

4.2 CUMULATIVE EFFECTS

The following subsections present the results for cumulative effects simulations of 1975, 1979, 1986, 1987, and 1988 hydrology scenarios under conditions of 2007 meteorology. Cumulative effects simulations include reasonably foreseeable actions that are anticipated to occur regardless of the implementation of any of the action alternatives or the no action alternative. Reasonably foreseeable actions included in the cumulative effects simulations which affect the simulated hydrology used in the dynamic temperature model include:

- Denver Water Moffat Collection System Project,
- Increased water use from population growth in Grand and Summit counties, and
- Changes in releases from Williams Fork (related to changes to recommended 19825 releases for fish flows in the 15-Mile reach and the expiration of Denver Water's contract with Big Lake Ditch)
- 5412 acre-ft (AF) releases from Granby Reservoir, per the release schedule presented in the 10825 Environmental Assessment (Table 25; BOR, 2011).

Note: Table 25 also includes a column of an "Alternate Schedule" for release of 5412 AF of water from Granby Reservoir for average flow years, with an earlier start date. 5412 releases for average and wet years will be determined by an "Operations Group" composed of representatives from the water users, the Service, Reclamation, and the State Division Engineer. The release numbers and schedule applied in the Environmental Assessment were established for modeling and analysis purposes. As such, the schedule of releases could be adjusted for average and wet years if deemed appropriate by the operations group. The alternative earlier-release schedule is simulated for 1975 cumulative effects (in addition to the EA-evaluated schedule for average flow years) to evaluate the possible benefits of a modified release schedule for average flow years. Of the 5 years simulated, 1975, 1979, 1987, and 1988 are average flow years. 1986 is a wet year.

Table 25. Granby 5412 Release Schedule. (All cfs)

Date	10825 EA-Evaluated Granby Release Schedule			Alternative Schedule
	Dry	Average	Wet	Average – Tested on 1975
July 1-14	0	0	0	
July 15-31	22	0	0	45
August 1-14	47	50	35	40 (August 1-15)
August 15-31	47	50	50	39 (August 16-31)
September 1	55	50	70	25
September 2-9	38	50	70	25
September 10-15	38	50	50	25
September 16-20	21	29	50	25
September 20-30	21	29	24	25

Source: USBR, 2011 .

Cumulative effect simulations for the dynamic temperature model include:

- No Action - Cumulative Effects (CE-NA) – River temperatures are simulated for the hydrology of the key years, overlaying cumulative effects on the actions that will be

taken by the Participants if Reclamation does not approve a new connection of WGFP facilities to C-BT facilities.

- Alternative 2 - Cumulative Effects (CE-Alt2) - River temperatures are simulated for the hydrology of the key years, overlaying cumulative effects on the actions and operations of the proposed action alternative.

For each simulation year, graphics are presented for input hydrology, showing Windy Gap pumping and flow rates below Windy Gap Reservoir. The hydrology figures are intended to provide an overview of the relative hydrology inputs across the simulations; however, they do not present the full complexity of differences in hydrology for cumulative effects for all years. Across cumulative effects simulations, there may be differences in Fraser River flows, Willow Creek flows, Williams Fork flows, and MPWCD diversions, etc. Major hydrologic differences that affect temperature results will be discussed with the corresponding temperature results. For each simulation year, graphics are also presented for hourly temperature output, WATs, and DMs. Tabular summaries of simulated temperature differences for alternatives relative to existing conditions and no action simulations are also presented.

4.2.1 1975 Cumulative Effects

The results of cumulative effects simulations applying 1975 hydrology scenarios under conditions of 2007 meteorology are presented in the following subsections. Cumulative effects simulations for 1975 included existing conditions, no action, and Alt2. Additionally, simulations of Alt2 and no action were conducted using a modified 5412 release schedule, recognizing that the operational committee that defines the 5412 releases each year will have latitude in setting the schedule for average and wet years (1975 was an average flow year). This alternative release schedule was only run for the 1975 hydrology, to provide insight into the possible temperature benefits of an earlier start to 5412 releases.

4.2.1.1 1975 Cumulative Effects Hydrographs

Figure 119 and Figure 120 present the differences in pumping at Windy Gap and corresponding flow below Windy Gap Reservoir for the cumulative effects alternatives simulated – existing conditions, no action, and alternative 2. Windy Gap pumping volumes (June through September) are summarized for each simulation in Table 26.

Overall, 1975 was an average year, with virgin annual flows ranking 23rd out of the 47 years of hydrology simulated for the WGFP. In June, existing conditions pumping is greater than Alt2 pumping, which is slightly greater than no action pumping. In July, Alt2 shows the highest levels of pumping, with 4,000 AF more than no action and 16,000 AF more than existing conditions. Flows below Windy Gap Reservoir show the effects of these pumping differences in

July and August, with the lowest flow in June for existing conditions and the lowest flow in July for Alt2 (Figure 120). Windy Gap pumping and river flows are higher for no action and Alt2 in August and September, as compared to existing conditions, due to the 5412 releases planned from Granby Reservoir.

As described above, additional simulations of Alt2 and no action cumulative effects were conducted using a modified 5412 release schedule to provide insight into the possible temperature benefits of an earlier start to 5412 releases. This earlier release schedule started on July 15 instead of August 1 (see Table 25). The effects of the ealier release schedule can be seen in higher flow rates below Windy Gap for Alt2 and no action in the last two weeks of July in Figure 121, as compared to Figure 120.

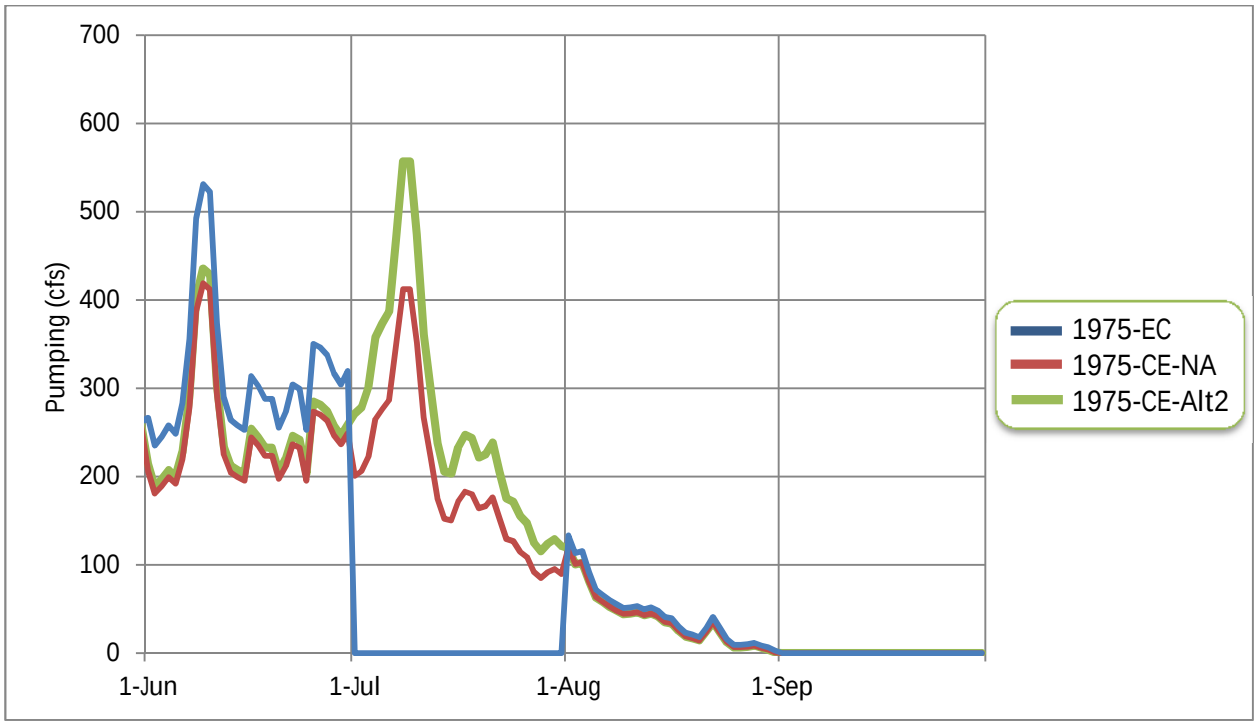

Figure 119. 1975 Cumulative Effects Windy Gap Pumping.

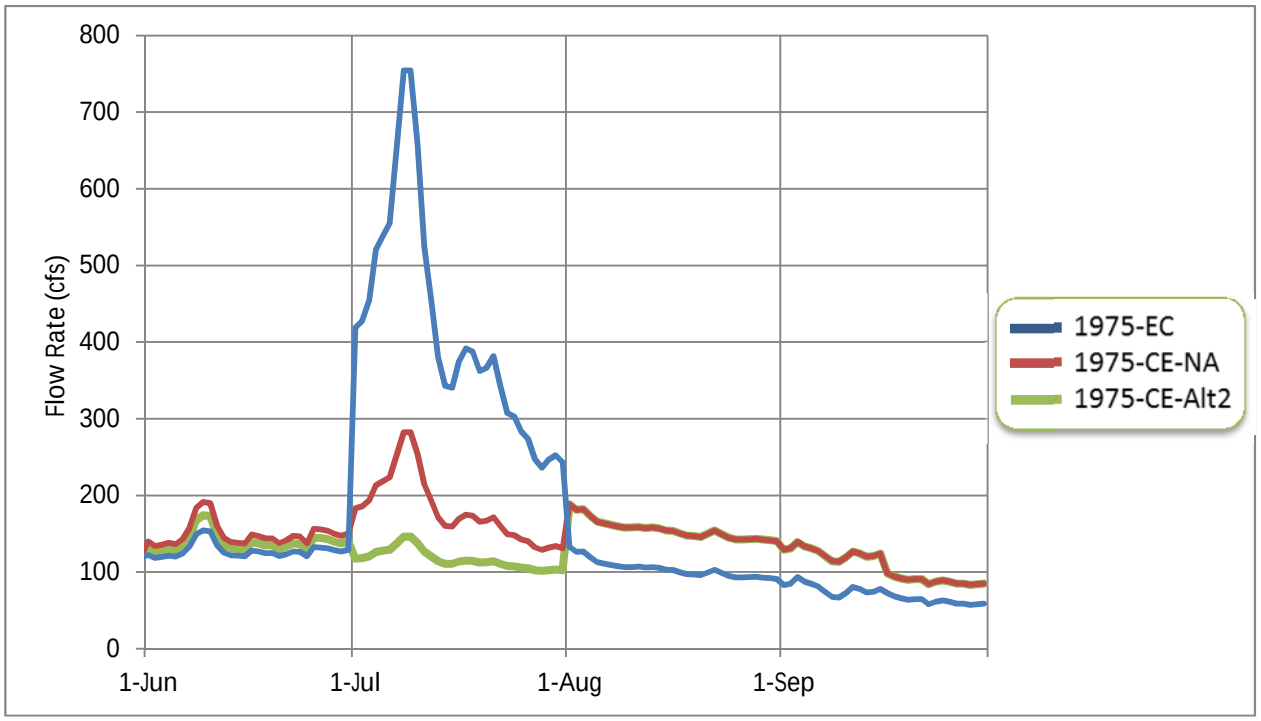

Figure 120. 1975 Cumulative Effects Flow Rates Below Windy Gap.

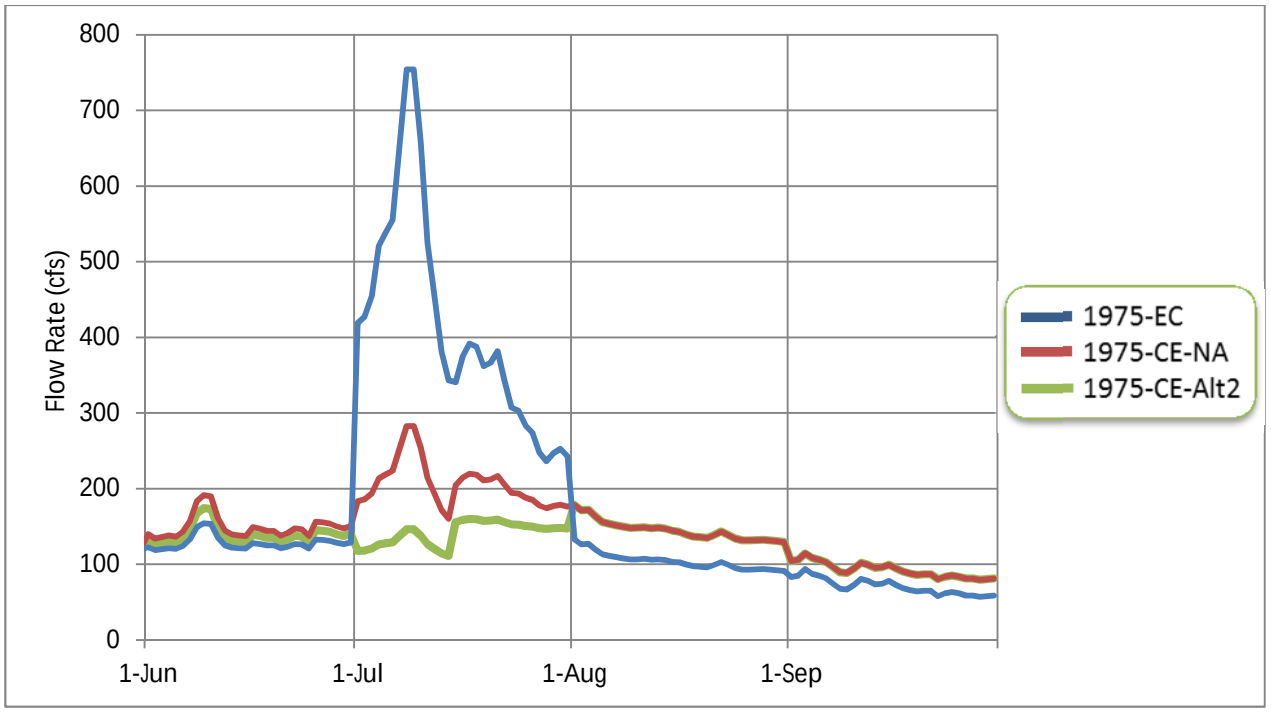

Figure 121. 1975 Cumulative Effects Flow Rates Below Windy Gap (July 15 Release Schedule)

Table 26. 1975 Cumulative Effects Windy Gap Pumping Volumes.

	1975-CE Monthly Pumping Totals (AF/month)			
	June	July	August	September
Existing Conditions	18,700	0	2,693	0
No Action	14,554	12,052	2,331	0
Alternative 2	15,147	16,290	2,309	0

4.2.1.2 1975 Cumulative Effects Hourly Temperature Plots

Figure 122 through Figure 127 present the hourly temperature plots produced by the model for thermistor locations CR-WGD, CR-HSU, and CR-WFU. Hourly temperature plots for the full simulation period are shown, as well as plots focusing on July and August. While temperature differences are also simulated for September, this is a period of cooler flows with no acute or chronic exceedances across the scenarios.

For 1975 cumulative effects simulations, warming due to Alt2 and no action pumping at Windy Gap is apparent in July, , relative to existing conditions. Across the reach, Alt 2 shows the highest simulated daily peak temperatures in July, followed by no action, then existing conditions. This pattern matches to the relative pattern of pumping below Windy Gap Reservoir (Figure 120). In August and September, Alt2 and no action results show cooler temperatures than existing conditions due to the planned 5412 releases from Granby. These 1975 cumulative effects temperature simulation results are summarized and discussed quantitatively in Section 4.2.1.3.

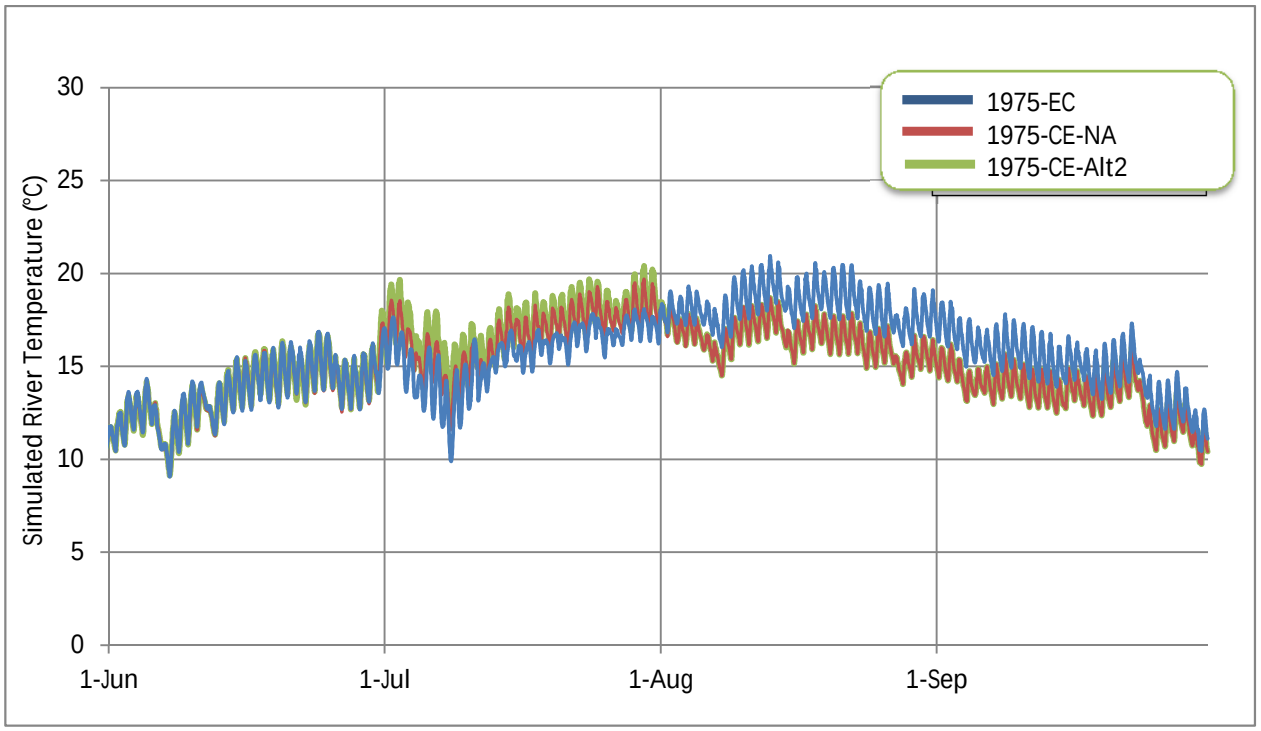

Figure 122. 1975 Cumulative Effects Hourly Temperature at CR-WGD.

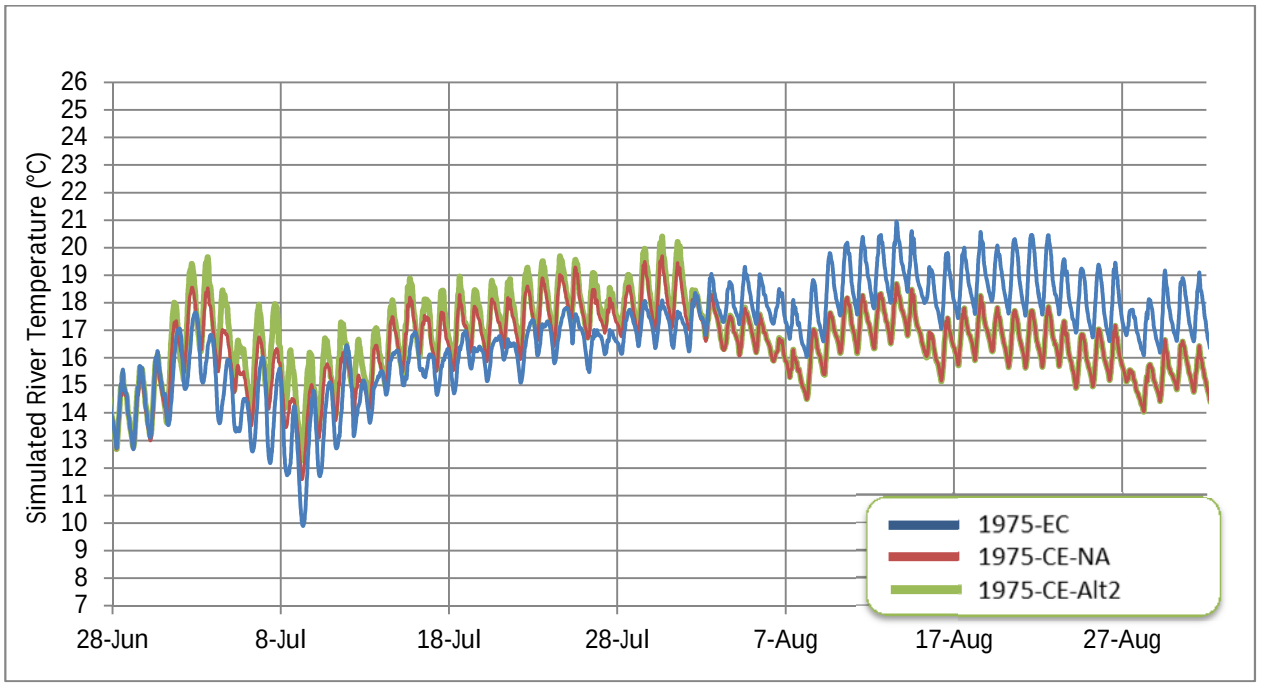

Figure 123. 1975 Cumulative Effects Hourly Temperature at CR-WGD- July-August Zoom.

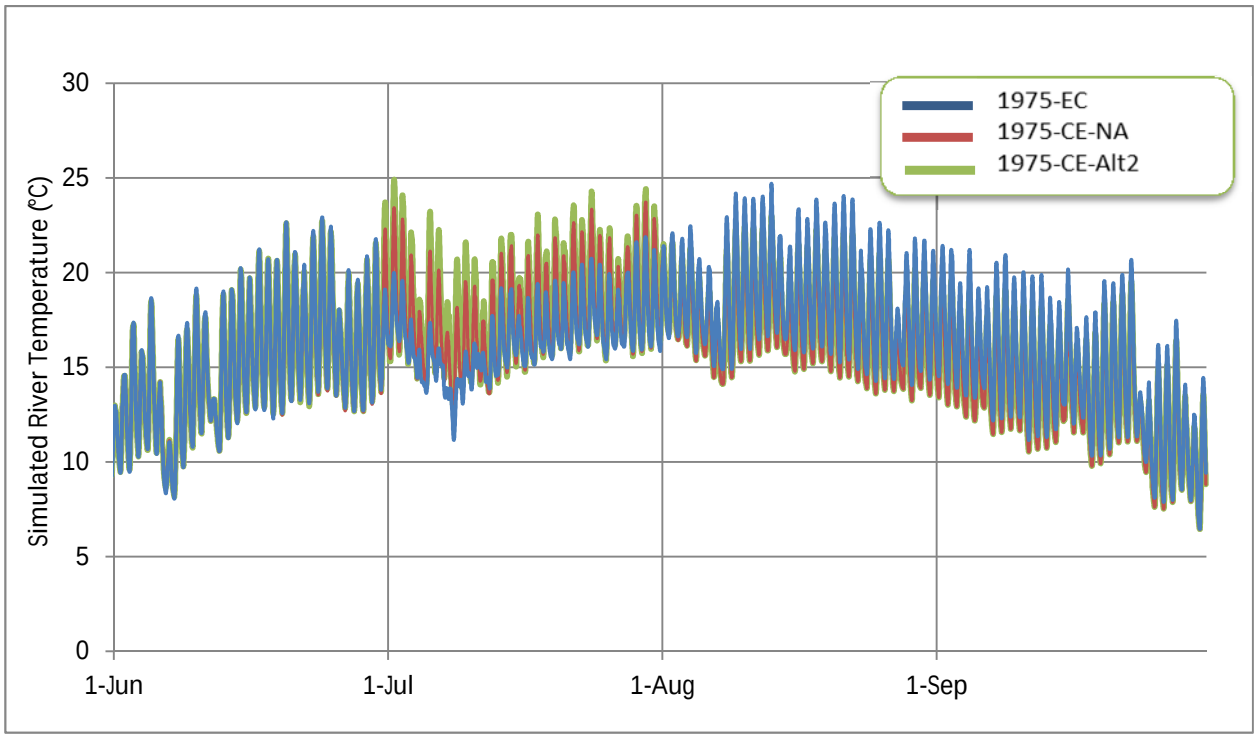

Figure 124. 1975 Cumulative Effects Hourly Temperature at CR-HSU.

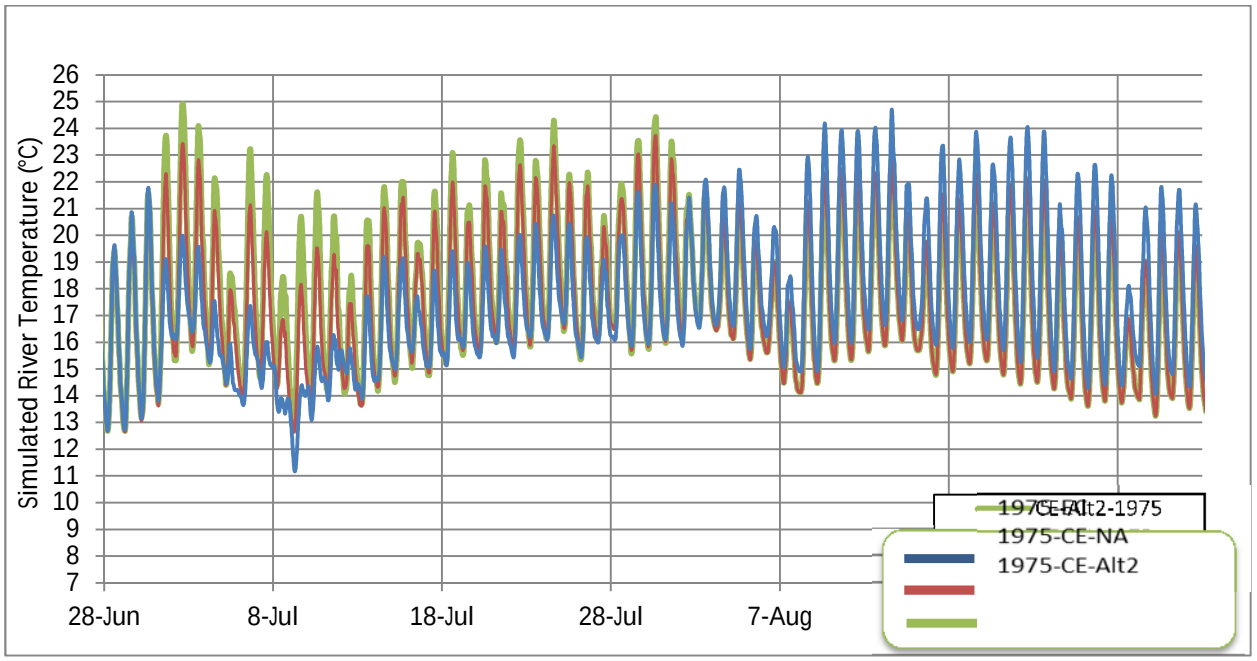

Figure 125. 1975 Cumulative Effects Hourly Temperature at CR-HSU - July-August Zoom.

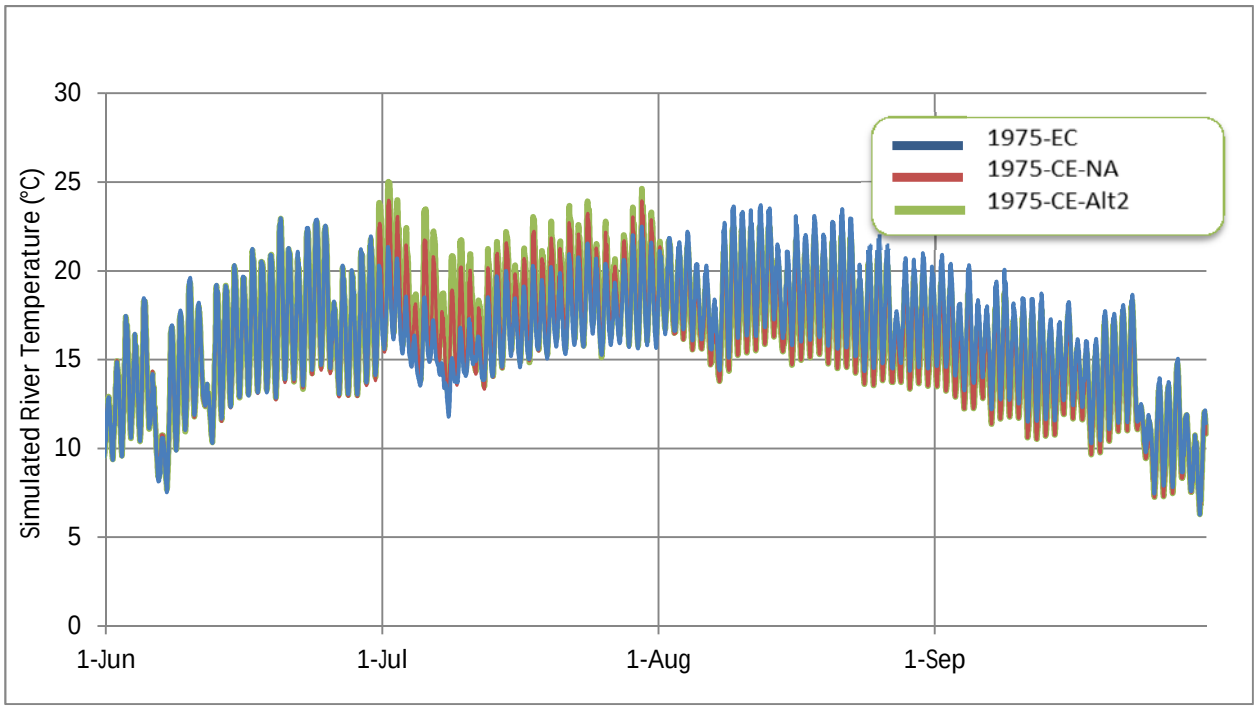

Figure 126. 1975 Cumulative Effects Hourly Temperature at CR-WFU.

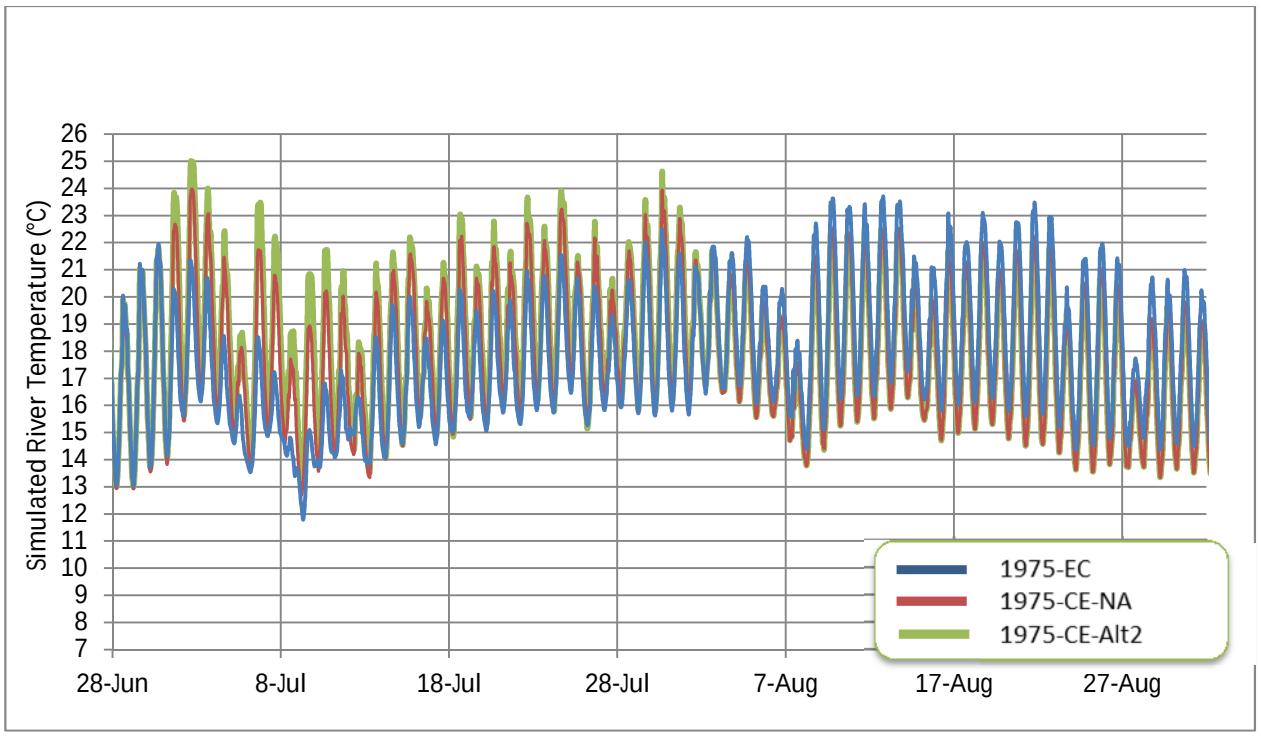

Figure 127. 1975 Cumulative Effects Hourly Temperature at CR-WFU - July-August Zoom.

As described above, additional simulations of Alt2 and no action cumulative effects were conducted using a modified 5412 release schedule to provide insight into the possible temperature benefits of an earlier start to 5412 releases (the earlier release schedule evaluated started on July 15 instead of August 1; see Table 25). Figure 128, Figure 129, and Figure 130 present the hourly temperature plots produced by the model for thermistor locations CR-WGD, CR-HSU, and CR-WFU, respectively. These graphs show reduced adverse temperature impacts for no action and Alt2 in the second half of July, as compared to the August-1 5412 release schedule shown in Figure 122, Figure 124, and Figure 126. These 1975 cumulative effects temperature simulation results for earlier 5412 releases are summarized and discussed quantitatively in Section 4.2.1.3.

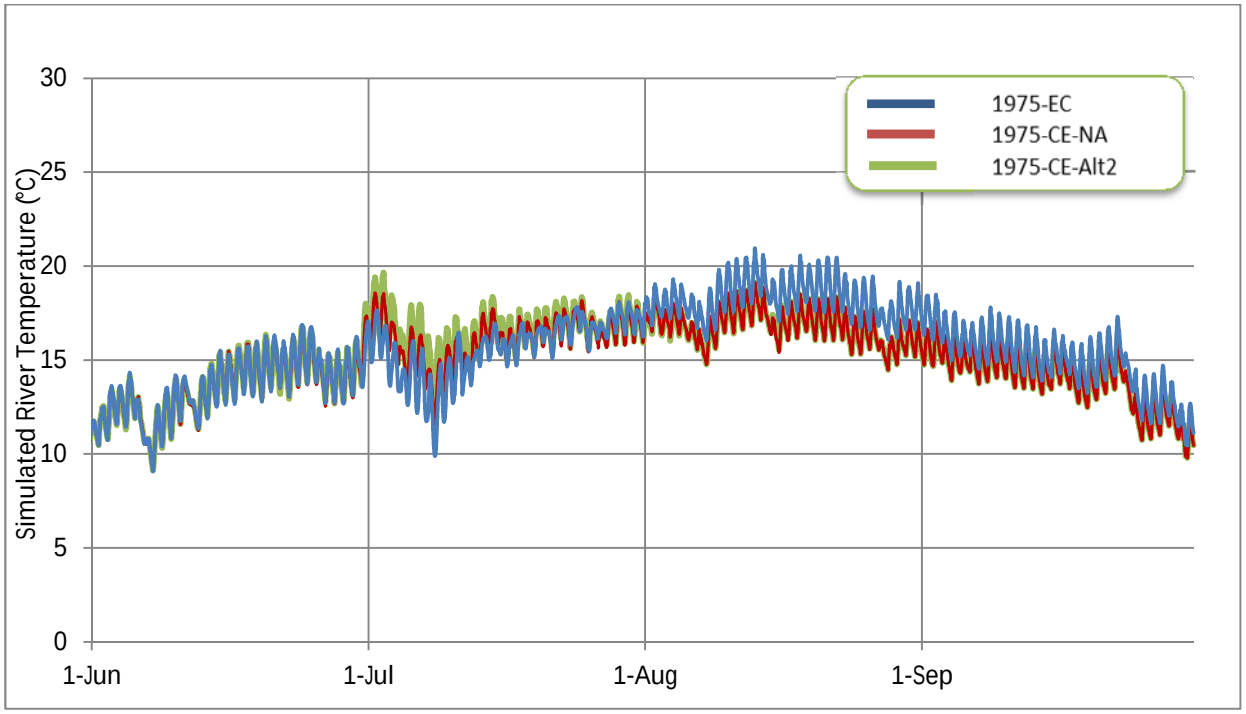

Figure 128. Cumulative Effects Hourly Temperature at CR-WGD (Earlier 5412 Release Schedule).

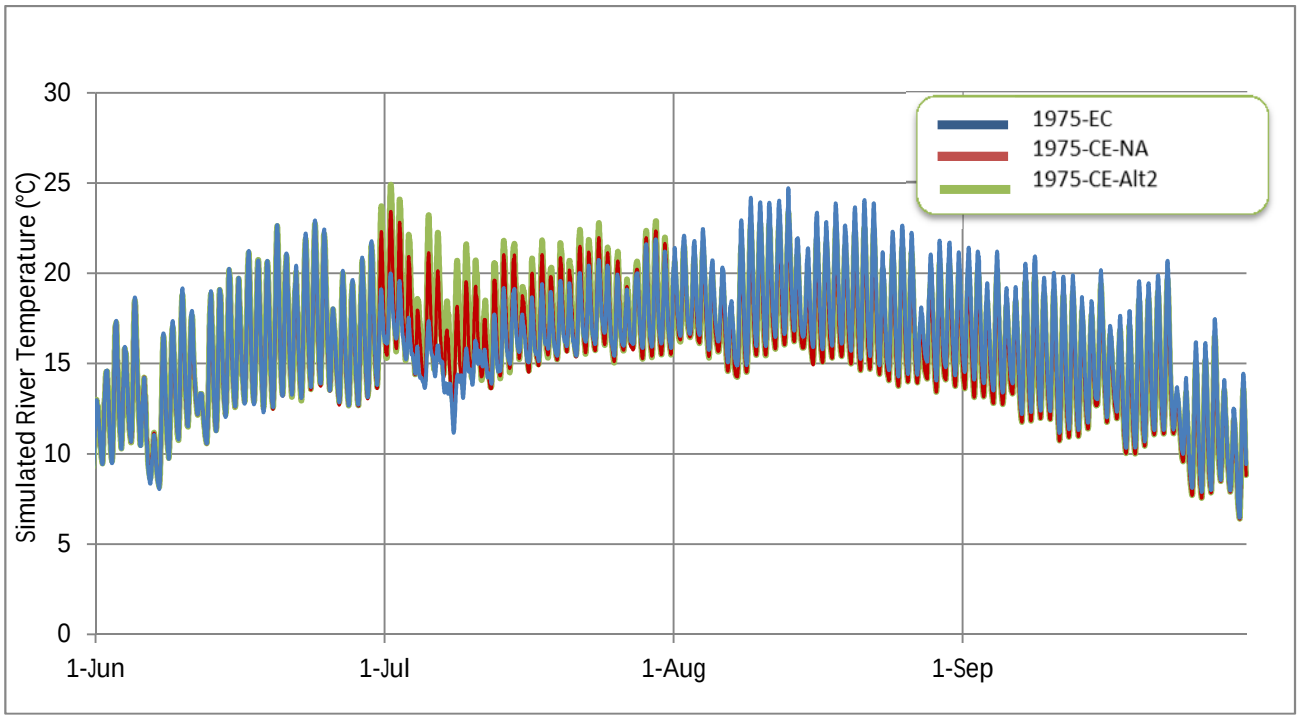

Figure 129. Cumulative Effects Hourly Temperature at CR-HSU (Earlier 5412 Release Schedule).

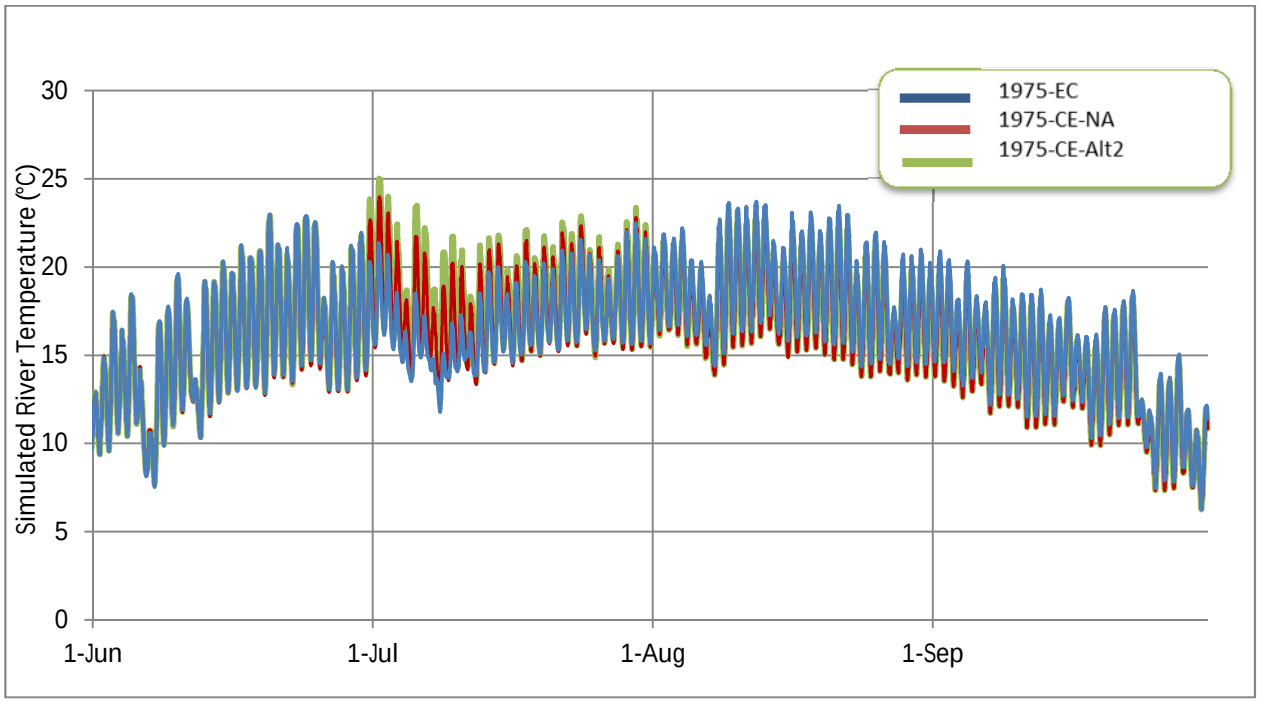

Figure 130. Cumulative Effects Hourly Temperature at CR-WFU (Earlier 5412 Release Schedule).

4.2.1.3 1975 Cumulative Effects Weekly Average and Daily Maximum Temperatures

WATs and DMs were all calculated using the appropriate Colorado Water Quality Control Division tool (Temp-program-V4.2; personal communication, Robert Hillegas, May 24, 2011) for this segment of the upper Colorado River. Figure 131 through Figure 133 present WATs for each simulated day, following the first week of simulation. DMs are presented for each simulated day in Figure 134 through Figure 136. These figure sets show results for thermistor locations CR-WGD, CR-HSU, and CR-WFU (August-1 5412 Release schedule).

The cumulative effects WATs and DMs show similar patterns. In July, WATs and DMs for Alt2 are greater than those for no action and existing conditions, corresponding to the increased pumping at Windy Gap at that time for Alt2. Likewise, the WATs and DMs for no action are greater than those for existing conditions in July, primarily due to greater pumping from Windy Gap. This pattern extends into the first week of August for WATs, due to the rolling average calculation of WATs. In the following weeks of August and September, no action and Alt2 show lower WATs and DMs, as compared to existing conditions, due to the cooling effects of planned 5412 releases from Granby Reservoir during this period.

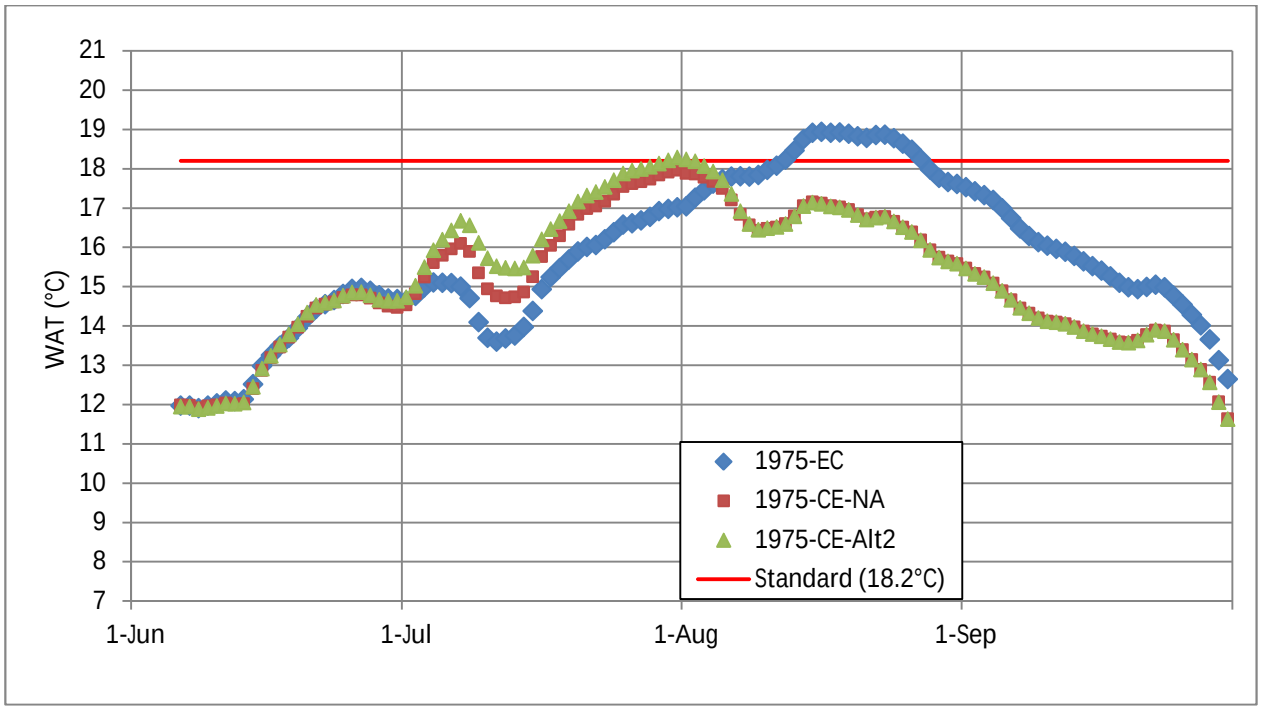

Figure 131. 1975 Cumulative Effects WATs at CR-WGD.

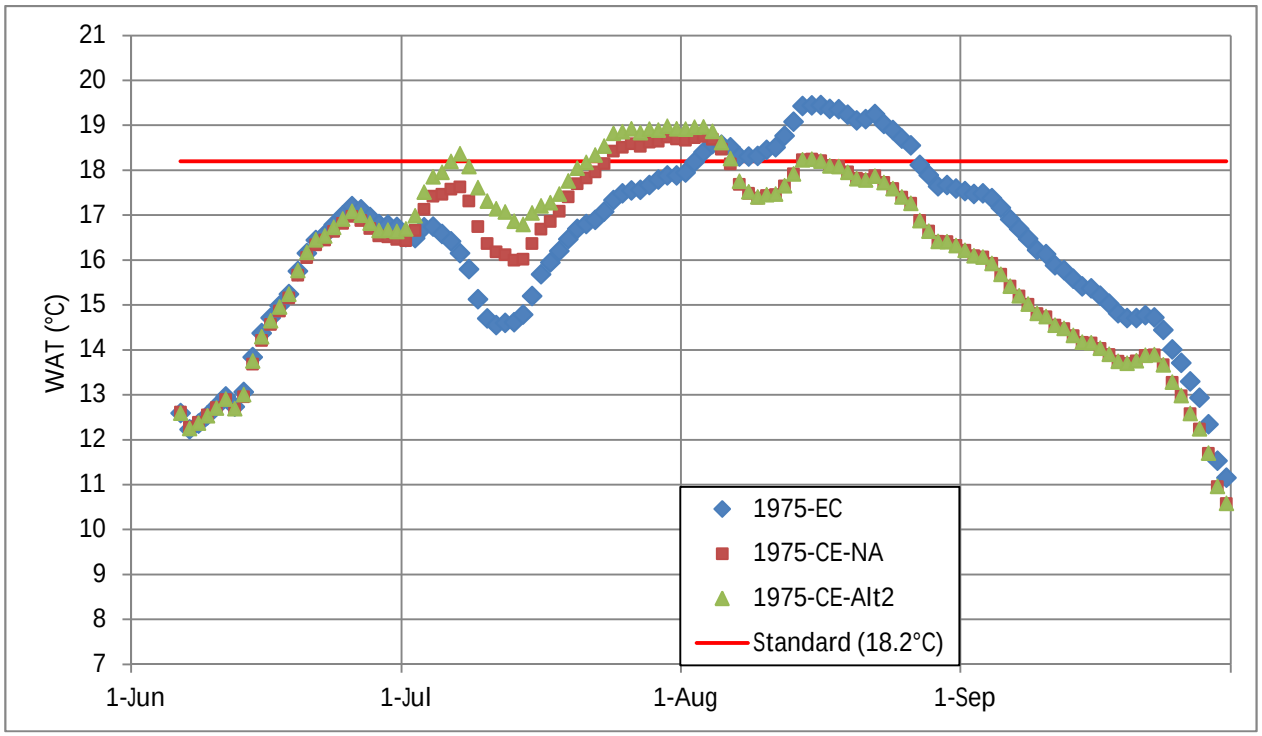

Figure 132. 1975 Cumulative Effects WATs at CR-HSU.

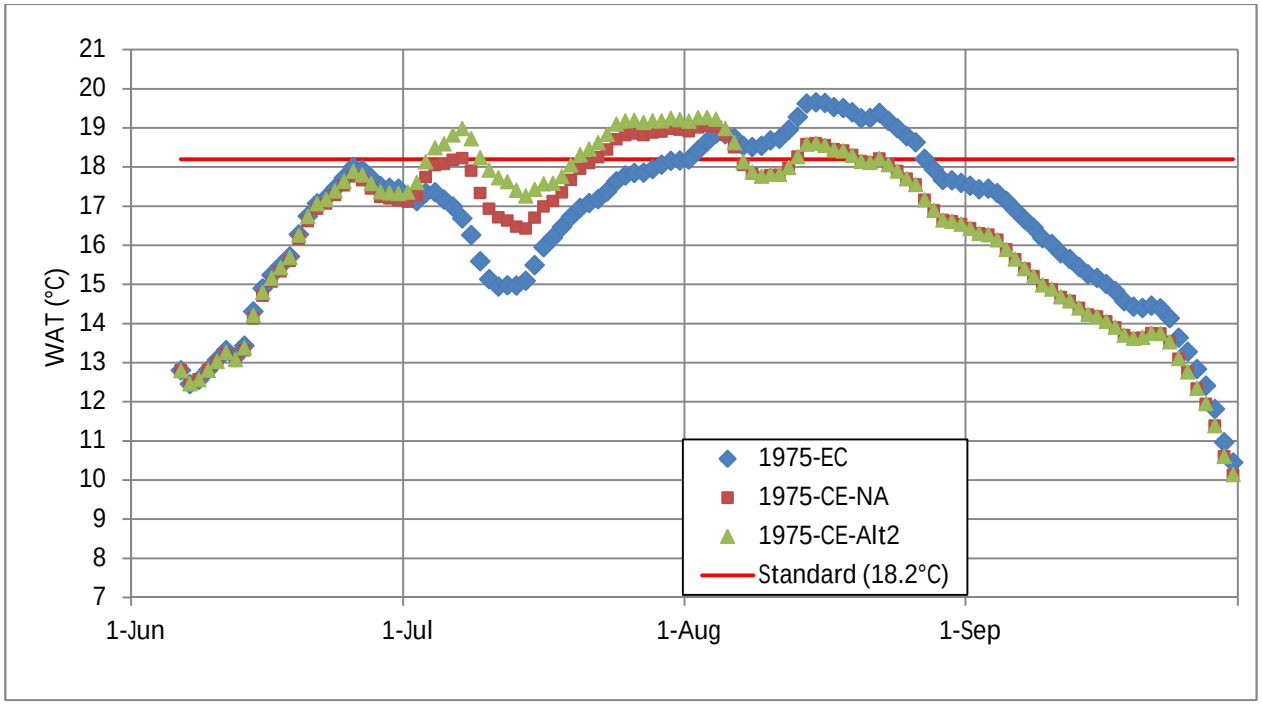

Figure 133. 1975 Cumulative Effects WATs at CR-WFU.

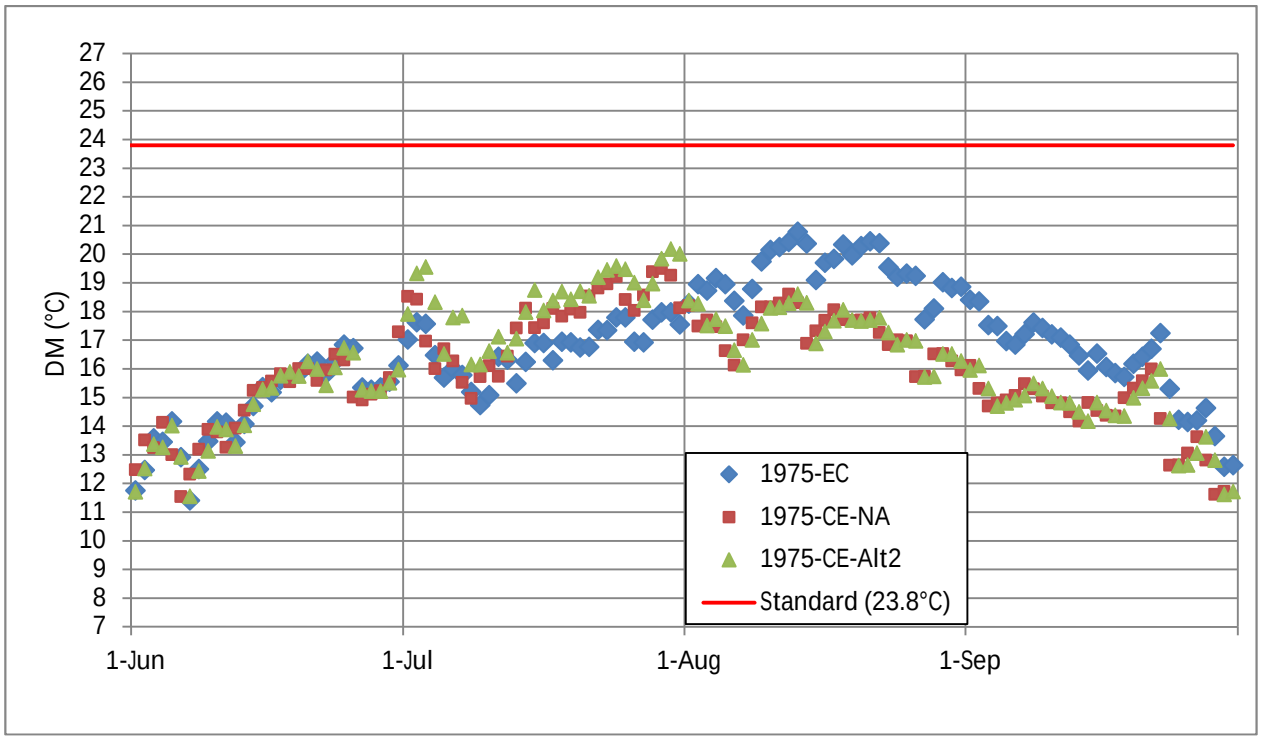

Figure 134. 1975 Cumulative Effects DMs at CR-WGD.

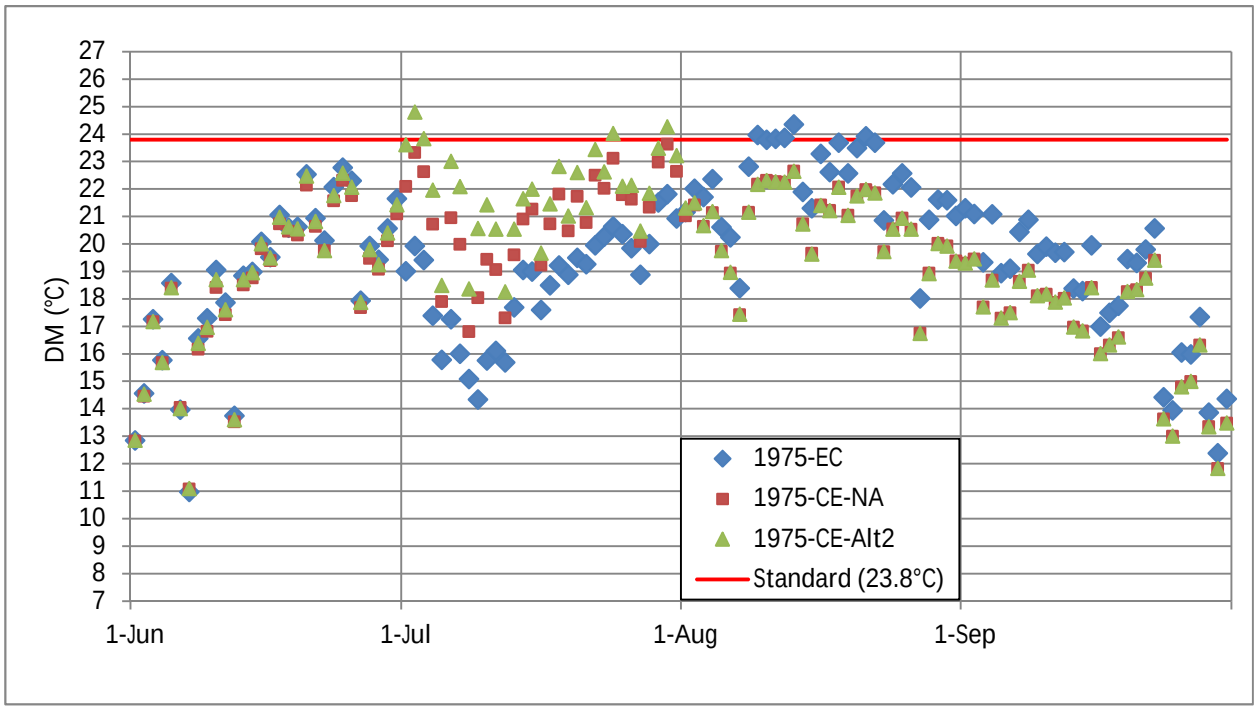

Figure 135. 1975 Cumulative Effects DMs at CR-HSU.

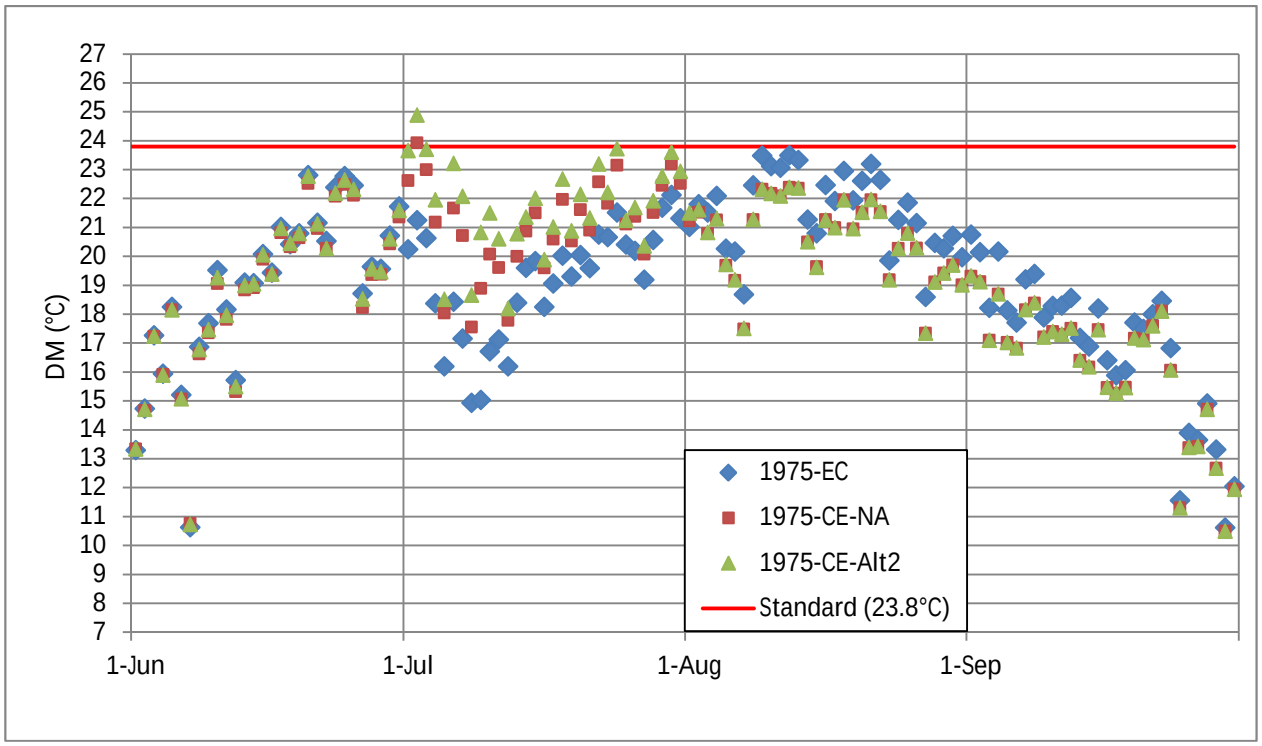

Figure 136. 1975 Cumulative Effects DMs at CR-WFU.

As described above, additional simulations of Alt2 and no action cumulative effects were conducted for 1975 using a modified 5412 release schedule to provide insight into the possible temperature benefits of an earlier start to 5412 releases (the earlier release schedule evaluated started on July 15 instead of August 1; see Table 25). WATs and DMs for these simulations are presented in Figure 137 through Figure 139 and Figure 140 through Figure 142, respectively. These graphs show reduced temperature effects of no action and Alt2 in late July (for WATs and DMs) and early August (for WATs), as compared to results from the August-1 5412 release schedule simulations (Figure 131 through Figure 136). These 1975 cumulative effects temperature simulation results for earlier 5412 releases are summarized and discussed quantitatively later in this section.

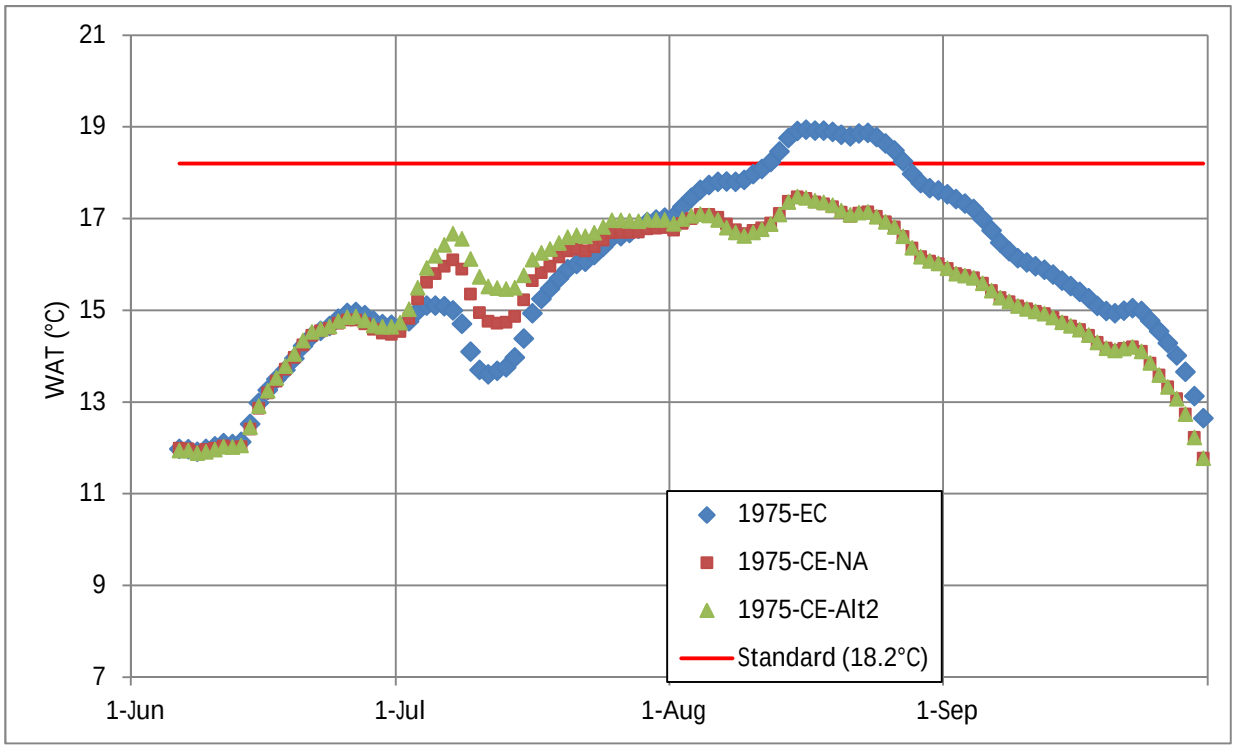

Figure 137. 1975 Cumulative Effects WATs at CR-WGD (Earlier 5412 Release Simulations).

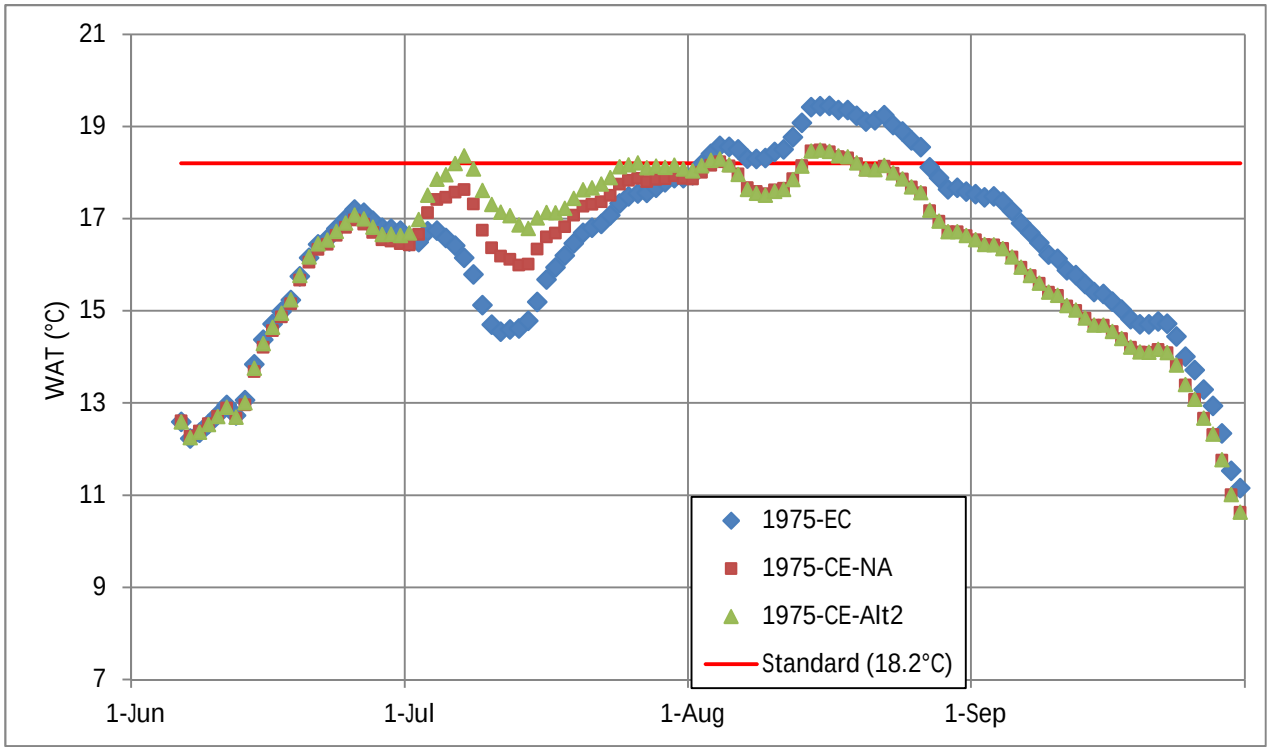

Figure 138. 1975 Cumulative Effects WATs at CR-HSU (Earlier 5412 Release Simulations).

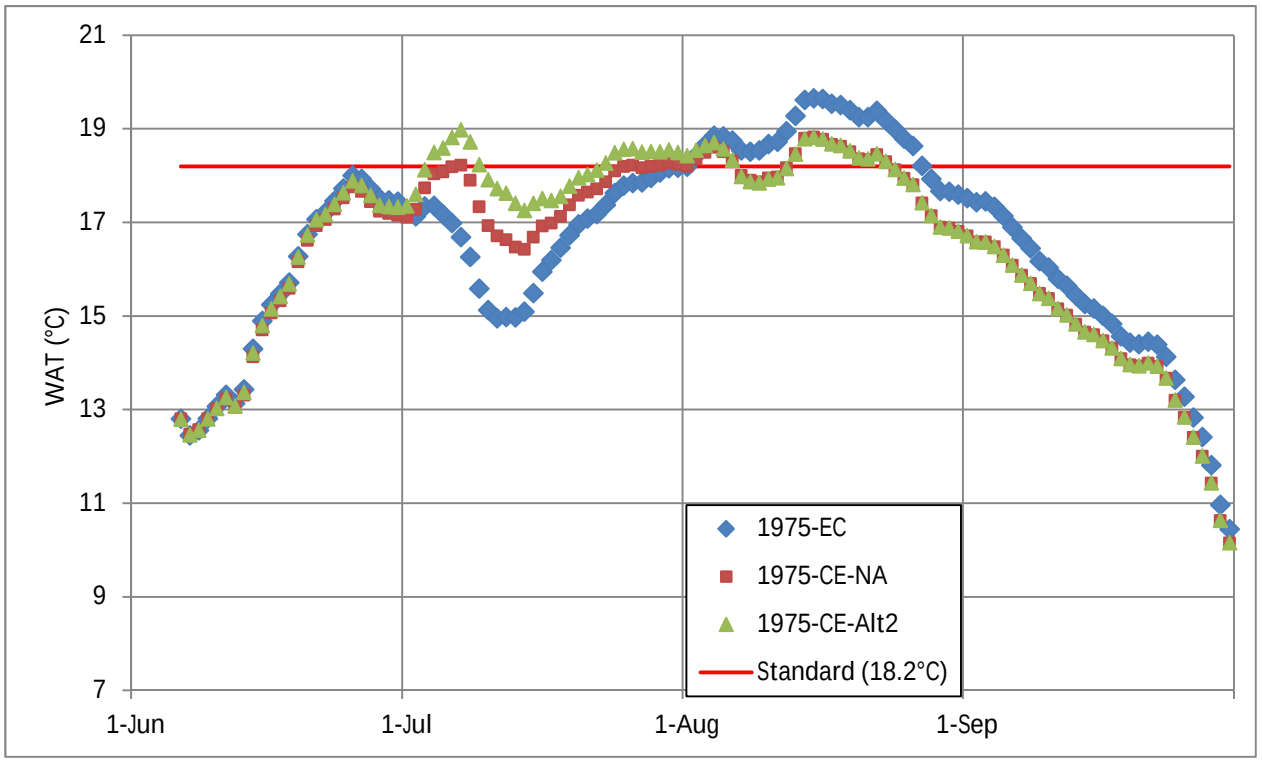

Figure 139. 1975 Cumulative Effects WATs at CR-WFU (Earlier 5412 Release Simulations).

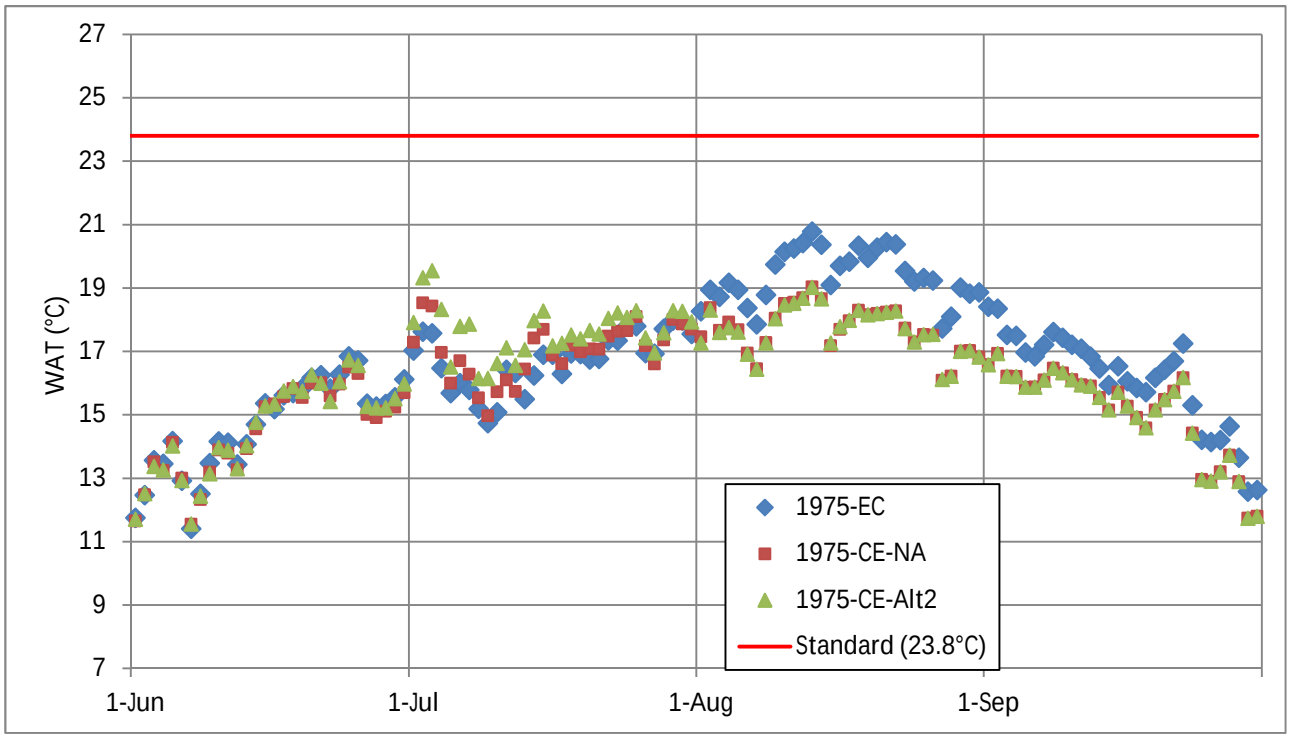

Figure 140. 1975 Cumulative Effects DMs at CR-WGD (Earlier 5412 Release Simulations).

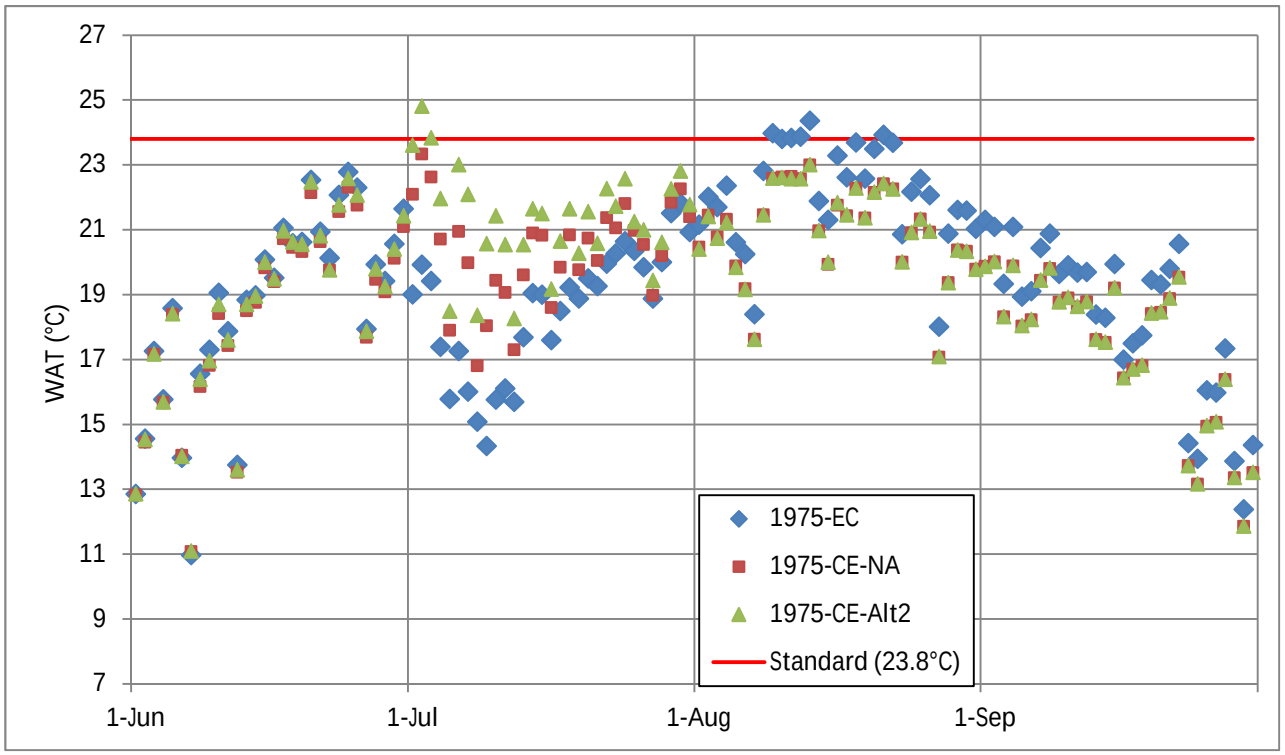

Figure 141. 1975 Cumulative Effects DMs at CR-HSU (Earlier 5412 Release Simulations).

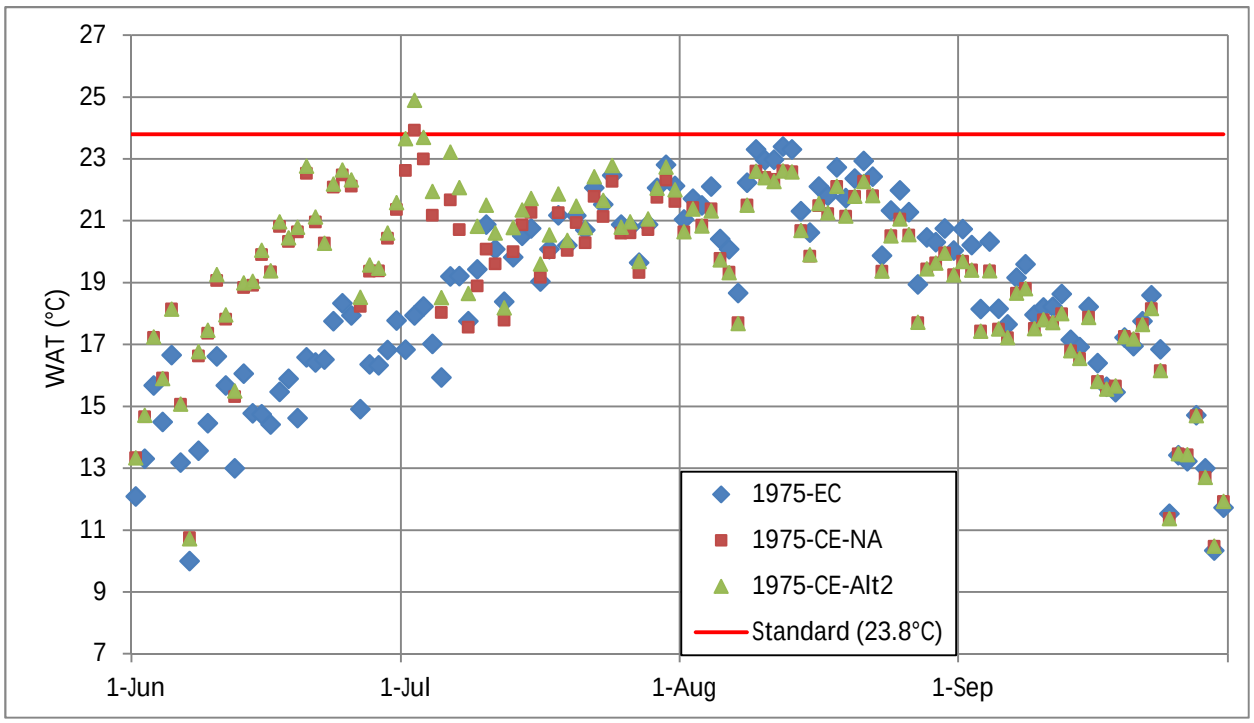

Figure 142. 1975 Cumulative Effects DMs at CR-WFU (Earlier 5412 Release Simulations).

For 1975 cumulative effects, Table 27 summarizes the results of a regulatory analysis of the data at the three thermistor locations, CR-WGD, CR-HSU, and CR-WFU for the August-1 5412 release start date. The maximum WAT was cooler for Alt 2, relative to existing conditions due to the planned 5412 releases from Granby Reservoir in August. For the same reason, the existing conditions run shows the highest number of acute and chronic exceedances in August. In July, Alt2 was simulated to have more acute and chronic exceedances than no action and existing conditions, due to greater pumping at Windy Gap (and no 5412 releases in July in this simulation).

For the earlier 5412 release start date (July 15) simulations, Table 28 summarizes the results of the regulatory analysis of the results at the three thermistor locations, CR-WGD, CR-HSU, and CR-WFU. Results are similar to those from the August-1 5412 release data simulations (Table 27); however, due to the July 15 start of the 5412 releases, there are fewer acute and chronic exceendaces for Alt2 and no action in July.

Table 27. 1975 Cumulative Effects Simulated Regulatory Results.

	1975-WGD			1975-HSU			1975-WFU		
	EC	NA	Alt2	EC	NA	Alt2	EC	NA	Alt2
Chronic									
MWAT (°C)	18.9	18.0	18.3	19.5	18.8	19.0	19.7	19.0	19.3
June # weeks > 18.2 °C	0	0	0	0	0	0	0	0	0
July # weeks > 18.2 °C	0	0	1	0	2	3	0	3	3
August # weeks > 18.2 °C	3	0	0	4	1	2	4	3	3
September # weeks > 18.2 °C	0	0	0	0	0	0	0	0	0
Acute									
Max DM (°C)	20.8	19.5	20.2	24.4	23.6	24.8	23.5	23.9	24.9
June # days > 23.8 °C	0	0	0	0	0	0	0	0	0
July # days > 23.8 °C	0	0	0	0	0	4	0	1	1
August # days > 23.8 °C	0	0	0	5	0	0	0	0	0
September # days > 23.8 °C	0	0	0	0	0	0	0	0	0

Table 28. 1975 Cumulative Effects Simulated Regulatory Results (Earlier 5412 Release Simulations).

	1975-WGD			1975-HSU			1975-WFU		
	EC	NA	Alt2	EC	NA	Alt2	EC	NA	Alt2
Chronic									
MWAT (°C)	18.9	17.5	17.5	19.5	18.8	19.0	19.7	18.8	19.0
June # weeks > 18.2 °C	0	0	0	0	0	0	0	0	0
July # weeks > 18.2 °C	0	0	0	0	2	3	0	2	2
August # weeks > 18.2 °C	3	0	0	4	1	2	4	3	3
September # weeks > 18.2 °C	0	0	0	0	0	0	0	0	0
Acute									
Max DM (°C)	20.8	19.0	19.6	24.4	23.6	24.8	23.5	23.9	24.9
June # days > 23.8 °C	0	0	0	0	0	0	0	0	0
July # days > 23.8 °C	0	0	0	0	0	4	0	1	1
August # days > 23.8 °C	0	0	0	5	0	0	0	0	0
September # days > 23.8 °C	0	0	0	0	0	0	0	0	0

Looking more closely at the 1975 cumulative effects simulations (August-1 5412 release start date), Table 29 and Table 30 present the simulated WAT and DM temperature effects of Alt2 relative to existing conditions and no action, respectively. For these 1975 simulations applying 2007 meteorology, the largest individual WAT increase due to Alt2, relative to existing conditions, was 2.8 °C (on July 10) at WFU. Relative to no action, the largest WAT increase was 1.0°C at WFU (on July 11). The largest simulated DM increases were during the same period in July, with an individual day maximum increase of 6.2°C relative to existing conditions at HSU on July 9, and a 2.5°C increase relative to the no action alternative (also at HSU on July 9).

For Alt2 relative to existing conditions, the average July WAT increase ranged from 1.3°C to 1.6°C. For Alt2 relative to no action, the average July WAT increase ranged from 0.4°C to 0.5°C. For Alt2 relative to existing conditions, the average July DM increase ranged from 1.6°C to 3.3°C. For Alt2 relative to no action, the average July DM increase ranged from 0.7°C to 1.0°C. In August, the planned 5412 releases from Granby, simulated for no action and Alt2, results in lower river temperatures as compared to existing conditions. Therefore, negative differences in DMs and WATs are indicated for Alt2 relative to existing conditions. Relative to no action, Alt2 shows essentially no difference (≤0.1°C) in DMs and WATs in August.

Table 29. 1975 Cumulative Effects Simulated WAT and DM Increases Relative to Existing Conditions.

	1975-WGD	1975-HSU	1975-WFU
	Increase Relative to Existing Conditions (°C)	Increase Relative to Existing Conditions (°C)	Increase Relative to Existing Conditions (°C)
	Alt2	Alt2	Alt2
Chronic			
Largest WAT Increase in July and August (°C)	2.0	2.6	2.8
Avg. July WAT Increase (°C)	1.3	1.5	1.6
Avg. Aug. WAT Increase (°C)	-1.4	-0.9	-0.7
Acute			
Largest DM Increase in July and August (°C)	2.5	6.2	5.8
Avg. July DM Increase (°C)	1.6	3.3	2.5
Avg. Aug. DM Increase (°C)	-2.0	-1.4	-0.9

Table 30. 1975 Cumulative Effects Simulated WAT and DM Increases Relative to No Action.

	1975-WGD	1975-HSU	1975-WFU
	Increase Relative to No Action (°C)	Increase Relative to No Action (°C)	Increase Relative to No Action (°C)
	Alt2	Alt2	Alt2
Chronic			
Largest WAT Increase in July and August (°C)	0.8	1.0	1.0
Avg. July WAT Increase (°C)	0.4	0.5	0.5
Avg. Aug. WAT Increase (°C)	0.1	0.0	0.0
Acute			
Largest DM Increase in July and August (°C)	2.6	2.5	1.9
Avg. July DM Increase (°C)	0.7	1.0	0.7
Avg. Aug. DM Increase (°C)	0.1	0.0	0.0

Simulated effects on DMs and WATs for the earlier (July 15 start) 5412 release schedule for 1975 hydrology with 2007 meteorology are presented in Table 31 and Table 32. These results are similar to those presented in Table 29 and Table 30 for the August-1 5412 release schedule, with the exception of lower average WAT and DM increases in July for Alt2 relative to existing conditions.

Table 31. 1975 Cumulative Effects Simulated WAT and DM Increases Relative to Existing Conditions (Earlier 5412 Release Schedule Simulations).

	1975-WGD	1975-HSU	1975-WFU
	Increase Relative to Existing Conditions (°C)	Increase Relative to Existing Conditions (°C)	Increase Relative to Existing Conditions (°C)
	Alt2	Alt2	Alt2
Chronic			
Largest WAT Increase in July and August (°C)	2.0	2.6	2.8
Avg. July WAT Increase (°C)	0.9	1.2	1.3
Avg. Aug. WAT Increase (°C)	-1.3	-0.8	-0.7
Acute			
Largest DM Increase in July and August (°C)	2.1	6.2	5.8
Avg. July DM Increase (°C)	0.9	2.8	2.2
Avg. Aug. DM Increase (°C)	-1.7	-1.2	-0.8

Table 32. 1975 Cumulative Effects Simulated WAT and DM Increases Relative to No Action (Earlier 5412 Release Schedule Simulations).

	1975-WGD	1975-HSU	1975-WFU
	Increase Relative to No Action (°C)	Increase Relative to No Action (°C)	Increase Relative to No Action (°C)
	Alt2	Alt2	Alt2
Chronic			
Largest WAT Increase in July and August (°C)	0.8	1.0	1.0
Avg. July WAT Increase (°C)	0.4	0.5	0.5
Avg. Aug. WAT Increase (°C)	0.0	0.0	0.0
Acute			
Largest DM Increase in July and August (°C)	1.6	2.5	1.9
Avg. July DM Increase (°C)	0.6	1.0	0.7
Avg. Aug. DM Increase (°C)	0.0	0.0	0.0

4.2.1.4 1975 Cumulative Effects Summary

For the simulated 1975 cumulative effects hydrology with 2007 meteorology, Windy Gap pumping differences occurred in June and July across the simulations, but the greatest flow differences and corresponding temperature effects were simulated to occur below Windy Gap Reservoir in July. Temperature increases were simulated at WGD, HSU, and WFU for Alt2 relative to both existing conditions and no action. Larger July temperature increases were simulated for Alt2 relative to existing conditions (versus no action), due to greater pumping differences. Increased exceedances were simulated for Alt2 relative to existing conditions and no action at all three locations (WGD, HSU, and WFU) in July. The largest WAT increase was simulated at WFU in July (+2.8°C as compared to existing conditions and +1.0°C as compared to no action). The largest DM increase for Alt2 was simulated at HSU in July (+6.2°C as compared to existing conditions and +2.6°C as compared to no action). In contrast, in August Alt2 and no action simulated river temperatures were lower than existing conditions due to 5412 releases from Granby Reservoir. There were no temperature exceedances in June or September for any of the scenarios. Comparing 1975 cumulative effects results to direct effects (Section 4.1.1), results in July were similar for Alt2 relative to existing conditions. Relative to no action, however, cumulative effects showed a smaller temperature increase for Alt2, due to higher Windy Gap pumping rates for the cumulative effects no action simulation. In August, due to planned 5412 releases from Granby Reservoir, cumulative effects temperatures for Alt2 and no

action were cooler than existing conditions, which is opposite to the simulation results for direct effects.

Planned 5412 releases from Granby Reservoir play an important role in cooling river temperatures in the 1975 cumulative effects simulations. For the August-1 release start date, the schedule evaluated in the 10825 Environmental Assessment (BOR, 2011), river temperatures are simulated to be cooler than existing conditions in August for both no action and Alt2. Additional simulations of Alt2 and no action cumulative effects were conducted for 1975 using a modified 5412 release schedule to provide insight into the possible temperature benefits of an earlier start to 5412 releases (the earlier release schedule evaluated started on July 15 instead of August 1; see Table 25). These earlier release simulations showed a reduction in Alt2 and no action river temperatures and exceedances in July. The Operations Group that will determine the 5412 release schedule each year for average and wet years may want to consider initiating the releases in July, recognizing the temperature benefits simulated here[14].

4.2.2 1979 Cumulative Effects

The results of cumulative effects simulations applying 1979 hydrology scenarios under conditions of 2007 meteorology are presented in the following subsections. Cumulative effects simulations for 1979 included existing conditions, no action, and Alt2.

4.2.2.1 1979 Cumulative Effects Hydrographs

Figure 143 and Figure 144 present the differences in pumping at Windy Gap and the corresponding flow below Windy Gap Reservoir for the cumulative effects alternatives

[14] Granby 5412 releases for average and wet years will be determined by an "Operations Group" composed of representatives from the water users, the Service, Reclamation, and the State Division Engineer. The release numbers and schedule applied in the Environmental Assessment were established for modeling and analysis purposes. As such, the schedule of releases could be adjusted for average and wet years if deemed appropriate by the operations group.

simulated – existing conditions, no action, and Alt2. Windy Gap pumping volumes (June through September) are summarized for each simulation in Table 33.

Overall, 1979 was an average to wetter year (classified as neither a dry or wet year in the WGFP analysis), with virgin annual flows ranking 14th out of the 47 years of hydrology simulated for the WGFP. For the 1979 Cumulative Effects simulations, Windy Gap pumping and river flows are similar for no action and Alt2. Pumping is higher in June for existing conditions; however, due to higher inflows, flows below Windy Gap are also higher for existing conditions. In July, pumping for Alt2 and no action are higher than existing conditions, and flows below Windy Gap reservoir are correspondingly lower. Due to planned 5412 releases from Granby Reservoir in August and September, flows for no action and Alt2 are higher than existing condition flows in those two months.

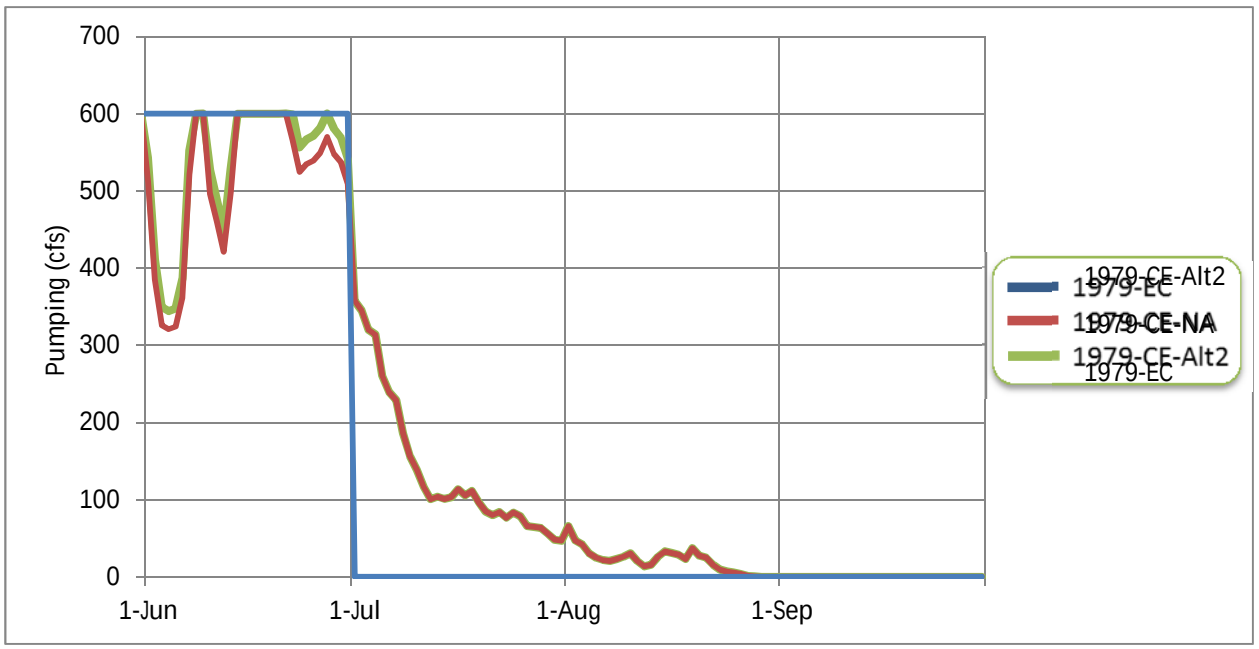

Figure 143. 1979 Cumulative Effects Windy Gap Pumping

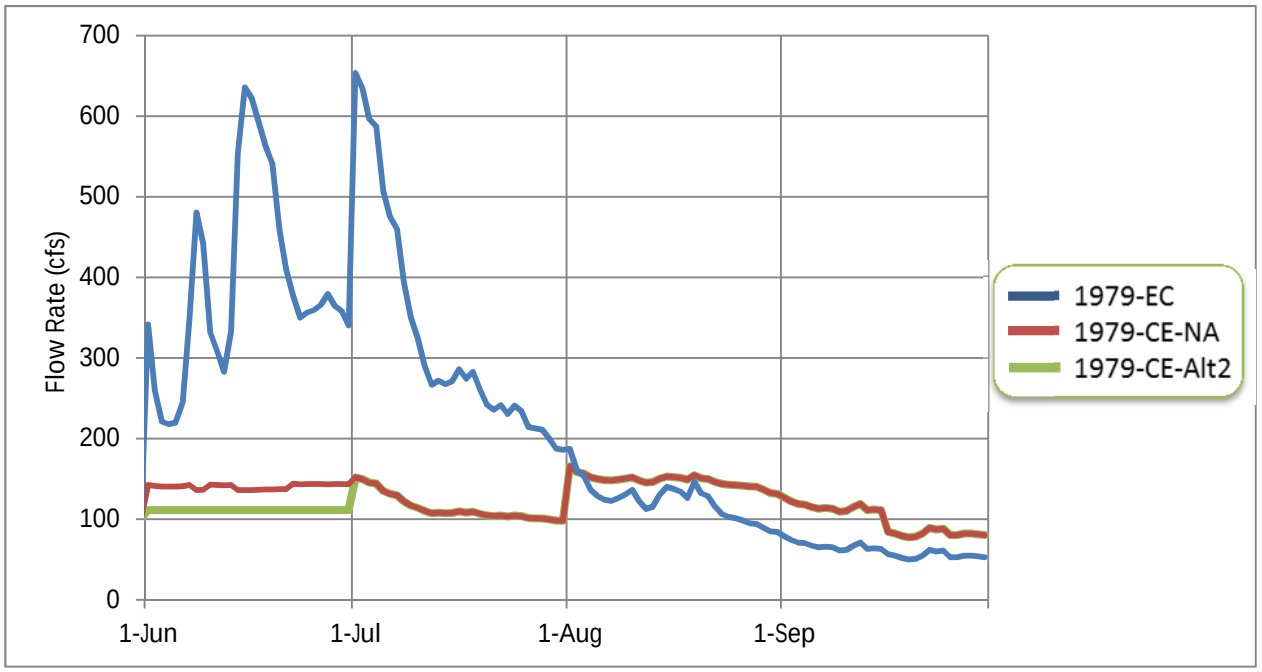

Figure 144. 1979 Cumulative Effects Flow Rates Below Windy Gap

Table 33. 1979 Cumulative Effects Windy Gap Pumping Volumes

	1979-CE Monthly Pumping Totals (AF/month)			
	June	July	August	September
Existing Conditions	35,700	0	0	0
No Action	30,746	8,589	1,302	0
Alternative 2	31,919	8,589	1,303	0

4.2.2.2 1979 Cumulative Effects Hourly Temperature Plots

Figure 145 through Figure 150 present the hourly temperature plots produced by the model for thermistor locations CR-WGD, CR-HSU, and CR-WFU. Hourly temperature plots for the full simulation period are shown, as well as plots focusing on the period of the simulation with notable differences in predicted temperatures. For 1979 cumulative effects simulations, the "Zoom" figures focus on July and August. While large temperature differences are also simulated for June and September, these are periods of cooler flows with no acute or chronic exceedances across the scenarios (as discussed in Section 4.2.2.3).

At all three locations, temperature patterns for Alt2 and no action are very similar due to similar Windy Gap pumping and underlying cumulative effects hydrology. In general, it is apparent from review of the "July-August Zoom" figures that an increase in daily temperatures (for Alt2 relative to existing conditions) is simulated in July. In contrast, temperatures are generally

cooler in August for Alt2 and no action relative to existing conditions in August, due to the planned 5412 releases from Granby Reservoir (simulated to start on August 1). The 1979 cumulative effects temperature simulation results are summarized and discussed quantitatively in Section 4.2.2.3.

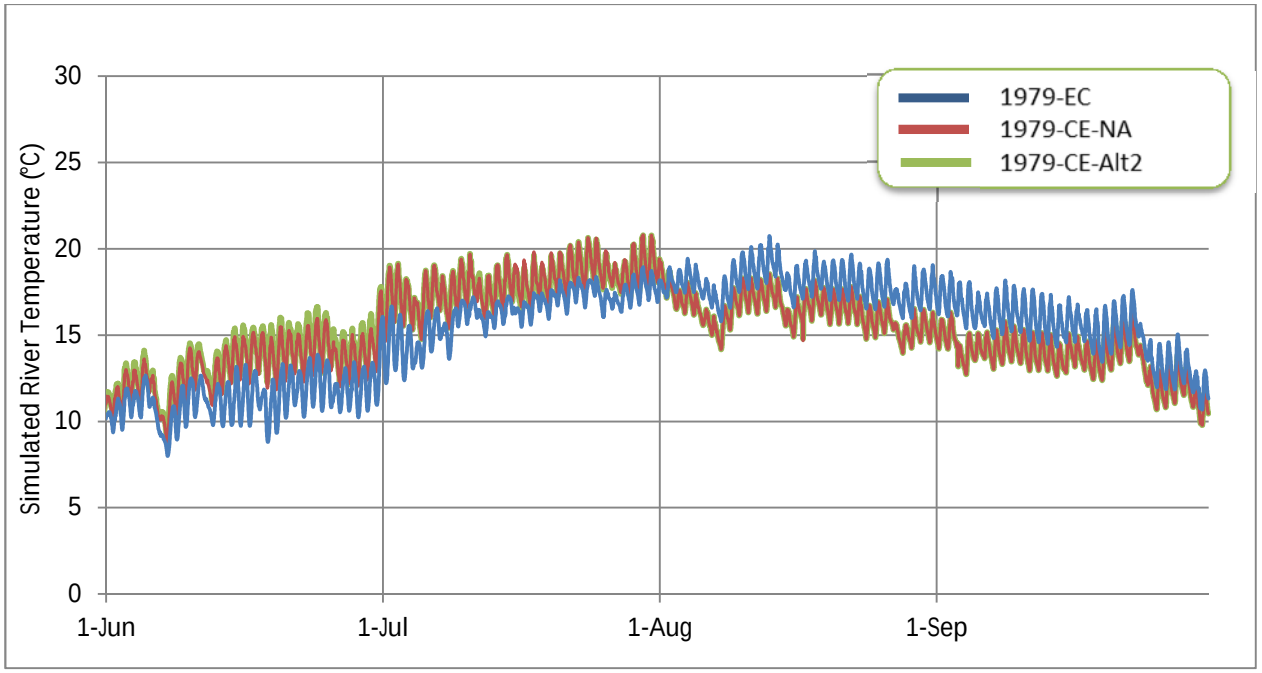

Figure 145. 1979 Cumulative Effects Hourly Temperatures at CR-WGD.

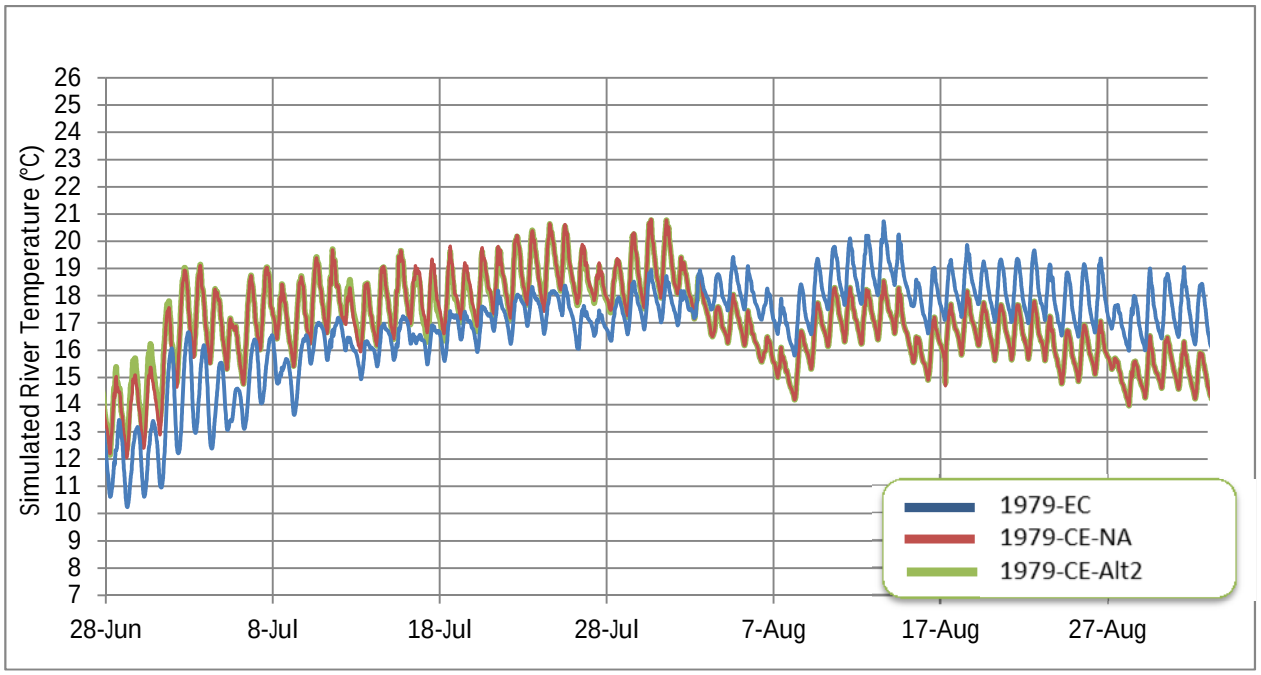

Figure 146. 1979 Cumulative Effects Hourly Temperatures at CR-WGD July-August Zoom.

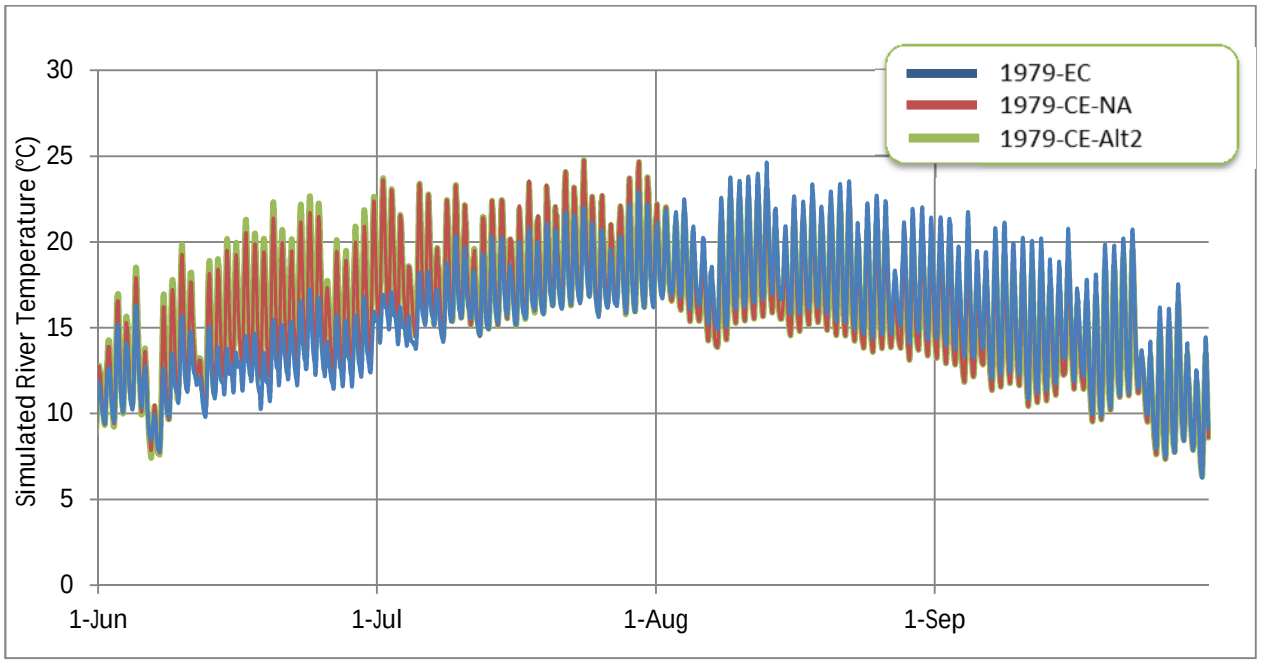

Figure 147. 1979 Cumulative Effects Hourly Temperatures at CR-HSU.

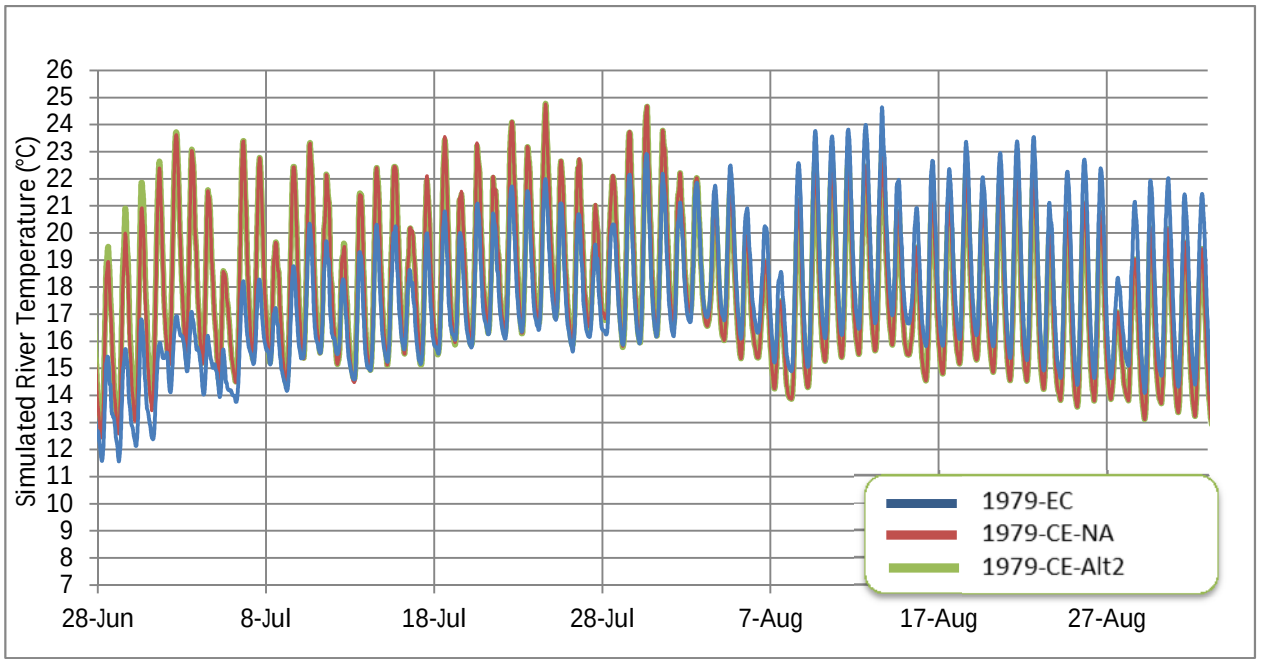

Figure 148. 1979 Cumulative Effects Hourly Temperatures at CR-HSU July-August Zoom.

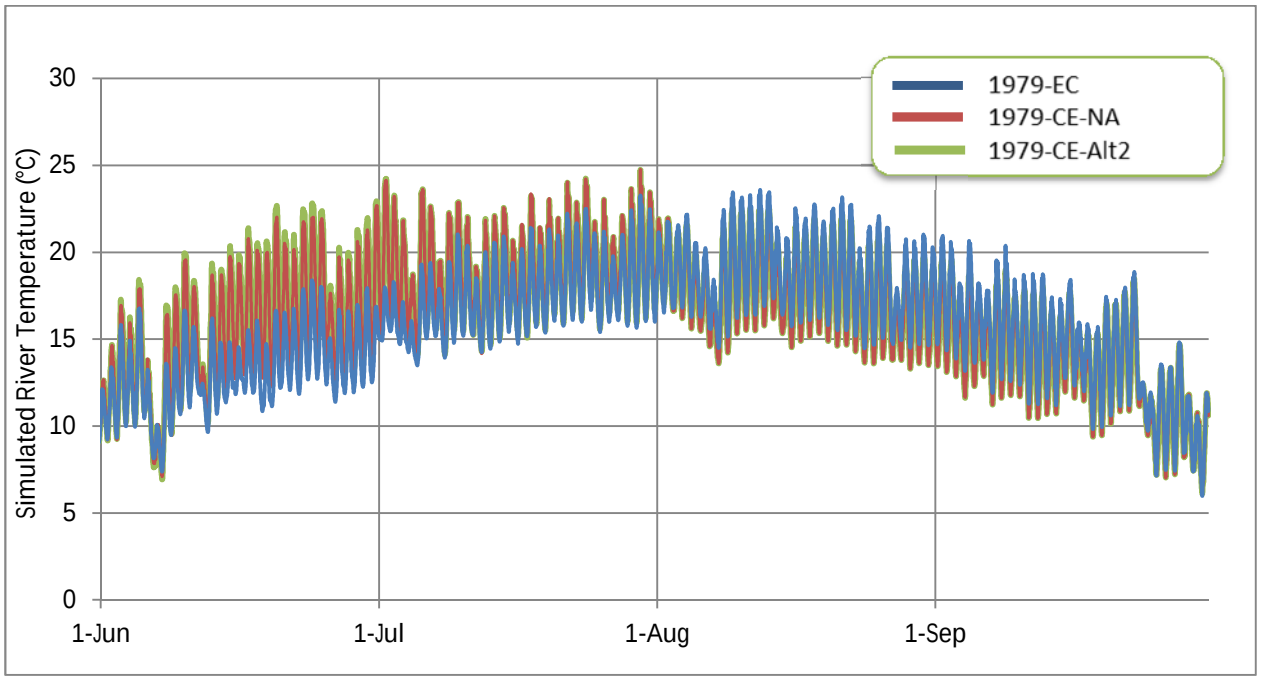

Figure 149. 1979 Cumulative Effects Hourly Temperatures at CR-WFU.

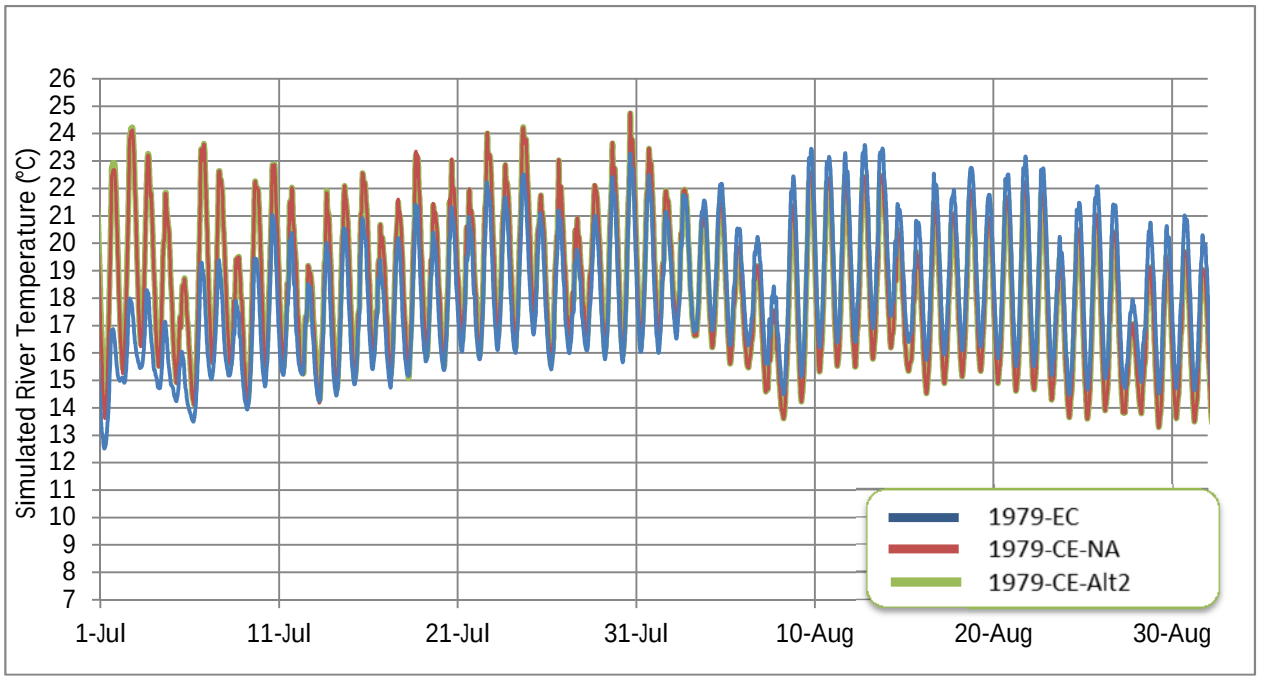

Figure 150. 1979 Cumulative Effects Hourly Temperatures at CR-WFU July-August Zoom.

4.2.2.3 1979 Cumulative Effects Weekly Average and Daily Maximum Temperatures

WATs and DMs were all calculated using the appropriate Colorado Water Quality Control Division tool (Temp-program-V4.2; personal communication, Robert Hillegas, May 24, 2011) for this segment of the upper Colorado River. Figure 151 through Figure 156 present WATs for each simulated day, following the first week of simulation. DMs are presented for each simulated day in Figure 157 through Figure 159. These figure sets show results for thermistor locations CR-WGD, CR-HSU, and CR-WFU.

Cumulative effects WATs and DMs show similar patterns. Alt2 and no action show similar results, with the exception of slightly greater warming effects for Alt2 in June (due to slightly greater pumping relative to no action). The greatest DM and WAT increases for Alt2 relative to existing conditions are in June; however the increases in exceedances due to Alt2 (relative to existing conditions) occur in July only. At all stations, WAT and DM exceedances in August decreased (or remained zero) relative to existing conditions, due to 5412 releases from Granby Reservoir.

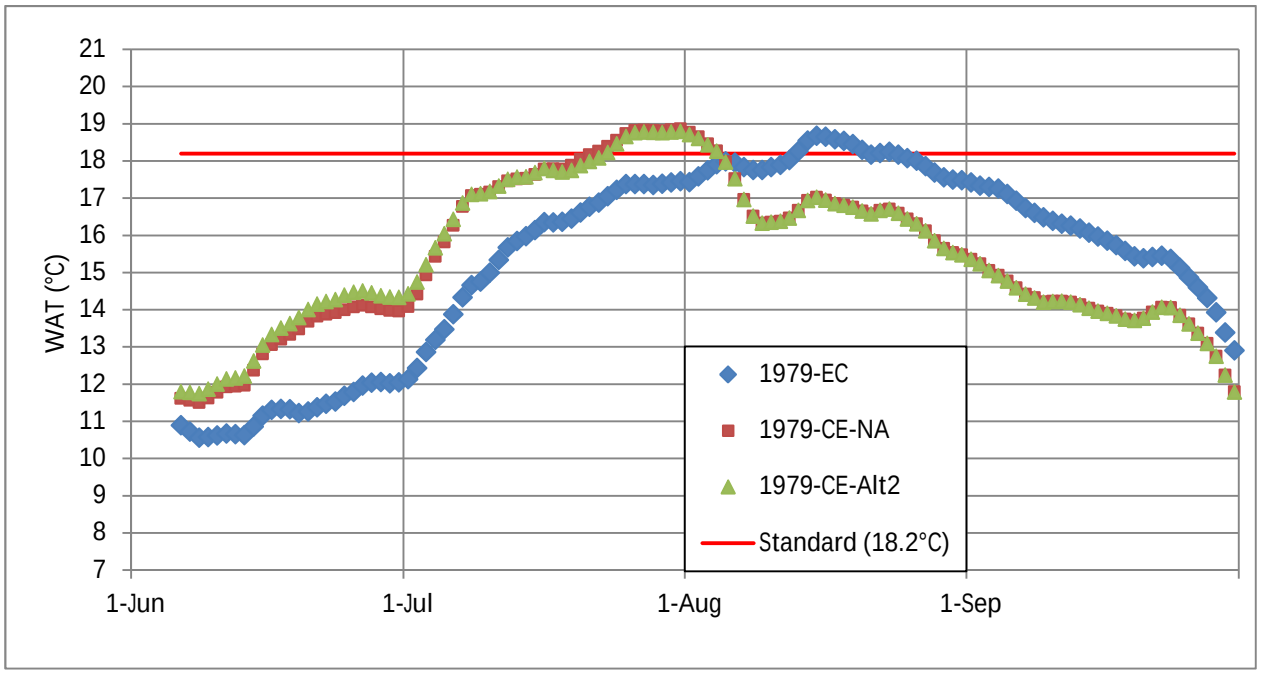

Figure 151. 1979 Cumulative Effects WATs at CR-WGD.

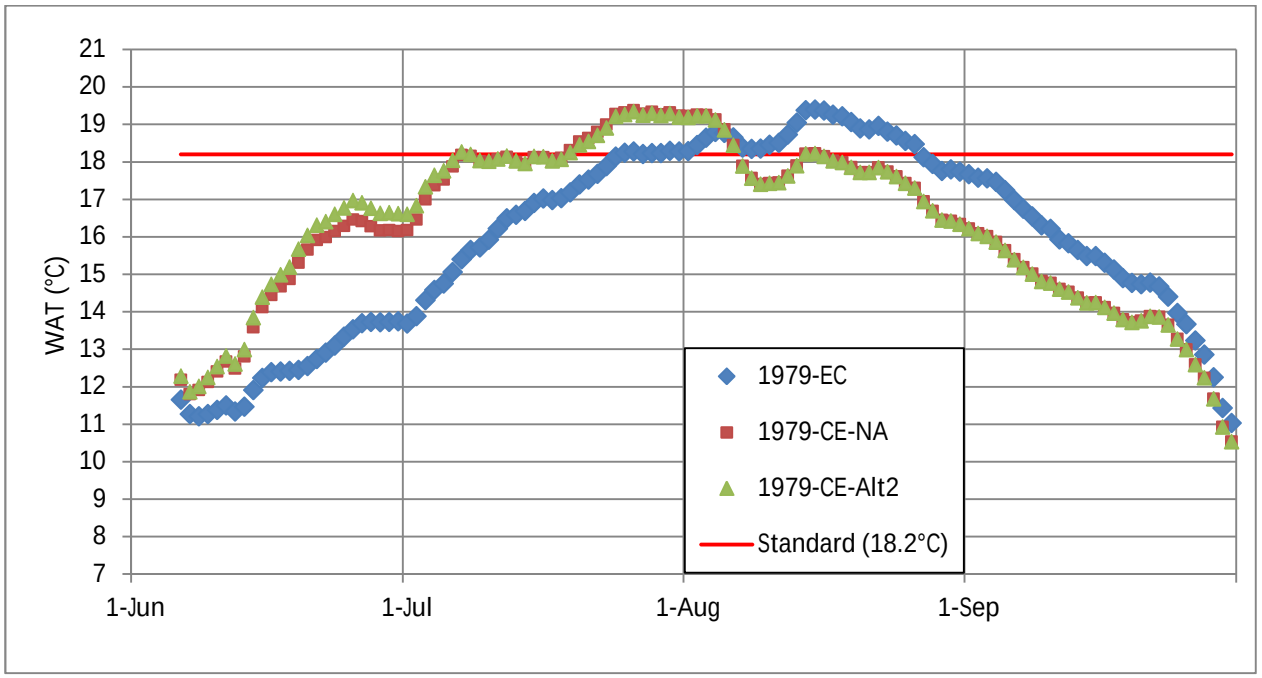

Figure 152. 1979 Cumulative Effects WATs at CR-HSU.

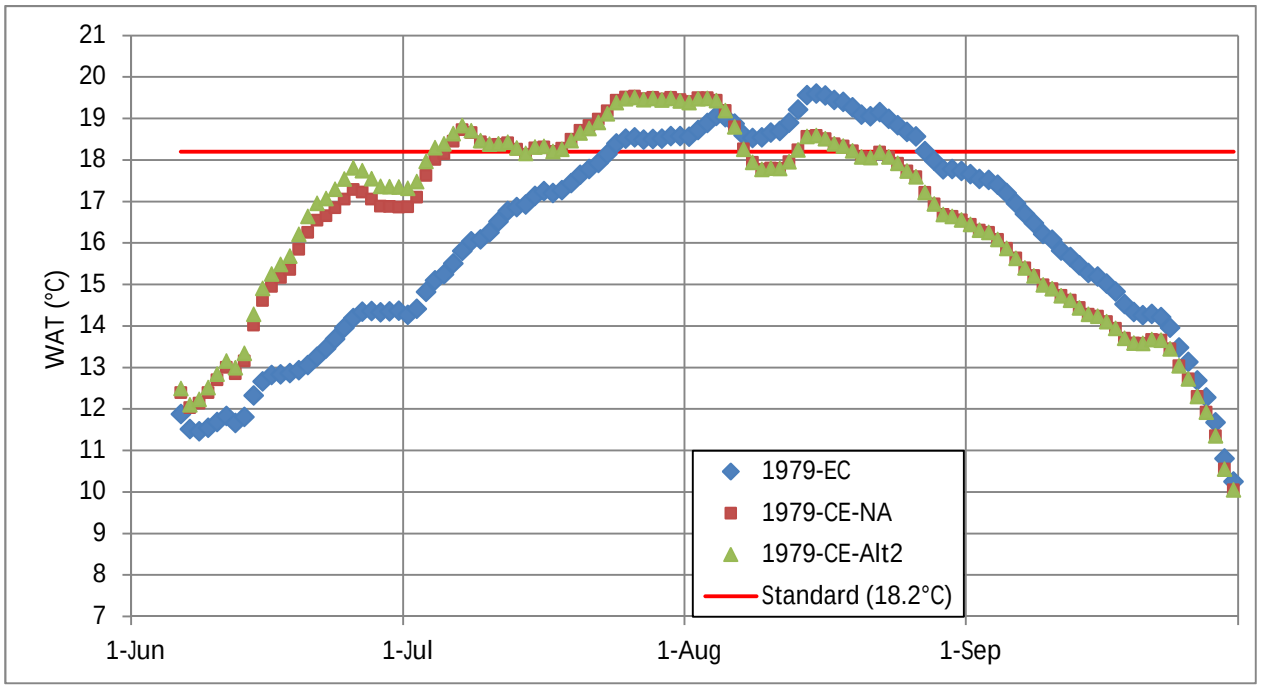

Figure 153. 1979 Cumulative Effects WATs at CR-WFU.

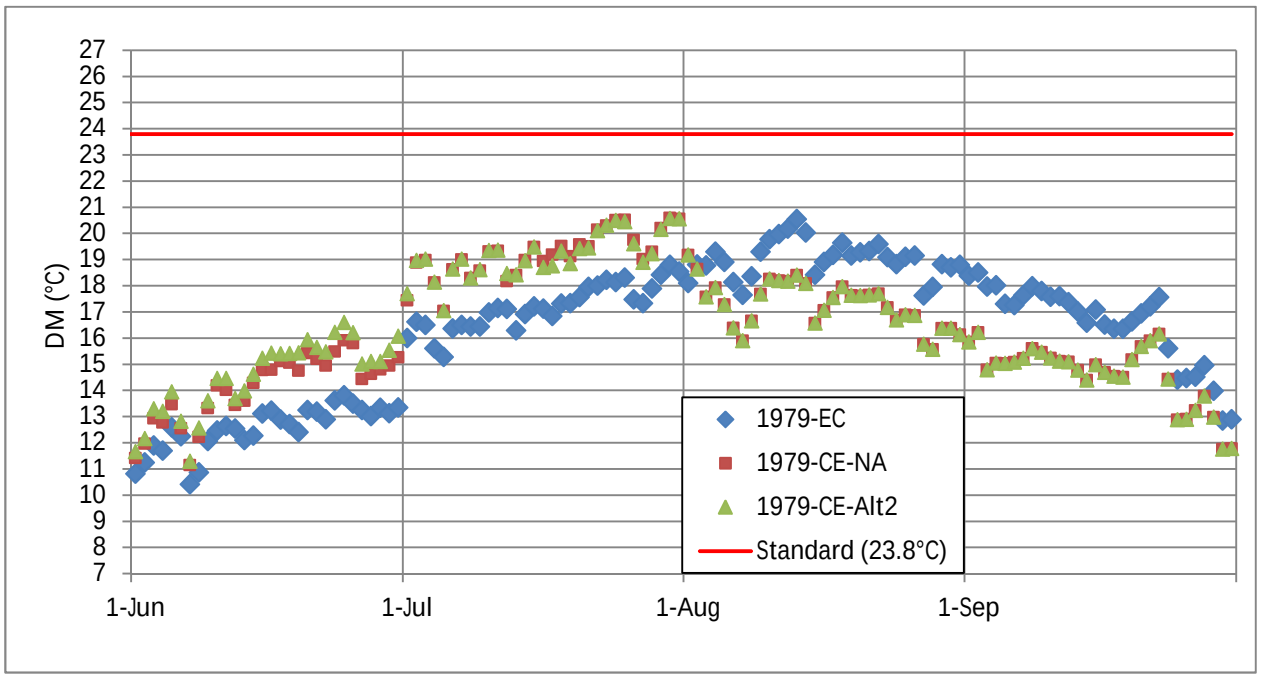

Figure 154. 1979 Cumulative Effects DMs at CR-WGD.

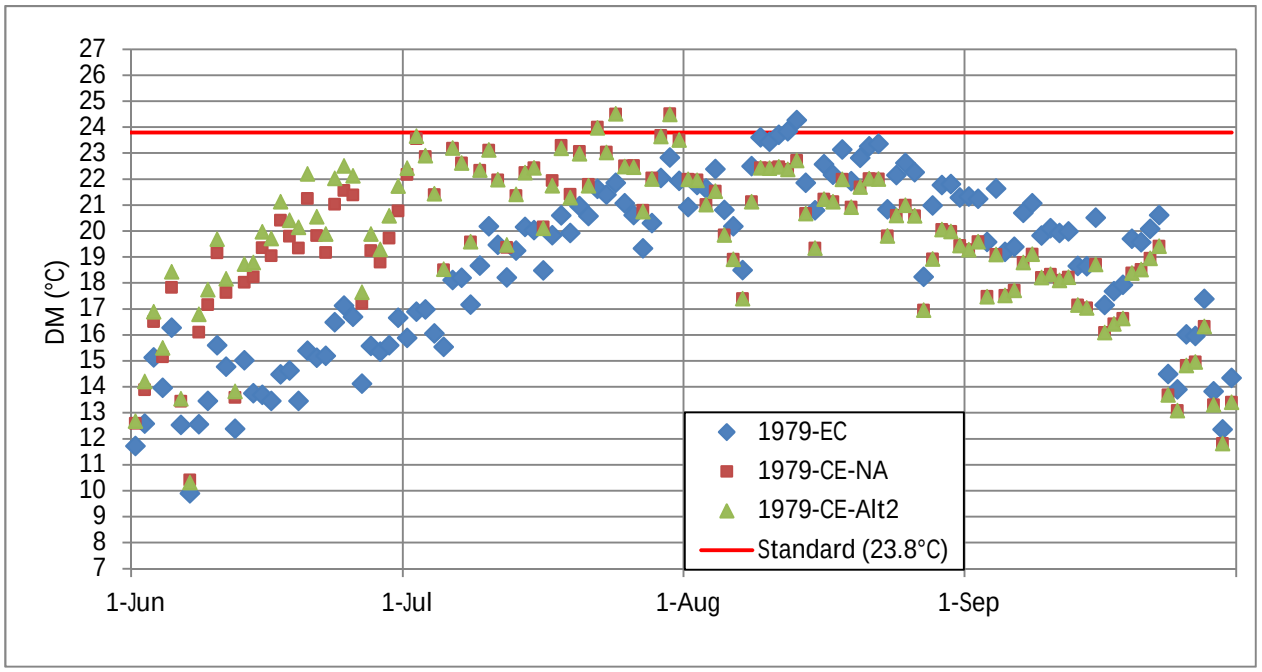

Figure 155. 1979 Cumulative Effects DMs at CR-HSU.

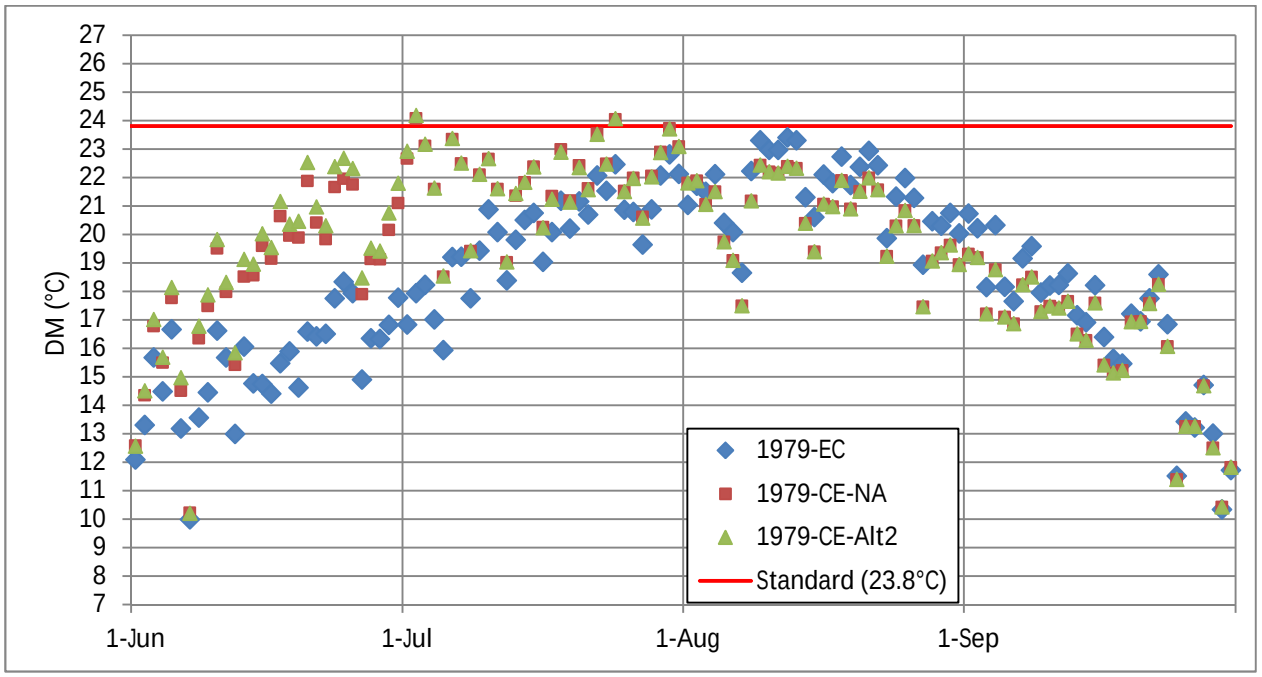

Figure 156. 1979 Cumulative Effects DMs at CR-WFU.

For 1979 cumulative effects, Table 34 summarizes the results of a regulatory analysis of the simulation results at the three thermistor locations, CR-WGD, CR-HSU, and CR-WFU. The maximum WATs over July and August varied only by 0.1°C for Alt2 relative to both existing conditions and no action. In July, there were two additional weeks of MWAT exceedances at all locations for Alt2 relative to existing conditions. In constrast, in August, there were two fewer weeks of MWAT exceedances simulated for Alt2 relative to existing conditions at WGD and HSU, and one less week at WFU. The only difference in WATs between Alt2 and no action was one additional week of MWAT exceedance in July at HSU (attributable to a single additional day above the standard for Alt2 on July 7).

DMs followed a similar pattern as that seen for WATs, with small increases in maximum DMs at HSU and WFU for alt2 relative to existing conditions, and very small differences relative to no action. The largest simulated maximum DM increase (comparing maximum values from July and August) was at WFU (0.8°C for Alt2, as compared to existing conditions). An increase in DM exceedances (relative to existing conditions) attributable to Alt 2 is simulated in July (+3 days at HSU and +2 days at WFU). In contrast, due to 5412 releases from Granby Reservoir, DM exceedances in August decrease for Alt2 relative to existing conditions. There were no differences in exceedances between Alt2 and no action. Further, there were no acute exceedances simulated at WGD for any of the simulations, and there were no chronic or acute exceedances simulated at any location in June or September.

Table 34. 1979 Cumulative Effects Simulated Regulatory Results.

	1979-WGD			1979-HSU			1979-WFU		
	EC	NA	Alt2	EC	NA	Alt2	EC	NA	Alt2
Chronic									
MWAT (°C)	18.7	18.9	18.8	19.4	19.4	19.3	19.6	19.5	19.5
June # weeks > 18.2 °C	0	0	0	0	0	0	0	0	0
July # weeks > 18.2 °C	0	2	2	1	2	3	2	4	4
August # weeks > 18.2 °C	2	0	0	4	2	2	3	2	2
September # weeks > 18.2 °C	0	0	0	0	0	0	0	0	0
Acute									
Max DM (°C)	20.6	20.6	20.6	24.3	24.5	24.5	23.4	24.1	24.2
June # days > 23.8 °C	0	0	0	0	0	0	0	0	0
July # days > 23.8 °C	0	0	0	0	3	3	0	2	2
August # days > 23.8 °C	0	0	0	2	0	0	0	0	0
September # days > 23.8 °C	0	0	0	0	0	0	0	0	0

Looking more closely at the 1979 cumulative effects simulations, Table 35 and Table 36 present the simulated WAT and DM temperature effects of Alt2 relative to existing conditions and no action, respectively. For these 1979 simulations applying 2007 meteorology, the largest individual WAT increase due to Alt2, relative to existing conditions, was 3.2 °C at WFU (July 4). For Alt2 relative to existing conditions, the average monthly WAT changes ranged from + 1.7°C in July to -1.2°C in August(decreases in WATs for Alt 2 are attributable to 5412 releases from Granby Reservoir). Relative to no action, the maximum July and August WAT increases due to Alt2 were small carry over values from rolling averages extending back to June (≤0.4°C). WAT differences relative to no action through July and August were minimal due to similar cumulative effects hydrology and Windy Gap pumping.

The largest simulated DM increase relative to existing conditions was 6.8°C, occurring at HSU (July 2). For Alt2 relative to existing conditions, the average monthly DM changes ranged from + 2.7°C in July to -1.7°C in August (decreases in DMs for Alt 2 are attributable to 5412 releases from Granby Reservoir). Relative to no action, Alt2 DM increases were limited largely to June, with a maximum difference in July/August of 0.3°C, occurring on July 1. DM differences relative to no action through July and August were minimal due to similar cumulative effects hydrology and Windy Gap pumping.

Table 35. 1979 Cumulative Effects Simulated WAT and DM Increases Relative to Existing Conditions.

	1979-WGD	1979-HSU	1979-WFU
	Increase Relative to Existing Conditions (°C)	Increase Relative to Existing Conditions (°C)	Increase Relative to Existing Conditions (°C)
	Alt2	Alt2	Alt2
Chronic			
Largest WAT Increase in July and August (°C)	2.6	3.1	3.2
Avg. July WAT Increase (°C)	1.7	1.7	1.7
Avg. Aug. WAT Increase (°C)	-1.2	-0.8	-0.7
Acute			
Largest DM Increase in July and August (°C)	2.5	6.8	6.2
Avg. July DM Increase (°C)	2.0	2.7	2.0
Avg. Aug. DM Increase (°C)	-1.7	-1.2	-0.9

Table 36. 1979 Cumulative Effects Simulated WAT and DM Increases Relative to No Action.

	1979-WGD	1979-HSU	1979-WFU
	Increase Relative to No Action (°C)	Increase Relative to No Action (°C)	Increase Relative to No Action (°C)
	Alt2	Alt2	Alt2
Chronic			
Largest WAT Increase in July and August (°C)	0.3	0.4	0.4
Avg. July WAT Increase (°C)	0.0	0.0	0.1
Avg. Aug. WAT Increase (°C)	0.0	0.0	0.0
Acute			
Largest DM Increase in July and August (°C)	0.3	0.3	0.3
Avg. July DM Increase (°C)	0.0	0.0	0.0
Avg. Aug. DM Increase (°C)	0.0	0.0	0.0

4.2.2.4 1979 Cumulative Effects Summary

For the simulated 1979 cumulative effects hydrology and 2007 meteorology, Windy Gap pumping differences occurred in June, July, and August. Simulated hydrology was very similar for no action and Alt2; therefore, there were only small differences in simulated results for Alt2 relative to no action. Larger temperature increases and increased exceedances were simulated at WGD, HSU, and WFU for Alt2 relative to existing conditions. Temperature exceedance increases for Alt2 relative to existing conditions were limited to July. The largest WAT increase was simulated at WFU in July (+3.2°C). The largest DM increase was simulated HSU in July (+6.8°). Simulated river temperatures (and corresponding exceedances) for Alt2 were lower than existing conditions temperatures in August due to 5412 releases from Granby Reservoir. There were no simulated exceedances of temperature standards in June or September.

Simulated cumulative effects results for Alt2 are similar to direct effects results for July; however, notable differences are apparent in June, August, and September. In June, due to cumulative effects, flow rates for Alt2 and no action are lower than existing conditions, resulting in increased temperatures relative to direct effects simulations, but no exceedances of the MWAT or DM temperature standards. In August and September, 5412 releases from Granby Reservoir simulated for cumulative effects result in lower river temperatures for Alt2 and no action, and correspondingly, no increases in MWAT or DM exceedances.

4.2.3 1986 Cumulative Effects

The results of cumulative effects simulations applying 1986 hydrology scenarios under conditions of 2007 meteorology are presented in the following subsections. Cumulative effects simulations for 1986 included existing conditions, no action, and Alt2.

4.2.3.1 1986 Cumulative Effects Hydrographs

Figure 157 and Figure 158 present the differences in pumping at Windy Gap and the corresponding flow below Windy Gap Reservoir for the cumulative effects alternatives simulated – existing conditions, no action, and alternative 2. Windy Gap pumping volumes (June through September) are summarized for each simulation in Table 37.

1986 was a wet year, with virgin annual flows ranking 4th out of the 47 years of hydrology simulated for the WGFP. For the 1986 cumulative effects simulations, Windy Gap pumping is zero for the entire four month period for existing conditions. No action shows higher pumping than Alt2 in July, but lower relative pumping in August. Due to high flows in the system across scenarios, the pumping in 1986 does not cause large differences in flow rates below Windy Gap Reservoir. The increased flows in August and September due to 5412 releases from Granby Reservoir for no action and the Alt2 show small effects on river flow rates in August and bigger

effects in early September. The 1986 simulated flows are the highest flow rates of the five years simulated.

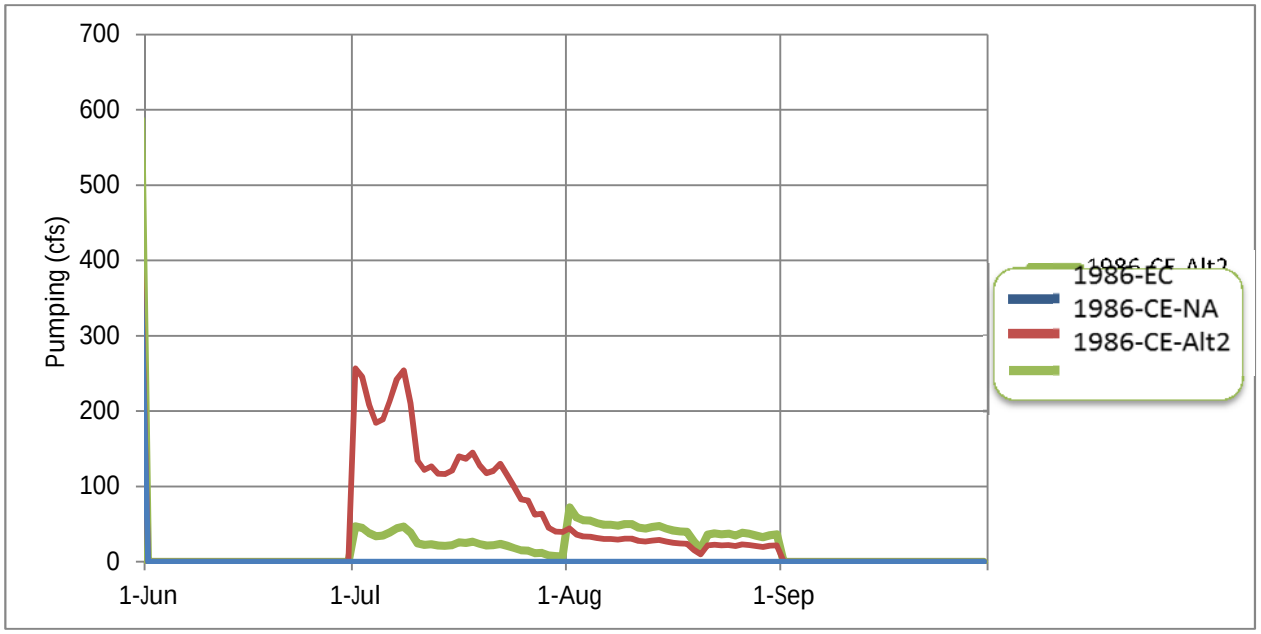

Figure 157. 1986 Cumulative Effects Windy Gap Pumping

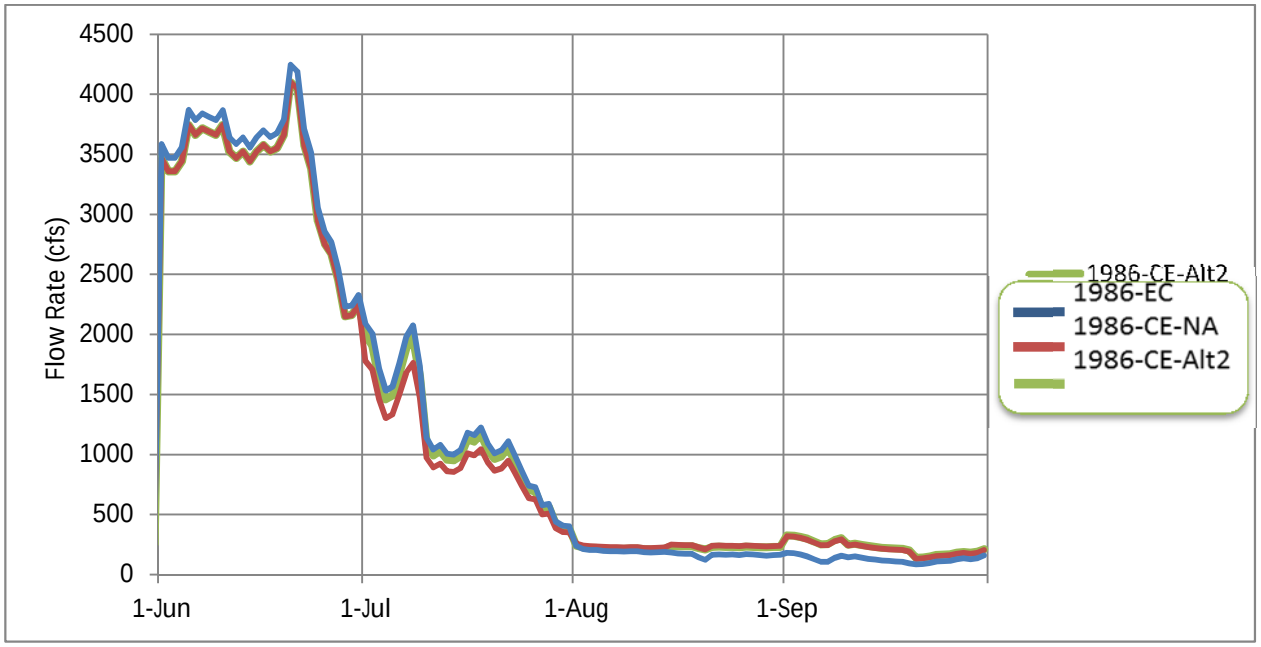

Figure 158. 1986 Cumulative Effects Flow Rates Below Windy Gap

Table 37. 1986 Cumulative Effects Windy Gap Pumping Volumes

	1986-CE Monthly Pumping Totals (AF/month)			
	June	July	August	September
Existing Conditions	0	0	0	0
No Action	0	8,502	1,597	0
Alternative 2	0	1,558	2,632	0

4.2.3.2 1986 Cumulative Effects Hourly Temperature Plots

Figure 159 through Figure 164 present the 1986 cumulative effects hourly temperature plots produced by the model for thermistor locations CR-WGD, CR-HSU, and CR-WFU. Hourly temperature plots for the full simulation period are shown, as well as plots focusing on July and August. For 1986 direct effects simulations, differences in simulated temperatures were largely limited to the months of August and September. While pumping differences occurred in both July and August, overall flow rates in this reach of the river were much higher in July as compared to August (Figure 158), resulting in only minor temperature differences. There were no temperature exceedances across scenarios for June and September.

In spite of pumping differences comparable to those simulated for 1975 and 1979 direct effects, temperature patterns for existing conditions, no action, and Alt2 showed only small differences. For Alt2 and no action relative to existing conditions, slight warming was simulated for July and slight cooling was simulated in August and September (due to 5412 releases from Granby). The limited effect of pumping differences can be attributed to the higher flow rates in the river for the 1986 hydrology. These 1986 cumulative effects temperature simulation results are summarized and discussed quantitatively in Section 4.2.3.3.

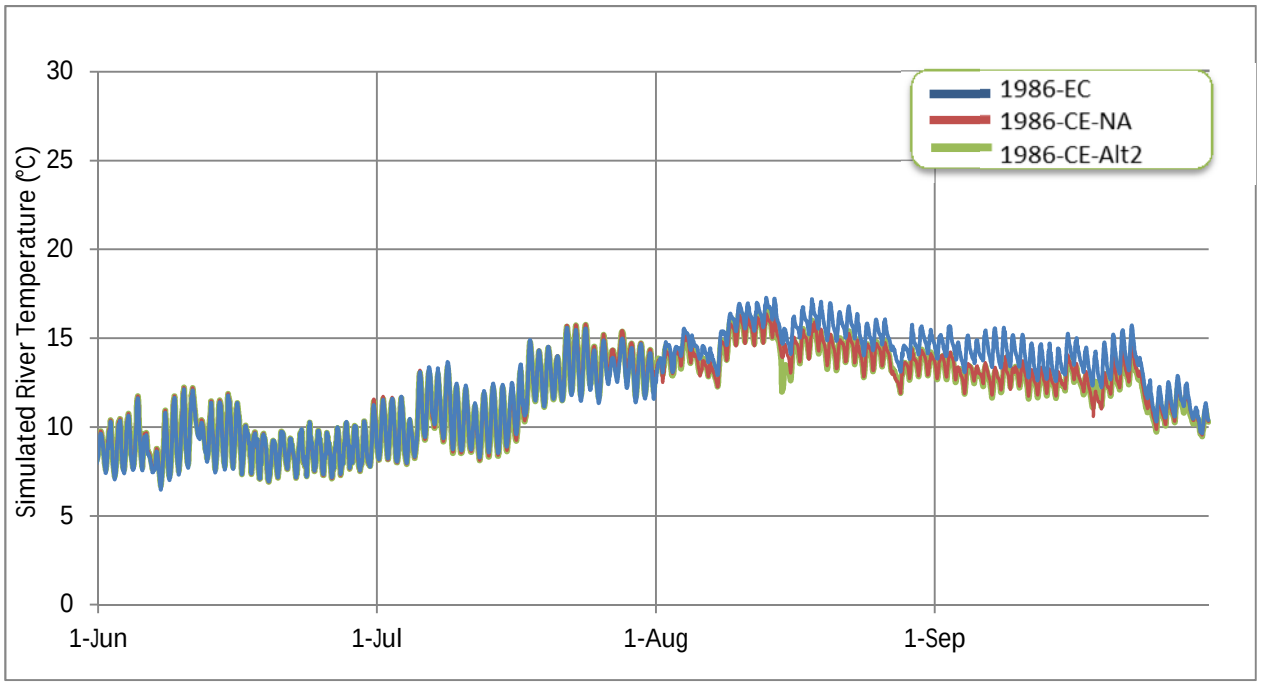

Figure 159. 1986 Cumulative Effects Hourly Temperatures at CR-WGD

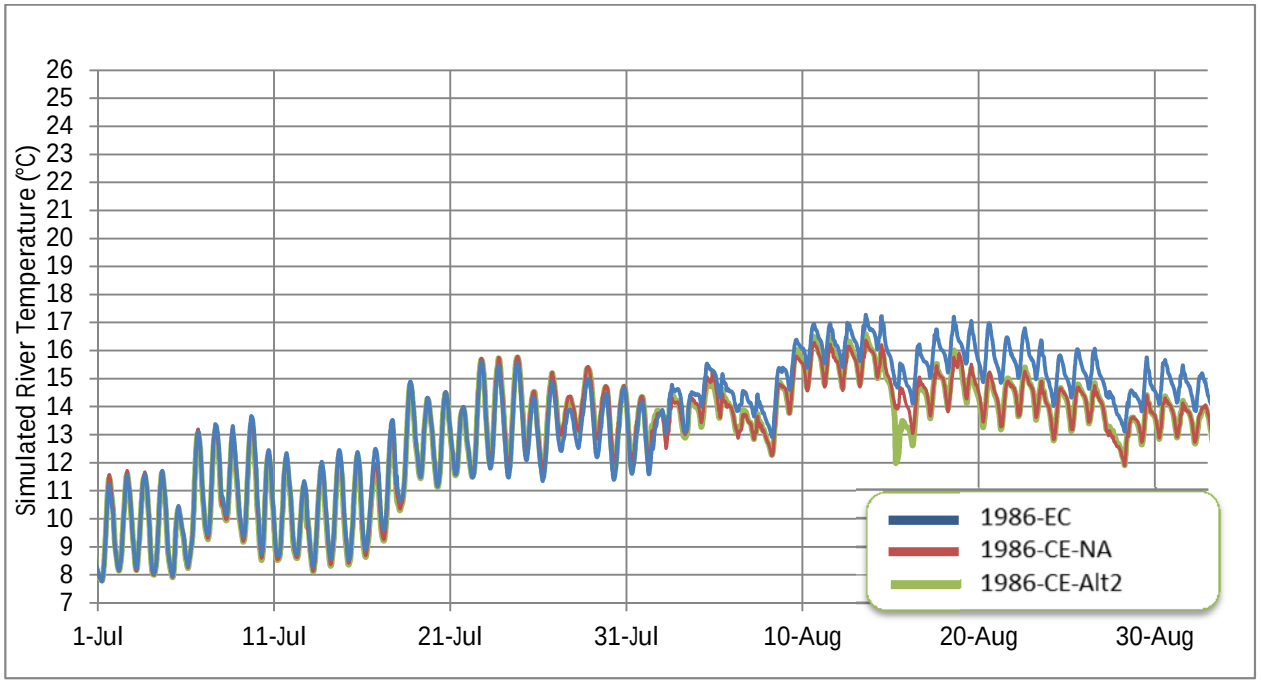

Figure 160. 1986 Cumulative Effects Hourly Temperatures at CR-WGD July-August Zoom

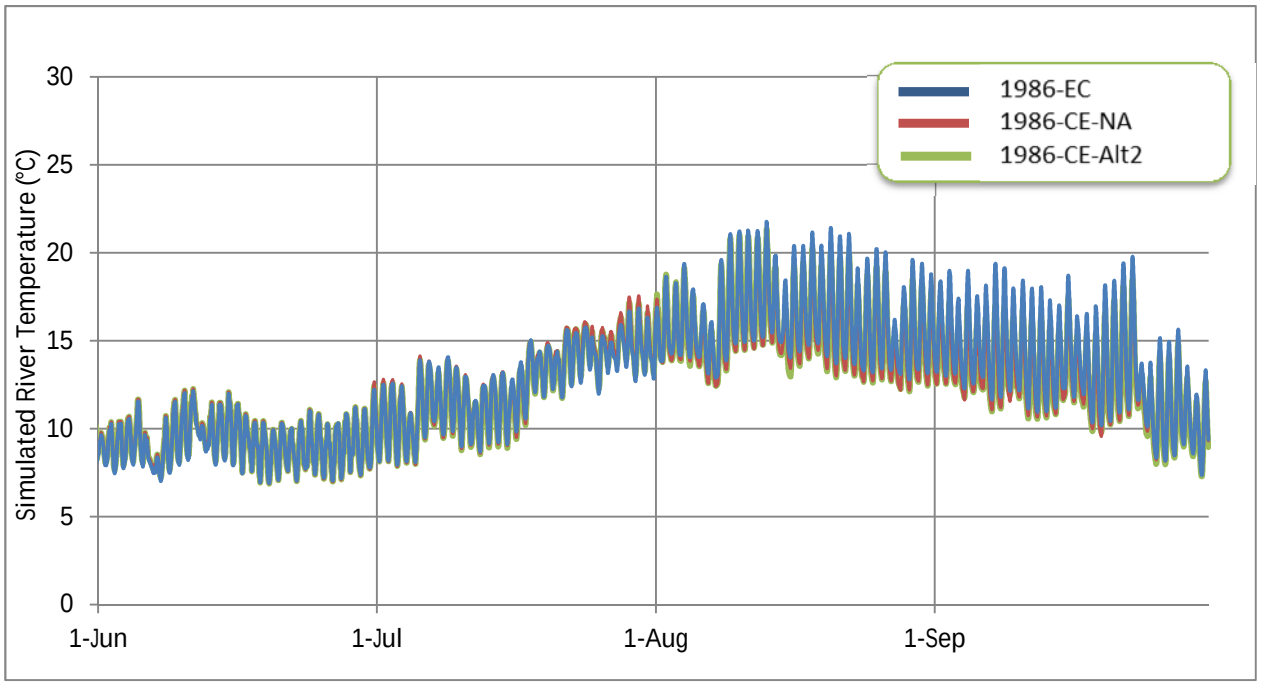

Figure 161. 1986 Cumulative Effects Hourly Temperatures at CR-HSU

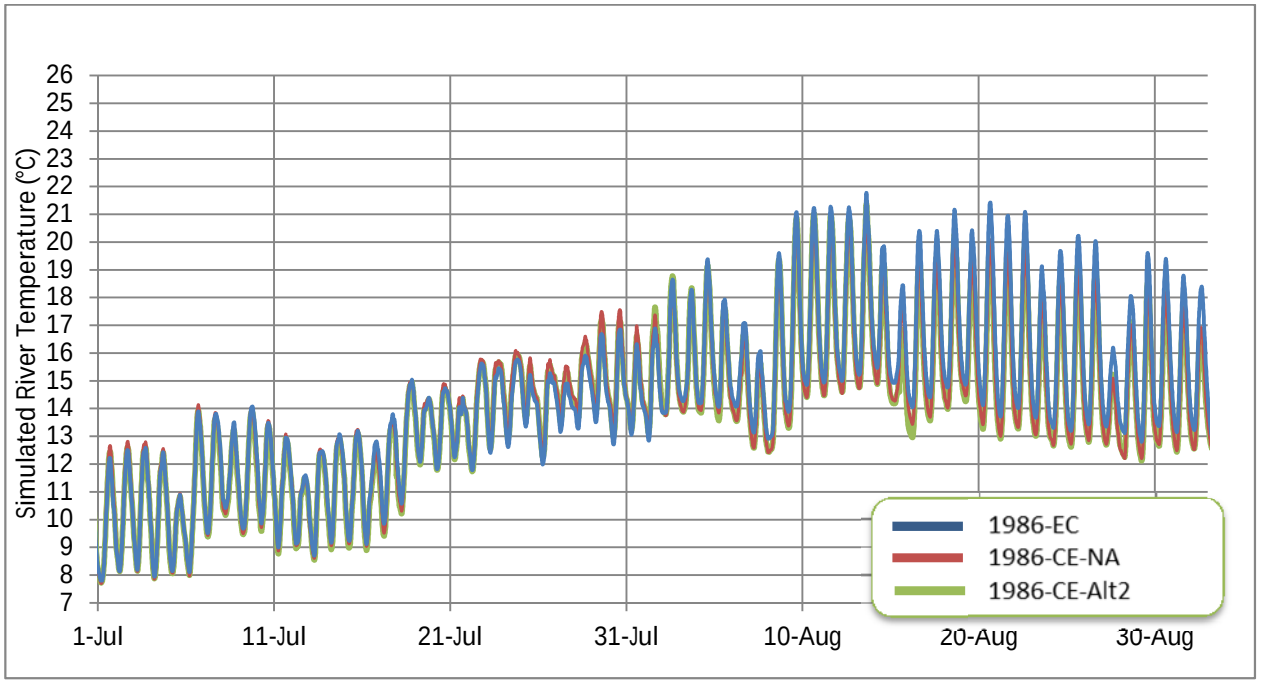

Figure 162. 1986 Cumulative Effects Hourly Temperatures at CR-HSU July-August Zoom

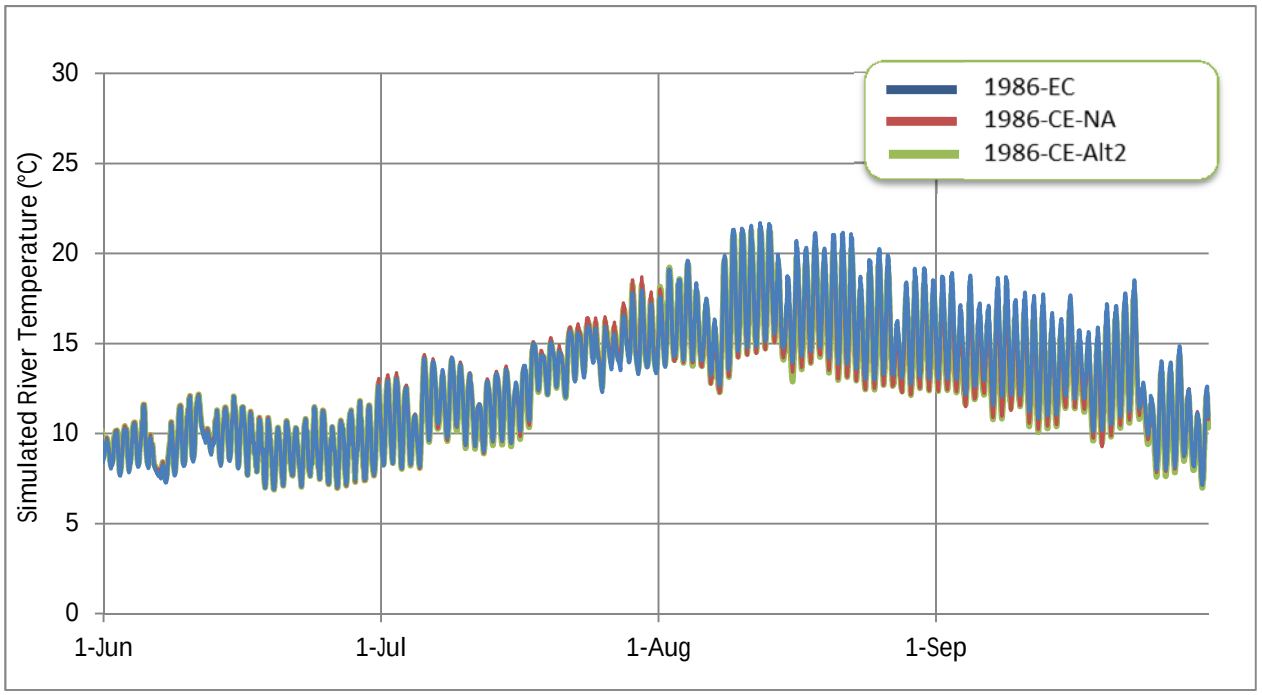

Figure 163. 1986 Cumulative Effects Hourly Temperatures at CR-WFU

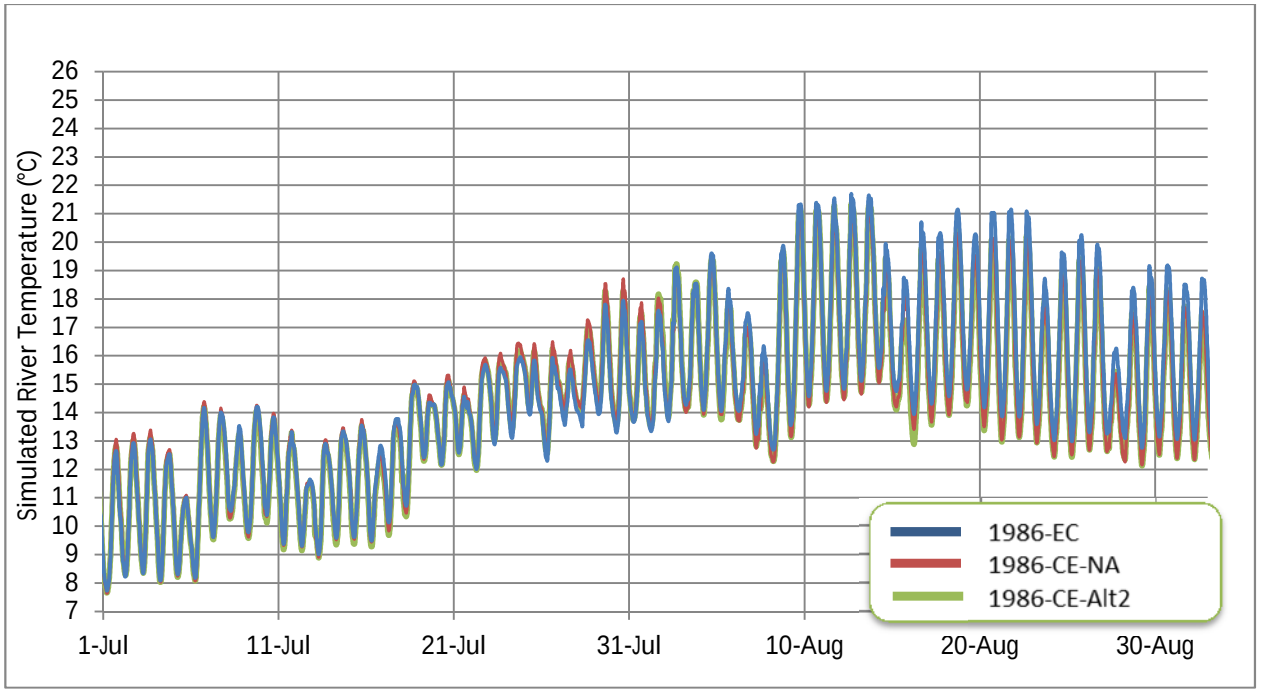

Figure 164. 1986 Cumulative Effects Hourly Temperatures at CR-WFU July-August Zoom

4.2.3.3 1986 Cumulative Effects Weekly Average and Daily Maximum Temperatures

WATs and DMs were all calculated using the appropriate Colorado Water Quality Control Division tool (Temp-program-V4.2; personal communication, Robert Hillegas, May 24, 2011) for this segment of the upper Colorado River. Figure 165 through Figure 167 present WATs for each simulated day, following the first week of simulation. DMs are presented for each simulated day in Figure 168 through Figure 170. These figure sets show results for thermistor locations CR-WGD, CR-HSU, and CR-WFU.

In agreement with the minimal hourly temperature differences presented in the previous subsection, the WAT and DM results show only very small differences, with differences largely limited to August and September, reflecting effects of the 5412 flows. Further, there are no WAT or DM exceedances simulated for any of the alternatives. This limited response to pumping differences is due to the relatively high flow rates in the river for the 1986 hydrology.

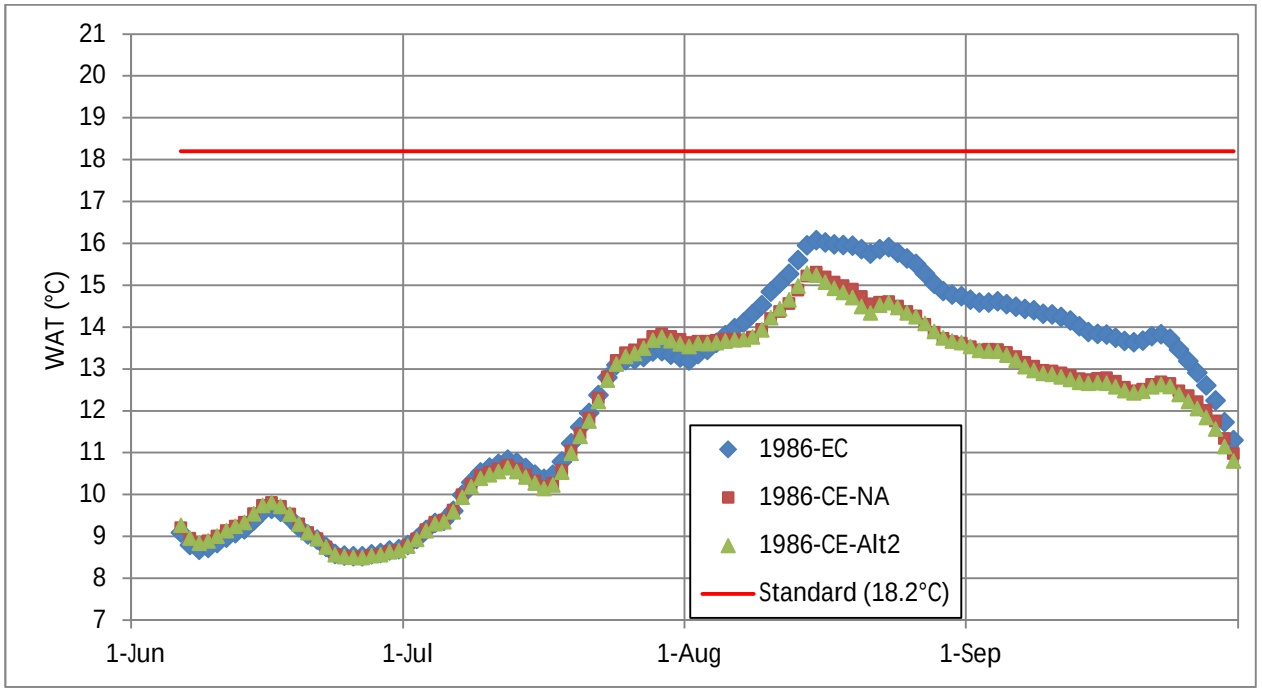

Figure 165. 1986 Cumulative Effects WATs at CR-WGD

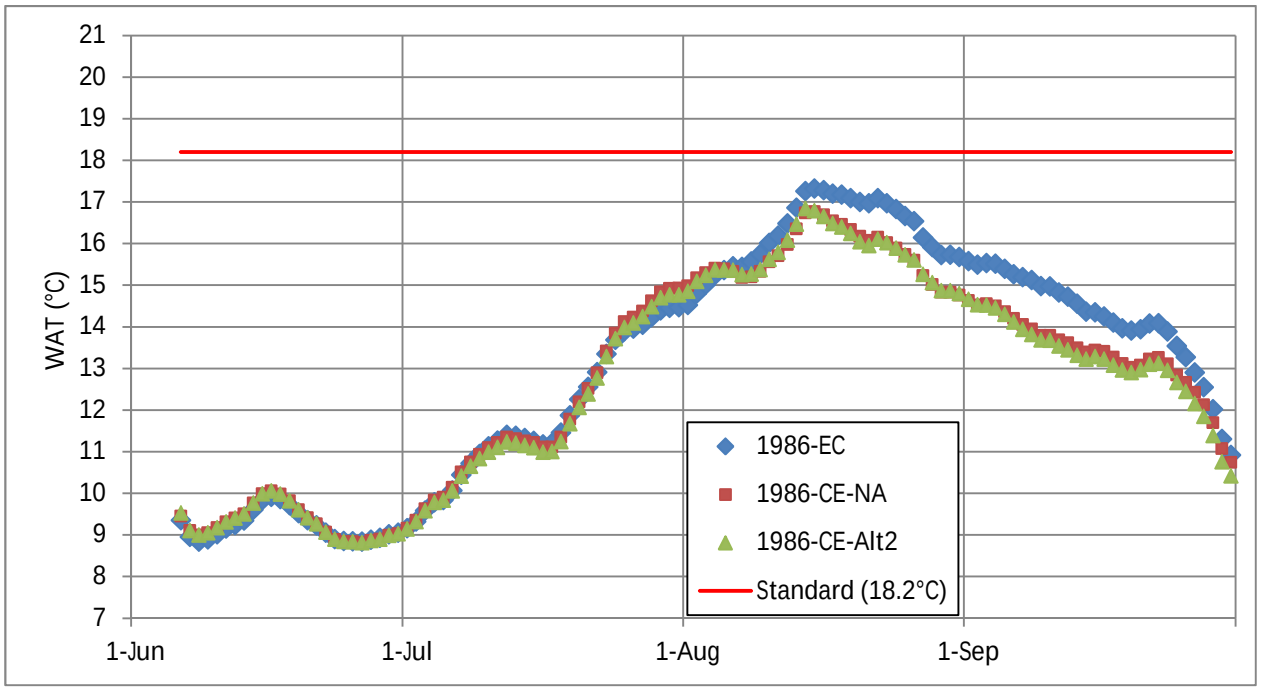

Figure 166. 1986 Cumulative Effects WATs at CR-HSU

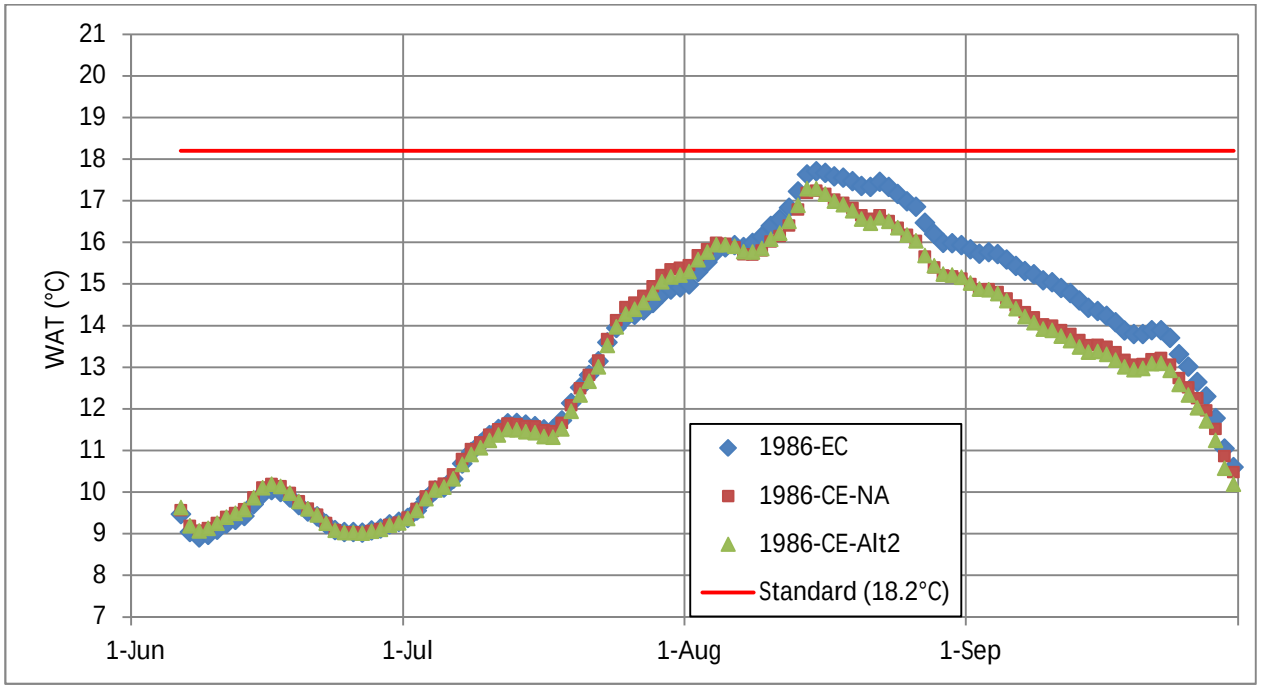

Figure 167. 1986 Cumulative Effects WATs at CR-WFU

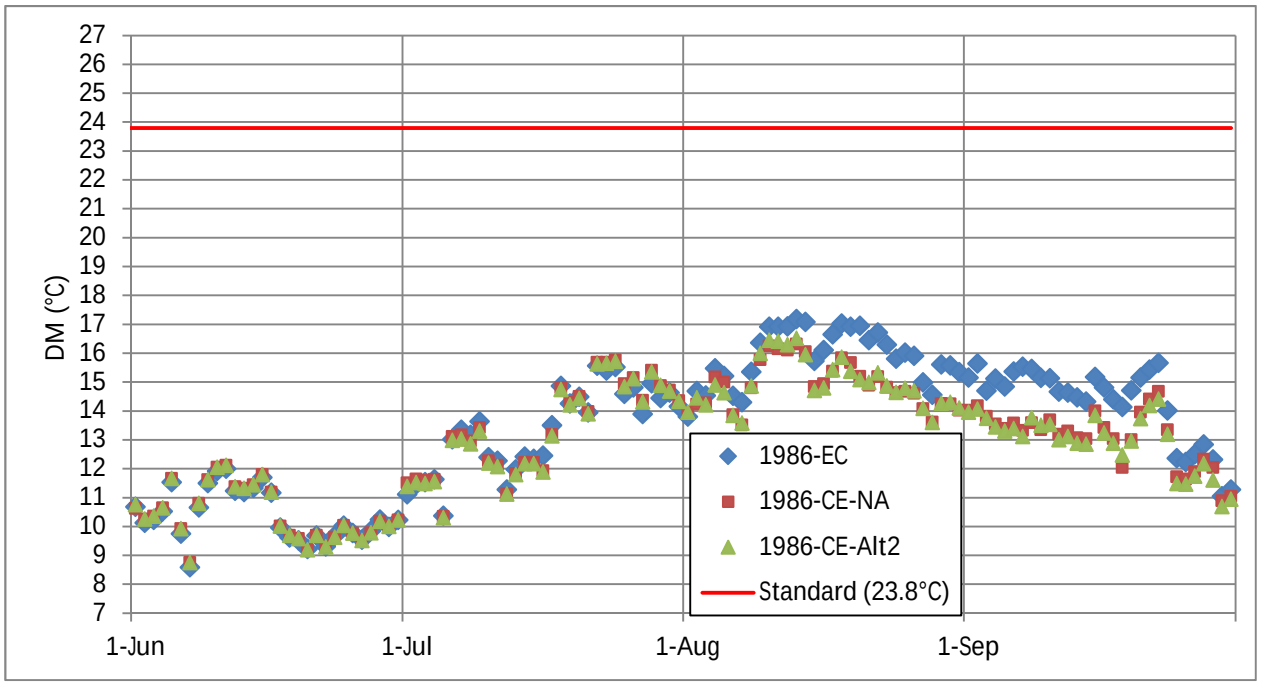

Figure 168. 1986 Cumulative Effects DMs at CR-WGD

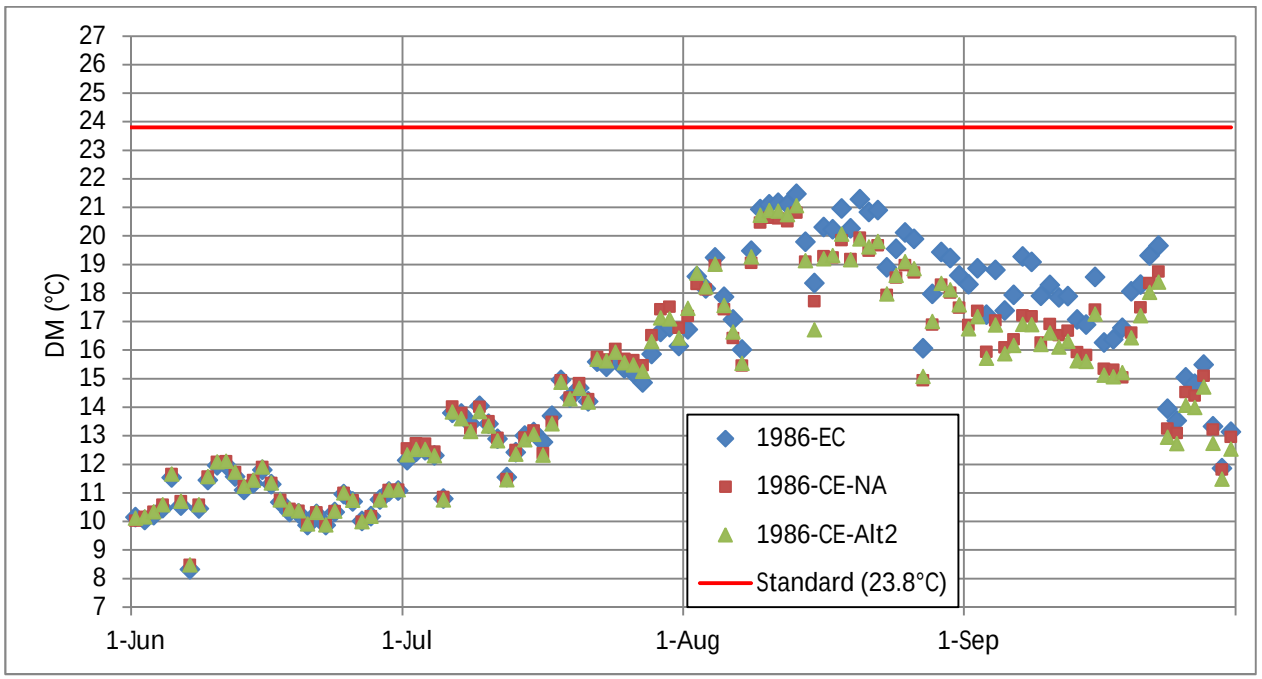

Figure 169. 1986 Cumulative Effects DMs at CR-HSU

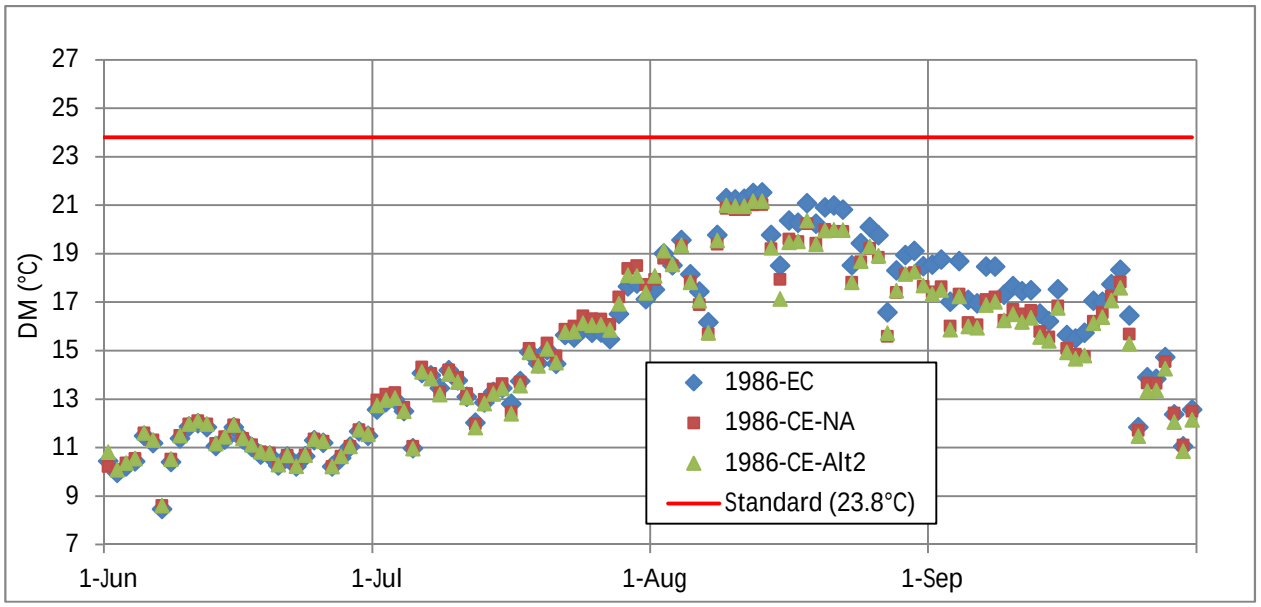

Figure 170. 1986 Cumulative Effects DMs at CR-WFU

For 1986 cumulative effects, Table 38 summarizes the results of a regulatory analysis of the simulation results at the three thermistor locations, CR-WGD, CR-HSU, and CR-WFU. The maximum WAT for the full period decreased slightly for Alt2 relative to existing conditions, due to 5412 releases. There were only small (<0.1°C) difference in the maximum WATs between Alt2 and no action. A similar pattern was simulated for maximum DMs. There were no exceedances of chronic or acute standards for any of the simulations for the 1986 hydrology.

Table 38. 1986 Cumulative Effects Simulated Regulatory Results

	1986-WGD			1986-HSU			1986-WFU		
	EC	NA	Alt2	EC	NA	Alt2	EC	NA	Alt2
Chronic									
MWAT (°C)	16.1	15.3	15.3	17.3	16.8	16.8	17.7	17.2	17.3
June # weeks > 18.2 °C	0	0	0	0	0	0	0	0	0
July # weeks > 18.2 °C	0	0	0	0	0	0	0	0	0
August # weeks > 18.2 °C	0	0	0	0	0	0	0	0	0
September # weeks > 18.2 °C	0	0	0	0	0	0	0	0	0
Acute									
Max DM (°C)	17.2	16.3	16.5	21.5	20.8	21.1	21.5	21.0	21.2
June # days > 23.8 °C	0	0	0	0	0	0	0	0	0
July # days > 23.8 °C	0	0	0	0	0	0	0	0	0
August # days > 23.8 °C	0	0	0	0	0	0	0	0	0
September # days > 23.8 °C	0	0	0	0	0	0	0	0	0

Looking more closely at the 1986 direct effects simulations, Table 39 and Table 40 present the simulated WAT and DM temperature effects of Alt2 relative to existing conditions and no action, respectively. For these 1986 simulations applying 2007 meteorology, the largest individual WAT increase due to Alt2, relative to existing conditions, was 0.3 °C. Relative to no action, WAT increases were even smaller, and in some cases negative due to greater pumping for no action as compared to the Alt2 at some times. Both average DMs and Average WATs were higher for existing conditions in August due to 5412 releases.

The largest simulated Alt2 DM increase relative to existing conditions was 0.7°C, occurring at HSU. Relative to no action, DM increases were even smaller, and in some cases negative due to greater pumping for no action as compared to the Alt2 at some times.

Table 39. 1986 Cumulative Effects Simulated WAT and DM Increases Relative to Existing Conditions.

	1986-WGD	1986-HSU	1986-WFU
	Increase Relative to Existing Conditions (°C)	Increase Relative to Existing Conditions (°C)	Increase Relative to Existing Conditions (°C)
	Alt2	Alt2	Alt2
Chronic			
Largest WAT Increase in July and August (°C)	0.3	0.3	0.3
Avg. July WAT Increase (°C)	0.0	0.0	0.0
Avg. Aug. WAT Increase (°C)	-0.8	-0.5	-0.4
Acute			
Largest DM Increase in July and August (°C)	0.4	0.7	0.6
Avg. July DM Increase (°C)	0.0	0.0	0.1
Avg. Aug. DM Increase (°C)	-0.9	-0.7	-0.6

Table 40. 1986 Cumulative Effects Simulated WAT and DM Increases Relative to No Action.

	1986-WGD	1986-HSU	1986-WFU
	Increase Relative to No Action (°C)	Increase Relative to No Action (°C)	Increase Relative to No Action (°C)
	Alt2	Alt2	Alt2
Chronic			
Largest WAT Increase in July and August (°C)	0.1	0.1	0.1
Avg. July WAT Increase (°C)	-0.1	-0.1	-0.1
Avg. Aug. WAT Increase (°C)	0.0	0.0	0.0
Acute			
Largest DM Increase in July and August (°C)	0.3	0.4	0.3
Avg. July DM Increase (°C)	-0.1	-0.2	-0.2
Avg. Aug. DM Increase (°C)	0.0	0.1	0.0

4.2.3.4 1986 Cumulative Effects Summary

For the simulated 1986 cumulative effects hydrology with 2007 meteorology, Windy Gap pumping differences occurred in July and August; however, due to relatively high flow rates in the river, temperature differences were minimal across scenarios. Small temperature increases were simulated at WGD, HSU, and WFU for Alt2 relative to existing conditions in July; however, in August and September, Alt2 and no action produced lower river temperatures than existing conditions, due to 5412 releases from Granby Reservoir. The largest WAT increase for Alt2 relative to existing conditions was simulated at WFU +0.3°C. The largest WAT increase for Alt2 relative to no action was also simulated at WFU (+0.1°C). The largest DM increase for Alt2 relative to existing conditions was simulated at HSU (+0.7°C). The largest DM increase for Alt2 relative to no action was also simulated at HSU (+0.4°C). There were no exceedances of WAT or DM standards for any of the simulations.

These cumulative effects results are nearly identical to the corresponding 1986 direct effects results, with the exception of the cumulative effects cooling response from 5412 flows in August and September for no action and Alt2.

4.2.4 1987 Cumulative Effects

The results of cumulative effects simulations applying 1987 hydrology scenarios under conditions of 2007 meteorology are presented in the following subsections. Cumulative effects simulations for 1987 included existing conditions, no action, and Alt2.

4.2.4.1 1987 Cumulative Effects Hydrographs

Figure 171 and Figure 172 present the differences in pumping at Windy Gap and the corresponding flow below Windy Gap Reservoir for the cumulative effects alternatives simulated – existing conditions, no action, and alternative 2. Windy Gap pumping volumes (June through September) are summarized for each simulation in Table 41.

Overall, 1987 was an average to drier year (classified as an average year in the WGFP DEIS), with virgin annual flows ranking 42nd out of the 47 years of hydrology simulated for the WGFP. For the 1987 cumulative effects simulations, in June pumping is greater for Alt2 and no action (both ≈18,500AF), as compared to existing conditions (≈8,700 AF). Windy Gap pumping and river flows are nearly identical in July with only slightly higher flow rates for existing conditions as compared to no action and Alt2. In August and September, river flows are higher for no action and Alt2 (compared to existing conditions) due to planned 5412 releases from Granby Reservoir (Figure 172).

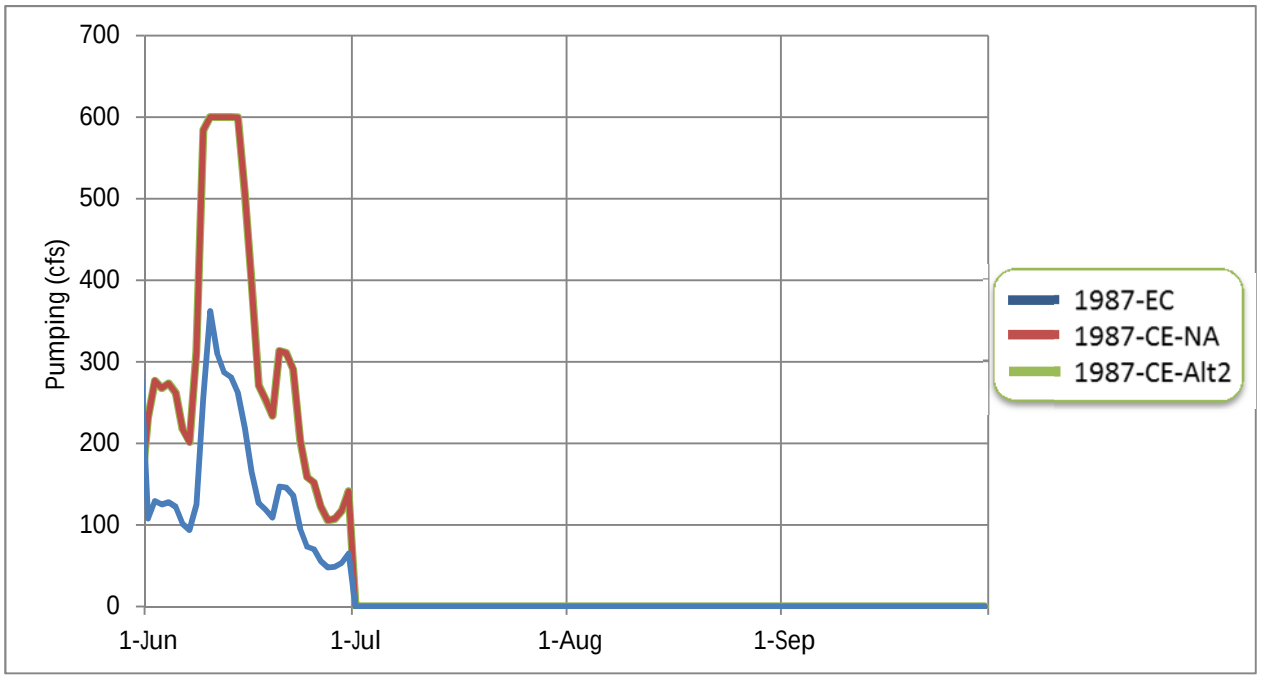

Figure 171. 1987 Cumulative Effects Windy Gap Pumping

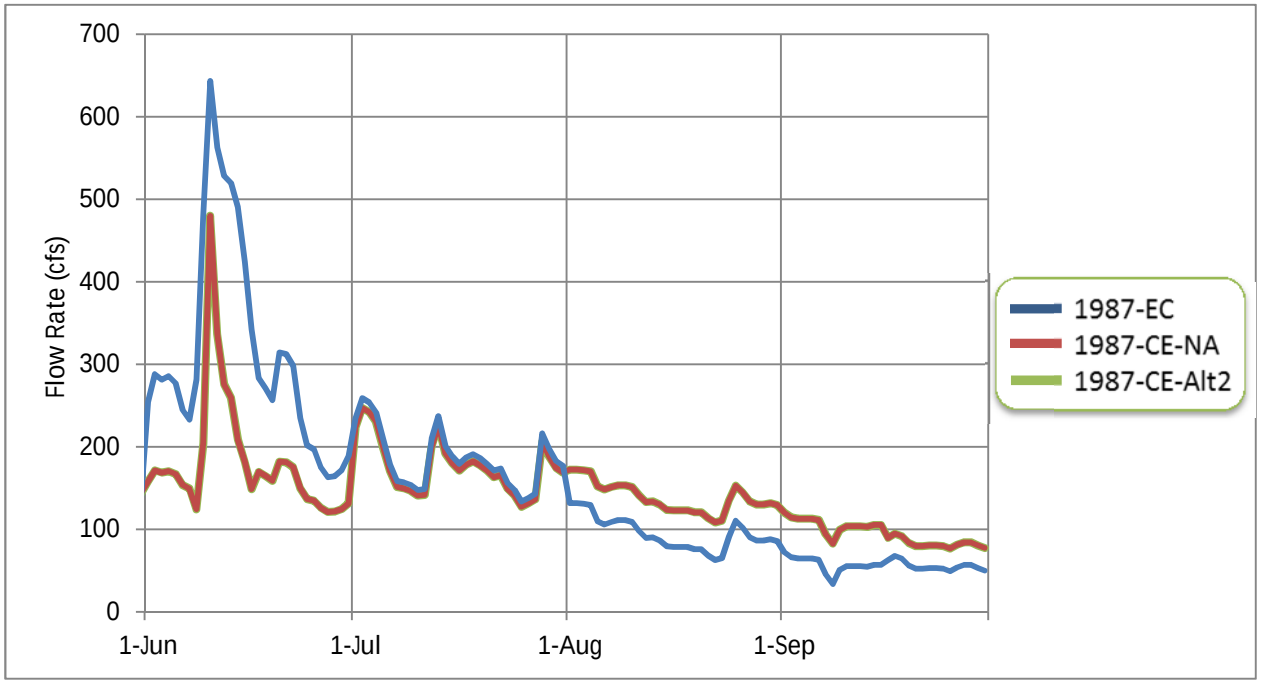

Figure 172. 1987 Cumulative Effects Flow Rates Below Windy Gap

Table 41. 1987 Cumulative Effects Windy Gap Pumping Volumes

	1987-CE Monthly Pumping Totals (AF/month)			
	June	July	August	September
Existing Conditions	8,659	0	0	0
No Action	18,465	0	0	0
Alternative 2	18,465	0	0	0

4.2.4.2 1987 Cumulative Effects Hourly Temperature Plots

Figure 173 through Figure 178 present the hourly temperature plots produced by the model for thermistor locations CR-WGD, CR-HSU, and CR-WFU. Hourly temperature plots for the full simulation period are shown, as well as plots focusing on the period of the simulation with notable differences in predicted temperatures. For 1987 direct effects simulations, major differences in simulated temperatures occured in June, August, and September. The temperature increases simulated for Alt2 in June are in agreement with the period of Windy Gap pumping differences. In August and September temperature differences show the cooling effects of 5412 releases for Alt2 and no action.

Relatively small differences in hourly temperatures are simulated across the scenarios during the time of pumping differences in June. Alt2 and no action show matching results, with higher daily peak temperatures than existing conditions in the "June Zoom" figures. This matches the expected relative pattern based on pumping differences. These 1987 cumulative effects temperature simulation results are summarized and discussed quantitatively in Section 4.2.4.3.

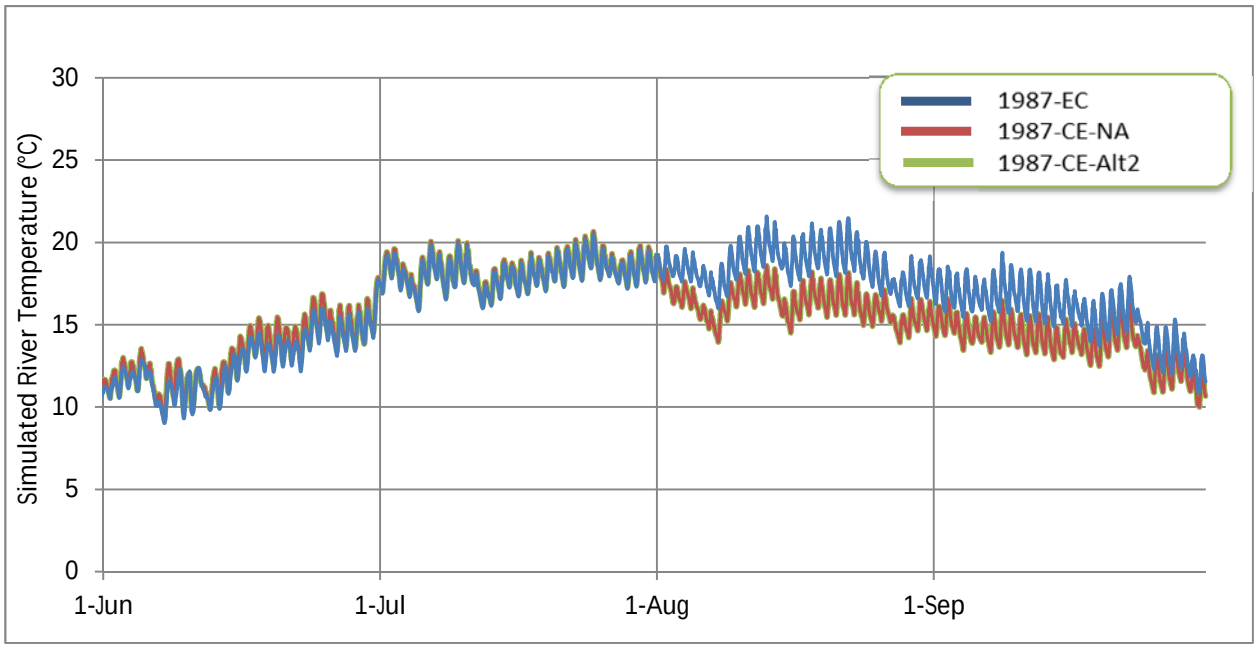

Figure 173. 1987 Cumulative Effects Hourly Temperature at CR-WGD

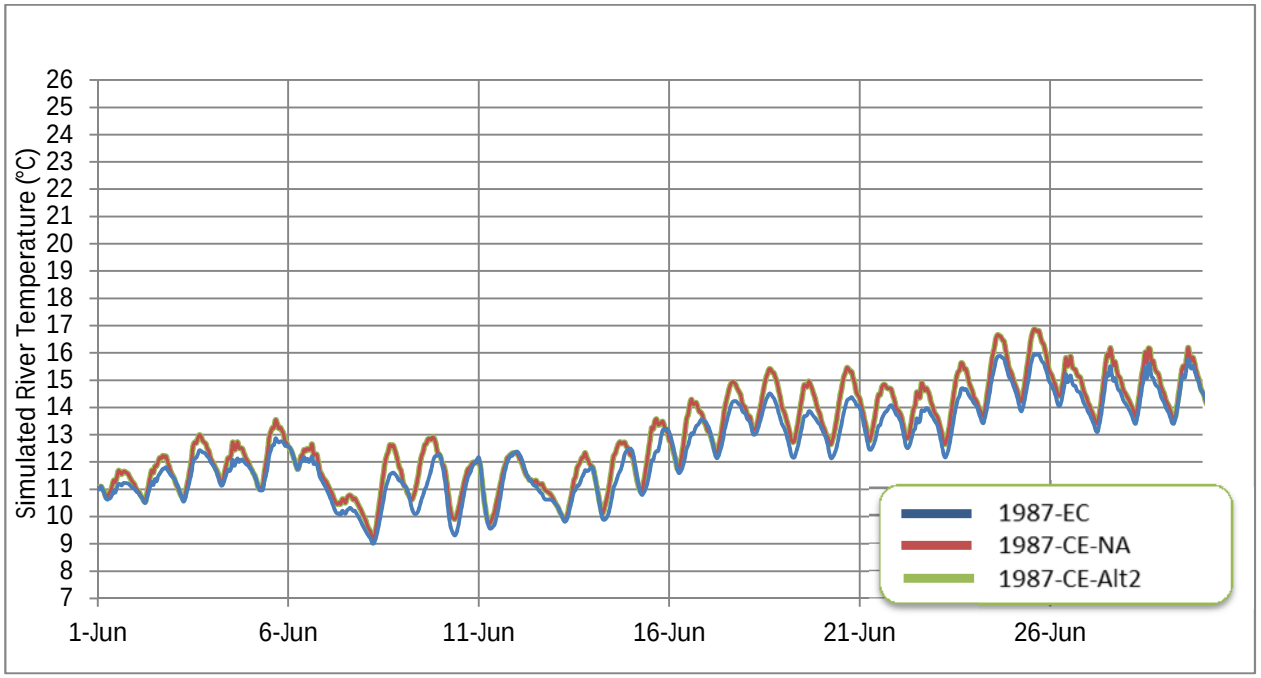

Figure 174. 1987 Cumulative Effects Hourly Temperature at CR-WGD June Zoom

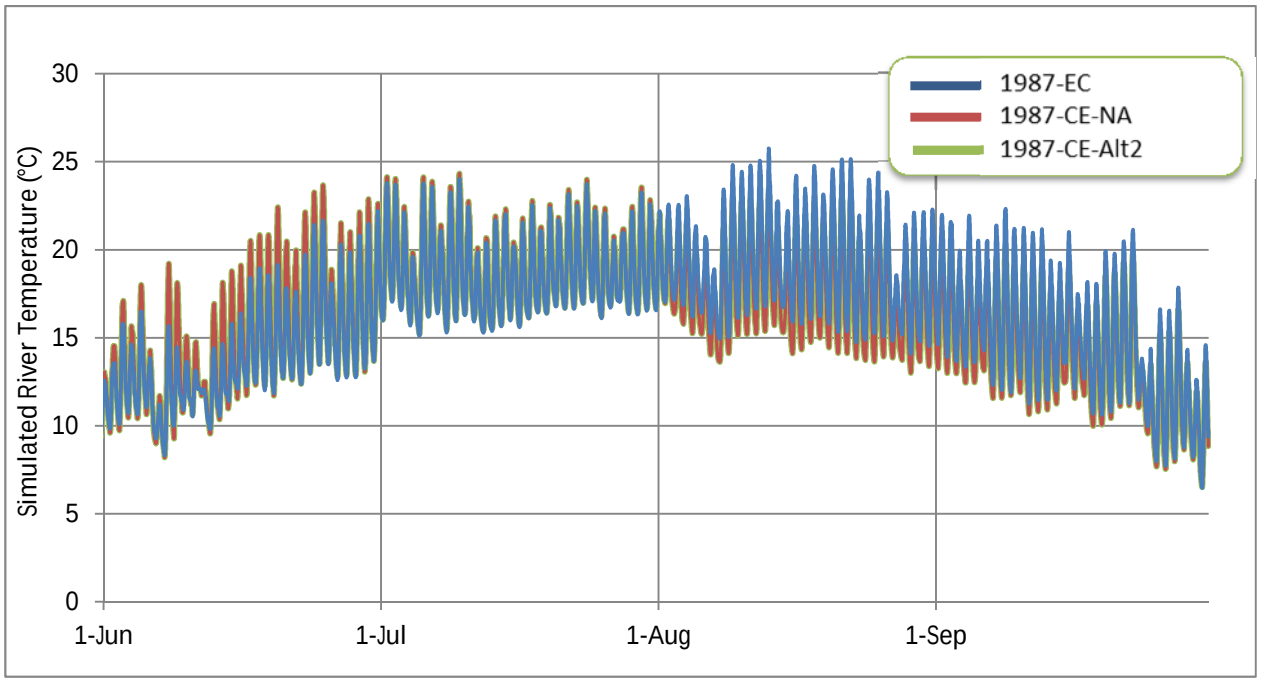

Figure 175. 1987 Cumulative Effects Hourly Temperature at CR-HSU

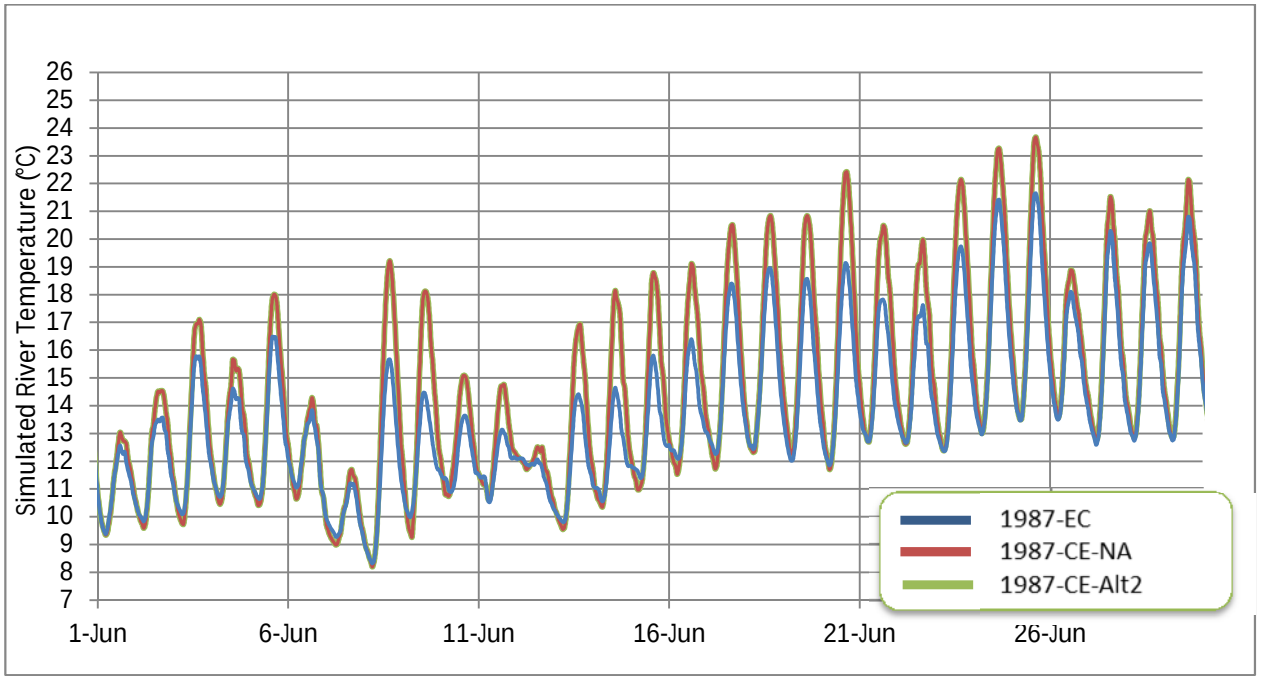

Figure 176. 1987 Cumulative Effects Hourly Temperature at CR-HSU June Zoom

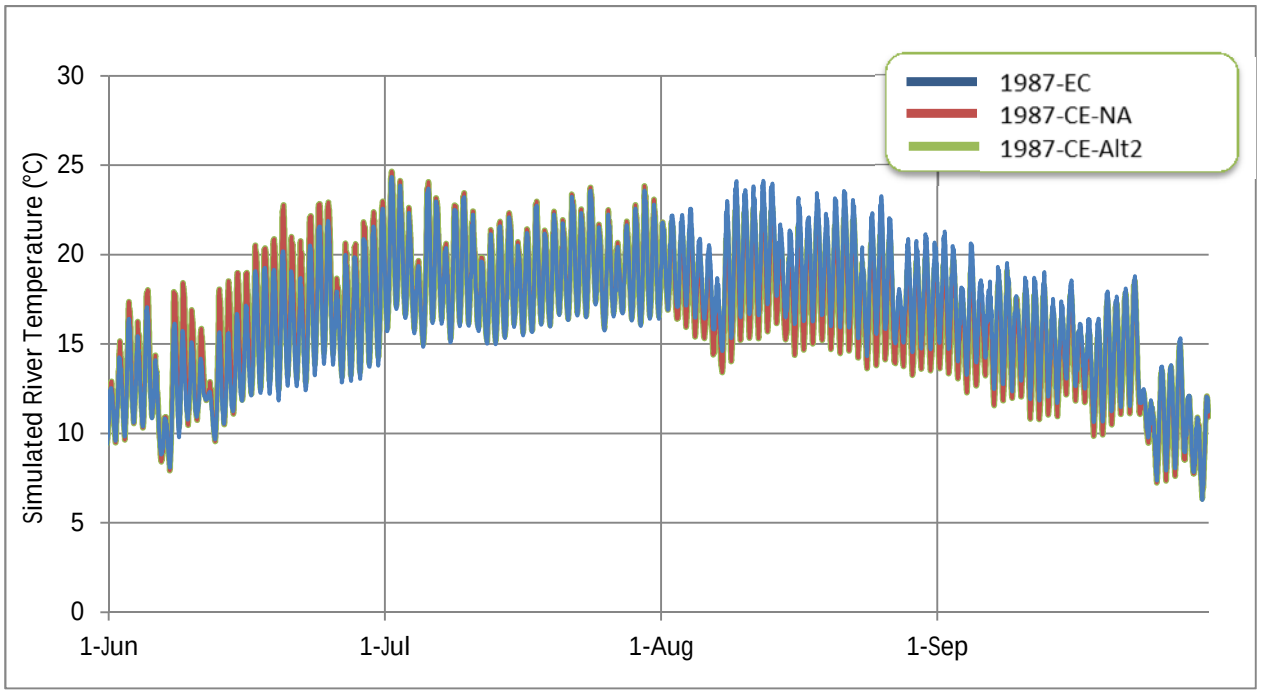

Figure 177. 1987 Cumulative Effects Hourly Temperature at CR-WFU

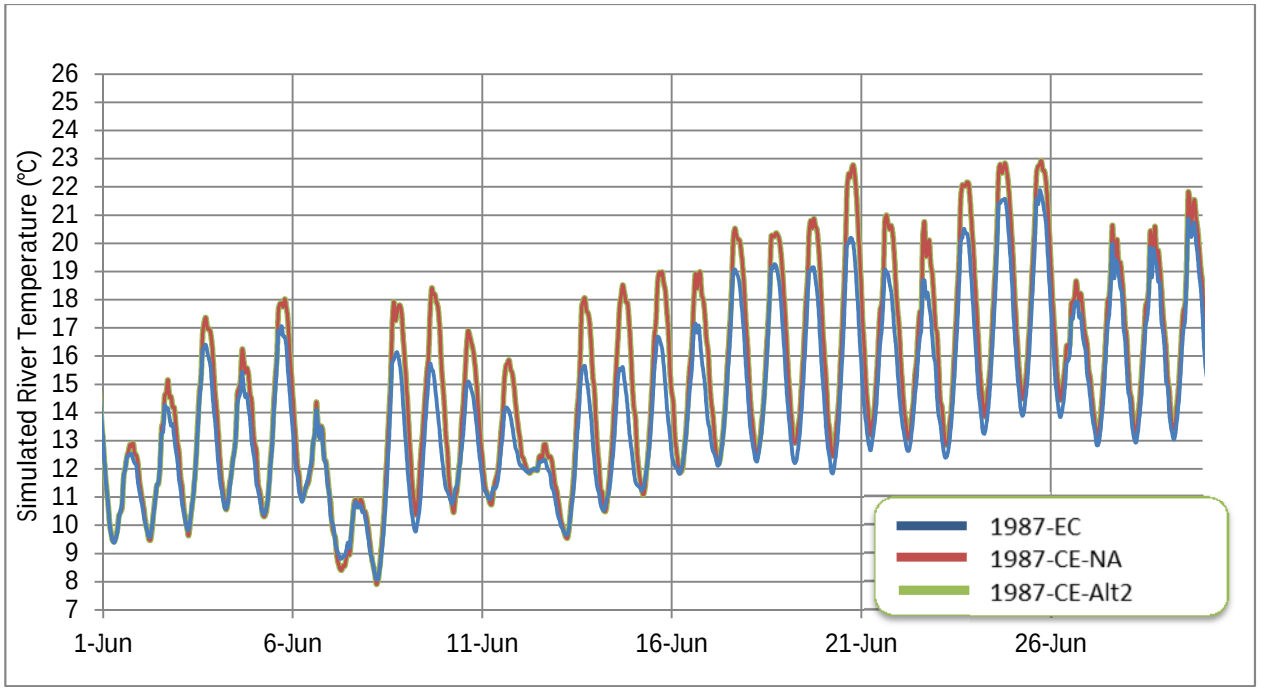

Figure 178. 1987 Cumulative Effects Hourly Temperature at CR-WFU June Zoom

4.2.4.3 1987 Cumulative Effects Weekly Average and Daily Maximum Temperatures

WATs and DMs were all calculated using the appropriate Colorado Water Quality Control Division tool (Temp-program-V4.2; personal communication, Robert Hillegas, May 24, 2011) for this segment of the upper Colorado River. Figure 179 through Figure 181 present WATs for each simulated day, following the first week of simulation. DMs are presented for each simulated day in Figure 182 through Figure 184. These figure sets show results for thermistor locations CR-WGD, CR-HSU, and CR-WFU.

In agreement with the temperature differences presented in the previous subsection, the WAT and DM results show only very small differences in June (and extending one week into July due to the rolling average nature of the WAT calculation). This limited response to pumping differences in June is due to the relatively high flow and cooler flows in the river during the time of the pumping differences. In August and September, Alt2 and no action simulation results show considerably lower WATs and DMs as compared to existing conditions, due to 5412 releases of cold water from Granby Reservoir.

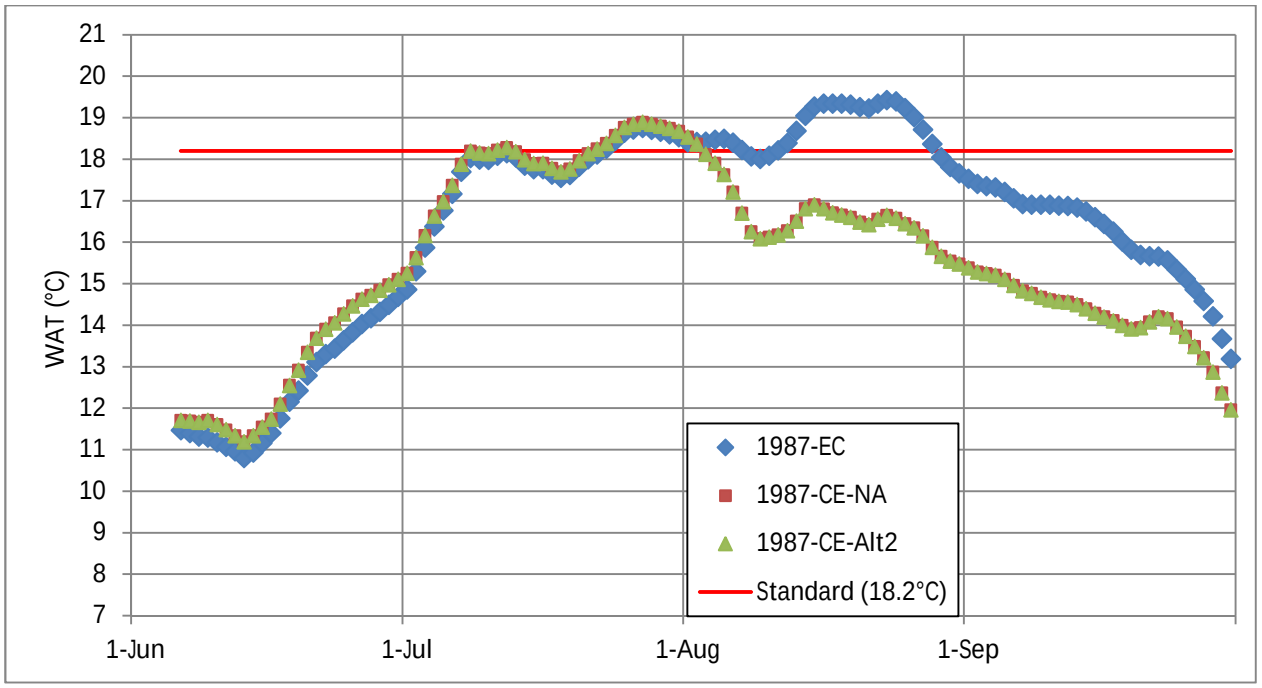

Figure 179. 1987 Cumulative Effects WATs at CR-WGD

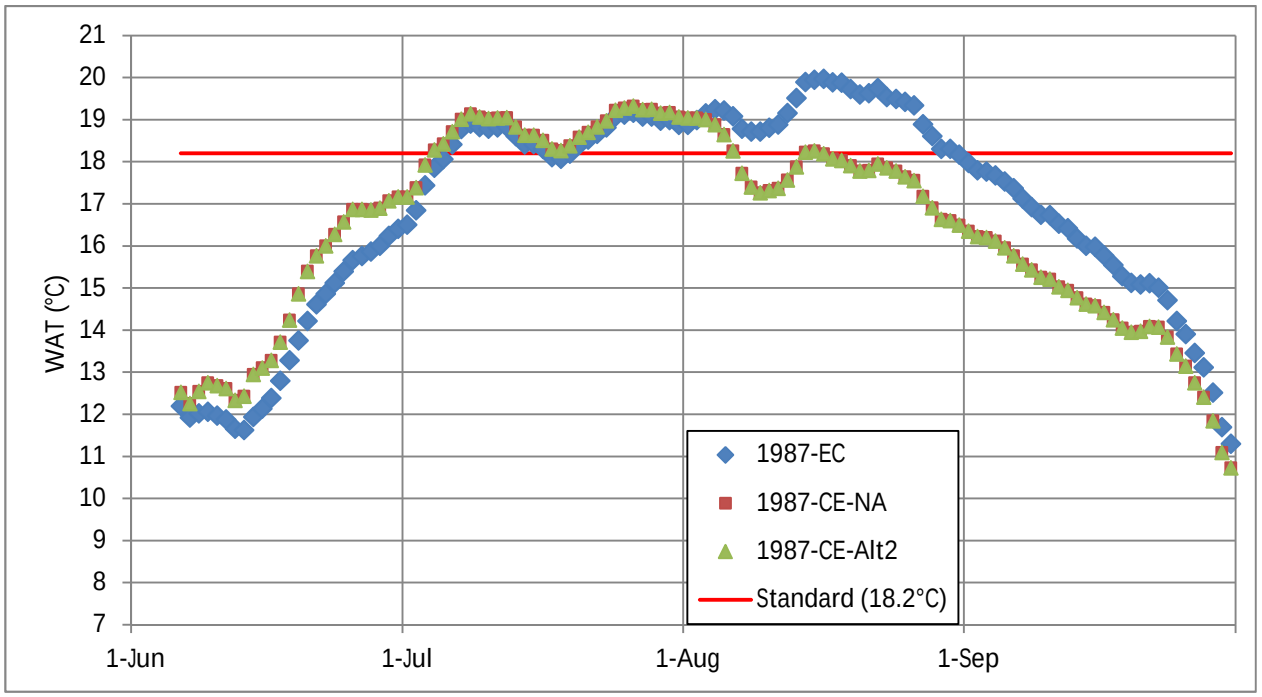

Figure 180. 1987 Cumulative Effects WATs at CR-HSU

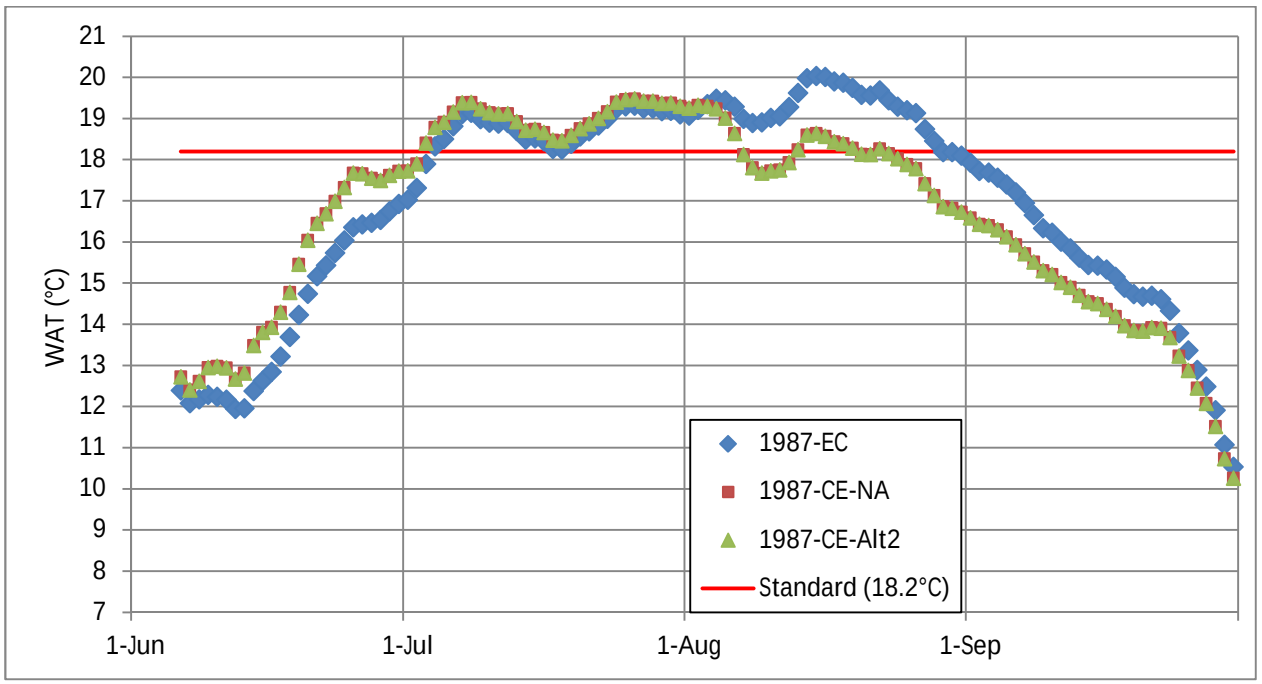

Figure 181. 1987 Cumulative Effects WATs at CR-WFU

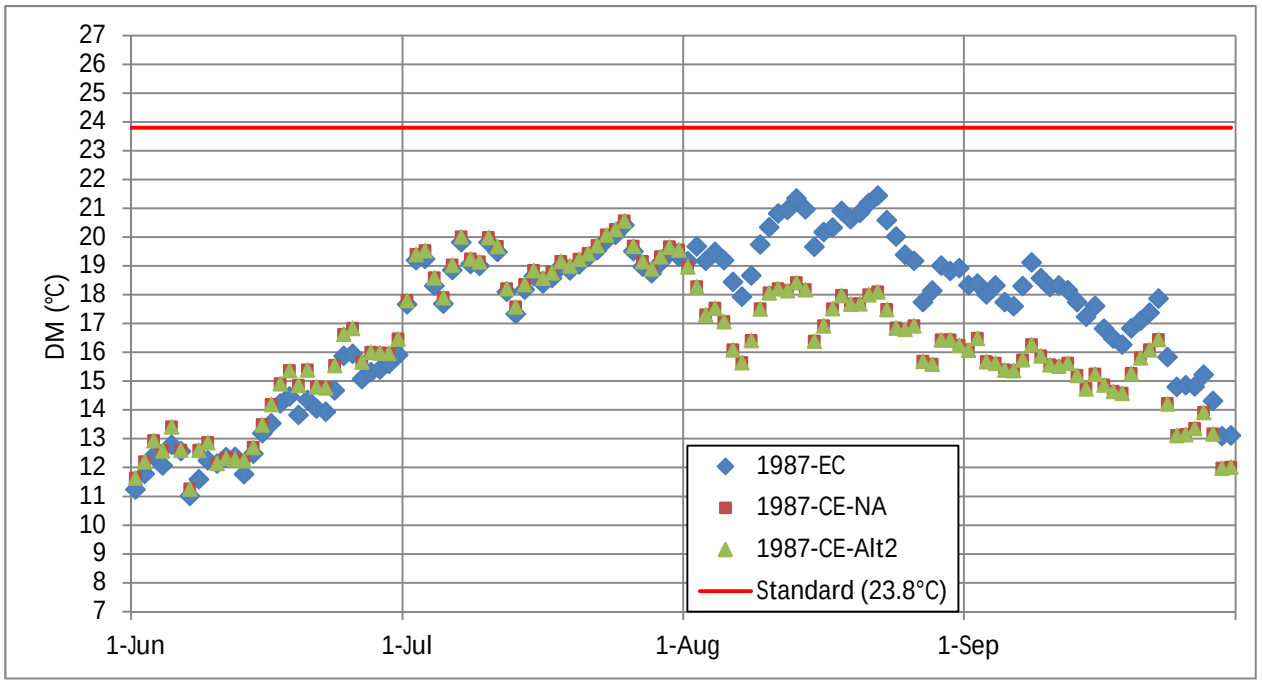

Figure 182. 1987 Cumulative Effects DMs at CR-WGD

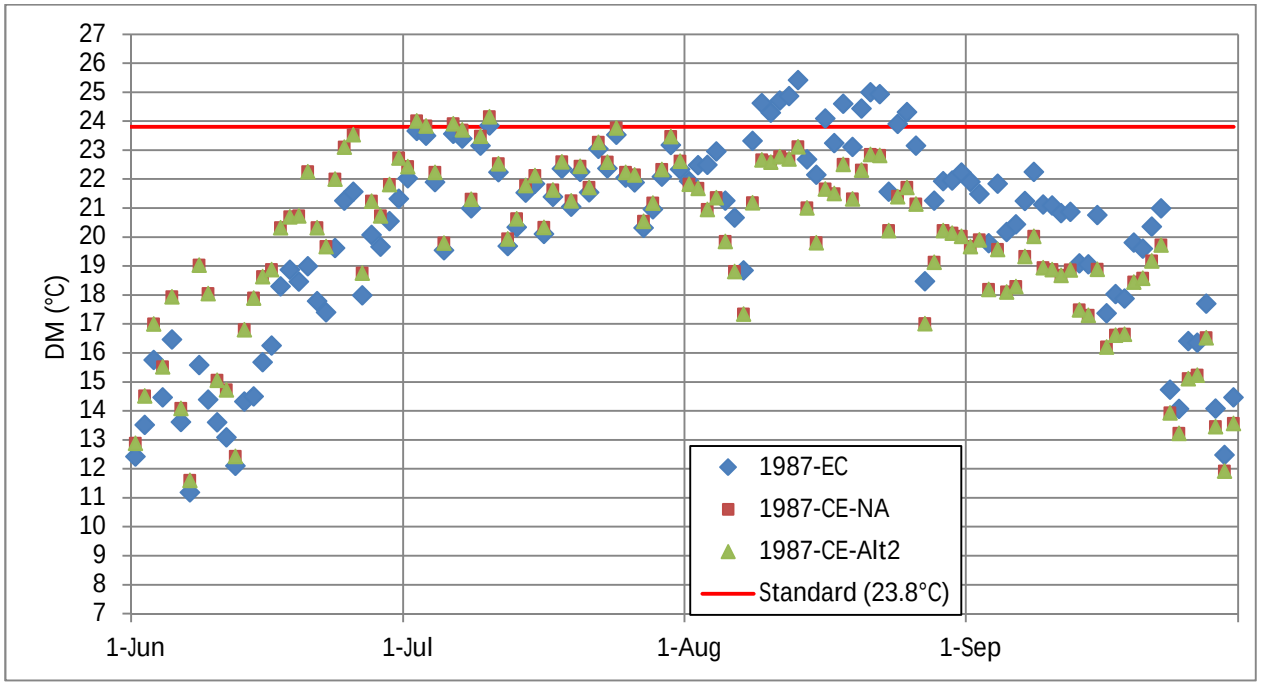

Figure 183. 1987 Cumulative Effects DMs at CR-HSU

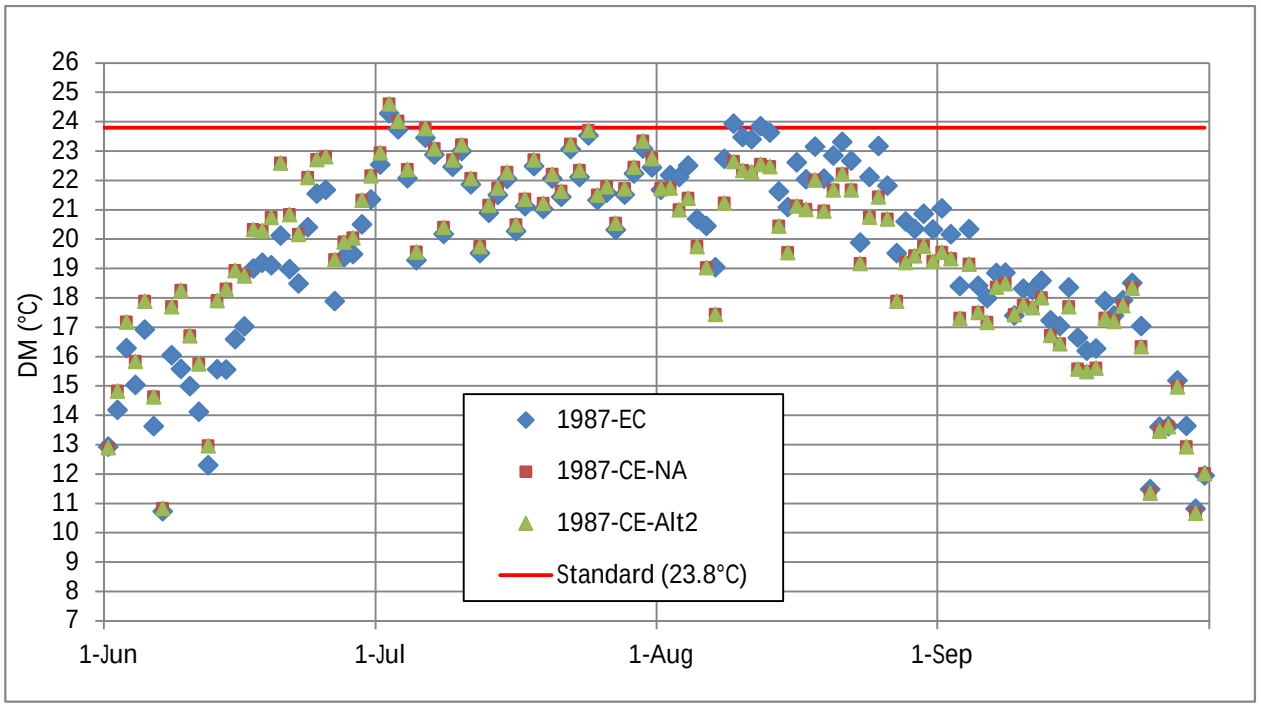

Figure 184. 1987 Cumulative Effects DMs at CR-WFU

For 1987 cumulative effects, Table 42 summarizes the results of a regulatory analysis of the simulation results at the three thermistor locations, CR-WGD, CR-HSU, and CR-WFU. The maximum WAT for the full period decreases for Alt2 relative to existing conditions due to 5412 releases from Granby in August. There were no MWAT increases for Alt2 relative to no action. A similar pattern was seen for maximum DMs, with only a small increases in the maximum DM for Alt2 relative to existing conditions (0.3°C), and no increase relative to no action. These very small increases in maximum WATs and DMs occur because the differences in Windy Gap pumping for this year occur in June, a time when flows.

The only increases in WAT and DM exceedances (one additional week above the chronic WAT standard in July at WGD and WFU, and one additional day of DM exceedances in July at WFU) are simulated to occur for Alt2 relative to existing conditions in July. Due to 5412 releases from Granby, WAT and DM decreases for Alt2 relative to no action are simulated for August. There are no differences in WAT or DM exceedances between Alt2 and no action.

Table 42. 1987 Cumulative Effects Simulated Regulatory Results

	1987-WGD			1987-HSU			1987-WFU		
	EC	NA	Alt2	EC	NA	Alt2	EC	NA	Alt2
Chronic									
MWAT (°C)	19.4	18.9	18.9	20.0	19.3	19.3	20.0	19.5	19.5
June # weeks > 18.2 °C	0	0	0	0	0	0	0	0	0
July # weeks > 18.2 °C	2	3	3	4	4	4	4	5	5
August # weeks > 18.2 °C	4	0	0	4	2	2	4	2	2
September # weeks > 18.2 °C	0	0	0	0	0	0	0	0	0
Acute									
Max DM (°C)	21.4	20.6	20.6	25.4	24.2	24.2	24.3	24.6	24.6
June # days > 23.8 °C	0	0	0	0	0	0	0	0	0
July # days > 23.8 °C	0	0	0	1	4	4	1	2	2
August # days > 23.8 °C	0	0	0	12	0	0	2	0	0
September # days > 23.8 °C	0	0	0	0	0	0	0	0	0

Looking more closely at the 1987 cumulative effects simulations, Table 43 and Table 44 present the simulated WAT and DM temperature effects of Alt2 relative to existing conditions and no action, respectively. For these 1987 simulations applying 2007 meteorology, the largest individual WAT increase in July and August due to Alt2, relative to existing conditions, was 0.7°C at WFU (July 1). The largest increase relative to existing conditions was in June, also at WFU (1.1°C on June 25). For Alt2 relative to existing conditions, the monthly average WAT increase in July was small (0.2°C to 0.3°C), and was due to differences in cumulative effects hydrology for Alt2 and no action as compared to existing conditions. There were no differences in WATs for Alt2 relative to no action.

As shown in Table 43, the largest individual DM increase in July and August due to Alt2, relative to existing conditions, was 0.4 °C at HSU (July 1). The largest overall DM increase relative to existing conditions was in June, also at HSU (3.7°C on June 9). Relative to no action, there were no DM increases for Alt2.

Table 43. 1987 Cumulative Effects Simulated WAT and DM Increases Relative to Existing Conditions.

	1987-WGD	1987-HSU	1987-WFU
	Increase Relative to Existing Conditions (°C)	Increase Relative to Existing Conditions (°C)	Increase Relative to Existing Conditions (°C)
	Alt2	Alt2	Alt2
Chronic			
Largest WAT Increase in July and August (°C)	0.4	0.7	0.7
Avg. July WAT Increase (°C)	0.2	0.2	0.3
Avg. Aug. WAT Increase (°C)	-2.0	-1.4	-1.1
Acute			
Largest DM Increase in July and August (°C)	0.3	0.4	0.4
Avg. July DM Increase (°C)	0.2	0.3	0.2
Avg. Aug. DM Increase (°C)	-2.5	-1.8	-1.2

Table 44. 1987 Cumulative Effects Simulated WAT and DM Increases Relative to No Action.

	1987-WGD	1987-HSU	1987-WFU
	Increase Relative to No Action (°C)	Increase Relative to No Action (°C)	Increase Relative to No Action (°C)
	Alt2	Alt2	Alt2
Chronic			
Largest WAT Increase in July and August (°C)	0.0	0.0	0.0
Avg. July WAT Increase (°C)	0.0	0.0	0.0
Avg. Aug. WAT Increase (°C)	0.0	0.0	0.0
Acute			
Largest DM Increase in July and August (°C)	0.0	0.0	0.0
Avg. July DM Increase (°C)	0.0	0.0	0.0
Avg. Aug. DM Increase (°C)	0.0	0.0	0.0

4.2.4.4 1987 Cumulative Effects Summary

For the simulated 1987 cumulative effects hydrology with 2007 meteorology, Windy Gap pumping differences occurred in June, when flow rates in the river were relatively high, minimizing temperature increase effects. In June, temperature increases were simulated at WGD, HSU, and WFU for Alt2 relative to existing conditions. There were no exceedances of WAT or DM standards for any of the simulations in June when pumping rates varied across scenarios; however, due to rolling averages, there was an increase in WAT exceedances (+1) in July at WFU and WGD. There were also increases in DM exceedances in July for Alt2 relative to existing conditions (+3 days at HSU and +1 day at WFU) due to slightly lower flow rates for Alt2 attributable to cumulative effects outside of WGFP proposed actions. The largest WAT increase for Alt2 relative to existing conditions was simulated at WFU in June (+1.3°C). The largest DM increase for Alt2 relative to existing conditions was simulated at HSU in June (+3.7°C). In August and September, river temperatures for Alt2 and no action were simulated to be cooler than existing conditions, due to planned 5412 releases from Granby reservoir. There were no temperature increases for Alt2 relative to no action.

Comparing cumulative effects results for 1987 hydrology to direct effects, differences are apparent in June, August, and September. In June, pumping differences for cumulative effects are greater than those of direct effects. Still, no exceedances of acute or chronic standards are simulated for any scenario in June. Additionally, pumping for no action is greater for cumulative effects, resulting in no simulated temperature differences between Alt2 and no action for cumulative effects. Simulated cumulative effects results for Alt2 are similar to direct effects results for July. In August and September, 5412 releases from Granby Reservoir for cumulative effects lead to cooler river temperatures for Alt2 and no action as compared to existing conditions, a pattern not seen for direct effects.

4.2.5 1988 Cumulative Effects

The results of cumulative effects simulations applying 1988 hydrology scenarios under conditions of 2007 meteorology are presented in the following subsections. Cumulative effects simulations for 1988 included existing conditions, no action, and Alt2.

4.2.5.1 1988 Cumulative Effects Hydrographs

Figure 185 and Figure 186 present the differences in pumping at Windy Gap and the corresponding flow below Windy Gap Reservoir for cumulative effects and the cumulative effects alternatives simulated – no action, and alternative 2. Windy Gap pumping volumes (June through September) are summarized for each simulation in Table 45.

Overall, 1988 was an average year, with virgin annual flows ranking 34th out of the 47 years of hydrology simulated for the WGFP. For the 1988 cumulative effects simulations, Windy Gap pumping and river flows are nearly identical for all scenarios in July, with higher Alt2 and no action flows in August and September. In June, pumping is greatest for Alt2, with no pumping for existing conditions and no action, resulting in lower river flow rates for Alt2.

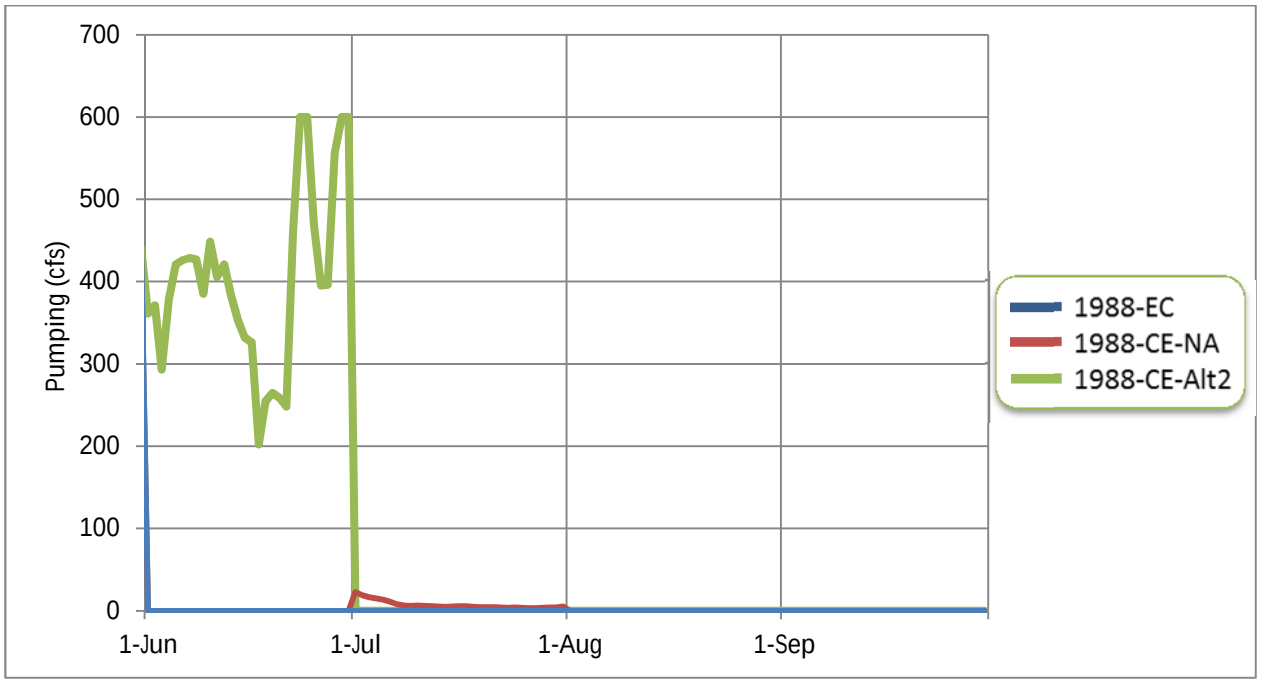

Figure 185. 1988 Cumulative Effects Windy Gap Pumping

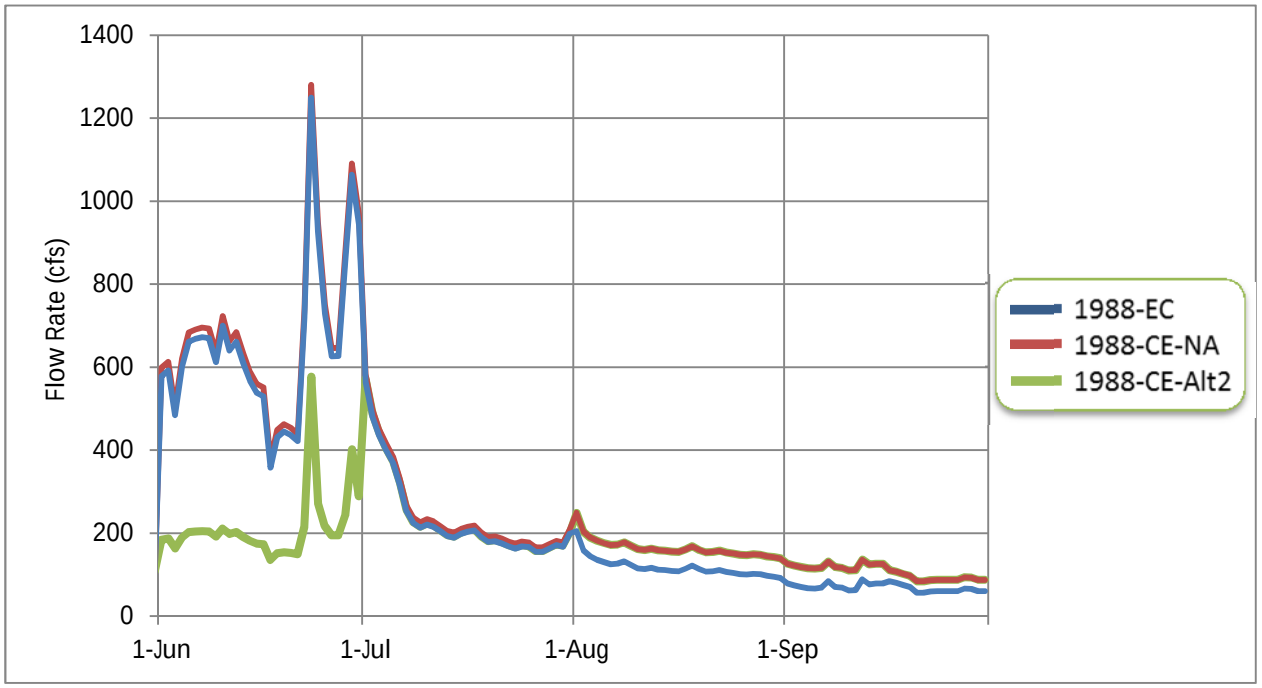

Figure 186. 1988 Cumulative Effects Flow Rates Below Windy Gap

Table 45. 1988 Cumulative Effects Windy Gap Pumping Volumes

	1988-CE Monthly Pumping Totals (AF/month)			
	June	July	August	September
Existing Conditions	0	0	0	0
No Action	0	445	0	0
Alternative 2	23,939	0	0	0

4.2.5.2 1988 Cumulative Effects Hourly Temperature Plots

Figure 187 through Figure 192 present the cumulative effects hourly temperature plots produced by the model for thermistor locations CR-WGD, CR-HSU, and CR-WFU. Hourly temperature plots for the full simulation period are shown, as well as plots focusing on the period of the simulation with notable differences in predicted temperatures. For 1988 cumulative effects simulations, notable increases in simulated temperatures due to Alt2 were limited to June, in agreement with the Windy Gap pumping differences and hydrographs below the Windy Gap Reservoir. Temperature differences were also simulated to occur in August and

September, but these months showed cooler temperatures for Alt2 relative to existing conditions, due to 5412 releases from Granby Reservoir.

Across the reach, Alt2 shows higher temperatures than existing conditions and no action in June. Simulated temperatures for all scenarios are similar in July when pumping and flow rates below Windy Gap are similar. In August and September, due to 5412 releases from Granby Reservoir, Alt2 and no action show cooler river temperatures than existing conditions. These 1988 cumulative effects temperature simulation results are summarized and discussed quantitatively in Section 4.2.5.3.

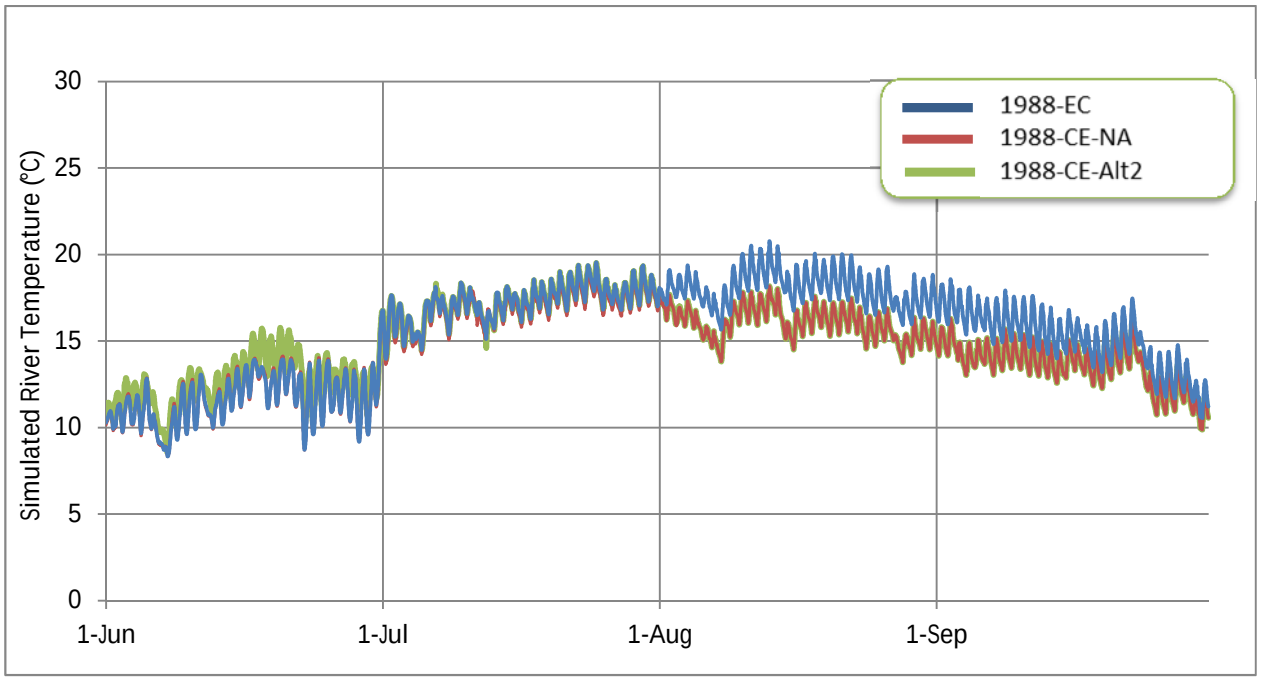

Figure 187. 1988 Cumulative Effects Hourly Temperature at CR-WGD

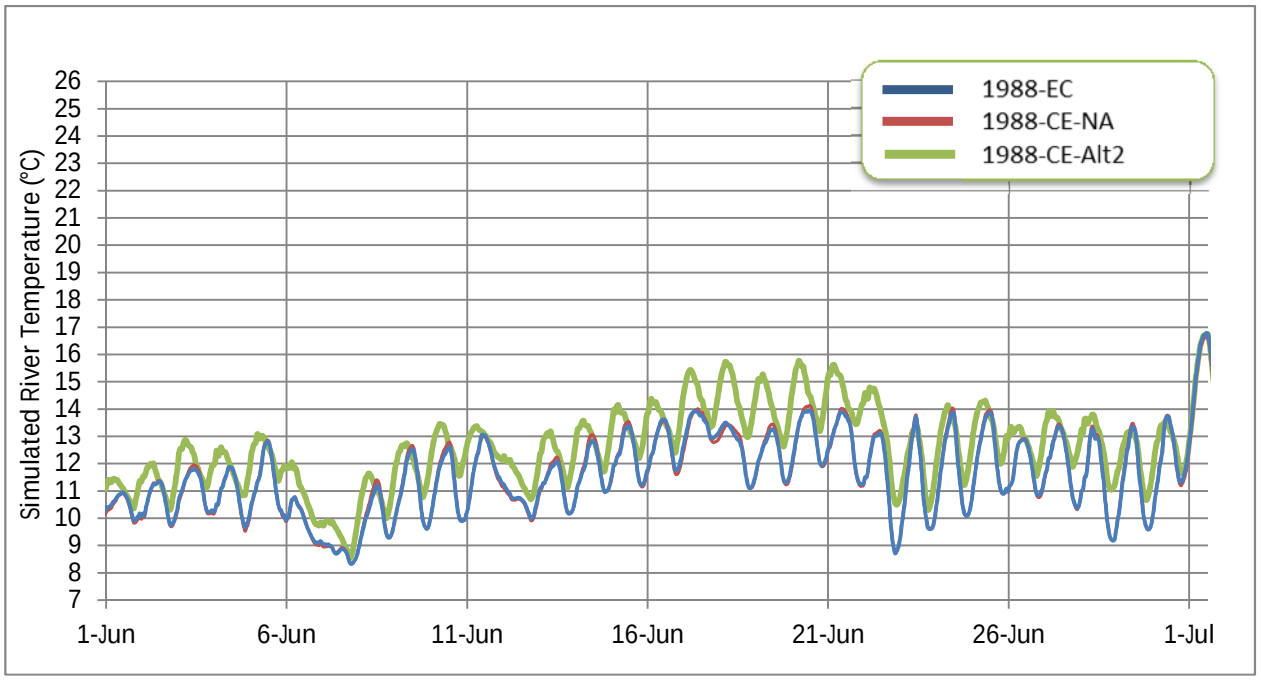

Figure 188. 1988 Cumulative Effects Hourly Temperature at CR-WGD June Zoom

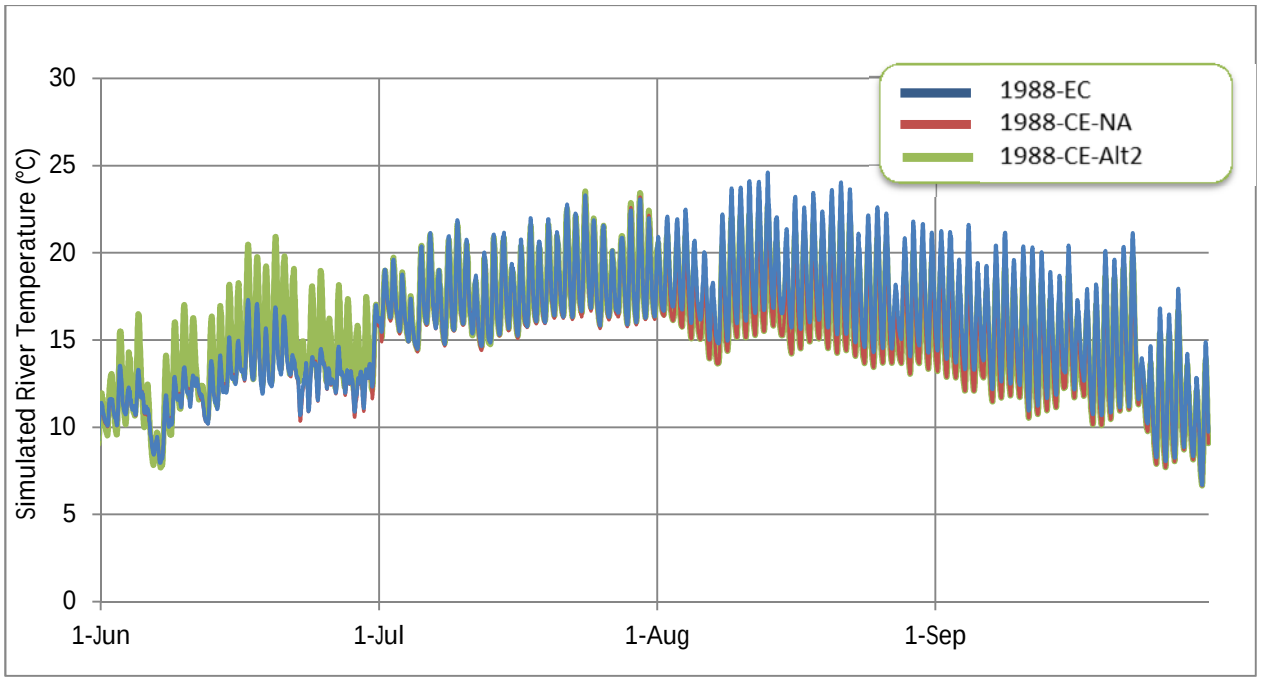

Figure 189. 1988 Cumulative Effects Hourly Temperature at CR-HSU

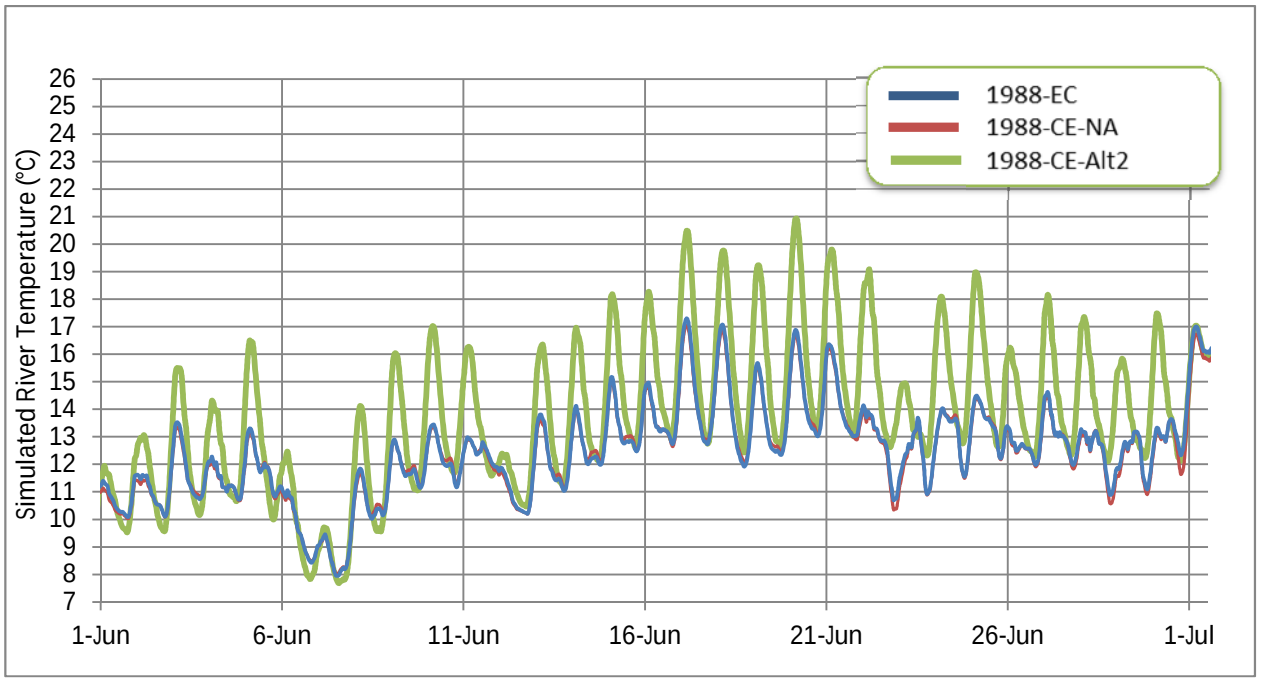

Figure 190. 1988 Cumulative Effects Hourly Temperature at CR-HSU June Zoom

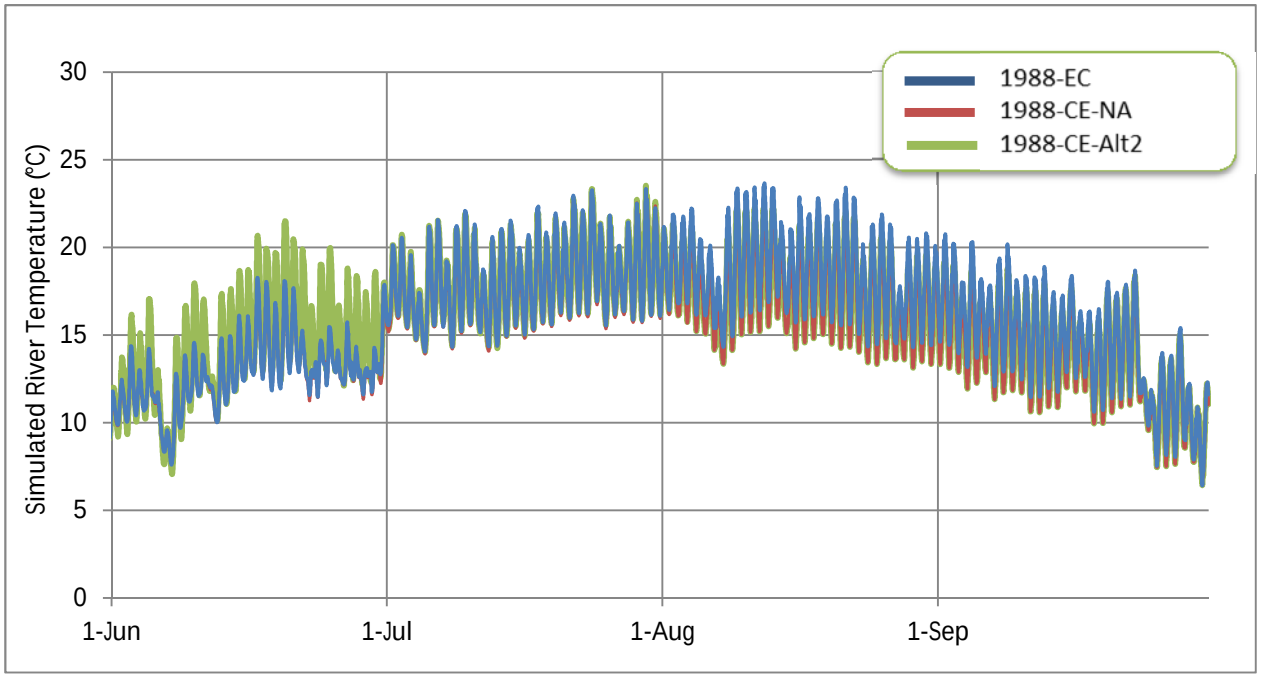

Figure 191. 1988 Cumulative Effects Hourly Temperature at CR-WFU

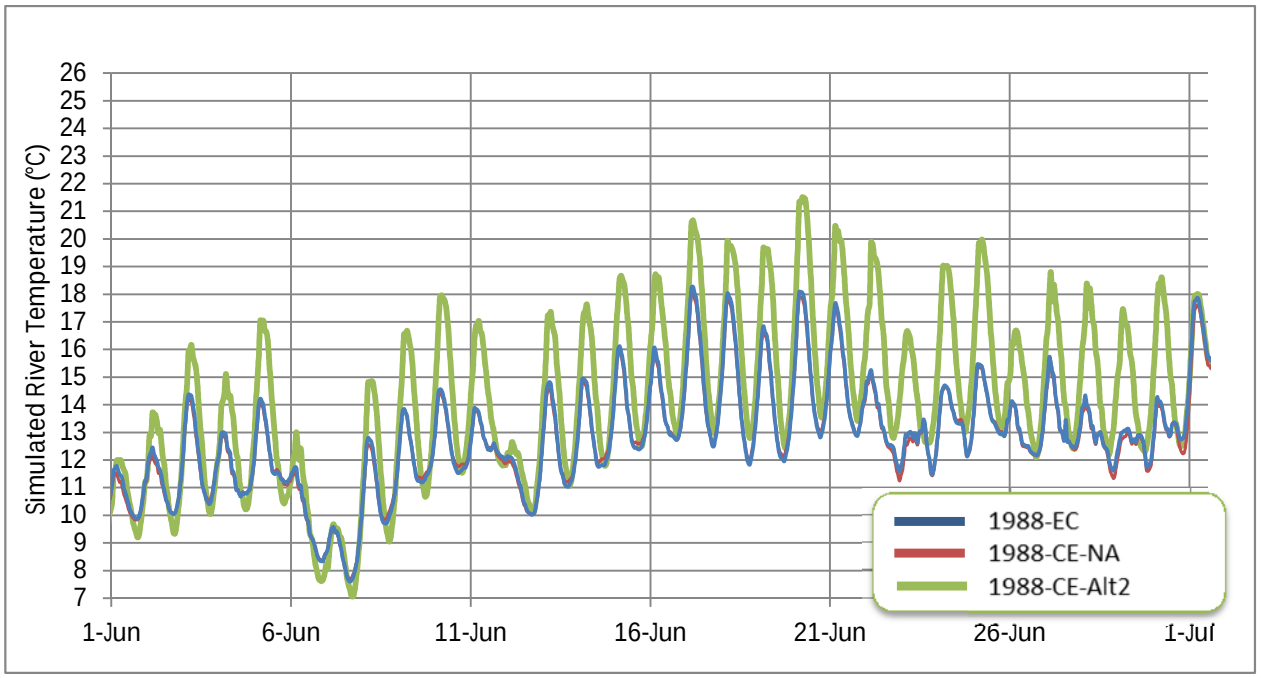

Figure 192. 1988 Cumulative Effects Hourly Temperature at CR-WFU June Zoom

4.2.5.3 1988 Cumulative Effects Weekly Average and Daily Maximum Temperatures

WATs and DMs were all calculated using the appropriate Colorado Water Quality Control Division tool (Temp-program-V4.2; personal communication, Robert Hillegas, May 24, 2011) for this segment of the upper Colorado River. Figure 193 through Figure 195 present WATs for each simulated day, following the first week of simulation. DMs are presented for each simulated day in Figure 196 through Figure 198. These figure sets show results for thermistor locations CR-WGD, CR-HSU, and CR-WFU.

WAT and DM increases relative to existing conditions occur primaily in June, in accordance with the time of pumping differences at Windy Gap. In June, Alt2 WATs and DMs are higher than those of existing conditions and no action; however, there are no exceedances of standards for any of the scenarios in June. WATs and DMs for Alt2 are comparable to no action and lower than existing conditions in August and September, due to 5412 releases from Granby Reservoir.

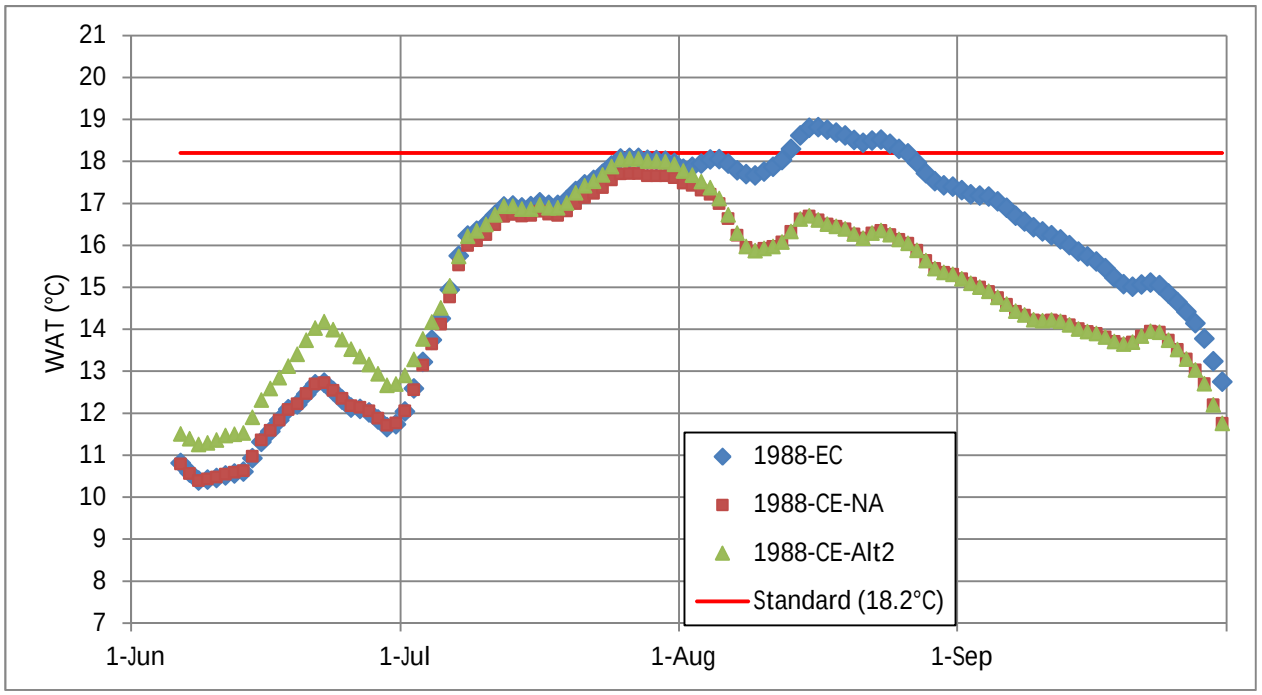

Figure 193. 1988 Cumulative Effects WATs at CR-WGD

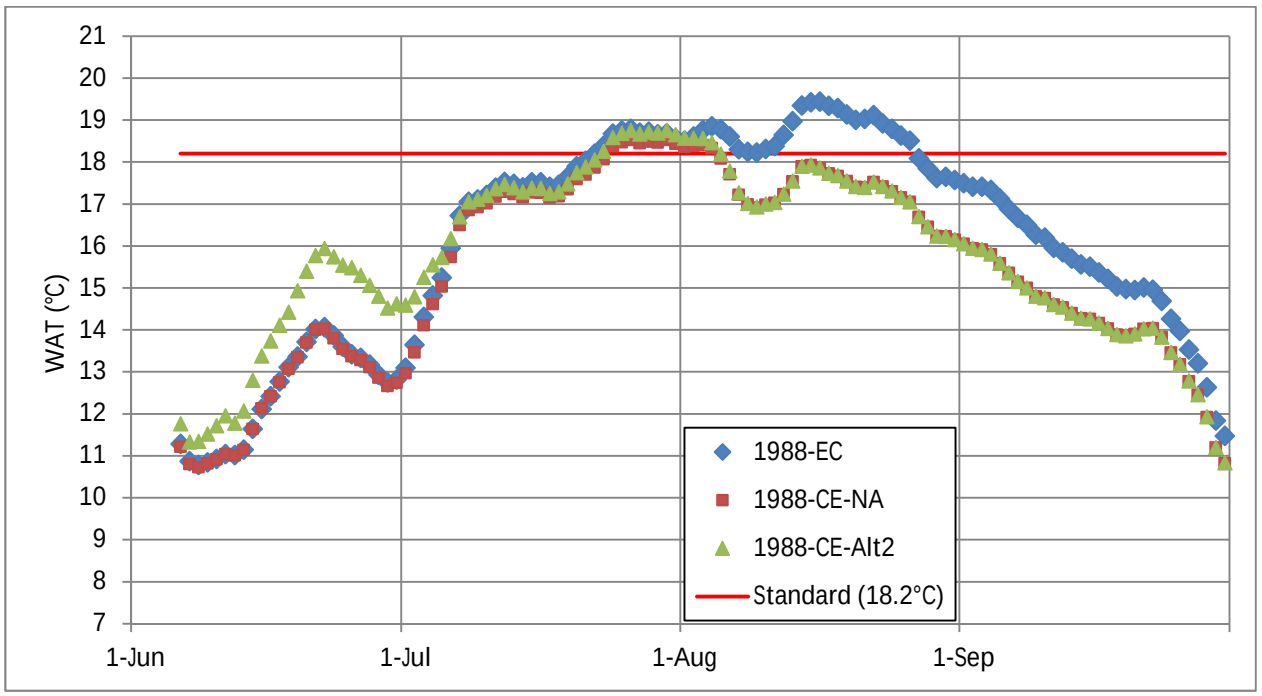

Figure 194. 1988 Cumulative Effects WATs at CR-HSU

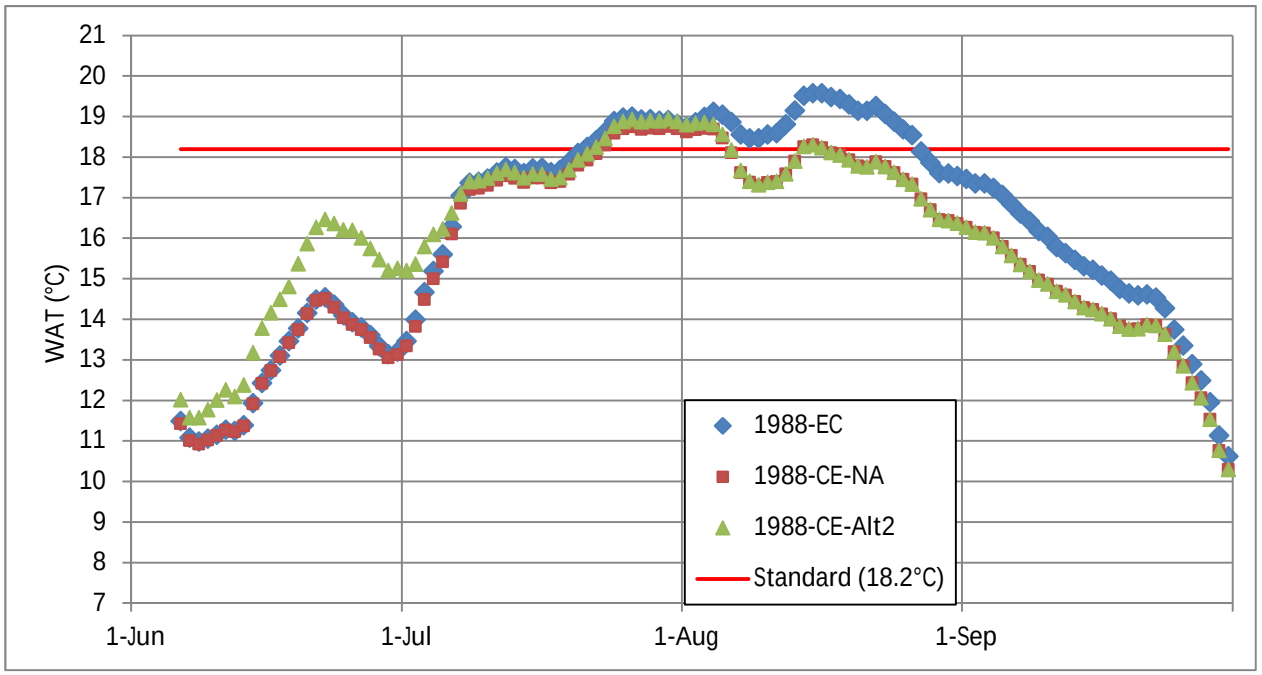

Figure 195. 1988 Cumulative Effects WATs at CR-WFU

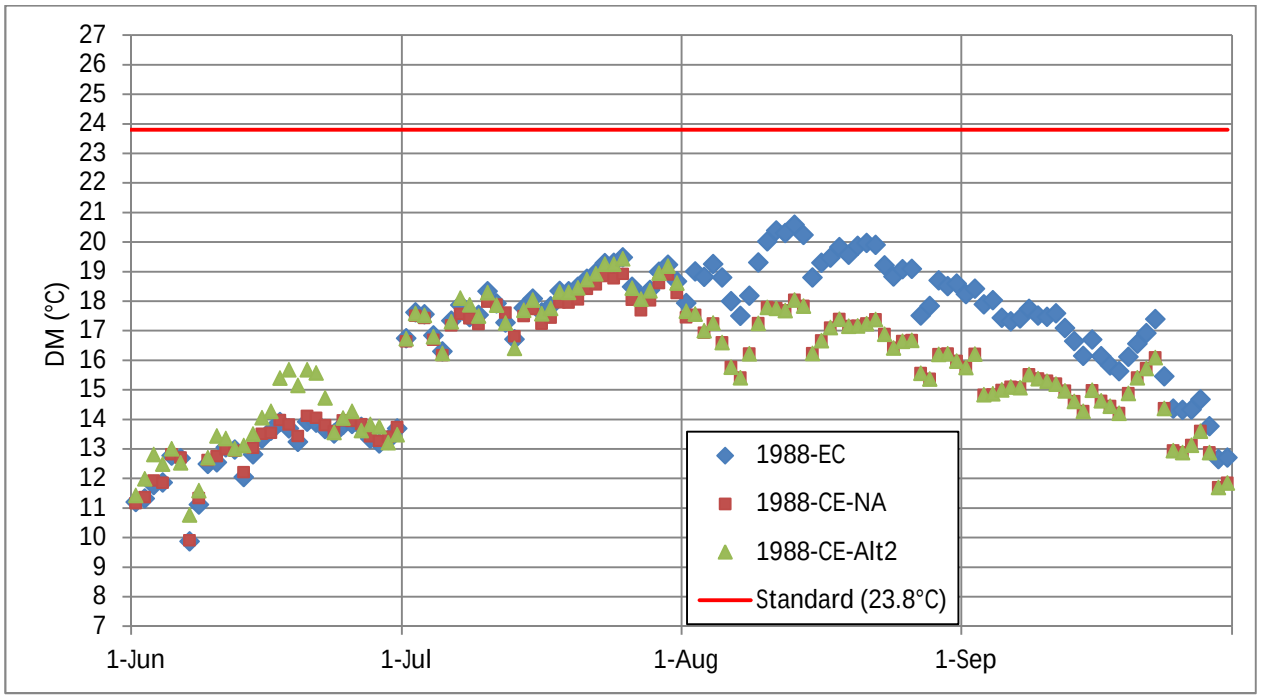

Figure 196. 1988 Cumulative Effects DMs at CR-WGD

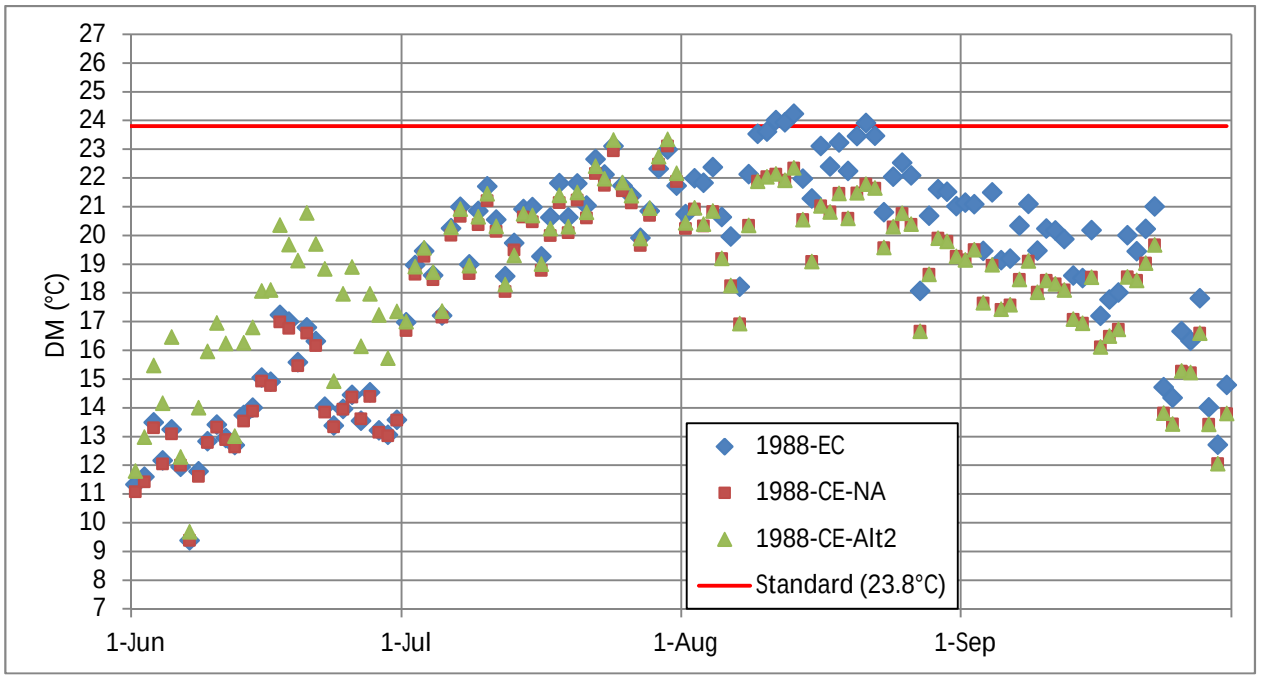

Figure 197. 1988 Cumulative Effects DMs at CR-HSU

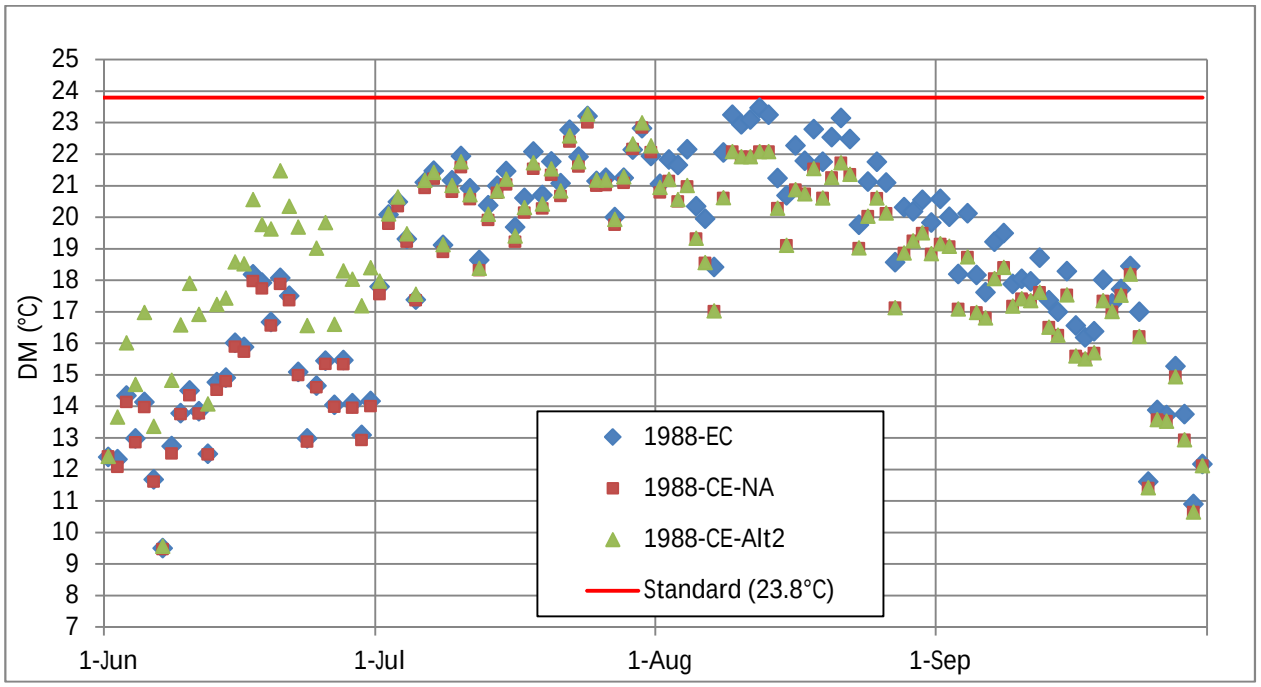

Figure 198. 1988 Cumulative Effects DMs at CR-WFU

For 1988 direct effects, Table 46 summarizes the results of a regulatory analysis of the simulation results at the three thermistor locations, CR-WGD, CR-HSU, and CR-WFU. The maximum WATs and DMs decreased for Alt2 relative to existing conditions, due to 5412 releases from Granby Reservoir. There were no increases in exceedances of WATs or DMs for Alt2 relative to existing conditions or no action.

Table 46. 1988 Cumulative Effects Simulated Regulatory Results

	1988-WGD			1988-HSU			1988-WFU		
	EC	NA	Alt2	EC	NA	Alt2	EC	NA	Alt2
Chronic									
MWAT (°C)	18.8	17.7	18.1	19.4	18.5	18.8	19.6	18.8	18.9
June # weeks > 18.2 °C	0	0	0	0	0	0	0	0	0
July # weeks > 18.2 °C	0	0	0	2	2	2	2	2	2
August # weeks > 18.2 °C	2	0	0	3	0	0	4	2	2
September # weeks > 18.2 °C	0	0	0	0	0	0	0	0	0
Acute									
Max DM (°C)	20.6	18.9	19.4	24.2	23.1	23.3	23.5	23.0	23.3
June # days > 23.8 °C	0	0	0	0	0	0	0	0	0
July # days > 23.8 °C	0	0	0	0	0	0	0	0	0
August # days > 23.8 °C	0	0	0	4	0	0	0	0	0
September # days > 23.8 °C	0	0	0	0	0	0	0	0	0

Looking more closely at the 1988 cumulative effects simulations, Table 47 and Table 48 present the simulated WAT and DM temperature effects of Alt2 relative to existing conditions and no action, respectively. For these 1988 simulations applying 2007 meteorology, the largest WAT increase for Alt2 relative to existing conditions was in June at WFU (2.3°C on June 25). The largest individual WAT increase in July and August due to Alt2, relative to existing conditions, was 1.7°C at WFU (July 1), a carryover from the rolling average extending back in June. Similar results were simulated for Alt2 WATs versus no action. The largest WAT increase for Alt2 relative to no action was 2.3°C , simulated on June 25. The largest WAT increase in July and August was 1.9°C (July 1), which was also a carryover from the rolling average extending back in June.

DM increases followed the general pattern simulated for WATs, with the largest increases simulated in June (4.6°C and 4.7°C on June 22 relative to existing conditions and no action, respectively). In July, as shown in Table 47 and Table 48, DM differences were generally small (all ≤0.5°C), due to only minor flow differences between scenarios in these months. In August,

DMs were cooler for Alt2 and no action, as compared to existing conditions, due to 5412 releases from Granby Reservoir, resulting in negative differences in Table 47.

Table 47. 1988 Cumulative Effects Simulated WAT and DM Increases Relative to Existing Conditions

	1988-WGD	1988-HSU	1988-WFU
	Increase Relative to Existing Conditions (°C)	Increase Relative to Existing Conditions (°C)	Increase Relative to Existing Conditions (°C)
	Alt2	Alt2	Alt2
Chronic			
Largest WAT Increase in July and August (°C)	0.9	1.5	1.7
Avg. July WAT Increase (°C)	0.1	0.1	0.1
Avg. Aug. WAT Increase (°C)	-1.8	-1.2	-1.0
Acute			
Largest DM Increase in July and August (°C)	0.4	0.4	0.3
Avg. July DM Increase (°C)	0.0	-0.1	-0.1
Avg. Aug. DM Increase (°C)	-2.3	-1.6	-1.1

Table 48. 1988 Cumulative Effects Simulated WAT and DM Increases Relative to No Action.

	1988-WGD	1988-HSU	1988-WFU
	Increase Relative to No Action (°C)	Increase Relative to No Action (°C)	Increase Relative to No Action (°C)
	Alt2	Alt2	Alt2
Chronic			
Largest WAT Increase in July and August (°C)	0.8	1.6	1.9
Avg. July WAT Increase (°C)	0.3	0.3	0.4
Avg. Aug. WAT Increase (°C)	0.0	0.0	0.0
Acute			
Largest DM Increase in July and August (°C)	0.5	0.4	0.4
Avg. July DM Increase (°C)	0.3	0.2	0.2
Avg. Aug. DM Increase (°C)	0.0	0.0	0.0

4.2.5.4 1988 Cumulative Effects Summary

For the simulated 1988 cumulative effects hydrology with 2007 meteorology, Windy Gap pumping differences occurred primarily in June. In June, temperature increases were simulated for Alt2 relative to existing conditions and no action; however, there were no exceedances of WAT or DM standards in June. The largest WAT increase for Alt2 relative to existing conditions was in June (2.3°C). The largest WAT increase for Alt2 relative to no action was also 2.3°C , simulated in June at WFU. The largest DM increases were simulated in June at HSS (4.6°C relative to existing conditions, and 4.7°C relative to no action). Differences for WATs and DMs in July were generally small, due to minimal differences in pumping and flow rates during those months. In August, 5412 releases from Granby Reservoir resulted in simulated cooler river temperatures for Alt2 and no action, relative to existing conditions. There were no increases in acute or chronic exceedances simulated for Alt2 relative to existing conditions or no action across the simulation period.

Comparing cumulative effects results for 1988 to 1988 direct effects, fewer temperature effects due to Alt2 occur in the cumulative effects simulations. This is largely attributable to the differences in pumping in July. There were not major pumping differences in July for cumulative effects Alt2 relative to existing conditions as was simulated for direct effects; therefore, there were generally smaller temperature impacts for cumulative effects Alt2. Additionally, the cooling effects of 5412 releases from Granby Reservoir are apparent in August and September for the cumulative effects alt2 and no action simulations.

5 SUMMARY

A dynamic temperature model was developed for the upper Colorado River. The calibrated and validated model was applied to evaluate the potential effects on river temperatures of the WGFP proposed action alternative (Alt2) relative to no action and existing conditions. Alternative 5 (Alt5) was also evaluated for direct effects as a representative example of the potential temperature effects of WGFP DEIS alternatives 3 through 5. The dynamic temperature model was run for various hydrologic conditions, with 2007 observed meteorology (the warmest year of the 5 years of river temperature transistor records) applied to each simulation. Direct effects and cumulative effects simulations were performed. The model generated hourly river temperatures for the period of June through September for each year. Model results were evaluated at the key sensitive temperature locations corresponding to thermistor locations CR-WGD, CR-HSU, and CR-WFU.

Of the 15-year period of simulated daily hydrology for the WGFP (WY1975-WY1989), only five years were identified that could potentially show temperature effects downstream of Windy Gap Reservoir in response to proposed increased pumping. Those five years (1975, 1979, 1986, 1987, and 1988) provided input hydrology for each simulated scenario (existing conditions, no action, Alt2, and Alt5). The five years provided a range of conditions over which to assess potential temperature effects of the alternatives, ranging from relatively dry (1987) to wet (1986) conditions, as compared to the 47 years of monthly hydrology simulated for the WGFP. Of the five years, four (1975, 1979, 1986, and 1988) had increases in pumping for alternatives in key river-temperature months of July and/or August. For 1987, pumping differences were limited to June. Of the five years simulated, flow rates below Windy Gap Reservoir ranged from 34 cfs to 4,250 cfs. 1986 had the highest flow rates across scenarios. The lowest flow rate in the key temperature months of July and August, 84 cfs, was simulated for the 1979 hydrology.

As stated above, all of the simulations applied the observed 2007 meteorological records. Looking at the 2007 meteorological records relative to the long-term record, it is clear that this year had a very hot July and August, typically the critical months for river temperature. Data indicate that July 2007 was the 6th hottest in the 62 years of record for that month (1949-2010), corresponding to the 95th percentile based on the statistical analysis. The 2007 average July temperature was 1.6°C warmer than the 62 year average. August 2007 was the hottest in the 63 years of record for that month (1948-2010), corresponding to the 98th percentile based on the statistical analysis. The 2007 average August temperature was 2.0°C warmer than the 63 year average. This is important perspective to maintain in evaluation of results, given the fact that air temperature is one of the major forcing functions determining river temperatures. As such, the number of exceedances simulated in July and August are likely to be higher than would be simulated for a more average meteorological year.

Results for direct effects and cumulative effects simulations are presented in detail in Section 4 and summarized in the following subsections. Conclusions from the analysis are presented after these summaries.

5.1 DIRECT EFFECTS SUMMARY

Direct effects simulations were performed to assess potential river temperature effects attributable to the WGFP alternatives. 2007 observed meteorology was applied to all simulation runs. Input hydrology was WGFP-simulated hydrology which was based on historical observed hydrology with an overlay of water use demands and operations relevant to the following scenarios:

- Existing Conditions;
- No Action - Direct Effects - Continuation of operations under existing agreements for conveyance of Windy Gap water through C-BT facilities, as well as the enlargement of Ralph Price Reservoir by the City of Longmont;
- Alternative 2 - Direct Effects - Increased diversions from Windy Gap and construction of a 90,000 AF Chimney Hollow Reservoir with prepositioning to allow storage of C-BT water in Chimney Hollow;
- Alternative 5 - Direct Effects - Increased diversions from Windy Gap and a 60,000 AF Dry Creek Reservoir and a 30,000 AF Rockwell Reservoir.

Relative to existing conditions, the greatest simulated direct effects temperature increases for Alt2 occurred for the 1975 and 1979 simulations (with 2007 meteorology). Focusing on values for July and August (no exceedances of standards were simulated for any scenario in June or September), the largest simulated Alt2 effects relative to existing conditions were:

- +2.7°C for WAT on July 10, 1975 (at WFU);
- +3 additional weeks above the WAT standard for the 1975 simulation (at HSU and WFU in July) and for the 1979 simulation (at WGD in July and August);
- +6.0°C for DM on July 7, 1975 (at HSU);
- +7 additional days above the DM standard for the 1979 simulation (at HSU in July and August).

Relative to no action, the largest July and August simulated increases in WATs and DMs for Alt2 were for the 1975 hydrology (with 2007 meteorology):

- +2.1°C for WAT on July 11, 1975 (at WFU);
- +2 additional weeks above the WAT standard for the 1975 simulation (at WFU and HSU July);
- +4.6°C for DM on July 9, 1975 (at HSU);
- +3 additional days above the DM standard for the 1975 simulation (at HSU in July).

In summary, of the 15 years of hydrology considered, four years (1975, 1979, 1987, and 1988) showed simulated temperature impacts due to direct effects for Alt2 that resulted in increased exceedances of WATs and/or DMs. Of these four years, simulated river temperature effects for 1987 were relatively small because pumping differences were limited to June, when river flow rates are higher. Table 49, Table 50, and Table 51 present the simulated relative maximum WATs and DMs as well as monthly acute and chronic exceedances for direct effects simulations for thermistor locations CR-WGD, CR-HSU, and CR-WFU, respectively. Bolded values in the table indicate increased exceedance counts relative to either existing conditions or no action.

Table 49. Direct Effects - WGD Simulation Results Summary.

	1975				1979				1986				1987				1988			
	EC	NA	Alt2	Alt5	EC	NA	Alt2	Alt5	EC	NA	Alt2	Alt5	EC	NA	Alt2	Alt5	EC	NA	Alt2	Alt5
Chronic																				
MWAT (°C)	18.9	19.0	19.0	19.0	18.7	19.1	19.1	19.1	16.1	16.4	16.4	16.6	19.4	19.5	19.5	19.5	18.8	18.8	18.8	18.8
June # weeks > 18.2 °C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
July # weeks > 18.2 °C	0	0	1	0	0	2	2	1	0	0	0	0	2	2	2	2	0	2	2	2
Aug. # weeks > 18.2 °C	3	3	3	3	2	3	3	4	0	0	0	0	4	4	4	4	2	2	3	3
Sept. # weeks > 18.2 °C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acute																				
Max DM (°C)	20.8	20.8	20.8	20.8	20.6	21.1	21.1	21.1	17.2	17.7	17.9	18.2	21.4	21.5	21.5	21.5	20.6	20.6	20.6	20.6
June # days > 23.8 °C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
July # days > 23.8 °C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aug. # days > 23.8 °C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sept. # days > 23.8 °C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 50. Direct Effects - HSU Simulation Results Summary.

	1975				1979				1986				1987				1988			
	EC	NA	Alt2	Alt5	EC	NA	Alt2	Alt5	EC	NA	Alt2	Alt5	EC	NA	Alt2	Alt5	EC	NA	Alt2	Alt5
Chronic																				
MWAT (°C)	19.5	19.5	19.5	19.5	19.4	19.7	19.7	19.7	17.3	17.6	17.7	17.8	20	20	20	20	19.4	19.4	19.4	19.4
June # weeks > 18.2 °C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
July # weeks > 18.2 °C	0	1	3	3	1	2	2	2	0	0	0	0	4	4	4	4	2	2	2	2
Aug. # weeks > 18.2 °C	4	4	4	4	4	4	4	4	0	0	0	0	5	5	5	5	3	4	4	4
Sept. # weeks > 18.2 °C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acute																				
Max DM (°C)	24.4	24.4	24.8	24.8	24.3	24.8	24.8	24.8	21.5	22.1	22.3	22.5	25.4	25.4	25.4	25.4	24.2	24.2	24.5	24.5
June # days > 23.8 °C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
July # days > 23.8 °C	0	0	3	3	0	2	2	2	0	0	0	0	1	1	1	1	0	1	2	2
Aug. # days > 23.8 °C	5	6	6	6	2	7	7	7	0	0	0	0	12	12	12	12	4	4	4	4
Sept. # days > 23.8 °C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 51. Direct Effects - WFU Simulation Results Summary.

	1975				1979				1986				1987				1988			
	EC	NA	Alt2	Alt5	EC	NA	Alt2	Alt5	EC	NA	Alt2	Alt5	EC	NA	Alt2	Alt5	EC	NA	Alt2	Alt5
Chronic																				
MWAT (°C)	19.7	19.7	19.7	19.7	19.6	19.9	19.9	19.9	17.7	18	18.1	18.2	20	20	20	20	19.6	19.6	19.6	19.6
June # weeks > 18.2 °C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
July # weeks > 18.2 °C	0	1	3	3	2	2	2	2	0	0	0	0	4	4	5	5	2	3	3	2
Aug. # weeks > 18.2 °C	4	4	4	4	3	4	4	4	0	0	0	0	4	4	4	4	4	4	4	4
Sept. # weeks > 18.2 °C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acute																				
Max DM (°C)	23.5	23.5	24.9	24.9	23.4	23.9	23.9	23.8	21.5	21.9	22	22.1	24.3	24.3	24.4	24.4	23.5	23.7	23.9	23.9
June # days > 23.8 °C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
July # days > 23.8 °C	0	0	1	1	0	1	1	1	0	0	0	0	1	1	1	1	0	0	1	1
Aug. # days > 23.8 °C	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	0	0	0	0
Sept. # days > 23.8 °C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

5.2 CUMULATIVE EFFECTS SUMMARY

Cumulative effects simulations were performed to assess potential river temperature effects attributable to the WGFP alternatives including reasonably foreseeable actions that are anticipated to occur regardless of the implementation of any of the action alternatives or the no action alternative. Reasonably foreseeable actions included in the cumulative effects simulations which affect the simulated hydrology used in the dynamic temperature model include:

- Denver Water Moffat Collection System Project,
- Increased water use from population growth in Grand and Summit counties,
- Changes in releases from Williams Fork (related to changes to recommended 10825 releases for fish flows in the 15-Mile reach and the expiration of Denver Water's contract with Big Lake Ditch), and
- 5412 releases from Granby Reservoir, per the release schedule presented in the 10825 Environmental Assessment (BOR, 2011).

Cumulative effect simulations for the dynamic temperature model include no action and Alt2. Existing conditions simulations generated for direct effects were also considered in the cumulative effects analysis for assessment of impacts.

Additionally, simulations of Alt2 and no action were conducted using a modified, earlier-start 5412 release schedule, recognizing that the operational committee that defines the 5412 releases each year will have latitude in setting the schedule for average and wet years. This alternative release schedule was only run for the 1975 hydrology (1975 was an average flow year), to provide insight into the possible temperature benefits of an earlier start to 5412 releases. This earlier release schedule started on July 15 instead of August 1.

Relative to existing conditions, the greatest simulated cumulative effects temperature increases for Alt2 occurred for the 1975 and 1979 simulations (with 2007 meteorology). Focusing on values for July and August (no exceedances of standards were simulated for any scenario in June or September), the largest simulated Alt2 effects relative to existing conditions were:

- +3.2°C for WAT on July 4, 1979 (at WFU)
- +3 additional weeks above the WAT standard for the 1975 simulation (at WFU and HSU, all in July)
- +6.8°C for DM on July 2, 1979 (at HSU)
- +4 additional days above the DM standard for the 1975 simulation (at HSU, all in July)

Relative to no action, the largest July and August simulated increase in WATs and DMs for Alt2 were for the 1975, 1979, and 1988 hydrologic inputs (with 2007 meteorology):

- +1.9°C for WAT on July 1, 1988 (at WFU)
- +2 additional weeks above the WAT standard for the 1975 simulation (at HSU in July and August)
- +2.5°C for DM on July 9, 1975 (at HSU)
- +4 additional days above DM standards for the 1975 simulation (at HSU, all in July)

The 1975 simulation of an earlier release schedule for 5412 releases from Granby Reservoir (July 15 start instead of Aug1 start) produced noteworthy results. July river temperatures were cooler under the earlier release data, resulting in fewer exceedances in July. A July start date for 5412 releases would also be expected to reduce exceedances in other simulated years.

In summary, of the 15 years of hydrology considered, three years (1975, 1979, and 1987) showed simulated temperature impacts due to cumulative effects for Alt2 that resulted in increased exceedances of WATs and/or DMs. Of these three years, simulated effects for 1987 were relatively small because pumping differences were limited to June, when river flow rates are higher. 5412 releases from Granby Reservoir have a noteworthy cooling effect on river flows, and earlier release start dates for average flow years should be considered. Table 52, Table 53, and Table 54 present the simulated relative maximum WATs and DMs as well as monthly acute and chronic exceedances for cumulative effects simulations for thermistor locations CR-WGD, CR-HSU, and CR-WFU, respectively. Bolded values in the table indicate increased exceedance counts relative to either existing conditions or no action.

Table 52. WGD - Cumulative Effects Simulation Summary.

	1975			1979			1986			1987			1988		
	EC	NA	Alt2	EC	NA	Alt2	EC	NA	Alt2	EC	NA	Alt2	EC	NA	Alt2
Chronic															
MWAT (°C)	18.9	18.0	18.3	18.7	18.9	18.8	16.1	15.3	15.3	19.4	18.9	18.9	18.8	17.7	18.1
June # weeks > 18.2 °C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
July # weeks > 18.2 °C	0	0	1	0	2	2	0	0	0	2	3	3	0	0	0
Aug. # weeks > 18.2 °C	3	0	0	2	0	0	0	0	0	4	0	0	2	0	0
Sept. # weeks > 18.2 °C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acute															
Max DM (°C)	20.8	19.5	20.2	20.6	20.6	20.6	17.2	16.3	16.5	21.4	20.6	20.6	20.6	18.9	19.4
June # days > 23.8 °C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
July # days > 23.8 °C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aug. # days > 23.8 °C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sept. # days > 23.8 °C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 53. HSU - Cumulative Effects Simulation Summary.

	1975			1979			1986			1987			1988		
	EC	NA	Alt2	EC	NA	Alt2	EC	NA	Alt2	EC	NA	Alt2	EC	NA	Alt2
Chronic															
MWAT (°C)	19.5	18.8	19.0	19.4	19.4	19.3	17.3	16.8	16.8	20.0	19.3	19.3	19.4	18.5	18.8
June # weeks > 18.2 °C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
July # weeks > 18.2 °C	0	2	3	1	2	3	0	0	0	4	4	4	2	2	2
Aug. # weeks > 18.2 °C	4	1	2	4	2	2	0	0	0	4	2	2	3	0	0
Sept. # weeks > 18.2 °C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acute															
Max DM (°C)	24.4	23.6	24.8	24.3	24.5	24.5	21.5	20.8	21.1	25.4	24.2	24.2	24.2	23.1	23.3
June # days > 23.8 °C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
July # days > 23.8 °C	0	0	4	0	3	3	0	0	0	1	4	4	0	0	0
Aug. # days > 23.8 °C	5	0	0	2	0	0	0	0	0	12	0	0	4	0	0
Sept. # days > 23.8 °C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 54. WFU - Cumulative Effects Simulation Summary.

	1975			1979			1986			1987			1988		
	EC	NA	Alt2	EC	NA	Alt2	EC	NA	Alt2	EC	NA	Alt2	EC	NA	Alt2
Chronic															
MWAT (°C)	19.7	19.0	19.3	19.6	19.5	19.5	17.7	17.2	17.3	20.0	19.5	19.5	19.6	18.8	18.9
June # weeks > 18.2 °C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
July # weeks > 18.2 °C	0	3	3	2	4	4	0	0	0	4	5	5	2	2	2
Aug. # weeks > 18.2 °C	4	3	3	3	2	2	0	0	0	4	2	2	4	2	2
Sept. # weeks > 18.2 °C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acute															
Max DM (°C)	23.5	23.9	24.9	23.4	24.1	24.2	21.5	21.0	21.2	24.3	24.6	24.6	23.5	23.0	23.3
June # days > 23.8 °C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
July # days > 23.8 °C	0	1	1	0	2	2	0	0	0	1	2	2	0	0	0
Aug. # days > 23.8 °C	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
Sept. # days > 23.8 °C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

5.1 CONCLUSIONS

A dynamic temperature model was developed to evaluate the potential effects on river temperatures of proposed increased pumping from the Windy Gap Reservoir as part of the WGFP EIS. The model was successfully calibrated and validated to pre-determined accuracy targets. The model was applied to simulate scenarios of existing conditions, no action, alternative 2, and alternative 5 for direct effects and cumulative effects. In general, as expected, the largest simulated temperature increases are associated with the largest pumping differences at times of relatively lower river flow rates. Further, hourly temperature simulation results show that the reduction in flow rates (and corresponding stage) result in greater relative increase in the upper range of daily temperatures (during daylight hours), with only small changes in evening temperatures. This pattern is apparent across all simulation results, reflecting the strong influence of water depth on heating by solar radiation, which only occurs during daylight hours.

For direct effects, simulated annual increases in chronic exceedances were as high as three additional weeks above the WAT standard relative to existing conditions and two additional weeks relative to no action. Simulated annual increases in acute exceedances were as high as seven additional days above the DM standard relative to existing conditions and three additional days relative to no action. Results for Alt5 were nearly identical to those for Alt2 due to very similar Windy Gap pumping patterns in the simulated years.

For cumulative effects, simulated annual increases in chronic exceedances were as high as three additional weeks above the WAT standard relative to existing conditions and two additional weeks relative to no action. Simulated annual increases in acute exceedances were as high as four additional days above the DM standard relative to existing conditions and four additional days relative to no action. 5412 releases from Granby Reservoir, simulated as cumulative effects for no action and Alt2, exhibit strong cooling effect on river flows. A release start data of August 1 was simulated. As evaluated in separate runs for 1975, a July start date for average flow years could further reduce WAT and DM exceedances.

Overall, direct effects model results indicate that increased pumping for Alt2 would increase regulatory exceedances of chronic and acute temperature standards in July and/or August for four years out of the fifteen year period considered (1975-1989). For cumulative effects, the increase in regulatory exceedances is limited to three years out of the fifteen year period, with no effects simulated in August due to 5412 releases from Granby Reservoir. No exceedances were simulated for any scenario or year in June or September.

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APPENDIX A: Calibration Monthly Plots

A. Calibration Monthly Summary Results

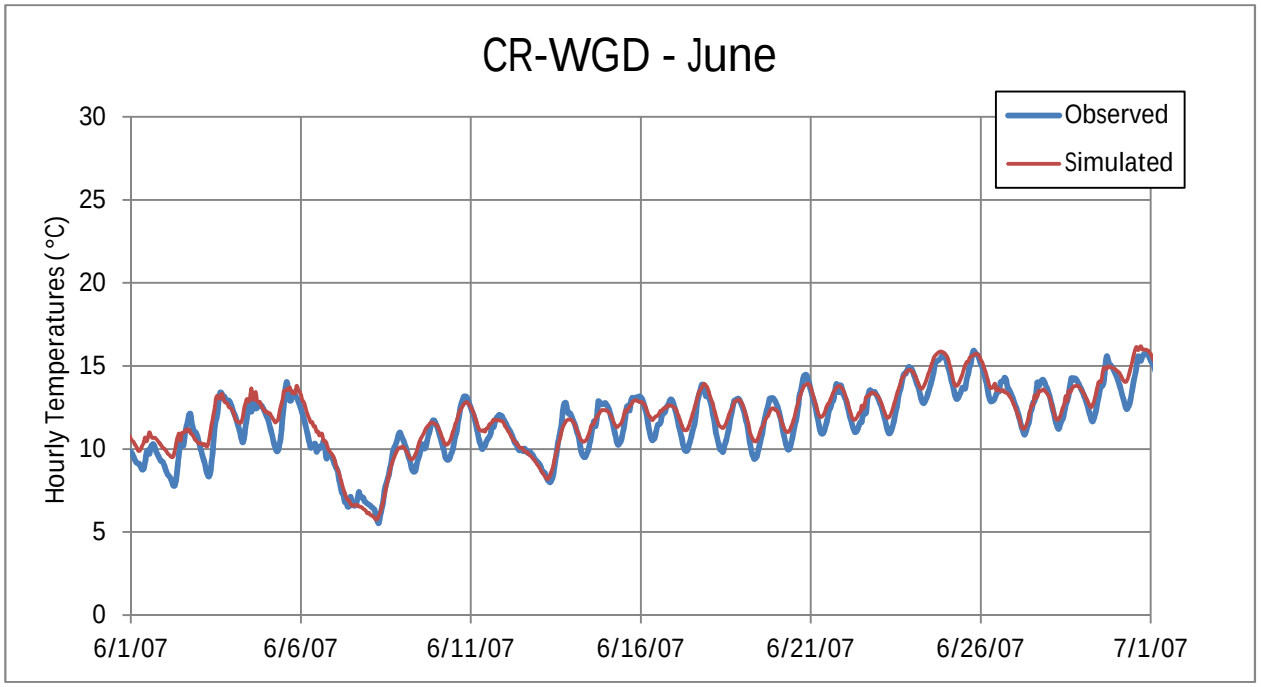

Figure A - 1. Observed and Simulated Hourly Temperatures at CR-WGD, June - Calibration Run.

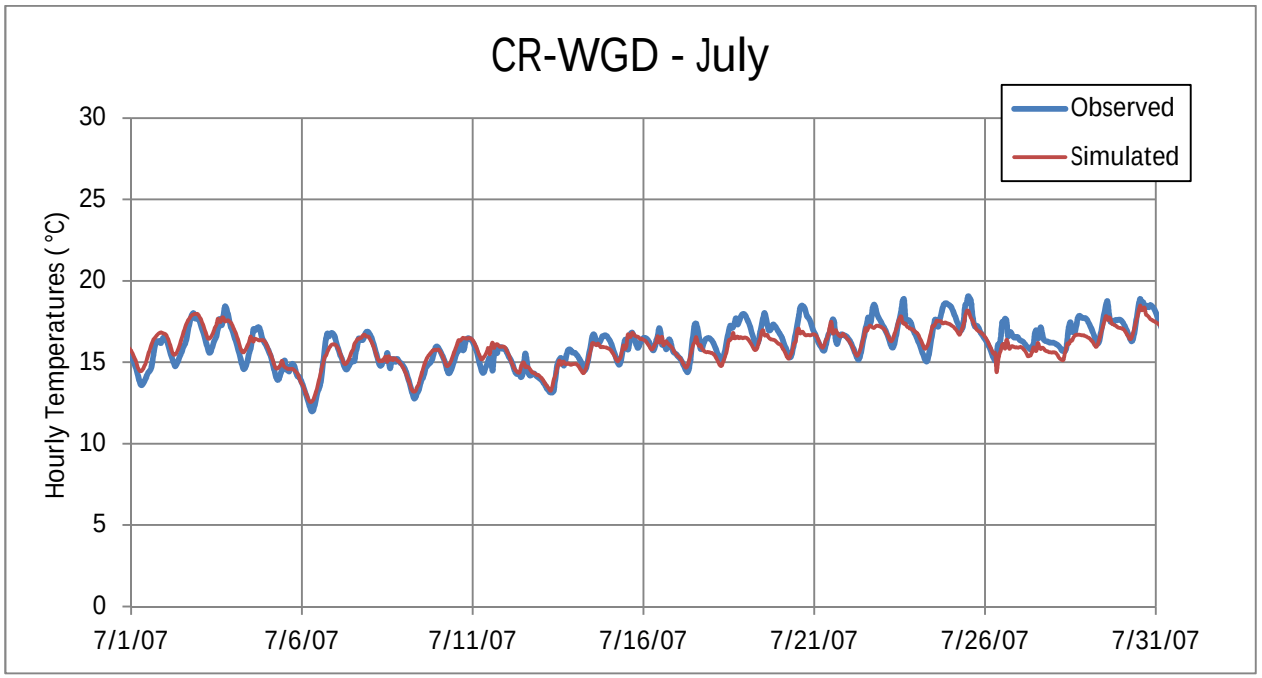

Figure A - 2. Observed and Simulated Hourly Temperatures at CR-WGD, July - Calibration Run.

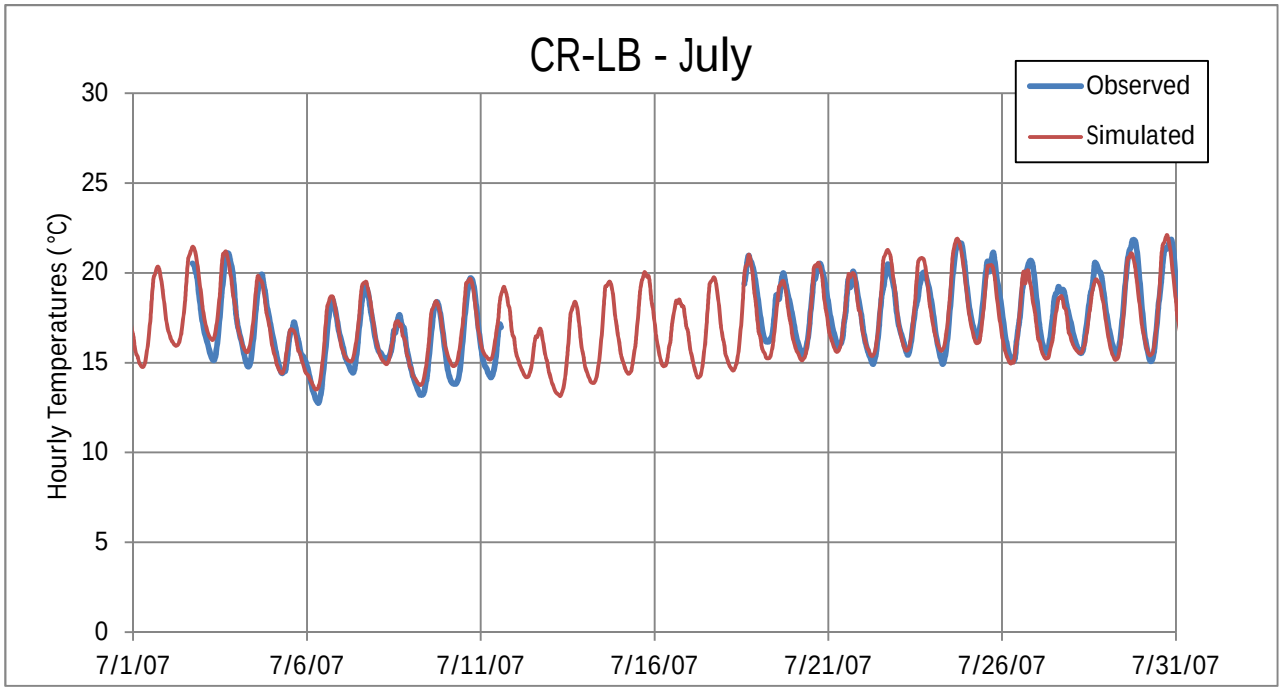

Figure A - 3. Observed and Simulated Hourly Temperatures at CR-LB, July - Calibration Run.

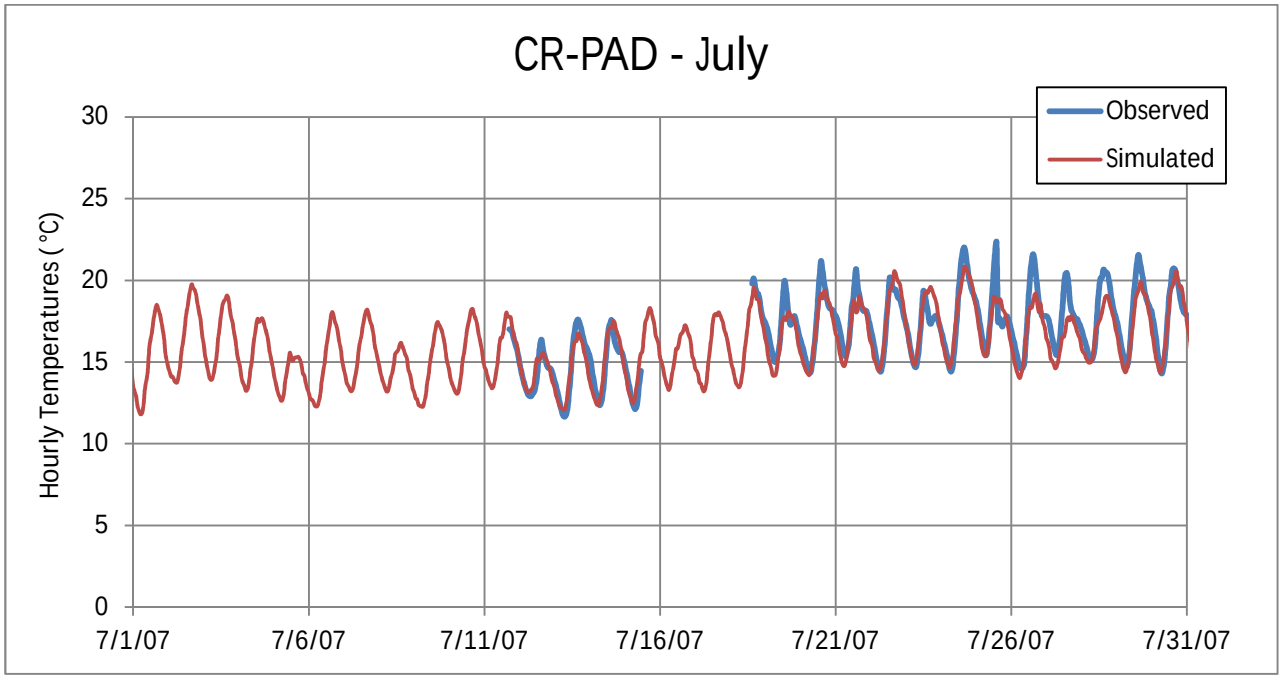

Figure A - 4. Observed and Simulated Hourly Temperatures at CR-PAD, July - Calibration Run.

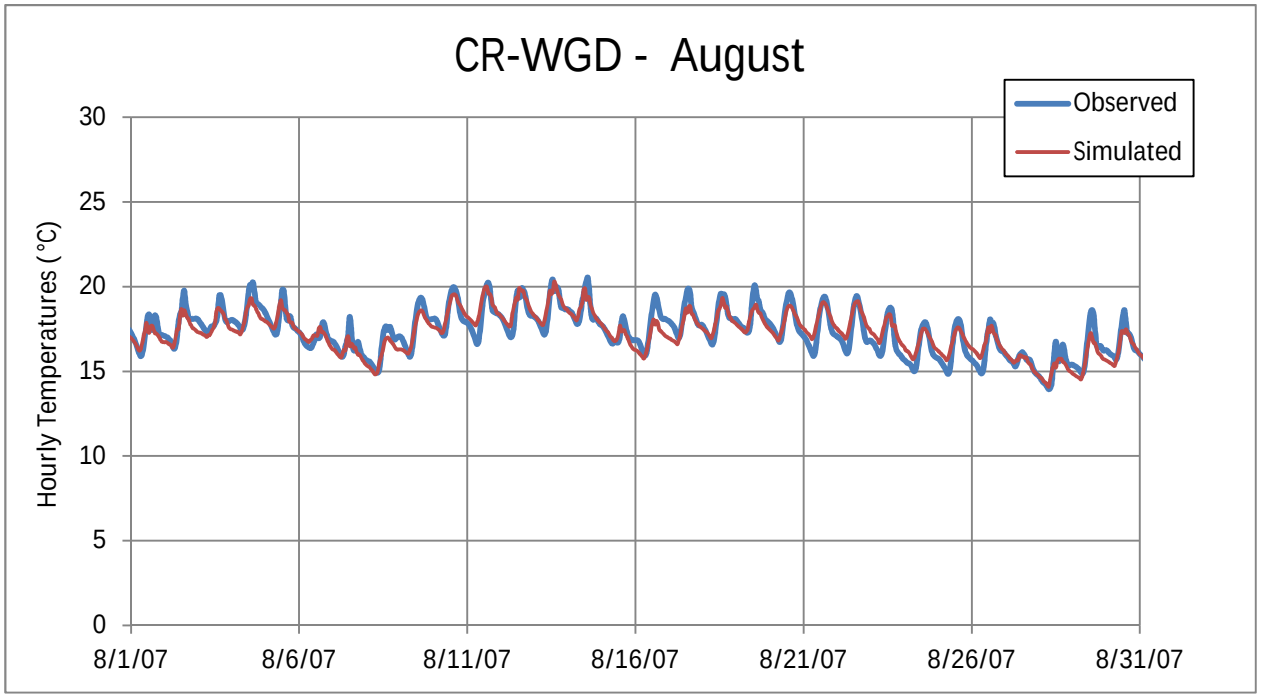

Figure A - 5. Observed and Simulated Hourly Temperatures at CR-WGD, August - Calibration Run.

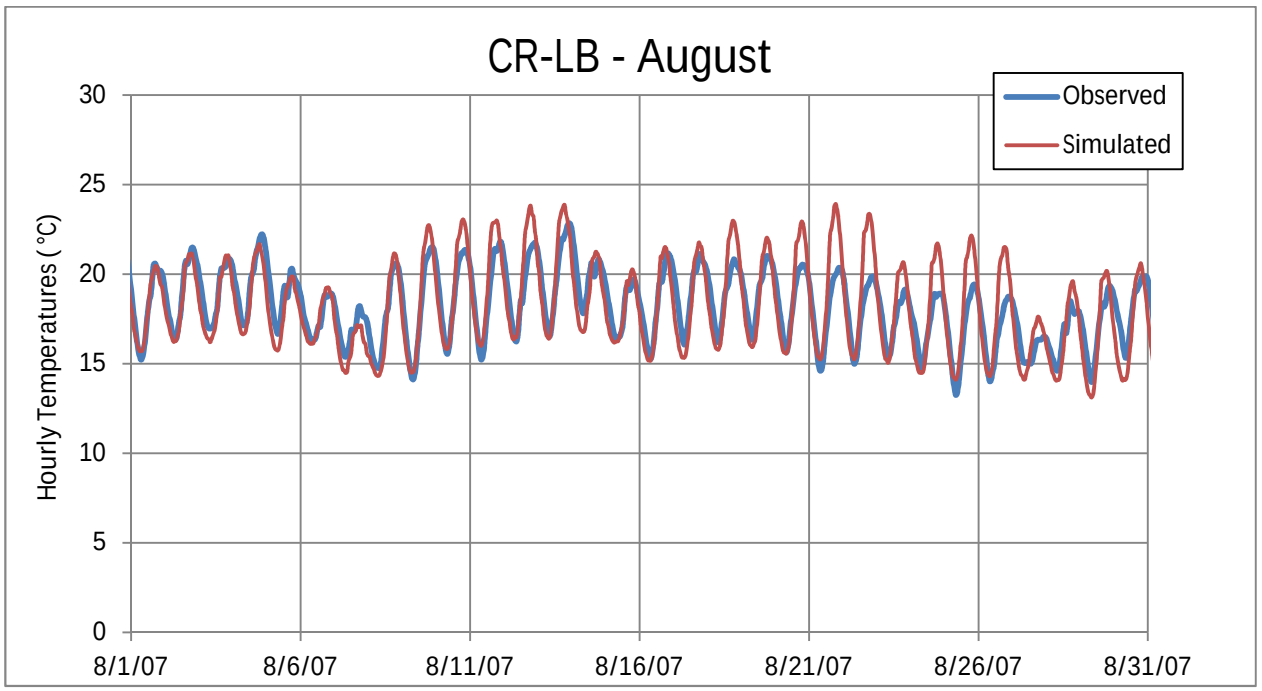

Figure A - 6. Observed and Simulated Hourly Temperatures at CR-LB, August - Calibration Run.

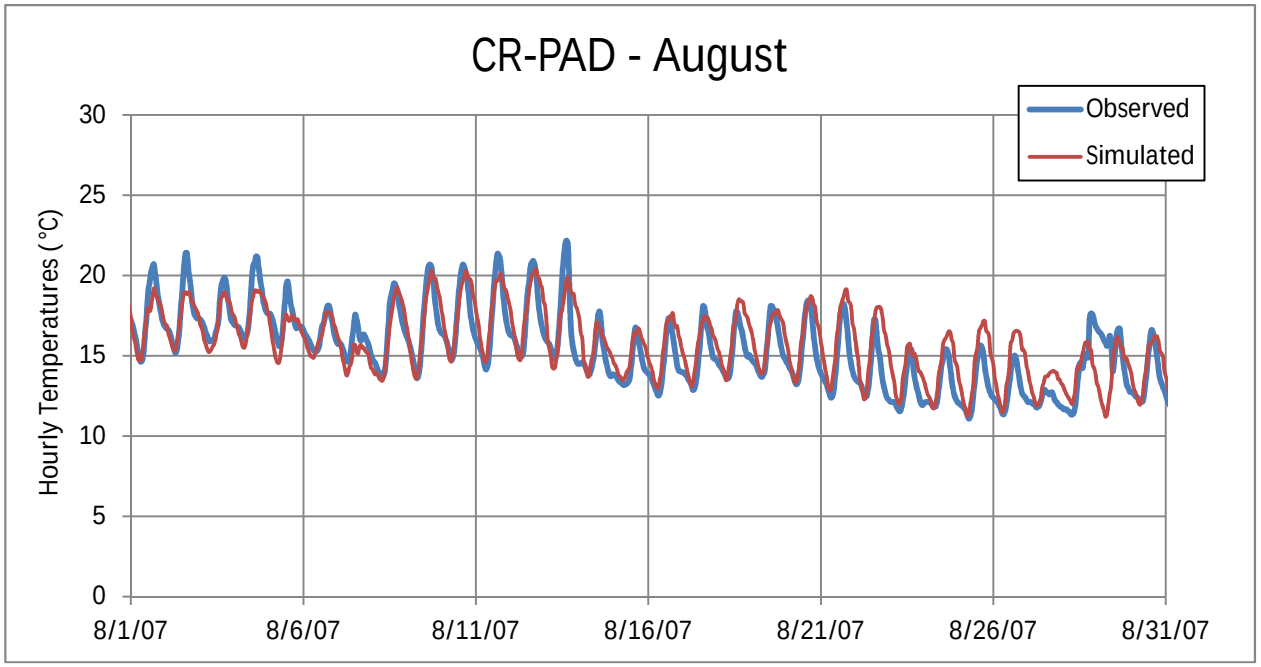

Figure A - 7. Observed and Simulated Hourly Temperatures at CR-PAD, August - Calibration Run.

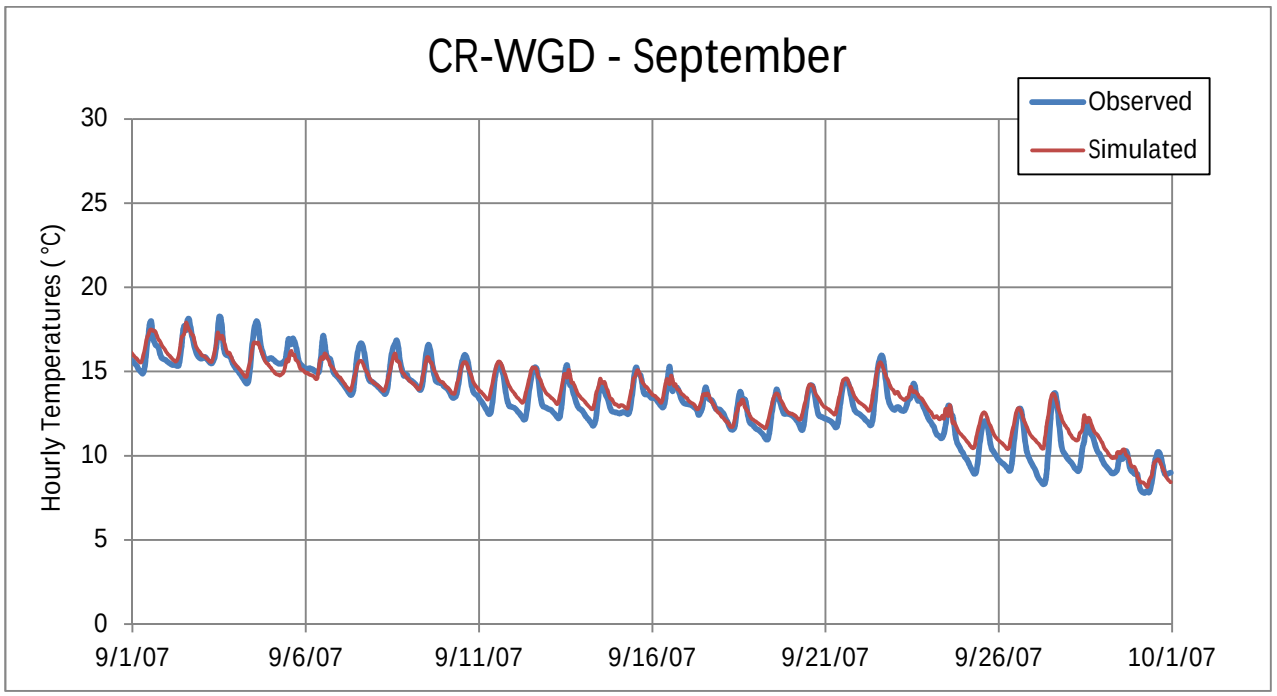

Figure A - 8. Observed and Simulated Hourly Temperatures at CR-WGD, September - Calibration Run.

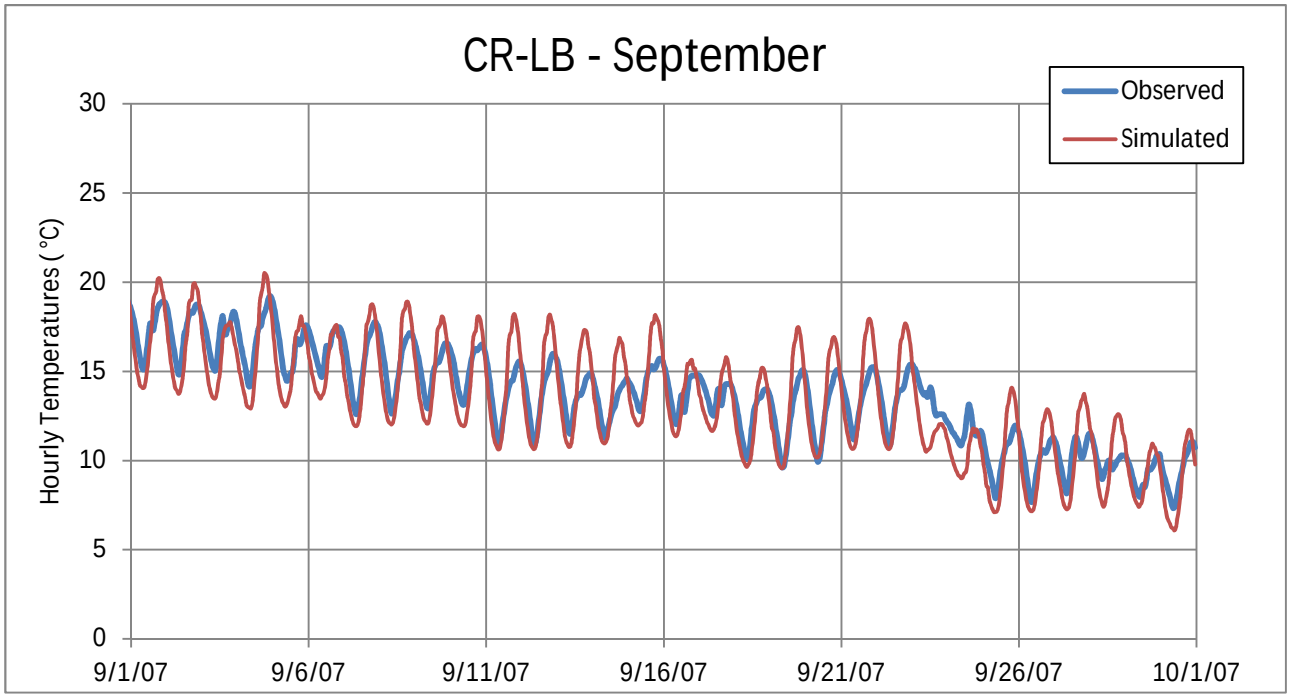

Figure A - 9. Observed and Simulated Hourly Temperatures at CR-LB, September - Calibration Run.

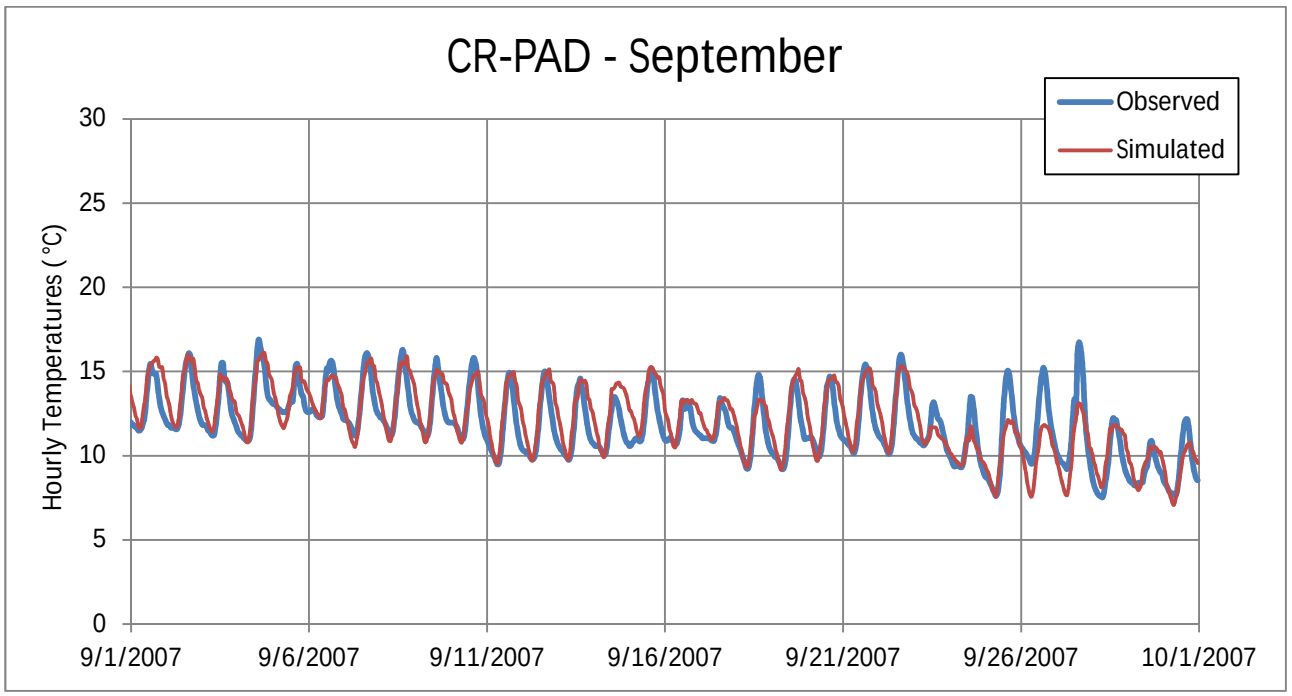

Figure A - 10. Observed and Simulated Hourly Temperatures at CR-PAD, September - Calibration Run.

Appendix B: Validation Monthly Plots

B. Validation Monthly Summary Results

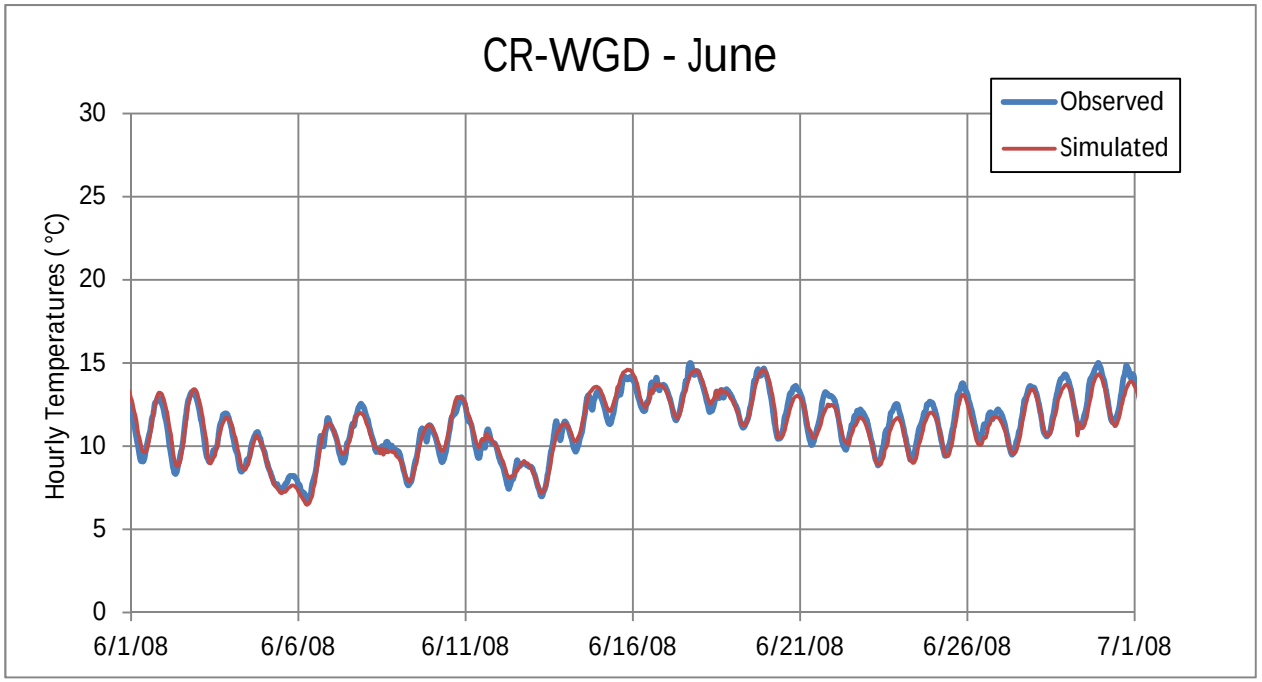

Figure B - 1. Observed and Simulated Hourly Temperatures at CR-WGD, June - Validation Run.

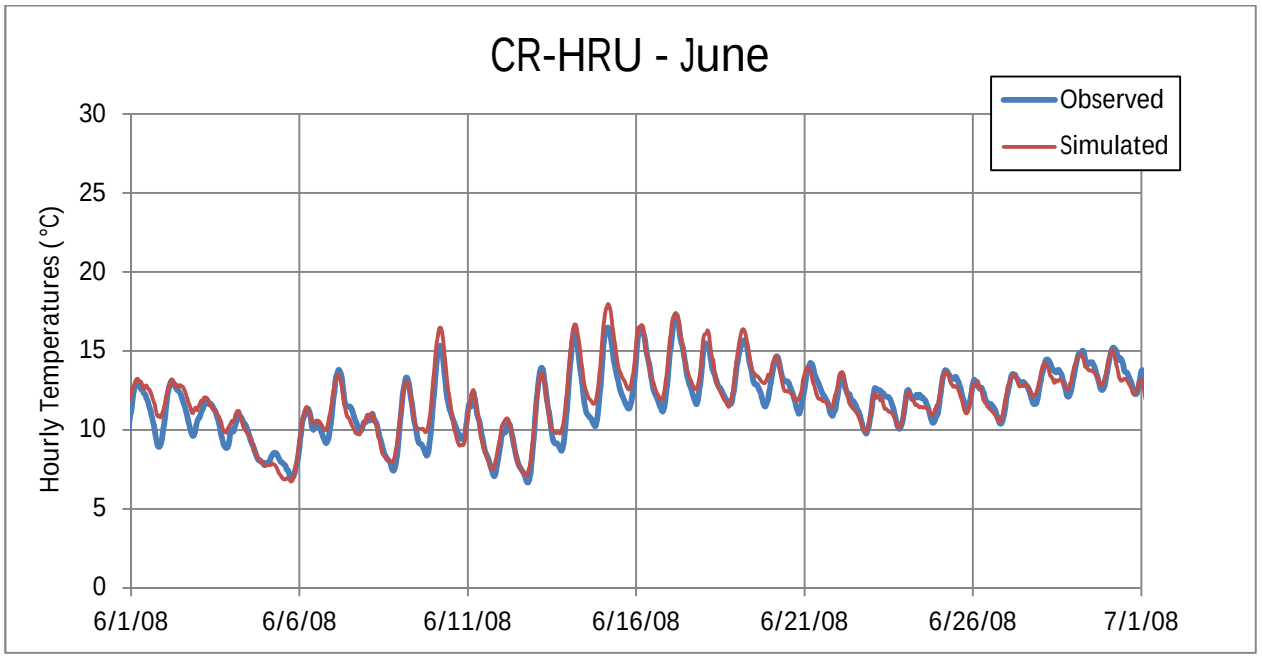

Figure B - 2. Observed and Simulated Hourly Temperatures at CR-HRU, June - Validation Run.

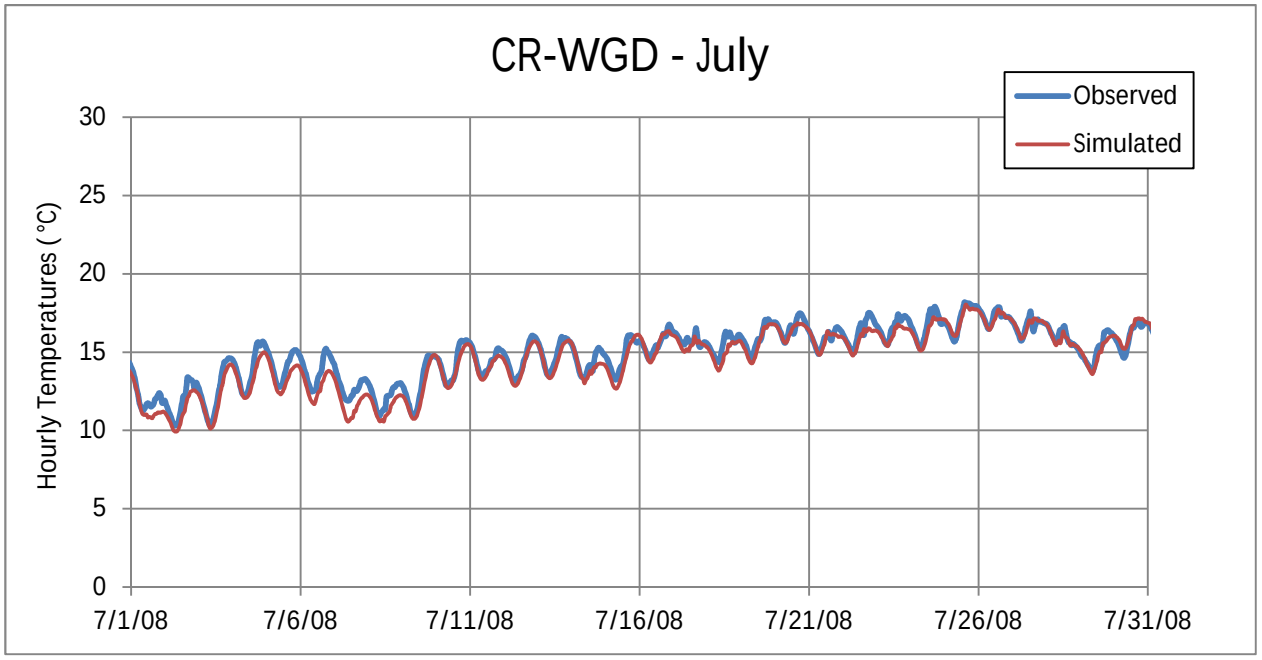

Figure B - 3. Observed and Simulated Hourly Temperatures at CR-WGD, July - Validation Run.

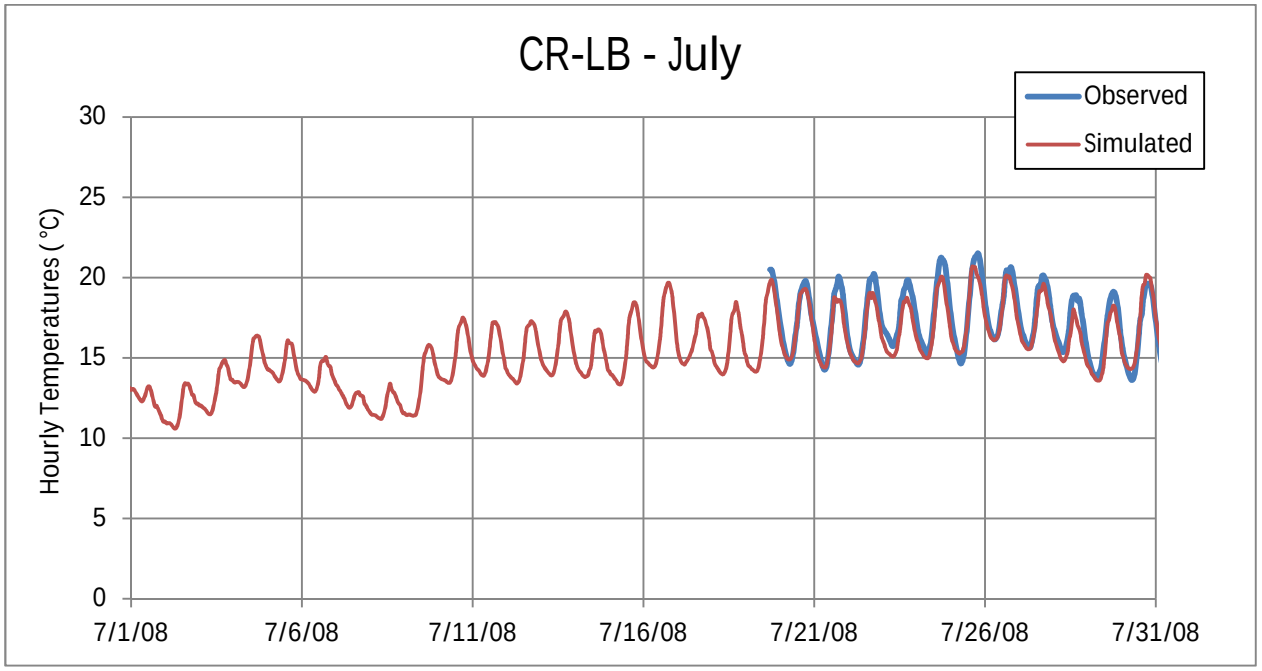

Figure B - 4. Observed and Simulated Hourly Temperatures at CR-LB, July - Validation Run.

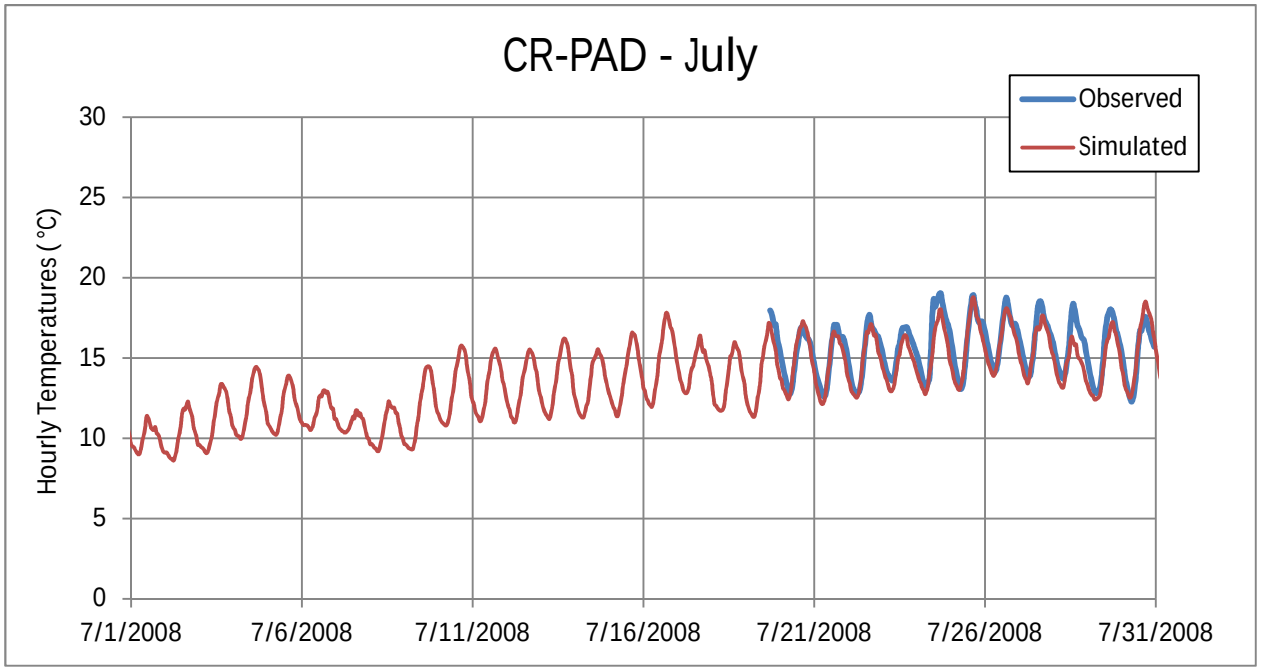

Figure B - 5. Observed and Simulated Hourly Temperatures at CR-PAD, July - Validation Run.

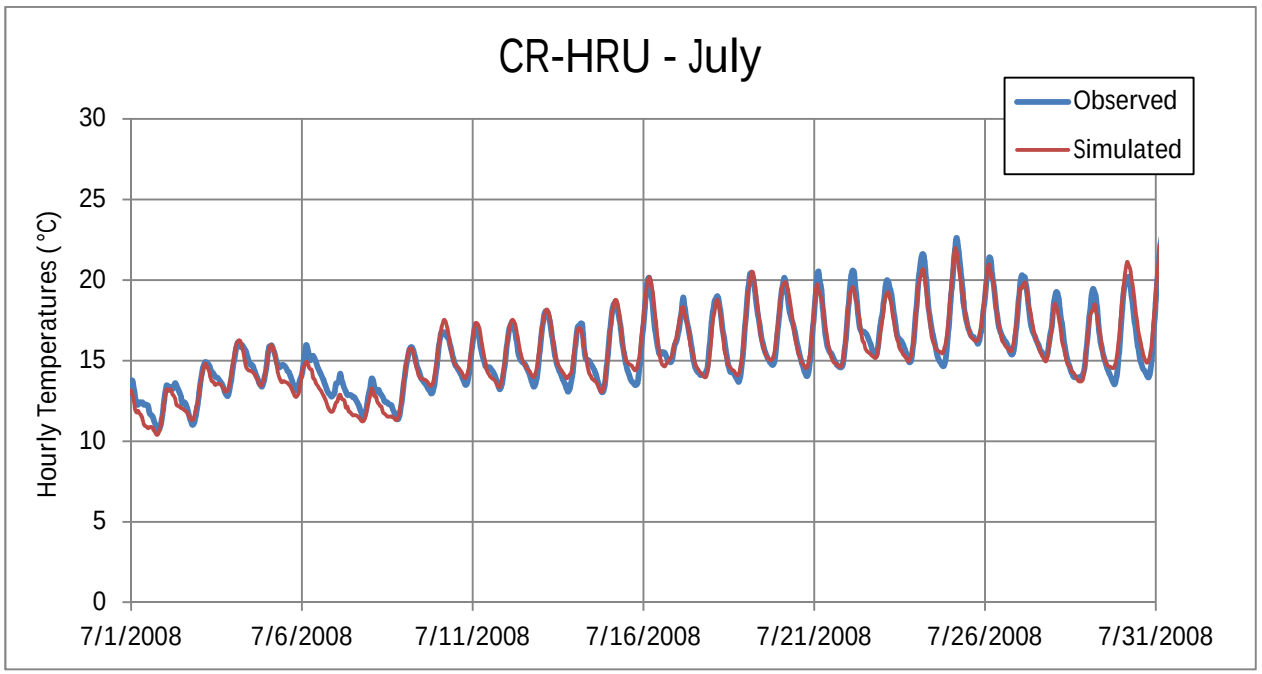

Figure B - 6. Observed and Simulated Hourly Temperatures at CR-HRU, July - Validation Run.

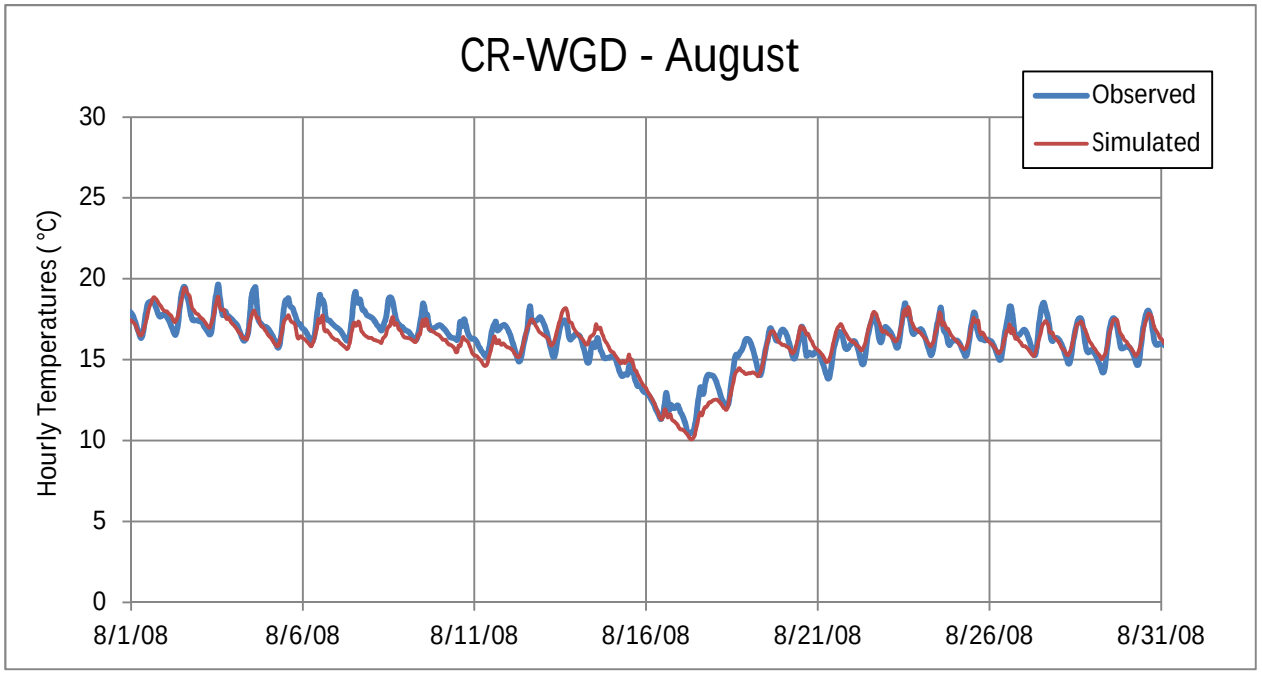

Figure B - 7. Observed and Simulated Hourly Temperatures at CR-WGD, August - Validation Run.

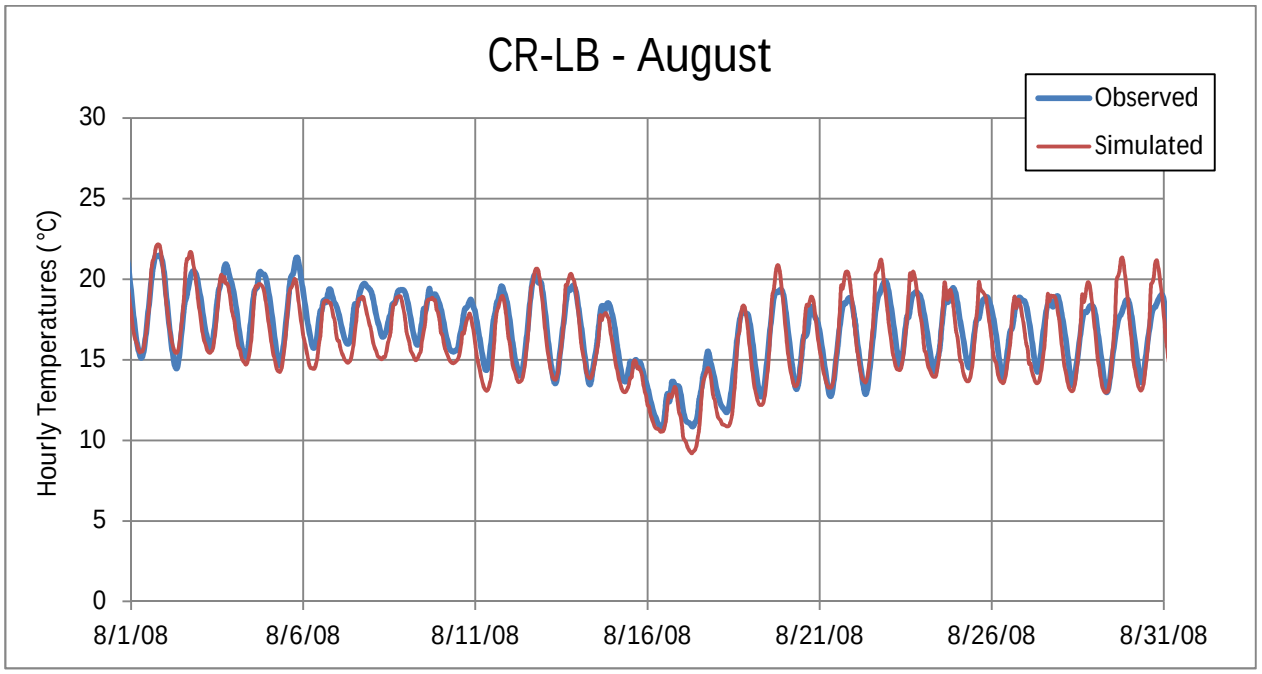

Figure B - 8. Observed and Simulated Hourly Temperatures at CR-LB, August - Validation Run.

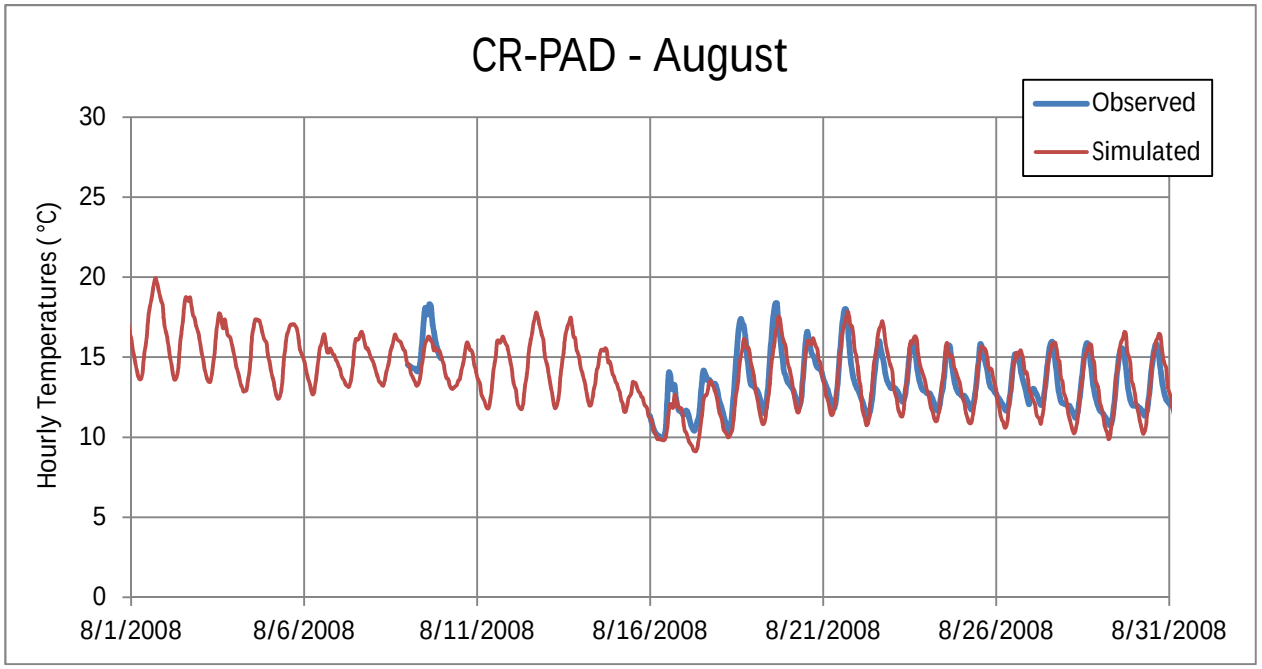

Figure B - 9. Observed and Simulated Hourly Temperatures at CR-PAD, August - Validation Run.

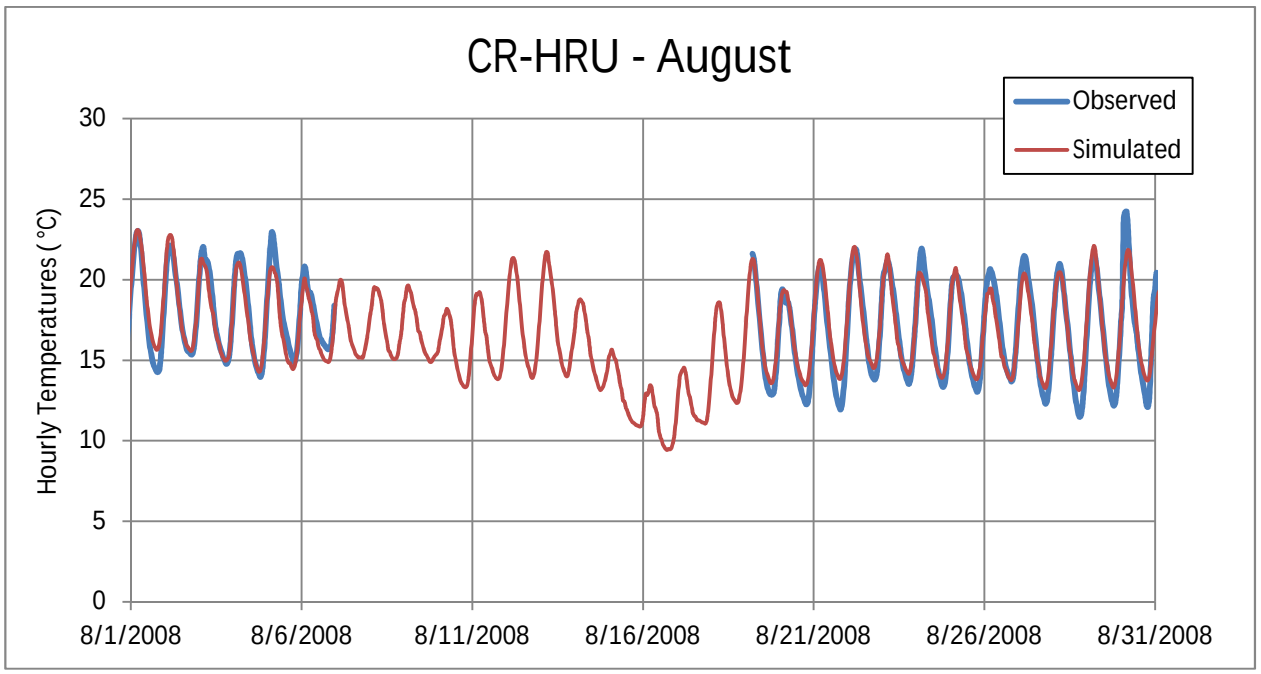

Figure B - 10. Observed and Simulated Hourly Temperatures at CR-HRU, August - Validation Run.

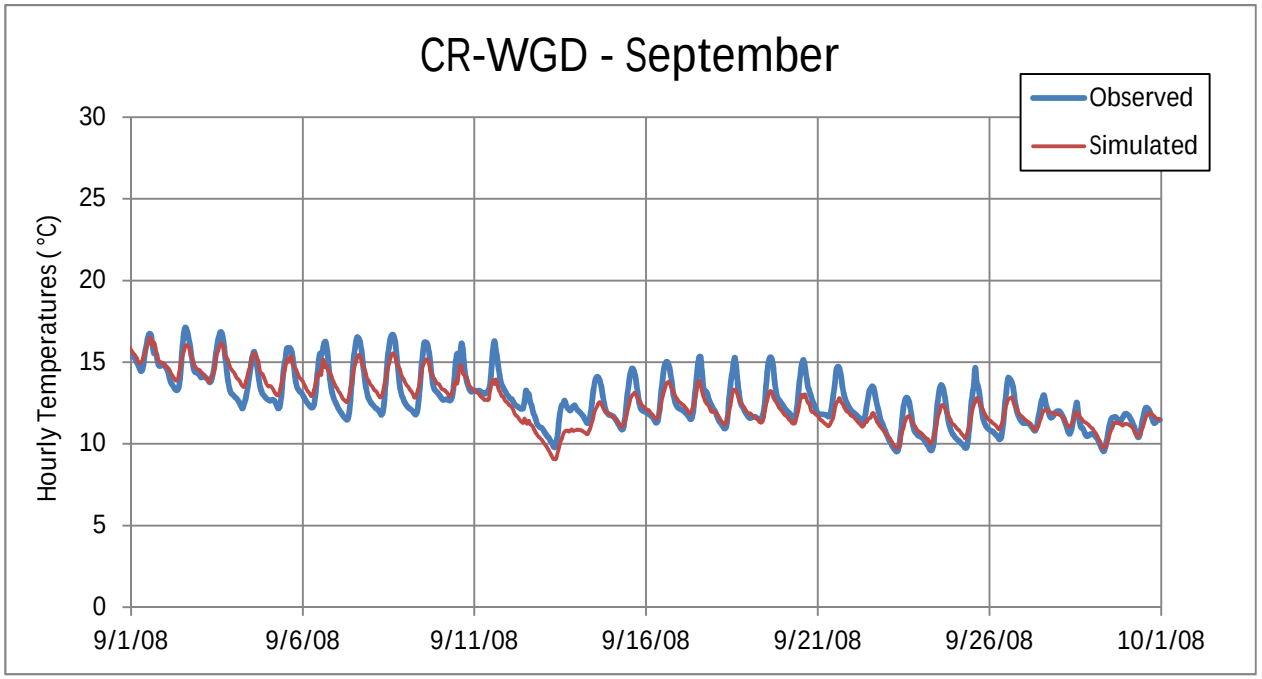

Figure B - 11. Observed and Simulated Hourly Temperatures at CR-WGD, September - Validation Run.

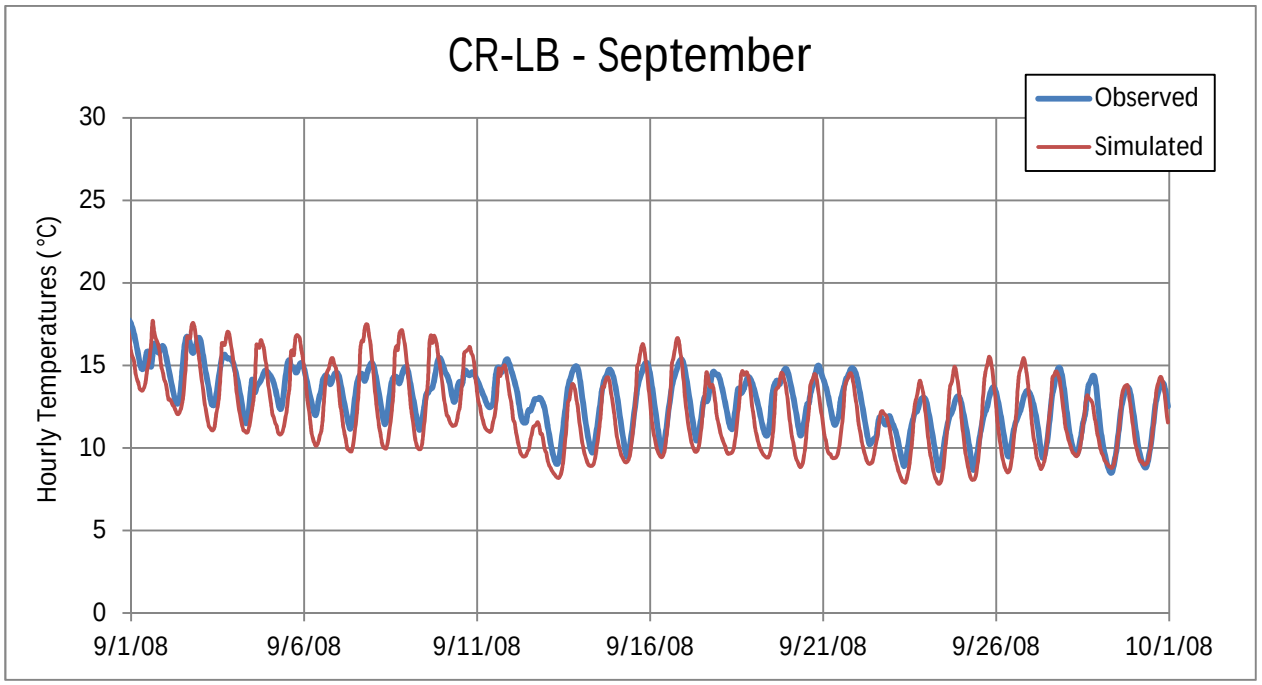

Figure B - 12. Observed and Simulated Hourly Temperatures at CR-LB, September - Validation Run.

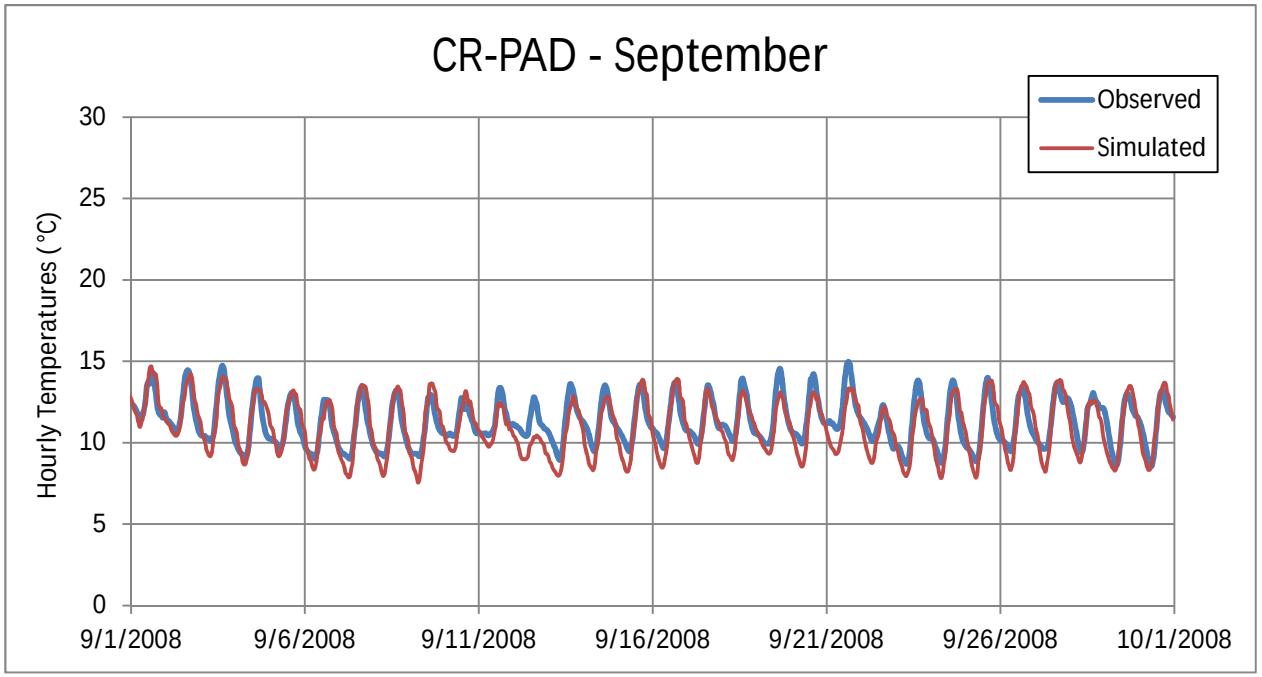

Figure B - 13. Observed and Simulated Hourly Temperatures at CR-PAD, September - Validation Run.

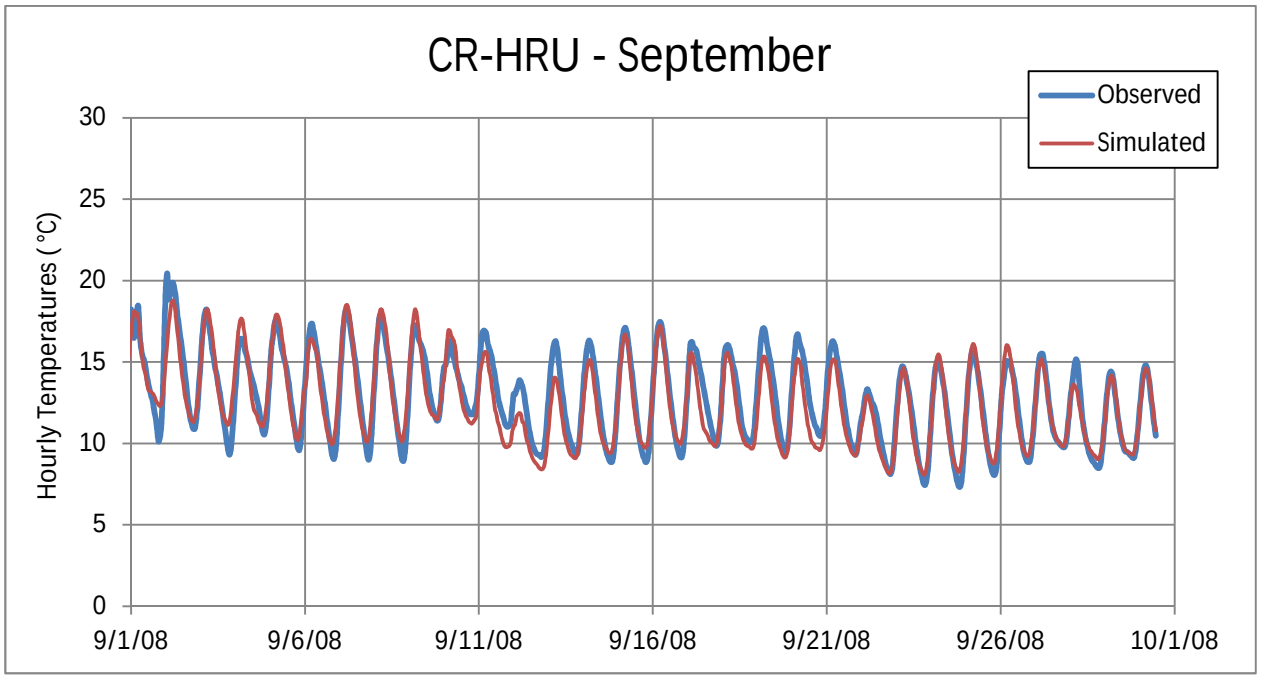

Figure B - 14. Observed and Simulated Hourly Temperatures at CR-HRU, September - Validation Run.