Attachment 4: DSM2 Temperature Modeling

5.B.A.4 DSM2 Temperature Modeling

5.B.A.4.1 Executive Summary

The work discussed in this report covers the application of a calibrated QUAL water temperature model, V8.1.2, to the two California WaterFix scenario simulations as well as additional data and explanatory background to assist in the interpretation of the model results. Additional documentation on the calibration and residual analysis of the water temperature model is found in the enclosed Appendix.

DSM2 is a suite of one-dimensional numerical models developed at the Department of Water Resources (DWR) of the State of California. DSM2-HYDRO calculates the hydrodynamics of the Sacramento-San Joaquin Delta region, while the dynamics of water temperature are conceptualized in the DSM2-QUAL mass transport model. The models are run consecutively, with QUAL using previously calculated HYDRO model output in its calculations for the transport of water temperature.

All of the DSM2 simulations represent hypothetical modeled water years 1921 – 2003, with California WaterFix scenarios representing proposed or predicted changes to: Delta operations such as exports and the volume and timing of reservoir releases; meteorological conditions due to climate change; and, stage at Martinez due to sea level rise. Changes to modeled Delta bathymetry associated with the largescale tidal marsh restoration included in previous Bay Delta Conservation Plan (BDCP) model scenarios are NOT included in the CWF scenarios discussed herein.

Differences in model output reflect differences between the California WaterFix Proposed Action (PA) scenario and the No Action Alternative (NAA) at year 2030 under assumed climate changes and sea level rise conditions as well as changes in export volumes, location and timing. Changes in water temperature at the inflow boundaries due to upstream effects from climate change, changes in runoff, changes in reservoir usage, changes in effluent volume or water temperature due to population changes, or other potentially influential parameters were not considered. However, as described below, the inflow temperatures are adjusted based on the projected temperature changes in the vicinity of the Delta as a result of the climate change assumed. A set of representative model output locations was selected and monthly averaged to represent an average result for each month at each location.

Input files for DSM2 HYDRO simulations were supplied to RMA, and then modified to represent hypothetical conditions for the calculation of water temperature. Changes to the HYDRO model input for this purpose consist of the addition of effluent inflow at twelve locations within the DSM2 model domain. Boundary conditions for water temperature were synthesized for the QUAL water temperature model from data as described below.

A single set of effluent boundary conditions for effluent inflow and water temperature, inflow water temperature and meteorology were synthesized from existing effluent data and applied to all of the scenarios. In the HYDRO model runs, effluent inflow representing current-day (2000 – 2005) conditions of wastewater treatment plants discharges into the Delta were included in all scenarios, but otherwise the hydrodynamic conditions and all other inputs to HYDRO used in the California WaterFix simulations were implemented without alteration.

Meteorological and water temperature boundary conditions were synthesized from time series of projected daily average temperatures supplied to RMA that represent a future climate change condition for the 2030 time frame. These time series were then used as a basis for formulating the hourly meteorological boundary conditions used in the QUAL nutrient model. The synthetic hourly meteorological time series was developed by first matching average air temperature under this climate change condition with historical air temperature used in DSM2 at approximately the same annual date (+/- 2 days), creating a correspondence between these historical dates and the model dates. Existing hourly meteorological data used in the calibration of the QUAL nutrient model from the historical dates was then used to build the model time series for meteorological and water temperature boundary conditions. This set of matched daily air temperature dates was also used to develop time series of daily water temperature at three model boundaries – Sacramento, Vernalis and Martinez – that were then used as water temperature boundary conditions at the model inflow boundaries.

Boundary conditions for effluent inflow and water temperature were synthesized on an annual year basis (January – December) using existing data for each modeled year (1976 – 1991), creating a correspondence between one model year and one historical year. Using the aforementioned year-correspondence, Sacramento Regional Wastewater Treatment Plant (SRWTP) effluent flows were scaled to maintain the percentage of effluent flow in Sacramento R. inflow at or below the historical 2000 - 2005 daily maximum (approximately 4.5%). All other effluent flows were applied without scaling using the same annual year selection.

The DSM2/QUAL temperature model was calibrated for the time span 1990 - 2008 (Guerin, 2010). Model calibration was followed by a validation step. Data availability and the spatial and temporal resolution of calibration data dictated the quality of the calibration. Details on the temperature model calibration are documented in (Guerin, 2010), and discussed briefly in the Appendix of this document.

Figures representing the model bias in the historical simulation of water temperature are included in the Appendix as a guide to the interpretation of model results for each of seven analysis regions specified in previous BDCP analyses in the DSM2 model domain. For example, modeled water temperature in the South Delta and the upstream section of the San Joaquin R. was biased by several Celsius degrees cooler than indicated by data in the summer. This bias in model calculations is mainly due to the limitation in QUAL to a single meteorological region – previous results indicated that a minimum of two meteorological regions are required for modeling water temperature over the entire Delta (Guerin, 2010). However, since the boundary condition data, including meteorology, applied in the California WaterFix scenarios is based on historical data used in the calibrated model, the average monthly bias in the historical model can be applied to the California WaterFix model as a regional correction to model output on a monthly-average basis.

5.B.A.4.2 Background

5.B.A.4.2.1 Objectives

The main objectives of the work discussed in this document are to: (1) document model parameterization, boundary conditions and results of California WaterFix DSM2 water temperature simulations; and, (2) provide information on regional model bias as an aid to the appropriate interpretation of the DSM2 scenario water temperature results.

5.B.A.4.2.2 DSM2 Simulations for California WaterFix

The Delta Simulation Model-2,[1] or DSM2, is a suite of one-dimensional models that were used in this project to model the hydrodynamics and water temperature dynamics in the Delta due to changes in Delta operations, sea level rise and climate change as conceptualized in the California WaterFix scenarios.

The DSM2 suite of models was developed by California's Department of Water Resources (DWR). The hydrodynamic and water quality modules, HYDRO and QUAL, respectively, have been developed by DWR to simulate historical conditions in the Delta – this implementation is called the "Historical Model" herein. DSM2 is also frequently used to model hypothetical scenarios, as it was in this project for the California WaterFix. The scenario simulations were run using sets of hypothetical conditions over the water years[2] 1922 – 2003. The conditions modeled in this time frame do not represent conditions that actually occurred during these years – however, inflow boundary conditions are based loosely on the natural flow conditions occurring in California watersheds during this time frame as described in Appendix B, Section 5.B.2.3.2.

5.B.A.4.3 DSM2 Model Description

5.B.A.4.3.1 DSM2 – General information

DSM2 is a suite of one-dimensional hydrodynamic and water quality simulation models used to represent conditions in the Sacramento-San Joaquin Delta. DSM2 was developed by the Department of Water Resources (DWR) and is frequently used to model impacts associated with projects in the Delta, such as changes in exports, diversions, or channel geometries associated with dredging in Delta channels. It is considered the official Delta model for many purposes.

The simplification of the Delta to a one-dimensional model domain means that DSM2 can simulate the entire Delta region rapidly in comparison with higher dimensional models. Although many channels in the Delta are modeled well in one dimension, the loss of spatial detail in areas that are naturally multi-dimensional, such as Suisun Bay, limit DSM2's accuracy in those areas. In addition, the DSM2 grid conceptualizes several open water areas, for example Franks Tract and Mildred Island, as zero-dimensional "reservoir" volumes. For the transport of QUAL constituents, reservoirs is assumed to be a fully-mixed volume.

[1] http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/dsm2/dsm2.cfm

[2] A water year runs from the first of October the previous year through the end of September in the given year.

DSM2 contains three separate models, a hydrodynamic model (HYDRO), a water quality model (QUAL), and a particle tracking model (PTM). HYDRO was developed from the USGS FOURPT model (USGS, 1997). DWR adapted the FOURPT model to the Delta, accounting for such features as operable gates, open water areas, and export pumps. The water quality model, QUAL, is based on the Branched Lagrangian Transport Model (Jobson, 1997), also developed by the USGS. QUAL uses the hydrodynamics simulated in HYDRO as the basis for its transport calculations. The capability to simulate nutrient dynamics and water temperature in QUAL was developed by Rajbhandari (1995a, 1995b). The third model in the DSM2 suite is PTM, which simulates the fate and transport of neutrally buoyant particles. PTM also uses hydrodynamic results from HYDRO to track the fate of particles released at user-defined points in space and in time.

Detailed descriptions of the mathematical formulation implemented in HYDRO and for constituents in QUAL, required data, and past applications of the DSM2 Historical Model are documented in a series of reports available at:

http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/annualreports.cfm.

Documentation on the calibration and validation of the HYDRO model and the QUAL model for salinity used in the current and prior versions of DSM2 is available at that website. The calibration of DSM2 has generally focused on hydrodynamics and the transport of salinity, modeled as electrical conductivity (EC), and of dissolved organic carbon (DOC). The calibration of HYDRO in DSM2 Version 8 for hydrodynamics used in this project is assumed to be sufficient for our purposes.

Recently (Guerin, 2010), the water temperature and nutrient modules in QUAL Version 6 were calibrated in the Delta for the years 1990 through 2008 to model the transport of nutrients and water temperature as an extension of the base Historical Model implementation. In QUAL, water temperature can be modeled independently of the nutrients. The Version 6 calibration (Guerin, 2010) required the collection and synthesis of a large quantity of data needed to set the model boundary conditions over the modeled time span (1990 – 2008) and to calibrate and validate the model calculations. The description of the data used for the initial calibration, in particular the results of the water temperature calibration, is covered in detail in (Guerin, 2010). Subsequently, the temperature and nutrient models were recalibrated as improved versions of QUAL were made available (Guerin, 2011).

With the introduction of a new bathymetry in the DSM2 model grid of the Delta to incorporate the flooding of Liberty Island in the Cache Slough area due to levee breaks in the late 1990's, a recalibration of the hydrodynamics in HYDRO was undertaken for this bathymetry change by CH2M HILL (2009), and a new version for the DSM2 suite of models, Version 8[3], was introduced. The hydrodynamic simulations discussed in this report were run using the executable HYDRO Verison-8.0.6 (the version used in previous BDCP DSM2 modeling), while the water temperature models were run using QUAL Version-8.1.2 (the most recent version in 2014). QUAL Version-8.1.2 corrects and improves QUAL's computational accuracy. The computational results from the HYDRO version (8.0.6) used are somewhat different from those

[3] http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/dsm2/dsm2.cfm

calculated in the most recent version (8.1.2), so the former version (8.0.6) of HYDRO was used as the hydrodynamic basis for the water temperature simulations for consistency with CWF BA NAA and PA hydrodynamic results.

5.B.A.4.3.2 California WaterFix Model Bathymetry

Figure 5.B-1 shows the changes to the network of the DSM2 model (CH2M HILL 2009) used for the scenario simulations used in this study. The major changes are the inclusion of the Liberty Island open water area - this is modeled as a zero-dimensional “reservoir” in DSM2 terminology - and an extension and refinement in the grid at the northern boundary of the model. Figure 5.B-2 shows the earlier DSM2 Version 6 grid with channels, nodes and general location of open water areas other than Liberty Island.

5.B.A.4.4 Description of the DSM2 HYDRO and QUAL models

The implementation of the DSM2 modules HYDRO and QUAL discussed in this report extends the standard configuration of the DSM2 “Historical Model” by including effluent inflow from most of the wastewater treatment plants (WWTPs) with outfalls within DSM2’s model domain in the Delta.

5.B.A.4.4.1 HYDRO flow and stage boundaries

Boundaries that define the movement of water into and out of the Delta consist of inflow boundaries, outflow boundaries and a stage boundary set at Martinez. In Figure 5.B-3, the main inflow boundaries are denoted by blue stars. These boundaries are found at the each of the major rivers (Sacramento, San Joaquin, Calaveras, Mokelumne and Cosumnes), and at the Yolo Bypass and the Lisbon Toe Drain (in the Yolo region). The Yolo boundary only has inflow during periods of high Sacramento River inflow which generally occurs late fall through early spring. Flows at the Lisbon Toe Drain near Liberty Island on the north western edge of the Delta, used in the Version 6 implementation of the nutrient model and the Version 8 calibration discussed herein, are incorporated in the Yolo flow boundary for the two California WaterFix scenarios discussed in this document.

Figure 5.B-4 shows the approximate location of effluent inflow boundaries used in California WaterFix scenarios discussed in this report – two effluent locations supplying inflow to the Delta at Woodland and Davis are not included at boundary conditions. The combined volume of effluent water is generally small in comparison with other inflow contributions except in periods of very low inflow. The effects of evaporation, precipitation, and channel depletions and additions ascribed to agricultural influences are modeled using the Delta Island Consumptive Use (DICU) model[4]. This model is used to set boundary conditions at 258 locations throughout the Delta – these locations are subdivided into 142 regions. DICU flow boundary conditions vary monthly by region and are set by Water Year Type.

[4] http://www.iep.ca.gov/dsm2pwt/reports/DSM2FinalReport_v07-19-02.pdf, http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/dicu/DICU_Dec2000.pdf

5.B.A.4.4.2 QUAL's Conceptual Model for Water Temperature

The conceptual model for portraying the transport of water temperature in DSM2-QUAL is based on equations adopted from QUAL-2E (Brown and Barnwell, 1987). DSM2 is limited to a single set of meteorological boundary conditions for the entire model domain. This constitutes a major simplification for the Delta as the conditions can vary substantially regionally – for example, wind speed can vary by a factor of two at different meteorological observation stations within the Delta. DICU inflow water temperature is specified as a single monthly time series that is repeated annually. Effluent inflow water temperature was developed from wastewater treatment plant data. Details on the development of scenario boundary conditions for QUAL are discussed in the Appendix.

5.B.A.4.5 California WaterFix Water Temperature Simulation Comparisons

DSM2 hydrodynamic and water temperature models were run and subject to QA/QC for the following California WaterFix scenarios:

NAA_Q5_ ELT

PA_Q5_ELT

The hydrodynamic models were run using the executable for HYDRO Verison-8.0.6, the version used in previous BDCP DSM2 modeling, while the water temperature models were run using the QUAL executable Version-8.1.2 (the most recent version as of 2014). The two versions are fully compatible.

5.B.A.4.5.1 Analysis Period

The analysis period was October 1921– September 2003. The months February - September 1921 were modeled as a spin-up period (mainly for the water temperature simulations).

5.B.A.4.5.2 Boundary Conditions for the Scenarios

5.B.A.4.5.2.1 Hydrodynamic boundary conditions

Hydrodynamic boundary conditions for all simulations were provided to RMA by CH2M Hill for DSM2 model input. Effluent inflow boundaries were added to the HYDRO for the water temperature modeling – this aspect is covered below in the section on setting effluent boundary conditions. With the exception of effluent inflow, the hydrodynamic boundary conditions for each of the California WaterFix model scenarios were used without alteration from the original. Identical effluent inflow conditions were used for all scenarios.

5.B.A.4.5.2.2 Water temperature boundary conditions

Boundary conditions must be specified for water temperature at inflow boundaries and at the tidal boundary at Martinez, as specified in Figure 5.B-3, and for effluent locations as specified in Figure 5.B-4. Water temperature must also be specified at each DICU inflow location. For the California WaterFix scenarios documented in this report, DICU inflow water temperature is given as a monthly average that repeats annually – the values are shown in Figure 5.B-5. For comparison, the DICU temperature used in the California WaterFix scenarios (purple line, adapted from (DWR, 1995)) is shown in comparison to a Delta-wide average of agricultural drain data (blue line) from DWR's Municipal Water Quality Investigations (MWQI) branch database, 1997 through 2004. Note that although DICU inflows and outflows are also specified as monthly averages, the flows vary by year type so do not repeat annually.

The boundary conditions for meteorological parameters required for QUAL water temperature simulations were developed for the year 2030 - the details are covered later in this section.

All computations for the meteorological and water temperature boundary condition development were performed using Matlab scripts. Compilation of the output was performed in either Matlab or EXCEL. The assembly and calculation of effluent boundary conditions was done in EXCEL.

5.B.A.4.5.2.3 Synthesis of meteorological and temperature boundary conditions

Meteorological and water temperature boundary conditions were developed separately from the effluent boundary conditions. A single set of synthetic meteorology was generated using historical data, for the future climate change conditions for year 2030. Meteorological boundary conditions for QUAL include air temperature (dry bulb), wet bulb temperature, atmospheric pressure, wind speed and cloud cover.

Projected daily average temperatures for the 2030 climate change condition were used as a basis for meteorological boundary condition development by closely matching the average air temperature specified for each time frame with historical air temperature at approximately the same annual date (+/- 2 days) using the meteorological data[5] from the calibrated QUAL water temperature model. For a given model day for one of the climactic conditions, the projected average daily temperature is compared with daily average temperatures within +/-two days for all available historical years from the calibrated model (i.e., 1990 – 2008). The closest temperature is chosen from the list, the selected day and year is recorded, and the set of hourly meteorological conditions from the chosen historical day and year is then used for that model day. The final day in February in leap years was developed separately using a similar protocol Figure 5.B-7 and Figure 5.B-8 document the monthly averages of the meteorological parameters used as California WaterFix boundary conditions in the 2030 time frame.

A single set of boundary conditions for water temperature were also generated using historical data by using the same dates used in matching the projected and historical air temperatures. The historical water temperatures used in the calibrated QUAL model at the Sacramento R., Martinez and the San Joaquin R. boundaries from that day is then mapped into the California WaterFix scenario boundary conditions for water temperature. There are the only three time series used in setting all boundary water temperatures. Figure 5.B-9 illustrates the monthly averaged time series for water temperature and the document the boundaries used in each. Note that that the inflow water temperatures for these boundary condition time series show less variability among the three time frames than that shown by the meteorological boundary conditions.

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[5] This methodology was adapted from a method developed by Don Smith (president of RMA) for creating meteorological boundary conditions from historical data.

5.B.A.4.5.2.4 Effluent boundary conditions

Effluent boundary conditions were set in two ways – for the previous California WaterFix models, the period 1975 – 1992, effluent was set using historical data from the years 2000 through 2005 - boundary conditions from a historical year were selected to represent each modeled year. The historical year to use for boundary condition during a given model year, 1975 – 1991, was selected using a similar water year type on the Sacramento River as a general guide.

Table 5.B-1 shows the annual correspondence established between the historical year (Column 3) and the modeled year (Column 1). Sacramento Regional Wastewater Treatment Plant (SRWTP) effluent flows were scaled, using this year-correspondence, to ensure the daily percentage of effluent flow in Sacramento R. inflow remained below the historical 2000 -2005 maximum (approximately 4.5%, see Figure 5.B-6). All other effluent flows were applied without scaling using the annual year selection shown in Table 5.B-1. Values for effluent inflow water temperature were not changed from the values recorded in the historical time series for any of the effluent locations.

For the remainder of the modeled years for these two scenarios, historical years 2000 – 2004 were used. For leap years, either 2000 or 2004 was used, and for the other model years, historical years 2001, 2002 and 2003 were used the correspondence and the scaling for SRWTP inflows are shown in Table 5.B-2 for the years 1921 – 1974 and Table 5.B-3 for the years 1992 -2003.

5.B.A.4.6 Discussion

The regular bias in the historical QUAL modeled water temperature calculations quantified in the Appendix can be used to improve the accuracy in interpreting the California WaterFix scenario model results in the seven California WaterFix subregions. Because the meteorology and water temperature boundary conditions for the California WaterFix scenarios was developed based on those of the calibrated Historical Model, the calculated average bias also applies to the regions identified in the California WaterFix scenarios. Note that since the meteorology and inflow water temperatures for 2030 time frame scenarios were developed using meteorology and inflow water temperatures from the present day Historical Model, the maximum values for boundary condition temperatures for the 2030 scenarios are bounded by present-day maximums.

As noted in previous discussions, the open water areas in DSM2 are conceptualized as zero-dimensional fully mixed volumes. The consequence of this simplification is that the water temperature in the open water areas is an average temperature for the volume, and as such water exiting the open water areas may be muted (i.e., the overall range may be diminished) depending on the timing and location. However, this observation is a general one and has not been specifically tested in reviewing the California WaterFix results in comparison with a higher dimensional model (as this would require additional model development not practical at this juncture).

Due to the simplifications used in the conceptualizations of California WaterFix scenarios for DSM2 HYDRO and QUAL-water temperature, it seems reasonable to use the model results from QUAL as monthly averages along with application of the calculated average regional bias in water temperature from the historical simulation results.

5.B.A.4.7 References

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Rajbhandari, H., DWR 1995 Annual Progress Report, Chap 3: Water Quality. 1995b.

USGS, 1997. http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/misc/FourPointUSGSWRI97_4016.pdf

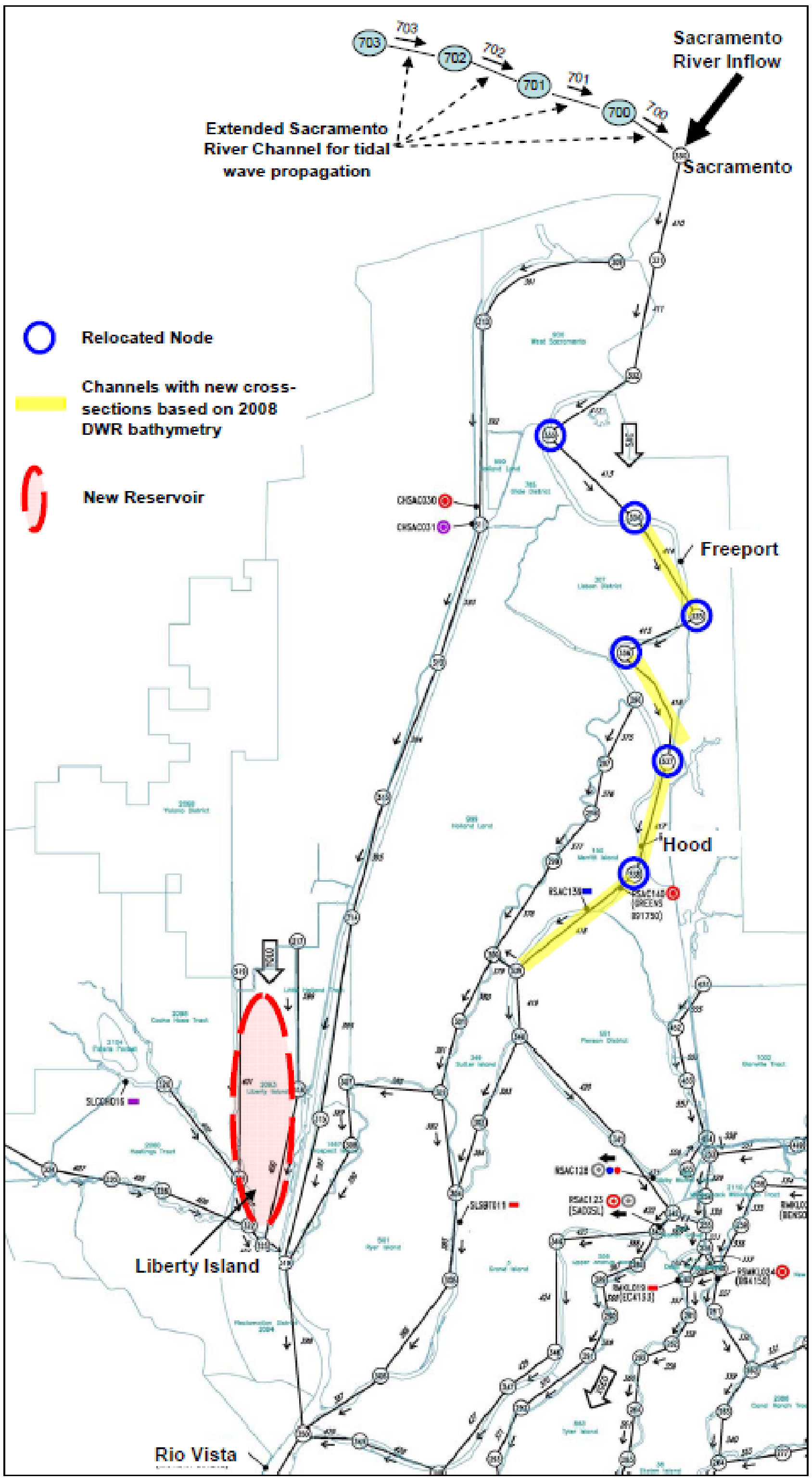


Figure 5.B-1 Changes implemented in the DSM2 V.8 model grid showing the new Liberty Island "reservoir" location, and changes to the grid and modes along the upstream portion of the Sacramento River.

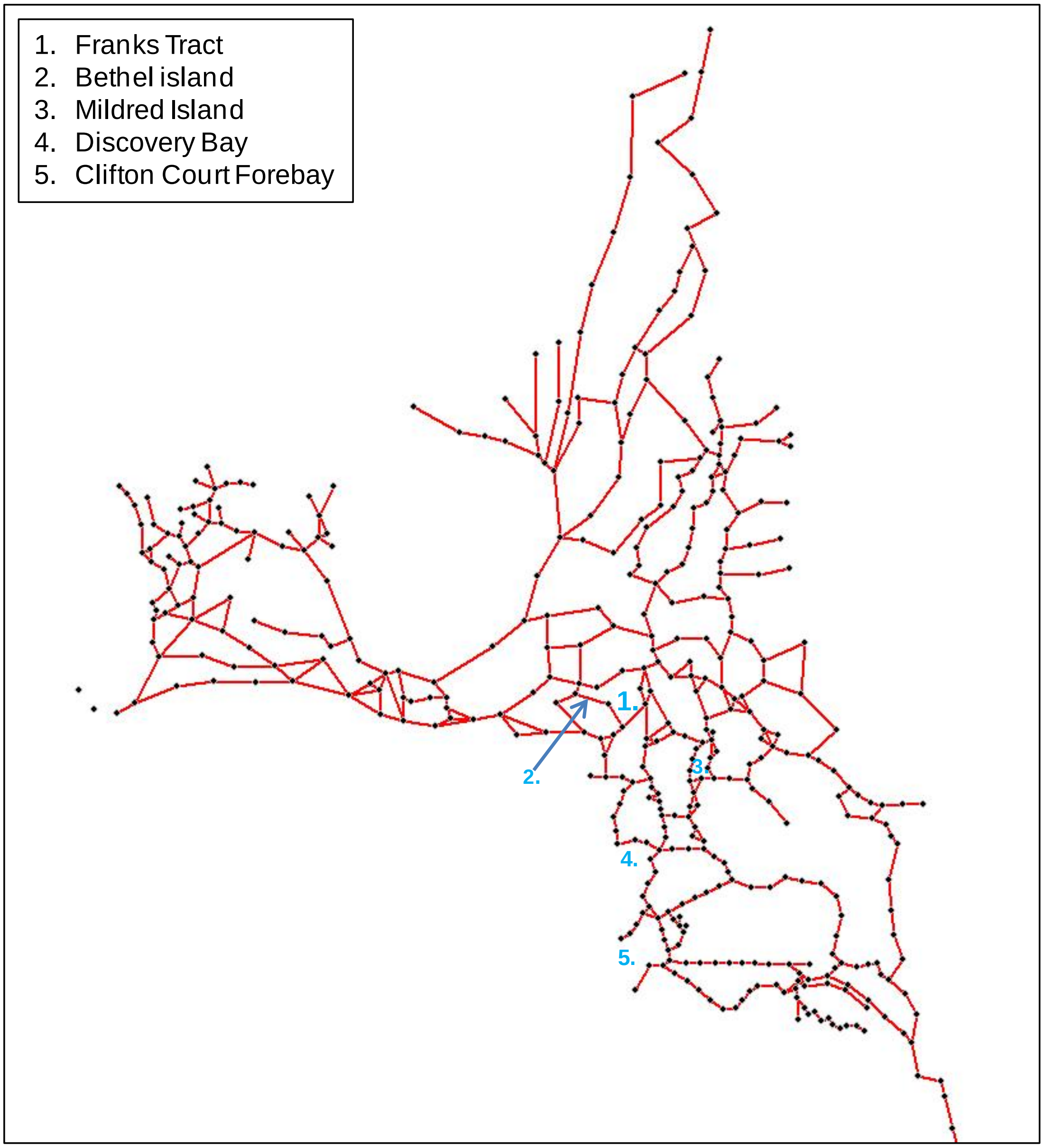


Figure 5.B-2 DSM2 Version 6 model grid showing channels (red), the approximate location of reservoirs (blue numbers), and nodes (black) between channels or at model boundaries.

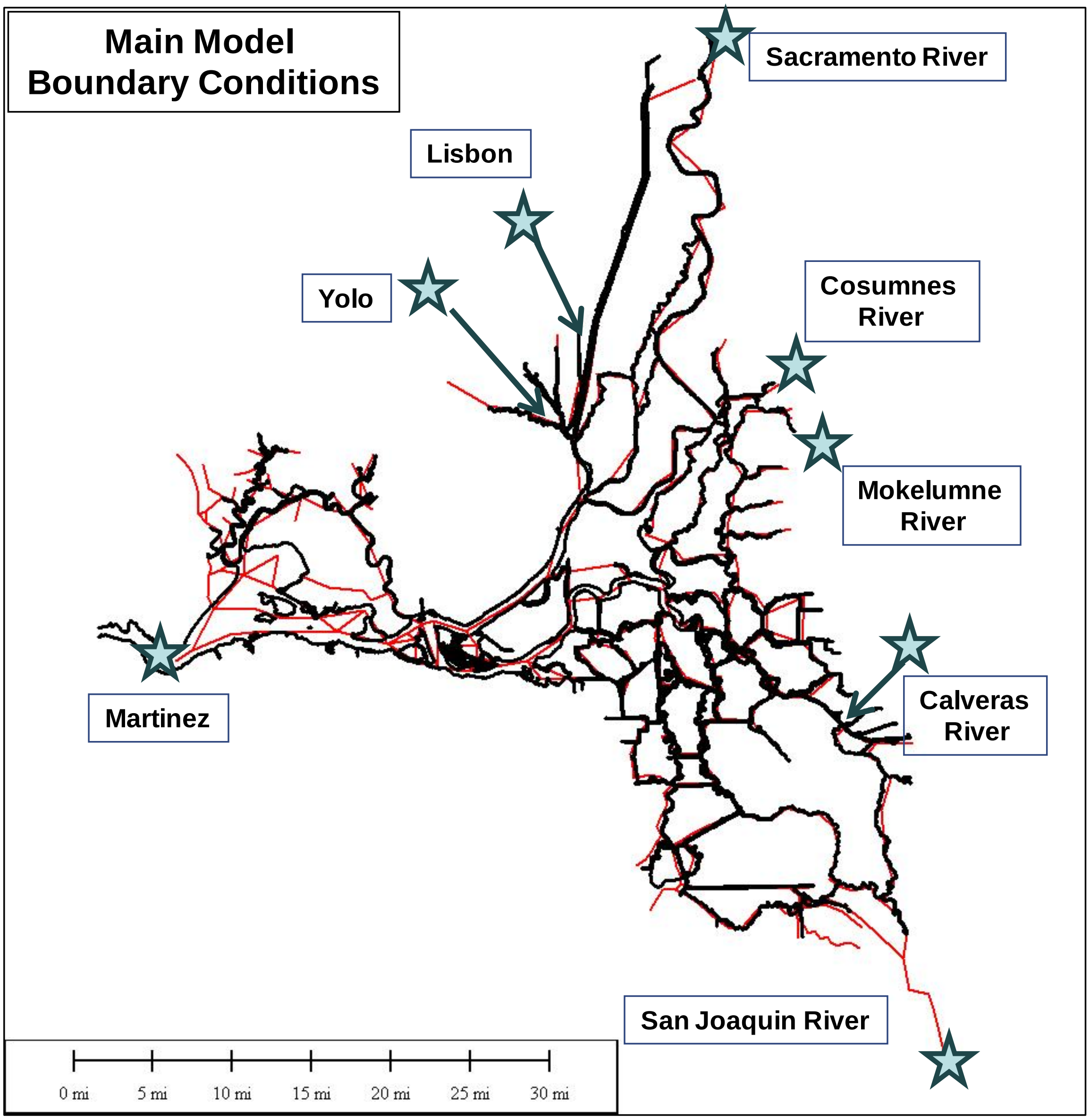


Figure 5.B-3 Approximate location of the model inflow (or outflow) boundaries (blue stars). The stage boundary is at Martinez.

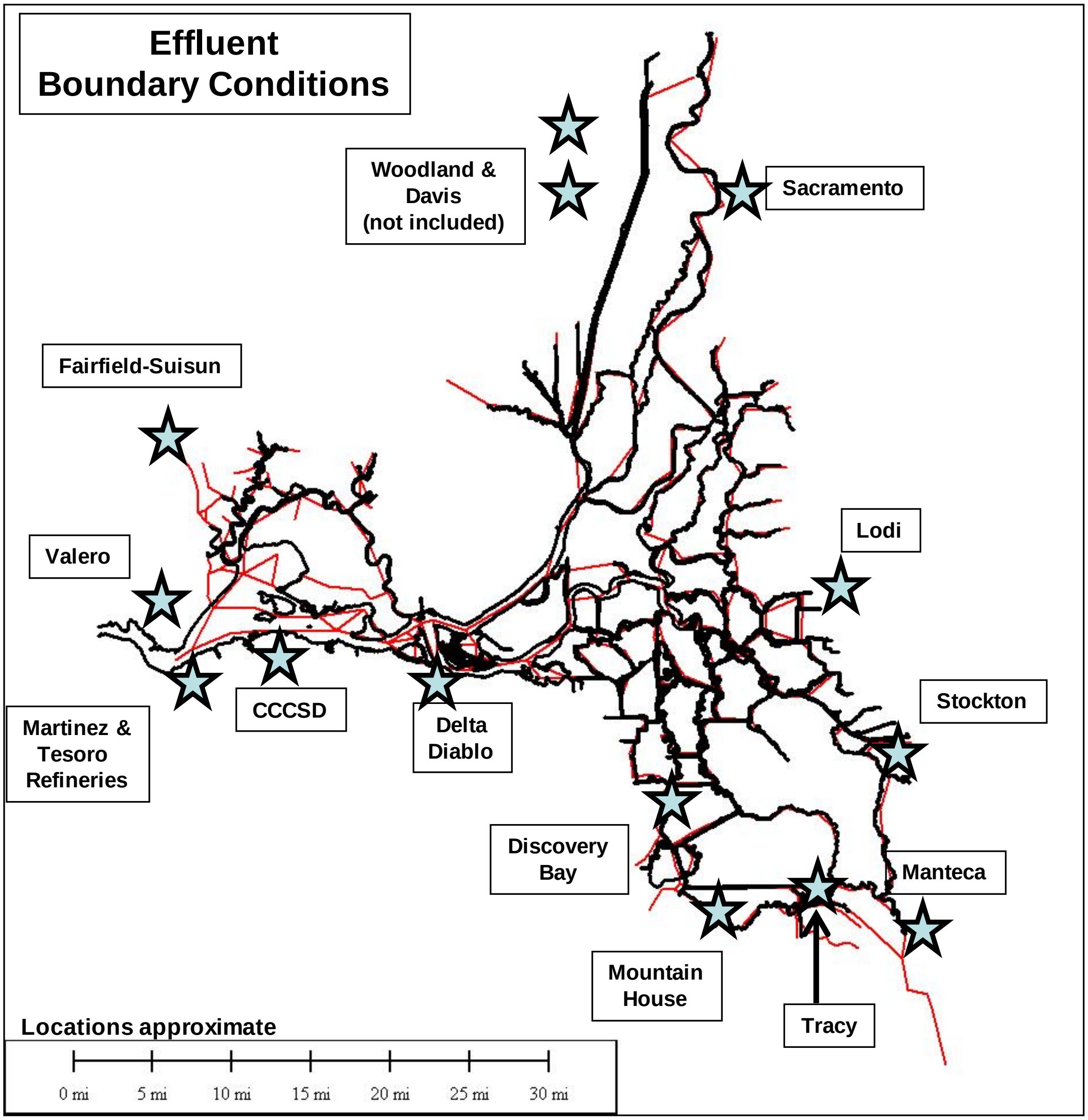


Figure 5.B-4 Approximate location of effluent boundary conditions for waste water treatment plants considered in this report.

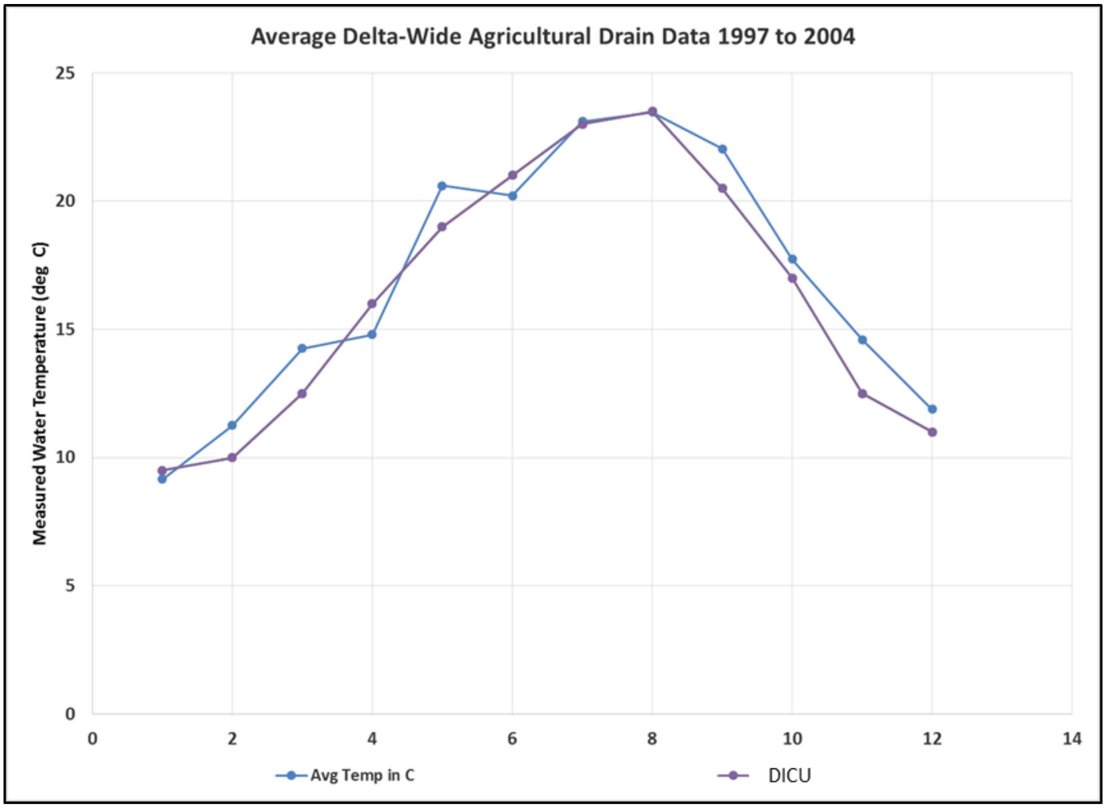


Figure 5.B-5 Comparison of DICU inflow water temperature (purple line) and a Delta-wide average of agricultural drain data (blue line) from the MWQI database.

Table 5.B-1 Correspondence between the former BDCP scenario model years (Column 1) and the Historical Model year (Column 3) used to apply all effluent BC, and the factor used to scale SRWTP effluent inflow (Column 4).

Model year	Sac WY Type	Historical BC Year	Factor*SRWTP Flow
1975	*W*	2000	1.0
1976	*C*	2004	1/1.4
1977	*C*	2002	1/1.6
1978	*AN*	2000	1.15
1979	*BN*	2004	1.0
1980	*AN*	2000	1.0
1981	*D*	2001	1.0
1982	*W*	2000	1.7
1983	*W*	2001	1.5
1984	*W*	2002	1.2
1985	*D*	2001	1.0
1986	*W*	2000	1.0
1987	*D*	2001	1/1.1
1988	*C*	2002	1/1.5
1989	*D*	2004	1/1.25
1990	***C***	2001	1/2.1
1991	***C***	2000	1/2

Table 5.B-2 Correspondence between the BDCP scenario years 1921 - 1974 and Historical years used to apply effluent BC, and the factor used to scale SRWTP effluent inflow).

Scenario Year	Sac WY Type	Historical BC Year	Factor*SRWTP Flow
1921	AN	2003	1
1922	AN	2003	1
1923	BN	2001	1/1.1
1924	C	2004	1/1.2
1925	D	2001	1
1926	D	2001	1
1927	W	2003	1
1928	AN	2000	1/1.4
1929	C	2001	1/1.1
1930	D	2001	1/1.3
1931	C	2001	1/1.3
1932	D	2004	1/1.2
1933	C	2001	1/1.1
1934	C	2001	1/2.5
1935	BN	2001	1/2.2
1936	BN	2004	1/1.1
1937	BN	2001	1
1938	W	2001	1
1939	D	2002	1/2.0
1940	AN	2000	1
1941	W	2003	1
1942	W	2003	1/1.4
1943	W	2003	1
1944	D	2000	1
1945	BN	2001	1
1946	BN	2001	1
1947	D	2001	1
1948	BN	2004	1/1.8
1949	D	2002	1/1.2
1950	BN	2002	1
1951	AN	2003	1
1952	W	2004	1
1953	W	2003	1
1954	AN	2003	1
1955	D	2001	1/1.3
1956	W	2000	1
1957	AN	2003	1
1958	W	2003	1
1959	BN	2001	1/1.3
1960	D	2004	1/1.1
1961	D	2001	1/1.2
1962	BN	2001	1
1963	W	2003	1
1964	D	2004	1/1.1
1965	W	2003	1
1966	BN	2001	1
1967	W	2003	1
1968	BN	2004	1
1969	W	2003	1
1970	W	2003	1
1971	W	2003	1
1972	BN	2004	1
1973	AN	2003	1
1974	W	2003	1

Table 5.B-3 Correspondence between the BDCP scenario years 1992 - 2003 and Historical years used to apply effluent BC, and the factor used to scale SRWTP effluent inflow).

Scenario Year	Sac WY Type	Historical BC Year	Factor*SRWTP Flow
1992	C	2004	1/1.5
1993	AN	2003	1
1994	C	2001	1/1.1
1995	W	2003	1
1996	W	2000	1
1997	W	2003	1
1998	W	2003	1
1999	W	2003	1
2000	AN	2000	1
2001	D	2001	1
2002	D	2002	1
2003	AN	2003	1

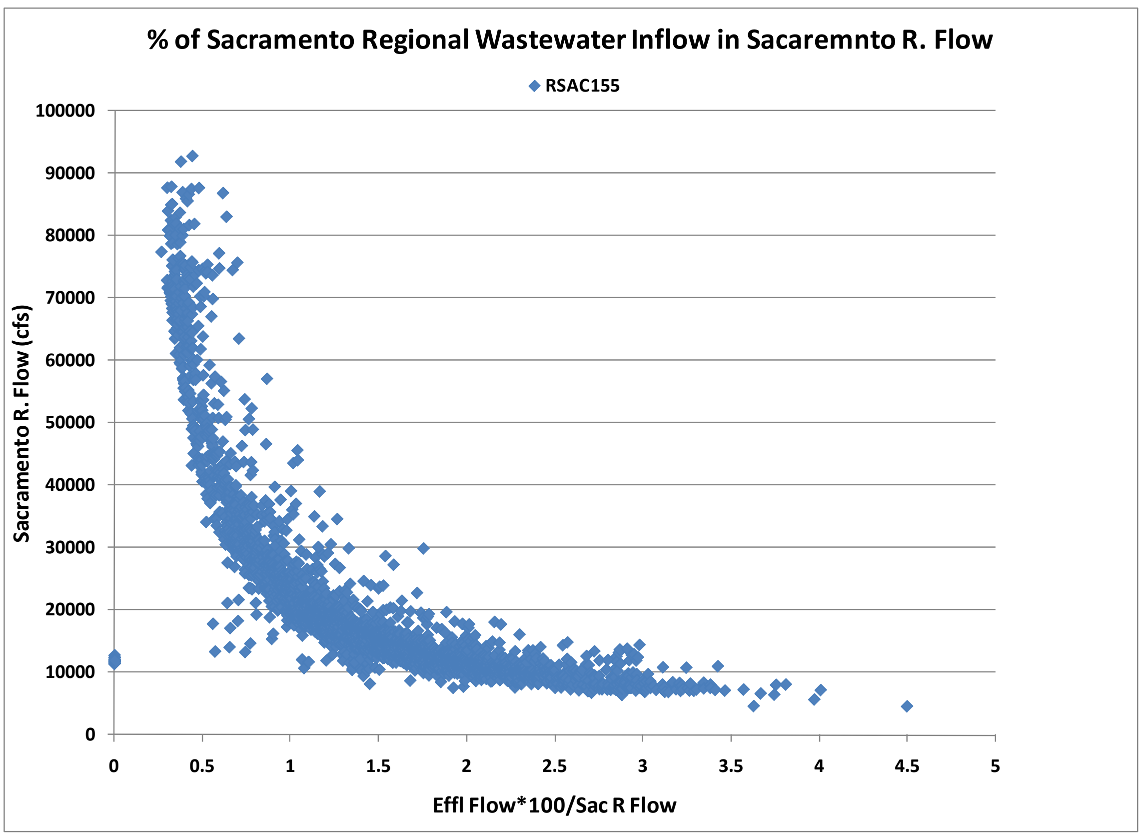


Figure 5.B-6 Maximum percentage of Sacramento Regional Wastewater inflow in Sacramento R. inflow was generally less than 4 %.

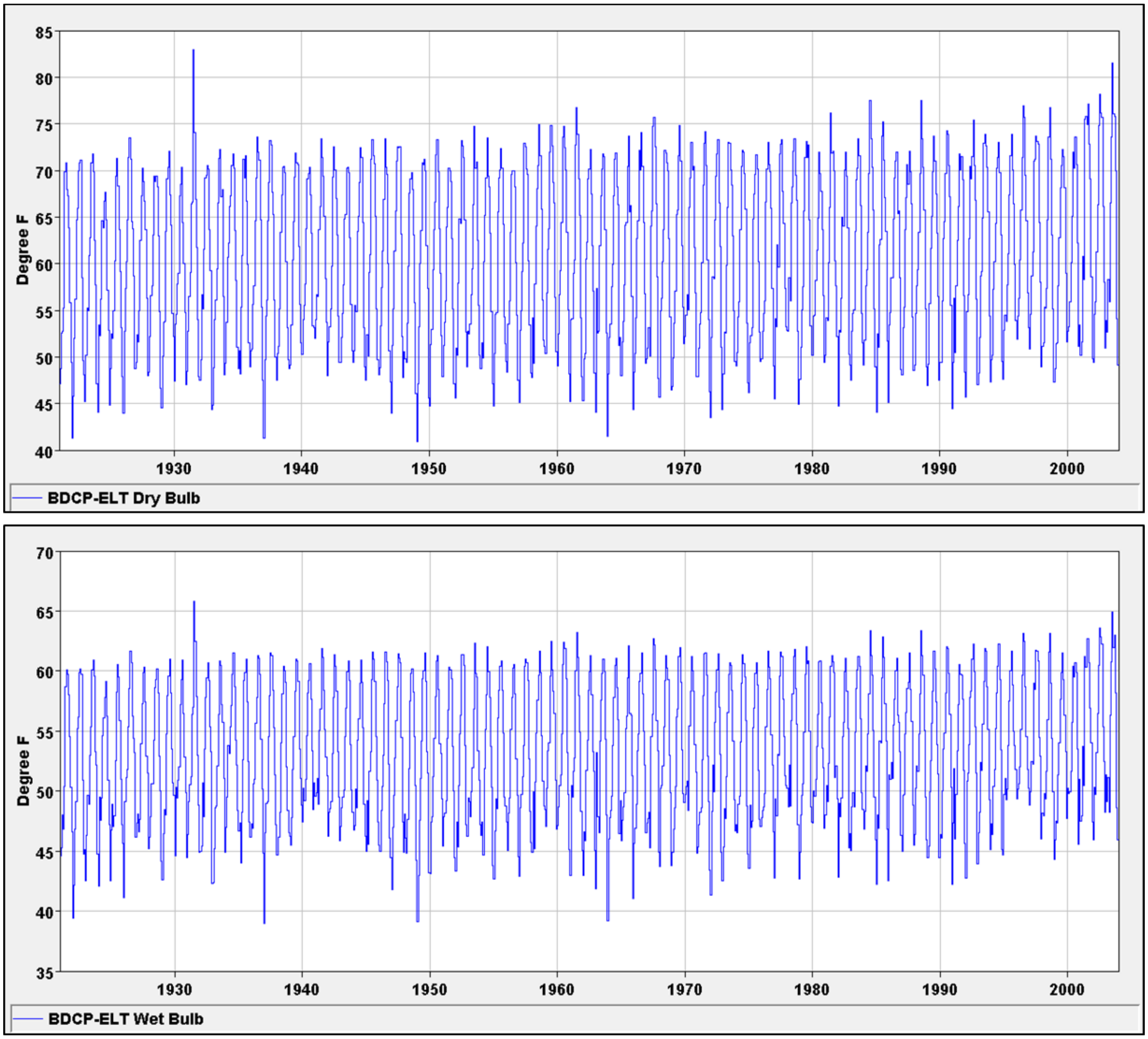


Figure 5.B-7 Monthly average air temperature (upper) and wet bulb temperature (lower) for the year 2030 time frame.

Figure 5.B-8 Monthly average wind speed (upper), fraction cloud cover and atmospheric pressure (lower) for the year 2030 scenario time frame.

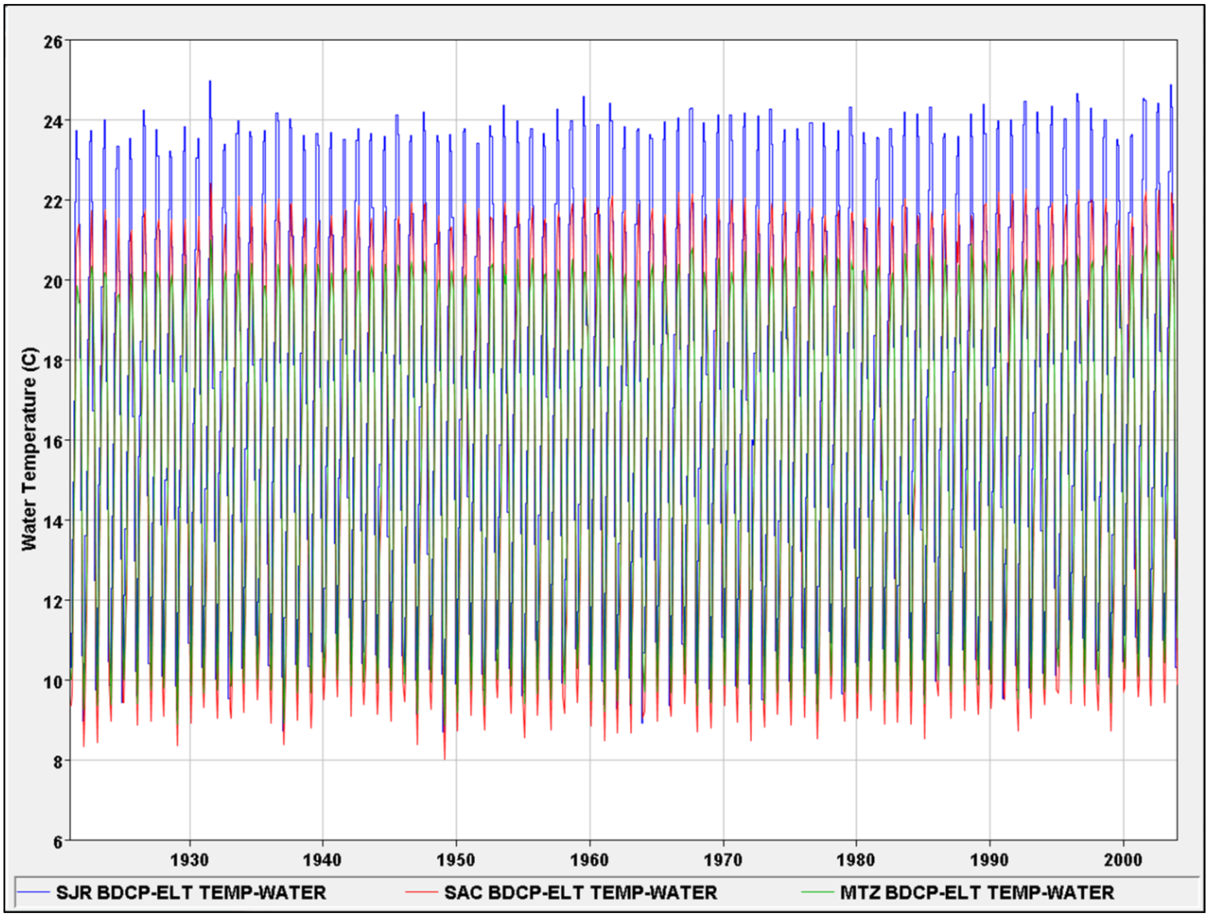


Figure 5.B-9 Inflow water temperature for the Sacramento and San Joaquin Rivers and the Martinez stage boundary for the year 2030 time frame. The San Joaquin River boundary is also applied to the Calaveras River. The Sacramento River boundary is applied to all remaining inflow boundaries.

5.B.A.4.8 Appendix

5.B.A.4.8.1 Water Temperature Model Calibration/validation

Data acquisition locations used to support the water temperature model calibration are shown in Figure 5.B-10. Discussion on the sources and quality of this data is covered in great detail in (Guerin, 2010) and in (Guerin, 2011). Both graphical and statistical model evaluation techniques were used in the analysis of calibration and validation results. Water temperature calibration and validation statistics were calculated on an annual basis by Wet or Dry Water Year Type at each available location. Residuals for water temperature were calculated as the difference (data – model) between the measured data and the modeled result on the same time scale, hourly or daily averages.

Selected plots documenting the quality of the water temperature model calibration are shown in Figure 5.B-11 through Figure 5.B-15. As discussed in (Guerin, 2010), the temperature model calibration results are generally Very Good. The main draw-back in the DSM2/QUAL temperature model is that meteorological boundary conditions are applied globally over the model domain, but model results indicate that a minimum of two temperature regions are required to improve results. The current model results are very good along the Sacramento River corridor where the calibration was focused. In the Central and South Delta, modeled water temperatures in the summer months can be several degrees Celsius cooler than indicated by the data, as illustrated at ROLD024 (Figure 5.B-15). However, the model temperature trends and diurnal variations are reasonable.

A more extensive analysis of the modeling of water temperature was undertaken to help define potential pitfalls with the conceptualization of Liberty Island as a fully mixed reservoir in DSM2. This analysis is documented in (RMA, 2015).

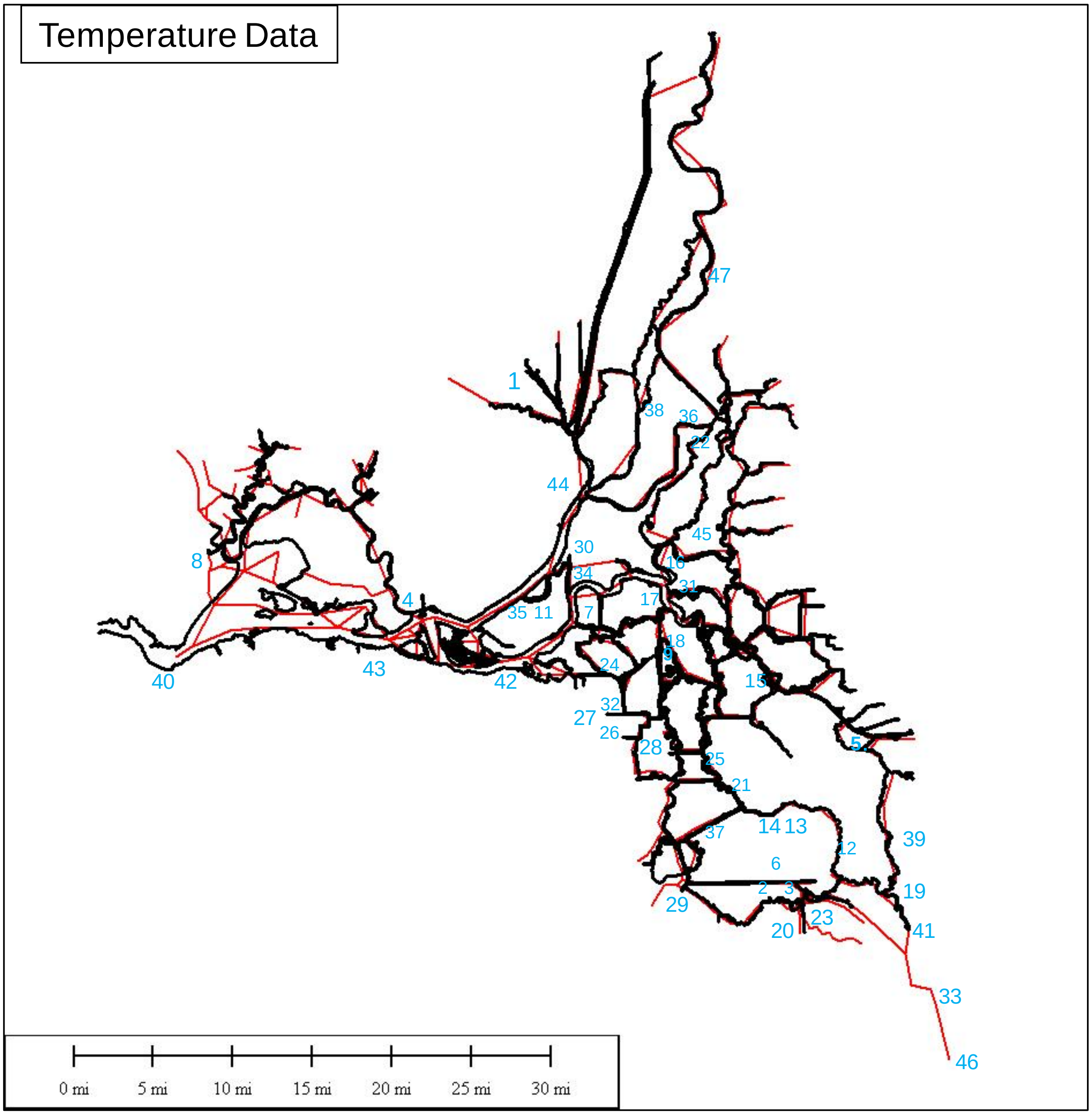


Figure 5.B-10 Locations of temperature data regular time series. Data quality and length of record was variable.

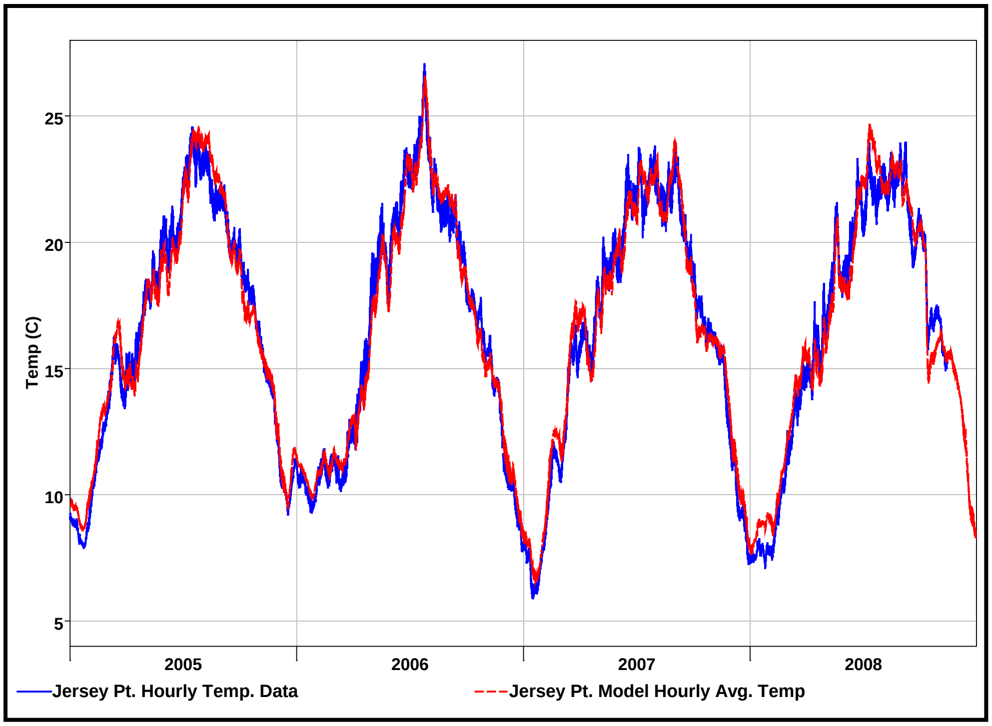


Figure 5.B-11 Hourly calibration results for water temperature at Jersey Point. Blue line is hourly data, red line is the modeled hourly result averaged from 15-minute model output.

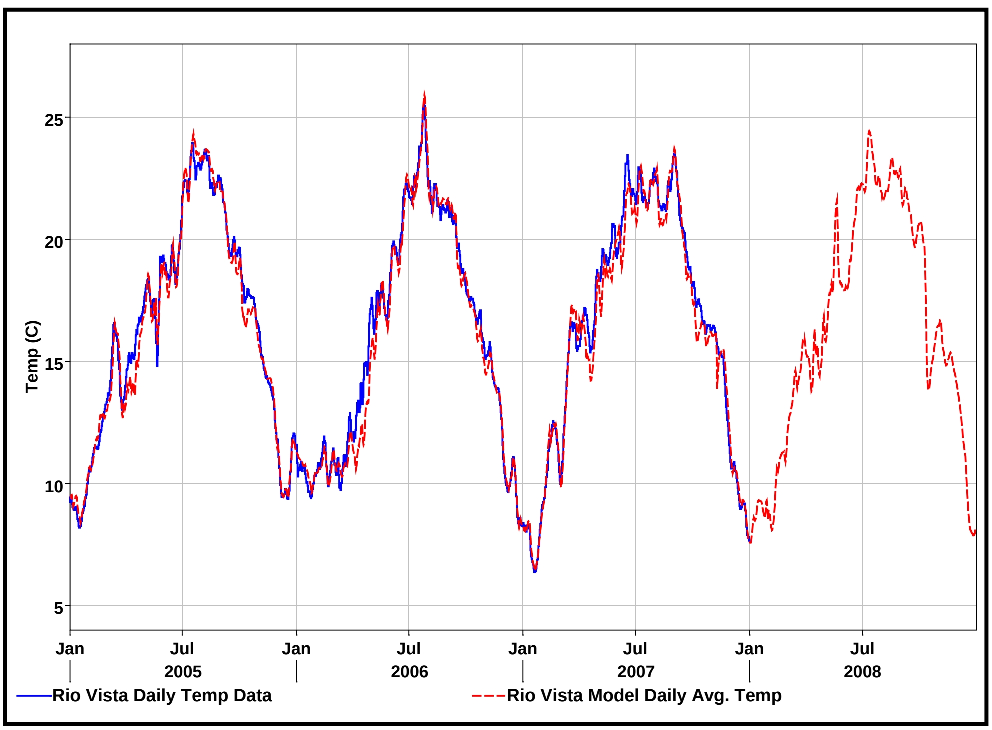


Figure 5.B-12 Daily calibration results for water temperature at Rio Vista. Blue line is daily data, red line is the modeled daily result averaged from 15-minute model output.

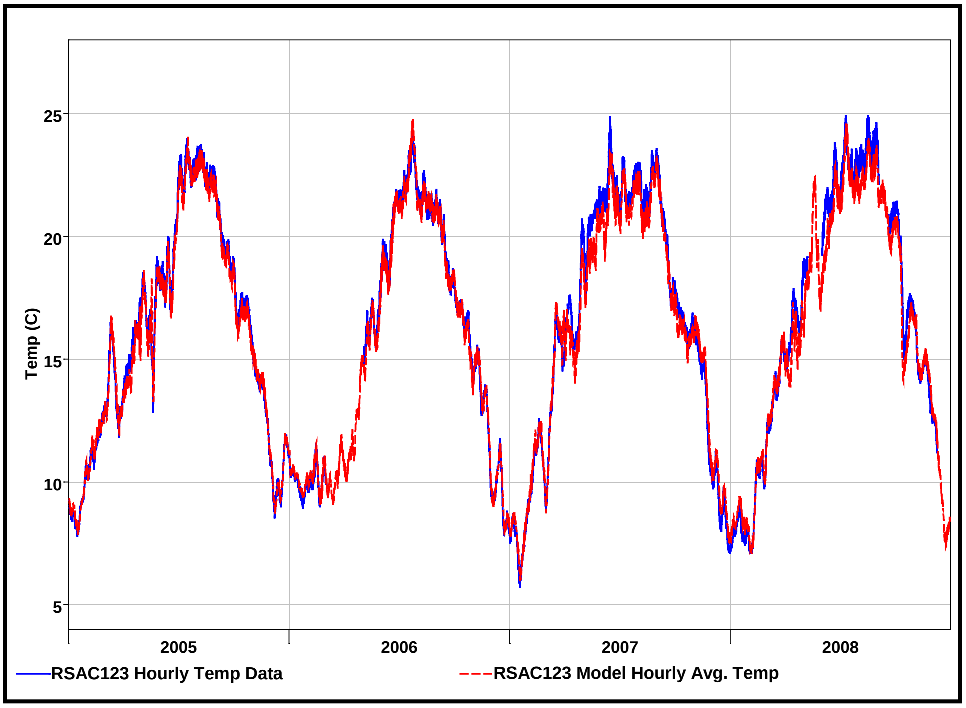


Figure 5.B-13 Hourly calibration results for water temperature at RSAC123. Blue line is hourly data, red line is the modeled hourly result averaged from 15-minute model output.

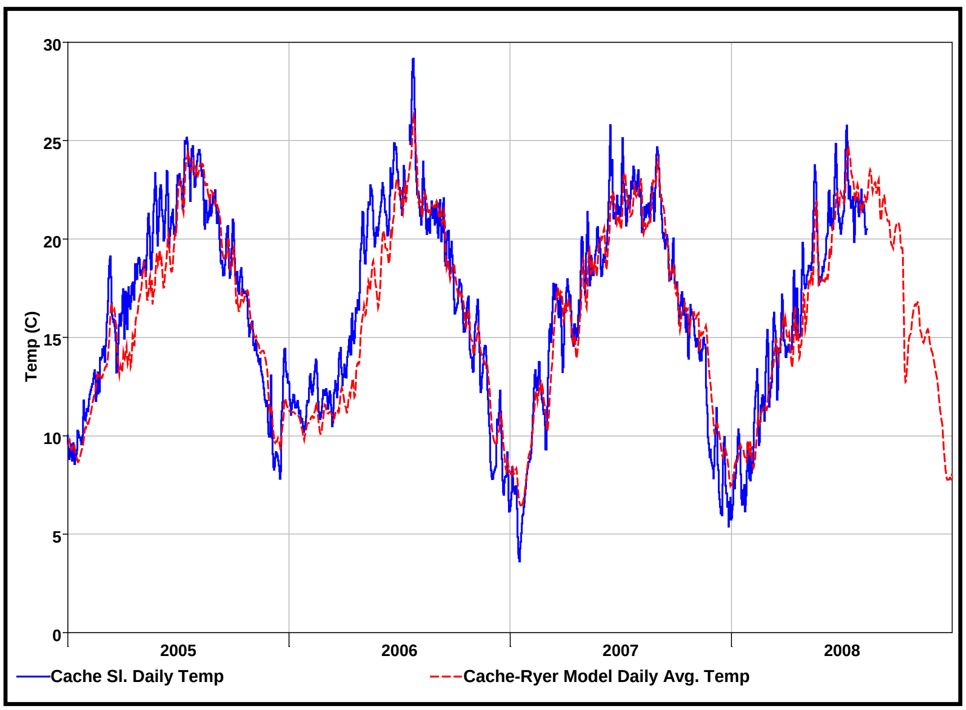


Figure 5.B-14 Hourly calibration results for water temperature at locations in the Cache Slough area. Blue line is daily data, red line is the modeled daily result averaged from 15-minute model output.

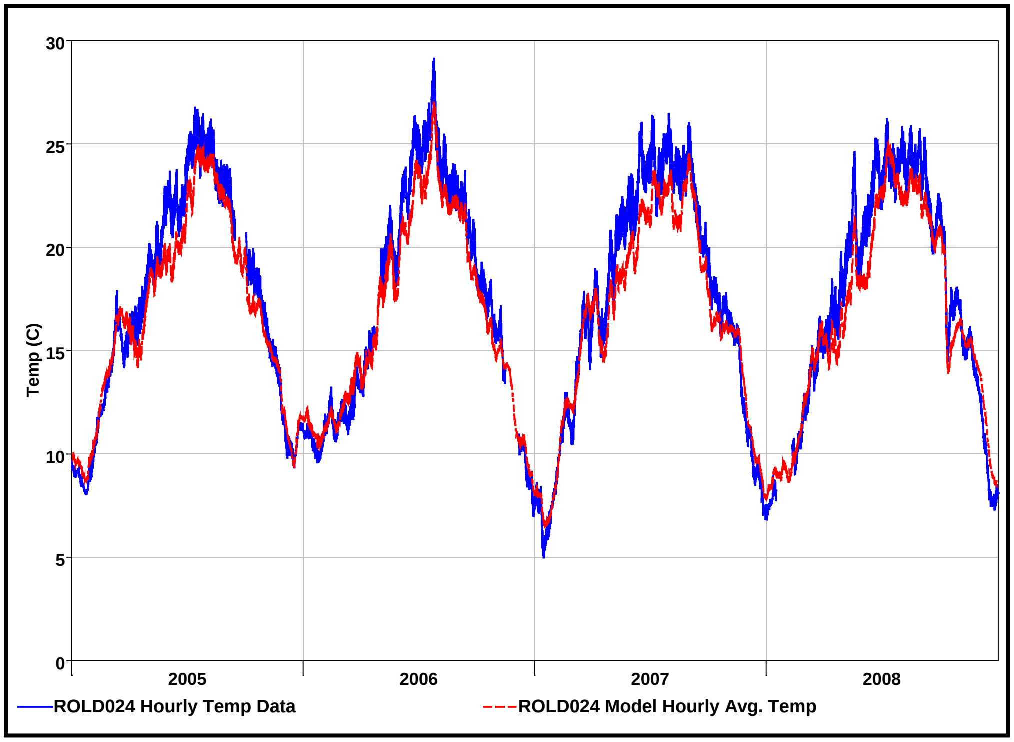


Figure 5.B-15 Hourly calibration results for water temperature at ROLD024. Blue line is hourly data, red line is the modeled hourly result averaged from 15-minute model output.

5.B.A.4.8.2 Residual analysis using recent data

The DSM2 Historical model was used to calculate estimates of bias in water temperature modeling at a monthly time step using model residuals (*i.e.*, model – data). The Historical water temperature model was run with boundary conditions relevant to the type of conditions used in the BDCP analyses. The following process was used to create estimates of QUAL model bias in water temperature using the seven regions identified in the BDCP scenarios (see Figure 5.B-22):

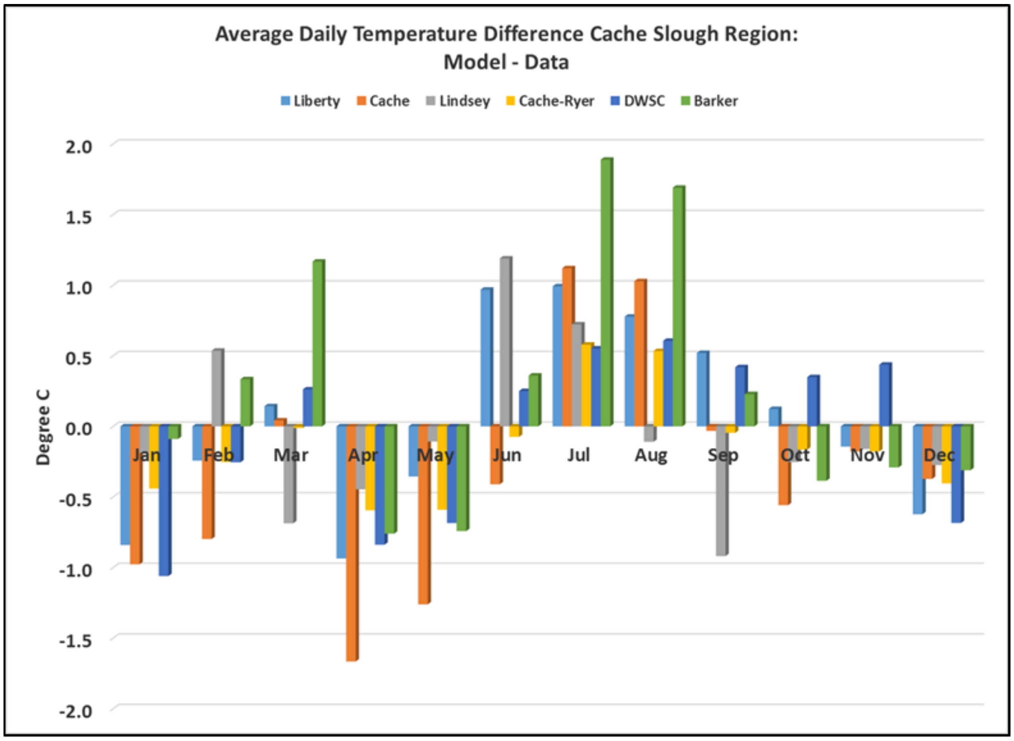
- Process Step 1: CDEC data was downloaded at each location where there was water temperature data in the Delta, with a focus on data from 12/2007 to 03/2012
- The data was examined and spurious data points were deleted – for most locations the gaps were then filled with a linear approximation.
- The data was then daily-averaged
- Process Step 2: The DSM2 Historical model output (15-min output) at each available CDEC data location was daily averaged.
- The difference (model-data) was calculated, sorted by month, and an overall average was calculated for each month at every data location.
- The individual location results were categorized by the BDCP region as individual bar charts, and then collated as a BDCP-regional bar chart and also in a tabular format.

The results in the individual and regional bar charts and tables give an estimate of the bias in the BDCP water temperature results, and the bias is generally regular, i.e., it the direction of the bias is consistent over the locations in a given region. For example, in the South Delta Region, the regional bar chart (Figure 5.B-22) shows that regional water temperature calculated by Historical DSM2 is too cold by 1- 2 °C from April to October annually. The estimates of bias found in the Tables as regional averages can be used in the interpretation of BDCP regional water temperature results.

Special notes:

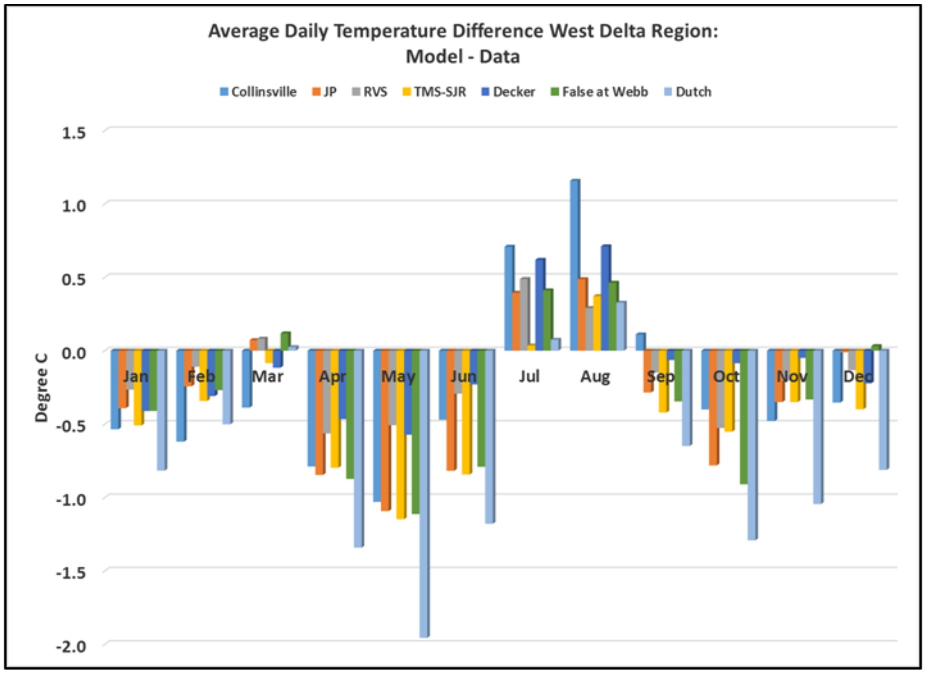
- Some locations had data that was harder to identify as spurious – those locations are noted in text near the individual bar chart
- At some locations, e.g. Dutch Slough in the West Delta Region, the results are quite different from the other locations, indicating that the influences on that location are complicated – possibly more of a mixture of the hydrodynamic influences on nearby regions and/or that DSM2 model results do not accurately reflect the data.

The water temperature and meteorological boundary conditions used in DSM2-CWF models were developed based on historical data, so it is expected that the magnitude of the regional (model – data) bias calculations documented herein are applicable to CWF models as a regional monthly bias in water temperature. The reason that the bias occurs in the DSM2 water temperature model is that DSM2 only allows a single meteorological region as a boundary condition when in fact the meteorological conditions influencing the Delta would more realistically require a minimum of two regions. When the bias is regular as it is in the South Delta, for example, this legitimately allows for correction in the interpretation of the CWF model results.



Cache Region: Average Monthly Temperature Difference From Daily Average Data (Deg C)							
	Liberty	Cache	Lindsey	Cache-Ryer	DWSC	Barker	Average
Jan	-0.8	-1.0	-0.2	-0.4	-1.1	-0.1	-0.6
Feb	-0.2	-0.8	0.5	-0.3	-0.3	0.3	-0.1
Mar	0.1	0.0	-0.7	0.0	0.3	1.2	0.2
Apr	-0.9	-1.7	-0.4	-0.6	-0.8	-0.8	-0.9
May	-0.4	-1.3	-0.1	-0.6	-0.7	-0.7	-0.6
Jun	1.0	-0.4	1.2	-0.1	0.3	0.4	0.4
Jul	1.0	1.1	0.7	0.6	0.6	1.9	1.0
Aug	0.8	1.0	-0.1	0.5	0.6	1.7	0.8
Sep	0.5	0.0	-0.9	0.0	0.4	0.2	0.0
Oct	0.1	-0.6	-0.3	-0.2	0.3	-0.4	-0.1
Nov	-0.1	-0.2	-0.2	-0.2	0.4	-0.3	-0.1
Dec	-0.6	-0.4	-0.3	-0.4	-0.7	-0.3	-0.4

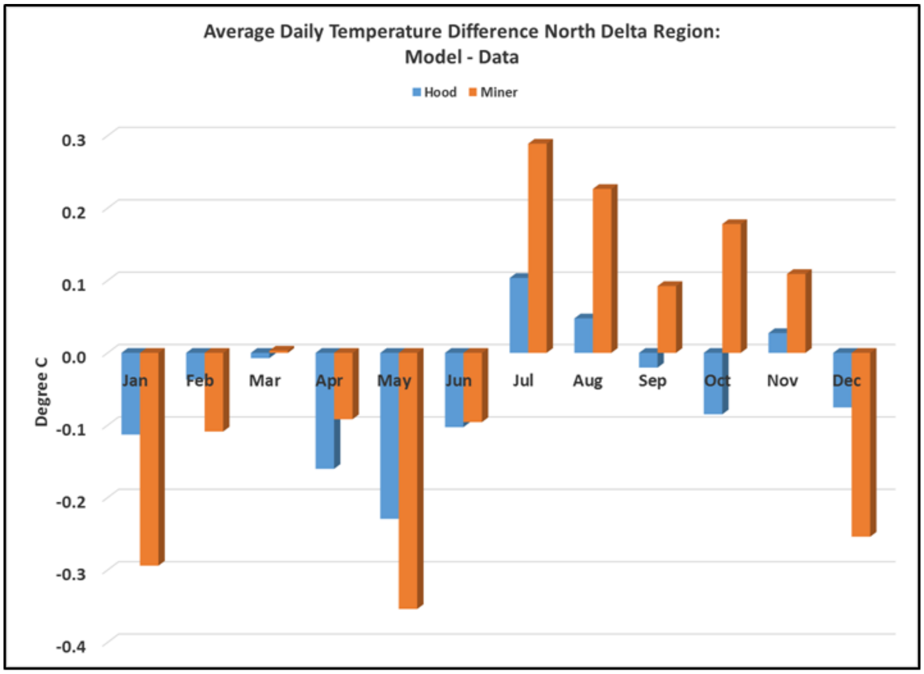
Figure 5.B-16 QUAL water temperature bias calculation for the Cache Slough region.



West Delta: Average Monthly Temperature Difference From Daily Average Data (Deg C)

	Collinsville	JP	RVS	TMS-SJR	Decker	False at Webb	Dutch	Average
Jan	-0.5	-0.4	-0.3	-0.5	-0.4	-0.4	-0.8	-0.5
Feb	-0.6	-0.2	-0.1	-0.3	-0.3	-0.3	-0.5	-0.3
Mar	-0.4	0.1	0.1	-0.1	-0.1	0.1	0.0	0.0
Apr	-0.8	-0.8	-0.6	-0.8	-0.5	-0.9	-1.3	-0.8
May	-1.0	-1.1	-0.5	-1.1	-0.6	-1.1	-2.0	-1.1
Jun	-0.5	-0.8	-0.3	-0.8	-0.2	-0.8	-1.2	-0.7
Jul	0.7	0.4	0.5	0.0	0.6	0.4	0.1	0.4
Aug	1.2	0.5	0.3	0.4	0.7	0.5	0.3	0.5
Sep	0.1	-0.3	-0.1	-0.4	-0.1	-0.3	-0.6	-0.3
Oct	-0.4	-0.8	-0.5	-0.6	-0.1	-0.9	-1.3	-0.6
Nov	-0.5	-0.3	-0.2	-0.3	0.0	-0.3	-1.0	-0.4
Dec	-0.4	0.0	-0.1	-0.4	-0.2	0.0	-0.8	-0.3

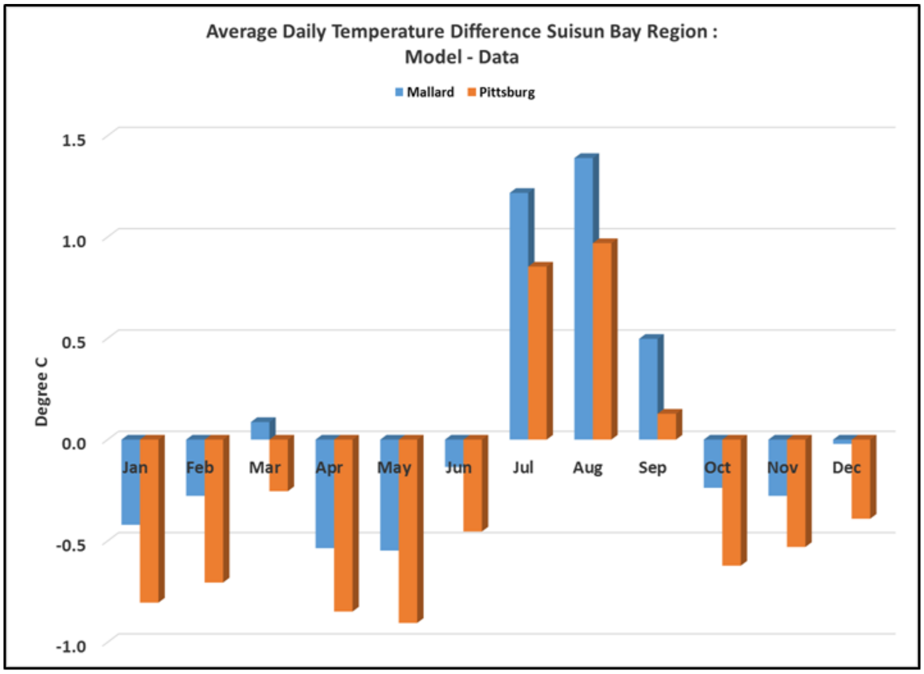
Figure 5.B-17 QUAL water temperature bias calculation for the West Delta region.



North Delta: Average Monthly Temperature Difference From Daily Average Data (Deg C)

	Hood	Miner	Average
Jan	-0.1	-0.3	-0.2
Feb	0.0	-0.1	-0.1
Mar	0.0	0.0	0.0
Apr	-0.2	-0.1	-0.1
May	-0.2	-0.4	-0.3
Jun	-0.1	-0.1	-0.1
Jul	0.1	0.3	0.2
Aug	0.0	0.2	0.1
Sep	0.0	0.1	0.0
Oct	-0.1	0.2	0.0
Nov	0.0	0.1	0.1
Dec	-0.1	-0.3	-0.2

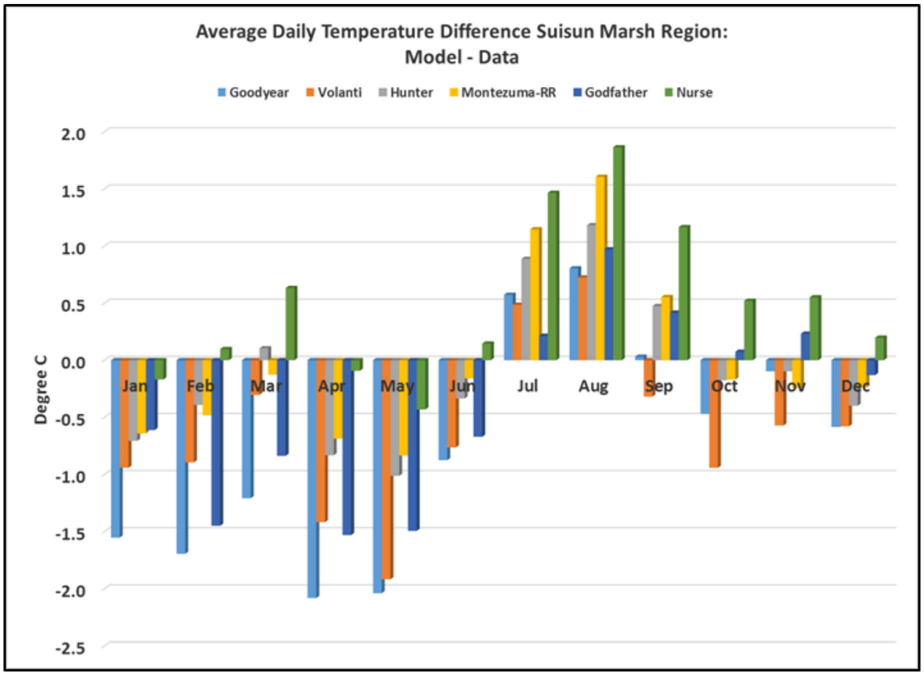
Figure 5.B-18 QUAL water temperature bias calculation for the North Delta region.



Suisun Bay: Average Monthly Temperature Difference From Daily Average Data (Deg C)

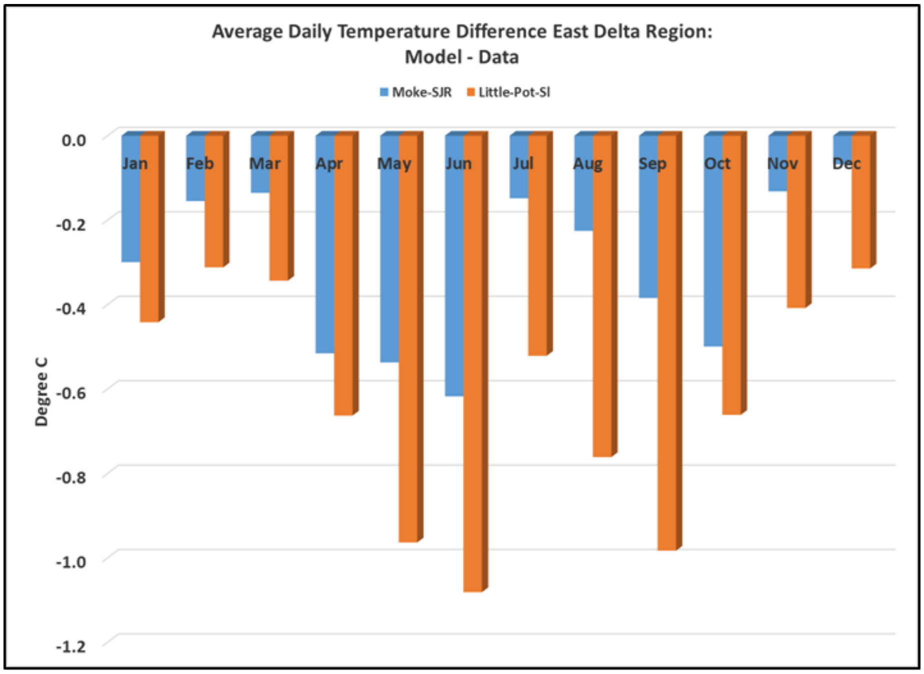
	Mallard	Pittsburg	Average
Jan	-0.4	-0.8	-0.6
Feb	-0.3	-0.7	-0.5
Mar	0.1	-0.3	-0.1
Apr	-0.5	-0.8	-0.7
May	-0.5	-0.9	-0.7
Jun	-0.1	-0.5	-0.3
Jul	1.2	0.9	1.0
Aug	1.4	1.0	1.2
Sep	0.5	0.1	0.3
Oct	-0.2	-0.6	-0.4
Nov	-0.3	-0.5	-0.4
Dec	0.0	-0.4	-0.2

Figure 5.B-19 QUAL water temperature bias calculation for the Suisun Bay region.



Suisun Marsh: Average Monthly Temperature Difference From Daily Average Data (Deg C)							
	Goodyear	**Volanti**	**Hunter**	**Montezuma-RR**	**Godfather**	**Nurse**	**Average**
Jan	-1.6	-0.9	-0.7	-0.6	-0.6	-0.2	-0.8
Feb	-1.7	-0.9	-0.4	-0.5	-1.4	0.1	-0.8
Mar	-1.2	-0.3	0.1	-0.1	-0.8	0.6	-0.3
Apr	-2.1	-1.4	-0.8	-0.7	-1.5	-0.1	-1.1
May	-2.0	-1.9	-1.0	-0.8	-1.5	-0.4	-1.3
Jun	-0.9	-0.8	-0.3	-0.2	-0.7	0.1	-0.4
Jul	0.6	0.5	0.9	1.1	0.2	1.5	0.8
Aug	0.8	0.7	1.2	1.6	1.0	1.9	1.2
Sep	0.0	-0.3	0.5	0.6	0.4	1.2	0.4
Oct	-0.5	-0.9	-0.2	-0.2	0.1	0.5	-0.2
Nov	-0.1	-0.6	-0.1	-0.2	0.2	0.6	0.0
Dec	-0.6	-0.6	-0.4	-0.2	-0.1	0.2	-0.3

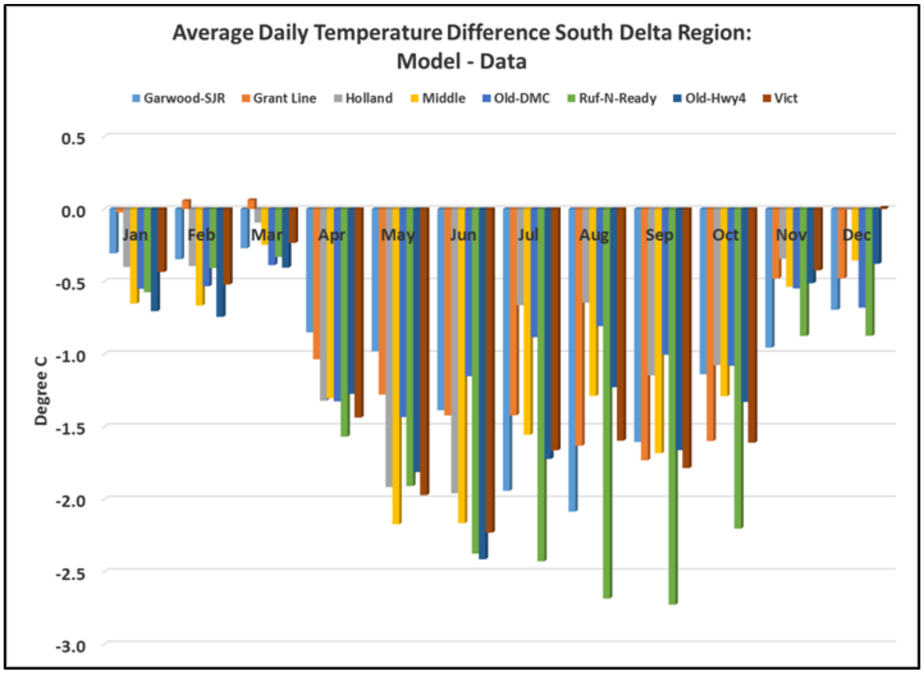
Figure 5.B-20 QUAL water temperature bias calculation for the Suisun Marsh region.



East Delta: Average Monthly Temperature Difference From Daily Average Data (Deg C)

	Moke-SJR	Little-Pot-Sl	Average
Jan	-0.3	-0.4	-0.4
Feb	-0.2	-0.3	-0.2
Mar	-0.1	-0.3	-0.2
Apr	-0.5	-0.7	-0.6
May	-0.5	-1.0	-0.8
Jun	-0.6	-1.1	-0.8
Jul	-0.1	-0.5	-0.3
Aug	-0.2	-0.8	-0.5
Sep	-0.4	-1.0	-0.7
Oct	-0.5	-0.7	-0.6
Nov	-0.1	-0.4	-0.3
Dec	-0.1	-0.3	-0.2

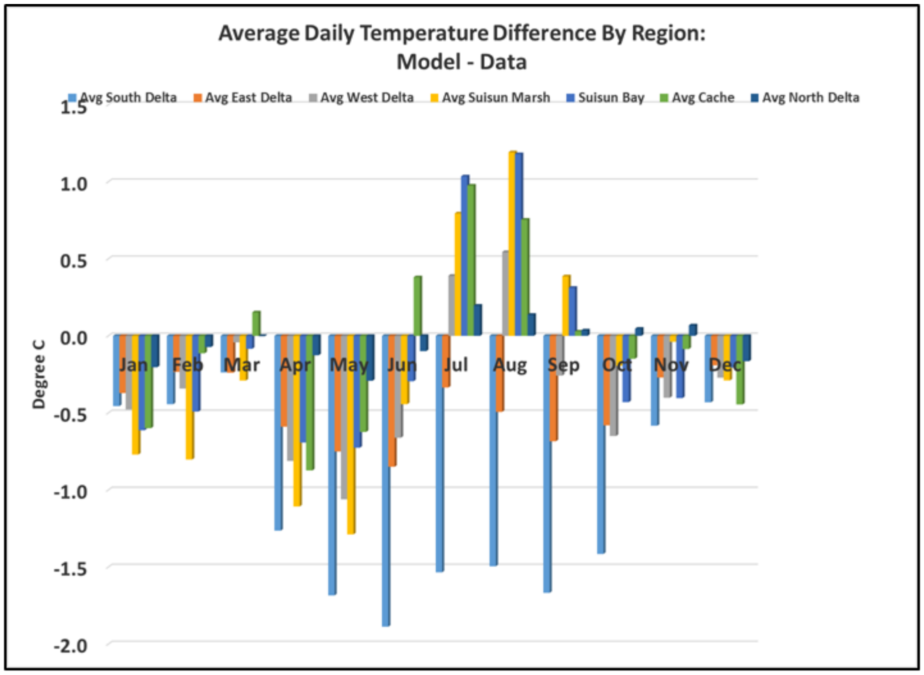
Figure 5.B-21 QUAL water temperature bias calculation for the East Delta region.



South Delta: Average Monthly Temperature Difference From Daily Average Data (Deg C)

	Garwood-SJR	Grant Line	Holland	Middle	Old-DMC	Ruf-N-Ready	Old-Hwy4	Vict	Middle-Holt	Average
Jan	-0.3	0.0	-0.4	-0.7	-0.5	-0.6	-0.7	-0.4	-0.5	-0.5
Feb	-0.3	0.1	-0.4	-0.7	-0.5	-0.4	-0.7	-0.5	-0.4	-0.4
Mar	-0.3	0.1	-0.1	-0.2	-0.4	-0.3	-0.4	-0.2	0.0	-0.2
Apr	-0.9	-1.0	-1.3	-1.3	-1.3	-1.6	-1.3	-1.4	-1.3	-1.3
May	-1.0	-1.3	-1.9	-2.2	-1.4	-1.9	-1.8	-2.0	-1.9	-1.7
Jun	-1.4	-1.4	-2.0	-2.2	-1.2	-2.4	-2.4	-2.2	-1.8	-1.9
Jul	-1.9	-1.4	-0.7	-1.6	-0.9	-2.4	-1.7	-1.7	-0.8	-1.5
Aug	-2.1	-1.6	-0.6	-1.3	-0.8	-2.7	-1.2	-1.6	-0.8	-1.5
Sep	-1.6	-1.7	-1.1	-1.7	-1.0	-2.7	-1.7	-1.8	-1.2	-1.7
Oct	-1.1	-1.6	-1.1	-1.3	-1.1	-2.2	-1.3	-1.6	-1.2	-1.4
Nov	-1.0	-0.5	-0.3	-0.5	-0.5	-0.9	-0.5	-0.4	-0.4	-0.6
Dec	-0.7	-0.5	0.0	-0.4	-0.7	-0.9	-0.4	0.0	-0.1	-0.4

Figure 5.B-22 QUAL water temperature bias calculation for the South Delta region.



Regional Averages Compiled: Average Monthly Temperature Difference From Daily Average Data (Deg C)

	Avg South Delta	Avg East Delta	Avg West Delta	Avg Suisun Marsh	Suisun Bay	Avg Cache	Avg North Delta
Jan	-0.5	-0.4	-0.5	-0.8	-0.6	-0.6	-0.2
Feb	-0.4	-0.2	-0.3	-0.8	-0.5	-0.1	-0.1
Mar	-0.2	-0.2	0.0	-0.3	-0.1	0.2	0.0
Apr	-1.3	-0.6	-0.8	-1.1	-0.7	-0.9	-0.1
May	-1.7	-0.8	-1.1	-1.3	-0.7	-0.6	-0.3
Jun	-1.9	-0.8	-0.7	-0.4	-0.3	0.4	-0.1
Jul	-1.5	-0.3	0.4	0.8	1.0	1.0	0.2
Aug	-1.5	-0.5	0.5	1.2	1.2	0.8	0.1
Sep	-1.7	-0.7	-0.3	0.4	0.3	0.0	0.0
Oct	-1.4	-0.6	-0.6	-0.2	-0.4	-0.1	0.0
Nov	-0.6	-0.3	-0.4	0.0	-0.4	-0.1	0.1
Dec	-0.4	-0.2	-0.3	-0.3	-0.2	-0.4	-0.2

Figure 5.B-23 Compilation of the QUAL water temperature bias calculation for seven regions used in previous BDCP simulations.