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BEFORE THE
CALIFORNIA STATE WATER RESOURCES CONTROL BOARD

HEARING IN THE MATTER OF CALIFORNIA DEPARTMENT OF WATER RESOURCES AND UNITED STATES BUREAU OF RECLAMATION REQUEST FOR A CHANGE IN POINT OF DIVERSION FOR CALIFORNIA WATER FIX

TESTIMONY OF DR. MARIANNE GUERIN

I, Marianne Guerin, do hereby declare:

I. INTRODUCTION

I have developed and applied numerical models in hydrodynamics, water quality, and aqueous transport phenomena including water temperature, nutrients and pollutants for over 24 years. I have worked extensively on Bay-Delta issues, including the Pelagic Organism Decline, with a recent focus on modeling water temperature and nutrient dynamics with DSM2-QUAL. In particular, I spearheaded the work to update the calibration and validation of DSM2-QUAL water temperature and nutrient modules (Version 6 and separately for Version 8), and implemented a major extension to the modules with the addition of effluent sources in the Delta. I have expertise in applying both the RMA Delta Model and DSM2 for hydrodynamics, for water quality including water temperature and nutrients, and for particle tracking simulations. I have extensive knowledge of Delta operations, hydrodynamics, and transport phenomena gained through numerous work projects, for example on CALSIM-scenario based DSM2 modeling for proposed projects in the Delta, and through the use of particle tracking applications to elucidate the effect of Delta operations and tidal influences on transport phenomena. As a member of several collaborative analysis teams, I was involved with modeling California WaterFix (CWF) scenarios using DSM2 for modeling water temperature, for modeling water temperature and nutrients in earlier Bay-Delta Conservation Plan (BDCP) tasks, and for using a combination of numerical models including RMA and DSM2 model applications for assessing sediment transport, turbidity and water clarity for the BDCP. Exhibit DWR-1005 is a true and correct copy of my Statement of Qualifications.

II. DISCUSSION OF TESTIMONY

This testimony covers topics and background on work products I produced for the CWF modeling of water temperature in the Delta using DSM2-QUAL (QUAL) simulations to represent CWF scenarios. The covered topics are: (A) the historical use of QUAL to model water temperature in the Delta; (B) the conceptual model used in the QUAL water temperature module; (C) the calibration and validation history of the water temperature module; (D) the development of boundary conditions used in the CWF water temperature scenarios; and, (E) a description of the utility of the QUAL water temperature module for modeling water temperature in the Delta for the CWF scenarios. Much of this information is covered in Exhibit SWRCB-104, Appendix 5B, Attachment 4: DSM2 Temperature Modeling. (Exhibit DWR-1041.)

The opinions I hold with regard to these topics are: (A) DSM2-QUAL is a widely used model suitable for use in assessing the CWF; (B) DSM2-QUAL Water Temperature Module can model water temperatures throughout the Delta; (C) DSM2-QUAL was validated and calibrated; (D) DSM2-QUAL Water Temperature Module utilizes sufficient boundary conditions to produce meaningful results; and, (E) DSM2-QUAL Water Temperature

Module produced results for CWF.

A. Use of QUAL

DSM2-QUAL is a widely used industry standard model suitable for use in assessing CWF, the characteristics of which are described in the testimony of Mr. Munevar. (Exhibit DWR-71, p.10.) To summarize, the key DSM2 characteristics relevant to my testimony, DSM2 is a suite of one-dimensional models developed by California's Department of Water Resources (DWR) that were used for CWF to model the hydrodynamics and water quality in the Delta due to changes in Delta operations, sea level rise and climate change as conceptualized in the CWF scenarios. The hydrodynamic and transport modules of DSM2, HYDRO and QUAL, respectively, have been used by DWR to simulate historical conditions in the Delta, referred to as the "Historical Model," and also to model CWF scenarios. QUAL uses the hydrodynamics simulated in HYDRO as the basis for its transport calculations. The simplification of the Delta to a one-dimensional model means that DSM2 can simulate the entire Delta region rapidly in comparison with higher dimensional models.

B. Conceptual Model within DSM2-QUAL

DSM2-QUAL "water temperature module" can model water temperature throughout the Delta. The subset of equations within DSM2-QUAL used for temperature, the numerical solution scheme and the capability to produce geo-referenced water temperature output, are denoted herein as QUAL's "water temperature module." As DSM2 was used extensively to simulate Delta hydrodynamics and salinity for CWF scenarios, the choice of QUAL's water temperature module was a natural choice for simulating CWF scenarios for the analysis of water temperature.

The capability to simulate water temperature in QUAL was developed by Rajbhandari (1995a, 1995b). (Exhibits DWR-1043 and DWR-1044.) The DSM2-QUAL water temperature module is not dependent on the use of other DSM2-QUAL modules. Simulations using the water temperature module require the development of meteorological input data as well as the specification of the water temperature at every inflow location to simulate the transport of heat that is the basis of QUAL's conceptual model. These data inputs and the specification of boundary conditions are described below.

C. Calibration and Validation

DSM2-QUAL was calibrated and validated. The conceptual model for the transport of heat in the simulation of water temperature in QUAL is based on equations adopted from a well-known and extensively utilized program QUAL-2E (Brown and Barnwell, 1987). (Exhibit DWR-1042.) This conceptual model for the simulation of water temperature and the QUAL-2E equations is physically-based[1] and has a long history of implementation. As such, it is considered that this conceptual model has general validity in implementation for CWF scenarios.

In early implementations of the water temperature (and nutrient) modules (2000, 2001, 2003, 2004, and 2005), Rajbhandari used QUAL to model the area in and around the San Joaquin River. (See Exhibits DWR-1046, DWR-1047, DWR-1048, DWR-1049, and DWR-1050, respectively.) The calibration scheme for those applications for the modules focused on this area. An extension of the QUAL (V8.0.6) water temperature module to include in-Delta effluent sources from waste water treatment plants was undertaken by Guerin in 2008/2009 along with an extension of the Historical Model to the years 1990 - 2008. The regional focus of this effort switched to the Sacramento River. This project required the collection of additional meteorological and inflow water temperature data and an extensive recalibration and validation effort. Description of the data used for this calibration effort and the results of the water temperature module calibration are covered in detail in Exhibit DWR-1037.

A subsequent calibration/validation effort on an improved version of QUAL (V8.1.2) is documented and discussed in Exhibit DWR-1038. Descriptions of the data acquired

[1] Physically-based models utilize governing equations for heat transport and fluid flow to simulate water temperature based upon user described system geometry (e.g. channel shape, slope), flow, and climatic conditions. See: http://cwemf.org/Pubs/BDMFTempReview.pdf for greater detail. (Exhibit DWR-1045.)

for the water temperature module, the methodology for transforming the data into boundary conditions suitable for model application, and summaries of data usage comprise only a portion of the document (the remainder covers QUAL's nutrient module calibration). As noted in that document, the adequacy of the water temperature module for use in any application is determined in part by the quality and availability of data used to develop the model application and set boundary conditions.

D. Boundary Conditions

DSM2-QUAL water temperature module utilizes sufficient boundary conditions to produce meaningful results. In order to implement the water temperature module, five meteorological data types need to be collected and developed into boundary conditions: wind speed; air temperature ('dry bulb'); 'wet bulb' temperature (related to thermodynamic cooling of air to saturation); atmospheric pressure; and cloud cover. DSM2 is limited to a single set of meteorological boundary conditions for the entire Delta model domain. This constitutes an important simplification for application as conditions at times can vary substantially in different regions of the Delta (*e.g.*, wind speed can vary by a factor of two).

Sensitivity analyses on meteorological boundary conditions showed that modeled water temperature was most sensitive to the values set for wind speed, so considerable effort was taken to set wind boundary conditions. (Exhibit DWR-1038.) The initial model calibration (Exhibit DWR-1037) for water temperature identified that the initial meteorological boundary conditions used by Rajbhandari worked better for the San Joaquin/South Delta region. In the 2009 and 2011 calibrations, alteration of wind speeds was used as a fitting parameter to improve modeled water temperature along the Sacramento River. This set of meteorological conditions was maintained as the basis for developing CWF meteorology, discussed below.

To set water temperature at inflow boundaries, daily or hourly time series data from online databases were available for many of the modeled years at or near the boundaries for the Sacramento and San Joaquin Rivers and Martinez. Missing data were filled as described in Exhibit DWR-1037. Water temperature at the Sacramento River boundary was set in large part with data from RKI location RSAC123, which was then modified to improve downstream results. Sacramento River boundary inflow temperature was also used at the Mokelumne and Cosumnes River boundaries. The San Joaquin River water temperature boundary was set mainly with data sourced at Mossdale (RSAN087), but time shifted. The San Joaquin River boundary time series was also used for the Calaveras River.

In addition to setting water temperature at tributary inflow locations, the temperature of inflow water is needed for agricultural sources (i.e., Delta Island Consumptive Use, (Exhibit DWR-1073) and for effluent. (Exhibit DWR-1040.) DICU inflow water temperature was specified as a single monthly-averaged time series repeated annually. The time series is based on an average of data collected over many years in agricultural outflow locations throughout the Delta. Effluent water temperatures were developed from wastewater treatment plant data.

Water temperature data locations used to support the 2011 water temperature module calibration and validation and to set boundary conditions are shown in Figure 1. Discussion of the sources and quality of water temperature data is covered in great detail in Exhibits DWR-1037 and DWR-1038. Both graphical and statistical 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. (Exhibit DWR-1038.) Statistics were based on the residuals for water temperature calculated as the difference (data – model) between the measured data and the modeled result. Validation statistics for water temperature are consistent with the use of the historical model simulation on an hourly to daily time scale.

In the DSM2/QUAL water temperature module a single meteorological boundary condition is applied globally over the model domain. Calibration results indicate that two temperature regions are needed in order to improve these results. The current model results are deemed very good along the Sacramento River corridor where the 2011 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 in the central Delta, Figure 2.

E. Use of DSM2-QUAL Water Temperature Module for CWF

QUAL's water temperature module was used to produce output for two CWF 82-year scenarios: the Biological Assessment No Action Alternative (BA NAA), and Biological Assessment Alternative H3+ (BA H3+). The implementation of the QUAL water temperature module for the CWF, and the underlying HYDRO module, discussed herein includes the extension of the standard configuration of DSM2 to include in-Delta effluent inflow. The standard hydrodynamic input files for the two CWF scenarios were supplied to DWR consultant RMA for use in QUAL's water temperature module. This input for HYDRO was modified to include in-Delta sources of effluent flow as these were included in the QUAL water temperature module calibration. The rest of the HYDRO input was implemented as supplied. Results of the modified HYDRO model were compared to the standard CWF scenario output for stage and flow to ensure these modifications only produced very minor changes in the HYDRO results.

The hydrodynamic module used as a basis for input to the QUAL water temperature calculations used the executable for HYDRO V8.0.6, the version used in other CWF DSM2 modeling. The QUAL water temperature module was implemented and run on Version 8.1.2. The two versions are fully compatible. The analysis period for the two CWF scenarios was October 1921 to September 2003. The months February to September 1921 were used as a spin-up period for the water temperature simulations, but were not included in analyses.

Delta Island Consumptive Use inflow temperature used in the CWF scenarios annually (Figure 3, purple line) is shown in comparison to a Delta-wide average of agricultural drain data from 1997 through 2004 (blue line) sourced from DWR's Municipal

Water Quality Investigations (MWQI) branch database. Note that although DICU inflows and outflows are also specified as monthly averages, the flows vary by year type so do not repeat annually.

Effluent inflow and water temperature time series were set in several ways for CWF scenarios. These boundary conditions were set identically for the BA NAA and BA H3+ scenarios. Sacramento Regional Wastewater Treatment Plant (SRWTP) effluent inflow was scaled annually to ensure the daily percentage of effluent flow in Sacramento River inflow remained below the historical 2000 - 2005 maximum (approximately 4.5%). All other effluent inflows were applied without scaling. To set effluent inflow and water temperature values, a correspondence was established between a model year (1922-2003) and a similar water year 1990-2008. For the years 1975 - 1991, the correspondence used in earlier CWF 16-year scenarios was retained, while for the years 1992 - 2003, historical values were used. Details on this correspondence are covered in CWF, Exhibit SWRCB-104, Appendix 5B, DSM2 Attachment 4 (Exhibit DWR-1041) and also in Exhibit DWR-1039. The approximate location of effluent sources is shown in Figure 4.

Meteorological and water temperature boundary conditions were developed separately from the effluent boundary conditions. A single set of synthetic meteorology representing the Early Long Term (ELT) future climate change condition was generated for both scenarios from boundary condition data developed for the calibrated QUAL historical model of water temperature (1990 – 2008). (Exhibit DWR-1038.)

Projected daily average temperatures for the ELT climate change condition were supplied to DWR consultant RMA to use as a basis for meteorological boundary condition development. A daily time series (1922-2003) of air temperature for use in CWF scenarios was developed using an algorithm that closely matched the average air temperature on each day of the ELT time series with a historical air temperature from the years 1990 – 2008 within 2 days of the same annual date used in the calibrated QUAL simulation. Hourly meteorological inputs (dry bulb, wet bulb, wind, air pressure and cloud cover) for the chosen historical day and year were then used for that model day in the CWF scenarios, and concatenated to produce hourly time series for the scenario time period, 1922-2003. (See DWR-1039 for more detail.)

A set of boundary conditions for daily water temperature was also generated using boundary condition data from the calibrated QUAL historical water temperature simulation by using the same dates used in matching the projected ELT air temperatures. The historical water temperatures used in the calibrated QUAL model at the Sacramento River, Martinez and the San Joaquin River boundaries from that day were then mapped into the CWF scenario boundary conditions for water temperature.

Figures 5 and 6 illustrate monthly-averaged time series of the meteorological boundary conditions used in the CWF scenarios, while Figure 7 illustrates the monthly averaged time series for water temperature and the boundaries at which these time series were used. Monthly averages were used instead of the applied hourly time series for clarity.

The water temperature and meteorological boundary conditions used in the QUAL water temperature simulations of the CWF scenarios models were developed based on historical data, so it is expected that the magnitude of (model – data) bias calculations would be applicable to CWF models as a regional monthly bias in water temperature. The reason that the bias occurs in the QUAL historical water temperature simulation is that QUAL only allows a single region for meteorological boundary conditions, as mentioned above. When the modeled historical bias is regular, as it is in the south Delta as shown in Figure 8 for example, this potentially allows for a similar interpretation of bias in the CWF model results.

A second consideration is that the meteorological conditions used in developing the ELT synthetic data are all based on matching a projected ELT daily air temperature with a temperature and a set of affiliated conditions from historical meteorology. There is inherent uncertainty in the assumption that the historical meteorology accompanying a given temperature would also occur under the climate change conditions found in the ELT time frame.

III. CONCLUSION

The opinions I hold with regard to these topics are: (A) DSM2-QUAL is a widely used model suitable for use in assessing the CWF; (B) DSM2-QUAL Water Temperature Module can model water temperatures throughout the Delta; (C) DSM2-QUAL was validated and calibrated; (D) DSM2-QUAL Water Temperature Module utilizes sufficient boundary conditions to produce meaningful results; and, (E) DSM2-QUAL Water Temperature Module produced results for CWF.

Executed on this 29th day of November, 2017 in Sacramento, California.

Marianne Guerin

(Marianne Guerin)

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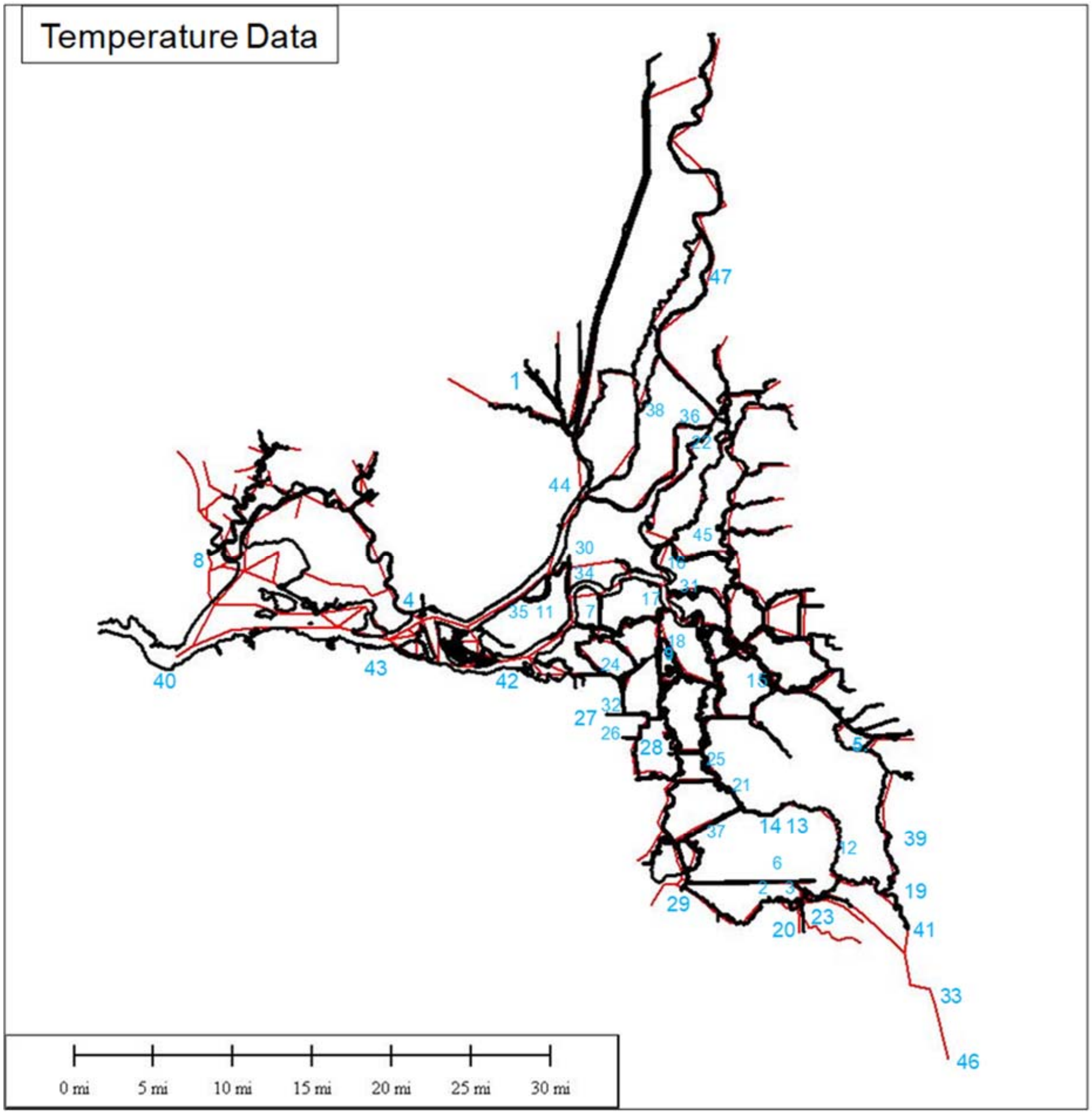


Figure 1 Locations of temperature data regular time series. Data quality and length of record was variable.

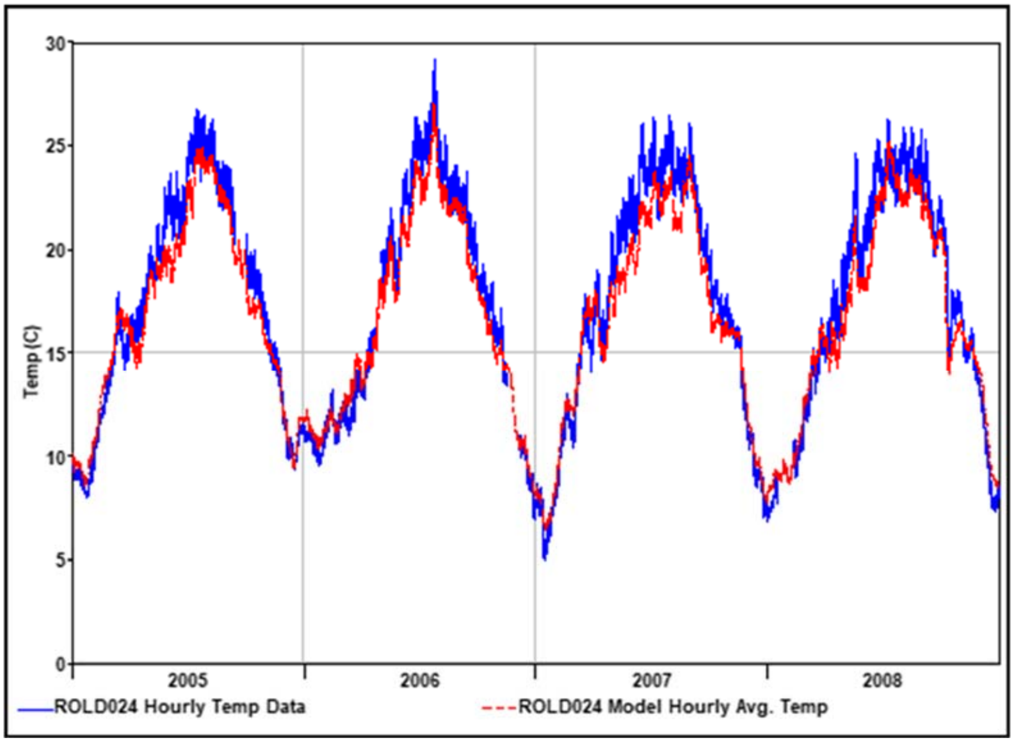


Figure 2 Hourly calibration results for water temperature at ROLD024. Blue line is hourly data, red line is the modeled hourly result averaged from 15-minute model output

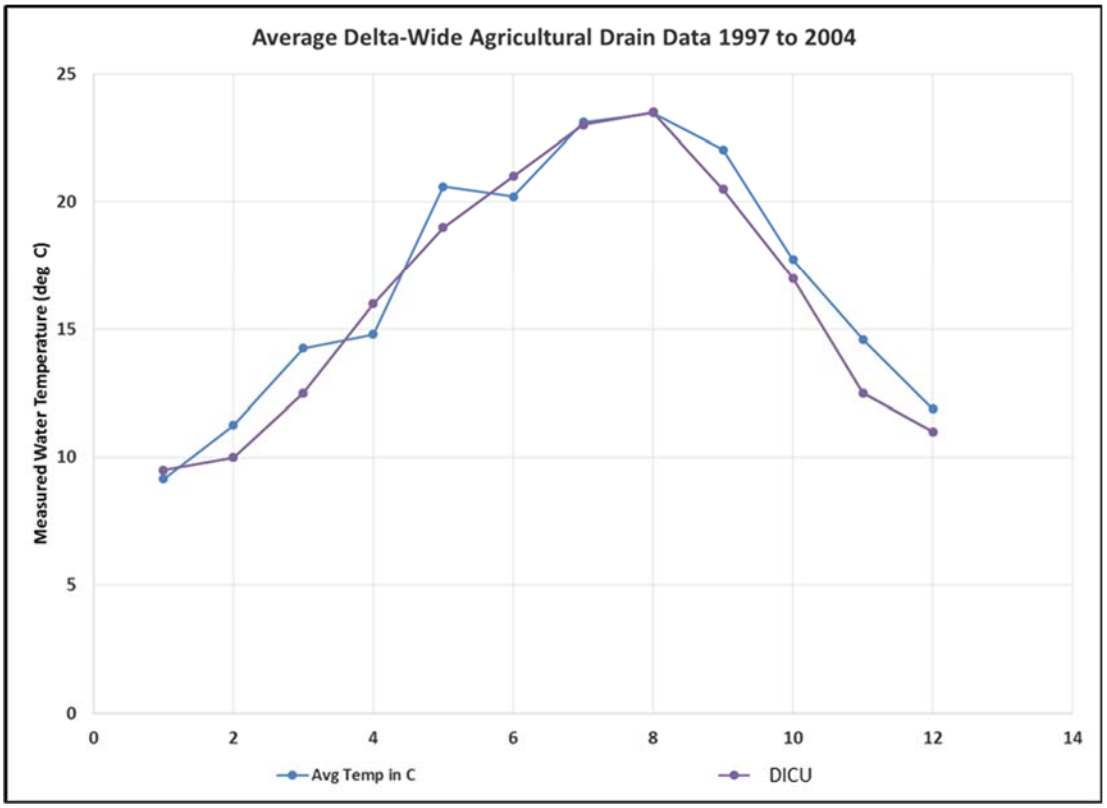


Figure 3 Comparison of DICU inflow water temperature (purple line) and a Delta-wide average of agricultural drain data (blue line) from the MWQI database.

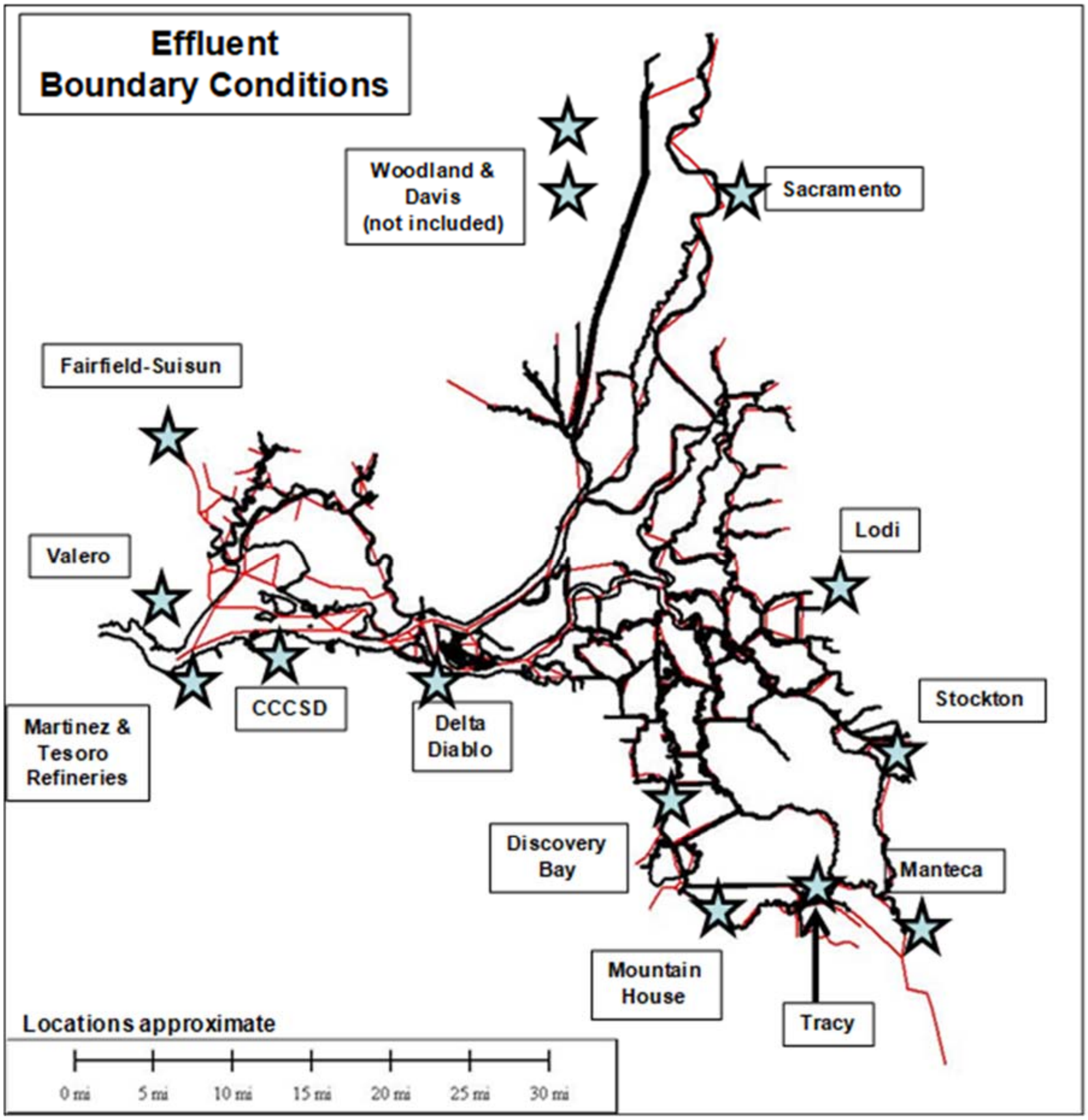


Figure 4 Approximate location of effluent boundary conditions for waste water treatment plants in CWF scenarios.

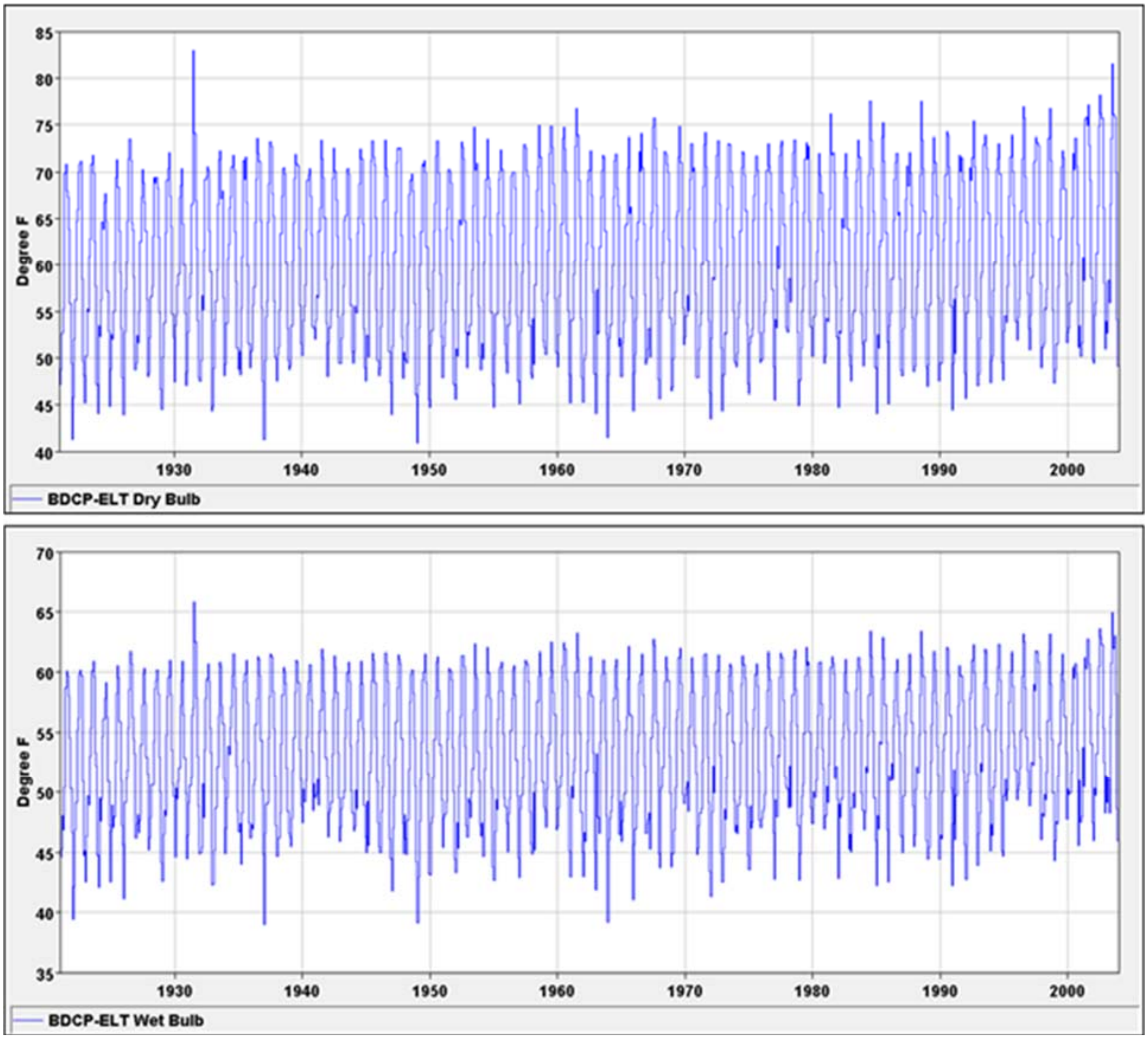


Figure 5 Monthly average air temperature (upper) and wet bulb temperature (lower) for the ELT scenario time frame.

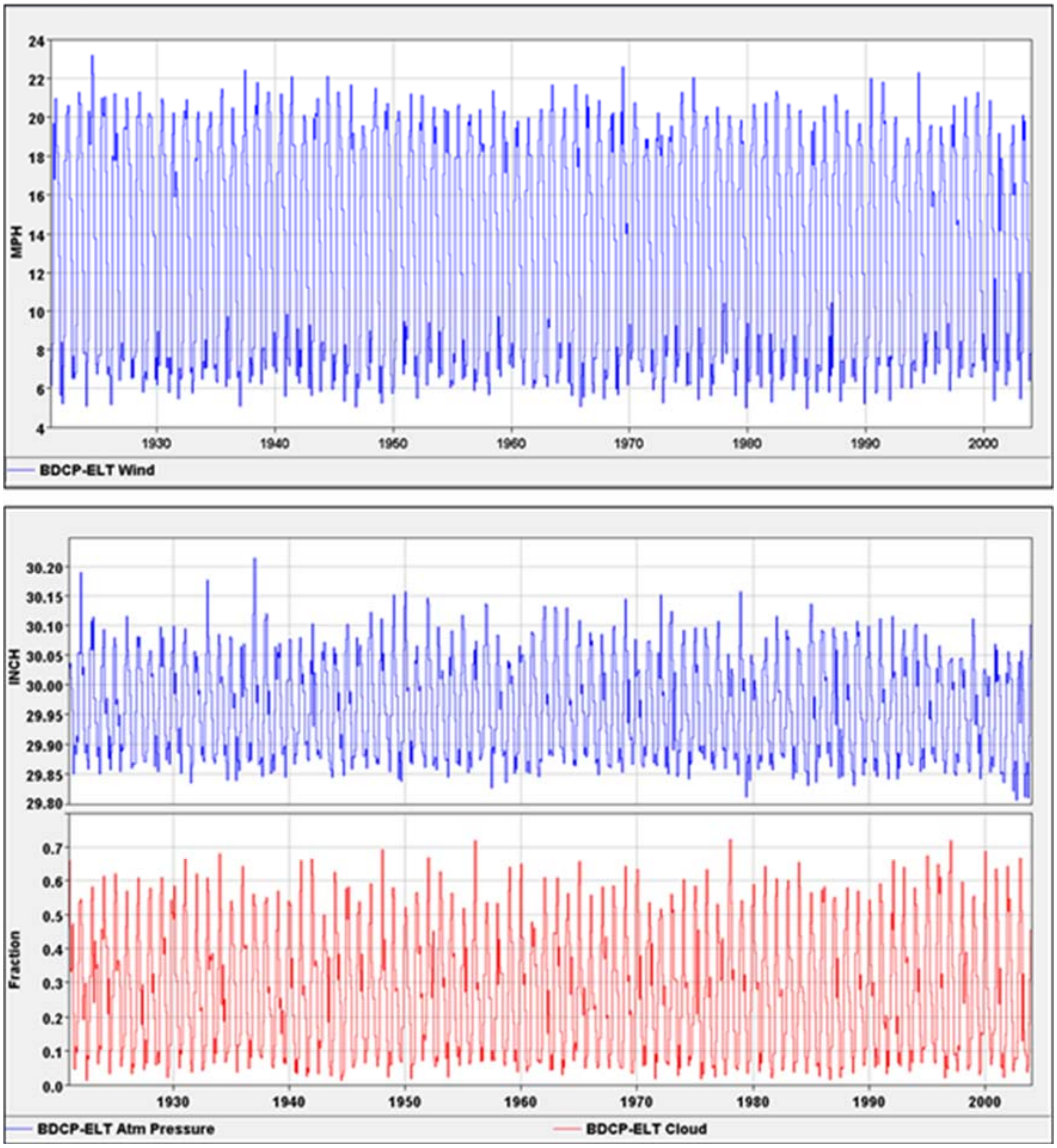


Figure 6 Monthly average wind speed (upper), fraction cloud cover and atmospheric pressure (lower) for the ELT scenario time frame.

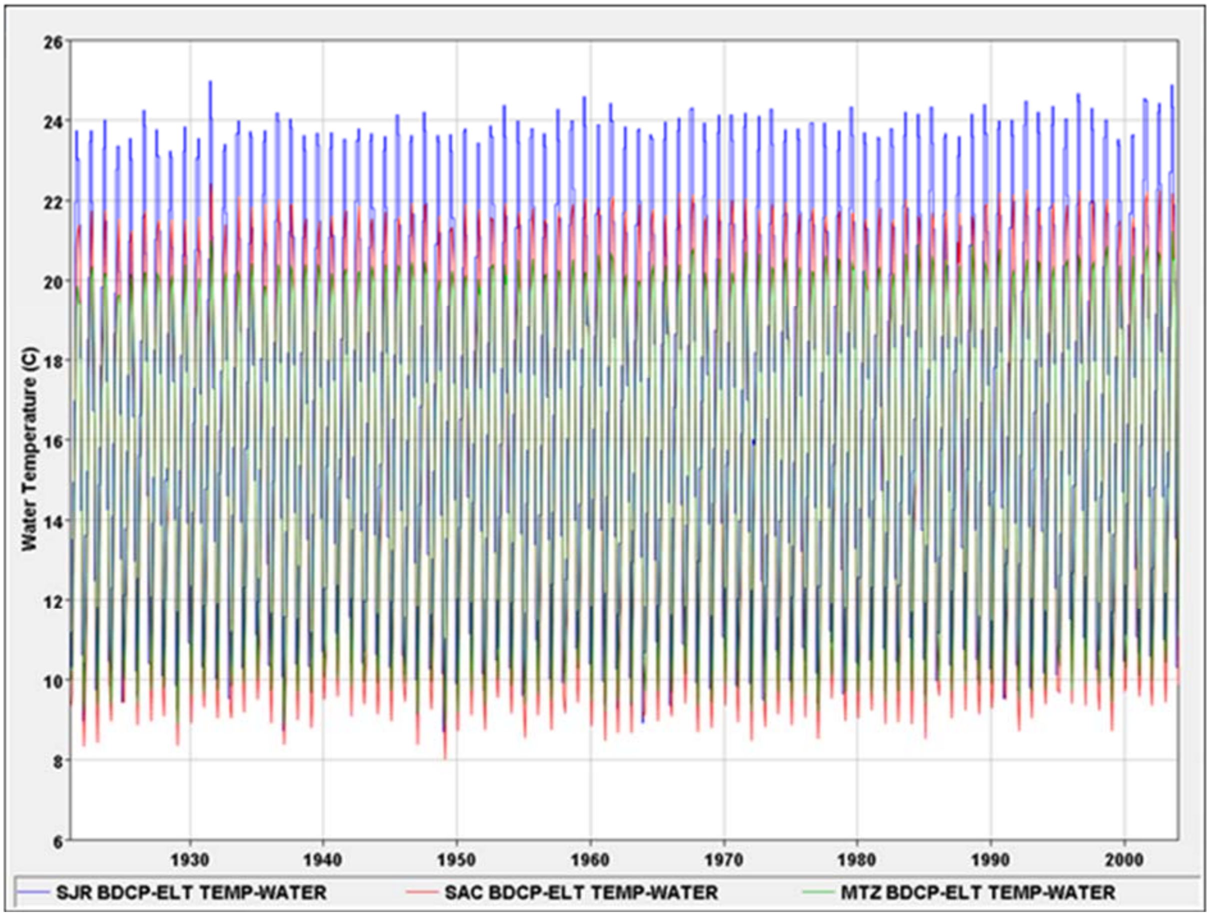
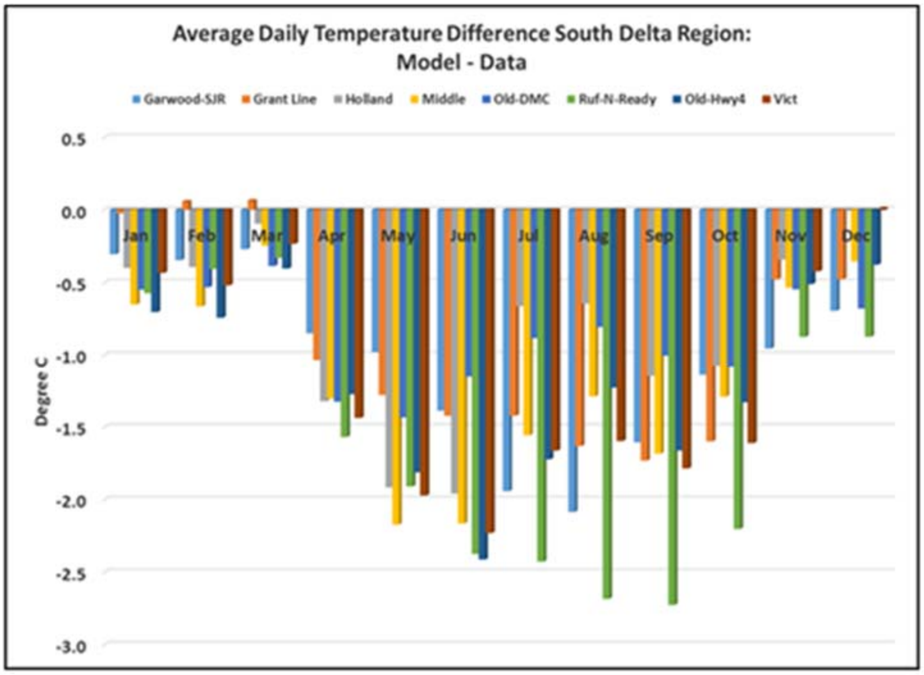


Figure 7 Inflow water temperature daily time series for the Sacramento and San Joaquin Rivers and the Martinez stage boundary for the ELT scenario time frame. The San Joaquin River boundary is also applied to the Calaveras River. The Sacramento River boundary is applied to all remaining inflow boundaries. The Martinez time series is only used at that location.



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 8 QUAL water temperature bias calculation basis at the indicated locations regionally in the south Delta.