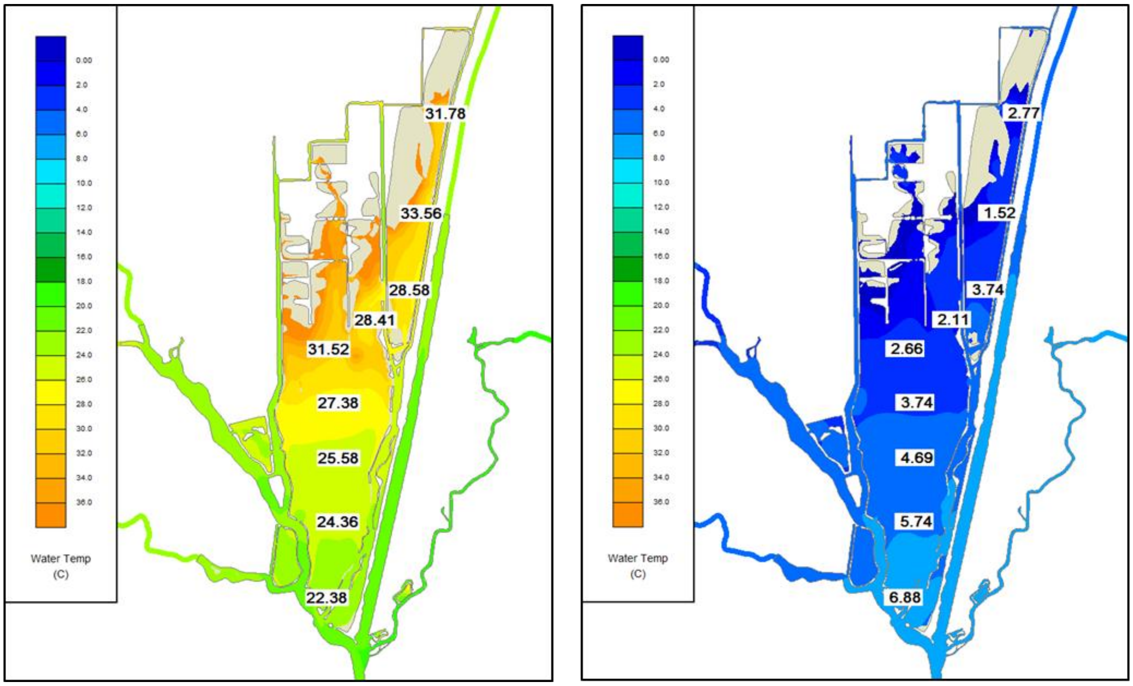
DWR-1040

Comparison of DSM2 and RMA Historical Models of Cache/Liberty Complex Water Temperature



RMA11 Water Temperature Contour Plots: July 02, 2011 13:30 (LEFT) and Dec. 24, 2011 04:00 (RIGHT)

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1 Executive Summary

The purpose of this report is to document an analysis of RMA11 and DSM2-QUAL water temperature model output in the Cache/Liberty region. The objective is to assess the sufficiency of DSM2's calculations with a focus on water temperature in Liberty Island. The differences in the equations conceptualizing water temperature in the two numerical models were minor. The major differences between the two models are: a difference in the application of meteorological boundary conditions; and, a difference in the dimensionality of the model grids. In particular, Liberty Island is a zero-dimensional water body in the DSM2 grid while it is a two-dimensional (depth-averaged) area in the RMA model grid.

DSM2 scenarios were developed to compare the effects of variations in inflow, water temperature and meteorological boundary conditions. Model results showed that, during the years 2010 – 2011 that were the focus of the analyses, meteorological boundary conditions were the most important factor determining modeled water temperature in this region. In addition, it was found that the meteorological boundary conditions developed for the RMA model during the Prospect Island project (RMA, 2014) was generally superior to the meteorological conditions used in the calibration of DSM2 for the entire Delta (RMA, 2011).

Although not specifically documented in this report, the comparison of measured data to model output locations showed that DSM2's one-dimensional representation of channel geometry was comparable to RMA's two-dimensional channel geometry for the calculation of water temperature. In the colder months October – April, both models under-predicted water temperature in this region (i.e., both were too cold).

A method for calculating a volume-averaged water temperature from RMA11 model output was developed to allow direct comparison with DSM2's Liberty Island calculation, as this quantity is not directly accessible from RMA11 model calculations. Since the volume of water in Liberty Island varies diurnally as well as over longer periods due to the spring-neap tidal variations, tidal effects were accounted for in the calculations. Volume-averaged water temperatures were calculated during periods when Liberty Island was filling and when it was draining. Additional analysis using RMA's particle tracking model in June 2011 showed that water entering Liberty Island from downstream locations in Cache Slough generally only mixed with waters in the deeper regions of Liberty Island. Similarly, water leaving Liberty Island came from the deeper areas.

A CDEC data location (data only in WY2011) at the south end of Liberty Island was used for evaluating the water temperature results in the model comparison. This location illustrates the temperature of water entering and exiting the representation of Liberty Island in each model, capturing the potential influence of water exiting Liberty Island on downstream locations.

At times when Liberty Island was filling, the difference in calculated Liberty Island water temperature between the two models was small, and in large part due to differences in meteorology. However, when Liberty Island was draining, the difference in water temperature between the two models increased with the RMA11 volume-averaged water temperature, with the volume-average temperature several degrees higher than DSM2's. This result is somewhat misleading when considering the particle tracking results, as the inclusion of the much warmer water in the shallower region of Liberty biases the volume-averaged temperature to higher values than the water that actually mixes in Liberty Island on entering and exiting during the times that were investigated.

In summary, the analysis of water temperature results calculated by RMA11 and by DSM2-QUAL in the Cache/Liberty region showed that the main differences in accuracy between the models in channel calculations were due to differences in meteorological boundary conditions. The RMA11 volume-averaged Liberty Island water temperature was up to 4.7 °C warmer than DSM2's zero-dimensional water temperature during warm periods. However, DSM2's calculations were within +/- 2°C (approximately) of RMA's deeper water temperatures in Liberty Island, which is arguably the correct volume-averaged temperature for comparison at least during the periods investigated, as it captures the influence of waters leaving Liberty on downstream locations. Note that the temperature differences in the Liberty Island comparison are also partly due to differences in meteorology. The results described in this report for assessing the sufficiency of DSM2's zero-dimensional representation of Liberty Island must be considered preliminary due to the single year of data available for comparison (WY2011).

2 Background

This report covers an analysis of water temperature modeling of historical conditions with the DSM2 HYDRO/QUAL numerical models and a comparison with similar water temperature modeling using the RMA2/RMA11 models. The modeling is limited geographically to the region in and around Liberty Island and Cache Slough (Cache/Liberty area) and to a time span for which there is good data coverage in this region, both for measured water temperature and for which a comprehensive set of hydrodynamic boundary conditions have been assembled for the RMA2 and RMA11 hydrodynamic models. The RMA11 water temperature model was recently calibrated for the Prospect Island project (RMA, 2014) in this region; the original time span for that modelling was extended for the analyses documented in this report. The DSM2-QUAL model for water temperature covered a longer time span.

The motivation for this work arose from questions of whether DSM2's zero-dimensional representation of Liberty Island and one-dimensional representation of nearby large channels adequately represent historical conditions of water temperature in this region. In comparison, the

RMA2/RMA11 model represents Liberty Island and larger channels as 2-dimensional depth averaged water bodies.

The report briefly covers:

- a comparison of the conceptual models for the simulation of water temperature in DSM2-QUAL and RMA11 models of the Delta
- the effect of variations in flow boundary conditions in DSM2-HYDRO on modeled water temperature in QUAL
- the effect of variations in water temperature boundary conditions in DSM2-QUAL
- the effect of variations in meteorological boundary conditions in DSM2-QUAL
- the effect of temperature exchange between the sediment bed and the overlying water column, represented in RMA11 but not in DSM2
- a comparison of model output to water temperature data for the two models, with a focus on Liberty Island

Note that many of the figures and tables and portions of the text in Section 4 and in almost entirely in Section 9.1 were sourced from the calibration/verification report for the RMA11 water temperature model prepared for the Prospect Island project (RMA, 2014). When this occurs, it is so noted in the caption for figures or tables or in the text.

For the results documented herein, the time frame of the model developed for the Prospect Island study was extended to include data in the Cache/Liberty area that were not available at the time of that study.

3 Introduction

3.1 Objectives

The objectives for work discussed in this report are to:

1. Use the comparison of RMA11 and DSM2-QUAL water temperature model output to determine if DSM2's zero-dimensional conceptualization of Liberty Island and one-dimensional representation of larger channels adequately represent these water bodies (under the assumption that RMA's 2-dimensional representations are adequate as documented in the calibration documentation). This is the primary objective.
2. Use DSM2 scenarios changing boundary flows and inflow water temperature to determine the effect of these boundary conditions in locations influencing and/or influenced by the conditions in the Cache/Liberty region.
3. Use the DSM2 scenarios changing meteorological boundary conditions to determine the magnitude of modeled water temperature changes associated with meteorological

boundary conditions in locations influencing and/or influenced by the conditions in the Cache/Liberty region.

3.2 Comparison of DSM2 and RMA11 functional models for water temperature

The conceptual models for RMA11 and DSM2-QUAL are based on the same template for the functional representation of water temperature; in the case of DSM2 the equations were adopted from QUAL-2E (Brown and Barnwell, 1987). The main difference in the implementation covered in this document is that RMA11 includes a term for the bed thermal flux – i.e., an exchange of temperature between the sediment bed and the overlying water body. This term is important in modeling shallow water and exposed intertidal areas to avoid unrealistically high or low water temperatures. Implementation of this term can moderate large temperature swings in shallow or intertidal areas.

Another major difference between the two implementations is in the specification of meteorological boundary conditions. DSM2 is limited to a single set of meteorological boundary conditions for the entire model domain, while RMA11 is capable of implementing region-specific meteorological conditions. However, since we are examining results in a limited area of the Delta for this project, RMA11 used a single set of boundary conditions for the meteorology.

4 Data Availability and Modeling Methodology

4.1 Data Sources for QA/QC

Table 4-1 through Table 4-3 list the boundary condition and observed data sources available for the calibration and verification runs (this information in this section is primarily sourced from RMA (2014)). Additional information is found in the Appendix, Section 9. Figure 4-1 through Figure 4-3 illustrate the time frames and locations of data used in the studies described in this document.

Data sources include:

Water temperature, flow and stage:

- CDEC (California Data Exchange Center): http://cdec.water.ca.gov
- DWR-DAYFLOW: http://www.water.ca.gov/dayflow
- DWR-DES (Division of Environmental Services): http://www.water.ca.gov/environmentalservices
- DWR-DMS (Delta Modeling Section): http://baydeltaoffice.water.ca.gov/modeling/deltamodeling
- DWR-NCRO (North Central Region Office): http://www.cd.water.ca.gov/
- DWR-WDL (Water Data Library): http://www.water.ca.gov/waterdatalibrary/
- SCWA (Solano County Water Agency): http://www.scwa2.com/
- USGS-NWIS (National Water Information System): http://waterdata.usgs.gov/nwis
- USGS provisional data: Provided by Brad Sullivan and Tara Morgan of USGS (data are the same as CDEC without time shift errors)
- Breach III Study: Provided by Peggy Lehman of DWR
- MWD (Metropolitan Water District of Southern California), provided by Chris Campbell of cbec, Inc.
- UC Berkeley Cache Slough Study (http://escholarship.org/uc/item/1wd050xm), provided by Mark Stacey of the University of California, Berkeley Dept. of Civil and Environmental Engineering

Meteorological Data:

- DWR-CIMIS: http://wwwcimis.water.ca.gov/cimis
- National Solar Radiation Database (NSRDB), Travis AFB cloud cover: http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2010

Table 4-1 North Delta flow and stage boundary condition data sources for the RMA11 water temperature simulations (Table sourced from RMA (2014)).

BC Location	Data Source	Station Name	Data Time Interval
Martinez Tidal Boundary	DWR-DES	Martinez	15 min
Sacramento River	USGS-NWIS	Sacramento River at Freeport	1 day
Yolo Bypass Toe Drain	DWR-WDL	Yolo Bypass near Lisbon	15 min
Yolo Bypass	USGS-NWIS	Yolo Bypass nr Woodland CA	1 hr
Inflows/diversions			
Upper Cache Slough / Hass Slough	DWR-NCRO	Upper Cache Slough (UCS)	15 min
Barker Slough	SCWA	Barker Slough Doppler Station (DOP)	15 min
Exports			
NBA, Barker Slough PP	DWR-DMS	SLBAR002	1 day
DICU	DWR-DMS		1 month

Table 4-2 North Delta meteorological data sources for the 2009 and 2010 calibration/verification runs (Table sourced from RMA (2014)).

Station Location	Data Source	Description	Data Time Interval
#122 Hastings Tract	DWR-CIMIS	Meteorological data prior to June 10, 2009	1 hour
#212 Hastings Tract East	DWR-CIMIS	Meteorological data, October 2009 -	1 hour
Travis AFB	NSRDB	Cloud cover data	1 hour

Table 4-3 Observed water temperature data stations for RMA11 model boundary conditions (Table sourced from RMA (2014)).

Water Temp Station ID	Description	Data Source
For BCs:		
SRH	Sacramento River at Hood (Interal BC)	DWR-CDEC
LIS	Yolo Bypass Toe Drain at Lisbon	DWR-WDL
DOP	Barker Slough Doppler Station	SCWA
CCS	Upper Cache Slough	USBR
For Calibr./ Verification:		
HWB	Miner Slough at Hwy 84 Bridge	USGS Provisional Data
RYI	Cache Slough at Ryer Island	USGS Provisional Data
SRV	Sacramento River at Rio Vista	USGS Provisional Data
RVB	Sacramento River at Rio Vista	DWR-CDEC
DWS	Sacramento Deep Water Shipping Channel	USGS Provisional Data
LIB	Liberty Island @ Approx Cnter S End	USGS Provisional Data
LSHB	Lindsey Slough at Hastings Bridge	SCWA
CCS	Upper Cache Slough	USBR
TOE	Toe Drain at Liberty Island	USGS Liberty Island Study
SHG	Shag Slough at Liberty Island	USGS Liberty Island Study
LBY	Liberty Cut at Liberty Island	USGS Liberty Island Study
MWD (1-7)	Locations in and around Liberty Island	MWD
UBP	Liberty Island, Upper Beaver Pond	Breach III
LBP	Liberty Island, Lower Beaver Pond	Breach III
MPNW	Liberty Island, Main Pond North West	Breach III
MPSE	Liberty Island, Main Pond South East	Breach III
UCB	UC Berkeley, Cache Slough near Shag Slough	Cache Slough Study

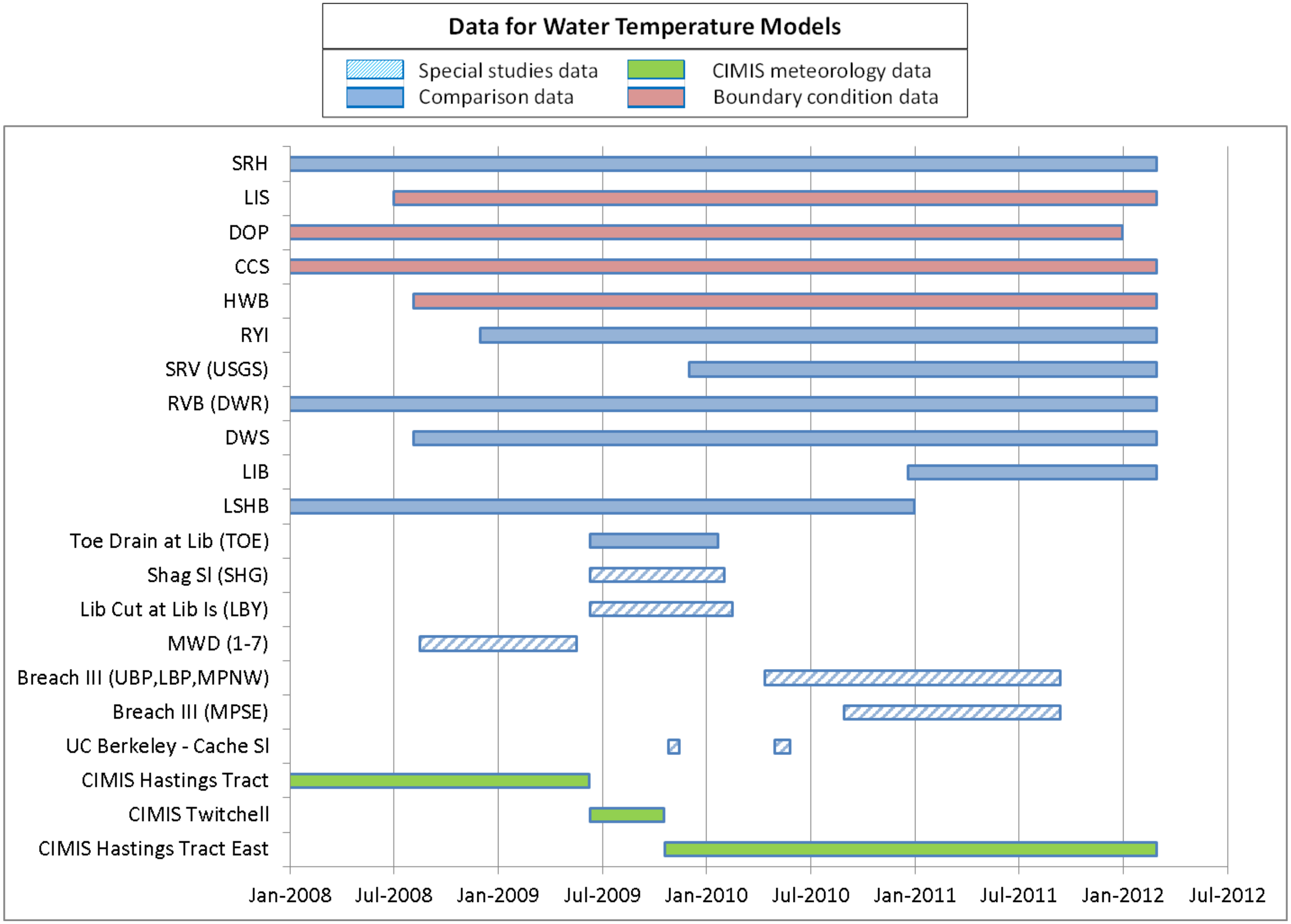


Figure 4-1 Availability of north Delta observed water temperature and meteorological data for January 2008 to March 2012. (Modified from RMA (2014)).

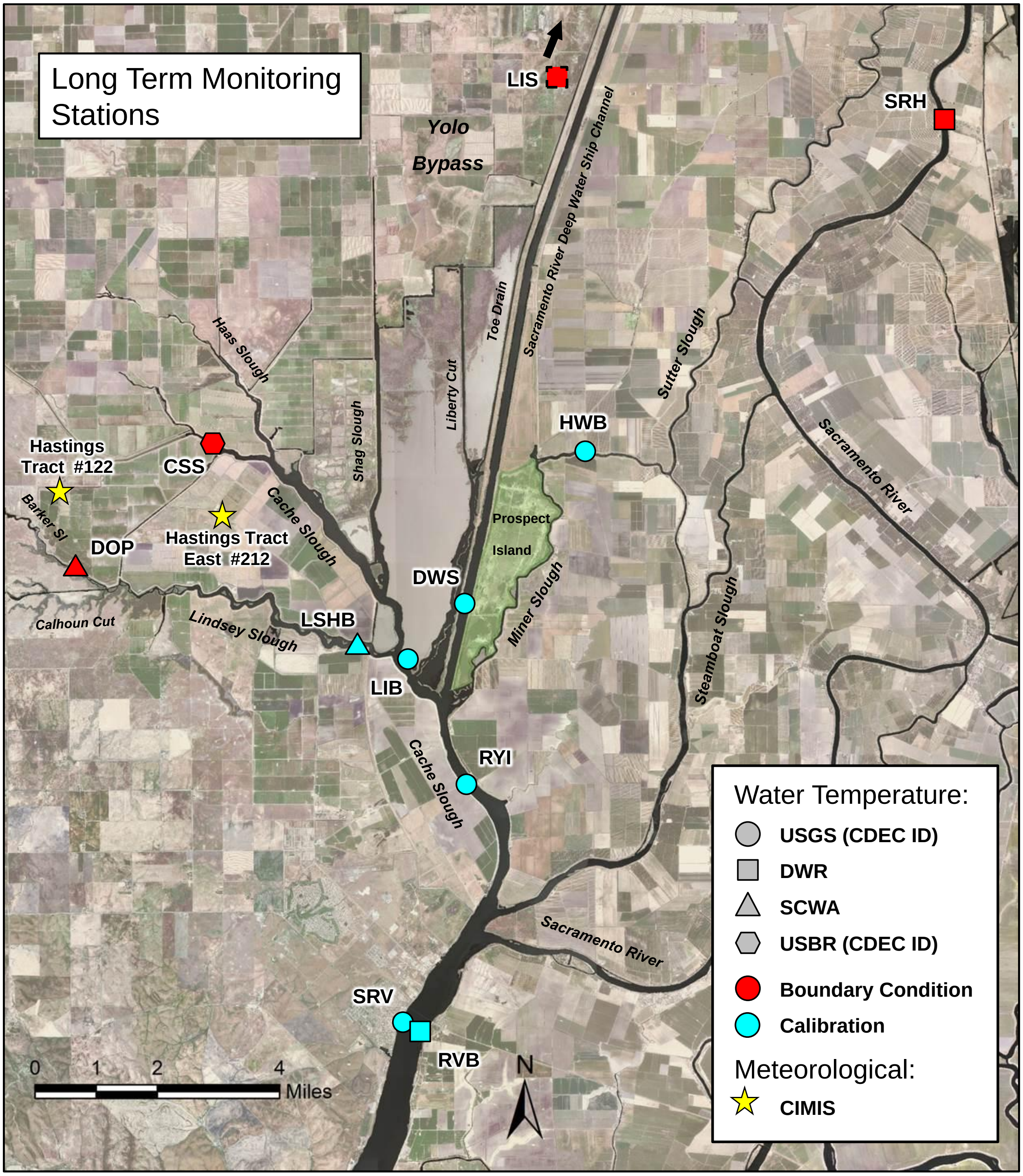


Figure 4-2 Location of long term north Delta water quality monitoring stations available for model water temperature boundary conditions or for observed data calibration sources. Weather data used for the model calibration/verification was collected at the CIMIS stations. (Figure sourced from RMA (2014)).

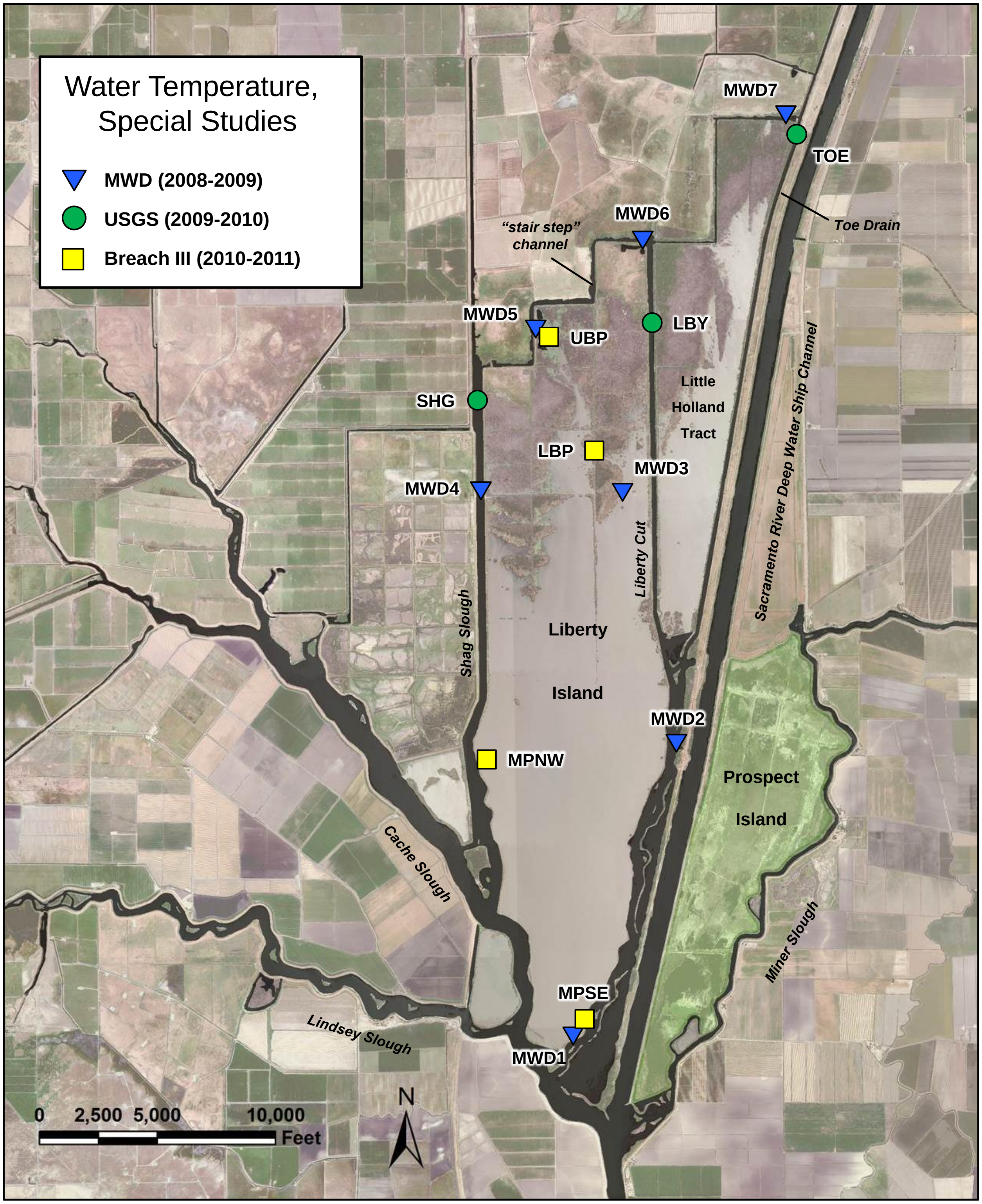


Figure 4-3 Locations of water temperature monitoring stations deployed on a temporary basis. (Figure sourced from RMA (2014)).

4.2 Model Comparison – grid and boundaries

4.2.1 Comparison of RMA and DSM2 model grids

The RMA Delta model suite used in this comparison study is a 2-D depth averaged / 1-D cross-sectionally averaged model extending from Martinez at the west end of Suisun Bay to the Sacramento River above the confluence with the American River, and to the San Joaquin River near Vernalis. DSM2 is a suite of one-dimensional hydrodynamic and water quality simulation models used to represent conditions in the Sacramento-San Joaquin Delta. The model domain for DSM2 is similar to the RMA Delta model domain, with the minor exception that the upstream extent of the Sacramento River is below the confluence with the American River.

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 Liberty Island, as zero-dimensional "reservoir" volumes. For the transport of constituents, a reservoir is assumed to be a fully-mixed volume in each computational step.

Figure 4-4 and Figure 4-5 illustrate a portion of the DSM2 grid, while Figure 4-6 shows a comparison of the RMA and DSM2 grids in the Cache/Liberty region. Figure 4-4 shows the Sacramento River flow direction as red arrows near Freeport (RSAC155) and near Rio Vista (RSAC101), and Figure 4-5 shows the three inflow locations varied in the DSM2 scenarios discussed in Section 4.2.2.3.

In both the RMA and DSM2 models, the effects of evaporation, precipitation, and channel depletions and additions ascribed to agricultural influences are modeled using the Delta Island Consumptive Use (DICU) model[1]. This model is used to set boundary conditions at 258 locations throughout the Delta. DICU flow boundary conditions vary monthly by region and annually Water Year type. There is significant uncertainty in the estimates of DICU inflow, outflow and constituent concentrations. In one location discussed herein, at Upper Cache Slough, the RMA boundary conditions for DICU were replaced with measured data. Note that DSM2 and RMA hydrodynamic models otherwise use essentially the same DICU flows, although the locations may be slightly different.

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

4.2.2 Time frame and boundary conditions

4.2.2.1 *RMA models*

RMA hydrodynamic and water temperature historical simulations were developed for the period 09/2008 – 03/2012. Because the month 09/2008 constituted a spin-up period, model output was specified for the period 10/2008 – 03/2012 in DSS format.

Model calibration was performed for the Prospect Island project (RMA, 2014). Boundary condition development for the current project followed the methodology developed for that project. Figures illustrating selected RMA flow and water temperature boundary conditions are shown in Figure 4-7, Figure 4-9 and Figure 4-10. Model input for other standard boundary conditions – such as Delta gate and barrier operations and DICU flows – is not documented herein. Note that the water temperature for DICU inflow is not specified as a boundary condition in RMA11 – instead, DICU inflow temperature assumes the temperature of the receiving water at each DICU location.

During the calibration process (RMA, 2014), wind speed was reduced by a factor of 0.75, with the assumption that vegetation attenuated wind speed near the surface of the water (Boyd and Kasper, 2003).

4.2.2.2 *DSM2 models*

The Version 8 calibration of DSM2-HYDRO for flow assumes a model start date in 2000[2], while the calibration period for DSM2-QUAL for water temperature using earlier versions of HYDRO and QUAL was 1990 – 2008. DSM2 historical simulations depend on the time frame modeled, as the model grid changes depending on the inclusion of Liberty Island. Liberty Island flooded after a series of levee breaks in the late 1990's.

Water temperature simulations from QUAL are available from 1990 – 3/2012, but for direct comparison with RMA11 model output and data, the simulation period in this report covers the period 10/2008 – 03/2012. DSM2 boundary conditions for HYDRO developed by DWR-Delta Modeling Section (DWR-DMS) were considered as the Base condition. In several other scenarios, boundary conditions used in the RMA model were also used in DSM2. Figure 4-7 through Figure 4-10 illustrate selected DSM2 flow and water temperature boundary conditions.

4.2.2.3 *DSM2 scenario definitions*

Multiple scenarios were developed to establish the factors affecting water temperature in and around the Cache/Liberty area in DSM2. The scenarios vary boundary conditions for inflow,

[2] https://dsm2ug.water.ca.gov/library/-/document_library/view/163187

water temperature, and meteorology. The objective is to test the magnitude of these various contributions to model error.

- Variation in inflow affecting this area:
    - DMS-development of flow boundary conditions
        - DMS Yolo inflow
        - DMS RSAC155 (Freeport) inflow
    - RMA flow BCs for the region
        - RMA Yolo/Lisbon inflow
        - Upper Cache Slough (UCS) drain and diversion
- Variation in water temperature:
    - Synthetic Yolo water temperature, the calibration boundary (1990 - 2008)
    - Lisbon CDEC data for Yolo water temperature
    - Freeport/Hood CDEC water temperature for the Yolo boundary, the Base case boundary
- RMA water temperature BCs used with RMA inflow BCs in DSM2
- Meteorology – variation by source location in the Delta and wind speed of the RMA source
    - NOAA-Stockton (cloud extended from NWS): DSM2-QUAL calibration meteorology
    - Hastings+Twitchell+NWS cloud from Travis AFB, wind*0.75: RMA11 calibration meteorology
    - Hastings+Twitchell +NWS cloud from Travis AFB, wind*1.0
    - Hastings+Twitchell +NWS cloud from Travis AFB, wind*1.25

Note that although the functional representation of heat flux is the nearly identical in the RMA and DSM2 water temperature models (see discussion on p.4), the parameters selected during the calibration process for each model differed for the characterization of wind-related effects. Thus, when RMA meteorology was used in DSM2, in additional to using the RMA-value for wind speed, two additional factors were used to bracket the effects of Hastings+Twitchell wind, by increasing wind speed to the original value (factor=1.0) and increasing wind speed above the original value (factor=1.25). The highest wind speed with a factor 1.25 produced the most accurate match for water temperature data.

4.2.2.4 *Boundary condition comparison*

This section covers selected RMA and DSM2-Base flow and water temperature boundary conditions. Figure 4-7 illustrates a comparison in flow boundary conditions relevant to the Cache/Liberty region. Part A (upper left) shows that the Freeport inflow boundary condition for the DSM2 and RMA are nearly the same. Part B (upper right) is an export boundary condition for both models. Part C (lower left) shows that under high flow conditions in the spring of 2011, the RMA-derived Yolo component of this boundary (red line) is significantly greater than the

DWR-DMS derived boundary inflow. Part D (lower right) is the RMA boundary condition at Upper Cache Slough (UCS) that replaces one of the DICU inflow locations – the blue line is a diversion (outflow) while the pink line is local inflow from drainage. As discussed above (see p. 11), measured data was available at this location to replace the estimated values for DICU flows (see also Figure 4-9).

Unlike RMA11, DICU inflow water temperature in QUAL is specified as an annually-repeating monthly temperature time series. The concentration of water quality constituents, such as water temperature, are rarely measured at any of the 258 DICU locations, so data are very sparse in time and space. Figure 4-8 illustrates this temperature time series developed in the 1990's by DWR (1995) from data available at that time in comparison with more recent average agricultural water temperature drain data from 1997 through 2004 from DWR's Municipal Water Quality Investigations section (MWQI). Figure 4-9 (upper) shows the monthly flow values used in DSM2's DICU at Node 320 – the location closest to where RMA's UCS flow location. The magnitude of DICU flows (upper plot) is much lower than the flow measured at UCS (lower plot), although the timing of the peak flows is similar between the two. The differences in estimated *vs.* measured data at the UCS location illustrate that there may locally be significant uncertainty in the DICU estimated flows.

Figure 4-10 illustrates a comparison in water temperature boundary conditions. Part A (upper left) shows a synthetic boundary condition (in green) used in the calibration 1990 – 2008 of the DSM2 water temperature model. Synthetic data was developed as there were no data available to use in that period. The blue line is CDEC water temperature at Freeport+Hood (*i.e.*, a combination of the two data sets) which was used as the Base water temperature at the Yolo inflow boundary in DSM2. The red line is measured Lisbon water temperature data from DWR's Water Data Library (WDL) smoothed with a 3-point average – this was used in the RMA model. Part B. (upper right) shows the water temperature boundary values used at Freeport for DSM2 (blue) and at an internal boundary condition at Hood (red) for the RMA model are nearly identical. Part C (lower plot) is the water temperature boundary used in the RMA model at the UCS inflow location.

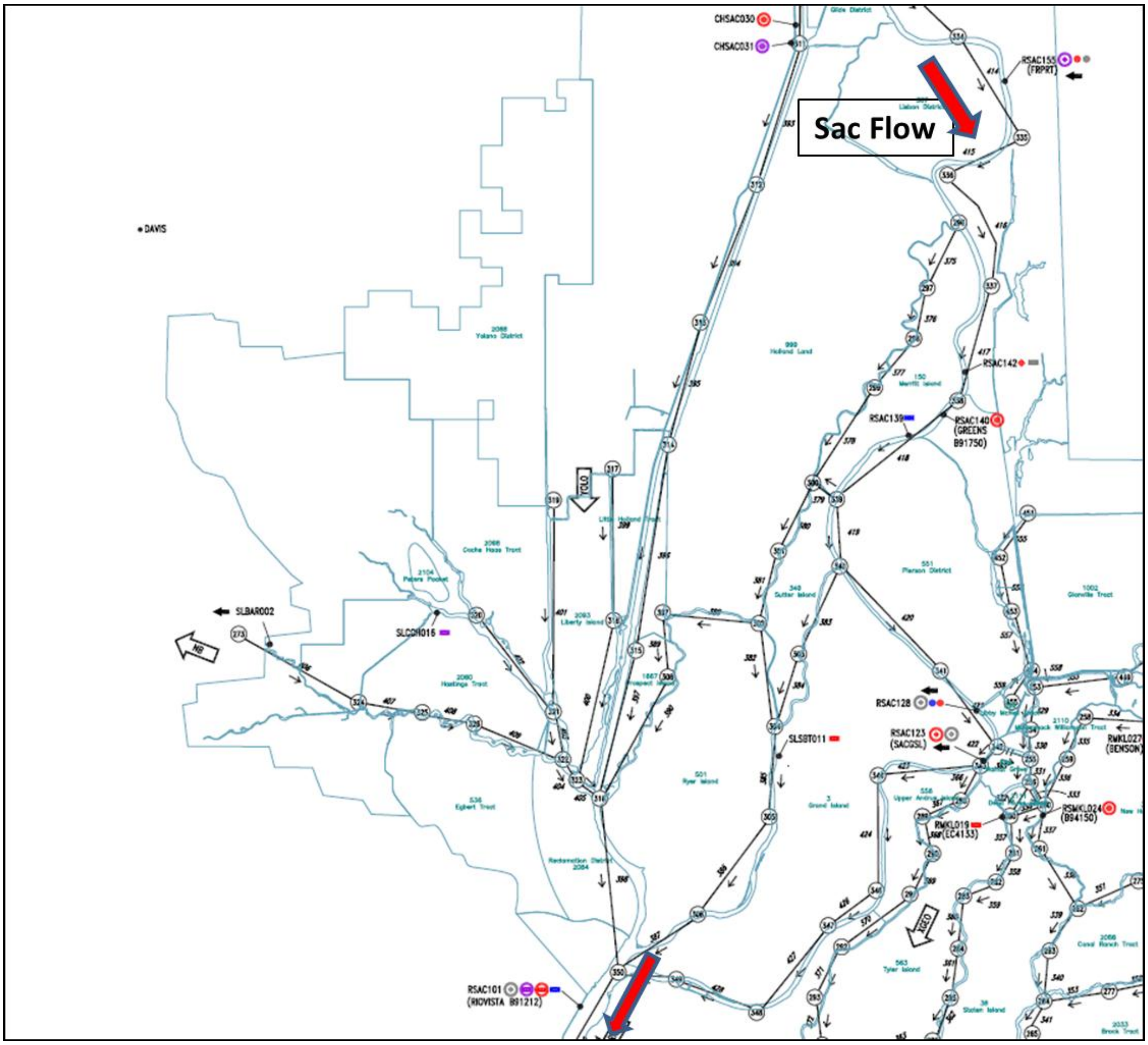


Figure 4-4 Northern region of the DSM2 grid showing the Sacramento River flow direction (red arrows) and the Cache/Liberty area.

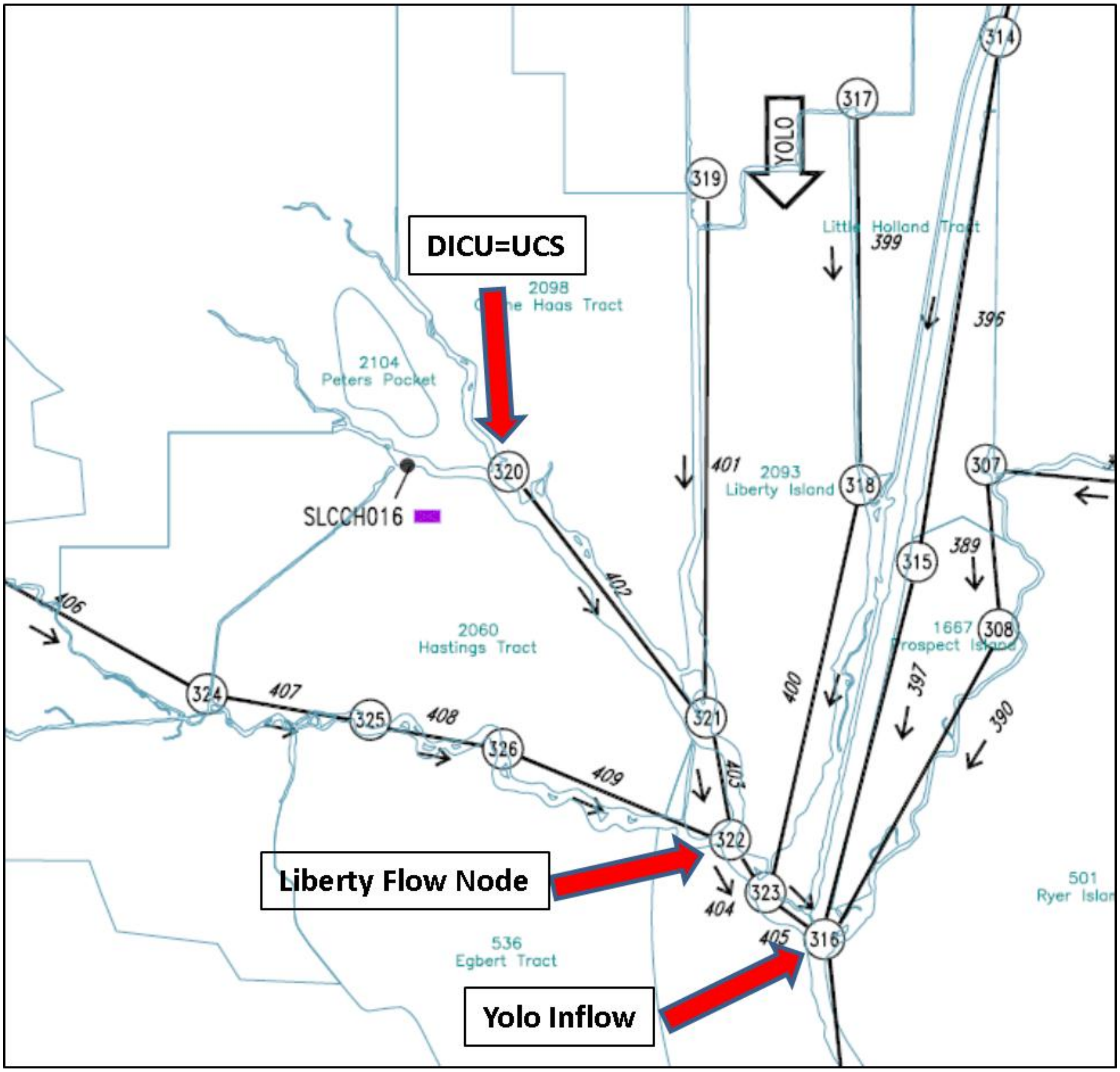


Figure 4-5 Cache/Liberty region in the DSM2 grid identifying three flow boundary locations used in the scenarios.

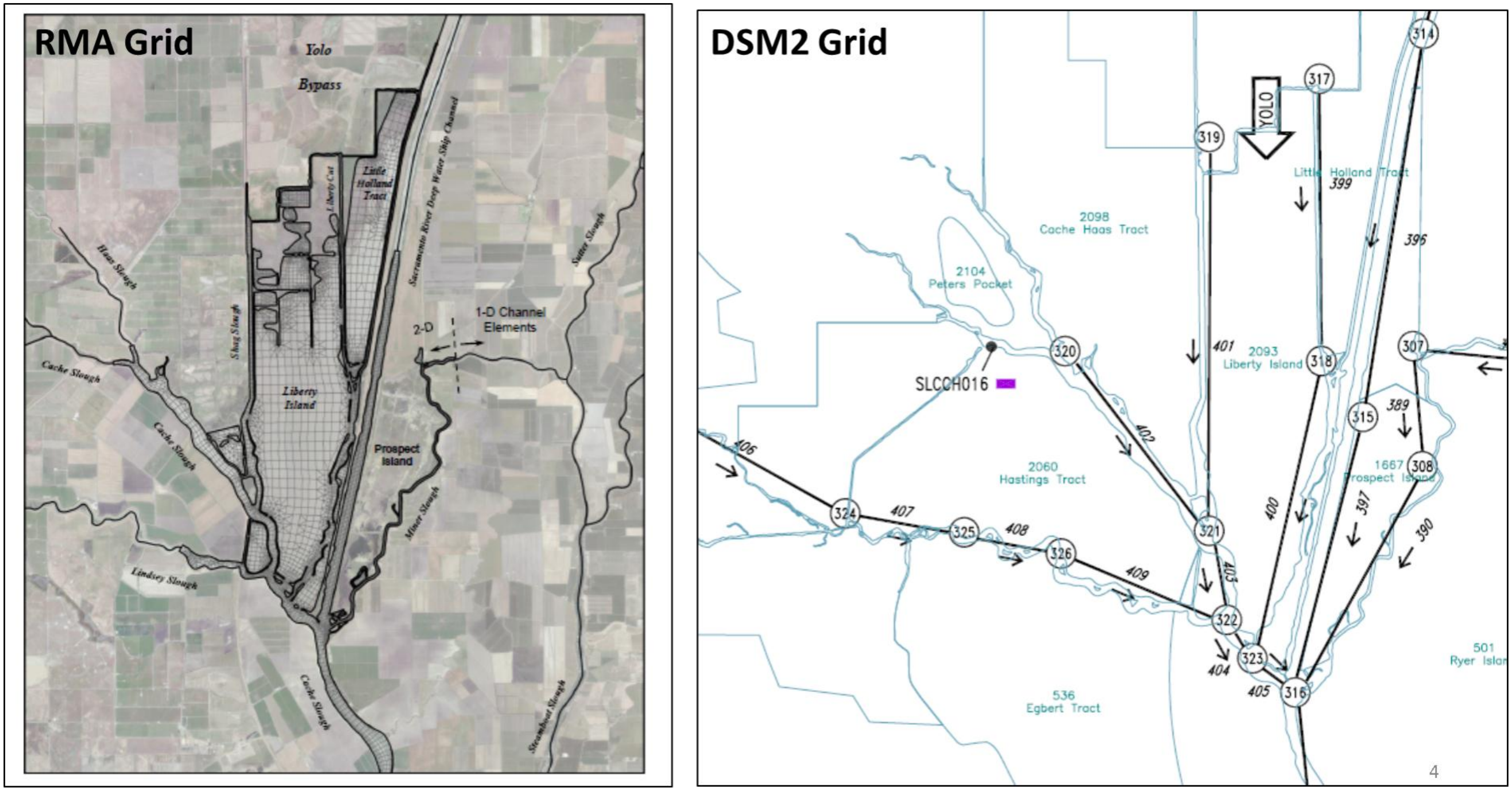


Figure 4-6 Comparison of RMA (left) and DSM2 (right) grids in the Cache/Yolo region.

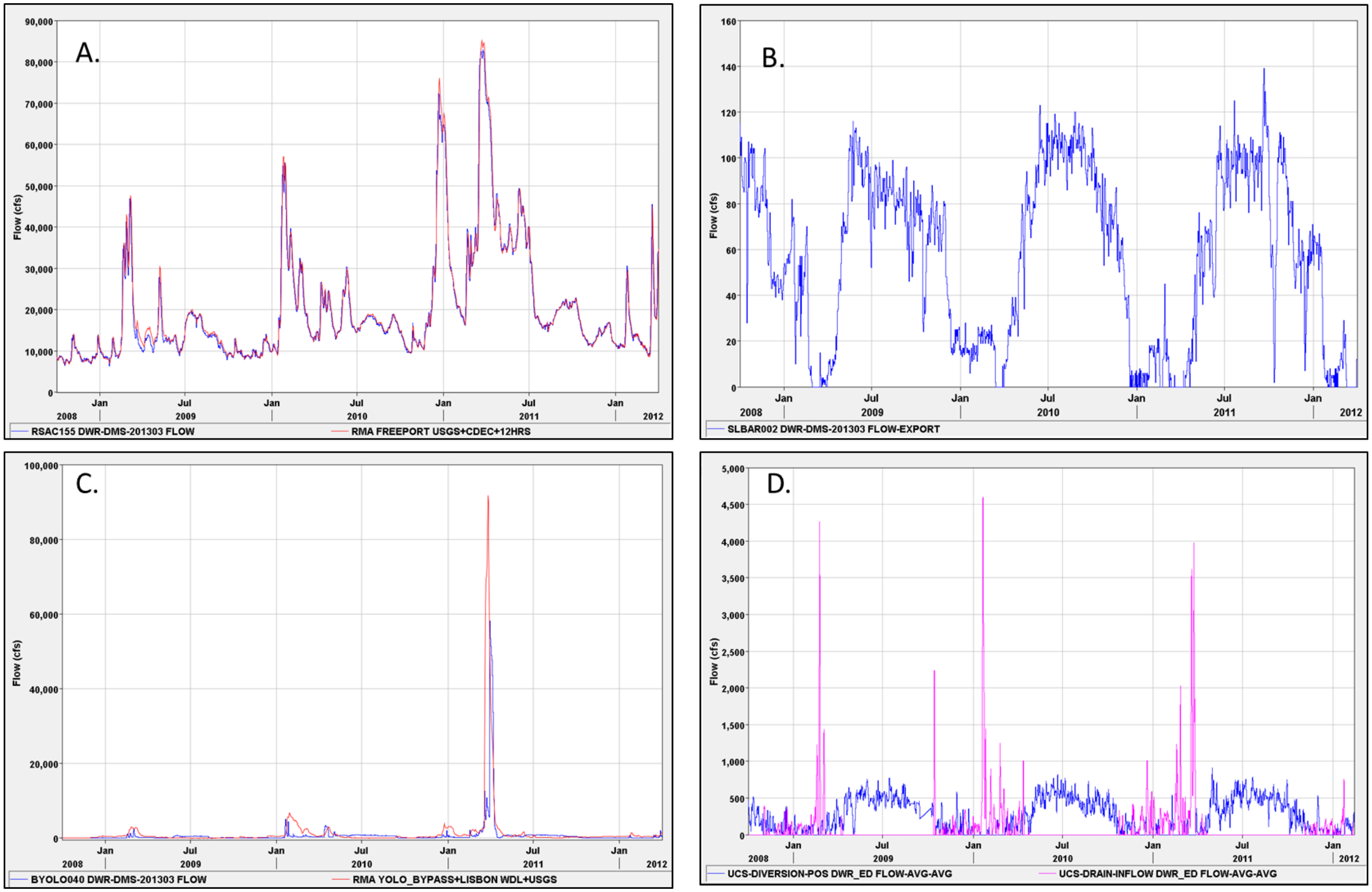


Figure 4-7 DSM2-HYDRO and/or RMA2 flow boundary conditions for A. Freeport (red is RMA), B. Export at Barker Slough, C. Yolo/Lisbon (red is RMA), D. Upper Cache Slough –boundary conditions developed for RMA2 and used in selected DSM2 scenarios.

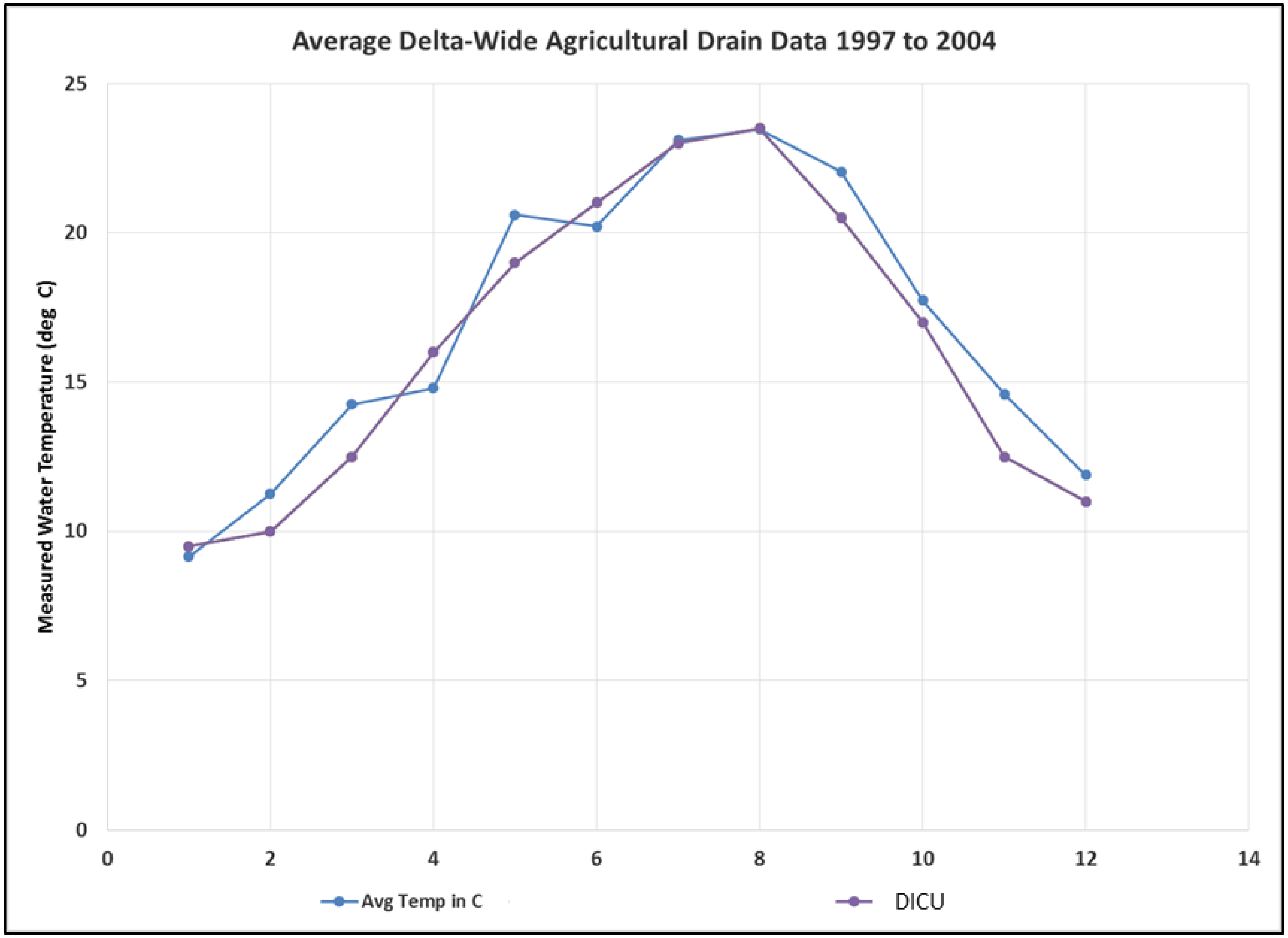


Figure 4-8 DICU annually-repeating monthly water temperature used in DSM2-QUAL (purple) in comparison to averaged drain data from MWQI (blue).

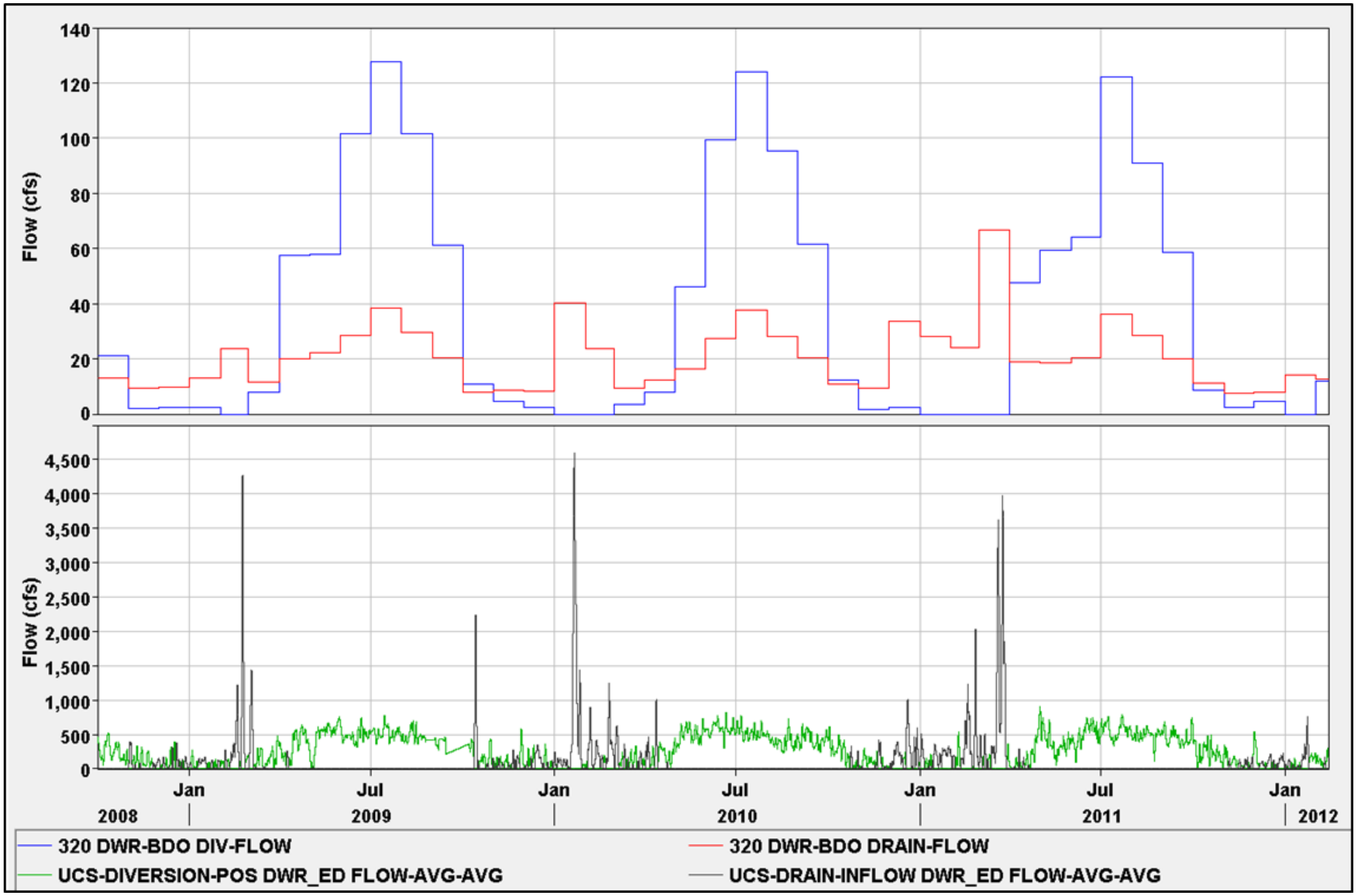


Figure 4-9 DICU annually-repeating monthly inflow (drain – red) and outflow (div – blue) used in DSM2 at Node 320 and the UCS diversion (green) and drain (black) flows developed for the RMA model at a similar location and used in selected DSM2 scenarios.

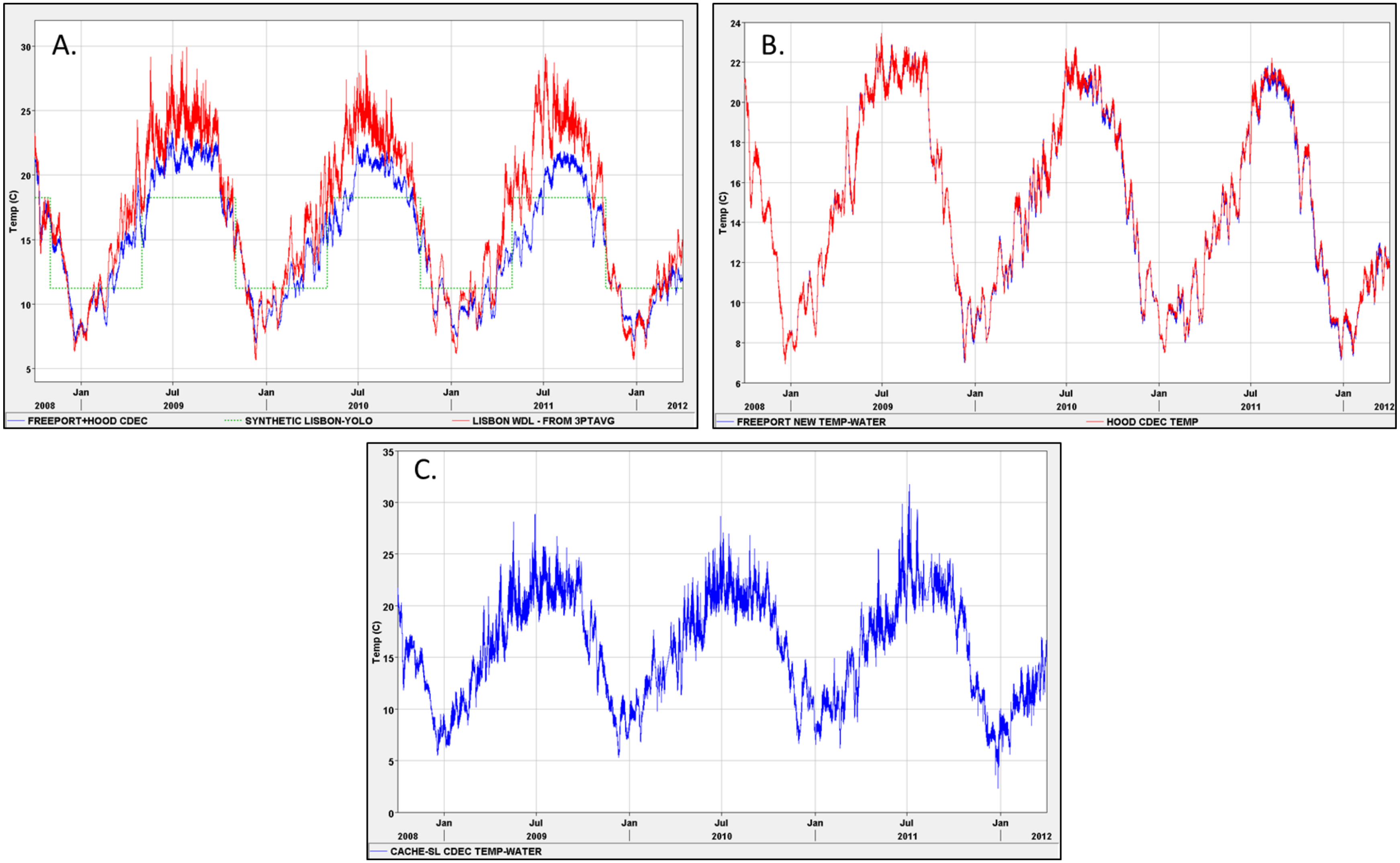


Figure 4-10 Water temperature boundary conditions for A. Lisbon+Yolo (red is WDL data smoothed with a 3-point average used by RMA), B. Freeport and Hood (red is RMA), C. Upper Cache Slough drainage temperature, boundary condition developed for RMA11 and also used in selected DSM2-QUAL scenarios.

5 Results for DSM2 Scenarios

5.1 Background

As discussed in Section 4.2.2.3, DSM2-HYDRO and QUAL simulations were developed with several different boundary conditions to investigate their effects on QUAL water temperature results in the Cache-Liberty region. Table 5-1 provides nomenclature and documentation on those scenarios that are discussed and compared in this section. Figures in this section compare daily-averaged data with daily averaged model output from the scenarios.

The boundary conditions on the Base scenario (DMS-SAC-FOR-YOLO) were chosen to reflect those in the original calibrated water temperature model and also in the BDCP temperature models. The main difference between the calibration model and the current Base scenario is the use of CDEC Freeport-Hood water temperature data at DSM2's Yolo inflow boundary – the calibration used a synthetic water temperature at Yolo as there were no data available at that time. All other boundary conditions are as supplied by DWR-DMS.

An initial comparison of model scenario output at important locations showed that differences just due to inflow boundary conditions or just due to water temperature boundary conditions were relatively small, so in what follows only those models with combined changes to inflow and water temperature are compared. Changes to meteorological boundary conditions are considered separately. Both DSM2-QUAL and RMA11 water temperature simulations tended to be several degrees Centigrade colder than the data October – March annually.

Figure 5-1 shows a comparison of CDEC water temperature data and Base case model output at Cache-Ryer and at Liberty south-end. Although the magnitude of the model output is different than the data at each location, the relative magnitudes of the model output follow similar trends to the data, as Liberty south-end tends to be warmer than Cache-Ryer in both data and model output.

Due to data availability limitations, only the years 2010 and 2011 are analyzed herein.

Table 5-1 Scenario names and differences in inflow, water temperature and meteorological boundary conditions in plots.

Scenario Name	Flow BCs	Temperature BCs	Meteorology
DMS-SAC-FOR-YOLO	**Sac**: DMS RSAC155 **Lis/Yolo**: DMS byolo040 **DICU**:DMS	**Sac**: Hood+Freeport **Lis/Yolo**: Hood+Freeport **DICU**:MG Monthly	DSM2 calibration
MG-BC-LIS+YOLO	**Sac**: DMS RSAC155 **Lis/Yolo:** RMA Lis+Yolo **DICU**: DMS	**Sac**: Hood+Freeport **Lis/Yolo**: CDEC LIS **DICU**: MG Monthly	DSM2 calibration
MG-BC-SAC-FOR-YOLO	**Sac**: DMS RSAC155 **Lis/Yolo**: RMA Lis+Yolo **DICU**: DMS	**Sac**: Hood+Freeport **Lis/Yolo**: Hood+Freeport **DICU**: MG Monthly	DSM2 calibration
RMA-BC-MET	**Sac**:RMA Freeport **Lis/Yolo**: RMA Lis+Yolo **DICU**: DMS + UCS flow at Node 320	**Sac**: Hood **Lis/Yolo**: CDEC LIS **DICU**: MG Monthly + CDEC Cache Sl. at Node 320	RMA calibration + wind*1.25
MG-BC-LIS+YOLO RMA MET	**Sac**: DMS RSAC155 **Lis/Yolo**: RMA Lis+Yolo **DICU**: DMS	**Sac**: Hood+Freeport **Lis/Yolo**: CDEC LIS **DICU**: MG Monthly	RMA calibration
MG-BC-LIS+YOLO REVISED RMA MET	**Sac**: DMS RSAC155 **Lis/Yolo**: RMA Lis+Yolo **DICU**: DMS	**Sac**: Hood+Freeport **Lis/Yolo**: CDEC LIS **DICU**: MG Monthly	RMA calibration + wind*1.25

5.2 DSM2 Scenario differences due to flows and water temperature

Figure 5-2 shows the comparison between Cache-Ryer data (blue dashed line) and four DSM2 scenarios from April to September in 2010 (upper plot) and in 2011 (lower plot), while Figure 5-3 shows the comparison between Liberty south-end data (blue dashed line) and four DSM2 scenarios from April to September in 2011, the only year data was available in these months during the modeled period.

At Cache-Ryer (Figure 5-2), all of the scenarios showed a tighter fit with the data in 2011 than in 2010. The DSM2 scenario RMA-BC-MET that used the RMA meteorology with the measured wind speed increased by a factor of 1.25 (see Table 5-1) followed the pattern of the CDEC data better than the other scenarios and was also a slightly better visual fit to the data than the scenarios using the original DSM2 calibration meteorology, which were all very similar.

At Liberty south-end (Figure 5-3), the DSM2 output is from the zero-dimensional representation of Liberty Island, so it is expected to be somewhat different than the CDEC point measurement (dashed blue line). Again, the RMA-BC-MET scenario output follows the data pattern somewhat better than the other scenarios. At this location, the MG-BC-LIS+YOLO scenario that uses the RMA inflow boundary condition (Lis+Yolo) and the Lisbon water temperature data for the Yolo boundary is warmer than the other scenarios using the original DSM2 calibration meteorology from April – June, but is only a marginally better match for the data. Note that the measured water temperature at Lisbon is warmer than either of the other Yolo boundary temperatures (see Figure 4-10).

5.3 DSM2 Scenario differences due to meteorology

Figure 5-4 through Figure 5-7 illustrate the comparison of January – December water temperature data at four locations in comparison with three meteorologically-focused scenarios. Note that the MG-BC-LIS+YOLO scenario for inflow and water temperature was used for this comparison as it generally gave the best data fits when used with the original DSM2 calibration meteorology. Note that the RMA meteorology was revised to give a better fit the data when used in DSM2 in the scenario MG-BC-LIS+YOLO REVISED RMA MET (i.e., measured wind speed was increased by a factor of 1.25).

At Hood, Figure 5-4 , there is practically no difference between the scenarios, as they all have a close fit with the data. The situation is quite different at Cache-Ryer (Figure 5-5). The scenario using the unaltered RMA calibration meteorology, MG-BC-LIS+YOLO RMA MET, was too warm May – October, and also warmer than the other scenarios. Visually, the scenario with the revised RMA meteorology, MG-BC-LIS+YOLO REVISED RMA MET, gave the best fit for both 2010 and 2011. The DSM2 calibration meteorology scenario (MG-BC-LIS+YOLO) was also a good fit, although variation was greater, at times too cool and other times too warm. In 2011, all of the scenarios are too cool during November – December. At Liberty, Figure 5-6, and at Rio Vista, Figure 5-7 the situation is similar to that at Cache-Ryer.

5.4 Summary of DSM2 boundary condition analysis

The analysis of scenarios varying DSM2 inflow, water temperature and meteorological boundary conditions showed that variations in the main flow and water temperature boundary conditions had only a minor effect on modeled water temperature in the Cache/Liberty region during the analysis period. The original DSM2 calibration meteorology was significantly better that the original RMA meteorology when used in DSM2. However, using a revised RMA wind speed at a higher value gave better results than the DSM2 meteorology at the locations surveyed.

During the years 2010 – 2011 investigated, meteorological boundary conditions were the most important factor in determining modeled water temperature in this region, and therefore are also the most important factor driving the quality of the model results in comparison with data.

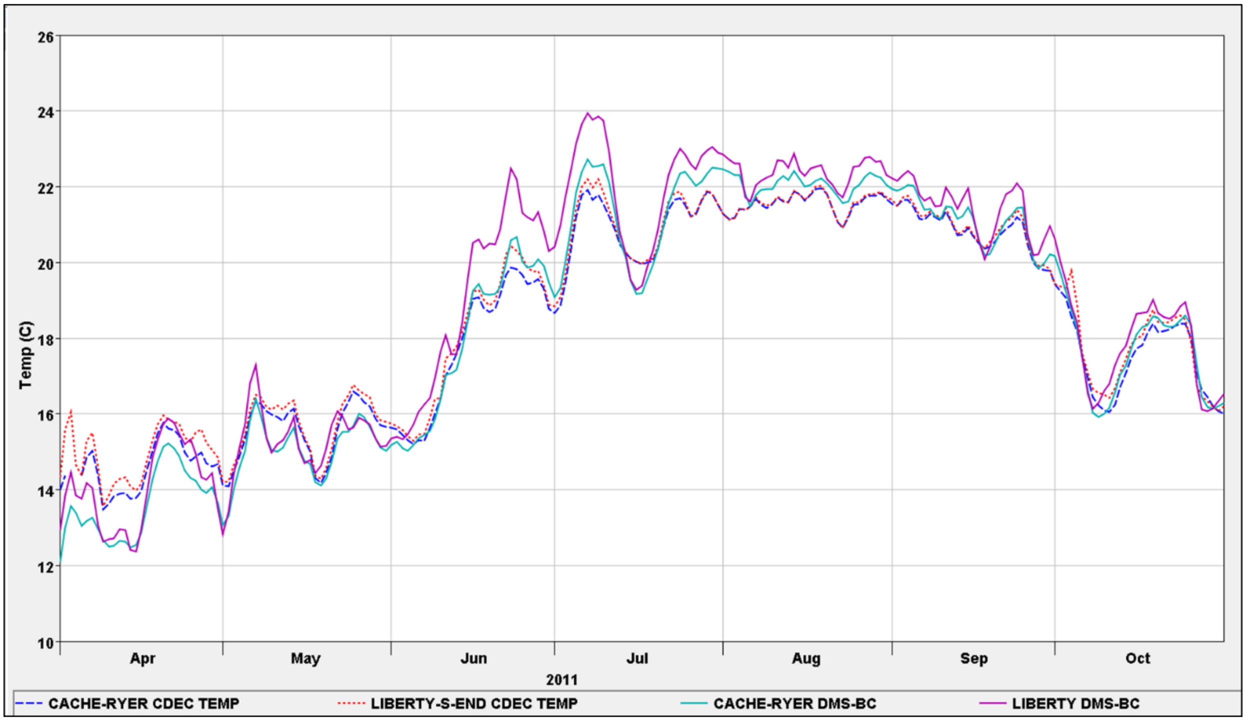
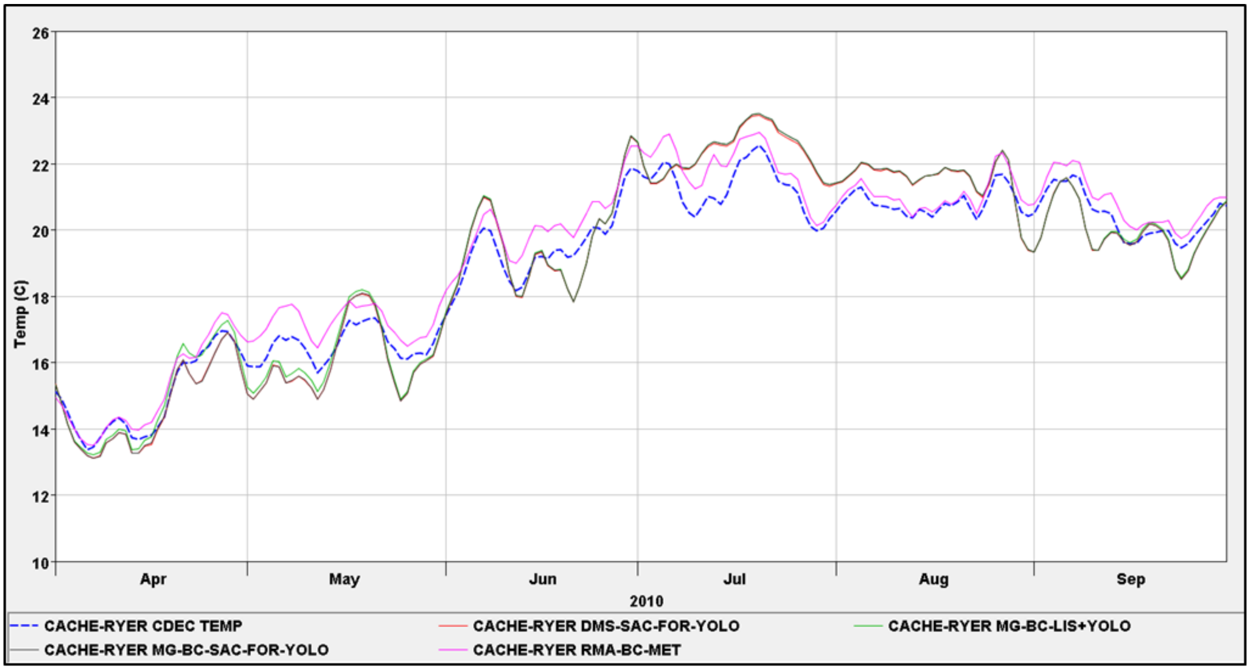


Figure 5-1 Comparison of daily-averaged CDEC data at Cache-Ryer and Liberty South-End with the DSM2 Base Case scenario, denoted DMS-SAC-FOR-YOLO in Table 5-1.



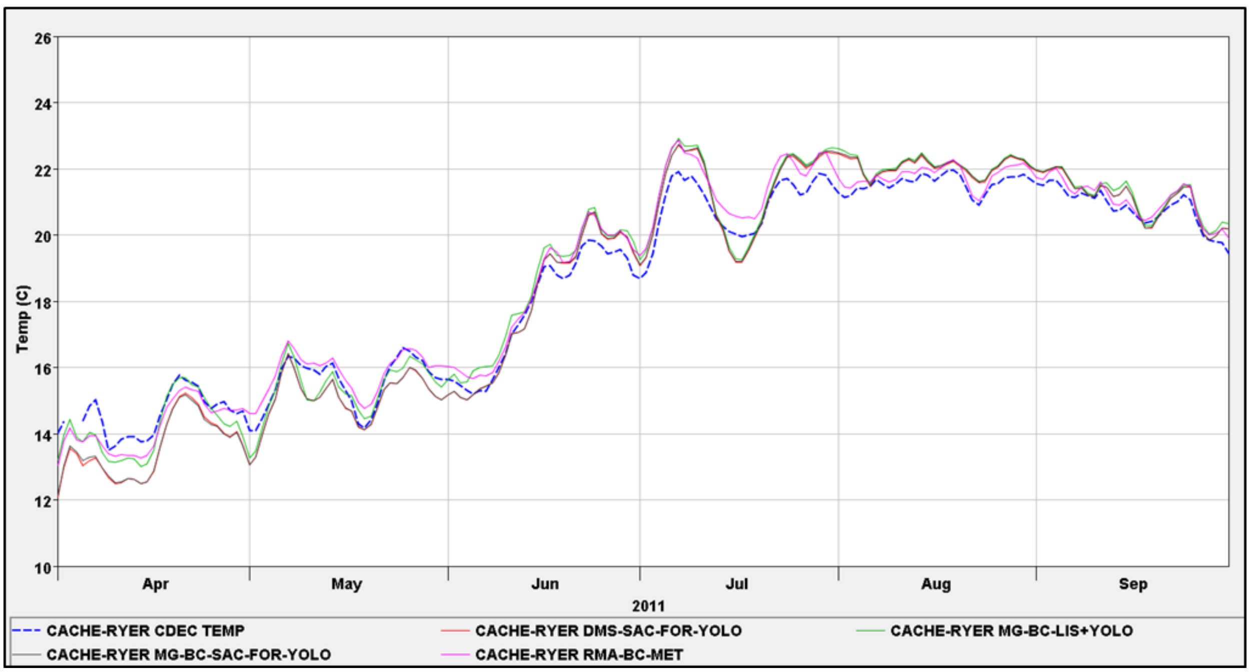


Figure 5-2 Daily-averaged DSM2 scenario water temperature differences at Cache-Ryer due to boundary changes in water temperature and Yolo-Lisbon inflow. Blue dashed line is the CDEC data.

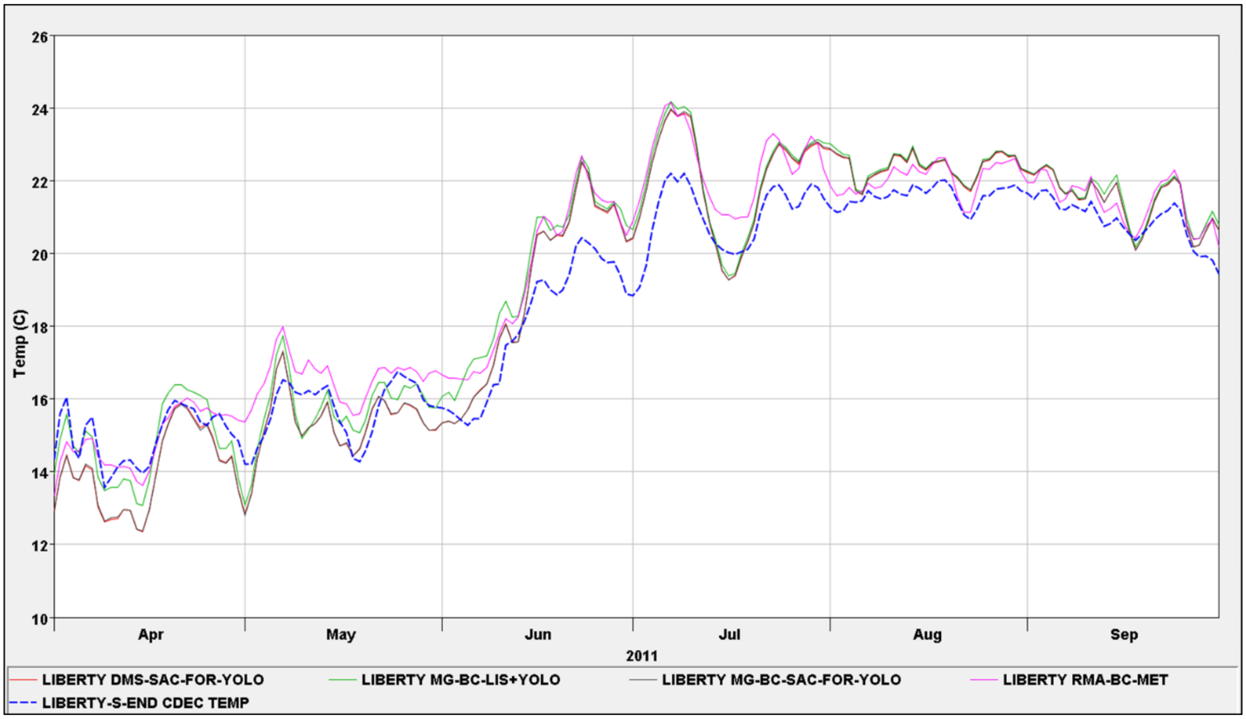


Figure 5-3 Daily-averaged DSM2 scenario water temperature differences in Liberty Island due to boundary changes in water temperature and Yolo-Lisbon inflow. Blue dashed line is the CDEC data.

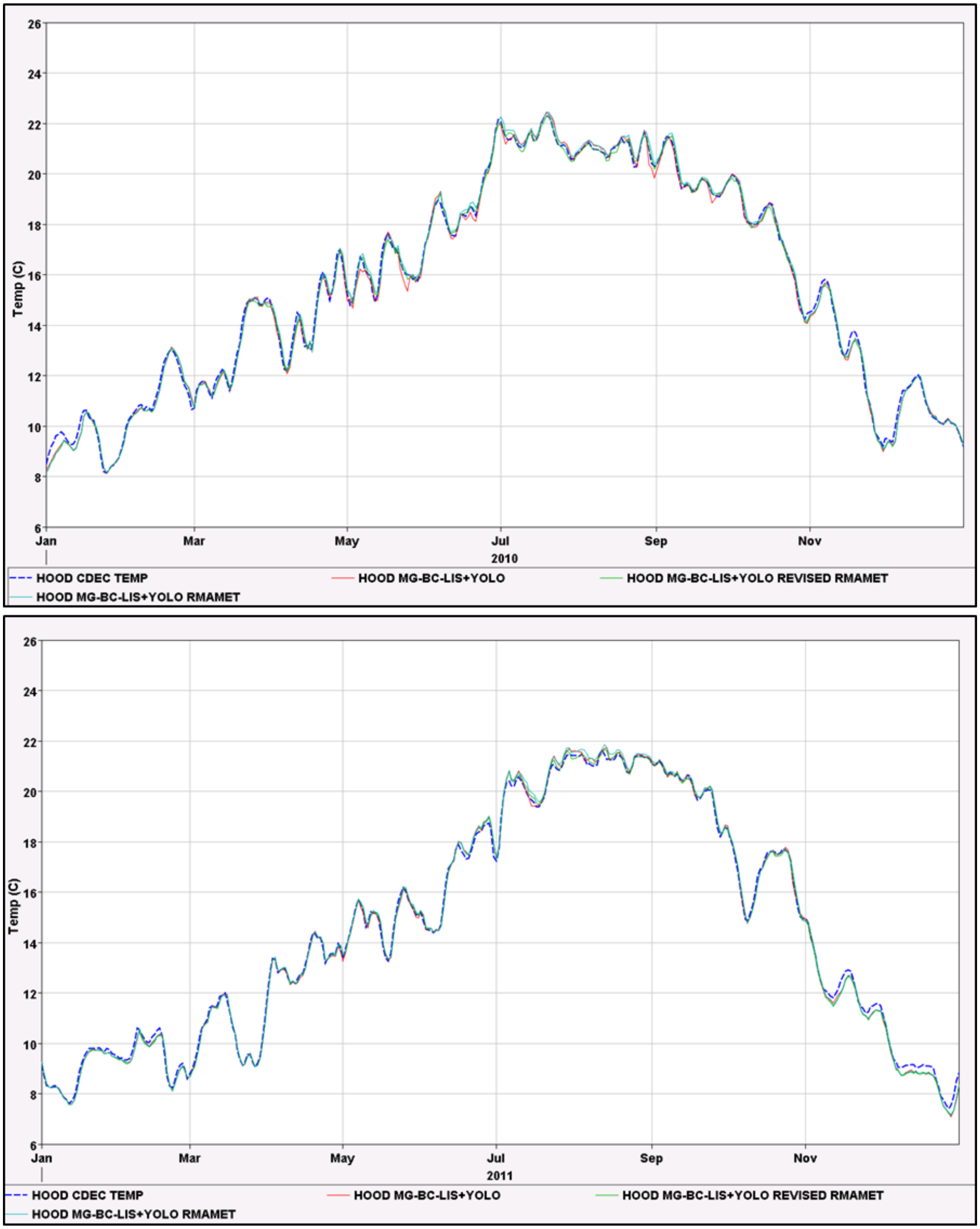


Figure 5-4 Daily-averaged DSM2 scenario water temperature differences at Hood due to boundary changes in meteorology. Blue dashed line is the CDEC data.

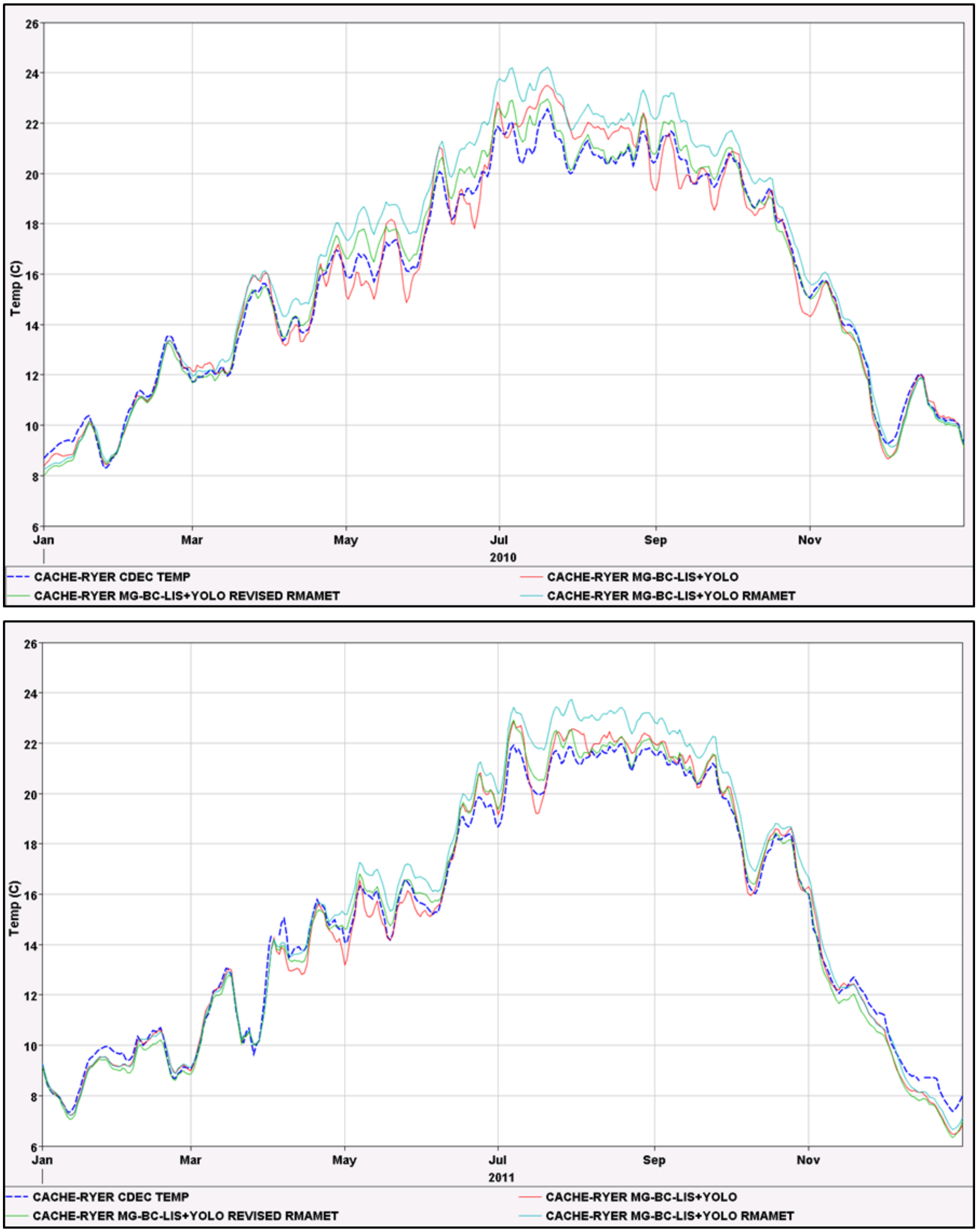


Figure 5-5 Daily-averaged DSM2 scenario water temperature differences at Cache-Ryer due to boundary changes in meteorology. Blue dashed line is the CDEC data.

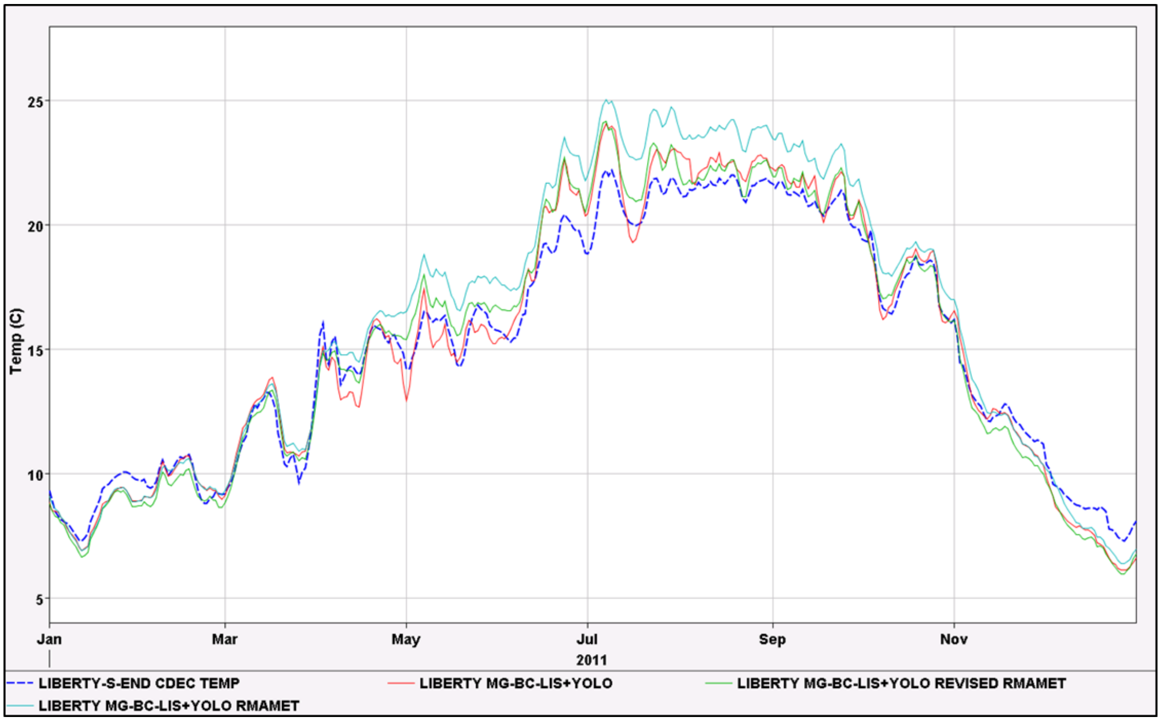


Figure 5-6 Daily-averaged DSM2 scenario water temperature differences at Liberty due to boundary changes in meteorology. Blue dashed line is the CDEC data.

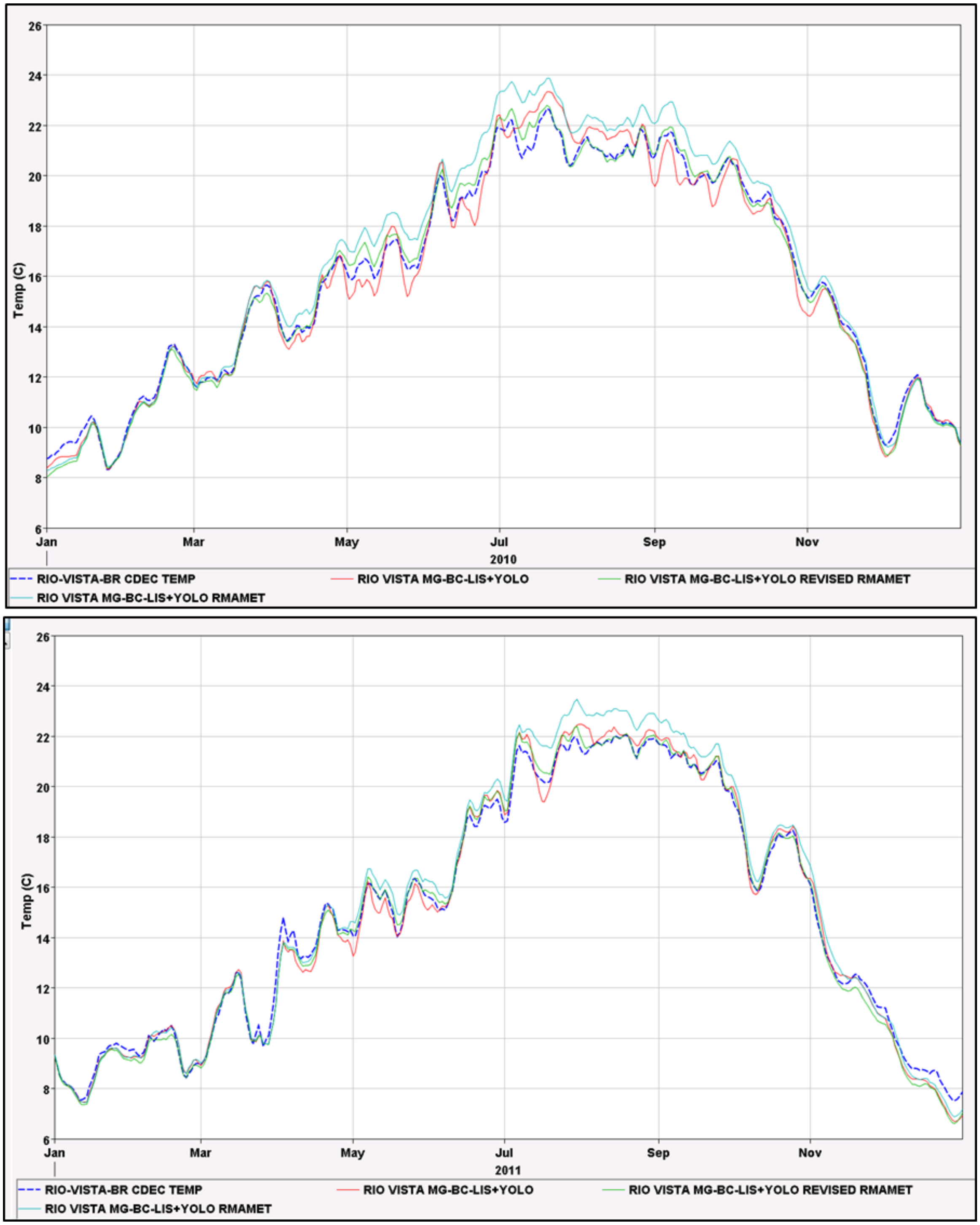


Figure 5-7 Daily-averaged DSM2 scenario water temperature differences at Rio Vista due to boundary changes in meteorology.

6 Liberty Island: RMA/DSM2 Comparison

6.1 RMA Model - Effect of bed heat flux term

As discussed in Section 3.2, the exchange of heat between water and bed is important in modeling shallow water and exposed intertidal areas as implementation of this term in RMA11 can moderate large temperature swings in shallow or intertidal areas. To test the effect on the shallow water areas in Liberty Island, the model was run with and without the term implemented and a location was chosen in the upper end (northern) of the island for comparison (denoted LIB_Up2 in Figure 6-1). At the higher end of modeled water temperature (Figure 6-1, upper plot), the bed term introduced differences of +/- 0.2 °C, while it introduced differences of -0.3 to 0.1 °C at lower temperatures. For our analysis objectives, the use of the bed heat flux term in RMA11 is considered to have only a very minor effect.

6.2 Calculating RMA11 volume-averaged Liberty Island water temperature

6.2.1 Background

Because the RMA model representation of Liberty Island is two-dimensional and DSM2's representation is zero-dimensional, a method needed to be developed to calculate a volume-averaged water temperature from the RMA11 results. A volume-averaged water temperature is not available directly from RMA model output.

In order to eliminate as much error as possible in the calculations, comparison times were chosen when the difference between the RMA11 model calculation at CDEC station Liberty south-end and the data was minimized. Figure 6-2 shows hourly-averaged data and model output in the period April – September, 2011 when there was data available. By observation, times in May and June (when the difference was very small) were chosen to capture times when Liberty was filling (at or approaching high tide) and draining (at or approaching low tide). Note that the difference between RMA11 model output and CDEC data in Cache Slough near Ryer Island (downstream of Liberty Island) was also very small in May and June (not shown).

Figure 6-3 illustrates the progressive warming of measured water temperature from upstream locations downstream to the shallow end of Liberty Island. Water from Hood (blue line) flows downstream to the CDEC data location in Cache Slough near Ryer Island (red line), then to the entrance of Liberty Island at the south end (green line). In the lower plot (refer to Figure 4-2 and Figure 4-3), we see that cooler water temperature at the south end of Liberty (blue line) heats progressively to location LBP (black line) in the shallow end of Liberty Island. Figure 6-4 through Figure 6-6 show comparisons between RMA11 model output and three BREACH III study locations (see Figure 4-3) in Liberty Island for comparison.

6.2.2 Contour plots

RMA11 water temperature contour plots are shown during two very warm water periods in Figure 6-7, and during very cold water periods in Figure 6-8. Although it is possible to make a rough approximation for the volume-averaged water temperature from these plots, because the depth of water varies from deeper at the downstream end to shallower at the upstream end, as indicated roughly in Figure 6-9, compensation needs to made for volume changes with water depth. Note that water depth, and therefore the volume of water in Liberty Island, changes diurnally with the tides and also with the spring-neap (approximately two-week) tidal cycle. Calculations made using the RMA models indicate that the volume fraction of the deeper region of Liberty Island (left plot in Figure 6-9) ranges from 0.85 to 0.92 and the shallower region (right plot in Figure 6-9) from 0.15 to 0.08, respectively.

6.2.3 Calculating Liberty volume-averaged water temperature and comparison with DSM2

In this subsection, a methodology is presented to estimate an RMA model volume-averaged Liberty Island water temperature to be used for comparison with DSM2 zero-dimensional results.

Figure 6-10 shows the locations of RMA model output transect taken in Liberty Island. At each point during comparison times, water temperature, water depth and distance along the transect were recorded. Between successive points, an area was calculated (average depth*distance between points) and multiplied by the average temperature of the end points. The fractional water temperature for each subarea is calculated by dividing by the total area along the transect (the sum of point-wise areas) for the deep region and for the shallow region (refer to Figure 6-9). Summing the fractional areas for the deeper and shallower regions separately yields an average temperature for each region. The final volume averaged temperature for Liberty Island is then calculated using (0.85*deeper average) + (0.15*shallower average).

Table 6-1 shows the results of these calculations as well as the DSM2-QUAL hourly average water temperature from model output. By observation, it is clear that the difference between the RMA volume-averaged and the DSM2 zero-dimensional temperatures is the greatest during times when Liberty Island is draining.

Figure 6-11 demonstrates this difference in a plot where it is seen that as the RMA model volume averaged temperature increases, the difference between the DSM2 and RMA Liberty Island temperatures increases, with DSM2's Liberty temperature cooler than RMA's. As a ground-truth comparison shown on the same plot, the temperature difference between DSM2 Liberty Island temperature on draining and the CDEC temperature at Liberty south-end at the same times is smaller, on the order of one °C or less (NOTE: DSM2 temperatures and temperature differences were rounded to the nearest degree to account for differences between hourly data and 15-min model output).

Table 6-1 Comparison of calculated RMA averaged Liberty Island temperatures and DSM2 hourly averaged model output. DSM2 Liberty temperatures were rounded to the nearest degree to account for differences in the output intervals of the time series.

Date	Tide	RMA Deep (°C)	RMA Shallow (°C)	RMA Vol. Average (°C)	DSM2 Liberty (°C)
06 May 2011	Drain	20	24.3	20.6	18
06 May 2011	Fill	18.1	20.1	18.4	18
19 May 2011	Drain	17.5	23.7	18.4	16
20 May 2011	Fill	15.1	16.5	15.3	15
04 Jun 2011	Fill	15.1	15.4	15.1	15
04 Jun 2011	Drain	15.8	17.3	16.0	16
21 Jun 2011	Fill	21	22.9	21.3	21
21 Jun 2011	Drain	25.5	33.2	26.7	22

6.2.4 Particle tracking simulation

An RMA particle tracking simulation was developed, with a late June 2011 time frame, to investigate the movement of water between Cache Slough and Liberty Island. Figure 6-12 documents that 5000 particles were inserted instantaneously at three locations along Cache Slough on June 22, 2011 on an incoming tide. Figure 6-13 shows the particle tracking simulation results at four times subsequent to insertion. During inflow (filling), water from Cache Slough mixes with waters in the deep portion of Liberty Island (refer to Figure 6-9). On the outgoing tide (draining), water from this deep region leaves Liberty Island (upper right panel) with a small proportion of the particles remaining in the south end of Liberty. After a couple of days, the particle insertion location in Cache Slough becomes insignificant, as the particle colors are now well-mixed.

6.2.5 Discussion of results

The particle tracking results provide additional information on explaining why DSM2 Liberty temperatures are quite close to CDEC Liberty south-end temperature data, but the volume-averaged RMA water temperature is significantly warmer than the DSM2 Liberty temperature. Interpreting the RMA particle tracking results indicates that water in the shallow region of Liberty Island is not readily exchanged with the water in Cache Slough downstream of Liberty. Water from Cache Slough mixes with the deeper Liberty waters, which move tidally in and out of Liberty Island. Thus, although the RMA volume averaged water temperature is much higher than DSM2's Liberty temperature when Liberty is draining, the RMA deep end temperature is much closer to the DSM2 temperature and also much closer to the CDEC data at Liberty south end. Note that the particle tracking also shows that the estimate for the deep end of Liberty Island (Figure 6-9) includes a greater proportion of the volume of Liberty Island than indicated by the particle tracking results, as particles (Figure 6-13) do not reach that far into Liberty Island.

Also, the water filling Liberty Island comes in at a temperature very close to data recorded at Cache Slough near Ryer Island, and both models do a reasonable job during the Liberty filling cycle at capturing the CDEC temperature data at Liberty south end.

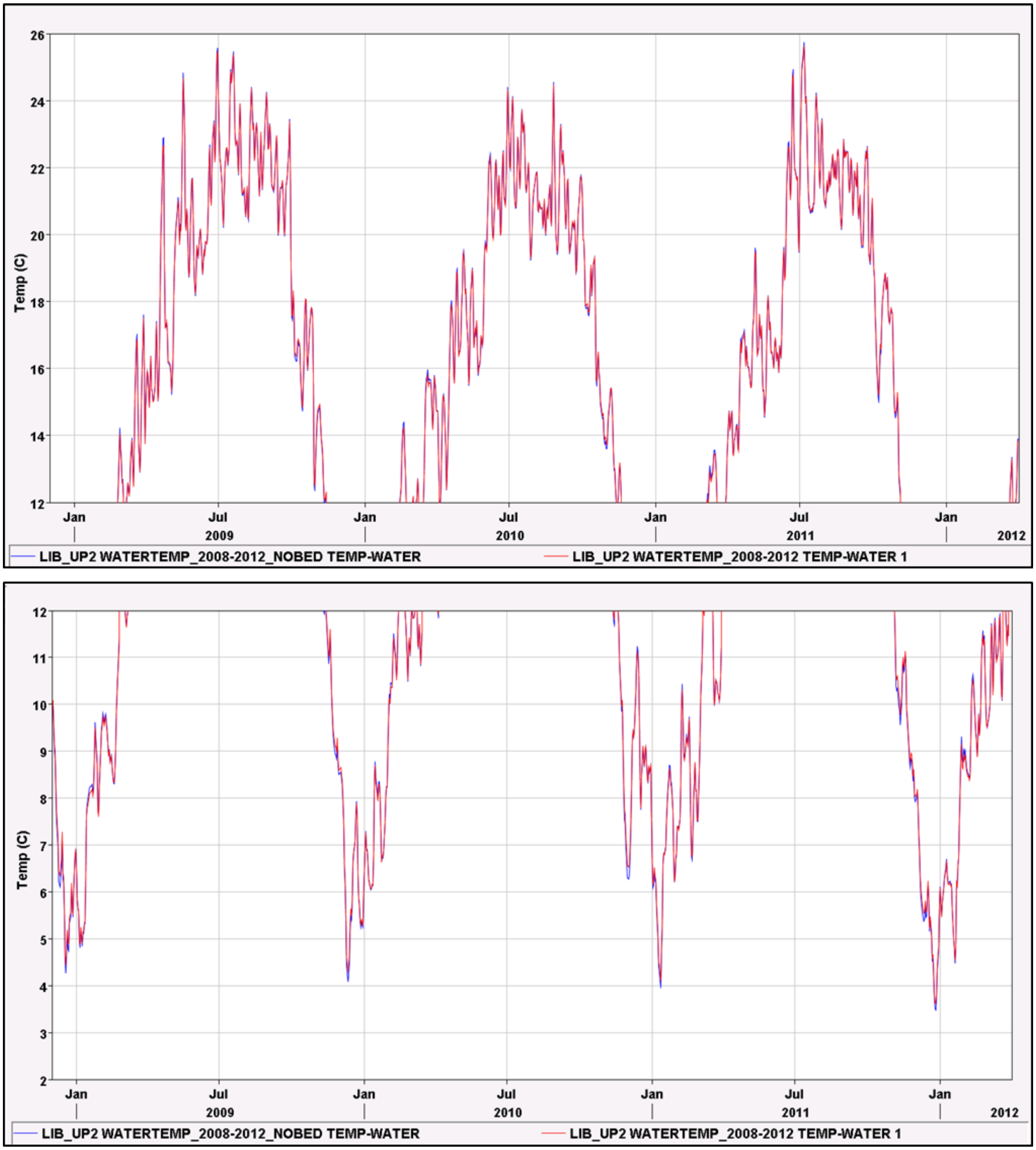


Figure 6-1 Effects of the RMA11 bed flux term on water temperature in a shallower sections of Liberty Island.

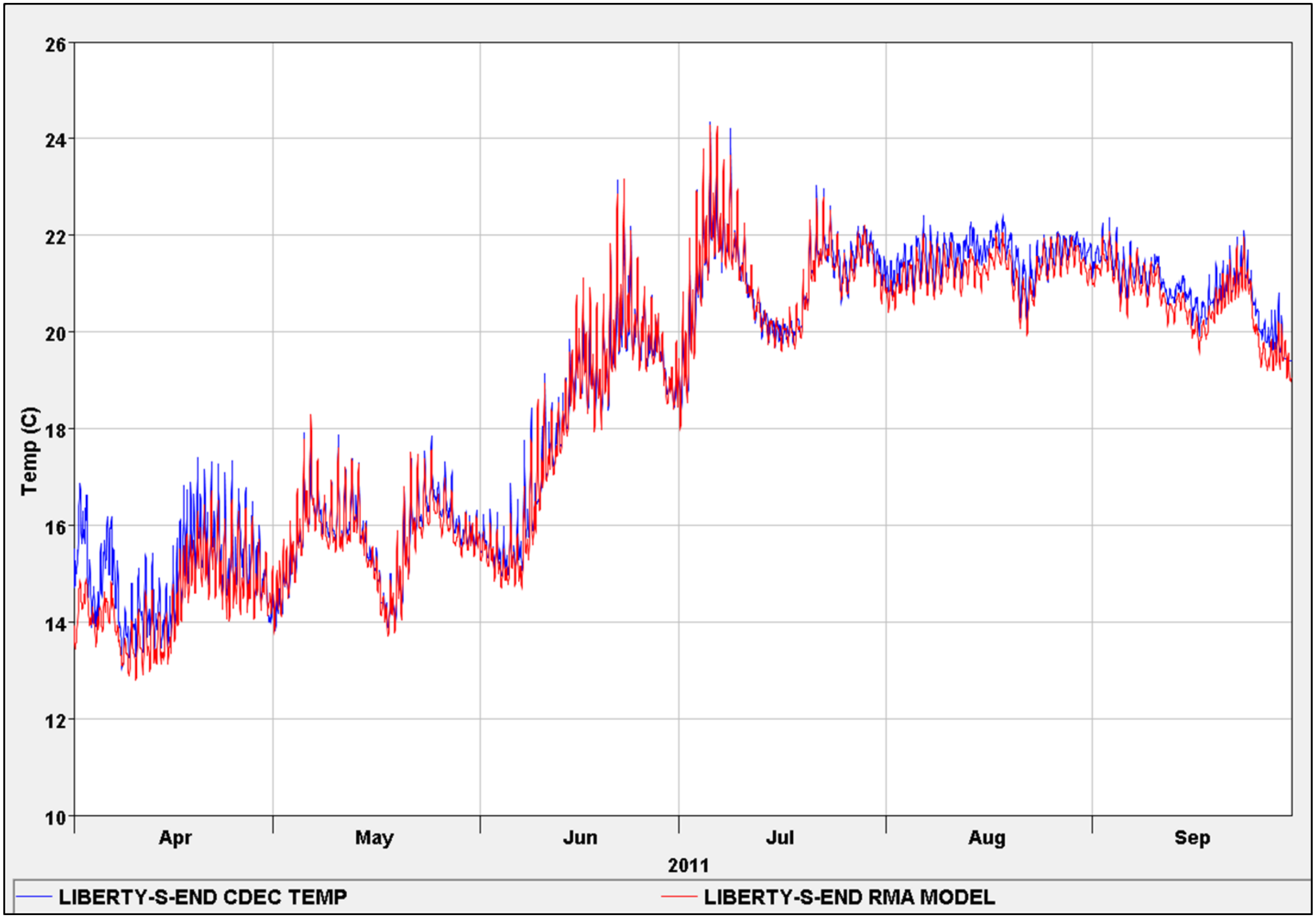


Figure 6-2 Comparison of CDEC hourly water temperature data (blue) and RMA11 model output (red) at the Liberty south-end location in 2011.

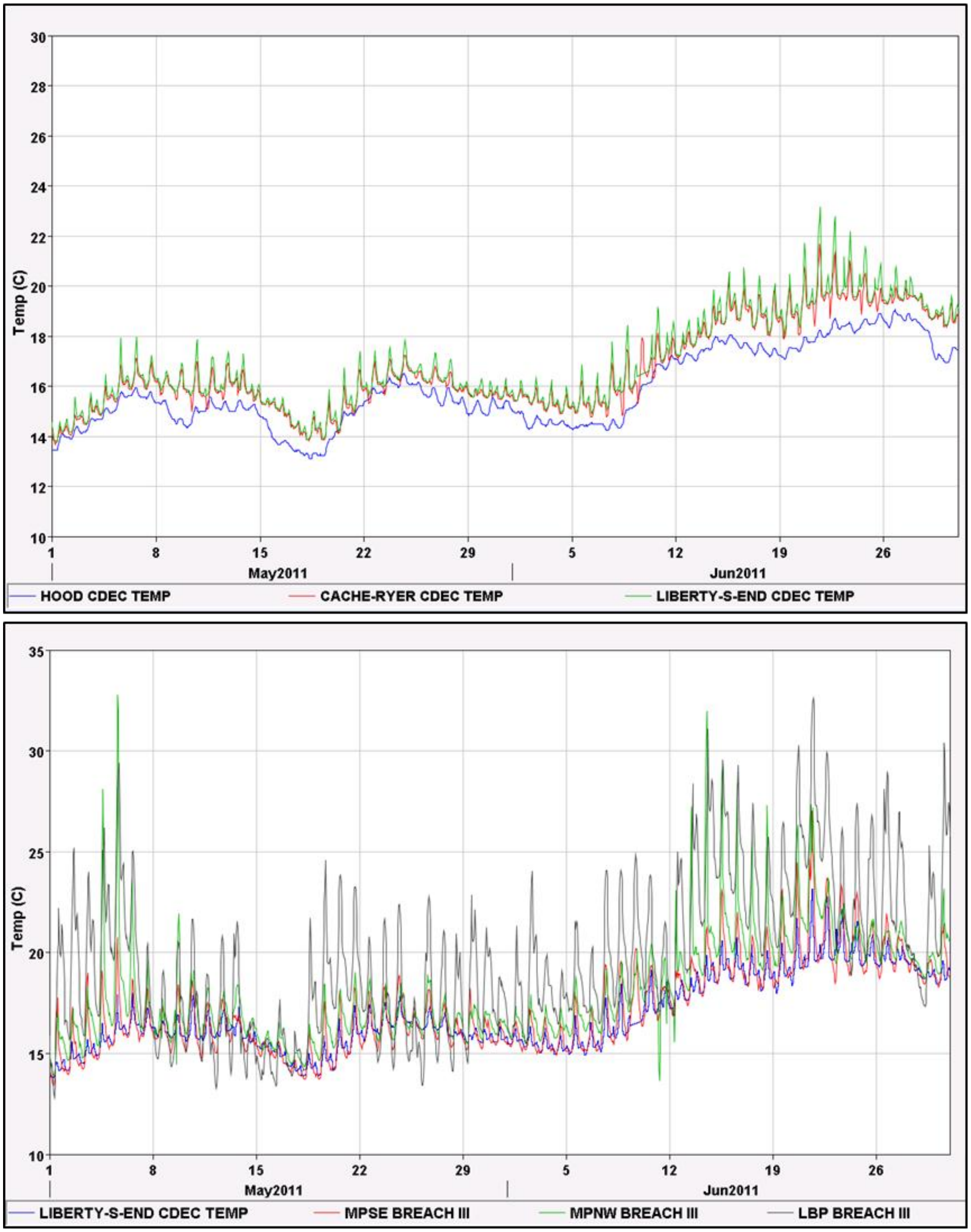


Figure 6-3 Comparison of measured water temperatures – (upper) Water from Hood flows into Cache Slough and then into and out of Liberty Island (lower) Water in Liberty Island from entry point in the south end (blue line), location MPSE (red) to the north east, location MPNW (green) to the north and west, and LBP (black) in the far north.

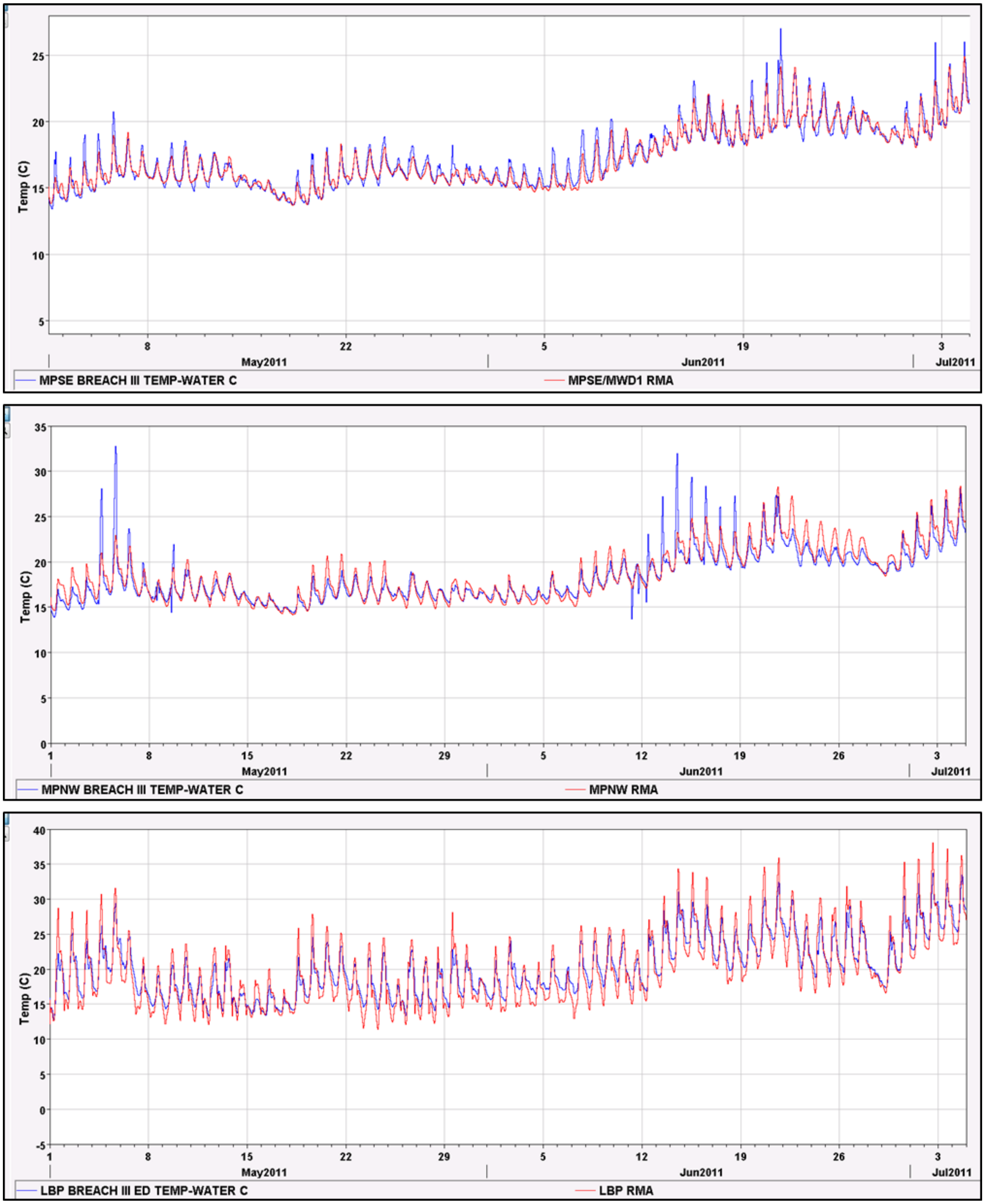


Figure 6-4 Comparison of Breach III hourly water temperature data (blue) and RMA11 model output (red) at three Liberty Island locations in 2011 (see Figure 4-3).

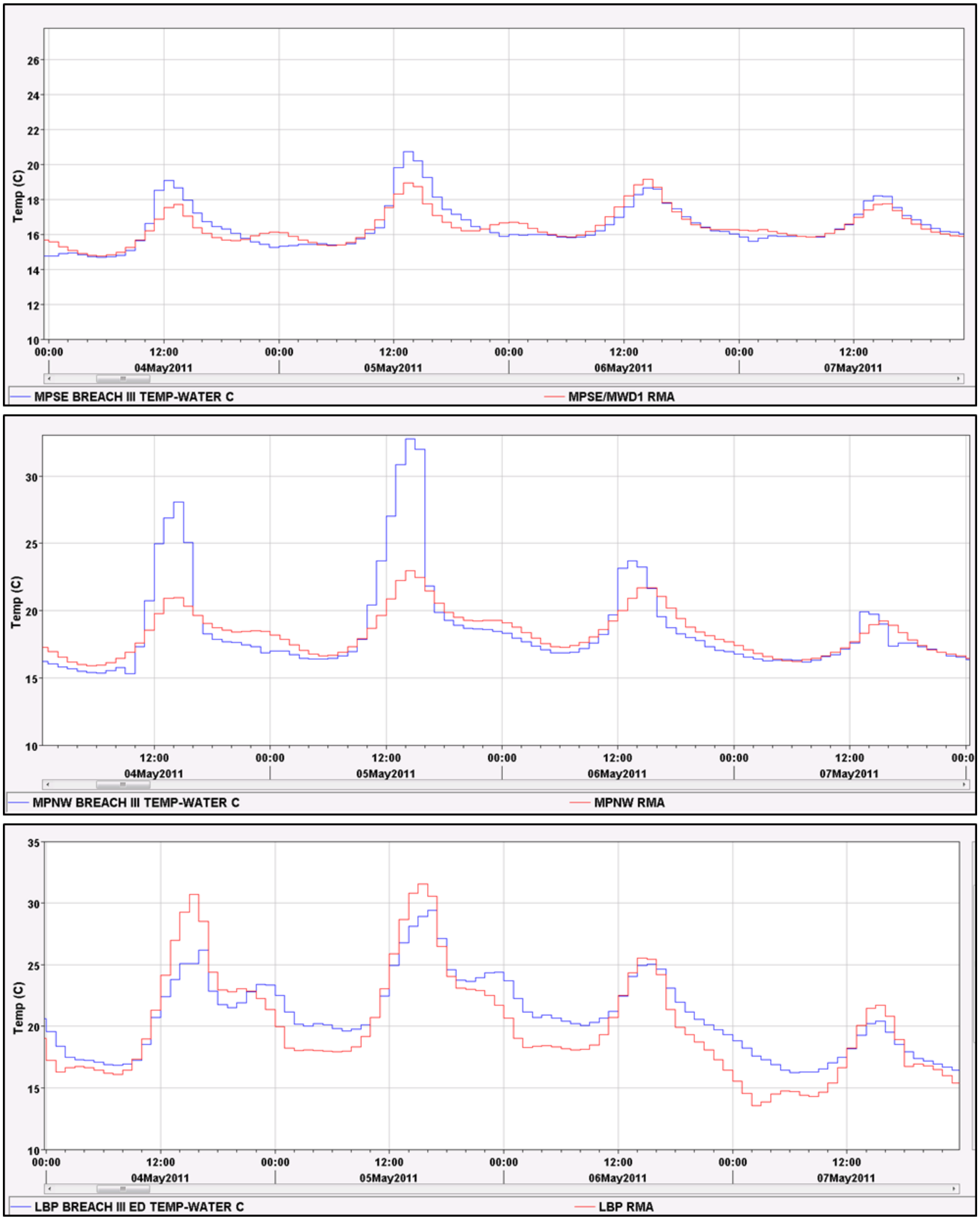


Figure 6-5 Comparison of Breach III hourly water temperature data (blue) and RMA11 model output (red) at three Liberty Island locations May 04 through May 07, 2011 (see Figure 4-3).

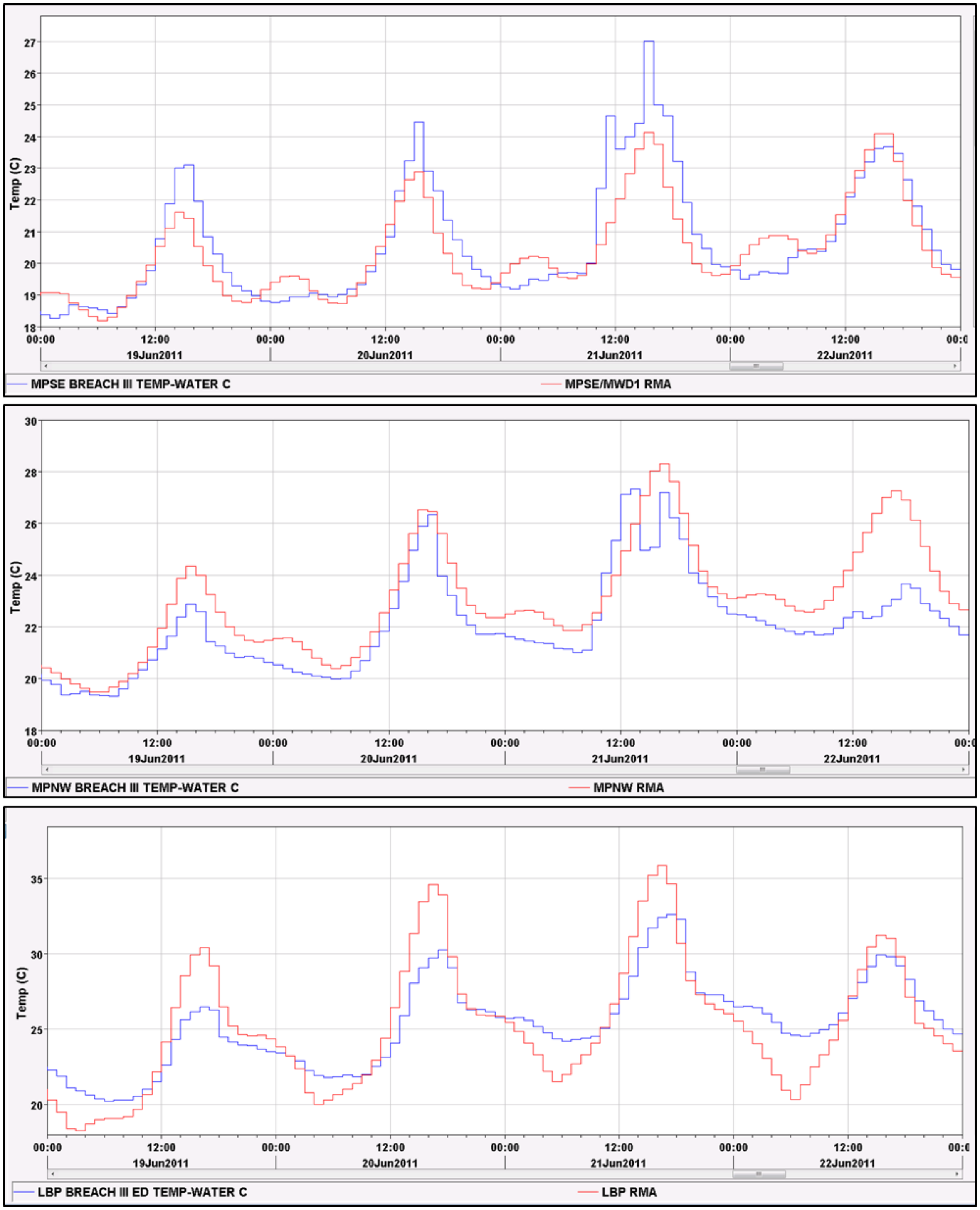


Figure 6-6 Comparison of Breach III hourly water temperature data (blue) and RMA11 model output (red) at three Liberty Island locations June 19 through June 22, 2011 (see Figure 4-3).

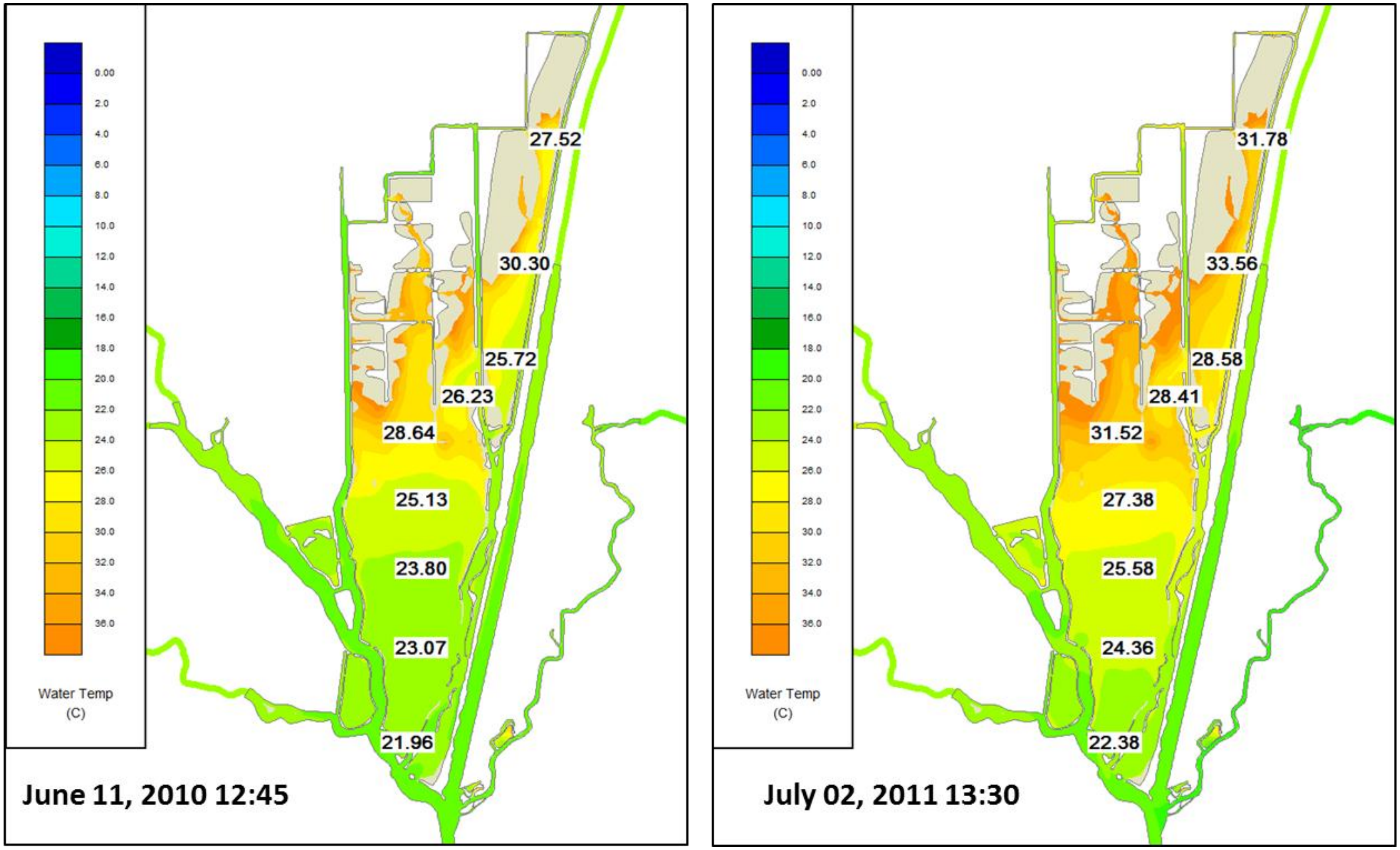


Figure 6-7 RMA11 water temperature contour plots in Liberty Island during two high temperature periods in WY2010 and WY2011. The brown area is mud flat, i.e., an area that wets and dries tidally.

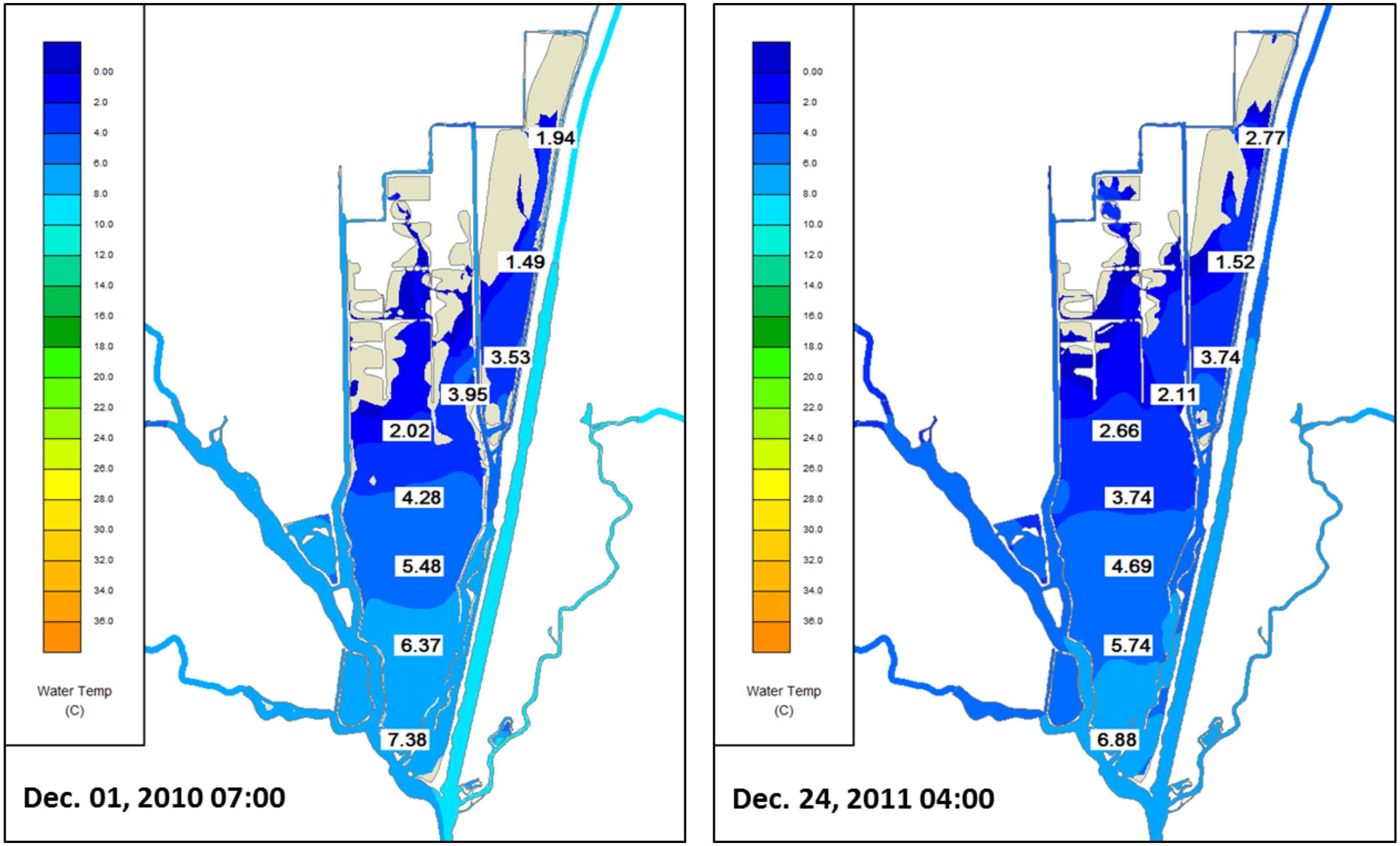


Figure 6-8 RMA11 water temperature contour plots in Liberty Island during two low temperature periods. The grey area is mud flat, i.e., an area that wets and dries tidally.

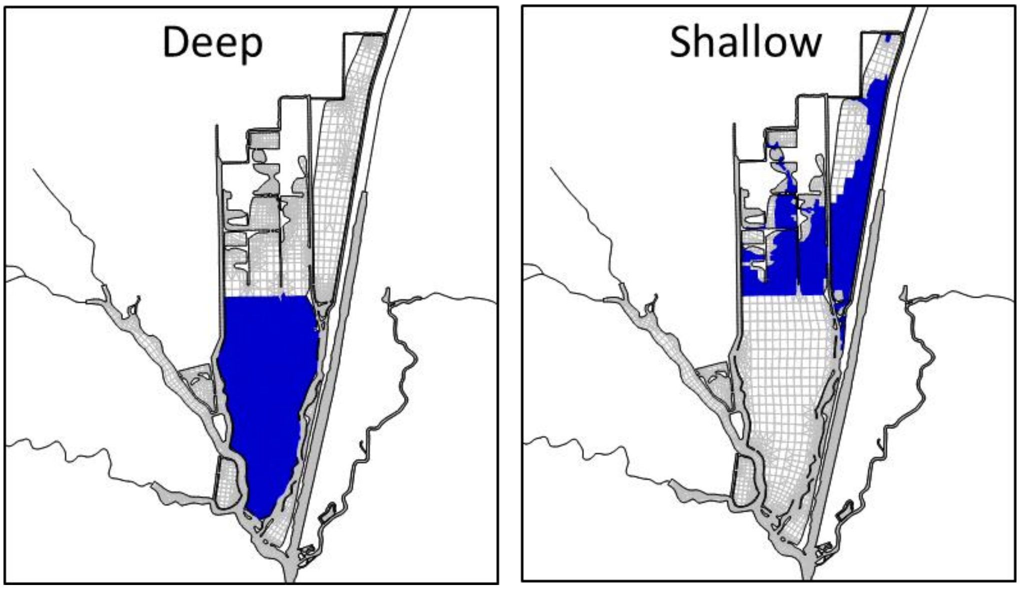


Figure 6-9 Rough guide to the differences in depth in Liberty Island from downstream (deeper, left) to upstream (shallower, right) ends.

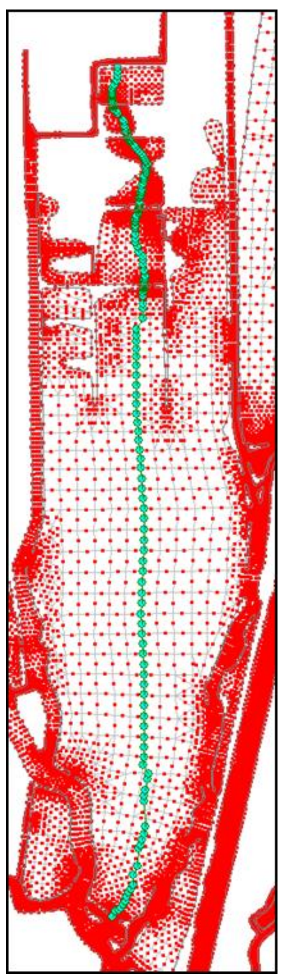


Figure 6-10 Graphic showing the transect data locations used in calculating an approximate area-weighted, volume-averaged water temperature of Liberty Island in the RMA model grid.

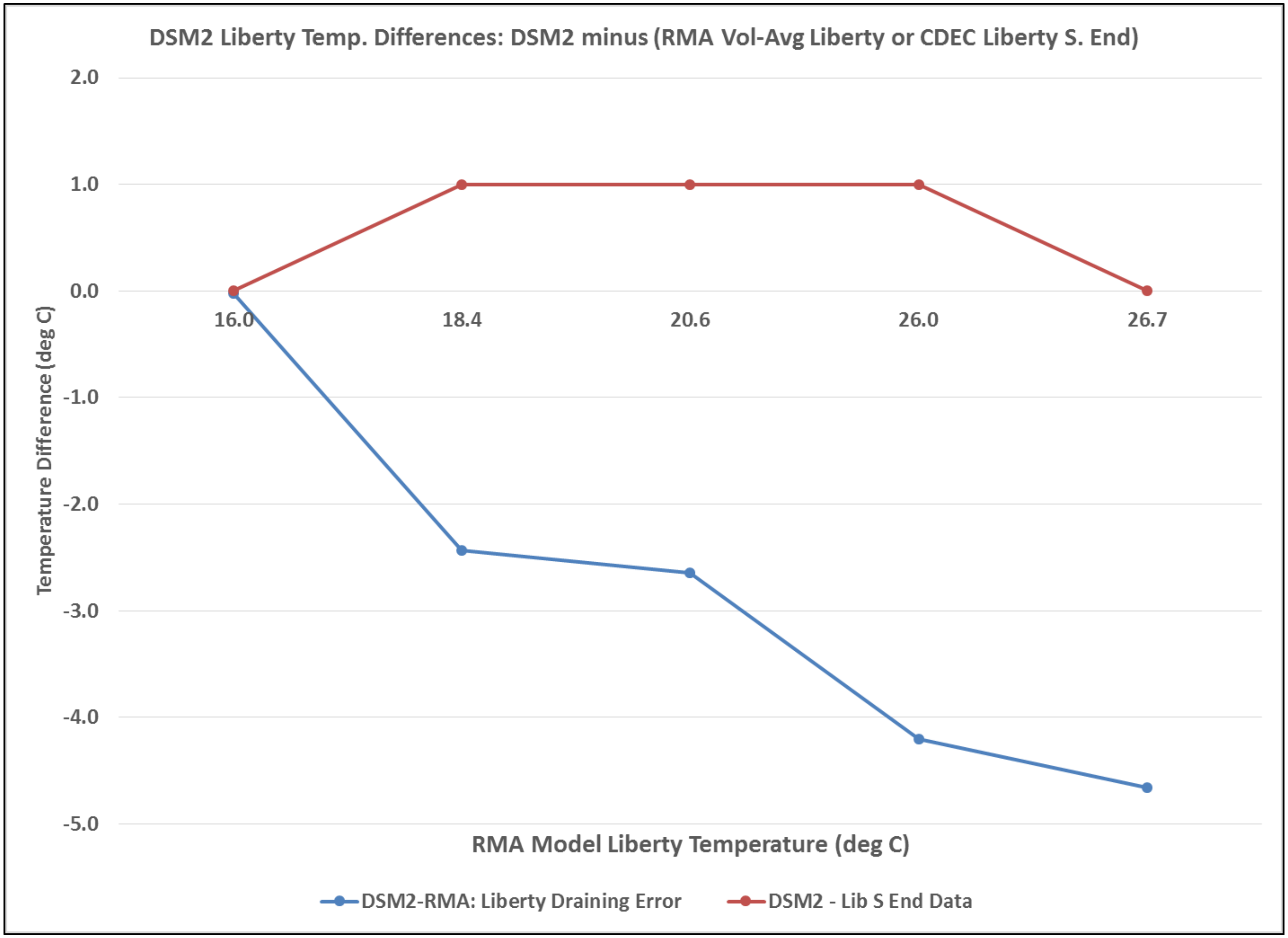


Figure 6-11 Results of difference calculations between DSM2's Liberty Island temperature and CDEC Liberty south end data (red line) and RMA11 volume-averaged water temperature at five times in the period May – June, 2011. Liberty Island was draining (i.e., at or near low tide) at each analysis time. DSM2 temperature differences were rounded to the nearest degree.

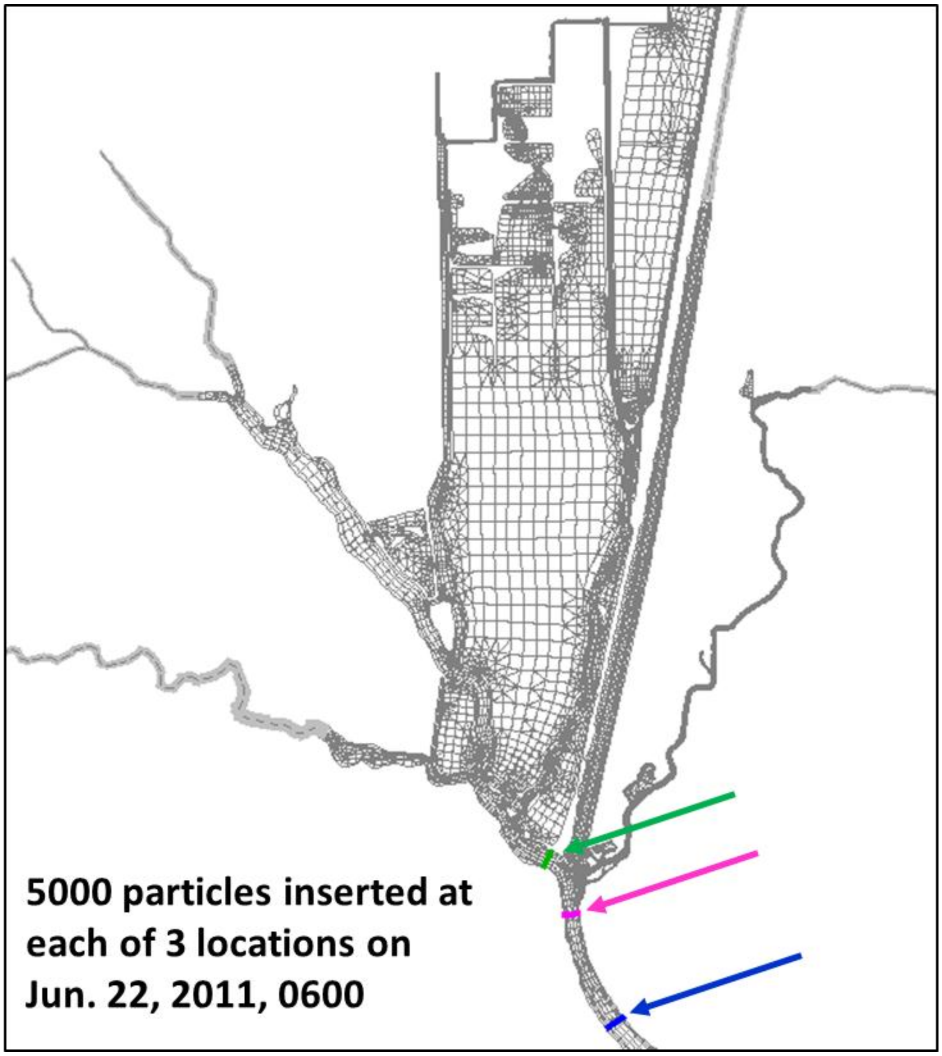


Figure 6-12 Location of particle insertions in Cache Slough in the RMA grid on June 22, 2011.

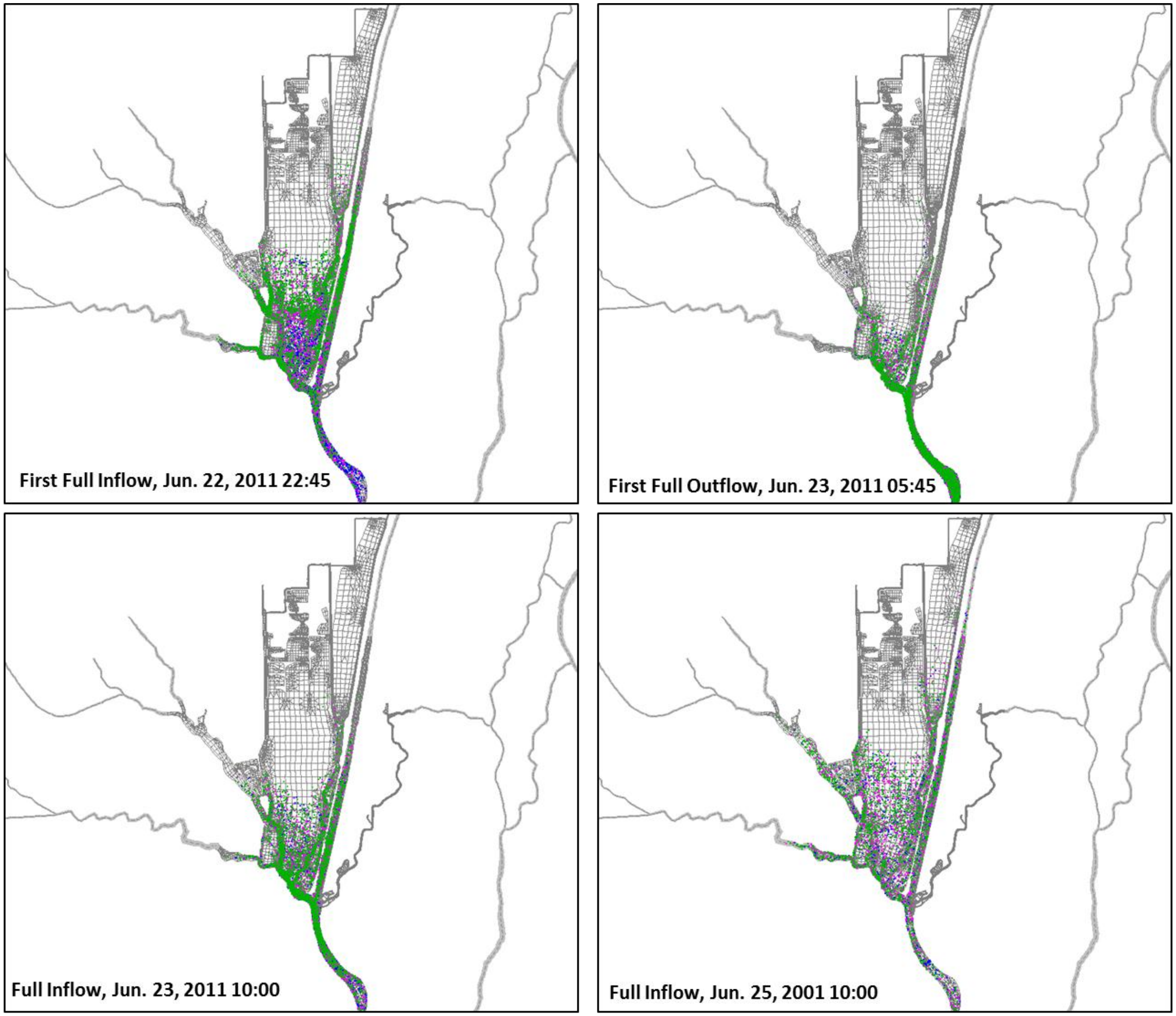


Figure 6-13 Particle tracking model results in Liberty Island at four times after the initial particle insertion on June 22, 2011.

7 Findings and Summary

This documentation illustrates and analyzes RMA11 and DSM2-QUAL water temperature model output in the Cache/Liberty region during the period 2010-2011, with a focus on water temperature in Liberty Island. The differences in the equations conceptualizing water temperature in the two numerical models were minor. The RMA11 term for exchange of heat between bed and overlying water body, not implemented in DSM2, was seen to be an insignificant factor in comparing model output (*i.e.*, it could be ignored). The major differences between the two models are: a difference in the application of meteorological boundary conditions, as DSM2's base site for meteorology was in the Lodi-Stockton area, while RMA's was local to the analysis region, near Hastings Tract; and, a difference in the dimensionality of the model grids. In particular, Liberty Island is a zero-dimensional water body in DSM2 while it is a two-dimensional depth-averaged area in RMA2 and RMA11.

The DSM2 scenario comparisons that varied inflow, water temperature and meteorological boundary conditions during the years 2010 – 2011 demonstrated that meteorological boundary conditions were the most important factor determining DSM2's modeled water temperature in this region. Implementation of RMA meteorological boundary conditions in DSM2, although with wind speed increased, was seen to be a better set of boundary conditions to use in the Cache/Liberty region those used in the original water temperature calibration.

Although not specifically documented in this report, comparison of model output with measured data locations in channels showed that DSM2's one-dimensional representation of channel geometry was comparable to RMA's two-dimensional channel geometry for the calculation of water temperature. This result is not surprising, as the channel measurements used in these comparisons are one-dimensional in nature (*e.g.*, the CDEC data in Cache Slough near Ryer Island). Although the RMA model was generally more accurate than DSM2 in these locations, this was primarily due to the superior meteorological boundary conditions developed for the RMA model in the Prospect Island project (RMA, 2014). As an additional note, in the colder months October – April, both models under-predicted water temperature in this region – i.e., they were both too cold.

In order to compare RMA's calculations for water temperature in Liberty Island with DSM2's, it was necessary to develop a method for calculating an estimate for volume-averaged water temperature from RMA11 model output as this quantity is not directly accessible from model calculations. As documented in the text, the volume of water in Liberty Island varies diurnally as well as over longer periods due to the spring-neap tidal variations – these effects were accounted for in the calculations. Using model output along a transect in Liberty Island, and splitting Liberty roughly into deeper and shallower regions, volume-averaged water temperatures were calculated during periods when Liberty Island was filling and when it was draining. Additional calculations using RMA's particle tracking model showed that the water entering Liberty from downstream locations in Cache Slough generally only mix with waters in the deeper regions of the island. Similarly, water leaving Liberty Island essentially comes from the deeper areas. In addition, our original estimate for the deeper waters included a greater proportion of Liberty Island than indicated by the movement and mixing of particles.

The CDEC data location at the south end of Liberty Island was used for evaluating the water temperature results in the model comparison. Note that this location captures the temperature of water entering and exiting Liberty Island, capturing the potential influence of water exiting Liberty Island on downstream locations. Unfortunately, there was only one year of data during the warmer season to use for comparisons with model output.

In comparing the RMA volume-averaged Liberty Island water temperature with DSM2's Liberty temperature, it was seen that at times when Liberty Island was filling, the difference in modeled water temperatures was due to differences as influenced by the meteorology. In other words, water entering Liberty was close to the water temperature downstream in Cache Slough in both models. However, when Liberty Island was draining, the difference in water temperature between the two models increased with the volume-averaged water temperature, with RMA's average temperature nearly five degrees higher than DSM2's. This result is somewhat misleading when considering the particle tracking results, as the inclusion of the warmer water in the shallower region of Liberty biases the volume-averaged temperature to higher values than the water that actually mixes in Liberty Island on entering and exiting.

In summary, the comparison of water temperature data with model output calculated by RMA11 and by DSM2-QUAL in the Cache/Liberty region showed that the main differences in accuracy between the models in channel calculations are due to differences in meteorological boundary conditions. Although the results for assessing the sufficiency of DSM2's zero-dimensional representation of Liberty Island must be considered preliminary due to the single year of data available for comparison (WY2011), it appears that DSM2's calculation is within +/- approximately 2°C of the water entering and exiting Liberty Island in the RMA11 model, with the differences increasing with overall water temperature in the region. In a volume-averaged sense, i.e. including water in Liberty that is not exchanged tidally, the DSM2 Liberty Island temperature differences with RMA11 model results are greater, and increase with the volume-averaged water temperature. These differences are also partly due to differences in meteorology.

8 References

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9 Appendix

9.1 RMA model details

All of the information in this section was either adapted or taken directly from (RMA, 2014).

9.1.1 Extent of the model domain

The RMA Delta model grid, shown in Figure 9-1, extends from Martinez at the west end of Suisun Bay to the Sacramento River above the confluence with the American River, and to the San Joaquin River near Vernalis.

A two-dimensional depth-averaged approximation is used to represent the Suisun Bay region, the Sacramento-San Joaquin confluence area, Sherman Lake, the Sacramento River up to Rio Vista, Cache Slough, Liberty Island, Shag Slough, portions of Lindsey Slough, the Sacramento River Deep Water Ship Channel (DWSC) and Miner Slough, Big Break, the San Joaquin River up to its confluence with Middle River, False River, Franks Tract and surrounding channels, Mildred Island, Old River south of Franks Tract, and the Delta Cross Channel area. The other Delta and Suisun Marsh channels and tributary streams are represented using a one-dimensional cross-sectionally averaged approximation. A detail view of the Project area, showing Cache Slough, Miner Slough and Liberty Island, is shown in Figure 9-2.

9.1.2 RMA boundary conditions

The overall Delta model boundary condition locations are presented in Figure 9-3. Each model inflow boundary condition requires a corresponding water temperature value to be specified. In addition, water temperature time series may be applied to internal grid locations as is indicated in the Figure 9-3 for the Sacramento River at Hood and the San Joaquin River at Mossdale. Sacramento River at Hood boundary condition corresponds to a field water temperature monitoring station, and was the model's upstream water temperature boundary condition for water flowing into the project area from the Sacramento River system.

Figure 9-4 provides a more detailed view of the model boundary conditions for the north Delta region near Prospect Island and the Cache Slough Complex. During the wet season, model boundary locations such as the Yolo Bypass Toe Drain, or Upper Cache and Haas Sloughs may be a source of inflow. Under dry season conditions, the same locations may be points of flow withdrawal. A water temperature boundary condition needs to be provided at time of inflow but is not required or applied during the periods of outflow. The DICU (Delta Island Consumptive Use) locations shown in Figure 9-4 are the points where the monthly estimated local agricultural diversions and returns are applied. The estimated temperatures of the return waters are not available. When they occur, the temperature for the DICU inflows to the channels are functionally set in the model to the ambient temperature of the receiving water.
The overall Delta flow and stage conditions are listed below:

Tidal boundary at Martinez

Inflows:
Sacramento River above American River
American River near Sacramento
San Joaquin River near Vernalis
Yolo Bypass and Yolo Bypass Toe Drain
Mokelumne River near Thornton
Cosumnes River
Calaveras River near Stockton
Barker Slough, Upper Cache and Hass Slough inflows

Exports/Diversions:
State Water Project (SWP), Clifton Court Forebay gates
Central Valley Project (CVP) Tracy Pumping Plant
Contra Costa Water District (CCWD) intakes at Rock Slough, Old River and Victoria Canal
North Bay Aqueduct (NBA), Barker Slough Pumping Plant
Delta Island Consumptive Use (DICU), throughout Delta
Barker Slough, Upper Cache and Haas Slough diversions

Major Control Structures:
Delta Cross Channel gates
Suisun Marsh Salinity Control Gate (SMSCG)
South Delta Temporary Barriers
Old River near Tracy (DMC) temporary barrier
Old River at Head temporary barrier
Middle River temporary barrier
Grant Line Canal temporary barrier

Weather: Historical (hourly) weather data required for the water temperature modeling includes:

Air Temperature
Dew Point Temperature/Relative Humidity/Vapor Pressure
Net Solar Radiation (can be estimated from sun position, cloud cover, atmospheric dust).
Wind Speed
Cloud Cover

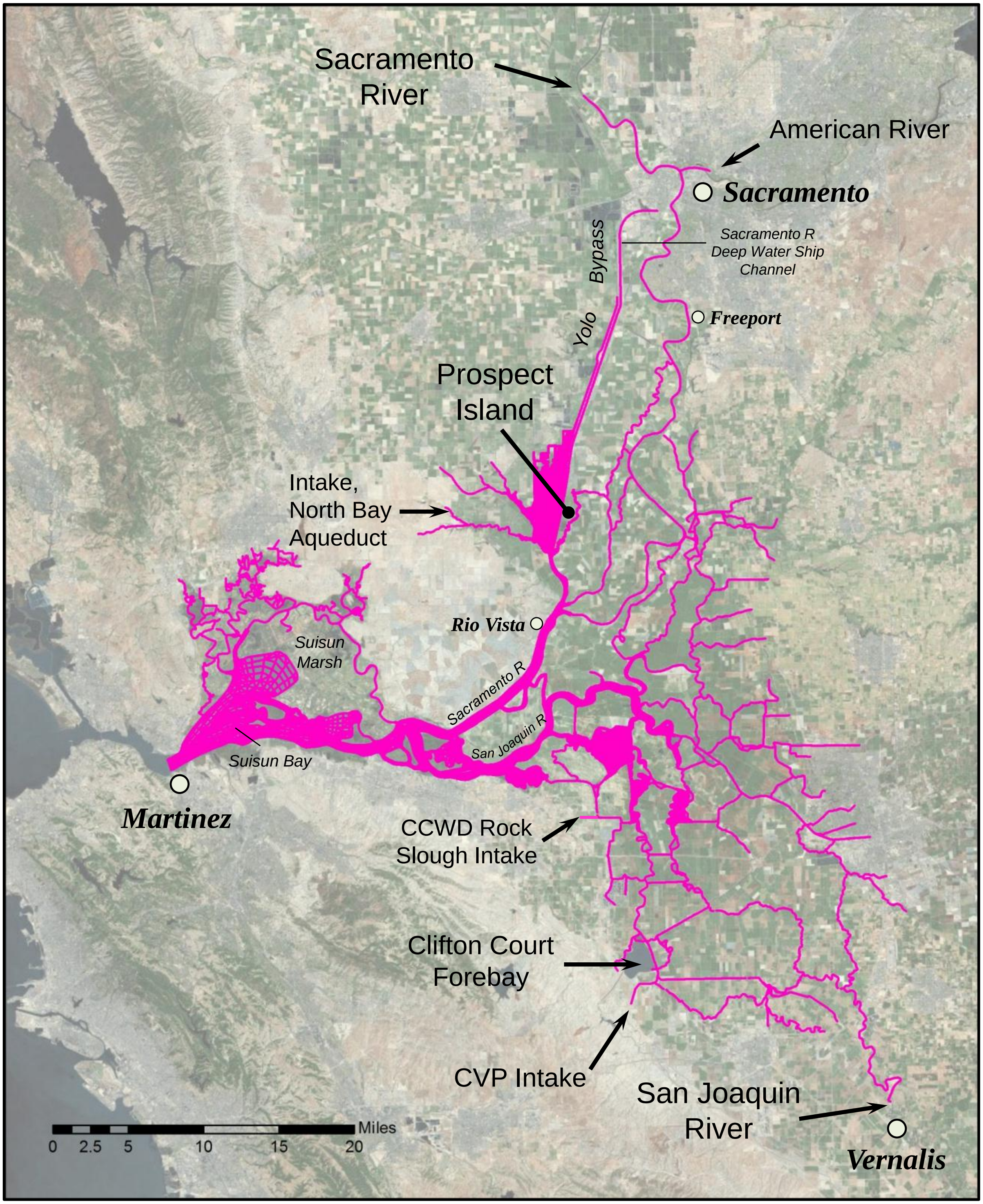

Figure 9-1 Extents of the RMA Delta model for the Prospect Island Project model analysis. (Figure sourced from RMA (2014)).

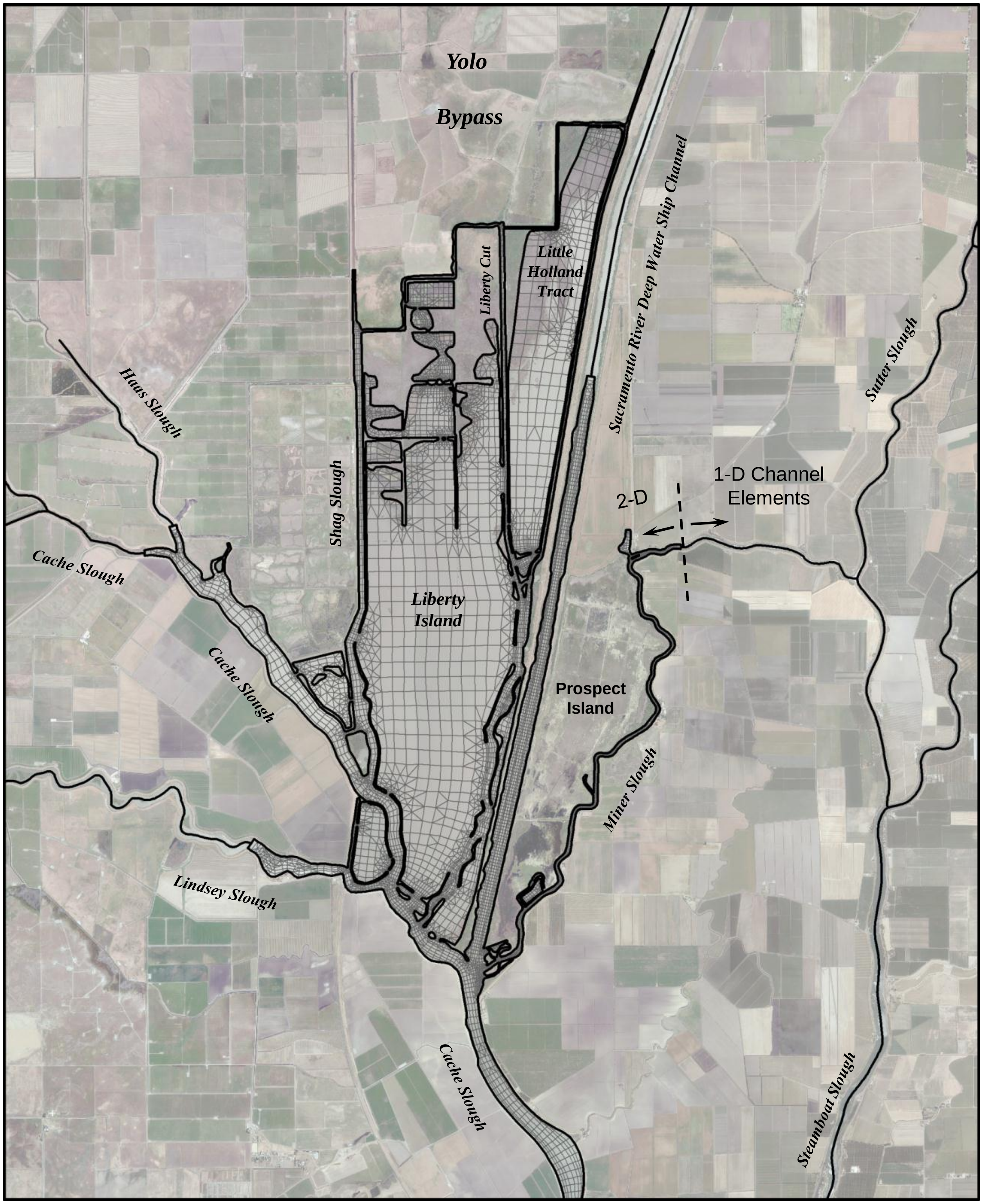

Figure 9-2 Detail view of model configuration in the Project area. (Figure sourced from RMA (2014)).

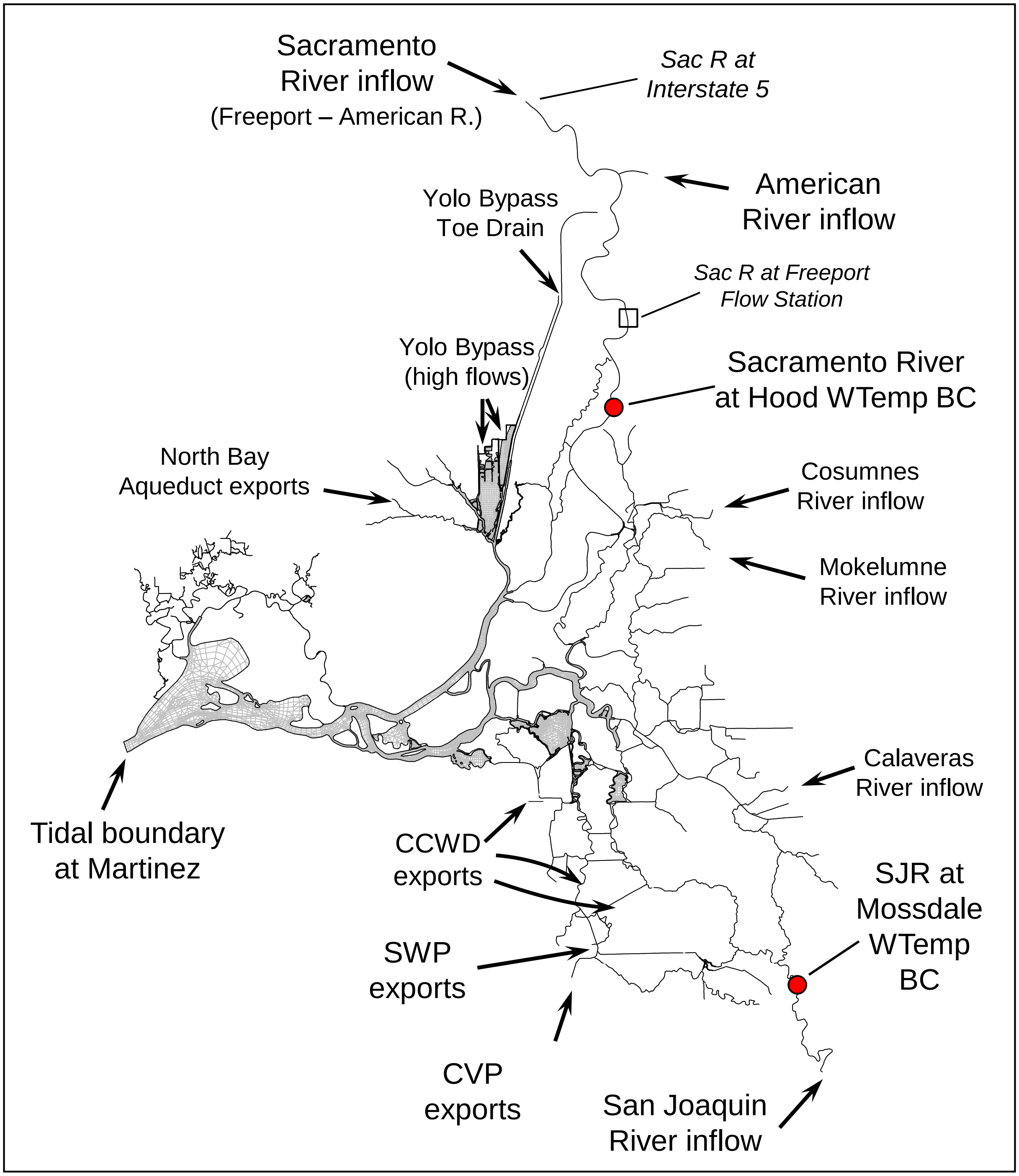

Figure 9-3 Model boundary condition locations. Internal water temperature boundary conditions are set for the San Joaquin River at Mossdale and for the Sacramento River at Hood. (Figure sourced from RMA (2014)).

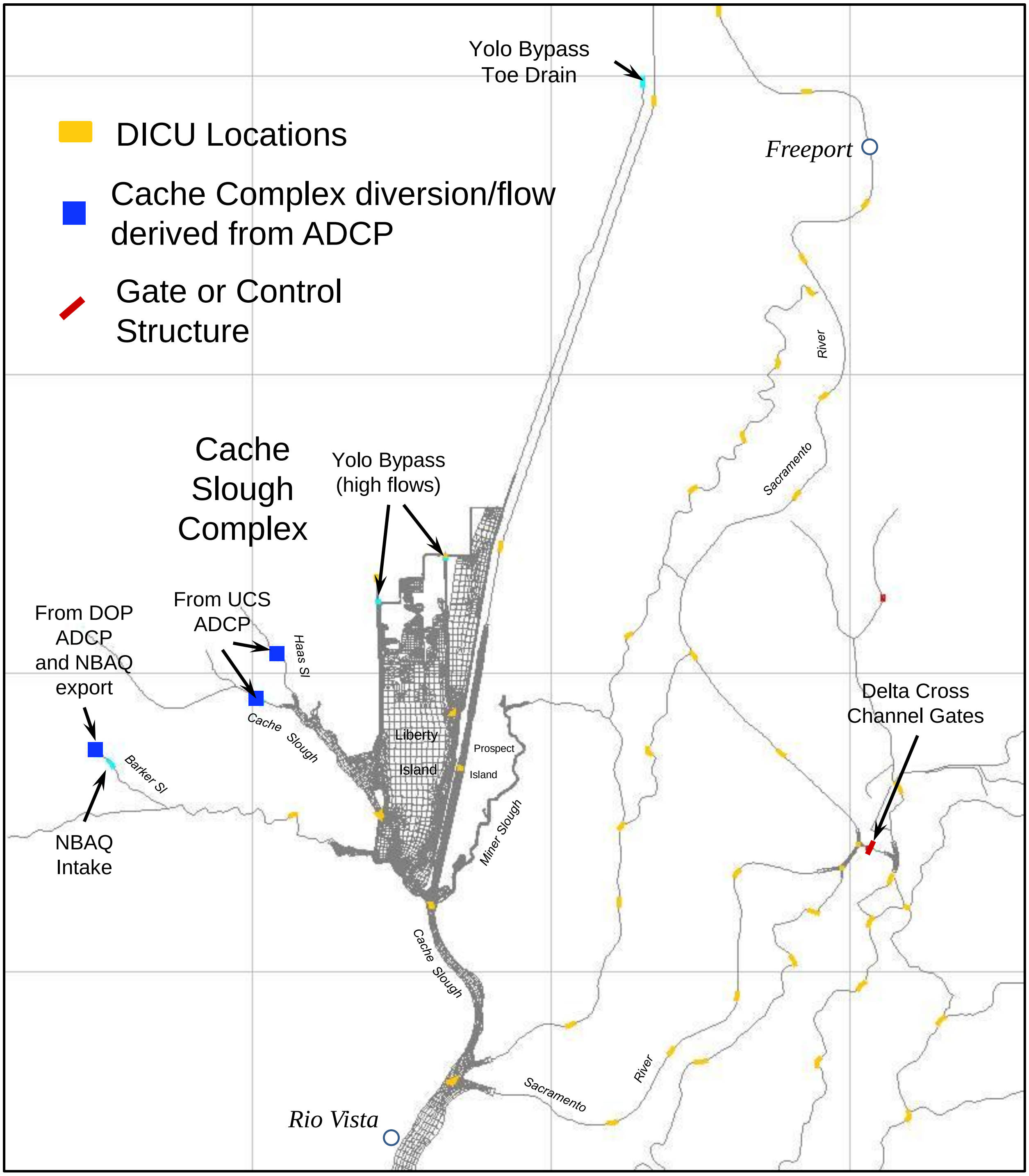

Figure 9-4 Flow boundary conditions for the Cache Slough Complex and DICU diversions and returns for the north Delta region near the Prospect Island site. DICU flows for Upper Cache Slough & Haas Slough, and Lindsey Slough are replaced with diversion flows computed from the long term ADCP stations UCS and DOP. (Figure sourced from RMA (2014)).

9.1.3 Data sources used in the RMA11 water temperature model calibration

Observed water temperature data is required both for setting the water temperature of the inflowing waters to the Delta and for the comparison of model values to field values for the calibration/verification. The observed water temperature data are available from two main sources. The first set of sources are the long term installed gauges operated by the United States Geological Survey (USGS), the California Dept. of Water Resources (DWR), the U.S. Bureau of Reclamation (USBR) and the Solano County Water Agency (SCWA) for the channels of the north Delta and the Cache Slough Complex. The second set of data is available from temporary gauges installed in and around Liberty Island and the Cache Slough Complex as part of special field data collection programs, such as the Breach III study (Lehman et al., 2013). The locations of the long term monitoring stations in or near Liberty Island are mapped in Figure 4-2. The monitoring stations for the special studies in the Cache Slough Complex/Liberty Island are shown in Figure 4-3. The deployment periods and the data availability for both the short term and long term stations are provided in Figure 4-1. Two intensive, but short term (approximately 4 weeks for each) field studies were conducted by the University of California, Berkeley (Wagner, 2012), near the junction of Cache Slough and Shag Slough in November 2009 and May 2010 (not shown). These deployments were notable in that temperature sensors were placed vertically at the near surface, near bed and mid-depth locations.

The model calibration to observed water temperature data in the Cache Slough Complex is of interest as the water temperature observations from the special studies provide a data set for model calibration to data collected in or near a shallow water environment.

The primary drivers of the water temperature model are meteorological factors such as air temperature, relative humidity (dew point or vapor pressure), incoming solar radiation, wind speed and cloud cover. The Department of Water Resources has established a system of climate stations throughout the state as part of its California Irrigation Management System (CIMIS). The CIMIS program collects and archives hourly weather data for over 200 active and inactive stations, and provides access to the data over the internet. The model water temperatures are sensitive to the input air temperature, relative humidity and wind speed. Thus it is desirable to apply weather data collected locally to the area of interest. There are two CIMIS stations near Liberty Island, #122 at Hastings Tract and #212 at Hastings Tract East. Station #122 was online March 1995 to June 2009. The station #122 was functionally replaced by station #212, Hastings Tract East, beginning October 2009. Air temperature, wind speed and solar radiation data are collected at the DWR-DES station at Rio Vista, RVB. However, the necessary dew point temperature (or relative humidity) was not provided for this station and limits the use of the station's meteorological data for driving the water temperature model. Cloud cover information was needed for the estimation of the net incoming long-wave radiation. The requisite cloud cover data for the modeling were available for the Travis Air Force Base location.

9.1.4 North delta river inflows and water temperatures

The river inflow locations to the full Delta model are shown in Figure 9-3. Daily average inflow boundary conditions were applied for the Sacramento River, American River, Yolo Bypass, San Joaquin River, Cosumnes River, Mokelumne River and Calaveras River. The model interpolates between the daily average flows at noon each day. Daily flows were downloaded from the USGS NWIS database and used to set boundary conditions for Sacramento, San Joaquin Rivers and the other Delta inflowing streams.

The two sources of inflow to the Project area are the upstream Sacramento River and the inflows into the Cache Slough Complex, principally from the Yolo Bypass (Figure 9-4). The Cache Slough Complex is a source of outflow in the winter and early spring months, but a source of flow diversion in the late spring and summer.

9.1.5 Meteorological conditions

The required meteorological data for the calibration/verification periods was available from two CIMIS field stations on Hastings Tract. See also Sections 4.1 and 9.1.3.