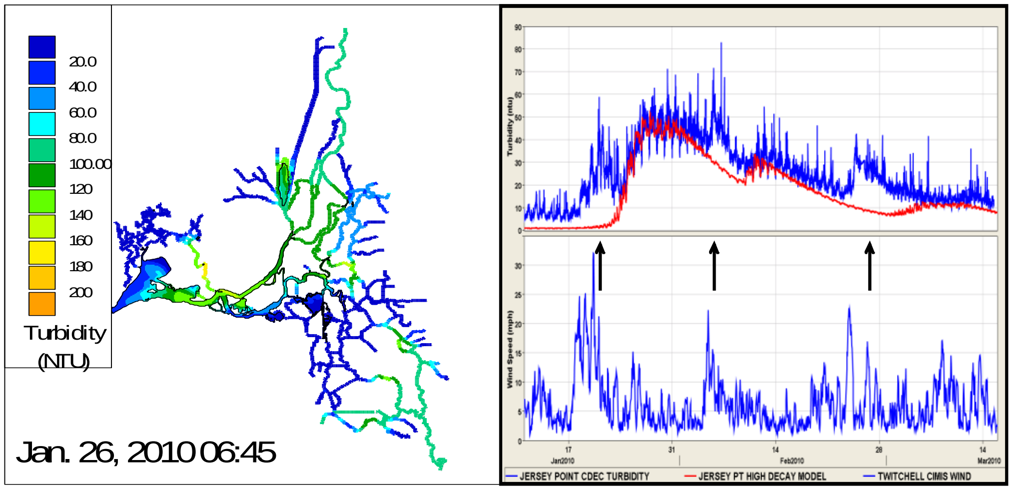
# RMA/Systech Collaboration to Improve WARMF Model Turbidity Estimates

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# 1 Executive Summary

RMA and Systech are under contract with Metropolitan Water District of Southern California to improve the accuracy of WARMF and RMA turbidity forecast. In this document, we use output from the RMA turbidity model to illustrate the improvements made in WARMF turbidity estimates and flow calculations developed during the collaborative RMA/Systech subtask. Under this subtask, RMA incorporated the results of successive updates to the WARMF historical model calibration as RMA boundary conditions to determine the downstream (in-Delta) consequences of WARMF's model output. After each run, RMA analyzed the results of the WY2010 and WY2011 hindcasts, sent result plots to Systech comparing RMA model output to turbidity data, and recommended turbidity and/or flow boundaries that needed to be improved in the WARMF model.

WARMF simulation results estimating turbidity from suspended sediment have improved substantially with this collaboration, although with some provisos. WARMF WY2011 results at Freeport and Vernalis are much better than WY2010 results at these locations. At the tributaries –Yolo Bypass and Calaveras, Mokelumne and Cosumnes Rivers – WARMF results were improved overall, although it was difficult to judge improvements in turbidity on the Calaveras River. Mokelumne and Cosumnes River results can only be judged in WY2011 when data became available at the split of the Mokelumne River into North and South branches. At two locations – Yolo Bypass and Calaveras River – RMA identified that WARMF calculated flows needed to be improved and supplied information on additional flow data locations that improved WARMF flow results.

RMA simulations were run with several variations in boundary conditions to isolate the improvements in WARMF flow and turbidity, as much as possible. The first set tested improvements in WARMF model results at the Yolo Bypass and Eastside inflow locations. Because the Freeport and Vernalis boundaries are the most dominant influences in Delta turbidity, WY2010 and WY2011 RMA simulations were run with these boundaries set using CDEC data (for flow and turbidity) while the tributary boundaries were set using WARMF model output for turbidity and CDEC data for flow. These results, discussed in Section 5.1, show that the final WARMF model turbidity estimation for these locations are very good, as illustrated by RMA model results throughout the delta.

Another set of comparisons (Section 5.2) were made between the initial improvements in the WARMF suspended sediment (and flow) calibration, denoted Original WARMF, and the final calibration run, denoted Final WARMF. These comparisons show that substantial improvements were made during the collaboration at all model boundaries, although the improvements were more substantial in WY2011. In both WY2010 and WY2011, WARMF missed turbidity peaks at the Freeport boundary, and in WY2010, also missed a peak at the Vernalis boundary. These results also illustrate that getting turbidity timing, peak width and height correct at the Freeport and Vernalis locations is crucial to the quality of the in-Delta model results.

A final set of comparisons (Section 5.3) illustrate the importance of the WARMF flow calculations. WARMF is generally very good at calculating inflow to the Delta, but there are times when it may miss some flow contributions. To try to capture the importance on WARMF flow to the quality of the in-Delta turbidity results, the Final WARMF model results were compared in RMA simulations using WARMF turbidity at all boundaries but using either WARMF flows or measured CDEC flows. These results generally indicate that, although errors in WARMF flows do contribute to errors in the RMA turbidity model results in-Delta, the major source of error in is the WARMF turbidity estimates.

The following are suggestions on ways to improve the turbidity modeling in the Delta using WARMF model output:

- Develop an RMA sediment model using WARMF sediment output. Although the ability of WARMF to simulate turbidity as RMA model boundaries has improved substantially, WARMF still misses some large peaks in turbidity at the Freeport and Vernalis boundaries in the RMA model domain. Using available suspended sediment data from the USGS at the Vernalis and Freeport locations, it may be possible to differentiate between silt and clay fractions more accurately at WARMF's downstream locations, and potentially improve WARMF estimates at these important locations.
- As WARMF actually models suspended sediment, the movement to an RMA sediment model using WARMF model output is a natural next step that would increase acceptance of the modeling results in the scientific community.

# 2 Objectives

The Objective of the work documented in this report was to improve WARMF turbidity estimates at the RMA model inflow boundaries by use of RMA model results from successive WARMF model suspended sediment runs.

# 3 Background and Methodology

In WY2010 and WY2011, RMA has been under contract with MWD to conduct weekly turbidity and Delta Smelt movement forecasts during the turbidity and Smelt migration season. The WARMF model has been used to estimate the turbidity boundary conditions for the RMA turbidity model. During the forecasting season in WY2011, the WARMF suspended sediment model was still undergoing calibration, and the results for the turbidity estimates at RMA model boundaries were not sufficiently accurate to use with confidence.

For WY2012, RMA and Systech historical simulations were run consecutively with WARMF historical model results incorporated in RMA simulations and the subsequent RMA turbidity downstream results used to help improve WARMF model calibration of suspended sediment, and therefore the estimates of turbidity.

In the RMA model, several types of simulations were run to identify WARMF model improvements. The two most important of these were:

1. RMA simulations were run with CDEC flow boundary conditions and turbidity boundary conditions estimated by WARMF. This isolated the effect of differences between CDEC measured flow and WARMF calculated flows on downstream turbidity results.
2. RMA simulations were run with CDEC flow and turbidity boundary conditions at the Freeport and Vernalis locations, and with WARMF flow and turbidity estimates at all other inflow boundaries. This isolated the improvements in WARMF model results at the Yolo Bypass and Cosumnes, Mokelumne and Calaveras River boundary calculations.

# 4 Improvements identified in WARMF model flow boundaries

RMA identified that the WARMF Yolo Bypass and Calaveras River flows were significantly different to the flows used in the RMA model. Systech staff identified an issue in the Yolo boundary flows that was resolved and which subsequently greatly improved the Yolo flow and turbidity estimates and also the downstream results when applied in the RMA turbidity model. RMA staff supplied an additional flow data location to Systech staff for the Calaveras River. Results illustrating WARMF improvements in the Yolo Bypass boundary and improvements at the Eastside tributaries are shown in the following sections.

# 5 Comparison of simulations illustrating improvements in WARMF model estimates of turbidity and flow

This section summarizes the results of selected RMA turbidity simulations run for WY2010 from January 01 – April 30, 2010 and for WY2011 from November 01, 2010 – April 30, 2011. All RMA models were run with historical stage and turbidity at Martinez, gate operations and DICU as specified by the DSM2 historical model, and with combinations of flow and turbidity boundary conditions at the inflow boundaries specified either with CDEC flow and/or turbidity data or with WARMF calculated flow and/or turbidity estimates. Several CDEC data locations were added in WY2011 (see Figure 55 in the Appendix), the most important of these for checking model results are below the split of the Mokelumne River into the North and South Mokelumne River. These sites enabled WARMF improvements in the Mokelumne and Cosumnes River to be tested.

## 5.1 RMA model comparisons showing improvements in WARMF historical simulations at the Yolo Bypass and at the Eastside Streams

In this set of simulations, the improvements in WARMF simulation results at the Yolo Bypass and at the Cosumnes, Mokelumne and Calaveras Rivers are highlighted. For both the WY2010 and WY2011 time periods, RMA models were run with CDEC turbidity and flow data at the Freeport and Vernalis boundary locations, and with WARMF Final run model output at the other locations – these simulations are called Partial WARMF. In each case, measured flow (generally obtained from CDEC) was used at all model boundaries. The RMA model run denoted the Final simulation was run with the final calibration sets of WARMF output for estimated turbidity. The figures show the comparison with data in cyan, Final WARMF results in red and the Partial WARMF results in black.

### 5.1.1 WY2010

The results for WY2010 are illustrated in Figure 1 through Figure 7.

The improvements in the WARMF Yolo Boundary condition are illustrated in Figure 1 (Cache Slough) and Figure 2 (Rio Vista), although these results also reflect the fact that CDEC turbidity data was used at the Freeport boundary.

At each of the other locations, we can see that the turbidity and flow estimates produced by WARMF in the Partial WARMF model (with data at Freeport and Vernalis only) produced excellent results in the RMA turbidity model. Increases in turbidity due to wind events not captured by the model are evident at some locations (e.g., Figure 5, Holland Cut).

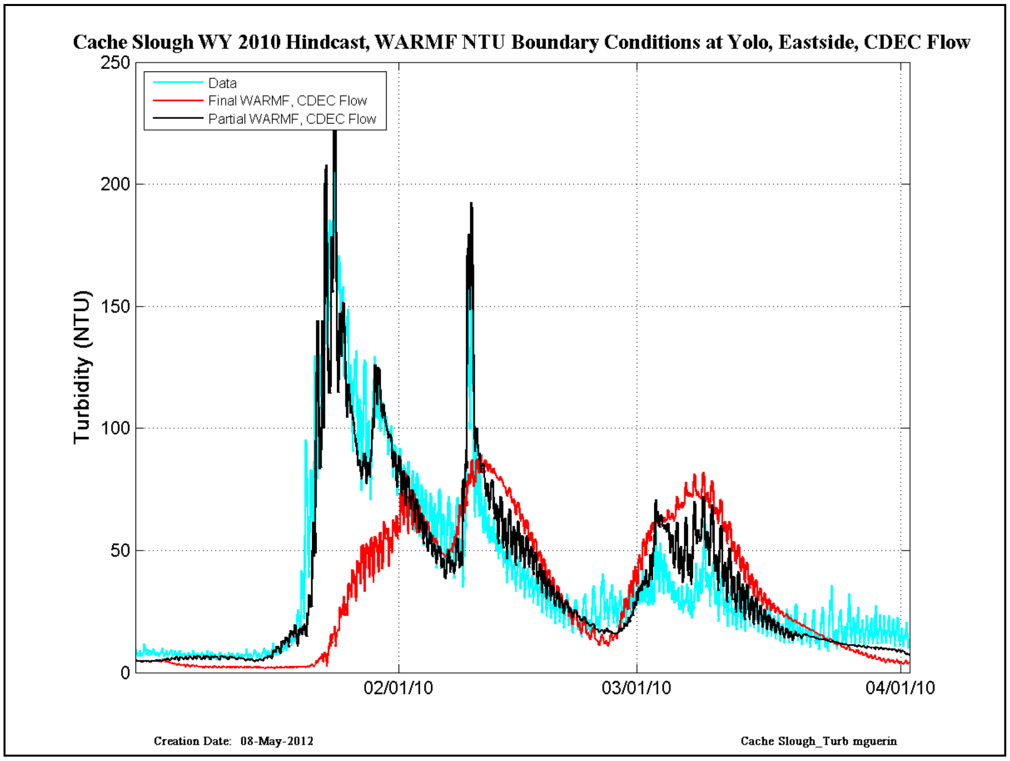


**Figure 1 CDEC data (cyan) compared with RMA simulations run with Final WARMF (red) and Partial WARMF (black) – results are shown at Cache Slough at Ryer in WY2010.**

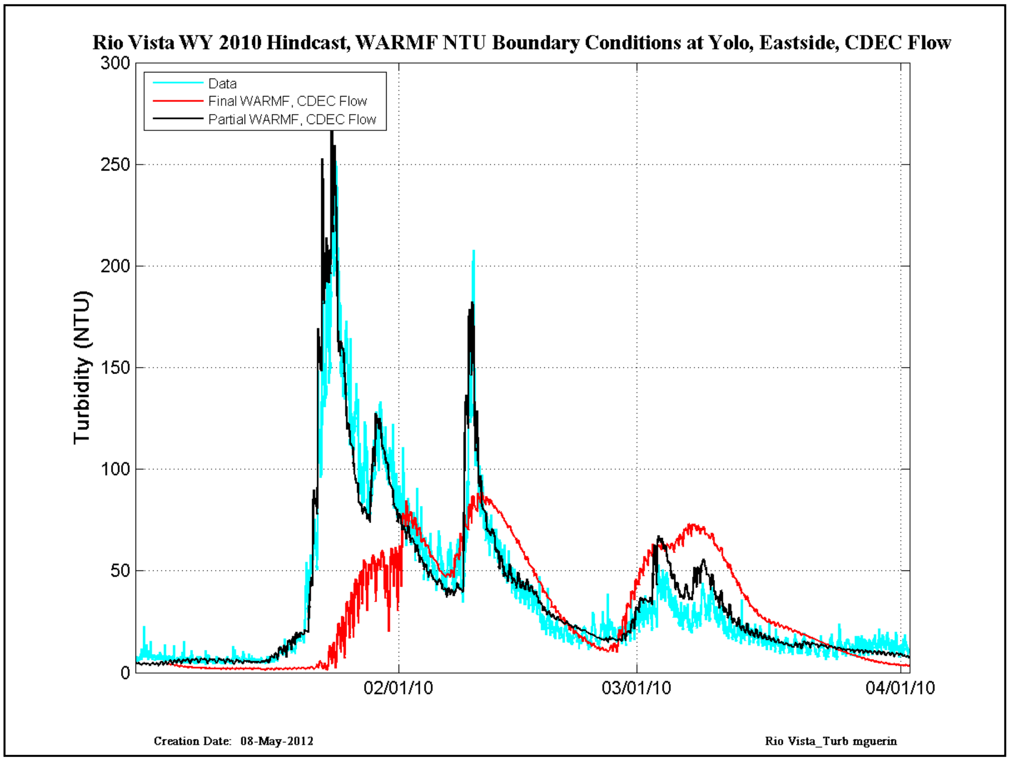


**Figure 2 CDEC data (cyan) compared with RMA simulations run with Final WARMF (red) and Partial WARMF (black) – results are shown at Rio Vista in WY2010.**

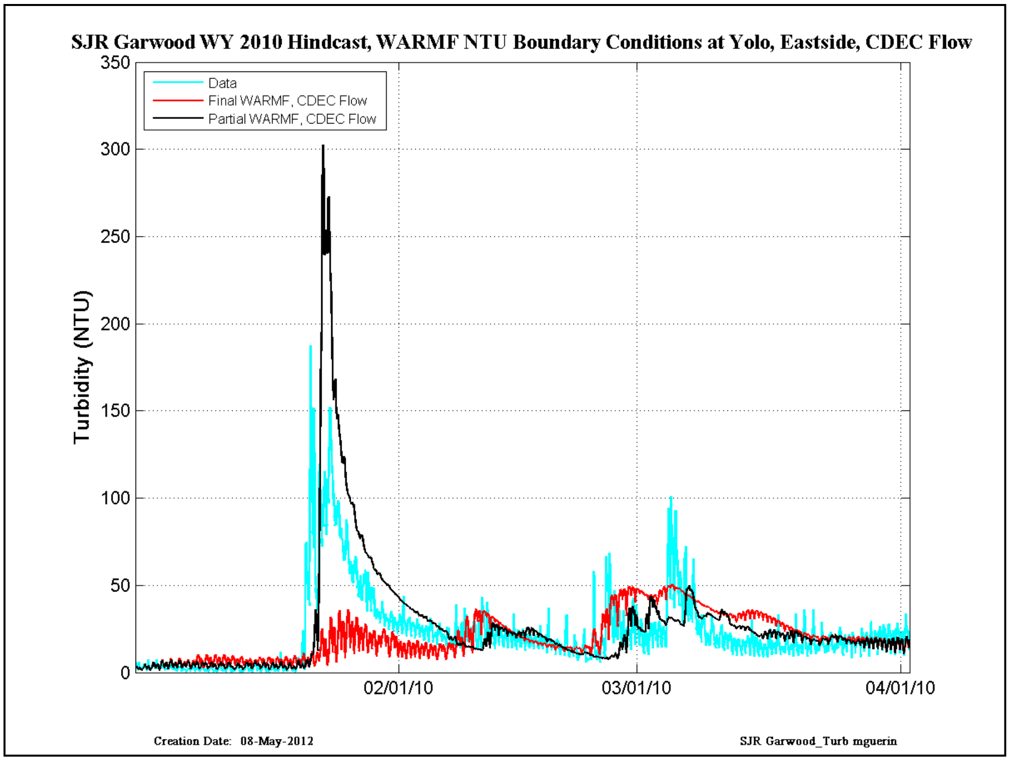


**Figure 3 CDEC data (cyan) compared with RMA simulations run with Final WARMF (red) and Partial WARMF (black) – results are shown at Garwood on the San Joaquin River in WY2010.**

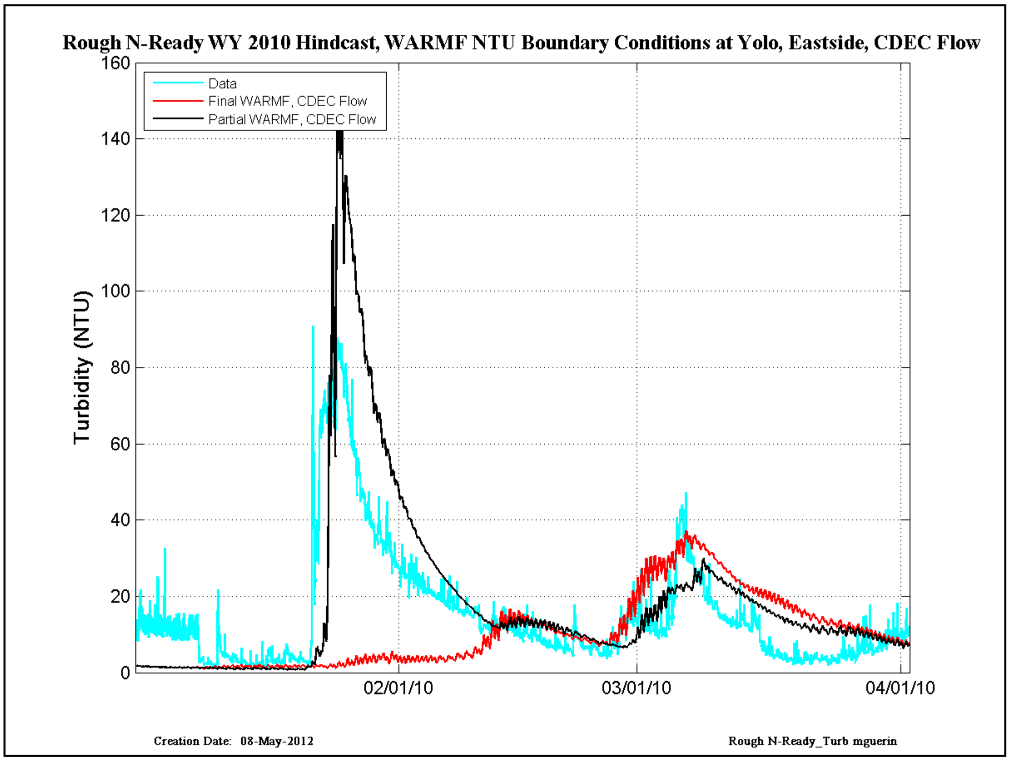


**Figure 4 CDEC data (cyan) compared with RMA simulations run with Final WARMF (red) and Partial WARMF (black) – results are shown at Rough N'Ready Island on the San Joaquin River in WY2010.**

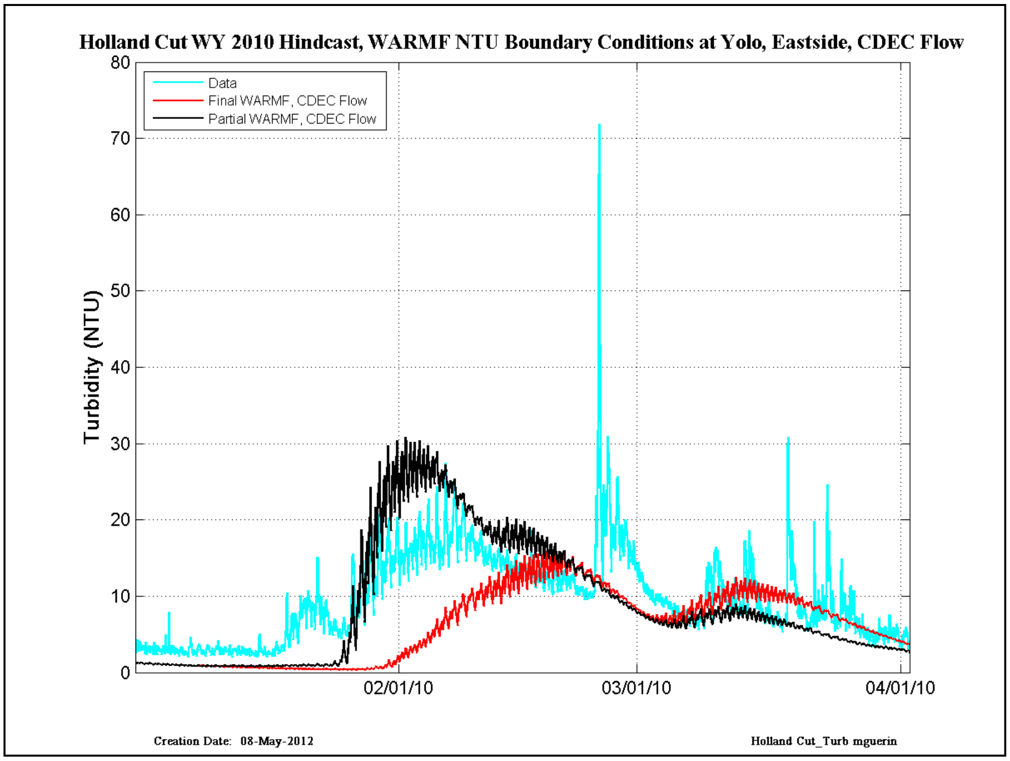


**Figure 5 CDEC data (cyan) compared with RMA simulations run with Final WARMF (red) and Partial WARMF (black) – results are shown at Cache Slough at Ryer in WY2010.**

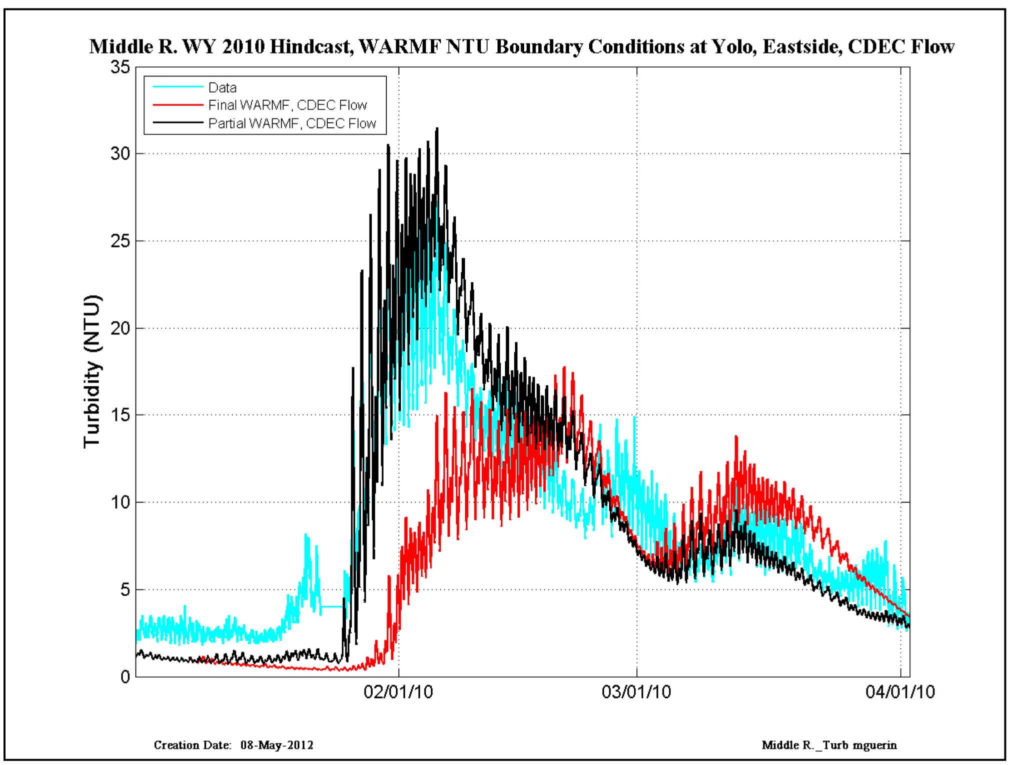


**Figure 6 CDEC data (cyan) compared with RMA simulations run with Final WARMF (red) and Partial WARMF (black) – results are shown at the Middle River location in WY2010.**

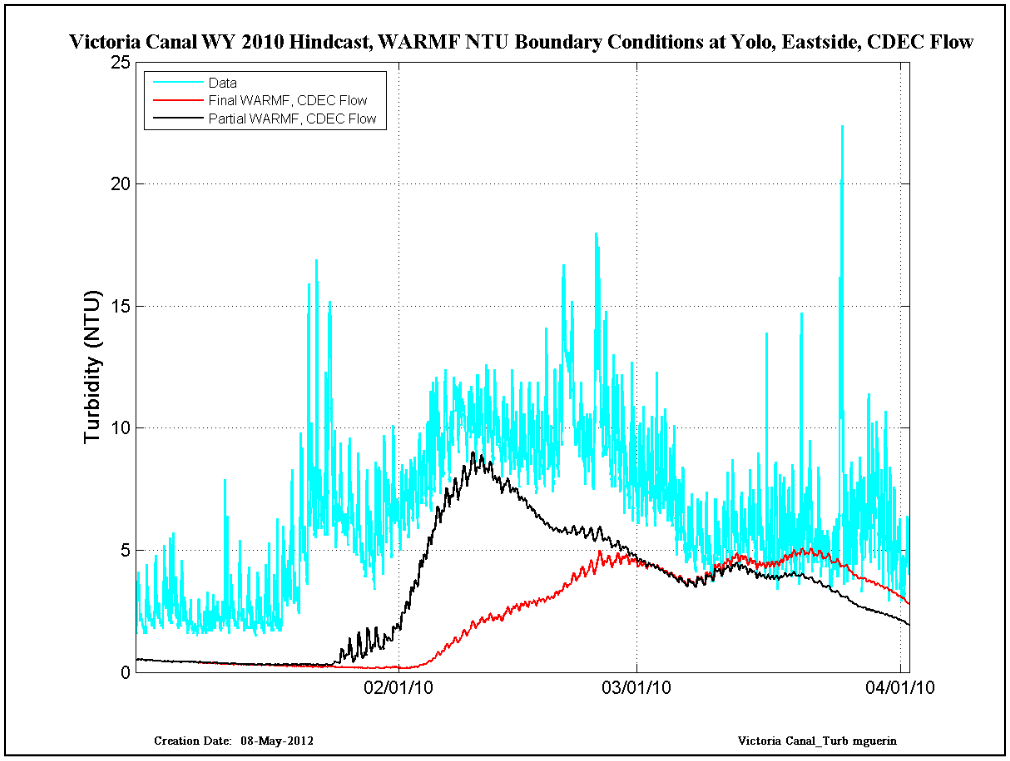


**Figure 7 CDEC data (cyan) compared with RMA simulations run with Final WARMF (red) and Partial WARMF (black) – results are shown at Victoria Canal in WY2010.**

### 5.1.2 WY2011

The results for WY2011 are illustrated in Figure 8 through Figure 16.

The improvements in the WARMF Yolo Boundary condition are illustrated in Figure 8 (Cache Slough) and Figure 9 (Rio Vista), although these results also reflect the fact that data was used at the Freeport boundary. At Cache Slough some structure that was missed in comparison with the turbidity data was due to wind events. In April, the final flow and turbidity event was a very high flow on the Yolo, and the WARMF estimated turbidity was low in comparison with the data due to an overestimate of Yolo flow.

At each of the other locations, we can see that the turbidity and flow estimates produced by WARMF in the Partial WARMF model (with data at Freeport and Vernalis only) produced excellent results in the RMA turbidity model.

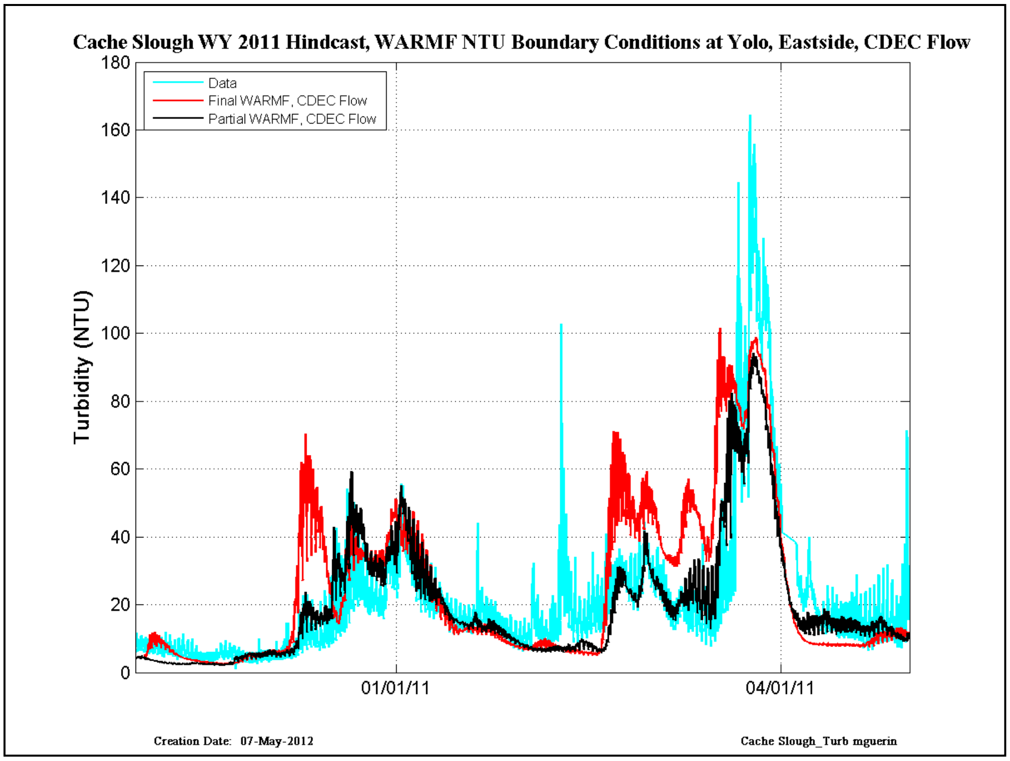


Figure 8 CDEC data (cyan) compared with RMA simulations run with Final WARMF (red) and Partial WARMF (black) – results are shown at Cache Slough at Ryer in WY2011.

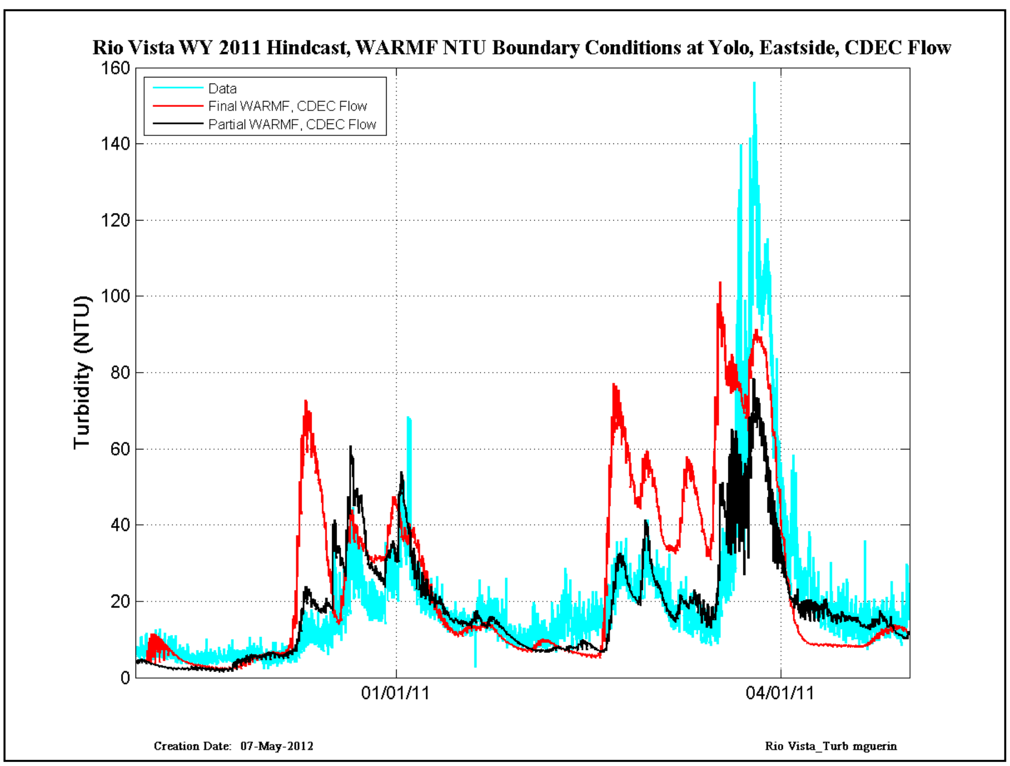


Figure 9 CDEC data (cyan) compared with RMA simulations run with Final WARMF (red) and Partial WARMF (black) – results are shown at Rio Vista in WY2011.

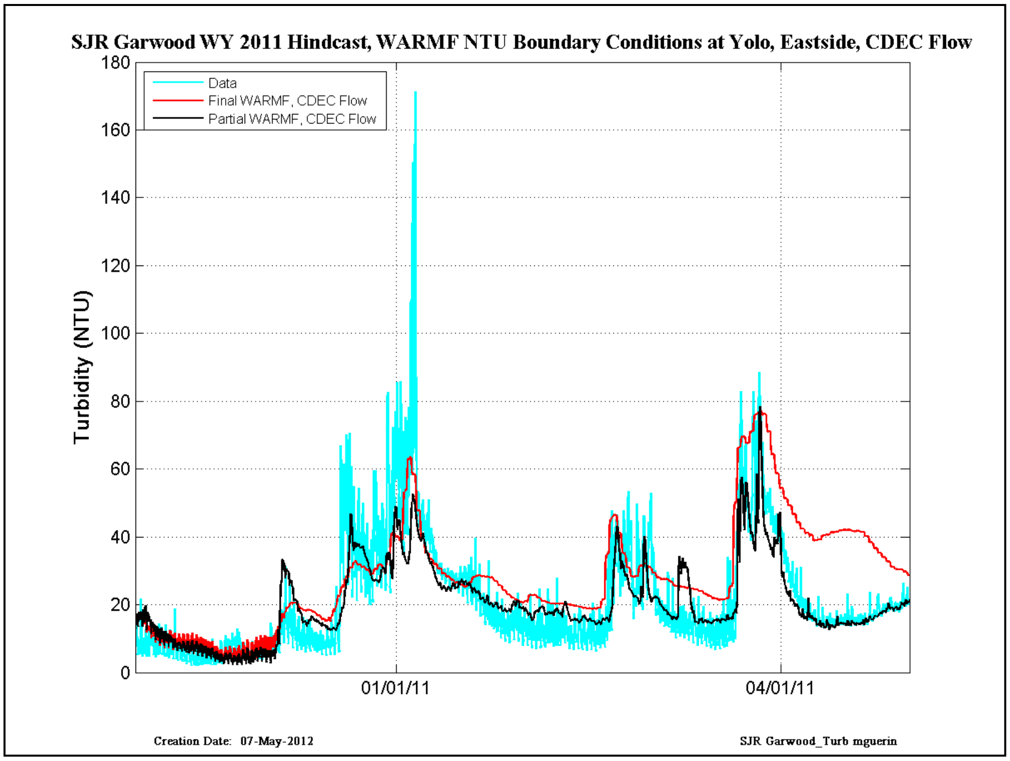


**Figure 10 CDEC data (cyan) compared with RMA simulations run with Final WARMF (red) and Partial WARMF (black) – results are shown at Garwood on the San Joaquin River in WY2011.**

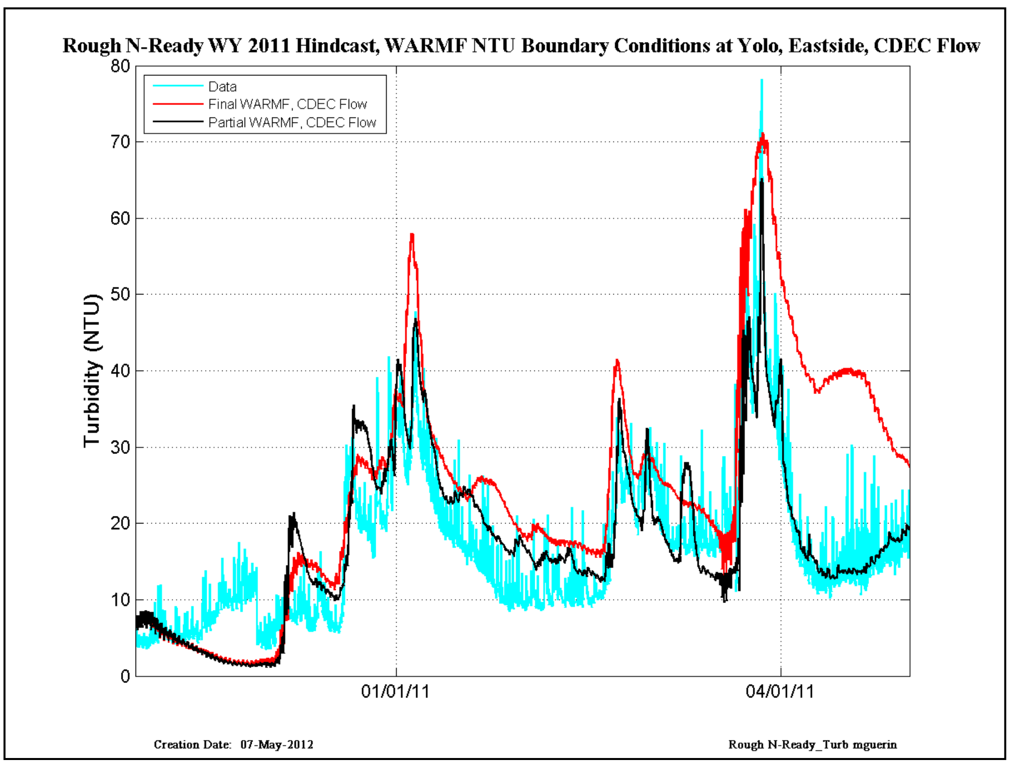


**Figure 11 CDEC data (cyan) compared with RMA simulations run with Final WARMF (red) and Partial WARMF (black) – results are shown at Rough N'Ready Island on the san Joaquin River in WY2011.**

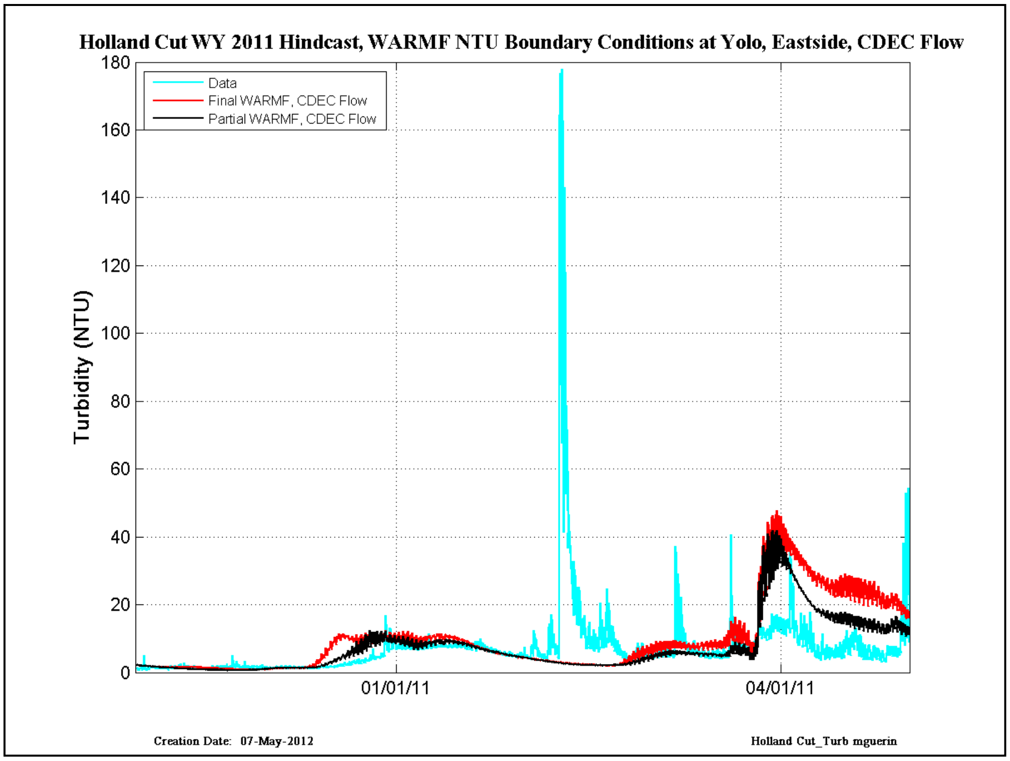


**Figure 12 CDEC data (cyan) compared with RMA simulations run with Final WARMF (red) and Partial WARMF (black) – results are shown at Holland cut in WY2011.**

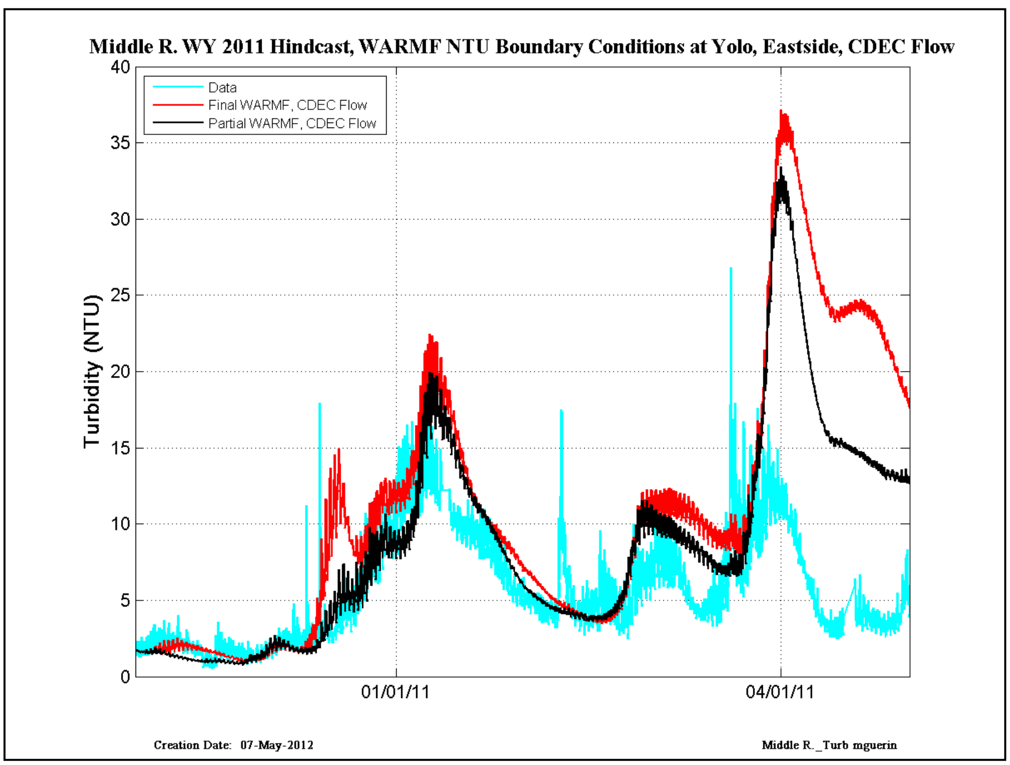


**Figure 13 CDEC data (cyan) compared with RMA simulations run with Final WARMF (red) and Partial WARMF (black) – results are shown at the Middle River location in WY2011.**

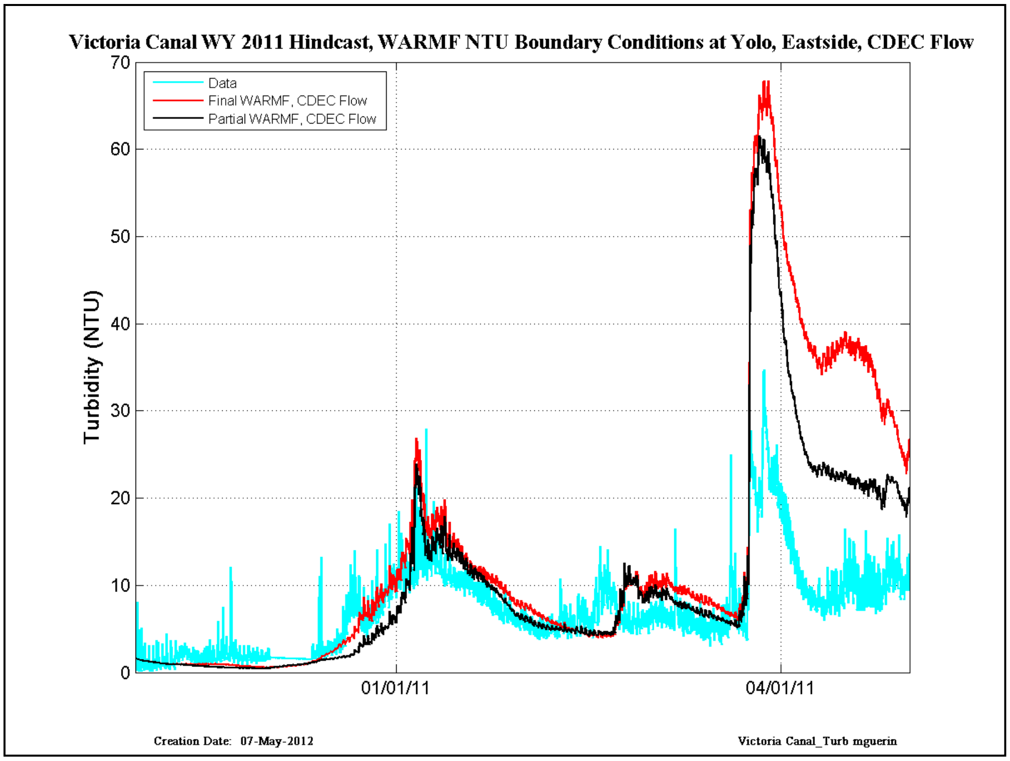


**Figure 14 CDEC data (cyan) compared with RMA simulations run with Final WARMF (red) and Partial WARMF (black) – results are shown at Victoria canal in WY2011.**

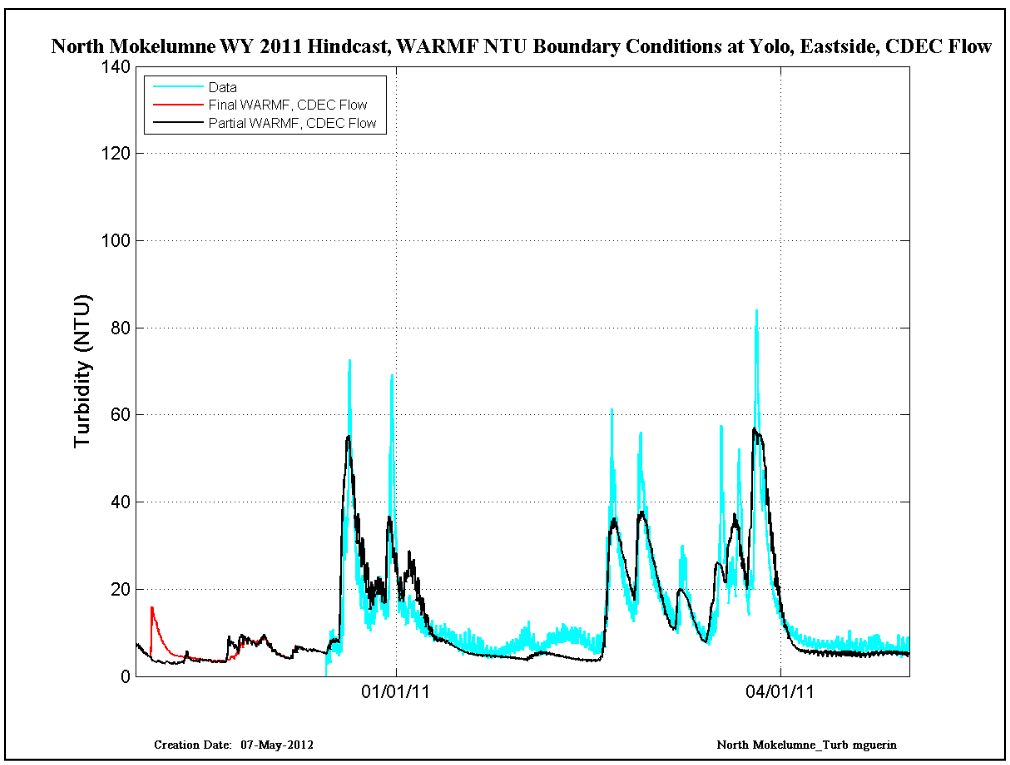


**Figure 15 CDEC data (cyan) compared with RMA simulations run with Final WARMF (red) and Partial WARMF (black) – results are shown at the North Mokelumne River location in WY2011.**

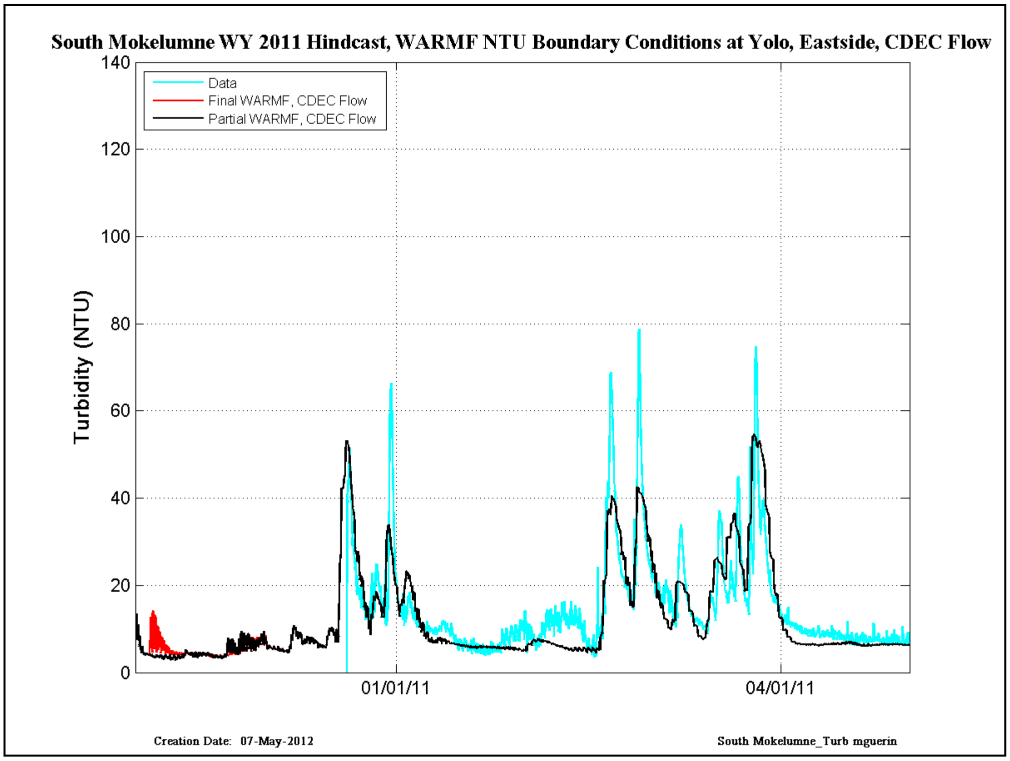


**Figure 16 CDEC data (cyan) compared with RMA simulations run with Final WARMF (red) and Partial WARMF (black) – results are shown at the South Mokelumne River location in WY2011.**

## 5.2 RMA model comparison of the initial and final WARMF historical simulations

These simulations were run with WARMF-supplied flow and turbidity boundary conditions at all inflow locations. The RMA model run denoted the Original simulation was run with the initial set of WARMF model output supplied by Systech for this subtask. The RMA model run denoted the Final simulation was run with the final set of WARMF output. In the figures below, CDEC 15-minute data is shown in cyan, the RMA turbidity model results using Original WARMF result are in red, and the RMA turbidity model results using Final WARMF are in black.

### 5.2.1 WY2010

Results for WY2010 are illustrated in Figure 17 through Figure 26.

The Original WARMF simulation produced in this subtask overestimated turbidity at Freeport (Figure 17) during several of the peaks and peak widths were generally too wide, while the Final results underestimated the first turbidity peak in January and the third peak which occurred in February, but captured the other peak heights and widths.  Both the Original and Final WARMF simulations produced in this subtask underestimated the turbidity peak at Vernalis (Figure 18) in January.

Figure 19 through Figure 26 show the downstream consequences of these boundary conditions. In Cache Slough (Figure 19) and at Rio Vista (Figure 20) – the over and under estimates, respectively, of the Freeport boundary condition supplied by WARMF is illustrated. At the rest of the locations, the overestimate of the Original WARMF model at Freeport compensates for the underestimate at Vernalis to produce results that occasionally makes the original WARMF turbidity results appear better (e.g., at Turner Cut,  Figure 25).

Overall, the Final WARMF model results at Freeport improve the Original WARMF results in WY2010, with the major exception that the initial turbidity peak in January is missed. At Vernalis, little change is seen between the Original and final WARMF model results.

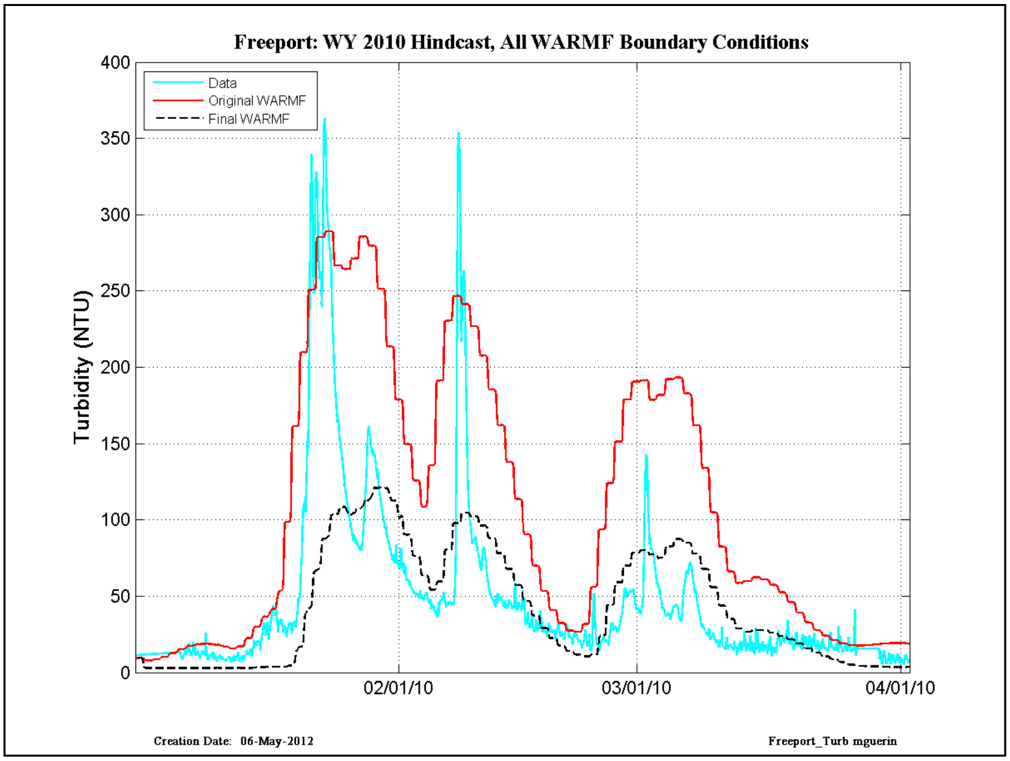


**Figure 17 CDEC data (cyan) compared with RMA simulations run with original WARMF (red) and Final WARMF (black) – results are shown at Freeport in WY2010.**

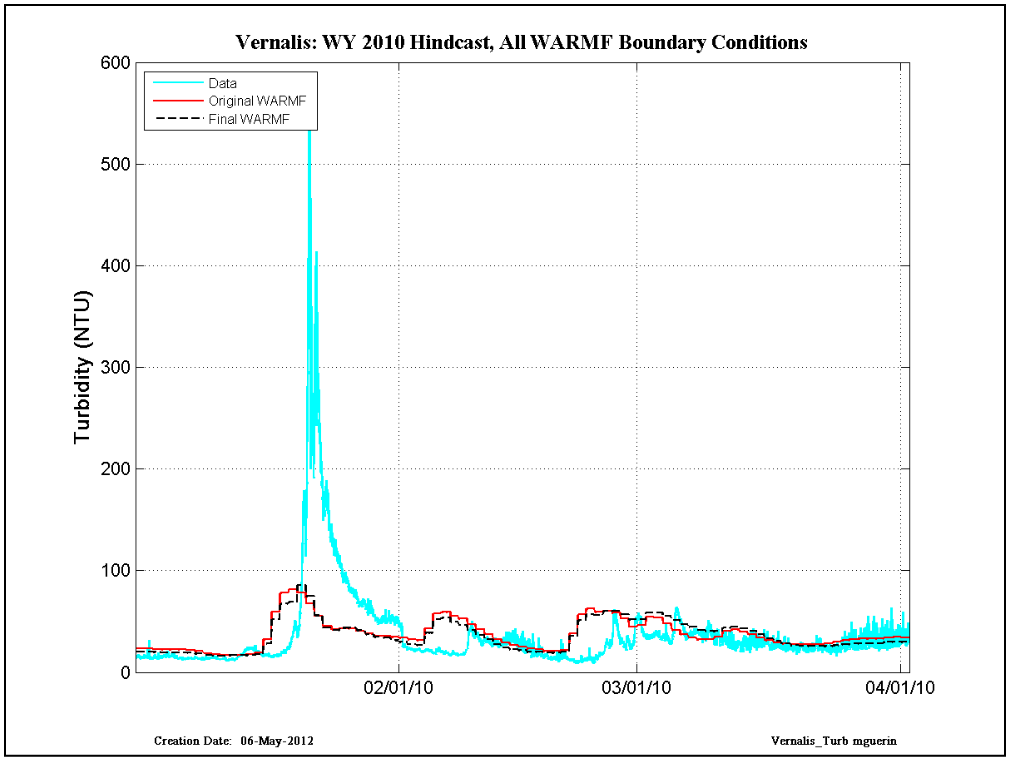


**Figure 18 CDEC data (cyan) compared with RMA simulations run with original WARMF (red) and Final WARMF (black) – results are shown at Vernalis in WY2010.**

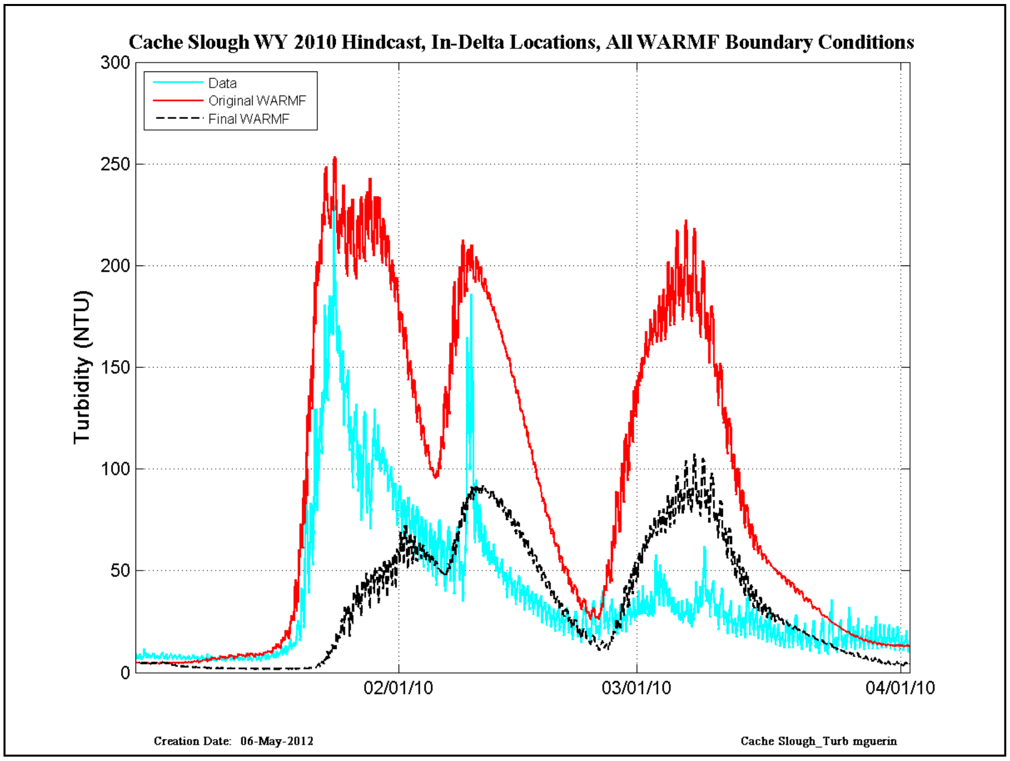


**Figure 19 CDEC data (cyan) compared with RMA simulations run with original WARMF (red) and Final WARMF (black) – results are shown at Cache Slough at Ryer in WY2010.**

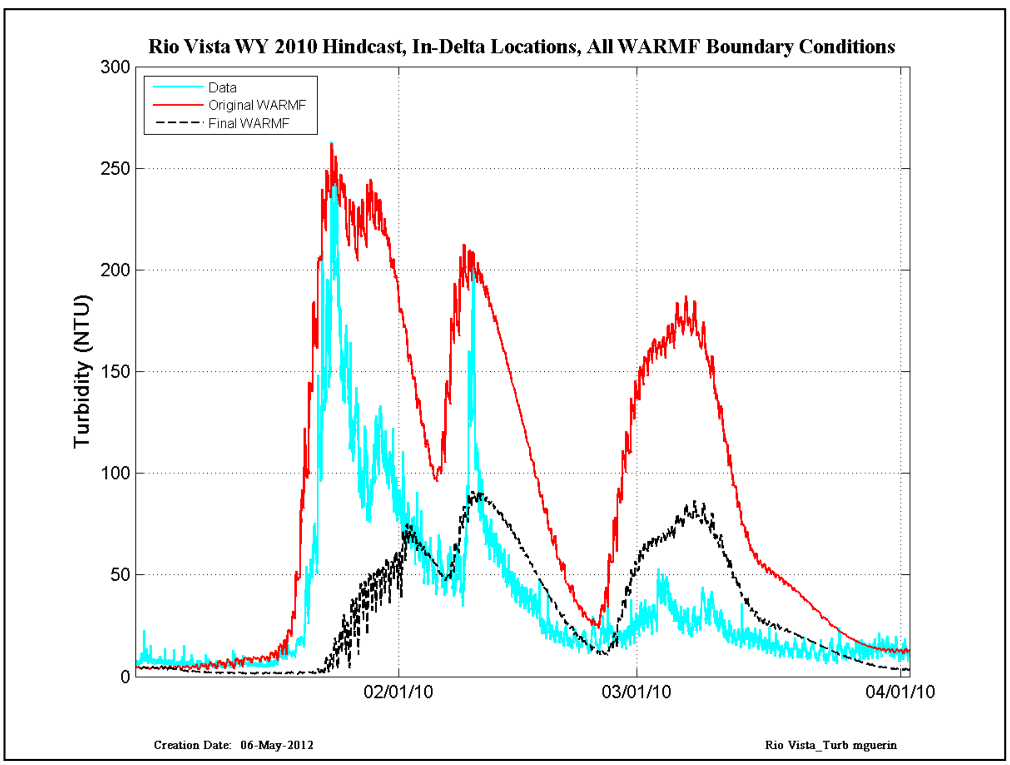


**Figure 20 CDEC data (cyan) compared with RMA simulations run with original WARMF (red) and Final WARMF (black) – results are shown at Rio Vista in WY2010.**

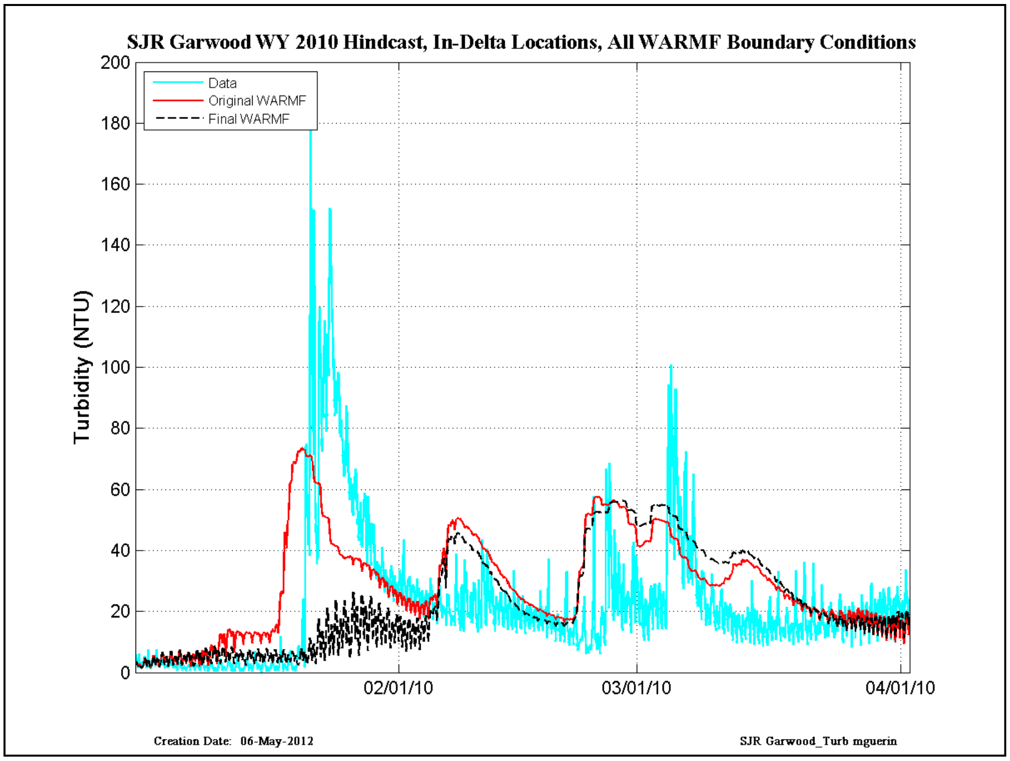


**Figure 21 CDEC data (cyan) compared with RMA simulations run with original WARMF (red) and Final WARMF (black) – results are shown at Garwood on the San Joaquin River in WY2010.**

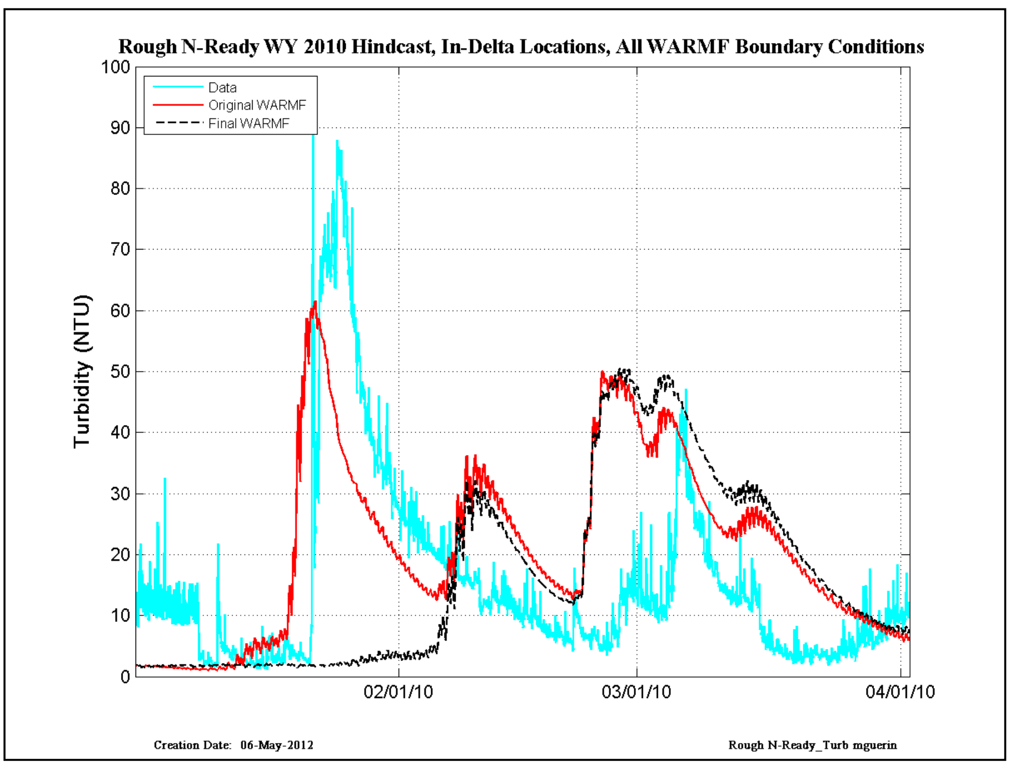


**Figure 22 CDEC data (cyan) compared with RMA simulations run with original WARMF (red) and Final WARMF (black) – results are shown at Rough N'Ready Island on the San Joaquin River in WY2010.**

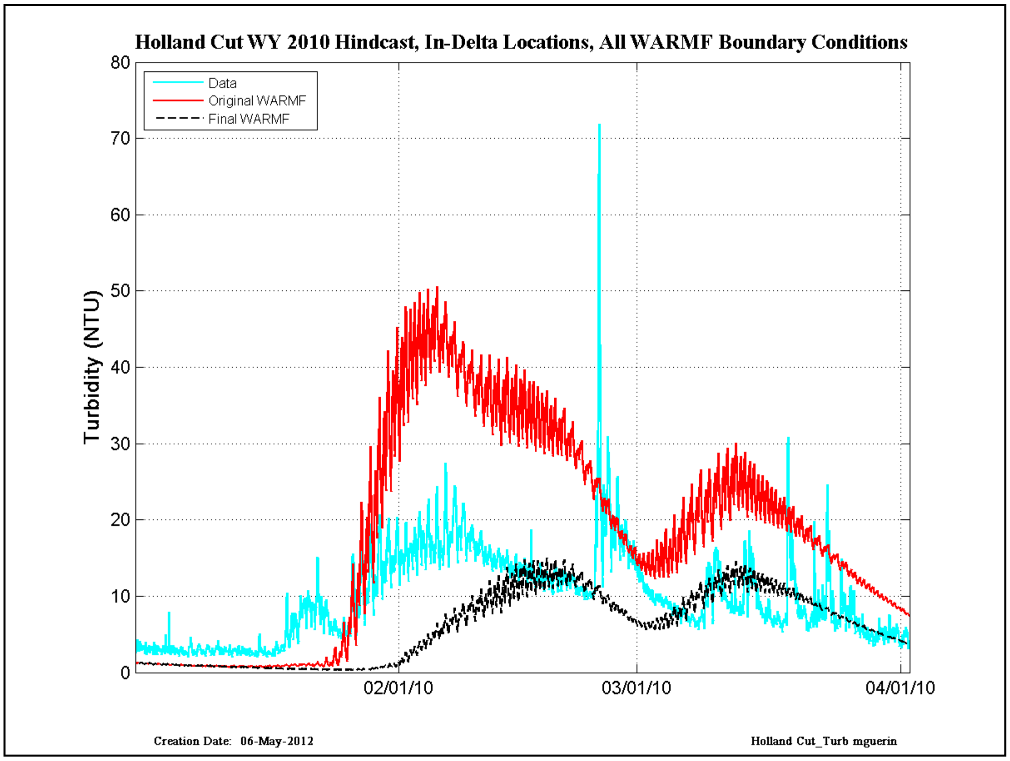


**Figure 23 CDEC data (cyan) compared with RMA simulations run with original WARMF (red) and Final WARMF (black) – results are shown at Holland Cut in WY2010.**

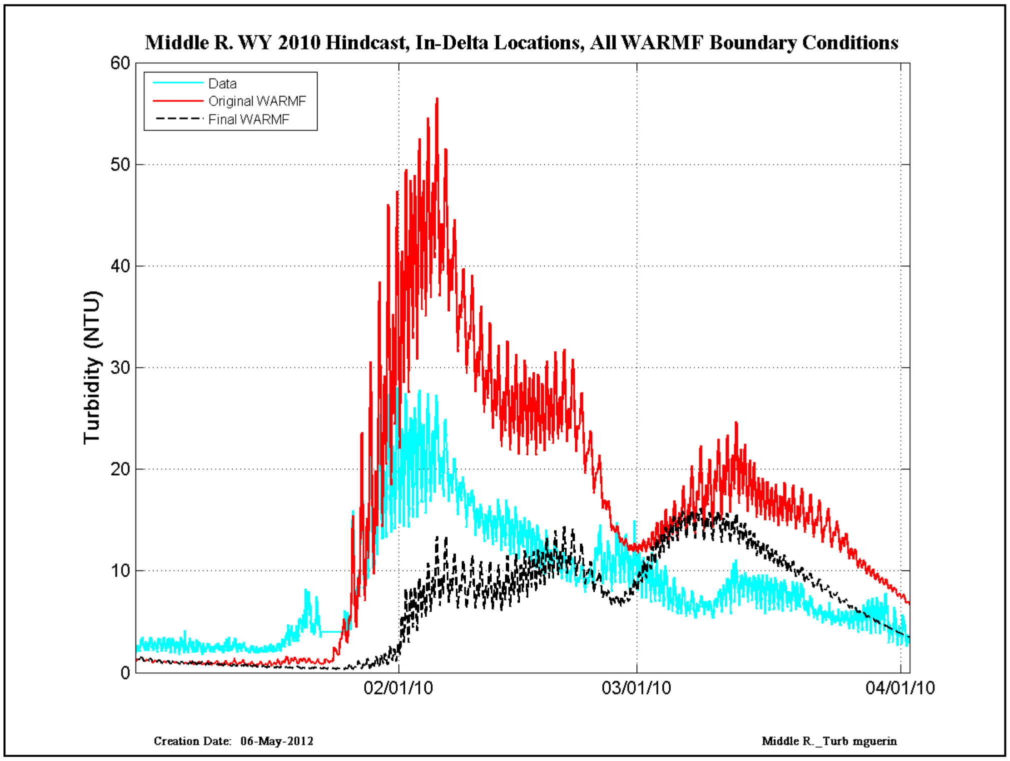


**Figure 24 CDEC data (cyan) compared with RMA simulations run with original WARMF (red) and Final WARMF (black) – results are shown at the Middle River location in WY2010.**

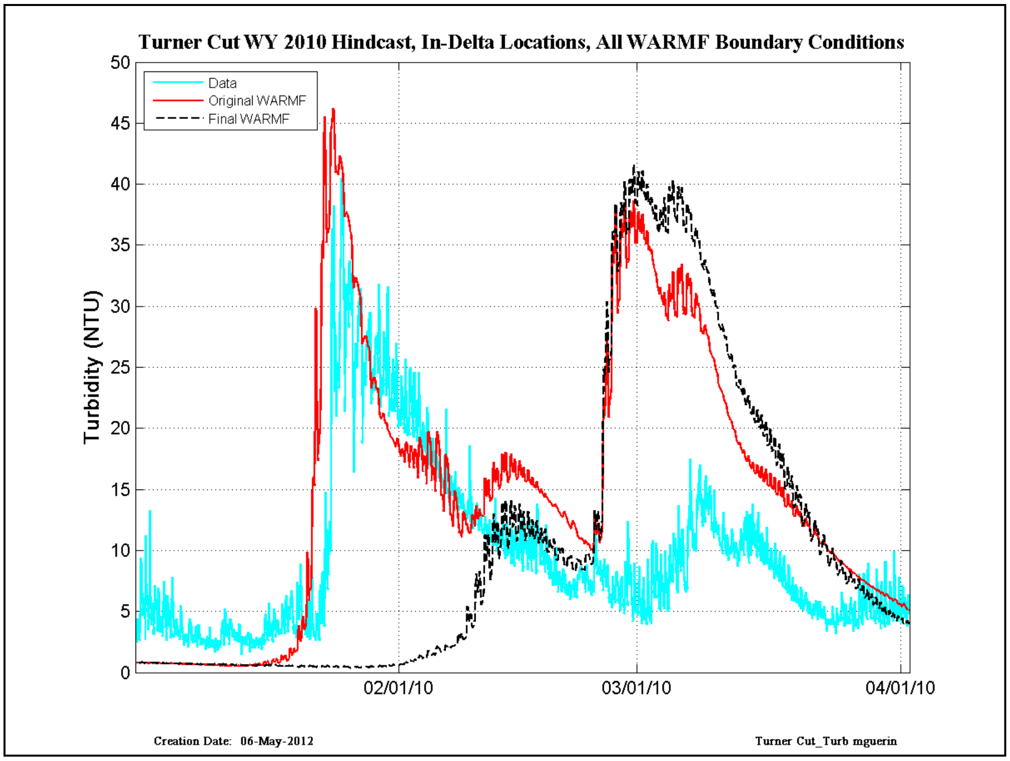


**Figure 25 CDEC data (cyan) compared with RMA simulations run with original WARMF (red) and Final WARMF (black) – results are shown at Turner Cut in WY2010.**

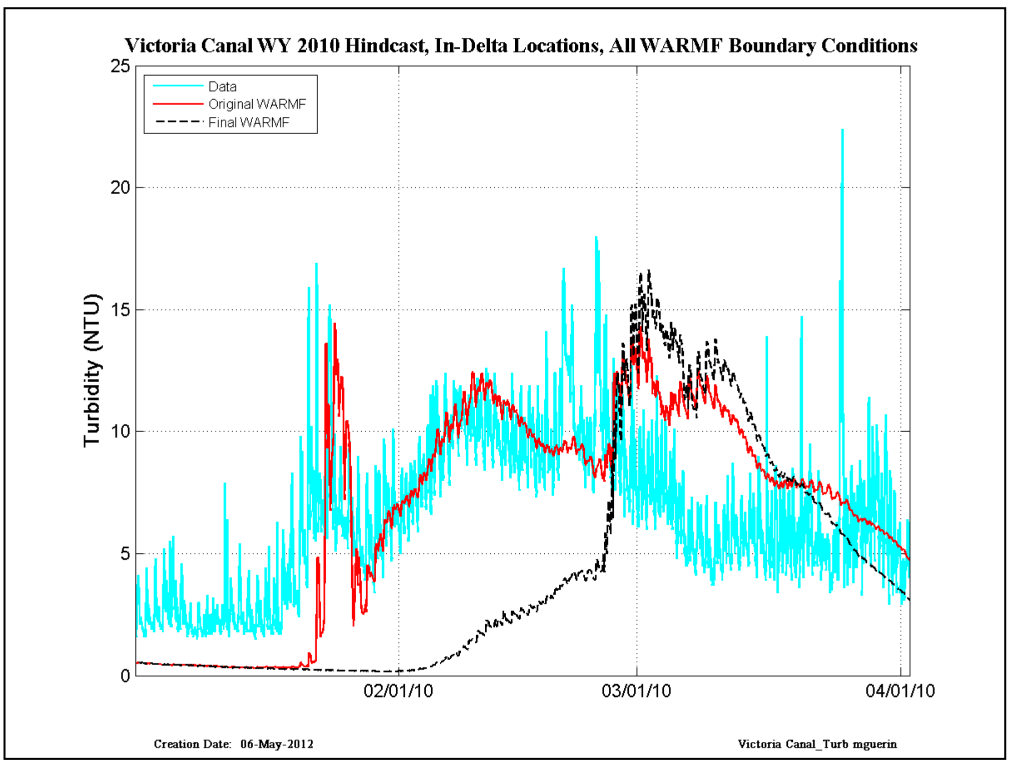


**Figure 26 CDEC data (cyan) compared with RMA simulations run with original WARMF (red) and Final WARMF (black) – results are shown at Victoria Canal in WY2010.**

### 5.2.2 WY2011

Turbidity results for WY2011 are illustrated in Figure 27 through Figure 38.

The Original WARMF simulation produced in this subtask overestimated turbidity at Freeport (Figure 27), while the Final results reduced this overestimation producing very reasonable results overall in peak heights and widths. However, in the Final WARMF boundary conditions, the initial turbidity peak in December 2010 was overestimated, with some downstream consequences. Both the Original and Final WARMF simulations produced in this subtask largely captured measured turbidity at Vernalis (Figure 28).

Figure 29 through Figure 38 show the downstream consequences of these boundary conditions. In Cache Slough (Figure 29) and at Rio Vista (Figure 30) – the WY2011 results are superior to the WY2010 results. At the rest of the locations, the Final WARMF model boundary conditions generally did a superior job at reproducing turbidity than the Original WARMF simulation. Figure 37 and Figure 38 illustrate the WARMF boundary conditions for the Mokelumne and Cosumnes Rivers produce very good results at downstream locations, below the Mokelumne split.

Overall, the Final WARMF model results in WY2011 show great improvements over the Original WARMF model results.

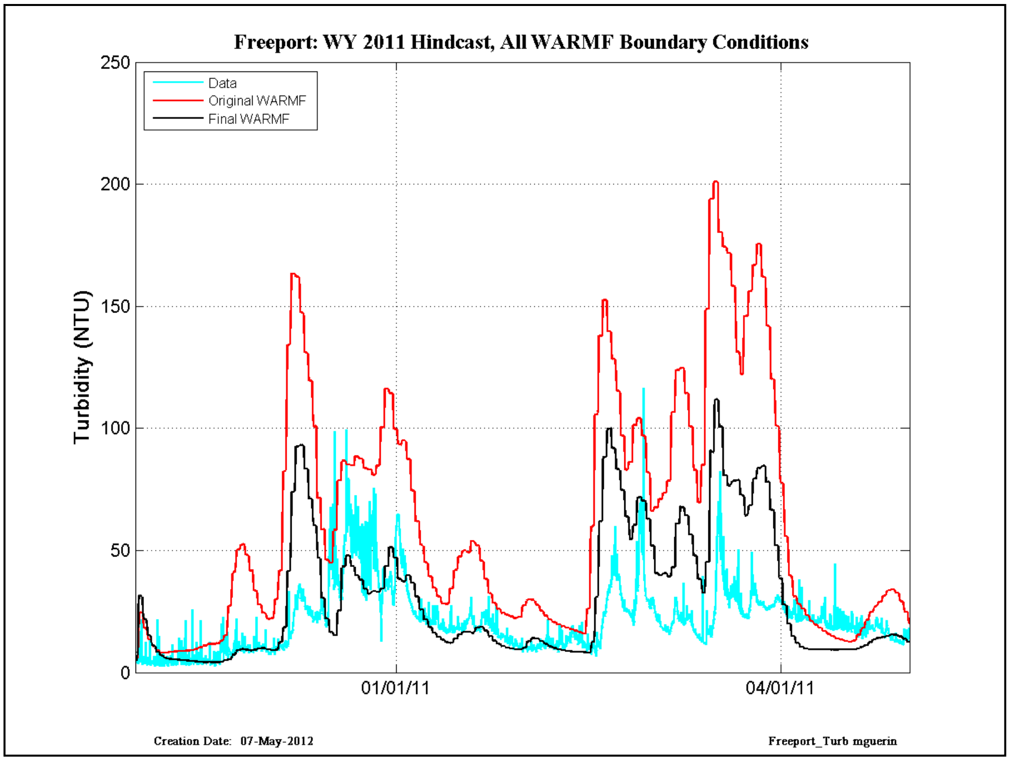


Figure 27 CDEC data (cyan) compared with RMA simulations run with original WARMF (red) and Final WARMF (black) – results are shown at Freeport in WY2011.

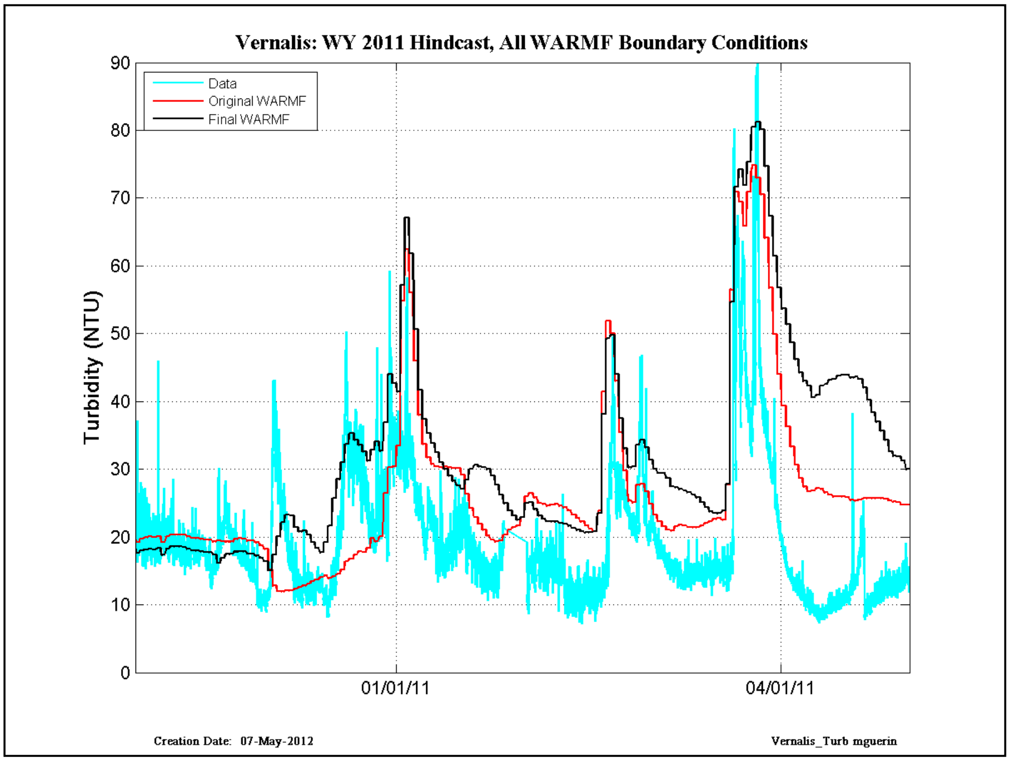


Figure 28 CDEC data (cyan) compared with RMA simulations run with original WARMF (red) and Final WARMF (black) – results are shown at Vernalis in WY2011.

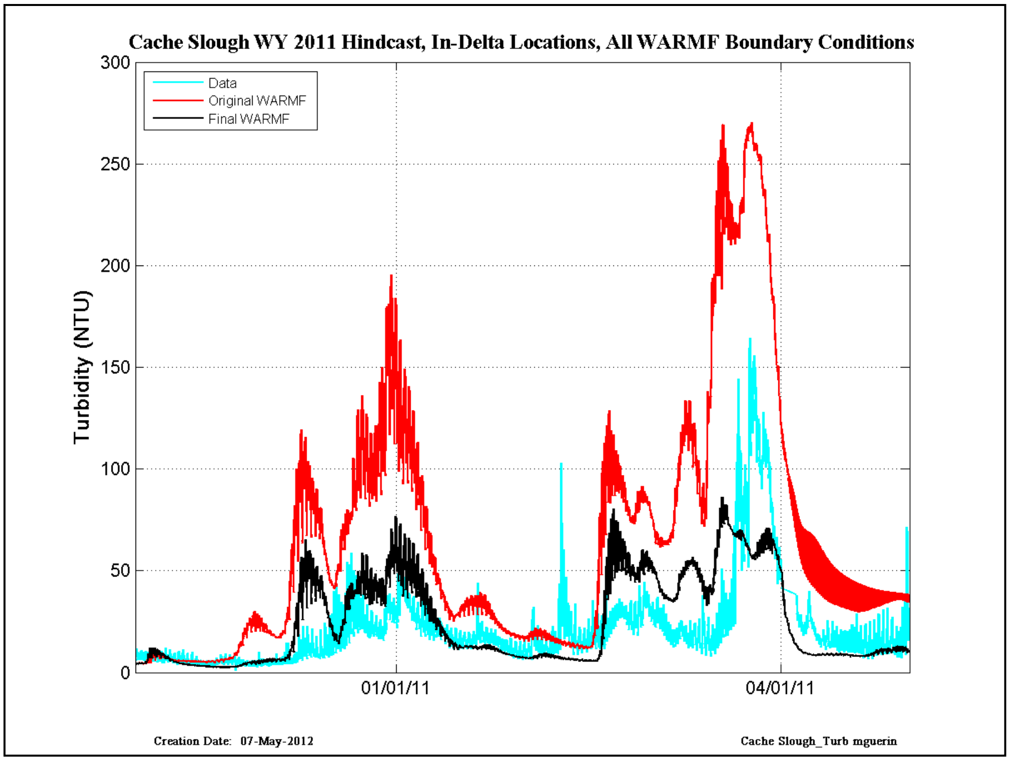


**Figure 29 CDEC data (cyan) compared with RMA simulations run with original WARMF (red) and Final WARMF (black) – results are shown in Cache Slough at Ryer in WY2011.**

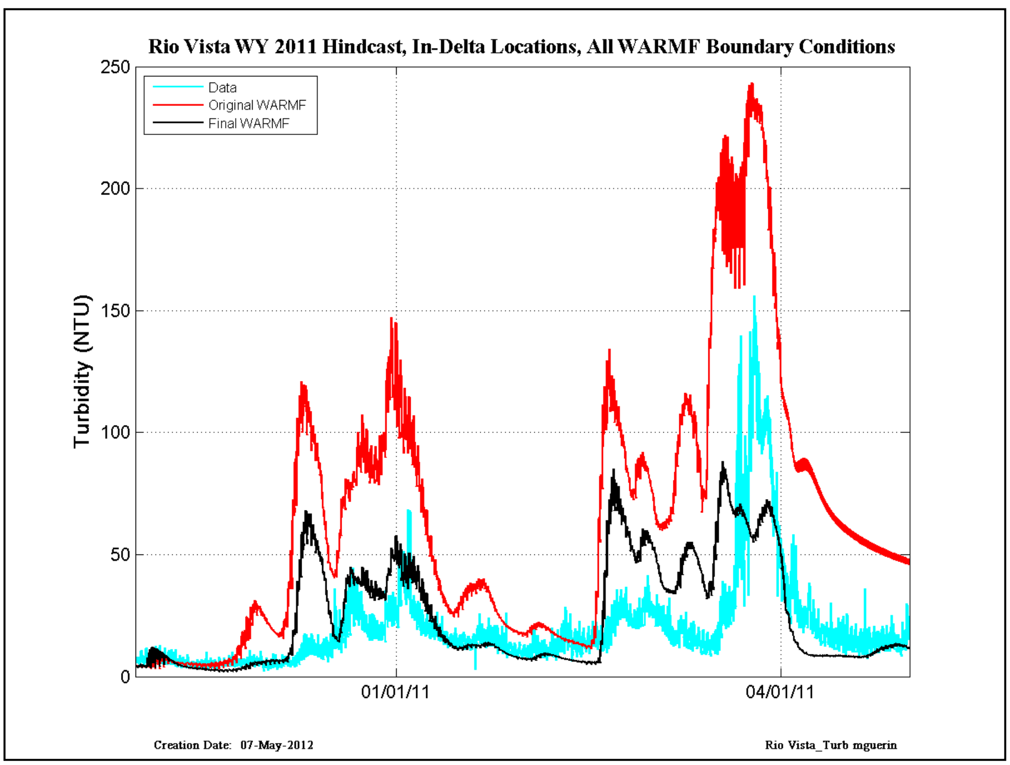


**Figure 30 CDEC data (cyan) compared with RMA simulations run with original WARMF (red) and Final WARMF (black) – results are shown at Rio Vista in WY2011.**

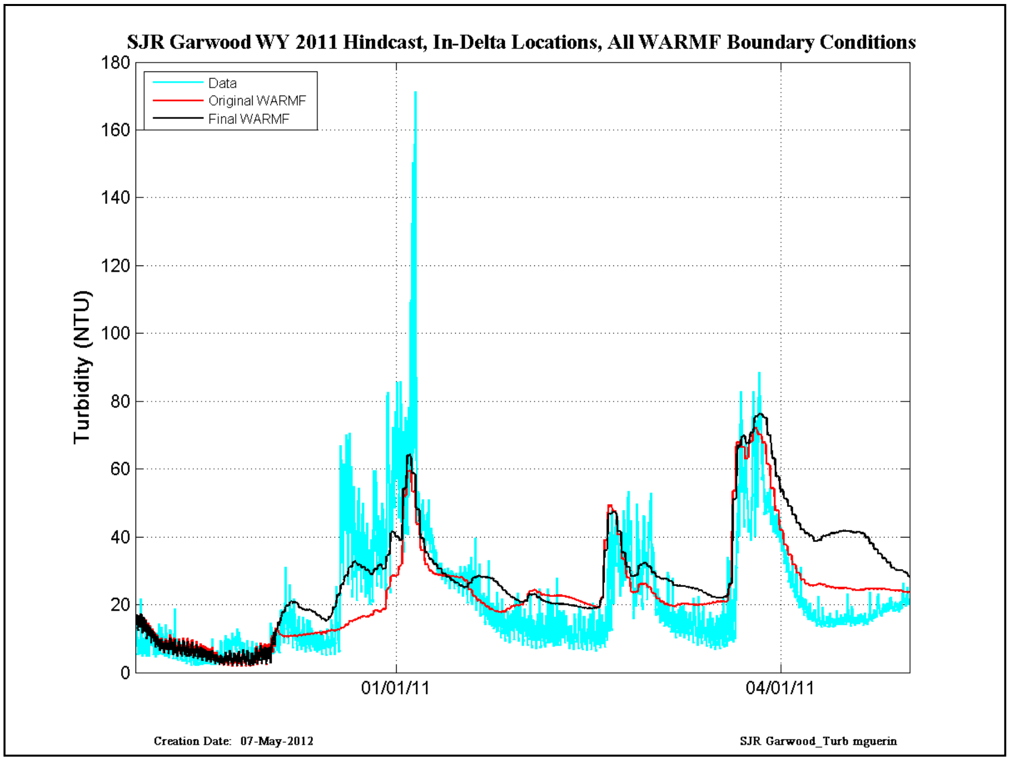


**Figure 31 CDEC data (cyan) compared with RMA simulations run with original WARMF (red) and Final WARMF (black) – results are shown at SJR Garwood in WY2011.**

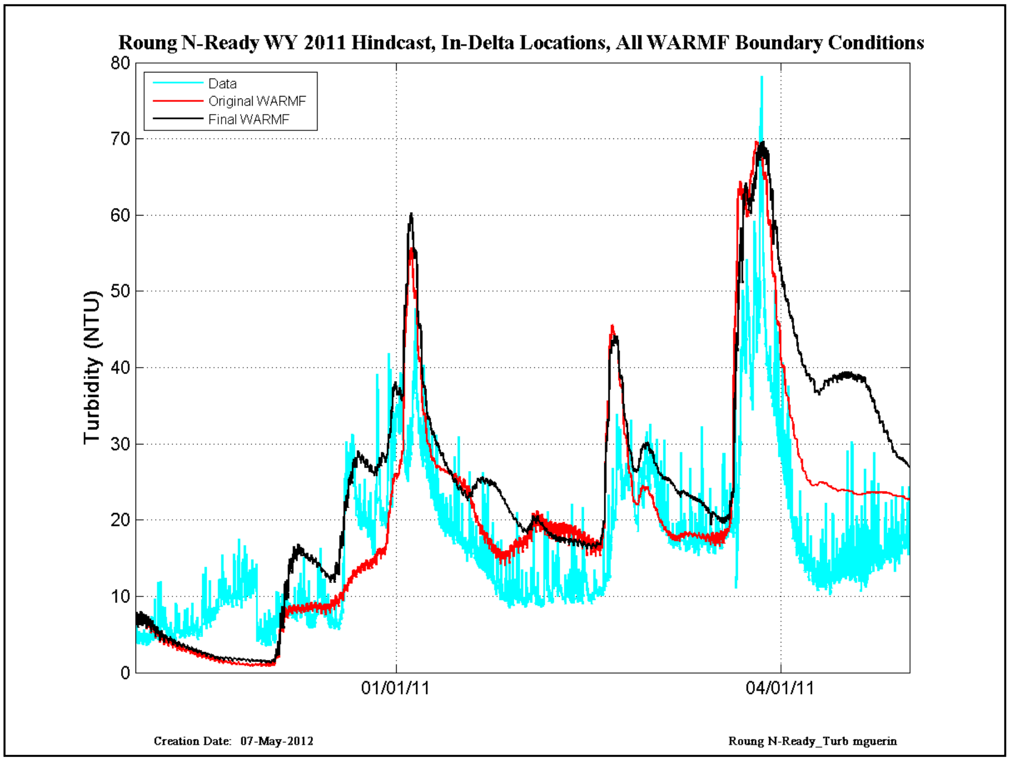


**Figure 32 CDEC data (cyan) compared with RMA simulations run with original WARMF (red) and Final WARMF (black) – results are shown at Rough N'Ready in WY2011.**

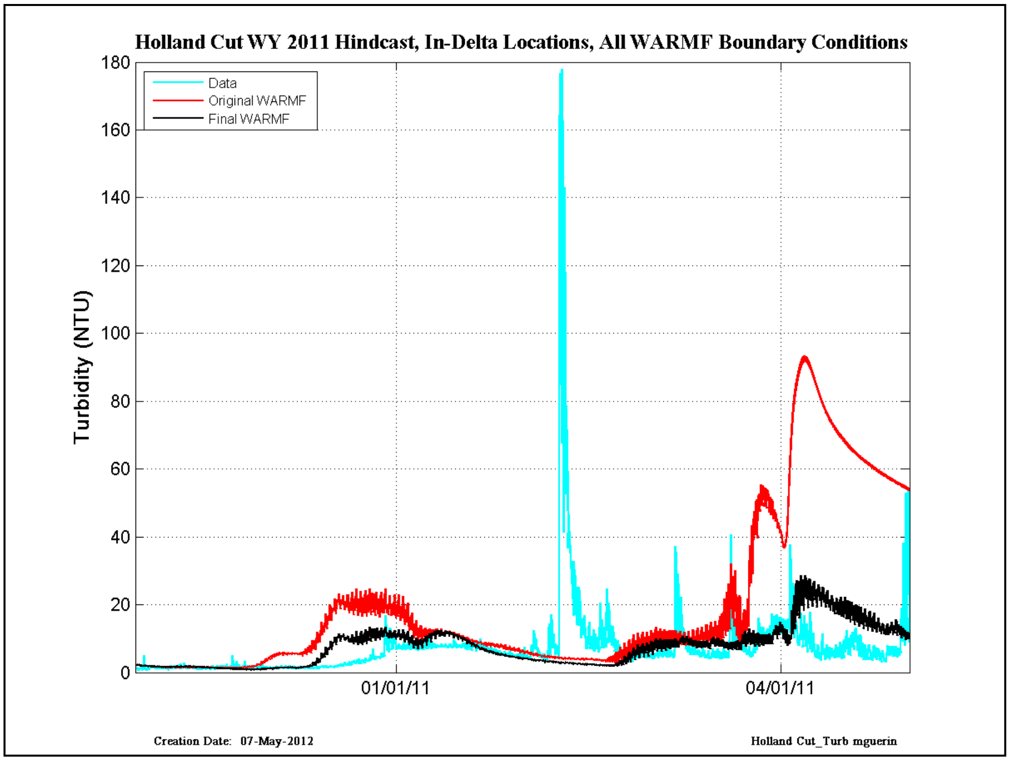


**Figure 33 CDEC data (cyan) compared with RMA simulations run with original WARMF (red) and Final WARMF (black) – results are shown at Holland Cut in WY2011.**

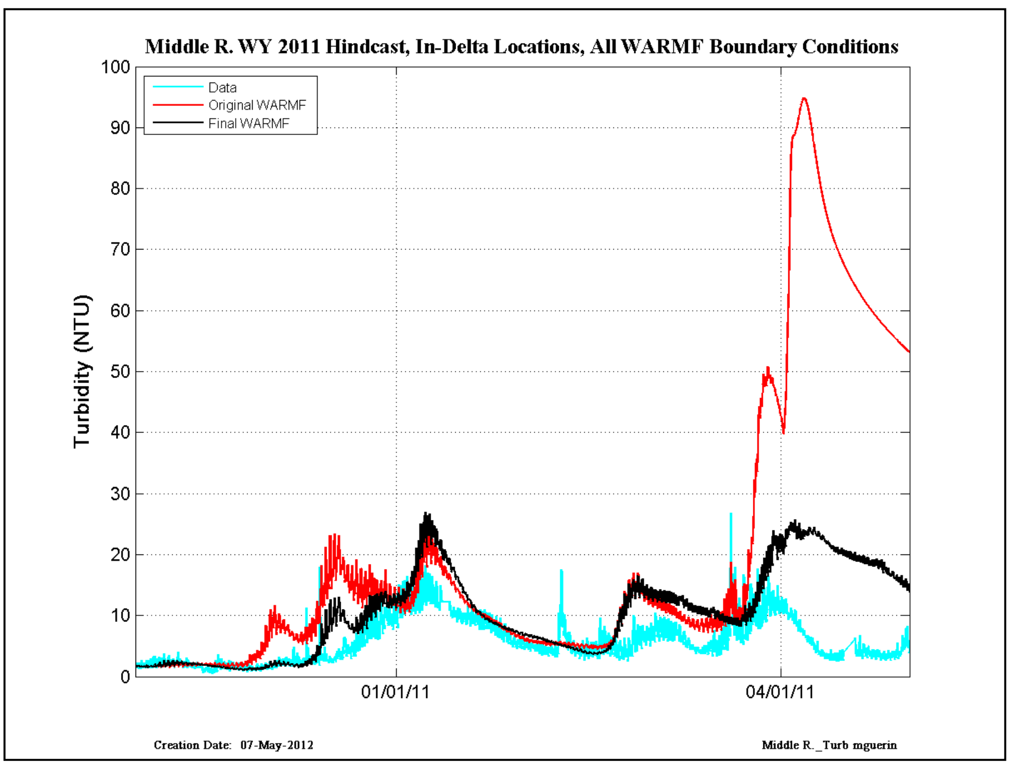


**Figure 34 CDEC data (cyan) compared with RMA simulations run with original WARMF (red) and Final WARMF (black) – results are shown at Middle River in WY2011.**

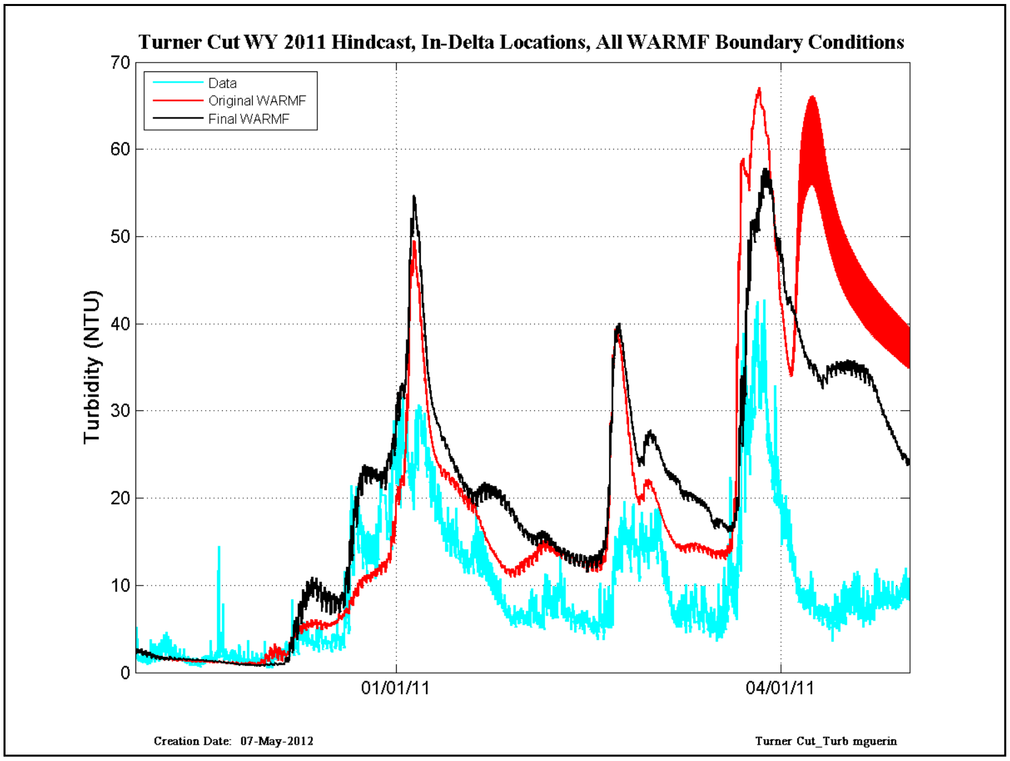


**Figure 35 CDEC data (cyan) compared with RMA simulations run with original WARMF (red) and Final WARMF (black) – results are shown at Turner Cut in WY2011.**

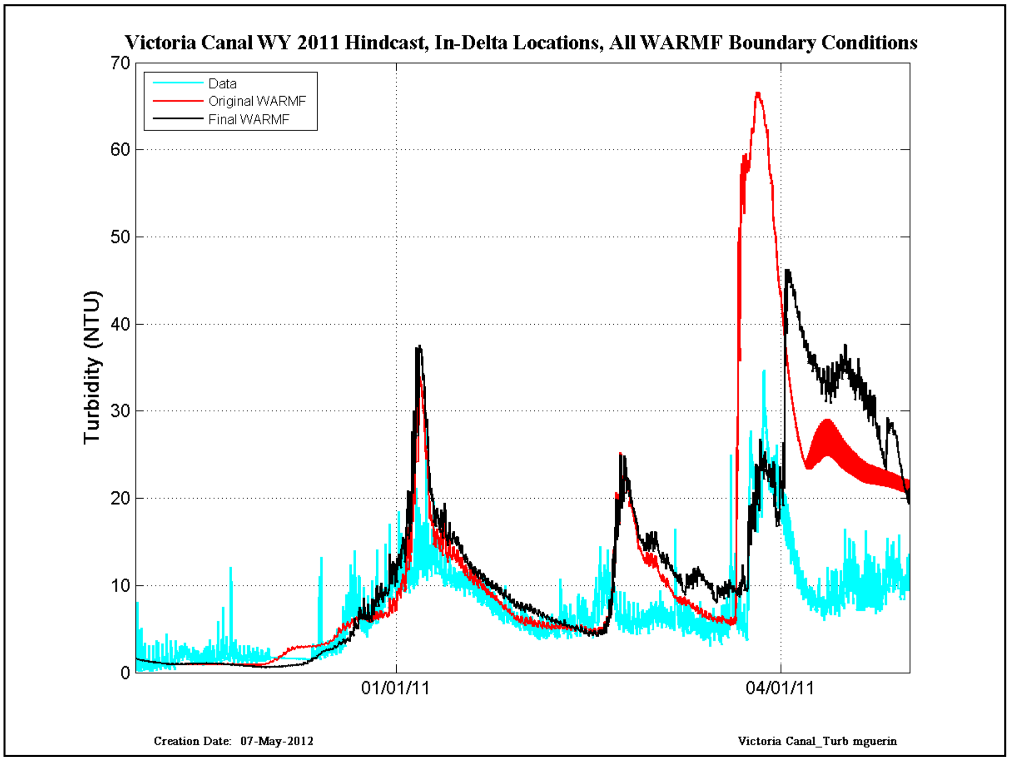


**Figure 36 CDEC data (cyan) compared with RMA simulations run with original WARMF (red) and Final WARMF (black) – results are shown at Victoria Canal in WY2011.**

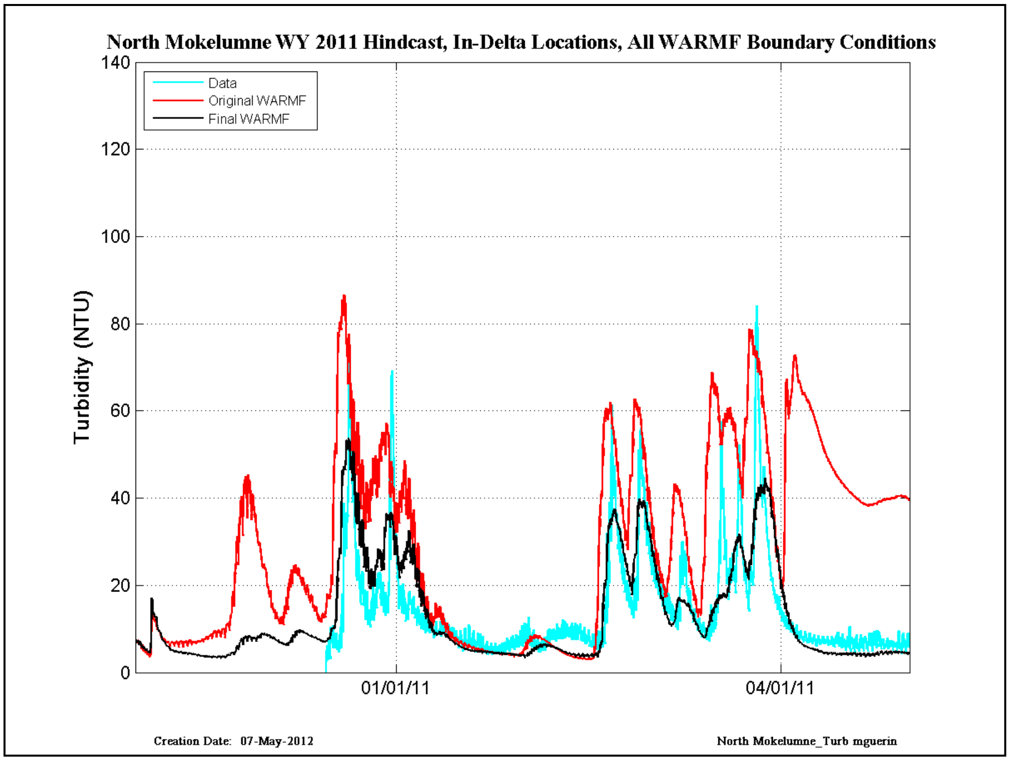


Figure 37 CDEC data (cyan) compared with RMA simulations run with original WARMF (red) and Final WARMF (black) – results are shown at the North Mokelumne location inWY2011.

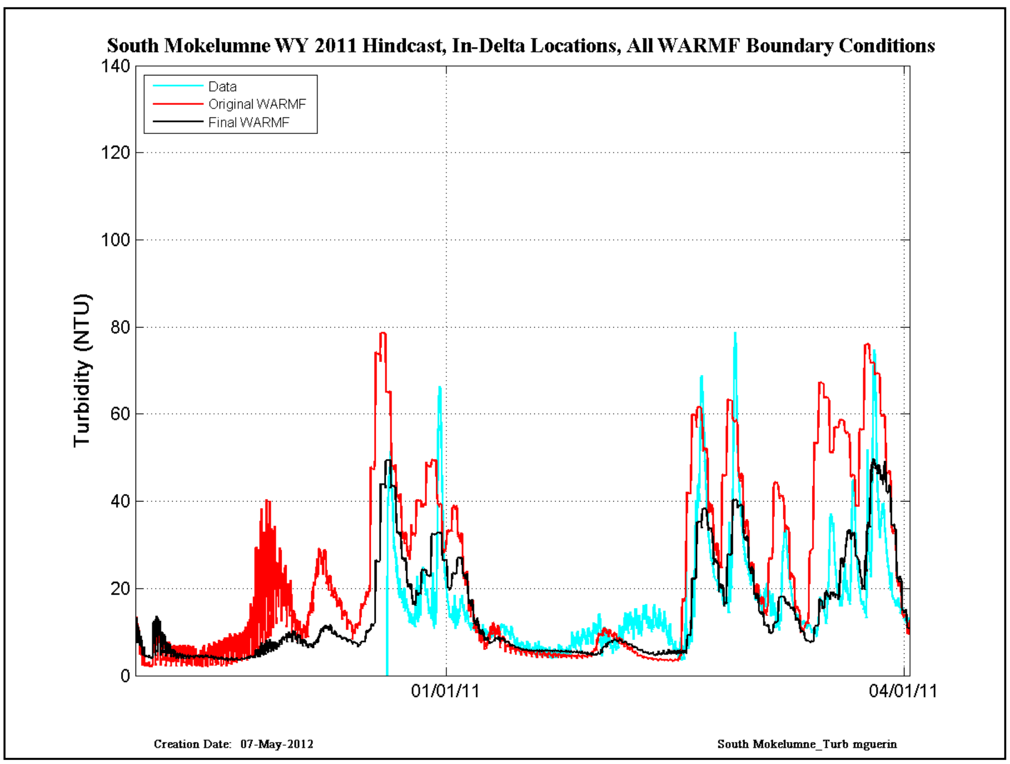


Figure 38 CDEC data (cyan) compared with RMA simulations run with original WARMF (red) and Final WARMF (black) – results are shown at the South Mokelumne location in WY2011.

## 5.3 Final WARMF results – comparison using CDEC flow or WARMF calculated flow

In this section, we illustrate RMA model results using Final WARMF estimates of turbidity at all boundaries, but running simulations to compare RMA model results using CDEC measured flows or WARMF calculated flows at model boundaries to isolate the effect of using WARMF calculated flows instead of measurements. In the figures below, CDEC 15-minute data is shown in cyan, the RMA turbidity model results using Final WARMF result for both flow and turbidity are in red, and the RMA turbidity model results using Final WARMF turbidity but measured flow are in black.

Results are shown at several locations for both WY2010 and WY2011 at several locations throughout the Delta in Figure 39 through Figure 54.

These results generally indicate that although errors in WARMF flows contribute to errors in the RMA turbidity model results, particularly in the central Delta, the major source of error in is the WARMF turbidity estimates.

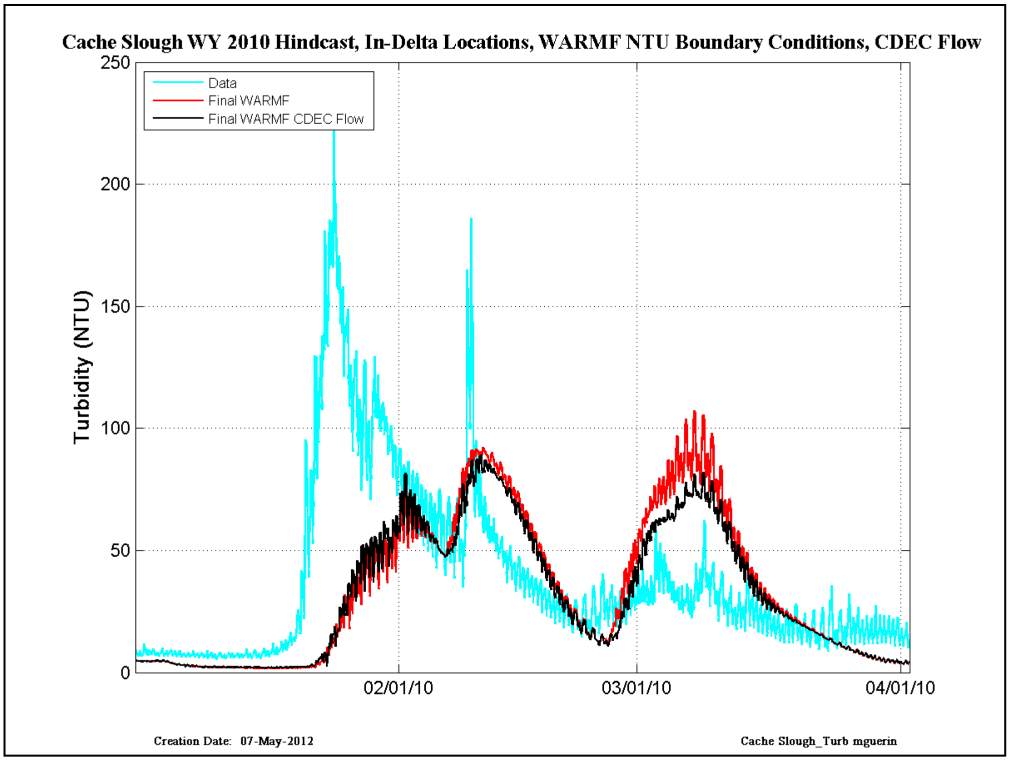


**Figure 39 CDEC data (cyan) compared with RMA simulations run with Final WARMF (red) and Final WARMF and CDEC flows (black) – results are shown in Cache Slough at Ryer in WY2010.**

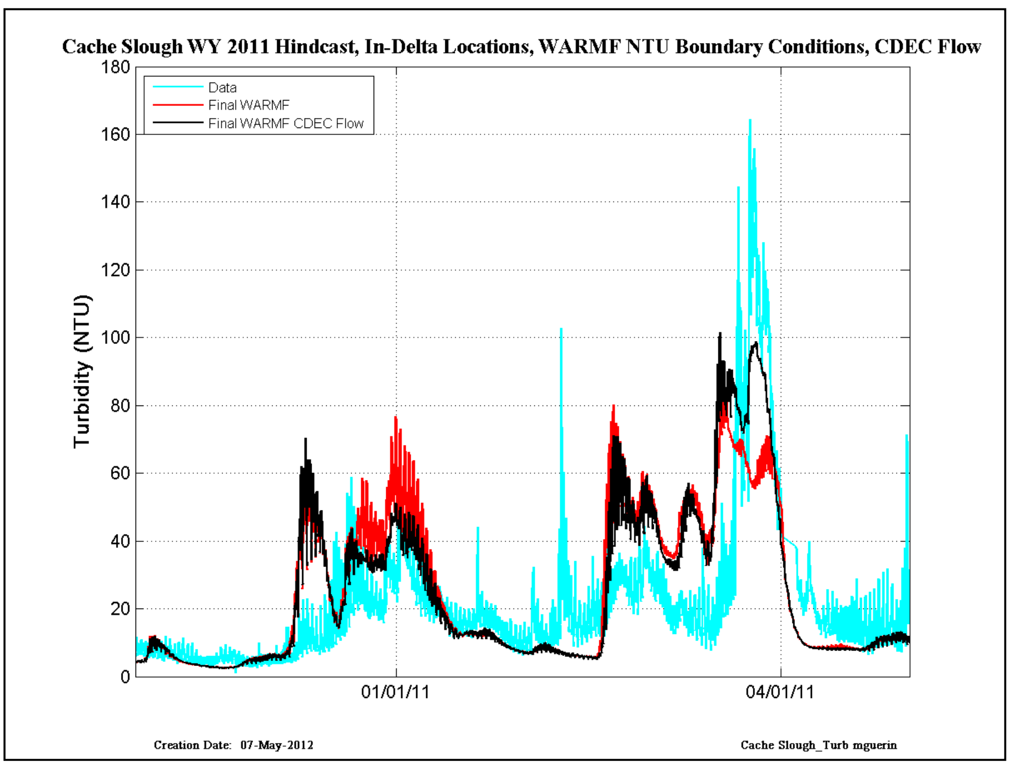


**Figure 40 CDEC data (cyan) compared with RMA simulations run with Final WARMF (red) and Final WARMF and CDEC flows (black) – results are shown in Cache Slough at Ryer in WY2011.**

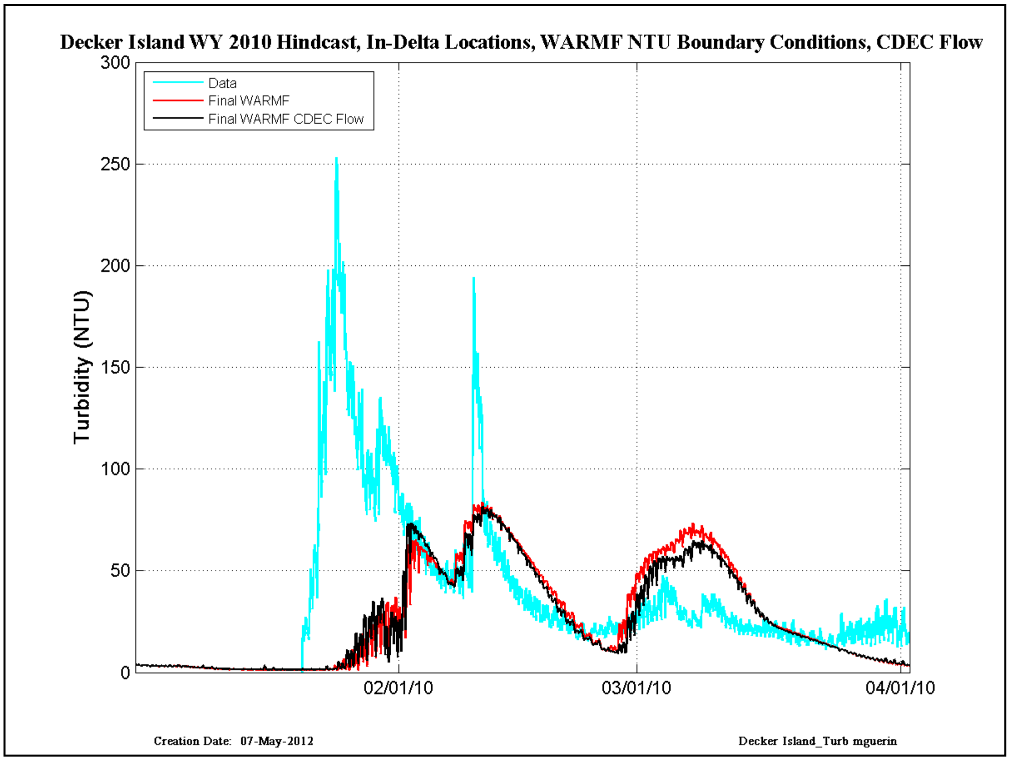


**Figure 41 CDEC data (cyan) compared with RMA simulations run with Final WARMF (red) and Final WARMF and CDEC flows (black) – results are shown in Decker Island on the Sacramento River in WY2010.**

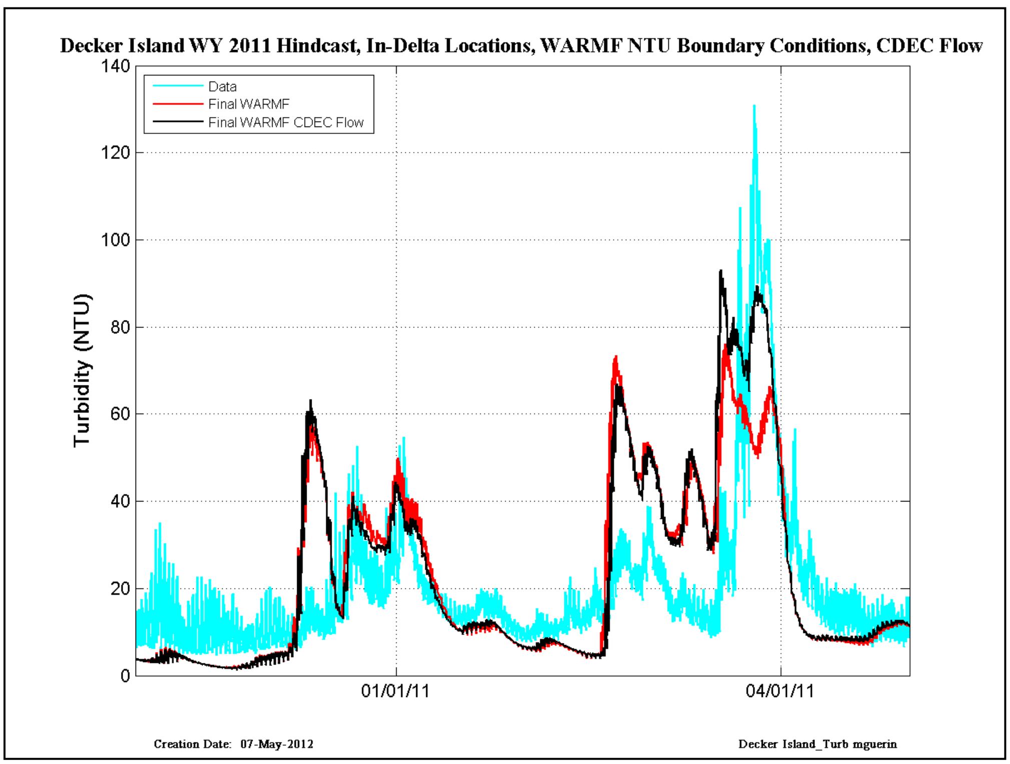


**Figure 42 CDEC data (cyan) compared with RMA simulations run with Final WARMF (red) and Final WARMF and CDEC flows (black) – results are shown in Decker Island on the Sacramento River in WY2011.**

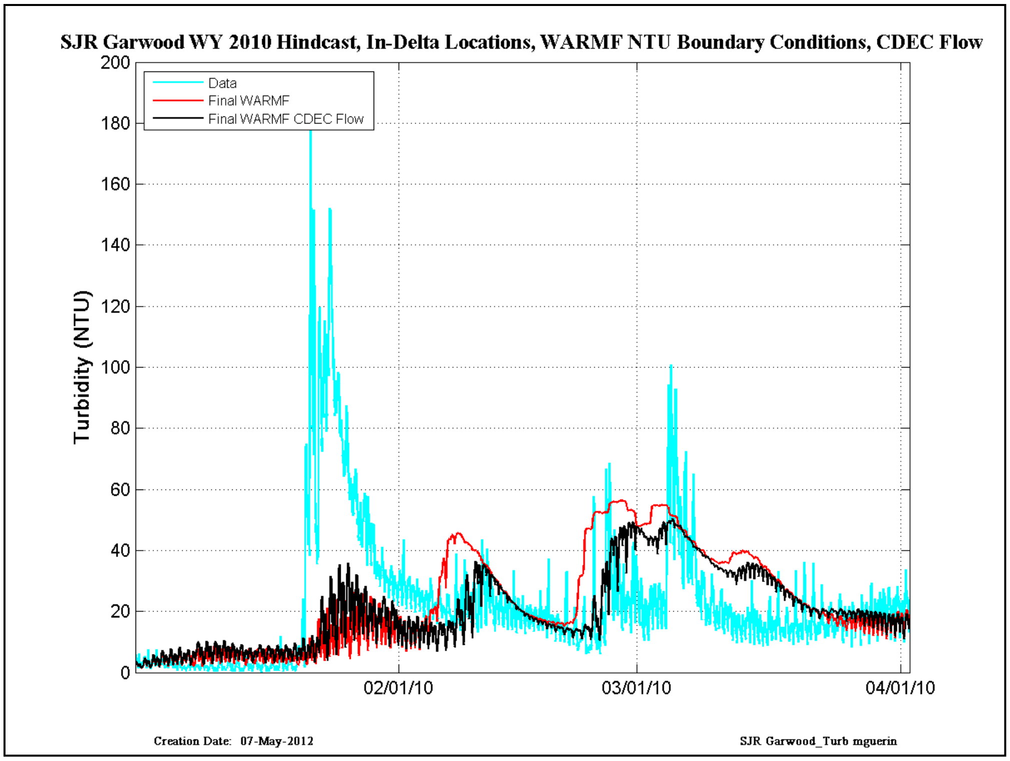


Figure 43 CDEC data (cyan) compared with RMA simulations run with Final WARMF (red) and Final WARMF and CDEC flows (black) – results are shown at Garwood on the San Joaquin River in WY2010.

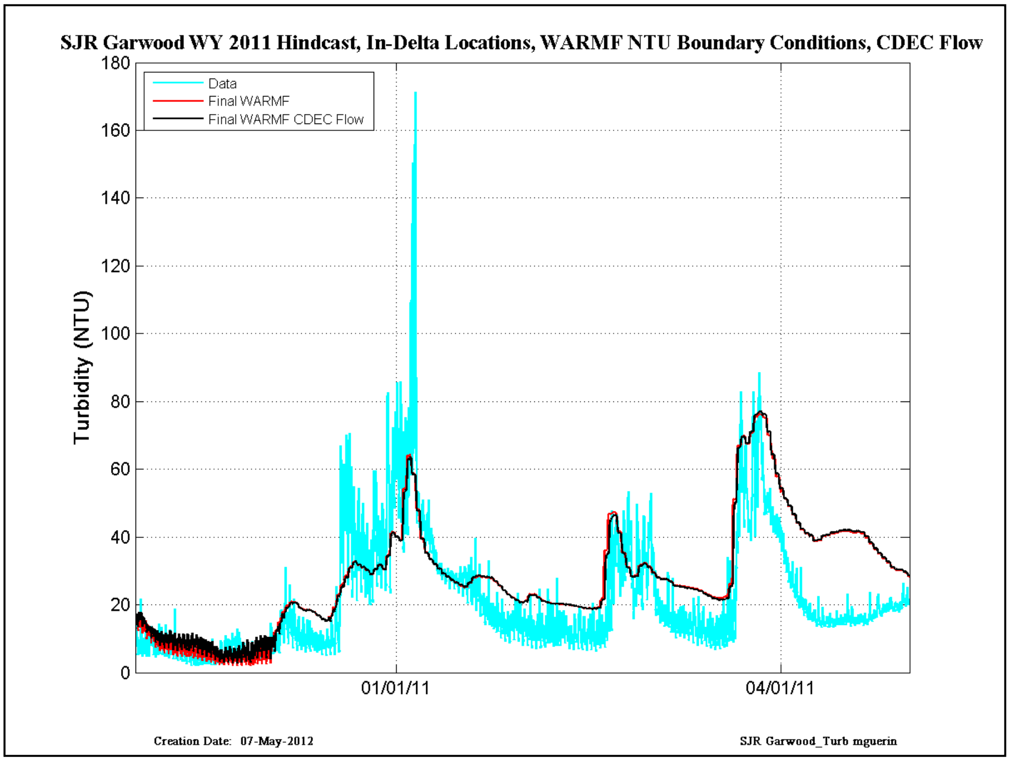


Figure 44 CDEC data (cyan) compared with RMA simulations run with Final WARMF (red) and Final WARMF and CDEC flows (black) – results are shown at Garwood on the San Joaquin River in WY2011.

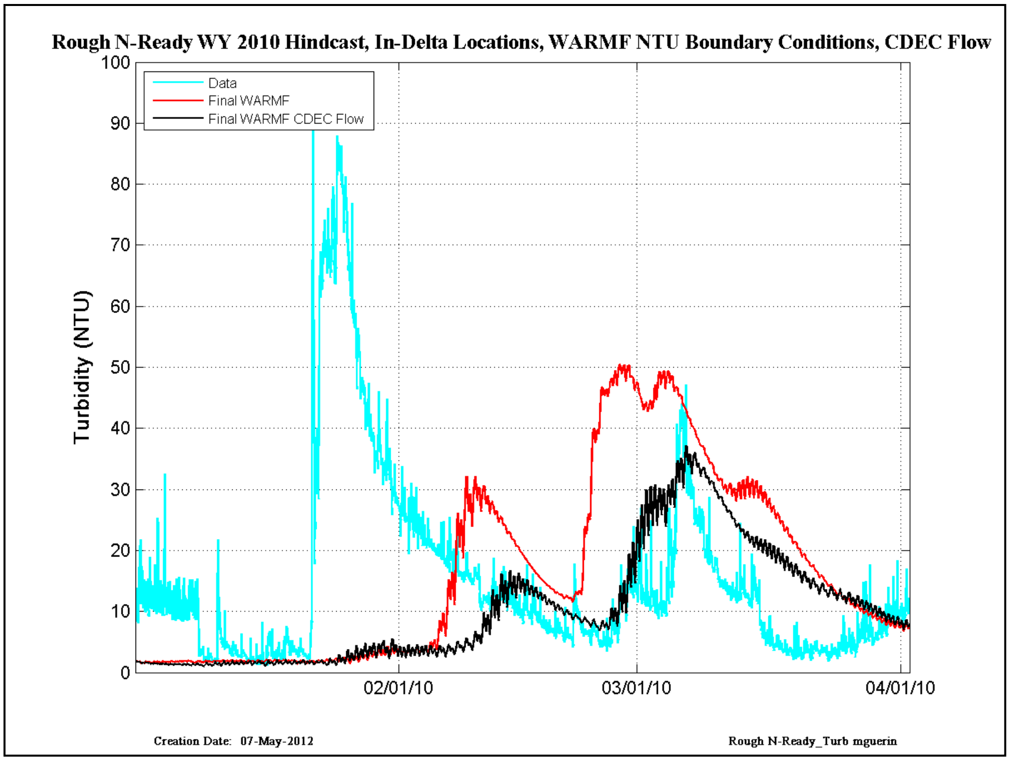


**Figure 45 CDEC data (cyan) compared with RMA simulations run with Final WARMF (red) and Final WARMF and CDEC flows (black) – results are shown at Rough N'Ready on the San Joaquin River in WY2010.**

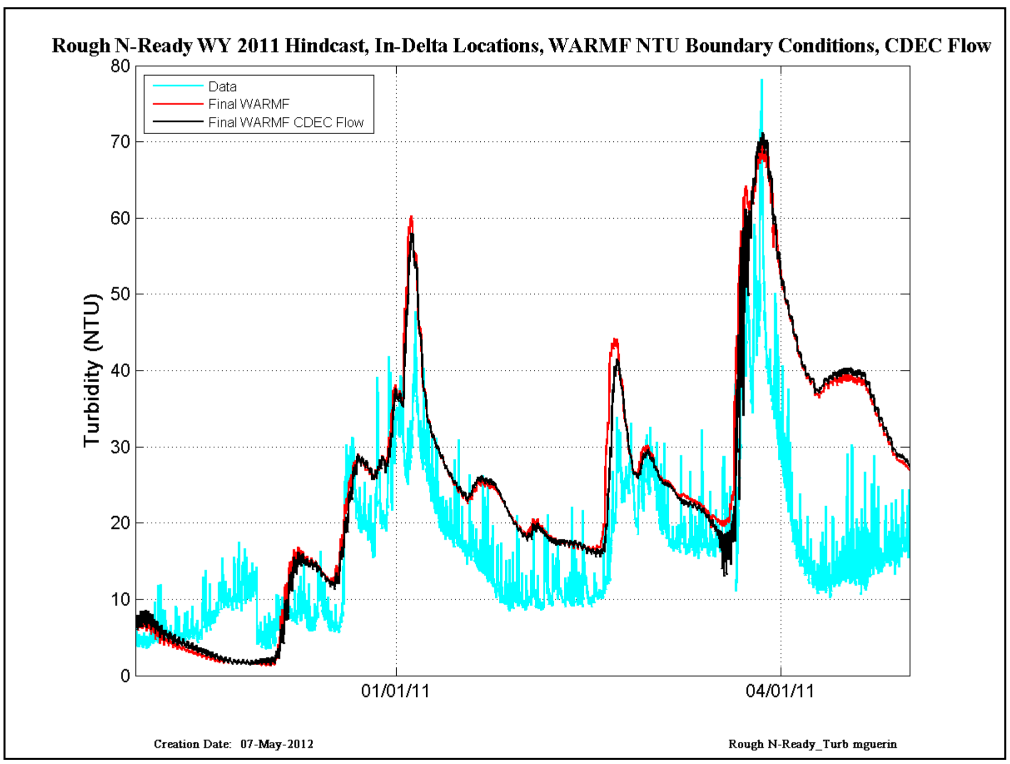


**Figure 46 CDEC data (cyan) compared with RMA simulations run with Final WARMF (red) and Final WARMF and CDEC flows (black) – results are shown at Rough N'Ready on the San Joaquin River in WY2011.**

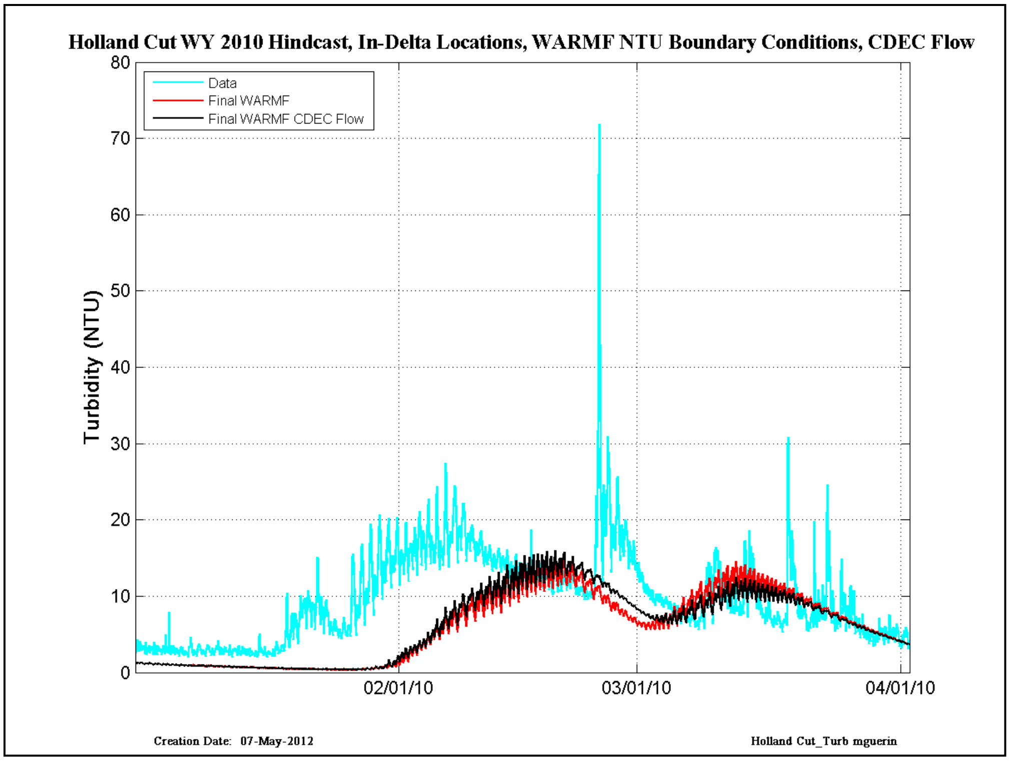


Figure 47 CDEC data (cyan) compared with RMA simulations run with Final WARMF (red) and Final WARMF and CDEC flows (black) – results are shown in Holland Cut in WY2010.

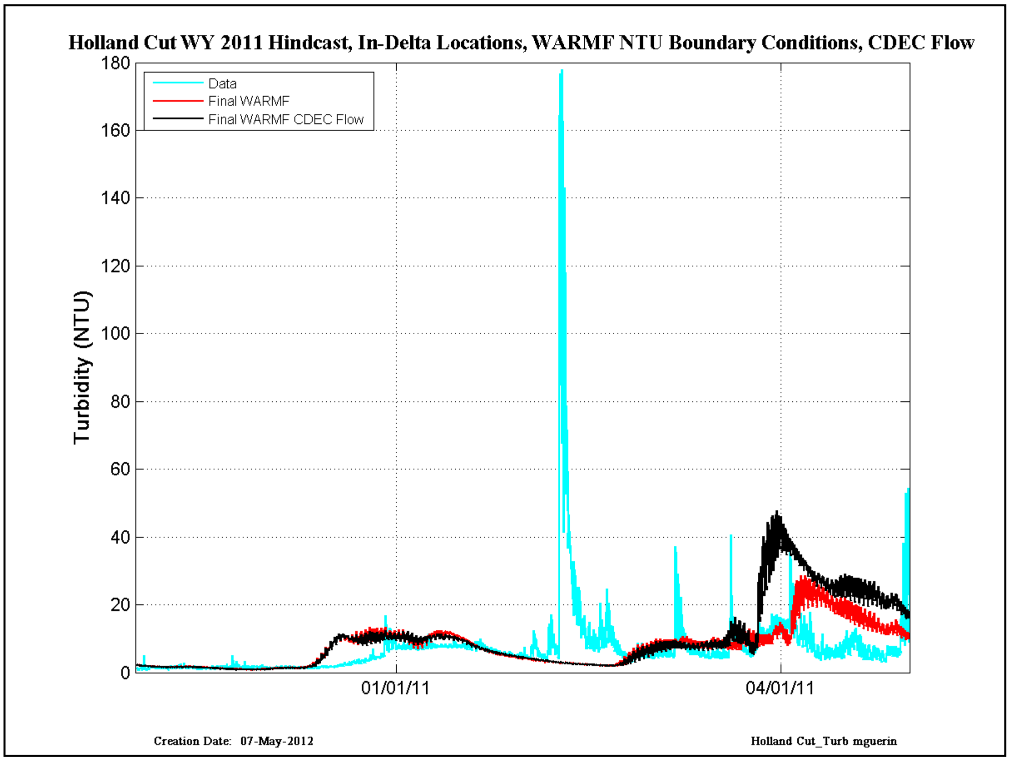


Figure 48 CDEC data (cyan) compared with RMA simulations run with Final WARMF (red) and Final WARMF and CDEC flows (black) – results are shown in Holland Cut in WY2011.

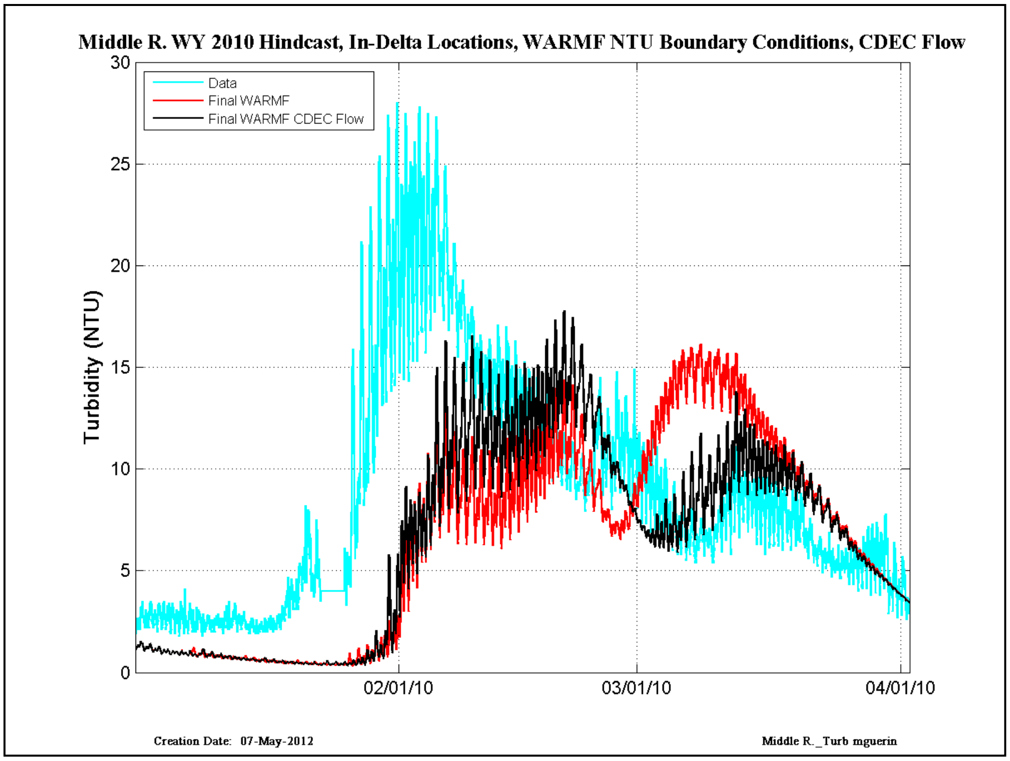


Figure 49 CDEC data (cyan) compared with RMA simulations run with Final WARMF (red) and Final WARMF and CDEC flows (black) – results are shown in Middle River in WY2010.

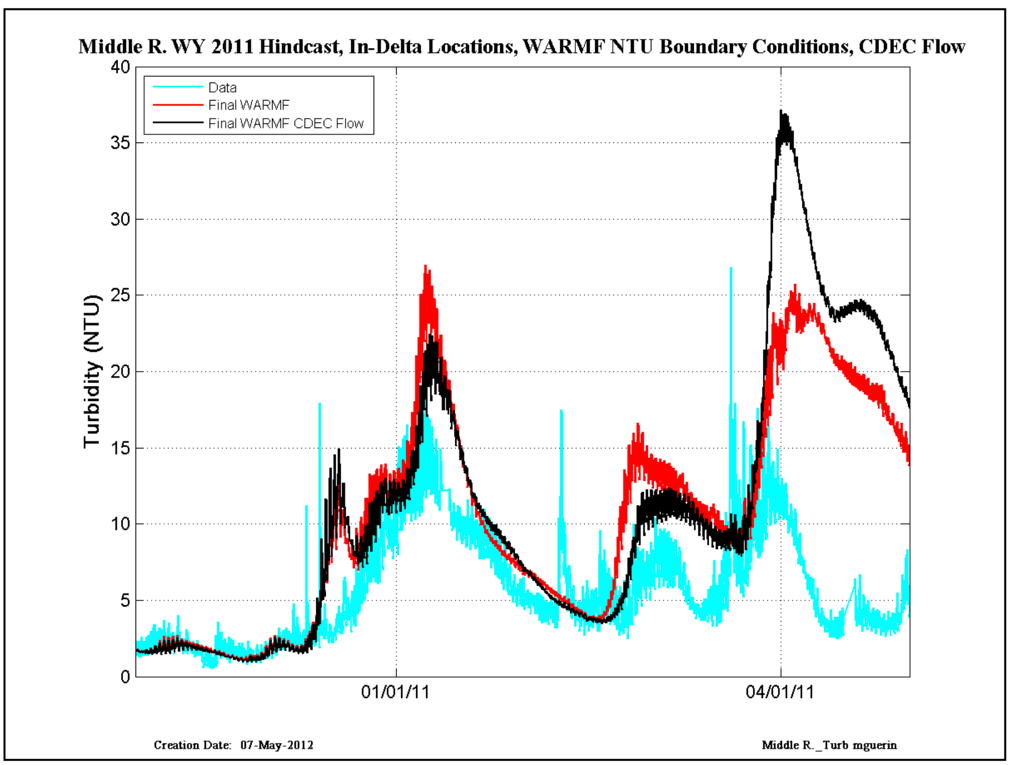


Figure 50 CDEC data (cyan) compared with RMA simulations run with Final WARMF (red) and Final WARMF and CDEC flows (black) – results are shown in Middle River in WY2011.

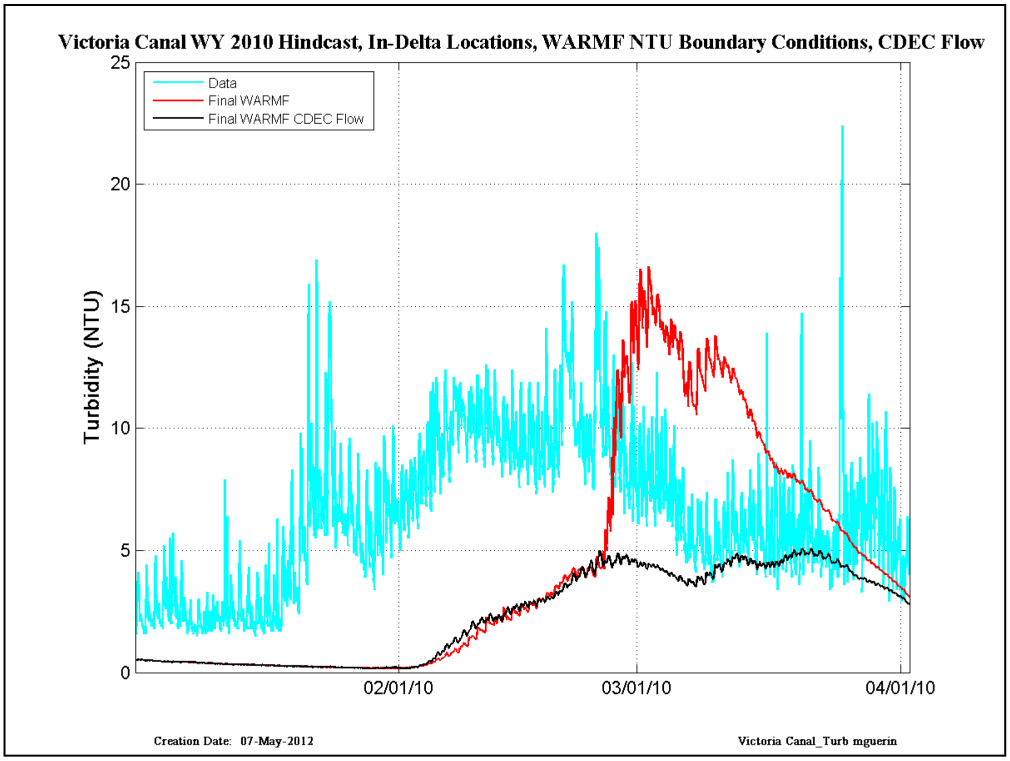


**Figure 51 CDEC data (cyan) compared with RMA simulations run with Final WARMF (red) and Final WARMF and CDEC flows (black) – results are shown in Victoria Canal in WY2010.**

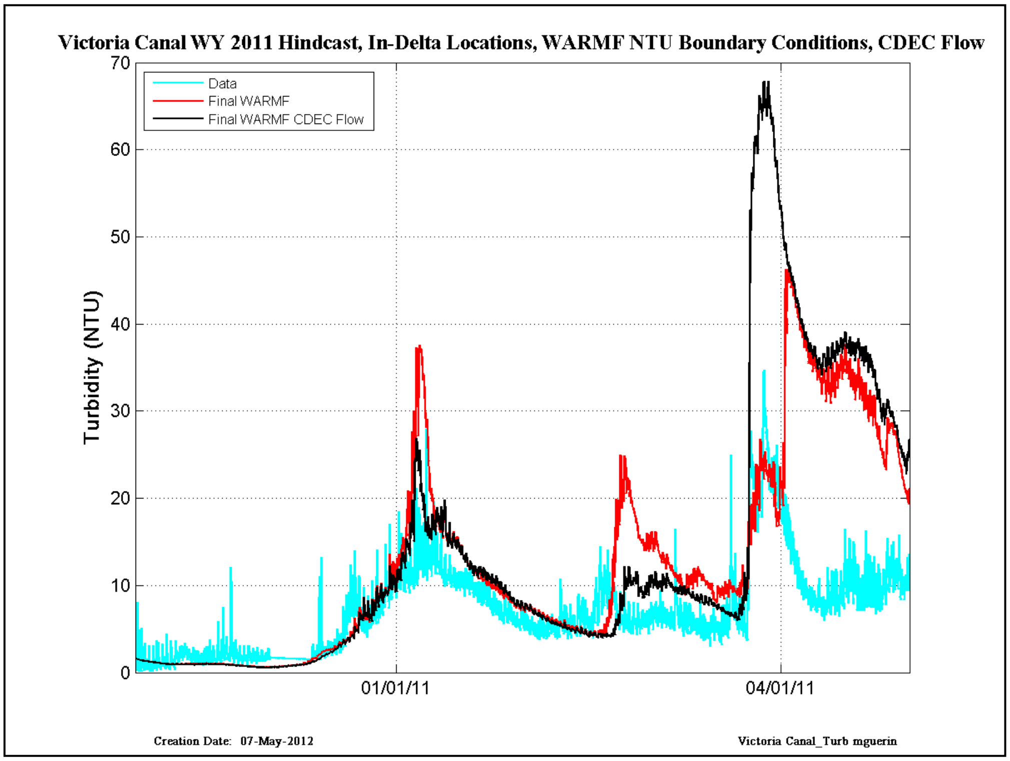


**Figure 52 CDEC data (cyan) compared with RMA simulations run with Final WARMF (red) and Final WARMF and CDEC flows (black) – results are shown in Victoria Canal in WY2011.**

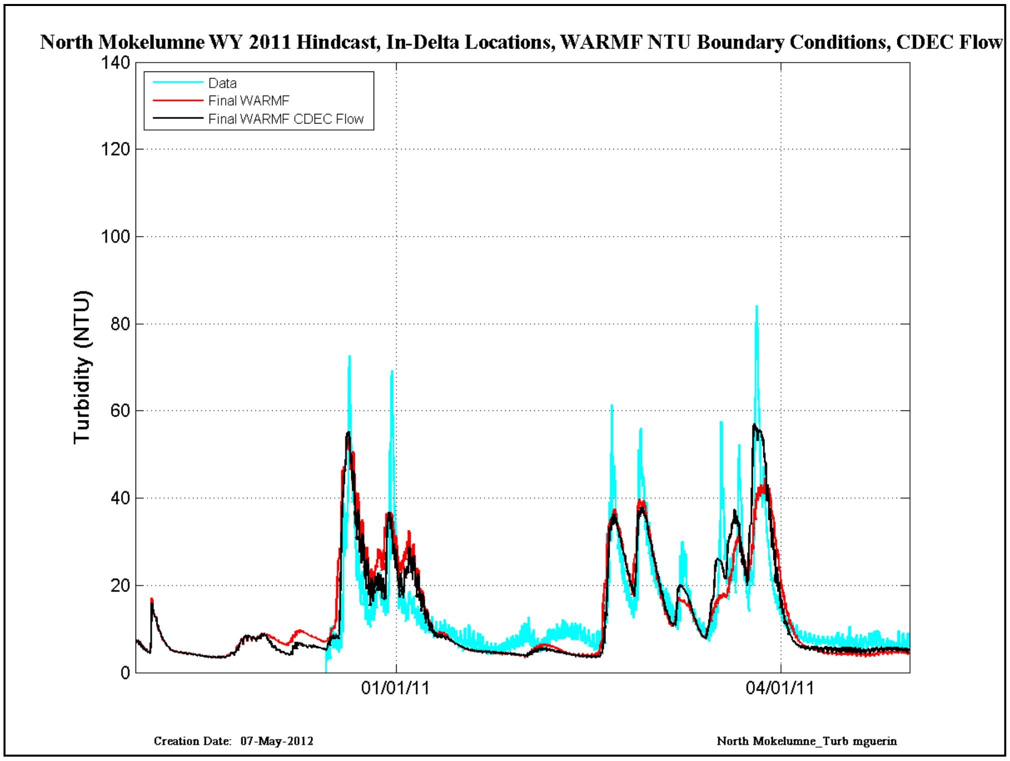


Figure 53 CDEC data (cyan) compared with RMA simulations run with Final WARMF (red) and Final WARMF and CDEC flows (black) – results are shown at the North Mokelumne in WY2011.

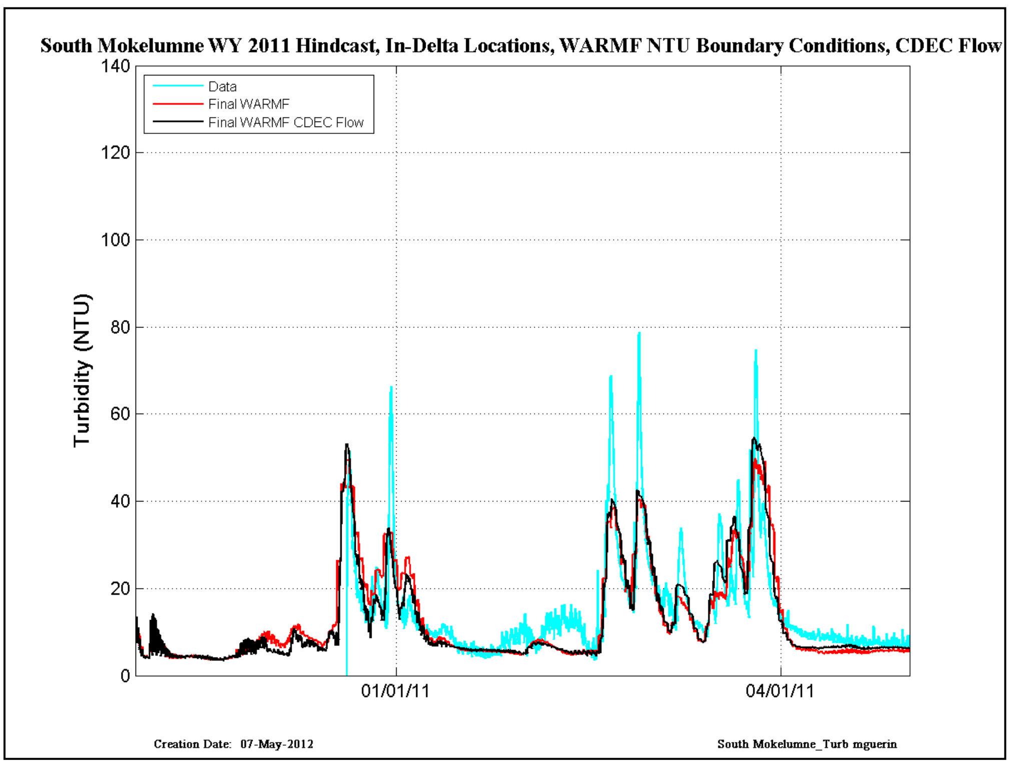


Figure 54 CDEC data (cyan) compared with RMA simulations run with Final WARMF (red) and Final WARMF and CDEC flows (black) – results are shown at the South Mokelumne in WY2011.

# 6 Summary

WARMF simulation results estimating turbidity from suspended sediment have improved substantially with the collaboration documented in this report, although with some provisos. WARMF calibration for WY2011 results at Freeport and Vernalis are much better than WY2010 results at those locations. At the tributaries –Yolo Bypass and Calaveras, Mokelumne and Cosumnes Rivers – WARMF results were improved overall. WARMF flow calculations also contribute error in RMA modeled turbidity, but the major contributions to model error (separate from errors in RMA turbidity model calibration) are from WARMF turbidity estimates at the Freeport and Vernalis locations. The consequence of this observation is that when developing model forecasts, WARMF flow boundary conditions can be used if desired instead of forecast flow data from CNRFC (California Nevada River Forecast Center) for the initial few days of the simulation, with the understanding that additional error will generally be introduced. It should be noted that that forecast flow data is also subject to miscalculation, and is of short duration (5 days) while WARMF forecast flows cover a longer time span. In a three week forecast simulation, the WARMF flows provide a source of forecast flow data beyond the available CNRFC forecast period.

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# 8 Appendix

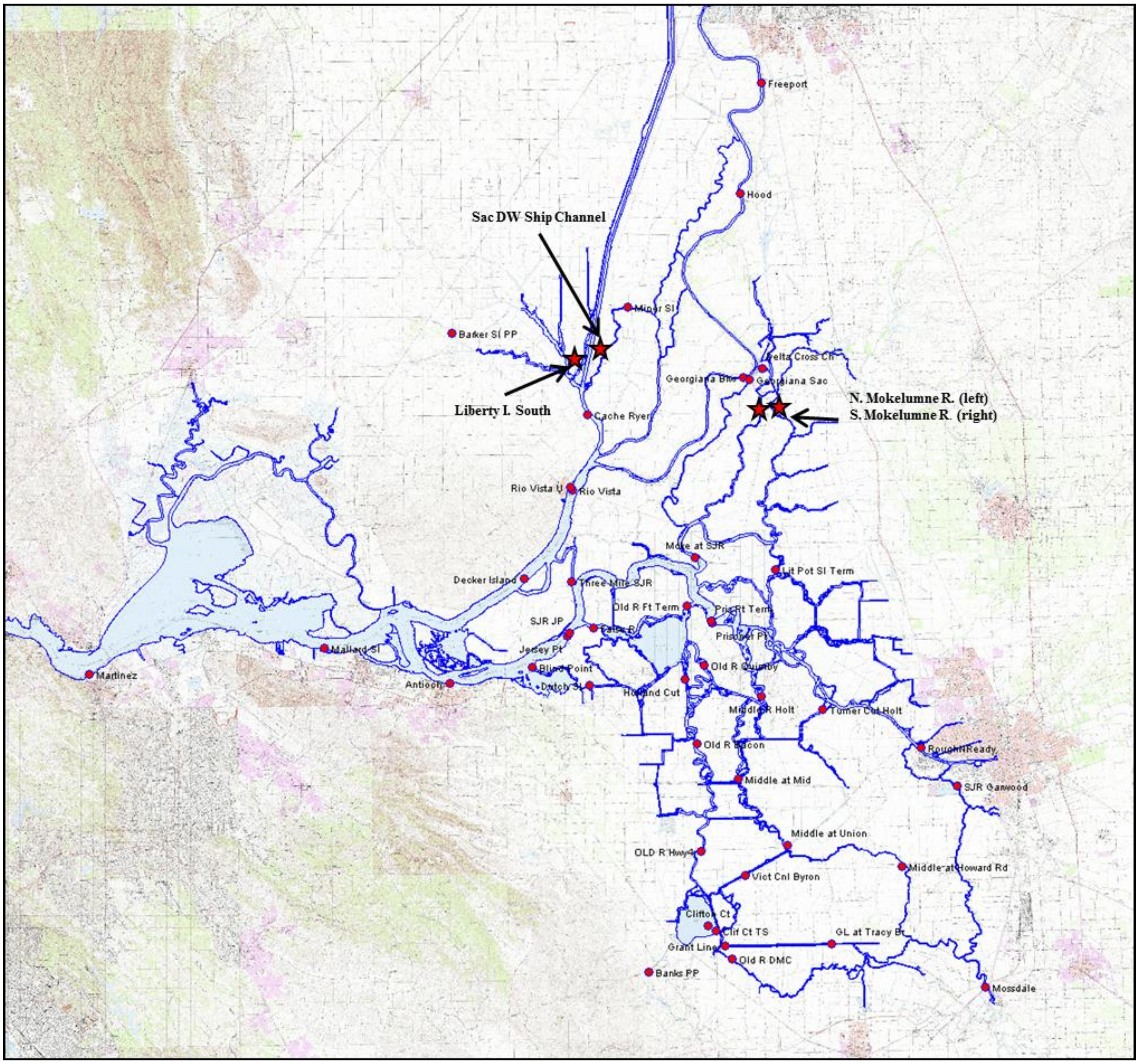


**Figure 55 Locations of WY2011 turbidity monitoring stations - new locations in WY2011are indicated by stars, while WY2010 monitoring station locations are indicated by circles.**