Addition of Turbidity to CALSIM Delta Boundary Conditions

A Technical Memorandum
For
Metropolitan Water District of Southern California

Prepared by

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TABLE OF CONTENTS

List of Figures

List of Tables

Background

The Sacramento-San Joaquin River Delta is a major water source for the Metropolitan Water District. The California Aqueduct delivers water from the Delta to Metropolitan's customers in Southern California. The Delta's multiple environmental constraints are an important consideration in operation of the Banks Pumping Plant at the origin of the California Aqueduct in the south Delta. The plant must be operated to minimize the incidental take of endangered salmon and Delta Smelt. The smelt are associated with high turbidity water, curtailing water exports when such water is present at the pumping plant.

Operational planning for the Banks Pumping Plant can be informed by simulation of historical conditions. To do this, a Delta model is being linked to CALSIM. CALSIM provides a time series of flow for water years 1922-2003 where the Sacramento River, San Joaquin River, and other tributaries enter the Delta. The CALSIM simulation uses historical hydrologic conditions but modern land use, water infrastructure, and operations. The Delta model also requires inputs of turbidity consistent with the flow inputs provided by CALSIM. To accomplish this goal, the WARMF model will be used to generate turbidity entering the Delta which is consistent with the CALSIM flow simulation.

WARMF Modeling

The Sacramento (Figure 1) and San Joaquin River (Figure 2) applications of the Watershed Analysis Risk Management Framework (WARMF) are used to dynamically simulate flow and water quality within their respective watersheds on a daily or hourly time step. The Sacramento River application of WARMF includes tributaries on the east side of the Delta including the Cosumnes River, Dry Creek, Mokelumne River, Calaveras River, and French Camp Slough. The model has been calibrated for flow and water quality parameters including turbidity (Systech 2011a, Systech 2011b). The San Joaquin River WARMF application is set up to simulate the watershed from Friant Dam to the Old River and has also been calibrated for flow, turbidity, and other water quality parameters (Systech 2011c). Turbidity is calculated in WARMF by simulating sediment transport and then applying a linear correlation to translate from suspended sediment concentration to turbidity.

In the process of simulating the watersheds, the WARMF models determine the sources and fates of pollutants. Many chemical and physical parameters are simulated in both models including temperature, nitrogen species, phosphorus, major ions, organic carbon, dissolved oxygen, suspended sediment, turbidity, phytoplankton, and electrical conductivity. The models have been used for a variety of purposes including phytoplankton study and management, organic carbon and salinity source identification, tracking nitrate and salinity, and simulation of turbidity.

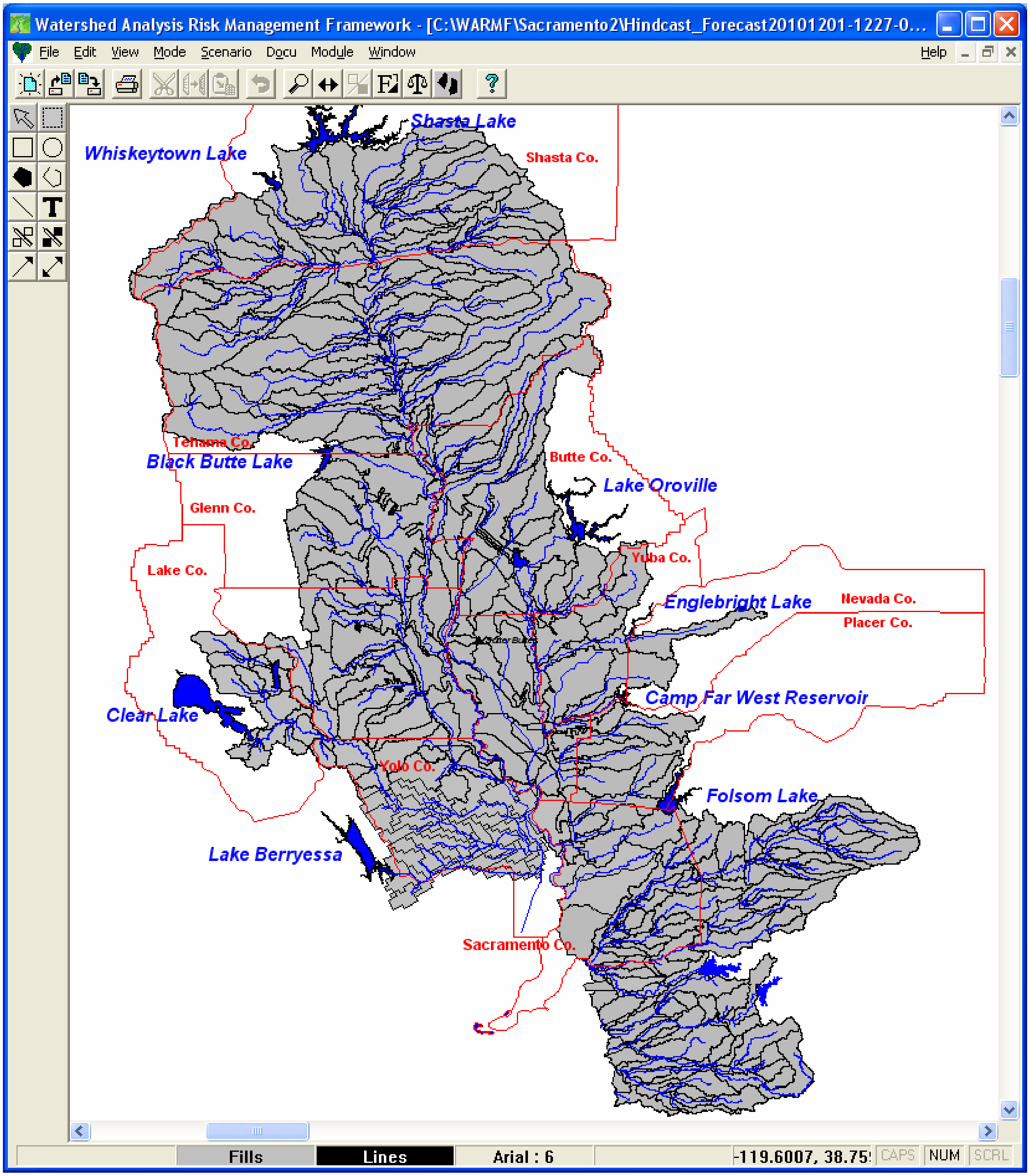

Figure 1: Sacramento River WARMF Application

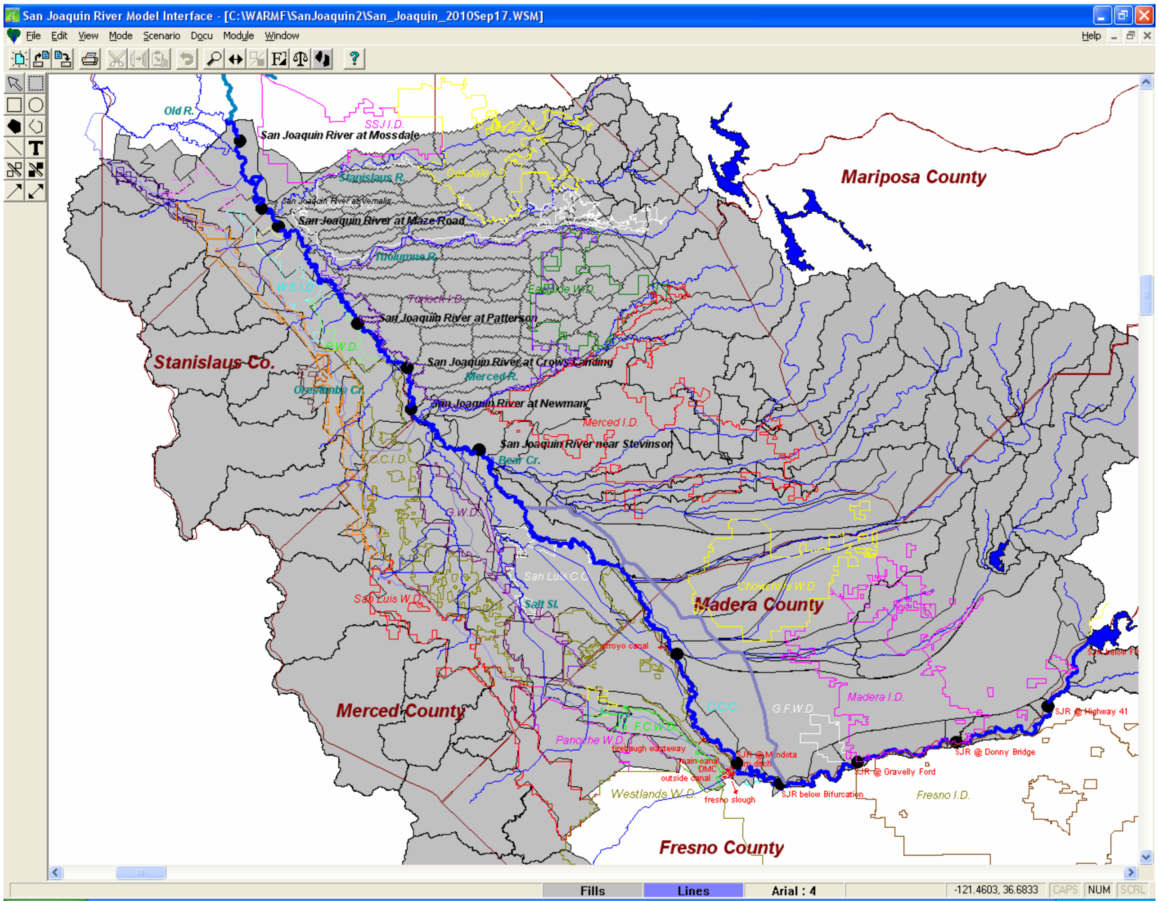

Figure 2 San Joaquin River WARMF Application

CALSIM Linkage

WARMF simulations are driven by time series inputs of meteorology, air/rain chemistry, point sources, boundary inflows, reservoir releases, and diversions. By default, these are based on historical data. The Sacramento and San Joaquin River WARMF applications have time series input data from 10/1/1921 through 9/30/2011. Alternate time series inputs can be used to drive simulations representing different conditions than the historical. WARMF has been set up to link to CALSIM for these time series inputs. CALSIM's network consists of flow pathways which meet at nodes. Simulations produce a monthly time series output of flow for each of the flow pathways. The CALSIM network has been compared against WARMF time series inputs to determine which both models have in common. Table 1 and Table 2 show those linkages for the Sacramento and San Joaquin River watersheds.

Table 1 Linkages Between CALSIM Outputs and WARMF Inputs: Sacramento River

CALSIM Pathway	WARMF File Type	Location Description
C3	Boundary Inflow	Clear Creek below Whiskeytown Reservoir
C5	Boundary Inflow	Sacramento River below Keswick Reservoir
C7	Boundary Inflow	Thermalito Afterbay discharge to Feather River
C9	Boundary Inflow	American River below Folsom Lake
C37	Boundary Inflow	Yuba River below Lake Englebright
C42	Boundary Inflow	Stony Creek below Black Butte Reservoir
C91	Boundary Inflow	Mokelumne River below Camanche Reservoir
C92	Boundary Inflow	Calaveras River below New Hogan Reservoir
C200A	Boundary Inflow	Feather River below Lake Oroville
C285	Boundary Inflow	Bear River below Camp Far West Reservoir
D104	Diversion	Cottonwood ID
D114	Diversion	Glenn-Colusa ID
D122B	Diversion	Provident ID 2
D124	Diversion	Moulton Weir
D125	Diversion	Colusa Weir
D126	Diversion	Tisdale Weir
D128	Diversion	Sutter Mutual WC
D129A	Diversion	Reclamation Dist 108
D160	Diversion	Fremont Weir
D162	Diversion	Natomas Central MWC
D163	Diversion	Conaway
D165	Diversion	City of West Sacramento
D166A	Diversion	Sacramento Weir
D172	Diversion	Kirkwood WD
D174	Diversion	Orland-Artois WD
D17502	Diversion	Colusa County WD
D180	Diversion	Provident ID 3
D182A	Diversion	Princeton-Codora ID 2
D182B	Diversion	Maxwell ID (008267)
D183	Diversion	Davis Ranches 1
D18302	Diversion	Davis Ranches 2
D285	Diversion	Camp Far West ID

Table 2 Linkages Between CALSIM Outputs and WARMF Inputs: San Joaquin River

CALSIM Pathway	WARMF File Type	Location Description
C18	Boundary Inflow	San Joaquin River below Friant Dam
C52	Reservoir Release	Fresno River below Hensley Lake
C528	Boundary Inflow	Stanislaus River at Ripon
C545	Boundary Inflow	Tuolumne River at Modesto
C566	Boundary Inflow	Merced River at Stevinson
C605B	Diversion	Eastside Bypass
D418	Boundary Inflow*	Delta-Mendota Canal at head
D540A	Boundary Inflow*	Modesto Canal
D540B	Boundary Inflow*	Turlock Canal
D630B	Diversion	Patterson WD (San Joaquin River)

* These linkages identified as diversions in CALSIM are boundary inflows to WARMF because the source waters are outside the WARMF model domains.

CALSIM simulations have two iterations: CONV first and then TXFR. The TXFR output should be used preferentially, and then CONV output should be used for those nodes not included in the TXFR simulation. Some of CALSIM's nodes may optionally be excluded from both simulations. The original WARMF time series inputs are used at nodes for which no CALSIM output is available.

WARMF Input Modifications

The WARMF models by default simulate historical conditions. They have been set up to simulate from 10/1/1921 through the present using historical meteorology, flow release, diversion, and point source data. The CALSIM simulation to which it was linked is the State Water Project Delivery Reliability Studies 2011, Current Conditions (2011) simulation. This simulation combines historical meteorology with modern infrastructure and operation. The WARMF simulation differs in that it uses historical infrastructure and operation. Much of the difference, such as boundary inflows and key diversions, is removed when CALSIM output is imported into WARMF. Many more diversions simulated in WARMF are too small to be resolved in the CALSIM network and are left out of the linkage between the two models. An analysis step was taken to determine if the WARMF time series inputs not modified by CALSIM outputs were consistent with the parameters of the CALSIM simulation over the 1922-2003 water year simulation period.

It is common for the historical record to contain inter-annual variability in diversion flow rates in response to hydrologic conditions. This variability is consistent with the CALSIM simulation and was left in the WARMF time series inputs. Some diversions, however, either began or ceased operations during the 1922-2003 period as seen in the historical flow records. Some point sources inputs to WARMF were extrapolated backward based on historical population growth to estimate historical discharge. These time series inputs were modified to be based on the 2002-2011 water years. Data from before 2002 was deleted from the files. The files were then extrapolated to put average values of 2002-2011 for each day of the year in the files for the years 1921-2001.

SIMULATED FLOW USING CALSIM LINKAGE

Both the Sacramento and San Joaquin River WARMF models have been set up and calibrated using historical data. When provided with CALSIM inputs instead of historical inputs, WARMF simulates the watershed processes to predict flow and water quality entering the Delta. Although WARMF and CALSIM use different means of simulating watershed inflows and outflows, they should produce similar simulated flow entering the Delta. Comparing the flow simulations between CALSIM and WARMF using CALSIM inputs provides a check on the linkage.

Figure 3 through Figure 8 show a comparison of simulated flow between WARMF and CALSIM at the inflows to the Delta. Table 3 shows a statistical comparison between the flow outputs of the two models. The Sacramento (Figure 3) and San Joaquin Rivers (Figure 8) show the closest match in flow, with WARMF simulations 6% and 3% less than CALSIM flows and r-squared greater than 0.9. Flow simulated by WARMF averaged 23% higher than the flow simulated by CALSIM for the Yolo Bypass (Figure 4) although the correlation between the two models was very high. WARMF simulated 2% less flow combined in the Sacramento River and Yolo Bypass than did CALSIM. The Cosumnes River (Figure 5) is an unregulated tributary for which WARMF simulated higher peak flows and on average 27% greater flow than CALSIM. CALSIM predicted zero flow for 70% of months where the Calaveras River (Figure 7) enters the Delta, but WARMF predicted some continuous flow and higher peak flows resulting in 59% higher simulated flow on average in WARMF. CALSIM release from Camanche Reservoir to the Mokelumne River (Figure 6) was not available for the simulation used for this analysis. WARMF used historical flow releases by default, resulting in different flow simulations.

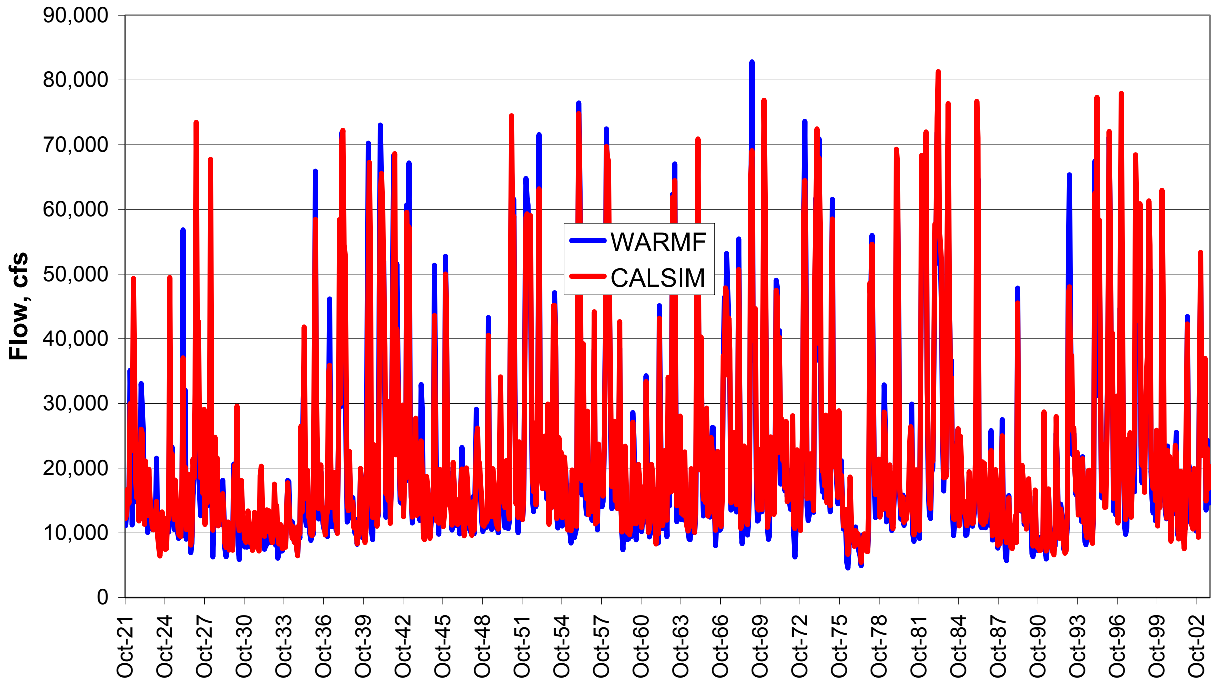

Figure 3 WARMF vs CALSIM Simulations, Flow of Sacramento River at Freeport

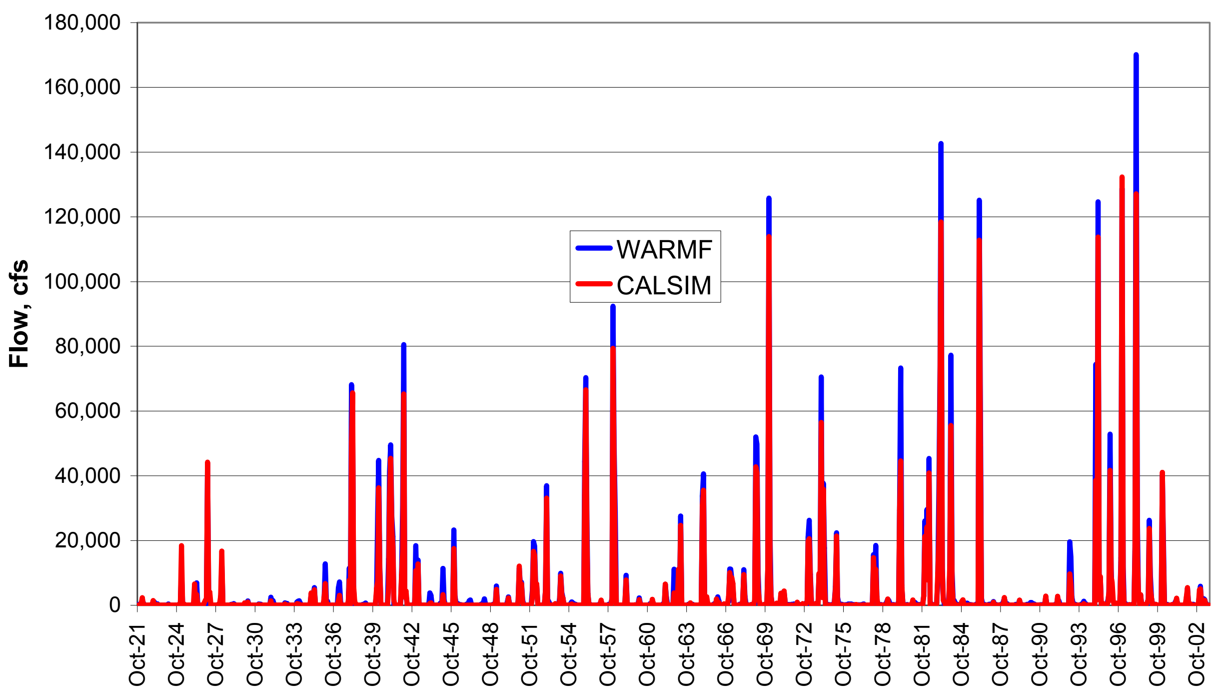

Figure 4 WARMF vs CALSIM Simulations, Flow of Yolo Bypass at Lisbon

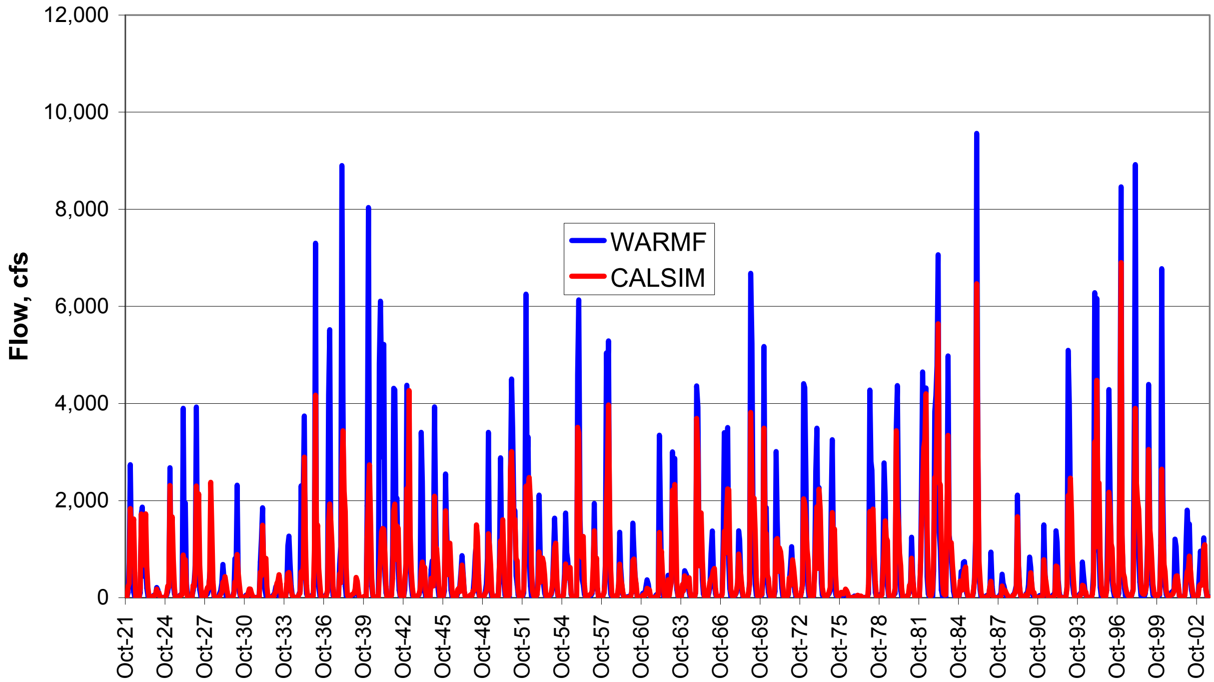

Figure 5 WARMF vs CALSIM Simulations, Flow of Cosumnes River at Mokelume River

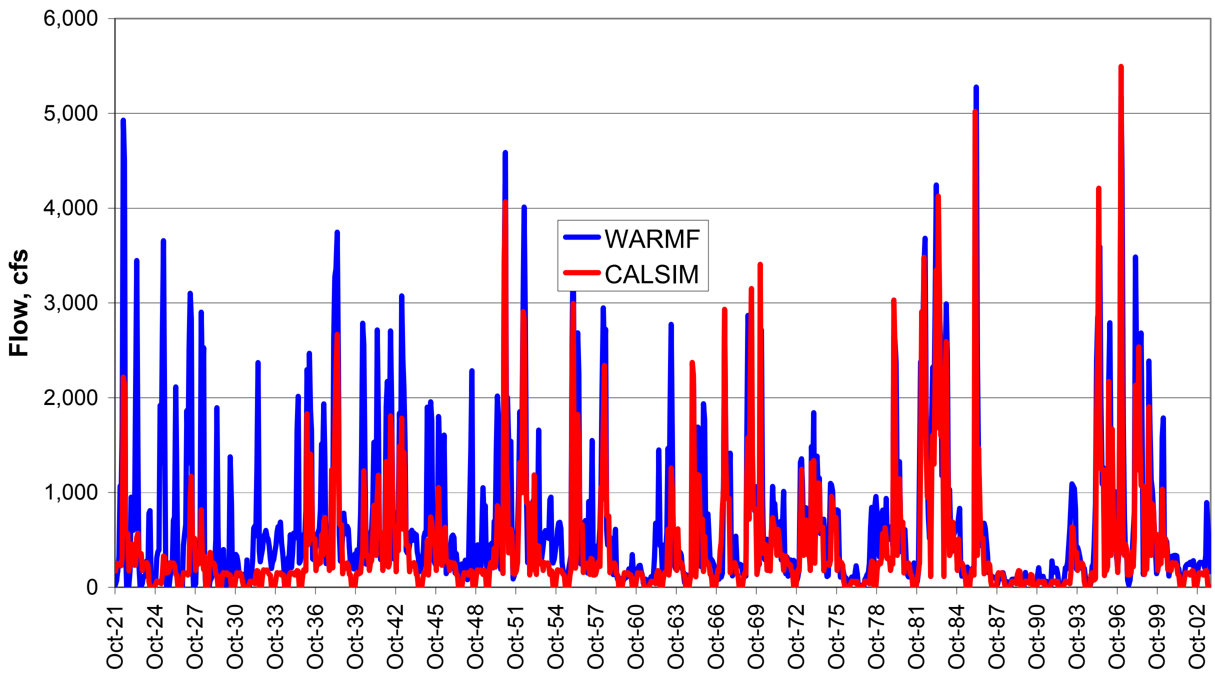

Figure 6 WARMF vs CALSIM Simulations, Flow of Mokelumne River at Cosumnes River

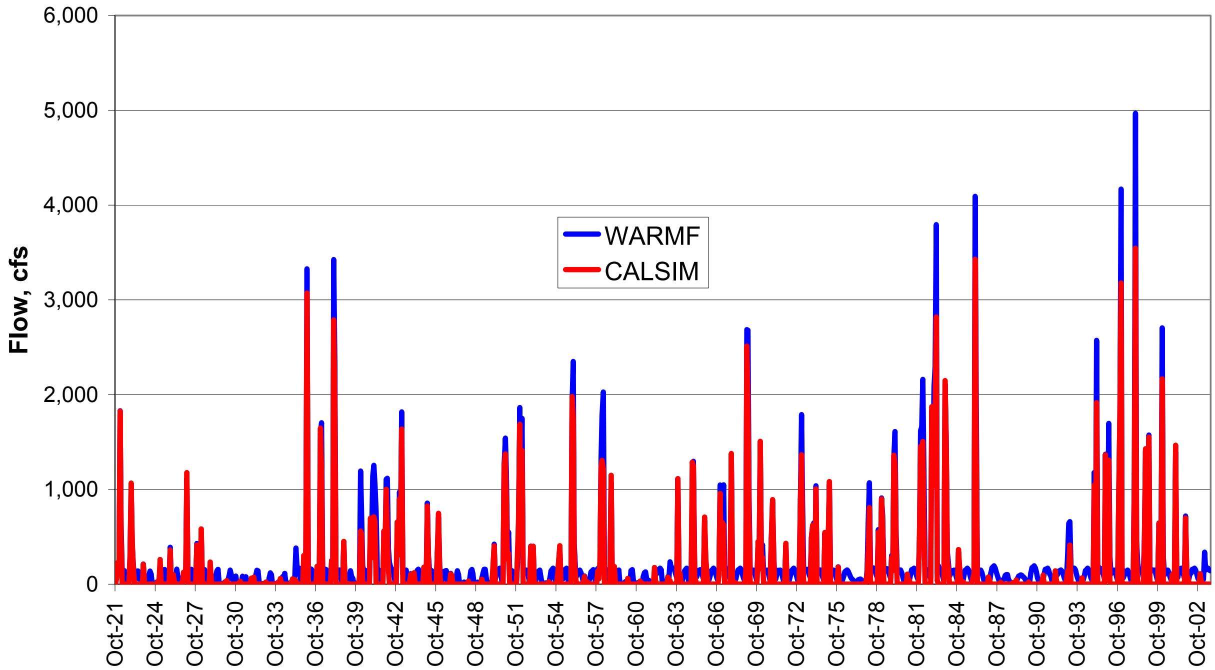

Figure 7 WARMF vs CALSIM Simulations, Flow of Calaveras River at Stockton

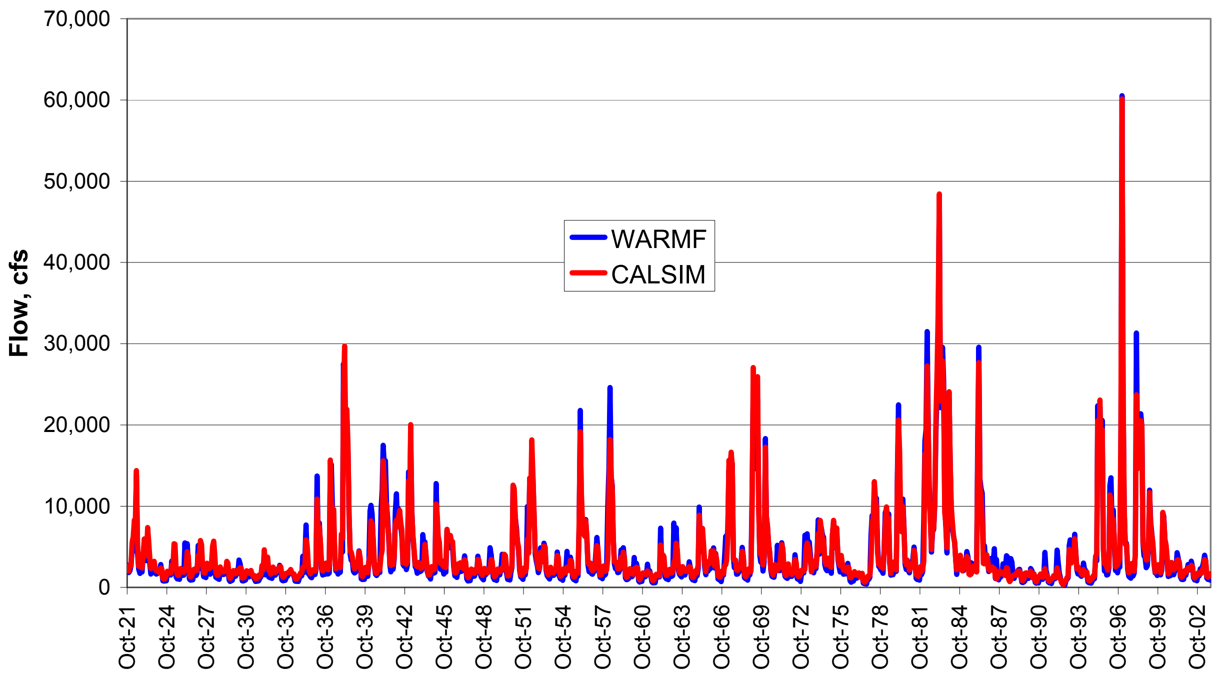

Figure 8 WARMF vs CALSIM Simulations, Flow of San Joaquin River at Vernalis

Table 3 Statistical Comparison of Simulated Flows, CALSIM and WARMF using CALSIM Output

River at Delta Inflow	Average CALSIM flow, cfs	Average WARMF flow, cfs	Flow Difference	WARMF vs CALSIM r-squared
Sacramento River	21,813	20,592	-6%	0.91
Yolo Bypass	3,122	3,850	+23%	0.97
Cosumnes River	502	639	+27%	0.73
Mokelumne River	422	693	+64%	0.61
Calaveras River	146	231	+59%	0.95
San Joaquin River	4,237	4,120	-3%	0.96

SIMULATED TURBIDITY WITH CALSIM LINKAGE

Turbidity in the Central Valley watersheds comes from three sources: boundary inflows from the reservoirs around the valley, runoff from the local watersheds, and scour from river beds. Most of the turbidity comes from sediment originating in the local watersheds; scour is a much smaller but significant source; inflow from reservoirs is least important. Since scour is a function of instantaneous flow, there is some loss of resolution in calculating that portion of turbidity when one is using the monthly flow outputs of CALSIM as WARMF boundary conditions. Since the WARMF simulation is run on a daily time step, however, it can simulate the turbidity caused by storms in the local watershed. Turbidity output from WARMF is produced on a daily basis and can then be aggregated into monthly data for use with CALSIM.

Turbidity simulation has been calibrated in WARMF for all the major rivers entering the Sacramento-San Joaquin River Delta (Systech 2011b). Unlike flow, CALSIM does not have simulated turbidity to compare against WARMF output. Observed data for turbidity is not available for the 1922-2003 water year simulation period. It is also not directly comparable to the WARMF simulated turbidity because of the monthly flow inputs provided by CALSIM and because the simulation is of modern rather than historical water management. Simulated turbidity from WARMF at the Delta inflows is provided here in Figure 9 through Figure 14. For each figure, the line in blue is the daily output of WARMF and magenta is the turbidity aggregated into monthly averages to use with CALSIM.

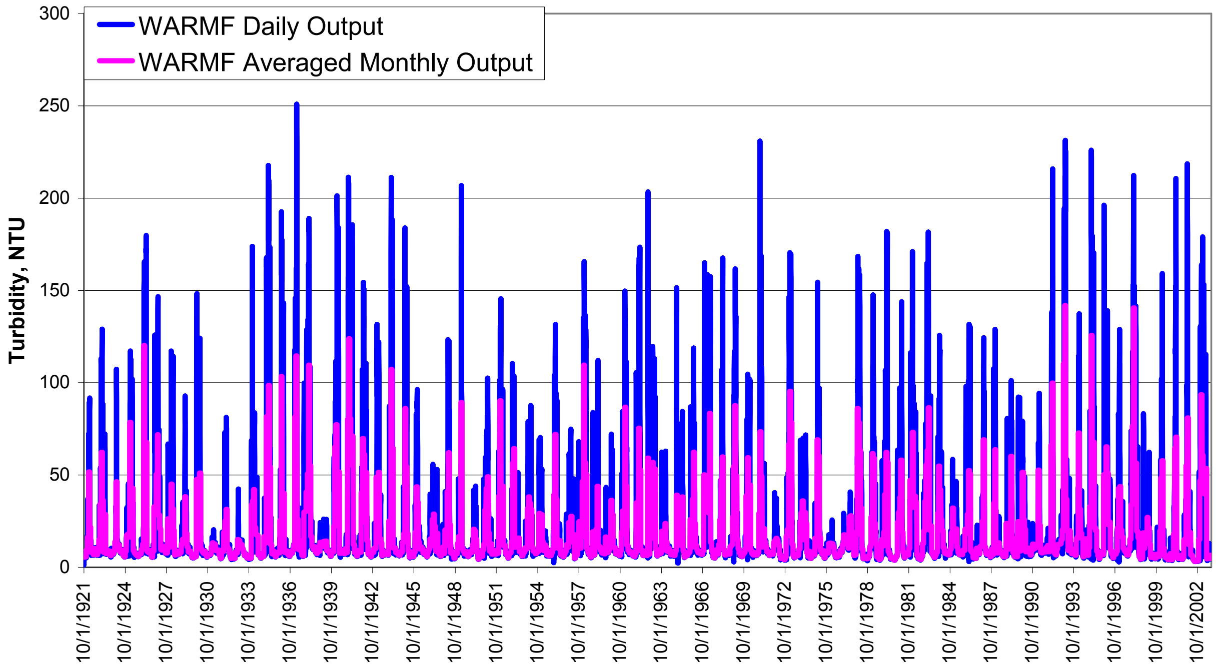

Figure 9 WARMF Simulation of Turbidity, Sacramento River at Freeport

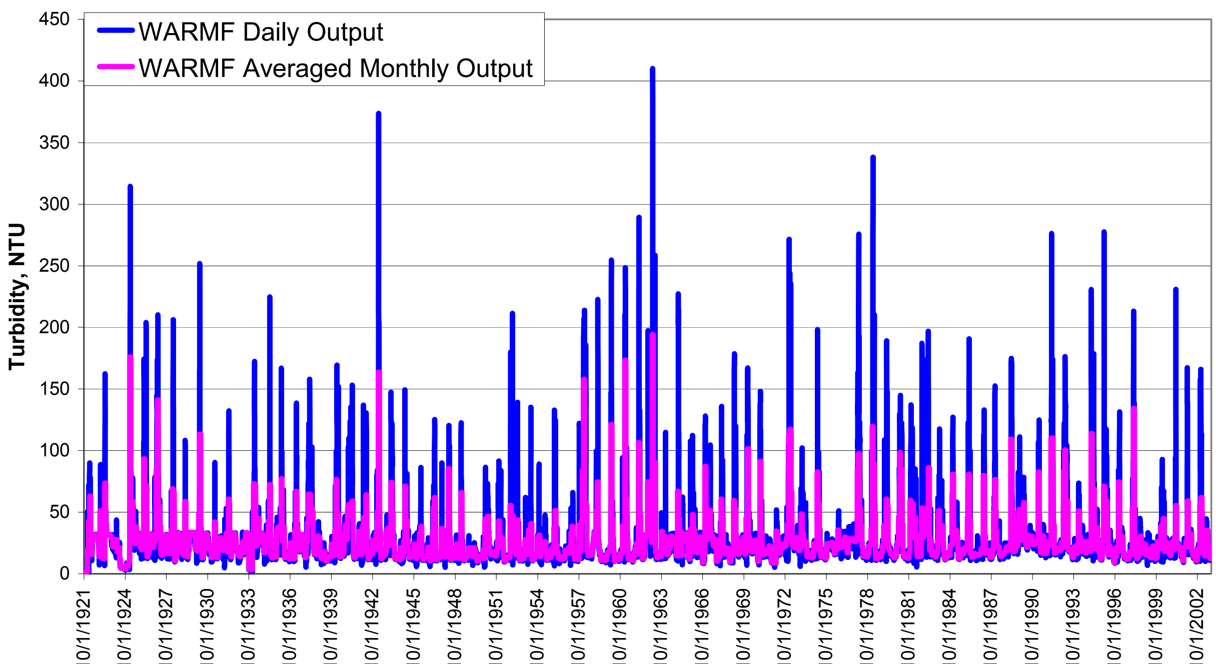

Figure 10 WARMF Simulation of Turbidity, Yolo Bypass at Lisbon

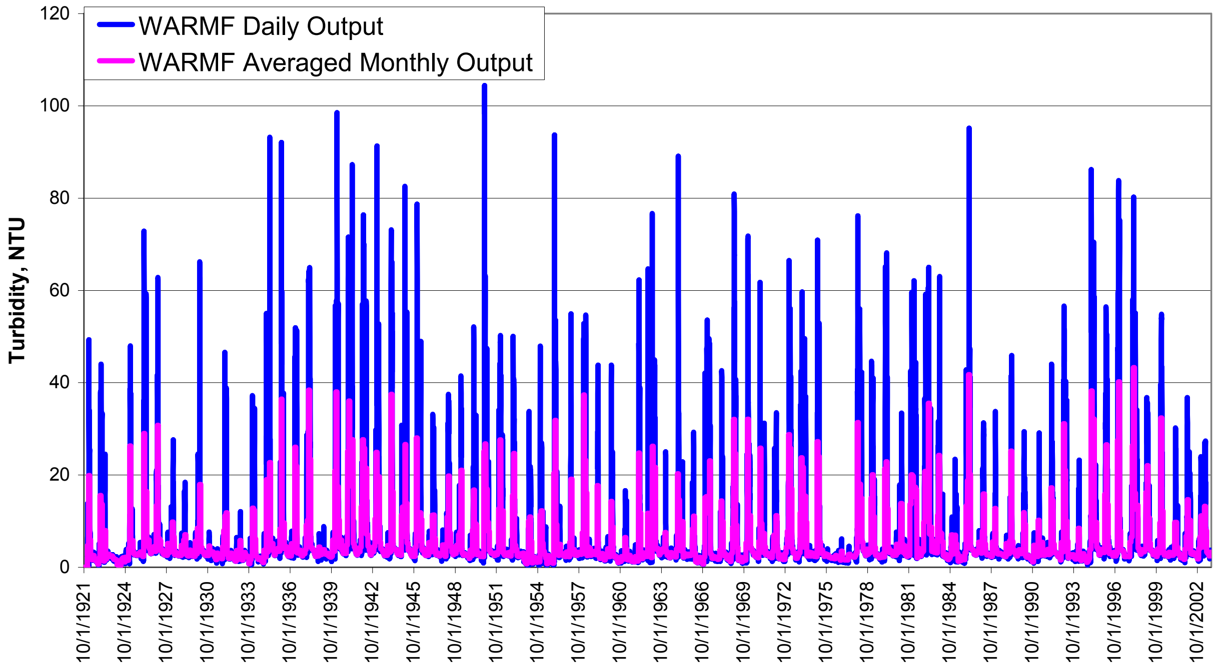

Figure 11 WARMF Simulation of Turbidity, Cosumnes River at Mokelume River

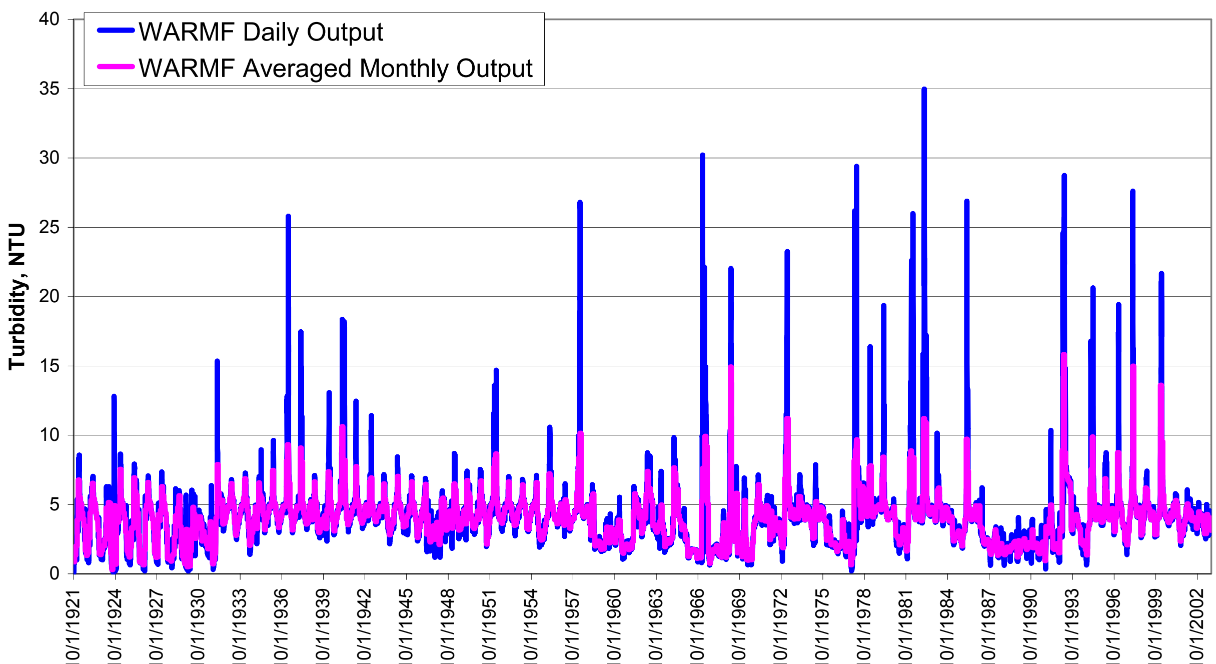

Figure 12 WARMF Simulation of Turbidity, Mokelumne River at Cosumnes River

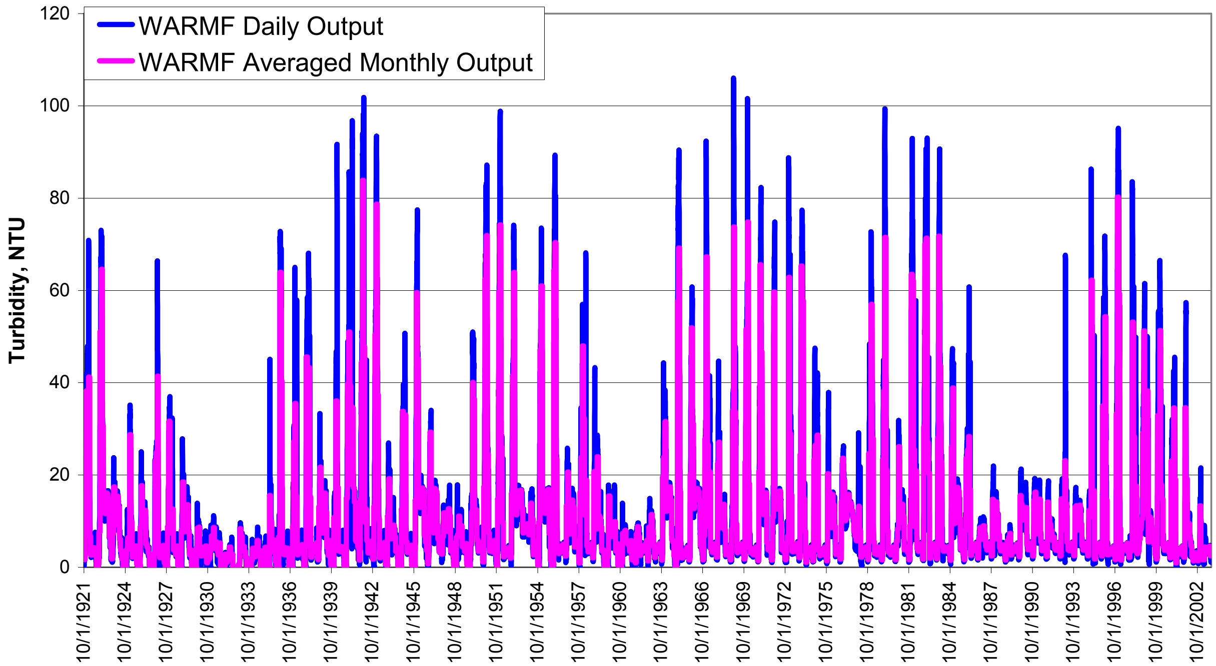

Figure 13 WARMF Simulation of Turbidity, Calaveras River at Stockton

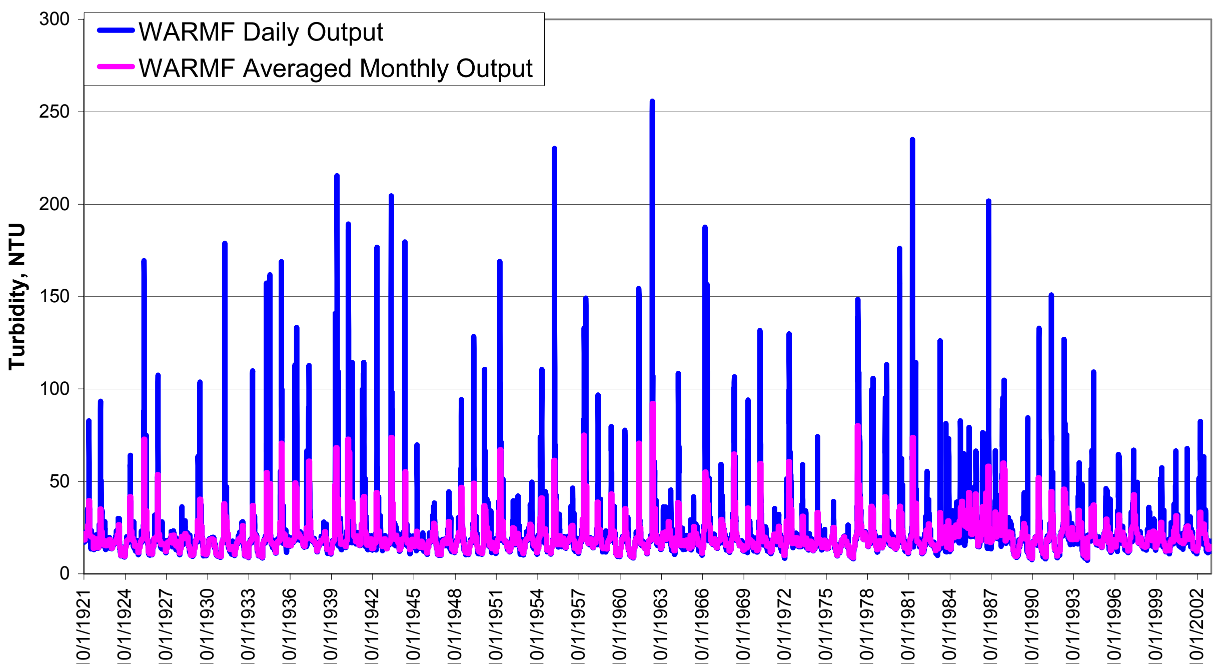

Figure 14 WARMF Simulation of Turbidity, San Joaquin River at Vernalis

Figure 15 and Figure 16 show the frequency distribution of turbidity at each of the Delta inflow locations for the daily simulation and monthly aggregated average respectively. The monthly aggregation affects primarily the top 20 percentile of turbidity events.

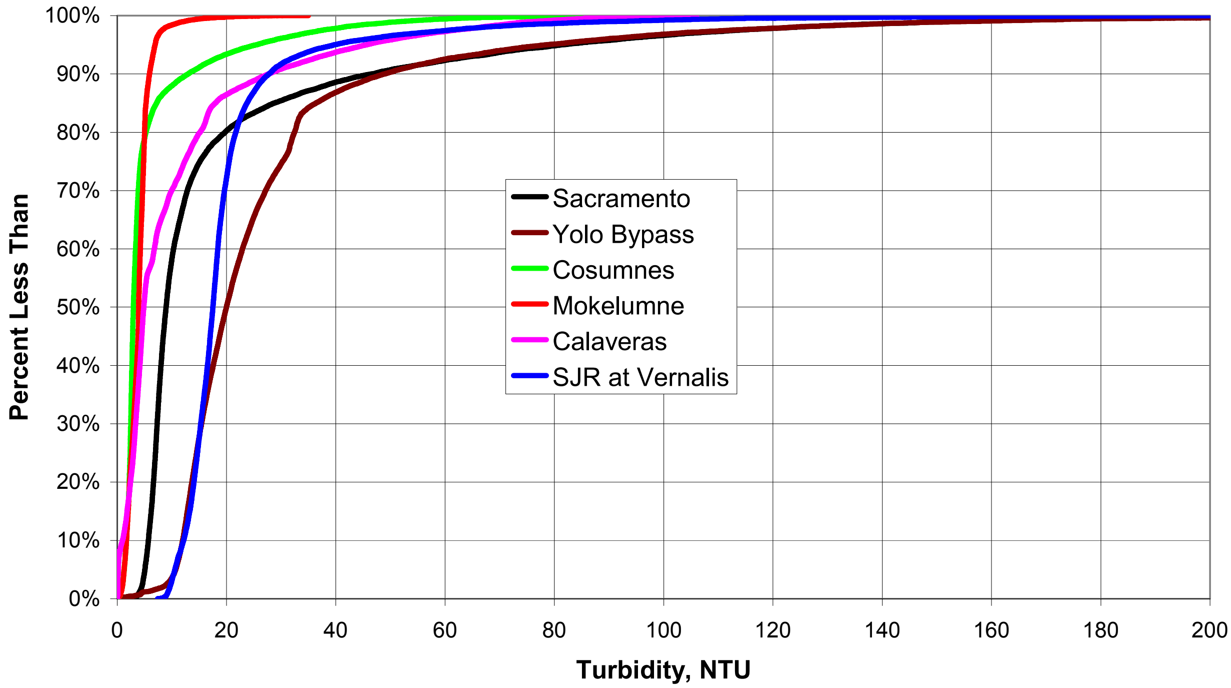

Figure 15 Frequency Distribution of Turbidity, Daily WARMF Output

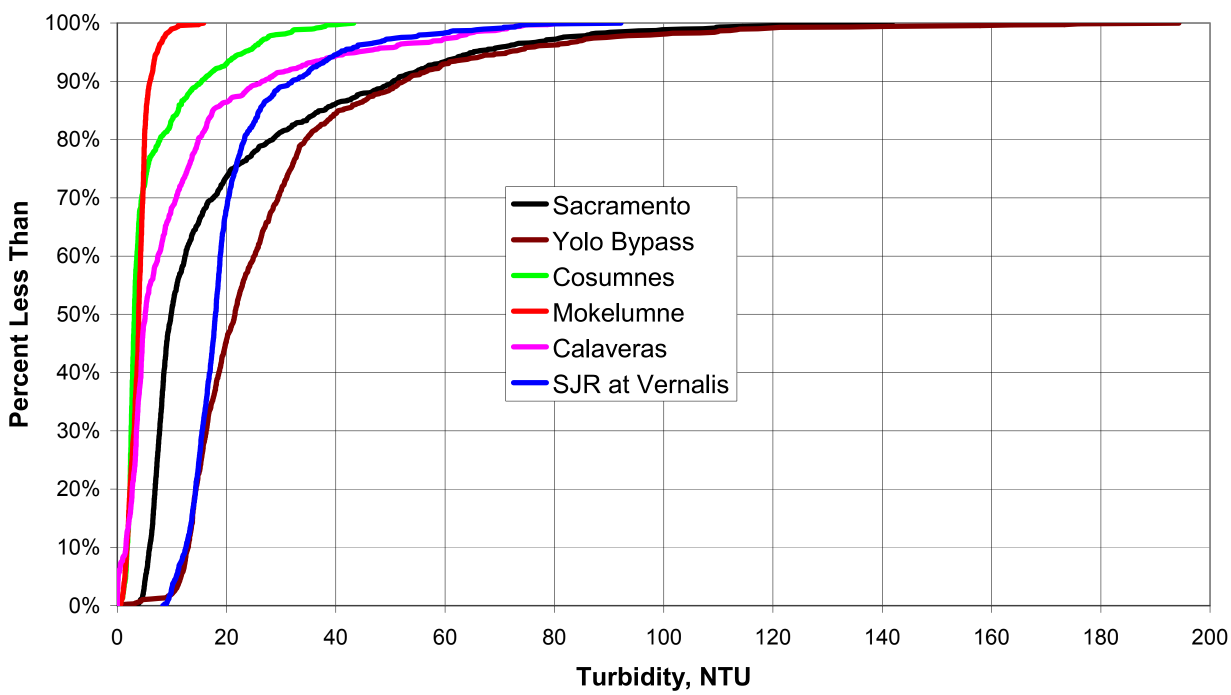

Figure 16 Frequency Distribution of Turbidity, Monthly Aggregated WARMF Output

CONCLUSION AND RECOMMENDATIONS

The previously developed linkage between WARMF and CALSIM was used to generate turbidity at the 6 major Delta tributary inflows for use with the CALSIM flow simulation. WARMF simulated flows were compared against CALSIM flows to determine the agreement. The average monthly flow was 6% different at the Sacramento River at Freeport and 3% different at the San Joaquin River at Vernalis. The greatest difference in flow between WARMF and CALSIM was for the Mokelumne and Calaveras Rivers, where WARMF simulated about 60% more flow entering the Delta than did CALSIM. CALSIM output of flow for the Calaveras River was usually zero, whereas WARMF simulated some flow entering the Delta continuously. The two models' simulations of flow in the Mokelumne River differed because there was no CALSIM simulated release from Camanche Reservoir available for linkage with WARMF.

The use of monthly CALSIM flows at the WARMF boundary inflows is a minor source of error in turbidity linked to river bed sediment scour and settling, but simulation of turbidity produced by local runoff is unaffected by the linkage between CALSIM and WARMF. Although there were large flow differences between WARMF and CALSIM for the Delta east side tributaries, the turbidity simulated by WARMF combined with flow simulated by CALSIM provides a reasonable estimate of what the turbidity load would be entering the Delta under the conditions simulated by CALSIM. Delta modelers should be aware of the potential source of error arising from the flow discrepancy when running their simulations.

REFERENCES

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