WARMF Forecasting, Automation, and Technical Support

A Deliverable
For
Metropolitan Water District of Southern California

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ABSTRACT

The Watershed Analysis Risk Management Framework (WARMF) has been applied to the Sacramento and San Joaquin Rivers of California's Central Valley to provide simulated flow and multiple water quality constituents. To use the model for short-term forecasting, upgrades were made to WARMF to allow for rapid updating of the time series data used to run the model. Processing tools and methodology were developed for the real-time and forecast data sources available in California to collect and process the data. A forecasting procedure was developed which can simulate up to two weeks into the future and can be performed within 4 hours to produce simulated flow and turbidity in near real-time. The forecasting procedure was tested in winter of 2010-2011 to make it as efficient as possible and to test its accuracy. Flow forecasts had 13-18% error compared to measured data for the Sacramento River at Freeport and error was 28-30% for the San Joaquin River at Vernalis. A problem with a boundary inflow in the San Joaquin River combined with an unusually large series of storms introduced a large amount of flow error. Forecast turbidity for the Sacramento River had low model bias but also low precision. Forecasted turbidity in the San Joaquin River was less than observed but improvements made to the model's calibration for total suspended sediment removed most of the model's bias after the forecasts had been performed. Future improvements to the model in its simulation of agricultural areas in both watersheds and elimination of a problematic boundary inflow in the San Joaquin River would likely improve model performance for forecasting as well.

1 INTRODUCTION

Delta Water Quality Constraints

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 relies on forecasts of water quality including turbidity. Modeling of the Delta tracks the transport of pollutants to the pumps from the bay and from the Sacramento, San Joaquin, and other Delta tributary rivers. Since major influxes of turbidity come from the tributary watersheds, it is necessary to forecast the loading from the tributaries to predict the turbidity at the pumping plant. A general purpose forecasting tool including other chemical constituents such as organic carbon would provide additional benefit for managing water supply and meeting unknown future water quality constraints.

WARMF Modeling

The Sacramento (Figure 1.1) and San Joaquin River (Figure 1.2) 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 watershed has been calibrated for flow and water quality parameters including turbidity (Systech 2011a, Systech 2011b). The San Joaquin River watershed is set up to simulate the watershed from Friant Dam to the Old River, but the model is not fully parameterized for the portion of the watershed between Friant Dam and the Lander Avenue gage on the San Joaquin River. Because of this, the watershed model is disconnected upstream of Lander Avenue, where the San Joaquin River is usually dry, so that simulations of the upper part of the watershed do not affect the lower watershed. Measured flow and water quality at Lander Avenue is used as a boundary inflow to the lower San Joaquin River. The San Joaquin River WARMF application has also been calibrated for flow, turbidity, and other water quality parameters (Systech 2011c).

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, and tracking nitrate and salinity.

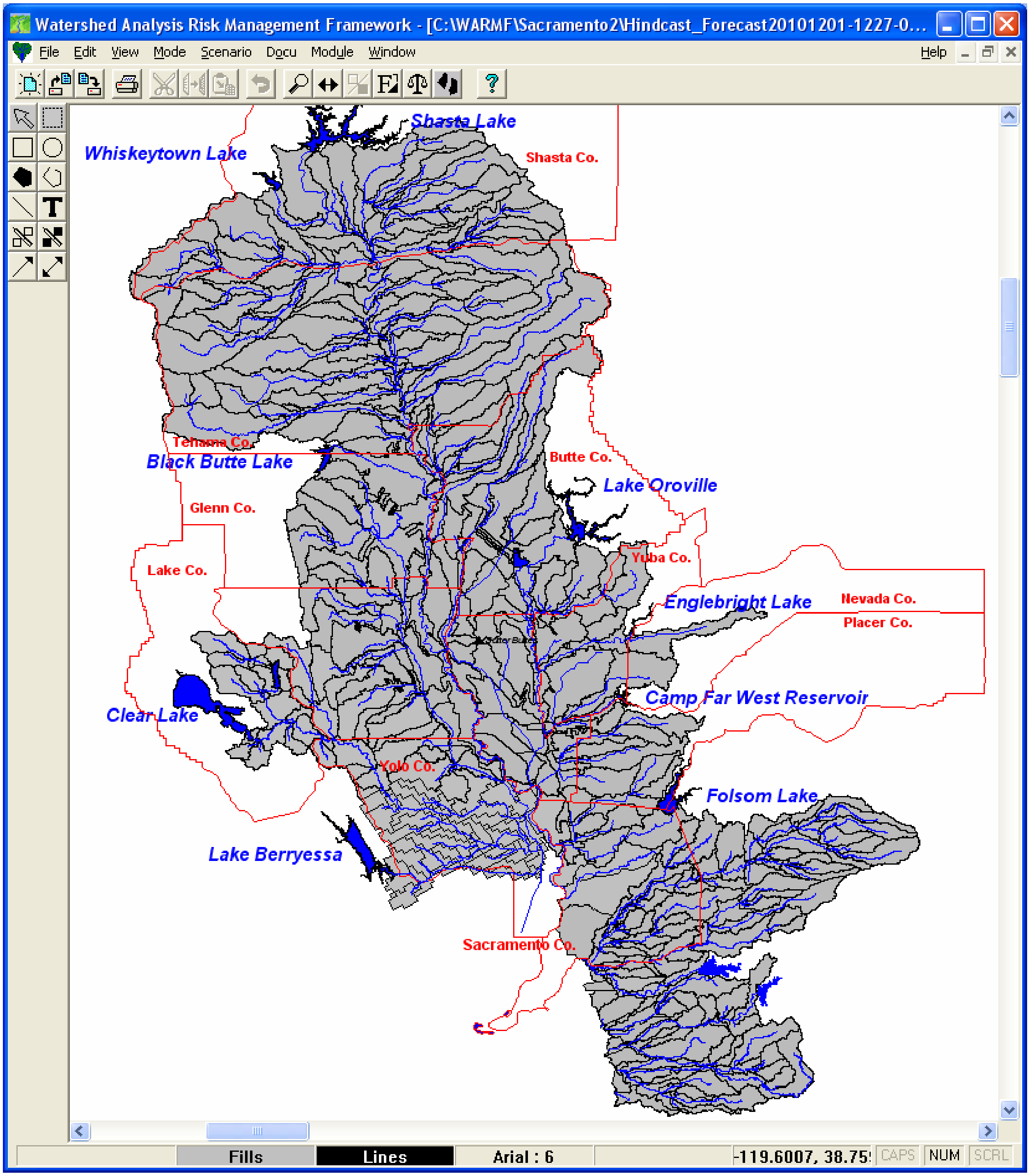


Figure 1.1: Sacramento River WARMF Application

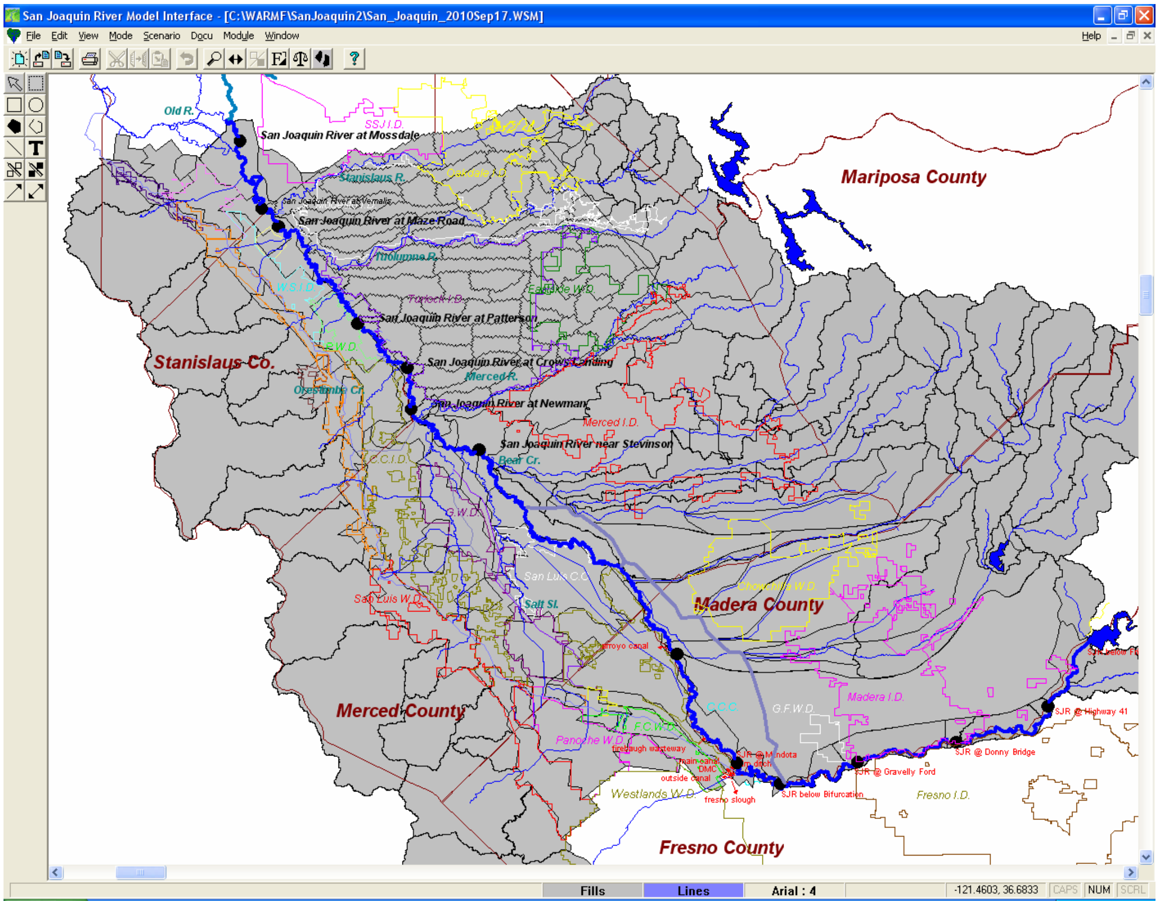


Figure 1.2: San Joaquin River WARMF Application

The WARMF models simulate the Central Valley rivers to the locations where they enter the Delta, but do not simulate the tidal flow and pollutant transport within the Delta. To link pollutants originating in the watersheds with water quality at the Banks Pumping Plant, WARMF is linked with a Delta model where the various tributaries enter the Delta. WARMF provides a time series of flow and concentration for many chemical and physical parameters at these interface points including the Sacramento River, Yolo Bypass, Mokelumne River, Cosumnes River, Calaveras River, and San Joaquin River.

Both the Sacramento and San Joaquin River models have been set up and calibrated using historical data. Most simulations of watershed management alternatives have been in historical mode. This is done by modifying historical data to simulate proposed watershed management alternatives. This type of simulation is used for long-term watershed management and determining total maximum daily load (TMDL) of pollutants allowable in the watershed.

It is also possible to use WARMF in real-time forecasting mode. The model simulates conditions right up to the time the simulation is run and then continues into the near future. Predicted meteorology, reservoir releases, diversions, and point source discharges are used to drive the model. The model's predictions of flow and water quality can then be used to make real-time management decisions. In July 2007, WARMF was tested in forecasting mode to predict the effect of eliminating discharge from the San Luis Drain on water quality in the San Joaquin River at Vernalis (Herr and Chen 2007). The model predicted decreases in phytoplankton and salinity of less than 5% resulting from the management action compared to the baseline "do nothing" case. There were significant errors in future projections of some model inputs, however, which propagated through to the simulation results. The process of generating time series model inputs for the forecast was also cumbersome and would have to be streamlined to perform forecasts on a regular basis.

2 FORECASTING WITH WARMF

A well calibrated model can be expected to produce good simulation results when provided with inputs from a time period other than that for which the model was calibrated. The goal of forecasting simulations is to project as far into the future as possible while retaining some predictive value. Forecasted meteorology only has predictive value for about six days into the future. Since the travel time from the upper reaches of the Sacramento River watershed to the Delta can be approximately one week, forecast simulations with WARMF should run two weeks into the future to take maximum advantage of the predicted meteorology. Simulations also need to be run up to the present day to provide proper initialization of the forecast and to evaluate the accuracy of previous forecasts.

WARMF can be run for any time period as long as it has concurrent inputs for all the time series used to drive simulations. The types of time series input files are shown in Table 2.1 with the number of each input file type for the Sacramento River and San Joaquin River applications of WARMF.

Table 2.1: WARMF Time Series Inputs

Type of Input File	Description	No. of Inputs Sacramento R.	No. of Inputs San Joaquin R.
Boundary Inflow	Flow and loading of chemical constituents from upstream model domain boundaries	12	10
Irrigation Inflow	Flow and loading of chemical constituents in pumped groundwater and other sources outside the model domain	54	106
Point Source	Flow and loading of chemical constituents from point sources	99	26
Diversion	Flow diverted from rivers	133	114
Recharge to Deep Groundwater	Flow recharged to groundwater	38	151
Air & Rain Quality	Air particulate, gaseous, and rain concentrations	5	1
Meteorology	Precipitation, min and max temperature, dewpoint, cloud cover, air pressure, wind speed	60	11

Table 2.1 lists approximately 400 time series files for each watershed which need to be updated for forecasting simulations, which is a large amount of data to process in the real-time constraints of forecasting. The majority of the time series inputs, however, are either relatively constant

(point sources), predictable (point sources, irrigation inflows, diversions, recharge, air & rain quality), lack real-time data sources, and/or do not markedly affect simulation results. Those inputs were synthesized by extrapolating inputs from the same months in previous years.

The two types of model inputs for which accurate real-time data and forecasts are very important are boundary inflows and meteorology. Those are necessary to simulate flow and water quality accurately. Available real-time data sources were identified and methodologies were developed to rapidly download, process, and update key meteorology and boundary inflow data.

Meteorology Data

Meteorology data in the Central Valley WARMF applications is derived from the National Climatic Data Center (NCDC) Global Summary of the Day, NCDC Cooperative Station Network, California Irrigation Management Information Service (CIMIS), California Data Exchange Center (CDEC), University of California Davis IPM Database, and UC Davis PestCast database. The locations of the meteorology stations are shown in Figure 2.1 and Figure 2.2. All of the meteorology stations require updating with real-time observed or estimated data and forecasts to perform forecast simulations. Inputs from stations without real-time data can be estimated from nearby stations which do have data.

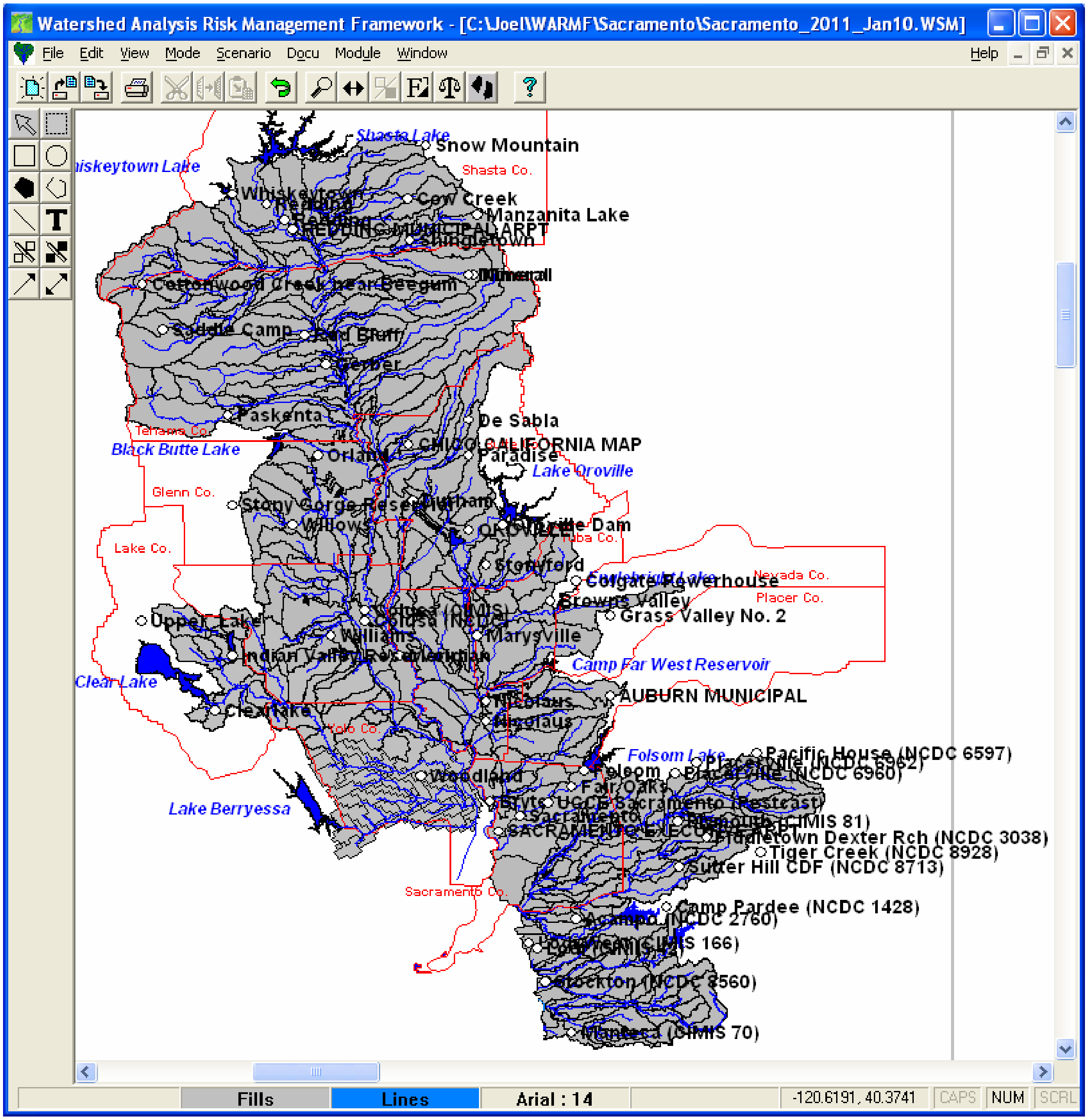


Figure 2.1 Meteorology Stations, Sacramento River and Delta East Side Watersheds

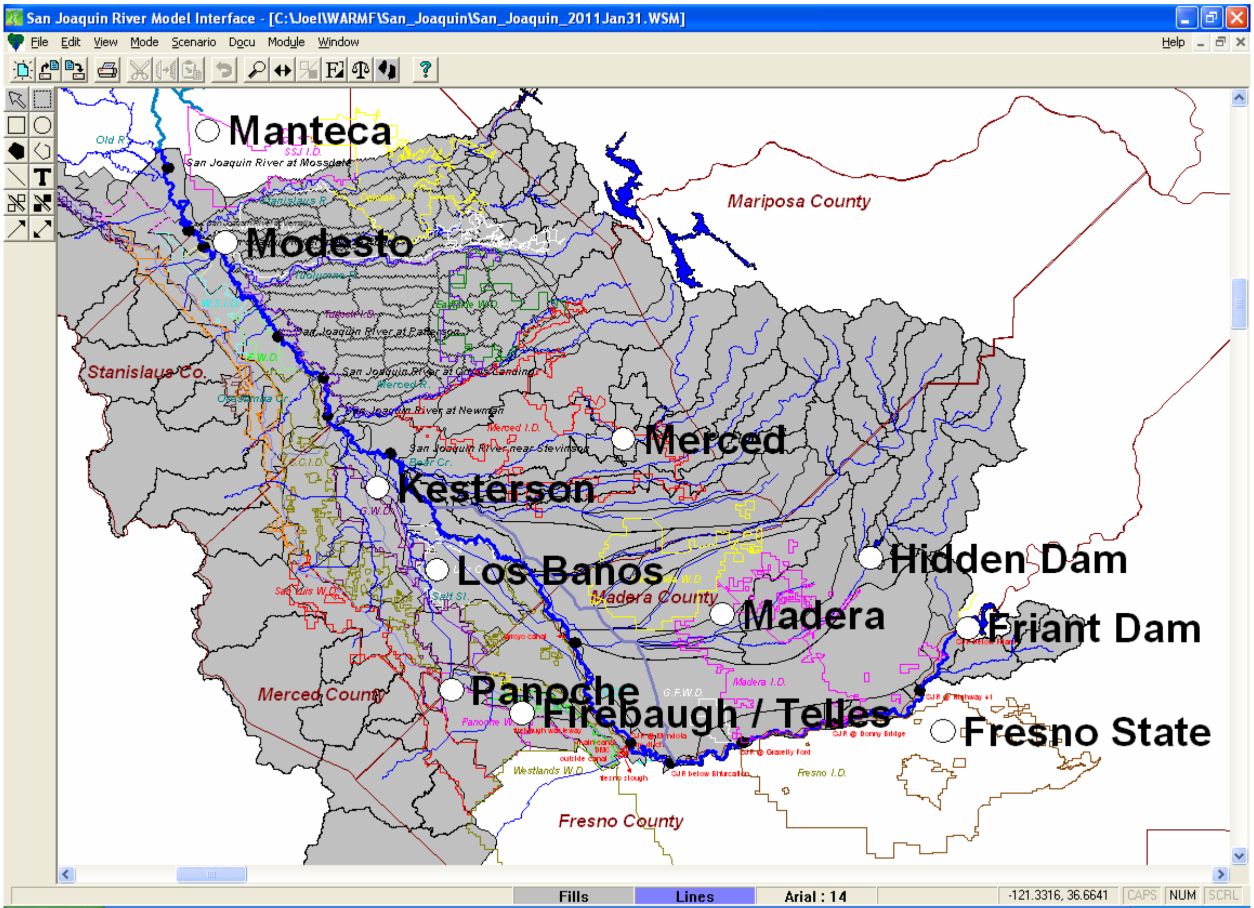


Figure 2.2 Meteorology Stations, San Joaquin River Watershed

Real-time Meteorology Data

Table 2.2 and Table 2.3 list the meteorology stations used in the WARMF Sacramento / Delta East Side watersheds and San Joaquin River watersheds respectively. For each station the real-time data source (if any) is listed. In some cases, the real-time data source is different from the data source used for historical data but is at the same or very near location. The tables also show which of the seven meteorology parameters used by WARMF (precipitation, minimum temperature, maximum temperature, cloud cover, dewpoint temperature, air pressure, and wind speed) have real-time data at each station. Simulations of flow and turbidity are most sensitive to precipitation. Minimum and maximum temperature can affect flow via calculations of evapotranspiration and snow accumulation and melting. Flow and turbidity are not very sensitive to cloud cover, air pressure, and wind speed because those are used to calculate water surface temperature and the very small amount of evaporation from rivers.

Table 2.2: Sacramento River and Delta East Side Watersheds Real-time Meteorology Data

Station	Data Source	Precip	T_{max}	T_{min}	Cloud Cover	T_{dew}	Air Press.	Wind Speed
Acampo	no real-time data							
Auburn	CDEC	X	X	X				
Browns Valley	CIMIS	X	X	X		X		
Bryte	CIMIS	X	X	X		X		
Camp Pardee	no real-time data							
Chico	no real-time data							
Clear Lake	CDEC	X						
Colgate	CDEC	X	X	X				
Colusa (CIMIS)	CIMIS	X	X	X		X		
Colusa (NCDC)	no real-time data							
Cottonwood Creek	CDEC	X	X	X				
Cow Creek	CDEC	X	X	X				
De Sabla	CDEC	X						
Durham	CIMIS	X	X	X		X		
Fair Oaks	CIMIS	X	X	X		X		
Fiddletown Dexter Rch	no real-time data							
Folsom	no real-time data							
Gerber2	CIMIS	X	X	X		X		
Grass Valley	CDEC	X						
Indian Valley	no real-time data							
Lodi	CIMIS	X	X	X		X		
Lodi West (Cimis 166)	CIMIS	X	X	X		X		
Manteca	CIMIS	X	X	X		X		
Manzanita_Lake	no real-time data							
Marysville	no real-time data							
Meridian	no real-time data							
Mineral	CDEC	X	X	X				
Mineral2	no real-time data							
Nicolaus	CIMIS	X	X	X		X		
Nicolaus2	no real-time data							
Oakdale	CIMIS	X	X	X		X		
Orland	no real-time data							
Oroville	GSOD	X	X	X		X		X
Oroville Dam	no real-time data							
Pacific House	CDEC	X	X	X				
Paradise	no real-time data							
Paskenta	CDEC							
Placerville (NCDC 6960)	CDEC	X						
Placerville (NCDC 6962)	no real-time data							
Plymouth	CIMIS	X	X	X		X		
Redbluff	GSOD	X	X	X		X		X
Redding	no real-time data							
Redding Airport	GSOD	X	X	X		X		X
Redding2	no real-time data							
Sacramento Executive Airport	GSOD	X	X	X		X		X
Sacramento	no real-time data							

Station	Data Source	Precip	T_{max}	T_{min}	Cloud Cover	T_{dew}	Air Press.	Wind Speed
Saddle Camp	CDEC	X	X	X				
Shingletown	CDEC	X	X	X				
Snow Mountain	CDEC	X	X	X				
Stockton	no real-time data							
Stonyford	no real-time data							
Stonygrg	no real-time data							
Sutter Hill CDF	no real-time data							
Tiger Creek	no real-time data							
UCCE Sacramento	no real-time data							
Upper Lake	no real-time data							
Whiskeytown	no real-time data							
Williams	no real-time data							
Willows	no real-time data							
Woodland	no real-time data							

Table 2.3 San Joaquin River Watershed Real-time Meteorology Data

Station	Data Source	Precip	T_{max}	T_{min}	Cloud Cover	T_{dew}	Air Press.	Wind Speed
Firebaugh	CIMIS	X	X	X		X		
Fresno	CIMIS	X	X	X		X		
Friant	no real-time data							
Hensley Dam	no real-time data							
Kesterson	CIMIS	X	X	X		X		
Los Banos	CIMIS	X	X	X		X		
Madera	CIMIS	X	X	X		X		
Manteca	CIMIS	X	X	X		X		
Merced	CIMIS	X	X	X		X		
Modesto	CIMIS	X	X	X		X		
Panoche	CIMIS	X	X	X		X		

Meteorology Forecasts

The National Weather Service provides online forecasts of precipitation and temperature, the most important components of meteorology data for driving WARMF simulations. Quantitative Precipitation Forecasts (QPFs) predicting the amount of precipitation each day for the upcoming six days are available from the California-Nevada River Forecast Center. The forecasts are divided into many river basins within the Central Valley but can all be downloaded in a single file. Each WARMF meteorology station was assigned the precipitation forecast for the river basin within which it lies. Quantitative precipitation forecasts more than 6 days into the future have very little accuracy, so days 7-14 of the forecast used average precipitation amounts for that time of year.

Forecasted temperature can affect simulated flow through predictions of snow accumulation and melting. The National Weather Service has readily available forecasts of daily minimum and maximum temperature for seven days. This data can be downloaded and processed quickly to provide a better estimate of temperature for the coming week than using typical values for the time of year. For days 8-14 of the forecast, average values for the time of year are used.

Filling Missing Meteorology Data

Data filling methods are used to estimate meteorology parameters which are not available in real-time and for meteorology stations which have no real-time data. Figure 2.3 shows a schematic of available data for meteorology stations which have both real-time data and forecasts. Shown in gray are the parameters and days which require filling using typical values. To generate these typical values, the historical data for the station is analyzed to create an average value for each parameter for each day of the year. Those values are then applied to the meteorology file for precipitation and temperature beyond the forecast period, for dewpoint temperature and wind speed for all current and future days, and for past, current, and future air pressure. Cloud cover is estimated from precipitation (P), average temperature (T_{ave}) and dewpoint temperature (T_{dew}) as follows:

When there is precipitation:

2 cm/day < P	CC = 1
1 cm/day < P ≤ 2 cm/day	CC = 0.9
0 cm.day < P ≤ 1 cm/day	CC = 0.8

When there is no precipitation:

$(T_{ave} - T_{dew}) < 4$ ˚C	CC = 0.6
4 ˚C ≤ $(T_{ave} - T_{dew}) < 6$ ˚C	CC = 0.3
6 ˚C ≤ $(T_{ave} - T_{dew})$	CC = 0

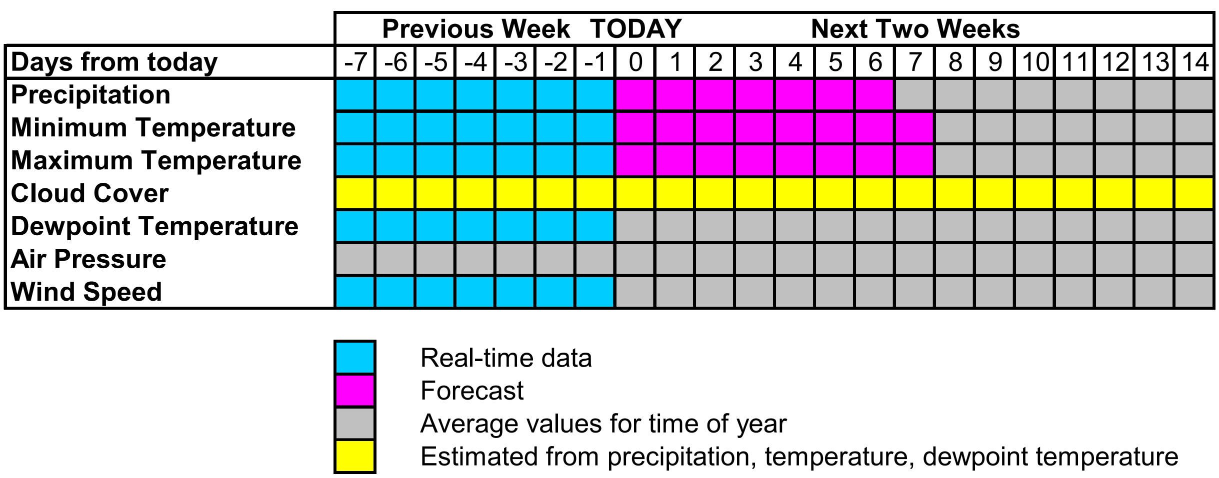


Figure 2.3 Meteorology Data Sources for Real-time Hindcast and Forecast Simulations

Stations are compared with each other to fill in missing data values for stations which do not have complete real-time and/or forecast data. When two stations are compared with each other, the average value is calculated for each parameter on days when both have data. With these average values, a difference (temperature) or ratio (other parameters) can be developed to relate the two stations for each parameter. Each station's data is scanned for cases where one station has data but the other does not. The missing value is then filled using the other station's value and the calculated difference or ratio between the stations. As long as there is at least one meteorology station with a value for each parameter on each day, a complete record is created for all the meteorology stations so simulations can be run.

Boundary Inflow Data

Boundary inflows are points where rivers enter the WARMF model domain from upstream. WARMF requires daily inputs of flow, temperature, and each simulated chemical constituent over the entire simulation period. Boundary inflows are placed at locations where there is complete flow data and good water quality data collection. In the Sacramento River WARMF application, these are downstream of major reservoirs. In the San Joaquin River WARMF application, the boundary inflows are at flow gaging stations on major tributaries. Flow data at these locations is primarily from the United States Geological Survey (USGS) or California Data Exchange Center (CDEC). Water quality data is from USGS, CDEC, and other sources. The locations of the boundary inflows are shown in Figure 2.4 and Figure 2.5. All of the boundary inflows require updating with real-time observed or estimated data and forecasts to perform forecast simulations. Since simulations are very sensitive to boundary inflows, it is important to use real data and forecasts whenever possible as opposed to estimated values for the flow part of the boundary inflow files. There is little or no real-time or forecast water quality data at boundary inflows, so typical values for the time of year are used.

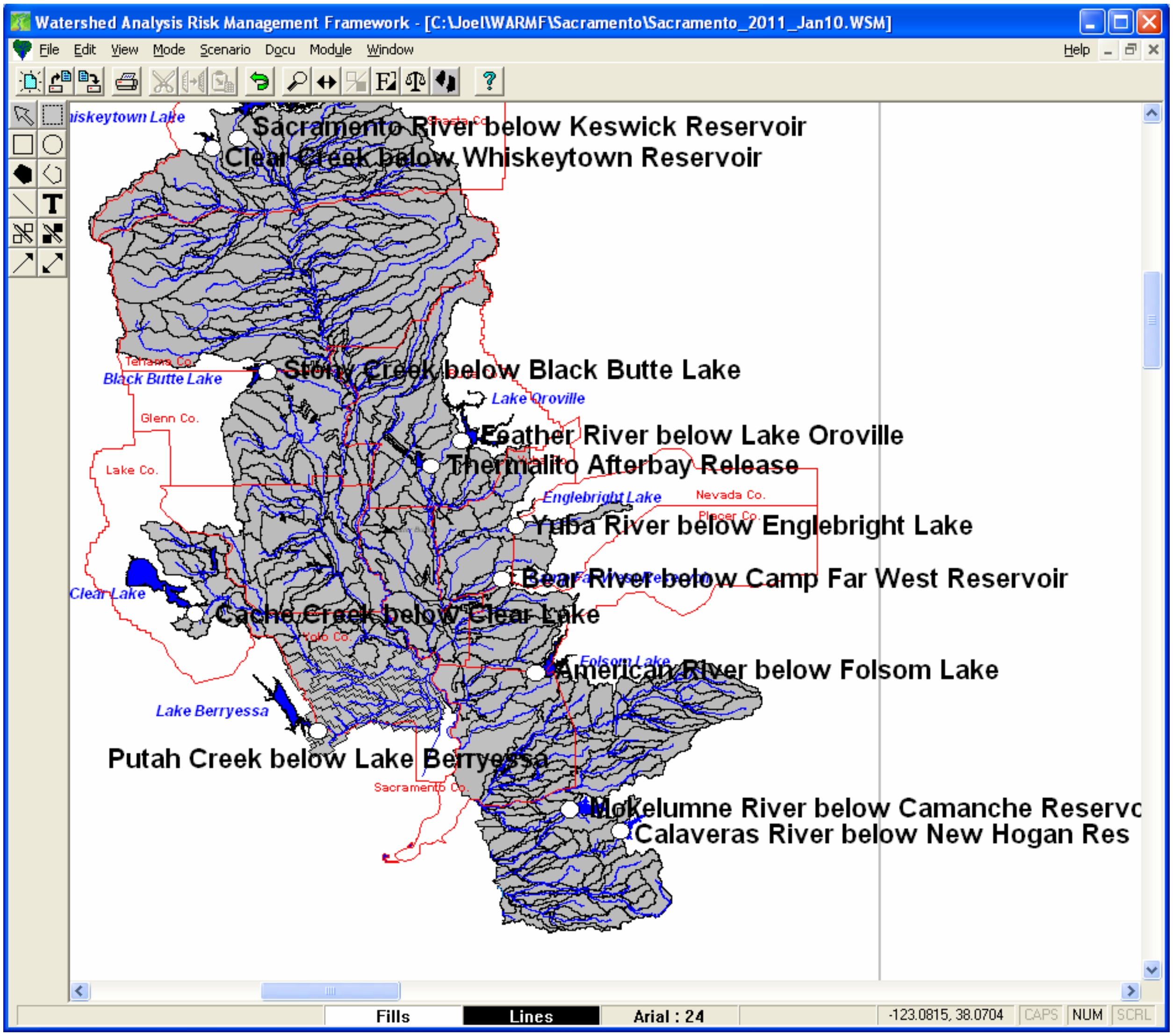


Figure 2.4 Boundary Inflows, Sacramento River and Delta East Side Watersheds

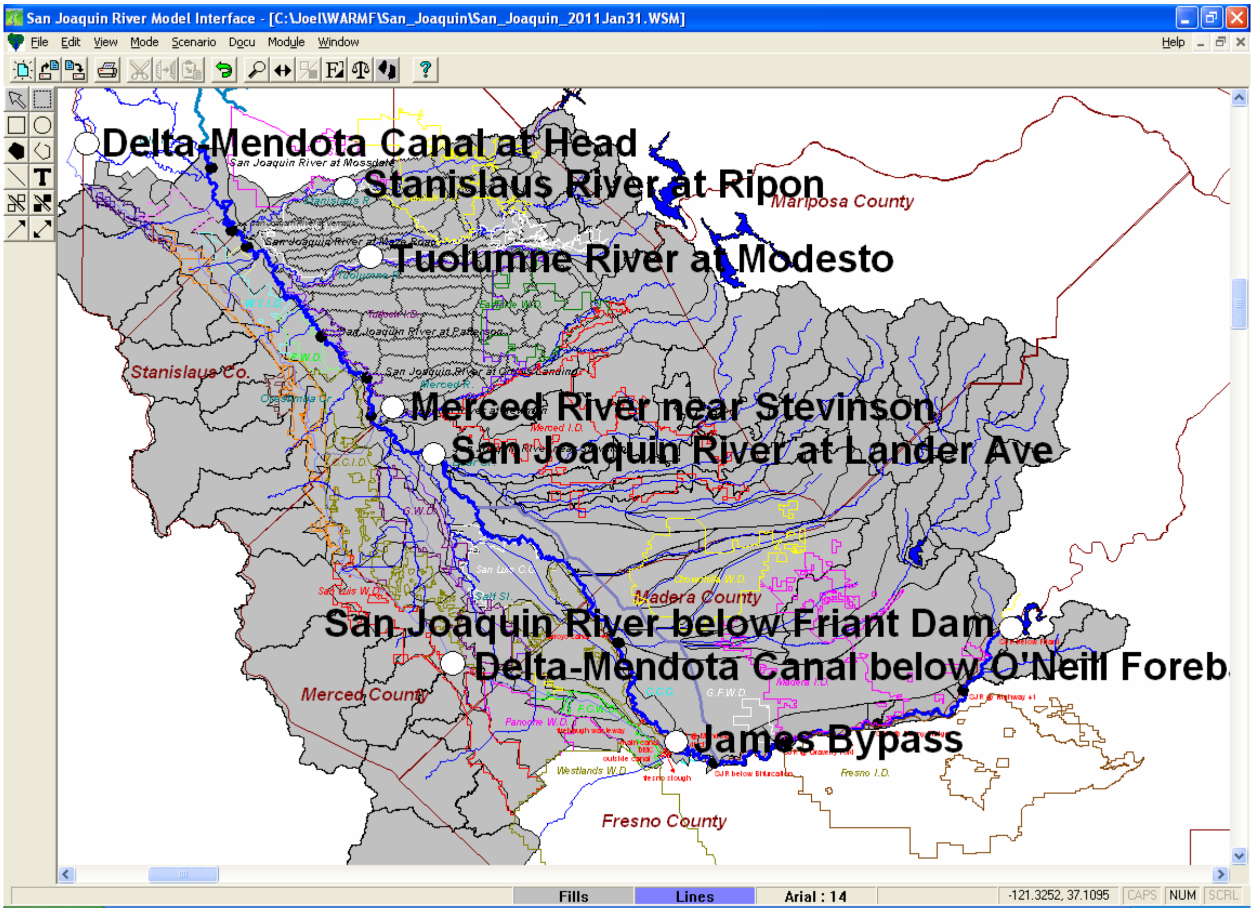


Figure 2.5 Boundary Inflows, San Joaquin River Watershed

Real-time Boundary Inflow Data

Figure 2.4 and Figure 2.5 list the flow data sources of boundary inflows used in the WARMF Sacramento / Delta East Side watersheds and San Joaquin River watersheds respectively. The real-time data source for each station is listed. All have active real-time flow measurement except for the San Joaquin River at Lander Avenue, which stopped reporting flow in March 2010. The Lander Avenue boundary inflow must therefore use average flow values for the time of year. Although the flow in the San Joaquin at Lander Avenue is generally less than the Stanislaus, Tuolumne, and Merced Rivers where they join the San Joaquin, the flow at Lander Avenue can be very high in very wet years. The 80^{th} percentile for flow at Lander Avenue is 410 cfs but the 90^{th} percentile flow is 1,720 cfs. In wet years especially, using averaged flows for this boundary inflow could be an important source of error.

Table 2.4: Sacramento River Boundary Inflow Data Sources

River	Real-time Data Station	Real-time Data Location
Stony Creek	CDEC BLB	Black Butte Reservoir
Mokelumne River	CDEC CMN	Camanche Reservoir
Bear River	USGS 11424000	Bear River near Wheatland
Cache Creek	CDEC RUM	Cache Creek at Rumsey Bridge
Yuba River	CDEC YRS	Yuba River near Smartville
American River	USGS 11446500	American River at Fair Oaks
N. Fork Cache Cr.[1]	CDEC INV	Indian Valley Reservoir
Putah Creek	USGS 11454000	Putah Creek near Winters
Feather River	CDEC ORO	Oroville Dam
Sacramento River	USGS 11370500	Sacramento River at Keswick
Calaveras River	CDEC NHG	New Hogan Lake
Feather River	CDEC THA	Feather River below Thermalito[2]
Clear Creek	CDEC IGO	Clear Creek near Igo

1 Not actually a boundary inflow, since the reservoir is within the WARMF model domain
2 Thermalito release is calculated by subtracting Lake Oroville release from total flow

Table 2.5 San Joaquin River Boundary Inflow Data Sources

River	Real-time Data Station	Real-time Data Location
Delta-Mendota Canal	CDEC TRP	Tracy Pumping Plant
Merced River	CDEC MST	Merced River near Stevinson
San Joaquin River	CDEC SJS[1]	San Joaquin River near Stevinson
Stanislaus River	USGS 11303000	Stanislaus River at Ripon
Tuolumne River	USGS 11290000	Tuolumne River at Modesto

1 Gage has not reported flow since March 5, 2010

Forecast Boundary Inflows

CDEC lists the most recent scheduled releases for California's major reservoirs. The schedule of posted release flows is irregular, although scheduled flow entries tend to be more frequent when release flows are changing. Although the actual release flows often differ from those in the release schedule, the scheduled releases provides a better estimate of future flows than a continuation of existing flows.

Filling Missing Boundary Inflow Data

WARMF simulations are sensitive to boundary inflows and the flows can be highly variable, so it is important to use real data and forecasts as much as possible. In cases where real-time data and/or forecasts are missing for a short time period, however, it is necessary to use the best available estimate of flow rate. Alternatives were investigated to synthesize data using previous years as a guide, but the most accurate method found was to just continue using the last known flow rate until any additional information is received.

3 WARMF FORECASTING PROCESS

The process of creating flow and water quality forecasts with WARMF has been designed so that it can be performed in less than 4 hours to facilitate taking management actions in near real-time based on the simulation results. The process starts with preparation done once so that all the WARMF inputs other than meteorology and boundary inflows have been set up using the most up-to-date information for the historical time period and typical values for the upcoming forecast season. A warm start simulation can then be run for a historical time period leading up to the beginning of forecasts. This will provide good initial conditions for the model simulation.

On the day of forecasting, meteorology and boundary inflow data must be gathered from data sources, pre-processed, and imported into WARMF before a model simulation can be run. External spreadsheet tools to pre-process the data from the form in which it is gathered into comma delimited files which can be imported into WARMF. Additional functions have been added to WARMF to rapidly import the data and fill in missing data to create a complete set of model inputs for running forecasting simulations.

The steps required to use the California Central Valley WARMF applications for forecasting are described below. Although the basic process can be applied to any WARMF application, the process developed for the Central Valley is customized to the specific data needed and the real-time sources of that data. The process descriptions assume a basic working knowledge of WARMF.

Preparation

There are some forecasting tasks which only need to be performed once before running forecast simulations. The first step is to gather as much historical time series data as is available. This will provide the most accurate inputs available to run WARMF up to the start of the forecast. The method for expanding the WARMF database is described in Chapter 7 of the WARMF User's Guide (Herr 2001).

Once the WARMF database has been expanded to the point practicable with real data, it needs to be expanded through the time period for which forecast simulations will be run. This is done using the extrapolation tool added to WARMF for forecasting. To use the data extrapolator, enter the Data Module by selecting Module / Data from the menu. There are seven types of data listed: Meteorology, Air Quality, Observed Hydrology, Observed Water Quality, Managed Flow, Point Sources, and Pictures. Observed data types and pictures are not used as model inputs, so those do not need to be updated. Special methods will be used to extrapolate meteorology data to make best use of real-time and forecasted data. The remaining three data types must be extrapolated using typical values.

Air Quality Data

Air Quality includes rain chemistry, particulate air quality and gaseous air quality. The Central Valley WARMF applications use air quality data from the National Atmospheric Deposition Program (NADP) and Clear Air Status and Trends Network (CASTNET). Neither of these databases has information in real-time, but simulation results from the Central Valley are not generally sensitive to atmospheric deposition. To extrapolate air quality data, select Air Quality as the Type of Data. Then select Edit / Extrapolate from the menu. The extrapolation tool (Figure 3.1) lists all the files of the selected data type along with a default data interval estimated by scanning each file and the default Typical fill method. The Typical fill method scans the historical data in each file to calculate average values for each day of the year. The average values are used on extrapolated data lines. If the Missing fill method is chosen, the extrapolated data lines are set to be missing, which means simulations for the extended time period could not be run until the data was made complete. The Zero fill method fills in all extrapolated values with zero. Above the spreadsheet is the date through which the extrapolation is to be made. Lines are appended to the end of each data file at the selected data interval until the chosen date has been reached. The extrapolation tool can also be used to extrapolate backward in time, but this is not needed for forecasting simulations. After pressing OK, all the air quality files will be modified to include extrapolations. When the Typical fill method is used, a note is put in the Data Source column of the Data Module on extrapolated data lines to indicate the years which were used to generate the average values for each day of the year.

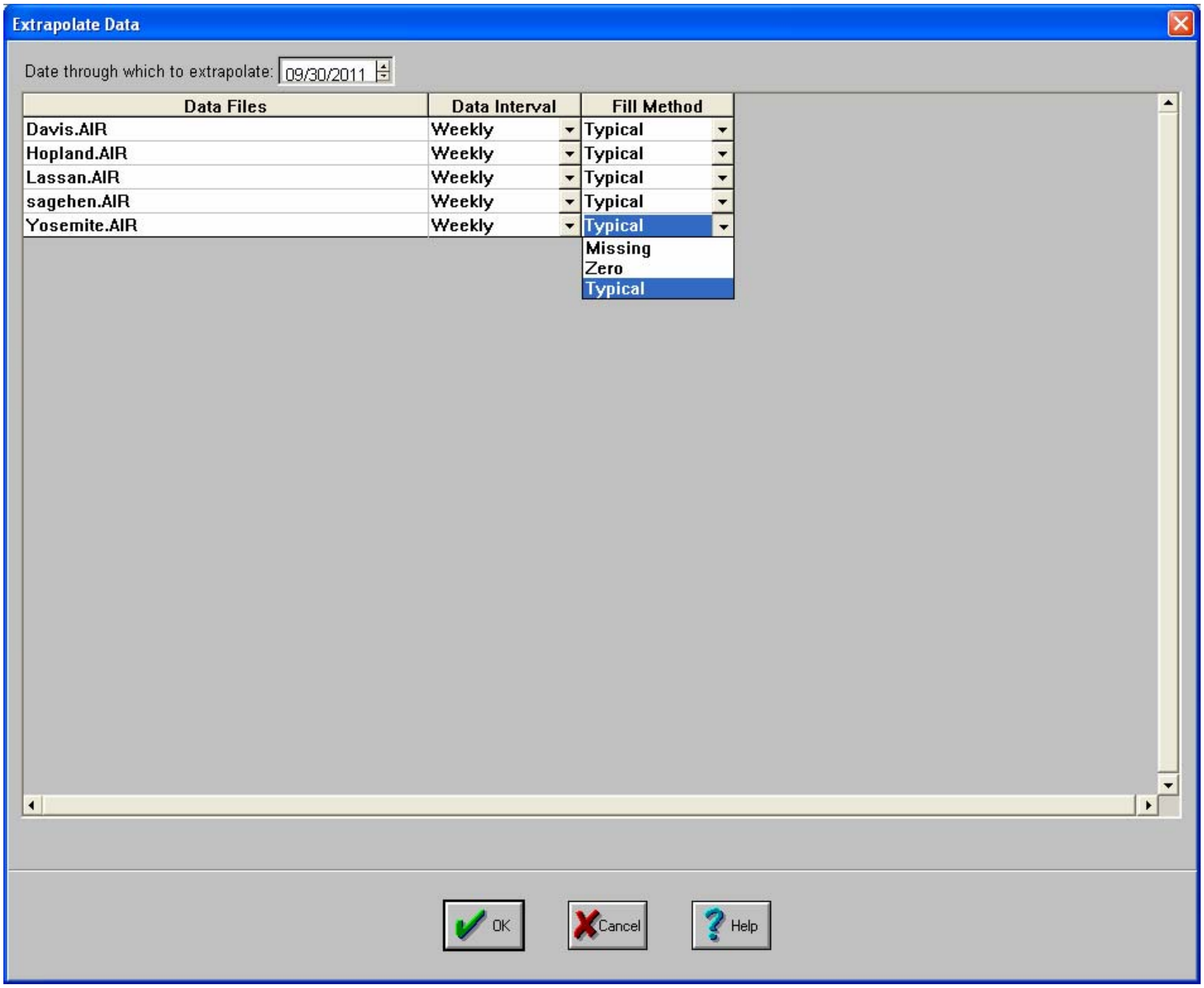


Figure 3.1 Extrapolation of Air Quality Data

Managed Flow

The "Managed Flow" data type in WARMF is used to store time series of all controlled or otherwise externally specified flows which originate within the watershed. This includes diversions, flood control weirs, groundwater recharge, and reservoir releases. Among these, real-time data and forecasts of managed flow are generally only available for reservoir releases. Only one reservoir is actively simulated in the Central Valley WARMF applications, Indian Valley Reservoir on the North Fork of Cache Creek in Lake County. All managed flow input files should be extrapolated using typical values. If real-time or forecast data is available for any of them, that can overwrite the extrapolated values. If the data is not available, the typical values provide a reasonable estimate. WARMF simulations can be sensitive to the amount of diversion flow during the dry season, and the amount of diverted water can vary significantly from year to year depending on whether it is a generally wet or dry year. The WARMF forecasting process was designed for first application predicting high flow / high suspended sediment conditions in winter. Since diversion flows are low in winter and natural flow is high, the error from assuming typical values for diversions is not likely to have a large impact on simulation results. To extrapolate managed flow input data, first select Managed Flow as the Type of Data and then select Edit / Extrapolate from the menu. A dialog will appear as shown in Figure 3.2 listing all the managed flow files. The Data Interval for managed flow files should be Daily and the Fill Method should be Typical.

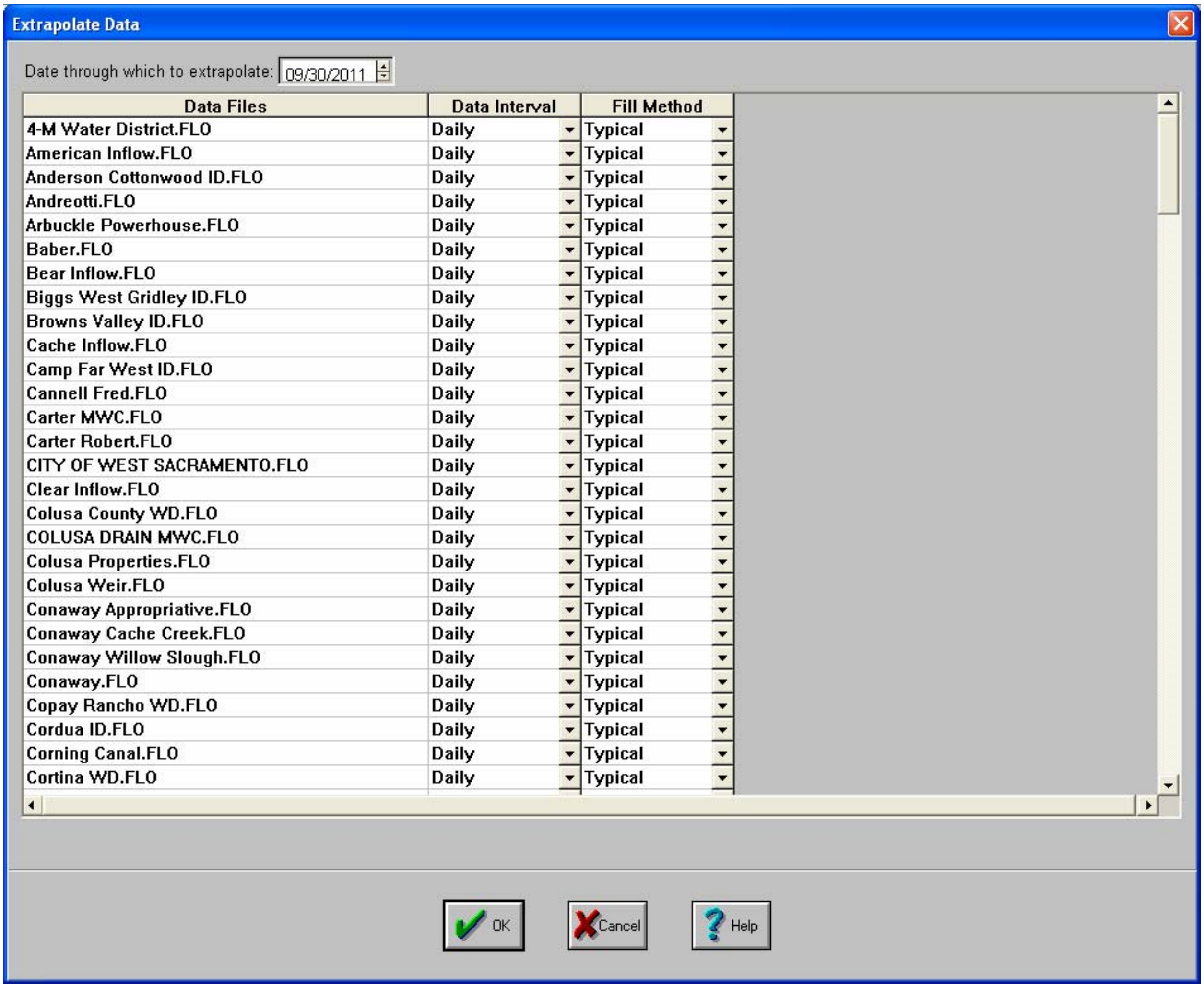


Figure 3.2 Extrapolation of Managed Flow Data

Point Sources

Within WARMF, point sources are all water sources entering the model domain from outside of it. This category of data not only includes actual permitted discharges but also includes groundwater pumping and boundary inflows. All point sources should be extrapolated using typical values. In the WARMF Data Module, select Point Sources for the Type of Data and then select Edit / Extrapolate in the menu. A dialog will appear as shown in Figure 3.3. All the point sources including the boundary inflows should be extrapolated using the Typical fill method. The flows in boundary inflows can be replaced later with real-time and forecast data.

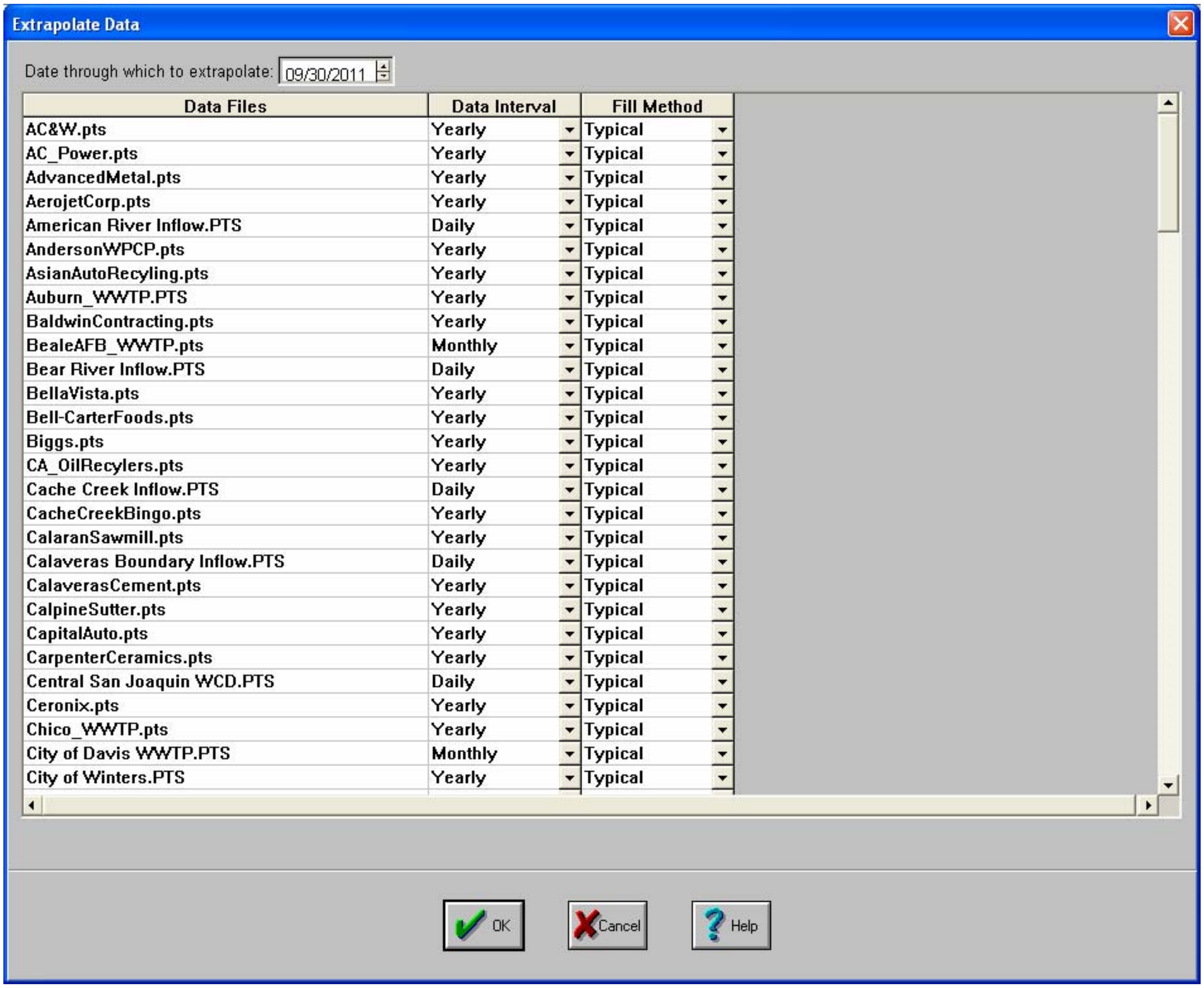


Figure 3.3 Extrapolation of Point Source Data

Meteorology

Expansion of the WARMF meteorology data set follows a different procedure than the other types of data because it is very important to use actual data instead of typical values. Before the start of forecasting season, the meteorology data should be updated up to the beginning of the forecasting season. Figure 3.4 shows the Extrapolate Data dialog for meteorology. Note two important differences when extrapolating meteorology compared to other data types: the date through which to extrapolate is the day before the start of forecast simulations and the fill method is Missing. This leaves the meteorology files black so they can be filled in with real data. There are various methods of bringing data into WARMF. The most efficient method is the same one used when creating forecast simulations. A comma delimited file must be created with a line for each date and a column for each meteorology parameter at each station. The data is then imported into WARMF and then the remaining missing data is filled in using the

WARMF Data Module's Fill Missing Data function. The process is described in detail in the Forecasting Day Procedure section of this report.

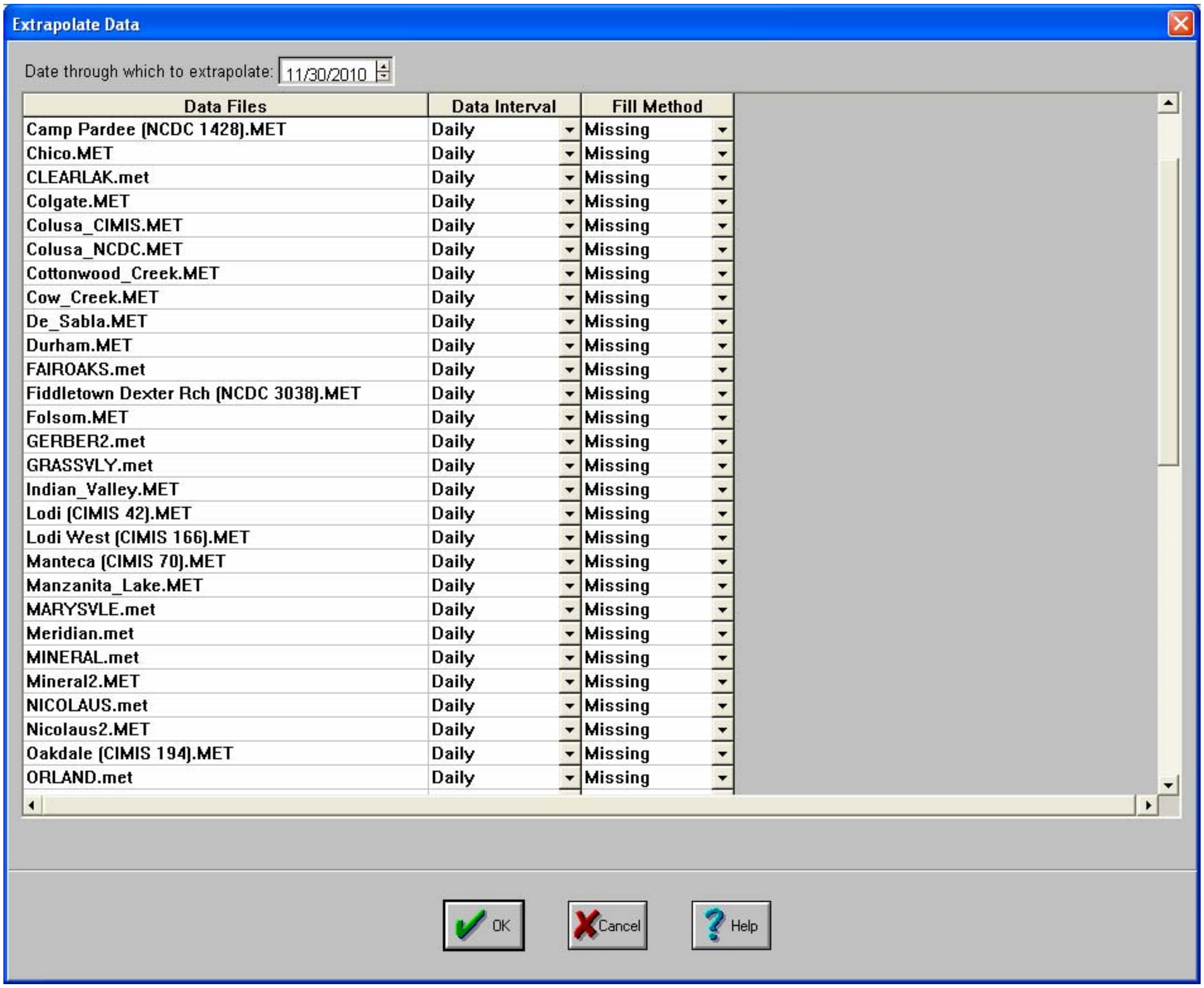


Figure 3.4 Extrapolation of Meteorology Data

Warm Start Simulation

Once there is a complete set of time series input data, the next step is to run a warm start simulation which will initialize forecast simulations. The results of a short-term forecast simulation are sensitive to its initial conditions including soil moisture content, river water depths, and chemical concentrations. A warm start simulation is run for at least one year to establish stable and reasonable conditions up to the beginning of forecast simulations. To run a warm start simulation, first create a scenario. If not already there, go to the WARMF Engineering Module by selecting Module / Engineering in the menu. Then select Scenario / Manager. Click on Copy and choose the name of the warm start scenario. Open it so it is one of the active scenarios on the right side of the Scenario Manager dialog as shown in Figure 3.5. Press OK on the Scenario Manager dialog, then select the warm start scenario at the bottom of the Scenario menu to activate it as shown in Figure 3.6. More detailed instruction on creating and manipulating scenarios is in Chapter 4 of the WARMF User's Guide.

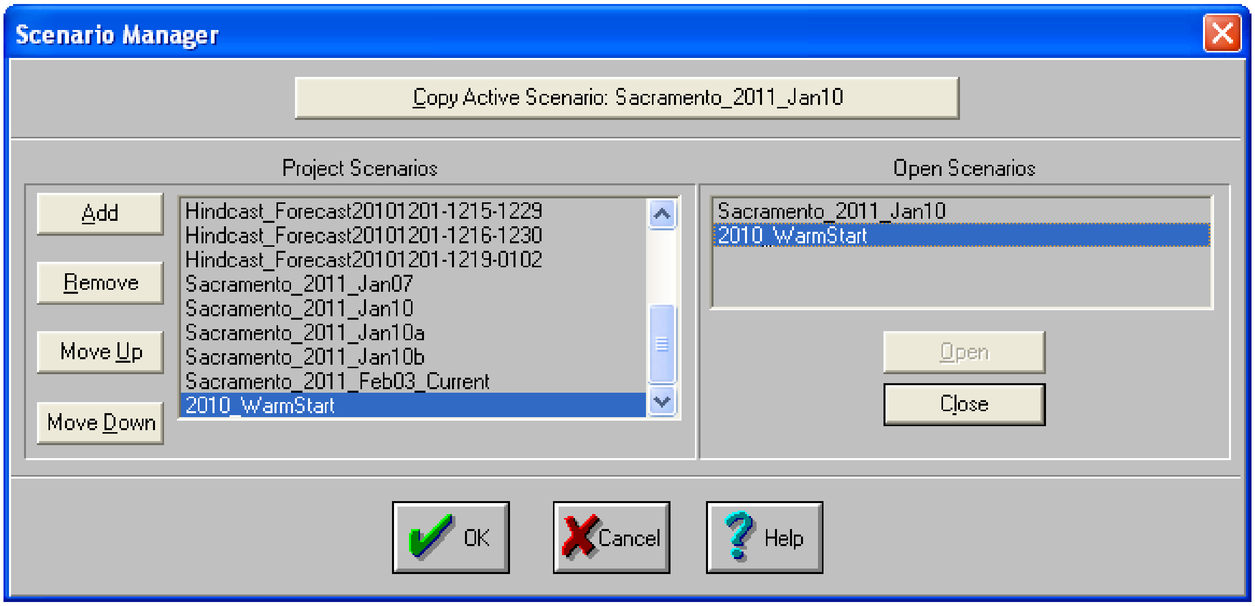


Figure 3.5 Scenario Manager with Warm Start Scenario

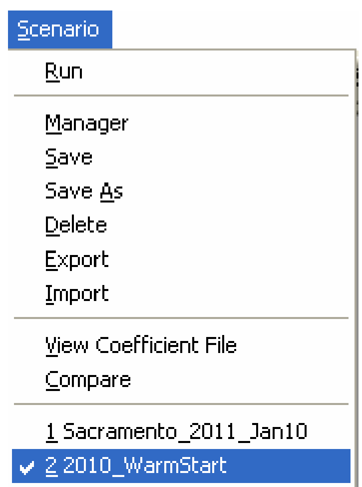


Figure 3.6 Warm Start Scenario Activated

To run the warm start scenario, select Scenario / Run in the menu. After checking the time series input files, the simulation dialog will appear as shown in Figure 3.7. The simulation period should be at least one year and should end the day before the time period for which forecast simulations will be run. It is recommended that the warm start simulation start on October 1st because this is a relatively stable time of the year at the end of the irrigation season but before the first winter rains. Figure 3.7 shows the simulation dates used to prepare a warm start simulation for forecasts beginning December 1, 2010. Press OK to initiate the warm start simulation. Perform the warm start simulation for both the Sacramento and San Joaquin River WARMF applications so that both are prepared for running forecast simulations.

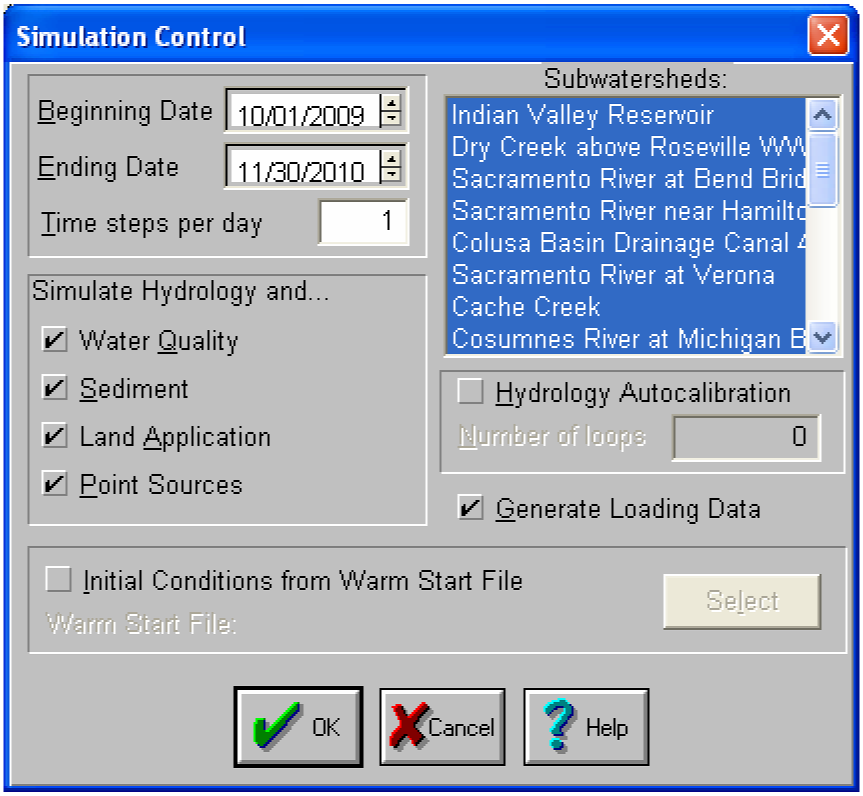


Figure 3.7 Warm Start Simulation Dialog

Before running forecast simulations, it is recommended that the meteorology files have a daily (as opposed to hourly) time step if that is not already the case. Meteorology files with an hourly time step can be aggregated to make the files more compact. This will make the data filling process much faster and more practical when running forecast simulations in near real-time.

Forecasting Day Procedure

Although the forecasting process has been set up to minimize the time required to perform forecast simulations, there are still many steps in the process. With practice, all the steps can be performed in about 4 hours to generate forecasted flow and water quality in near real-time.

Collect and Process Observed Meteorology Data

Real-time observed meteorology data for California is available from three on-line sources: California Irrigation Management Information System (CIMIS), National Climatic Data Center Global Summary of the Day (GSOD), and California Data Exchange Center (CDEC). All of the data is available without cost. The data is initially collected in the format made available on-line and then Excel 2007 processors are used to process the data into files which can be imported into WARMF. The Excel processor for observed meteorology data is called

MET_Observed_Processor.xlsm . Inside the Excel file there is a tab called Instructions which describes in detail the process to download and process the data, which is also described below.

Download CIMIS Data

1. Go to http://www.cimis.water.ca.gov/cimis/frontDailyReport.do . CIMIS requires a username and password, but there is no charge to register.
2. Select "Stations by Region". In the list of regions, select Sacramento Valley, San Joaquin Valley, and Sierra Foothills while holding the Ctrl key down to make multiple selections.
3. Do not select sensors
4. Select Metric for the units.
5. Choose the dates over which data is to be collected, up to the day before the day the forecast is performed
6. Select "CSV with headers" as the format of the file.
7. Press Submit to generate the file, which should be saved to a Raw Data directory as "CIMIS_mmyyyy.csv" where mm is the current month number and yyyy is the current year.

Figure 3.8 shows a screenshot of the CIMIS data download web page.

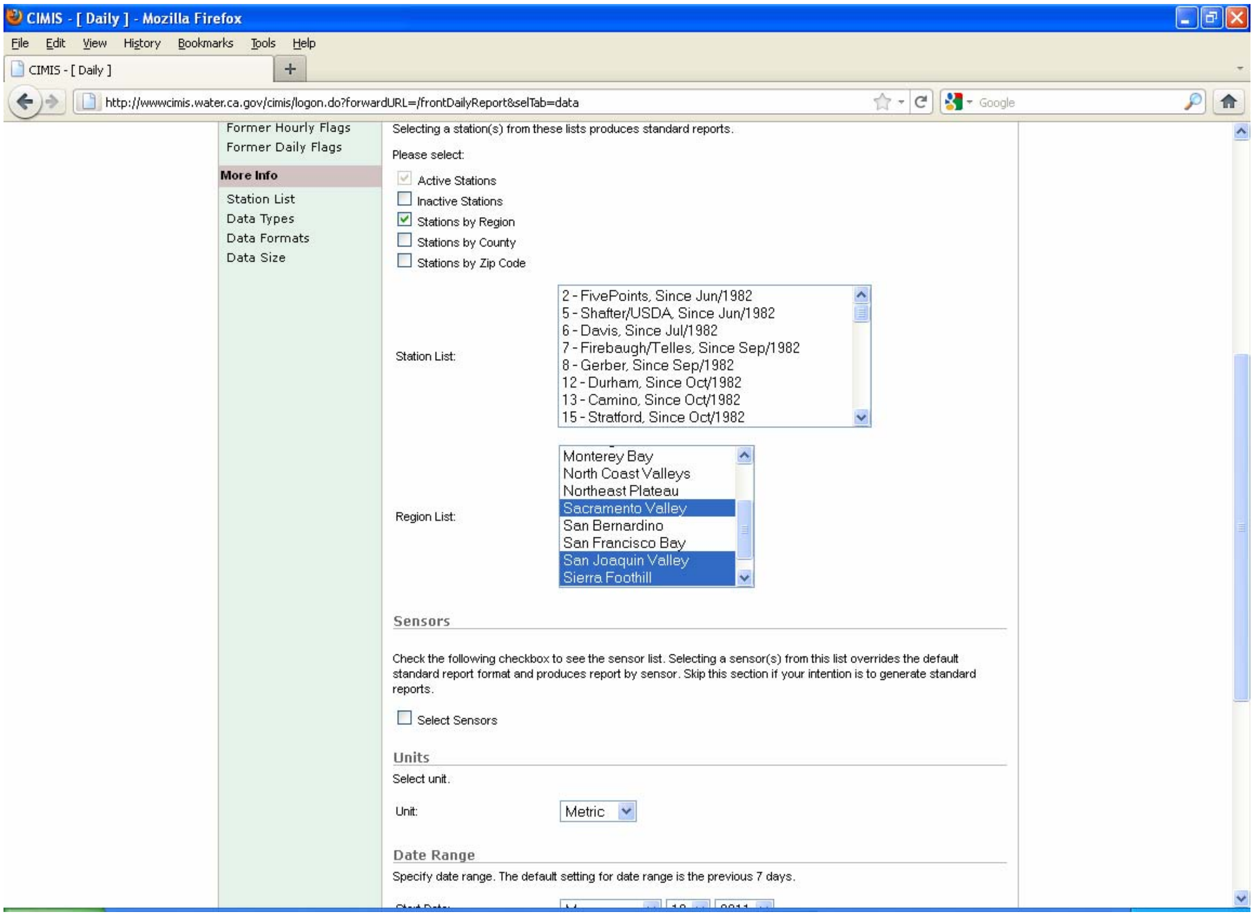


Figure 3.8 CIMIS Meteorology Data Web Page

Download GSOD Data

1. Go to http://www7.ncdc.noaa.gov/CDO/cdoselect.cmd?datasetabbv=GSOD&countryabbv=&georegionabbv= .
2. Click on "Country" and press Continue.
3. On the next page, choose California and retrieve data for Selected Stations in the state.
4. Select four stations by holding down the Ctrl key: Oroville Muni (the one with the most recent dates), Red Bluff Municipal, Redding Municipal, and Sacramento/Executiv. The end of the date range in each case should be the current month and year.
5. Select "Use Date Range" and choose From the first day of the month and To yesterday's date.
6. Keep other default settings (Space Delimited Tabular Data Output) and press Continue.
7. Save the contents of the *.txt file link to the Raw Data directory on your computer with the file name "GSOD_mmyyyy.csv" where mm is the current month and yyyy is the current year.

A screenshot of the last step of the GSOD data download is shown in Figure 3.9.

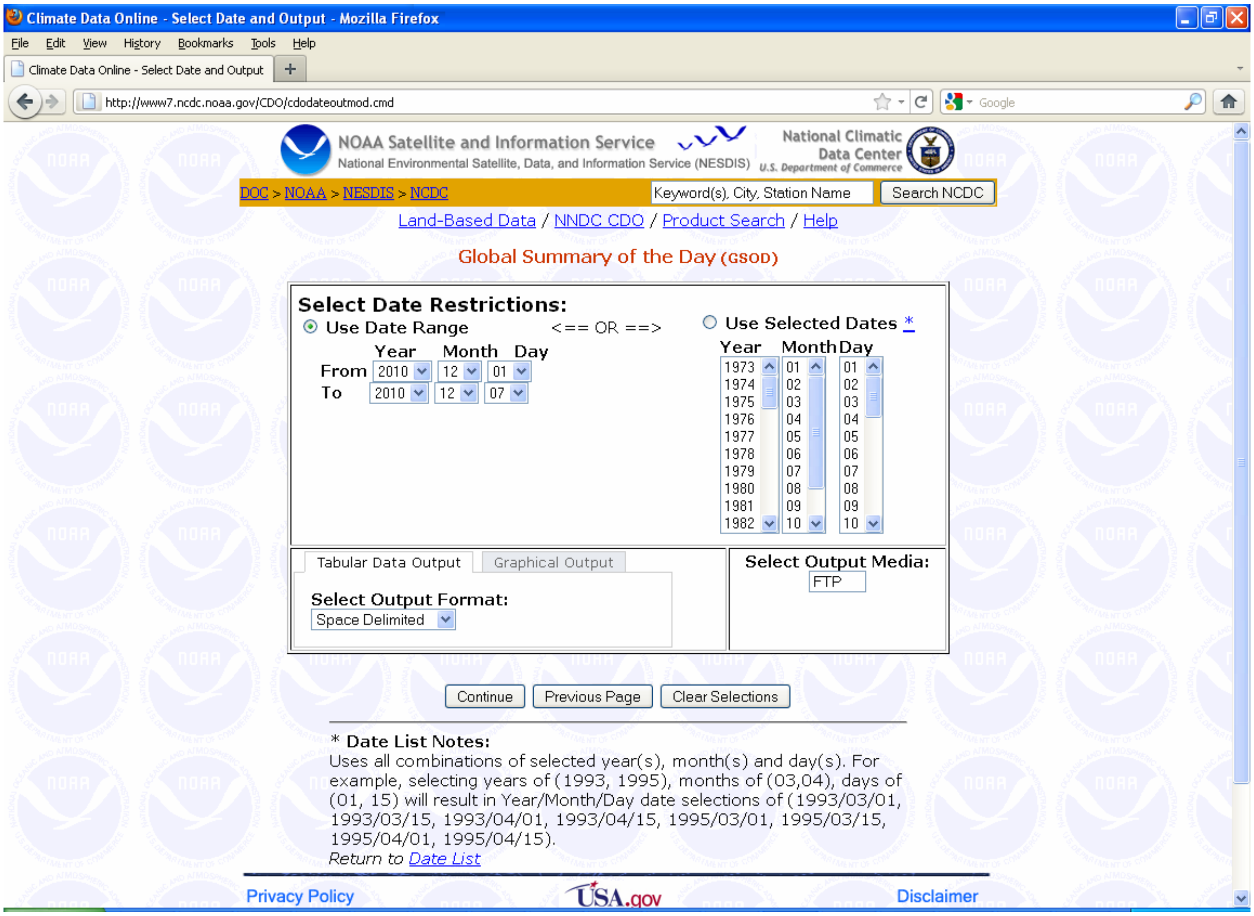


Figure 3.9 GSOD Meteorology Data Web Page

Download CDEC Data

1. Go to http://cdec.water.ca.gov/cgi-progs/queryGroupCSV .
2. Enter Group ID: SF2, Start Date: 1st of the month, leave the end date blank. The group ID has been set up to include the meteorology stations needed for Central Valley WARMF forecasting.
3. Click "Download CSV Data Now", save the file to the Raw Data directory with filename in the form "CDEC_MET_mmyyyy.csv" where mm is the current month and yyyy is the current year.

A screenshot of the CDEC group download web page is shown in Figure 3.10.

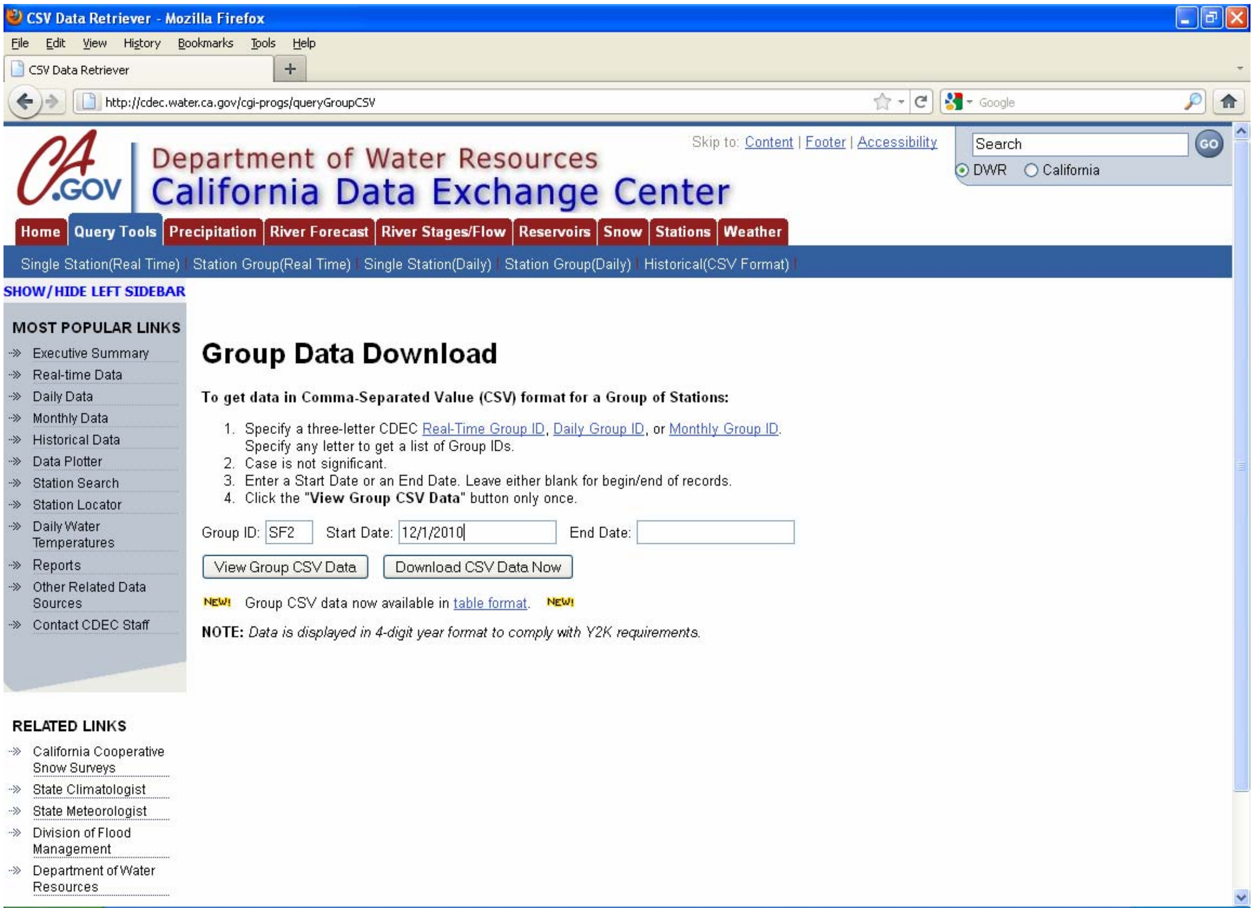


Figure 3.10 CDEC Group Data Download Web Page

Process Observed Meteorology Data

The next steps are done in the Met_Observed_Processor.xlsm Excel file. The processing macros are run from the Control tab of the spreadsheet. Update the Process Data Start Date and Process Data End Date highlighted in yellow. The dates can span any number of months but all the data for those months must be stored in the Raw Data directory. Below the start and end dates are the paths to the Raw Data directory and the WARMF Import directory. Change those file paths to agree with the directory structure on your computer. Press the Process and Export all data button to run the macros and generate the WARMF Import files. As necessary, adjust Excel settings to allow the use of macros. To check the data for errors, go to the Check_Data tab and click on Create Chart. If outliers are detected, they can be corrected either in the raw data files (then re-run the processor) or in the WARMF Import files.

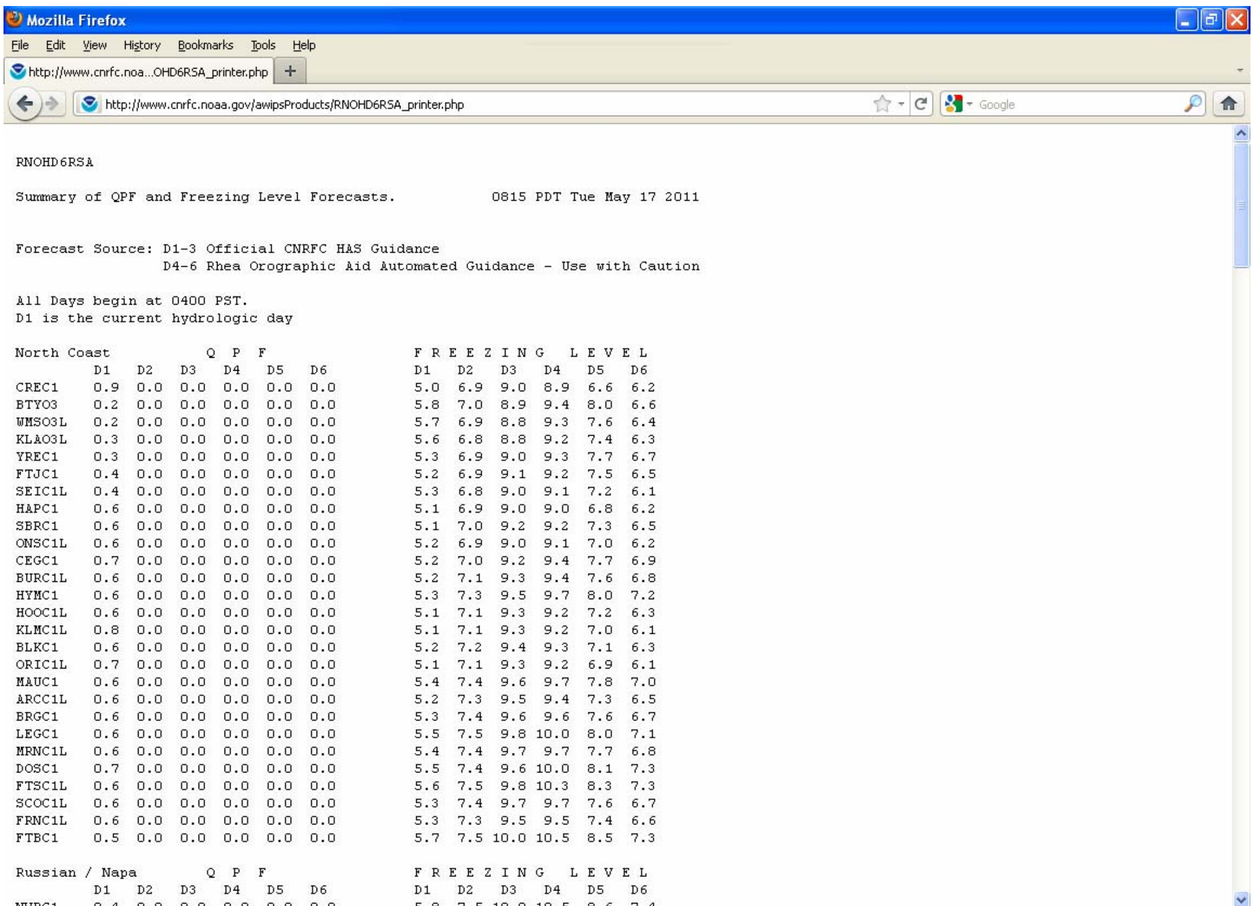
Collect and Process Meteorology Forecast

Meteorology forecasts for California are available from the California Nevada River Forecast Center. Precipitation forecasts run from the current day through 5 days into the future. Temperature forecasts run from the current day through 6 days into the future. The Excel 2007 processor for meteorology forecasts is called MET_Forecast_Processor.xlsm . The Instructions tab of the spreadsheet contains detailed instructions which are also described below.

Quantitative Precipitation Forecasts

1. Go to http://www.cnrfc.noaa.gov/awipsProducts/RNOHD6RSA_printer.php to get the current forecast.
2. From the browser, Save As a text file in the Raw Data directory with file name of the form “QPF_mmddyyyy.txt” where mm is the current month, dd is the current day, and yyyy is the current year.

A screenshot of the quantitative precipitation forecast web page is shown in Figure 3.11.



RNOHD6RSA

Summary of QPF and Freezing Level Forecasts. 0815 PDT Tue May 17 2011

Forecast Source: D1-3 Official CNRFC HAS Guidance
D4-6 Rhea Orographic Aid Automated Guidance - Use with Caution

All Days begin at 0400 PST.
D1 is the current hydrologic day

North Coast	Q P F						F R E E Z I N G L E V E L					
	D1	D2	D3	D4	D5	D6	D1	D2	D3	D4	D5	D6
CREC1	0.9	0.0	0.0	0.0	0.0	0.0	5.0	6.9	9.0	8.9	6.6	6.2
BTYO3	0.2	0.0	0.0	0.0	0.0	0.0	5.8	7.0	8.9	9.4	8.0	6.6
WMSO3L	0.2	0.0	0.0	0.0	0.0	0.0	5.7	6.9	8.8	9.3	7.6	6.4
KLAO3L	0.3	0.0	0.0	0.0	0.0	0.0	5.6	6.8	8.8	9.2	7.4	6.3
YREC1	0.3	0.0	0.0	0.0	0.0	0.0	5.3	6.9	9.0	9.3	7.7	6.7
FTJC1	0.4	0.0	0.0	0.0	0.0	0.0	5.2	6.9	9.1	9.2	7.5	6.5
SEIC1L	0.4	0.0	0.0	0.0	0.0	0.0	5.3	6.8	9.0	9.1	7.2	6.1
HAPC1	0.6	0.0	0.0	0.0	0.0	0.0	5.1	6.9	9.0	9.0	6.8	6.2
SBRC1	0.6	0.0	0.0	0.0	0.0	0.0	5.1	7.0	9.2	9.2	7.3	6.5
ONSC1L	0.6	0.0	0.0	0.0	0.0	0.0	5.2	6.9	9.0	9.1	7.0	6.2
CEGC1	0.7	0.0	0.0	0.0	0.0	0.0	5.2	7.0	9.2	9.4	7.7	6.9
BURC1L	0.6	0.0	0.0	0.0	0.0	0.0	5.2	7.1	9.3	9.4	7.6	6.8
HYMC1	0.6	0.0	0.0	0.0	0.0	0.0	5.3	7.3	9.5	9.7	8.0	7.2
HOOC1L	0.6	0.0	0.0	0.0	0.0	0.0	5.1	7.1	9.3	9.2	7.2	6.3
KLMC1L	0.8	0.0	0.0	0.0	0.0	0.0	5.1	7.1	9.3	9.2	7.0	6.1
BLKC1	0.6	0.0	0.0	0.0	0.0	0.0	5.2	7.2	9.4	9.3	7.1	6.3
ORIC1L	0.7	0.0	0.0	0.0	0.0	0.0	5.1	7.1	9.3	9.2	6.9	6.1
MAUC1	0.6	0.0	0.0	0.0	0.0	0.0	5.4	7.4	9.6	9.7	7.8	7.0
ARCC1L	0.6	0.0	0.0	0.0	0.0	0.0	5.2	7.3	9.5	9.4	7.3	6.5
BRGC1	0.6	0.0	0.0	0.0	0.0	0.0	5.3	7.4	9.6	9.6	7.6	6.7
LEGC1	0.6	0.0	0.0	0.0	0.0	0.0	5.5	7.5	9.8	10.0	8.0	7.1
MRNC1L	0.6	0.0	0.0	0.0	0.0	0.0	5.4	7.4	9.7	9.7	7.7	6.8
DOSC1	0.7	0.0	0.0	0.0	0.0	0.0	5.5	7.4	9.6	10.0	8.1	7.3
FTSC1L	0.6	0.0	0.0	0.0	0.0	0.0	5.6	7.5	9.8	10.3	8.3	7.3
SCOC1L	0.6	0.0	0.0	0.0	0.0	0.0	5.3	7.4	9.7	9.7	7.6	6.7
FRNC1L	0.6	0.0	0.0	0.0	0.0	0.0	5.3	7.3	9.5	9.5	7.4	6.6
FTBC1	0.5	0.0	0.0	0.0	0.0	0.0	5.7	7.5	10.0	10.5	8.5	7.3

Russian / Napa	Q P F						F R E E Z I N G L E V E L					
	D1	D2	D3	D4	D5	D6	D1	D2	D3	D4	D5	D6
NVRC1	0.4	0.0	0.0	0.0	0.0	0.0	5.8	7.5	10.0	10.5	8.6	7.4

Figure 3.11 Quantitative Precipitation Forecast Web Page

Temperature Forecasts

Separate web pages need to be saved for the Sacramento and San Joaquin Valleys. The procedure for collecting the data from each valley is the same, but with a different web page. The web pages are as follows:

Sacramento Valley:
http://www.wrh.noaa.gov/total_forecast/getprod.php?wfo=sto&prod=XXXSFTSTO&version=0&print=yes
San Joaquin Valley: http://www.wrh.noaa.gov/hnx/printprod.php?sid=hnx&pil=sft

1. Go to the appropriate web page for each valley
2. From the browser menu, go to Edit / Select All to highlight the entire page.
3. Enter Ctrl-C to copy the selected text
4. Open a text editor such as Notepad or Wordpad
5. Enter Ctrl-V to paste the selected text into the text editor.
6. In the text editor, select File / Save As and save the file into the Raw Data directory with file name format SAC_TempFcst_mmddyyyy.txt (Sacramento Valley) or SJR_TempFcst_mmddyyyy.txt (San Joaquin Valley) where mm is the current month, dd is the current day, and yyyy is the current year.

Process Meteorology Forecast

The next step is done from the MET_Forecast_Processor.xlsm . The processing macros are run from the Control tab of the spreadsheet. Set the Forecast Date highlighted in yellow to the current date. Check the file paths on the two lines below the Forecast Date and make sure they are correct for the directory structure on your computer. Click on the Process and Export button to run the macros and generate the WARMF Import files. Ensure that Excel settings allow for running macros. After running the macros, the imported forecast precipitation and temperature can be viewed graphically to identify any errors. Go to the ProcessQPF tab to view precipitation forecast and the ProcessTemp tab shows minimum and maximum temperature graphically. If there are outliers which look like errors, they can be corrected either in the raw data (then re-run the processor) or in the WARMF Import files. By default, the import files are placed in the "WARMF Import" directory. Copy the import file to the WARMF project (Sacramento or San_Joaquin_ directory for importing.

Import Meteorology Data into WARMF

The Excel processors took the raw data downloaded from the Internet and produced comma delimited files which can be imported into WARMF. The files are written to the WARMF Import directory specified on each processor spreadsheet's Control tab. The file names contain METOBS for observed data and METFCST for forecast data and the dates for which the files contain data. Copy those files and paste them into both the WARMF Sacramento River and San Joaquin River application project directories. The project directories by default are called Sacramento and San_Joaquin respectively and are found in the installation path specified by the user.

Before importing meteorology data, the WARMF meteorology files should be returned to the original version before any forecasting began. The set of WARMF meteorology files with data running up to the beginning of the forecasting season should be saved for this purpose before any forecasting is done. By starting with the original meteorology files, all forecasted data will be cleared from the files so after importing new data historical time periods will have only real data or estimates derived from real data.

Extend WARMF Meteorology Files

The first step is to extend the meteorology files into the forecast period. In WARMF, go to the Data Module (Module / Data through the menu). Select Meteorology as the Type of Data. Then choose the Edit / Extrapolate function from the menu. Extrapolate through 5 days after the current day and set the Fill Method to Missing as shown in Figure 3.12. Some of the missing values will be replaced with the real-time and forecast data and the rest will be filled in using data from neighboring stations.

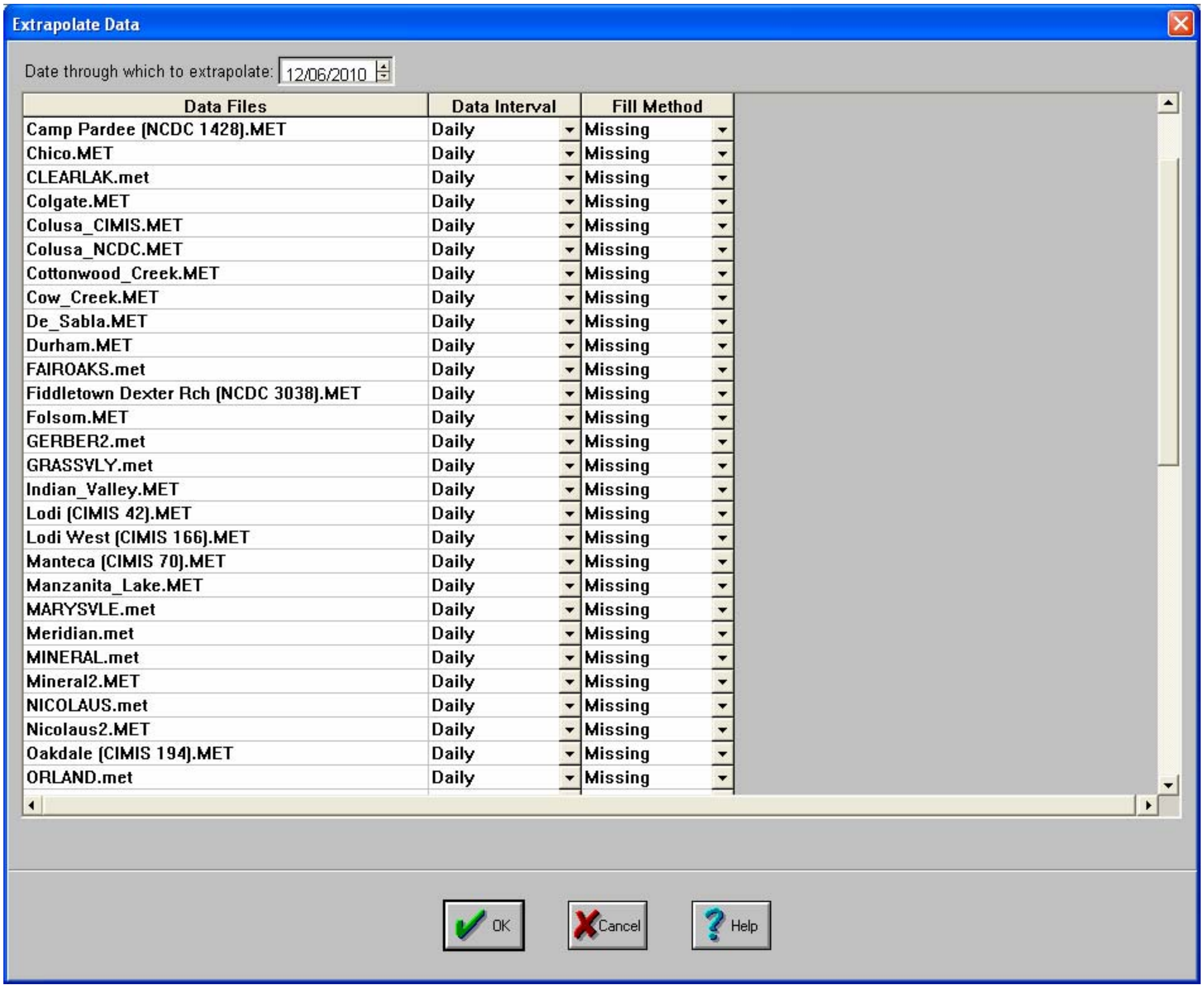


Figure 3.12 Extrapolating Meteorology Data for Forecasting, Step 1

Beyond the forecast period, meteorology predictions are not reliable. To allow the model to run for two weeks into the future, we can extrapolate the meteorology out to 13 days after the current day. Use the Typical fill method to apply average values of meteorology for 6 to 13 days after the current day as shown in Figure 3.13.

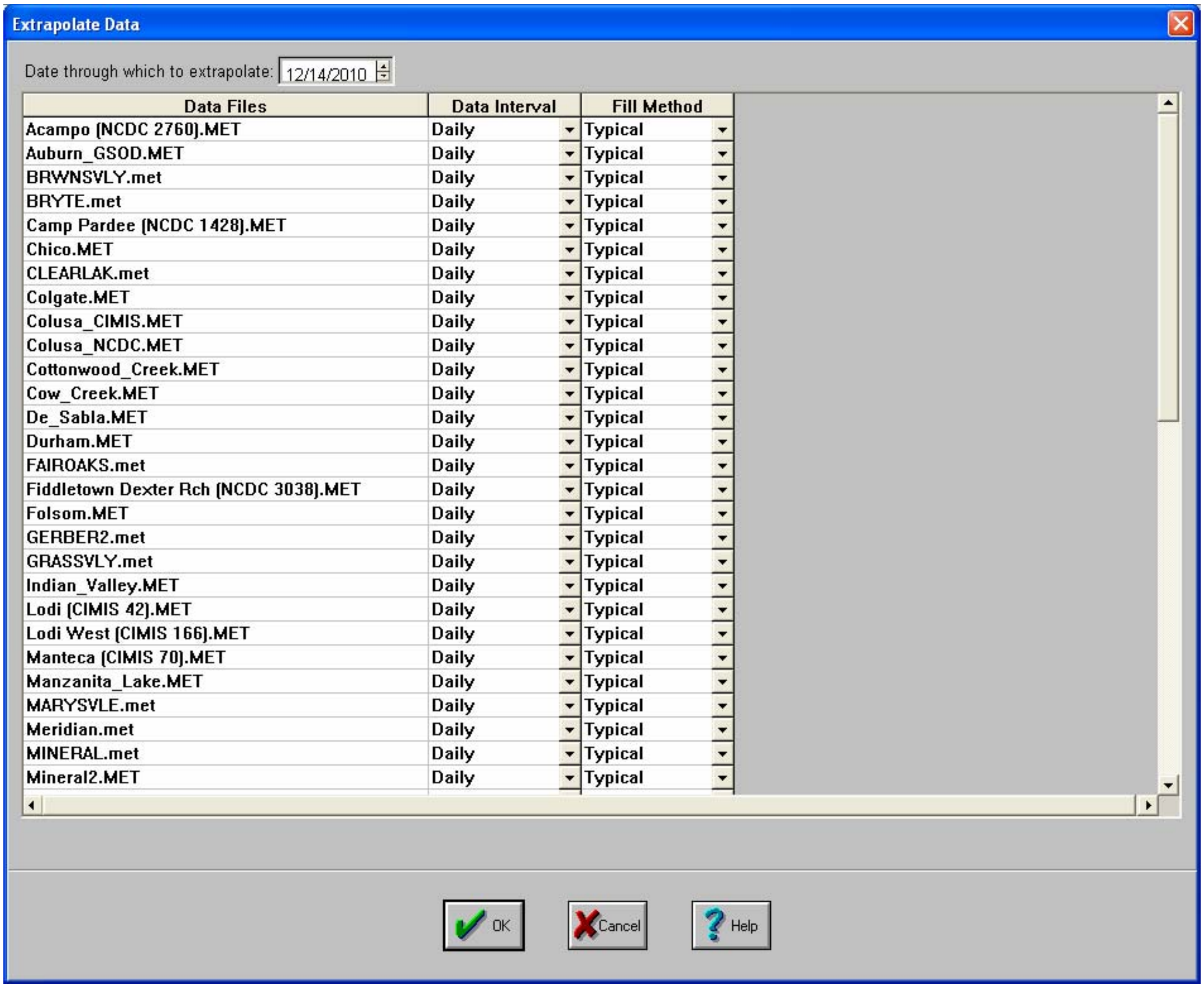


Figure 3.13 Extrapolating Meteorology Data for Forecasting, Step 2

Import Observed and Forecast Data

The WARMF meteorology files are now ready to be filled in with imported observed and forecast data. Select the Edit / Import Delimited function from the Data Module menu. Open the METOBS comma delimited file created by the Excel processor. When the dialog shown below in Figure 3.14 appears, enter 1 line to ignore and 2 header lines and press OK.

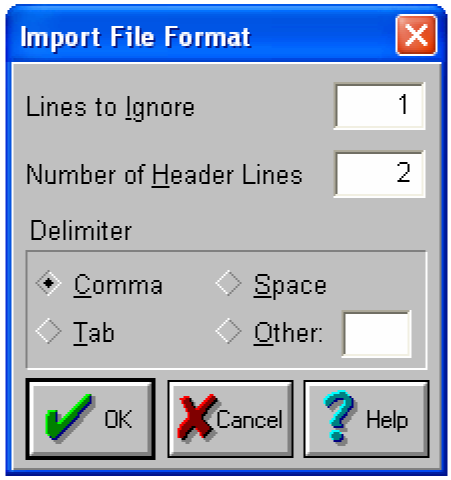
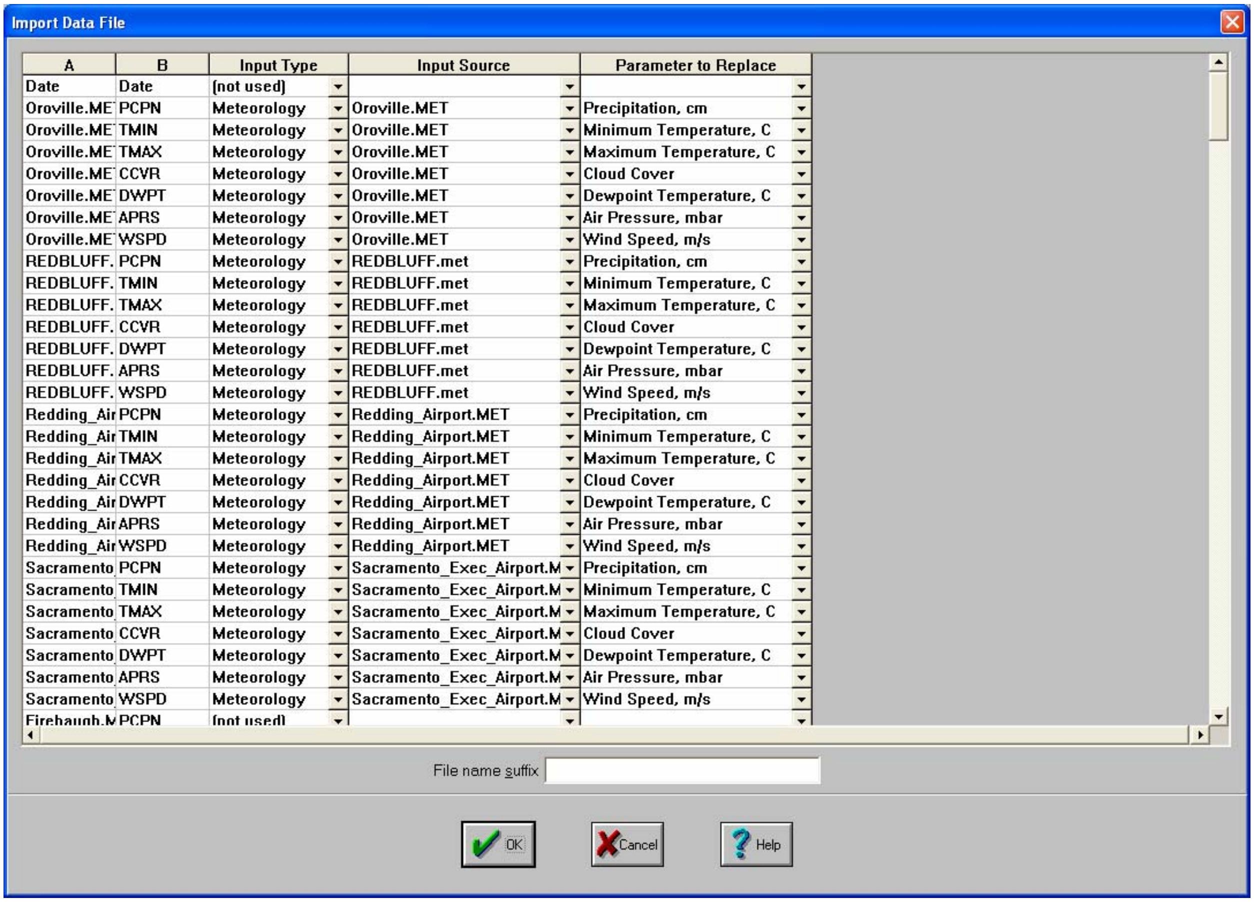


Figure 3.14 Import File Format Dialog

The headers of the comma delimited import file are read and displayed as shown in Figure 3.15. The headers in the import file are lined up with a WARMF data type, data file, and parameter. If the import has been performed before, the settings from the previous import are saved for the new one. Press OK on the dialog to bring the data in the import file into the WARMF meteorology files.



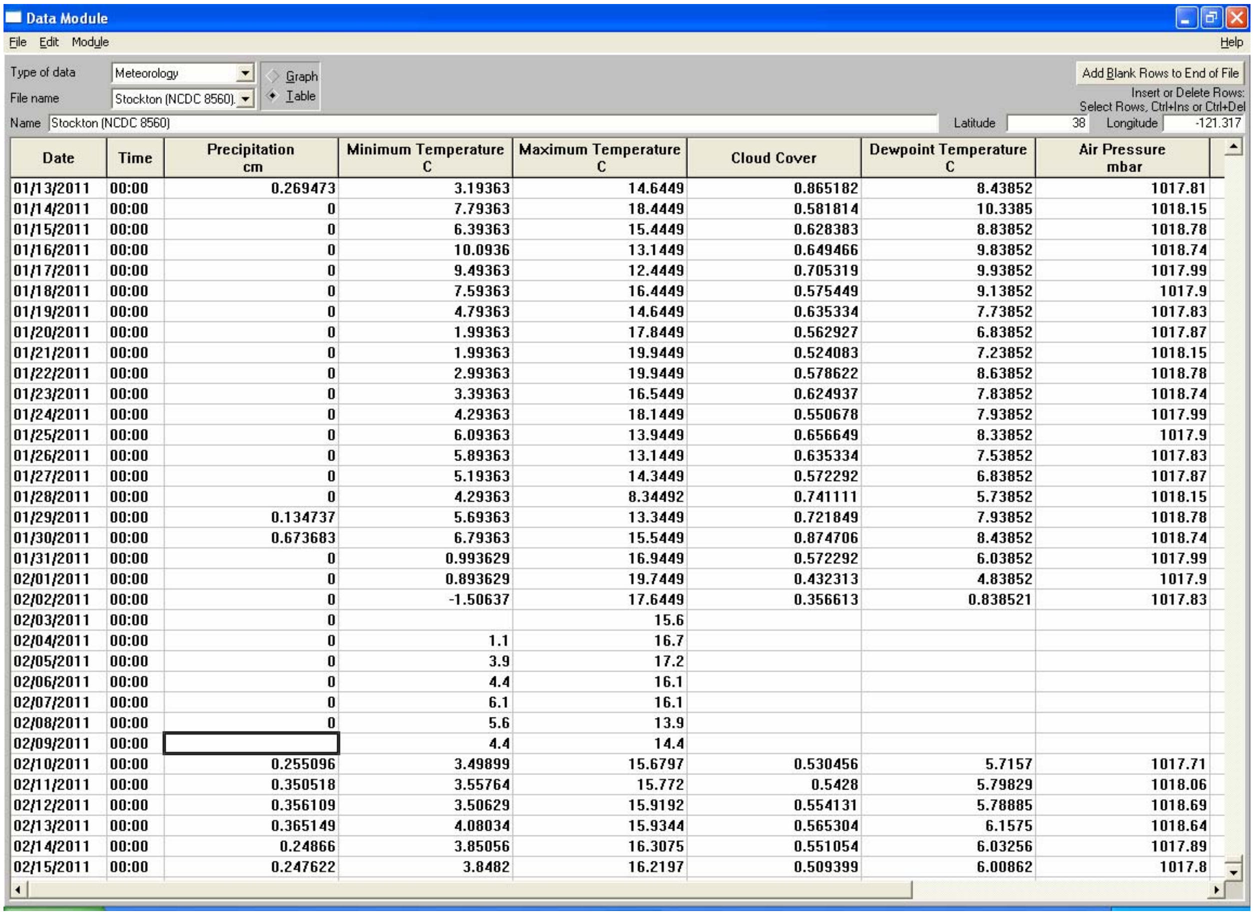
A	B	Input Type	Input Source	Parameter to Replace
Date	Date	(not used)		
Oroville.ME	PCPN	Meteorology	Oroville.MET	Precipitation, cm
Oroville.ME	TMIN	Meteorology	Oroville.MET	Minimum Temperature, C
Oroville.ME	TMAX	Meteorology	Oroville.MET	Maximum Temperature, C
Oroville.ME	CCVR	Meteorology	Oroville.MET	Cloud Cover
Oroville.ME	DWPT	Meteorology	Oroville.MET	Dewpoint Temperature, C
Oroville.ME	APRS	Meteorology	Oroville.MET	Air Pressure, mbar
Oroville.ME	WSPD	Meteorology	Oroville.MET	Wind Speed, m/s
REDBLUFF.	PCPN	Meteorology	REDBLUFF.met	Precipitation, cm
REDBLUFF.	TMIN	Meteorology	REDBLUFF.met	Minimum Temperature, C
REDBLUFF.	TMAX	Meteorology	REDBLUFF.met	Maximum Temperature, C
REDBLUFF.	CCVR	Meteorology	REDBLUFF.met	Cloud Cover
REDBLUFF.	DWPT	Meteorology	REDBLUFF.met	Dewpoint Temperature, C
REDBLUFF.	APRS	Meteorology	REDBLUFF.met	Air Pressure, mbar
REDBLUFF.	WSPD	Meteorology	REDBLUFF.met	Wind Speed, m/s
Redding_Air	PCPN	Meteorology	Redding_Airport.MET	Precipitation, cm
Redding_Air	TMIN	Meteorology	Redding_Airport.MET	Minimum Temperature, C
Redding_Air	TMAX	Meteorology	Redding_Airport.MET	Maximum Temperature, C
Redding_Air	CCVR	Meteorology	Redding_Airport.MET	Cloud Cover
Redding_Air	DWPT	Meteorology	Redding_Airport.MET	Dewpoint Temperature, C
Redding_Air	APRS	Meteorology	Redding_Airport.MET	Air Pressure, mbar
Redding_Air	WSPD	Meteorology	Redding_Airport.MET	Wind Speed, m/s
Sacramento	PCPN	Meteorology	Sacramento_Exec_Airport.M	Precipitation, cm
Sacramento	TMIN	Meteorology	Sacramento_Exec_Airport.M	Minimum Temperature, C
Sacramento	TMAX	Meteorology	Sacramento_Exec_Airport.M	Maximum Temperature, C
Sacramento	CCVR	Meteorology	Sacramento_Exec_Airport.M	Cloud Cover
Sacramento	DWPT	Meteorology	Sacramento_Exec_Airport.M	Dewpoint Temperature, C
Sacramento	APRS	Meteorology	Sacramento_Exec_Airport.M	Air Pressure, mbar
Sacramento	WSPD	Meteorology	Sacramento_Exec_Airport.M	Wind Speed, m/s
Firebaugh.M	PCPN	(not used)		

Figure 3.15 Import File Dialog

After the observed data has been imported, repeat the procedure with the forecast data produced by the Excel preprocessor.

Filling Missing Meteorology Data

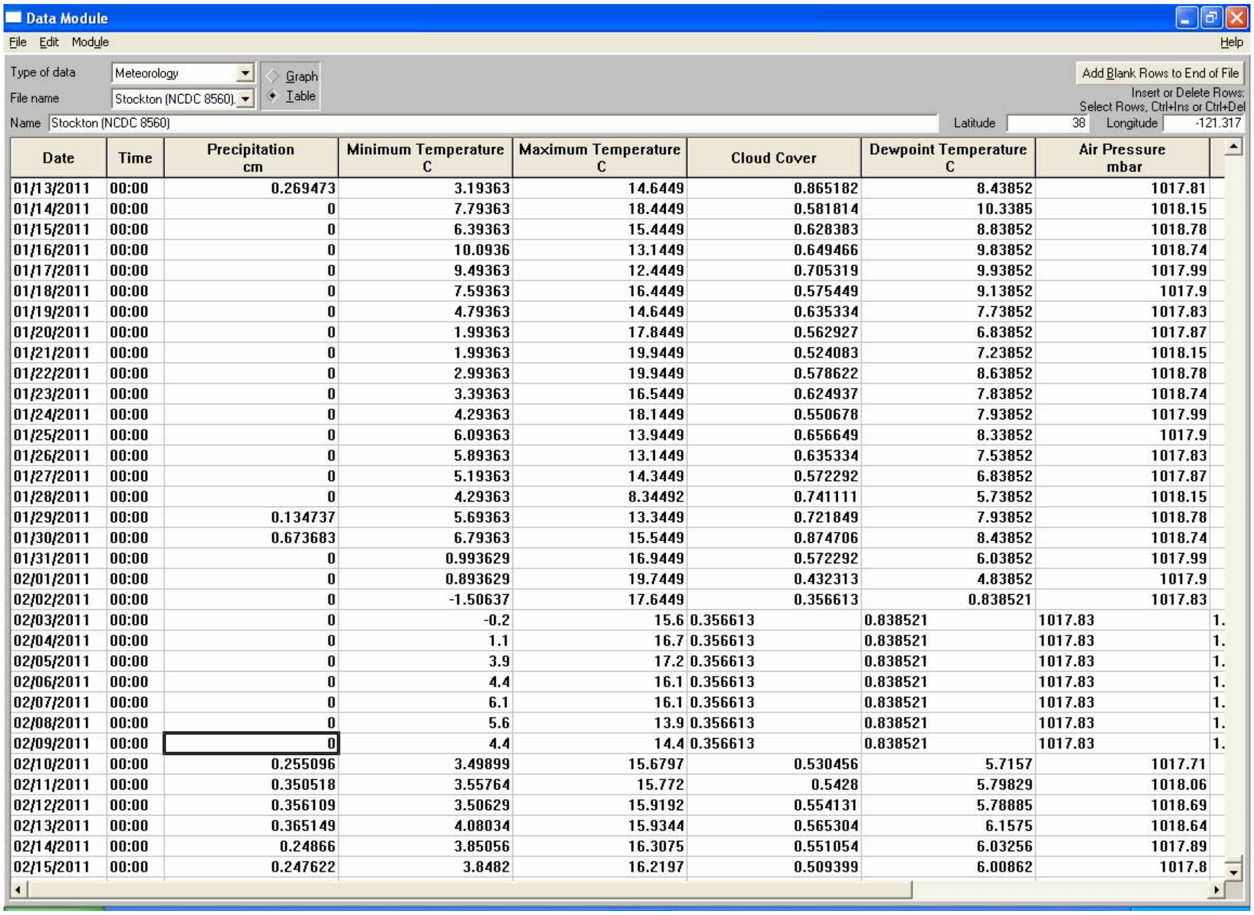
The import process does not provide data for every meteorology parameter nor every meteorology station. To create a complete dataset, the missing data needs to be filled in using values from neighboring stations which have data. Figure 3.16 shows an example meteorology file (for Stockton) after importing real-time observed data and the meteorology forecast. There is no meteorology forecast for cloud cover, dewpoint temperature, air pressure, or wind speed. Some stations will also be missing temperature and/or precipitation forecasts. As long as at least one station has complete data, then the data filling process will be able to fill all the missing data. To do this with forecast data, manually fill in missing values for a single station so it is complete.



Date	Time	Precipitation cm	Minimum Temperature C	Maximum Temperature C	Cloud Cover	Dewpoint Temperature C	Air Pressure mbar
01/13/2011	00:00	0.269473	3.19363	14.6449	0.865182	8.43852	1017.81
01/14/2011	00:00	0	7.79363	18.4449	0.581814	10.3385	1018.15
01/15/2011	00:00	0	6.39363	15.4449	0.628383	8.83852	1018.78
01/16/2011	00:00	0	10.0936	13.1449	0.649466	9.83852	1018.74
01/17/2011	00:00	0	9.49363	12.4449	0.705319	9.93852	1017.99
01/18/2011	00:00	0	7.59363	16.4449	0.575449	9.13852	1017.9
01/19/2011	00:00	0	4.79363	14.6449	0.635334	7.73852	1017.83
01/20/2011	00:00	0	1.99363	17.8449	0.562927	6.83852	1017.87
01/21/2011	00:00	0	1.99363	19.9449	0.524083	7.23852	1018.15
01/22/2011	00:00	0	2.99363	19.9449	0.578622	8.63852	1018.78
01/23/2011	00:00	0	3.39363	16.5449	0.624937	7.83852	1018.74
01/24/2011	00:00	0	4.29363	18.1449	0.550678	7.93852	1017.99
01/25/2011	00:00	0	6.09363	13.9449	0.656649	8.33852	1017.9
01/26/2011	00:00	0	5.89363	13.1449	0.635334	7.53852	1017.83
01/27/2011	00:00	0	5.19363	14.3449	0.572292	6.83852	1017.87
01/28/2011	00:00	0	4.29363	8.34492	0.741111	5.73852	1018.15
01/29/2011	00:00	0.134737	5.69363	13.3449	0.721849	7.93852	1018.78
01/30/2011	00:00	0.673683	6.79363	15.5449	0.874706	8.43852	1018.74
01/31/2011	00:00	0	0.993629	16.9449	0.572292	6.03852	1017.99
02/01/2011	00:00	0	0.893629	19.7449	0.432313	4.83852	1017.9
02/02/2011	00:00	0	-1.50637	17.6449	0.356613	0.838521	1017.83
02/03/2011	00:00	0		15.6			
02/04/2011	00:00	0	1.1	16.7			
02/05/2011	00:00	0	3.9	17.2			
02/06/2011	00:00	0	4.4	16.1			
02/07/2011	00:00	0	6.1	16.1			
02/08/2011	00:00	0	5.6	13.9			
02/09/2011	00:00		4.4	14.4			
02/10/2011	00:00	0.255096	3.49899	15.6797	0.530456	5.7157	1017.71
02/11/2011	00:00	0.350518	3.55764	15.772	0.5428	5.79829	1018.06
02/12/2011	00:00	0.356109	3.50629	15.9192	0.554131	5.78885	1018.69
02/13/2011	00:00	0.365149	4.08034	15.9344	0.565304	6.1575	1018.64
02/14/2011	00:00	0.24866	3.85056	16.3075	0.551054	6.03256	1017.89
02/15/2011	00:00	0.247622	3.8482	16.2197	0.509399	6.00862	1017.8

Figure 3.16 Example Meteorology File After Importing Real-time and Forecast Data

To modify the meteorology file, view it in Table form and scroll to the dates which cover the forecast period. Select one which already has a relatively complete dataset including precipitation and temperature forecasts. Simulation results are not sensitive to cloud cover, air pressure, and wind speed, so errors in estimating these parameters are not likely to cause errors in model simulations. Dewpoint temperature is important in calculations of evapotranspiration, but the model is more sensitive to these calculations in the long-term than in the short-term. A simple approach to fill in these parameters is to copy them from the last line of real-time data. Note that there is also a missing precipitation value 6 days after the current day because precipitation forecasts project 5 days after the current day but temperature forecasts project out an extra day. Fill in the missing precipitation with zero, copy the typical value from the following day, or refer to an extended weather forecast to make a different estimate. Figure 3.17 shows the same data file with manually filled data so it is complete.



Date	Time	Precipitation cm	Minimum Temperature C	Maximum Temperature C	Cloud Cover	Dewpoint Temperature C	Air Pressure mbar	
01/13/2011	00:00	0.269473	3.19363	14.6449	0.865182	8.43852	1017.81	
01/14/2011	00:00	0	7.79363	18.4449	0.581814	10.3385	1018.15	
01/15/2011	00:00	0	6.39363	15.4449	0.628383	8.83852	1018.78	
01/16/2011	00:00	0	10.0936	13.1449	0.649466	9.83852	1018.74	
01/17/2011	00:00	0	9.49363	12.4449	0.705319	9.93852	1017.99	
01/18/2011	00:00	0	7.59363	16.4449	0.575449	9.13852	1017.9	
01/19/2011	00:00	0	4.79363	14.6449	0.635334	7.73852	1017.83	
01/20/2011	00:00	0	1.99363	17.8449	0.562927	6.83852	1017.87	
01/21/2011	00:00	0	1.99363	19.9449	0.524083	7.23852	1018.15	
01/22/2011	00:00	0	2.99363	19.9449	0.578622	8.63852	1018.78	
01/23/2011	00:00	0	3.39363	16.5449	0.624937	7.83852	1018.74	
01/24/2011	00:00	0	4.29363	18.1449	0.550678	7.93852	1017.99	
01/25/2011	00:00	0	6.09363	13.9449	0.656649	8.33852	1017.9	
01/26/2011	00:00	0	5.89363	13.1449	0.635334	7.53852	1017.83	
01/27/2011	00:00	0	5.19363	14.3449	0.572292	6.83852	1017.87	
01/28/2011	00:00	0	4.29363	8.34492	0.741111	5.73852	1018.15	
01/29/2011	00:00	0.134737	5.69363	13.3449	0.721849	7.93852	1018.78	
01/30/2011	00:00	0.673683	6.79363	15.5449	0.874706	8.43852	1018.74	
01/31/2011	00:00	0	0.993629	16.9449	0.572292	6.03852	1017.99	
02/01/2011	00:00	0	0.893629	19.7449	0.432313	4.83852	1017.9	
02/02/2011	00:00	0	-1.50637	17.6449	0.356613	0.838521	1017.83	
02/03/2011	00:00	0	-0.2	15.6	0.356613	0.838521	1017.83	1.
02/04/2011	00:00	0	1.1	16.7	0.356613	0.838521	1017.83	1.
02/05/2011	00:00	0	3.9	17.2	0.356613	0.838521	1017.83	1.
02/06/2011	00:00	0	4.4	16.1	0.356613	0.838521	1017.83	1.
02/07/2011	00:00	0	6.1	16.1	0.356613	0.838521	1017.83	1.
02/08/2011	00:00	0	5.6	13.9	0.356613	0.838521	1017.83	1.
02/09/2011	00:00	0	4.4	14.4	0.356613	0.838521	1017.83	1.
02/10/2011	00:00	0.255096	3.49899	15.6797	0.530456	5.7157	1017.71	
02/11/2011	00:00	0.350518	3.55764	15.772	0.5428	5.79829	1018.06	
02/12/2011	00:00	0.356109	3.50629	15.9192	0.554131	5.78885	1018.69	
02/13/2011	00:00	0.365149	4.08034	15.9344	0.565304	6.1575	1018.64	
02/14/2011	00:00	0.24866	3.85056	16.3075	0.551054	6.03256	1017.89	
02/15/2011	00:00	0.247622	3.8482	16.2197	0.509399	6.00862	1017.8	

Figure 3.17 Example Meteorology File with Data Filled Manually

The final step for meteorology data processing is to automatically fill in missing data. In the Data Module menu, select Edit / Fill Missing Data. A list of all meteorology files in the directory is displayed. Click OK on the dialog to start the data filling process. The meteorology files are then modified by filling in their missing data using values estimated from other meteorology stations. The method is described under Filling Missing Meteorology Data in Chapter 2 of this report. The automatic data filling process may take an hour or more. While it is working, the boundary inflow data can be collected and processed.

Collect and Process Boundary Inflow Data

Table 2.4 and Table 2.5 listed the boundary inflows and their data sources. An Excel 2007 processor called Inflow_Processor.xlsm is used to translate data files collected from USGS and CDEC into comma delimited files which can be imported into WARMF.

Real-time USGS Flow Data

1. Go to http://waterdata.usgs.gov/nwis/dv?referred_module=sw&search_criteria=site_no_file_attachment&search_criteria=site_tp_cd&submitted_form=introduction
2. Under File of Site Numbers, click on Browse and select USGSsites.txt

3. In the last section on the page, Retrieve USGS Surface-Water Data for Selected Sites, set the date range for downloading. The beginning date is the 1st of the current month and the end date should be left blank. Choose Tab-separated data and click on Submit.
4. Save the file to the Raw Data directory with file name of the form USGS_mmyyyy.txt where mm is the current month and yyyy is the current year.

A screen shot of the USGS website with the appropriate settings is shown in Figure 3.18.

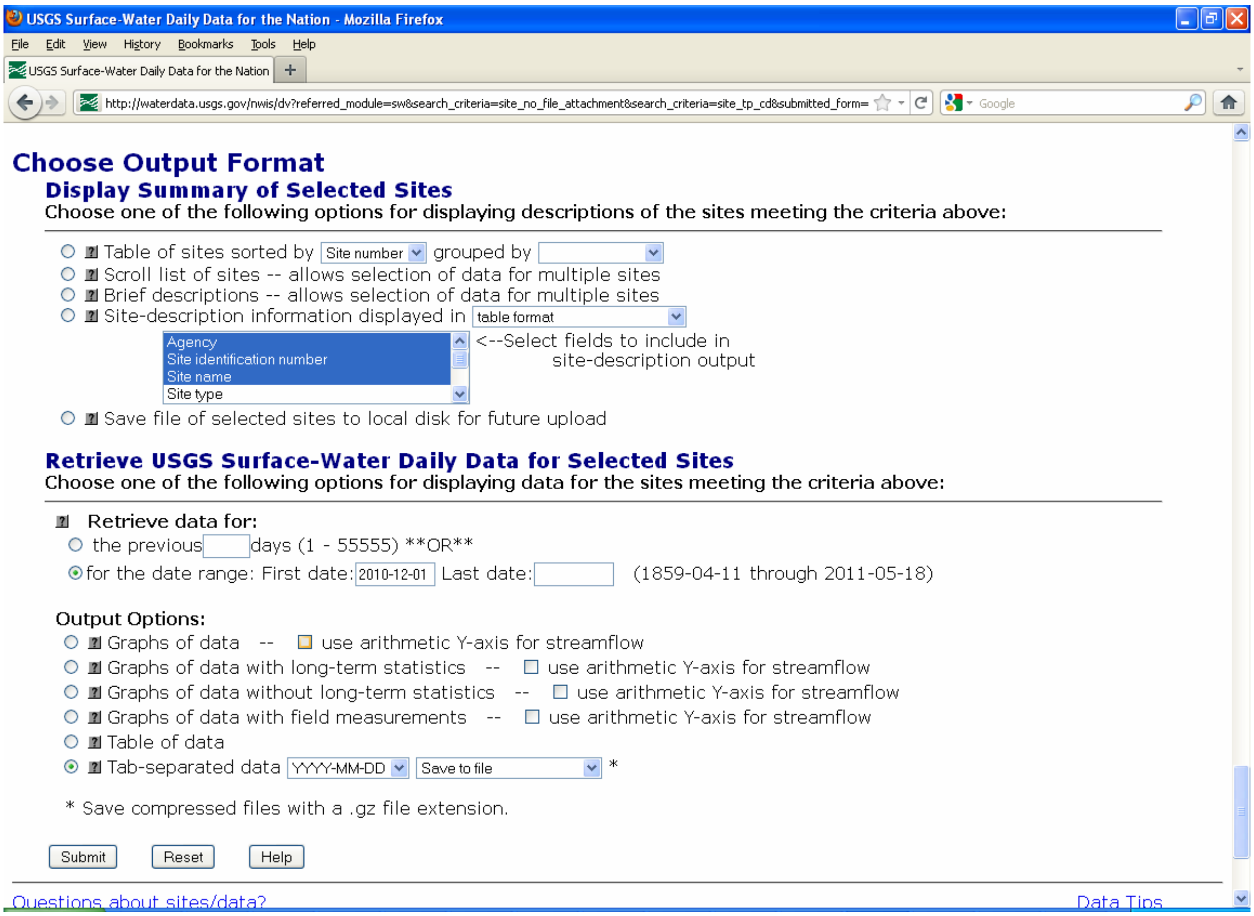


Figure 3.18 USGS Web Site for Downloading Real-time Flow

Real-time CDEC Flow Data

1. Go to http://cdec.water.ca.gov/cgi-progs/queryGroupCSV
2. Enter Group ID SF1, the 1st of the current month for the Start Date, and leave End Date blank
3. Click Download CSV Data Now and save to the Raw Data directory with file name in the form CDEC_mmyyyy.csv where mm is the current month and yyyy is the current year

A screenshot of the CDEC web site for downloading group data is shown in Figure 3.19.

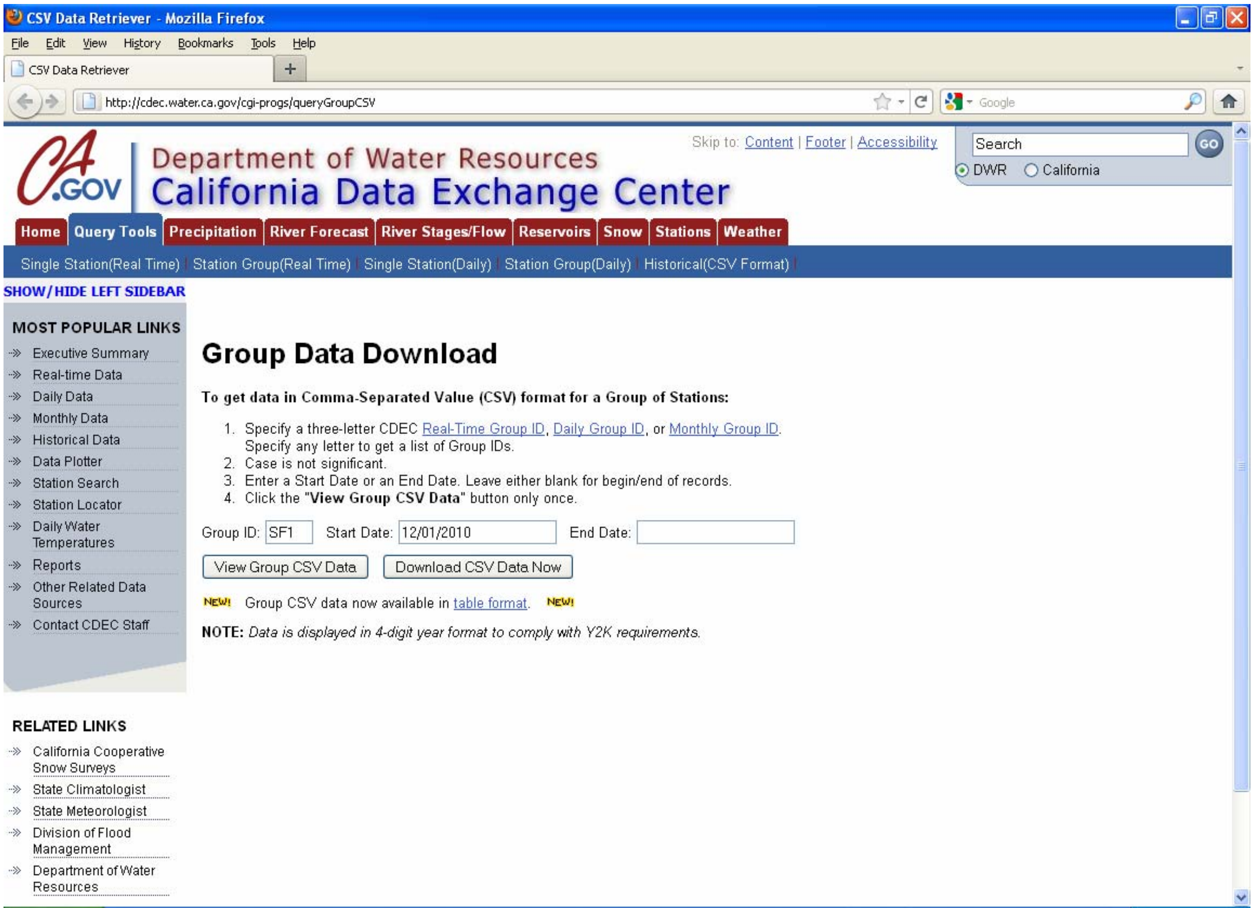
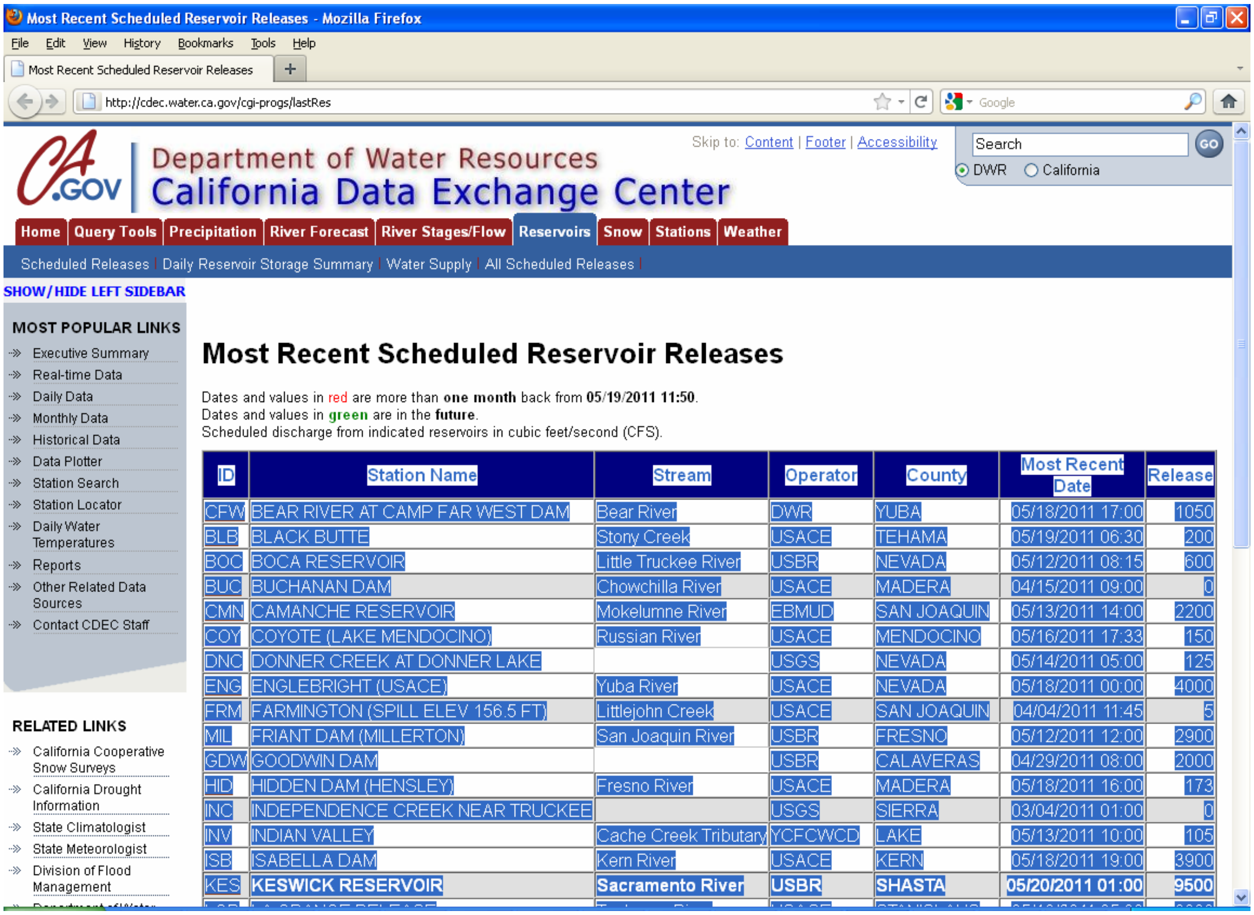


Figure 3.19 CDEC Web Site for Downloading Group Data

Scheduled Reservoir Releases

1. Go to http://cdec.water.ca.gov/cgi-progs/lastRes
2. Highlight the entire table including headings and copy it (Ctrl+C or Edit / Copy in the browser menu)
3. Open Notepad and paste in the table, checking to make sure all columns were copied successfully.
4. In Notepad, save the file in the inflow Raw Data directory as Scheduled_Releases_mmddyyyy.txt where mmddyyyy refers to the day, month, and year of the current date.

A screenshot of the CDEC scheduled releases website with table highlighted is shown in Figure 3.20.



Most Recent Scheduled Reservoir Releases - Mozilla Firefox

http://cdec.water.ca.gov/cgi-progs/lastRes

Department of Water Resources
California Data Exchange Center

Home | Query Tools | Precipitation | River Forecast | River Stages/Flow | Reservoirs | Snow | Stations | Weather

Scheduled Releases | Daily Reservoir Storage Summary | Water Supply | All Scheduled Releases

Most Recent Scheduled Reservoir Releases

Dates and values in red are more than **one month** back from **05/19/2011 11:50**.
Dates and values in **green** are in the **future**.
Scheduled discharge from indicated reservoirs in cubic feet/second (CFS).

ID	Station Name	Stream	Operator	County	Most Recent Date	Release
CFW	BEAR RIVER AT CAMP FAR WEST DAM	Bear River	DWR	YUBA	05/18/2011 17:00	1050
BLB	BLACK BUTTE	Stony Creek	USACE	TEHAMA	05/19/2011 06:30	200
BOC	BOCA RESERVOIR	Little Truckee River	USBR	NEVADA	05/12/2011 08:15	600
BUC	BUCHANAN DAM	Chowchilla River	USACE	MADERA	04/15/2011 09:00	0
CMN	CAMANCHE RESERVOIR	Mokelumne River	EBMUD	SAN JOAQUIN	05/13/2011 14:00	2200
COY	COYOTE (LAKE MENDOCINO)	Russian River	USACE	MENDOCINO	05/16/2011 17:33	150
DNC	DONNER CREEK AT DONNER LAKE		USGS	NEVADA	05/14/2011 05:00	125
ENG	ENGLEBRIGHT (USACE)	Yuba River	USACE	NEVADA	05/18/2011 00:00	4000
FRM	FARMINGTON (SPILL ELEV 156.5 FT)	Littlejohn Creek	USACE	SAN JOAQUIN	04/04/2011 11:45	5
MIL	FRIANT DAM (MILLERTON)	San Joaquin River	USBR	FRESNO	05/12/2011 12:00	2900
GDW	GOODWIN DAM		USBR	CALAVERAS	04/29/2011 08:00	2000
HID	HIDDEN DAM (HENSLEY)	Fresno River	USACE	MADERA	05/18/2011 16:00	173
INC	INDEPENDENCE CREEK NEAR TRUCKEE		USGS	SIERRA	03/04/2011 01:00	0
INV	INDIAN VALLEY	Cache Creek Tributary	YCFCWCD	LAKE	05/13/2011 10:00	105
ISB	ISABELLA DAM	Kern River	USACE	KERN	05/18/2011 19:00	3900
KES	**KESWICK RESERVOIR**	**Sacramento River**	**USBR**	**SHASTA**	**05/20/2011 01:00**	**9500**

Figure 3.20 CDEC Web Site with Most Recent Scheduled Reservoir Releases

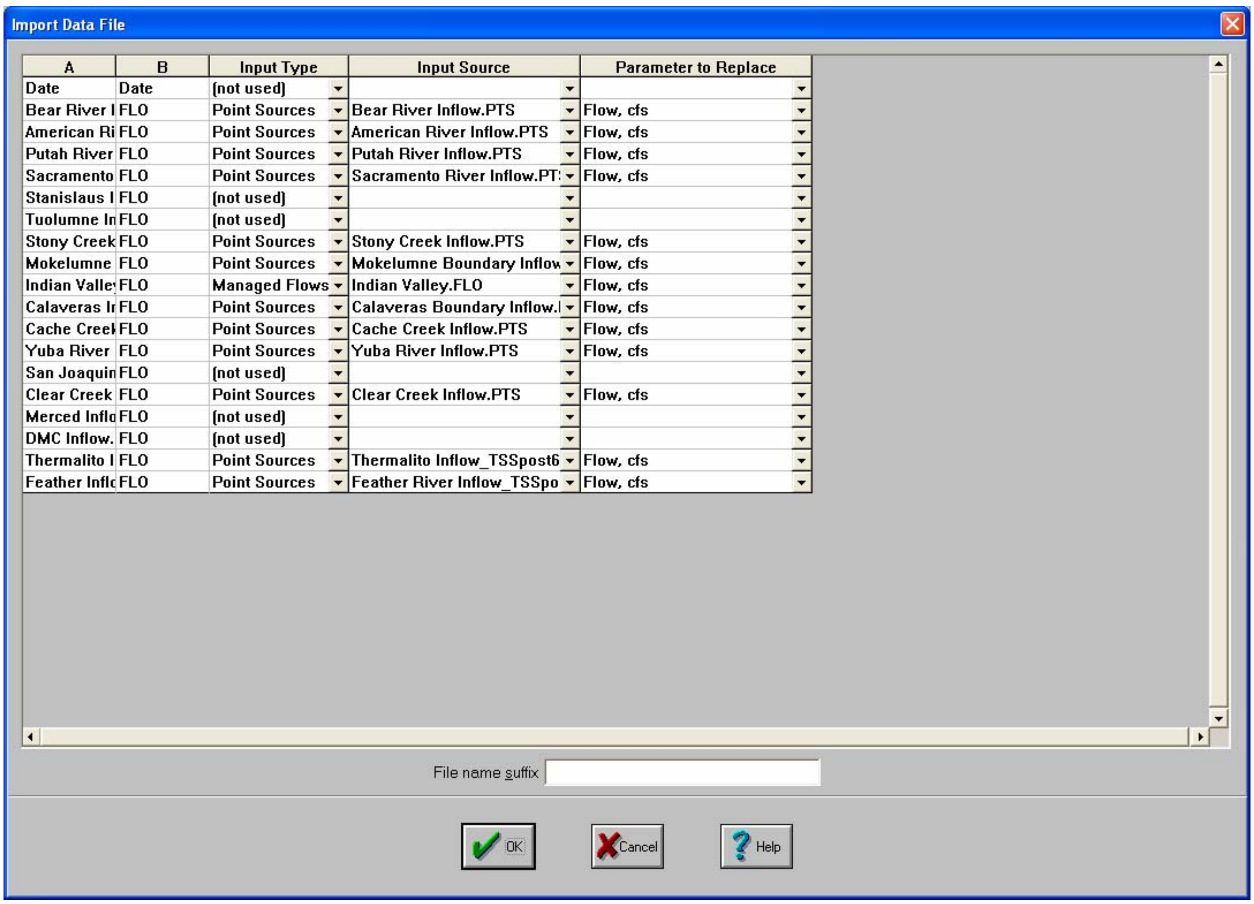
Process Boundary Inflows

The next step is done from the Inflow_Processor.xlsm spreadsheet. The processing macros are run from the Control tab of the spreadsheet with instructions on the Instructions tab. On the Control tab, set the Start Date to the beginning of the forecast period and the End Date to 13 days after the current date. Make sure the file paths shown below the start and end dates reflect the correct directory structure. Then press the Process and Export button to generate the WARMF import files.

After generating the WARMF input files, it might be desirable to manually adjust them to show multiple future scheduled flow changes. Column G of the Forecasts tab highlights in yellow cases where forecasts are in the future. Making adjustments is important if there are multiple future scheduled flows for a single reservoir. At the CDEC most recent scheduled reservoir releases web page, click on the 3-letter ID code to the left of a reservoir highlighted in bold green. The ensuing page may show multiple future scheduled releases. Make manual changes to the spreadsheet's Forecasts page and then click on the Update Releases button to re-create the WARMF import file. By default the import files appear in the "WARMF Import" directory. Copy the import file to the WARMF project (Sacramento or San_Joaquin) directory for importing.

Import Boundary Inflow Data

Once the WARMF import file has been generated by the Inflow_Processor.xlsm spreadsheet, copy it into the project directories for the Sacramento and San Joaquin River WARMF applications. Open WARMF and go to the Data Module (Module / Data in the menu). In the Data Module, select Edit / Import Delimited. Chose the WARMF import file, 1 line to ignore, and 2 header lines. The headers of the file will be read and displayed as shown in Figure 3.21 to be linked to WARMF time series inputs. If the import routine has been run before, the previous settings are remembered so the input type, file name, and parameter to not have to be entered by hand.



A	B	Input Type	Input Source	Parameter to Replace
Date	Date	(not used)		
Bear River I	FLO	Point Sources	Bear River Inflow.PTS	Flow, cfs
American Ri	FLO	Point Sources	American River Inflow.PTS	Flow, cfs
Putah River	FLO	Point Sources	Putah River Inflow.PTS	Flow, cfs
Sacramento	FLO	Point Sources	Sacramento River Inflow.PT:	Flow, cfs
Stanislaus I	FLO	(not used)		
Tuolumne In	FLO	(not used)		
Stony Creek	FLO	Point Sources	Stony Creek Inflow.PTS	Flow, cfs
Mokelumne	FLO	Point Sources	Mokelumne Boundary Inflow	Flow, cfs
Indian Valle	FLO	Managed Flows	Indian Valley.FLO	Flow, cfs
Calaveras Ir	FLO	Point Sources	Calaveras Boundary Inflow.I	Flow, cfs
Cache Creel	FLO	Point Sources	Cache Creek Inflow.PTS	Flow, cfs
Yuba River	FLO	Point Sources	Yuba River Inflow.PTS	Flow, cfs
San Joaquin	FLO	(not used)		
Clear Creek	FLO	Point Sources	Clear Creek Inflow.PTS	Flow, cfs
Merced Inflo	FLO	(not used)		
DMC Inflow.	FLO	(not used)		
Thermalito I	FLO	Point Sources	Thermalito Inflow_TSSpost6	Flow, cfs
Feather Inflc	FLO	Point Sources	Feather River Inflow_TSSpo	Flow, cfs

Figure 3.21 Boundary Inflows Import Dialog

Run Forecast Simulation

Once the observed meteorology, forecast meteorology, and boundary inflows have been imported into WARMF, the model is ready to run. Create a new scenario using the same method outlined in the Warm Start Simulation section of this chapter and open it in the Scenario Manager so it appears at the bottom of the Scenario menu. Select the scenario to activate it and then select Scenario / Run. The run dialog will appear. Set the simulation start date to the beginning of the forecast season, the end date to 13 days after the current date, and choose the warm start file created for forecasting. The simulation dialog will appear as shown below.

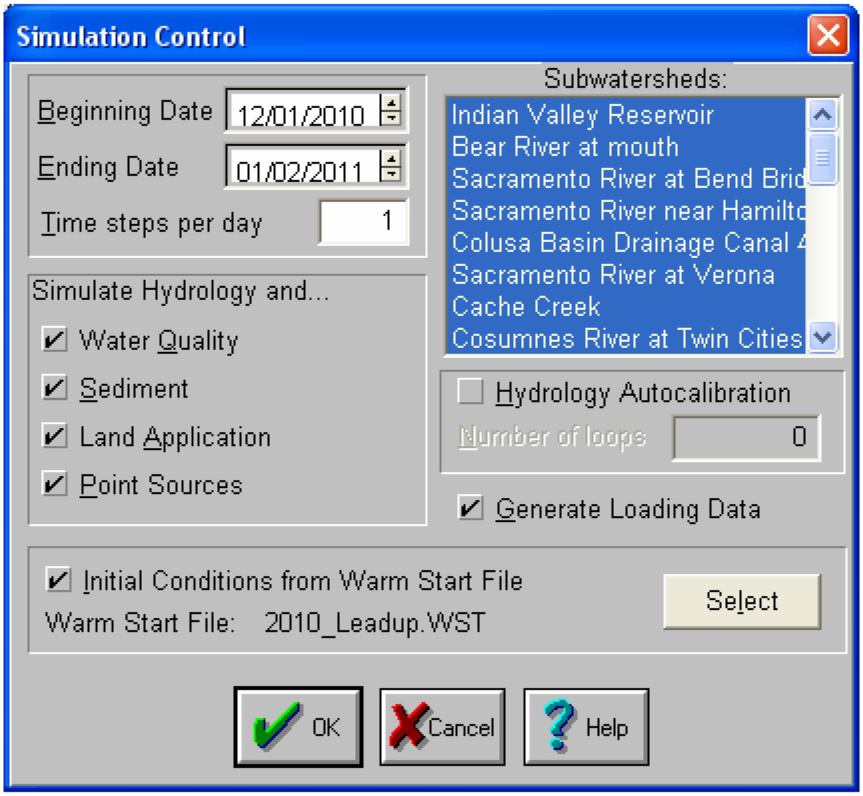


Figure 3.22 Forecast Simulation Dialog

Forecasting Procedure Summary

This section summarizes the steps described in detail earlier in this chapter.

Perform these actions once at the beginning of the forecasting season:

1. Extrapolate air quality data through the forecasting season using the Typical fill method. (Page 3-17)
2. Extrapolate managed flow data through the forecasting season using the Typical fill method. (Page 3-18)
3. Extrapolate point source data through the forecasting season using the Typical fill method. (Page 3-19)
4. Extrapolate meteorology data through the forecasting season using the Missing fill method. (Page 3-20)
5. Import available meteorology data into WARMF. (Page 3-31)
6. Import available air/rain chemistry, managed flow, and point source data into WARMF.
7. Run a warm start simulation ending the day before the forecast season. (Page 3-21)
8. Save a copy of all meteorology files before performing any forecasts.

Perform these actions on the day a forecast is needed:

1. Download CIMIS meteorology data. (Page 3-24)
2. Download GSOD meteorology data. (Page 3-25)
3. Download CDEC meteorology data. (Page 3-26)
4. Pre-process real-time meteorology data using Met_Observed_Processor.xlsm. (Page 3-27)
5. Download precipitation forecast. (Page 3-28)
6. Download temperature forecast. (Page 3-28)
7. Pre-process meteorology forecast using Met_Forecast_Processor.xlsm. (Page 3-29)
8. Copy meteorology files saved from before forecasting season to overwrite files containing forecasts.
9. Extrapolate meteorology files through 5 days after the current date using the Missing fill method. (Page 3-30)
10. Extrapolate meteorology files through 13 days after the current date using the Typical fill method. (Page 3-30)
11. Import real-time meteorology data into WARMF. (Page 3-31)
12. Import meteorology forecast into WARMF. (Page 3-31)
13. Manually fill missing data during forecast period for one meteorology station. (Page 3-33)
14. Use Fill Missing Data function to automatically fill in meteorology data. (Page 3-33)
15. Download USGS real-time flow data. (Page 3-35)
16. Download CDEC real-time flow data. (Page 3-36)
17. Download CDEC Most Recent Scheduled Reservoir Releases. (Page 3-37)
18. Pre-process real-time and forecast flow data using Inflow_Processor.xlsm. (Page 3-38)
19. Import real-time and forecast flows into WARMF. (Page 3-39)
20. Run forecast simulation from first day of forecast season through 14 days after the current day. (Page 3-39)

4 WARMF FORECASTING RESULTS

The WARMF forecasting process was tested from December 1, 2010 through February 3, 2011. During the forecast period there was a storm in early December and a series of storms from mid to late December but the remainder of the forecast period was dry. Fifteen forecasts were performed over this time period, weekly when conditions were dry but daily when major storms were approaching. It is important to know the accuracy of the forecasts if they are used to guide management actions. The accuracy of the forecast results depends on the accuracy of the inputs and the accuracy of the model. The accuracy of WARMF simulation results is not known at the time a forecast is made, but for the forecasts made during the testing process an analysis was performed after the forecasts were complete to determine how the flow and turbidity forecasts compared against measured data.

Meteorology Forecast Results

The Quantitative Precipitation Forecast issued by the California-Nevada River Forecast Center was the key component for generating projected future meteorology inputs for WARMF. The results can be scored by their accuracy and by volumetric error. A full analysis of meteorology forecast error and its potential effect on WARMF simulation errors would require analyzing forecasts and measured precipitation throughout the Sacramento and San Joaquin River watersheds. A simpler analysis was done by choosing one meteorology station as an example.

The Mineral meteorology station in northeast Tehama County averages 55 inches of precipitation per year, more than all but two of the 71 meteorology stations used by WARMF in the Sacramento and San Joaquin River watershed combined. Selection of a relatively wet station allows for a comparison under conditions for which the model is most sensitive. Various methods can be used to evaluate meteorology forecasts including volume balance and absolute error (Charba et al. 2003).

Figure 4.1 shows daily measured precipitation in black and the 15 meteorology forecasts in colors. In 29 cases both the forecast and actual precipitation were zero while 13 times both forecast and actual precipitation were greater than zero. There were twelve cases where precipitation of at least 0.1 cm occurred when there was no precipitation in the forecast. On two occasions, the precipitation forecast was greater than zero but no precipitation occurred. Figure 4.2 shows cumulative precipitation over the forecasting period. The forecast precipitation averaged 60% of actual precipitation. As a result, flow simulated in WARMF is expected to be less than observed because too little precipitation will produce too little runoff.

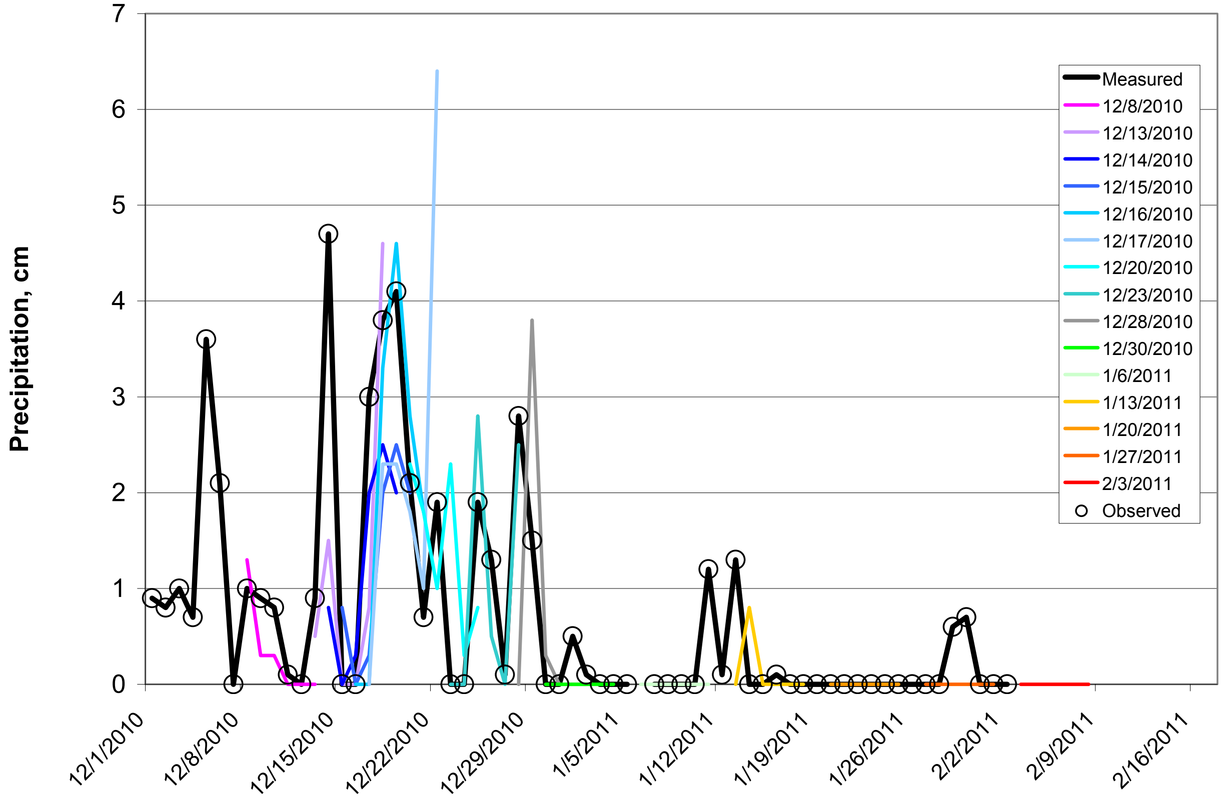


Figure 4.1 Measured and Forecast Precipitation by Date, Mineral Station

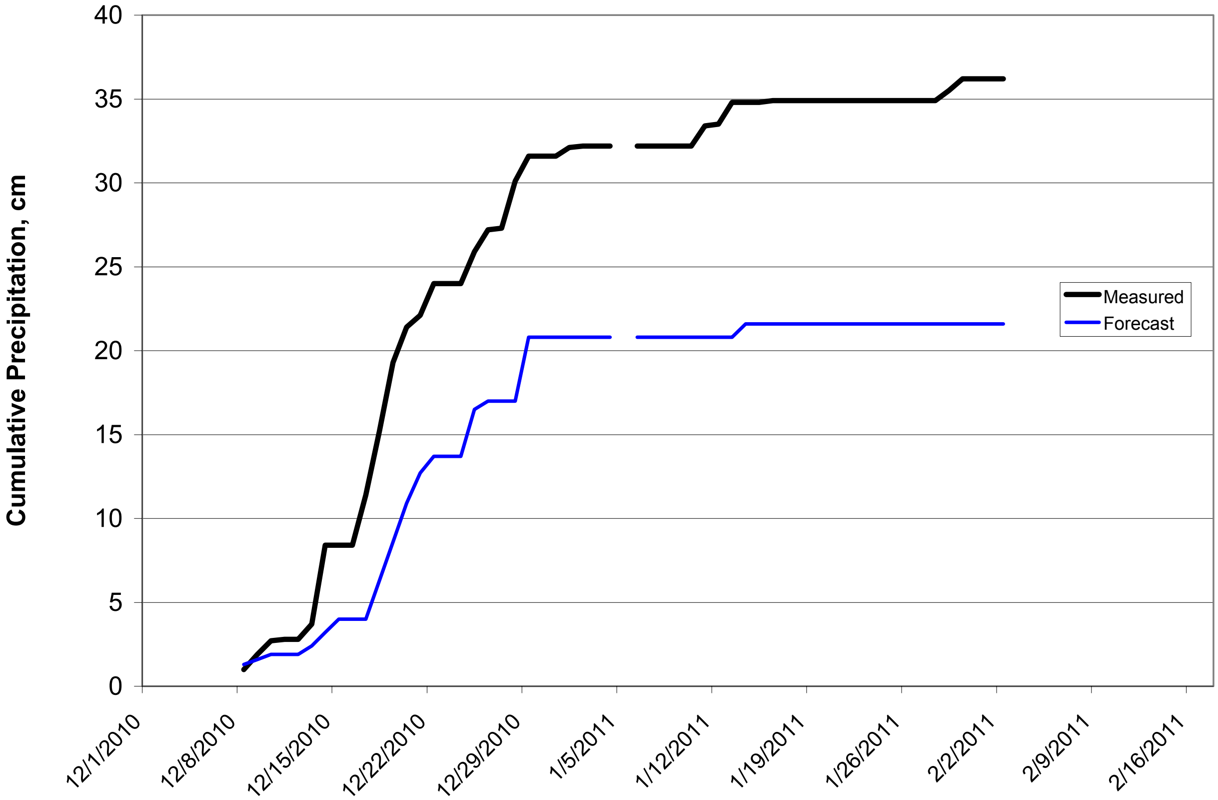


Figure 4.2 Measured and Forecast Cumulative Precipitation Volume, Mineral Station

Table 4.1 shows the relative and absolute errors for each forecast day. Relative error is the average of the differences between simulated and measured values. Absolute error is the average of the absolute values of the differences between simulated and measured. Relative error is a measure of model accuracy or bias, so as expected from Figure 4.2 the forecast precipitation is less than observed for all days of the forecast. The absolute error is a measure of forecast precision. The day of the forecast simulation is listed as "Day 1" shown in the table. The error is actually highest on the first forecast day and decreases for days further into the future. This is not an expected result, likely the effect of random chance.

Table 4.1 Precipitation Error for each Forecast Day, Mineral Station

Measure	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Relative Error, in	-0.28	-0.11	-0.17	-0.06	-0.12	0.02
Absolute Error, in	0.36	0.35	0.25	0.22	0.20	0.34
Relative Error, %	-64%	-28%	-36%	-14%	-31%	3%
Absolute Error, %	80%	86%	54%	50%	49%	63%

Boundary Inflow Forecast Results

Scheduled reservoir releases did not generally have dynamic release schedules reflecting expected changes in release given meteorology forecasts. Figure 4.3 and Figure 4.4 show the combined flow of all model boundary inflows in the Sacramento River watershed and San Joaquin River watershed respectively. For the San Joaquin River, the San Joaquin River at Lander Avenue boundary condition is excluded because the gage at that location is no longer operational. Flow input to WARMF at that location is based on average flows for the day of the year, but there is no measured data to directly evaluate the error at that location. The forecast flows are in colors with the measured combined flow in black. Because the forecast flows change little, the error increases toward the end of the forecast time period.

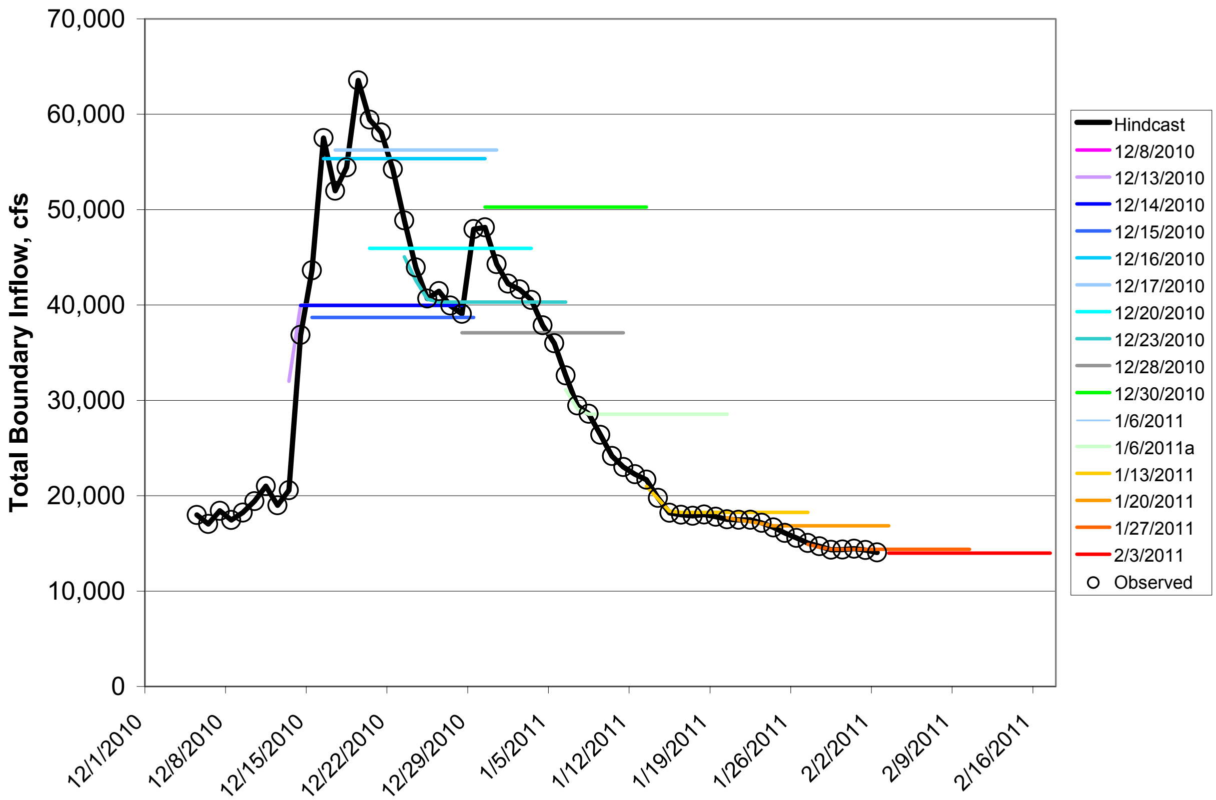


Figure 4.3 Measured Hindcast and Forecast of Combined Inflows, Sacramento River

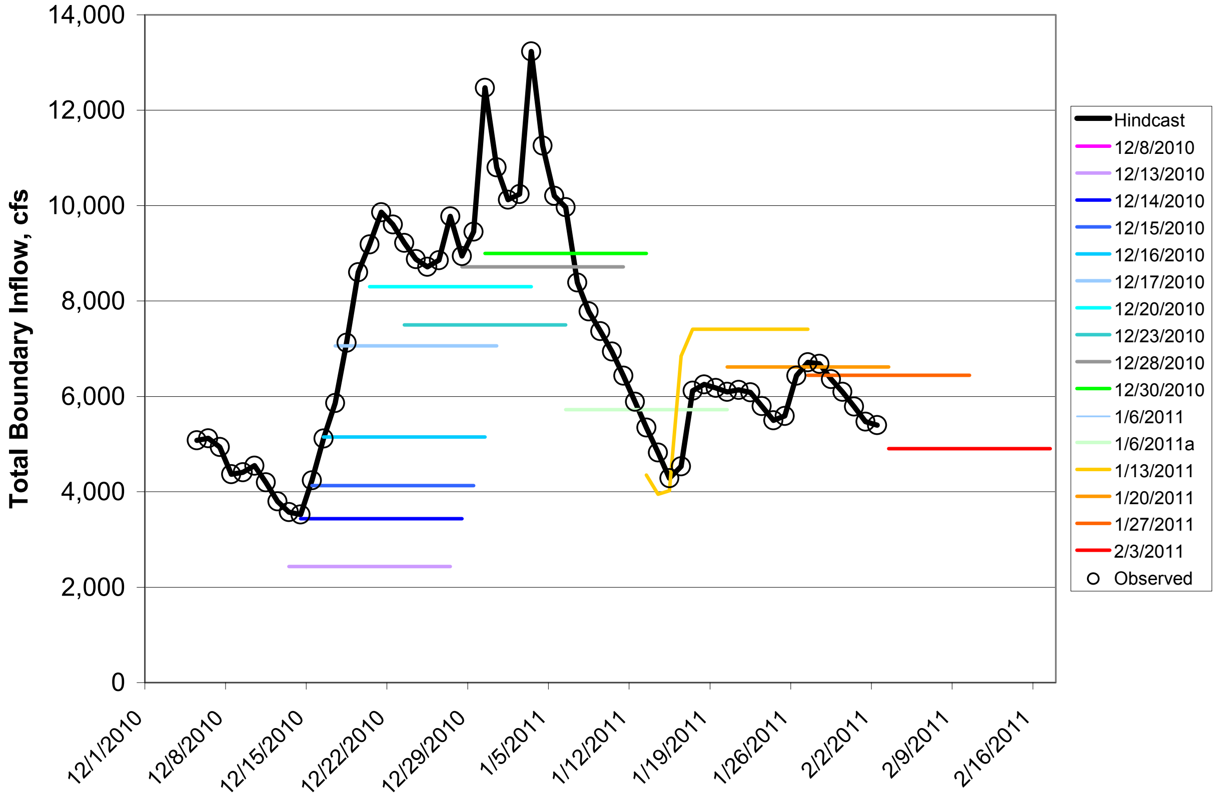


Figure 4.4 Measured Hindcast and Forecast of Combined Inflows, San Joaquin River

Table 4.2 and Table 4.3 show the error of boundary inflow forecasts for the Sacramento River and San Joaquin River boundary inflows. As expected, error tends to increase for forecast days father in the future.

Table 4.2 Combined Boundary Inflow Error for Six Forecast Days, Sacramento River

Measure	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Relative Error, cfs	-1,784	-3,668	-5,119	-5,564	-4,595	-4,220
Absolute Error, cfs	4,806	5,717	6,432	7,149	7,036	8,154
Relative Error, %	-5%	-10%	-13%	-14%	-12%	-11%
Absolute Error, %	13%	15%	16%	18%	18%	21%

Table 4.3 Combined Boundary Inflow Error for Six Forecast Days, San Joaquin River

Measure	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Relative Error, cfs	-1,125	-1,202	-1,599	-1,546	-2,061	-2,067
Absolute Error, cfs	1,376	1,271	1,687	2,043	2,500	2,518
Relative Error, %	-17%	-18%	-22%	-21%	-26%	-26%
Absolute Error, %	20%	19%	23%	28%	32%	32%

Table 4.3 shows the total error for the forecasts of the three major tributaries to the San Joaquin River: the Stanislaus, Tuolumne, and Merced Rivers. The fourth boundary inflow is the San Joaquin River at Lander Avenue. Lander Avenue is used as a boundary inflow because upstream of that point for many miles the San Joaquin River is normally dry. In most years, peak winter flows at Lander Avenue are less than 600 cfs so estimating inflows at that location based on previous years would usually not introduce a large amount of error in the forecast process. The blue line in Figure 4.5 shows the boundary inflow at Lander Avenue estimated by averaging the flow from years for which there was data. December 2010 was very wet in the southern Sierra Nevada, resulting in high flow releases from Friant Dam shown in black in Figure 4.5. For the second time in the last ten years, flow released into the San Joaquin River at Friant Dam passed through to the lower San Joaquin River. The line in gray in Figure 4.5 shows the measured flow in the San Joaquin River at Fremont Ford, the first gage downstream of Lander Avenue, with peak flow corresponding to the release from Friant Dam. Given the high flow condition, the estimated boundary inflows were a very poor estimate of the flow. This also caused error in turbidity calculation since sediment in the San Joaquin River is in large part generated by scour from the river bed at high flow.

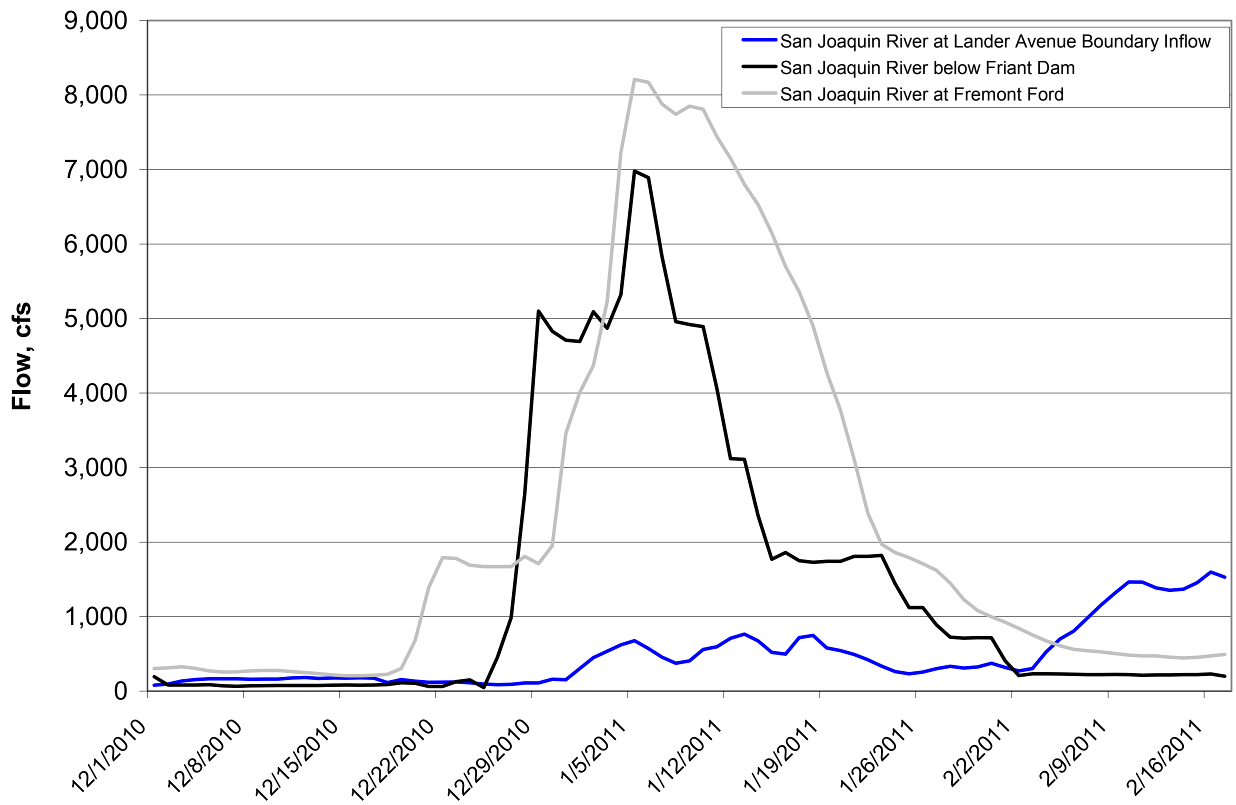


Figure 4.5 Forecast Period Flows in the San Joaquin River, Friant Dam to Fremont Ford

Simulated Flow

The WARMF model as calibrated to the Sacramento and San Joaquin watersheds performs calculations of watershed processes to translate time series inputs of boundary inflows and meteorology into flow in rivers throughout the watershed. Accuracy of simulated flow is a function of the model setup and of the time series inputs used to drive the model. Hindcast simulations were performed for the forecast period up to the current date for forecasting simulations. The hindcasts used actual reservoir releases and measured meteorology from stations with real-time data. The difference between forecast and hindcast simulations arises from the inaccuracy of flow and meteorology predictions. The difference between the hindcast and measured data is a combination of model error and inaccuracies caused by filling in missing meteorology data.

Figure 4.6 shows the hindcast flow in black and the forecast flows for each day forecasts were performed in color for the Sacramento River at Freeport. The hindcast tracks the flow closely but does not simulate the peak flows as high as the observed around December 10th and January 1st. The flow forecasts are all two weeks long and have an inflection point near the middle. This is the point where meteorology forecasts end and an assumption of average conditions begins. During the storms, the first week of the forecast simulation underpredicts flow because reservoir releases were greater than originally scheduled and the forecast precipitation was less than what eventually occurred. The forecasting simulation run on December 15th predicted a peak flow of 45,000 cfs, the forecast run on the 16th predicted 68,000 cfs, and the run done on the 17th predicted a peak flow of 85,000 cfs. The actual flow peak was 70,000 cfs. The second week of forecasts uses average meteorological conditions for each day of the year. Average conditions for winter meteorology means constant light rain. This caused an overprediction of flow in January, which was unusually dry.

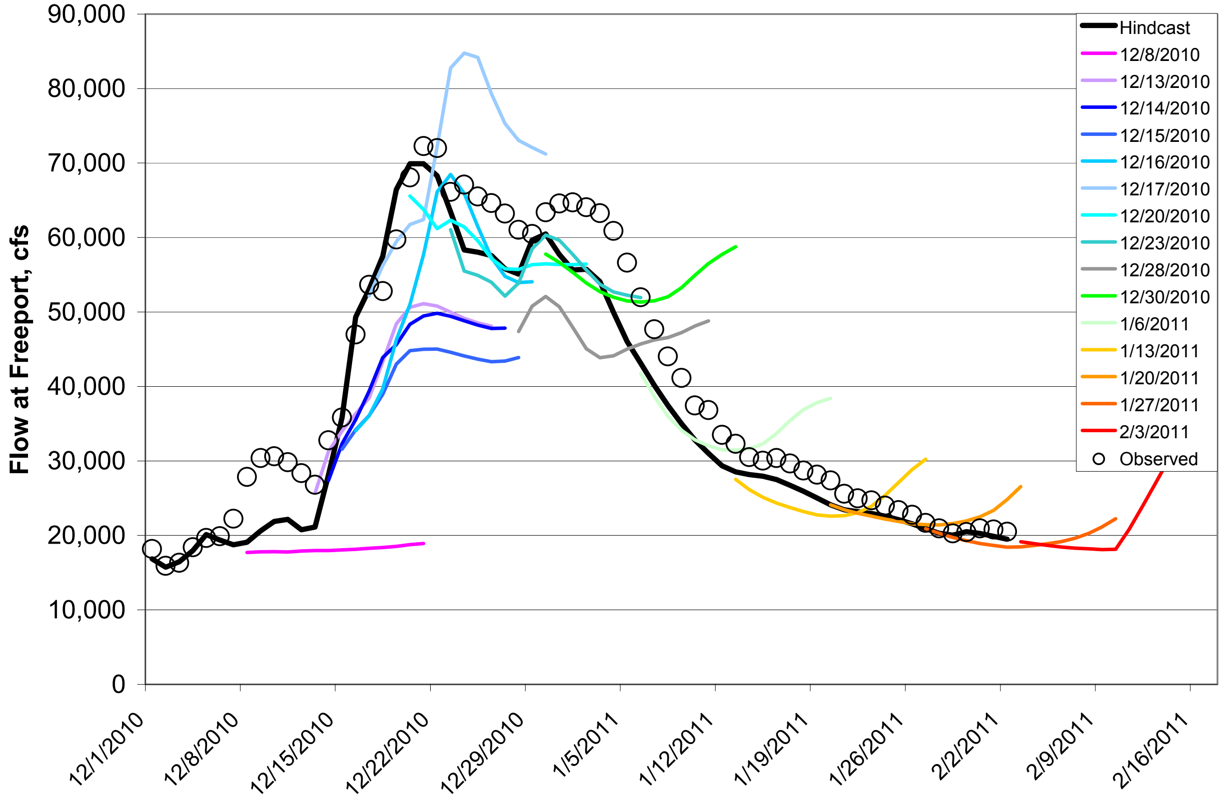


Figure 4.6 Hindcast and Forecast Flow, Sacramento River at Freeport

The hindcast flow simulation of the San Joaquin River shown in Figure 4.7 tracks measured flow at Vernalis closely through January 3rd but is then far below measured flow until late January. The problem was at the San Joaquin River at Lander Avenue boundary inflow, at which there is no longer an operating flow gage. Normally, all the flow released from Friant Dam is either diverted or percolates into the soil so that the lower San Joaquin River starting at Lander Avenue is hydrologically disconnected from the river farther upstream. Flow releases from Friant Dam were high enough in January 2011 to actually reach the lower San Joaquin River, however, causing error in the flow forecast. Alternative forecasts and a hindcast were run starting on January 20 where flow from Friant Dam was linked in WARMF to the lower watershed at Lander Avenue. In Figure 4.7, the regular forecasts and hindcast are shown with solid lines and the simulations with Friant Dam release connected to the lower watershed are shown with dashed lines. Connecting the Friant Dam flow to the lower watershed improved the simulation of flow at Vernallis during the time of high Friant Dam releases, but made flow simulation too high the rest of the time. If the possibility of large Friant Dam releases were to be incorporated into forecasting simulations, a more robust technique would have to be employed taking into account the flow losses which occur between the upper and lower parts of the San Joaquin River watershed.

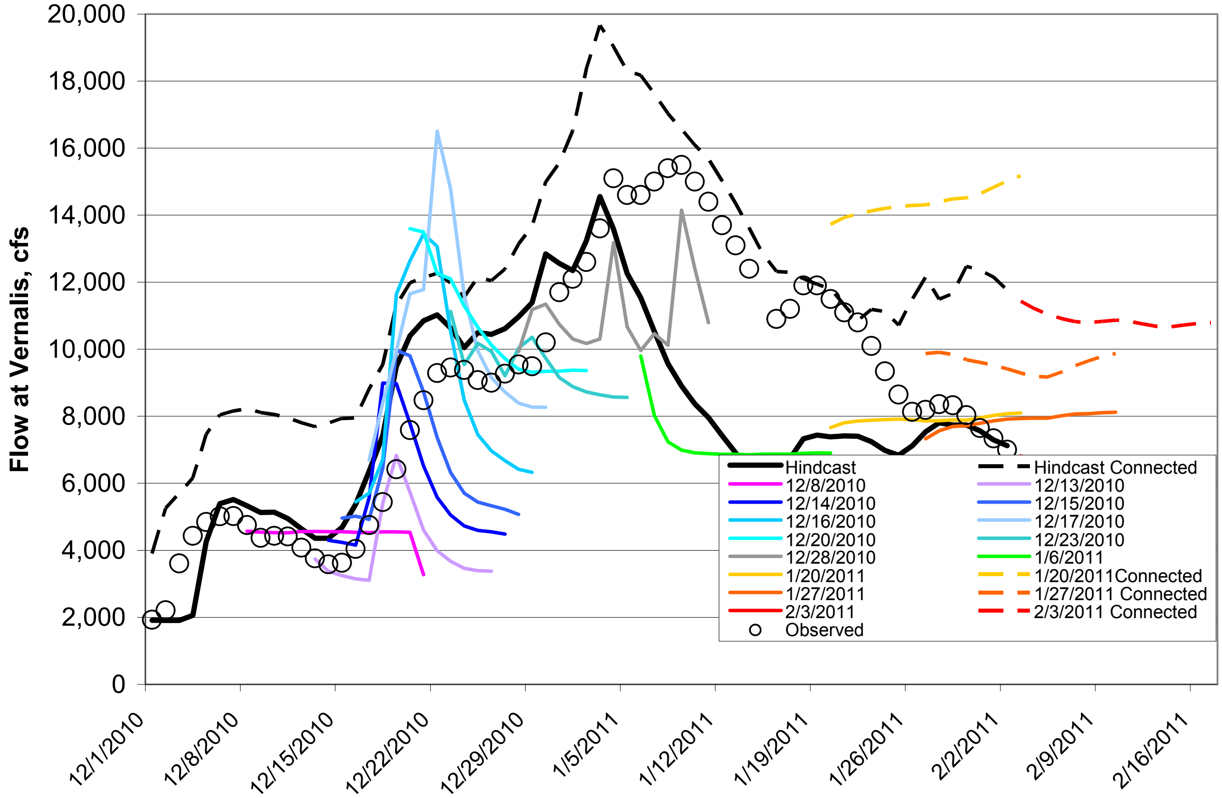


Figure 4.7 Hindcast and Forecast Flow, San Joaquin River at Vernalis

Below in Table 4.4 and Table 4.5 are statistics describing how well the hindcast and forecast simulations agree with observed data. Relative error is the average of the simulated flow minus the observed flow, a measure of accuracy. Absolute error is the average of the absolute values of the differences between simulated and observed, a measure of precision. The difference between the hindcast error and the forecast error is the result of the forecast; the hindcast error is from model error and estimation of some meteorology data and other model inputs.

The Sacramento River has a relative error of -9% indicating a small but systematic underprediction of flow as shown in Figure 4.6. The forecasts add to this underprediction because of systematic forecast underpredictions of boundary inflows and precipitation.

Table 4.4 Error Statistics of Simulated Flow for Hindcast and First Six Forecast Days, Sacramento River at Freeport

Measure	Hindcast	Forecast					
		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Relative Error, cfs	-3,557	-5,798	-7,029	-8,181	-8,955	-9,750	-8,929
Absolute Error, cfs	4,068	5,798	7,521	8,181	8,955	9,750	8,960
Relative Error, %	-9%	-13%	-15%	-17%	-18%	-19%	-18%
Absolute Error, %	-10%	13%	16%	17%	18%	19%	18%

Table 4.5 shows the flow simulation errors of hindcast and forecast simulations for the original model setup without linking Friant Dam release flows to the lower watershed. As a result, the hindcast simulation of the San Joaquin has an underprediction of flow because it does not include those flows.

Table 4.5 Error Statistics of Simulated Flow for Hindcast and First Six Forecast Days San Joaquin River at Vernalis

Measure	Hindcast	Forecast					
		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Relative Error	-116	-451	167	-289	-101	91	-116
Absolute Error	2,254	2,244	2,065	2,406	2,669	2,813	2,254
Relative Error, %	-11%	-1%	-6%	2%	-3%	-1%	1%
Absolute Error, %	24%	29%	28%	28%	28%	30%	30%

Simulated Turbidity

In WARMF, turbidity is assumed to be proportional to total suspended sediment. The predicted turbidity entering the Delta is a function of its sources. These include boundary inflows, overland flow over erodible lands during storm events, and scour from river beds during high flow. The Sacramento and San Joaquin River WARMF applications have been calibrated for turbidity. Accurate flow simulation is essential for simulating turbidity correctly. The preceding section of this report discusses the accuracy of forecasted flow calculated by WARMF.

Turbidity is measured continuously at Freeport with its results posted in real-time to CDEC. There are anomalies in the data like the example shown in Figure 4.8. The peaks at 1200 NTU obviously do not reflect the actual turbidity in the Sacramento River, but the status of smaller peaks like those on the morning of December 17th and the afternoon of December 18th are less clear. Sudden peaks in measured turbidity interspersed with typical readings were removed from the data set, but in cases where there was uncertainty the turbidity data was left unmodified.

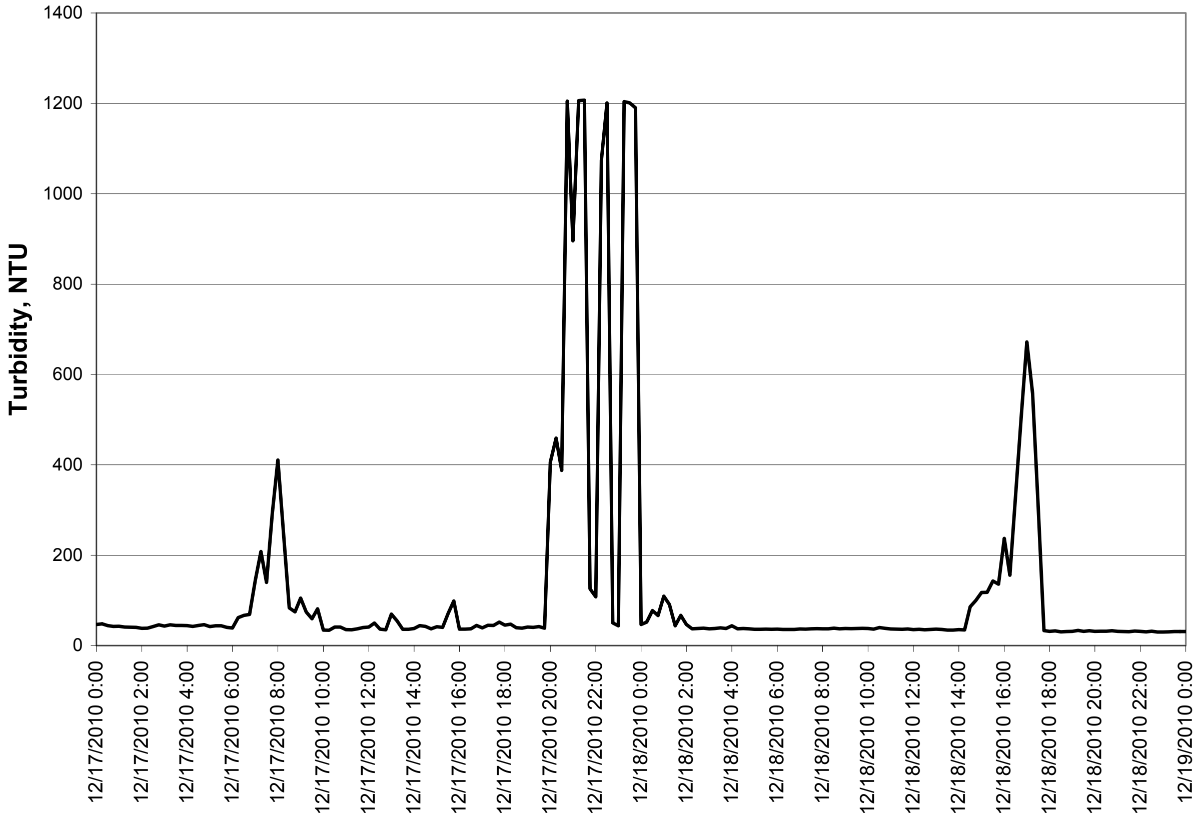


Figure 4.8 Real-time Turbidity Measurement with Data Anomalies

Figure 4.9 shows the hindcast turbidity in black and the forecast turbidity for each day forecasts were performed in color for the Sacramento River at Freeport. High turbidity occurs with high flow because two of its sources, overland flow and river bed scour, increase exponentially with flow. The flow peak of December 10th was underpredicted, resulting in a turbidity underprediction as well. The predicted turbidity associated with the late December storms was higher than the measured turbidity. The measured turbidity returned to 20 NTU or less in January like it had been before the December storms, but the simulated turbidity decreased more slowly than the observed after the storms and returned to a level of about 30 NTU. Forecast turbidity generally followed the hindcast for the first week of the forecast. The second week of the forecasts, using average meteorology with light but steady precipitation, resulted in upward inflections of the forecasts which did not come to fruition during the relatively dry January.

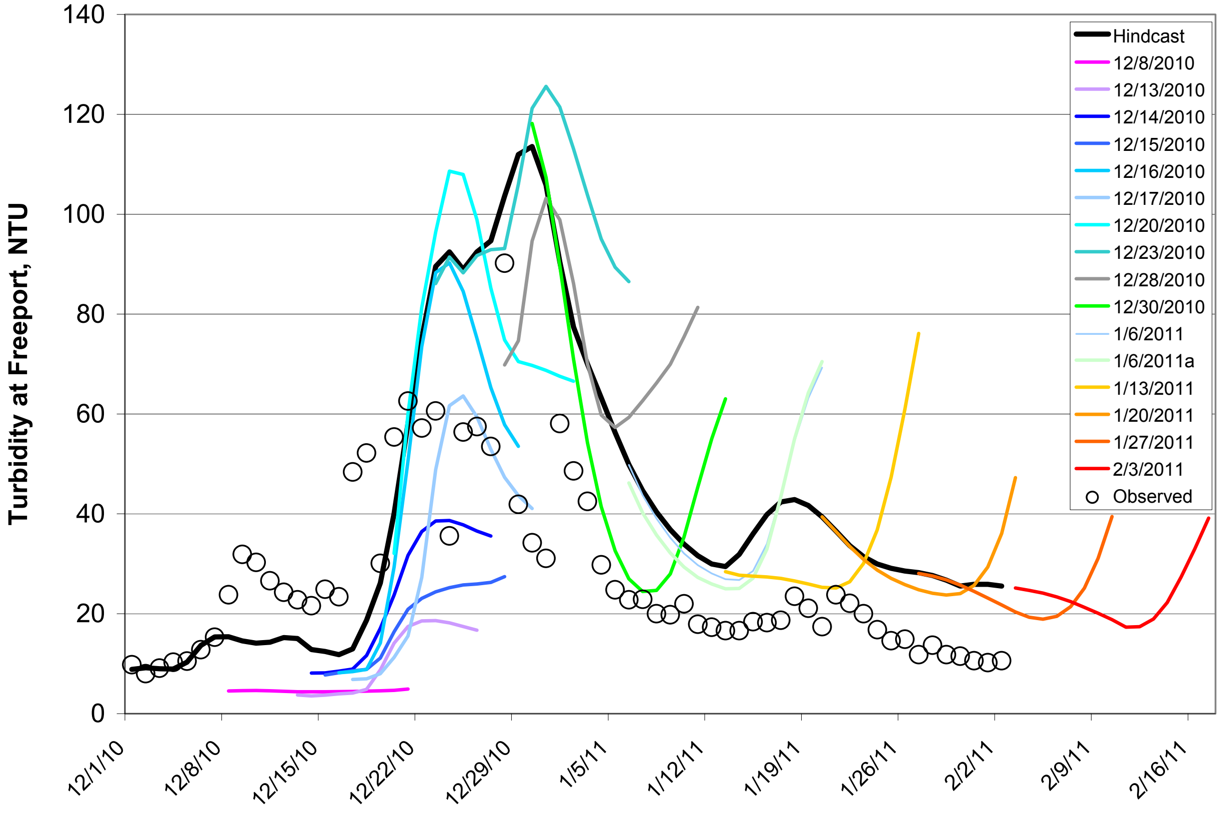


Figure 4.9 Hindcast and Forecast Turbidity, Sacramento River at Freeport

The hindcast turbidity simulation of the San Joaquin River shown in Figure 4.10 tracks through the center of the range of observed data, but does not show as much variation. The observed turbidity peak in late January is suspect since there wasn't any rainfall or high flow condition to cause high turbidity. When the forecast simulations were performed, the sediment calibration was still being modified as part of a separate concurrent project. The hindcast simulation reflects the improved sediment calibration. Dashed lines represent forecasts and hindcast with flow release from Friant Dam connected to the lower San Joaquin River. Neither the simulated nor the measured turbidity were as high as measured during the December storms in the Sacramento River at Freeport.

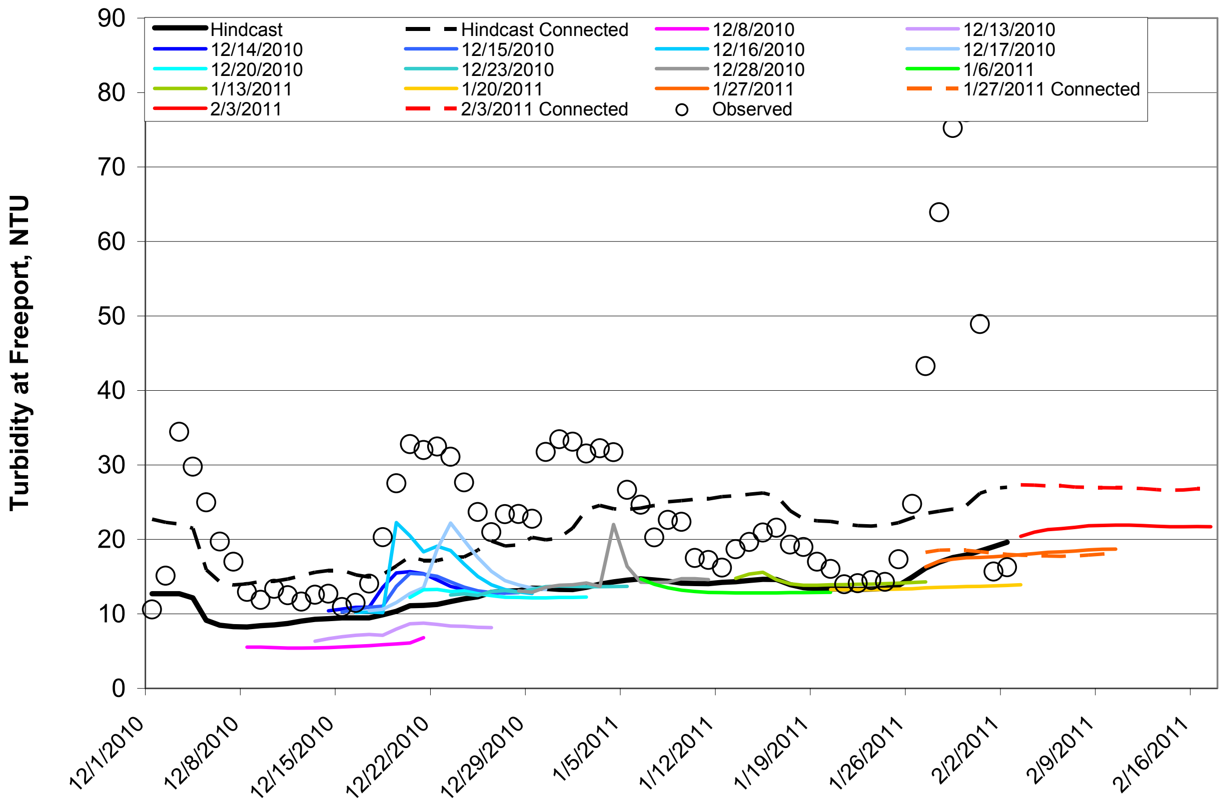


Figure 4.10 Hindcast and Forecast Turbidity, San Joaquin River at Vernalis

Below in Table 4.6 and Table 4.7 are statistics describing how well the hindcast and forecast turbidity simulations agree with observed data. Relative error is the average of the simulated flow minus the observed flow, a measure of accuracy. Absolute error is the average of the absolute values of the differences between simulated and observed. The difference between the hindcast error and the forecast error is the result of the forecast; the hindcast error is from model error and estimation of some meteorology data and other model inputs.

The hindcast simulation of the Sacramento River had an average model bias of 14 NTU from over-predicting turbidity during and after the December storms, while the forecasts actually had very little model bias. The precision of the daily simulated turbidity as measured by absolute error was low, which is typical for sediment simulation.

Table 4.6 Error of Simulated Turbidity for Hindcast and First Six Forecast Days Sacramento River at Freeport

Measure	Hindcast	Forecast					
		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Relative Error, NTU	14	1	4	2	2	1	-1
Absolute Error, NTU	20	25	27	26	28	29	22
Relative Error, %	49%	3%	12%	7%	5%	2%	-3%
Absolute Error, %	72%	74%	85%	75%	79%	76%	53%

Simulations of turbidity in the San Joaquin River were systematically too low until the model calibration was improved at the end of the forecast period. The relative error of the hindcast simulation, which included the improvements in sediment simulation, was -3 NTU. The precision of the forecast simulations was within 44-51% of observed, but this error would be about 7% less had the forecasts been made using the model with improved sediment simulation for the whole forecast period.

Table 4.7 Error of Simulated Turbidity for Hindcast and First Six Forecast Days San Joaquin River at Vernalis

Measure	Hindcast[1]	Forecast					
		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Relative Error	-3	-9	-11	-13	-14	-12	-10
Absolute Error	9	9	11	13	14	12	11
Relative Error, %	-14%	-45%	-47%	-52%	-51%	-48%	-43%
Absolute Error, %	37%	45%	47%	52%	51%	48%	44%

1 Hindcast simulation includes improvement made to sediment calibration

5 CONCLUSION AND RECOMMENDATIONS

The objective of performing WARMF forecasting was to predict flow and turbidity in near real-time with enough accuracy to provide useful information for managing operations at the Banks Pumping Plant. Processing tools both external to and within WARMF were created to make the process as efficient as possible. Real-time and forecast data sources were found to provide key meteorology and boundary inflow data to drive WARMF simulations. The processors made it possible to perform forecasts in four hours to provide flow and water quality inputs to a Delta model in a timely manner.

The forecast methodology was tested from December 1, 2010 through February 3, 2011. There were three sources of error in simulation results: error in the forecast, incomplete model input data, and model error. Error of forecasted flow was 13-18% for the Sacramento River at Freeport and 28-30% for the San Joaquin River at Vernalis. The WARMF boundary inflow at the San Joaquin at Lander Avenue (near Stevinson) proved to be problematic. Although this inflow is generally not large compared to the other tributary inflows to the San Joaquin River, during the forecast testing period unusually large releases from Friant Dam propagated downstream past the Lander Avenue gage. The gage itself stopped operating in March 2010, which meant that the inflow had to be estimated from historical data. This introduced a large error in flow simulation.

Forecast turbidity in the Sacramento River at Freeport had low relative error but high absolute error. The forecast turbidity for Freeport was higher than observed during the peak of the storms and after the storms had passed. Forecast simulations of the San Joaquin River occurred concurrently with a separate project which included improvement to the suspended sediment (and therefore turbidity) calibration. Forecast turbidity averaged 9-14 NTU too low, but after the improvements were made to the suspended sediment simulation the turbidity hindcast averaged 3 NTU too low. Absolute error in the San Joaquin River was lower than for the Sacramento River although the model did not capture the full range of variation in measured turbidity.

Some errors are inevitable when combining a model with forecasted model inputs, but errors should be minimized to make the forecast as accurate as possible. While the WARMF forecasting was being tested, a few sources of error were found which could be reduced for future modeling. The San Joaquin River at Lander Avenue gage is no longer a good location for a boundary inflow to WARMF because the gage is no longer operational. It is recommended that the WARMF San Joaquin River model be upgraded so that the watershed is connected from Friant Dam to the Delta. This will eliminate the need for the boundary inflow at Lander Avenue. As flows from the court settlement are returned to the San Joaquin River, it will be increasingly important to simulate the connection.

Concurrent to the forecasting work from December 2010 through February 2011, two other projects were underway making improvements to the Sacramento and San Joaquin River WARMF applications. These improvements included very detailed land use representation, simulation of additional deep groundwater – surface water interaction, and the use of tightly constrained model coefficients for agricultural inputs such as applied water rates. In the course of these concurrent modeling efforts, it was determined that some of these model inputs were likely incorrect, as it made it impossible for the model to simulate flow correctly in some cases given the constraints of the physical processes simulated by WARMF. While some coarse corrections were made to the San Joaquin River, improvments to both the Sacramento and San Joaquin River WARMF applications should be made so that hydrology is simulated more accurately in agricultural areas.

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