Placer County Water Agency
Middle Fork American River Project
(FERC No. 2079)

Operations Model Description Summary

Placer County Water Agency
P.O. Box 6570
Auburn, CA 95604

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1.0 Introduction

The Middle Fork Project Operations Simulation Model (Model) was developed to aid with analyzing the potential effects of proposed license conditions on streamflows, reservoir conditions, water supply, and hydroelectric generation operations associated with the Federal Energy Regulatory Commission's (FERC or Commission) relicensing of Placer County Water Agency's (PCWA) Middle Fork American River Project (MFP) (Figure 1). This document is intended to be a high level overview (executive summary) of the Model description and the underlying OASIS software that implements Model logic. A more detailed, comprehensive Model description will be available shortly. An OASIS software user manual is available upon request.

In concept, the model is a mass balance tracking tool. Water is routed through the system on a daily time step according to a set of operational rules and limited by the physical capacities of the project facilities. The Model uses unimpaired inflow which was calculated based on historic hydrology records with the exception of the Rubicon watershed which includes flows impaired by SMUD's upstream UARP diversions. Inflow into project facilities is either routed into storage, released through MFP generation facilities, bypassed, or spilled. Diversions to and from storage and generation change daily in response to a set of programmed priorities that include:

- Meeting all minimum release requirements;
- Meeting consumptive water supply demands;
- Filling storage reservoirs without spilling;
- Arriving at an end of year reservoir carryover storage target; and
- Generating electricity during the highest energy demand periods.

The Model was developed to allow PCWA and stakeholders to test and evaluate the impacts to water supply and generation that result from changes to system variables, such as:

- Minimum instream flow requirements;
- Specified pulse flow requirements such as riparian, geomorphic, or recreation flows; and
- Proposed project betterment.

The Model also will provide flow output data in the bypass and peaking river reaches (time series flow data) and reservoir water level time series to support instream habitat analysis, water temperature modeling, and recreation analysis efforts.

By using a 33 year period of historic hydrology (1975–2007) that ranges from the wettest to the driest years on record, the Model introduces stakeholders to the hydrologic variability of the MFP watershed, and allows consideration of the effect of variable hydrology on future Project operations. The Model can also be easily modified by a user to incorporate potential changes to MFP facilities or operations that may be identified during the development of protection, mitigation, and enhancement (PM&Es) measures.

The Model was developed and verified by PCWA in coordination with the Model Technical Team Subgroup, which was made up of members from the California Department of Fish and Game (CDFG), the State Water Resources Control Board (SWRCB), and the U.S. Department of Agriculture - Forest Service (USDA-FS).

2.0 Model Limitations and Use

A concerted effort was made to ensure that Model parameters and inputs (described in greater detail in the following sections) are as realistic as possible. However, numerous assumptions and simplifications were required for development of the Model. Because of these assumptions and simplifications, the Model will not, in an absolute or predictive sense, inform the user, for example, what reservoir elevation would actually be on a given day nor during a particular month should a proposal (alternative) be implemented. Therefore, the appropriate use of the Model is as a comparative tool, not a predictive one, to understand Project effects on river flows, reservoir elevations, water supply, and electrical generation based on inputs (e.g., minimum stream flows, reservoir carryover levels, etc.) provided by the user. The Model is not intended to directly quantify environmental conditions or impacts, but provides the resulting reservoir levels and stream flows that can be used to address these issues.

As a comparative tool, the Model allows the user to compare the relative effects of an alternative operation scenario, such as changes to minimum instream flow requirements, to a baseline condition, such as existing FERC license minimum instream flow requirements, on metrics such as reservoir storage (water levels), river flows, water supply, and electrical generation. In other words, the Model allows users to understand the potential changes to reservoir elevation that an alternative operation scenario has relative to a particular baseline condition.

3.0 Model Operators and Runs

PCWA anticipates that alternative flow proposals (scenarios) will typically be developed in a consensus fashion in the stakeholder collaboration forum. ECORP Consulting will be available to operate the Model at the direction of the collaborative. In addition, Model software has been provided to the CDFG and the USDA-FS for use by those agencies’ modeling teams.

4.0 Model Structure and Operation

In the Model logic, the MFP is described by a series of arcs and nodes (Figure 2). A node is a point of interest (e.g., a reservoir, junction of two river reaches, diversion point, etc) and an arc connects two nodes and represents a flow of water (e.g., a river reach, tunnel, penstock, etc). The node and arc structure of the Model represents the Middle Fork American River watershed and the MFP facilities (dams, diversions, tunnels, powerhouses, etc.) that lie within the watershed.

Operating constraints were built into the Model to represent the current physical capacities of the MFP as well as the current regulatory and contractual requirements the MFP operates under. Physical capacities built into the Model include maximum reservoir storage, maximum tunnel/diversion flow, maximum powerhouse flow, and minimum operational levels (for reservoirs and diversions). Examples of regulatory and contractual requirements include current FERC license requirements for minimum instream flows, water rights for diversions for power and consumptive demand, and PCWA contractual water delivery requirements.

The Model is designed to maximize the achievement of specific objectives given the constraints specified. When limited water is available, the Model may not be able to achieve all specified objectives. The priorities of the Model's objectives are specified by user-assigned "weights." The objectives specified (in order of current priority) in the Model include:

- Providing minimum instream flows;
- Meeting consumptive water demands;
- Filling the reservoirs by the end of spring;
- Avoiding spilling the reservoirs;
- Hitting end of year storage targets;
- Generating power during periods of highest electrical demand; and
- Conducting a maintenance outage during the fall.

After the operating constraints and operating objectives are defined and the input hydrology (described later) are selected, the model simulation is run day-by-day. The Model processes the constraints, objectives, and other inputs through an optimization routine using mathematical equations to best meet the objectives each day. The starting points (flows, storage, etc) for the next day are the ending points from the previous day. Through the optimization routine, the Model allocates daily releases for power generation to meet consumptive and energy demands only after meeting the other operating constraints (requirements) and objectives. Since consumptive demand obligations are met at the bottom of the MFP system (below the most downstream impoundment), consumptive demand can be met using required minimum instream flows as well as water dispatched for power generation. The Model then utilizes water to generate power during periods of highest electrical demand. After the simulation is complete, the Model provides a daily time series of river flows and reservoir storage and summarizes the results in a series of tables and graphs.

5.0 Model Input

The following describes important Model inputs and operating characteristics.

5.1 HYDROLOGIC INPUTS

Watershed Hydrology: The Model contains a time series database of unimpaired hydrology (with the exception of the Rubicon watershed which includes flows impaired by SMUD's upstream UARP diversions) that was developed for the MFP relicensing.

The data is based on the hydrologic period of record established for the relicensing of 1975 through 2007. This period of record includes the driest (1977) and wettest (1983) years on record since the construction of the MFP. A Model simulation can be run for the entire period of record (the default), a single year, or a series of years.

Bulletin 120 Forecasts: The Model utilizes DWR Bulletin 120 forecasts for the period of record of the MFP

Precipitation Records: The Model uses precipitation records from the Blue Canyon gage as a weather forecast. The precipitation records are used to simulate real-world conditions in which a project operator would use real-time weather to slightly modify project operations between Bulletin 120 forecasts.

5.2 PHYSICAL CONSTRAINTS

Project Physical Capacities: Tunnel and penstock capacities are fixed in the model and based on known capacities established through operating the MFP. Similarly, reservoir volumes, spillway capacities, and inlet and outlet capacities are fixed in the model based upon the actual physical constraints of the MFP.

Ralston Afterbay Storage Limits: During normal operations (e.g., not maintenance outages), Ralston Afterbay has upper and lower boundary storage constraints that are specified in the Model. These constraints were established using MFP operations records and typical operating practices.

5.3 REGULATORY CONSTRAINTS

Water Year Types: The current FERC license for the MFP contains three water year types for reservoir storage requirements (Wet, Normal, Dry) and two water year types for minimum instream flow requirements (Wet, Dry). A new water year type structure that establishes six water year types (Wet, Above Normal, Below Normal, Dry, Critically Dry, Extreme Critical) is proposed for the MFP relicensing process. The Model is capable of utilizing the current or the proposed water year type classifications.

The Model's water year type structure is based on the Folsom Reservoir Unimpaired Inflow (FUI) forecasts published in the California Department of Water Resources' (DWR) Bulletin 120. The current FERC license requires the water year type to be established on June 1 of each year based on the April FUI forecast. The proposed water year type structure has the capability to update the water year type on the 15th of each month, February through May, based on each month's current DWR Bulletin 120 FUI forecast.

Minimum Instream Flow Requirements: The MFP is currently required to maintain minimum instream flow at seven sites as a condition of the MFP FERC license. Currently required flows vary by water year type and, at one location, by time of year. The Model user can specify different minimum instream flow requirements by the time period, the flow rate, and the water year type trigger.

Reservoir Storage Requirements: The current MFP FERC license contains minimum reservoir storage requirements for French Meadows and Hell Hole reservoirs.

5.4 MFP OBLIGATIONS

Consumptive Demands: Consumptive demand for the Model is based on recent actual consumptive demand. The monthly pattern for consumptive demand also is based on recent observation, and daily consumptive demand is represented by equally distributing the monthly demand for each day of the month. Build-out consumptive demand is based on PCWA's Integrated Water Resources Plan (PCWA 2006) and is consistent with the Sacramento Area Council of Governments regional plan and with PCWA's water rights holdings for the American River.

Dry Year Storage: The contract between PCWA and the U.S. Bureau of Reclamation (USBR) stipulates that during a dry year PCWA is required to release water from the MFP such that the total quantity stored by the MFP shall be no more at the end of the year than it was at the beginning. The Model ensures that this condition is always met.

Water Forum Agreement: PCWA is a member of the Water Forum and a signatory to the Water Forum Agreement. Under the Water Forum Agreement (Water Forum 2000), PCWA has committed to dry year actions to enhance flows in the Lower American River that affect current and future operations. The Model implements these actions.

5.5 MODELED OPERATIONS – MODEL EMULATION OF CURRENT OPERATIONS

Forecasting Inflow: The Model uses DWR Bulletin 120 to forecast inflows, as real operators do, in order to optimize its operations during the reservoir filling period of the year (generally the spring). The forecast function is updated biweekly from February through June.

Duncan Creek Diversion: Duncan Creek Diversion is a passive system with limited operational control. The dam has an outlet that releases approximately 8 or 4 cubic feet per second (cfs) (depending on water year type) when diverting or natural inflow, whichever is less. The wooden stoplog slide gate is typically left open, and all flow greater than 8 cfs is diverted up to the capacity of the diversion (400 cfs). Flows greater than 408 cfs are spilled over the Duncan Creek Dam. The Model replicates this behavior.

Long Canyon Creek Diversions: South Fork and North Fork diversions have outlets that release the minimum instream flows when diverting (5 or 2.5 cfs for South Fork Long Canyon, depending on water year type, 2 cfs for North Fork Long Canyon) or natural flows, whichever is less. The South Fork diversion capacity is 200 cfs; the North Fork capacity is 100 cfs. Water diverted at these locations will flow to Middle Fork Powerhouse when it is operating or to Hell Hole Reservoir when Middle Fork Powerhouse is offline. Flows greater than the diversion and outlet capacities are spilled over the dams. The Model replicates this behavior.

Middle Fork and Ralston Powerhouses: The Middle Fork and Ralston powerhouses are operated synchronously in the Model. These powerhouses are operated together because of the limited storage capacity of Middle Fork Interbay and the similar flow capacities of the two powerhouses. The Model replicates this behavior.

Combined Reservoir Storage: Past practice for MFP operations is that Hell Hole and French Meadows reservoirs operate as a single reservoir from a water supply and generation standpoint, although the reservoirs are not necessarily operated in balance. Model operational decisions are based on the combined storage volume of the two reservoirs, and algorithms in the Model attempt to balance the reservoirs according to historic operations.

MFP Carryover Storage Target: The MFP is operated to an end-of-year (December 31) combined storage target. The combined storage target is intended to ensure that the MFP carries over sufficient water to meet the following year's demands in the event of a dry year, but also ensure sufficient vacant reservoir capacity to allow runoff to be captured but not spilled in the event of a wet year. Historic combined carryover levels have ranged from over 165,000 AF to less than 100,000 AF. Based on historical average, the combined storage target (Carryover Storage Target) is set at 142,000 AF in the Model.

Generation – Fill Cycle: The fill cycle is the period of the year when the Model's main goal is filling, but not spilling, the reservoirs, while meeting requirements and obligations. During the fill cycle, meeting minimum instream flow requirements and filling the reservoirs are more important constraints than generating power. If the forecasted inflow (based on DWR's Bulletin 120) is insufficient to fill the reservoirs, then generation is minimized. If the forecasted inflow indicates that a reservoir will spill, then generation is increased until that condition is eliminated. If water is dispatched for generation during the fill cycle, then it is dispatched according to the power demand index when electrical demand would be highest.

Generation – Dispatch Cycle: The dispatch cycle is the period of year after significant rainfall and runoff has abated when the Model's goal is to deliver water for consumptive use, electrical generation, and create reservoir storage space to prepare for subsequent winter and spring runoff, while meeting requirements and obligations. During the dispatch cycle, the Model looks ahead to the end of the year carryover storage target to assign a volume of water to be used to meet requirements, demands, and to generate electricity. The volume is updated monthly as the simulation progresses.

Reservoir Spills: French Meadows Reservoir has radial spill gates that must remain up (open) from November 15 until April 1. Hell Hole Reservoir has an ungated, passive spillway. When reservoir inflows exceed the capacities of the reservoirs to release flows through powerhouses (French Meadows Powerhouse for French Meadows Reservoir and Middle Fork Powerhouse for Hell Hole Reservoir) and the reservoirs are at full capacity, the Model will spill the excess water through the spillway arc.

Oxbow Powerhouse: The default Model operation for Oxbow Powerhouse is peaking, similar to that of Ralston Powerhouse. This operation maintains storage in Ralston Afterbay relatively constant, particularly during the summer when runoff is negligible. An Hourly Model (described later) was developed to allow users to specify the manner in which Oxbow Powerhouse is operated to meet objectives other than generation (e.g., recreational flows).

Maintenance Outages: The MFP undergoes annual scheduled maintenance outages. For modeling purposes the maintenance outage at French Meadows Powerhouse is assumed to begin the first Monday in May and lasts nine days. In wet years, the French Meadows Powerhouse outage is foregone. The maintenance outages at Middle Fork, Ralston, and Oxbow powerhouses have historically varied from two weeks to 12 weeks or more, depending on the work to be accomplished. In the Model, Middle Fork, Ralston, and Oxbow outages are assumed to occur together and to begin the first Tuesday in October and last 28 days. During outages, no flow goes through the affected powerhouses.

During the fall outage, Ralston Afterbay is drawn down to an elevation of 1149 ft (FERC required annual inspection of radial gates), and releases from Hell Hole Reservoir are increased to 70 cfs to ensure minimum instream flow compliance downstream of Ralston Afterbay.

5.6 MODELED OPERATIONS – VARIABLES THAT CAN BE INVESTIGATED

Pulse Flow Requirements: The Model is capable of providing pulse flows for riparian maintenance, geomorphic processes, or recreation below the seven MFP dams (Duncan, North Long Canyon, South Long Canyon, French Meadows, Hell Hole, Middle Fork Interbay, and Ralston Afterbay). The pulse flow magnitude, timing, and duration can be specified by the Model user. Pulse flows from the major reservoirs (French Meadows & Hell Hole) can be provided from storage, pulse flows from the other impoundments are provided (or are attempted to be provided) by foregoing diversions.

Recreation Flows: Similar to pulse flows, the user can specify recreation flows in the Model below Ralston Afterbay.

Power Demand Index: The Model contains a power demand index that shapes seasonal and daily generation releases to days with higher overall energy demand. Within days, it is assumed that the MFP operates during hours that have the highest value. Actual energy demands follow seasonal trends but are variable day to day.

Generation Dispatch Patterns: The Model uses a family of dispatch curves based on water availability that was developed from the power demand index. The dispatch curves specify the hours per day that would be used for generation given the volume of water available for generation. Each powerhouse has a preferred flow rate according to its powerhouse efficiency curve that the Model utilizes when generating.

Betterments: PCWA is considering a single betterment for the MFP relicensing: the Hell Hole Seasonal Storage Increase. The Model can simulate project operations, including this betterment. This betterment increases active storage in Hell Hole Reservoir by 7,600 ac-ft by raising the maximum reservoir elevation by six feet. The storage increase is seasonal and occurs when the gates would be in place, April through November 15 (similar to current gate operations at French Meadows Reservoir). The water captured with this betterment would be utilized the year that it is captured and dispatched according to water supply demand power demand index.

6.0 Hourly Model

The purpose of the Hourly Model is to provide a means to evaluate peaking operations, and potential changes to those operations, at Oxbow Powerhouse and the resultant effects to Ralston Afterbay and the Middle Fork American River downstream of Oxbow Powerhouse. The Hourly Model uses the Daily Model output of inflow to Ralston Afterbay and redistributes it into hourly input data. The Hourly Model focuses on the Ralston Afterbay complex, including Middle Fork American and Rubicon river inflows, Ralston Powerhouse discharge, Ralston Afterbay storage, Ralston Afterbay spill, and Oxbow Powerhouse discharge. Because the Hourly Model relies on data from the Daily Model, operating constraints must be consistent between the Hourly Model and the Daily Model.

Several inputs and/or outputs from the Daily Model are disaggregated and redistributed across the day in the Hourly Model. Inflows from the Middle Fork American River, the Rubicon River, the North Fork of the Middle Fork American River (located downstream of Ralston Afterbay), and any releases from Ralston Afterbay Dam are all distributed evenly (daily volume divide by 24 hours) over the day in the Hourly Model. Note that releases from Ralston Afterbay Dam are not the same as releases through Oxbow Powerhouse.

Other inputs are re-operated in the Hourly Model. Power generation volumes (French Meadows, Middle Fork, and Ralston powerhouses) from the Daily Model are redistributed in the Hourly Model according to an hourly priority designation based electricity demand. This priority recognizes that certain periods of time during the day have higher electricity demands than others, and the Hourly Model preferentially generates electricity during the periods of highest demand. These hours are defined in the peak hour designation table.

In the Hourly Model, Ralston Afterbay is operated according to a set of criteria that were established based on typical recent historical operations and physical limits. In the default operation, Oxbow Powerhouse will generate according to the peak hour designation table while ensuring that Ralston Afterbay elevations remain within the normal operating range. If more water is available than can be discharged through Oxbow Powerhouse, then Ralston Afterbay will spill. Oxbow Powerhouse operations also accommodate independent hourly ramp up and ramp down rates.

Recreation flows in the peaking reach can be requested by the Hourly Model user. The request includes specified flows based on an hour-by-hour and day-of-week priority. The day-of-week priority allows the model user to specify a priority for preferred recreation days (e.g., Saturdays) during periods or years when available water is limited. The Hourly Model will provide recreation flows on as many of the days as possible using the day-of-week priority. The Hourly Model also calculates travel time and utilizes a travel time rate of 2.5 miles per hour that was established using empirical data.

A recreation flow request will override the peak hour designation table for power generation at Oxbow Powerhouse. If sufficient volume is not available in the Hourly Model to meet a recreation flow for the duration requested, then the Hourly Model will not increase flows beyond those determined by the power priority table for any hour that day. The Hourly Model provides recreation flows according to the day-of-week priority to the extent possible. In order to fulfill a recreational flow request the Hourly Model cannot meet, the model user must make modifications to the Daily Model to ensure a sufficient volume of water is supplied to the Hourly Model, then rerun the Hourly Model. The Hourly Model results output provides the volume of water that the recreational flow request requires to facilitate modifications to the Daily Model.

Model Output and Post Processing

After the Model completes a simulation, the data are available in graphical and tabular format within OASIS. Outputs include hourly data on flows, reservoir elevation and storage, generation, and consumptive water delivery. These data also can be exported as DSS or Excel spreadsheet files. Standard output metrics also have been prepared that summarize the results of a Model simulation. The metrics include comparisons of the following:

- Monthly and daily reservoir elevation;
- Monthly and daily flow by location;
- Flow exceedance plots;
- Reservoir spills; and
- Generation by location.

Following the completion of a model run, output metrics will be distributed by PCWA to stakeholders.

7.0 Literature Cited

Placer County Water Agency. 2006. Integrated Water Resources Plan. Prepared by: Brown and Caldwell, August 2006. Available at: http://www.pcwa.net/

Water Forum. 2000. Water Forum Agreement. Accessed on: November 17, 2009. Available at: http://www.waterforum.org/agreement.cfm

FIGURES

Figure 1. Map of the Middle Fork American River Project, Including Model Nodes and Instream Flow Study Sites.

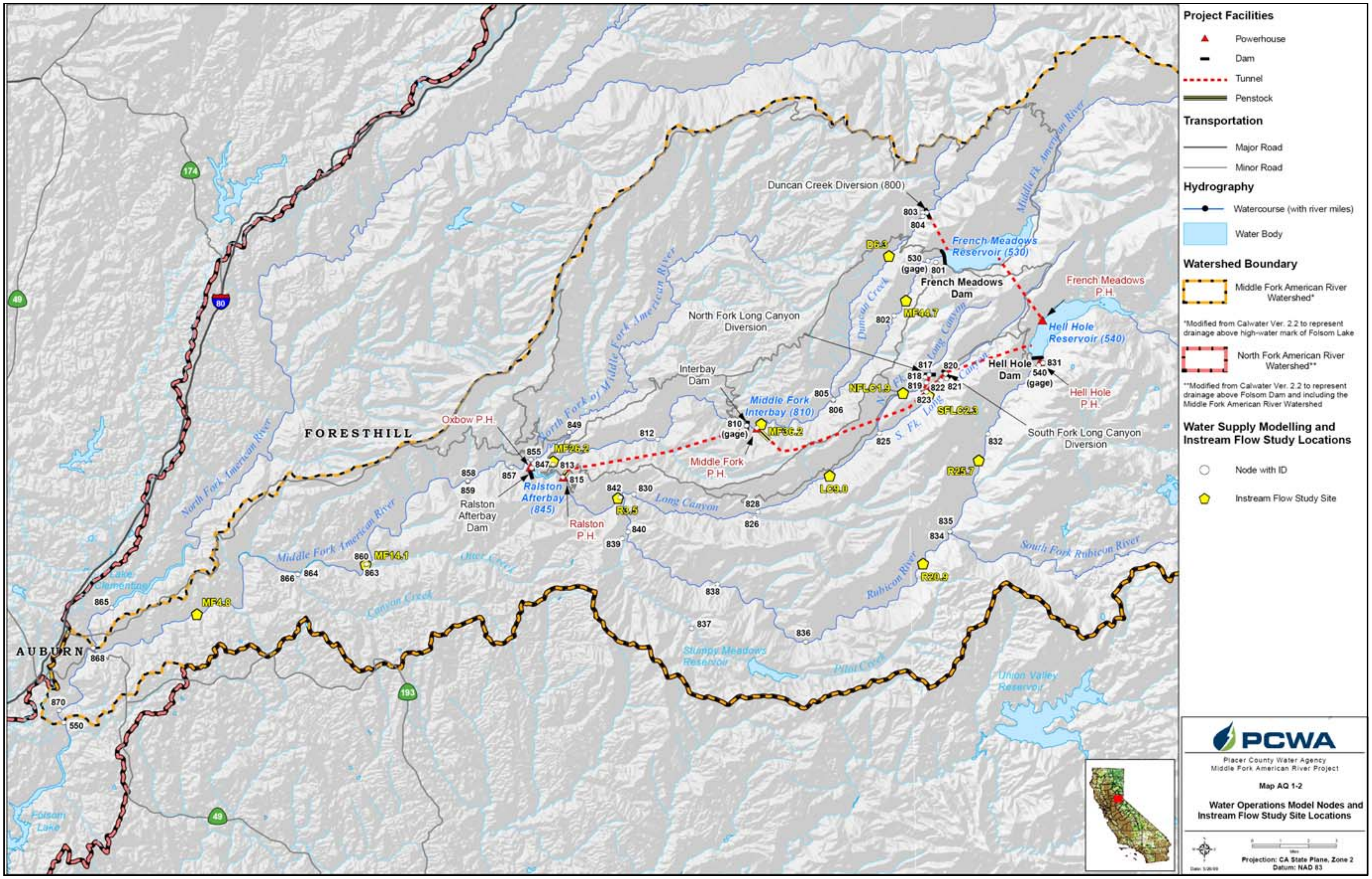

Figure 2. Schematic of the Middle Fork American River Project, Including Model Nodes and Arcs.