Dewberry

TECHNICAL MEMORANDUM

PREPARED FOR:

MERCED IRRIGATION DISTRICT
WATER & POWER

744 W. 20th Street
Merced, CA 95340

Merced Irrigation District Hydrologic and Hydraulic Optimization Model (MIDH2O)

VERSION 1.0

MARCH 30, 2017

PREPARED BY:

Dewberry
1760 Creekside Oaks Drive
Suite 280
Sacramento, CA 95833

TABLE OF CONTENTS

EXECUTIVE SUMMARY 1
1.0 INTRODUCTION 3
Project Location 3
Project Purpose 5
2.0 RAINFALL RUNOFF MODEL 8
Terrain Development 8
Drainage Basin Area Delineation 8
Runoff Losses 8
Hydrograph Transform 9
Channel Routing 9
Canopy and Evapotranspiration 10
Snowmelt Modeling 10
Calibration 10
3.0 RESERVOIR SIMULATION MODEL 14
Introduction 14
Inventory 14
Hydrology 16
Operations 16
Physical Properties 20
Reservoir Releases 20
4.0 RIVERINE HYDRAULICS MODEL 22
Introduction 22
Steady HEC-RAS Constant Manning's Roughness Calibration 23
Steady HEC-RAS Calibration with Vertically Variable "n" Values 24
Calibration and Stabilization of the Unsteady Flow HEC-RAS Model 26
5.0 REAL TIME SIMULATION MODEL 31
Introduction 31
WISKI and Data Storage 33
Meteorology 33
Custom Scripting and System Automation 35
Planning scenarios 35
6.0 CONCLUSION 43
7.0 REFERENCE 44

LIST OF FIGURES

Figure 1: Subbasins within Merced River Watershed 4
Figure 2 Active and Inactive Stream Gages in Merced River Watershed 11
Figure 3: April 2006 Calibration Results 12
Figure 4: October 2010 Calibration Resultsin Projects] 13
Figure 5: Operation Rules Input Screen of the HEC-ResSim Model at Lake McClure 18
Figure 6: Operation Rules Input Screen of HEC-ResSim Model at Lake McSwain 19
Figure 7: Comparison of modeled water surface elevation as compared to observed stage elevation as measured at CDEC Gage MMF assuming a constant Manning's coefficient. 24
Figure 8: Vertical Variation of N Values 25
Figure 9: Comparison of Constant and Vertically Varied "n" Values to the Rating Curve at Merced River below Merced Falls (CDEC Gage: MMF). 26
Figure 10: Unsteady HEC-RAS Hydrograph at Shaffer Bridge with Constant "n" values. (CDEC Gage ID: MBN) 27
Figure 11: Flow Roughness Factors upstream of Snelling 28
Figure 12: Flow Roughness Factors Downstream of Snelling Road 28
Figure 13: Hydrograph at Shaffer Bridge with Roughness Factors 29
Figure 14: Hydrograph at Cressey with Roughness Factors 29
Figure 15: Schematic for MIDH2O HEC-RTS System 32
Figure 16: Lake McClure Storage 2005-2010 36
Figure 17: Average Daily Flow for Merced River at Shaffer Bridge 37
Figure 18: Fish Pulse Flows at Shaffer Bridge 41
Figure 19: Fish Pulse Water in Excess of the Minimum Flow Requirements for 2011-2016 (from MID) 42

LIST OF TABLES

Table 1: HEC Software Version Used. 5
Table 2: Rating Curve Comparison at CDEC Gage, Merced River below Merced Falls (CDEC Gage ID: MMF) 23
Table 3: Comparison of Constant and Vertically Varied N Values at CDEC Gage MMF 25
Table 4: Constant N Values for Unsteady HEC-RAS Model 26
Table 5: HEC-RTS Program Sequence 33
Table 6: Total Release vs Total Demands 38

Executive Summary

Dewberry has developed a real-time hydrologic, hydraulic, and reservoir operational model for the Merced River watershed system to provide Merced Irrigation District (MID) with tools to support maximizing operational flexibility, meeting the current compliance regulations, assisting in flood management, planning for irrigation season diversions and allocations, assisting in hydroelectric power scheduling and assisting in enhancing groundwater management practices. The model is referred to as Merced Irrigation District Hydrologic and Hydraulic Optimization (MIDH2O). The U.S. Army Corps of Engineers' (USACE) Hydrologic Engineering Center (HEC) suite of models was selected for this project. These models are publicly available without charge from the HEC.

The primary software for this project is the HEC Real Time Simulation (HEC-RTS) program. The HEC-RTS program integrates various data developed through hydrologic models, hydraulic models, reservoir simulation models, meteorological forecasting tools, and flood inundation analysis programs. Dewberry worked with MID as part of an integrated team to develop a comprehensive water management system that integrates meteorological data collection, hydrologic modeling, reservoir operation simulation, and hydraulic analysis. The integration includes collecting real time data from MID's hydrologic database - Water Information System KISTERS (WISKI) and Supervisory Control and Data Acquisition (SCADA) data system, the California Data Exchange Center (CDEC), prior simulation results, and gridded temperature and precipitation data from CustomWeather. MIDH2O provides an automated management report every six hours. The individual models developed as a part of the HEC-RTS system were customized to simulate the watershed geography and meteorology, and to model MID's operational rules of New Exchequer and McSwain Dams. In addition, the model includes potential future reservoir scenarios such that more detailed feasibility studies may be performed, if applicable.

MIDH2O is a fully automated system - data collection, data validation, model run and generation of custom report are entirely automated. MIDH2O is run every six hours (four o'clock and ten o'clock PST). Each forecast run looks back at two weeks of observed data and looks ahead using one week of forecast data. MIDH2O is also manually checked periodically for model accuracy and calibration. MIDH2O has already provided significant benefits to MID. During the winter of 2016-17, MIDH2O provided flow estimates at any location in the watershed up to two days prior to the California Nevada River Forecast Center (CNRFC). The model is still in the calibration phase and the estimates were comparable to CNRFC. With time, we expect the MIDH2O model to consistently equal or outperform the CNRFC estimates.

Existing instream minimum flow requirements pursuant to the Federal Energy Regulatory Commission (FERC) are incorporated in MIDH2O. MIDH2O simulates the existing rule curve and flow requirements to compare with actual current operations to identify potential opportunities to conserve water and improve water supply operations. For example, MIDH2O was used to forecast flows at Shaffer Bridge during the fish pulse in October, 2016. Based on these forecasted flows, MID adjusted actual releases from Merced Falls reservoir to meet the fish pulse requirements conserving an estimated 2,500 acre-feet of water that otherwise would have been released. As a result of comparing forecasted and actual flows, the need for improved rating curves at several stream flow gaging stations along the Merced River were identified.

MIDH2O was used to simulate operations for a six year period (2005-2011) and during the flood of 1997 based on current operations rules. Existing operational rule curves for New Exchequer and McSwain Dams are based on USACE flood control rules and Emergency Spillway Release Decision curves. MIDH2O results indicate that by following the existing USACE flood control rules and Emergency Spillway Release Decision curves during this time would have potentially resulted in releases in excess of the channel capacity suggesting that the rules could be optmized.

MIDH2O includes a planning version of the model which runs on a 12-hour time step. This model can be run for months and can provide estimates of snowmelt runoff for the entire snowmelt season under three weather scenarios. The MIDH2O planning model includes rainfall and temperature grids for 10th, 50th, and 90th percentile weather conditions. MIDH2O is a powerful tool for future planning studies and daily operational support. MIDH2O is ideally suited for water delivery operations, climate change, Forecast Based Operations and power generation optimization scheduling and studies.

1.0 INTRODUCTION

Project Location

Merced River watershed is located in the western slopes of Central Sierra Nevada Mountain range in California. The Merced River flows into the San Joaquin River approximately 25 miles west of the City of Merced. The total drainage area of the Merced River watershed is 1,266 square miles. The elevation in the watershed ranges from 52 feet to 13,090 feet. The entire watershed has one major dam - New Exchequer Dam which forms Lake McClure - built in 1967. The storage capacity of New Exchequer Dam is 1.024 million acre-feet and the catchment area is 1,037 square miles. The top of New Exchequer Dam elevation is 882 feet (NAVD88). The watershed upstream of Lake McClure is a part of Yosemite National Park and has natural non-regulated streams. Downstream of Lake McClure, there are three small flow regulating reservoirs and diversion dams. Figure 1 shows the subbasins in the Merced River watershed included in MIDH2O model.

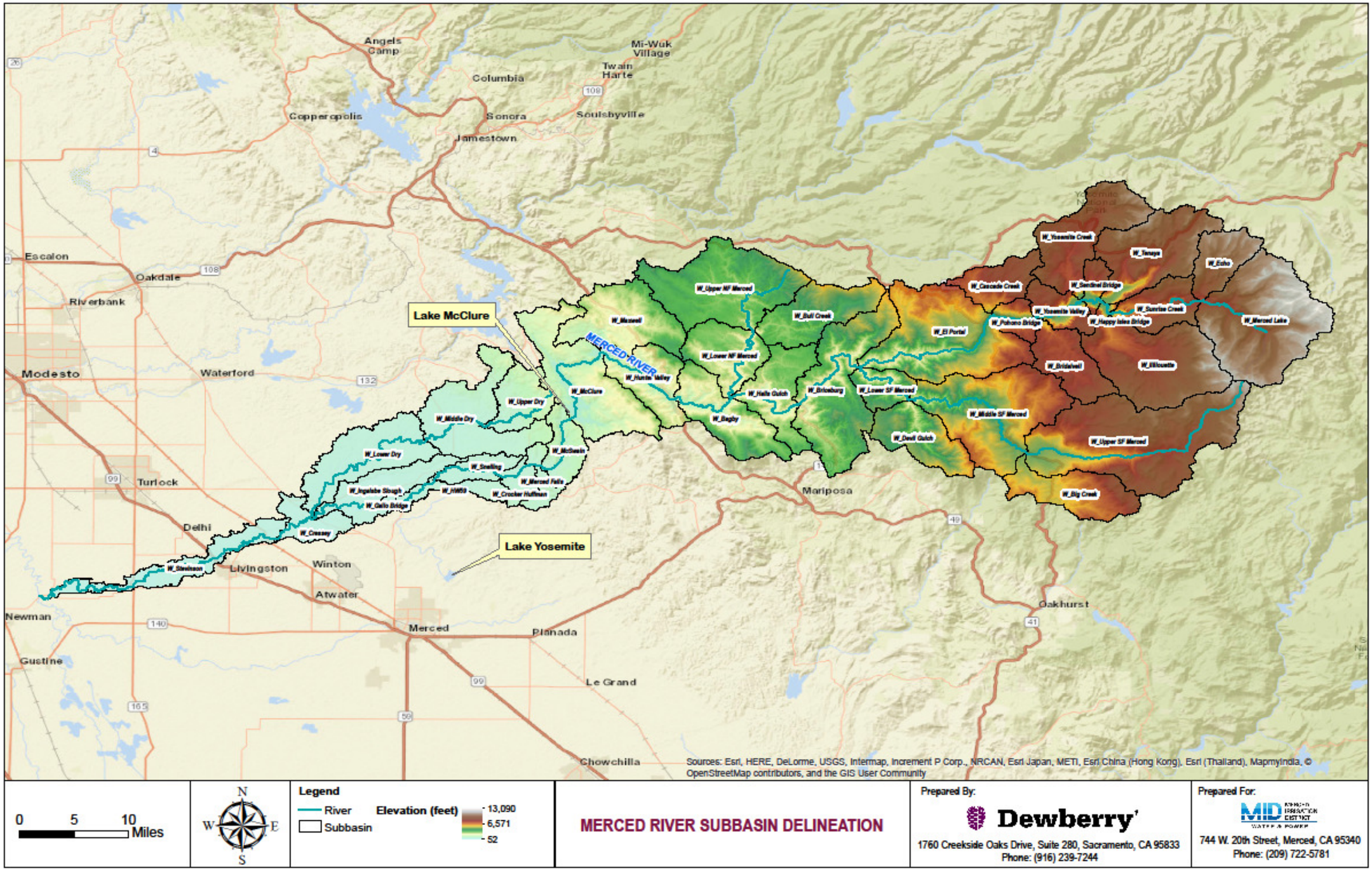


Figure 1: Subbasins within Merced River Watershed

Project Purpose

The purpose of the project is to develop a real-time hydrologic, hydraulic, and reservoir optimization model (MIDH2O) for the Merced River watershed system. MIDH2O provides MID a decision support tool to help maximize operational flexibility, meet the current compliance regulations, assist in flood management, plan for irrigation season diversions and allocations, assist in hydroelectric power scheduling and assist in enhancing groundwater management practices. The USACE's suite of hydrologic and hydraulic models was selected for this project. These models summarized in Table 1 are publicly available without charge from the HEC. The primary software used for this project is the HEC-RTS program. The HEC-RTS program integrates various data developed through hydrologic models, hydraulic models, reservoir simulation models, meteorological forecasting tools, and flood inundation analysis programs. The HEC tools may also be used for flood damage assessment, analyses of ecosystem functions, sediment transport, climate change impact assessment and temperature modeling of the river. Dewberry worked with MID as part of an integrated team to develop a comprehensive water management system that integrates meteorological data collection, hydrologic modeling, reservoir operation simulation, and hydraulic analysis. The individual models developed as a part of the HEC-RTS system were customized to simulate the watershed geography and meteorology and to model MID's operational rules of New Exchequer and McSwain Dams.

The HEC software versions used for the project are listed in Table 1.

Table 1: HEC Software Version Used.

Software	Version
HEC-RTS	3.0
HEC-GeoHMS	5.0
HEC-HMS	4.1
HEC-ResSim	3.3
HEC-GeoRAS	10.0
HEC-RAS	5.01

A major goal of the project is to develop a planning level version of the HEC-RTS model and run a minimum of five different scenarios as provided by MID. A copy of the MIDH2O model was created with a 12 hour time step that can be used for long-term planning.

The MIDH2O project includes preliminary analysis of six scenarios that demonstrate how the program can be used to identify potential water savings. These analyses are for demonstration purposes only.

In total six scenarios were defined as further described below.

1. **Compare normal historic operations to rule based operations.** Using available data, generate a database of daily inflows into Lake McClure, Dry Creek at the gage site, irrigation diversions and estimated local inflows to match observed Merced River flows at Shaffer and/or Cressey. Run the inflows through MIDH2O model using the reservoir operation rules provided by MID. Compare the storage in Lake McClure generated by MIDH2O using current operating rules to the observed storage for that period. These two are not expected to match as the daily operations do not follow a rigid set of rules. For example, releases during flood events are often affected by decisions made by the USACE.

2. **Compare normal historic operations to rule based operations with the proposed Montgomery Reservoir included in the system.** Create a version of the HEC-ResSim model with the 500,000 ac-ft Montgomery Reservoir connected to Lake McClure. Develop rules and run one scenario using the base flow created in (Scenario 1) above. This model will be used in subsequent studies to determine the feasibility of multiple alternatives.

3. **Compare historic Exchequer Dam operations during the 1997 flood to rule based operations.** Run an hourly simulation of the 1997 flood with the current HEC-ResSim rules and the current configuration. This will not reflect the actual releases made during the event but rather release when applying current rules as coded into the HEC-ResSim model.

4. **Compare historic operations during the 1997 flood to rule based operations with Montgomery Reservoir.** Re-run the event with the facilities described above with transfers to Montgomery Reservoir beginning prior to the storm. Review the discharges to Merced River below Merced Falls and determine how much water could have been diverted to Montgomery Lake.

5. **Compare historic operations to rule based operations with Black Rascal Reservoir.** Add a 500 ac-ft reservoir on Black Rascal to the HEC-ResSim model. The dam will capture local flows from Black Rascal Slough which can be used for irrigation. Determine the annual flows and the potential to fill the reservoir from local inflows.

6. **Model the 2016 Fish Pulse Event to check and verify MIDH2O.** Run the MIDH2O model every few days during the 2016 Fish Pulse to predict flows at various points along the

Merced River. Use the results and observed data to calibrate the model and adjust releases on subsequent days to prevent having excess flows on November 1. MID will not get credit for any flow above 200 cfs on or after November 1.

2.0 RAINFALL RUNOFF MODEL

HEC-HMS Version 4.1 was used to create a rainfall-runoff model for the Merced River. The rainfall-runoff model was created for the entire Merced River basin; from the headwaters in the Sierra Nevada mountains to its confluence with the San Joaquin River. The total drainage area of the Merced River at its confluence with San Joaquin River is 1,276 square miles.

The purpose of the Merced River HEC-HMS model is to create a rainfall-runoff model that can be used to perform a short-term forecast of the total inflow into Lake McClure. Downstream of Lake McClure, the Merced River HEC-HMS model was used to estimate the local flows contributing to the Merced River. The Merced River HEC-HMS model is a part of the Merced River HEC-RTS model – MIDH2O. In the MIDH2O model, the flow hydrographs computed from HEC-HMS are transferred to HEC-ResSim to perform reservoir operations simulations.

Terrain Development

A 10-foot cell size Digital Elevation Model (DEM) was created from the MID LiDAR data collected January 30-31, 2015 (Dewberry, 2015). The LiDAR data covers the Merced River floodplain from its confluence with San Joaquin River to Lake McClure. For the remaining portion of the watershed, a 10-meter United States Geologic Survey (USGS) DEM was used. The DEMs from these two sources were combined to produce one 30-foot by 30-foot DEM used in the HEC-GeoHMS to create the basin files for the HEC-HMS model.

Drainage Basin Area Delineation

The basin boundaries were delineated using HEC-GeoHMS program Version 5.0 software. HEC-GeoHMS delineates the watershed based on the user provided topographic data and divides the watershed into subbasins. In addition to dividing the subbasins at the confluence with the major tributaries of the Merced River, subbasins were divided at the locations of the available flow gage stations. In the Merced River HEC-HMS model, there is a total of thirty-nine subbasins. There are twenty-seven subbasins upstream of Lake McClure and twelve subbasins downstream of Lake McClure.

Runoff Losses

The Deficit and Constant method was used to calculate the runoff losses. This method was preferred over the Initial and Constant method because the HEC-HMS model is used as a continuous simulation model and not just for an event-based simulation. The Deficit and Constant method in conjunction with canopy

method and evapotranspiration allows the loss to recover over time instead of resetting the initial loss at every new simulation.

Hydrograph Transform

The Modified Clark (ModClark) transform method was used to transform the rainfall excess into a flow hydrograph for each subbasin. The ModClark method is required if gridded subbasins are used. The time of concentration and storage coefficient were initially based on the 2001 USACE HEC-HMS (USACE, 2001) report. The report provides the following equation that relates basin physical parameters to the time of concentration:

$Tc = 1.67*(L*LCA*S^{1/2})^{0.29}$ where,

Tc is time of concentration, in hours

L is length of longest flowpath in the subbasin, in miles

LC is length of flowpath from basin centroid to basin outlet, in miles

S is slope of longest flowpath, in ft/mile

The slope was adjusted to account for waterfalls in the Yosemite National Park which can result in overestimation of the effective energy slope.

Similarly, R = 3.1 * Tc where R is storage coefficient.

These parameters were later updated during model calibration.

Channel Routing

Modified-Puls routing was used for Merced River reaches downstream of Lake McClure. Muskingum-Cunge routing was used for the remaining routing reaches in the model.

In order to generate storage-discharge functions for the Modified Puls reach, a HEC-RAS model was created. A range of flows (50 - 20,000 cfs) was applied and the change in the cross section storage volume between the HEC-RAS cross section at the start and at the end of the reach was calculated to get the storage-discharge function.

Canopy and Evapotranspiration

The canopy method was utilized to represent rainfall interception and evapotranspiration. Maximum canopy storage represents the maximum amount of water that can be intercepted by plants. All precipitation is intercepted until the canopy storage capacity is filled. All further precipitation falls to surface. The canopy will also consume all potential evapotranspiration until the water in the storage has been eliminated. The monthly average evapotranspiration values for all subbasins in the watershed was entered in the meteorological model.

Snowmelt Modeling

The gridded temperature index method was used for the snowmelt modeling. The gridded temperature index method is a temperature index approach that includes a conceptual representation of the snowpack energy. In the gridded temperature index method, the precipitation and temperature datasets are provided in a gridded format and this method is compatible with the gridded ModClark transform method.

The snowmelt simulation also requires five initial condition parameters: snow water equivalent, cold content, liquid content, cold content antecedent temperature index and melt antecedent temperature index. All of these parameters were provided in the form of gridded datasets. ATI Meltrate function, ATI Coldrate function and the Annual Groundmelt pattern from the USACE 2016 HEC-HMS (USACE, 2016) model and Big Creek Hydrologic and Hydraulic Operations (BCH2O) HEC-HMS models (Dewberry, 2012) were used. The BCH2O HEC-HMS model is a HEC-HMS model for the Upper San Joaquin River (upstream of Friant Dam) and share many of the same geographical and hydro-meteorologic conditions found in the Merced River Watershed.

Calibration

The HEC-HMS model was calibrated using two events: i) 2006 April event with snowmelt and ii) 2010 October event without snowmelt. These two events were chosen because the precipitation, temperature and initial snow water equivalent data were available and the most number of flow gages in the watershed were active. Figure 2 shows the active and inactive stream gages in the Merced River watershed.

The event-based calibration helped adjust the basin parameters such as loss, transform and routing parameters. Figure 3 and Figure 4 show the results of the calibration for the two events.

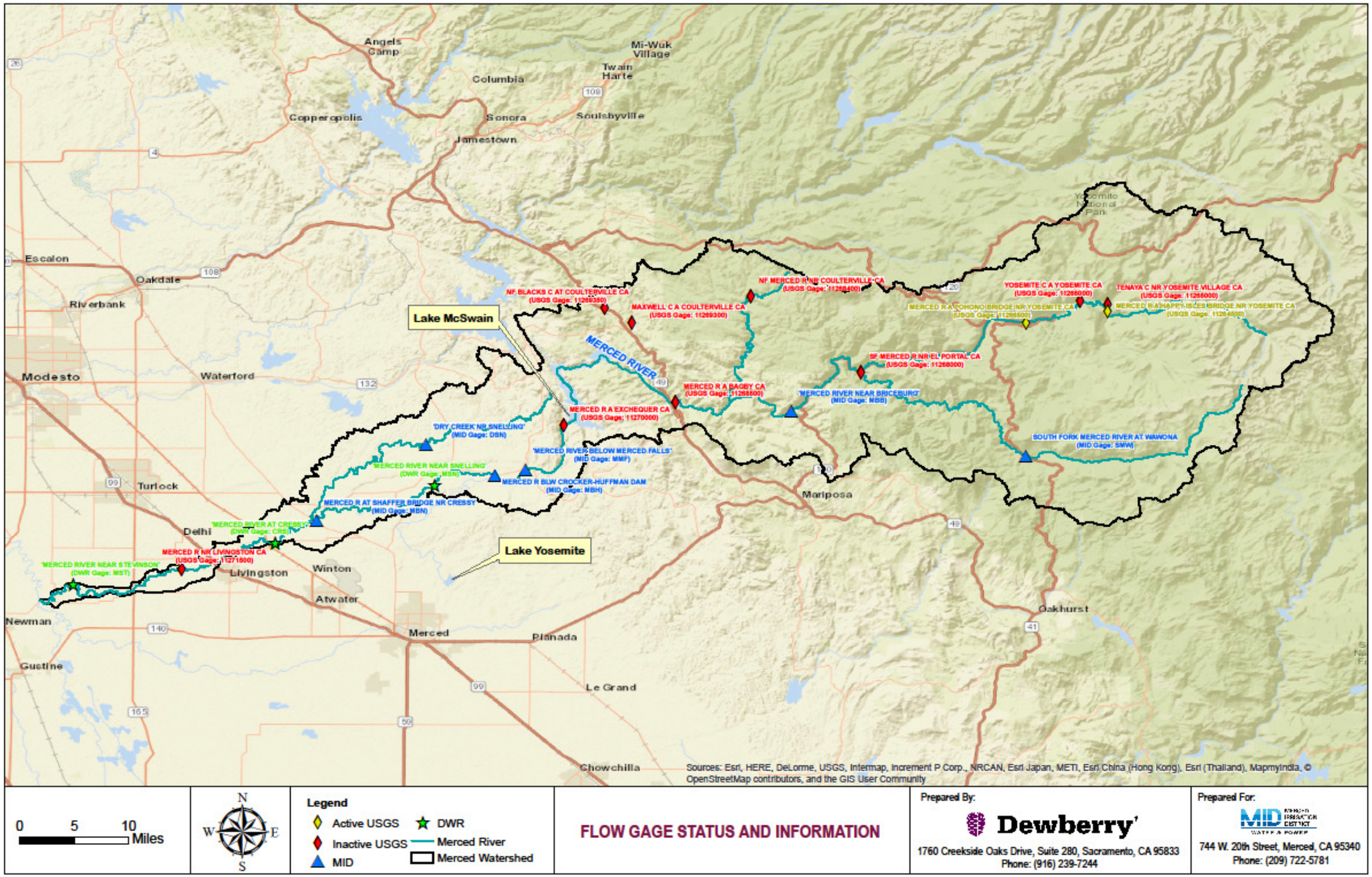


Figure 2 Active and Inactive Stream Gages in Merced River Watershed

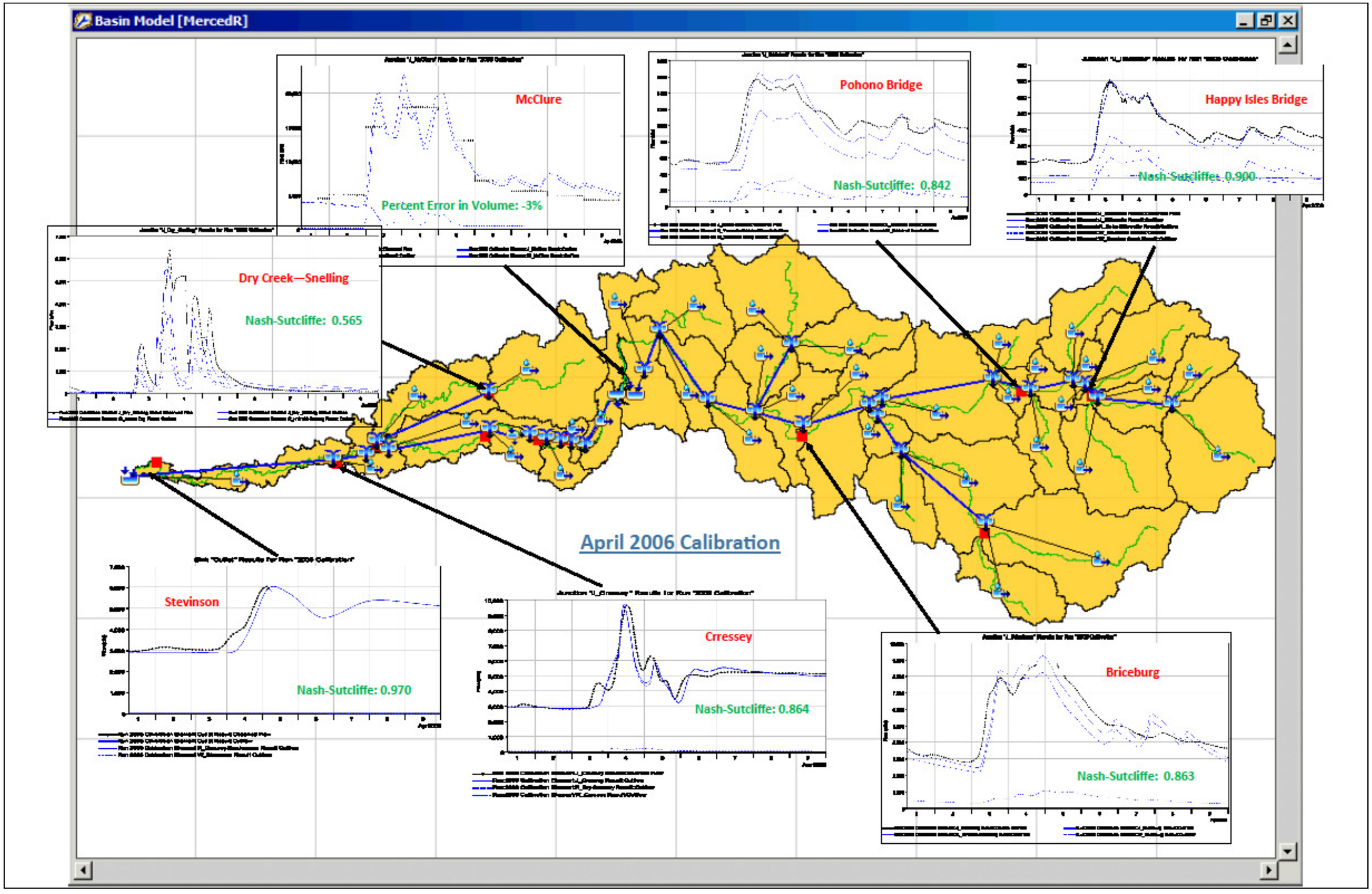


Figure 3: April 2006 Calibration Results

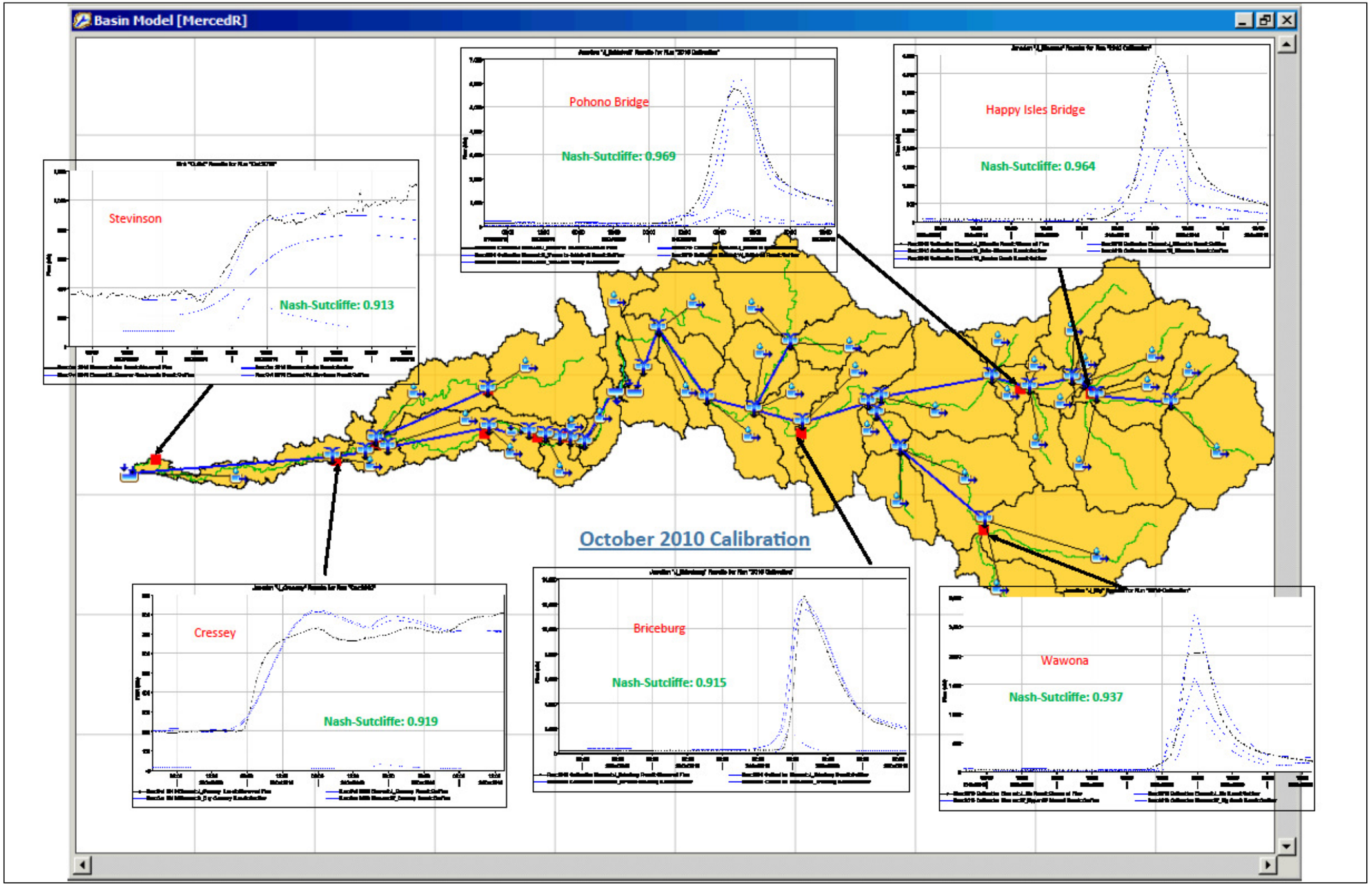


Figure 4: October 2010 Calibration Results

3.0 RESERVOIR SIMULATION MODEL

Introduction

The HEC-ResSim model starts at Lake McClure and ends at the confluence with San Joaquin River. The inflow hydrograph to Lake McClure is computed by the HEC-HMS model and transferred into the HEC-ResSim model. Downstream of Lake McClure, local inflows computed by the HEC-HMS model are added to the HEC-ResSim model. The stream alignment used in the HEC-ResSim model is based on the alignment used in the HEC-RAS modeling. The stream routing method is set to Muskingum or Modified-Puls for all reaches. Routing parameters are estimated based on calibrated HEC-RAS model.

There are 4 reservoirs on the system – McClure, McSwain, Merced Falls, and Crocker-Huffman. These reservoirs are in series and releases from one reservoir are captured by the reservoir located downstream. Lake McClure is the upper and the largest reservoir. The total storage capacity of Lake McClure is 1.024 million acre-feet. Lake McClure is the 'storage reservoir' whereas the three downstream reservoirs are regulating pools and diversion dams. Flows from Lake McClure discharge into Lake McSwain. Lake McSwain is a regulating reservoir with a storage capacity of 9,730 acre-feet. Water released from Lake McSwain flows directly into Merced Falls reservoir that is owned and operated by Pacific Gas and Electric (PG&E). North Canal diverts water from the Merced Falls Forebay. Releases from Merced Falls reservoir flow into an impoundment behind Crocker-Huffman Dam. Diversions at the Main Canal occur upstream of the Crocker-Huffman Dam. Downstream of Crocker-Huffman Dam, numerous riparian water users divert water from and return water to the Merced River. Both Lake McSwain and Merced Falls have hydroelectric power plants. However, hydropower production is an ancillary benefit of water supply and flood control operations.

Inventory

Data for each reservoir, including storage curve, dam geometry, outlet and spillway geometry, and power plants were obtained from different sources. An inventory of the data and operational assumptions obtained from these various sources and incorporated in MIDH2O is provided in this section.

All data from USACE *Water Control Manual, Appendix VII to Master Water Control Manual, San Joaquin River, CA* (WCM) (USACE, 1981) for New Exchequer Dam was in NGVD 1929 and therefore converted to NAVD 1988 by adding 2.385 feet to all elevations. Elevation-related data was checked and confirmed against the latest LiDAR data.

New Exchequer Dam

Dam features that are significant to the HEC-ResSim model include:

- An 18-foot diameter intake conduit diverging to powerhouse penstock (13-foot diameter) and 9-foot diameter bypass
- A gated spillway consisting 6 x 40-foot x 30-foot bays at elevation 839.38 feet (837.0 NGVD 1929)
- A 1,080-foot long emergency spillway at elevation 870.35 feet (868.0 NGVD 1929)

Inventory data was compiled from the WCM for New Exchequer Dam (USACE, 1981). According to MID, the minimum and maximum capacity of the powerhouse penstock is 400 cfs and 3,400 cfs. It normally operates between 600 cfs and 3,200 cfs. The capacity curve for the 9-foot bypass excludes flow through the powerhouse. The bypass has a maximum capacity of 9,000 cfs. The maximum release through the dam is 12,400 cfs. With the exceptions of major flooding conditions, the release is limited to 6,000 cfs due to restricted channel capacity downstream.

Lake McSwain

Dam features that are significant to the HEC-ResSim model include:

- An 8-foot diameter powerhouse penstock directs water to either the generator or the bypass
- Low flows are bypassed
- There are two emergency spillways - the 470-foot spillway is at 402.4 feet elevation (NAVD1988) and the 150-foot spillway is at 404.4 feet elevation

Inventory data was compiled from the WCM for New Exchequer Dam (USACE, 1981). According to MID, power generation begins when flow reaches 700 cfs and ends when flow drops to 500 cfs.

Merced Falls Forebay

Dam features that are significant to the HEC-ResSim model include:

- There is only one penstock. It can send water either to the generator or a bypass
- The gated spillway consists of three 20-foot wide x 13.5-foot tall bays
- The dam is the emergency spillway
- Powerhouse intake
- Diversion to Northside Canal.

The inventory data was compiled from the *Merced Falls Hydroelectric Project - Technical Due Diligence Study* (HDR, 2013). The powerhouse conduit has a reported capacity of 2,100 cfs. Flow less than 2,100 cfs is routed to the turbine.

Crocker-Huffman Dam

Dam features that are significant to the HEC-ResSim model include:

- There is no penstock, bypass outlet, or gated spillway
- Entire dam is a spillway

The main purpose of the dam is to create backwater to facilitate diversions to the Main Canal.

Hydrology

Inflow to Lake McClure and local flows calculated by the HEC-HMS model are fed into the HEC-ResSim model at model junctions. Inflow time-series are linked to the results of the calibrated HEC-HMS model.

Operations

The entire MID system is operated to provide a reliable supply of water to its customers based on the following criteria:

- The primary purpose of Lake McClure and Lake McSwain is to meet irrigation demands. Power production is incidental
- There are several contractual agreements and FERC requirements that dictate minimum flows in the Merced River
- The maximum storage in the reservoir changes through the year to provide a safety buffer and flood control volume below the maximum capacity. The flood control capacity is based on a severe rain event and additional Conditional Storage for snowmelt runoff. The standard Reservoir Guide Curve between the Conservation Pool and the Flood Pool does not change. The additional Conditional Storage for snowmelt runoff changes, depending on the estimated volume of snow water equivalent in the watershed above Lake McClure
- The minimum flow to the downstream fishery is 25 cfs at Shaffer Bridge gage
- The maximum channel capacity if the river is 6,000 cfs. This will only be exceeded during rare flood events

Within the HEC-ResSim model, each reservoir is provided a set of Operational Rules. There are multiple sets of rules for each reservoir. The program switches from one set of rules to another as the reservoir level enters a new zone. The zones are dead pool, conservation pool, flood control and surcharge. The program attempts to keep the reservoir in the conservation pool at all times. These rules are prioritized in the order that they appear in the Operations tab of the Reservoir Editor for each reservoir. Lower level rules can and will be violated to meet a higher priority rule. To avoid conflicts between rules for the various reservoirs, all demands were assigned to Lake McSwain. New Exchequer dam will release only enough water to meet fish flow requirements, avoid exceeding the maximum pool elevation of Lake McClure, and keep McSwain within its operational range. The timing of the releases from Exchequer can be limited to periods when power generation is desired. Dewberry developed the Reservoir Operation rules in a manner that will provide robust and stable calculations.

New Exchequer Dam

The HEC-ResSim model Operations tab includes rules to control release for daily operation (non-event period). In this model, the conservation pool guide curve was set to the conditional space curve which is equal to the rain storage curve subtracting the forecasted snowmelt. Induced surcharge rule and Emergency Release Diagram Discharge (ESRD) rules were added to the flood control zone and surcharge zone. These rules were used in the USACE's Corps Water Management System (CWMS) HEC-ResSim model (USACE, 2016) to allow additional releases when forecasted incoming flows exceed available storage in the lake and dam overtopping may occur. Conservation pool rules were added to control releases based on McSwain's normal operating pool elevation (between 396.4 feet and 401.4 feet (NAVD1988). In other words, McClure would release flow (minimum 2,500 cfs) when McSwain pool is less than 396.4 feet (NAVD 1988). When McSwain pool reaches 401.4 (NAVD 1988) feet, release is set to 25 cfs for fish flow requirement. McClure would not be releasing more than minimum fish flow while McSwain is being drawn down until 396.4 feet. (NAVD 1988) The release occurs only for 8 hours between 4:00pm and 12:00am. Rate of increase/decrease is limited to 300 cfs/hr. The HEC-ResSim Operations tab for MIDH2O is shown in Figure 5.

When there is large snowpack, the USACE requests MID to lower the water level in Lake McClure below the normal "rain limit" operations curve to capture the anticipated runoff. The USACE calculates Conditional Storage daily during period when snowmelt runoff is possible. The Conditional Storage is based on the California Department of Water Resources (DWR) Bulletin 120 which estimates current snowpack conditions. Bulletin 120 is updated by DWR every 14 to 31 days. From the Conditional Storage calculation, the Supplemental Release to achieve the additional storage over time is calculated. These

calculations have been coded into the WISKI database. In the HEC-ResSim model, Supplemental Releases are extracted from Lake McClure and discharged into Lake McSwain.

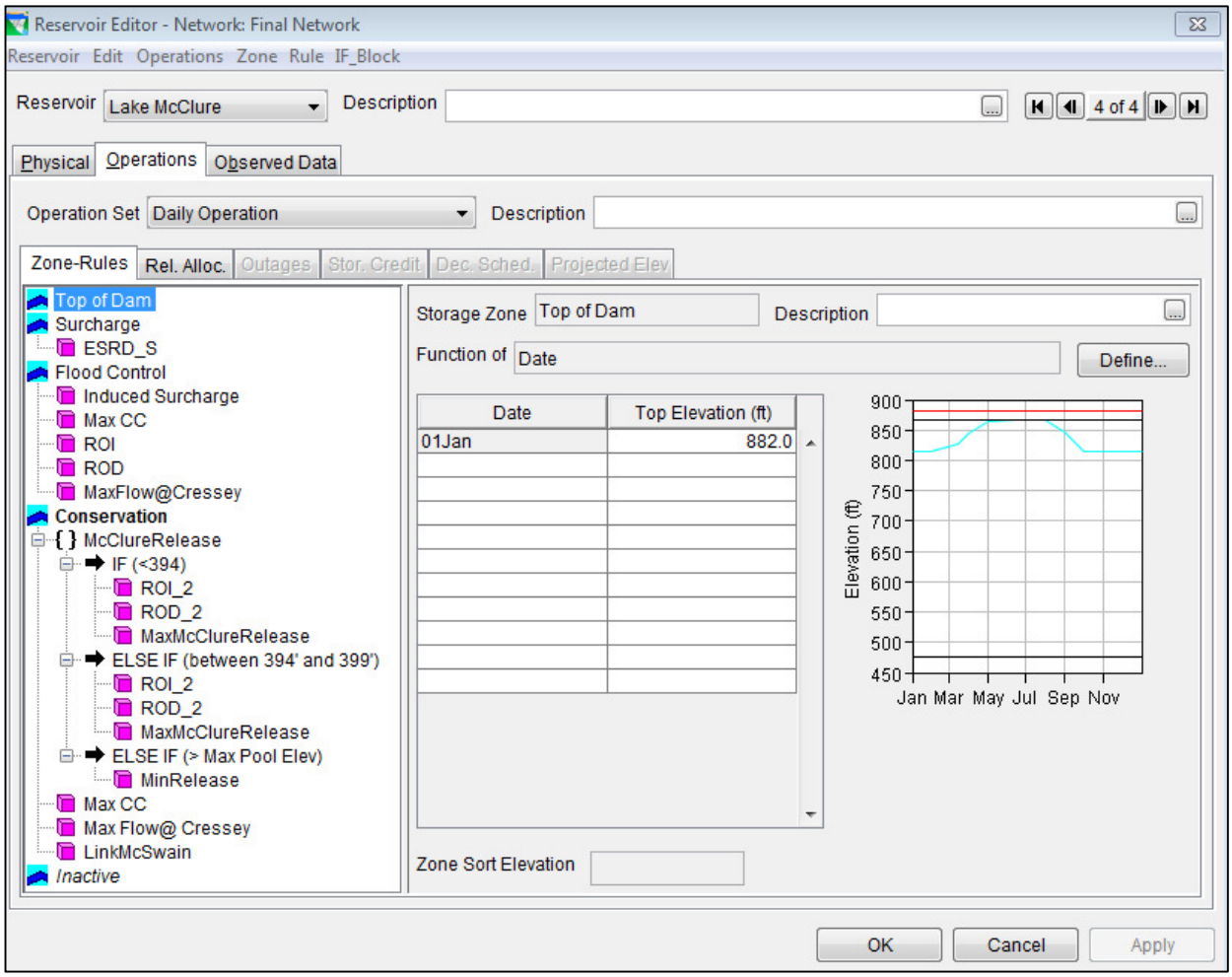


Figure 5: Operation Rules Input Screen of the HEC-ResSim Model at Lake McClure

Lake McSwain

According to MID, the operating elevation for the reservoir is between 396.4 feet (NAVD 1988) and 401.4 feet(NAVD 1988). Surcharge elevation is set to 430.4 feet which is 0.5 feet below top of the dam. There is no available information about the top of flood control pool elevation so it was assumed to be 406.4 feet (NAVD 1988) which is 4 feet above the crest of the emergency spillway. Conservation pool elevation set to 402.4 feet (NAVD 1988) which is at the lower crest elevation of the two spillways. According to the MID's reservoir operator, flow less than 600 cfs is routed through the bypass. Flow higher than 600 cfs is routed through the powerhouse penstock. For MIDH2O, downstream control rules were added to Conservation pool to control release to meet the minimum flow requirement at Shaffer Bridge and

maximum allowable flow at Cressey. Minimum daily flow requirement at Shaffer for normal year and dry year was calculated based on historical data provided by MID. The flow requirement is the sum of flows from FERC, Davis-Grunsky agreement, fish pulse, irrigation, and other water transfer. The HEC-ResSim Operations tab for McSwain is shown in Figure 6.

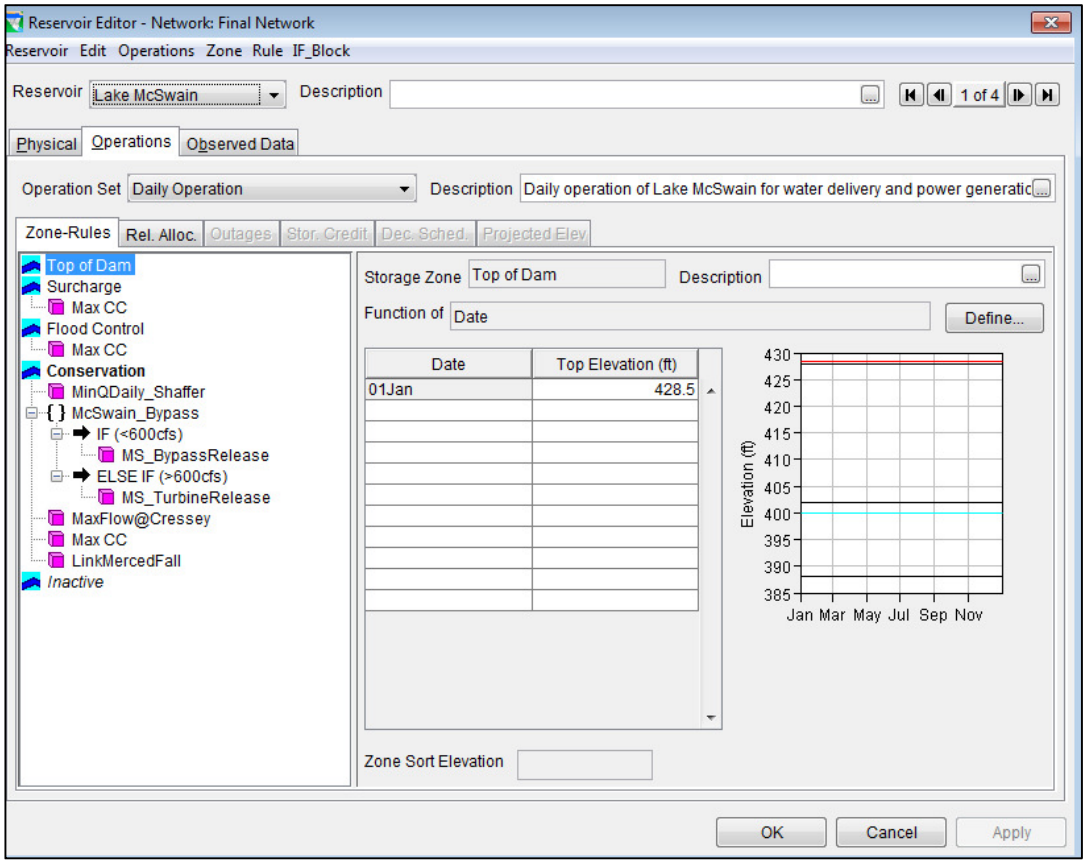


Figure 6: Operation Rules Input Screen of HEC-ResSim Model at Lake McSwain

Merced Falls Forebay

The reservoir is being operated with constant volume. Flow through rule: Inflow = outflow.

Crocker-Huffman Dam

It is being operated with constant volume. Flow through rule: Inflow = outflow

Physical Properties

New Exchequer Dam

According to MID, if more than 25 cfs is being released through any other outlet, the fish flow is turned off. Release is through the conduit which diverts flow to powerhouse penstock and bypass. Normally, flow up to 3,100 cfs is routed through the penstock. Excess flow above 3,100 cfs is routed through the bypass. The installed powerhouse capacity is 105MW. Table 6 of the *Merced River Hydroelectric Project Water Balance/Operations Model Documentation and Validation* (MBK, 2010) tabulates turbine efficiency as a function of release and heads (350 feet, 400 feet and 450 feet) (NAVD 1988). It was observed that since the efficiency is more dependent on release rate than the head, an efficiency curve with a head of 400 feet was used in the MIDH2O HEC-ResSim model. The tailwater elevation is set to McSwain pool elevation.

Lake McSwain

According to MID, the powerhouse penstock has a 2,500 cfs maximum capacity. A flow of 600 cfs is the minimum flow required to generate power. Flows less than 600 cfs are routed through the bypass. For the HEC-ResSim model, the turbine capacity curve was calculated using constant head of 55 feet (McSwain Conservation Pool, 502.4 feet (NAVD 1988) – Merced Falls Conservation Pool, 447.4 feet (NAVD 1988)) and Equation 4 in the *Merced River Hydroelectric Project Water Balance/Operations Model Documentation and Validation* (MBK, 2010).

Merced Falls Forebay

The powerhouse conduit has a reported capacity of 2,100 cfs. All flow less than 2,100 cfs is sent to the turbine. For flows between 2,100 and 12,000 cfs, one to three spillways are opened to pass the excess flow. For flows between 12,100 and 55,000 cfs, needle beam spillways are opened to maintain the 346.4' (NAVD 1988) water surface elevation. Turbine capacity curve was calculated using constant head of 35' (Merced Falls Conservation Pool, 352.4 feet (NAVD 1988) – DS constant elevation, 317.4 feet) (NAVD 1988) and Eq4 in the *Merced River Hydroelectric Project Water Balance/Operations Model Documentation and Validation* (MBK, 2010). A flow of 500 cfs is the minimum flow required to generate power. A constant efficiency of 86% was applied.

Reservoir Releases

Northside Canal Diversion at Merced Falls and Main Canal Diversion at Crocker-Huffman Dam

The diverted flows in the model are set to default time-series which were developed using historical data provided by MID. However, during the live simulation of the HEC-RTS model, the flow time-series are subject to change daily depending on the input from MID personnel.

Cowell Agreement Diversion Points

There are nine Cowell Agreement Diversion (CAD) points between Crocker-Huffman Dam and Shaffer Bridge. CADs are riparian rights holders who can take their water at any time and do not coordinate their actions with MID. The diverted flows in the model are set to default time-series which were developed using historical data provided by MID. During the live simulation of the HEC-RTS model the flow time-series are subject to change daily depending on the input from MID personnel.

Supplemental Releases

The Supplemental Release is a release over and above normal irrigation and power generation demands. The MIDH2O system uses the Corps' Conditional Storage for the look back period and calculates the future Conditional Use and Supplemental Release for the next fourteen days for the HEC-ResSim model. The Supplemental Release is modeled as a separate demand at Shaffer Bridge.

4.0 RIVERINE HYDRAULICS MODEL

Introduction

Dewberry created a HEC-RAS model for the Merced River from Lake McClure to the San Joaquin River. The lower portion of the model utilizes with permission the model Dewberry created for DWR during the Central Valley Flood Evaluation and Delineation (CVFED) program (DWR, 2013). The upper boundary of the CVFED model was approximately one mile downstream of N. Santa Fe Drive. In 2015, MID collected LiDAR data and aerial imagery along the Merced River from the confluence with the San Joaquin River to the upper end of Lake McClure. Dewberry digitized the river centerline of the new reach from the 2015 LiDAR terrain and aerial imagery. The reach from Merced Falls to Cressey is connected to the HEC-RTS system. The model can be run in either steady or unsteady mode.

Dewberry performed calibration on both models. The calibration of the models was a two-step process. Step 1 was an attempt to calibrate the models using a single channel roughness to match the CDEC rating curves at Cressey, Shaffer Bridge and Merced Falls. The rating curve at Crocker-Huffman is only accurate for very low flows. Step 2 was to vary the roughness factor based on flow or stage. For low flow, the vegetation, rocks and boulders along the stream bed are relative major obstructions causing the roughness values to be very high. As the water level increases these roughness elements become less important and the Manning's n value for the channel decreases. In the steady mode, HEC-RAS allows the user to define Manning's n values for each stage. In the unsteady mode, HEC-RAS requires the user to provide Roughness Flow Factors to adjust n values. The Roughness Flow Factors vary by flow and are used to multiply the original n value.

Normally, the gage datum plus the gage stage is equal to the elevation above mean sea level. However, several of the published datums for the streamgages on the Merced River below Lake McClure appear to be assumed, or inaccurate, as they are off by up to 70 feet when compared to other sources including LiDAR data. In order to match the rating curves, Dewberry calculated an additional manual adjustment at each gage. It is recommended that the datum for each streamgage be tied to NAVD88 datum.

The steady HEC-RAS model is very accurate for predicting stages at the stream gages. The Manning's n values used in the steady model are lower than those developed for the unsteady model. The unsteady model predicts the timing of the arrival of the peak very well, but the stages are approximately one foot higher than in the steady model. Underwater cross-section geometry is planned to be added to the model in 2017, requiring recalibration of the models.

Steady HEC-RAS Constant Manning's Roughness Calibration

Initially, Dewberry calibrated a steady state HEC-RAS model assuming the Manning's roughness parameter ("n" values or channel roughness coefficient) are constant for all flows. The channel roughness coefficient for very low flows can typically be two to four times higher than the coefficient for flood flows. The roughness coefficients are relatively constant beyond a five or ten-year flood level.

The cross-sections extracted from the LiDAR data did not include the underwater portion of the section. The bank stations were placed at the edge of water based on aerial photographs. The model was run with a flow of 195 cfs, which was the flow the day the aerial photographs and LiDAR data was collected by MID in 2015. Points were added to the underwater portion of the cross-section. These points were iteratively lowered until the model produced a water surface profile that followed the profile to the elevation of the banks at a flow of 195 cfs. At gage locations, the rating curves were used to match at multiple flow rates. At Merced Falls and Shaffer Bridge, points collected by MID's hydrologic consultant during their stream flow measurement were used to shape the below water cross-section. The following tables and figures compare the rating curve between the California Data Exchange Center (CDEC) gages and associated HEC-RAS model cross section. Table 2 and Figure 7 are not the final curve used in MIDH2O but reflects the assumption that Manning's n values are constant for all flows.

Table 2: Rating Curve Comparison at CDEC Gage, Merced River below Merced Falls (CDEC Gage ID: MMF)

CDEC Stage (feet)	CDEC Discharge (cfs)	Elevations* (feet)	HEC-RAS WSE (feet)	Delta WSE (feet)
3	***105***	314.9	314.1	***-0.8***
4	***258***	315.9	315.0	***-0.9***
5	***659***	316.9	316.1	***-0.8***
6	***1288***	317.9	317.4	***-0.5***
7	***2095***	318.9	318.5	***-0.4***
8	***3121***	319.9	319.7	***-0.2***
9	***4373***	320.9	320.9	***0.0***
10	***5707***	321.9	321.9	***0.0***
11	***7042***	322.9	322.8	***-0.1***
12	***8500***	323.9	323.8	***-0.1***
13	***10590***	324.9	324.9	***0.0***
14	***12858***	325.9	326.1	***0.2***
15	***15372***	326.9	327.1	***0.2***

** sum of CDEC data (reference elev, stage, 4/17/16 shift) and +1.9 ft manual adjustment*

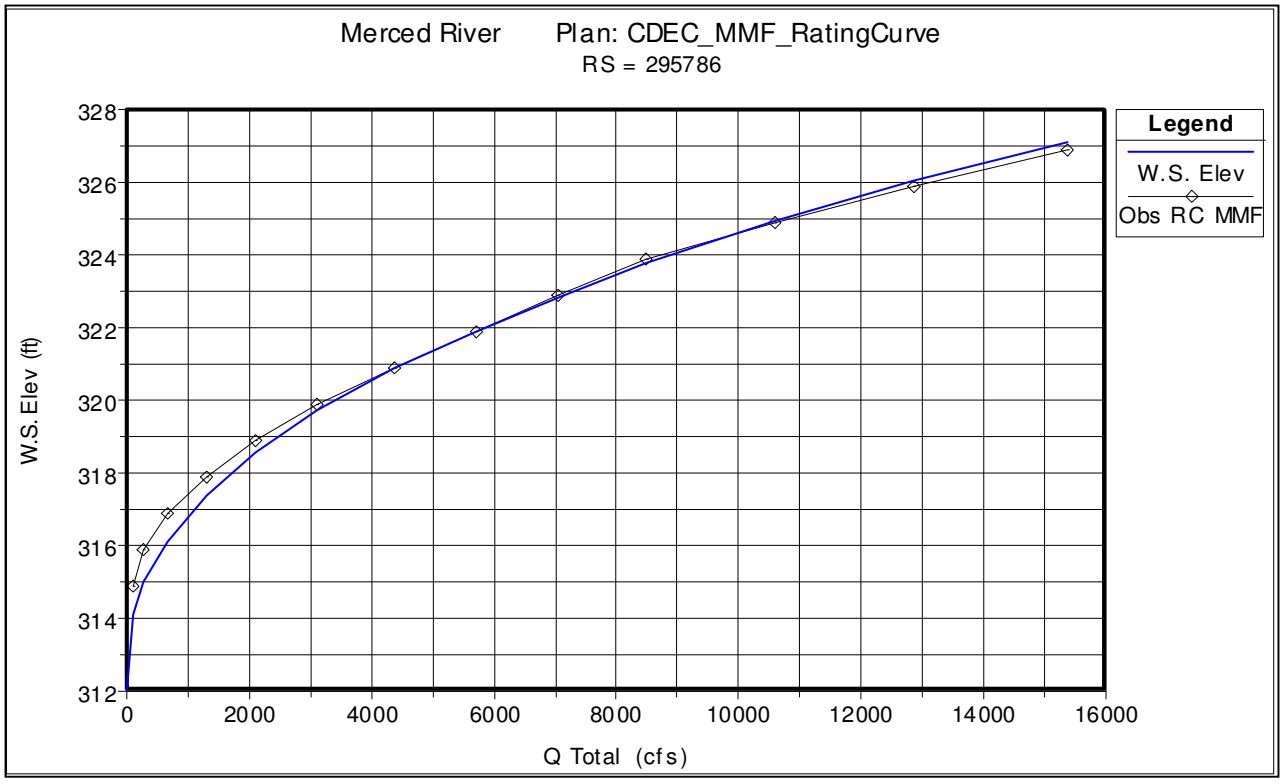
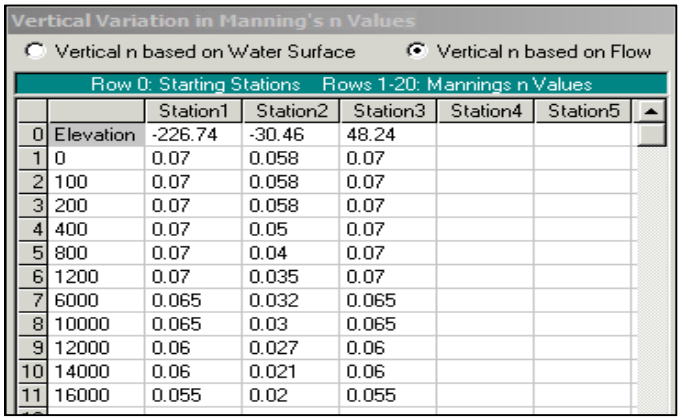


Figure 7: Comparison of modeled water surface elevation as compared to observed stage elevation as measured at CDEC Gage MMF assuming a constant Manning's coefficient.

Steady HEC-RAS Calibration with Vertically Variable "n" Values

Vertically varied "n" values were applied to better match the gage rating curves. The vertically varying "n" values were very helpful at the upstream end of the model (River Station 263060 to 296289). Vertical variation "n" values are shown in Figure 8. In this area the stream bed is rock with exposed bedrock. From Snelling Road, the bed material is small gravel and transitions from gravel to sand downstream of Shaffer Bridge. For the steady state model, only minor adjustments were necessary to "n" values downstream of Snelling Road to match the rating curves.



		Station1	Station2	Station3	Station4	Station5
0	Elevation	-226.74	-30.46	48.24		
1	0	0.07	0.058	0.07		
2	100	0.07	0.058	0.07		
3	200	0.07	0.058	0.07		
4	400	0.07	0.05	0.07		
5	800	0.07	0.04	0.07		
6	1200	0.07	0.035	0.07		
7	6000	0.065	0.032	0.065		
8	10000	0.065	0.03	0.065		
9	12000	0.06	0.027	0.06		
10	14000	0.06	0.021	0.06		
11	16000	0.055	0.02	0.055		

Figure 8: Vertical Variation of N Values

Columns 4 and 5 of Table 3 shows that without using a variable "n" values the lower portion of the rating curve differs from the CDEC rating curve for the MMF gage by as much as 0.9 feet. The last column shows that by increasing the channel "n" value for lower flows, the rating curve is within 0.1 feet. Figure 9 is a plot of the three rating curves.

Table 3: Comparison of Constant and Vertically Varied N Values at CDEC Gage MMF

HEC-RAS Observed Rating Curve (MFF @ XS 295786)						
CDEC Stage (feet)	CDEC Discharge (cfs)	Elevations* (feet)	HECRAS WSE (feet)	Delta WSE (feet)	RAS Variable N	Delta
3	***105***	314.9	314.1	***-0.8***	315.04	0.1
4	***258***	315.9	315.0	***-0.9***	315.94	0.0
5	***659***	316.9	316.1	***-0.8***	316.96	0.1
6	***1288***	317.9	317.4	***-0.5***	317.86	0.0
7	***2095***	318.9	318.5	***-0.4***	319	0.1
8	***3121***	319.9	319.7	***-0.2***	320.1	0.2
9	***4373***	320.9	320.9	***0.0***	321.16	0.3
10	***5707***	321.9	321.9	***0.0***	322.08	0.2
11	***7042***	322.9	322.8	***-0.1***	322.89	0.0
12	***8500***	323.9	323.8	***-0.1***	323.7	-0.2
13	***10590***	324.9	324.9	***0.0***	324.77	-0.1
14	***12858***	325.9	326.1	***0.2***	325.86	0.0
15	***15372***	326.9	327.1	***0.2***	327.09	0.2
* sum of CDEC data (reference elev, stage, 4/17/16 shift) and +1.9 ft manual adjustment						

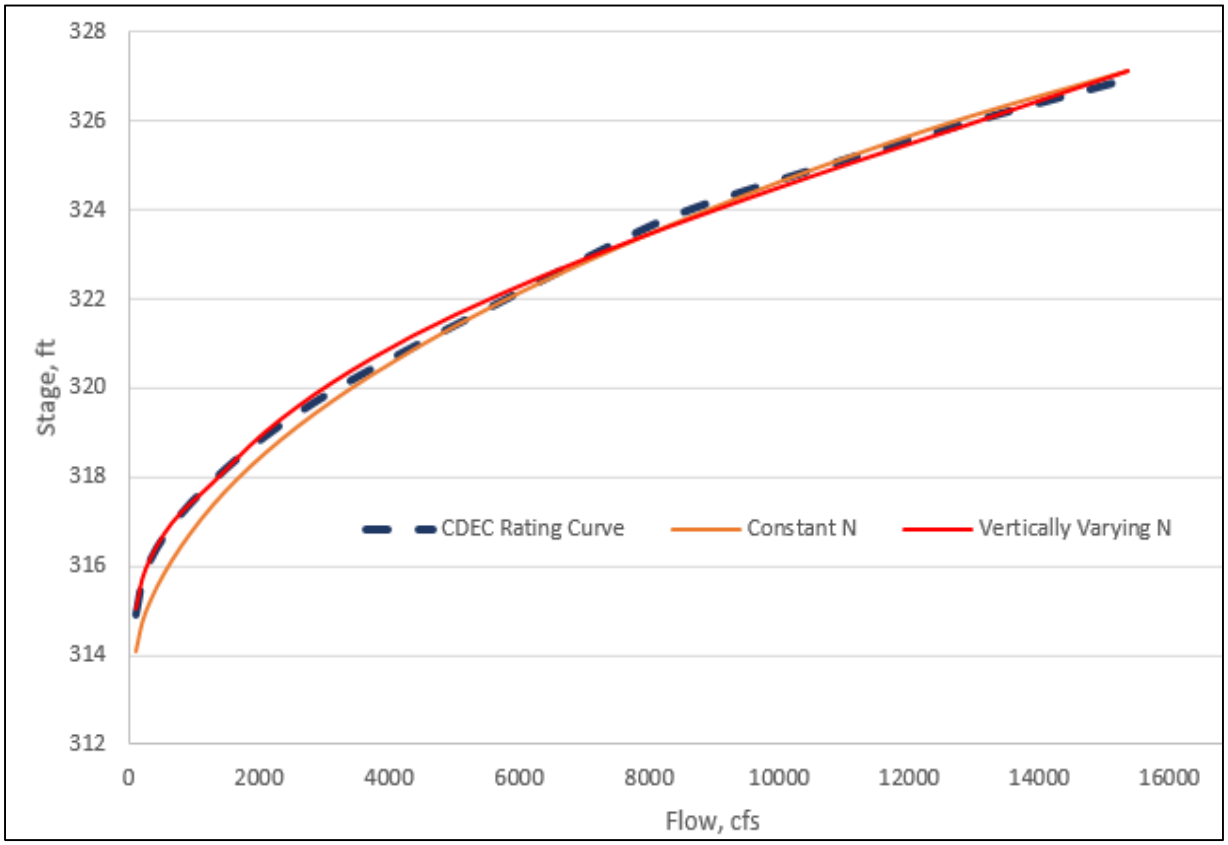


Figure 9: Comparison of Constant and Vertically Varied "n" Values to the Rating Curve at Merced River below Merced Falls (CDEC Gage: MMF).

Calibration and Stabilization of the Unsteady Flow HEC-RAS Model

After the steady state HEC-RAS model was calibrated an unsteady flow run was performed. The unsteady HEC-RAS model was created with constant "n" values as shown in Table 4. Figure 10 shows the unsteady model predicts the hydrograph peak reaches Shaffer Bridge several hours too early.

Table 4: Constant N Values for Unsteady HEC-RAS Model

Reach	Overbank "n" values	Channel "n" Values
296289 to 294596	.060	0.042
293771 to 282488	0.05 to 0.060	0.033
281812 to 277028	.050	0.055
275954 to 245442	0.05 to 0.06	0.033
244547 to 140150 except 176283	0.050	0.030
176283	0.050	0.035

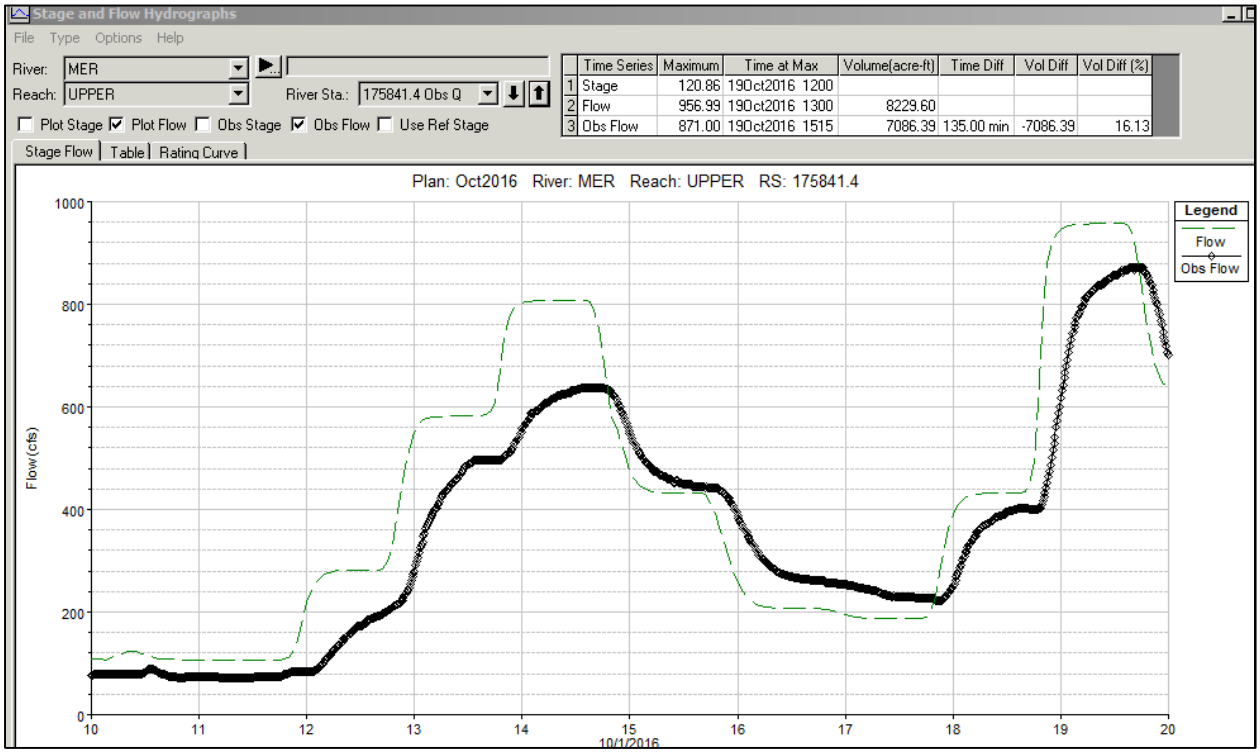


Figure 10: Unsteady HEC-RAS Hydrograph at Shaffer Bridge with Constant "n" values. (CDEC Gage ID: MBN)

Vertical varied "n" values are not available for unsteady flow models. The unsteady HEC-RAS model allows the use of Flow Roughness Factors that are multiplied by the base roughness factors for either stage or flow ranges. The flow option was chosen for this calibration effort. Separate factors were determined for each reach between gage stations. Figure 11 shows an example of the Flow Roughness Factors used.

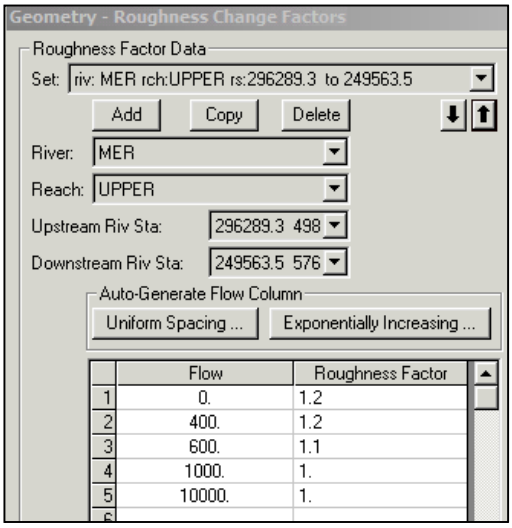


Figure 11: Flow Roughness Factors upstream of Snelling

The next step was to add Flow Roughness Factors (i.e., "n" values) downstream of Snelling Road. After several iterations the factors shown in Figure 12 were chosen. These values slowed the arrival of the modeled hydrograph peak to match observed flows (see Figure 13 and Figure 14).

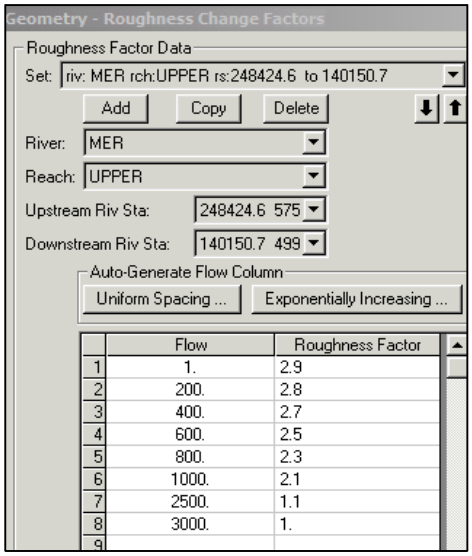


Figure 12: Flow Roughness Factors Downstream of Snelling Road

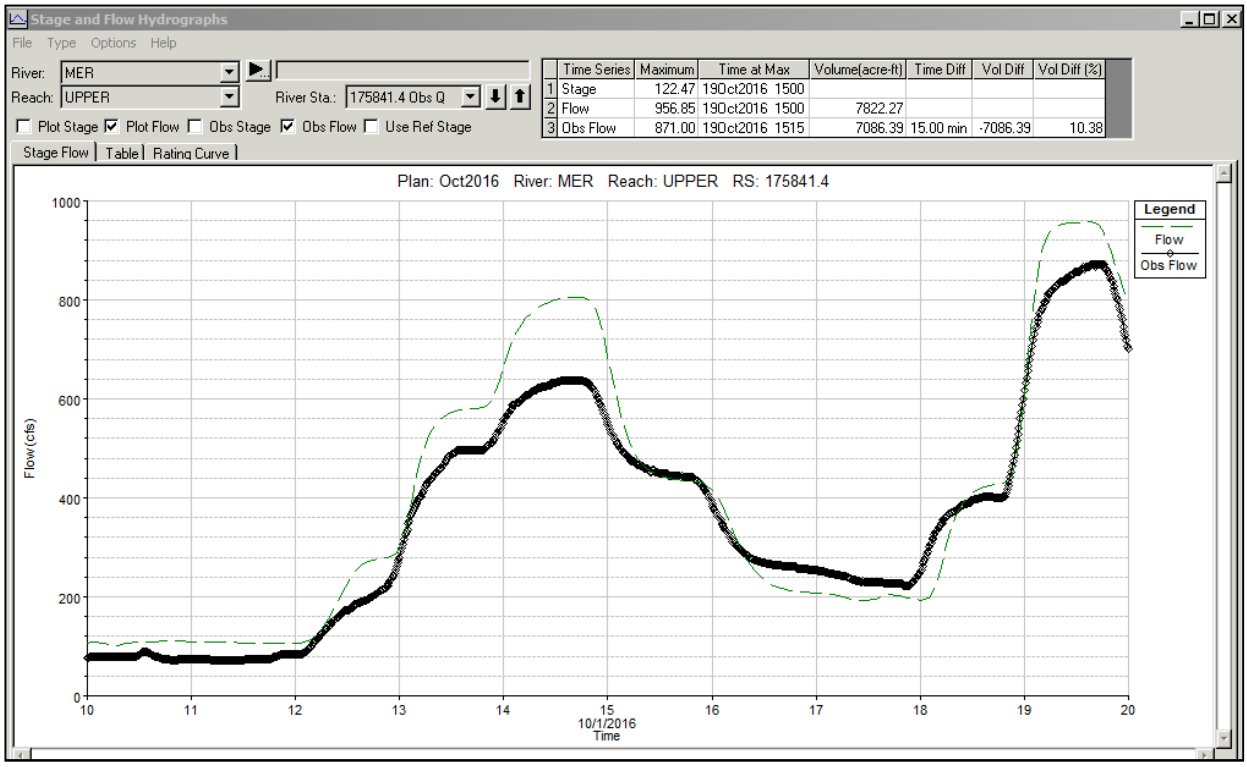


Figure 13: Hydrograph at Shaffer Bridge with Roughness Factors

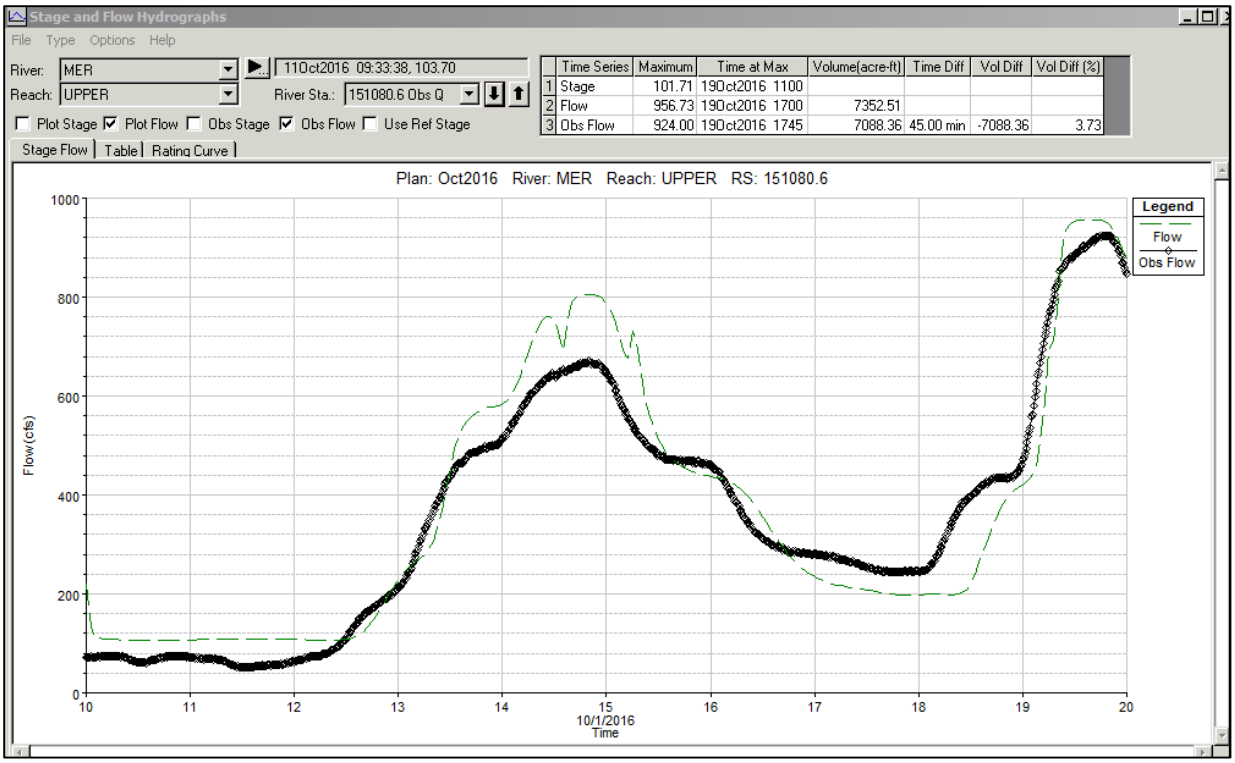


Figure 14: Hydrograph at Cressey with Roughness Factors

The Flow Roughness Factors necessary to slow the movement of the flow hydrograph causes the water surface elevation to exceed the levels in the steady state HEC-RAS model.

The rating curves from the steady analysis closely match the current gage rating curves. The unsteady model requires much high roughness factors, especially at low flows to match the timing of the peaks. The stage values, however are too high.

The rating curves using Flow Roughness Factors may be more similar to the Steady Flow rating curves when the underwater cross-sections are pulled from the green water penetrating LiDAR that MID recently obtained. The HEC-RAS model cross-sections will be updated in 2017.

5.0 REAL TIME SIMULATION MODEL

Introduction

The HEC has developed a real-time data acquisition, hydrologic and hydraulic modeling, and reservoir operation model system for a short-time decision support of water control operations. This system, known as Corps Water Management System (CWMS), is used by USACE offices throughout the country. The CWMS Control and Visualizatoin Interface (CAVI) is the component of CWMS that integrates multiple HEC produces. HEC-RTS is the public version of the CWMS CAVI.

The HEC-RTS program provides support for operational decision making by using short-term forecast-based modeling. This program integrates observed and forecast meteorological data with hydrologic, hydraulic, reservoir operations, and flood inundation analysis programs. The program calls up and runs the specific models in a pre-determined sequence, and incorporates specified operational constraints. Typical constraints include maximizing pool elevation for water supply, recreation and energy production, maintaining an appropriate reserve for flood storage, and providing minimum releases for environmental uses. Local inflow from the watershed is calculated by the HEC-HMS model and read into the reservoir simulation model, which route flows between reservoirs to balance the system. All the inputs and outputs of the models are stored in the HEC Data Storage System (DSS) database.

Since the HEC-RTS program provides a platform to integrate a variety of inputs, each of the models such as HEC-HMS, HEC-ResSim, and HEC-RAS need to be set up and calibrated individually. After each model is calibrated, the models are moved to the HEC-RTS program folder. Once in the program folder, HEC-RTS calls each program based on a pre-defined program sequence. The schematic for the MIDH2O is illustrated in Figure 15.

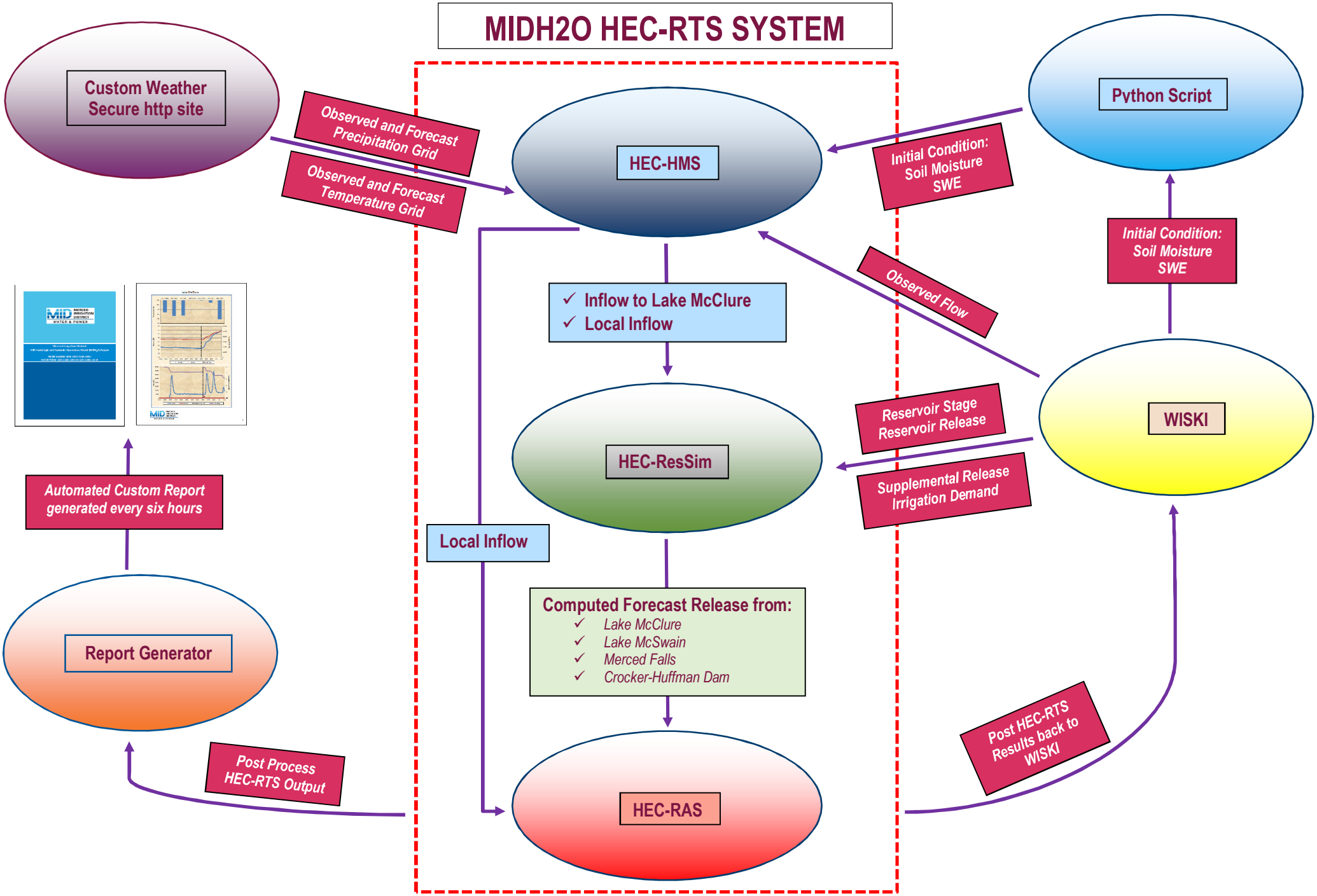


Figure 15: Schematic for MIDH2O HEC-RTS System

Besides using the suite of publicly available HEC software, the HEC-RTS program also allows users to add scripts or external programs in the model sequence. For MIDH2O, two scripts were developed and added to the program sequence. The first script runs before the HEC-HMS model and the second script runs immediately after the HEC-HMS model. The first script, *SoilMoisture.py*, takes the initial soil moisture deficit for each sub-basin from the last HEC-HMS run and updates the HEC-HMS basin file for the current run with the new initial soil moisture deficit values.

The second script, *CopySnowback.py*, copies gridded snow water equivalent, cold content, liquid water content, meltrate antecedent temperature index and cold content antecedent temperature index to a HEC-DSS file. These snow grids are used as the initial condition grids for the next HEC-RTS forecast run.

The program sequence used in this HEC-RTS model is shown in Table 5 below:

Table 5: HEC-RTS Program Sequence

	Program	Default Input
1	Script – SoilMoisture.py	-
2	HEC-HMS	
3	Script – CopySnowback.py	
4	HEC-ResSim	HEC-HMS
5	HEC-RAS	HEC-ResSim

MIDH2O is a fully automated system - data collection, data validation, model run and generation of custom report are entirely automated. MIDH2O is run every six hours (four o'clock and ten o'clock PST). Each forecast run looks back two weeks of observed data and looks ahead one week of forecast data. MIDH2O is also manually checked periodically for model accuracy and calibration.

WISKI and Data Storage

MID has a time series hydrologic database - WISKI - that stores observed reservoir levels, stream flows, and meteorological data with a time based stamp. As a part of this project, an interface was built so that the HEC-RTS can query and extract the time-series data from WISKI. After each forecast run, a selected number of HEC-RTS time-series outputs are posted back to WISKI. The time-series posted back to WISKI includes precipitation, SWE, moisture deficit, and flow from HEC-HMS; reservoir storage, elevation, release from HEC-ResSim; and flow and stage at each HEC-RAS cross section.

Meteorology

CustomWeather Inc. (CustomWeather) creates forecasted precipitation and evapotranspiration (ETo) grids for MID using proprietary software techniques. The model that CustomWeather uses is initialized

from an ensemble of models to produce optimal results. The input that CustomWeather puts into its model is weighted according to past accuracy and resolution. Models run by National Oceanic and Atmospheric Administration (NOAA) (and Environment Canada) with higher resolution and higher frequency are given greater weight, particularly in the short term.

Some of the models that go into the precipitation forecasts include the GFS, NAM, regional GEM, global GEM (GDPS), RAP, HRRR, and HiRes CONUS NAM nest. These models are further downscaled to a very high resolution to correspond with the complex terrain of the watershed. Using an Akima spline fit, the ensemble of models is interpolated to 1-hour resolution. The DSS grids delivered to MID are approximately 570 meters in average resolution.

ETo grids delivered by CustomWeather to MID are created by solving the CIMIS Penman equation using hourly grids from CustomWeather's proprietary Uncoupled Surface Layer (USL) model. The CIMIS Penman equation was developed by agronomists at the University of California-Davis. The weather variables that go into the CIMIS Penman equation are modeled at 100-meter resolution in 1-hour increments over the entire MID basin.

The USL model that provides the backbone of the ETo forecasts is a physics-based model that focuses on near-ground conditions. It incorporates complex topography and picks up on microclimates caused by surface features. The USL model achieves optimal accuracy by utilizing all of the weather models run by NOAA as input in a weighted fashion to determine upper atmospheric conditions. By utilizing upper atmospheric data from NOAA models, the CustomWeather model is able to focus on atmospheric modeling in the lowest 100 meters of the atmosphere. This focused approach helps to reduce computational time down to manageable levels that other models simply cannot achieve.

The USL model has won numerous forecasting competitions. It utilizes NASA land feature data at 10-meter resolution and contains machine learning algorithms that further improve the forecasts over time. The fine resolution and accuracy of the USL forecasts going into the ETo grids for MID is unmatched in the industry today.

Custom Scripting and System Automation

MIDH2O required custom scripts to perform the following tasks:

- Retrieve temperature and precipitation grids from CustomWeather's website
- Copy the snowpack parameters from hour 6 of the prior run to the start of the current run
- Copy the soil moisture parameters from hour 6 of the prior run to the start of the current run
- Calculate Conditional Storage and Supplemental Releases as specified by the USACE
- Create a custom report

The scripts were written in the Python programming language.

Planning scenarios

The MIDH2O project includes preliminary analysis of at least five scenarios that demonstrate how the program can be used to identify potential water savings. Based on discussions with MID, six scenarios were identified and modeled. These analyses are for demonstration purposes only.

Scenario 1 – Compare Normal Historic Operations to Rule Based Operations

MIDH2O was programmed to release water from Lake McClure and Lake McSwain to meet downstream demands and flood storage requirements. The rules for operating the system were provided by MID and USACE. MID operators generally follow these rules but have the flexibility to deviate from the rules based on their judgment. By running a comparison of the actual operations to historic data, it is possible to develop reccomendations for improvements to the MIDH2O rules or how the operators make decisions.

The HEC-ResSim model in MIDH2O was run using daily inflows to McClure, daily flows at Dry Creek near Snellings and actual irrigation demands for the period January 2, 2005 through December 30, 2010. MID has estimated daily inflows to Lake McClure. These estimates are based on daily changes in storage and estimates of releases through Exchequer Dam. The record has many zeroes in the data for days when the calculation of inflow resulted in a negative value.

Dewberry ran the inflows through MIDH2O model using the reservoir operation rules provided by MID. Figure 16 compares the historical and modeled daily storage in Lake McClure with and without the Supplemental Releases for snowmelt. Figure 17 shows the Conditional Storage calculated by the USACE for 2011 (in gray). The "HEC-ResSim Snowmelt Guide Curve" reflects the maximum amount of

Conditional Storage. These three are not expected to match, as the daily operations do not follow a rigid set of rules. For example, releases during flood events are often affected by decisions made by the USACE. The run was made assuming the only releases from Lake McClure would be to meet the demands including FERC and Davis Grunsky flows, Main and Northside Canal, and CAD users. Water transfers were not included.

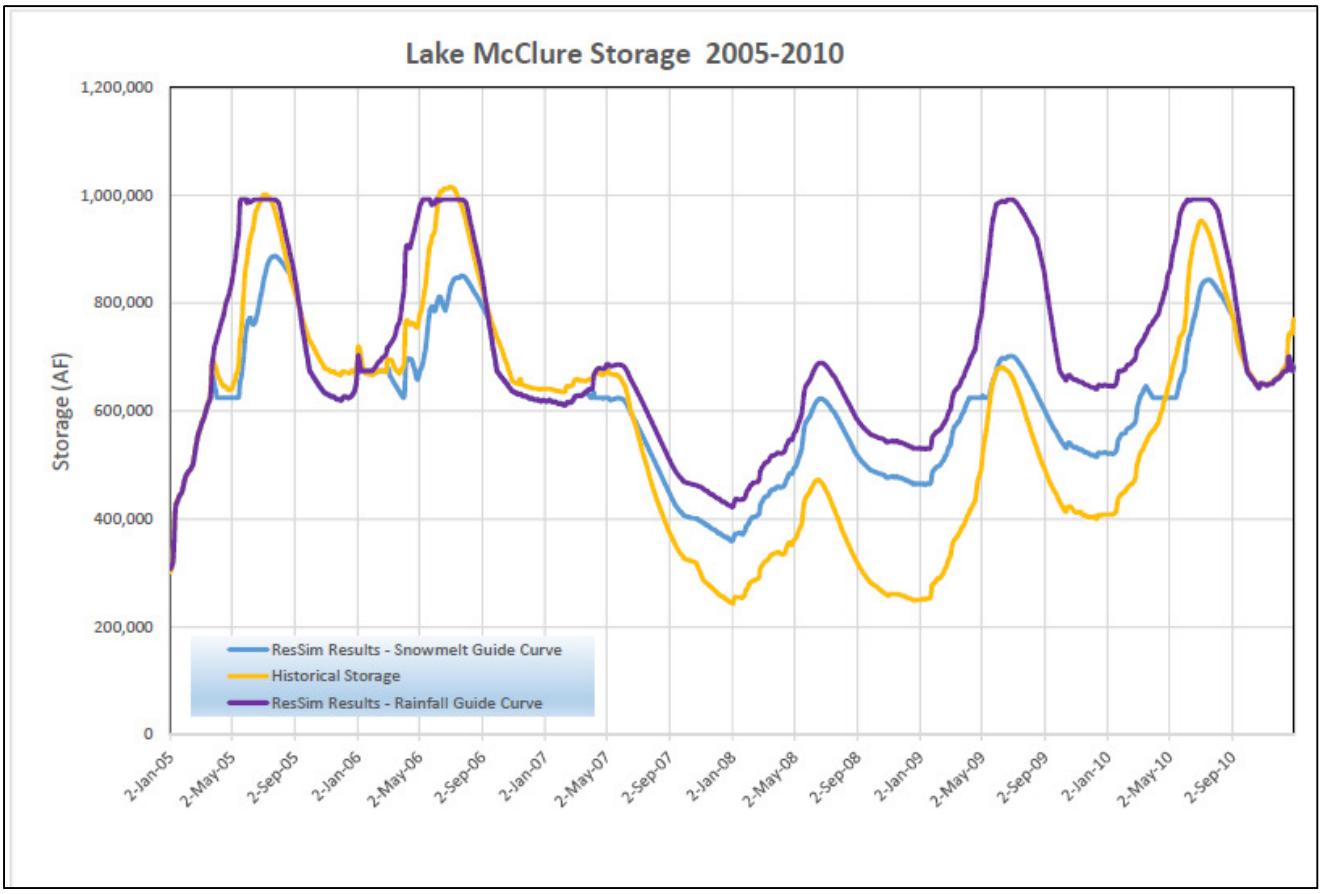


Figure 16: Lake McClure Storage 2005-2010

Another observation from this scenario is the average flow at Shaffer Bridge between June 1 and Aug 31 of 2015 was estimatd to be at least twice the minimum fish flow (25 cfs). It is important to note that there is a discrepancy between the flow rates recorded at the same location by USGS and the CDEC.

Assuming the CDEC data is correct, the average daily flow was 57 cfs. MID released water to meet the CAD demands. Uncertainty of when and how much water the CAD users divert on a given day causes MID to release extra water to ensure the minimum fish flow requirements are met. Between June 1st and August 31st, 5,876 acre-feet in excess of the minimum flow was recorded at Shaffer Bridge.

MIDH2O reflects the minimum releases required to meet demands and environmental requirements. MID releases additional water to ensure minimum environmental flows, even if a riparian water rights holder were to take more water than anticipated. Figure 17 shows the minimum flow requirement (pursuant to FERC) and observed flows according to USGS and CDEC. Note there is only one gage at this site and the reason for the discrepancy is unknown at this time.

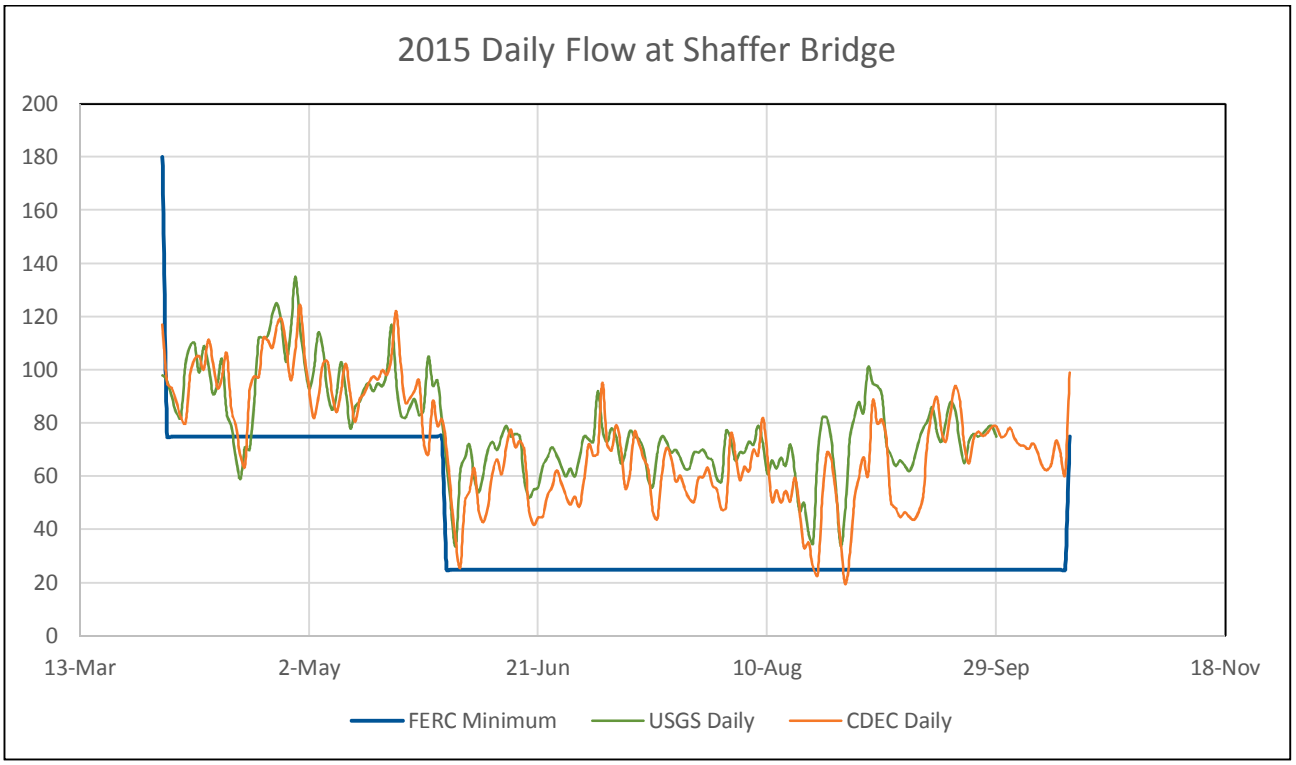


Figure 17: Average Daily Flow for Merced River at Shaffer Bridge

Scenario 2 – Compare Normal Historic Operations to Rule Based Operations with the Proposed Montgomery Reservoir Included in MIDH2O

The period used in Scenario 1 (January 2, 2005 through December 30, 2010) was simulated assuming up to 2,000 cfs would be transferred from Lake McClure to a proposed 500,000 acre-foot Montgomery Reservoir. The goal was to either eliminate Supplemental Releases from Lake McClure or to recapture the Supplemental Release in excess of demands (minimum FERC flows and irrigation demands) in Montgomery Reservoir. This was compared to the releases without Montgomery Reservoir. Table 6 shows the total releases from Lake McClure and the Total Demands (which includes 35% Losses and Fish Flows but excludes Transfers outside of the District), the total releases in excess of demands, and the amount of water that could have potentially been sent to Montgomery Reservoir making the historical daily releases but only capturing up to 2,000 cfs. Even during the drought years when storage fell in Lake

McClure there were days when excess water had to be released from Lake McClure that could have potentially been routed to Montgomery Reservoir.

Table 6: Total Release vs Total Demands

Year	Total Demand with 35% Losses without Transfers, ac-ft	Total Releases from Lake McClure, ac-ft	Potential Water Available to Transfer to Montgomery Reservoir, ac-ft	Potential Water Transferred to Montgomery Reservoir with 2000 cfs limit to capacity, ac-ft
2005	753,936	1,268,001	514,065	460,427
2006	766,933	1,687,477	920,544	653,954
2007	792,769	717,051	30,018	30,018
2008	598,522	588,475	31,992	31,992
2009	744,797	660,095	40,747	40,747
2010	903,204	869,241	82,950	82,950

During the six years, the daily release exceeded the demands by more than 2,000 cfs only 169 days. Therefore, with preplanning Montgomery Reservoir could potentially have been completely filled in 2005 and 2006.

Scenario 3 – Compare Historic Exchequer Dam Operations during the 1997 Flood to Rule Based Operations

During the 1997 flood, the USACE delayed releases from Lake McClure to allow the San Joaquin River to convey releases from other reservoirs and local runoff. The MIDH2O model cannot make these types of decisions. It can be used to estimate what would have happened if the reservoir had been operated based on the rules (USACE, 2001) currently programmed in the model.

MID has estimated Lake McClure daily inflows for the 1997 event. The USGS gages at Happy Isles Bridge and Pohono Bridge are the only gages in the entire watershed that were operable during the 1997 flood. Dewberry assumed the 1997 flows on Dry Creek were similar to the January 1969 event.

MIDH2O was used to simulate the 1997 flood. Using the rules provided by the USACE (USACE, 2016), the peak flow from Lake McClure is estimated to have been 60,000 cfs.

Two alternatives were modeled.

A. Alternative 1 – Base with No Early Release

Assumptions for Alternative 1 include:

a. No discharge until Lake McClure elevation reaches 862.4' (NAVD 1988) (Conservation elevation was artificially set to 862.4' in order to hold the release).
b. Maximum release is 6,000 cfs until the Induced Surcharge Rules and Emergency Release Diagram from the Corps are reached
c. Simulation period is from Dec 1, 1996 to Jan 31, 1997.
d. Starting pool elevation was set to 819.9' (or 689,800 ac-ft) (NAVD 1988).

Under the release rules, the model projected a maximum release of 60,000 cfs (@ 1:00pm on Jan 01) which far exceeds the maximum channel capacity of 6,000 cfs. This excessive discharge can potentially cause serious downstream flooding and damages to infrastructures.

This indicates that the Induced Surcharge Rules and Emergency Release Diagram from the USACE are likely not realistic.

B. Alternative 2 – Base with Early Release

Assumptions for Alternative 2 include:

a. Begin following the Operation Rules for Induced Surcharge on December 1.
b. Max release is 6,000 cfs
c. Simulation period is from Dec 1, 1996 to Jan 31, 1997
d. Starting pool elevation was set to 819.9' (NAVD 1988) (or 689,800 AF)

Under this scenario, releases are estimated to have never exceeded 6,000 cfs.

Scenario 4 – Compare Historic Operations during the 1997 Flood to Rule Based Operations with the Proposed Montgomery Reservoir

This scenario evaluates the potential additional water supply available to MID if water had been diverted to Montgomery Reservoir from Lake McClure before December 24, 1996, during the 1997 flood, assuming flow in Dry Creek would have been similar to the January 1969 flood.

Dewberry used the daily average flows and the peak flow during the January, 1969 flood to estimate an hourly hydrograph. We also estimated 6-hour inflow into Lake McClure from the daily average flows.

On December 5, 1996 the storage in Lake McClure was 680,800 ac-ft. Several small storms increased the storage to 756,800 ac-ft on December 25. Storage decreased to 739,300 ac-ft by December 27, when a major storm occurred. Between December 27 and January 31, an estimated 410,242 ac-ft entered Lake McClure.

MIDH2O results suggest that if MID had begun transferring 2,000 cfs to Montgomery Reservoir on December 5, 226,119 ac-ft would have been transferred and the flow at MMF could have been held to 100 cfs with a maximum storage of 1,008,441 ac-ft (versus 1,009,000 ac-ft that actually occurred).

If MID wanted to end January at the same storage as what actually existed on January 31, 1997, the flow from December 14 through January 31 is estimated to have to be 3,615 cfs. The total flow released at Merced Falls between December 6 and January 31 is estimated to have been 165,837 ac-ft less than actually released in 1997. An additional 226,119 ac-ft would have been captured in Montgomery Reservoir.

Scenario 5 – Compare Historic Operations to Rule Based Operations with Black Rascal Reservoir

The Main Canal conveys up to 2,000 cfs to meet delivery obligations south of the Merced River. There is one significant reservoir on the system (Yosemite Lake). This scenario simulated an additional 500 ac-ft regulating reservoir to better regulate flow in the canal while meeting varying delivery needs. The additional reservoir will capture flows in Black Rascal Diversion that are currently not being captured. Dewberry reviewed the available Black Rascal Diversion flow records. The total flow in Black Rascal Diversion between June, 2009 and October, 2016 was approximately 20,400 ac-ft, or 234 ac-ft/month. Based on the assumptions for this scenario, this additional regulating reservoir could capture a minimum of 1,000 ac-ft per year.

Scenario 6 – Model Fish Pulse Event

MID releases water each fall to provide additional flows for salmon migration. The Fish Pulses are released in October and must be completed by November 1. MID does not get "credit" for flows after November 1. Therefore, the flow needs to be at base flow levels on November 1. During the 2016 Fish Pulse, Dewberry ran the MIDH2O model every day to predict flows at Shaffer Bridge. Refinements to the roughness factors in the unsteady HEC-RAS model were made to better match observed flows. MID made several adjustments to planned releases based on the results of the model.

As shown in Figure 18, MID was able to reduce the flows below 134 cfs on October 30th. The minimum fish flow increases to 200 cfs on November 1. In 2014 and 2015 the flow on November 1 was 417 cfs and 231 cfs, respectively. In 2016, the total flow at Shaffer Bridge for November 1st was 431 ac-ft and 61 ac-ft less than the prior two years, respectively.

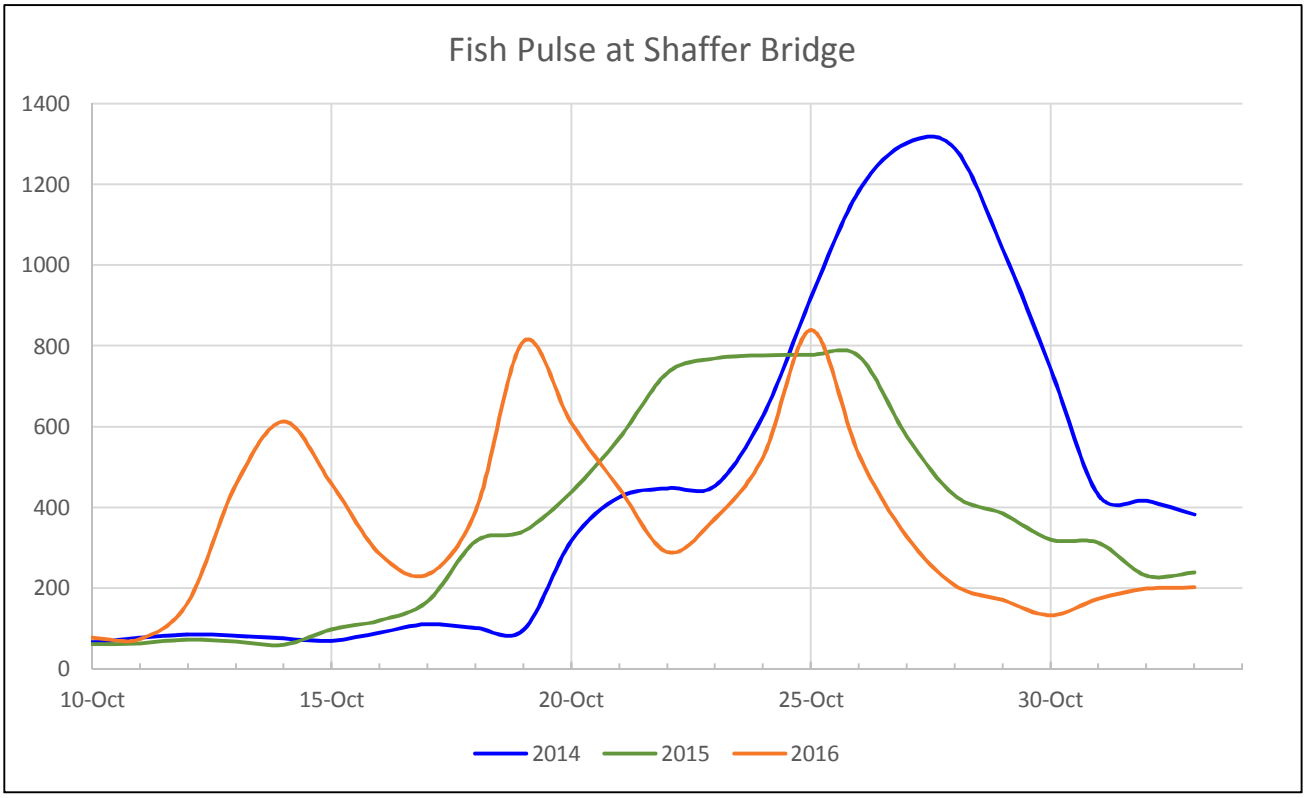


Figure 18: Fish Pulse Flows at Shaffer Bridge

MID calculated the releases in excess of the minimum flow requirements during the Fish Pulse Flows for 2011 through 2016 as shown in Figure 19.

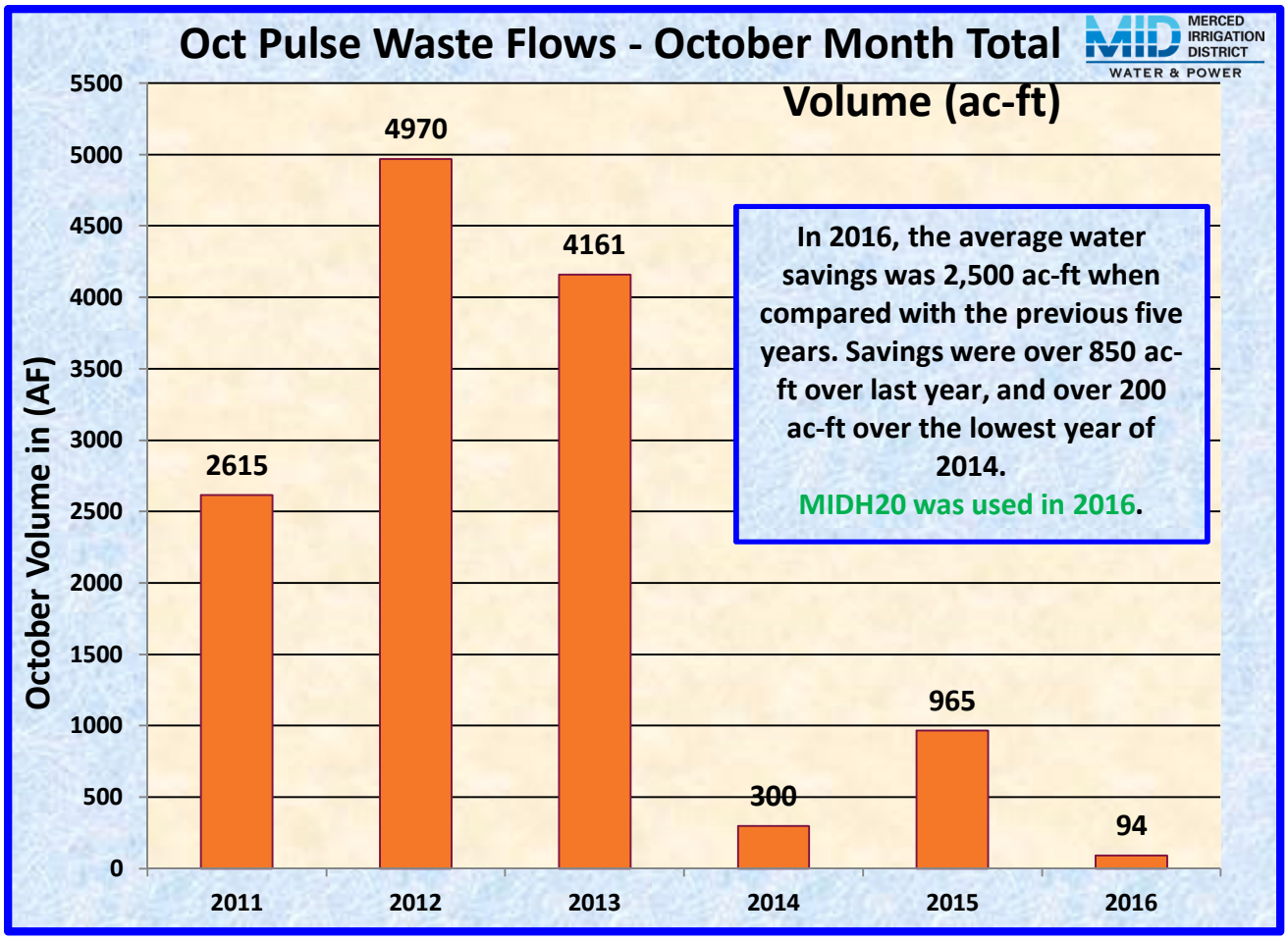


Figure 19: Fish Pulse Water in Excess of the Minimum Flow Requirements for 2011-2016 (from MID)

6.0 CONCLUSION

The MIDH2O model was developed to allow MID to analyze storage and operational alternatives to optimize irrigation deliveries. It is a powerful tool for future planning studies and daily operational support. MIDH2O is ideally suited for water delivery operations, climate change assessment, Forecast Based Operations and power generation optimization scheduling and studies.

MIDH2O can be used to maximize operational flexibility, meet the current compliance regulations, assist in flood management, plan for irrigation season diversions and allocations, assist in hydroelectric power scheduling and assist in enhancing groundwater management practices. The HEC-RTS program integrates various data developed through hydrologic models, hydraulic models, reservoir simulation models, meteorological forecasting tools, and flood inundation analysis programs. Dewberry worked with MID as part of an integrated team to develop a comprehensive water management system that integrates meteorological data collection, hydrologic modeling, reservoir operation simulation, and hydraulic analysis.

The model was calibrated using the limited available data. Calibration is a continuous process and should be performed during and after each storm. The results of each calibration should be documented so the range of values for each parameter can be determined. Eventually, MID will be able to develop equations to predict the parameters based on prior weather conditions as additional data is recorded and anlayzed. Future work will also include developing performance metrics to identify subbasins where the meteorological and/or hydrologic models need to be adjusted. It will be important to determine whether errors are being caused by forecast temperature and precipitation grids, observed temperature and precipitation grids, or hydrologic model parameters.

The lack of streamgages in the Lake McClure watershed is hampering calibration efforts. Seven streamgages have been abandoned in the upper watershed. The only two streamgages that are properly functioning are in Yosemite Valley.

7.0 REFERENCE

Dewberry, 2012. Big Creek Hydrologic and Hydraulic Optimization Model, Southern California Edison – Northern Hydro Division, 2012.

DWR, 2013. Central Valley Floodplain Evaluation and Delineation Program, California Department of Water Resources, 2013. URL: http://www.water.ca.gov

HDR, 2013. *Merced Falls Hydroelectric Project -Technical Due Diligence Study*.

MBK Engineers, 2010. *Merced River Hydroelectric Project Water Balance/Operations Model Documentation and Validation*, November, 2010.

National Climatic Data Center. 2017. URL: http://www.ncdc.noaa.gov/nexradinv/chooseday.jsp?id=khnx

USACE 1981. *Water Control Manual, Appendix VII to Master Water Control Manual, San Joaquin River, CA*. Sacramento District, Sacramento, CA.

USACE 2001. *HEC-HMS for the Sacramento and San Joaquin River Basins Comprehensive Study*, August 2001.

USACE, 2016. HEC-HMS and HEC-ResSim models from Corps Water Management System.

Dewberry, 2015. *Merced Irrigation District LiDAR Project*, April 2015.

Dewberry Engineers Inc.

1760 Creekside Oaks Drive
Suite 280
Sacramento, CA 95833