



Reservoir Forecasting Tool

Prepared for:
San Jacinto River Authority

MAY 2021



Reservoir Forecasting Tool

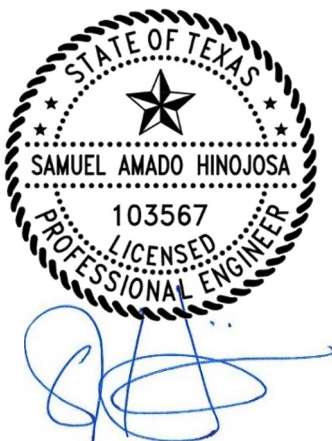
Prepared for

SAN JACINTO RIVER AUTHORITY

by

**HALFF ASSOCIATES, INC.
TBPE Firm Registration No. 312**

With Freese and Nichols, Inc. (TBPE #2144) and HDR, Inc. (TBPE #754)



**AVO 34589
MAY 2021**



May 28th, 2021
34589

Ivan Ortiz, CFM
Flood Mitigation Grants
Texas Water Development Board
1700 N. Congress Ave., P.O. Box 13231

RE: Contract No. 1800012313 – Comment Addressal

Dear Mr. Ortiz:

Please review the responses below that Halff has provided to the comments pertaining to the San Jacinto River Authority Reservoir Forecasting Tool made by TWDB on March 8th, 2021. The responses are as follows:

1. Please ensure that all graphics are clear and legible. Please, see p. 15, Figure 10. SJRA Application Architecture for an example of a graphic that could be updated.

Graphics have been modified to be clear and legible within the report body and user's manual.

2. Please conduct a final edit of the document for readability, grammar, spelling, typographical errors, and inconsistent usage of acronyms, and abbreviations. Please spell out all acronyms, with the acronym in parentheses, the first time they are used. Please include a list of acronyms used in the report after the Table of Contents.

Both the report and user's manual have been reviewed and edited for spelling and grammatical errors. A list of acronyms has been provided within the table of contents section and the correct acronyms have been used within the body of the report and user's manual.

Thank You Mr. Ortiz for providing these comments.

Sincerely,
HALFF ASSOCIATES, INC.

A handwritten signature in blue ink, appearing to read "SH", with a long horizontal flourish extending to the right.

Sam Hinojosa, P.E., CFM
Water Resources Regional Practice Leader

Cc: Paul Giany, P.E., CFM

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List of Acronyms

SJRA - San Jacinto River Authority
TWDB - Texas Water Development Board
HEC-HMS - Hydrologic Engineering Center's Hydrologic Modeling System
NWS - National Weather Service
WGRFC - West Gulf River Forecast Center
HEC-RTS - HEC-Real Time Simulation
USGS - United States Geological Survey
QPE - Quantitative Precipitation Estimates gridded rainfall
QPF - Quantitative Precipitation Forecast gridded rainfall
HDR - Henningson, Durham and Richardson, Inc.
USACE - United States Army Corps of Engineers
HCFCD - Harris County Flood Control District
HEC-ResSim - HEC-Reservoir System Simulation
WFSJFPPS - West Fork San Jacinto Flood Protection Planning Study
FEMA – Federal Emergency Management Agency
HEC-RAS - HEC-River Analysis System
SJMDP - San Jacinto Regional Watershed Master Drainage Plan
BDF - Basin Development Factor
GARR - Gage-Adjusted Radar Rainfall
Vieux - Vieux & Associates, Inc
HGAC - Houston-Galveston Area Council
HEC-DSS - HEC-Data Storage System
HEC-FIA – HEC-Flood Impact Analysis
MRMS - Multi-Radar/Multi-Sensor System
MPE - Multisensor Precipitation Estimates
NOAA - National Oceanic and Atmospheric Administration
SQL - Structured Query Language
LDM - Local Data Manager
ASP.NET - Active Server Pages

List of Acronyms (cont.)

HTML - Hypertext Markup Language

CSS - Cascading Style Sheets

JSON - JavaScript Object Notation

API - Application Programming Interface

MFP - Meteorological Forecast Processor

CWMS - Corps Water Management System

GMT - Greenwich Mean Time

GMT-06:00 - US Central Time Zone

CSV - comma-separated values

FNI - Freese and Nichols, Inc

IT - information technology

EXECUTIVE SUMMARY

The San Jacinto River Authority (SJRA) obtained a Flood Protection Planning Grant in 2016 (Phase 1) from the Texas Water Development Board (TWDB) to perform a study targeting the upper portion of the West Fork San Jacinto River. The study included the development of a new state-of-the-art rainfall-runoff model in the Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) that could be coupled with real-time rainfall and/or National Weather Service (NWS) West Gulf River Forecast Center (WGRFC) forecasts for reservoir level forecasting at Lake Conroe. The grant also included funding to both expand and improve the network of rain gauges in the Lake Conroe watershed and update the gauge network communications system and platform. In July 2018, SJRA applied for and was subsequently awarded a TWDB grant to fund Phase 2 efforts, including development of a reservoir forecasting tool for Lake Conroe which would leverage the HEC-HMS model developed in Phase 1. The HEC-HMS model was completed in September 2019.

The reservoir forecasting tool consisted of creating a HEC-Real Time Simulation (HEC-RTS) model in conjunction with the Lake Conroe Watershed HEC-HMS model to provide lake level forecasts for Lake Conroe. Adjustments were made to the HEC-HMS model to enable it for forecasting including new subbasin delineation refinements, updated rating curves, slider adjustments and forecast alternatives. The HEC-HMS model was used to simulate historical storm events and calibrated by adjusting loss parameters to match observed data from the two United States Geological Survey (USGS) gages within the Lake Conroe watershed. The calibrated parameters were used to create a baseline conditions model within HEC-HMS to be used for forecast events in HEC-RTS.

A spreadsheet tool used for lake operations was modified to include additional calculations, in which lake levels and estimated future gate openings are projected based on forecast inflows from HEC-HMS via HEC-RTS.

The reservoir forecasting tool required the development of a digital repository for rainfall, flow and reservoir level information available from the SJRA, WGRFC, and USGS. The development of custom scripts to fetch the data from the digital repository and prepare it for modeling as well as prepare modeling results for the reservoir operations model were performed. The configuration of HEC-RTS to communicate with the HEC-HMS model and the scripts was performed to forecast inflows to Lake Conroe. After configuration of the platform and necessary software, testing was performed to ensure the components were communicating properly.

A manual describing a working process was developed for the reservoir forecasting tool. The manual includes simplified instructions and screenshots to provide a visualization of the process for setting up a model in HEC-RTS.

1.0 Introduction

1.1. Background

The San Jacinto River Authority (SJRA) obtained a Flood Protection Planning Grant in 2016 (Phase 1) from the Texas Water Development Board (TWDB) to perform a study targeting the upper portion of the West Fork San Jacinto River. The study included the development of a new state-of-the-art rainfall-runoff model that could be coupled with real-time rainfall and/or National Weather Service (NWS) West Gulf River Forecast Center (WGRFC) forecasts for reservoir level forecasting at Lake Conroe. The grant also included funding to both expand/improve the network of rain gauges in the Lake Conroe watershed and update the gauge network communications system/platform. In July 2018, SJRA applied for and was subsequently awarded a TWDB grant to fund Phase 2 efforts, including development of a reservoir forecasting tool for Lake Conroe which would leverage the Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) model developed in Phase 1 completed in September 2019.

1.2. Purpose

The overall goal of Phase 2 is to develop a real-time Lake Conroe reservoir forecasting tool to be used by SJRA to perform anticipated lake level analysis, as-needed, based on actual and forecast rainfall. Lake Conroe covers a surface area of approximately 20,000 acres and has a watershed of 450 square miles. The forecasting tool would leverage the following available real-time hydrometeorological data for the Lake Conroe watershed: Quantitative Precipitation Estimates gridded rainfall (QPE), Quantitative Precipitation Forecast gridded rainfall (QPF), rainfall gauge data (Contrail®), United States Geological Survey (USGS) Lake Conroe reservoir level, and USGS streamflow data. The project will also provide forecast information that will be useful to the Authority and provide information to emergency managers during storm events. The project is not intended to replace the current gate operations policy but will provide forecast lake level information that will be useful to the operator, community partners and emergency managers.

1.3. Software Selection

In March 2019, SJRA initiated the project by conducting a software evaluation and selection effort for reservoir forecasting and reservoir modeling. Two forecasting platforms were evaluated that could be used by SJRA to forecast reservoir inflows. The platforms evaluated were Aviso© and HEC-Real Time Simulation (HEC-RTS). Aviso© is a platform that was developed by David Ford Consulting Engineers, Inc. which is now a part of Henningson, Durham and Richardson, Inc. (HDR) and is used by various agencies to aid in reservoir inflow forecasting and release selection. HEC-RTS is a platform that was developed by the United States Army Corps of Engineers (USACE) for non-USACE offices and is used to aid in reservoir inflow forecasting and release selection.

For the reservoir forecasting, several key requirements for the platform were identified including forecast capability, user friendliness, use of available data, offsite use, and output capabilities. Halff provided a technical memorandum in May 2019 summarizing the software platforms. The SJRA ultimately selected HEC-RTS as the platform for reservoir forecasting. This platform is also used by Harris County Flood Control District (HCFCD) for forecasting water surface elevations in the bayous across Harris County.

For reservoir modeling, Halff reviewed HEC-Reservoir System Simulation (HEC-ResSim) in contrast to an inflow-based spreadsheet tool similar to what is used for gate operations by the

SJRA. HEC-ResSim is a software that simulates reservoir operations for flood management, low flow augmentation and water supply studies, detailed reservoir regulation plan investigations, and real-time decision support. The SJRA selected an inflow-based spreadsheet tool as the best option for reservoir modeling. The software evaluation memorandum and the response from SJRA are included in **Appendix A**.

1.4. Summary of Project Tasks

The development of the reservoir forecasting tool required the following tasks:

1. Development of a Rainfall-Runoff-Routing Model for the Lake Conroe Watershed – The existing HEC-HMS hydrologic model developed by Halff for the 2019 West Fork San Jacinto Flood Protection Planning Study included the Lake Conroe watershed and was used as the baseline rainfall-runoff-routing model for this study. The purpose of the HEC-HMS model is to calculate Lake Conroe inflows using actual rainfall and forecasted rainfall. Adjustments to the model were needed to enable it to be used for forecasting.
2. Development of a Reservoir Model for Lake Conroe – SJRA uses a reservoir level spreadsheet tool. A version of the spreadsheet tool was adapted to use Lake Conroe inflows from the HEC-HMS model to calculate reservoir levels.
3. Reservoir Forecasting Tool Development and Testing – The reservoir forecasting tool required the development of a digital repository to store rainfall, flow and reservoir level information available from the SJRA, WGRFC, and USGS. The development of custom scripts to fetch the data from the digital repository and prepare it for modeling as well as prepare modeling results for the reservoir model was needed. The configuration of HEC-RTS to communicate with the HEC-HMS model and the scripts was needed to forecast inflows to Lake Conroe. After configuration of the platform, testing was performed to ensure the components were communicating properly.
4. Reservoir Forecasting Tool Refinement – Refinements of HEC-RTS, HEC-HMS parameters, spreadsheet tool and scripting were needed to make final adjustments for forecasting.
5. Documentation – A technical memorandum summarizing the development of the tool and any recommendations for utilizing the tool was required. Also needed was the development of a concise user manual for operating the reservoir forecasting tool.
6. Implementation and Training – Hands-on training for SJRA staff who would be using the reservoir forecasting tool was provided.

1.5. Public Engagement

SJRA held three public meetings to provide information on the goals and progress status of the project. The meetings were announced in advance. Due to the outbreak of COVID-19, the last two public meetings were held virtually. The public meetings were held on the following dates with a representative of the TWDB present:

- October 24, 2019
- April 29, 2020
- September 10, 2020

2.0 Rainfall Runoff Routing Model

HEC-HMS version 4.2.1 was used to model the hydrologic conditions of Lake Conroe and the encompassing watershed. The HEC-HMS model used in this study was derived from an existing Lake Conroe model which had been utilized in previous studies. Adjustments were made to the HEC-HMS model to enable it for forecasting including new subbasin delineation refinements, updated rating curves, slider adjustments and forecast alternatives. The HEC-HMS model was used to simulate up to two historical storm events and calibrated by adjusting loss parameters to match observed data from the USGS gages. The calibrated parameters were used to create a baseline conditions model within HEC-HMS to be used for forecast events within HEC-RTS.

2.1. Flood Protection Study Model

The *West Fork San Jacinto Flood Protection Planning Study* (WFSJFPPS) consisted of developing strategies to respond to flooding on Lake Conroe, the West Fork San Jacinto River upstream of Lake Creek, and Alligator Creek to formulate flood mitigation recommendations. The HEC-HMS version 4.2.1 model of Lake Conroe was used to develop a calibrated rainfall-runoff model to calculate inflow volumes into Lake Conroe during various frequency events. The study was completed September 2019.

The Initial and Constant loss method was used to calibrate infiltration, interceptions and depression storage while the Clark Unit hydrograph method was used to calculate direct runoff. Modified Puls routing was used to route flow through the major tributaries contributing to Lake Conroe with the storage-outflow relationships created from limited-detail hydraulic models built in HEC-River Analysis System (HEC-RAS) version 4.1. The WFSJFPPS model was calibrated to four historical storms including October 1994, November 1998, May 2016 (Memorial Day) and August 2017 (Harvey). Calibration was completed by adjusting appropriate model parameters to match the observed flow and stage data from the USGS gages located in Huntsville (USGS 08067548) and Lake Conroe (USGS 08067600). To calibrate, the watershed was separated into zones based on the USGS gages. The four uppermost subbasins of the Lake Conroe watershed comprised the zone for the USGS Huntsville Gage and the remaining subbasins comprised the zone for the USGS Lake Conroe Gage.

Once the model was calibrated, pre-Atlas 14 frequency storm events ranging from 5- to 500-YR storm events were modeled to determine the peak inflows, storage and lake elevations in the model. A screenshot of the model is shown in **Figure 1**.

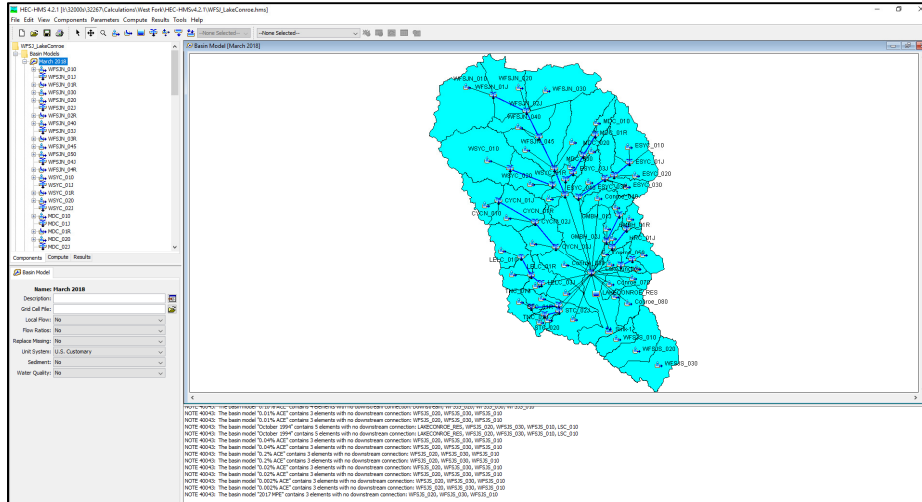


Figure 1. Flood Protection Planning Study HEC-HMS Model

2.2. SJMDP Model

The *San Jacinto Regional Watershed Master Drainage Plan* (SJMDP), led by the HCFCD, consisted of identifying the vulnerabilities within the San Jacinto watershed pertaining to flood hazards by developing comprehensive hydrology and hydraulics models for the entire upper San Jacinto River watershed. The study was funded by a Federal Emergency Management Agency (FEMA) grant, HCFCD, SJRA, Montgomery County, and the City of Houston. The WFSJFPPS hydrologic model for Lake Conroe was updated with the hydrologic methodology used for the SJMDP study. Basin delineations within the Lake Conroe watershed were unchanged from the previous WFSJFPPS. A map of the SJMDP watersheds is shown below in **Figure 2** with the Lake Conroe watershed highlighted in green.

New rainfall data derived from Atlas 14, Volume 11 was used to update the frequency events for the Lake Conroe HEC-HMS model. Atlas 14 shows significant increases in rainfall depths compared to the previous rainfall depths that had been based on TP-40 across the Texas region. Changes to the methodology with respect to the Lake Conroe hydrologic model consisted of updating Clark Unit hydrograph parameters using the basin development factor (BDF) methodology to calculate the time of concentrations and storage coefficients for each subbasin. BDF parameters were developed using a stepwise method recommended in peer-reviewed white papers provided by the HCFCD. The BDF value is determined by dividing the drainage area into equal thirds by area and assigning a value of 0, 0.5, or 1 to each third based on four different categories: channel improvements, channel linings, storm sewers, and curb-and-gutter streets. All numbers are then summed to determine the overall basin BDF value. The overall BDF in the subbasin is the sum of the four indices. BDF does not directly account for impervious cover but changes in BDF reflect improvements in drainage systems that accompany urbanization.

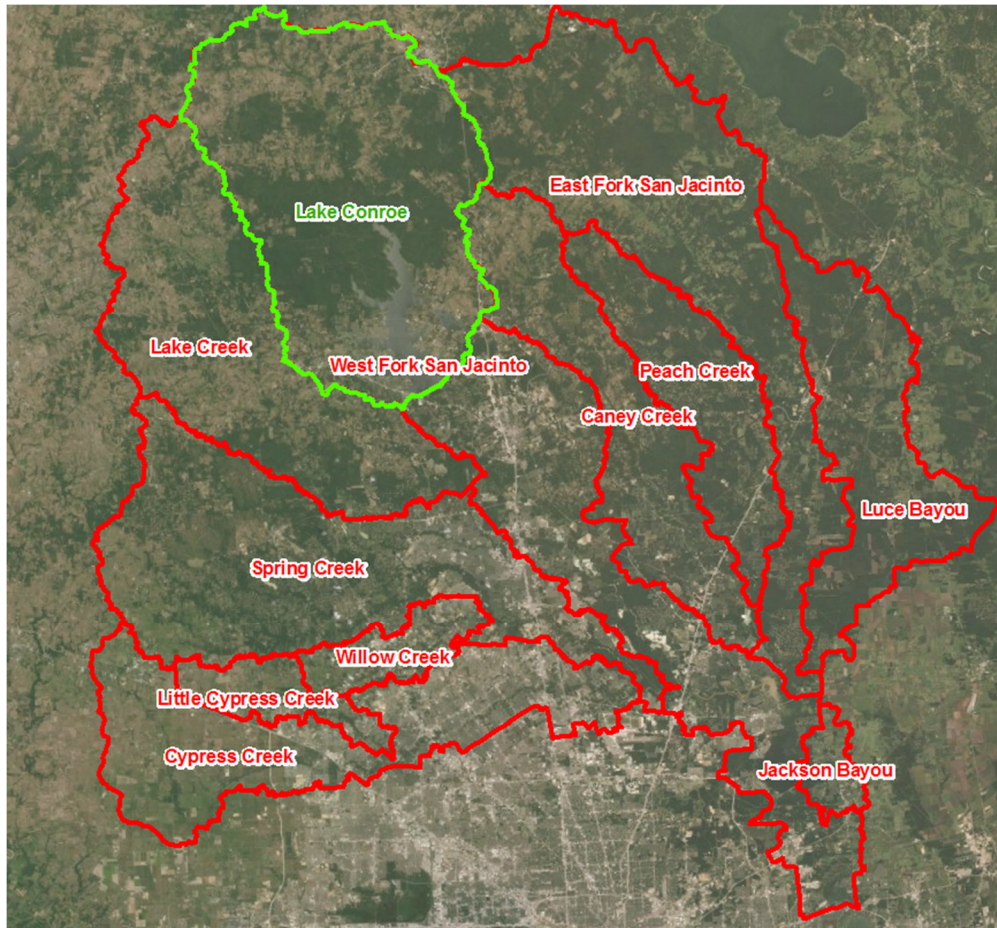


Figure 2. SJMDP watershed Map

The SJMDP hydrologic model was calibrated to several historical storm events with updated parameters using gage-adjusted radar rainfall (GARR) data provided by Vieux & Associates, Inc (Vieux) for August 2017, May 2016 and October 1994. The hydrologic model was calibrated similarly to the WFSJFPPS by dividing the subbasins into zones based on the Huntsville and Lake Conroe USGS gages. Initial and constant loss parameters were adjusted to match the observed data on the USGS gages for each historical storm event. Once the storm events were calibrated on Lake Conroe, the updated frequency events reflecting Atlas 14 rainfall depths were simulated in the HEC-HMS model to update lake inflows, storage and lake elevations for the 5- through 500-year, Atlas 14 frequency events. The 2-year, Atlas 14 frequency event was added to the model.

2.3. Reservoir Forecasting Tool HEC-HMS Model

The Lake Conroe HEC-HMS hydrologic model for the reservoir forecasting tool was refined from the SJMDP hydrologic model. Several updates were needed within the Lake Conroe model to allow more ease of use in HEC-RTS. These updates included simplification of subbasins within the watershed, an averaged outflow rating curve based on the Atlas 14 frequency events, slider adjustments to aid in calibrating storm events, and forecast alternatives.

2.3.1. Refinement

The hydrologic model was refined to reduce the number of routing reaches. This was accomplished by combining subbasins of major tributaries in the model to reduce complexity and

number of calibration points. The subbasin layout from the previous studies consisted of areas broken out at major crossings with Modified Puls routing reaches. These reaches routed the upstream flow through the subbasins to the stream outfalls in Lake Conroe. Subbasins were also redelineated in some areas based on new 2018 LiDAR data from the Houston-Galveston Area Council (HGAC). Lake Conroe itself was delineated as a separate drainage basin based on normal pool elevation to model impacts of rainfall directly on the lake. The number of basins was increased from 30 to 31 due to the Lake Conroe subbasin being broken out into 9 separate subbasins while subbasins from the major tributaries were combined to reduce the number of routing reaches in the model. The breaking out of the Lake Conroe subbasins was done to simulate the lake response to storm events. BDF calculations were updated based on the new subbasin delineations as well as updated impervious percentages based on the 2018 HGAC land use file.

Storage-outflow relationships between the storage in Lake Conroe and the Lake Conroe dam for each Atlas 14 frequency event were determined from the SJMDP. As storage increases in Lake Conroe, outflows from the dam increase in a step wise fashion. The curves were used to create an averaged rating curve to be used to observe potential outflows in HEC-HMS. Each ordinate for the existing rating curves from the previous studies regardless of frequency storm event was organized based on storage and plotted using a scatter plot in a spreadsheet. A polynomial trendline was then created from the scatter plot and was used to determine the hypothetical outflows based on the storage values. The frequency and averaged rating curves are shown below in **Figure 3**. This curve is an estimate of releases only and is not intended to be used to make decisions on releases. Releases will be made per SJRA gate operations protocol. The intent of the curve is to allow the modeler to visualize an average release scenario in the HEC-HMS model and is not intended to reflect actual or potential releases based on operations protocol. Potential releases will be reflected in the reservoir modeling spreadsheet tool.

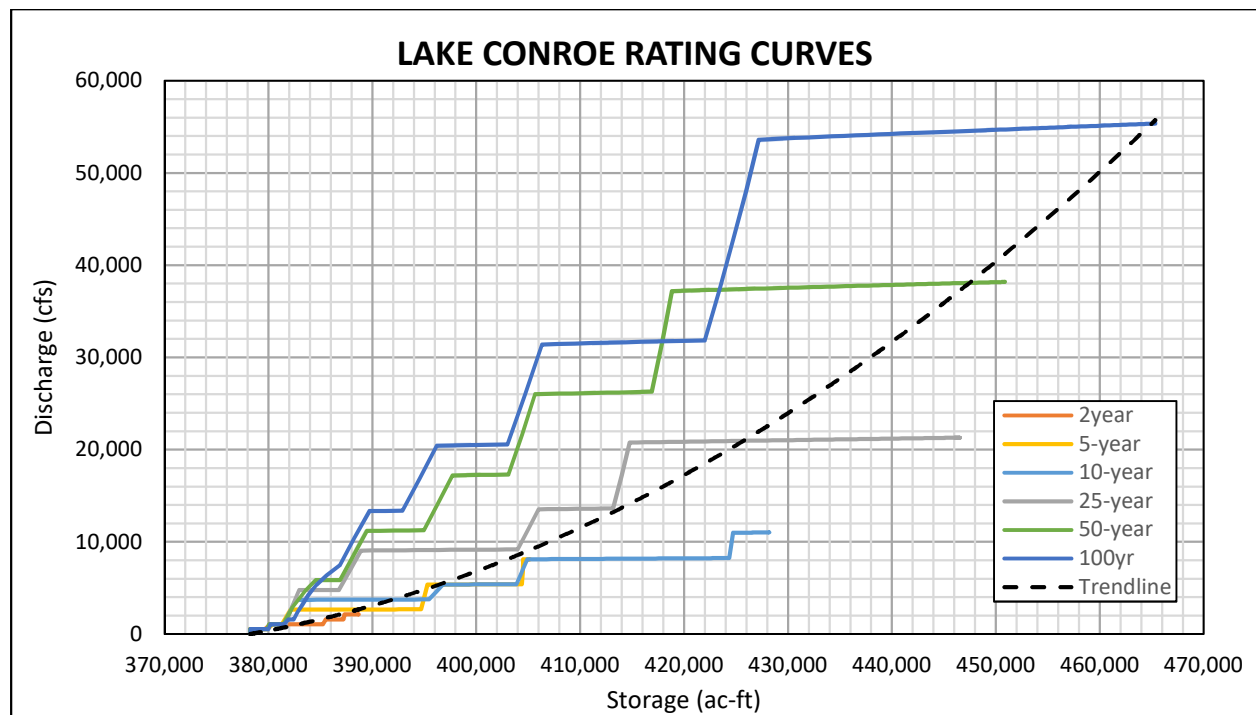


Figure 3. Estimated Lake Conroe Rating Curves

Forecast alternatives were created in HEC-HMS to be used for the forecast runs in HEC-RTS. These alternatives referenced specific meteorological models consisting of QPE and Conrail® rainfall data separated by subbasin and zone configurations. In addition to this precipitation data, QPF forecast data was spliced into these datasets to be incorporated in the forecast time frame. The base basin model was used for the forecast alternatives in HEC-RTS. Zone configurations were set up based on the USGS gages at Huntsville and Lake Conroe for the four upstream subbasins and remaining subbasins near Lake Conroe, respectively. Configuration parameters were set based on losses, transform and routing parameters and were referenced to each zone configuration. Dates and times were set to arbitrary values as these would be overwritten by HEC-RTS in the forecasting process. A map of the zone configurations is shown in **Figure 4** .

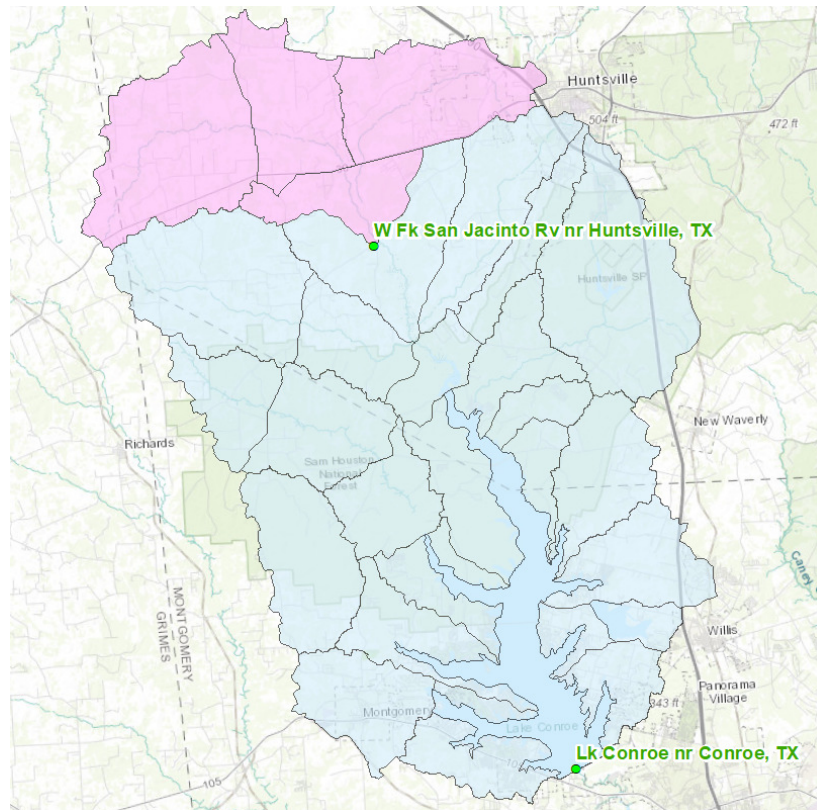


Figure 4. Zone Configurations

Slider adjustments were added into the forecast alternatives to allow the user to adjust model parameters (rainfall losses, transform and routing methods) as needed for calibration during rainfall events. Slider adjustments incorporate a slider bar that applies a multiplier to specified parameters. Multipliers could be increased above or decreased below 1 to allow the user to easily change model parameters without adjusting the base values. Simulations are automatically computed after each slider change and can be checked against observed data in real time. Slider adjustments were referenced by zone configurations set up within the zone configuration manager to both the Huntsville and Lake Conroe USGS gages. Slider adjustments were used to calibrate the model to two historical storm events using the base parameters from the SJMDP HEC-HMS model. It is recommended that slider adjustments only be used for loss parameters. The slider adjusters are shown below in **Figure 5**.

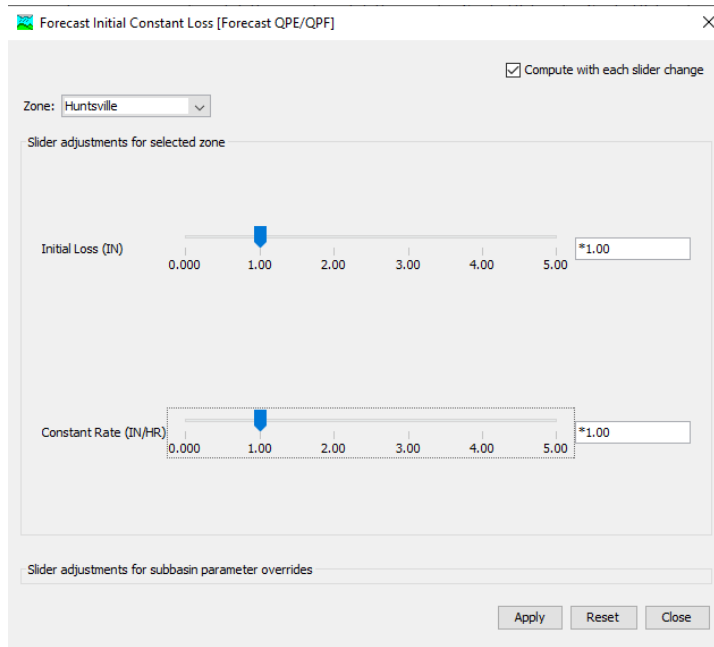


Figure 5. Slider Adjusters

2.3.2. Calibration

As previously described, two historical storms were evaluated with the updated HEC-HMS model and were used to create the baseline parameters to be used in the HEC-HMS model for the forecast events. Observed gage data from the USGS gages and release data from the Lake Conroe dam provided by SJRA were used as calibration points for these historical storms. Calibration mainly consisted of adjusting the initial and constant loss parameters based on zone configurations for Huntsville and Lake Conroe. Once the multipliers for the initial and constant loss parameters for both calibrations events suitably matched the observed data, the multiplier loss parameters were copied into the basin models of the historical events and were established as the new basin parameters for the historical events. The two sets of loss parameters were averaged to form the base parameters for the forecast basin model. After the HEC-HMS model was calibrated, it was imported into HEC-RTS for use in forecasting reservoir inflows.

3.0 Reservoir Modeling Tool

A key function of the reservoir forecasting tool is the ability to forecast lake levels by considering hypothetical reservoir operations. SJRA uses a spreadsheet tool that calculates Lake Conroe inflows and recommends gate openings based on observed lake levels. This spreadsheet was modified to include additional calculations, in which levels and estimated future gate openings are projected based on forecast inflows from HEC-HMS via HEC-RTS. The guide to using the reservoir modeling tool is in Appendix A.1 of the Reservoir Forecasting Tool Manual in Appendix C.

3.1. Refinements

Since the forecast calculations are based on the Gate Operations Plan, and a useful feature for any forecast is the ability to compare to the observed/actual data, the forecast tool is built on the base of the Gate Operations Spreadsheet. A few of the elements requested at the beginning of the project by SJRA for inclusion in the updates related to the forecast tool include:

- Simplified lake level data entry
- Minimized copy-paste in workflows
- Similar workflow in new forecast tool compared to operations spreadsheet
- Efficient calculation times to allow multiple forecasts

These refinements have been implemented throughout the project, with significant improvement to calculation efficiency.

3.1.1. Testing

The spreadsheet modifications were first tested with an internal quality control once the major changes such as new forecast tabs, macros, etc. were added. Comments from the quality control review were addressed and used to improve the functionality of the spreadsheet.

Since no significant storm events occurred during the tool testing timeline, further testing was implemented using historical storms.

3.2. Summary of Additions

The following ease of use and forecast process components were added to the spreadsheet:

3.2.1. Instructions [New Tab]

Added a tab with generic instructions for use of the new Forecast tab of the spreadsheet.

3.2.2. Lake Levels

Added the “Import SQL Lake Levels” button to populate the Raw Lake Level. An Excel ActiveX macro was designed to pull USGS Lake Conroe water surface elevation readings from a new SQL database and store them in a formatted Excel® document for an Event. The macro was set up with user inputs for start and end dates and times to specify the data to be imported from the database.

Once date and time parameters have been input by the user and the “Import SQL Lake Levels” button is clicked, the macro makes a request for the readings from the start date and time to the end date and time. If the end date and time are not specified, the macro will request the readings up to the current date and time. Once the data is received, it is parsed and formatted into the Date & Time and Raw Lake Level sections of the spreadsheet.

If data is already entered in the spreadsheet when the macro is run, the macro will overwrite the existing data.

A historic event may be imported to the spreadsheet using the “Import SQL Lake Levels” button, as long as the database contains the requested data.

It is assumed that this “Import SQL Lake Levels” will be the primary method for populating observed lake levels.

3.2.3. Entry Form

Added calculations in cells P1:R2 that populate the date and time of the most recent gate operation for plotting on the Chart tab. These calculations are only used to provide the data necessary for plotting the current time on the Chart tab, and do not affect the gate operations calculations.

3.2.4. Chart

Added graphical representations of the Current Time, Forecast Inflow, Forecast Outflow, and Forecast Lake Level for comparison with observed values.

3.2.5. Forecast [New Tab]

Added a tab that reads a regular time series of inflow values and estimates gate operations based on the TARGET gate operation plan curve.

Added the “Import Forecast Inflows” button to read full time series of forecast inflows from forecast.csv file generated by the “Write_to_CSV” macro in RTS. This button activates a new macro in the spreadsheet with a subroutine called “OpenInflow”.

Added the subroutine “OpenInflow”, which reads the file path listed in sheet Forecast, cell V4. The user is prompted to select a column to import, so that a specific forecast inflow may be imported. The macro then skips a certain number of rows, then copies and pastes the date, time, and forecast inflow in the appropriate columns. Note that this script assumes a fixed format file and will need to be revised if the forecast.csv output is changed.

Added the “Reset Gate Overrides” button to reset the gate overrides column to read the TARGET gate opening column instead of the manual overrides input. This button activates a new macro in the spreadsheet with a subroutine called “FillDown”.

Added the subroutine “FillDown” that changes the values input in cells K12:K1010 to the formula =I12:I1010. Activating this subroutine will automatically remove all entered gate overrides and reset to the Target gate opening value.

Added the “Calculate Lake Levels” button to iterate the computed lake levels and estimated gate openings on the Calcs_FCST hidden tab. This button activates a new macro in the spreadsheet with a subroutine called “FastLakeLevel”.

Added the subroutine “FastLakeLevel” that copies and pastes the Calc Lake Level column in tab Calcs_FCST onto the Current Lake Level column in tab Calcs_FCST. This subroutine will iterate up to 10 times if the lake level calculation tolerance does not converge at each timestep within the value listed in cell V5.

Added the “Import Observed Gate Openings” button to automatically populate actual gate openings from the Entry Form tab. This button activates a new macro in the spreadsheet with a subroutine called “UpdateGatesforObs”.

Added the subroutine “UpdateGatesforObs” that parses the observed gate openings on sheet “Entry Form” and updates the gate openings in the forecast on sheet “Forecast” to match the actual gate openings used on sheet “Entry Form”. Forecast outflows are computed based on the gate openings for each timestep automatically by the spreadsheet. Observed inflow rates are not updated and it is up to the forecaster to verify that the modeled inflows match observed inflows up to the forecast time.

Added the “Reset Lake Levels” button to reset lake levels to the normal pool elevation to avoid errors in calculation when initiating a new forecast. This button activates a new macro in the spreadsheet with a subroutine called “ResetCalcLakeLevels”.

Added the subroutine “ResetCalcLakeLevels” that populates all Lake Levels on the new, hidden Calcs_FCST tab to be elevation 201 to ensure a proper initialization for the forecast algorithm. This is simply an initial value that is necessary to compute the actual lake level for each timestep. When the “Calculate Lake Levels” button is clicked, the Lake Level is recalculated for each timestep.

3.2.6. Calcs_FCST [New Hidden Tab]

Added a tab that performs the calculations used in the Forecast tab.

4.0 Tool Development and Testing

The reservoir forecasting tool required the development of a digital repository for rainfall, flow and reservoir level information available from the SJRA, WGRFC, and USGS. The development of custom scripts to fetch the data from the digital repository and prepare it for modeling as well as prepare modeling results for the reservoir operations model were needed. The configuration of HEC-RTS to communicate with the HEC-HMS model and the scripts was needed to forecast inflows to Lake Conroe. After configuration of the platform and necessary software, testing was performed to ensure the components were communicating properly. The general workflow overview for the forecast process is shown in **Figure 6**.

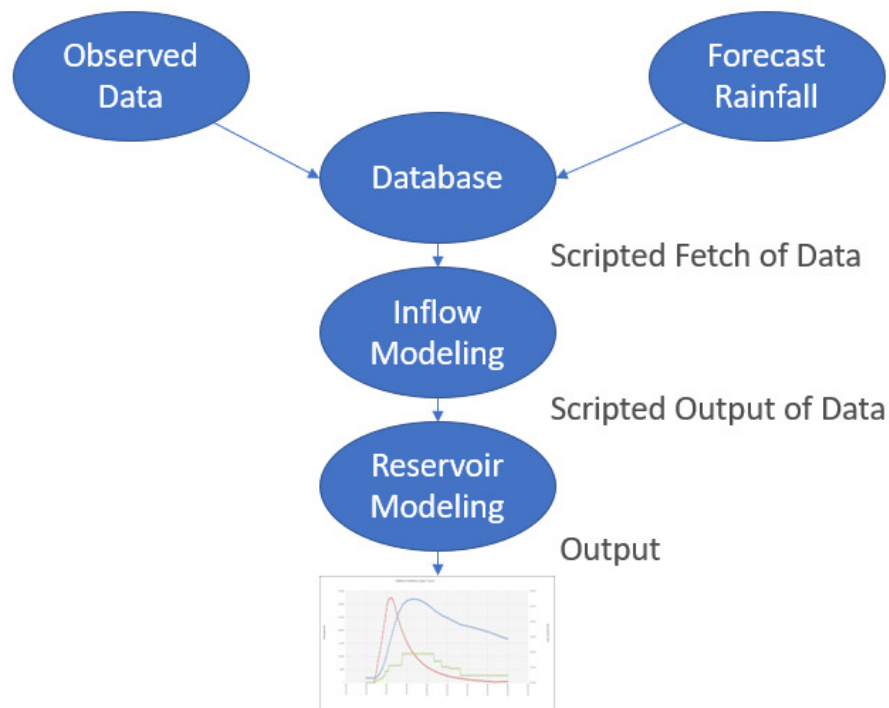


Figure 6. General Reservoir Forecast Workflow Overview

4.1. Data Sources

The backbone of forecasting inflow volumes into Lake Conroe is the HEC-HMS model, however, the model requires rainfall data, both observed and forecasted, to calculate reservoir inflows during a rain event. In order to use the model during a rainfall event, the user must fetch the available rainfall data, configure it into an appropriate database such as HEC-Data Storage System (HEC-DSS) that the model can use, feed it into the HEC-HMS model, adjust any appropriate parameters such as infiltration losses, and then simulate the HEC-HMS model to calculate potential inflows and volumes. The data sources for observed and forecast data are SJRA Rain Data from Contrail®, Lake Conroe Gage water surface elevation data from USGS, Multi-Radar/Multi-Sensor System (MRMS) / Multisensor Precipitation Estimates (MPE) from the National Oceanic and Atmospheric Administration (NOAA) and National Weather Service (NWS), Quantitative Precipitation Forecast (QPF) from NOAA, and user input.

- SJRA Rain Data (Contrail®) – SJRA operates and maintains a network of rain gages at 13 locations in the Lake Conroe watershed. The existing gages were updated to ALERT 2 as part of the WFSJFPPS effort. The rain gages monitor rainfall in the watershed. Rainfall data can be obtained at <https://sanjacinto.onerain.com/>.
- Lake Conroe Gage (USGS) – The U.S. Geological Survey (USGS) operates and maintains a gage (08067600) at the Lake Conroe Dam. The gage reports reservoir storage and lake levels. The available gage data can be accessed at https://waterdata.usgs.gov/nwis/uv?site_no=08067600.
- MRMS/MPE (NOAA/NWS) – The National Oceanic and Atmospheric Administration (NOAA) uses Multi-Radar/Multi-Sensor System (MRMS) to collect rainfall data. MRMS is a system with automated algorithms that quickly and intelligently integrates data streams from multiple radars, surface and upper air observations, lightning detection systems, and satellite and forecast models. QPE uses the most advanced polarimetric radar technologies and provides high-resolution information about precipitation types and amounts for the nation. More than 70 government agencies, universities, and private companies use the products for flash flood and river flood warnings and water resources management. The data can be obtained at <https://mrms.ncep.noaa.gov/data/2D/>. QPE data consists of a 4km x 4km grid with rainfall data and is averaged within the subbasin. The QPE/QPF grids are shown in **Figure 7**.
- QPF Forecast (WGRFC) – The West Gulf River Forecasting Center (WGRFC) provides rainfall forecasts in 6-hour blocks. This data is used to consider potential rainfall to fall in the Lake Conroe watershed. These datasets are available at https://tgftp.nws.noaa.gov/data/rfc/wgrfc/xmrq_qpf/.
- User Input – An application was developed for the user to input lake level data into the digital repository in the event that lake level data is not available.

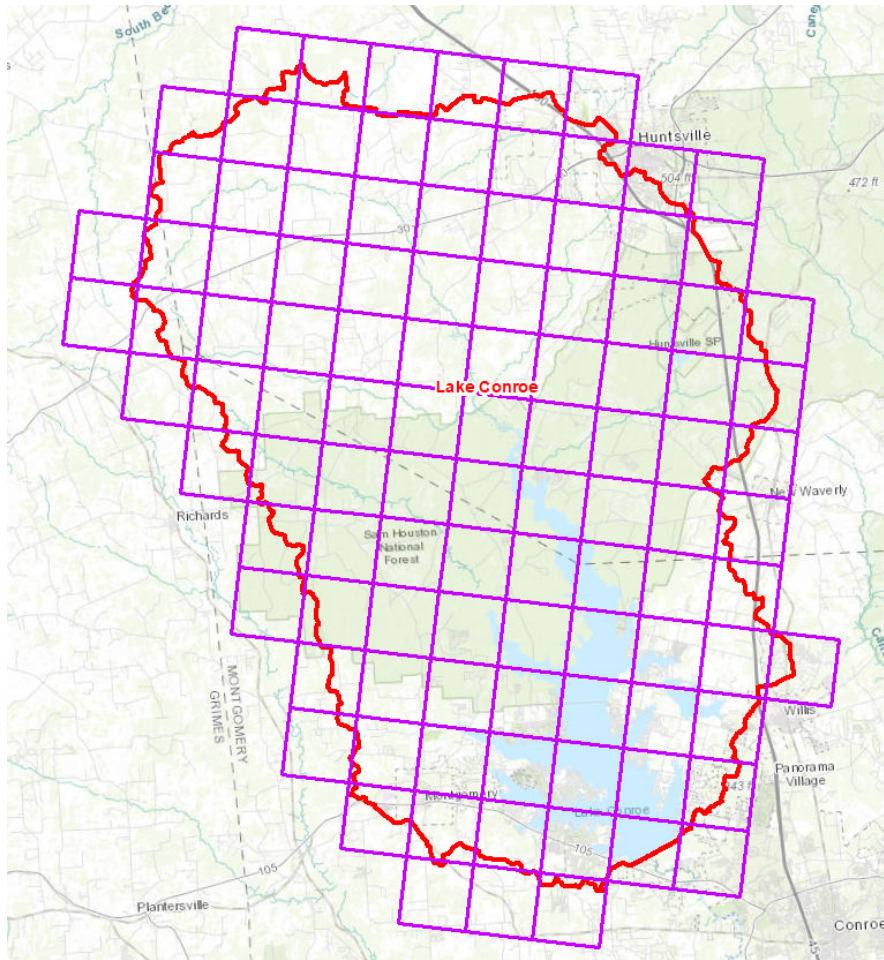


Figure 7. QPE/QPF Grid Coverage

A Structured Query Language (SQL) server database was developed to serve as the digital repository of the data. Each of these datasets is made available at different times and in different formats. Therefore, the SQL Server was setup to continuously collect data from these sources and format them into an acceptable format for importing to the reservoir forecasting tool. A visualization of the process is shown below in **Figure 8**.

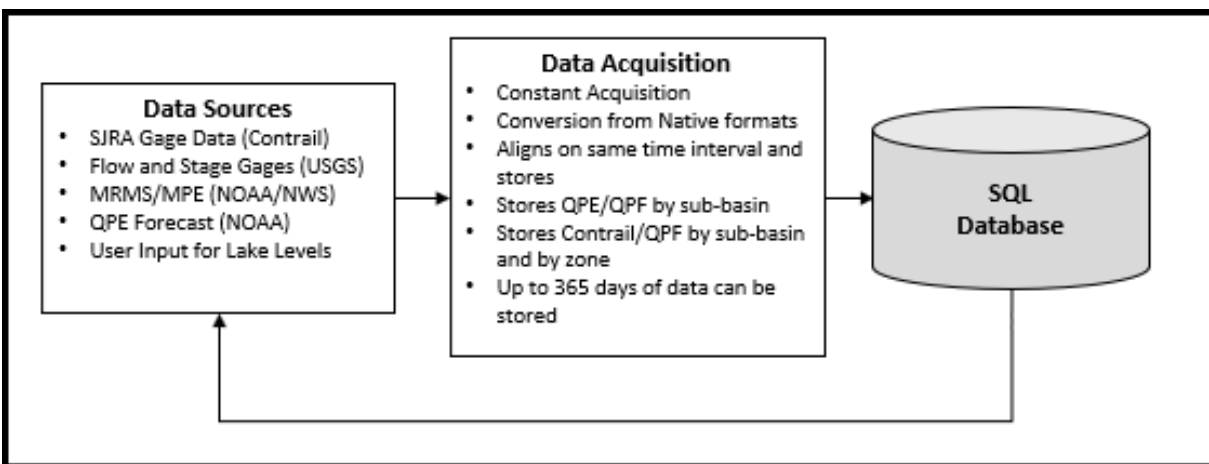


Figure 8. SQL Server Database Data Retrieval

A total of 13 rainfall gages located within the Lake Conroe watershed were utilized to determine rainfall data for each subbasin. Rainfall data was assigned for each subbasin using two methods which consisted of a Thiessen polygon method and interpolation based on the zone configurations for Huntsville and Lake Conroe. The first method divided the area between the 13 rainfall gages using Thiessen polygons to determine the area of influence from these gages. The Thiessen polygons are then intersected with the subbasin delineations and an average rainfall dataset is created using an area-weighted method. The Thiessen polygons for the rainfall gages are shown in **Figure 9**. The second method consisted of interpolating the rainfall gage data and assigning an average rainfall dataset for each subbasin based on the zone configuration. This method is applied when one or more gages either is reading NULL data or inconsistent rainfall values.

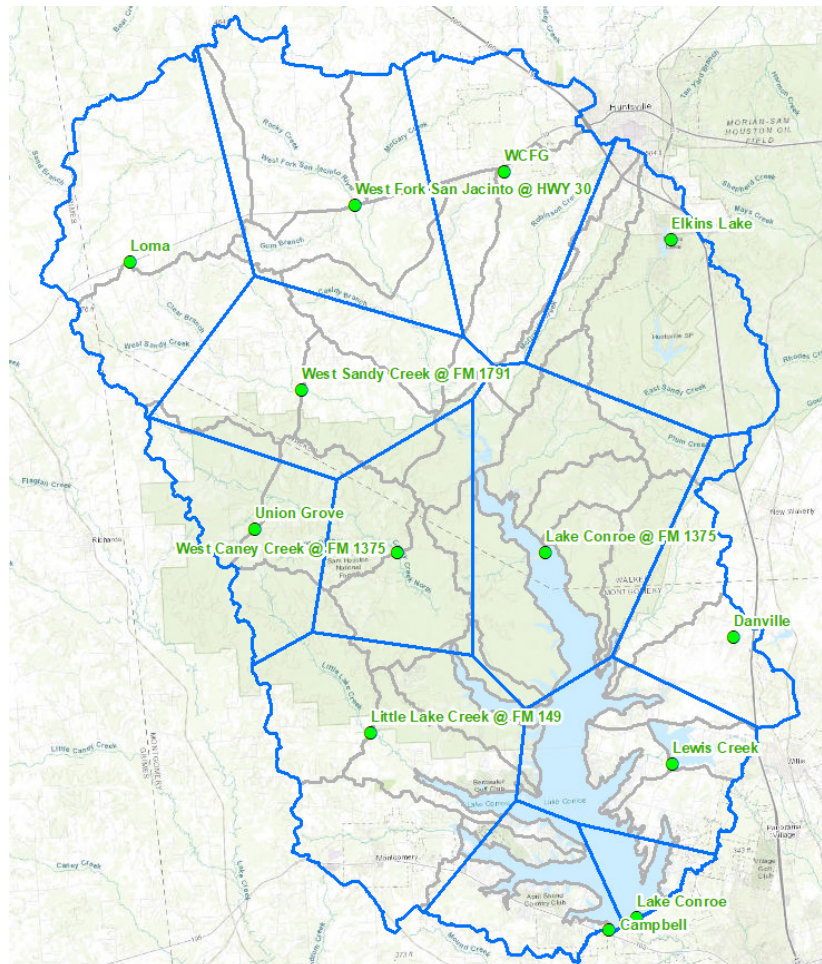


Figure 9. Thiessen Polygons

4.2. SQL Server Development

The SQL Server was set up to house the input data necessary for the reservoir forecasting tool. The technical workflow is shown in **Figure 10**.

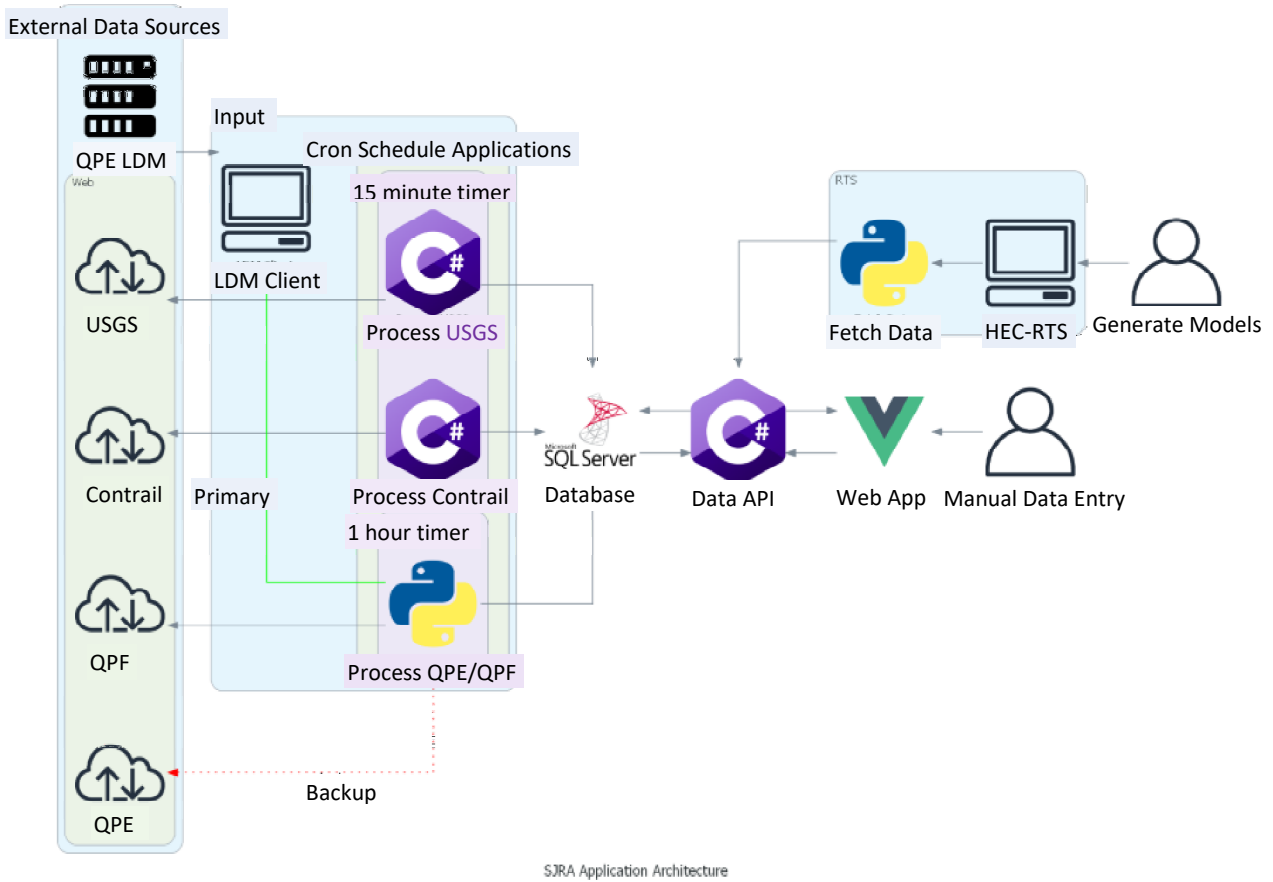


Figure 10. SJRA Application Architecture

4.2.1. Technologies

Halff is using the following technologies to provide an automated, repeatable solution for the San Jacinto River Authority:

- Local Data Manager (LDM)
- Linux
- Python
- C#
- Active Server Pages (ASP.NET)
- SQL Server
- Jython
- Hypertext Markup Language (HTML) / Cascading Style Sheets (CSS) / JavaScript
- Vue.js

- Hourly Quantitative Precipitation Estimation (QPE) data retrieval
 - Local Data Manager (LDM)
 - LDM is a distributed software system for efficiently and reliably distributing arbitrary but finite-size data-products via the Internet. It provides mechanisms to inject, request, receive, relay, and locally process data-products. These mechanisms are event-driven, which means that processes are done with the data-products as soon as possible.
 - Fallback to get QPE files from https://mrms.ncep.noaa.gov/data/2D/RadarOnly_QPE_01H/ if LDM does not retrieve the needed files
 - Python script
 - Reads the data from grib2 format
 - Grabs the data needed
 - Builds a JavaScript Object Notation (JSON) of all the data and stores it into our QPERaw table
 - Inserts a record for each reading into our QPE table
 - Matches each record to a location in our location table so we can average out values based on Basin
 - Logs all info to rolling log file of my_log.log that's located at the same location as the script
- Quantitative Precipitation Forecasts (QPF) data retrieval
 - Python script
 - Runs a web scraper to find the eight most recent grib2 forecast files from https://ftp.wpc.ncep.noaa.gov/2p5km_qpf/
 - Reads the data from grib2 format
 - Grabs the data needed
 - Builds a JSON of all the data and stores it into our QPFRaw table
 - Inserts a record for each reading into our QPF table
 - Matches each record to a location in our location table so we can average out values based on Basin
 - Logs all info to rolling log file of my_log.log that is located at the same location as the script
- U.S. Geological Survey (USGS) data retrieval
 - C# service
 - Queries <https://waterservices.usgs.gov/nwis/iv/> for the specific sites we want
 - Builds a JSON of all the data and stores it into our USGSRaw table
 - Overwrites all data over the last 24 hours - as the data will sometimes be updated and we want the most up to date data
 - Logs all info to daily file located at the service's location/log/SJRA-USGS-{Date}.log
- Contrail® gauge data retrieval
 - C# service
 - Queries <https://cs-010-exchange.onerain.com> for the specific sites we want
 - Builds a JSON of all the data and stores it into our ContrailRaw table

- Overwrites all data over the last 24 hours - as the data will sometimes be updated and we want the most up to date data
 - Logs all info to daily file located at the service's location/log/SJRA-OneRainContrail@-{Date}.log
- Manual entry for missing records
 - Front end web app (Vue.js) that allows the user to see what USGS data is missing over the last 24 hours and manually enter readings
- HEC-RTS DSS Creation
 - Application Programming Interference (API) is called to collect the data - Provides:
 - *lookbackDate* (earliest date/time to grab the data)
 - *forecastDate* (date/time that we switch over from looking at previous readings to looking at forecasted readings)
 - *endDate* (end date/time)
- API queries SQL server and gets the needed data
 - Provides Contrail® data from *lookbackDate* to *forecastDate*
 - Provides USGS data from *lookbackDate* to *forecastDate*
 - Averages QPE data based on location by Basin and by Zone and date range of *lookbackDate* to *forecastDate*
 - Averages QPF data based on location by Basin and by Zone and date range of *forecastDate* to *endDate*.
 - This is combined with QPE data
 - Contrail® data is split it out to basins and zones via C#
 - Data is converted into HEC-DSS format via Jython
 - Logs all info to dated log file inside of forecast run/Logs/{date}.txt
 - HEC-DSS is copied to generic forecast folder for easier accessibility and overwrites any existing HEC-DSS file in that location

4.2.2. LDM Connection

LDM is a distributed software system for efficiently and reliably distributing arbitrary but finite-size data-products via the Internet. It provides mechanisms to inject, request, receive, relay, and locally process data-products. These mechanisms are event-driven, which means that things are done with the data-products as soon as possible.

4.2.3. Maintenance

The SQL Server and data collections procedures were established by Halff and provided to the SJRA to host locally. SJRA will maintain and operate the SQL Server moving forward.

4.3. HEC-RTS

HEC-RTS version 3.0.3 was the platform used to merge rainfall data with the HEC-HMS model to forecast Lake Conroe inflows. HEC-RTS incorporates several HEC software products including MetVue, Meteorological Forecast Processor (MFP), HEC-HMS, HEC-ResSim, HEC-Flood Impact Analysis (FIA) and HEC-RAS. For this study, only the MFP and HEC-HMS programs were utilized for forecast simulations of Lake Conroe. MFP is a Meteorological Forecast Processor that combines observed precipitation with future precipitation. The goal in combination with the spreadsheet is to see potential lake levels from future forecasted events within Lake Conroe.

4.3.1. Introduction

HEC-RTS was developed by the USACE and is based on Corps Water Management System (CWMS) software. HEC-RTS was developed for use by non-USACE personnel and provides the same data and information CWMS provides but functions in a different manner than CWMS. CWMS provides data and information, which includes precipitation data, forecasts about the future conditions and consequence of management actions of watershed conditions. HEC-RTS provides data and information needed by water managers readily through HEC-DSS files and a user-created database. A graphic user interface provides the user the ability to configure the watershed, view and edit data/information, create and run forecasts and view results. The graphic user interface of HEC-RTS is shown below in **Figure 11**.

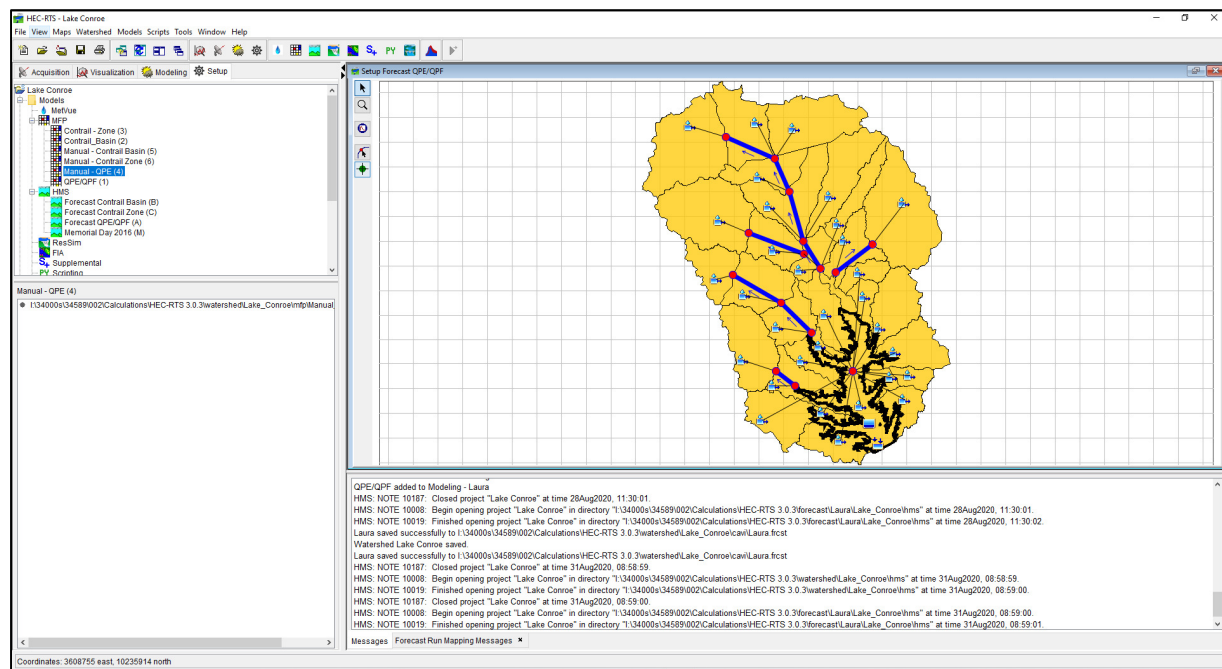


Figure 11. HEC-RTS Interface

4.3.2. Uses

Forecasted scenarios can be set up to read future precipitation data provided from external sources or the user can create manual forecasts within a watershed using MFP within HEC-RTS. The flexibility allows users to simulate potential impacts within the watershed from future rainfall data and simulate “what-if” scenarios with manual forecasts setup by the user. Precipitation data can be extracted from HEC-DSS files or a separate database to be used in forecast scenarios. Scripts can also be used to pull data into the forecasts in real time.

4.3.3. Setup

The functions of HEC-RTS are organized into four groups which consist of the Acquisition, Visualization, Modeling, and Setup modules.

The Acquisition module is made up of commands for acquiring the model input data, monitoring the data received from HEC-DSS files, validating data quality, transforming data, and editing data as required.

The Visualization module consists of commands to display observed data and forecast data for visualization. The Visualization module also allows the user to facilitate a review of large amounts of data using graphs, spreadsheets, tables, river profiles, maps or a combination of these. The data is linked to a watershed map so the user can click on icons and review the data and computed results associated by location.

The Modeling module consists of commands for simulation of created forecast events. The forecast is set up and executed in this module and allows the user to review results.

The Setup module consists of the grouping of commands for the watershed setup. These commands configure the inputs, models and outputs for the watershed. The module also develops a visual map of results for the watershed elements to be displayed in the graphic user interface.

The analysis programs, HEC-HMS and MFP, are linked so individual models can be executed in an organized fashion. Data and multiple inputs are exchanged between each software through the HEC-DSS data exchange referencing the extract list. For this project, only the Modeling and Setup modules are enabled for use. The Setup and Modeling module windows with callouts for the features within the modules are shown below in **Figure 12** and **Figure 13**.

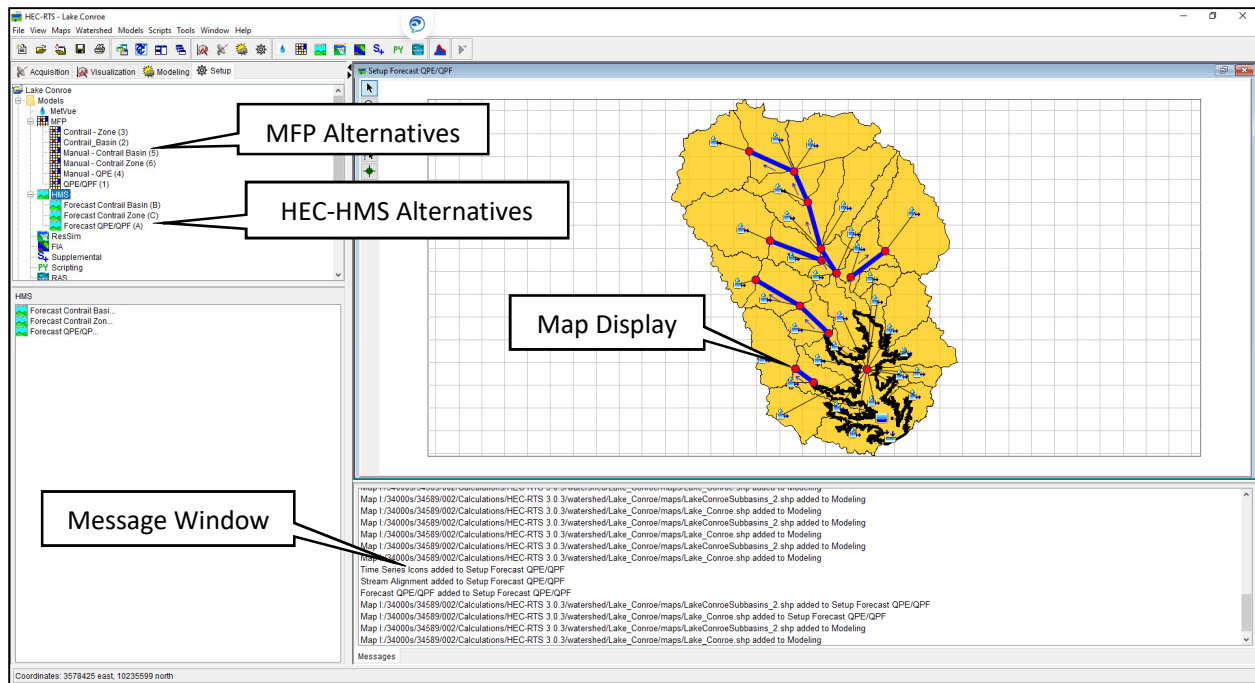


Figure 12. Setup Module

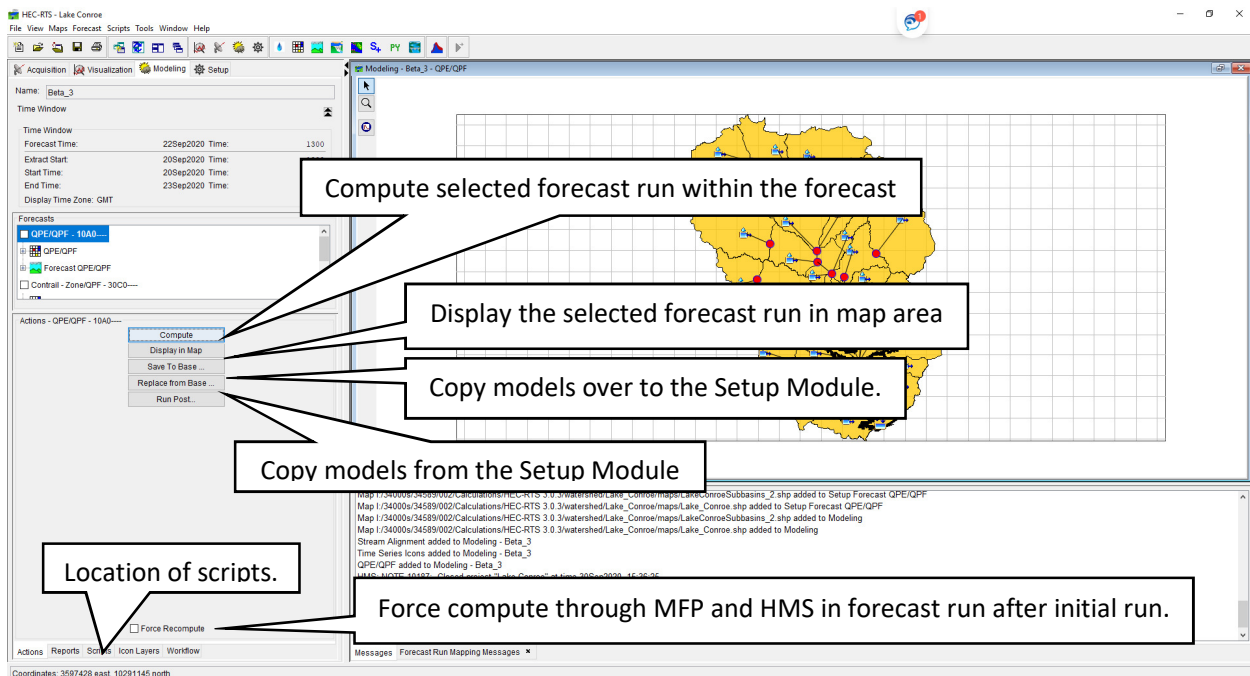


Figure 13. Modeling Module

A referenced time zone must be specified within the watershed and typically is set either at the Greenwich Time Zone (GMT) or the time zone in which the watershed resides. For the HEC-RTS model, the US Central Time Zone (GMT06:00) was referenced for the Lake Conroe watershed. Datasets that are pulled from the fetch data script consist of QPE/QPF data which is referenced in the Greenwich Time Zone and Contrail® and USGS observed data referenced in the US Central Time Zone. Several test forecasts were run to test if the QPE/QPF rainfall datasets were aligned with observed data and it was determined that the datasets were aligned. Therefore, the time zone chosen within the watershed did not affect the fetched data using the script.

4.3.4. Script

Scripts provide a way to automate actions for HEC-RTS with a simple trigger. Scripting simplifies user operation, ensures the repeatability and consistency of input data and reduces time to export results. For the reservoir forecasting tool, a script was created to fetch rainfall data from the SQL Server based on a time window specified by the user. The data available in the SQL Server is collected from USGS gages, Contrail® gages, NOAA, and WGRFC data. The data is split into 15-minute intervals and split across sections of the lake. The data is then collected and stored into a HEC-DSS file. That file is accessible from HEC-RTS by selecting the Tools drop down menu, and then selecting HEC-DSSVue.

4.3.5. MFP

The Meteorological Forecast Processor (MFP) alternatives were created to process forecast rainfall data to be referenced within the Lake Conroe HEC-HMS model. The MFPs were assigned to the created precipitation zone configuration in the HEC-HMS model. MFPs were created for both the QPE/QPF and Contrail®/QPF rainfall datasets. These rainfall datasets splice Contrail® and QPE rainfall to QPF rainfall depending on the specified forecast date and time. Manual forecast MFPs for the Contrail® and QPE rainfall datasets were created to allow the user to create

forecast data. Manual forecasts are entered as hourly rainfall data and can range from 1 to 240 hours in length. The MFP alternatives available are listed below.

1. **Contrail – Zone:** Consists of merging the average rainfall as recorded by SJRA gages in the two configuration zones with QPF rainfall at the time of the forecast. If a gage is inactive during a rainfall event, it is not included in the computation of the rainfall average. This alternative is best used when a rainfall gage is not functioning or producing erroneous readings.
2. **Contrail – Basin:** Consists of merging the rainfall as recorded by SJRA gages in the Thiessen polygons with QPF rainfall at the time of the forecast. If (a) gage(s) become(s) inactive during a rainfall event, the basins in the Thiessen polygon associated with the gage are not assigned any rainfall.
3. **Manual – Contrail Basin:** Same as MFP Alternative 2 (Contrail – Basin) but the user is allowed to input forecast rainfall manually.
4. **Manual – Contrail Zone:** Same as MFP Alternative 1 (Contrail – Zone) but the user is allowed to input forecast rainfall manually.
5. **Manual – QPE:** Consists of using Radar Rainfall Data in lieu of SJRA gage rainfall data but the user is allowed to input forecast rainfall manually.
6. **QPE/QPF:** Consists of using Radar Rainfall Data in lieu of SJRA gage rainfall data merged with QPF data at the time of forecast.

The MFP alternative window is shown below in **Figure 14. Halff recommends the use of MFP Alternative 1 (Contrail – Zone) for conducting forecasts. MFP Alternative 2 (Contrail – Basin) is a recommended alternative to MFP Alternative 1. Alternative 6 (QPE/QPE) is recommended if the Contrail® network is not providing rainfall data.**

Figure 14. MFP Alternative Window

4.3.6. Forecast

A forecast consists of retrieving data from the SQL server database, running the relevant forecast simulations, adjusting model parameters to match observed data and exporting results to a comma-separated values (CSV) file. A new forecast is created within the modeling module and prompts the user to enter the forecast dates and times along with the name of the forecast. Dates for the lookback and forecast are defaulted to the day of when the forecast was created and the default time window. Values within the default time window can be changed to alter the number of days in the lookback and forecast periods. **Halff recommends a lookback period of 48 hours and a forecast period of 24 hours.** The name of the forecast defaults to the date and time of the forecast along with the referenced time zone specified in the watershed. The name can be changed based on the user's preference. In addition to establishing the names, dates, and times, the user must choose which of the created simulations to include within the forecast from the setup module. A forecast event can contain multiple forecast runs. Once the specifications for the forecast event are satisfied, the MFP and HEC-HMS models tied to the specified forecast runs created within the Setup module are copied into the Modeling module. The forecast window is shown below in **Figure 15**.

The screenshot shows the 'Create New Forecast' dialog box. The 'Name' field is '2020.09.08-1500 GMT' and the 'Description' field is '2020.09.08-1500 GMT'. The 'Folder' field shows a path: 'I:/34000s/34589/002/Calculations/HEC-RTS 3.0.3/forecast/20...'. The 'Select Type' dropdown is set to 'New Forecast'. The 'Time Window' section includes: 'Forecast Time: 08Sep2020 Time: 1500', 'Extract Start: 06Sep2020 Time: 1500', 'Start Time: 06Sep2020 Time: 1500', and 'End Time: 09Sep2020 Time: 1500'. The 'Watershed Time Zone' is 'GMT'. Below this is a table with columns 'Se...', 'Forecast Run', and 'Description'. The table contains five rows: 'QPE/QPF' (checked), 'Memorial Day 2016' (unchecked), 'Contrail - Zone/QPF' (checked), 'QPE/Manual' (unchecked), and 'Contrail_Basin/Manual' (unchecked). 'OK' and 'Cancel' buttons are at the bottom.

Se...	Forecast Run	Description
<input checked="" type="checkbox"/>	QPE/QPF	
<input type="checkbox"/>	Memorial Day 2016	
<input checked="" type="checkbox"/>	Contrail - Zone/QPF	
<input type="checkbox"/>	QPE/Manual	
<input type="checkbox"/>	Contrail_Basin/Manual	

Figure 15. Forecast Window

After the new forecast event is created, a folder appears within the forecast folder which contains the data for the new forecast and stores both the copied over MFP and HEC-HMS models from the forecast runs. Each forecast event creates a new folder to keep the data from each forecast separate from other forecasts and stores the data created from the embedded scripts within HEC-RTS. Before the forecast simulations within the forecast event can be modeled, rainfall data

needs to be retrieved from the SQL server database. This process is conducted using a script within HEC-RTS that fetches the data from the SQL server database which includes the QPE/QPF and Contrail®/QPF rainfall datasets and the observed USGS gage data for Huntsville and Lake Conroe. The script will pull this data in the time frame specified from the forecast event and it is placed in the HEC-DSS file located within the forecast folder.

After the rainfall data is retrieved using the script, the forecast simulations can be modeled within the modeling module. The forecast simulations can either be executed one at a time or all at once. Data from the HEC-DSS file created from the script is automatically extracted to the forecast simulations based on the specified extract list in the setup module. After the forecast simulations have run, results can be viewed within the map display of the modeling module which includes summary, time-series and graphical results. Results can also be compared to observed data at the specified USGS gages for both the flow at Huntsville and lake level at Lake Conroe. Slider adjustments can also be made while viewing these graphs to show the model response to these changes and allow the user to calibrate the storm event to the observed data. A graph comparing the observed and modeled data is shown in **Figure 16**. The resultant lines in blue in the graph are computed results from the HEC-HMS elements connected to the junction.

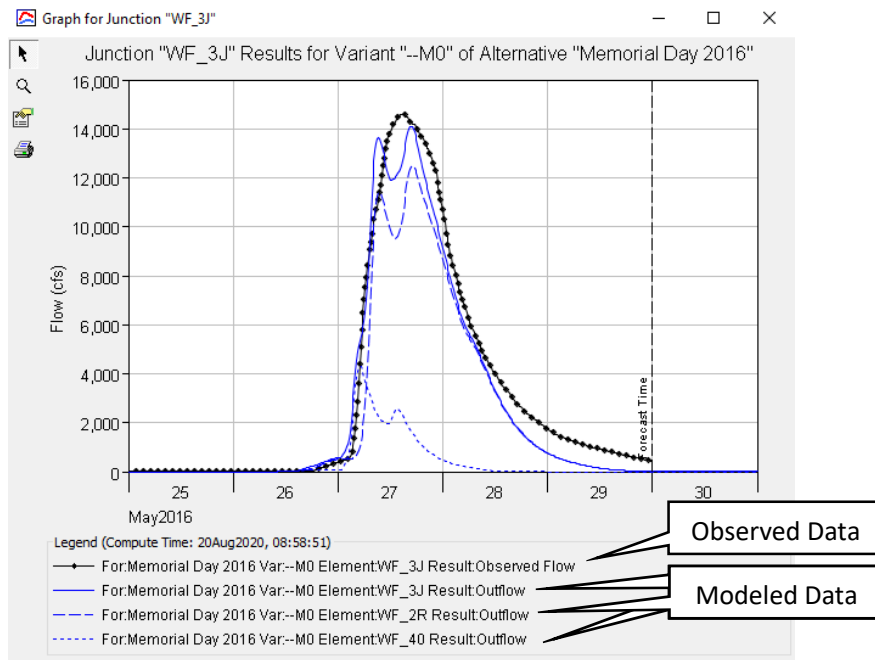


Figure 16. Observed and Model Results

After the results from the forecast runs are finalized, Lake Conroe inflow and stage results from the HEC-HMS model can be exported to a CSV file to be input into the forecast operations spreadsheet. A script was created to export these datasets and is in the same location as the data retrieval script. Once the export-dataset script is finished, a CSV file containing forecast event data is shown within the main forecast folder outside of the dated forecast folders. The CSV file contains the lake level and inflows for each forecast simulation from the forecast event and separates the date and time into two separate columns to be read within the operations spreadsheet. The complete forecast workflow is shown in **Figure 17**.

HEC-RTS (Local or Remote)

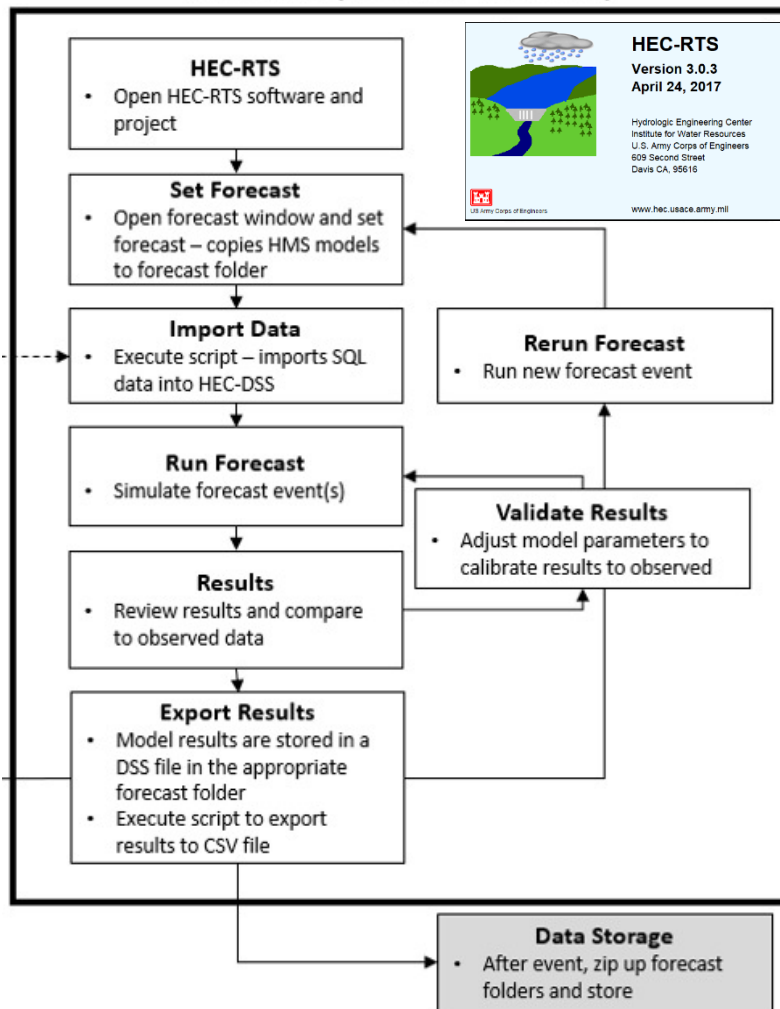


Figure 17. HEC-RTS Forecast Flowchart

4.3.7. Archive Event

HEC-RTS allows the user to archive forecasts to reduce the amount of data within the forecast folder while still having access to previous forecasts. The archiving process is conducted within the modeling module and allows the user to select which forecasts to archive. HEC-RTS provides the date and time of when the forecast was archived. The folder for the archived forecasts must be specified and can be referenced to any folder. Comments can also be added to the archived forecasts if needed. After the specifications for the archive are finished, HEC-RTS copies and zips the forecast folder into the archive folder with the date of the archive. The zipping process typically reduces the file size of the forecasts to 10 to 20 percent of original file size. The folder structure for the archive is shown in **Figure 18**.

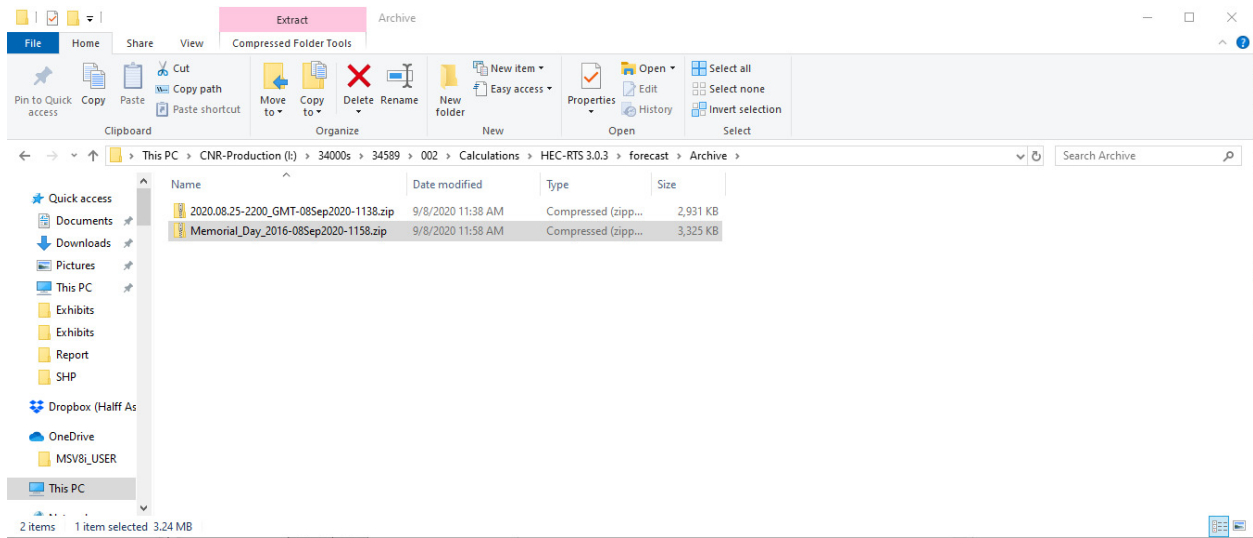


Figure 18. Forecast Archive Folder Structure

5.0 Tool Refinement

The preliminary HEC-RTS model was created with an updated HEC-HMS model of Lake Conroe, forecast alternatives, and scripts to allow data to be pulled from the SQL server and exported to a CSV file. Several historical storms including the Memorial Day 2016 event were used to test the validity of the retrieved data and the model. The model was also sent to third-party reviewers, Freese and Nichols, Inc (FNI) and HDR to provide any recommendations to make the model more robust and user-friendly.

5.1. HEC-RTS Testing

To update the existing Lake Conroe hydrologic model from the previous studies to be used within the reservoir forecasting tool, FNI and HDR provided recommendations to make the HEC-HMS model work better within HEC-RTS. These recommendations included:

- Removing unnecessary basin and meteorological models and control specifications

The original model contained several basin, meteorological, and control specifications that were tied to several storm events and based on particular rainfall datasets. FNI and HDR recommended to reduce the basin models so that only one model would be used for the forecast. Meteorological models were also reduced to correspond to only the rainfall datasets that would be used within the DSS tool. Control specifications were also deleted from the model as forecast alternatives do not require a control specification.

- Removing HEC-DSS linkage to paired data

FNI and HDR also recommended removing any HEC-DSS linkage to the paired datasets such as storage-discharge and storage-elevation curves. This was done to reduce the possibility of broken linkage when transferring the model to outside sources.

- Removing baseflow methodology

Baseflow was also eliminated from the subbasins within the basin models. FNI and HDR stated that the baseflow methodology contributes to higher lake levels on the receding limb when compared to observed data of a historical storm. Halff agreed and removed baseflow so as to not add any additional flow during historical storm events.

- Delineating the footprint of Lake Conroe

The original subbasin of Lake Conroe included areas outside of the lake itself which potentially affected the lake response in the model. Rainfall on the lake responds more quickly when compared to areas outside of the lake. As a result, FNI and HDR recommended that the adjacent areas around the lake be separated from the lake itself. The subbasin was redelineated to the normal pool elevation of the lake and the immediate, adjacent areas draining to the lake were redelineated into eight different subbasins, or nine subbasins total.

- Zone Configurations

Zone configurations were recommended by both FNI and HDR to provide a real time calibration process for the forecast events. The configurations were set by applying the relevant subbasins and routing reaches to the areas upstream of the USGS gages at Huntsville and Lake Conroe. Parameters including loss (initial and constant), transform (Clark), and routing (Modified Puls) methods can be adjusted with more ease as opposed to using an external spreadsheet. The zone configurations allowed for the implementation of slider adjustments to provide an easy way to adjust parameters to calibrate forecast events.

Once all recommendations were implemented into the existing Lake Conroe HEC-HMS model, the model was imported into HEC-RTS. Historical storms were then simulated in the model to test the use of the slider adjustments for calibrating the model to observed data. The Memorial Day 2016 event was one of the events used to test the refinements. In addition to the observed flow and stage at the Huntsville and Lake Conroe gages, the observed outflow for Lake Conroe was used to simulate the releases during the event. Comparisons of the results to the Huntsville and Lake Conroe gage data are shown below in **Figure 19** and **Figure 20**.

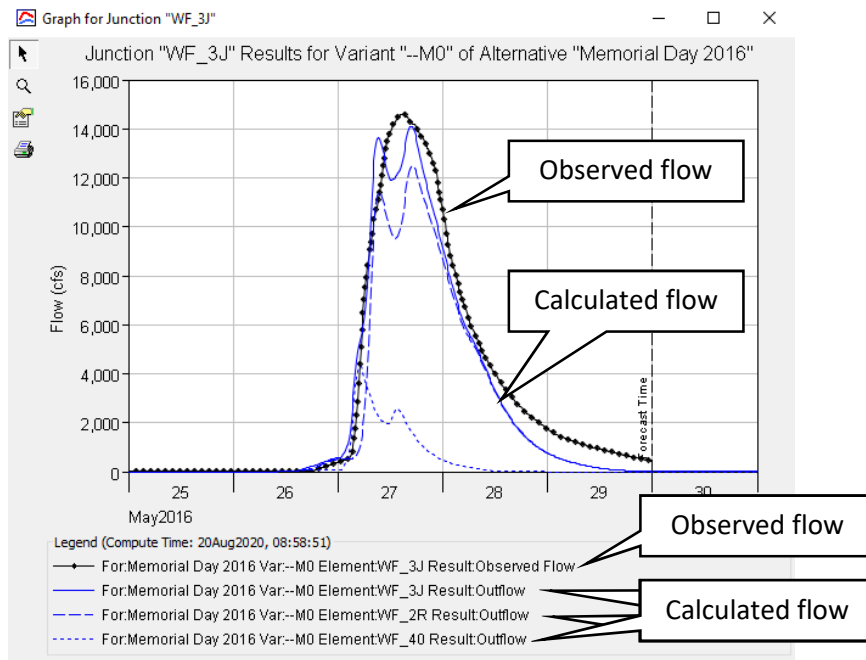


Figure 19. Memorial Day 2016 Forecast - Huntsville Gage

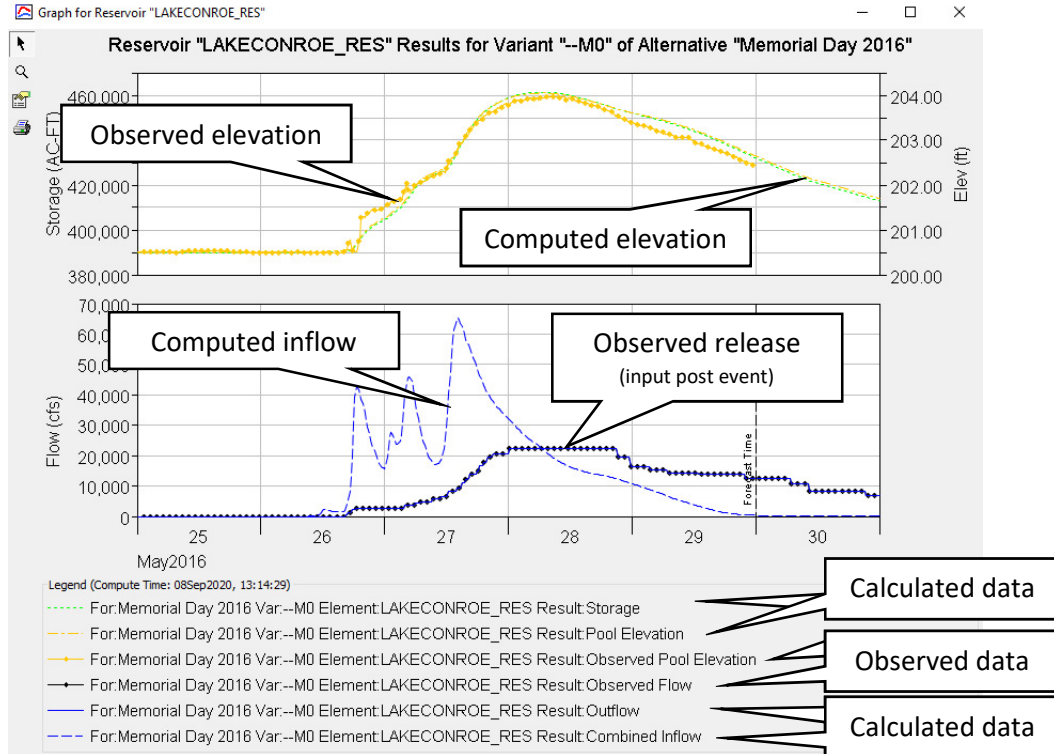


Figure 20. Memorial Day 2016 Forecast - Lake Conroe Gage

The results for the Memorial Day 2016 event show that the flow and stage hydrograph for both the Huntsville and Lake Conroe gages match closely with the modeled data respectively. The flow hydrograph at Huntsville is relatively matching with observed data on the rising limb while the peak shape is different with two peaks as opposed to one peak observed at the gage. The gage at Lake Conroe shows the modeled elevations are nearly in line for most of the storm event with the model accurately capturing portions of the rising limb and peak. Overall, the HEC-HMS model calibrated well with observed results.

Once the loss and transform parameters were adjusted to match the observed data for the historical events, the parameters were averaged to form the loss and transform parameters to be used in the base model within HEC-HMS.

5.2. Final Adjustments

FNI and HDR provided recommendations on the HEC-RTS model to simplify the forecast process. These recommendations included:

- Upgrade HEC-RTS version 3.0.1 to HEC-RTS version 3.0.3

The original HEC-RTS model was created using version 3.0.1 which is no longer available for download on the USACE website. FNI and HDR initially had issues running the embedded scripts with this version and suggested an upgrade to version 3.0.3 since it is readily available on the USACE website. FNI and HDR tested the scripts in version 3.0.3 and were able to run them successfully. As a result, HEC-RTS was upgraded to version 3.0.3 with no issues.

- Reference observed data in correct viewport for Lake Conroe

The observed data for Lake Conroe was referenced within the HEC-HMS model incorrectly. A simple adjustment in the HEC-HMS model corrected the issue and the data is now referenced in the correct viewport.

- Flow Blending at the Huntsville gage

HDR suggested applying flow blending at the Huntsville gage to aid in calibrating the forecast events. Flow blending forces the flow at the junction within the HEC-HMS model to follow the observed data up to the forecast time frame. As a result, model flow at the Huntsville gage was forced to follow the observed data providing better calibration for Lake Conroe. Flow blending is an option to the user but must be used with care.

- Renamed scripts

The initial scripts were named “DSS” and “CSV” to fetch data from the SQL server database and export model data to CSV, respectively. The naming was seen as confusing to the user and subsequently were renamed to “Fetch Data” and “Write to CSV” to indicate the actions of these scripts.

- Simplify CSV export

The previous CSV export script exported all the data from the model for each forecast run. This process made the script run longer, increasing chance of failure and added additional data that wasn't needed. The script was refined by reducing the amount of the data that was exported and only exporting the lake inflow and lake level for each forecast run. The script runs faster due to the simplification.

6.0 Manual

A manual describing a working process of using HEC-RTS was developed for the reservoir forecasting tool. The manual includes simplified instructions and screenshots to provide a visualization for the process of setting up and running models and forecasts in HEC-RTS. The manual is included in **Appendix C**. Appendix A.1 to the manual describes the process of utilizing the spreadsheet reservoir modeling tool described in Section 3 of this report.

6.1. Purpose

The purpose of the manual is to provide a working reference for users with little-to-no experience using the HEC-RTS software. The manual also shows the capabilities that can be used within HEC-RTS and how to set them up, as well as how to utilize the reservoir modeling tool, including incorporating data output from HEC-RTS in the tool.

6.2. Summary

The manual summarizes the setup of the HEC-RTS model including any processes within HEC-HMS that need to be prepared. The manual first goes over how to create a new watershed within HEC-RTS and what parameters to set for it. The manual also covers the process within the setup module which includes importing HEC-HMS models, setting up forecast alternatives, creating MFP alternatives, and linking the MFP and HEC-HMS models together. The manual also covers the steps to set up a forecast within the modeling module, which consists of selecting the relevant forecast simulations for a new forecast, running the embedded scripts, running each forecast simulation, and exporting data to a CSV file. For SJRA, the main focus of the manual should be the modeling module section which covers the creation of the forecasts. The setup module should not be altered unless needed otherwise. Appendix A.1 to the manual summarizes the process of utilizing the reservoir modeling tool, including importing/inserting observed reservoir and operations data, importing forecast data from HEC-RTS, and forecasting reservoir conditions.

6.3. Remarks

The reservoir forecasting tool manual is intended to serve as a guide for operating the tool. The manual is not intended to be a comprehensive guide for every rainfall scenario which the user may encounter. A basic understanding of hydrologic principles and a fundamental knowledge of using HEC-HMS will be needed for a user to effectively utilize all facets of the tool. It is also recommended that users familiarize themselves with the HEC-RTS User's Manual which is available from the HEC website. Finally, the user will need to understand the SJRA gate operations and tools. The reservoir forecasting tool is not intended to replace SJRA gate operations protocol. Instead, this tool will allow the SJRA to evaluate how the lake may respond to forecast rainfall and provide such information to appropriate parties.

The reservoir forecasting tool will require continued testing over time to validate the accuracy of the models to forecast inflows based on forecast rainfall. Reviewing the performance of the tool by the user after rainfall events is critical to preparing to use the tool for the next rainfall event. The user can accomplish this by reviewing the adjustments needed to hydrologic parameters every time a forecast was made. The antecedent conditions of the watershed can impact what parameter changes or adjustments are needed in the model during an event. Updates may be made to the tool to improve performance and ease of use in the future.

Finally, additional stream gages in the watershed can improve the reliability of the tool and its performance during events. Currently, the only stream gage is the USGS Huntsville gage.

Expanding the stream gage network to the major tributaries to Lake Conroe will give the user more points in the model to calibrate during storm events. Lake Conroe watershed streams on which to further evaluate the benefit of stream gages would be East Sandy Creek, Caney Creek, Little Lake Creek, and West Sandy Creek.

7.0 Deliverables

This tool incorporated several components working simultaneously alongside one another in order to produce forecast events for the Lake Conroe watershed. These components include databases and models with supporting documentation on how those components work with one another. The items used to facilitate this study were given to SJRA to use for their forecast modeling of Lake Conroe. These deliverables are discussed below, as well as what is needed to implement these deliverables successfully.

7.1. Database

The SQL server database setup was provided to SJRA information technology (IT) staff. The SQL server is set up to continuously collect available rainfall, stage, and stream flow data.

7.2. HEC-RTS

HEC-RTS is the software platform that merges rainfall data inputs and simulates the hydrologic model for reservoir inflow forecasts. The version of HEC-RTS utilized for the tool is version 3.0.3 which was released in April 2017. The HEC-RTS package is located on the USACE website for download. **Halff recommends that HEC-RTS be installed on a computer/workstation that can be backed up on a regular basis. Remote access to the computer/workstation should be enabled if desired by the SJRA. The HEC-RTS watershed files should be saved on a server instead of on the computer/workstation.** Complete installation instructions are highlighted in Sections 2.1 and 2.2 in the “*Real-Time Simulation (HEC-RTS) Quick Start Guide*” located on the USACE website under the HEC-RTS documentation. Requirements to run HEC-RTS include the following:

- 3 GB of hard disk space
- Windows 64-bit operating system
- Java 8 – Included within installation package

The model provided to SJRA includes a complete HEC-RTSv3.0.3 model of the Lake Conroe watershed with the embedded model alternatives such as MFP and the HEC-HMS model. The model also includes the scripts to retrieve data from the SQL server database and to export results to a CSV file to be used in the reservoir modeling tools. The setup module within HEC-RTS is already established and will not need to be adjusted unless needed.

7.3. HEC-HMS

HEC-HMS is a software provided by the USACE that is designed to simulate rainfall-runoff processes for established watersheds. The version used for the tool is version 4.2.1 and was released in March 2017. The installation package is included on the USACE website and can be installed on either a Microsoft Windows or Linux operating system. The HEC-HMS model is already embedded within the provided HEC-RTS model and includes the established zone configurations and forecast alternatives for the various rainfall datasets. **HEC-HMS version 4.2.1 must be installed on the computer/workstation on which HEC-RTS is installed.**

7.4. Reservoir Modeling Tool

The reservoir modeling tool was developed in Microsoft Excel. The spreadsheet forecasts reservoir releases and lake levels by considering hypothetical reservoir operations. Embedded macros in the spreadsheet upload data that is exported from the HEC-RTS model to model the reservoir. **Microsoft Office must be installed on the computer/workstation on which HEC-RTS is installed.**

7.5. Manual

A manual describing a working process of using HEC-RTS was developed for the reservoir forecasting tool. The manual includes simplified instructions and screenshots to provide a visualization for the process of setting up and running models and forecasts in HEC-RTS. For SJRA, the section covering the modeling module should be sufficient to use the HEC-RTS model since both the watershed and setup module have already been established.

Reservoir Forecasting Tool

Appendix A – Software Recommendation and Selection

MEMORANDUM

TO: Chuck Gilman, PE
Director of Water Resources and Flood
Management
San Jacinto River Authority

DATE: 5/24/2019

FROM: Sam Hinojosa, PE, CFM
Director of Water Resources, Conroe
Halff Associates, Inc.

AVO: 34589

EMAIL: shinojosa@halff.com

SUBJECT: Work Order No. 1: Flood Forecasting and Reservoir Operations Tool – Software
Evaluation (Contract No. 19-0048-1)

1 INTRODUCTION

In August 2016, the San Jacinto River Authority (SJRA), along with Montgomery County and the City of Conroe, obtained a Flood Protection Grant from the Texas Water Development Board (TWDB) to perform a study of the upper portion of the West Fork San Jacinto River Watershed through Lake Conroe down to IH-45. The study included the development of new state-of-the-art rainfall-runoff models that could be coupled with real-time rainfall and/or National Weather Service West Gulf River Forecast Center (WGRFC) forecasts for predicting runoff volumes and inflows into Lake Conroe during rainfall events. The grant also included funding to both update the SJRA rain gauge network to Alert 2 and add gauges to the Lake Conroe watershed. This effort was the first phase of a multi-phased approach to address flood mitigation in the watershed. In July 2018, SJRA applied for a grant to fund a second phase that would develop a tool to forecast reservoir inflows, volumes, and peak levels that will help the reservoir operator make timely operation decisions. SJRA was awarded the grant and entered into a contract with Halff Associates, Inc. (Halff) to develop and implement the proposed flood forecasting and reservoir operations tool herein referred to as a decision support system (DSS). Halff contracted sub-consultant agreements with HDR, Inc. (HDR) and Freese and Nichols, Inc. (FNI) for this phase. The first work order of the project is to perform an evaluation of software platforms that could be used for the DSS. The project was initiated in March 2019.

The overall goal of this project is to develop a flood forecasting and reservoir operations real-time DSS for the Lake Conroe Division to be used by SJRA as needed during storm events. For this project, the phrase “flood forecasting” is defined as forecasting inflows and volumes into Lake Conroe during rainfall events. The system would leverage the following available real-time hydrometeorological data for the Lake Conroe watershed: Quantitative Precipitation Estimates (QPE) gridded rainfall, Quantitative Precipitation Forecast (QPF) gridded rainfall, gauge adjusted radar rainfall data, USGS reservoir level (Lake Conroe Dam), USGS streamflow data, and Lake Conroe release data. The DSS will allow SJRA staff to better predict the potential inflow volumes and potential reservoir releases based on both actual rainfall and WGRFC forecast rainfall. The project is not intended to replace the current gate operations policy but will provide forecast information that will be useful to the operator in preparing for lake releases and for improving communications with community partners. The purpose of this document is to provide a brief summary of the DSS software platform evaluation effort and provide recommendations for SJRA.

2 RESERVOIR INFLOW FORECAST WORKFLOW

The SJRA has developed a gate operations policy that may be implemented during rainfall events when water is being released from the reservoir. During rainfall events, the SJRA monitors rainfall and makes releases to maintain the reservoir levels within the flowage easement of 207 ft-msl. The SJRA has recently upgraded and enhanced the rain gauge network in the Upper West Fork San Jacinto River Watershed to improve the staff's ability to monitor rainfall events. The updates and expansion of gauges have provided SJRA with resources to use in conjunction with a DSS that will estimate potential inflows into the reservoir during rainfall events. This capability will be useful to the reservoir operator in preparing for potential lake releases and improving communication with community partners.

The calculation of inflow rates and volume estimates into reservoirs using available rainfall data can be performed by hydrologic models. Half developed for SJRA a comprehensive HEC-HMS (Hydrologic Modeling System) computer model of the Upper West Fork San Jacinto River watershed (see Figure 1). HEC-HMS is a hydrologic modeling software developed by the US Army Corp of Engineers (USACE) and is commonly used by engineers to calculate runoff hydrographs and volumes. The Upper West Fork San Jacinto River watershed computer model was calibrated to historical rainfall events and has the capability to use available rainfall data to calculate inflows into Lake Conroe with consideration of factors such as land use and infiltration losses. The following narrative describes the workflow to forecast inflows without using a DSS. A generic reservoir inflow forecast workflow diagram is shown in Figure 2.

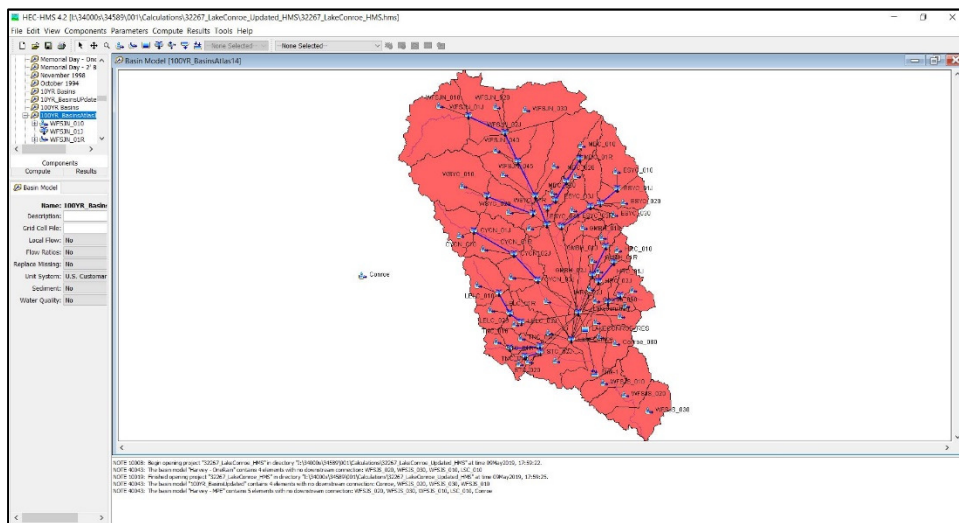


Figure 1. West Fork San Jacinto River Watershed HEC-HMS Model

The backbone of forecasting inflow volumes into Lake Conroe will be the HEC-HMS model. However, the model requires user input and adjustments during rainfall events to calculate inflows and volumes into the reservoir. The user must determine a forecast time, look back period, and forecast period. In order to use the model during a rainfall event, the user must obtain or fetch the available rainfall data, configure it into an appropriate database such as HEC-DSS (Data Storage System) that the model can use, feed it into the HEC-HMS model, adjust any appropriate parameters such as infiltration losses, and then simulate the HEC-HMS model to calculate potential inflows and volumes. HEC-DSS is shown in Figure 3.

Once inflows and volumes have been calculated, the user can then feed the results from the HEC-HMS model into a reservoir computer model such as HEC-ResSim (Reservoir System Simulation) to forecast reservoir levels and flow releases. HEC-ResSim (see Figure 4) is a reservoir modeling software developed by the USACE and is used to model reservoir operations at one or more reservoirs for a variety of

operational goals and constraints. A fully functional HEC-ResSim model has not been developed for Lake Conroe.

An alternative to using a reservoir computer model like HEC-ResSim is to use an inflow-based spreadsheet model. The reservoir inflows calculated from the HEC-HMS model can then be fed into an inflow-based spreadsheet model to calculate reservoir levels and target gate openings. The spreadsheet model would be very similar in appearance to the Gate Operations Policy reservoir level spreadsheet model currently used by the SJRA. The major difference between the two spreadsheet models is that the inflow-based spreadsheet model calculates reservoir levels based on inflows and gate openings whereas the current reservoir level spreadsheet model calculates inflows based on observed reservoir levels and gate openings.

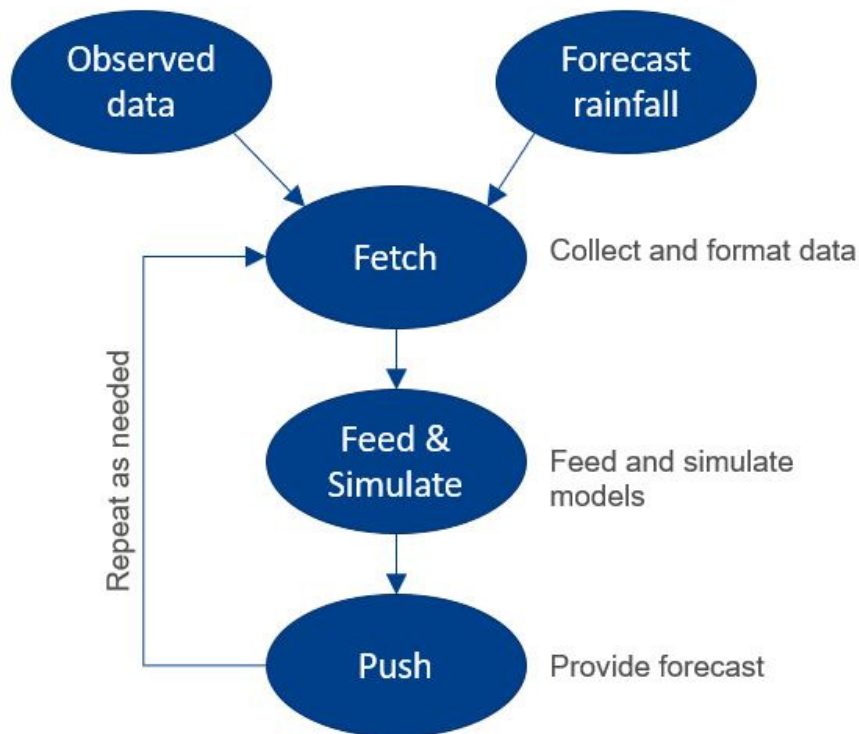


Figure 2. Reservoir Inflow Forecast Workflow

Once a reservoir simulation has been performed using a reservoir computer model or a spreadsheet model, the user can then obtain the forecasted reservoir levels and corresponding gate openings and evaluate the results to prepare for probable lake releases. The process may be repeated on a regular cycle as needed before, throughout, and after the rainfall event.

The process of fetching rainfall data, feeding the HEC-HMS model, simulating the HEC-HMS model and reservoir model, and then reporting results in customizable formats is both complex and time consuming, especially during a rainfall event. Recognizing the need for a DSS platform to reduce the effort and time needed to fetch, feed, simulate, and report, various agencies and groups have developed software platforms to nearly automate the process. Half recommends that the SJRA select a DSS software platform to perform the necessary calculations to forecast reservoir inflows, volumes, and levels. Using a DSS will allow SJRA to plan for potential releases and inform the local emergency management agencies of potential releases with more lead time.

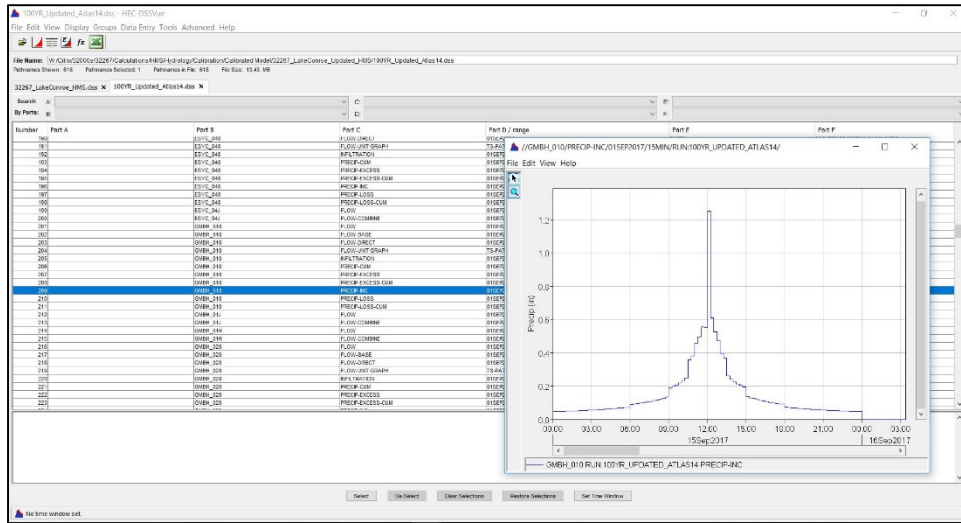


Figure 3. Hydrologic Engineering Center Data Storage System (HEC-DSS)

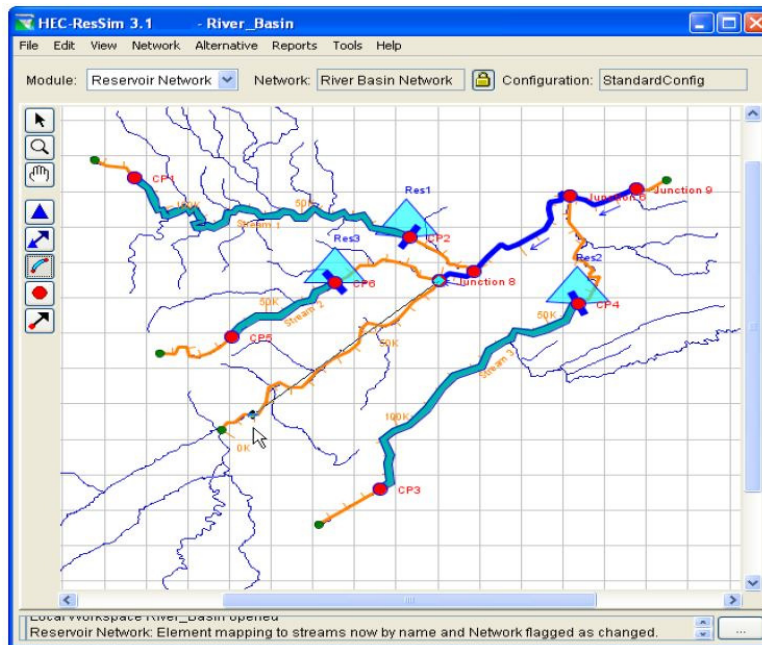


Figure 4. HEC-ResSim

(Source: HEC-ResSim User Manual)

3 SOFTWARE PLATFORM SUMMARY

Various DSS software platforms have been developed over the years to assist users in simulating hydrologic and hydraulic models to forecast flows and water surface elevations by integrating available and forecasted rainfall. Many of these software platforms are proprietary and only use specific proprietary hydrologic and hydraulic models. For example, ICMLive, developed by Innovyze, Inc., is a live modeling tool that integrates with hydraulic models, SCADA, and weather forecast databases. However, ICMLive

only uses InfoWorks ICM models. In a recent study of flood forecasting tools¹, Harris County Flood Control District (HCFCD) ruled out ICMLive since it did not use HEC products. HCFCD had already invested heavily in HEC products county-wide. Therefore, ICMLive was not considered to be cost effective to implement. Since SJRA has already invested in an HEC-HMS model that covers the Lake Conroe watershed, only software platforms which can readily simulate HEC models were considered for this evaluation. The two software platforms considered for this project are listed below. Summaries of each platform are also included in this section.

- Aviso developed by Ford Consulting, Inc. (now HDR, Inc.)
- HEC-RTS (Real Time Simulation) developed by the USACE

3.1 Aviso

Aviso is a flexible Windows[™]-based reservoir operation decision support system (DSS). Aviso (see Figure 5) can provide reservoir operators with data and information required to inform decisions to manage reservoirs optimally during rainfall events. Aviso provides quick-and-easy access to real-time rainfall, streamflow, and reservoir data; these data may be displayed within Aviso with graphs and tables pre-configured to meet a user's preferences. The user can set a forecast window in Aviso which includes a look back period and forecast period. Aviso can provide the user with reservoir inflow forecasts made with the HEC-HMS watershed runoff model integrated in Aviso. Aviso also permits a user to simulate reservoir operations with forecasted inflow and a candidate release schedule, thus providing information about future reservoir levels if the candidate schedule is followed. Through a common customizable Windows interface, a user can adjust the release schedule and re-simulate to find the schedule that best achieves desired reservoir levels. Again, results are displayed quickly and easily in user-selected graphs or tables. A workflow diagram for Aviso is shown in Figure 6. As shown, the process of fetching and configuring available data, feeding and simulating the models, and pushing output is all performed by Aviso.

Key features of Aviso system are:

- **Flexible data connectivity.** Aviso can connect to and retrieve data from a variety of commercial weather and water database management systems, including the Contrail database and USGS database. Aviso also can be configured to retrieve data from SJRA-designed Oracle, SQL Server, or other database management systems that comply with modern standards for querying, exporting, loading, and transforming data.
- **Efficient data management for models.** Internally, Aviso uses the state-of-practice USACE Hydrologic Engineering Center Data Storage System (HEC-DSS). This means all models from the USACE Hydrologic Engineering Center can be used readily by Aviso. It also means that any model that can be modified to access an HEC-DSS database can be used by Aviso for forecasting or reservoir operation analysis. For example, a worksheet can be added to the SJRA reservoir level spreadsheet model to permit the spreadsheet to retrieve inflow forecasts created by HEC-HMS from an HEC-DSS database, loading those into appropriate rows or columns of the spreadsheet. This automated data connection will greatly simplify the use of the spreadsheet, in a way that is transparent to the SJRA user. The user can use this data for comparisons to actual data.
- **Customizable display.** Aviso will permit an SJRA user to view tables and graphs of all data and of all computational results. Information that is geographically oriented—such as the distribution of rainfall over the watershed upstream of the reservoir—can be displayed in Aviso with color-coded maps, if desired.

¹ HCFCD did not make this study available to Half. The results of the study were relayed to Half by staff

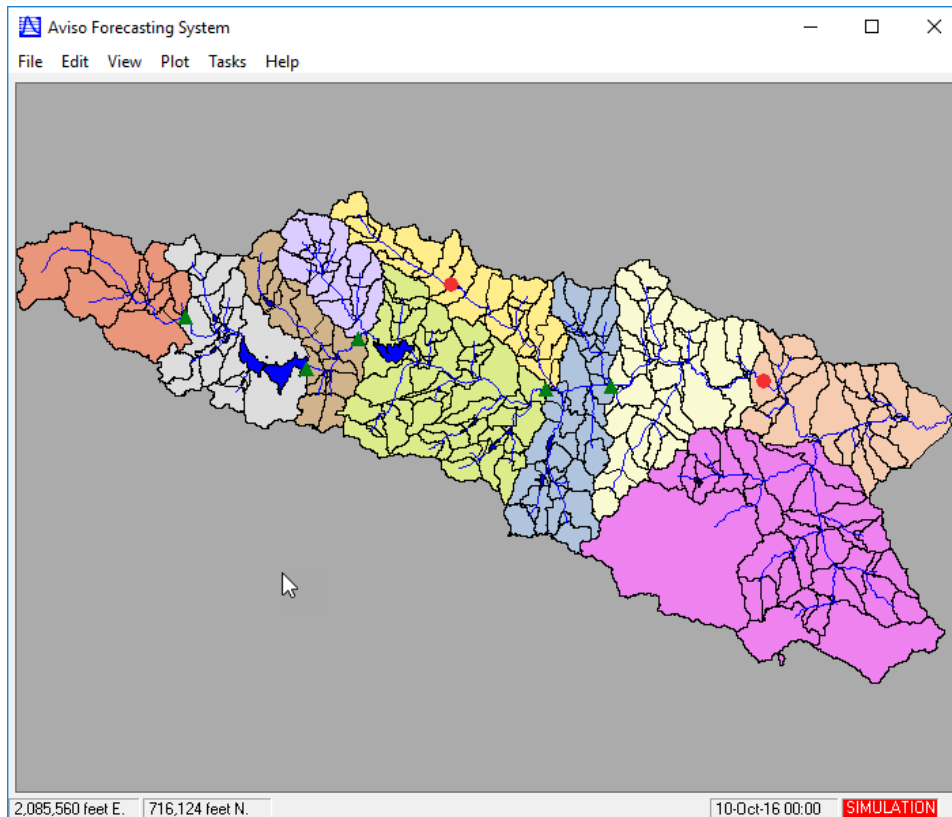


Figure 5. Aviso Interface

(Source: HDR, Inc.)

- **Flexibility for runoff forecasting.** Aviso will forecast runoff using the HEC-HMS model. However, the manner of use of the model is flexible. For example, if SJRA refines its HEC-HMS model in the future to forecast flows at additional locations within the watershed, Aviso can be adjusted simply to use and display results at those locations.
- **Flexibility for reservoir operation modeling.** As noted above, Aviso will simulate reservoir operation using inflows forecasted by the watershed model and display results in easy to read charts and graphs. The reservoir model used for this is flexible and can be changed if needs change. So, for example, an inflow-based spreadsheet model can be used initially, but replaced in the future with the Corps' HEC-ResSim if desired.
- **Access to training and support.** Training in use of Aviso and the component models (HEC-HMS and/or HEC-ResSim) is available as a component of engineering services provided by Half and HDR. Support in use, customization, and model calibration or adjustment are available similarly.

Known users of Aviso system are:

- **Tarrant Regional Water District (TRWD), Tarrant County.** TRWD uses Aviso as the platform for managing inflow and local flow forecasting, reservoir release selection, and downstream impact assessment. Aviso integrates rainfall data, HEC-HMS, HEC-ResSim, and HEC-RAS.
- **Mecklenburg County, North Carolina.** Aviso is used to forecast flows and stages in the metropolitan Charlotte, NC area. With the forecasts, they inform decisions about flood emergency response.
- **Overland Park, Kansas.** Aviso is used to forecast riverine flows and stages.

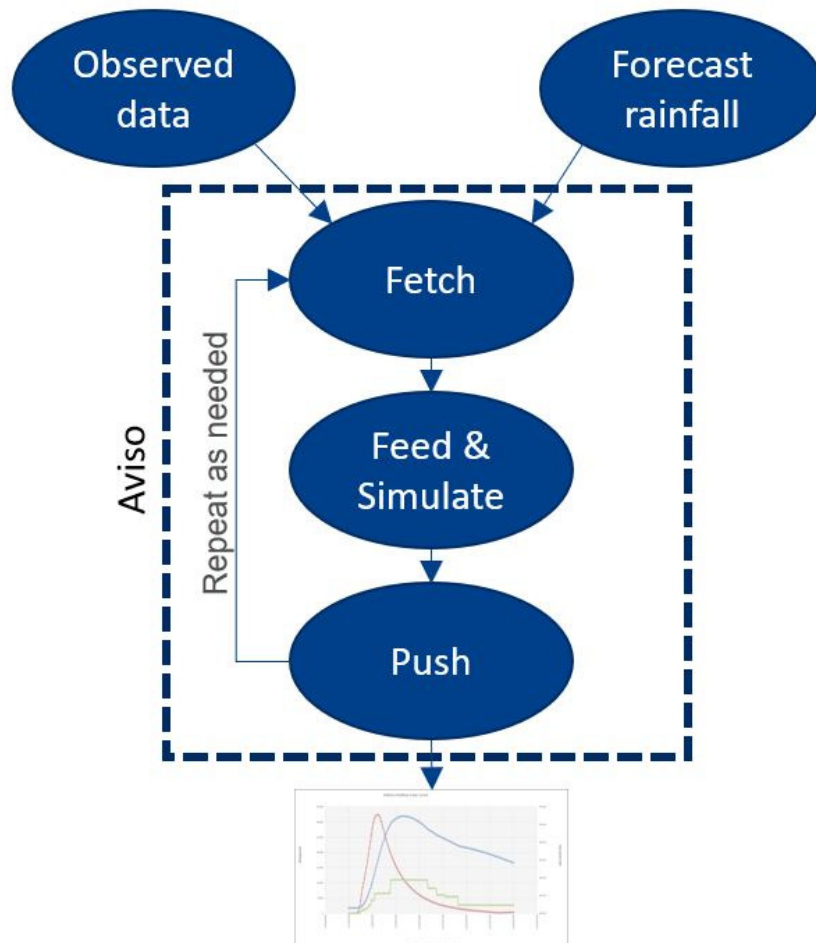


Figure 6. Aviso Forecast Workflow

3.2 HEC-RTS

HEC-RTS, a Windows™-based program, is a comprehensive data acquisition and hydrologic modeling system for short-term decision support of water control operations in real time. It encompasses data collection, validation and transformation, data storage, visualization, real time model simulation for decision-making support, and data dissemination. The USACE developed the Corps Water Management System (CWMS) software to assist in real-time decision-making regarding water control management. HEC-RTS is based on the CWMS and was developed for non-USACE offices. HEC-RTS (see Figure 7) provides the framework to link multiple common engineering software programs (HEC-HMS, HEC-ResSim, HEC-RAS, etc.) such that the output from one software becomes the input to another. This is facilitated in part using the HEC-DSS system, which is a common input/output format used by USACE software. Files in the DSS format may be manipulated through custom software components using commonly available tools such as Python or Excel Add-Ins to transfer data from one format to another, such as converting lake releases from discharges in cubic feet-per-second (cfs) to equivalent gate-feet.

In HEC-RTS, the retrieval, processing, and analysis is set up to execute in a near-automated fashion, from rainfall and forecast processing, to hydrologic modeling, to reservoir operation simulations, and the potential for other tools to analyze the impacts of certain scenarios. The user can set a forecast time, look back

period, and forecast period in HEC-RTS. A workflow diagram for HEC-RTS is shown in Figure 8. As shown, the process of fetching and configuring available data has to be performed using scripts. HEC-RTS feeds and simulates the models. Scripts are needed to push customized output.

Key features of HEC-RTS are:

- **Data Sources Flexibility.** HEC-RTS can use rainfall data from a variety of commercial weather and water database management systems. Once the data has been formatted and placed into HEC-DSS, HEC-RTS will simulate HEC-HMS to calculate inflows.
- **Model Integration.** HEC-RTS uses HEC-DSS for fetching and reporting data. This means all models from the USACE Hydrologic Engineering Center can be used readily by HEC-RTS.
- **Scripting.** HEC-RTS has a robust implementation of the Python scripting language, which allows for customized tools to post-process the inputs or the outputs to the ideal form or function desired by the user. This could lead to a blending of the current Gate Operations Policy reservoir level spreadsheet model with the HEC-RTS program such that the spreadsheet is only used to record operations and present selected forecast results for different scenarios. The scripts can be run automatically on a schedule or as part of the model simulation process.
- **Runoff forecasting.** HEC-RTS will forecast runoff using the HEC-HMS model.

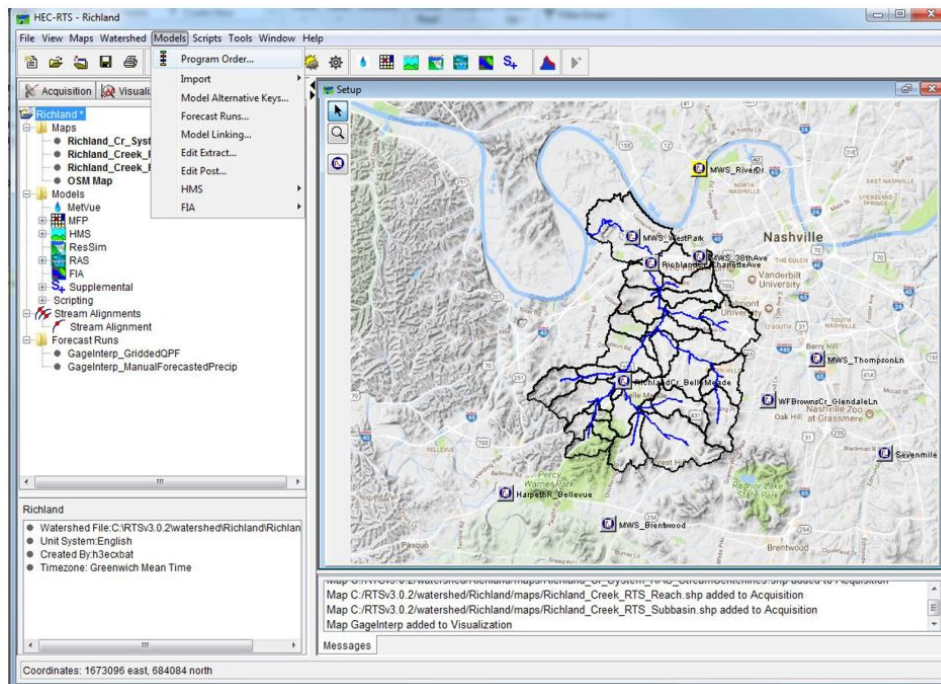


Figure 7. HEC-RTS Interface

(Source: https://silverjackets.nfrmp.us/Portals/0/doc/presentations/Realtime_Modeling_Webinar_PowerPoint.pdf)

Known users of HEC-RTS system are:

- **Harris County Flood Control District (HCFCD), Harris County.** HCFCD has recently begun to expand their flood forecasting capabilities by integrating rainfall data, existing HEC-HMS models and HEC-RTS.
- **County of San Diego, California.** The County implemented a flood warning system for the 420 square mile San Diego River watershed using HEC-RTS software. The flood forecasting system

is intended to provide San Diego County staff with timely information on potential flooding to support emergency response planning and operations.

In general, Aviso and HEC-RTS are both DSS tools that use the same HEC products to run real time simulations to forecast reservoir inflows and levels. However, there are some differences in how the user must interact with the platforms and in how the platforms can be customized. The differences are evaluated in the next section.

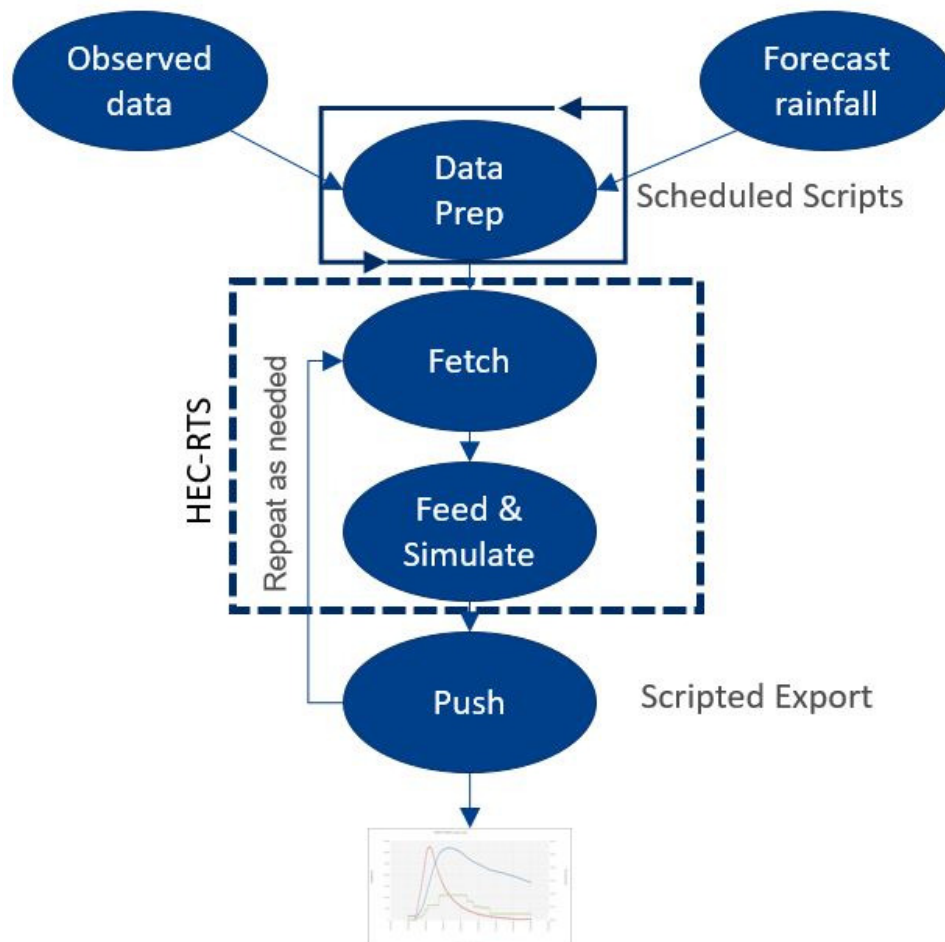


Figure 8. HEC-RTS Forecast Workflow

4 SOFTWARE EVALUATION

A half day workshop was conducted with SJRA staff and members of the consulting team on March 29, 2019 at the SJRA offices. The purpose of the workshop was to better understand SJRA's current capabilities to operate a DSS and desires/needs for the delivered DSS. The topics discussed were project goals, hydrologic modeling, reservoir operation modeling, and data storage. At this meeting, SJRA staff defined several key requirements for the DSS. In general, the key requirements of the DSS include:

- Forecast – The DSS should be capable of running in 15 minutes and be able to forecast every 30 minutes what gate operations (target) will result in regarding lake level, release, and inflow based

on both actual and forecast rainfall. The DSS should have the option of performing simulations prior to receiving rainfall.

- User Friendly – This means (a) no copy-paste of data; (b) very low probability of failure to provide a forecast; (c) must run with minimal human intervention, i.e. “one button”.
- Use available data/models – The DSS must be able to leverage available data sources to which SJRA has access or can readily get access (i.e., NWS QPE and QPF). The DSS should be able to use the available hydrologic model.
- Offsite Use – The DSS must be usable from “off site.” In other words, the software can be used off campus.
- Output – The DSS should provide output in the form of tables and graphs. The DSS should duplicate the look, feel, and functionality of the current Gate Operations Policy reservoir level spreadsheet model. Output should be familiar in look and feel to that of the current spreadsheet model.

4.1 Evaluation Criteria

Halff evaluated the two DSS platforms based on the key requirements as determined by the SJRA staff. Halff also considered other factors by which to evaluate the two DSS software platforms. A list of the factors considered is listed below and discussed further in this section.

- Produce forecasts at least every 30 minutes
- Ease of use for operations personnel
- Ability to use existing available data and models
- Customization options for future model improvements
- Scalability should additional areas/function need to be added in the future
- User support, training, and implementation
- Licenses and Maintenance costs
- Software updates

4.1.1 Regular Forecasts

SJRA prefers that the DSS have the ability to provide forecasts on a 30-minute cycle as needed. This allows the user to update the plan for reservoir elevations and releases. Both platforms have the ability to perform forecasts on 30-minute intervals.

Summary: Both Aviso and HEC-RTS have the ability to perform forecast on 30-minute intervals.

4.1.2 Ease of use for operations personnel

Ease of use for operations personnel may be the top priority in terms of the DSS. Given limited ability of SJRA staff to operate hydrologic and hydraulic modeling software, the simpler and more automated the DSS, while still achieving the end results, the better. A DSS that only includes features and “buttons” that SJRA needs would be helpful to ease the use of operations personnel. Having the ability to turn off additional features and options within the interface to avoid confusion would be desirable.

HEC-RTS may include features, buttons, and commands that are not needed for the SJRA application. Since the interface for HEC-RTS is standardized, there are limited options to turn off features and controls that are not needed for a specific application.

Aviso is completely customizable and the interface can be as simple and functional as needed with complete control over menus that are displayed and the commands and functions associated with those menu options.

SJRA would like to be able to execute the DSS from “offsite” using virtual desktops and/or VPN connections. In addition to executing a forecast remotely, SJRA would like to be able to push results (hydrographs/tables) to mobile devices for others within the SJRA organization to view. Both of these applications (remote access and pushing results) can be accomplished with both HEC-RTS and Aviso.

Summary: Due to its ability to be customized, Aviso has the advantage over HEC-RTS.

4.1.3 Ability to use existing available data and models

SJRA would like to leverage not only available data sources, but also available models.

In regard to the data sources, both software platforms will utilize existing available hydrometeorological data or readily available hydrometeorological data. This includes data from the existing OneRain Contrail system at SJRA (point rainfall data, gauge adjusted radar rainfall data, stage gauges), USGS stage data (Lake Conroe Dam headwater elevation), USGS streamflow data (West Fork San Jacinto River near Huntsville, TX – Station ID 08067548), NWS QPE, and NWS QPF data. Since both software platforms will utilize HEC-HMS for the hydrologic modeling component, all relevant data must be in an HEC-DSS format. This will include automatically fetching the required data feeds in native formats, processing/formatting the data into an HEC-DSS format, and then saving in a local database at SJRA. Again, data fetching and processing will be required and be the same procedure independent of the selected software platform.

As previously stated, Half Associates recently developed an HEC-HMS model of the Upper West Fork San Jacinto River watershed for SJRA. Although this model is not currently being used for real-time operations at SJRA, the intent is to leverage this model as the hydrologic modeling (Lake Conroe inflow) component of the DSS. Both HEC-RTS and Aviso will be able to integrate and utilize this existing hydrologic model.

In regard to the reservoir operations (gate operations) for Lake Conroe Dam, there are a couple of options available. Currently, SJRA relies on a reservoir level spreadsheet model developed by FNI to derive minimum, target, and maximum gate openings based on the Gate Operations Policy. This tool currently does not consider projected lake inflows but is used to evaluate gate operations based on current measured reservoir levels. During the workshop with SJRA on March 29, 2019, it became apparent that SJRA staff is comfortable with this spreadsheet model look, feel, and functionality, and would like output from the DSS to have a similar appearance and functionality. The new spreadsheet is not intended to replace the current Gate Operations Policy spreadsheet model but be similar in appearance meanwhile forecasting inflows and potential target openings.

For more complicated reservoir operations, HEC has developed the HEC-ResSim software. HEC-ResSim utilizes gate operation rules to evaluate and “recommend” reservoir releases for a range of constraints and goals. HEC-ResSim is the default reservoir operations tool within HEC-RTS. Other programs, spreadsheets, etc. can be scripted into HEC-RTS using the Jython programming language to replace HEC-ResSim.

Programming is required for either platform to populate an inflow-based spreadsheet model in lieu of using HEC-ResSim.

Summary: Both platforms can use available rainfall data and the HEC-HMS model.

4.1.4 Customization options for future model improvements

Aviso software code is controlled by the consulting team and can be customized to utilize spreadsheets or other programs. The developer has customized the software for various users according to their need and ability.

The HEC-RTS interface is standardized and not customizable. Therefore, scripts must be developed to perform any tasks that are not already in the interface. HCFCD is currently developing and refining customized scripts for HEC-RTS to fetch QPE and gauge rainfall data. The scripts can be programmed to run automatically to obtain the data from the sources and format it into an HEC-DSS. The scripts appear as buttons in the tabs as shown in Figure 9. HCFCD is developing scripts to customize output data so that results can be quickly interpreted and disseminated to key staff. One of the challenges HCFCD has on developing the scripts is the lack of documentation from HEC. Therefore, HCFCD has invested much effort and is continuing to invest effort in developing customized scripts.

HDR has years of experience in customizing the Aviso tool for user. This experience will help keep the project on schedule should Aviso be selected by SJRA. Should HEC-RTS be selected by SJRA, the team would need to coordinate with HCFCD and the USACE to develop scripts. The coordination and HEC-RTS script development could increase the project schedule by approximately 6 months.

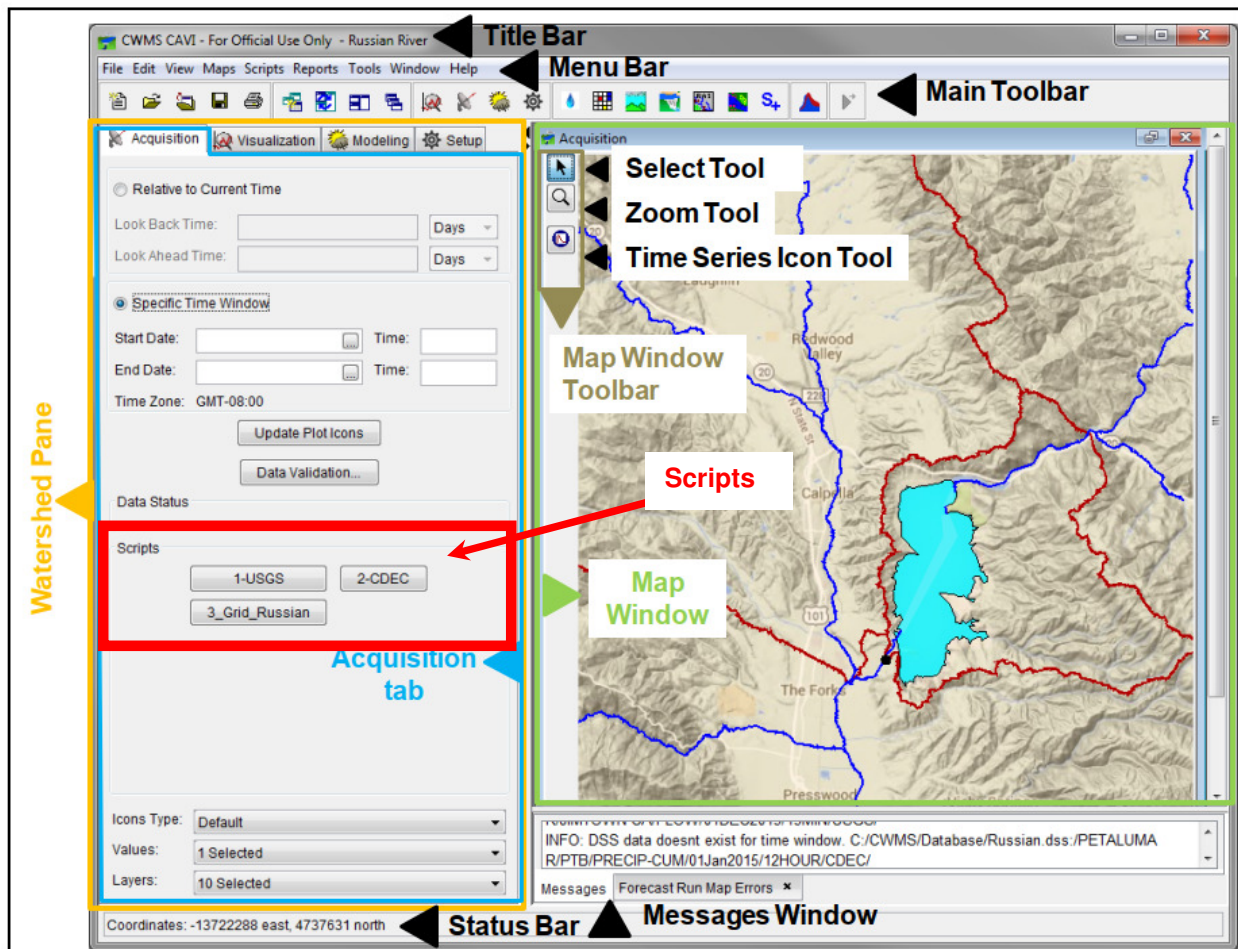


Figure 9. HEC-RTS Interface with Scripts

(Source: HEC-RTS User's Manual 3.0.3 Figure 7.1)

Summary: Aviso has the advantage over HEC-RTS in that the interface can be customized (simplified) to meet the user's needs for input and output. HEC-RTS will require the user to run the necessary scripts to obtain the data needed.

4.1.5 Scalability

The initial development and deployment of the DSS at SJRA will only be focused on Lake Conroe. Detailed hydraulic modeling is not included within the DSS and runoff modeling is only included for the watershed above Lake Conroe. At some time in the future, SJRA may elect to include additional areas or features into the DSS. Without knowing the additional areas or features that might be contemplated in the future, it is difficult to discuss the details of that integration into either software package. However, features such as river modeling and inundation mapping can be incorporated in the future as needed.

Summary: Features such as river modeling and inundation mapping can be added to both Aviso and HEC-RTS.

4.1.6 User support, training, and implementation

The consultant team will provide a technical memorandum, one-day hands-on training, and deployment of the selected DSS as part of a future work order after a DSS selection has been made. Upon deployment of the DSS at SJRA and training session, future troubleshooting and user support can be provided by the consultant under a separate contract. Again, the goal of the DSS is to make it as user friendly as possible to meet the needs of SJRA staff.

HEC-RTS is a U.S. Army Corps of Engineers software package, so access to the code and custom programming will be difficult if not impossible without going through the Hydrologic Engineering Center of the U.S. Army Corps of Engineers.

Since SJRA is a non-USACE user, support from HEC is very limited. The following excerpt is from the USACE website (<https://www.hec.usace.army.mil/software/hec-rtts/>): “Unfortunately, CEIWR-HEC is unable to provide phone or email technical support to non-USACE customers. However, CEIWR-HEC does encourage anyone who finds an issue with CEIWR-HEC software, to please report that issue through the [HEC-RTS Bug Report](#) page. Also, please review CEIWR-HEC’s [Support Policy](#) page for further details.”

“New features in the software are funded by two sources, (1) USACE Research & Development Directorate, (2) special projects for District offices or their local partners. If you are part of USACE, you can request a new feature through one of these channels. If you do not know who to contact in your chain-of-command to begin the process, please contact CEIWR-HEC and we will reply with an appropriate Point-of-Contact for your office.”

SJRA expressed a concern as well about a proprietary software package such as Aviso FS and continued support. This is a valid concern, but again the goal is to deliver a simple and customizable DSS tool for SJRA. Aviso was originally developed by David Ford Consulting Engineers and custom deployments have been made for multiple non-USACE entities. David Ford Consulting Engineers was acquired by HDR, Inc. in 2018, but Aviso continues to be supported and utilized following that acquisition.

Summary: Aviso has the advantage over HEC-RTS in that user support is available from the developer.

4.1.7 Licenses and maintenance costs

HEC-RTS is a publicly available software package developed with taxpayer dollars. There is no license fee associated with the HEC-RTS software package and no recurring maintenance fees. Similarly, Aviso is a customized decision support software system with no license fee or recurring maintenance fees. An on-call support contract can be obtained with the Aviso software developer. Ongoing user support can be provided by a consultant with either software platform.

Summary: Both Aviso and HEC-RTS do not have license fees or recurring maintenance fees.

4.1.8 Software updates

HEC-RTS is updated periodically by HEC. New features are funded by two sources within the USACE, so software updates are dependent on funding availability within USACE. At the time of development of this memo in April 2019, the latest version of HEC-RTS is Version 3.0.3.

Both HEC-RTS and Aviso will utilize HEC-HMS for the hydrologic modeling component. HEC-HMS is another HEC software product that is widely used around the USA. HEC-HMS is updated more frequently than HEC-RTS. At the time of development of this memo in April 2019, the latest version of HEC-HMS is Version 4.3. The Upper West Fork San Jacinto River HEC-HMS model is in HEC-HMS version 4.2 and is supported by both Aviso and HEC-RTS.

Often these software packages will be updated to add a few new features, correct a known bug issue, etc. However, not all of these additional features or bug repairs will impact the functionality of the software for the SJRA application. Therefore, it will most likely not be necessary to upgrade the software for the SJRA DSS each time a new version is released by HEC. Updating models to new versions of software can be a costly investment as recalibration efforts and model parameter adjustments may be required. When HCFCD remapped the floodplains in Harris County after Tropical Storm Allison, they required that any changes to the models be performed in the original software versions so that consistency in results could be maintained. HCFCD is now remapping the floodplains in Harris County after Hurricane Harvey and will be using the latest versions of the HEC products. It is expected that the new models will require that future users operate the models in the version in which they will now be developed as part of the current remapping effort.

The current versions of either Aviso or HEC-RTS will be used for this project. HEC-HMS v. 4.2 will be used for the project. HCFCD has observed that the current version of HEC-RTS does not function well with HEC-HMS v. 4.3 and is therefore using HEC-HMS v. 4.2.

Summary: Software updates for both Aviso and HEC-RTS are generally not required.

4.2 Comparison Summary

A comparison of the two DSS platforms shows that Aviso has an advantage over HEC-RTS in ease of use and customization. A comparison table is shown on Table 1.

5 RESERVOIR MODELING

Reservoir modeling of levels and releases can be accomplished with HEC-ResSim or an inflow-based spreadsheet model. As previously mentioned, HEC-ResSim is a reservoir modeling software developed by the USACE that is used to model reservoir operations at one or more reservoirs for a variety of operational goals and constraints.

According to HEC, *“The software simulates reservoir operations for flood management, low flow augmentation and water supply for planning studies, detailed reservoir regulation plan investigations, and real-time decision support. HEC-ResSim can represent both large and small scale reservoirs and reservoir systems through a network of elements (junctions, routing reaches, diversion, reservoirs) that the user builds. The software can simulate single events or a full period-of-record using available time-steps. HEC-ResSim is a decision support tool that meets the needs of modelers performing reservoir project studies as well as meeting the needs of reservoir regulators during real-time events.”*

Using HEC-ResSim is certainly an option for the SJRA to use to model Lake Conroe. HEC-ResSim can provide simulation comparisons for min, max and target gate operations. The user can also input gate settings for the next forecast to estimate reservoir levels depending on releases. This is important to the user so that appropriate planning steps can be taken. The HEC-ResSim model will need to be simulated at least three times during a forecast simulation in order to determine the simulation comparisons. The

simulation run times will likely be unnoticeable to the user. The disadvantage to using HEC-ResSim is that it introduces one more modeling component to monitor during a rainfall event. The user will need to be familiar with using HEC-ResSim and be capable of running it outside of the DSS platform.

Table 1. DSS Platform Comparison

Criteria	Aviso	HEC-RTS
Regular Forecasts	Yes	Yes
Ease of Use	Customizable interface	Complex interface, Data input, Data Output
Offsite Use	Yes	Yes
Use Available Models	Yes	Yes
Customizable	Customizable interface and output	Customizable output
Scalability	Reservoir modeling, river modeling, mapping	Reservoir modeling, river modeling, mapping
Support	Developer supported / On call	No official support
License Costs	No license fee	No license fee
Maintenance Costs	No recurring fees	No recurring fees
Software Updates	As needed	As needed
Development Cost	Current budget*	10% to 20% increase in project budget* **

* Assumes only one reservoir model type: HEC-ResSim or the spreadsheet model.

**Cost increase for HEC-RTS is to account for the development of scripts.

As previously mentioned, an alternative to using HEC-ResSim is to use an inflow-based spreadsheet model as shown in Figure 10. The DSS feeds the reservoir inflows calculated from the HEC-HMS into the inflow-based spreadsheet model to calculate reservoir levels and target gate openings. The advantage to using an inflow-based spreadsheet model is that it provides the user a dataset that is similar to the current reservoir level spreadsheet model. The spreadsheet can be modified so that the user can input desired gate openings. The disadvantage to using an inflow-based spreadsheet model is that additional programming effort that may be required to configure the DSS to populate the model. Additional programming effort is expected if HEC-RTS is selected depending on the customization that the user requires.



INPUT		Max Inflow	32,373	cfs														
OUTPUT		Max Outflow	11,028	cfs													Lag (min)	0.00
		Max Lake Level	203.64	ft-msl		Hold lake level by	0	foot										
		Total release	75,042	Acre-ft													12/7/18 1:00	12/8/18 0:00
READING		RECOMMENDED OPENING			ACTUAL OPENING													
Date & Time	Current Lake Level (ft-msl)	Total Inflow (cfs)	Asc. / Desc (A/D) Inflow	MIN	TARGET	MAX	Individual New Gate Openings (gate-ft)					New Total Gate Opening (gate-ft)	Total Discharge (cfs)	Date & Time of Execution				
				Gate Opening (gate-ft)	Gate Opening (gate-ft)	Gate Opening (gate-ft)	G1	G2	G3	G4	G5							
1	2	3	4	5	6	7	8					9	10	11				
7-Dec-18	0:00	201.0500	0											0.00	0	7-Dec-18	0:00	
7-Dec-18	1:00	201.0500	0	D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	7-Dec-18	1:00	
7-Dec-18	2:00	201.0500	0	D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	7-Dec-18	2:00	
7-Dec-18	3:00	201.0500	0	D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	7-Dec-18	3:00	
7-Dec-18	4:00	201.0500	0	D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	7-Dec-18	4:00	
7-Dec-18	5:00	201.0500	0	D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	7-Dec-18	5:00	
7-Dec-18	6:00	201.0500	4	A	0.50	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	7-Dec-18	6:00	
7-Dec-18	7:00	201.0501	24	A	0.50	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	7-Dec-18	7:00	
7-Dec-18	8:00	201.0503	64	A	0.50	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	7-Dec-18	8:00	
7-Dec-18	9:00	201.0508	204	A	0.50	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	7-Dec-18	9:00	
7-Dec-18	10:00	201.0530	814	A	0.50	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	7-Dec-18	10:00	
7-Dec-18	11:00	201.0595	2,175	A	0.50	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	7-Dec-18	11:00	

Figure 10. Reservoir Inflow Spreadsheet Model

(Source: Freese and Nichols, Inc.)

Setting up the DSS to use both HEC-ResSim and an inflow-based spreadsheet model is redundant. HEC-ResSim is a powerful reservoir modeling software that is generally used for modeling multiple reservoirs and provides another layer of vulnerability during forecast simulations. Halff recommends that the SJRA consider using the reservoir inflow spreadsheet model. Once SJRA has gained familiarity with the DSS platform, SJRA could explore the development and implementation of the HEC-ResSim model.

6 DSS IMPLEMENTATION

The DSS platform evaluation showed that the major differences between Aviso and HEC-RTS are ease of use and customization. The potential approach of implementation is shown in Table 2. The largest differences between the two potential implementation efforts are customization versus development.

Table 2. DSS Implementation Approach

Aviso	HEC-RTS
Configure process to fetch data	Develop process to fetch data
Configure existing HMS model parameters	Configure existing HMS model parameters
Customize user interface	Develop customized scripts
Setup simulations	Setup simulations
Customize Push (output)	Develop process to Push (output)
Refinement and Testing	Refinement and Testing
Implementation and Training	Implementation and Training

Halff estimates that the effort to develop the HEC-RTS model will increase the budget cost. Developing both the spreadsheet and the HEC-ResSim models together will also impact the project costs. The estimated budget remaining for this project is \$259,854.64. Table 3 summarizes the potential development costs depending on the platform and the reservoir model combination selected. The customization of Aviso and the spreadsheet model could be completed within the current budget. Selecting HEC-RTS as the DSS platform and selecting both the spreadsheet model and HEC-ResSim as the reservoir models could increase the project costs up to 35% from the current budget due to script development and programming.

Table 3. Estimated Project Development Costs

DSS and Reservoir Model	Estimated Development Cost*
Aviso + Spreadsheet Model	\$250,000 to \$260,000
Aviso + HEC-ResSim	\$255,000 to \$260,000
Aviso + Spreadsheet Model + HEC-ResSim	\$286,000 to \$299,000
HEC-RTS + Spreadsheet Model	\$286,000 to \$312,000
HEC-RTS + HEC-ResSim	\$286,000 to \$312,000
HEC-RTS + Spreadsheet Model + HEC-ResSim	\$312,000 to \$351,000

* Detailed level of effort will be developed upon the selection of the platform and reservoir model. Effort costs include project management, HEC-HMS adjustments, reservoir model development and testing, DSS refinement, documentation, implementation and training.

7 CONCLUSION/RECOMMENDATION

Half has performed a software evaluation of two DSS platforms that can be used by SJRA to forecast reservoir inflows and releases. The DSS platforms evaluated are Aviso and HEC-RTS. Aviso is a DSS platform that was developed by Ford Consulting, Inc. (now HDR, Inc.) and is being used by various agencies to aid in reservoir inflow forecasting and release selection. HEC-RTS is a DSS platform that was developed by USACE for non-USACE offices and is also being used to aid in reservoir inflow forecasting and release selection. After the kickoff meeting in March, several key requirements for the DSS were identified. Below is a summary of how the DSS platforms stand in contrast to the key requirements.

- Forecast – Both DSS platforms are capable of providing forecasts on 30-minute intervals.
- User Friendly – Aviso has an advantage over HEC-RTS because it is customizable to the user’s needs.
- Use available data/models – Both DSS platforms are capable of using rainfall data as well as the existing HEC-HMS model.
- Offsite Use – Both DSS platforms are capable of being operated remotely.
- Output – Aviso has an advantage over HEC-RTS in customizing output.

Both DSS platforms will provide SJRA with the ability to forecast reservoir inflows and potential releases. In general, the advantage of Aviso over HEC-RTS is customization which improves ease of use and formatting of output. Configuring HEC-RTS to meet the needs of SJRA can increase the project budget by 10% to 35%. Since SJRA prefers a user-friendly platform that is easy for the user to operate, **Half recommends that SJRA consider implementing a customized version of Aviso as the DSS platform to perform forecasts of reservoir levels and releases.** Since SJRA staff finds the current reservoir level spreadsheet model acceptable, **Half recommends that SJRA move forward with using the inflow-based spreadsheet model to calculate potential reservoir levels and gate operations.**



Half Associates, Inc.
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Conroe, Texas 77301
(936) 756-6832
Fax (936) 756-6833

Please let me know if you have any questions or need additional information.

HALFF ASSOCIATES, INC.
TBPE #312

A handwritten signature in blue ink, appearing to read "SH" with a long horizontal stroke extending to the right.

Sam Hinojosa, PE, CFM
Director of Water Resources, Conroe



Cc. Andrew Ickert, PE
David Ford, PE
Mike Reedy, PE



San Jacinto River Authority

ADMINISTRATIVE OFFICE
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May 29, 2019

Sam Hinojosa, PE, CFM
Director of Water Resources, Conroe
Halff Associates, Inc.
100 I-45 North, Suite 260
Conroe, TX 77301-2701

**Re: Software Decision
Flood Forecasting and Reservoir Operations Tool
LCPR0039.1001.2c001**

Dear Sam:

After review of your revised Technical Memorandum submitted May 24, 2019, as well as additional evaluation of the two software options presented for consideration in the project, it is the decision of SJRA Lake Conroe Division operations staff to proceed with HEC-RTS as the DSS platform, and the spreadsheet model as the reservoir model. Regarding specific functionality for the DSS, it is SJRA's desire that the tool output a single Excel file with the following general functions and content:

- 1) TAB1 – Automatically (i.e. no cut and paste) populate ACTUAL lake levels throughout an event in SJRA's existing operations spreadsheet, with all other functionality (manual input of time stamps, etc.) remaining the same.
- 2) TAB 2 – Create a chart, similar to existing spreadsheet, graphically displaying results of TAB 1.
- 3) TAB 3 – Automatically import (no manual input required except starting the process) results of HEC-HMS forecast modeling (combination of actual and forecast rainfall) and populate spreadsheet providing this data, including but not limited to lake levels, inflows, gate settings, and releases for min, target, and max scenarios (similar layout to existing spreadsheet).
- 4) TAB 4 – Create charts graphically displaying results of TAB 3 (envision 3 charts, 1 for each min, target, and max scenarios).

SJRA recognizes that as development of the tool advances, further coordination and refinement of the output will likely be required, but wanted to provide the above for your use in development of the scope of work for Work Order No. 2.

Sincerely,

Bret Raley
Lake Conroe Division Manager
San Jacinto River Authority

Cc: Chuck Gilman, PE
Matt Barrett, PE
File No. E2.2.1

Reservoir Forecasting Tool

Appendix B – Models

(DIGITAL SUBMITTAL)

Reservoir Forecasting Tool

Appendix C – Manual

Reservoir Forecasting Tool Manual

Prepared for:
San Jacinto River Authority

MAY 2021

HALFF ASSOCIATES, INC.

TBPE Firm Registration No. 312

Reservoir Forecasting Tool Manual

Prepared for

SAN JACINTO RIVER AUTHORITY

by

HALFF ASSOCIATES, INC.
TBPE Firm Registration No. 312

FREESE & NICHOLS, INC.
TBPE Firm Registration No. 2144



**Introduction, Create New Watershed,
Open Existing Watershed, Setup Module,
Modeling Module**



Jeremy Dixon
05/27/2021
FREESE AND NICHOLS, INC.
**TEXAS REGISTERED
ENGINEERING FIRM
F-2144**

Appendix A.1

**AVO 34589
MAY 2021**

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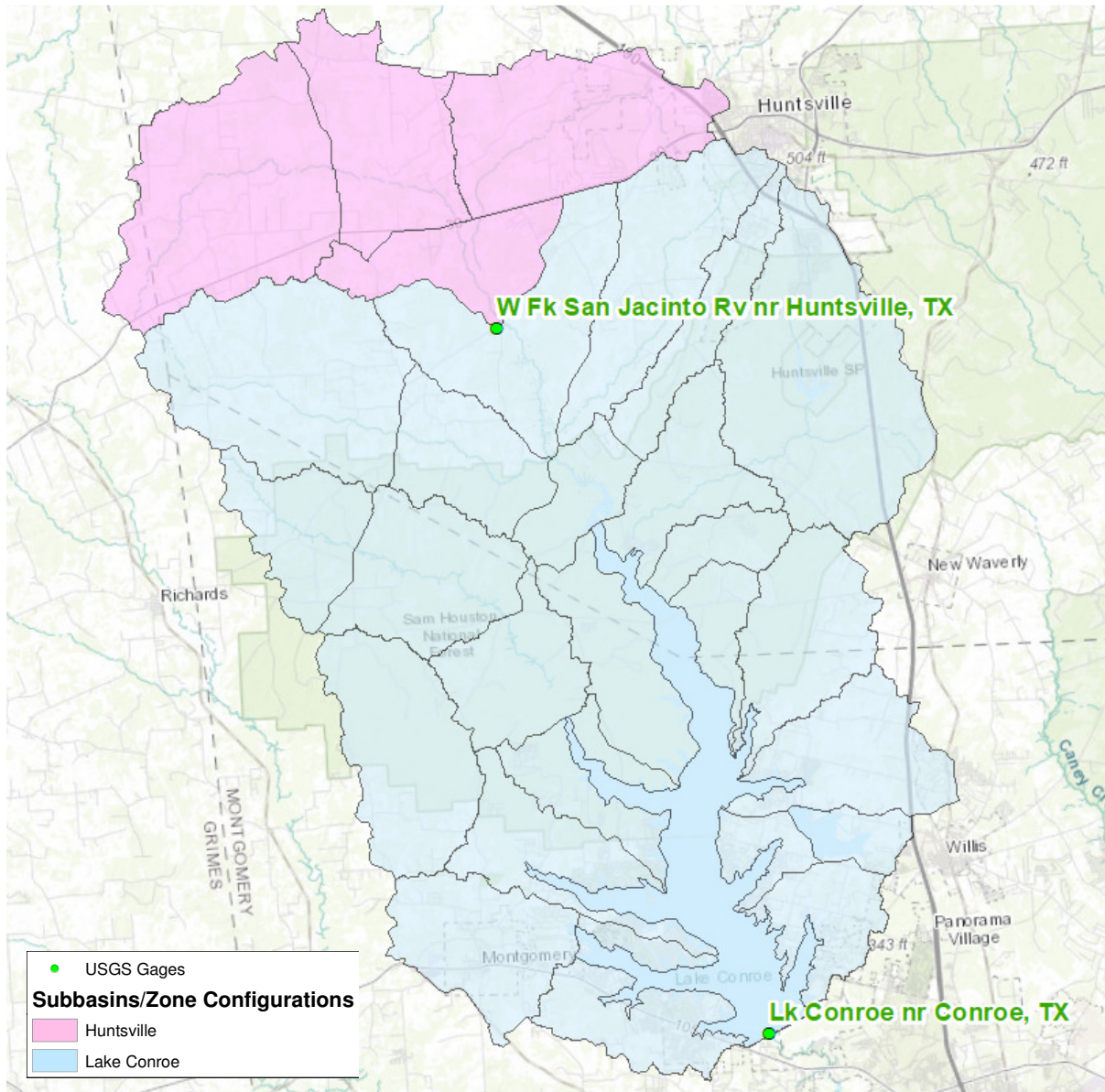
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Appendix A.1 – Reservoir Modeling Tool Process

(This document was prepared under the direction of Jeremy Dixon TX PE 12161, Freese and Nichols, Inc. for review purposes only)

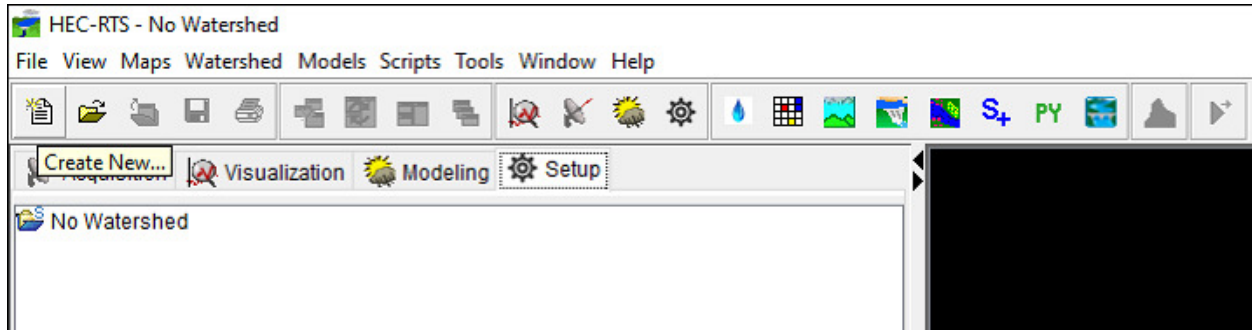
Introduction

This document describes the setup and execution of a forecast event in HEC-RTS for Lake Conroe. Forecasts are setup using the Meteorologic Forecast Processor (MFP) and HEC-HMS models. This document does not discuss the installation process for HEC-RTS. Please refer to Appendix A in the *Running HEC-RTS for Mill Creek* document provided by the USACE for installation setup.



Create New Watershed

Open the HEC-RTS program and click the “Create New Watershed” icon located on the upper left hand corner of the RTS window



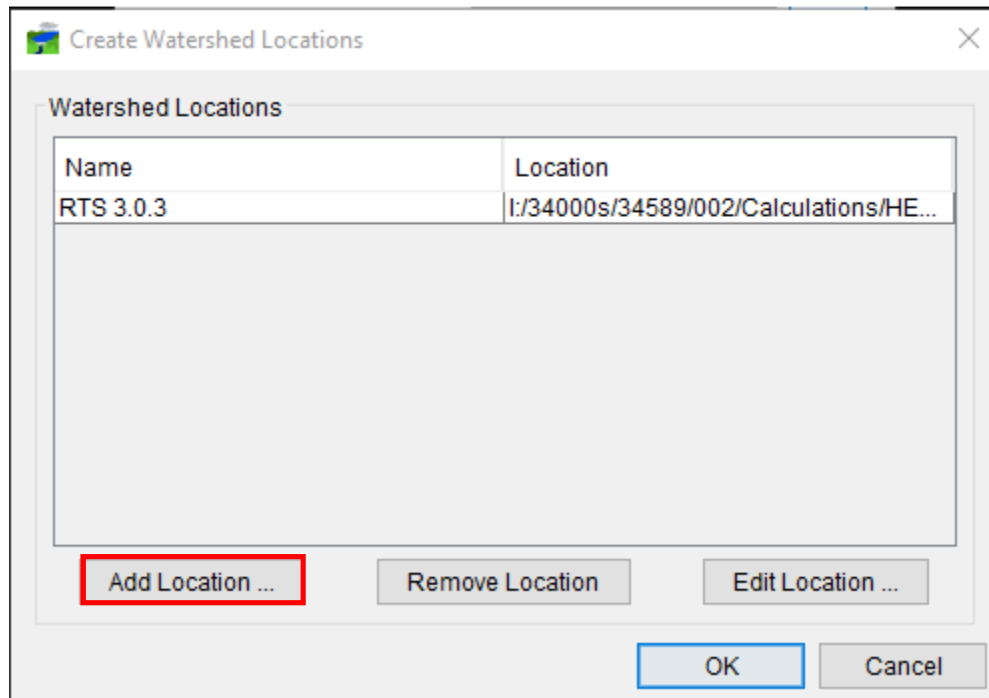
A window will show up with the inputs needed to describe the watershed including the name, unit system, coordinate system, time zone and file location of the watershed.

 A screenshot of the "Create New Watershed" dialog box. The dialog has a title bar with a close button (X). It contains several input fields and buttons:

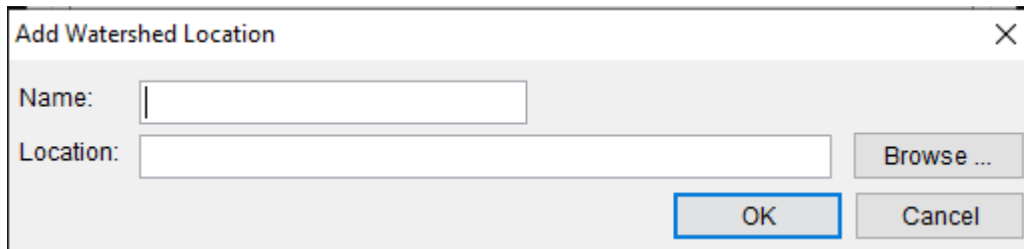
- Watershed Name:** A text input field.
- Description:** A text input field with a browse button (...).
- Watershed Location:** A dropdown menu showing "RTS 3.0.3" and a browse button (...).
- Unit System:** A dropdown menu showing "English".
- Map Layers:** An "Add Map Layers..." button.
- Coordinate System:** A text input field and an "Edit..." button.
- Import CWMS 2.1 Watershed:** A text input field and a "Browse..." button.
- Settings:** A section with two radio buttons: "U.S. Time Zones" (selected) and "International Time Zones". Below them is a dropdown menu.
- World Map:** A world map showing continents in green and oceans in blue.
- Time Zone DOES NOT Use Daylight Savings:** A text label below the map.
- Buttons:** "OK" and "Cancel" buttons at the bottom.

Step 1: Set Watershed Location

To set the file location of where the watershed will be saved, click the “...” icon near the watershed location row and the “Create Watershed Locations” window will open.



To add a location, click the “Add Location” icon and set a name to be used for the location. Pick a specified folder within the Windows Explorer window by click the “Browse...” button and click “OK” once completed.



Assign the watershed location within the “Create New Watershed” window

Watershed Name: Lake Conroe

Description: ...

Watershed Location: RTS 3.0.3 ...

Unit System: English

Map Layers: Add Map Layers...

Coordinate System: Edit...

Import CWMS 2.1 Watershed: Browse...

Settings

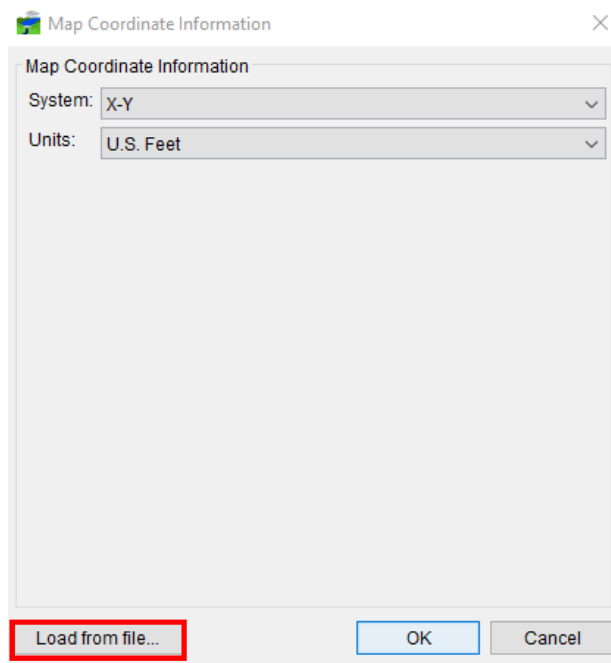
U.S. Time Zones International Time Zones

Time Zone DOES NOT Use Daylight Savings

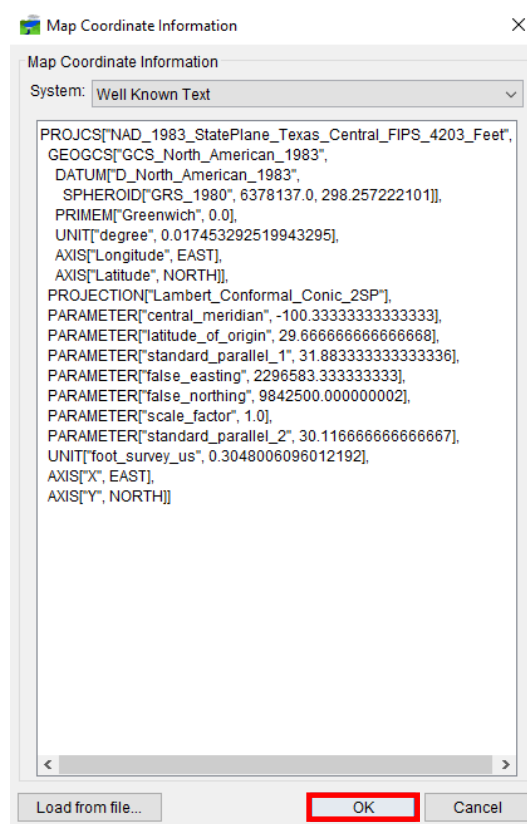
OK Cancel

Step 2: Set Coordinate System

To set the coordinate system, click the “Edit” icon located next to the coordinate system row in the “Create New Watershed” window. The “Map Coordinate Information” window opens and requires a coordinate system and units.

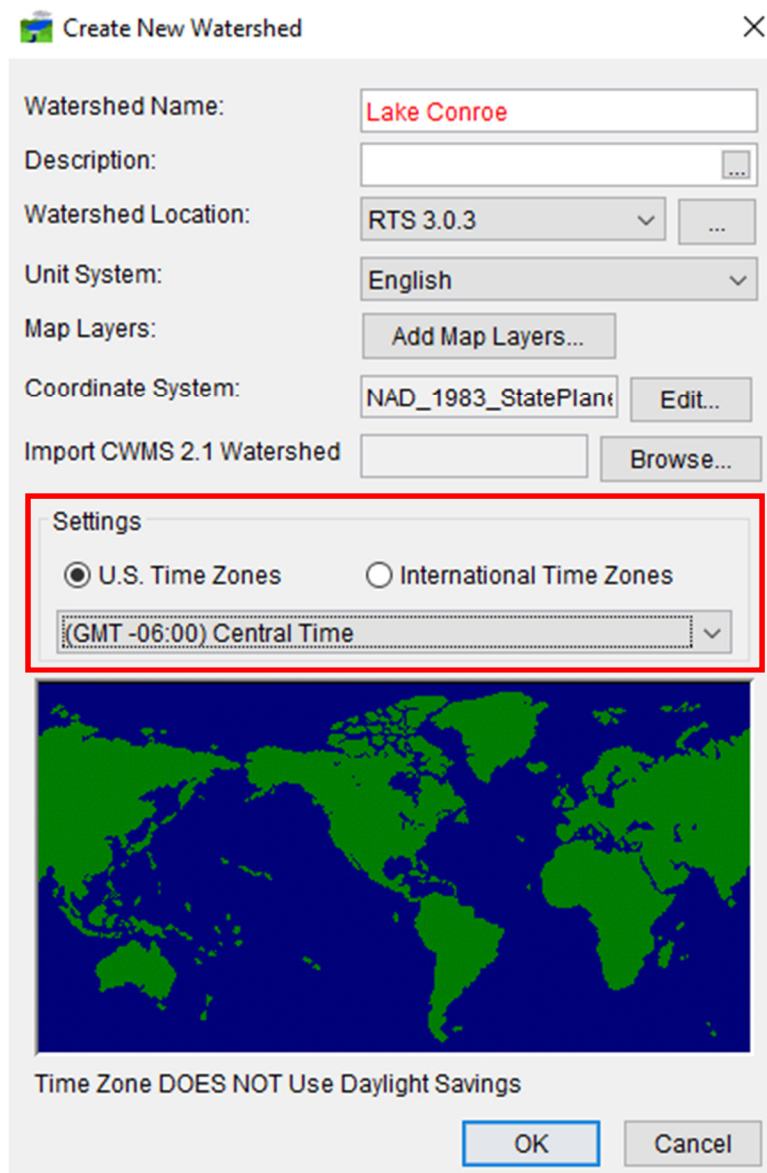


For Lake Conroe, the State Plane coordinate system was chosen to reference the watershed with units of US feet. Lake Conroe is located within the Texas Central Zone (4203) using the State Plane coordinates. Select the relevant projection file (.prj) referencing the Texas Central Zone State Plane coordinate system by clicking the “Load from file” icon within the “Map Coordinate Information” window. Once the coordinate system is selected, click the “OK” button.



Step 3: Set Time Zone

Selection of the time zone is located within the settings portion of the “Create New Watershed” window with the options to assign a US or International time zone. Click the “U.S. Time Zones” option and from the drop down box select “(GMT-06:00) Central Time”. This time zone is selected since the observed gage data is based on this time zone.

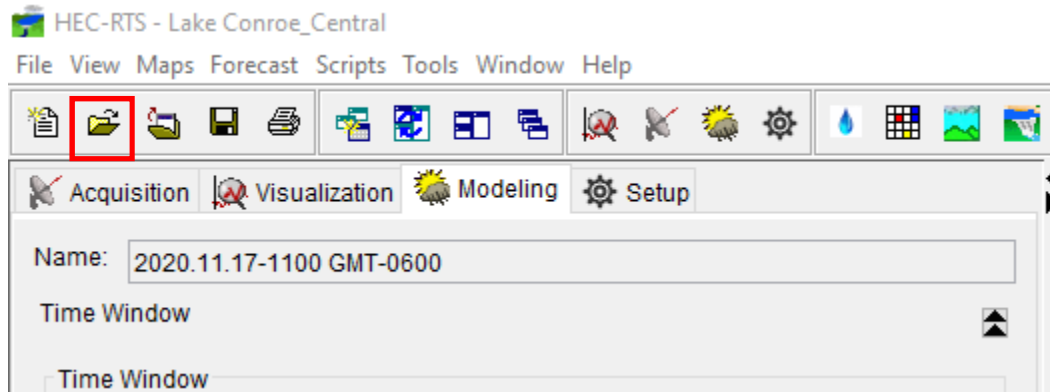


The screenshot shows the "Create New Watershed" dialog box. The "Settings" section is highlighted with a red box. It contains two radio buttons: "U.S. Time Zones" (selected) and "International Time Zones". Below the radio buttons is a dropdown menu showing "(GMT-06:00) Central Time". Below the settings is a world map. At the bottom of the dialog box, there is a checkbox labeled "Time Zone DOES NOT Use Daylight Savings" and two buttons: "OK" and "Cancel".

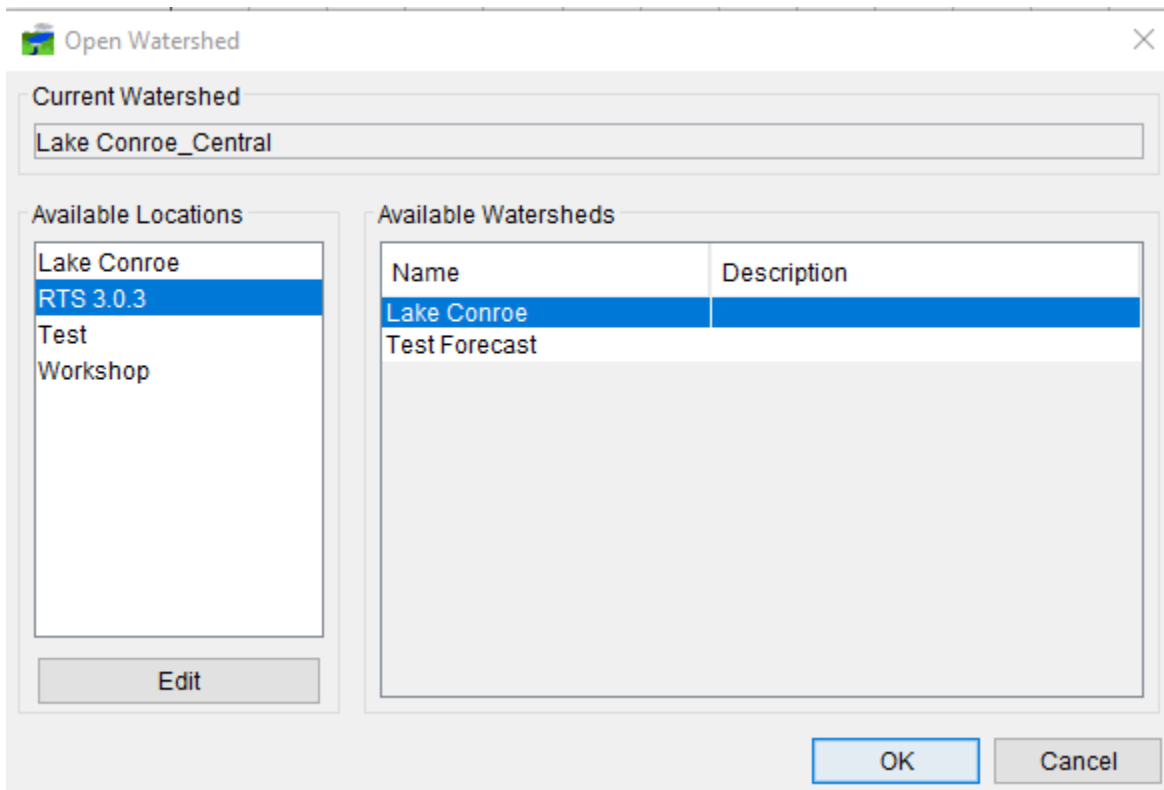
After the options are chosen within the “Create New Watershed” window, click ‘OK’ to create the new watershed

Open Existing Watershed

To open an existing watershed, open the HEC-RTS program and click the “Open a Watershed” icon on the main menu

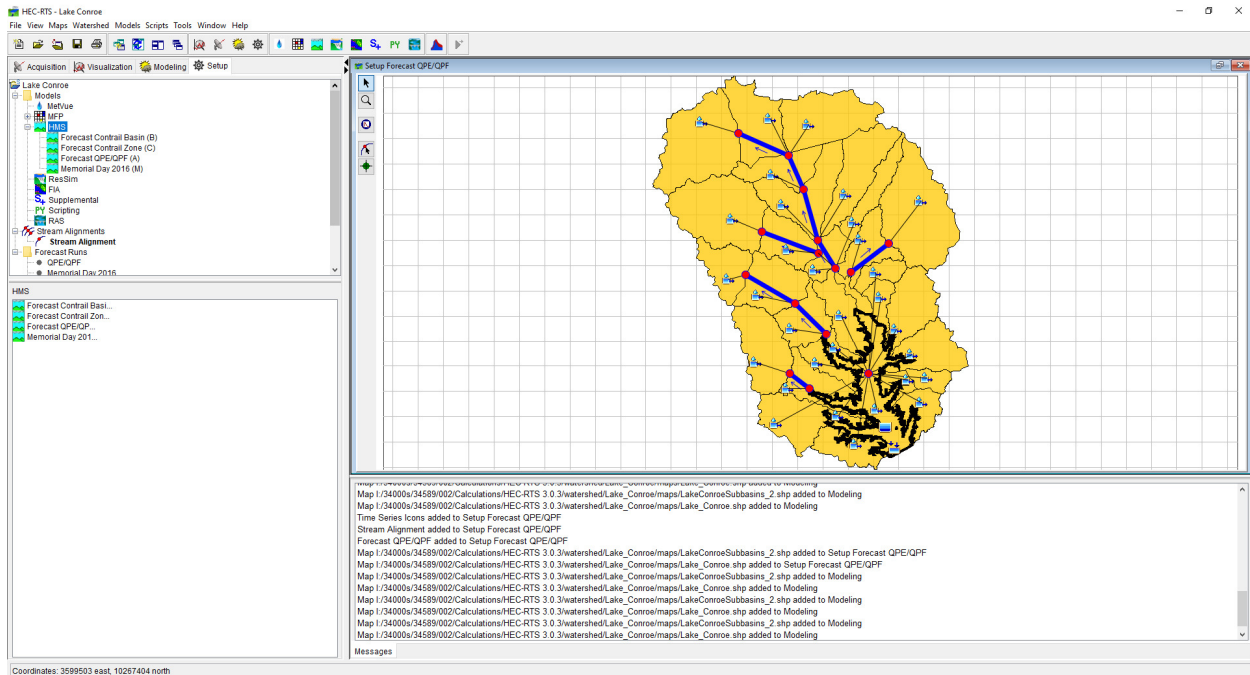


A menu will pop up showing the available locations and watersheds associated with those locations. Select the relevant location and choose the available watershed within the location and click “OK”.



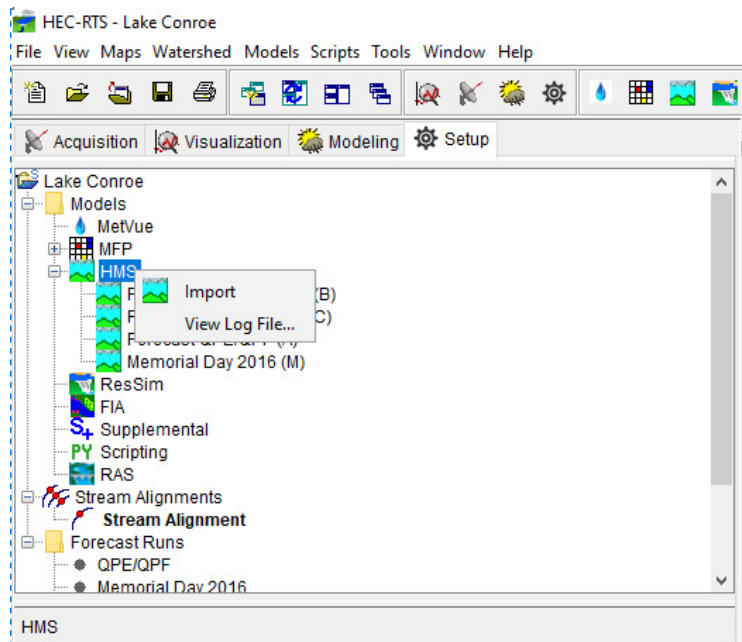
Setup Module

The setup module is where the watershed inputs, models and outputs are configured to describe the watershed. A visual representation of the watershed is displayed within the graphic user interface that is map-based. Once the steps have been completed in the setup module, the interface should look like this below:

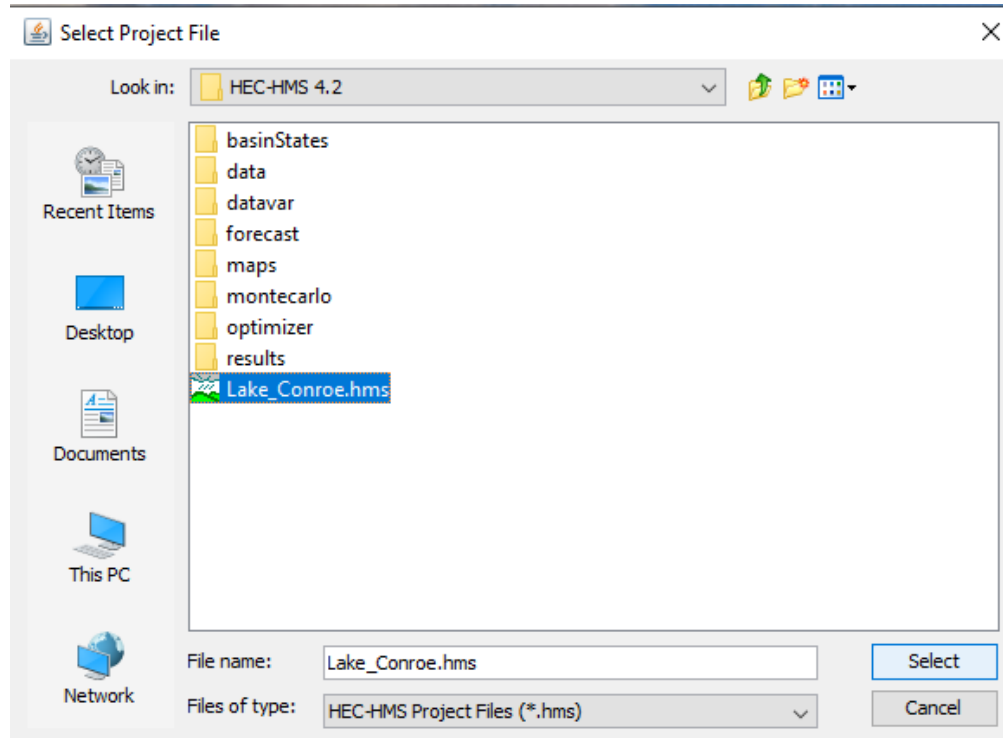


Step 1: Import HEC-HMS model

To import the HEC-HMS model, right click the “HMS” title located in the Setup module window and click “Import”. If a HEC-HMS model is already imported, skip this step.

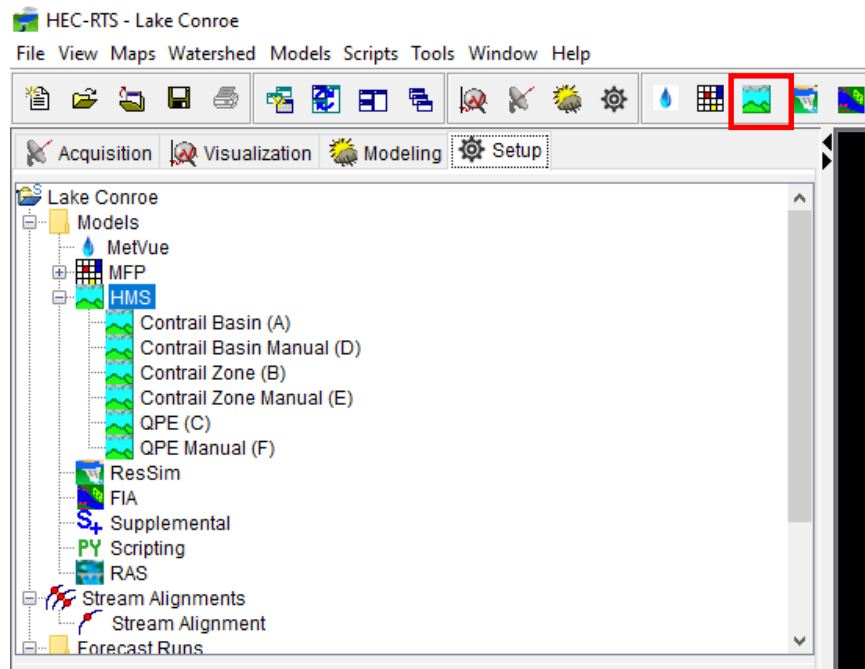


An explorer window will pop-up and prompt the user to select the relevant .hms file. Select the .hms needed for the RTS model and click the “Select” button.

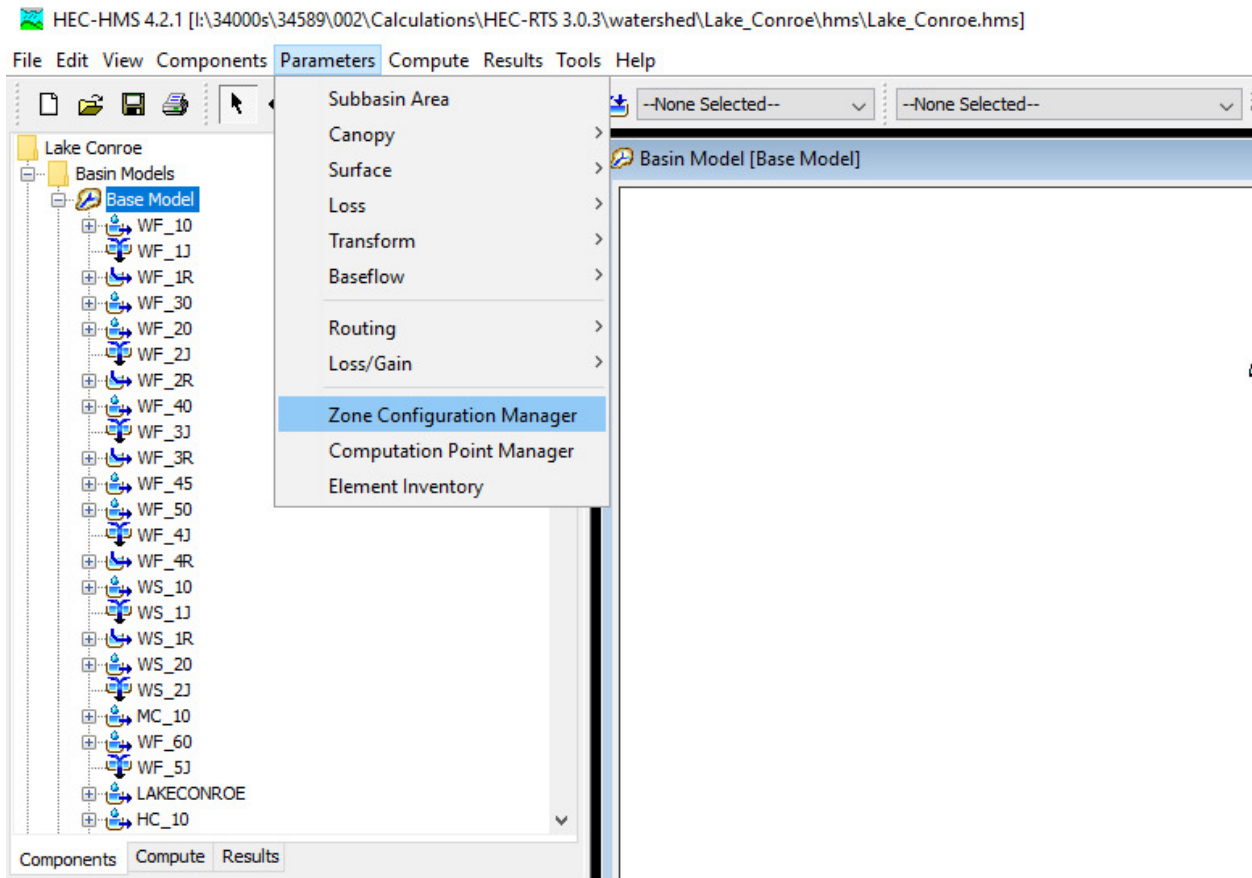


Step 2: Create Zone Configurations in HEC-HMS

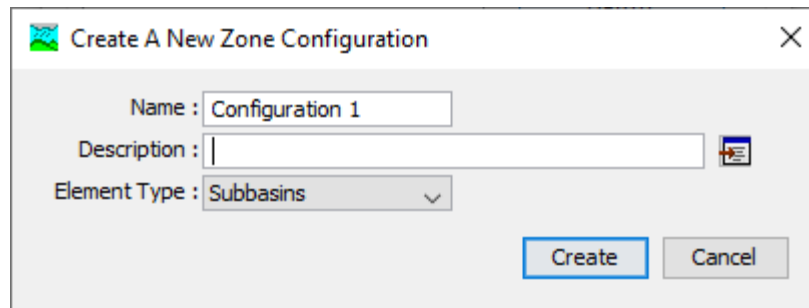
Once the HEC-HMS model is imported into HEC-RTS, click the “Hydrologic” icon located on the menu bar within the Setup module to open the HEC-HMS model.



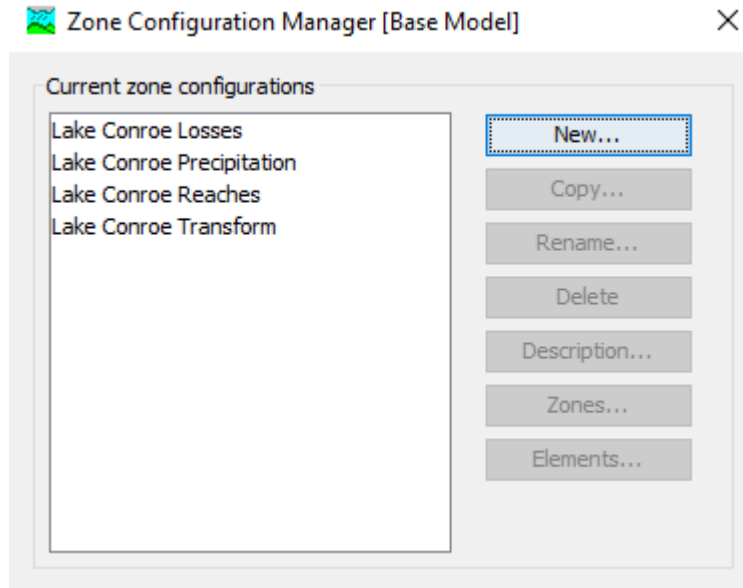
Within the HEC-HMS model, select a basin model and click on the “Parameters” tab located along the menu bar and select the “Zone Configuration Manager”



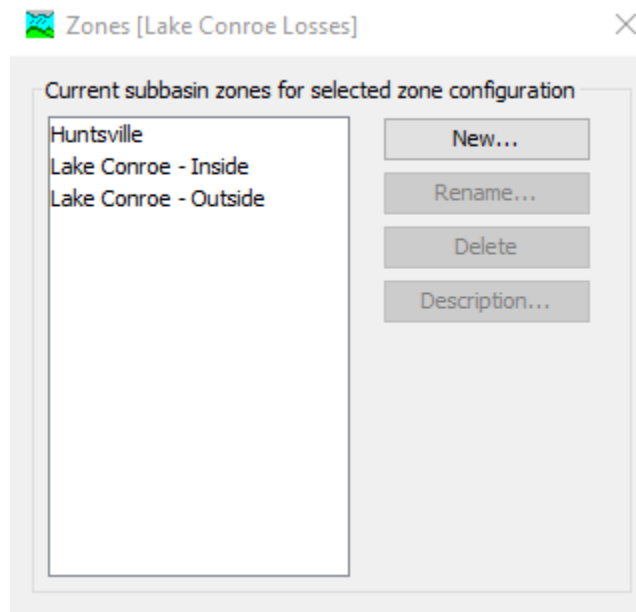
A window will open up where the set zone configurations are stored. To create a new zone configuration, click the “New...” icon. A window will appear prompting the user to name the zone configuration and which element type to assign it to.



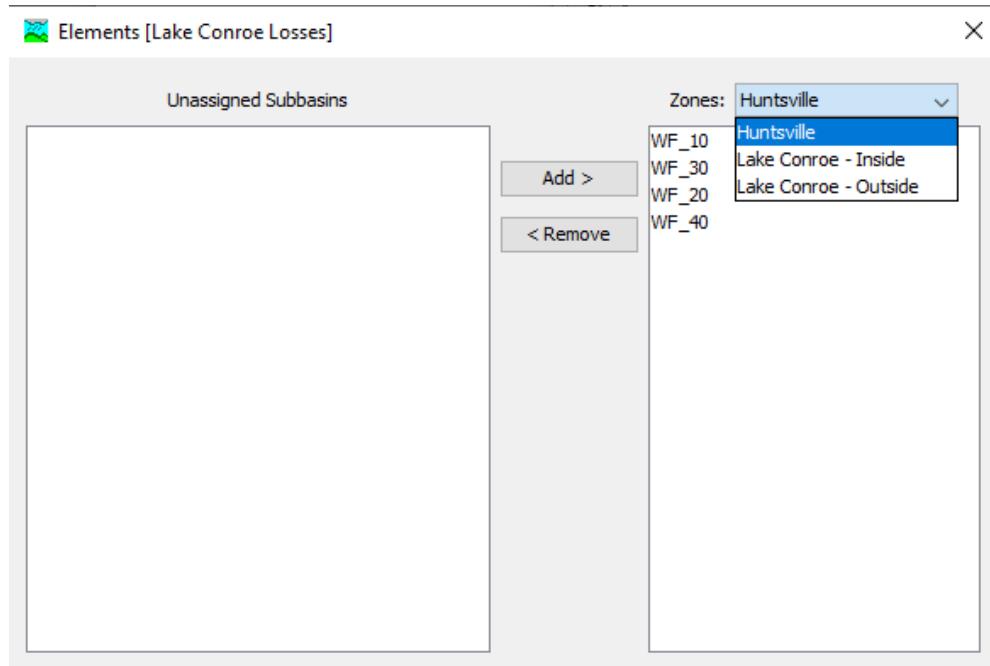
Configuration zones need to be created for the precipitation, losses, transform and routing reaches parameters. An example of these zones is shown below:



After the zone configurations are established, zones need to be created to assign the relevant subbasins and routing reaches by calibration zone. For Lake Conroe, the calibrations zones are setup based on the USGS Huntsville and Lake Conroe gages. To create these zones, click on one of the zone configurations and click the “Zones...” icon within the Zone Configuration Manager.



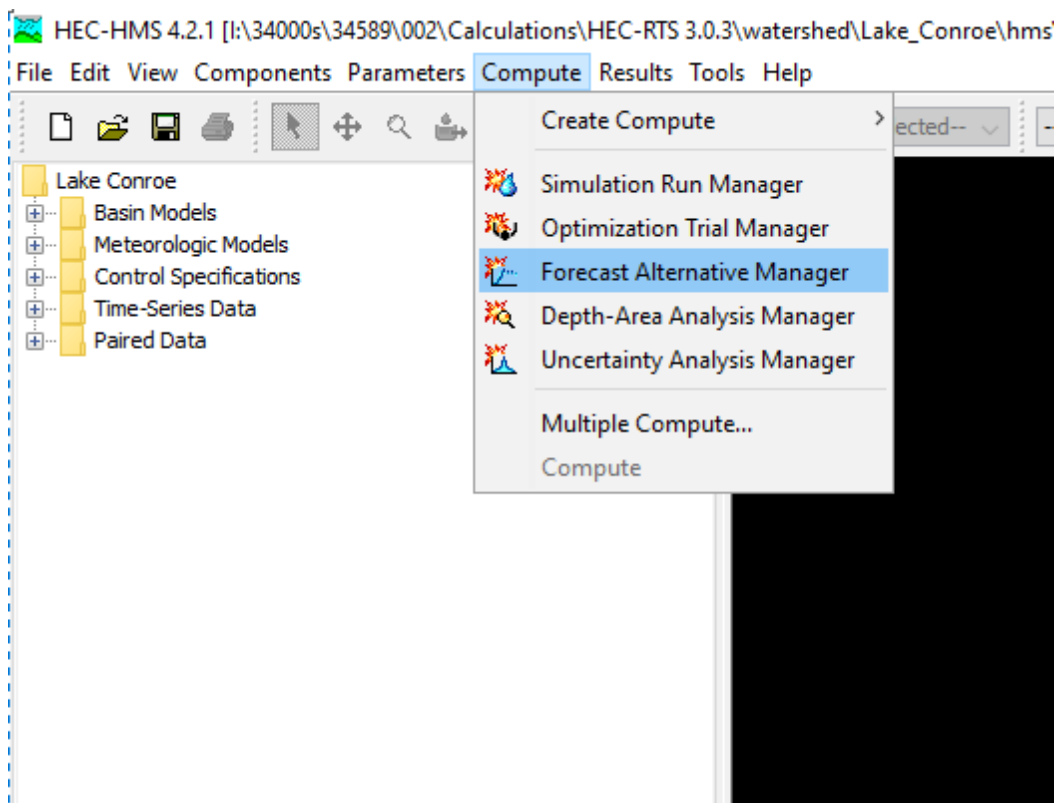
Click the “New...” icon and create a zone based on the calibration zones identified earlier. Repeat this process for the remaining zone configurations. To assign the relevant subbasins and reaches, click the “Elements...” icon within the Zone Configuration Manager. Once the window opens, choose the zone created earlier from the drop down menu located on the upper right hand side.



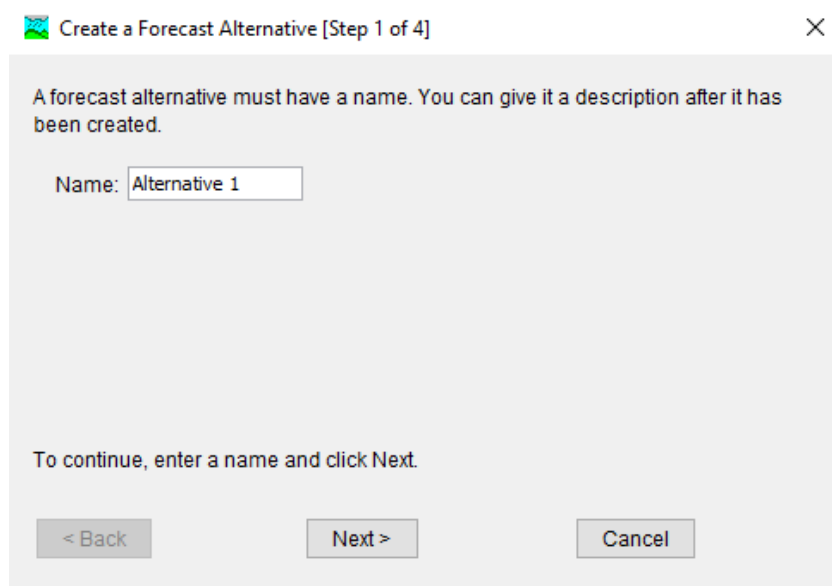
Select the relevant subbasins and routing reaches for each zone and repeat the process for the remaining zone configurations.

Step 3: Create Forecast Alternatives in HEC-HMS

Within the HEC-HMS model, select the “Compute” tab at the top of menu and select “Forecast Alternative Manager”



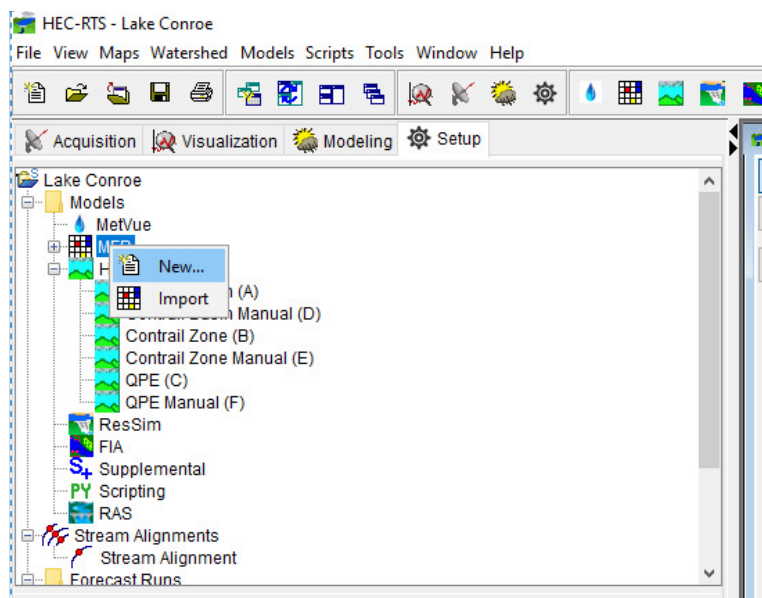
The “Forecast Alternative Manager” window will open and show a list of forecast alternatives created. Before creating a forecast, ensure that the rainfall datasets that are needed to be referenced are established using the “Meteorologic Models” within HEC-HMS. Please refer to the HEC-HMS user’s manual for more guidance on the setup of the meteorologic models. To create a new forecast alternative, select “New” within the “Forecast Alternative Manager” window.



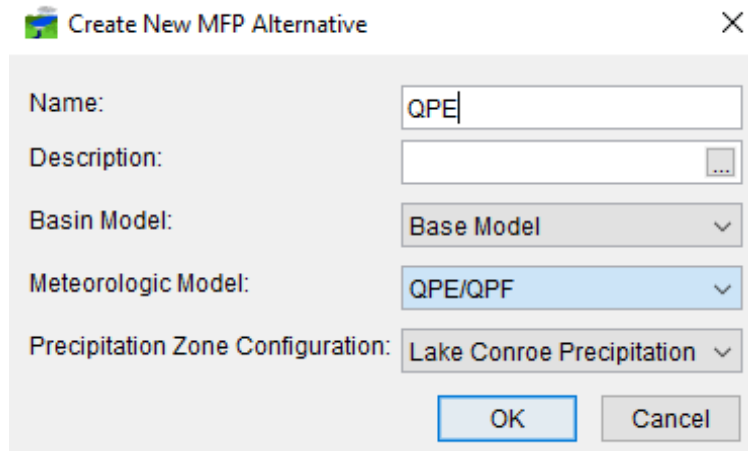
Type in the name and select the relevant basin model, meteorologic model, time interval and zone configurations for the loss, transform and routing configurations. Click “Finish” and the forecast alternative is created within the Forecast Alternative Manager. Save the model and exit out of the HEC-HMS program

Step 4: Create MFP Alternatives

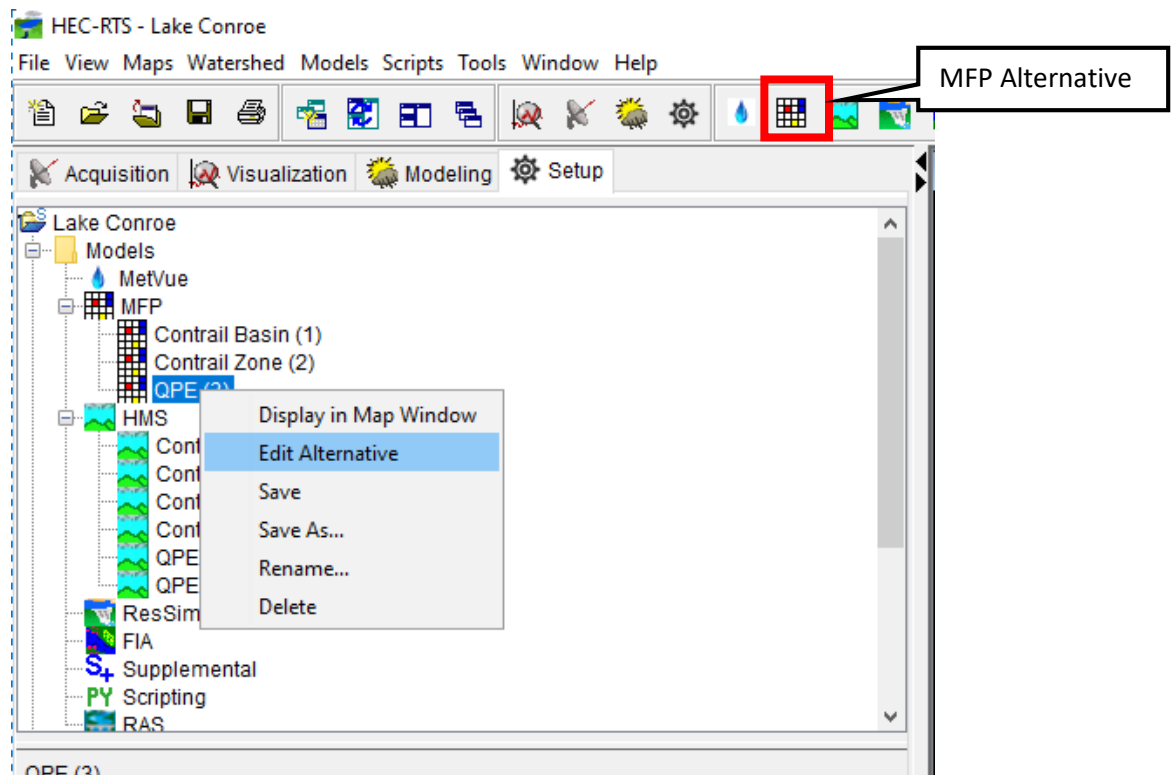
To create a new MFP alternative within RTS, right click the “MFP” located within the models of the setup module and click “New”



The “Create New MFP Alternative” window will open and prompt the user to name the MFP alternative and choose the relevant basin model, meteorologic model and precipitation zone configuration created earlier in HEC-HMS.



Open the recently created MFP Alternative by either right clicking the newly created MFP and select “Edit Alternative” or by clicking on the MFP icon located on the top menu and the MFP alternative window will open.



To create a manual forecast, apply precipitation values based on the zone configurations located at the bottom half of the window. Time increments are separated in hours with user having the ability to adjust the time frame of the forecast from 1 to 240 hours. The area to enter in the precipitation values is highlighted in the box in the figure below.

MFP Alternative Editor

Edit

Precip Alt: QPE Zone Configuration: Lake Conroe Precipitation

Description:

Grid Cell File: Meteorologic Model: QPE/QPF

Specific Start Time Start Date: 27May2021

Relative Start Time Start Time: 1100

Time Interval: 1 Hour Duration of Future Precip: 3 Hours

Fcst Precip Obs Precip

Manual Time Series Gridded Pathname...

Time	Zone		
	Huntsville	Lake Conroe - Inside	Lake Conroe - Outside
Time of Forecast			
+1 hr.	1.000	1.000	1.000
+2 hrs.	1.000	1.000	1.000
+3 hrs.	1.000	1.000	1.000
Total Future Precip:	3.000	3.000	3.000

Graphical Edit

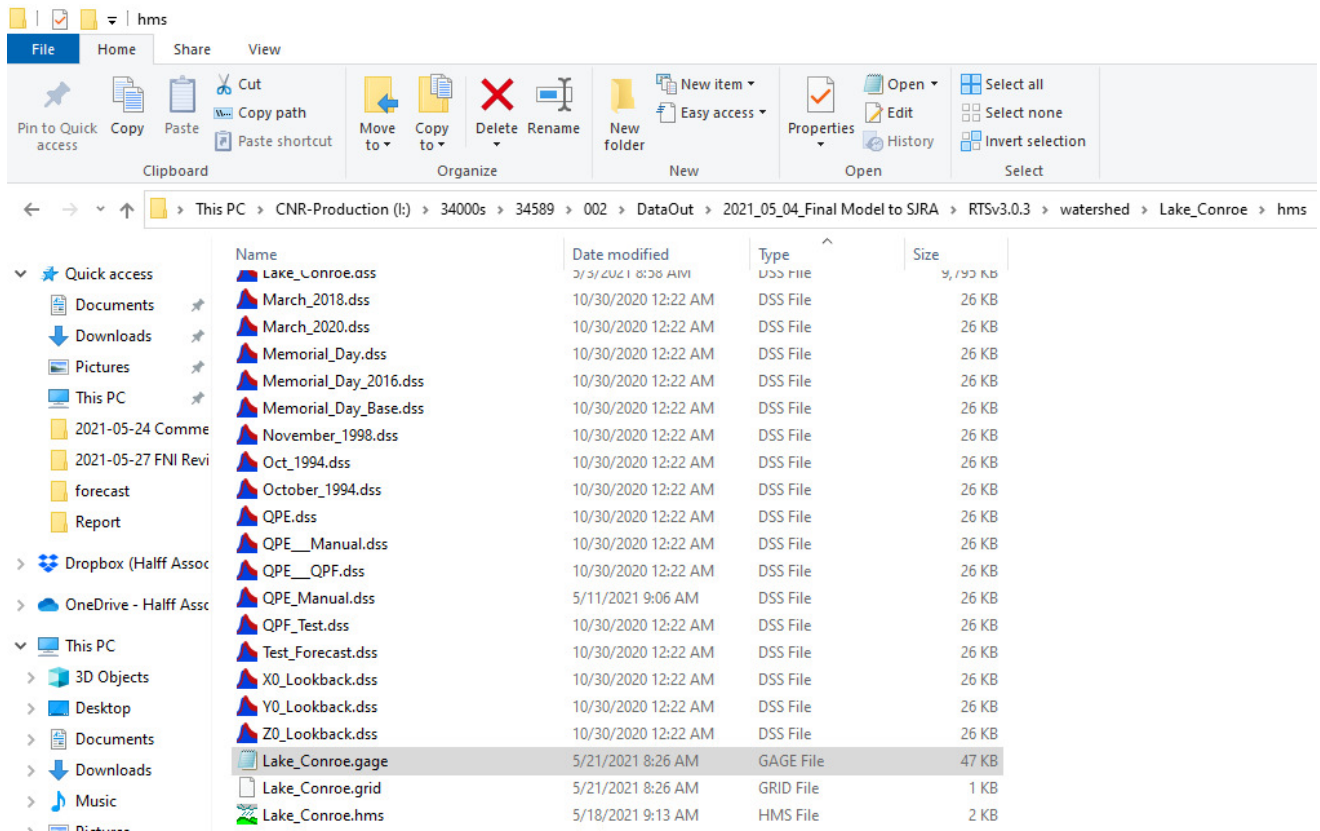
OK Cancel Apply

Once the desired MFP parameters are set, click “OK”

Step 5: Reference Gage Data

The rainfall, discharge and stage gages must be referenced appropriately to the relevant forecast DSS file in order for the Manual forecasts to work properly. The process involves updating the referenced DSS file path name within the gage file of the HEC-HMS model. HEC-RTS must be closed in order to conduct this step.

Open the “watershed” folder within Windows Explorer and open the folder of the user named watershed. From there, open the “hms” folder and then open the GAGE file.



Open the GAGE file using notepad and copy all of the relevant data. A quick approach to accomplish this is to press “Ctrl + A” then “Ctrl + C”.

```

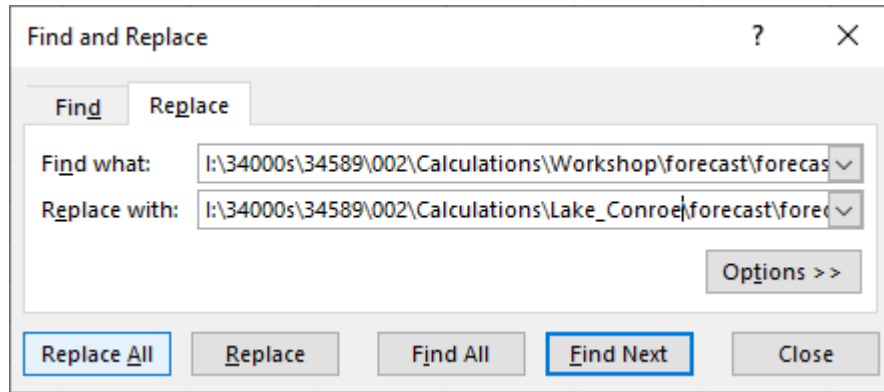
Lake_Conroe.gage - Notepad
File Edit Format View Help
Gage Manager: Lake Conroe
Version: 4.2.1
Filepath Separator: \
End:

Gage: Huntsville-Base
Last Modified Date: 28 October 2020
Last Modified Time: 22:50:48
Reference Height Units: Feet
Reference Height: 33
Gage Type: Flow
Units: cfs
Data Type: INST-VAL
Data Source Type: Modifiable DSS
Variant: Variant-1
Last Variant Modified Date: 27 October 2020
Last Variant Modified Time: 20:20:39
Default Variant: Yes
DSS File Name: I:\34000s\34589\002\Calculations\HEC-RTS 3.0.3\forecast\forecast.dss
DSS Pathname: /REGULAR/TIMESERIES/FLOW/01OCT2020/15MIN/STREAMFLOW
Start Time: 1 January 2010, 00:00
End Time: 2 January 2030, 00:00
End Variant: Variant-1
End:

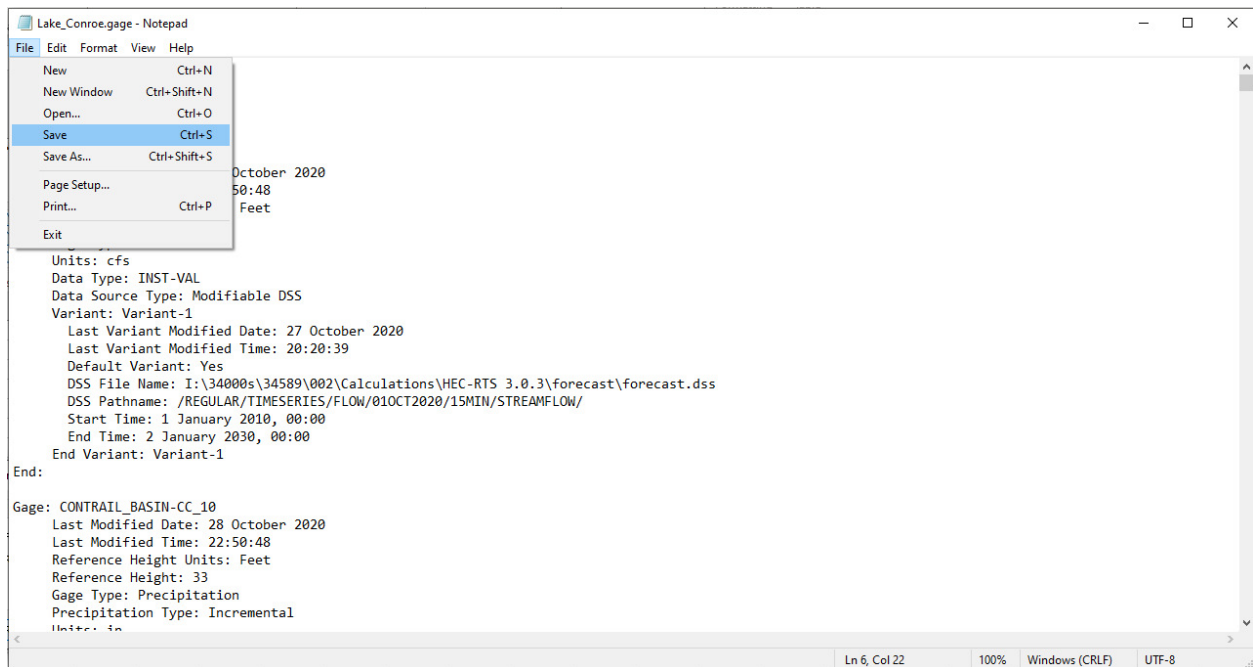
Gage: CONTRAIL_BASIN-CC_10
Last Modified Date: 28 October 2020
Last Modified Time: 22:50:48
Reference Height Units: Feet
Reference Height: 33
Gage Type: Precipitation
Precipitation Type: Incremental
Units: in

```

Paste the data into Excel. Once the data has been pasted, press “Ctrl + F” to bring up the Find & Replace tool in Excel. Switch to the Replace tab and copy and paste the DSS file path from the gage file into the “Find what:” row. Paste the DSS file path from the “forecast” folder in Windows Explorer into the “Replace with:” row and click “Replace All”



Once the file name has been replaced, copy the entire gage data and paste it back into the GAGE file and click “Save” under the “File” tab.



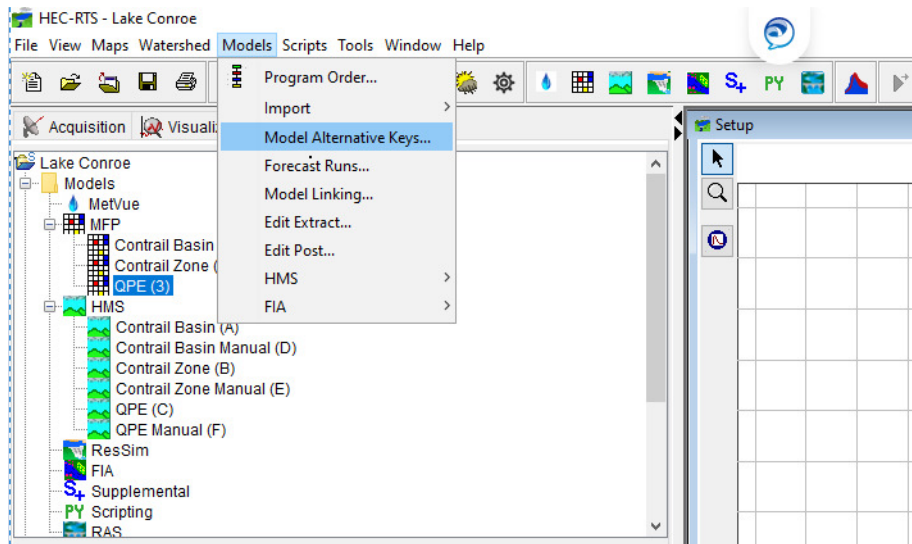
The data should now be saved to reference the correct forecast DSS file.

Step 6: Model Setup

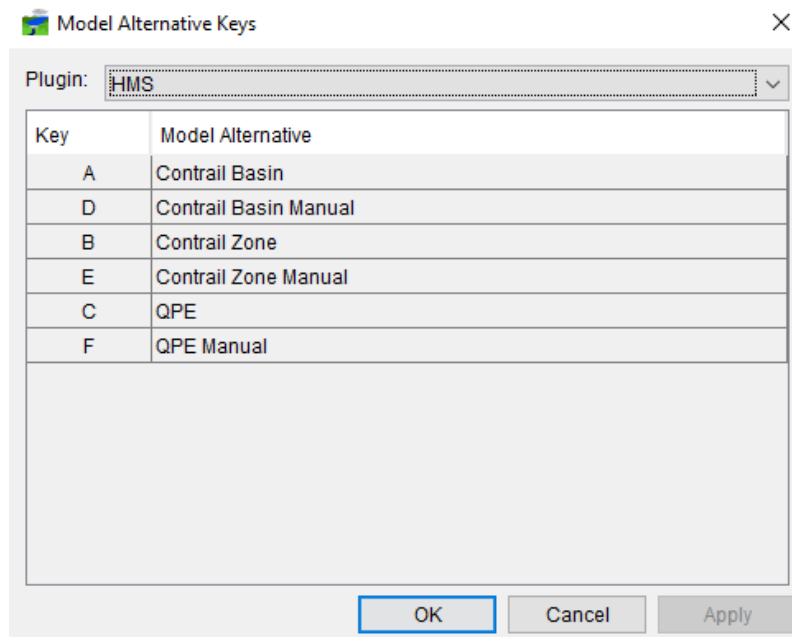
The process to setup the model involves assigning keys to the MFP and HEC-HMS alternatives, creating forecast runs, model linkage and editing the extract list. The process is detailed below.

Step 1: Assign Model Alternative Keys

Within the setup module, click on the “Models” tab located in the menu bar and then click into the “Model Alternative Keys” tab.

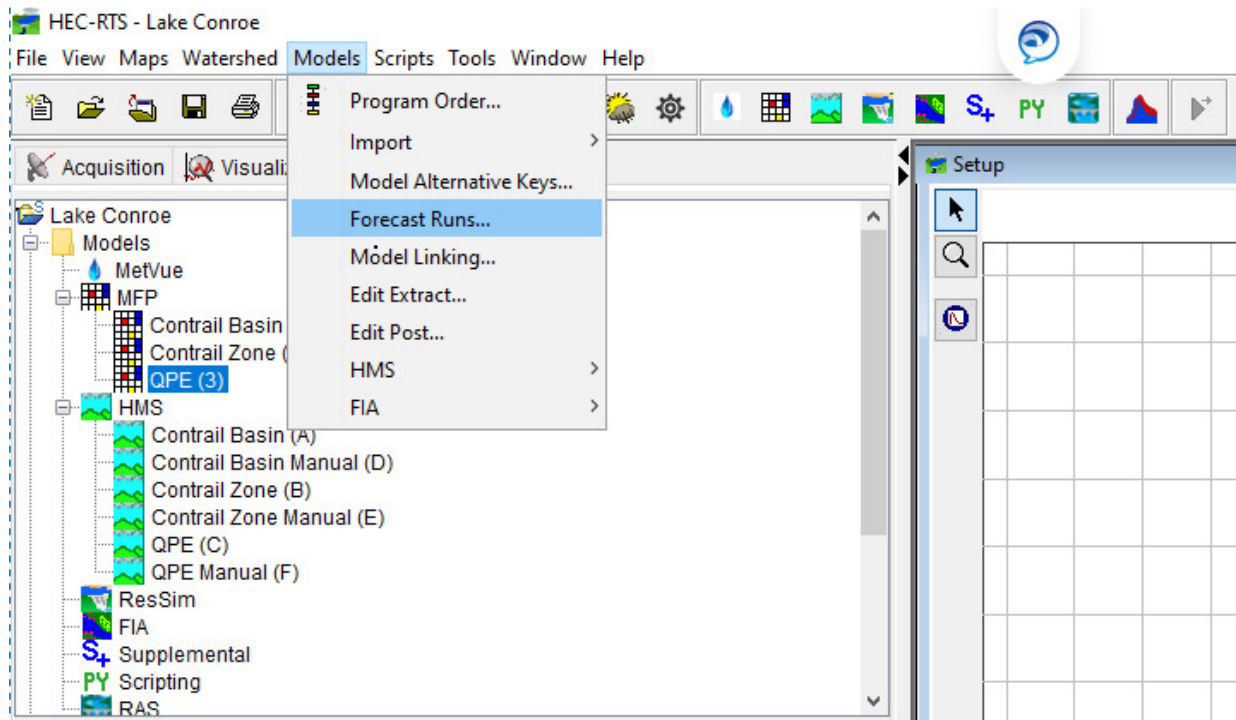


From here, a dropdown list with the various plugins is shown with the established MFPs and HEC-HMS forecast alternatives. An alternative key consists of a single digit numerical or alphabetical character and is assigned by the user. For better organization, assign MFP and HEC-HMS with numerical and alphabetical character respectively.

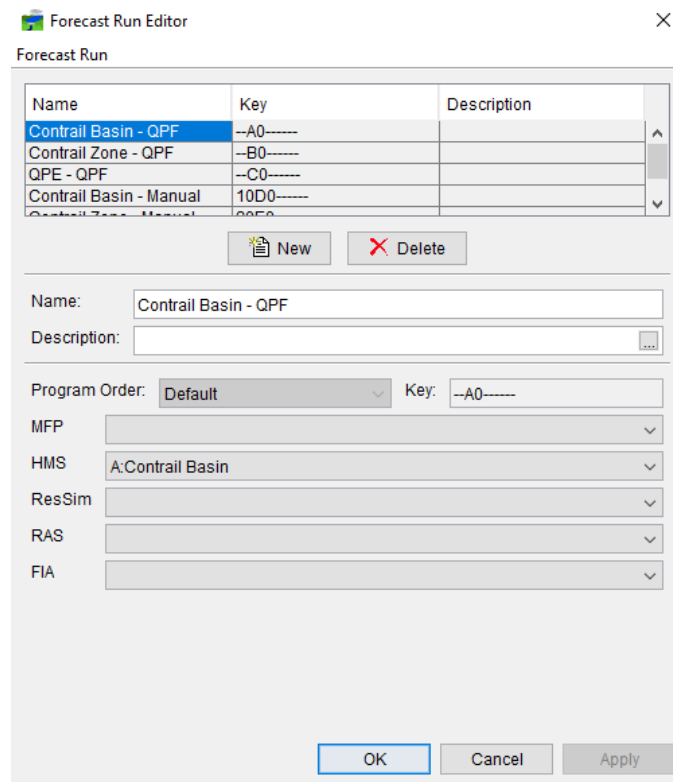


Step 2: Create Forecast Runs

To create the forecast runs to be used within the forecast simulations, within the “Models” tab, select the “Forecast Runs...” tab.

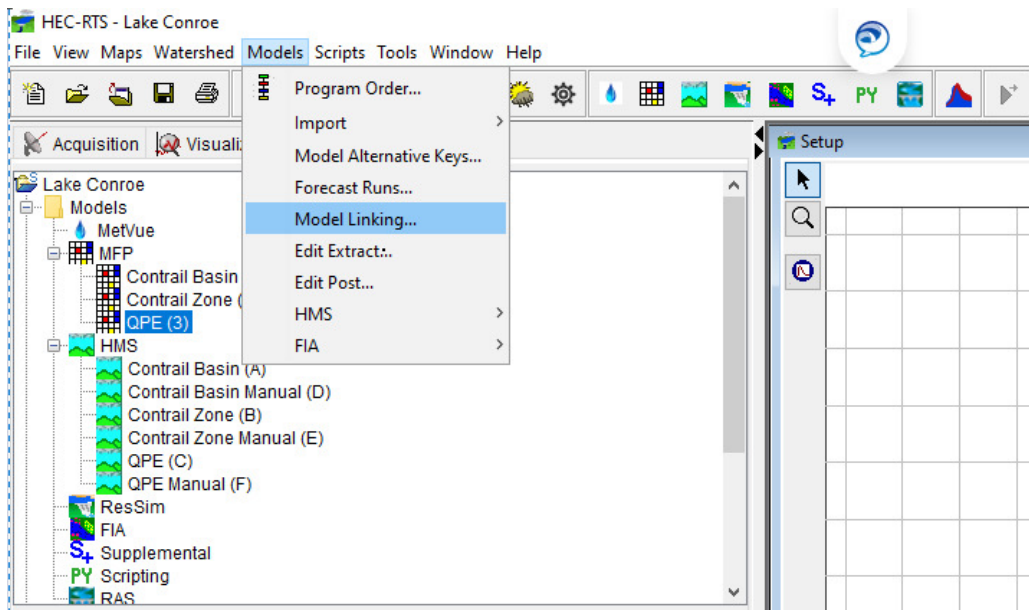


Click the “New...” icon to open a new forecast run. A dropdown list of the various plugins within RTS will pop up along with text boxes for the names and descriptions. Name the forecast and select the relevant MFP and HEC-HMS alternatives to it. Descriptions of the forecast runs can be added to detail the actual and forecasted rainfall that is being applied. After all the forecast runs are set, click “OK” within the forecast run window.

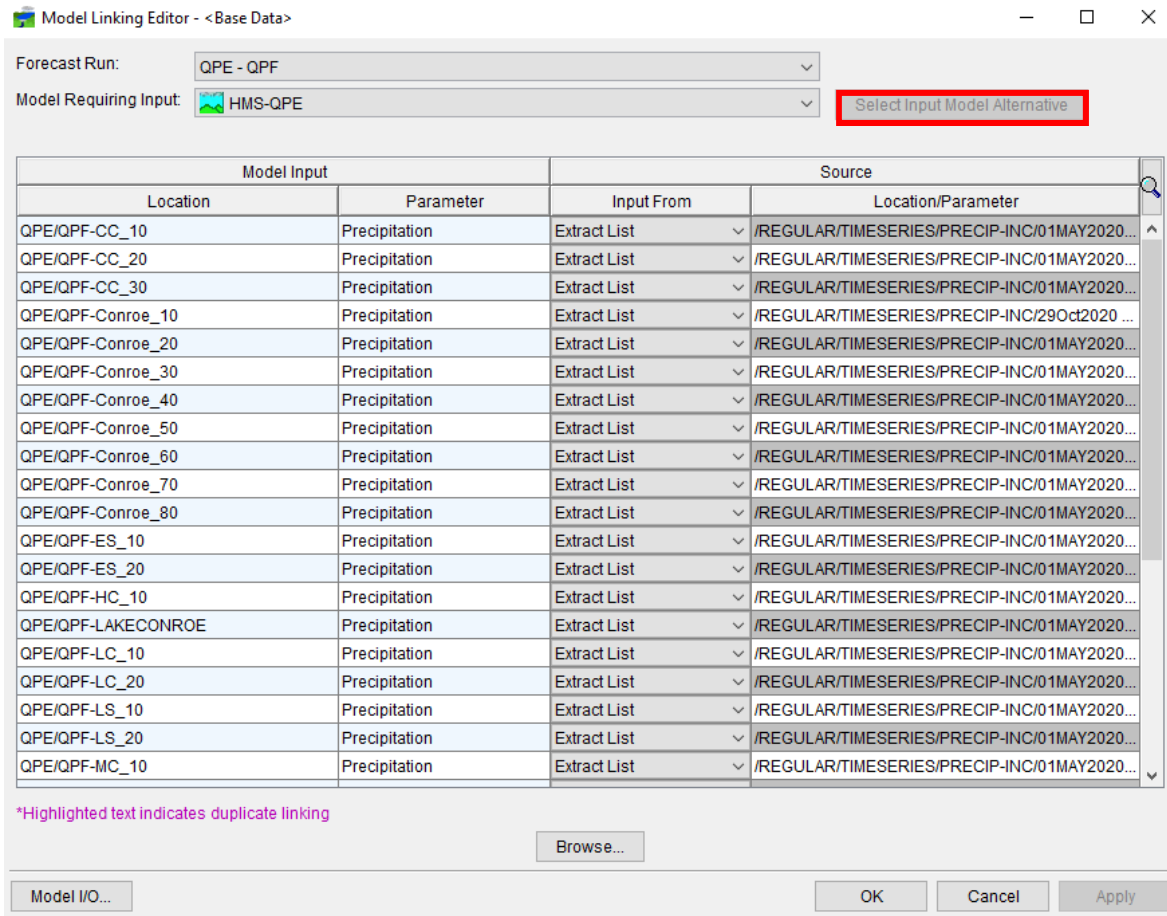


Step 3: Model Linking

To link the MFP and HEC-HMS models together, select the “Model Linking” tab within the “Models” tab.

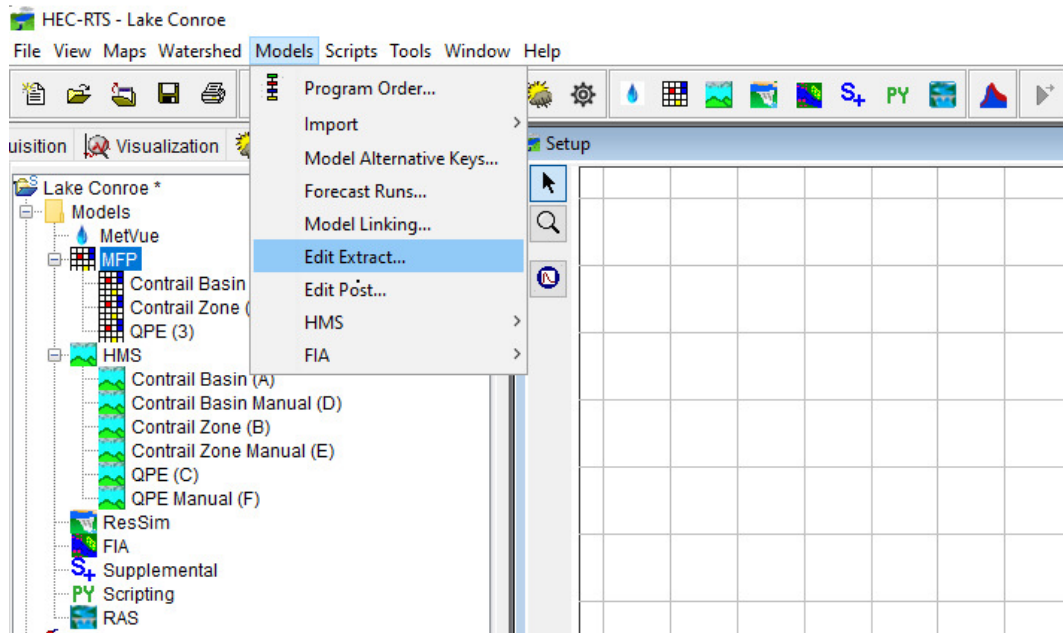


Within the Model Linking Editor, a set of dropdown lists are shown relating to the forecast run and alternative models. Select the relevant forecast and alternative model (MFP and HEC-HMS) and assign the linkage to either the MFP or extract list for the HEC-HMS alternative. The MFP alternative is automatically referenced to the extract list. Select the fields with the “Precipitation” parameter and press the “Select Input Model Alternative” to assign the HEC-HMS alternative to the MFP or extract list. For QPF forecasts, reference the HEC-HMS alternative to the extract list. For manual forecasts, reference the HEC-HMS alternative to the MFP alternative. Repeat for each forecast run and click “OK’ within the window.



Step 4: Edit Extract List

To reference the DSS file created from the “Fetch_Data” script, select the “Edit Extract” tab under the “Models” tab.



Within the “Edit Extract” window, click the “New Extract Group” icon located in the bottom left hand corner. A window will appear prompting the user to name the group, DSS file to be referenced and the time window. All other parameters can be left with the default settings. Name the extract group and set the path name for the referenced DSS. The referenced DSS file should be the forecast DSS located within the “forecast” folder in Windows Explorer. Set the time window to start and end of the simulation.

New Extract Group

Name:

Type:

Source:

File:

DSS Storage Options

Override Protection

Regular:

Irregular:

Run As Default

Time Window

Start: Offset:

End: Offset:

After the extract group is created, a list of required inputs located at the top of the extract window shows alternatives with the referenced DSS pathnames. Select the relevant paths to be used for the extract list by clicking the “Add to Group” icon located below. For this model, select all of the required inputs to be used in the extract list. Once finished, click “OK” in the extract window.

Extract Editor

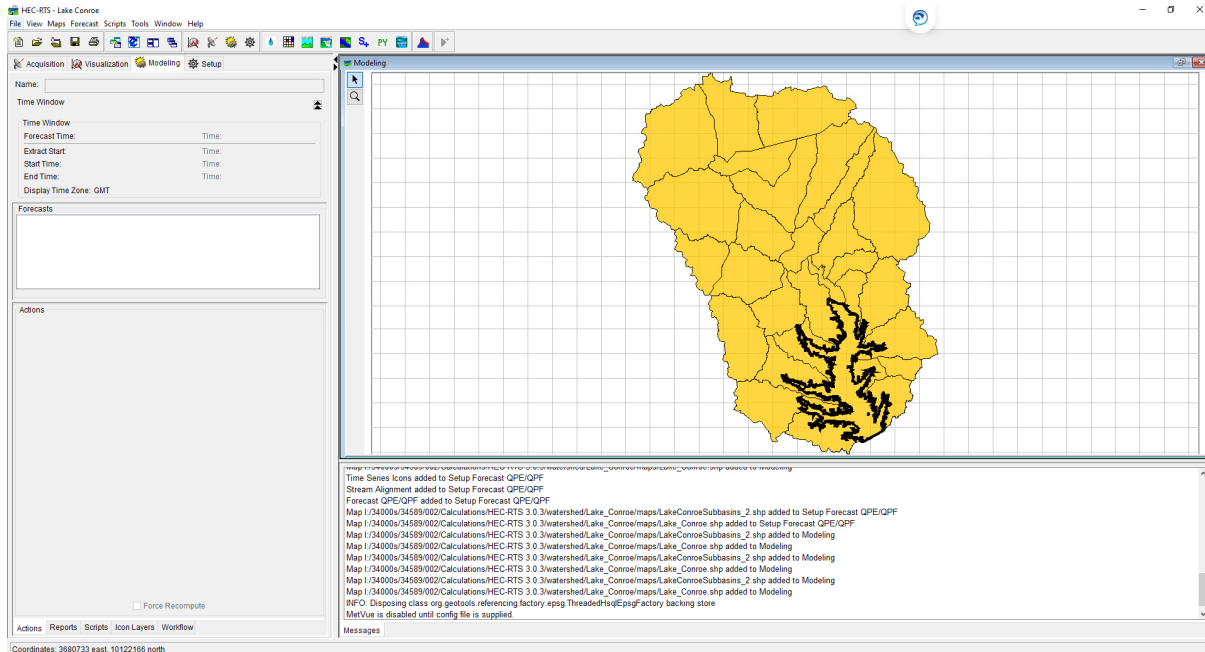
Alternative	Destination
Memorial Day 2016	//MEMORIAL DAY- RELEASE/FLOW/24MAY2016 - 29MAY2016/5MIN/GAGE/
Contraill_Basin	/REGULAR/TIMESERIES/PRECIP-INC/01MAY2020/15MIN/CYCN 010CONTRAILINCREMENT/
Contraill_Basin	/REGULAR/TIMESERIES/PRECIP-INC/01MAY2020/15MIN/CYCN 020CONTRAILINCREMENT/
Contraill_Basin	/REGULAR/TIMESERIES/PRECIP-INC/01MAY2020/15MIN/CYCN 030CONTRAILINCREMENT/
Contraill_Basin	/REGULAR/TIMESERIES/PRECIP-INC/01MAY2020/15MIN/CONROE 010CONTRAILINCREMENT/
Contraill_Basin	/REGULAR/TIMESERIES/PRECIP-INC/01MAY2020/15MIN/CONROE 020CONTRAILINCREMENT/
Contraill_Basin	/REGULAR/TIMESERIES/PRECIP-INC/01MAY2020/15MIN/CONROE 030CONTRAILINCREMENT/
Contraill_Basin	/REGULAR/TIMESERIES/PRECIP-INC/01MAY2020/15MIN/CONROE 040CONTRAILINCREMENT/
Contraill_Basin	/REGULAR/TIMESERIES/PRECIP-INC/01MAY2020/15MIN/CONROE 050CONTRAILINCREMENT/
Contraill_Basin	/REGULAR/TIMESERIES/PRECIP-INC/01MAY2020/15MIN/CONROE 060CONTRAILINCREMENT/

Setup Conclusion

Most of the steps highlighted in this process are not necessary for the SJRA to undertake in order for the Lake Conroe model to simulate forecasts. However, some steps such as editing the extract list are needed to reference the correct DSS file once the model is handed over..

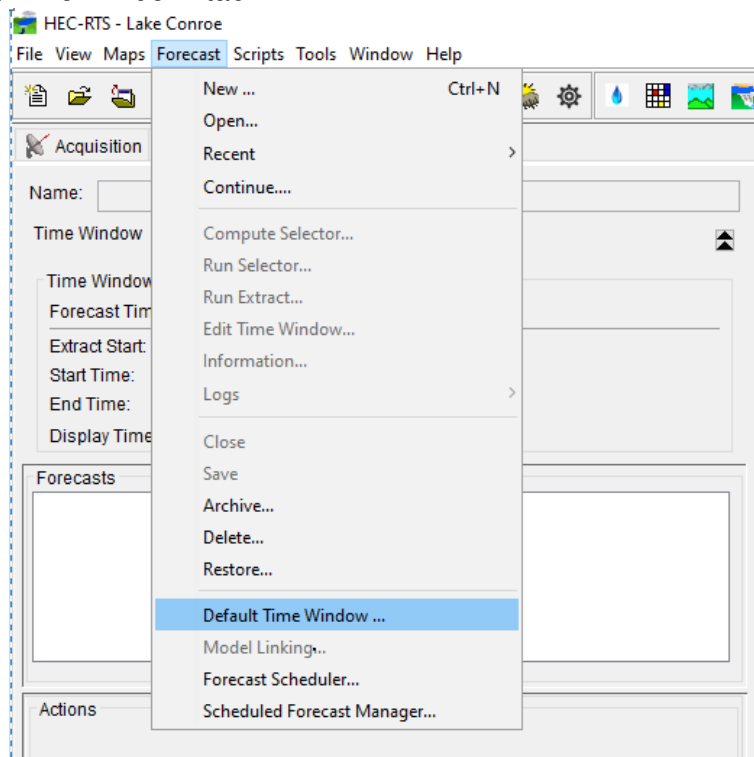
Modeling Module

To switch to the modeling module, click the “Modeling” tab located next to Setup module.

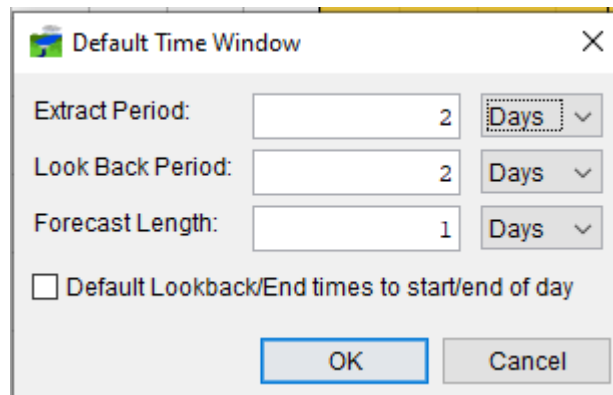


Step 1: Default Time Window

To change the default time window used when creating a forecast, click the “Forecast” tab and select the “Default Time Window” tab.

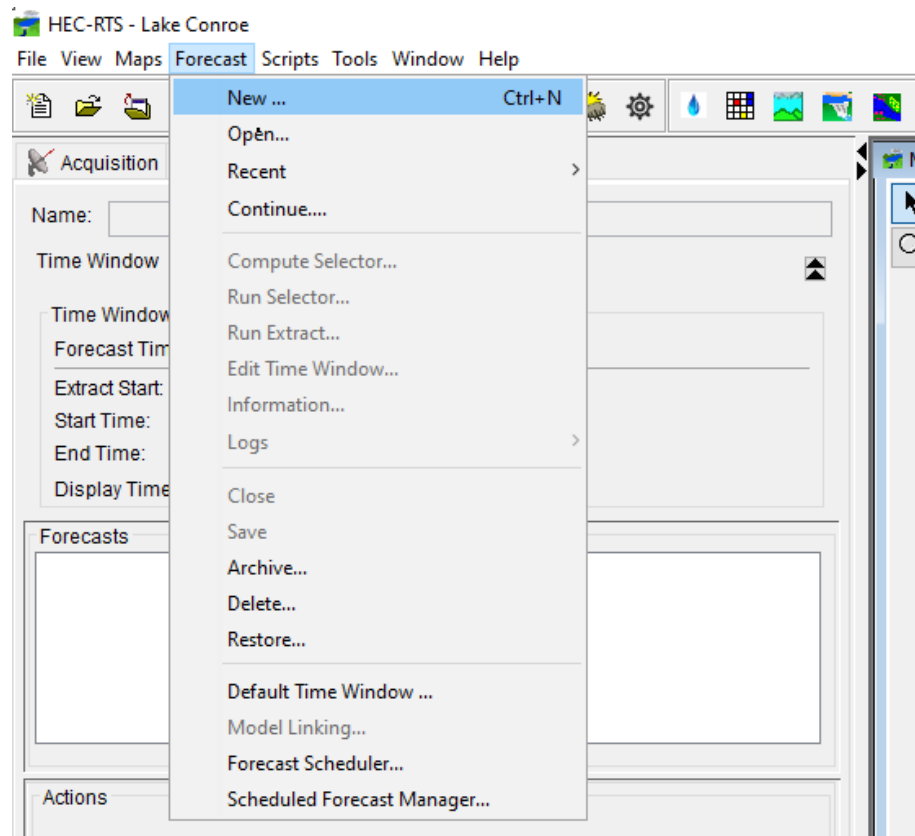


The Default Time Window shows the default lookback, extract and forecast times that are referenced when creating a new forecast. Times can be changed either in hours or days. Once the desired times are set, click "OK" within the window.



Step 2: Create New Forecast

To create a new forecast, click the "Forecast" tab and click the "New.." tab



The Create New Forecast window opens and defaults a specified forecast, usually within the next 6 hours of when the forecast was created. The user can edit the forecast name, description, lookback and forecast time windows and select the forecast runs to be used within the forecast.

Create New Forecast X

Name:

Description:

Folder:

Select Type:

Time Window

Forecast Time: Time:

Extract Start: Time:

Start Time: Time:

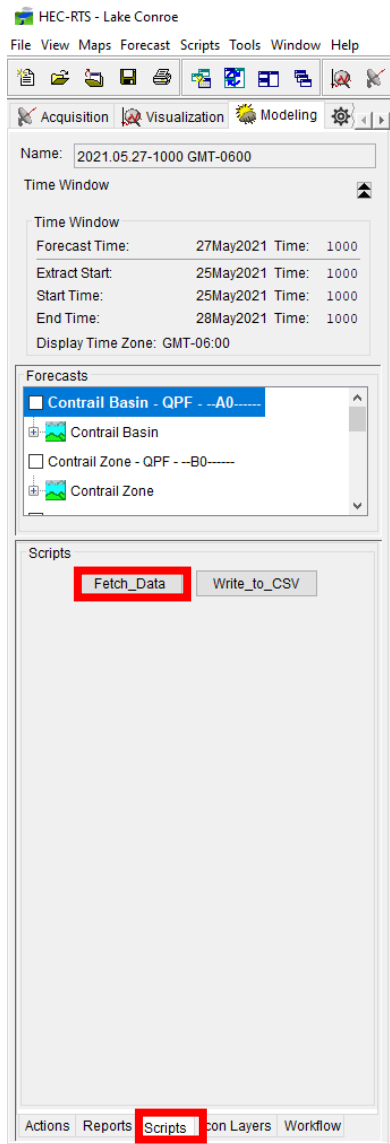
End Time: Time:

Watershed Time Zone: GMT-06:00

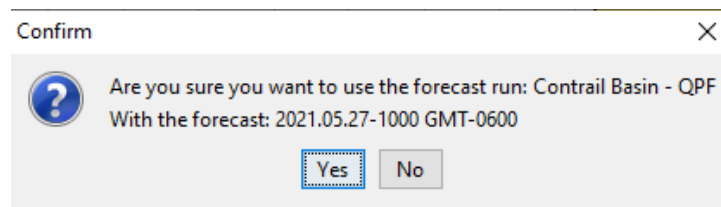
Se...	Forecast Run	Description
<input checked="" type="checkbox"/>	Conrail Basin - QPF	
<input checked="" type="checkbox"/>	Conrail Zone - QPF	
<input checked="" type="checkbox"/>	QPE - QPF	
<input checked="" type="checkbox"/>	Conrail Basin - Manual	
<input checked="" type="checkbox"/>	Conrail Zone - Manual	

Step 3: Run Fetch Data Script

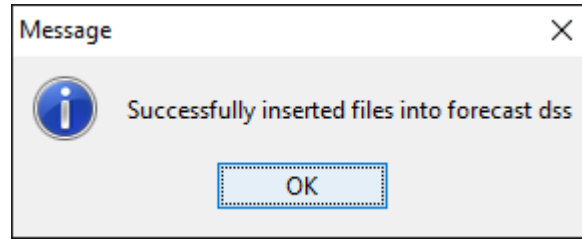
To retrieve rainfall data from the created forecast, select the “Scripts” tab located a bottom left hand corner of the Modeling Module then click the “Fetch_Data” script icon.



A prompt will show up asking the user if they want to run the script. Click “Yes” to begin the data retrieval from the SQL server database.



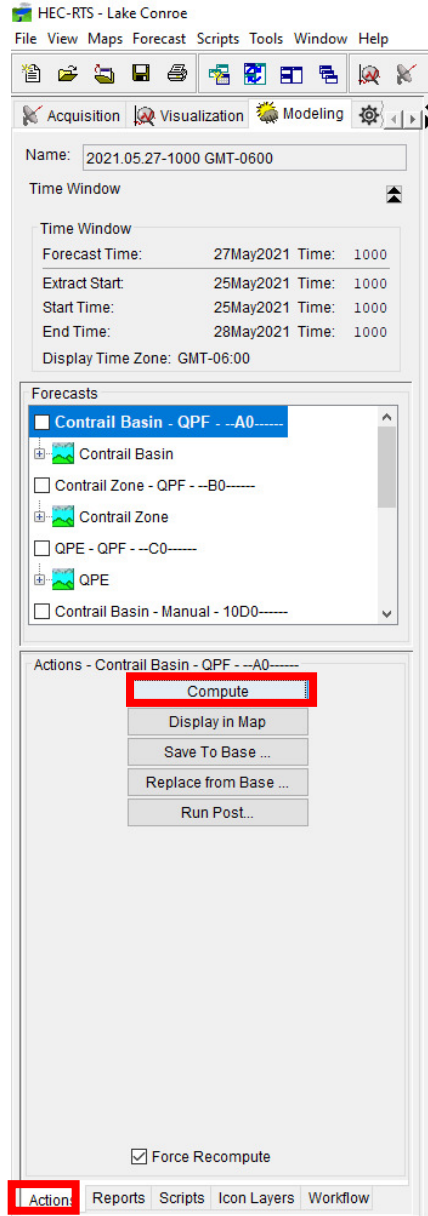
Once the script has finished compiling the data, a prompt will pop up to let the user know that the retrieved files have been inserted into the referenced DSS file and the script has run successfully.



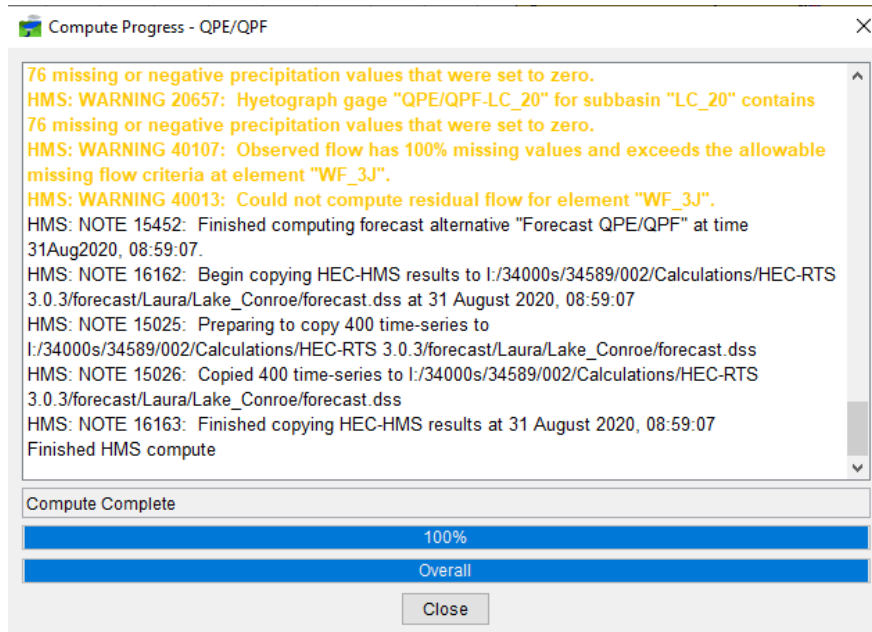
The script will pull data into all of the forecast runs within the created forecast event and will only need to be run once in order for the forecast runs to simulate results.

Step 4: Simulate Forecast Runs in Forecast

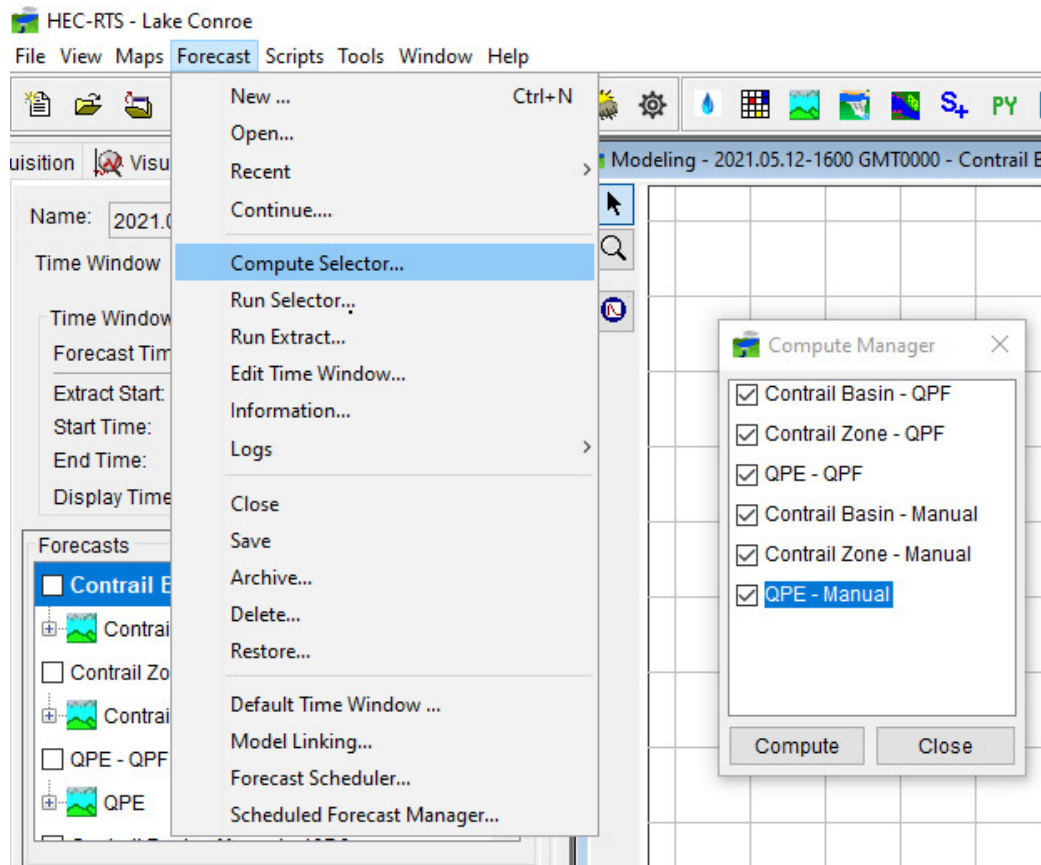
To simulate the forecast runs in the created forecast, click the “Actions” tab on the lower left hand corner of the RTS window and click on the forecast run that is to be simulated and click “Compute”.



The forecast run will simulate through both MFP and HEC-HMS alternatives and produce any warning or error messages that may affect the results.

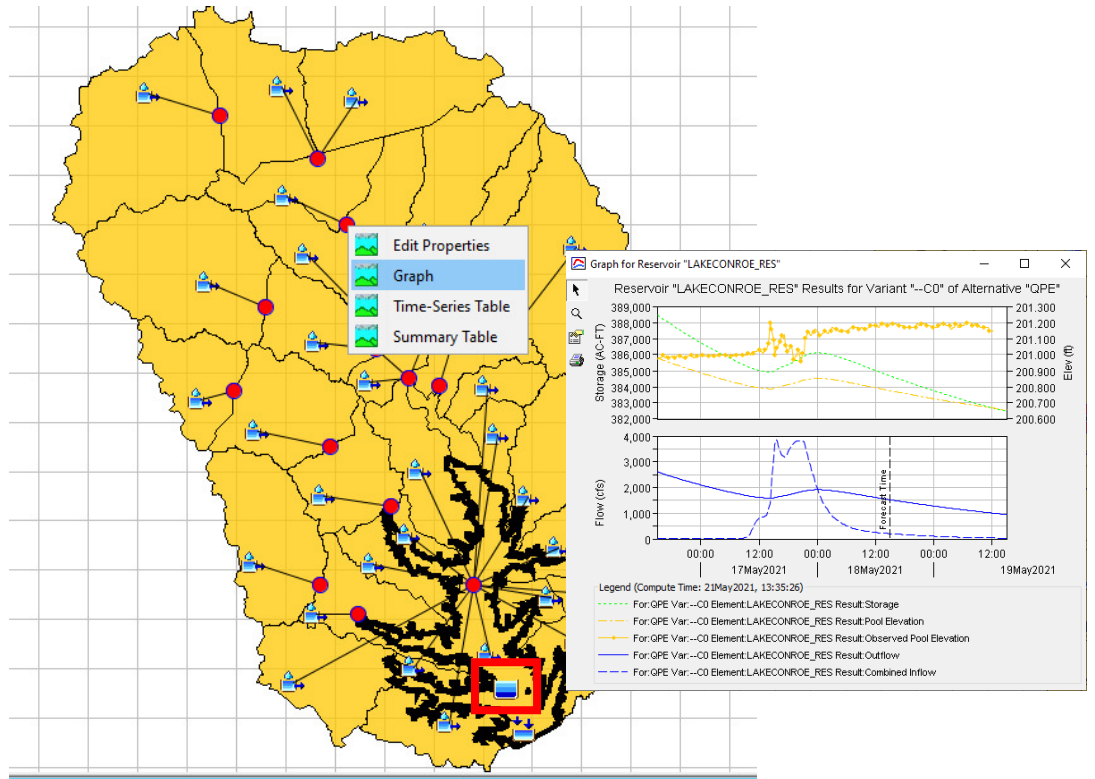


Repeat this process for any additional forecast runs within the forecast. The forecast runs can also be simulated at once using the "Compute Selector" under the "Forecast" tab.

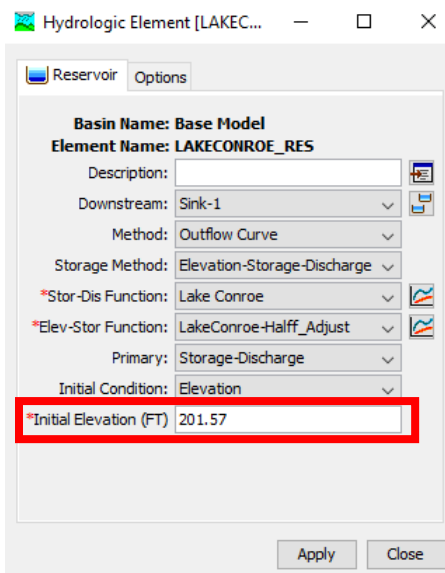


To view the results from the forecast run, right click the HEC-HMS icon within the map display and choose either to graph, tabulate or summarize results. The "LAKECONROE_RES" HEC-

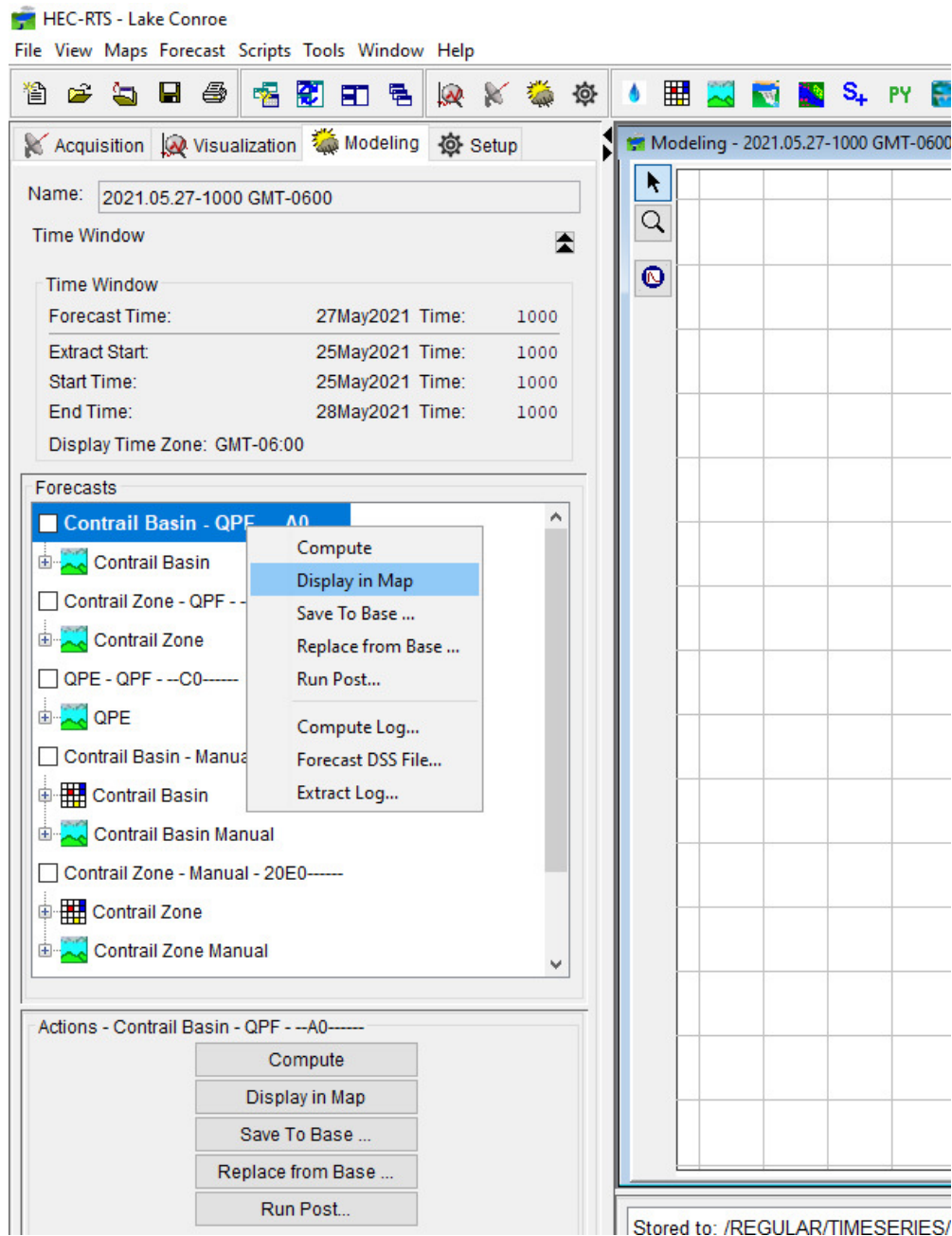
HMS element should be selected to view the total inflow coming into Lake Conroe. The element is selected below in the red box.



For the first iteration, the forecast lake elevation might not exactly match the first observed water surface elevation point based on the graph. If this occurs, the initial lake elevation needs to be set to the first observed water surface elevation. Right click the "LAKECONROE_RES" HEC-HMS element and click the "Edit Properties" option. At the bottom of the dialog box, enter the initial lake elevation from the observed data and click "Apply". After the initial lake elevation is applied, the alternative should be re-ran to set the initial elevation within the forecast.

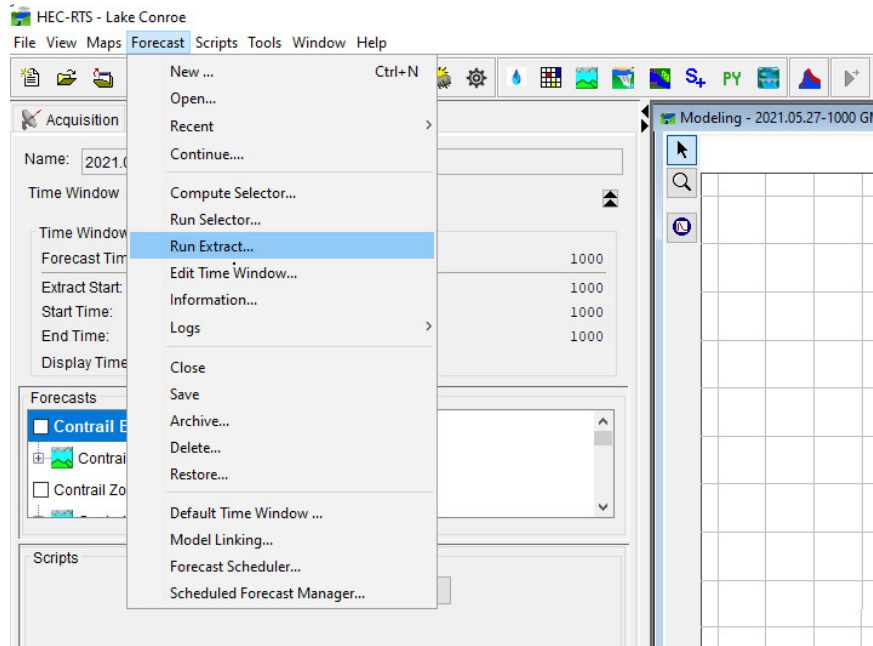


To view other forecast runs, right click the forecast run within the forecasts window and click “Display in Map” tab. The tab will bring up the model related to the forecast run in which results can be viewed.

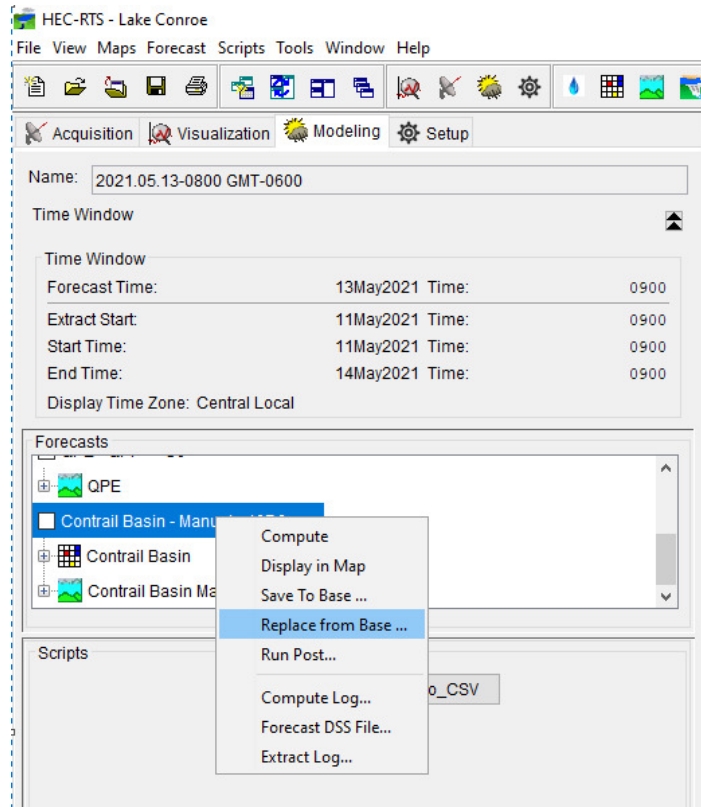


Both the QPF and manual forecasts can be simulated for the created forecast events. The QPF forecasts typically have no issue running since they are referenced to the extract list, while the manual forecasts may or may not run right away when selected. If this occurs, these options can be undertaken specified below:

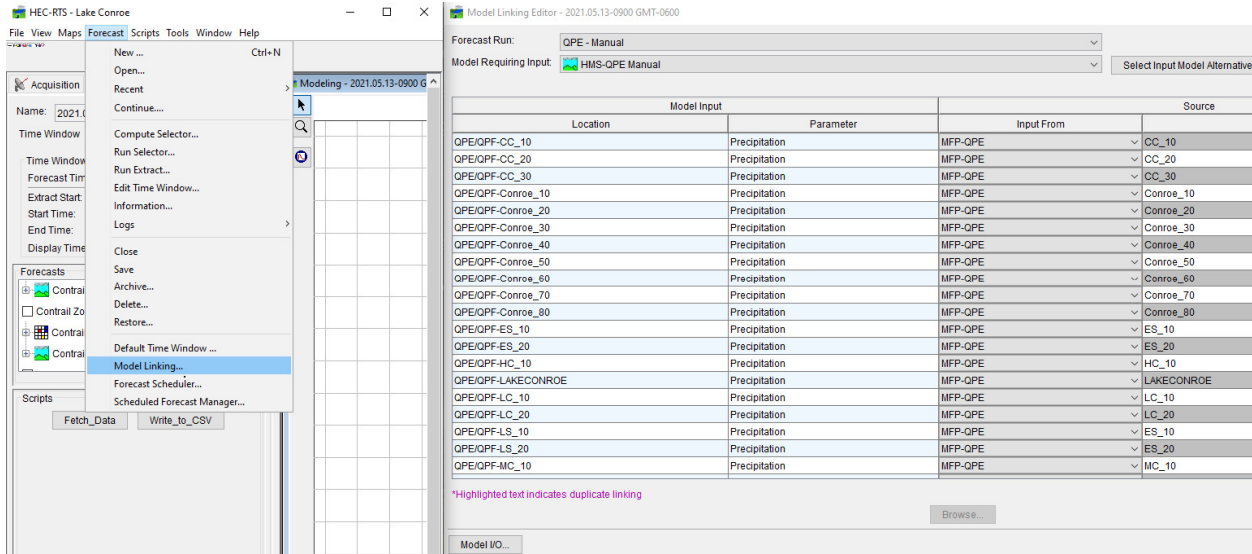
- Run Extract – Click the “Forecast” tab at the very top of the HEC-RTS window and click “Run Extract”. This option will rerun the extract list that is referenced within the MFP.



- Replace from Base – Replace the manual forecast HEC-HMS model with the HEC-HMS model from the Setup Module by right clicking the forecast run click “Replace from Base” and select only the HEC-HMS model to be replaced.

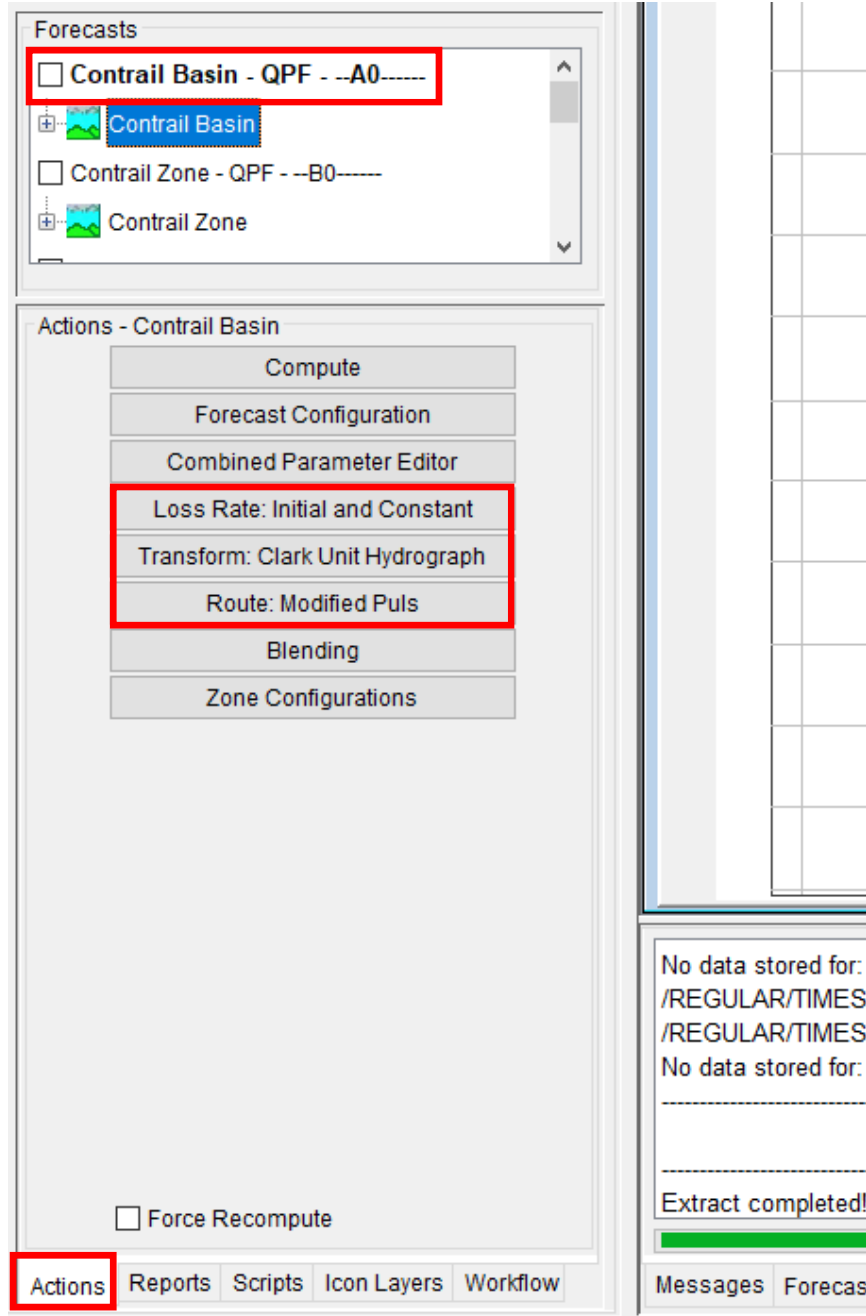


- Link HEC-HMS model to Extract List – If the first two options do not solve the errors with the manual forecast, the HEC-HMS model should be linked to the extract list, simulated, then linked back to the MFP alternative. Click the “Forecast” tab at the very top of the HEC-RTS window and click “Model Linking”. Select the manual forecast and set the “Input Model Alternative” as the extract list. Run the simulation and return to the “Model Linking” window and select the “Input Model Alternative” to the relevant MFP.

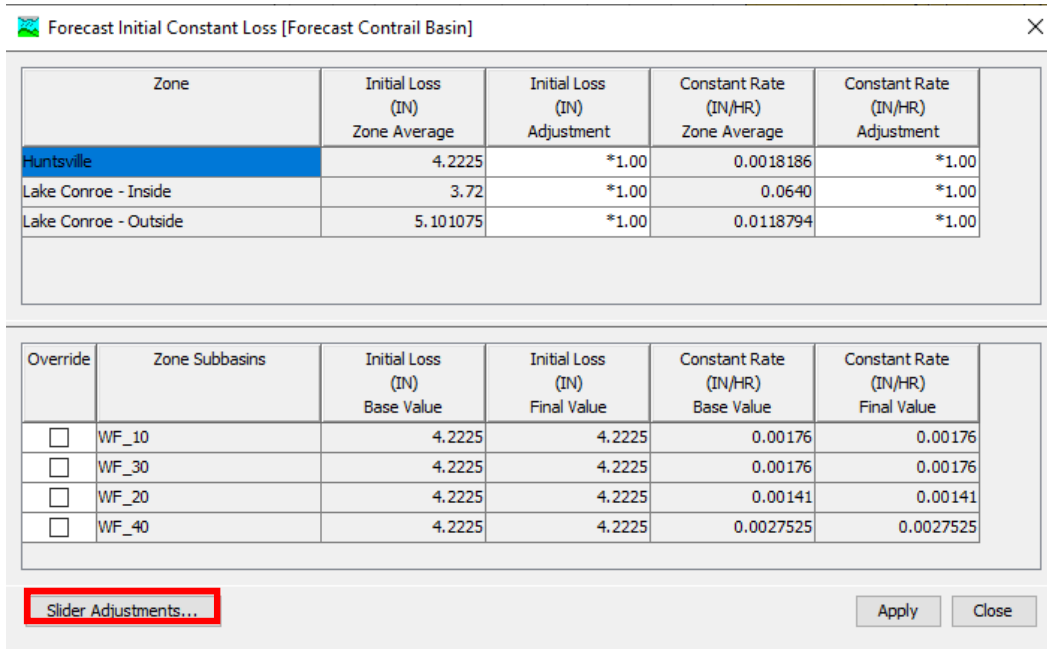


Step 5: Slider Adjustments

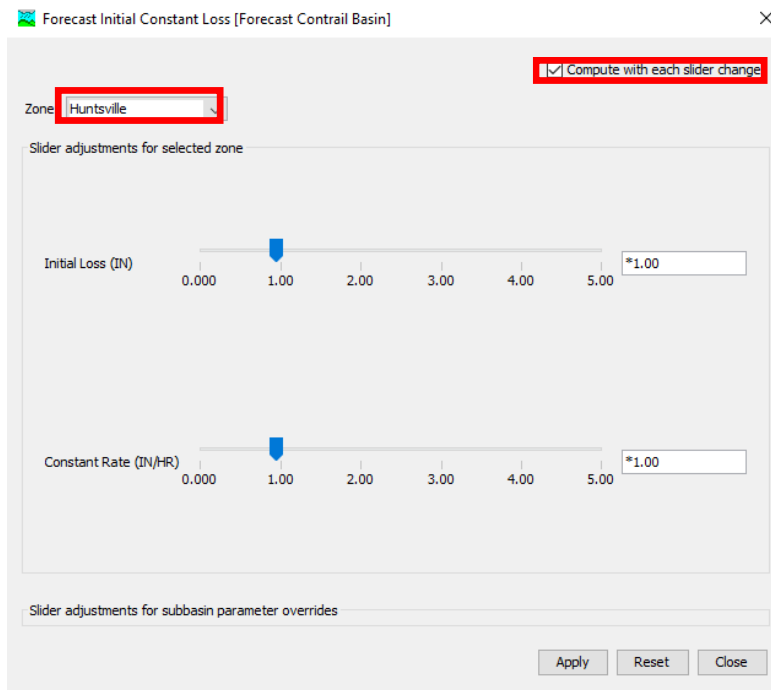
To match the modeled to the observed USGS gage data, slider adjustments are provided to easily adjust the model parameters to calibrate the forecast event. To access the slider, select the HEC-HMS alternative under the “Actions” tab and select either the Loss, Rate, Transform or Route actions.



Once one of the actions is selected, the adjustments window pop up. From here, select the slider adjustments button to open the slider adjustments.



The slider adjustments window pops up and allows the user to slider the factor for each parameter and which calibration zone to change it in. The option to run the simulation after each slider change can be applied by selection the “Compute with each slider change” option. The modeled data is changed after each slider adjustment and can be compared against the observed data. Once the calibration is sufficient, no more adjustments are needed to be made.

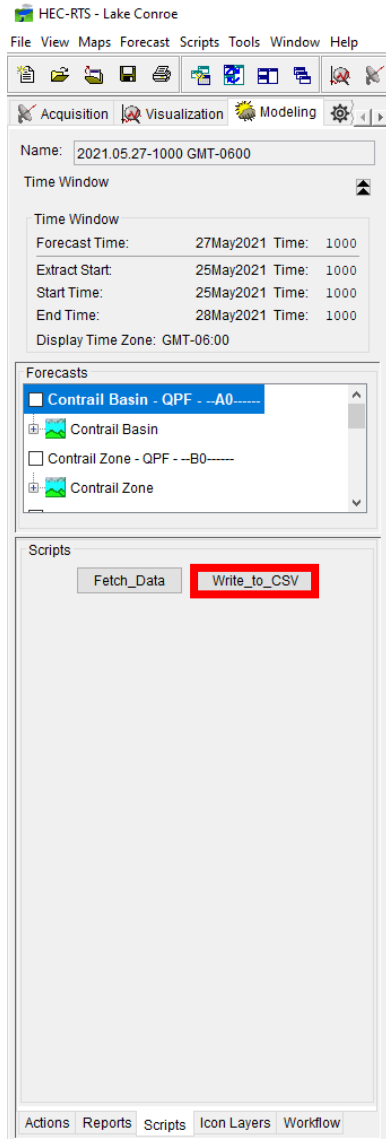


For calibration of forecast events, it is recommended to only adjust the loss parameters as these can fluctuate based on the antecedent conditions of the soil in the watershed. Transform and

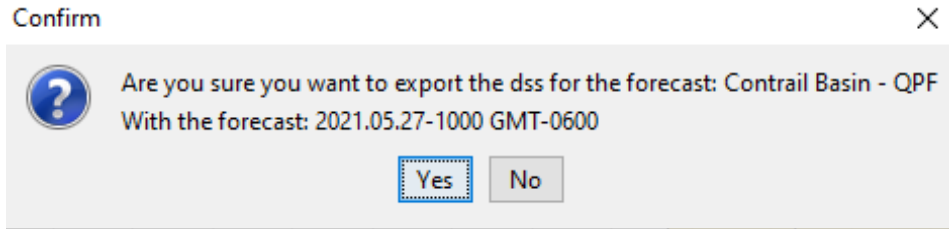
Route parameters are based on the characteristics of the subbasin and reaches and rarely fluctuate unless physical changes are made in these areas.

Step 6: Export Data to CSV

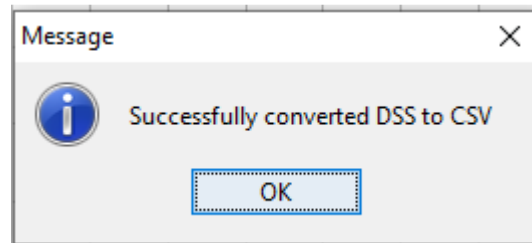
To export the lake inflow and elevation data, click on the “Scripts” tab located a bottom left hand corner of the Modeling Module then click the “Write_to_CSV” script icon.



A prompt will show up asking the user if they want to run the script. Click “Yes” to begin the exporting to CSV process.

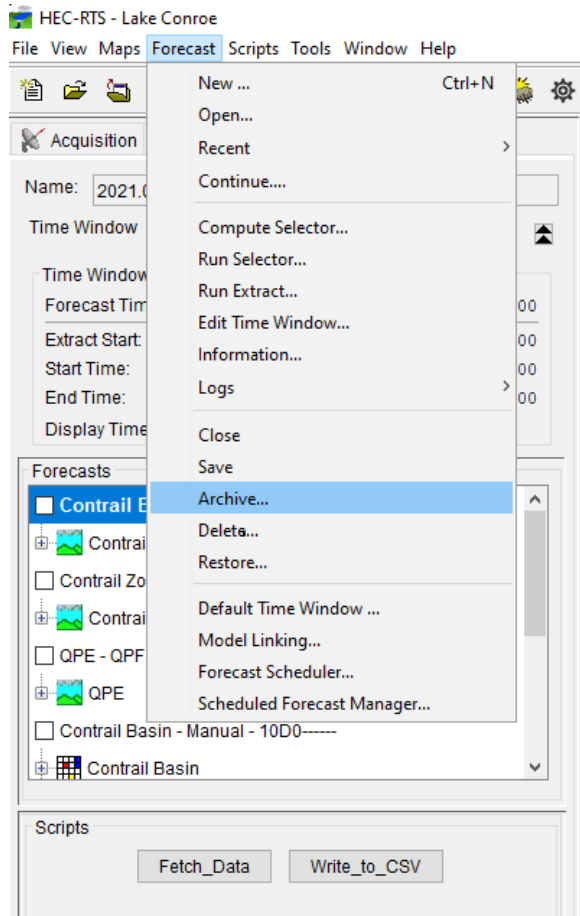


Once the script has finished compiling the data, a prompt will pop up to let the user know that the CSV file was exported successfully. The CSV is saved within the “forecast” folder of the saved location for the watershed.



Step 7: Archive Results

Archiving a forecast reduces the file size of the forecast event and is zipped to a specified folder. To archive a forecast, Click the “Forecast” tab and select the “Archive...” tab. Select the forecast that will be archived.



The archive window will pop up and prompt the user to add any comments to the archive forecast and the referenced folder to archive the forecast into.

Enter Archive Comments

Forecast to Archive

Forecast Name: 2021.05.13-0900 GMT-0600

Archived By: ah2866

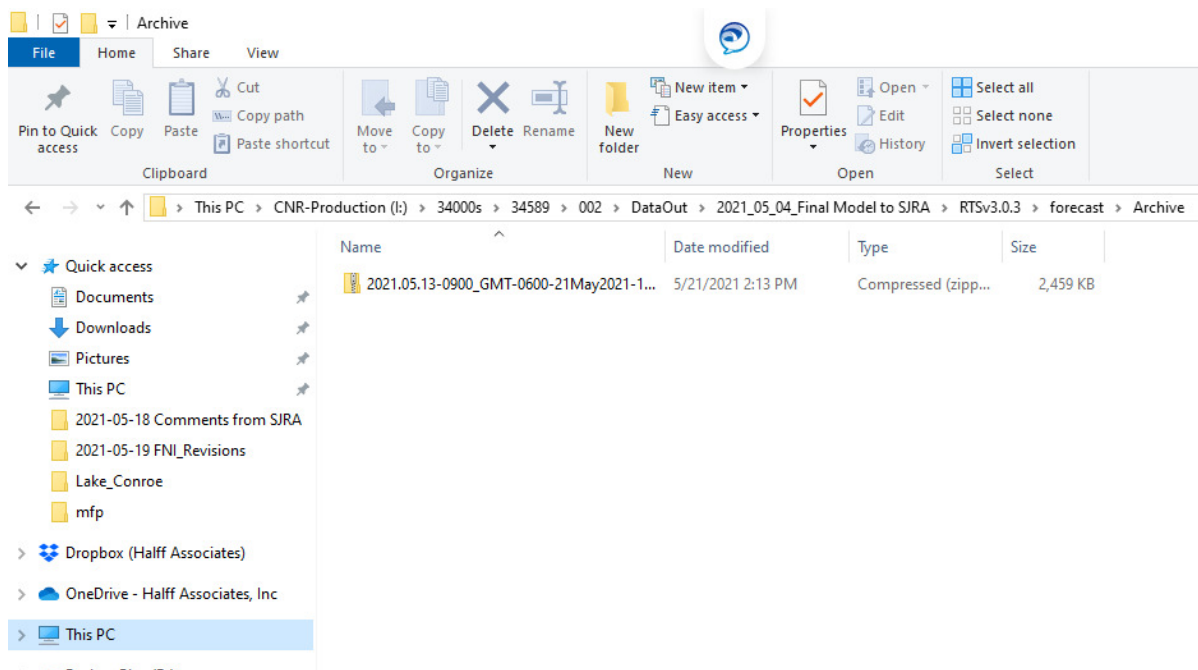
Archived On: 21May2021, 14:02

Archive Folder: I:\34000s\34589\002\DataOut\2021_05_04_Final Model to SJRA\RTSv3.0.3\forecast\Archive

Archive File: 2021.05.13-0900_GMT-0600-21May2021-1402.zip

OK Cancel

Once the comments are added and the folder is referenced, click “OK” to begin the zipping process. Once completed a zipped folder will appear in the referenced folder with the archive date and time. The archive process does not delete the original forecast folder, it creates a copy of the forecast into the archive.

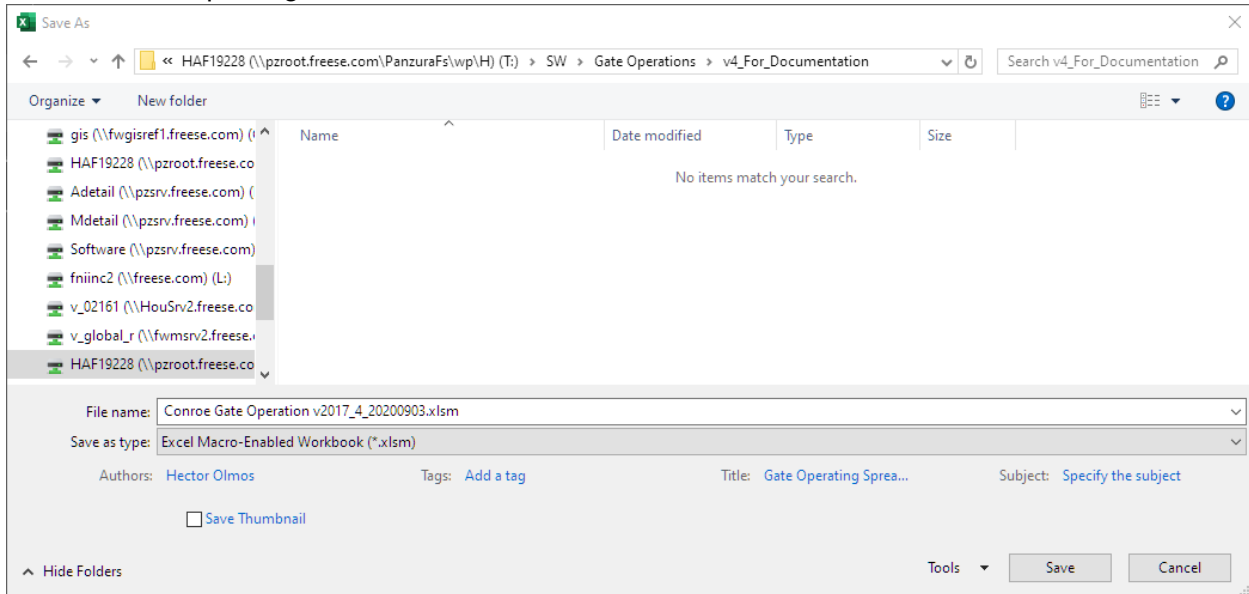


Appendix A.1 – Reservoir Modeling Tool Process

Following the execution of a forecast in HEC-RTS, the reservoir modeling tool is the next step in the forecast. A step-by-step set of instructions is provided below, with some discussion of how the steps were developed in the following subsections. The forecast modeling below is not intended to replace the SJRA gate operations policy. The purpose of the steps below is to forecast how the lake may respond to forecast rainfall.

Save template file as a new document – all macros migrate with the saved version.

Recommend replacing “Blank” with the current date.



Open “Lake Levels” Tab



Insert the start date in cell C1 and start time in cell D1. If an event is ongoing, the end date and time may be omitted from cells C2 and D2. If analyzing a historic event, the end date and end time should also be populated. It is unlikely that the start date and time will be updated during an event.

	A	B	C	D	K	L	M	N	
1	INPUT	Enter START DATE in cell 'C1', Ent				or	Average over last	1	hours
2	OUTPUT	Enter END DATE in cell 'C2' - If the					Average over last		entries
3	READING								
4	Date & Time		Raw Lake Level	Average Lake Level					
5			(ft-msl)	(ft-msl)					
6									
7									
8	1		2	3					
9	1				0.00				
10	2				0.00				
11	3				0.00				
12	4				0.00				

Click the “Import SQL Lake Levels” button. This will automatically copy and paste the date, time, and lake levels from the USGS Lake Conroe gage data stored in SQL database for the specified duration.

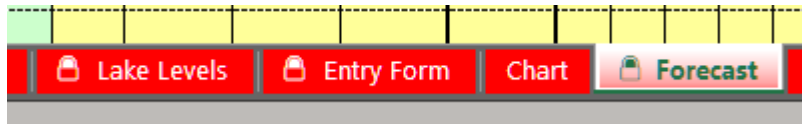
	A	B	C	D	K	L	M	N	
1	INPUT	Enter STAR	08/17/2020	00:00		or	Average over last	1	hours
2	OUTPUT	Enter END	08/22/2020	00:00			Average over last		entries
3	READING								
4	Date & Time		Raw Lake Level	Average Lake Level					
5			(ft-msl)	(ft-msl)					
6									
7									
8	1		2	3					
9	1				0.00				
10	2				0.00				
11	3				0.00				
12	4				0.00				

Change tabs to the “Entry Form” tab and note that the first date and time from the Lake Levels tab has been populated. The user can choose to update these values if needed. As a reminder, the “Entry Form” tab includes data definitions that only allow Date values defined in the “Lake Levels” tab. The user may select from a dropdown or manually type in the date. Time values must be input in the HH:MM format, ranging from 00:00 to 23:59. Data validation is applied that will prevent the user from applying an incorrect time format. Lake levels associated with the input time values are interpolated from the data on the “Lake Levels” tab.

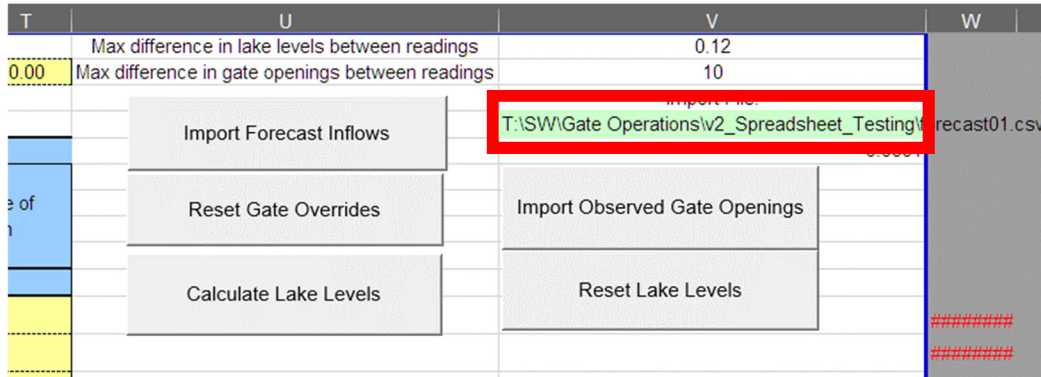
READING		
Date & Time	Average Lake Level	
	(ft-msl)	
	1	2
1	17-Aug-20 01:00	199.77

The “Entry Form” tab should be populated as the storm progresses in accordance with the current gate operations procedure, which remains unchanged as part of this project.

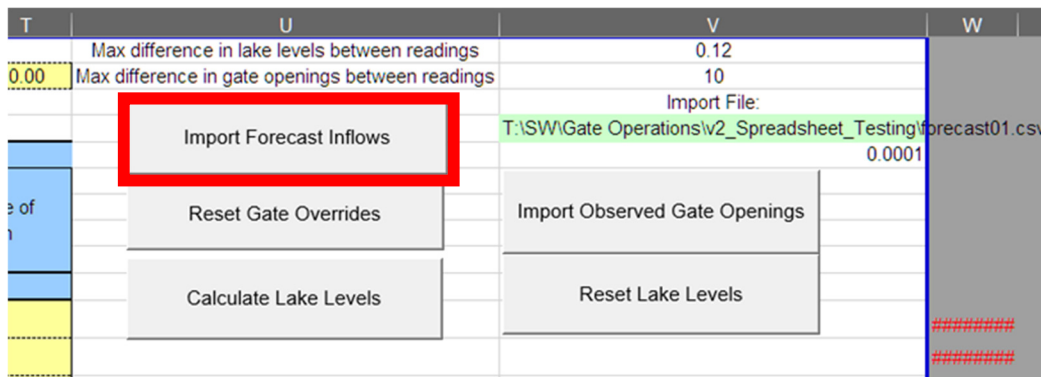
Change tabs to the “Forecast” tab to begin the process of forecasting.



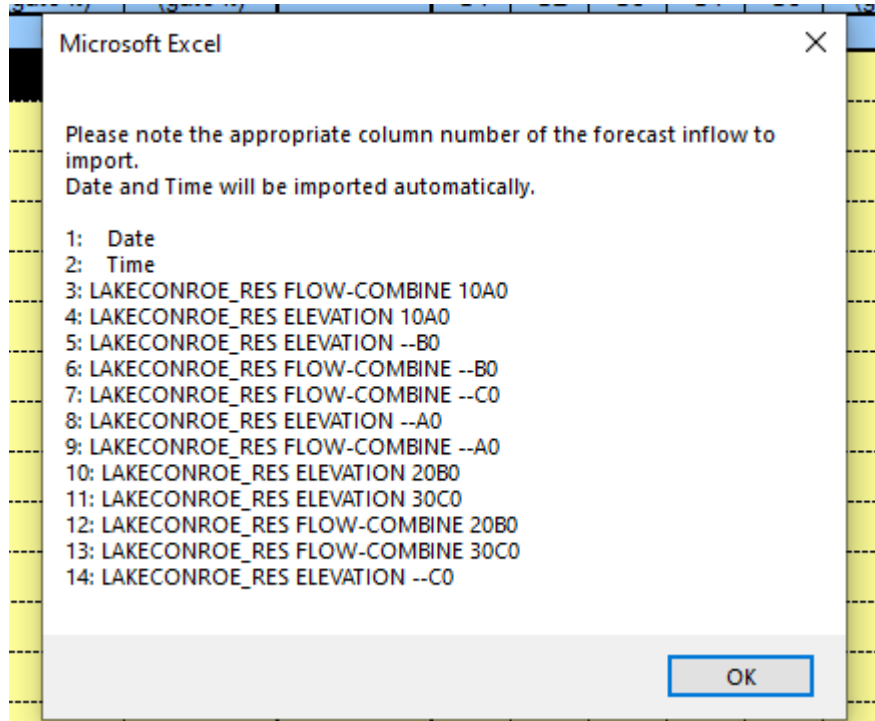
Update forecast.csv file path in cell V4 (if necessary).



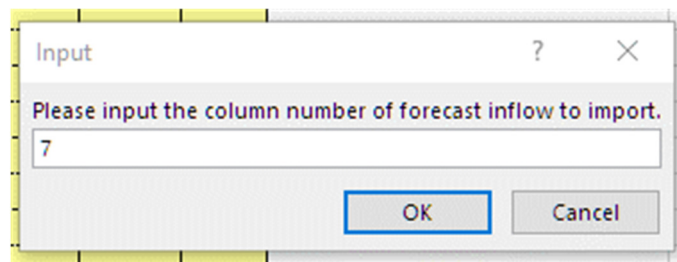
Click the “Import Forecast Inflows” button.



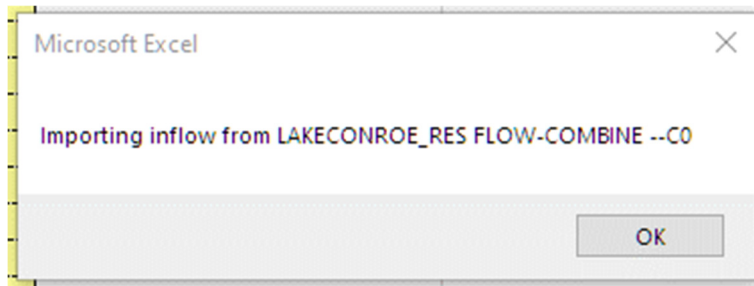
After clicking the “Import Forecast Inflows” button, a message box will display an enumerated list of column headers from the forecast.csv file in cell V4. The alpha-numeric designators at the end of each header (ex: “B0”) each correlate to a forecast run from HEC-RTS. The key for these designators can be found within HEC-RTS, in the Setup Module, under Models->Forecast Runs (as shown in the Setup Module section of the Reservoir Forecasting Tool Manual, under “Step 6: Model Setup”). After determining the number of the desired inflow scenario press the “OK” button. Note that only columns associated with flow should be selected.



Enter the column number of the forecast inflow to import and click “OK”. Date and Time will be imported automatically.



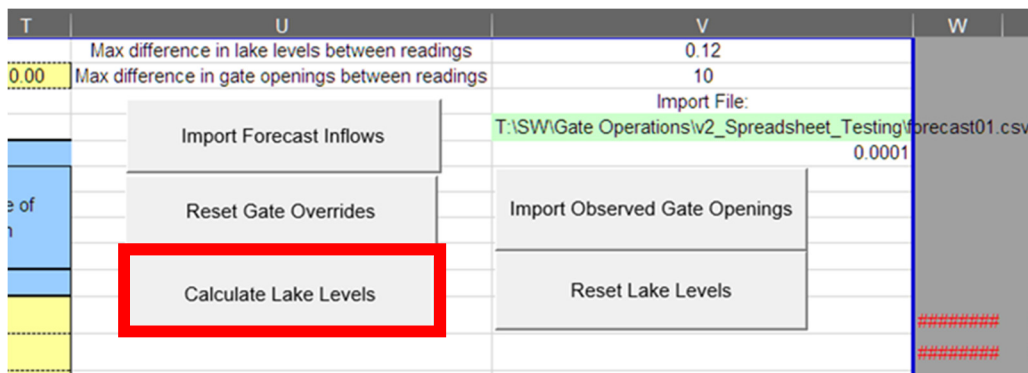
A confirmation message box will appear indicating the imported data set. Click “OK,” and the imported data will be imported to the “Total Inflow (cfs)” column.



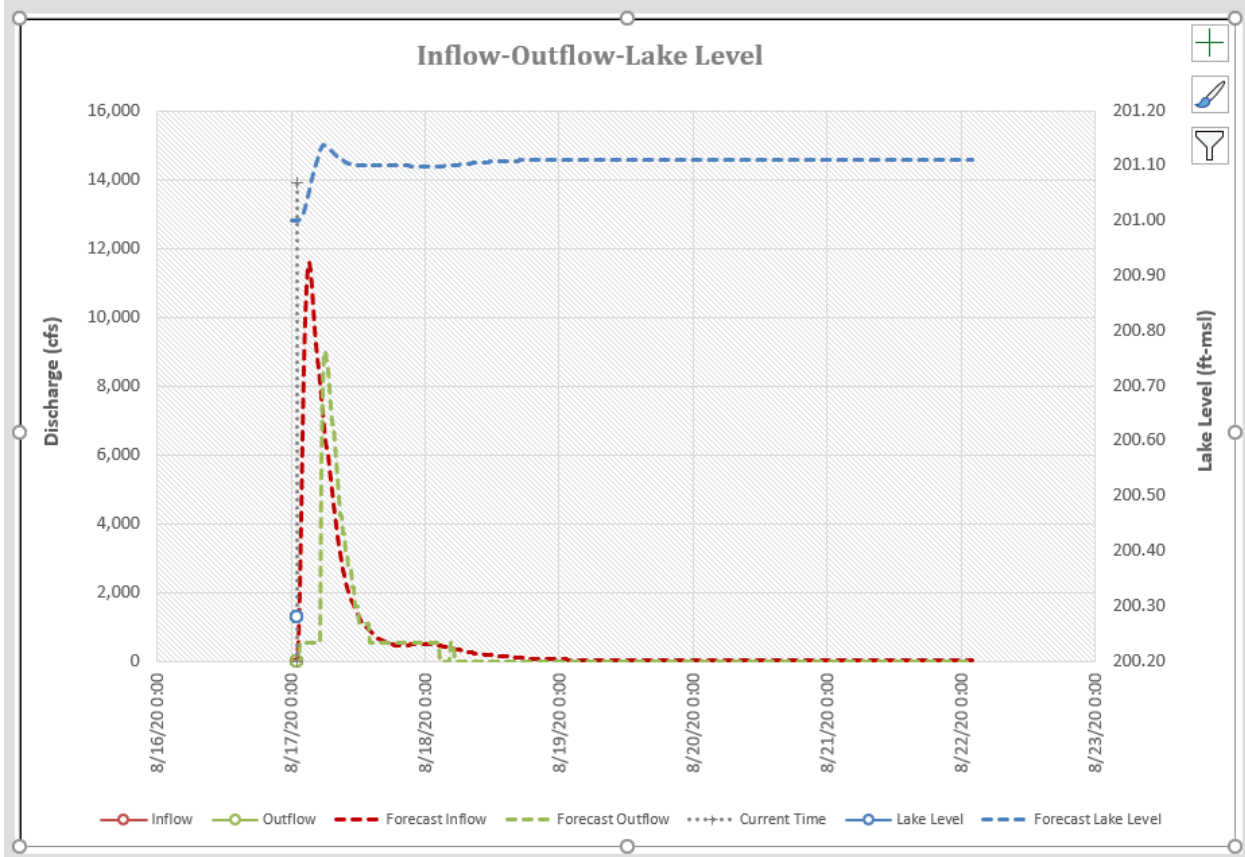
Once imported, the gate operations calculated for the forecast are considered invalid if the computed lake levels do not converge within the tolerance listed in Cell V5. The convergence is based on the underlying iterative calculations of lake level and outflow, which are interdependent throughout the forecast. These calculations take place on a hidden tab, “Calcs_FCST”. Make sure to update the initial lake level in Cell D11, which may become an automatic step in future updates to the tool.

READING				
	Date & Time	Current Lake Level (ft-msl)	Total Inflow (cfs)	
	1	2	3	
11	17-Aug-20 00:00	199.7700	0	
12	17-Aug-20 00:15	201.0000	0	
13	17-Aug-20 00:30	201.0000	1	

Click the “Calculate Lake Levels” button to compute predicted lake levels and verify all computed lake levels are within the specified tolerance (Sheet “Forecast”, Cell V5).



The screen will flash gray and Excel will be unresponsive until the subroutine finishes computing. In tests, this was approximately 5 seconds. Once complete, the screen will change automatically to the “Chart” tab, where the user may review the forecast gate operations, inflow, and lake level results compared to the observed values entered on the “Entry Form” tab. At this point, the user has a forecast that is valid, and simply needs to be reviewed for consistency.



Following the review of the chart, the user may return to the “Forecast” tab and make any changes to the forecast operations on an as-needed basis. The user should verify that forecast inflows and lake levels are consistent with observed inflows and lake levels for the lookback period (start of the event through to the current/forecast time). If the observed inflows and lake levels are inconsistent with the forecast values, the user may need to re-run the forecast in HEC-RTS after making slider adjustments to develop more consistent inflows for the lookback period.

By default, the Gate Override column is referencing the Target column, but can be modified with any valid gate opening value (i.e. non-arbitrary gate opening values). Forecast gate openings should use the same increments as would be used for gate operations — generally 0.5’ to 1’ increments. This technique can be used to analyze a “what-if” scenario.

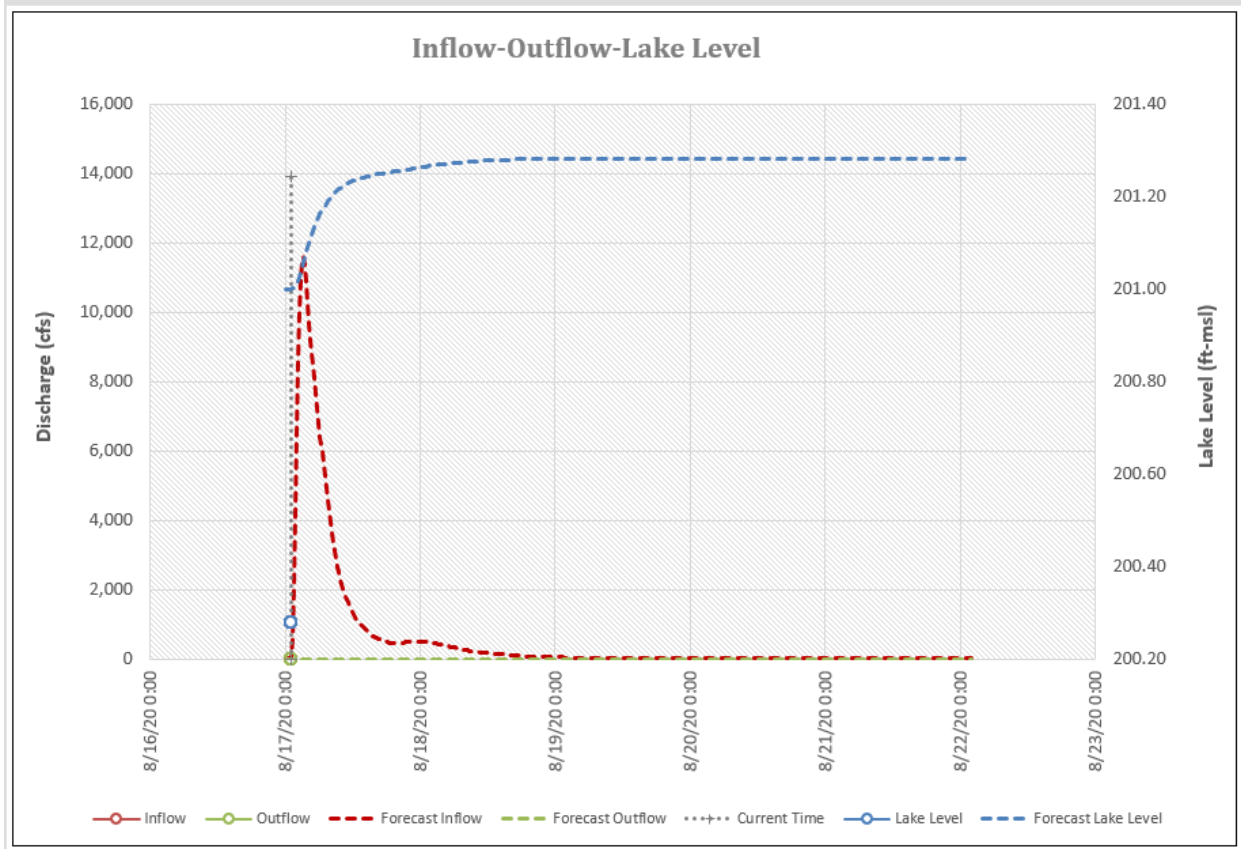
Note that as forecast durations are extended beyond the original forecast duration, it may be necessary to click the “Reset Lake Levels” button. This button resets the initial estimate of lake level to 201 for all timesteps. This should be followed by clicking the “Calculate Lake Levels” button to produce a valid forecast. This step should also be followed whenever the calculations produce a series of #VALUE calculations on the Forecast tab.



As an example of a “what-if” scenario, the following step shows how to set all forecast release overrides to 0 to see if the gates will be overtopped by not releasing. When a gate override is used, the cell will be highlighted yellow. If the gate override value differs from the calculated Target release value, the number text will be red. As shown below, the gate override has been set to 0 for the duration of this example forecast.

READING		Total Inflow (cfs)	Asc. / Desc (A/D) Inflow	RECOMMENDED OPENING			GATE OVER-RIDE	Individual Ne (ft)	
Date & Time	Current Lake Level (ft-msl)			MIN Gate Opening (gate-ft)	TARGET Gate Opening (gate-ft)	MAX Gate Opening (gate-ft)		G1	G2
1	2	3	4	5	6	7	7.1		
17-Aug-20	00:00	201.0000	0						
17-Aug-20	00:15	201.0000	0	D	0.00	0.0	0.00	0.00	0.00
17-Aug-20	00:30	201.0000	1	A	0.00	0.0	0.00	0.00	0.00
17-Aug-20	00:45	201.0000	2	A	0.00	0.0	0.00	0.00	0.00
17-Aug-20	01:00	201.0000	3	A	0.00	0.0	0.00	0.00	0.00
17-Aug-20	01:15	201.0003	567	A	0.00	0.0	0.00	0.00	0.00
17-Aug-20	01:30	201.0016	2,051	A	0.50	0.5	0.50	0.00	0.00
17-Aug-20	01:45	201.0043	4,126	A	0.50	0.5	0.50	0.00	0.00
17-Aug-20	02:00	201.0089	6,506	A	0.50	0.5	2.50	0.00	0.00
17-Aug-20	02:15	201.0157	8,588	A	0.50	0.5	3.50	0.00	0.00
17-Aug-20	02:30	201.0242	9,992	A	0.50	0.5	4.00	0.00	0.00
17-Aug-20	02:45	201.0338	10,876	A	0.50	0.5	4.50	0.00	0.00
17-Aug-20	03:00	201.0441	11,429	A	0.50	0.5	4.50	0.00	0.00
17-Aug-20	03:15	201.0547	11,595	A	0.50	0.5	4.50	0.00	0.00
17-Aug-20	03:30	201.0653	11,352	D	0.50	0.5	4.50	0.00	0.00
17-Aug-20	03:45	201.0755	10,875	D	0.50	0.5	4.50	0.00	0.00
17-Aug-20	04:00	201.0852	10,258	D	0.50	0.5	4.50	0.00	0.00

As described earlier, the calculated lake levels will not be valid with any change to date, time, inflow, or gate override. To have a valid forecast, the user must click the “Calculate Lake Levels” button again.

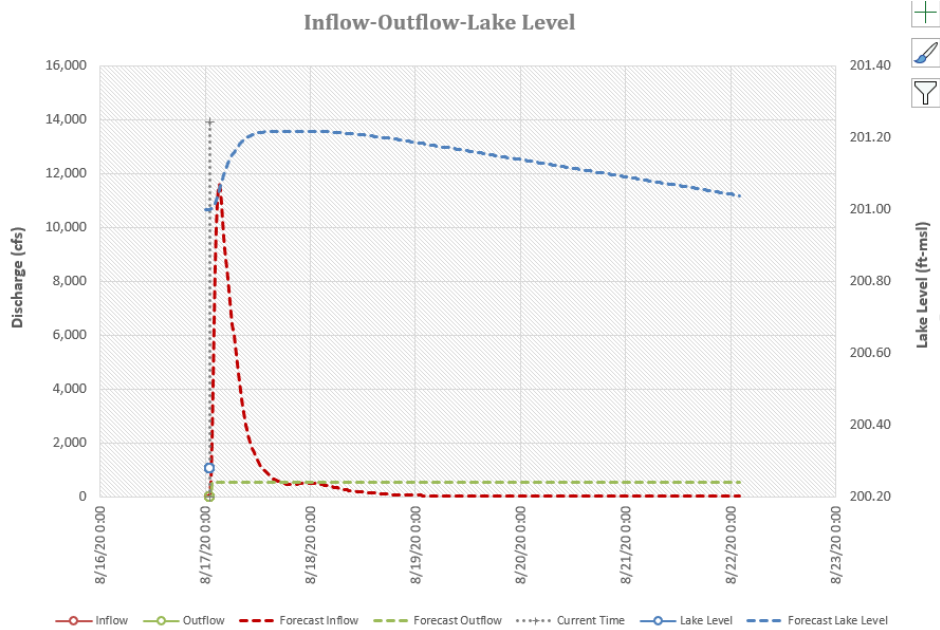


Continuing with the example, using the gate override of 0 for the entire forecast results in a maximum lake level of 201.28, indicating that there may be no need based on the HEC-RTS forecast inflows to open the gates to prevent their overtopping. This is not an explicit reason for not opening gates but allows the operator to know in advance that this is a potential outcome if within the protocol range.

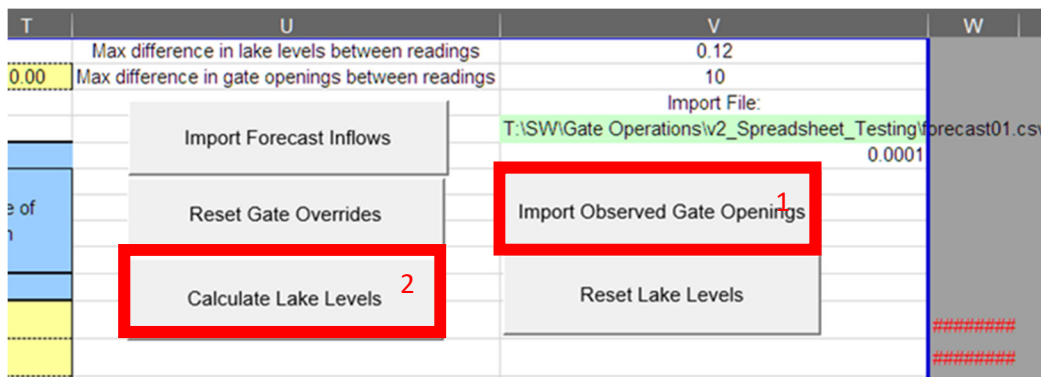
As another example, if keeping the gates closed is not desirable, the user can click the “Reset Gate Overrides” button, then the “Calculate Lake Levels” button to revert to the default Target operations curve.

T	U	V	W
	Max difference in lake levels between readings	0.12	
0.00	Max difference in gate openings between readings	10	
		Import File:	
	Import Forecast Inflows	T:\SW\Gate Operations\lv2_Spreadsheet_Testing\precast01.csv	
		0.0001	
	Reset Gate Overrides 1	Import Observed Gate Openings	
	Calculate Lake Levels 2	Reset Lake Levels	
			#####
			#####

Proceeding with this example, assume a maximum gate opening of 0.5 feet is desirable and update the gate override to 0.5 feet for some time after the inflow drops below the 0.5 gate-foot discharge (approximately 520-530 cfs). In the following example, this has been continued for the remainder of the forecast. As a reminder, the “Calculate Lake Levels” button must be pressed again to have a valid forecast.



As an event progresses, actual gate openings should be incorporated into the forecast. The “Import Observed Gate Openings” button provides this functionality. By clicking this button, the user activates a script that reads the observed gate openings from the “Entry Form” tab and translates the actual gate opening values to the “Forecast” tab in the “Gate Overrides” column. Gate openings are applied at the first timestep greater than or equal to the actual operation timestep. Once the gate openings are updated, the user must click the “Calculate Lake Levels” button to update the forecast.



Once a satisfactory forecast is produced, save the spreadsheet. To perform a subsequent forecast based on new data, repeat the above steps.

Reservoir Forecasting Tool

Appendix D – GIS and Support Data

(DIGITAL SUBMITTAL)