New Modeling Capability in HEC-HMS

By Matthew Fleming, P.E.[1]

[1] Hydraulic Engineer, U.S. Army Corps of Engineers, Institute for Water Resources, Hydrologic Engineering Center, 609 Second Street, Davis, CA 95616; 530-302-3701; matthew.fleming@usace.army.mil.

Abstract

The Hydrologic Modeling System (HEC-HMS) is developed by the U.S. Army Corps of Engineers, Hydrologic Engineering Center. Many new capabilities have been released in recent software versions. This paper will document a few of the new modeling capabilities released recently and new software capabilities that provide improved control for results generation and visualization.

The Meteorologic Model underwent a major change starting in HEC-HMS version 4.9. An effort was made to streamline the meteorologic model and solidify its purpose as a meteorologic data provider to the Basin Model. For example, snow accumulation and melt were moved to the basin model since this is a land surface process. No longer do modelers have to define the same meteorologic data multiple times for different processes, like temperature data for evapotranspiration and snowmelt processes. Flexibility was also added where gridded and non-gridded data can be utilized within the same meteorologic model. Finally, a new Interpolation option was added to options within the meteorologic model and includes options for bias and lapse adjustments.
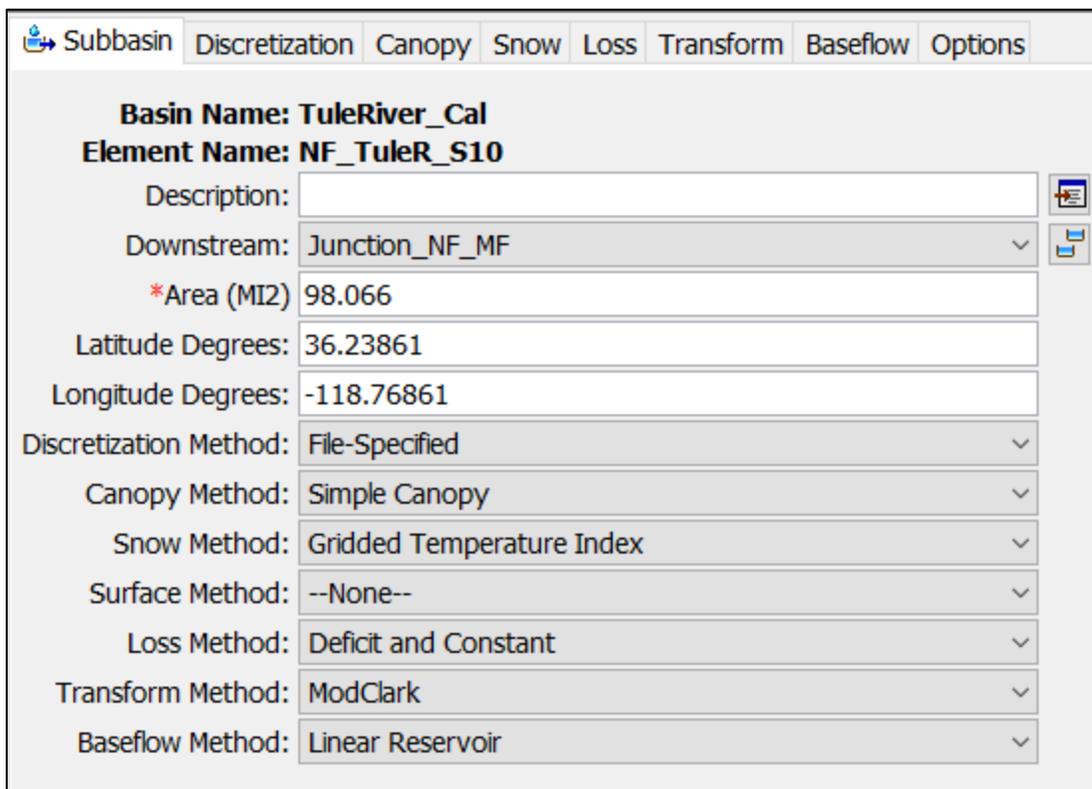
HEC-HMS has included a reservoir modeling component since the first version; however, modeling of reservoir storage and outflow was limited to structures that could be modeled using uncontrolled releases. Uncontrolled releases mean discharge is computed based on the elevation/storage and outlets in the reservoir element, regardless of the state at any other element in the model. The ability to model reservoir releases in a controlled manner was added to HEC-HMS version 4.11. The new controlled release option allows modelers to define target elevation/storage values for a reservoir component and flow targets (minimum/maximum values) at elements within the basin model. The program will go through several iterations to identify reservoir releases that meet the operation and flow targets.

Results visualization is key to understanding model results and performance. New capabilities have been added to HEC-HMS that allow the modeler to customize how model results are saved and how boundary condition data and model results, including time-series, gridded, and statistical metric results, are displayed. Spatial results allow modelers to see how precipitation and other meteorologic data fall on the watershed, and the spatial results can be viewed as gridded or subbasin average values. Tools allow modelers to plot individual grid cell information, export spatial results as raster datasets for further analysis, and to create animations for presentations. Finally, improvements made to time-series plots make it easier to create report quality plots directly from the software.

The HEC-HMS Meteorologic Model

Within HEC-HMS, the meteorologic model computes boundary conditions for the basin model. For most modeling applications, the boundary condition is subbasin average or gridded precipitation. Over time, more options were added to the meteorologic model to support continuous simulation. For example, options for computing potential evapotranspiration and snowmelt were added to the meteorologic model. The meteorologic model underwent a major change starting in HEC-HMS version 4.9. An effort was made to streamline the meteorologic model and solidify its purpose as a meteorologic data provider to the Basin Model.

Snow accumulation and melt were moved to the basin model since this is a land surface process. As shown in Figure 1, you can select a snow method from the main subbasin component editor. Options include gridded and elevation band approaches for the temperature index, energy balance, and hybrid methods. Boundary condition, like temperature, radiation, and others are passed from the meteorologic model to the snowmelt method.

Figure 1. Subbasin component editor with snow method

No longer do modelers have to define the same meteorologic data multiple times for different processes, like temperature data for evapotranspiration and snowmelt processes. Figure 2 shows the Component Editor for a meteorologic model. Notice there are options for computing subbasin average or gridded meteorologic time-series for shortwave and longwave radiation, precipitation, temperature, windspeed, air pressure, dew point, and potential evapotranspiration. When you open the component editor for the Evapotranspiration and Snowmelt models, you will no longer see a requirement to specify temperature. Both evapotranspiration and snowmelt options look for the temperature dataset (time-series or gridded) computed by the meteorologic model.
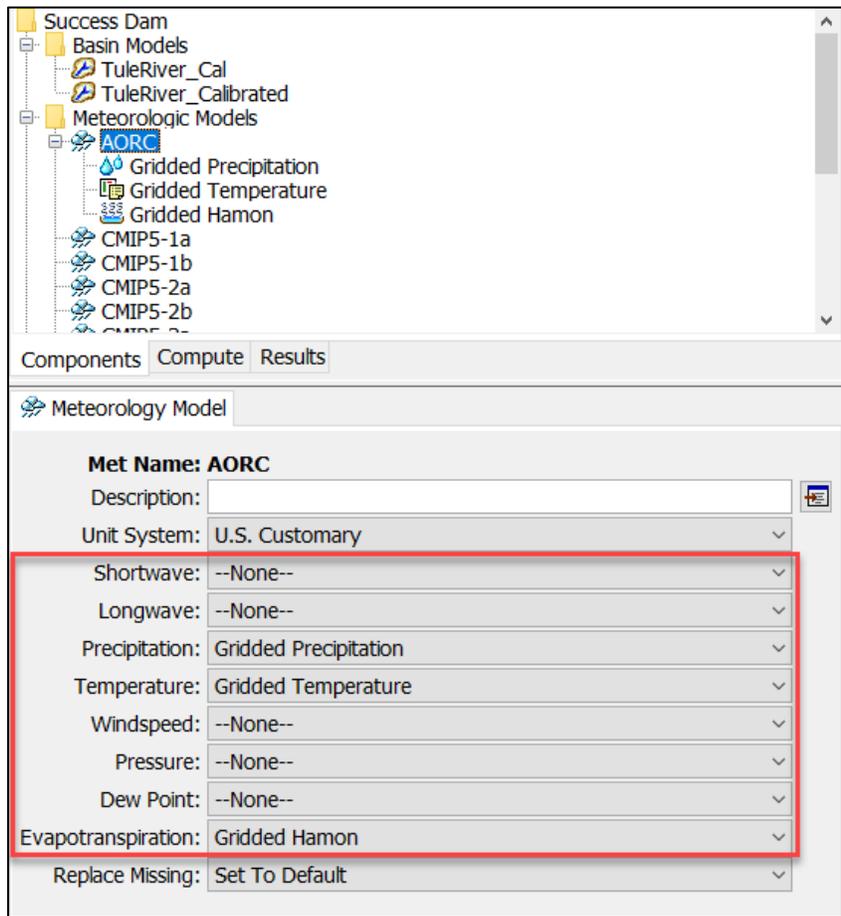
Figure 2. Example HEC-HMS meteorologic model

Flexibility was added where gridded and non-gridded data can be utilized within the same meteorologic model. For example, you can use gridded precipitation and temperature with a non-gridded evapotranspiration method. Or, you can make use of the new gridded interpolation option added for each of the meteorologic time-series. The interpolation user interface includes options for the interpolation method and bias and lapse adjustments. Figure 3 shows the Component Editor for interpolating precipitation gages to create precipitation grids. There is a bias option which when selected allows you to choose a grid for the bias adjustment. You are also able to add available precipitation gages and choose the radius of influence used for the interpolation calculations.
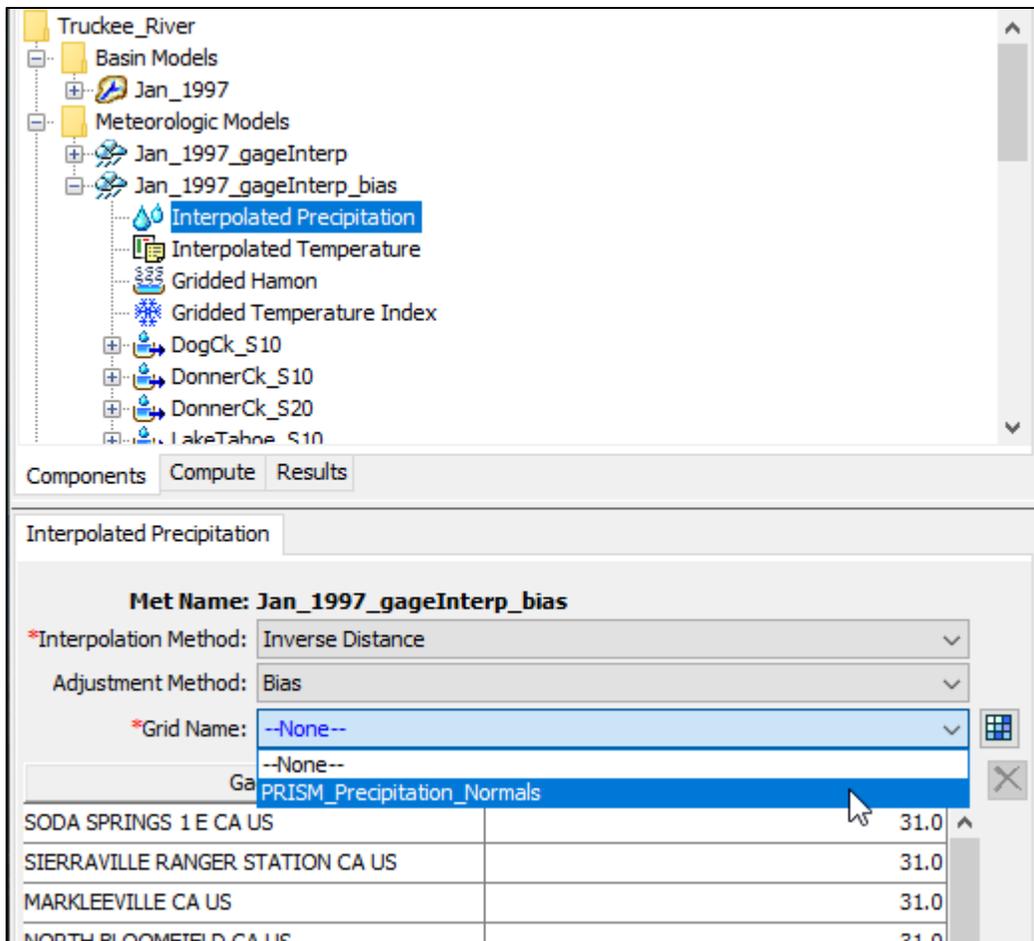
Figure 3. The new Interpolated Precipitation option

The HEC-HMS Reservoir Element

Historically, the HEC-HMS reservoir element could only be used to model reservoir storage and discharge in uncontrolled systems. HEC-HMS included options to model a reservoir using a storage-discharge curve, uncontrolled structures (outlets, spillways, pumps, and others), or a user specified release time-series from the reservoir. The ability to model reservoir releases in a controlled manner was added to HEC-HMS version 4.11. Uncontrolled releases mean discharge is computed based on the elevation/storage, outlets in the reservoir element, and user defined rules.

The new rule-based option allows modelers to define target elevation/storage values for a reservoir component and flow targets (minimum/maximum values) at elements within the basin model. The HEC-HMS rule-based option are limited and initially include releases based on minimum and maximum flows and rate of change rules. For complex system operation, or operations that evaluate complex criteria for flood, irrigation, and environmental releases, HEC-ResSim contains flexible capabilities.

The HEC-HMS reservoir element can have both controlled and uncontrolled outlets. An uncontrolled outlet might be a spillway with no gates. The new reservoir operations are designed to work with outlets that have gates which can be operated. A new Outlet type was added to HEC-HMS version 4.11 that allows the program to automatically adjust gate opening to meet release targets. The component editor for

an Outlet with the General Outlet and Adjustable Gate Control methods is shown in Figure 4. Eventually, gate adjustment options will be added to the other HEC-HMS reservoir outlet types. As shown in Figure 4, the minimum and maximum discharge rating curves are defined to bound possible releases from the General Outlet. You can create multiple general outlets or combine possible operations into one general outlet. Figure 5 shows typical elevation-discharge rating curves for a gated outlet. For this example, you would use the maximum opening curve to define the upper bound of the outlet's discharge. The minimum bound could be an elevation-discharge curve that contains minimum downstream channel flow. The minimum time between adjustments is a user setting that can be used to model the frequency when gate changes are made. Figure 4 shows gates will only be adjusted when the time since the last gate adjustment exceeds one day.

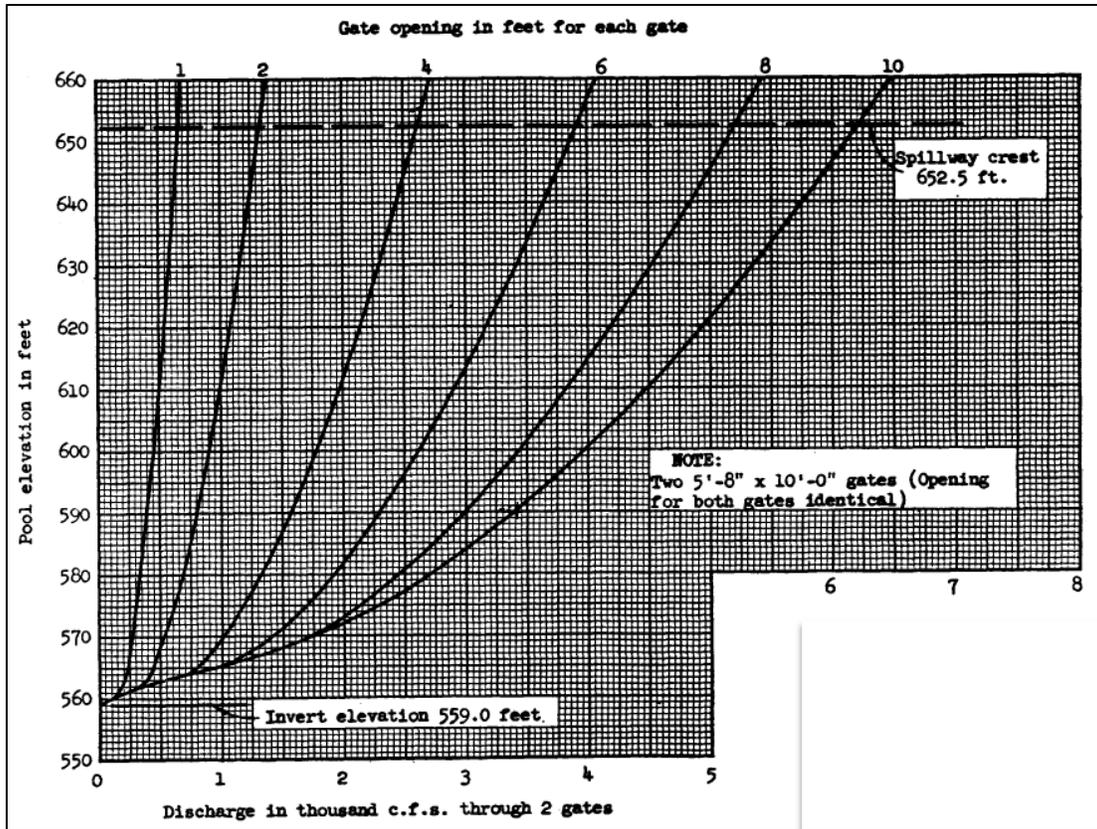**Figure 4. New general outlet with adjustable gate control method**

Figure 5. Elevation-discharge curves for gated spillway

Zones, storage objectives, and rules can be configured to approximate releases from reservoirs with controlled operations. As shown in Figure 6, you can define the number of operational zones. A zone is defined by a daily elevation curve and a storage objective along with rules that guide how releases are made to keep the reservoir at the storage objective. In many cases, the storage objective is the reservoir's guide curve.
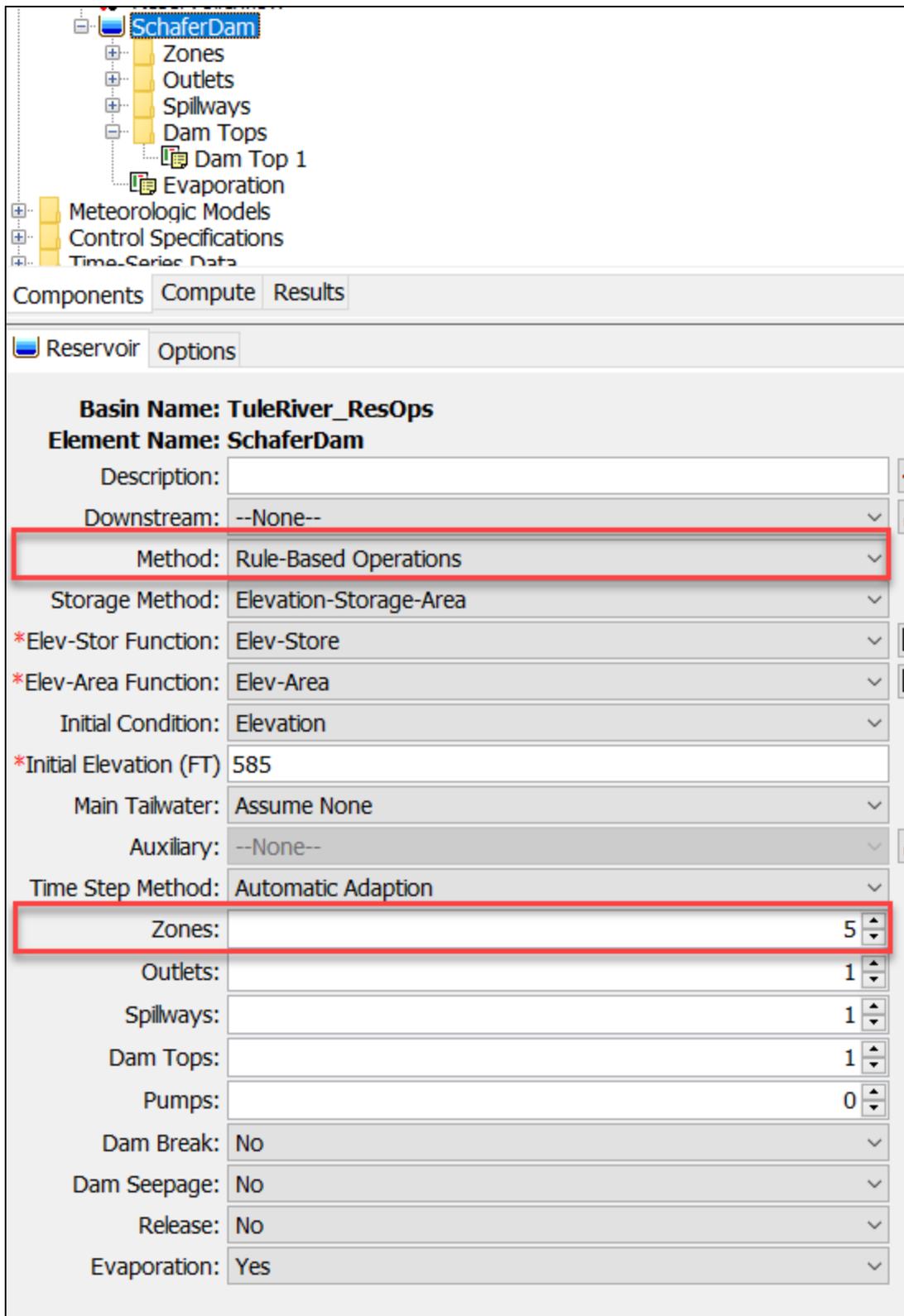
Figure 6. Reservoir component editor with rule-base operations chosen and five zones selected

Figure 7 shows an example reservoir configuration where the black line (solid and dashed) represents the elevation (converted to storage for the storage objective)

where operators try to maintain the reservoir elevation/storage. Each zone contains different release criteria used to guide releases in order for the computed reservoir storage to match the storage objective. In this example, the guide curve represents seasonal operations where the pool is drawn down for winter floods and then allowed to fill with spring/summer snowmelt. Zone 1, from July 1 – September 30, represents a period where water is released for irrigation.
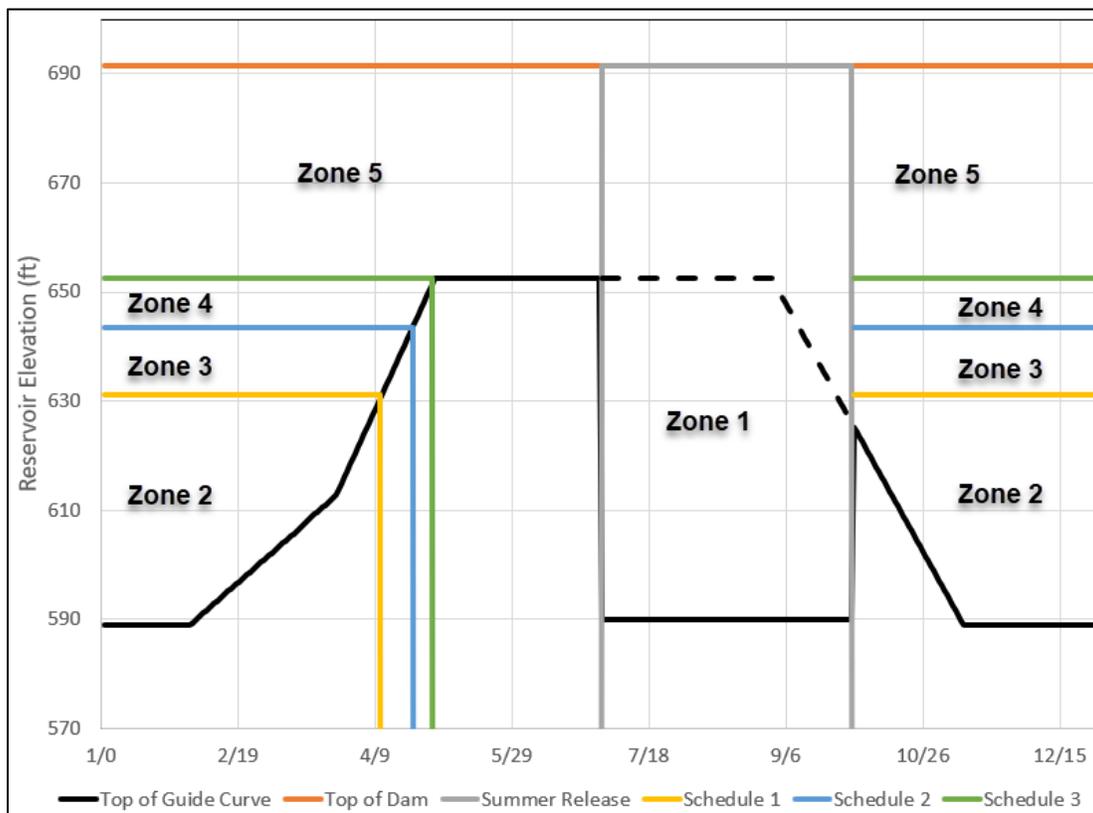

Figure 7. Example elevation zones for seasonal operations

Within HEC-HMS, a daily elevation pattern would be created for the top of each of the zones shown in Figure 7. A daily elevation pattern is new in HEC-HMS version 4.11. The daily elevation pattern is a paired data curve that has an entry for each day of the year (01Jan-31Dec). If the entry is left blank for a date, then the reservoir will not use that Zone for operations for that date.

In addition to the daily elevation pattern, each zone must have a storage curve and at least one rule. The storage curve, used to define the storage objective, is added to HEC-HMS as a Storage Pattern paired data curve. Figure 8 shows an example storage pattern curve with a seasonal pattern. The rules can be minimum and maximum releases, maximum rate of flow change, and minimum and maximum downstream flow rules (any element downstream of the reservoir). The rules are used to guide releases to meet the storage objective. Figure 9 shows the watershed explorer and different rules, rule one – rule three, for each of the five zones in an example application.
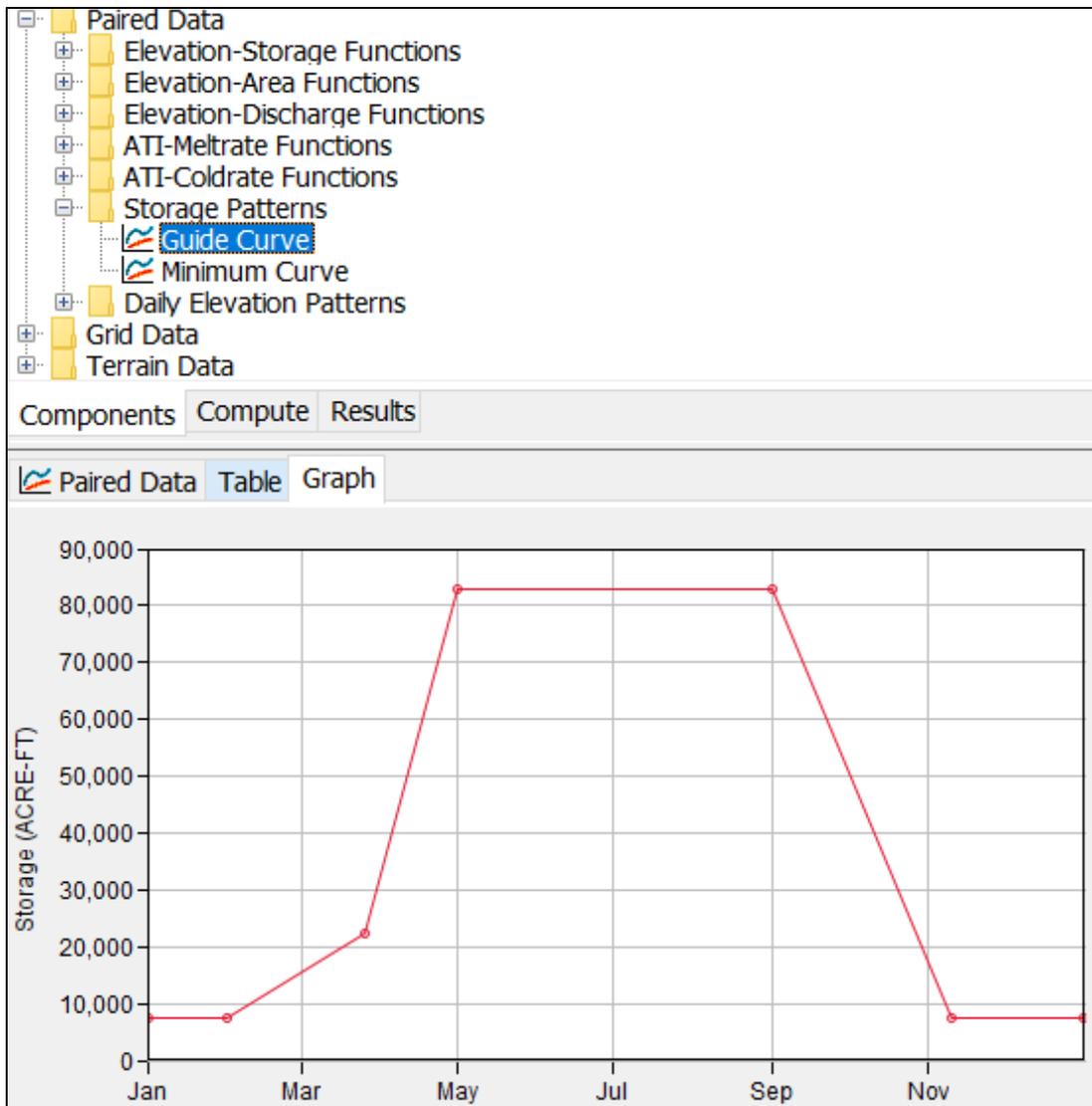
Figure 8. Example storage pattern curve used for a zone's storage objective
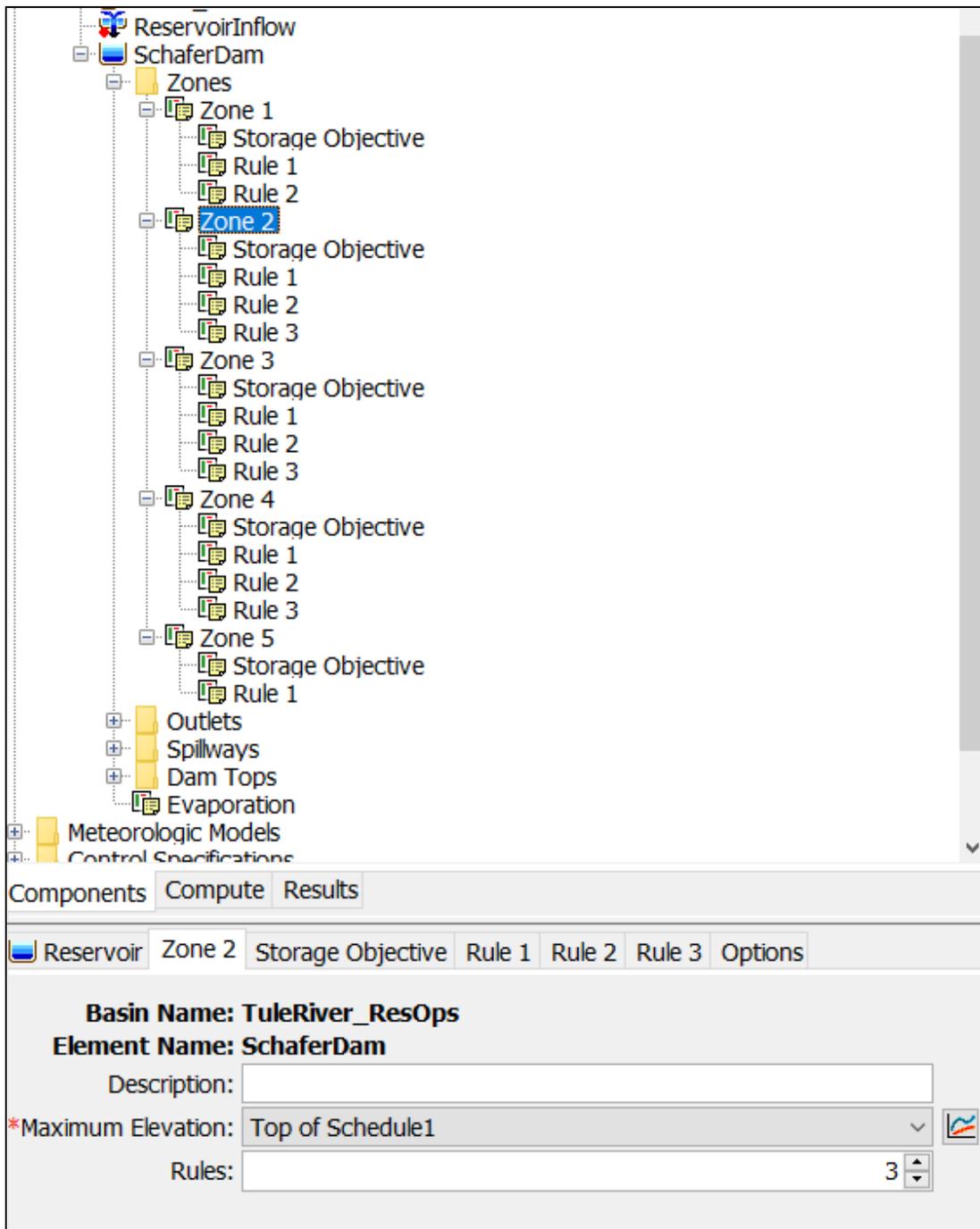
Figure 9. Zone component editor

Figure 10 shows results from an example simulation where the new reservoir operations were used to approximate releases from a reservoir with complex operations. The black lines are observed reservoir elevation, upper plot, and observed reservoir outflow, lower plot. The results show the model can approximate flood flows January – March 2017, when the computed storage was above the storage objective in zones 2, 3, and 4. Maximum releases from the reservoir are allowed to increase as the reservoir's storage increases above the storage objective. Releases in the July – September period approximate irrigation withdrawals from the reservoir while taking the reservoir down to the bottom of the conservation storage. You will

notice HEC-HMS makes several releases the spike up and ramp down (because the program is attempting to keep the reservoir storage at the storage objective). As shown by the observed results, actual reservoir operations hold reservoir releases constant over multiple days, and there is some allowance for deviating from operations when forecasted inflow into the reservoir is low.
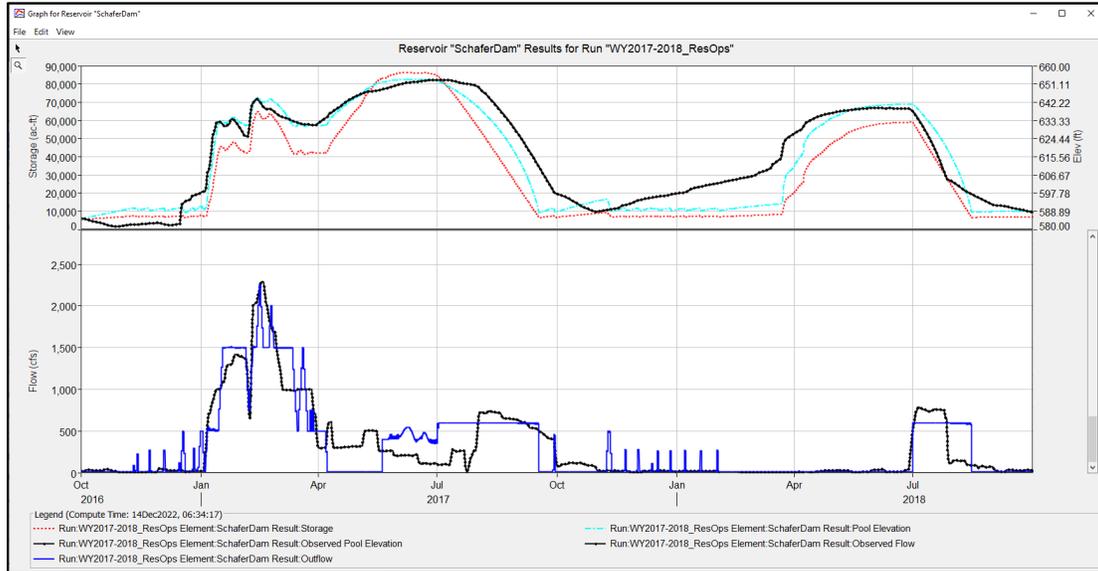

Figure 10. Results plot from a reservoir configured to use the rule-based operations method

Results Visualization HEC-HMS

New capabilities have been added to HEC-HMS that allow the modeler to customize how model results are saved. In addition, new options have been added to HEC-HMS that allow the modeler to visualize boundary condition data and model results, including basin average, gridded, and statistical metric results. Finally, improvements have been made to time-series results plots that aid modelers in analyzing results.

Figure 11 shows the Component Editor for a Simulation Run. There are three options for saving time-series results from an HEC-HMS simulation. The All option is the default selection and will save all results for each element in the basin model using the simulation time step. When the Minimal option is selected, only boundary condition data (from the meteorologic model) and flow results are saved for each element in the basin model using the simulation time step. Finally, the Selected option allows you to choose which results are saved to the output DSS files, these results are in addition to the minimum results. As shown in Figure 12, there are options to filter the list of results based on the element name or the time-series type. There is also an option to change the output interval. By default, the simulation time step is selected.
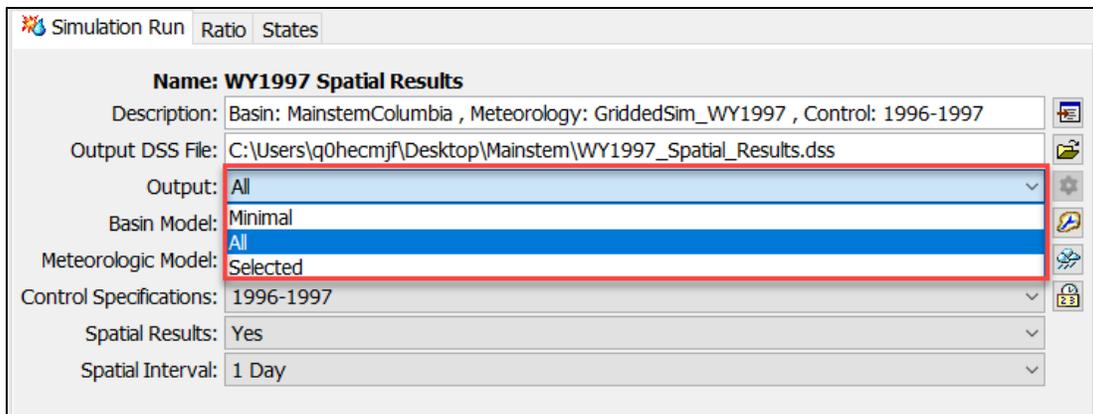
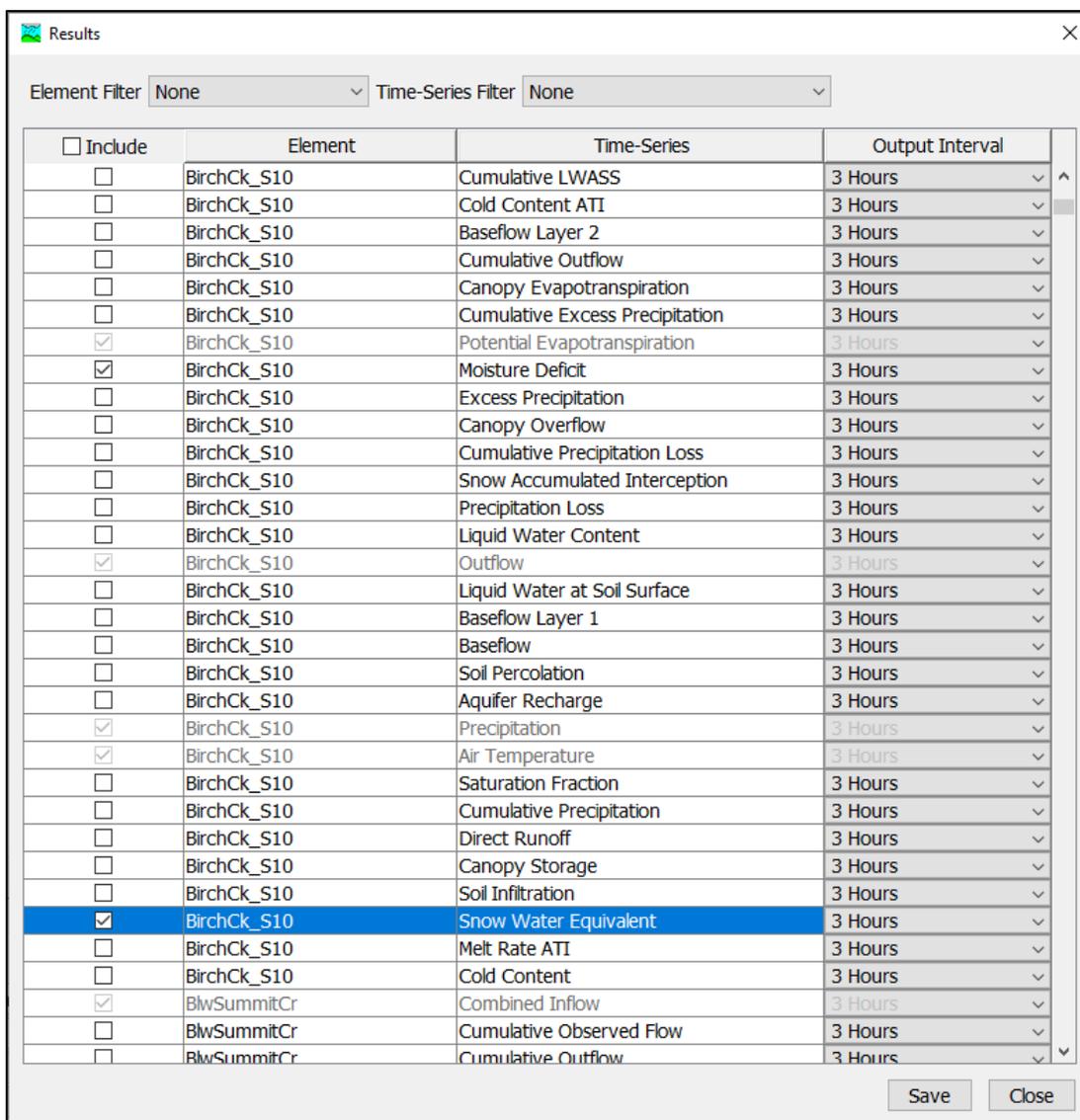**Figure 11. Output options for a simulation**

Figure 12. Custom output editor

Spatial results were recently added to HEC-HMS. Spatial results allow modelers to see how precipitation, and other meteorologic data and simulation results are

distributed across the watershed. The spatial results can be viewed as gridded or subbasin average values. Figure 13 shows where you turn on spatial results from the Simulation's Component Editor. By default, the spatial interval is set to the simulation time step, but you can increase the time interval up to 1 Day to reduce the amount of results saved for the simulation.
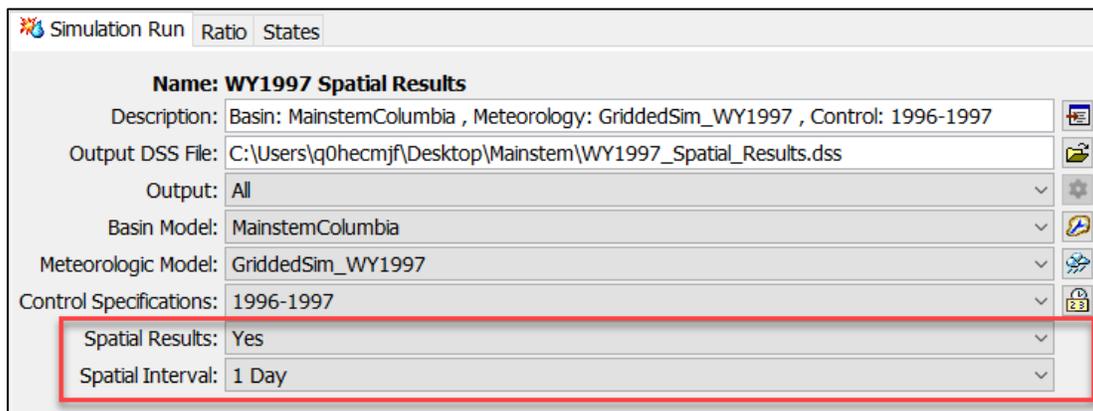

Figure 13. Spatial results option

Tools allow modelers to plot individual grid cell information, export spatial results as raster datasets for further analysis, and to create animations for presentations. Figure 14 shows Air Temperature selected from the Spatial Results toolbar. The progress bar was advanced to January 26, 1997. The gear icon within the spatial results toolbar opens a display properties editor that allows you to modify how the spatial data is displayed. There are options from the View menu to turn on a north arrow, scale bar, and spatial results legend.

There are also animation controls that let you play an animation of the computed results. Tools are available to control the animation speed. The Min and Max buttons show plots of the minimum or maximum values for each grid cell.
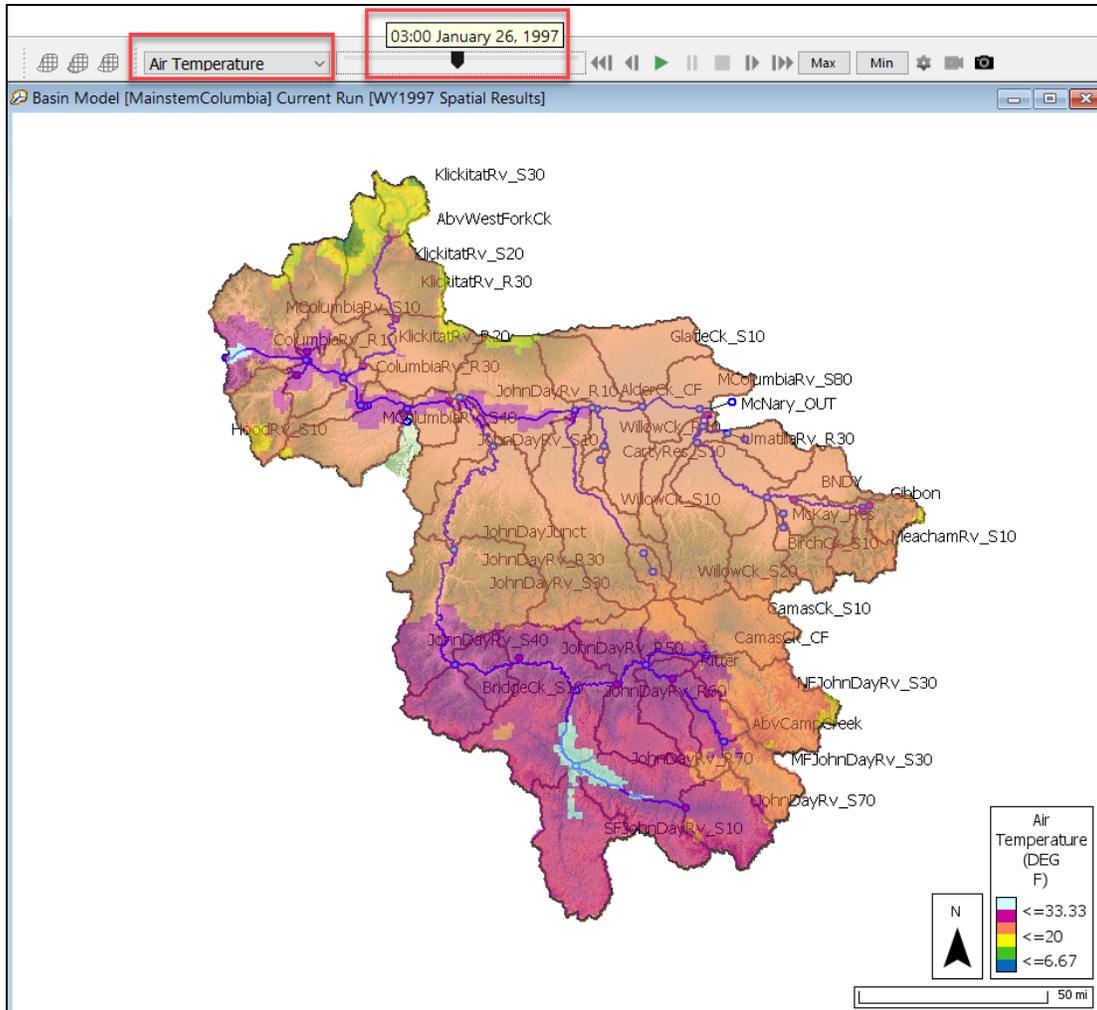
Figure 14. Gridded air temperature displayed in the basin model

As shown in Figure 15, the tool tip will display the grid cell value as you hover the mouse pointer on the spatial results. You can open a plot and table by right clicking on a grid cell and choosing the Plot Spatial Results option. Figure 15 shows air temperature for grid cell -972, 1419.
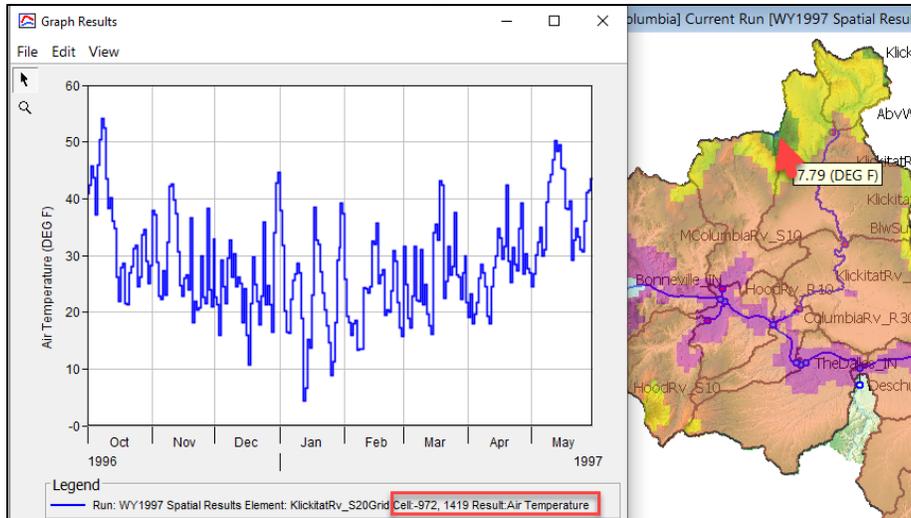
Figure 15. Air temperature plotted for one grid cell

Spatial results for flow and snow water equivalent statistical metrics are also available from the spatial results toolbar. Nash Sutcliffe Efficiency (NSE), Coefficient of Determination (R2), Root Mean Square Error / Standard Deviation (RSR), and Percent Bias (PBIAS) are displayed as subbasin average map layers. When plotting statistical metric results for snow water equivalent, results are only plotted for subbasins with observed SWE gages. When plotting statistical metric results for flow, the program groups subbasins above and between gages into "zones" and assigns the same statistical metric for all subbasins within the zone. Displaying the statistical metrics is a quick option for analyzing model performance and identify areas within the model where addition calibration should be performed.
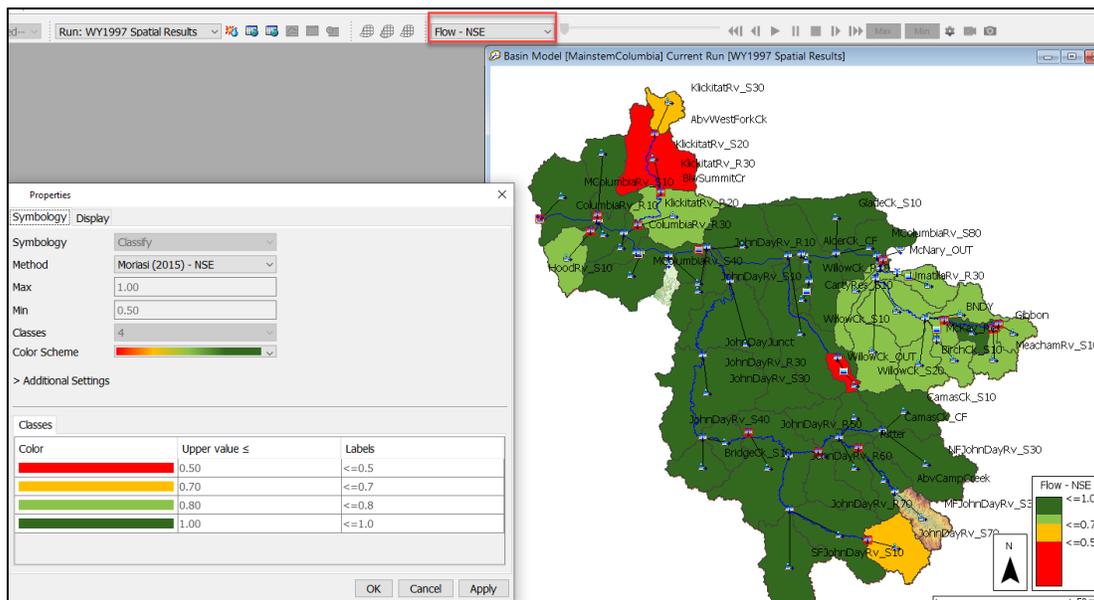

Figure 16. Displaying calibration metrics in the basin model

Finally, recent improvements made to time-series plots aid in analyzing model performance and make it easier to create report quality plots directly from the software. Improvements includes the ability to add and remove marker points and lines, modify line styles (including hiding results), and highlighting specific results

by selecting it in the legend. Changes to the plot now persist, even after recomputing a simulation. This means that if you zoom into a certain flood peak within a long time window the program will no longer snap the display window out to the entire simulation time window.
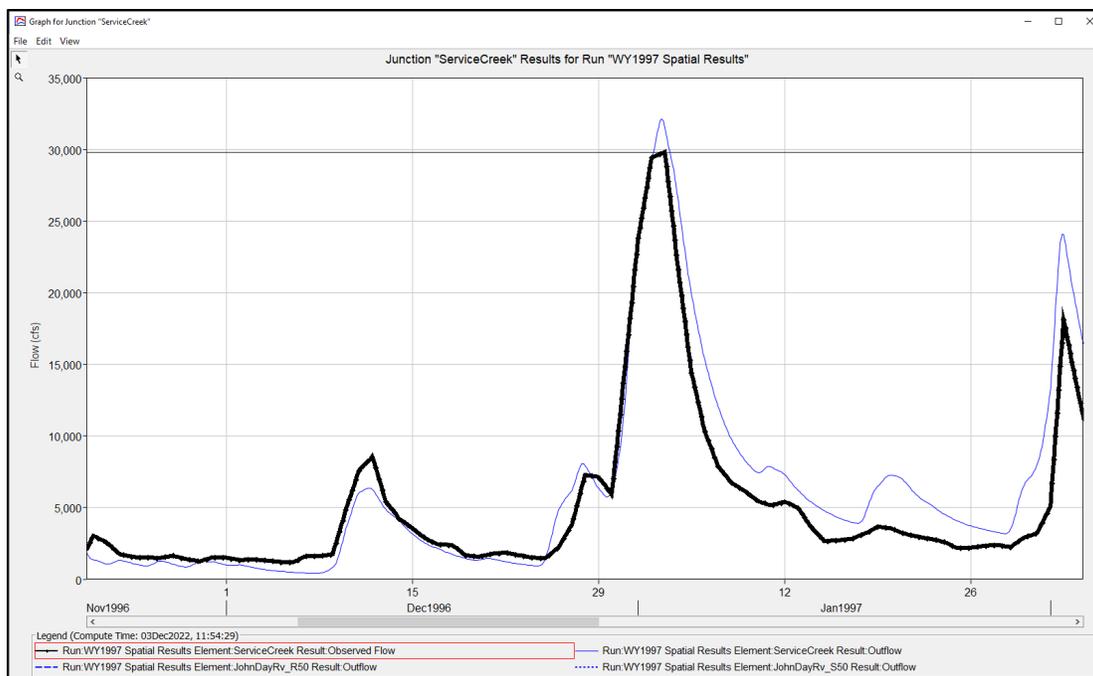

Figure 17. Improvements for time-series plots

Summary

Many new capabilities have been added to the HEC-HMS software recently. In addition to new simulation capabilities, the HEC-HMS software development team is adding capability to help modelers efficiently set up and run model simulations and evaluate model results. Many of the new capabilities have examples where you can download HEC-HMS project files and walk-through step by step instructions for using specific capabilities. You can access these examples from: https://www.hec.usace.army.mil/confluence/hmsdocs/hmsguides.

The HEC-HMS software development team would like to thank several programs and organizations for their support in adding the software features described in this paper. These programs include the USACE Science and Engineering Technology Program, the USACE CWMS National Implementation Program, the USACE Mississippi River Geomorphology and Potamology Program, the USACE Dam and Levee Safety Programs, the USACE Hydrologic Studies General Investigation Program, and FEMA.