![US Army Corps of Engineers logo]

**US Army Corps
of Engineers**®

Hydrologic Engineering Center

# Hydrologic Modeling System
# HEC-HMS

# *Release Notes*

Version 4.3
September 2018

## Hydrologic Modeling System HEC-HMS, Release Notes

2018.  This Hydrologic Engineering Center (HEC) Manual is a U.S. Government document and is not subject to copyright.  It may be copied and used free of charge.  Please acknowledge the U.S. Army Corps of Engineers Hydrologic Engineering Center as the author of this Manual in any subsequent use of this work or excerpts.

Use of the software described by this Manual is controlled by certain terms and conditions.  The user must acknowledge and agree to be bound by the terms and conditions of usage before the software can be installed or used.  For reference, a copy of the terms and conditions of usage are included in the *HEC-HMS User's Manual*, Appendix E so that they may be examined before obtaining the software.

This document contains references to product names that are used as trademarks by, or are federally registered trademarks of, their respective owners.  Use of specific product names does not imply official or unofficial endorsement.  Product names are used solely for the purpose of identifying products available in the public market place.

*Microsoft* and *Windows* are registered trademarks of Microsoft Corp.

*Linux* is a registered trademark of Linus Torvalds.

## *Introduction*

Version 4.2 of the Hydrologic Modeling System (HEC-HMS) was completed in August 2016 and released for general use shortly thereafter. An interim release called Version 4.2.1 was completed in March 2017 primarily to correct a number of errors.

A number of new capabilities have been under development since 2016. The most significant is the redesign of the optimization trial to support maximization and minimization problems. A new search method has also been added to the trial; Markov Chain Monte Carlo. This new search method provides probabilistic parameter estimates. There is a new reach routing method, enhancements to another, plus a new initial condition option for all routing methods. The Clark and ModClark transform methods offer new capabilities and it is now easier to work with gridded methods. There is a new shortwave radiation method in the meteorologic model and the Penman Monteith evapotranspiration method has been enhanced.

Users have reported some difficulties with several features. The development team has also continued careful and systematic testing of the program. The results of that testing in combination with reports from users have allowed the identification and repair of various problems. Some of these problems affected simulation results and are described in detail later in this document.

The combination of new capabilities and error corrections is this Version 4.3 release. It is currently available for the Microsoft Windows® operating system and the Linux® operating system.

The program has been designed to be easy to use. However, an understanding of how the program works is critical to producing accurate results. It is suggested that a new user read the *HEC-HMS Quick Start Guide* (Version 4.3 January 2018). The guide briefly describes the basic features of the program in enough detail to begin using it. The guide also includes a step-by-step tutorial.

## *Installation*

The installation package and all documentation are available on the HEC website at http://www.hec.usace.army.mil/. This new release is installed independently of any previous versions of the program so you will need to uninstall the previous versions if you do not wish to use them anymore. However, you may keep different versions of the program installed for parallel use or testing if you choose. This new version will automatically open projects developed with any previous version of the program. However, once a project has

been opened in Version 4.3, it will not be possible to open it with older versions of the program.

## *Windows*

The new installation package is designed to be easy to use. It will take you through the steps of selecting a directory for the program files and making other settings. Use the following steps to install the program on the Microsoft Windows® operating system:

1. Download the installation package from the HEC website to a temporary folder on the computer.

2. Run the installation program. In Windows Explorer, double-click the icon for the installation program. You must have administrator privileges to run the installer.

3. Follow the on-screen prompts to install the program.

## *Linux*

The installation package is delivered as a compressed TAR file. It has several dependencies that must be installed before extracting the installation package. The following commands can be used to configure the dependencies prior to extraction of the installation package.

### Red Hat Enterprise Linux 7

```
yum install libldb.i686 libXext.i686
libXrender.i686 libXtst.i686 libgcc.i686
libstdc++.i686
```

### Ubuntu 14.04

```
sudo apt-get install libc6-i386 libstdc++6:i386
libxtst6:i386 libxrender1:i386 libgcc1:i386
libxi6:i386
```

# New Capabilities

A total of eighteen notable new capabilities have been added to the program. Summary descriptions are given below.

## *Clark and Modclark Transform Parameters*

The subbasin element includes the Clark and Modclark transform methods, among others. Previous versions erased the parameter values when switching from Clark to Modclark, or from Modclark to

Clark methods. The parameters have exactly the same meaning in both methods. The parameter values are now automatically preserved when switching between these methods.

### Clark Transform Variable Parameters

Unit hydrograph theory assumes a linear relationship between precipitation and the runoff response. This assumption can lead to errors in timing and peak magnitude when simulating events that result from extremely large excess precipitation rates, such as the Probable Maximum Precipitation. For the Clark transform method, users now have the option of inputting tables relating time of concentration and storage coefficient to the excess precipitation. This allows for the user to recreate a non-linear runoff response when excess precipitation rates vary. These tables are entered in the paired data manager and then used in the Clark transform.

### Lag and K Routing

The Lag & K method is a hydrologic storage routing method based on a graphical routing technique that is extensively used by the National Weather Service (NWS) in their forecast modeling tools. The method is a special case of the Muskingum method where channel storage is represented by the prism component alone with no wedge storage, i.e. Muskingum X = 0. The lack of wedge storage means that the method should only be used for slowly varying flood waves. Like all hydrologic routing methods, it does not account for complex flow conditions such as backwater effects and hydraulic structures. The Lag term refers to the travel time for a flood wave to move downstream. The K term accounts for attenuation. Lag and K parameters can be entered as constants or variable. For variable Lag and K, Lag is entered as an Inflow-Lag paired data function and K is entered as an Outflow-Attenuation paired data function. Evaluation of historical flood hydrographs provides the basis for Lag and K relationships within a reach.

### Muskingum Cunge Tabular Cross Section

The Muskingum Cunge channel routing method has always included several conceptual cross section shapes: circle, trapezoid, triangle, and rectangle. There has also been an option for a simple 8-point cross section shape. The new tabular shape has been added so that complex cross section shapes can be represented as hydraulic property tables. The underlying equations require several properties as a function of flow depth: discharge, flow area, and top width. The conceptual shapes and 8-point shape compute these properties using basic hydraulic formulas or simple geometry formulas. Conversely, the new tabular shape takes these

properties as hydraulic tables specified by the user. The tables can be entered directly in the paired data manager as elevation-discharge, elevation-area, and elevation-width tables. There is also a special editor available from the Tools menu for entering all the tables simultaneously. From a practical perspective, these tables will usually be externally computed with the aid of a hydraulic model.

### *Normal Depth Routing*

A new channel routing method called Normal Depth uses the modified Puls method for performing a routing, but presents the user with parameters for normal depth calculations. The modified Puls channel routing method uses a curve of storage versus outflow plus a number of subreaches to perform routing calculations. The normal depth routing approach calculates storage versus outflow using Manning's equation for normal depth. This assumes a uniform normal depth throughout the channel. The normal depth approach calculates the number of subreaches by dividing the travel time by the simulation time interval.

### *Reach Routing Initial Conditions*

The reach element in the basin model includes a number of different hydrologic routing methods. All of these methods have used the same initial conditions. That is, the total inflow to the reach at the simulation start time is used as the initial conditions throughout the entire reach length. All of the routing methods have been enhanced to offer two choices for the initial conditions. It is still possible to use the total inflow at the start time. It is now also possible to specify the outflow from the reach at the start time. For this second choice, the initial conditions are set so that the outflow from the reach matches the specified value with a smooth transition to the total inflow at the upstream end of the reach.

### *Automatic Initial Reach Discharge in Forecasts*

The forecast alternative already includes special tools for automatically computing subbasin initial baseflow and reservoir initial pool storage using observed gage data. A new tool is now available to automatically compute reach initial outflow using observed gage data. The new tool is specially designed to work in conjunction with the new outflow initial condition for all routing methods. An observed flow gage can be selected for each reach element. Optional properties can be specified to screen the observed data for validity before using it during a forecast. The observed data is processed and automatically used as the initial

conditions in the reach.  An override option can be used at the discretion of the user if automatic processing does not produce good results.

### Hargreaves Shortwave Radiation

A new shortwave radiation method has been added to the meteorologic model.  The method uses only maximum and minimum temperature data along with latitude and longitude to compute shortwave radiation according to the methodology of Hargreaves and Samani, 1985, Eq. 2.  The adjustment coefficient, $k_{Rs}$, is set to a default value of 0.17 and can be adjusted by the user.  The new method can be used with gridded and non-gridded subbasins.

### Hargreaves Evapotranspiration

A new evapotranspiration method has been added to the meteorologic model.  The method uses average daily temperature data combined with solar radiation to compute evapotranspiration according to the methodology of Hargreaves and Samani, 1985, Eq. 1.  The coefficient is set to a default value of 0.0135 and can be adjusted by the user. When the Hargreaves evapotranspiration method is combined with the Hargreaves radiation method the evapotranspiration calculation takes the form of Hargreaves and Samani, 1985, Eq. 8.  The user can control the coefficient through the Hargreaves shortwave and evapotranspiration methods. The new method can be used with gridded and non-gridded subbasins.

### Hamon Evapotranspiration

A new evapotranspiration method has been added to the meteorologic model.  The method uses average daily temperature data combined with latitude and longitude to compute evapotranspiration according to the methodology of Hamon, 1963, Eq. 2.  The Hamon coefficient is set to a default value of 0.0065 and can be adjusted by the user.  If the simulation time interval is sub-daily the daily evapotranspiration amount is distributed between sunrise and sunset according to a sinusoidal pattern.  The new method can be used with gridded and non-gridded subbasins.

### Optimization Trial

The optimization trial is a flexible tool for automatically estimating model parameters when observed flow is available.  An objective function is used to compute model performance by comparing the simulated and observed flow.  A search method is used to automatically adjust model parameters in order to minimize the

objective function.  Up until now, two search methods have been available.  The "univariate gradient" method was a modernization of the original HEC-1 algorithm.  The "Nelder Mead" method used a simplex algorithm.

The univariate gradient method has been eliminated.  The method typically offered poor performance in estimating parameters.  It often showed very slow convergence and frequently failed to identify the global minimum.  It almost always underperformed when compared to the Nelder Mead method.

The Nelder Mead method has been replaced by the "simplex" method.  The replacement is functionally the same since it is based on the original work by researchers John Nelder and Roger Mead in 1965.  The simplex method uses an improved algorithm that is more efficient.  Old projects will be automatically upgraded to use the replacement method.

A new "univariate" method has been added.  This new method works with only a single parameter.  While the simplex method is powerful, it requires a minimum of two parameters in order to operate.  The univariate method is now available for cases where only one parameter needs to be estimated.

Both the simplex and univariate search methods can now be used for minimization and maximization problems.  In a minimization problem, the model parameters are automatically adjusted in order to find the smallest possible value of the objective function.  The root mean square error is a common choice for the objective function in a minimization problem.  A small value of the root mean square usually means that the simulated and observed results are close together over much of the simulation.  All past versions of the program only solved minimization problems.  In a maximization problem, the model parameters are automatically adjusted in order to find the largest possible value of the objective function.  The Nash Sutcliffe coefficient or total runoff volume are common choices for the objective function in a maximization problem.  Allowing for maximization problems is a new feature with this version.  One example application of maximization is using the HMR52 precipitation method and allowing the optimization search method to find storm parameters that result in the largest possible runoff volume.

### *Markov Chain Monte Carlo in the Optimization Trial*

A new search method called "Markov Chain Monte Carlo" has been added to the optimization trial.  This method results in a robust assessment of parameter uncertainty as part of the optimization

and effectively converts the deterministic modeling components into a probabilistic flow simulation system. The search process begins with a Latin Hypercube Sample (LHS) which generates an initial number of parameter sets that cover the entire parameter space box as defined by user-specified lower and upper bounds for each adjustable model parameter. The LHS initialization serves as the basis for a population of Markov Chain directed random walks which run in parallel and characterize the flow simulation. A data likelihood function is associated with each evaluated parameter set. Currently, the squared deviation likelihood is the only option available. The definition for this classical likelihood includes the simple root mean square error (RMSE) function from traditional optimization. During the Markov Chain directed random walks, proposed jumps are evaluated for acceptance or rejection using the Metropolis acceptance probability rule. Given that a quantitative convergence diagnostic can prematurely assess equilibrium, we recommend assessing equilibrium using a weight-of-evidence approach that involves user interaction. To support this approach, plots are provided for (1) the likelihood function (RMSE), (2) the quantitative convergence diagnostic (Gelman and Rubin) for each parameter, and (3) traces of all chains for each parameter. When all of these point to convergence, then most likely a thinned history of subsequent draws will be from the equilibrium target distribution and can be used for inference. The post burn-in monitoring period draws empirically estimate the target posterior distribution and provide the basis to estimate the probability of simulated output for model design alternatives. For example, a robust estimate of the peak flow with only a 1% chance of being exceeded.

## *Depth Area Analysis*

The depth area analysis was designed to make it easy to compute flow-frequency results throughout a large basin model. The analysis included the selection of an existing simulation run where the included meteorologic model used the frequency precipitation method. Then the analysis added one or more points where results would be computed, automatically linking the drainage area at the selected points to the storm area in the frequency storm.

The depth area analysis no longer includes the selection of a simulation run. Instead, a basin model and meteorologic model are selected directly. A start time, end time, and interval are also chosen. Then points are added for computing results matched to the drainage area. It is still required that the meteorologic model use the frequency precipitation method. Management of components and results is now much easier and more consistent

with other simulations such as optimization trials and forecast alternatives.

## *Uncertainty Analysis Specified Sampling*

The uncertainty analysis has included three different methods for sampling a selected parameter in the basin model: simple distribution, monthly distribution, and regression with additive error. A new method called "specified sampling" is now available. This new method uses a parameter table created in the paired data manager. The table is configured for a specific parameter type within the basin model, and a sequence of parameter values manually entered. The table can then be selected for specified sampling in the uncertainty analysis. The sampling process will sequentially use the values in the table, repeating as many times as necessary to complete the specified total number of samples.

Specified sampling is designed to be used in two different ways. First, it can be used when a parameter can take on a limited number of different values with equal probability. Dam breach parameters are a good example. The scientific literature provides a small number of equations for calculating dam breach parameters. Each of the equations produces a slightly different parameter estimate. There is no consensus on which equation is "best" so they may all be treated as equally likely. The user could use all of the equations external to HEC-HMS and then prepare a table for specified sampling. Second, it can be used with results from an optimization trial using the Markov Chain Monte Carlo search method. The results from such a trial typically include hundreds of equally likely parameter sets. The trial needs to be configured first and successfully computed. Then a special command on the Tools menu can be used to automatically create parameter tables in the paired data manager. The tables are created in a way which maintains the correlation inherent in the trial results. All of the parameters analyzed in the trial should be included in the uncertainty analysis with specified sampling.

## *Observed Stage and Pool Elevation*

All elements in the basin model include the option for observed flow and observed stage. Additionally, reservoir elements include the option for observed pool elevation. Element result summary tables have included a special section when observed flow is used. This special section provides summary information about the observed flow during the simulation and provides certain comparison statistics relative to the computed flow. Similar special sections are

now included in results summary table when observed stage or observed pool elevation are selected.

## *Forecast Alternative Results*

The forecast alternative stores the same time-series results for all of the basin model elements as would be found from a simulation run. When the special forecast option for blending is used, additional time-series results specific to forecasts are computed and available for viewing. Activating the blending option at an element replaces computed outflow with observed outflow from the start time up to the forecast time. The observed outflow then transitions to the computed flow from the forecast time to the end time. Previously, an element using blending provided a result graph that showed the combination of observed flow (before the forecast time) and computed flow (after the forecast time). The result graph has been enhanced to show both the computed and observed outflow from the start time to the forecast time. The outflow from the forecast time to the end time is the same.

The forecast alternative can be used in its own right to produce stream flow forecasts. It is also specially designed to integrate with the Corps Water Management System (CWMS) and the Real Time Modeling System (HEC-RTS) to produce integrated forecasts in conjunction with meteorologic, hydraulic, reservoir, and economic software. A key feature in this integration is the use of *data variants*. Data variants are used by CWMS/HEC-RTS to connect results from other software to the forecast alternative, and to connect results from the forecast alternative to other software. Data variants can only be created and managed when using HEC-HMS within CWMS/HEC-RTS. New enhancements now make it possible to compute a forecast alternative configured with data variants directly from the HEC-HMS interface. Additional enhancements make it possible to view the primary forecast alternative results as well as results produced using data variants.

## *Uncertainty Analysis Results*

The uncertainty analysis does not store all time-series results at all basin model elements. Instead, time-series results are only stored when specifically selected at elements. Special results have been available when choosing outflow at any type of element. Special results have also been available when choosing pool elevation at a reservoir element. It is now possible to choose additional time-series results. Incremental precipitation can now be selected for subbasin elements.

### Selecting Elements in the Basin Map

The basin map provides an intuitive spatial display of the elements in the basin model.  An element can be selected by clicking on it in the map.  An element can also be selected by name from the Edit menu using the "Select By Name" command.  It is now possible to select all of the elements upstream or downstream of an element in the basin model.  The element should first be selected by clicking on it in the map.  The "Select Upstream" command on the Edit menu can be used to automatically select all elements upstream of initial selection.  The "Invert Selection" command on the Edit menu can be used to unselect all of the currently selected elements, and select all of the currently unselected elements in a single action.

# Enhancement and Revisions

Occasionally it becomes necessary to revise how an existing feature operates in order to create more capability or correct a problem.  Several changes of this nature have occurred since the last software release.  A complete description of each enhancement or revision is given below.  In general, revisions result in changes in the computed results when compared to previous program versions.

### Subbasin, Reach, and Reservoir GIS Data

Previous program versions included the option to add geospatial data to subbasin, reach, and reservoir elements.  Subbasins and reservoirs could be represented with polygons while reaches could be represented with polylines.  The spatial data was stored in three Esri shapefiles with a separate file for each of the three element types.  A special naming convention was used to implicitly link the Esri shapefiles to a basin model.  The geospatial data was primarily used for drawing in the basin map.  An important exception was that the geospatial data was required for subbasins when using the HMR52 precipitation method.

The previous method of storing geospatial data has been eliminated and replaced with a new method using the Spatial Lite file format.  Each basin model now has a Spatial Lite file to accompany the basin model ASCII file.  The Spatial Lite file is automatically managed by the program and holds all of the geospatial data for elements in the basin model.

Geospatial data can be added to the elements in the basin model using a special georeferencing feature.  The georeferencing feature is capable of reading from Esri shapefiles and many other common

file formats for storing polygons and polylines.  In this way, geospatial data can be added to existing elements in the basin model.  There is no upgrade of spatial data stored according to the old conventions.  Users should use the new georeferencing feature to transfer spatial data from the Esri shapefiles to the new Spatial Lite file.

Geospatial data continues to be required for subbasins when the HMR52 precipitation method is used.  The old spatial data must be imported before the simulations using the HMR52 precipitation method can be computed successfully.

### *Grid Cell Files and Grid Regions*

Grid cell files have been associated with gridded precipitation and the ModClark transform.  The grid cell file contains a section for each subbasin in the basin model.  Each section is actually a list of the grid cells for the subbasin with key properties including the coordinates of each cell, area within the subbasin, and travel index.  The grid cell file has almost always been created by the companion product HEC-GeoHMS.

Grid regions are a new project component designed to make it easier to define the grid cells for a basin model.  Each grid region includes a coordinate system, cell size, and extent.  This information is implicit when using grid cell files created by HEC-GeoHMS.  Future program versions will allow for the creation of grid regions based on the Standard Hydrologic Grid (SHG), Hydrologic Rainfall Analysis Project (HRAP), and Universal Transverse Mercator (UTM), all of which require explicit specification of the coordinate system, cell size, and extent.

Old projects with a grid cell file are automatically upgraded when opened with the new version.  The grid cell file is converted to a grid region that allows for backward compatibility.  The grid region created during upgrade is automatically configured in all of the basin models that used the grid cell file.  Any simulations using the basin model will continue to operate just as they did in previous versions.

New basin models that will utilize gridded simulation methods will require a grid region.  The best approach is to create a grid region and link it to the grid cell file created by HEC-GeoHMS.

### *Muskingum Cunge 8-Point Cross Section*

Previous versions required the elevations in the 8-point cross section to be strictly greater than zero.  This effectively prevented

use in coastal watersheds that otherwise met the usage criteria for Muskingum Cunge routing. Negative elevations are now allowed. However, a warning message is issued because in most circumstances a negative elevation is incorrect.

## *Muskingum Cunge and Kinematic Wave Index Flow*

The Muskingum Cunge and kinematic wave reach routing methods are similar in that both subdivide the reach into a number of equal-length segments. These segments are often called "dx" because the need for them arises when developing a numerical solution scheme for the underlying equations. An important part of determining the length of each dx is the consideration of the wave celerity as expressed in the courant condition. All previous versions automatically considered the courant condition without input from the user. This was possible because the basin model completed a simulation from upstream to downstream. Consequently, the entire upstream hydrograph was available for a reach using either of these two routing methods. An index flow could be calculated automatically, from which the wave celerity could be calculated, and the courant condition satisfied.

Major changes have been made in how the basin model completes a simulation. These changes are foundational to powerful new features that will be added in future program versions. Briefly, the basin model no longer completes a simulation from upstream to downstream. The practical effect of this change is that the upstream hydrograph is no longer available for each reach. This complicates the use of Muskingum Cunge and kinematic wave routing because the index flow can no longer be determined automatically. The user must now manually enter either an index flow or an index wave celerity. If the index flow is entered, the wave celerity is automatically calculated from the index flow using hydraulic formulas related to the cross section shape. The entered or computed wave celerity is then used to satisfy the courant condition when calculating the dx length. In the case of Muskingum Cunge routing, the user also has the option of explicitly specifying the "dx" and "dt" in which case the index flow or index celerity is not needed. <u>Any existing basin model that uses Muskingum Cunge or kinematic wave routing will need to have either index flow or index celerity added to each reach element. This change in the specification of the index flow may change computed results by small amounts.</u>

## Kinematic Wave Transform

The kinematic wave transform in the subbasin is typically used to represent urban hydrology. This application is different from flood wave routing in reach channels, but the fundamental equations are the same. The program uses common algorithms for both reaches and subbasins. This means that in general the changes described above for reaches also apply for subbasins. However, there are some differences in subbasins that make it possible to avoid requiring the entry of an index flow. The main difference is that runoff in the subbasin is caused by precipitation. Especially in urban areas where infiltration rates are typically small, there is a strong correlation between the maximum precipitation rate and the maximum runoff flow. The maximum precipitation rate for the simulation is automatically identified and used with the area of each plane to compute an estimated peak flow. This estimated peak flow is used to compute the segment length dx for each plane and each channel. As a final control, the user still has the option of specifying the minimum number of spatial steps.

## Unit Hydrograph Volume Check

A volume check has been added to all unit hydrograph methods in the subbasin: Clark, Snyder, SCS, s-graph, and user specified. A note is now displayed with the computed volume of runoff in the unit hydrograph. If the volume is significantly different from 1 mm (1 inch) then a warning will be displayed. The note or warning does not stop continued simulation for each subbasin using a unit hydrograph, but is provided for information purposes.

## Reservoir Culvert Outlet Structure

The culvert outlet was originally added to the reservoir element for HEC-HMS Version 3.0 (2005). The algorithms for the culvert outlet were adapted from the HEC-RAS program. Since that time, the original algorithms used in HEC-RAS have been enhanced based on several unique test cases that became available. The enhancements primarily affect the transition from submerged flow to pressurized flow. The resulting differences in flow rate through the culvert are relatively small on a percentage basis. The results both below and above the transition zone are almost identical. <u>This update in the algorithms may change computed results for some previous projects.</u>

## Reservoir Piping Breach

The reservoir element includes the option for a dam breach, either by overtopping failure or by piping failure. An error was discovered

in the piping failure under some circumstances. Parameter combinations with the piping elevation above the midpoint of the top and bottom elevations caused the incorrect results. Results remained correct if the piping elevation was at or below the midpoint. The piping breach has been corrected so that all possible piping elevations produce correct results. This correction may change computed results for some parameter combinations.

## Sign Convention in Latitude and Longitude

Version 4.1 and earlier versions only used latitude and longitude for the inverse distance precipitation method. The standard convention for specifying longitude required positive values east of the Greenwich meridian and negative values west of the meridian. Specifying latitude required positive values north of the Equator and negative values south of the Equator. The User's Manual stated that negative values could be excluded if all subbasins were in the same hemisphere. Version 4.1 added new capabilities for shortwave radiation, longwave radiation, and evapotranspiration that required latitude and longitude. In general these new methods require strict adherence to the sign convention. The User's Manual has been updated to always discuss sign convention as a strict requirement.

## Bristow Campbell Radiation

It was discovered that the Bristow Campbell shortwave radiation method was not correctly using the specified longitude. The method is intended to internally calculate a time zone offset between the subbasin longitude and the central longitude of the time zone containing the subbasin. It was found that the time zone of the user's computer was used instead of the time zone containing the subbasin. The internal calculation has been changed to correctly determine the time zone offset. This correction may change computed results for previous projects.

## FAO56 Radiation

It was discovered that the FAO56 shortwave and longwave radiation methods were not correctly using the specified longitude. The methods are intended to internally calculate the number of degrees west of the zero longitude line. This difference in degrees should be used in calculations. It was found that the longitude of the subbasin was used in error instead of calculating the difference. The calculations have now been corrected to use the difference in degrees between the subbasin and zero longitude. This correction may change computed results for previous projects.

## *Frequency Storm*

The frequency storm precipitation method no longer allows an unspecified or blank storm area. The storm area is used to compute the correct depth-area reduction factor for the storm. Previous versions allowed the storm area to be left blank, and then automatically recomputed the storm for each subbasin using the subbasin area as the storm area. This automatic behavior during a simulation run is no longer allowed. A storm area must be specified as part of the storm properties. There are still many applications where it is necessary to compute results for various size storms over the watershed. This application can be satisfied using the depth-area analysis. The depth-area analysis allows the user to select one or many locations in the basin model (potentially every subbasin) and then the area in the frequency storm is automatically adjusted to compute the correct storm at each selected location.

The conversion between annual duration and partial duration has also been simplified. Choices are now provided for converting annual duration input precipitation depths to partial duration output, and for converting partial duration input to annual duration output. These choices are provided for specific exceedance probabilities. No conversion should be selected if the input data is annual duration and an annual duration output is required. Additionally, no conversion should be selected if the input data is partial duration and a partial duration output is required. Finally, conversion is never used for exceedance probabilities less frequent than 10%.

## *HMR52 and Standard Project Storm Precipitation*

The HMR52 and Standard Project Storm precipitation methods share certain characteristics. Both methods start from a precipitation depth and a temporal pattern then build a time-series of precipitation depths. The algorithms in both methods cannot be applied to simulation time intervals less than five minutes. Previous versions either stopped a simulation with a shorter time interval, or experienced an uncontrolled error. Both methods have now been enhanced to operate at a 1-minute time interval. This is implemented by assuming a 5-minute time interval and then dividing each of these intervals equally to produce a 1-minute output.

## *Penman Monteith Evapotranspiration*

The Penman Monteith evapotranspiration method is based on the energy balance concept and consequently requires a number of atmospheric variables: air pressure, windspeed, temperature, and either dew point temperature or relative humidity. The equations

underlying the method are designed to use atmospheric data recorded at an interval of 1 hour or less.  The original equations are used in HEC-HMS for all simulations with time intervals from 1 minute up to 1 hour.

The FAO56 report presents an alternate set of equations known as *reduced set* that can be used with atmospheric data at intervals greater than 1-hour, with daily interval being the most common.  Some atmospheric variables are not used at all with the reduced set equations; informed assumptions are substituted instead.  The reduced set equations are now used in HEC-HMS for all simulations with time intervals from 2 hours up to 1 day.

The computed results from Penman Monteith will be closest to the intentions of the reduced set assumptions when the Hargreaves shortwave radiation and FAO56 longwave radiation methods are selected.  For time intervals between 2 hours and 12 hours, the equations are applied at daily interval and interpolated to the actual interval.

## Simulation Time Window

All simulations include a start time, end time, and time interval.  This information has always been checked to make sure it is valid.  For example, the end time must be after the start time, and the difference between the start and end times must be a natural number of intervals (no partial intervals).  The time intervals that may be used come from a list.  The available intervals have been carefully chosen to facilitate both data storage and automatic interpolation.

Changes in how the basin model completes a simulation now require the start time and time interval to be consistent.  Consistency is now enforced when checking the other time window information.  The start time must be a natural number of time intervals after midnight.  For example, a time interval of 6 hours can be used with a start time of 00:00, 06:00, 12:00, or 18:00.  <u>This means that some old simulations using inconsistent start time and time interval will no longer be able to compute.</u>  This can be fixed by adjusting the start time to be a natural number of intervals after midnight.

## Simulation Save States

Save states has been an optional feature of simulation runs.  The save states represent all of the information necessary to exactly restore a basin model to a moment in time during a simulation run.  This includes, for example, subbasin soil moisture and excess

precipitation in the process of moving over the land surface. Save states could be created at the end of simulation run or at the end of any time interval during the run. The save states could be used later to initialize a new simulation run. It was required that the basin model be the same in both runs. It was also required that the simulation time of the save states exactly match the start time of the run using them for initialization.

Save states can now be used with both simulation runs and forecast alternatives, and are also much more flexible. Save states can now be created by both runs and forecasts. The save states can be created at the end of a run or forecast, at the forecast time during a forecast, or at the end of any time interval during the run or forecast. Once a save state has been created, it can be used with any other simulation run or forecast alternative regardless of how it was created. There are no limits due to the basin model used or the simulation time represented by the information in the save states. If the basin model used to create the save states does not match the basin model in the simulation using the states, a warning message will be shown and the data in the states still used. If the simulation time used to create the save states does not match the start time of the simulation using the states, a warning message will be shown and the data in the states still used. If a basin model element cannot be found in the save states, then the values from the basin model will be used.

In summary, save states can still be used to take a very long simulation and break it into a sequence of simulation runs. For this use, the saves states are created at the end of a run and used to start the next run. It is now also possible to treat the save states like an optional replacement for the initial conditions specified in the basin model either for simulation runs or forecast alternatives.

# *Problems Repaired*

Several errors were found in the program and repaired. Complete descriptions of each error are given below.

## *Observed Snow Water Equivalent*

It is an option to add observed snow water equivalent to a subbasin element. When included, the observed snow water equivalent is used to calculate the residual snow water equivalent (observed minus subbasin average). A unit conversion error was found in the calculation, even though the units of the observed and subbasin average values were correct. The calculation of the residual snow water equivalent is now correct.

### *Outflow Curve Reservoir Routing*

The outflow curve routing method in the reservoir element uses storage as the state variable. There are several options for specifying the initial value of the state variable, and the variable is updated during the simulation based on inflow and a solution of the Modified Puls algorithm with one routing step. There is an option in the simulation run for "Save States." Once saved, the states can be used to initialize a new simulation run. It was found that the outflow curve routing method did not initialize correctly when using states at the beginning of the simulation run. This error has been corrected.

### *Reservoir Evaporation*

The outlet structures routing method in the reservoir allows various ways of specifying how water leaves the storage. One of those ways is by evaporation. The amount of evaporation can be specified as a depth for each month of the year. It was discovered that the evaporation for each time interval was calculated correctly, but there was a unit conversion error when storing the time-series of calculated evaporation. This means that the mass balance for the reservoir storage was correct, but appeared wrong when reviewing the stored time-series of evaporation. The unit conversion error has been corrected and the stored time-series of evaporation is now correct.

### *Forecast Alternative Initial Baseflow*

The forecast alternative includes the option of automatically computing subbasin initial baseflow using an observed flow gage. It was discovered that under some circumstances, renamed flow gages were not updated in the forecast alternative. Observed flow gage selections in the forecast alternative are now always updated when the gage is renamed.

### *Missing File When Opening a Project*

As part of opening a project, the project is checked for missing file references. Missing files may have been manually moved or deleted since first being used in the project. When missing files are identified, a window is presented to the user for an opportunity to find the missing files and update them in the project. It was discovered that files used in some components of the project were not checked or where incorrectly displayed in the window. All project components are now checked and missing files correctly displayed in the window.

### Missing Precipitation Data

The meteorologic model checks for missing values in all of the precipitation data prior to beginning calculations. Users have the option of replacing missing data with a zero value, but it remains important to correctly determine and report in an error message the number of missing values. It was found that if a precipitation gage was missing a value at exactly the start time of the simulation, it would be reported in an error message. This is incorrect because precipitation data is only required beginning with the first time interval after the simulation start time. The check for missing precipitation values has been corrected.

### Subbasin Canopy with Kinematic Wave Transform

It was discovered that the program interface would become unresponsive (frozen) when attempting to use any canopy method in combination with the kinematic wave transform method. This has been corrected. It is now possible to use a canopy method with the kinematic wave transform method.

### Global Editors and Column Reordering

It was discovered that all of the global editors in the basin model allowed the user to reorder the columns. While this flexibility allowed the user to customize the look of the global editors, it also caused all of the parameter data to be saved incorrectly. Fully supporting column reordering would have required a large amount of work. This issued was fixed by locking the columns and eliminating reordering.

### Gage Weights Precipitation

It was discovered that a simulation could fail if the gaged weights for a subbasin did not sum to 1.0. No message was displayed when the error occurred and the simulation attempted to continue. This condition is now checked and an appropriate message displayed before stopping the simulation.

### HMR52 Precipitation

It was discovered that under some circumstances the calculated precipitation was displayed with values in millimeters but labels in inches. However, the calculated values were correctly used in subsequent calculations for infiltration and surface runoff. This error was limited to basin models using the ModClark transform method, and limited to the incorrect units label. All other transform methods produced a precipitation display with values and labels

that matched correctly. The precipitation display has been corrected so that the units match the values for ModClark in addition to all other transform methods.

## *Copy Project*

It was discovered that some project components were "lost" when making a copy of a project. All components of the project were reviewed to be sure they are included during the copy process. The copy now correctly includes all components of the original project.

## *Temperature Index Snowmelt Default Parameters*

The temperature index snowmelt method includes several optional parameters: rain rate limit, ATI-meltrate coefficient, cold limit, ATI-coldrate coefficient, and water capacity. If an optional parameter is left blank in the *Component Editor*, then a default value will be used instead. It was discovered that the optional parameters were not checked correctly at the beginning of a simulation. Further, it could be ambiguous to the user exactly what default value was used. The parameter checking has been made consistent and the clarity of the messages improved.

## *XML Reports*

It was discovered that subbasin components (canopy, surface, loss rate, transform, and baseflow) were not placed below the subbasin at the correct nesting level in the basin model XML file. It was also discovered that the reservoir peak storage was not labeled correctly in the simulation run XML file. For both reports, it was found that the decimal separator used inside the XML files was not correct if the program settings were configured to use a comma as the decimal separator. Both XML reports have been corrected of all three issues.

## *Import Meteorologic Model*

There is a feature on the File menu for importing a meteorologic model to the current project. The feature includes the option of importing time-series gages, paired data, and grid data used by the meteorologic model. It was discovered that grid data was not imported correctly. The import feature for meteorologic models has been corrected.

### Forecast Alternative Zone Configurations

The forecast alternative uses zone configurations to manage adjustments for subbasin parameters in loss rate, transform, and baseflow components.  A zone configuration can also be used to manage adjustments for reach parameters in the routing component.  Each zone configuration can be applied to subbasins or reaches, but not both.  It was discovered that some aspects of routing parameter management were not correctly performed with respect to the zone configuration selected for reaches.  This could lead to subbasins being displayed instead of reaches.  Zone configuration and parameter adjustment management has now been corrected for subbasins and reaches.

### Kinematic Wave Transform

It was discovered that kinematic wave transform parameters may not be loaded correctly when opening a basin model by clicking on it in the *Watershed Explorer*.  While parameters entered through the program were always processed correctly, there could be a problem when manually editing the basin model file outside the program.  Processing has been improved so that even if parameters are incorrectly modified in the basin model file, the program can recover and correct the problem.

### Meteorologic Model Parameter Tracking

The program is designed to automatically track all parameters and other data used in the meteorologic model.  This tracking is used to determine if the last computed results are current or expired.  It was discovered that some types of data in the meteorologic model were not tracked correctly.  The tracking has been improved to cover all parameters and all other data.

## Documentation

The *Hydrologic Modeling System HEC-HMS: Quick Start Guide* (Version 4.3 August 2018) provides a brief description of the program for new users.  It describes the different parts of the interface and the basic steps necessary to obtain simulation results.  A tutorial takes the user through the creation of a new project and shows how to obtain results.  The guide has been updated to reflect changes in the interface.

The *Hydrologic Modeling System HEC-HMS: User's Manual* (Version 4.3 August 2018) contains extensive information on installing and using the program.  Details on the use of each of the features and capabilities in the program are included.  The manual

has been updated with information describing new features added to the program for this Version 4.2 release.

The *Hydrologic Modeling System HEC-HMS: Validation Guide* (Version 4.3 August 2018) contains information on the procedures used to certify the software for release. The manual describes the tests that have been established and the procedures used for determining the correct result for each test. An accompanying data kit includes all of the project data necessary to replicate the tests performed at HEC prior to certifying a new release for distribution.

The *Hydrologic Modeling System HEC-HMS: Applications Guide* (March 2015) illustrates how to apply the program in a variety of different studies. Data requirements, calibration procedures, and typical results presentation styles are provided for studies ranging from flood risk management to sediment yield.

The *Hydrologic Modeling System HEC-HMS: Technical Reference Manual* (March 2000) continues to accurately describe the mathematical models included in the program. New simulation capabilities have been added to the program and are not included in the manual. The manual is currently undergoing a major revision to expand documentation of existing mathematical models and fully describe the newly added models.

# *Support Policy*

Technical support for program users within the U.S. Army Corps of Engineers is provided through an annual subscription service. Subscribing offices can expect full support from HEC staff in the routine application of the program. Users are strongly urged to consult with HEC staff on the technical feasibility of using the program before beginning a project with unique requirements such as grid cell hydrology, snow melt, continuous simulation, sediment transport, or water quality. Special guidance is also available for the development of models for flow forecasting. Extended support for large or complex projects can be arranged under a separate reimbursable project agreement.

Support cannot be provided to users outside the U.S. Army Corps of Engineers. Several companies and organizations offer varying levels of support, some through a fee-for-service support similar to the support provided to subscribing Corps offices. Such service agreements are between the user and the vendor and do not include HEC staff. Vendors can be located through internet searches.

Reporting of suspected program errors is unrestricted and we will reply to all correspondence concerning such errors. We are continuously working to improve the program and possible bugs should always be reported. Reports should include a written description of the steps that lead to the problem and the effects that result from it. If we cannot reproduce the reported problem, we may ask you to send a copy of your project.

Request support or report program errors through the following channels:

- Visit our web site at http://www.hec.usace.army.mil.

- Send email to *hec.hms@usace.army.mil* on the internet.

- Fax 530.756.8250 any time.

- Call +1.530.756.1104, 7:30 am to 4:30 pm Pacific Time Monday through Friday.

The postal address for the development team:

U.S. Army Corps of Engineers

Institute for Water Resources

Hydrologic Engineering Center

609  2nd  Street

Davis, CA  95616

United States