ADVANCES
in Hydrologic Engineering

Winter 2019

Director's Comments

By Christopher N. Dunn, P.E., D.WRE

Welcome to the latest edition of the Institute for Water Resources' Hydrologic Engineering Center (CEIWR-HEC) Newsletter. HEC has long been known for innovation and the articles in this Newsletter support that thought. What the HEC staff can do continues to impress. From the new features and capabilities in HEC-HMS, to the new ways to explore and analyze hydrologic hazards, to the innovative ways people are using HEC-WAT to answer questions that we formerly could not answer or at least not answer easily, the HEC staff and the work they do is advancing the profession. In addition to the technical articles, you will be introduced to two new HEC engineers and a day in the life of one of our staff. Members of the CWMS team discuss the concept of Team Modeling and summarize a recent trip to Texas. Finally, the newsletter identifies the FY 2019 and FY 2020 PROSPECT classes. I am excited about the classes we are offering in FY 2019 and FY 2020. While all the classes for FY 2019 are full, you still might inquire about them as you never know when a slot might open. The time to sign up for the FY 2020 classes is upon us so if you are interested in an FY 2020 class you should sign up soon.

Over the holidays, like many of you, I had the luxury of having some time off. No, that time off was not because of the

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HEC-HMS Version 4.3 Release

By Matthew Fleming P.E., William Scharffenberg Ph.D., Michael Bartles P.E., Thomas Brauer, P.E., and Gregory Karlovits P.E.

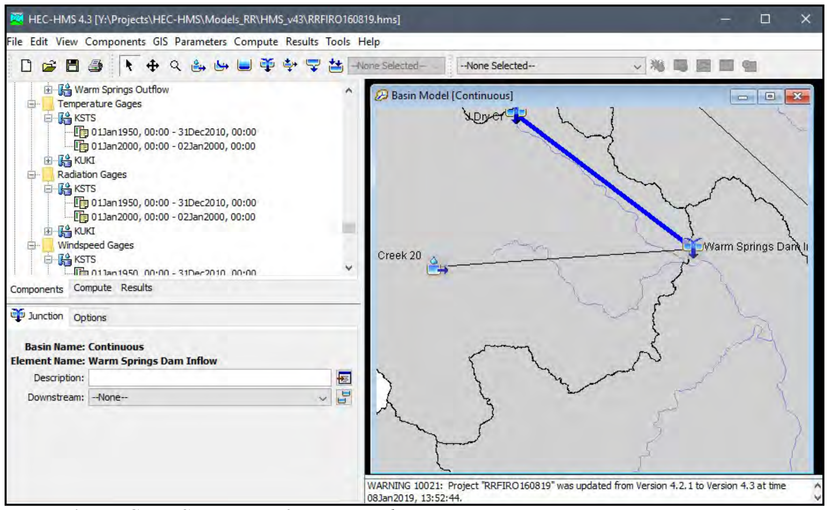

Figure 1. HEC-HMS Version 4.3 Main Window

The Hydrologic Engineering Center s Hydrologic Modeling System HEC-HMS Version 4.3 software (Figure 1) was officially released in November, 2018. HEC-HMS is designed to simulate hydrologic processes of dendritic watershed systems. The software can be applied to model a single flood event or applied to a continuous simulation that spans weeks, months, or years. HEC-HMS includes many traditional hydrologic analysis procedures such as infiltration, unit hydrographs, baseflow, and hydrologic routing. Additional procedures include evapotranspiration, snowmelt, and soil moisture accounting. The software can utilize lumped processes at a subbasin scale and/or distributed processes at a smaller gridded scale. There are many simulation types in HEC-HMS that support model optimization, depth-area analysis specific for frequency based precipitation simulations , flow forecasting, uncertainty assessment, and erosion and sediment transport. HEC-HMS Version 4.3 includes new hydrologic modeling options, new optimization and uncertainty analysis techniques, and new capabilities for decreasing the time required to create and calibrate an HEC-HMS model. The HEC-HMS software development team has been working with multiple partners over the past two years to add these new capabilities. For a full description of the new capabilities, please refer to the HEC-HMS 4.3 Release Notes and HEC-HMS 4.3 User's Manual https://www.hec.usace.army.mil/software/hec-hms/documentation.aspx .

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US Army Corps of Engineers
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Government Shutdown. As part of the Department of Defense (DOD), HEC was spared from the shutdown and we were working full throttle. However, the time away from the office let me think about work at HEC and my role. In addition, with the advent USACE's new performance evaluation system, it is clear that I am to be taking on a slightly different role at HEC. The key is not to be so caught up in the details of the daily happenings at HEC but rather take a broader, more strategic view. Taking on a different role may be more difficult than it seems. First of all, I like the details. That said, and most people at HEC would agree, I am not in the details like they are but still there is a level of involvement with the HEC staff that makes me feel connected. I would never want to lose that. Secondly, HEC is not so large that we have multiple layers of management that can address many of the topics. Only one layer of management separates me from the detailed work. So it doesn't take long for questions to come to me. I certainly have trust in our Division Chiefs (we have three at HEC) but there are times when either they would like to bounce something off of me or look to me for institutional knowledge. So the dilemma is to figure out how to separate myself from some of the details while still being supportive and feeling connected.

In an effort to help me address my dilemma and also to develop an improved and more strategically aligned management team at HEC, the Division Chiefs and I started a book club and the first book we read was "The Five Dysfunctions of a Team". The author of that book, Patrick Lencioni, talks about how to build better teams. Several items jumped out at me as to how the HEC management team, which also includes our Chief Administrative Officer, could become a stronger and more cohesive team. First and foremost, we all have to have a common goal. In our case, I would suggest it is to continue to bring innovation into our software to provide the best hydraulics and hydrology, water management, and water resources planning software for USACE. If the goal is not clear, then the members of the management team may not be working for the same purpose which brings about any number of problems. To help assure the management team is marching to the beat of the same drum, we have to look at our team, the management team, as our number one priority. Meaning we have to invest in the members of our team first. We have to develop an environment where conflict is okay. We have to feel safe to say what we need to say without fear of retribution or judgment. Now this doesn't mean we can t be challenged in what we say. Just the opposite, we want to be challenged, but be challenged in such a way that is safe and constructive. And, just as importantly, we have to be receptive to those challenges and understand that our ideas are not always or, at least, initially the best ideas. Our ideas can be improved by a team conversation so that our ideas are then transformed into an idea that more efficiently or completely addresses the real issue. Being heard and seeing our ideas included as part of the greater solution would help develop a better team community.

While I understand the concept, it can be difficult to leave behind the realities of insecurities and competitive characteristics. The competitive juices that flow in most of us are, in part, the reason for us being where we are today. We, individually, want to strive to be the best we can be and get as far ahead as our ambitions want to take us. Therefore, putting our individual pursuits behind us for the benefit of one team is not the easiest thing to do.

So how do we build this environment where the management team is more cohesive and where conflict is used to shape ideas? I suppose there are many ways; some much less expensive, more practical than others. In the book, "The Five Dysfunctions of a Team", their management team frequently travels for a two- or three-day offsite workshop to Napa Valley or another nice location. They stay in nice hotels with accommodations that Federal workers are unlikely to afford following the joint travel regulations. They meet often in the office as well. I believe the recommendation in the book is to meet two to three days per month to discuss management strategy etc. It is unlikely that the HEC management team is going to meet two to three days per month let alone schedule frequent two- to three-day offsite workshops, but maybe we could afford one offsite workshop per year. Maybe we do not go to the best hotels in Napa but maybe we could find something close by a Federal facility. The idea of an offsite to talk about long-term planning and strategy for HEC makes perfect sense. Now I am not saying the HEC management team does not meet at all. Of course we do, but, we tend to meet at HEC for shorter duration meetings to discuss the tactical needs of the Center. We meet monthly for our Division Chiefs Meetings and we meet quarterly for our Quarterly Process Reviews and budgeting meetings. However, we tend to push through as efficiently as possible to return

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Director:
Christopher N. Dunn, P.E., D.WRE

Water Resource Systems Chief:
Lea G. Adams, P.E.

to our "real work". We do not take the time to build the relationships, trust, and family Patrick Lencioni recommends. He suggests that building these teams and spending time with your management team is your "real work".

In addition to the yet to be planned "offisite" and the introduction of the book club, to foster a better management community, HEC has have also initiated our Monthly Managers Lunch where once a month the entire HEC Management Team goes to lunch somewhere in Davis. The Management Team take turns choosing the restaurant we all pay for our own lunches and we have a pact that we do not talk about work. We are trying to get to know each other on a more personal basis. We talk about family, sports, travel, news of the day, and world events. Of course work conversations do happen but we try to return to non-work topics as soon as possible. The idea is to get to know the others on the team more deeply so that we care more about them as a person. If we care about them as a person, we should promote their successes by working together to make them successful. If we all have the same goals, their successes are our success. After all, if we are all rowing in the same direction and at the same cadence we are more likely to get there faster having consumed less energy.

While our efforts to build a more integrated HEC Management Team are still in its infancy and our strategies are still very much a work in progress, we are striving on a daily basis to become incrementally better. We are open to ideas about how you have built more integrated management teams. What have been your strategies? How have they been successful? In the latest book we are reading, "The New One Minute Manager" a classic that has been revised to reflect newer working expectations, authors Ken Blanchard and Spencer Johnson provide three primary ways to build rapport in individuals: create clearly defined goals, catch people doing things right, and correct people when they have done something wrong but correct them in such a way that they still feel valued. Our book club has yet to discuss this book but we will, no doubt, try to incorporate some of these management concepts as well.

Well enough dime store psychology for today. I hope you enjoy our Newsletter and if there is anything HEC can do for you, please just let us know.

Chris Dunn, P.E., D.WRE
Director

HEC-HMS Version 4.3 Release (continued)

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A significant amount of effort went into new capabilities for HEC-HMS Version 4.3 that support the U.S. Corps of Engineers (USACE) water management mission, the Flood and Coastal Storm Damage Reduction (FCSDR) Research and Development program, the USACE Dam and Levee Safety program, Districts, and external customers. Funding for software development activities comes from proposals submitted to multiple USACE programs, from Districts, other federal agencies, and external agencies. An Interagency Agreement (IA) is required to accept funding from other federal agencies and a Memorandum of Agreement (MOA) is required to accept funding from non-federal agencies. HEC has experience and success developing and awarding IAs and MOAs. We look forward to hearing from the user base about ideas for new features and capabilities to add to the software that support both USACE missions and customer needs.

The HEC-HMS team actively provides training to the field in the use of the software. HEC has two USACE PROSPECT training classes for HEC-HMS, a basic hydrologic modeling with HEC-HMS class and an advanced modeling with HEC-HMS class. Descriptions for both classes can be found at http://www.hec.usace.army.mil/training/list.aspx . The PROSPECT classes alternate each year at HEC. The HEC-HMS team does deliver off-site classes and recently provided classes for the Walla Walla and Nashville District offices. Please contact the HEC-HMS team if you are interested in a class. Training material for the basic hydrologic modeling with HEC-HMS class is on our website, http://www.hec.usace.army.mil/training/materials.aspx#HYDROLOGIC_MODELING_WITH_HEC-HMS_2018 . Material for the advanced modeling with HEC-HMS class will be posted after the March, 2019 class.

The following paragraphs provide some details on the new capabilities available in HEC-HMS Version 4.3.

Variable Clark Unit Hydrograph - Synthetic unit hydrographs have been used in HEC-HMS since the first software release in 1998. One of the challenges of calibrating, validating, and applying a model using synthetic unit hydrographs is the assumption of linear watershed response to increasing precipitation inherent to the application of unit hydrographs. Hydrologists have long observed that watersheds respond differently as precipitation intensity increases, but this often

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nonlinear variation can be difficult to quantify with a single model. As a result, the assumption of linearity is used as a practical means for simplifying the modeling process, especially when empirical observations are limited. The changes in unit response can be seen by evaluating changes in observed flow in response to precipitation over a watershed for a range of small to large flood events. Another way to visualize how the runoff response changes is use of a two-dimensional (2D) shallow water flow model. The 2D model can be calibrated to a watershed and then varying precipitation intensities applied to the model. Figure 2 shows how the unit response changed for a watershed in the Northeast United States as precipitation rates varied between one and eight inches per hour. An HEC-RAS (River Analysis System) software model of the watershed was used for this example. Notice changes to both the timing and attenuation of the unit hydrograph the runoff volume is one-inch for all unit hydrographs contained in Figure 2 . Unit hydrograph theory does not capture the changes to timing and magnitude of the runoff response as excess precipitation rates increase.

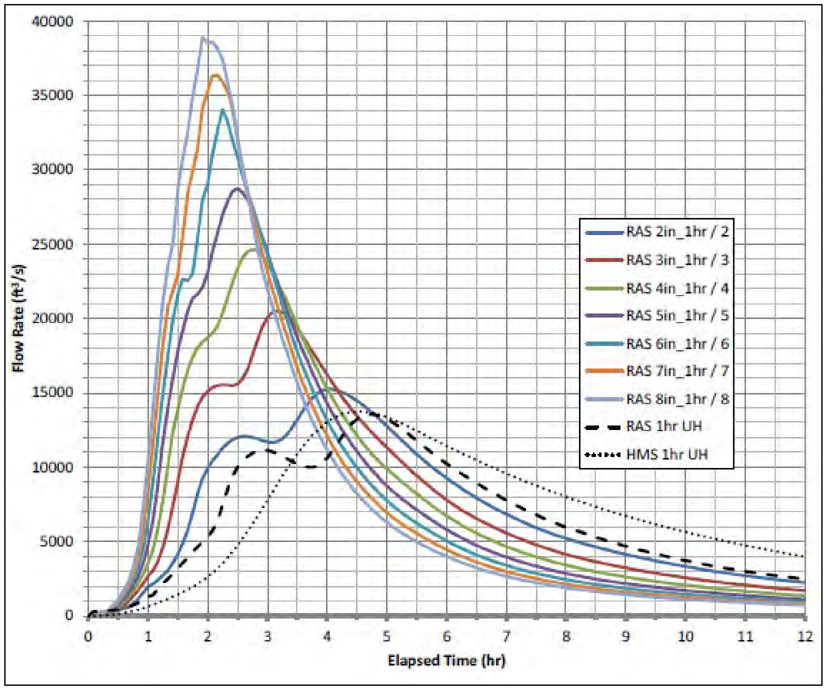

Figure 2. Development of Design Storms

The Clark unit hydrograph method requires one set of parameters to describe the translation and attenuation of the unit response. HEC-HMS Version 4.3 includes a variable Clark unit hydrograph option where its parameters, time of concentration (TC) and the storage coefficient (R), can vary based on excess precipitation rates, see Figure 3. The relationships between excess precipitation and TC and R could be created using multiple historic storms to develop unit hydrographs for each one; or evaluation of unit hydrograph parameters from models calibrated to multiple storm events the events would need varying precipitation magnitudes ; or a 2D model. Yet another approach would be to create a simple relationship between excess precipitation and time of concentration that is based on

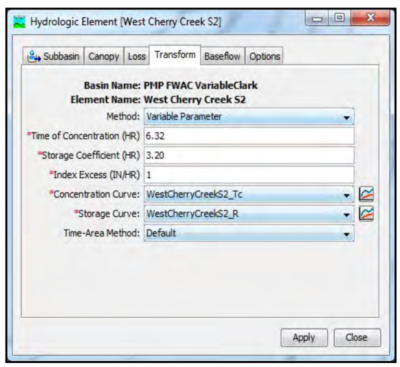

Figure 3. Updated Clark unit hydrograph component editor with the variable parameter option selected. The base unit hydrograph parameters can be updated based on relationships between excess precipitation and TC (time of concentration) and R (storage coefficient).

channel velocity computed from Manning s equation or a hydraulics model. HEC-HMS will re-compute the TC and R parameters for each time step with excess precipitation. This new variable TC and R option for the Clark unit hydrograph method is best suited for those studies where precipitation rates vary significantly within a storm event, like event simulations where frequency storms or the Probable Maximum Precipitation PMP is applied, and for continuous simulation of longer durations that include small to large precipitation events. It can also be useful for simulations where the applied precipitation is far more intense than the precipitation in the events used for calibration, and an estimate for watershed behavior by extrapolation is desired.

Forecasting Features - Support from the Corps Water Management System CWMS nationwide implementation program and from District offices have led to new features and improvements to HEC-HMS Version 4.3 that support the USACE water management mission.

A new reach routing method, the Variable Lag and K method, was added and is now available in HEC-HMS Version 4.3. The lag parameter controls timing of the flood wave as it travels through the river reach, and the K parameter controls the amount of attenuation due to channel and overbank storage. The Lag and K method also allows the modeler to vary the Lag and K parameters based on inflow rate. Just like the variable Clark unit hydrograph method,

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observed flood events and hydraulic models can be used to build relationships for travel time and attenuation versus inflow rates. This routing option can be helpful to forecasters because once the variable relationships are prepared during model development; they do not have to be updated during real time calibration as might be necessary for the other hydrologic routing methods.

HEC-HMS Version 4.3 includes a new tool for automatically estimating the initial reach outflow at the beginning of a forecast alternative. With this latest addition, modelers can use observations to set initial baseflow, initial reservoir elevation, and initial reach outflow and do not have to manually set these initial conditions at each modeling component when creating a new forecast alternative. These options will decrease the amount of time needed to configure and calibrate a model.
One of the strengths of CWMS is the ability to create multiple forecast scenarios where alternative meteorologic and hydrologic conditions are simulated. The alternatives are used to help water management staff make decisions when operating USACE projects. Enhancements were made to HEC-HMS Version 4.3 so that modelers can plot results from multiple variants in the same plot variants are forecast alternatives developed in a CWMS/HEC-RTS Real Time Simulation watershed .

HEC-HMS has included the option to save model states during a simulation run, and also use a saved model states to initialize a simulation run. Saved and start states now work within the forecast alternative simulation type within HEC-HMS Version 4.3. Also, more flexibility was added so that modelers can choose any previously saved states. The state of the model includes moisture states in subbasin elements, reservoir storage, reach flow, and other information. A modeler can choose to create a file with model states at any time step during the simulation; the file represents a snapshot of the model states at that time. For modelers running forecasts day to day, the saved states could be used to initialize the model and reduce the amount of time required to manually set initial conditions.

Finally, an enhancement was added to HEC-HMS Version 4.3 where the software no longer resets the Clark unit hydrograph or ModClark parameters when switching between the Clark and ModClark methods. Additionally, there is a nice time-saving option built into the program when using gridded precipitation and the unit hydrograph methods not ModClark : if the simulation has already been computed, then the program will not process the gridded precipitation when running the simulation a second time and will use the previously computed basin average precipitation time-series as long as no user changes were applied to the meteorologic model). This option can significantly reduce simulation run times for forecasting models and help modelers calibrate models when there are time constraints.

Optimization and Uncertainty Analyses - HEC-HMS Version 4.3 includes a completely redesigned optimization capability with several new features. The original optimization trial was released in Version 1.0 back in 1998, and included a very basic optimization capability that provided some help in calibrating hydrology models. Only minor enhancements were offered in the years since 1998. A work unit in the FCSDR program provided funding to revamp the optimization capability and to further advance the uncertainty analysis tools. The development of the new optimization capabilities has been a joint effort between the Coastal and Hydraulics Laboratory at the Engineer Research Development Center USACE, ERDC-CHL and HEC-HMS team members. The new optimization and uncertainty analysis capabilities have already been applied on projects within USACE.

The term optimization is commonly invoked when using automatic software algorithms to estimate model parameters while fitting the model to observed information. The classical approach to optimization begins with choosing a target location with observed flow data. Next, an objective function must be selected for calculating model performance. An objective function measures the agreement between the simulated and observed data, which can be quantified in a number of ways. One common objective function is the root mean square error between the modeled and observed flow. Next, a set of parameters that affect the modeled flow are chosen and given a bounding range. A deterministic algorithm then searches for parameter values that minimize the value of the root mean square error. In theory, a value of zero for the root mean square error would mean that the modeled flow exactly matches the observed flow. Strictly speaking, there are difficulties in hydrologic modeling that make this goal impossible to achieve. Nevertheless, the automatic algorithms can still be very helpful in estimating parameter values more efficiently than a manual calibration approach. Automatic algorithms offer repeatability and can provide a tracking history. They are also helpful to newer users of the software.

One of the reasons for revamping the optimization capability was to facilitate new features. In addition to the software changing parameters within the basin model, HEC-HMS Version 4.3 allows the user to choose certain parameters within meteorologic models. Another important new feature is the ability for the optimization engine to operate with both minimization and maximization goals. In the minimization goal, parameter values are sought that minimize objective functions that measure the difference between the modeled and observed data. The HEC-HMS User's Manual details all the available objective functions that

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can be selected for minimization. There are other objective functions, like the Nash-Sutcliffe measure, where model performance improves as the objective function becomes larger. For these objective functions, a maximization goal can be chosen. In the maximization mode, parameter values are sought that maximize one of the summary statistics. The maximization mode can also be used for optimization simulations where Hydrometeorological Report (HMR) 52 storm parameters, such as centering and orientation, are needed that maximize the peak flow at a stream junction or maximize the pool elevation in a reservoir. The optimization running with a maximization goal is much more efficient at determining the storm parameters compared to a manual approach. An example of using maximization to estimate storm parameters is shown in Figure 4. Figure 4 shows the evolution of the x and y-coordinates for the center of a Probable Maximum Precipitation (PMP) storm. The optimization converges on a storm centering that produces the maximum possible peak flow at the inlet of a reservoir.

The most significant new optimization feature in HEC-HMS Version 4.3 is the Markov Chain Monte Carlo option (MCMC). Application of the new MCMC option converts HEC-HMS from a deterministic to a probabilistic flow simulation tool. The MCMC algorithm implementation leverages recent related academic research in the field of water resources. The heart of the algorithm is the use of Bayes Theorem. Bayes Theorem updates our prior knowledge about the unknown parameters on the basis of observed data. In water resources, this means we can assume parameter values based on best available information, and then update the estimate of those values based on observed flow. The algorithm uses Markov Chain directed random walks to empirically characterize our knowledge of the unknown parameters. The entire process is carried out in a probabilistic framework. Application of the new MCMC feature in HEC-HMS yields empirical estimates of the marginal probability for each of the selected parameters, including their correlation with one another. An example of evolving parameter estimates in a MCMC application are shown in Figure 5. An example of a posterior distribution for a single model parameter generated from the probabilistic framework is shown in Figure 6.

One of the critical steps in using optimization is determining if the algorithm has converged to a final set of parameter values. Classical optimization algorithms attempt to converge to a single point, or a single set of model parameters. Because the MCMC algorithm operates in a probabilistic

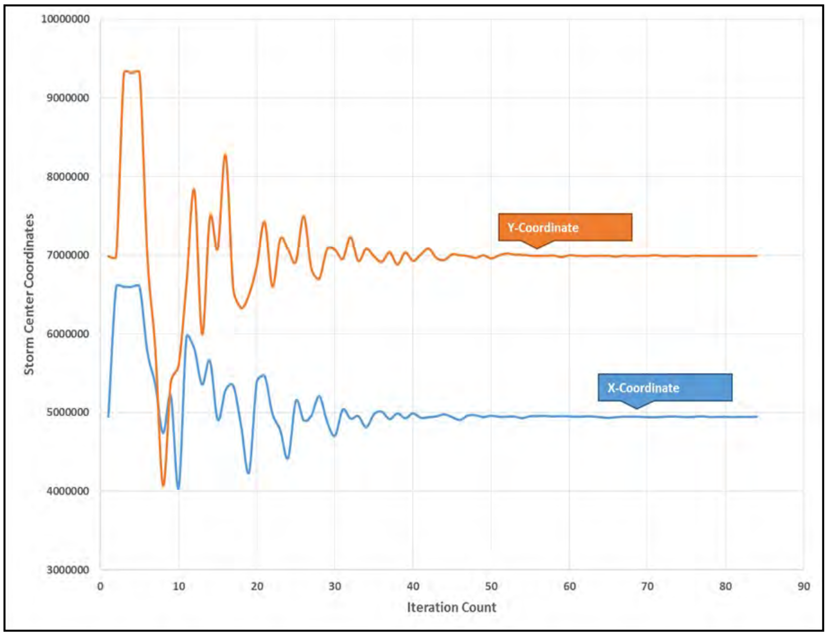

Figure 4. Simulation of a Probable Maximum Precipitation (PMP) storm centering to maximize peak flow. The figure shows how the x and y coordinates of the storm center evolve over the optimization.

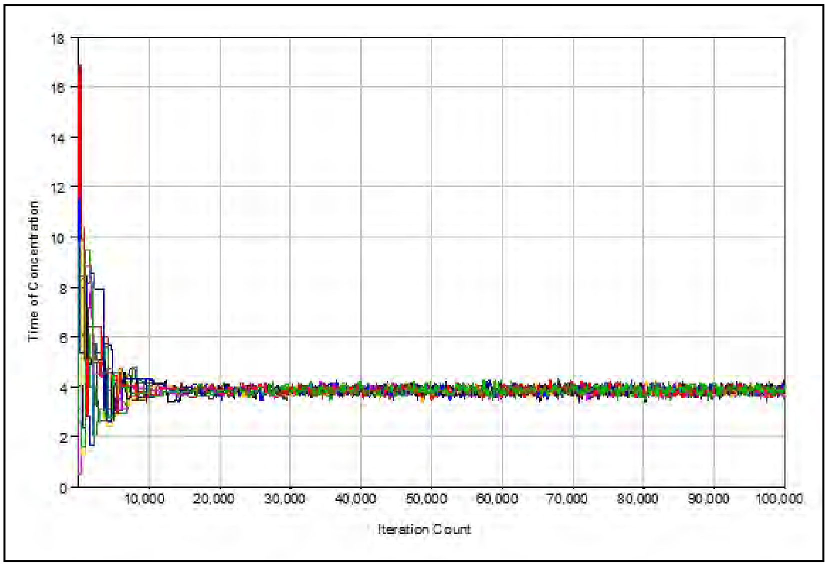

Figure 5. Use of Markov Chain Monte Carlo optimization trial to estimate time of concentration measured in hours for a subbasin.

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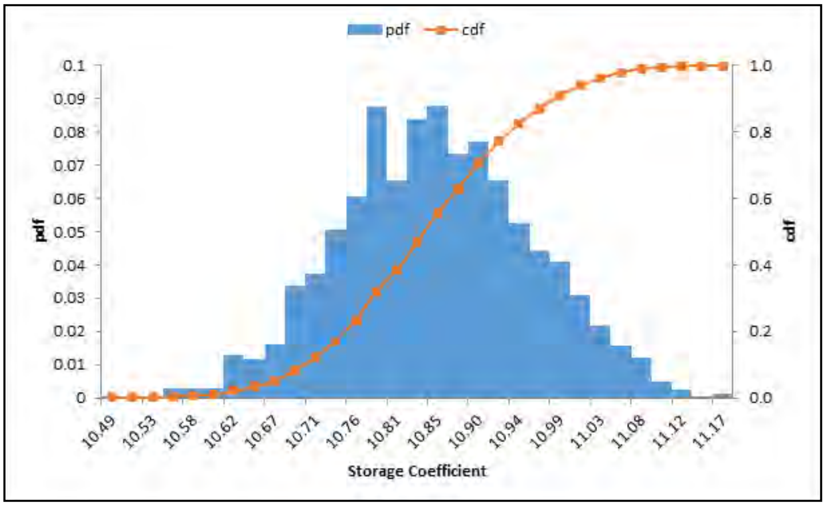

Figure 6. A posterior distribution of storage coefficient (measured in hours) for a subbasin using the Markov Chain Monte Carlo optimization trial.

framework, convergence is to a distribution for each parameter. Converging to a distribution complicates assessment of its completion and accentuates the need for a weight-of-evidence approach. Evidence for the evaluation of convergence includes the Gelman-Rubin statistic, a model performance measure such as the root mean square error, and the evolution of each parameter. The program can also contain plots showing the evolution of the likelihood function and parameters during the simulation.

The new MCMC algorithm will provide a significant new tool for state of the art model calibration, wherein its application results in formal quantification of HEC-HMS model parameter uncertainty. Its MCMC allows HEC-HMS to operate as a probabilistic flow simulation tool. Output from the MCMC algorithm will provide a leap forward in studies requiring probabilistic results, such as risk-informed engineering analyses. Output from the MCMC optimization includes correlated parameter sets that can be used within the HEC-HMS uncertainty analysis simulation type. A new parameter sampling method has been added to HEC-HMS Version 4.3 and is referred to as the Specified Values Method. This method allows the user to specify one or more sequences of parameter values (parameter paired data curves). Sampling of the parameter sequences proceeds index-wise. The sampling will proceed by choosing all values in Index 1 (these values represent one parameter set), then the second sample will choose all parameter values in Index 2, and so on. Each index represents a single set of parameters (correlation is inherent). In addition to using output from an MCMC optimization to create parameter sets for an uncertainty analysis, users could simply create realistic parameter sets from manual calibrations and use the new Specified Values Method sampling option to evaluate how these different parameter sets impact results within an uncertainty analysis simulation.

Temperature-based Evapotranspiration - Evapotranspiration is an important component in the water balance, especially over long durations. HEC-HMS has had continuous simulation capability, using monthly-average evapotranspiration, for more than fifteen years. More recent releases of HEC-HMS brought Penman-Monteith, an energy-balance evapotranspiration method, and Priestley-Taylor, a simplification of the Penman-Monteith method, into the program. The Penman-Monteith method requires solar radiation, temperature, wind speed, and relative humidity data. The Priestley-Taylor method requires net radiation, and temperature data.

HEC-HMS Version 4.3 brings some intermediate complexity evapotranspiration methods to the software. These methods require only air temperature to compute evapotranspiration. Temperature-based evapotranspiration were added to support a USACE study in the Trinity River Basin where synthetic weather events drove a hydrologic model in a stochastic modeling framework; the requirement was to run continuous simulations with synthetically generated precipitation and temperature data. After a literature review, the HEC-HMS team decided to add both the Hamon and Hargreaves evapotranspiration methods to the program.

The Hamon evapotranspiration method, based on the 1963 formulation, requires daily average temperature data along with basin location, i.e., latitude and longitude. When using the Hamon method with sub-daily simulation time steps, the daily evapotranspiration will be distributed to the sub-daily intervals using a sinusoidal distribution.

The Hargreaves evapotranspiration method, based on the Hargreaves 1975 formulation, requires daily average temperature and solar radiation data. Solar radiation can be approximated using temperature data and the Hargreaves and Samani 1982 approach. Combining the Hargreaves 1975 evapotranspiration approach with the Hargreaves and Samani 1982 solar radiation approach yields the Hargreaves and Samani 1985 evapotranspiration approach, where temperature is the only data requirement. The HEC-HMS team implemented Hargreaves evapotranspiration in HEC-HMS in an unintegrated manner to keep the evapotranspiration and radiation pieces modular. For

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evapotranspiration that is equivalent to the Hargreaves and Samani 1985 formulation, the modeler should use Hargreaves radiation with Hargreaves evapotranspiration in the HEC-HMS meteorologic model.

Hamon evapotranspiration, Hargreaves evapotranspiration, and Hargreaves solar radiation all include empirical coefficients that the modeler can adjust during model calibration. Academic literature provides suggestions on how and to what extent these coefficients should be adjusted.

In addition to the Hamon and Hargreaves evapotranspiration methods, the HEC-HMS team added an additional evapotranspiration method that is a simplification to the Penman-Monteith implementation that has been available in the program. This new option is the "reduced-set" Penman-Monteith evapotranspiration method. Reduced-set Penman-Monteith can use any solar radiation data stream, but the suggested approach is to use the Hargreaves solar radiation method, which requires just temperature. The relative humidity requirement is negated by assuming dew point temperature is at or near daily minimum temperature. So, the reduced-set Penman-Monteith approach can be driven with just temperature and wind speed data; there are suggestions for approximating wind speed when no data is available.

The added capability of intermediate complexity evapotranspiration methods should be a huge boon for setting up continuous simulation models. The HEC-HMS teams anticipates these simpler methods will rise in popularity over more complex methods given the scarcity of good hydrometeorologic data around the world. In addition to work on evapotranspiration, the HEC-HMS team looks forward to enhancing the shortwave and longwave radiation components that drive evapotranspiration and snowmelt algorithms in HEC-HMS.

The Beginnings of Integrated GIS Tools - As the HEC-HMS team begins directly integrating geographic information system (GIS) capabilities within HEC-HMS, Version 4.3 provides initial GIS capabilities that can be used to quickly setup a basin model or modify an existing basin model. Within HEC-HMS Version 4.3, the user can now define the coordinate system for a basin model. Once a coordinate system has been defined, GIS features for subbasins and reaches can be imported into the project, or existing subbasin and reach basin model elements can be georeferenced using GIS features. Instead of interacting with element icons, the user can interact with polygons and lines for subbasin and reach elements once GIS features have been added to the basin model.

Figure 7 shows a basin model map where the element icons have been turned off. The subbasin elements are represented with polygons and the reach elements are represented with lines because GIS features were imported.

The option to import subbasin and reach elements from GIS features allows users to quickly create a basin model. Once subbasin and reach elements have been imported from shapefiles, the user can manually add junctions and other elements to the basin model. Finally, the user can connect the elements from upstream to downstream to form the hydrologic network.

Integration of HEC-HMS within HEC-WAT and CWMS HEC-RTS – HEC-HMS is a major component of both the HEC s Watershed Analysis Tool

Figure 7. A basin mode map with the element icons turned off. The user can interact with the subbasins by selecting subbasin polygons and reaches by selecting reach lines. The grey polygon represents a selected subbasin element.

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(HEC-WAT) and the CWMS/ HEC-RTS software. Both HEC-WAT and HEC-RTS are integration tools that manage passing output and visualization of modeling elements and results for software applications. HEC-WAT also contains options for sampling precipitation and flow within a Monte Carlo compute. HEC-HMS can be applied within an HEC-WAT simulation where precipitation or flow is sampled including magnitude of the event, spatial and temporal pattern of the precipitation, and date of the event) while also performing an uncertainty analysis on internal HEC-HMS model parameters. HEC -WAT facilitates the passing of HEC-HMS model output to other HEC software for evaluation of uncertainty in hydraulics, reservoir operation, and consequence analysis.

Future Efforts

The HEC-HMS team has plans for new capabilities/features in versions 4.4 and 4.5. HEC-HMS Version 4.4 is currently scheduled to be released in the Spring of 2019. The flagship feature planned for Version 4.4 is automated GIS delineation of subbasins and reaches. This new GIS capability will allow modelers to set up the basin model directly within HEC-HMS. HEC-GeoHMS has been the tool used to date to create the subbasin and reach element network. One goal of the HEC-HMS team is to provide GIS capabilities directly within the software; the GIS capabilities will be customized for the HEC-HMS workflow. There are other new modeling options targeted for HEC-HMS Version 4.4, as well as enhancements aimed at reducing model run times. The main new software feature scheduled for HEC-HMS Version 4.5 will be a 2D flow and sediment transport option. The HEC-HMS and HEC-RAS teams have been collaborating to bring the HEC-RAS 2D flow code directly into the HEC-HMS computation framework. Modelers will be able to define subbasins that use both standard unit hydrograph methods and the new 2D overland flow option within a basin model. There will also be new capabilities that support water management simulations, new hydrologic process simulation options, additional GIS capabilities, and further improvements to run times with HEC-HMS Version 4.5. The HEC-HMS team is excited about the next two versions of the software, so please stay tuned!

CWMS (Corps Water Management System) Team Modeling

By Myles McManus, P.E. and Matthew McPherson, P.E., D.WRE

The CWMS Corps Water Management System **Team Modeling** feature delivered in CWMS Version 3.1.1 provides a significant new functionality that CWMS users should take note of – it enables multiple users to work together on the same forecast with **efficient semi-automatic file management capabilities.**

The **Team Modeling** feature was designed to facilitate collaboration between multiple modelers who share forecasting and reservoir regulation responsibility within a complex watershed that is represented with several models in CWMS. One modeler may only be responsible for the HEC-HMS (Hydrologic Modeling System) model, while another may be in charge of the HEC-ResSim (Reservoir System Simulation) and HEC-RAS (River Analysis System) models. **Team Modeling** allows each modeling team member to focus only on the models and alternatives they are responsible for.

A Team Modeling Watershed - A team modeling watershed consists of a Master Watershed and its Forecasts, which are stored in a shared location such as a networked drive or the CWMS server . Team members share data by uploading and downloading changes to and from the Master Watershed, interacting with a local copy that resides on their computer. When one team member uploads changes to the Master Watershed, other team members actively working on the same watershed are notified of the changes by a real-time notification system. Designating a CWMS Watershed to be a Master Watershed is easy; from the Watershed Properties dialog (Figure 8), opened from within the CWMS CAVI (Control And Visualization Interface), from the Setup tab, Watershed menu, the user simply clicks a checkbox and specifies the Network Directory where the Master Watershed will be stored.

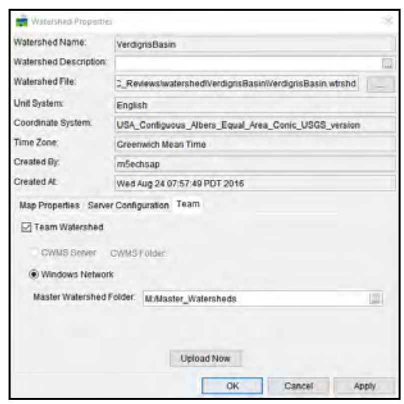

Figure 8. Watershed Properties Dialog.

Automatic Change Notifications - When a team modeling watershed is opened in CWMS, the user is immediately notified of any changes that have been made to the Master Watershed in the Master Watershed Synchronization dialog (Figure 9) along with the revision

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CWMS Corps Water Management System Team Modeling continued)

By Myles McManus, P.E. and Matthew McPherson, P.E., D.WRE

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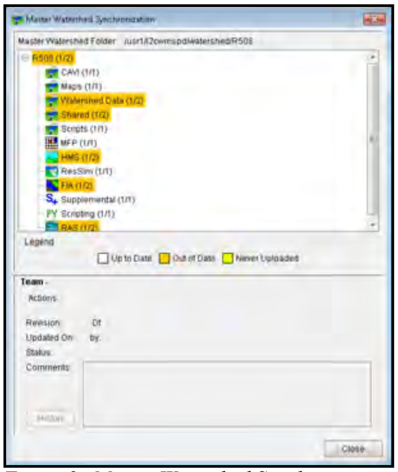

Figure 9. Master Watershed Synchronization Dialog

numbers and any comments made by the uploading modelers.

When working with a team modeling watershed, any new forecast that is created and uploaded to the Master Watershed becomes a Master Forecast. When a Master Forecast is opened locally by a teammate, they will be notified if any changes have been made to the Master Forecast which they can then sync to their local copy of the forecast.

Efficient File Management - The synchronizations to and from Master Watersheds or Master Forecasts will only affect files that have been changed, making the **Team Modeling** system effective in low-bandwidth environments, since files that have not been changed will not be uploaded or downloaded.

Easy Access to Synchronization Tools - The Team tab, located at the bottom of the Forecast Control Panel of the Modeling Module Figure 10 in the CWMS CAVI, contains the Upload & Download action buttons to enable the user to synchronize the local copy of the Team Forecast with the Master Forecast.

Users can also protect specific models in the program order of their Master Forecast from being overwritten during synchronization.

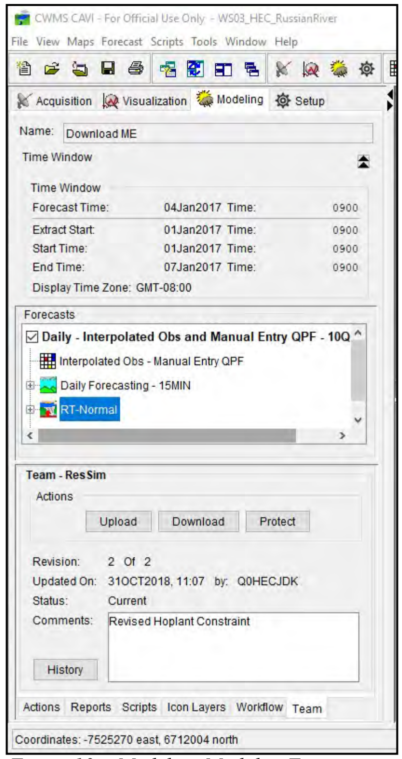

Figure 10. Modeling Module - Forecast Control Panel – Team Tab

This capability reduces the potential for other team members uploading incorrect or unwanted revisions to the models. Models can be protected and unprotected from the Team tab using the Protect action button which appears when a specific model alternative is selected from the Forecasts tree.

Also available from the Team tab is the History button, which opens the Revision History dialog (Figure 11). The Revision History dialog can be used to keep track of every file changed between revisions of each synchronization of the Team Forecast.

The **Team Modeling** feature in CWMS will help the Water Management community to be more efficient and productive in forecasting by allowing multiple users to work together and make use of automated file versioning and archiving of their forecasts. No longer should modelers need to work from the same network location and risk read/write errors or spend time manually archiving forecasts. With **Team Modeling**, CWMS becomes a more powerful tool no matter your workflow – both event-based forecasting and continuous forecasts become more easily managed using this great new tool.

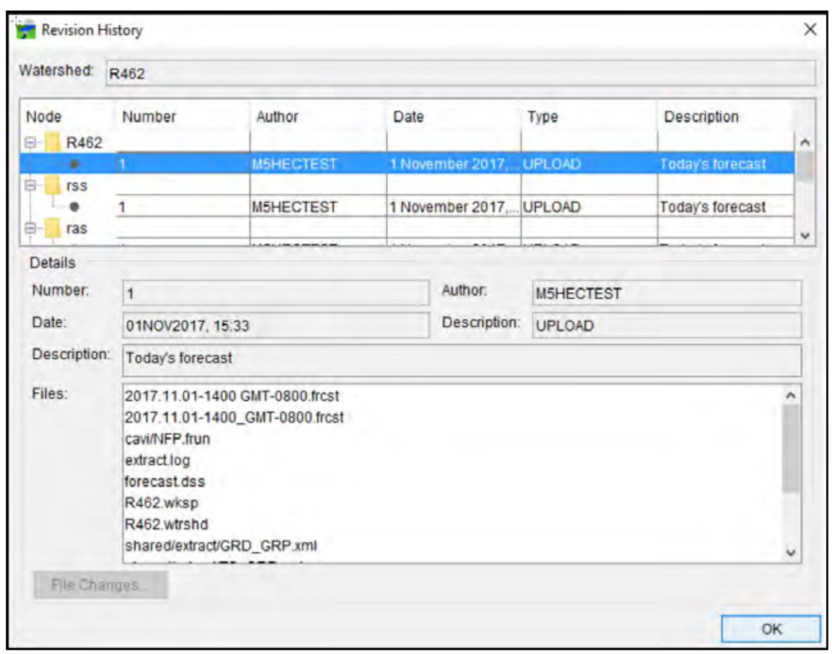

Figure 11. Revision History Dialog

HEC CWMS Team Visits Texas Water Management Offices

By Matthew McPherson, P.E., D.WRE

The Hydrologic Engineering Center's (HEC) CWMS (Corps Water Management System) team members Mr. Matthew McPherson, Mr. Michael Perryman, Ms. Joan Klipsch, Mr. Fauwaz Hanbali, and Mr. Myles McManus participated in the Water Management Implementation Support Team (WMIST) meeting in Arlington, Texas on 6 - 7 November 2018. The broad spectrum of participants from across the country shared experiences, discussed related issues, and leveraged the networking opportunity to assist each other and collaborate.

The USACE U.S. Army Corps of Engineers' Southwestern Division (CESWD) was heavily represented among the participants, but about half of the session was devoted to sharing and discussing water management operations at CESPK (Sacramento District), CENWK (Kansas City District), CESAJ (Jacksonville District), CENWP (Portland District), CESAW (Wilmington District), and CEMVN (New Orleans District). The HEC team members noted the different implementations and requirements related to water management software at each office, and contributed to the discussions about the challenges and potential ways forward. One of the most significant topics was the use of CWMS during flood emergencies caused by recent hurricanes. The USACE Districts have been very successful at leveraging CWMS data and modeling to provide the information required to make operational decisions, inform local partners, and satisfy upward reporting requirements within the USACE. Technical support from the Mapping, Modeling, and Consequence Center (MMC) and HEC was often an essential part of the operation.

While in Texas for the WMIST meeting, Mr. McPherson, Mr. Hanbali, and Mr. McManus also visited several water management offices in Texas who use CWMS. Our visits included observing operations and software implementations, troubleshooting technical issues, and planning future activities. The Lower Colorado River Authority in Austin, Texas uses the publicly available version of CWMS, HEC–RTS Real-Time Simulation to help manage operations at its system of reservoirs in central Texas. The reservoir control office in Austin overlooks the Tom Miller Dam (Figure 12) which was making releases after historic flooding in the Highland Lakes watershed. The HEC team provided updated software, consulted on data processing implementations and HEC-HMS modeling, logged software issues to resolve in subsequent versions, and planned a future training activity.

The HEC team next participated in the Addicks and Barker Emergency Table Top Exercise in Houston, Texas. The Galveston District (CESWG), Harris County Flood Control District, and other partners practiced emergency response coordination and communication given a series of escalating flood hazard scenarios. The situations were all predicated on inundation maps and release schedules generated from the District's CWMS forecast models. The HEC team joined the Deputy District Commander on a quick tour of the Addicks and Barker project, learning about its performance during Hurricane Harvey and the major improvements underway. The HEC contingent subsequently visited the Galveston District office to discuss water management operations, data and modeling issues, and software improvements.

The Fort Worth District (CESWF) also hosted the HEC team, demonstrating water management operations making heavy use of REGI (Report Generation Interface)

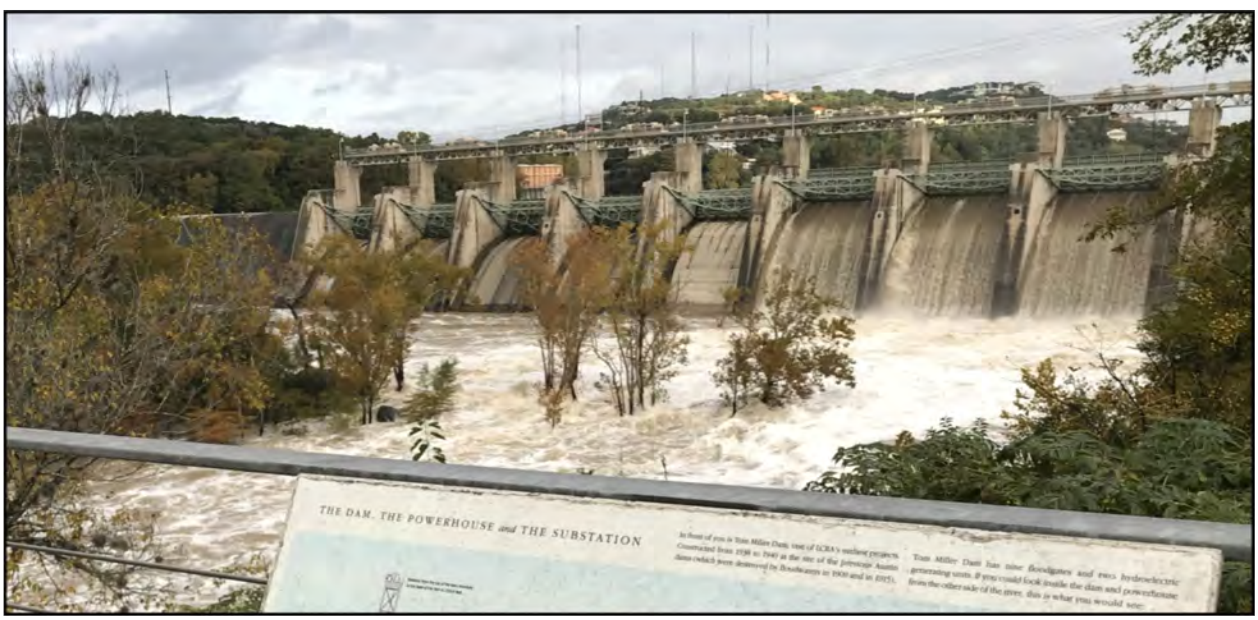

Figure 12. Tom Miller Dam, Texas

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HEC CWMS Team Visits Texas Water Management Offices (continued)

By Matthew McPherson, P.E., D.WRE

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and CWMS. The discussion underlined the complementary nature of the software packages and suggested areas of further development and better integration. The group experimented with the **Team Modeling** page 10 feature in CWMS Version 3.1.1, engaged in troubleshooting, and logged software issues for subsequent follow-up.

Overall, the trip was very beneficial as the HEC team learned much from several field offices who are implementing CWMS. What was learned will provide future direction to CWMS development and enhancements. In addition, the HEC CWMS group was also able to directly interact with the field offices and provide support that should benefit the field offices as they conduct their daily operations.

Trinity River Basin Hydrologic Hazards Study

By Gregory Karlovits P.E.

Assessing hydrologic hazards for large dams is part art and part science. Flood control dams are, by design, intended to withstand hazards created by very rare, large floods. For the purposes of a risk assessment for one of these kinds of dams, the probability of overwhelming the dam to the point of causing economic damages or loss of life must be estimated. Often, the magnitude of the probability of interest is on the order of 10^{-4} to 10^{-6}, or roughly the probability of flipping a coin and getting thirteen to twenty tails in a row. No universal recipe exists for estimating what floods of that magnitude look like for every dam in the U.S. Army Corps of Engineers (USACE) portfolio. This is where the art of hydrologic hazards comes into play. Developing an estimate for the frequency of large, dam-threatening floods, quantifying uncertainty in that estimate, and doing so within the budget and schedule of the project requires creativity and active problem-solving. Fortunately, a wealth of tools are available to dam safety engineers which make a scientifically-defensible finding within these constraints possible.

Designing a solution to answer the question "how likely is this hazard, and how confident is that estimate" requires a balance of three components: adequate representation of the flood hazard, appropriate representation of uncertainty and the project budget (Figure 13).

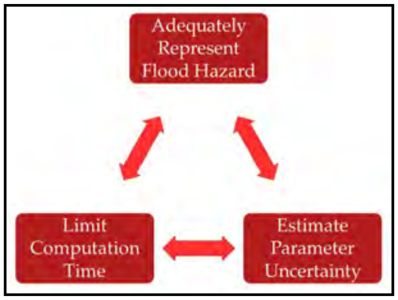

Figure 13. The three competing needs of a hydrologic hazards solution.

The adequacy of the representation of the flood hazard is measured by whether or not a decision can be made regarding the appropriate measures needed to reduce risk. Often this is the driving factor in the complexity of the scope of a hydrologic hazards assessment. The representation of the flood hazard should be as simple as possible to decide what action to take on the dam's risk, but no simpler. A decision-maker must be able to look at the results of a risk assessment and decide what actions, if any, are necessary to make the risk posed by the dam tolerable. When additional simplifying assumptions are made in the analysis, the uncertainty in the final answer generally increases as the information content of the result decreases. Not all uncertainties are practical to include in the modeling effort, but the ones that are most likely to influence the outcome generally sample error in the input data must be included to provide any confidence in the findings. Some uncertainties are impractical to model, or are the infamous "unknown unknowns" which make any uncertainty characterization limited, especially with limited resources to complete the study. Computation time is the currency with which precision and accuracy of the study can be bought. More complex models, robust representation of uncertainty and inference about rare events requires additional computational time. Techniques can be employed to stretch the computation time "dollar" further and achieve more modeling with less investment. Models of higher complexity require more detailed and thorough documentation and review, which are part of a project's budget.

Hydrologic hazard analyses typically result in an estimate of the relationship between a dam's annual maximum reservoir pool elevation and the frequency of that pool elevation, such as the idealized cartoon in Figure 14. Important pieces of information readily gleaned from such a plot are the annual probability of spillway activation, the annual probability of overtopping the dam, and a working order-of-magnitude quantification of the uncertainty in those quantities. Most large dams do not experience a flood which threatens to overtop it in a human lifetime due to the intentional rarity of such an event. The information contained in the operational history of a dam, typically less than a hundred years, is not enough to provide estimates for floods potentially many times larger than the flood of record. As a heuristic, the largest event in 100 years *T* has an estimated probability of being exceeded *p* of 1% *1/T* in any year. Additional information is required in order to make inferences far beyond the period of

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Trinity River Basin Hydrologic Hazards Study continued)

By Gregory Karlovits P.E.

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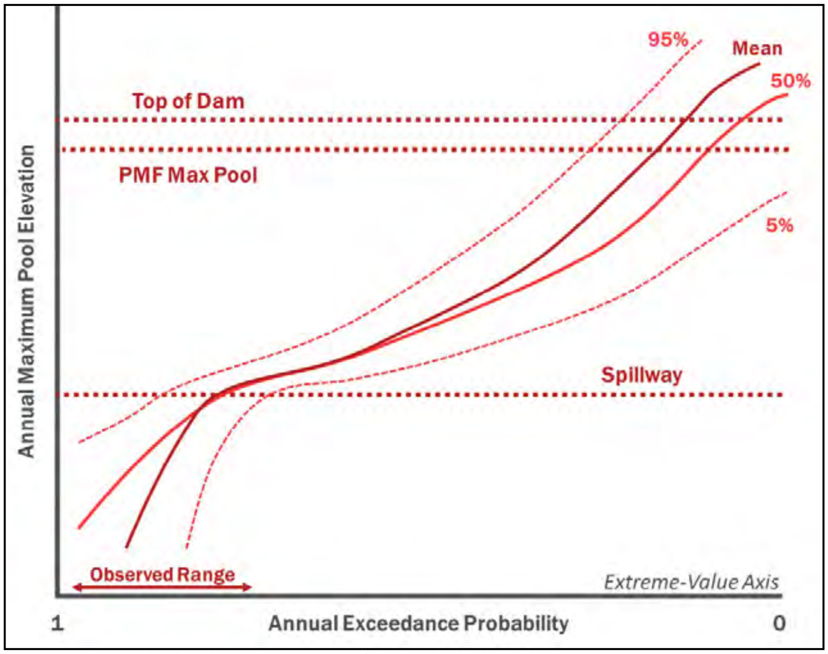

Figure 14. An idealized representation of a dam hydrologic hazard curve.

observations into the realm of *p* 0.01% or smaller. The nature and quantity of this information is dictated by the decision at hand and the detail necessary to adequately represent the flood hazard.

The Trinity River Basin

Historically, the United States Army Corps of Engineers (USACE) hydrologic hazards assessments have been focused on a single dam at a time. Recently, in an effort to do more with less, studies have been scoped with the intention to estimate reservoir stage-frequency curves for multiple dams at a time. The Trinity River Basin above Dallas, Texas presented an opportunity to do exactly that. Five USACE dams in this watershed regulate the tributaries of the upper Trinity Basin, a highly urbanized 6,000 square mile watershed in north central Texas, which flow together in the Dallas-Fort Worth Metroplex (Figure 15). The nature of flood regulation in the basin, particularly to reduce flood damages in Dallas, requires a systems approach to reservoir operations modeling which entangles the hydrologic risk for the different dams. In order to assess hydrologic hazards for a single dam, the entire basin must then be simulated. As a beneficial side-effect, a well-constructed basin-wide model can be used to estimate the hydrologic hazards for all of the dams in the basin in one modeling exercise.

Inference about remote-probability events requires construction of a model to represent the population of those events, and calibration of the model parameters using observed data. A challenge to the parameter estimation part of such an effort is the notion of mixed populations. Improperly identifying the causal mechanism or mechanisms behind extreme events can lead to inaccurate inferences about the rarest events. Such a challenge occurs in the Trinity Basin, where several distinct types of storms, with varying scale in time and space as well as seasonality, can occur and

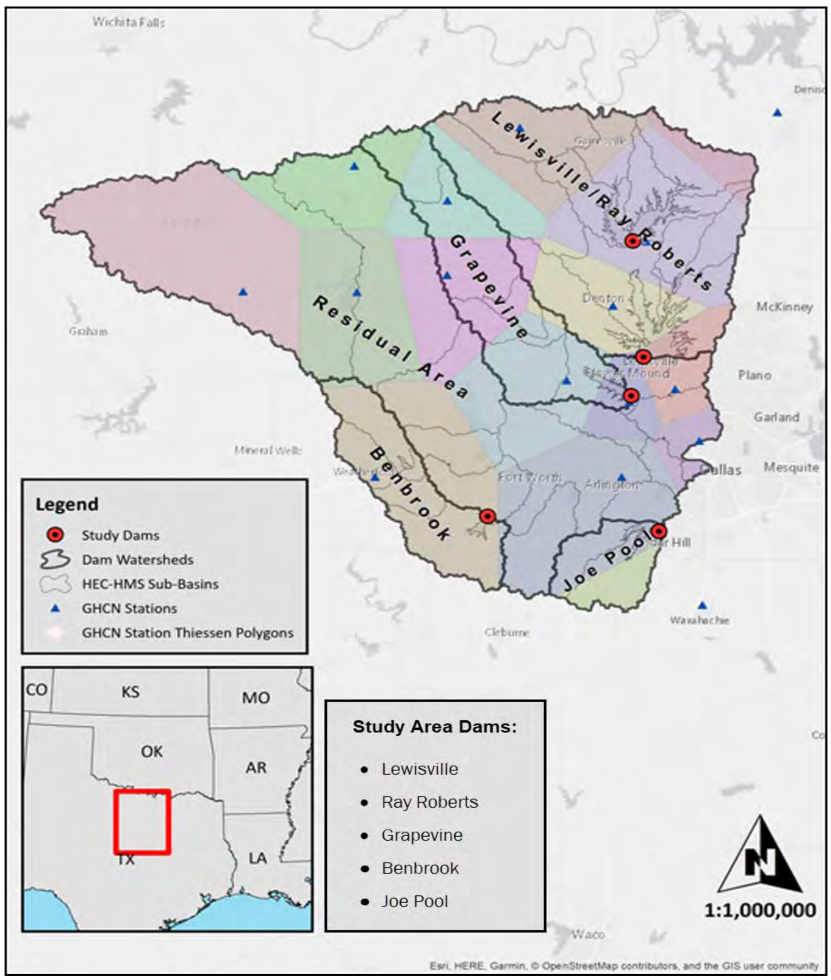

Figure 15. Study area map including locations of the five dams and their drainage areas.

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create flood hazards. Mixtures of flood mechanisms occur in many other places as well, such as the combination of rain and snow-driven flooding, ice jams and debris flows, and other combinations of separate flood-inducing mechanisms. To overcome the impact of this mixture, new approaches to the rare event inference process are required.

Modeling Framework

Floods affecting the Trinity Basin are characterized by their highly variable meteorology. Storms may be brief and locally intense, widespread and long-lasting and many shades in-between. In order to capture this variation, a modeling framework which allows for variable meteorological boundary conditions to drive changes in reservoir operations is necessary.

Synthetic weather generators (SWG) are a tool for creating artificial data sequences which behave, in a statistical sense, identically to the weather for an area of interest. They are not deterministic weather forecast models; instead, they coarsely represent meteorological processes using statistical models. SWG are most often used to augment observed meteorological data for design or risk analysis purposes. In this study, an SWG was developed with the purpose of generating extreme precipitation events from the controlling storm type while also creating "background" weather necessary for continuous hydrologic modeling. This model also generates multiple "realizations" of synthetic weather by varying the parameters used to generate the events in each realization, expressing parameter uncertainty in a discrete way. Realizations each contain a large number of events in order to capture the natural variability that occurs when sampling from a distribution. A large number of realizations is used to fully express the uncertainty as it is captured in the model. This process is called *two-stage Monte Carlo simulation*, a procedure used for modeling both knowledge uncertainty and natural variability in a numeric model Figure 16 . Precipitation-runoff models are necessary to translate storm events into floods which can be regulated by reservoir models. Additionally,

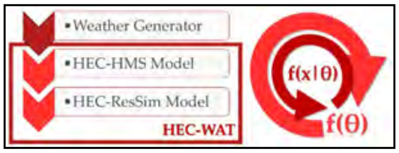

Figure 16. A schematic of the HEC-WAT model framework left and the two-stage Monte Carlo approach to uncertainty right .

the parameter uncertainty in the boundary conditions as well as the hydrologic model must be explicitly modeled. By coupling together an HEC-HMS (Hydrologic Engineering Center's Hydrologic Modeling System) model and HEC-ResSim (Reservoir System Simulation) model for the basin, flood operations can be modeled for these events. The boundary conditions are generated externally and must be provided to the HEC-HMS model in an orderly manner. The HEC Watershed Analysis Tool HEC-WAT meets these needs, and offers additional power and flexibility in handling and processing the model output. Externally-generated storm events enter the HEC-WAT model through a plug-in called the Stochastic Data Import Tool (SDI) which manages the connection between the meteorology in the SWG and the elements of an HEC-HMS model. HEC-WAT then manages the simulations performed in the HEC-HMS and HEC-ResSim models, captures the desired model output, and processes it so that the desired results of the model can be visualized.

Model Details

Synthetic Weather Generator SWG -The SWG was used to create hourly temperature and precipitation data for the entire Trinity Basin which meets three primary goals:

- Create zero or more watershed-wide extreme floods per year with behavior derived from a precipitation-frequency analysis Figure 17 .
- Develop continuous precipitation and temperature data, over a four month window, which characterize watershed conditions prior to those floods.
- Describe the uncertainty in the statistical parameters in the generation process.

The SWG model applied in this study is loosely based on one used in a prior dam safety study for Herbert Hoover Dike in central Florida, but includes improvements to the model procedures to improve flood characterization for the Trinity watershed. A novel procedure for spatiotemporal disaggregation of precipitation was developed for this study in order to

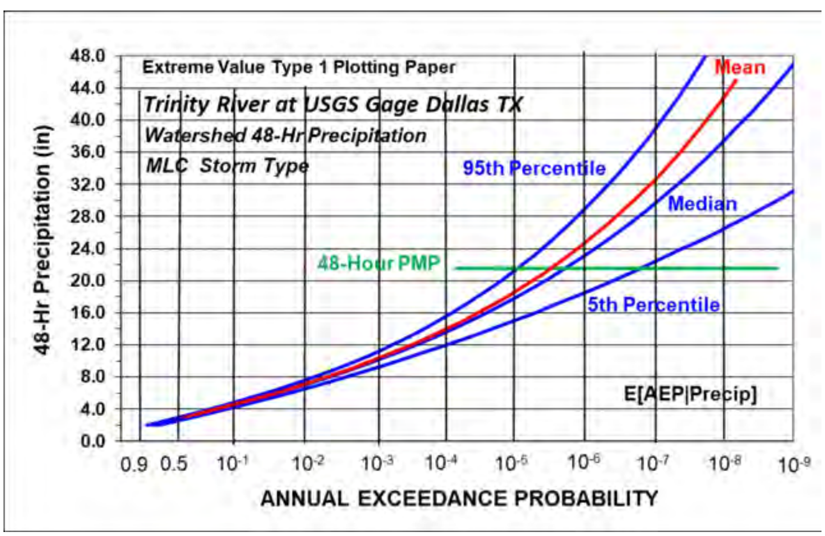

Figure 17. Precipitation-frequency curve for the driving storm type mid-latitude cyclones .

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produce hourly-resolution precipitation data.

One additional goal met by the model is to reduce the number of events required to adequately describe the full probability range of interest. By using a random sampling technique called **importance sampling**, the "more interesting" parts of the frequency curve get more samples than the other parts. Importance sampling was implemented using a stratified sampling strategy. This technique requires additional post-processing using HEC-WAT plug-ins to make sense of the results, but reduces the number of samples required to understand watershed response to precipitation events at rare frequencies. The precipitation-frequency analysis was completed by MetStat, a contractor, with the weather generator developed at HEC.

Hydrologic Model HEC-HMS - A hydrologic model is necessary for turning these extreme precipitation events into floods which can be used to estimate reservoir response. Additionally, the uncertainty in the parameters used to model the water cycle are to be captured. This need led to the development of a basin-wide HEC-HMS model with parameter uncertainty characterized using a new HEC-HMS capability, *Markov Chain Monte Carlo* (MCMC). After the initial calibration for the basin model was completed, large samples of model parameter sets were generated using the MCMC procedure. Event simulations then used these parameter sets to vary the hydrologic response according to the magnitude of the uncertainty in those parameters. Development of the HEC-HMS model was completed by engineers at Ft. Worth District with assistance from HEC. Brian Skahill ERDC-CHL made significant contributions to the parameter uncertainty development using MCMC.

Reservoir Operations HEC-ResSim - Reservoir response to floods is simulated using an operations model that captures how a dam would operate in a set of given conditions based on its regulation rules. An HEC-ResSim model was developed to work with the simplified basin. Dallas is not the only point in the Trinity Basin for which these five dams operate, but is the only one included in the model and the HEC-ResSim model was adjusted to maintain good performance compared to observed operations. Although operations may in real life vary during a flood event, current policy is to treat reservoir operations as deterministic and as reflective of current operational rules as possible. The HEC-ResSim model was originally developed at Ft. Worth District with modifications for Monte Carlo simulations made by HEC.

Model Coupling and Post-Processing HEC-WAT - Management of these complex simulations was greatly aided by use of HEC-WAT. Its features provided numerous benefits to the study, for example, HEC-WAT:

- managed a distributed compute in which simulation work was split up over numerous computers for:
    - 1,000 realizations of 1,000 events ranging from 0.5 to 10-8 AEP,
    - Total compute burden of 1,000,000 events each four months long at hourly or finer time step, and
    - Eighty compute nodes divided into four "grids" of computers;
- organized large meteorological inputs and connected them to the correct
- HEC-HMS model elements using the SDI plug-in;
- aided model validation with a results-processing plug-in which allowed for feedback on model performance; and
- accelerated processing of results by handling the stratified results which occur due to the SWG importance sampling scheme and producing meaningful output.

The greatest flexibility came with widespread use of the plug-in API. Several custom plug-ins were rapidly developed by Mr. Will Lehman (HEC) which greatly enhanced the team's capacity for completing the study.

Conclusion

Stage-frequency curves were generated for the five dams of interest Figure 18 and will be used as part of the risk analysis process in the ongoing Issue Evaluation Study in the Trinity River watershed. While the project deliverables were the primary focus, many of the successes engineered during the course of the study are extremely valuable for future studies:

- close collaboration between HEC, CESWF USACE, Fort Worth District , ERDC-CHL USACE, Engineer Research   Development Center - Coastal and Hydraulics Laboratory and RMC USACE, Risk Management

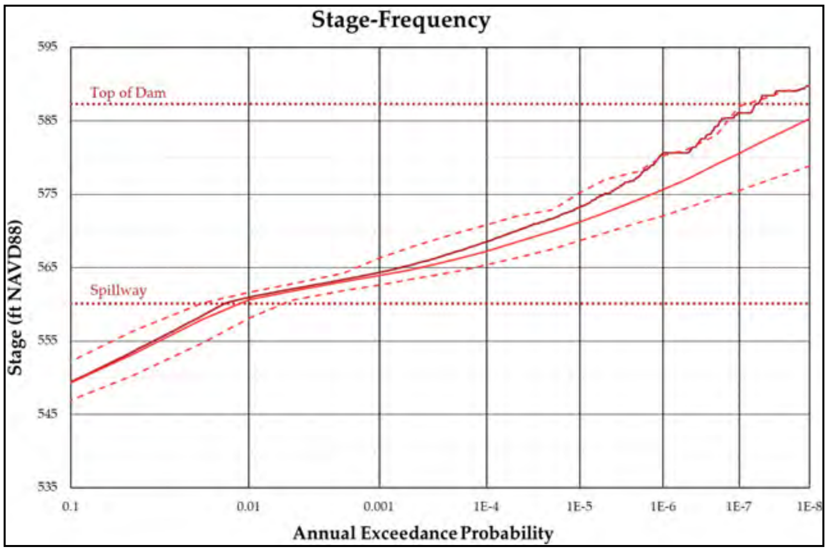

Figure 18. Stage frequency curve for one of the five upper Trinity dams.

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Trinity River Basin Hydrologic Hazards Study continued)

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Center resulting in knowledge transfer as well as innovations for software development;

- successful inclusion of coupled-model performance validation in the modeling framework;
- envelope-pushing application of HEC-WAT, including several new plug-ins and distributed computation;
- computational burden-reducing statistical techniques in the synthetic weather generator;
- development of novel statistical weather generation procedures for improved flood characterization;
- application of MCMC parameter uncertainty in HEC-HMS, both in optimization and uncertainty simulations;
- application of the new variable Clark time of concentration and storage coefficient option captures non-linear precipitation-runoff response ;
- code enhancements to reduce run times in HEC-HMS; and
- clear elucidation of research and development needs in extreme flood hydrology, especially uncertainty-based hydrologic modeling and synthetic weather generation.

Acknowledgements

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Contractor-collaborators: Mel Schaefer (MGS Engineering), MetStat, Inc. (notably Debbie Martin), Tye Parzybok, Jason Caldwell, Katie Ward, Victoria Bahls, Brian Crow, Bradley Wells , and Wayne Gibson (Applied Climate Services).

Novel Uses of HEC-WAT (Watershed Analysis Tool) Output

By William Lehman (CEIWR-HEC), Stanford Gibson (CEIWR-HEC) Ph.D., and Woodrow Fields (CEIWR-RMC)

The Hydrologic Engineering Center s Watershed Analysis Tool (HEC-WAT) is a software application designed to support watershed analysis with uncertainty. The HEC-WAT's purpose is:

> "*To provide a water resources tool that integrates engineering and consequence software to support a wide range of USACE applications, including watershed and systems based risk analysis*".

This article details two recent HEC-WAT applications that supported novel water resources analyses. The first example, "Actuarially-Based Insurance Rates", develops actuarially-based flood insurance rates on a per structure basis. The second example, "Sedimentation Case" illustrates storm sequencing effects on a sediment life cycle analysis.

Actuarially-Based Insurance Rates - This example utilized HEC-WAT to evaluate risk-based flood insurance premiums on structures in the floodplain north of the American River in Sacramento, California. To support the evaluation of risk-based premiums, HEC-WAT used the Hydrologic Sampler, HEC-RAS (River Analysis System), the Fragility Curve Sampler, and a damage computation plug-in. These software programs were used within a Flood Risk Analysis FRA compute i.e., considering uncertainty to produce three outputs, Annual Exceedance Probability (AEP) grids, Expected Annual Damage(EAD) with uncertainty per structure, and AEP per structure. The EAD estimates and their uncertainty distribution can be used to determine a risk-based premium per structure.

The Hydrologic Sampler, a plug-in for HEC-WAT, generated flow events for the upstream boundary condition of HEC-RAS. Figure 19 illustrates a sample of fifty events of varying magnitude, with each event separated from one another in time. This technique made each HEC-RAS model simulation result independent from previous events.

This project utilized the two-dimensional compute engine within HEC-RAS. The levee structure was set with two breach locations, one on the North East Main Drainage Channel NEMDC and one on the American River. The HEC-WAT

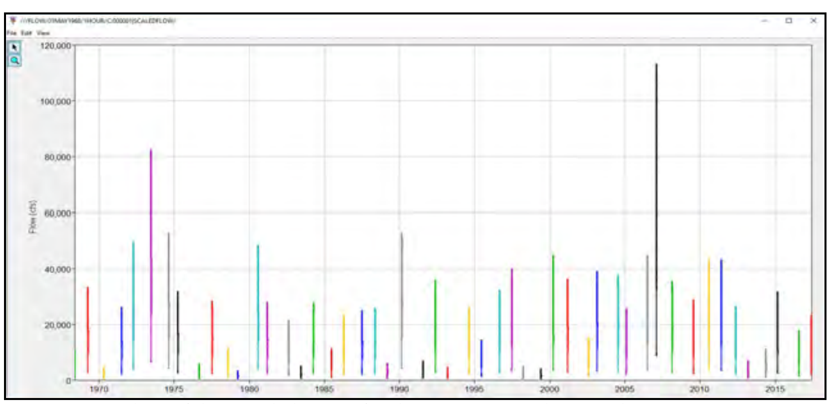

Figure 19. Subset of the sampled events for the insurance study example.

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Fragility Curve Sampler randomly generated breach trigger elevations for each breach location. This process allowed for the computation of an AEP grid which represented the impact of levee fragility on the computed AEP for each grid cell (Figure 20). This grid can also generate the boundaries of any floodplain requested for any return frequency.

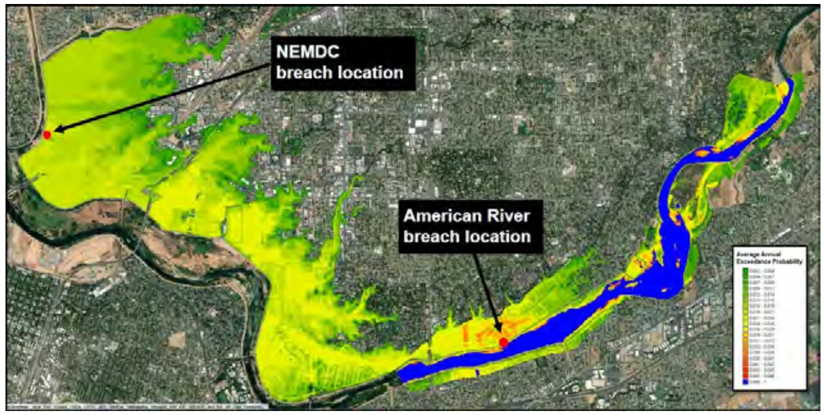

Figure 20. AEP grid for Insurance example study.

The hydraulic outputs from HEC-RAS were utilized to compute damages at each structure for each event. Depths for each event were extracted for each point in the structure inventory, and damages were calculated and stored for each event. Figure 21 shows a single event from HEC-RAS compared to the locations of structures in the structure inventory.

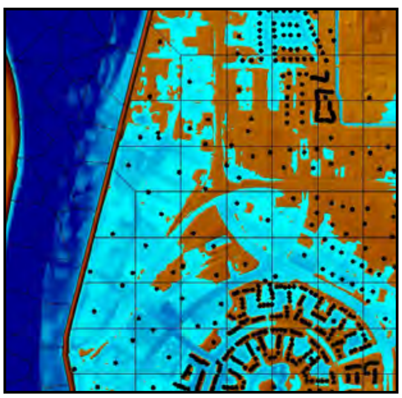

Figure 21. Depth grid and structures displayed together.

HEC-WAT summarized all events into EAD estimates for each of the twenty realizations simulated, which generated a distribution of EAD for each structure. The distribution of EAD represents the knowledge uncertainties of the simulation, while the EAD itself represents the natural variability impacting the damage estimates at each structure. Figure 22 illustrates the average of all EAD estimates for each structure, classified by dollar ranges.

In addition to computing EAD at each structure, this process also allows for the extraction of AEP per structure, so that AEP can be reported on a per structure basis (Figure 23). AEP per structure allows for communication of the likelihood of inundation at a structure to facilitate understanding of the hazard.

Sedimentation Case – HEC-RAS supports the computation of sedimentation processes during a one day computation. For this example application, HEC used a new feature in the Hydrologic Sampler in conjunction with an HEC-RAS sediment model of Lewis and Clark reservoir (Gibson and Boyd, 2015). The unsteady HEC-RAS model simulates the deposition of the Niobrara River in the downstream-most reservoir on the Missouri Cascade.

The sedimentation study used the Hydrologic Sampler to produce the upstream boundary conditions for

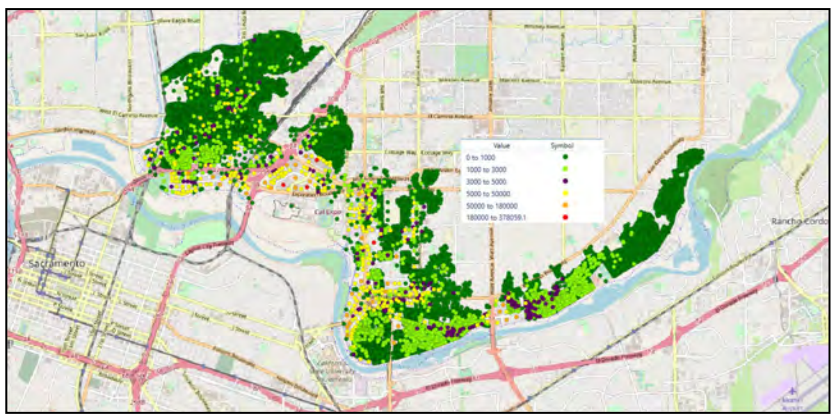

Figure 22. Annual Exceedance Probability (of depth above ground) by structure.

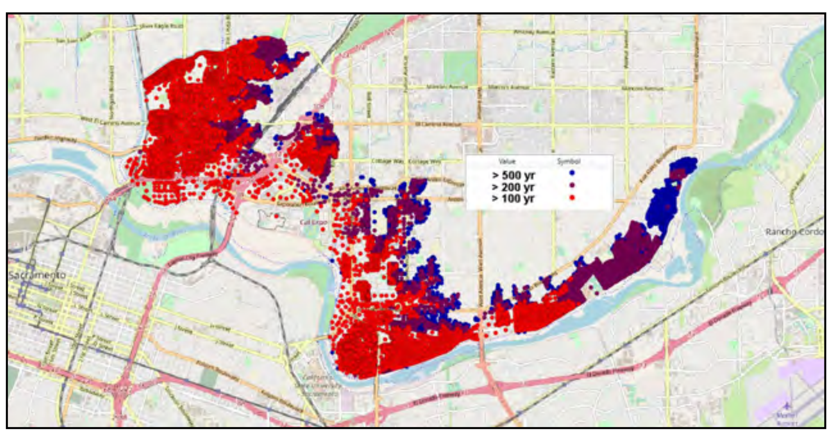

Figure 23. Annual Exceedance Probability (of depth above ground) by structure.

continued on page 18

By William Lehman CEIWR-HEC , Stanford Gibson CEIWR-HEC Ph.D., and Woodrow Fields CEIWR-RMC

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HEC-RAS. Unlike the insurance case study where events were independent, this time the events were continuous for fifty years at a time. The new feature of the Hydrologic Sampler produces continuous events for multiple years of duration. Therefore, the modeled events and their sequences impacted the outcomes for HEC-RAS. In this example, the Hydrologic Sampler sampled historic storms, weighting each storm identically and combining them into fifty-year flow series i.e., historical bootstrapping techniques . Figure 24 includes the actual historical record red and one sampled lifecycle fifty years of continuous flow derived from the historical record (green). The synthetic series (green) did not sample the largest historical event, and placed the second largest event halfway through the period of record. Other time series sampled the largest event more than once. Sediment processes and life cycle analyses are sensitive to this variability in magnitude and timing.

HEC-WAT ran the HEC-RAS sediment model with three hundred randomly generated fifty-year flow event sequences, developed from historical flow data. Sediment transport is non-linear with flow. The sequence and magnitude of the future flow events is a dominant factor in sediment transport uncertainty. The timing of large events is particularly important because these large events may account for much of the scour or deposition, affect the project life cycle analysis, and affect future distribution of benefits.

Figure 25 illustrates the uncertainty in bed change erosion at a model cross section in the HEC-RAS model across the lifecycle of the analysis in HEC-WAT. The vertical red distributions summarize the impact of hydrologic uncertainty on the channel invert over the fifty-year simulation, which increases with time.

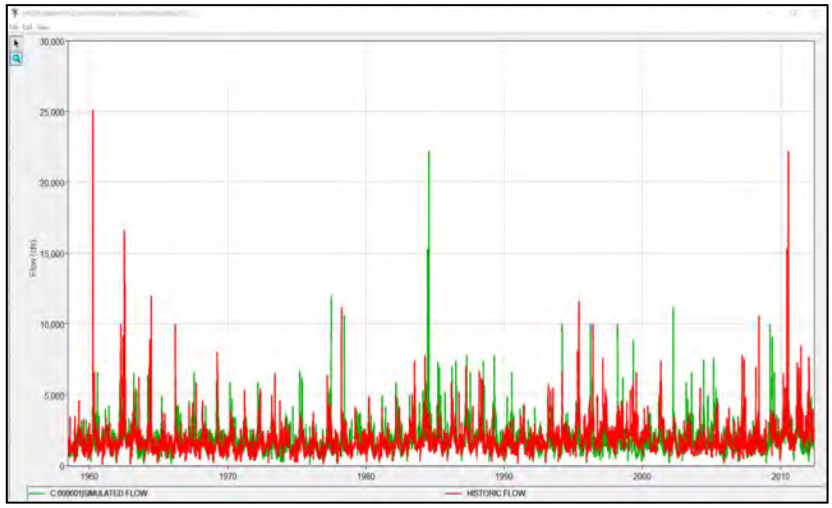


Figure 24. Historical flow record red compared to one of the three-hundred 50-year synthetic (boot strapped) flow records (green) used in the sediment example.

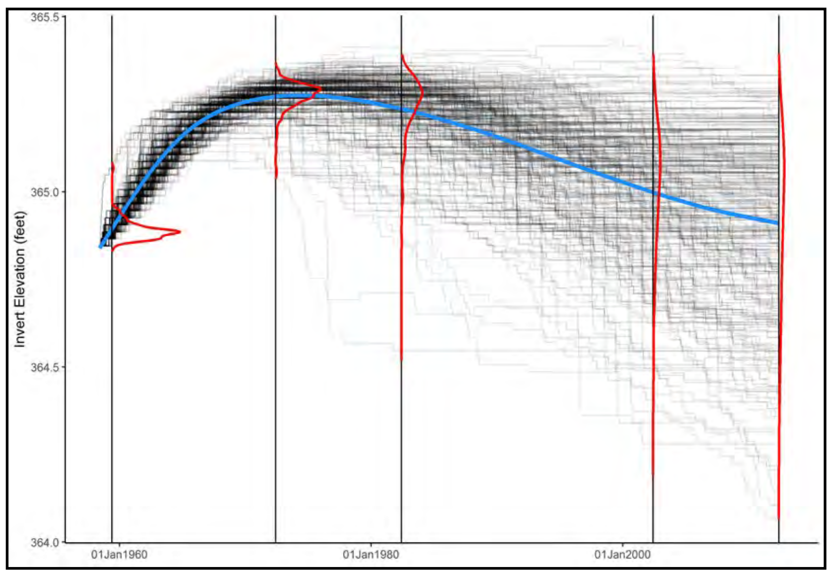


Figure 25. Three hundred traces of the invert elevation of a cross section across time.

Conclusion

HEC-WAT presents a flexible framework for evaluating a range of study goals with uncertainty. Utilizing HEC-WAT could improve a project delivery team's ability to characterize their uncertainty on specific outputs in ways that were previously only theoretical. The flexibility of the HEC-WAT framework creates opportunities that are only limited by our users imaginations. We challenge you to use HEC-WAT and provide us feedback on your experience – you are the reason we built this, let us know how we can help.

One Hydrologic Technician's Experiences

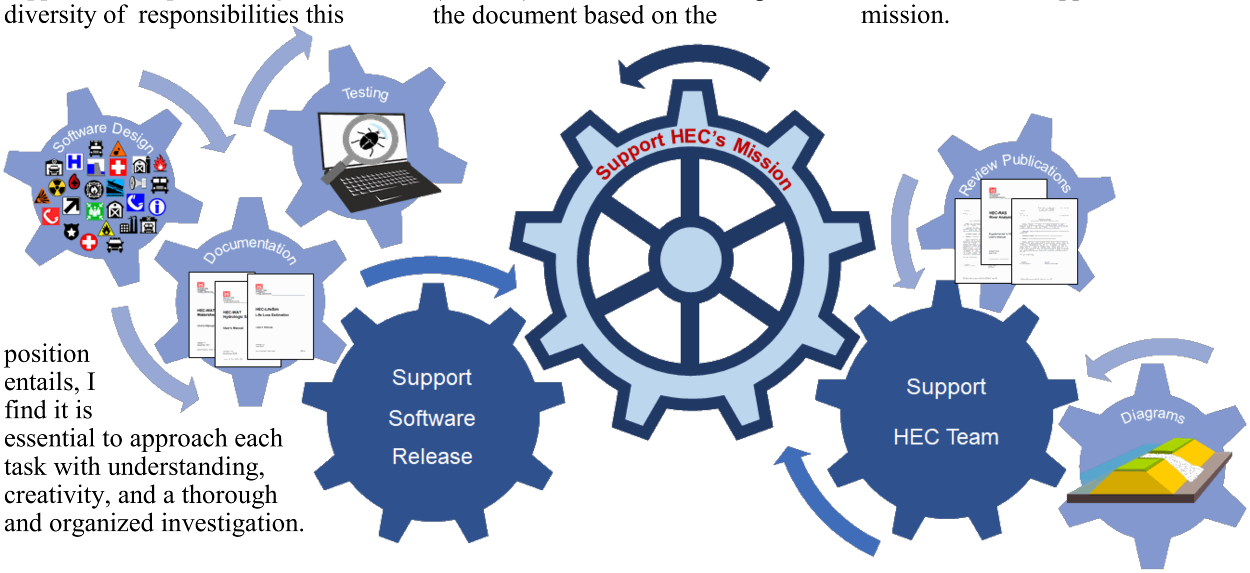
By Julia Slaughter

After beginning my hydrologic technician position over three years ago, I soon discovered that I should expect the unexpected nearly every day at the Hydrologic Engineering Center (HEC). This expectation grew from the wide range of different services I have been asked to provide in support of HEC's mission, which at times vary on a daily basis. Services performed include but are not limited to software testing and documentation for validation; USACE guidance documentation; training assistance; software users' documentation; and project, technical, and business support. When performing the diversity of responsibilities this position entails, I find it is essential to approach each task with understanding, creativity, and a thorough and organized investigation.

creativity and ingenuity to complete the task. Overall, I have found that communication with the software development team is paramount to support the team efficiently by resolving questions and clarifying problems logically.

Furthermore, it has become my experience that when undertaking software testing and working on software documentation, a thorough investigation and understanding of the interworking of the software is vital. For example, one of my very first tasks at HEC was to review the Corps Water Management System (CWMS) User's Manual and update the document based on the

might pop in to request an illustration for a presentation, a software design recommendation, help with an issue they have encountered, or a quick review of a document. Therefore, a balance between a task s arranged timetable and significance must be determined to accomplish each task with efficiency. Through my experiences I have found that the responsibilities of a hydrologic technician at HEC require creativity, objectivity, and flexibility to adapt to a dynamic and varied workload. In other words, I have come to wear a wide range of different hats in support of HEC's mission.



Conceptual diagram illustrating the dynamic workload and various hats worn in support of the HEC's mission.

Supporting HEC's mission does contain a certain amount of routine in software testing and documentation, which is a crucial component of developing new and innovative software for USACE. Analyzing and understanding the intended audience and composition of the logical workflow process is important for reaching this goal. Furthermore, testing the software from a non-developer's perspective can be beneficial by finding potential snags or pitfalls users might encounter, and can help me provide ideas for improving the product's design. Occasionally, specific software design improvements are requested. For example, I was asked to create vector icons for HEC-LifeSim, which allowed me to apply

improvements made to the control and visualization interface (CAVI) of CWMS. A colleague described this task as being thrown in the deep end and being expected to learn how to swim, as the task involved several HEC analysis applications. Consequently, this task provided me an important introduction to a number of HEC's software applications simultaneously, and furthered my understanding of the importance and value of HEC's products and mission.

Overall, communication and organization are important for balancing the multitude of different assigned tasks. For example, in the course of a day several individuals

By Dawn Palma

Ms. Kristy Riley - joined HEC in March 2018 as HEC s first employee dedicated to Project Management (PM). Kristy has her undergraduate degree in Civil Engineering from Cal Poly, San Luis Obispo and masters in Civil Engineering from UC Davis. She started her career in the Sacramento District in Hydraulic Design. There she worked on large feasibility studies (Common Features and West Sacramento) developing HEC-RAS models and inundation maps.

Kristy Riley

In January 2015 Kristy switched to Water Management when she joined the Seattle District (NWS). She regulated NWS reservoirs west of the Cascades as well as Libby and Albeni Falls in the Upper Columbia basin. She assisted with some Columbia River Treaty (CRT) work and was the District lead for CWMS watershed development.

While in Seattle she helped on the CRT effort when USACE, Bonneville Power Administration (BPA)and British Columbia (BC Hydro) were trying to decide on the hydraulic capacity of Grohman Narrows (in Canada) which are affected by Libby Dam (in the U.S.) operations. After years of discussion, she offered a proposal that the agencies accepted. Since there were so many hydraulic capacity curves, they asked what it should be named and someone suggested calling it the Riley curve. The name continues to this day.

Kristy enjoyed leading technical projects, so when the job opportunity at HEC came up to fill a PM role, it seemed to be a good fit. Kristy and her family are also very happy to be back in sunny California!

Mr. Karl Tarbet - joined HEC in the summer of 2018 as a Civil Engineer (Hydraulics) in the Water Management Systems Division. He has an undergraduate and masters in Civil and Environmental Engineering from Utah State University, Logan.

Prior to joining HEC, he worked 20 years for the U.S. Bureau of Reclamation in Idaho. The first two years were as a consultant with CH2M Hill. Karl got tired of travel and joined the U.S. Bureau of Reclamation. He eventually became the manager of the water data system called Hydromet in the Pacific Northwest Region in Boise.

Karl Tarbet

Karl wanted to spend the last half of his career working more directly with the software development world: people, computers, bugs, and code. He discovered HEC works with people, computers, bugs, code, and great weather as a bonus!

PROSPECT Training Program

Current Program & FY 2020 Proposed PROSPECT Training Program

By Christopher N. Dunn, P.E., D.WRE, Lea G. Adams, P.E., Penni Baker, and Julia Slaughter

The PROSPECT (Proponent-Sponsored Engineer Corps Training) program for FY 2019 has begun with three classes completed and seven more to be taught. Please note that while the FY 2019 classes are currently filled, if you are still interested, it never hurts to inquire about joining a class. Sometimes people cancel and you might be able to join the class if they do.

The table below provides the FY 2020 Proposed PROSPECT training program for the Hydrologic Engineering Center. (CEIWR-HEC). The PROSPECT training program is provided through the USACE Learning Center ULC . The ULC is located in Huntsville, Alabama and if you are interested in one or more of the courses, please let the training program lead in your District/ Division know so they can report your interest to the ULC. ULC has implemented a new policy that if minimum enrollment requirements are not met ninety days prior to the start date of a class it will be cancelled. If you have an interest in a class, you need to get your request in sooner than later.

To register for our courses, please contact the appropriate party in your office or contact ULC, http://ulc.usace.army.mil.

Registration is handled by Training and Operations (CEHR-P-RG).

Course descriptions are provided at the ULC site: (http://ulc.usace.army.mil/ CrsSchedule.aspx).

A short description along with a course agenda is also provided on CEIWR-HEC s web site (http:// www.hec.usace.army.mil/training/ course_list.html). To obtain enrollment information, please contact the USACE Learning Center. When doing so, please note the course number, name, date, and location, and contact:

USACE Learning Center
550 Sparkman Drive, NW
Huntsville, AL 35816-3416
Phone: (256) 895-7401
FAX: (256) 895-7469

CEIWR-HEC's FY 2020 Proposed PROSPECT Training Program

Course Number	Course Title all classes located in Davis, CA	Dates
164	Water and Watershed	13 - 17 Jan 2020
155	CWMS Modeling for Real-Time Water Management	27 - 31 Jan 2020
098	Reservoir Systems Analysis with HEC-ResSim	10 - 14 Feb 2020
209	Risk Analysis for Flood Damage Reduction Projects	24 - 28 Feb 2020
320	Hydraulics and Hydrology for Dam Safety Studies	9 - 13 Mar 2020
161	Hydrologic Analysis for Ecosystem Restoration	6 - 10 Apr 2020
188	Unsteady Flow using HEC-RAS	20 - 24 Apr 2020
123	Flood Frequency Analysis	4 - 8 May 2020
178	Hydrologic Modeling with HEC-HMS	8 - 12 Jun 2020
352	Advanced 1D/2D Modeling with HEC-RAS	20 - 24 Jul 2020