ADVANCES
in Hydrologic Engineering

Spring 2017

Director's Comments

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

In June of 1964, the Hydrologic Engineering Center (CEIWR-HEC or just HEC) opened its doors with one of its prime objectives to develop hydrologic computer programs for the U.S. Army Corps of Engineers (USACE) hydrologic community. Some of the initial software packages developed were HEC-1 (watershed hydrology), HEC-2 (river hydraulics), HEC-3 (reservoir analysis) and HEC-4 (stochastic streamflow generation). Over the next ten years, HEC began to create analytical methods for planning activities as well. Almost 53 years later, we are still hard at it, producing some of the world's most popular hydrologic, hydraulic and water resources software. So how did HEC go from producing software to help institutionalize USACE technical expertise to being a major contributor to the world's water resources profession?

You could say it originated in a letter dated 21 October 1970 where HEC was authorized to release computer programs to governmental agencies, universities, and other organizations. Later in 1972, the USACE granted HEC the authority to release our software to these groups for free. Over the years, USACE loosened the interpretation of who could request and receive the software so that in 1975, authority was granted to release

continued on page 2

Evaluating Alternative Reservoir Operations using HEC-WAT

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

Lake Mendocino (Coyote Valley Dam), Northern California, USA

Reservoir modelers traditionally rely primarily on analyses using historical data to estimate the difference in flood risk associated with changes to reservoir regulation plans. The Probable Maximum Flood (PMF) or other design events may help identify potential failure modes, but do not provide a basis to evaluate risk across a spectrum of possible large events. However, the HEC-WAT (Hydrologic Engineering Center's (HEC), Watershed Analysis Tool) provides reservoir modelers with a framework to associate changes in reservoir operations with differences in consequences and their probability. Recent investigations of flood risk associated with Forecast-Informed Reservoir Operations (FIRO) at Lake Mendocino (Coyote Valley Dam) on the Russian River (Northern California) provides an example of the procedure.

Lake Mendocino (Coyote Valley Dam) operates for water supply and flood protection for downstream communities. The dam features a hydropower plant, an outlet gate, and an uncontrolled spillway. Increased demands on the conservation pool have led to

continued on page 4

In This Issue:

some of the HEC software to the general public. Groups still had to request the software and HEC had to assure that the release of the software would satisfy any security requirements.

That series of events certainly supports HEC's business model whereby we produce generic software that can be used anywhere in the world. Of course, the user needs to have data to support the modeling, but given that they do, the HEC suite of software is to be written so it can be used in the State of Oregon as easily as it is used in Texas and as easily as it is used in Afghanistan. Because the software can be applied worldwide, the software has captured a certain user base. However, there are five other reasons, I believe, the HEC software suite has become, at least in some cases, a professional/industry standard. Those reasons are provided below:

1. **HEC software is good software**. Okay, I understand that I am contractually obligated to say that, but if it wasn't the case, why would the profession choose to use HEC software? All districts within USACE use HEC software. Other Federal agencies have adopted HEC software. State and local agencies use HEC's software as does the water resources profession and academia. Surely, if it was not good software, it would have been exposed by now and since plenty of other options are available for people to use, they could have chosen to use the competing software. Next week, I will be going to the ASCE/EWRI conference in Sacramento, CA and I fully expect to hear many presentations made by many groups that discuss how HEC software was used to help solve one of their problems. We also track downloads of our software and after an official release, it is not unusual to experience thousands of downloads of that software in the first couple of weeks.

2. **HEC software is fully documented.** HEC does not release software unless it has an accompanying User's Manual. As you probably know, software can be extremely difficult to use if you do not have some sort of document to guide you through the process. It takes a lot of discipline by the HEC staff to make sure the documentation is available when they want to release the software. They understand the benefits of releasing the software only after the documentation is completed. In addition to the User's Manuals, often, but not always, we also offer Technical Reference Manuals and Application Guides as well. These make understanding the inner workings of the software and how to apply the software much easier.

3. **Training is offered for all software.** HEC provides training courses for all of our software. The courses can be taught at HEC in Davis, California or we can take the training on the road as well. Typically our training is for USACE District and Division offices but we can teach for others as well as long as the proper approvals are in place. In addition, much of our software has been taught overseas demonstrating the interest others have in HEC software. And it is not just HEC staff that teach our classes. A cottage industry has started where multiple other groups such as ASCE, universities and consultants teach our classes nationwide. In some cases, a user would not have to wait too long before a course would be offered in their area. For a list of our classes, you can go to www.hec.usace.army.mil and search on the Training tab. Not only will you find the courses we plan to teach but also a description of all of the courses we offer. Understanding that not everyone can participate in our classes, HEC has just begun an effort to provide our classes on our website. The courses can be downloaded for free including the workshops.

4. **HEC software is supported.** While not all users are supported equally, all users can receive some

continued on page 3

US Army Corps of Engineers
Hydrologic Engineering Center
http://www.hec.usace.army.mil

ADVANCES is an unofficial publication authorized under the provisions of AR 360-1 and published biannually by the U.S. Army Corps of Engineers, Institute for Water Resources, Hydrologic Engineering Center, 609 Second Street, Davis, CA 95616-4687. Telephone: (530) 756-1104; FAX: (530) 756-8250. Views and opinions expressed in this publication are not necessarily those of the Department of the Army.

Director: Christopher N. Dunn, P.E., D.WRE
Water Resource Systems Chief: Lea G. Adams, P.E.

Director's Comments (continued)

some support. Technical support for those within USACE is provided through an annual subscription service. Subscribing offices receive full support from the HEC staff in the application and use of the software. Subscribing offices may request support by calling HEC, sending a direct email, or by emailing the appropriate address listed on the HEC website. For non-USACE users, HEC used to provide a list of possible vendors for assistance or support for HEC software. However, USACE counsel determined that the inclusion of this list could be interpreted as HEC recommending specific vendors over other vendors that were not included on the list. Therefore, by direction of USACE counsel HEC discontinued this practice and removed the list from our website. Now, non-USACE individuals and organizations can use any internet search engine to locate a vendor that can provide support for HEC software of interest. That said, the reporting of suspected software errors is not subject to the support restrictions outlined above. We are continuously working to improve the performance of HEC software and possible bugs should always be reported directly to HEC. Ideally, suspected errors should be reported in written form with a description of the problem and the steps that lead to its occurrence. On the HEC website, from the Software tab, the user can find a list of e-mail addresses for each piece of software. If a bug is suspected, the user should report the bug via this e-mail address.

5. **HEC software is free.** I do not want to discount how important this is and how important that decision was in 1970 that started the series of requests and approvals which eventually led to the authority to release HEC software for free. It may be a challenge for some local agencies, university students, or private engineering firms to pay a seat license for a piece of software. It also may be challenging for a developing Country to pay for a seat license. So, if all things are equal, and one alternative is free, it is logical to assume the user would choose the free option. Now free in itself is nice, but if the software doesn't produce, it still won't be used. That is why it is important to start with the fact that the HEC suite of software is good.

Some people have suggested that since the HEC software is free, doesn't that mean it is open source. The answer to that question is no. While our code is in the public domain, meaning users can download the executables for free, the HEC software is not open source. HEC does not provide the source code to the software that is actively being developed and many pieces of HEC software are actively being developed. Because it is actively being developed, we cannot share it with others. Otherwise, it would create significant confusion as to whose code someone is using. We have had many discussions over the years about why our software is not open source and the negatives far outweigh the positives. In the past, we have been challenged on this interpretation but it was determined that as long as our software was actively being developed, the software did not have be made available. Depending on the particular piece of software in question, there are other ways to connect to the software to have it perform certain tasks. If a user wanted to know more about how to do that they could contact us through the e-mail lists provided under the Software/Support Policy on the HEC website.

While I talked a lot about the HEC software and this edition does focus on new releases of software and the application of the software, other articles include a short summary of our FY17 and proposed FY18 PROSPECT training program and some personnel subtractions and additions that have occurred recently. Obviously, we are sadden by the retirements but very excited about the new people that we have brought on to the HEC team. More about the personnel moves can be found toward the back of this newsletter. Finally, while some of the articles in the newsletter are somewhat longer, because it is mostly read on-line (we used to mail out hard copies), we really didn't think that was a problem. We purposely provide some longer articles to show you more about the software and if you are interested, you can keep reading. If not, maybe another article will grab your attention.

We hope you enjoy this edition of the HEC Newsletter.

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

PROSPECT Training Program

Current Program & FY2018 Proposed PROSPECT Training Program

By Penni Baker

The PROSPECT (Proponent-Sponsored Engineer Corps Training) program for FY 2017 has begun with four classes completed and four more to be taught (table below). Spaces are available in the Water Data Management with HEC-DSSVue (11-15 Sep 2017; #152) class.

The table below provides the FY2018 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 90 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 2018 Proposed PROSPECT Training Program

Course Number	Course Title (all classes located in Davis, CA)	Dates
164	Water and Watershed	13-17 Nov 2017
155	CWMS Modeling for Real-Time Water Management	22-26 Jan 2018
098	Reservoir Modeling with HEC-ResSim	12-16 Feb 2018
209	Risk-Based Analysis for Flood Damage Reduction Projects	26 Feb-2 Mar 2018
320	H&H for Dam Safety Studies	5-9 Mar 2018
161	Hydrologic Analysis for Ecosystem Restoration	9-13 Apr 2018
178	Hydrologic Modeling with HEC-HMS	23-27 Apr 2018
188	Unsteady Flow using HEC-RAS	4-8 Jun 2018
123	Flood Frequency Analysis	7-11 May 2018
352	Advanced 1D/2D Modeling with HEC-RAS	16-20 July 2018

Evaluating Alternative Reservoir Operations using HEC-WAT (continued)

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

continued from page 1

proposals involving use of forecast information to allow more efficient use of the flood control space, and conditionally use some of conservation pool for water supply. The HEC-WAT software was used to estimate how much more conservation storage could be available without increasing flood risk in the system. The HEC-WAT model incorporated individual HEC-HMS (Hydrologic Modeling System), HEC-ResSim (Reservoir System Simulation), HEC-RAS (River Analysis System), and HEC-FIA (Flood Impact Analysis) models.

The regulation plan for Lake Mendocino (Coyote Valley Dam) is relatively straightforward - guide curve, reserving the most flood control space during the storm season (winter), then allowing the reservoir to fill to a higher summer pool in order to meet water supply needs during the dry season. The flood operations are also relatively straightforward, when the river downstream rises above a certain threshold, Lake Mendocino (Coyote Valley Dam) curtails releases. The releases resume as the river recedes, or if Lake Mendocino (Coyote Valley Dam) reaches high into its flood storage. The existing regulation plan was modeled in HEC-ResSim over the sixty-year period of record to establish baseline results for comparison against alternative operations.

continued on page 5

continued from page 4

Then a rule was added to the current regulation plan to demonstrate a simple FIRO alternative. The new rule allowed Lake Mendocino (Coyote Valley Dam) to encroach into the flood pool during the latter part of winter in the absence of a significant precipitation forecast. When large storms appeared in the forecast, the plan attempted to release the encroached storage, subject to the existing outflow constraints. For simplicity, the analysis used observed future precipitation for this purpose (i.e., a "perfect" forecast). Trial-and-error computes over the period of record with HEC-ResSim established the threshold for "significant precipitation forecast" as three inches over five days. The results of the iterations were evaluated against baseline simulation results to ensure that the alternative did not increase incidence of flow over the uncontrolled spillway, cause higher peak flows at the downstream control point, or reduce compliance with the downstream threshold for flood operations. Over the sixty-year analysis period of historical data, the more efficient flood operations of this simple encroachment rule yielded a very large gain in storage available for summer water supply (Figure 1).

Although encouraging, the results from the standalone HEC-ResSim model provided only an approximation of the relative difference in flood risk between the alternatives. U.S. Army Corps of Engineers (USACE) policy requires a systems-based approach when evaluating flood risk, at a level of detail provided by hydraulic modeling, so an HEC-WAT model was constructed using HEC-HMS, HEC-ResSim, HEC-RAS, and HEC-FIA models.

Hydraulic modeling revealed differences regarding the ways that the timing of reservoir outflow changes affected downstream flood peaks and inundation depths among various events in the period of record. For instance, higher peak stages at downstream damage centers occurred when the flows from nearby tributaries coincided with the receding tail of prior reservoir releases. Consequence modeling in the systems-approach also addressed differences among the historical events regarding the areas inundated.
The net difference in downstream flood damages between the baseline and alternative regulation plans turned out to be negligible for the period-of-record analysis. Complexities cut both ways regarding the timing of hydrologic, reservoir regulation, and hydraulic interactions. For example, sometimes releases due to a heavily encroached pool added slightly to downstream flood peaks, while other times the forecast information allowed the FIRO plan to reduce outflows sooner than the existing operation plan and reduce downstream peaks.

The HEC-WAT analyses computed an annual average damage of $6.1 million for both reservoir operation plans, based on the period-of-record. To estimate total project flood control benefits, the HEC-ResSim model was reconfigured, replacing the reservoir with a routing reach. Without Lake Mendocino (Coyote Valley Dam), the annual average damage amounted to $10.0 million.

However, a credible estimate of Expected Annual Damage (EAD) requires a more robust calculation, including potential events that did not occur in the period of record. The Hydrologic Sampler, is a tool within the HEC-WAT framework, which can generate 5,000 events based on observed meteorology, which were modeled using the Flood Risk Analysis (FRA) compute option in HEC-WAT. The

continued on page 6

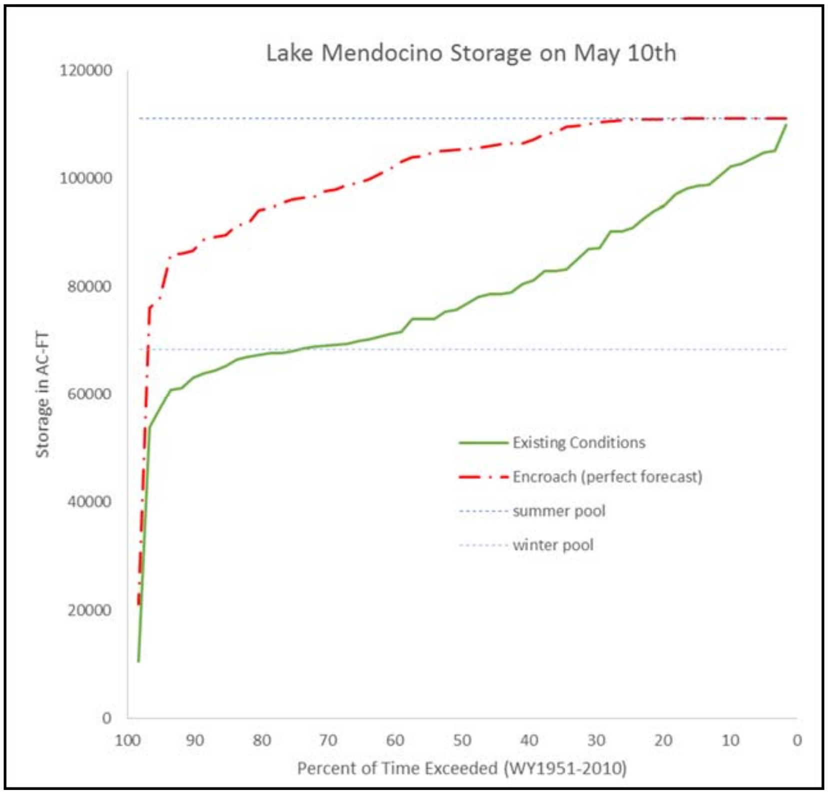


Figure 1. Potential Gains in Conservation Storage

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

continued from page 5

FRA compute, groups the events into 100 lifecycles of fifty events (years). The events in this probabilistic approach allowed modelers to understand how the existing operations and the FIRO plan affected flood damages across a wide and deep range of large events.

HEC-WAT output (Figure 2) provided a graphical look at the range of stages computed for a key damage center. Out the 5,000 events that were run, 870 exceeded the stage modeled for the largest event in the period-of-record. Some of the events were much greater than the period-of-record event. Many of these events caused higher damages under the encroached reservoir operating plan than the existing plan, due to a flood risk mechanism not observed in the period-of-record results, where flow over the uncontrolled spillway happened sooner and added to downstream flood peaks. However, the very largest of the events exceeded the reservoir capacity so much that the plans made no difference.

After factoring in probabilities, the flood risk mechanism demonstrated by spillway flow in very large events proved insufficient to cause a difference in EAD between the plans. Figure 3 further illustrates the inadequacy of period-of-record analyses in evaluating flood risk. As displayed in Figure 3, the dollar sign represents the average damage for each of the 100 lifecycles (i.e., the mean of each group of fifty events); while, the solid line represents a running average as the lifecycles are included.

The first lifecycle averages $34 million across its fifty events (Figure 3), which happens to be the third highest of all of the

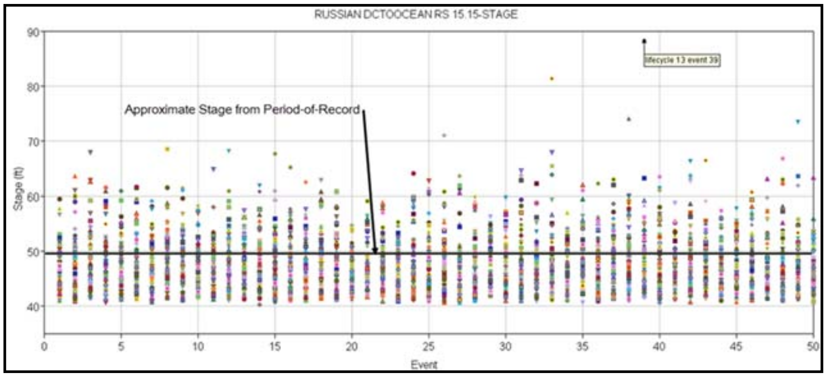


Figure 2. HEC-WAT - FRA Events

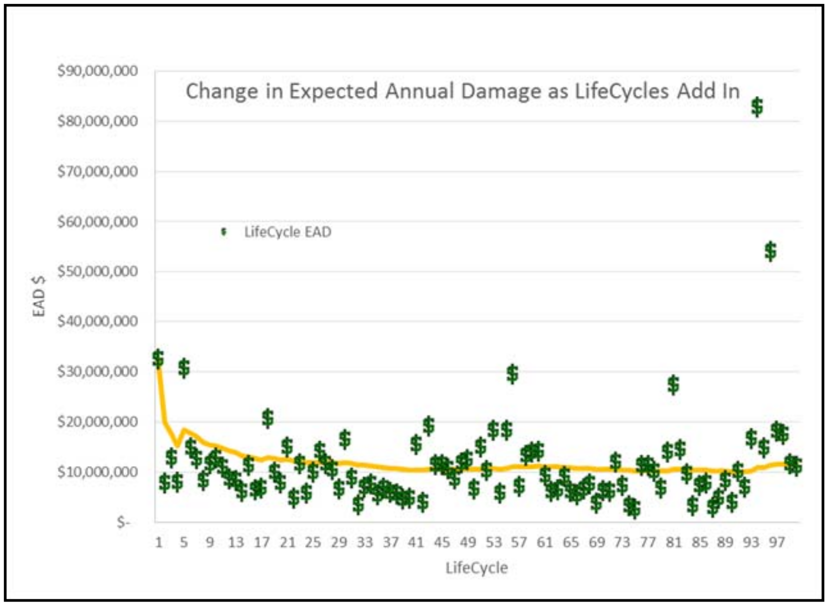


Figure 3. Period-of-Record Results

lifecycle averages, and results in a misleading running average. Likewise, the $6.1 million average computed over the sixty-years of historical record can be considered analogous to just one of the lifecycles. The $10.4 million EAD calculated in this analysis reflects a fuller range of potential flood events than the historical record, and provides a much more robust estimate than possible with period-of-record analysis.

The HEC-WAT analyses confirmed that up to 29 kAF (kilometers acre-feet) more conservation storage could be gained from more efficient flood operations made possible by perfect forecast precipitation, without increasing flood risk. The comprehensive and robust systems-based approach inspired confidence in the results, and provided a deeper understanding of the drivers of flood risk along the Russian River regarding events that have occurred, and those that could occur.

Updating Flood Frequency Analysis – The Change from Bulletin 17B to Bulletin 17C (Expected Moments Algorithm)

By Beth Faber, PhD, P.E.

Why a guidance document - Many applications in flood risk management require estimation of a flood frequency curve. Some make use of the entire curve, and others, such as the NFIP (National Flood Insurance Program) floodplain maps, focus on a point on the "100-year flood" curve (the 1 percent annual chance exceedance flood). Federal guidance for flood frequency analysis was established to ensure that all agencies or individuals working with the same data would produce the same estimated flood frequency curve. The current version of the federal guidance document, "Guidelines for Determining Flood Flow Frequency" (https://water.usgs.gov/osw/bulletin17b/dl_flow.pdf), is Bulletin 17B, and the approaching update will be Bulletin 17C (https://acwi.gov/hydrology/Frequency/b17c/index.html). This article describes the basic frequency analysis theory, then the changes introduced in the new guidance.

How has Flood Frequency Analysis Been Done - The flood frequency analysis guidance was developed in a series of document updates, from Bulletin 13 in 1966 though Bulletin 17B in 1982. In that development, which focused primarily on estimation of the 100-year flood, various key assumptions and choices were introduced, as well as adjustments required by the challenges presented in real-world data.

The frequency analysis process uses a record of unregulated annual maximum streamflows (gaged or approximated) that is assumed to be a sample of random, independent and identically-distributed (IID) values from which a probability distribution of future annual maximum flows can be estimated. These assumptions imply that the largest flow of each year is unrelated to previous years, and that the state of the watershed and the meteorology have not notably changed over the length of the record (though it is not uncommon to make adjustments to gaged peak flows to account for known changes). Distribution parameters are estimated from the moments of the sample data (i.e., sample mean, standard deviation and skew) following the Method of Moments algorithm (Figure 1; note the linear versus log scales).
A choice that has been retained through all updates to the Bulletin is the use of the Log-Pearson type III (LP3) probability distribution for annual maximum flow. The LP3 distribution is sometimes called "skewed Normal", adding the flexibility of non-zero skew to the broad applicability of the Normal distribution. The use of a log-transformation of flow (in LP3) is convenient for both decreasing the often extreme positive skew of the flow data and sensibly maintaining values above zero.

Several adjustments were introduced over time to manage the inevitable irregularities in gaged data. Examples of that data include:

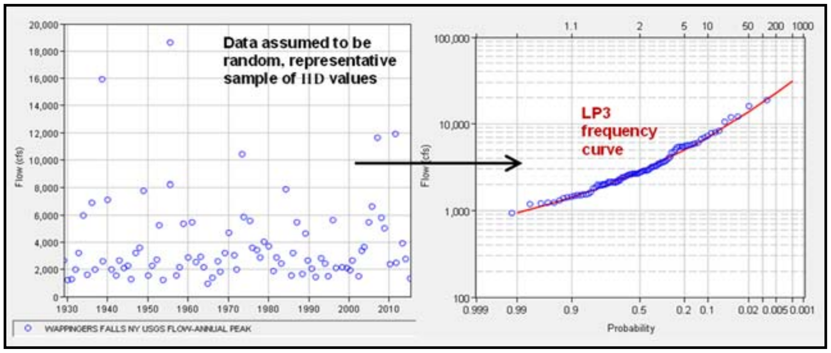


Figure 1. Basic Bulletin 17B frequency analysis - method of moments algorithm

times the gage is out of service; zero flows (which confound the log-transform); small "floods", that are an annual maximum flow but not caused by the same flood-producing mechanism as the larger floods (also called low outliers); large floods that might be more rare than the length of record would imply; and, large historical floods prior to the start of the gage record. Information about large historical floods may be found among records from local residents, such as newspaper articles or high water marks, or physical evidence in the watershed (paleo-floods). Another adjustment incorporates regional skews that can improve frequency curve estimates for shorter record stations. The order in which these adjustments were applied affected the final flow-frequency curve.

What's is New in Bulletin 17C - The inter-agency Hydrologic Frequency Analysis Workgroup (HFAWG) is responsible for federal flood frequency analysis guidance, and has produced the latest update, Bulletin 17C. The update retains assumptions and choices, but introduces some new methods. Importantly, the choice to use the LP3 probability distribution remains, as does the need to manage low outliers and the desire to make use of historical information and regional skews. The most visible difference in Bulletin 17C is a new method for estimating the LP3 distribution parameters called the Expected Moments Algorithm (EMA). The algorithm brings several benefits:

- EMA provides the ability to characterize flood data as flow intervals, including both observed flood peaks and unobserved time periods.

continued on page 8

By Beth Faber, PhD, P.E.

continued from page 7

- In place of the array of adjustments for non-standard data outlined in Bulletin 17B (that are sensitive to the order in which they are performed), EMA incorporates that data all at once, which also allows an estimate of equivalent record length considering outliers, historical information and regional skew.
- EMA produces improved confidence intervals that correctly account for the uncertainty in the volatile skew coefficient, and incorporates diverse information appropriately based on the equivalent record length above.

In the absence of flow ranges, historical information and low outliers, the LP3 frequency curve estimated by EMA is identical to that estimated using Bulletin 17B methods.

Flow Ranges and Perception Thresholds

EMA (Bulletin 17C) allows for a more general representation of observed flood peaks and unobserved time periods than the Bulletin 17B approach. In Bulletin 17B, each year's peak flow can only be characterized as a point value. With EMA, every annual peak flow in the analysis period, whether observed or not, is represented by a flow range. The range can simply be limited to the gaged value when one exists, however it can also reflect an uncertain flow estimate, or a span from zero to a non-exceedance threshold for unobserved years or censored values.

The EMA procedure introduces a new concept of "perception thresholds" that provide additional, valuable information about the streamflow record. The perception thresholds define the range of streamflow for which a flood event would have been observed, had it happened. The accompanying assumption is that any year in which an event was not observed and recorded in some way must have had a peak streamflow outside the perception range. The perception range is independent of the streamflows that have actually occurred, and is a feature of the watershed itself, although often such physically-based thresholds are not available.

Use of historical flood data provides an example of perception thresholds and implied flow ranges. Historical flood data, from a period prior to installation of a stream gage, is available when large floods were noted by nearby residents or left physical evidence in the watershed, making it possible to later estimate the flow level of that event. Consider the example of an historical flood in the year 1882 that was estimated at 50,000 cfs (cubic feet per second), before a gage was installed in the year 1926 (Figure 2). This flood estimate suggests a perception threshold range of 50,000 to infinity, because a value as low as 50,000 cfs can be (and was) perceived during an ungaged period. A further assumption is that any flow larger than 50,000 cfs during the intervening period would have been similarly perceived, and so flows not perceived must have been less than 50,000 cfs. Therefore, for the unobserved period of 1883 to 1925, for the complementary flow range the assignment is zero (0) to 50,000 cfs. For years prior to the 1882 event, a similar statement could be made, if there is a period for which it is known an event as large as 50,000 cfs would have been observed, had it occurred.

For the EMA analysis, every year in the analysis period, both systematic and historical, observed or unobserved, must have both a flow range and a perception threshold range specified. For systematic (gaged)

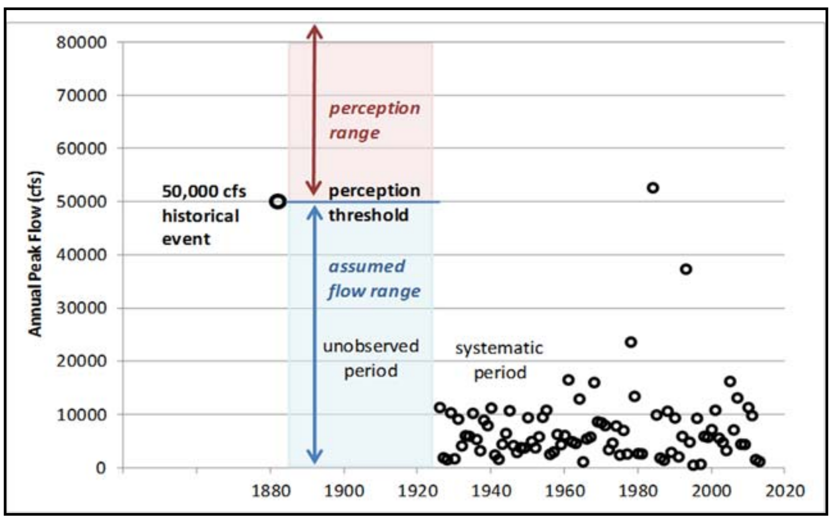


Figure 2. Perceptions Thresholds - historical event, flow range, unobserved years

flood events, the flow range is simply the gage estimate, or if there is uncertainty about that estimate, the range can expand to represent the possible value. The perception threshold range for these gaged years is set as zero to infinity, which implies that any flood peak that occurred could be perceived and recorded. For unobserved years in the historical period, this zero to infinity perception range is not appropriate (as it implies it is not possible to have an unobserved flow), and so some lower bound of "observable flow" must be assumed for that time period. (When possible, a perception threshold should be defined by some physical feature of the watershed, as in the next example.) As noted previously, the flow range for these unobserved years is the complement of the

continued on page 9

continued from page 8

perception range, as zero to lower bound. For observed historical years, the flow range is set as either a point estimate or a flow range that captures the uncertainty, and the perception threshold range is the same as the unobserved historical years.

Figure 3 shows another dataset with both a systematic record and several historical floods. In Figure 4, flow ranges and a possible set of perception ranges associated with the data is shown. In this example, the historical period and perception thresholds are defined by a railroad grade for which any inundation since its construction would have been noted. Figure 5 shows a comparison of the results of the Bulletin 17B and Bulletin 17C methods applied to a dataset. Note, that although the estimated flood frequency curves are very similar, the 90 percent confidence interval for the Bulletin 17C method is significantly wider, more correctly capturing the uncertainty in the skew coefficient.

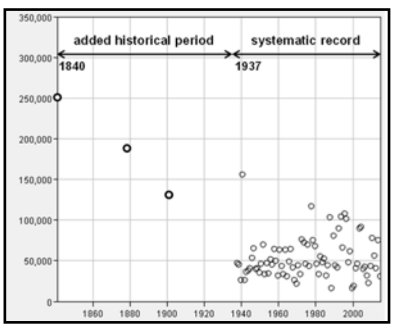


Figure 3. Dataset - systematic data & historical data

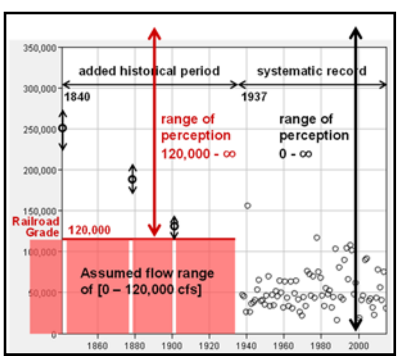


Figure 4. Possible perception thresholds & flow ranges for a dataset

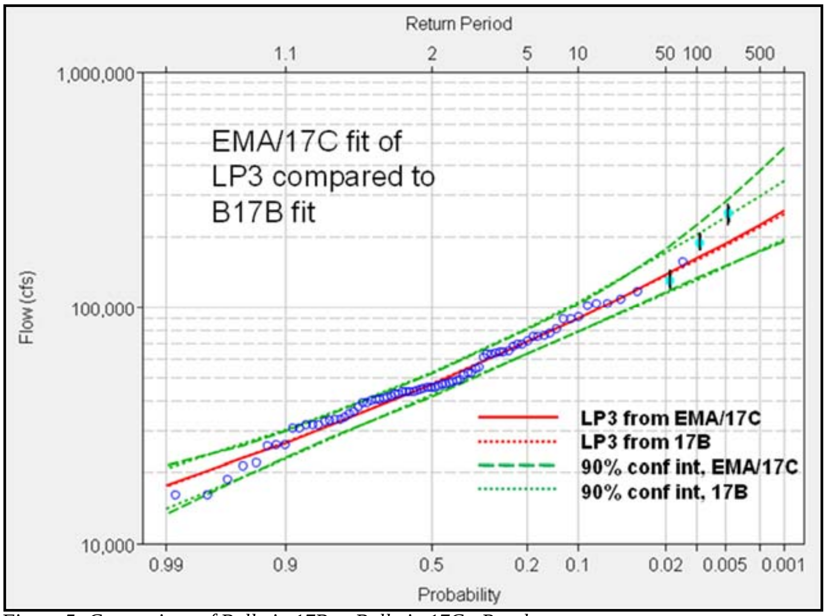


Figure 5. Comparison of Bulletin 17B to Bulletin 17C - Results

Censoring Low Values – low outliers or PILFs (potentially influential low floods)
Bulletin 17B uses the "single" Grubbs-Beck (GB) test to identify possible low outliers in the data set (i.e., all values less than the computed low outlier threshold), which are then censored. Censoring values refers to retaining the knowledge that the peak flow for that year was quite low (which is relevant to the frequency of larger events), but not using its value in parameter estimation. In Bulletin 17B, low values are censored using one of the many adjustments for non-standard data.

EMA (Bulletin 17C) censors values by simply replacing the peak flow estimate by a flow range from zero to a specified value, and requiring no further adjustment to the resulting LP3 parameters. However, the algorithm can be more sensitive to the lowest values in the data set than the Bulletin 17B methods, allowing the important upper tail of the frequency curve to be too strongly influenced by values in the lower tail. To combat this influence, a more aggressive version of the low outlier test (Multiple Grubbs-Beck (MGB) test) was developed to identify and perhaps censor more low values. Rather than "low outliers", the censored values are referred to in Bulletin 17C as Potentially Influential Low Floods (PILFs), due to their undesired influence on the upper tail of the frequency curve. Censoring the PILF events by replacing those values by the range of zero to 'the lowest retained flood peak' can greatly increase the robustness of the frequency curve estimate. Figure 6 shows nine values censored by the MGB test, two values identified by the GB test used for Bulletin 17B's low outlier adjustment, and the frequency curve fitted for each.

Bulletin 17C computation with HEC-SSP - The U.S. Army Corps of Engineers (USACE), Hydrologic Engineering Center's (HEC) Statistical Software Package, HEC-SSP (an article about the current release of the software is included in this newsletter), has the EMA computations within its Bulletin 17 analysis module. The user may choose between Bulletin 17B and Bulletin 17C methods. When Bulletin 17C methods are selected, the HEC-SSP interface will include

continued on page 10

By Beth Faber, PhD, P.E.

continued from page 9

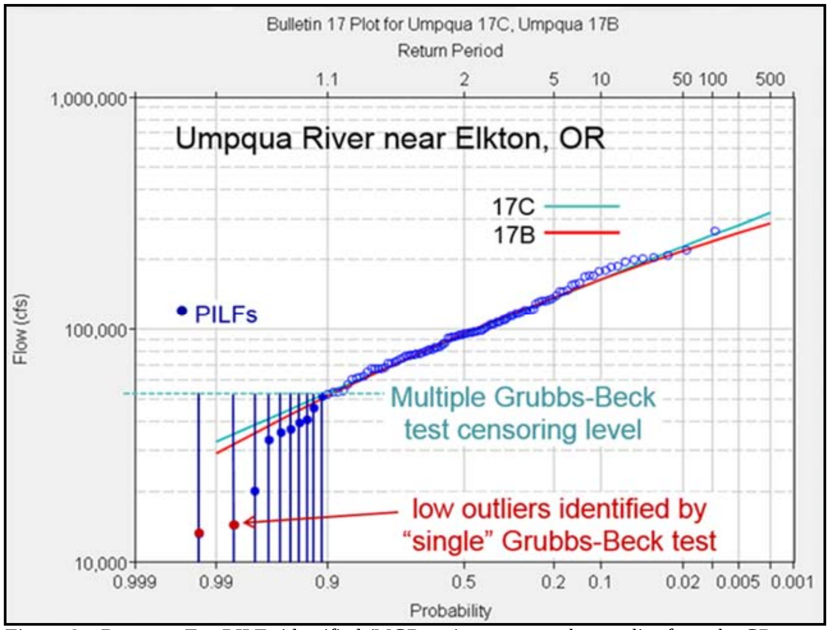


Figure 6. Dataset - Ten PILFs identified (MGB test), versus one low outlier from the GB test

an "EMA data" tab for entry of perception thresholds and flow ranges. Figure 7 shows an image of the HEC-SSP interface, with the perception threshold table at the top, the resultant flow range table below it, and a plot of the data points and ranges to the right. Perception thresholds were inferred from the historical observations. Peak flow data may be imported from the USGS (U.S. Geological Survey) website (https://www.usgs.gov/), HEC-DSS (HEC Data Storage System) files (http://www.hec.usace.army.mil/software/hec-dss/), Microsoft Excel®, and CSV (comma separated values) files, and the computation engine for EMA shares its code with the USGS PeakFq (https://water.usgs.gov/software/PeakFQ/) software, producing the same results.

Bayesian Generalized Least Squares (GLS) estimation of Regional Skew - While the use of the EMA algorithm is the most prominent change in Bulletin 17C, adding the concepts of flow intervals, PILF censoring, and improved confidence intervals, to Bulletin 17C has also updated the method for estimating regional skews. With the relatively short records available for flood frequency analysis (100 years is not a lot for estimating a skew coefficient), regional skews increase the robustness of the results significantly. The USGS has taken the lead in re-estimating regional skew coefficients for instantaneous peak flows by using a Bayesian Generalized Least Squares (GLS) regression procedure. The USGS has plans to have updated skew estimates for the entire United States within a few years. The resultant skew estimates are not only more reasonable, the estimates carry a much smaller mean squared error (MSE), giving them more weight in the weighted-skew concept in Bulletin 17C.

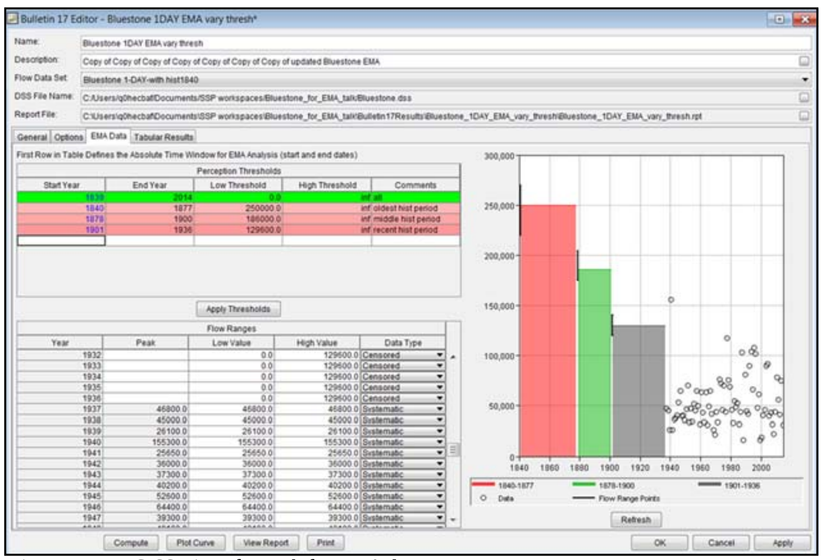


Figure 7. HEC-SSP interface tab for EMA data entry

When - As of the date of this newsletter, Bulletin 17C has passed its public comment period and expert review, and the committee is receiving some updates in response to helpful recommendations. The document will be published as a USGS Techniques and Methods report, with an expected release in 2017, though many federal agencies including USGS, the U.S. Bureau of Reclamation (USBR), and USACE have already started making use of Bulletin 17C's EMA computation. Additional details on the Bulletin 17C document and related materials can be obtained at https://acwi.gov/hydrology/Frequency/b17c/.

Future Updates - Future guidance updates on flood frequency analysis are being planned by the Hydrologic Frequency Analysis Work Group (HFAWG) under the Subcommittee on Hydrology. Updates may include flood frequency procedures for ungaged sites, regulated flows, urbanization and watershed change.

Ecology and Hydrology - Developing Rules for Reservoir Operations

By John Hickey, PhD, P.E.

A recently completed project investigated a simple question: When a reservoir has too much water, how should that water be released to best benefit ecosystems?

The Alamo Dam and Reservoir is located on the Bill Williams - a remote river in a largely undeveloped Arizona watershed. Alamo is operated by the Los Angeles District (CESPL) of the U.S. Army Corps of Engineers (USACE). The dam and reservoir have a high degree of control on river flows. Below the dam, the river courses through a series of canyons and valleys to its confluence with the Colorado River. The riparian corridor in this stretch is largely intact, a rarity in the southwest. The river provides important habitat for resident animals and for an array of bird species that visit the river along their migratory paths. Land and water managers for the Bill Williams River, including representatives of the national wildlife refuge located along the river near its mouth, have identified this corridor as a critical resource for management considerations (www.billwilliamsriver.org).

The hydrology of the Bill Williams watershed is characterized by episodic high flows of short duration, primarily occurring in winter and early spring. The associated inflows to Alamo can raise pool elevations above target levels. Reservoirs in that condition are referred to as "encroached", which means that a portion of the space normally held vacant to accommodate potentially damaging high flows is filled. Water managers release this water to return to target levels in accordance with prevailing basin conditions. For the most part, these releases are not made with an ecological strategy. While the opportunity to do so may be especially pronounced for a system like the Bill Williams – arid lands river with occasionally available water and a regionally significant ecosystem – shaping these releases to achieve ecological purposes is an expansive and underutilized strategy with potential to affect hundreds of rivers across the country.

The challenge for Alamo was to use flow-ecology information about riparian species to define a reservoir operating rule that addressed the following question - Given a volume of available water, how should that water be released to maximize establishment of native cottonwood and willow seedlings and minimize establishment of invasive salt cedar? Three Hydrologic Engineering Center (HEC) technologies –Ecosystem Functions Model (HEC-EFM) HEC -GeoEFM (HEC-EFM's spatial component), and, River Analysis System (HEC-RAS) - were applied to quantify the benefits of different release patterns. Models were developed and verified using field observations from a 2006 experimental release from Alamo designed to recruit cottonwood seedlings (Figure 1). Verified models were then applied to a set of 9,207 candidate release patterns, with each resulting in a simulated area of seedling recruitment.

Hydrographs that generated less seedling area than others using the same volume or more were discarded. Hydrographs that generated the most seedling area per volume of water were retained to help define an operating rule for Alamo. Collectively, these maximizing hydrographs formed a family of curves that allow water managers to translate a volume of water available for riparian management to an area of recruitment and the release hydrograph (peak, shape, and volume) required to generate it (Figure 2).

To illustrate how this information is used, consider a hypothetical inflow event that leaves Alamo with 20,000 hectare-meters of water above its target pool (roughly twenty percent encroached) and available for seedling recruitment. Using the 4.0 cm/day curve, the volume intersects the curve between two design hydrographs. The first has a peak flow of 125 m3/s, a volume of 19,597 hectare-meters, and is estimated to generate 1,583 hectares of seedling area. The second has a peak flow of 150 m3/s, a volume of 22,348 hectare-meters, and is estimated to generate 1,615 hectares of seedling area. Choice of hydrograph is left to the operator with the associated peak flow and recession guiding its implementation.

continued on page 12

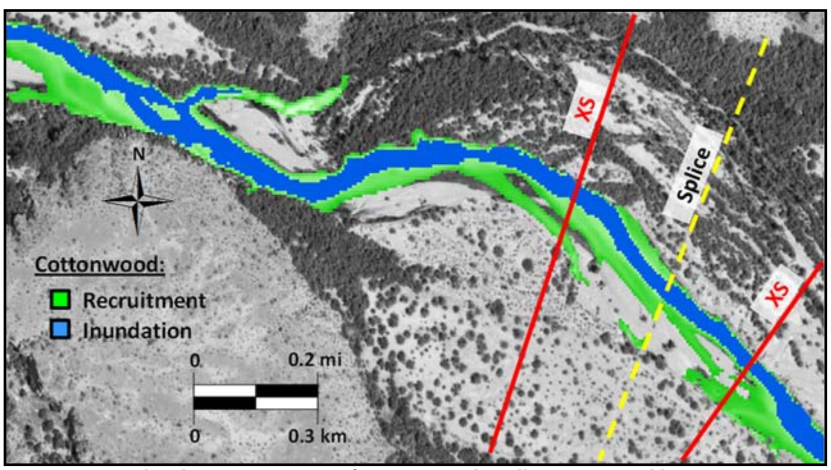


Figure 1. Simulated recruitment areas for cottonwood seedlings generated by an experimental release from Alamo Dam in March 2006. Simulated and observed seedling patches were compared and found to be strongly and positively correlated.

Ecology and Hydrology - Developing Rules for Reservoir Operations (continued)

By John Hickey, PhD, P.E.

continued from page 11

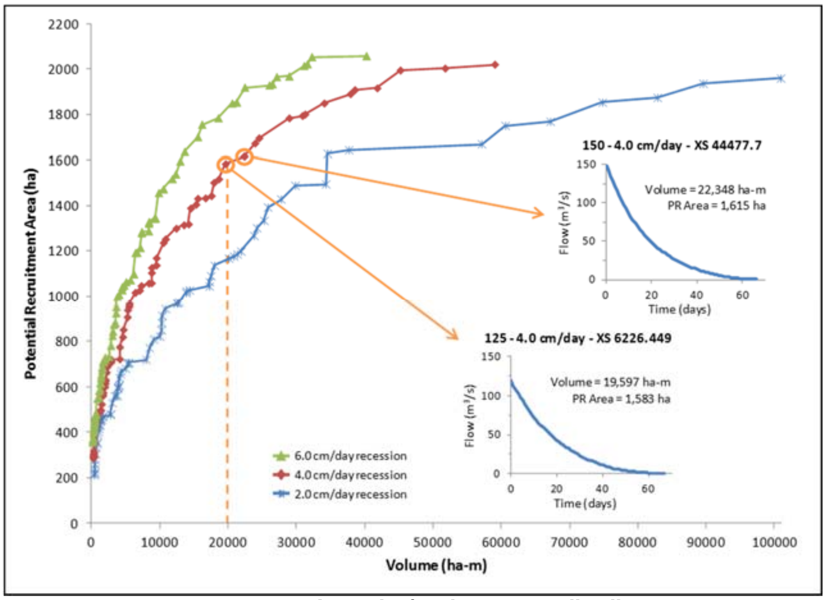


Figure 2. Reservoir operations guidance plot for Alamo Dam, Bill Williams River. Curves for three recession rates are shown. Each point on the curves represents a hydrograph recession that maximizes seedling recruitment.

The synthesis of the modeling effort is offered as guidance for management of stored waters in Alamo. Results are detailed in a report, "Managing Water and Riparian Habitats on the Bill Williams River with Scientific Benefit for Other Desert River Systems", which is available from HEC's website (http://www.hec.usace.army.mil/publications/ProjectReports/PR-97.pdf).

HEC thanks the Desert Landscape Conservation Cooperative (LCC) for supporting this work. The Desert LCC provides scientific and technical support, coordination, and communication to resource managers in the Mojave, Sonoran, and Chihuahuan Desert regions of the southwestern United States and northern Mexico (https://desertlcc.org/). The LCC is one of twenty-two individual, self-directed partnerships working collectively to conserve and maintain landscapes and seascapes as part of the Department of the Interior's LCC Network (https://lccnetwork.org/).

HEC also thanks the U.S. Geologic Survey, the U.S. Fish and Wildlife Service, and the Bill Williams River Corridor Steering Committee for contributions to this work and to the continued collaborative stewardship of the Bill Williams River (www.billwilliamsriver.org).

The Bill Williams River is one of 14 river systems engaged in the Sustainable Rivers Program. Sustainable Rivers is an ongoing national effort to improve the health and life of rivers by reoperating reservoirs to improve ecosystems, while maintaining or enhancing other project benefits (http://www.iwr.usace.army.mil/Missions/Environment/Sustainable-Rivers-Project/

Application of the Continuous Hydrologic Simulation Capabilities within HEC-HMS for a Reservoir Re-Operation Study

By Thomas Brauer

HEC-HMS (Hydrologic Engineering Center's (HEC), Hydrologic Modeling System) software allows users to create a custom hydrology model providing a flexible interface between hydrologic components. For each hydrologic process, users can select from an array of modeling methods that range in capability from event to continuous, lumped to distributed, and empirical to conceptual.

A preliminary reservoir re-operation study of Coyote Valley Dam (Lake Mendocino) in the Russian River watershed (California) applied the continuous hydrologic simulation features of HEC-HMS to simulate soil moisture and discharge into Coyote Valley Dam (Lake Mendocino) and throughout the Russian River watershed for a sixty-year period, water years 1951-2010. The Russian River HEC-HMS model simulated soil moisture by incorporating the Penman-Monteith evapotranspiration method with the Soil Moisture Accounting (SMA) loss method. The soil moisture state indicates the soil moisture capacity available for infiltration. In the Russian River comprehensive study, subbasin soil moisture informed several reservoir re-operation scenarios. The reservoir re-operation study tested the feasibility of increasing reservoir storage without increasing flood risk in the watershed. The study sought to address the question - *Can knowledge of the soil moisture state and corresponding runoff potential allow for more efficient management of the reservoir pool?* The answer to this question has

continued on page 13

Application of the Continuous Hydrologic Simulation Capabilities within HEC-HMS for a Reservoir Re-Operation Study (continued)

By Thomas Brauer

continued from page 12

implications for both regional water supply and flood risk. This article highlights the continuous hydrologic simulation features of HEC-HMS used to model discharge into Coyote Valley Dam (Lake Mendocino) as a part of the Russian River reservoir re-operation study. The goal of the HEC-HMS modeling effort was to provide the reservoir re-operation study team with a reliable hydrology model that accurately predicted soil moisture and runoff for the drainage above Coyote Valley Dam (Lake Mendocino) and runoff for the watershed downstream of the dam. HEC is partnering with the U.S. Army Corps of Engineers (USACE) Engineer Research and Development Center (ERDC), USACE Districts, and other federal agencies to understand how additional information, like precipitation and flow forecasts, could be used to operate reservoirs and then quantify the resulting impacts of including forecasts for reservoir operations.

Background. Coyote Valley Dam (Lake Mendocino) is located on the East Fork of the Russian River, about two miles Northeast of Ukiah, California (Figure 1). Below Coyote Valley Dam (Lake Mendocino), the East Fork of the Russian River flows approximately one mile to the confluence with the mainstem Russian River. From there, the Russian River flows approximately 100 miles south to southwest terminating at the Pacific Ocean. The total drainage area for the watershed above Coyote Valley Dam (Lake Mendocino) is approximately 105 square miles. The drainage area for the entire Russian River watershed is approximately 1,480 square miles. The drainage upstream of Coyote Valley Dam (Lake Mendocino) ranges in elevation from a conservation pool elevation of 748 feet to over 3,500 feet in the headwaters. The drainage area is characterized by evergreen forests, cropland, and rangeland. Precipitation in the region follows a historical pattern of wet October thru March and dry June thru September. Average annual precipitation for the drainage above Coyote Valley Dam (Lake Mendocino) ranges from forty inches at lower elevations to fifty inches at higher elevations.

Figure 1. Russian River Basin

Meteorology. The precipitation and evapotranspiration boundary conditions are controlled from the HEC-HMS Meteorologic Model. The precipitation boundary condition was formed starting with point precipitation records, provided by the National Climatic Data Center (NCDC, https://www.ncdc.noaa.gov/), for 28 gages in or near the Russian River basin. HEC's GageInterp utility software (http://www.hec.usace.army.mil/software/hec-gridutil/) was used to spatially interpolate a gridded precipitation record from point precipitation records. The option in GageInterp to apply a bias grid, or a grid of average annual precipitation, was used to improve the spatial interpolation of the point precipitation values. Gridded average annual precipitation was gathered from the PRISM Climate Group (http://prism.oregonstate.edu/).

HEC-HMS includes Penman-Monteith evapotranspiration as presented in the Food and Agriculture Organization's Irrigation and Drainage Paper No. 56 (http://www.fao.org/docrep/X0490E/x0490e00.htm). The Penman-Monteith method requires air temperature, air moisture, wind speed, and solar radiation time-series data. The U.S. Air Force 14th Weather Squadron provided the required hydrometeorologic data at two weather stations in the study area. For periods of missing data, Climate Normals (https://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets/climate-normals) supplemented the time-series records. Complete hydrometeorologic time-series were imported into HEC-HMS as time-series gages. The Penman-Monteith evapotranspiration method, within the HEC-HMS Meteorologic Model, referenced the time-series gages and calculated Penman-Monteith evapotranspiration for each simulation time step.

Losses. HEC-HMS includes two loss methods for continuous simulation, a Deficit and Constant method and the SMA method. Both loss methods connect with the evapotranspiration method to extract moisture from the basin during dry periods. SMA simulates moisture in five conceptual storage volumes – canopy, surface, soil, Groundwater Layer 1, and Groundwater Layer 2 (for further

continued on page 14

Application of the Continuous Hydrologic Simulation Capabilities within HEC-HMS for a Reservoir Re-Operation Study (continued)

By Thomas Brauer

continued from page 13

information refer to the HEC-HMS Technical Reference Manual, CPD-74B; http://www.hec.usace.army.mil/software/hec-hms/documentation/HEC-HMS_Technical%20Reference%20Manual_(CPD-74B).pdf). For the Russian River study, the SMA loss method computed losses for the area upstream of Coyote Valley Dam (Lake Mendocino), which was the focus of the reservoir re-operation study. The Deficit and Constant loss method modeled losses for other subbasins in the watershed. SMA simulated soil moisture content over the sixty-year simulation. The modeled soil moisture content approached capacity for the wet-season months, December thru March, and approached a dry state during summer and fall months, June thru September. High runoff events occurred when soil moisture was near capacity.

Calibration. Computed and observed runoff signatures were compared at multiple gages in the watershed, including runoff from a gage upstream of Coyote Valley Dam (drainage area modelled with subbasin "EF Russian 20"). The runoff signatures were: 1) average monthly runoff volume, 2) flow-frequency curve, 3) timing of peak flows, and 4) recession limb of hydrographs. The Penman-Monteith evapotranspiration method is physically based and inputs are based on measured atmospheric parameters. The method was developed for estimating plot scale crop evapotranspiration and incorporates a crop coefficient that adjusts the rate of evapotranspiration for a variety of vegetative surfaces. For the Russian River study, Penman-Monteith evapotranspiration was applied at the catchment scale for a composite of vegetative surfaces. The crop coefficient was adjusted to reproduce the monthly runoff distribution of the watershed. This portion of calibration focused on agreement between computed and observed average monthly flow volume. SMA is a conceptual loss method. While some parameters are loosely based on physically properties (e.g., *Maximum Infiltration Rate*), all parameters are subject to calibration. For the Russian River Study the *Maximum Infiltration Rate* was adjusted to reproduce observed hydrograph peaks. Calibration of the model to observed peak flows focused on agreement between computed and observed flow-frequency curves (Figure 2). Clark unit hydrograph parameters *Time of Concentration* (T_c) and *Storage Coefficient* (R) were adjusted to reproduce timing of the hydrograph peak; *Groundwater 1* and *Groundwater 2 Coefficients* were adjusted to reproduce the interflow and baseflow portions of the hydrograph. Calibrating the model by adjusting unit hydrograph, interflow, and baseflow parameters focused on agreement between the computed and observed runoff hydrographs. Agreement between computed and observed runoff hydrographs was evaluated using the following measures of performance: Nash-Sutcliffe efficiency (NSE), Root Mean Square Error (RMSE)–Observed Standard Deviation Ratio (RSR), coefficient of determination (R^2), and Percent bias (PBIAS).

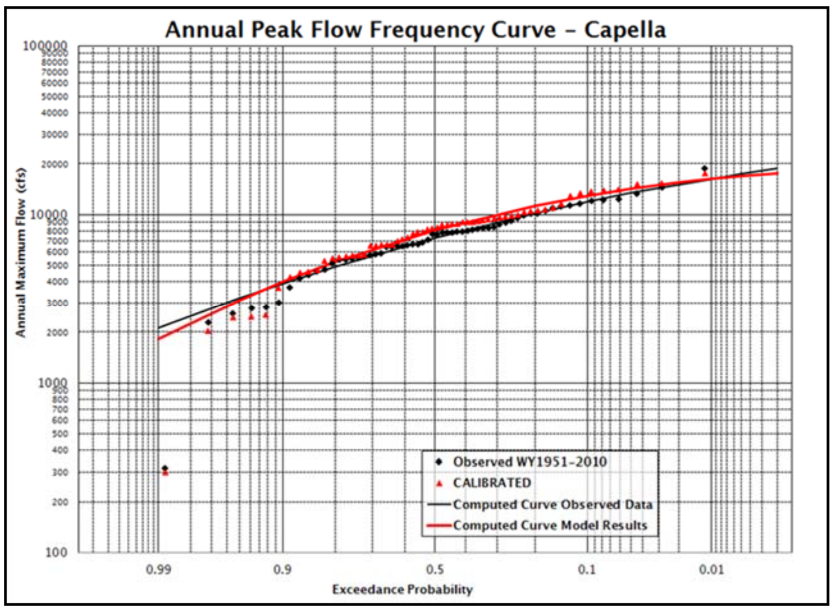


Figure 2. Annual flow-frequency curve observed vs computed for calibration point EF Russian River at Calpella

Results. The Russian River SMA/Penman-Monteith hydrology model reproduced observed runoff for subbasin "EF Russian 20" with a NSE of 0.854 a RSR of 0.382, a R^2 of 0.892 and PBIAS of -1.242 for the sixty-year simulation (simulated results compared against the Calpella Gage). Model performance at the other flow gage location was similar as at the Calpella Gage. With this performance, the model provided the re-operation study team a reliable prediction of subbasin soil moisture and discharge for testing reservoir re-operation scenarios for Coyote Valley Dam (Lake Mendocino). Figure 3 shows a sample of the type of information HEC-HMS provides for a continuous simulation. The time-series show early and late season precipitation events that correspond

continued on page 15

Application of the Continuous Hydrologic Simulation Capabilities within HEC-HMS for a Reservoir Re-Operation Study (continued)

By Thomas Brauer

continued from page 14

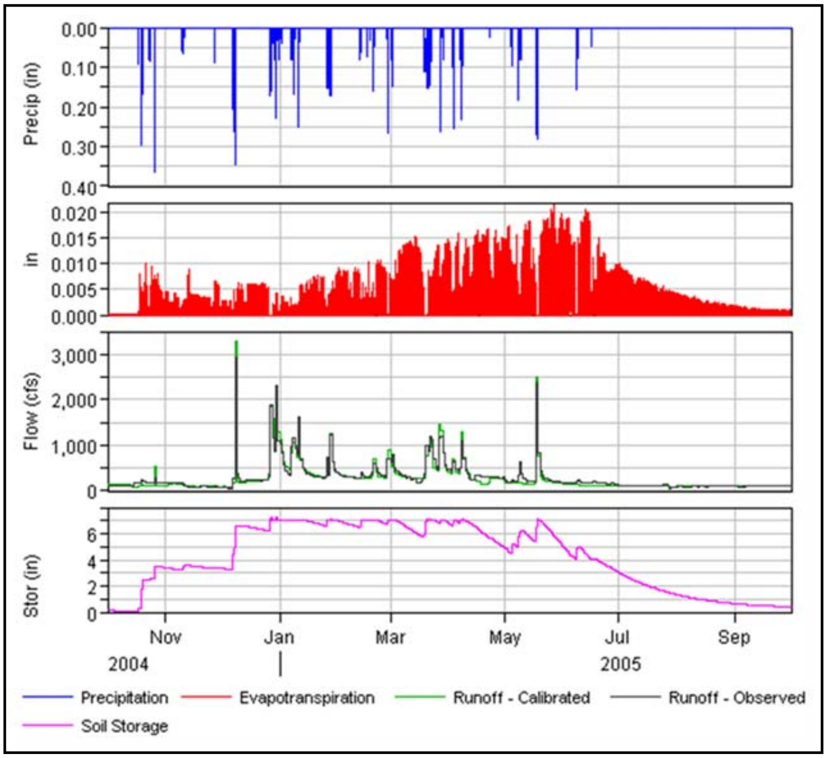


Figure 3. Precipitation, evapotranspiration, computed vs observed runoff, and soil storage for subbasin "EF Russian 20," water year 2005

with a reduced soil moisture state and result in little or no runoff. These types of observations have engineers asking if a more efficient approach to water management is possible: *When a late spring storm event is forecasted, is it necessary to release from the reservoir pool when we don't expect the event to produce a high runoff volume? Will holding excess water in the reservoir result in increased flood risk downstream?* An accurate and detailed hydrology model is the first step in a technical approach to answer these types of questions.

Modeling with Gridded Data in HEC-HMS and HEC-DSS Outside of the Continental United States (OCONUS)

By Thomas Evans, P.E., D.WRE

Since its first release in the middle 1990s, the HEC-HMS (Hydrologic Engineering Center's (HEC), Hydrologic Modeling System) software has been able to use grids to represent precipitation inputs to rainfall-runoff transformation methods. The grids are stored in records in HEC-DSS (Data Storage System) files and linked to subbasins in HEC-HMS basin models using a special parameter file that is a part of an HEC-HMS project. The linkage of cells in the precipitation grids to subbasins in an HEC-HMS basin model is accomplished using index numbers, which requires that a consistent numbering system be used in both the DSS grid records and the grid parameter file. In the continental (contiguous) United States (CONUS), HEC has supported the use of two number systems, HRAP and SHG, but outside the continental United States (OCONUS) no such system has been established. In 2016, however, a number of enhancements were made to HEC-HMS, HEC-DSS, and a number of gridded data utility programs that will make OCONUS HEC-HMS modeling with gridded inputs much more practicable.

Grid-Numbering Systems:
The first use of grids for precipitation inputs to HEC-HMS was for the modified-Clark hydrograph method using National Weather Service (NWS) radar products from the Arkansas-Red Basin River Forecast Center (ABRFC). The cells in these radar grids were numbered by row and column using a system called the Hydrologic Rainfall Analysis Project (HRAP) grid. This grid was derived from the Limited Fine Mesh, a grid system based on a spatial reference system that uses a Polar Stereographic projection. The HRAP grid was difficult to use in conjunction with other GIS (geographic information system) datasets used for hydrologic analysis, so in 1996, HEC proposed a similarly structured grid-numbering system based on the Albers projection used by USGS (U.S. Geological Survey) and NRCS (U.S. Natural Resources Conservation Service) for national datasets, including STATSGO (State Soil Geographic Database) soil maps. This grid-numbering system was optimistically named the Standard Hydrologic Grid (SHG) and has been widely used for HEC-HMS models using radar

continued on page 16

Modeling with Gridded Data in HEC-HMS and HEC-DSS Outside of the Continental United States (OCONUS) (continued)

By Thomas Evans, P.E., D.WRE

continued from page 15

products within CONUS. The HRAP and SHG grid systems were thoroughly described by Reed and Maidment in a 1999 article in the ASCE Journal of Hydrologic Engineering.

Neither the HRAP nor the SHG grid-numbering system, however, is applicable for OCONUS. To support users in the rest of the world, HEC has implemented a new grid-numbering system in HEC-HMS and HEC-DSS using the Universal Transverse Mercator (UTM) coordinate systems as the basis for cell locations and numbering. The positioning of the cells and the assignment of row and column numbers works the same way as in SHG. The result is that by selecting a UTM zone and a cell size, a user can define the cells over an HEC-HMS model with consistent row and column numbering in both DSS grid records and the grid parameter file.

Implementation in HEC-HMS, HEC-DSS, and Utility Programs

The new grid features are supported in HEC-HMS Version 4.2.1, the version now available on the HEC website (http://www.hec.usace.army.mil/). A grid parameter file based on UTM coordinates can be built in HEC-GeoHMS Version 10.2, and grid data can be loaded into UTM-based DSS grids with the asc2dss utility program. The gageInterp program can also be used to generate UTM grids from time-series data at point locations.

Once the grids are loaded into DSS, they can be exported to ASCII files and viewed in ArcGIS®. Viewing the UTM grids in HEC-DSSVue, however, requires a newer version of the program than the one currently on the HEC web page. A more complete package of viewing and loading programs that include support for the UTM-based grids will be available from HEC in the near future.

Reference:

Reed, S. and Maidment, D. April 1999. "Coordinate Transformations for Using NEXRAD Data in GIS-Based Hydrologic Modeling," *Journal of Hydrologic Engineering* Vol. 4, No. 3. ASCE, New York.

HEC Software

HEC-SSP, Version 2.1

By Michael Bartles, P.E.

On 31 August 2016, the Hydrologic Engineering Center (CEIWR-HEC) released Version 2.1 of the Statistical Software Package (HEC-SSP). The last release of HEC-SSP was made in October 2010. As such, this new version contains substantial improvements and enhancements that will benefit statistical analyses of hydrologic data.

HEC-SSP Version 2.1 contains major updates to the Bulletin 17 Analysis, which was formerly known as the Bulletin 17B analysis. This component of the software allows the user to analytically perform annual peak flow frequency analyses. The software now implements two algorithms for computing annual peak flow frequency curves. The first is contained within Bulletin 17B (https://water.usgs.gov/osw/bulletin17b/dl_flow.pdf), which was published by the Interagency Advisory Committee on Water Data in 1982. The Bulletin 17B algorithms were included in previous versions of HEC-SSP. The second algorithm, and brand new to HEC-SSP, is contained within Bulletin 17C (https://acwi.gov/hydrology/Frequency/b17c/index.html), which was released in draft form by the Subcommittee on Hydrology in December 2015 (an article about Bulletin 17C is included in this newsletter).

The new capabilities within the Bulletin 17C procedures represent a substantial improvement to the older Bulletin 17B procedures. While both procedures are used to fit a Log-Pearson Type III (LP3) analytical distribution to an independent and identically distributed annual maximum series of peak flow rates, the parameter fitting, low outlier test, plotting position, and confidence limit algorithms have all been reformulated within Bulletin 17C. Bulletin 17C procedures fit a Log Pearson Type III analytical distribution using the Expected Moments Algorithm (EMA). Additionally, the Multiple Grubbs-Beck Test is used within Bulletin 17C to screen for potentially influential low floods (low outliers). Previously, the Single Grubbs-Beck Test was used within the Bulletin 17B procedures to screen for low outliers. Also, the Hirsch/Stedinger plotting position formula has been added for use with Bulletin 17C procedures. This new plotting position formula complements the existing Weibull, Median, Hazen, and user-specified plotting position

continued on page 17

HEC-SSP, Version 2.1 (continued)

By Michael Bartles, P.E.

continued from page 16

formulas that were part of previous HEC-SSP versions. Finally, improved confidence limits are computed using Bulletin 17C procedures that incorporate skew uncertainty and diverse information appropriately, as historical data and censored values impact the uncertainty in the estimated frequency curve. Users should expect the confidence limits to be wider when computed using Bulletin 17C procedures as compared to Bulletin 17B procedures for the same data set due to the inclusion of skew uncertainty.

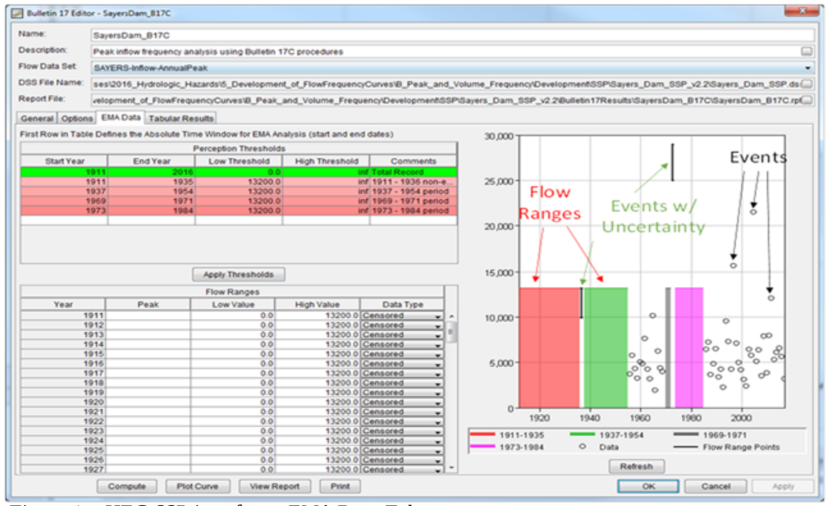


Figure 1. HEC-SSP interface - EMA Data Tab

When using the Bulletin 17C (EMA) methodology, additional data is required in order to compute a peak flow frequency curve, confidence intervals, and plotting positions. This new information includes perception thresholds and flow ranges. A perception threshold and a flow range must be defined for each year contained within a frequency curve analysis. Perception thresholds are used to define the range of streamflow for which a flood event could have been observed. The inherent assumption and consequence is that any year for which an event was not observed and recorded must have had a peak flow rate outside of (usually below) the perception threshold/range. The flow range includes the uncertainty in the observed, or estimated, flow. The flow range can be a single value or represented by low and high values that span an estimate of the observed flow.

The perception threshold and flow range data necessary within a Bulletin 17 analysis using EMA and Bulletin 17C procedures is entered/ accessed on the EMA Data tab. An example of the types of data that are entered on this tab is shown in Figure 1. For this analysis, the start and end year has been set to 1911 and 2016, respectively. Evidence presented in a March 1936 event post-flood report (Bogardus & Ryder, 1936) suggests that the March 1936 event was the largest peak flow rate in this watershed since at least 1911. his implies that had an event larger than the March 1936 event occurred in the timeframe between 1911 and 1936, it would have been documented. Therefore, the analysis period was extended beyond the systematic record to 1911.

Two large events outside of the systematic record were documented in March 1936 and June 1972. Due to the use of indirect measurement techniques, uncertainty in the peak flow rate for each event was entered by using a high and low value that were greater than and less than, respectively, the best estimate peak flow rate.

Within HEC-SSP, the first perception threshold that is specified must have a low value of zero (0) and a high value of infinity. Additional rows within the perception threshold table supersede the rows above for the specified time frame. **Within HEC-SSP, perception threshold time frames should not overlap one another.** For any missing years in the analysis period, perception thresholds **other than** zero to infinity must be entered after the first row. A perception threshold of zero to infinity presumes any flow that occurred could have been observed, implying that unobserved years would not be possible. Therefore, unobserved years must have a perception threshold with either a lower bound greater than zero or an upper bound less than infinity. Most commonly, since very large flows do tend to be observed in some way (as historical events are estimated based on some evidence in the watershed), a lower bound greater than zero is chosen.
Perception thresholds other than zero to infinity were added for the missing years (1911 – 1935, 1937 – 1954, 1969 – 1971, and 1973 – 1984) in the analysis period. Since the March 1936 event had an upper bound estimate of peak flow of approximately 13,200 cfs (cubic feet per second), this flow rate can be used as a low threshold for the perception thresholds of missing years. The use of this perception threshold assumes that had a peak flow rate occurred in excess of 13,200 cfs, it would have been documented.

Once computed, the resulting flow frequency curve, confidence limits, historical/systematic/flow ranges (for which there can be uncertainty

continued on page 18

HEC-SSP, Version 2.1 (continued)

By Michael Bartles, P.E.

continued from page 17

in the actual flow value) can be plotted as shown in Figure 2. Additional information on the types and uses of data within this analysis can be found within the HEC-SSP User's Manual (http://www.hec.usace.army.mil/software/hec-ssp/documentation/HEC-SSP_21_Users_Manual.pdf) and the Bulletin 17 report. Currently, HEC-SSP uses the same FORTRAN code as the U.S. Geological Survey's (USGS) PeakFQ (https://water.usgs.gov/software/PeakFQ/) Version 7.0 software (Veilleux, A.G., Cohn, T.A., Flynn, K.M., Mason, R.R., Jr., and Hummel, P.R., 2014). In addition to the modifications made within the Bulletin 17 Analysis, a new Balanced Hydrograph Analysis was added to HEC-SSP for Version 2.1. In this type of analysis, observed data, flow, and volume-frequency curves are used to create a hypothetical hydrograph that "balances" flow rates, volumes, and frequency. Within a balanced hydrograph, the flow and/or volume across multiple durations satisfies the relation between flow/volume and duration for a given frequency. For example, a 0.2 percent annual chance exceedance (ACE) balanced hydrograph using instantaneous peak, one-day, and two-day durations would have individual hydrograph ordinates arranged in such a way that the flow volumes for the instantaneous peak, one-day, and two-day durations would each equal the 0.2 percent ACE flow rates and/or volumes. An example of the user-defined flow and/or volume frequency curves, along with the information that is extracted and used within the balanced hydrograph analysis, is shown in Figure 3. An example of a balanced hydrograph using a template hydrograph shape and user-defined flow and/or volume frequency information is shown in Figure 4.

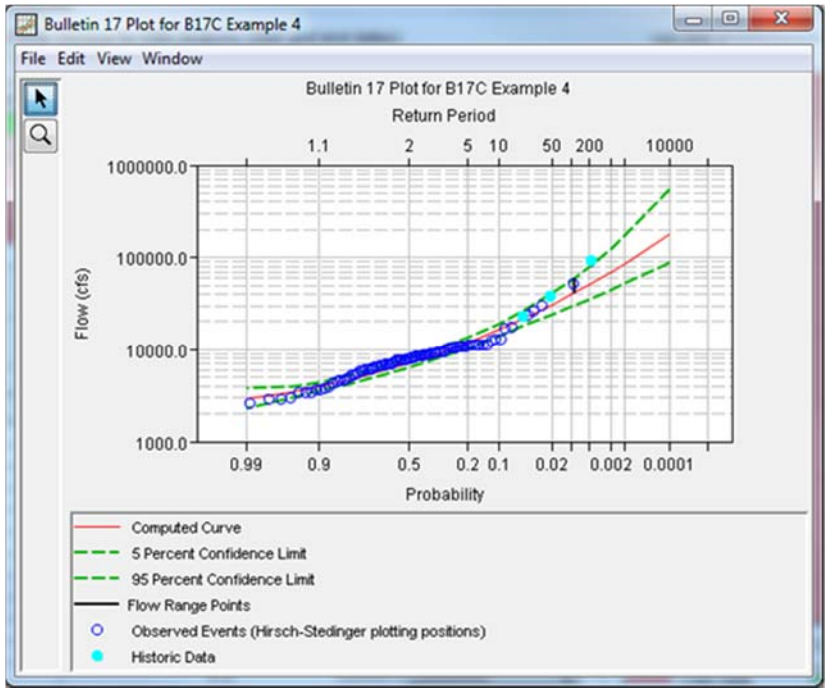


Figure 2. Bulletin 17 Analysis Plot

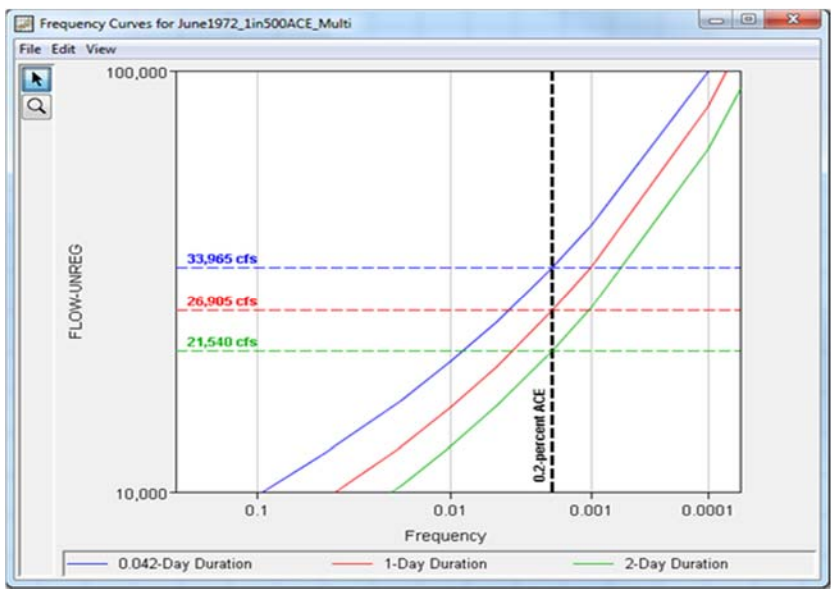


Figure 3. Example of Flow and Volume Frequency Curves used in a Balanced Hydrograph Analysis

For the HEC-SSP Version 2.1 release, enhancements were also made to the General Frequency Analysis to allow for the expanded use of Partial Duration datasets, as shown in Figure 5. Furthermore, the Volume Frequency Analysis was modified to more accurately extract duration-specific flows or volumes using an updated algorithm. Finally, numerous bug fixes were performed which enhanced the usability of the software.

continued on page 19

HEC-SSP, Version 2.1 (continued)

By Michael Bartles, P.E.

continued from page 18

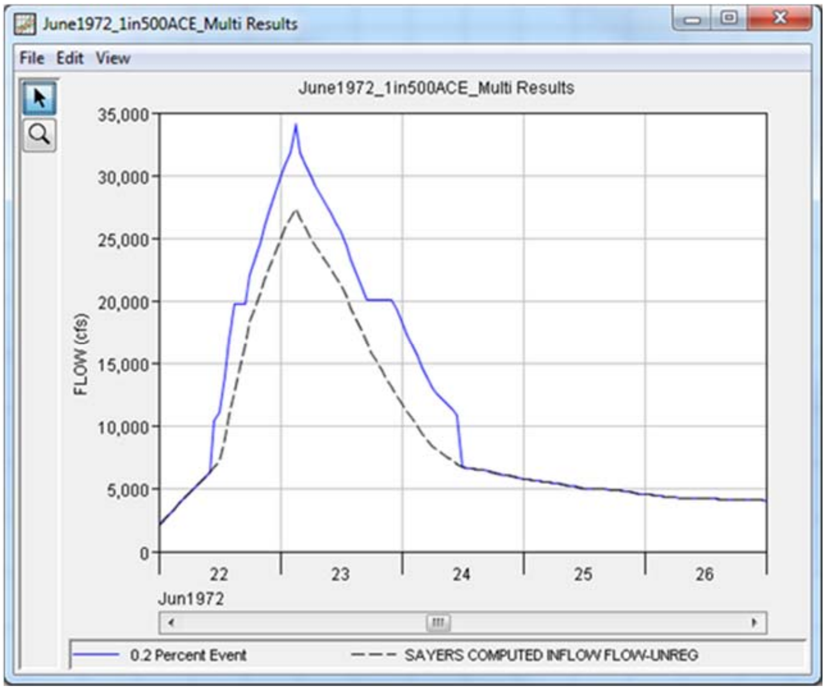


Figure 4. Example of a Balanced Hydrograph

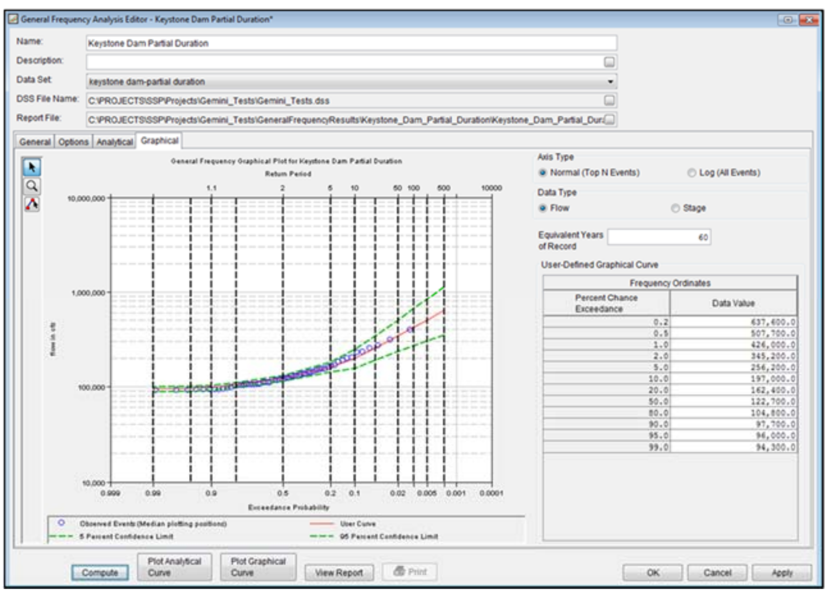


Figure 5. Example of a Partial Duration Series used within the General Frequency Analysis

HEC-SSP Version 2.1 is available from the HEC-SSP webpage: http://www.hec.usace.army.mil/software/hec-ssp/ along with updated documentation and example datasets. HEC-SSP Version 2.1 is on the ACE-IT software approval list and a Certificate of Networthiness (CoN) application has been submitted. Once the CoN has been approved, CEIWR-HEC will add the CoN to the HEC-SSP webpage.

New capabilities are currently being designed and included within HEC-SSP. These new features include enhancements to Bulletin 17, General Frequency, and Volume Frequency Analyses. Also, a Distribution Fitting Tool is being implemented that will fit up to sixteen different analytical distributions of varying complexity to nearly any type of hydrologic data using two different fitting routines. Also, a new Mixed Population Analysis and a redesigned Curve Combination Analysis will be included in a future release of HEC-SSP.

HEC-RAS, Editing Tools (Version 5.1)

By Cameron Ackerman, P.E., D.WRE

Introduction

The widespread availability and use of geospatial data has changed the way river hydraulic models are developed. Hand entry of individual data points from cross section surveys has been replaced with the layout of geometric features and extraction of ground surface information from digital terrain models. The seminal tool built for developing an HEC-RAS (Hydrologic Engineering Center's (HEC) River Analysis System) model using geospatial data was HEC-GeoRAS (ARC/INFO version), released in 1999. HEC-GeoRAS provided a user interface for the command-line GIS (geographic information system) that allowed for the placement of cross section locations and other pertinent features to extract elevation information for import into HEC-RAS. Over the last fifteen years, advancements to HEC-GeoRAS have taken place to provide for more flexible data options and capabilities; however, the tool has always been separate from HEC-RAS as a GIS extension which required the user to learn an additional software package. Recent endeavors within the HEC-RAS software have focused on the development of geospatial tools to assist in creating geometric data for hydraulic model development directly within the HEC-RAS modeling framework. This seamless integration of development tools within HEC-RAS for geospatial data takes one more step forward in improving the efficiency of the river hydraulic modeling process. This article will preview the tools and capabilities that will be available within HEC-RAS Version 5.1 and RAS Mapper (a tool in the HEC-RAS software) for extracting GIS information from digital terrain models and geometric data to be used for hydraulic modeling within HEC-RAS.

In the past, use of geospatial data for analysis and visualization was primarily used for geography and scientific analysis, but today it is common place. The first widely spread public use of maps with geospatial data was the local news with temperature highs (or lows) scattered throughout the coverage region, and then there were rainfall patterns and storm depths and tornado paths. Soon, the use of geospatial data began to permeate people's everyday life. Today, mobile devices allow people to navigate from place to place; identify traffic congestion, identifying gas stations and the availability of food (markets, restaurants) along the way – and yes, checking the weather at the same time. This common place use of geospatial data has not only changed *what* people expect from mapping but shaped *how* people expect to interact with maps. Therefore, the underlying design philosophy that HEC has taken with creating editing tools within HEC-RAS is that working with the tools must be intuitive.

Intuitive Design

The primary goal in developing editing capabilities directly in HEC-RAS Version 5.1 is to provide tools where the user's specific knowledge and capabilities of HEC-RAS can be utilized, and freeing the user of having to learn and using (or pay) another piece of software. Further, HEC wants to assist the modeler in making the software easy to use and understand and reduce the learning process. Therefore, the editing tools in HEC-RAS are intended to be intuitive. An intuitive tool must not only function as expected but it must also provide feedback to the user that the expected action is indeed available. Feedback allows the user to more quickly learn the software capabilities and adapt their behavior. Feedback is provided through changes to the visualization of data and cursor as the mouse is moved and clicked within the map display. For instance, when in the Edit Feature mode, the cursor is a simple (default) arrow. As the cursor moves over a feature, the feature becomes highlighted (to indicate to the user an action is available) and the mouse cursor changes to a hand (indicating the feature is now selectable, by the mouse, to move or edit). This immediate feedback ultimately provides a blueprint for the user; if something is available or can be done, the interface will indicate an available action. Figure 1 provides a demonstration of the progression

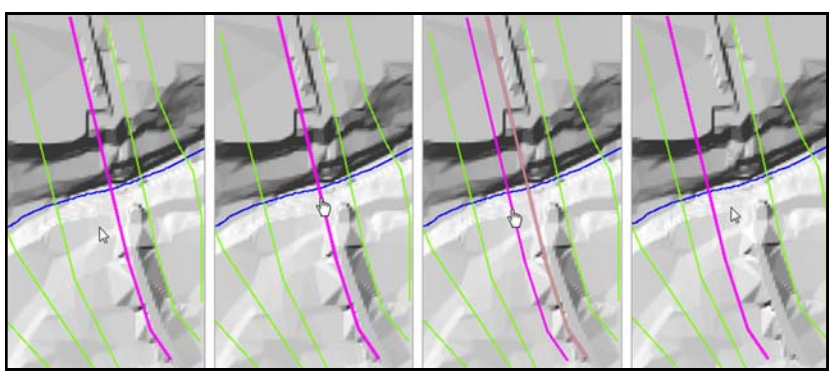


Figure 1. Progression of cursor interaction when moving a selected feature (cross section). Notice how the mouse curser transitions from a pointer to a hand as the mouse curser moves closer to the cross section. When the mouse curser is represented with the hand icon, then the click action will select the cross section, and then the cross section can be moved.

continued on page 21

By Cameron Ackerman, P.E., D.WRE

continued from page 20

of moving the selected cross section away from a bridge abutment. Another feedback mechanism is the reporting and visualization of data errors when features are created (this is discussed in a later section of this artivle). Lastly, a concerted effort was made to limit the number of tools available to the user during an editing session to make those editing tools that are appropriate (and available) more obvious to the user. This limitation is HEC's attempt to reduce distractions to data development and focus user actions.

Editing Tools

The Editing Toolbar (Figure 2) becomes available when the user starts editing a layer. The editing tools are: Add New Feature, Select/

Figure 2. Editing Toolbar

Edit Feature(s), Undo Edit, Redo Edit, and Plot Terrain Profile. The editing tools work with point, line, or polygon feature types. Creating a new feature, undoing an edit, and redoing an edit work as a user might expect. The Select/Edit Feature(s) tool handles multiple tasks so that the user is not "looking" for the correct tool. The editing environment has been designed such that a feature must first be selected before any changes can take place. If a feature is selected, that feature can then be moved, deleted, or opened for editing. Once a feature is opened for editing, points on the feature can be moved or deleted and new points can be inserted. Each action is performed using the same tool with the cursor providing feedback for the option available. For instance, if the cursor is not over a point then it appears as an arrow (Selection Mode), but as the cursor nears a point the cursor changes to a hand, indicating that a point can be deleted or moved. If the cursor is

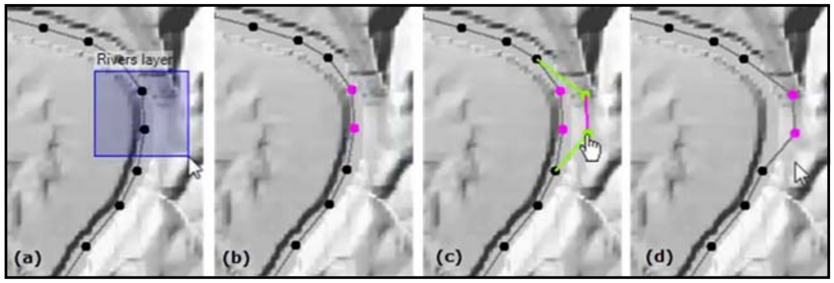


Figure 3. The progression of actions show (a) selecting multiple points, (b) highlighting of the selected set, (c) moving selected points with perspective resulting line shown, and (d) the resulting placement. At this point the operation may be undone or the selected set could be deleted.

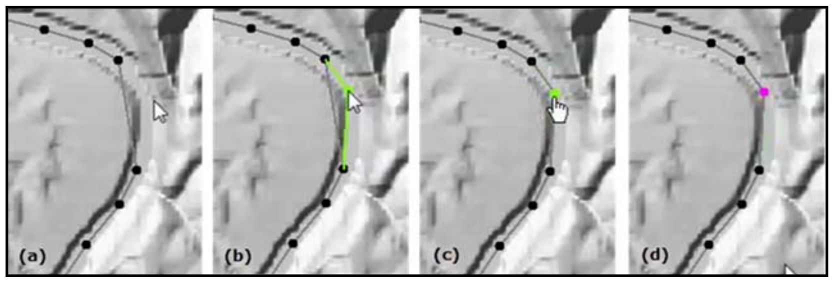


Figure 4. The progression of actions show (a) mouse cursor is not near to the feature, (b) point insert action is available with the perspective resulting line shown, (c) cursor automatically changes to allow user to move the new point, and (d) the final resulting point highlighted for possible next action (undo or delete).

near a line, the cursor shows what the line would look like if a new point was inserted. Figure 3 shows interacting with a line to select points to move, while Figure 4 shows cursor interactions during a point insertion.

The ability to add and edit points, lines, and polygons will allow HEC-RAS users to efficiently create geospatial data such as river networks, cross sections, hydraulic structures, storage areas, and two-dimensional areas. Creating these features directly in HEC-RAS will also allow HEC-RAS to help identify possible data errors specific to HEC-RAS requirements. For instance, HEC-RAS requires that a cross section "lives" on a unique river-reach. Therefore, after creating cross sections, the modeler will be informed of cross sections that do not have a unique intersection with the river layer. These "errors" will be saved to a layer that will not only have a description of the problem, but geospatial information that can be plotted to signal where data is not complete. An example, Figure 5, provides a plot of the errors (with labels turned on) generated when intersecting a the cross sections layer and bank station lines layer. Visual identification of the location of the error and description of the problem should prove valuable in quickly finding and remedying data problems without having to wait for problems to manifest when trying to run a model simulation.

After geometric data has been created to represent hydraulic elements, data will automatically be extracted. For example, cross section river stations are computed based on their intersection with the river network; bank stations locations are computed based on the intersection with bank lines; elevation profiles are extracted from the ground surface terrain model, as shown in Figure 6. Also, elevation-volume information can be

continued on page 22

By Cameron Ackerman, P.E., D.WRE

continued from page 21

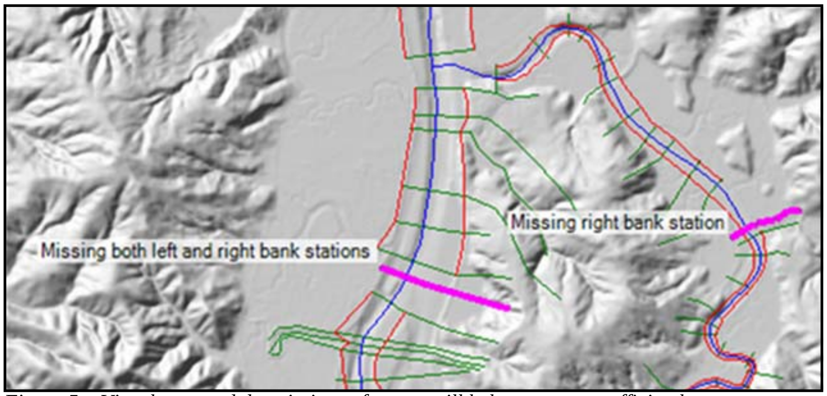


Figure 5. Visual cues and descriptions of errors will help users more efficiently create complete datasets. In this example, the intersection of bank lines and cross sections is not complete for two cross sections.

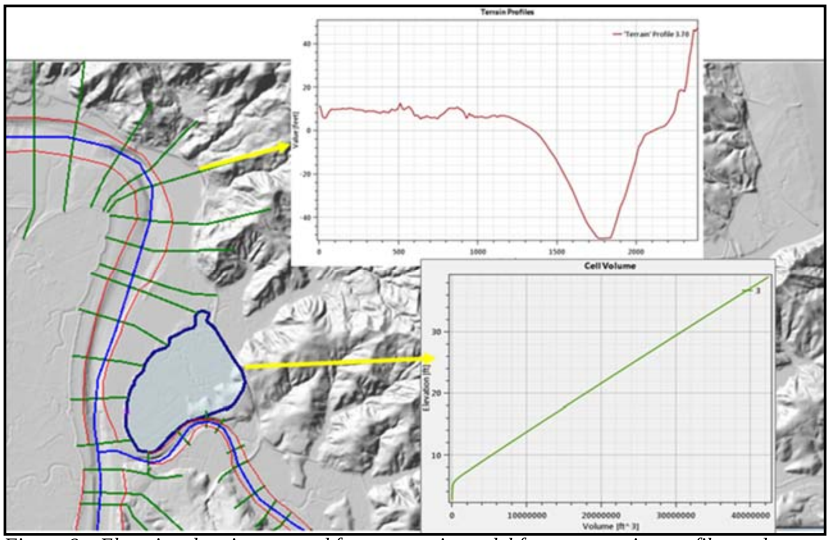


Figure 6. Elevation data is extracted from a terrain model for cross section profiles and elevation-volume information

computed for storage areas and two-dimensional cells from the ground surface terrain model (Figure 6). Automation of data extraction routines allows for rapid model generation. Spending less time manually entering model data will allow for more time to analyze and refine model results and result in less typos when entering information.

Mapping and Analysis

The most important process in hydraulic model development is the analysis of model results and refinement of model parameters to best represent the physical system. Incorporating editing tools directly into HEC-RAS not only allows for more efficient model creation, but also improves the modeler's capability to make changes to the model construct through interpretation of model results in the form of floodplain maps. Additional cross sections can be added to a model in locations where the water surface varies more rapidly than was initially considered. Cross sections can be lengthened so they capture the entire floodplain or are properly realigned to be perpendicular to flow. In some instances, the cross section layout has been done properly to compute the water surface elevation; however, the resulting flood inundation map does not properly map backwater areas.

The editing tools in HEC-RAS provide the user the opportunity to modify the study limit (boundaries) polygon to include areas not represented by the one-dimensional model framework. Figure 7a, displays an unsuccessful flood map creation of inundates areas that should be dry, and fails to inundate other areas that should be wet based on the generation of the study limits from cross sections attempting to accommodate a leveed river system (Figure 7b). Figure 7c further shows redefined cross sections resulting in a much improved flood map (Figure 7d). Illustrated in Figure 8, are the problems that result from mapping results based on cross sections that do not capture backwater areas. The cross sections are laid out properly to compute the water surface elevations correctly, but the cross sections do not allow for proper inundation mapping.

Summary

The addition of editing tools with the HEC-RAS Version 5.1 software will allow modelers to more efficiently study river systems. Using a terrain model and background data in RAS Mapper will allow the HEC-RAS user to establish river centerlines, cross section locations, storage areas, two-dimensional flow areas and many other layers to create a geometry representing the real world river system. The editing tools are being designed to be intuitive, making the choice of actions easy to identify, access, and utilize. HEC believes the capability to quickly modify geometry directly within HEC-RAS, using previous simulation results, will encourage HEC-RAS users to develop river hydraulic models through the iterative approach of data development, simulation, evaluation, and refinement. HEC is excited to get these new capabilities into the field and trust users of HEC-RAS Version 5.1 will enjoy using the new editing capabilities.

continued on page 23

By Cameron Ackerman, P.E., D.WRE

continued from page 21

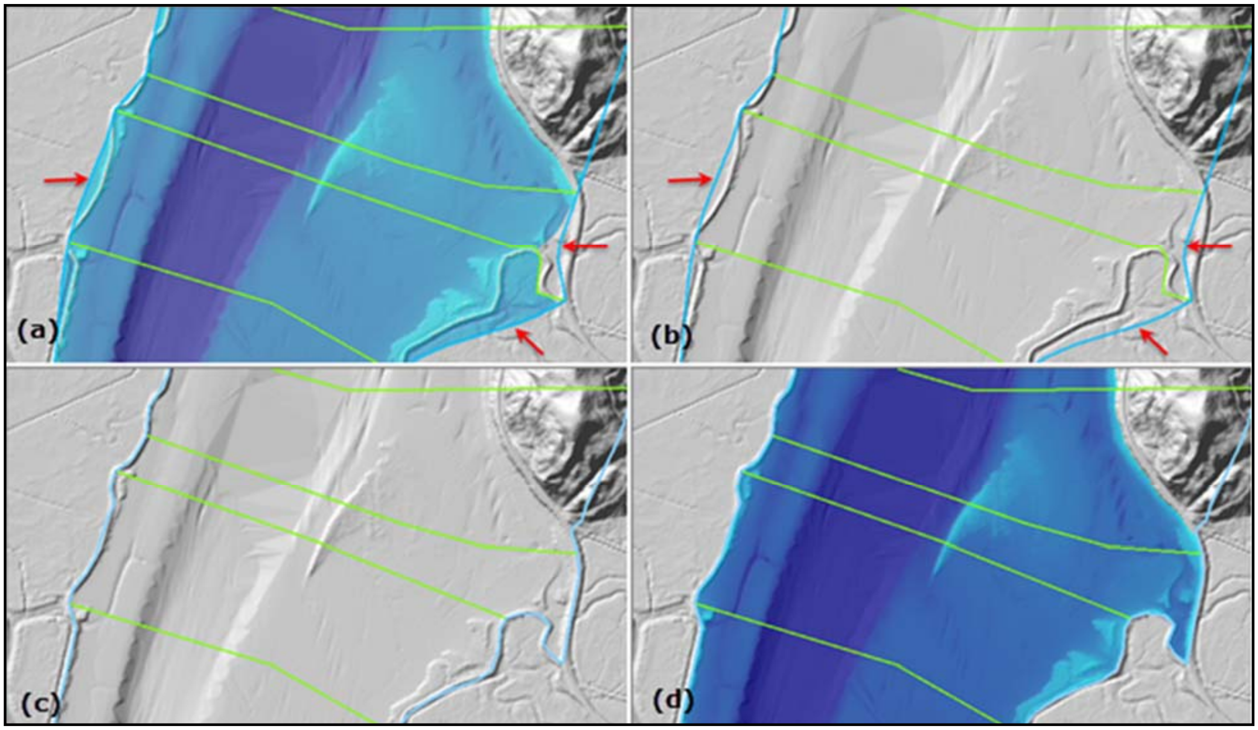


Figure 7. Improper mapping shown in (a) was the resulted from study limits that do not follow top of levee (b). The correction of study limit polygon using the HEC-RAS editing tools (c) results in a more appropriate inundation map (d).

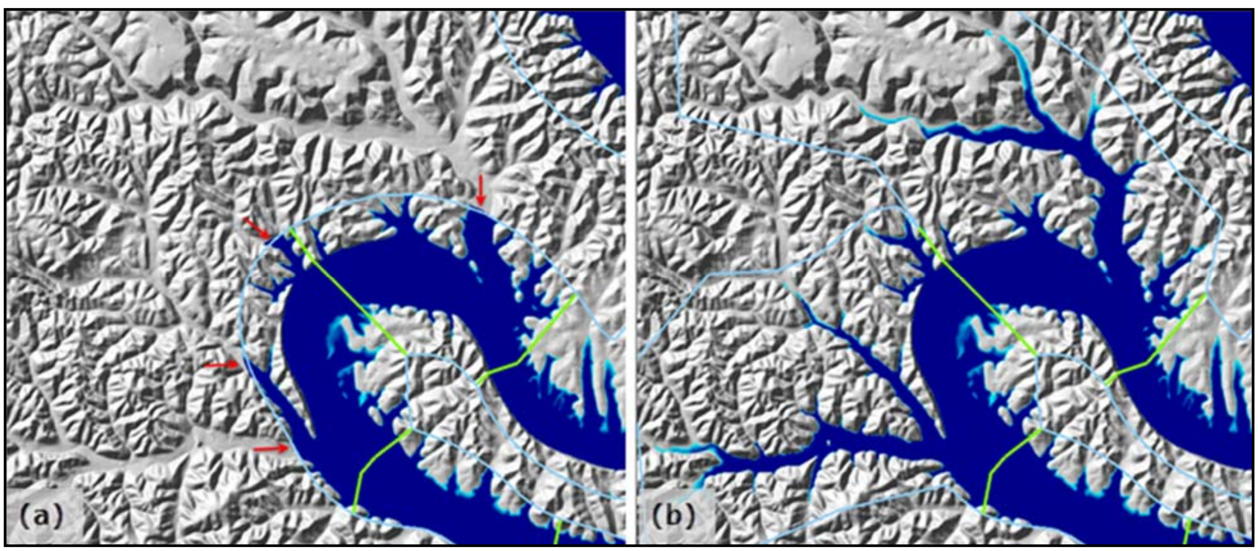
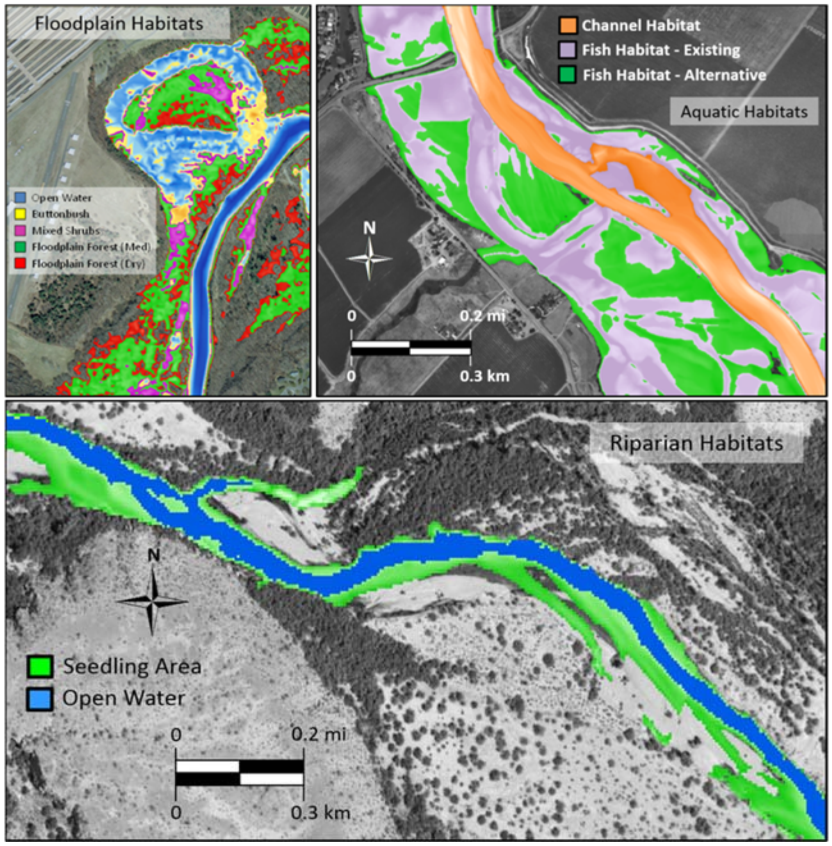


Figure 8. Editing study limits shown for specified locations in (a) allows for backwater areas to be mapped correctly in (b). ation

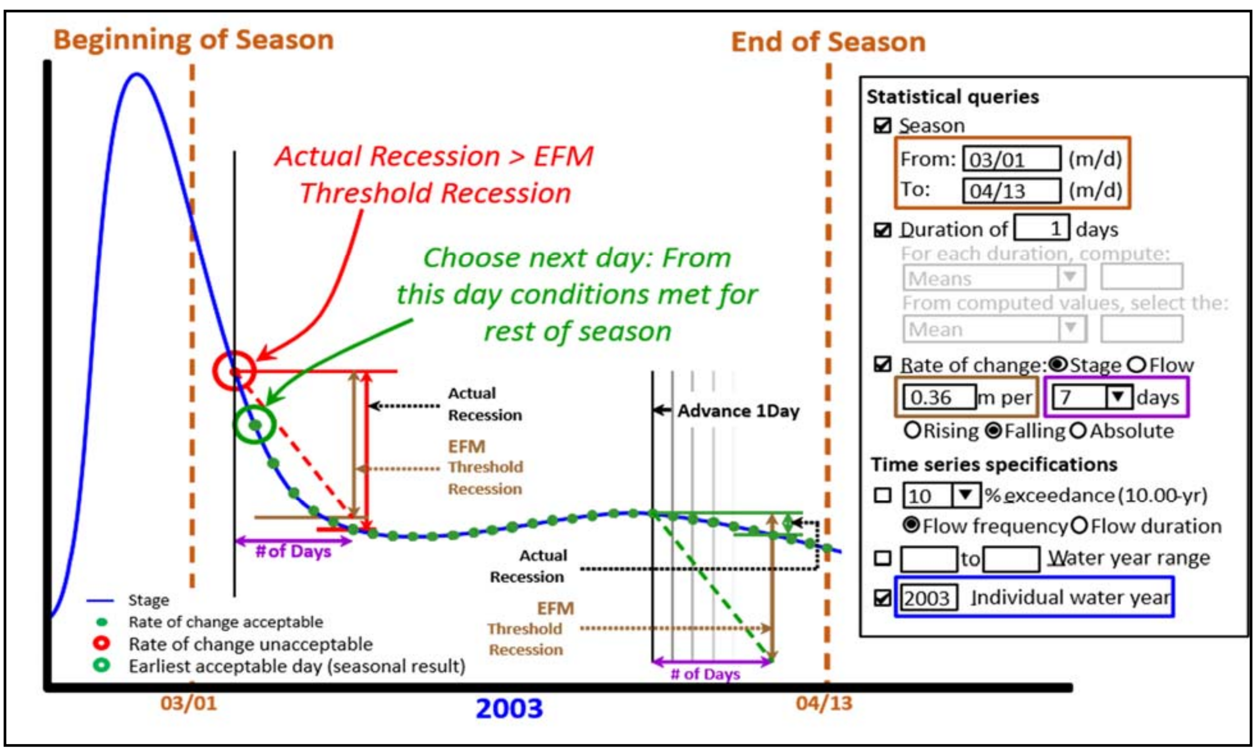
HEC-EFM (Ecosystem Functions Model, Version 4.0

By John Hickey, PhD, P.E.



On 6 April 2017, the Hydrologic Engineering Center (CEIWR-HEC) released Version 4.0 of the HEC-EFM software. This version of HEC-EFM, includes: Significant enhancements include: 1) importers to bring pieces of existing applications into new ones, 2) allowing users to create and assess "groups" of connected ecological relationships or water and ecosystem management scenarios, 3) letting users pick which output to generate, 4) format options for output display, 5) input/output parsing for big compute jobs, 6) summations to tally services provided by different management scenarios, 7) batch computing for restoration design, and 8) use of two -dimensional spatial and temporal data in habitat mapping.

The software is available from the HEC-EFM webpage (http://www.hec.usace.army.mil/software/hec-ras/) along with updated HEC-EFM documentation. HEC-EFM Version 4.0 is on the ACE-IT Software Approval list and a Certificate of Networthiness (CoN) application has been submitted; once the CoN has been approved, CEIWR-HEC will add the CoN to the HEC-EFM webpage.



CEIWR-HEC Comings & Goings

By Dawn Palma

Ms. Diane Cuming, the Hydrologic Engineering Center (HEC) Chief Administrative Officer (CAO), retired on 31 December 2016 with thirty years of civilian service, all with HEC. Diane will be sorely missed as she has been the backbone for HEC her entire career. Her historical knowledge and can-do attitude proved invaluable as she kept HEC in-line with contracting, finance, facilities, human resources, and many, many other activities. Diane has graciously agreed to come back as an intermittent re-employed annuitant so that she can continue to help with contracting actions until the new CAO has completed training to be certified.

Mr. Carl Franke, Civil Engineer (Hydraulics), retired on 31 December 2016 with 27 years of civilian service, all with HEC. Carl was instrumental in working on the CWMS suite of software and data tools. His expertise with providing technical assistance to end-users over the years has been extraordinary, and we are certain that many end-users will miss his guidance (and humor). He continues to live in Woodland, CA and enjoys the fruits of his labor.

Ms. Dawn Palma, joined HEC as the new Chief Administrative Office (CAO) on 16 October 2016. Immediately before joining HEC Dawn was a Supervisory Human Resources Specialist with the US Army Civilian Human Resources Agency, Civilian Personnel Advisory Center (CPAC). She worked in the Federal civilian human resources field for 29 years. Her first few years with the Sacramento Army Depot, the last 26 years with the local CPAC. Dawn is very excited to join the HEC team and looks forward to many years serving as the CAO.

Mr. Greg Karolvits, joined HEC as a Civil Engineer (Hydraulics) effective 19 February 2017. Greg formerly worked for the RMC and supported hydrologic and statistical analysis for Dam and Levee Safety studies. At HEC, Greg will work with the HEC-HMS and HEC-SSP teams to further software development and provide technical support. Greg will also continue to support ongoing Dam and Levee Safety projects as a Hydrologic Hazards Team (HHT) member.

Mr. Brent Palmberg, joined HEC as a Civil Engineer (Hydraulics) effective 2 April 2017. Mr. Palmberg has a BS in Civil Engineering from Vanderbilt University and holds a PE license with the state of Minnesota. He has worked for the St. Paul District since October 2009 where he worked in the Hydrology and Water Management Section as a System Administrator and DevOps engineer for production water management servers. In his new role with HEC he will support the CWMS team.

Mr. Myles McManus joins HEC. Mr. McManus from the Tulsa District recently accepted a position with HEC as a Civil Engineer. Myles has worked for the Tulsa District since April 2013. He received both his Bachelor's and Master's degrees in Civil Engineering from the University of Alabama at Birmingham. Myles will join the Water Management Systems Division, working on CWMS data management. We are looking forward to Myles relocating to Davis, CA summer 2017.

Mr. Eric Tichansky joins HEC. Mr. Tichansky from the Tulsa District recently accepted a position with HEC as a Civil Engineer. Eric has worked for the Tulsa District since August 2013. He received a Bachelor's degree in Environmental Engineering from the University of Oklahoma. Eric will join the Water Management Systems Division. He will work on CWMS modeling and address questions developed during the national implementation of CWMS. We are looking forward to Eric relocating to Davis, CA summer 2017.

CEIWR-HEC Engineering/Software Technical Support to USACE

By Diane Cuming

The Hydrologic Engineering Center (CEIWR-HEC) is responsible for creating and maintaining various pieces of software that can be categorized in seven different engineering modeling areas:

1) River Hydraulics
2) Hydrologic Analysis
3) Hydrologic Statistical Analysis
4) Reservoir Systems
5) Data Storage
6) Flood Risk and Consequence Analysis, and
7) Environmental Analysis

By assigning CEIWR-HEC software to one of these seven areas, CEIWR-HEC can provide engineering and technical support to U.S. Corps of Engineers (USACE). USACE offices can voluntary elect any of the areas and then purchase technical support. This engineering and technical support provides USACE offices with access to the CEIWR-HEC developers of individual pieces of software. Unfortunately, CEIWR-HEC is not funded to provide support to those outside of USACE. Non-USACE individuals and organizations should search the Internet to locate a vendor that can provide support for the CEIWR-HEC software of interest.

For those new to CEIWR-HEC software, an overview of each of the categories is discussed in the following paragraphs.

1. **River Hydraulics** (HEC-RAS, HEC-GeoRAS, HEC-UNET, HEC-2, HEC-6). HEC-RAS (River Analysis System) is the most widely used river hydraulics model in USACE offices. The software is used in every USACE District office for studies ranging from risk analysis to dam breach scenario simulation and is one of the main tools used by the Mapping, Modeling, and Consequences Center (MMC). HEC-RAS computes water surface profiles based on one and two-dimensional, rigid and mobile boundary, steady and unsteady flow principles. HEC -RAS Version 5.0.3, is the current version and is available from the CEIWR-HEC website. HEC-2 (Water surface Profiles), HEC-6 (Sediment Transport), and HEC-UNET (One-Dimensional Unsteady Flow Through a Full Network of Open Channels) are legacy software that provides steady-flow water surface profiles, sediment transport computations, and, unsteady flow analysis, respectively. Most, if not all of the legacy software's features have been superseded by the capabilities found in HEC-RAS. HEC-RAS Version 5.0.3 includes:two-dimensional modeling features, sediment transport and water quality capabilities which will continue to be developed and enhanced. RAS Mapper is a tool that is available in HEC-RAS Version 5.0.3, which provides the capability to handle large terrain data sets, for inundation mapping. For the future, Version 5.1 will continue with enhancements to the two-dimensional modeling features, support for extraction of geometric information from terrain datasets using the RAS Mapper Tool, and include uncertainty analysis capabilities.

2. **Hydrologic Analysis** (HEC-HMS, HEC-GeoHMS, HEC-1, HMR52). The Hydrologic Modeling System (HEC-HMS) is the most widely used precipitation-runoff program in USACE. Version 4.2.1 is the current version of HEC-HMS available from the CEIWR-HEC website and computes precipitation-runoff from all types of watersheds. The software can be applied to studies of water availability, urban

drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood risk management reduction, floodplain regulation, systems operation, sediment transport, and water quality. In conjunction with the probable maximum storm generator software, HMR52 (Probable Maximum Storm - Eastern United States), HEC-HMS can be used to compute the probable maximum flood for project safety, spillway adequacy studies, and perform spatially distributed precipitation-runoff analysis and continuous simulation. HEC-GeoHMS is a GIS extension that can be used to rapidly develop HEC-HMS basin models from digital elevation models. The extension dramatically reduces staff time necessary to construct models, especially large or complex models. Version 4.2.1 includes new GIS capabilities (automatic subbasin delineation directly in the program), new forecasting features, new modeling capabilities (including an energy balance snowmelt method), and a HMR52 meteorologic model option directly within HEC-HMS.

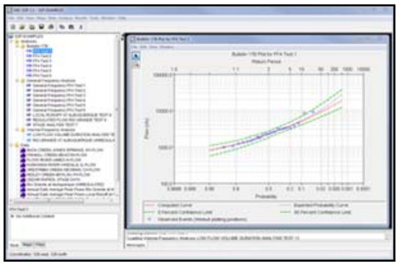
3. **Hydrologic Statistical Analysis** (HEC-SSP, HEC-FFA, STATS). Version 2.1 of the Statistical Software Package, HEC-SSP, includes capabilities from the Flood Frequency Analysis (HEC-FFA) software and some of the capabilities available from the Statistical Analysis of Time-Series Data (STATS) software. HEC-SSP also plans to include capabilities found in the Regional Frequency Computation (REGFRQ) and

continued on page 27

CEIWR-HEC Engineering/Software Technical Support to USACE (continued)

By Diane Cuming

continued from page 26



Multiple Linear Regression Program (MLRP) software packages in a future version. The software can perform flood flow frequency analysis based on guidelines in Bulletin 17B, "Guidelines for Determining Flood Flow Frequency" (1982). Also, HEC-SSP contains tools for developing a generalized frequency analysis using other hydrologic data types, a volume frequency analysis on high and low flows, a duration analysis, a coincident frequency analysis, and a curve combination analysis. Flow-frequency is an integral part of USACE risk analysis and proper development of flow-frequency curves is an instrumental piece of the risk analysis procedure. Version 2.1 of HEC-SSP will be released in FY 2016 and will include a new Balanced Hydrograph analysis along with the Expected Moments Algorithm for computing flow frequency analyses.

4. **Reservoir Systems** (HEC-ResSim, HEC-ResFloodOpt, HEC-PRM, HEC-5, HEC-5Q). The HEC-ResSim (Reservoir System Simulation) software can simulate the operation of complex reservoirs and reservoir systems for both planning studies and real-time water management needs. Like the other engineering modeling software in the current generation of CEIWR-HEC products, HEC-ResSim provides a graphical user interface for model building, file management, program execution, and output displays. Version 3.1 is the current release of HEC-ResSim and is available from the CEIWR-HEC website. The two other available reservoir-modeling programs are optimization tools. The Prescriptive Reservoir Model (HEC-ResPRM) software optimizes reservoir release decisions to maximize multiple system objectives, and is useful in developing operation rules to meet reservoir system goals. HEC-ResFloodOpt (Reservoir Flood Control Optimization) optimizes single-objective flood event operations. Both HEC-ResPRM and HEC-ResFloodOpt combine the physical system model from HEC-ResSim with a linear programming or mixed-integer programming optimization solver. HEC-5 (Simulation of Flood Control and Conservation Systems) is CEIWR-HEC's legacy reservoir simulation model and can determine reservoir releases for flood reduction, water supply, and electric energy demands. HEC-5 can simulate the operation of multiple-purpose reservoir systems using time intervals from minutes to months. A companion program, HEC 5Q (HEC-5, Water Quality Analysis), provides water quality analysis for reservoir and river systems.

5. **Data Storage** (HEC-DSS, HEC-DSSVue). HEC-DSS (Data Storage System) provides for the

management of time series data used in studies and water management activities. Data may be entered, edited, tabulated, graphed, and exchanged between a variety of hydrologic engineering and planning analysis-modeling programs. In particular HEC-DSS plays a role in ensuring data is managed in a way that is efficient for hydrologic, planning, and real time operations. For example, HEC-DSS is an integral part of the HEC-WAT (Watershed Analysis Tool) and CWMS (Corps Water Management System) pieces of software. The primary user interface for HEC-DSS is HEC-DSSVue, a Java-based graphical interface that is supported both on UNIX and Windows computers. The software plots and tabulates data in an HEC-DSS database file using simple mouse selections. Over sixty mathematical manipulation functions are available for operations on data sets within a HEC-DSS file, as well as data entry functions, and several utility and database maintenance functions. Data can be displayed from a selection of data set names or from spatially referenced locations with a map background. Common data stored in HEC-DSS include time series data, such as hourly or daily flow, stages, precipitation, elevation, and storage data; curve data, such as rating tables and frequency curves; gridded data, such as NexRad data; and a variety of other data types.

6. **Flood Risk and Consequence Analysis** (HEC-FDA, HEC-FIA). The Flood Impact Analysis (HEC-FIA) software was developed for the CWMS modernization project in the early 2000s. The current version of HEC-FIA is an improved GIS-enabled version, which is also used to support consequence estimates for USACE Dam and Levee Safety Risk Assessments. These improvements were made to assist the USACE Modeling Mapping and Consequences (MMC) in evaluating the risk associated with various failure scenarios for dams and levees. Some of the improvements were associated with modifying the capability to model warning issuance, adding the capability of using arrival time grids, duration grids, and depth x velocity grids. Improvements include the ability to use higher resolution data, such as parcel level inventories, to represent the structures within the floodplain.

continued on page 28

By Diane Cuming

continued from page 27

The Flood Damage Reduction Analysis (HEC-FDA) software provides the capability to perform an integrated hydrologic engineering and economic analysis during the formulation and evaluation of flood risk management plans. HEC-FDA is USACE's number one tool for the formulation and evaluation of flood risk management measures. The software is designed to assist study team members in using risk analysis procedures for formulating and evaluating flood risk management measures and analyzing the economics of flood risk management projects.

7. Environmental Analysis (HEC-RPT, HEC-EFM, HEC-GeoEFM, HEC-EFMSim). The Regime

Prescription Tool (HEC-RPT), the Ecosystem Functions Model (HEC-EFM), with its accessories for statistical (HEC-EFM Plotter) and spatial analyses (HEC-GeoEFM), and new software known as HEC-EFMSim, comprise a suite of tools designed for use in ecosystem restoration projects, water allocation studies, and efforts to improve the ecological sustainability of land and water management practices. The purpose of HEC-RPT is to help interest groups reach consensus about how rivers should be managed. The software does this by plotting and comparing desired river flows from a range of perspectives (e.g., flood risk management, water supply, hydropower, navigation, and ecosystem maintenance). These flows are defined by the interest groups and presented in a common format, which provides a foundation for resolving areas of conflict. Flows created in HEC-RPT are exported for analysis in other programs, including reservoir simulations, river hydraulics, and ecosystem functions. HEC-EFM is a planning tool that analyzes ecosystem response to changes in river flow and stage. Using a combination of statistical and spatial features, HEC-EFM enables project teams to define existing ecologic conditions, highlight promising restoration sites, and rate alternatives according to their relative changes in ecosystem aspects. HEC-EFM Plotter allows users to display and assess the statistical analyses performed in HEC-EFM applications. HEC-GeoEFM is an extension (ESRI ArcMap Version 9.3) that provides three primary capabilities for users planning ecosystem restoration projects or water management scenarios: 1) management of spatial data sets, 2) computation and comparisons of habitat areas, and 3) assessment of habitat connectivity. HEC-EFMSim performs continuous simulations (spatially and temporally) of ecosystems. Applications of HEC-EFMSim can be as simple as one community for one location and as complex as the user would like to simulate. The software is being designed to simulate ecosystems for large spatial areas and long time periods.