History of The HEC-Hydrologic Modeling System (HEC-HMS)

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1. HEC Director's Comments for 45th Anniversary

In June 2009 the Hydrologic Engineering Center (HEC) celebrated its 45th anniversary. A lot has changed within the hydrologic and water resources profession in the last 45 years but one thing that hasn't changed is HEC's mission. HEC was established 45 years ago to serve as a Corps Center of Expertise in the technical areas of hydrologic engineering and water resources planning analysis. HEC still conducts research and develops software, performs training and provides technical assistance that reflects the state-of -the-art in hydrologic engineering and the closely associated planning analysis. And finally, while the software HEC produces is developed for the Corps, this software is still available for free in the public domain. Like HEC Director, Mr. Chris Dunn, said, much has changed but much has stayed the same.

2. The HEC-1 to HEC-HMS Transformation

It is not an understatement to say that HEC-1 changed the way engineers performed hydrologic analyses. The first version was completed in the fall of 1968 with most of the work done by Leo Beard. It quickly gained wide acceptance for a number of reasons. First, HEC-1 provided a comprehensive description of the hydrologic cycle, combining precipitation, infiltration, surface runoff, baseflow, channel routing, and reservoir simulation. Previously it was necessary to use a separate software package for each logical component. The user was required to manually pass results from program output

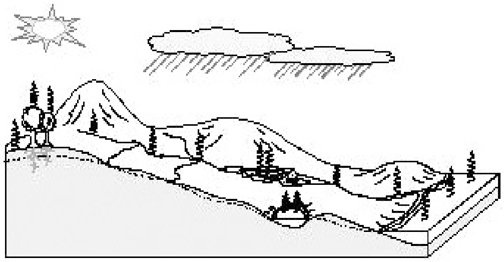

Figure 1. Hydrologic Cycle

to program input until the final result was obtained at the outlet of the watershed. Second, HEC-1 benefited from being the first program available. University researchers were simultaneously working on similar software for hydrologic simulation. However, these tools were applied primarily on academic projects. They lacked the extensive documentation and ongoing maintenance that supported HEC-1. Third, it was very fast compared to the alternative of slide rules and mechanical calculators. For the first time it was becoming possible for engineers to focus on the hydrologic processes (Figure 1) at work instead of the methodologies of making manual calculations.

The HEC-1 program was enhanced through out the 1970's and into the 1980's. Engineers working on the project at various times during that period included Arlen Feldman, John Peters, Dr. David Goldman, Gary Brunner, Darryl Davis, Michael Burnham, Paul Ely, and Troy Nicolini. It was connected to the Data Storage System (DSS) in the early 1980's for storing and retrieving time-series data. This made it possible to develop large databases of precipitation and observed flow data for use in comprehensive studies. The DSS connection also made it possible to connect surface runoff from HEC-1 to the companion HEC-2 program for detailed one-dimensional hydraulic analysis. But more than data management features were added to the program. The kinematic wave surface runoff component was added for urban hydrology needs. The Muskingum-Cunge channel routing method was also added during this period to improve the physical representation of flood wave routing. The Green and Ampt infiltration method was added as well. A parameter optimization feature was added to help with model calibration. Finally, a dam break module was added to the reservoir.

The success of HEC-1 bred several products for specialized application. The best known of these was called HEC-1F. It was used as the hydrologic component of the Water Control Data System (WCDS). It helped usher in an era of system operation based on near real-time simulation. This proved a significant improvement over using measured precipitation (rain on the ground) and static regulation manuals. A lesser known variant was called HEC-1C. This software experimented with continuous simulation. However, while the continuous capabilities it demonstrated where similar to cutting edge research happening at the time in academia, the capabilities were never merged with the main HEC-1 program. The final variant was the HEC-IFH program for interior flood system simulation. It borrowed heavily from the algorithms and other codes used to make HEC-1, but it was intended for very small watersheds with only two subbasins and a routing reach. It had a very different reservoir component for simulating culverts and pump stations. It also experimented with a rudimentary graphical user interface.

By the end of the 1980's, engineers at HEC had developed an extensive experience with HEC-1. Many application projects had been completed and the value of computer software for hydrologic simulation had been clearly demonstrated. However, HEC-1 and all of its related tools were conceived in the era before the invention of the Personal Computer. They were optimized for running on mainframe and mini computers, in environments where memory was scarce. As such they operated from input and output files and generally speaking had crude graphical user interfaces, if they had interfaces at all. The internal code structures were also difficult to maintain because the memory optimizations often resulted in algorithms that were difficult to read.

HEC-1 had been stunningly successful within the scope of past application projects. However, it did have one important technical limitation; it could only compute hydrographs with up to 2,000 ordinates. This was sufficient for modeling a single storm event in a watershed of moderate size. However, Dr. David Goldman began to envision a replacement to HEC-1 working with much larger watersheds that would require longer hydrographs. Beyond just working in larger watersheds, it was also deemed desirable to begin working with continuous simulation models that could provide for multi-decade simulations. This requirement would demand a fundamental shift in the technology used to build the software, since the original program framework was built with software design approaches originally developed for punch card data entry.

In 1991 a new Research and Development project started at HEC called "NexGen." The sole purpose of the project was to design and develop the Next Generation of HEC software. Several teams were formed, including: hydrologic analysis, river hydraulics, reservoir systems modeling, and flood damage analysis. This research and development project was the beginning of several new pieces of software at HEC, including the Hydrologic Modeling System (HEC-HMS). HEC-HMS was designated to become the primary hydrologic software for HEC and replace HEC-1. The HEC-HMS team conducted a careful study, and then made the decision to move from the FORTRAN language used for HEC-1 to the C++ language. Language features in C++ like dynamic memory allocation would allow for very long hydrographs, and organizing simulation modules as reusable objects would increase flexibility. It was the first project at HEC to use an object-oriented programming language.

The conversion project began by building on the success of HEC-1. Engineers contributing to the project included Art Pabst, Bill Charley, Dick Fong, John Peters, Lisa Pray, Paul Ely, and Tony Slocum. Many algorithms were extracted from the old software and organized as a library. Advances had been made in computer science and numerical analysis since the creation of HEC-1. These advances were used to modernize the algorithms before placing them in the library. The vision for HEC-HMS also included a graphical user interface as a fundamental component of the program. This requirement would mean important changes in the management of model data and simulations. A design template known as "model-view-controller" architecture was selected as the best way to meet the project requirements. This template separates the functions of managing data, from viewing the data and results, from manipulating the data. Separating the three software functions allows one portion of the software to be altered without impacting any of the remaining portions. As such it provides significant capability to "grow" with the software as new features and capabilities are added.

Several years of work were required to build the new HEC-HMS software. Version 1.0 was finally finished and released for general use. It included many of the simulation features from HEC-1 including: precipitation, loss rate, transform, baseflow, channel routing, reservoirs, and diversions. All of the components were designed for simulating individual storm events. However, there was no limit on the number of ordinates in a hydrograph. For the first time with HEC software, it was possible to use very short time intervals, on the order of minutes, and still run a simulation for several days. HEC-HMS was also capable of importing a HEC-1 input file to make it as easy as possible for users to migrate to the next generation software. Finally, a new parameter optimization facility was built that provided significantly more capability and user control than was available previously. A Cooperative Research and Development Agreement (CRADA) was established with ESRI to develop HEC-GeoHMS. The companion tool used a Geographic Information System (GIS) to automatically extract a watershed model from a digital elevation model.

There was a major new capability in the initial release of HEC-HMS that vaulted HEC hydrologic simulation software back to the forefront of hydrologic simulation: ModClark. Dr. Thomas Evans had been working for several years to find a way to use the precipitation radar product from the National Weather Service WSR-88D weather radar systems. It was hoped that the distributed precipitation product would prove useful in real-time operational requirements as well as application studies. The ModClark proved ingenious by utilizing unit hydrograph concepts familiar to many engineers, but expanding them for use with a gridded representation of the watershed. Best called quasi distributed, the ModClark opened the door for the first time to hydrologic simulation with data sources other than precipitation gages. The program was the first widely accessible program to use gridded precipitation.

Work continued on HEC-HMS with the focus shifting to continuous simulation. Technologies were borrowed from the legacy HEC-IFH for interior flood hydrology. The infiltration model included in that program used a single layer to represent water movement in the soil. The algorithm was converted to the "deficit and constant" loss rate method within HEC-HMS. At the same time, graduate student intern Todd Bennett was evaluating other continuous simulation models in use by other agencies and in the academic community. A multi-layer model was developed and also added to HEC-HMS. This new model was called the "soil moisture accounting" loss rate method. The capabilities for continuous simulation were rounded out by adding a monthly average evapotranspiration method. The result of all the work on continuous simulation was Version 2.0. That important release made it possible for HEC-HMS to be used for either event or continuous simulation, depending on the choices made by the user for loss rate method.

Technology in the software development world was moving very fast. The development tools used to create the graphical user interface for HEC-HMS were becoming obsolete. The company that created the tools soon declared bankruptcy. The HEC-HMS development team evaluated a number of options. The decision was made to move the entire program from the C++ language to the Java programming language. Where previously the graphical user interface was created with third-party tools, all of the necessary interface tools were a native part of the Java language. The Java language also provided for operating on a wide variety of computer operating systems, including two used through out the Corps of Engineers. Both languages use the same syntax so the conversion process moved very quickly. Conversion began immediately on the data model, with Lisa Pray, Paul Ely, and William Scharffenberg performing most of the work. Instead of simply replicating the interface in Java, the opportunity was taken to completely redesign the interface to meet modern design guidelines and improve the user experience. The result of the conversion process was Version 3.0.

Initially, the conversion from C++ to Java was envisioned as the only significant change for the Version 3.0 release. However, a decision was made to also add major new capability. A snowmelt module was added to the meteorologic model through the assistance of Dr. Steven Daly from the Corps' Cold Regions Research and Engineering Laboratory. The snowmelt module used a temperature index approach that had been used in the Distributed Snow Process Model (DSPM), which in turn, had taken the algorithm from the Streamflow Synthesis and Reservoir Regulation (SSARR) model. As implemented in HEC-HMS, the algorithm could operate on elevation bands or grid cells. The addition of a snowmelt module rounded out the major components necessary to simulate the entire hydrologic cycle. The reservoir element was also enhanced with the remainder of the functionality necessary to duplicate the capabilities of the HEC-IFH program. A culvert library from the River Analysis System (HEC-RAS) was borrowed to add true culvert flow to the reservoir outlets in HEC-HMS. A pump component was also built. The addition of these features made it possible for HEC-HMS to provide all of the simulation capability in the legacy software family.

Work has continued on HEC-HMS toward

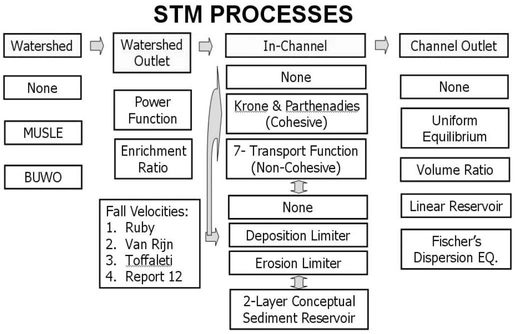

Figure 2. Sediment transport processes.

the next major release, led by Dr. William Scharffenberg and including Dr. Jang Hyuk Pak, Matthew Fleming, and Paul Ely. This release will be called Version 4.0 and is scheduled for early 2010. Several years have been spent on the development of a complete set of sediment and water quality simulation modules. The sediment capabilities begin with two choices for surface erosion and wash off in the subbasin element. A very sophisticated erosion, deposition, and transport capability was added to the reach element as shown in Figure 2. Other modules were added to the reservoir element to simulate settling, and to the diversion element as well. The water quality features will initially focus on nitrogen and phosphorus, from the subbasin, through the reaches, and into the reservoirs. The nutrient fate calculations are performed with the aid of the Nutrient Sub Module (NSM) developed by a team led by Dr. Billy Johnson at the Corps' Environmental Laboratory.

3. Sediment Transport Module

The subbasin element is one of seven hydrologic elements that compose a basin model network in an HEC-HMS model. The subbasin element is used to represent a drainage basin where precipitation falls, infiltration occurs, and surface runoff may result. Outflow from the subbasin element is calculated by subtracting precipitation losses due to interception by the canopy, storage been computed, the excess precipitation is treated as surface runoff and transformed to stream flow at the subbasin outlet, and baseflow is added. Initially, two surface erosion methods were included in the subbasin element: the Modified Universal Soil Loss Equation (MUSLE) and the build-up and wash-off methods. The MUSLE method simulates the sediment yield processes from a pervious land segment and the build-up and wash-off method simulates sediment yield processes from an impervious land segment. Future work will eventually include adding additional erosion methods suitable for both pervious and impervious areas, allowing the engineer to select the best method for a specific watershed study. Before sediment from the land surface is available to the reach element, a sediment enrichment ratio is introduced to determine the relationship between particle size of watershed sediment and fluvial suspended sediments. The enrichment ratio presents a mechanism to translate the sediment distribution from the land surface throughout the basin to a sediment distribution representative to that found at the basin outlet.

The reach element is one of seven hydrologic elements that compose a basin model network in an HEC-HMS model. The reach element is used to convey stream flow downstream in the basin model. Inflow into the reach element can come from one or many upstream hydrologic elements. Outflow from the reach is calculated by accounting for translation and attenuation of the inflow hydrograph. Multiple methods for modeling sediment transport and erosion/deposition within the channel will be added to the reach element. Several sediment transport equations can be used to route sediment through the stream network in HEC-HMS. The sediment continuity equation was used in conjunction with a sorting algorithm to solve for the actual volume of deposition or erosion.

The reservoir element can be used to model a natural lake, man made reservoir, or small detention pond. Inflow into the reservoir elements can come from one or many upstream hydrologic elements. If there is more than one inflow, all inflow is added together before computing the outflow. It is assumed that the water surface in the reservoir pool is level. Three different routing methods are available for the reservoir elements. One routing method simply represents the reservoir using a user-defined storage and discharge relationship. The second method uses a specified release and computes the storage that would result. This method is useful when observed releases are available and can assist in the calibration of model parameters affecting inflow into the reservoir. The final method is designed to represent individual components of the outlet works. In this case, the user would enter an elevation and storage relationship and supply information about the outlets. The sediment routing option for a reservoir element only works for the first method, the user-defined storage and discharge relationship. The user must define elevation-area-discharge curves in order to use the variable trap efficiency method (Chen's Method). With this choice, the program automatically transforms the elevation-area curve into an elevation-storage curve using the conic formula (ref HEC-1 manual). The routing is performed using only the storage-discharge curve. After the routing is complete the program will compute the elevation and surface area for each time step. Based on the calculated discharge, surface area and settling velocity, the trap efficiency is then calculated.

Source elements provide a way to add measurement inflows, including water and sediment to the flow network, or to represent upstream boundary conditions. Junction elements are used in the flow network to combine multiple inflows, often at a confluence. The diversion element is used to represent locations where water is withdrawn from the channel. Finally, sink elements are used to represent the outlet of a watershed.

The new features will make it possible to use HEC-HMS to estimate background and anthropogenic nonpoint source sediment loads that can be used in the TMDL studies for watersheds containing significant nonpoint sources of pollution. An effort was made to ensure that sediment output from HEC–HMS could be easily used as boundary conditions in HEC–RAS for more detailed river mechanics modeling. These new sediment capabilities of HEC–HMS focus on runoff volume, and sediment loading to streams, rivers and lakes. HEC–HMS will be able to model the amount of sediment from pervious and impervious areas in a watershed and route it to the stream. In addition, HEC–HMS utilizes hydraulic parameters calculated based on the fixed channel geometry and one of seven transport capacity equations to solve the sediment continuity equation in the stream for sediment processes. Future versions of the program will include a convenient user interface to specify the necessary data for a sediment analysis and a wide range of available outputs for analyzing results.

4. Conclusions

HEC–HMS now represents over 40 years of HEC experience with hydrologic simulation. It has already been through several major changes in programming language and architecture and the software will continue to evolve to meet the future needs of the Corps of Engineers. For example, continuous simulation studies are becoming more common and requirements to evaluate potential future climate scenarios validate the investments already made in HEC–HMS in this respect. The integration of sediment and water quality simulation capabilities currently underway is expected to be similarly prognostic. One thing is sure, the HEC–HMS program will continue to grow and increase in capability in the future to the benefit of all who use it.