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Status of HEC Next Generation Software Development Project

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This document consists of four papers which were presented at a special session of the American Society of Civil Engineers' **North American Water and Environment Congress,** June 1996, in Anaheim, California. The papers summarize the current status of the U.S. Army Corps of Engineers Hydrologic Engineering Center's (HEC) "Next Generation (NexGen) Software Development Project." The NexGen project is both a change to the modern windows, graphic-user-interface, computer environment and an expansion of technical engineering capabilities. The first paper provides a summary of the entire NexGen project and the other three papers highlight specific developments in the watershed hydrology, river hydraulics, and flood damage software development.

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The HEC NexGen Software Development Project

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Abstract

The NexGen project is developing successor software packages to the existing family of HEC computer programs. Development is occurring via teams comprised of technical specialists, computer scientists, and consultants. Modern software engineering methods are being used and object-oriented program architecture is being employed. Version 1.0 of the River Analysis System (HEC-RAS) was released in August 1995. The Beta version of the Hydrologic Modeling System (HEC-HMS) and Flood Damage Analysis program (HEC-FDA) are targeted for release in winter/spring 1996. This paper describes the evolution and status of the HEC family of programs, the objectives and management approach for NexGen, and findings and status of the project to date.

Introduction

The existing family of HEC programs is the result of 25 years of program development activities. The programs are operational in a batch mode on mainframe and minicomputers. For personal computers, major programs are assembled into packages comprised of one or more applications programs, supporting utilities, and a shell menu system for user interface. The programs include advanced computation and display capabilities. There are 91 programs in the existing family with 21 categorized as major software packages. The structure of the programs and their essential functioning remains batch. The programs are powerful, technical state-the-art software products. They will be supported for the near-term without further modifications.

The engineering applications computing environment has become that of the desktop computer, both high-end personal computers and engineering workstations. The engineer-user expects software that is state-of-the-art in technical capability, highly interactive, supported by high quality graphics, and controlled via a graphical

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user interface. The current HEC programs are not well structured for efficient adaptation to this new environment and the need to continually improve program capabilities dictates that computer code be easy to modify and maintain.

The NexGen project was formulated to respond to these needs; that is develop successor generation software to the present family of HEC programs. The project began in 1990 and the initial phase scheduled for completion in 1995. Another phase has begun.

NexGen Project

Begun in October 1990, the NexGen project is now in the sixth year of work. The first year was devoted to forming project teams, investigating the array of software engineering issues, and documenting the technical requirements of the software packages. Technical teams developed preliminary requirements statements for the areas of hydrologic analysis, river analysis, reservoir analysis, and flood damage analysis. Software support teams developed preliminary concepts for the areas of software architecture and design, graphical user interface, data base support, graphics, and program development environment and standards.

The teams were each headed by a senior HEC engineer and comprised 3 to 5 technical staff. All 28 HEC technical staff served on at least one team. Staff participated in team activities on a part-time basis while continuing to perform their regular duties. The teams developed consensus on their respective assignments, developed plans for their accomplishment, and provided a study report of findings. The teams were encouraged to seek Center-wide participation through seminars and circulation of concept papers. Consultants from outside the Corps with specialized knowledge also participated. Management oversight is provided through a committee comprised of the team leaders and chaired by the director. The oversight committee continues to meet at one- to two month intervals to monitor progress, ensure coordination, and surface for resolution common issues that might impede progress.

Team Findings. The technical teams confirmed the NexGen goal of developing a family of software packages to serve the US Army Corps of Engineers into the next century. The packages would be designed for interactive use as single station programs or in multi-tasking, multi-user network environments. The hydrologic modeling and river analysis software packages were designated for accelerated development with development for reservoir and flood damage analysis delayed until later in the initial phase.

The Software Architecture and Design, User Interface, and Development Environment teams addressed the issues of computation environment, program architecture, coding language relationship to architecture, software engineering related to program design, and computer hardware and software industry standards. The teams concluded that development should target both RISC-chip based engineering workstations running standard AT&T UNIX, and high-end Intel-chip based personal computers running in a Windows environment. Programs would employ a graphical user interface (GUI). In UNIX, the X Window standard using Motif for the GUI would be followed. In MS-DOS and successor systems, Microsoft Windows 3.1, Windows 95, and Windows NT would be the targets. Object-oriented programming using C++ and advanced features of Fortran 90 were recommended. Program architecture consistent with the above was formulated and recommended for testing. The program architecture includes deliberate separation of the GUI, graphics, compute engine, and date base.

The Data Base Support team addressed the issue of providing for the data persistence necessary to support the GUI, graphics, and technical analysis envisioned for NexGen. The team concluded that the HEC-DSS system (USACE, 1995) best meets the time-series and paired-function data management needs. Model-parameter, and geometry data management needs were concluded to be relatively modest compared to the capabilities of commercial systems. Therefore, the need for a commercial data base management system was discounted. The team recommended continued monitoring of data management needs and emerging systems. Spatial and image data management support for NexGen is necessary with the emerging availability of NEXRAD (WSR-88D) spatial precipitation. HEC-DSS was targeted for extension to handle this data, and linkage to commercial GIS systems recommended for managing certain spatial-type data.

The Graphics team addressed the issues of the nature and amount of data to display, types of displays, and approach to incorporate graphics into NexGen. The team concluded that graphics should follow published and de facto industry standards such as X Windows, and be targeted for common display and output devices. The team recommended use of high-level graphics packages rather that custom coding. The team recommended that a commercial package be tested for the UNIX environment and Visual Basic (Microsoft Inc., 1995) be tested for the Windows environment. Graphics is a particularly vexing problem when a commitment is made to platform portability, as in NexGen.

<u>NexGen Activities, Events, Time Line</u>. Two development teams were formed in the second year to work on the hydrologic modeling and river analysis systems, the successors to HEC-1 and HEC-2 (USACE, 1995). Both teams focused on critical software development and technical decision items and development of early stage working prototypes. Their initial efforts carried through the third year with functioning prototypes successfully developed. The teams continue to exist.

The hydrologic modeling team took the lead in implementing object-oriented design and coding and worked in the UNIX operating system environment. UNIX and object-oriented development were both new areas for HEC and thus required substantial commitment change and learning. Until that time, HEC was a seasoned Fortran batch program developer. The river analysis modeling team focused on the DOS Microsoft Windows environment and Fortran 90.

At the end of the third year, we assessed: what we had learned; where we were; and identified critical technical and software development decision items. We learned 1) that developing GUI's and interactive graphics were hard and increased the development effort several fold, 2) that working in UNIX is particularly difficult, and 3) that undertaking object-oriented design and coding is not only difficult, but requires a change in approach to program design and coding. The change needed would amount to a software development cultural change for HEC. We concluded that we could make rapid progress toward a new river hydraulics package in the Microsoft Windows environment but the product would not be platform portable (e.g. would not run on UNIX workstations, etc.). It was also clear that object-oriented program development was desirable but would initially be slower, and staff skills to would need to be enhanced. We also concluded that contrary to our earlier belief, we should adopt a multi-platform development product for GUI development. The Galaxy development system (Visix, 1994) was selected. Portability of interactive graphics continued to be a sticky issue that is believed to now be settled with adoption of a higher-level, multi-platform graphics system.

A decision was made to move forward with the river hydraulics model (now named River Analysis System, HEC-RAS) to complete and field a Beta, then maiden version by the end of 1995. To meet this target, HEC-RAS was to be fielded as a Microsoft Windows application. We decided to continue the HEC-HMS team as the lead in new software development concepts and operating system environments and thus targeted them to field the initial multi-platform product. This decision resulted in HEC-HMS development lagging HEC-RAS by about a year. These decisions resulted in advancing HEC-RAS development to the Beta version by the end of the fourth year (over 200 testers world-wide participated) and fielding of Version 1.0 in the summer of 1995. HEC-HMS development continued on its pioneering path resulting in fielding a multi-platform Beta version in winter/spring 1996.

River Analysis System (HEC-RAS)

When completed, the HEC-RAS software package will include one-dimensional steady-flow, unsteady-flow, and sediment transport capabilities. It will thus be successor to HEC-2, HEC-6, and UNET (USACE, 1995). The program will use common geometry for all analyses, and hydraulic properties will be computed by the same routines. Version 1.0 implements the steady-flow model. Versions to be released later, at one to two year intervals, will include the unsteady-flow and sediment transport components. HEC-RAS computes sub- and supercritical profiles, locating critical depth and hydraulic jumps as appropriate. The analysis for bridges has been improved and hydraulics of junctions added. The program is used through a GUI where data entry, editing, graphics, and computations are performed in an interactive environment. Because many thousands of HEC-2 format data sets exist, and large numbers of flood plains have been delineated with HEC-2, special care has been taken to permit importing existing data sets, and to reconcile HEC-RAS results with profiles computed with HEC-2. A large number of identical data sets have been run with HEC-2 and HEC-RAS to identify when different results might occur and to provide the basis for satisfactory reconciliation.

Technical computations routines are coded in Fortran 90 and the GUI is coded in Visual Basic. HEC-RAS is designed to run as a DOS Microsoft Windows program thus taking advantage of features available for Windows programs. Graphics are performed by calls to the Windows GDI (Microsoft Inc., 1995) so run-time licencing is not an issue. Version 1.0 is available for Intel-chip Personal Computers running Windows 3.1 or Windows 95 plus Intel-chip PC's and RISC-chip engineering workstations running the Windows NT operating system. Multi-platform porting is now underway. The GUI is being re-coded with the Galaxy system using C++ and graphics are likewise being re-coded to make calls to the Galaxy library.

Hydrologic Modeling System (HEC-HMS)

The HEC-HMS program, when completed, will include single event and continuous record analysis capabilities. It will incorporate HEC-1, HEC-1C (continuous), elements of HEC-1F (forecasting), and several other limited scope programs. The several modes of analysis will use common time-series data and basin modeling routines. Version 1.0 will implement a basic continuous simulation capability along with existing single event model capabilities and will have spatial precipitation-runoff analysis capabilities. Subsequent releases will have additional capabilities.

Besides existing HEC-1 capabilities, notable technical additions will include accepting raster-spatial precipitation and associated runoff transform (such capability will be needed for analysis with emerging NEXRAD radar output); and soil moisture accounting for runoff estimation. Significant innovations on the user side include interactive point and click, drag and drop model construction, interactive editing, results visualization and animation, and improved data management.

The model architecture is object-oriented and is coded in C++, technical routines are coded in C++ and Fortran 90, and the GUI is built using the Galaxy multi-platform system. Graphics for the Beta and maiden versions will be developed via a proprietary multi-platform graphics development system. It remains to be seen whether this approach is the long-term solution to portable graphics we are seeking.

Flood Damage Analysis (HEC-FDA) Software

The existing HEC-FDA package is being recast in an object-oriented framework, linked to a generic data base file structure for inventory data, and enhanced to include capability for risk and uncertainty analysis in estimating expected annual damage and project performance. The program is an integrated piece of software rather than separate components that were previously executed separately. The HEC-FDA architecture is object-oriented and is coded in C++, technical routines are coded in C++ and Fortran 90, and the GUI is built using the Galaxy multi-platform system. Graphics for the Beta and maiden versions are being developed with a multi-platform graphics development system. In winter/spring 1996, a Beta version of the package will be released.

Reservoir System Software

Work is also underway on reservoir system software products of the NexGen project. The HEC-PRM prescriptive reservoir system analysis program (USACE, 1995) is now available for test applications within the Corps. The program is a network-flow programming reservoir system optimization model with particular utility in study of reservoir system operation plans. A design and prototype development project is underway that will create a GUI for both HEC-PRM and HEC-5. Both programs make use of similar physical system and operation specification data. Also, design and testing of an object-oriented reservoir simulation module with a focus on real time operations has been initiated.

Conclusions

The NexGen project is developing successor generation software packages for the hydrologic engineering community of the US Army Corps of Engineers. Concepts of object-oriented software design and development offer significant potential benefit in NexGen software development and maintenance. Adherence to published hardware and software standards where available, and de facto standards otherwise, is critical to NexGen program platform portability. Developing prototype hydrologic and river analysis models proved to be essential to surfacing and resolving critical technical and software engineering issues. A structured management approach which employs investigative and development teams proved to be successful. The NexGen project will deliver the promised software products, serving the Corps and the larger water resources community into the next century.

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Hydrologic Modeling System

John Peters and Arlen Feldman[1]

Abstract

The Hydrologic Modeling System (HEC-HMS) is "new-generation" software for precipitation-runoff simulation that will supersede the Hydrologic Engineering Center's HEC-1 program. Technical capabilities and operational features of HEC-HMS are described, with emphasis on technical capabilities that differ from those in HEC-1.

Introduction

The HEC-HMS software provides a variety of options for simulating precipitation-runoff processes. In addition to unit hydrograph and hydrologic routing options similar to those in HEC-1 (HEC, 1990), capabilities currently available include a quasi-distributed runoff transformation that can be applied with gridded (e.g., radar) rainfall data, and a simple "moisture depletion" option that can be used for continuous simulation. The software is designed for interactive use in a multi-tasking, multi-user network environment, and can be used with both X-Windows and Microsoft Windows. HEC-HMS is comprised of a graphical user interface (GUI), integrated hydrologic analysis components, data storage and management capabilities, and graphics and reporting facilities.

Technical Scope

Simulation with HEC-HMS is based on representing a watershed with *hydrologic elements*, types of which are subbasin, routing reach, junction,

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uncontrolled reservoir, diversion, source and sink. Functionality of the elements is as follows.

Subbasin. A subbasin is conceptually an element that produces a discharge hydrograph at its outlet. Its properties include area and percent imperviousness. The discharge hydrograph is based on subtracting "losses" from input precipitation, transforming the resulting rainfall excess to direct runoff at the outlet, and adding baseflow. Computational options for subbasins are also listed in Table 1. If the modClark transform is used (with gridded rainfall), it is necessary to specify characteristics of subbasin grid cells.

River reach. A river reach is conceptually a linear element for which there is a "known" discharge hydrograph at its upstream end, and which produces a discharge hydrograph at its downstream end. Data requirements vary from a single parameter for the simplest routing method to specification of a representative cross section and channel properties for more complex methods. Routing options are listed in Table 1.

Junction. A junction is a location where two or more inflow hydrographs are added together to produce an outflow hydrograph.

Reservoir. A reservoir is similar to a routing reach in that there is a "known" discharge hydrograph that depicts inflow to the reservoir, and the reservoir element produces an outflow hydrograph. In the current version of HEC-HMS, capability exists only for routing through an uncontrolled reservoir, for which there is a monotonically increasing relationship between reservoir storage and outflow.

Diversion. A diversion is an element for which a portion of the inflow to the element is diverted, and the remainder passes through. In the current version of HEC-HMS, the diversion is based on a user-specified relationship between inflow and diverted flow. The diverted flow can be brought back into the basin network at a hydrologic element downstream from the point of diversion.

Source. A source is an element with which a discharge hydrograph is imported into the basin network. The element might be used to retrieve an observed hydrograph, or a hydrograph generated in a prior simulation.

Sink. A sink is an element for which there is an inflow but no outflow.

A watershed is modeled by arranging hydrologic elements in a dendritic network. Computations are performed with a user-specified (constant) time interval. Extended time periods can be modeled with the deficit/constant loss method. It is planned to add soil moisture accounting options in the future which will further support period-of-record type analyses.

Several options are available for defining the precipitation input for a watershed, see Table 1. The options include capability to process "point" data from gages, gridded data such as is obtained from radar, and generalized data associated with frequency-based or Standard Project design storms.

Table 1. HEC-HMS Options

Losses	Routing
initial/constant deficit/constant Green & Ampt SCS Curve No.	lag Muskingum Modified Puls Muskingum Cunge
Transform	Precipitation
modClark kinematic wave Clark Unit Hydrograph Snyder Unit Hydrograph SCS Dimensionless Unit Hydrograph Input Unit Hydrograph	grid-based precipitation average grid-based precipitation import hyetograph specify gage weights inverse distance gage weighting frequency-based design storm Standard Project Storm (eastern U.S.)
Baseflow	
exponential recession	

Program Attributes

A GUI is provided to enable the user to configure a basin model, specify or edit model inputs and view results. Figure 1 shows a window that contains a schematic representation of a basin. Such a representation can be created by "dragging" and connecting icons that represent hydrologic elements. Editors can be accessed for individual elements, or "global" editors can be accessed which enable entering or editing values for parameters of a given type for all associated elements. Upon completion of a simulation, summary tables and graphical displays of results can be accessed from pop-up menus associated with the icons.

HEC-HMS will function on a variety of platforms, including those that utilize Windows 3.1, Windows 95, Windows NT and X-Windows (i.e., UNIX-based workstations). The program is written in C^{++} and utilizes several libraries, some of which contain routines written in Fortran and C (Charley et al., 1995). The software has an interface to HEC-DSS (HEC, 1994) for storage of time series, paired function and gridded data. Input and computations can be in either SI or English units.

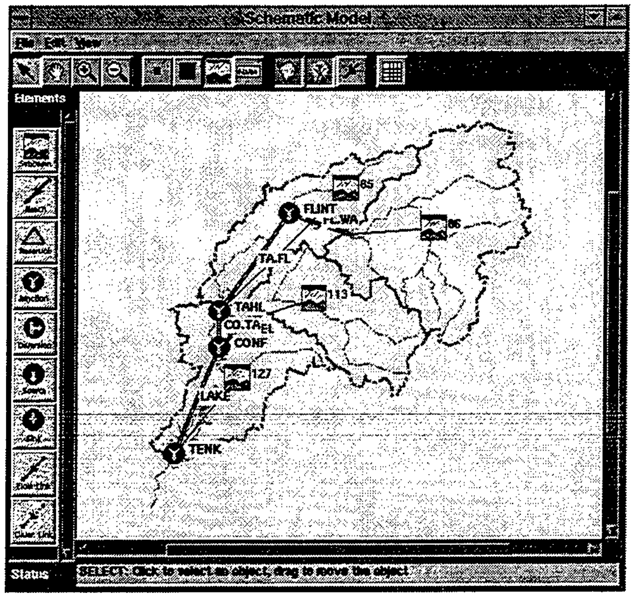

Figure 1. HEC-1 Schematic Model User Interface

<u>Technical Capabilities of HEC-1 and HEC-HMS Compared</u>

As shown in Table 1, many of the precipitation-runoff capabilities of HEC-1 are available in HEC-HMS. Unique to the current version of HEC-HMS are the capabilities to process gridded precipitation data, perform inverse-distance weighting of gage (precipitation) data, simulate runoff on a gridded basis (modClark method), and calculate losses with the deficit/constant method.

HEC-HMS can utilize gridded precipitation data in two ways: (1) the data can be used directly with the modClark method, and (2) the data can be spatially averaged for use as a lumped input. The inverse-distance weighting option is the same as that used in the program PRECIP (HEC, 1989) and requires specification of the locations of gages and subbasin "nodes" in terms of latitude and longitude. An advantage of the option is that if gage data is missing, data from the next nearest gage is automatically utilized.

The modClark method (HEC, 1995a) is based on the Clark conceptual model (Clark, 1945), in which direct runoff is represented by translating precipitation excess to the subbasin outlet, and routing the excess through a linear reservoir. With the modClark method, precipitation and excess are calculated individually for each grid cell (or portion of a grid cell) within a subbasin, and lagged by a cell travel time to the subbasin outlet. The lagged excess for a cell is routed through a linear reservoir. The routed cell contributions are summed, and baseflow is added to produce a total-runoff hydrograph for the subbasin.

To use the modClark method, it is necessary to access a text file that contains identifying coordinates for each grid cell, a travel distance (to the subbasin outlet) for the cell, and the area of the cell within the subbasin. Procedures have been developed to generate the required cell-parameter file using a Geographic Information System (HEC, 1995b). In addition, values for a time of concentration and a storage coefficient for the subbasin are required. The travel time (i.e., lag time) for a cell is obtained by multiplying the subbasin time of concentration by the ratio of the cell's travel length to the travel length for the cell that is farthest from the subbasin outlet.

The deficit/constant loss method is similar to that contained in the Interior Flood Hydrology Package (HEC-IFH) (HEC, 1992). The moisture capacity for a subbasin must be filled for precipitation excess to occur. A moisture deficit is diminished by precipitation, and during precipitation-free periods is increased at a user-specified rate. Input requirements for the method include the moisture capacity (maximum moisture deficit), an initial moisture deficit, and recovery rates which can be specified with daily or mean-monthly values.

The deficit/constant loss method permits simulation over extended time periods. Future versions of HEC-HMS will incorporate soil moisture accounting algorithms that account for evapotranspiration and enable simulation of subsurface contributions to total runoff.

Capabilities of HEC-1 not incorporated in the current version of HEC-HMS include parameter optimization, flood damage analysis and flood control system optimization. It is not planned to add the latter two capabilities to HEC-HMS, as they will be available in other HEC software. However it is planned to incorporate a comprehensive capability for parameter optimization that will provide alternative objective functions, a wide selection of parameters subject to optimization, and graphical displays to aid in interpretation of results.

Also not incorporated in the present version of HEC-HMS are capabilities to model snow accumulation and melt. HEC-1 has both energy budget and degree-day options for snow simulation. Alternatives of snow modeling for HEC-HMS are presently under consideration.

For flood control planning and design studies, a common hydrologic requirement is a set of discharge-frequency relationships for existing and alternative future conditions. For some applications, discharge-frequency relationships based on statistical analyses of discharge records are available. Such relationships, when used in conjunction with design (frequency-based) storms, provide a basis for determining the effects of land use changes and projects on discharge-frequency relationships. Capabilities that facilitate such applications will be incorporated in HEC-HMS.

Concluding Comments

HEC-HMS is designed with object-oriented concepts to provide a foundation for future development and expansion. The program is totally interactive; the GUI is not a preprocessor and postprocessor for a "batch" type program. However the GUI and computational "engine" are essentially independent, which would facilitate the utilization of an alternative GUI in the future, should this be desirable. Interfaces to data bases other than HEC-DSS are envisioned.

Although the GUI provides a convenient means for entering data and viewing results, the use of a GUI can be tedious when it is desired to execute a series of model applications with alternative sets of parameters. Also it may be desirable to execute HEC-HMS as part of a modeling process in which HEC-HMS is only a contributing component. For these reasons, a scripting capability is planned which will enable the user to define macro scripts that can be invoked for application of HEC-HMS without accessing the GUI.

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HEC-RAS (River Analysis System)

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Abstract

HEC-RAS (River Analysis System) is an integrated system of software, designed for interactive use in a multi-tasking environment. The system is comprised of a graphical user interface (GUI), separate hydraulic analysis components, data storage and management capabilities, graphical and tabular output, and reporting facilities. HEC-RAS (HEC, 1996) is the successor to the current steady-flow HEC-2 (HEC, 1991) Water Surface Profiles Program. The capabilities of the current version of HEC-RAS will be described.

Introduction

HEC-RAS is designed to perform one-dimensional hydraulic calculations for a full network of natural and constructed channels. The HEC-RAS system will ultimately be able to perform one-dimensional steady flow, unsteady flow, and sediment transport calculations. The current version of the software supports steady flow water surface profile calculations. The basic computational procedure is based on the solution of the one-dimensional energy equation. Energy losses are evaluated by friction (Manning's equation) and contraction/expansion (coefficient multiplied by the change in velocity head). The momentum equation is utilized in situations where the water surface profile is rapidly varied. These situations include mixed flow regime calculations (i.e. hydraulic jumps), hydraulics of bridges, and evaluating profiles at river confluences (stream junctions).

Graphical User Interface - Overview

The HEC-RAS system of software uses a Graphical User Interface (GUI) for file management, data entry and editing, hydraulic analyses, tabulation and graphical displays of input and output data, reporting facilities, and on-line help. The main focus in the design of the GUI was to make is easy to use the software, while still maintaining a high level of efficiency for the user.

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When using HEC-RAS to perform a steady flow analysis, there are five main steps in developing the hydraulic model: 1. Create a project file; 2. Develop the river system schematic and enter the geometric data; 3. Enter the flow data and define the boundary conditions; 4. Perform the hydraulic analysis; and 5. Review the results and produce a report.

A **Project File** is the top level file in a set of files that make up the data for a particular river system. The project file contains the title of the project, a list of all the files contained in the project, and a reference to the last plan that the user was working with. **Plans** are developed as combinations of geometry, flow data and boundary conditions, and run specifications. All input and output data are linked to a specific plan through the simulation manager.

Entering Geometric Data

Geometric Data are saved separately and consist of: the river system schematic; cross section information; hydraulic structures data (bridges, culverts, weirs, and spillways); and modeling approach information. The river system schematic is defined by drawing, with a mouse, a schematic of the river reaches as shown in Figure 1. Each reach is identified with a unique name. As reaches are connected, junctions are automatically formed.

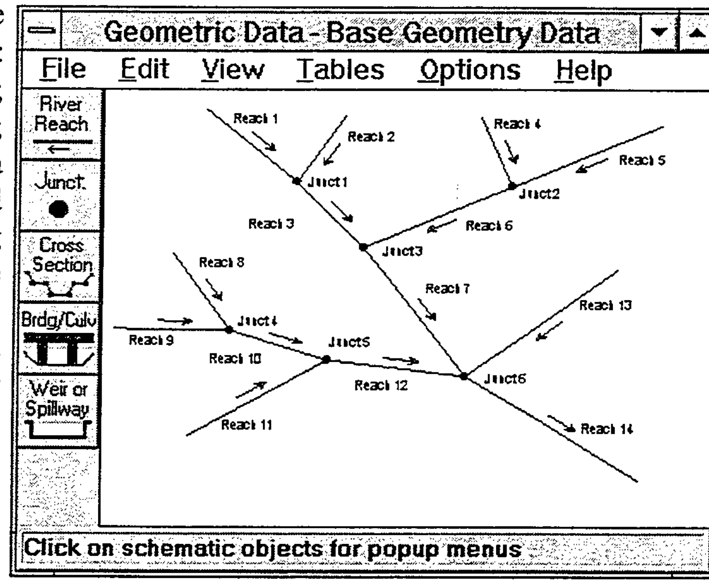

Figure 1. Geometric Data Window.

Junctions appear where reaches are combined or split apart. Each junction is given a separate identifier. The user can choose to compute the water surface profile through a junction with either an energy or momentum-based solution technique.

Cross Sections are located by specifying a reach name and entering a river station identifier. River station identifiers are used to order the cross sections within a reach, assuming highest river stations are upstream and lowest are downstream. The required information for each cross section includes: station-elevation coordinates; downstream reach lengths; Manning's n values; location of main channel bank stations; and contraction and expansion coefficients. Optional cross section properties include: ineffective flow areas; levees; blocked obstructions; and horizontal variation of n-values. Cross sections can be easily added or modified in any order. Options are available for cut, copy, and pasting of information. Geometric cross-section interpolation routines are available for supplementing surveyed data.

Hydraulic structures data can be entered for bridges, culverts, weirs, gated spillways, and multiple openings. Each hydraulic structure is identified by a reach and river station location. Separate data editors are available to enter the geometric information and the required coefficients. A graphic of the hydraulic structure gives the user direct feedback as to the accuracy and consistency of the information as it is entered.

Steady Flow Data

Steady flow data consist of the number of profiles to be computed, the peak flow data (at least one flow for every river reach, per profile), and any required boundary conditions. Boundary conditions are defined at the downstream or upstream ends of the river system, depending upon the flow regime. The user has the choice of four boundary condition types: known water surface elevation; rating curve; normal depth; or critical depth. Steady flow data options include: specifying a change in energy between two cross sections; specifying a change in water surface between two cross sections; inserting a known water surface at any cross section; and adding an additional energy loss to be included in the energy balance.

Steady Flow Water Surface Profile Calculations

Once the geometric data and steady flow data have been entered, the user can begin calculating the steady flow water surface profiles. The first step in performing the analysis is to put together a Plan. The Plan defines which geometry and flow data are to be used, as well as providing a description of the run. The user must select a flow regime for the computations (subcritical, supercritical, or mixed flow regime). Options are available for: controlling output; setting calculation tolerances; selecting computation modes for conveyance calculations, friction slope averaging, and critical depth calculations; and checking data for consistency and completeness before execution.

Viewing Output

After the steady flow water surface profile computations are performed, the user can begin to view the output. Output is available in a graphical and tabular format. All output can be sent directly to the default printer, or it can be passed through the Windows Clipboard to another program (e.g. a word processor).

Tabular output is available in two forms, detailed tables that contain many hydraulic variables for a single location and a single profile, or profile tables that show a few hydraulic variables for many locations and profiles simultaneously. Detailed tables are available for: cross sections, bridges, culverts, weirs and spillways. A flow distribution table can also be requested for any cross section. There are several standard types of profile tables available to the user. Additionally, the user can create their own output tables by selecting variables from a list of over 170 variables computed at each cross section. User defined table headings can be stored and later recalled.

Graphical displays consist of: cross section plots; profiles; rating curves; a pseudo 3D multiple cross section plot; plotting one computed variable against another (e.g. discharge versus flow area); plotting computed variables in profile (e.g. velocity versus distance along the channel); and a velocity distribution plot for a cross section. User control is provided for: zooming in and out; which plans and profiles to plot; which variables to plot; labels; legend; lines and symbols; scaling; and overlaying a grid. An example graphic of the 3D multiple cross section plot is shown in Figure 2.

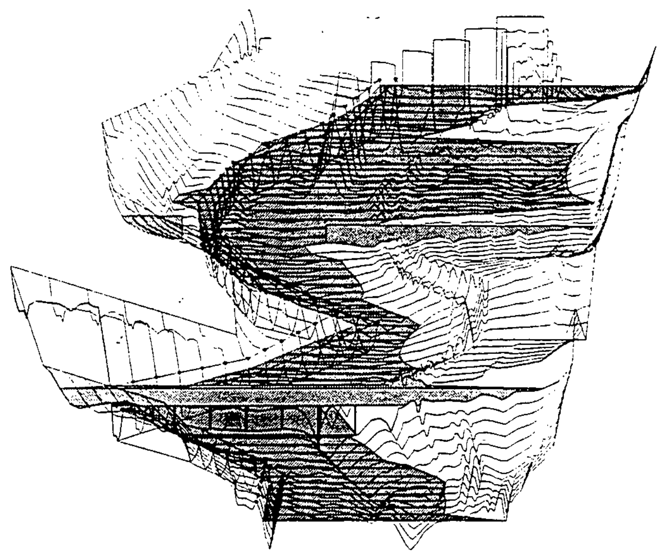

Figure 2. 3D Plot of Multiple Cross Sections

Reports of input and output data can be generated and written to a text file. The user has complete control over which input and output data will be included in the report.

Hydraulic Computation Features

The computational portion of HEC-RAS is a separate program that is controlled by the user interface. The steady flow module performs water surface profile calculations by solving the one-dimensional energy equation. The software can be used for a single reach, a dendritic river system, or a fully looped network. The following is a list of the major technical capabilities that have been included in the steady flow simulation module:

Flow Regime. The HEC-RAS software is capable of performing water surface profile calculations in either a subcritical, supercritical, or mixed flow regime mode.

Bridge Routines. The bridge routines in HEC-RAS give the user various options for modeling a bridge. The software is capable of handling all three types of low flow through the bridge: subcritical flow throughout (class A low flow); flow passes through critical depth inside the bridge (class B low flow); and supercritical flow throughout (class C low flow). For class A low flow, the user can choose any of four methods for computing the water surface profile: an energy based method, a momentum based method, Yarnell's equation, or the WSPRO (FHWA, 1990) method. For class B low flow, the program automatically uses the momentum based method. For class C low flow, the user can choose between the energy based method and the momentum based method. High flows (flows that come into contact with the maximum low chord of the bridge deck) can be modeled by either an energy based method or by using a separate set of hydraulic equations for pressure and/or weir flow. Pressure flow equations are available for submerged inlet only, and also for fully submerged inlet and outlet. Weir flow computations automatically account for submergence on the weir.

Culvert Routines. The culvert routines in HEC-RAS have the ability to model single culverts; multiple identical culverts; or multiple non-identical culverts. Available culvert shapes include: box (rectangular); circular pipe; arch; low profile arch; high profile arch; pipe arch; elliptical (vertical or horizontal ellipse); and semi-circle. The program has the ability to model up to ten different culvert types simultaneously at any one location. Each culvert type can have up to 25 identical barrels.

Multiple Openings. HEC-RAS has the ability to model openings at a single location. Three types of openings can be modeled: bridges; culvert groups (a group of culverts is considered to be a single opening); and conveyance areas (an area where water will flow as a separate open channel, other than a bridge or culvert). The program can handle up to seven openings at any one river crossing.

Inline Weirs and Gated Spillways. A new feature in HEC-RAS (version 1.5) is the ability to model inline weirs and gated spillways. Weirs and gated spillways can be modeled separately or in combination. Up to ten different gates can be entered at any one location. Each gate can have up to 25 identical openings, which allows for a total of 250 gate openings. The user can vary the gate opening and number of gates that are opened for each profile.

Flow Distribution Calculations. Additional output showing the distribution of flow in the left and right overbanks, as well as the main channel, can be requested by the user. Each cross section can be subdivided up to 45 total slices. The output for each slice includes; percent of flow; flow area; wetted perimeter; conveyance; hydraulic depth; and average velocity.

Floodplain Encroachment Analysis. HEC-RAS has the ability to evaluate the impact of floodplain encroachments on the water surface profile. Five encroachment methods are available for performing the floodway analysis: Method 1 - user enters right and left encroachment station; Method 2 - user enters a fixed topwidth; Method 3 - user specifies a percent reduction in conveyance; Method 4 - User specifies a target water surface; Method 5 - User specifies a target water surface and maximum change in energy. Encroachment data are entered in a tabular format. Encroachment results are available in both tabular and graphical forms.

Scour at Bridge. The bridge scour equations as outlined in HEC No. 18 (FHWA, 1996) have been added to HEC-RAS as a separate set of hydraulic design functions. Once the water surface profiles have been calculated, bridge scour can be calculated at any or all of the bridges for each of the profiles. Scour computations include contraction scour, pier scour, and abutment scour.

Channel Modification Analysis. This feature allows the user to easily incorporate channel modifications to the natural stream geometry. Channel modifications are incorporated through the use of trapezoidal excavation and fill options. Users have the ability to specify up to three trapezoidal cuts. Each cut can be specified at a different elevation with varying side slopes. Channel modifications can be specified to run at a constant slope over a wide range of cross sections. The modified channel geometry is saved as a separate set of geometric data and a sperate plan. Once profiles are computed for all of the plans, the results can be viewed in both a graphical and tabular format.

Concluding Remarks

HEC-RAS has been developed to function in Windows 3.1 (or 3.11), Windows 95, and Windows NT. Future versions of the software will also run on UNIX based workstations. Interfacing with GIS systems is currently under development. The GIS interface will allow users to cut cross section data from a digital terrain model and export it to HEC-RAS. Results from HEC-RAS will be able to be exported back to the GIS to facilitate the creation of flood inundation maps.

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Next Generation Flood Damage Analysis Program

Michael W. Burnham[1]

Abstract

The Hydrologic Engineering Center (HEC) has developed a next generation Flood Damage Analysis computer program for formulating and evaluating flood damage reduction plans. The program design is consistent with federal and Corps of Engineers policy and technical requirements. It includes risk-based analysis procedures. The program operates on Windows NT and 95, and Unix-based Motif platforms.

Introduction

The Corps of Engineers requires use of risk-based analysis procedures for formulating and evaluating flood damage reduction measures (USACE, 1994). Procedures developed are now applied to ongoing Corps studies. They quantify uncertainty in discharge-frequency, stage-discharge, stage-damage functions and incorporate it into economic and performance analyses of alternatives. The process applies Monte Carlo simulation (Benjamin et al., 1970.), a numerical-analysis procedure that computes the expected value of damage while explicitly accounting for the uncertainty in the basic functions. The Hydrologic Engineering Center (HEC) has developed a next generation Flood Damage Analysis (FDA) computer program to assist in analyzing flood damage reduction plans using these procedures.

Program Overview

The HEC-FDA program is designed to expedite the Corps plan formulation and evaluation technical analysis for flood damage reduction studies. It includes risk-based analysis methodologies. HEC-FDA operates on multiple Windows NT and 95, and Unix-based Motif platforms. The program has a modern user interface, enhanced

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calculations, and graphical outputs consistent with federal and Corps of Engineers policy and technical regulations and requirements.

HEC-FDA streamlines the plan formulation and evaluation process following functional elements of a study involving coordinated study layout, hydrologic engineering analysis, economic analysis, and plan formulation and evaluation. The program is used continuously throughout the planning process as the study evolves from the base without-project conditions analysis through the analysis of alternative plans for reducing flood damage. Plans are evaluated as the expected annual damage associated with a given analysis year or the equivalent annual damage over the project life of the plan. Information on the flood risk performance is also included in the results. Output includes tables and selected graphics of information by plan, analysis year, stream, and damage reach for the plan. Results of the various plans may also be compared.

Setup and Study Layout

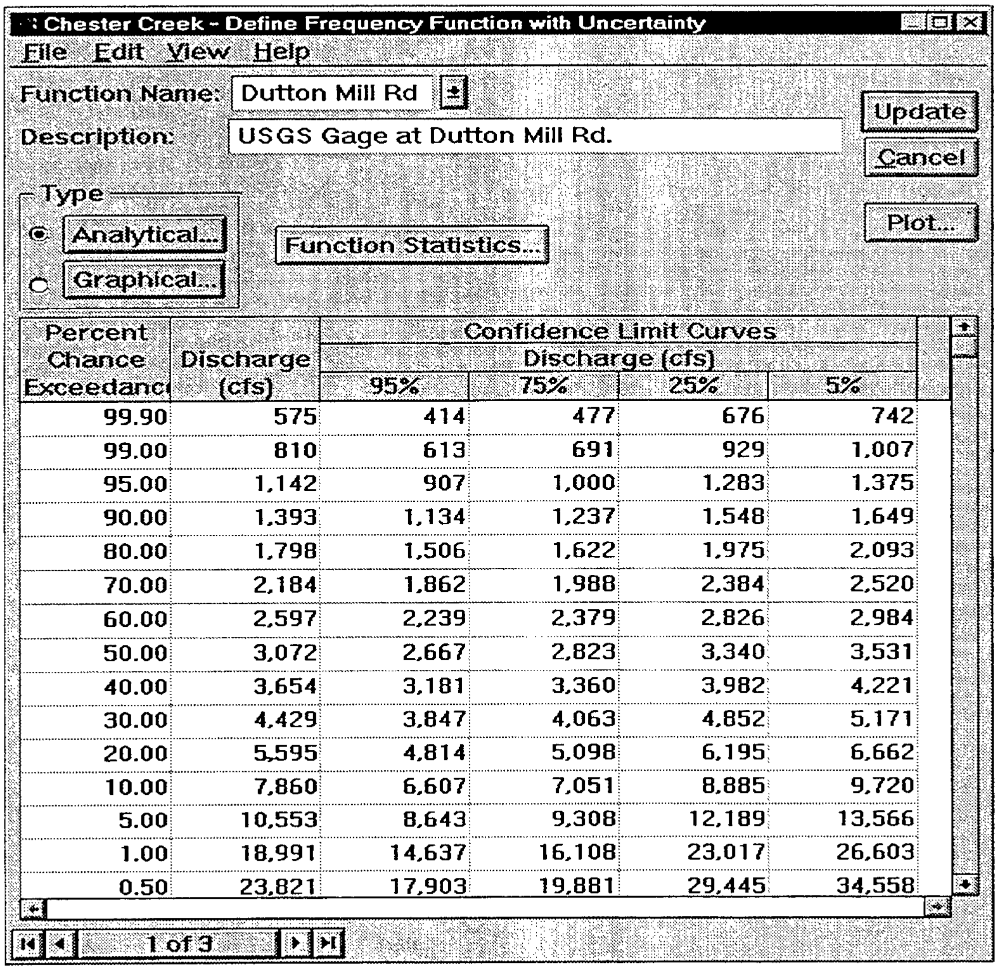
Getting Started. The HEC-FDA program application requires coordinated effort from the various elements involved in the study. The study configuration, hydrologic engineering, and economic analysis information for the study are developed and specified. All study information is stored under a study directory.

Study Configuration. Study Configuration is where information in common with all elements are defined. Once defined, most of the data remains constant throughout the progression of the study. The study streams, damage reaches, plans, analysis years, price indexes, and monetary and computational units are defined under Configuration. The study information is referenced so that water surface profile stationing, damage reach definition, and structure locations are consistent with stream stationing.

Hydrologic Engineering

Water Surface Profiles. Water surface profiles are required to aggregate stage-damage-uncertainty functions at damage reach index locations. They are also used in development of the stage-discharge functions. The profile data are normally imported from stream hydraulics programs such as the HEC River Analysis System package (HEC-RAS). The data may also be entered manually. The HEC-FDA program requires specific water surface profiles for the 50-, 20-, 10-, 4-, 2-, 1-, .50-, and .20- percent chance exceedance frequency flood events.

Frequency Functions. Discharge-frequency derivations depend on data availability. For gaged locations and where analytical methods are applicable, HEC-FDA uses procedures defined by the Interagency Advisory Committee on Water Data (1982). Uncertainties for discrete probabilities are computed using the non-central T distribution. For ungaged locations, the cumulative discharge-frequency is adopted from applying a variety of approaches (Water Resources Council, 1981). The adopted function statistics are then computed similar to gaged locations. The equivalent record length is specified based on the perceived reliability of the information. Regulated discharge-frequency, stage-frequency, and other non-analytical or graphical frequency functions require different methods. An approach referred to as order statistics (Morgan et al., 1990) is used to compute the cumulative frequency and uncertainty relationships for these situations. Figure 1 shows an example frequency screen of HEC-FDA with tabulated results.



Percent Chance Exceedanc	Discharge (cfs)	Confidence Limit Curves Discharge (cfs)			
		95%	75%	25%	5%
99.90	575	414	477	676	742
99.00	810	613	691	929	1,007
95.00	1,142	907	1,000	1,283	1,375
90.00	1,393	1,134	1,237	1,548	1,649
80.00	1,798	1,506	1,622	1,975	2,093
70.00	2,184	1,862	1,988	2,384	2,520
60.00	2,597	2,239	2,379	2,826	2,984
50.00	3,072	2,667	2,823	3,340	3,531
40.00	3,654	3,181	3,360	3,982	4,221
30.00	4,429	3,847	4,063	4,852	5,171
20.00	5,595	4,814	5,098	6,195	6,662
10.00	7,860	6,607	7,051	8,885	9,720
5.00	10,553	8,643	9,308	12,189	13,566
1.00	18,991	14,637	16,108	23,017	26,603
0.50	23,821	17,903	19,881	29,445	34,558

Figure 1. HEC-FDA Frequency Function Screen

Stage-discharge Functions. Stage-discharge or rating functions are defined by observed data or computed water surface profiles. The relationships and uncertainty are entered directly into HEC-FDA for both types. Probability density functions of errors may be normal, log normal, triangular, or uniform. For observations, uncertainty is calculated from deviates of the best fit cumulative rating function. Computed profiles are required for ungaged locations and modified conditions. For these, the corresponding water surface profile data set provides eight discharge-stage ordinate values plus the invert for zero discharge as initial definition of the rating at the damage reach index station locations. Additional points may be added to define the function.

Economics

General. Economic analysis aggregates stage-damage-uncertainty functions by damage category, damage reach, stream, plan and analysis year using the structure inventory data and water surface profiles. These functions are used in the plan evaluation.

Damage Categories. Damage categories are used to consolidate large number of structures into specific groups of similar characteristics for analysis and reporting.

Depth-Damage Functions. Depth-damage functions define the percent of the structure damage for a range of flood stages at a structure. The percent-damage is multiplied by the structure value to get a unique depth-damage function at the structure. The zero depth is assume to coincide with stage (elevation) of the first floor. The depth-percent damage functions input directly or imported from external files.

Structure Inventories. Inventories of floodplain structures are performed to develop structure attribute information on unique or groups of structures relevant to flood damage analysis. The information is entered and stored in HEC-FDA for subsequent calculations to produce stage-damage-uncertainty information at the damage reach index locations. Structure attributes include: location address, stream station and/or coordinates; reference stages; damage category and depth-percent damage function assignments; structure and content values, and uncertainty parameters. The data may also be imported from external files.

Nonstructural. HEC-FDA performs several nonstructural measure options. These options modify the stage-damage functions at each structure and therefore, the aggregated stage-damage function at the index location used for analysis. The options are specified by damage categories and by base or future years. They include: raising all structures prior to and inclusive of the base year; raising all future structures after the base year; flood proofing all structures prior to and inclusive of the base year; flood proofing future structures after the base year; and relocating all structures prior to and inclusive of the base year.

Stage-damage Functions. Stage-damage-uncertainty functions are required for each damage category, damage-reach, plan and analysis year. They may be entered directly or computed based on the structure inventory attributes and specifications and associated water surface profiles.

Evaluation

Evaluation is where HEC-FDA performs computations for specified plans and output results are available for viewing. The analyses are performed using Monte Carlo simulation to numerically integrate the large number of possible combinations of damage-frequency functions associated with defined uncertainties in the frequency, stage and damage functions. Information on the flood risk performance and expected annual damage is included in the results. Output includes tables and selected graphics of information by plan, analysis year, stream, and damage reach for the entire plan. Plan comparisons may also be performed. An example output for an analysis of several alternative levee plans for a damage reach is shown in Table 1. Output for plan performance associated with the various levee sizes is shown in Table 2.

Table 1
Expected Annual Damage by Plan

Plan Name	Plan Description	Expected Annual Damage ($1000)		
		Without Project	With Project	Damage Reduced
Without	Without Project	78.3	--	--
Plan 1	16.5' Levee	78.3	72.9	5.4
Plan 2	19.1' Levee	78.3	63.1	15.2
Plan 3	21.9' Levee	78.3	49.1	29.2
Plan 4	23.0' Levee	78.3	43.1	35.2
Plan 5	24.0' Levee	78.3	30.2	48.1
Plan 6	25.5' Levee	78.3	26.6	51.7
Plan 7	26.0' Levee	78.3	23.1	55.2
Plan 8	27.0' Levee	78.3	17.4	60.9

Conclusions

The HEC-FDA program provides comprehensive state-of-the-art analysis capabilities for formulating and evaluating flood damage reduction that includes risk-based analysis procedures. The program has a modern user plans interface and operates on multiple platforms. Computational procedures and output reports are consistent with federal and Corps of Engineers policy and technical element regulations. Version 1.0 release is scheduled for early summer of 1996. The release will include a user's manual.

Table 2
Plan Performance

Plan Name	Plan Description	Target Stage	Expected Annual Stage Exceedance Probability	Long-term Risk in Percent for Indicated Years			Conditional Annual Percent Chance Non-Exceedance for Indicated Events		
				10	25	50	4%	1%	.2%
Without	Without Project	15.1	0.059	46.0	78.5	95.4	16.9	0.0	0.0
Plan 1	16.5' Levee	16.5	0.043	35.5	66.6	88.9	49.1	0.3	0.0
Plan 2	19.1' Levee	19.1	0.023	20.5	43.6	68.2	92.7	9.5	0.0
Plan 3	21.9' Levee	21.9	0.012	11.4	26.2	45.5	99.5	48.8	0.5
Plan 4	23.0' Levee	23.0	0.010	9.2	21.4	38.2	99.8	64.4	1.6
Plan 5	24.0' Levee	24.0	0.008	5.6	13.5	25.1	100.0	87.0	12.9
Plan 6	25.5' Levee	25.5	0.005	4.8	11.6	21.9	100.0	91.1	19.0
Plan 7	26.0' Levee	26.0	0.0045	4.1	9.9	18.7	100.0	94.1	26.8
Plan 8	27.0' Levee	27.0	0.0029	2.8	6.9	13.3	100.0	97.7	45.6

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13. ABSTRACT *(Maximum 200 words)*
This document consists of four papers which were presented at a special session of the American Society of Civil Engineers' North American Water and Environment Congress, June 1996, in Anaheim, California. The papers summarize the current status of the U.S. Army Corps of Engineers Hydrologic Engineering Center's (HEC) "Next Generation (NexGen) Software Development Project." The NexGen project is both a change to the modern windows, graphic-user-interface, computer environment and an expansion of technical engineering capabilities. The first paper provides a summary of the entire NexGen project and the other three papers highlight specific developments in the watershed hydrology, river hydraulics, and flood damage software development.

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