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US Army Corps of Engineers
Institute for Water Resources
Hydrologic Engineering Center
609 Second Street
Davis, CA 95616

(530) 756-1104
(530) 756-8250 FAX
www.hec.usace.army.mil

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The Hydrologic Modeling System (HEC-HMS): Design and Development Issues

William Charley, Art Pabst and John Peters[1]

Abstract

The Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) is a software package for precipitation-runoff simulation. Software development and architecture issues associated with development of HEC-HMS are described. The software's object-oriented structure and the role of its graphical user interface are presented.

Introduction

The Hydrologic Engineering Center (HEC) of the US Army Corps of Engineers develops software for application in the disciplines of hydrologic and hydraulic engineering, and water resource planning. A project named NexGen is underway to develop "next-generation" software to replace current, widely-used software such as HEC-1 (for precipitation-runoff simulation) and HEC-2 (for steady-flow water surface profile computations).

The HEC-HMS, which will replace HEC-1, is intended for precipitation-runoff simulation using observed or hypothetical (design) precipitation. The user can select from a variety of technical options for each of the major computational elements: precipitation specification, loss estimation, excess-to-runoff transformation, and hydrologic routing. The program can be used to simulate runoff from complex subdivided watersheds, and can utilize distributed rainfall, which is now available from a new generation of weather radars. A basin "schematic" capability enables the user to configure the hydrologic elements of a watershed (such as subbasins, routing reaches, reservoirs, diversions) graphically, and to access editors and simulation results from schematic components. Requirements for the HEC-HMS include the following:

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[1]Respectively, Hydraulic Engineer; Chief, Technical Assistance Division; and Senior Hydraulic Engineer; Hydrologic Engineering Center, 609 Second St., Davis, CA 95616-4687

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- o state-of-the-art engineering algorithms
- o comprehensive Graphical User Interface (GUI)
- o substantial use of graphics
- o operational in native X-window and Microsoft Windows environments
- o substantial use and manipulation of time series data
- o inter-program data exchange
- o an interface to Geographic Information Systems
- o use of existing computational algorithms written in FORTRAN
- o extensible and easy to maintain
- o distribution of the software unrestricted, with no run-time license fees

Languages, Toolkits and Libraries

Historically, HEC software was developed in FORTRAN, primarily by engineers. Development environments followed the typical progression of mainframe to mini-computer to personal computer and workstations. In preparation for NexGen software development, the "world" of windowing environments, event programming, GUI's, the C language, and finally, object oriented programming with C++ were explored. Prototype applications were developed. Initial skepticism with object-oriented programming turned into significant support for this technology; HEC-HMS is being developed with object oriented techniques.

To facilitate GUI development and porting to the requisite platforms, a commercial multi-platform toolkit was acquired. Although adoption of such a toolkit adds significantly to an already steep learning curve, the effort to develop and maintain separate platform-specific versions of source code is avoided. Some graphics are being developed with relatively low-level calls to routines in the multi-platform toolkit. A commercial graphics library was acquired to facilitate development of time series graphics. Versions of the graphics library are available for the various target platforms.

A specialized management system designed for efficient handling of time series data has been under progressive development since 1979. The Data Storage System (HEC-DSS) makes use of a library of routines that have capability to read and write variable-length, named records in a direct access file. Storage and retrieval of time series data is accomplished with blocks of data of pre-specified size based on the interval of the data. To facilitate use of HEC-DSS in object-oriented applications, a set of time series manager classes were developed that utilize the HEC-DSS library.

Existing HEC software contain a base of well documented and tested FORTRAN algorithms for performing hydrologic computations. The algorithms will be useful in the new software and have been incorporated into a library labeled *libHydro*. Thus, development of HEC-HMS draws on mixed languages (C++, C and FORTRAN), and utilizes a variety of libraries.

HEC-HMS Architecture

Figure 1 illustrates the internal architecture of HEC-HMS. Although linked into a single executable, there is a clear separation between the GUI and the simulation engine, where all computations are managed and performed. This permits independent development of the GUI and the engine, and facilitates the utilization of an alternative GUI in the future, should this become desirable. The GUI has access to objects within the engine through public interfaces. There are no references to the GUI from the engine, except for calls to a generic error message dialog box. The user interacts with the GUI through the windowing system, whether that is on an X device connected to a UNIX workstation, or Microsoft Windows on a PC.

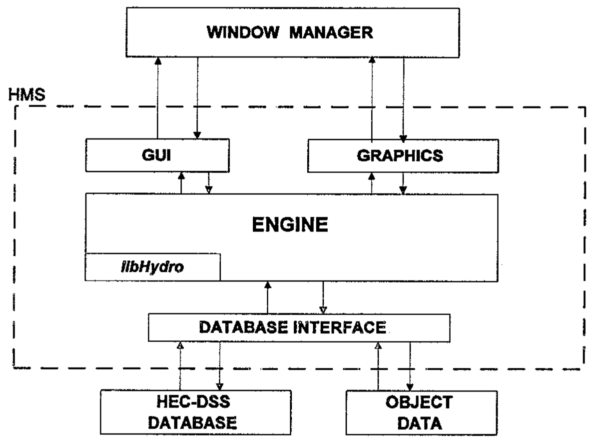

Figure 1 Software Architecture

For similar reasons, clear separations are maintained between the simulation engine and the graphics module, and the engine and the database interface module. The engine uses objects that interface to the database, and objects that perform graphics, but these objects could easily be modified to access a different database system or graphics package.

Currently, time series and similar data are stored using HEC-DSS, while persistent object data, such as parameters and coefficients, are stored in ASCII text files. The HEC-DSS provides a convenient and efficient way of entering, storing, retrieving and displaying series type data. ASCII text files provide a convenient means for testing the simulation engine independent of the GUI. It is anticipated that the text files may be replaced by a database in the future.

The engine is comprised of three major components: the project manager, the precipitation analysis model, and the basin runoff model. The project manager handles the control of the simulation time window, the utilization of precipitation and basin runoff models, file names, and various other management tasks. The precipitation analysis model computes subbasin average precipitation from either historical gaged data or from design storms that are frequency-based or that utilize Standard Project Storm criteria. The basin runoff model uses this precipitation to compute subbasin discharge hydrographs, which can be routed through river reaches or reservoirs, and diverted or combined with other hydrographs.

Figure 2 illustrates use of objects in HEC-HMS. The BasinManager object creates, manages and destroys the various HydrologicElement objects that comprise the simulated watershed. When a compute is requested by the user, the BasinManager finds the hydrologic object which is acting as the outlet (all links, except for diversions, eventually point to this object), then sends it a message to compute. Because the outlet object requires hydrographs from objects above it for its computation, it requests objects upstream of itself to compute, which in turn request hydrographs from their upstream links. Thus, the request is propagated to all hydrologic objects that constitute the watershed.

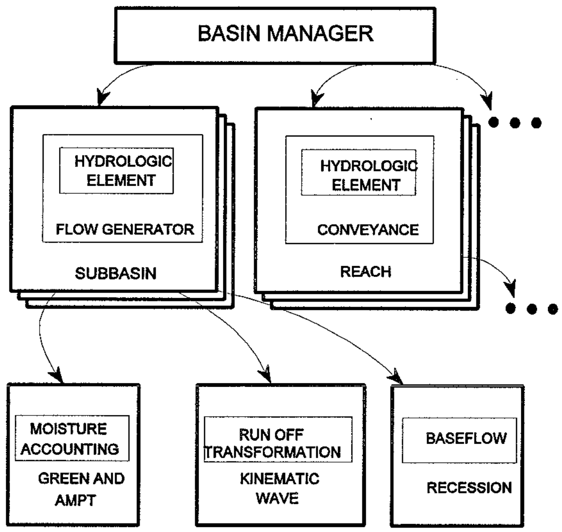

Figure 2 HEC-HMS Objects

Hydrologic classes inherit from a fundamental base class titled HydrologicElement. Data members of this class contain information pertinent to all element types, such as name, description, type, etc. The classes Conveyance, FlowGenerator, Node, and SinkBase each inherit from the HydrologicElement base class to provide certain types of connectivity functions. For example, the Conveyance class allows a link to one upstream object (from which to retrieve an inflow hydrograph), and one downstream object. The FlowGenerator class does not allow links to an upstream object; it can only link to downstream objects. Member functions of these classes provide a variety of capabilities, such as establishing and deleting links to other objects, and determining the cumulative basin area. The primary hydrologic classes, which inherit from these intermediate classes, are Reach and Reservoir (from Conveyance), Source and Subbasin (from FlowGenerator), Diversion and Junction (from Node), and Sink (from SinkBase). The data members of a derived class include data associated with its base class as well as data defined directly within the derived class.

Member functions of these classes provide the capability of setting and accessing data parameters, computing discharge hydrographs, and performing other desired object behaviors.

The primary hydrologic objects generally use "process" objects to implement the different computational methods. For example, Subbasin objects instantiate objects from a moisture accounting class, a runoff transform class, and a baseflow class. The object instantiated depends on the hydrologic method used. A GreenAmpt object or a InitialConstant object might be instantiated for moisture accounting, depending on the method selected by the user. A Snyder object, or Clark object, or Kinematic Wave object might be instantiated for the runoff transform. A process object has as data members the unique parameter data required for the particular method, and a member function to compute (e.g., compute excess given the precipitation). In many cases the "compute" member functions call routines from libHydro to perform the actual computation.

Each process class inherits from a base class for the process group that contains capabilities common to all the method classes within that group. For example, the moisture accounting base class defines time series objects to retrieve the subbasin precipitation and store the computed excess precipitation that are needed by all derived classes. Likewise the runoff transform base class defines time series objects that obtain the excess precipitation and store the computed hydrograph for all types of derived transform classes.

The TimeSeries class inherits from the DataManager class, which accesses the HEC-DSS database software. DataManager contains several "static" member functions, one of which points to buffers of data retrieved and stored. When an object retrieves (or stores) a set of data that is already in a memory buffer, no actual file access is required.

As previously indicated, persistent storage of data parameters and coefficients is presently achieved with ASCII text files. As an example of objects interacting and working with each other, when the user requests to save data parameters in persistent storage, the BasinManager sends a message to each hydrologic object to save its own data. After saving its data, each hydrologic object in turn sends a message to its processor objects to save their data. To re-establish a "model" from a persistent data file, a data loading object recreates hydrologic objects via the BasinManager, and sets their data parameters and coefficients through their public interfaces. In this procedure, as far as the engine is concerned, the objects are created and parameters set just as if this action were being done by the user through the GUI.

Graphical User Interface

The GUI is the window through which the user interacts with HEC-HMS. It enables specification of information to be retrieved or stored (e.g., data files), specification of application-specific information (both data and task instructions), and viewing of results. The GUI enables the user to easily and effectively perform the various types of analysis for which the program is capable.

With the GUI, the user can define, change, control, and view a model's configuration, inputs and results. The multiple windows shown in Figure 3 illustrates some of the screens that comprise the GUI for an example watershed. The screens are, in a

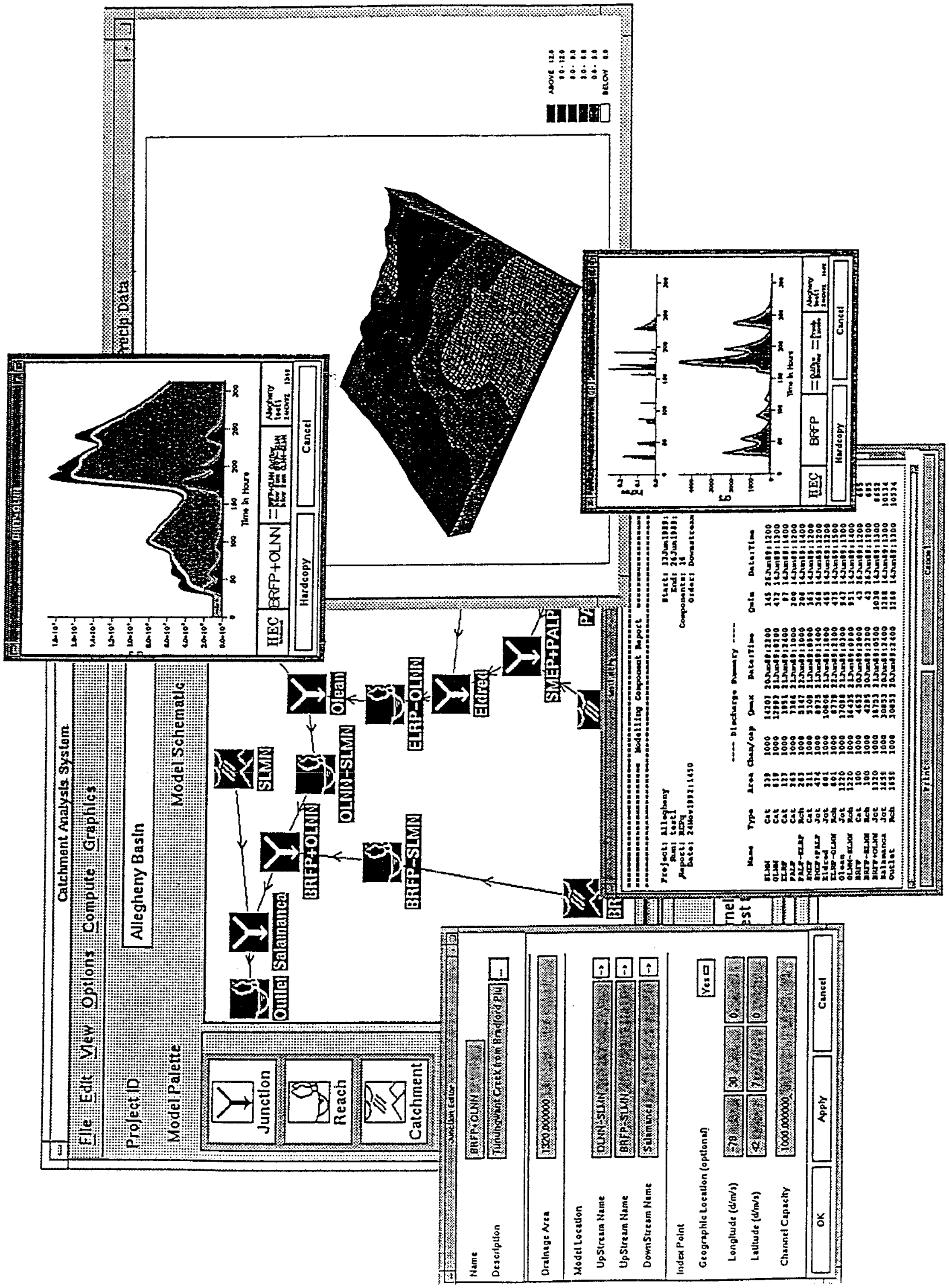

Figure 3 Graphical User Interface

counter clockwise order from the upper left: 1) the schematic configuration of hydrologic elements that make up the example Allegheny Basin model; 2) a data editor for entering or changing information for a junction object; 3) a tabular report of critical flows for each hydrologic element; 4) a graphic of subbasin precipitation and flow results; 5) a perspective view of a precipitation field over the entire basin; and 6) a graphic of the flows entering and leaving a junction. Each of these windows make up a portion of the complete GUI. The user may open any number of graphical and tabular windows to display reports and model information for any hydrologic element of interest.

The user-controlled schematic representation of the components of a hydrologic system is a key element of the GUI. The schematic employs icons to represent subbasins, routing reaches, reservoirs, diversions, etc., and their topological connections. In creating a new watershed model, the user selects an element type (e.g., subbasin) from a popup menu and drags it to a desired location on the schematic background. Other elements are established in a similar fashion, as are connecting links between elements. An element can then be selected, and access to a data editor for that element is provided as an option from a popup menu. After a simulation has been executed, an element can again be selected, and a popup menu provides access to a display of simulation results for that element.

Navigation through the schematic is facilitated with a view finder window that shows a miniature view of the entire schematic, and a frame around that portion of the schematic presently visible. The user can move the frame to bring other portions of the schematic into view. Capability is also provided to "collapse" portions of the schematic so that unwanted detail can be hidden from view.

The schematic capability is required in a number of NexGen software products besides HEC-HMS, such as those for simulating reservoir systems and river hydraulics, and for analyzing flood damage. Hence the approach for developing the capability was to develop a Schematic Model Library (SML) which consists of C++ classes for general application. The SML links with libraries from the multi-platform toolkit so that the schematic capability is portable across platforms.

Where several GUI windows display the same data value or information related to a data value, it is necessary to provide a mechanism to assure that the contents of all windows remain current. If, for example, the drainage area in the data edit window were changed, then the tabular report, which shows each element's area, would need to be updated. All model results that are affected by the drainage area value would no longer be current. To provide a mechanism to systematically handle the update of windows, "observer" objects are used. An observer object allows a window to register its interest in being notified when specific model data is changed. Thus, the object that generates the report could use an observer object to notify a hydrologic element object of its interest in knowing of a change in drainage area. The report object would then be able to update the particular data value, or regenerate the complete report.

While the user is able to interact with the model through the GUI to accomplish her or his modeling needs, it is frequently desirable to repeat a sequence of model interactions over and over again with different model parameters. Under this scenario the GUI as the means of carrying out repeated operations can become the user's greatest frustration. A similar need for an alternate to the GUI model control capability occurs when a model must be operated unattended, or under the control of another higher level modeling process that sees the hydrologic model as only a contributing component. In each of these cases the ability to drive the model from a script of instructions which include both control and data values is needed. In its full implementation the model design will permit the user to define any number of macro scripts that can be invoked to simplify often repeated model GUI sequences. An example might be a tool bar allowing the selection of a macro to trigger the routine generation of six hardcopy plots and four reports to summarize model results.

The GUI design requires careful consideration of many issues such as, the mental image a user will have of the problem solving steps, logical navigation through those steps, the organization of related data into specific GUI screens, the aesthetic layout of the information on each screen, look and feel consistent with the parent windowing system, and adequate handling of error conditions.

Closing Comment

The current architecture and development plans for HEC-HMS reflect the set of requirements listed in the Introduction and experience to date in model development. While the learning curves have been steep and initial development has progressed much more slowly than was originally anticipated, we find that we are now able to extend existing modeling capabilities and continue model development in a reasonably efficient and straight forward manner. We also anticipate that software maintenance will be facilitated, and that future adoption of alternative graphics, GUI or database features will not require a major rewrite of the computational engine or other components.

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Anthony Slocum has contributed significantly to the design of HEC-HMS and is the developer of the Schematic Model Library. Paul Ely is the developer of libHydro.

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