

Watershed Analysis with the Hydrologic Engineering Center's River Analysis System (HEC-RAS) Model

The Hydrologic Engineering Center's River Analysis System (HEC-RAS) is an integrated software system, designed for interactive use in a multi-tasking environment. HEC-RAS is designed to perform one-dimensional hydraulic calculations for a full network of natural and constructed channels. HEC-RAS is capable of performing steady flow and unsteady flow water surface profile calculations, and will include sediment transport and several hydraulic design computations in the future. This SMARTnote provides a general description of the HEC-RAS model, its capabilities and limitations, data requirements, traditional and innovative methods for HEC-RAS hydraulic model calibration, and presents a case study in which the capabilities of HEC-RAS are demonstrated as a means to support watershed modeling and assessment in a usable decision-support framework.

CAPABILITIES AND LIMITATIONS. HEC-RAS has the following major capabilities:

Steady Flow Water Surface Profiles, intended for calculating water surface profiles for steady gradually varied flow. For steady flow 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. The effects of various obstructions (bridges, culverts, weirs, etc.) may be considered in the computations. The steady flow system is designed for application in flood plain management and flood insurance studies to evaluate floodway encroachments. The change in water surface profiles due to channel improvements and levees can also be assessed.

Unsteady Flow Simulation, capable of simulating one-dimensional unsteady flow through a full network of open channels. The unsteady flow equation solver was adapted from Dr. Robert L. Barkau's UNET model, primarily for subcritical flow regime calculations. However, with the release of Version 3.1, the model can now perform mixed flow regime (subcritical, super-critical, hydraulic jumps, and drawdowns) calculations in the unsteady flow computations module.

MODEL DESCRIPTION: The HEC-RAS system is comprised of:

- A graphical user interface (GUI) that manages files; enters, edits, and analyzes data; and displays and provides online help.
- Separate hydraulic analysis components.
- Data storage and management capabilities.
- Graphics and reporting facilities.

Sediment Transport/Movable Boundary Computations, currently under development and intended for the simulation of one-dimensional sediment transport/movable boundary calculations resulting from scour and deposition over moderate time periods (typically years, although applications to single flood events are possible). Sediment transport potential is computed by grain size fraction, thereby allowing the simulation of hydraulic sorting and armoring. Major features will include the ability to model a full network of streams, channel dredging, various levee and encroachment alternatives, and the use of several different equations for the computation of sediment transport.

USING THE MODEL

Collection of Geographic and Hydrographic Data. This step can be as simple as determining the structural dimensions of a concrete-lined canal or as complicated as performing a full-coverage survey of the study area, including in-channel hydrosurveys. The traditional method is to survey individual cross sections at strategic locations, such as at slope changes, changes in land use, around bridges, etc. More and more common is the full coverage survey approach, in which the entire study area is surveyed and stored electronically as a digital terrain model (DTM). From this DTM, the software user can cut cross sections at any location. This step is usually the most expensive and time-consuming and includes collection of high water marks and/or gauge data for use in the calibration step.

Collection of hydrologic data. Hydrologic data are collected and analyzed to determine the boundary conditions for the HEC-RAS model. A simple steady flow, sub-critical model will only require a downstream

stage and an upstream inflow as boundary conditions. More complex models may have multiple inflow and outlet boundary conditions. Typically, for a steady flow model, frequency events (i.e., 100-year, 20-year, etc.) are used as inflow boundary controls. In unsteady models, inflow hydrographs, representing a time-series of flows (real or fictitious) are used to define the inflow boundary control. Outlet boundary controls include normal depth, critical depth, rating curves, flow and stage hydrographs, or tidal cycles.

Input of data. Accomplished by manually entering cross section and boundary condition data, or through GeoRAS, an ArcView extension designed to process geospatial data with HEC-RAS. Generally speaking, this includes station-elevation data for each cross section, roughness values, ineffective flow areas, hydraulic structure (bridges, culverts, dams) geometry, and boundary conditions.

Data Storage and Management. Data are stored in "flat" files (ASCII and binary), as well as the HEC-DSS (Data Storage System). Data input files for a project are categorized as follows: plan data, geometric data, steady flow data, unsteady flow data, sediment data, and hydraulic design data. Output data are stored in separate binary files. Data can be transferred between HEC-RAS and other programs by utilizing the HEC-DSS.

Data are managed through the user interface. Once the modeler enters a single filename for the project being developed, all other files are automatically created and named by the interface as needed. The interface provides for renaming, moving, and deletion of files on a project-by-project basis.

Run the model. Running the model may take seconds or many hours, depending upon its size and complexity. Depending on the results, adjustments can be made to the model input. This is necessary if errors are reported, or if the model run fails, as in the case of severe instabilities for unsteady flow models.

Calibrate the model. Once the model has successfully run, the results must be validated by calibrating to one or more known events. Observed points can be entered into the model output for direct comparison with model results. The model input should then be adjusted to try to match the model output with the observed points.

Analyze the results. A variety of output options are available for use in HEC-RAS, including profile plots, cross section plots, 3-D perspective plots, and tables. Most commonly, water surface elevations for various frequency events are desired for floodplain/inundation mapping, levee levels of protection determination, and navigation studies.

USING HEC-RAS FOR STEADY FLOW CALCULATIONS.

- Access the first window in HEC-RAS (Figure 1). Enter the necessary geometric data.

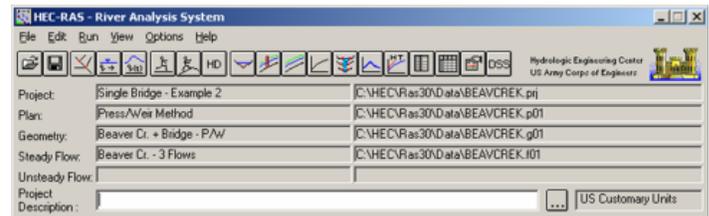


Figure 1.

- Enter cross-section and hydraulic structure data (Figure 2). The basic data required for each cross section are shown in Figure 3. Additional cross section features are available under "Options" from the menu bar. Edit features include cut, copy, paste, insert, and delete data from the Cross Section X-Y Coordinates grid.

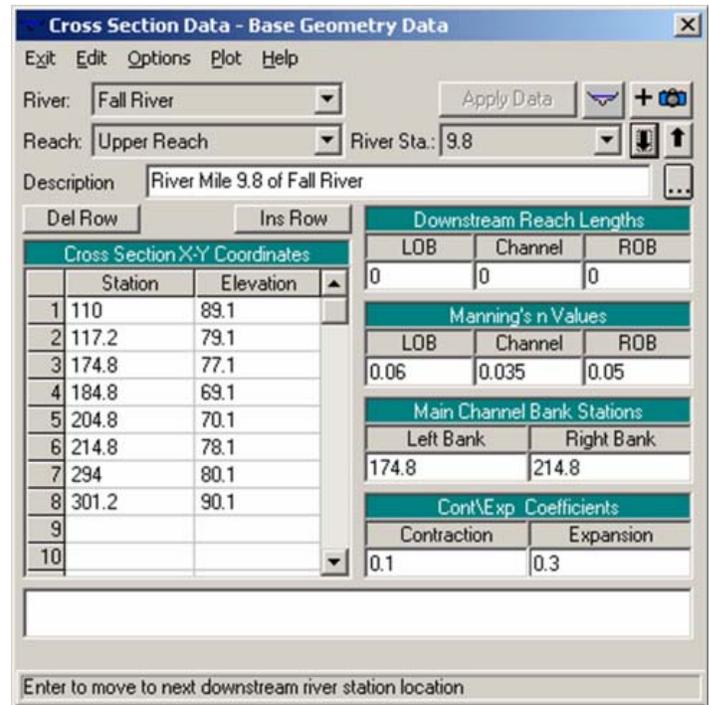


Figure 2.

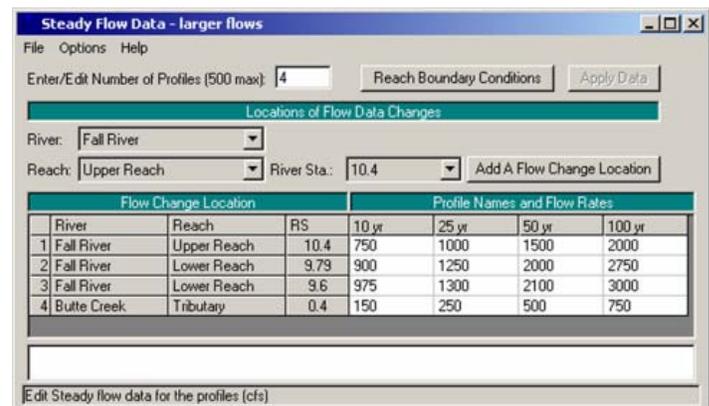


Figure 3.

- Add any hydraulic structures such as bridges, culverts, weirs and spillways using data editors. Additional data are required for any stream junctions in the river system.
- Enter flow data and boundary conditions. Figure 3 is the steady flow data entry form. Steady flow data consist of: the number of profiles to be computed; the flow data; and the river system boundary conditions. Boundary conditions are required in order to perform the calculations.
- Perform hydraulic computations, once all of the geometric data and flow data are entered. Three types of calculations can be performed in the current version of HEC-RAS: steady flow analysis, unsteady flow analysis, and hydraulic design functions.

USING HEC-RAS FOR UNSTEADY FLOW CALCULATIONS:

With this option, the user is required to enter boundary conditions at all of the external boundaries of the system, as well as any desired internal locations, and set the initial flow and storage area conditions at the beginning of the simulation.

- Select the “Boundary Conditions” tab from the Unsteady Flow Data editor, shown in Figure 4. River, reach, and river station locations of the external bounds of the system will automatically be entered into the table. Boundary conditions are entered by first selecting a cell in the table for a particular location, then selecting the boundary condition type that is desired at that location.
- Establish the initial conditions of the system at the beginning of the unsteady flow simulation. Initial conditions consist of flow and stage information at each of the cross sections, as well as elevations for any storage areas defined in the system. Initial conditions are established from within the Unsteady Flow Data editor by selecting the “Initial Conditions” tab.
- Three components are used in performing an unsteady flow analysis within HEC-RAS: a geometric data pre-processor; the unsteady flow simulator; and an output post-processor. The pre-processor processes the geometric data into a series of hydraulic properties tables, rating curves, and a family of rating curves. This speeds up the unsteady flow calculations.
- A modified version of the UNET (Unsteady NETWORK model) program is used to process the unsteady flow simulation, which is a three-step process: the RDSS program (Read DSS data) runs, the UNET program runs, and the TABLE program runs.
- The post-processor is used to compute detailed hydraulic information for a set of user-specified time lines during the unsteady flow simulation period.
- Once the post-processor is finished running, the user can view output from all of the HEC-RAS plots and tables.

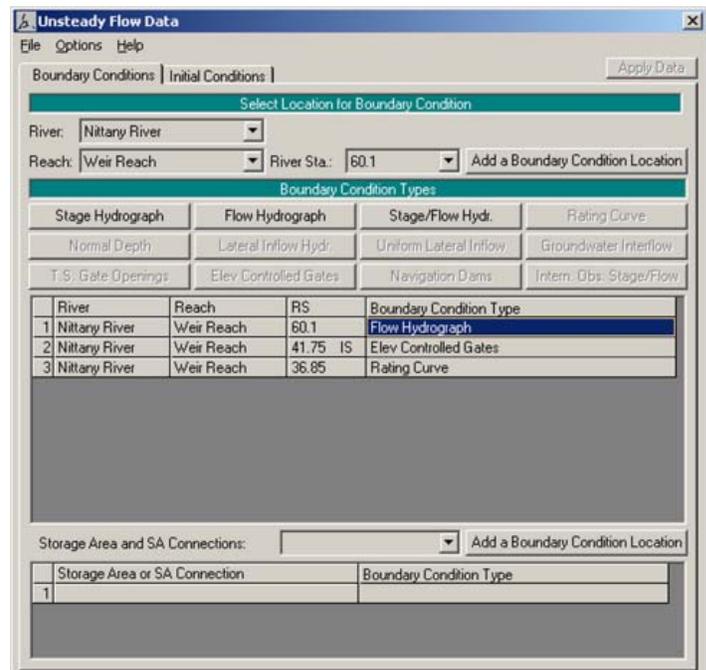


Figure 4.

SUPPORT SOFTWARE: HEC-GeoRAS: HEC-GeoRAS is an ArcView GIS extension specifically designed to process geospatial data for use with HEC-RAS. The current version of HEC-GeoRAS creates an import file, referred to as the *RAS GIS Import File*, containing river, reach, and station identifiers; cross-sectional cut lines; cross-sectional surface lines; cross-sectional bank stations; downstream reach lengths for the left overbank, main channel, and right overbank; and cross-sectional roughness coefficients. Additional geometric data defining levee alignments, ineffective flow areas, and storage areas may be written to the RAS GIS Import File. Hydraulic structure data are not written to the import file at this time. Water surface profile data and velocity data exported from HEC-RAS may be processed into GIS data sets. For more detailed information on HEC-GeoRAS, consult ERDC/TN SMART-04-2.

CASE STUDY APPLICATION-ANACOSTIA RIVER:

The purpose of this study was to provide the Baltimore District of the U.S. Army Corps of Engineers (NAB) with a HEC-RAS model of the Anacostia River from the Queens Chapel Bridge on the northwest branch and the East-West Highway on the northeast branch down to the Bladensburg Marina on the main stem. The Anacostia model was developed from a combination of digital terrain data, existing HEC-RAS and HEC-2 models, CADD-generated cross sections, surveyed cross-section data, and site visits.

The goal of the modeling effort was to evaluate the conditions on the northwest and northeast branches of the Anacostia River up to the 500-year flood,

including areas of levee and high ground overtopping, and to provide NAB with a useable tool for future evaluations.

Development. The Anacostia model was developed by importing cross-section data extracted from the ArcView GIS system. Bathymetric data were inserted in the cross-section data where available. When not available, the bathymetric data were interpolated or extrapolated, using the HEC-RAS interpolation routines and adjusted to represent actual conditions at bends, bridges, and other known features. The next step was to complete the missing cross-sectional data and modify existing data, which includes Manning's n values, contraction and expansion coefficients, ineffective flow areas, and levees. All plans were run in mixed flow regime, primarily to account for the supercritical flow experienced under most conditions in a high-velocity channel constructed for flood control.

Calibration. To calibrate the Anacostia River model, two gauges and a physical model study were used. Recent changes to the river were left out of the geometry file. Once the model was calibrated, all of the geometry was copied to a new geometry file ("future conditions"), and the environmental restoration changes were added. For the northwest branch, this included an increase of the n value in the main channel between river station 4740 and the 38th St. Bridge from 0.035 to 0.07 to simulate a boulder garden. On the northeast branch, a smaller fish habitat improvement was found just downstream of the Riverdale Road Bridge. This is captured in the "future conditions" model with an increase in n value from 0.03 to 0.05 at river station 17986.

Results. The purpose of this study was to determine the approximate capacity of the levees along the northwest, northeast, and main stem of the Anacostia River. For the analysis, three RAS plans were studied: the northwest, northeast, and main stem centering-

future conditions. Currently, the only environmental enhancements added into these plans are the boulder garden just upstream of the 38th St. Bridge on the northwest branch, and the rocky fish habitat improvement just downstream of the Riverdale Road Bridge on the northeast branch. Others changes can be easily added in by adjusting n values, or physically altering the cross-section geometry.

Based on the future conditions, it was determined that the levees contain the 100-year (1-percent chance exceedence) event, with the exception of the extreme upper limits of the northwest branch. While the levee system did not contain the 200-year event everywhere, it appears that the northeast branch levee system can contain lower frequency flows than the northwest branch. The Arundel Rd. Canal appears to follow the same trend as the two main branches. The 200-year profile briefly overtops the right levee just upstream of the 37th St. Bridge. The 500-year profile overtops the levees at all points along the canal. The main stem of the Anacostia River contains the 200-year profile within its levees at all points except at river station 6372. The 500-year profile is still well contained between the main stem levees, with breaches occurring on the left levee at river stations 8625, 6737, and 6372.

POINTS OF CONTACT: This technical note was written/edited by Chris Goodell at the Hydrologic Engineering Center, Davis, CA, using excerpts from HEC publications and original work. For additional information, contact Chris Goodell (530-756-1104, christopher.r.Goodell@usace.army.mil) or Gary Brunner (530-756-1104, gary.w.brunner@usace.army.mil), or the Manager of the System-wide Modeling, Assessment, and Restoration Technologies Program, Dr. Steve Ashby, (601-634-2387, Steven.L.Ashby@erdc.usace.army.mil).

A more detailed version of this data can be found in ERDC/TN SMART-04-2.

This publication is intended to be used as a tool to distribute information on research being conducted under the System-wide Modeling, Assessment, and Restoration Technologies (SMART) Program. Communications are welcomed and should be addressed to the SMART Program Manager, Dr. Steve Ashby (Steven.L.Ashby@erdc.usace.army.mil), U.S. Army Engineer Research and Development Center, ATTN: CEERD-EP-P, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199; telephone (601) 634-2387. The contents of this publication are not to be used for advertising, publication, or promotional purposes nor are they to be published without proper credit. Citation of trade names does not constitute an official endorsement or approval of the use of such commercial products.



US Army Corps
of Engineers ®