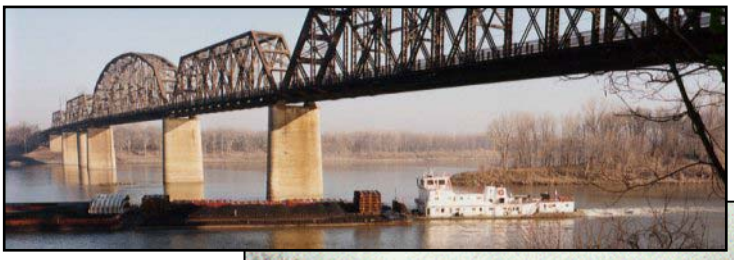
FLOODPLAIN MODELING MANUAL

HEC-RAS Procedures for HEC-2 Modelers



Federal Emergency Management Agency
Mitigation Directorate
500 C Street, SW
Washington, DC 20472

April 2002

Floodplain Modeling Manual

HEC-RAS Procedures for HEC-2 Modelers

Prepared by
Dewberry & Davis LLC
for the
Federal Emergency Management Agency

April 2002

TABLE OF CONTENTS

CHAPTER 1: INTRODUCTION 1

1.1 Organization of the Manual 2

1.2 Acknowledgment 2

CHAPTER 2: FLOODPLAIN MODELING - HEC-RAS AND HEC-2 PROCEDURES 3

2.1 Governing Equations and the Solution Procedure 4

2.2 Analysis of Subcritical, Supercritical, and Mixed Flows 4

2.3 Analysis of Flow Junctions 4

2.4 Cross Section Conveyance Computation 5

2.5 Critical Depth Computation 5

2.6 Ineffective Flow Areas and Levees at Cross Sections 6

2.7 Geometric Cross Section Interpolation 6

2.8 Analysis of Flow Distribution at a Cross Section 7

2.9 Analysis of Special Types of Flows 8

CHAPTER 3: ANALYSIS OF FLOODPLAINS WITH BRIDGES AND CULVERTS 9

3.1 Analysis of Floodplains with Bridges 9

3.1.1 Low Flow Analysis 9

3.1.2 High Flow Analysis 9

3.1.3 Parallel Bridges (bridge openings in series) 10

3.2 Analysis of Floodplains with Culverts 10

3.2.1 Culvert Shapes 10

3.2.2 Culverts in Series 11

3.2.3 Parallel Culverts with Same Invert Elevation 11

3.3 Analysis of Floodplains with Multiple Bridge Openings 11

3.4 Analysis of Flow Through Gated Spillways and In-line Weirs 12

3.5 Analysis of Flow Over Drop Structures 12

CHAPTER 4: FLOODWAYS - ENCROACHMENT ANALYSES 13

CHAPTER 5: ANALYSIS OF COMPLEX FLOODPLAINS 14

5.1 Wide Floodplains 14

5.2 Split Flow Modeling 14

5.3 Analysis of Flow through Long Pipes – Storm Sewer Analysis 15

CHAPTER 6: QUALITY ASSURANCE SOFTWARE – CHECK-2 AND CHECK-RAS 16

CHAPTER 7: DEVELOPMENT OF THE HEC-RAS MODEL 17

7.1 Schematic of the River System 17

7.1.1 River Junctions 17

7.1.2 Cross Sections 17

7.2 The Input Data 18

7.2.1 Locating the Input Data – HEC-RAS Index 18

7.3 Geometric Data of Cross Sections 18

7.4 Calibrating to Observed High-water Marks 18

7.5 Special Features to Review the Results 19

CHAPTER 8: PROFILE PLOTTING SOFTWARE - RASPLOT 20

CHAPTER 9: CONVERSION OF HEC-2 INPUT DATA FILES TO HEC-RAS 21

9.1 Importing HEC-2 Input Data 21

9.2 The HEC-RAS Index 21

9.3 Comparison of Solution Methods and Computational Procedures 25

9.4 Precautions to be Taken when Importing HEC-2 Input Data 31

9.4.1 Conveyance Computation 31

9.4.2 Imported Bridge Modeling Data 32

9.4.3 Critical Depth Computation 32

9.4.4 Other Observations 32

CHAPTER 10: ACQUIRING HEC-RAS 33

APPENDIX A: USE OF HEC-RAS FOR FLOOD INSURANCE STUDIES A-1

APPENDIX B: CONVERSION OF HEC-2 INPUT DATA TO HEC-RAS (EXAMPLES) B-1

Example 1: Importing HEC-2 Natural Floodplain Model B-2

Example 2: Importing HEC-2 Bridge and Culvert Models B-8

Example 3: Importing HEC-2 Model with a Tributary B-19

Example 4: Importing HEC-2 Ice-jam Model B-23

Example 5: Importing HEC-2 Encroachment Model B-26

Example 6: Importing HEC-2 Split Flow Model B-28

CHAPTER 1: INTRODUCTION

The U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center's River Analysis System (HEC-RAS) supersedes its HEC-2 program, widely used in the preparation of Flood Insurance Studies. The Federal Emergency Management Agency (FEMA) has adopted the guidance that hydraulic analyses for newly contracted Flood Insurance Studies (FISs) and restudies of entire watersheds (with detailed HEC-2 hydraulic analysis) should be conducted using HEC-RAS instead of HEC-2. Details of this guidance are documented in FEMA Memoranda dated March 14, 1997, and October 19, 2000. FEMA has also issued guidance that encourages the use of HEC-RAS to revise floodplains with effective HEC-2 analyses. This guidance is documented in a FEMA memorandum dated April 30, 2001. Copies of these memoranda are included in Appendix A.

In order to ensure the accurate modeling of floodplains analyzed for FISs, FEMA's study contractors and the Flood Map Production Coordination Contractors (FMPCCs) have to familiarize themselves with the capabilities and limitations of the HEC-RAS program to model floodplains.

This floodplain modeling manual is prepared as a guide to introduce the HEC-RAS Version 3.0 modeling procedures to engineers who have experience in preparing floodplain models with the HEC-2 computer program. The first version 1.0 of HEC-RAS was released in July 1995 and there have been six releases since then. The major advancement of Version 3.0 over the previous releases is the inclusion of unsteady flow routing. The unsteady flow equation solver is adopted from the program UNET, developed by Dr. Robert L. Barkau and supported by the USACE. However, the discussion provided in this manual is limited to the steady flow water-surface profile calculations and complements the following three HEC-RAS documents:

- HEC-RAS River Analysis System Version 3.0 User's Manual (UM);
- HEC-RAS River Analysis System Version 3.0 Hydraulic Reference Manual (HRM); and
- HEC-RAS River Analysis System Version 3.0 Applications Guide (AG), all dated January 2001, and published by the USACE.

Before preparing a HEC-RAS model of a floodplain, it is recommended that the user read and understand the aforementioned HEC-RAS documents.

1.1 Organization of the Manual

The hydraulic principles and computational procedures used in the HEC-RAS and HEC-2 programs are summarized in this manual, and the differences are identified. Chapter 2 discusses the issues relevant to modeling floodplains unobstructed by structures. Issues related to modeling the floodplains obstructed by structures are discussed in Chapter 3. Floodway considerations are discussed in Chapter 4.

Chapter 5 of this manual summarizes the HEC-RAS features that can be used in modeling complex floodplains such as multiple bridges, culverts in series, flow junctions, and split flow. A brief summary of the quality assurance software, CHECK-RAS, recently published by FEMA, is included in Chapter 6 of the manual. Issues related to the general development of a HEC-RAS model are discussed in Chapter 7. In Chapter 8, the manual summarizes the graphical capabilities and the post processing programs available for HEC-RAS. The issues related to the conversion of HEC-2 input data to HEC-RAS are discussed in Chapter 9.

Chapter 9 of the manual provides quick reference facts about HEC-RAS program. These facts include, information necessary to purchase the program, tables summarizing the capabilities of HEC-RAS program with reference to pages where detailed discussion on the topic is provided in the HEC-RAS documentations, and the variations between HEC-RAS and HEC-2 modeling procedures. In addition, a HEC-RAS index included in this section summarizes the different locations where hydraulic data are stored by HEC-RAS computer program. Chapter 10 of this manual provides information on acquiring the HEC-RAS program.

A copy of FEMA's memoranda providing guidance on the use of HEC-RAS is included in the Appendix A. Appendix B summarizes six sensitivity analyses conducted using the HEC-RAS import feature to import HEC-2 files. The HEC-2 input data with floodplain modeling, bridge and culvert modeling, tributary modeling, ice-jam modeling, and encroachment modeling are included in the sensitivity analysis. The enclosed computer disk includes the models prepared for each of the six sensitivity analyses.

1.2 Acknowledgment

This report was prepared by Dewberry & Davis LLC, under contract with the Federal Emergency Management Agency.

CHAPTER 2: FLOODPLAIN MODELING - HEC-RAS AND HEC-2 PROCEDURES

HEC-RAS, operated in the MS Windows© environment, consists of:

- A graphical user interface
- Separate hydraulic analysis components
- Data storage and management capabilities
- Graphical and report preparation capabilities

In addition, FEMA has published the post-processing program RASPLOT to prepare flood profiles suitable for publication in FISs. The quality assurance software CHECK-RAS is published by FEMA to facilitate the preliminary technical review of a HEC-RAS floodplain model.

The governing equations and the solution methods used by HEC-2 and HEC-RAS to model steady flow in a floodplain unobstructed by structures are generally similar. The theory and data requirements for the hydraulic computations performed by the HEC-RAS computer program, Version 3.0, are documented in the Hydraulic Reference Manual. Major differences between the solution methods used by HEC-2 and HEC-RAS are found in the following computations:

- Cross section conveyance
- Critical depth

The following computational capabilities are newly added (or enhanced) in HEC-RAS:

- Analysis of flow in a mixed flow regime and the location of the hydraulic jump
- Ineffective flow area and levees at cross sections
- Geometric cross section interpolation
- Analysis of flow distribution at a cross section
- Analysis of the effect of air entrainment in high velocity streams
- Split flow optimization at stream junctions and lateral weirs
- Analysis of flow over Inline weirs and bridges with multiple openings
- Unsteady flow analysis (this capability will not be discussed in this report)

The governing equations used by HEC-2 and HEC-RAS to model floodplains and the solution methods used are summarized in this section.

2.1 Governing Equations and the Solution Procedure

HEC-2 can analyze the flow in simple dendritic systems. HEC-RAS, Version 3.0, is capable of performing one-dimensional steady-state hydraulic computations for a full network of natural and constructed channel. The basic solution procedure is based on the solution of one-dimensional energy equation. The energy losses are evaluated by considering the friction and expansion and contraction losses between the cross sections that represent the topography of the floodplain.

2.2 Analysis of Subcritical, Supercritical, and Mixed Flows

HEC-RAS have the capability to conduct backwater and forewater computations necessary to analyze channel flows in subcritical, supercritical, and mixed flow regimes. HEC-RAS conducts the backwater and forewater computations and assigns the appropriate flow regime. HEC-2 has the capability to conduct backwater and forewater computations necessary to analyze channel flows in subcritical, and supercritical, flow regimes. However, the HEC-2 requires the user to prepare a different input data set from downstream to upstream to analyze subcritical flows and from upstream to downstream to analyze supercritical flows. In order to analyze mixed flows using HEC-2, both the supercritical and subcritical flow models of the stream must be prepared. However, hand computations are needed to compute the exact location of the hydraulic jump.

2.3 Analysis of Flow Junctions

HEC-2 has the capacity to analyze simple dendritic channel systems. HEC-RAS have the capability to analyze a full network of channels, including a dendritic system. In order to model a channel network, the program must have the capability to analyze the flow at junctions. Generally, a flow junction consists of a flow-split; where, a main upstream channel splits to form two or more tributaries downstream; or a flow-combination, where, two or more upstream tributaries join to form a downstream main channel.

The “Tributary” option available in HEC-2 is capable of analyzing flow-combinations. However, HEC-RAS has the capability to analyze flow-splits and flow combinations. When a flow-split at a junction is analyzed, a trial and error procedure is necessary to determine the discharge in each branch.

The HEC-RAS junction solution procedure also has the capability to compute flood elevations at flow-combinations by considering the energy losses at the junction. HEC-RAS offers two solution methods to compute this energy loss. First, the energy

method is suitable for subcritical flow combinations and is based on the conservation of energy principles. Second, the momentum method is suitable for supercritical flow combinations and is based on the conservation of momentum principles. The flow combinations frequently considered in the FISs are those of a main river and its tributary. In these cases, it is generally assumed that the flooding in the main river and its tributary will not occur at the same time. Therefore, the flow-combination solution procedure available in the HEC-RAS may not be generally used for FISs. The HEC-2 program does not have the option to compute energy losses at junctions.

Both, HEC-2 and HEC-RAS offer split flow optimization procedures that offer the capability to model flows over lateral weirs, spillways or overtopping of watershed divides. In addition, both HEC-2 and HEC-RAS allows the use of a lateral rating curve to determine the split flow discharge. The optimization procedure determines the split flow discharges and flood elevations along the split flow path. Unlike HEC-2, HEC-RAS is capable of defining split flows that occur on either or both sides of the channel banks. In HEC-RAS, split flow location can be defined on left or right channel banks or at left or right overbanks.

2.4 Cross Section Conveyance Computation

The total conveyance of the overbank floodplain is computed in HEC-2 by adding the individual conveyance computed between each coordinate point used to define the cross section. The conveyance of a cross section is a function of the different roughness coefficients assigned. The channel conveyance for the channel in HEC-2 is computed by estimating one equivalent roughness coefficient for the entire channel (if more than one roughness values are assigned).

The HEC-2 method is used by HEC-RAS to compute the conveyance of the channel. The individual conveyance is computed for each portion of the floodplain with a different Manning's roughness coefficient is computed by HEC-RAS, when assessing the overbank conveyance. However, HEC-RAS also supports the HEC-2 method of computing overbank conveyance; i.e., computing for smaller areas (between each coordinate point) and then adding these individual conveyance estimates.

2.5 Critical Depth Computation

HEC-2 and HEC-RAS compute the critical depth at a cross section by minimizing the total energy computed at that section. There are differences in the computational algorithms used to locate the minimum total energy of the cross section.

HEC-2 uses a "parabolic" method (HRM, Appendix C, Page C-4) to find the critical depth associated with the minimum total energy. HEC-RAS has two methods to find the critical depth by minimizing the total energy. The first method is similar to HEC-2

parabolic method. If the parabolic method did not yield satisfactory results, HEC-RAS uses a more robust "secant" method to arrive at a solution. The HEC-RAS secant method is capable of finding up to three minimum values from the energy verses depth relationship. Whenever, multiple minimum values are found, the HEC-RAS secant method has the capability to locate the lowest of all the minimum values. Alternatively, when multiple minimum values are inherent in an energy verses depth relationship, the parabolic method will terminate at the first minimum value found.

A large variation can be found between the critical depths computed by HEC-2 and HEC-RAS models of the same cross section. The computational features available in HEC-RAS are superior to compute a more reliable minimum total energy estimate and the corresponding critical depth.

2.6 Ineffective Flow Areas and Levees at Cross Sections

HEC-2 and HEC-RAS have the capability to model ineffective flow areas. Ineffective flow areas are frequently used where wide floodplains have the capacity to store water with minimal conveyance. In HEC-2 large roughness coefficients are assigned to model the storage effect of an ineffective flow area. Large roughness coefficients can also be used in HEC-RAS to model ineffective flow. In addition, HEC-RAS has the capability to define portions of a cross section as not contributing in the flow but where flow can be stored.

Levees are generally modeled in HEC-2 using X3 statements. X3 statements allow the water to be constrained within a portion of a cross section until it reaches a water level specified by the user. HEC-RAS offers the user the option to identify levees at cross sections. In addition, HEC-RAS can place vertical walls at specified locations of a cross section to simulate the effect of levees. When levees are used in a cross section, HEC-RAS restricts the flow to the riverside of the levee until overtopped.

2.7 Geometric Cross Section Interpolation

HEC-2 and HEC-RAS have the capability to create interpolated cross sections. The difference in velocity head between adjacent cross sections is one criterion used for interpolating additional cross sections in HEC-2. When the velocity head difference exceeds a user specified maximum value, up to three cross sections are interpolated. However, additional cross sections will not be interpolated for the following scenarios:

- When length between cross sections is smaller than 50 feet
- When encroachments are specified at the cross sections

- When downstream cross section is also used to define the bridge geometry for a HEC-2 Special Bridge or a Special Culvert analysis

In HEC-2, the option to interpolate cross sections is selected for the entire stream reach modeled.

In HEC-RAS, interpolated cross sections are created in response to requests by the user. Additional cross sections are added between two adjacent cross sections or within a specified stream reach. The HEC-RAS Hydraulic Reference Manual states that HEC-RAS computes the topography of the interpolated cross section by interpolation. In addition, HEC-RAS computes the following hydraulic parameters by interpolation:

- Manning's roughness coefficients
- Reach lengths
- Channel bank stations
- Contraction and expansion coefficients
- Normal ineffective flow areas, when upstream and downstream cross sections have ineffective flow areas
- Levees, when upstream and downstream cross sections have levees
- Normal blocked obstructions, when upstream and downstream cross sections have obstructions

Interpolated cross sections created by HEC-RAS are accepted for hydraulic analyses prepared for the NFIP.

2.8 Analysis of Flow Distribution at a Cross Section

HEC-2 and HEC-RAS has the capability to compute the flow distribution within a cross section. In HEC-2, the flooded portions of the channel and overbanks are divided into subsections. The depth of flow, flow area, velocity, and the discharge conveyed through each portion is computed and printed out. The HEC-2, flow distribution option, when selected, will apply to all of the cross sections used in the model. The number of subsections used for flow distribution is internally determined by HEC-2. Three to thirteen subsections are used by HEC-2 for flow distribution.

Unlike in HEC-2, in HEC-RAS, the user selects the individual cross sections where flow distribution computations are requested. In addition, flow distribution parameters (velocity, flow, and flow area) are computed for the subsections specified by the user. In HEC-RAS, the flow distribution results are viewed as tables or velocity distribution plots.

2.9 Analysis of Special Types of Flows

HEC-2 and HEC-RAS have capabilities to analyze ice-covered stream flows, determine floodways and to determine the effects of channel modifications as well as sediment deposition. In addition, HEC-RAS has the capability to analyze the effects of air entrainment in high-velocity stream flows and bridge scour.

Chapter 3: Analysis of Floodplains with Bridges and Culverts

HEC-2 and HEC-RAS have the capability to compute the energy losses associated with the low and high flows through bridges and culverts. HEC-RAS offers a solution routine to analyze flows through culverts and bridges located at different invert elevations.

3.1 Analysis of Floodplains with Bridges

HEC-RAS has the capability to analyze flows through single and multiple bridges. Similar to the HEC-2 Special Bridge analysis, the HEC-RAS Bridge analysis requires four cross sections and the bridge geometry to model the flow through a bridge.

The HEC-2 offers two types of bridge analyses, the Special Bridge analysis and the Normal Bridge analysis. HEC-RAS bridge analysis is designed differently than the HEC-2 bridge analysis. HEC-2 offers the "Normal Bridge" and "Special Bridge" routines to analyze flow through bridges. The Normal Bridge analysis is generally used to model flow situations in which bridge is a small obstruction to the flow (may exist in both, low and very high bridge flows), and the flow is similar to open channel flow. Similarly, Special Bridge analysis is generally used with high bridge flows, where the flow in the bridge barrel is pressurized and there is a possibility of weir flow over the bridge deck. The names, "Normal Bridge," and "Special Bridge," used by HEC-2 are not followed in HEC-RAS. Instead, the bridge flow analyses are classified as "Low Flow" and "High Flow."

3.1.1 Low Flow Analysis

HEC-RAS offers four different user selected methods for the analysis of low flow through bridges, including: Energy balance method, Momentum balance method, Yarnell equation, and Federal Highways WSPRO method. The Energy method is similar to the HEC-2 Normal Bridge analysis. HEC-2 has the Momentum balance method and the Yarnell equation method for analysis of low flow through bridges. The assignment of one of these two methods is done internally by the HEC-2 Special Bridge analysis as a function of the momentum computed just down stream of the bridge and inside the bridge opening.

3.1.2 High Flow Analysis

The Energy Method, and Pressure and Weir flow methods are available in HEC-RAS to perform high flow computations. As mentioned earlier, the energy method is similar to the HEC-2 normal bridge analysis. When upstream and the downstream low chords

of the bridge is submerged, the HEC-RAS Pressure and Weir flow analysis is similar to the HEC-2 Special Bridge analysis. When the upstream low chord of the bridge is submerged and the downstream low chord is not submerged, HEC-RAS analysis is similar to the analysis of a sluice gate flow.

3.1.3 Parallel Bridges (bridge openings in series)

Flow through parallel bridges, situated close to each other, can be modeled using HEC-RAS bridge analysis. The upstream and downstream cross sections are shared by the bridges and low flows are not allowed to expand between two bridges. This modeling procedure is similar to that adopted by HEC-2.

3.2 Analysis of Floodplains with Culverts

The Federal Highways Administration's (FHWA's) inlet control and outlet control procedures described in the 1985 hydraulic design series report Number 5 entitled, "Hydraulic Design of Highway Culverts" is used by the HEC-2 and HEC-RAS to analyze the flow through culverts. Inlet control flow occurs when the flow capacity of the culvert entrance is less than that of the culvert barrel. Outlet control flow occurs when the flow carrying capacity of the culvert is limited by downstream conditions or the size of the culvert barrel. The inlet control equations developed by the FHWA are used by the HEC-2 and HEC-RAS. For outlet control flow, the required upstream energy to maintain the flow is computed using energy balance equations.

3.2.1 Culvert Shapes

HEC-RAS has the capability to model the eight most commonly used culvert shapes. They are:

- Circle
- Box (Rectangular)
- Arch
- Pipe arch
- Low profile arch
- High profile arch
- Elliptical
- Semicircle
- ConSpan

The HEC-RAS culvert solution routine is similar to the HEC-2 special culvert analysis.

3.2.2 Culverts in Series

Culvert analysis of the HEC-RAS program has the ability to model culverts in series. Any change in shape, slope, roughness, or FWHA chart and scale number will require the definition of a new culvert. However, data is scarce to determine the transition loss when culverts of different shapes and dimensions are used. This application is similar to the use of the HEC-2 special culvert analysis to model culverts in series.

3.2.3 Parallel Culverts with Same Invert Elevation

Culvert analysis of the HEC-RAS program has the ability to model up to 9 types of culverts in parallel and with the same invert elevation. Any change in shape, slope, roughness, or FWHA chart and scale number will require the definition of a new culvert. In addition, HEC-RAS can analyze up to 25 identical culvert barrels (of each type). The HEC-RAS culvert computations are done for the flow through one barrel only. The flow rate is equally divided among the identical culvert barrels specified. HEC-2 Special culvert analysis is less flexible than HEC-RAS and has the ability to model up to 10 parallel culverts of one type.

3.3 Analysis of Floodplains with Multiple Bridge Openings

HEC-RAS has the capability to analyze the different types of flows (low, pressure, pressure and weir) through multiple bridge and/or culvert openings at one cross section. This often occurs with wide floodplains, where bridges and culverts at different elevations are built to convey the main river discharge as well as the flood discharges on the overbanks. Seven types of bridge openings can be analyzed at one cross section using the HEC-RAS multiple bridge opening analysis.

The types of openings at a bridge location can be a combination of:

- Bridges
- Culverts
- Open conveyance areas

Multiple opening approach and divided flow options are available to analyze the flow through multiple bridges at one cross section. In the multiple opening approach, a constant “energy” elevation is computed for upstream and downstream cross sections of the structure. This approach allows the water-surface elevations to vary. The divided flow option will compute different flood elevations to the flow paths used. The user must provide the different discharges through each flow path.

In HEC-2, multiple bridge/ culvert openings has to be analyzed by preparing separate HEC-2 model for each opening and obtaining the combined discharge rating curve at the upstream cross section.

3.4 Analysis of Flow Through Gated Spillways and In-line Weirs

HEC-RAS has the capability to analyze flows over gated spillways such as radial gates (or under sluice gates), inline weirs, or a combination of both. HEC-2 does not have the capability to model weir flows and flows through sluice gates. However, the broad-crested weir computations done by the HEC-2 special bridge analysis is sometimes used to model weir flows.

HEC-RAS has the capability to analyze flows over spillways ogee shape or broad-crested weir shape. The program has the ability to account for the effects of submergence. Up to 10 sets of spillways and weirs can be analyzed for one cross section. Similar to its weir analyses, the HEC-RAS program requires four cross sections to model the flow through control structures (cross sections 1 and 2 in the downstream expansion reach and 3 and 4 on the upstream contraction reach). HEC-RAS applies the crest information of the weir and the spillway to cross section 3.

3.5 Analysis of Flow Over Drop Structures

In HEC-RAS program, the flow over a drop structure can be analyzed as an inline weir or as a series of cross sections. HEC-2 Special Bridge analysis can be used to flow over drop structures.

CHAPTER 4: FLOODWAYS - ENCROACHMENT ANALYSES

Similar to HEC-2, the HEC-RAS floodplain encroachment procedure is based on calculating the flood elevations reflecting the existing topographic (natural) conditions as well as floodplain encroachments. The first step in conducting an encroachment analysis is to select the locations of the encroachment boundaries (encroachment stations) at the left and right overbanks. The encroachment analysis assumes that the cross section area within the encroachment stations (floodway) is available to convey the flood discharge. The encroachment analysis computes the flood elevations using the encroached topography (floodway elevations). The encroachment stations are selected such that the surcharge value, the difference between the natural flood elevation and the floodway elevation, remains smaller than a maximum surcharge value selected by the user. The floodplain encroachment analyses are conducted with an objective of determining an optimum floodway that will yield the maximum possible surcharges within the floodplain, and therefore, are iterative in nature.

HEC-RAS has five floodway determining procedures available.

- Method 1: The left and right encroachment stations are provided as input.
- Method 2: The desired floodway width is provided as input.
- Method 3: The desired reduction in conveyance is provided as input.
- Method 4: The desired surcharge is provided as input.
- Method 5: The desired surcharge and maximum energy increase are provided as input.

The first three methods are similar to Methods 1, 2 and 3 available in the HEC-2 program. HEC-RAS encroachment Method 4 is conceptually similar to HEC-2 Method 4. However, the HEC-RAS iterative solution procedure used for Method 4 is more efficient than that used in HEC-2. HEC-RAS Method 5 is a combination of HEC-2 encroachment methods 5 and 6.

In HEC-2 and HEC-RAS, the encroachment at bridges and other structures in the floodplain could be made effective or ineffective. However, unlike HEC-2, the default option in HEC-RAS, at bridges and structures, is to perform the encroachment analysis. In HEC-2 encroachment analysis, fixed encroachments specified in X3 record will override the encroachments computed using the ET record. However, in HEC-RAS, blocked obstructions (equivalent to HEC-2 X3 record) and encroachments (similar to HEC-2 ET record) can be simultaneously applied.

Chapter 5: Analysis of Complex Floodplains

HEC-RAS and HEC-2 have the capability to analyze one-dimensional steady-state open channel flows. In this analysis, the river channels are assumed to have small slopes. In addition, the flow is assumed to vary gradually, except at hydraulic structures. The flow in the vicinity of the hydraulic structures are analyzed using momentum equation or by empirical equations. In complex floodplains one or more of these basic assumptions are violated. As a result the appropriateness of the HEC-RAS and HEC-2 analyses to predict the floodplain properties becomes highly questionable. Examples are wide floodplains, two-dimensional flow near bridges, flow through long pipes, and storm sewer flows. The availability of data and funds often decide the choice of the hydraulic model. There may be occasions, where it is necessary to use the HEC-RAS model to analyze these flow situations. Some techniques that can be applied to improve the ability of the HEC-RAS model to analyze such complex floodplains are discussed in this chapter.

5.1 Wide Floodplains

Wide floodplains are caused by flat topography of the overbanks. The surveyed cross sections will allow the floodplains to extend to very large lengths before the flood can be contained by high grounds. The assumption of one-dimensional flow is often violated in very wide floodplains. In reality, a floodplain area further away from the channel will store flood waters rather than convey them as efficiently as the floodplain adjoining the channel. Therefore, the wide floodplain is divided into two areas; one area which would contribute to the conveyance of water and the other area which will only store water. Calibration to historic events as high as the 100-year flow will help to estimate the effective flow areas of the floodplain.

Because of the flood storage available on the overbanks, the steady flow assumption used in the HEC-RAS program may not reflect the flow conditions of a wide floodplain. An unsteady flow model has the capability to reflect the effects of the conveyance as well as the flood storage potential of floodplains. Therefore, more accurate answers may be obtained by using the unsteady flow routing available in HEC-RAS.

5.2 Split Flow Modeling

The split flow analysis option available in HEC-2 and HEC-RAS provides for the automatic determination of the main flow and spill-over flow discharges in situations where flow is lost from the main channel. The HEC-2 and HEC-RAS split flow models can estimate the flow lost by side weirs and watershed divides. HEC-2 split flow model does not relate the lateral weir length to the channel and overbank distances of the cross sections used to model the floodplain. The HEC-RAS split flow model provides means to accurately specify the locations where split flow is likely to occur.

Unlike HEC-2, HEC-RAS is capable of defining split flows that occur on either or both sides of the channel banks. In HEC-RAS, split flow location can be on the left or right channel banks or at the left or right overbanks. Long lateral weirs that cross as many as eight cross sections can be defined in HEC-RAS. Unlike HEC-2, in HEC-RAS, the split flow modeled using lateral rating curve cannot be brought back into the main channel. Similar to HEC-2, HEC-RAS split flow computations can also be based on equating the water-surface or energy elevations within a tolerance of 2%.

5.3 Analysis of Flow Through Long Pipes - Storm Sewer Analysis

The unsteady flow models such as SWMM, FEQ, and adICPR are more suitable to model urban runoff where storm drainage is collected by inlets and transmitted through long pipes. However, if a steady state analysis is to be performed, the series culvert modeling procedures and the “lid” option available in HEC-RAS to generate closed cross sections can be used to approximate the flow through storm sewers and long pipes. These procedures can be approximated with the bridge and culvert options available in the HEC-2 program.

CHAPTER 6: QUALITY ASSURANCE SOFTWARE – CHECK-2 AND CHECK-RAS

FEMA has developed quality assurance software that have the capability to provide an initial assessment of HEC-2 and HEC-RAS analyses. CHECK-2 is the quality assurance software that will scan HEC-2 input and output files and highlights areas that need further review. CHECK-RAS is the quality assurance software for HEC-RAS analyses. This software can be downloaded from FEMA web site at:

http://www.fema.gov/tsd/frm_soft.htm

CHECK-RAS extracts information from the HEC-RAS input and output data files to generate a summary output. This summary output highlights areas that need further review. CHECK-RAS also provides help screens to assist HEC-RAS users in correcting potential errors. CHECK-RAS will run under Windows 95/98/NT operating systems.

Both CHECK-2 and CHECK-RAS have the ability to check the suitability of the following five areas of the hydraulic analysis.

- Roughness coefficient and transition loss coefficients
- Cross sections
- Structure modeling
- Floodway modeling
- Multiple profiles

CHAPTER 7: DEVELOPMENT OF THE HEC-RAS MODEL

The main objective of preparing a HEC-RAS model of a floodplain is to compute water-surface elevations of the floodplain for a given discharge. In order to achieve this objective, the program must be supplied with geometric data of the floodplain, steady flow data defining the discharge rates for the floodplain and a criteria to define the starting water-surface elevation. The same data are required to prepare a HEC-2 model of a floodplain. Since, HEC-RAS has the capability to analyze flow junctions, the geometric data will include the connectivity of the river system, as well as the cross section data, reach lengths, energy loss coefficients, and the hydraulic structural data necessary to model floodplains obstructed by structures.

7.1 Schematic of the River System

The connectivity of the river system is referred to as the schematic of the river system and generally would be the first task in creating a HEC-RAS model. The schematic of the river system is developed using the geometric data editor available in HEC-RAS. The different river reaches are determined and the schematic is drawn from an upstream to downstream direction on a reach by reach basis.

HEC-RAS also has the capability to import an existing HEC-2 input data file and create an equivalent HEC-RAS input data. During this procedure, the river schematic is created by HEC-RAS.

7.1.1 River Junctions

As reaches are connected together, junctions are automatically formed by the interface. Each river reach is assigned with a name given by the user. Similarly, each junction used in the schematic is also given a name.

7.1.2 Cross Sections

The next stage of the development of a schematic would be to define the locations of the cross sections and enter the geometric data associated with each cross section. Each cross section used in a HEC-RAS model will be associated with a river, reach, and a river station (cross section) label.

Similar to HEC-2 program, the river station label should consist of numbers. However, for HEC-RAS models, the numbering system should be consistent and the

labels should be higher for upstream cross sections (increasing from downstream to upstream).

7.2 The Input Data

Unlike HEC-2, the topographic data, discharge data, and the boundary conditions are entered using the Graphical User Interface (GUI) of the HEC-RAS. The cross sectional data and structural data are entered from the geometric data window. The discharges and boundary conditions are entered from the steady flow data window. Up to 100 topographic data points (to provide station and elevation data) can be used to define HEC-2 cross sections. HEC-RAS cross section data can have up to 500 topographic data points.

7.2.1 Locating the Input Data – HEC-RAS Index

Data for each cross section are displayed under one window and include River Name, Reach Name, River Station, Reach Lengths, Roughness Coefficients, Contraction/Expansion Coefficients, Ground Stations and Elevations. The user can also access the reach lengths, n-values, and contraction/expansion loss coefficients at all the cross sections under one window by clicking “Geometric Data” button and “Tables” menu. The input data in the HEC-RAS model can be checked by clicking “Steady Flow Analysis” button, “Options” menu, and “Check data before execution” command.

The HEC-RAS Index is given in Section 9.2 of this document. This index will help the user to find the locations of the variables and coefficients used in the HEC-RAS analysis.

7.3 Geometric Data of Cross Sections

Cross sections can have up to 500 data points for HEC-RAS and 100 for HEC-2. The data points should be surveyed from left to right looking downstream. Negative station numbers can be used in a cross section. The channel banks, reach lengths and Manning's roughness coefficients should be entered for each of the cross sections defined.

7.4 Calibrating to Observed High-water Marks

HEC-2 and HEC-RAS have the ability to plot observed high water marks against computed water-surface profiles. Calibration to high-water marks is generally done manually by the user.

7.5 Special Output Features to Review Results

HEC-2 and HEC-RAS have the ability to present the hydraulic properties computed during a flow simulation. HEC-2 out put is limited to 40 flow and topographic variables to describe the floodplain. HEC-RAS has the ability to print up to 250 flow and topographic variables to describe the floodplain. A complete list of these variables can be found in the Appendix C of the HEC-RAS River Analysis System User's Manual. The hydraulic properties can be reviewed as graphs or tables. In HEC-RAS, the flow distribution within a cross section could be requested and reviewed in a graphical or a tabular format.

CHAPTER 8: PROFILE PLOTTING SOFTWARE - RASPLOT

FEMA has developed the software RASPLOT to create profiles for Flood Insurance Studies (FISs). RASPLOT will run under Windows 95/98/NT operating systems and this software can be downloaded from FEMA web site at:

http://www.fema.gov/tsd/frm_soft.htm

RASPLOT extracts data from HEC-2 and HEC-RAS files and automatically creates the profile database necessary to generate FIS flood profiles. In addition, RASPLOT provides a blank profile table database into which data from input and output files of other programs, such as WSP-2 or WSPRO, can be manually inserted. After creating the profile database, RASPLOT creates a DXF file that meets the Federal Emergency Management Agency's specifications for FIS flood profiles. The user can use a DXF Viewer/Edit program to open the DXF file and plot the profiles.

Chapter 9: Conversion of HEC-2 Input Data Files to HEC-RAS

HEC-RAS has the capability to import HEC-2 input files. Chapter 3 of HEC-RAS User's Manual provides information on what user should be aware of before importing HEC-2 file. It also provides step by step instruction on how to import an HEC-2 input file. The User's Manual identifies the HEC-2 features that are not imported in HEC-RAS. Eight HEC-2 features that are not available in HEC-RAS are listed below:

- HEC-2 SF statement for split flow optimization
- HEC-2 IC statement for ice jam modeling
- HEC-2 NV statement for modeling vertical variations in Manning's roughness coefficients
- HEC-2 option to compute Manning's roughness coefficients using high water marks (J1, 3)
- HEC-2 statement RC to define internal rating curves
- HEC-2 statement AC to create archives
- HEC-2 command FR allowing the input data file to be in free format
- HEC-2 statement J4 to create storage – outflow data

HEC-2 input data files with the above mentioned statements will be imported into HEC-RAS. However, these features will not be converted to HEC-RAS modeling. HEC-RAS does not have the ability to create HEC-2 files from a HEC-RAS input data set.

9.1 Importing HEC-2 Input Data

A HEC-2 input data set can be imported in to a HEC-RAS project that is already open. Alternatively, a new HEC-RAS project can be opened using the "File" command of the HEC-RAS main window and the "Import HEC-2 data" feature available at the "File" command can be used to import a HEC-2 input data file.

HEC-2 input data files created in free format cannot be generally imported into HEC-RAS. However, EDIT-2 program available in the HEC-2 package has the capability to create a formatted echo of the HEC-2 file (Tape 16). This file can be imported by HEC-RAS.

9.2 The HEC-RAS Index

After importing a HEC-2 input file, the user will want to know where HEC-RAS stores all the data. In HEC-2, the user can search for or edit the data within one file. However, in HEC-RAS the data from HEC-2 is stored under different windows. Table 1 shows a HEC-RAS index that relates different hydraulic parameters and the corresponding location in the HEC-RAS input file.

This index has two columns in which the hydraulic parameter and its HEC-RAS location are tabulated. This index will assist the user to access the hydraulic data in HEC-RAS, starting from HEC-RAS main window. The topographic data and the hydraulic parameters of a cross section (given in HEC-2 records; X1, GR, and NC) are stored in the "Cross Section" screen, which is accessed through the "Geometric Data" screen. The "Geometric data screen can be found on the main HEC-RAS main screen. For example, the information about the channel bank stations of a cross section is given on the seventh row of the HEC-RAS index. This information is summarized in the HEC-RAS index as follows:

Channel Bank Stations: From "Geometric Data" screen, select "Cross Section"; "Main Channel Bank Stations" located on this screen.

Figure 1, HEC-RAS Main Window (copied from the HEC-RAS User's Manual), illustrates the HEC-RAS main screen which shows the various menus.

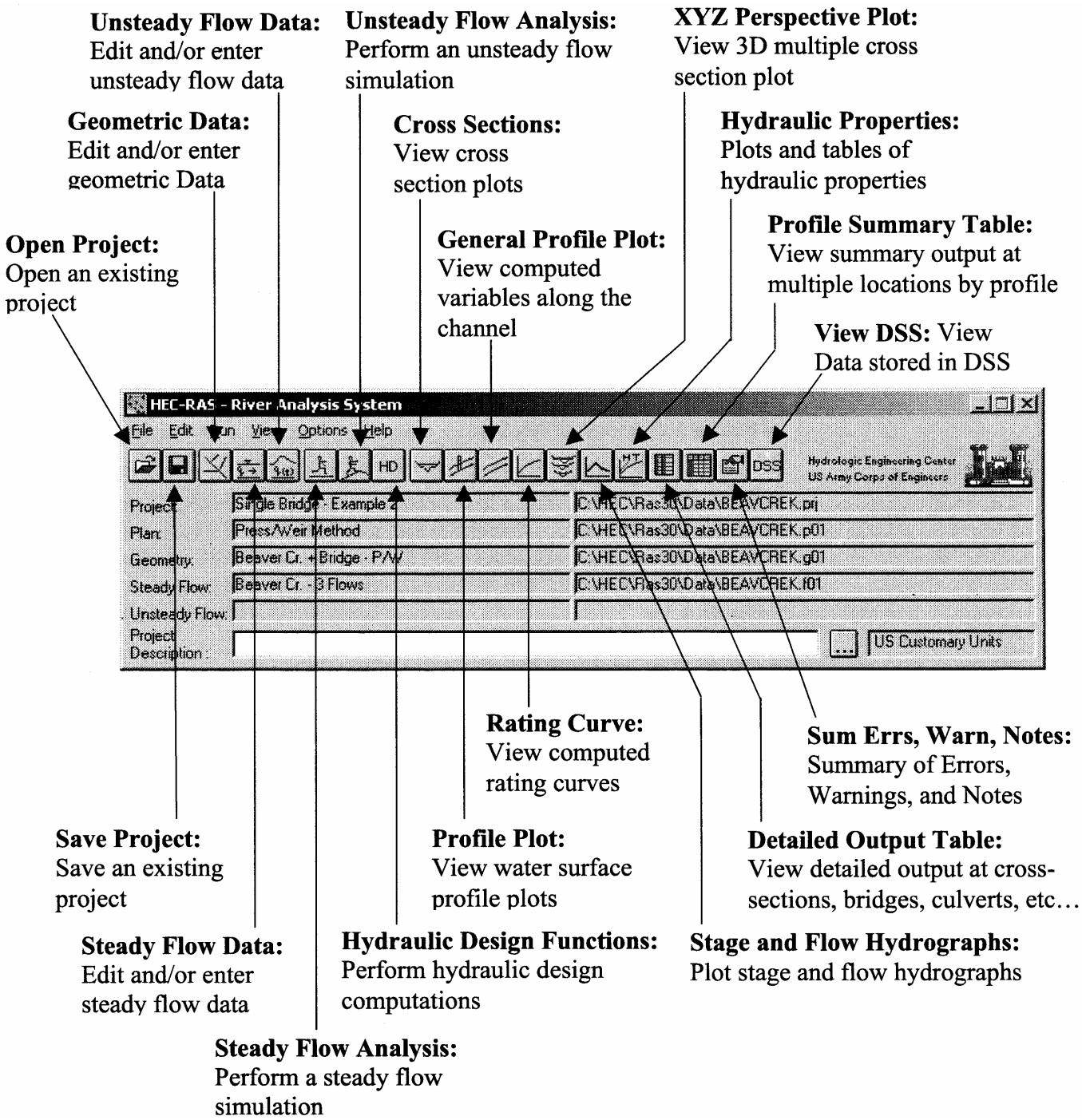


Figure 1: HEC-RAS Main Window

Table 1: HEC-RAS Index

Feature/ Parameter	Location
Add a New Cross Section :	From "Geometric Data" in main screen, select "Cross Section" screen, then "Options", and to, "Add a new Cross Section"
Bank Erosion :	From "Hydraulic Design" in main screen, select "Functions", and then "Bank Erosion"
Blocked Obstructions :	From "Geometric Data" in main screen, select "Cross Section" screen and then "Options", and to "Blocked Obstructions"
Boundary Conditions :	From "Steady Flow Data" screen, select "Reach Boundary Conditions"
Bridge Design Editor :	From "Geometric Data" screen, select "Brdg/Culv".
Bridge Modeling Approach :	From "Geometric Data" screen, select "Brdg/Culv", "Bridge Modeling Approach"
Channel Bank Stations :	From "Geometric Data" screen, select "Cross Sections"; "Main Channel Bank Stations" located on this screen
Channel Modification :	From "Geometric Data" screen, select "Options", and to "Channel Modification".
Cont/Exp Coefficients :	From "Geometric Data" screen, select "Cross Sections" screen, and to "Cont/Exp Coefficients" **or** "Tables" from main screen to "Coefficients"
Copy Current Cross Section :	From "Geometric Data" screen, select "Cross Section", under "Edit", select "Copy"; "Paste" section where needed
Cross Section Interpolation :	From "Geometric Data" screen, under "Options", select "XS Interpolation"
Cross Section Stationing :	From "Geometric Data" screen, select "Cross Section"
Culvert Data :	From "Geometric Data" screen, select "Brdg/Culv", "Culvert".(included on this screen are the *culvert chart #, diameter, D/S invert elev., exit loss coeff., length, "n" value, scale #, shape, U/S invert elev*)
Deck/ Roadway Data :	From "Geometric Data" screen, select "Brdg/Culv", "Deck/Roadway"
Delete Cross Sections :	From "Geometric Data" screen, select "Cross Section", then "Options", to "Delete Cross Section"
Discharge Changes :	From "Steady Flow Data" screen, select "Add a Flow Change Location"
Discharges :	Select "Edit" on HEC-RAS main screen, "Steady Flow Data"
Drag Coefficient, C_d :	From "Geometric Data" screen, select "Brdg/Culv", Bridge Modeling Approach"
Encroachment Stations :	From "Steady Flow Analysis" screen, "Options", "Encroachments"
Equivalent Roughness K :	From "Geometric Data" screen, select "Cross Section"
Errors, Warnings,& Notes :	"Summary of Errors, Warnings and Notes" is located under "View" in the HEC-RAS main screen

Table 1: HEC-RAS Index (continued)

Feature/ Parameter	Location
Floodway Data :	Press "Steady Flow Analysis" button, "Options", "Encroachments"
Flow Dist'n (Q_L, Q_R, Q_{ch}) :	From "Steady Flow Analysis" screen "Options" "Flow Distribution Locations"
Flow Regime :	From "Steady Flow Analysis" screen
Friction Slope Method :	From "Steady Flow Analysis" screen, "Options", "Friction Slope Method"
Gated Spillway Data :	Press "Geometric Data" button, select "Inline Weir/Spillway"
Horiz. Variation in "n" Values :	From "Geometric Data" screen, select "Cross Sections", "Options", "Horizontal Variation in n Values"
Import Geometric Data :	From "Geometric Data" screen, "Import Geometric Data" is located within "File" menu
Import HEC-2 :	"Import HEC-2 Data" is located in the "File" option from main screen
Ineffective Flow Areas:	From "Geometric Data" screen, select "Cross Sections", "Options", "Ineffective Flow Areas"
Inline Weir Data :	From "Geometric Data" screen, select "Inline Weir/Spillway"
Junction Data :	From "Geometric Data" screen, select "Junct"
Levees :	From "Geometric Data" screen, select "Cross Section", "Options", "Levees"
Low Chord :	From "Geometric Data" screen, select "Brdg/Culv", select "Deck/Roadway"
Manning's n Values :	From "Geometric Data" screen, select "Cross Section", or select "Tables", "Manning's n or k values"
Multiple Opening Analysis :	From "Geometric Data" screen, select "Brdg/Culv", select "Multiple Opening Analysis"
Pier Data :	From "Geometric Data" screen, select "Brdg/Culv", select "Pier"
Pier Shape "K" :	From "Geometric Data" screen, select "Brdg/Culv", "Bridge Modeling Approach"
Rating Curves :	Under the "View" menu in the HEC-RAS main menu, select "Rating Curves"
Reach Lengths :	From "Geometric Data" screen, select "Cross Section", or select "Tables", "Reach Lengths"
Rip-Rap Design :	From "Hydraulic Design" screen, select "Functions", "Rip-Rap Design"
Scour at Bridges :	From "Hydraulic Design" screen from HEC-RAS main screen
Sediment Elevations:	From "Geometric Data" screen, select "Tools", "Fixed Sediment Elevation"
Sloping Abutment :	From "Geometric Data" screen, select "Brdg/Culv", "Sloping Abutment"
Starting WSEL :	From "Steady Flow Data" screen, select "Reach Boundary Conditions"
Weir Crest Shape :	From "Geometric Data" screen, select "Brdg/Culv", select "Deck/Roadway"
X-Y-Z Perspective Plots :	In "View" option in HEC-RAS main screen, select "X-Y-Z Perspective Pots"

9.3 Comparison of Solution Methods and Computational Procedures

One-dimensional steady flow analysis forms the basis of the computations done by the HEC-RAS (Version 3.0) computer program. The HEC-2 computer program also uses the same analysis to compute water-surface profiles.

The types of flows analyzed by both these programs, along with the general solution methods, are compiled from the HEC-RAS documentation and provided as a reference in Table 2 entitled "Solution Methods Used for Analysis". Similarly, a brief summary of the computational procedures used by HEC-2 and HEC-RAS is given in Table 3 entitled "General computational Procedures Used for analysis".

Table 2 and 3 contain the following information:

Column 1: Type of flow (Table 2) and hydraulic parameter (Table 3)

Column 2: Solution methods (Table 2) and computational procedures (Table 3) used by HEC-2 and HEC-RAS

Column 3: Reference to sections of the HEC-RAS reference documentation that contain discussions on the solution method.

The following annotations are used in column 3:

- UM: HEC-RAS River Analysis System Version 3.0 User's Manual
- HRM: HEC-RAS River Analysis System Version 3.0 Hydraulic Reference Manual
- AG: HEC-RAS River Analysis System Version 3.0 Applications Guide (AG)
- All of these documents are dated January 2001, and published by the USACE.
- In addition, following notations are used in column 3:
- Ch: - Chapter
- Ex: - Example
- p - Page number

Column 4: Remarks, related to the HEC-2 and HEC-RAS solution methods, are noted in this column.

Table 2: Solution Methods Used for Analysis

A: Floodplains Unobstructed by Bridges and Culverts			
Type of flow	**Solution Method HEC-2 & HEC-RAS**	**Reference from HEC-RAS Manuals**	**Remarks**
Open channel flow: subcritical flow	Backwater analysis downstream to upstream	HRM Ch: 2 AG Ex: 1, P1-1	None
Open channel flow: supercritical flow	Draw down analysis upstream to downstream	HRM Ch:4, P4-6, Ch: 3, P3-22 UM Ch:3, P3-11 AG Ex:1, P1-10	HEC-RAS: the flow regime is specified in the steady flow analysis window HEC-2: rearranging of the cross sections is done manually
Open channel flow: Mixed flow	Backwater analysis	HRM Ch: 4, P4-6, Ch: 3, P3-22 UM Ch:3, P3-11 AG Ex:1, P1-10	HEC-RAS: the flow regime is specified on the steady flow analysis window HEC-2: independent sub and supercritical runs are used
Water-surface level with air entrainment	EM 1110-2-1601 Method	HRM Ch:2, p2-20	Available in HEC-RAS only
Modeling energy losses	Friction loss and transition loss	HRM Ch:3, P3-12	None
Modeling friction loss	Friction loss is evaluated as the product of friction slope and discharge weighted reach length.	HRM Ch:2, UM Ch:4, P4-5	None
Boundary roughness	Manning's roughness coefficients (n) and roughness heights (k) can be used; horizontal variation	HRM Ch: 2, p2-6 Ch:3, p3-12 AG Ex: 2, P2-6 UM Ch:6, P6-16 Ch:6, P6-74	HEC-RAS: based on main channel slope, a single composite n value is computed for channel, k-values are not generally used in FISs
Expansion and contraction coefficients	Coefficients are multiplied by the mean kinetic energy head of the two cross sections concerned.	HRM Ch:3, p3-19 UM Ch: 3, p3-8 Ch: 6, p6-9	None
Ineffective flow: water is stored, not conveyed	Water will be stored but will not be conveyed.	HRM Ch:3, p-3-7 UM Ch:6, p6-12	High Manning's roughness coefficients are used in HEC-2. Instead, blocked ineffective flow option available in HEC-RAS can be used.
Ineffective flow: water flow is blocked by high ground	Water will not be stored or conveyed. High grounds will cause contraction and expansion of flow.	HRM Ch:3, p3-8 to 11 UM Ch:6, p6-12 to 16	None
Levee on floodplain	Wetted perimeter computed	HRM Ch:3, p3-8 AG Ex:2, p2-7	In HEC-2, X3 is used to model in effective areas caused by levees. HEC-RAS has a levee option to model the flow.
Floodplain with a meandering channel	Reflected in the Manning's roughness coefficient.	None	None

Table 2: Solution Methods Used for Analysis (continued)

B: Flow Junctions			
Type of flow	**Solution Methods HEC-2 & HEC-RAS**	**Reference from HEC-RAS Manuals**	**Remarks**
Flow combination: subcritical flow	Default is energy balance method. Momentum balance method is also available	HRM Ch:4, p4-9 UM Ch:6, p6-3, 18 AG Ex:10, p10 AG Ex:8, p8-3	Similar to HEC-2 Tributary option. Momentum balance is not available in HEC-2. Unless coincident peaks occur; not used for FISs.
Flow split: subcritical flow	Default is energy balance.	HRM Ch:4, p4-11 UM Ch:6, p6-3, 18	None
Flow combination: supercritical flow	Default is energy balance. Momentum balance method is more suitable.	HRM Ch.4, p4-12 UM Ch. 6, p6-3, 18 AG Ex:10. p10-11	Generally, not used for FISs.
Flow split: supercritical flow	Default is momentum balance. Momentum balance is more suitable.	HRM Ch:4, p4-13 UM Ch:6, p6-18	None
Flow combination: mixed flow	HEC-RAS uses the appropriate method (momentum or energy).	HRM Ch:4, p4-14 UM Ch:6, 6-18 AG Ex:10, p10-5	Not available in HEC-2
Flow split: mixed flow	HEC-RAS uses the appropriate method (momentum or energy).	HRM Ch:4, p4-15 UM Ch:6, 6-18	Not available in HEC-2
Split flow discharge computation	HEC-RAS and HEC-2 have the capability to model the flow over levees or side weirs and the overtopping of watershed divides.	AG Ex:8, p8-5	In both programs, lateral weirs and lateral rating curves are used to model split flows.
Looped stream	Discharges in each branch are computed by trial and error.	AG Ex:8, p8-5	HEC-2 cannot model a looped stream system. In HEC-RAS, iterative procedures are used by the user to determine the discharges in each branch.

Table 2: Solution Methods Used for Analysis (continued)

C: Flow Obstructed by Structures			
Type of Flow	**Solution Method HEC-2 & HEC-RAS**	**Reference From HEC-RAS Manuals**	**Remarks**
Bridges and culverts	Flow compression upstream of the structure, flow across the structure, and flow expansion downstream of the structure are considered.	HRM Ch:5, p5-1 HRM Ch:6, p6-1 UM Ch:6, p6-19	None
Topographic data necessary to model bridge flow	Four cross sections and the bridge geometry are given as input data. Cross sections4 and 3 are upstream of the bridge; 1 and 2 are downstream.	HRM Ch:5, p5-2,11 UM Ch:6, p6-20 UM Ch:6, p6-30, 35, UM Ch:6, p6-39, 47 AG Ex:2, p2-3-12	Similar to HEC-2 special bridge model. However, using the input data, HEC-RAS can create internal bridge cross sections inside of the bridge structure. These cross sections can be changed/edited by the user.
Upstream contraction of flow	Ineffective flow areas defined at cross section 3, immediately upstream of the bridge. Guidance is given to select the contraction reach length. Recommended contraction coefficient is 0.3.	HRM Ch:5, p5-8 UM Ch:6, p6-22 AG Ex:2, p2-26 AG EX:3, p3-19	None
Downstream expansion of flow.	Ineffective flow areas defined at cross section 2, just downstream of bridge. Guidance is given to select an expansion reach length. Recommended expansion coefficient is 0.5.	HRM Ch:5, p5-8 UM Ch:6, p6-22 AG: Ex:2, p2-24 AG EX:3, p3-19	None
Ineffective flow areas	Ineffective flow area is modeled as normal ineffective area (no wetted perimeter is added) or blocked ineffective area (wetted perimeter is added).	HRM Ch:3, p3-7 HRM Ch:5, p5-5 to 8 UM Ch:6, p6-12, 30 AG Ex:2, p2-12 AG Ex:3, p3-4	In HEC-2 X3 statements are used to define ineffective flow areas at two locations on the cross section. HEC-RAS has option to model many blocked obstructions.
Low flow through the bridge	Energy equation, momentum balance, Yarnell equation, and FHWA WSPRO method are available. Momentum balance is suitable for super critical low flow passes through the bridge.	HRM Ch:5, p5-9 to 18 HRM Ch:5, p5-26 UM Ch:6, p6-34 AG Ex:2, p2-14	Energy equation is similar to HEC-2 Normal bridge analysis. Yarnell equation and Momentum balance analyses were available in HEC-2 Special bridge analysis. HEC-RAS gives the user to choose the method of computation.
High flow through the bridge	Energy equation, pressure flow analysis, and pressure and weir flow analysis are the three methods available.	HRM Ch:5, p5-18 to23 UM Ch:6, p6-34 AG Ex:2, p2-16	Similar to HEC-2 Special bridge analysis. Subcritical flow regime is used for FIS analyses.

Table 2: Solution Methods Used for Analysis (continued)

C: Flow Obstructed by Structures (continued)			
Type of flow	**Solution Method HEC-2 & HEC-RAS**	**Reference to HEC-RAS Manuals**	**Remark**
High flow : perched bridges	Iterative methods will be used to analyze the low flow in the bridge and weir flow on the over banks.	HRM Ch:5, p5-28	HEC-2 Special bridge analysis is used with iterative method to compute flood elevations. HEC-RAS Multiple Opening Option automates the iterative procedure.
High flow : perched bridge	Pressure and weir flow through the high bridge and low flow on both overbanks.	None	None
High flow : low water bridges	Energy equations available in HEC-RAS are suitable to model highly submerged bridge flows.	HRM Ch:5, p5-29	Similar to HEC-2 Normal bridge analysis.
Flow through bridges in a skew	Adjustments are done to the bridge dimensions to reflect the effective flow area.	HRM Ch:5, p5-29	Bridge data are revised by the user to reflect effective area. HEC-2 and HEC-RAS can do this adjustment internally.
Parallel bridges	Low flow analysis or high flow analysis.	HRM Ch:5, p5-31	Cross section immediately upstream of one bridge (#3) will be used as the downstream cross section of the next bridge (#2).
Flow through culverts: subcritical flow	Inlet control, outlet control computations based on the 1985 FHWA publication titled, "Hydraulic Design of Highway Culverts."	HRM Ch:6, p6-9 UM Ch:6, p6-40	Similar to HEC-2 special culvert analysis. This analysis is not suitable for supercritical flows through culverts.
Flow through culverts: supercritical flow	Results of culvert analysis for super critical flow regime should be carefully checked with those of mixed flow and sub critical flow regime. Alternatively, energy equation can also be used to analyze super critical flows through culverts.	HRM Ch:6, p6-18	HEC-2 cannot model super critical flow through culverts.

Table 3: General Computational Procedures Used for Analysis

A: Floodplains Unobstructed by Structures			
Parameter	**Computation method HEC-RAS & HEC-2**	**Reference from HEC-RAS Manuals**	**Remarks**
Conveyance	Cross section is subdivided to compute the conveyance.	HRM Ch:2, p2-5 UM Ch:7, p7-10, 13	Overbanks of the cross sections are subdivided at locations where the Manning's roughness coefficients change. In HEC-2, these subdivisions occurred at each coordinate point. The HEC-2 method of computation is also available in HEC-RAS.
Composite roughness coefficient	Horton's method is used.	HRM Ch:2, p2-6	When main channel side slope is larger than 5:1 (vertical to horizontal), a composite channel roughness coefficient is computed in HEC-RAS.
Reach lengths	Weighted average reach length.	HRM Ch:2, p2-3	None
Mean kinetic energy head	Discharge-weighted velocity heads computed for overbanks and the channel are summed.	HRM Ch:2, p2-8	None
Friction loss evaluation	Default is the average conveyance equation.	HRM Ch:2, p2-9 Ch:4, p4-2	Option to choose the friction loss equation based on flow is not used in FISs.
Contraction and expansion loss	Difference of mean kinetic energy head between the two cross sections is multiplied by the coefficient.	HRM Ch:2, p2-11	None
Computation of the water-surface elevation	Iterative procedure is used.	HRM Ch:2, p2-11	Default tolerance in metric system is 0.003 meter. This tolerance is 0.01 meter in HEC-2.
Checking the flow regime	Critical depths are computed for flows with Froude number >0.94	HRM Ch:2, p2-13	None
Critical depth computation	Elevation with the minimum specific energy. HEC-RAS: secant method available to determine critical depth when multiple minimum; specific energy points exist.	HRM Ch:2, p2-13 HRM Ap:C, pC-1 AG EX:1, p1-9 UM Ch: 7, p7-14	Multiple critical depth search option is available in HEC-RAS.
Ineffective flow area computations	No additional wetted parameter is computed.	HRM Ch:3, p3-7	None
Flow distribution within a cross section	Hydraulic properties are computed for segments within a cross section.	HRM Ch:4, p4-19	Up to 45 segments can be defined. Similar feature is available in the J2 statement of HEC-2.

9.4 Precautions to be Taken when Importing HEC-2 Input Data

The observations from a series of sensitivity tests conducted with importing HEC-2 input files are summarized in this section. Detailed observations are provided in appendix B and the models are available in the enclosed computer disk. Six HEC-2 input files are selected to test the import feature of HEC_RAS. The tests were done on the following models:

- Natural Floodplain Model (Appendix B-1)
- Floodplain Model with Structures (Appendix B-2)
- Model with Tributaries (Appendix B-3)
- Ice-jam Model (Appendix B-4)
- Encroachment Model (Appendix B-5)
- Split Flow Model [Appendix B-6]

The sensitivity tests indicated that water-surface elevations computed by using raw HEC-RAS input data, created from HEC-2 (using the "Import" feature), were generally different than the HEC-2 results. In many cases, these differences are small and of the order of 0.2 foot. Since there are differences in the computational methodology between HEC-2 and HEC-RAS, a HEC-RAS input data created by importing a HEC-2 input has not produced water-surface elevations that are identical to HEC-2 results. However, many of the differences can be eliminated by identifying the cause and selecting HEC-RAS computational procedures that are similar to HEC-2. Following HEC-RAS computations were observed to cause differences in computed results:

- Conveyance Computation
- Imported bridge modeling data
- Critical depth computation

9.4.1 Conveyance Computation

In all cases observable differences in water-surface elevations were created by the different conveyance computation methods used by HEC-RAS and HEC-2. The HEC-RAS method appears to compute higher water-surface elevations than the HEC-2 method. However, as pointed out in section 2.4, the HEC-2 conveyance computation method is available in HEC-RAS. Changing the conveyance computation method in HEC-RAS to the HEC-2 method always produced water-surface elevations that are closer to HEC-2 results. HEC-2 conveyance computation method can be selected from the "Steady Flow Analysis" screen. The "Options" feature of the "Steady Flow Analysis" screen contains the menu bar to change the conveyance computation method from HEC-RAS to HEC-2.

9.4.2 Imported Bridge Modeling Data

Adjustments were necessary to the imported HEC-2 Bridge and Culvert input data to obtain correct modeling in HEC-RAS. Either one or more of the following adjustments were included to the HEC-RAS bridge modeling data that was imported from HEC-2:

- Revision of the internal cross section data (accessed through "options" feature available in the "Bridge Culvert Data "screen)
- Revision of the bridge deck data (accessed through the "Deck/ Roadway" feature available in the "Bridge/Culvert Data" screen)
- Revision of the pier data (accessed through "Pier" feature in "Bridge/ Culvert Screen"

The skew factor applied to the bridge and bridge deck geometry was imported correctly into the HEC-RAS model.

9.4.3 Critical Depth Computation

Generally, the critical depth computed by HEC-2 and HEC-RAS matched closely. However, in some cases, the critical depth computed by HEC-2 was smaller than that computed by the HEC-RAS program.

9.4.4 Other Observations

The sensitivity tests included importing HEC-2 input data with tributary modeling, ice jam modeling, and encroachment modeling. HEC-2 model with tributary option was imported into the HEC-RAS; minor modifications were necessary to model flow junction accurately according to HEC-RAS guidelines. Even though, HEC-RAS imported the Ice-jam model into HEC-RAS, the input data needed adjustments before it could be analyzed (by HEC-RAS). Generally, the encroachment data was imported correctly into HEC-RAS. However, minor differences in the surcharge values were observed for HEC-2 and HEC-RAS cross sections located near the bridges. The split flow records were not imported into the HEC-RAS model. However, when the lateral weir and lateral rating curves were manually included HEC-RAS computed corresponding split flow discharges and water-surface elevations. There were minor differences in the results computed by HEC-RAS and HEC-2.

CHAPTER 10: ACQUIRING HEC-RAS

The HEC-RAS computer program and the documentation, HEC-RAS User's Manual, HEC-RAS Hydraulic Reference Manual, and HEC-RAS Applications Guide, can be downloaded from the Internet from the Hydrologic Engineering Center (HEC) home page at:

http://www.hec.usace.army.mil

This home page has useful information on installation problems and ways to resolve these problems.

The program and documentation can be purchased from the official vendors of the HEC as well as from the NTIS. The installation procedure is discussed in Chapter 2 of the HEC-RAS User's Manual.

HEC-RAS is a federally developed program and available to users; there are no copyright restrictions.

APPENDIX A: USE OF HEC-RAS FOR FLOOD INSURANCE STUDIES

The Federal Emergency Management Agency (FEMA) has adopted guidance that hydraulic analyses for contracted Flood Insurance Studies and restudies of entire watersheds (with detailed HEC-2 hydraulic analysis) should be conducted using HEC-RAS instead of HEC-2. Details of this guidance are documented in FEMA Memoranda dated March 14, 1997, October 19, 2000, and February 8, 2000. In addition, FEMA issued a guidance that encouraged the use of HEC-RAS for revisions to effective HEC-2 analyses. This guidance is documented in a FEMA memorandum dated, April 30, 2001. Copies of these memoranda are included in Appendix A.

Federal Emergency Management Agency
Washington, D.C. 20472

March 14, 1997

MEMORANDUM FOR: Regional and Headquarters Engineers
Technical Evaluation Contractors

FROM: Michael K. Buckley, P.E., Director
Hazard Identification & Risk Assessment Division, MT

SUBJECT: Policy for Use of HEC-RAS

The Hydrologic Engineering Center - River Analysis System (HEC-RAS) is planned by its developers at the HEC as a family of hydrologic and hydraulic models for modeling riverine type flows. The purpose of this memorandum is to clarify under what circumstances the one dimensional, steady flow hydraulic model in HEC-RAS may be used for revising NFIP maps, both for FEMA generated studies and restudies, community generated map revisions, as well as for the establishment of BFEs in areas designated as Zone A on NFIP maps. (Note that this is presently the only model in HEC-RAS that has been completed and released to the user community. For the remainder of this memorandum it will be referred to as "RAS".)

GENERAL

RAS is not a new version of HEC-2; it is a new computer program. It meets FEMA's requirements for computer programs specified at 44CFR, Part 65.6(a)(6). Like HEC-2, it is a one dimensional, steady flow, hydraulic backwater model. However, some of its default options for computing water surface profiles, bridge routines, and input and output features are different than HEC-2. A HEC-2 file can be easily imported into RAS. However, the user must change the conveyance computations in RAS and make necessary modifications to the bridge modeling before running RAS to duplicate the results obtained using HEC-2. (The current translator included with RAS is only partially able to convert HEC-2 bridge modeling into a RAS bridge model.)

POLICY FOR USING RAS AS BASIS FOR REVISION TO NFIP MAPS

Studies, Restudies, and Limited Map Maintenance Program Studies (LMMPs). The regional project officer has the responsibility to approve the computer model proposed for use by the study contractor. (See FEMA 37, "Flood Insurance Study Guidelines and Specifications for Study Contractors", January 1995, page 5-2.) The use of RAS for studying previously unstudied streams is encouraged. For contracts not yet negotiated, Version 2.0 should be specified. (Three versions of RAS have been distributed by the HEC to date. Version 2.0 is scheduled for release in the Spring of 1997 and is expected to remain current for some time.)

The use of RAS for restudying a previously studied stream is encouraged, as long as one of the following conditions is met.

- The entire stream is rerun using RAS.
- The stream reach remodeled using RAS is hydraulically independent from the rest of the stream, e.g., the stream is restudied from the downstream confluence with the receiving stream (or other hydraulic control section) upstream to a dam, or other hydraulic control section.

Physical Map Revisions (PMRs) and Letters of Map Revision (LOMRs) Issued Under 44CFR, Part 65.6. The regulations under this part at (a)(8) are applicable and serve to limit the use of RAS (just as they limit the use of other computer programs) unless the basis of the request is that the currently effective model yields less accurate results than RAS, or of course, unless the effective model is RAS. As a practical matter, "less accurate" is always subject to argument. However, if RAS is used as the basis for a PMR or LOMR, one of the two conditions specified above for restudies must be met. Specifically:

- The entire stream must be rerun using RAS.
- The stream reach remodeled using RAS must be hydraulically independent from the rest of the stream, e.g., the stream must be restudied from the downstream confluence with the receiving stream (or other hydraulic control section) upstream to a dam, or other hydraulic control section.

Appeals of Proposed BFEs under 44CFR, Part 67. The policy for PMRs and LOMRs is applicable.

Establishing BFEs for LOMA and LOMR-F Determinations under 44CFR, Part 65.5 and Part 70. RAS, like any other computer program meeting the requirements at 44CFR, Part 65.6(a)(6), may be used for determining BFEs in support of a LOMA or LOMR-F in areas designated Zone A without BFEs.

Federal Emergency Management Agency
Washington, D.C. 20472

October 19, 2000

MEMORANDUM FOR: Doug Bellomo, P.E., Project Officer
Eastern Studies Team

Bill Blanton, Project Officer
Central Studies Team

Mike Grimm, Project Officer
Western Studies Team

Matthew B. Miller

FROM: Matthew B. Miller, P.E., Chief
Hazards Study Branch

SUBJECT: Procedure Memorandum No. 16 – Use of HEC-RAS Version 2.2

Background: The U.S. Army Corps of Engineers (USACE) released HEC-RAS Version 2.2 in late 1998. The changes and improvements in the model can result in significant differences in water surface elevation computations when compared to previous versions of the model, especially in the analysis of bridges and culverts. Attached to this memorandum is a February 8, 2000, memorandum that provides direction on the implementation of the new version.

Issue: Improper use of previous versions of HEC-RAS or improper conversions to Version 2.2 could cause significant processing delays and additional costs in Flood Insurance Study/Restudies and map revision requests.

Final Procedure: Ensure that all applicable requirements for in-house processing of Letter of Map Change requests and Flood Insurance Studies/Restudies are followed as explained in the attached February 8, 2000, memo. Also ensure that all newly contracted studies and restudies utilize Version 2.2 of HEC-RAS as appropriate.

In addition, USACE released a software patch in March 1999 to update the portion of the Version 2.2 that performs the steady flow water-surface profile calculations (SNET) to Version 2.2.1. It is worth noting that, although the patch does update SNET to Version 2.2.1, the version of HEC-RAS remains 2.2. For more information regarding this patch as well as the HEC-RAS program, please visit the USACE Hydrologic Engineering Center's Web site at www.hec.usace.army.mil.

Attachments

cc: See Attached Distribution List

Federal Emergency Management Agency
Washington, D.C. 20472

February 8, 2000

MEMORANDUM FOR: Regional Mitigation Division Directors
Technical Services Division Staff
(See attached distribution list)

[Original signed]

FROM: Michael K. Buckley, P.E., Director
Technical Services Division

SUBJECT: Implementation of HEC-RAS Version 2.2 for NFIP Mapping

The U.S. Army Corps of Engineers released a new version of their hydraulic computer model, HEC-RAS, Version 2.2, in September 1998. The changes and improvements that have been made to this new version are significant. This memorandum outlines the procedures to follow for implementing HEC-RAS Version 2.2 for flood hazard mapping in the National Flood Insurance Program (NFIP). Please note that the accepted models list entitled, "Numerical Models Accepted for NFIP Usage," has been revised to include this version of HEC-RAS.

Summary of Changes in HEC-RAS Version 2.2

The attached document, "HEC-RAS Version 2.2, September Release Notes," outlines the modifications that have been made to this version of the model. The most significant changes are the corrections in bridge and culvert modeling. The previous versions of HEC-RAS incorrectly calculated conveyance through bridges and culverts in pressure flow situations. Specifically, the problems occurred in the momentum equation calculations for bridge analysis and in distinguishing between inlet and outlet control situations for culvert analysis. In general, culverts analyzed with HEC-RAS Version 2.2 under pressure flow will show lower water-surface elevations than previous versions of the model. However, bridges analyzed with Version 2.2 under pressure flow generally show higher water-surface elevations using this version compared to previous versions of the model. The differences in water-surface elevations can be as much as several feet in some instances.

Because of the potential magnitude of the water-surface elevation differences between the versions of HEC-RAS, we request that all entities involved in flood map production begin using Version 2.2 as soon as possible, if they are not already doing so. The following sections outline the procedures to be followed for using HEC-RAS Version 2.2 for all map change requests and Flood Insurance Studies (FISs) in the NFIP flood hazard mapping program.

Procedure for Map Revision and Amendment Requests

Effective immediately, all new map revision and map amendment cases using HEC-RAS will be required to use Version 2.2. For cases that are currently in-house that use previous versions of HEC-RAS, the Technical Evaluation Contractors/Map Coordination Contractors (TECs/MCCs) should rerun the model using Version 2.2 and assess the differences in water-surface elevation. Significant differences, i.e., greater than 0.5 foot, should be remapped to show the correct elevations reported in the Version 2.2 run.

Procedure for Pre-Preliminary Studies (at TECs/MCCs)

For all studies the TECs/MCCs have in-house, the models should be rerun and the differences in water-surface elevation should be assessed. Water-surface elevation differences greater than 0.5 foot and the impacts to the mapping should be brought to the National Office Project Engineer's attention during a regular monitoring visit. At that time, options will be discussed and an estimate should be provided for the required work necessary to correct the mapping to correspond to the Version 2.2 results. Decisions on remapping would be made on a case-by-case basis, with coordination between the FEMA National Office Project Engineers and Regional Engineers.

Procedure for Post-Preliminary Studies (at TECs/MCCs)

At this time, no efforts should be taken to rerun the models for FISs where Preliminary maps have been issued based on previous versions of HEC-RAS.

Procedure for On-Going Studies

For all contracted FISs that have not yet been delivered to the TEC/MCC for processing, the Regional Engineers (Project Officers) should immediately contact their Study Contractors who are performing hydraulic analyses with HEC-RAS and request that they use version 2.2 for the study. All hydraulic models and mapping should be updated prior to delivery to the TEC/MCC.

I trust that this adequately explains the procedures to be taken in utilizing HEC-RAS version 2.2 for NFIP mapping. If you have any questions regarding this matter, please feel free to contact Ms. Sally Magee of our National Office staff at (202) 646-8242, or by e-mail at sally.magee@fema.gov.

Federal Emergency Management Agency

Washington, D.C. 20472

APR 30 2001

MEMORANDUM FOR: Hazards Study Branch, Washington, DC Office
Regional Engineers, Regions I-X
Map Coordination Contractors

FROM: Michael K. Buckley, P.E.
Director, Technical Services Division
Mitigation Directorate

SUBJECT: Policy for Use of HEC-RAS in the NFIP

Background:
The U.S. Army Corps of Engineers (USACE) is a leading Federal agency in the development of hydrologic and hydraulic computer modeling programs. These programs have been used throughout the history of the National Flood Insurance Program (NFIP) for flood hazard mapping and the creation of Flood Insurance Studies (FISs) and Flood Insurance Rate Maps (FIRMs). The HEC-2 computer model is one specific model that has been used extensively throughout the history of the NFIP for hydraulic calculations to determine base (1-percent-annual-chance) flood elevations (BFEs).

The Hydrologic Engineering Center of the USACE released the River Analysis System, HEC-RAS, to replace the HEC-2 hydraulic model. It is a completely new piece of software; in fact, none of the hydraulic routines from HEC-2 were used in the HEC-RAS software. This memorandum addresses the policy for the use of HEC-RAS to replace HEC-2 models for flood hazard mapping in the NFIP.

Issues:
The majority of detailed FISs and FIRMs in existence today have used the HEC-2 model to calculate BFEs. Paragraph 65.6(a)(8) of the NFIP regulations states that computer model used in support of a map revision must use the same computer model as was used in the original study. Since the USACE no longer supports the use of the HEC-2 model, FEMA must determine when it is appropriate to use HEC-RAS when the original study used HEC-2 to determine BFEs.

FEMA issued a policy statement on March 14, 1997, that explained the appropriate uses of HEC-RAS. Briefly, it stated that HEC-RAS could be used for a FIS revision or restudy when one of the following conditions had been met:

- The entire stream was rerun using HEC-RAS; or
- the stream reach remodeled using HEC-RAS was hydraulically independent from the rest of the stream, e.g. the stream was restudied from the downstream confluence with the receiving stream (or other hydraulic control section) upstream to a dam or other hydraulic control section.

Given that the USACE replaced HEC-2 with HEC-RAS, FEMA is hereby revising its policy statement to encourage the use of HEC-RAS when appropriate, using the following guidance.

Final Procedure:

New detailed Flood Insurance Studies:

For FISs that have not yet been started, and for streams for which there is not an effective detailed study, FEMA encourages the use of HEC-RAS rather than HEC-2. Note that other computer models may also be used; FEMA's complete list of acceptable computer models may be viewed on our web site at http://www.fema.gov/mit/tsd/EN_modl.htm. HEC-2 is still considered an acceptable hydraulic model; however the use of HEC-RAS instead of HEC-2 is strongly encouraged.

Revisions to Effective Flood Insurance Studies:

For revisions or restudies of detailed-studied streams, where the effective model is HEC-2, the conversion to HEC-RAS is encouraged. The following guidelines must be followed to convert an effective HEC-2 model to HEC-RAS.

- The effective HEC-2 model should be rerun on the requestor's computer in HEC-RAS to create the duplicate effective model. The differences in water-surface elevation between the effective model and the duplicate effective model must be fully documented and thoroughly explained. Most differences in water-surface elevation can be attributed to the (1) differences in bridge/culvert modeling routines, (2) method of conveyance calculations, (3) critical depth default, and (4) floodway computations. The *HEC-RAS User's Manual* and the *HEC-RAS Hydraulics Reference Manual* provide details on computational differences between the two models and guidance on simulating HEC-2 results; these manuals should be consulted to explain the differences between the effective and duplicate effective models.

- Once the duplicate effective model has been established, the corrected effective, existing conditions, and post-project conditions models can be created in HEC-RAS, using the duplicate effective HEC-RAS model as the basis.

- The HEC-RAS models must tie in to the effective water-surface profile within 0.5 foot at the upstream and downstream ends of the revised reach, in compliance with Subparagraph 65.6(a)(2) of the NFIP regulations.

Because the USACE has replaced the HEC-2 model with HEC-RAS, we support the use of HEC-RAS wherever practicable. I trust that this adequately explains the procedures to convert HEC-2 models to HEC-RAS for flood hazard mapping purposes in the NFIP. If you have any comments or questions, please do not hesitate to contact Ms. Sally P. Magee of our Headquarters staff in Washington, D.C. at (202) 646-8242, or by e-mail at sally.magee@fema.gov.

APPENDIX B: CONVERSION OF HEC-2 INPUT DATA TO HEC-RAS (EXAMPLES)

HEC-RAS can import data from HEC-2 and calculate water-surface elevations based on that data. Some HEC-2 features, however, are treated differently in HEC-RAS. This appendix lists the important observations of sensitivity tests conducted with importing HEC-2 input data sets into HEC-RAS to compare the results.

The HEC-2 model data sets used for examples are as follows:

- **Example 1: Importing HEC-2 Natural Floodplain Model**
- **Example 2: Importing HEC-2 Bridge and Culvert Models**
- **Example 3: Importing HEC-2 Model with a Tributary**
- **Example 4: Importing HEC-2 Ice Jam Model**
- **Example 5: Importing HEC-2 Encroachment Model**
- **Example 6: Importing HEC-2 Split Flow Model**

Example 1: Importing HEC-2 Natural Floodplain Model

INTRODUCTION

This sensitivity test used the HEC-2 model fplnhc.dat. This model is given in the attached computer disk. The HEC-RAS model fplain30.prj is created by importing the HEC-2 model. Few modifications were added to the imported HEC-RAS data in order to obtain results that matched closely with HEC-2.

HEC-2 MODEL OF NATURAL FLOODPLAIN

The floodplain contained no structures. The following HEC-2 features were used in the HEC-2 model fplnhc.dat:

- Title Records, T1, T2, T3
- Comment Records
- Job control records, J1, J2, J3, J5, EJ, and ER
- Manning's roughness coefficient records NC and NH
- Discharge record QT
- Cross section records, X1, GR, X2, X4, and X5

The schematic diagram created by HEC-RAS for this HEC-2 input data is shown in Figure 1.1.

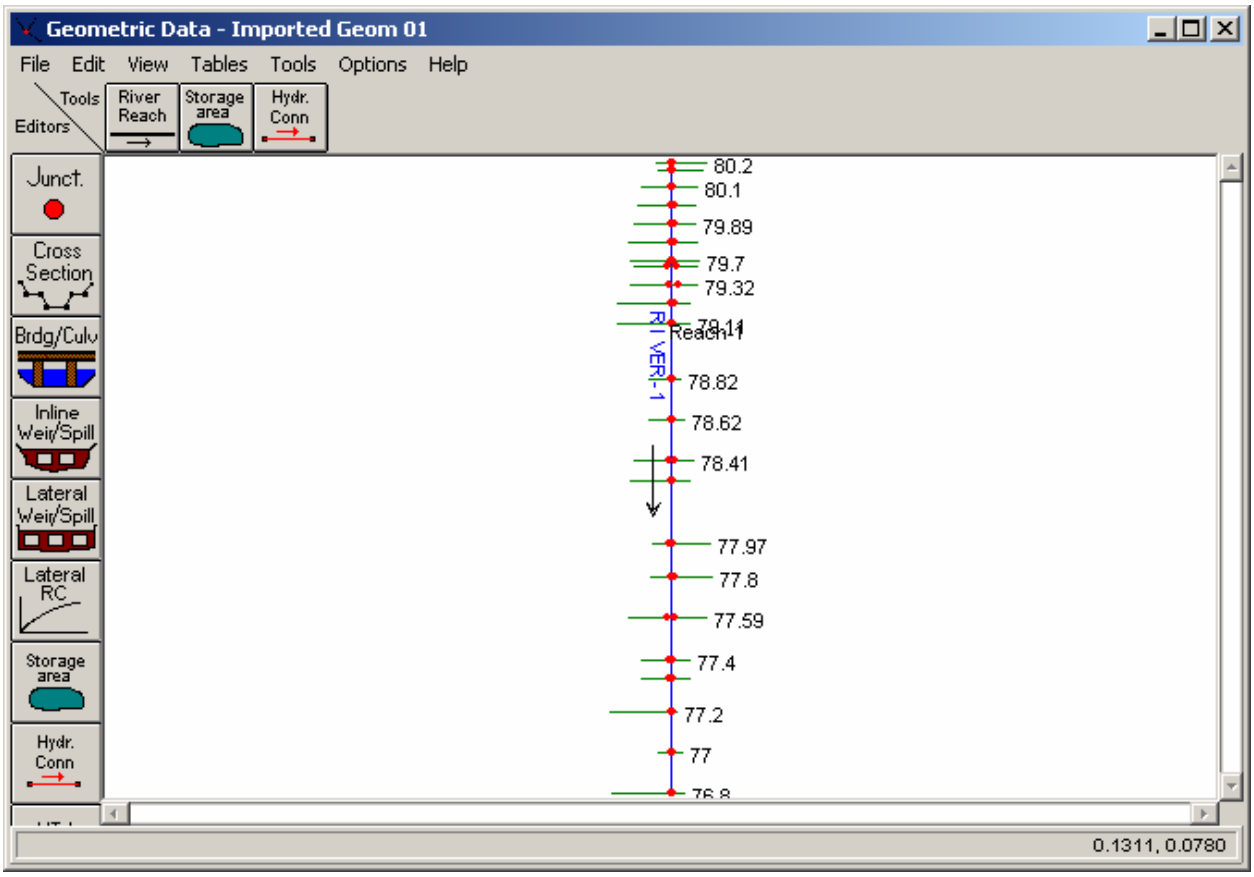


Figure 1.1: Schematic Diagram – Natural Floodplain Model

OBSERVATIONS

The water-surface elevations computed by the HEC-2 model and the HEC-RAS models are compared in Table 1.1. With some revisions to the imported HEC-RAS input data set, HEC-2 and revised HEC-RAS produced comparable results. The differences in HEC-2 and the initial HEC-RAS (raw input data created by HEC-RAS import feature) results appear to be caused by the different algorithms used for the computation of the critical depth of the flow and the conveyance of a cross section. This section summarizes our observations on the performance of the HEC-RAS import feature in importing the HEC-2 model fplnhc.dat.

Table 1.1: Comparison of Water-Surface Elevations – Natural Floodplain Models

Cross Section	Elevation (Feet NGVD)		
	HEC-2	HEC-RAS imported	HEC-RAS Revised
76.8	644.69	644.86	644.69
77	644.89	645.06	644.89
77.37	645.25	645.26	645.25
77.4	645.29	645.31	645.29
77.59	645.36	645.38	645.36
77.8	645.40	645.42	645.40
77.97	645.46	645.49	645.46
78.3	645.60	645.63	645.60
78.41	646.38	645.75	645.71
78.62	645.78	645.82	645.78
78.82	645.86	645.90	645.86
79.11	746.03	746.08	646.03
79.22	646.12	646.16	646.11
79.32	646.25	646.29	646.25
79.89	646.61	646.67	646.61
80.1	646.86	646.91	646.85

Title Records

The alphanumeric data given the first title record T1 are displayed in the project description window of the HEC-RAS main window. The first six lines of the HEC-2 title data (T1 to T6) are imported as the detailed project summary and can be viewed by expanding the project summary window. When "Generate Report" command (HEC-RAS main window under the "File" menu) is used all the title records used in the HEC-2 file are printed.

Comment Records

The HEC-2 comment records placed (using *) within the first six lines of the HEC-2 input data are imported into the detailed project summary available on the HEC-RAS main window. All of the HEC-2 comment records can be viewed in the project summary report generated using "Generate Report" command. The HEC-2 comment record created using record C is reproduced in the description area of the cross section data window. In addition, whenever a cross section is repeated, HEC-RAS creates a note in the description area of the cross section data window. However, in Example 2, "Importing HEC-2 Bridge and Culvert Models", we noted that comment records placed in between HEC-2 GR and BT records interfered with the function of the HEC-RAS import feature. The topographic data entered in HEC-2 GR and BT

records subsequent to a comment record were not imported into the HEC-RAS input data.

Job Control Records

HEC-2 Job control records define the following features:

- Flow regime (J1, field 4)
- Boundary condition (J1, field 5)
- Starting water-surface elevation (J1, field 9)
- English/ Metric Units (J1, field 6)
- Interpolated Cross sections (J1, field 7)
- Discharge (J1, field 8)
- Flow distribution (J2, field 10)
- Multiplying factors for discharge (J1, field 10), and Manning's roughness coefficients (J2, field 6)
- Number of profiles (J2, field 1)
- End job and end run (EJ and ER)

Flow Regime (J1, field 4)
Supercritical and subcritical flow regimes defined in HEC-2 are reflected in the imported HEC-RAS input. Subcritical and supercritical flow regimes are defined in the "Steady Flow Analysis" screen accessed through the "Simulate" command available in the HEC-RAS main screen.

Boundary Condition (J1, field 5)
HEC-RAS imports all starting water-surface conditions that HEC-2 uses. Except for the rating curve, HEC-RAS can also apply different starting water-surface conditions for individual profiles. If HEC-RAS imports a multi-profile HEC-2 model where one of the profiles uses a rating curve, HEC-RAS will assign that rating curve to all other profiles. Boundary conditions are defined in the "Steady Flow analysis" screen accessed through the "Simulate" command available in the HEC-RAS main screen.

English/ Metric Units (J1, field 6)
The definition of units in HEC-2 input data set (J1, 6) is imported correctly into HEC-RAS. The unit system is defined in the "Options" menu available in the main screen.

Interpolated Cross Sections (J1, field 7)
HEC-2 provides a cross section interpolation option, where the interpolation is performed between cross sections with a change in velocity head greater than the value assigned in field 7 of the J1 record. HEC-RAS import feature did not import the HEC-2 input data requesting automatic interpolated cross sections (J1, 7). In HEC-RAS, interpolated cross sections can be created using the "Option" menu in the "Geometric Data" screen. This window is accessed through the HEC-RAS main screen.

Multiplication Factors for Discharge (J1, field 10) and
Manning's Roughness Coefficients (J2, field 6)
Discharge multiplication factor was not imported into HEC-RAS. Manning value multiplication factor was imported into HEC-RAS. However, this factor was used to adjust the roughness coefficient values for all of the profiles. This application is different from HEC-2, where the factors alter the roughness coefficients of the first profile only. In HEC-RAS, the roughness coefficients can be viewed from the "Cross Section Window". This window is accessed through the "Edit" menu of the main HEC-RAS screen.

Discharges (J1, field 8)
The discharge defined in the J1 record of the HEC-2 model is reflected correctly in the imported HEC-RAS input data set. Discharges used in HEC-RAS analysis are defined in the "Steady Flow analysis" screen. This screen is accessed through the "Simulate" menu available in the HEC-RAS main screen.

Number of Profiles (J2, field 1)
The maximum number of profiles computed by the HEC-2 program is 15. Sometimes in HEC-2, this number, which is read in the J2 record (field 1), is used to terminate a multiple profile execution. HEC-RAS ignores this application and proceeds to compute all the profiles originally requested in the imported HEC-2 input.

End Job and End Run (ER and EJ)
In HEC-2 input data set, an ER record placed after J2 record at the end will terminate the HEC-2 computation process with that execution. However, HEC-RAS ignores the ER record and proceeds to complete the runs listed below the ER record (in the imported HEC-2 input file).

Roughness, and Expansion, Contraction Coefficients - NC and NH Records

HEC-RAS imports NC and NH cards from HEC-2 and assigns the roughness coefficients and the expansion, contraction coefficients to the appropriate cross sections except in one case. A NC record added after an NH record to define new expansion and contraction coefficients has made the HEC-RAS to use the roughness coefficients used in the previous NC record in the HEC-2 data set (instead of the data defined in the NH statement for that cross section). A summary of the roughness coefficients and expansion, contraction coefficients used in the HEC-RAS model for all the cross sections can be viewed by using the "Tables" option available at the Geometric Data screen or in the "Cross Section Data" screen for individual cross sections.

Discharge Record QT

HEC-RAS assigns discharge values to cross sections in a downstream direction as opposed to an upstream direction in HEC-2. The discharges assigned in the HEC-2 model are imported correctly into the HEC-RAS input data set. A summary of the discharges used in the HEC-RAS model can be viewed at the "Steady Flow Data" screen.

Cross Section Records, X1, GR, X2, X4, and X5

X1Record
X1 record assigns a numeric name to a cross section and defines the following:

- number of points used in the topographic data (X1, 2);
- channel bank stations (X1, fields 3 and 4);
- distance between cross sections (X1, fields5, 6, and 7); and
- horizontal and vertical adjustments to surveyed stations and elevations (X1, fields 8 and 9).

These data are imported correctly into HEC-RAS and can be viewed through the "Cross Section Data" screen of individual cross sections. The horizontal and vertical adjustments defined in X1 (fields 8 and 9) would have been applied to the HEC-RAS cross section data.

GR Record
Topographic data defined in the GR record are imported correctly into HEC-RAS and can be viewed through the "Cross Section Data" screen of individual cross sections. However, in Example 2, "Importing HEC-2 Bridge and Culvert Models", we noted that comment records placed in between HEC-2 GR and BT records interfered with the function of the HEC-RAS import feature. The topographic data entered in HEC-2 GR and BT records subsequent to a comment record were not imported into the HEC-RAS input data.

X2 Record
Observed water-surface elevations specified in X2 cards are included in HEC-RAS output tables. These elevations can be viewed from the "Options" menu available in the "Steady Flow Data" screen.

X4 Record
Cross section station and elevation adjustments specified in X4 records are imported into HEC-RAS cross section values. Similar to HEC-2, HEC-RAS will not use the specified vertical adjustments (X1, field 9) to modify the data given in an X4 record. Information provided in X1, GR, X2, and X4 records can be viewed using the Cross Section Data screen (through Geometric Data screen).

X5 Record
The known water-surface elevations specified in X5 cards are imported correctly into HEC-RAS. This data can be viewed at "Set Changes in WS and EG" command of the "Options" menu available at the "Steady Flow Data" screen.

CONCLUSION

This sensitivity test indicates that with appropriate changes, the HEC-RAS model computed water-surface elevations identical to those computed by the imported HEC-2 model.

Example 2: Importing HEC-2 Bridge and Culvert Models

INTRODUCTION

HEC-2 models, structure.dat and struct2.dat (provided in the enclosed computer disk) are used in the sensitivity test. These models are identical, except for the removal of unnecessary comment records in struct2.dat. In this sensitivity test, we noted that the HEC-RAS did not import the topographic data (such as the data entered on HEC-2 GR and BT records) entered after HEC-2 comment (*) records in the corresponding HEC-2 model. The str2.prj data file contains the HEC-RAS model created by importing HEC-2 input data in struct2.dat. The HEC-2 model used Normal Bridge, Special Bridge, and Special Culvert procedures to model the flow through 18 bridges and 2 culverts.

HEC-2 MODEL OF FLOODPLAIN WITH BRIDGES AND CULVERTS

In addition to the records necessary to model flows through natural floodplains (which are discussed in Example 1), the following HEC-2 features were used in Struct2.dat:

- Definition of the bridge geometry and piers, BT, X2, GR
- HEC-2 Normal bridge analysis: low flow
- HEC-2 Special bridge analysis: low flow SB
- HEC-2 Special bridge analysis: pressure and weir flow
- HEC-2 Special culvert analysis:
- HEC-2 long pipe flow: SB
- Bridge crossing with a skew

The schematic diagram for this example is shown in Figure 2.1. This diagram is created by HEC-RAS using the imported HEC-2 input data.

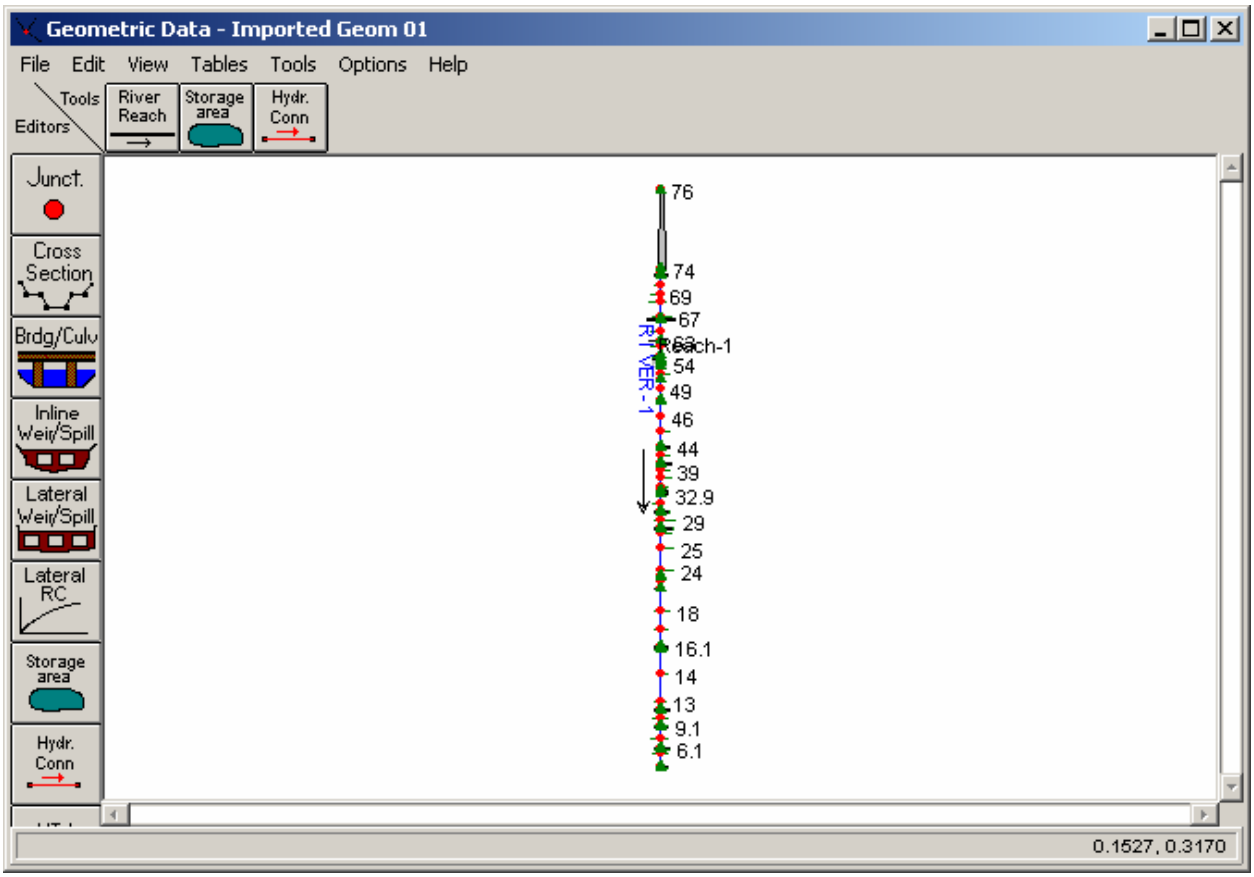


Figure 2.1: Schematic Diagram – Model with Bridges and Culverts

OBSERVATIONS

The water-surface elevations computed by the HEC-2 model and the HEC-RAS models are compared in Table 2.1. The imported HEC-2 geometric data needed some revisions to correctly model the flow through these structures with the HEC-RAS. Except for the HEC-2 Special Bridge Analysis of low-flows in bridges, the modified HEC-RAS model computed flood elevations that compared well with the HEC-2 results. This section summarizes our observations on the performance of the HEC-RAS import feature in importing the HEC-2 model struct2.dat and the modifications included into the raw imported HEC-RAS input data. These modifications were necessary to model the bridge and culvert flows according to HEC-RAS guidelines. A brief summary of methods used by HEC-2 and HEC-RAS to analyze bridge and culvert flows precedes the discussion on modifications included to the HEC-RAS data.

Analysis of Flow Through Bridges and Culverts

In HEC-2, bridge flow is analyzed using Special Bridge, and Normal Bridge analyses. Low flows through bridges are generally analyzed using HEC-2 Normal Bridge analysis. Friction losses and contraction and expansion losses occurring in the vicinity of the bridge structure are considered in computing the water-surface elevations. The pressure and weir flow parameters are defined in the HEC-2 SB and X2 records. The bridge geometry (bridge opening, bridge deck, piers, and over banks) is generally defined using the BT, GR, and X2 records. The culvert flow is analyzed using the input data defined in HEC-2 SC and X2 record.

Table 2.1: HEC-2 to HEC-RAS – Bridge and Culvert Models

Bridge	Cross Section	HEC-2 Method	Changes to HEC-RAS Data	Elevation (feet NGVD)		
				HEC-2	HEC-RAS Imported	HEC-RAS Revised
Private Drive	1.9	Normal Bridge	Define pier Delete cross sections 2&3 Revise the bridge distance	**410.63**	410.57	**410.57**
	2			**410.64**	410.59	**410.58**
	3			**410.67**	410.64	**410.61**
	3.1			**410.72**	410.65	**410.65**

Table 2.1: HEC-2 to HEC-RAS – Bridge and Culvert Models (continued)

Bridge	Cross Section	HEC-2 Method	Changes to HEC-RAS Data	Elevation (feet NGVD)		
				HEC-2	HEC-RAS Imported	HEC-RAS Revised
Visco Drive	4.9	Normal Bridge	Delete cross sections 5&6 Revise the bridge distance Define the piers in "Pier Data" Remove the piers from Internal Cross Section or Road/ Deck data	**411.41**	411.35	**411.35**
	5			**411.41**	411.35	**411.36**
	6			**411.43**	411.38	**411.37**
	6.1			**411.6**	411.55	**411.54**
Rail Road	7.9	Normal Bridge	Delete cross sections 8&9 Add bridge distance at "Road/ Deck" screen Define the piers in "Pier Data" Remove the piers from Internal Cross Section or Road/ Deck data	**412.56**	412.51	**412.51**
	8			**412.51**	412.46	**412.46**
	9			**412.59**	412.54	**412.53**
	9.1			**412.76**	412.72	**412.71**
Unnamed Road	10.9	Normal Bridge	Delete cross sections 11&12 Add bridge distance at "Road/ Deck" screen	**413.73**	413.69	**413.69**
	12			**412.33**	415.86	**415.96**
	12.1			**416.94**	416.9	**416.90**
Interstate 24-40	14.9	Normal Bridge	Delete cross sections 15&16 Add bridge distance at "Road/ Deck" screen	**418.65**	418.63	**418.62**
	15			**418.62**	418.6	**418.6**
	16			**418.76**	418.74	**418.74**
	16.1			**418.87**	418.85	**418.87**

Table 2.1: HEC-2 to HEC-RAS – Bridge and Culvert Models (continued)

Bridge	Cross Section	HEC-2 Method	Changes to HEC-RAS Data	Elevation (feet NGVD)		
				HEC-2	HEC-RAS Imported	HEC-RAS Revised
Rail Road	18.9	Normal Bridge	Delete cross sections 19&20 Add bridge distance at "Road/ Deck" screen	**420.55**	420.54	**420.55**
	19			**420.41**	420.57	**420.41**
	20			**420.57**	420.97	**420.57**
	20.1			**420.72**	420.9	**420.72**
Murfrees.	21.9	Normal Bridge	Delete cross sections 22&23 Add bridge distance at "Road/ Deck" screen Change roughness coefficients of the internal bridge cross sections to match HEC-2 data	**421.83**	421.91	**421.84**
	22			**420.24**	420.41	**420.24**
	23			**421.08**	424.18	**421.10**
	23.1			**430.91**	432.97	**430.92**
Hart St.	26.9	Normal Bridge	Delete cross sections 27&28 Add bridge distance at "Road/ Deck" screen	**432.12**	433.59	**432.14**
	27			**432.14**	433.59	**432.17**
	28			**432.15**	433.6	**432.18**
	28.1			**432.14**	433.6	**432.18**
Factory Street	30	Normal Bridge	Same as other normal bridges	**432.38**	433.7	**432.38**
	31			**432.4**	433.73	**433.43**
RR	32.9	Special Bridge	Adjust pier center line for internal cross sections X5 used to correct HEC-2	**433.63**	434.3	**433.64**
	34			**433.63**	441.2	**440.90**
	34.1			**441.13**	441.41	**441.13**
Moor Av.	39.9	Special Bridge	None	**442.90**	443.01	**442.90**
	40			**442.90**	443.15	**443.06**
Nolensvlle	43	Special Bridge	None	**445.63**	445.64	**445.64**
	44			**446.91**	448.09	**448.05**

Table 2.1: HEC-2 to HEC-RAS – Bridge and Culvert Models (continued)

Bridge	Cross Section	HEC-2 Method	Changes to HEC-RAS Data	Elevation (feet NGVD)		
				HEC-2	HEC-RAS Imported	HEC-RAS Revised
Private Dr.	46.9	Normal Bridge	Same as other normal bridges	**451.23**	451.25	**451.25**
	47			**453.8**	452.77	**453.76**
	48			**454.58**	455.08	**454.55**
	48.1			**454.46**	455.07	**454.44**
Private Dr.	49.9	Special Culvert	None	**457.51**	457.61	**457.51**
	50			**457.51**	457.6	**457.58**
Private Dr.	53	Normal Bridge and Culvert	Same as other normal bridges	**456.58**	456.69	**456.58**
	54			**458.06**	458.08	**457.84**
	54.1			**458.7**	458.74	**458.42**
Private Dr.	55.9	Normal Bridge	Delete cross sections 56&57 Add bridge distance at “Road/ Deck” screen	**461.21**	461.25	**461.26**
	56			**461.22**	461.25	**461.27**
	57			**461.22**	461.25	**461.27**
	57.1			**461.22**	461.26	**461.28**
Private Dr.	58.9	Normal Bridge	Delete cross sections 59&60 Add bridge distance at “Road/ Deck” screen	**461.23**	461.27	**461.29**
	59			**461.24**	461.27	**461.29**
	60			**461.25**	461.27	**461.30**
	60.1			**461.25**	461.28	**461.31**
Bransford	62	Special Culvert	None	**461.52**	461.55	**461.57**
	63			**462.16**	462.4	**462.42**

Table 2.1: HEC-2 to HEC-RAS – Bridge and Culvert Models (continued)

Bridge	Cross Section	HEC-2 Method	Changes to HEC-RAS Data	Elevation (feet NGVD)		
				HEC-2	HEC-RAS	HEC-RAS
Craighead	64.9	Normal Bridge	Delete cross sections 65 & 66 Add bridge distance Define the piers in "Pier Data" Remove the piers from Internal Cross Section or Road/ Deck data	**464.46**	464.46	**464.48**
	65			**464.51**	464.49	**464.53**
	66			**464.14**	464.63	**464.64**
	66.1			**464.64**	464.63	**464.64**
RR	70	Special Bridge	None	**470.05**	470.05	**470.05**
	71			**472.92**	472.75	**472.75**
	72			**477.74**	477.71	**477.71**
	73			**477.81**	477.78	**477.78**
I-440	74	Special Bridge	Revise bridge deck definition for internal cross sections	**477.57**	477.54	**477.54**
	75			**511.19**	499.23	**511.32**

Normal Bridge

In HEC-2 six cross sections are used to define flow through a bridge. Cross sections 1 and 6 represent stream flows that are unaffected by the structure. Cross sections 5 and 2 reflect stream flows just upstream and downstream of the bridge; contraction of flow occurs upstream of the bridge (between cross section 6 and 5) and expansion of flow occurs downstream of the bridge (between cross sections 2 and 1). Cross sections 3 and 4, at the downstream and upstream faces of the bridge, and the bridge deck and road information available in HEC-2 BT records define the geometry of the bridge opening.

Special Bridge

HEC-2 uses four cross sections to reflect a special bridge. Cross sections 1 and 4 represent stream flows that are unaffected by the structure. Contraction of flow occurs upstream of the bridge (between cross sections 4 and 3) and expansion of flow occurs downstream of the bridge (between cross sections 2 and 1). Cross sections 3 and 4 are at the downstream and upstream of the bridge, respectively and the bridge deck and road information available in HEC-2 BT records define the geometry of the bridge opening. The coefficients provided in HEC-2 SB records are used to analyze pressure and weir flow through the bridges.

HEC-RAS Analysis of Flow Through Bridges
HEC-RAS used four stream cross sections and two internal bridge cross sections to define the flow through a bridge. Cross sections 1 and 4 represent stream flows that are unaffected by the structure. Contraction of flow occurs upstream of the bridge (between cross sections 4 and 3) and expansion of flow occurs downstream of the bridge (between cross sections 2 and 1). The bridge geometry is defined through the "Bridge Culvert Data" screen accessed through the Geometric Data editor. To define the bridge geometry, HEC-RAS requires two internal cross sections (defining the bridge opening), bridge deck data, and pier data. The HEC-RAS internal bridge cross sections are automatically altered to match the cross sections immediately upstream and downstream of the bridge (HEC-RAS cross sections 3 and 2). However, this automatic alteration feature is terminated once the internal cross section is manually revised.

HEC-RAS does not distinguish between a 'normal' and 'special' bridge as HEC-2 does. For low flows through bridges, the user can select from four methods: Energy, Momentum, Yarnell, and WSPRO. For, high flows, two methods are available. They are Energy method, and Pressure and Weir method. Generally, Energy method is assigned to HEC-RAS bridge flow data imported from HEC-2 Normal Bridge data. Pressure and Weir method is assigned to HEC-RAS bridge flow data imported from HEC-2 Special Bridge data.

Analysis of Flow through Culverts
Both, HEC-2 and HEC-RAS uses the Federal Highways Administration's inlet control and outlet control analysis method to compute the flood elevations for flow through culverts.

Skew Angles
HEC-RAS reflected the skew factor in defining the bridge and bridge deck geometry for the bridge at cross section 28. HEC-RAS internally adjusted the ineffective flow areas on the internal bridge cross sections were also adjusted to reflect the skewed geometry of the bridge.

Summary of Modifications to HEC-RAS Bridge and Culvert Models

General
Roughness Coefficients:
For the bridge at cross section 23, roughness coefficients defined at HEC-2 cross section just inside the downstream face of the bridge (Cross section 3 for HEC-2 normal bridge model) were not imported into the HEC-RAS model. The correct roughness coefficients of the internal bridge cross sections were revised to match those defined in the HEC-2 model. In HEC-RAS, these roughness coefficients are accessed through "Options" feature available in the "Bridge Culvert Data "screen.

Imported HEC-2 Normal Bridge Model

Piers:
HEC-RAS model, created by the imported HEC-2 input data, reflected the piers through the bridge deck data or internal cross section data. In this example, four Normal Bridge models used pier data and needed revision. Generally, the revision of pier data in HEC-RAS included one or all of the changes listed below:

- Revision of the internal cross section data (accessed through "options" feature available in the "Bridge Culvert Data "screen)
- Revision of the bridge deck data (accessed through the "Deck/ Roadway" feature available in the "Bridge/Culvert Data" screen)
- Revision of the pier data (accessed through "Pier" feature in "Bridge/ Culvert Screen")

Bridge Cross Sections:
HEC-RAS created the internal cross sections from the upstream and downstream cross sections (HEC-2 cross sections 4 and 3) used in the normal bridge analysis. However, these cross sections are also repeated as stream cross sections (HEC-RAS Bridge Sections 3 and 2) in the HEC-RAS model at zero distance from the faces of the bridge, respectively. In order to comply with the HEC-RAS bridge modeling guidance, the stream cross sections at the bridge faces should be deleted (using the "Options" feature available in the "Cross Section Data" screen). The pier data can be revised using the "Pier Data Editor" available in the "Bridge and Culvert" Screen of the HEC-RAS.

Imported HEC-2 Special Bridge Model

Piers:
HEC-RAS assumed that the pier defined in the SB record is located at the center of the channel bank stations. If the location of the pier is different, the HEC-RAS model will need a revision. It has to be noted that the actual number of piers present in the bridge structure may be more than one. It is recommended that the number of piers and their location, if known, should be included in the HEC-RAS input. In this example, the bridge at cross section 34 needed to be revised.

Class A low Flow:
Large differences in water-surface elevations were observed between the HEC-2 class A low flow computation for the bridge at cross section 34 and the HEC-RAS result. In this case, the HEC-2 computation appears to use unrealistically large flow areas. Therefore, for comparison purposes, the computed water-surface elevation at cross section 34 of the HEC-2 model struct2.dat was revised to match the HEC-RAS result. HEC-2 X5 statement was used for this purpose.

Discharge Coefficients:
Weir and pressure flow coefficients used in the HEC-2 model are imported accurately into the HEC-RAS model.

Long Pipe Flow:
The downstream bridge deck data of the HEC-RAS model for the bridge at cross section 75 was revised to match the downstream cross section geometry. HEC-2 defines the bridge deck geometry at the upstream cross section location only. Due to the large distance between the cross sections, it was necessary to revise the upstream bridge opening geometry to match the downstream topography.

Bridge Opening Area:
In the special bridges considered for the sensitivity test model, the bridge opening area computed by HEC-RAS from the Deck/Roadway data generally matched that used in the HEC-2 special bridge analysis. The maximum difference was 10%, and the bridge opening area computed by the HEC-RAS was larger. However, according the HEC-2 Special Bridge modeling guidelines, the HEC-2 cross sections 2 and 3 (upstream and down stream of the bridge) will reflect the valley sections. These sections, when combined with the Deck/Roadway geometry may not reflect the bridge opening accurately, as required for the HEC-RAS internal bridge cross sections. It is recommended that, if the bridge opening area between the HEC-2 and HEC-RAS differ, additional data to represent the bridge opening should be entered into the HEC-RAS input files.

Cross Section 44:
A difference of 1.22 feet was observed between the bridge flow computations at section 44. The HEC-2 elevation for this cross section is computed by assuming critical flow. However HEC-RAS does not assume critical flow conditions to prevail at this cross

section. HEC-RAS uses energy method to compute the elevation. The cause of this difference is explained in a letter by the USACE as follows:
"Both programs are trying to use the Pressure and Weir flow method to get a solution for the bridge. The solution that both models come up with yields an energy elevation lower than the downstream energy grade line. This is not a valid solution, so HEC-2 just defaults to critical depth. However, HEC-RAS is more advanced, in that when pressure and weir method fails to come up with a valid solution, it will automatically defaults back to trying the energy based method. In this case, HEC-RAS is able to get a solution with energy method, but HEC-2 defaults to critical depth. The HEC-RAS answer is more appropriate, as critical depth is not the right answer.

Imported HEC-2 Special Culvert

Culvert models were imported correctly from HEC-2 Special Culvert model input data.

CONCLUSION

The results of the sensitivity test indicate that with appropriate changes to the imported HEC-RAS model, both the HEC-2 and HEC-RAS models, can compute comparable water-surface elevations. One major difference was noted between the water-surface elevations computed by the HEC-2 special bridge analysis for low bridge flows. In this case, it appeared that the HEC-RAS computations were more appropriate than the HEC-2 results.

Example 3: Importing HEC-2 Model with a Tributary

INTRODUCTION

HEC-2 model, prop.dat (provided in the enclosed computer disk) is used in the sensitivity test. The HEC-2 model reflected a floodplain with one tributary and a long culvert. The Tributary option available in HEC-2 was used to determine the overland flow that existed in the vicinity of the long culvert. In the HEC-2 model, an internal rating curve is used to determine the flow through the culvert.

HEC-2 MODEL WITH A TRIBUTARY

In addition to the records necessary to model flows through natural floodplains and culverts, the following HEC-2 features were used in prop.dat:

- Definition of the tributary flow with a negative station number, X1
- Internal rating curve, RC

The schematic diagram for this example is shown in Figure 3.1. This diagram is created by HEC-RAS using the imported HEC-2 input data.

OBSERVATIONS

Table 3.1 compares the flood elevations computed by HEC-2 and HEC-RAS models. The results of the sensitivity test indicated that, with some revisions, the HEC-2 and HEC-RAS models computed comparable water-surface elevations. Major differences (up to 0.7 foot) were created when the computed water-surface elevations were obtained from the critical depth computations.

The HEC-2 input data used identical cross sections to model the main flow path as well as the over flow path. In HEC-RAS, different cross section numbers are necessary to define tributaries. Therefore, imported HEC-RAS model created its own cross section numbers to identify cross sections. These cross section numbers varied from 1 to 24.

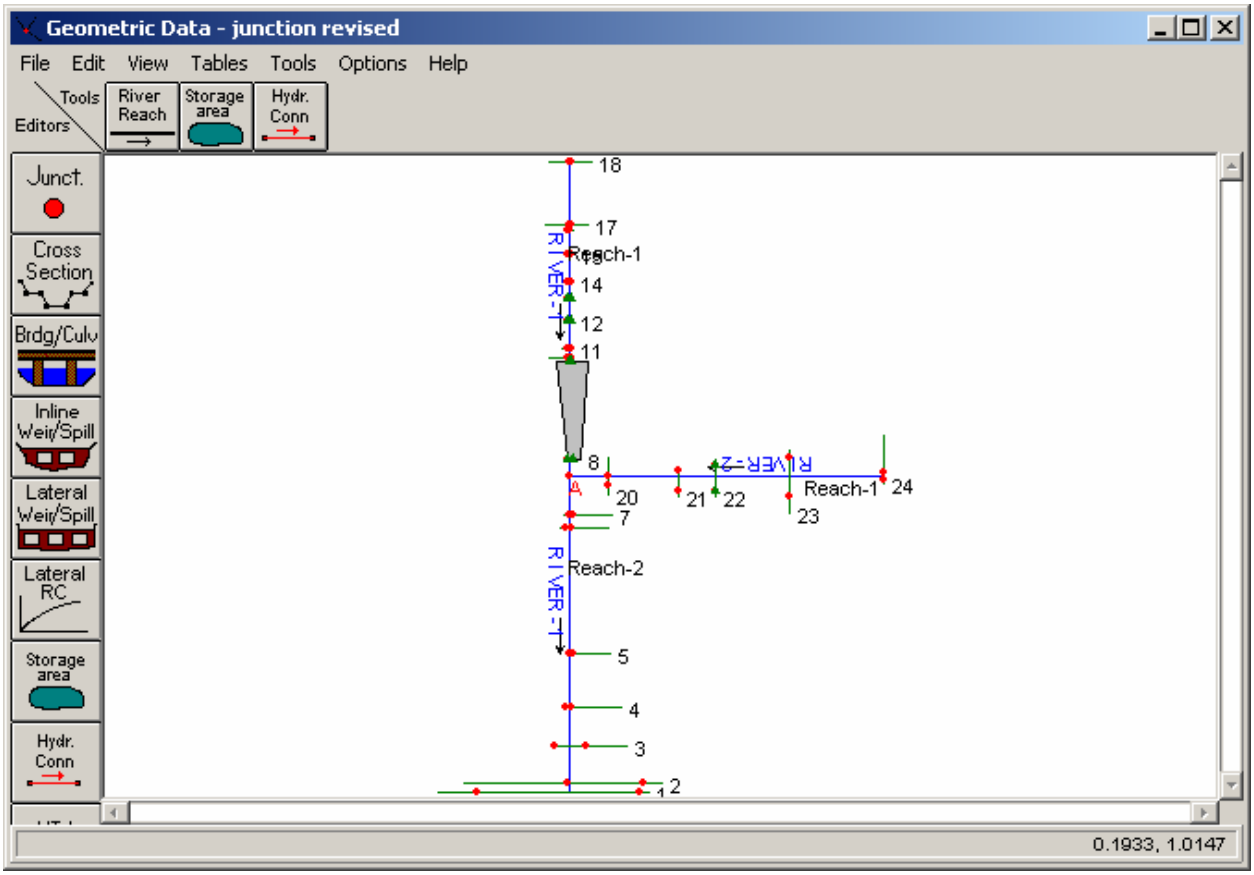


Figure 3.1: Schematic Diagram – Model with a Tributary

Table 3.1: HEC-2 to HEC-RAS – Model with a Tributary

HEC-2 Cross Section	HEC-RAS Cross Section	Elevation (feet NGVD)	
		HEC-2	HEC-RAS Revised
1	1	844.20	844.20
20	2	844.20	844.20
108	3	844.20	844.20
200	4	844.07	844.07
330	5	844.02	844.02
630	6	843.89	843.89
690	7	844.00	844.00
870	8	845.48	845.48
1470	9	852.34	852.39
1485	10	854.00	854.00
1535	11	853.98	853.98
1687	12	854.00	854.00
1805	13	854.01	854.02
1895	14	854.25	854.25
2042	15	854.39	854.39
2167	16	854.54	854.54
2090	17	855.21	855.21
2420	18	857.02	857.03
Tributary			
-690	19	844.00	--
890	20	851.51	851.98
1070	21	853.45	853.44
1170	22	853.76	853.75
1360	23	853.79	853.77
1486	24	853.79	853.77

The river system schematic reflected the origin of the tributary correctly. The river system can also be modeled as looped network using the junction option available in the HEC-RAS. However, HEC-RAS has the capability to compute the discharges in different branches of the loop. However, the imported HEC-RAS model was not modified to model a looped network.

The distances of the cross sections at the junction were not correctly defined in the HEC-RAS model. The distance of the most downstream cross section of the tributary from the junction was imported incorrectly. The correct distance of 200 feet was typed in. Differences in computed water-surface elevations between HEC-2 and HEC-RAS models appear to be at locations where these elevations were equal to critical depths.

It has been generally observed that HEC-2 and HEC-RAS programs compute different critical depths for the same flow at a cross section.

CONCLUSION

This sensitivity test illustrates that a HEC-2 model with tributary option was imported into the HEC-RAS. However, minor revisions were necessary to model flow junctions according to HEC-RAS guidelines.

Example 4: Importing HEC-2 Ice Jam Model

INTRODUCTION

The HEC-2 model icejam.dat provided in the enclosed computer disk is used in the sensitivity test. This model has four floodplain cross sections, two of which are modeled to reflect ice cover in the channel. The imported HEC-RAS model is stored in icejam.prj. Computed water-surface elevations computed by HEC-2 and HEC-RAS agreed well.

HEC-2 MODEL WITH ICE-JAM MODELING

In addition to the records necessary to model flows through natural floodplain, the HEC-2 model contained the HEC-2 record IC to reflect ice cover thickness. The schematic diagram for this example is shown in Figure 4.1. This diagram is created by HEC-RAS using the imported HEC-2 input data.

OBSERVATIONS

HEC-RAS imported the ice analysis data correctly from the HEC-2 input file. However, zeros and repeated ice parameters of the HEC-2 data set had to be retyped in the imported plan. Both programs computed similar water-surface elevations. Table 4.1 compares the water-surface elevations computed by these two programs.

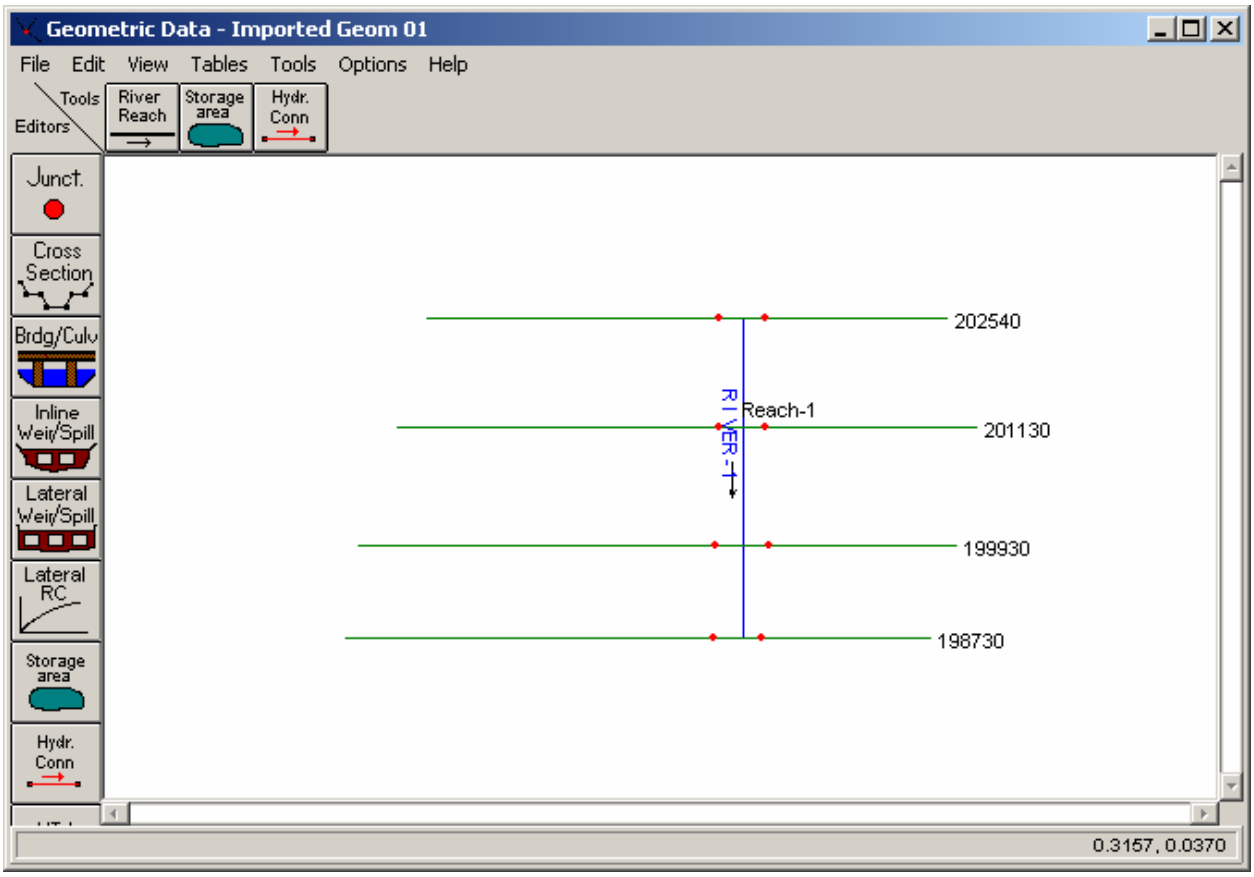


Figure 4.1: Schematic Diagram – Ice Jam Model

Table 4.1: HEC-2 to HEC-RAS – Ice Jam Model

Cross Section	Remarks	Elevation (feet NGVD)	
		HEC-2	HEC-RAS Revised
198730	known	1103.10	1103.10
199930	ice	1103.45	1103.40
201130	ice	1104.24	1104.30
202540	no ice	1104.52	1104.58

CONCLUSION

The results of this sensitivity test indicate that the ice analysis data was imported correctly into HEC-RAS and similar flood elevations are computed by HEC-2 and HEC-RAS.

Example 5: Importing HEC-2 Encroachment Model

INTRODUCTION

This sensitivity test used the HEC-2 model enc-br.dat (provided on the enclosed disk). The encroachment analysis methods 4 (equal conveyance reduction method) and 1 (known encroachment stations), available in the HEC-2 program were used in enc-br.dat. This model analyzed the flow in a floodplain with one bridges. The bridge was modeled using HEC-2 special bridge modeling method.

HEC-2 MODEL WITH ENCROACHMENT MODELING

In addition to the records necessary to model flows through natural floodplain, and bridges, the HEC-2 model enc-br.dat contained the HEC-2 Encroachment record ET.

The schematic diagram for this example is shown in Figure 5.1. This diagram is created by HEC-RAS using the imported HEC-2 input data (encbrdge.prj).

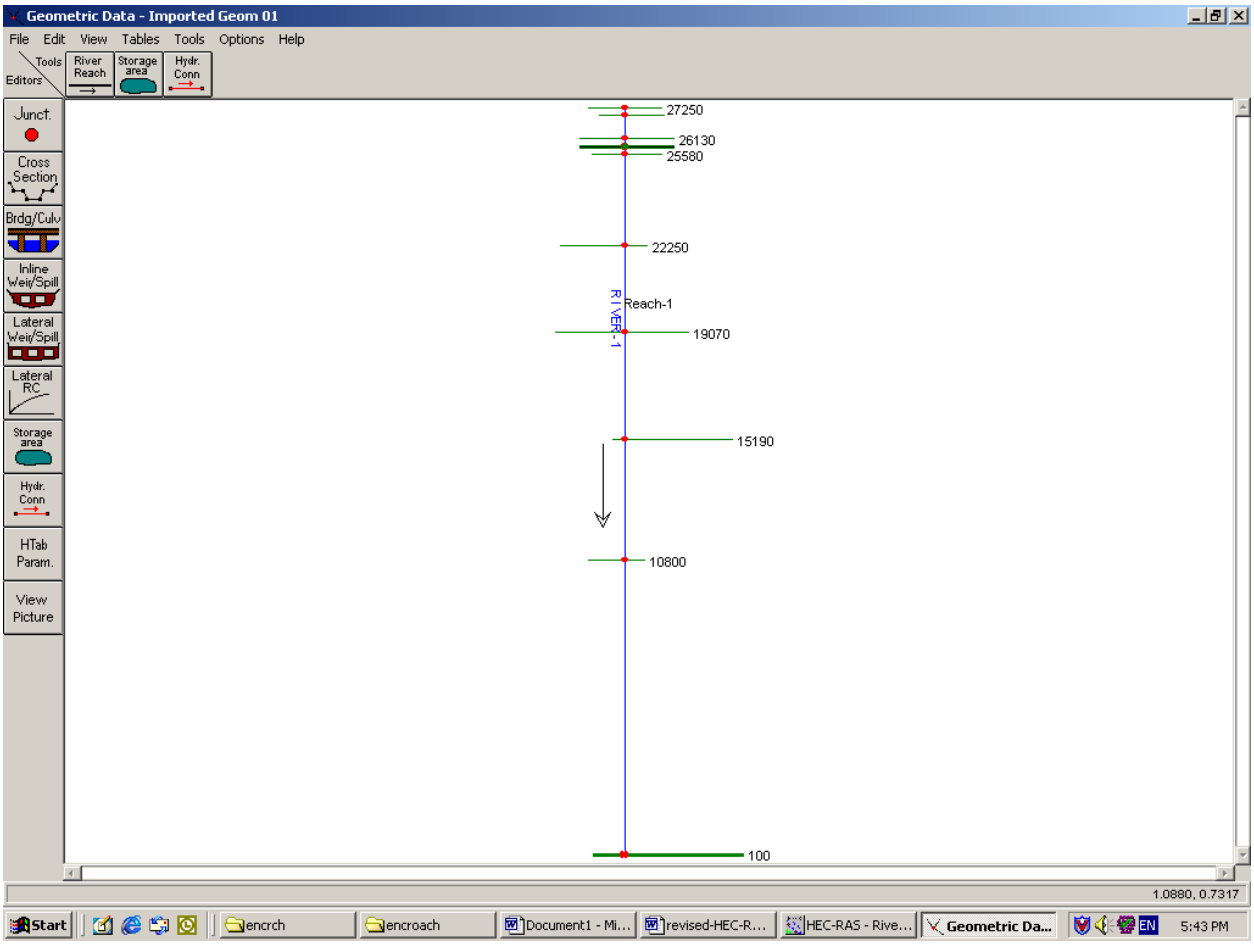


Figure 5.1: Schematic Diagram – Encroachment Model

OBSERVATIONS

HEC-RAS imported the encroachment analysis data correctly from the HEC-2 input file enc-br.dat. However, the ineffective flow modeling done using ET records for the natural profile were not imported into the HEC-RAS model. In the HEC-2 model encrs.dat, the ineffective flow modeling is conducted using X3 records. This allowed the ineffective flows to be correctly imported into the HEC-RAS input data using the options, Ineffective Areas and Blocked obstructions. These features are accessible through the "Options" menu available in the "Geometric Data" screen.

In the sensitivity test, the HEC-RAS input was modified (as explained in Example 1) so that the HEC-2 method was used to compute the conveyance. The flood elevations computed for the natural flood profile generally matched with the HEC-2 results, the maximum difference being 0.22 foot. However, the flood elevations computed by the HEC-RAS for the encroached floodplain matched more closely with those computed by HEC-2. The differences of approximately 0.2 foot were observed between the surcharge values computed by HEC-2 and HEC-RAS programs.

CONCLUSION

Encroachment data was imported correctly into HEC-RAS. The minor differences in the water-surface elevations observed between the HEC-2 and HEC-RAS computations appear near the bridge locations.

Example 6: Importing HEC-2 Split Flow Model

INTRODUCTION

This sensitivity test used simple HEC-2 models split.dat with six cross sections and splitwr.dat with four cross sections (provided on the enclosed disk). The HEC-2 rating curve option was used in split.dat. The HEC-2 model splitwr.dat used weir flow option to model split flow. These two models analyzed the flow in a floodplain with out any bridges. In the sensitivity test, it was necessary to redefine the lateral weir geometry in HEC-RAS from the topographic data. Split flows modeled using the lateral weir flow option as well as the rating curve option available in HEC-2 (splitwr.dat and split.dat) and HEC-RAS (splwweir.prj and splitrat.prj) computed comparable results.

HEC-2 MODEL WITH SPLIT FLOW MODELING

In addition to the records necessary to model flows through natural floodplain, the HEC-2 models split.dat and splitwr.dat included the HEC-2 split flow records SF, TW, TC, WS, WC, CS, CR, and EE. In addition, X3 records were used to model ineffective flow on the over banks. The schematic diagram for the imported HEC-2 model splitwr.dat (lateral weir example) is shown in Figure 6.1. The schematic diagram for the imported HEC-2 model split.dat (rating curve example) is shown in Figure 6.2. These diagrams are created by HEC-RAS using the imported HEC-2 input data and manual inclusion of lateral weir flow and rating curve data necessary to model the split flow.

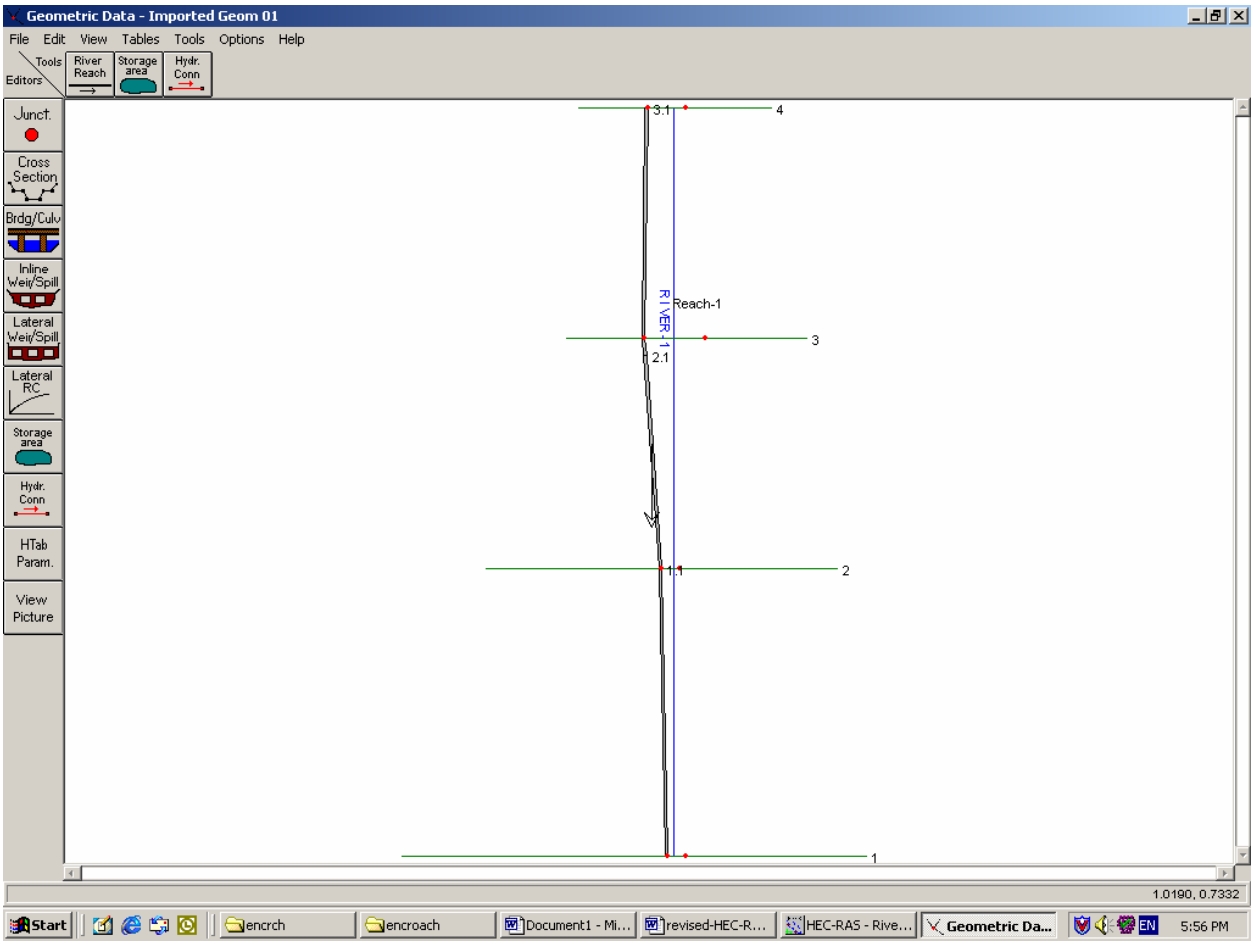


Figure 6.1: Schematic Diagram – Split Flow Model, Lateral Weir Example

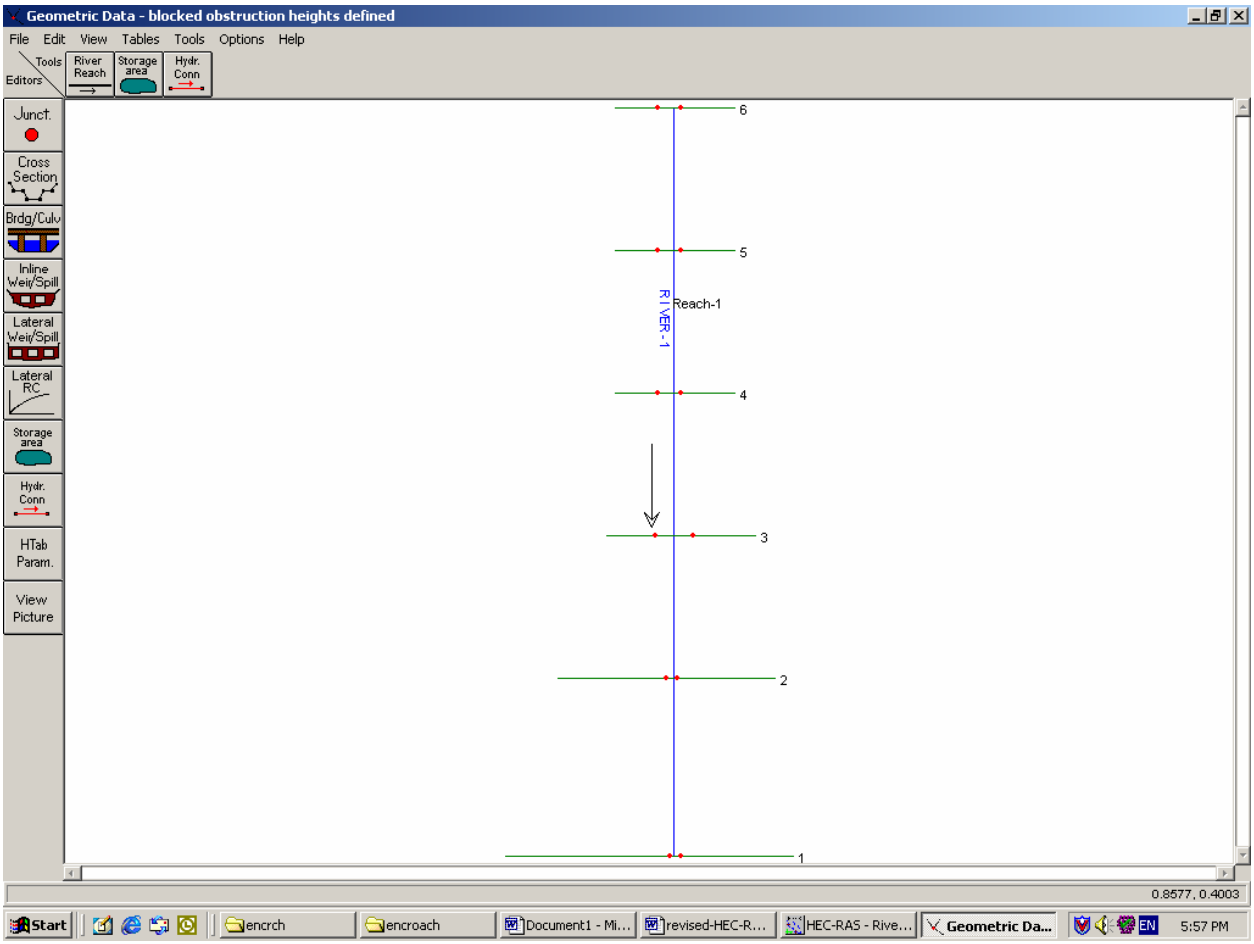


Figure 6.2: Schematic Diagram – Split Flow Model, Rating Curve Example

OBSERVATIONS

The split flow parameters are not imported by HEC-RAS. However, the floodplain modeling data of the HEC-2 input file, i.e., the data below the HEC-2 title records T1, T2, and T3 were imported. In order to match the HEC-2 results without split flow, the HEC-RAS model cross section data needed to be modified. When the lateral weir dimensions and the rating curve were manually inserted into the input, HEC-RAS computed split flow discharges and flood elevations that are comparable to HEC-2 results.

In HEC-RAS, the lateral weir can be defined more accurately along the left or right over bank of the channel than it is possible with HEC-2. This may be one factor that contributed in causing different results. HEC-2 lateral weirs can have lengths larger than the overbank flow distance. For the most downstream cross section, HEC-RAS expected the weir lengths to be shorter than the overbank flow distance.

In HEC-2, the weir geometry is defined from the downstream cross section. HEC-RAS defines the weir geometry from upstream to downstream. This fact should be considered when HEC-2 split flow data are converted into HEC-RAS.

OBSERVATIONS

HEC-RAS imported the floodplain modeling data correctly from the HEC-2 input file. HEC-RAs conducted split flow analysis when the lateral weir and rating curve information was manually included. Differences in results were observed between the HEC-2 and HEC-RAS outputs. Table 6.1 compares the water-surface elevations and discharges computed by these two programs.

Table 6.1: HEC-2 to HEC-RAS – Split Flow Model, Lateral Weir Example

Cross Section	Remarks	Elevation (feet NGVD)		Discharge (cubic feet/ second)	
		HEC-2	HEC-RAS	HEC-2	HEC-RAS
1		20.07	20.77	24,409	24,594
2	Lateral weir	24.75	25.47	26,765	24,594
3	Lateral weir	26.34	26.11	39,816	39,966
4	Lateral weir	28.48	28.05	40,000	40,000

Table 6.2: HEC-2 to HEC-RAS – Split Flow Model, Rating Curve Example

Cross Section	Remarks	Elevation (feet NGVD)		Discharge (cubic feet/ second)	
		HEC-2	HEC-RAS	HEC-2	HEC-RAS
1		25.26	25.26	38,281	35,258
2		31.00	30.99	38,281	35,258
3		33.74	33.73	38,281	35,258
4	Rating Curve	33.73	33.83	40,000	40,000
5		34.50	34.40	40,000	40,000
6		35.22	35.14	40,000	40,000

CONCLUSION

Split flow data was not imported into HEC-RAS. However, when these data were manually typed into the imported HEC-2 model, HEC-RAS results compared well with HEC-2 results.