CHAPTER 8

GUIDELINES FOR HYDRAULIC MODELING USING HEC-RAS

8.1 Purpose

The USACE Hydrologic Engineering Center (HEC) has long been recognized as one of the most respected centers for hydraulic modeling software in the water resources community. In the mid 1960's, the HEC began development of models that soon became the water surface profile program HEC-2. For nearly 30 years, HEC-2 was probably the most widely used and accepted program worldwide for determination of water surface elevations. In 1993, the HEC introduced HEC-RAS (River Analysis System), the first version of their Windows based software for water surface profile calculation. The current version of HEC-RAS can be obtained from HEC's website.

The IDNR encourages the use of HEC-RAS for regulatory and floodplain management purposes within Indiana. While models developed with other software packages are acceptable, this chapter is written from the point of view of developing a HEC-RAS model acceptable to IDNR. The purpose of this chapter is to offer suggestions for more effectively creating and using a HEC-RAS model. Many of the concepts presented here are applicable to many other software packages. Additional issues regarding other modeling packages are discussed in Chapter 9 of these guidelines.

The HEC-RAS steady state model uses the standard step-backwater method for calculation of water surface profiles. The HEC-RAS manual, along with many basic hydraulic engineering texts, describes this computational methodology. The modeler should have a good working knowledge of methodologies the program uses in the calculation of the water surface profiles. Problems often seen in modeling results could easily be avoided if common hydraulic principles were understood and applied by model developers.

8.2 Program Versions

The most current version of HEC-RAS should be used unless it is necessary to reproduce the results of a previous model. Updates and improvements to the software cause differences in the versions that sometimes produce different results. When it is necessary to reproduce the results of a previously developed model, care should be taken to ensure that the correct version of HEC-RAS is used.

8.3 Program Defaults

The cross-section conveyance default method within HEC-RAS should be used unless the goal of a model is to match a previous HEC-2 model. Refer to Chapter 9 for a more detailed discussion of this topic.

HEC-RAS also allows the user to choose from a number of different methods for calculating the friction slope between cross-sections or allows the program to choose the friction slope equation based on given criteria. The default equation in HEC-RAS, which is the Average Conveyance Equation, should be used.

8.4 Discharges

Options for obtaining discharges are described in Chapter 7. The 100-year peak discharge is used for regulatory purposes in Indiana.

8.5 Multiple Plans

HEC-RAS has the ability to develop multiple plans within a given project using different combinations of geometry and flow data. This ability facilitates review and comparison of plans by allowing the modeler or reviewer to display more than one plan on the tables and plots.

The use of multiple plans also allows the model developer to easily retain elements that do not change between model runs. For example, the modeler saves the Corrected Effective geometry as the Pre-Project geometry and modifies only the data needed to make it the Pre-Project geometry. This geometry is then combined with the appropriate flow file to create the Pre-Project Plan. Results of the Corrected Effective Plan and the Pre-Project Plan can then easily be compared. Use of this feature is strongly encouraged for models that will be submitted to IDNR for review. When submitting to IDNR all extraneous project plans should be removed.

8.6 Starting Water Surface Elevations

In the development of a hydraulic model using the standard step-backwater method, a boundary condition is required for starting water surface profile calculations. If the flow condition being analyzed is subcritical, the starting water surface elevation at the downstream study reach must be determined using an appropriate method.

The 100-year flood for most Indiana streams and rivers typically occurs within the subcritical flow regime. However, the modeler should carefully review flow conditions to determine if supercritical flow occurs in any portion of the study reach. In the event that supercritical flow occurs, application of supercritical or mixed flow (subcritical and supercritical) regime calculations schemes should be discussed with IDNR staff prior to development of a flood model for that reach of stream.

If the flow regime of the entire study reach is determined to be within the subcritical flow regime, several factors affect the selection of the appropriate starting water surface elevation that should be used for the base model, regulatory elevation, and floodway model. Find the situation for your model in Table 8-1 to select the appropriate starting water surface elevation. Each option is explained following the table.

Table 8-1: Determination of Starting Water Surface Elevation

<table>
<tr><td colspan="2" rowspan="2">Scenario</td><td colspan="3">Starting Water Surface Elevation for:</td></tr>
<tr><td>Floodplain Model</td><td>Regulatory elevation</td><td>Floodway model</td></tr>
<tr><td rowspan="3">stream does not include a confluence with a large receiving stream or river</td><td>accepted flood study has previously been developed downstream</td><td>Option 1</td><td>Option 1</td><td>Option 1 elevation +0.1’ & use published floodway encroachment locations</td></tr>
<tr><td>Accepted flood study has not previously been developed but historic flood profiles are available</td><td>Option 2</td><td>Option 2</td><td>Option 2 elevation + 0.1’</td></tr>
<tr><td>None of the above are available</td><td>Option 3</td><td>Option 3</td><td>Option 3 elevation + 0.1’</td></tr>
<tr><td rowspan="2">Stream does include a confluence with a large receiving stream or river</td><td>peak flow conditions of the tributary and the larger receiving stream or river can be assumed to be coincident*</td><td>Option 4</td><td>Option 4</td><td>Option 4 elevation + 0.1’</td></tr>
<tr><td>peak flow conditions of the tributary and the larger receiving stream cannot be assumed to be coincident*</td><td>Option 5</td><td>water surface elevation that has been computed/ published for the larger receiving stream extended horizontally back up the tributary until it meets the tributary’s computed flood elevation</td><td>Option 5 elevation + 0.1’</td></tr>
</table>

upstream of a flood control reservoir	Option 6	Option 6	Option 6 elevation + 0.1'; assume the floodway is as wide as the 100-year floodplain at each cross-section that falls within the 100-year level of the reservoir.

* ratio of the drainage areas at the confluence lies between 0.6 and 1.4, the times of peak flows are reasonably similar for the two combining watersheds, and the likelihood of both watersheds being covered by the storm being modeled is high

Starting Water Surface Options:

1. If an accepted flood study has previously been developed downstream, use the ending 100-year flood elevation of the downstream study as the starting elevation and, if possible, use the accepted flood study cross section at that point as the first cross section. For this to be applicable the downstream study must abut the downstream end of the proposed study reach, there must be no separation.

2. If historic flood profiles are available, use the average slope of the historic profile which most closely approximates a 100-year flood profile at the start of the proposed study reach, as defined by the equation in Section 3.5.1, and apply the slope-area method to determine the starting water surface elevation.

3. Use the average thalweg slope, from best available mapping, at the start of the proposed study reach, as defined by the Equation in Section 3.5.1, and apply the slope-area method to determine the starting water surface elevation.

4. Use the larger receiving stream's computed/published water surface elevation for the flood event being analyzed as the starting elevation for the tributary profile computations.

5. Use the average thalweg slope and slope-area method to start the flood profile near the mouth of the tributary.

6. Use the computed peak flood stage of the reservoir for the flood event being modeled as the starting elevation

8.7 Manning's Roughness Coefficients

Values of Manning's roughness coefficients ("n") applied in all new flood models require supporting documentation. Also, any modification of "n" values from published or accepted flood models requires supporting documentation. Many hydraulic engineering texts include tables of "n" values and, in some cases, photographs showing representative values. Many of the sources listed in the bibliography include discussions of applying "n" values. These values are typically representative for streams and rivers in Indiana.

Some factors to consider in selecting roughness coefficients are:

- When choosing "n" values for the base condition model, select values that most likely existed at the time the cross-section data that are being used were obtained. If any new construction existed at the time, use "n" values assuming an aged condition for that portion.

- When choosing "n" values for calibration of a model, use values representative of the conditions existing at the time of the flood being used for calibration.

- When modeling a new project, choose "n" values appropriate for the aged condition of the project.

8.8 Flood Model Calibration

Calibration of a flood model is a tool or procedure to assess "n" values for a flood model. Calibration can also be used to identify areas where more in depth evaluation of ineffective flow areas or elevations is needed. Being able to closely replicate observed flood elevations with a flood model lends credibility to the model. If available and applicable, use high water marks and discharges provided by the IDNR. Consider other sources of information, such as USGS published discharges and USACE high water marks. If available, use stream gage information to the extent that it is applicable.

Consider the quality of the high water marks or gage data when trying to match model results to observations. Tie into any upstream study that has been approved unless errors are discovered in the upstream study's elevations. If conditions have changed significantly since the time of the historic flood for which high water marks exist, use the high water marks as a guide instead of for direct calibration. Use cross-section data appropriate for the conditions at the time of the flood being calibrated. A model is considered calibrated if it matches good quality, applicable high water marks within six (6) inches.

8.9 Cross-Sections

Cross-section location and orientation guidance is provided in Chapter 5.
The user should verify that the transition top width between any two sections can reasonably occur in the distance between the sections. The user should also verify that changes in distribution of flow between cross-sections are reasonable. As an example, cross-sections that are spaced very close should show similar flow rates in each overbank and the channel. In the event that the flow rates are not similar, the cross-section geometry or parameters may not be appropriate.

Lengths between cross-sections should be measured in each overbank along the anticipated path of the center of mass of the overbank flow. Channel reach lengths are typically measured along the thalweg.

8.10 Ineffective Flow Areas and Blocked Obstructions

Ineffective flow areas and blocked obstructions are often used to represent or approximate the resulting effects of structures or constrictions in a flood model. Ineffective flow represents areas where flow velocities are very low (i.e., areas having a combination of flow velocities less than 0.5 feet per second and depths less than three feet). Using the ineffective flow area option does not add wetted perimeter to the cross-section so is more appropriately used for reducing the flow area based on upstream or downstream constrictions. Ineffective flow stations should not be set inside the bank stations.
Blocked obstructions can be used where the cross-section geometry does not include an obstruction. The blocked obstruction option does add wetted perimeter and should be used appropriately. An example of the appropriate use of blocked obstructions would be to model a large building.

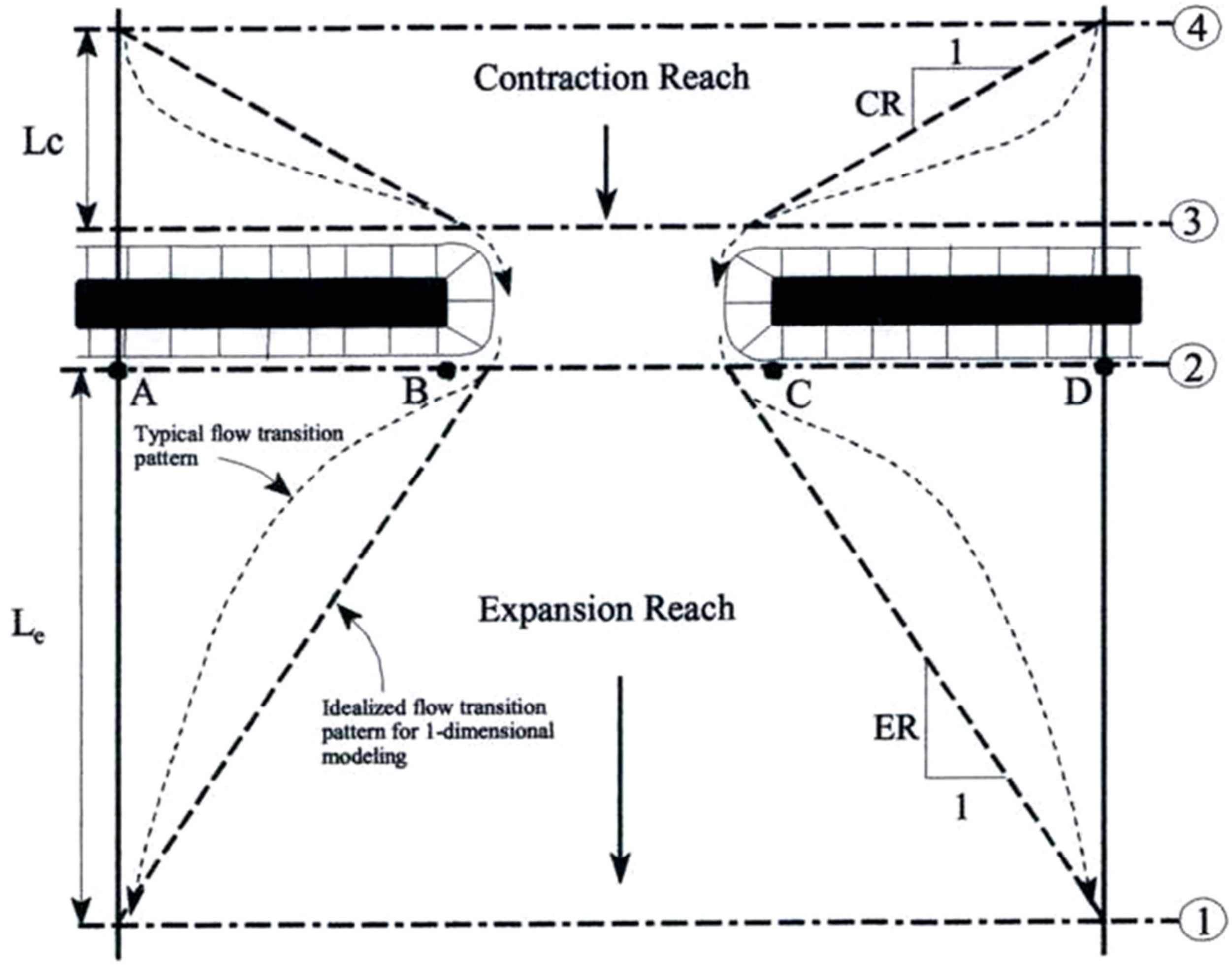
8.11 Bridges

Suggestions for obtaining bridge data are presented in Chapter 5. Presented here are ideas on how to effectively use the bridge data in HEC-RAS.

Figure 8-1 shows the four cross-sections typically needed in the vicinity of a bridge. Cross-section 1 is downstream of the expansion effect of flow coming out of the bridge and its location is usually based on a 2:1 expansion ratio (ER=2) downstream from the bridge.

Cross-sections 2 and 3 should be located at the toe of the bridge fill, respectively, on the downstream and upstream side of the bridge face. These cross sections should represent the natural ground adjacent to the bridge. If there are roadside ditches along the bridge fill, the cross-sections should not include the ditch. If flow is confined to the bridge opening, these cross-sections will not be fully effective across their entire length. Typically, ineffective flow limits are set at these sections to adjust for the contraction and expansion of flow at the bridge. In most cases, the effective flow is wider than the bridge opening at these sections and, therefore, the horizontal placement of the ineffective flow stations should be wider than the bridge opening, based on the expansion and contraction limits at the bridge. Because these ineffective flow limits are representing a water to water interface, under no circumstances should cross-sections 2 or 3 include the fill for the bridge. Also, make sure to use applicable upstream and downstream embankment side slopes on the Bridge Deck/Roadway data editor.

Figure 8-1. Four cross-sections are typically needed in the vicinity of a bridge to adequately represent the bridge in HEC-RAS.



The elevations specified for the ineffective flow limits should correspond to the elevations where flow passes over the bridge/culvert approaches. For cross-section 2, the left and right overbank ineffective limiting elevations should initially be set between the maximum elevation of the low chord and the minimum approach roadway elevation on each side of the bridge opening. For cross-section 3, the left and right overbank ineffective limiting elevations should be initially set at the minimum approach roadway elevation on each side of the bridge opening.

After each program run, the bridge calculations output should be reviewed to be sure the flow calculations (e.g. pressure/weir, low flow) are appropriate for the computed water surface elevations and that the ineffective limiting elevations are appropriate. Adjustment to the ineffective elevations may be necessary to create flow locations that are consistent through the bridge reach.

Cross-section 4 is upstream of the contraction effect of the bridge and is usually set based on a 1:1 contraction ratio (CR=1). On some occasions, conditions dictate that cross-sections either be taken or interpolated within either the contraction or the expansion reach. This is acceptable, provided care is taken so that appropriate ineffective flow limits are included for any interior cross-sections.

Typically, contraction and expansion coefficients in and around a bridge are increased from a standard of 0.1 and 0.3 to values of 0.3 and 0.5. These coefficients should be increased at cross-section 2 (modeling the losses between 1 and 2) and changed back to normal values after cross-section 4. In some instances different values for these coefficients may be appropriate. However, confer with the IDNR in advance of using different coefficients.

Piers and abutments should be represented in the HEC-RAS model. Refer to Chapter 5 for discussion of pier and abutment data.

Energy, momentum, Yarnell, and WSPRO are the four low flow methods within HEC-RAS. Typically the energy and momentum methods are both run and the highest energy answer is used. The Yarnell method, a holdover from HEC-2, is no longer acceptable for modeling purposes. Using the WSPRO method is acceptable but note that additional data are needed for the proper application of this method. Refer to the HEC-RAS or WSPRO manuals for details.

For high flow methods, the two options are the pressure and weir method and the energy (standard step) method. The pressure and weir method should be used where weir flow over the road could occur, typically with one to five feet of flow over the road with relatively narrow floodplains. The weir length used in the model must be consistent with the flow width upstream and downstream of the bridge. The energy method should be used in cases where friction losses will dominate such as for very wide floodplains, very shallow or very deep flow over the bridge, and perched bridges. Verify that if pressure flow is calculated for a bridge, the resulting elevation is such that pressure flow can really occur.

HEC-RAS has the option to use the Multiple Bridge opening method, which can mix and match the high flow methods with culvert methods and “normal cross-section” methods to more accurately model a bridge. See the HEC-RAS manual for more information. Other types of hydraulic structures can be modeled using HEC-RAS, including weirs, gates, and spillways. Refer to the HEC-RAS manual for the proper application of the program for these cases.

Skewed bridge crossings do not provide effective flow area equal to the actual opening. Therefore adjustment to an equivalent cross section perpendicular to flow may need to be made. The decision of how to adjust the bridge dimensions (and piers and corresponding bounding cross sections) is based on the skew angle and whether or not the road approaches are overtopped. The skew angle is the angle of the flow as it goes through the bridge compared with a line perpendicular to the bridge opening or cross sections bounding the bridge. The skew angle should not be based on the direction of the flow upstream of the bridge as the flow will likely turn somewhat before going through the bridge opening. The modeler is referred to the HEC-RAS Hydraulic Reference Manual and the Federal Highway Administration Hydraulic Design Series 7 (HDS 7) for detailed explanation of adjusting the data. Below in Table 8-2 is a summary of the angles for which adjustments are required. The method used should be noted in the bridge description.

Table 8-2: Skew angle applications

Skew Degrees	Adjustment to bridge <u>opening</u> (low flow)	Adjustment to <u>bridge approaches</u> if road overtopping
0-20	No adjustment necessary	No adjustment necessary
20-30	Adjust bridge opening based on the projected opening as described in the RAS manual and HDS 7	If weir flow – no adjustment necessary If energy flow – adjust same way as for opening
>30	Consider alternative modeling approach such as 2D analysis	Adjust based on requirements of selected modeling approach

8.12 Culverts

In HEC-RAS, the techniques for setting up a culvert model are essentially the same as setting up a bridge model. Refer to the HEC-RAS manual for typical coefficients used for different culvert losses. Carefully examine model results for the reasonableness of the computation scheme, that is, inlet or outlet control.

8.13 Critical Depths

HEC-RAS will default to a critical depth solution in two common instances:

- The program cannot solve the equations in a specified number of trials (usually 20)

- The normal depth solution indicates that the flow regime has changed from subcritical to supercritical flow.

The first of these instances is usually indicative of a deficiency with the input data. Engineering judgment is needed to apply corrective measures in these instances. If ineffective flow elevations are close to the water surface elevation they may need changed. Variations in top width should also be checked and abrupt changes should be smoothed by using ineffective flow areas. Abrupt changes in area should also be reduced by the addition of transition sections. Intermediate or interpolated cross-sections could also be added. The HEC-RAS interpolation routine is useful for this, however, the HEC-2 interpolation routine is flawed and should not be used. In some cases, more field data may be necessary to alleviate the problems in the model.

If the program is defaulting to critical depth because of an indicated change in the flow regime, the model should be examined carefully to be sure that critical depth would be a reasonable solution. One key that supercritical flow may be a reasonable solution is when a series of consecutive cross-sections default to critical depth. In many cases, deficiencies that prevent solving the equation also cause an apparent switch of the flow regime. HEC-RAS has the ability to model a mixed flow regime, and indicate the location of hydraulic jumps, if present. Instances of supercritical flow are rare in Indiana. Therefore, a model must be carefully evaluated before supercritical or mixed flow can be accepted. Discuss these cases with the IDNR before the submission of models for review.

8.14 Floodways

A floodway is defined by encroaching on each cross-section in succession, reducing equal conveyance on each overbank, so as not to exceed the maximum allowable surcharge. In Indiana, the maximum allowable surcharge is 0.14 feet. Steps that should be followed in the development of the floodway are:

- Calculate the floodway based on the 100-year peak discharge.
- Retain bridges in the model for floodway computations (for detailed models that are required to include all crossings).
- Because cross-sections should span the entire floodplain as previously described, a floodway may not be calculated by a model that uses truncated cross-sections unless those cross sections span the entire naturally effective flow area.
- Base a floodway on a channel improvement project as long as that improvement is maintained and operated by a government entity or is an IDNR approved flood control project.

- In the past, “eye-balled” floodways (floodways drawn by following the floodplain but cutting off odd shaped portions to create smooth looking delineations) were allowed. These should be avoided unless there is no alternative. Prior approval should be obtained through the IDNR. If there is no alternative and an “eye-balled” floodway is used, the reason must be documented.

- Use method 4 (the equal conveyance method) within HEC-RAS, for the preliminary determination, setting a surcharge limit of 0.1 (or 0.14) feet, to get a computer generated floodway. HEC-RAS method 4 will automatically set the starting elevation for the floodway profile 0.1 (or 0.14) feet higher than the base run water surface elevation.

- Plot the computer generated encroachment stations on the project mapping. Plot the floodplain limits as a guide for critiquing the preliminary floodway.

- Do not encroach, for floodway purposes, within the channel banks. If the 100-year flow is confined within the channel banks, set the encroachment stations at the channel bank stations.

- Apply encroachments for determining a floodway at any cross-section with ineffective flow if the effective flow is defined as a “natural” ineffective flow area and is not due to a bridge.

- If the model required the establishment of ineffective flow limits at a bridge, set the encroachment stations at the limits of the base model ineffective flow. The floodway to be plotted on mapping, however, should not be based on these stations but on the encroachment stations at the closest stations that are not artificially narrowed. In other words, the floodway should not be “necked down” at a bridge, but should be delineated using the cross-sections just outside the contraction or expansion zones (cross-sections 1 and 4 as defined in Figure 8-1)

- After plotting the computer generated encroachment stations, choose revised encroachment stations to be input to the model and tested for allowable surcharges based on:

    - Smooth floodway boundaries (avoid hour glass effect)

    - Maximum surcharges of less than 0.15 feet when comparing the “base model” elevation and the “base model with floodway” elevation

    - Choose easily definable and locatable boundaries where possible

- When road overflow occurs, adjust the initially calculated encroachment stations to be aligned with properly adjusted upstream and downstream delineations.

- When the 100-year flood discharge is confined to a long culvert approved under the Flood Control Act (or existing prior to January 1, 1973) and there is no overland flow, the floodway is delineated overland as the vertical extension of the width of the culvert.

- If a culvert approved under the Flood Control Act features overland flow during the 100-year flood, the vertical extension of the width of the culvert plus the overland flow area is the floodway.

- If the culvert was not approved or grandfathered under the Flood Control Act, the floodway should be both the pre-construction floodway plus the post-construction floodway.

- If used, interpolated cross-sections should be identified as such and then used as a guide for, but not exact stationing for, the floodway boundary.

- Where levees are approved and credited with 100-year protection, draw the floodway limit on the landward toe of the mainline and tributary levees.

- When delineating the floodway boundary between cross-sections in the model, the floodway should:

    - not be narrower at any spot between sections than at the section on either end

    - follow the general shape of the valley

    - be contained within the floodplain

- As a default, the floodway upstream of a restrictive structure (e.g., some railroad crossings) or approved flood control structure which temporarily stores water should be the entire area used for storage of the 100-year flood if a routed elevation is used for the floodplain elevation upstream of the structure. When delineation of an encroached storage floodway becomes necessary on a case by case basis, an encroached storage floodway boundary may be calculated by excluding storage volume associated with shallow areas along the perimeter of the ponding area until the maximum surcharge reaches 0.14 feet. Since equal conveyance concept is not applicable for a storage floodway area, the proposed delineation should be performed in such a way that the impacts on all affected property owners are as equitable as possible. An advance consultation with the IDNR staff is highly recommended.

- The floodway option in HEC-RAS often calculates wide floodways with velocities less than 0.5 feet per second and shallow (less than three feet) depths if there is a wide floodplain and low velocities in the overbank. Because of the low velocities and depths, it is often hard to justify calling portions of the area floodway. (This applies to significant reaches where this occurs, not just a couple of cross-sections here and there.) When this situation occurs, options must be discussed with IDNR staff prior to delineation.

- Naturally occurring areas (not elevated as a result of construction or land development) which are above the BFE but which lie planimetrically within the final calculated encroachment stations may be shown to be out of the floodway if the “island” is included in the model.

- The final floodway stations for each cross-section should be specifically entered into the model, using method 1. This will allow future users of the model to know explicitly where floodway stations were chosen at the time of the delineation of the floodway.

- Decisions made regarding the floodway boundary based on criteria other than that described in the preceding should be annotated in the floodway model after discussion with the IDNR.

8.15 Check RAS

FEMA developed Check-RAS, a program that performs a basic level check of a HEC-RAS model for various errors and reasonableness. The program offers these five checking routines:

- NT (Manning’s roughness coefficients and transition loss coefficients)

- XS (cross-sections)

- Structures (bridges and culverts)

- Floodways

- Profiles (if more than one is computed)

Proper completion of the Hydraulic Modeling Checklist requires the modeler to run and submit all applicable reports using this program. All errors or warnings shown as comments in the Check-RAS reports should be reviewed by the modeler and either fixed or explained in a written report to be included with the submitted model. Check-RAS messages should be evaluated using engineering judgment since some messages can be explained by examination of the model. The reports are intended to be a useful guide for correcting coding errors and determining values for bridge coefficients.