Notes on Critical Depth

This document should not be considered a complete discussion on the topic of open channel hydraulics or stream modeling; it is not a substitute for a good hydraulics text or the HEC-RAS program manuals. Refer to the document [General Guidelines for the Hydrologic-Hydraulic Assessment of Floodplains in Indiana] for general information regarding modeling requirements for the Division of Water. This is written assuming HEC-RAS as the modeling program; but the general concepts are applicable to any hydraulic modeling program. I acknowledge that there may be situations where these items might not be applicable, the complexities of hydraulic modeling precludes a comprehensive look at every possible instance of critical depth problems.

What is critical depth?

In open channel hydraulics, critical depth is the depth of flow (for a given discharge) where the specific energy is at a minimum. The total energy head (specific energy) for a cross section is given by:

$$H = WS + \frac{\alpha V^2}{2g}$$

Where H is the total energy head, WS is the water surface elevation and $\alpha V^2 / 2g$ is the velocity head. Typically, the minimum specific energy can be shown in an Energy vs. Water Surface Elevation diagram, as shown below:

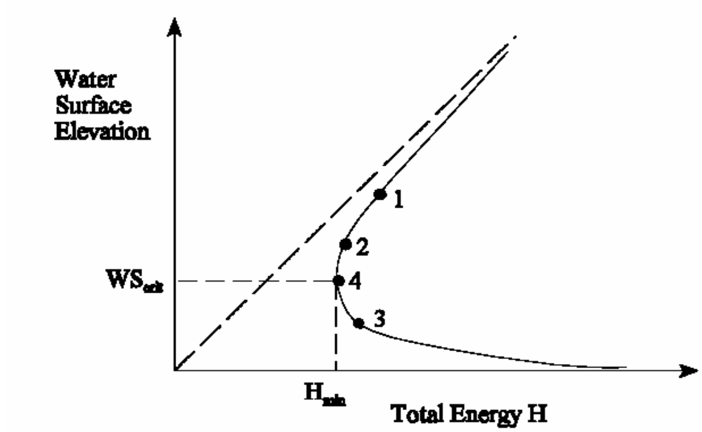

Figure 2.6 Energy vs Water Surface Elevation Diagram

Depths of flow greater than WS_{crit} are known as subcritical flow while depth of flow less than WS_{crit} indicates supercritical flow.

What does it mean when HEC-RAS defaults to critical depth?

It means mainly either of two things:

- The steady flow equations cannot be solved in a given number of trials (typically 20 trials)
- During the iteration process, depth of flow for a trial goes below critical depth (assuming a subcritcal profile), indicating a possible hydraulic jump, and an invalid subcritical solution.

Why is defaulting to critical depth not acceptable?

- The program is not really calculating an answer, it is "giving up" on trying to solve the equations, either because its tried too many times, or conditions indicate that a proper solution is not obtainable.
- Critical depth assumptions can mask project surcharges, or can cause calculation problems in defining floodways.

What can be done?

- Look at not only the offending cross section, but at the section downstream. The program is having a problem with the calculations between the cross section in question and the section just downstream. Often the problem section is the downstream section.
- Check cross sections for obvious errors, many problems of this type are caused by bad data in the model. When importing old HEC-2 files, "spikes" in the data are often apparent.
- Also when importing HEC-2 files, look for "cracks" in low chord data at bridges. HEC-2 required that the low chord data matched the cross section exactly. However, this was easy to mess up, resulting in small openings that do not contribute much cross sectional area to a section, but a large amount of wetted perimeter. Delete extraneous low chord data and let HEC-RAS "clip" the road profile to the section automatically.
- Bridges that are coded with the road fill within the section often cause critical depth errors, since extra losses are introduced into the bridge solution by artificially extending the bridge to the bounding sections, which is not appropriate.
- Check cross section locations – are the cross sections located correctly?
    - Is the cross section going up a tributary swale?
    - Are they located perpendicular to flow?
- Are more cross sections needed in the model?
    - Check alpha – does it change greatly from section to section

  - Is the flow distribution reasonable? (between overbank and channel, or between left and right overbank, and/or between downstream and current section)
  - Is there a large difference in cross section shape from the downstream cross section?
- Look at sections for possible ineffective flow regions – is there a case to be made for adding ineffective flow to a section? Look for portions of the cross section where you may have very shallow "split flow" that would be adding wetter perimeter to a section without adding much cross sectional area.
- Also look for inappropriate top width transitions. Can flow reasonably contract / expand in the distance between sections?
- Look at channel stations for each cross section – are they consistent from section to section?
- Look at channel slopes between sections – are changes due to localized pools and riffles (or a scour hole) than can/should be ignored?
- Commonly, cross sections are taken from detailed contour mapping, where the thalweg of the stream is estimated. Since most contour mapping does not reflect elevations under water, stream slopes may not be representative using only mapping data. Enhance the mapping data by taking field channel sections.
- Try removing the offending cross section – does the critical depth go away? Or is it transferred to the next section upstream?
- Interpolate cross sections…

What can be gained or lost by interpolating sections?

Interpolation of extra cross sections between two sections is the most common way critical depth problems are solved at the Division of Water. The interpolation routine within HEC-RAS is easy to use (and undo if you have problems). There are items to consider when interpolating:

- Interpolation should be considered only a "mathematical" solution to help solve the equations, so don't treat them like "real" cross sections.
- Don't use more than a couple (maybe 5 max) interpolated cross sections between any two sections. Too many sections make the model a pain to debug and review, and you reach a point of diminishing returns (if 5 sections don't work, then 50 sections won't work either).
- Make sure the interpolation looks reasonable.
- Use judicially – only interpolate when necessary.
- Don't use the interpolation routine within HEC-2. The interpolation parameters are based on flow depth, so differences in depths will give you different interpolated cross sections, making your model inconsistent from run to run.

Are there times when defaulting to critical depth is acceptable?

A true hydraulic jump or supercritical flow is rare, given the basic models reviewed or complied by the Division of Water are

- Larger streams (with a drainage area greater then 1 square mile)
- Have fairly flat slopes
- Are modeling the 100 year frequency flood discharge

But if you are looking at modeling a small upland stream, with a steep slope, or a low flow discharge, then it may be reasonable to have mixed or supercritical flow. This is often apparent by a series of cross sections defaulting to critical depth, not just one or two. It is easy to set HEC-RAS to calculate a supercritical or mixed flow profile.

Another instance where it might be reasonable to assume critical depth is at some sort of structure that is changing the flow characteristics of a stream. One place that the Division of Water encounters supercritical or mixed flow (legitimately) is for a spillway for a dam. Indeed, the "Pressure and Weir" solution for a bridge is an assumption of critical depth at the weir; since it's not an "error" it's not reported as such.

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Version 0.1 February 2003