

Advanced Unsteady Features in HEC-RAS

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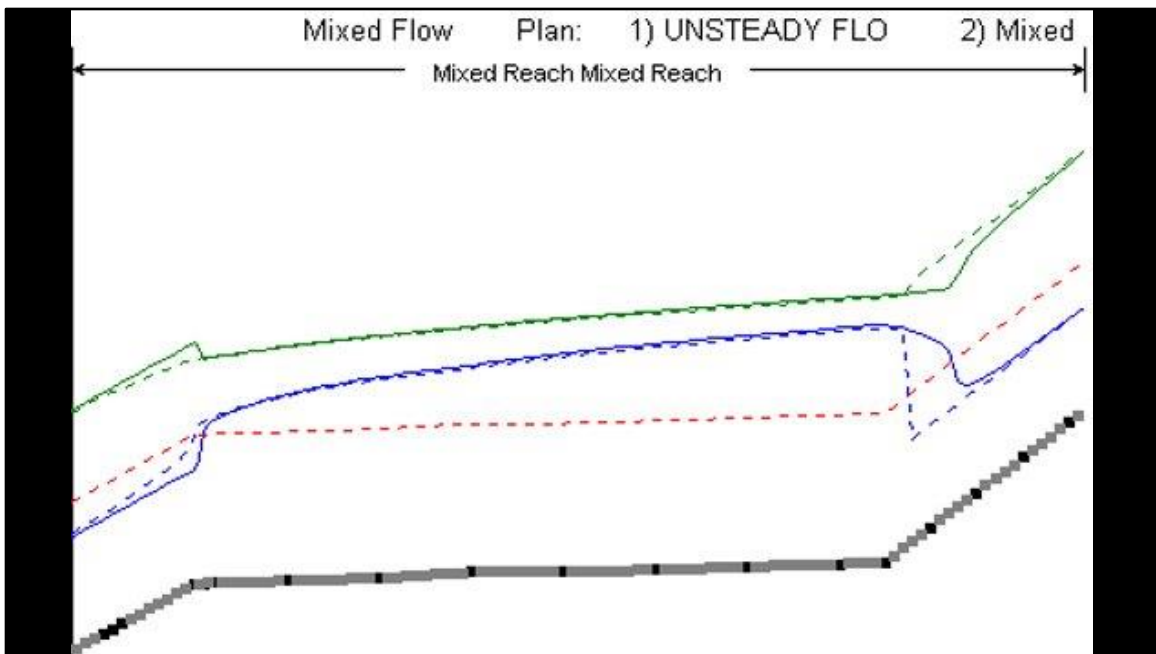




Overview:

1. Mixed/Supercritical Flow
2. Modified Puls (Hydrologic Routing)
3. Pressurized Pipes





This may actually be a better representation since the steady flow assumption of the jump happening entirely between two adjacent cross sections is unrealistic when the cross sections are closely spaced. However, in the vicinity of the hydraulic jump the inertial terms can be quite large (rapid change in velocity with respect to distance), so the water surfaces in this region should be regarded as approximate at best. The subcritical region in the middle has a very good match. The unsteady flow dips back down to supercritical flow more quickly than the steady flow run--it even shows a slight rise in energy. The steady flow answer is more realistic. For the rapidly changing velocities associated with the draw down, the inertial terms are again significant (but ignored). Furthermore, the unsteady flow momentum equation may be slightly under computing the values associated with the quick contraction in flow area.

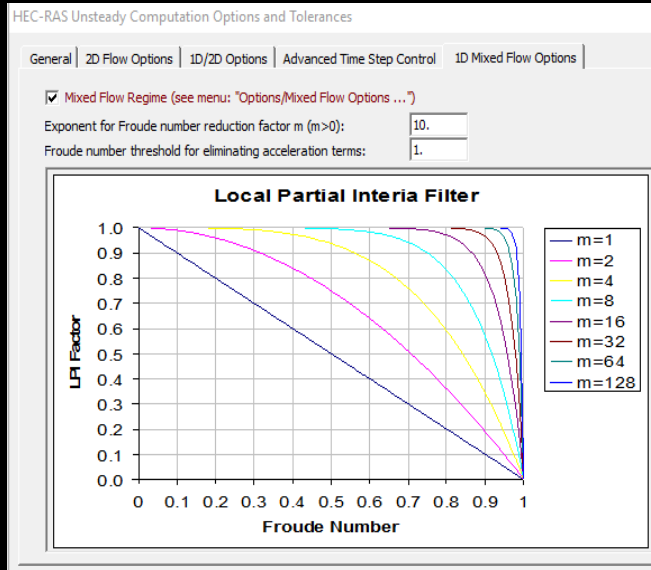
For more discussion see:

Fread, "An LPI Numerical Implicit Solution for Unsteady Mixed-Flow Simulation", ASCE North American Water & Environmental Congress, 1996.

U.S. Army Corps of Engineers, 1993. River Hydraulics, EM 1110-2-1416

U.S. A.C.E., 1993. Flood-Runoff Analysis, EM 1110-2-1417

Mixed/Supercritical Flow



- Checking Mixed Flow Regime Box
- Allows Subcritical/ Supercritical Mixed Flow
- Allows Critical Depth/ Hydraulic Jump Moving Interfaces

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When the mixed flow option is checked, the program will modify the unsteady flow equations. This can increase model stability when there is subcritical flow, supercritical flow, hydraulic jumps, and/or draw downs (sub to supercritical transitions). This option should only be selected if you actually have a mixed flow regime situation.

Local Partial Inertia (LPI) Technique

$$\sigma \left[\frac{\partial Q}{\partial t} + \frac{\partial \left(\frac{BQ^2}{A} \right)}{\partial x} \right] + gA \left(\frac{\partial h}{\partial x} + S_f + S_e \right) = 0$$

$$\sigma = \begin{cases} F_t - F_r^m & (F_r \leq F_t; m \geq 1) \\ 0 & (F_r > F_t) \end{cases}$$



The methodology used for mixed flow regime analysis is called the **Local Partial Inertia (LPI)** solution technique (Fread, 1996). When this option is turned on, the program monitors the Froude number at all cross section locations for each time step. As the Froude number gets close to F_t (which has a default value of 1.0), the program will automatically reduce the magnitude of the inertial terms in the momentum equation (the terms in the large bracket on the top equation). Reducing the inertial terms increases the model's stability. When the Froude number is equal to or greater than F_t (1.0), the inertial terms are completely zeroed out and the model is reduced to a diffusion wave routing procedure. For Froude numbers close to F_t (1.0), the program will use partial inertial effects, and when the Froude number is low, the complete inertial effects are used. The reduction factor for the inertial terms is the power function shown in the lower equation where:

σ = LPI Factor to multiply the inertial terms by.

F_t = Froude number threshold at which the factor is set to zero. This value can range from 1.0 to 2.0 (default is 1.0)

F_r = Froude number.

m = Exponent of equation, which changes shape of the curve. This exponent can range between 1 and 128 (default value is 10).

Mixed Flow Considerations

SUBCRITICAL

For a model that is primarily Subcritical, Mixed Flow option can improve stability.

SUPERCritical

For a model that is primarily Supercritical, unsteady flow less important. Steady flow analysis may be preferable.



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Even though the diffusion routing technique may have acceptably small errors for steep streams, it is not necessarily the best choice. Steep streams tend to have relatively little storage and less attenuation of the flood hydrograph than mild streams. In this situation, there may be little justification for the additional data and stability problems inherent in an unsteady flow model. A steady flow analysis may give comparable (or even better) answers with far less work.

Where the mixed flow option is most useful is in subcritical models that have short sections of supercritical flow. Without the mixed flow option, in order to maintain stability, the user would have to arbitrarily change the data in order to keep the flow subcritical.

For the mixed flow option, the user should choose the largest values of F_t (Froude Threshold) and m (the exponent) that allow the model to maintain stability.

Model stability may require more than just the mixed flow option.

Jarrett eqn. for Steep Streams

$$n = 0.39 S^{0.38} R^{-0.16}$$

- Manning's n for slope > 0.002
- S = Friction Slope
- R = Hydraulic Radius of Channel



Because of the turbulence (that is otherwise not accounted for), Manning's n for steep streams is often higher than many user's realize. In addition to potentially more accurate results, the higher n value will generally improve stability. Jarrett (1984) developed an equation for high gradient streams (slopes greater than 0.002). Jarrett performed a regression analysis on 75 data sets that were surveyed from 21 different streams.

Jarrett (1984) states the following limitations for the use of his equation:

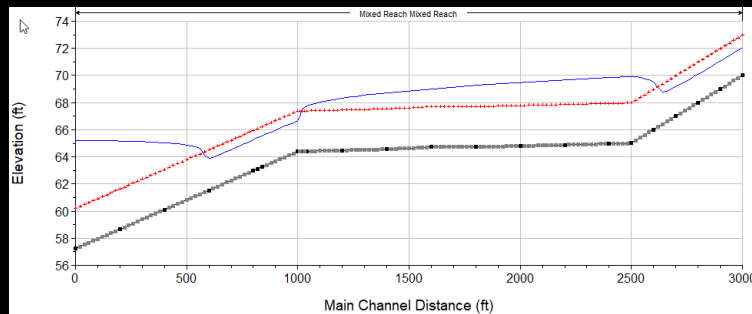
1. The equations are applicable to natural main channels having stable bed and bank materials (gravels, cobbles, and boulders) without backwater.
2. The equations can be used for slopes from 0.002 to 0.04 and for hydraulic radii from 0.5 to 7.0 feet (0.15 to 2.1 m). The upper limit on slope is due to a lack of verification data available for the slopes of high-gradient streams. Results of the regression analysis indicate that for hydraulic radius greater than 7.0 feet (2.1 m), n did not vary significantly with depth; thus extrapolating to larger flows should not be too much in error as long as the bed and bank material remain fairly stable.

See the HEC-RAS Hydraulic Reference manual for more limitations on the Jarrett

equation.

Mixed Flow Stability

- Mixed Flow Not a Panacea
- Cross Section Spacing/Time Step
- Manning's n (Jarrett's eqn.)
- Consider Rating Curve to "Drown Out" Supercritical Flow
- Use Modified Puls for Steep Section(s)



The mixed flow option does not guarantee that supercritical stretches will be stable. In areas that have rapidly changing depths and velocities, it is important to have close cross sections spacing. This includes the region upstream of critical depth (before the flow goes supercritical), the supercritical region itself, and the downstream hydraulic jump, if any.

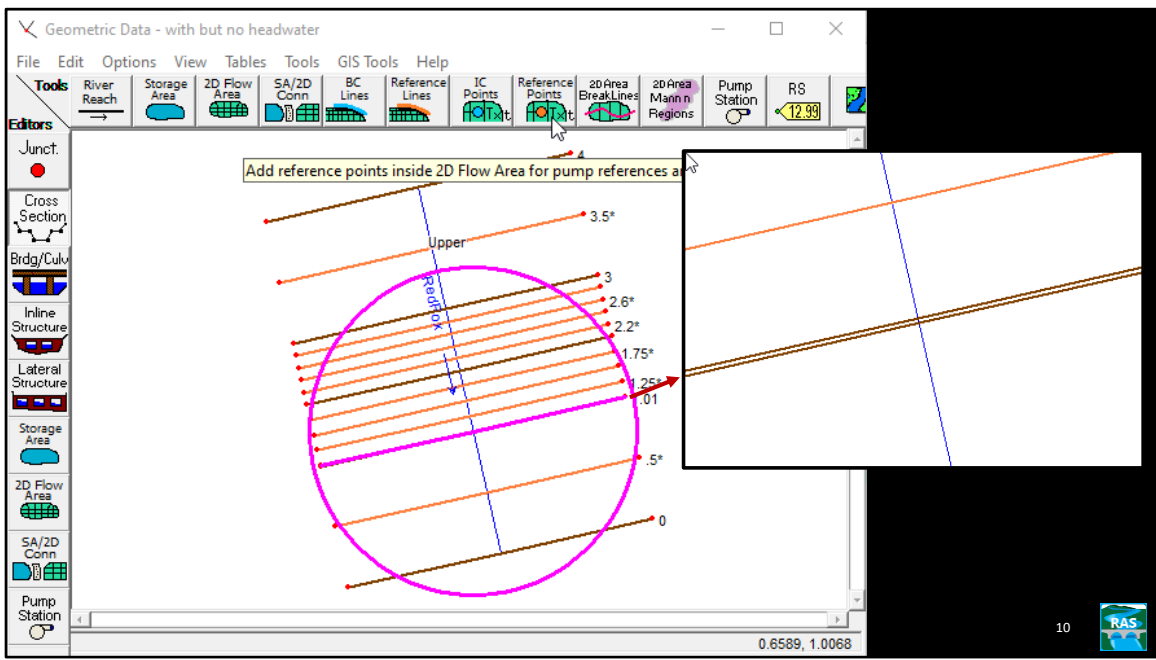
In addition, a short time step may also be required.

Check Manning's N against Jarrett's equation.

For a short and steep reach section, a rating curve can be used to "drown out" the supercritical flow. This may be useful in solving stability problems.

To do this, choose a cross section at the downstream end of the supercritical region.

Make a copy of this cross section and put this new cross section immediately upstream of the existing cross section so that they are only a short distance apart (i.e., one foot). Add a rating curve to the upstream cross section (from the cross section editor, go to "options" and choose "add a rating curve"), by entering a series of flows and the corresponding water surfaces.



Care (and some experimentation) should be used in developing the rating curve. A higher rating curve will generally be more stable. However, a higher water surface could affect the results further upstream. For the profile on the right, the water surface almost touches critical depth. This should have minimal, if any, effect on the results further upstream. Steady flow experimentation may be quicker.

As an additional rating curve option, the user can select the “Headwater Check” box on the rating curve. If this is done, the program will check to make sure that water surface in the upstream cross section (“headwater”) is at least as high as the water surface in the downstream cross section (“tailwater”). If the rating curve returns a water surface lower than the tailwater, the program will ignore it and instead it will use the downstream water surface (because this water surface is “horizontally projected,” as opposed to being computed, it is important that the two cross sections be identical and close together). This is useful if the water surface does not pass through critical depth at higher flows, such as the profile on the left. To do this, add additional points on the rating curve for high flows, but put in arbitrarily low water surfaces (Note: the program will extrapolate the rating curve, so make sure large enough flows are entered in the table!)

Concerns: the water surfaces in the formerly supercritical region are obviously “fake,” but make sure that any region that is affected upstream is not used as an “official” water surface; the location of the hydraulic jump is no longer apparent—in reality the supercritical flow may continue downstream of the rating curve; short

cross section spacing, a short time step, and even mixed flow may still be required.

Set Downstream Rating Curve

Add a Rating Curve to XS

Internal Rating Curve	
Stage(ft)	Flow(cfs)
1	103.7
2	103.85
3	103.99
4	104.09
5	104.23
6	104.34
7	104.45
8	104.55
9	104.65
10	104.74
11	104.84
12	104.93

Plot ... Clear

Headwater Check (recommended)

OK Cancel

Add a Rating Curve to XS

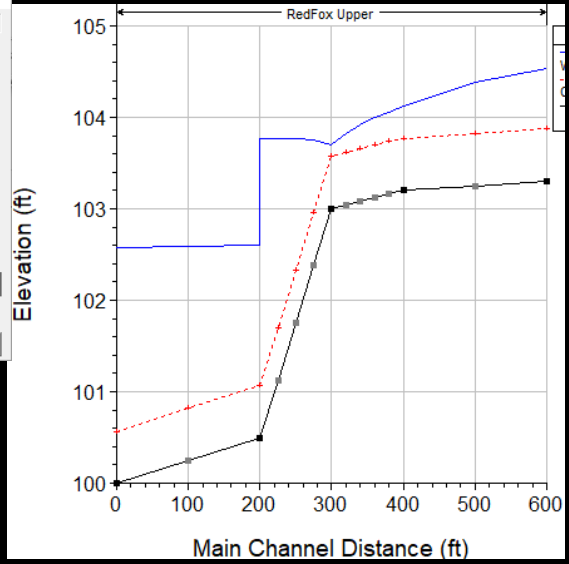
Internal Rating Curve	
Stage(ft)	Flow(cfs)
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	

Plot ... Clear

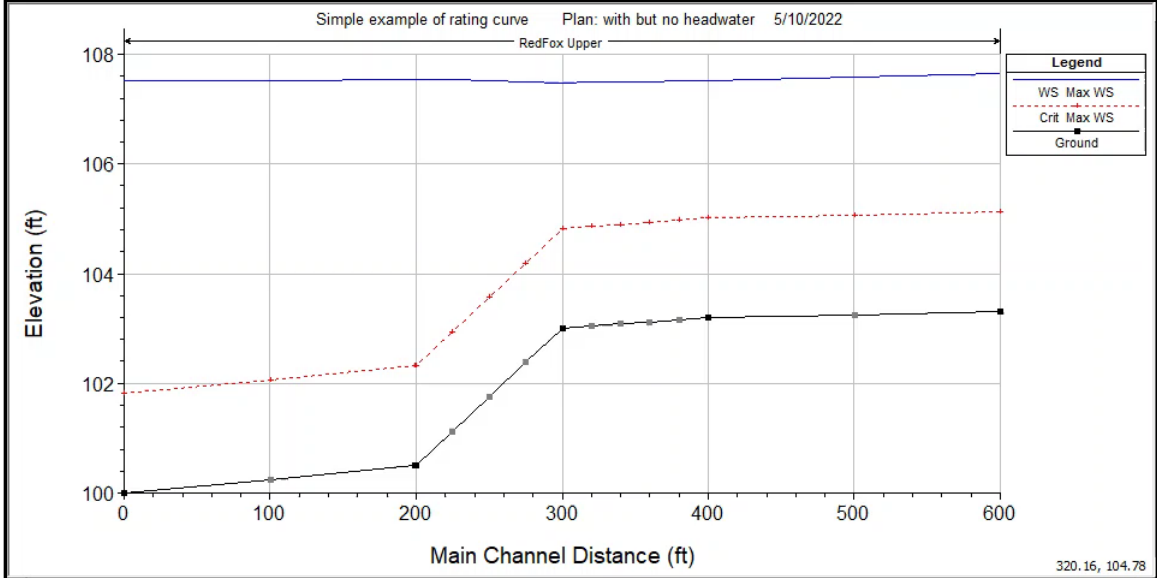
Headwater Check (recommended)

OK Cancel

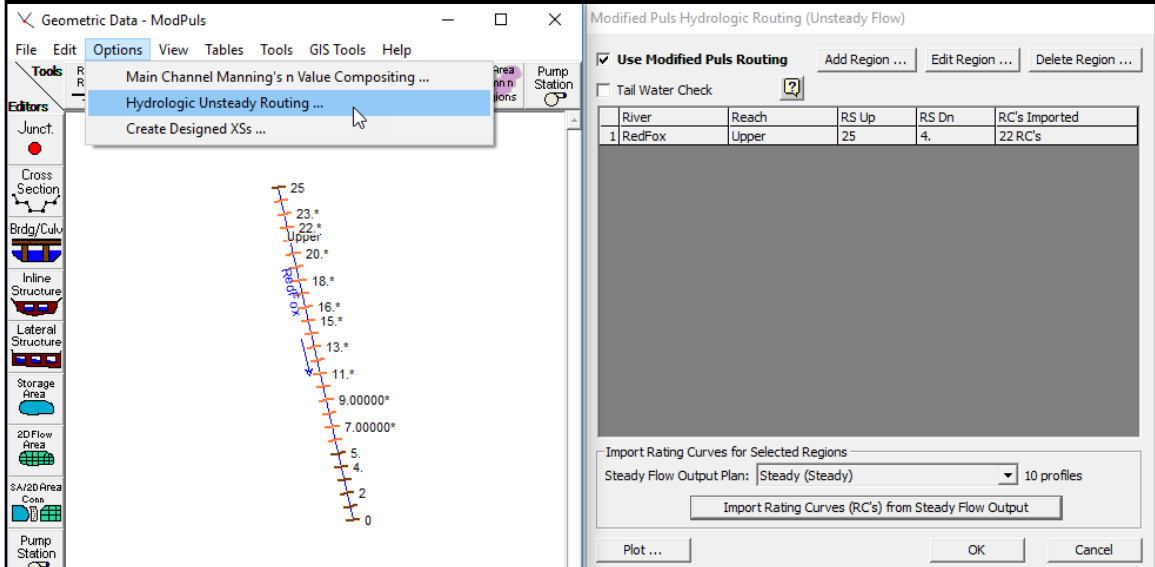
- Add a Lid to XS ...
- Add Ice Cover ...
- Add a Rating Curve ...
- Horizontal Variation in n Values
- Horizontal Variation in K Values
- Vertical Variation in n Values ...



Rating Curve for Stability



Modified Puls



Another option for solving stability problems at steep sections is to use the modified puls method. Modified puls does not solve the unsteady flow equation. Instead, it computes flows and water surfaces based on a simplified, hydrologic routing methodology.

A MP region can be two or more continuous cross sections. A given region must be in the same reach—it cannot cross a junction.

RAS will use the normal, unsteady flow solver for cross sections upstream or downstream of a modified puls region. The MP region itself is not part of the unsteady flow solver and is immune from the typical instability that steep sections cause in unsteady flow.

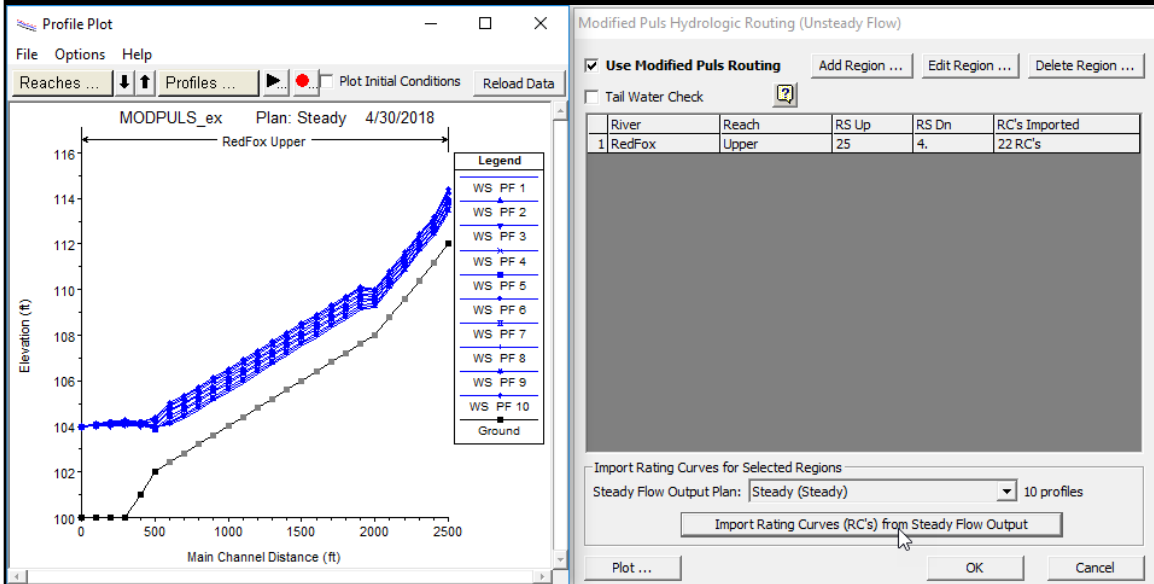
The MP region takes a flow on the upstream end. This flow can come from any source: a normal cross section (that is part of the unsteady solver), an external boundary hydrograph, a reach connected to a storage area, or the flow can come from an inline structure (the MP region starts immediately downstream of an inline structure).

The MP region routes the flow and sends it to whatever is connected downstream (cross sections, storage area, etc.).

The unsteady flow solution, if any, upstream of a MP region is based on the upstream water surface that is computed by the MP method.

The MP solution is not influenced by any downstream water surface unless the Tailwater check is turned on. However, the Tailwater check can cause instability.

Import Steady Profiles



The MP method requires flow/water surface rating curve at every cross section in the MP region.

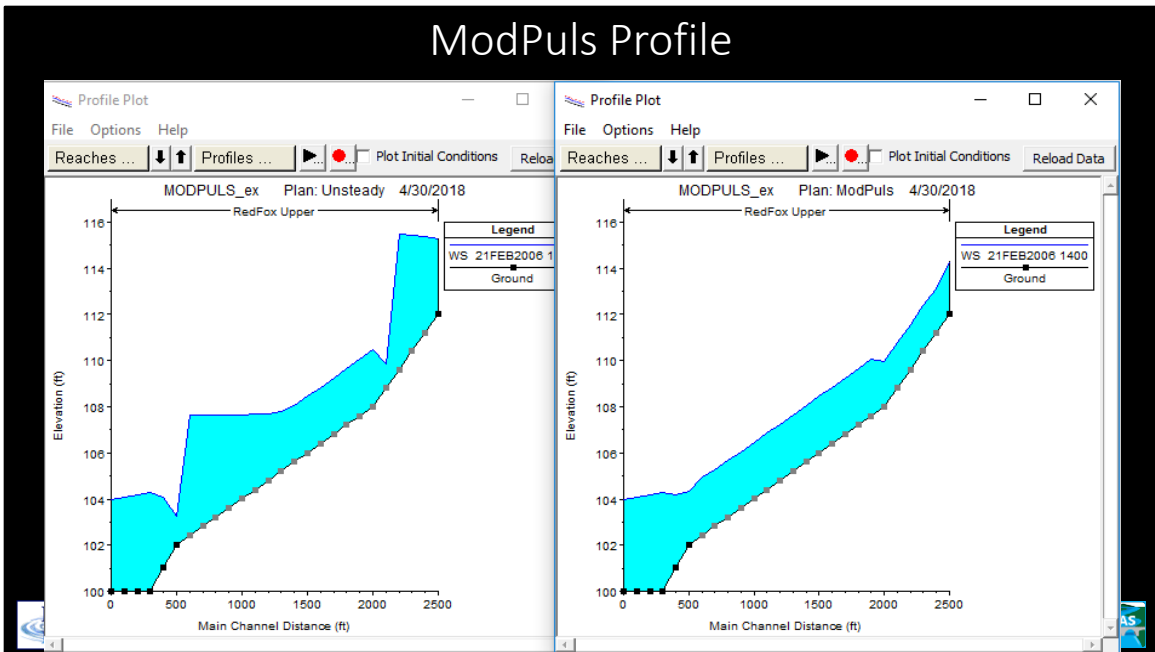
This is done by performing a series of steady flow profiles (shown on left) and then importing the results (shown on right). The steady flow profiles should encompass all of the flows that the MP region will experience during the unsteady flow. (The first steady flow profile should have a lower flow than any of the unsteady flows, likewise, the last profile should be larger.)

The computed/reported water surfaces in the MP region is based entirely on the rating curves. For instance, in the example above, the downstream end of the MP region is at river station 4. The water surface at river station 4 is based entirely on the flow and the rating curve, regardless of what the unsteady flow solver computes the water surface at river station 3 to be. So there may be a jump or drop in water surface between river station 3 and 4.

The MP method works best on steep sections that do not have looped rating curve effects. For instance, if a tributary is modeled with a MP region and the tributary is heavily influenced by the junction water surface, but the flow in the tributary is not correlated with the main river, the backwater effects from the main stream will not

be captured. On the other hand, if the tributary flow and main flow are well correlated (e.g., they both experience a “ten-year” flood at the same time), the backwater effects will be captured by the steady flow model and the results should be much better.

ModPuls Profile



The profile on the left was performed using normal unsteady flow (and has gone unstable). The profile on the right is the same data with a MP region from the top (river station 25) to river station 4 (at 400 feet main channel distance).

In addition to steep sections, other places where the unsteady solution has stability problems because of high velocity and/or water surfaces near/at/or below critical depth, are potential candidates for using modified puls. For instance, immediately below dam breaks, especially for dams in mountain canyons.

If MP is used for regions that are not steep, then care should be taken that the water surfaces upstream of the MP region are not being adversely affected. (This is not usually an issue if the MP region starts immediately below an inline structure.)

The tailwater check option can be used to keep the water surface from “dropping” (ie being lower than the downstream unsteady solution) at the downstream end of a MP region. However, this option should be used with care as it can cause greater instability in the unsteady flow solver.

Finite Volume

- 1D Unsteady Finite Volume (FV)
- Improved stability for:
 - Supercritical / Mixed flow
 - Flow shocks
- Allows wetting / drying

HEC-RAS Unsteady Computation Options and Tolerances

General | 2D Flow Options | 1D/2D Options | Advanced Time Step Control | 1D Mixed Flow Options

1D Unsteady Flow Options

Theta [implicit weighting factor] (0.6-1.0): 0.6

Theta for warm up [implicit weighting factor] (0.6-1.0): 0.8

Water surface calculation tolerance [max=0.2](ft): 0.01

Storage Area elevation tolerance [max=0.2](ft): 0.1

Flow calculation tolerance [optional] (cfs):

Max error in water surface solution (Abort Tolerance)(ft): 100.

1D/2D Unsteady Flow Options

Number of warm up time steps (0 - 100,000): 3

Time step during warm up period (hrs):

Minimum time step for time slicing (hrs): 0

Maximum number of time slices: 20

Lateral Structure flow stability factor (1.0-3.0): 2.

Inline Structure flow stability factor (1.0-3.0): 1.

Weir flow submergence decay exponent (1.0-3.0): 1.

Gate flow submergence decay exponent (1.0-3.0): 1.

Gravity (ft/s²): 32.174

1D Numerical Solution

Finite Difference (classic HEC-RAS methodology)

Finite Difference Matrix Solver

Skyline/Gaussian (Default: faster for dendritic systems)

Pardiso (Optional: may be faster for large interconnected systems)

Finite Volume (new approach)

Number of cores to use with Pardiso solver: All Available

Eulerian

Hsu (1988)

Boundaries

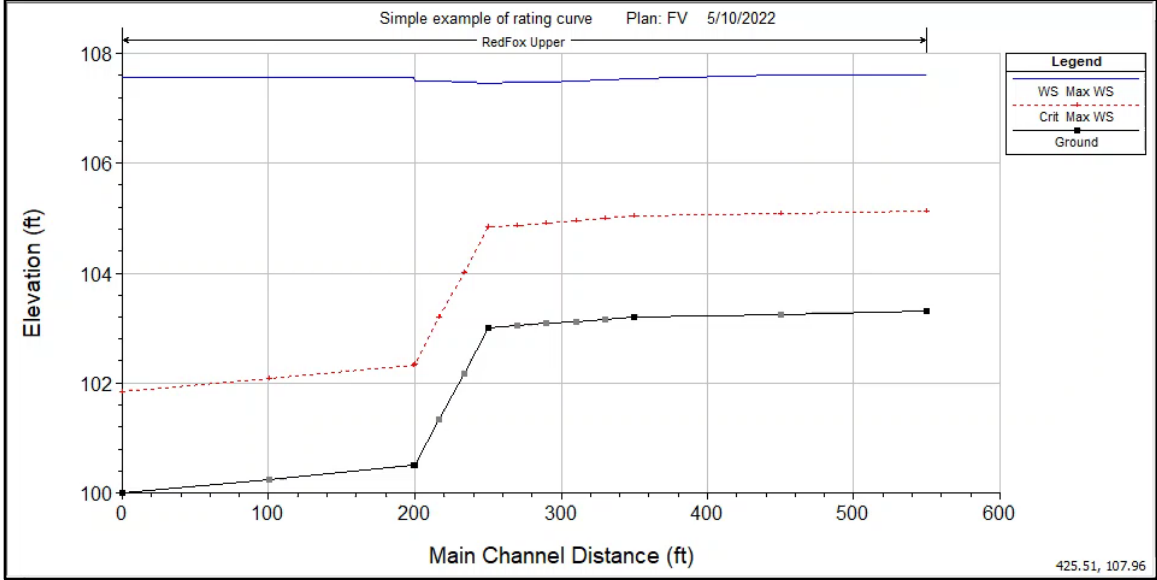
ables when possible.

eries

OK Cancel Defaults ...

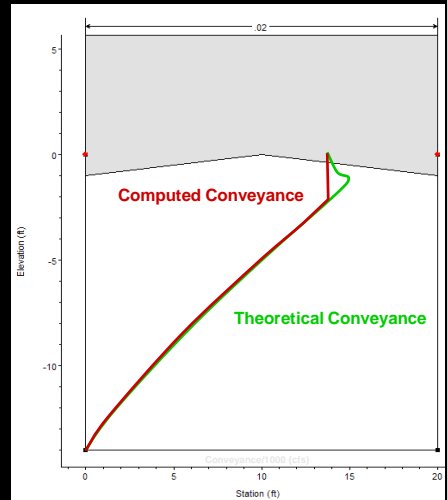


1D Finite Volume



Pressurized Pipe Flow

- Conveyance and wetted perimeter are cut off at top of pipe
- Area is added, but it is negligible
- Conveyance curve is truncated to local minimum to increase stability



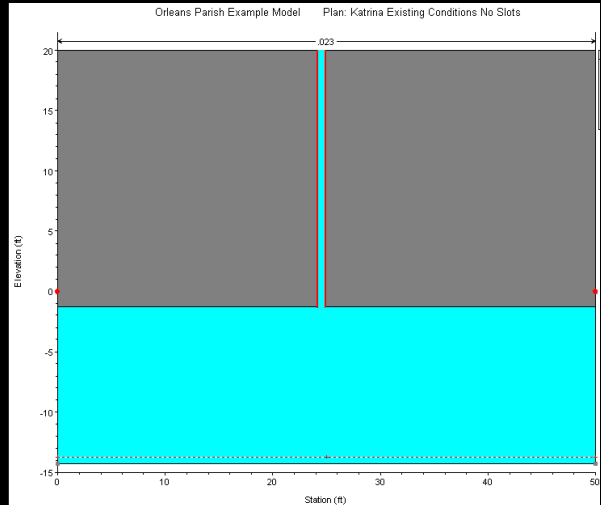
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For most unsteady flow situations, water is treated as a non-compressible fluid. This is not strictly true. The volume of water in the slot can be thought of as the amount of water compressed under pressurized flow.

Pressurized Pipe Flow

- Priessman Slot:
Insert a of an thin slot into
the XS lid
- Any Pipe Shape
- Allows the water surface to
rise to the pressure head
(hydraulic grade line)



A Priessman slot can be added to any cross section that has a lid. From the Geometric editor, go to the Tables menu and select Priessman Slot.

This adds a very narrow slot to the lid. The slot continues indefinitely upward, it is not limited to the “top” of the lid.

Computationally, the slot allows a free water surface at the height of the hydraulic grade line. This represents the static pressure component of the full pipe flow.

RAS determines the width of the slot (which is typically only a small fraction of an inch), such that the pressure wave, inside of a pipe flowing full, travels at the correct speed. That is, the unsteady solver computing the water surface in the slot represents the behavior of a pressure wave in a pipe.