Experiment Name: Steady Flow Modeling – Modeling Water Surface Profile with a Venturi Flume

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1. Upstream Depth Calculation and Comparison

Analytical calculations:

From equation 1:

$$Q = \left(\frac{2}{3}\right)^{3/2} B\sqrt{g}H^{3/2}$$

Given:

- Discharge, $Q = 0.2\ \text{m}^3/\text{s}$
- Constricted width, $B = 0.5$ m

Hence,

$$0.2 = \left(\frac{2}{3}\right)^{3/2} \times 0.5 \times \sqrt{9.81} \times H^{3/2}$$

$$\therefore H = 0.38\ m$$

Comparison with model results:

- HEC-RAS model depth (station 6): $0.46\ m$
- Difference: $0.46 - 0.38 = 0.08$ m

Equation 1 assumes an ideal, frictionless transition where critical depth is achieved at the throat under free-flowing conditions. However, the model was built with specified downstream boundary condition of $44/100 = 0.44$ m which is well above the critical depth of 0.16 m causing the flume to operate in submerged flow condition than the assumed free-flow condition. This downstream restriction creates a backwater effect, forcing the upstream water level to rise to 0.46 m.

2. Analytical Critical Depth Calculation and Comparison

Analytical calculations:

For a rectangular channel, critical depth,

$$y_c = \left(\frac{Q^2}{gB^2}\right)^{1/3}$$

At normal cross sections ($B = 1$ m):

$$y_{c,normal} = \left(\frac{0.2^2}{9.81 \times 1^2}\right)^{1/3}$$

$$\therefore y_{c,normal} = 0.16 \text{ m}$$

At throat ($B = 0.5$ m):

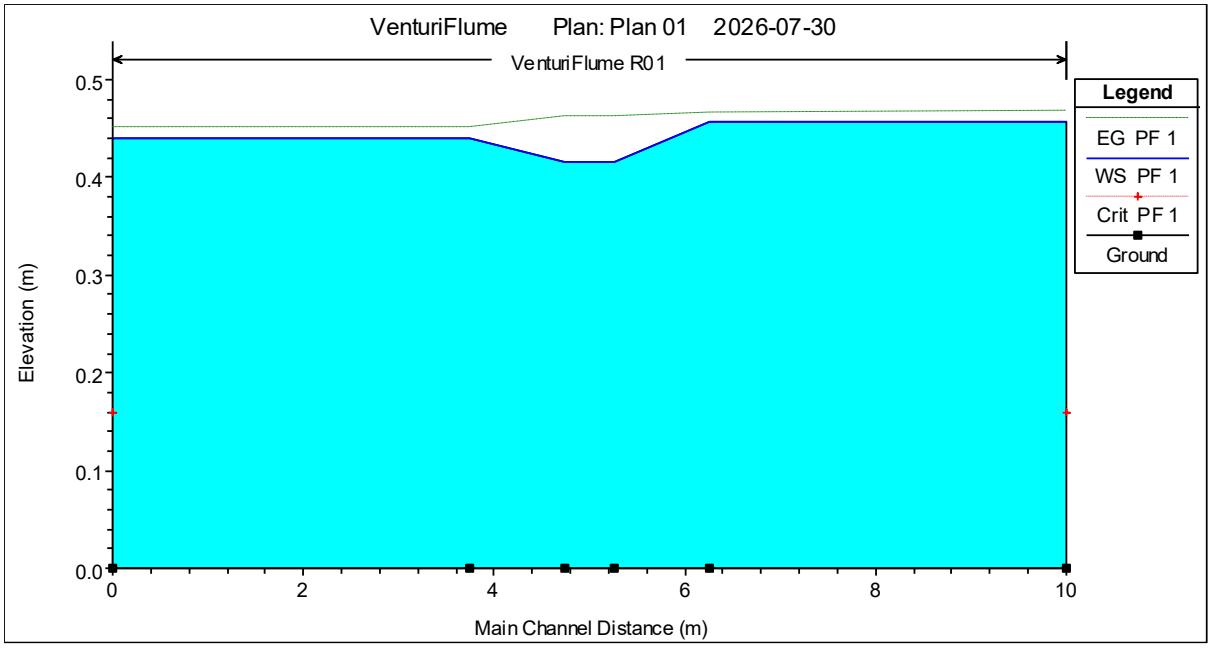
$$y_{c,throat} = \left(\frac{0.2^2}{9.81 \times 0.5^2}\right)^{1/3}$$

$$y_{c,throat} = 0.25 \text{ m}$$

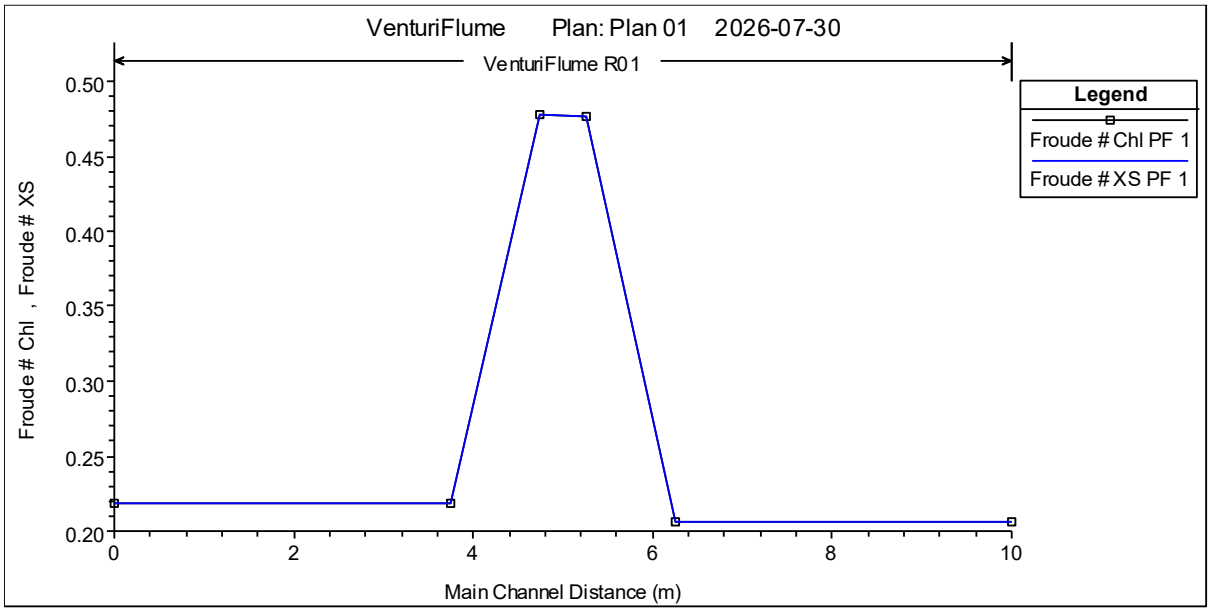
Comparison:

The HEC-RAS model shows critical depth (Crit W.S) as 0.16 m at stations 6 and 1. The analytical value matches this HEC-RAS calculation perfectly for the 1 m wide channel sections. However, HEC-RAS does not output value for other sections.

3. Longitudinal Profile of Water Surface Elevation



4. Longitudinal Profile of Froude Number



5. Shock Capturing Schemes

Shock-capturing schemes are numerical methods used in computational fluid dynamics to solve partial differential equations when sharp discontinuities (such as hydraulic jumps) form in the flow field.

Examples:

1. TVD (Total Variation Diminishing) Schemes: Prevent the creation of new spurious oscillations by ensuring the total variation of the solution does not increase over time.
2. WENO (Weighted Essentially Non-Oscillatory) Schemes: High-order accurate schemes that dynamically adjust stencils to prioritize smooth regions over discontinuities, preventing mesh oscillations.
3. Godunov's Method (Exact/Approximate Riemann Solvers): A conservative flux-evaluation scheme that treats cell boundaries as local Riemann problems to accurately compute shock propagation.

6. Necessity of Shock Capturing in Transcritical Flow

Transcritical flow involves transitions between subcritical flow (Froude number $Fr < 1$) and supercritical flow ($Fr > 1$).

When flow transitions from a supercritical state back to a subcritical state, it does so abruptly via a hydraulic jump. Mathematically, this jump represents a sharp discontinuity where velocity drops, and depth spikes over an incredibly short distance.

Shock capturing schemes solve this issue numerically, allowing HEC-RAS to do its job.

7. Discussion

A Venturi flume is theoretically designed to restrict channel width so flow reaches critical depth ($Fr = 1.0$) inside the throat, transitioning from subcritical to supercritical flow under free discharge. However, the HEC-RAS model showed entirely subcritical flow throughout the 10 m reach, with Froude numbers remaining between 0.21 in the main channel and 0.48 at the throat. And velocity increased from 0.44 m/s upstream to 0.96 m/s inside the constriction.

This deviation from expected behavior happens because the high downstream boundary condition (0.44 m) submerges the flume. Instead of acting as a free-flow control structure, the tailwater creates a strong backwater effect that drowns the throat.

Despite the drowning effect, the model successfully validated basic channel hydraulics. The computed critical depth of 0.16 m for the 1 m wide main channel matched the analytical value exactly.

Experiment Name: Steady Flow Modeling – Modeling Water Surface Profile with a Culvert

1. Longitudinal Profile of Water Surface

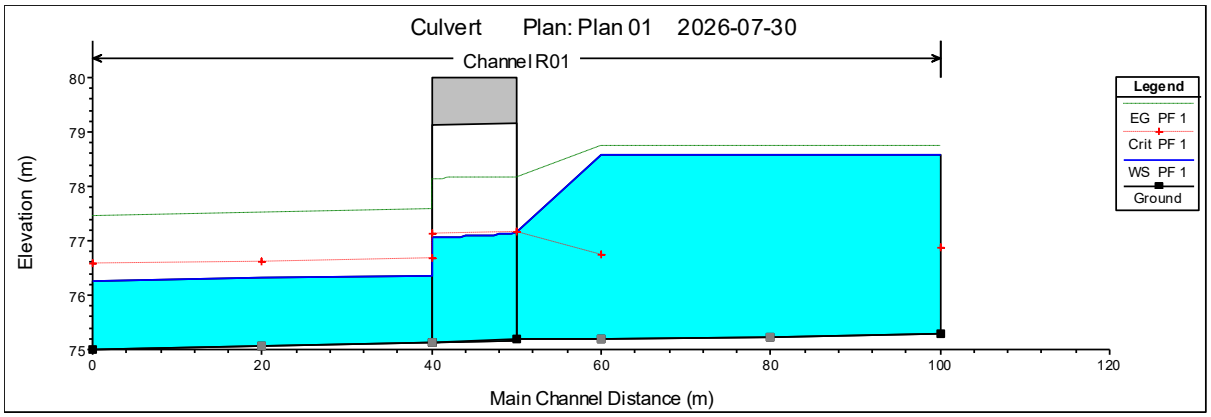


Figure 1 Flow at 200 cumec

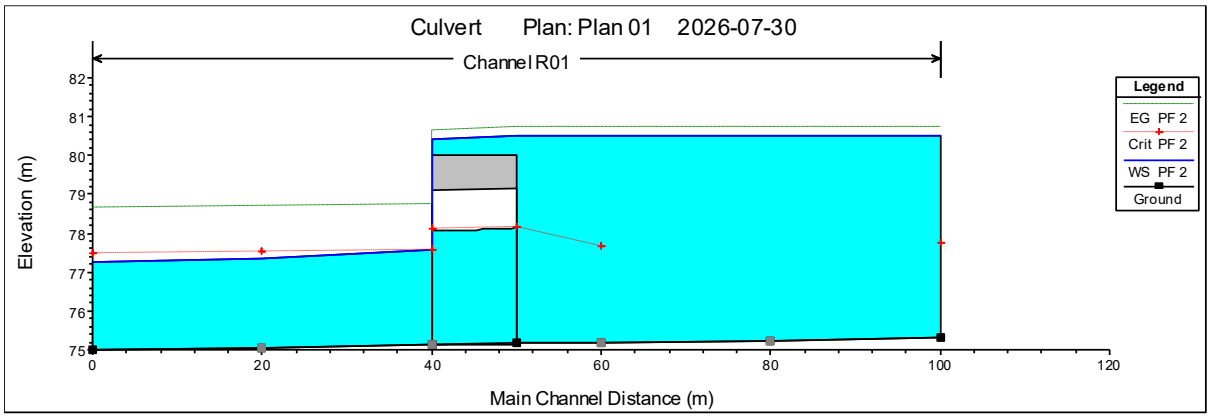


Figure 2 Flow at 500 cumec

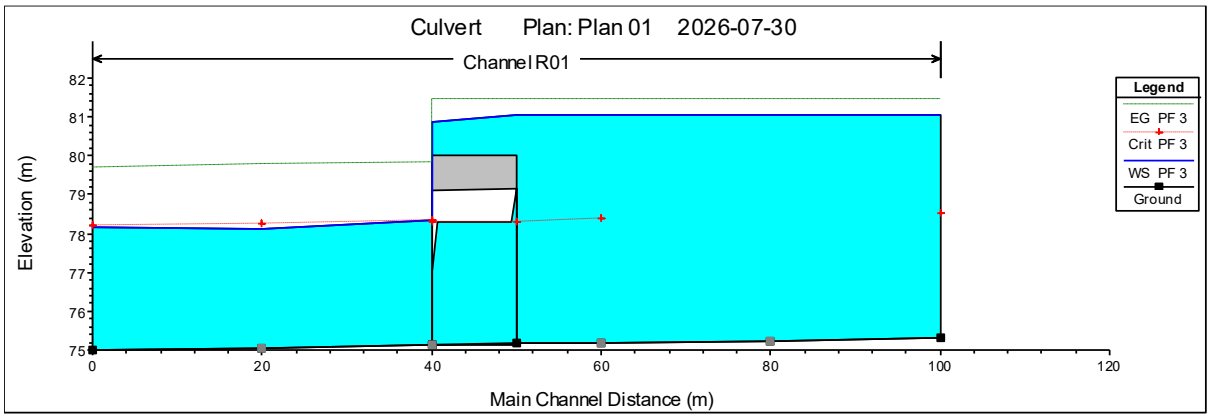


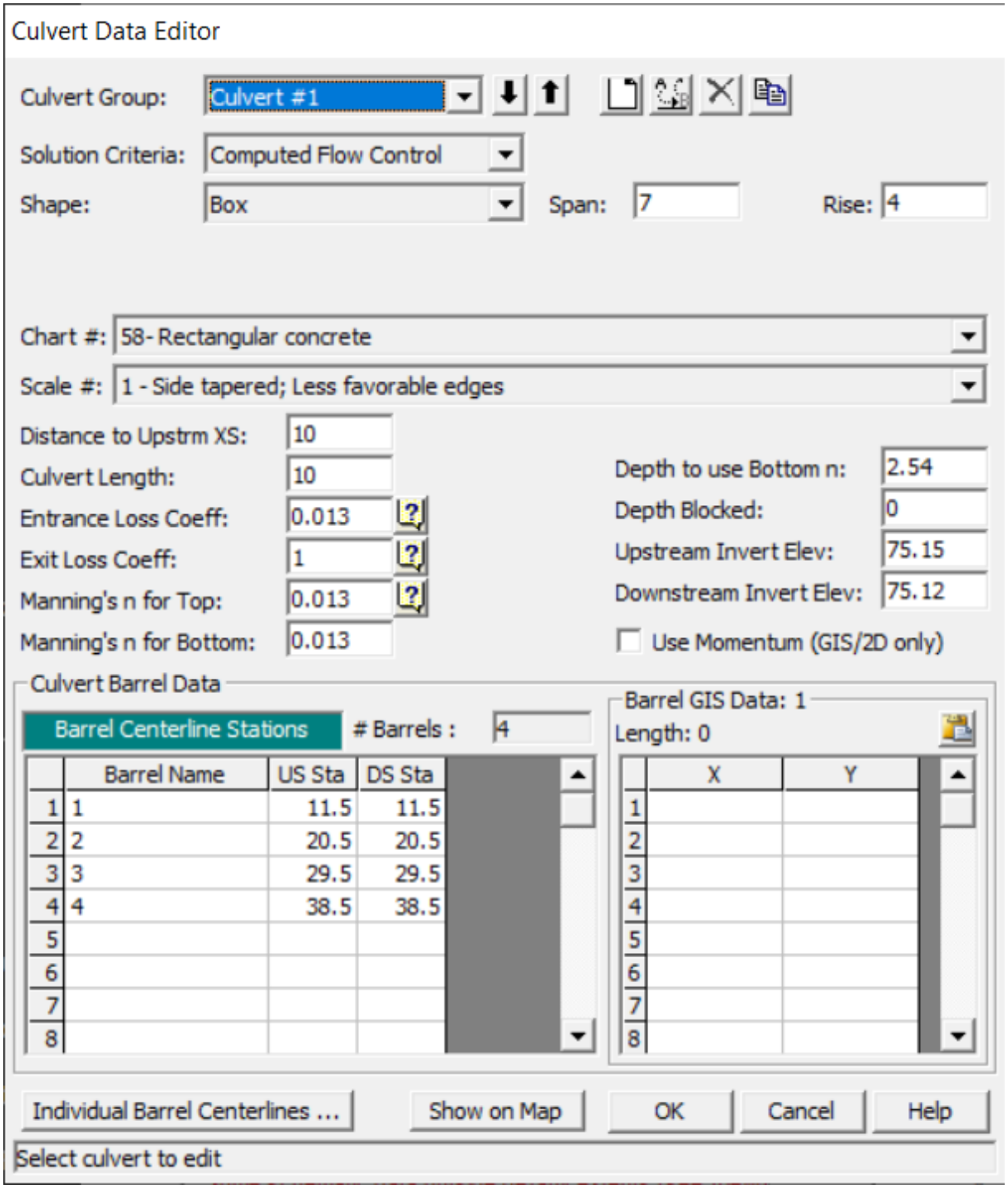
Figure 3 Flow at 750 cumec

2. Output Table

HEC-RAS Plan: 01 River: Channel Reach: R01

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(m3/s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
R01	100	PF 1	250.00	75.30	78.58	76.87	78.74	0.000128	1.76	142.08	46.57	0.32
R01	100	PF 2	500.00	75.30	80.50	77.76	80.73	0.000109	2.13	235.04	50.00	0.31
R01	100	PF 3	750.00	75.30	81.06	78.51	81.48	0.000173	2.85	263.14	50.00	0.40
R01	80.000*	PF 1	250.00	75.24	78.58		78.74	0.000120	1.72	144.97	46.69	0.31
R01	80.000*	PF 2	500.00	75.24	80.50		80.73	0.000105	2.10	238.14	50.00	0.31
R01	80.000*	PF 3	750.00	75.24	81.07		81.47	0.000167	2.82	266.31	50.00	0.39
R01	60.000*	PF 1	250.00	75.18	78.59	76.75	78.73	0.000113	1.69	147.85	46.81	0.30
R01	60.000*	PF 2	500.00	75.18	80.50	77.64	80.72	0.000101	2.07	241.23	50.00	0.30
R01	60.000*	PF 3	750.00	75.18	81.07	78.38	81.46	0.000161	2.78	269.46	50.00	0.38
R01	50		Culvert									
R01	40.000*	PF 1	250.00	75.12	76.36	76.68	77.58	0.003289	4.90	50.98	42.47	1.43
R01	40.000*	PF 2	500.00	75.12	77.58	77.58	78.75	0.001329	4.78	104.57	44.93	1.00
R01	40.000*	PF 3	750.00	75.12	78.32	78.32	79.82	0.001243	5.42	138.46	46.41	1.00
R01	20.000*	PF 1	250.00	75.06	76.31	76.63	77.51	0.003177	4.85	51.53	42.50	1.41
R01	20.000*	PF 2	500.00	75.06	77.37	77.52	78.70	0.001643	5.11	97.77	44.62	1.10
R01	20.000*	PF 3	750.00	75.06	78.10	78.26	79.78	0.001487	5.74	130.73	46.08	1.09
R01	0	PF 1	250.00	75.00	76.25	76.57	77.45	0.003154	4.84	51.65	42.50	1.40
R01	0	PF 2	500.00	75.00	77.25	77.46	78.66	0.001800	5.26	94.97	44.50	1.15
R01	0	PF 3	750.00	75.00	78.18	78.20	79.70	0.001280	5.47	137.18	46.35	1.01

3. Culvert Data Editor Window



4. Discussion

The modeled hydraulic structure is a box culvert featuring four identical boxes, each with a 7.0 m span, set 2.0 m inside the bottom-left edge of the trapezoidal channel with a center-to-center spacing of 9.0 m. Upstream of this structure (Stations 100 to 60), the flow remains deep, slow, and subcritical across all three discharge profiles, with Froude numbers ranging between 0.30 and 0.40 and velocities between 1.69 m/s and 2.85 m/s. As discharge increases from 250 m^3/s to 750 m^3/s, the severe geometric contraction causes a backwater effect, elevating the upstream water surface at Station 100 from 78.58 m to 81.06 m.

This multi-barrel arrangement serves as a major hydraulic control point where the reduced flow area accelerates water through the conduit. Immediately downstream of the exit (Stations 40 to 0), the flow shifts into a critical or supercritical state. At 250 m^3/s, the flow becomes fully supercritical downstream, reaching a Froude number of 1.43. At 500 m^3/s and 750 m^3/s, the water passes through critical depth ($Fr = 1.00$) at Station 40 and remains slightly supercritical downstream, peaking at Froude numbers of 1.15 and 1.09 with velocities up to 5.74 m/s.

Overall, the four-barrel culvert pools the flow upstream into a subcritical reservoir and discharges it downstream as a high-velocity, supercritical flow controlled by the critical depth downstream boundary condition.