Regulatory Review Webinar Series

Lesson 3
Hydraulics, Part 2

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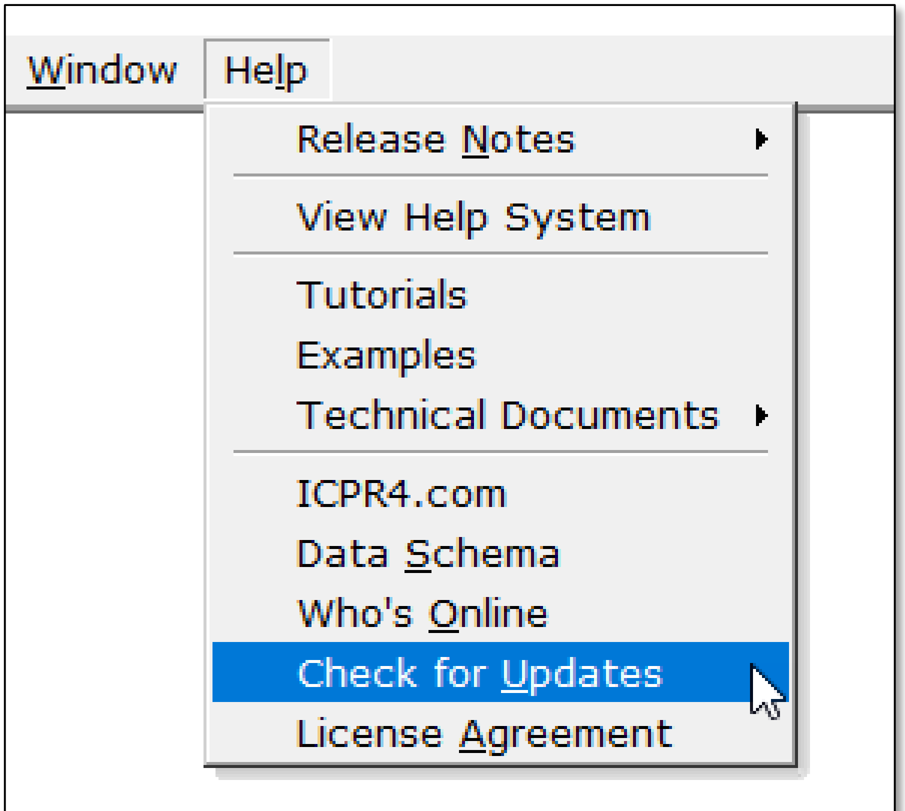
Streamline Technologies, Inc.

Tuesday – October 29, 2019

Next Webinar – Lesson 4: Hydraulics, Part 3

Thursday October 31, 2019
11:30 – 1:30 (EDT)



We will try to post a recording of this webinar and/or the presentation material as soon as we can.

To find them:
"Check for Updates"
sometime tomorrow.

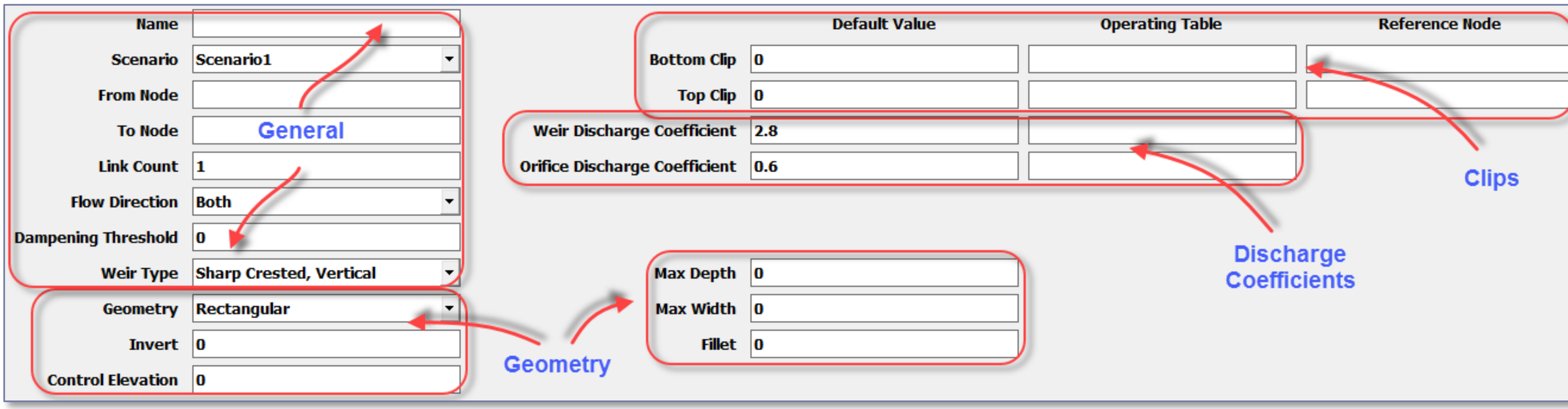
support@icpr4.com

Lesson 3 Topics

- Weir Links
- Drop Structure Links
- Rating Curve Links

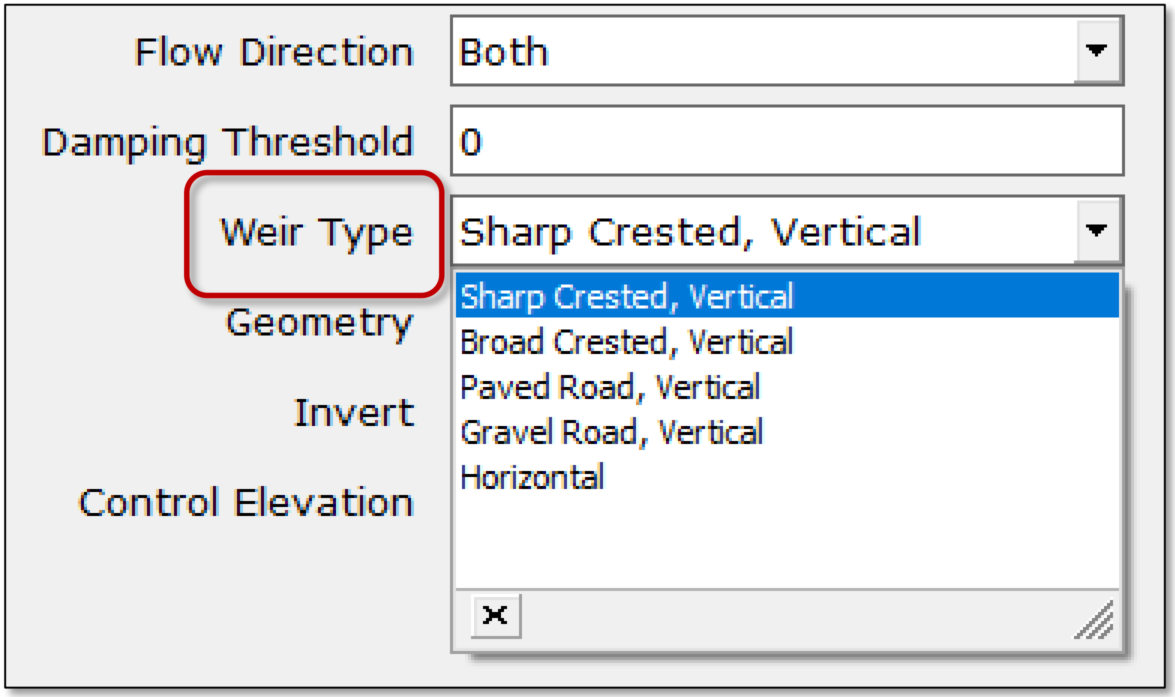
Weir Links

Data Form



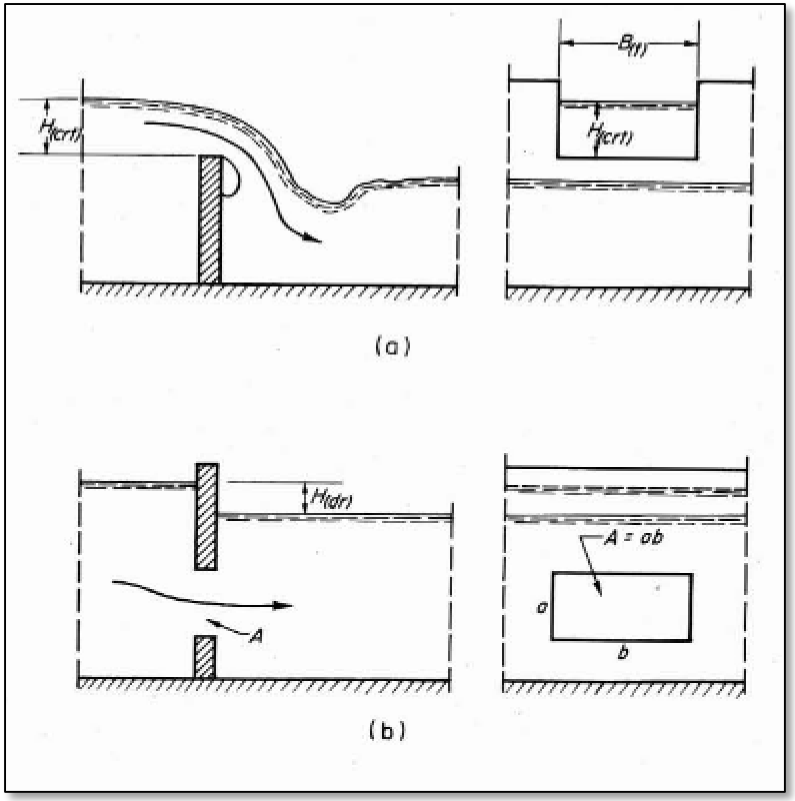
Weir Links

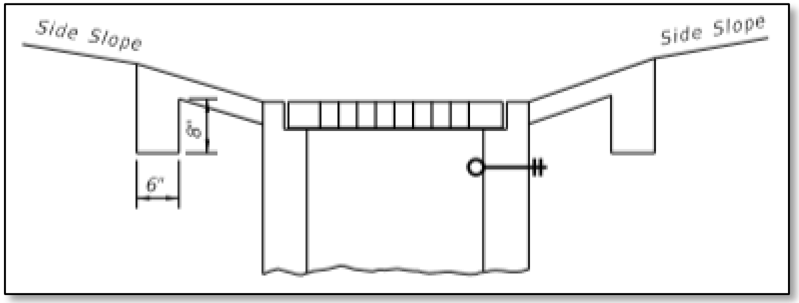
Five (5) Weir Types

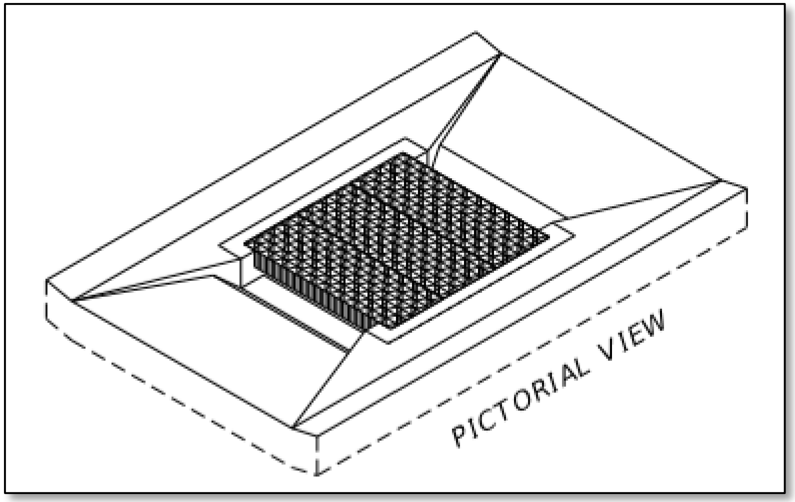


Weir Links

Types







Vertical

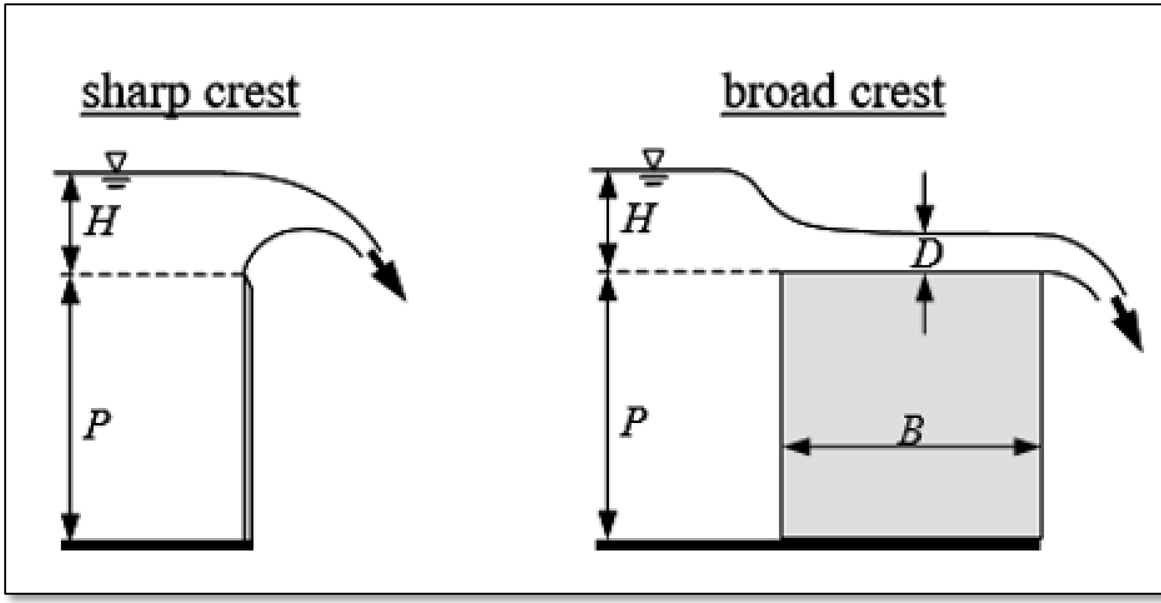
(source: FAO)

Horizontal

(source: FDOT)

Weir Links

Types



The only difference between sharp (narrow) crested and broad crested weirs is how submergence is treated

Weir Links

Basic Weir Equations

$$Q_{free} = C_w L h^{3/2} \quad \text{(rectangular weirs)}$$

$$Q_{free} = C_w A \sqrt{h} \quad \text{(generalized form)}$$

where,

Q_{free}	free discharge flow rate ($f^3 s^{-1}$, $m^3 s^{-1}$)
C_w	weir discharge coefficient ($f^{0.5} s^{-1}$, $m^{0.5} s^{-1}$)
A	cross sectional area (f^2, m^2)
L	weir length (f, m)
h	head as measured above the invert elevation (f, m)

Weir Links

Submergence

If the water elevation on the downstream side of a weir submerges the invert elevation, then a flow reduction factor must be applied to the free discharge flow rate.

$$Q_{submerged} = Q_{free} R_f$$

Computation of the flow reduction factor depends on the weir type.

Weir Links

Submergence – Sharp and Narrow Crested Weirs

$$Q_{submerged} = Q_{free} R_f$$

$$R_f = 1.0 - \left[0.45S + \frac{0.55}{2^{(10-10S)}} \right]$$

Flow is reduced immediately as the downstream water elevation begins to submerge the invert of the sharp/narrow crested weir.

The modified Mavis formula is used to determine the flow reduction factor.

$S = (A_2 H_2^{1/2}) / (A_1 H_1^{1/2})$ submergence ratio

H_1 depth above invert on upstream side (f, m)

H_2 depth above invert on downstream side (f, m)

A_1 cross sectional area at H_1 (f², m²)

A_2 cross sectional area at H_2 (f², m²)

Weir Links

Submergence – Broad Crested Weirs

$$Q_{submerged} = Q_{free} R_f$$

$$R_f = 1.0 - 27.8\left(\frac{H_2}{H_1} - 0.67\right)^3$$

The Fread equation (Fread, 1980) is used for broad crested weirs and begins reducing the discharge rate when the depth of the downstream water level above the weir invert reaches 67% of the upstream depth.

for $\left(\frac{H_2}{H_1}\right)$ > 0.67 (decimal)

H_1 depth above invert on upstream side (f, m)

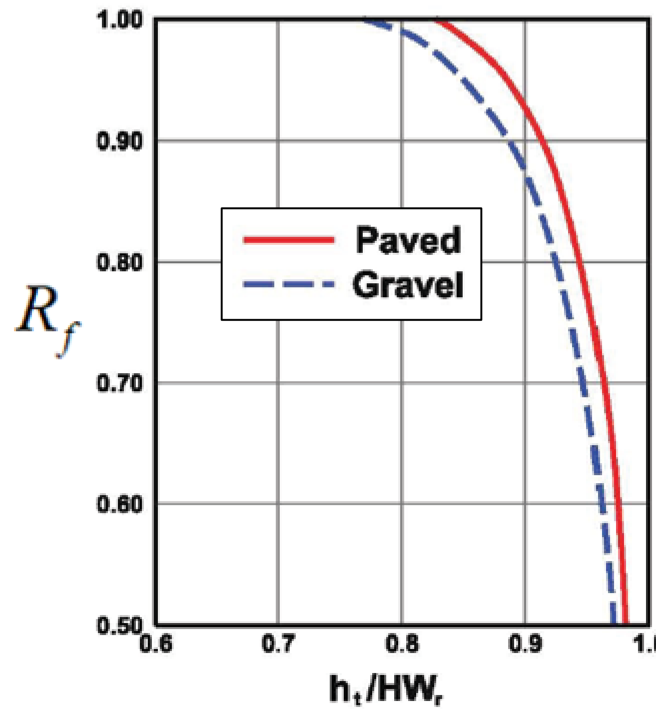
H_2 depth above invert on downstream side (f, m)

Weir Links

Submergence – Paved & Gravel Roads

$$Q_{submerged} = Q_{free} R_f$$

The reduction factors for paved and gravel roads are similar to the Fread equation except the chart to the right is used for the factors. Flow reductions for paved and gravel roads begin at submergences of 80% and 74%, respectively.

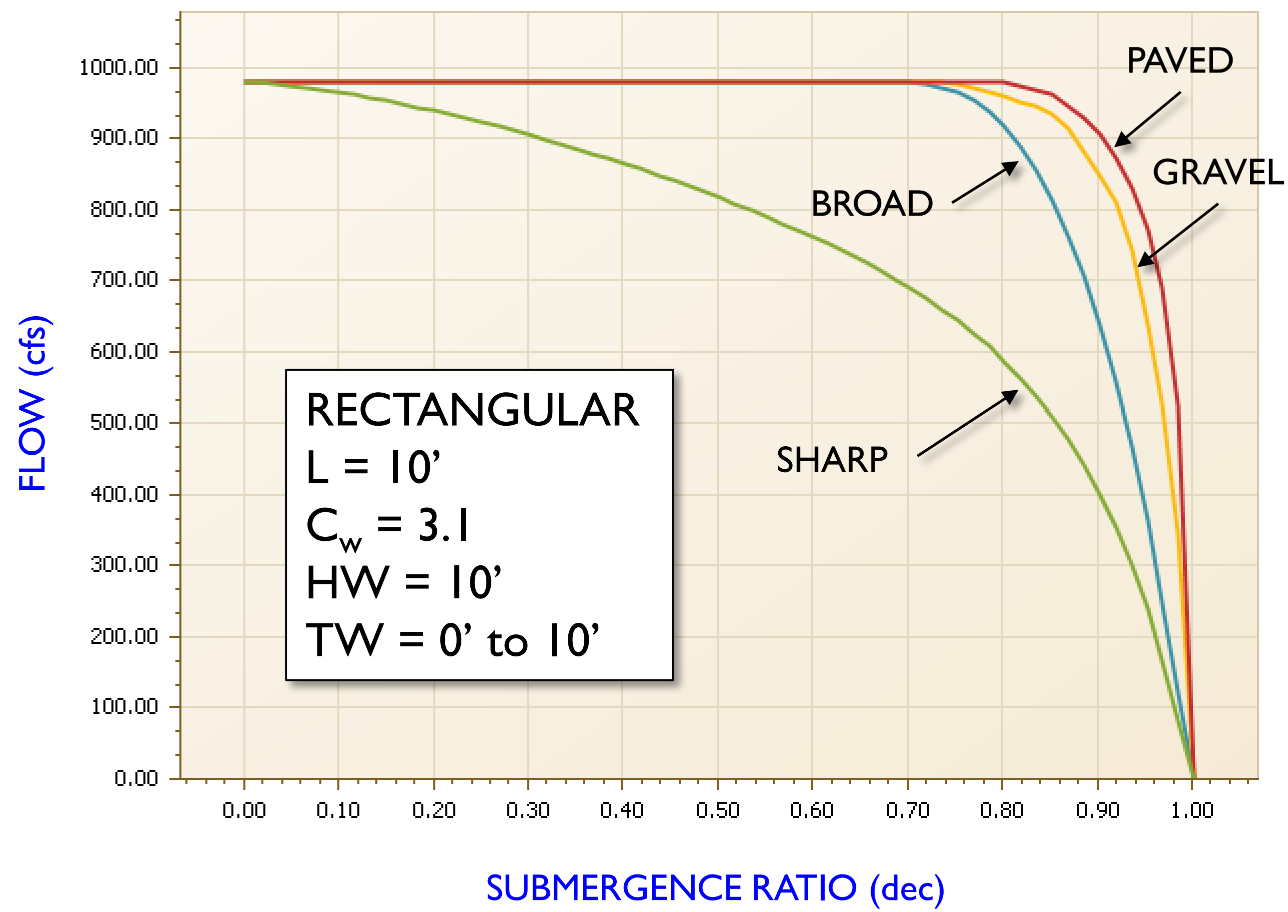


C) Submergence Factor

Source: FHWA 2012

Weir Links

Effects of Submergence



Weir Links

Orifice Flow

$$Q_{orifice} = C_{orifice} A \sqrt{2gh}$$

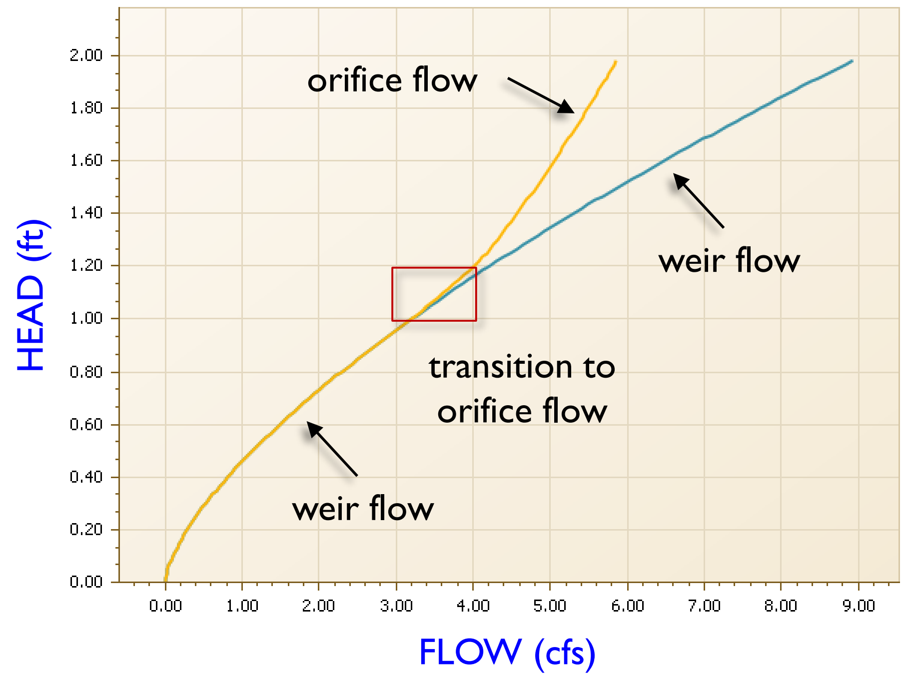
where,

$Q_{orifice}$	orifice discharge flow rate (f^3s^{-1}, m^3s^{-1})
$C_{orifice}$	orifice discharge coefficient (decimal)
A	cross sectional area of flow (f^2, m^2)
g	gravitational constant (32.16 fs^{-2}, 9.80 ms^{-2})
h	head across orifice as measured from the center of gravity (f, m)

Weir Links

Transition from Weir Flow to Orifice Flow
- Vertical Weirs -

- Weir flow is used exclusively between the invert of the opening and the top of the opening. At "max depth"
- Complete orifice flow occurs for depths at and above 1.2 x max depth.
- A linear relationship is used for the transition between the max depth and 1.2 times the max depth.

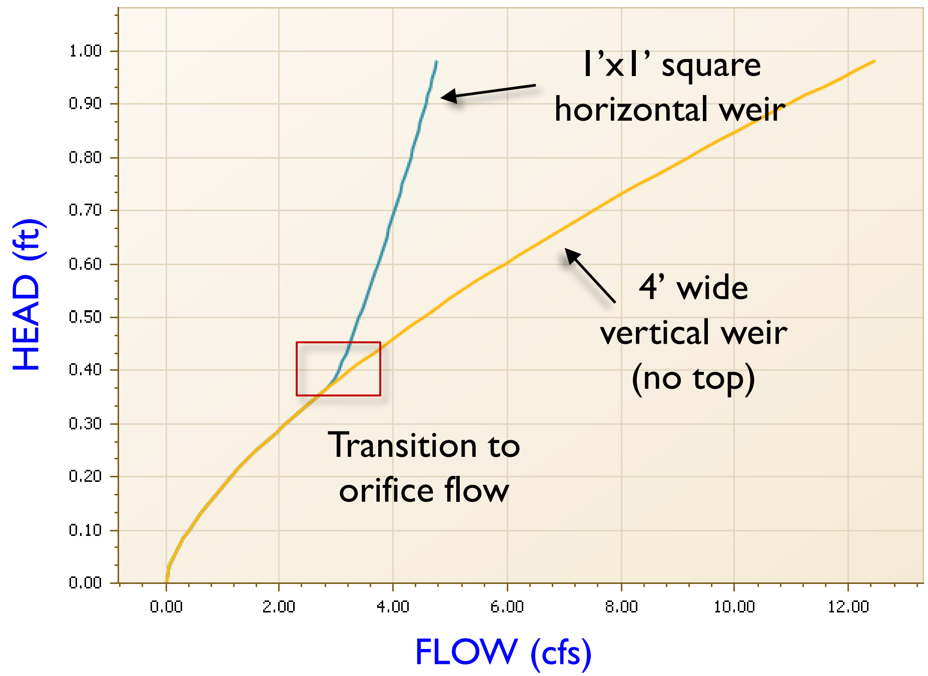


VERTICAL RECTANGULAR
MAX WIDTH = 1.0'
MAX DEPTH = 1.0'

Weir Links

Transition from Weir Flow to Orifice Flow
- Horizontal Weirs -

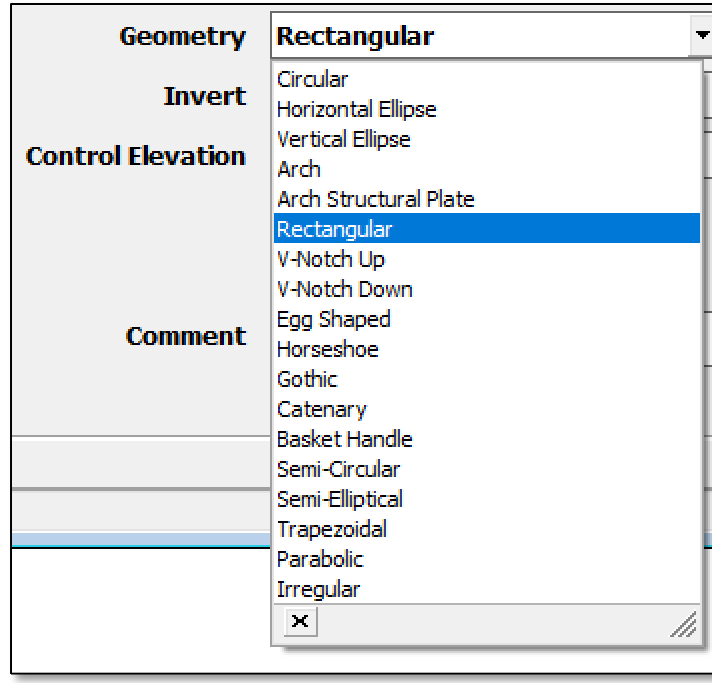
- Flow is first calculated as if the weir is vertical and rectangular, using the perimeter of the weir as its length.
- Then a second calculation is made assuming orifice flow based on the cross sectional area of the opening.
- ICPR then compares the two and takes the lesser value as the controlling flow for the opening.

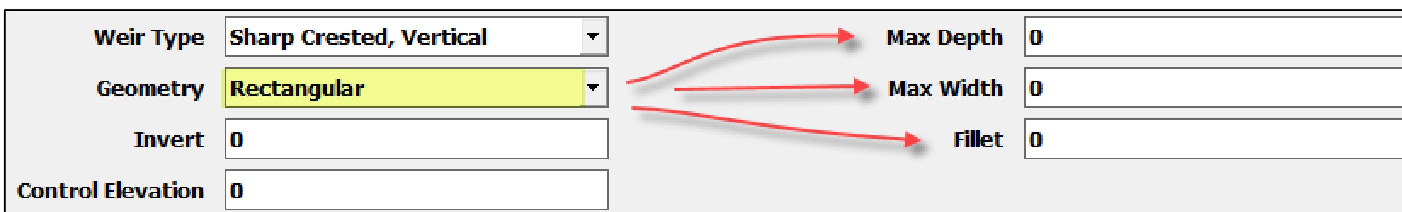


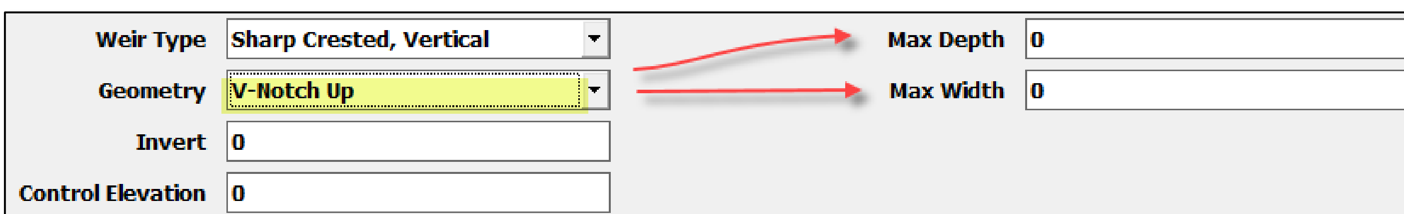
Weir Links

Geometry

- There are eighteen geometry types available for weirs
- Specific data fields depend on the geometry type selected



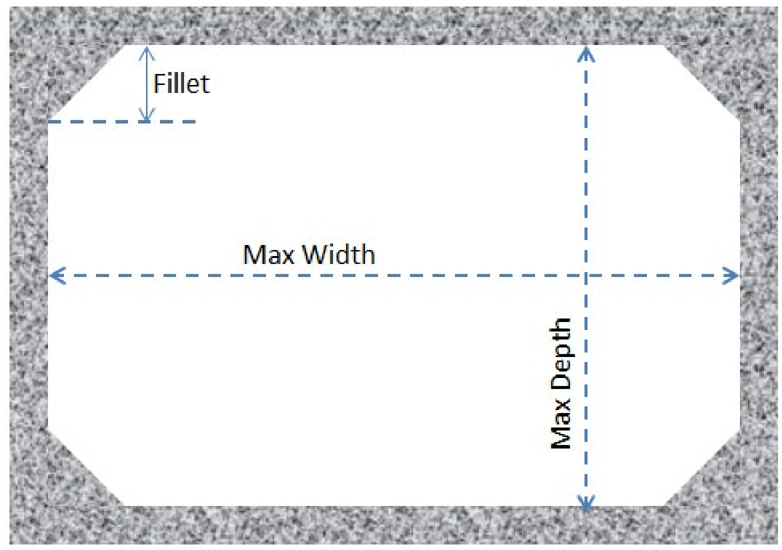




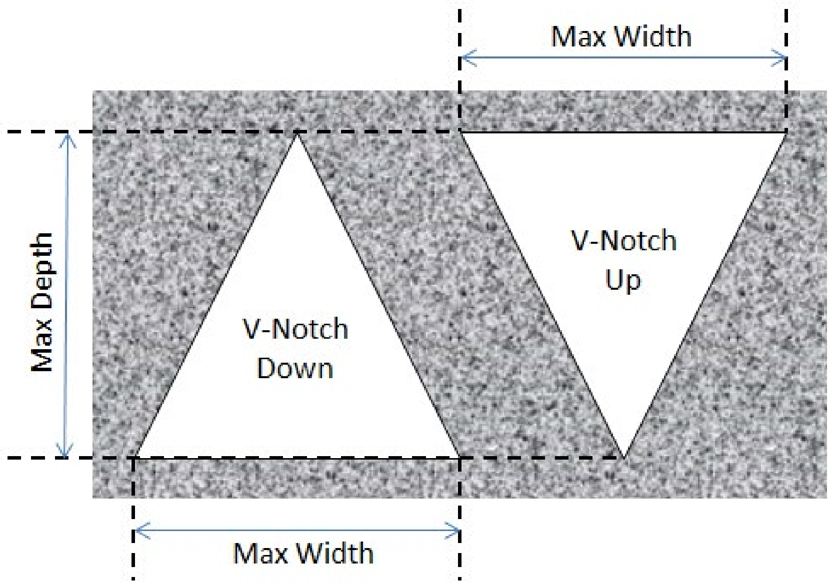
Weir Links

Geometry

In all cases except for irregular sections, the max depth parameter is used to define the beginning of the transition between weir flow and orifice flow.



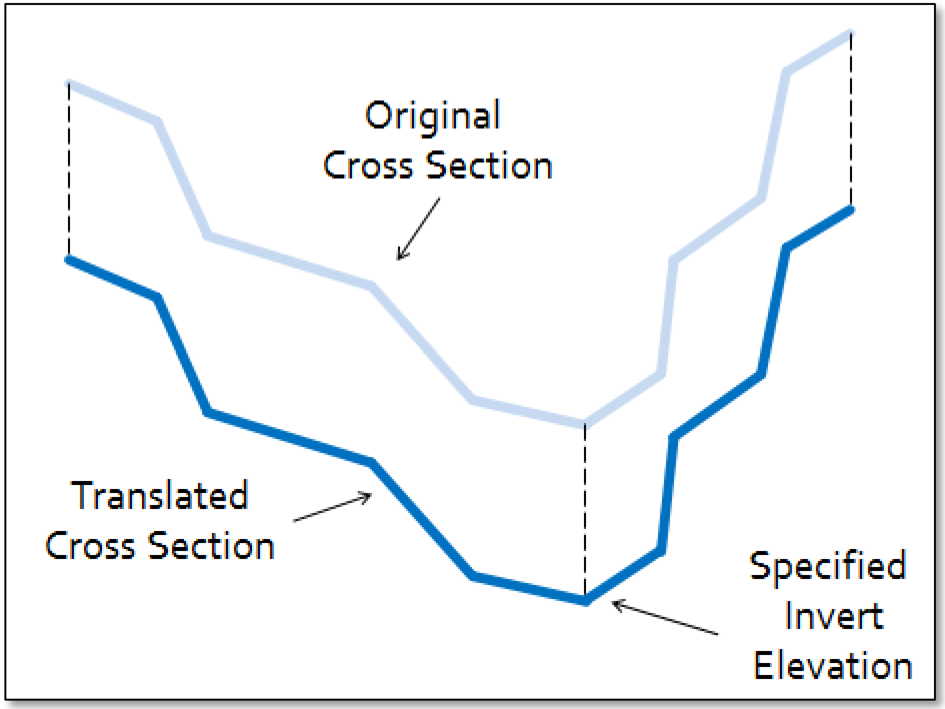
Rectangular Geometry



Weir Links

Geometry

If the cross section has a "lid", then orifice flow is possible. Otherwise, only weir flow is possible. Also, if an irregular section geometry type is specified, the cross section is automatically shifted vertically into the invert elevation. The cross section serves as a template.



Weir Links

Discharge Coefficients

$$Q_{free} = C_w L h^{3/2}$$

$$Q_{orifice} = C_{orifice} A \sqrt{2gh}$$

	Default Value	Operating Table	Reference Node
Bottom Clip	0		
Top Clip	0		
Weir Discharge Coefficient	2.8		
Orifice Discharge Coefficient	0.6		

Weir Links

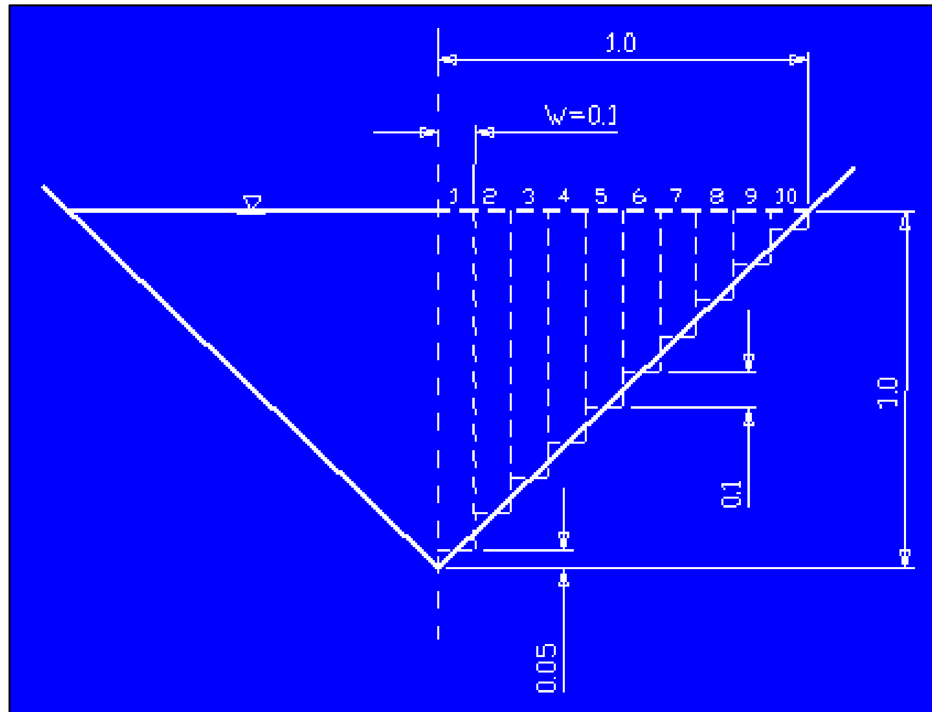
Orifice Discharge Coefficient

- Orifice discharge coefficients can be obtained from standard hydraulic handbooks such as (Brater and King, 1976).
- Typically, the orifice discharge coefficient will range between 0.5 and 0.7 but varies depending on specific conditions.
- Note that the orifice coefficient is dimensionless and therefore no special consideration is required when working in either English or metric units.

Weir Links

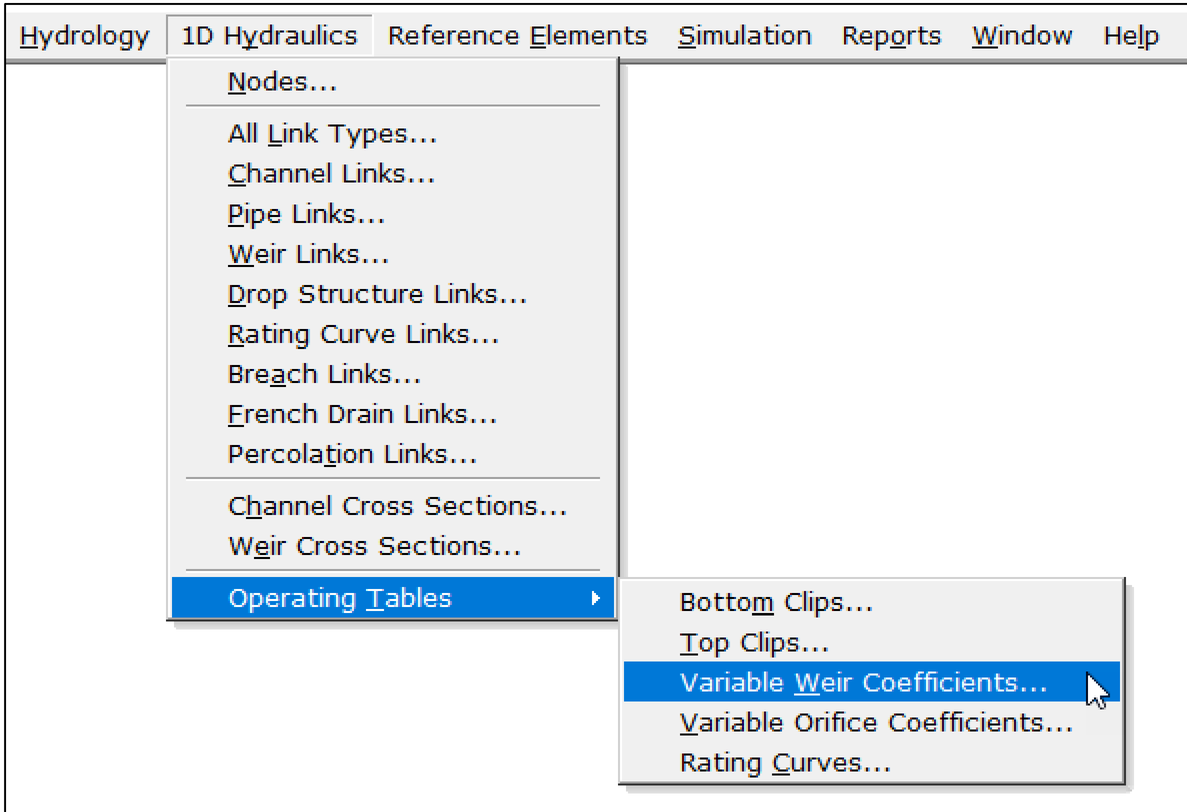
Weir Discharge Coefficient

- ICPR converts all weir geometries into a series of equivalent rectangles.
- Regardless of the geometric shape, the weir discharge coefficient should always be set as if it were a rectangular geometry type.
- Typically, the weir discharge coefficient will range between 2.6 and 3.4 $f^{0.5}s^{-1}$ (1.44 and 1.88 $m^{0.5}s^{-1}$), but varies depending on specific conditions.
- Weir coefficients can be obtained from standard hydraulic handbooks such as (Brater and King, 1976).



Weir Links

Variable Weir Discharge Coefficient



Weir Links

Variable Weir Discharge Coefficient

Name: OGEE-1

Scenario: OGEE SPILLWAY

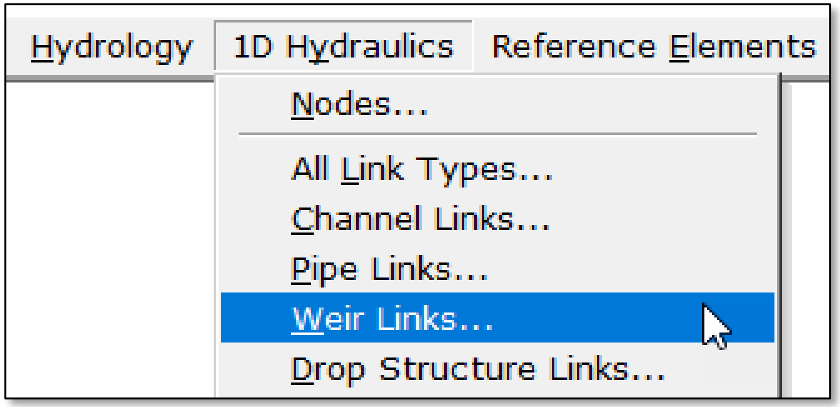
Comment:

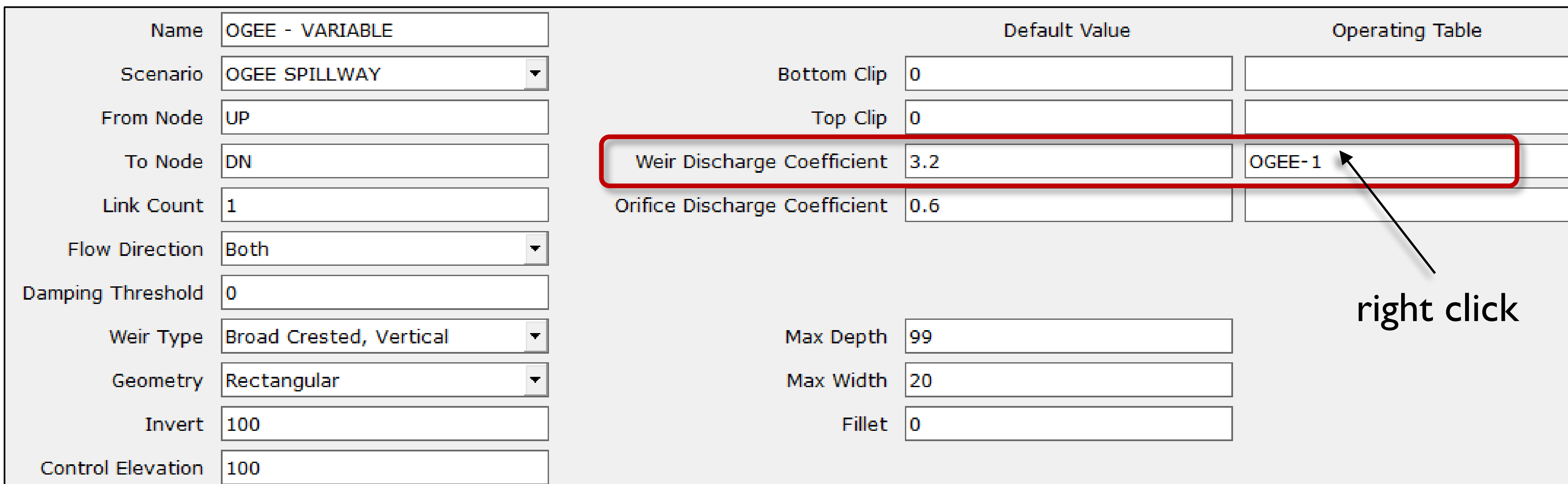
Variable Weir Coefficient Point Edit

Upstream Depth	Discharge Coefficient
0	3.08
0.6	3.39
1.2	3.56
1.8	3.68
2.4	3.76
3	3.8
3.6	3.83
4.2	3.85
4.8	3.87
5.4	3.88
6	3.89
9	3.92
12	3.94
18	3.95

Weir Links

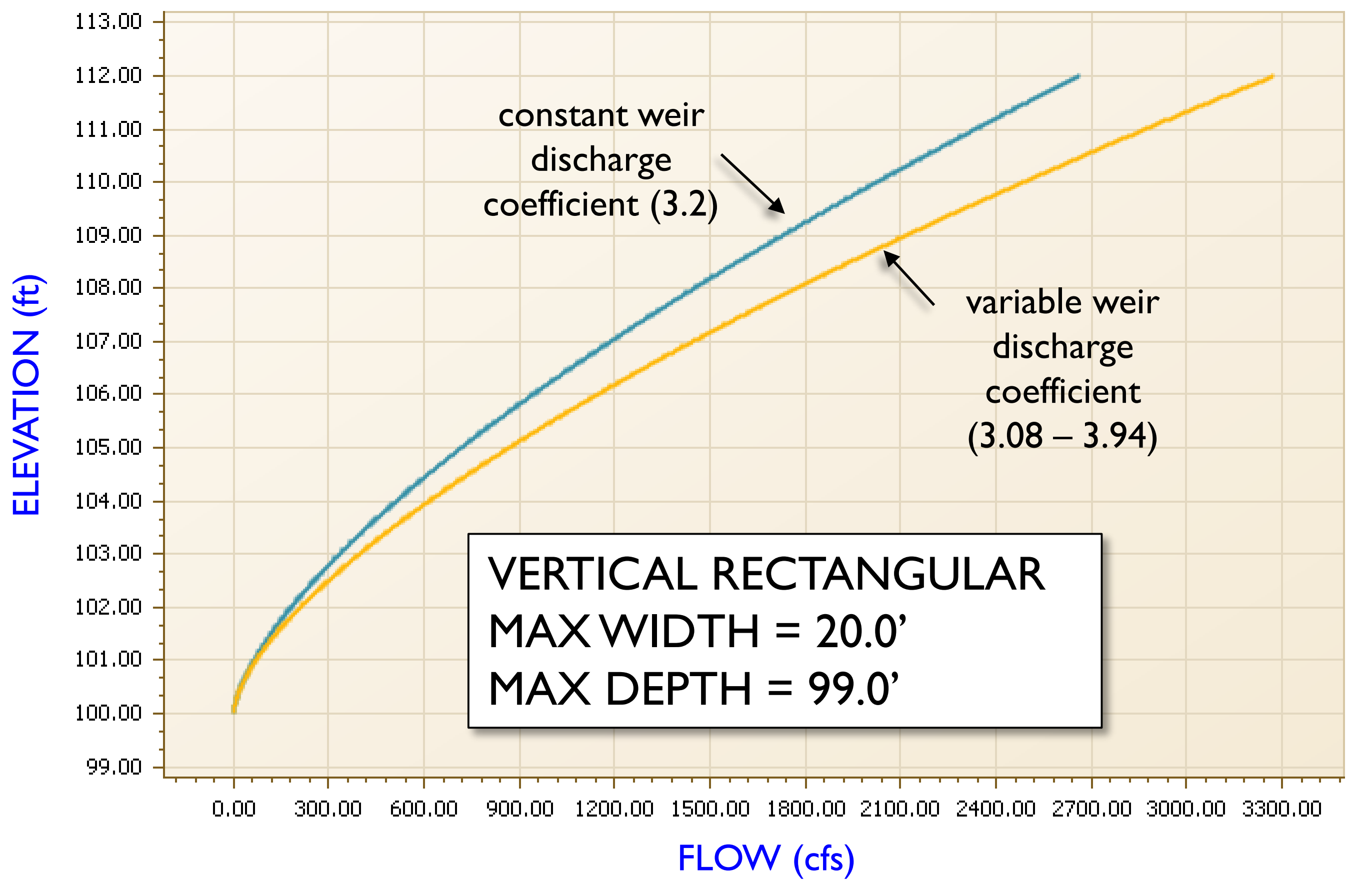
Variable Weir Discharge Coefficient





Weir Links

Variable Weir Discharge Coefficient



Weir Links

Bottom and Top Clips

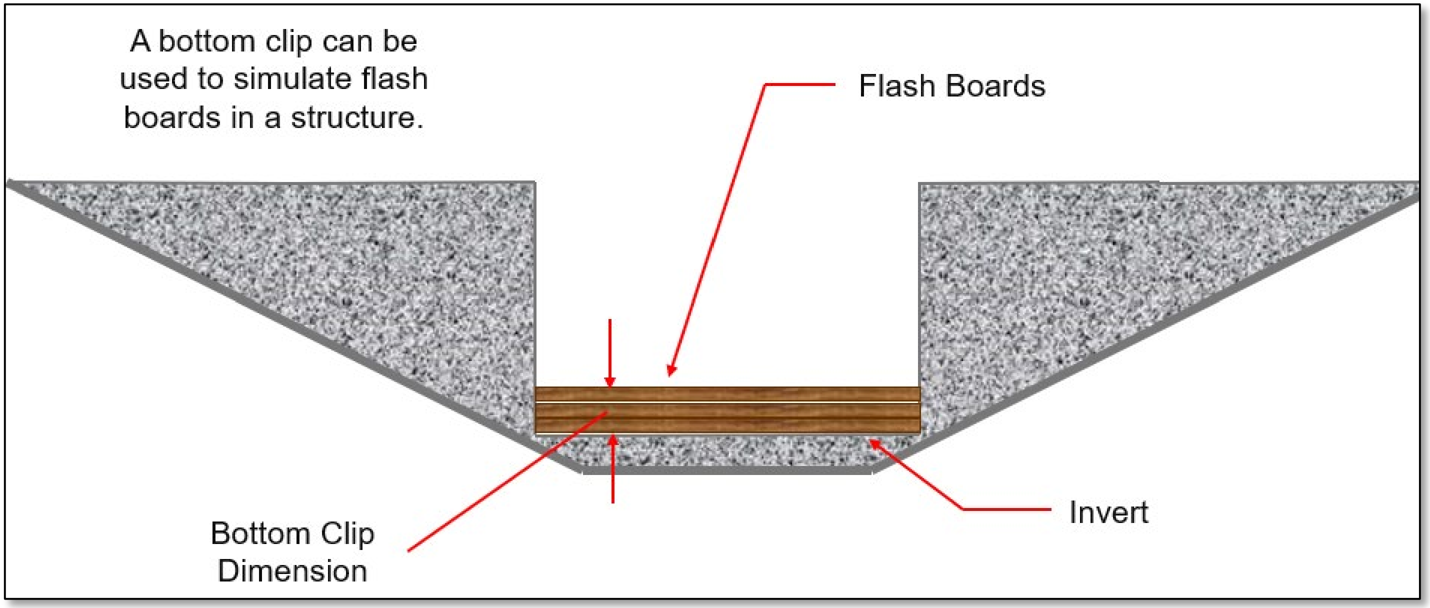
The clip feature can be used to block off a portion of the weir opening. Bottom clips are measured upward from the invert elevation. Top clips are measured downward from the invert elevation plus the max depth.

An operating table can be used to "schedule" opening and closing of these gates based on operational criteria.

	Default Value	Operating Table	Reference Node
Bottom Clip	0		
Top Clip	0		
Weir Discharge Coefficient	2.8		
Orifice Discharge Coefficient	0.6		

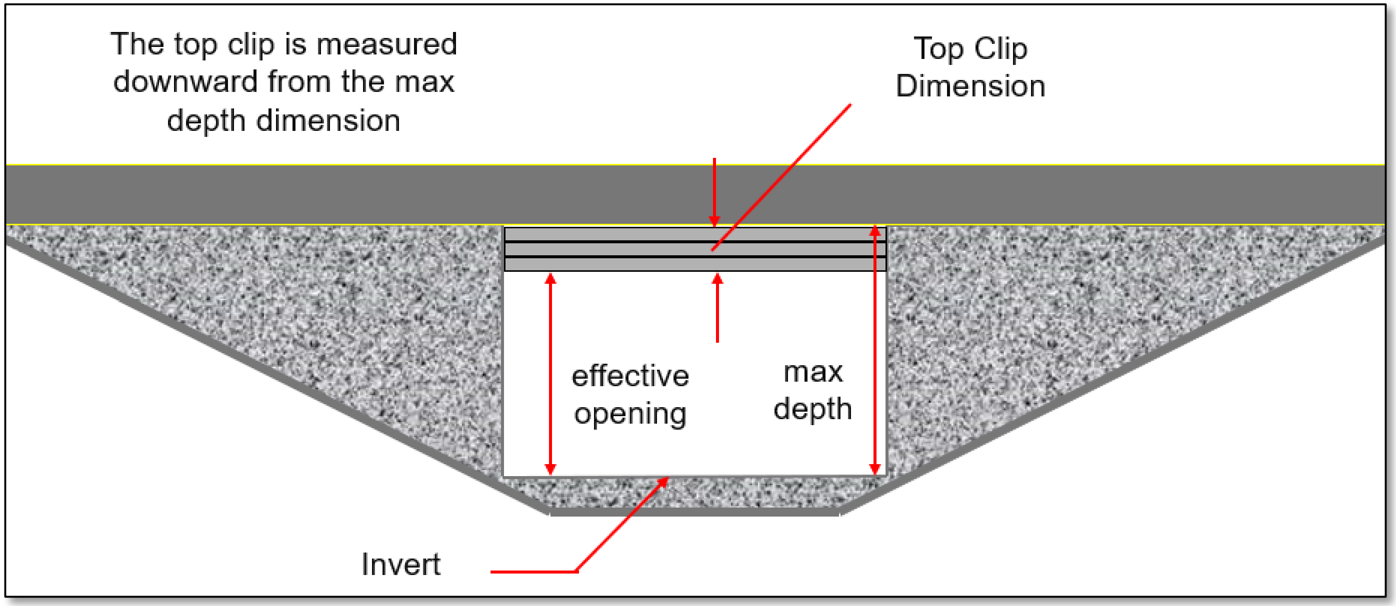
Weir Links

Bottom and Top Clips



Weir Links

Bottom and Top Clips



Weir Links

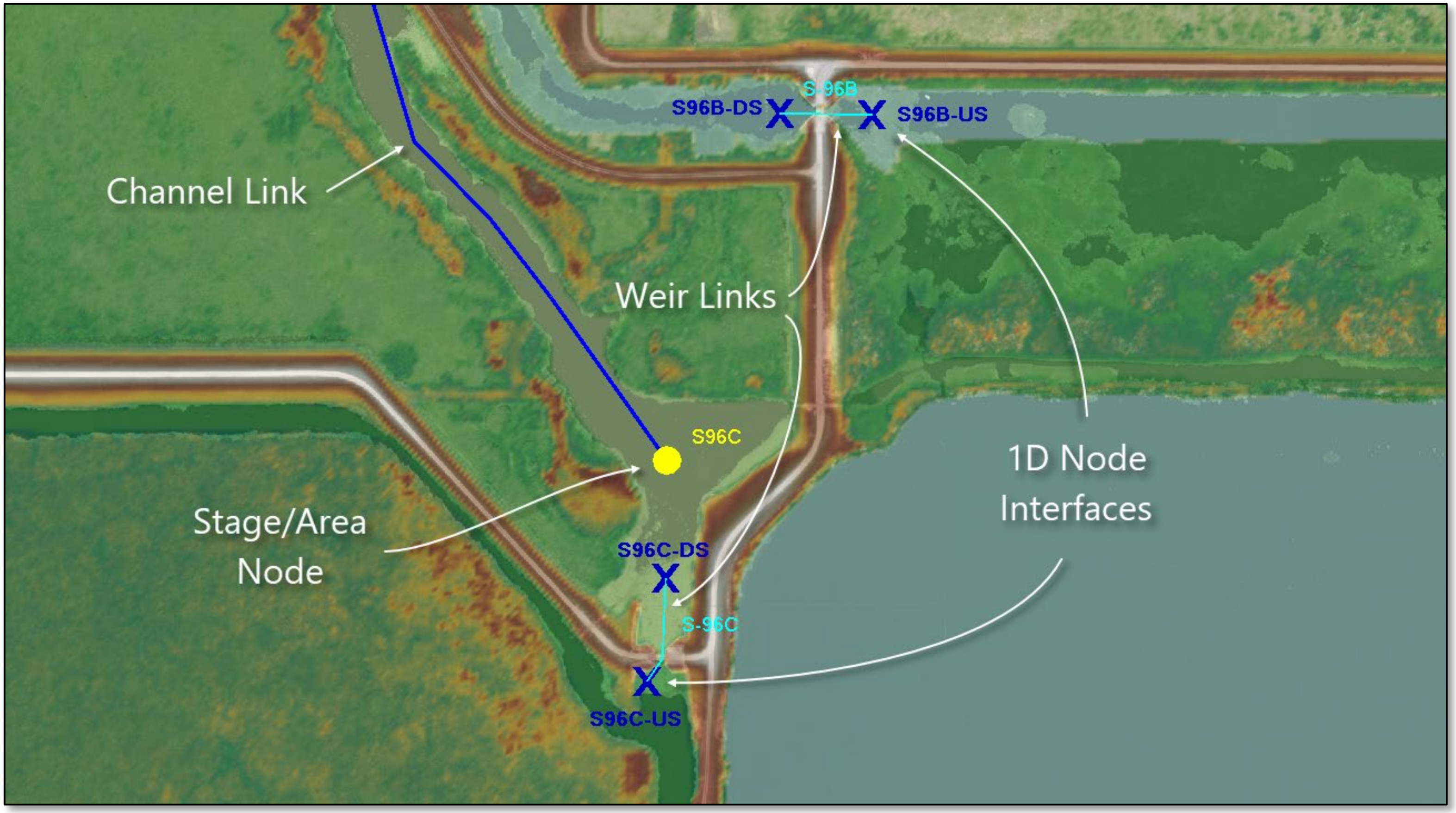
Bottom and Top Clips

Gate Structures S-96B and S-96C, USJRB

Source: Star Controls

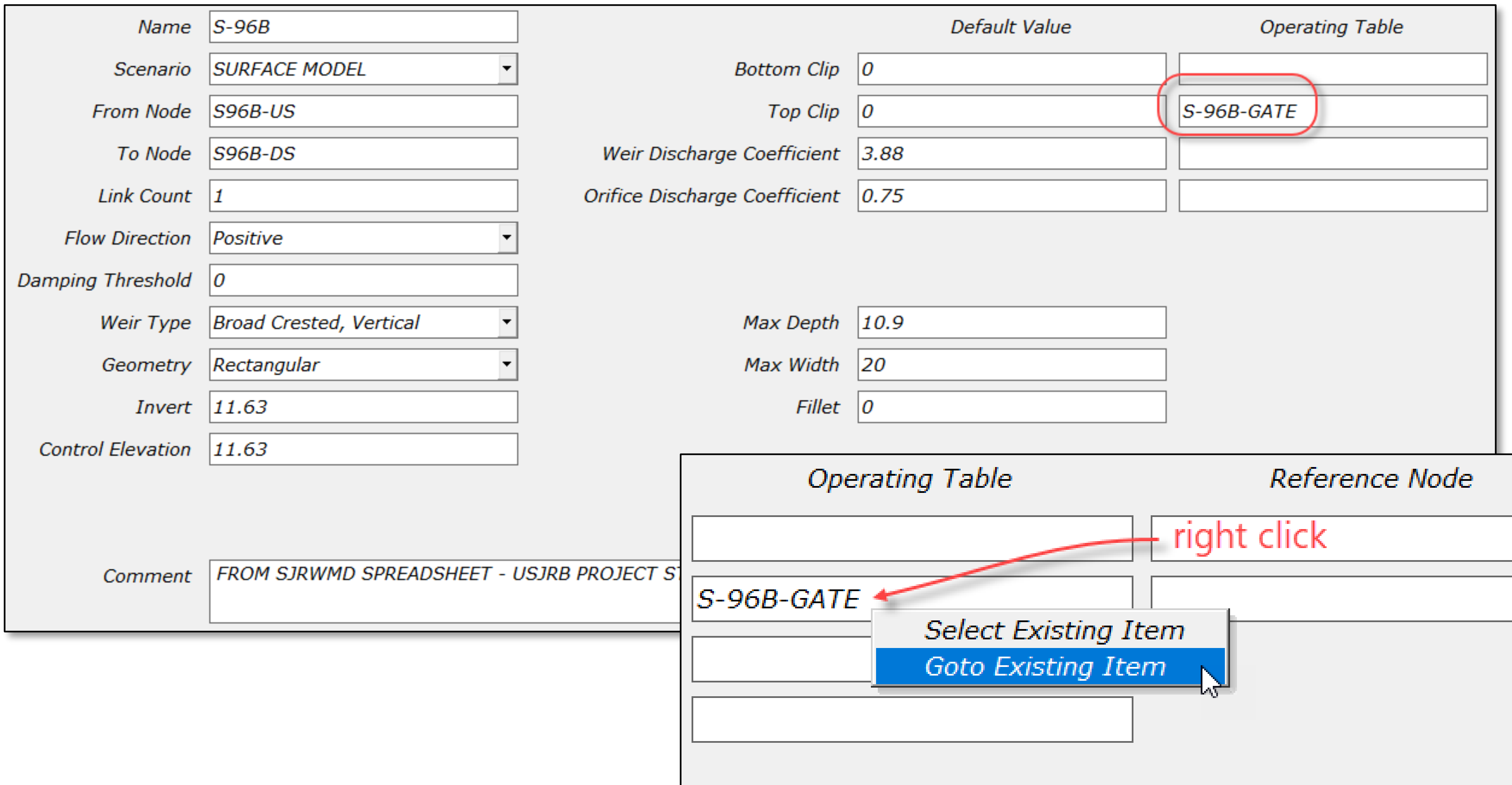
Weir Links

Bottom and Top Clips



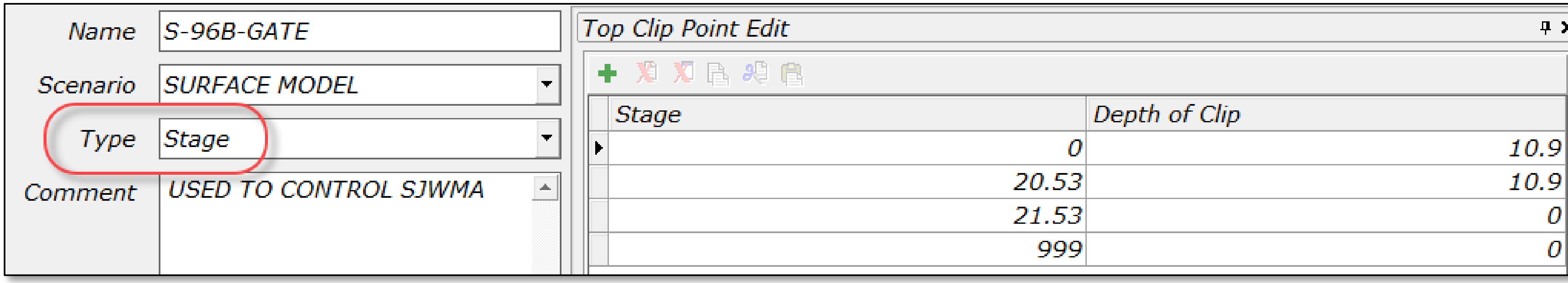
Weir Links

Bottom and Top Clips



Weir Links

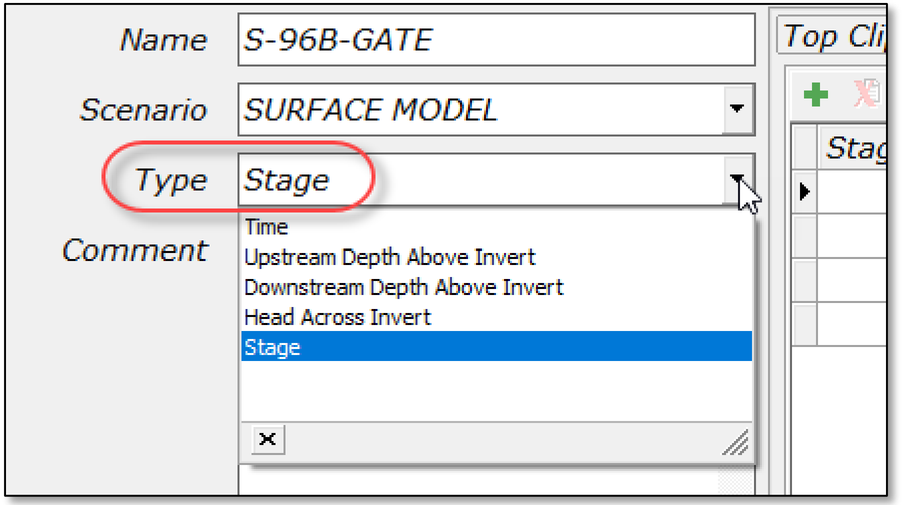
Bottom and Top Clips



- This is a top clip operating table based on the upstream stage of the corresponding weir link (S-96B).
- The top clip is set to 10.9 feet (measured downward from the maximum depth of the weir) when the water surface at node "S96B-US) is at or below elevation 20.53 ft (NAVD88).
- The clip depth decreases linearly to zero between elevations 20.53 ft and 21.53 ft (NAVD88). When the top clip depth is zero, the structure is fully opened.

Weir Links

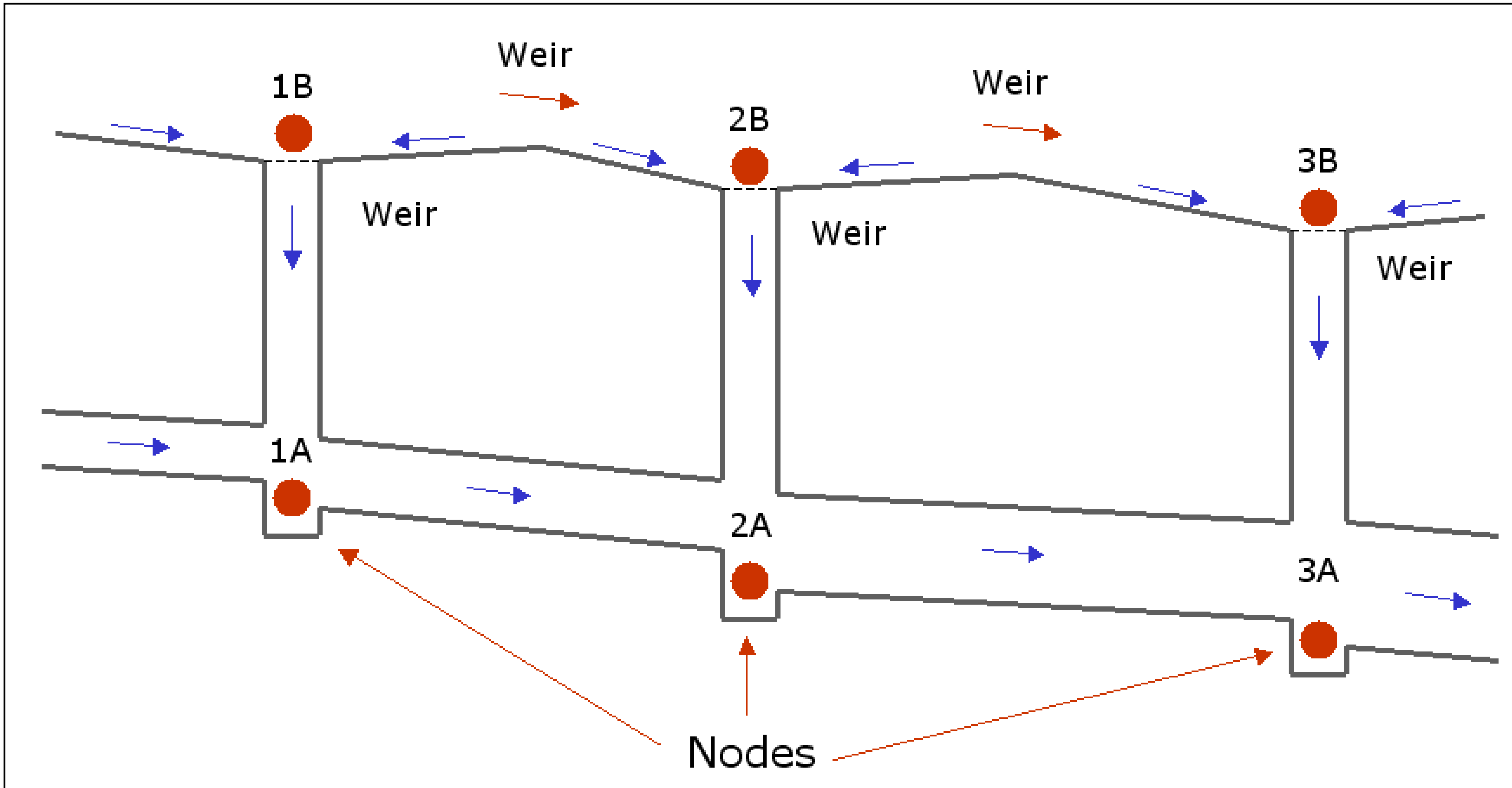
Bottom and Top Clips



- The operating table type can be changed depending on how you would like to operate the structure.
- The top clip can be based on time, upstream and downstream depths above the invert elevation or head across the structure (measured as upstream elevation minus downstream elevation).

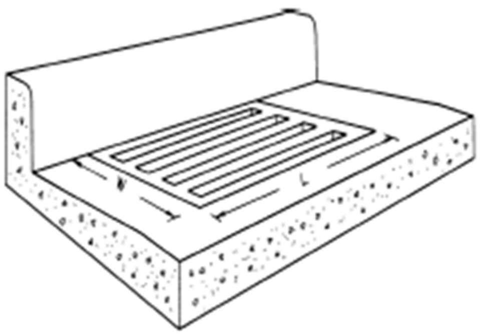
Weir Links

Curb Inlets

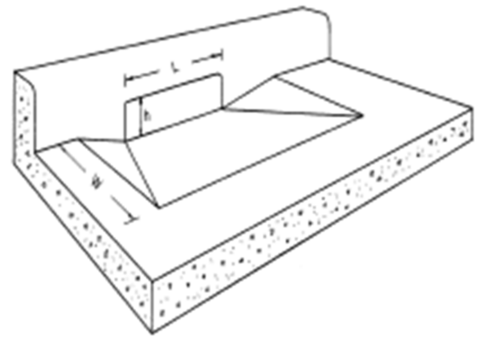


Weir Links

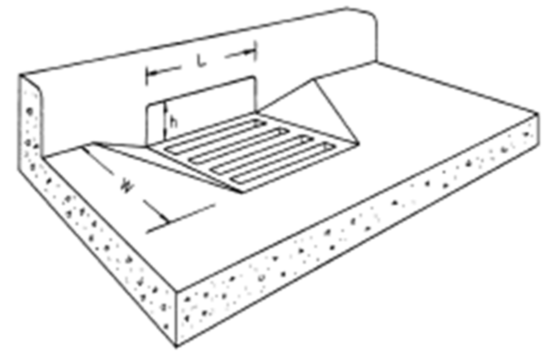
Curb Inlets



a. Grate



b. Curb-opening Inlet



c. Combination Inlet

Horizontal Weir

- use rectangular geometry
- set max depth and max width to single slot dimension
- set count to number of slots
- set invert & control to average elevation of grate

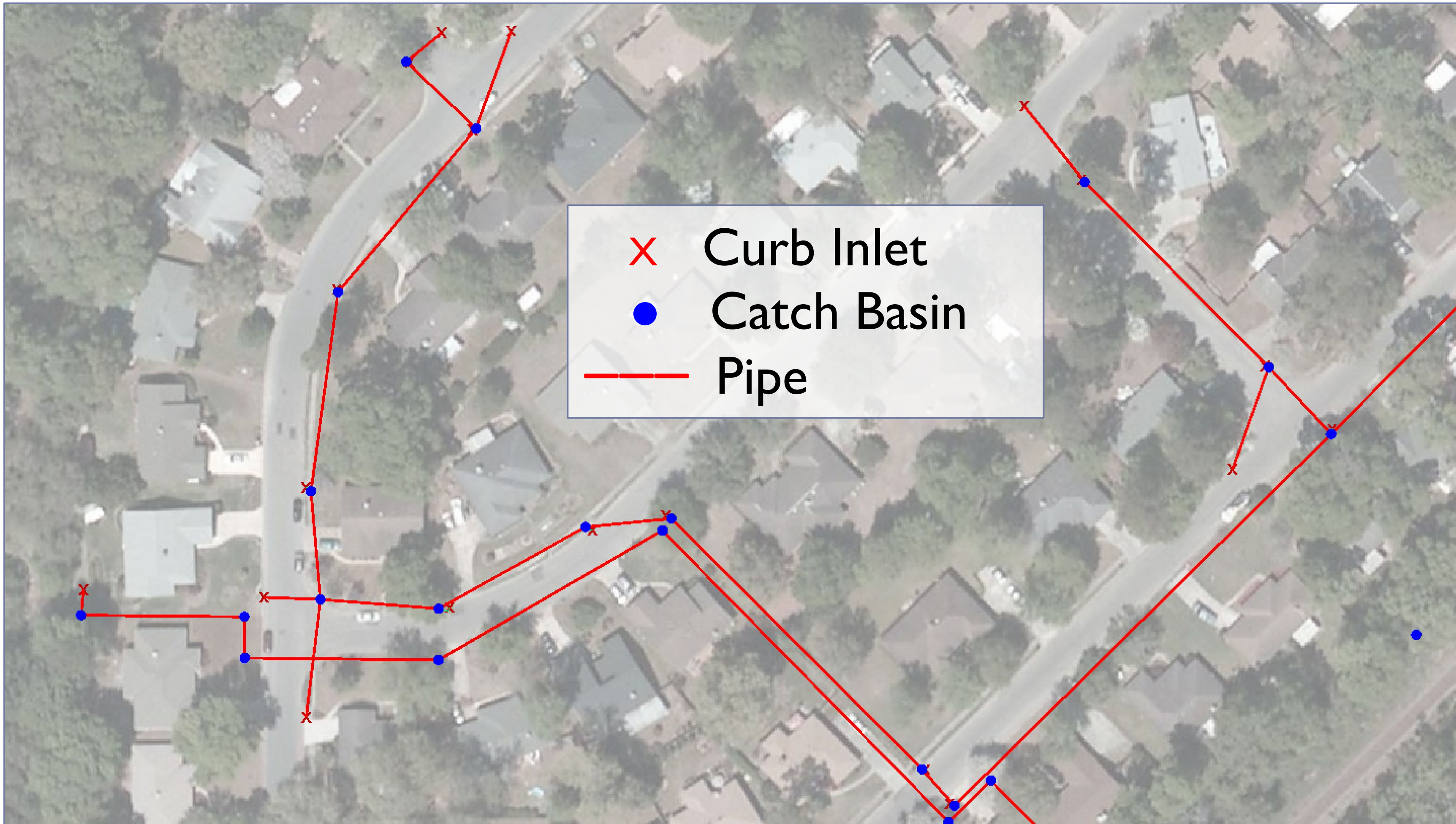
Vertical Weir

- use rectangular geometry
- set max depth to vertical opening dimension
- set max width to horizontal dimension

Use 2 Weir Links

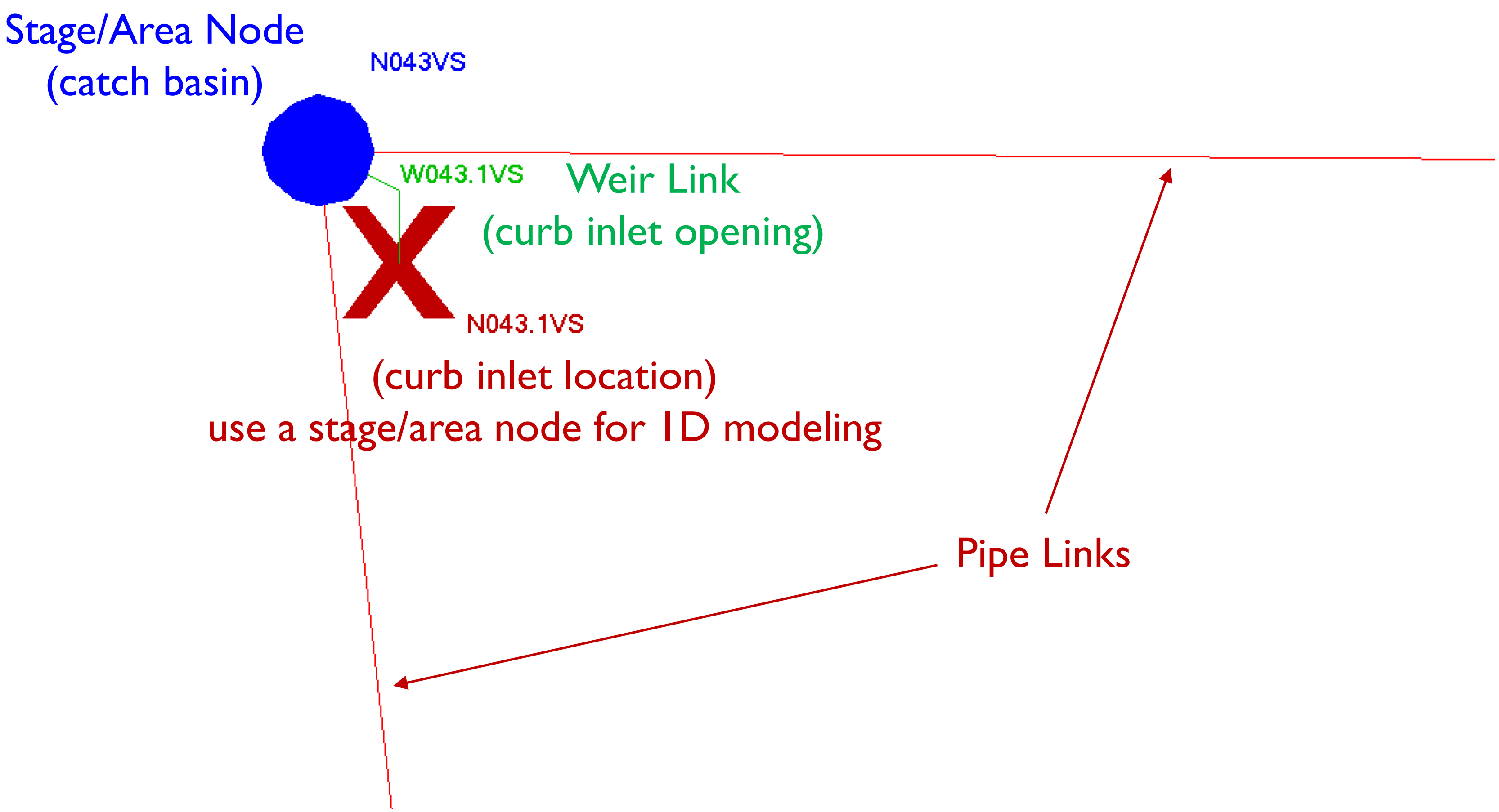
Weir Links

Curb Inlets



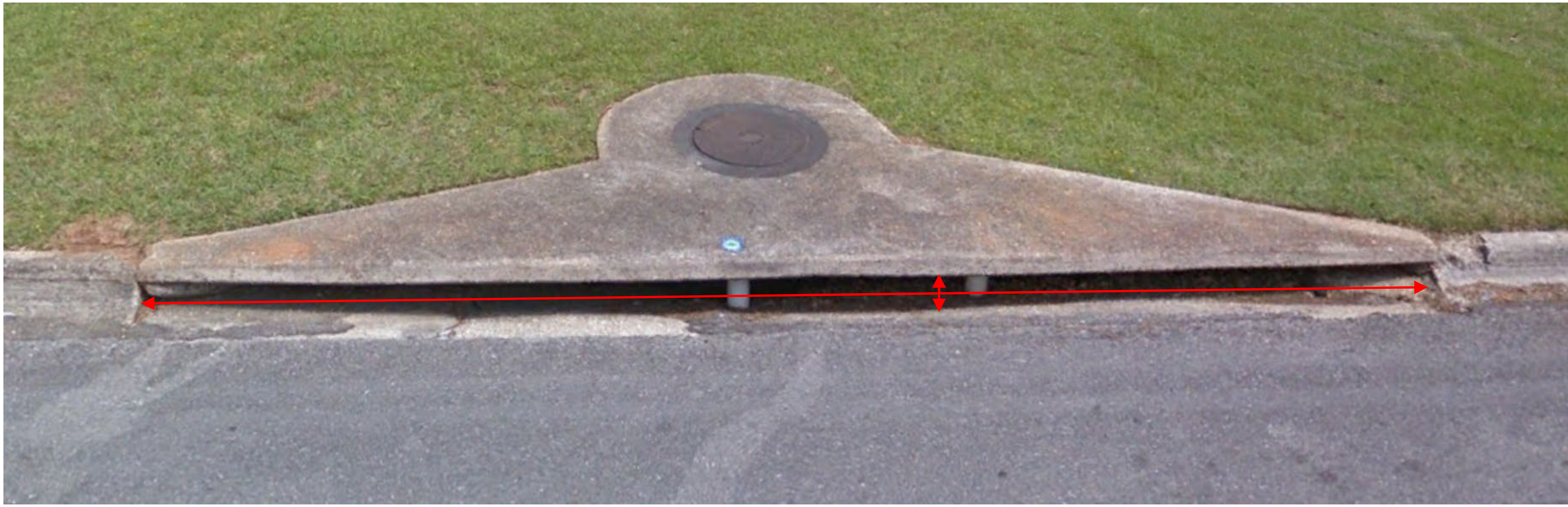
Weir Links

Curb Inlets



Weir Links

Curb Inlets



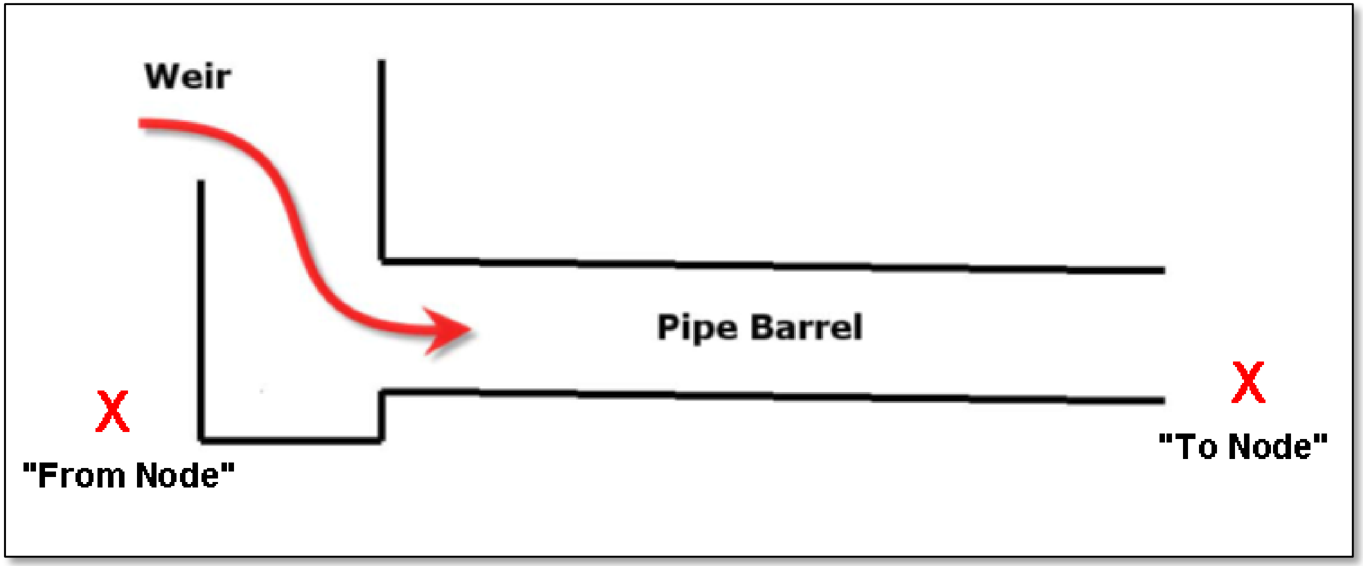
Weir Type	Sharp Crested, Vertical	Max Depth	0.5
Geometry	Rectangular	Max Width	12
Invert	119.72	Fillet	0
Control Elevation	119.72		

Drop Structure Links

Basics

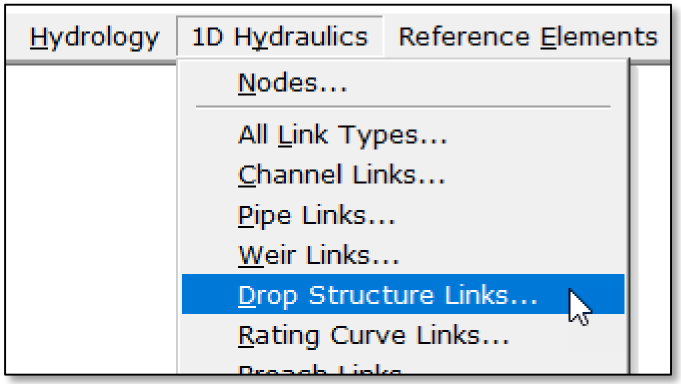
A drop structure of a weir component and a pipe component.

- Weir component in series with pipe component
- Upstream node (the “from node”) is always located at the upstream end of the weir component
- Downstream node (the “to node”) is always placed at the downstream end of the pipe component
- Pipe hydraulics must balance with weir hydraulics

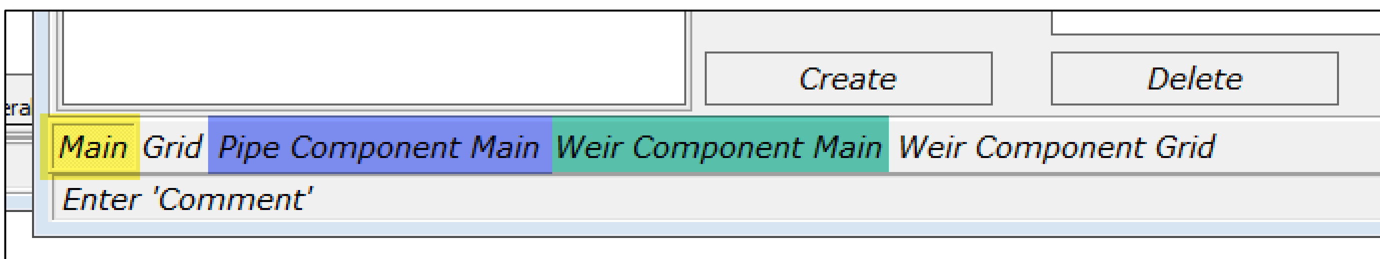


Drop Structure Links

Data Form



There are 5 tabs on the drop structure link data form, three (highlighted below) will be discussed.



Drop Structure Links

Data Form – Main Tab

Name	DROP
Scenario	DROP STRUC
From Node	UP
To Node	DN
Link Count	1
Flow Direction	Both
Solution	Combine
Increments	10

Main tab includes:

- Connectivity
- Link Count (# of identical drop structures)
- Flow Direction
- Solution (combine & split methods)

Drop Structure Links

Data Form – Pipe Component Tab

Pipe Count	1
Damping Threshold	0
Length	100
FHWA Culvert Code	0
Entrance Loss Coefficient	0.5
Exit Loss Coefficient	1
Bend Loss Coefficient	0
Bend Location	0
Energy Switch	Energy

	Upstream	Downstream
Invert	-2	-2
Manning's N	0.024	0.024
Geometry		
Type	Circular	Circular
Max Depth	1.5	1.5

Drop Structure Links

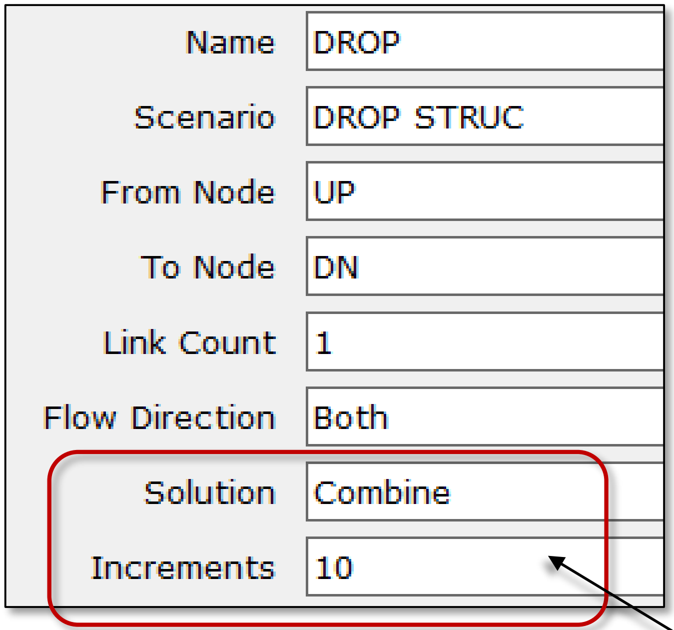
Data Form – Weir Component Tab

Name	1
Weir Count	1
Weir Flow Direction	Both
Damping Threshold	0
Weir Type	Sharp Crested, Vertical
Geometry	Rectangular
Invert	0
Control Elevation	0

	Default Value	Operating Table	Reference Node
Bottom Clip	0		
Top Clip	0		
Weir Discharge Coefficient	3.2		
Orifice Discharge Coefficient	0.6		

Drop Structure Links

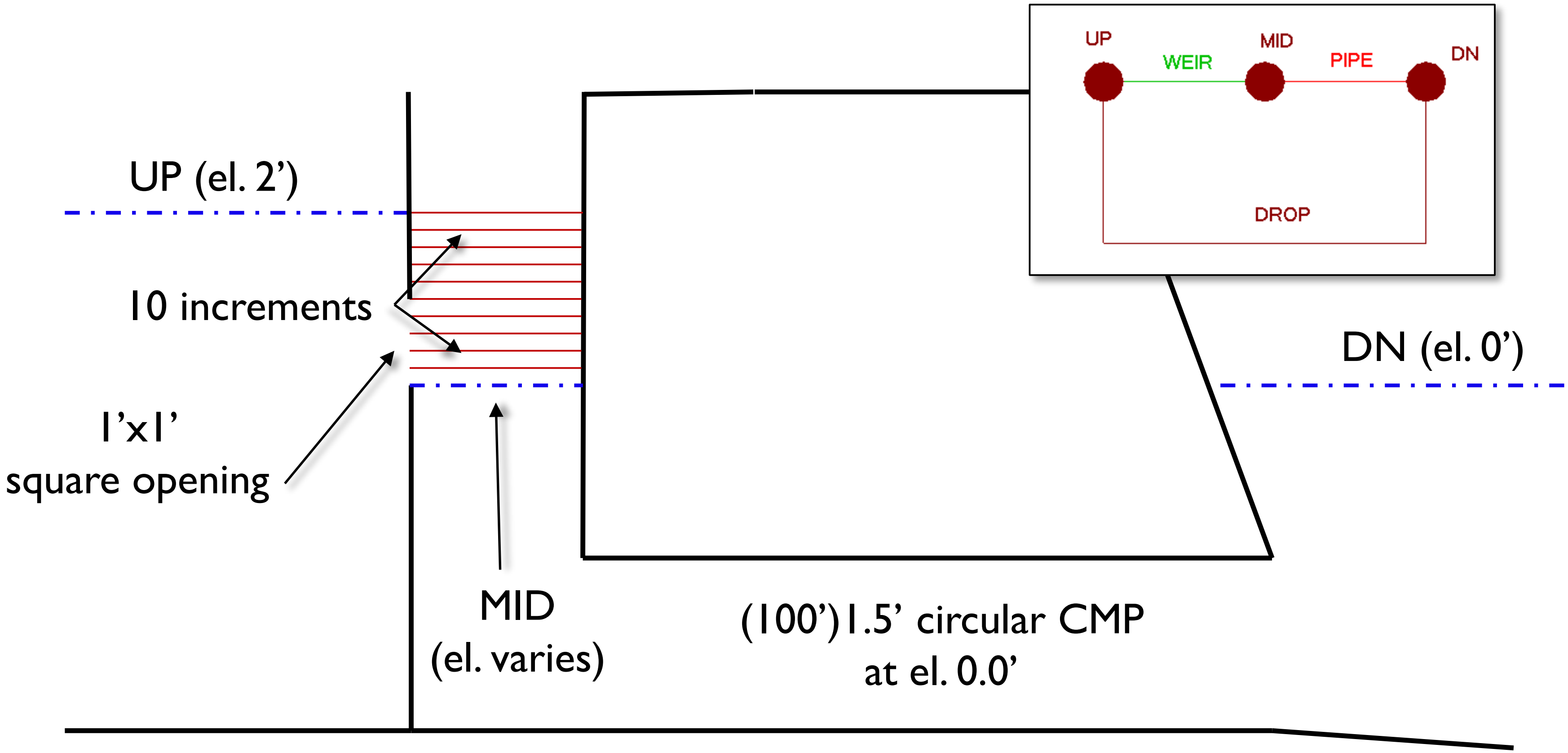
Solution Method: “Combine” with 10 “Increments”



ICPR3 solution method used with “Combine” method and non-zero “Increments”. Pipe storage not included in calcs. Pipe velocities not valid.

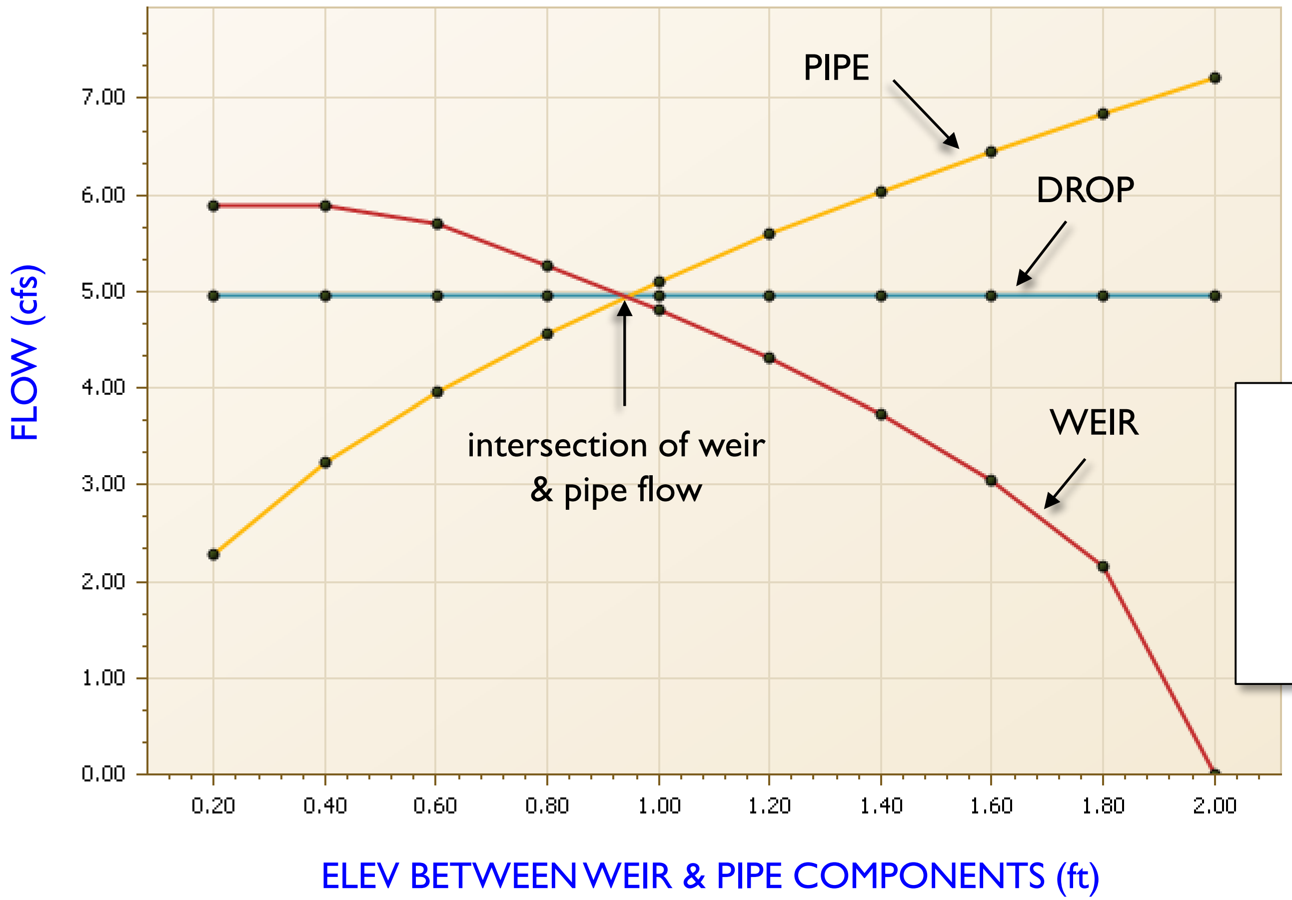
Drop Structure Links

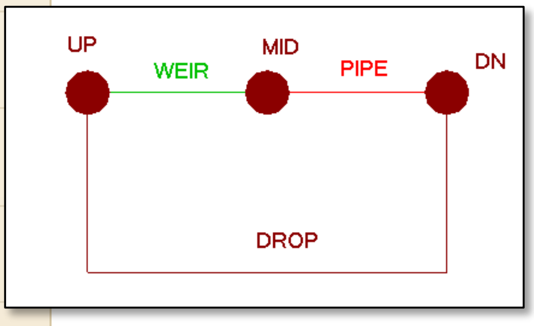
Solution Method: “Combine” with 10 “Increments”



Drop Structure Links

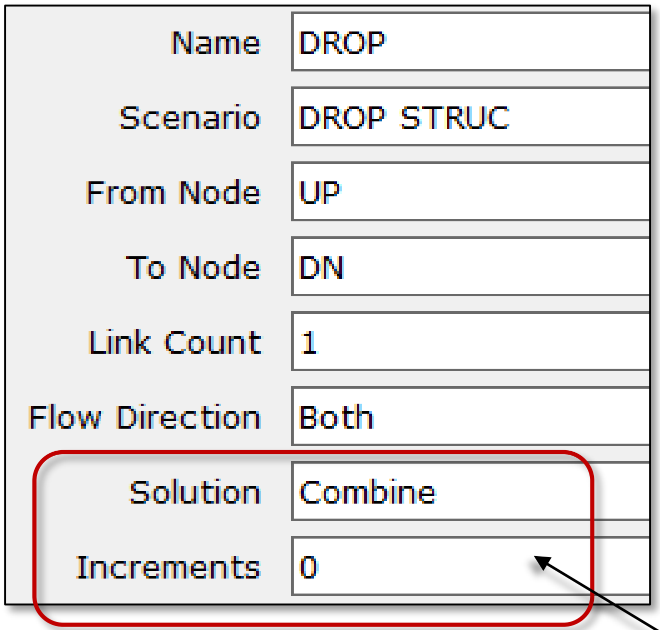
Solution Method: “Combine” with 10 “Increments”





Drop Structure Links

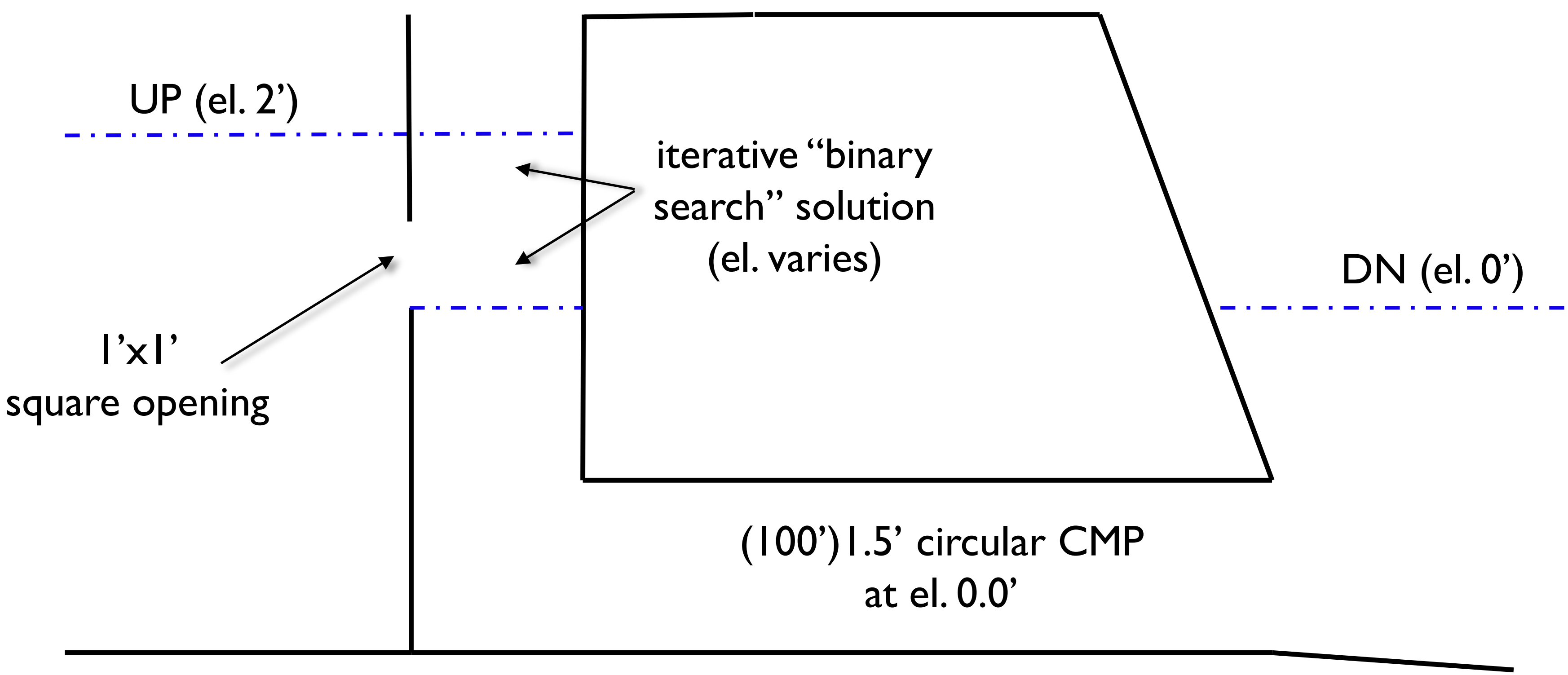
Solution Method: “Combine” with 0 “Increments”



“Binary Search” method used with “Combine” solution and zero “Increments”. Pipe storage not included in calcs. Pipe velocities not valid.

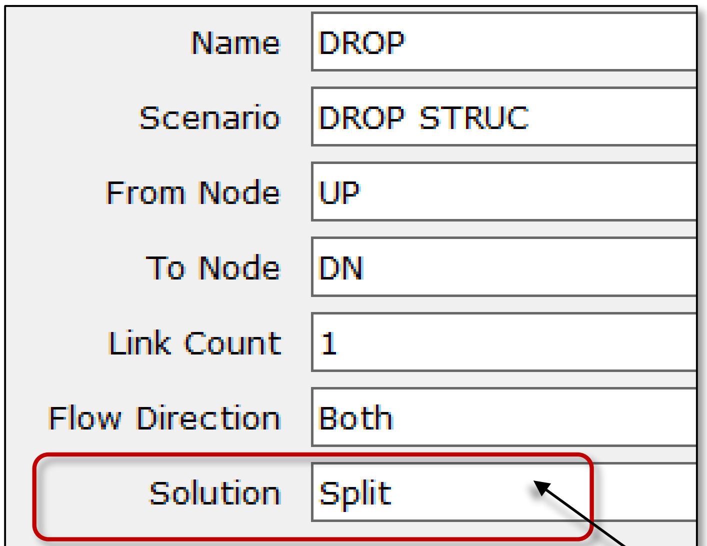
Drop Structure Links

Solution Method: "Combine" with 0 "Increments"



Drop Structure Links

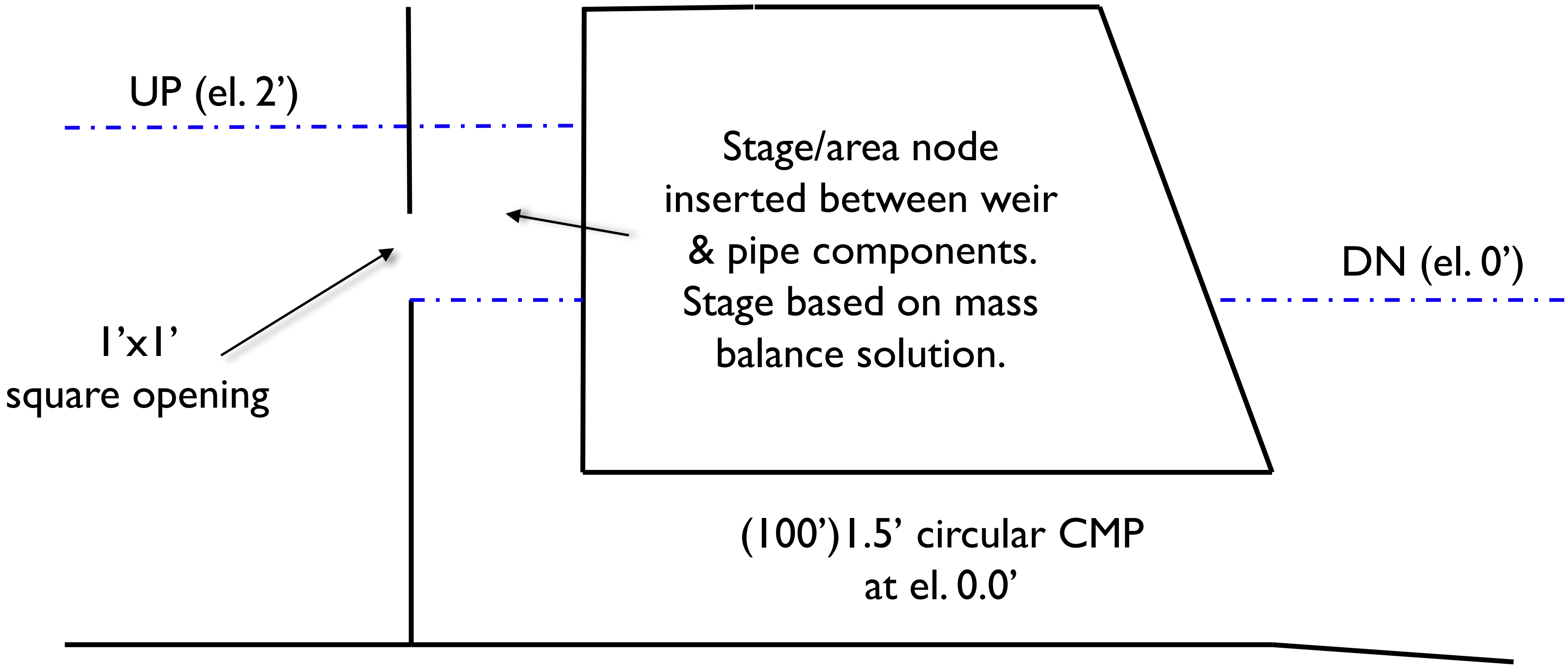
Solution Method: “Combine” with 0 “Increments”



“Split” method decomposes drop structure into separate links. Pipe storage included in calcs. Includes accurate velocities.

Drop Structure Links

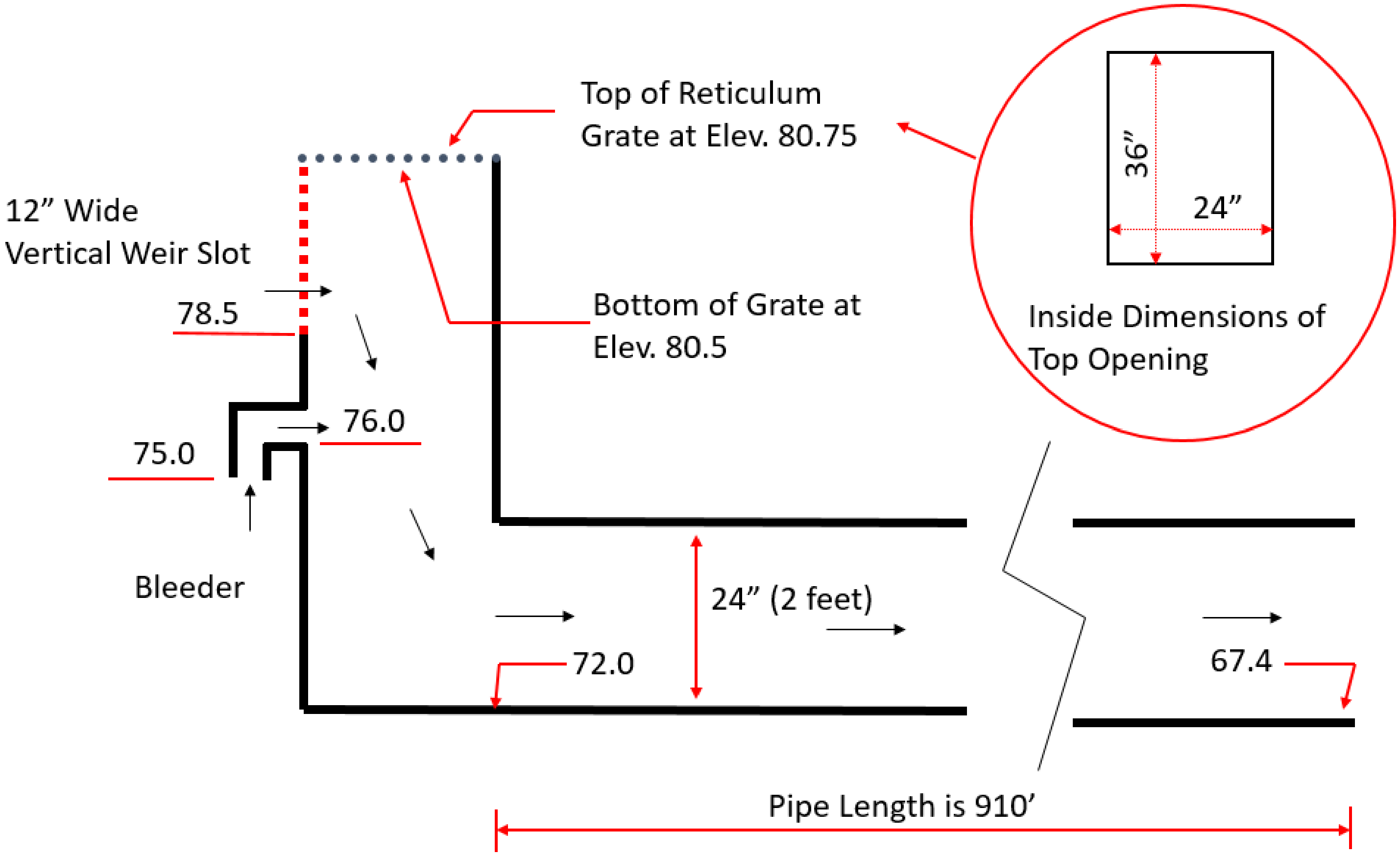
Solution Method: “Split”



Drop Structure Links

Example DS#1

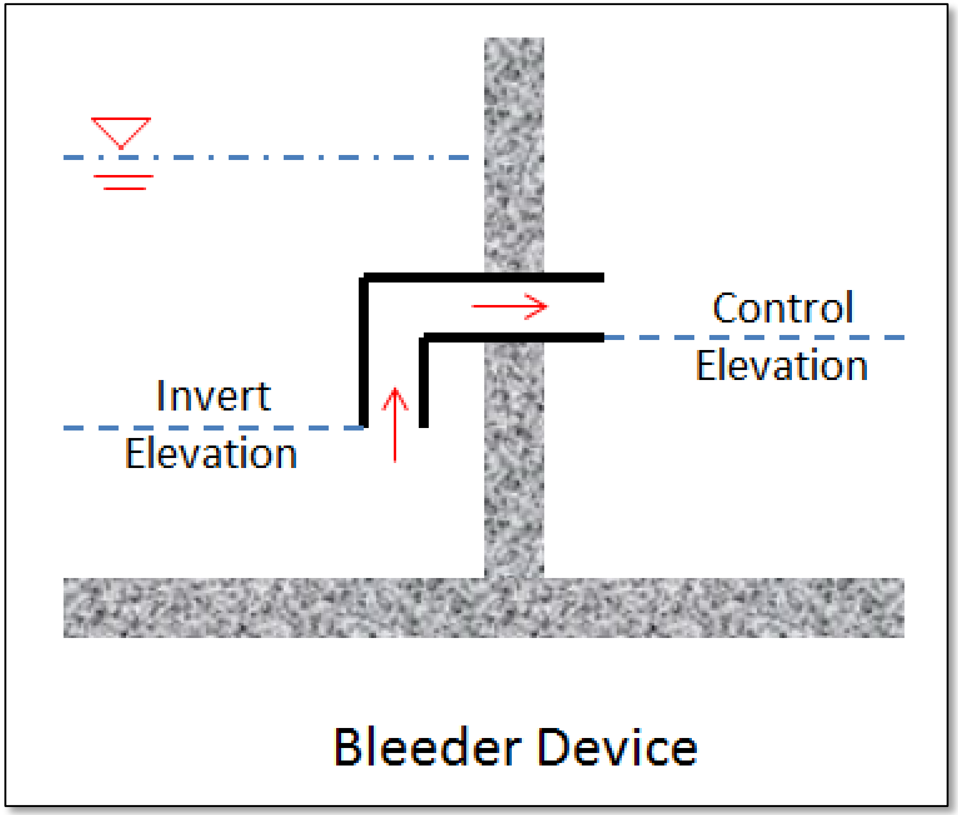
There are three (3) weir components in the example shown below including a circular bleeder orifice, a vertical rectangular slot and an overflow inlet.



Drop Structure Links

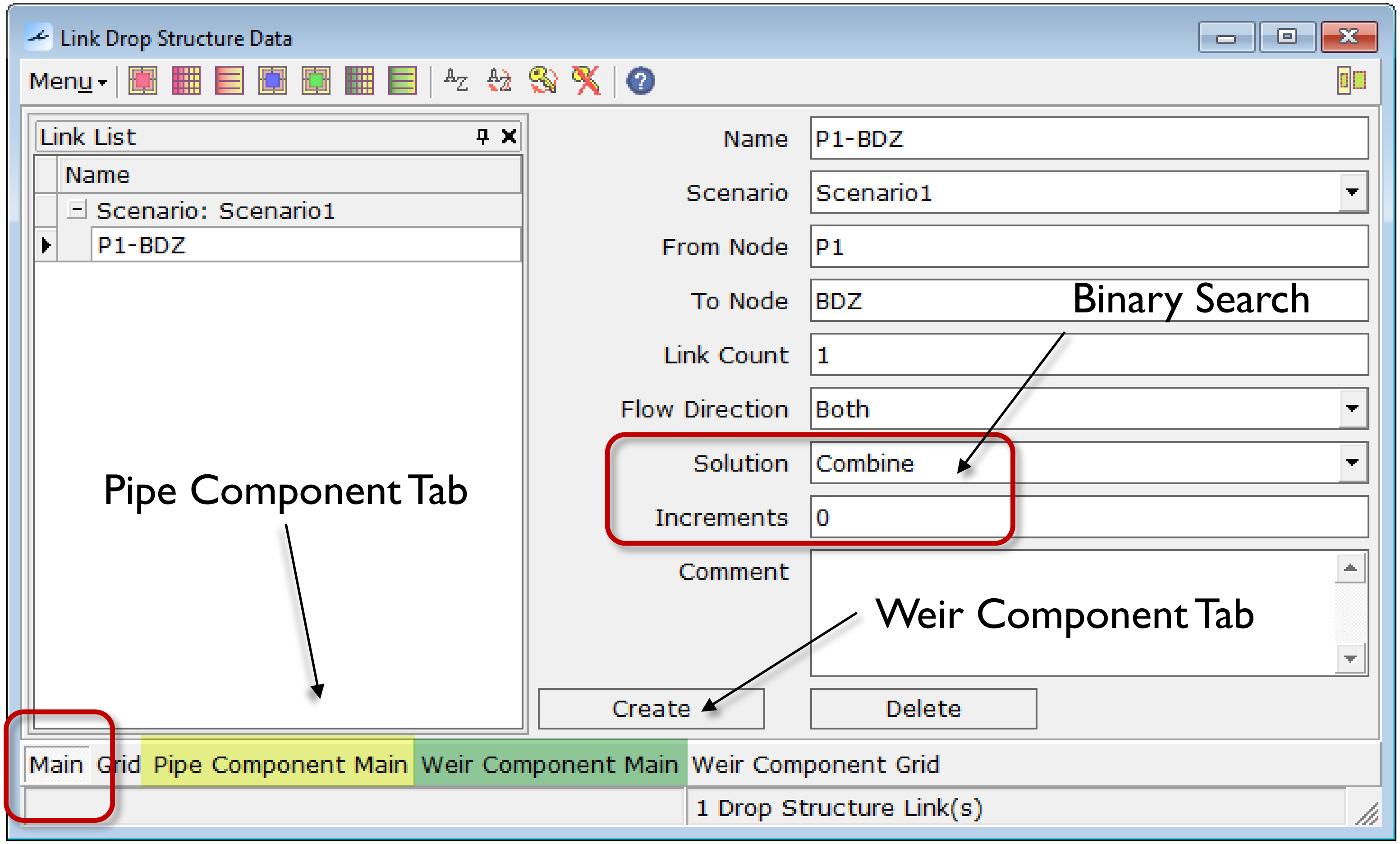
Example DS#1

Invert and Control Elevations for a Bleeder Device



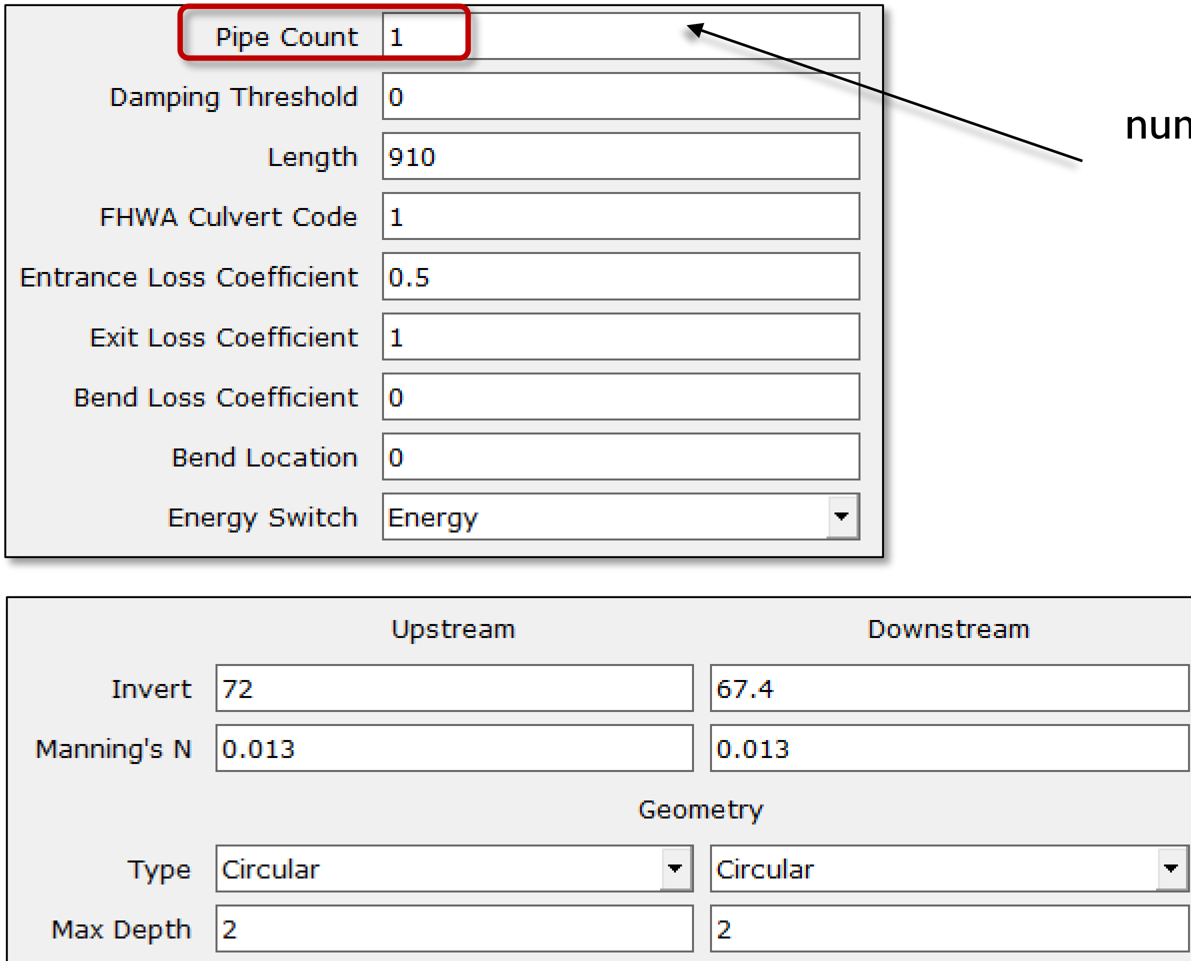
Drop Structure Links

Example DS#1: Main Tab



Drop Structure Links

Example DS#1: Pipe Component Tab



number of identical pipe barrels

Drop Structure Links

Example DS#1: Weir Component Tab (#1)

Name	1
Weir Count	1
Weir Flow Direction	Both
Damping Threshold	0
Weir Type	Horizontal
Geometry	Circular
Invert	75
Control Elevation	76

names of weir component is automatic and is a numeric value based on sequencing of creation

number of identical weir #1 components

Max Depth	0.5

bleeder

	Default Value	Operating Table
Bottom Clip	0	
Top Clip	0	
Weir Discharge Coefficient	3.2	
Orifice Discharge Coefficient	0.6	

Drop Structure Links

Example DS#1: Weir Component Tab (#2)

Name	2
Weir Count	1
Weir Flow Direction	Both
Damping Threshold	0
Weir Type	Sharp Crested, Vertical
Geometry	Rectangular
Invert	78.5
Control Elevation	78.5

vertical slot

Max Depth	2
Max Width	1
Fillet	0

	Default Value	Operating Table
Bottom Clip	0	
Top Clip	0	
Weir Discharge Coefficient	3.2	
Orifice Discharge Coefficient	0.6	

Drop Structure Links

Example DS#1: Weir Component Tab (#3)

Name	3
Weir Count	1
Weir Flow Direction	Both
Damping Threshold	0
Weir Type	Horizontal
Geometry	Rectangular
Invert	80.75
Control Elevation	80.75

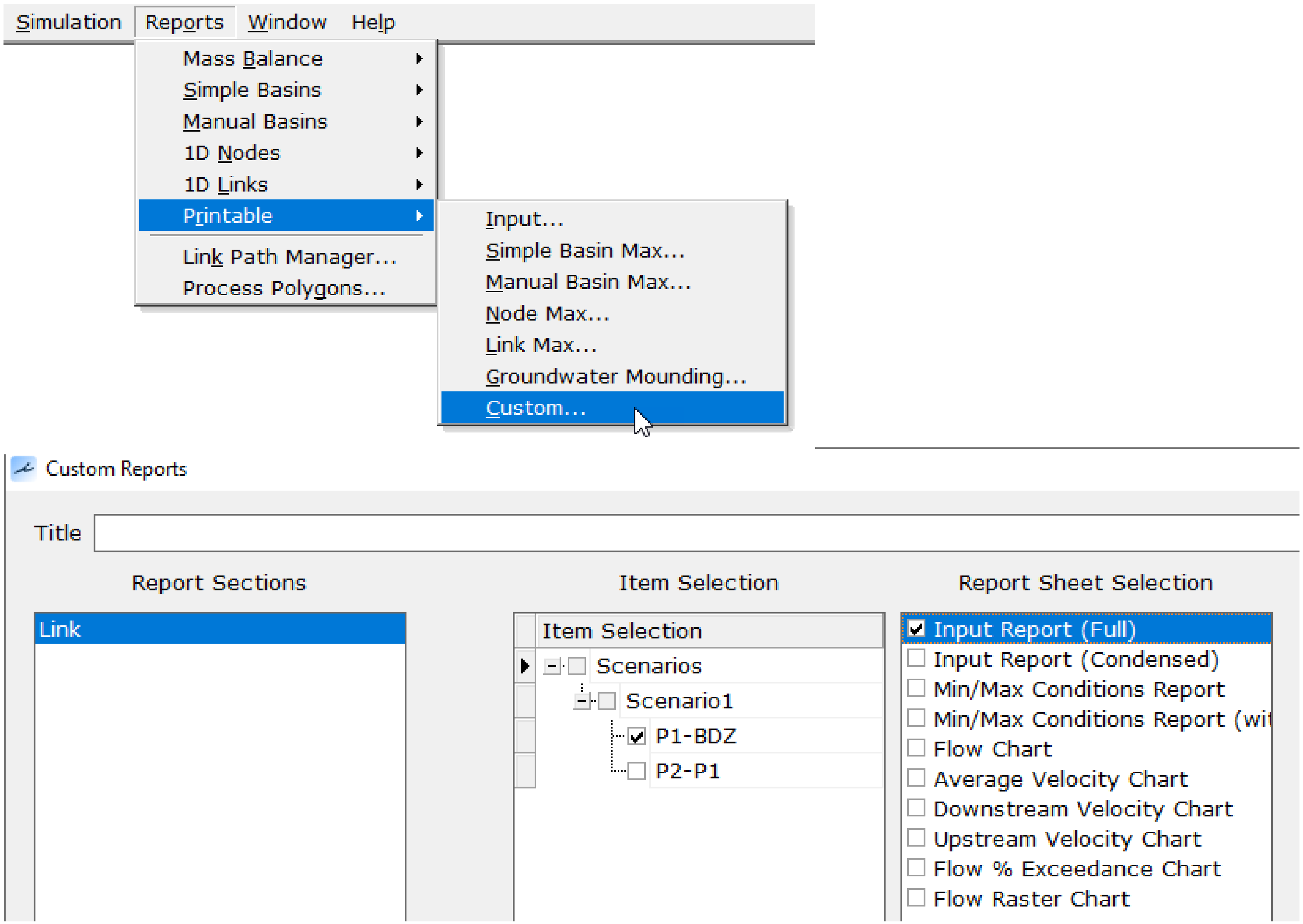
grate opening

Max Depth	3
Max Width	2
Fillet	0

	Default Value	Operating Table
Bottom Clip	0	
Top Clip	0	
Weir Discharge Coefficient	3.2	
Orifice Discharge Coefficient	0.6	

Drop Structure Links

Example DS#1: Input Report



Drop Structure Links

Example DS#1: Input Report

Pipe Component

1

Drop Structure Link: P1-BDZ		Upstream Pipe		Downstream Pipe	
Scenario:	Scenario1	Invert:	72.00 ft	Invert:	67.40 ft
From Node:	P1	Manning's N:	0.0130	Manning's N:	0.0130
To Node:	BDZ	Geometry: Circular		Geometry: Circular	
Link Count:	1	Max Depth:	2.00 ft	Max Depth:	2.00 ft
Flow Direction:	Both	Bottom Clip			
Solution:	Combine	Default:	0.00 ft	Default:	0.00 ft
Increments:	0	Op Table:		Op Table:	
Pipe Count:	1	Ref Node:		Ref Node:	
Damping:	0.0000 ft	Manning's N:	0.0000	Manning's N:	0.0000
Length:	910.00 ft	Top Clip			
FHWA Code:	1	Default:	0.00 ft	Default:	0.00 ft
Entr Loss Coef:	0.50	Op Table:		Op Table:	
Exit Loss Coef:	1.00	Ref Node:		Ref Node:	
Bend Loss Coef:	0.00	Manning's N:	0.0000	Manning's N:	0.0000
Bend Location:	0.00 ft				
Energy Switch:	Energy				
Pipe Comment:					

Example DS#1: Input Report

Weir Component #1 (bleeder)

Weir Component		Bottom Clip	
Weir:	1	Default:	0.00 ft
Weir Count:	1	Op Table:	
Weir Flow Direction:	Both	Ref Node:	
Damping:	0.0000 ft	**Top Clip**	
Weir Type:	Horizontal	Default:	0.00 ft
Geometry Type:	Circular	Op Table:	
Invert:	75.00 ft	Ref Node:	
Control Elevation:	76.00 ft	**Discharge Coefficients**	
Max Depth:	0.50 ft	Weir Default:	3.200
		Weir Table:	
		Orifice Default:	0.600
		Orifice Table:	
Weir Comment:			

Weir Component #2 (vertical slot)

Weir Component		Bottom Clip	
Weir:	2	Default:	0.00 ft
Weir Count:	1	Op Table:	
Weir Flow Direction:	Both	Ref Node:	
Damping:	0.0000 ft	**Top Clip**	
Weir Type:	Sharp Crested Vertical	Default:	0.00 ft
Geometry Type:	Rectangular	Op Table:	
Invert:	78.50 ft	Ref Node:	
Control Elevation:	78.50 ft	**Discharge Coefficients**	
Max Depth:	2.00 ft	Weir Default:	3.200
Max Width:	1.00 ft	Weir Table:	
Fillet:	0.00 ft	Orifice Default:	0.600
		Orifice Table:	
Weir Comment:			

Drop Structure Links

Example DS#1: Input Report

Weir Component #3 (horizontal grate)

2

Weir Component	
Weir:	3
Weir Count:	1
Weir Flow Direction:	Both
Damping:	0.0000 ft
Weir Type:	Horizontal
Geometry Type:	Rectangular
Invert:	80.75 ft
Control Elevation:	80.75 ft
Max Depth:	3.00 ft
Max Width:	2.00 ft
Fillet:	0.00 ft

Bottom Clip	
Default:	0.00 ft
Op Table:	
Ref Node:	

Top Clip	
Default:	0.00 ft
Op Table:	
Ref Node:	

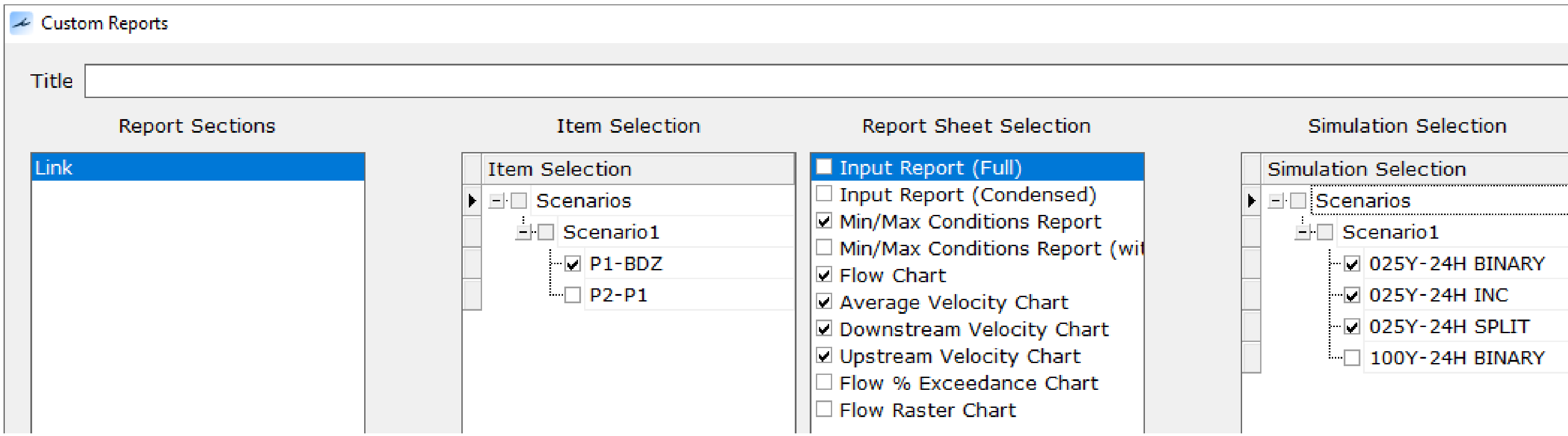
Discharge Coefficients	
Weir Default:	3.200
Weir Table:	
Orifice Default:	0.600
Orifice Table:	

Weir Comment:

Drop Structure Comment:

Drop Structure Links

Example DS#1: Understanding Velocity Reports



Drop Structure Links

Example DS#1: Understanding Velocity Reports

1

Link Min/Max Conditions [Scenario1]

Link Name	Sim Name	Max Flow [cfs]	Min Flow [cfs]	Min/Max Delta Flow [cfs]	Max Us Velocity [fps]	Max Ds Velocity [fps]	Max Avg Velocity [fps]
P1-BDZ - Pipe	025Y-24H BINARY	6.81	0.00	-0.01	0.00	0.00	0.00
P1-BDZ - Weir: 1	025Y-24H BINARY	1.85	0.00	0.00	9.43	9.43	9.43
P1-BDZ - Weir: 2	025Y-24H BINARY	4.96	0.00	-0.01	3.70	3.70	3.70
P1-BDZ - Weir: 3	025Y-24H BINARY	0.00	0.00	0.00	0.00	0.00	0.00
P1-BDZ - Pipe	025Y-24H INC	6.81	0.00	-0.01	0.00	0.00	0.00
P1-BDZ - Weir: 1	025Y-24H INC	1.85	0.00	0.00	9.43	9.43	9.43
P1-BDZ - Weir: 2	025Y-24H INC	4.96	0.00	-0.01	3.70	3.70	3.70
P1-BDZ - Weir: 3	025Y-24H INC	0.00	0.00	0.00	0.00	0.00	0.00
P1-BDZ - Pipe	025Y-24H SPLIT	6.81	0.00	-0.01	3.08	4.47	3.63
P1-BDZ - Weir: 1	025Y-24H SPLIT	1.85	0.00	0.00	9.43	9.43	9.43
P1-BDZ - Weir: 2	025Y-24H SPLIT	4.96	0.00	-0.01	3.70	3.70	3.70
P1-BDZ - Weir: 3	025Y-24H SPLIT	0.00	0.00	0.00	0.00	0.00	0.00

Drop Structure Links

Example DS#1: Understanding Velocity Reports

COMBINE with INCREMENTS METHOD (like ICPR3)

Link Name	Sim Name	Max Flow [cfs]	Max Us Velocity [fps]	Max Ds Velocity [fps]	Max Avg Velocity [fps]
P1-BDZ - Pipe	025Y-24H INC	6.81	0.00	0.00	0.00
P1-BDZ - Weir: 1	025Y-24H INC	1.85	9.43	9.43	9.43
P1-BDZ - Weir: 2	025Y-24H INC	4.96	3.70	3.70	3.70
P1-BDZ - Weir: 3	025Y-24H INC	0.00	0.00	0.00	0.00

no pipe velocities

COMBINE with BINARY SEARCH METHOD

Link Name	Sim Name	Max Flow [cfs]	Max Us Velocity [fps]	Max Ds Velocity [fps]	Max Avg Velocity [fps]
P1-BDZ - Pipe	025Y-24H BINARY	6.81	0.00	0.00	0.00
P1-BDZ - Weir: 1	025Y-24H BINARY	1.85	9.43	9.43	9.43
P1-BDZ - Weir: 2	025Y-24H BINARY	4.96	3.70	3.70	3.70
P1-BDZ - Weir: 3	025Y-24H BINARY	0.00	0.00	0.00	0.00

valid pipe velocities

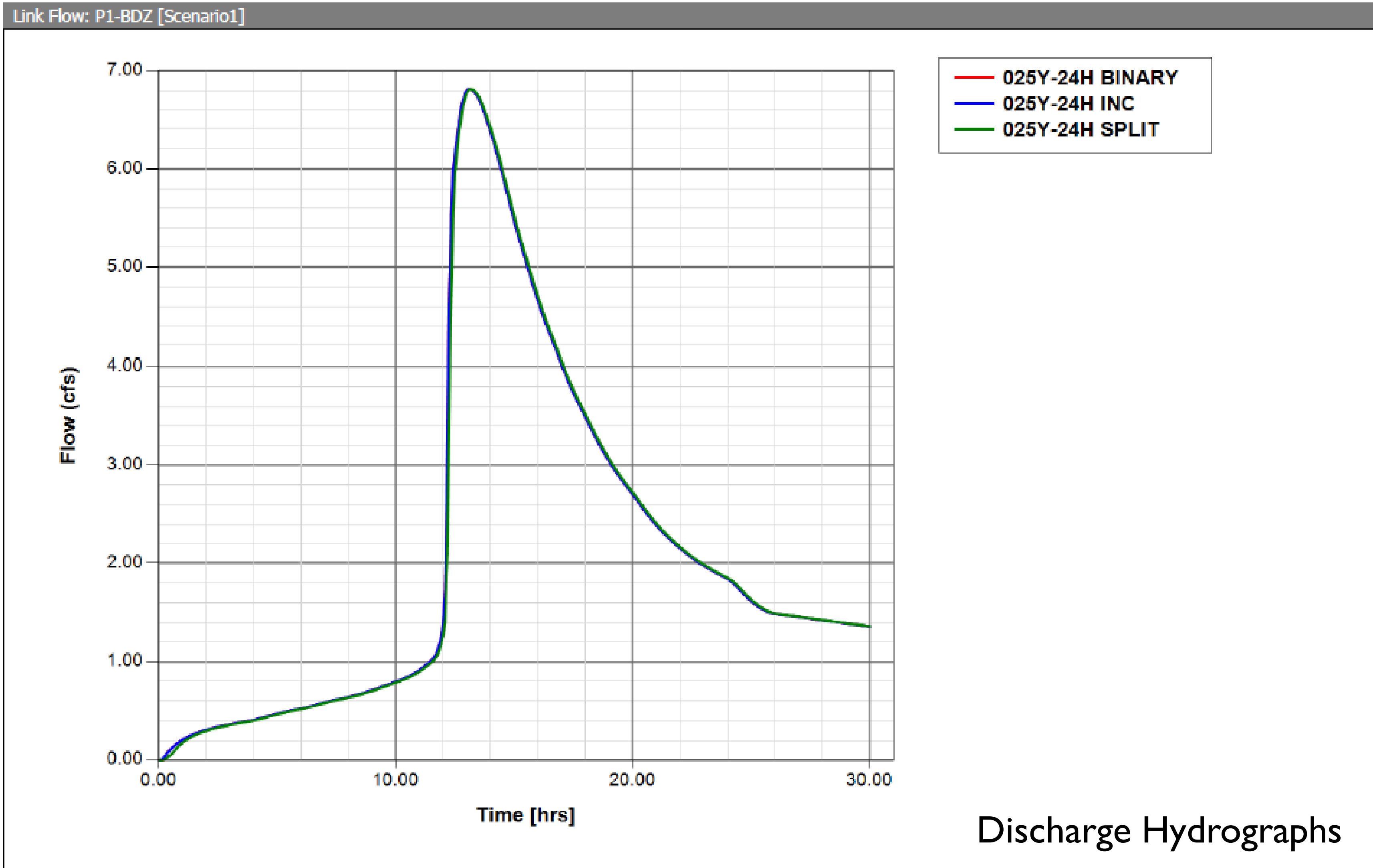
SPLIT METHOD

Link Name	Sim Name	Max Flow [cfs]	Max Us Velocity [fps]	Max Ds Velocity [fps]	Max Avg Velocity [fps]
P1-BDZ - Pipe	025Y-24H SPLIT	6.81	3.08	4.47	3.63
P1-BDZ - Weir: 1	025Y-24H SPLIT	1.85	9.43	9.43	9.43
P1-BDZ - Weir: 2	025Y-24H SPLIT	4.96	3.70	3.70	3.70
P1-BDZ - Weir: 3	025Y-24H SPLIT	0.00	0.00	0.00	0.00

max flows match for the
3 solution methods

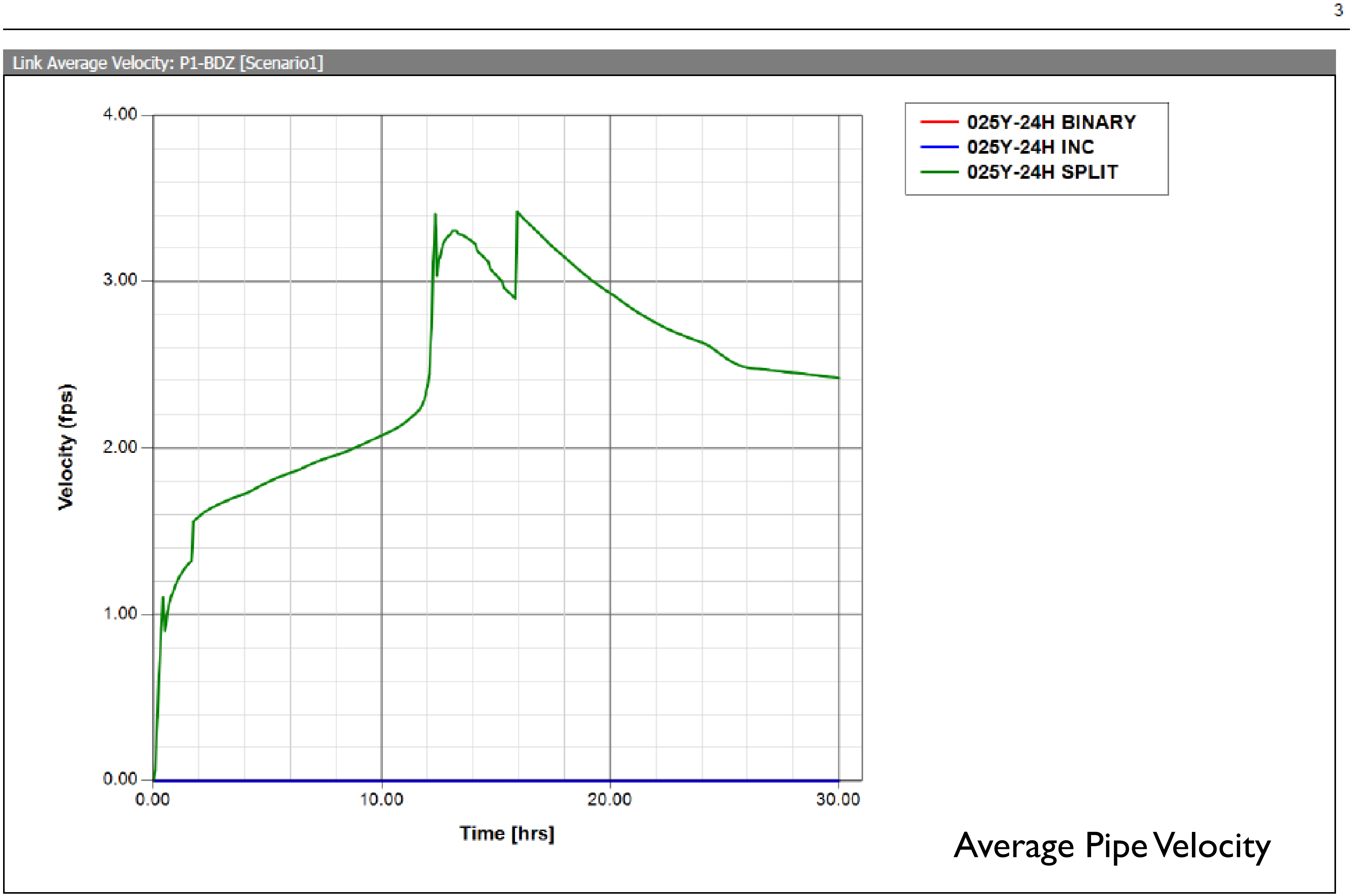
Example DS#1: Understanding Velocity Reports

2



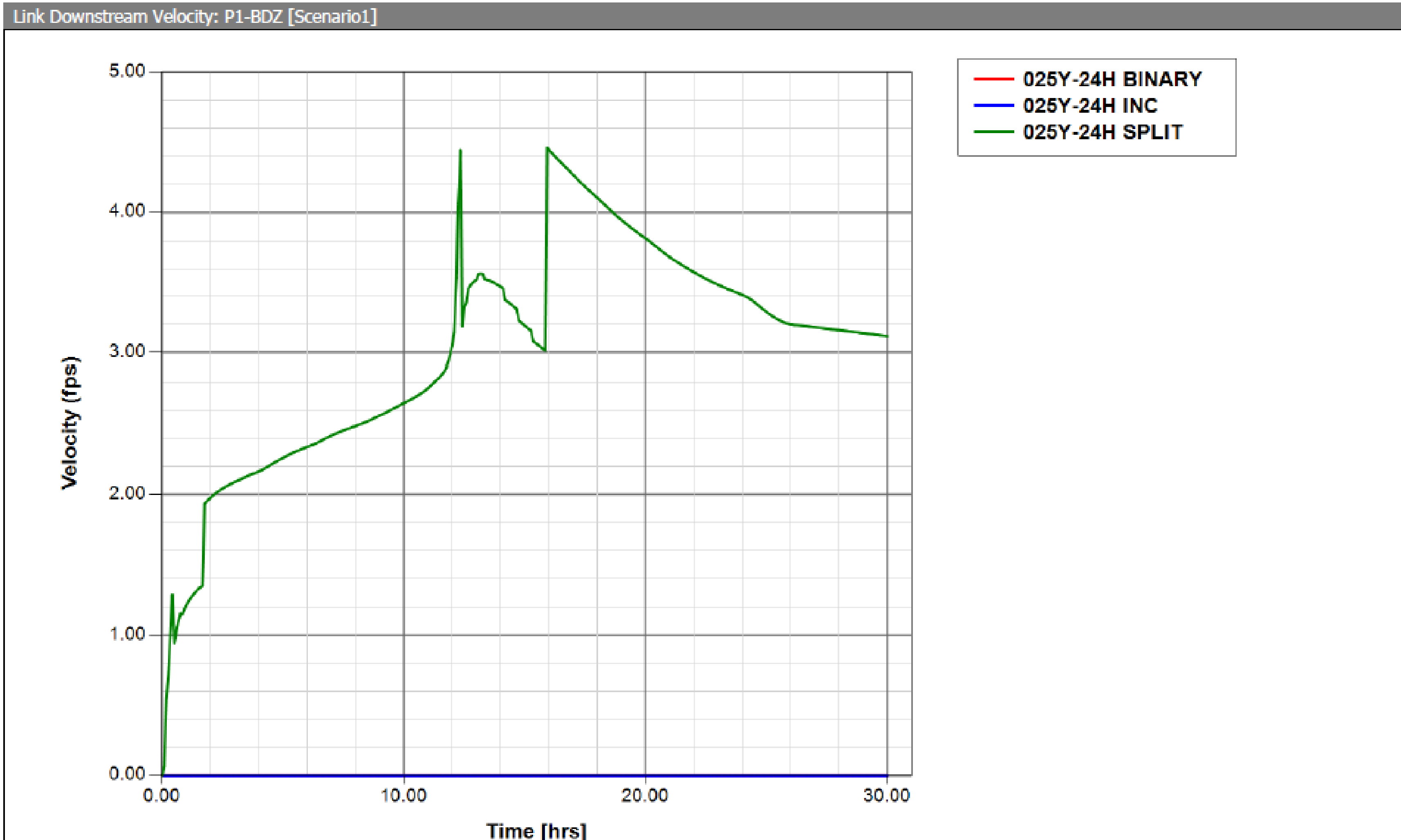
Discharge Hydrographs

Example DS#1: Understanding Velocity Reports



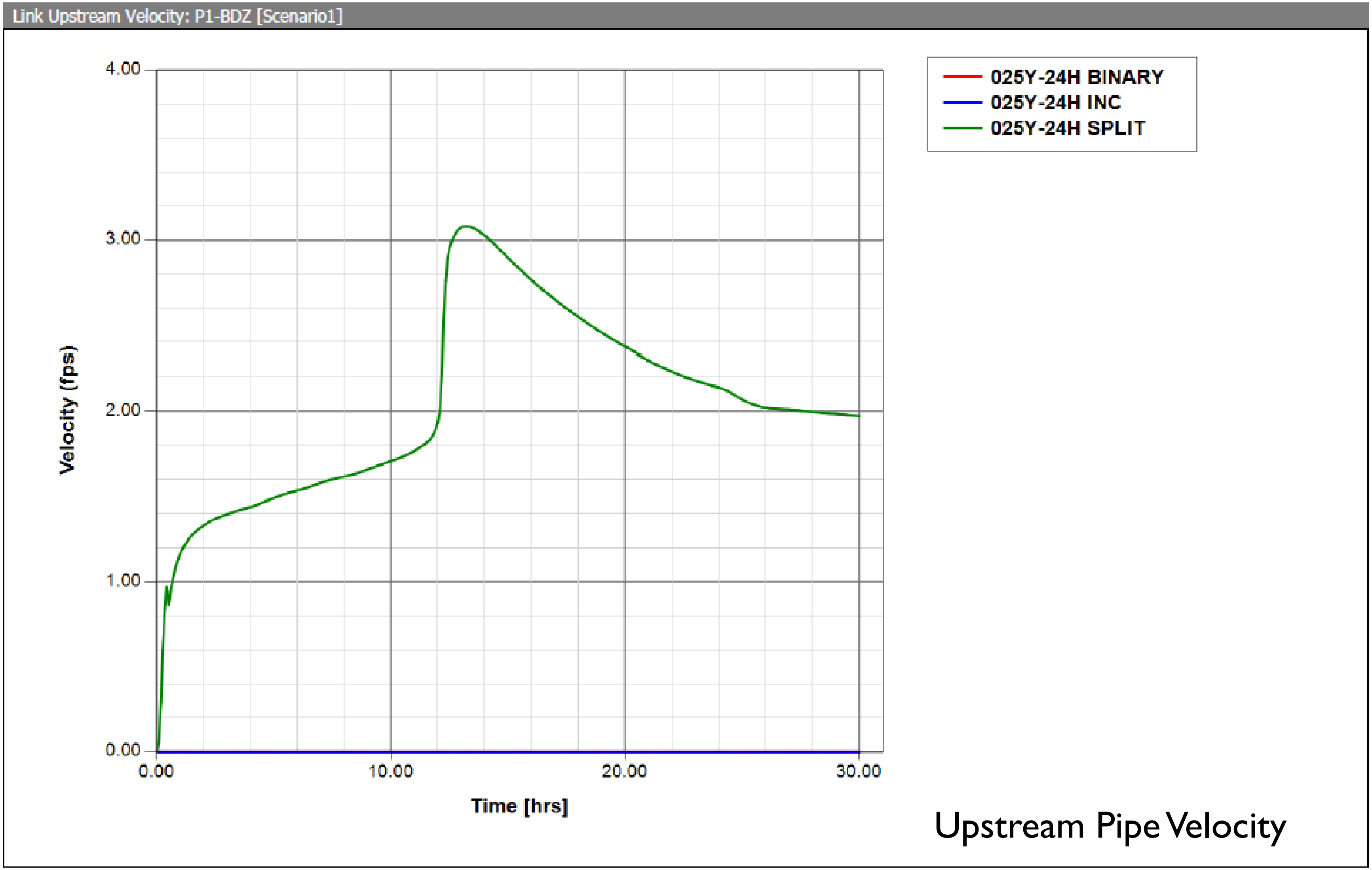
Average Pipe Velocity

Example DS#1: Understanding Velocity Reports



Downstream Pipe Velocity

Example DS#1: Understanding Velocity Reports



Upstream Pipe Velocity

Drop Structure Links

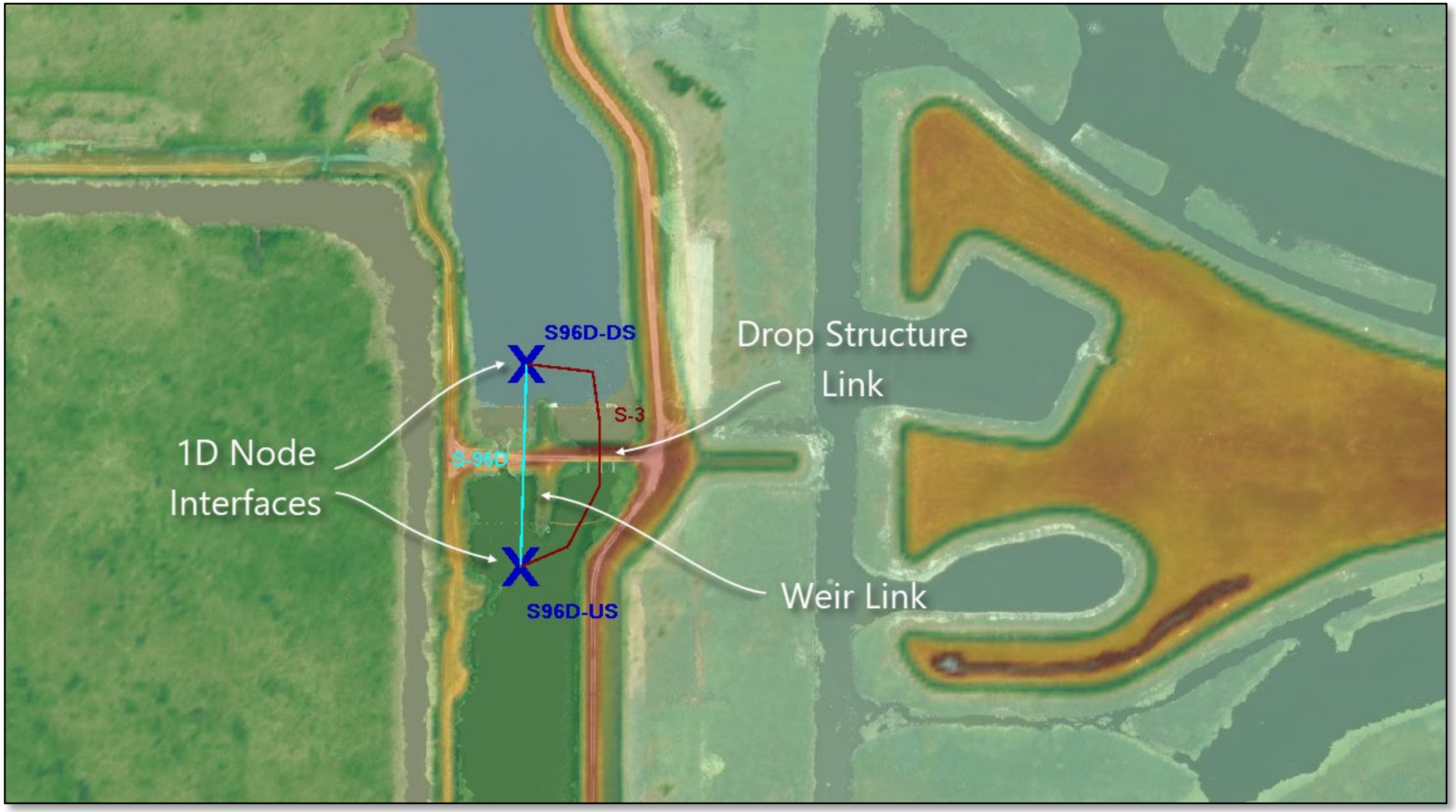
Example DS#2

Gate Structure S-96D and S-3 USJRB

Source: Star Controls

Drop Structure Links

Example DS#2

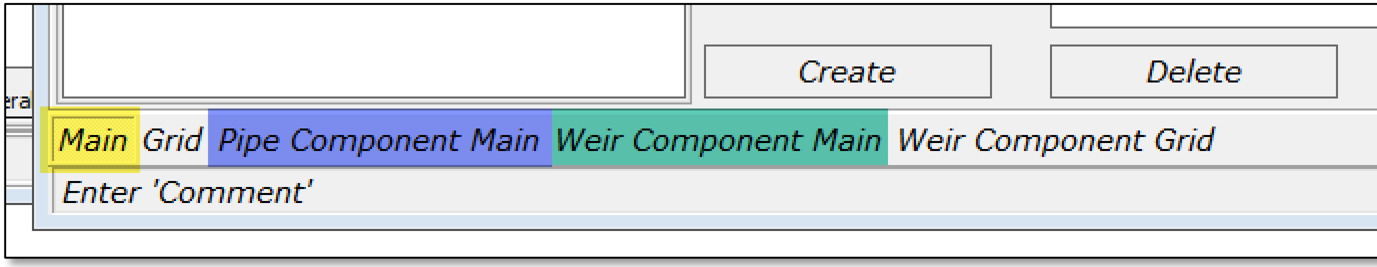


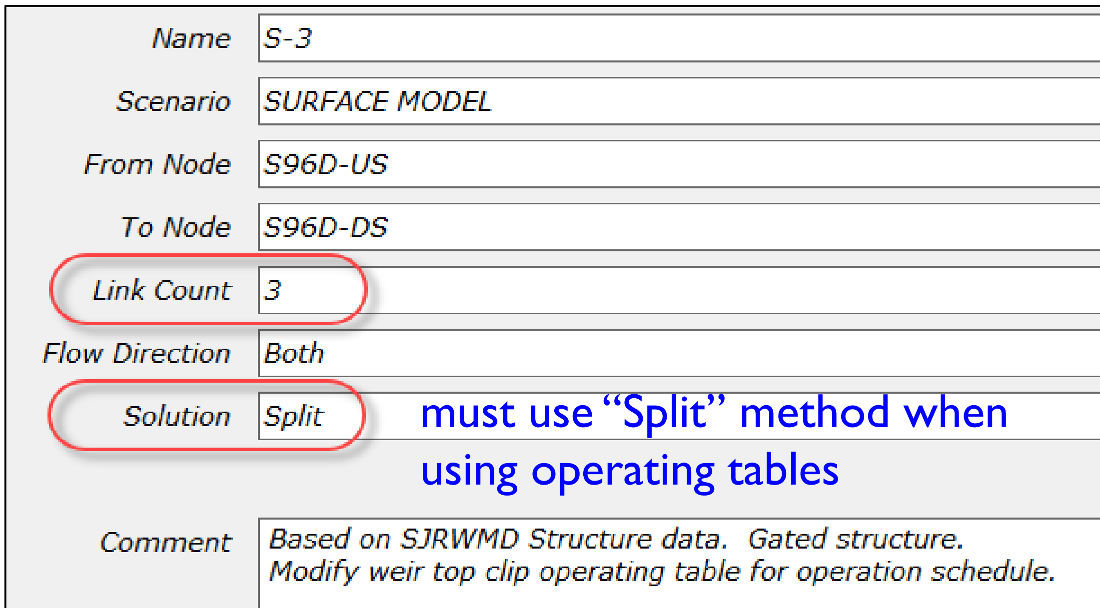
Gate Structure S-96D and S-3

Source: Star Controls

Drop Structure Links

Example DS#2



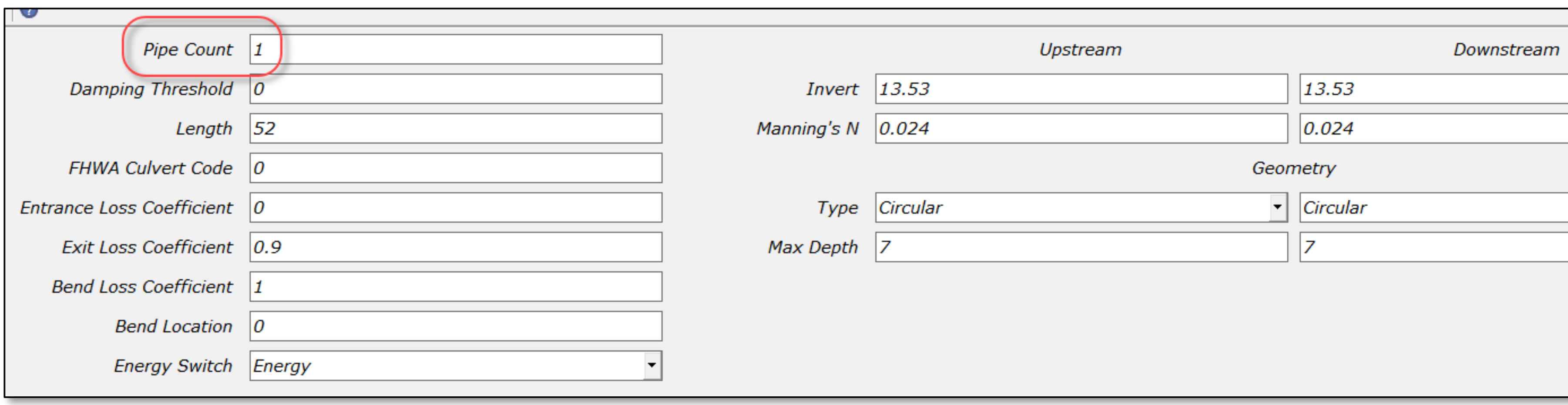


must use "Split" method when using operating tables

MainTab

Drop Structure Links

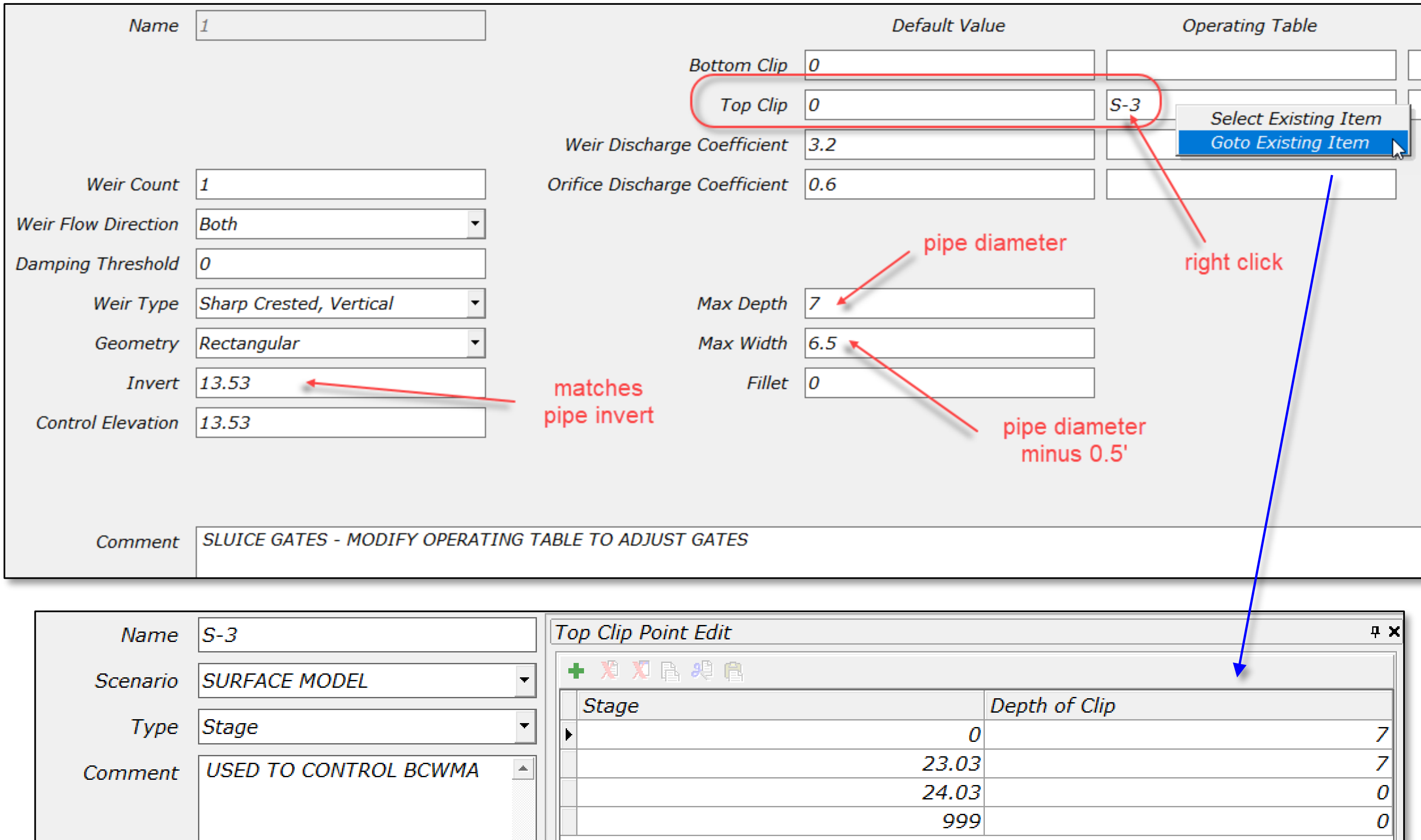
Example DS#2



Pipe Component Tab

Drop Structure Links

Example DS#2

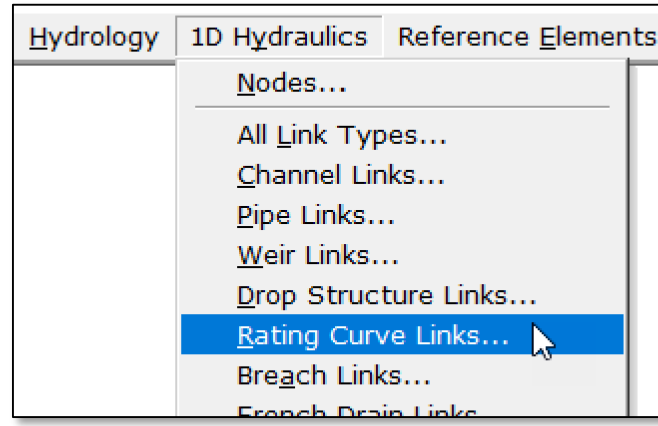


Weir Component Tab & Operating Table

Rating Curve Links

Basics

- Rating curve links are a general-purpose tool for modeling many things like pump stations and bridges.
- At least one operating table must be set up prior to using the rating curve link.
- Although the link moves water from one node to another, it is the operating table that establishes the rates and conditions for flow.
- There are four types of operating tables that can be used with a rating curve link as listed above.



Upstream Stage versus Discharge

Time versus Discharge

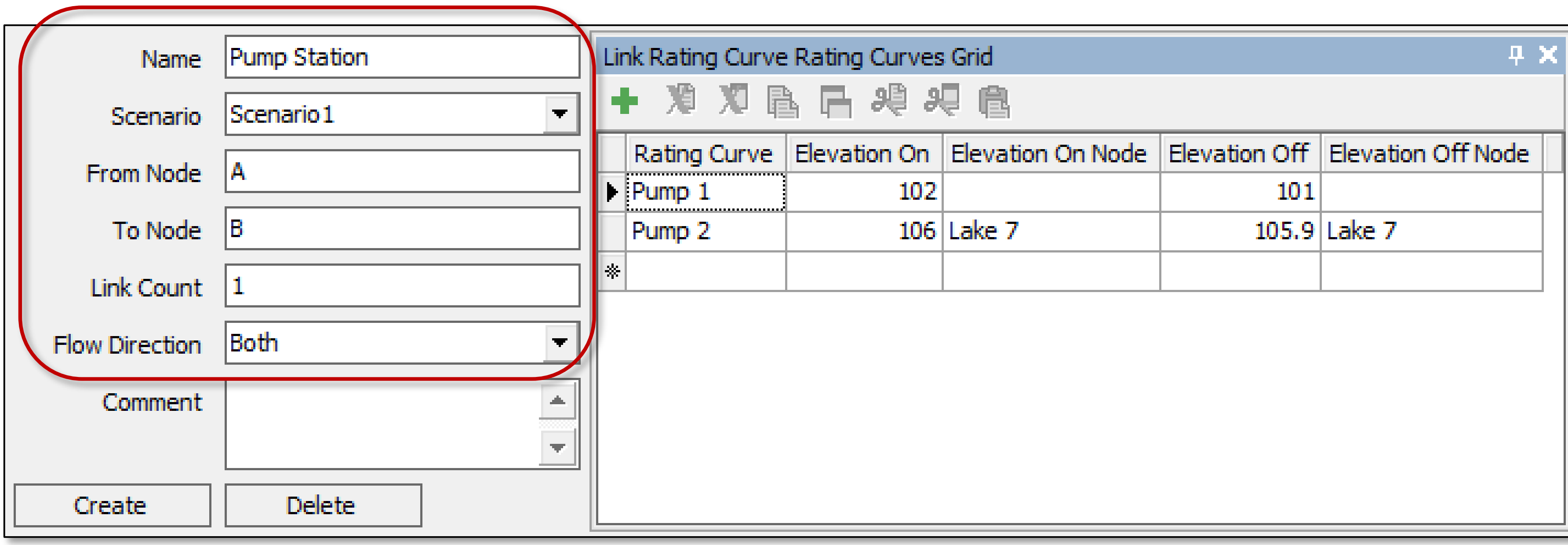
Head versus Discharge

Family of Stage vs. Discharge Curves

Rating Curve Links

Data Form

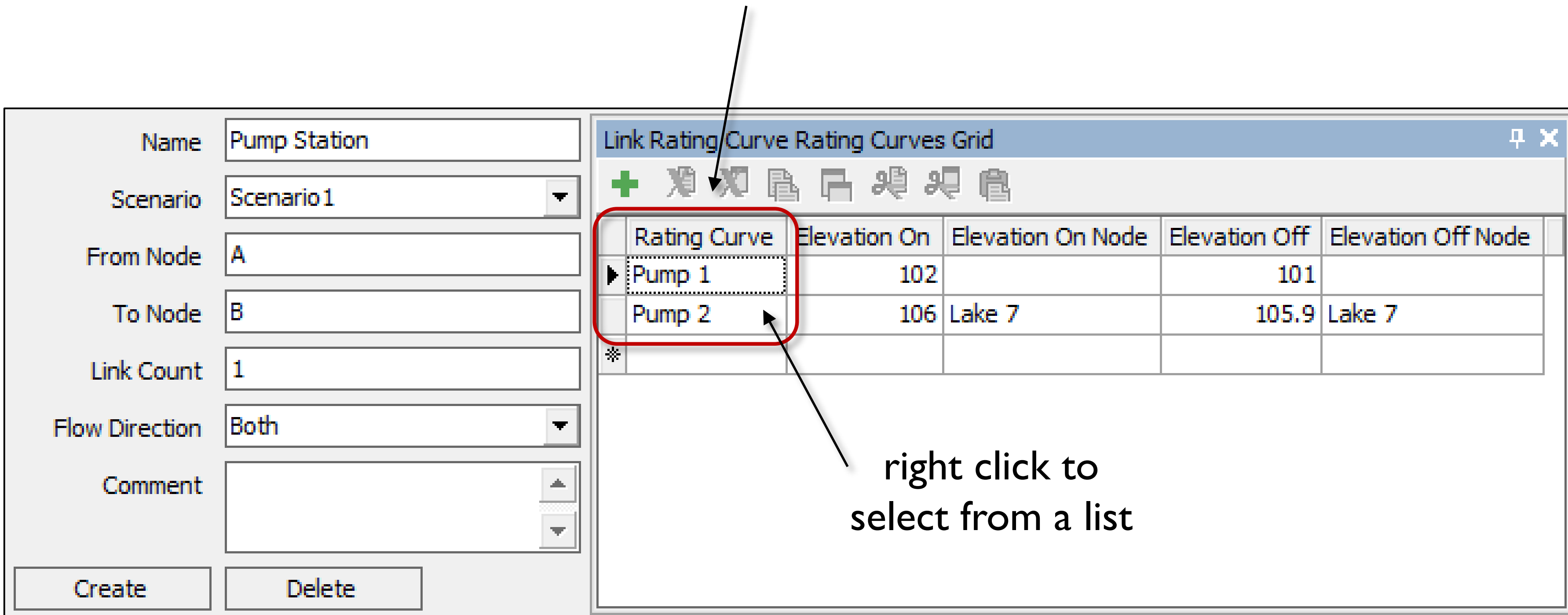
Rating curve links have the usual name, connectivity, count and flow direction parameters.



Rating Curve Links

Data Form

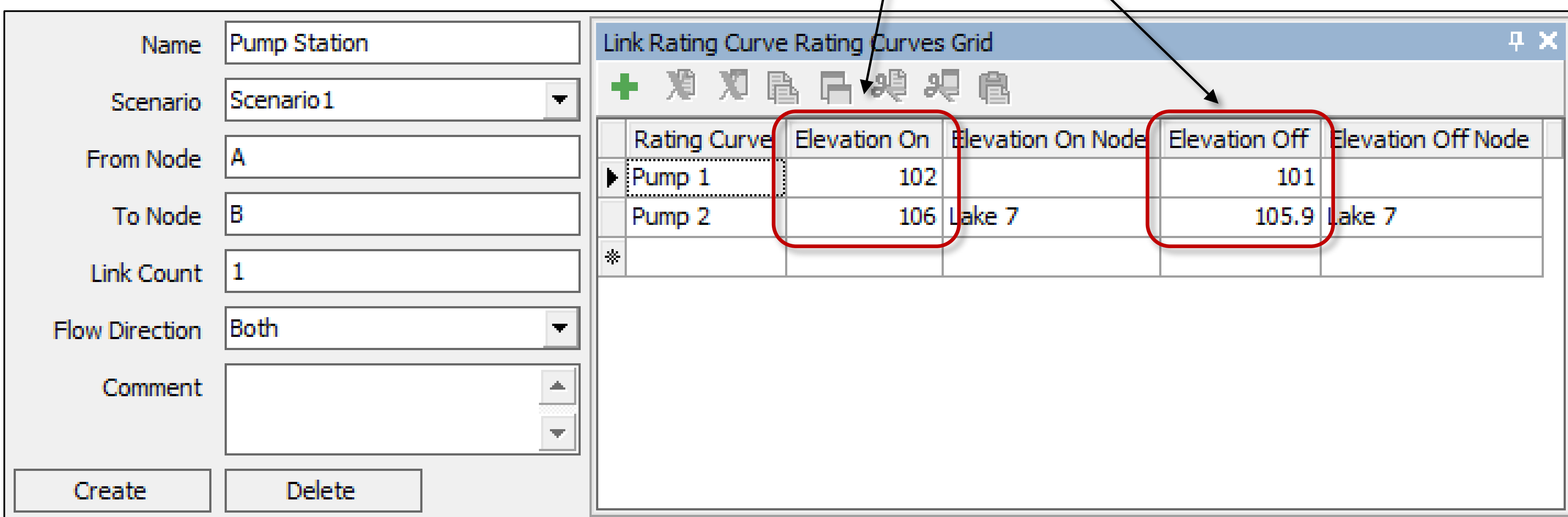
Specific operating tables are referenced in the grid on the right side of the data form under the "Rating Curve" column. There is no practical limit as to the number of operating tables that can be used.



Rating Curve Links

Data Form

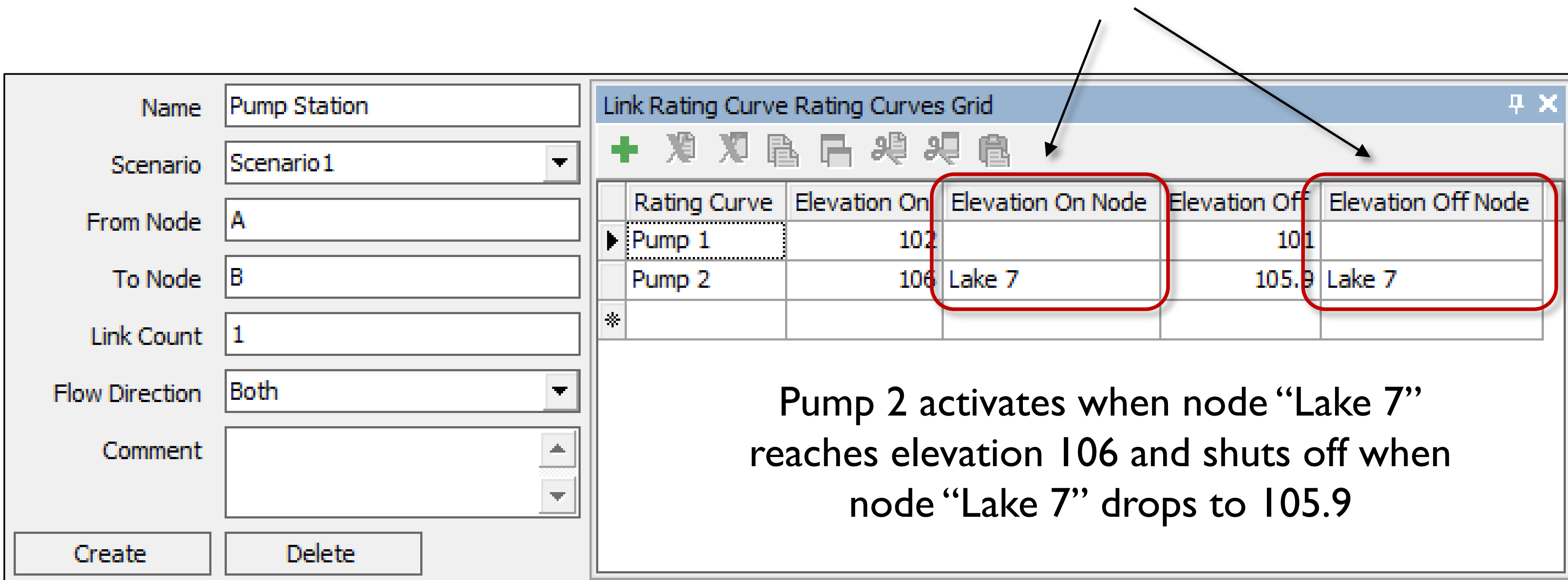
On and off switches can be set for each referenced operating table using the “Elevation On” and “Elevation Off” columns in the grid. Think of these as level switches in a pump station.



Rating Curve Links

Data Form

When the "Elevation On Node" and "Elevation Off Node" are left blank, the default reference node is the "from node" for the link. As an option, reference nodes other than the "from node" can be specified.

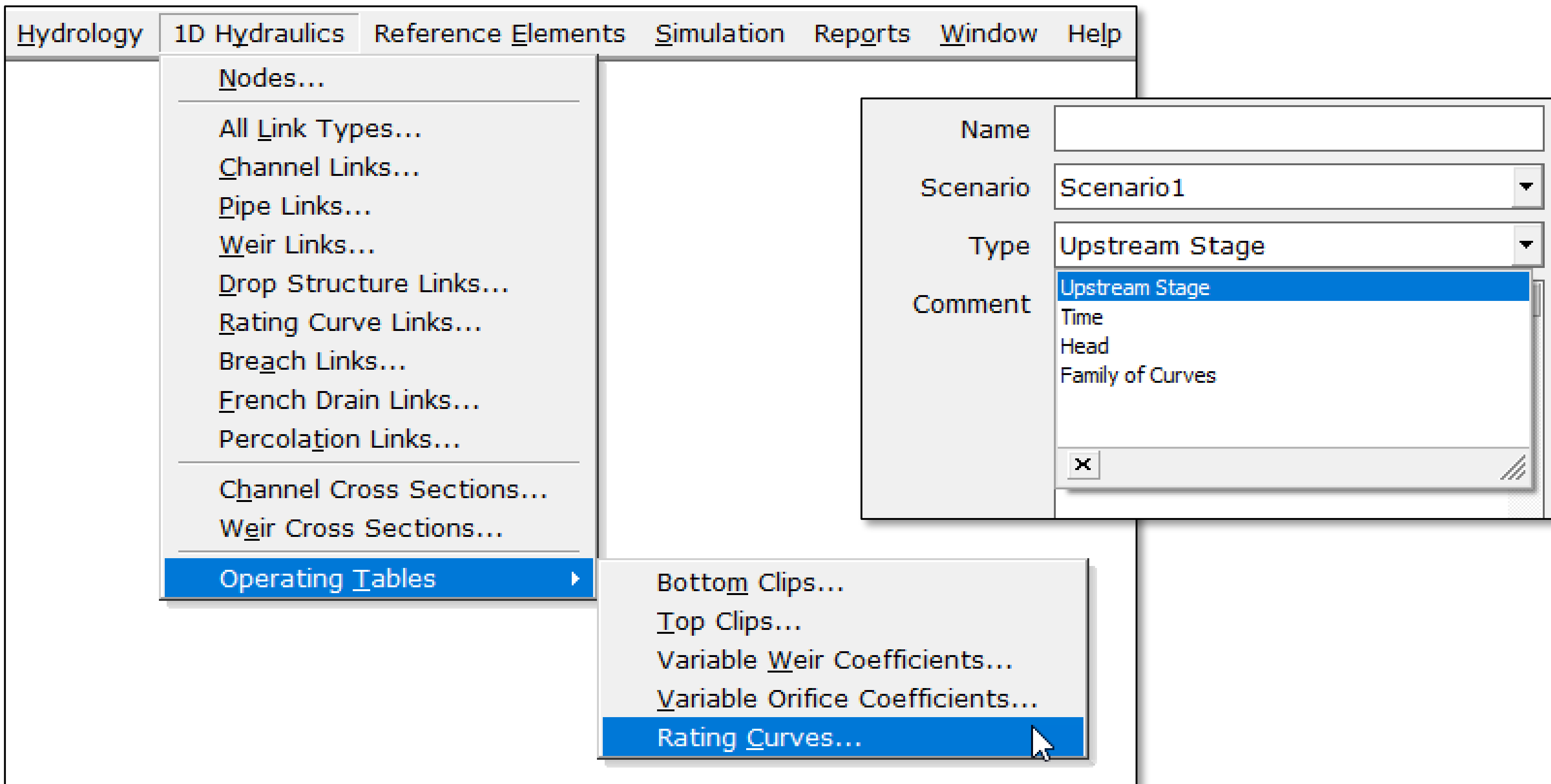


Pump 2 activates when node "Lake 7" reaches elevation 106 and shuts off when node "Lake 7" drops to 105.9

Rating Curve Links

Operating Tables

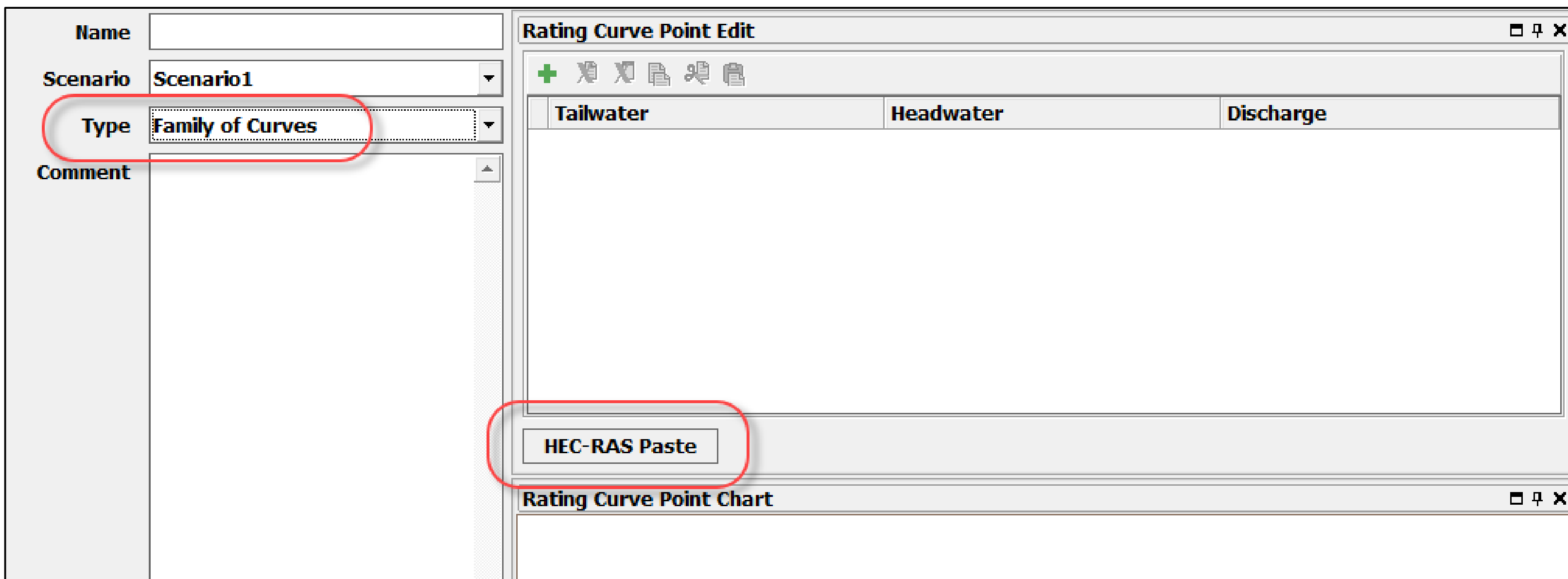
Rating curve "links" require at least one rating curve "operating table". They can be used to establish relationships between flow and time, stage, or head. Also, a family of rating curves can be used to account for variable tailwater conditions.



Rating Curve Links

Operating Tables

A family of rating curves is a set of stage-discharge relationships for various tailwater conditions. It is also possible to build a family of rating curves in HEC-RAS, copy those rating curves into the clipboard, and paste them into the ICPR rating curve data form by clicking the HEC-RAS Paste button. This is particularly useful for modeling bridges.



Rating Curve Links

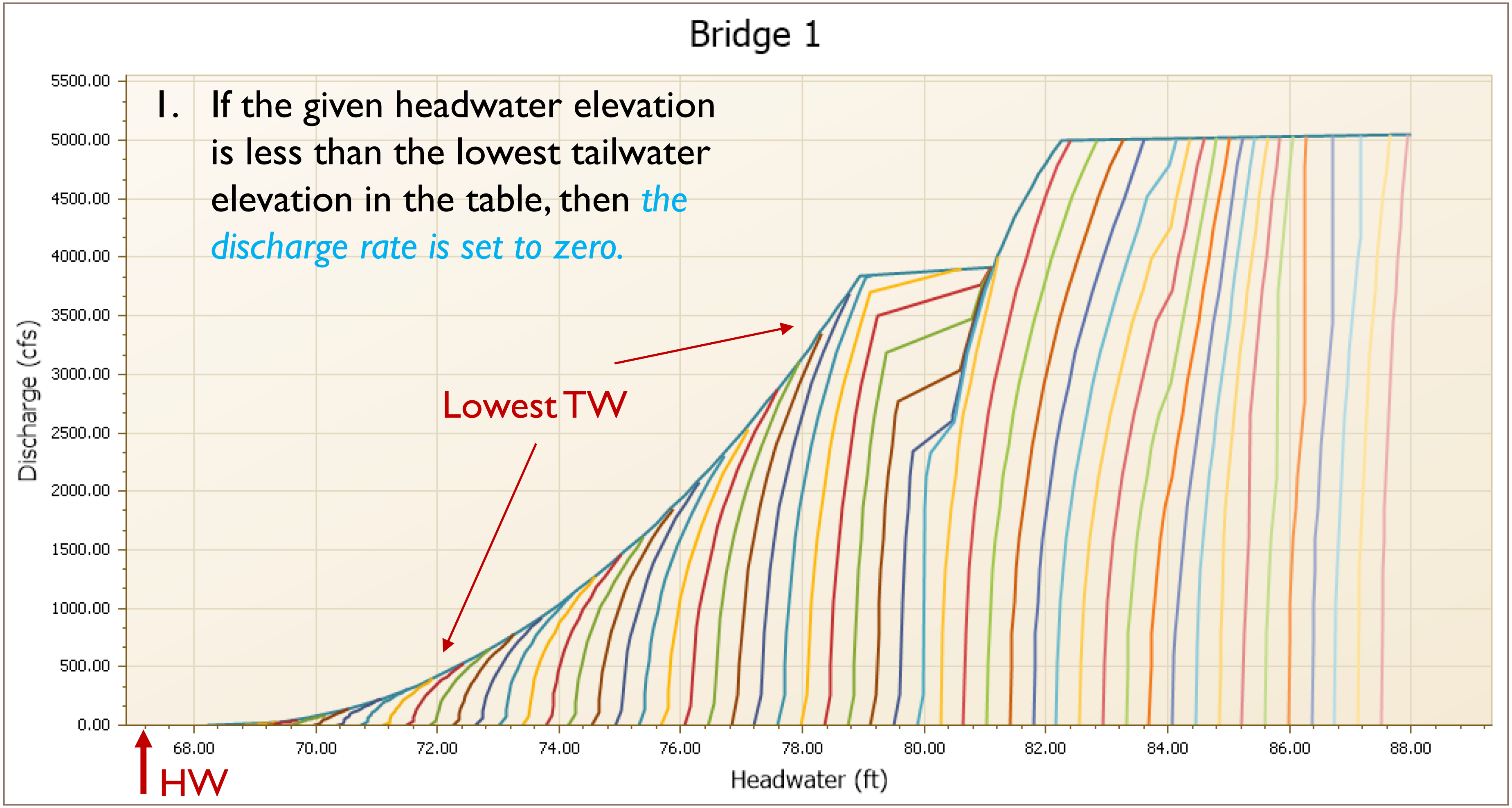
Operating Tables

ICPR performs a double linear interpolation to extract a discharge rate for a given tailwater and headwater elevation combination.

If the tailwater and headwater elevations are outside the range, then the extrapolation rules on the following slides are used

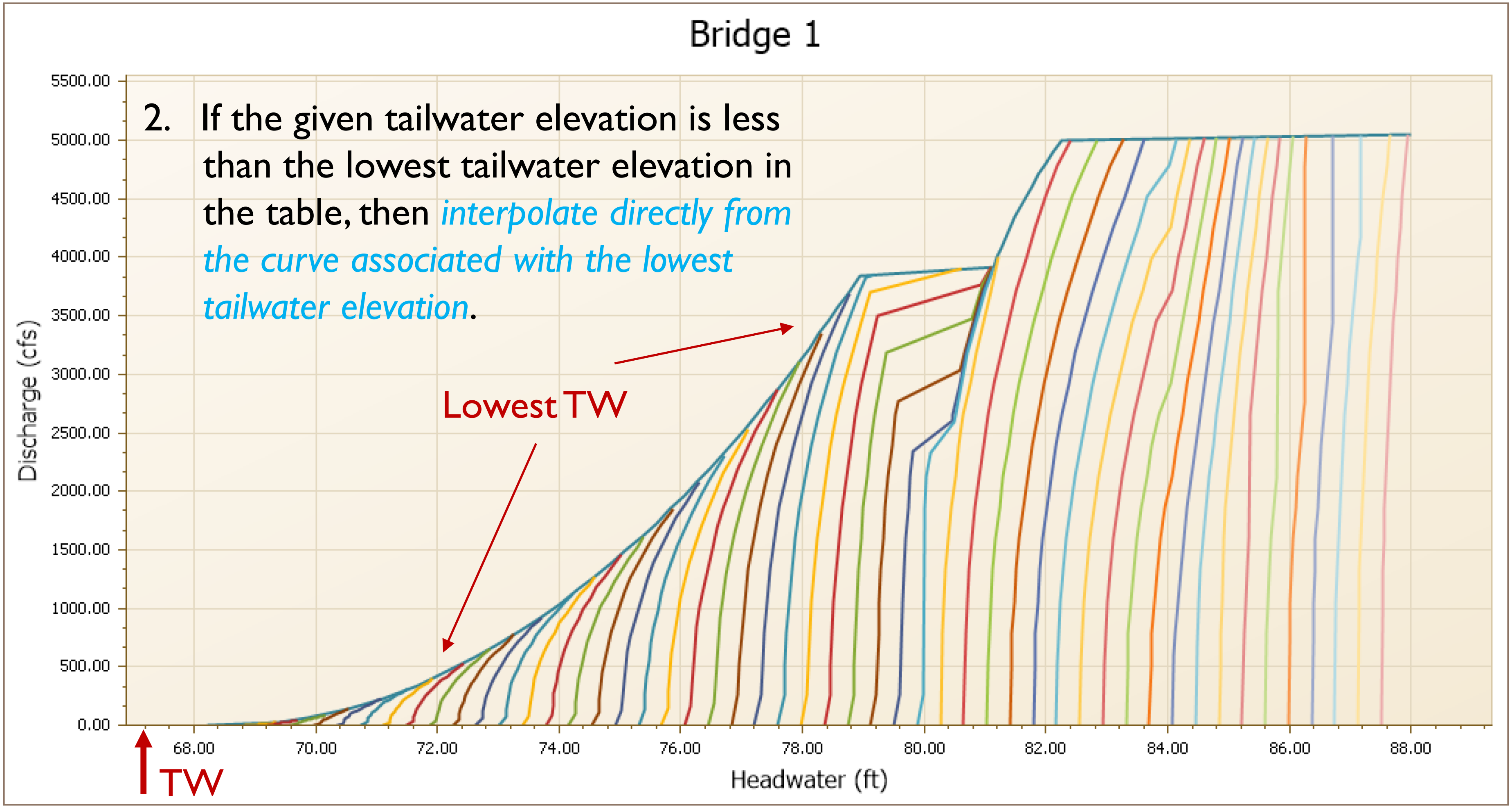
Rating Curve Links

Operating Tables



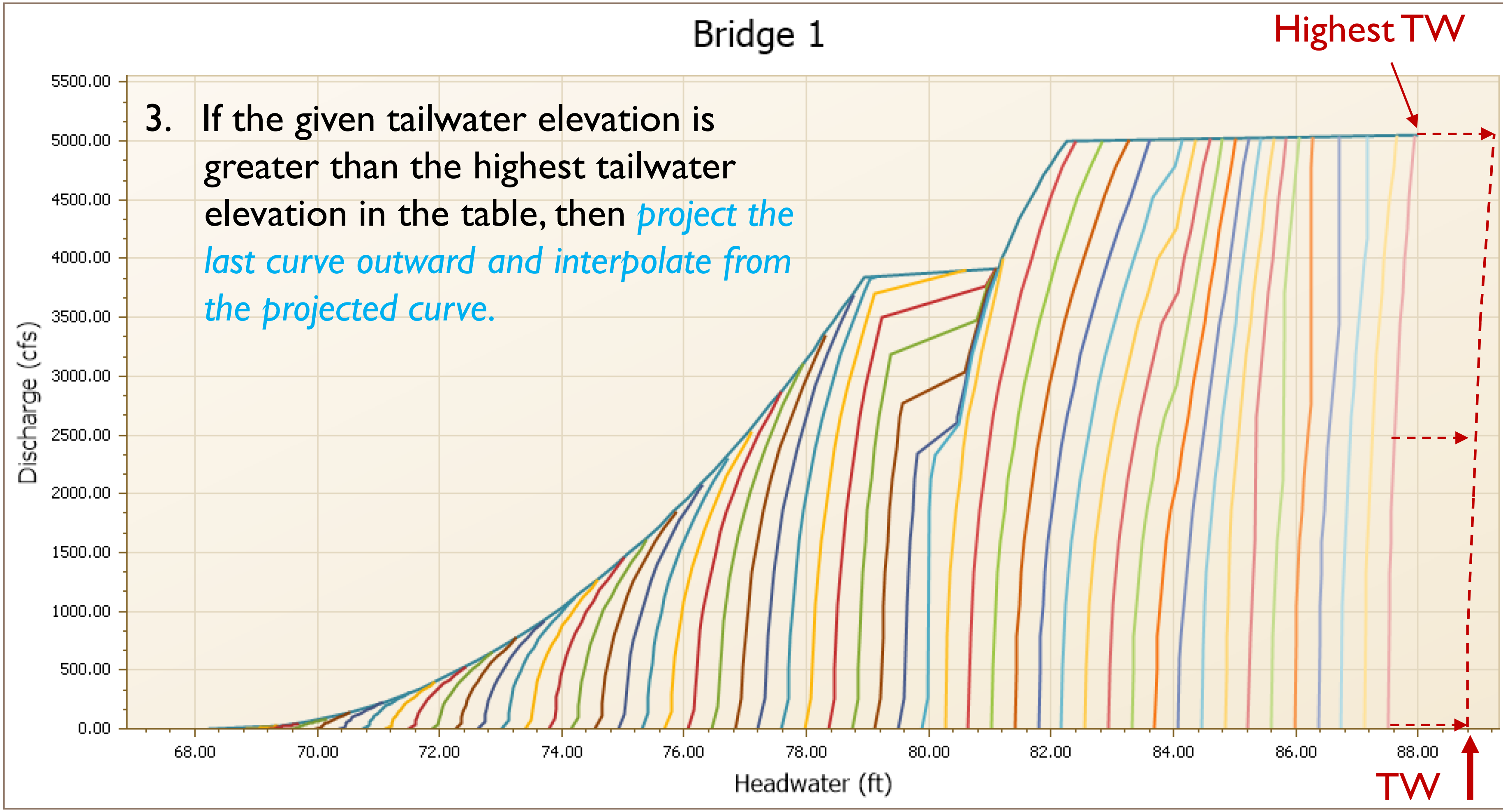
Rating Curve Links

Operating Tables



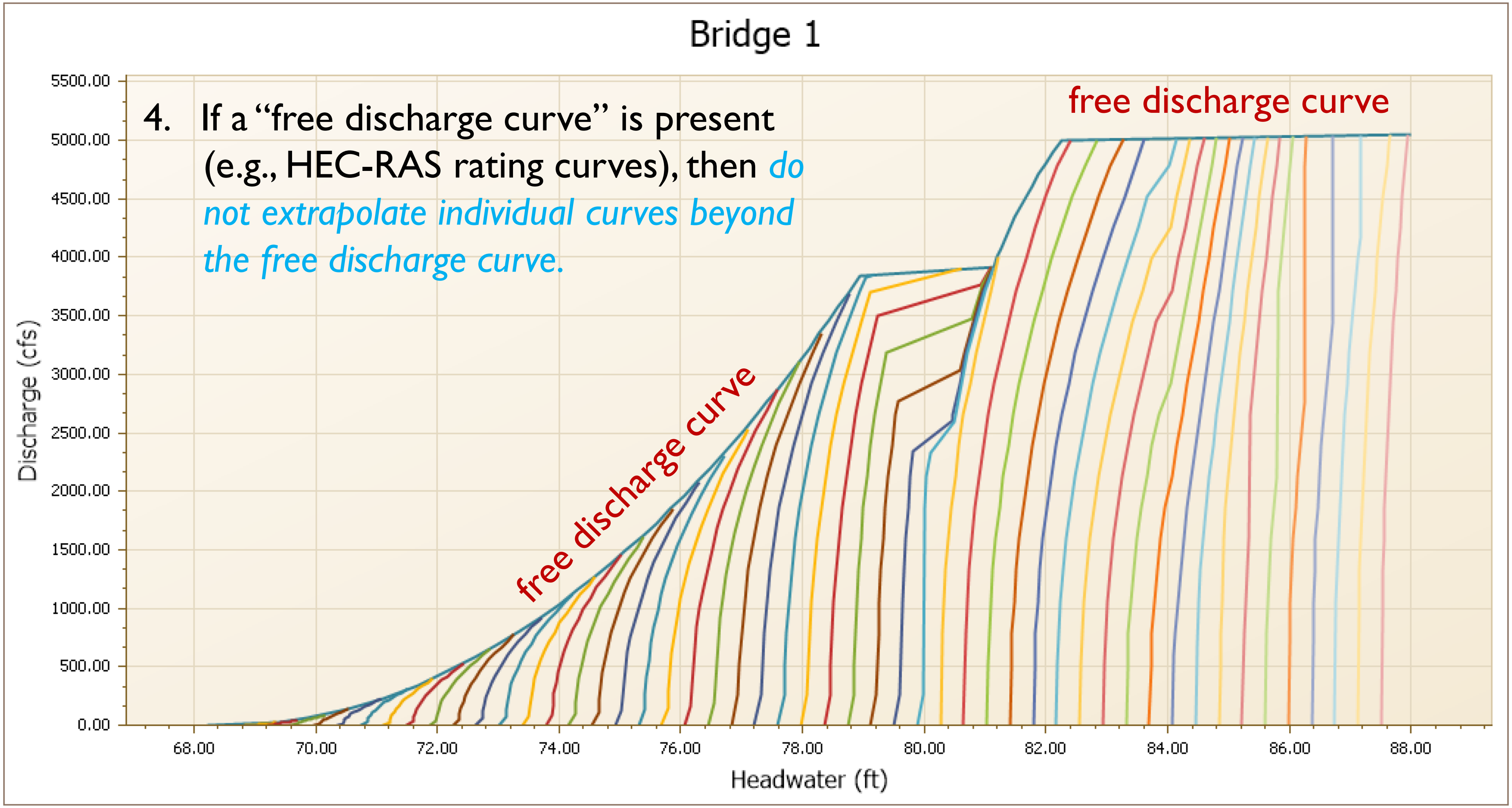
Rating Curve Links

Operating Tables



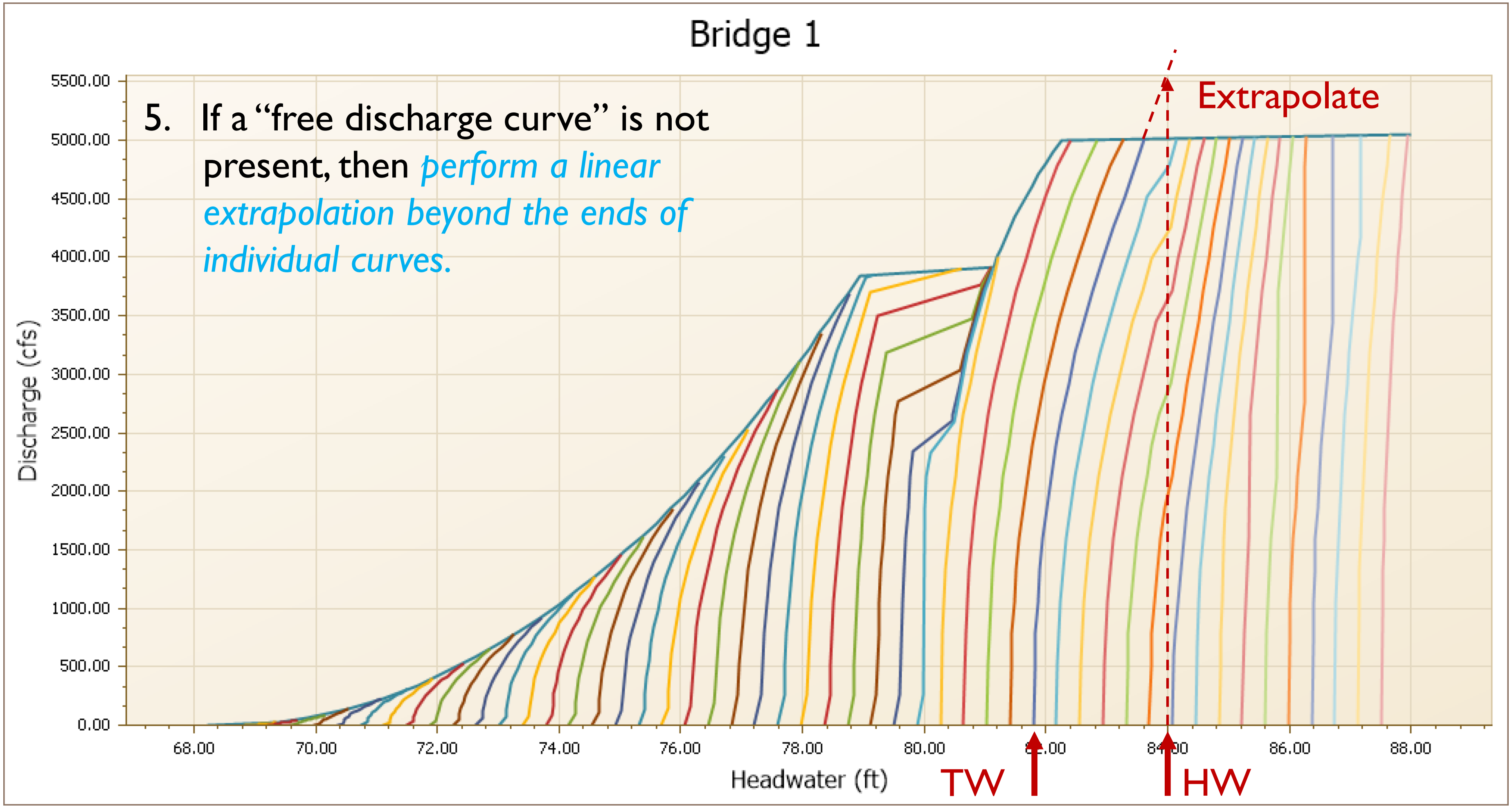
Rating Curve Links

Operating Tables



Rating Curve Links

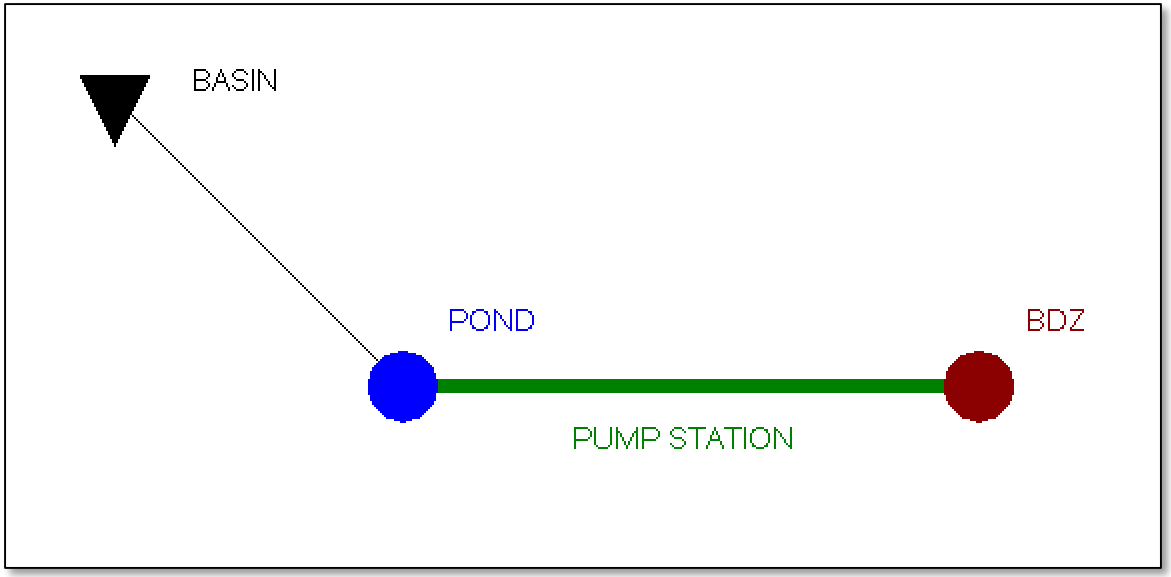
Operating Tables



5. If a "free discharge curve" is not present, then *perform a linear extrapolation beyond the ends of individual curves.*

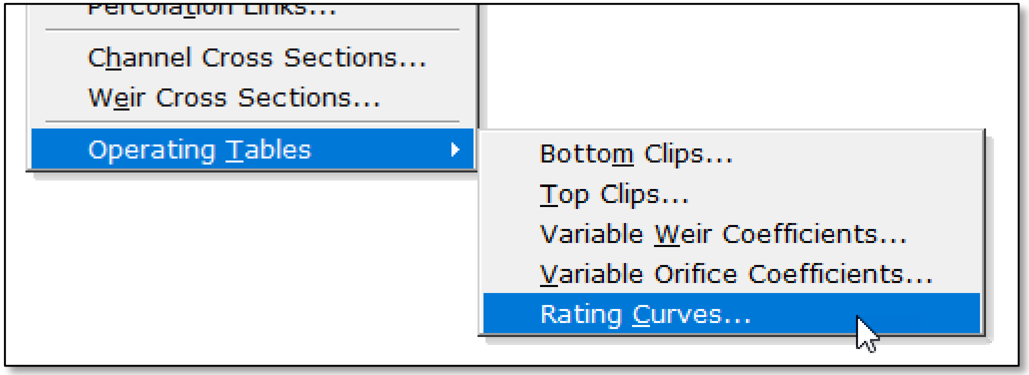
Rating Curve Links

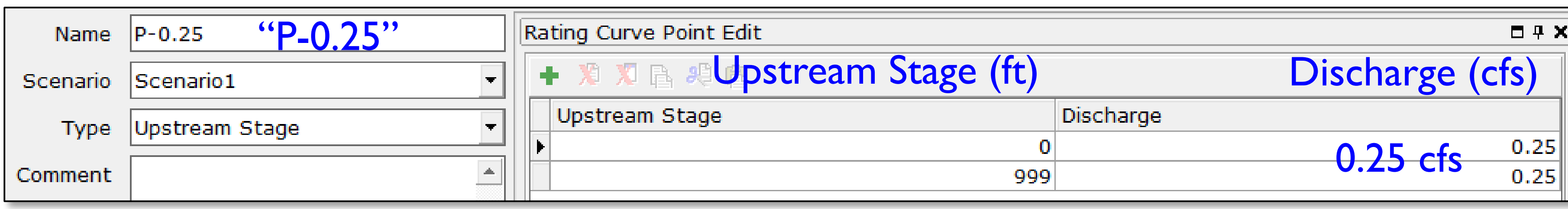
Example RC#1: Triplex Pump Station

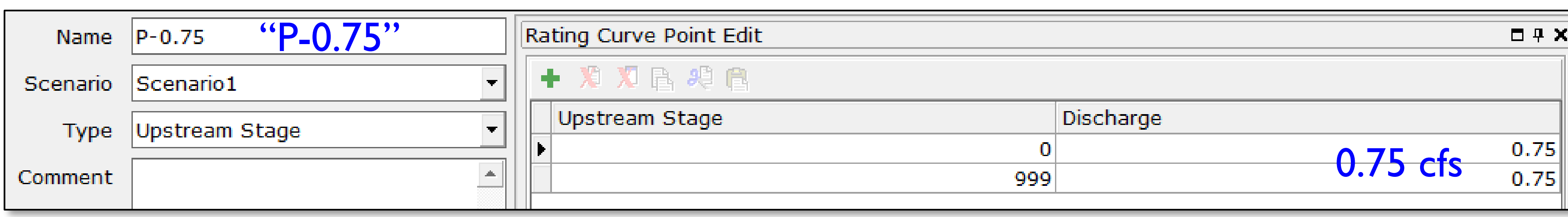


Rating Curve Links

Example RC#1: Triplex Pump Station

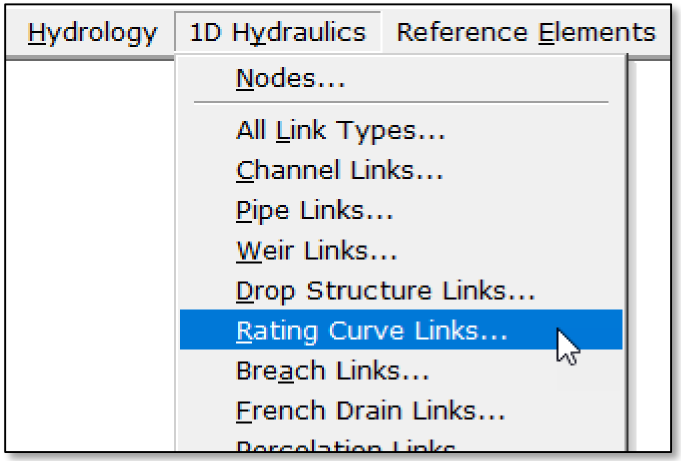


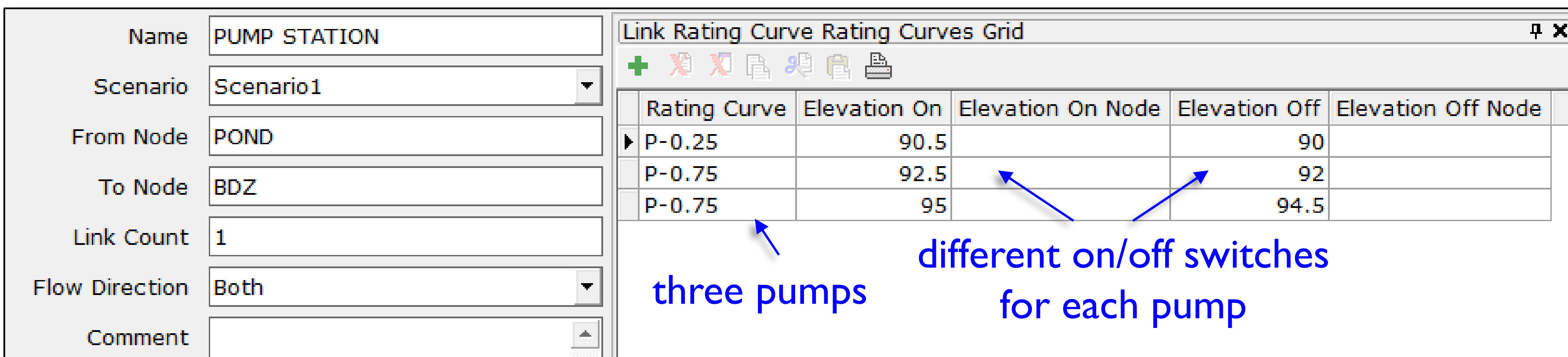




Rating Curve Links

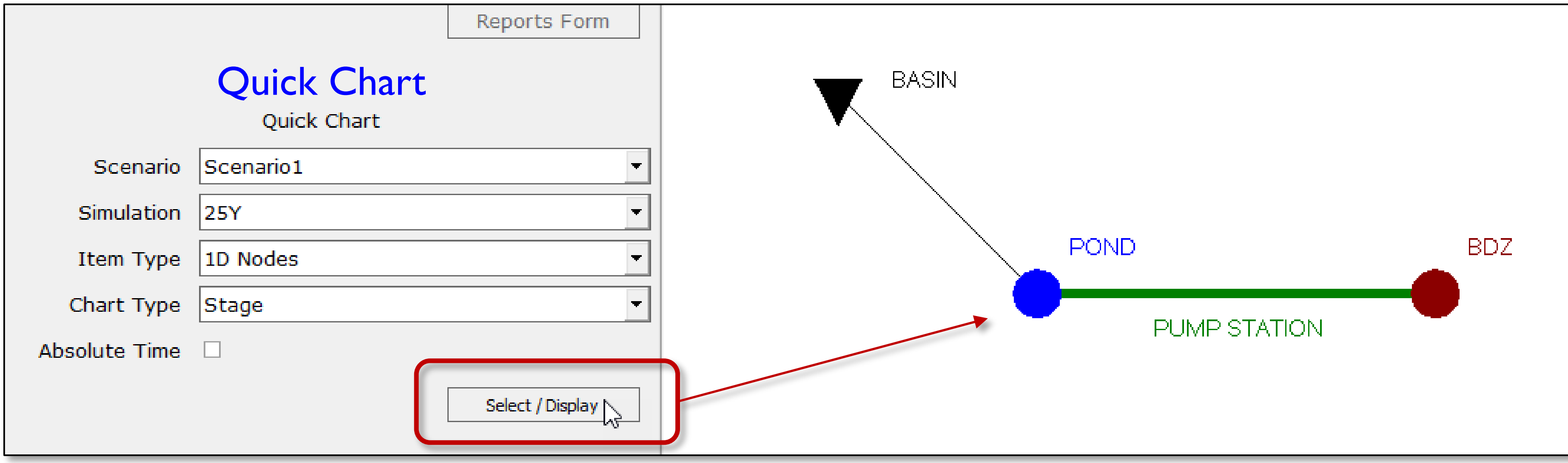
Example RC#1: Triplex Pump Station

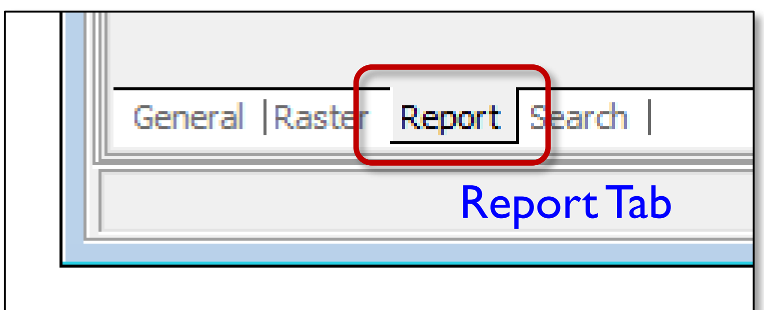




Rating Curve Links

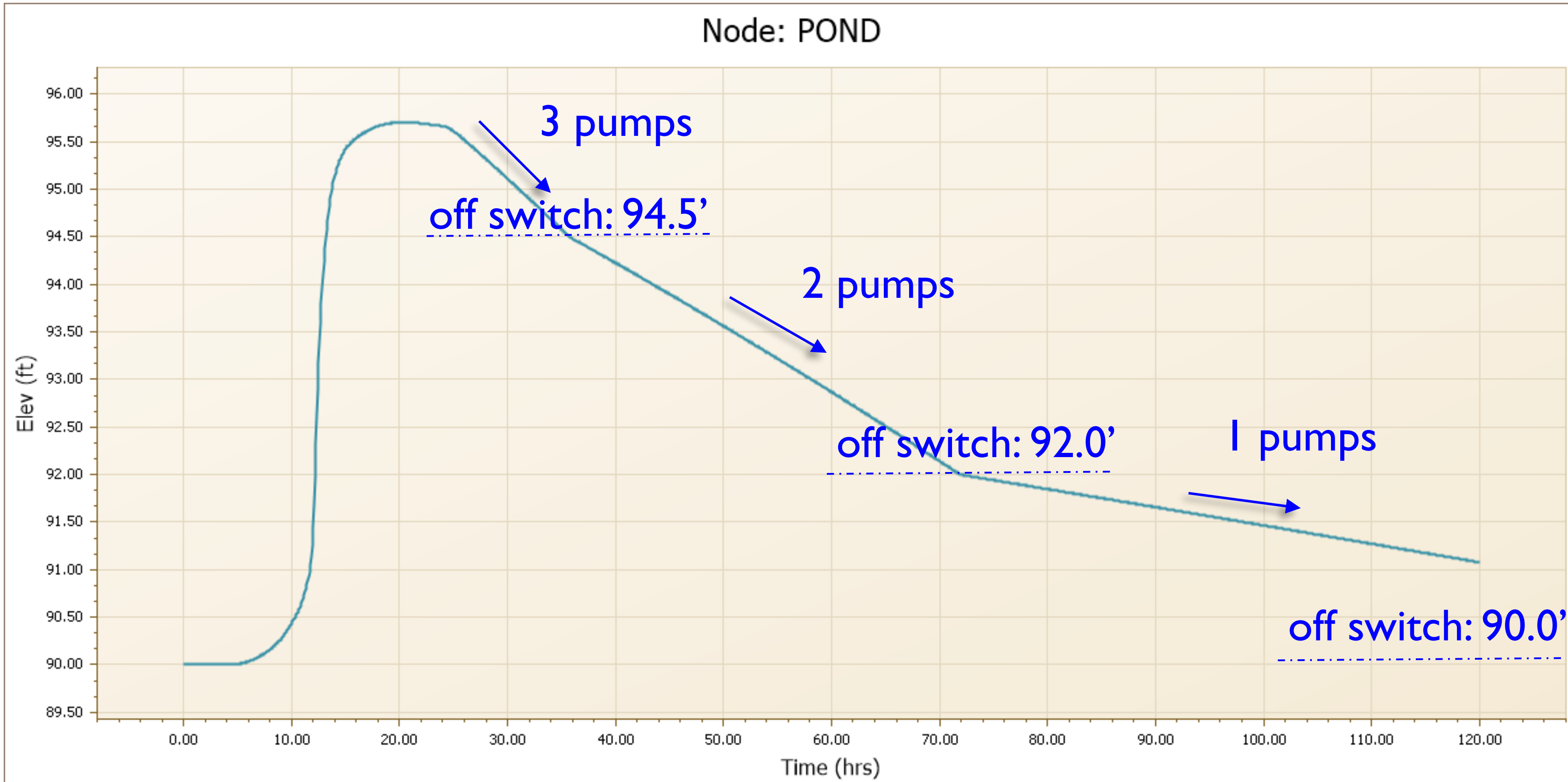
Example RC#1: Triplex Pump Station





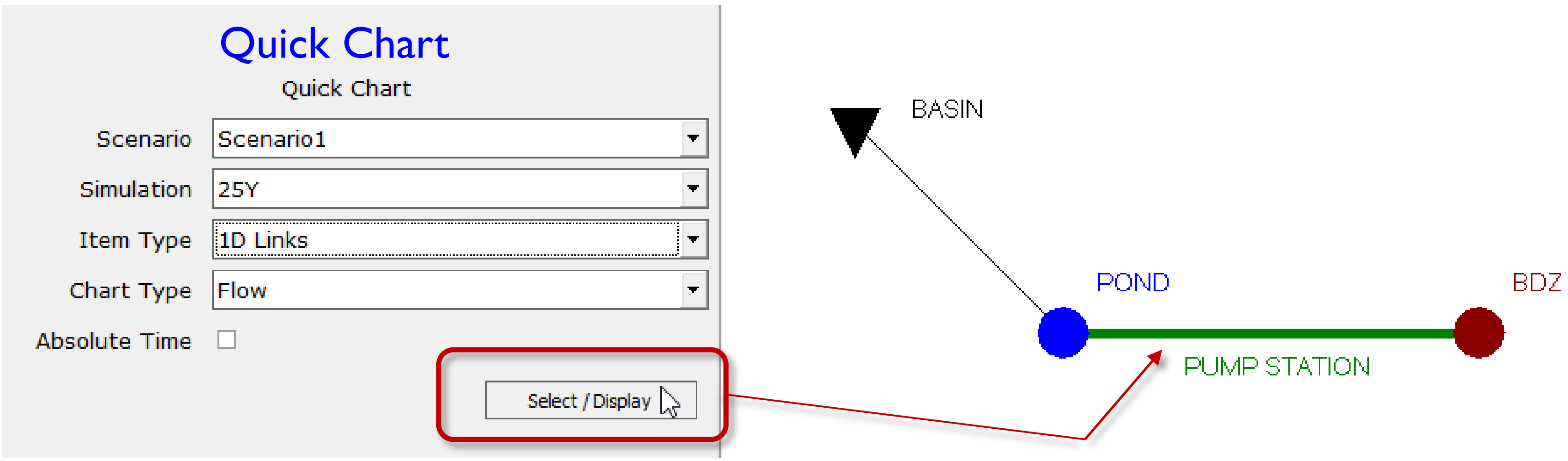
Rating Curve Links

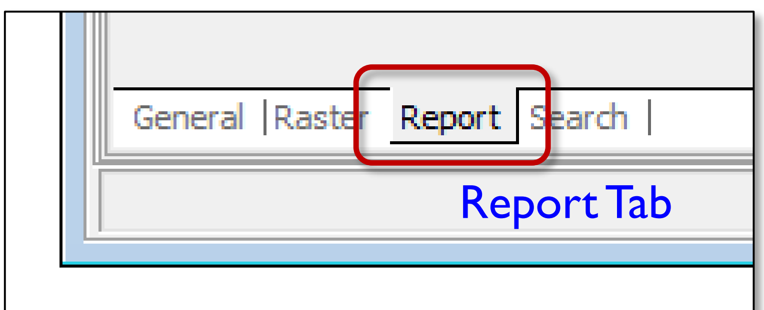
Example RC#1: Triplex Pump Station



Rating Curve Links

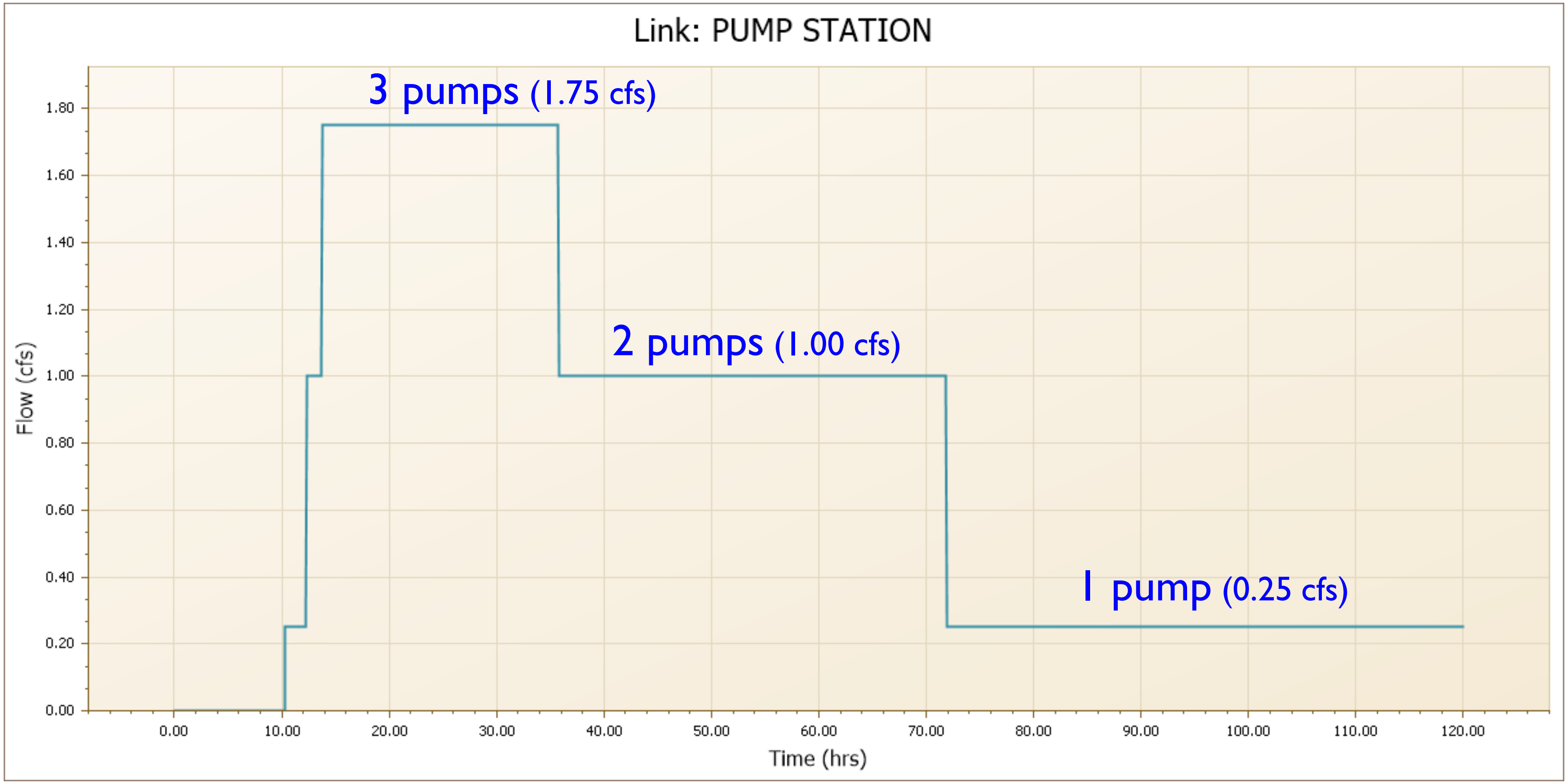
Example RC#1: Triplex Pump Station





Rating Curve Links

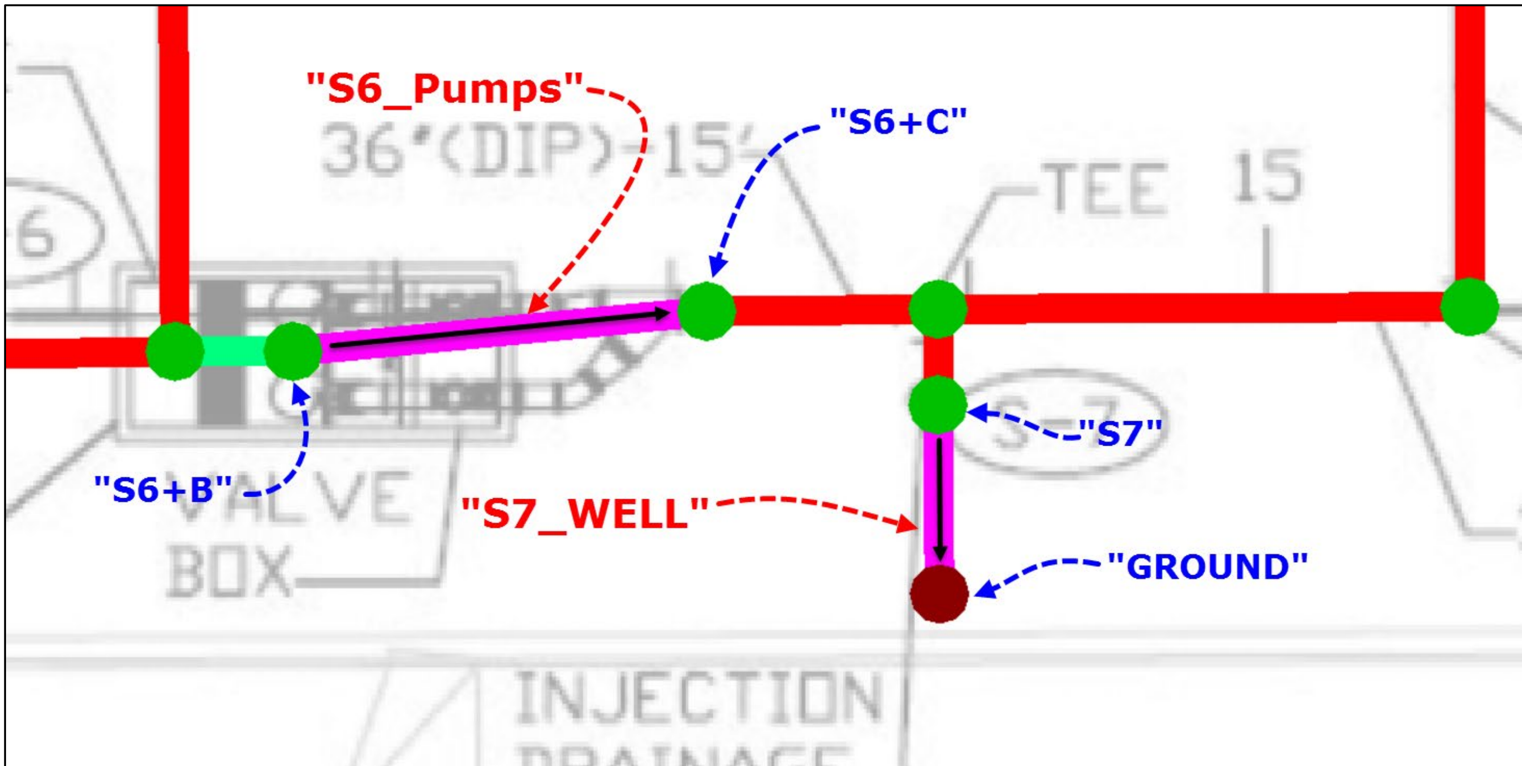
Example RC#1: Triplex Pump Station



Rating Curve Links

Example RC#2: Roadway Pump Station & Drain Well

This example is taken from the publication "ICPR Applications Manual" (January 2008) prepared by ADA Engineering for the FDOT District 6.



Rating Curve Links

Example RC#2: Roadway Pump Station & Drain Well

HEAD LOSS CALCULATION FOR MODIFICATION OF PUMP CURVE

eq. 1 - Head Loss (Hazen-Williams Formula) Hf=0.002083*L(100/C)^1.85(Q^1.85/d^4.8655)

eq. 2 - Head Loss by Fittings and Valves Hf=K(V^2/2g)

Gravity (g)	32.2	ft/sec^2
Hydraulic Diameter (d)	18	inch
Resistance Coefficient (C)	140	
Pipe Length (L)	20	ft

Fitting #	Description	Quantity	Loss Coef. (K)
1	90d elbow	4	0.55
2	Reducer (36"-12")	1	0.21

Flow Rate - Q (gpm)	Flow Rate - Q (cfs)	Velocity - V (18" pipe) (fps)	Hf (pipe) (ft)	Hf (90d elbow) (ft)	Hf (reducer) (ft)	Hf (total) (ft)
1400.590	3.12	1.77	0.01	0.11	0.01	0.13
1572.170	3.50	1.98	0.01	0.13	0.01	0.16
1743.320	3.88	2.20	0.02	0.17	0.02	0.20
1913.660	4.26	2.41	0.02	0.20	0.02	0.24
2082.640	4.64	2.63	0.02	0.24	0.02	0.28
2249.570	5.01	2.84	0.03	0.27	0.03	0.33
2413.870	5.38	3.04	0.03	0.32	0.03	0.38
2575.140	5.74	3.25	0.04	0.36	0.03	0.43
2733.350	6.09	3.45	0.04	0.41	0.04	0.48
2888.820	6.44	3.64	0.04	0.45	0.04	0.54
3042.200	6.78	3.84	0.05	0.50	0.05	0.60
3194.390	7.12	4.03	0.05	0.55	0.05	0.66
3346.260	7.46	4.22	0.06	0.61	0.06	0.72
3498.690	7.80	4.41	0.06	0.66	0.06	0.79
3652.180	8.14	4.60	0.07	0.72	0.07	0.86
3806.990	8.48	4.80	0.07	0.79	0.08	0.94
3962.740	8.83	5.00	0.08	0.85	0.08	1.01
4119.030	9.18	5.19	0.08	0.92	0.09	1.09
4275.180	9.53	5.39	0.09	0.99	0.09	1.18
4430.910	9.87	5.59	0.10	1.07	0.10	1.27
4586.300	10.22	5.78	0.10	1.14	0.11	1.35
4742.070	10.57	5.98	0.11	1.22	0.12	1.45

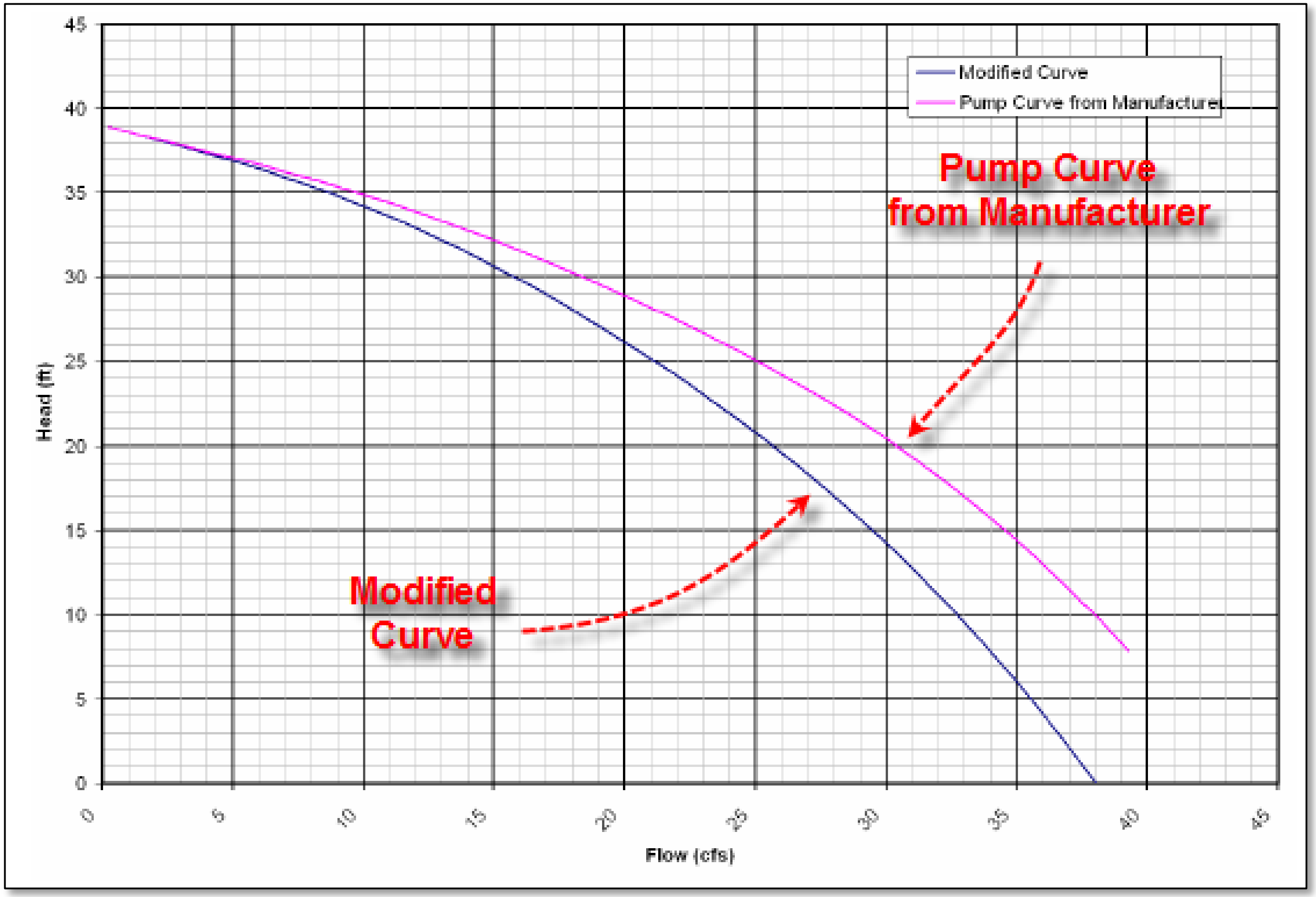
Rating Curve Links

Example RC#2: Roadway Pump Station & Drain Well

Flow Rate - Q	Head from chart	Hf losses due to friction	Resultant Head	ICPR Head Value	Flow Rate - Q
(gpm)	(ft)	(ft)	(ft)	(ft)	(cfs)
1400.59	26.458	0.13	26.33	-26.33	3.12
1572.17	25.415	0.16	25.25	-25.25	3.50
1743.32	24.368	0.20	24.17	-24.17	3.88
1913.66	23.318	0.24	23.08	-23.08	4.26
2082.64	22.255	0.28	21.97	-21.97	4.64
2249.57	21.179	0.33	20.85	-20.85	5.01
2413.87	20.086	0.38	19.71	-19.71	5.38
2575.14	18.964	0.43	18.53	-18.53	5.74
2733.35	17.826	0.48	17.34	-17.34	6.09
2888.82	16.661	0.54	16.12	-16.12	6.44
3042.2	15.483	0.60	14.88	-14.88	6.78
3194.39	14.295	0.66	13.64	-13.64	7.12
3346.26	13.101	0.72	12.38	-12.38	7.46
3498.69	11.917	0.79	11.13	-11.13	7.80
3652.18	10.732	0.86	9.87	-9.87	8.14
3806.99	9.554	0.94	8.62	-8.62	8.48
3962.74	8.380	1.01	7.37	-7.37	8.83
4119.03	7.205	1.09	6.11	-6.11	9.18
4275.18	6.024	1.18	4.85	-4.85	9.53
4430.91	4.836	1.27	3.57	-3.57	9.87
4586.3	3.645	1.35	2.29	-2.29	10.22
4742.07	2.448	1.45	1.00	-1.00	10.57

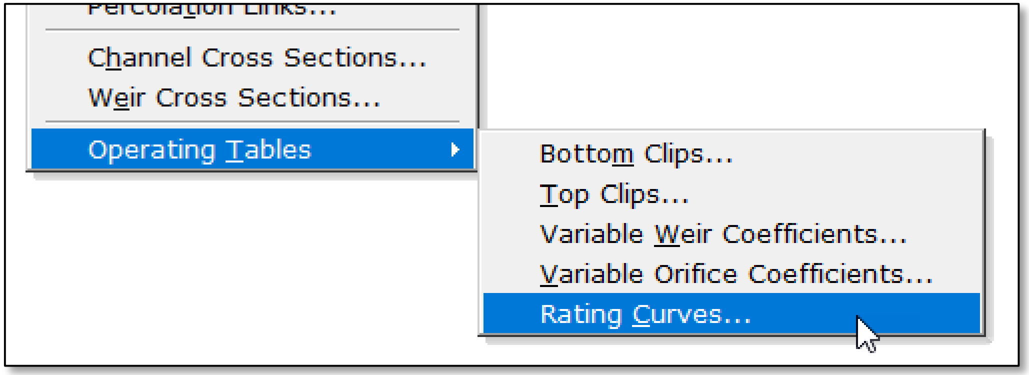
Rating Curve Links

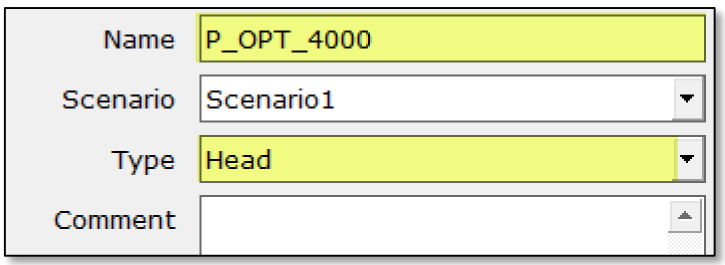
Example RC#2: Roadway Pump Station & Drain Well



Rating Curve Links

Example RC#2: Roadway Pump Station & Drain Well





Rating Curve Links

Example RC#2: Roadway Pump Station & Drain Well

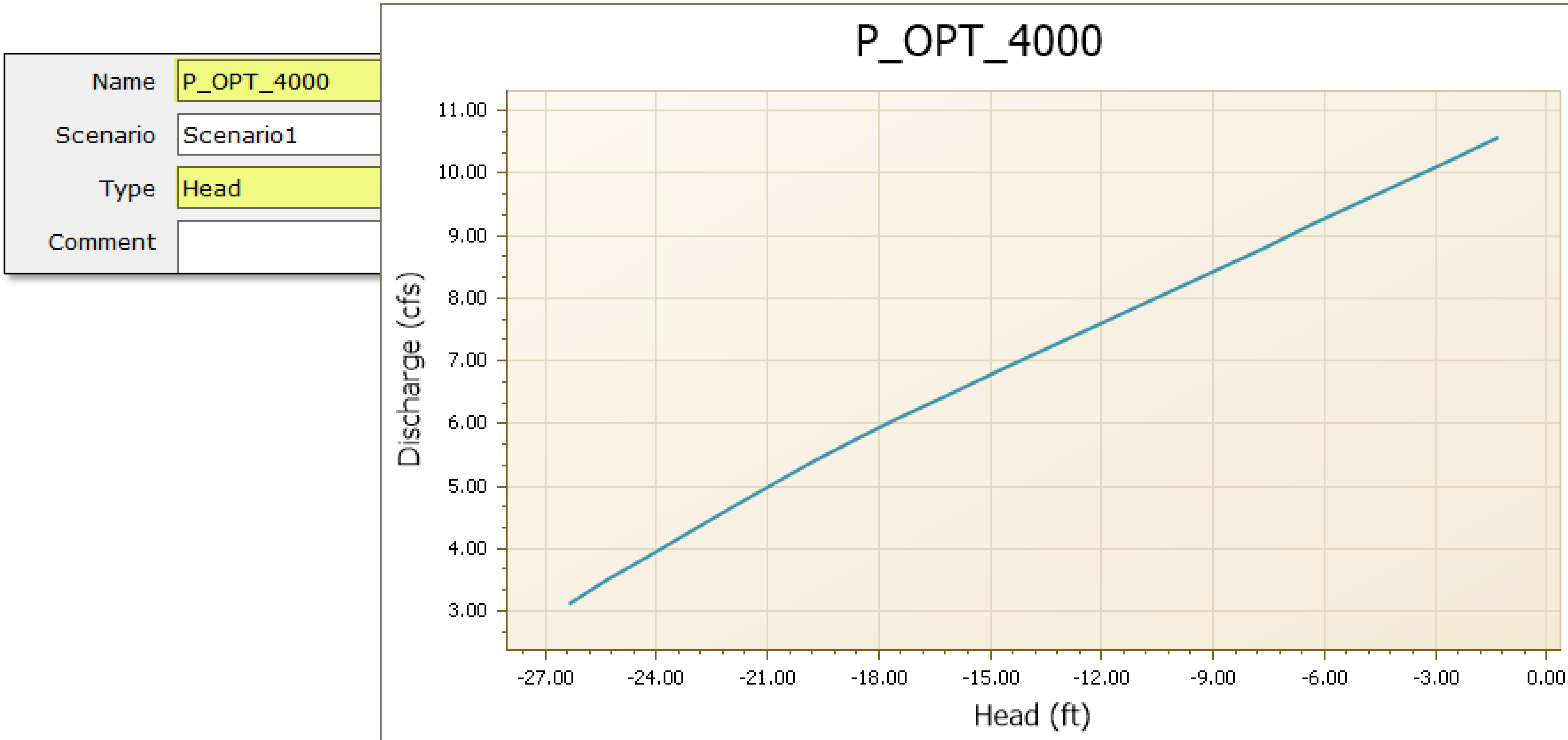
Name	P_OPT_4000
Scenario	Scenario1
Type	Head
Comment	

Rating Curve Point Edit

Head	Discharge
-26.36	3.12
-25.29	3.5
-24.21	3.88
-23.13	4.26
-22.03	4.64
-20.92	5.01
-19.79	5.38
-18.62	5.74
-17.44	6.09
-16.23	6.44
-15.01	6.78
-13.77	7.12
-12.53	7.46
-11.29	7.8
-10.05	8.14
-8.82	8.48
-7.58	8.83
-6.34	9.18
-5.09	9.53
-3.84	9.87
-2.58	10.22
-1.3	10.57

Rating Curve Links

Example RC#2: Roadway Pump Station & Drain Well



Rating Curve Links

Example RC#2: Roadway Pump Station & Drain Well

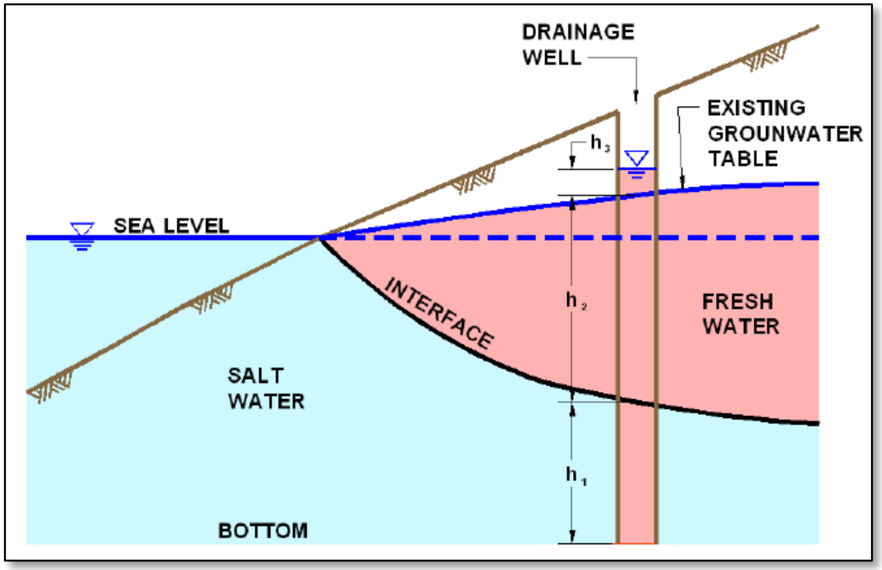
Injection Drainage Well Operating Table

Injection drainage wells are used frequently in southeast Florida as a means of disposing stormwater runoff because of limited open space for stormwater ponds and because of the high conductivities of the aquifer system.

Additional head is required when the injection well discharges below the salt water interface line because of different water densities.

The additional head requirement is calculated as:

$$h_3 = 0.025\,(h_1)$$



Rating Curve Links

Example RC#2: Roadway Pump Station & Drain Well

In this example, the injection well is 90 feet deep and penetrates 80 feet beyond the salt water interface. Therefore, the additional head, h3, necessary to overcome the density differences between fresh and salt water is 2 feet (0.025 x 80 = 2.0). The ambient water table is at elevation 2.0'. Therefore, a minimum water elevation of 4.0 feet is needed to push fresh water into the salt water. The well capacity is 700 gpm per foot of head up to elevation 8.0 feet at which point an overflow occurs to a surface outlet. Therefore, the upstream stage versus discharge relationship is as follows (per the original FDOT example):

Upstream Stage (ft)	Discharge (cfs)
4.0	0.00
8.0	6.24
30.0	6.24

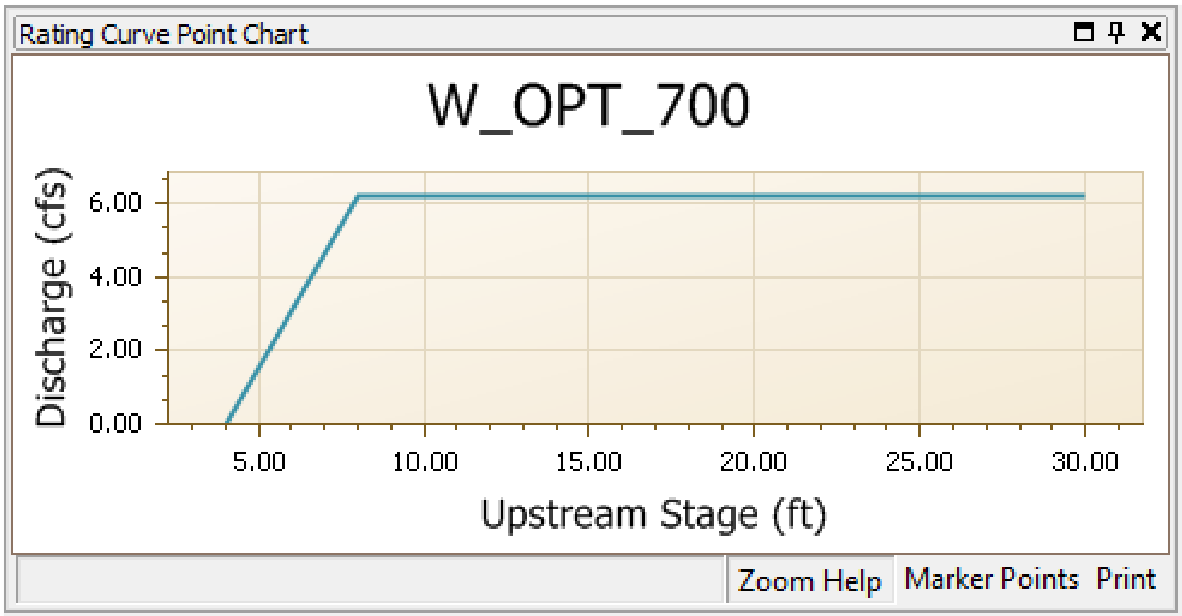
Rating Curve Links

Example RC#2: Roadway Pump Station & Drain Well

Name: W_OPT_700
Scenario: Scenario1
Type: Upstream Stage
Comment:

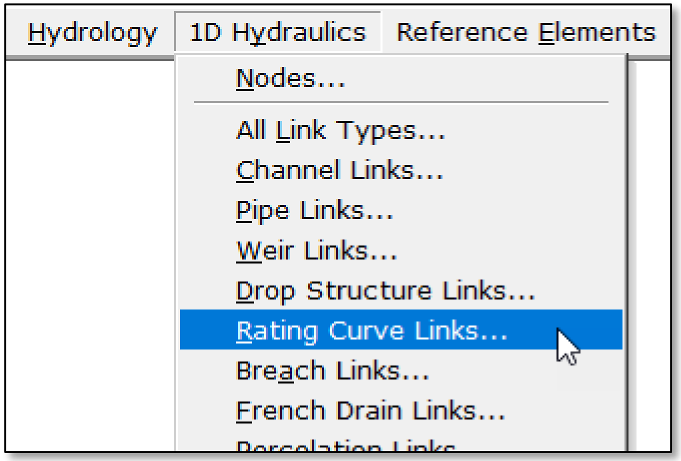
Rating Curve Point Edit

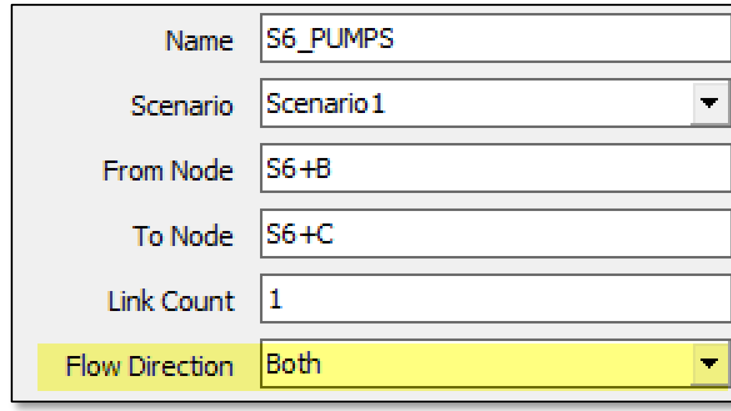
Upstream Stage	Discharge
4	0
8	6.24
30	6.24



Rating Curve Links

Example RC#2: Roadway Pump Station & Drain Well



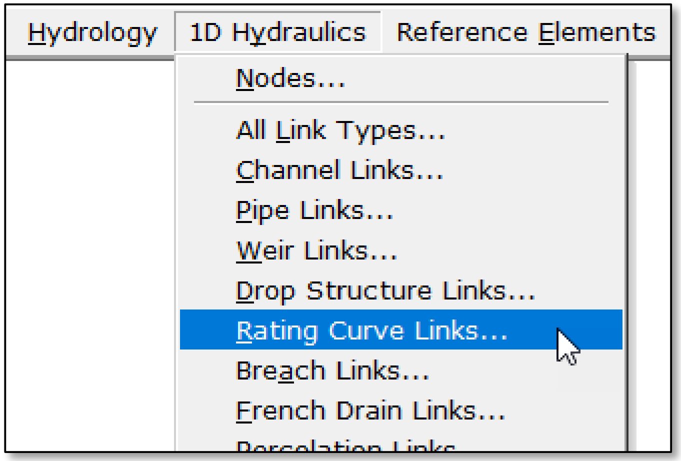


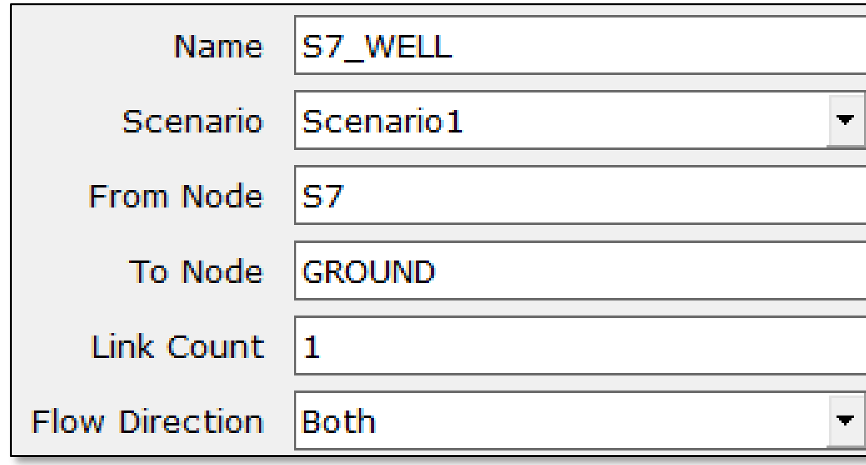
Link Rating Curve Rating Curves Grid

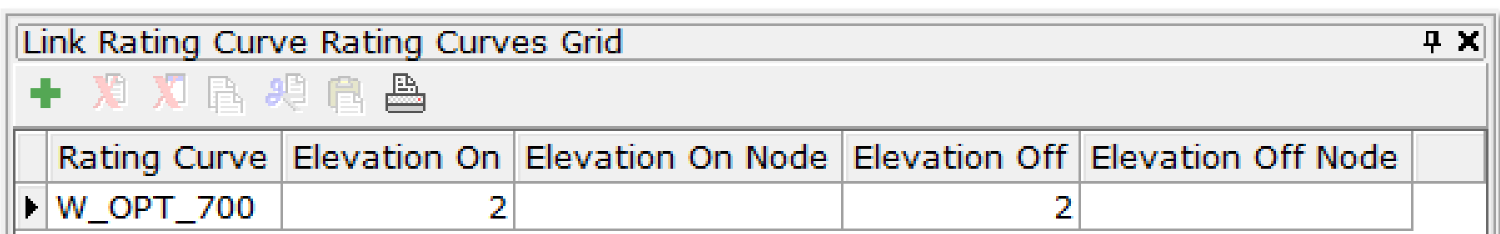
Rating Curve	Elevation On	Elevation On Node	Elevation Off	Elevation Off Node
P_OPT_4000	5		1.5	
P_OPT_4000	5.33		1.5	

Rating Curve Links

Example RC#2: Roadway Pump Station & Drain Well

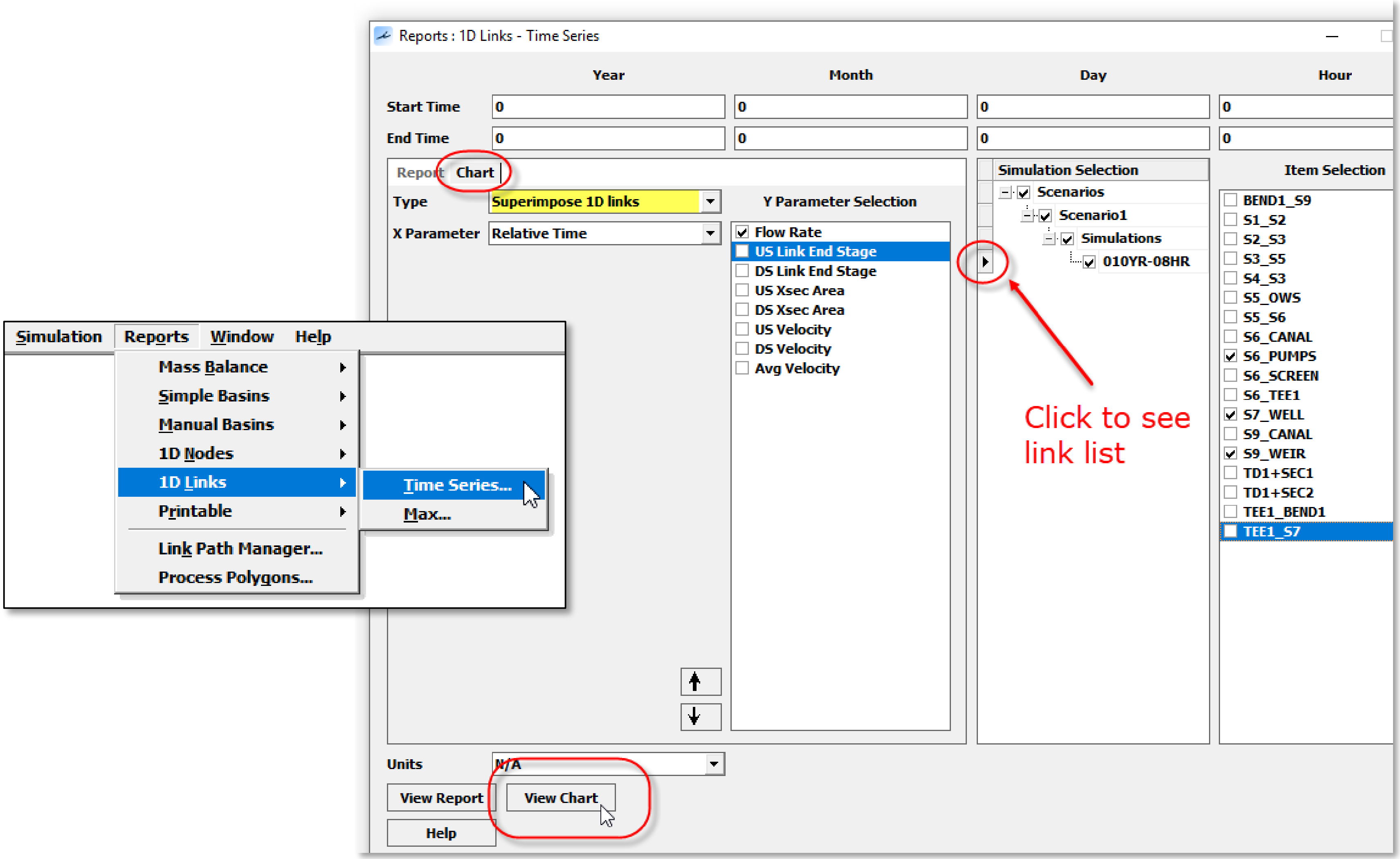






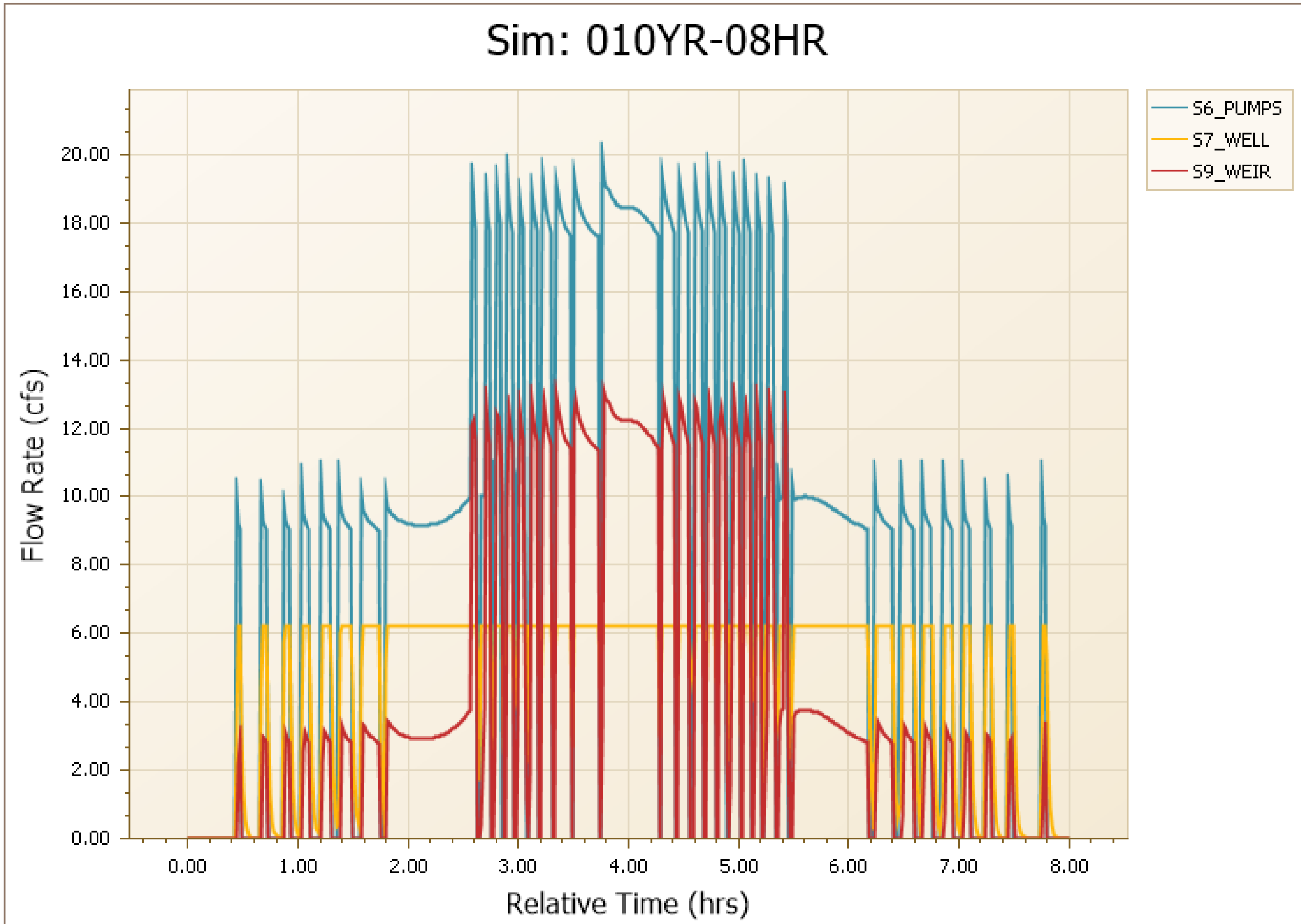
Rating Curve Links

Example RC#2: Roadway Pump Station & Drain Well



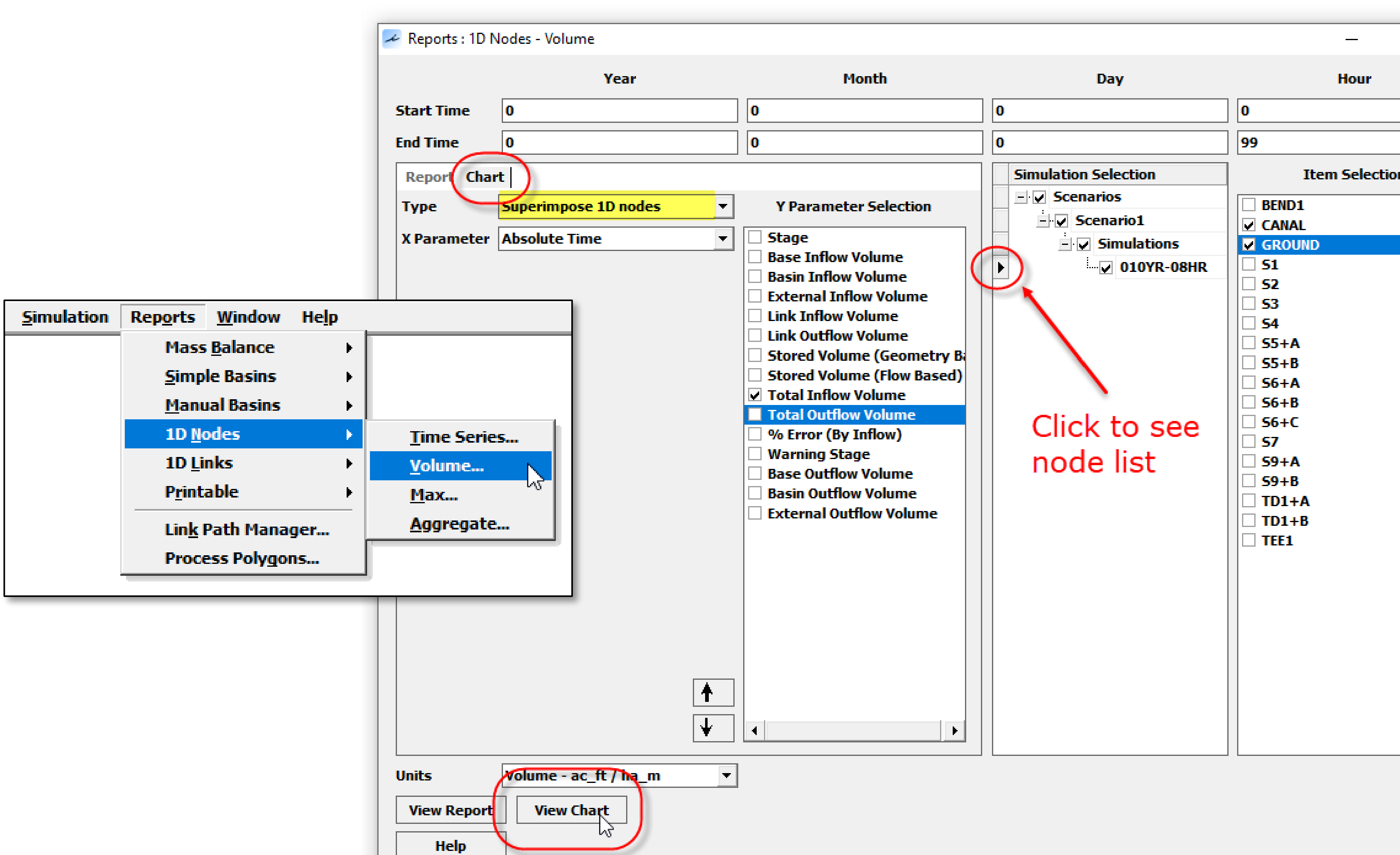
Rating Curve Links

Example RC#2: Roadway Pump Station & Drain Well



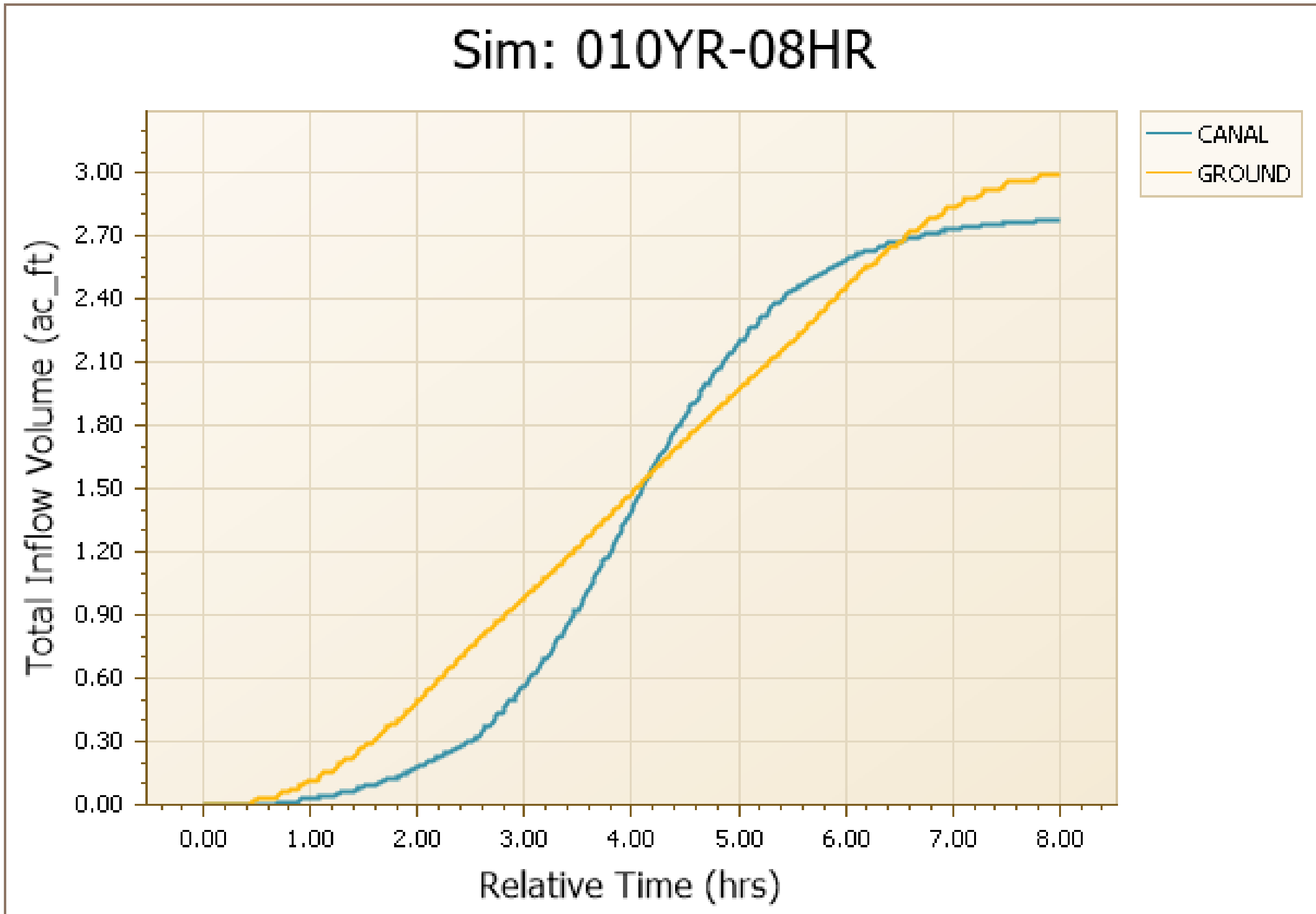
Rating Curve Links

Example RC#2: Roadway Pump Station & Drain Well



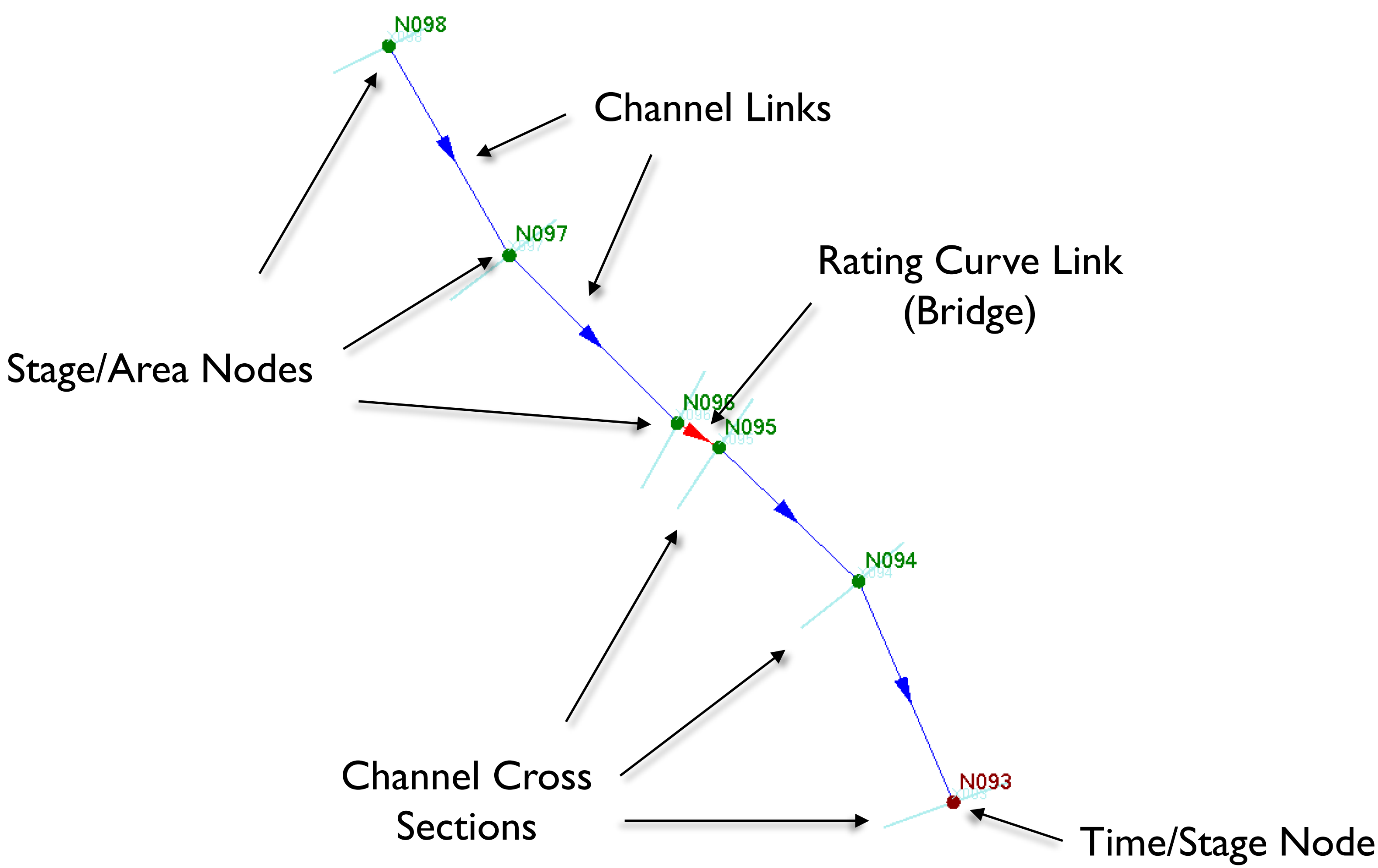
Rating Curve Links

Example RC#2: Roadway Pump Station & Drain Well



Rating Curve Links

Example RC#3: Bridge

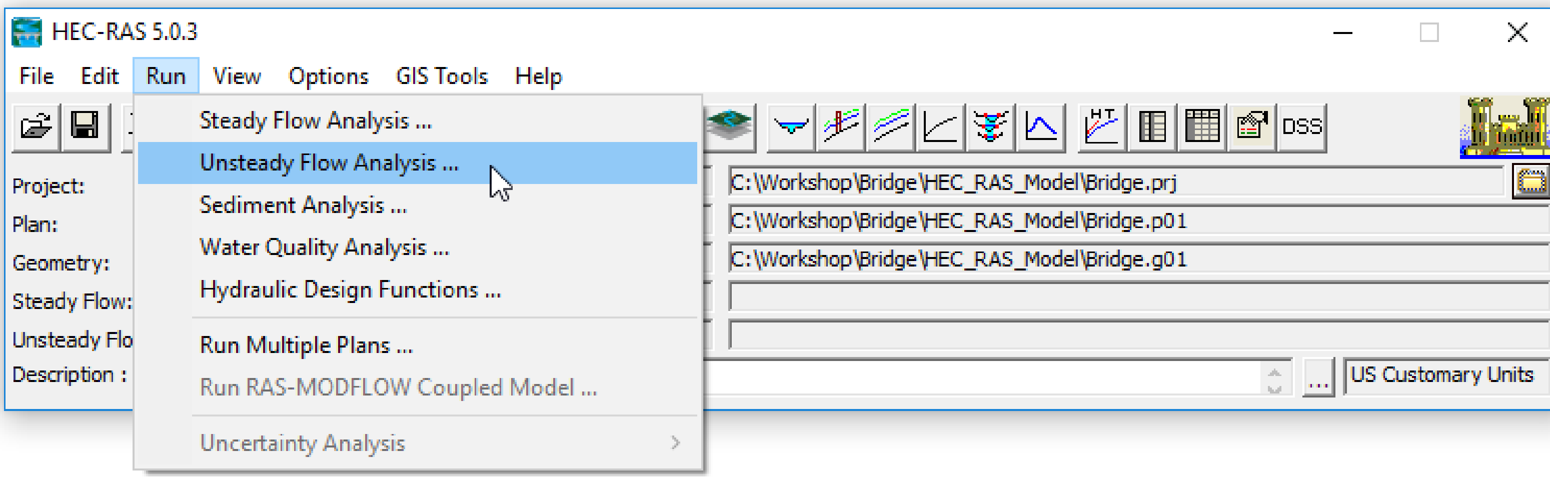


Rating Curve Links

Example RC#3: Bridge

HEC-RAS

When modeling unsteady flow in HEC-RAS, bridges must be preprocessed to develop a family of rating curves. The rating curves are then used during the routing process rather than the actual bridge hydraulics.

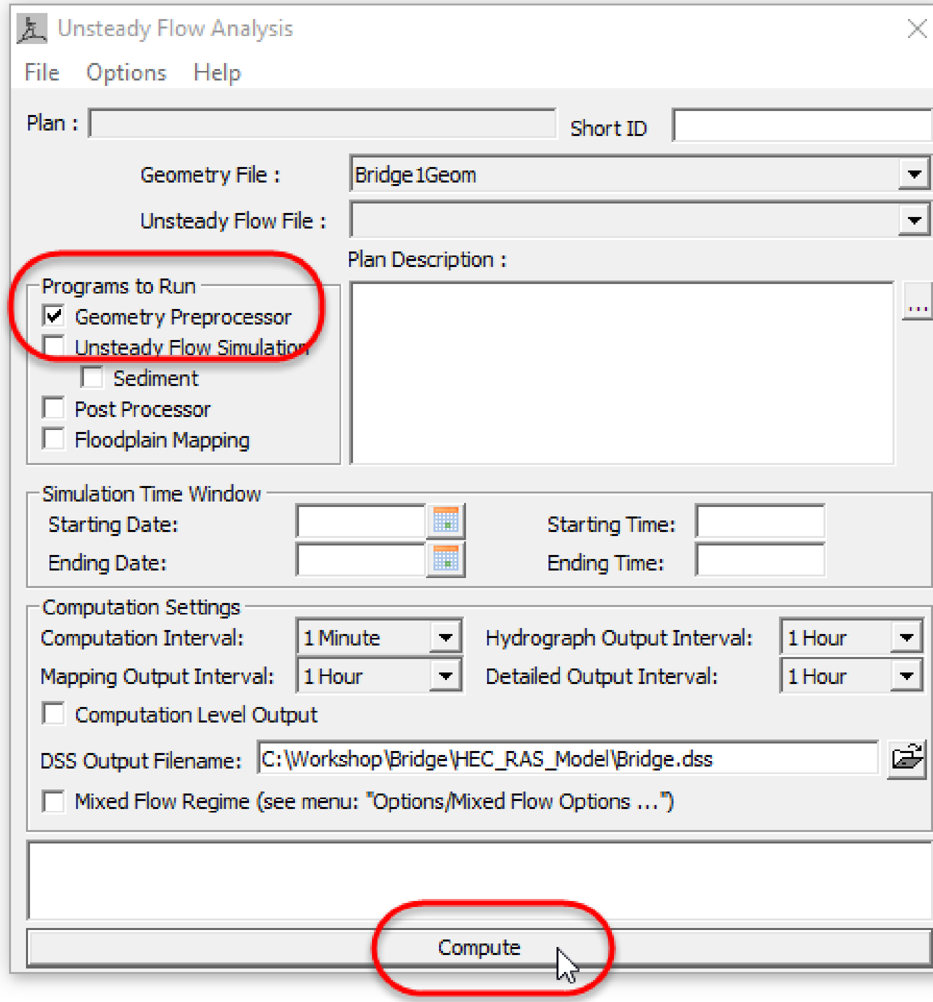


Rating Curve Links

Example RC#3: Bridge

HEC-RAS

Make sure the "Geometry Preprocessor" option is checked under "Programs to Run". Then click the "Compute" button at the bottom of the Unsteady Flow Analysis data form.

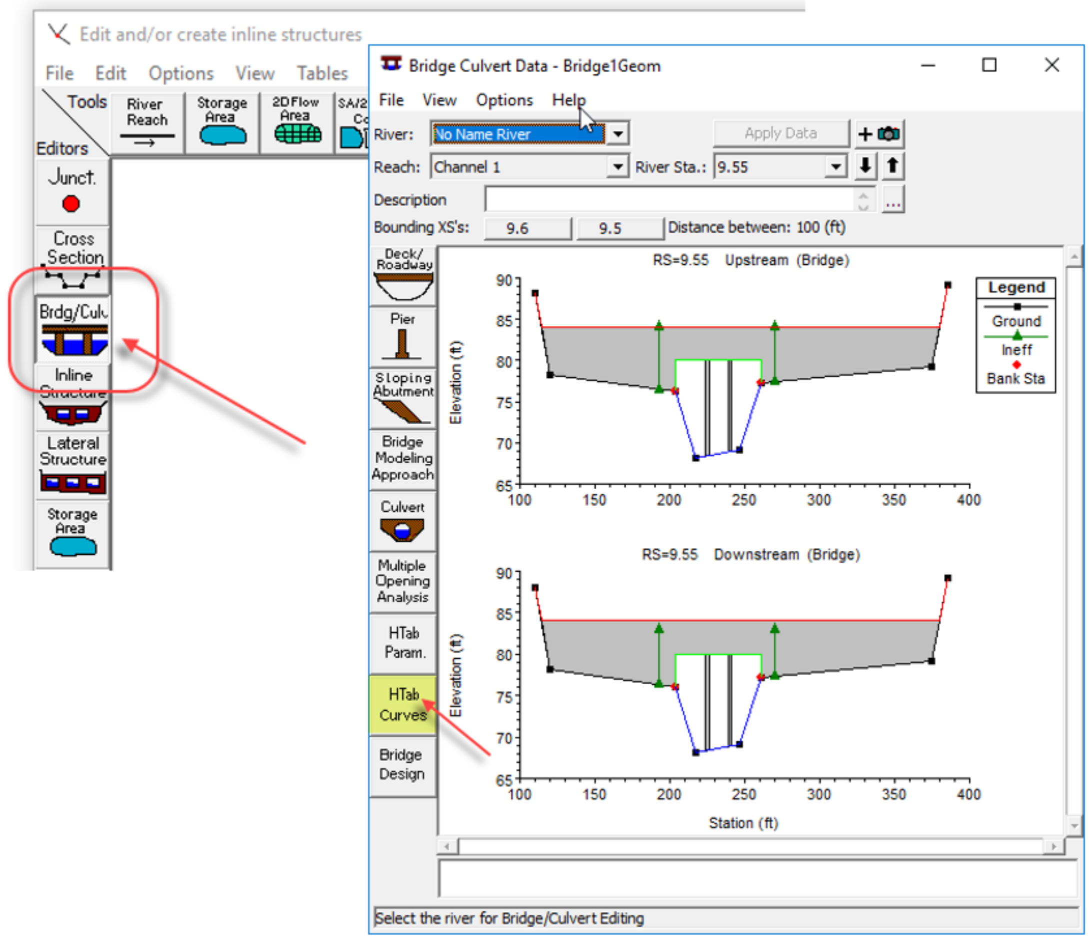


Rating Curve Links

Example RC#3: Bridge

HEC-RAS

Open the bridge/culvert data form and click the “Htab Curves” icon.

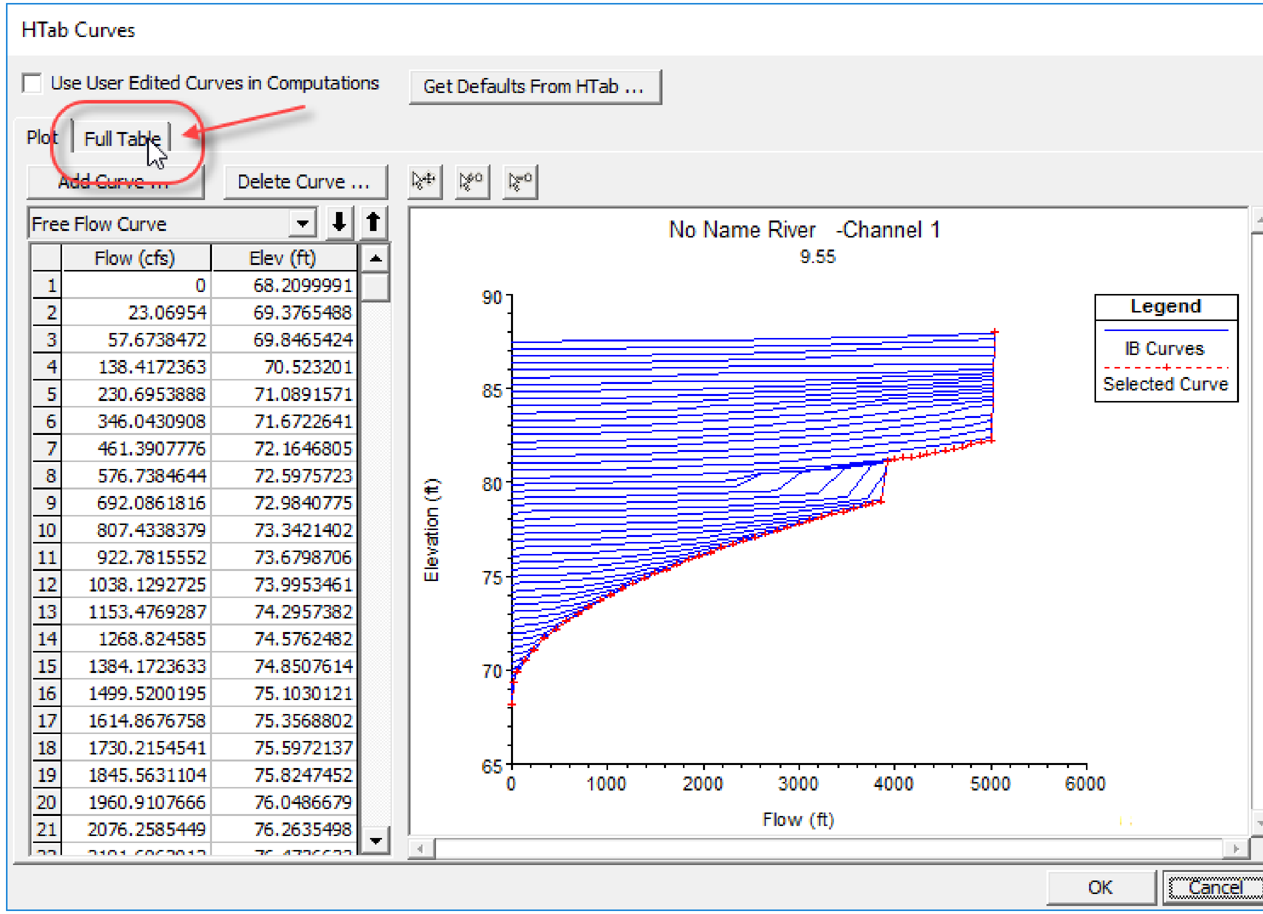


Rating Curve Links

Example RC#3: Bridge

HEC-RAS

The bridge rating curves appear … click the "Full Table" tab to see the values.

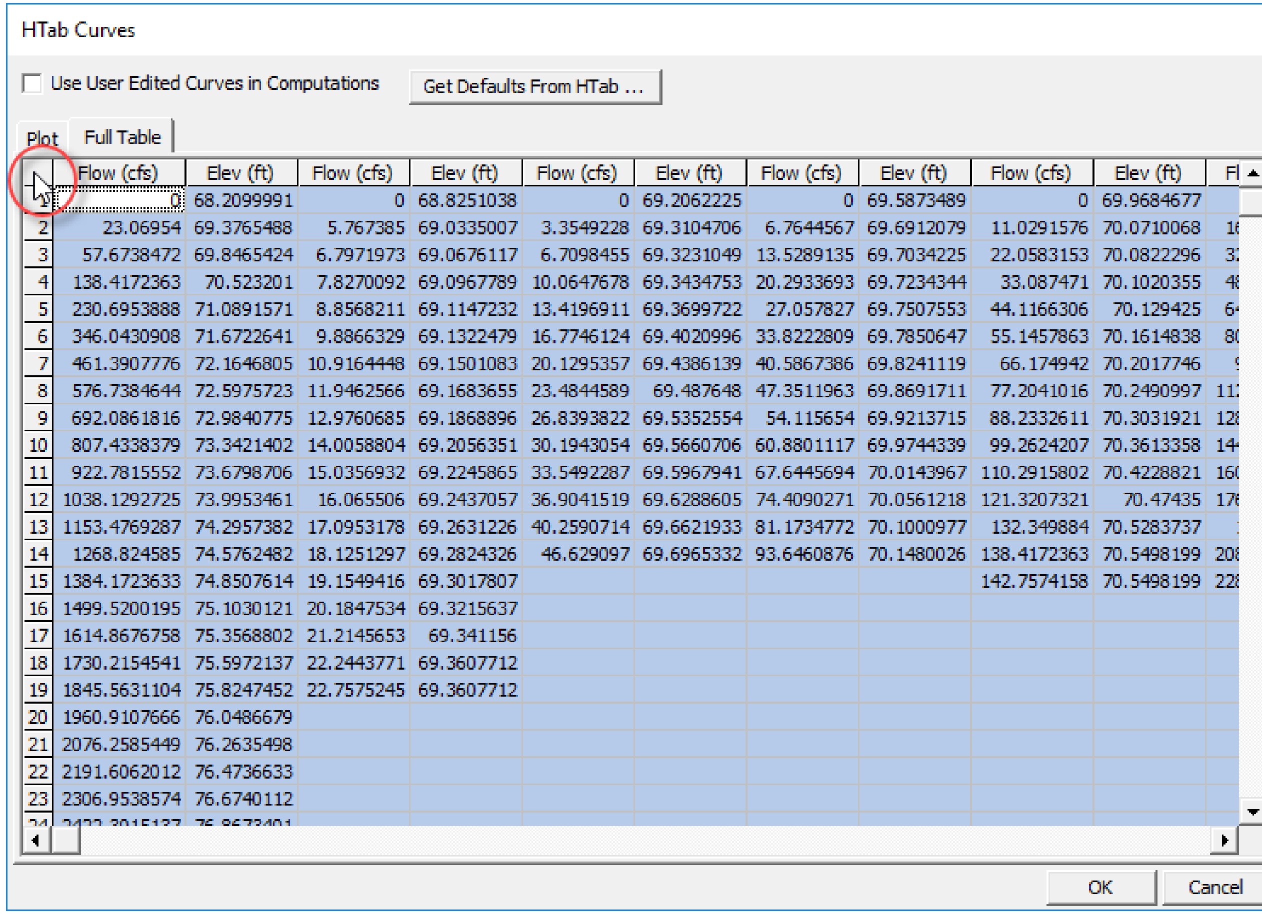


Rating Curve Links

Example RC#3: Bridge

HEC-RAS

Click the “Select All” button in the upper left corner of the grid. Press “Ctrl C” to copy the rating curves into the clip board.



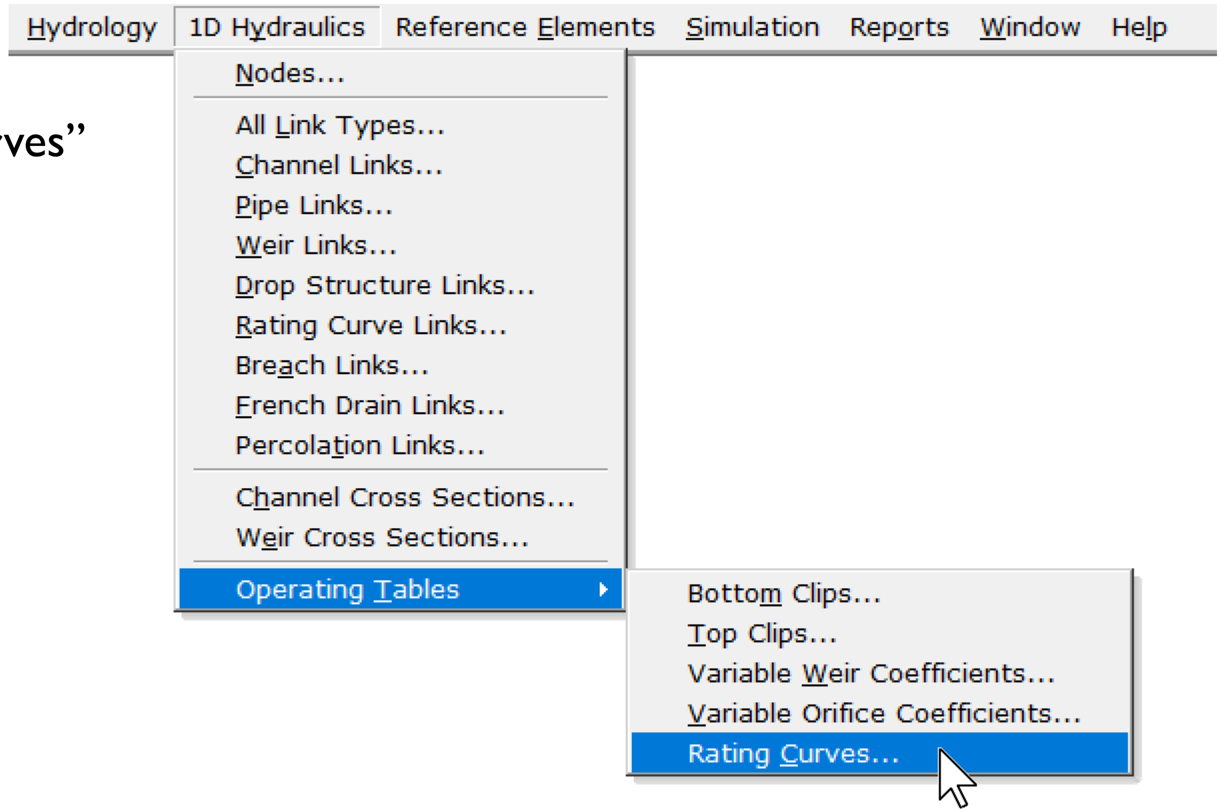
	Flow (cfs)	Elev (ft)	Flow (cfs)	Elev (ft)	Flow (cfs)	Elev (ft)	Flow (cfs)	Elev (ft)	Flow (cfs)	Elev (ft)
1	0	68.2099991	0	68.8251038	0	69.2062225	0	69.5873489	0	69.9684677
2	23.06954	69.3765488	5.767385	69.0335007	3.3549228	69.3104706	6.7644567	69.6912079	11.0291576	70.0710068
3	57.6738472	69.8465424	6.7971973	69.0676117	6.7098455	69.3231049	13.5289135	69.7034225	22.0583153	70.0822296
4	138.4172363	70.523201	7.8270092	69.0967789	10.0647678	69.3434753	20.2933693	69.7234344	33.087471	70.1020355
5	230.6953888	71.0891571	8.8568211	69.1147232	13.4196911	69.3699722	27.057827	69.7507553	44.1166306	70.129425
6	346.0430908	71.6722641	9.8866329	69.1322479	16.7746124	69.4020996	33.8222809	69.7850647	55.1457863	70.1614838
7	461.3907776	72.1646805	10.9164448	69.1501083	20.1295357	69.4386139	40.5867386	69.8241119	66.174942	70.2017746
8	576.7384644	72.5975723	11.9462566	69.1683655	23.4844589	69.487648	47.3511963	69.8691711	77.2041016	70.2490997
9	692.0861816	72.9840775	12.9760685	69.1868896	26.8393822	69.5352554	54.115654	69.9213715	88.2332611	70.3031921
10	807.4338379	73.3421402	14.0058804	69.2056351	30.1943054	69.5660706	60.8801117	69.9744339	99.2624207	70.3613358
11	922.7815552	73.6798706	15.0356932	69.2245865	33.5492287	69.5967941	67.6445694	70.0143967	110.2915802	70.4228821
12	1038.1292725	73.9953461	16.065506	69.2437057	36.9041519	69.6288605	74.4090271	70.0561218	121.3207321	70.47435
13	1153.4769287	74.2957382	17.0953178	69.2631226	40.2590714	69.6621933	81.1734772	70.1000977	132.349884	70.5283737
14	1268.824585	74.5762482	18.1251297	69.2824326	46.629097	69.6965332	93.6460876	70.1480026	138.4172363	70.5498199
15	1384.1723633	74.8507614	19.1549416	69.3017807					142.7574158	70.5498199
16	1499.5200195	75.1030121	20.1847534	69.3215637						
17	1614.8676758	75.3568802	21.2145653	69.341156						
18	1730.2154541	75.5972137	22.2443771	69.3607712						
19	1845.5631104	75.8247452	22.7575245	69.3607712						
20	1960.9107666	76.0486679								
21	2076.2585449	76.2635498								
22	2191.6062012	76.4736633								
23	2306.9538574	76.6740112								

Rating Curve Links

Example RC#3: Bridge

ICPR

Open the "Rating Curves" "Operating Tables"

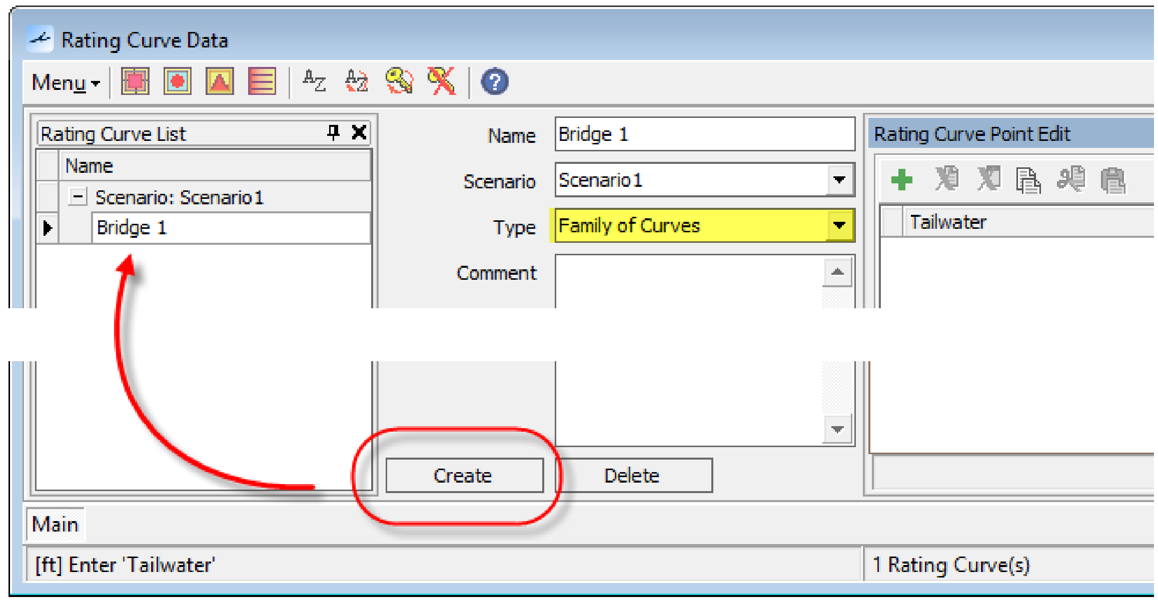


Rating Curve Links

Example RC#3: Bridge

ICPR

Create a new Rating Curve table named "Bridge 1". Set the "Type" to "Family of Curves".

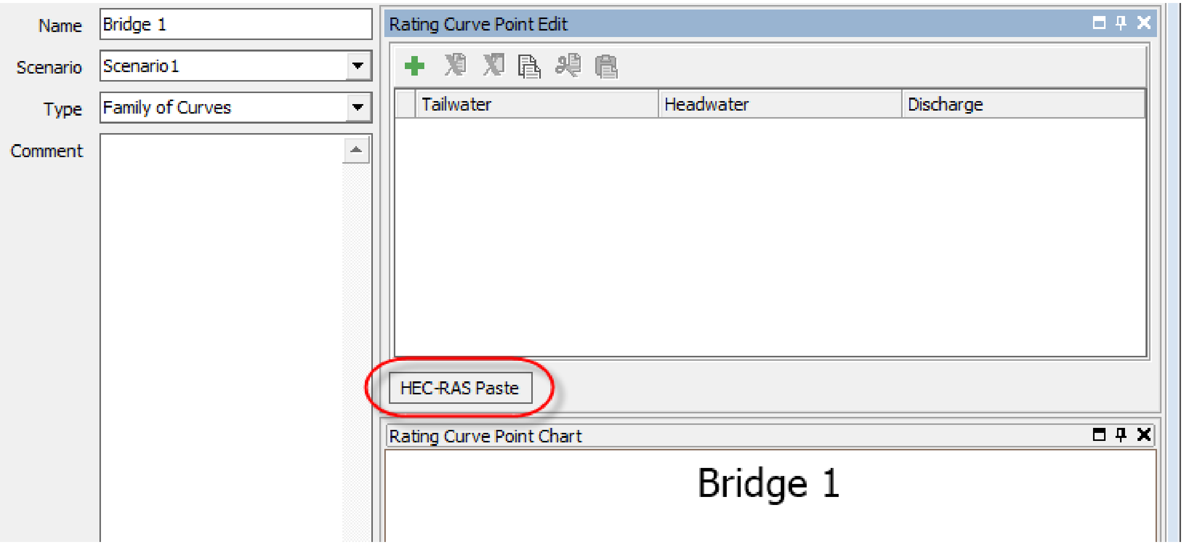


Rating Curve Links

Example RC#3: Bridge

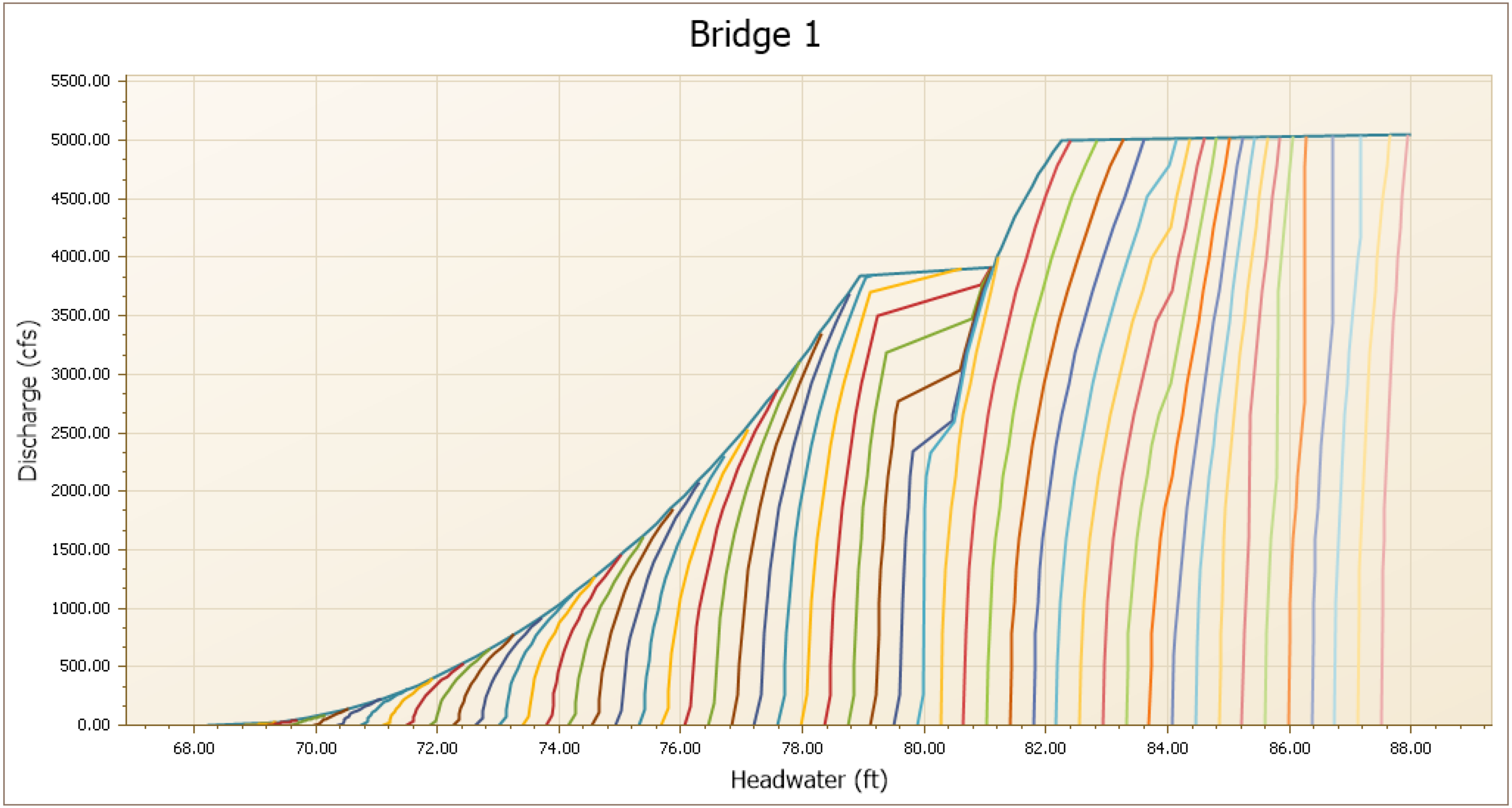
ICPR

Click the "HEC-RAS Paste" button.



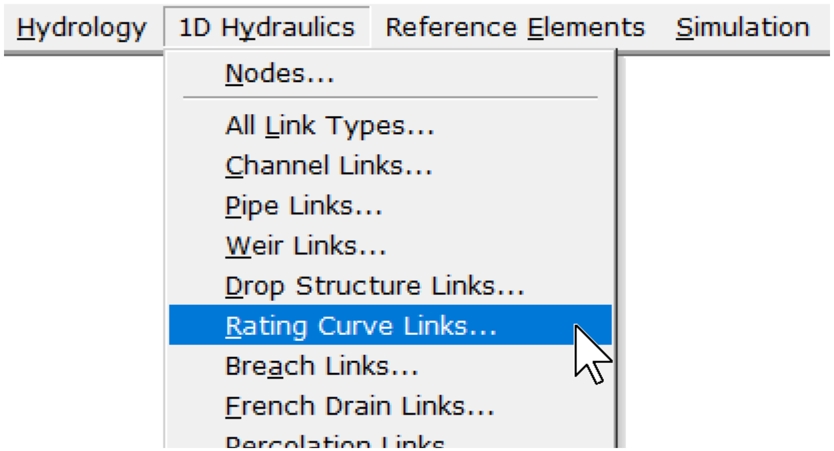
Rating Curve Links

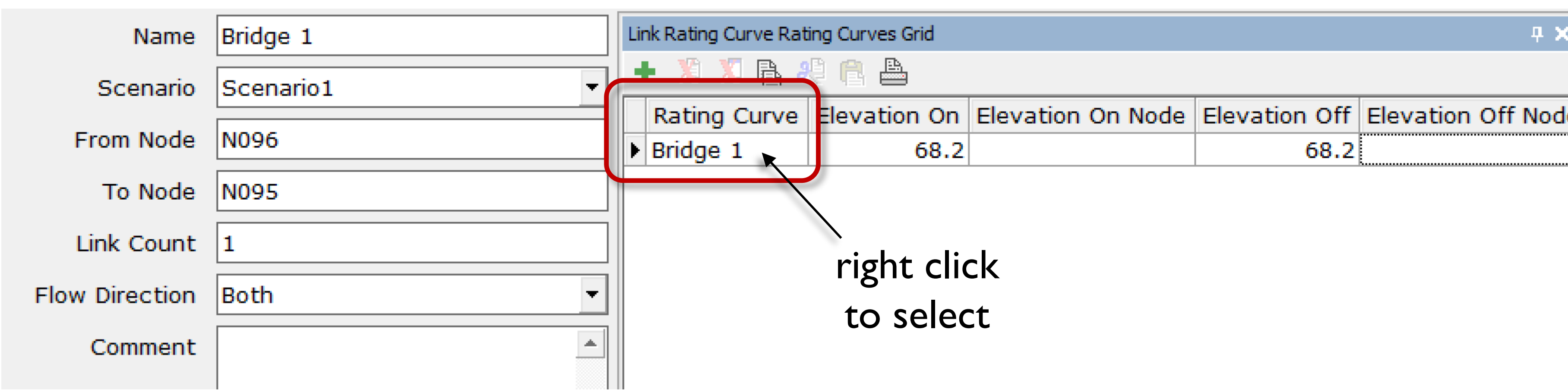
Example RC#3: Bridge



Rating Curve Links

Example RC#3: Bridge





Rating Curve Links

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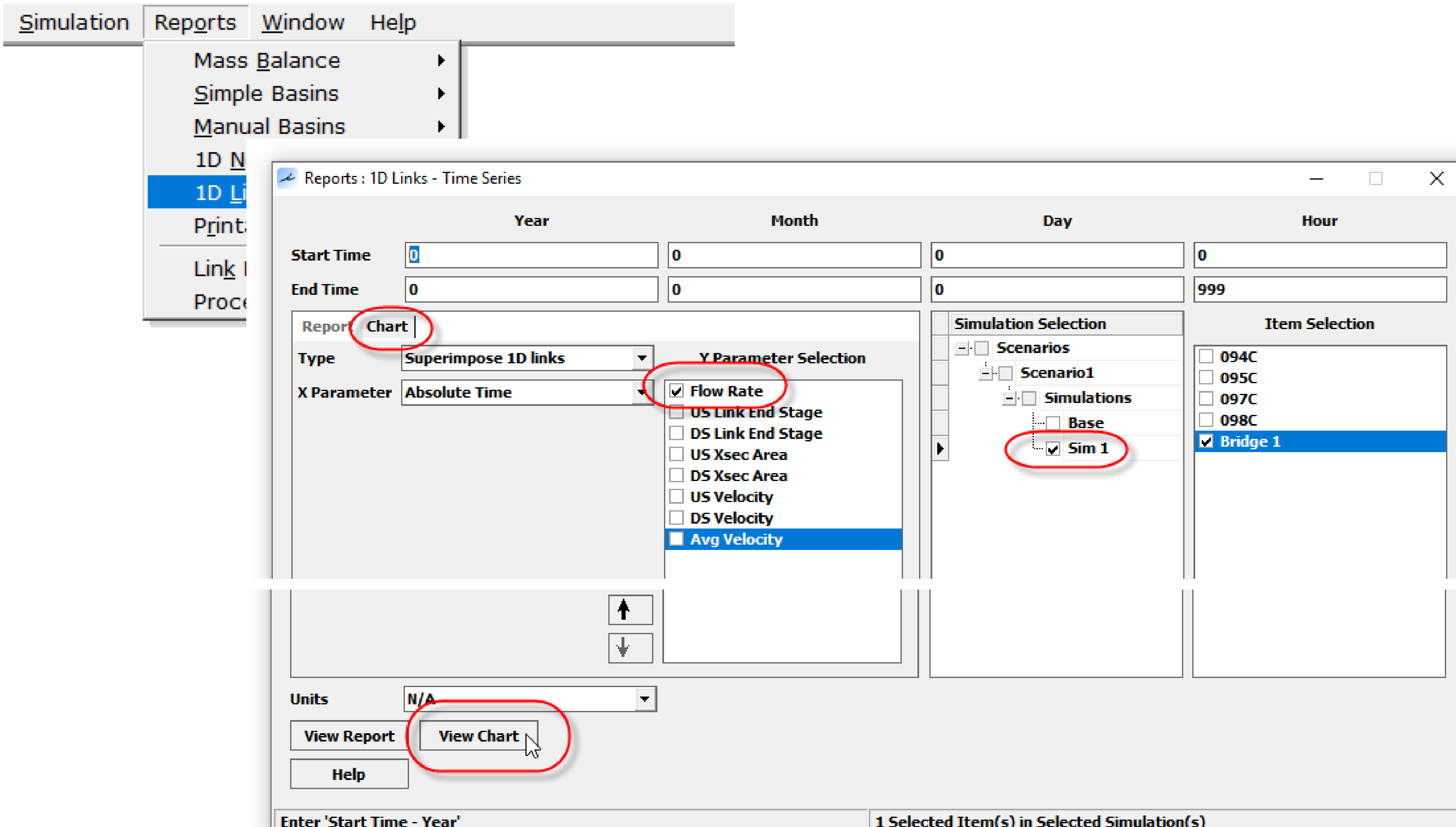

Rating Curve Links

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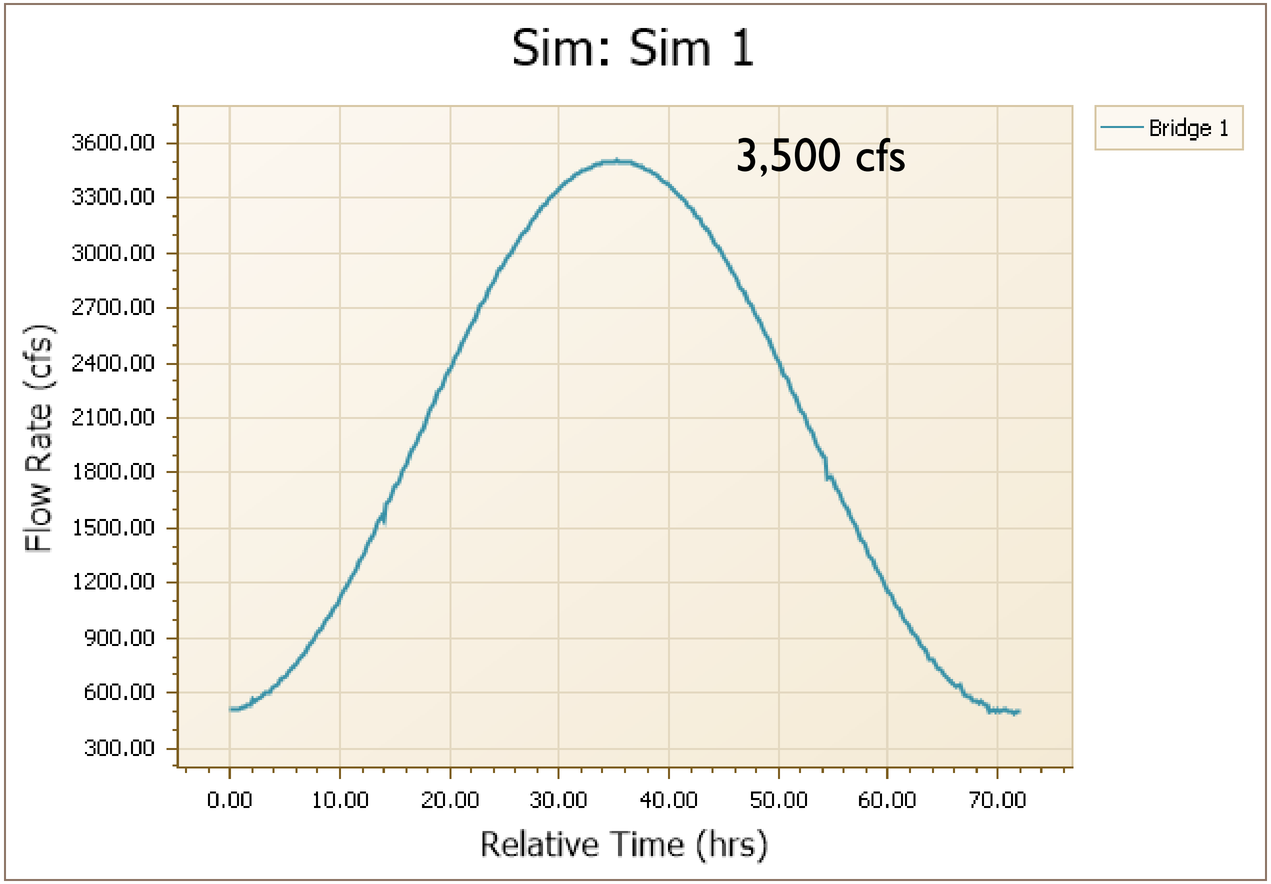

Rating Curve Links

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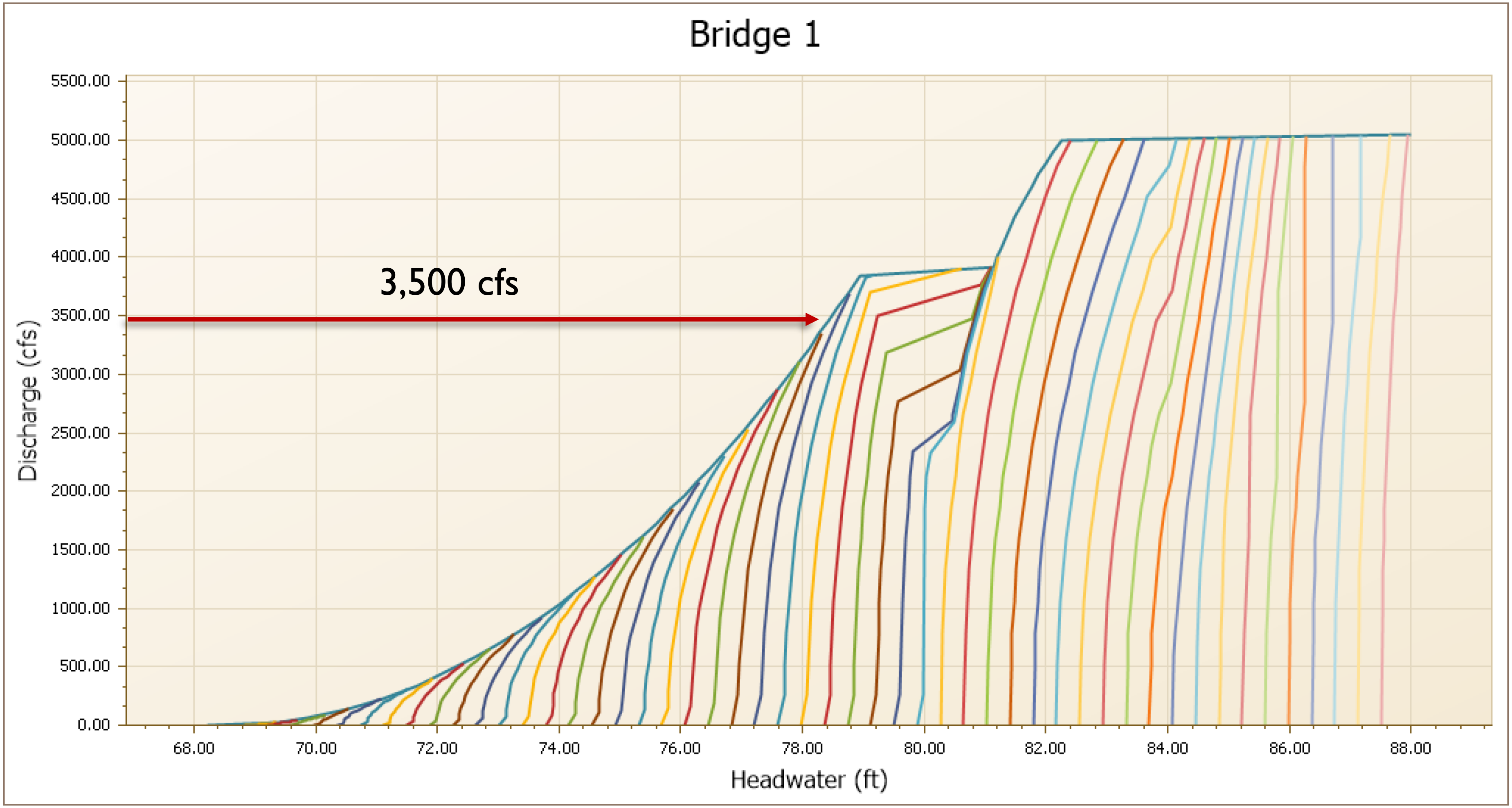
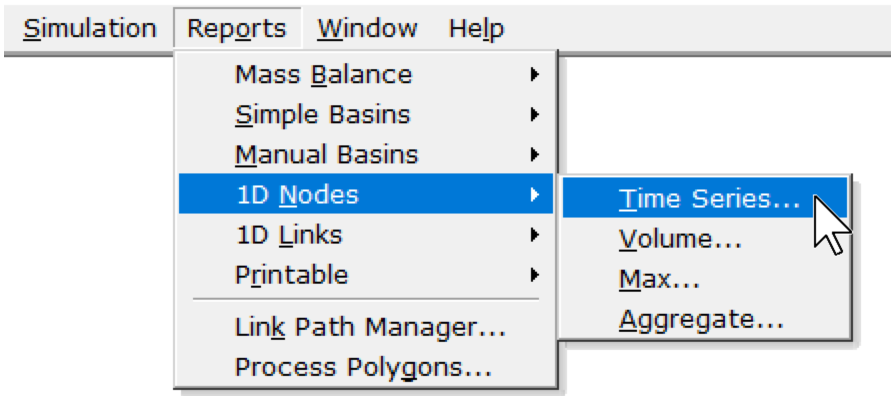
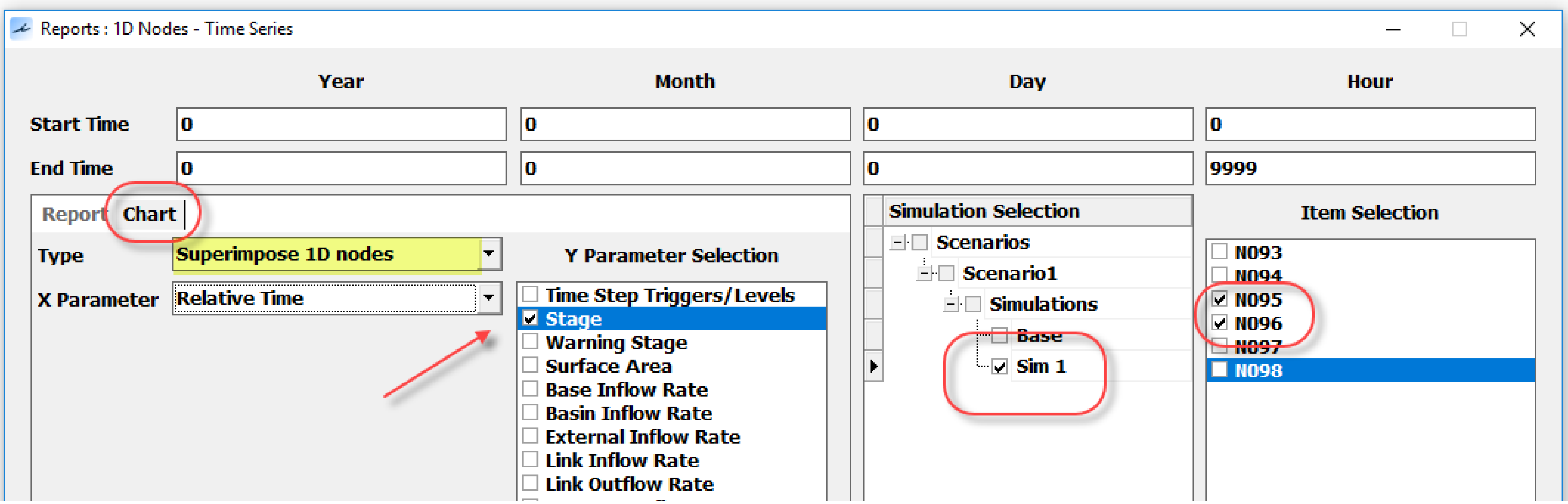


Rating Curve Links

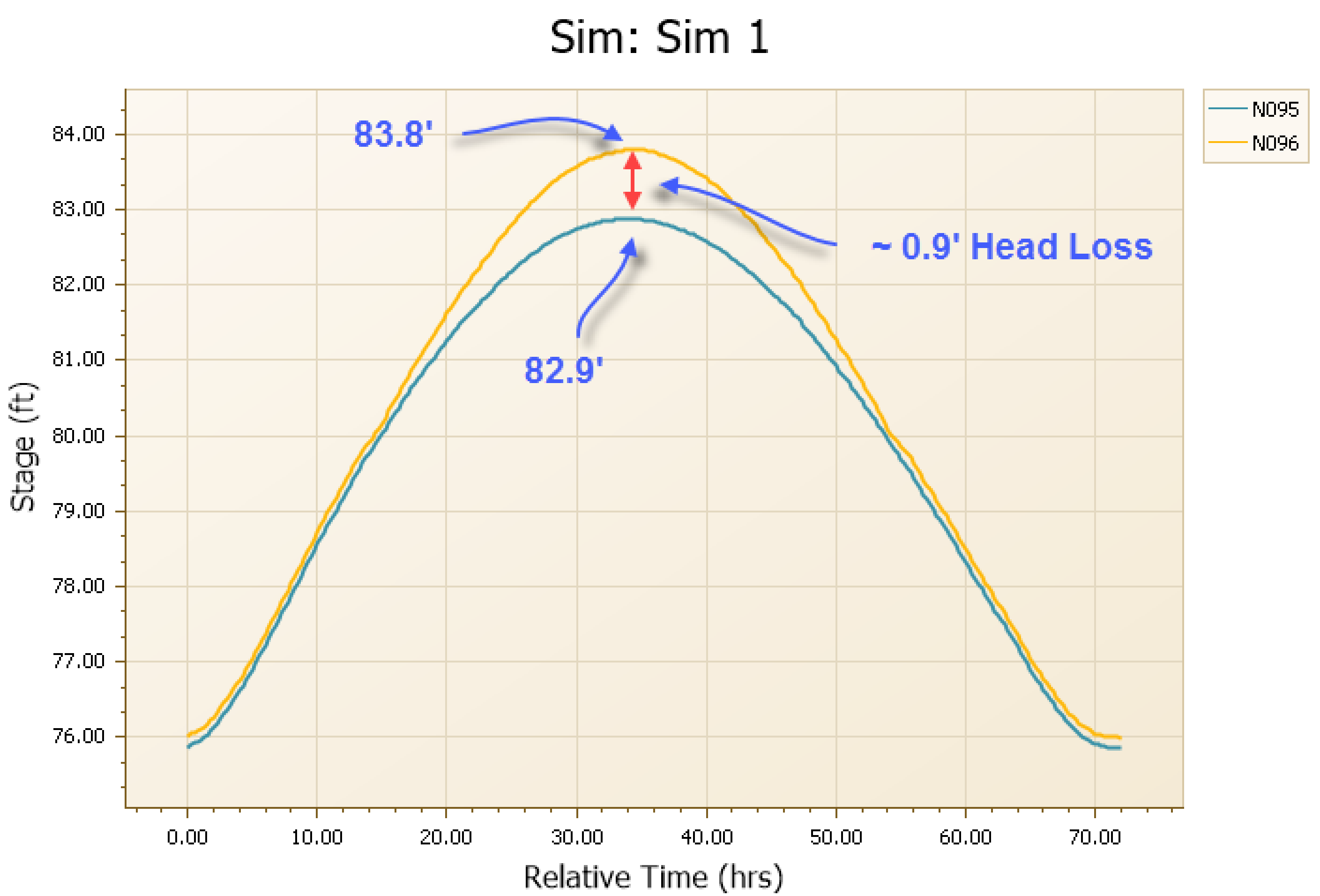
Example RC#3: Bridge





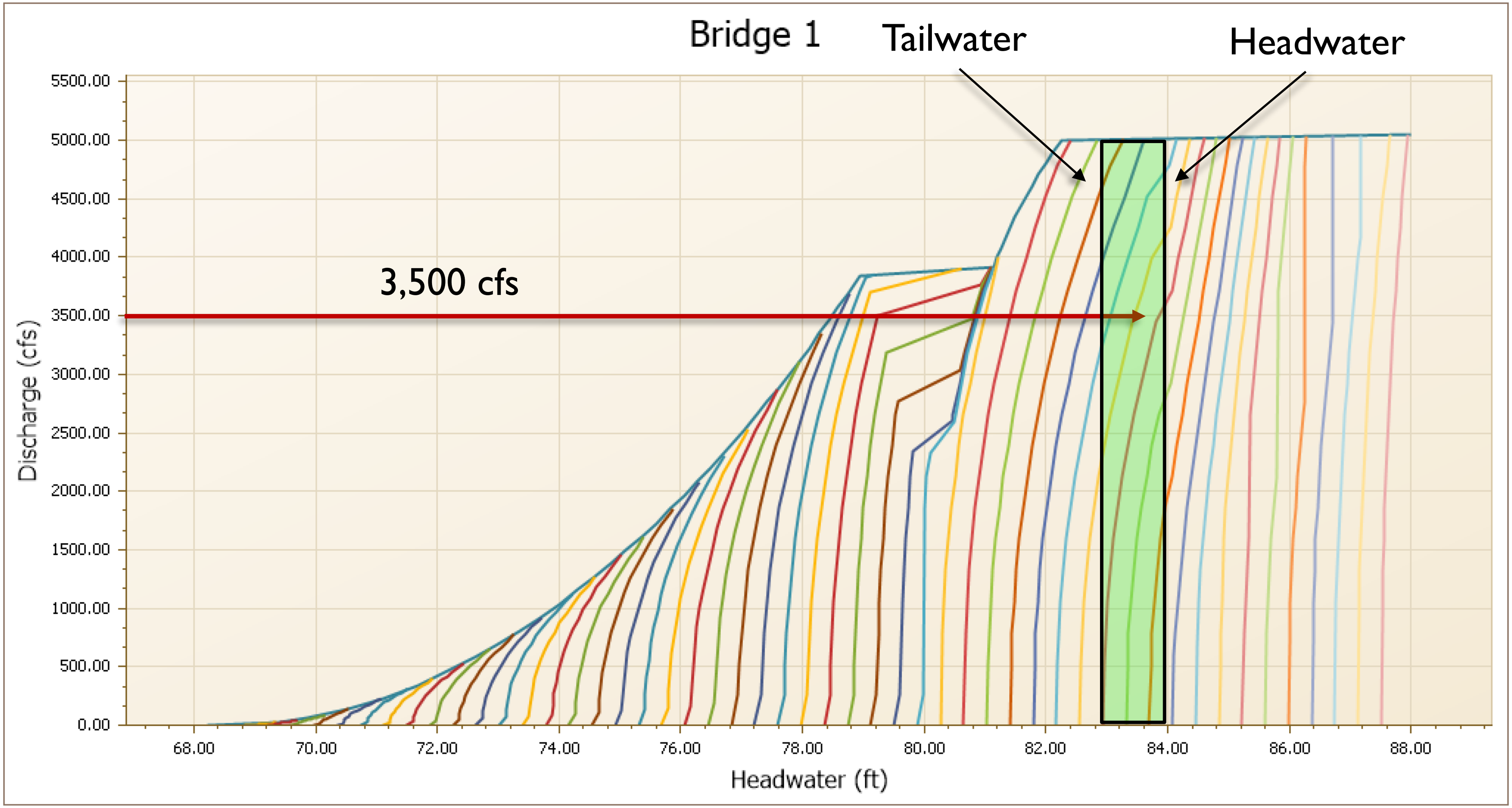
Rating Curve Links

Example RC#3: Bridge



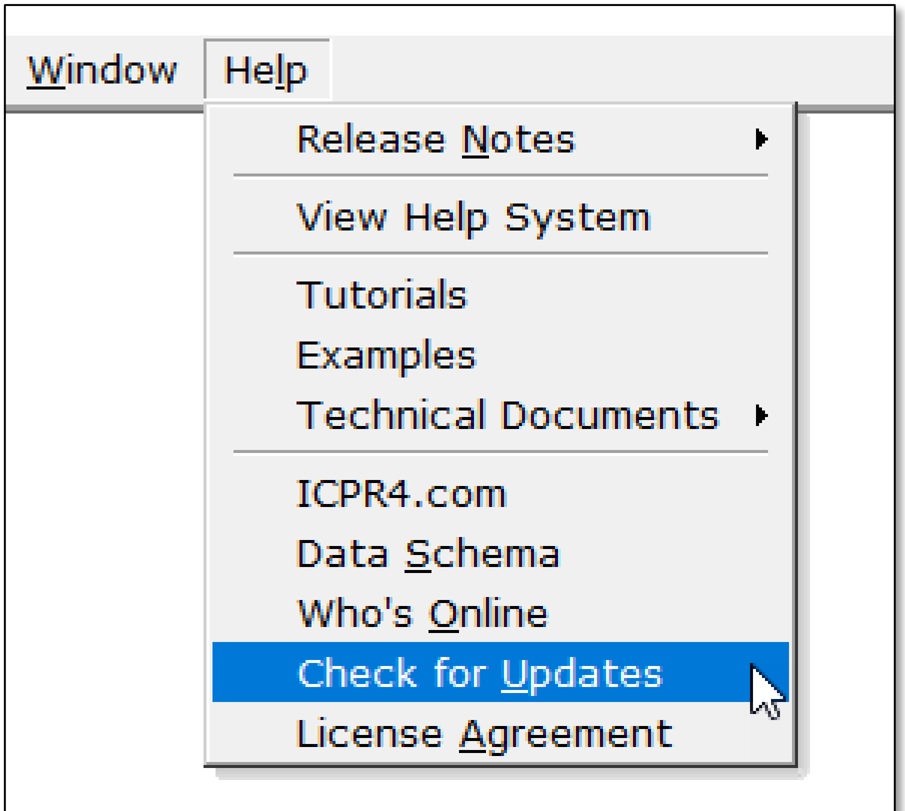
Rating Curve Links

Example RC#3: Bridge



Next Webinar – Lesson 4: Hydraulics, Part 3

Thursday October 31, 2019
11:30 – 1:30 (EDT)



We will try to post a recording of this webinar and/or the presentation material as soon as we can.

To find them:
"Check for Updates"
sometime tomorrow.

support@icpr4.com