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Modeling the Veolia Water Technologies TTT (Thistle Tube Throttle) in Washington

Introduction

The Thistle Tube Throttle (TTT) from Veolia Water Technologies is a membrane flow regulator which operates on the Bernoulli principle whereby an increase in velocity occurs simultaneously with a decrease in pressure. The TTT consists of a PVC tube having two elliptical shaped openings on either side of the tube and a resilient acrylonitrile butadiene rubber membrane which is fitted over the outside of the tube. As the upstream water level rises and water flows through the tube, the pressure inside of the tube is reduced below the pressure outside of the tube and the membrane is pressed through the elliptical shaped openings into the interior of the tube, thereby reducing the cross sectional area of flow, and in turn reducing the flow rate. In the ideal condition, the reduction in cross sectional area would happen in direct proportion to the change in velocity; however, the cross sectional area of flow is actually reduced at a rate which is greater than the change in velocity, such that as the upstream pressure continues to increase, the flow rate through the TTT is reduced (see Figure 1). The relationship between the rate of change in cross sectional area and the change in velocity can be partially controlled by increasing or decreasing the size of the elliptical shaped openings through either side of the tube. (see Figure 2). Extensive laboratory testing has resulted in the development of a mathematical model (FluidHose) which accurately predicts this relationship for a variety of membrane types and opening geometries. The TTT is manufactured by Veolia Water Technologies Canada, under license from Umwelt- und Fluid-Technik of Germany. It was originally developed for flow control in combined sewer applications, but it has uses in many flow control applications including stormwater flow control.

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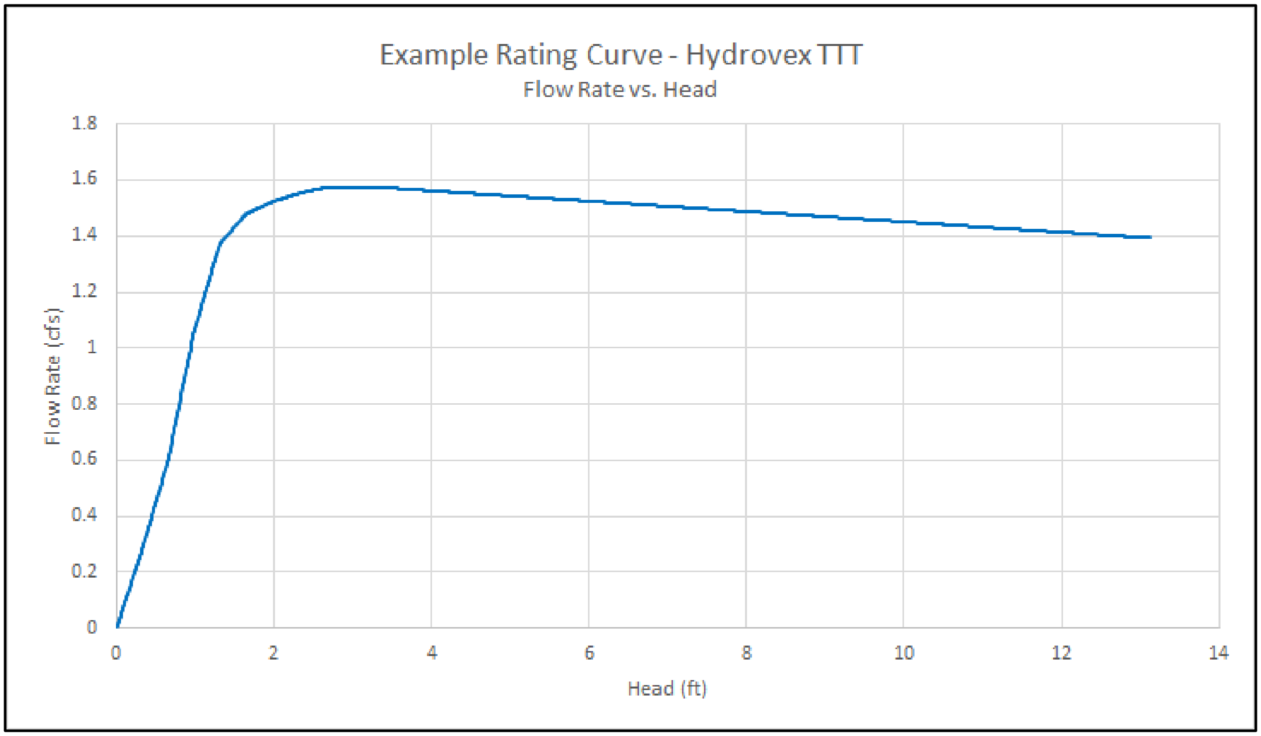


Figure 1

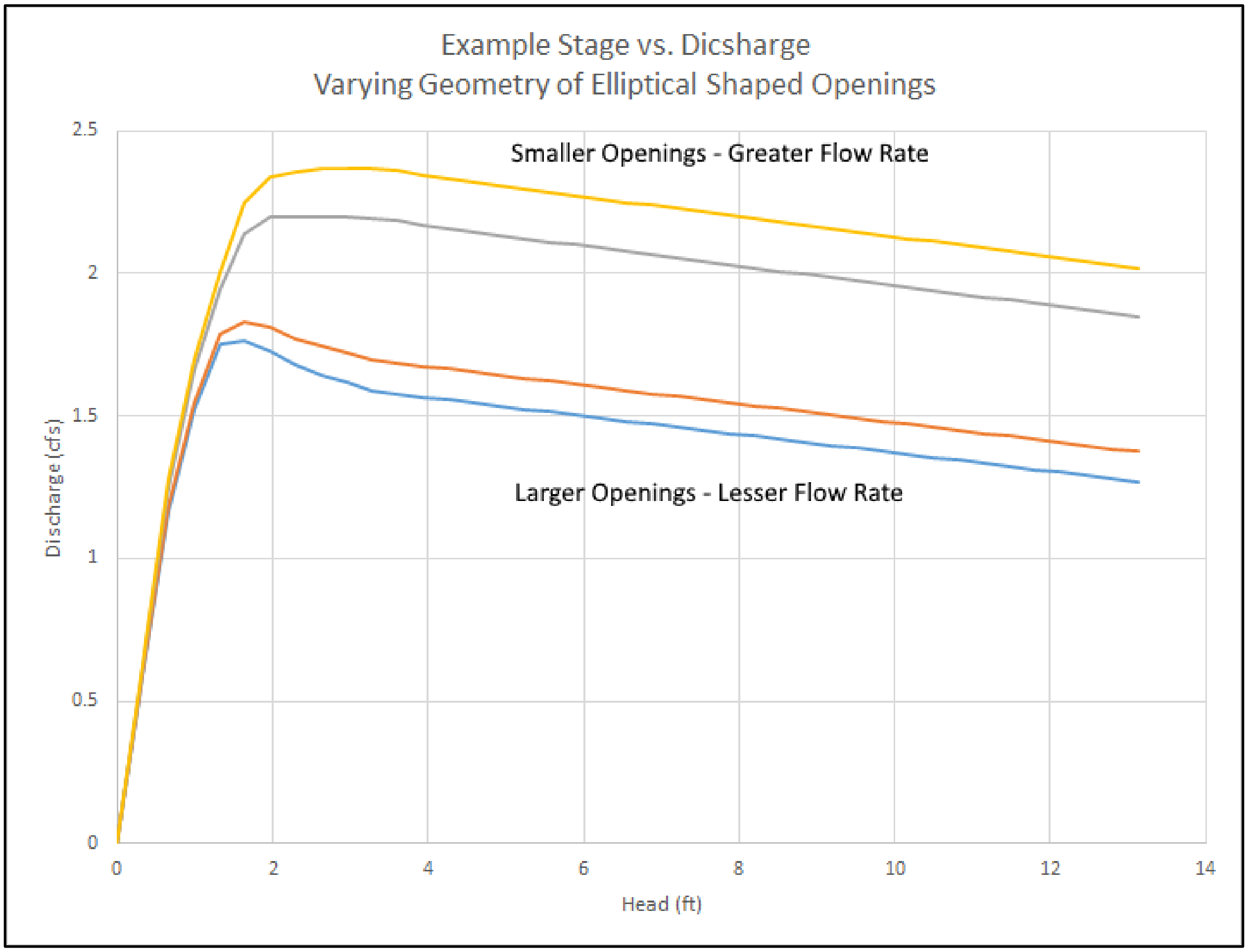


Figure 2

The Washington Department of Ecology Flow Control Standard

The Washington Department of Ecology has established a flow control performance standard applicable to the design of all stormwater detention systems constructed in the state. For the western portion of the state, the current standard generally requires post development discharge rate durations match pre-development discharge rate durations from a percentage of the 2-year flow rate to the 50-year peak flow rate. The percentage of the 2-year flow rate may be 8% or 50% depending on whether or not the LID performance standards apply. For the eastern portion of the state, the standards generally require post-development discharge rates match pre-development flow rates for the 25-year design storm event and either 50% or 100% of the pre-development peak flow rate for the 2-year design storm event depending upon the classification of the receiving body.

Flow Control Riser

Limiting the post development discharge to the applicable design criteria is generally accomplished with a flow control riser. The flow control riser has at least one orifice, slot or weir situated at such an elevation that the detention storage can be completely recovered during dry weather periods while appropriately limiting the discharge to required rate(s) and or duration(s).

It is most common to have a plurality of flow control devices such as weirs, orifices, slots, etc. located at varying elevations along the length of the riser to more efficiently use the available detention storage volume. The flow control riser is typically located in a manhole located downstream of the detention storage; however, it is not uncommon for the riser to be located in the interior of a stormwater vault or tank system. When a system is designed to use a TTT as one of the flow control mechanisms on the riser, it is generally situated such that it is the flow control mechanism located at the lowest elevation.

Stage, Storage, Discharge (SSD) Tabulation

Regardless of the design criteria applicable to a project and the modeling software used to conduct the analysis, it is generally necessary for the engineer to tabulate the relationship between elevation, volume and discharge for entry into the software package. Most modern software packages such as WWHM, MGS Flood, HydroCad, StormShed, etc. are capable of automatically generating this relationship when common storage configurations and flow control mechanisms such as weirs, orifices, slots, etc. are used. For designs where other flow control mechanisms such as vortex valves, buoyant flow control devices (Thirsty Duck), bending weirs, membrane regulators and the like are used, most software packages allow the user to manually input or import the SSD relationship.

Initial TTT Sizing

In the ideal circumstance, the TTT should be sized and configured to produce the allowable discharge rate; however, since the WWHM and MGS Flood classify flows at the allowable rate as an exceedance, the TTT should be sized and configured to produce a maximum flow rate which is slightly less than the allowable flow rate. A good rule of thumb is that the initial sizing should be done at 90% of the allowable threshold flow rate whether that be 8%, 50% or 100% Q2.

Example Design-Western Washington Flow Control Standard

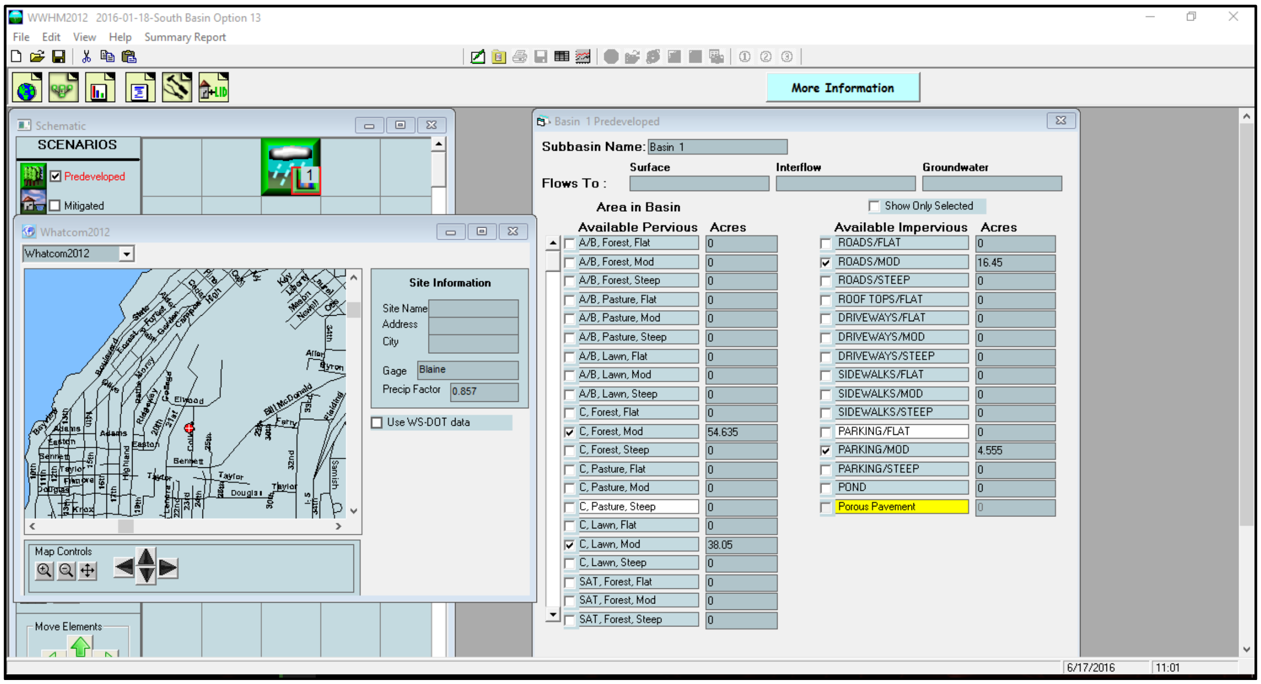
For this example, the WWHM is used to complete the analysis.

Step 1: Input Project Design Data:

Project Location:	Whatcom County
Rain Gage:	Blaine
Precipitation Factor:	0.857

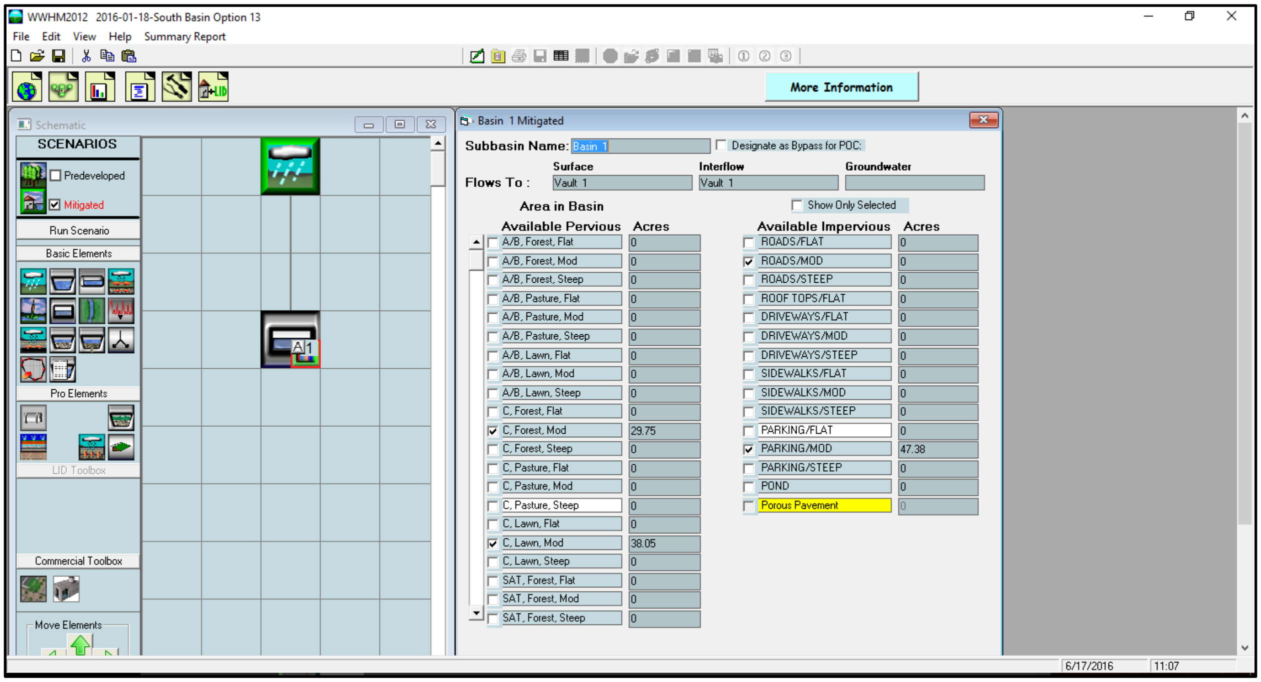
<u>Pre-development conditions:</u>

54.635 acres, C soils, Forested condition, Moderate slopes
38.05 acres, C soils, Lawn condition, Moderate slopes
16.45 acres, Roads, Moderates slopes
4.555 acres, Parking, Moderate slopes



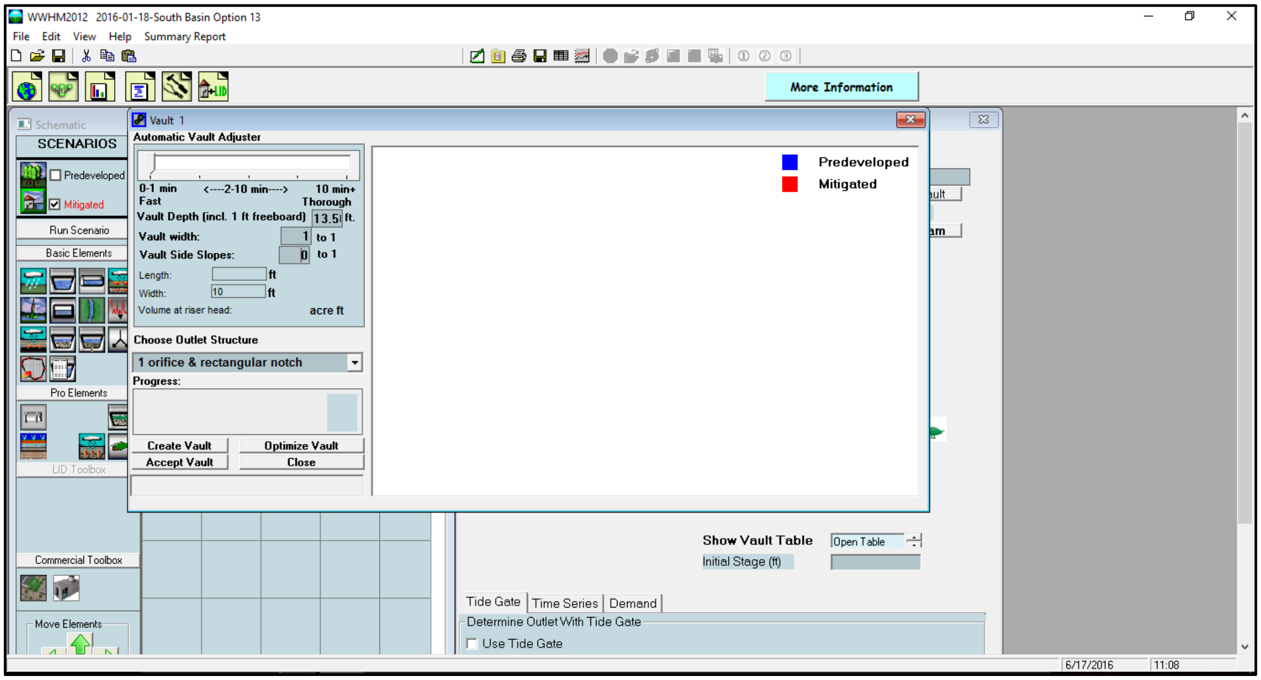
<u>Post-development conditions:</u>

29.75 acres, C soils, Forested condition, Moderate slopes
38.05 acres, C soils, Lawn conditions, Moderate slopes
47.38 acres, Parking, Moderate slopes



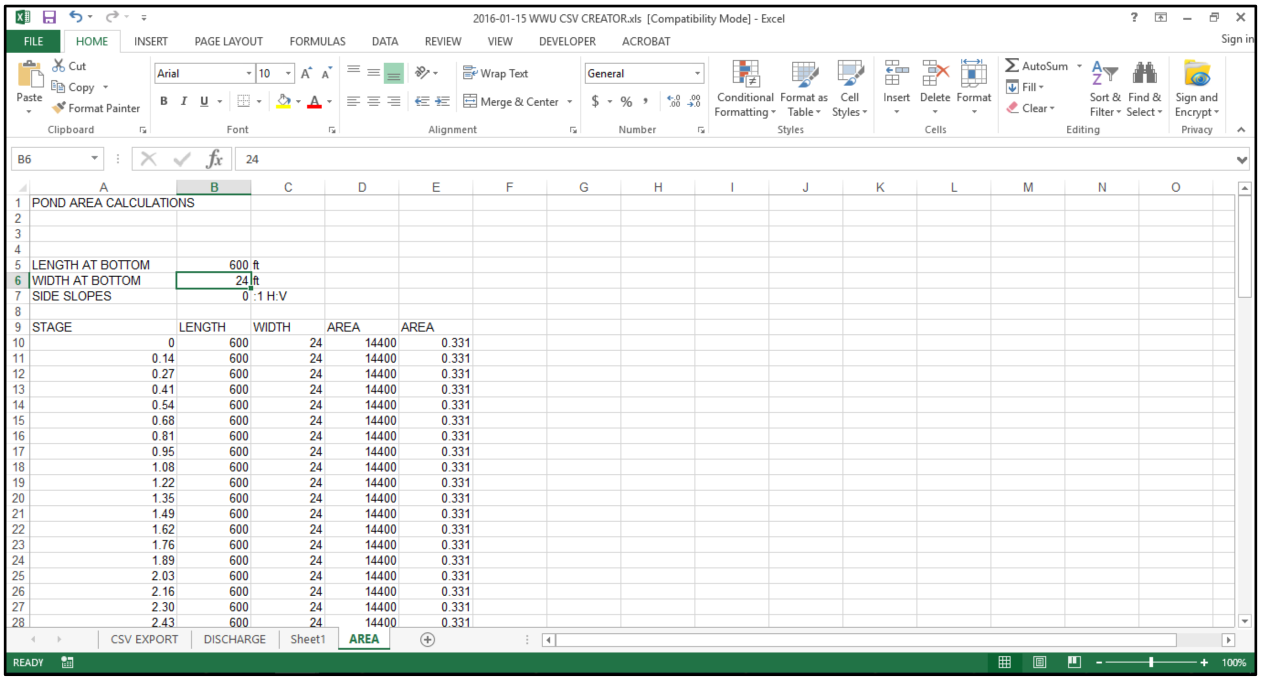
Step 2: Trial Vault Design

It is useful to use the "Auto-Vault" feature to generate an initial vault and riser design, or an initial vault design can be generated by trial and error.
Proposed Detention Vault Depth: 13.5 feet



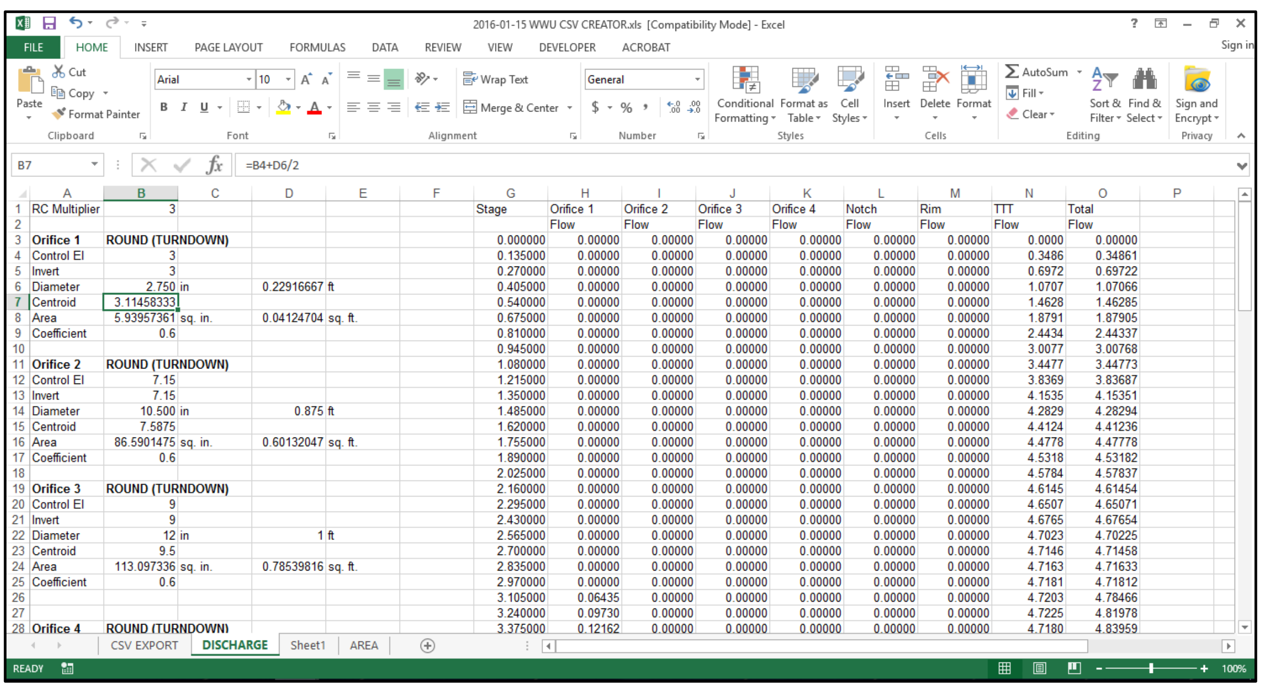
Step 3: SSD Tabulation

Prepare a tabulation of the SSD relationship generated using the vault generated in Step 2 and replace that portion of the relationship representing the lowest orifice on the flow control riser with the TTT stage discharge relationship provided by the manufacturer.



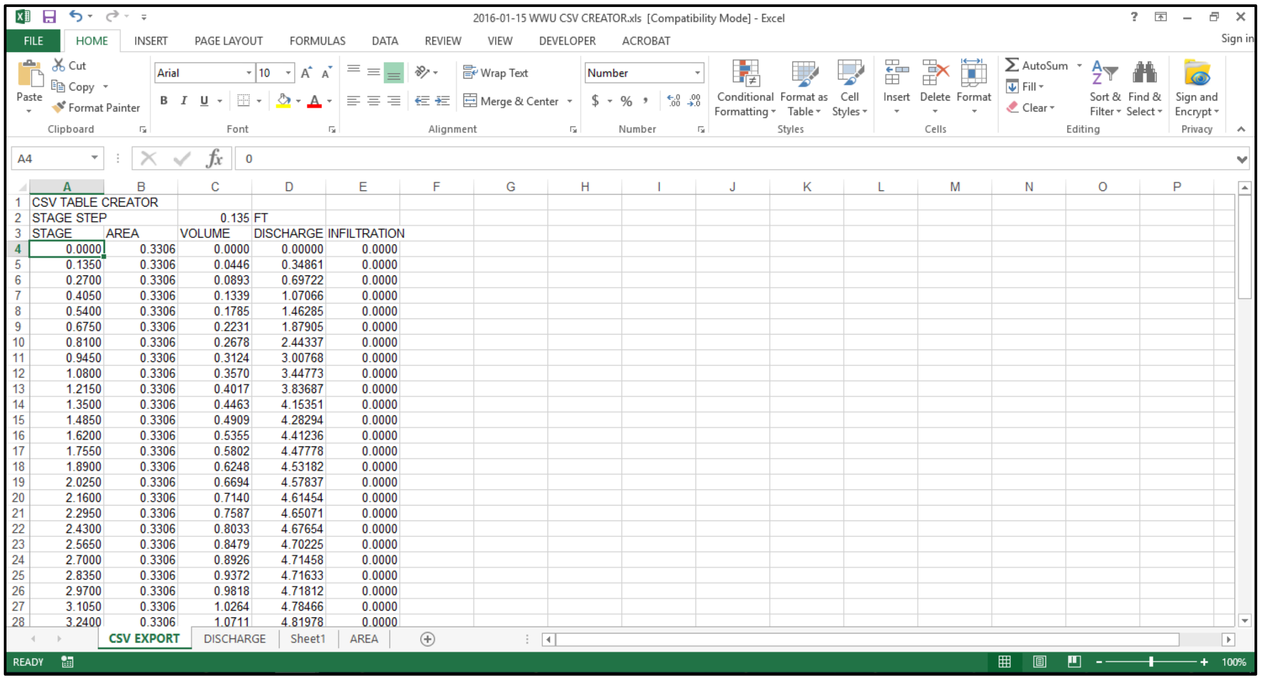
	A	B	C	D	E
1	POND AREA CALCULATIONS				
2					
3					
4					
5	LENGTH AT BOTTOM	600	ft		
6	WIDTH AT BOTTOM	24	ft		
7	SIDE SLOPES	0	:1 H:V		
8					
9	STAGE	LENGTH	WIDTH	AREA	AREA
10	0	600	24	14400	0.331
11	0.14	600	24	14400	0.331
12	0.27	600	24	14400	0.331
13	0.41	600	24	14400	0.331
14	0.54	600	24	14400	0.331
15	0.68	600	24	14400	0.331
16	0.81	600	24	14400	0.331
17	0.95	600	24	14400	0.331
18	1.08	600	24	14400	0.331
19	1.22	600	24	14400	0.331
20	1.35	600	24	14400	0.331
21	1.49	600	24	14400	0.331
22	1.62	600	24	14400	0.331
23	1.76	600	24	14400	0.331
24	1.89	600	24	14400	0.331
25	2.03	600	24	14400	0.331
26	2.16	600	24	14400	0.331
27	2.30	600	24	14400	0.331
28	2.43	600	24	14400	0.331

Stage/Area Relationship



	A	B	C	D	E	G	H	I	J	K	L	M	N	O
1	RC Multiplier	3				Stage	Orifice 1	Orifice 2	Orifice 3	Orifice 4	Notch	Rim	TTT	Total
2							Flow	Flow	Flow	Flow	Flow	Flow	Flow	Flow
3	**Orifice 1**	ROUND (TURNDOWN)				0.000000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.0000	0.00000
4	Control El	3				0.135000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.3486	0.34861
5	Invert	3				0.270000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.6972	0.69722
6	Diameter	2.750	in	0.22916667	ft	0.405000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.0707	1.07066
7	Centroid	3.11458333				0.540000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.4628	1.46285
8	Area	5.93957361	sq. in.	0.04124704	sq. ft.	0.675000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.8791	1.87905
9	Coefficient	0.6				0.810000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	2.4434	2.44337
10						0.945000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	3.0077	3.00768
11	**Orifice 2**	ROUND (TURNDOWN)				1.080000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	3.4477	3.44773
12	Control El	7.15				1.215000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	3.8369	3.83687
13	Invert	7.15				1.350000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	4.1535	4.15351
14	Diameter	10.500	in	0.875	ft	1.485000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	4.2829	4.28294
15	Centroid	7.5875				1.620000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	4.4124	4.41236
16	Area	86.5901475	sq. in.	0.60132047	sq. ft.	1.755000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	4.4778	4.47778
17	Coefficient	0.6				1.890000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	4.5318	4.53182
18						2.025000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	4.5784	4.57837
19	**Orifice 3**	ROUND (TURNDOWN)				2.160000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	4.6145	4.61454
20	Control El	9				2.295000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	4.6507	4.65071
21	Invert	9				2.430000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	4.6765	4.67654
22	Diameter	12	in	1	ft	2.565000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	4.7023	4.70225
23	Centroid	9.5				2.700000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	4.7146	4.71458
24	Area	113.097336	sq. in.	0.78539816	sq. ft.	2.835000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	4.7163	4.71633
25	Coefficient	0.6				2.970000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	4.7181	4.71812
26						3.105000	0.06435	0.00000	0.00000	0.00000	0.00000	0.00000	4.7203	4.78466
27						3.240000	0.09730	0.00000	0.00000	0.00000	0.00000	0.00000	4.7225	4.81978
28	**Orifice 4**	ROUND (TURNDOWN)				3.375000	0.12162	0.00000	0.00000	0.00000	0.00000	0.00000	4.7180	4.83959

Stage/Discharge Relationship

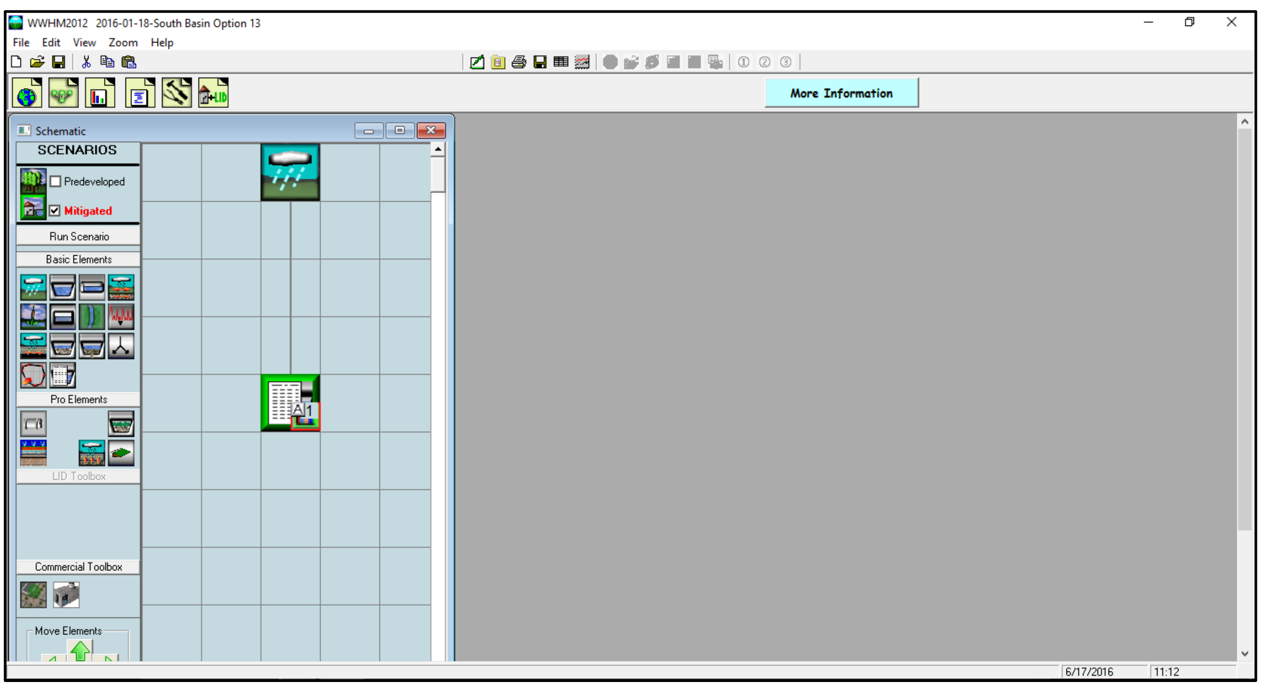


	A	B	C	D	E
1	CSV TABLE CREATOR				
2	STAGE STEP		0.135	FT	
3	STAGE	AREA	VOLUME	DISCHARGE	INFILTRATION
4	0.0000	0.3306	0.0000	0.00000	0.0000
5	0.1350	0.3306	0.0446	0.34861	0.0000
6	0.2700	0.3306	0.0893	0.69722	0.0000
7	0.4050	0.3306	0.1339	1.07066	0.0000
8	0.5400	0.3306	0.1785	1.46285	0.0000
9	0.6750	0.3306	0.2231	1.87905	0.0000
10	0.8100	0.3306	0.2678	2.44337	0.0000
11	0.9450	0.3306	0.3124	3.00768	0.0000
12	1.0800	0.3306	0.3570	3.44773	0.0000
13	1.2150	0.3306	0.4017	3.83687	0.0000
14	1.3500	0.3306	0.4463	4.15351	0.0000
15	1.4850	0.3306	0.4909	4.28294	0.0000
16	1.6200	0.3306	0.5355	4.41236	0.0000
17	1.7550	0.3306	0.5802	4.47778	0.0000
18	1.8900	0.3306	0.6248	4.53182	0.0000
19	2.0250	0.3306	0.6694	4.57837	0.0000
20	2.1600	0.3306	0.7140	4.61454	0.0000
21	2.2950	0.3306	0.7587	4.65071	0.0000
22	2.4300	0.3306	0.8033	4.67654	0.0000
23	2.5650	0.3306	0.8479	4.70225	0.0000
24	2.7000	0.3306	0.8926	4.71458	0.0000
25	2.8350	0.3306	0.9372	4.71633	0.0000
26	2.9700	0.3306	0.9818	4.71812	0.0000
27	3.1050	0.3306	1.0264	4.78466	0.0000
28	3.2400	0.3306	1.0711	4.81978	0.0000

Complete SSD Tabulation

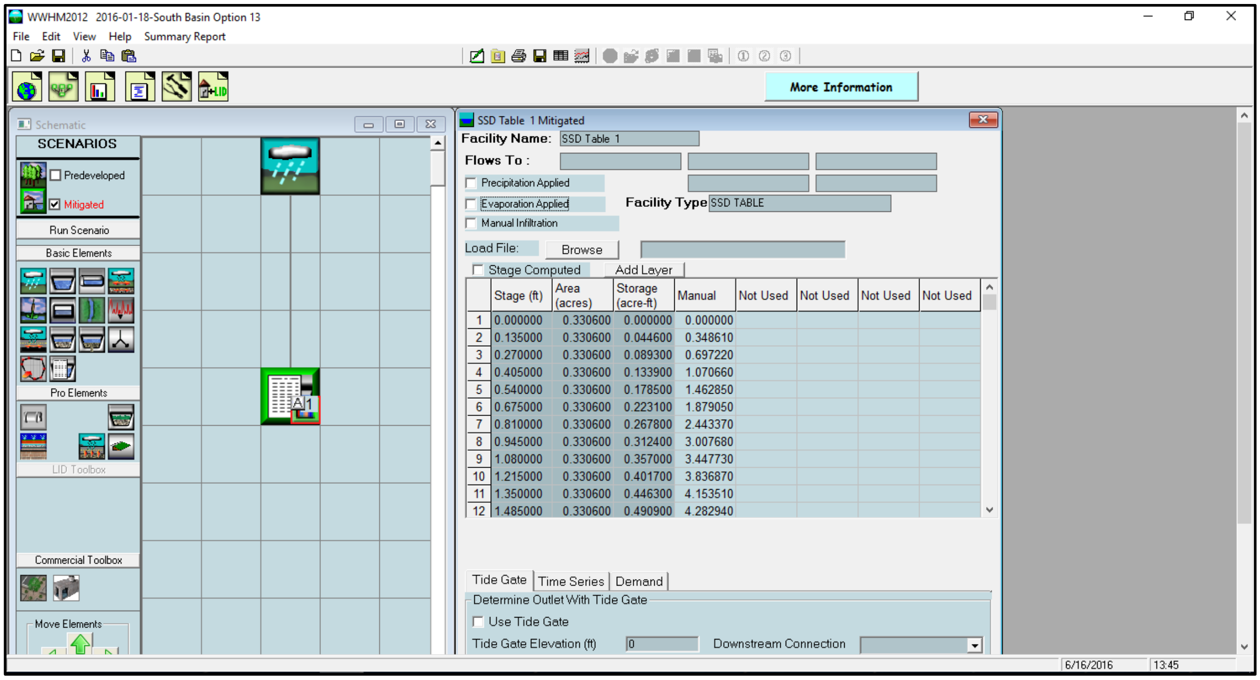
Step 4: Replace the Vault with an SSD Table Element

Delete the vault created in Step 2 and replace it with an “SSD Table” element and replicate the appropriate connectivity.



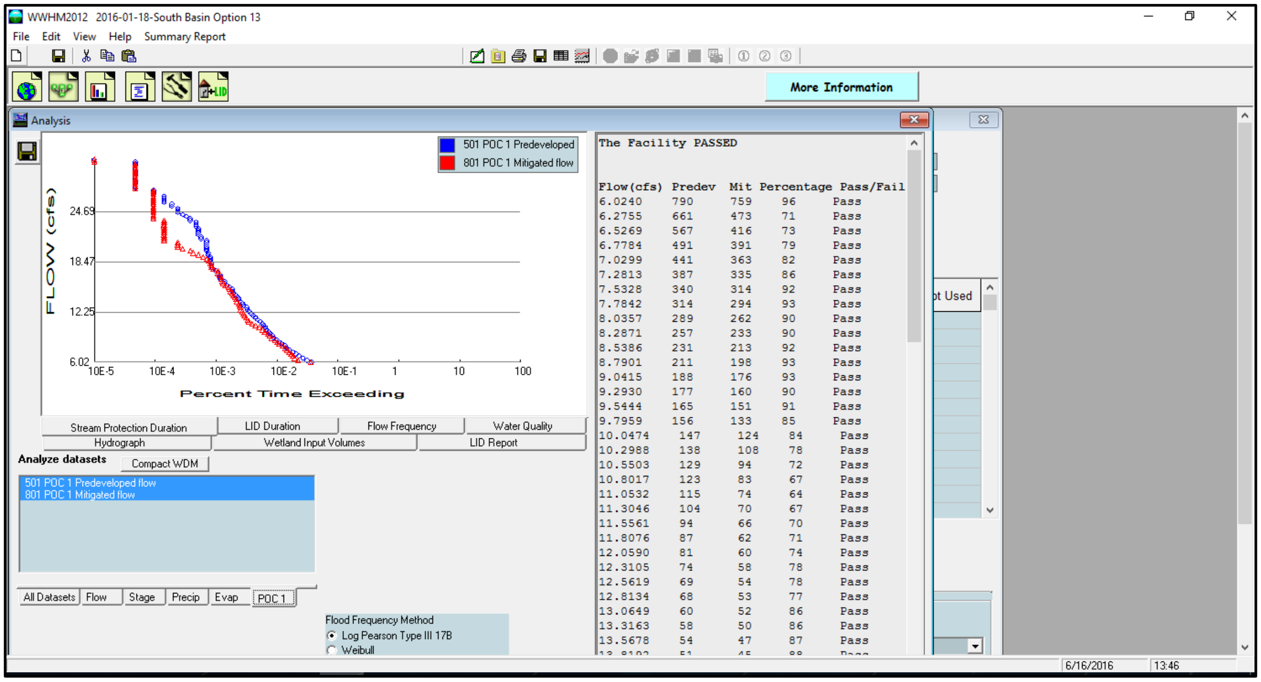
Step 5: Import the SSD Tabulation

Copy the SSD tabulation generated in Step 3 into the “SSD Table” element generated in Step 4. Be sure to unselect “Stage Computed” and use “Manual” for the discharge column of the SSD.



Step 6: Execute the WWHM model

Use the analysis tools provide in WWHM to determine whether the facility "Passes" or "Fails". Revise the SSD tabulation as necessary to achieve any unmet project design goals as well as all required design criteria. (Note: It is not uncommon that multiple design iterations may be required prior to achieving the final project design).



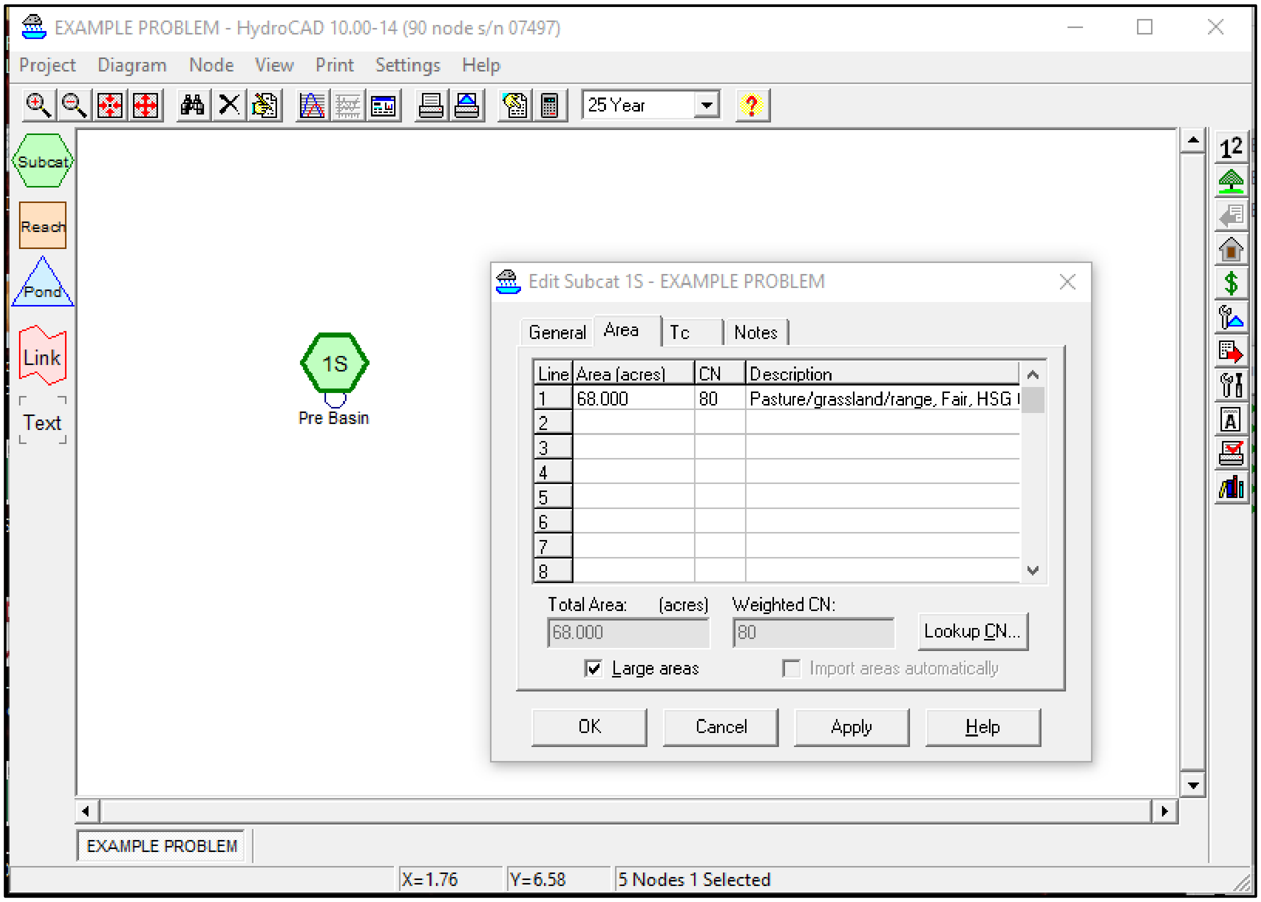
Example Design-Eastern Washington Flow Control Standard

For this example, HydroCad software is used to complete the analysis

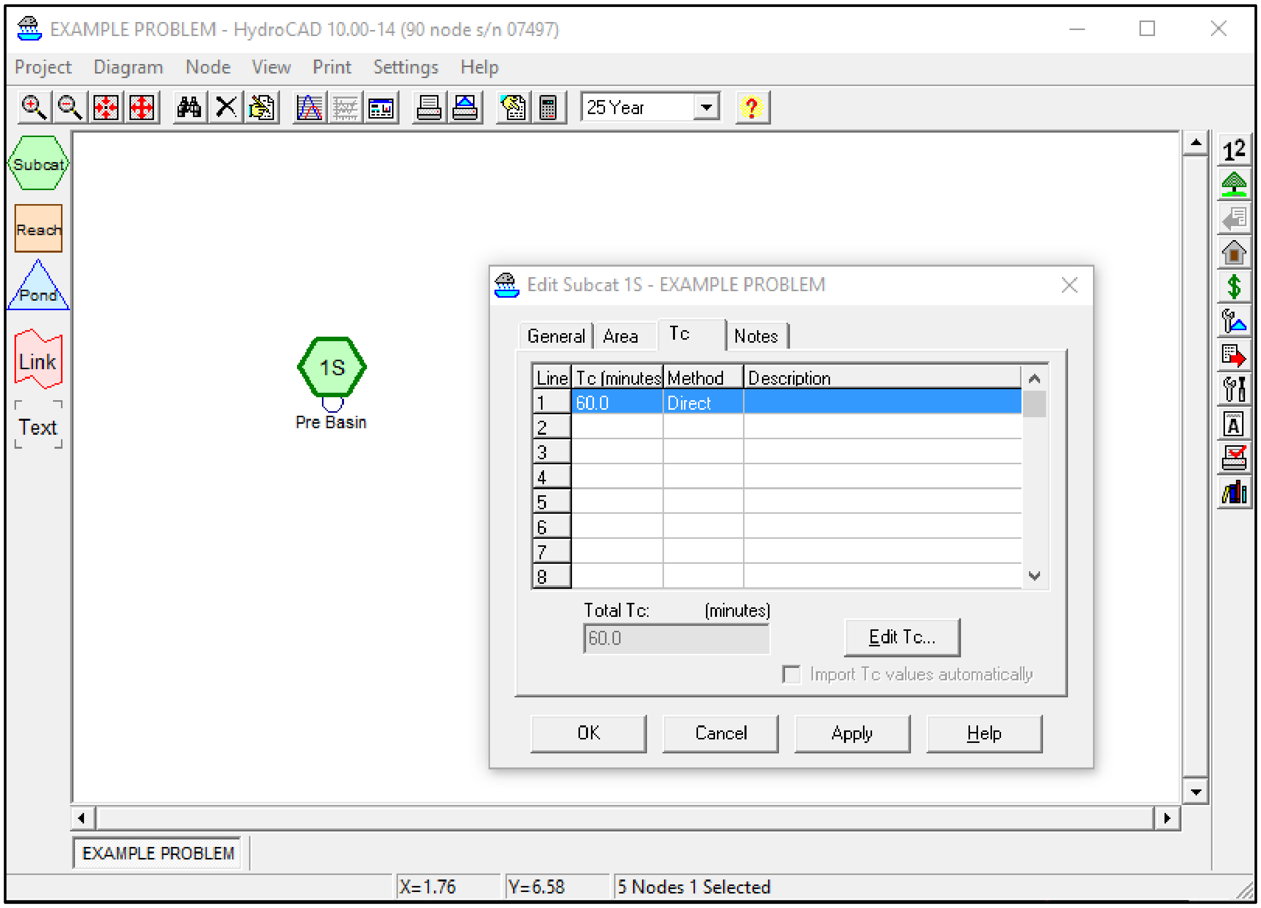
Step 1: Input Pre-Development Conditions

Project Location: Region 2
Mean Annual Rainfall Depth: 14 inches.
Receiving Body: Lake/Wetland

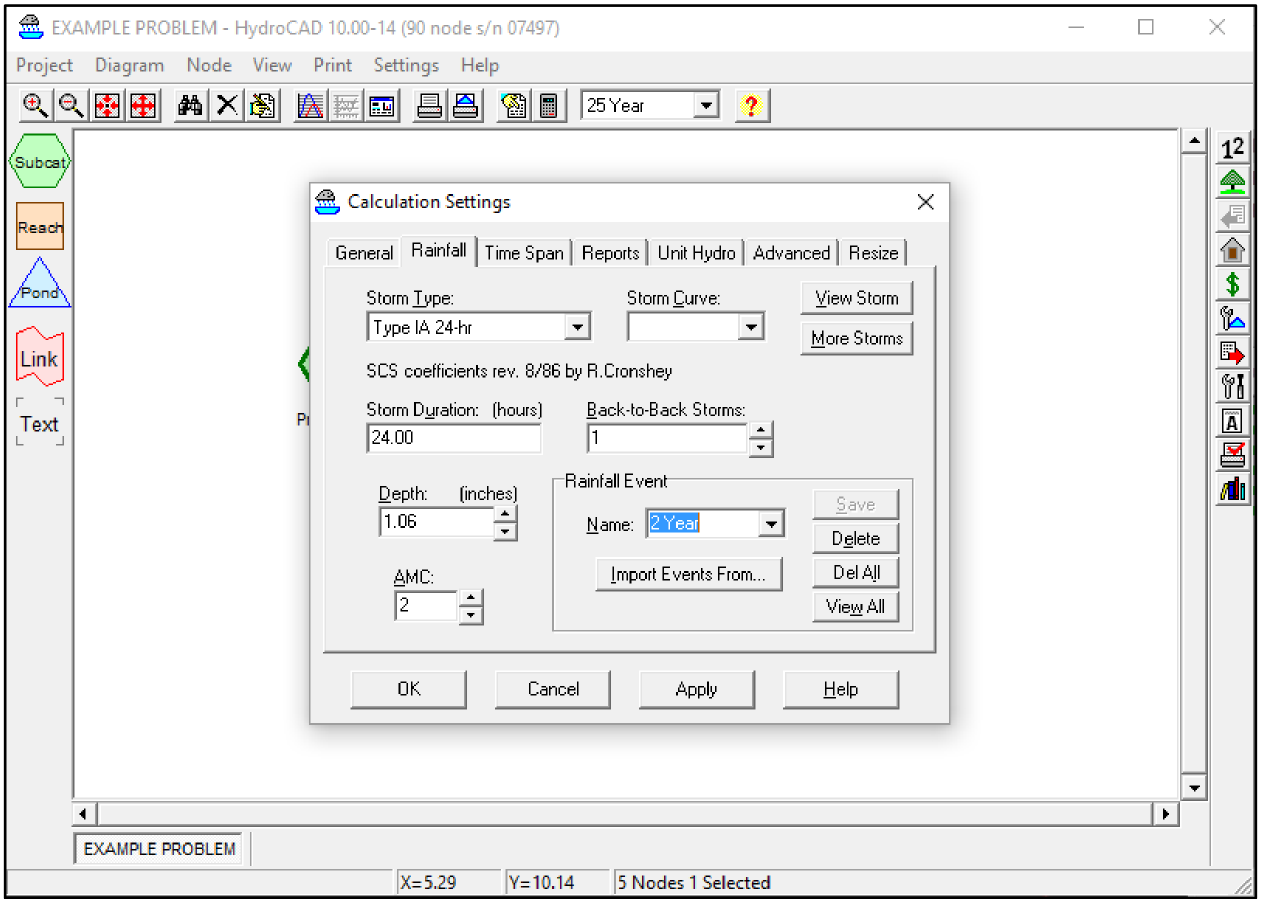
Basin Area: 68 acres
CN: 80



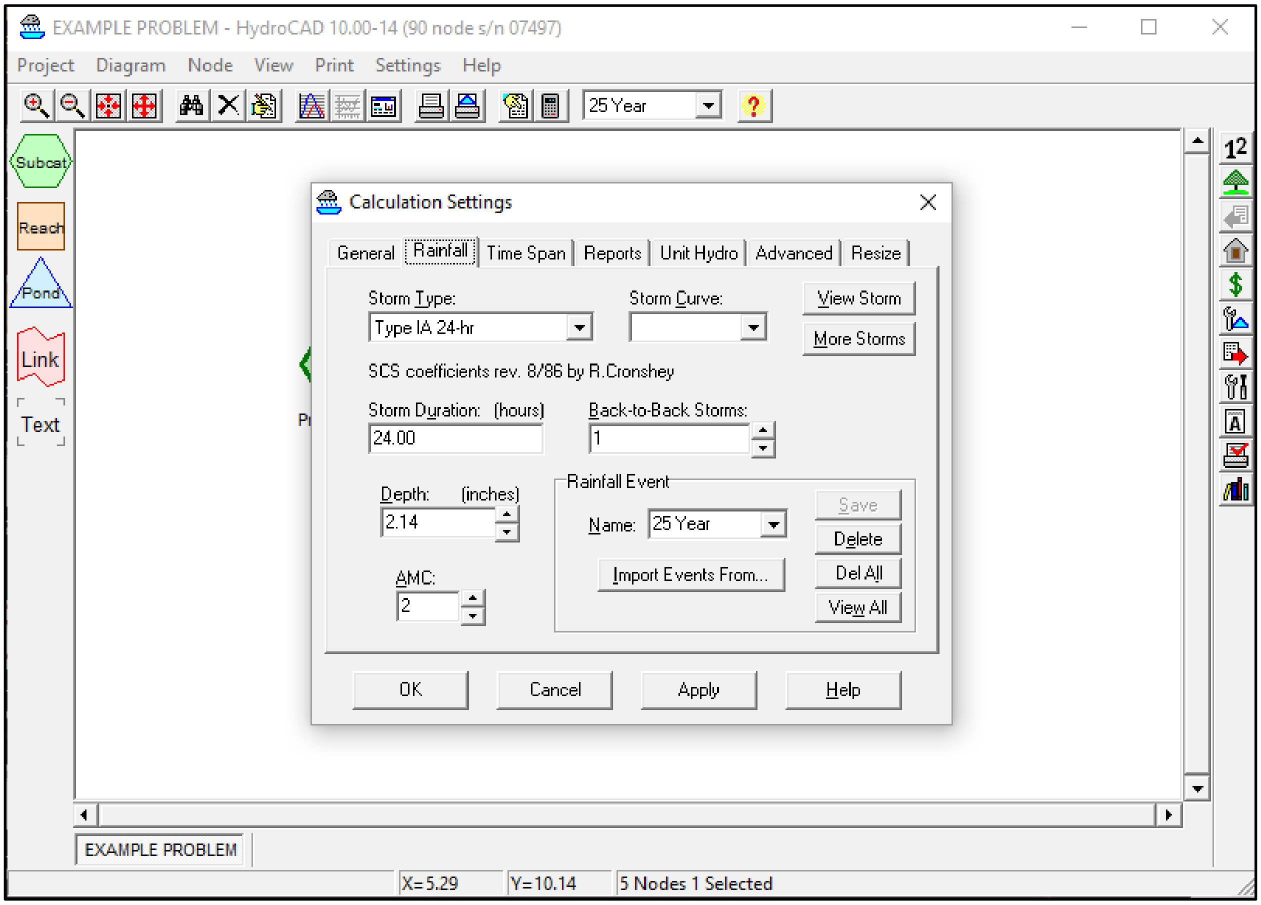
Tc: 60 minutes



Rainfall Distribution: SCS Type IA
Duration: 24 hours
Rainfall Depth (2 year): 1.06 inches

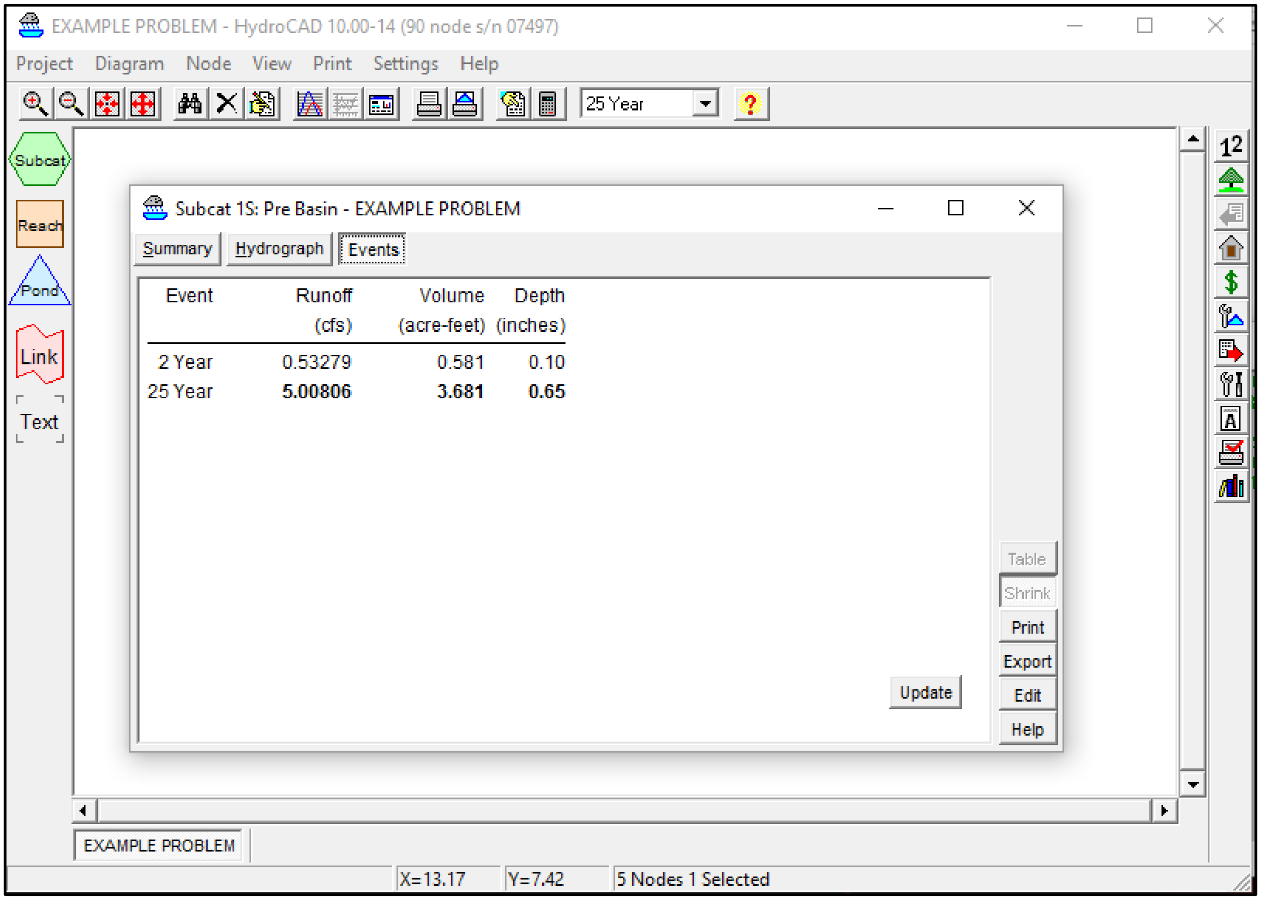


Rainfall Distribution: SCS Type IA
Duration: 24 hours
Rainfall Depth (25 year): 2.14 inches



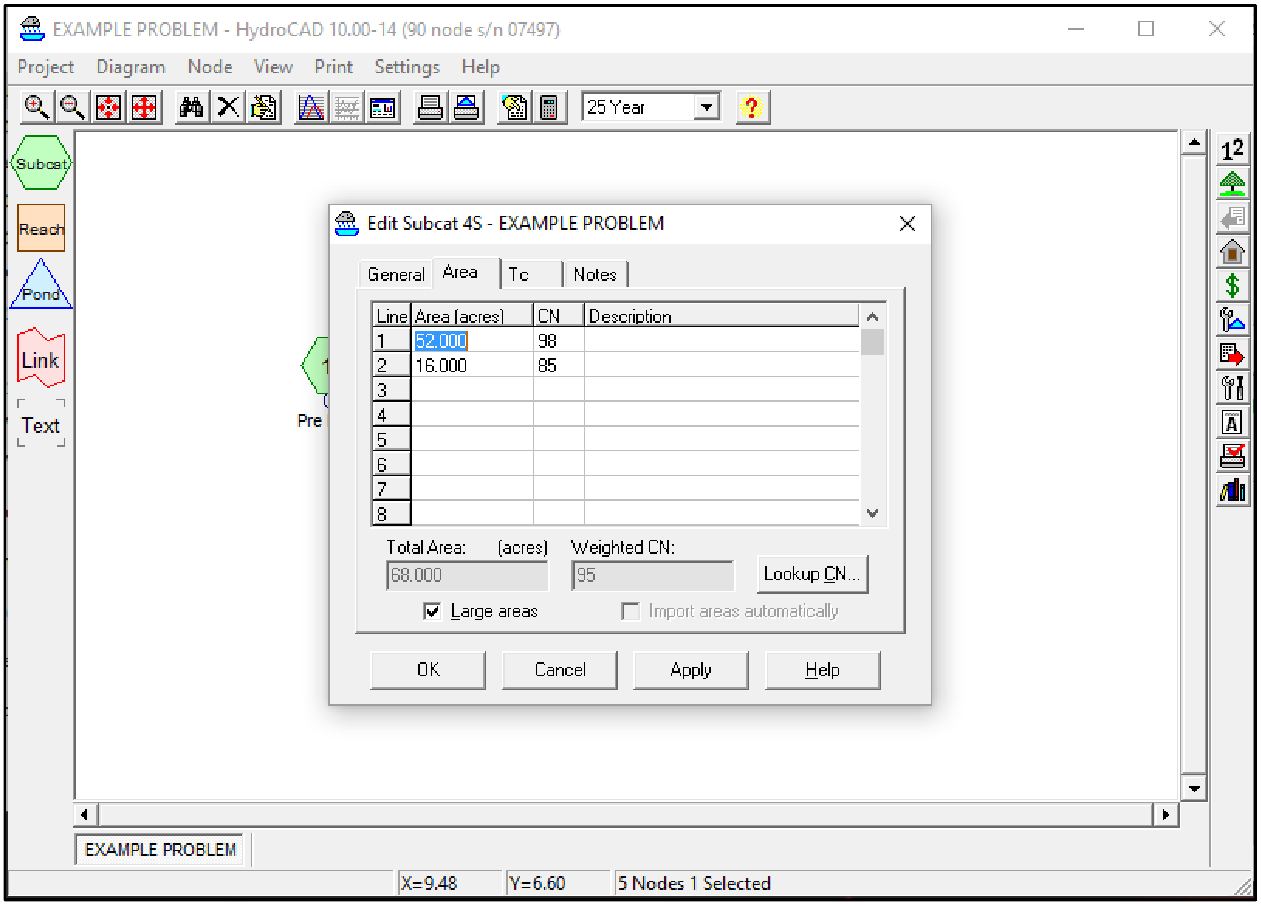
Step 2: Execute HydroCad model to determine pre-development peak flow rates

2 year peak flow rate: 0.53 cfs
25 year peak flow rate: 5.0 cfs

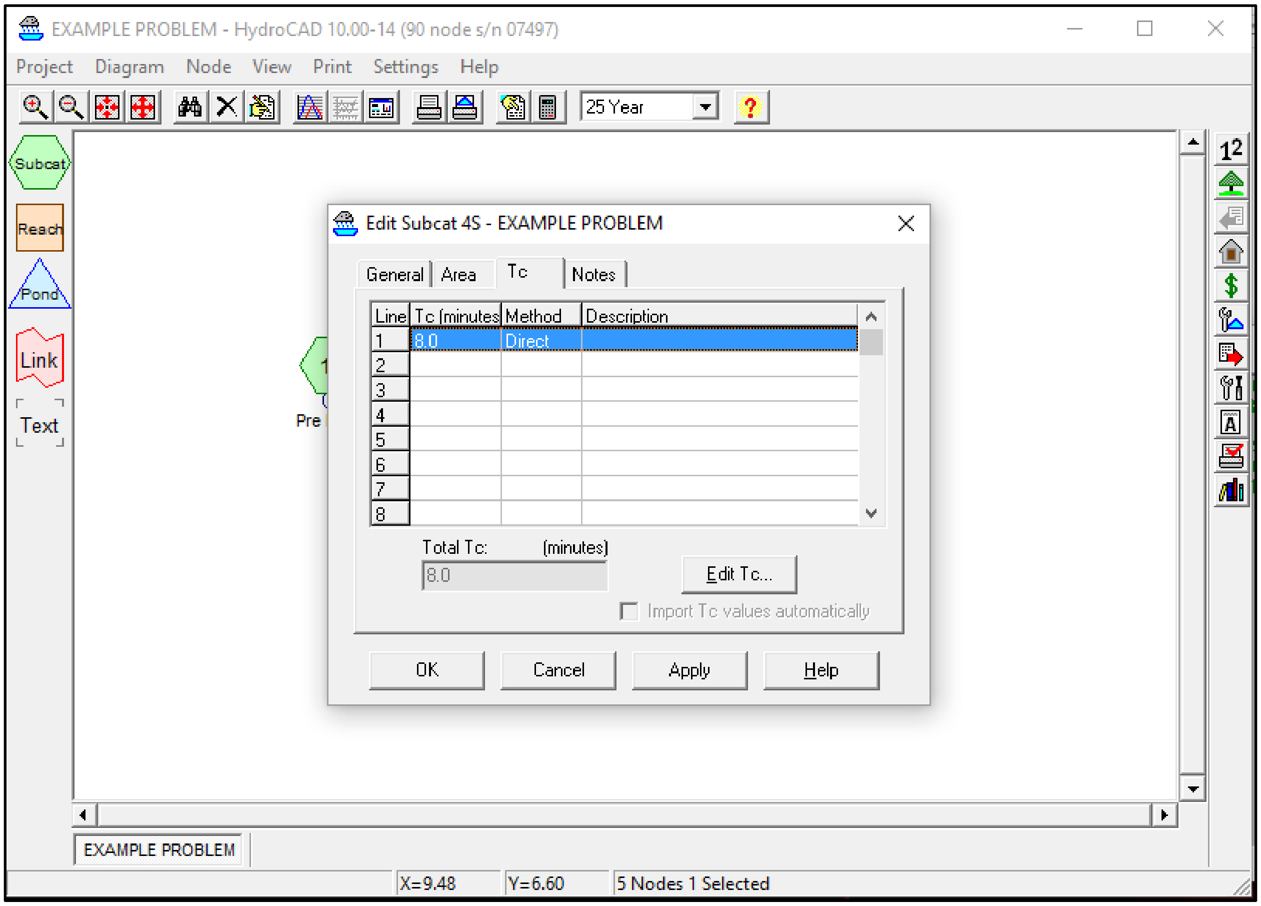


Step 3: Input Post-development conditions

Impervious Area: 52 acres (CN 98)
Pervious Area: 16 acres (CN 85)

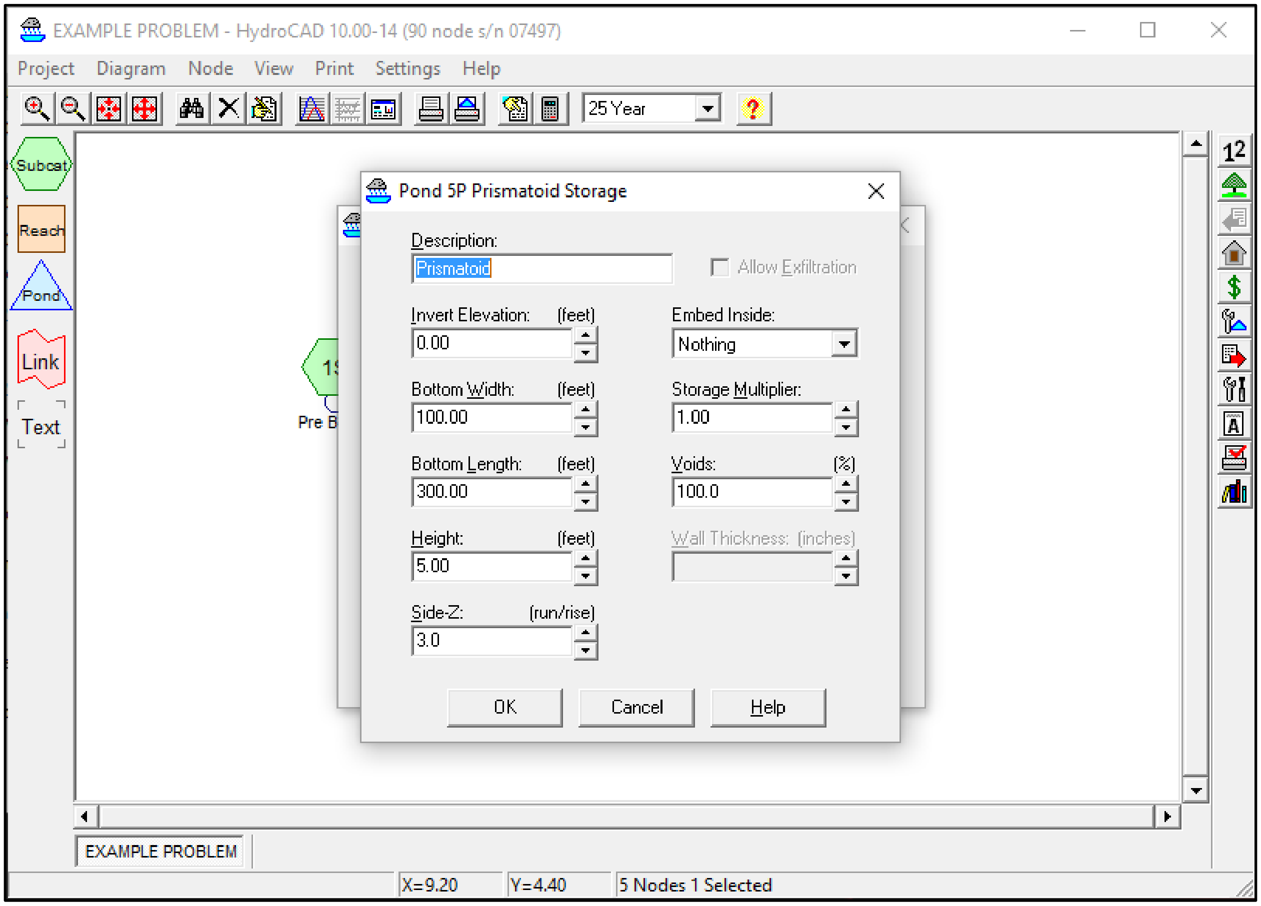


Tc: 8 minutes


EXAMPLE PROBLEM - HydroCAD 10.00-14 (90 node s/n 07497)
Project Diagram Node View Print Settings Help
25 Year
Subcat
Reach
Pond
Link
Text
Edit Subcat 4S - EXAMPLE PROBLEM
General
Area
Tc
Notes
Line
Tc (minutes
Method
Description
1
8.0
Direct
2
3
4
5
6
7
8
Total Tc:
(minutes)
8.0
Edit Tc...
Import Tc values automatically
OK
Cancel
Apply
Help
EXAMPLE PROBLEM
X=9.48
Y=6.60
5 Nodes 1 Selected

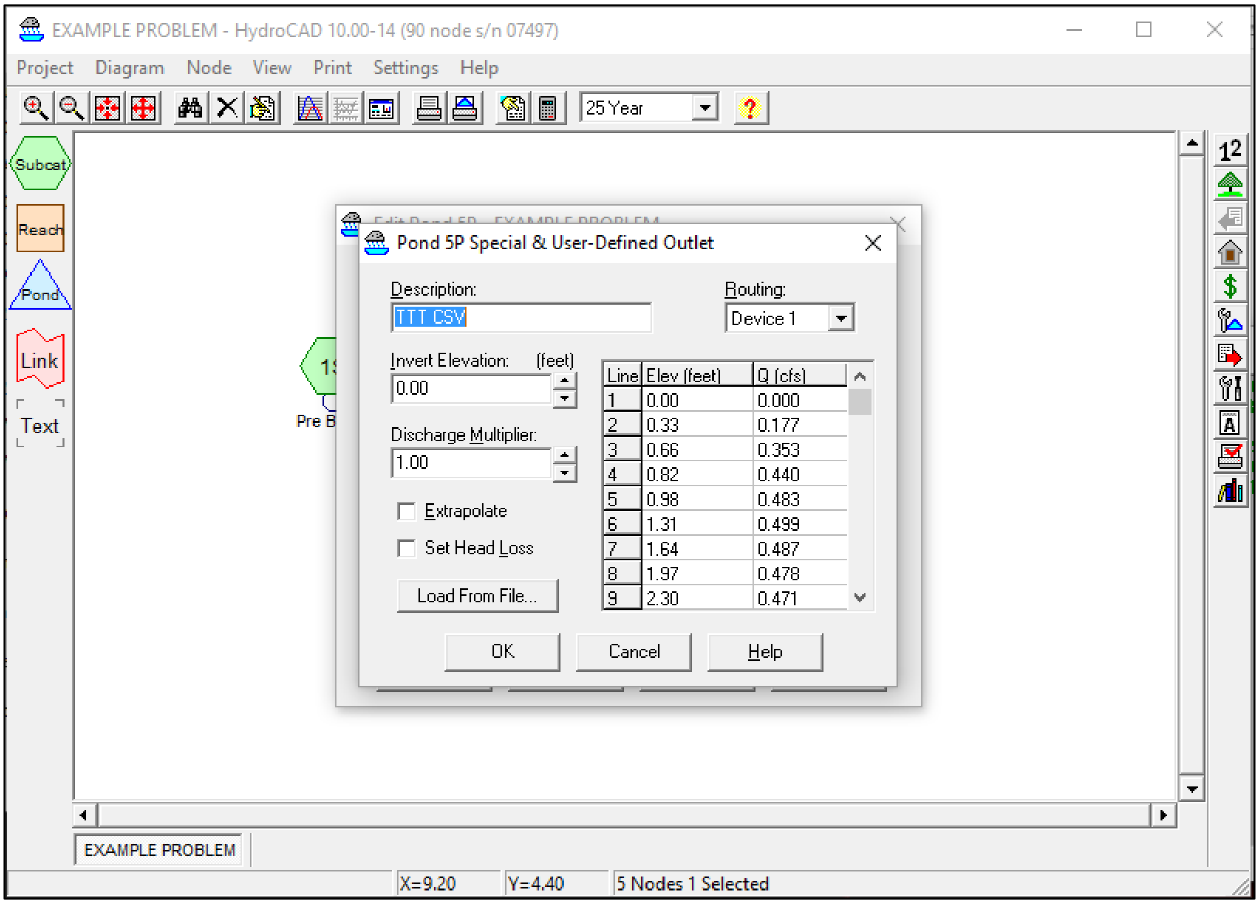
Detention Pond Dimensions

Bottom Width 100 ft
Bottom Length 300 ft
Side Slopes: 3:1
Depth 5 ft



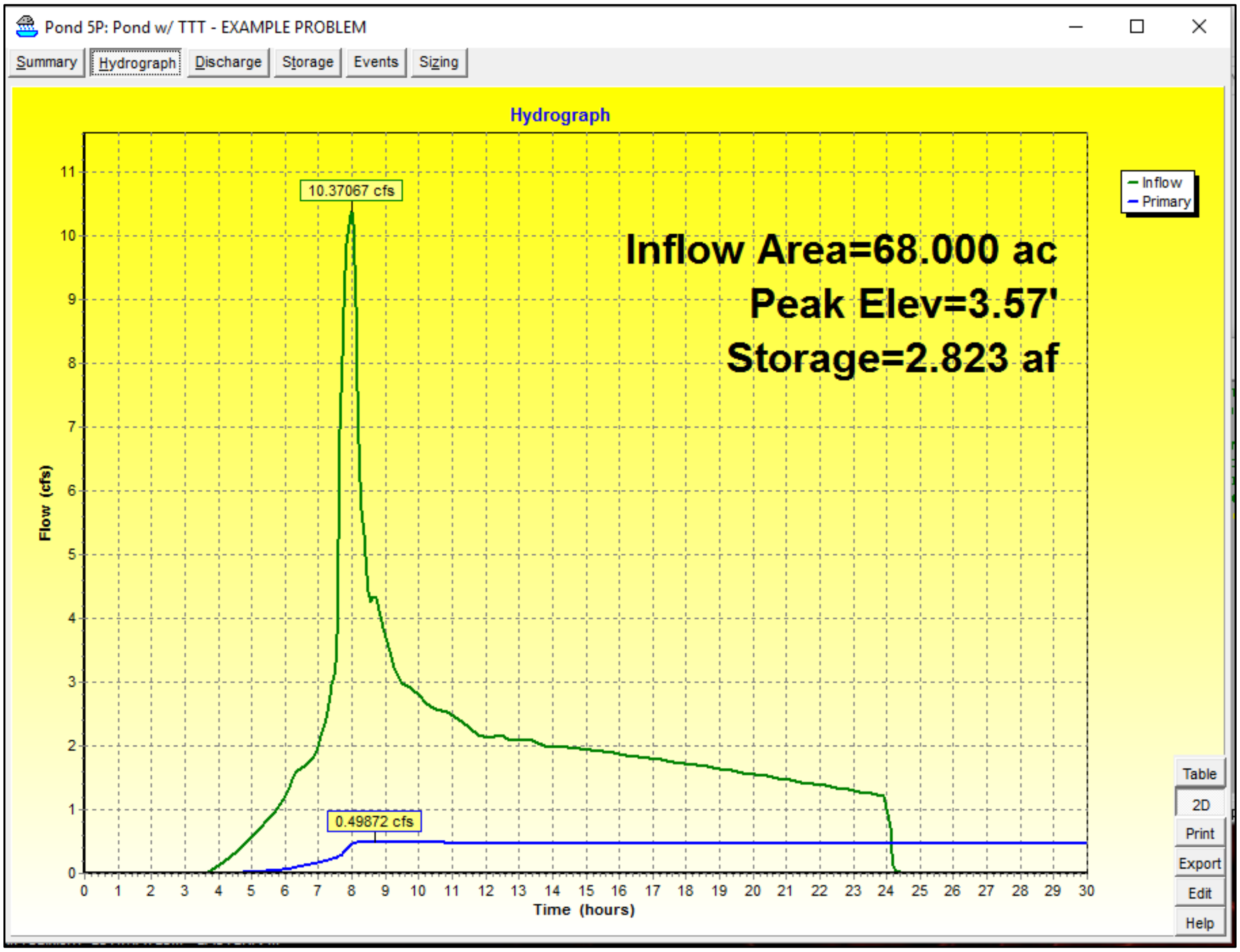
Step 4: Input proposed flow control riser data:

Using the Special & User-Defined Outlet function, import the TTT rating curve provided by the manufacturer. The TTT should be sized such that its peak flow rate is less than or equal to the peak pre-development discharge rate for the most frequent event for which flow control criteria must be met. For this example, the TTT should be sized to deliver no more than 0.53 cfs (100% 2-year peak flow rate).



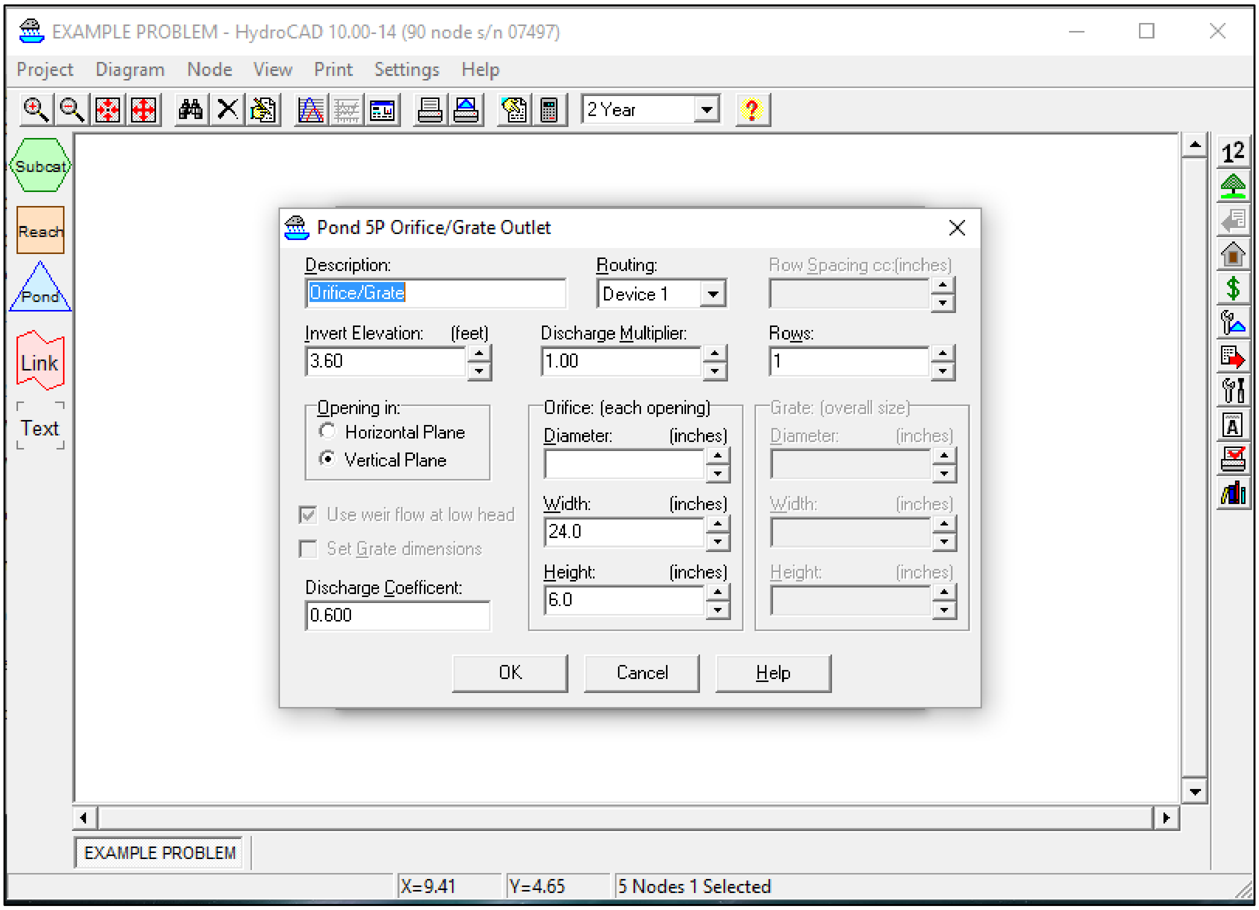
Step 5: Execute the HydroCad model for the 2-year event and determine the peak water surface elevation

For this example, the model reports a peak water surface elevation of 3.57 ft.



Step 6: Design a second flow control device to regulate the 25-year peak flow rate

For this example, we have chosen a 24” wide slot with an invert elevation of 3.60 ft. and a height of 6 in.



Step 7: Execute the HydroCad model for the 25-year event and evaluate the results to ensure compliance with the flow control requirements and peak water surface limits.

For this example, HydroCad reports a peak flow rate of 4.98 cfs and a peak water surface elevation of 4.74 feet for the 25-year event which comply with the flow control standard. (Note: It is not uncommon that multiple design iterations may be required prior to achieving the final project design).