



# Exploring Regenerative Stormwater Conveyances for Tennessee:

Design, Installation, and  
Performance Evaluation Workshop



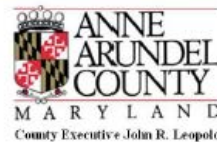
THE UNIVERSITY OF  
**TENNESSEE**  
KNOXVILLE

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# Regenerative Step Pool Storm Conveyance (SPSC) – also known as Coastal Plain Outfalls

<http://www.aacounty.org/departments/public-works/wprp/watershed-assessment-and-planning/step-pool-conveyance-systems/>

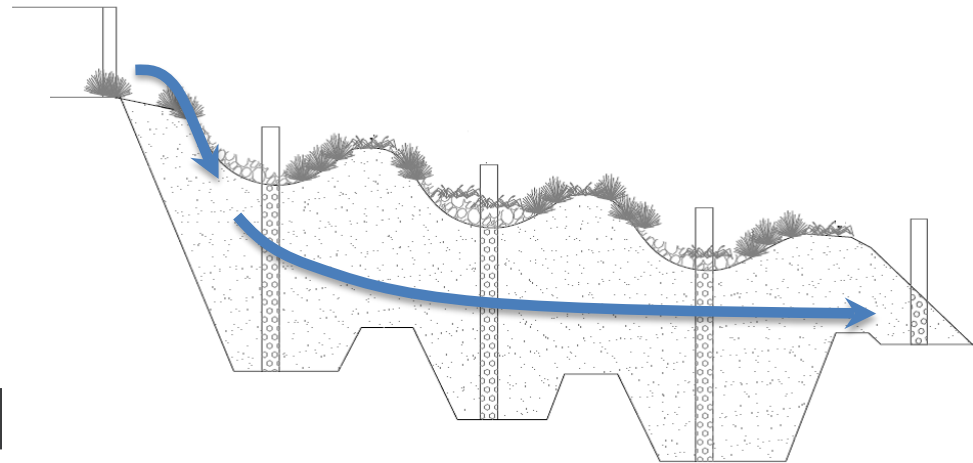
Design Guidelines



Original : June 2009  
Revision 1: August 2010  
Revision 2: November 2010  
Revision 3: July 2011  
Revision 4: November 2011  
Revision 5: December 2012

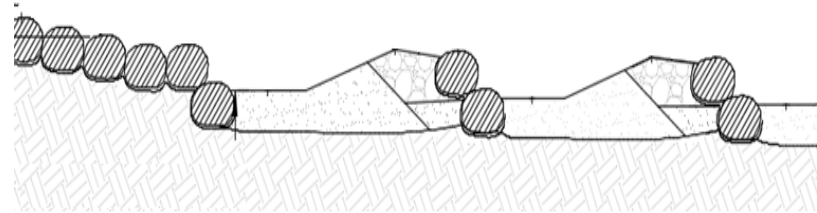
# RSC Design - Hydraulics

- Transmit 100 year event
- Provide as much subsurface flow as possible
- Slow water to avoid erosive flow



# Design Process

1. Develop hydrologic design parameters
  - Peak discharge calculations
2. Establish and quantify restoration goals
  - Safe conveyance of flows
  - Volume reduction
  - Water Quality Improvement



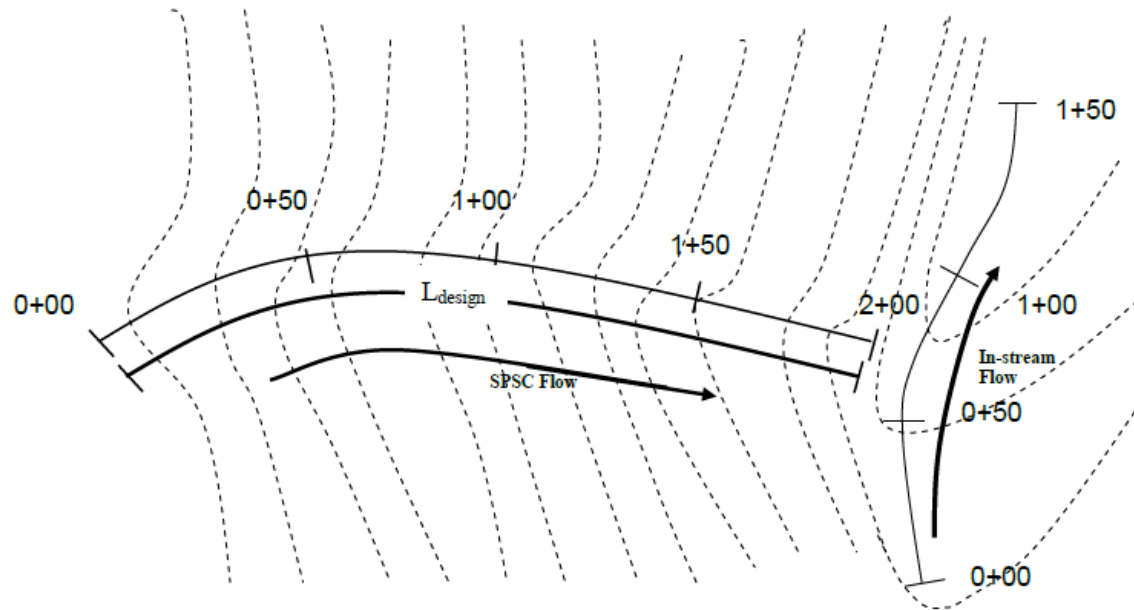
# South Doyle - Rational Method

South Doyle												
	sq ft	Acres	sq miles									
Area, Watershed	215,652	4.95	0.007735	Type II rainfall Distribution								
Impervious Area	159,225	3.66	0.005711	added 13,000 sf for sidewalks (est w/ GIS)								
Percent Impervious	74%			Impervious includes buildings, paved structure, roads								
Rational Method												
Q=(Cf)ciA	Runoff coefficient											
	Commercial HSG B, 2-6% slopes		c	0.89								
	tc		0.07 hrs 4.2 minutes									
			1	2	5	10	25	50	100	200	500	1000
Cf	frequency factor		1	1	1	1	1.1	1.2	1.25	1.25	1.25	1.25
C	runoff coeff		0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89
I, for tc = 5 min, in/hr	avg rainfall intensity for duration equal to tc		3.79	4.45	5.24	5.99	6.95	7.73	8.54	8.54	10.5	11.4
A, acres	drainage area contributing to the design		4.95	4.95	4.95	4.95	4.95	4.95	4.95	4.95	4.95	4.95
Q, cfs	max rate of runoff		16.70	19.61	23.09	26.39	33.68	40.87	47.04	47.04	57.83	62.79

# Design Process

## 3. Map the horizontal alignment

- Follow the grade
- Minimize impacts to natural features
- Look for floodplain connectivity



# Design Process

## 4. Map Vertical Alignment

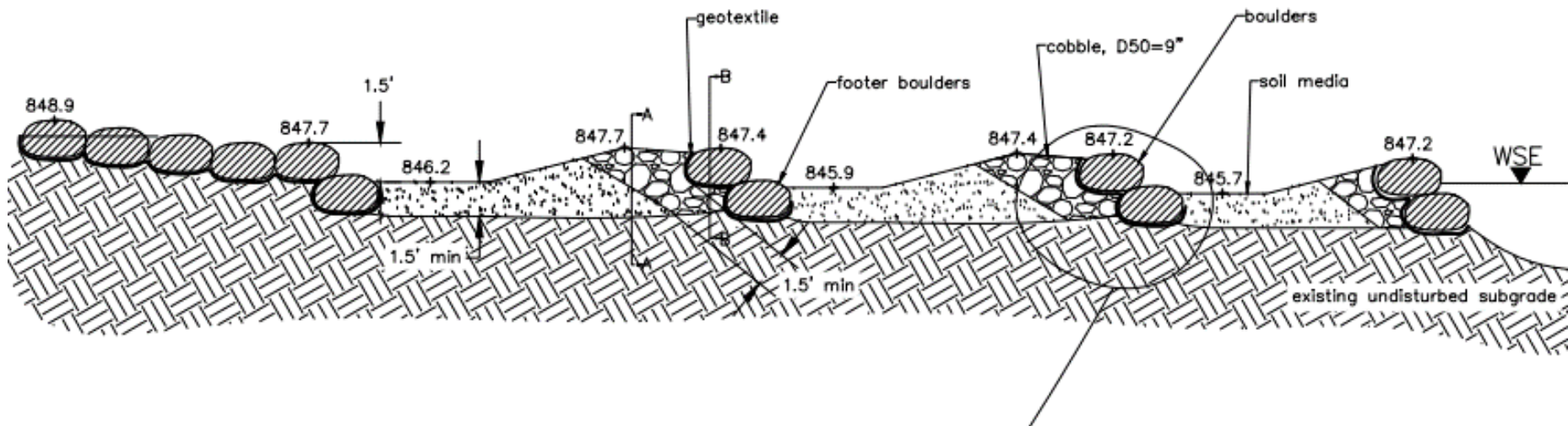
- Find system slope (try to keep  $< 5\%$ )
- Alternate pools and riffles
- Pools are flat!
- Riffles drop 1 foot or less
- Pool length = 2x riffle length
- 3:1 sideslope on pool
- 18 inch pool depth minimum

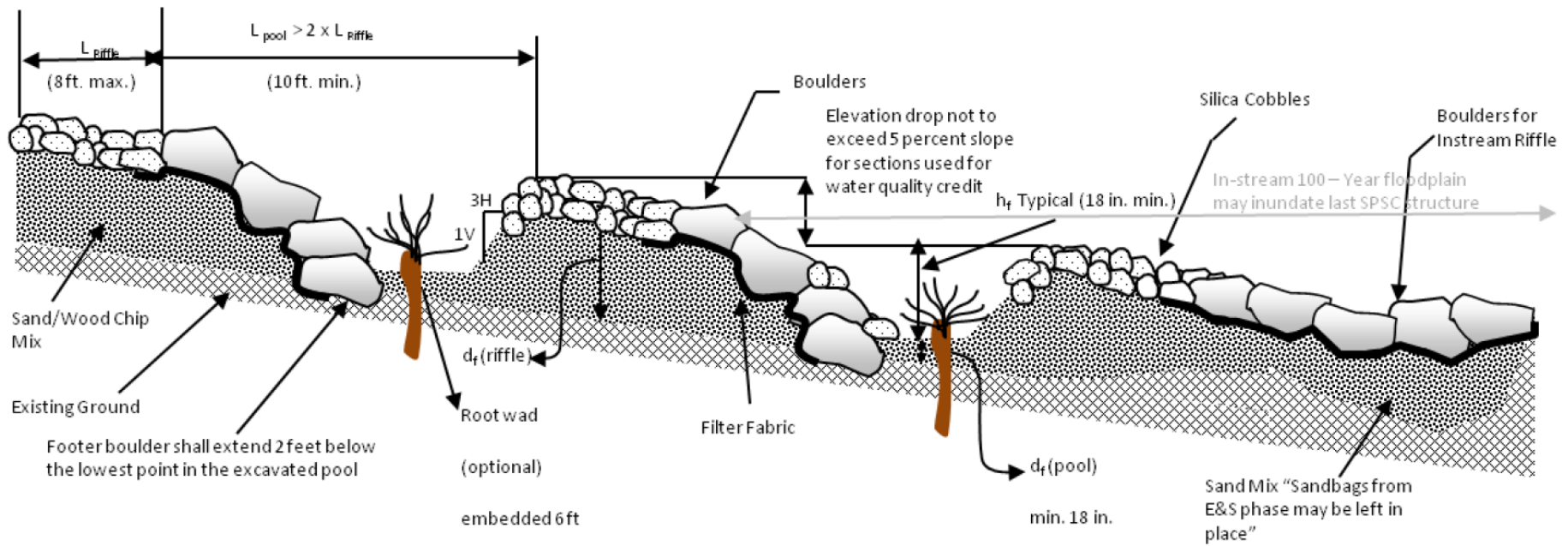


<https://www.linkedin.com/pulse/new-afps-fishway-starts-operating-tim-marsden>

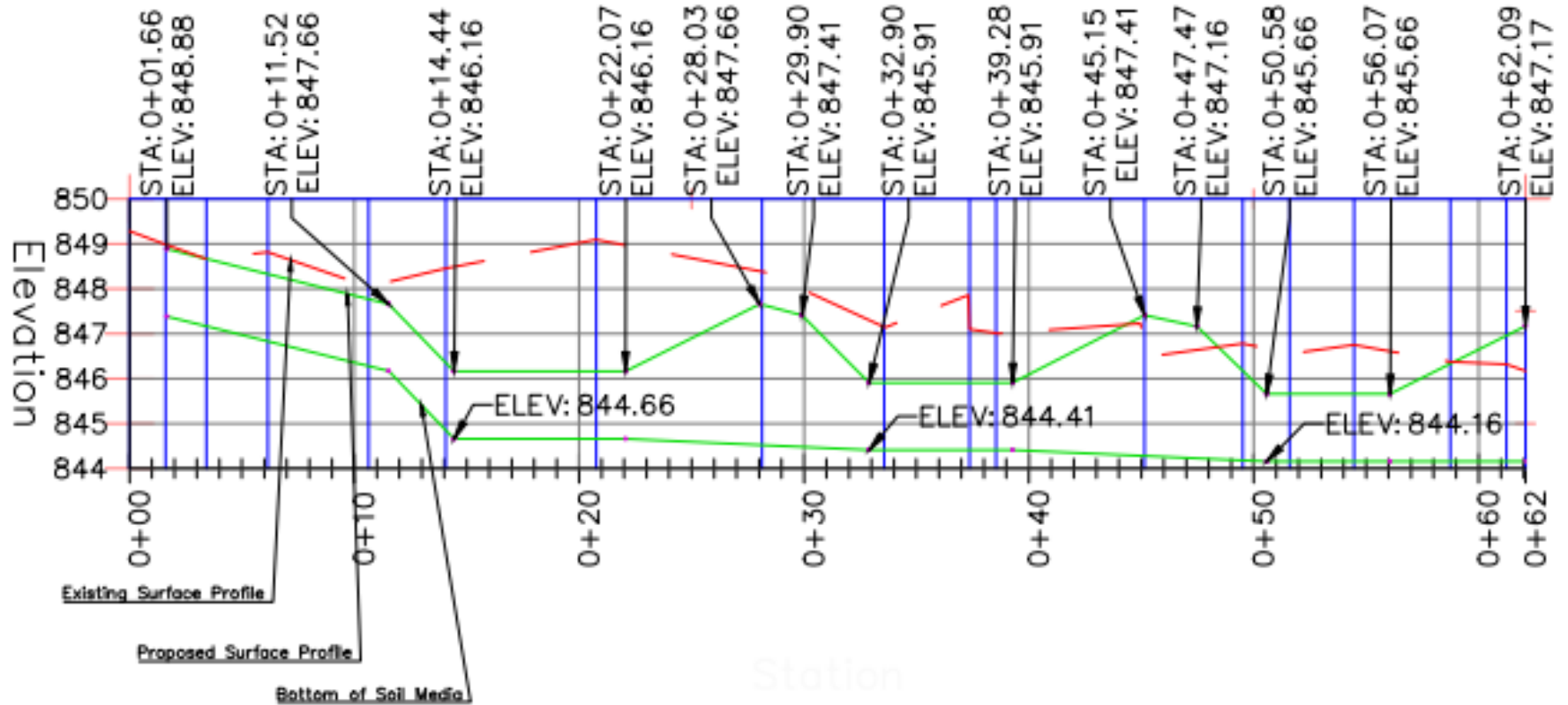
# Site Design – Longitudinal x-sect

1. Determined elevation difference from inlet to outlet
2. Determined number of pools/riffles
3. Determined required **elevation drop per riffle** (pools to not change elevation)
4. Determined required **riffle length** to not exceed 5% slope
5. Pool length  $> 2 \times$  riffle length  $\rightarrow$  set **pool length** =  $2 \times$  riffle length and then modified to fit the system length
6. Set pool depth to 18 inches (minimum)
7. Pool bottom dimensions determined by known top dimensions and 3:1 side slopes



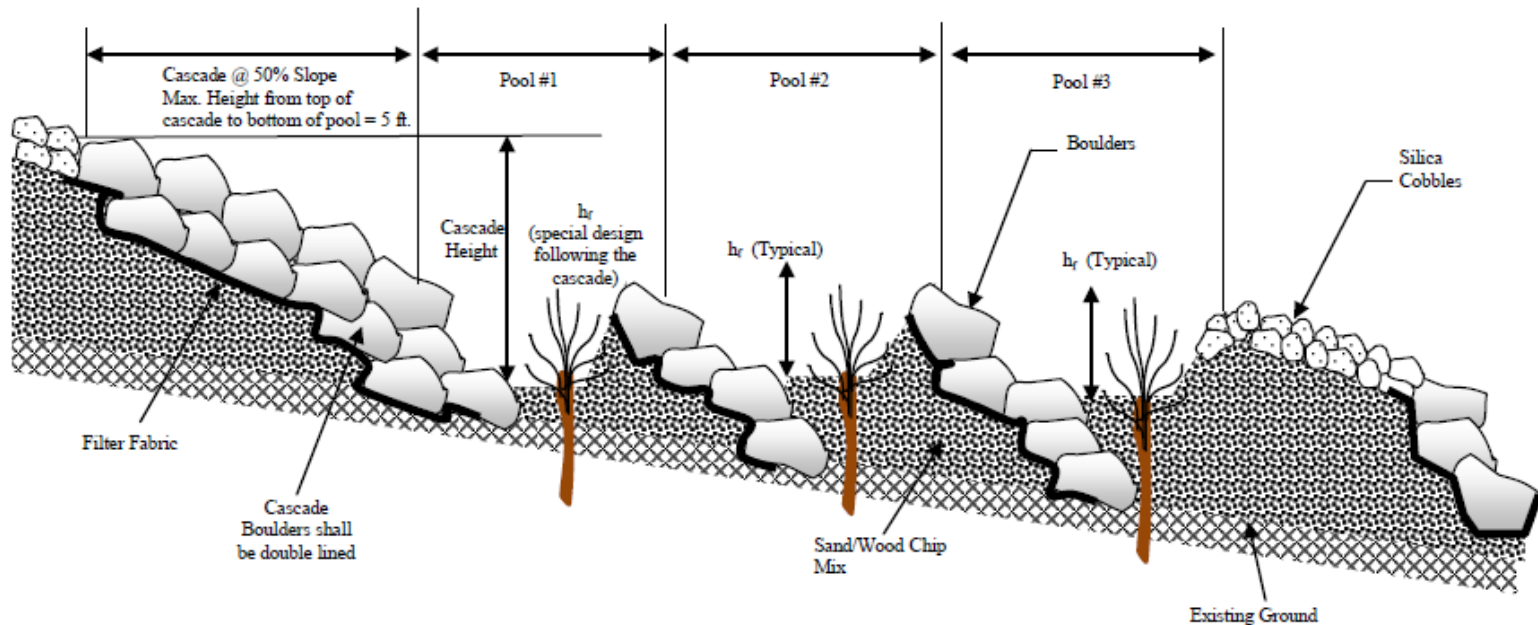


# Site Design – Longitudinal x-sect



# Cascades

- Can handle larger elevation drops
- Must be followed by three consecutive pools



Cascade Profile – Three pools following Cascade

# Design Process

## 5. Design Typical Cross Sections

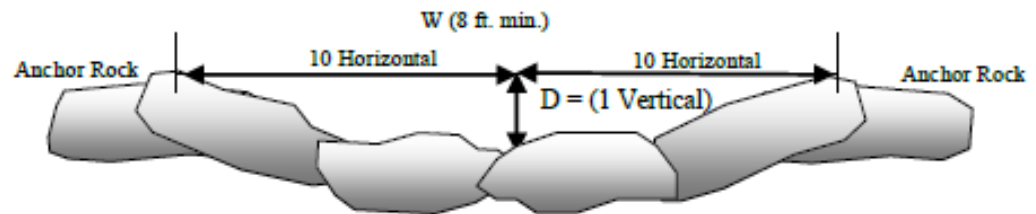
- Parabolic in shape (all elements)
- Design to carry 100 year storm (more on this later)
- Min. riffle width is 8 ft

$$Area = \frac{2WD}{3}$$

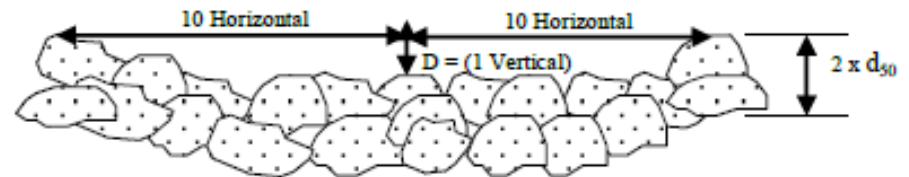
*Mathematical Solution*

$$Hydraulic\ Radius = \frac{2W^2D}{3W^2 + 8D^2}$$

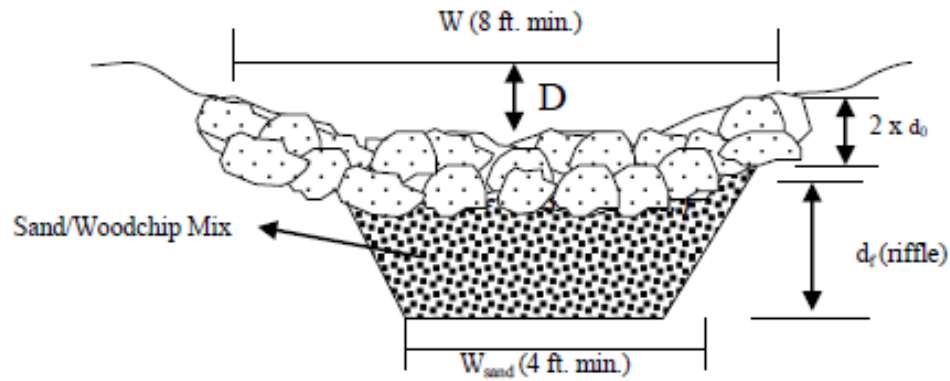
*Chow, 1959*



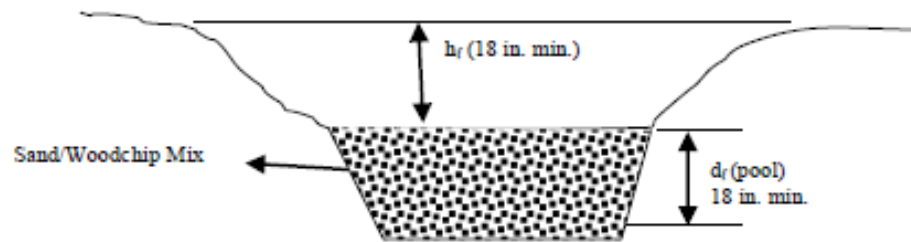
**Riffle Section through Boulder**



**Riffle Section through Cobble**



**Section A-A'**  
Riffle Weir Cross Section through Cobble



**Section B-B'**  
Pool Cross Section

# Manning's n

$$n = D^{1/6} / (21.6 \log (D/ d_{50}) + 14), \quad (\text{USDA, 2006}).$$

Where:

n = Manning's n, use 0.05 for cascades.

D = depth of water in the riffle channel associated with unmanaged  
100 year  $Q_{\text{design}}$ , feet,

$d_{50}$  = Median cobble size, feet

# Design Process

- Trial and Error Approach
  - Riffle / weir depth
  - Riffle / weir width
  - Use Manning's to determine flow and velocity
    - Meet or exceed 100 year
  - Ensure subcritical flow to extent possible
    - Calculate Froude number
  - Ensure velocity is less than allowable based on cobble size

# Manning's equation

$$Q = (1.49/n) (A) (R_h)^{2/3} (S)^{1/2}$$

Where:

Q = 100 year ultimate flow (cfs)

1.49 = conversion factor

n = Manning's n, determined by USDA, 2006 equation

A = cross-section area of a riffle channel, which for a parabola =  $2/3(W)(D)$ ,  
where W is top constructed width (feet) and D is the constructed depth (feet)

$R_h$  = hydraulic radius (feet), calculated using Chow 1959 relationship for parabolas

S = average slope over entire length of project (feet/feet)

V = velocity in the riffle channel (feet/second),  $V = Q/A$

# Design Checks

- Froude Number

$$Fr = \frac{V}{\sqrt{gD}}$$

- Velocity Check

$$\text{Maximum Allowable Velocity} = C \times \left( 2 \times g \times \frac{\gamma_s - \gamma_w}{\gamma_w} \right)^{0.5} \times (D_{50})^{0.5} \quad \text{Isbash Formula}$$

Where:

C = 0.86 for prevailing supercritical flow and 1.2 for prevailing subcritical flow

g = 32.2 ft/sec<sup>2</sup>

$\gamma_s$  = stone density (lb/ft<sup>3</sup>)

$\gamma_w$  = water density (lb/ft<sup>3</sup>)

d<sub>50</sub> = For the purpose of SPSC design, D<sub>50</sub> is a median size of cobble stone diameter (feet).

# Site Design – Cross Section Calcs

Calculated flow

Determined through goal seek function using calculated flow to equal design flow

South Doyle																				
d50= 10"																				
Q		47.04	ft <sup>3</sup> /s																	
y, rock		145	lb/ft <sup>3</sup>	For Sandstone																
Δelevation		3.1 ft		From pipe outlet to top bank of Baker Creek																
Slope		0.05 ft/ft																		
d50, ft	n	y, flow depth	y1, riffle depth	B, flow width	B1, riffle width	Area of flow	x	Wetted Perimeter	Rc	D (=A/B)	V	Q	F	H:V	10H:1 V	5H:1 V	Vmax, subcrit	Vmax, supercrit	τ0, bed shear	τc; τ*=0.054
0.83	0.064	0.9	1.00	18.974	20.00	11.384	0.200	19.099	0.596	0.600	3.681	41.901	0.837	10.000	ok	ok	9.482	6.796	2.768	3.717
0.83	0.064	1.0	1.00	18.735	19.00	12.144	0.211	18.873	0.643	0.648	3.873	47.040	0.848	9.500	check	ok	9.482	6.796	2.990	
0.833	0.064	0.997	1.000	17.974	18.000	11.948	0.222	18.121	0.659	0.665	3.937	47.040	0.851	9.000	check	ok	9.482	6.796	3.067	
0.83	0.064	1.0	1.00	17.204	17.00	11.745	0.235	17.361	0.677	0.683	4.005	47.040	0.854	8.500	check	ok	9.482	6.796	3.150	
0.83	0.064	1.1	1.00	16.423	16.00	11.535	0.250	16.592	0.695	0.702	4.078	47.040	0.858	8.000	check	ok	9.482	6.796	3.240	
0.83	0.064	1.1	1.00	15.631	15.00	11.315	0.267	15.814	0.716	0.724	4.157	47.040	0.861	7.500	check	ok	9.482	6.796	3.340	
0.83	0.064	1.1	1.00	14.827	14.00	11.086	0.286	15.026	0.738	0.748	4.243	47.040	0.865	7.000	check	ok	9.482	6.796	3.449	

checking for subcritical flow F<1

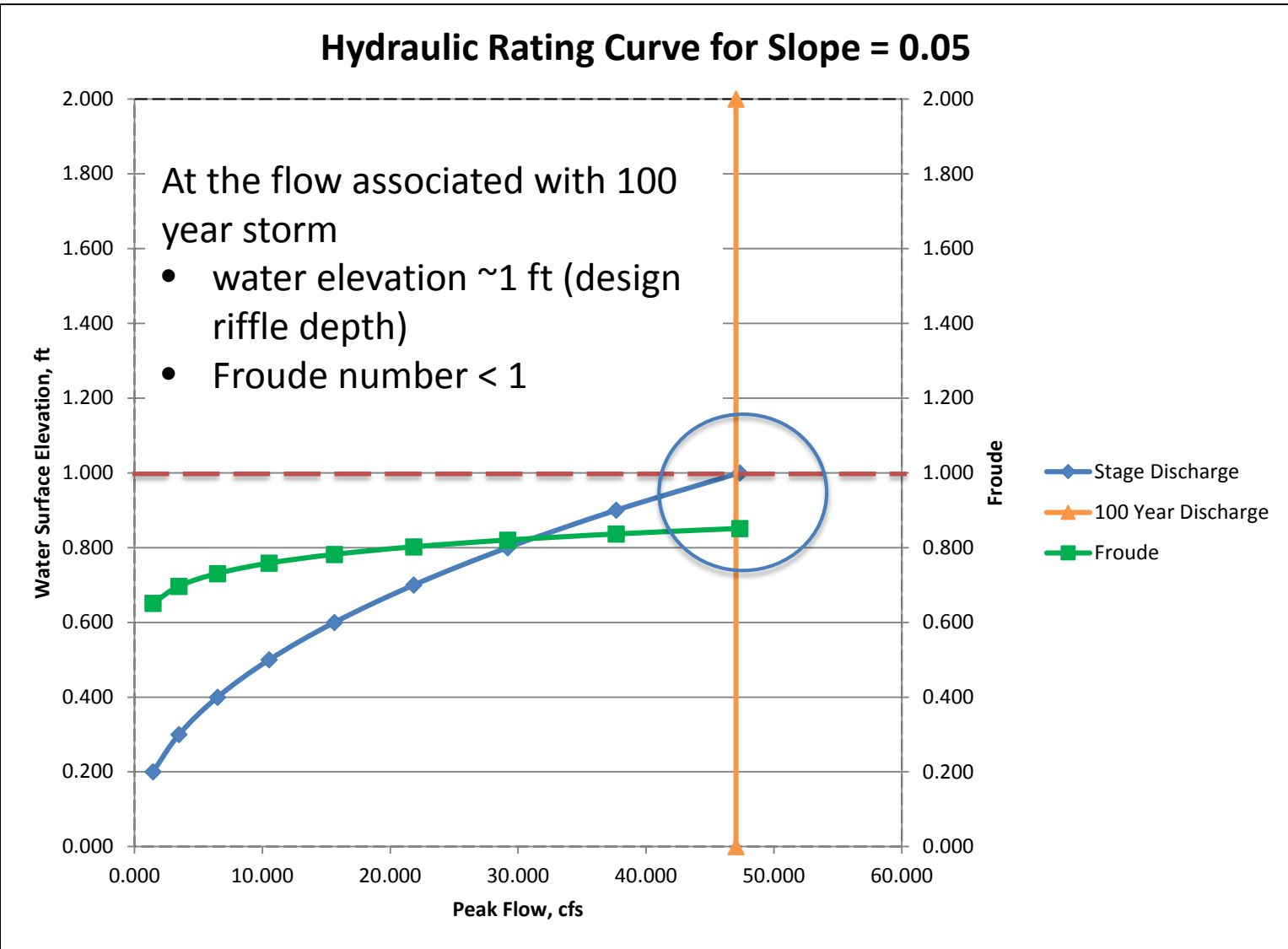
design variables

geometric calculations for parabolic x-sect

entrenchment ratio

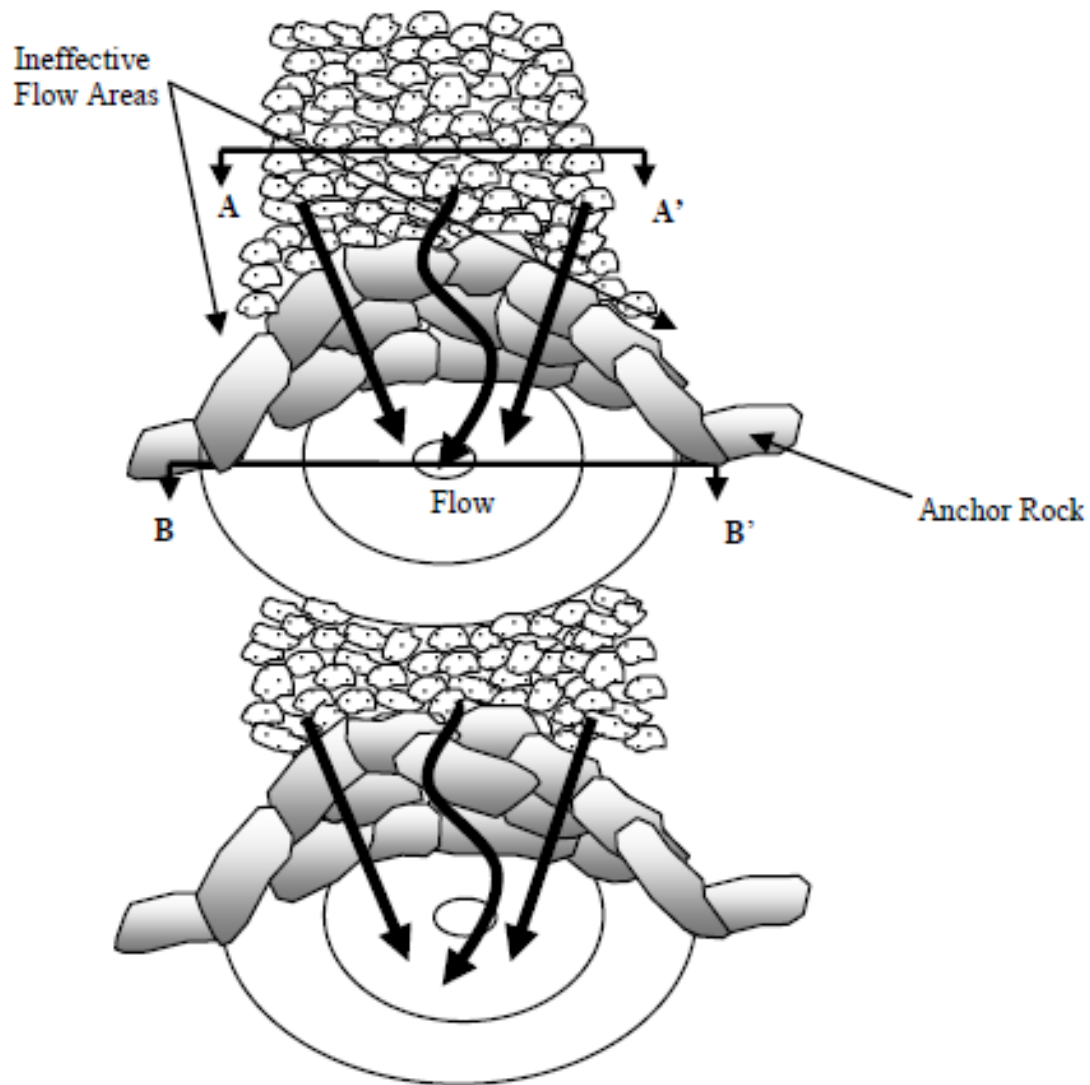
Checking max allowable velocity

# Site Design – Cross Section Calcs

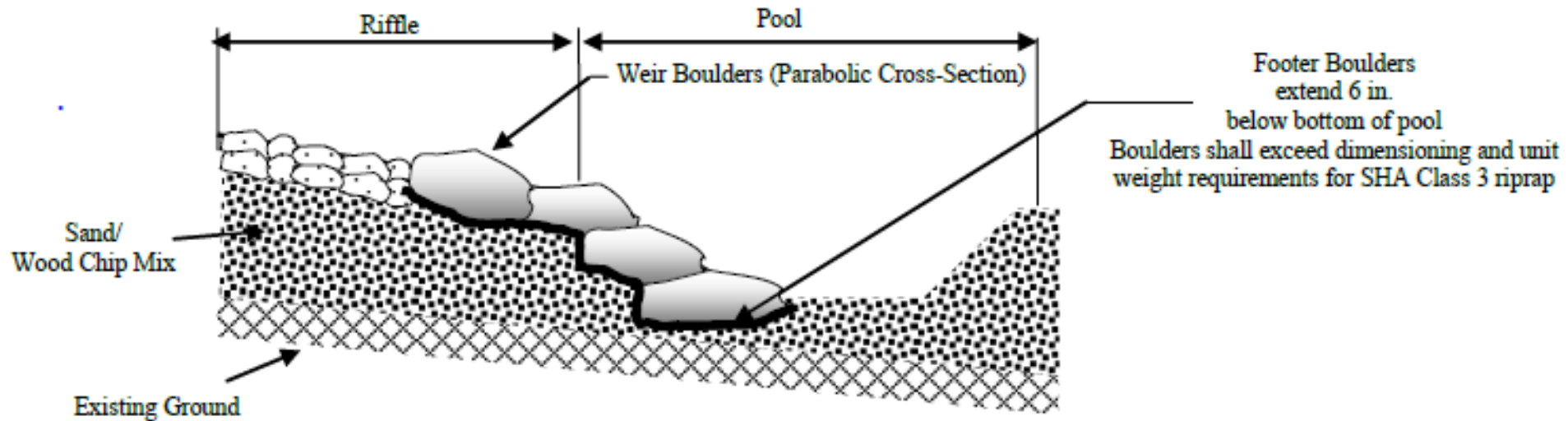


# Design Process

- Boulders used to hold grade / serve as weir
- Arrange in parabolic shape across cross section
- 3 or 4 times heavier than selected cobble
- Footer rocks



**Riffle – Pool Sequence (Typical)**



# Design Process

- The sand/wood chip filter medium shall meet the AASHTO-M-6 or ASTM-C-33, 0.02 inches to 0.04 inches in size. Sand substitutions such as Diabase and Graystone (AASHTO) #10 are not acceptable. No calcium carbonate or dolomitic sand substitutions are acceptable. No “rock dust” can be used for sand. The woodchips are added to the sand mix, approximately 20 percent by volume, to increase the organic content and promote plant growth and sustainability.