Surface water flow resistance due to emergent wetland vegetation

Biological Systems Engineering

Virginia Tech
Invent the Future

Karen Hall

Wetlands provide……

- Habitat for a variety of plant and animal species
- Water quality improvement
- Flood relief and excess water storage

54% of the wetlands in the United States have been lost

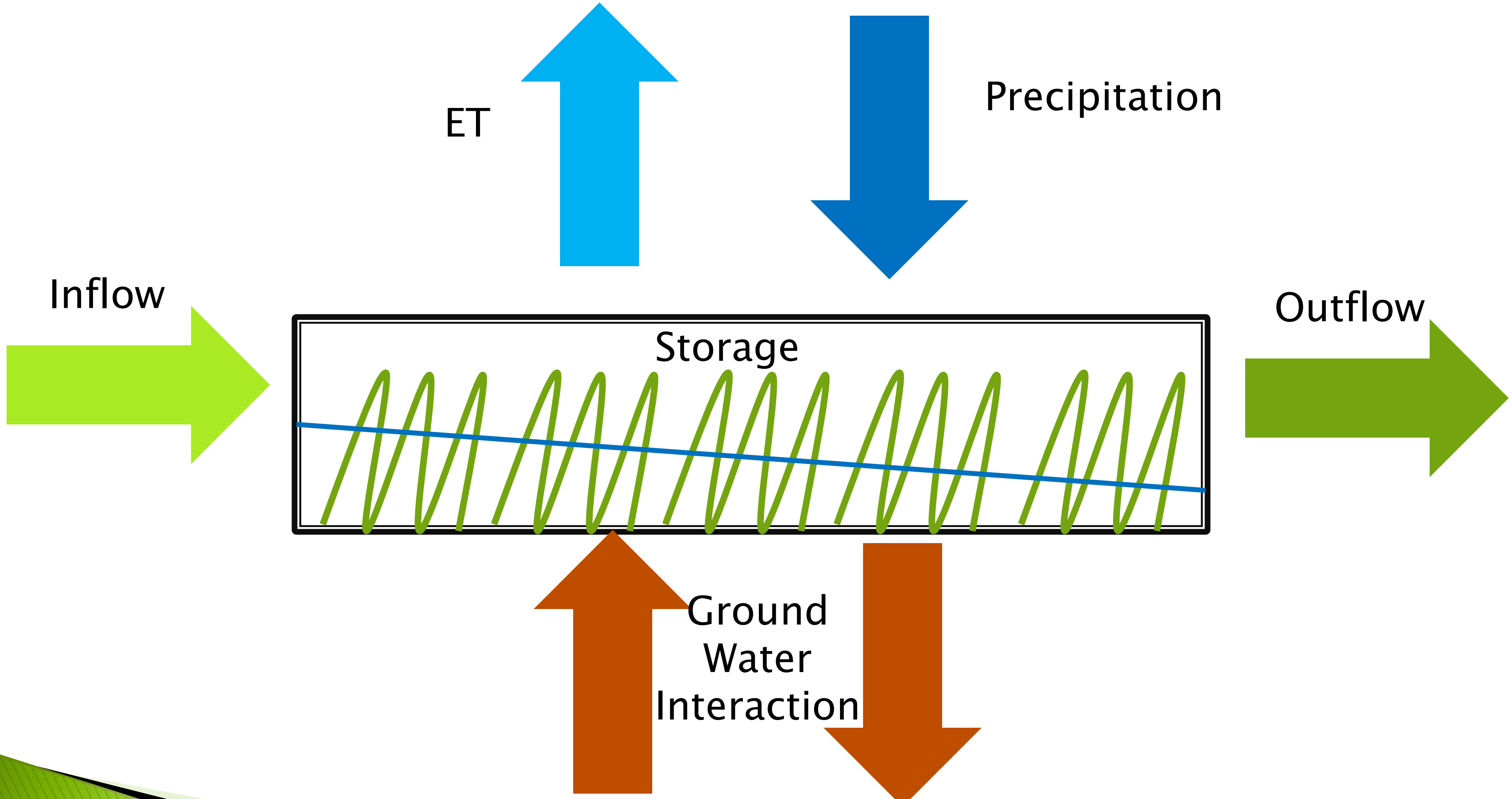
Wetlands have been destroyed for a variety of reasons:

- Housing Development
- Ditches, Levees, and Canals
- Draining

Compensating for losses:

- U.S. adopted a “no net loss” policy in 1989
- Wetland loss is mitigated with constructed wetlands
- Constructed wetlands must meet hydrology and vegetation requirements

Designing wetland hydrology appropriately is crucial for mitigation success



Currently the impact of vegetation during design is quantified using Manning's n

$$Q = \frac{K}{n} R^{2/3} S_f^{1/2} A$$

Where Q is flow rate, K is a conversion constant, n is Manning's coefficient, R is hydraulic radius, S is slope, and A is area

- However wetland flows violate assumptions made by Manning's and is not appropriate

The goal of this study is to further explore the relationship between vegetation properties and friction factor

- To evaluate the significance of clumping relative to other vegetative parameters, such as stem diameter
- To develop an improved prediction equation

Clumping

Three Piedmont wetlands were sampled to understand how vegetation changes over time.

Younger Wetland

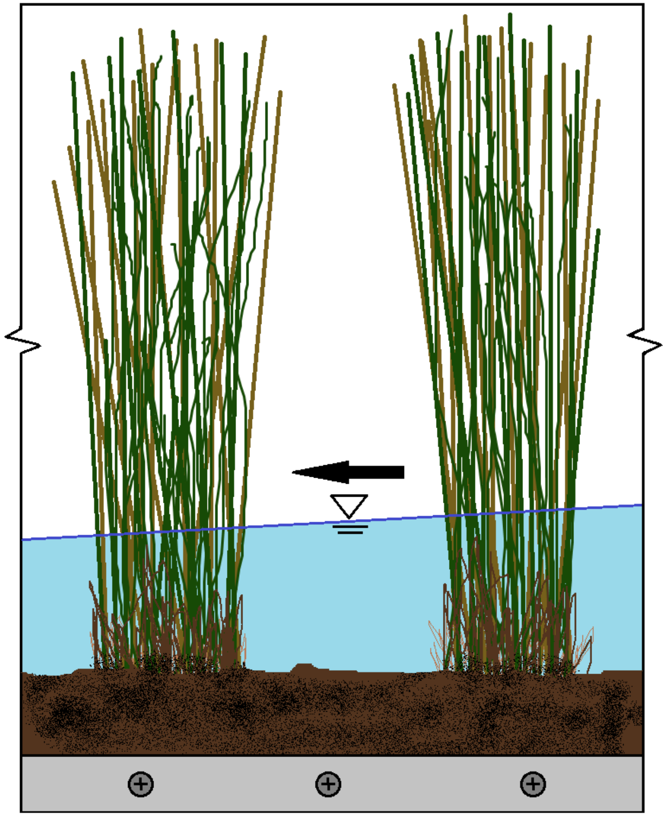
Older Wetland

In the younger wetland the plant clumps were more numerous and larger in size than in the older wetland where the trees had shaded them out.

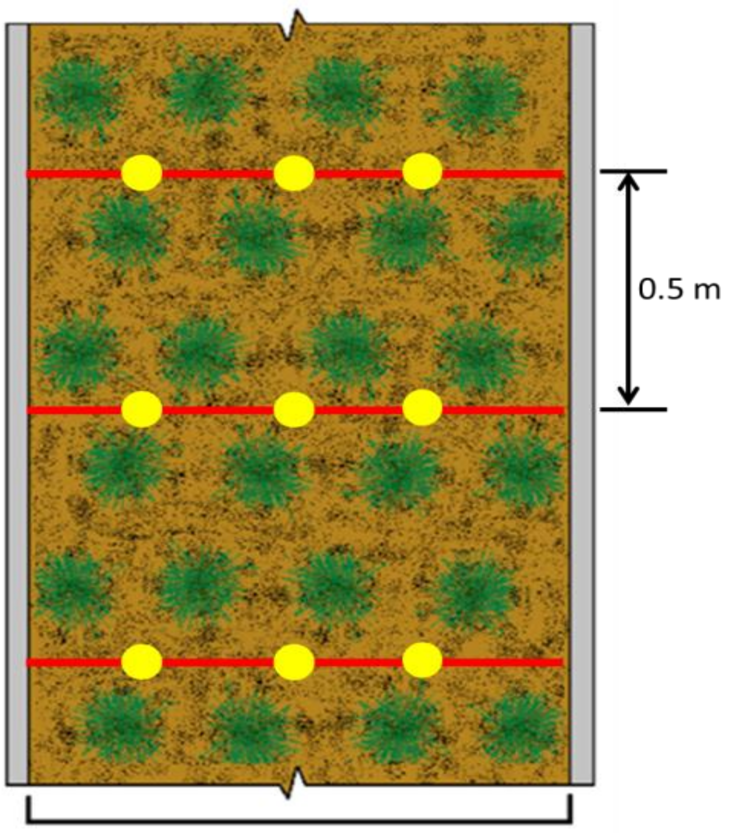
Soft Rush (*Juncus effusus*) were planted in a 1-m x 6-m flume

Three flow rates and tail gate heights were varied to create different water surfaces

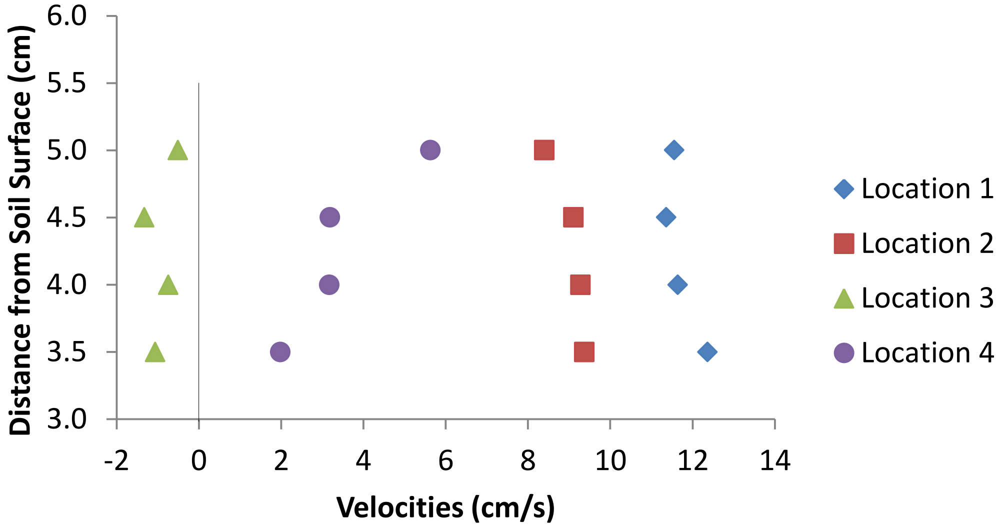
- Tail Gate Heights: 0, 2.5, and 7 cm
- Flow rates: 3, 4, and 5L/s
- Clump Diameters: 8 and 12 cm
- Clump Spacing: 20 and 25 cm

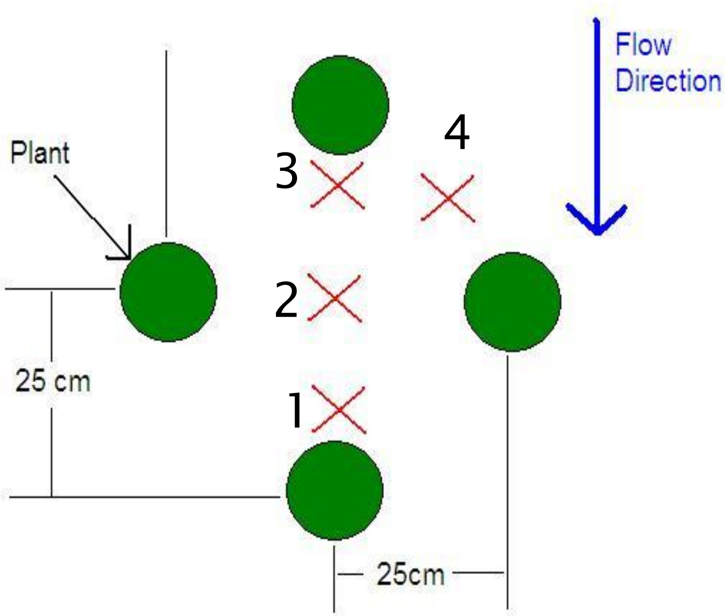


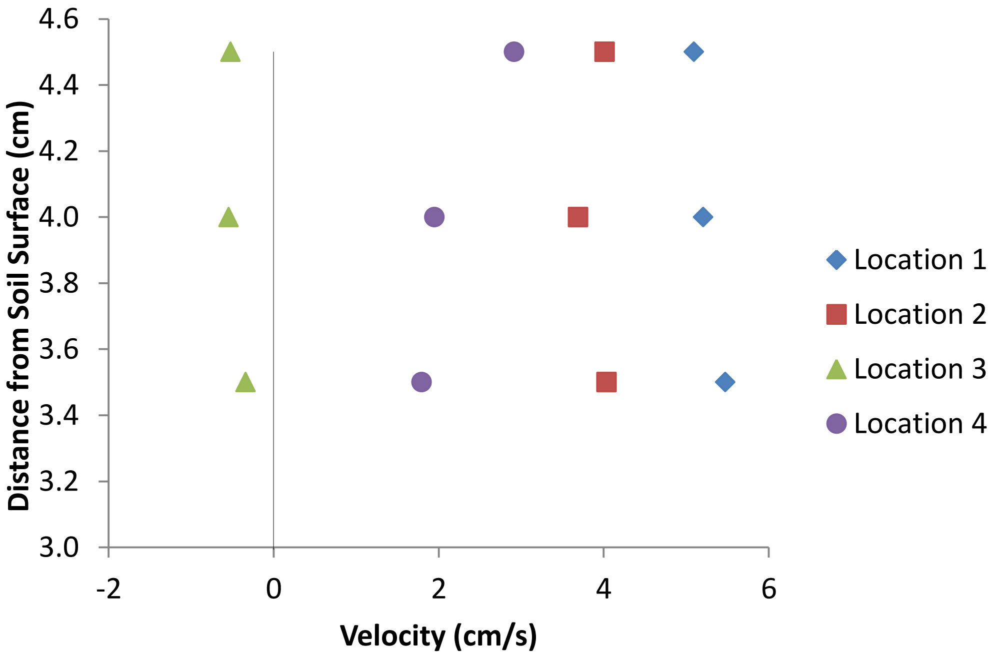
Measurements were taken at seven cross sections in the flume at three locations for each cross section



Velocity Profiles



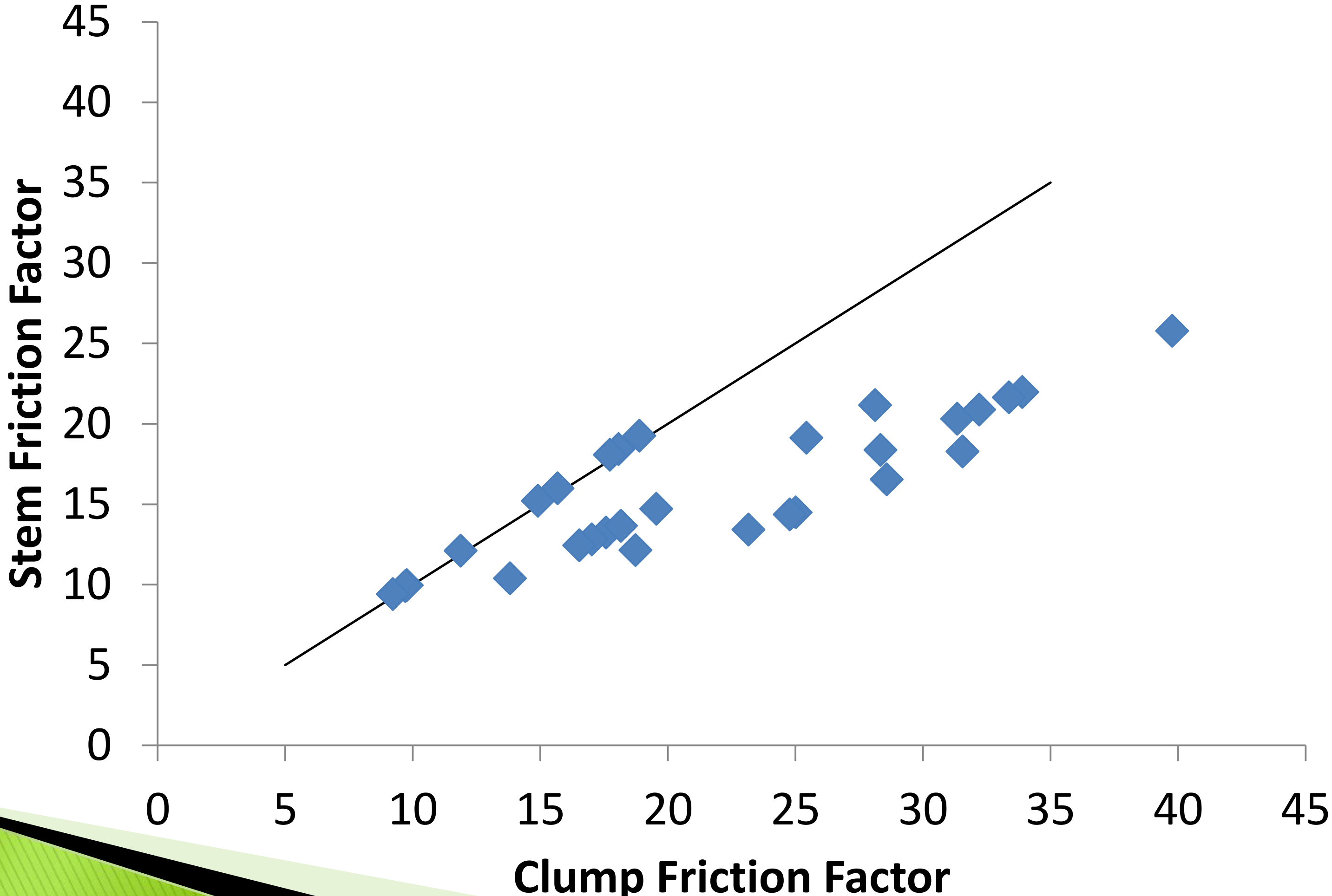




Plant Data

		Spacing (cm)	Clump Diameter (cm)	
			12	8
Avg. Stems per Clump		-	69	44
Clumps per m^2		20	22.5	-
		25	15	-
Stems per m^2		20	1549	985
		25	1032	657
P	Clumps	20	0.25	0.11
		25	0.17	0.08
	Stems	20	0.02	0.01
		25	0.01	0.01

Comparing clump and stem friction factors shows that stem friction factors do not reach values as high as the clump friction factors



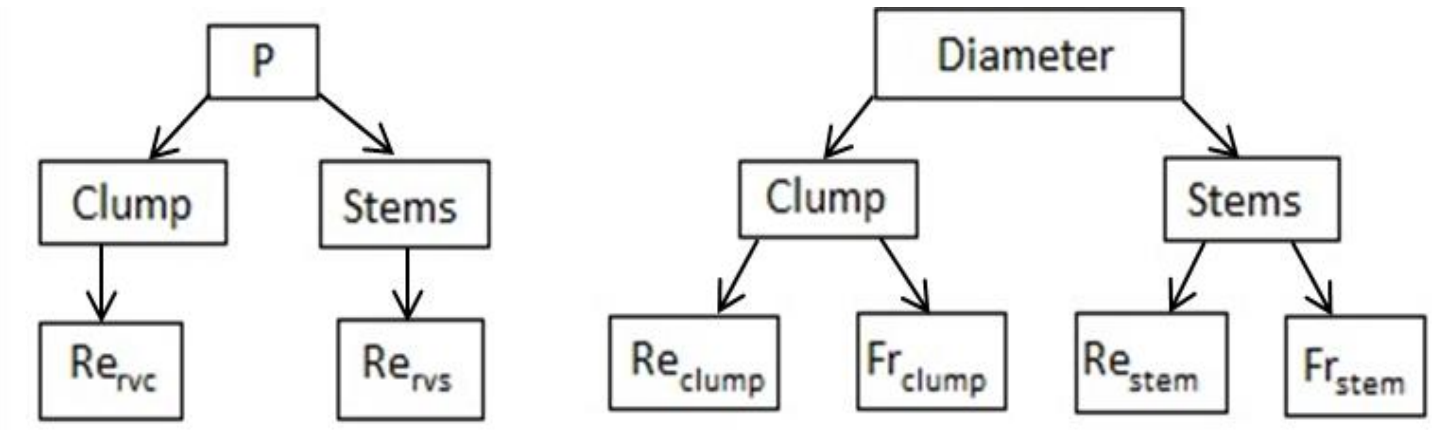
Buckingham Pi

Parameters	f, D, H, MAA, V, S, ρ, μ, P, g
π Terms	f, S, P, MAA · D, D/H, Re, Fr

- D is diameter
- H is water depth
- MAA is momentum absorbing area
- V is velocity
- S is slope
- μ is viscosity
- P is fraction of plant occupied bed area
- g is gravity
- ρ is density

Two sets of length scales were used to calculate four Reynolds Numbers

- Clump/Stem Diameter
- Vegetated Hydraulic Radius, r_v



$$r_v = \frac{(1-\lambda)BhL}{Nhd} = \frac{\pi}{4}\frac{1-\lambda}{\lambda}d$$

Cheng, 2010

Statistic Methods

- Found collinearity among Buckingham Pi terms
- Used Mallows Cp, Adjusted R^2, and Stepwise regression to find the best subsets
- Compared all the best subsets
- Ranked model performance based on number of leverage points, Press statistic, and R^2

The most significant parameter from the regression was plant occupied bed area (P)

Because every model contained that parameter simple models were developed that only contained P

Simple Clump Model:

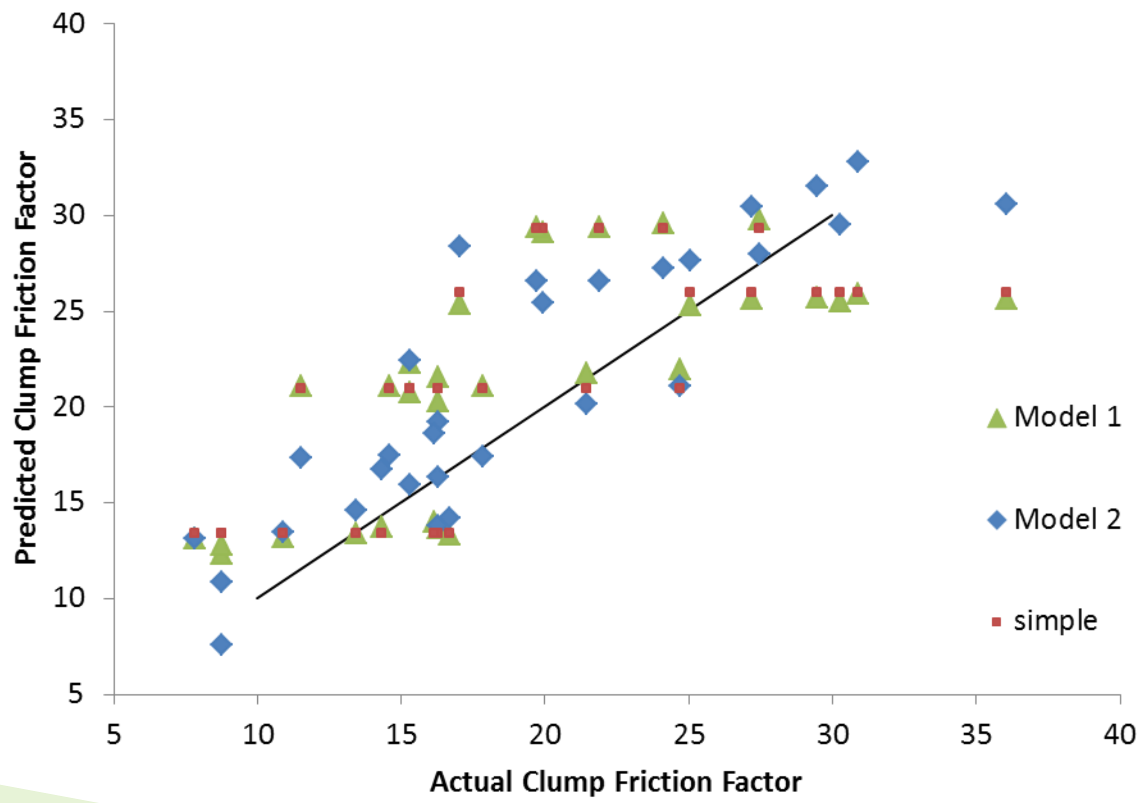
$$f = 36.0197 - (88.9369 \times P_{clump})$$

Simple Stem Model:

$$f = 16.1 - (463 \times P_{stem})$$

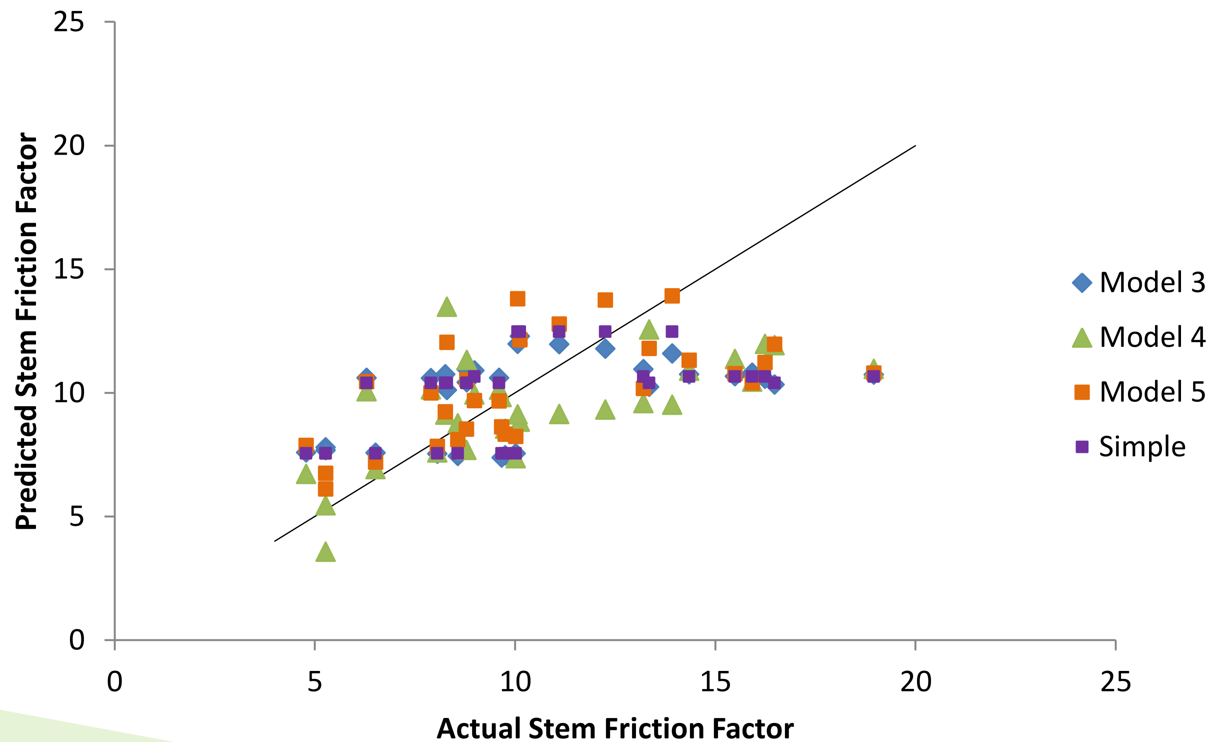
Clump Models

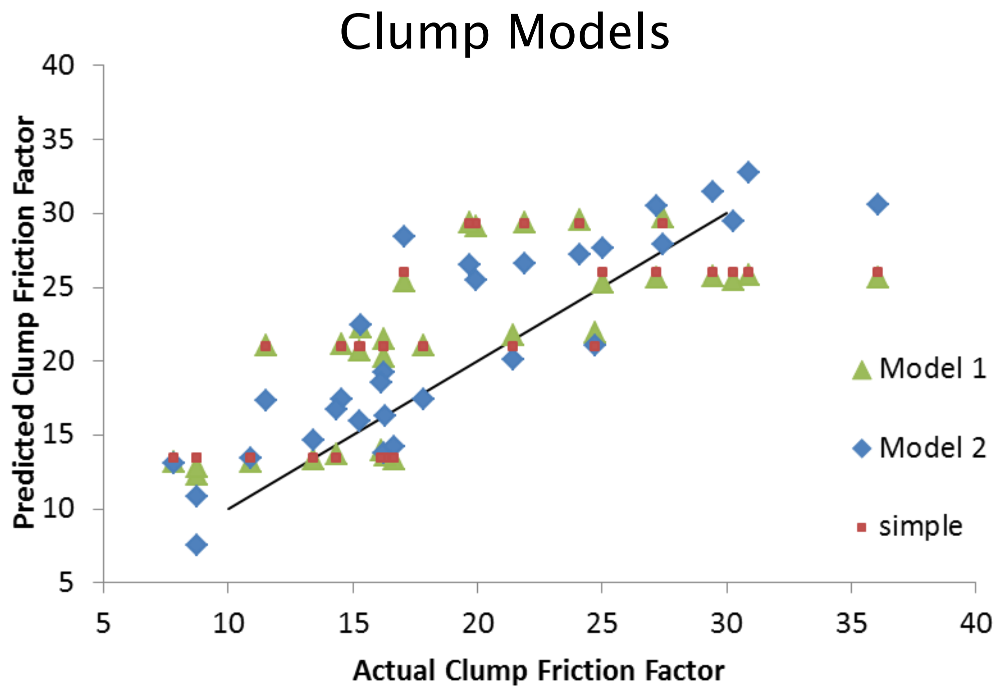
Model #	Model	R^2
1	$f = 34.5 - (49.9 \times P) + (0.000312 \times Re_{clump})$	58
2	$f = 28.5 - (133 \times P) - (0.000473 \times Re_{rvc}) + (1284 \times Fr)$	79
Simple	$f = 36.02 - (88.94 \times P_{clump})$	58

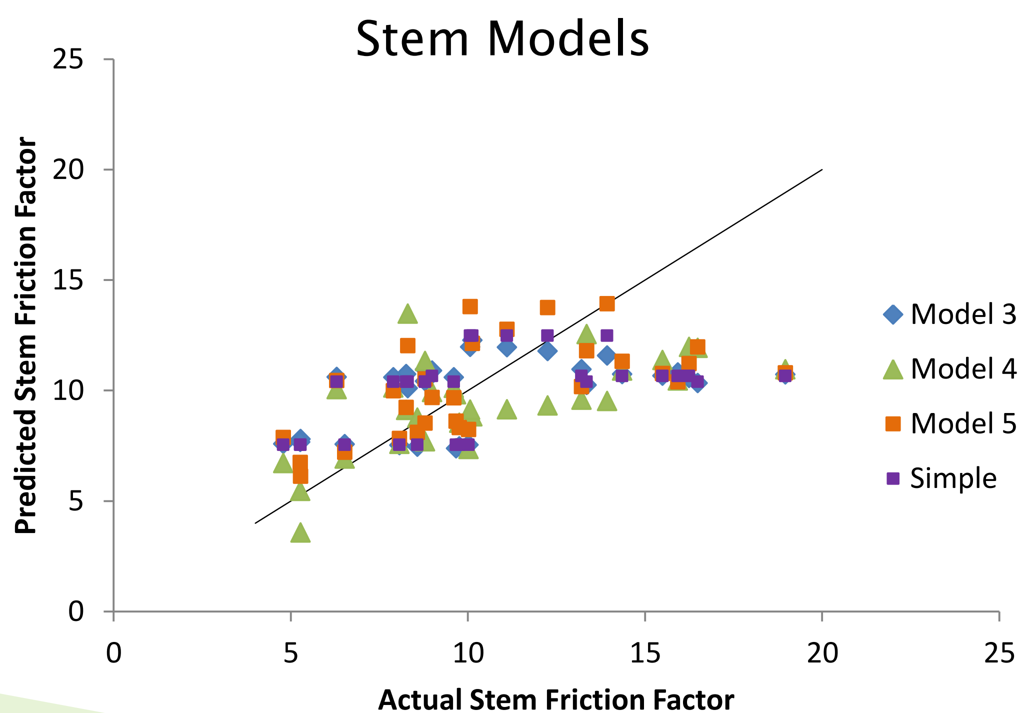


Stem Models

Model #	Model	R^2
3	$f = 18.6 - (558 \times P) - (0.00076 \times Re_{stem})$	38
4	$f = 14.7 - (998 \times P) - (0.000691 \times Re_{rvs}) + (182 \times Fr)$	64
5	$f = 8.65 - (359 \times P) + (42.5 \times Fr) + (26.7 \times {}^{D}/_{H})$	43
Simple	$f = 16.1 - (463 \times P_{stem})$	37




Clump Models
Predicted Clump Friction Factor
Actual Clump Friction Factor
Model 1
Model 2
simple
5
10
15
20
25
30
35
40


Stem Models
Predicted Stem Friction Factor
Actual Stem Friction Factor
Model 3
Model 4
Model 5
Simple
0
5
10
15
20
25

Model Use

- The clump models predict friction factor better for wetlands that are dominated by clumping vegetation

- The simple model should be used as a preliminary tool for a rough estimate of friction factor

- The full model can be used in an iterative approach to calculate friction factor. More research should be done to determine if it is worthwhile to use the full model or if the simple model is sufficient for design purposes.

Conclusions

- Clumps influenced surface water flow through the simulated wetland
- Friction factors were greatest at lower flow depths where clumping was dominant
- Stem models did not effectively predict friction factors at lower depths
- Clump models were able to predict friction factors at a range of flows

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- Questions?