Feedbacks between Wetland Vegetation and Hydrology

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Biological Systems Engineering

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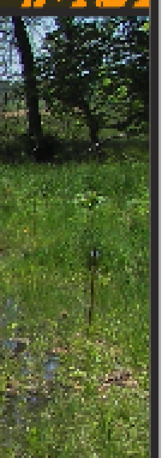
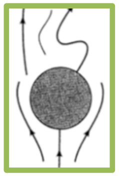


Vegetation feedbacks in wetlands



Vegetated hydraulic resistance

Flume methods

Evaluate flow resistance models

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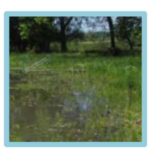
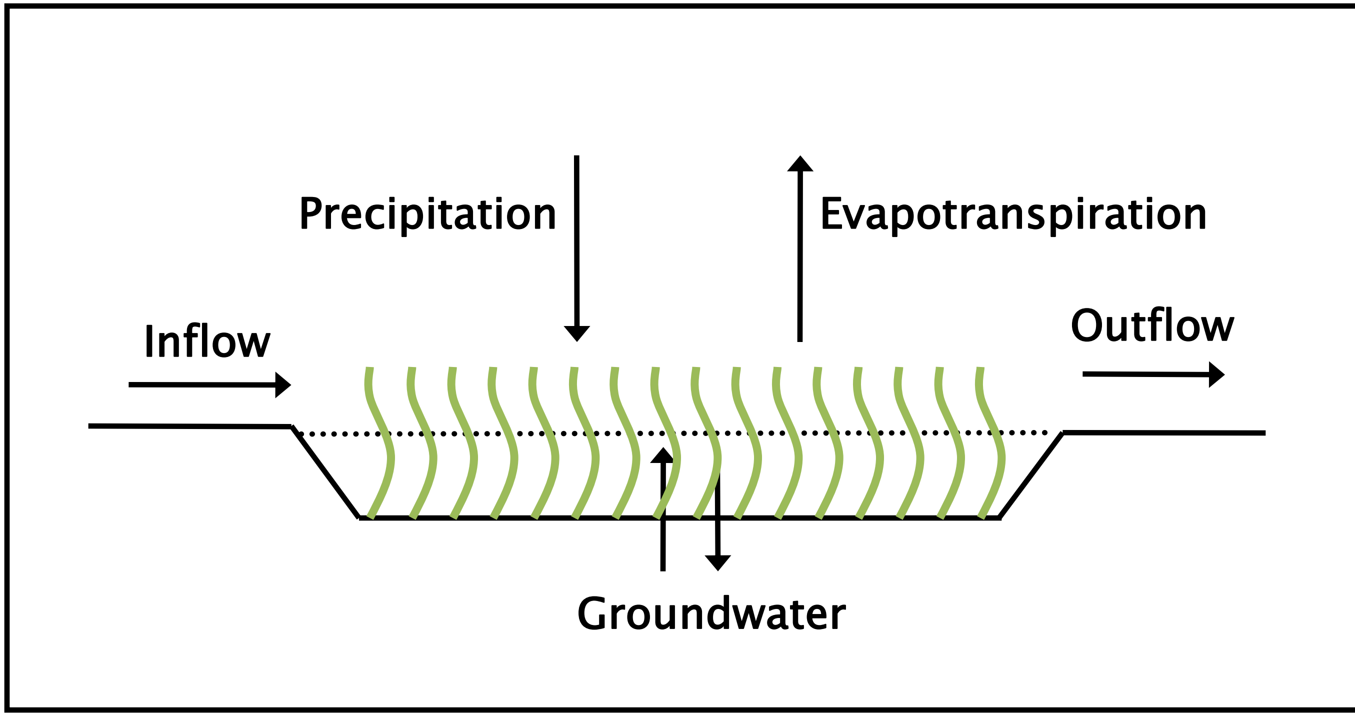
Determine properties of vegetation that predict resistance



Model hydraulic resistance in a constructed wetland

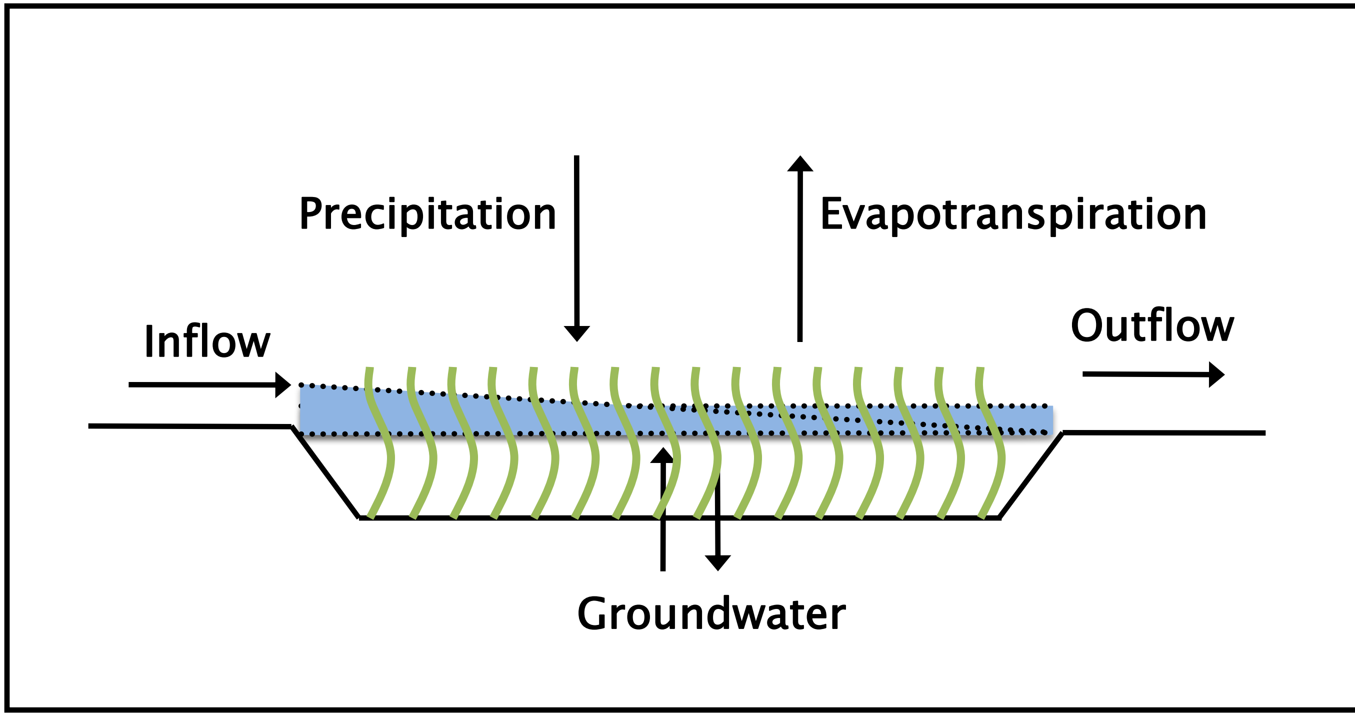
Summary and conclusions

The wetland water balance changes depending on the temporal scale



Event Seasonal Succession

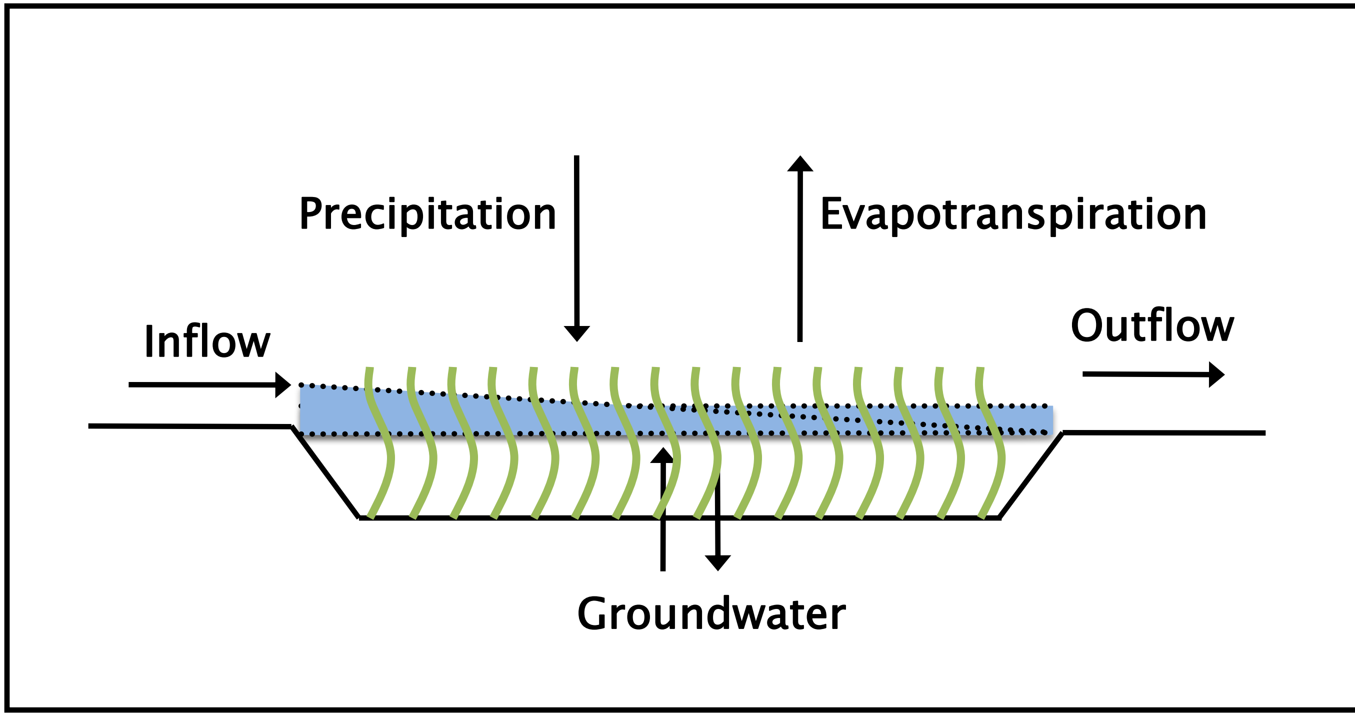
During a surface flow event, vegetated hydraulic resistance affects flow structure and conveyance



In systems with outlet control, outflow can be determined primarily by hydraulic resistance

(Kadlec, 1990)

Seasonal changes in precipitation, solar radiation, and vegetation affects the water balance



In systems with outlet control, outflow can be determined primarily by hydraulic resistance

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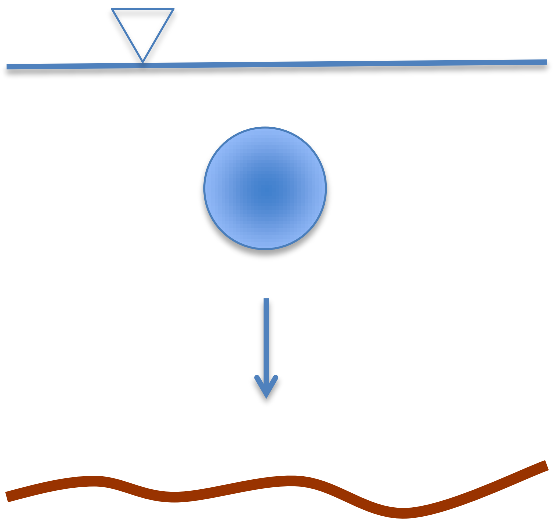
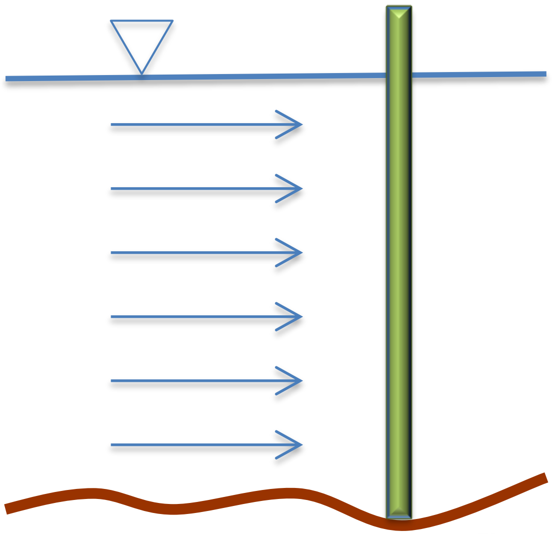
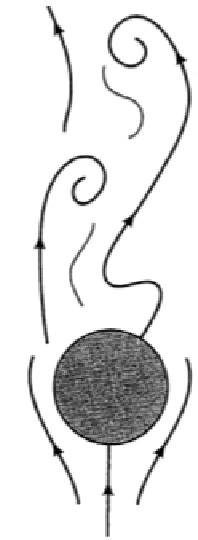
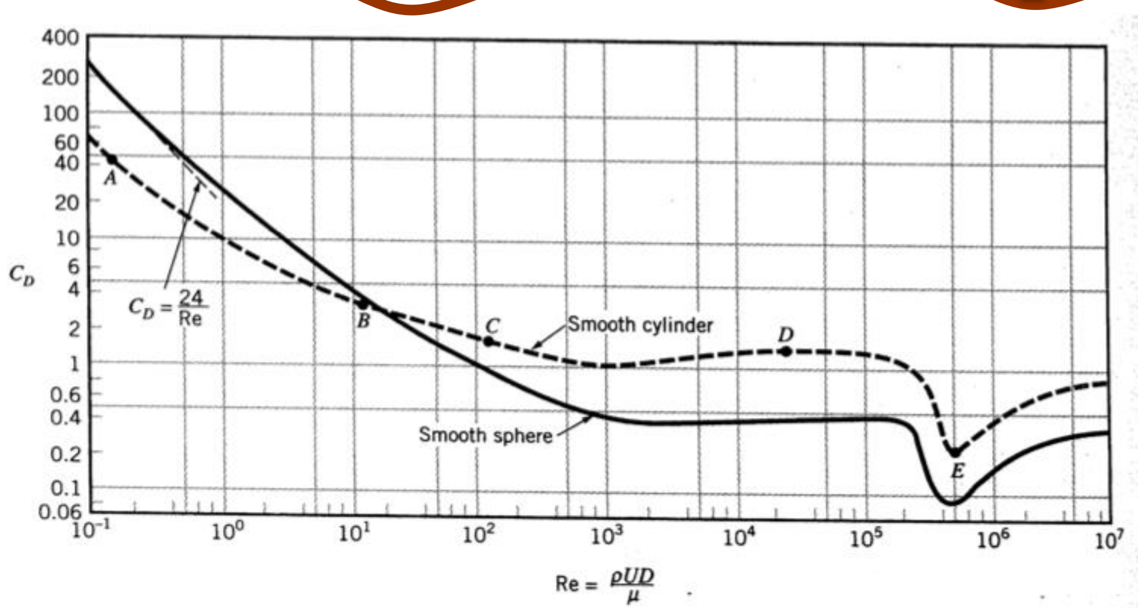
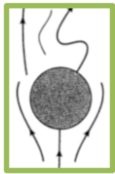
Hydraulic resistance for simple shapes is predictable



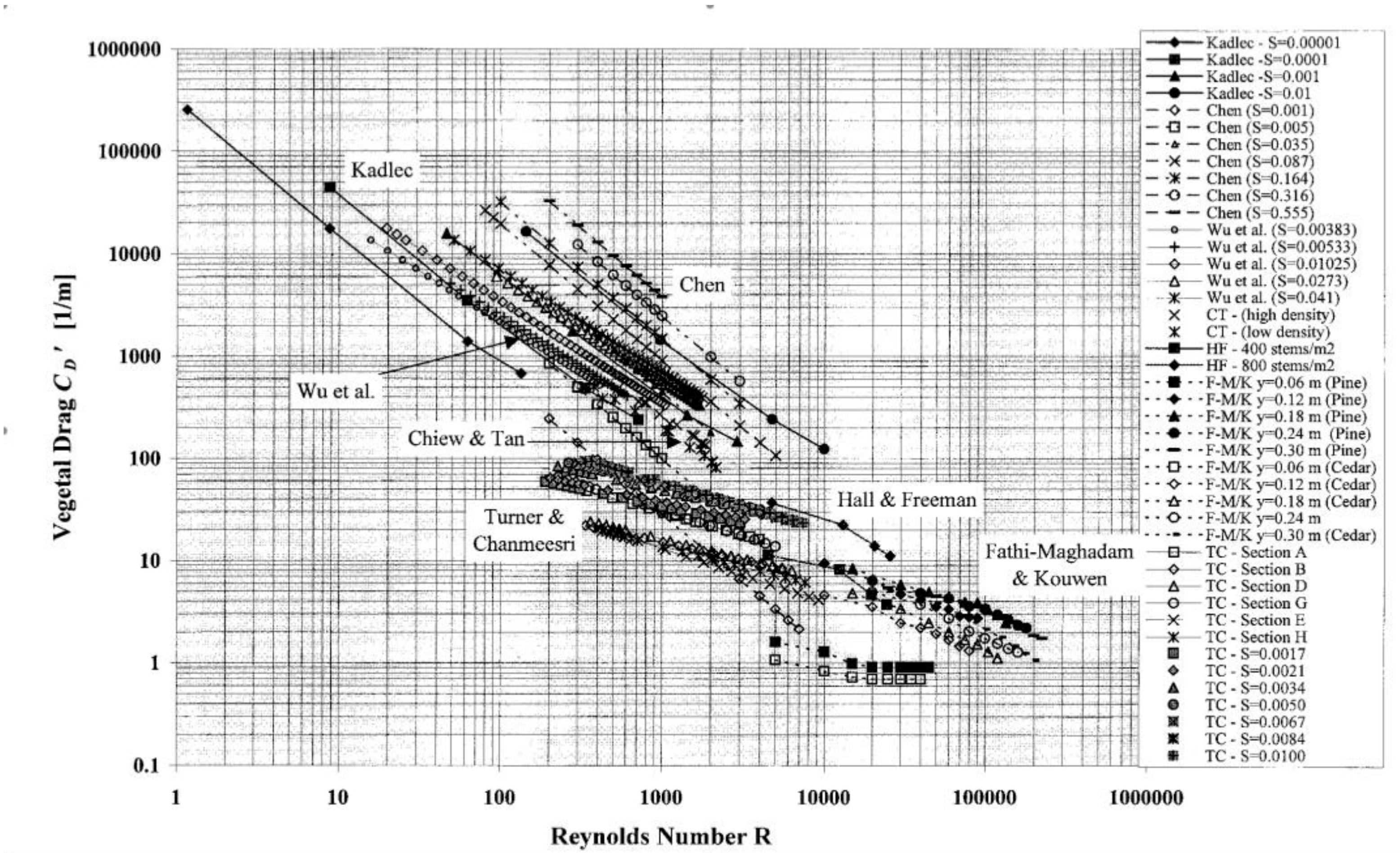








For more complex shapes, the geometry is more complex and the drag coefficient is less predictable



Vegetated resistance can be completely described by various dimensional and dimensionless flow and vegetation properties

f = F (
- Reynolds number
- Froude number
- water surface slope
- bed slope
- relative bed roughness
- vegetation geometry metric
- vegetation flexibility
- vegetation submergence
- vegetation density

) (Yen, 2002)

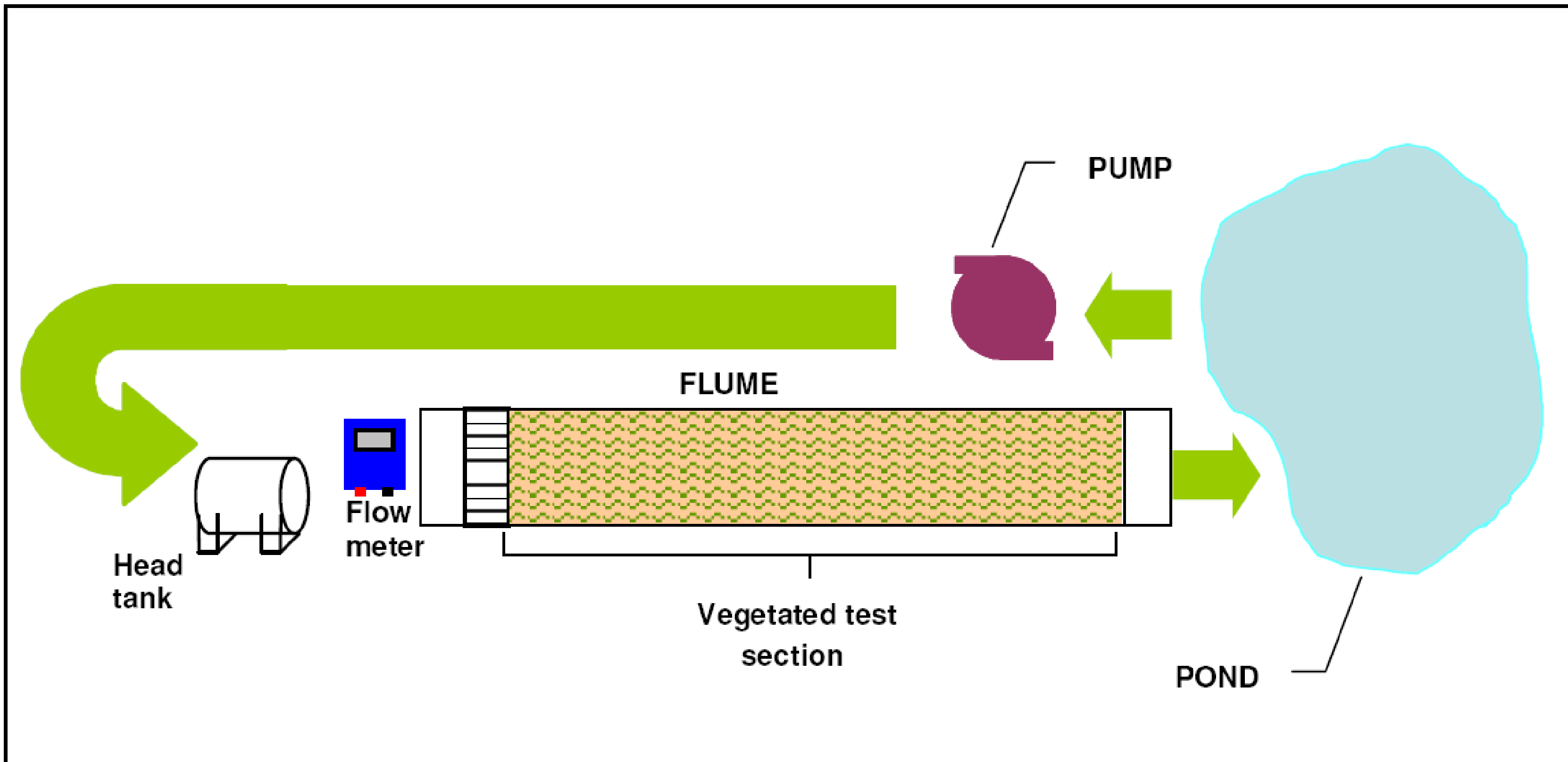
Many previous studies used simulated vegetation so some of these vegetation properties (flexibility or complex geometry) have not been extensively studied.

The goal of this research was to determine how emergent herbaceous vegetation affects hydraulic resistance in laminar to transitional flows typically observed in wetland systems.

Objectives

1. Identify and assess the usefulness of existing models applicable to low-Reynolds number flows typical of wetlands;
2. Determine the relationship between friction factor and measureable properties of natural vegetation; and,
3. Model wetland surface water flow through a small constructed wetland using properties of the wetland emergent vegetation to determine the hydraulic resistance.

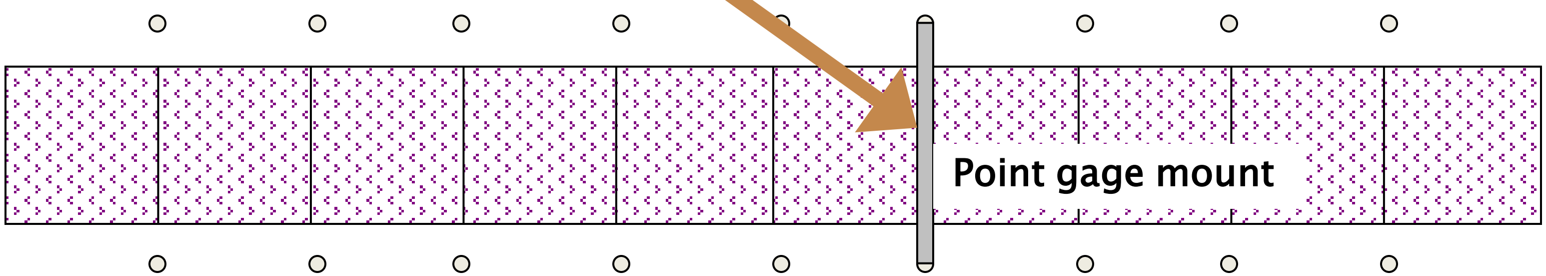
A 14.6-m x 1.2-m x 0.9-m flume was constructed and planted with woolgrass (*Scirpus cyperinus*)

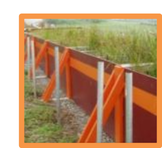


Three replications each of two different flow rates were conducted for each planting density

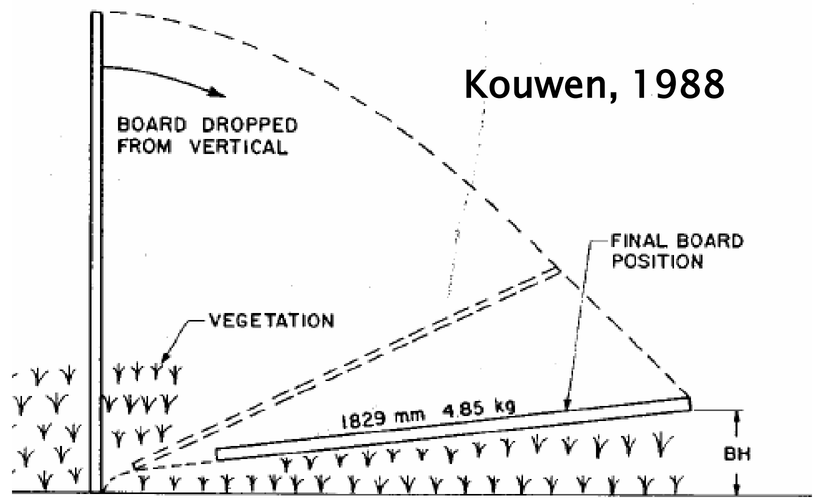
Water Level	Tailgate Height (m)
Low	0.0
Medium-Low	0.1
Medium-High	0.2
High	0.4

Level poles set beside flume

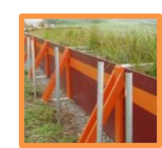




After each set of flume runs, vegetation data were measured using non-destructive techniques



Parameters such as frontal area, stem diameter and density, vegetation height, and modulus of elasticity were measured



Objective 1: Evaluate the flow resistance models using actual emergent vegetation

C_d constant value, isolated cylinder, 4 empirical relationships

$\frac{A_r}{A_*}$ varies with each drag model (6 models)

$$ghS = \frac{1}{2} C_d \frac{A_r}{A_*} V^2$$

h is depth

S is friction slope

C_d is drag coefficient

A_r is the drag reference area

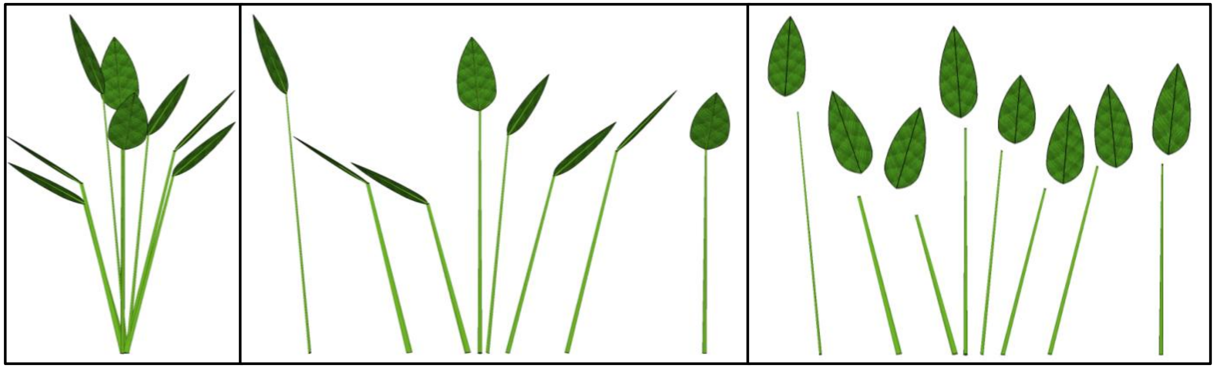
A_* is the “bottom area” over which A_r is measured

V is the cross-sectionally averaged velocity

$$C_d' = C_d \frac{A_r}{A_* \cdot h}$$

The flow models differed in reference and bottom area definitions

Reference area definitions (leafy vegetation)

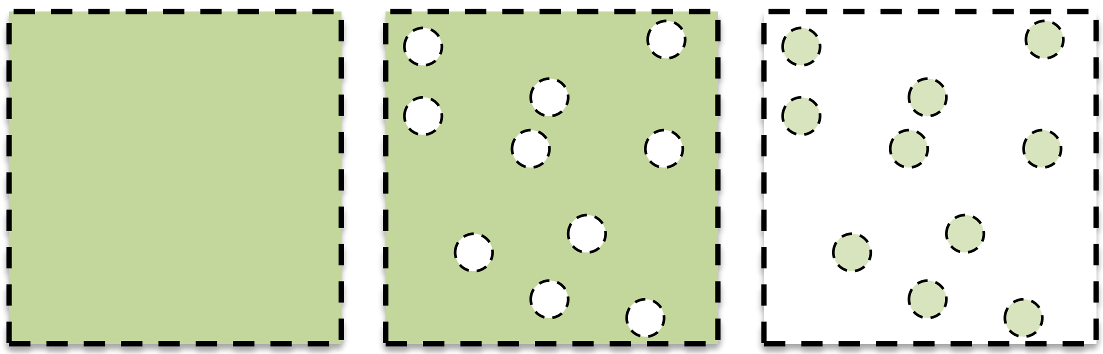


Kadlec

Nepf,
Stone & Shen

Fathi-
Moghamdam &
Kouwen

Bottom area definitions (cylindrical vegetation)



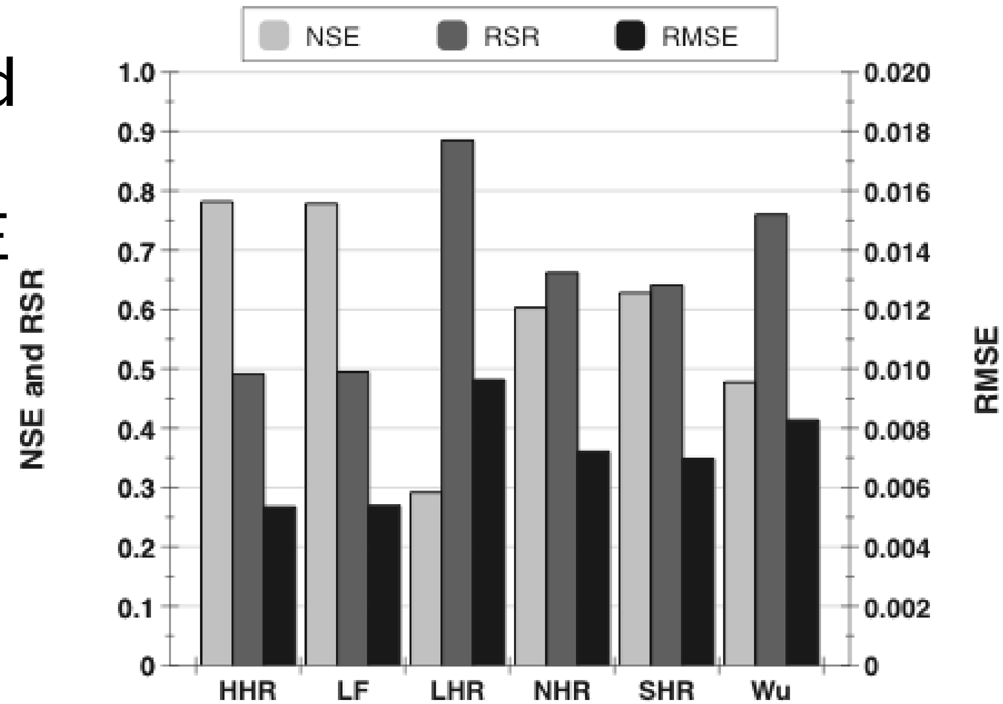
Nepf

Stone & Shen

Fathi-
Moghamdam &
Kouwen

Six combinations of characteristic area and drag coefficient produced positive NSE values (model R^2)

Abbrev. Key
HHR – Hoffman area + Harvey Ridge C_d
LF – Lee et al. (field conditions) C_d'
LHR – Lindner area + Harvey Ridge C_d
NHR – Nepf area + Harvey Ridge C_d
SHR – Stone & Shen area + Harvey Ridge C_d
Wu et al. C_d'

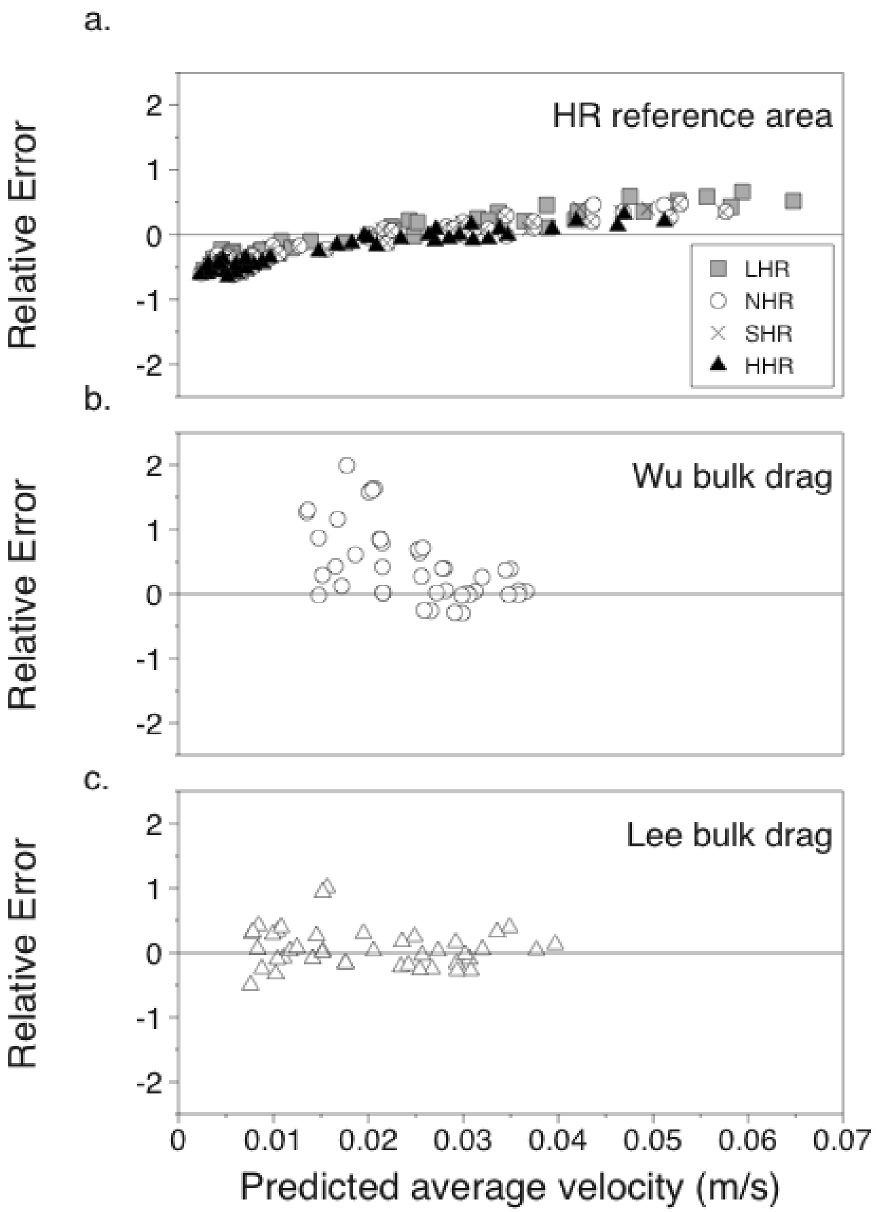


- The Harvey-ridge C_d model and the Lee-field C_d' were both derived from data collected in the Everglades
- Once a C_d model was selected, the reference area definition as well as the “bottom area” was important

Model error was not random

The models were not performing consistently across the entire velocity range

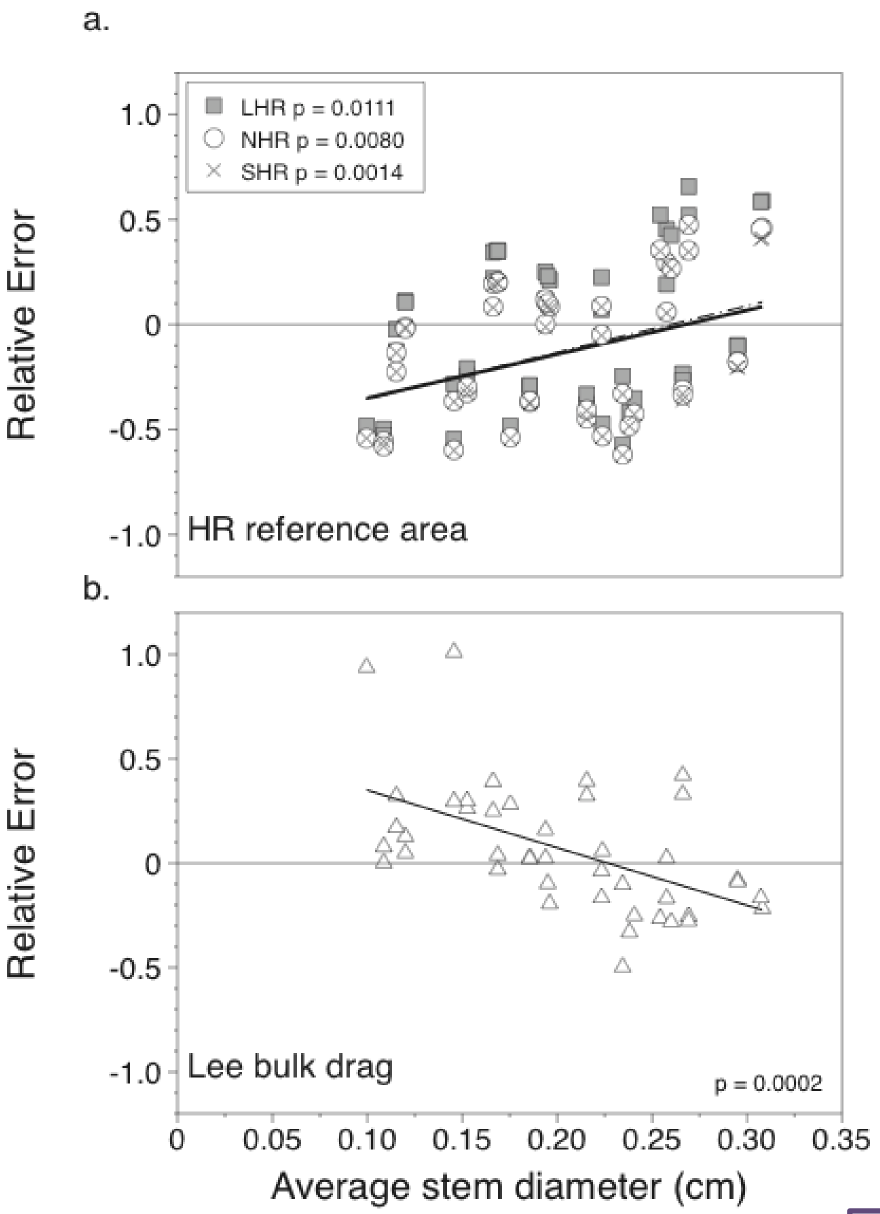
Additional variables may be required to refine the model fit



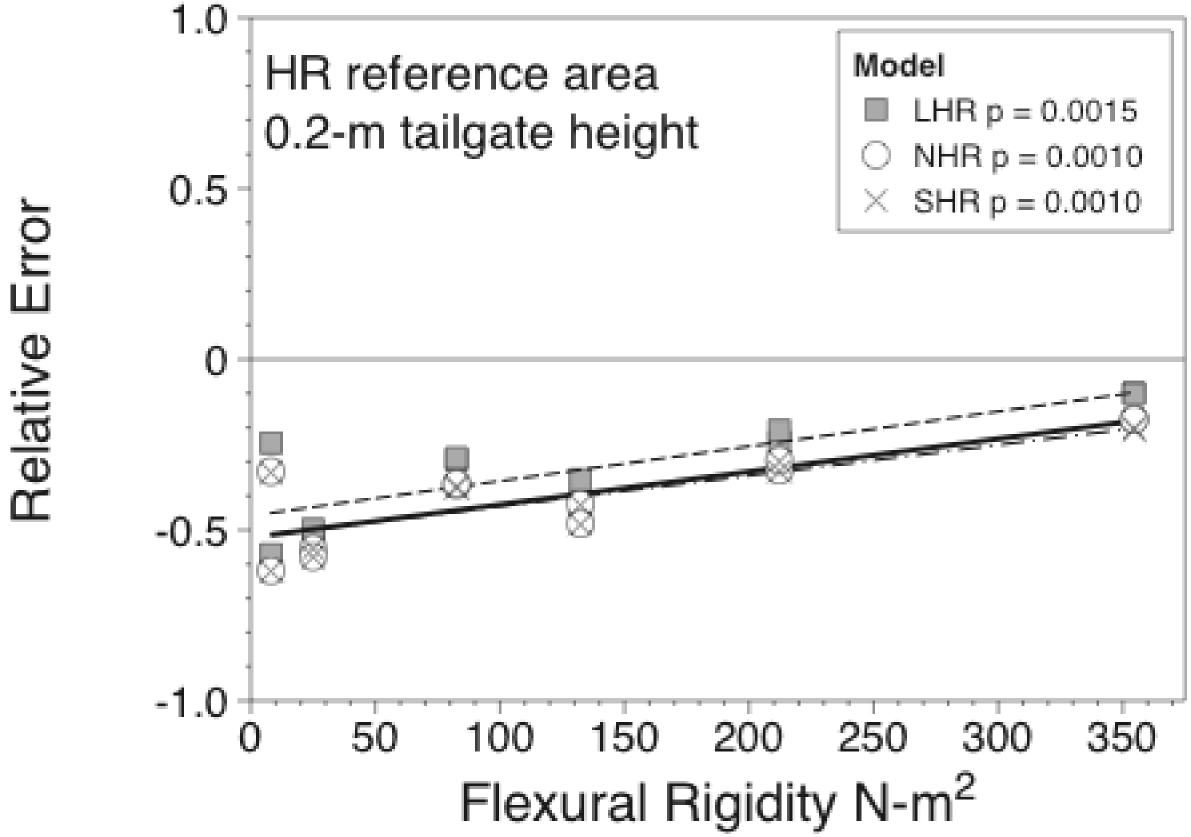
Model interactions were examined to explain the heteroscedasticity of the model error

Model interactions were significant for

- tailgate height
- stem diameter
- blockage factor (proportion of flow cross-sectional area blocked by plants)




Interactions were also examined by tailgate height



Additional interactions were significant for flexural rigidity and stem density

Empirical equations developed from actual vegetation predict C_d most accurately

- Drag reference areas for low-velocity flows should be based on the entire projected vegetation area without overlap (streamwise or total)
- Model lack-of-fit suggests existing empirical relations may be improved by the addition of variables such as flexibility
- Model fit varies with the proportion of the vegetation submerged

Objective 2: Determine which properties of the vegetation influence roughness and construct regression models to predict hydraulic resistance from field conditions

- Buckingham Π analysis was conducted to develop dimensionless parameters to describe friction factor
- Robust regression was used to determine the combination of dimensionless parameters that best predict friction factor
- Robust regressions were validated using Everglades flow and vegetation data (Harvey et al., 2009)

Π

Buckingham Π theorem was used to select an independent combination of variables for regression

$f = F$ (

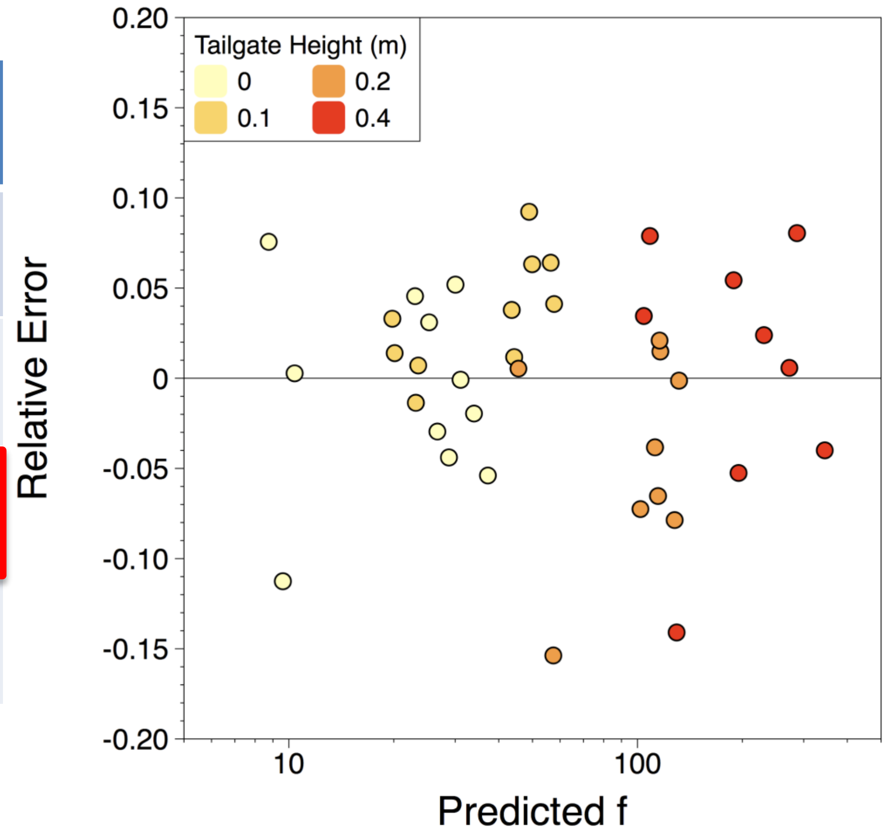
- Reynolds number (stem diameter or depth)
- Froude number
- friction slope
- area coefficient (MAA or PA)
- vegetation flexibility
- vegetation submergence
- vegetation shape ratio

)

Only results using the area coefficient based on the momentum absorbing area (MAA) are presented. Projected area (PA) regressions were significant but were not as strong as the MAA regressions.

Four regressions were selected for high R^2 values and low multicollinearity

Equation	Robust R^2
$f = 10^{4.98} (maa \cdot d)^{0.47} \mathrm{Re}_{stem}^{-1.52}$	0.71
$f = 10^{-1.11} (maa \cdot d)^{0.43} \left(\frac{MEI}{\rho V^2 d^4}\right)^{0.09} \left(\frac{d}{h}\right)^{-1.27}$	0.72
$f = 10^{3.50} (maa \cdot d)^{0.44} \left(\frac{MEI}{\rho V^2 d^4}\right)^{0.08} \mathrm{Re}_{stem}^{-1.31}$	0.71
$f = 10^{1.39} (maa \cdot d)^{0.44} \left(\frac{MEI}{\rho V^2 d^4}\right)^{0.08} \left(\frac{d}{h}\right)^{-0.64} \mathrm{Re}_{stem}^{-0.69}$	0.73



Regression was repeated with a tailgate height interaction term

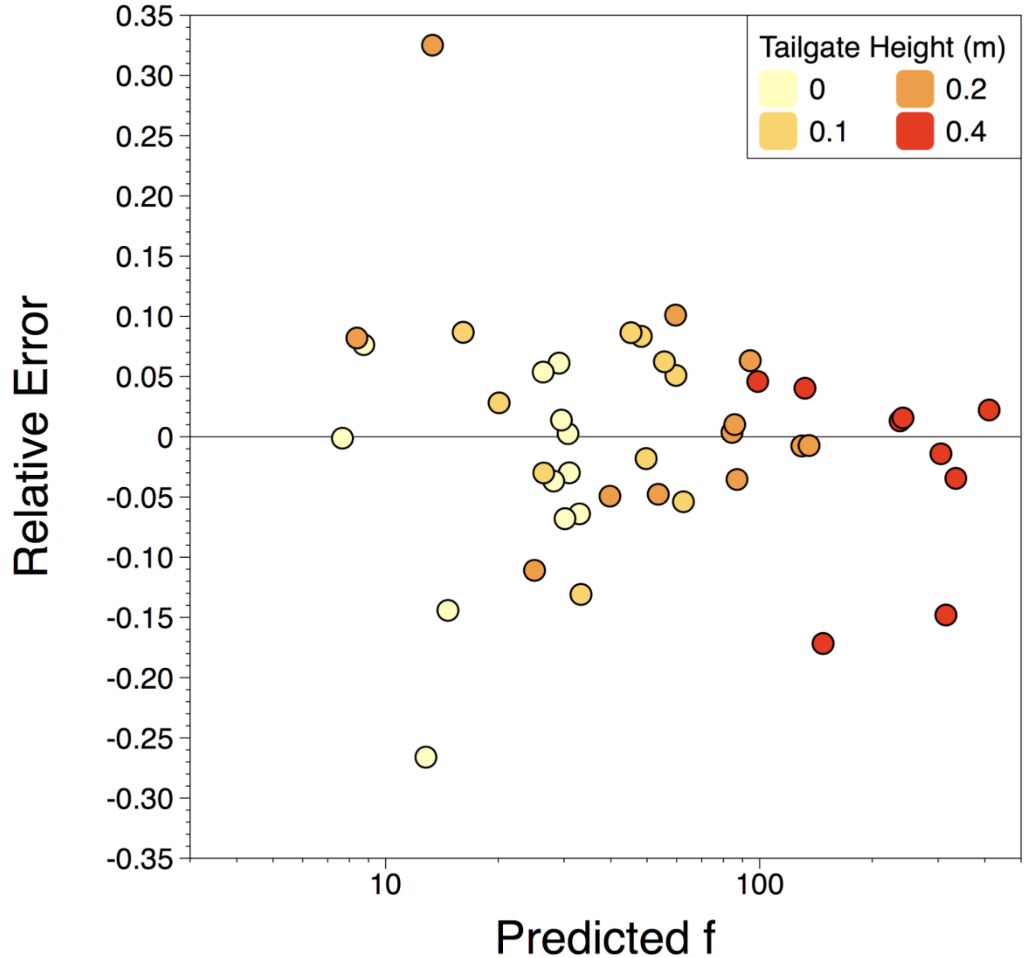
The coefficients for vegetation density was significantly different for the 0.2-m tailgate height

If TG = 0.2 m

$$f = 10^{3.61}\left(maa \cdot d\right)^{0.56}\left(\frac{MEI}{\rho V^2 d^4}\right)^{0.09} \mathrm{Re}_{stem}^{-1.43}$$

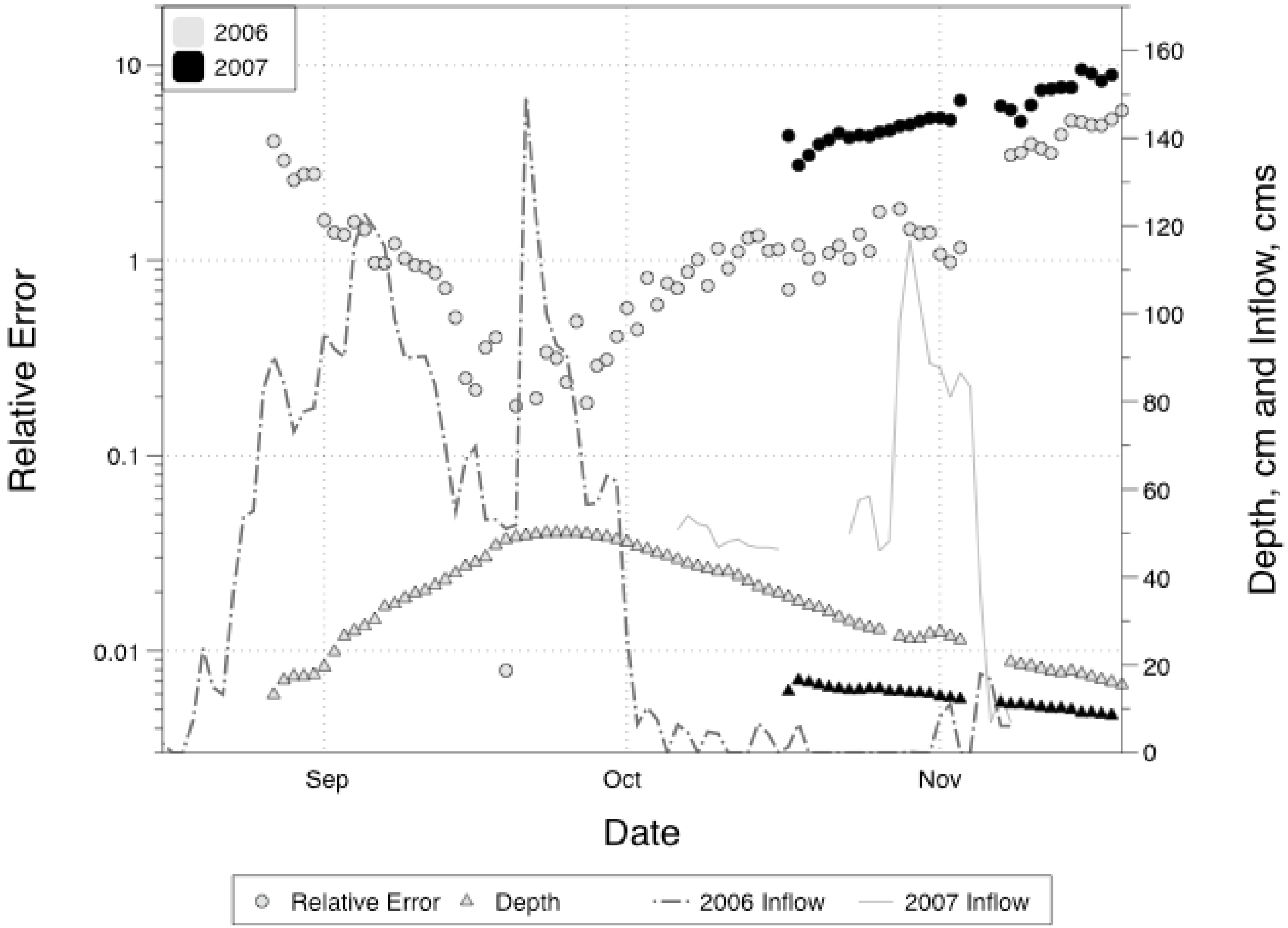
Otherwise

$$f = 10^{3.61}\left(maa \cdot d\right)^{0.46}\left(\frac{MEI}{\rho V^2 d^4}\right)^{0.09} \mathrm{Re}_{stem}^{-1.43}$$

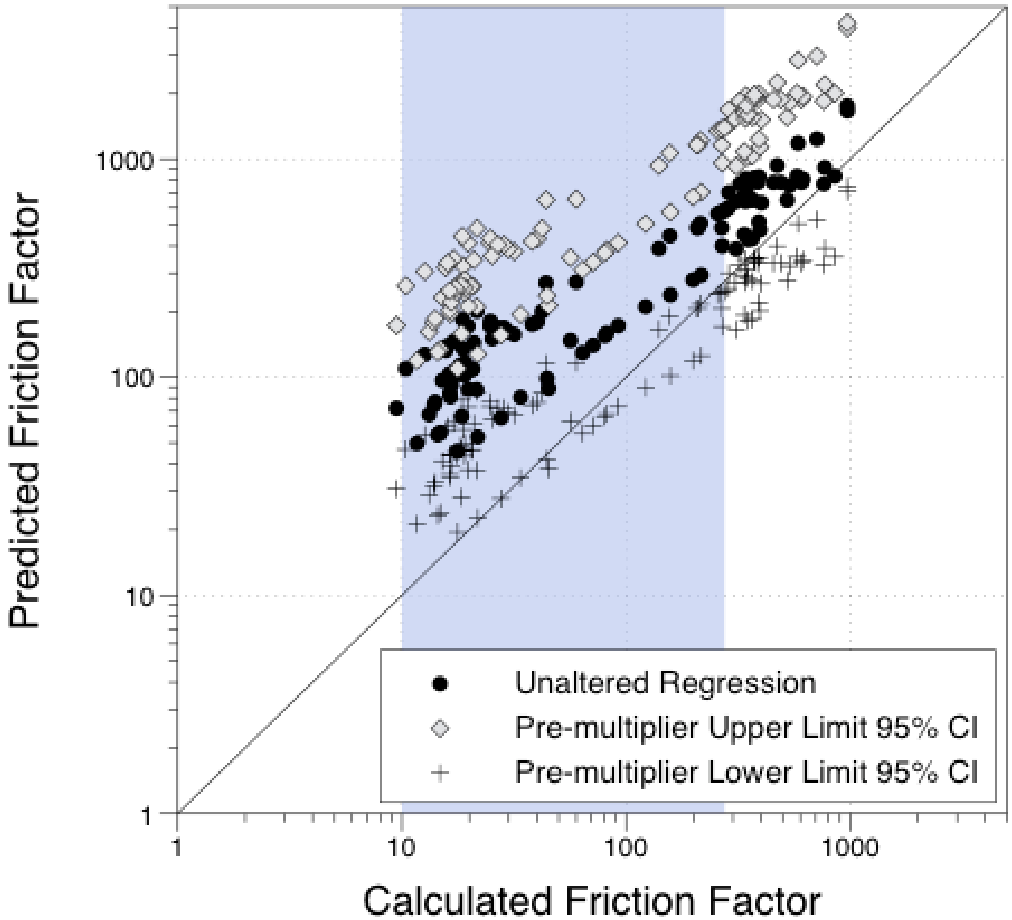


Fit improved to robust $R^2 = 0.76$ (versus 0.71)

Validation error was correlated with time and inflow rate



The predicted friction factor was sensitive to the regression premultiplier coefficient

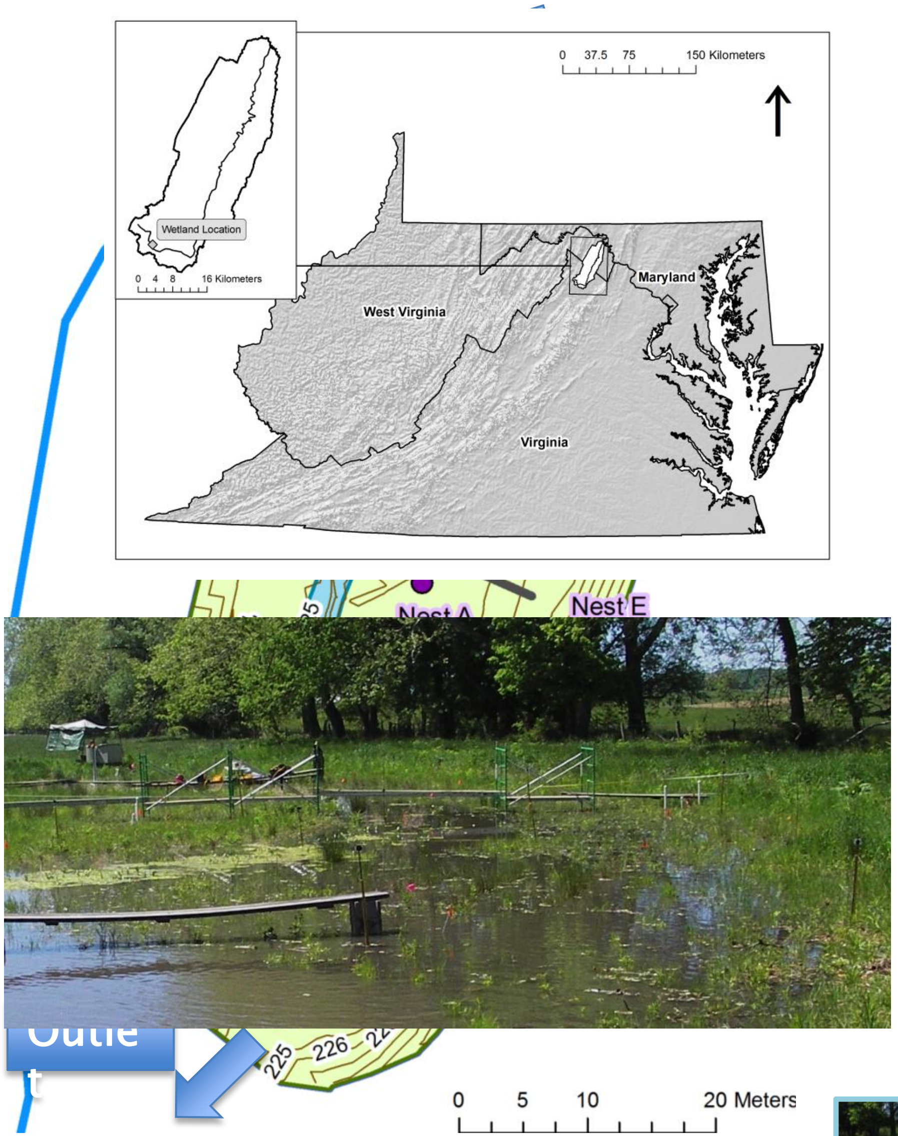


Friction factor is a function of flow Reynolds number, vegetation area and shape, and vegetation flexibility

- The total vegetation area (MAA) is more predictive of friction factor than the projected vegetation area with overlap (PA)
- The friction factor relationships are sensitive to the value of the regression premultiplier
- Differences in vegetation architecture and velocity distributions between the Everglades and the flume is a likely cause of the poor performance of the friction factor model for the Everglades ridge community

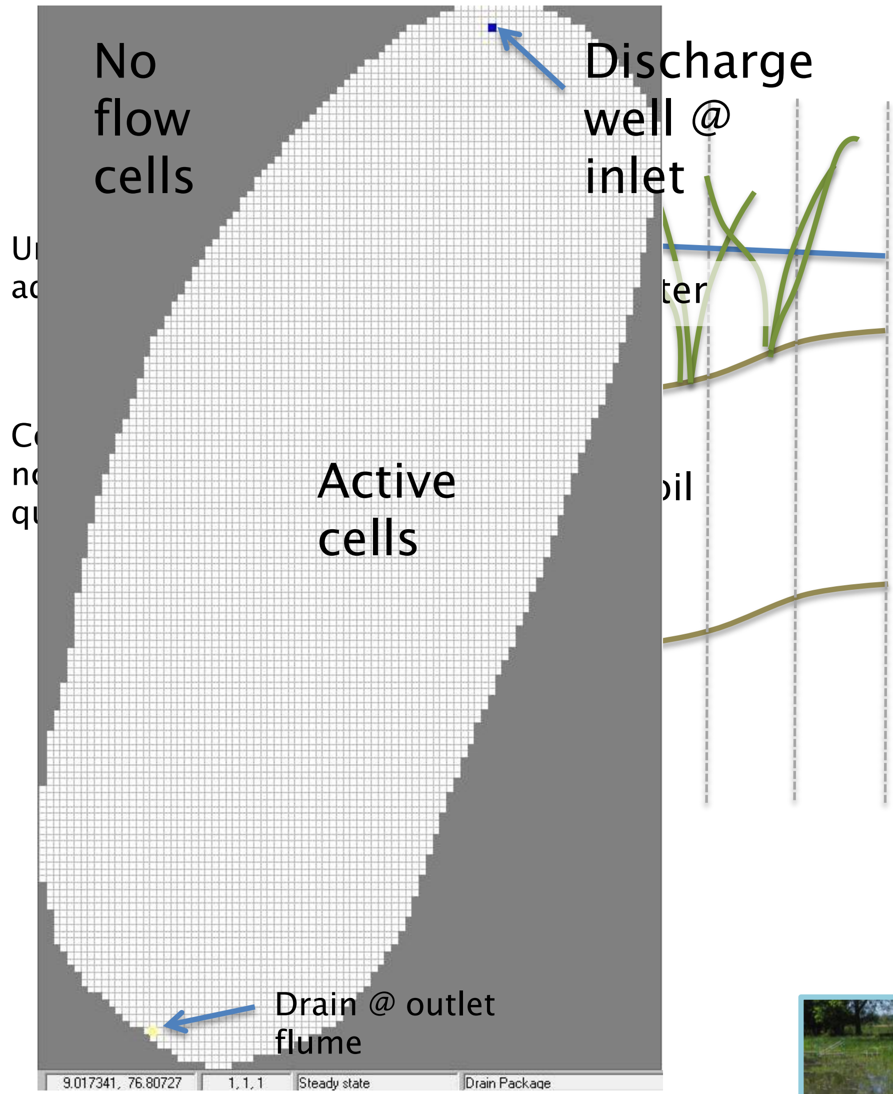
Objective 3: Field-test stage-discharge and regression models to predict vegetation resistance due to flow

- Field site located near Winchester, VA
- Small (~0.5-acre constructed floodplain wetland)
- Conducted two 8-hour flood events over the course of two days in May 2009
- Measured inflow, outflow, GW potentiometric surface, surface water stage, and surface water velocity



Wetland was modeled in MODFLOW as a two-layer aquifer system

- Pump was simulated as a discharge well
- Outlet flume was simulated as a drain
- Surface K values were estimated from vegetation characteristics



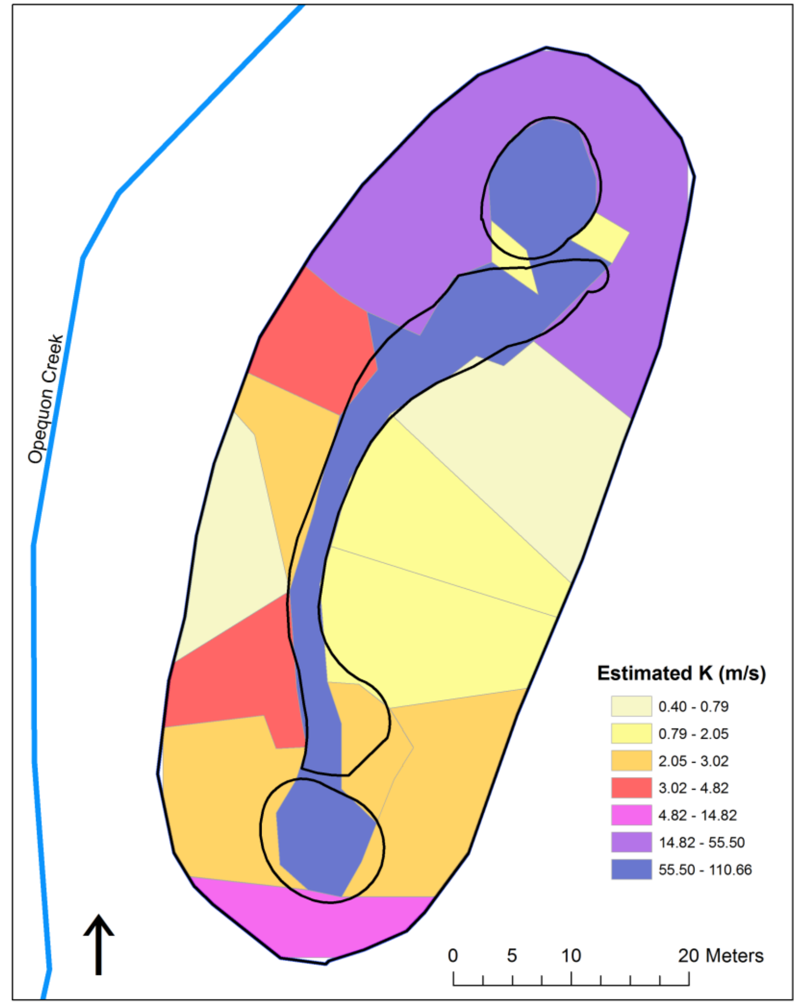
Surface hydraulic conductivity was predicted from vegetation properties

$$f = 10^{4.98}(maa \cdot d)^{0.47}\,\mathrm{Re}_{stem}^{-1.52}$$

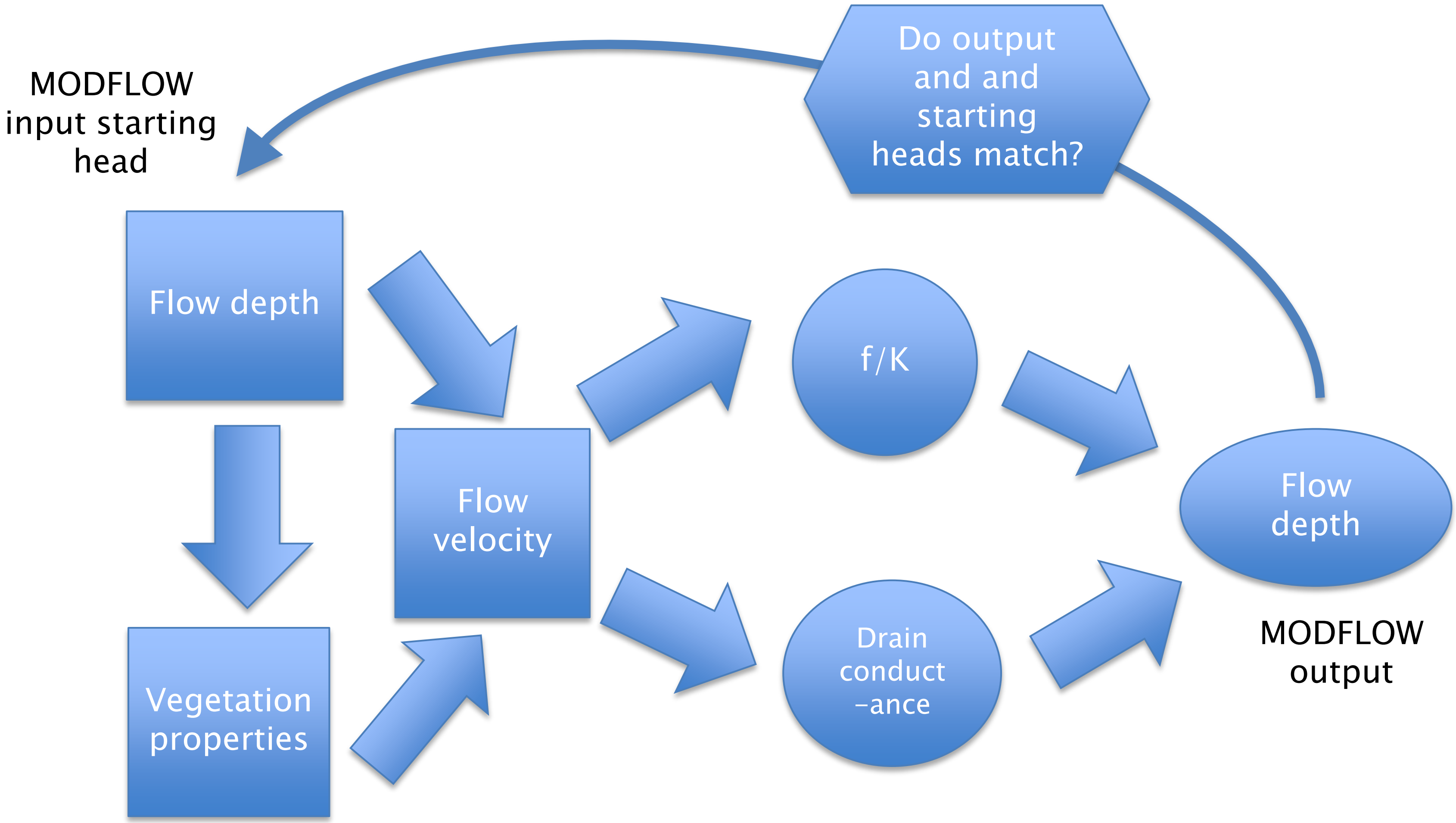
↓ from Obj. 2

$$K = \frac{8gR}{fv}$$

f is friction factor
maa is momentum absorbing area per unit volume
d is stem diameter
Re_{stem} is stem Reynolds number
K is hydraulic conductivity
g is acceleration due to gravity
R is hydraulic radius (depth)
v is flow velocity

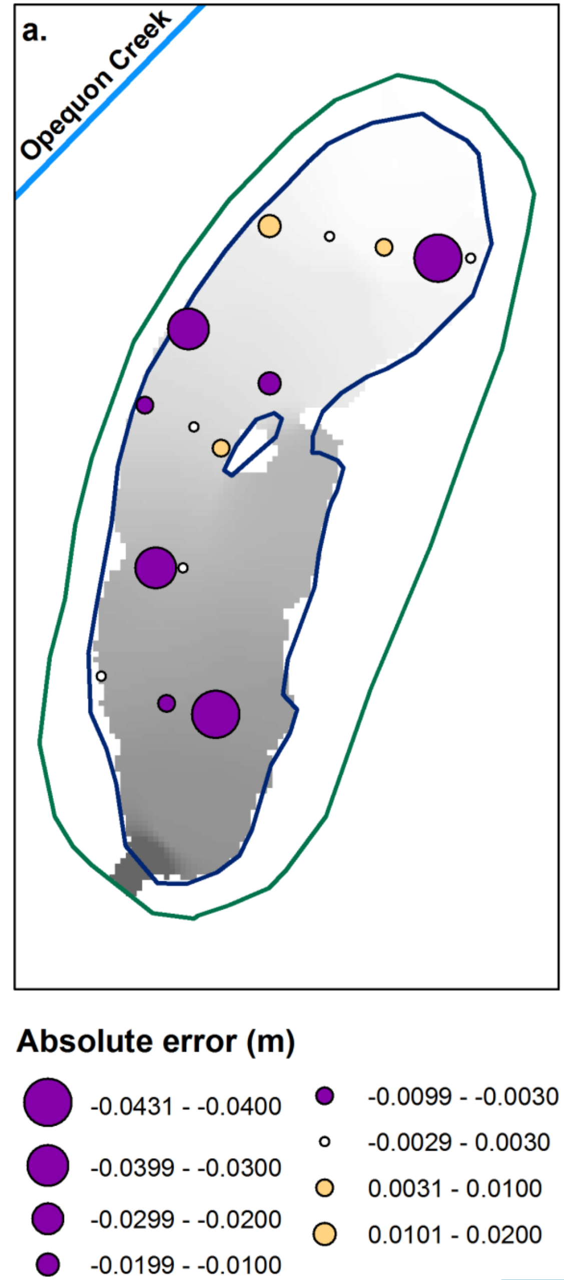


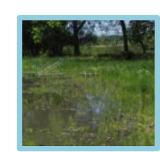
MODFLOW iteration process



Error ranged from −4.3 cm to 1.4 cm with a mean error of −1.1 cm

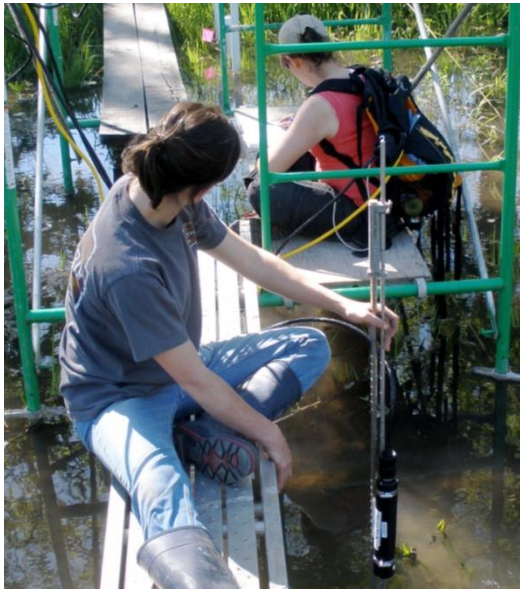
- Low marsh (slough) mean error was -0.1 cm
- High marsh (ridge) mean error was -1.4 cm
- On average, MODFLOW slightly underpredicted the water surface elevation
- The overall error is close to the survey and digitization error

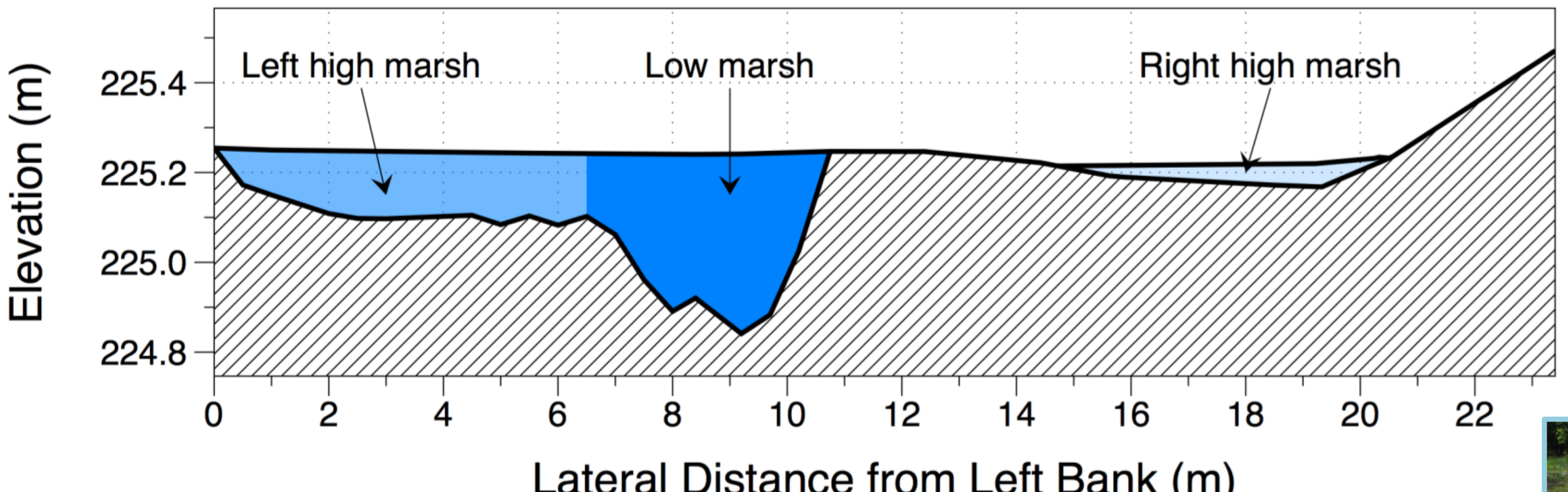




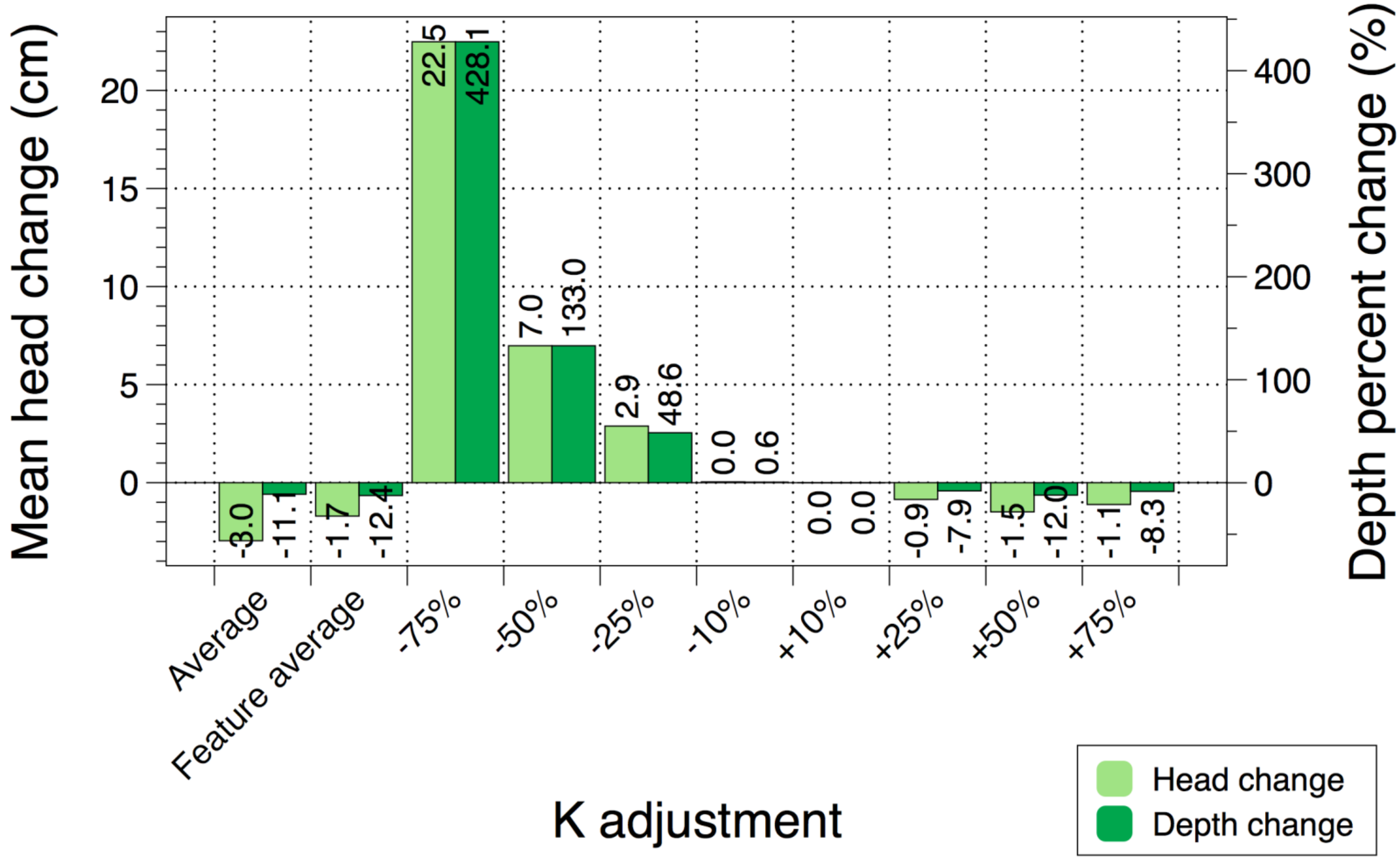
Model velocity was underestimated in the low marsh and overestimated in the high marsh

Feature	Estimated average velocity (cm/s)	Measured average velocity (cm/s)
Left high marsh	2.0	2.9
Low marsh	3.4	5.7
Right high marsh	2.3	0





Decreasing the surface K increased the surface water depth

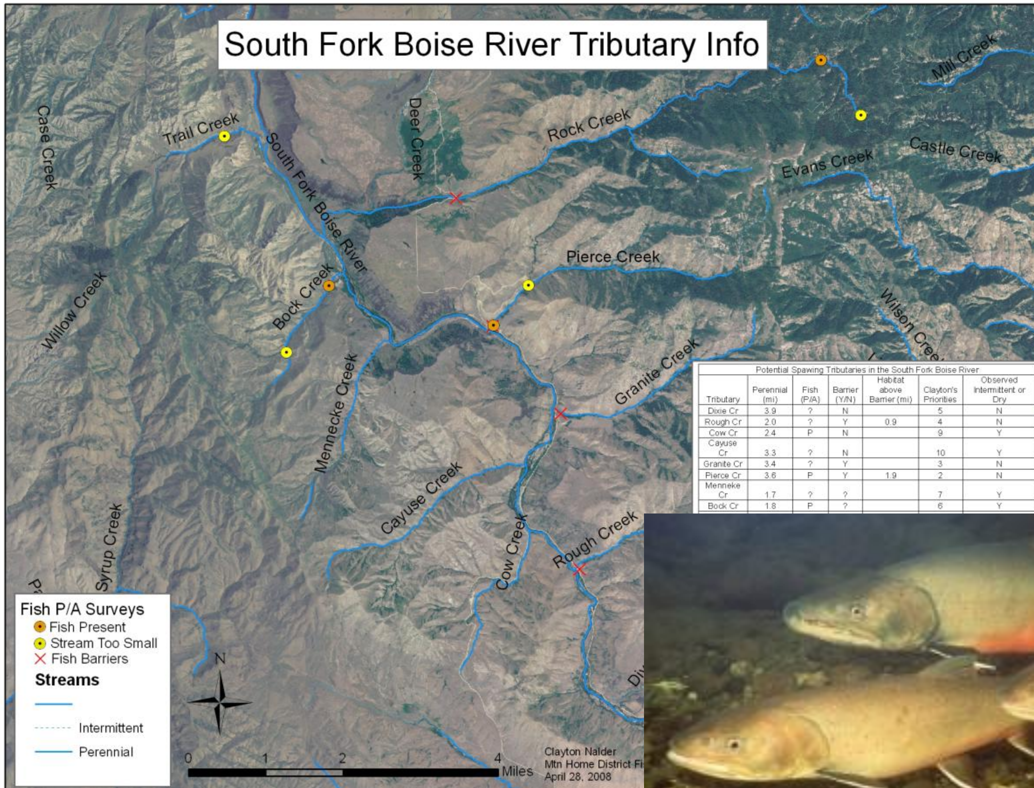


Generally MODFLOW underpredicted the water surface elevation

- MODFLOW performed poorest in areas of rapid changes in water surface elevation
- The model velocity was underestimated in the low marsh and overestimated in the high marsh
- MODFLOW output is most sensitive to reductions in hydraulic conductivity

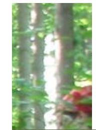
Study limitations and future questions

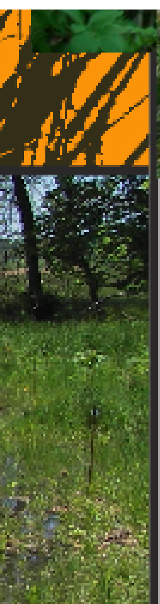
- The flume study was limited in a number of ways
  - One vegetation species
  - Limited flow range
  - One bed slope
- The application of MODFLOW was limited to steady state saturated conditions
- Future studies should include measurements of vegetation flexibility
- Future studies should include multiple bed slopes and vegetation structures
- Ideally, vegetation geometry measurement techniques should be designed to be applied to a variety of vegetation structures



Potential Spawing Tributaries in the South Fork Boise River

Tributary	Perennial (mi)	Fish (P/A)	Barrier (Y/N)	Habitat above Barrier (mi)	Clayton's Priorities	Observed Intermittent or Dry
Dixie Cr	3.9	?	N		5	N
Rough Cr	2.0	?	Y	0.9	4	N
Cow Cr	2.4	P	N		9	Y
Cayuse Cr	3.3	?	N		10	Y
Granite Cr	3.4	?	Y		3	N
Pierce Cr	3.6	P	Y	1.9	2	N
Menneke Cr	1.7	?	?		7	Y
Bock Cr	1.8	P	?		6	Y





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Questions?