Collaborative Research Initiative on Sustainability and Protection of Springs (CRISPS): Quantifying **Silver River Hydraulics and Hydrodynamics**

Spring Meeting, March 10th, 2016, Palatka, FL

David Kaplan (UF Lead), Pete Sucsy (SJRWMD Lead), Ed Carter, Nathan Reaver, Jodi Slater, Joseph Stewart, Yanfeng Zhang

UF | UNIVERSITY of FLORIDA
The Foundation for The Gator Nation

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

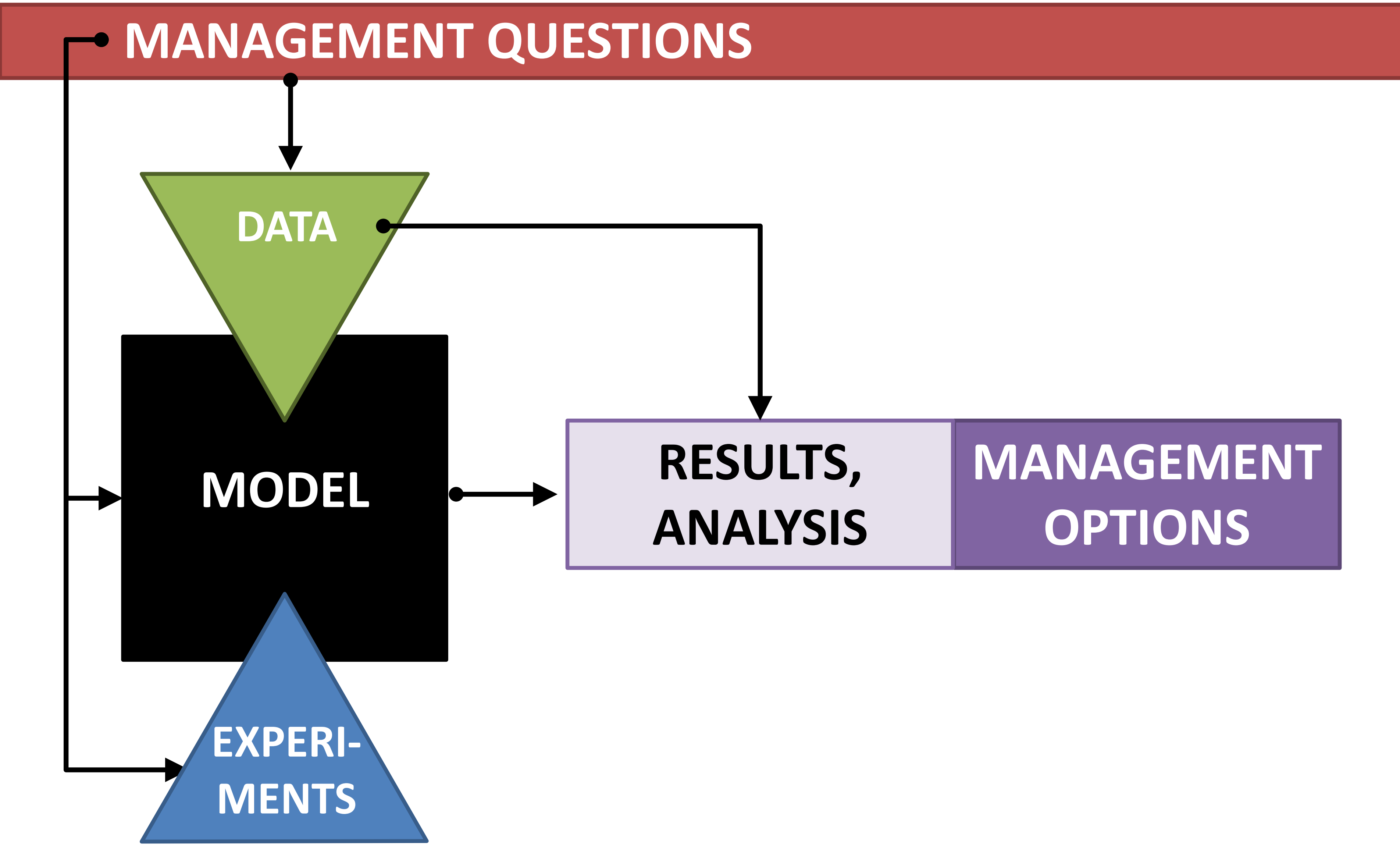
H & H Objective (simplified)

SJRWMD Team

"…determine whether velocity is an important non-nitrate factor influencing the community structure and function of primary producers in the system."

UF Team

H & H Approach (simplified)

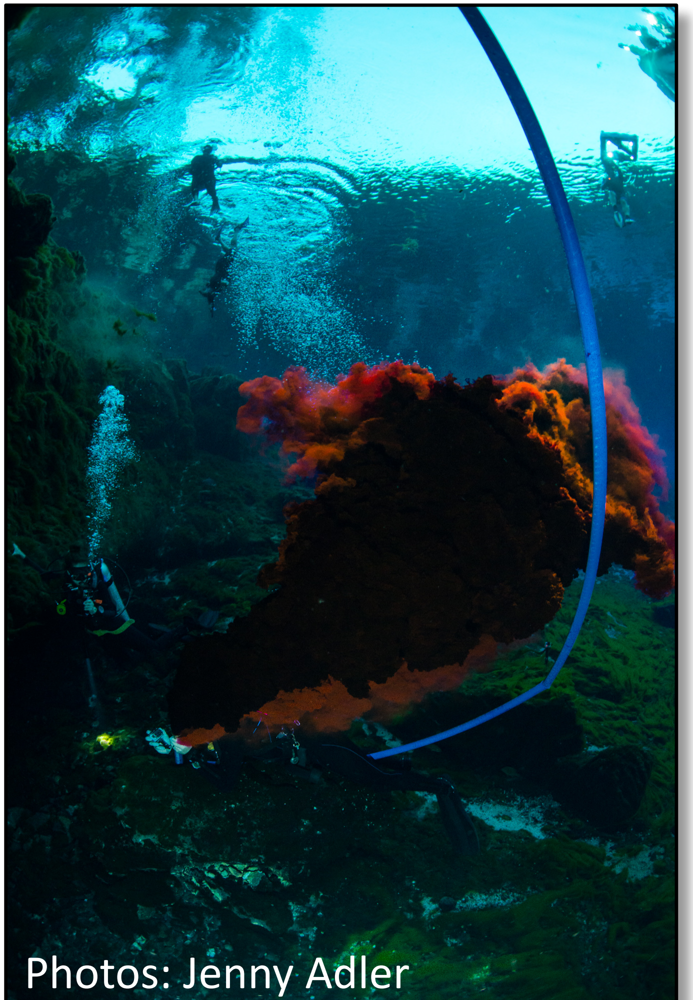


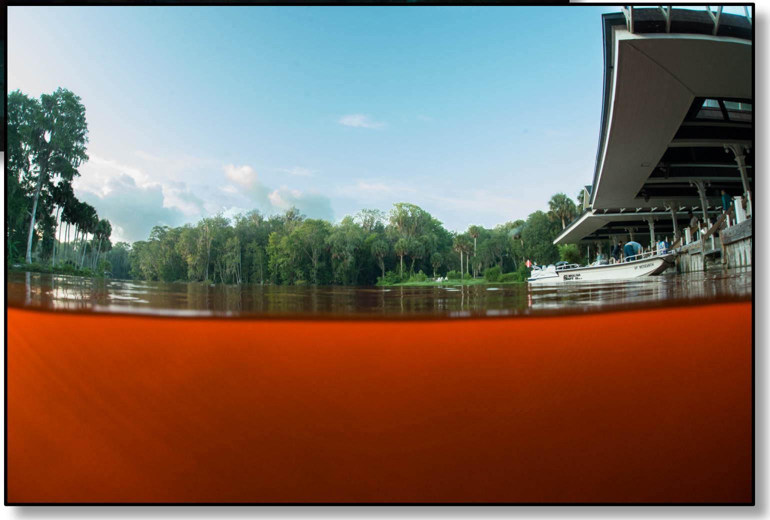
Management-Driven Research Objectives

1. **Measure reach-and point-scale velocity variation**
   – Dye trace experiments/modeling **(UPDATE)**
   – Direct measurements; ADCP and vertical profiles **(SUCSY ET AL.)**
2. **Develop/refine velocity-algae-SAV relationships**
   – Observational **(UPDATE)**
   – *In-situ* flow-ways **(UPDATE)**
   – Optical methods
3. **Understand changes in stage-discharge relationship**
   – Historical data analyses **(UPDATE)**
   – Modeling **(UPDATE)**
4. **Analyze management scenarios**
   – EFDC Modeling **(SUCSY ET AL.)**

1. Reach-Scale Velocity

- **<u>Dye tracer experiments</u>**: 5 gallons Rhodamine WT at Mammoth





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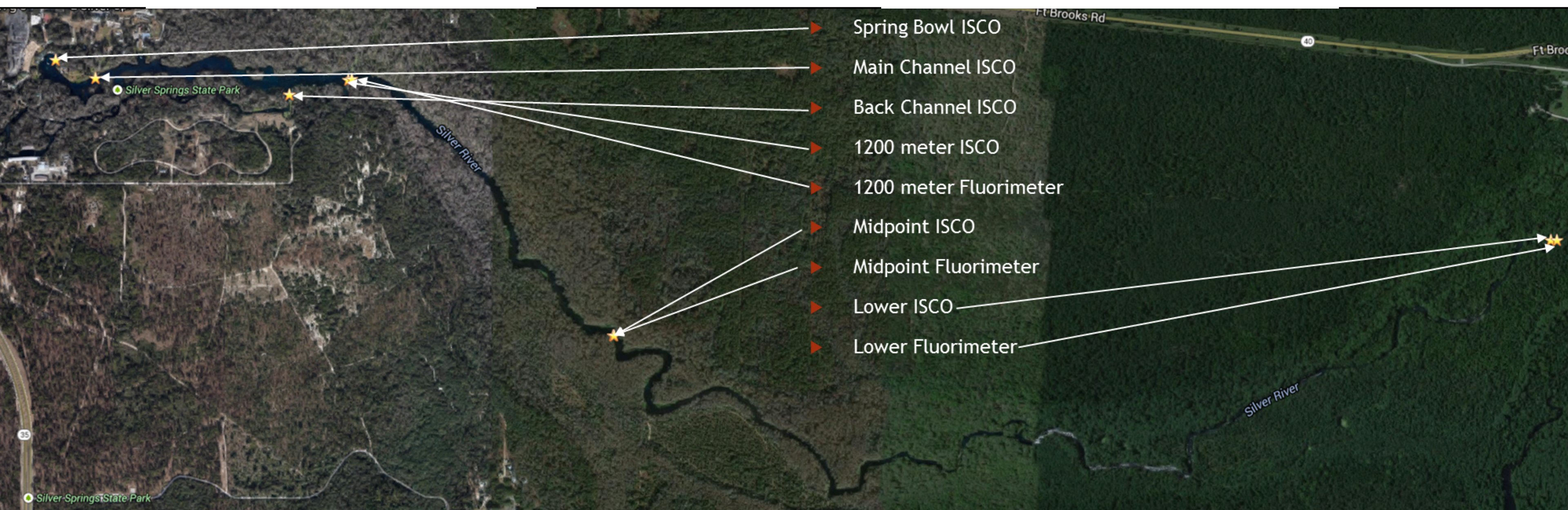
- Measure dye concentration at multiple downstream locations

Upstream Reach | Downstream Reach



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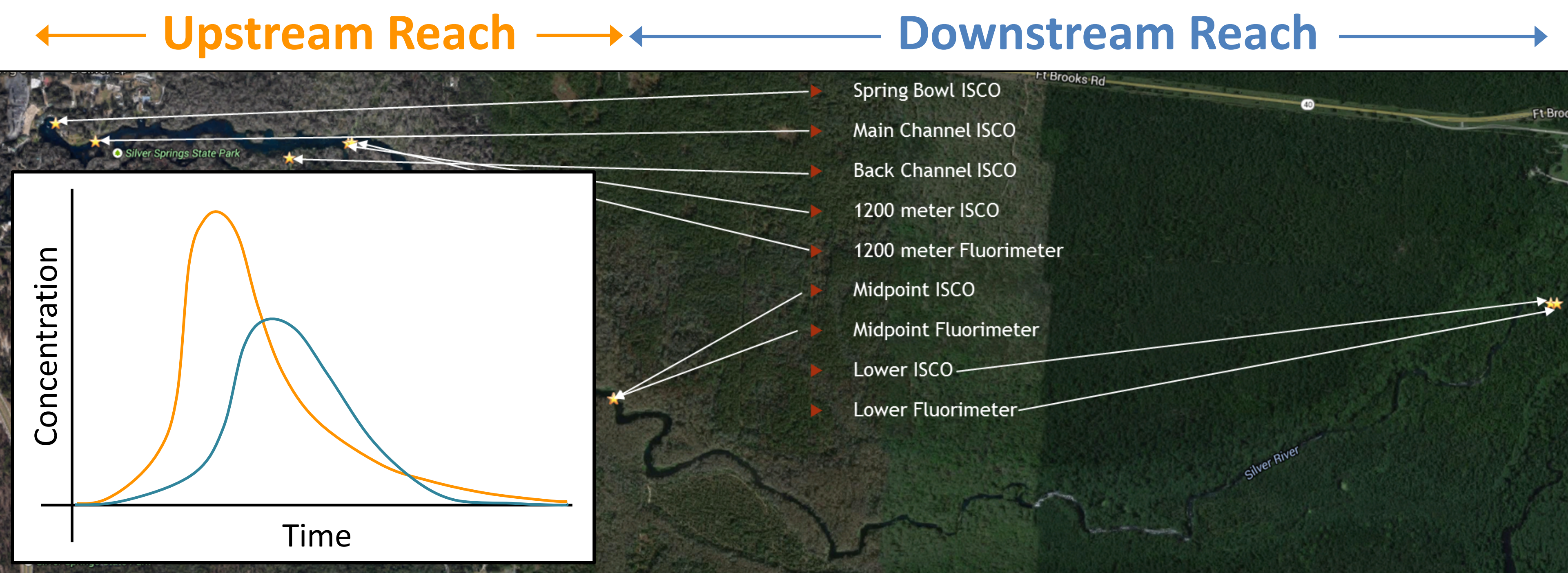
- Calculate velocity, residence time, mixing characteristics



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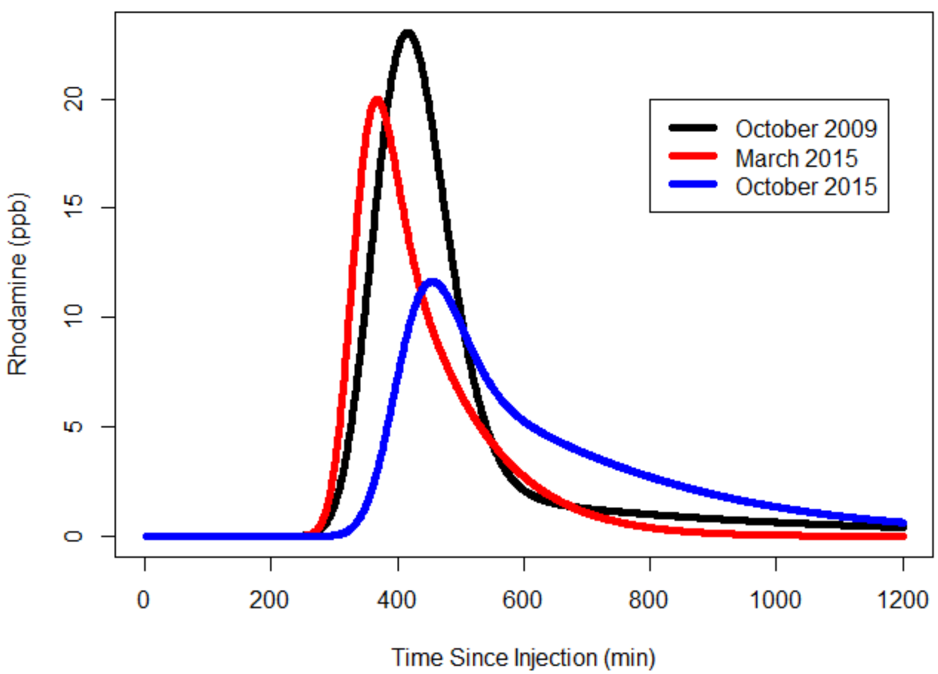

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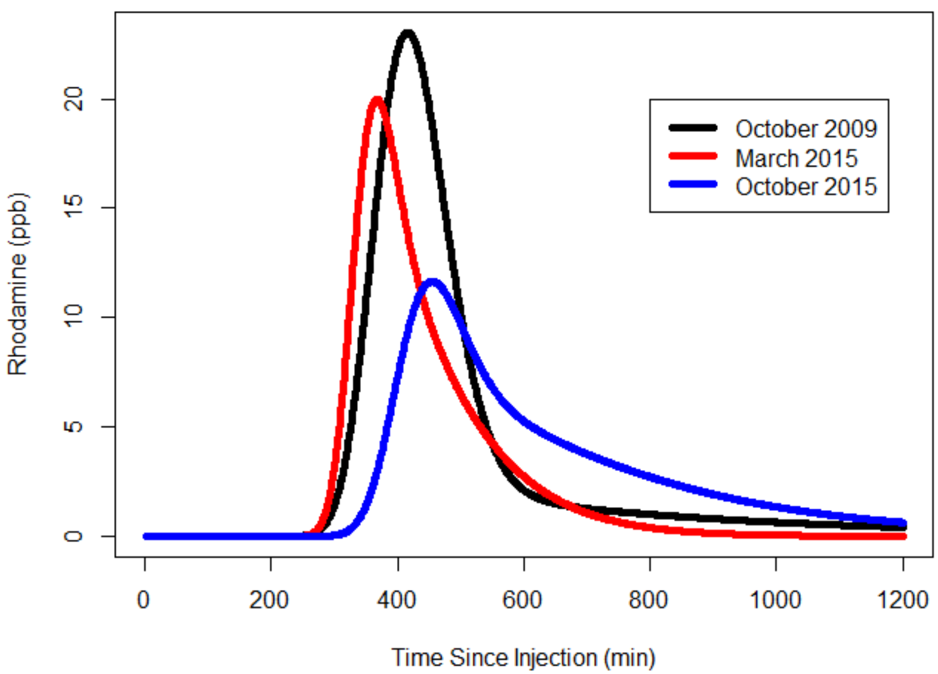
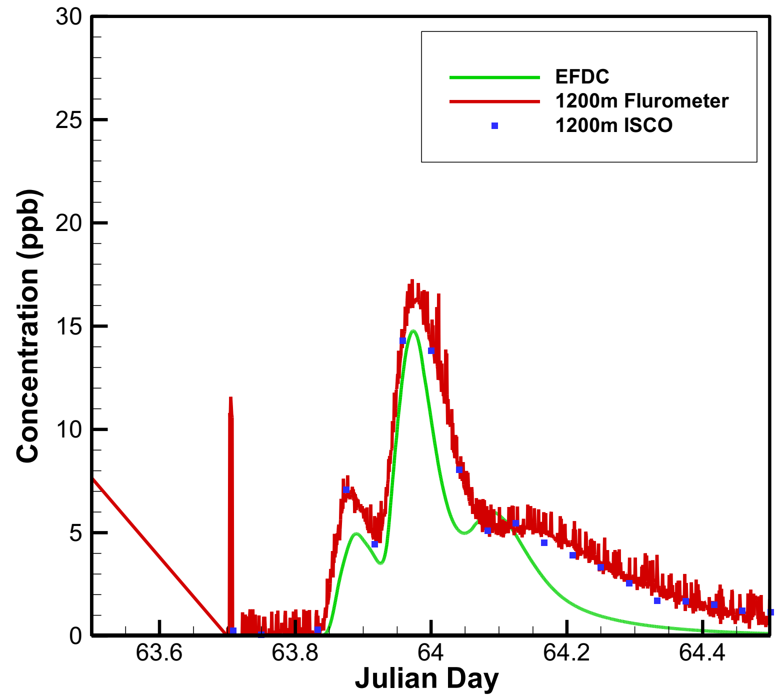
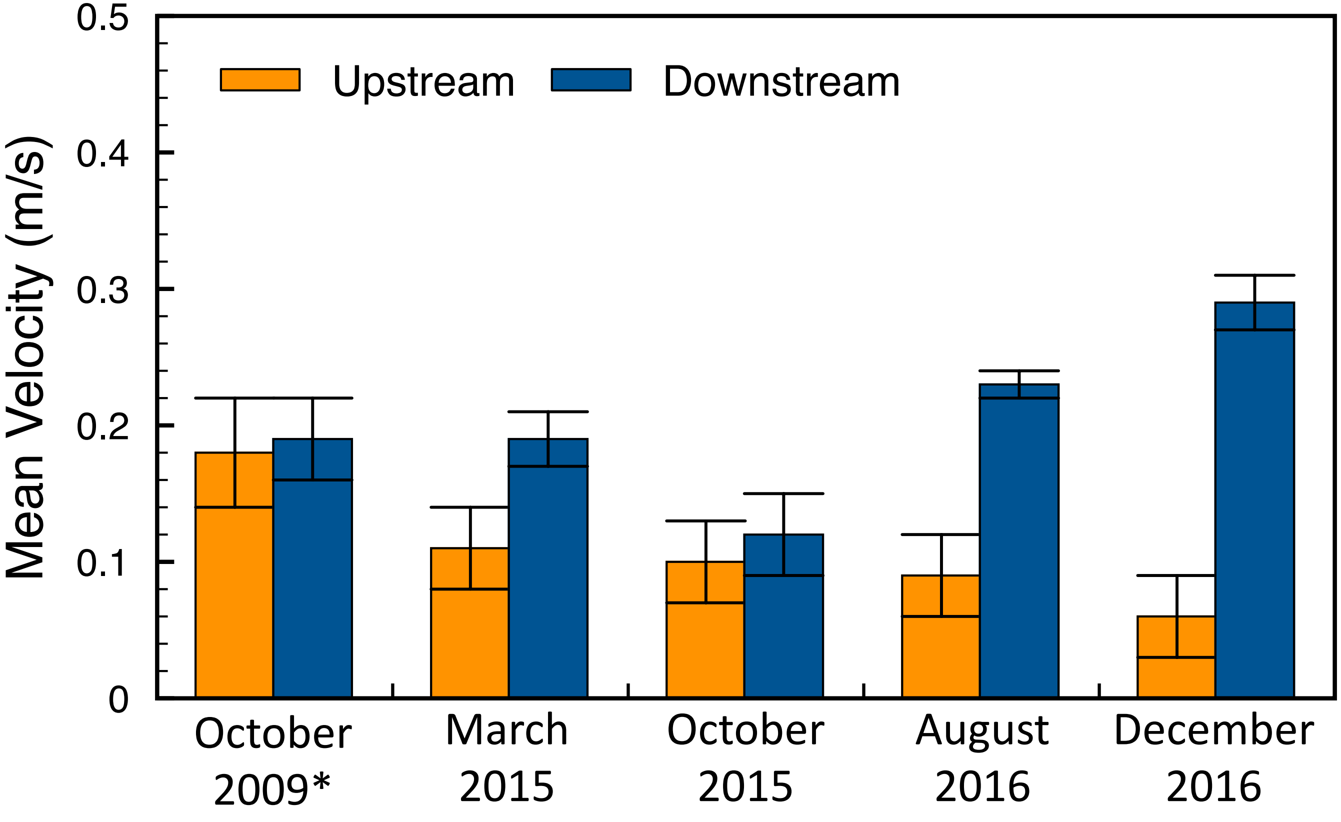
- Couple with EFDC model (calibration, MGMT scenario testing)





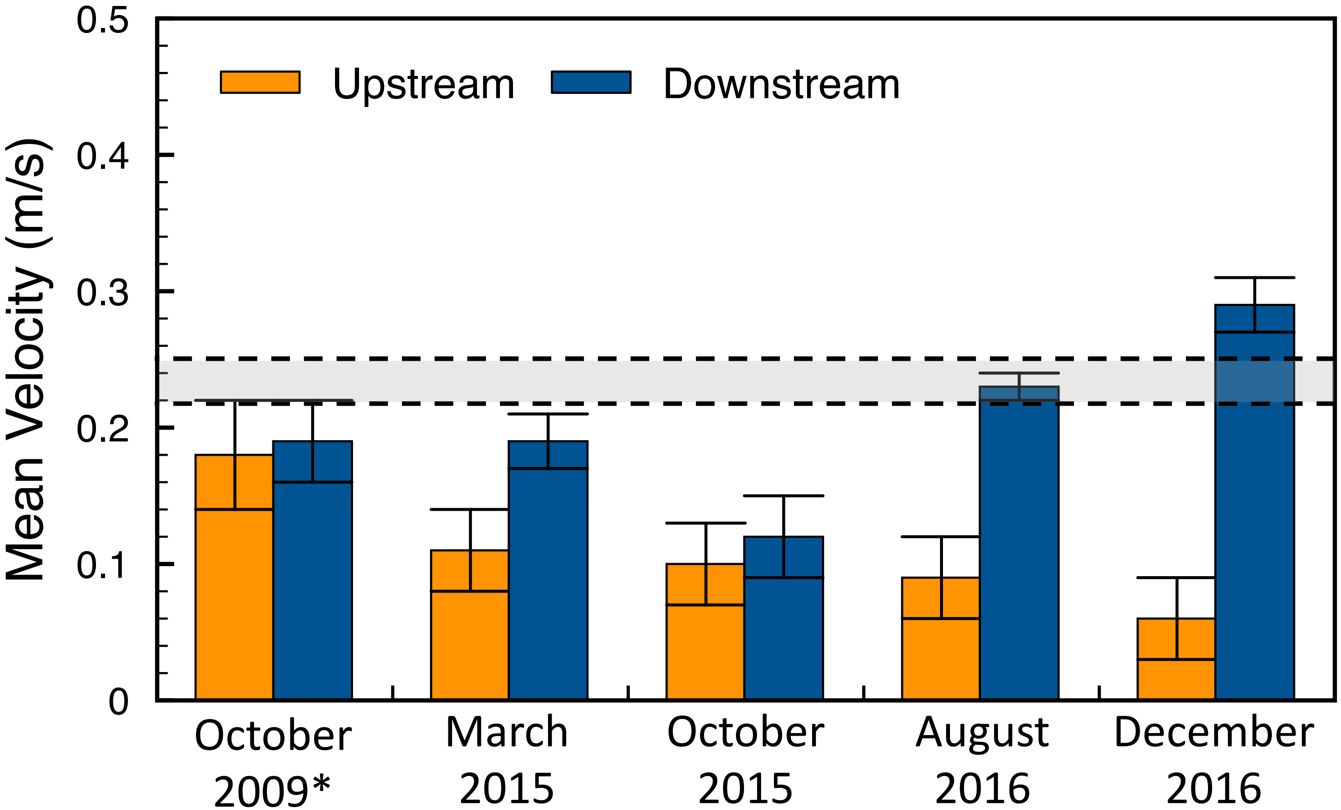
1. Reach-Scale Velocity

- Mean +/- SD velocity by reach from five tracer studies



1. Reach-Scale Velocity

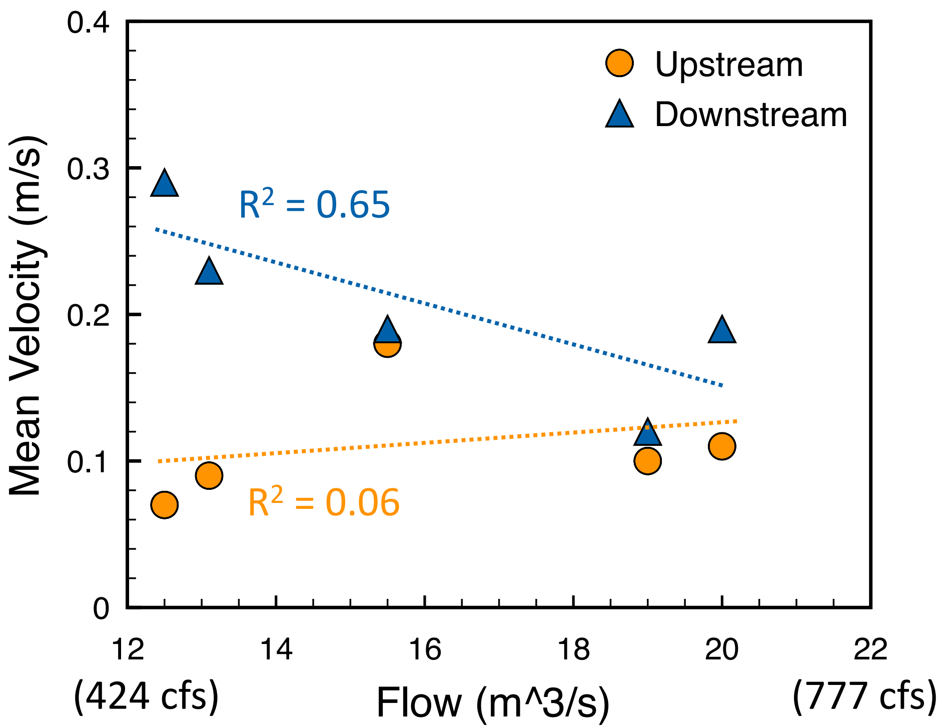
- Mean +/- SD velocity by reach from five tracer studies
- Versus velocity thresholds? (Objective 2)
  - **<u>MGMT Implication</u>**: Silver River mean velocities vary in time and are often below threshold for (macro)algae presence…temporal trends?

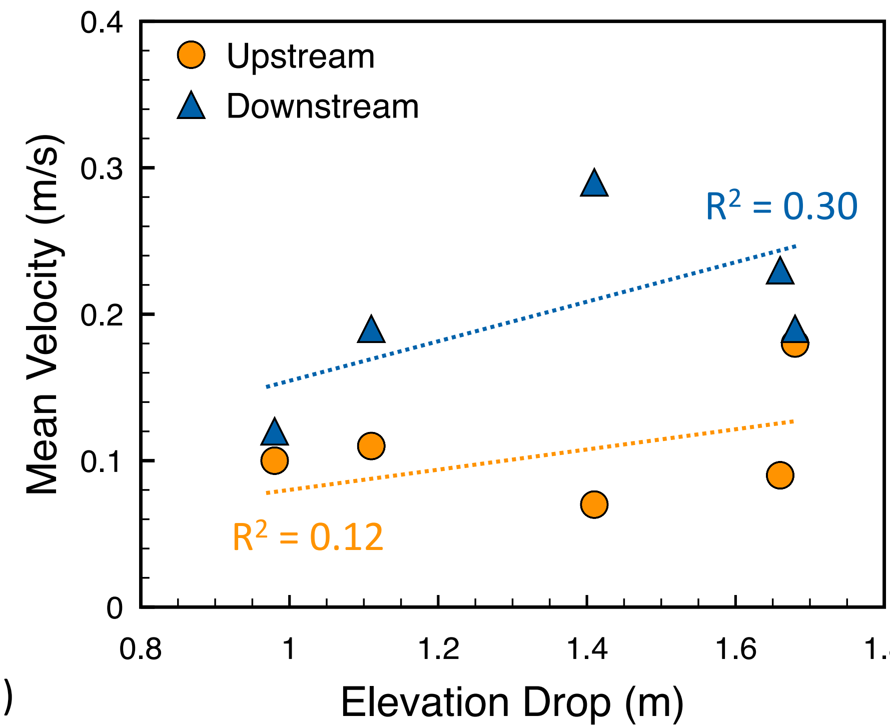


0.22 – 0.25 m/s
(Hoyer et al. 2004; King 2014)

1. Reach-Scale Velocity

- Mean +/- SD velocity by reach from five tracer studies
- Versus velocity thresholds? (Objective 2)
- Role of flow vs. stage vs. vegetation (Objective 3)
  - **MGMT Implication**: Increased discharge does not equate directly to increased velocity; need to consider changes in *Q*, *h*, and vegetative drag





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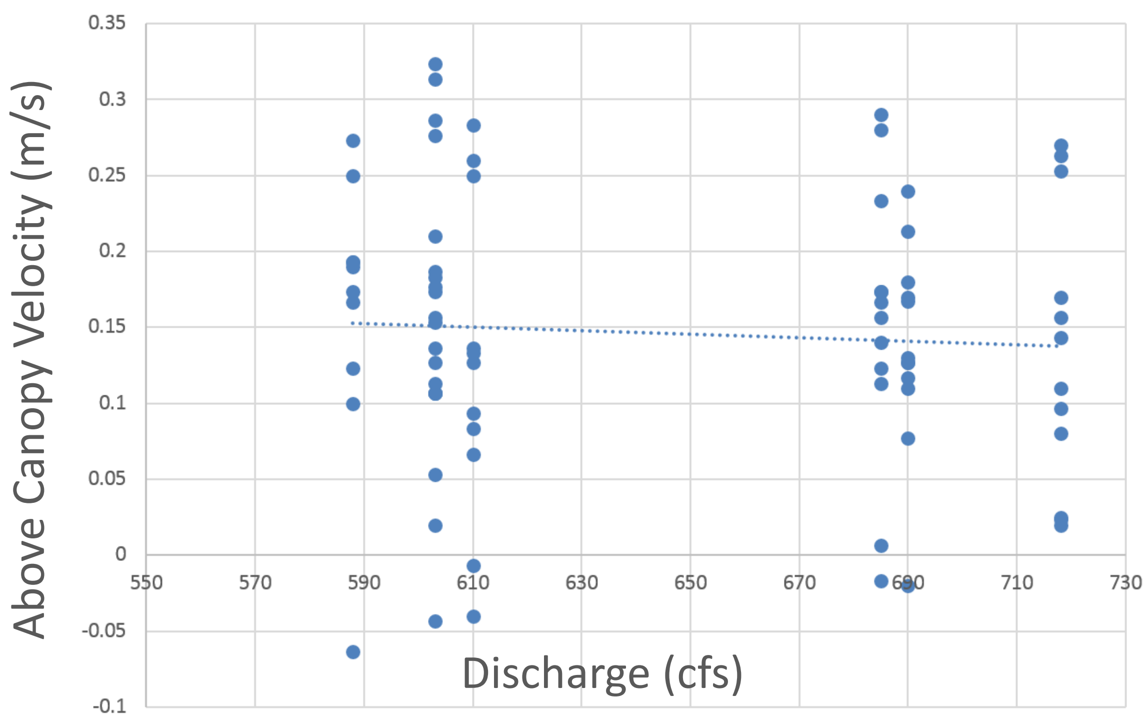
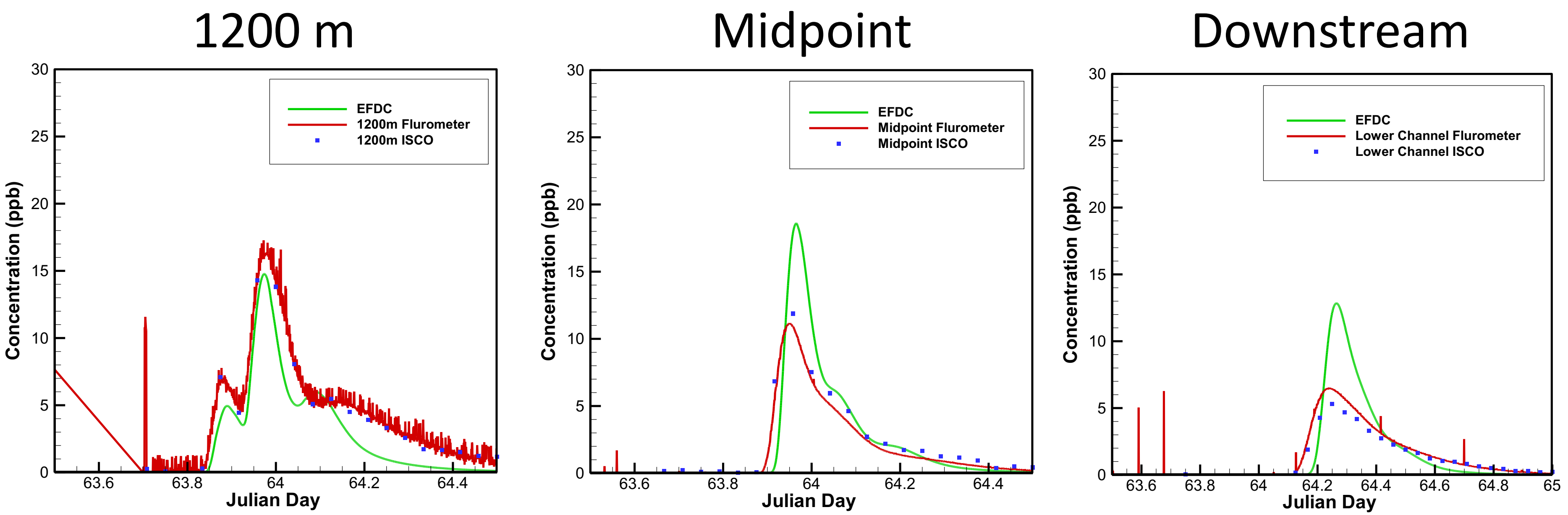


Data from Ed Carter

1. Reach-Scale Velocity

- Mean +/- SD velocity by reach from five tracer studies
- Versus velocity thresholds? (Objective 2)
- Role of flow vs. stage vs. vegetation (Objective 3)
- Data for calibrating EFDC model (Objective 4)
  - **MGMT Implication**: EFDC is the primary tool for assessing how changes in management that affect flow and stage impact velocity and solute transport



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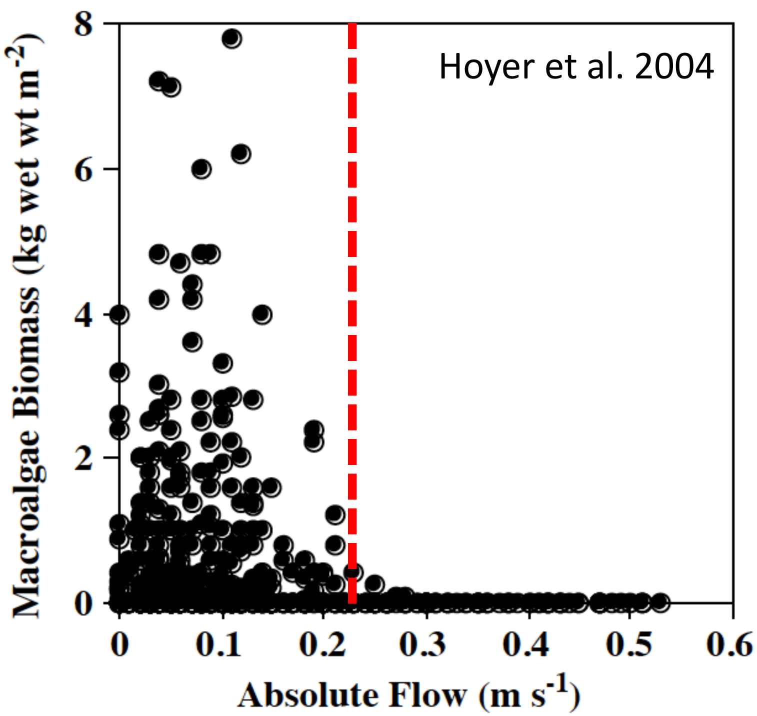
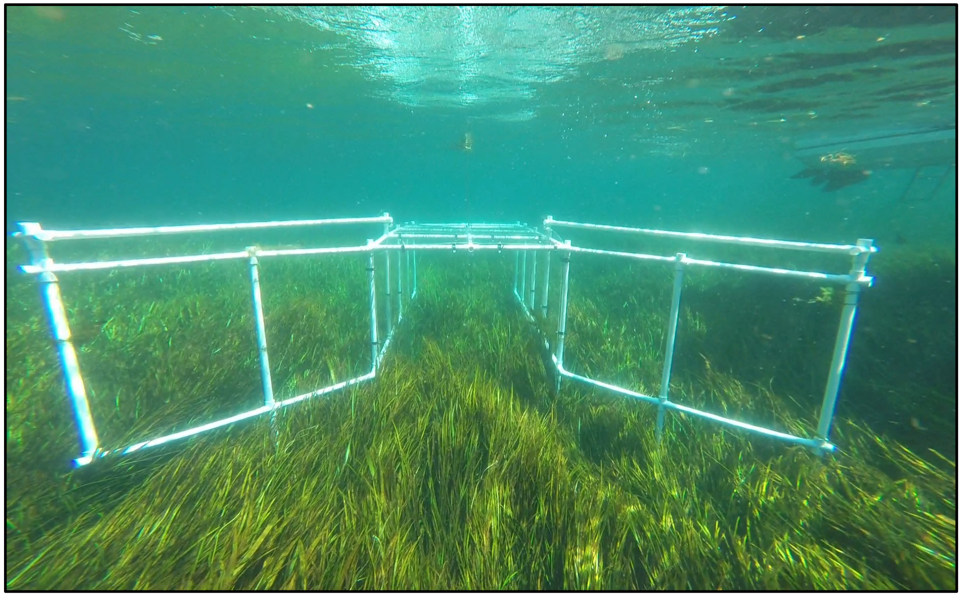
2. Velocity-Algae: What do we want to know?

1. Critical velocity and/or shear stress for algal sloughing
2. Algal colonization/growth rate on SAV
3. Are there hysteretic effects after algae are established?

- Two approaches: **Observational (1)** vs. Experimental (1-3)

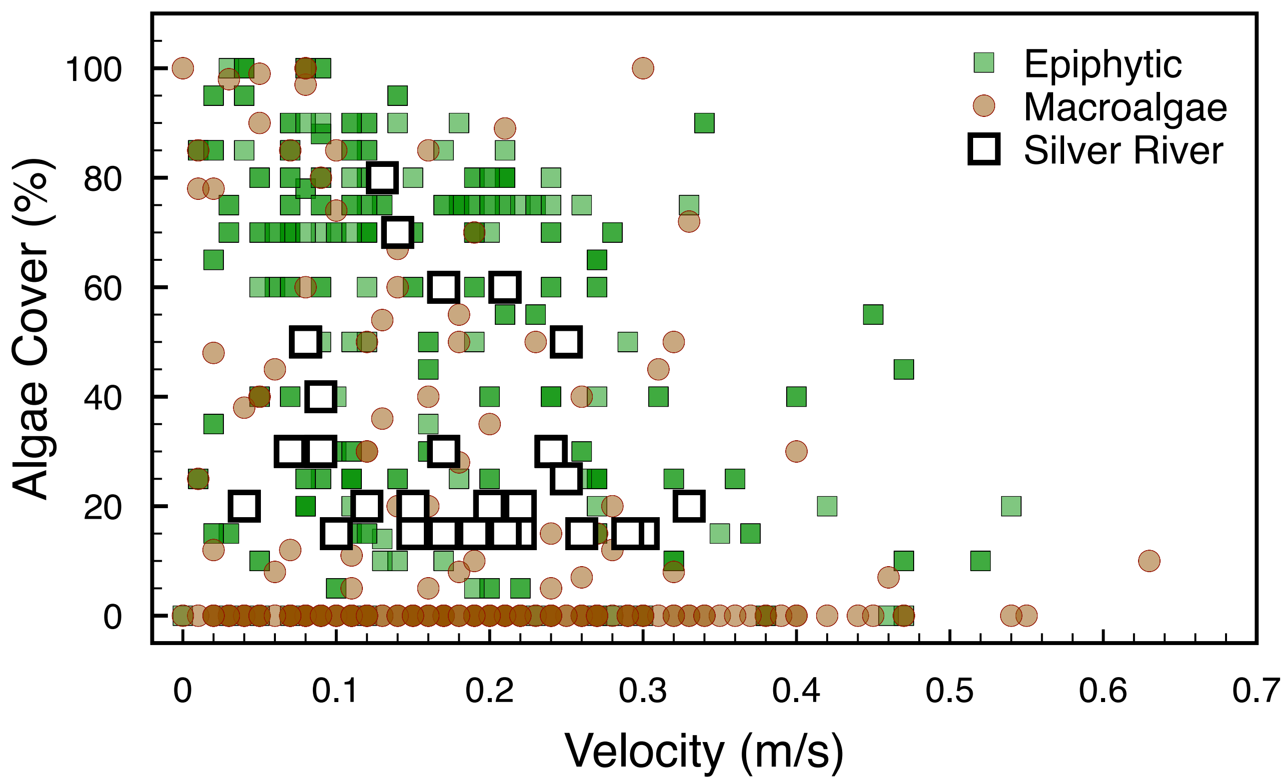




2. Velocity-Algae: Mining Observations, Pt. I

Synoptic Springs Survey

- SJRWMD/AMEC-FW
- 14 Springs, 26 Transects
- Veg, algae, sediment, macroinvertebrates, water quality, etc.



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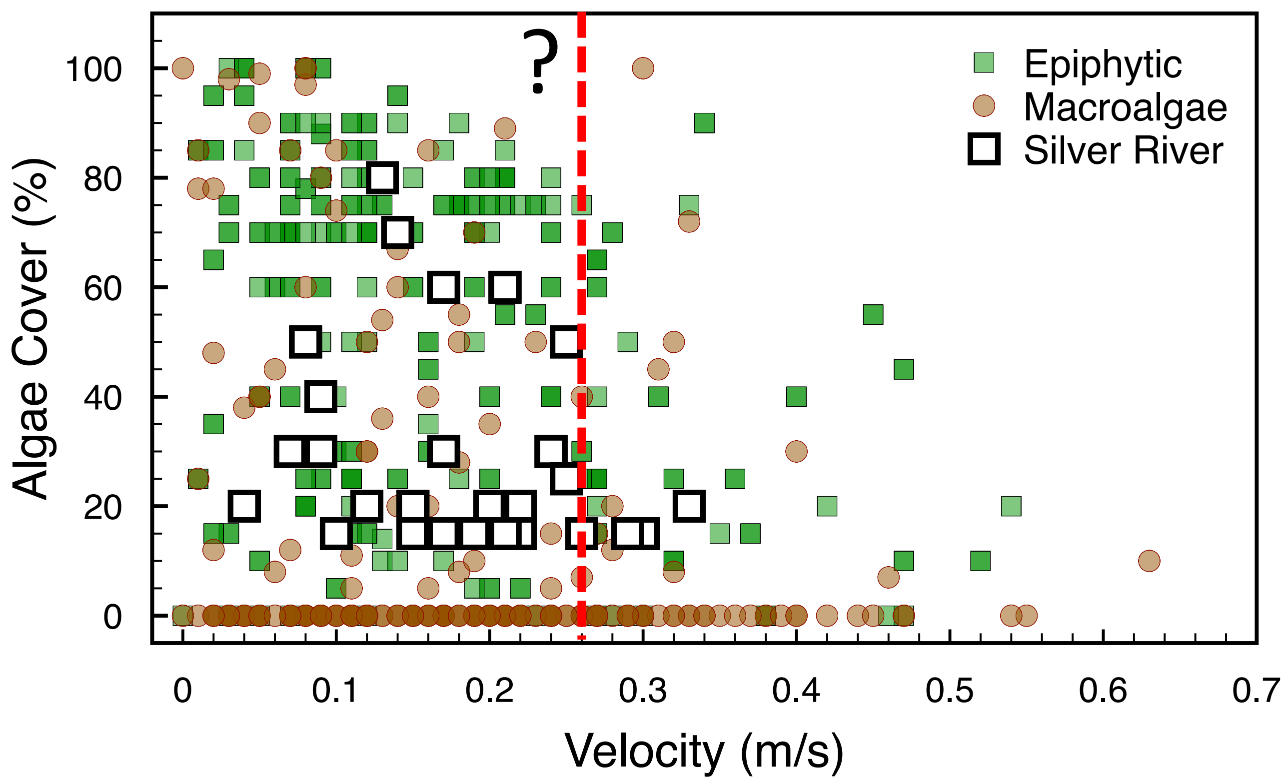

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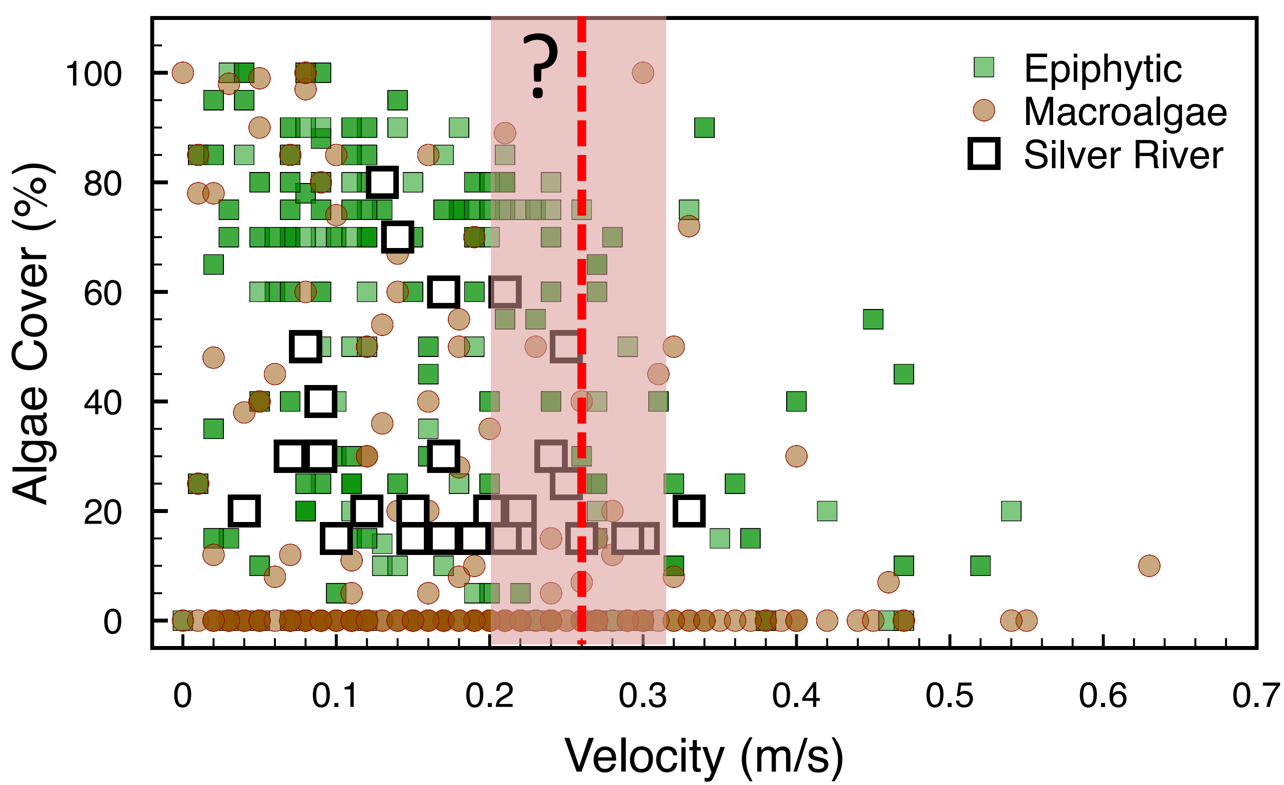


2. Velocity-Algae: Mining Observations, Pt. II

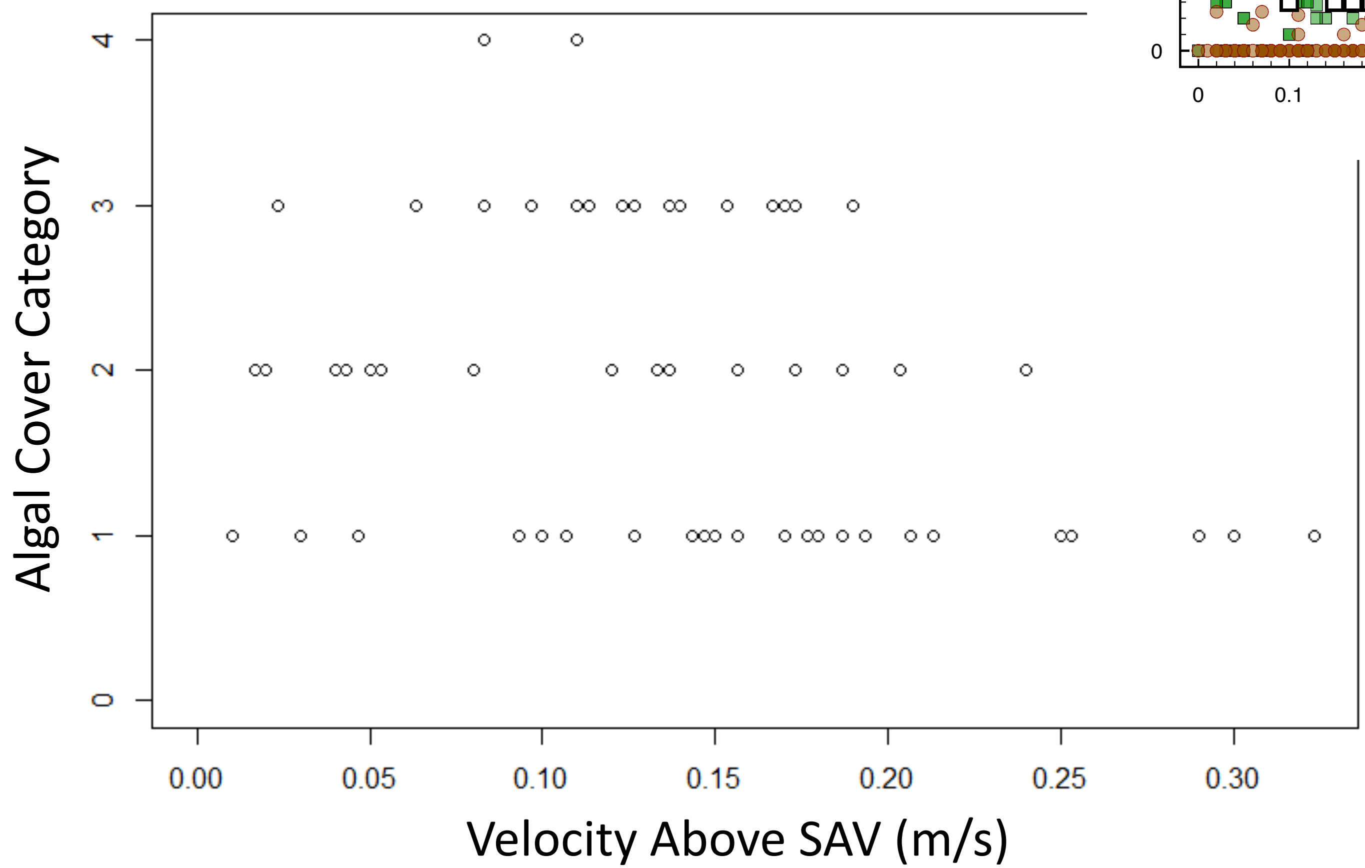
<u>Silver R. SAV Monitoring (SJRWMD/Karst Environmental)</u>

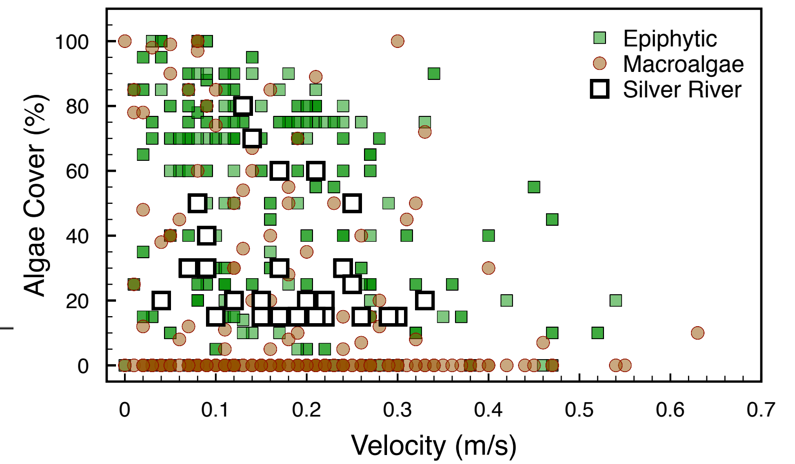
- Study focused on SAV, but divers took notes on algal abundance and velocity measurements (above/within SAV)
- We compiled velocity ***data*** and algal ***notes*** (Silver R. transects)

Top of SAV (cm)	Velocity height - above (cm)	Velocity height – within (cm)	Velocity - above (m/s)	Velocity – within (m/s)	…	Algal abundance
100	105	50	0.351	0.041		Medium
30	50	15	-0.007	-0.007		High
133	133	66	0.053	0.001		High
0	20	0	0.007	0.000		
65	66	33	0.020	0.001		Very High
70	70	35	0.225	0.221		Medium
25	30	13	0.070	0.066		Low

2. Velocity-Algae: Mining Observations, Pt. II

- Categorical → % cover?
- Velocity threshold?
- Need a simple model…





$$p\left(\theta_1,\theta_2,\theta_3,\mu_1,\mu_2,\beta_1,\beta_2,V_c \middle| \{v_i\},\{v_j\},\{v_k\},\{v_q\}\right)$$

$$\propto \left[\prod_{i=1}^{N_1} \frac{\int_0^{\theta_1} x^{\frac{\mu_1\Phi(v_i)+(\mu_2-\mu_1)\Phi(v_i-V_c)}{1-\mu_1\Phi(v_i)-(\mu_2-\mu_1)\Phi(v_i-V_c)}(\beta_1\Phi(v_i)+(\beta_2-\beta_1)\Phi(v_i-V_c))-1}(1-x)^{\beta_1\Phi(v_i)+(\beta_2-\beta_1)\Phi(v_i-V_c)-1}dx}{\int_0^{1} x^{\frac{\mu_1\Phi(v_i)+(\mu_2-\mu_1)\Phi(v_i-V_c)}{1-\mu_1\Phi(v_i)-(\mu_2-\mu_1)\Phi(v_i-V_c)}(\beta_1\Phi(v_i)+(\beta_2-\beta_1)\Phi(v_i-V_c))-1}(1-x)^{\beta_1\Phi(v_i)+(\beta_2-\beta_1)\Phi(v_i-V_c)-1}dx}\right]$$

$$\left[\prod_{j=1}^{N_2} \frac{\int_{\theta_1}^{\theta_2} x^{\frac{\mu_1\Phi(v_j)+(\mu_2-\mu_1)\Phi(v_j-V_c)}{1-\mu_1\Phi(v_j)-(\mu_2-\mu_1)\Phi(v_j-V_c)}(\beta_1\Phi(v_j)+(\beta_2-\beta_1)\Phi(v_j-V_c))-1}(1-x)^{\beta_1\Phi(v_j)+(\beta_2-\beta_1)\Phi(v_j-V_c)-1}dx}{\int_0^{1} x^{\frac{\mu_1\Phi(v_j)+(\mu_2-\mu_1)\Phi(v_j-V_c)}{1-\mu_1\Phi(v_j)-(\mu_2-\mu_1)\Phi(v_j-V_c)}(\beta_1\Phi(v_j)+(\beta_2-\beta_1)\Phi(v_j-V_c))-1}(1-x)^{\beta_1\Phi(v_j)+(\beta_2-\beta_1)\Phi(v_j-V_c)-1}dx}\right]$$

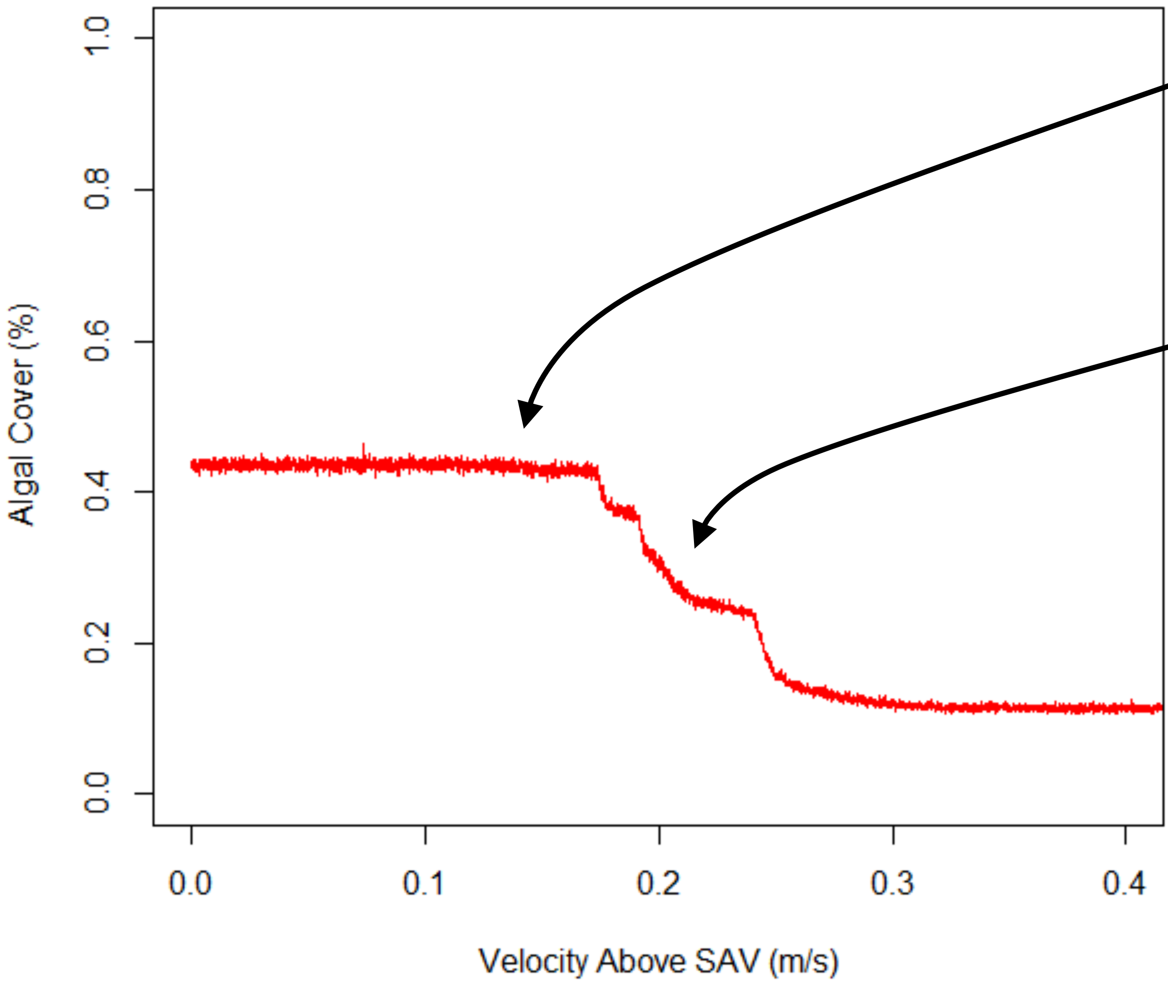
$$\left[\prod_{k=1}^{N_3} \frac{\int_{\theta_2}^{\theta_3} x^{\frac{\mu_1\Phi(v_k)+(\mu_2-\mu_1)\Phi(v_k-V_c)}{1-\mu_1\Phi(v_k)-(\mu_2-\mu_1)\Phi(v_k-V_c)}(\beta_1\Phi(v_k)+(\beta_2-\beta_1)\Phi(v_k-V_c))-1}(1-x)^{\beta_1\Phi(v_k)+(\beta_2-\beta_1)\Phi(v_k-V_c)-1}dx}{\int_0^{1} x^{\frac{\mu_1\Phi(v_k)+(\mu_2-\mu_1)\Phi(v_k-V_c)}{1-\mu_1\Phi(v_k)-(\mu_2-\mu_1)\Phi(v_k-V_c)}(\beta_1\Phi(v_k)+(\beta_2-\beta_1)\Phi(v_k-V_c))-1}(1-x)^{\beta_1\Phi(v_k)+(\beta_2-\beta_1)\Phi(v_k-V_c)-1}dx}\right]$$

$$\left[\prod_{q=1}^{N_4} \frac{\int_{\theta_3}^{1} x^{\frac{\mu_1\Phi(v_q)+(\mu_2-\mu_1)\Phi(v_q-V_c)}{1-\mu_1\Phi(v_q)-(\mu_2-\mu_1)\Phi(v_q-V_c)}(\beta_1\Phi(v_q)+(\beta_2-\beta_1)\Phi(v_q-V_c))-1}(1-x)^{\beta_1\Phi(v_q)+(\beta_2-\beta_1)\Phi(v_q-V_c)-1}dx}{\int_0^{1} x^{\frac{\mu_1\Phi(v_q)+(\mu_2-\mu_1)\Phi(v_q-V_c)}{1-\mu_1\Phi(v_q)-(\mu_2-\mu_1)\Phi(v_q-V_c)}(\beta_1\Phi(v_q)+(\beta_2-\beta_1)\Phi(v_q-V_c))-1}(1-x)^{\beta_1\Phi(v_q)+(\beta_2-\beta_1)\Phi(v_q-V_c)-1}dx}\right]$$

$$\left[\frac{1}{\beta_1\sigma_{\beta_1}\sqrt{2\pi}}e^{-\frac{\left(ln(\beta_1)-\gamma_{\beta_1}\right)^2}{2\sigma_{\beta_1}{}^2}}\right]\left[\frac{1}{\beta_2\sigma_{\beta_2}\sqrt{2\pi}}e^{-\frac{\left(ln(\beta_2)-\gamma_{\beta_2}\right)^2}{2\sigma_{\beta_2}{}^2}}\right]\left[\frac{1}{P_{V_c}}\right]$$

2. Velocity-Algae: Mining Observations, Pt. II

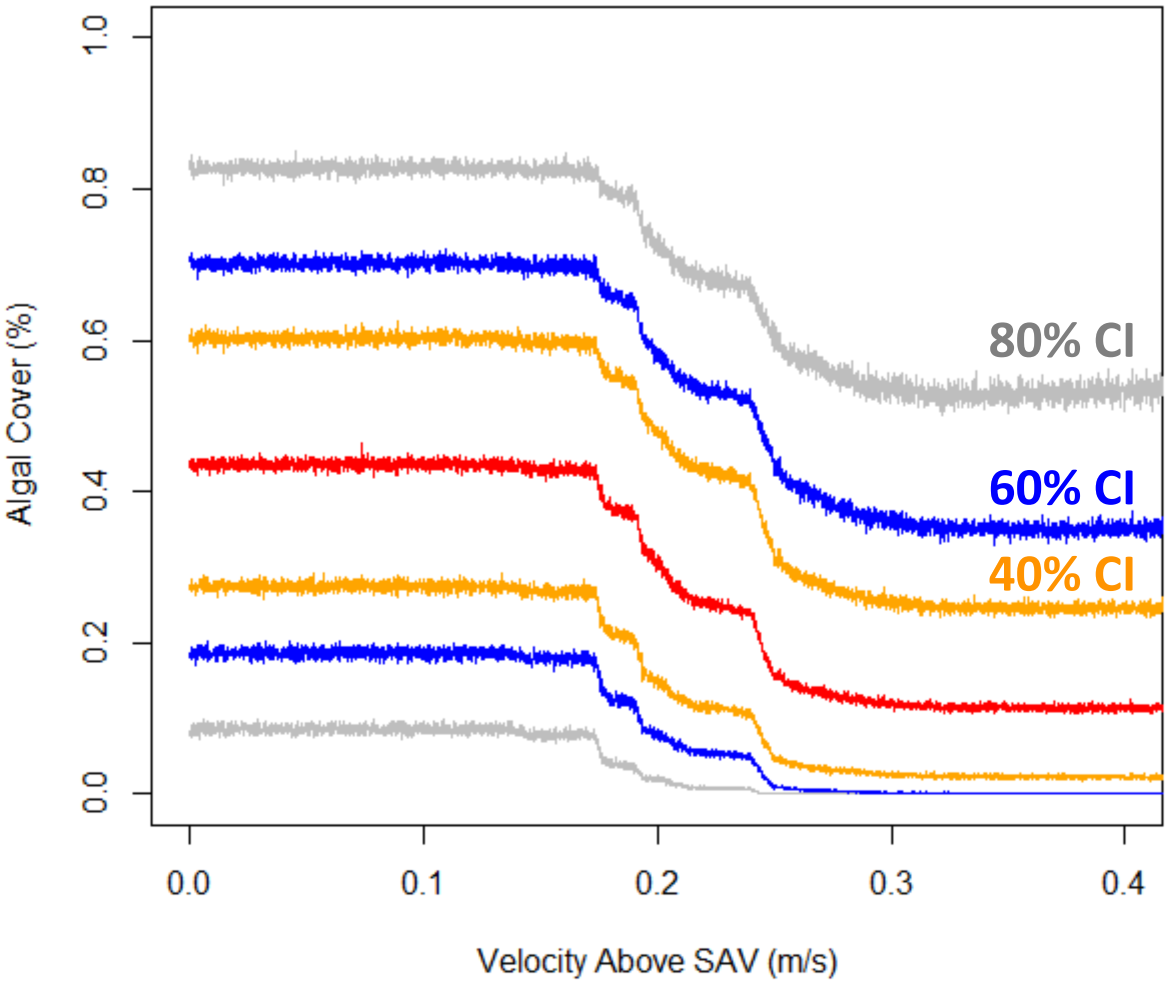
- **Mean** algal % cover as *f*(above-canopy velocity)



- NOT an algae prediction model!
- An indicator of critical velocity threshold range (if present)

2. Velocity-Algae: Mining Observations, Pt. II

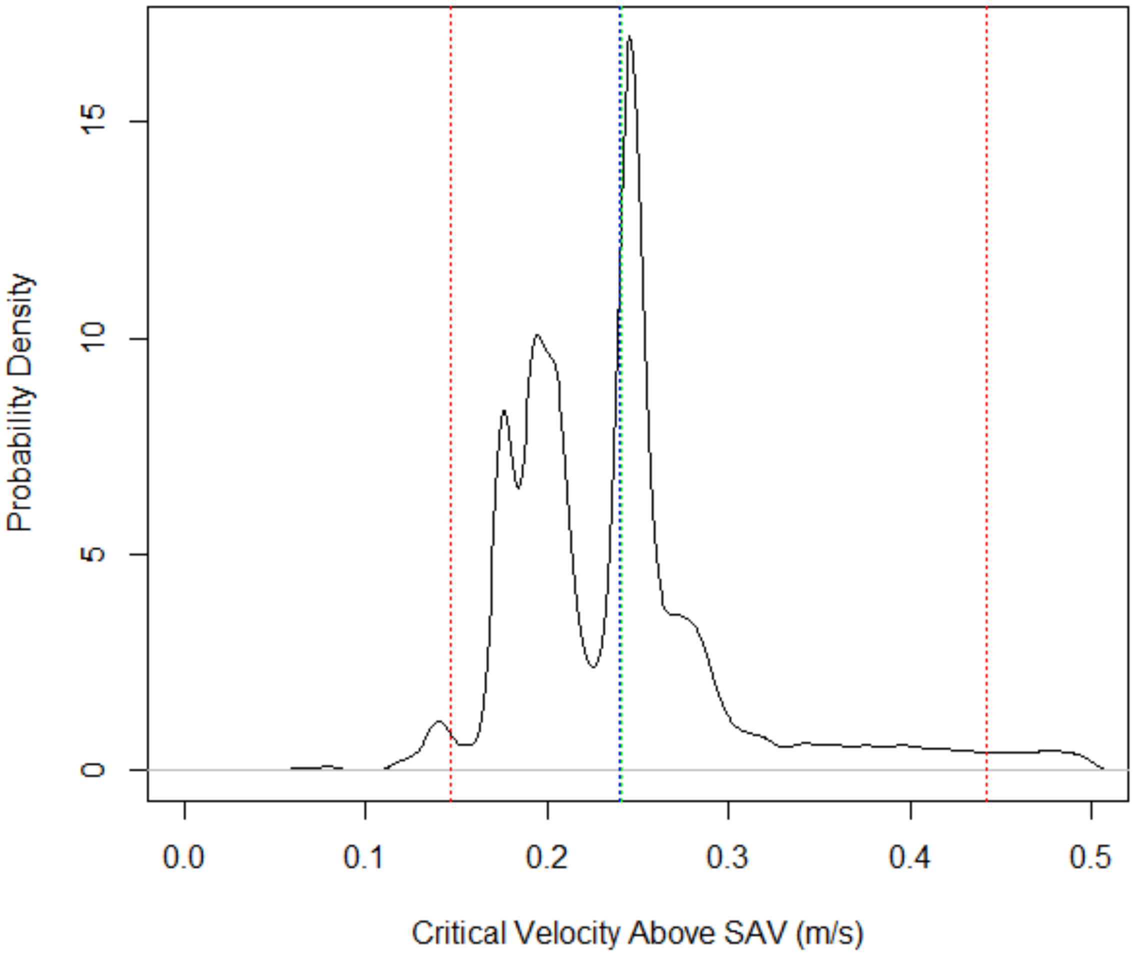
- **Mean +/- CI** algal % cover as *f*(above-canopy velocity)



- High variation in algal cover *across* measured velocities
- ...yet differences in mean algal cover above/below a consistent velocity threshold **range**...

2. Velocity-Algae: Mining Observations, Pt. II

- Distribution of critical velocity for algae absence (*removal*?)
- Mean value: = 0.240 m/s



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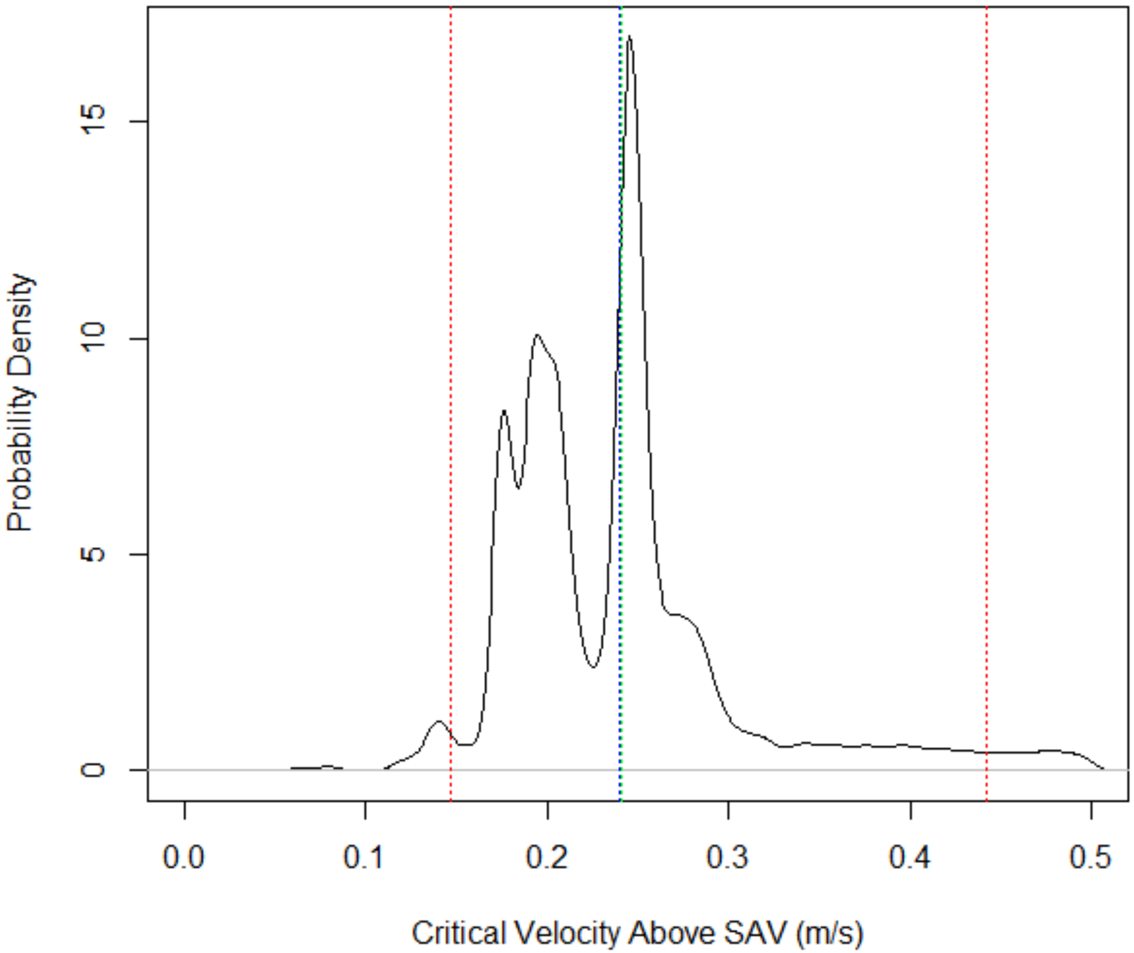
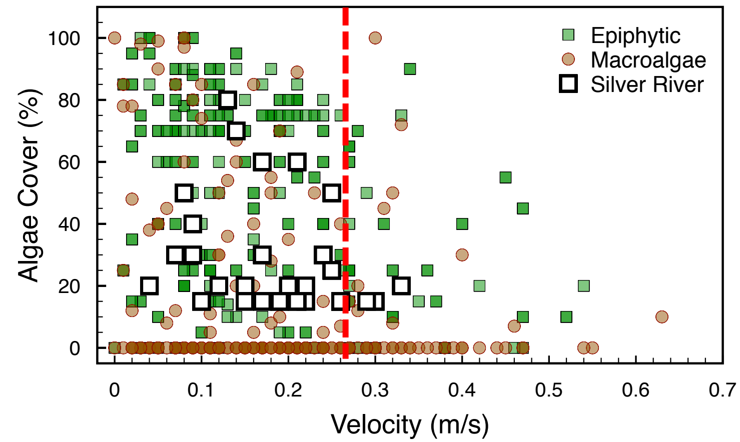
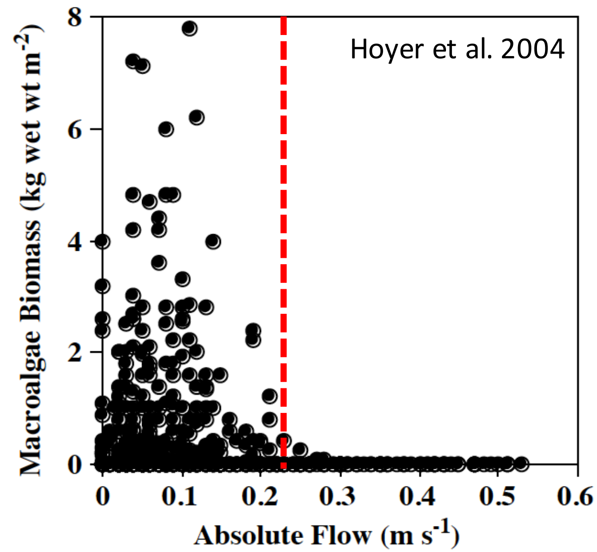
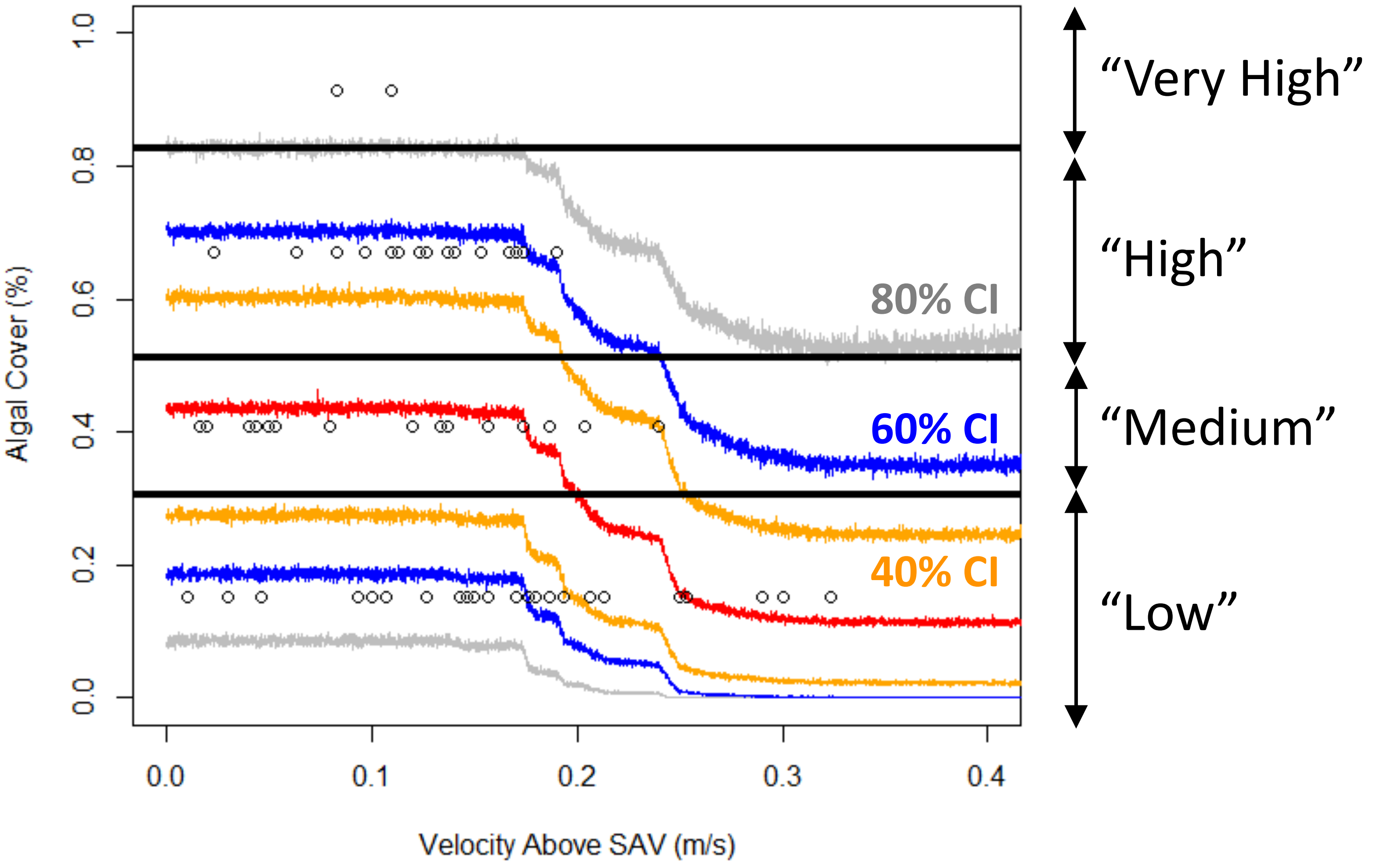






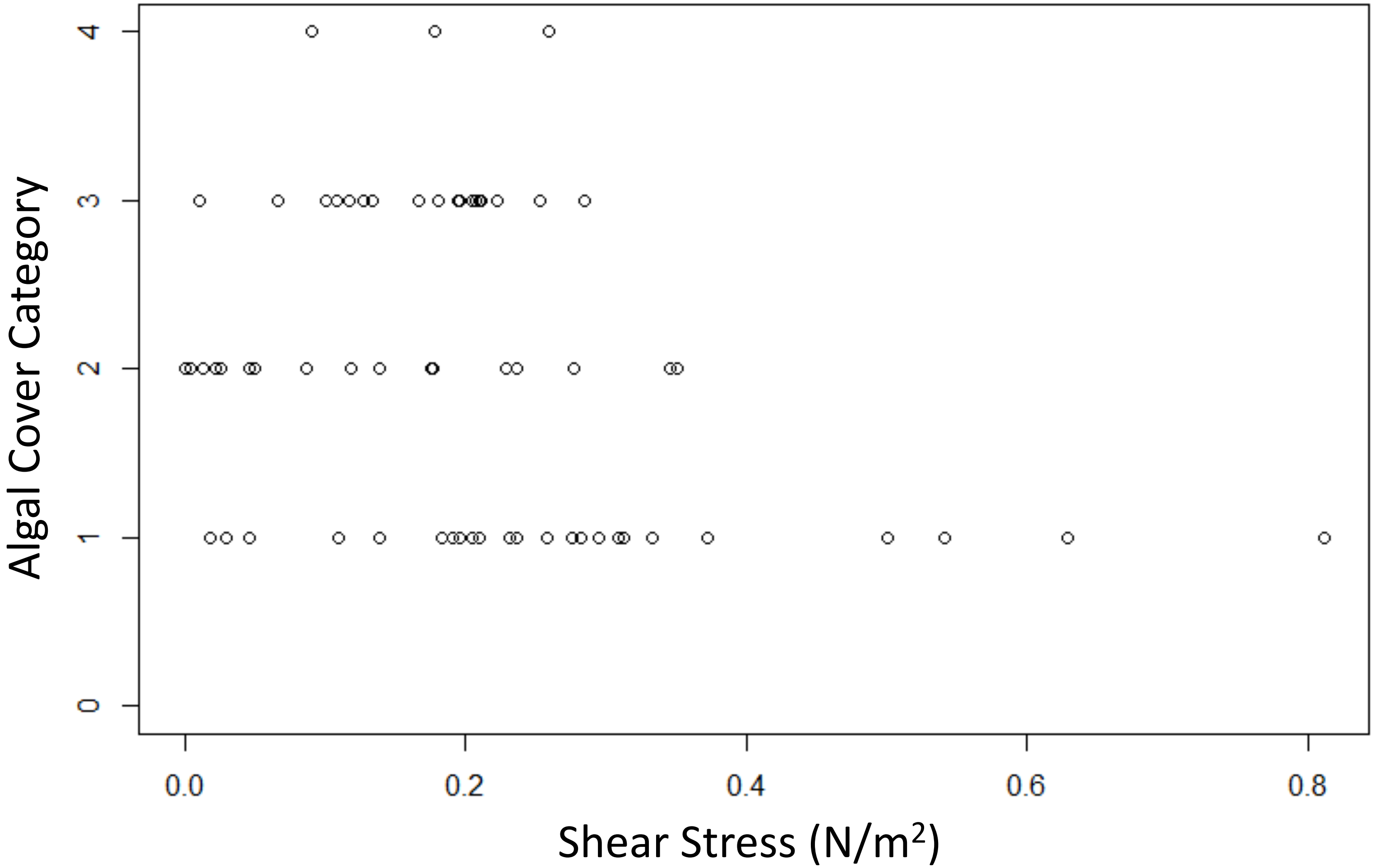
2. Velocity-Algae: Mining Observations, Pt. II

- % cover vs. velocity, with raw data and fitted cutoff values



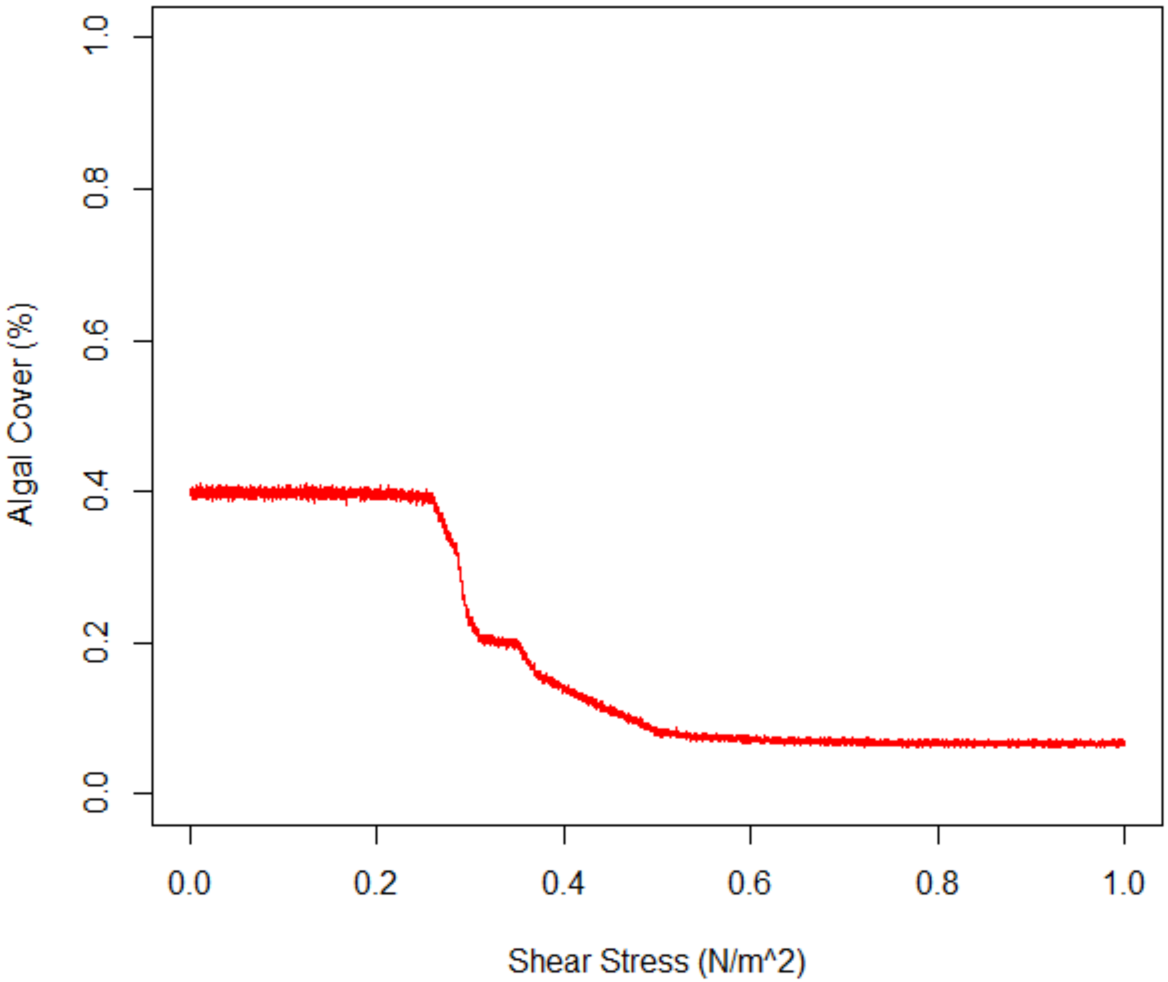
2. Velocity-Algae: Mining Observations, Pt. II

- Categorical algae vs. shear stress…same approach



2. Velocity-Algae: Mining Observations, Pt. II

- **Mean** algal % cover as *f*(shear stress)



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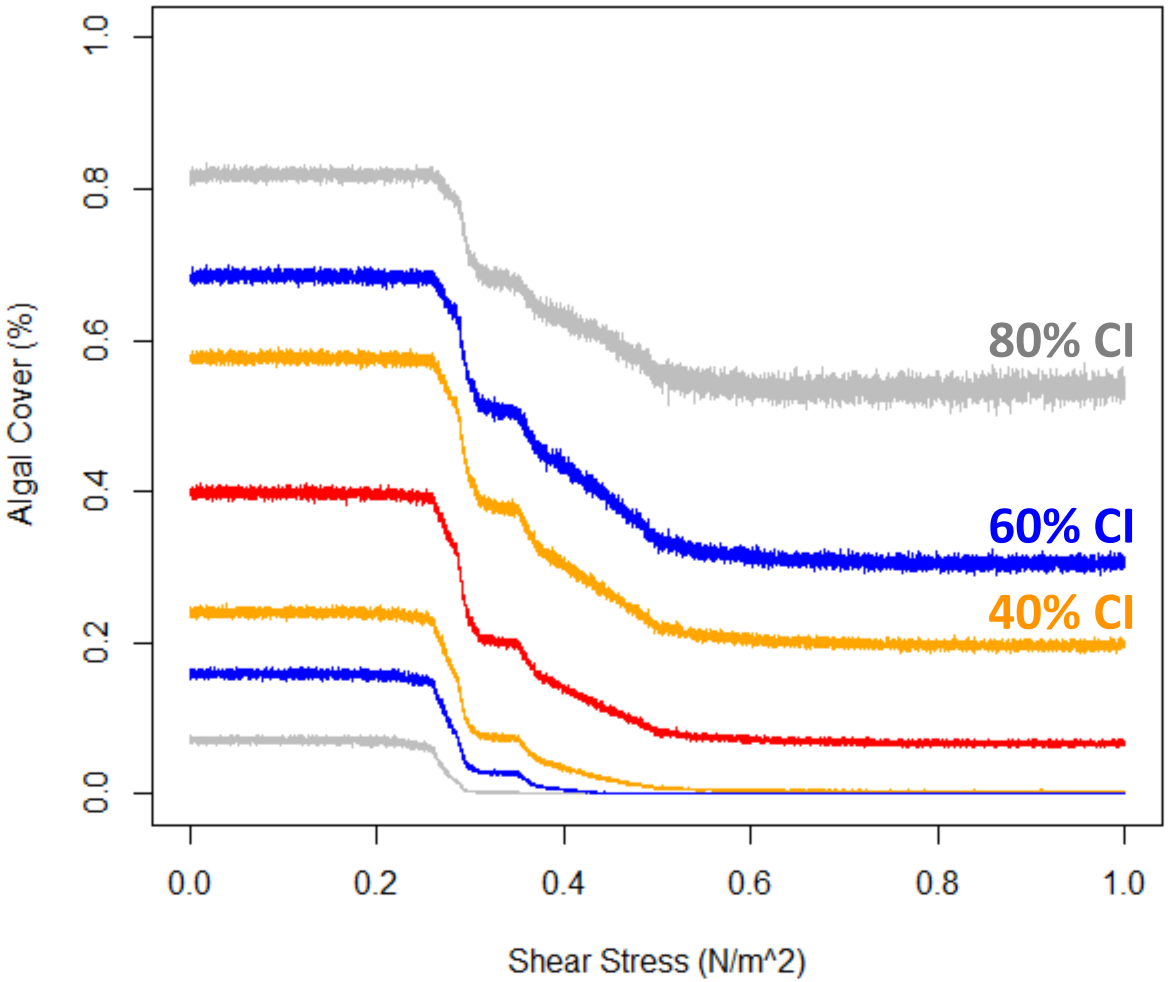
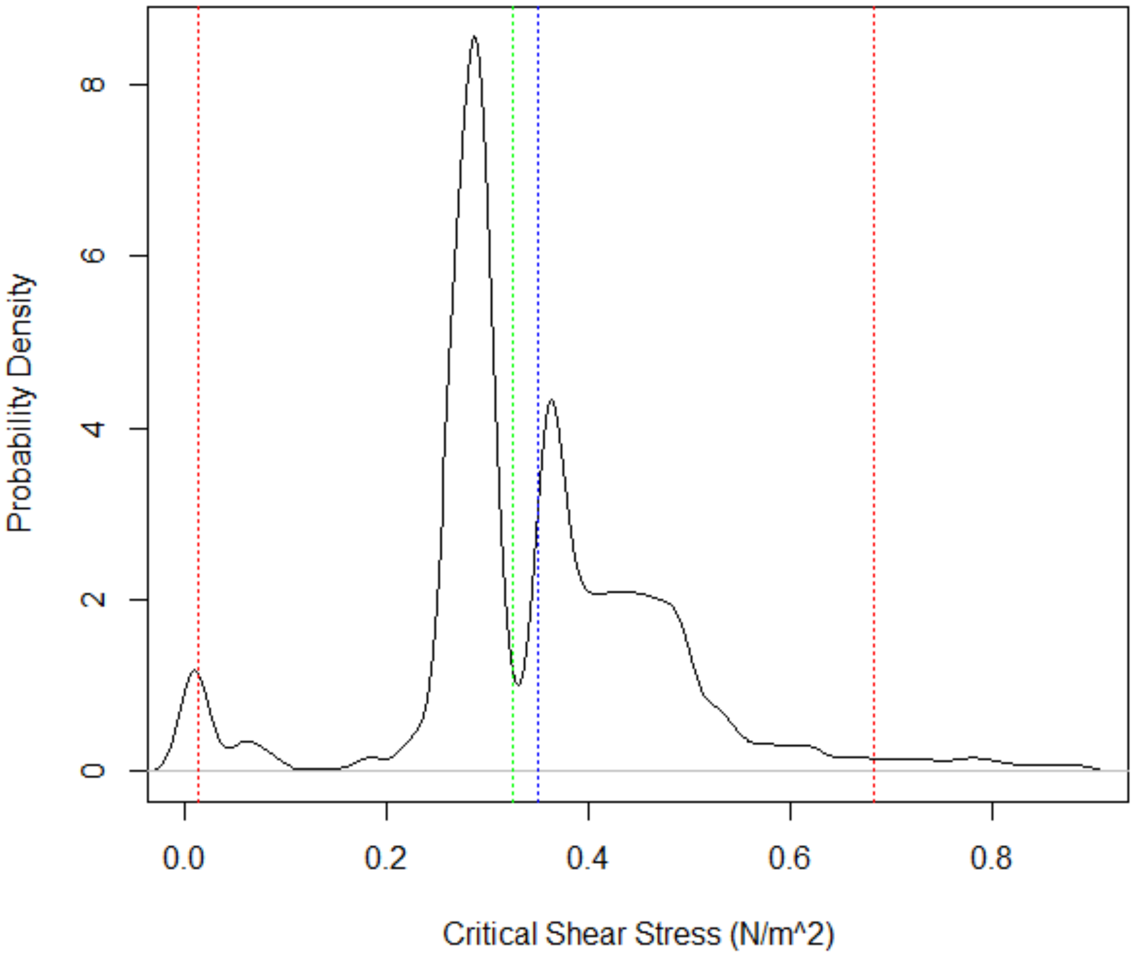
- **Mean +/- CI** algal % cover as *f*(shear stress)



- High variation in algal cover *across* measured shear stresses
- ...yet differences in mean algal cover above/below a consistent shear stress threshold **range**...

2. Velocity-Algae: Mining Observations, Pt. II

- Distribution of critical shear stress for algae absence (r*emoval*?)
- Mean value: = 0.35 N/m^2



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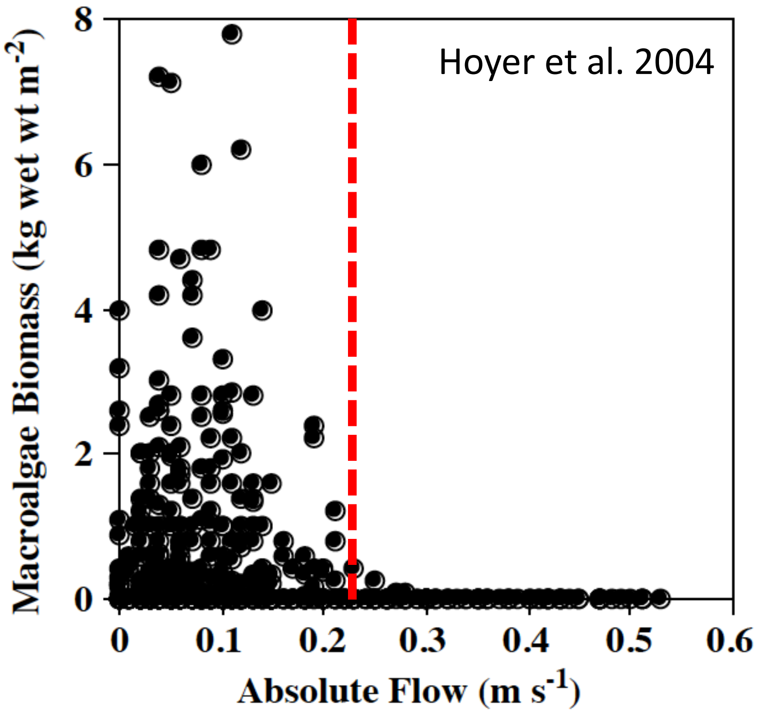
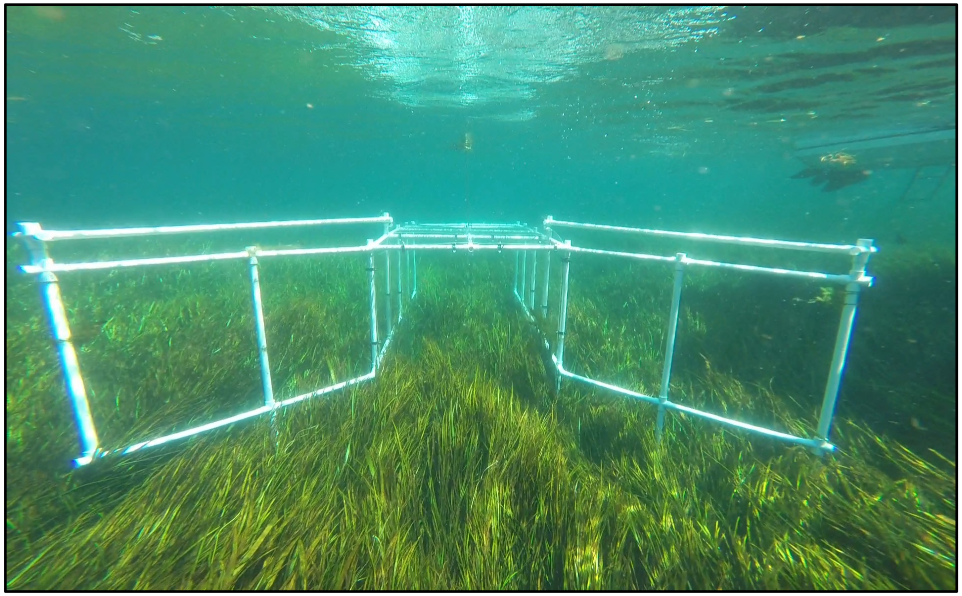
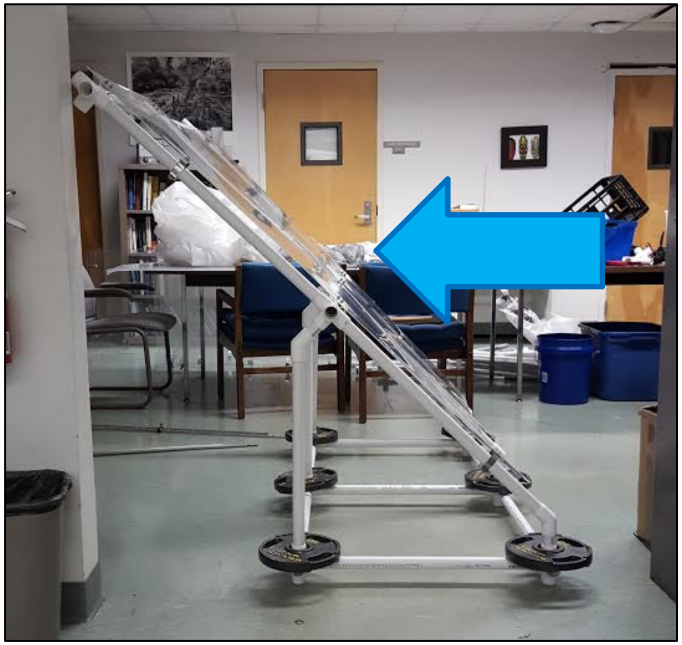




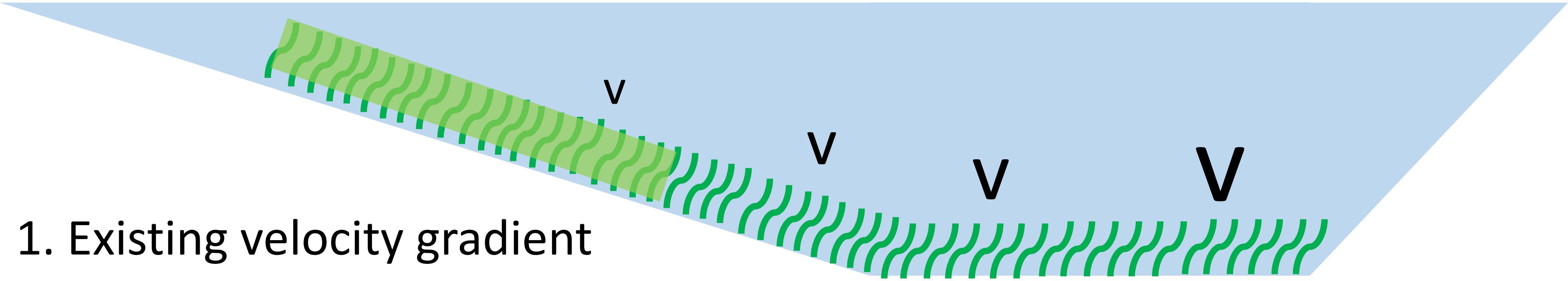
2. Velocity-Algae: *In-Situ* Experiments



Introducing…
"The Shadow"

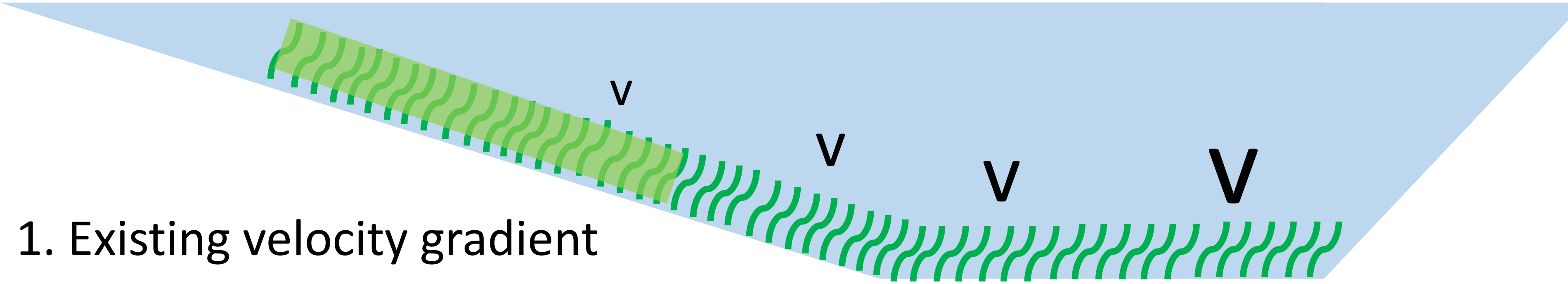
1. Thresholds
2. Algae growth
3. Hysteresis

2. Velocity-Algae: *In-Situ* Experiment III



1. Existing velocity gradient

2. Velocity-Algae: *In-Situ* Experiment III



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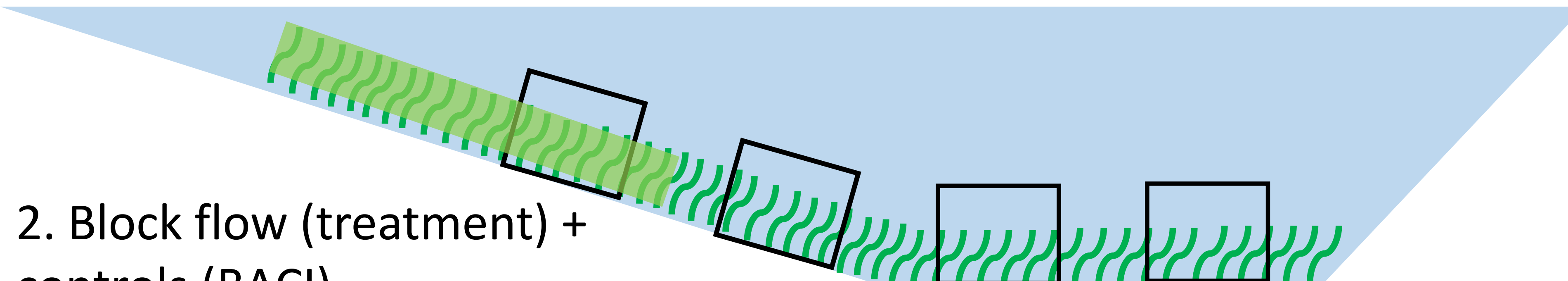

2. Block flow (treatment) + controls (BACI)

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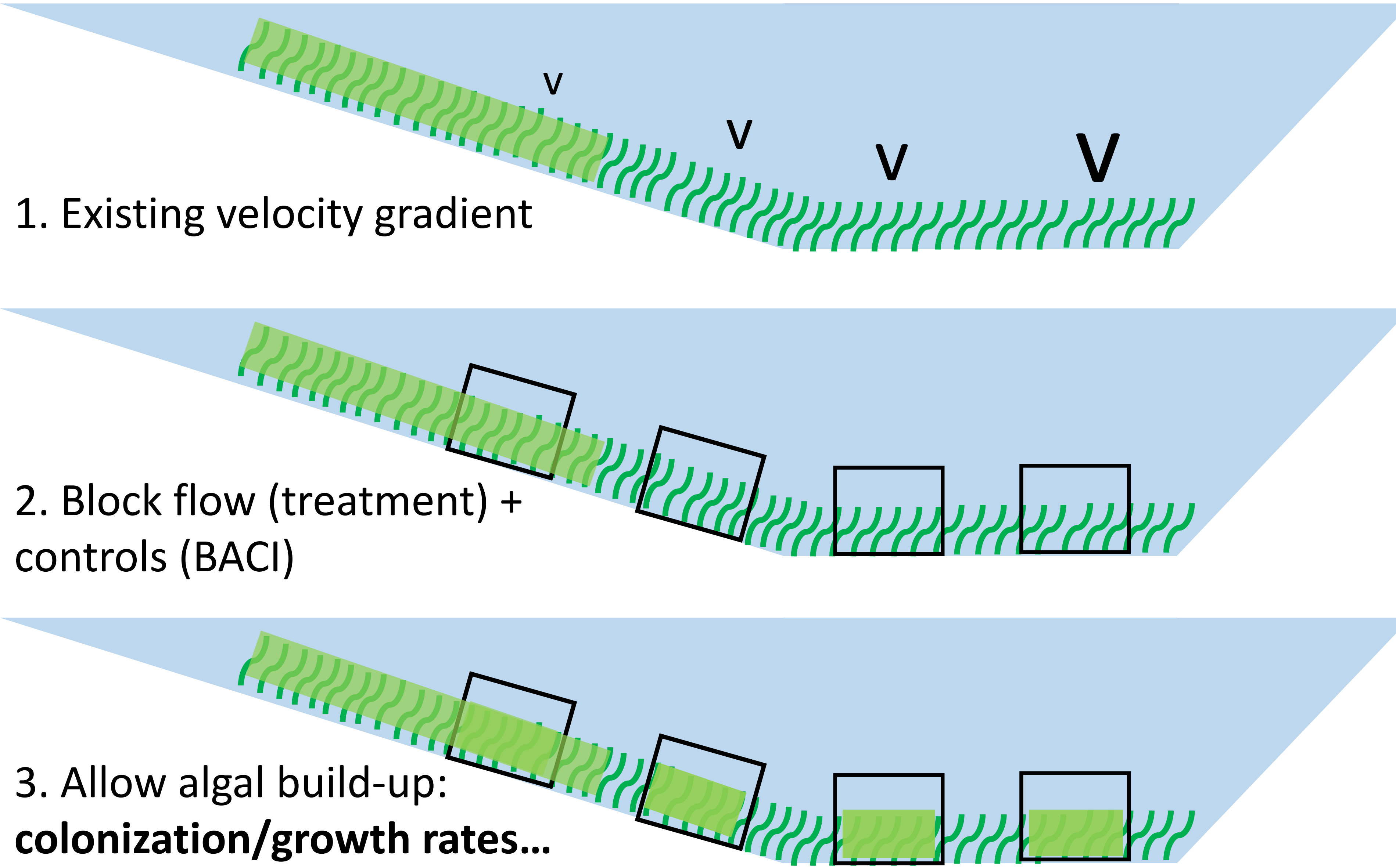

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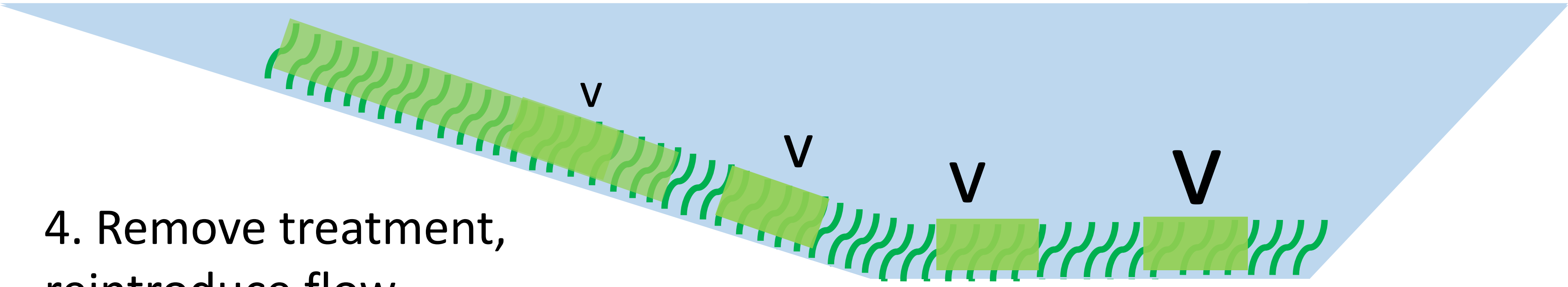
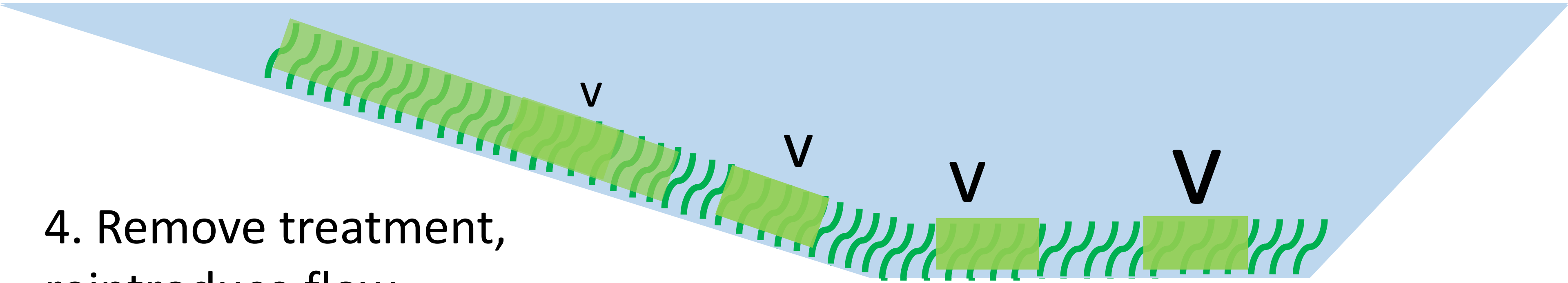
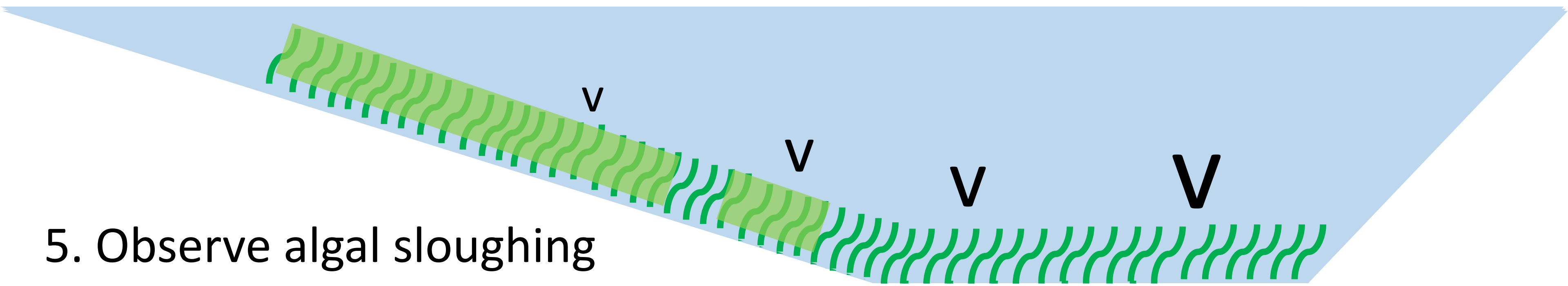


4. Remove treatment, reintroduce flow

2. Velocity-Algae: *In-Situ* Experiment III

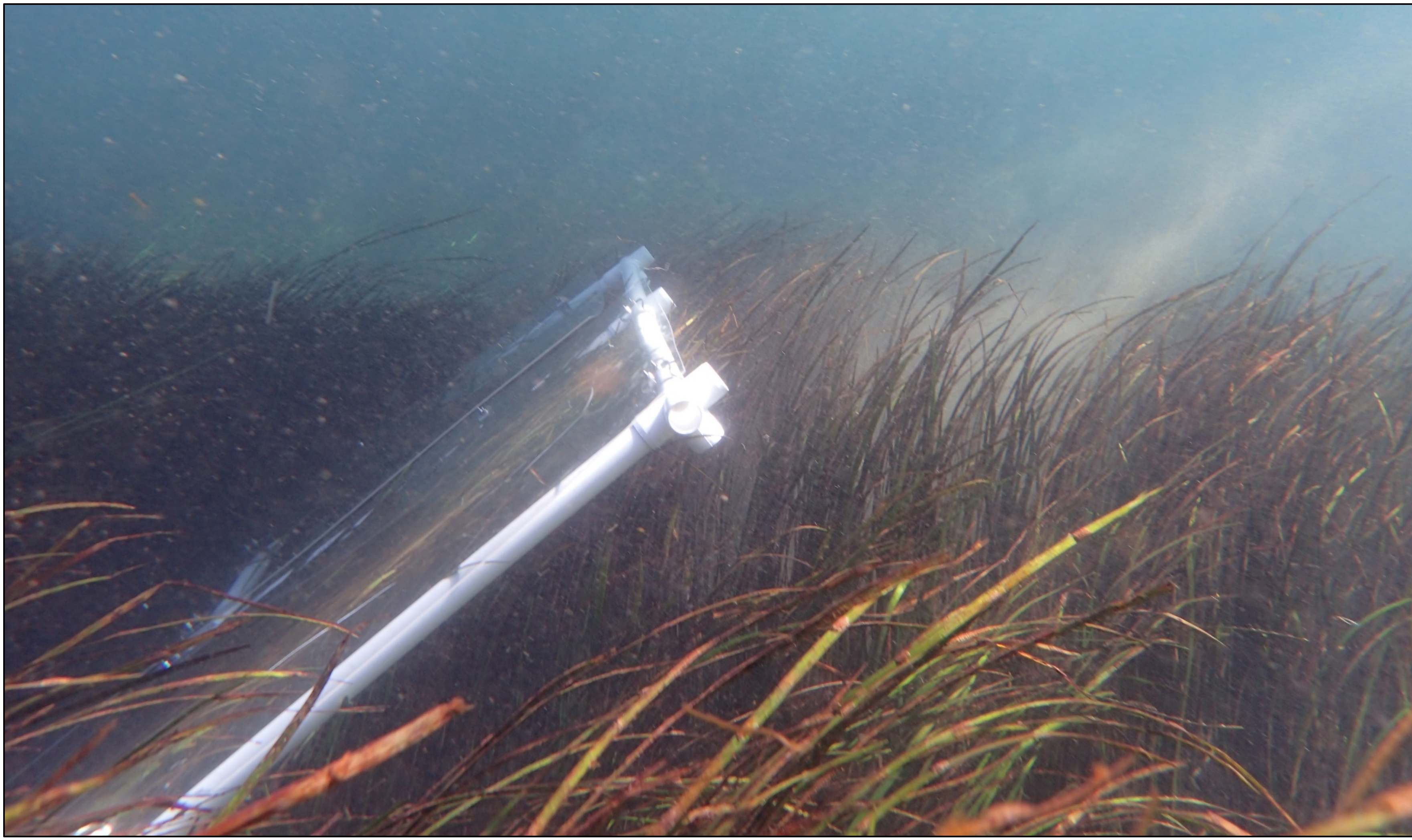


4. Remove treatment, reintroduce flow

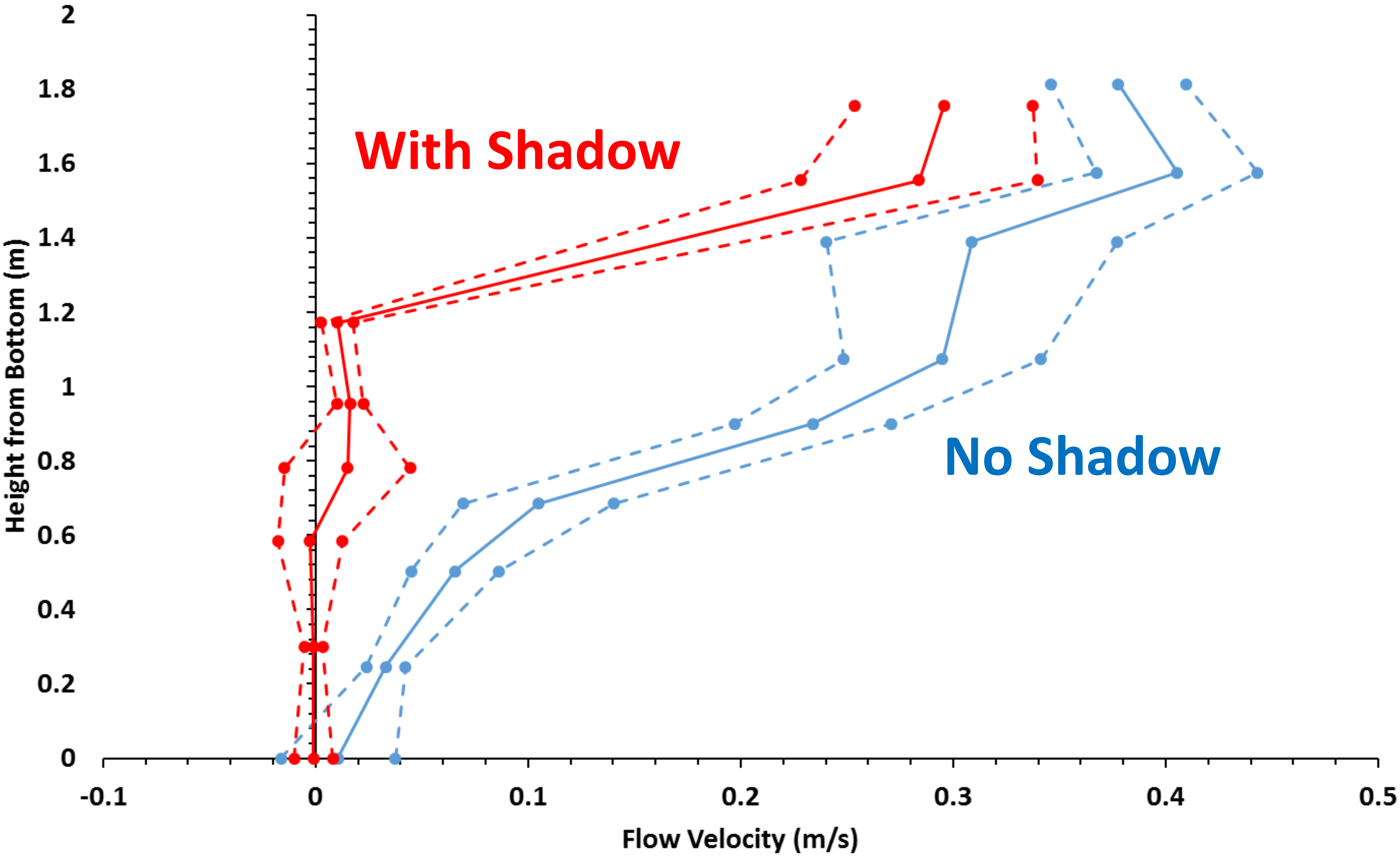


5. Observe algal sloughing along velocity gradient: **threshold velocity/shear stress, algae sloughing rates, hysteretic behavior**

2. Velocity-Algae: *In-Situ* Experiment III



2. Velocity-Algae: *In-Situ* Experiment III

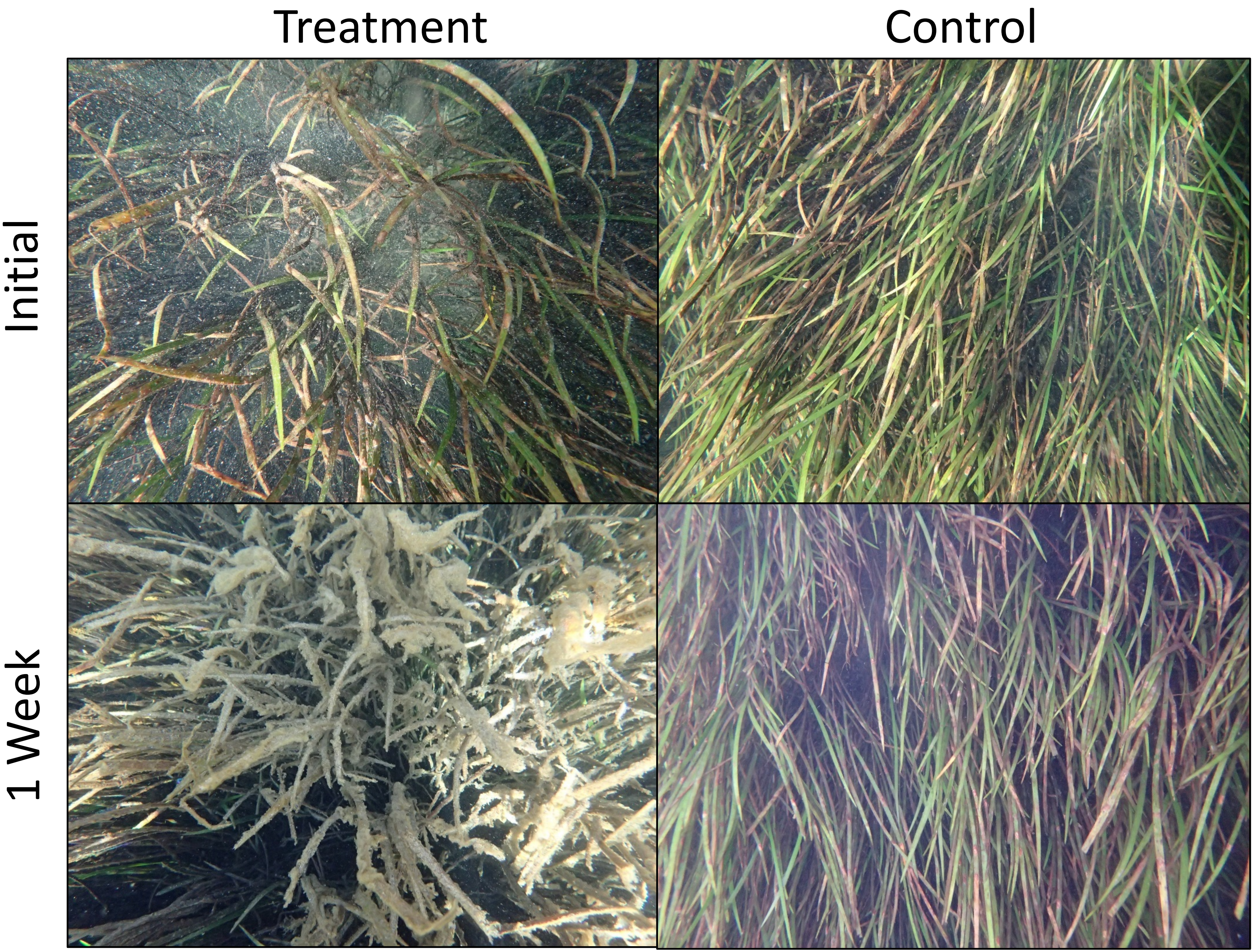


2. Velocity-Algae: *In-Situ* Experiment III

Treatment

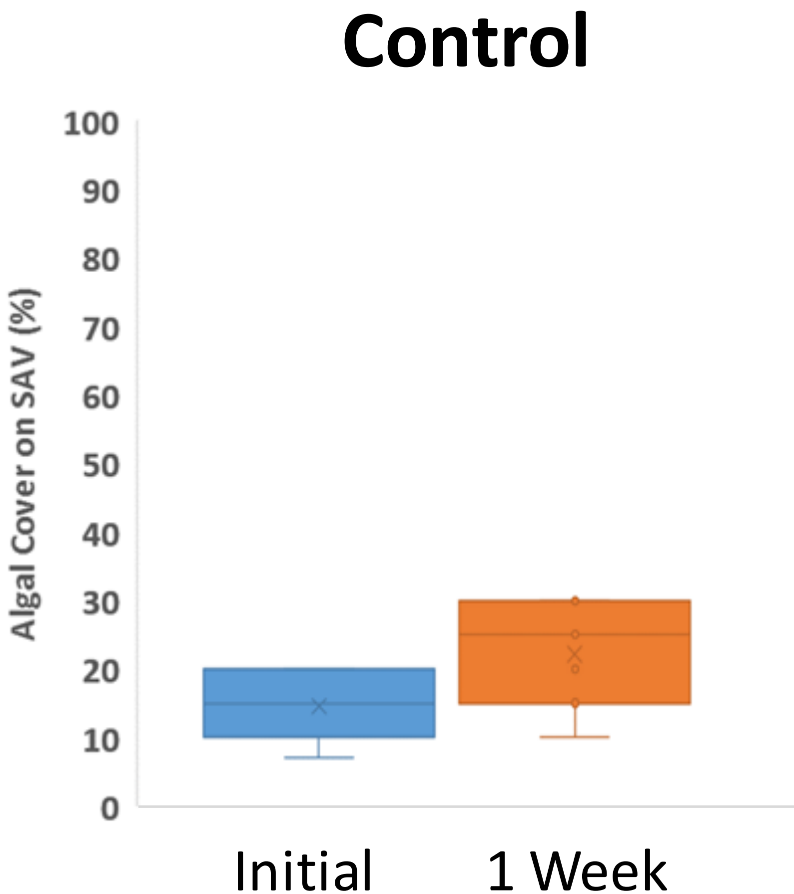
Control

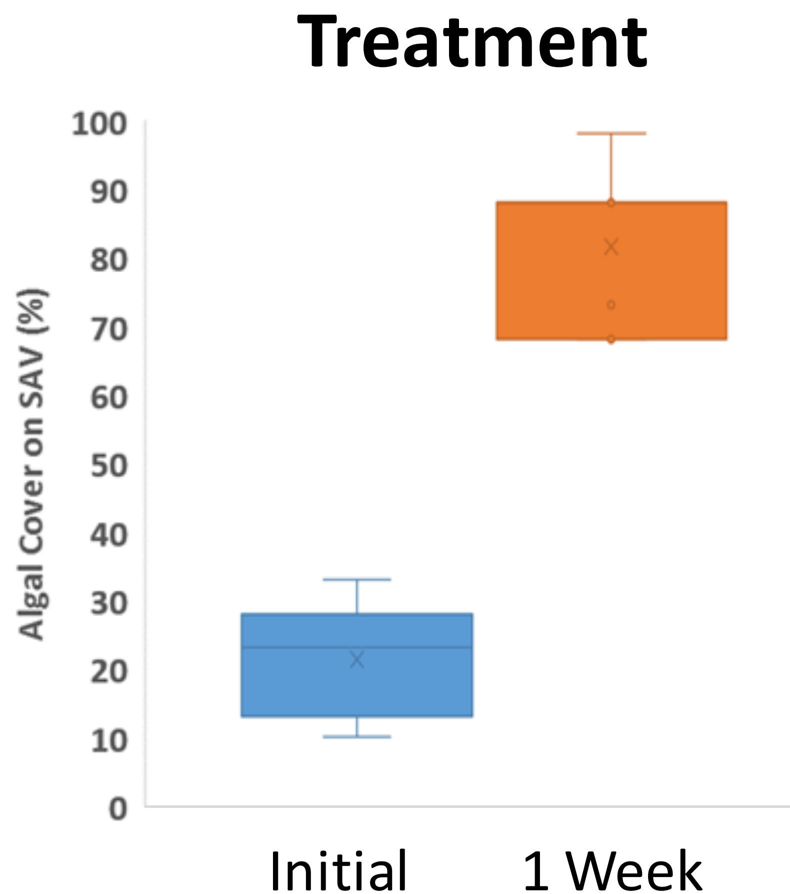
Treatment
Control
Initial


Treatment
Control
Initial
1 Week

2. Velocity-Algae: *In-Situ* Experiment III

2. Velocity-Algae: *In-Situ* Experiment III





<u>Expected results from deployments of “The Shadow”:</u>

1) Thresholds; 2) Algal Colonization/Growth/Sloughing; 3) Hysteresis

Management-Driven Research Objectives

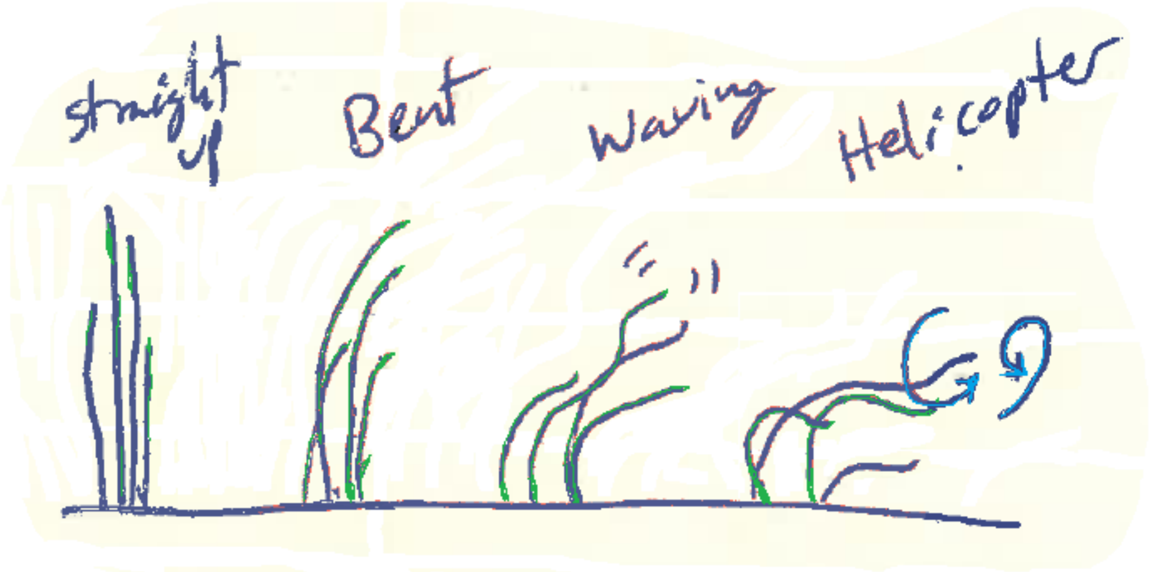
1. Measure reach-and point-scale velocity variation
   – Dye trace experiments/modeling (UPDATE)
   – Direct measurements; ADCP and vertical profiles (SUCSY ET AL.)
2. Develop/refine velocity-algae-SAV relationships
   – Observational (UPDATE)
   – *In-situ* flow-ways (UPDATE)
   – Optical methods
3. **Understand changes in stage-discharge relationship**
   – **Historical data analyses (UPDATE)**
   – Modeling (UPDATE)
4. Analyze management scenarios
   – EFDC Modeling (SUCSY ET AL.)

3. Stage-Discharge-Velocity Relationships

Apparent shift in stage-discharge relationship in Silver River:

1. Increased spatial coverage of SAV?
2. Expansion of hydrilla in the lower Silver and Ocklawaha?
3. Reconfiguration of vegetation under low discharge?
4. Change in bed slope? Artifact?

Importance: Causes river to flow more slower for given Q; possible mechanism of algal proliferation in upper river.



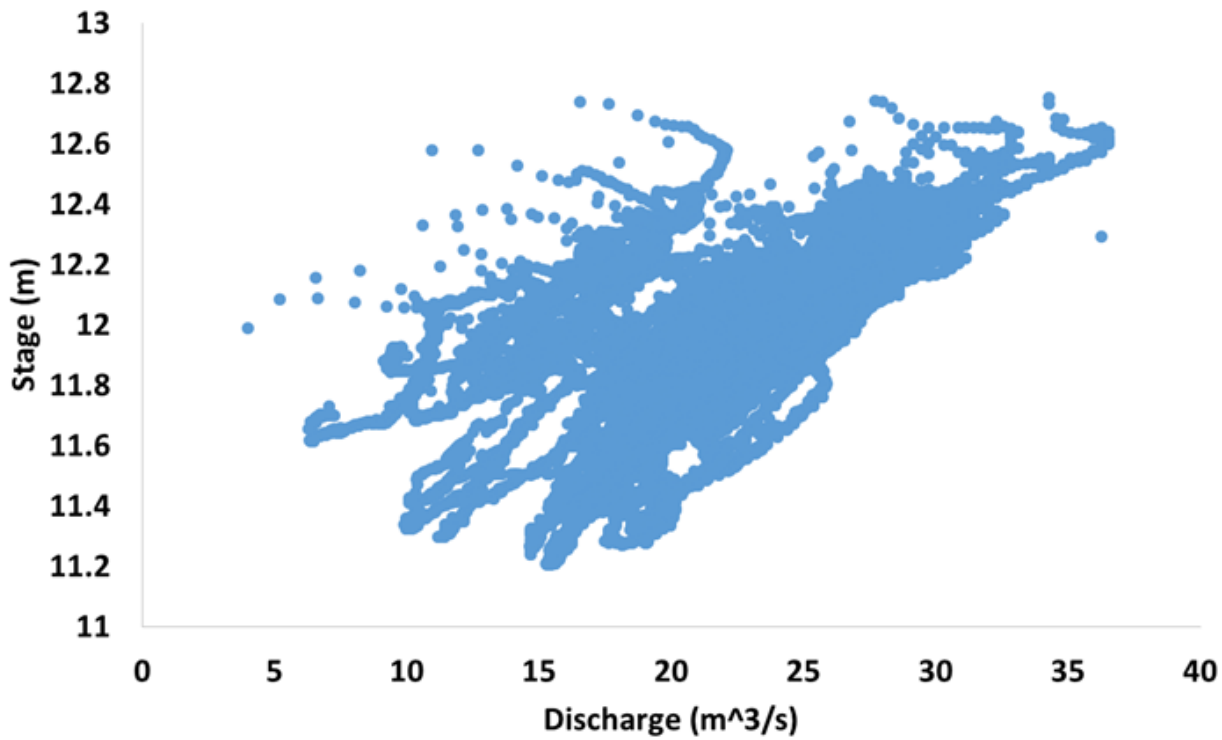
Drawing by Ed Carter

3. Stage-Discharge-Velocity Relationships

Importance: Causes river to flow more slower for given Q; possible mechanism of algal proliferation in upper river.

Spring Pool

1947-2015



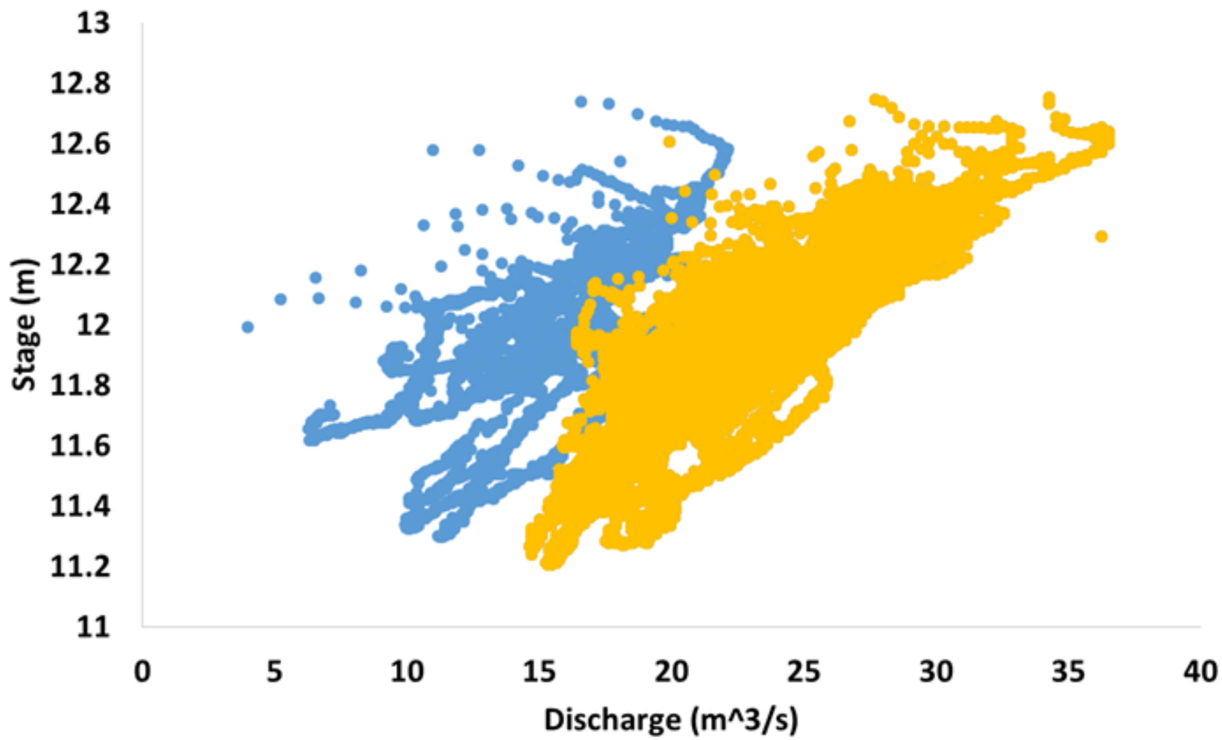
2. Stage-Discharge-Velocity Relationships

<u>Importance</u>: Causes river to flow more slower for given Q; possible mechanism of algal proliferation in upper river.

<u>Spring Pool</u>

1999-2015

1947-1999



3. Stage-Discharge-Velocity Relationships

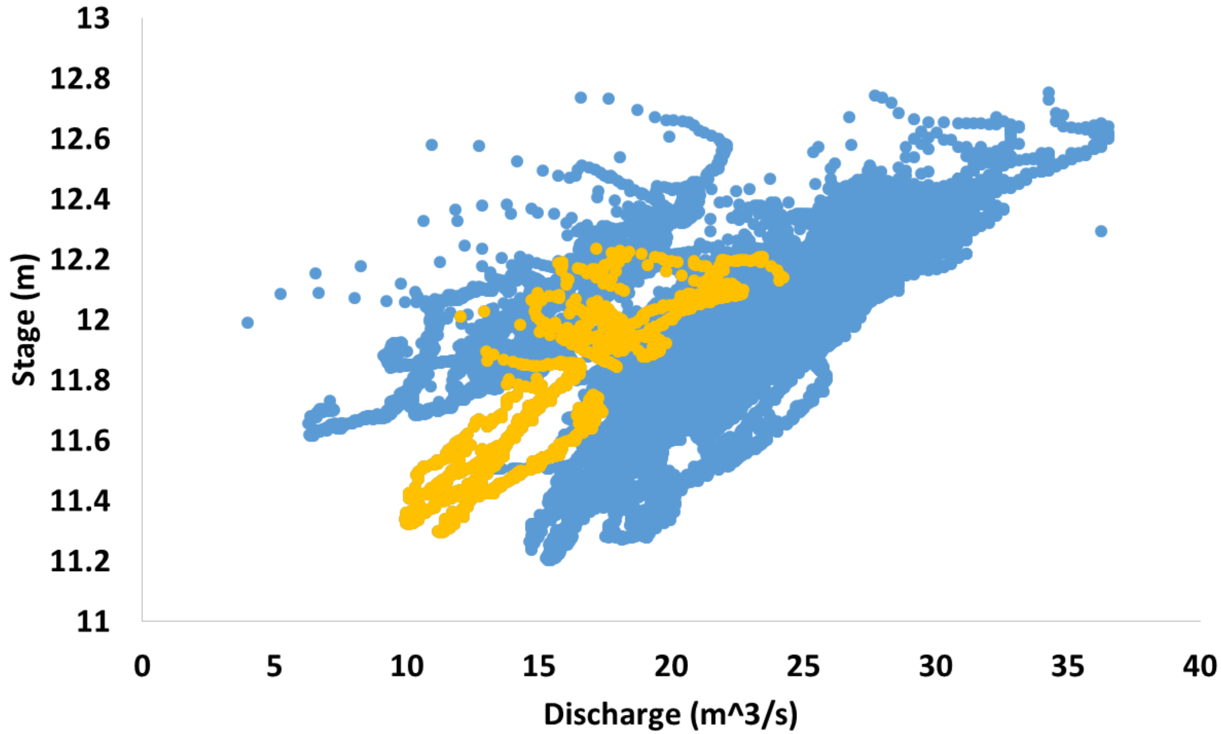
Importance: Causes river to flow more slower for given Q; possible mechanism of algal proliferation in upper river.

Spring Pool

1947-1999

2000-2003

2004-2015



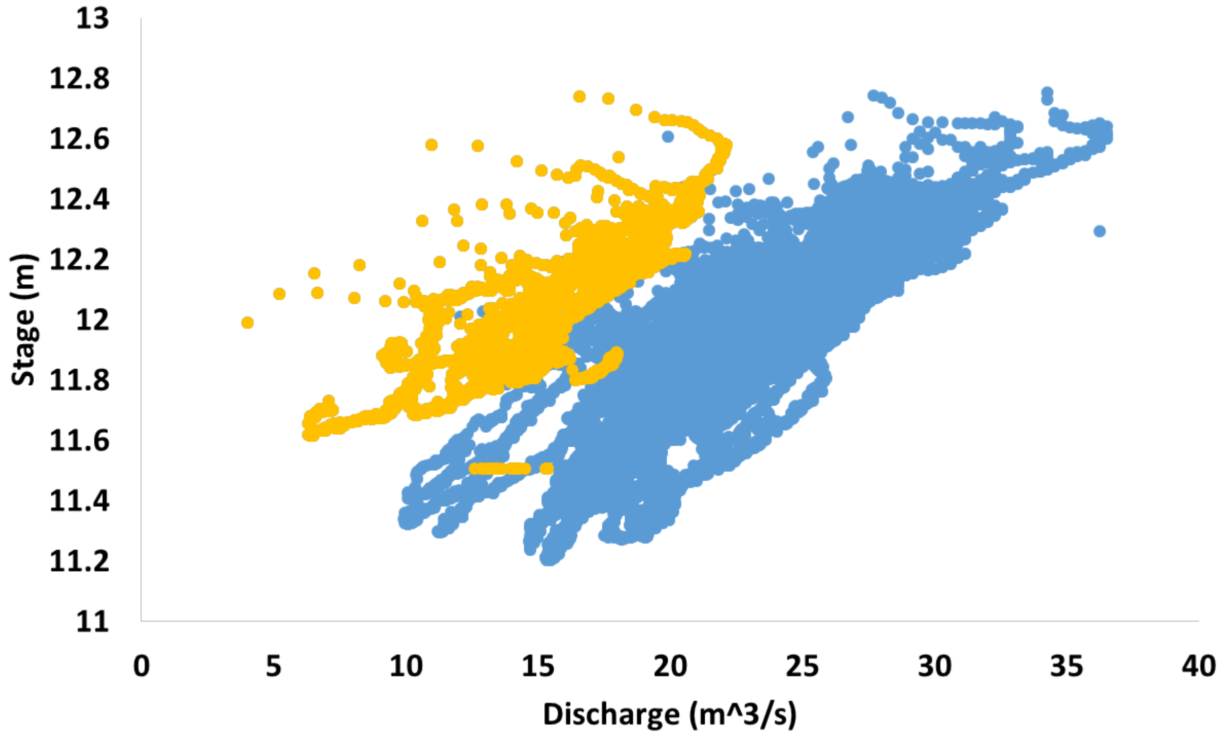
2. Stage-Discharge-Velocity Relationships

<u>Importance</u>: Causes river to flow more slower for given Q; possible mechanism of algal proliferation in upper river.

<u>Spring Pool</u>

1947-2003

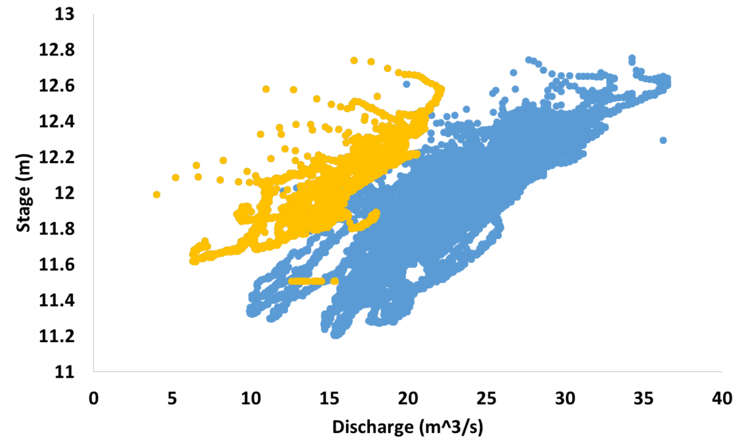
2004-2015



3. Stage-Discharge-Velocity Relationships

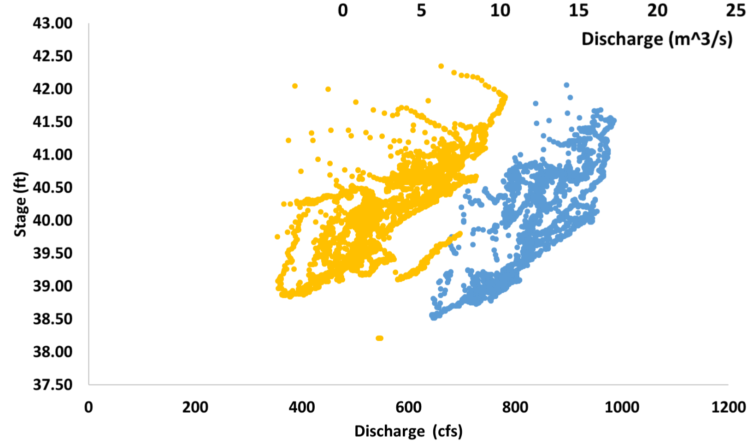
Spring Pool

1947-2003 | **2004-2015**



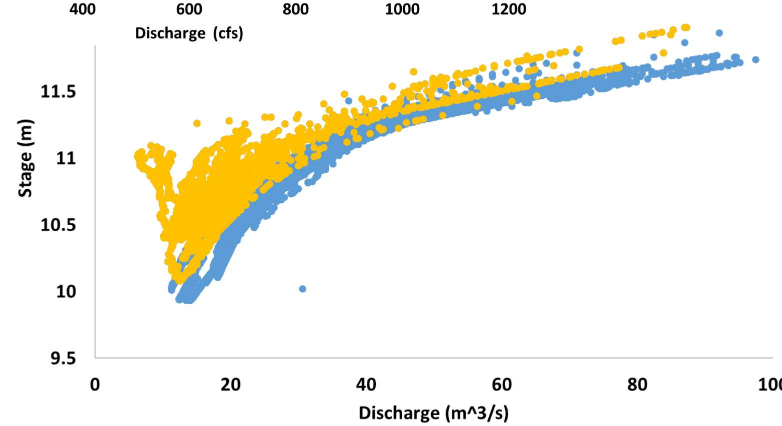
1200 m

1967-1972 | **2003-2015**

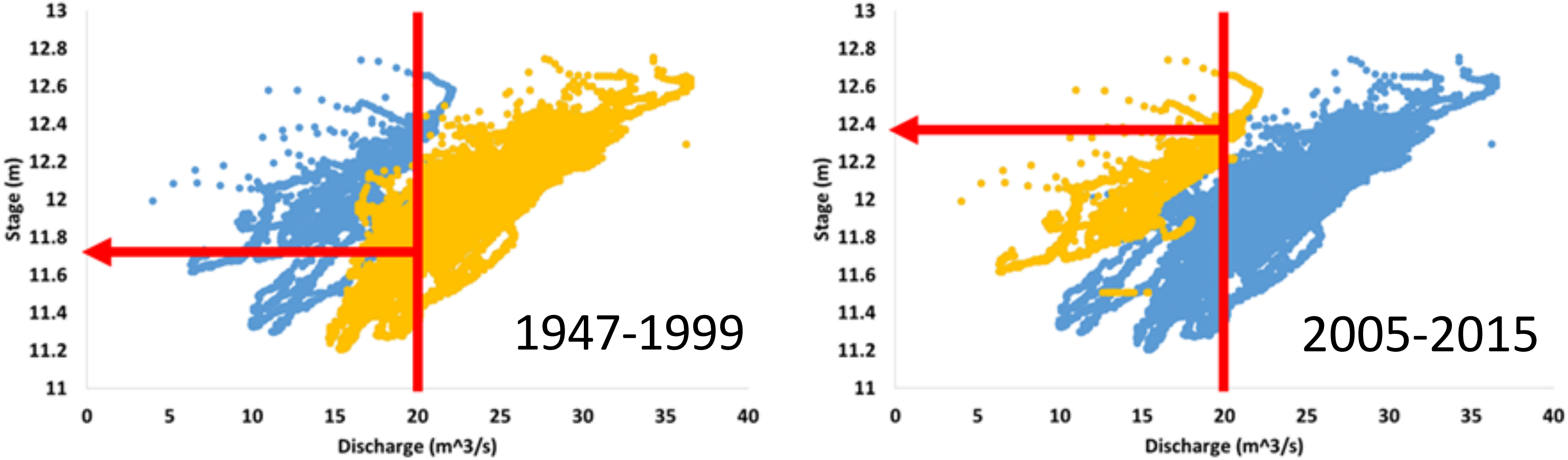


Conner

1932-2003 | **2004-2015**



3. Stage-Discharge-Velocity Relationships



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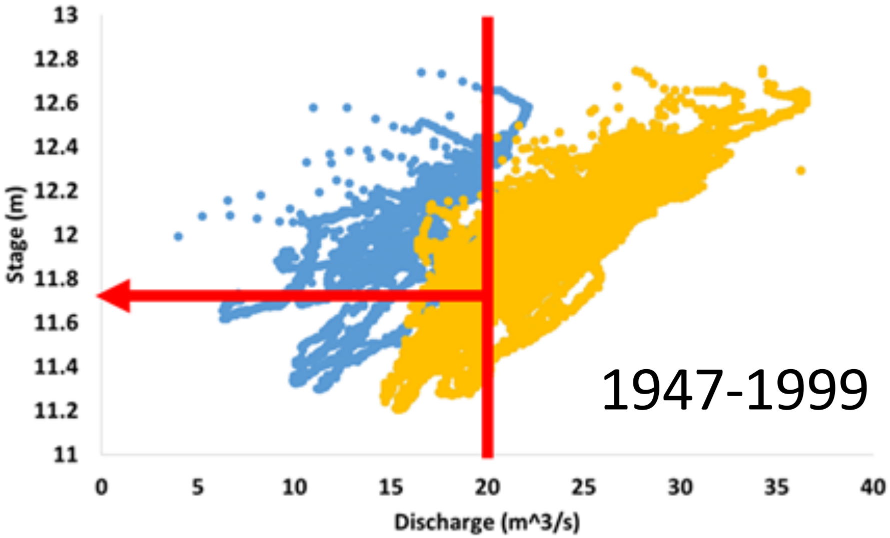
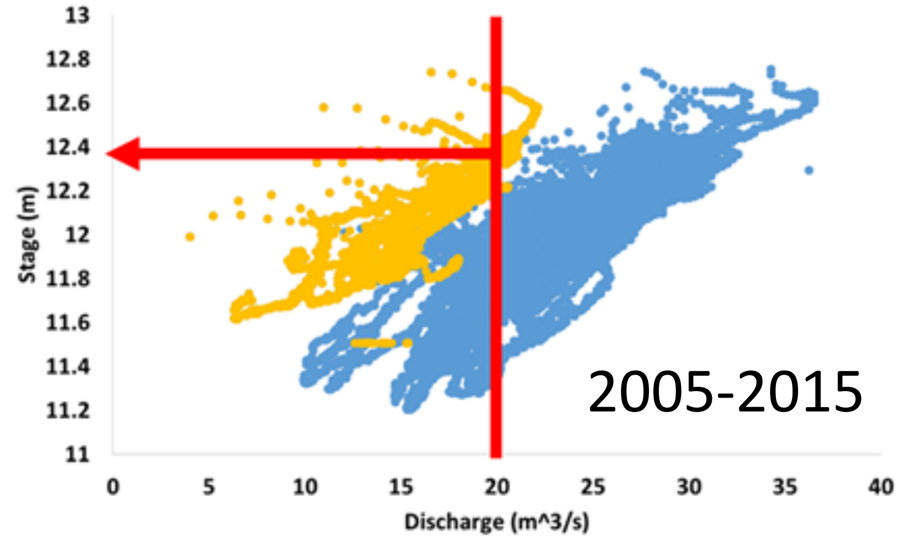
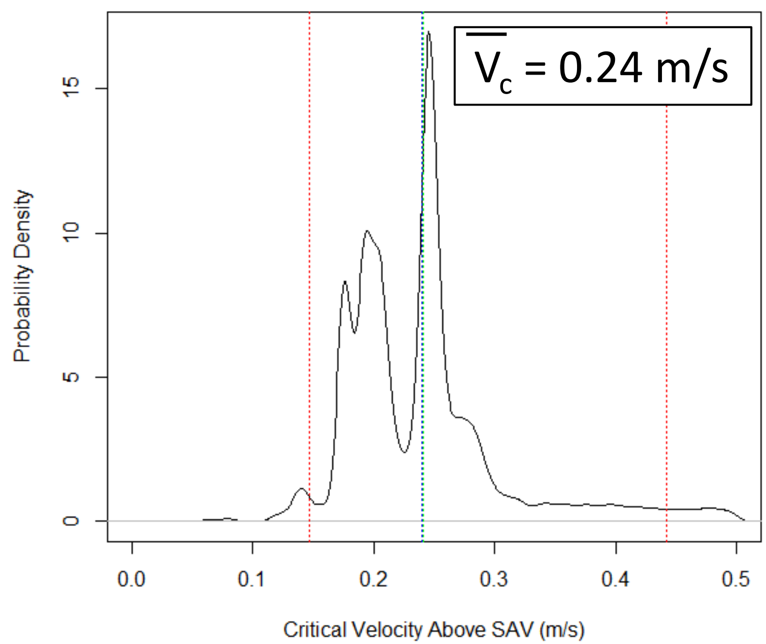




Historic

- Q = 20 m^3/s
- v = 0.244 m/s (avg. v out of spring pool)
- ***At/near critical threshold***

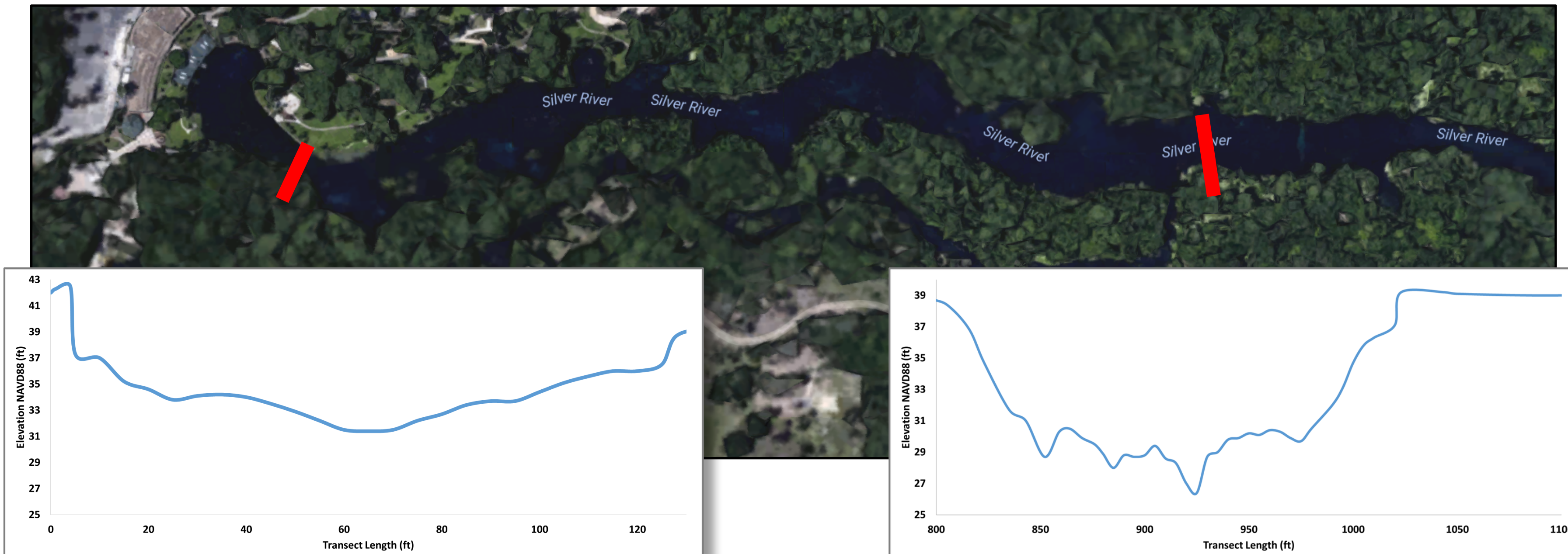


Current

- Q = 20 m^3/s
- v = 0.159 m/s (avg. v out of spring pool)
- ***Well below critical threshold***

3. Stage-Discharge-Velocity Relationships

- **<u>MGMT Implication</u>:** Higher stage for same discharge → larger cross-sectional flow area → reduced velocity



Mean velocity at 700 cfs

$V_{historic}$ = 0.24 m/s

$V_{current}$ = 0.16 m/s

Mean velocity at 700 cfs

$V_{historic}$ = 0.16 m/s

$V_{current}$ = 0.13 m/s

3. Stage-Discharge-Velocity Relationships

- **Possible Mechanisms:** Increased roughness (more/different/ reconfigured SAV), decreased river slope?
- **Ongoing Work:** Simplified model to hind-cast historic SAV cover and explore SAV dynamics (sloughing, seasonality, manatees?)

$$Q = \frac{k}{n}\left(\frac{A}{P}\right)^{\frac{2}{3}}(S)^{\frac{1}{2}}A$$

$$v = \frac{Q}{A}$$

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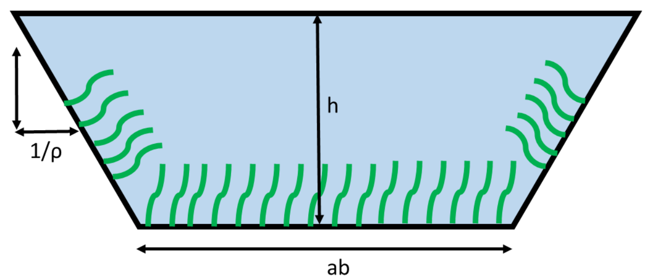
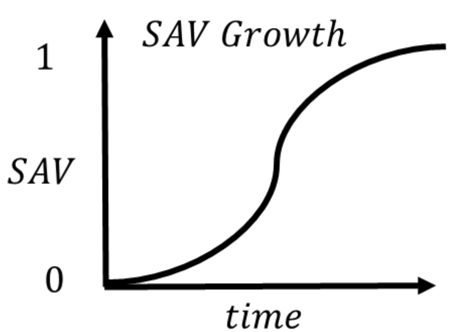
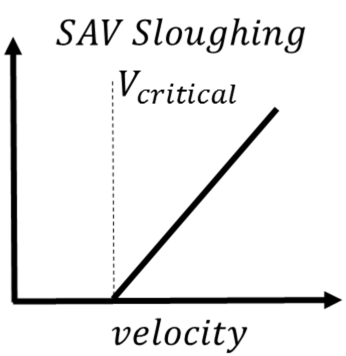
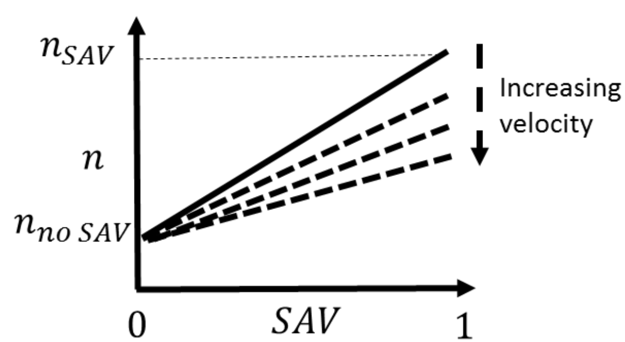


$$n = n_{no\ SAV} + \left(\frac{n_{SAV} - n_{no\ SAV}}{1 - 0} - [N_v V \Phi(V) + (n_{saturated} - N_v V)\Phi(V - V_{sat})]\right) SAV$$







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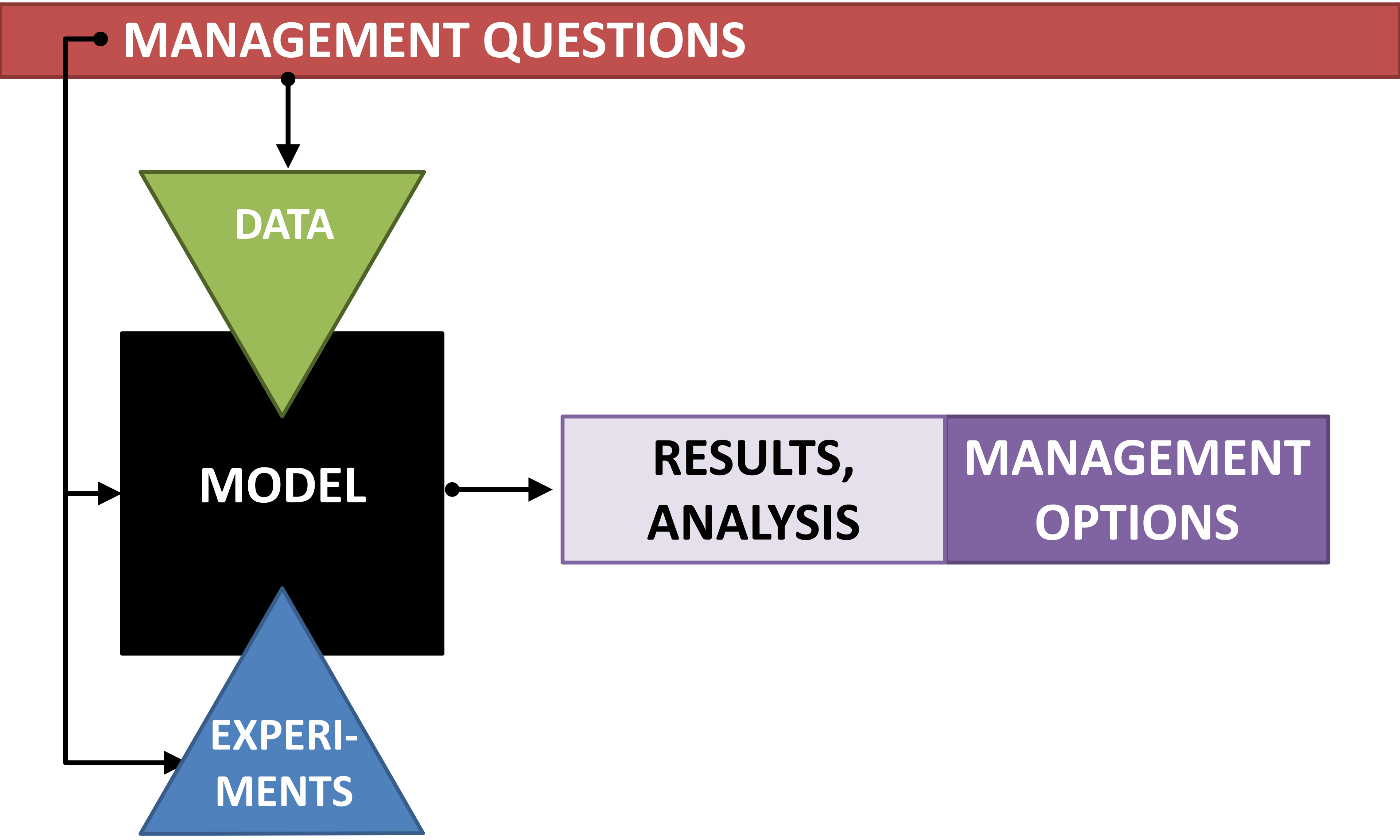
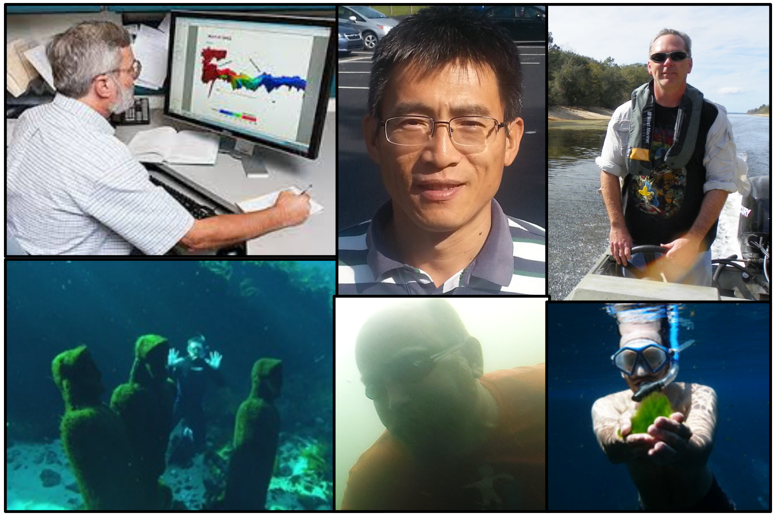
4. MGMT Modeling: Scenario Analyses



4. MGMT Modeling: Scenario Analyses

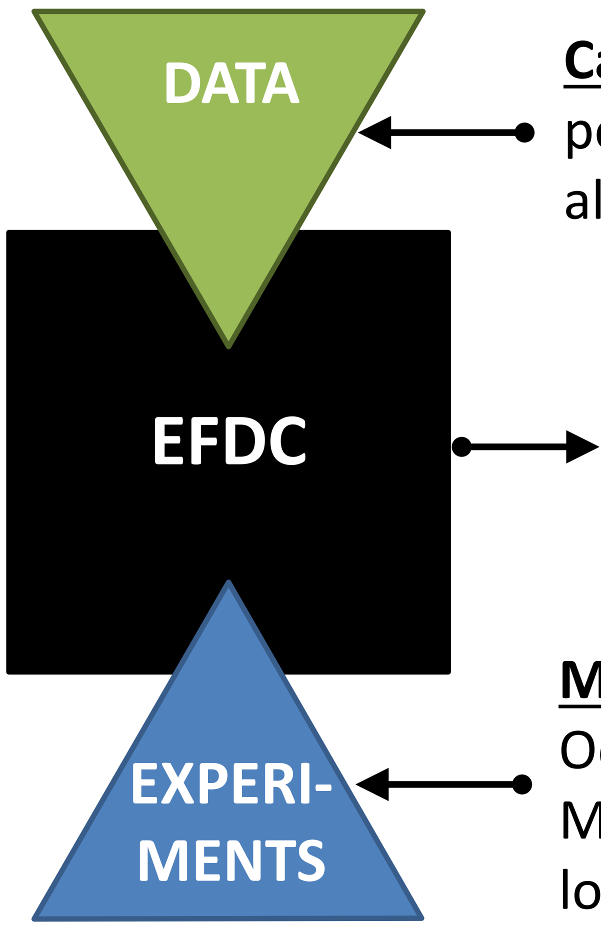
- **<u>The Six Questions</u>:**



1. What is the relationship between veg. resistance and velocity?
2. How sensitive are stage and velocity to changes in resistance?
3. How has altered tail-water resulted in stage and velocity changes?
4. How does present-day velocity compare with historical condition?
5. Given thresholds for algae, can velocity control algae under different hydraulic conditions?
6. **What management methods can be applied to control algae by altering velocity?**

4. MGMT Modeling: Scenario Analyses

What management methods can be applied to control algae by altering velocity?



<u>Calibration/validation data:</u> reach- and point-scale velocity, mixing, vegetation, algae, thresholds, etc...

<u>Model scenarios:</u> lower tail-water in the Ocklawaha River; increase discharge from Mammoth Vent; remove vegetation from lower Silver (or Ocklawaha); dredging...

Thank you!

Questions?

Special thanks to: FL DEP, Silver River State Park, Park Manager Sally Lieb, UF Scientific Dive Team

dkaplan@ufl.edu

www.watershedecology.org