Annual Report: Springs Ecosystems Supergroup: Hydraulics and Hydrodynamics

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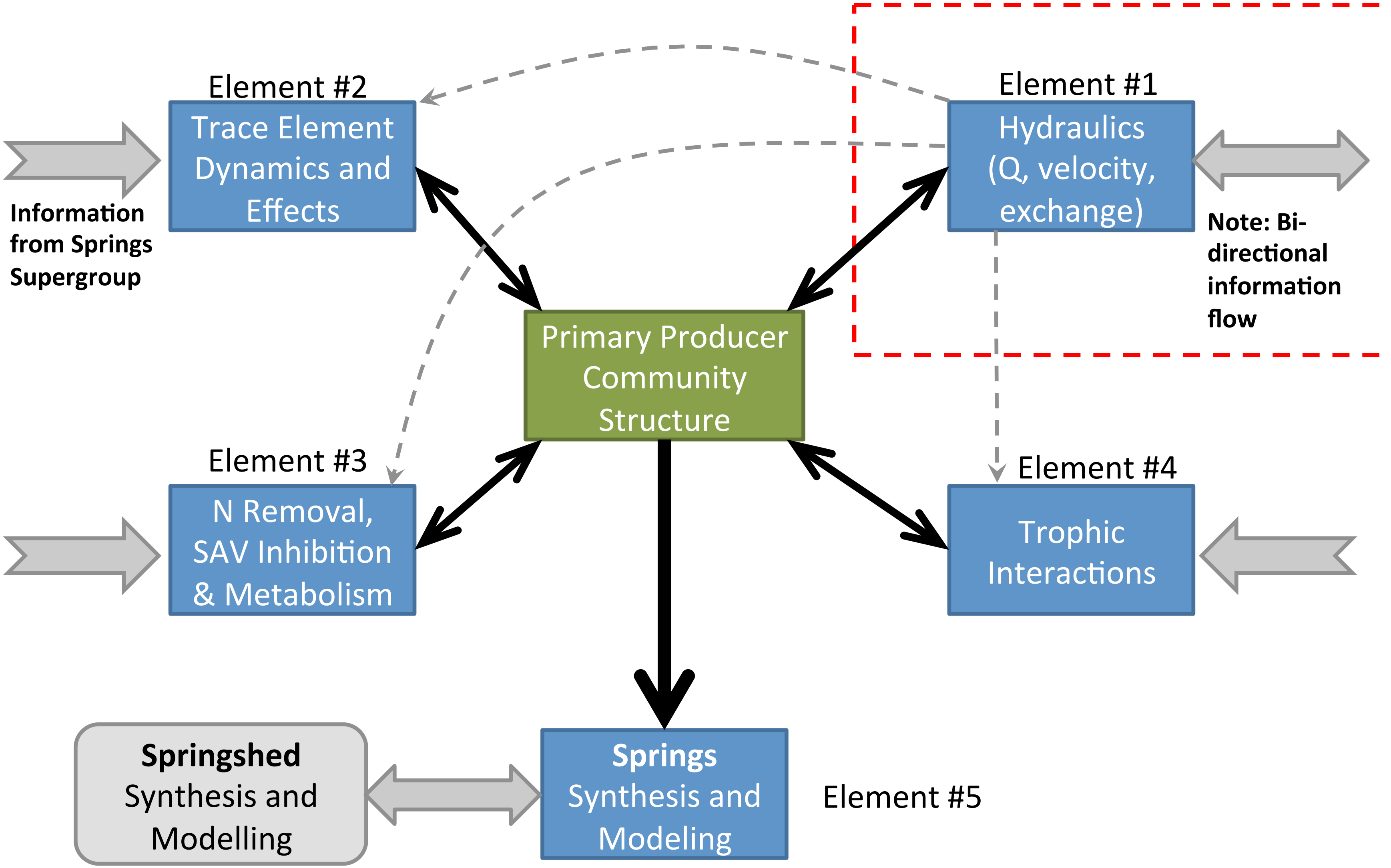
September 1, 2015

UF UNIVERSITY of FLORIDA
The Foundation for The Gator Nation

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

Integration of Research Elements



H & H Objectives (from 7/2/14 Meeting)

SJRWMD Team

1. Predict unsteady **water level** profiles as f(Q, aquatic vegetation)
2. Predict 3D **velocities** in meadow-type (e.g., *Sagittaria*) and canopy-type (e.g., *Hydrilla*) SAV
3. Develop guidance for selection of **Mannings *n*** in different channel types (vegetation type, substrate)
4. Develop **vegetative resistance and/or turbulence algorithms** for 3-D hydrodynamic modeling

UF Team

5. Links to 3-D modeling: **velocity validation, turbulence msmnts.**
6. Measure **velocity** and **RTDs** under variety of Q and management
7. Quantify the location and magnitude of **hyporheic vs. channel storage and exchange**
8. Identify **critical shear stresses** for entrainment and detachment of filamentous algae

Mostly Models ⟷ Mostly Data

H & H Objectives (simplified)

SJRWMD Team

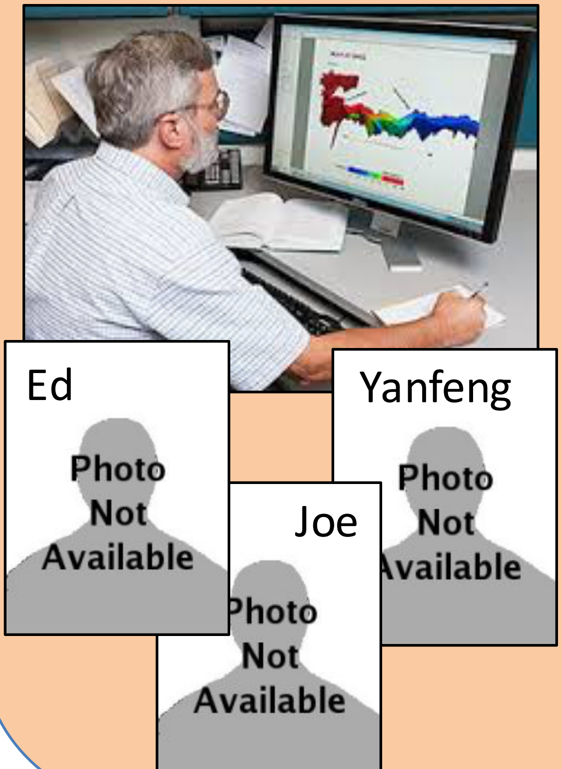
"…determine whether velocity is an important non-nitrate factor influencing the community structure and function of primary producers in the system."
(Chapter 6.4)

UF Team

Mostly Models ⟷ Mostly Data

H & H Objectives (simplified)

SJRWMD Team



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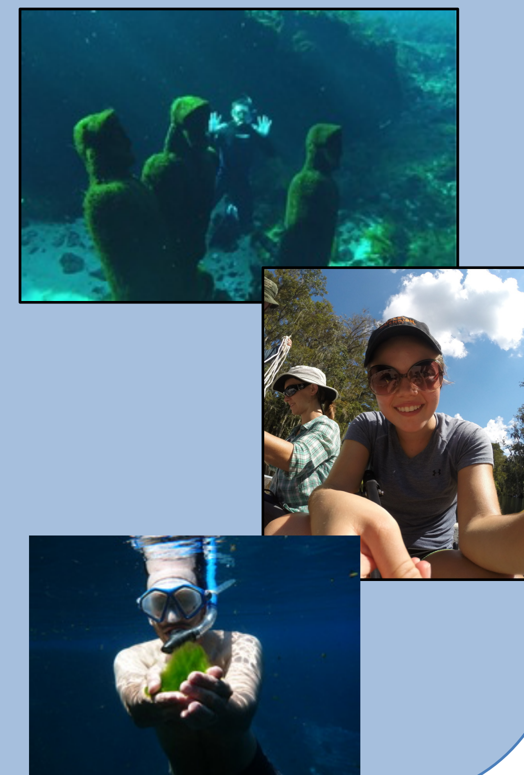
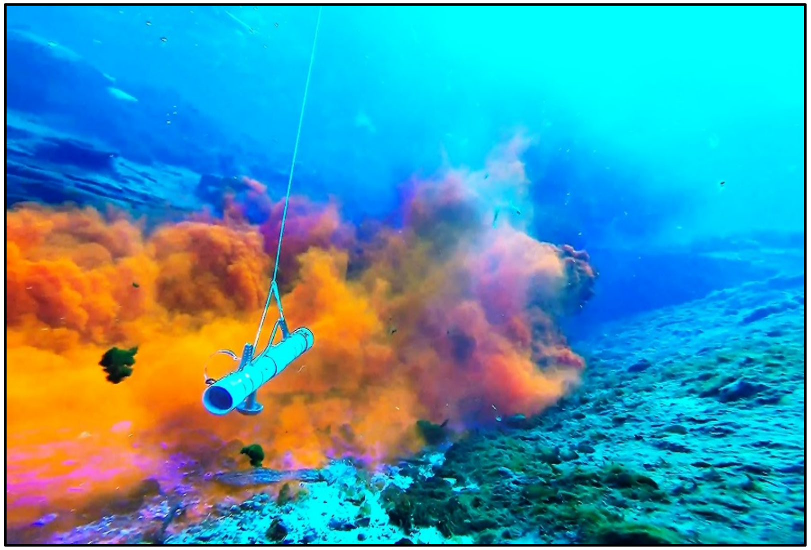
UF Team

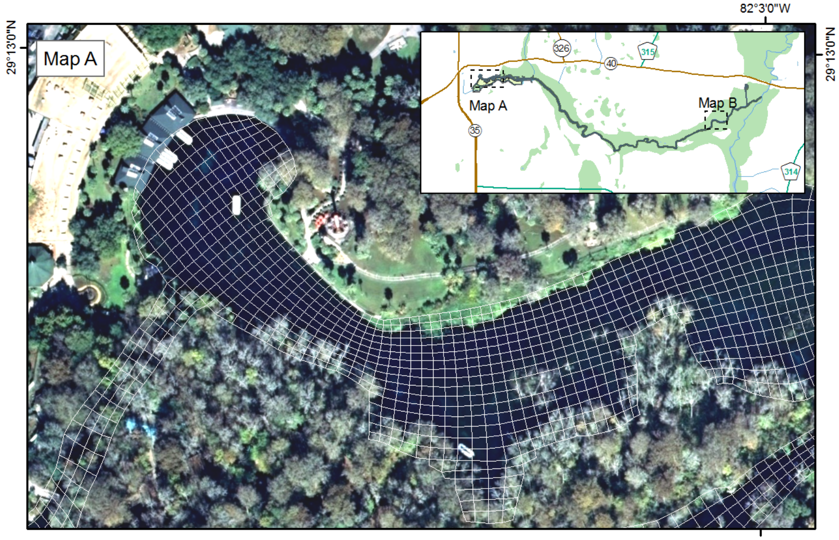


Mostly Models ⟷ Mostly Data

Today’s Outline

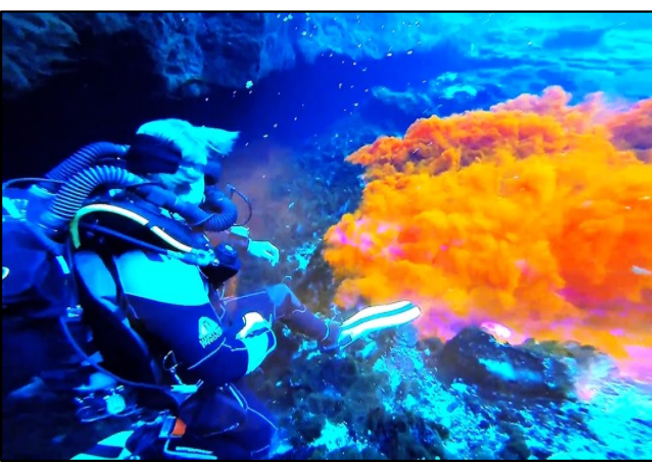
1. **Dye trace experiment**
   - **Velocity and residence time distributions**
   - **EFDC model calibration**
2. Critical velocity/shear stress
   - *In-situ* flow-ways
   - Optical methods
3. EFDC Modeling
   - Domain development
   - Friction/turbulence formulation
   - Initial calibration





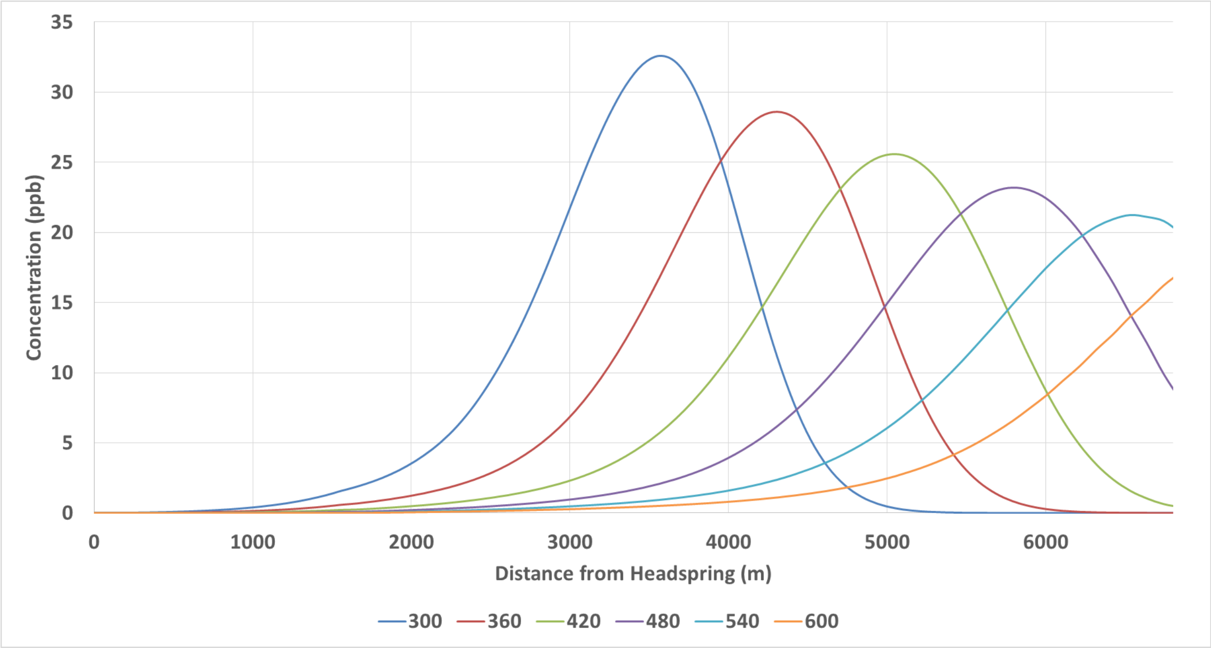
1. Dye Trace – Background

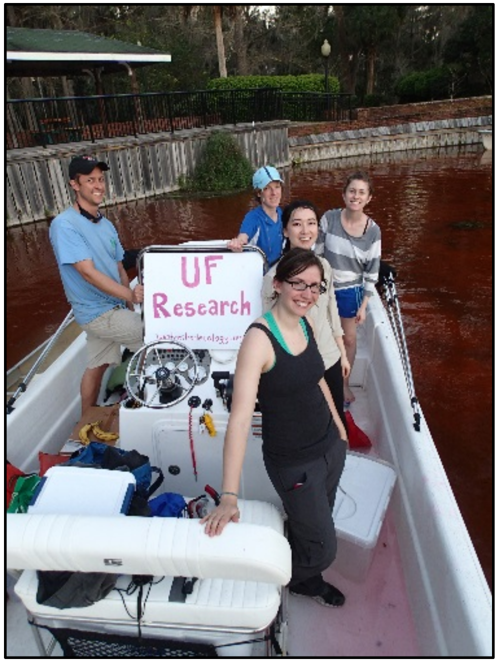
- **<u>Reach-scale</u>** hydrologic characterization
- Calculate residence time and exchange rates with storage zones
  - Nutrient uptake and cycling potential
- Determine if river "behaves" substantially different under different conditions:
  - Channel roughness effects (*vegetation build-up downstream?*)
  - Water surface profile effects (Δ *up/downstream river stage?*)
  - Couple with EFDC model



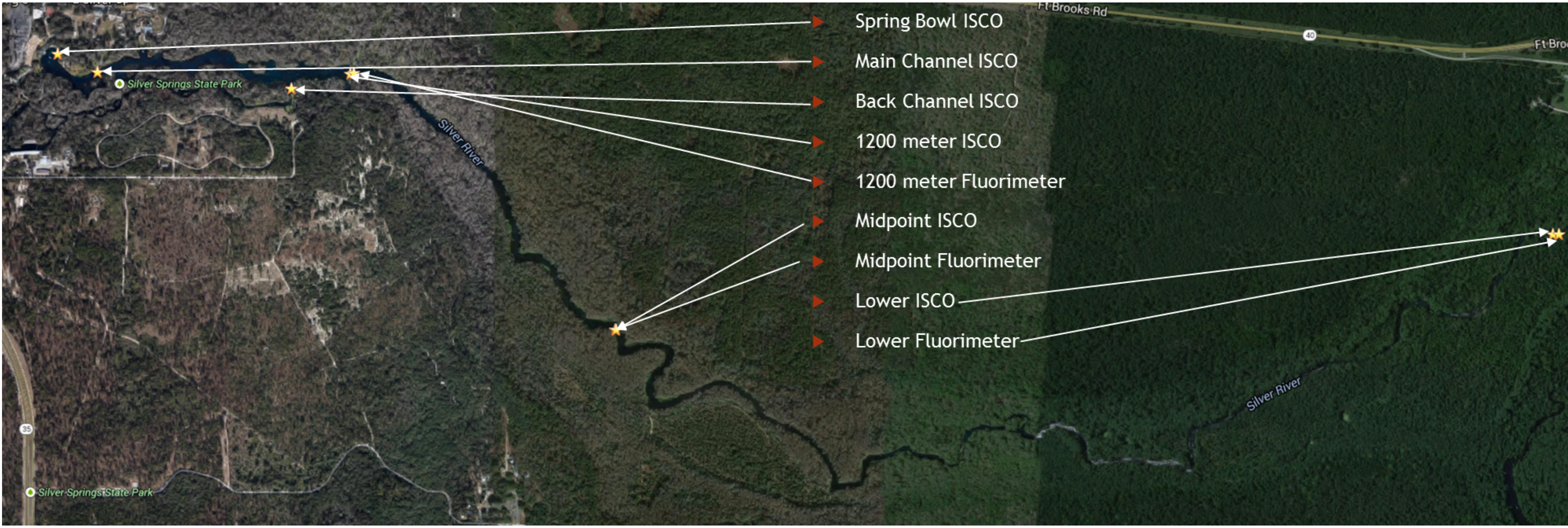
1. Dye Trace – Background

- Release a tracer; monitor its movement through the system
- Salts, dyes, labeled molecules, etc.
- Measure at set location over time: breakthrough curve (BTC)
- **<u>Fitted</u>** BTCs → transport properties: advection, dispersion, transient storage…





1. Dye Trace – Methods



- Injected 18.9 L of 20% Rhodamine WT at Mammoth Vent
- Tracked dye at 9 fixed stations (3 in-stream fluorometers and 9 ISCO automated samplers)
- Collected 318 grab samples to characterize differential mixing

Dye Study at Silver Springs
March 4, 2015

1. Dye Trace – Methods

- 1-D Advection-Dispersion Equation vs. **OTIS**

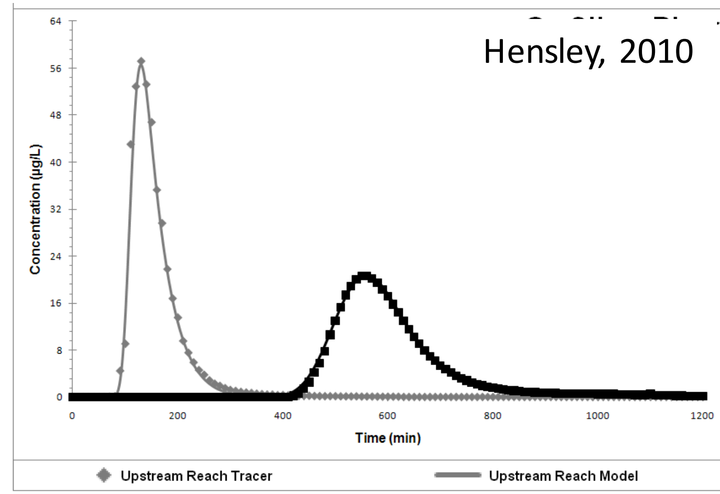
$$\frac{\partial C}{\partial t} = -\frac{Q}{A}\frac{\partial C}{\partial x} + \frac{1}{A}\frac{\partial}{\partial x}\left(AD\frac{\partial C}{\partial x}\right) + \boxed{\frac{q_{LIN}}{A}(C_L - C) + \alpha(C_S - C)}$$

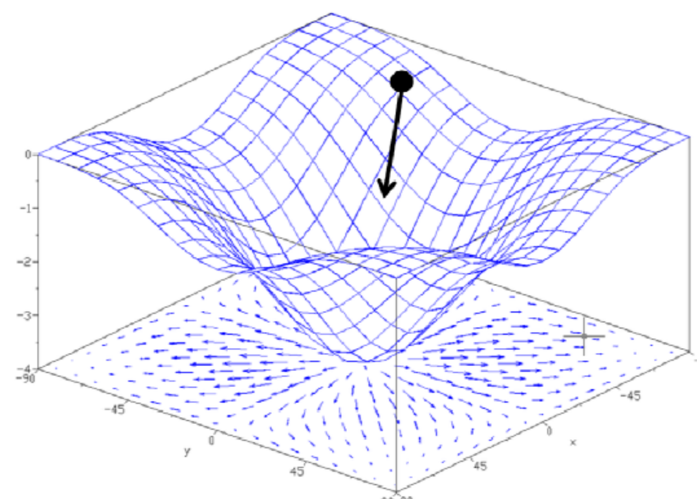
$$\boxed{\frac{dC_s}{dt} = \alpha\frac{A}{A_S}(C - C_S)}$$

A	- main channel cross-sectional area [L^2]	Q	- volumetric flow rate [L^3/T]
A_S	- storage zone cross-sectional area [L^2]	q_{LIN}	- lateral inflow rate [L^3/T–L]
C	- main channel solute concentration [M/L^3]	t	- time [T]
C_L	- lateral inflow solute concentration [M/L^3]	x	- distance [L]
C_S	- storage zone solute concentration [M/L^3]	α	- storage zone exchange coefficient [/T]
D	- dispersion coefficient [L^2/T]		

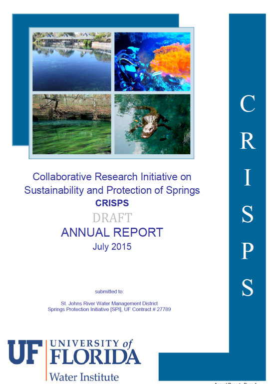
1. Dye Trace – Methods

- Fitting model to data (get best fit parameters)
- Objective function: e.g., *min*(SSE), weighting?
- Bayesian parameter fitting
- Parameter identifiability and uniqueness (Kelleher et al. 2013)





Kelleher, C., et al. "Identifiability of transient storage model parameters along a mountain stream." *Water Resources Research* 49.9 (2013): 5290-5306.



1. Dye Trace – Results

Figure: Ed Carter, SJRWMD

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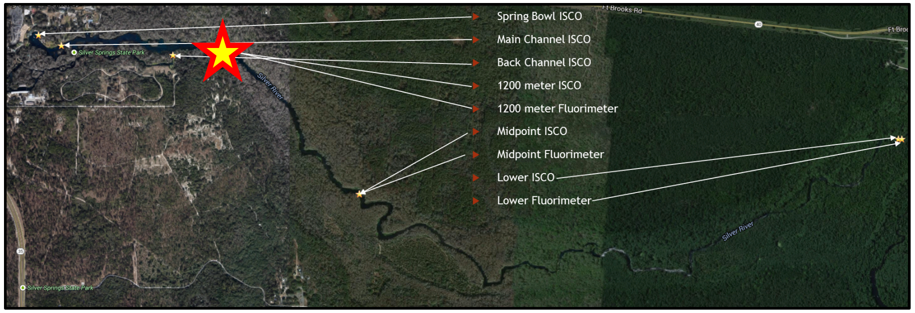
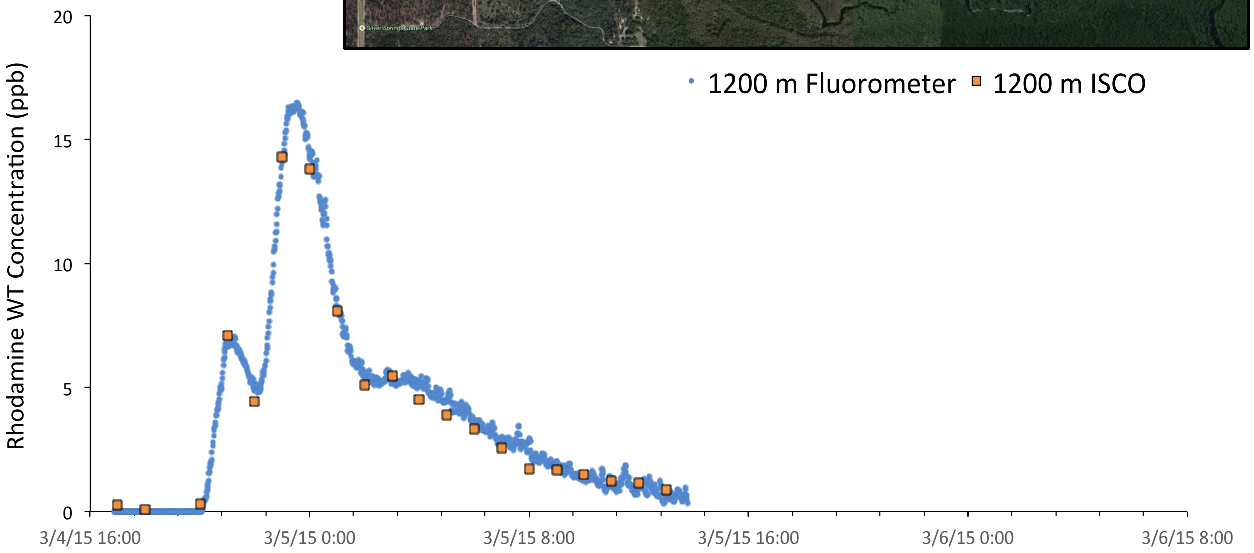


- Three **upstream** peaks (2 back channel flowpaths)
- Full mixing not achieved by 1200 m



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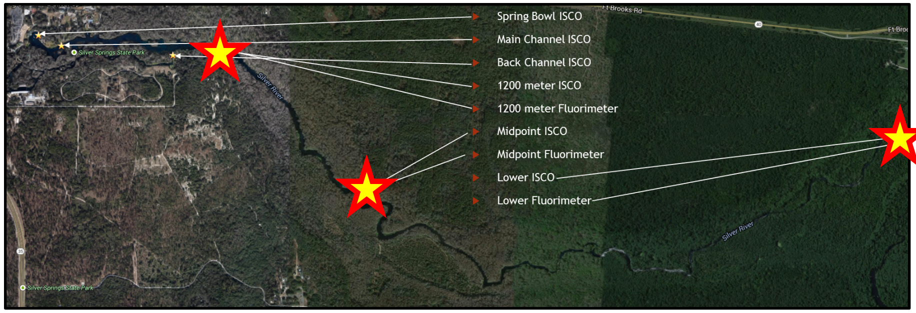

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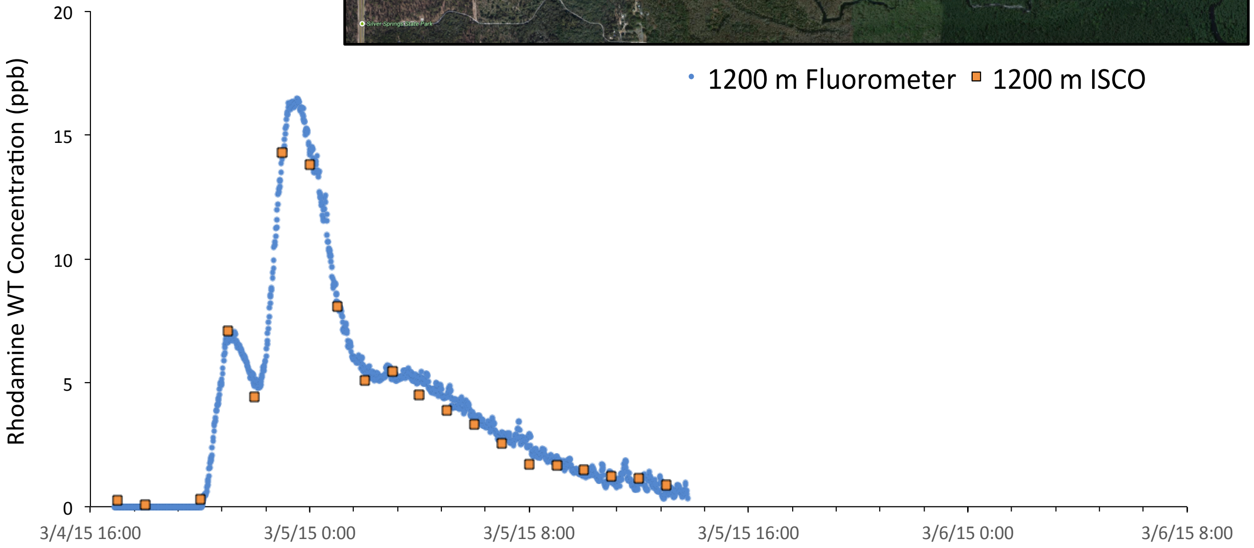
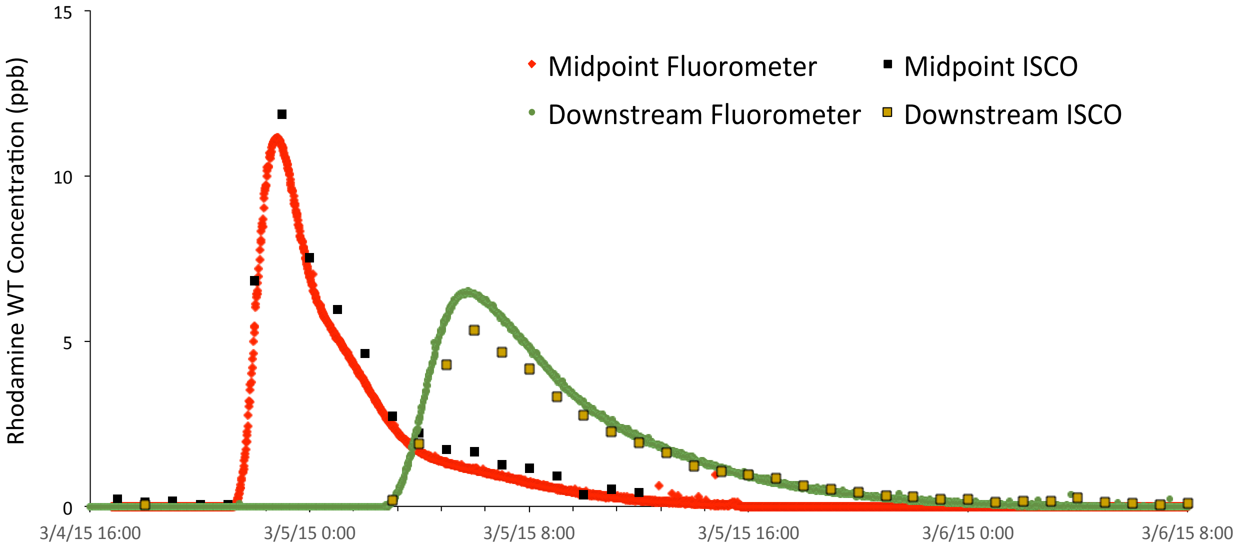


- **Downstream** delay and attenuation
- Comparison to previous study…



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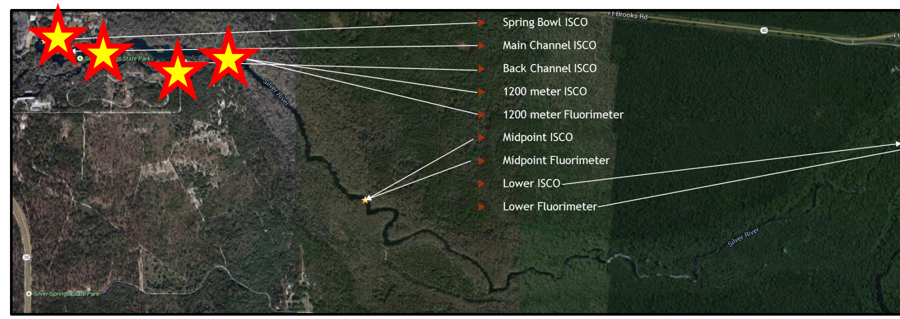
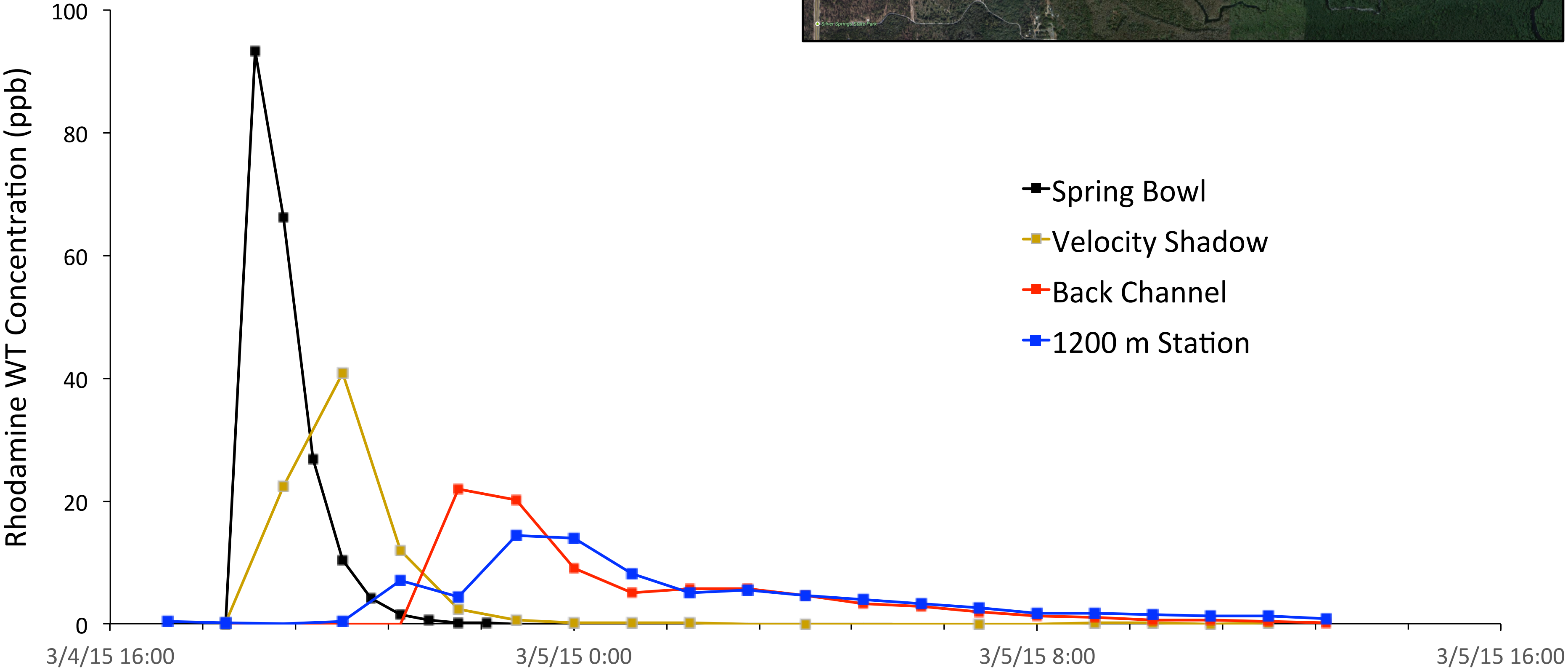
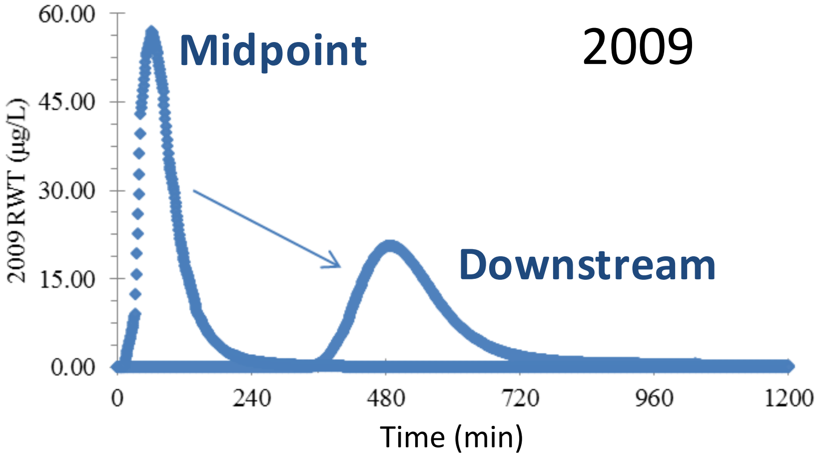
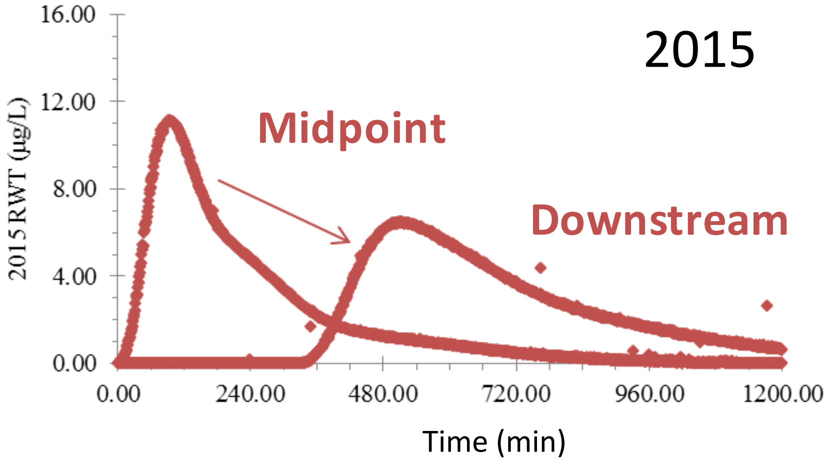




- Spring bowl cleared in <6 hours
- Back channel flow: delayed, 2-paths, substantial portion of flow

1. Dye Trace – Results: 2009 vs. 2015





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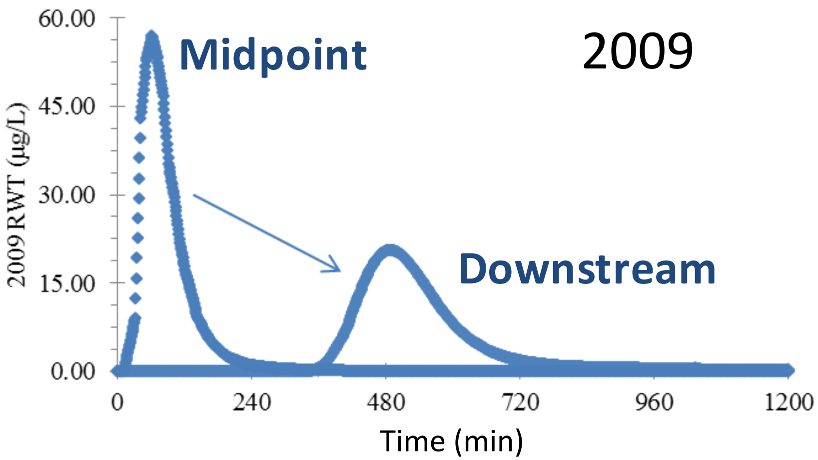
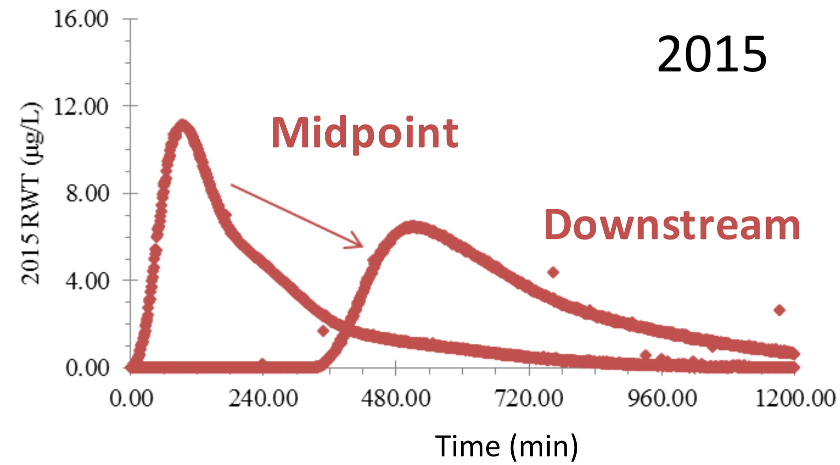
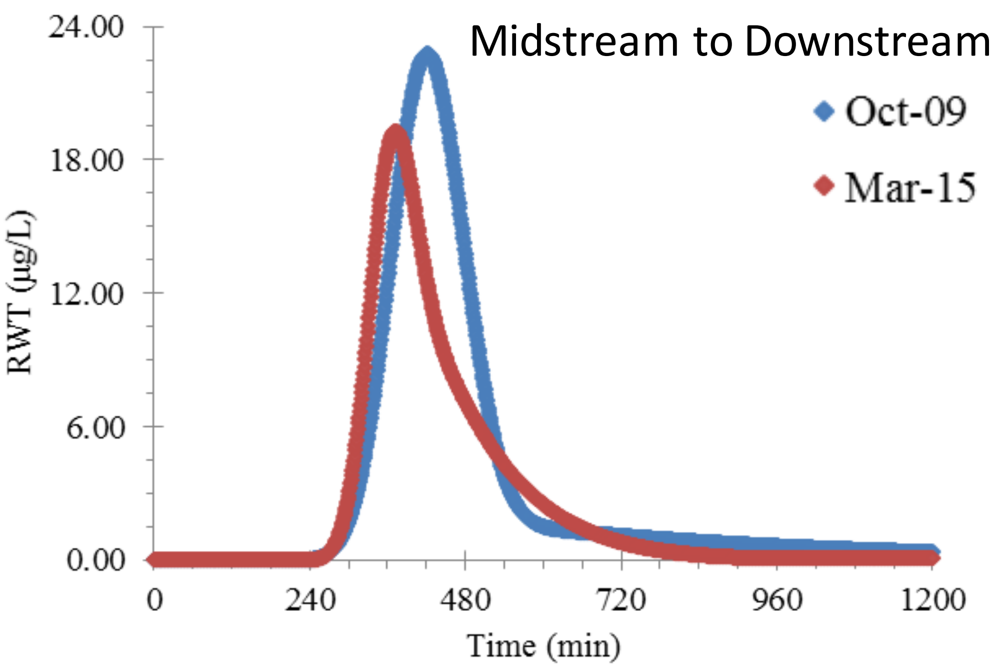
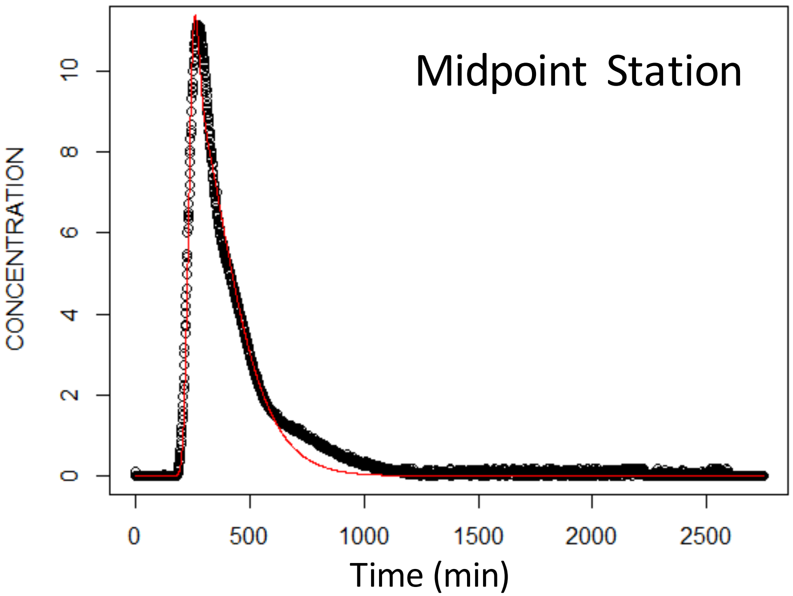


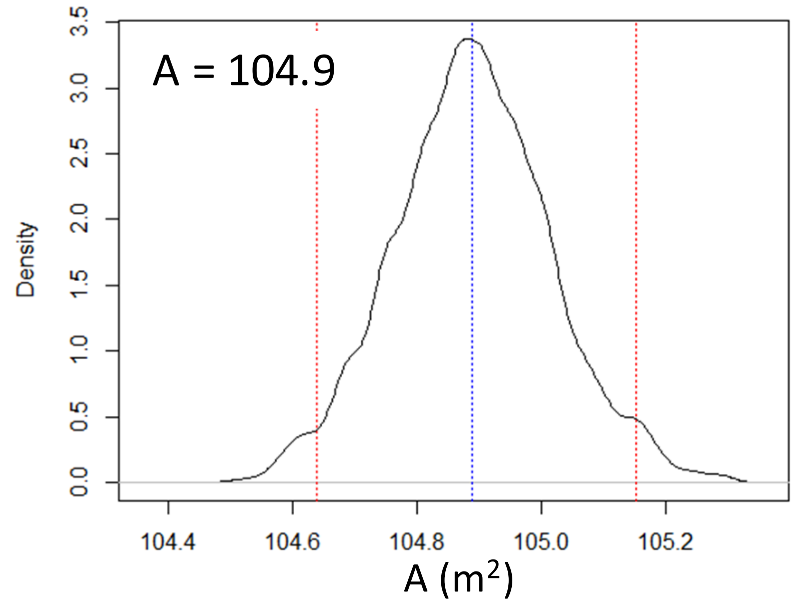


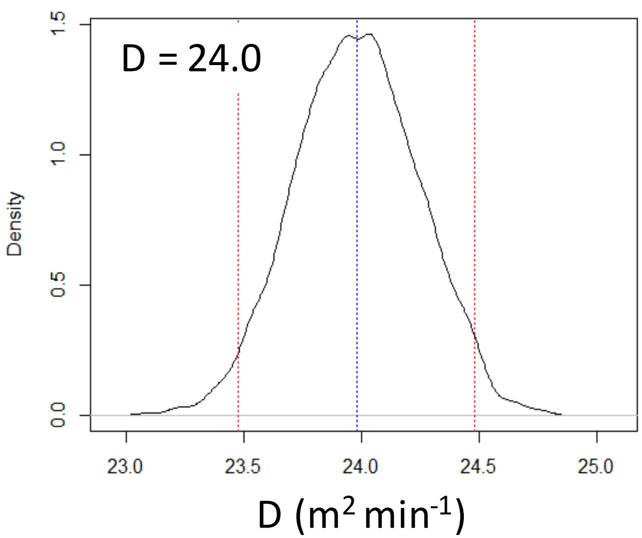


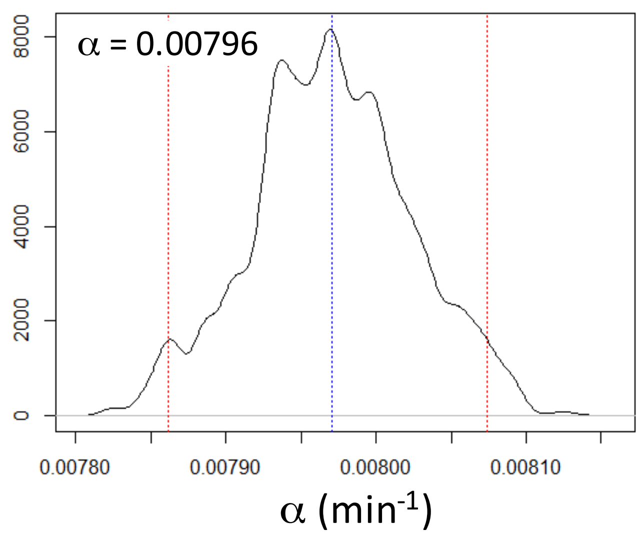
Parameter	2009	2015	Units
Q	15.5	20.0	m^3/s
L	5300	5300	m
A	73.4	80.8	m^2
A_S	18.1	17.3	m^2
D	10.7	5.8	m^2/s
α	0.00001	0.00005	1/s
τ	418	357	min
u	0.21	0.25	m/s

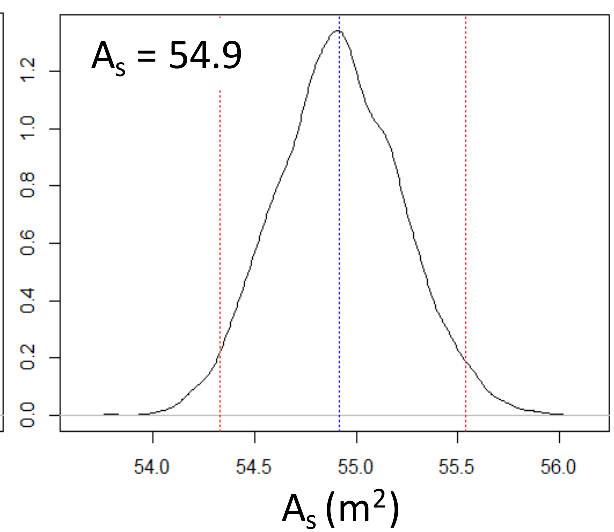
1. Dye Trace – Results: Standard vs. Bayesian





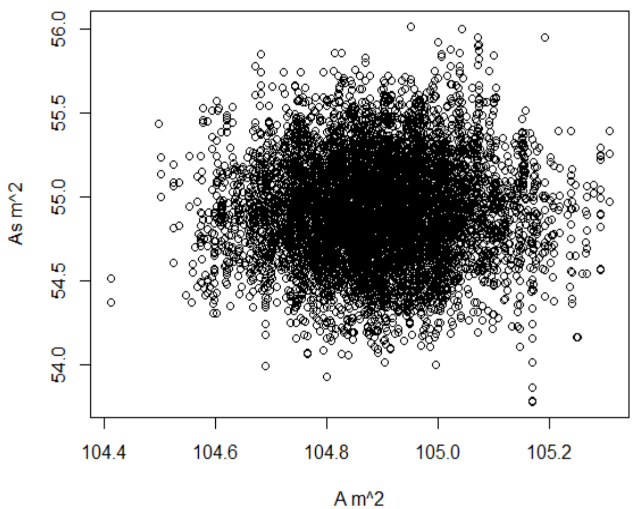




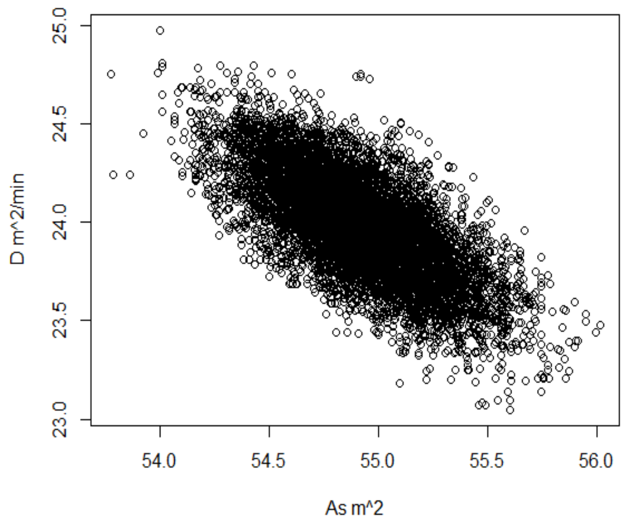


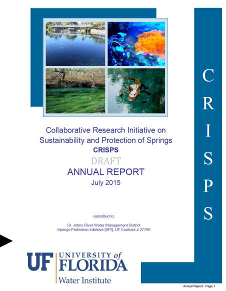
1. Dye Trace – Results: Standard vs. Bayesian

Parameter Independence

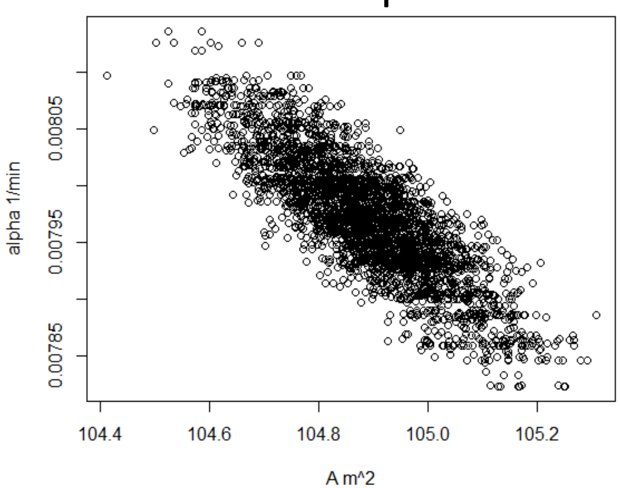


Parameter Dependence

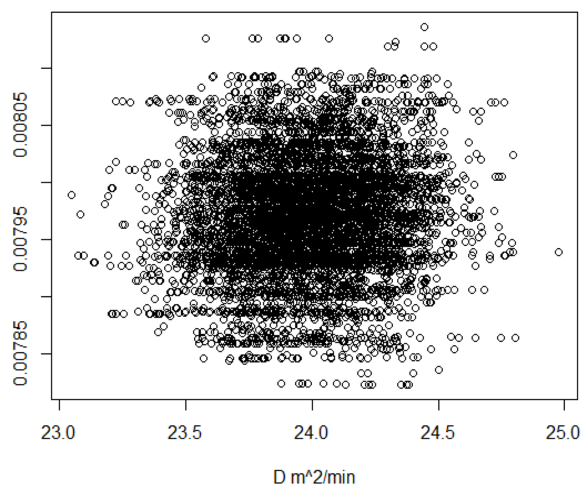




Parameter Dependence



Parameter Independence



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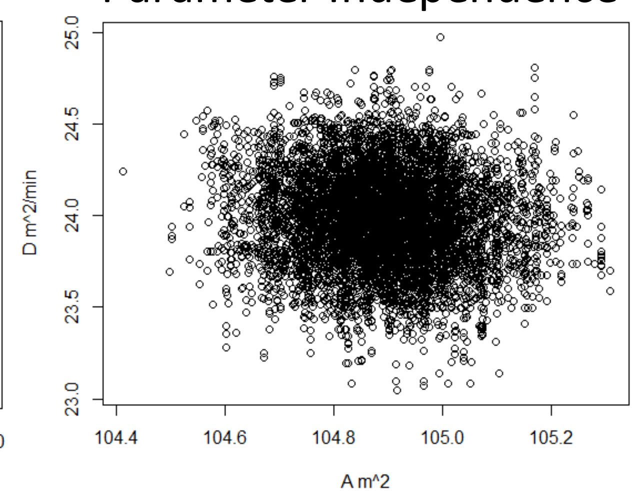
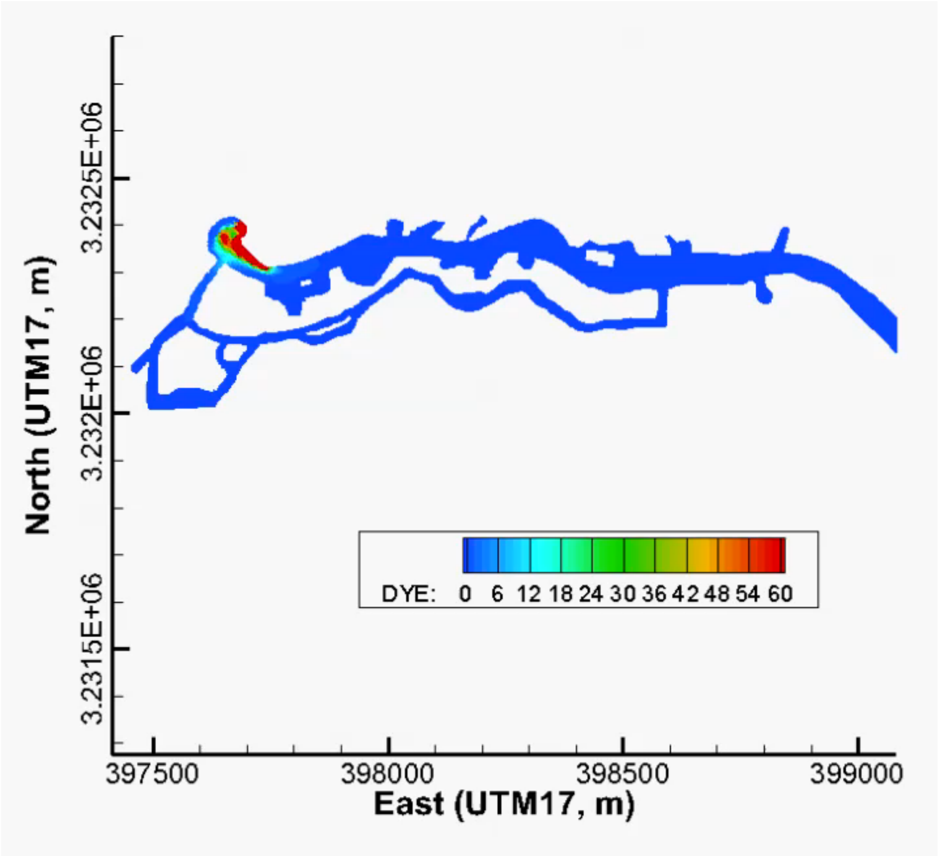
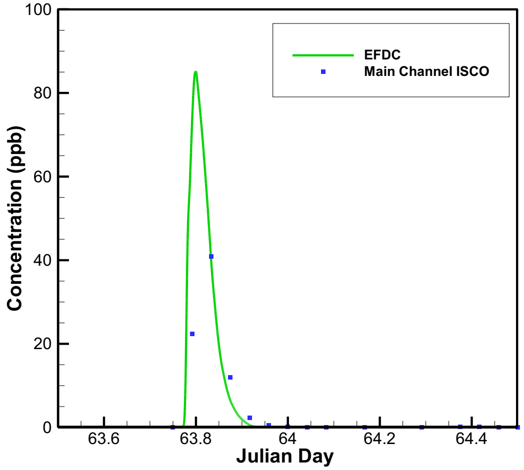


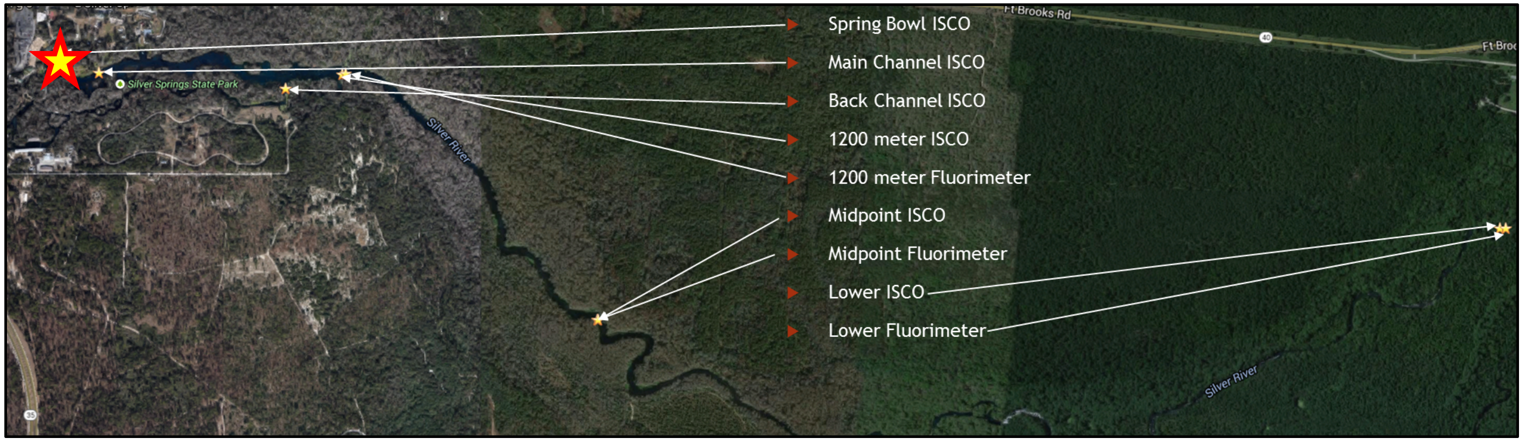
1. Dye Trace – Results: EFDC vs. Measured

- **EFDC vs. Measured Data**
  - *Initial* simulation of pulsed dye release at Mammoth Vent
  - Compare to data observed from field experiment…

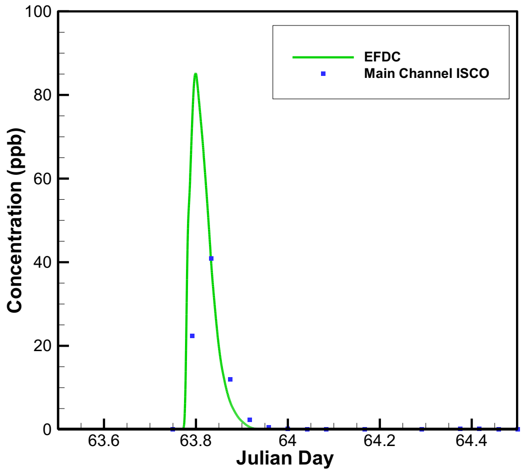




EFDC
Main Channel ISCO
Concentration (ppb)
Julian Day
100
80
60
40
20
0
63.6
63.8
64
64.2
64.4



Spring Bowl ISCO
Main Channel ISCO
Back Channel ISCO
1200 meter ISCO
1200 meter Fluorimeter
Midpoint ISCO
Midpoint Fluorimeter
Lower ISCO
Lower Fluorimeter
Silver Springs State Park
Silver River
Ft Brooks Rd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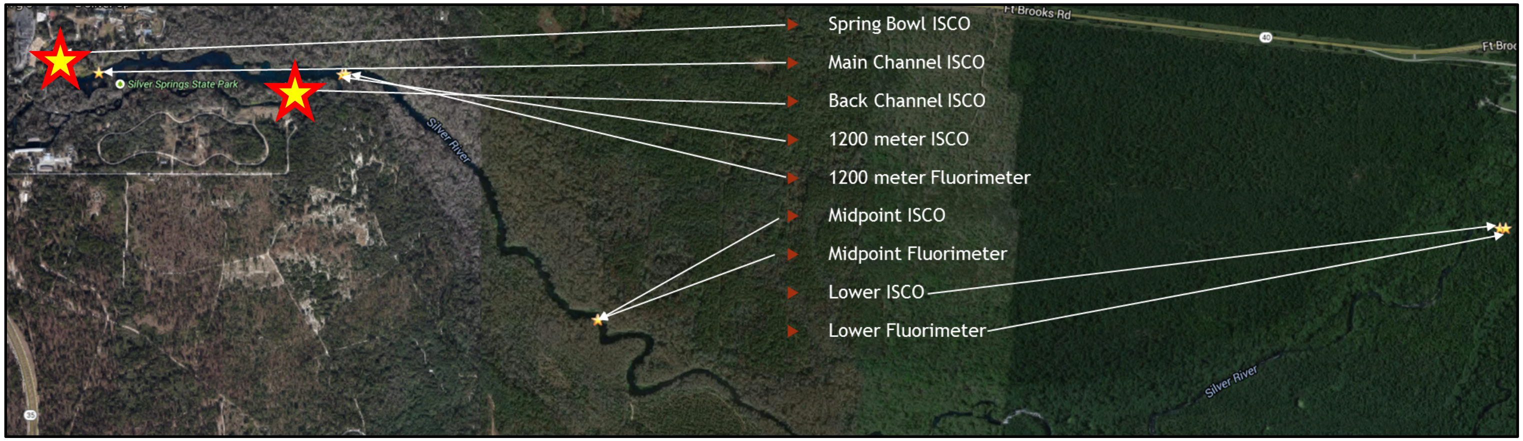
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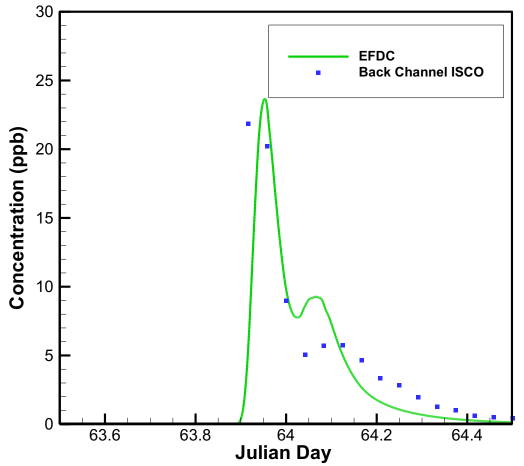
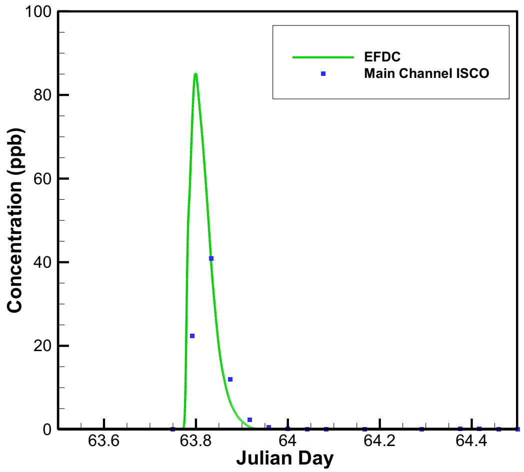

EFDC
Back Channel ISCO
Concentration (ppb)
Julian Day
0
5
10
15
20
25
30
63.6
63.8
64
64.2
64.4


100
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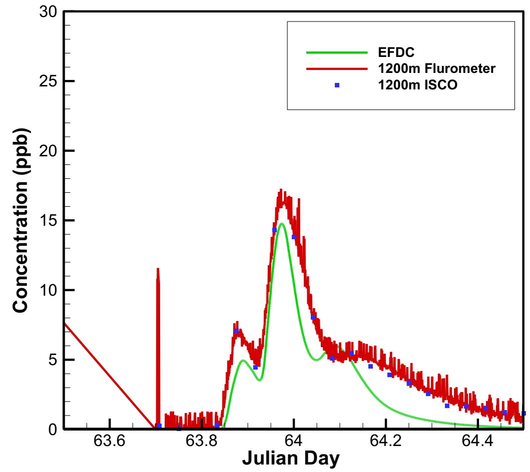
Julian Day
EFDC
Main Channel ISCO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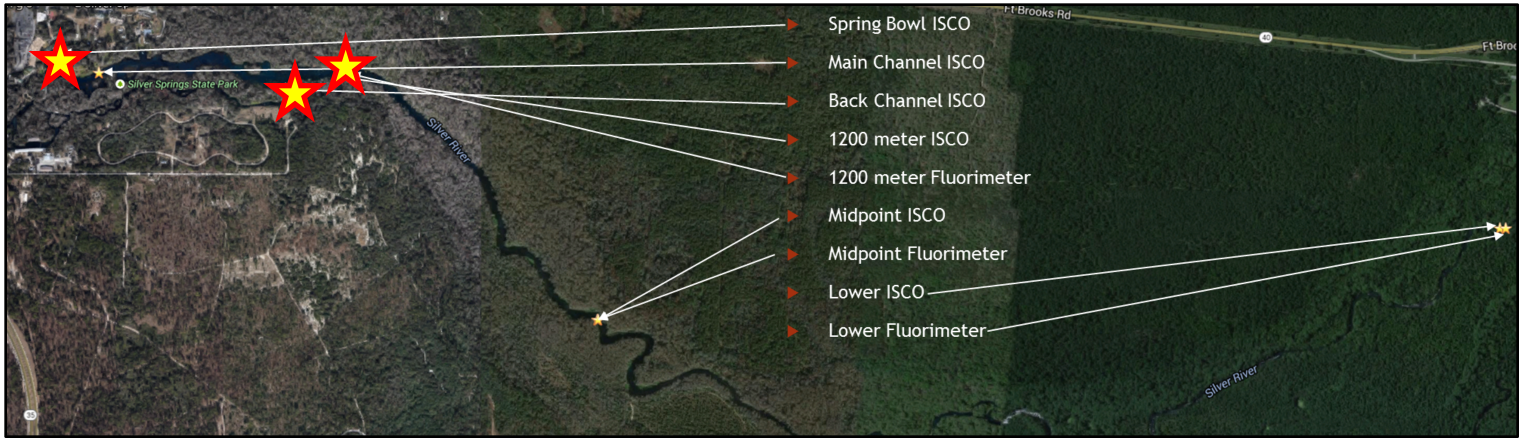
EFDC
1200m Flurometer
1200m ISCO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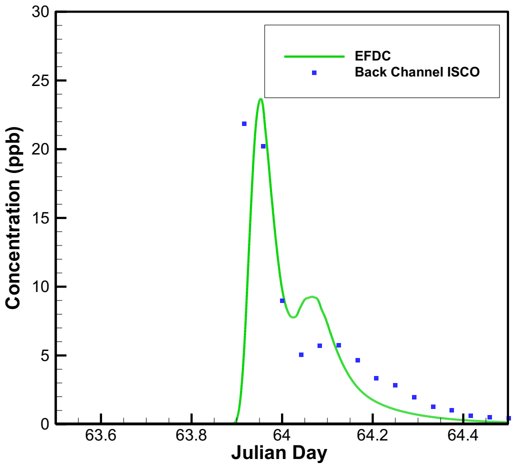
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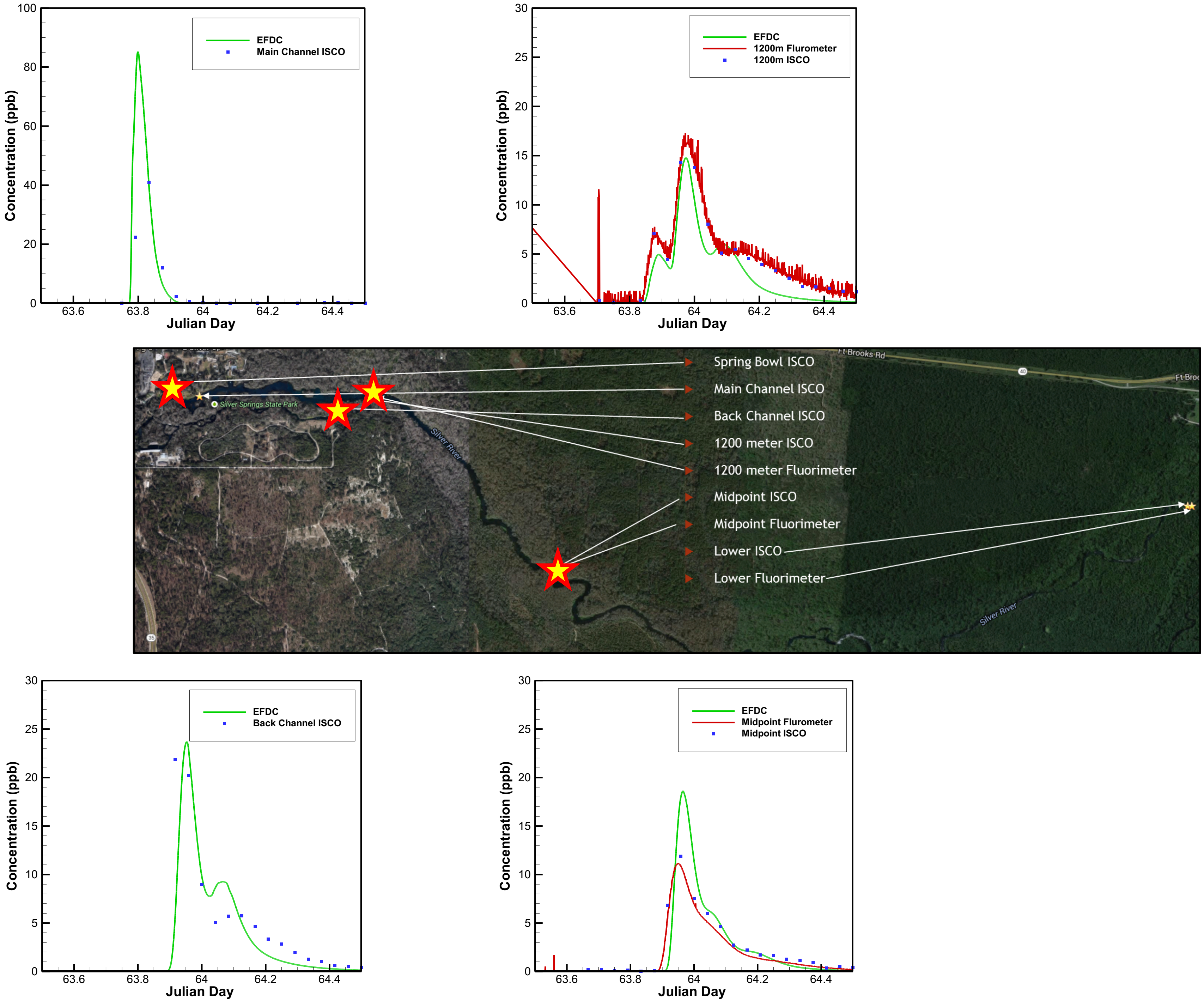

Concentration (ppb)
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EFDC
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1200m Flurometer
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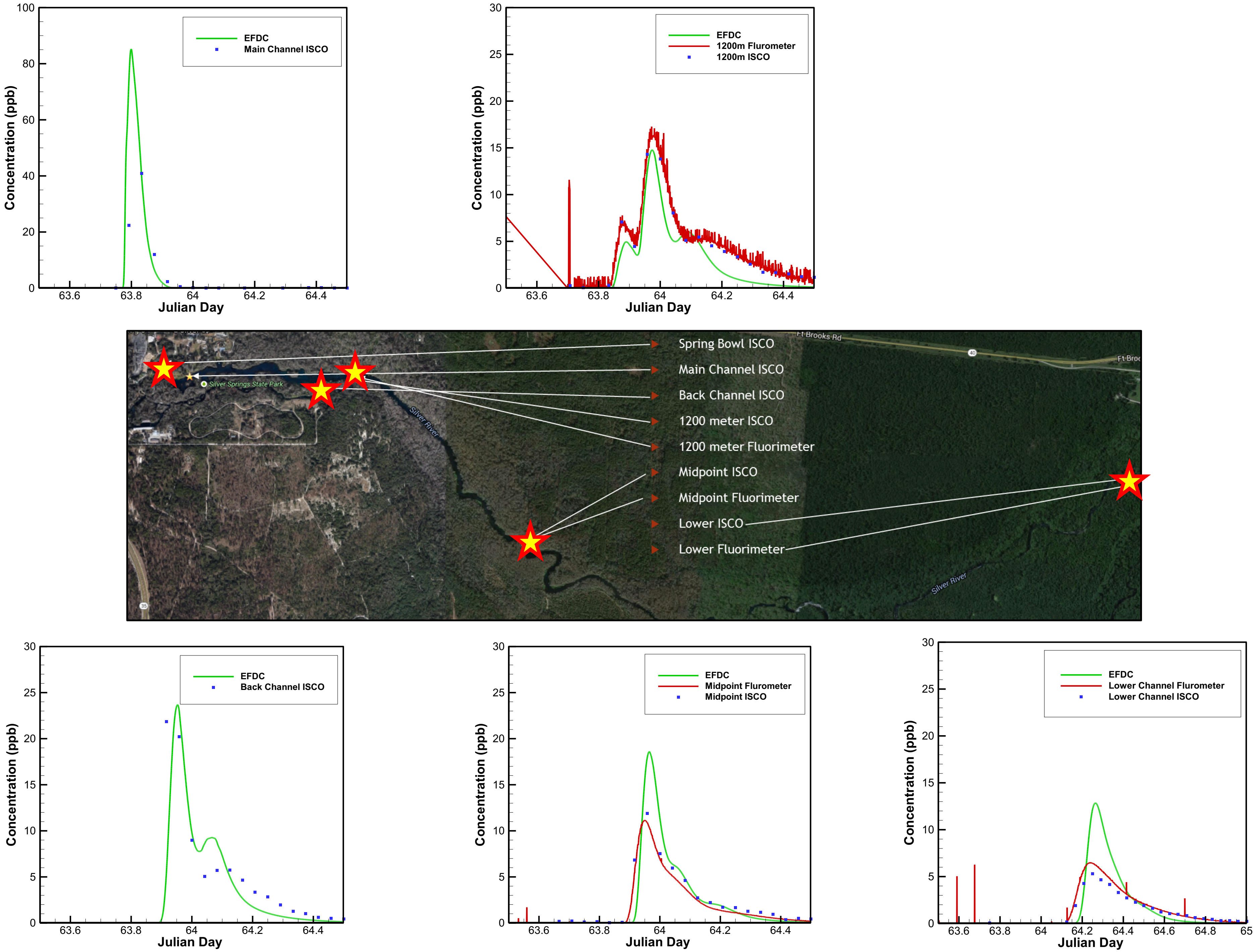

EFDC
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Concentration (ppb)
Julian Day
EFDC
Lower Channel Flurometer
Lower Channel ISCO
Concentration (ppb)
Julian Day

Today's Outline

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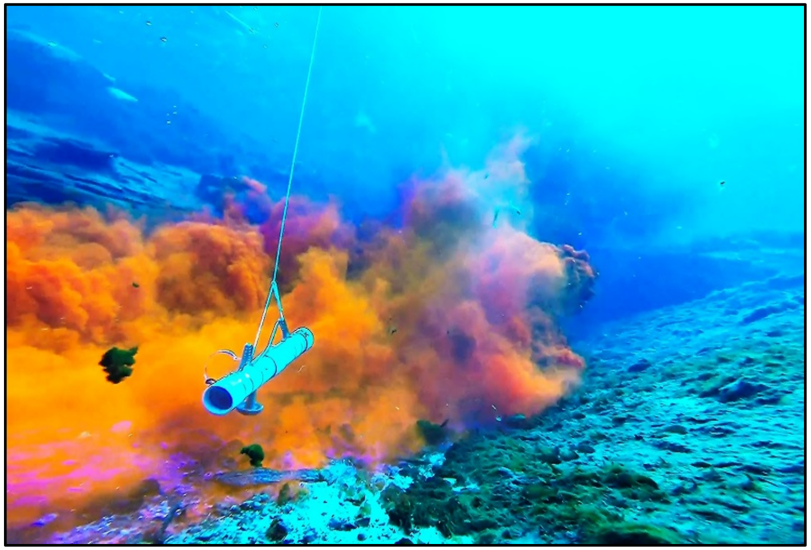
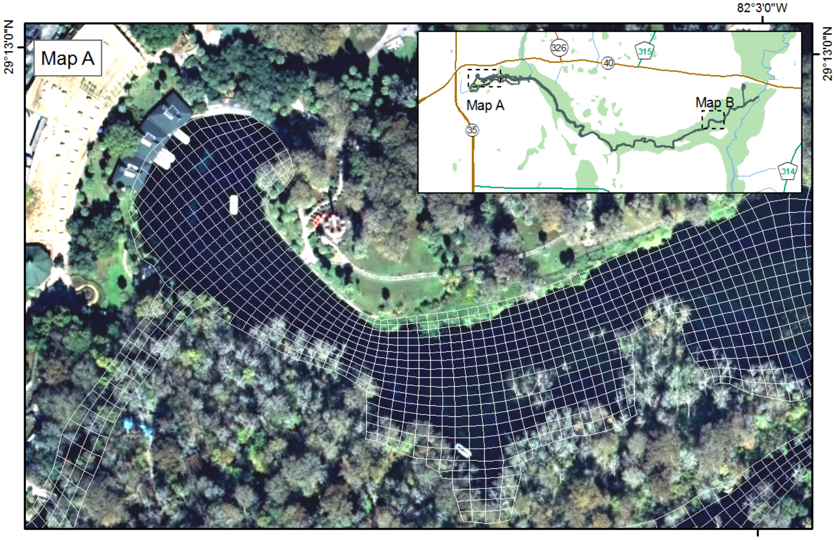
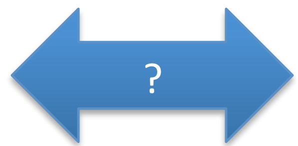
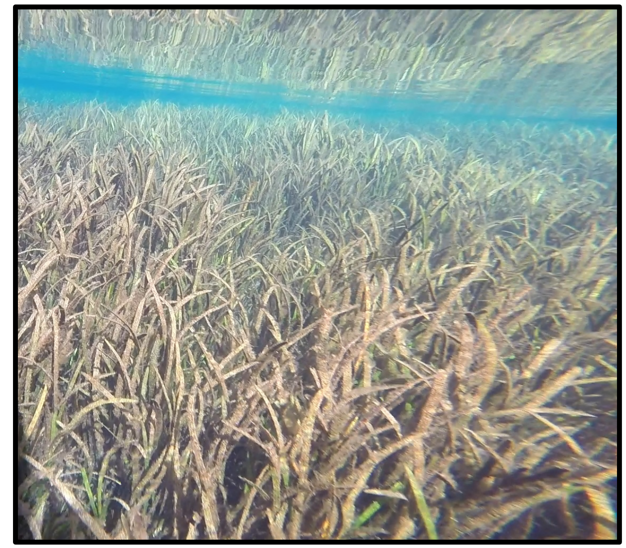
   - Velocity and residence time distributions
   - EFDC model calibration
2. **Critical velocity/shear stress**
   - ***In-situ* flow-ways**
   - **Optical methods**
3. EFDC Modeling
   - Domain development
   - Friction/turbulence formulation
   - Initial calibration

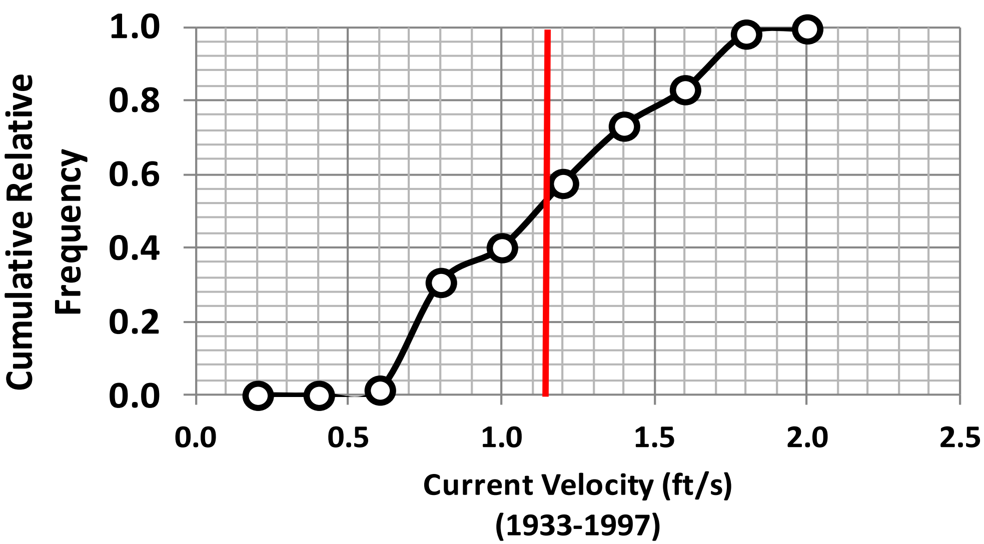


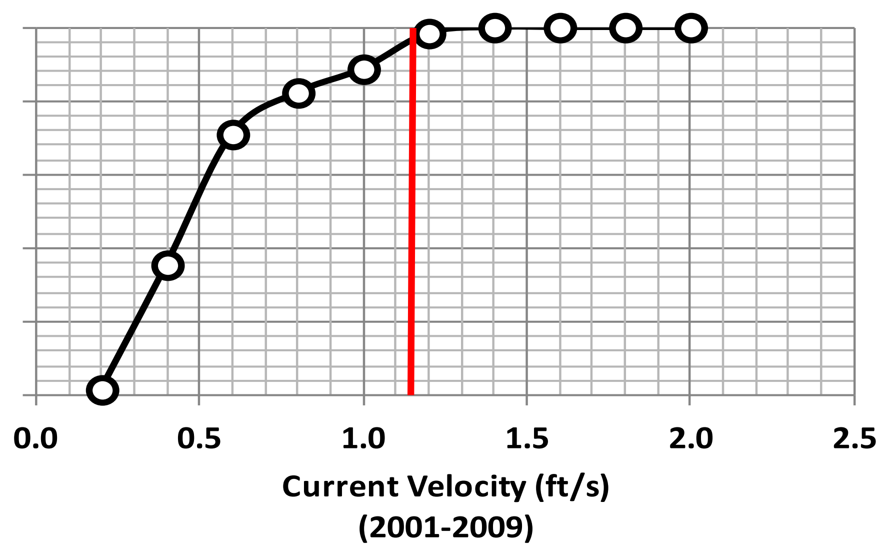


2. Critical Velocity/Shear Stress

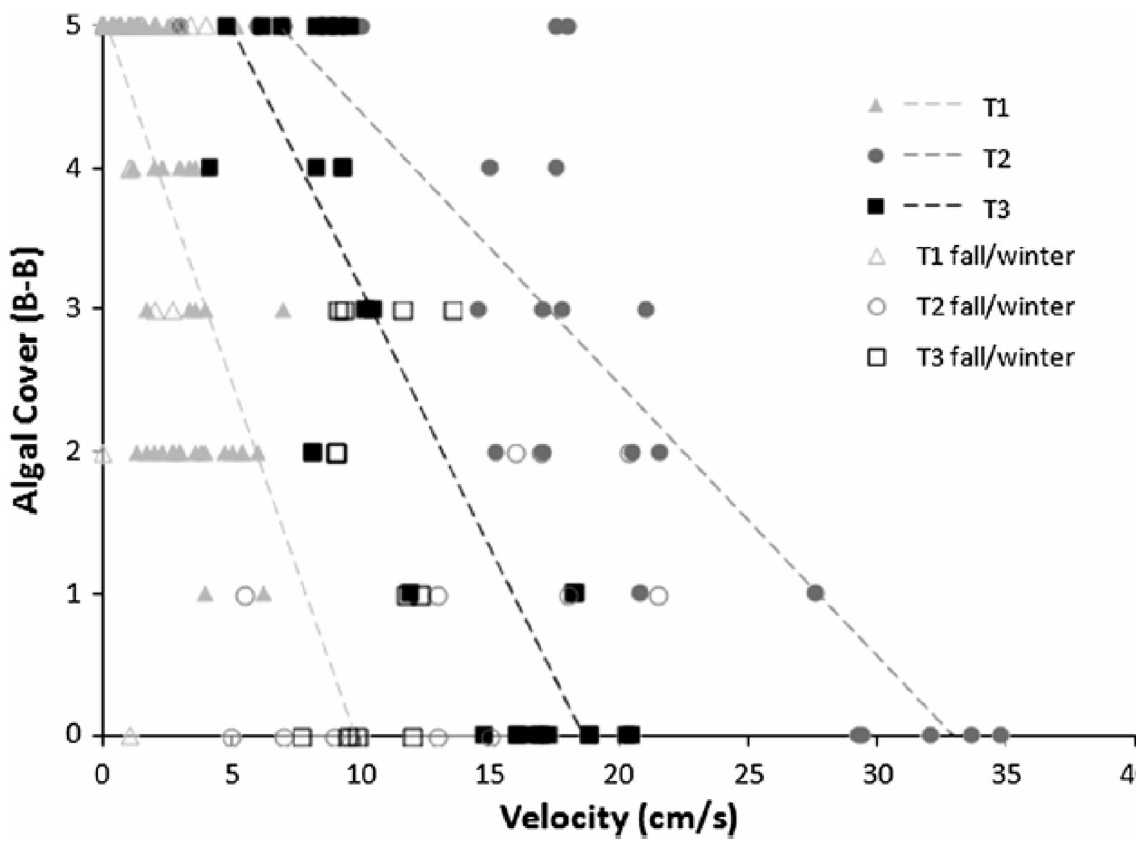








2. Critical Velocity/Shear Stress

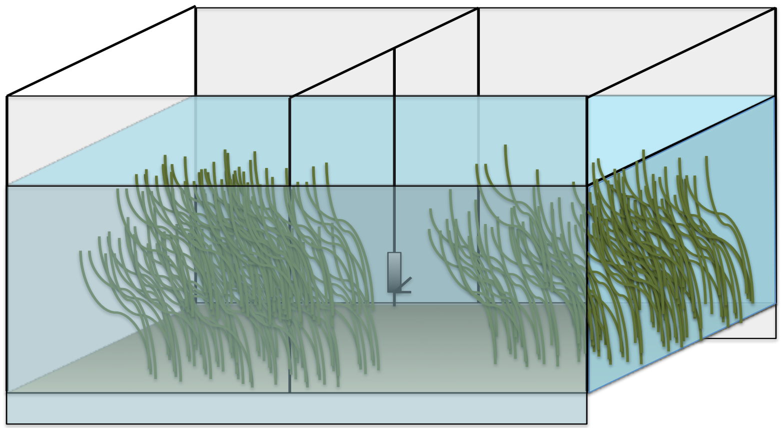


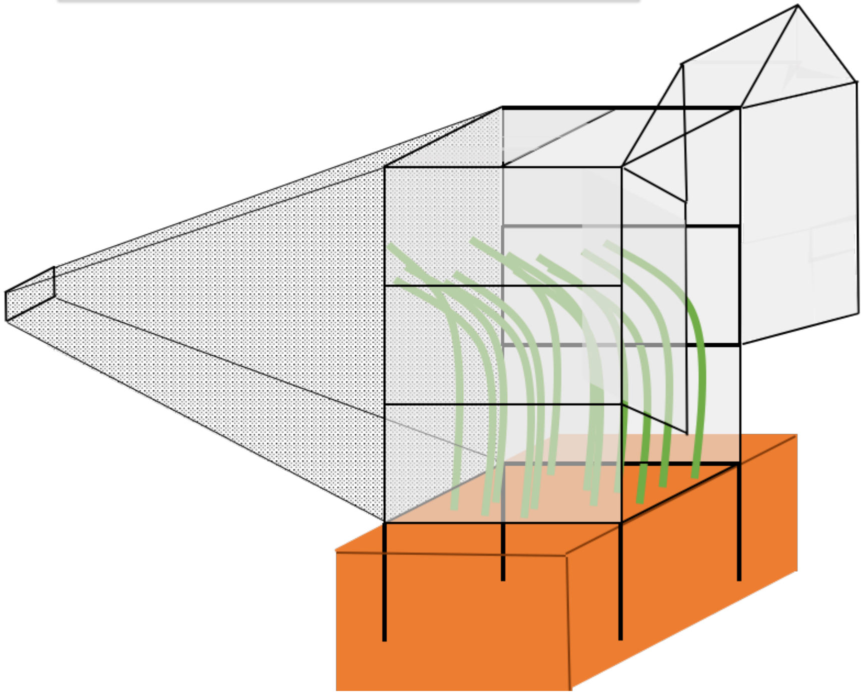
King, Sean A. "Hydrodynamic control of filamentous macroalgae in a sub-tropical spring-fed river in Florida, USA." Hydrobiologia 734.1 (2014): 27-37.

2. Critical Velocity – Methods

A. Flow-ways

- Submerged structure placed in flat areas with relatively uniform flow
- Deployed with "control" structure for comparison
- Modify opening to channel or exclude flow
- Measure velocity profiles, cover, downstream transport
- **Status**: scouting locations, developing prototype…

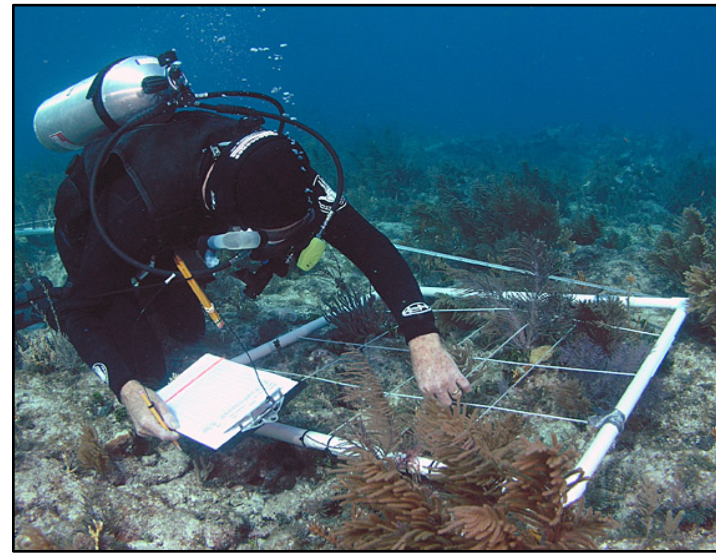




2. Critical Velocity – Methods

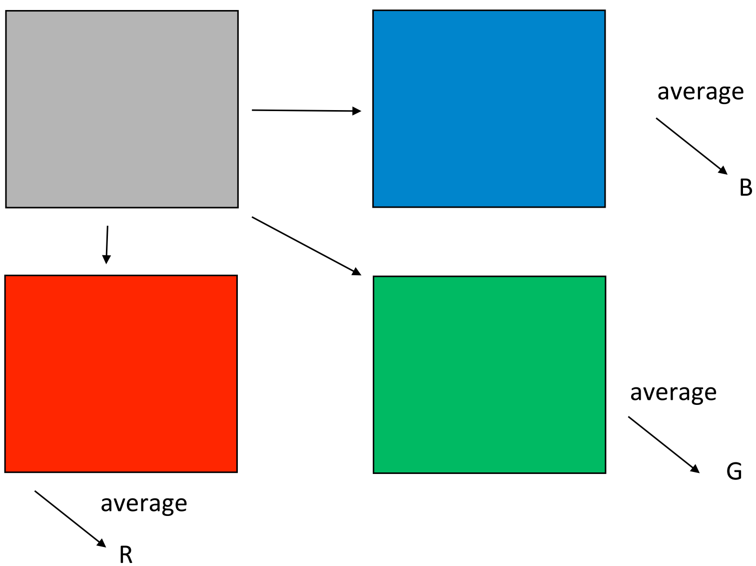
B. Optical Methods

- Goal: collect algal cover and velocity data over wide area to explore correlations and critical velocity
- Current methods impractical for high resolution, spatially distributed data and relies on human estimation
- We seek a rapid, quantitative method to cover large areas (image processing)



2. Critical Velocity – Methods

B1. Average Image Color Shift



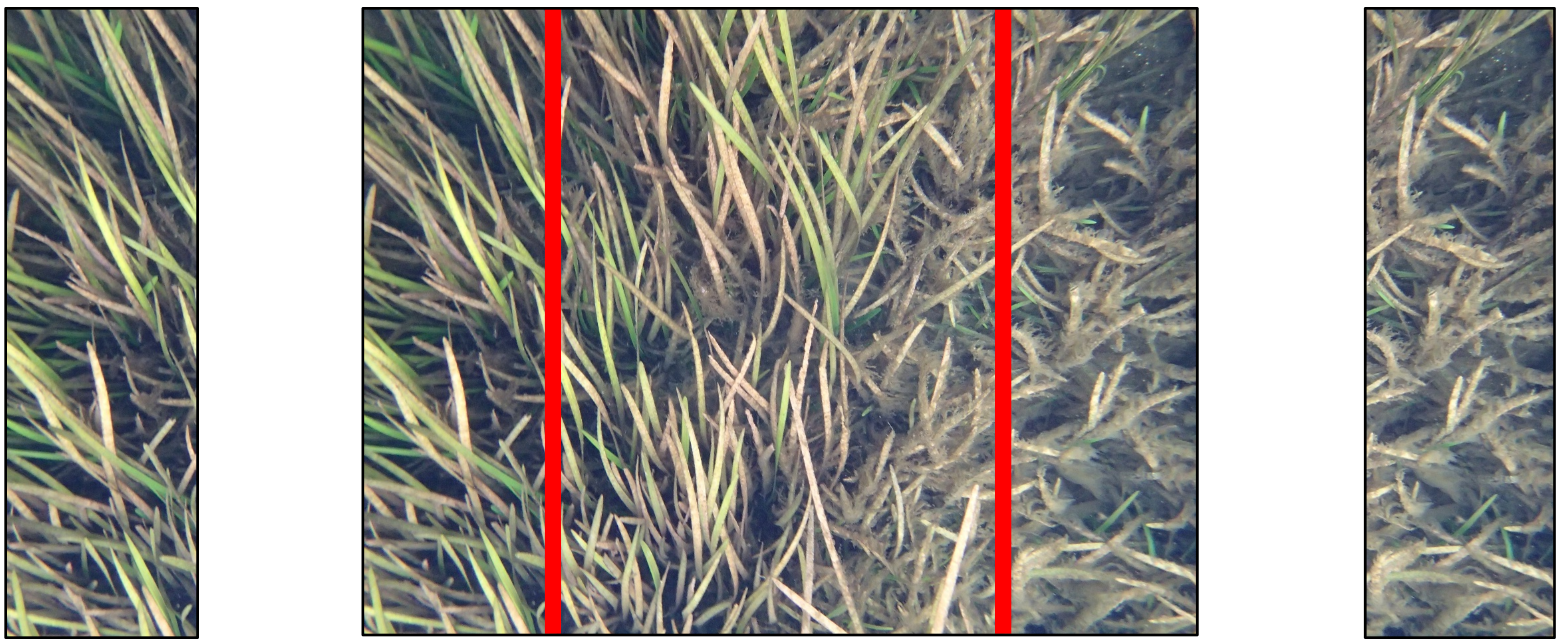
$$Color = \log(Band\ 1) - \log(Band\ 2) = \log\left(\frac{Band\ 1}{Band\ 2}\right)$$

$$ColorBG = \log(B) - \log(G) = \log\left(\frac{B}{G}\right)$$

$$ColorGR = \log(G) - \log(R) = \log\left(\frac{G}{R}\right)$$

2. Critical Velocity – Methods

B1. Average Image Color Shift



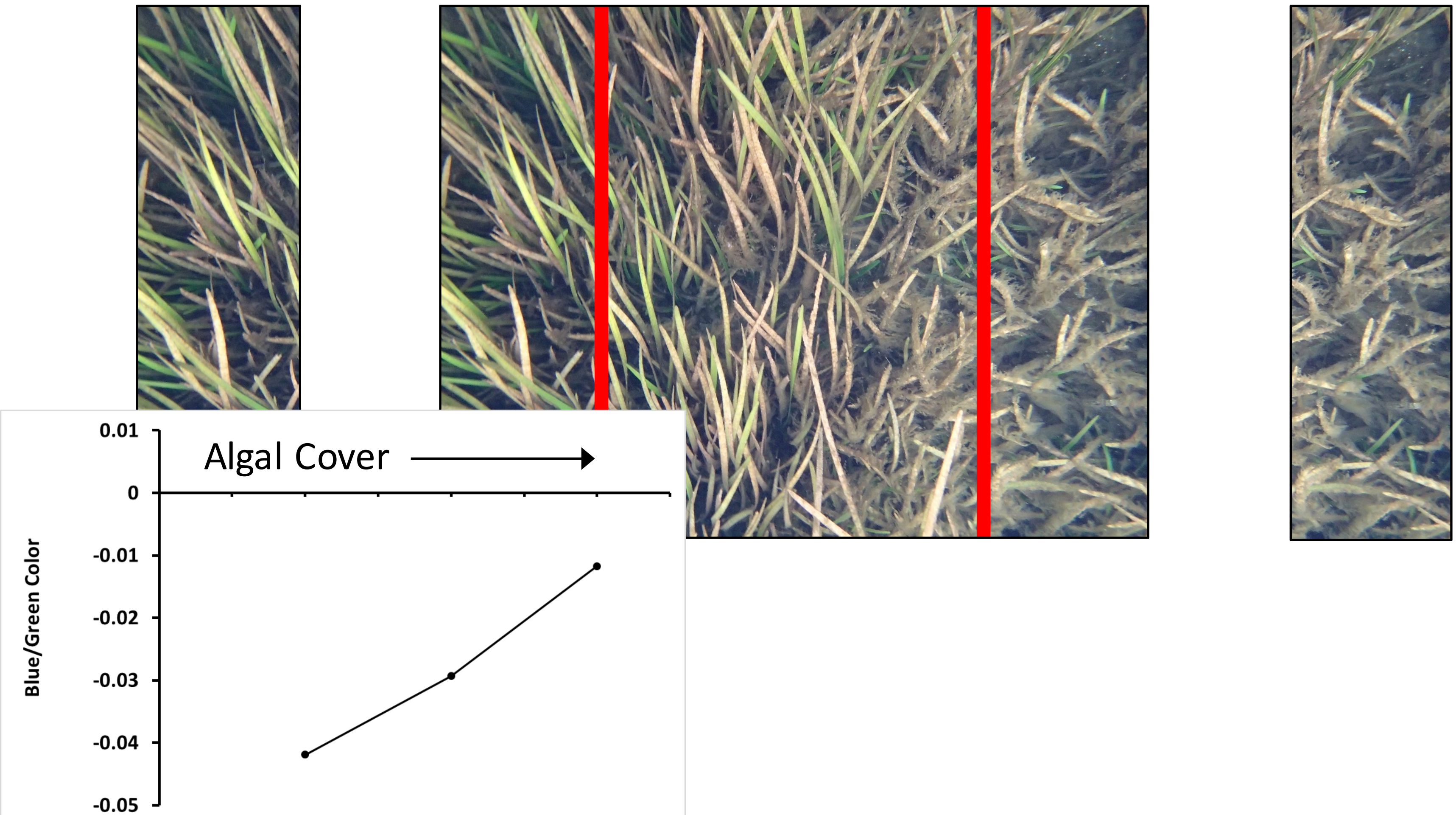
2. Critical Velocity – Methods

B1. Average Image Color Shift

BG Color = -0.0419

BG Color = -0.0293

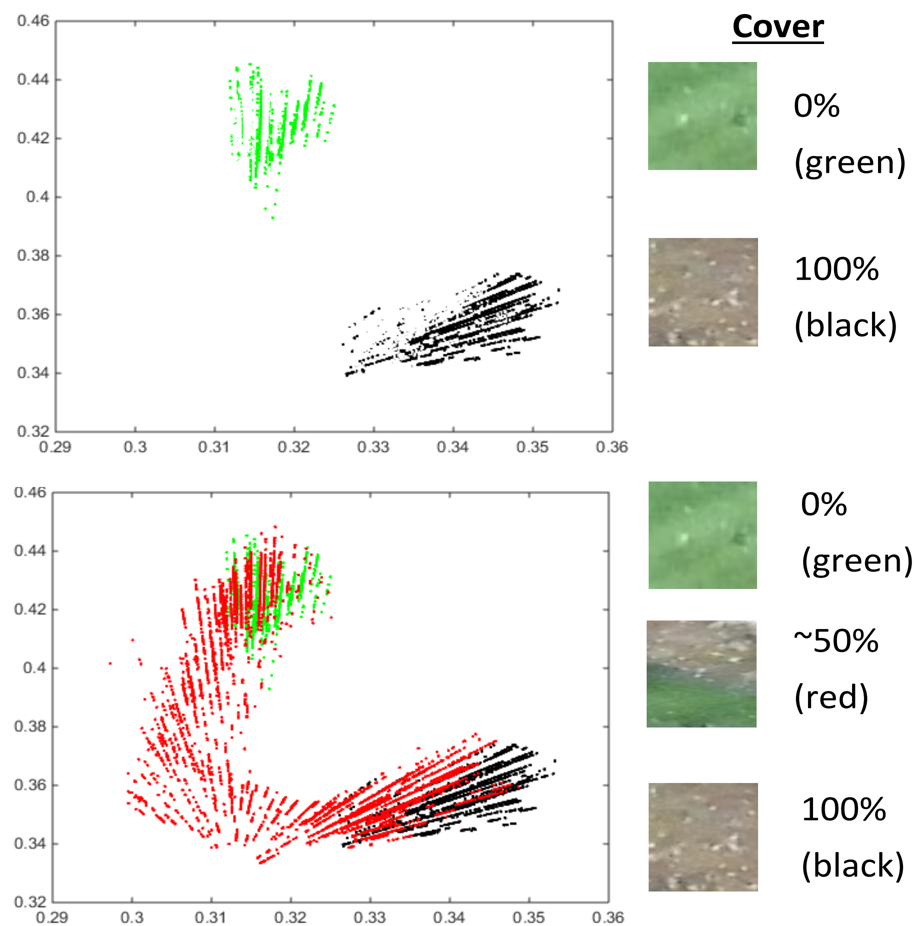
BG Color = -0.0117



2. Critical Velocity – Methods

B2. Chromaticity – Pixel-based

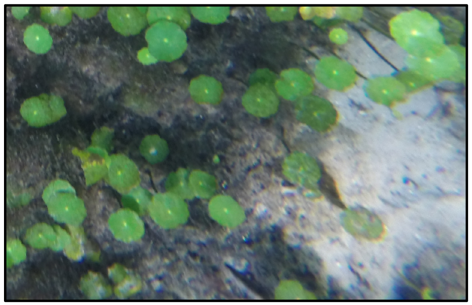
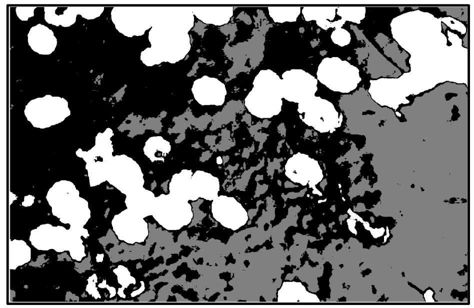
- E.g., chromaticity of SAV does not overlap with epiphytic algae
- For 50% algal cover, chromaticity concentrated in the same locations
- Adding spatial (x,y) information allows image clustering



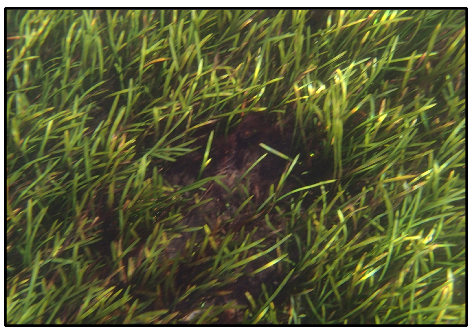
Chromaticity pixel distributions of various algal covers

2. Critical Velocity – Methods

B2. Chromaticity – Pixel-based

Itchetucknee: Three Clusters (SAV, benthic algae, bottom)



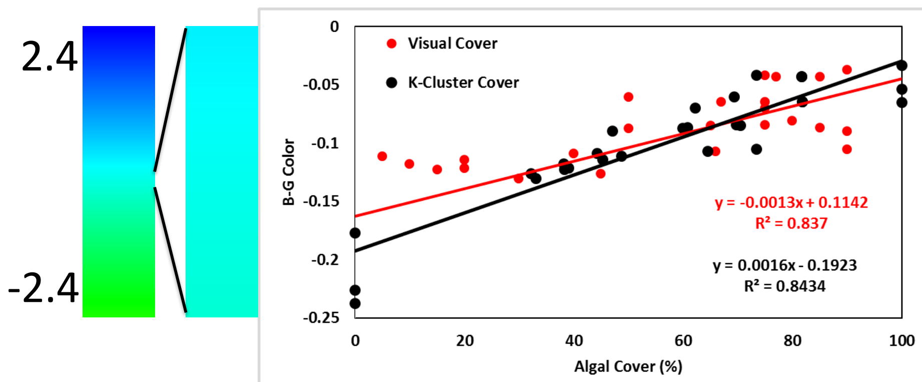

Rainbow: Two Clusters (SAV, benthic algae)

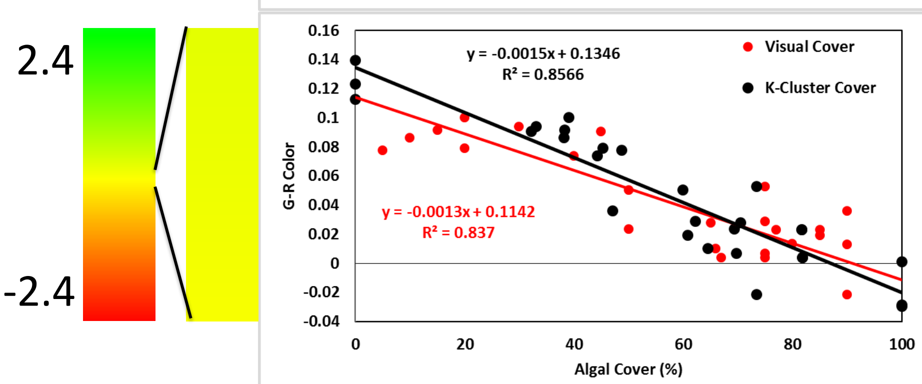

Silver: Two Clusters (SAV, benthic algae)

2. Critical Velocity – Initial Results

B1. Average Image Color Shift

- Good correlation with both BG and GR

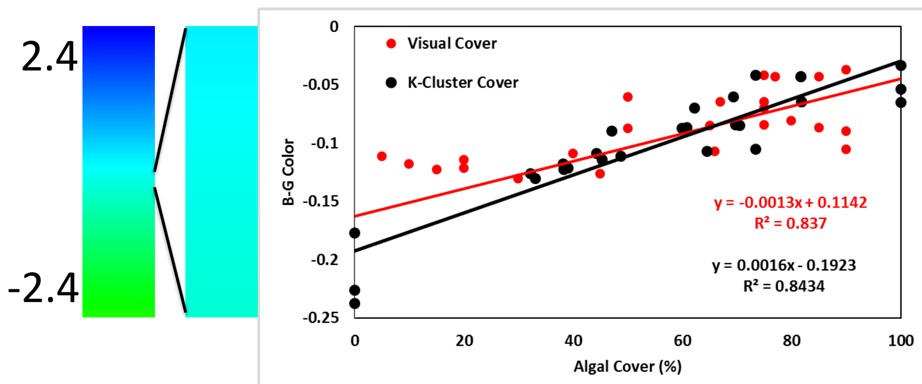


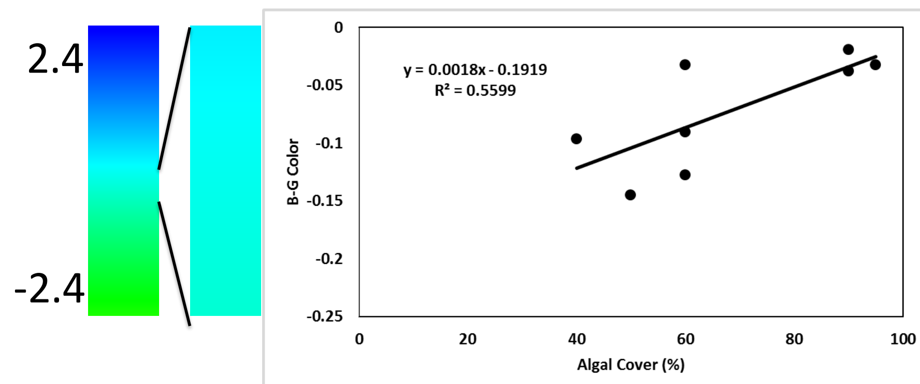


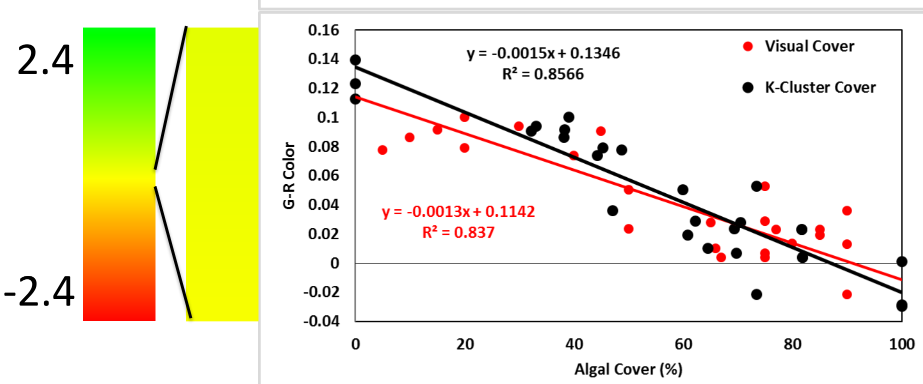
2. Critical Velocity – Initial Results

B1. Average Image Color Shift

- Good correlation with both BG and GR
- Training image and field data: similar slope



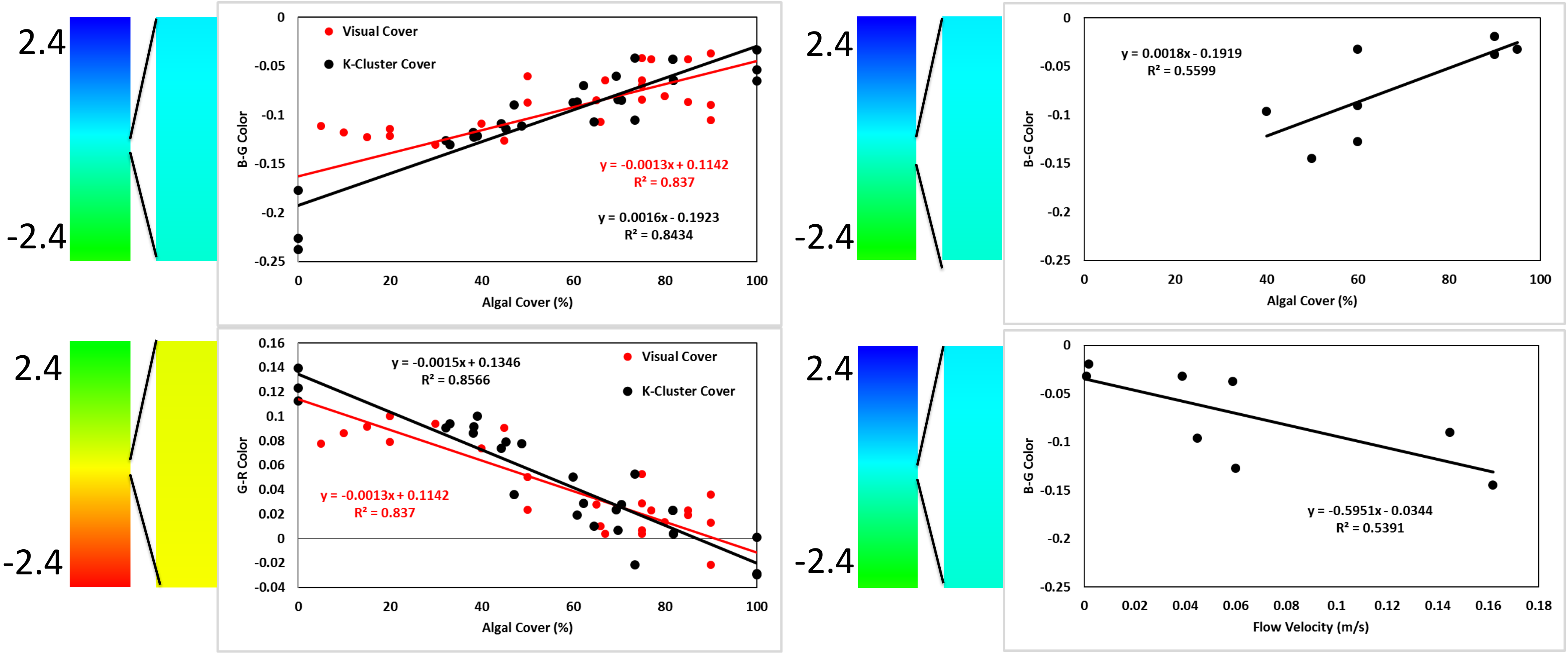




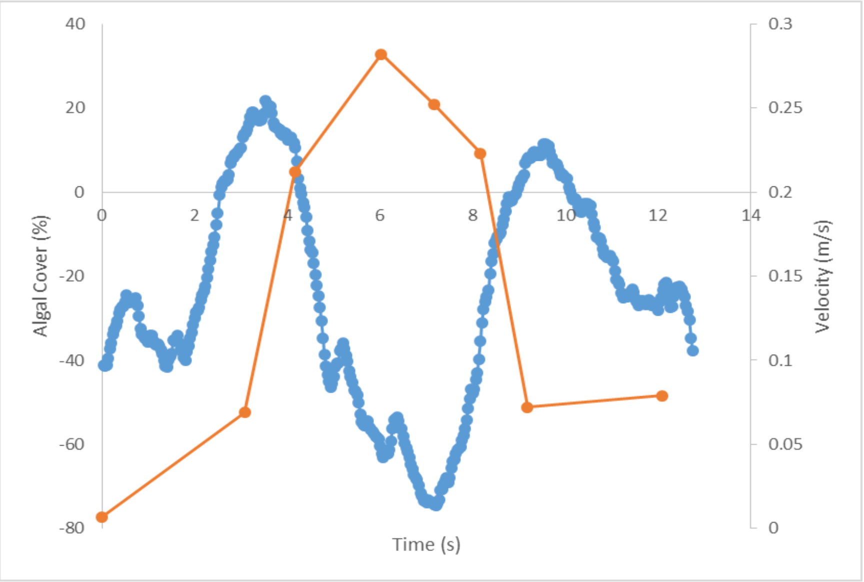
2. Critical Velocity – Initial Results

B1. Average Image Color Shift

- Good correlation with both BG and GR
- Training image and field data: similar slope
- Both B-G color and algal cover ~ velocity



2. Critical Velocity – Initial Results



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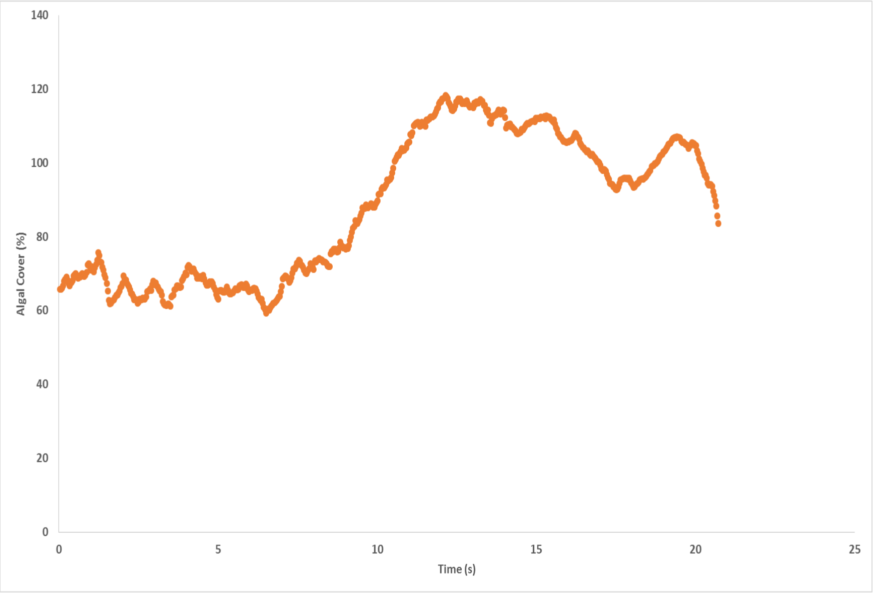
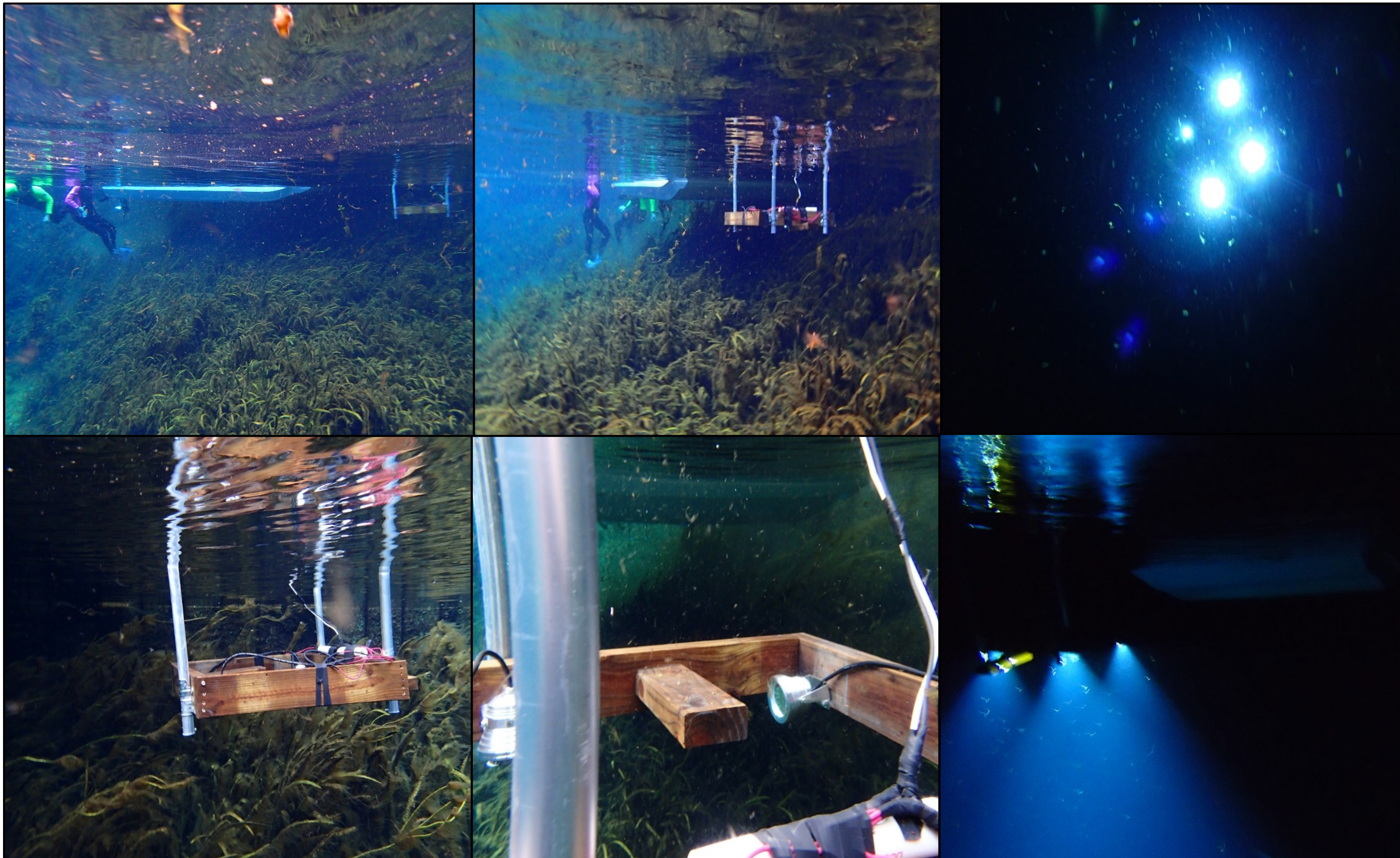
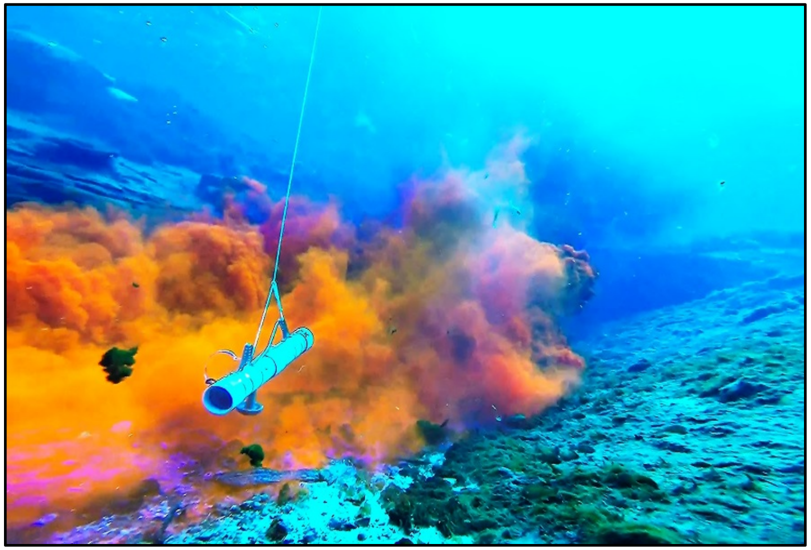


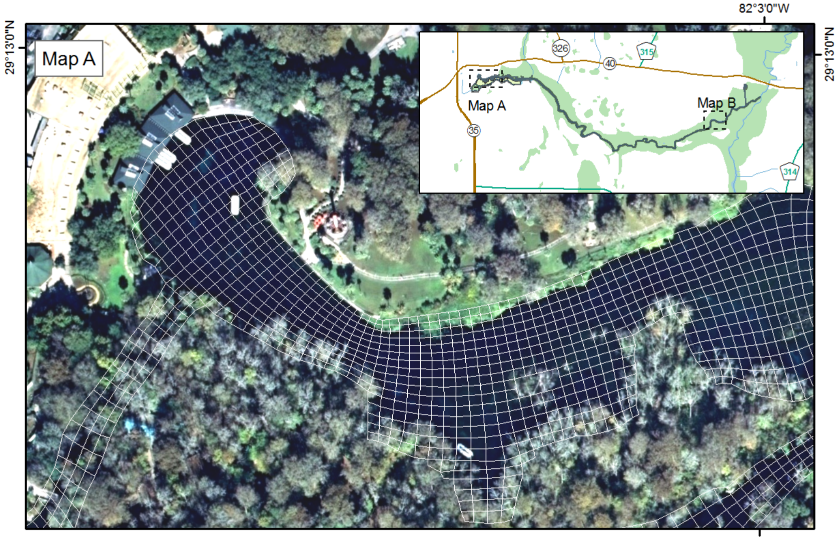
2. Critical Velocity – Next Steps



Today's Outline

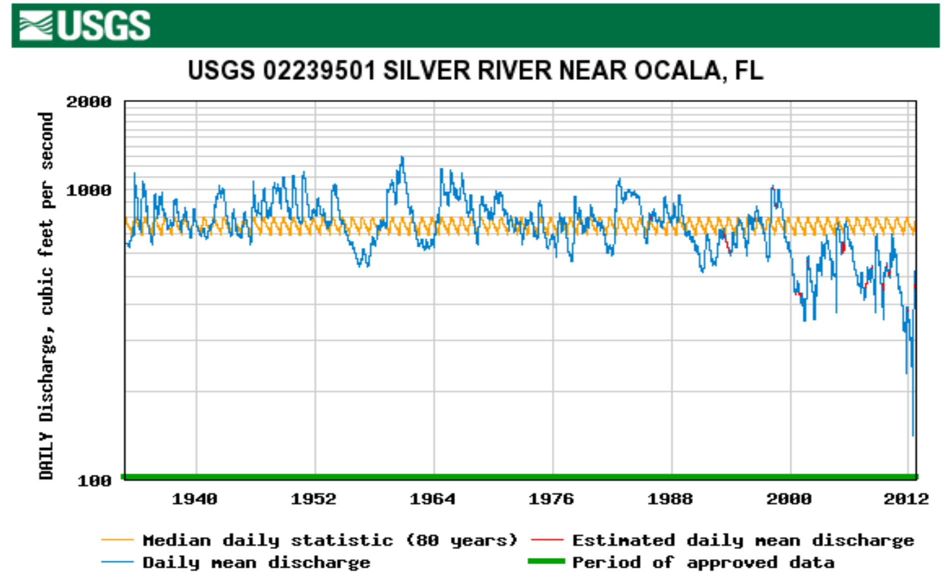
1. Dye trace experiment
   - Velocity and residence time distributions
   - EFDC model calibration
2. Critical velocity/shear stress
   - *In-situ* flow-ways
   - Optical methods
3. **EFDC Modeling**
   - **Domain development**
   - **Friction/turbulence formulation**
   - **Initial calibration**

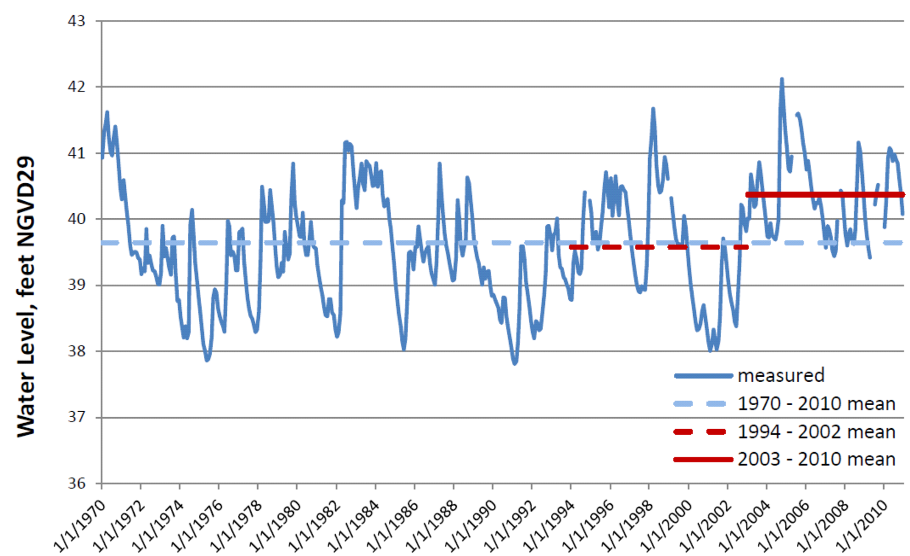




3. EFDC Modeling – Background

- Contemporary trends: declining discharge and increasing pool elevation
- Flow → Vegetation → Flow
- **<u>EFDC</u>**: 3-D hydrodyanamic model to incorporate interactions between velocity, discharge, stage and flow resistance (veg)





From Baird and Johnson, 2014.

3. EFDC Modeling – Background

Apparent shift in stage-discharge relationship in Silver River:

1. Increased spatial coverage of submersed aquatic vegetation?
2. Expansion of hydrilla in the lower Silver and Ocklawaha?
3. Reconfiguration of vegetation under low discharge?

Figure by Ed Carter

3. EFDC Modeling – Methods

$$\partial_t(mHu) + \partial_x(m_y Huu) + \partial_y(m_x Hvu) + \partial_z(mwu) - (mf + v\partial_x m_y - u\partial_y m_x)Hv$$
$$= -m_y H\partial_x(g\zeta + p) - m_y(\partial_x h - z\partial_x H)\partial_z p + \partial_z(mH^{-1}A_V\partial_z u) + Q_u - c_t\sqrt{u^2 + v^2}umH \qquad (1)$$

$$\partial_t(mHv) + \partial_x(m_y Huv) + \partial_y(m_x Hvv) + \partial_z(mwv) + (mf + v\partial_x m_y - u\partial_y m_x)Hu$$
$$= -m_x H\partial_y(g\zeta + p) - m_x(\partial_y h - z\partial_y H)\partial_z p + \partial_z(mH^{-1}A_V\partial_z v) + Q_v - c_t\sqrt{u^2 + v^2}vmH \qquad (2)$$

$$\partial_z p = -gH(\rho - \rho_0)\rho_0^{-1} = -gHb \qquad (3)$$

$$\partial_t(m\zeta) + \partial_x(m_y Hu) + \partial_y(m_x Hv) + \partial_z(mw) = 0 \qquad (4)$$

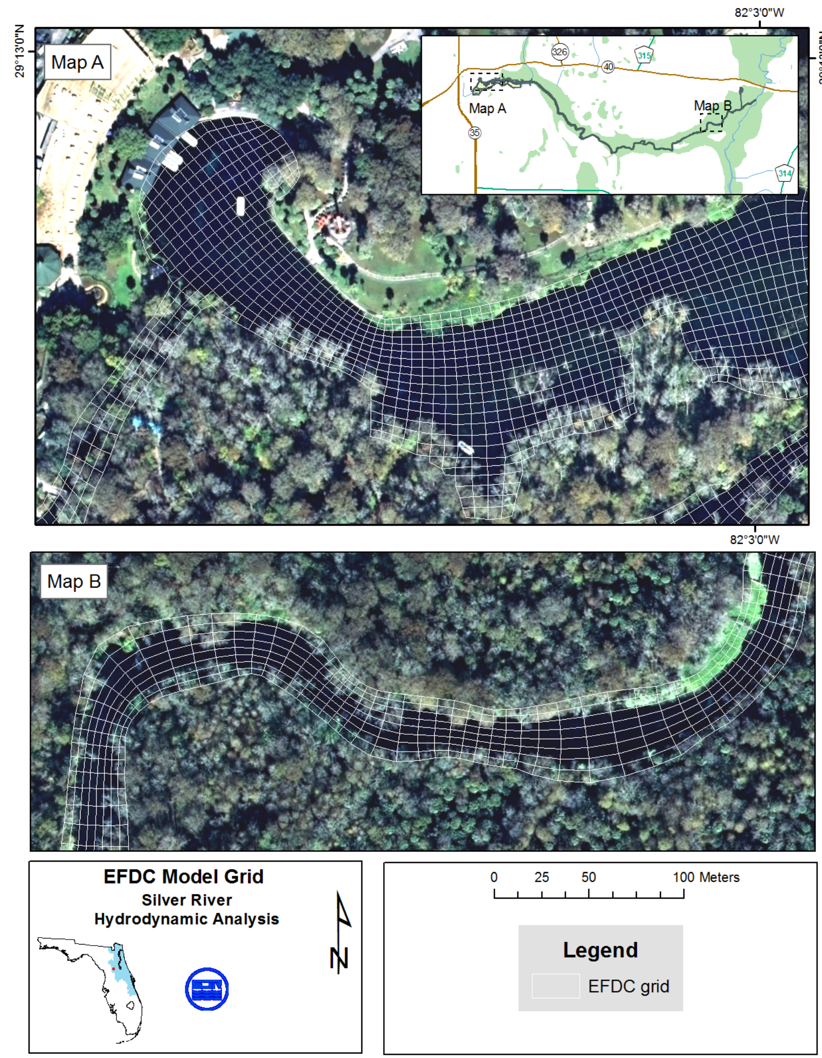
$$\partial_t(m\zeta) + \partial_x\left(m_y H\int_0^1 udz\right) + \partial_y\left(m_x H\int_0^1 vdz\right) = 0$$

$$\rho = \rho(p, S, T)$$

3. EFDC Modeling – Methods

Environmental Fluid Dynamics Code

- 3-D, vertically hydrostatic, free surface, turbulent-averaged flow equations
- Dynamically-coupled transport equations for turbulent kinetic energy, turbulent length scale, salinity and temperature
- Applied to entire Silver River (finer scale) and Lower Ocklawaha from Moss Bluff to Eureka (coarser scale)



3. EFDC Modeling – Methods

1. **Defining the shoreline**
2. Defining bottom type
3. Model grid development
4. Model formulation

3. EFDC Modeling – Methods

1. Defining the shoreline
2. **Defining bottom type**
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4. Model formulation

Bare	Sandy, rocky, or muddy bottom with less than 5% rooted vegetation. Logs may be present.
Patchy	Clumped, thin, or widely spaced vegetation.
Vegetated	Continuously vegetated with the bottom mostly obscured; open water above canopy deeper than 1 m.
Heavily Vegetated	Continuously vegetated with the bottom mostly obscured; vegetation takes up the majority of the water column.
Topped Out	Vegetation reaches completely to the surface; emergent vegetation may be present.
Trees	Extensive roots and trunks of cypress and other trees.

3. EFDC Modeling – Methods

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3. **Model grid development**
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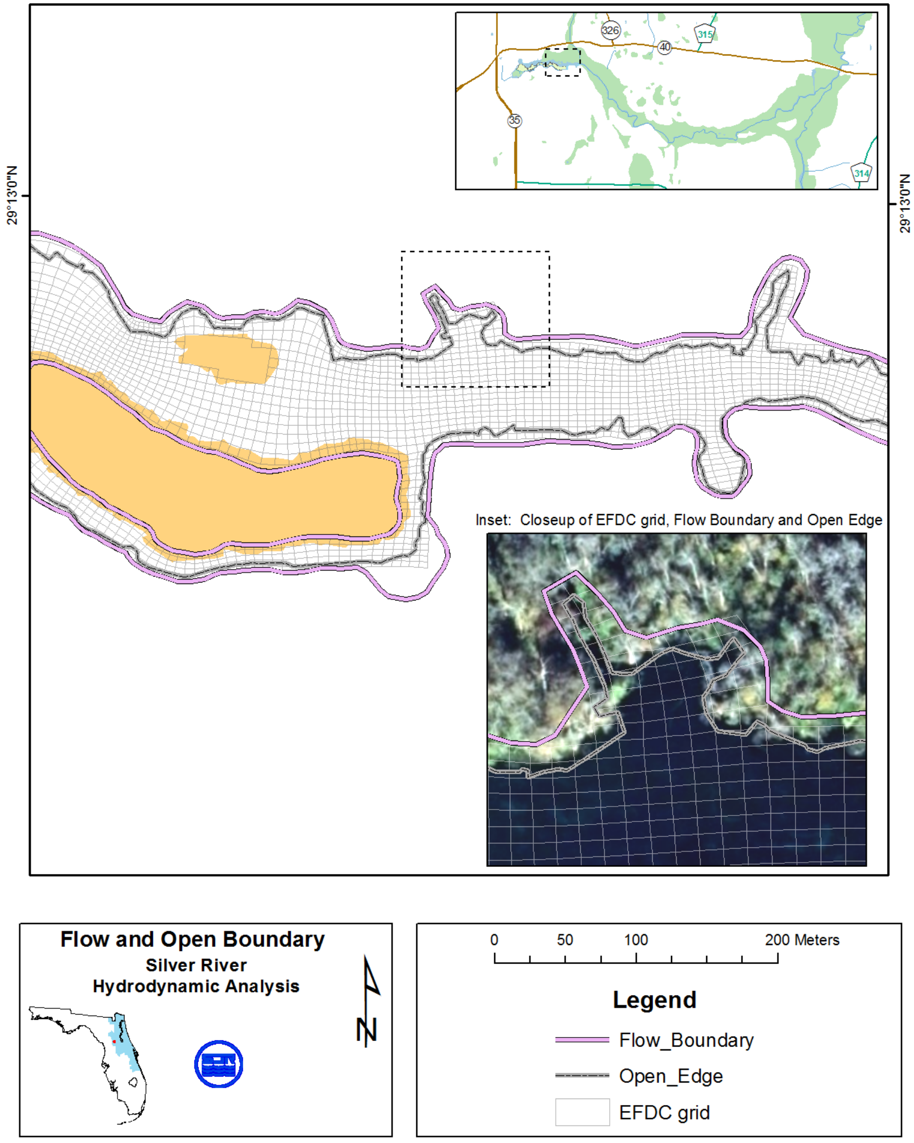

- Curvilinear, orthogonal grid (developed jointly by Jones Edmunds, Janicki, SJRWMD)
- 13,439 horizontal cells; 8 vertical cells: **107,512 total**
- Cell size variable; average horizontal cell length = 5.8 m

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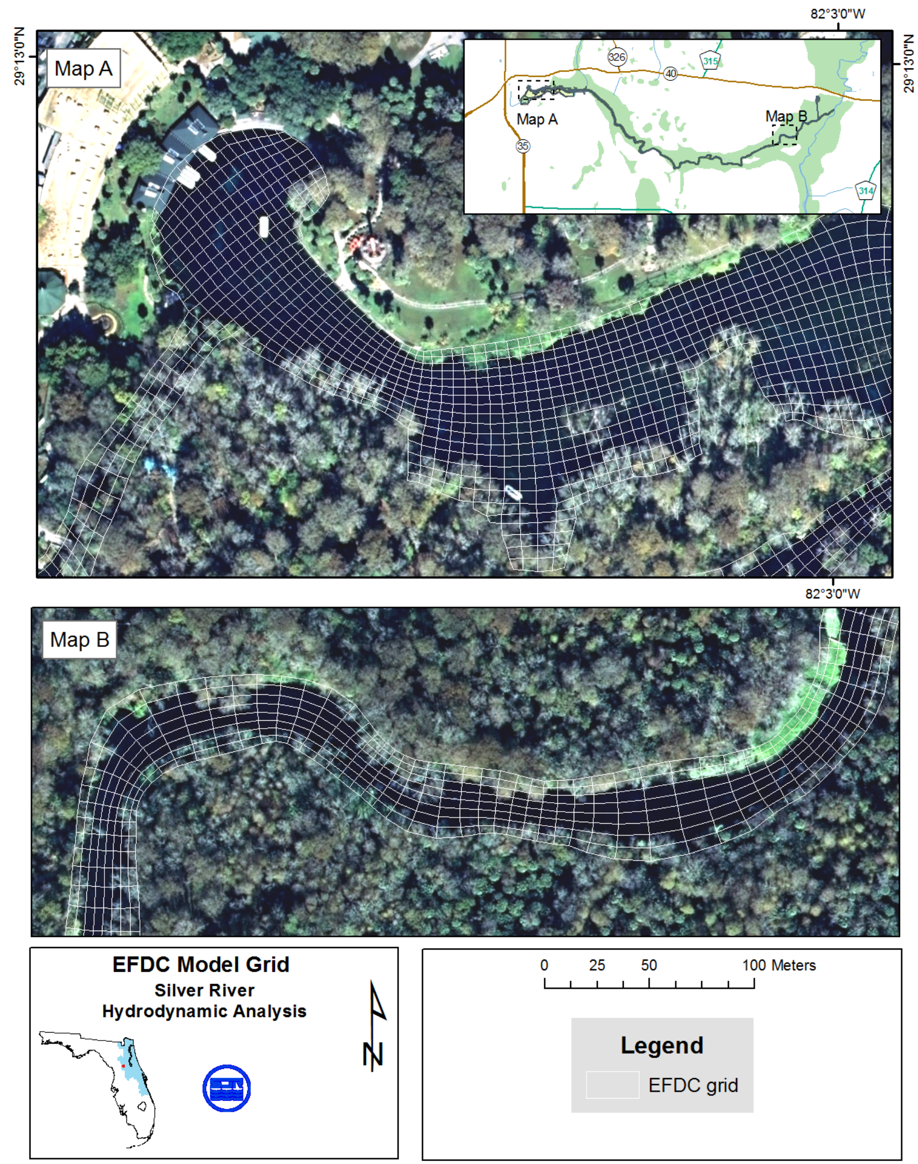

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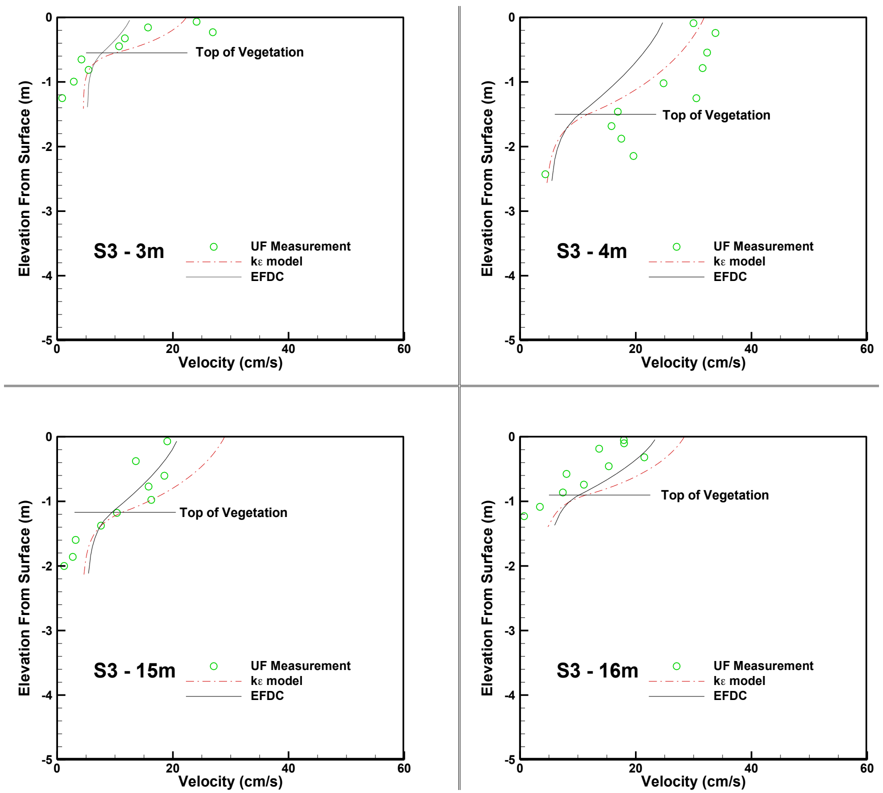
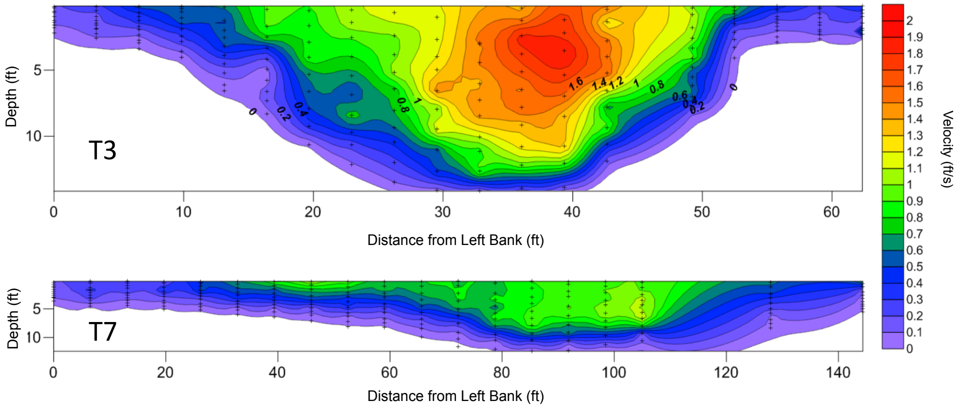


A.

B.



3. EFDC Modeling – Results

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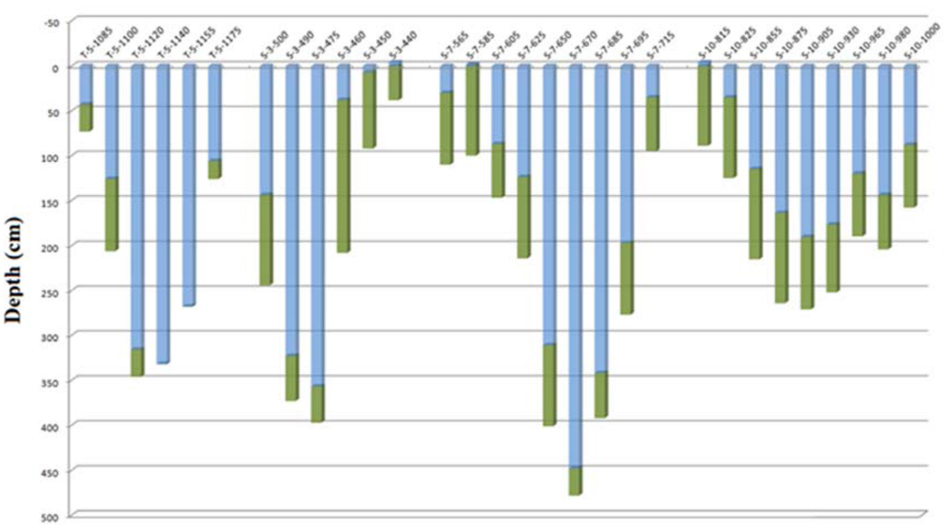
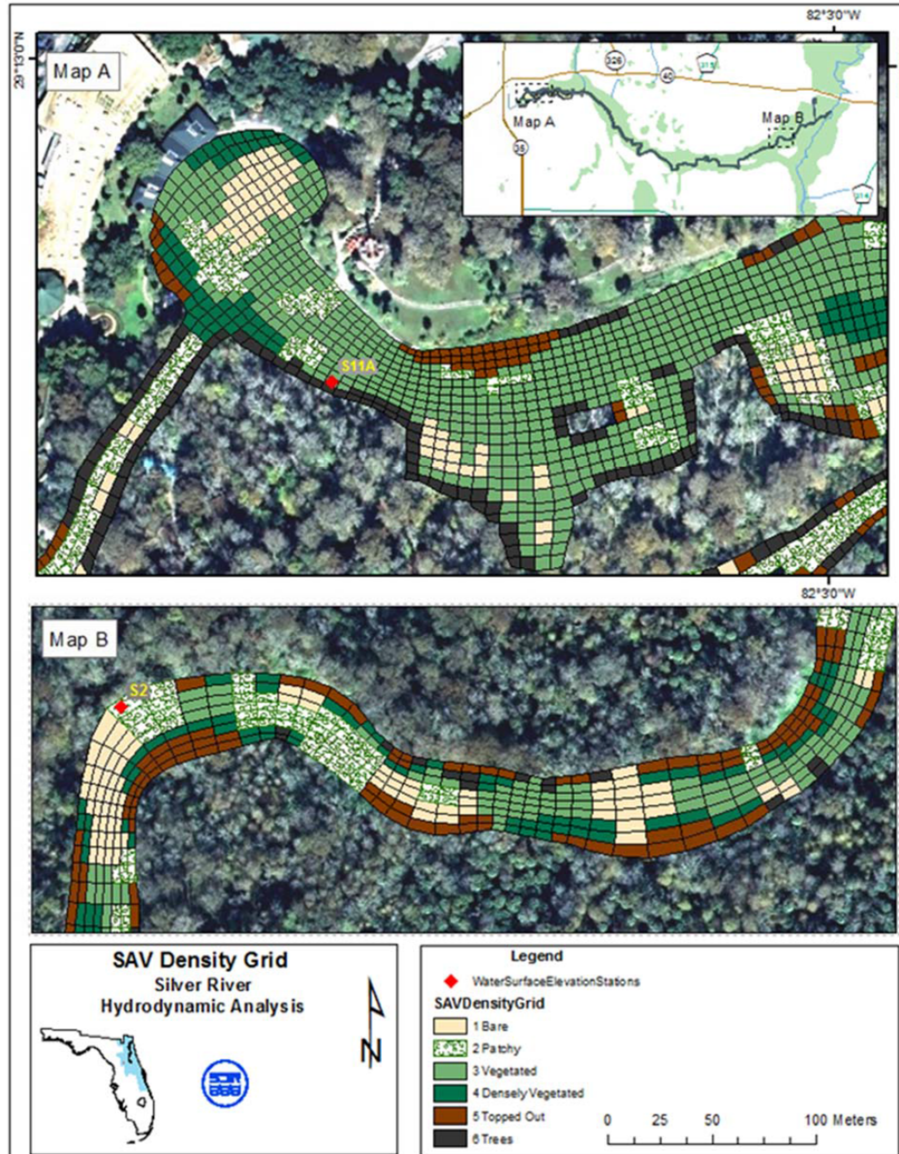
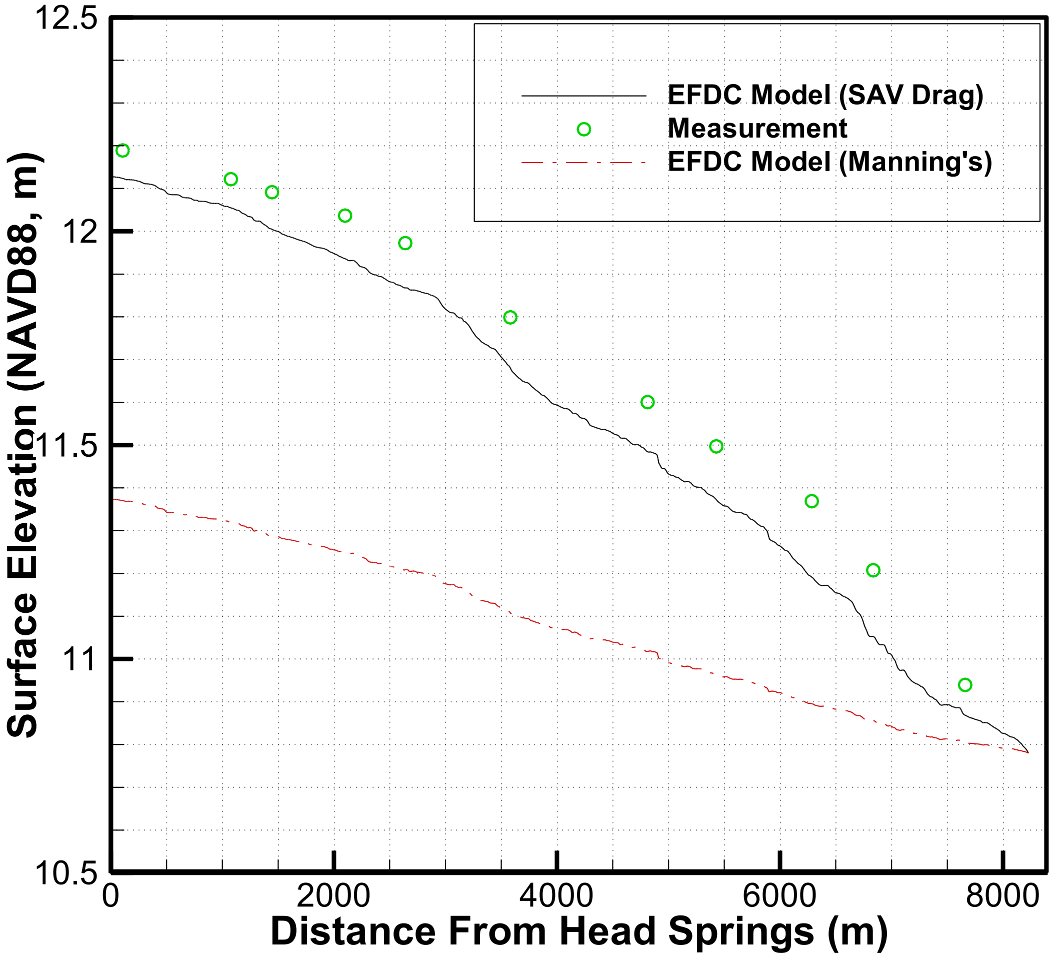




3. EFDC Modeling – Results

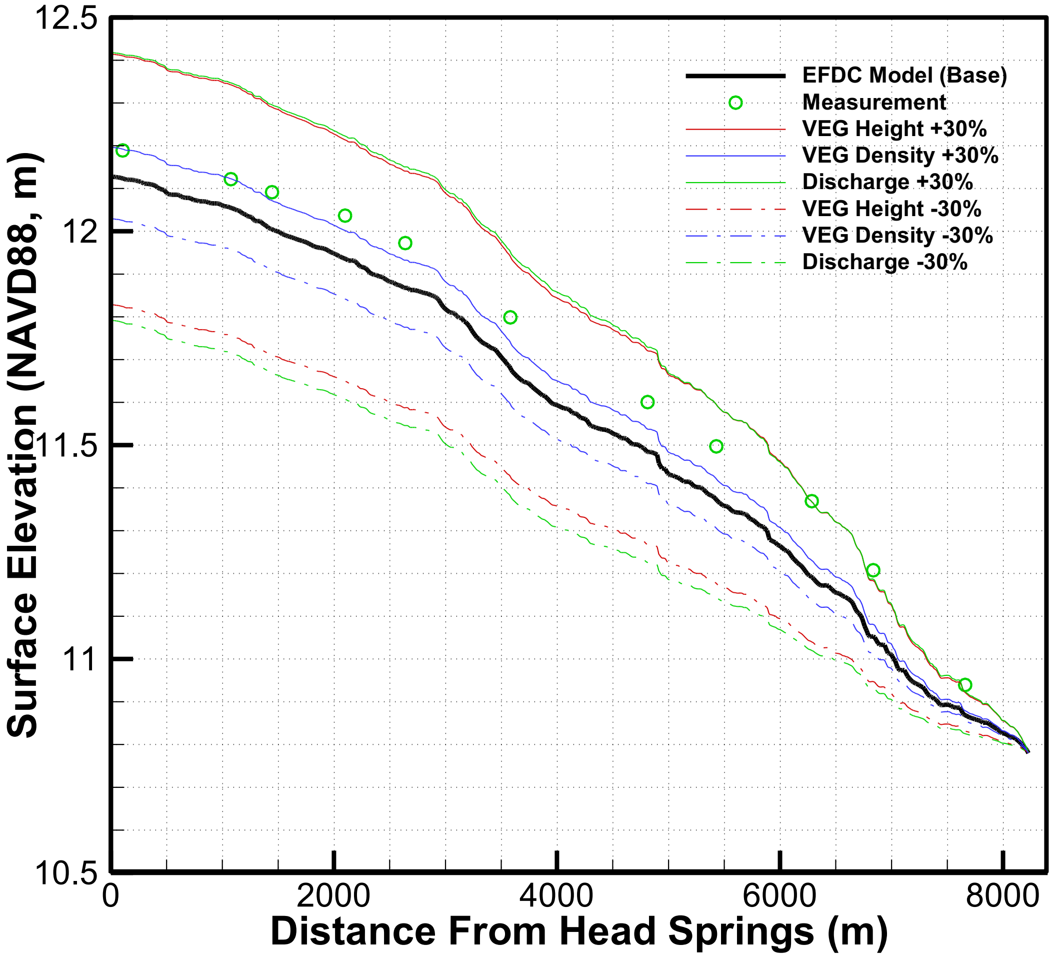
Hydrodynamic Model Test: May 2014



- 17 $m^3 s^{-1}$ (605 cfs)
- Downstream stage 10.75 m (35.27 ft) at Conner
- Compare use of (unrealistic) Manning's n vs. vegetation algorithms (SAV drag)
- *Uncalibrated…*

3. EFDC Modeling – Results

Hydrodynamic Model Test: May 2014



- Sensitivity analysis:
  - Veg. parameters: density and ***<u>height</u>***
  - Discharge
  - Reconfiguration…

3. EFDC Modeling – Initial Conclusions

Apparent shift in stage-discharge relationship in Silver River:

1. Increased spatial coverage of submersed aquatic vegetation?
2. Expansion of hydrilla in the lower Silver and Ocklawaha?
3. Reconfiguration of vegetation under low discharge?

Whitford, 1952:

> "After the first mile Silver Springs run becomes narrow and the banks heavily wooded. It also receives some brown water down run. Consequently *about 2 ½ miles from the boil flowering plants largely disappear* probably due to reduced light. Mats of Vaucheria with some filamentous blue-green algae, and a few of the usually dominant diatoms, are abundant in the shallows. The deeper channel has *relatively little plant life*."

Odum,1957:

> "Except for its thick bed of rich muck Silver River would be a rushing canal through a pipe of limestone rock. *Further downstream below the study area it is of this nature*"

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…estimated velocity = 0.21 m/s during Odum study
mud, mud/sand, sand, rock: 0.08, 0.11, 0.16 and 0.22 m/s
& "little or no SAV" >0.25 m/s (Hoyer et al. 2004)

3. EFDC Modeling – Initial Conclusions

Apparent shift in stage-discharge relationship in Silver River:

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- Velocity may play a role in determining vegetative structure and density, especially downstream (e.g., Odum)
- Evidence for recent expansion of vegetation cover in Silver River is not convincing (Duarte et al. 1990; FWC 2014)
- Hydrilla in Ocklawaha? Only recently observed (2011; FWC 2014) and seasonally removed via discharge?
- Vegetation reconfiguration? Model sensitivity to veg. height; lower discahrge/velocity after prolonged drought (1999-2000)
- Likely a combination of all three…

Thanks! Questions?

1. Dye trace experiment
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