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Challenges and trends of hydro-environmental solutions and research for water security

5—7 July 2021

Digital Transition of Resilient Constructed Wetlands for Ecosystem Conservation

By Ni-Bin Chang

Presented to "Digital Transformation of Urban Water Systems Session"

July 7 2021

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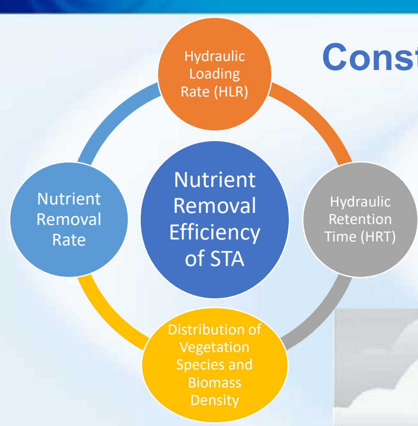
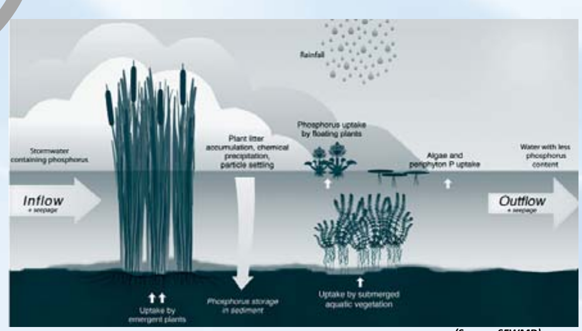
Constructed Wetland and Nutrients Removal



⇨ Nutrient removal efficiency

Nutrient removal techniques ⇦



(Source: SFWMD)

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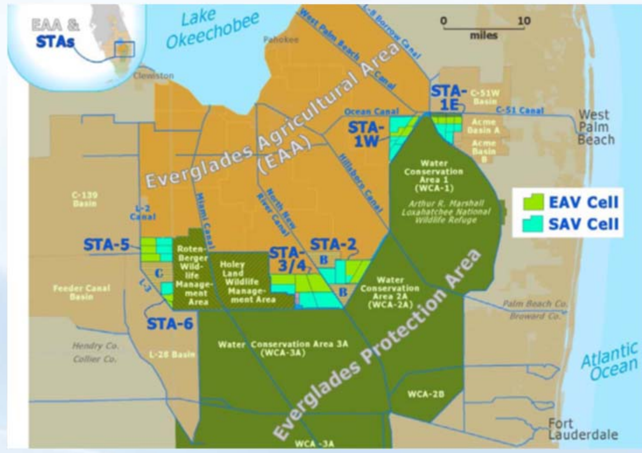
Study Area

- An STA Cell 3B was considered as the study site
- The cell is a part of STA-3/4 area
- Total cell area is 8.40 sq.km
- Whole cell area is primarily composed of submerged aquatic vegetation (SAV) with strips of emerged aquatic vegetation (EAV)
- Inflow entering the individual cells is then primarily managed by controllable weirs located at the influent and effluent sides



Source: SFWMD

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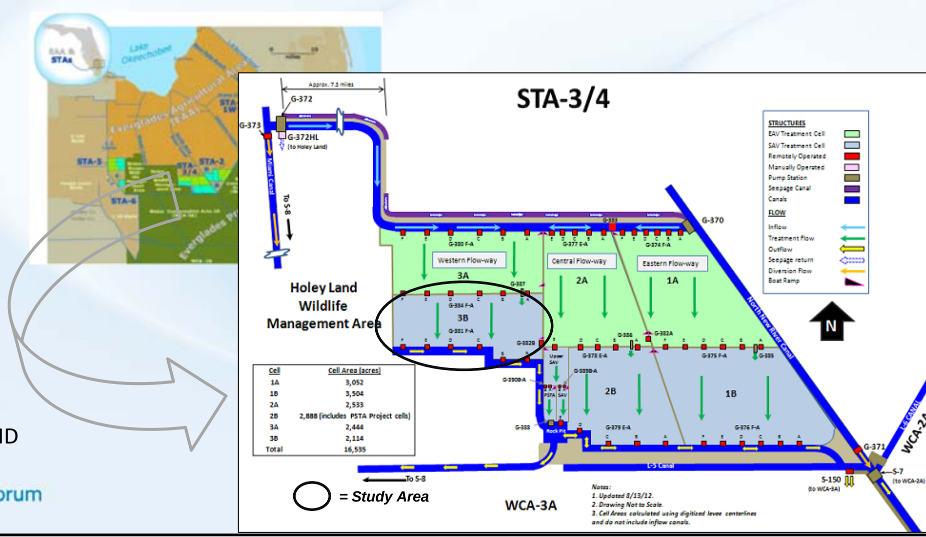
Study Area – Stormwater Treatment Area (STA)



Cell	Cell Area (acres)
1A	3,052
1B	3,504
2A	2,533
2B	2,888 (includes PSTA Project cells)
3A	2,444
3B	2,114
Total	16,535

Source: SFWMD

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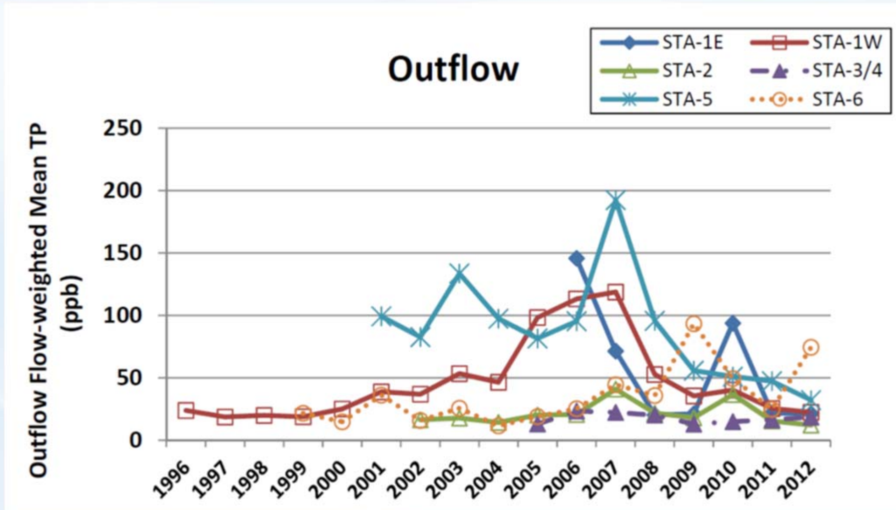
From 1996 to 2012, these wetlands have retained about 1,560 metric tons of TP and reduce inflow load by 73% from an overall annual TP flow-weighted mean (FWM) concentration of 140 ppb to 37 ppb.



Source: SFWMD

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Study Objectives

1. To predict the distribution of biomass inside of treatment wetland using machine learning models
2. To predict the distribution of vegetation species inside of treatment area using traditional and machine learning models
3. To predict the velocity magnitude, direction and hydraulic retention time of water inside of an STA area using machine learning models

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Satelite Images: NDVI

- ❑ **Pleiades satellite** : a cooperation program initiated by France and Italy which provides an earth observation system with metric resolution
- ❑ Pleiades bundle : **0.50 m panchromatic and 2m multispectral bands**
- ❑ Four bands in the multispectral band as red, green, blue and near-infrared

Acquisition date	**Sun Elevation (°)**	**Sun Azimuth (°)**
21st May, 2014	73.037	106.869
Band	**Spectral Region (μm)**	**Centre Wavelength (μm)**
Panchromatic	0.47 - 0.83	0.65
B1 - Blue	0.43 - 0.55	0.49
B2 - Green	0.50 - 0.62	0.56
B3 - Red	0.59 - 0.71	0.65
B4 - Near Infrared	0.74 - 0.94	0.84

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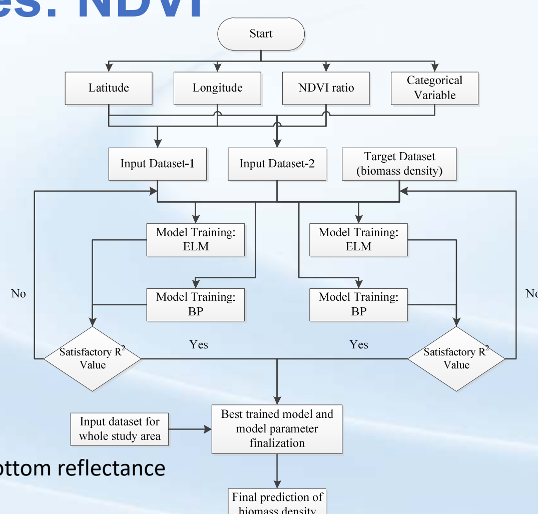
Satelite Images: NDVI

- ❑ 1294 training pixels
- ❑ Two approaches for model training:
  1. Inputs without any categorical variable [Latitude, Longitude and NDVI (red)]
  2. Inputs with categorical variable [Latitude, Longitude, NDVI (red), Categorical Variable
- ❑ Categorical Variables:
  1 = SAV, 2 = EAV and 3 = NAV
- ❑ For both cases, measured "***biomass density***" used as target for the supervised learning process.

$$NDVI = \frac{NIR\ (ref) - Red(ref)}{NIR\ (ref) + Red\ (ref)}$$



❖ Hypothesis: Negligible difference between surface reflectance and bottom reflectance [Extremely shallow water level (0.5 – 2.0 ft) and low turbidity]

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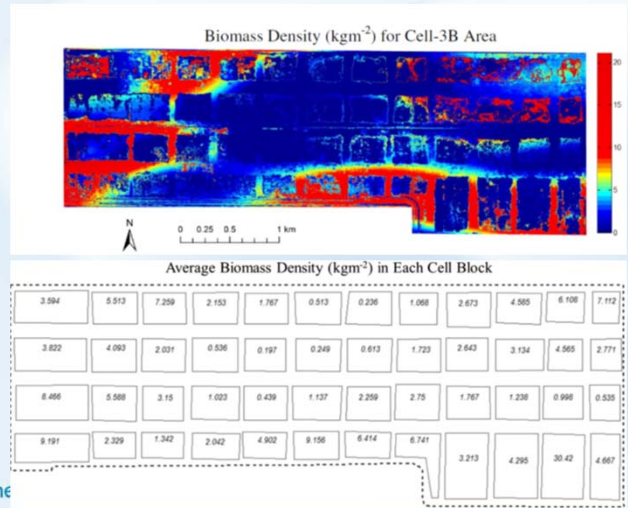
Biomass Predcition for Cell 3B



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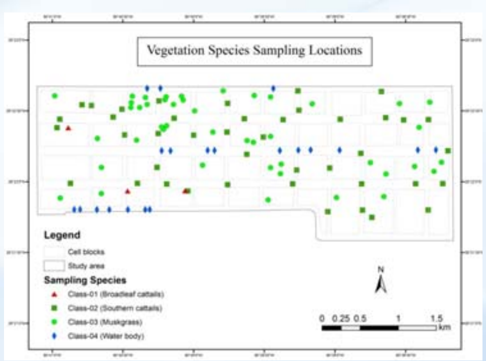
Vegetation Patterns



- 109 sampling points
- Two emerged (*broadleaf cattail* and *southern cattail*) and one submerged vegetation (*muskgrass*) species were found in the study area
- Different species locations were collected using hand-held GPS system to develop a training dataset for supervised classification

Broadleaf Cattail **Southern Cattail** **Muskgrass**

Source: Chang et al., 2015

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- Two different modeling approaches were used:
  - Species location (Latitude, Longitude) and satellite reflectance values were used as input to the model. Vegetation species types (*1= Broadleaf cattail, 2 = southern cattail, 3 = muskgrass and 4 = water body*) were considered as the target for the model

Traditional Classification Algorithm

- Minimum Distance Method (MD)
- Parallelepiped Method (PD)
- Discriminant Analysis (DA)

Neural Network Based Algorithm

- Back Propagation (BP)
- Extreme Learning Machine (ELM)

Species	Class	Number of training samples used for comparing learning capacity	Number of new training samples used for developing prediction map
Broadleaf Cattails	Class-01	3	3318
Southern Cattails	Class-02	42	46539
Muskgrass	Class-03	44	48607
Water	Class-04	20	22049

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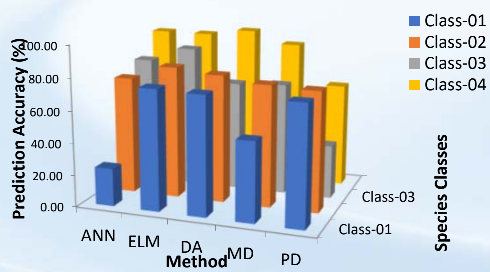
Categorical Biomass Predcition for Cell 3B

Model	Classification accuracy				Computational time (sec)		
	Training	Validation	Test	Overall	Training	Test	Total
ELM	0.94	----	0.67	0.86	0.004	0.001	0.005
ANN-BP	0.84	0.72	0.68	0.81	0.731	0.018	0.748
DA	0.82	----	0.72	0.79	0.005	0.002	0.007
MD	1.00	----	0.57	0.87	27.09	2.5	29.59
PP	0.65	----	0.39	0.68	37.71	3.0	40.71



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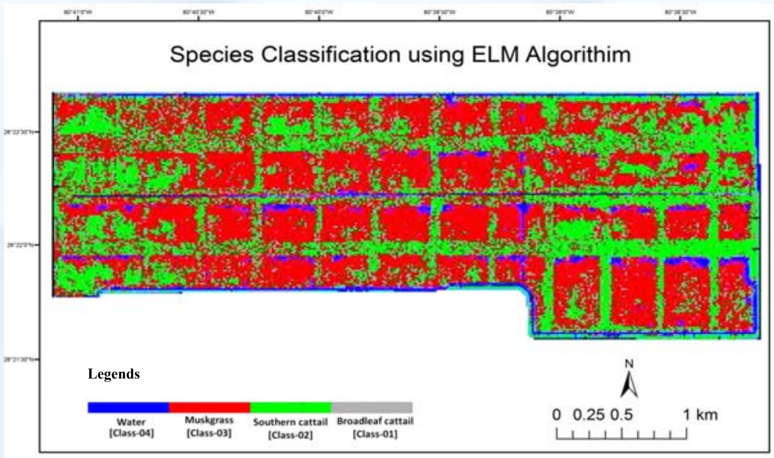
Categorical Biomass Predcition for Cell 3B

The prediction map for species was developed by using the best training and prediction result found using ELM algorithm



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Sensor Network Development

1st Component

- Developed by SFWMD
- Hydrological , meteorological, hydrogeological and water quality data
- DBHYDRO database management system
- Example: Inflow, Outflow, Upstream stage, Rainfall, etc

2nd Component

- Developed using Acoustic Doppler Velocimeter (ADV)
- ADV measures velocity of water using "Doppler Effect"
- Assumption: suspended particle in water has same velocity as water
- Three dimensional velocity measurement

Field Deployment of ADV

ADV Sensor

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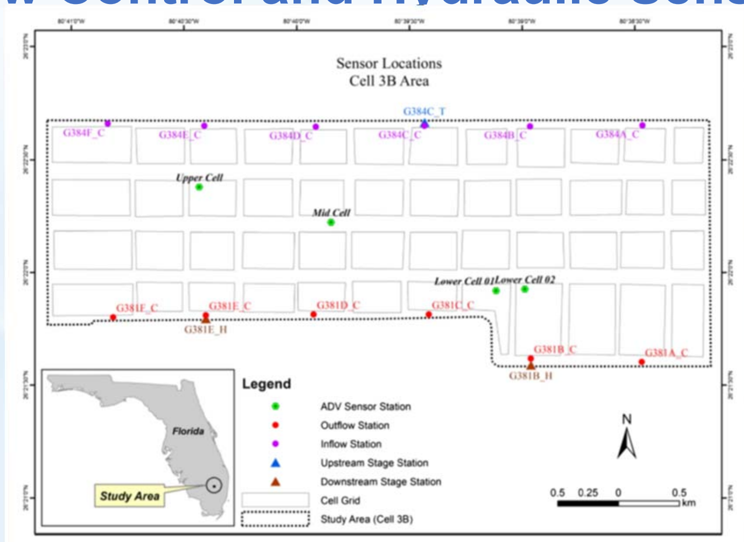
STA Flow Control and Hydraulic Sensors



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The best results were found using 80% training, 10% validation and 10% test dataset

Statistical Parameter	***ANN Model (BP)***		***GP Model***		***ELM***	
	VM	*VD*	*VM*	*VD*	*VM*	*VD*
R-square (Training)	**0.96**	0.45	0.90	0.17	0.90	**0.99**
R-square (Validation)	**0.93**	0.35	0.84	0.39		
R-square (Test)	**0.91**	0.24	0.88	0.001	0.97	**0.03**
R-square (Overall)	**0.95**	0.42	0.87	0.28	0.92	**0.76**
Time	24 hour	24 hour	24 hour	24 hour	0.15 sec	0.54 sec

VM: Velocity Magnitude ; VD: Velocity Direction

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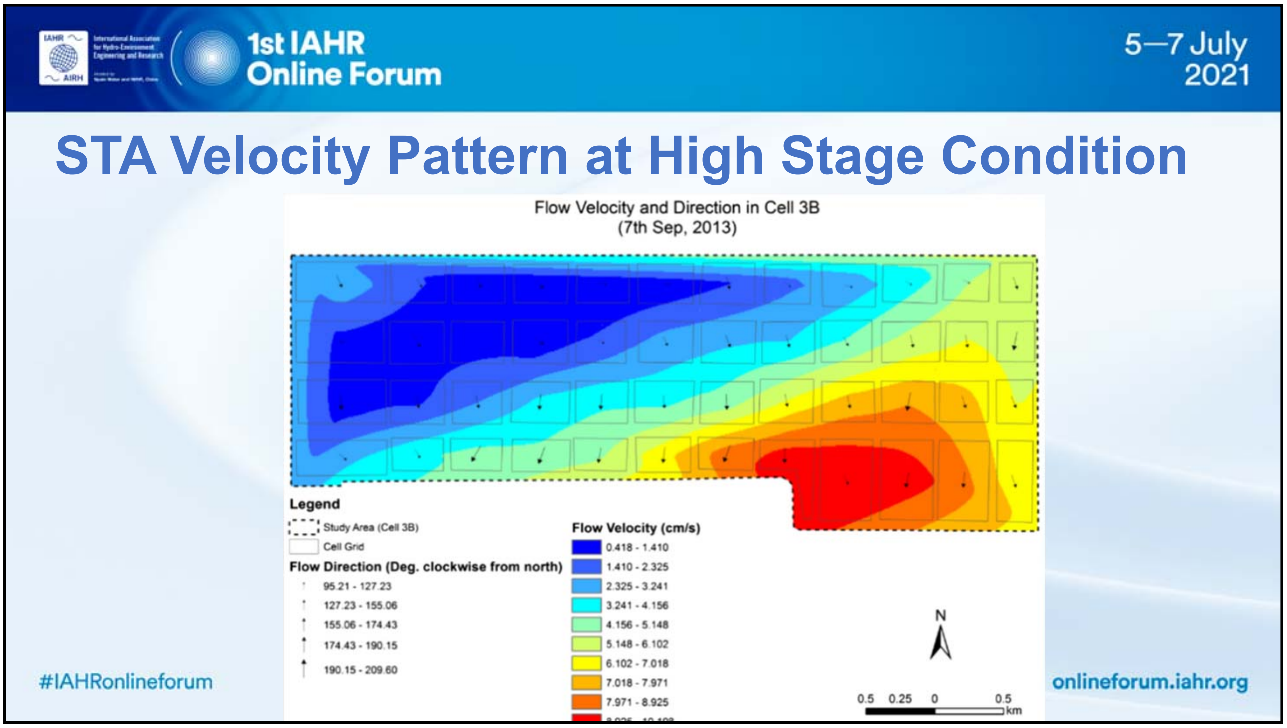

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STA Velocity Pattern at High Stage Condition
Flow Velocity and Direction in Cell 3B
(7th Sep, 2013)
Legend
Study Area (Cell 3B)
Cell Grid
Flow Direction (Deg. clockwise from north)
95.21 - 127.23
127.23 - 155.06
155.06 - 174.43
174.43 - 190.15
190.15 - 209.60
Flow Velocity (cm/s)
0.418 - 1.410
1.410 - 2.325
2.325 - 3.241
3.241 - 4.156
4.156 - 5.148
5.148 - 6.102
6.102 - 7.018
7.018 - 7.971
7.971 - 8.925
N
0.5 0.25 0 0.5
km
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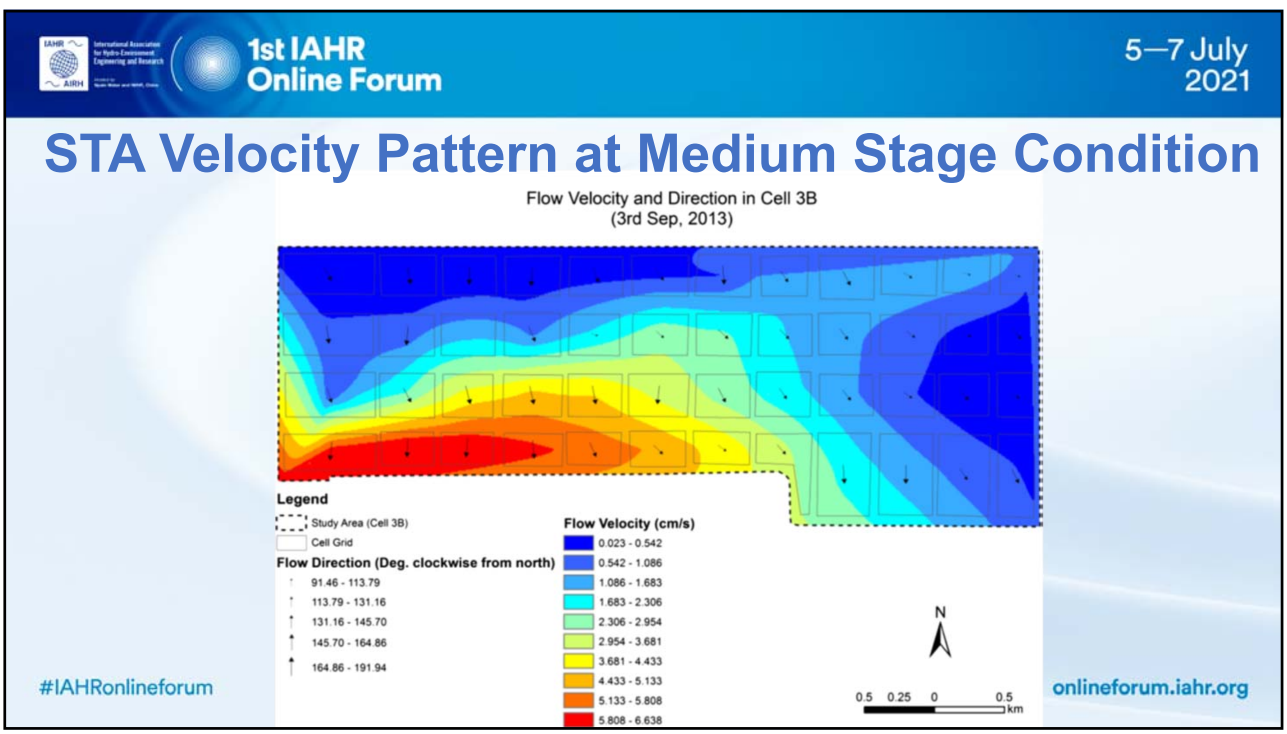

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STA Velocity Pattern at Medium Stage Condition
Flow Velocity and Direction in Cell 3B
(3rd Sep, 2013)
Legend
Study Area (Cell 3B)
Cell Grid
Flow Direction (Deg. clockwise from north)
91.46 - 113.79
113.79 - 131.16
131.16 - 145.70
145.70 - 164.86
164.86 - 191.94
Flow Velocity (cm/s)
0.023 - 0.542
0.542 - 1.086
1.086 - 1.683
1.683 - 2.306
2.306 - 2.954
2.954 - 3.681
3.681 - 4.433
4.433 - 5.133
5.133 - 5.808
5.808 - 6.638
N
0.5 0.25 0 0.5
km
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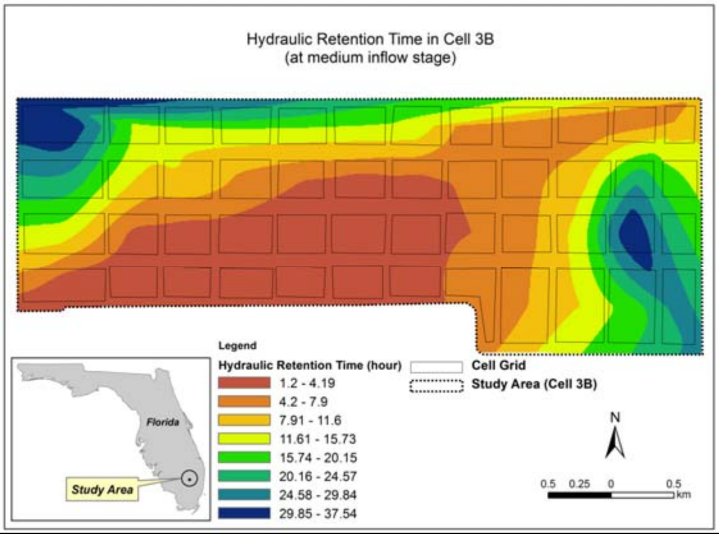
STA Hydraulic Retention Time



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Conclusion

1. The integrated remote sensing and in situ sensor network does help the ecohydraulic pattern recognition.
2. Flow field measurements and assessment reveal that the ecohydraulic pattern requires advanced adjustment.
3. Such adjustment can be fulfilled by reducing biomass at the northwest and southeast corner of the STA 3B.

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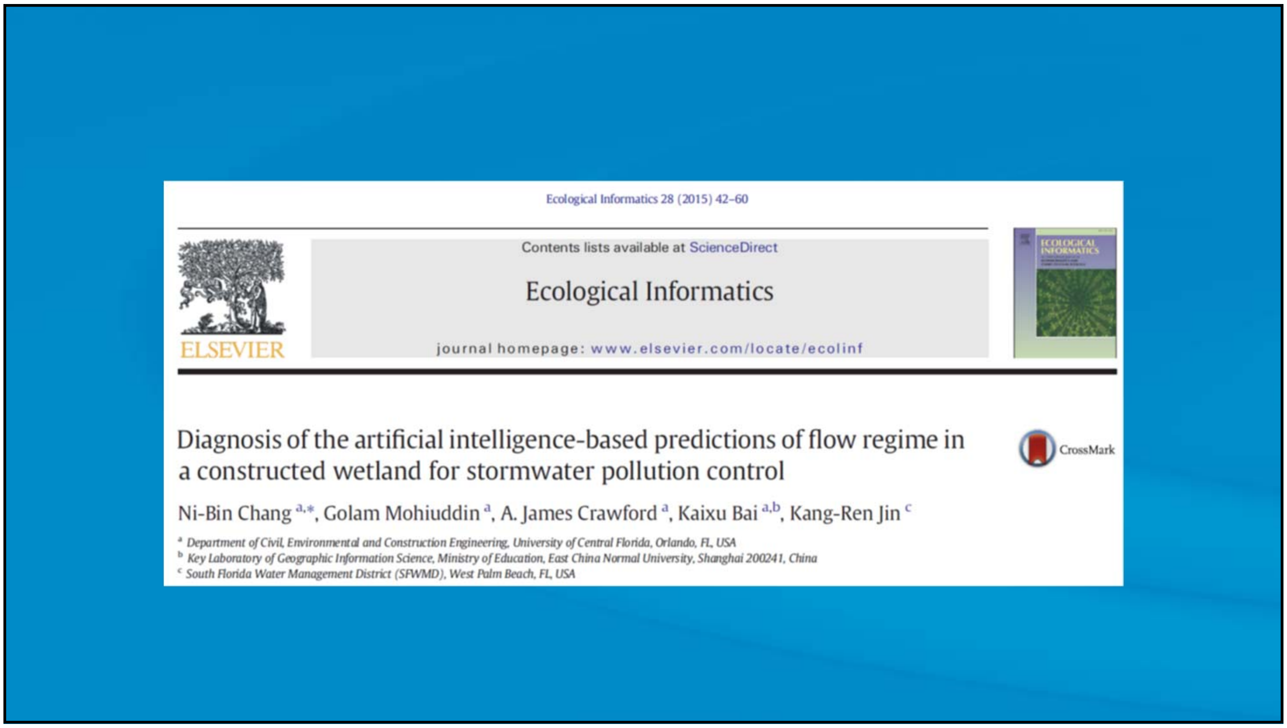

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Diagnosis of the artificial intelligence-based predictions of flow regime in a constructed wetland for stormwater pollution control

CrossMark

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