



*Managing Sheetflow to
Restore a High-Functioning
Everglades Ecosystem*

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Hydroecology of Flowing Waters

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Decomartmentalization Physical Model (DPM) team: SFWMD, USGS, FIU, ENP, and U. HI

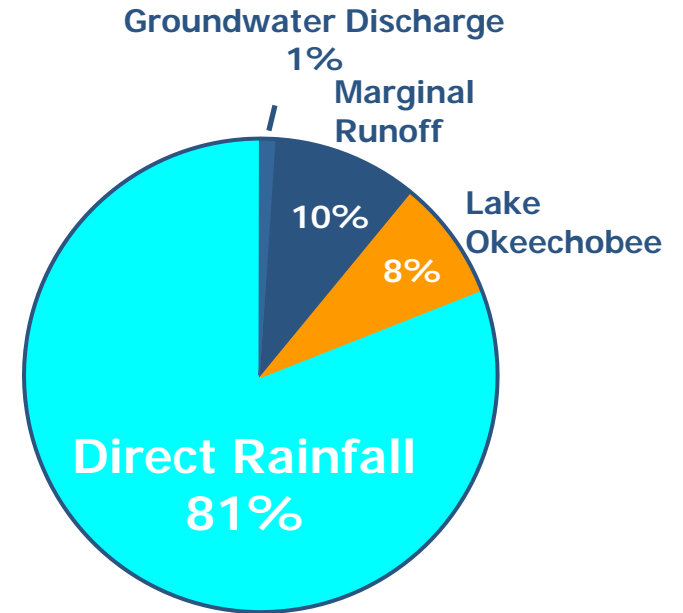
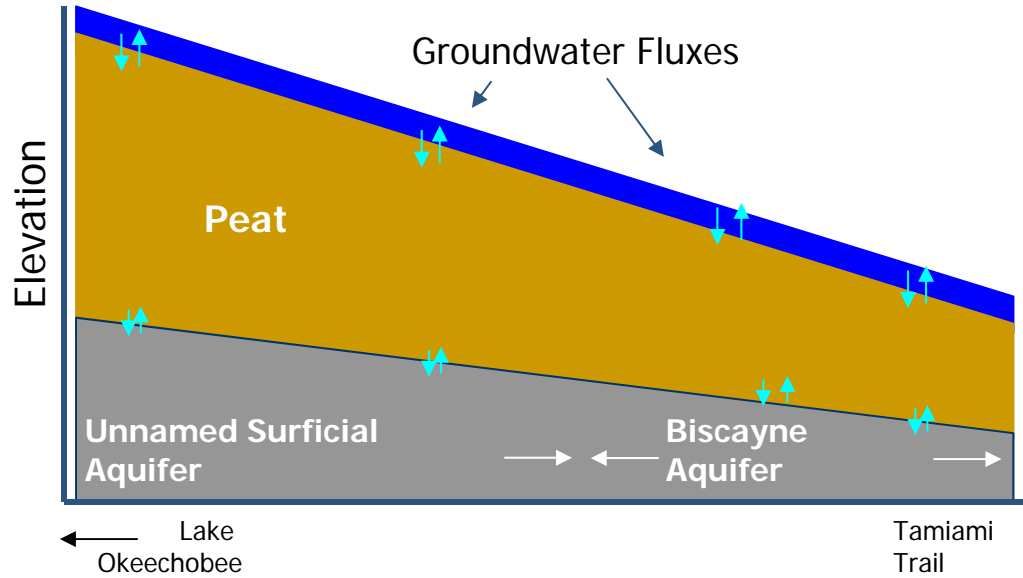
Synthesis of Everglades Restoration and Ecosystem Services (SERES)

funding from USGS, National Park Service, National Science Foundation, and

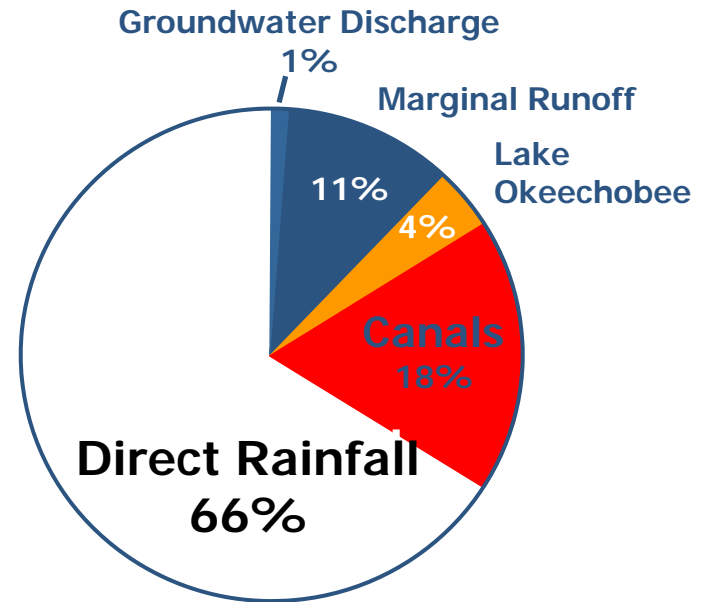
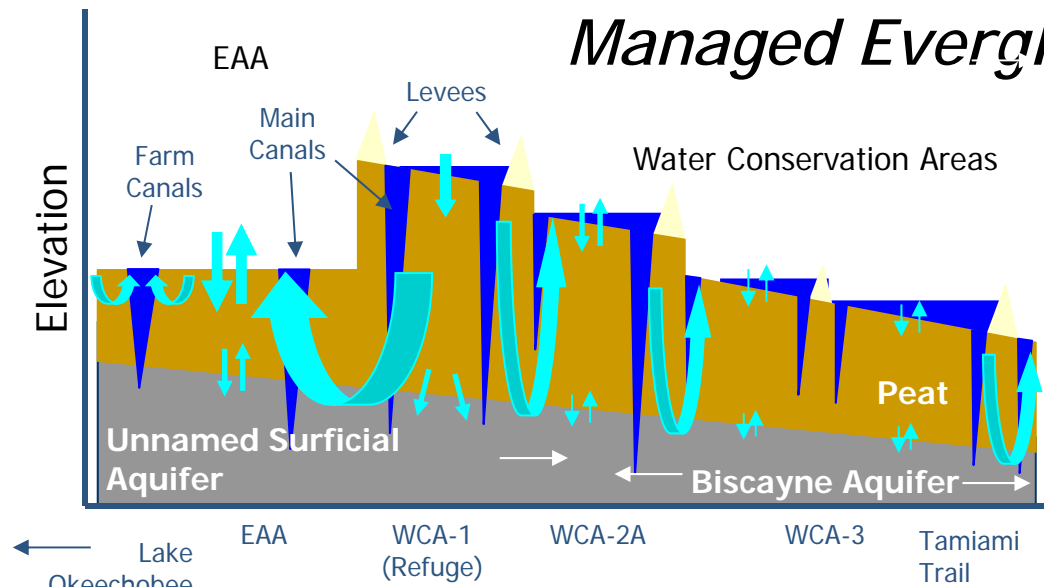


Army Corps of Engineers

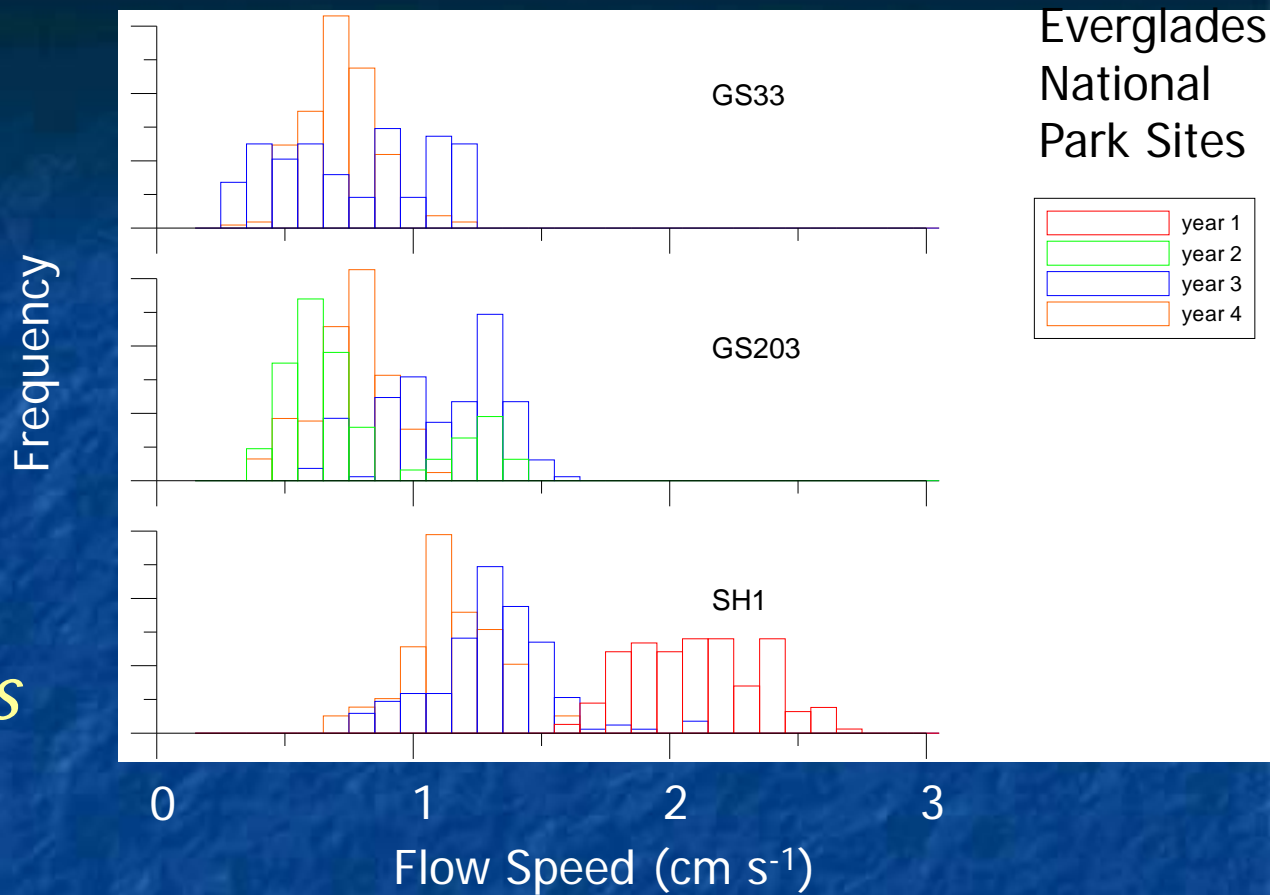
Pre-drainage Everglades



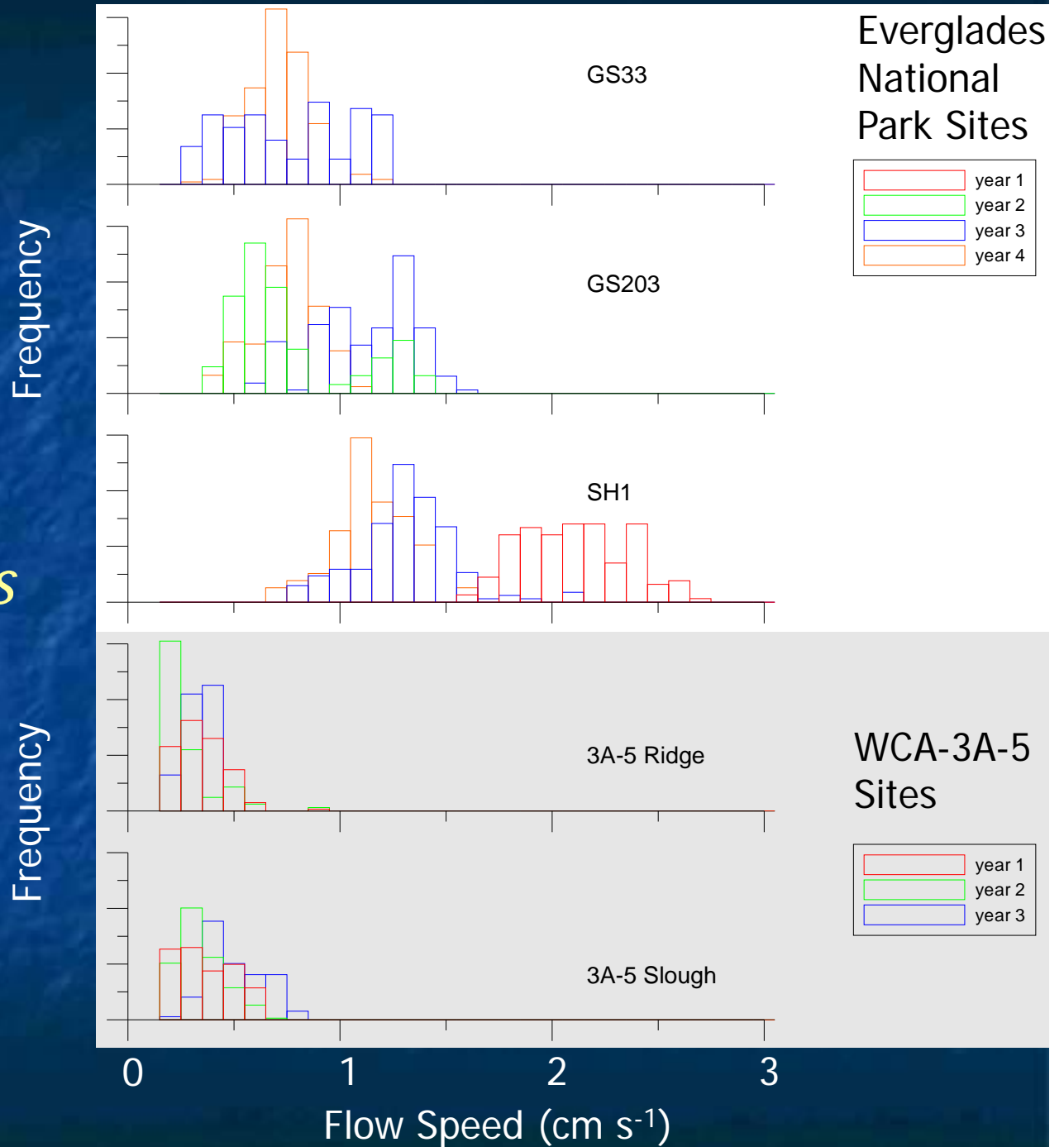
Managed Everglades



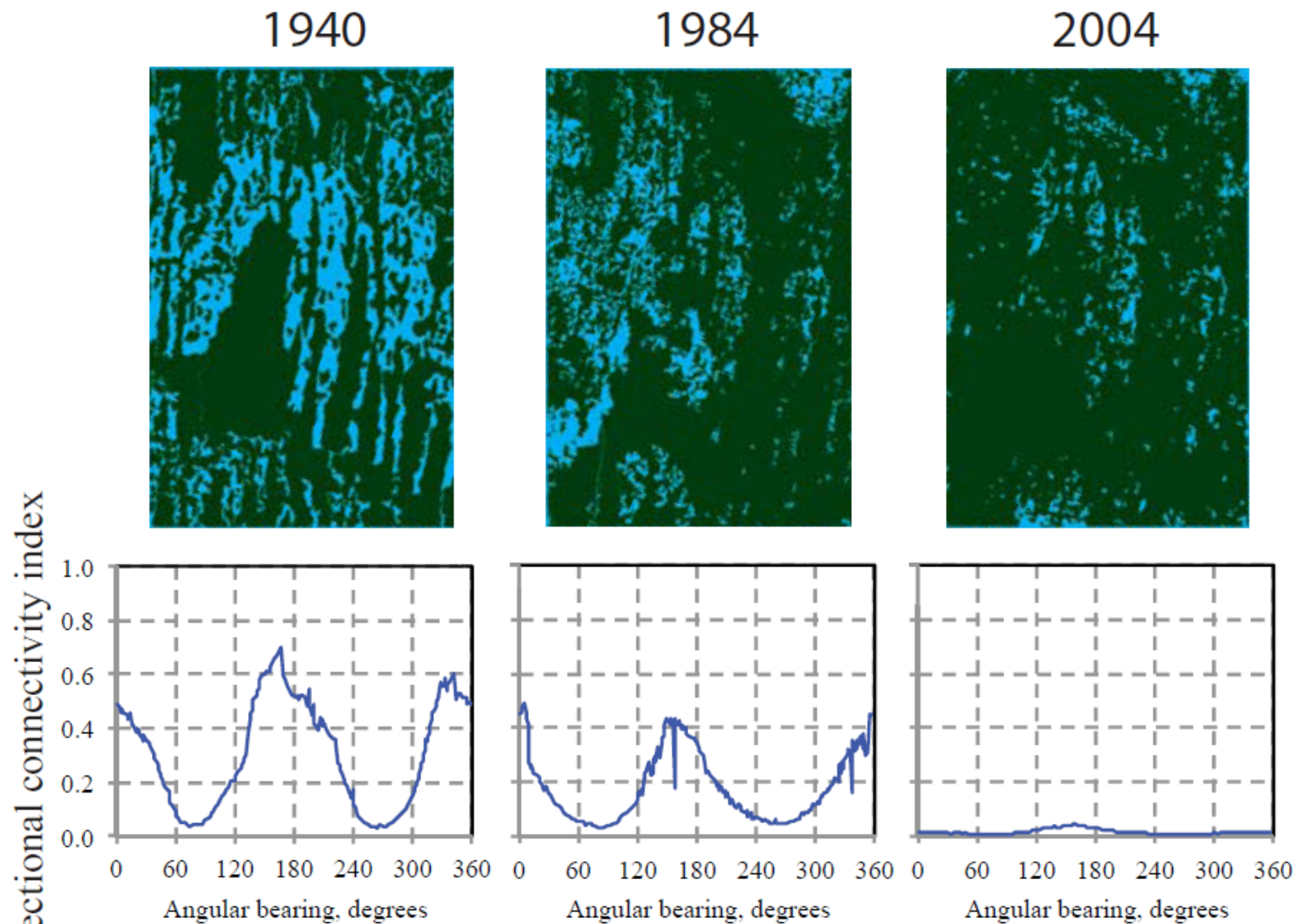
Managing water by pooling it in levee-surrounded basins decreased flow velocities in WCAs relative to areas such as Everglades National Park



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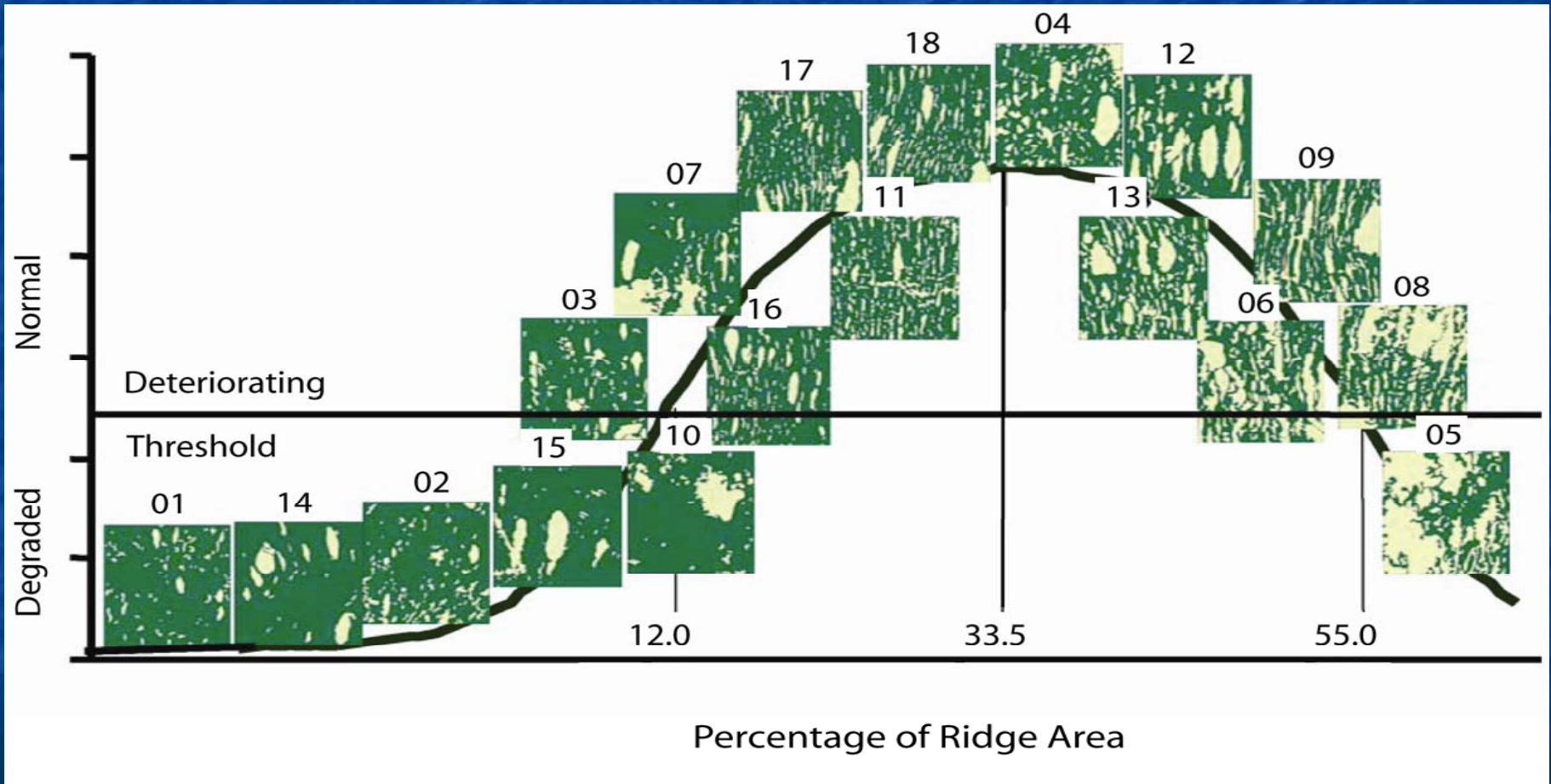
Directional Connectivity of Sloughs Declined



Nungesser, *Wetlands Ecology and Management*, 2011

Larsen, Choi, Nungesser, and Harvey, *Ecological Applications*, in review

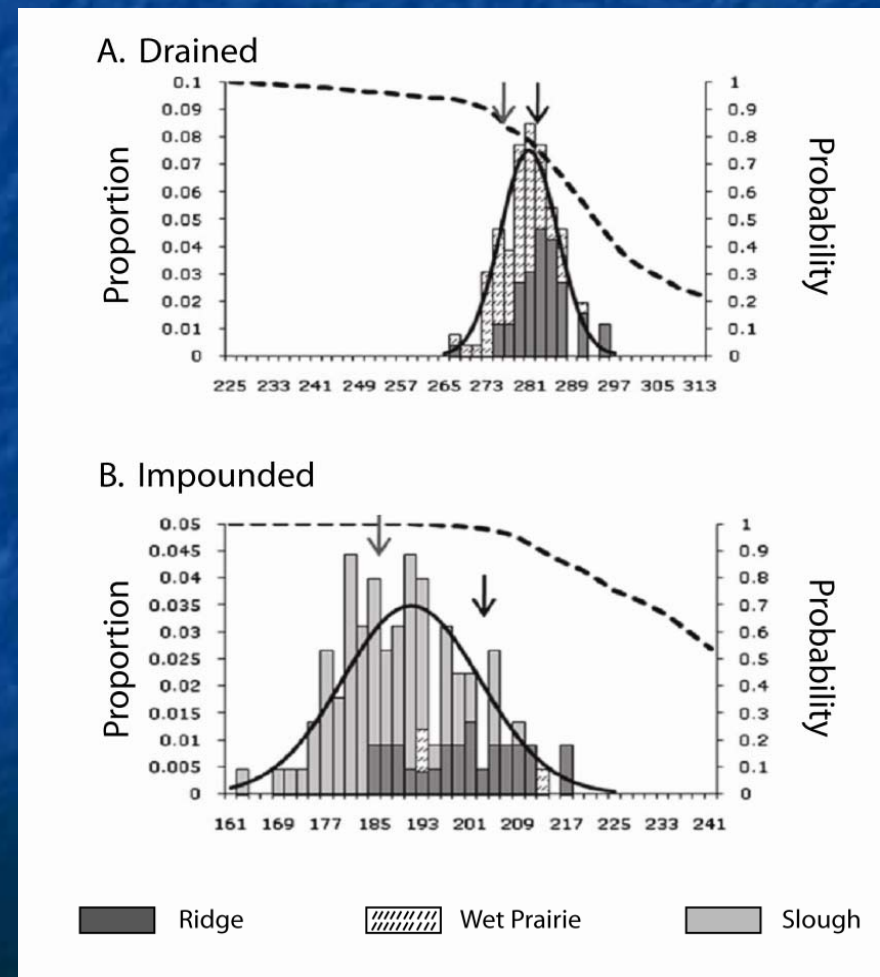
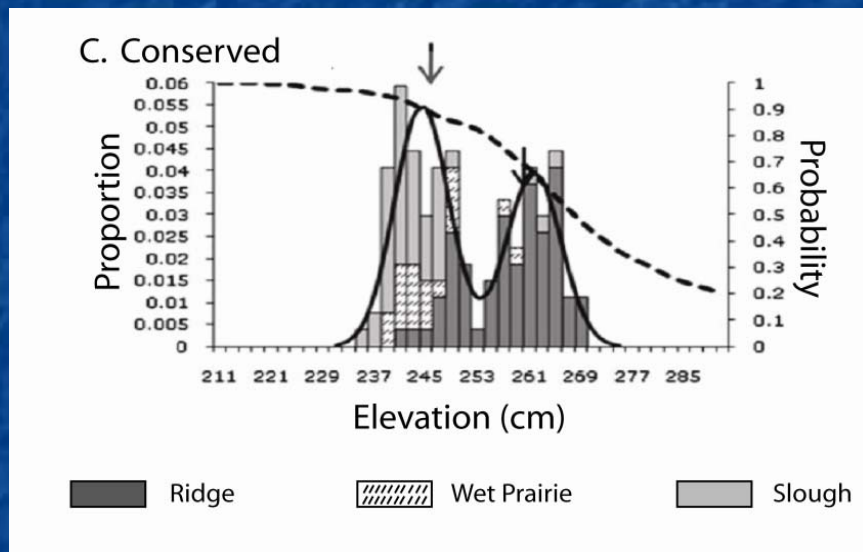
Ridge-Slough Functionality Metrics - Percent Sawgrass Coverage



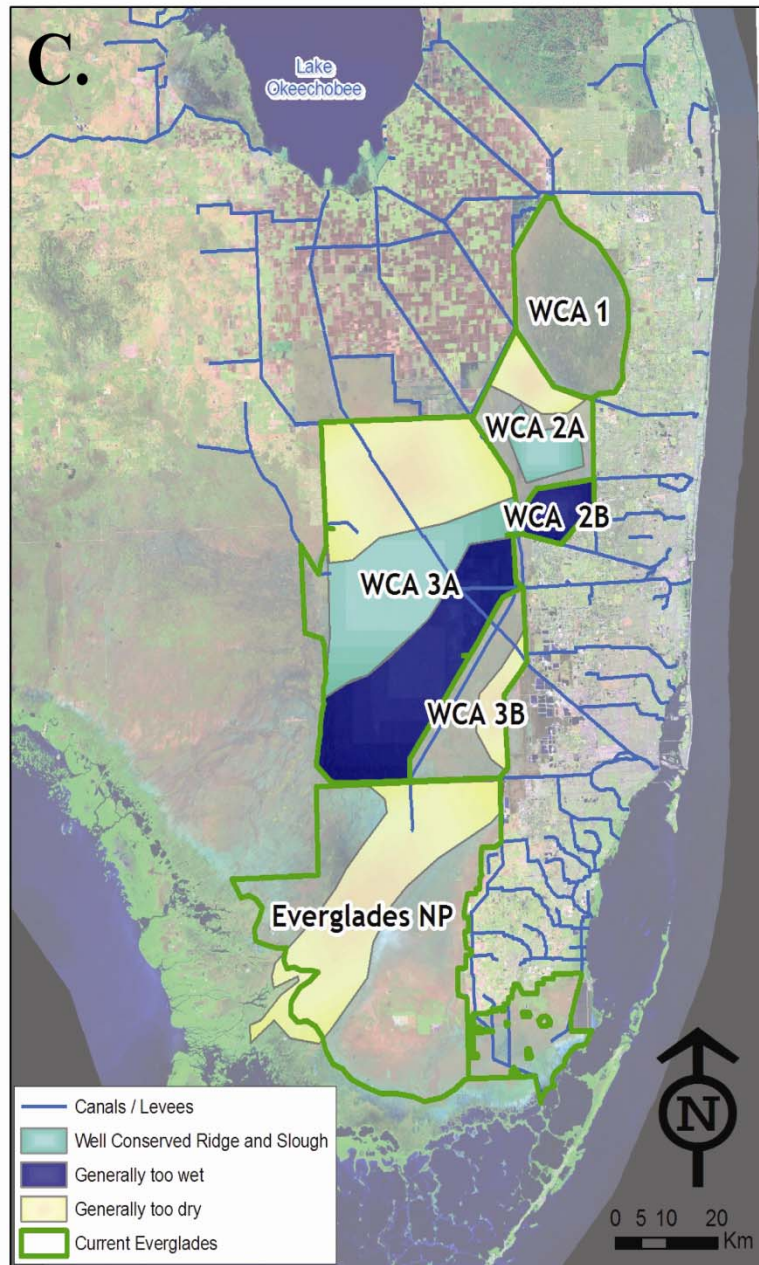
Homogenization of Vegetation and Microtopography

Well Conserved, High-functioning

Degraded, Moderate to Low Functioning



Watts et al., *Ecosystems*, 2010



Location of Well Conserved, High-Functioning Ridge and Slough

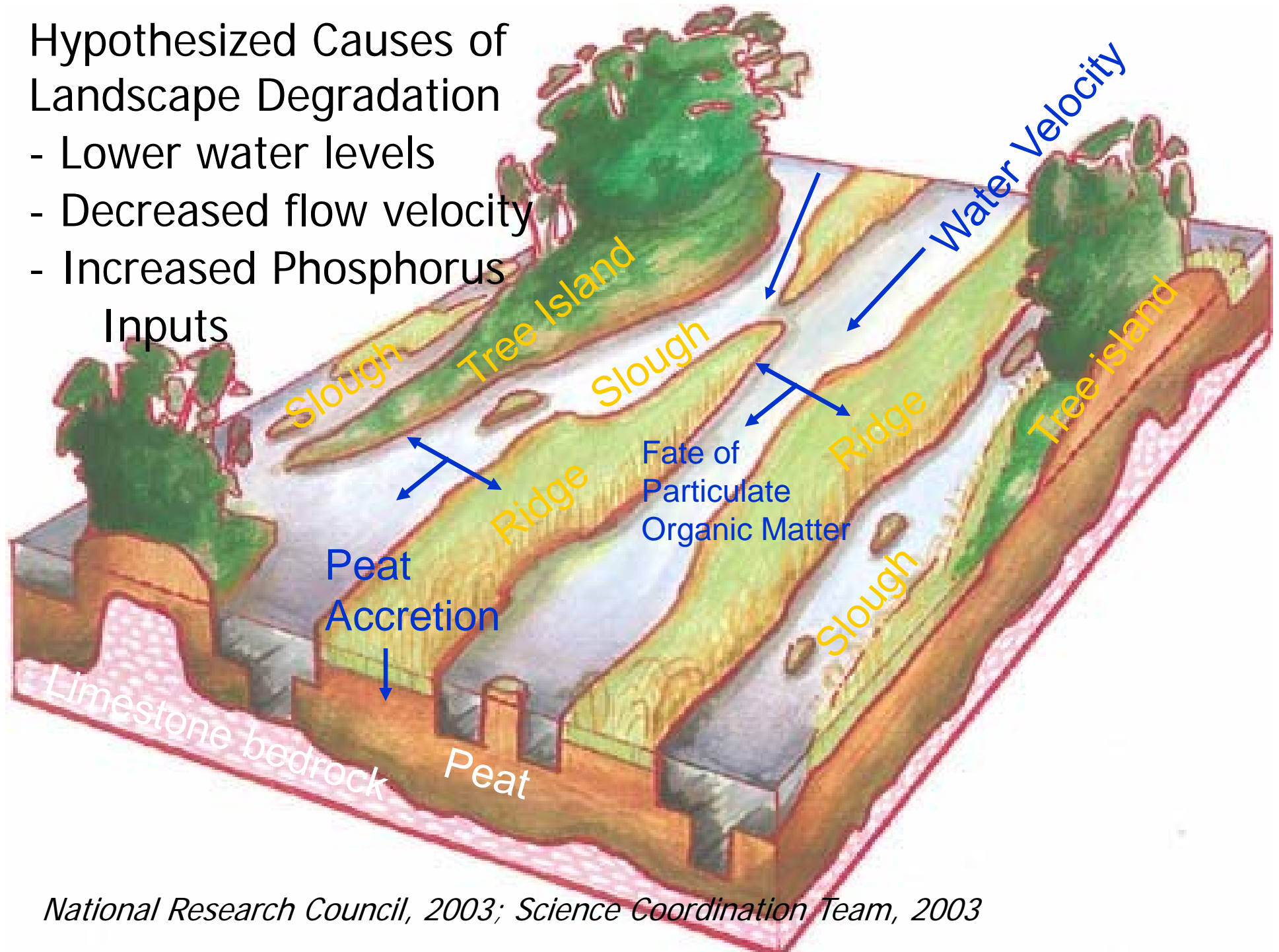
(Note; WCA-1 not considered)

Synthesis of Everglades Restoration and Ecosystem Services (SERES), 2011

<http://www.everglades-seres.org>

Hypothesized Causes of Landscape Degradation

- Lower water levels
- Decreased flow velocity
- Increased Phosphorus Inputs

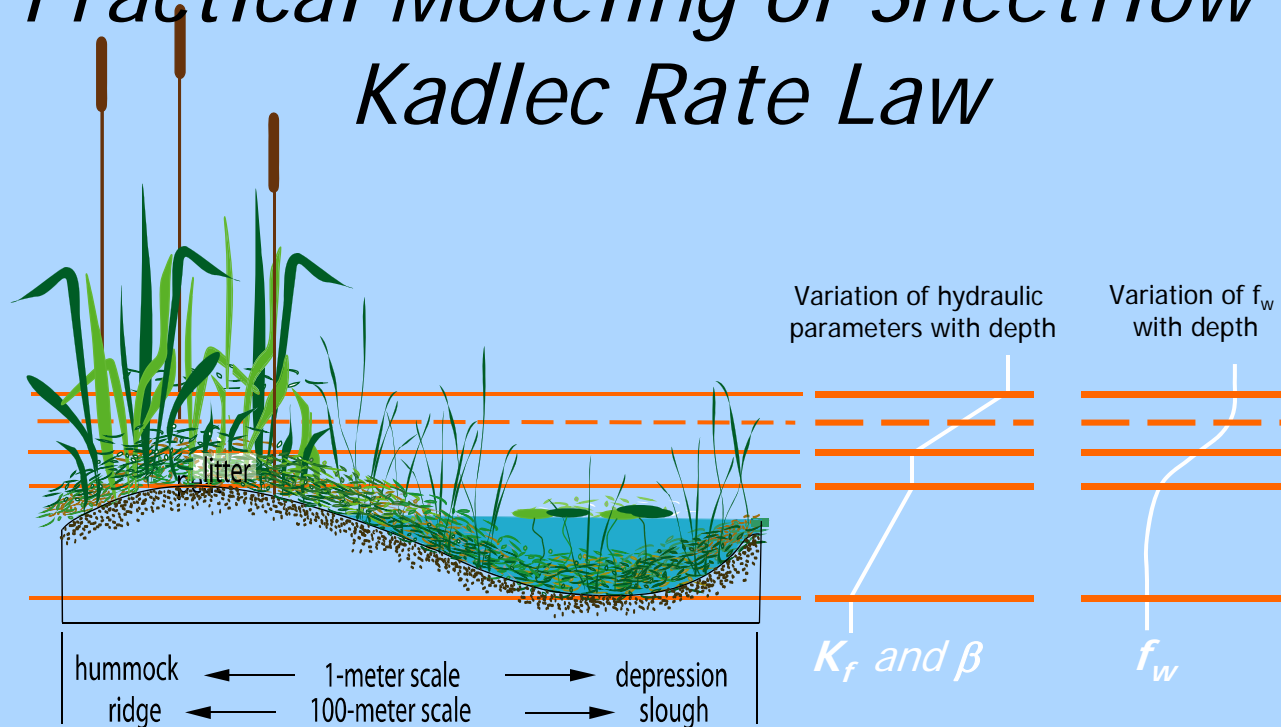


National Research Council, 2003; Science Coordination Team, 2003

Hydraulics of Sheetflow

- ❑ *Water depth* is controlled in managed Everglades by structure operations to achieve target pool elevations
- ❑ In restored Everglades *water depth* will be controlled by balance between the forces driving flow (*water surface slope*) and forces opposing flow (*drag on vegetation stems*)
- ❑ There are two fundamental problems with using Manning's equation to estimate how water depth will change with restoration
 - 1) Manning's is appropriate where drag is at the channel boundaries. In wetlands drag is vertically distributed on vegetation stems
 - 2) Manning's appropriate for turbulent flows where flow resistance is independent of velocity but wetland flow is typically laminar and thus flow resistance is a function of velocity

Practical Modeling of Sheetflow - Kadlec Rate Law



$$v = K_f \cdot d^\beta \cdot S_f^\lambda$$

$$f_w \cdot S_s \cdot \frac{dh}{dt} + (1 - f_w) \cdot S_y \cdot \frac{dh}{dt} = \frac{d}{dx} \left(f_w \cdot K_f \cdot d^{\beta+1} \cdot \frac{dh}{dx} \right) + (P - ET + GW_i)$$

f_w = fraction of free surface water

P = precipitation

S_s = surface-storage coefficient,

ET = evapotranspiration

h = water-surface elevation,

GW_i = ground-water inflow

S_y = specific yield of the wetland sediments

v = velocity

β = the depth exponent

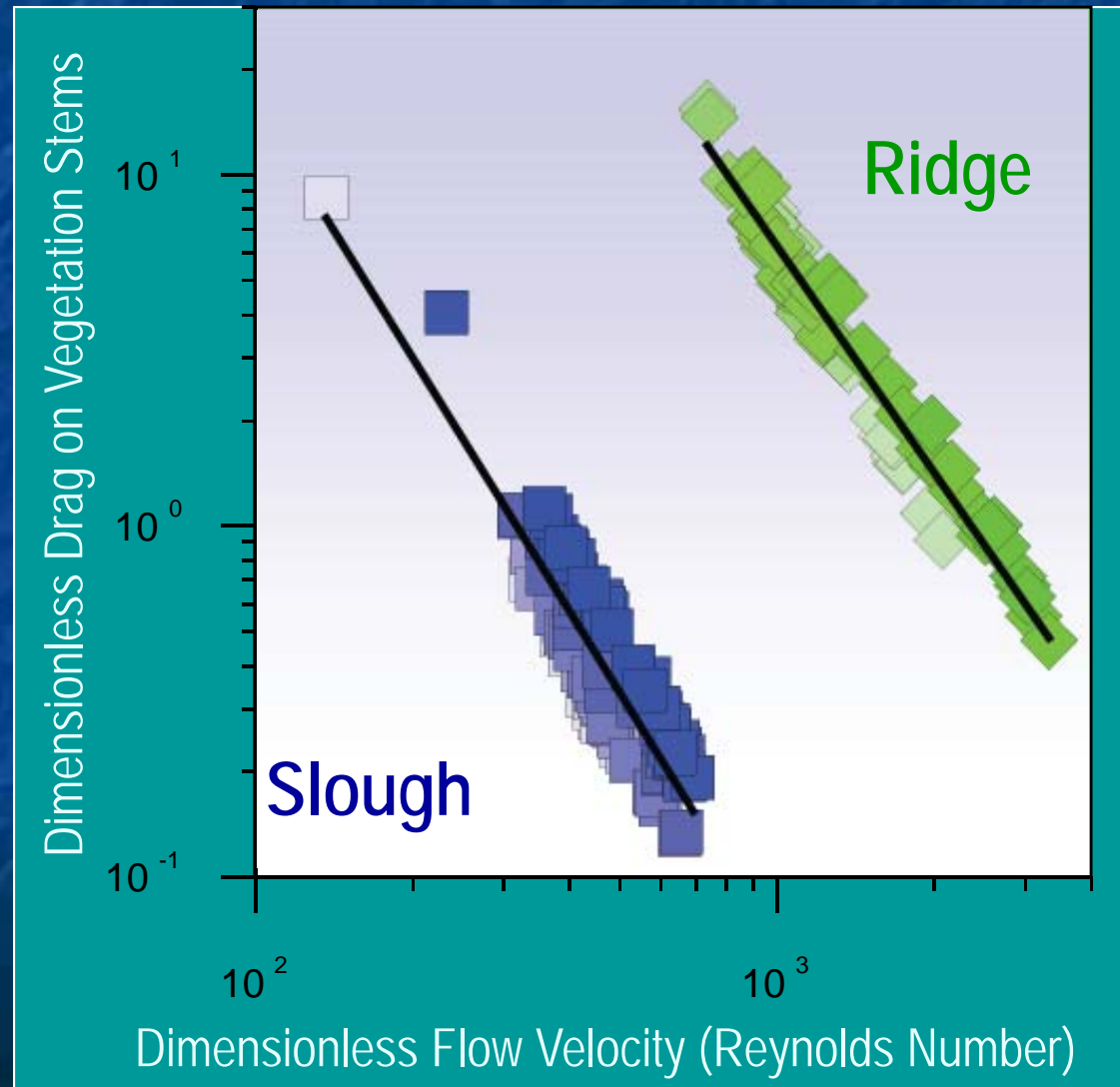
K_f = friction resistance coefficient

S_f = friction slope

d = the depth,

λ = the slope exponent

Vegetative Drag is Orders of Magnitude Higher in Sawgrass Ridges Compared with Sloughs



Measurement Date	
◆	8/7 to 8/21
◆	8/22 to 9/5
◆	9/6 to 9/20
◆	9/21 to 10/5
◆	10/6 to 10/20
◆	10/21 to 11/4
◆	11/5 to 11/19
◆	11/20 to 12/4

Harvey et al.,
*Water Resources
Research*, 2009

Restoration Tools: A New Rate Law for Everglades Sheetflow

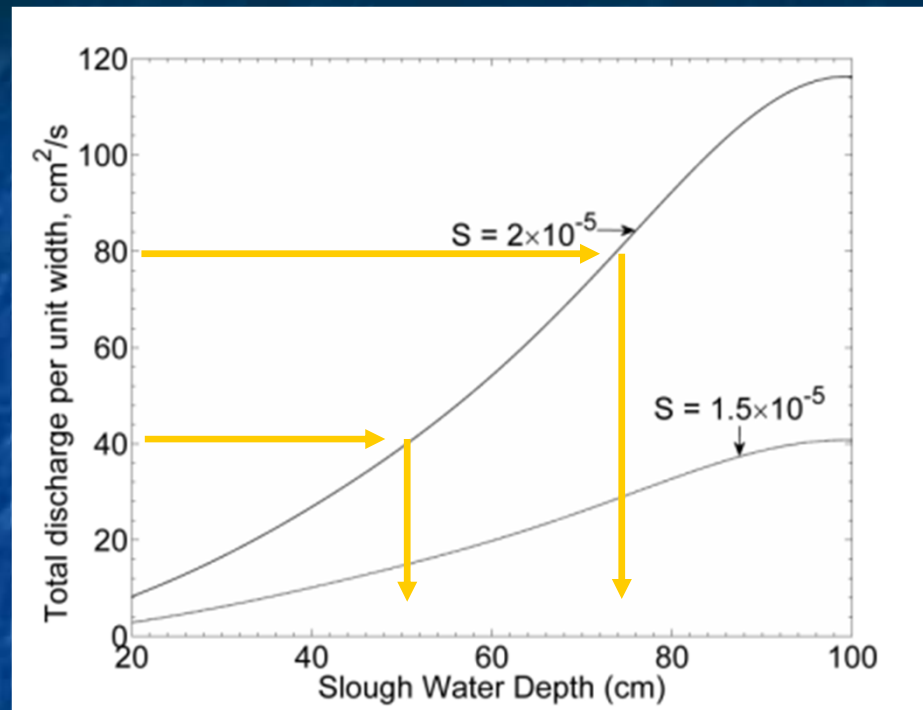
$$\text{Ridge: } U\{h\} = \left[\frac{gS(d\{h\})^{2.04}}{10^{2.37} \nu^{1.54} (a\{h\})^{0.5}} \right]^{2.17}$$

$$\text{Slough: } U\{h\} = \left[\frac{gS(d\{h\})^{2.23}}{10^{0.29} \nu^{1.73} (a\{h\})^{0.5}} \right]^{3.70}$$

$U\{h\}$ = local flow velocity, cm/s
 g = gravitational acceleration, 981 cm s⁻²
 S = water surface slope, dimensionless
 $d\{h\}$ = mean stem diameter as function of local water depth (**h** , see below), cm
 $a\{h\}$ = mean frontal area per unit volume as function of local water depth (see below), cm⁻¹
 ν = kinematic viscosity of water, 0.01 cm²/s

	Ridge	Slough
$a\{h\}$	$1.2 \times 10^{-9} h^4 - 3.7 \times 10^{-7} h^3 +$ $4.0 \times 10^{-5} h^2 - 0.0016h + 0.042$	$2.3 \times 10^{-8} h^3 - 2.7 \times 10^{-6} h^2 + 0.00015h + 0.036$
$d\{h\}$	$1.6 \times 10^{-5} h^2 - 0.0061h + 1.2$	$-8.3 \times 10^{-9} h^3 + 9.5 \times 10^{-7} h^2 - 2.9 \times 10^{-5} h + 0.1$

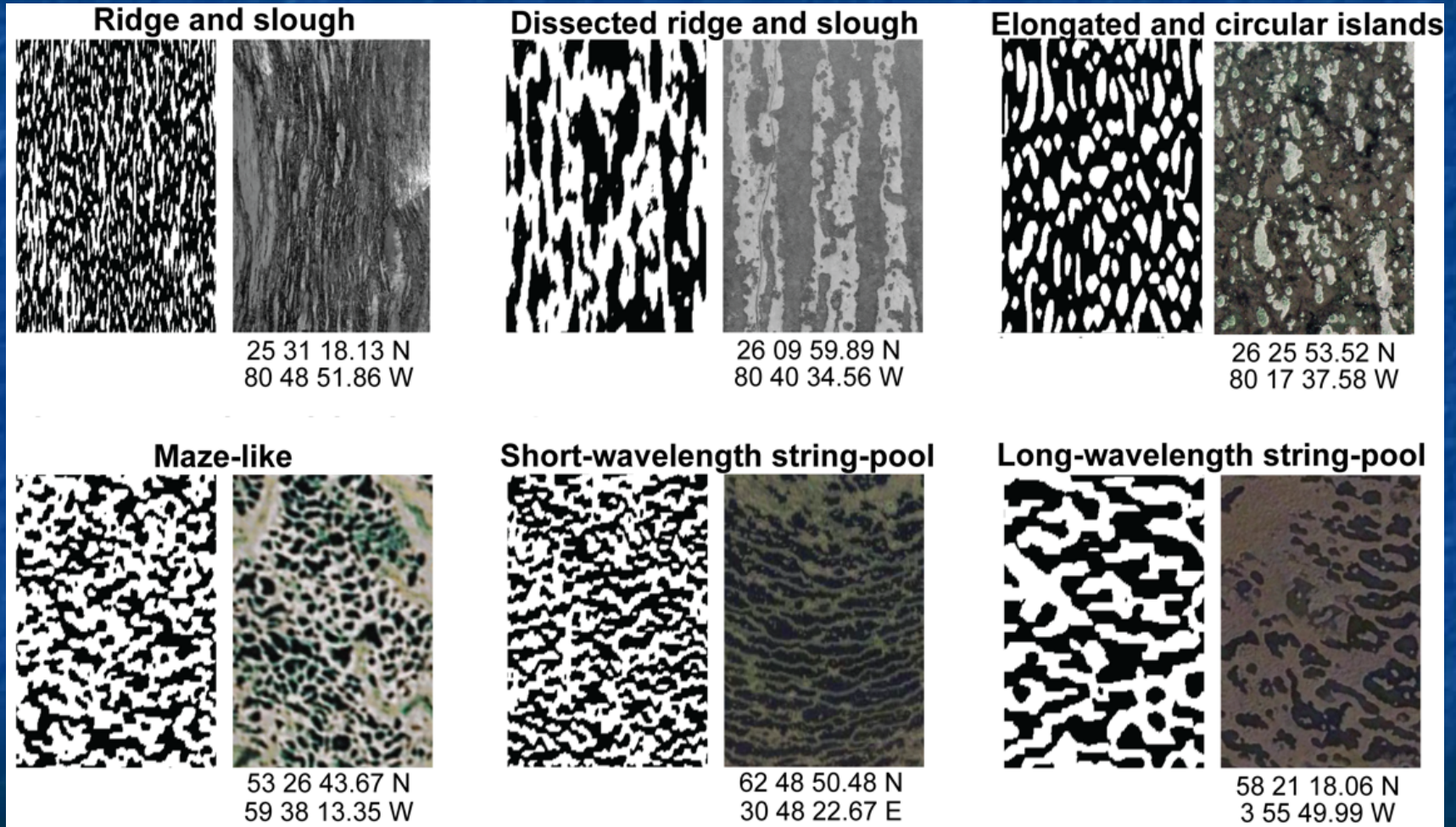
Response of Water Depth to Flow Increase



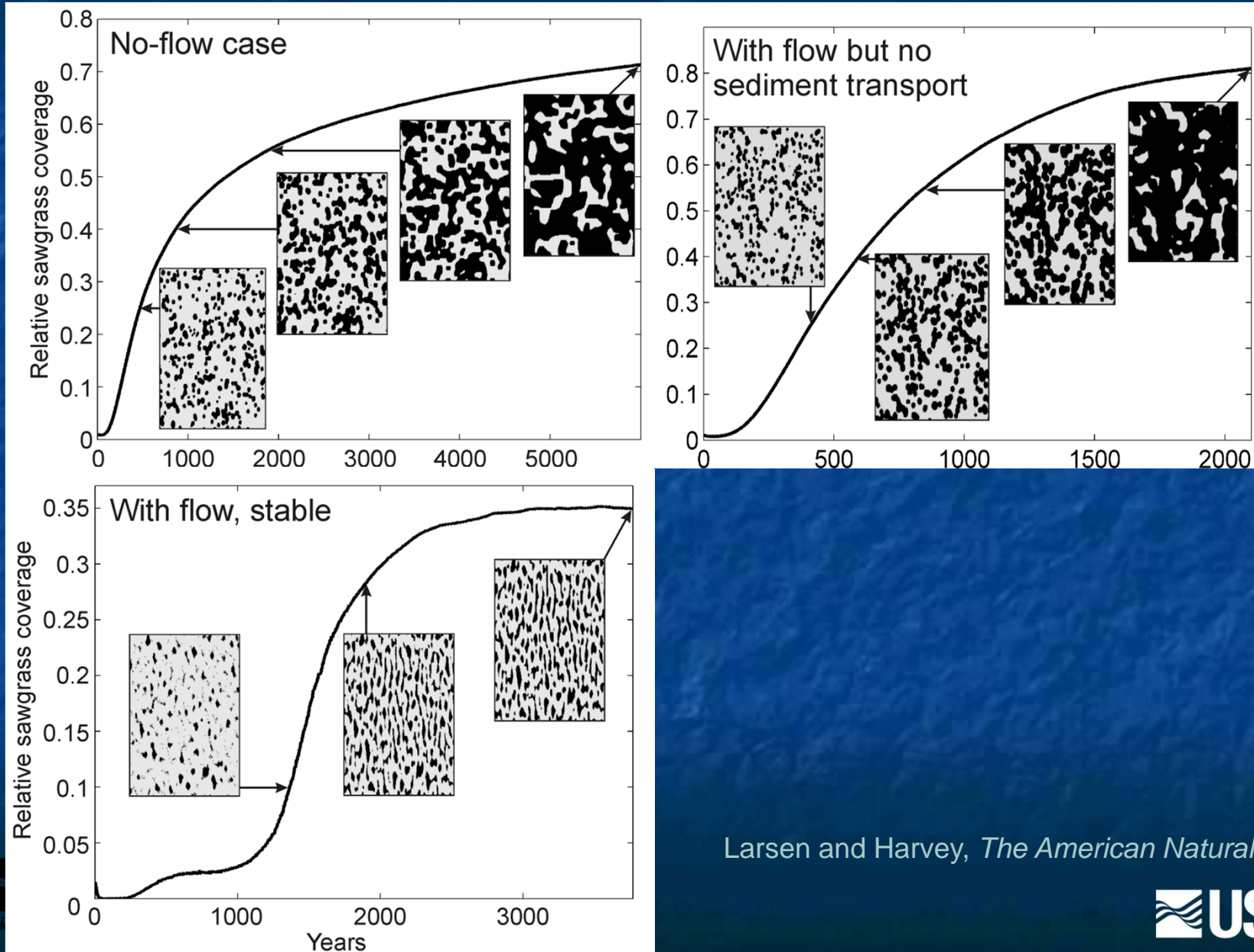
- Vegetation community and its architecture can change on a 3 – 10 year timescale. Need modeling tools that can account for changing vegetation drag
- New rate law accounts for influence of vegetation type, biomass, frontal area and stem diameter . Example: doubling of flow results in approximately a 45% increase in water depth

Hydrologic Connectivity – Interactions between Landscape Form, Flow Conductance and Material Storage and Processing

Flow

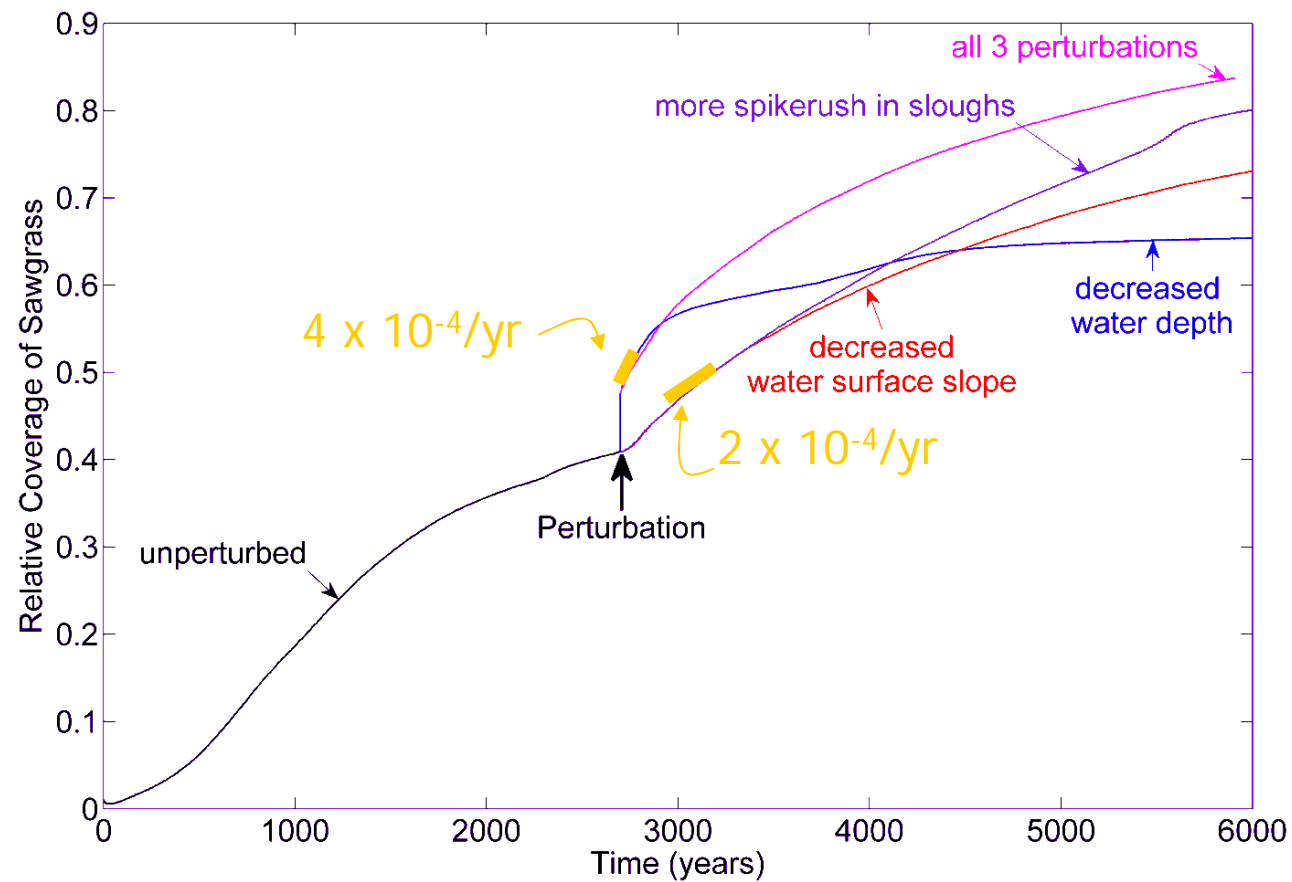


Only Simulations with Flow Pulses and Sediment Redistribution Produced Stable, Well Connected Sloughs



Larsen and Harvey, *The American Naturalist*, 2010

Decreased Water Depth Degrades Fastest Decreased Water Slope and Spikerush Invasion Degrade More Slowly



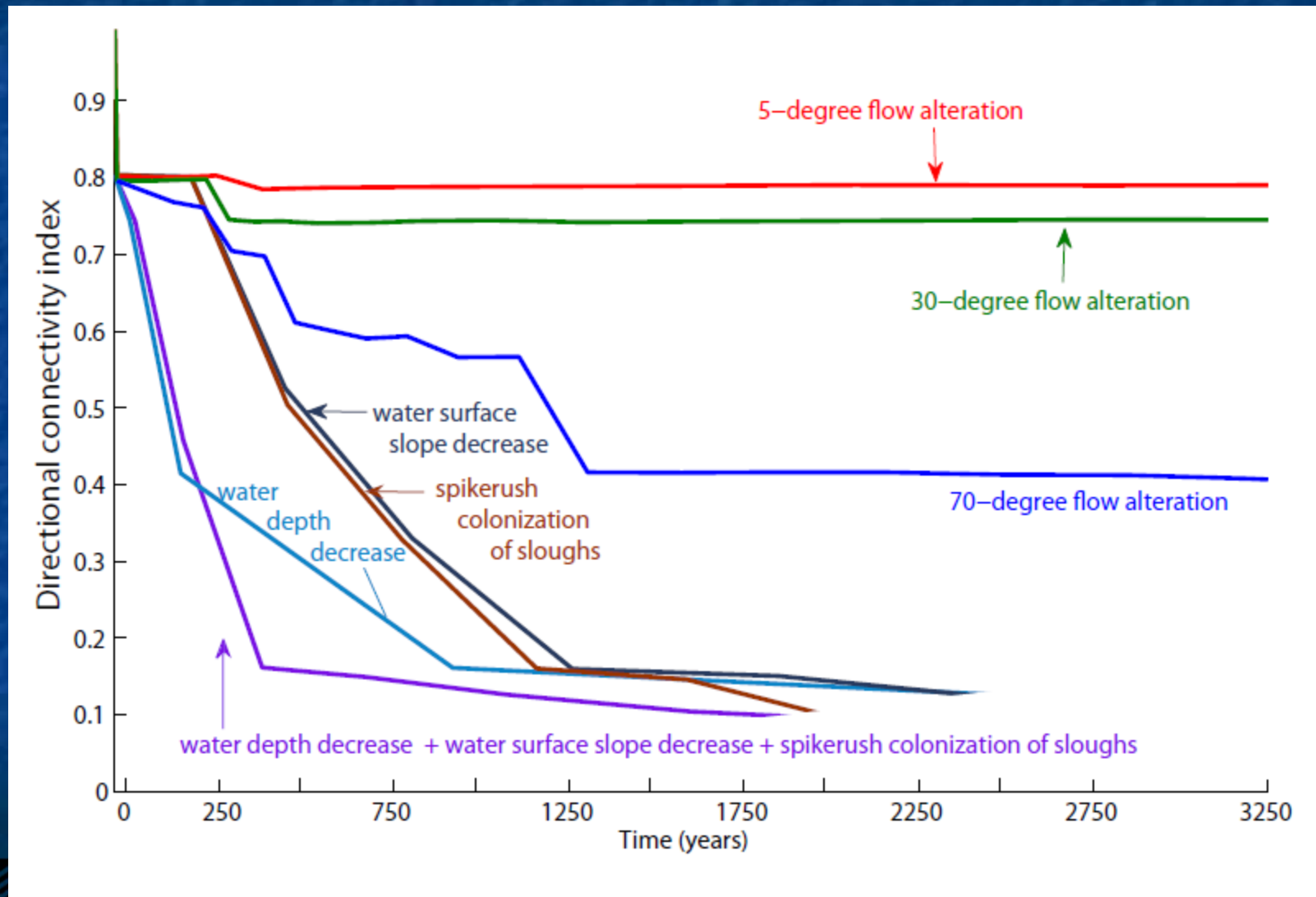
Compare to data:

- Ridges in WCA-1 expanding 30 cm/yr , or $8 \times 10^{-4}/\text{yr}$

(Paul McCormick, *personal communication*, 2009)

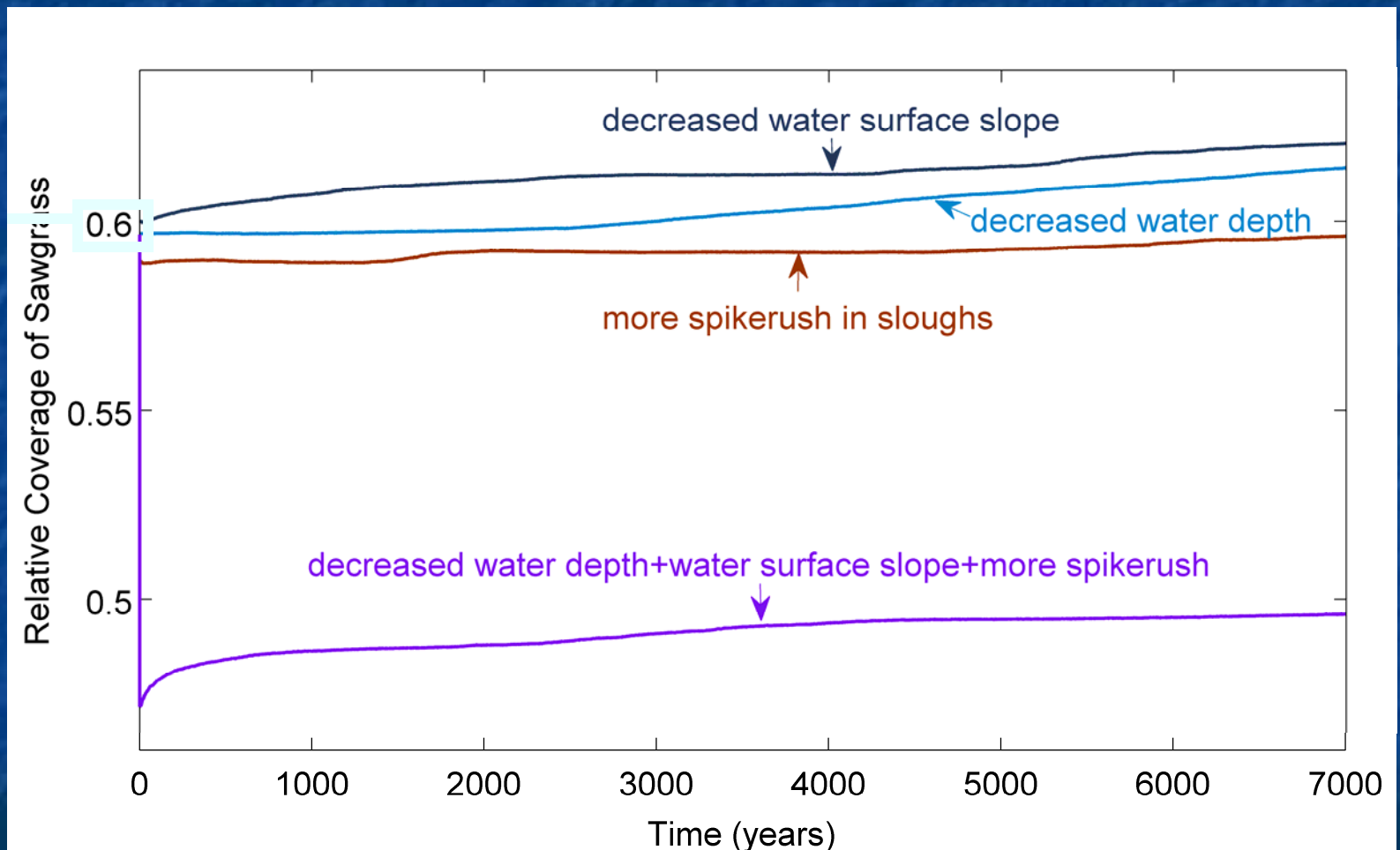
Note: Unit conversion assumes mean ridge dimensions of 500 m x 175 m

Directional Connectivity Metric is a More Sensitive Indicator of Degradation

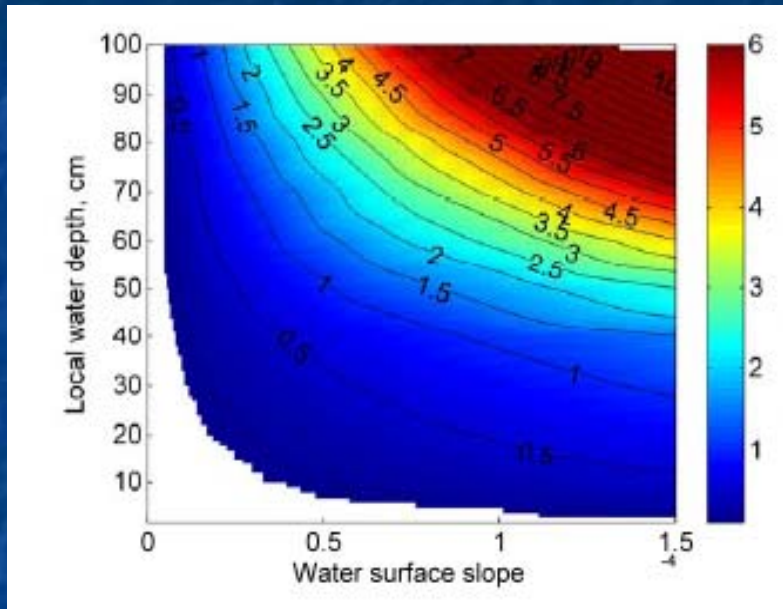


Restoration Hard to Achieve Where Sawgrass Expanded in Overly Dry Areas

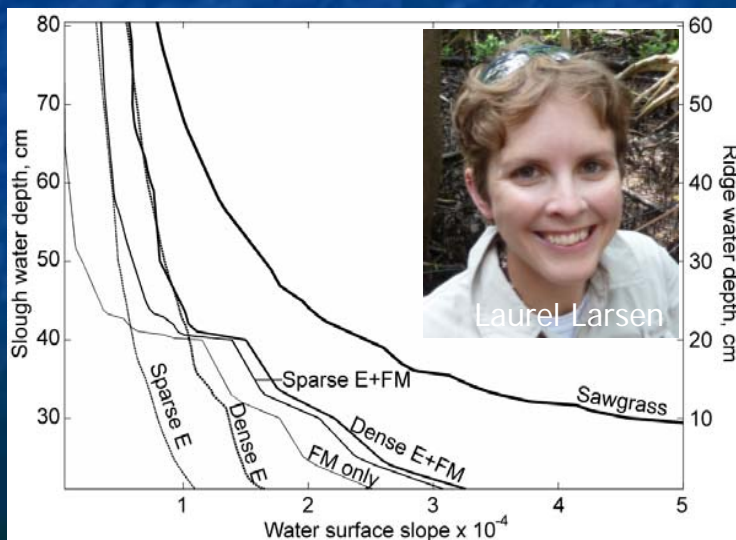
“Restoration” simulations performed on degraded landscapes that had reached 60% sawgrass coverage



Scientifically-based Strategies to Preserve Remaining Ridge and Slough Landscape

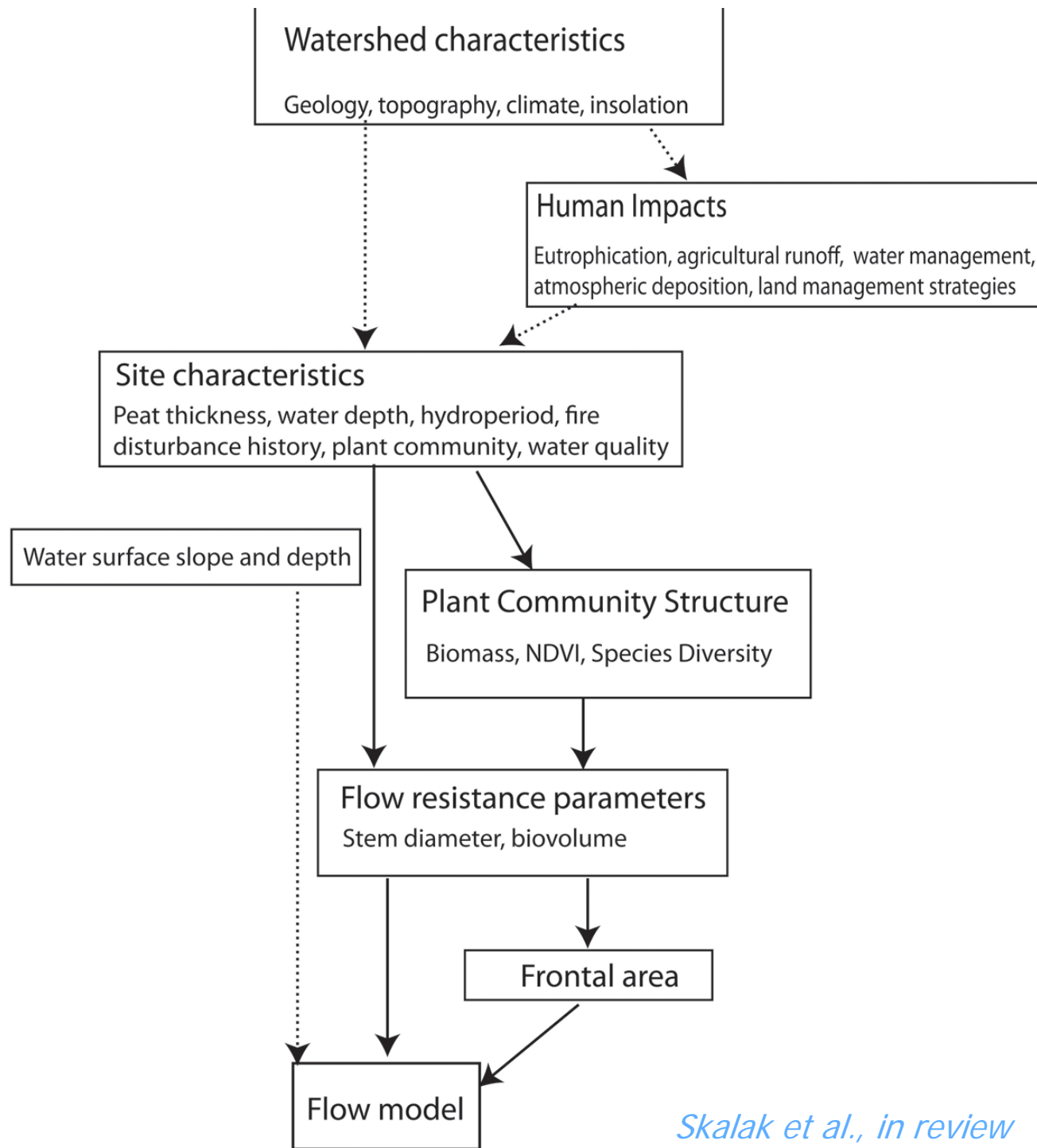


- Modeled flow velocity and shear stresses as a function of water depth, water surface slope, and vegetation community
- Reveals a narrow combination of conditions that cause entrainment and transport of floc in sloughs and deposition on ridges.

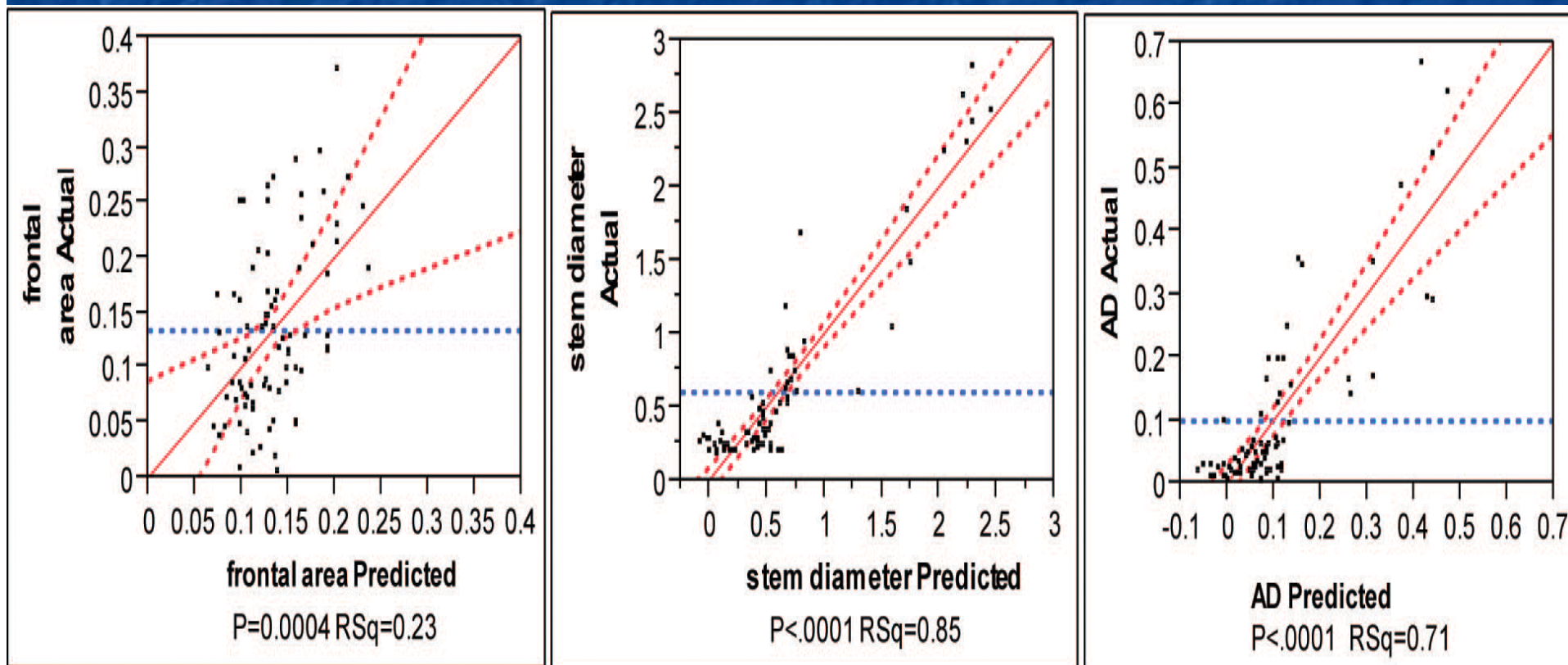


- The most effective way to preserve habitat connectivity will be through pulsed flow releases that maximize water surface slope.

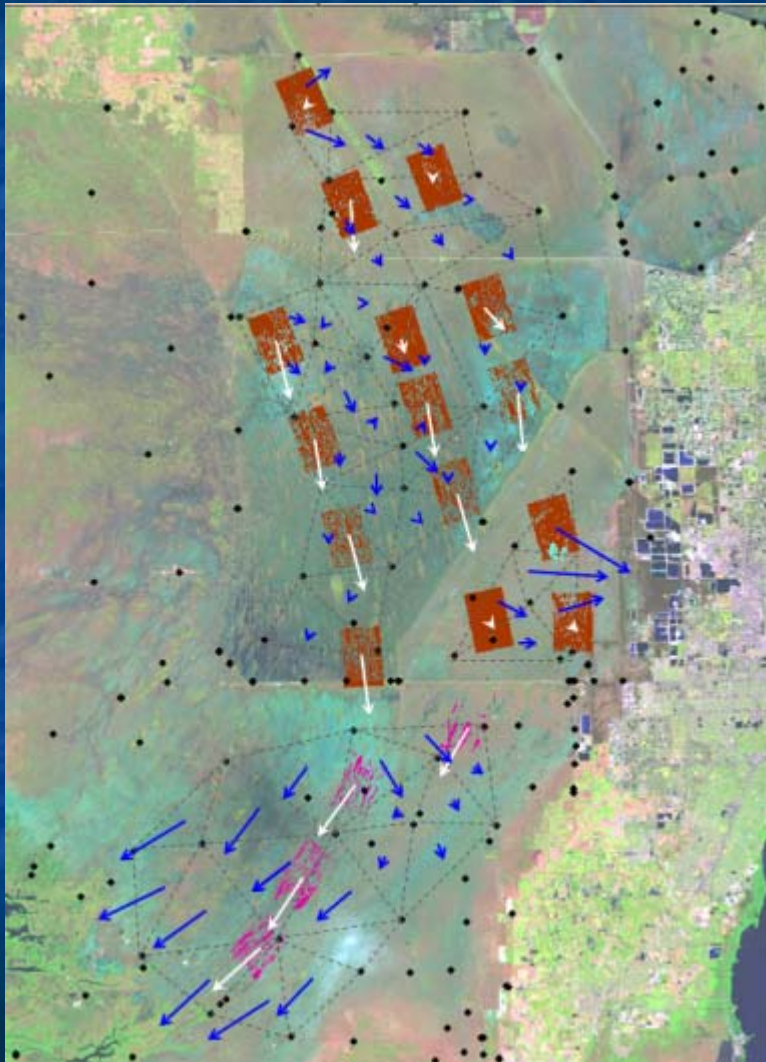
Restoration Tools - Remote Sensing Based Estimation of Flow Resistance



Plant Biomass and Community Based Estimation of Flow Resistance Parameters



CEL: Connectivity of Everglades Landscapes: an excel tool for visualizing connectivity



- Triangular Irregular Network (TIN) established based on location of USGS-EDEN gaging stations. Fifty-five triangular polygons defined in WCA-3A, 3B, and ENP
- HAED (high accuracy elevation dataset with 400x400 meter resolution) was obtained from USGS-EDEN and planar fitted to calculate *ground slope* (direction and magnitude)
- In a similar manner, water level data from 1/1/2007 to 12/31/2011 were obtained from USGS-EDEN and were fitted to calculate *surface water slope* (direction and magnitude)
- 19 digitized ridge-slough landscape patterns were obtained from SFWMD to quantify directional hydrologic connectivity of sloughs

→ Surface water slope
→ Landscape connectivity

Improving the Toolbox for Hydrologic Restoration

❑ Hydrology managed by structure inflows and outflows to achieve target water depths. The resulting stair-step of pools generally are too dry at upper ends and too wet at lower ends. Landscape patterning and microtopography are rapidly disappearing in overly dry areas.

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- ❑ Drag on vegetation depends on vegetation community type and patterns of connectivity and will change due to hydroperiod, fire, and other drivers.
- ❑ Rate law also should account for microtopography which plays a direct role in reducing flow cross section, increasing tortuosity of flow paths, and water storage-exchange.