Biophysical Simulation of Wetland Surface Flow at DPM and Everglades-wide to Assess Restoration Effectiveness

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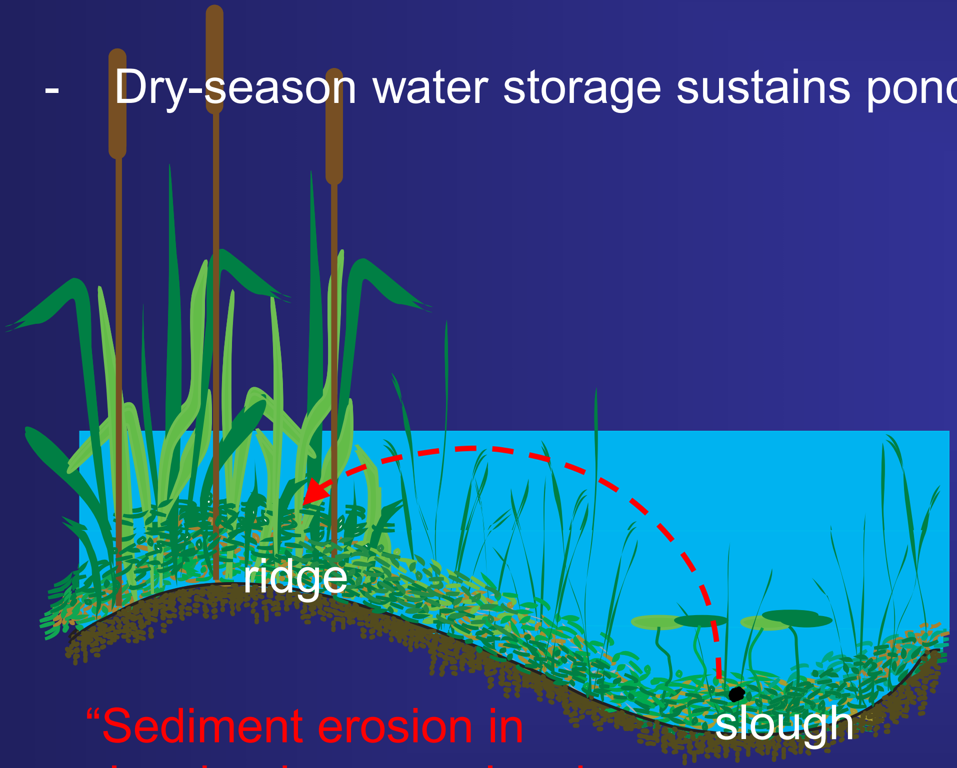
With acknowledgements to our SFWMD colleagues :

Colin Saunders, Sue Newman, Walter Wilcox, and Fred Sklar

Everglades Flow and Associated Functions

- Sloughs convey water during wet season to lessen flood heights
- Sloughs store water during dry season to moderate dry-downs and fires
- Dry-season water storage sustains ponded waters that concentrate prey during critical season for wading birds



"Sediment erosion in sloughs deepens sloughs and builds ridges during wet season

Everglades hydrologic models do not currently consider vegetation and microtopographic flow resistance

Hydraulic Flow Resistance = function of (slough vegetation density, ridge proportion, microtopographic height, ridge shape, and water depth)

How Can High-Functioning Everglades System Be Restored?

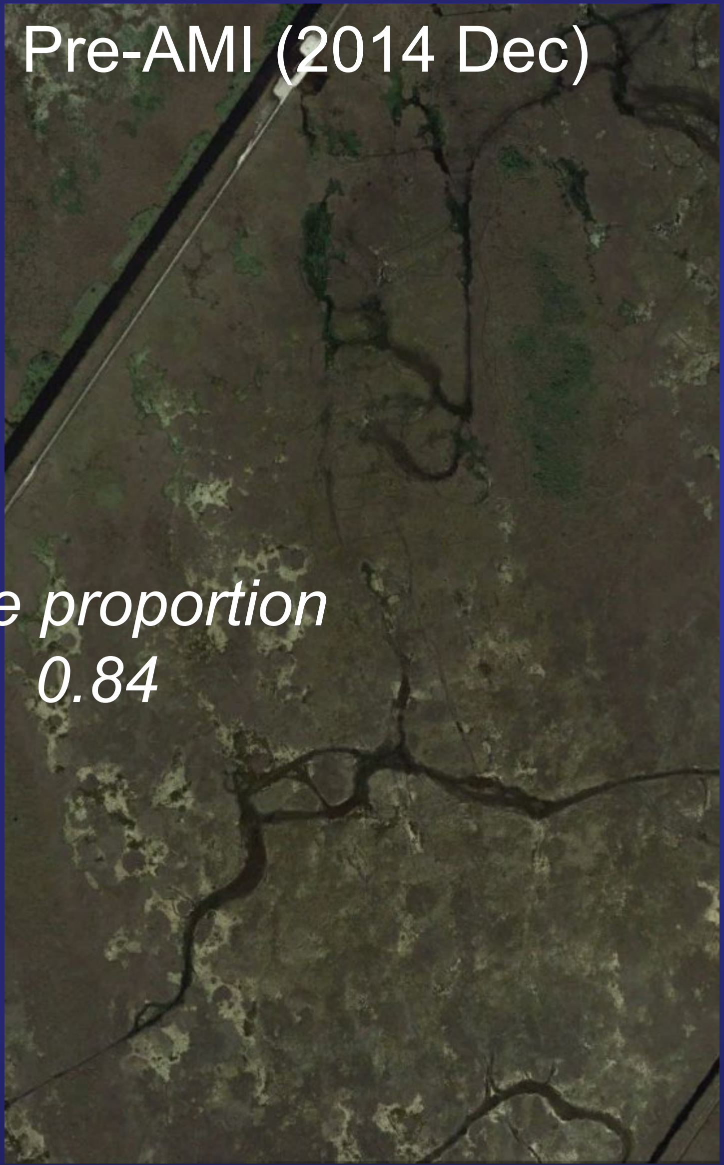
Loss of microtopography, deep-water sloughs, water storage capacity, and habitat value

Prototype Restored Flow Outcomes at Decomp Physical Model

S-152 Discharge Structure

L67C canal backfill & levee removal

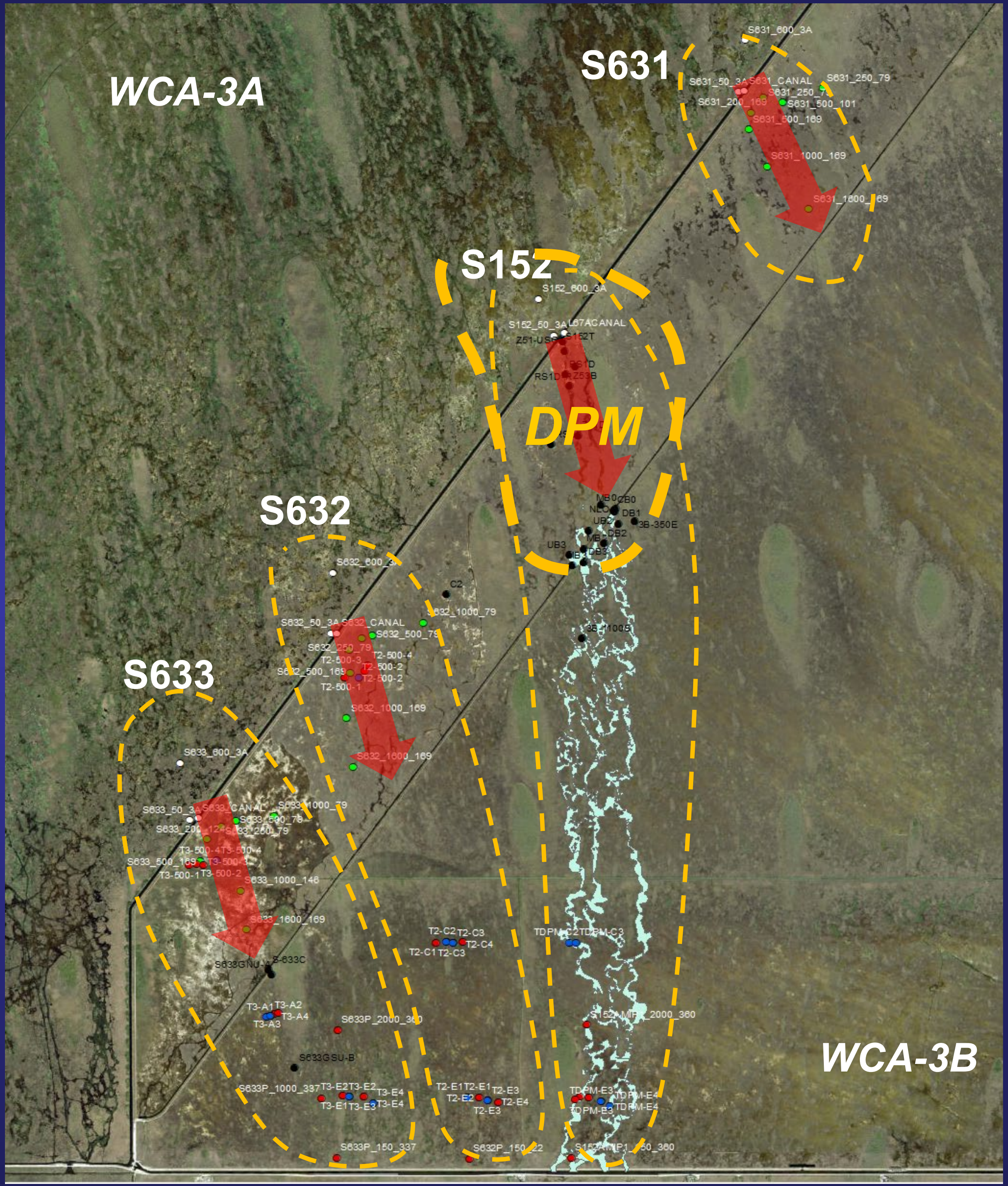
DPM Active Marsh Improvement (AMI) Reconnected Historical Sloughs



DPM lessons currently being applied in Southern Everglades Restoration:

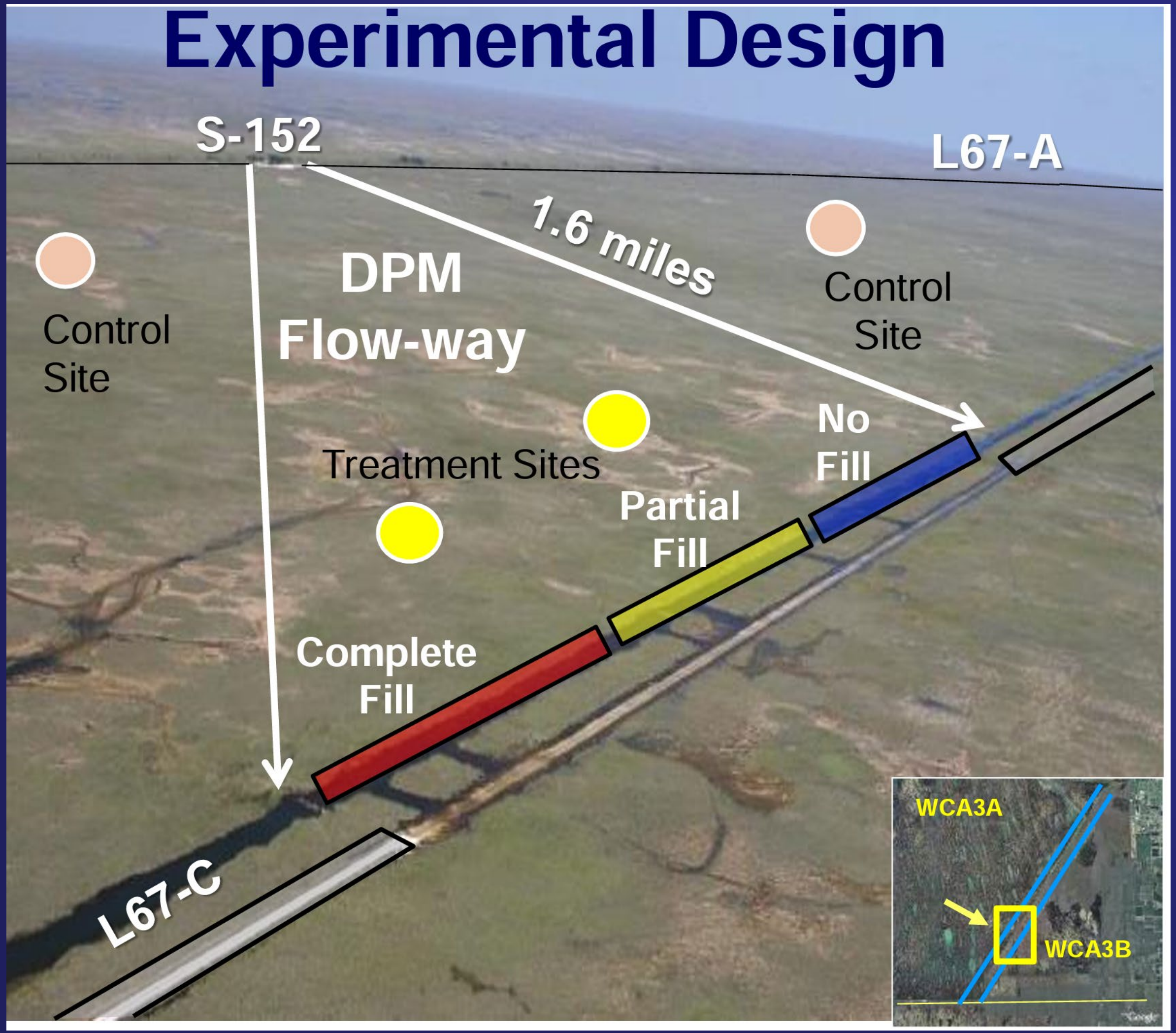
CEPP-S Project (2024-2028)

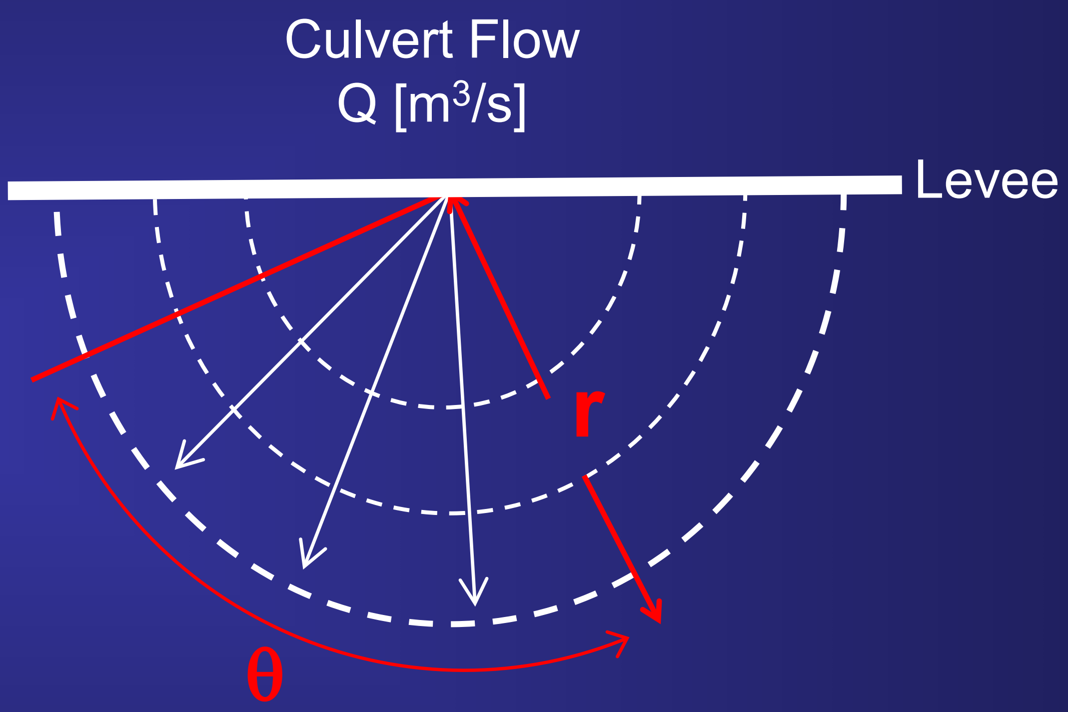
- Additional construction of S-631, S-632, and S-633 culverts.
- Expand levee removal along the L67C
- Expand Active Marsh Improvement



Restored High Flow Prototyped at DPM

Seasonal high-flow releases conducted between 2013 and 2022





***Bio*FRE**, a biophysical flow rate expression for overland flow

$$q = \text{Conveyance} \times \text{Slope}$$

$$\boldsymbol{Conveyance} = \text{overland flow per unit “driving force”}$$

$$= \boldsymbol{q/S} = \frac{1}{n_{eff}} \cdot h^{\frac{5}{3}}$$

$$\textit{Bio}\text{FRE}\ \boldsymbol{Conveyance} = \left[p \left(n_r^{-3/5} (\mathbf{h} - \mathbf{z_p}) \right)^{\omega} + (1-p) \left(n_s^{-3/5} h \right)^{\omega} \right]^{5/3\omega}$$

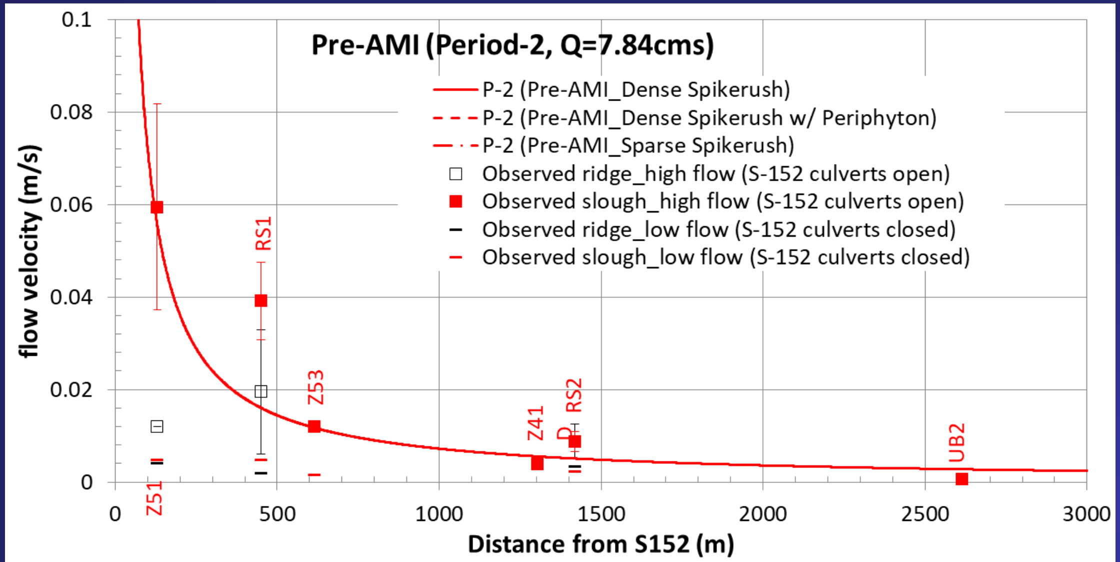
***q**:* overland flow per unit width [L^2T^{-1}]
S: surface water slope [unitless]
***h**:* water depth in slough [L]
S: surface water slope [unitless]
n_{eff}: effective roughness [$TL^{-1/3}$]

n_s, n_r: roughness in slough and ridge [$TL^{-1/3}$]
p: ridge proportion [unitless]
z_p: ridge elevation [L]
ω: landscape averaging exponent [unitless]

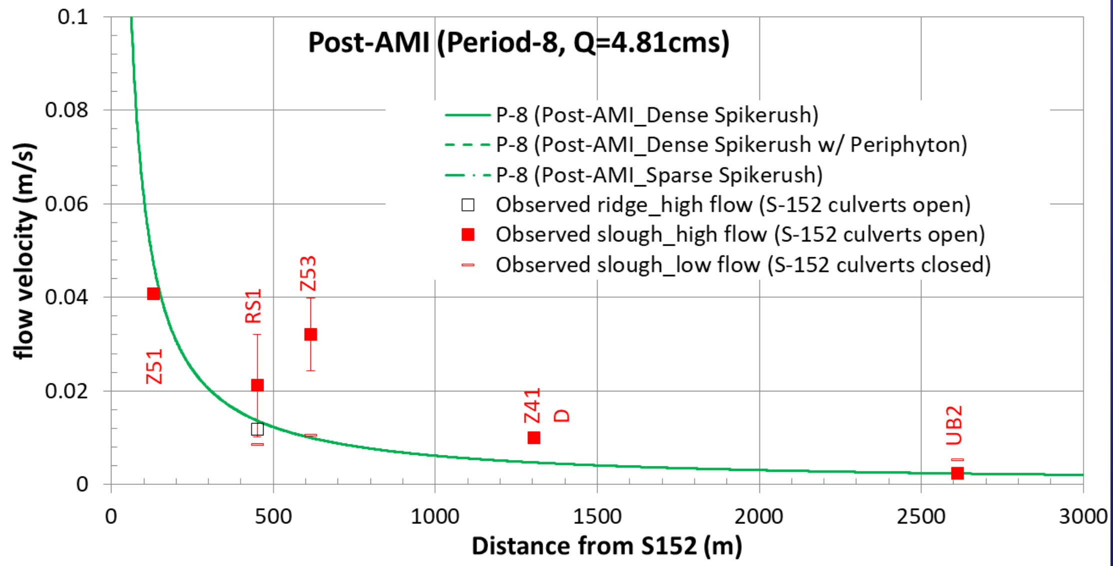
Harvey et al. 2009: *Larsen et al., 2017*

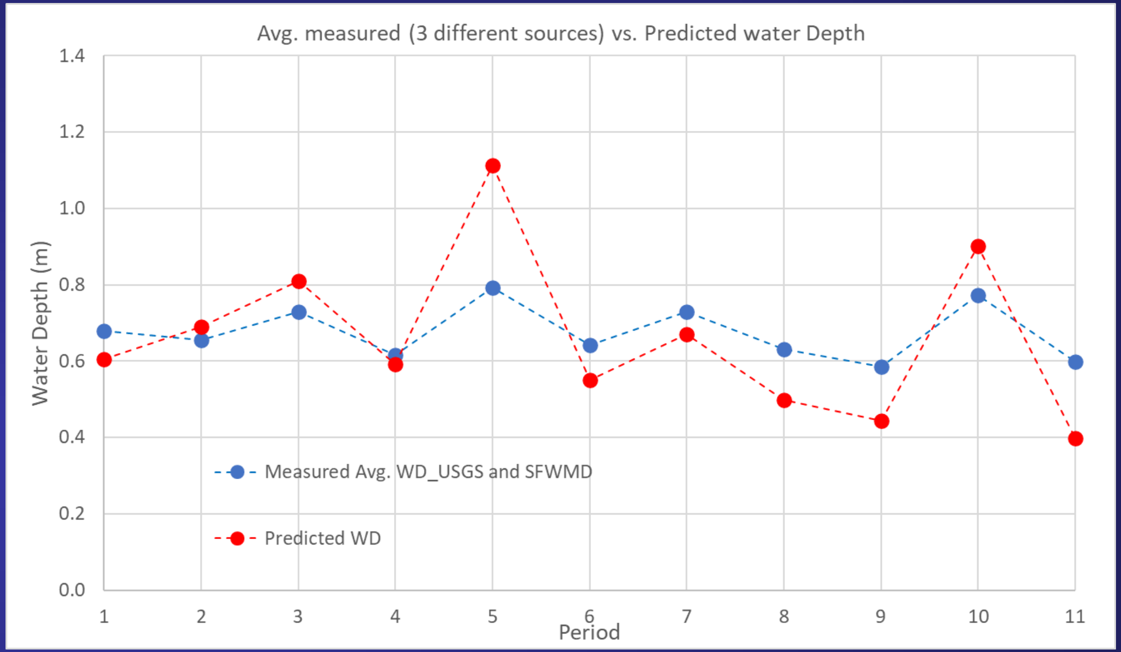
BioFRE Compares Well with Measured Flow and Water Depth at DPM

11/17/2014 - 12/27/2014



10/15/2018 - 12/15/2018



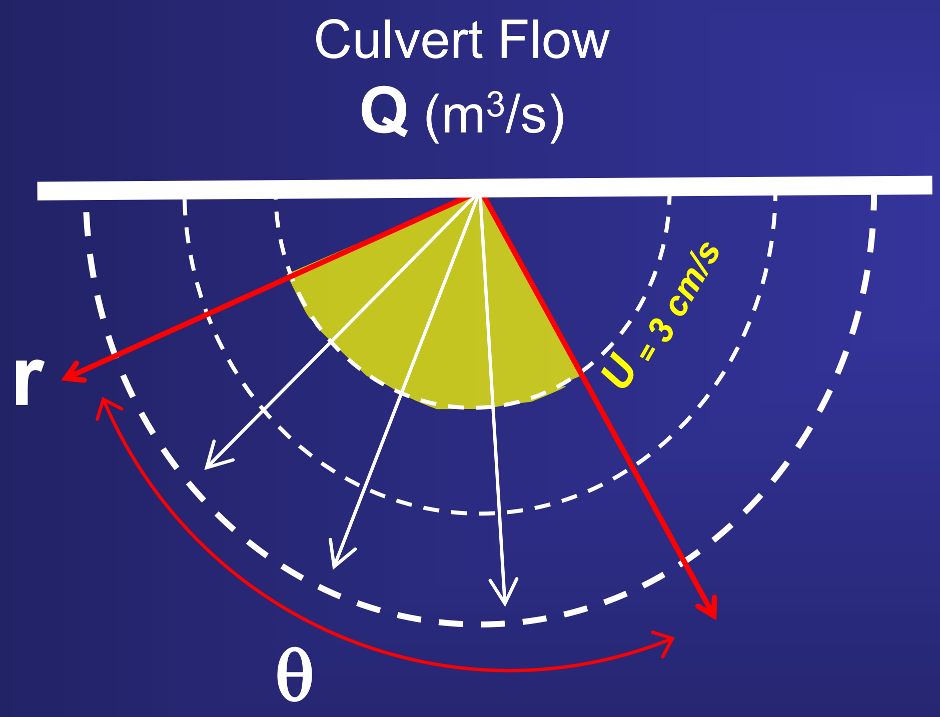


BioFRE (Biophysical Flow Rate Expression) can be a tool used for exploring the relative importance of factors controlling high flows in the Everglades

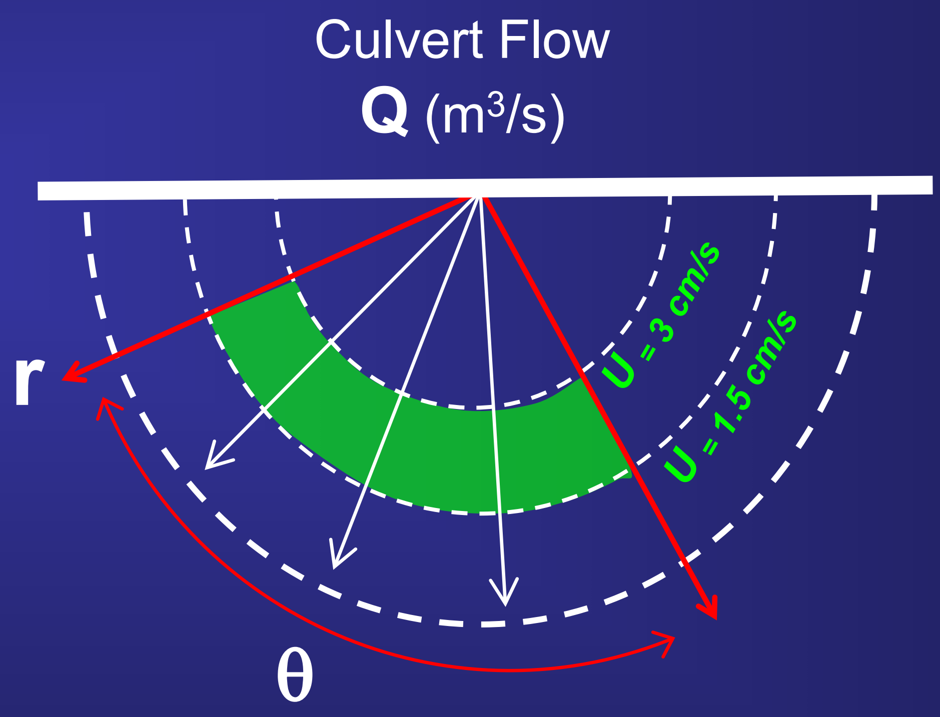
Harvey et al., USGS-OFR, 2025

Modeling Sediment Transport that is Potentially Helpful to Sustaining Microtopography but Potentially Harmful due to Transporting Excess Phosphorus

Sediment Entrainment Area



Sediment Redistribution Area



Larsen et al., Ecological Engineering (2009), Saunders et al., S. Florida Environmental Report (2025)

BioFRE Sensitivity Ranks Importance of Controlling Factors

Controlling Factors

Management-related:
- Structure discharge (Q)
- Spreading angle (θ)

Landscape-related:
- ridge proportion
- ridge shape (fractal dimension)
- Slough directional connectivity
- Microtopographic height
- Vegetation roughness (density, stem spacing)

$$\textit{Calculation of Dimensionless Sensitivity (\%)} = \left\{\frac{\Delta objective}{objective_{Base}}\right\} \times 100$$

Vegetation roughness > ridge proportion > culvert Q > spreading angle > microtopography > ridge shape (fractal dimension) > slough directional connectivity

Harvey et al., USGS-OFR, 2025

BioFRE Model Scenarios Reveal Challenge of Restoring Full Functionality

Scenarios that vary slough vegetation density and ridge proportion	Slough water depth (m)	Flow velocity (cm/s)	Sediment entrainment area (acres)	Sediment redistribution area (acres)
BASELINE: Pre-AMI-Dense Spikerush with 0.84 ridge proportion	0.69	1.5	9.9	29.7
MINOR LANDSCAPE RESTORATION: Post-AMI-Dense Spikerush with 0.73 ridge proportion	0.64	1.6	11.5	34.5
MINOR LANDSCAPE RESTORATION: Post-AMI-Dense Spikerush with Periphyton and 0.73 ridge proportion	0.64	1.6	11.5	34.6
FULL RESTORATION: Dense Spikerush and 0.42 ridge proportion	0.34	3.1	42.1	126.4
FULL RESTORATION: Dense Spikerush with Periphyton and 0.42 ridge proportion	0.43	2.5	26.3	78.8
FULL RESTORATION: Sparse Spikerush and 0.42 ridge proportion	0.30	3.5	52.7	158.4
FULL RESTORATION: Deep Water Slough and 0.42 ridge proportion	0.12	9.0	348.8	1,047.5

- Ridge proportion dominates velocity/sediment outcomes, with slough vegetation density important for full restoration
- For full restoration, the positive higher sediment redistribution is balanced against negative lowered water depth
- For full restoration there is an undesirable increase in sediment entrainment (and likely phosphorus transport), a consequence of water release from canal point sources through culverts
- Present discharge (~ 7.4 cms through culverts) and locally high velocity sources are a challenge to full restoration

Summary of *Bio*FRE Lessons Learned at DPM

- *Bio*FRE only uses landscape features as input and can therefore be used to help explain past changes and explore future restoration scenarios

- *Bio*FRE was validated against observed flow velocities and water depth at DPM

- Slough vegetation roughness is the most sensitive controlling factor but its influence depends strongly on related factors, i.e., ridge proportion, microtopographic height and ridge shape

- Need to consider changing vegetation and landscape conditions to achieve optimal outcomes for drought and flood resilience and ecosystem health

Expressing gratitude for 30 years working in this enriching and supportive Everglades community as I transition from USGS and find new ways to contribute

Best wishes and let's stay in touch!

Jud Harvey
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Jud's talk: **Performance Standards from a Biophysical Simulation of Everglades Sheet Flow**

System-wide *Bio*FRE applications informed by RECOVER Data

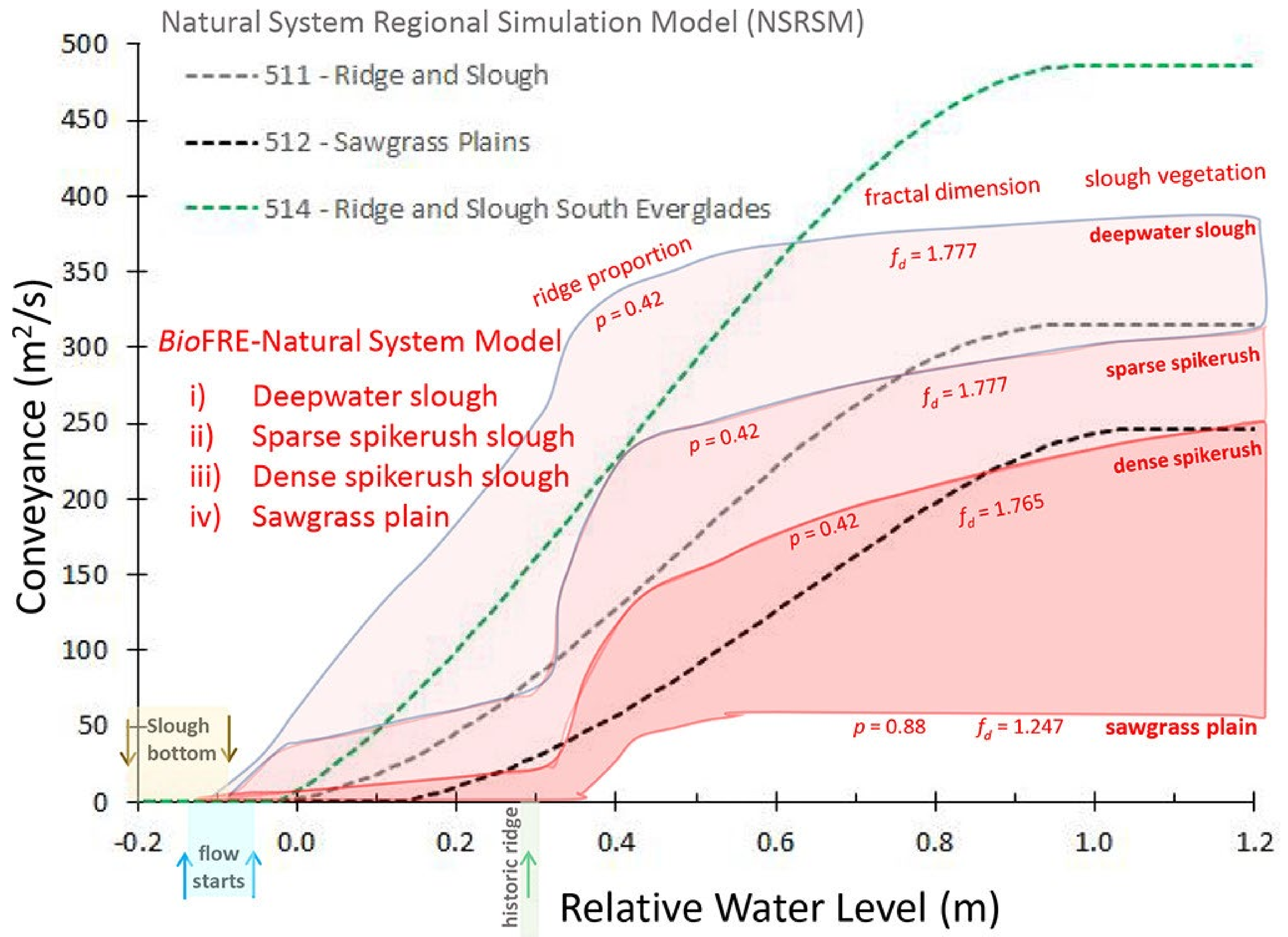
Harvey et al. Ecological Engineering, 2025

***See Wednesday poster*:**

Nature-based Re-connection of Everglades Wetlands to Sustain Water and Ecological Resources

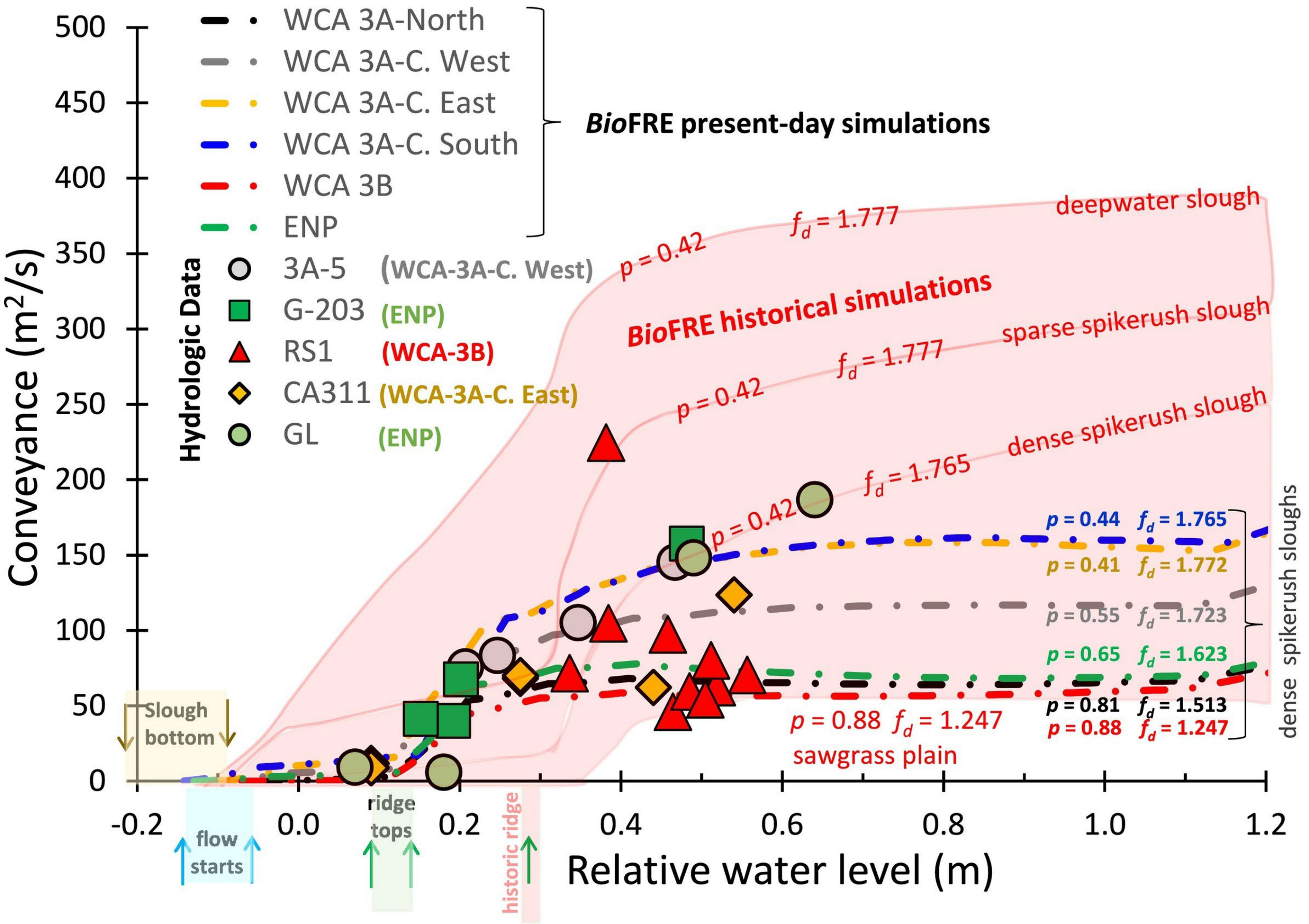
Jud Harvey[1], Colin Saunders[2], Sue Newman[2], Jay Choi[1], Fred Sklar[2], Walter Wilcox[2], Wasantha Lal[2], Clay Brown[2], Jing Yuan[1], Christa Zweig[2], Jie Zeng[2], Towsif Bhuiyan[3], and John Jones

Biophysical Model (*Bio*FRE) Furthers Understanding of Natural System



Harvey et al. Ecological Engineering, 2025

*Bio*FRE Model Helps Explain Present-day Reduction in Flow Capacity



Harvey et al. Ecological Engineering, 2025

BioFRE Sensitivity Analysis Ranks Importance of Controls

Natural system that is degrading –

increasing slough roughness and ridge proportion, and **decreasing** ridge-slough edge (fractal dimension) dominate loss of functions

BioFRE_Well base case sensitivity	Percent change (%) In conveyance (perturbed – base)		
base case value	-	-	-
perturbations			
Combined landscape changes (excluding vegetation roughness)	-56	-39	-64
Ridge proportion (*p*) increase	-53	-13	13
Directional connectivity of sloughs (*DCI*) decrease	-16	0.7	-1.0
Fractal dimension of ridge-slough edges (f_d) decrease	0.0	-38	-67
Microtopography (z_p) decrease	0.0	3.8	3.4
Ridge roughness (n_r) increase	0.0	-20	-18
Slough roughness (n_s) increase	-66	-44	-45
tested slough water depth =	0.15 m	0.4 m	0.65 m

Degraded system that is restoring –

decreasing ridge proportion and ridge-slough roughness, and **increasing** microtopography dominate recovery of functions

BioFRE Poor_base case sensitivity	Percent change (%) In conveyance (perturbed – base)		
base case value	-	-	-
perturbations			
Combined landscape changes (excluding vegetation roughness)	198	3.1	8.7
Ridge proportion (*p*) decrease	194	2.6	0.8
Directional connectivity of sloughs (*DCI*) increase	-17	0.0	0.1
Fractal dimension of ridge-slough edges (f_d) increase	0.0	0.1	7.5
Microtopography (z_p) increase	0.0	-40	-4.2
Ridge roughness (n_r) decrease	0.0	60	75
Slough roughness (n_s) decrease	74	6.7	0.4
tested slough water depth =	0.08 m	0.25 m	0.50 m

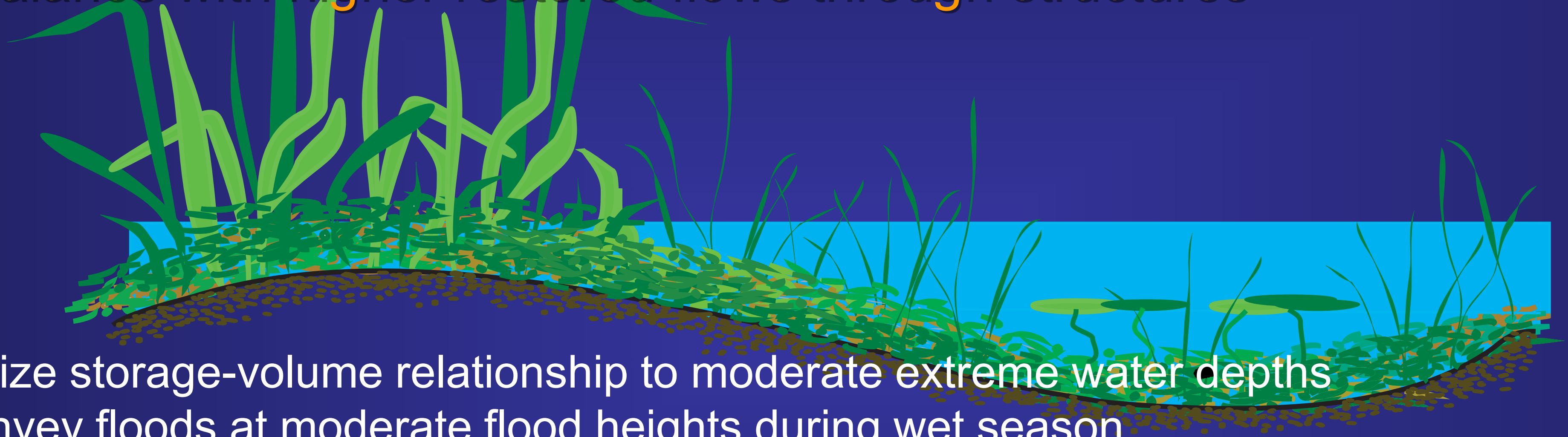
Opportunities for Improving Performance Measures

Outcomes of Restored Flow	Response Variables and Potential Performance Measures √ indicates variables commonly used as performance measures **bold** indicates potential variables to add as performance measures
Hydraulic responses to restored flow	Water depth√, **flow conveyance, vegetation roughness** and other factors which affect water storage, flood height improvement, water supply and societal use
Sediment/phosphorus transport	Phosphorus concentration√, **phosphorus loading** to biological communities, **sediment entrainment** and **sediment redistribution** areas
Microtopographic and vegetation change	**Microtopographic height**, **slough proportion, slough vegetation** type**, directional connectivity** of sloughs**, fractal dimension** of ridge-slough edges
Ecological productivity and diversity	**Aquatic metabolism** and related habitat quality indicators, secondary productivity of invertebrates and fish

Biophysical feedback

Conclusion – Revisit What it Means to "Get the Water Right"

To optimize desirable functions, develop new performance measures that help steer **slough proportion**, **slough vegetation community types**, and **microtopography** into balance with higher restored flows through structures



- Optimize storage-volume relationship to moderate extreme water depths
  - convey floods at moderate flood heights during wet season
  - store water and release it slowly during dry season

- Optimize flow velocities, high enough to keep sloughs open by entraining slough sediment but low enough to deposit sediment and phosphorus on nearby ridges, slowing downstream loading

- Optimize depths to maintain significant areas of productive, sparsely vegetated sloughs
  - Supports productivity and diversity
  - prolongs water-level recession and concentrates prey during critical nesting and rearing seasons