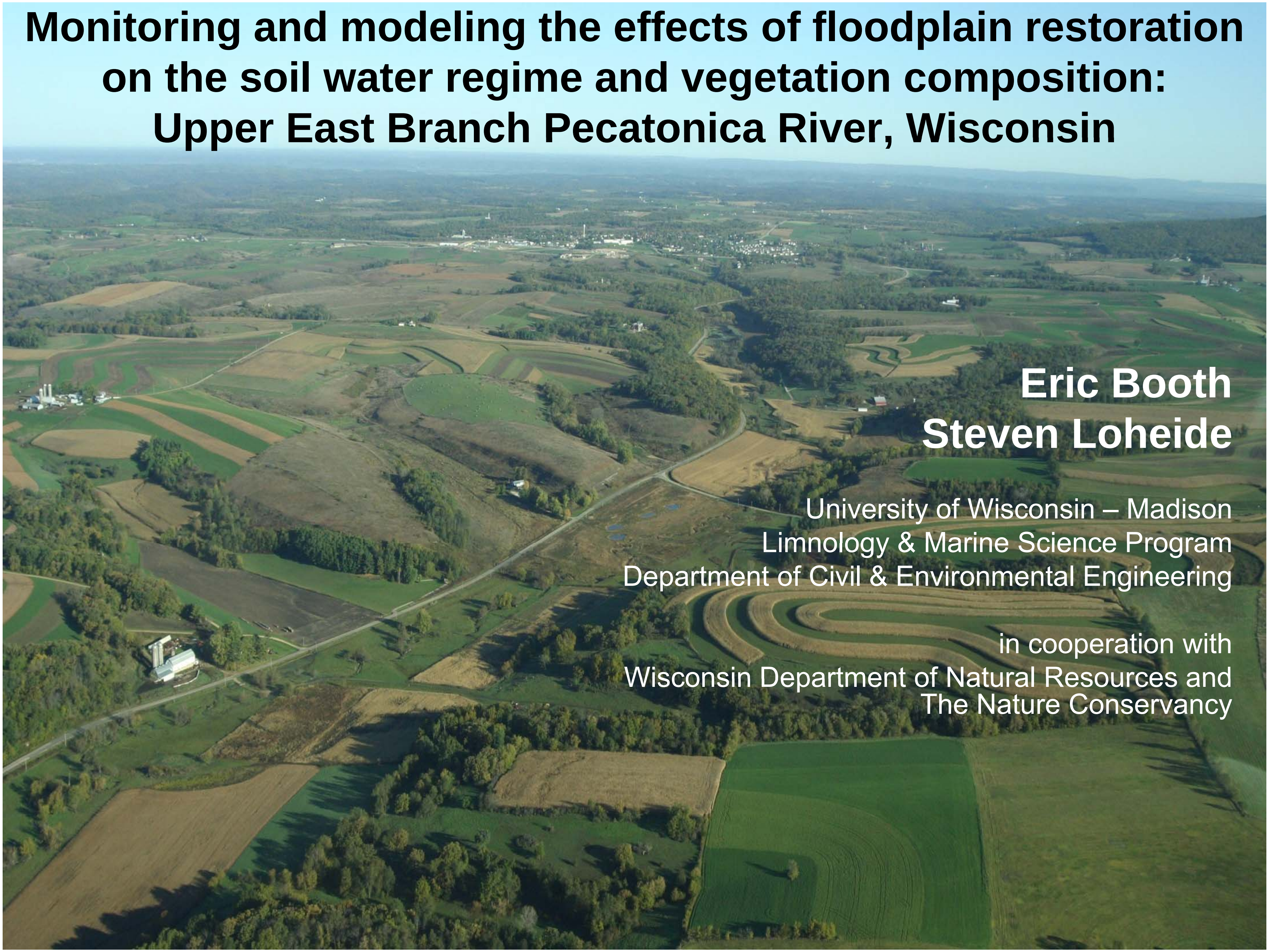
Monitoring and modeling the effects of floodplain restoration on the soil water regime and vegetation composition: Upper East Branch Pecatonica River, Wisconsin



Eric Booth
Steven Loheide

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Limnology & Marine Science Program
Department of Civil & Environmental Engineering

in cooperation with
Wisconsin Department of Natural Resources and
The Nature Conservancy

Outline

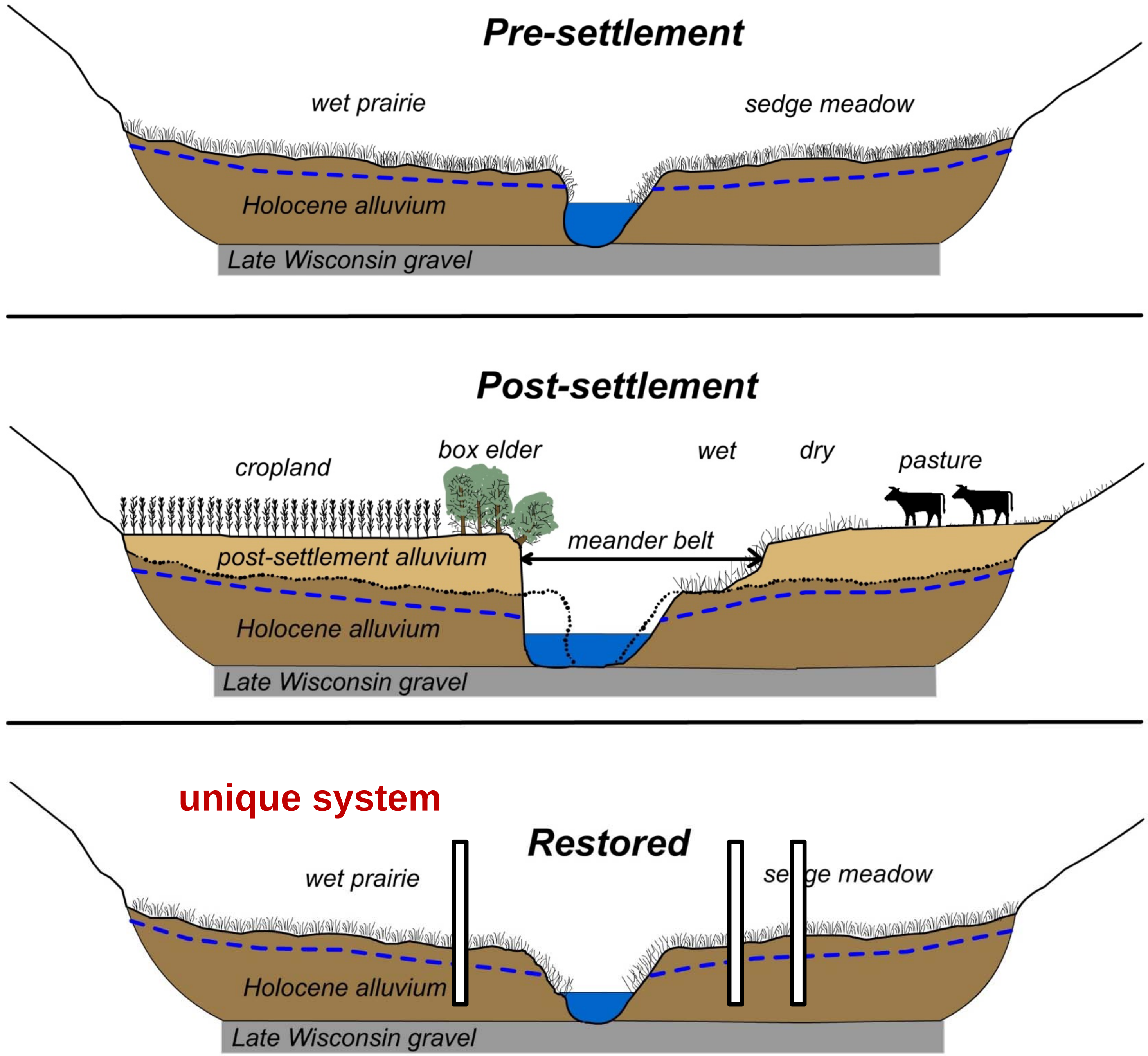
- Assessing a novel floodplain wetland restoration activity

1. Examining the link between hydrology and vegetation composition
2. Field monitoring/observations
   a) Extreme flooding
   b) Channel width adjustments
   c) Stream temperature

Introduction

- Examining the link between hydrology and vegetation composition
  - 2-way interaction

1. Understanding what controls the soil water regime under changing conditions
2. Quantifying the relationship between soil water regime and plant composition



Pre-settlement
wet prairie
sedge meadow
Holocene alluvium
Late Wisconsin gravel
Post-settlement
cropland
box elder
wet
dry
pasture
meander belt
post-settlement alluvium
Holocene alluvium
Late Wisconsin gravel
unique system
Restored
wet prairie
se ge meadow
Holocene alluvium
Late Wisconsin gravel

EBP08

UNRESTORED

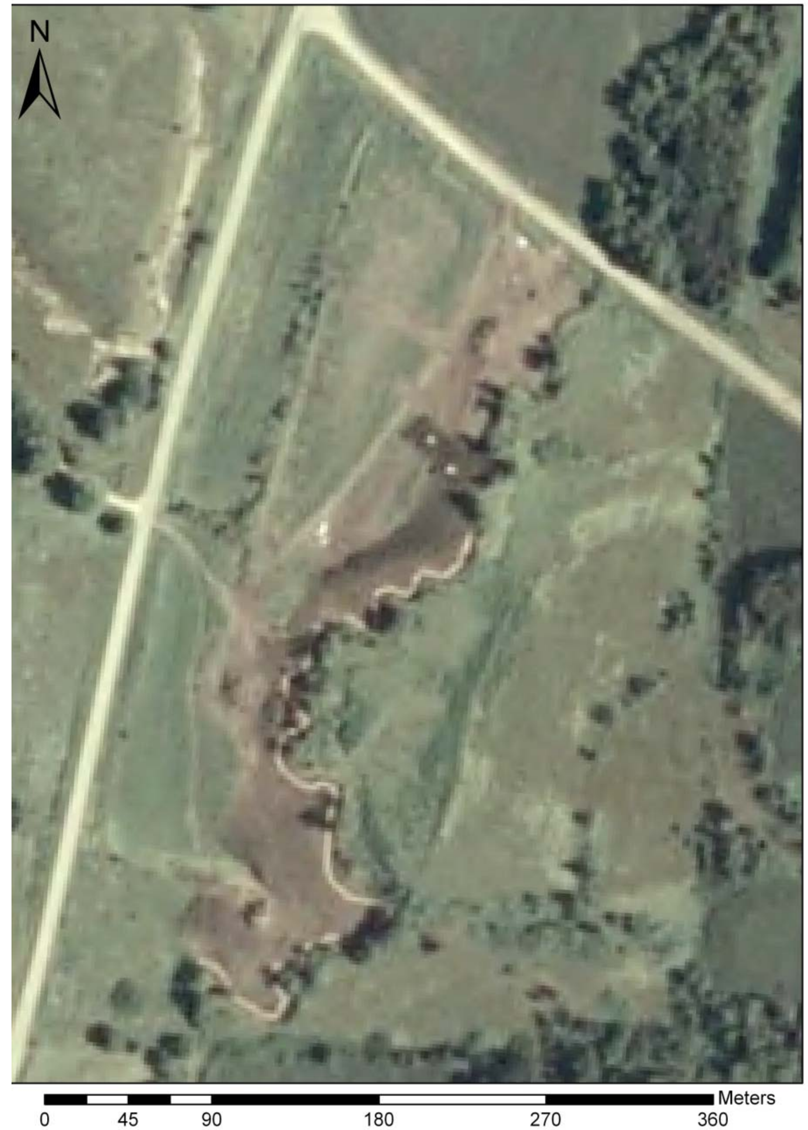
2005

EBP06

UNRESTORED

EBP08 Aug 2006 EBP06

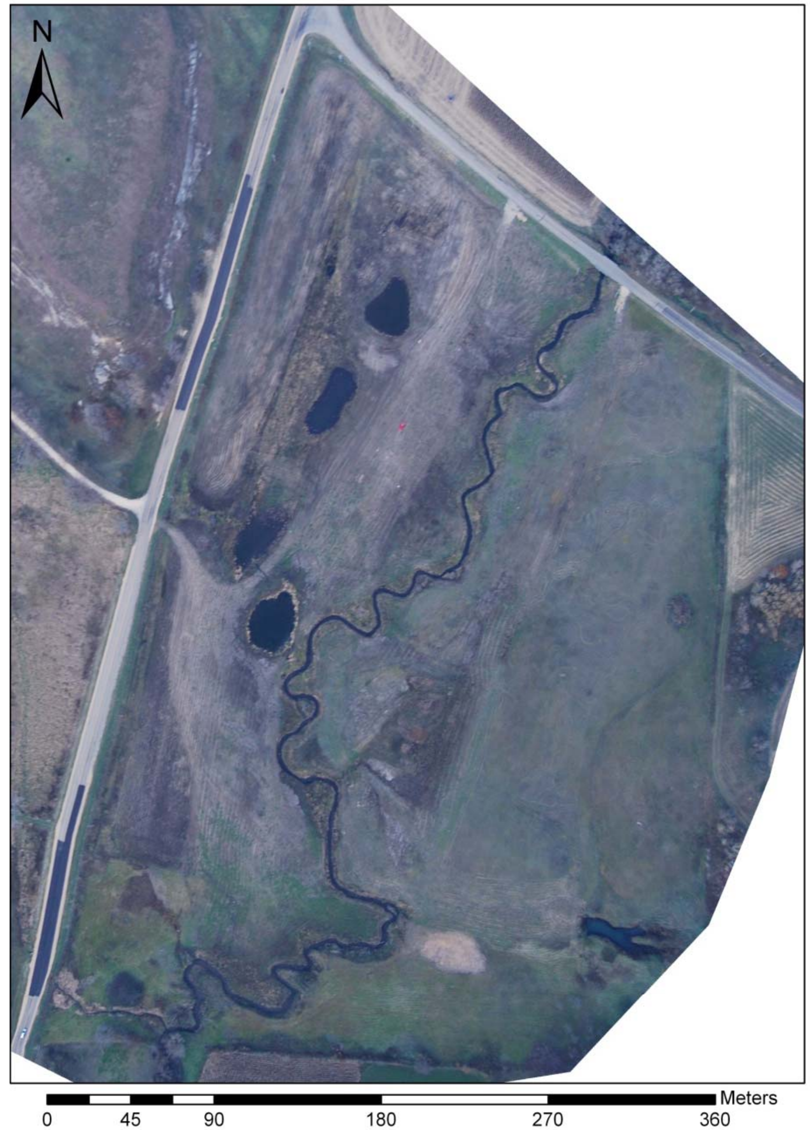
UNRESTORED **RESTORING**



EBP08 Nov 2007 EBP06

UNRESTORED

RESTORED



EBP08 Jul 2008 EBP06

UNRESTORED **RESTORED**

EBP08 **Sep 2009** EBP06

RESTORING **RESTORED**

EBP08 **Jul 2008** EBP06

UNRESTORED | **RESTORED**

Study Sites

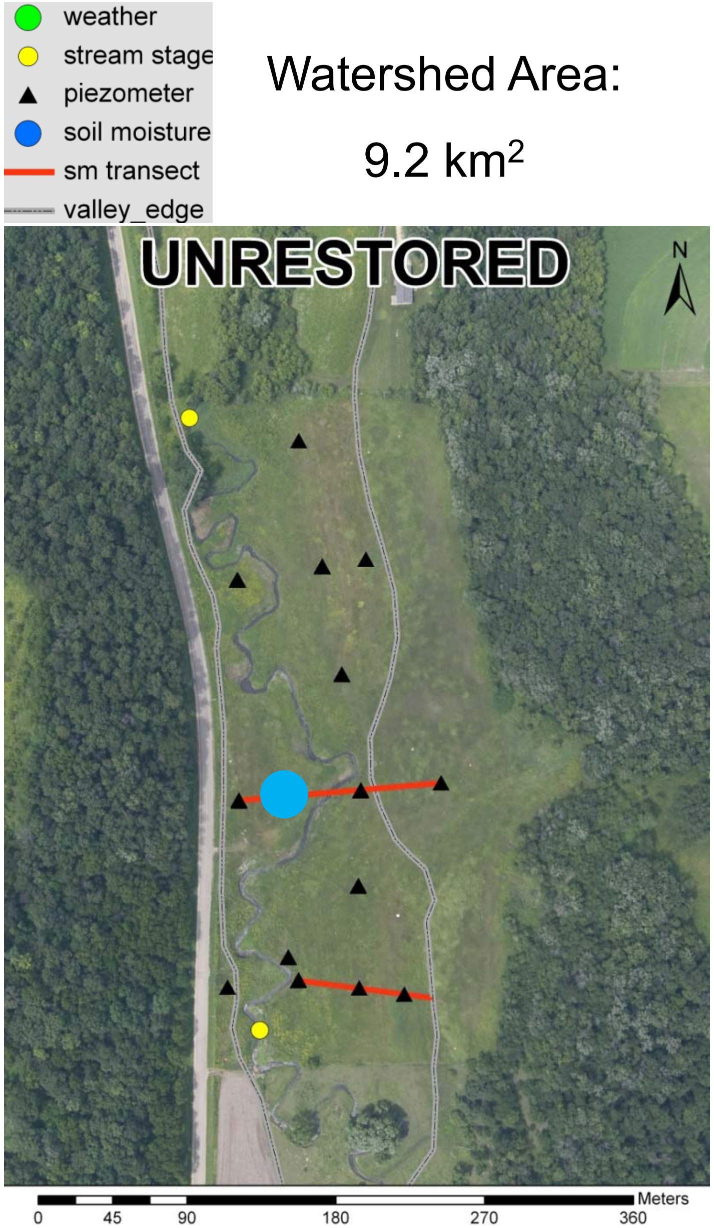
Watershed Area:

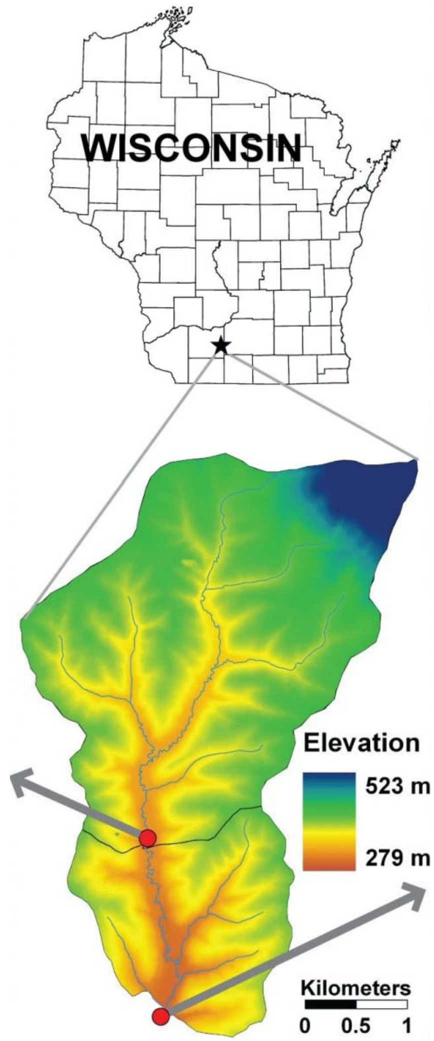
9.2 km^2

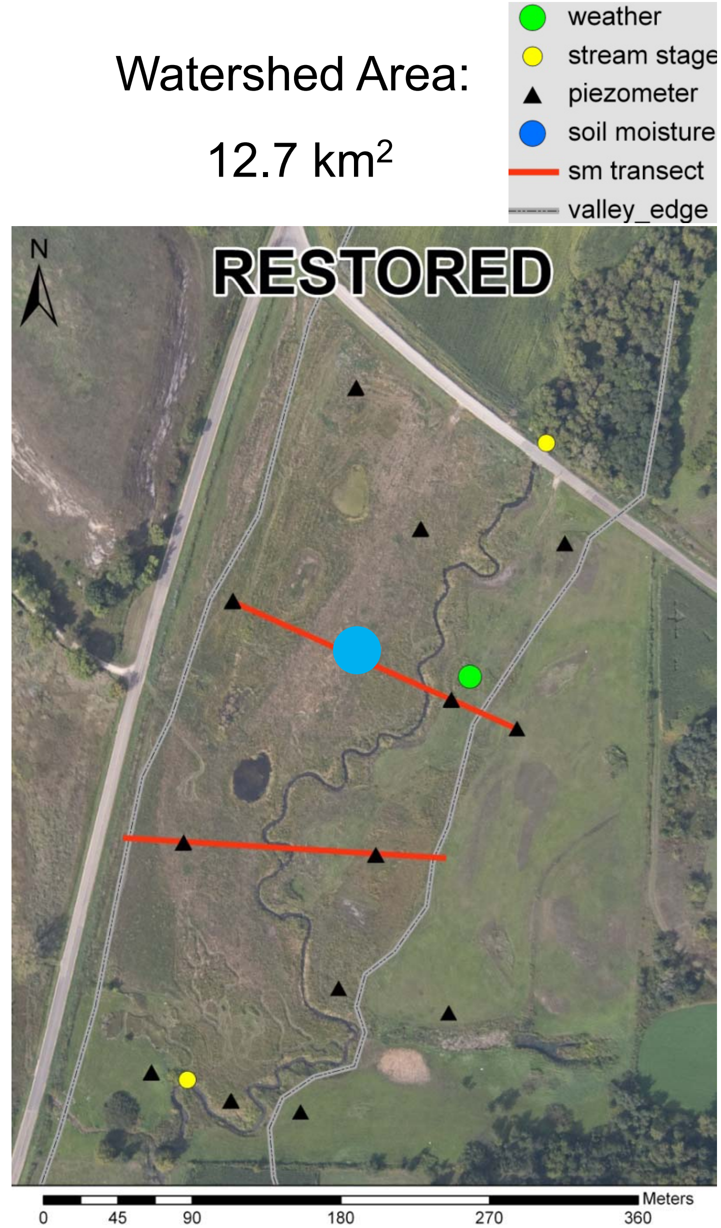
Upper East Branch Pecatonica River

Watershed Area:

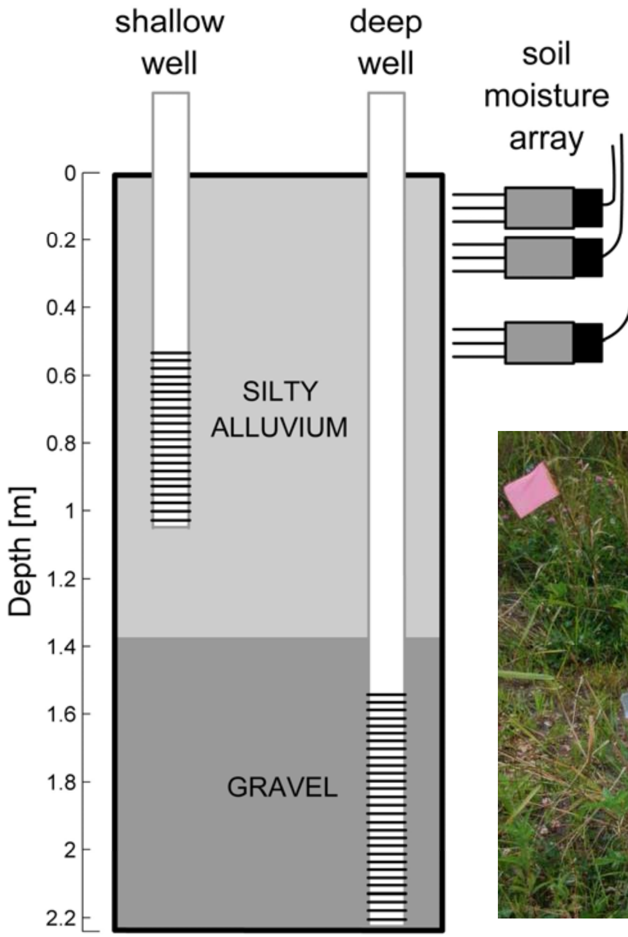
12.7 km^2







Field Instrumentation



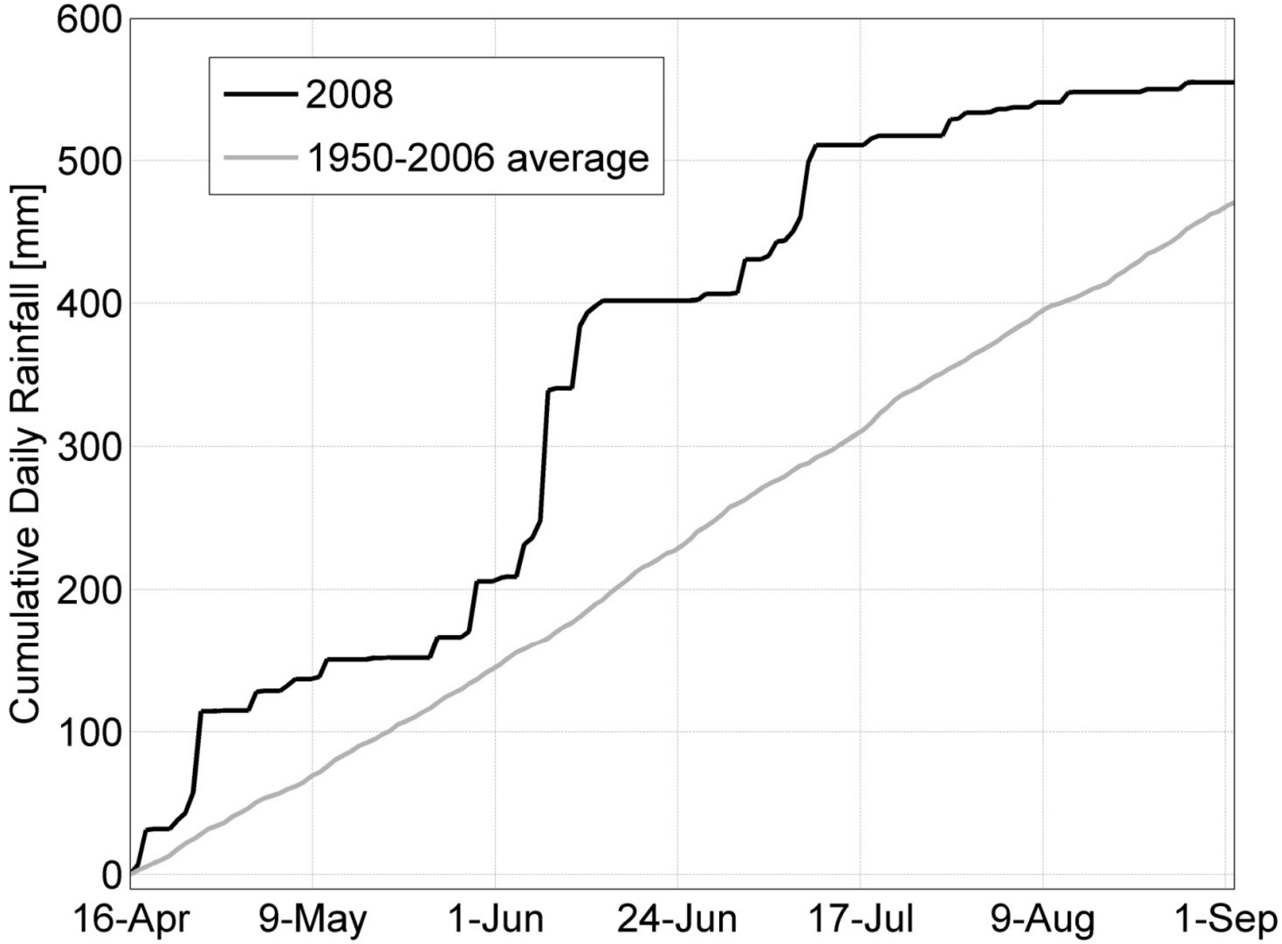
UNRESTORED

- Higher Leaf Area Index
    - more transpiration
- Brome grass dominant
    - upland

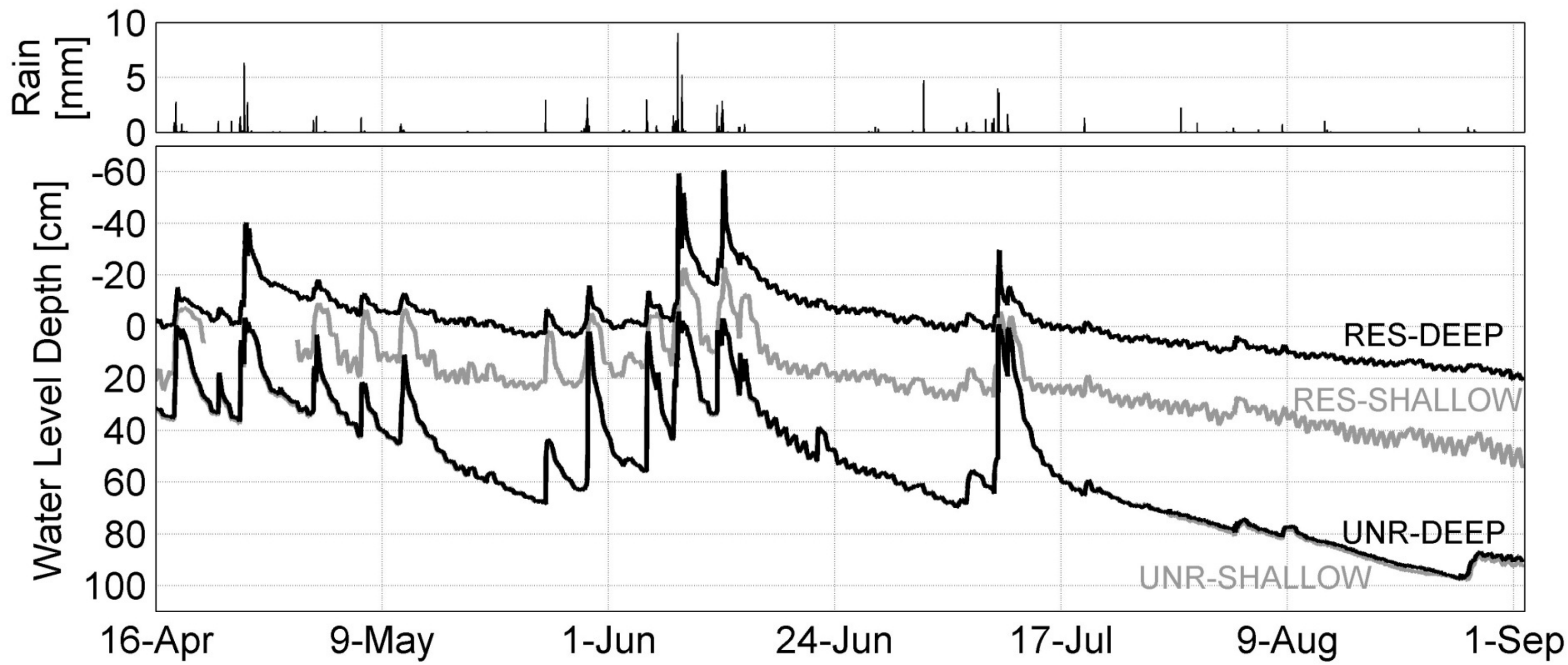
RESTORED

- More bare ground
    - more evaporation
- Virginia wild rye dominant
    - facultative wetland (-)

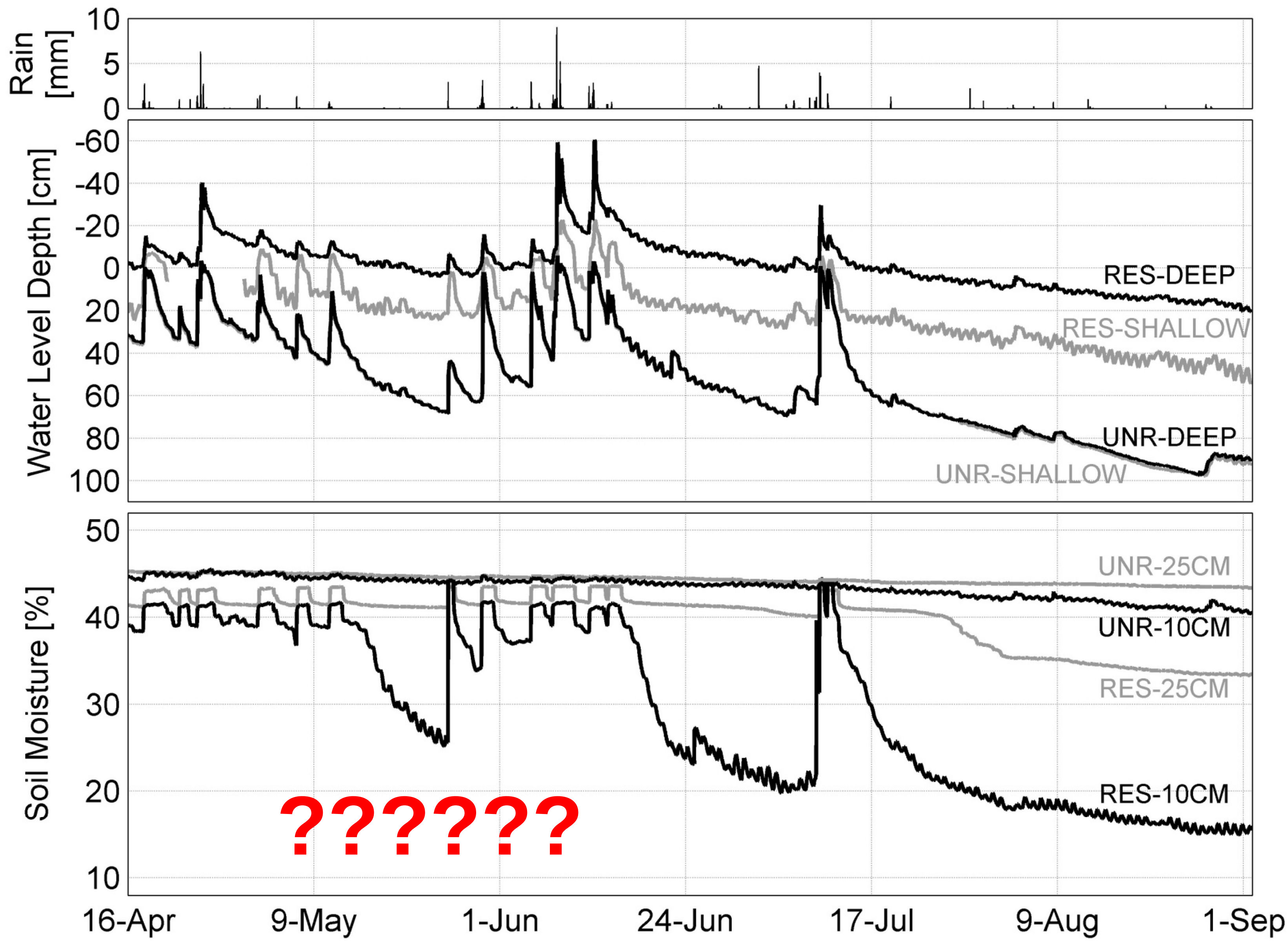
Cumulative Rainfall
2008 Growing Season



Field observations: Shallow well water level data



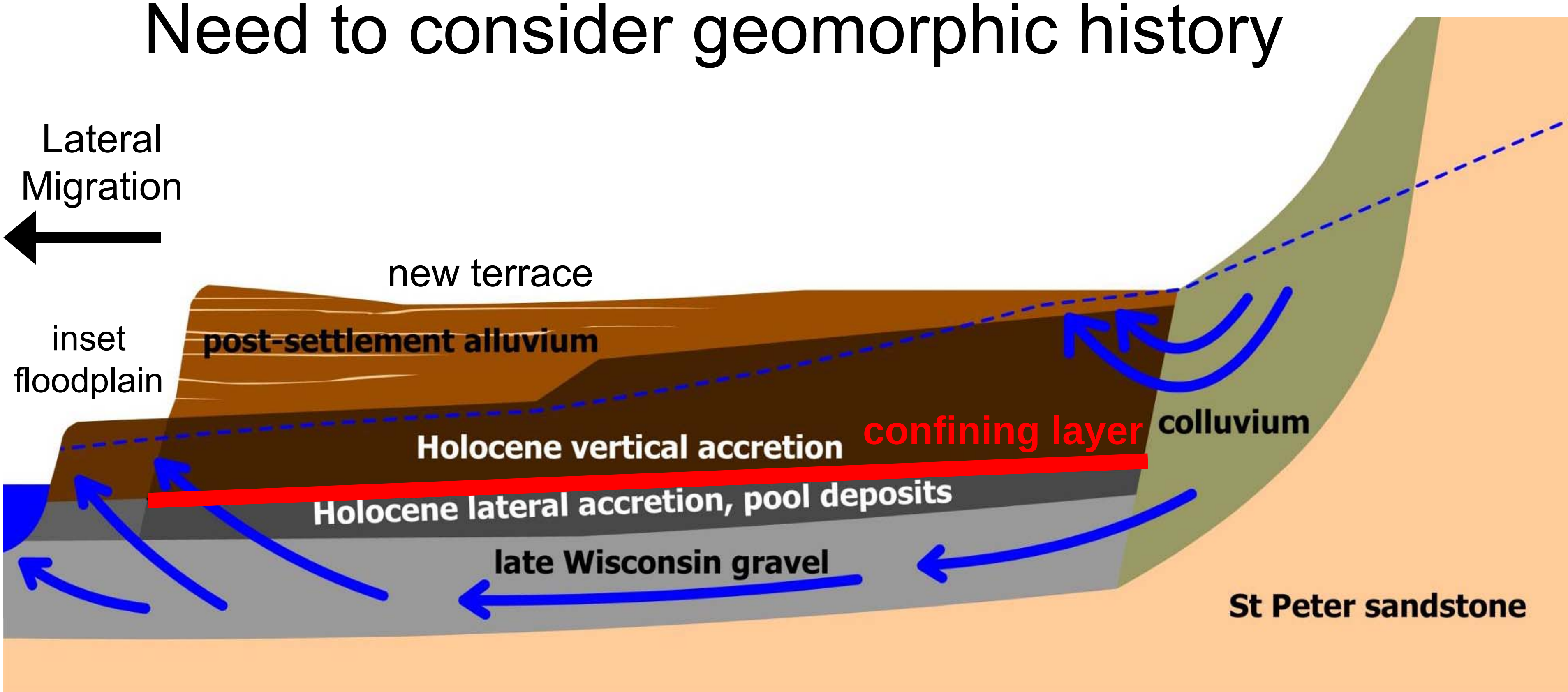
Field observations: Shallow well water level data



Research Questions

- How do the following influence the soil moisture regime?
  - hydrostratigraphy
  - surface characteristics (plant cover)
  - plant behavior under saturated conditions
  - removal of post-settlement alluvium

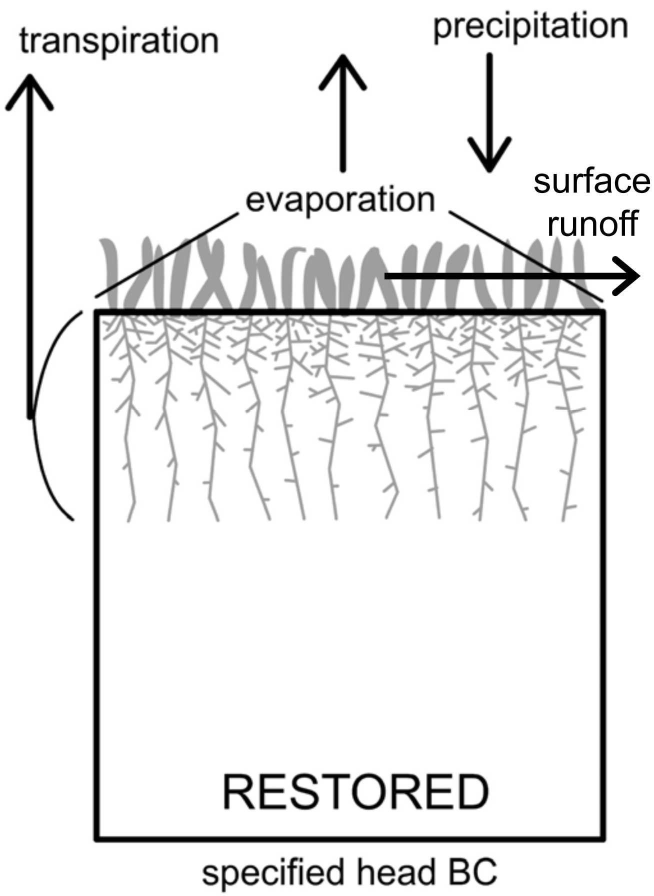
Need to consider geomorphic history

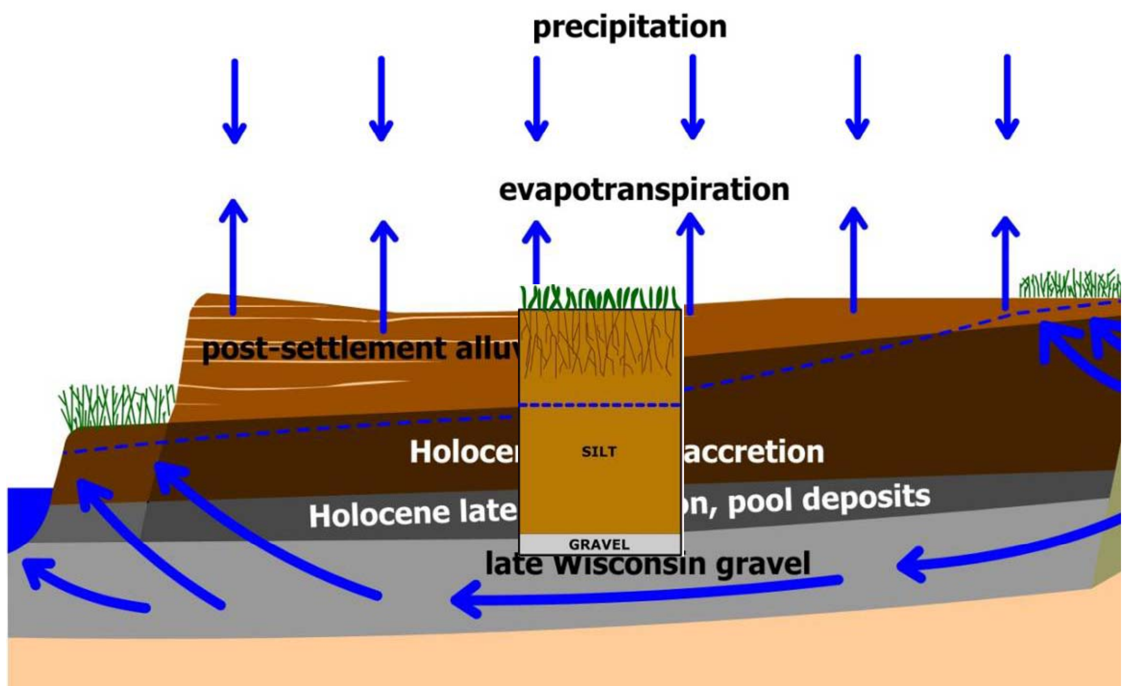


- Late Wisconsin braided stream
- Holocene alluvium
- Post-settlement alluvium
- Dual-aquifer system

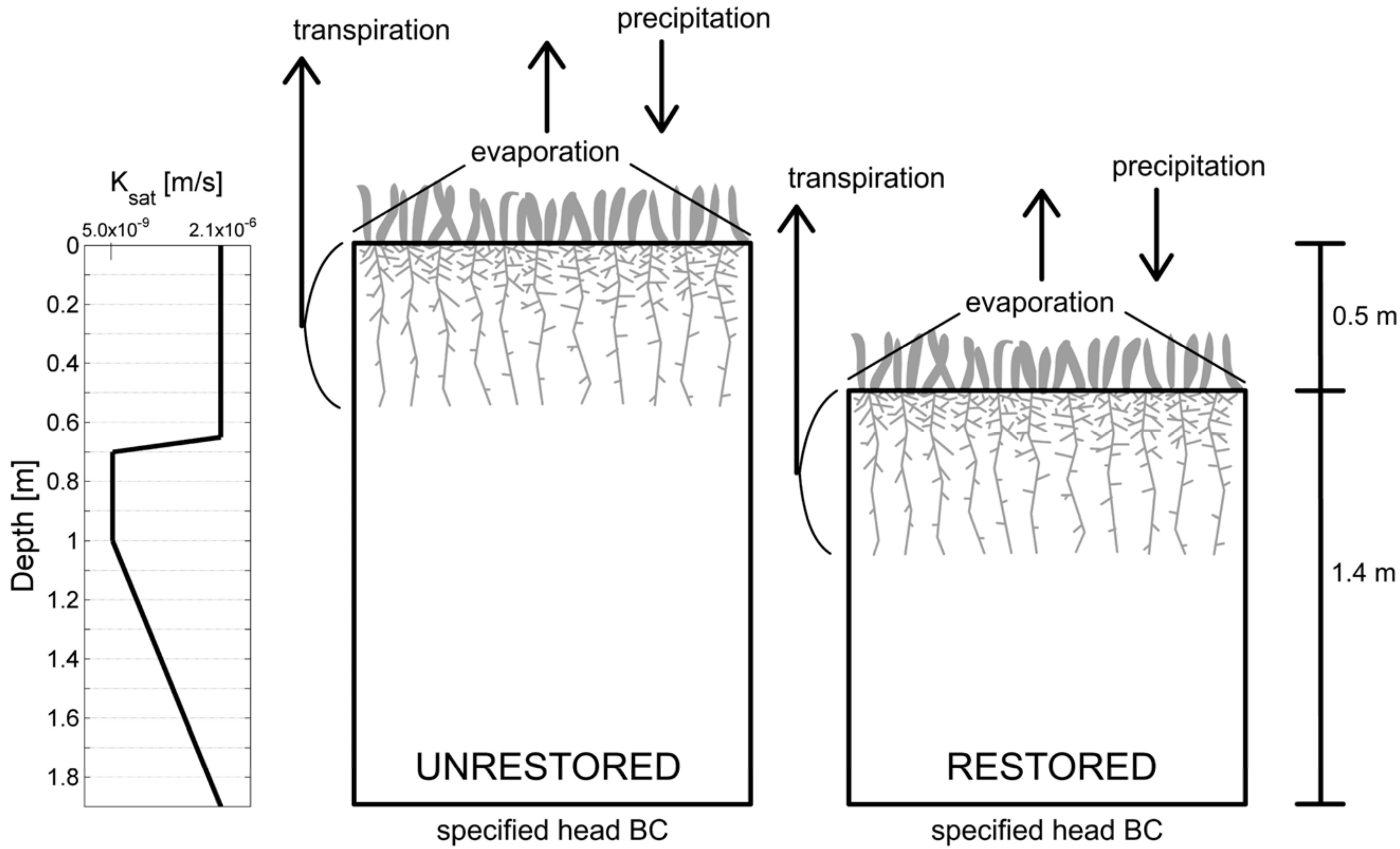
Floodplain Hydrologic Model

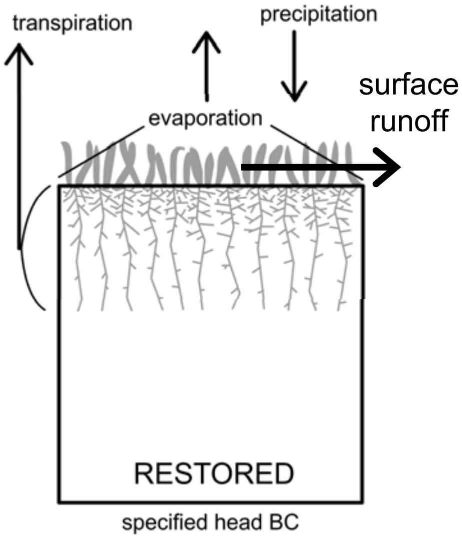
- 1-D model, vertical flow
- Richards equation with finite-element solver (COMSOL)
- Brooks-Corey soil moisture characteristic function





Hydrostratigraphy

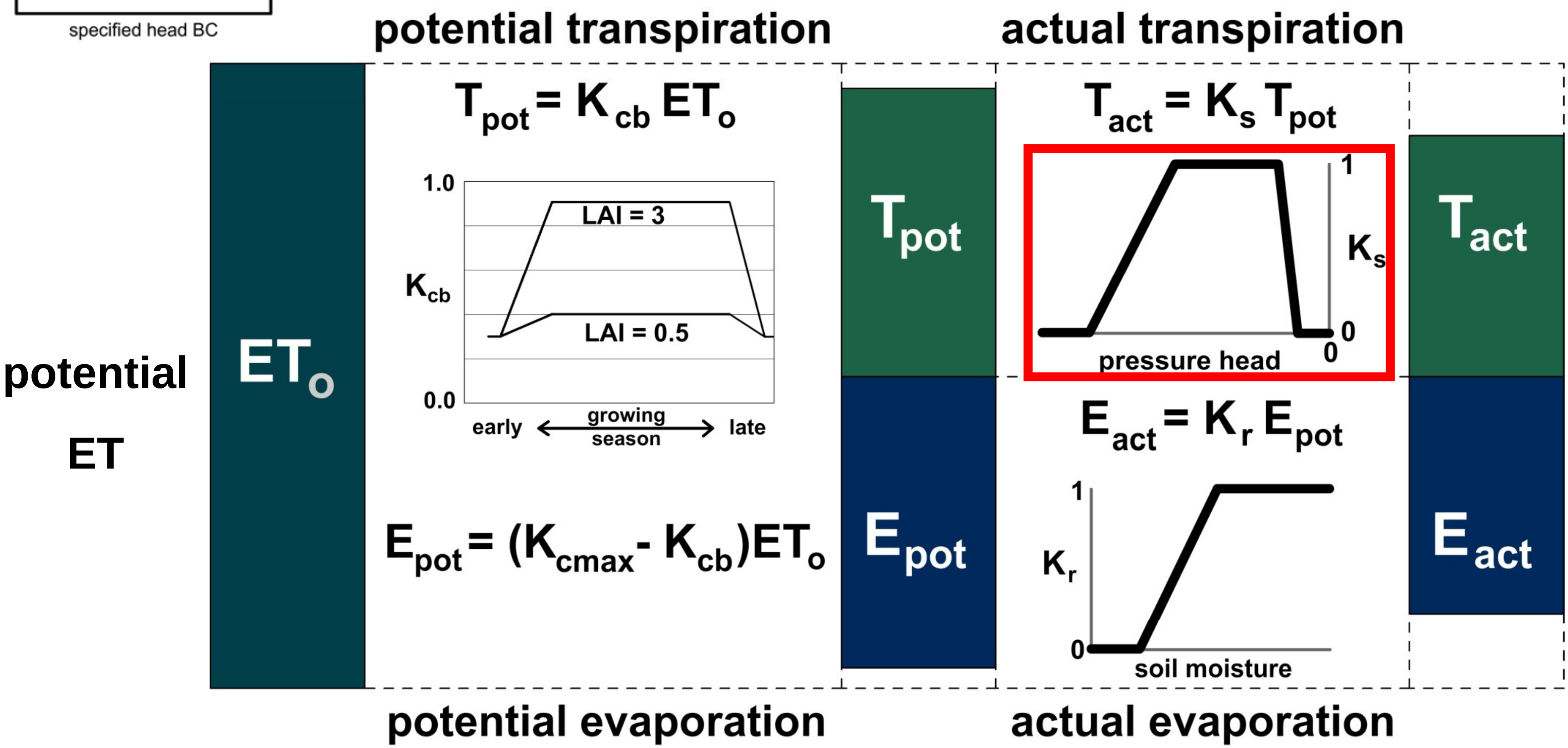




Evapotranspiration

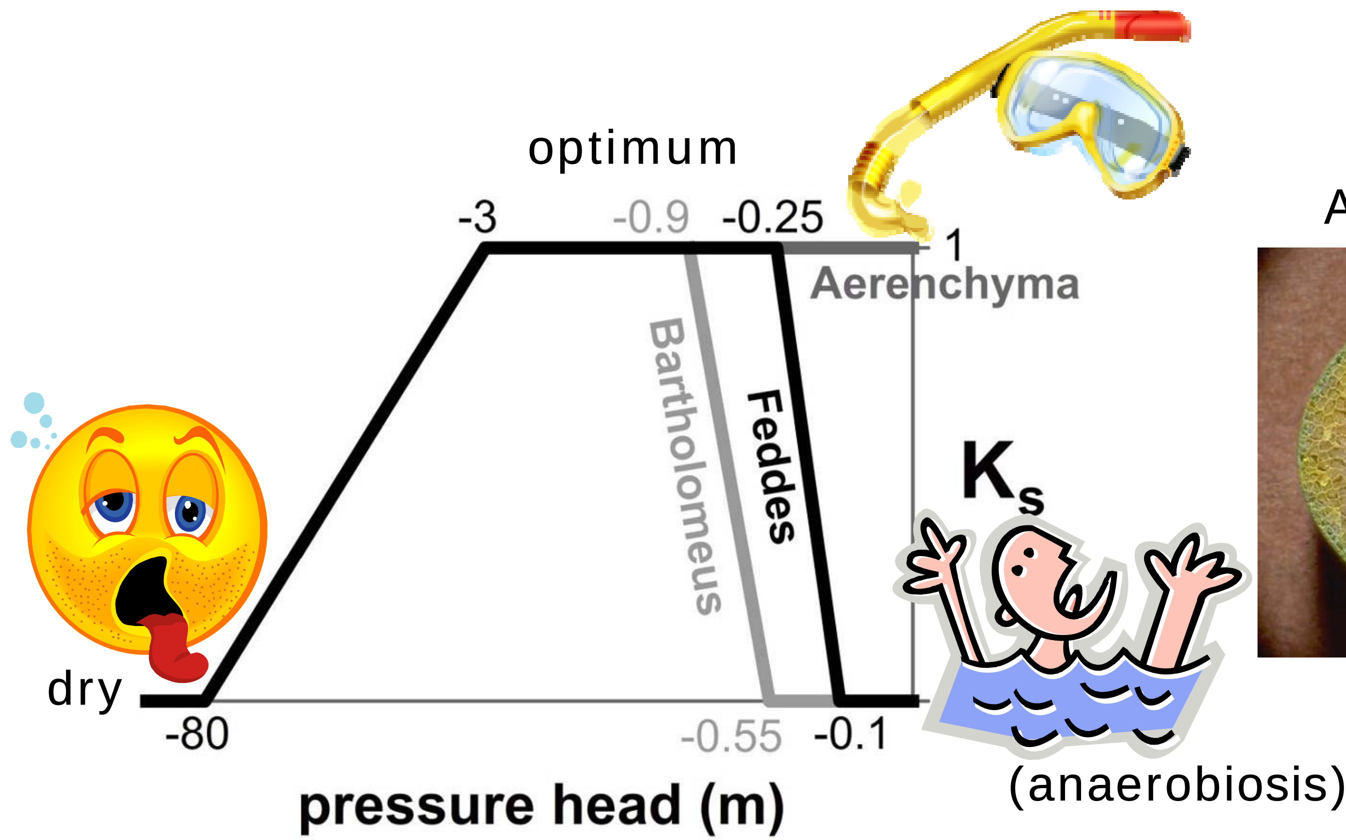
(modified FAO method)

Allen et al. 1998



Plant water stress function

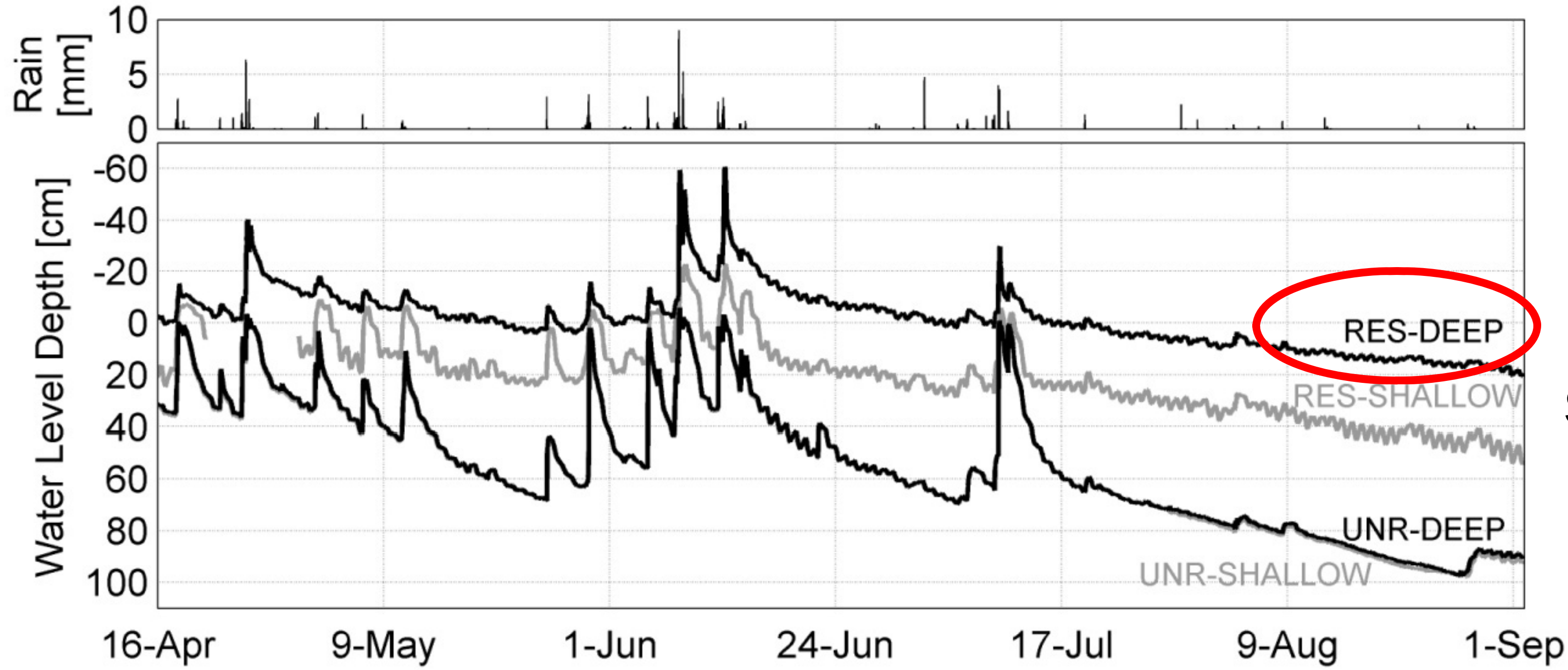
- Feddes et al. 1978 (grass)
- Bartholomeus et al. 2008 (silty loam, grassland)
- Aerenchyma effect (wetland plants)



Aerenchyma in bulrush

S. Eggers, MN DNR

Boundary conditions: 2008 field observations

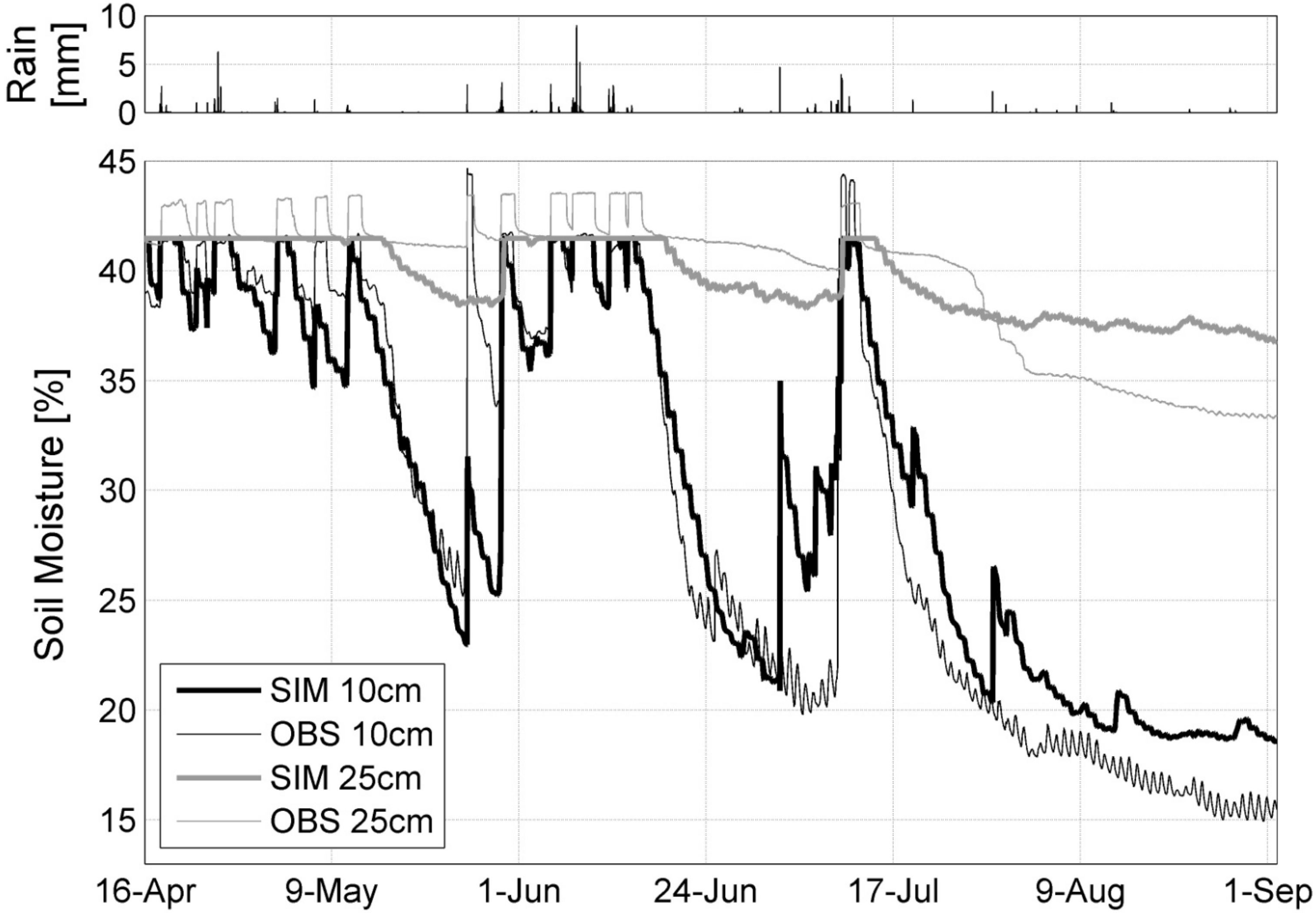


RAIN

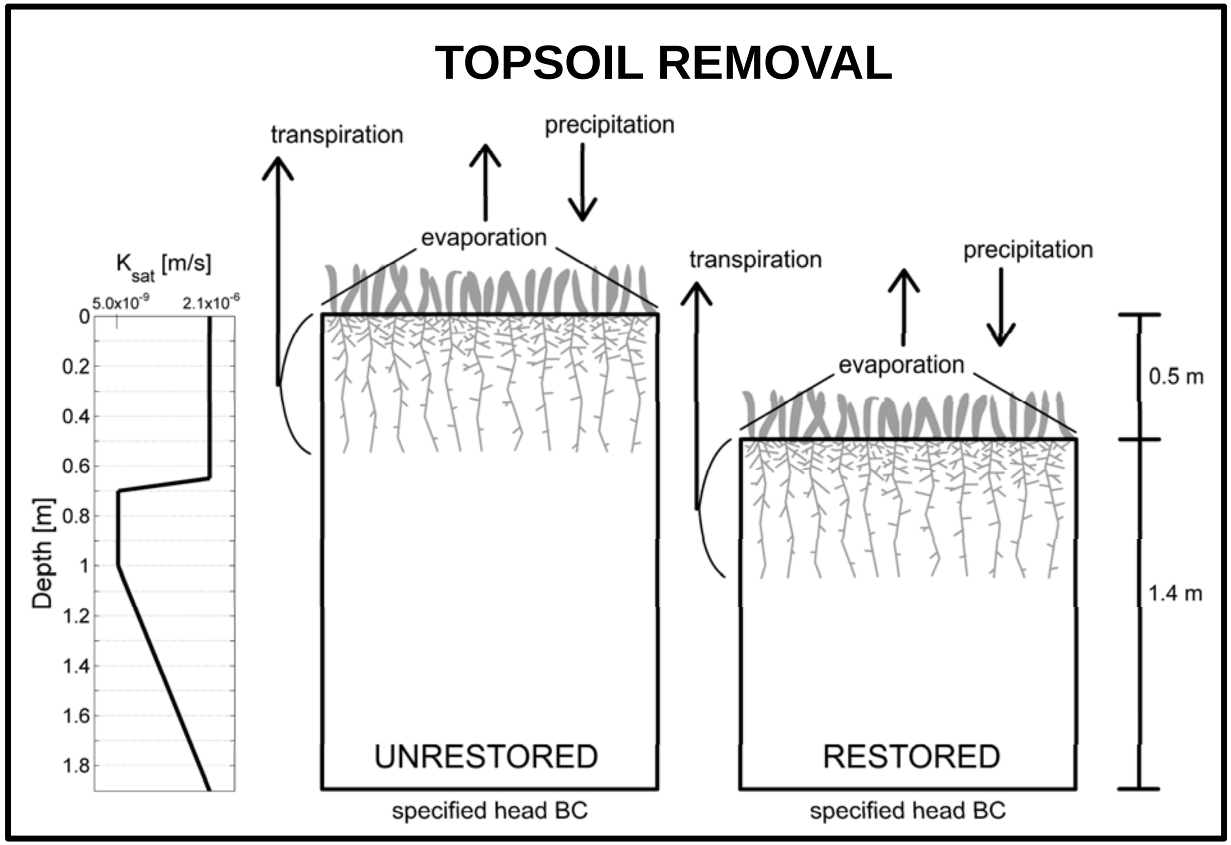
SPECIFIED HEAD

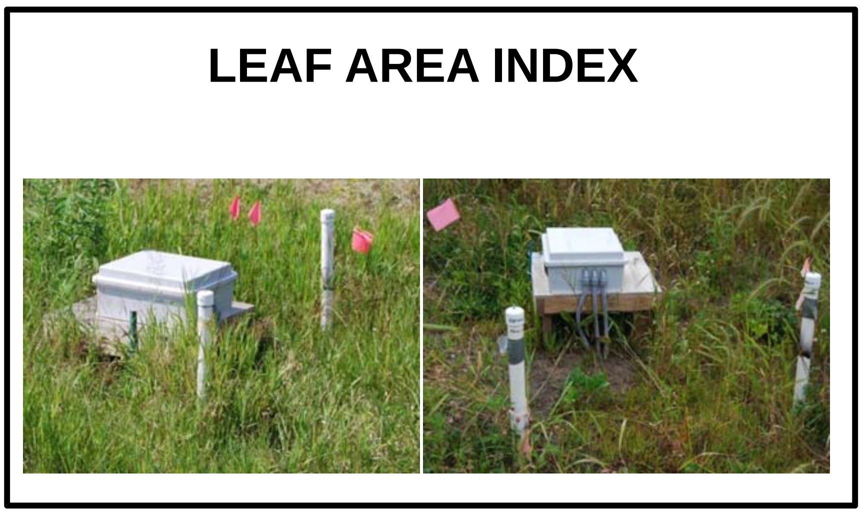
Model Validation

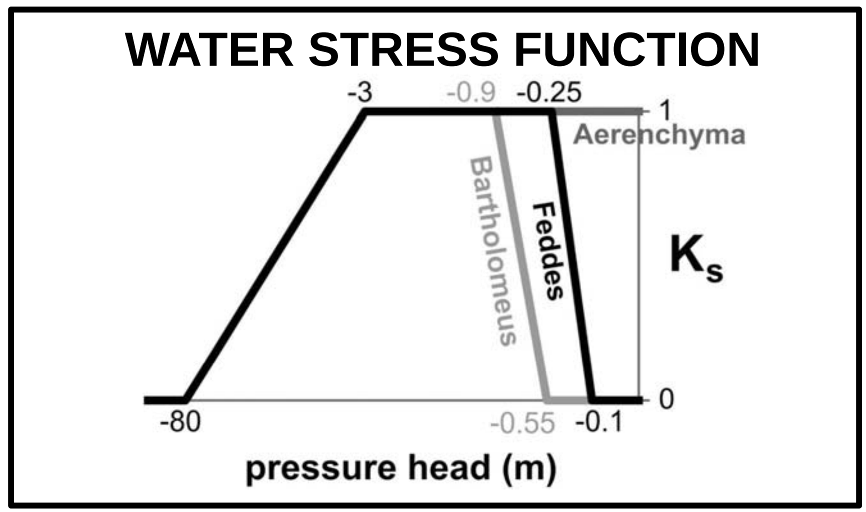
Feddes function, LAI = 2.0

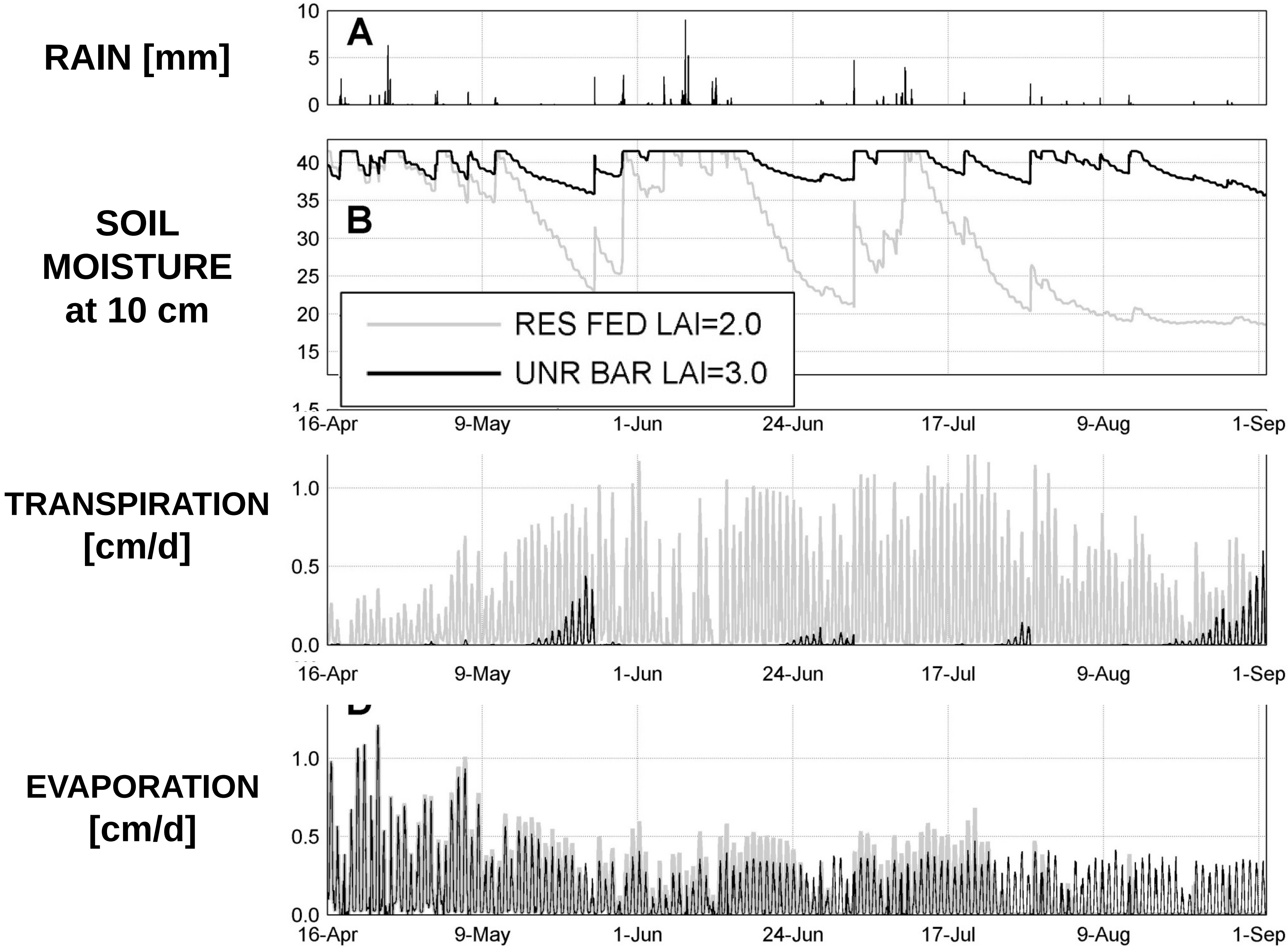


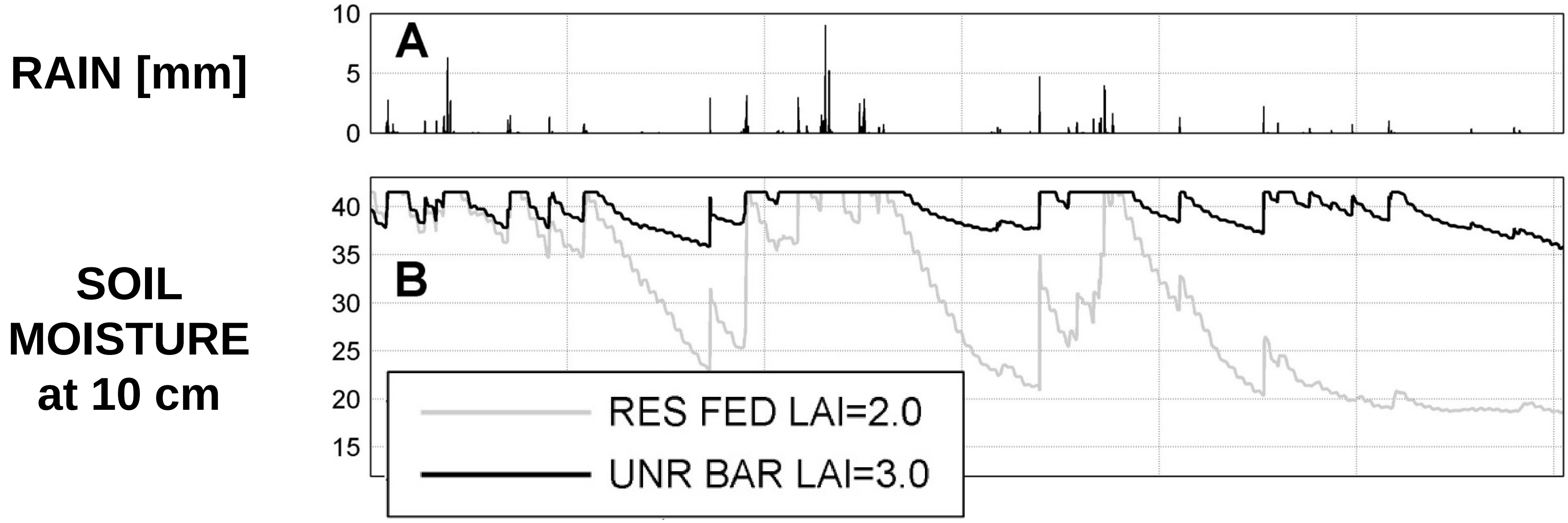
Model Changes








RAIN [mm]
SOIL MOISTURE at 10 cm
TRANSPIRATION [cm/d]
EVAPORATION [cm/d]
A
B
D
RES FED LAI=2.0
UNR BAR LAI=3.0
10
5
0
40
35
30
25
20
15
1.0
0.5
0.0
16-Apr
9-May
1-Jun
24-Jun
17-Jul
9-Aug
1-Sep



Why is the restored case ***drier?***

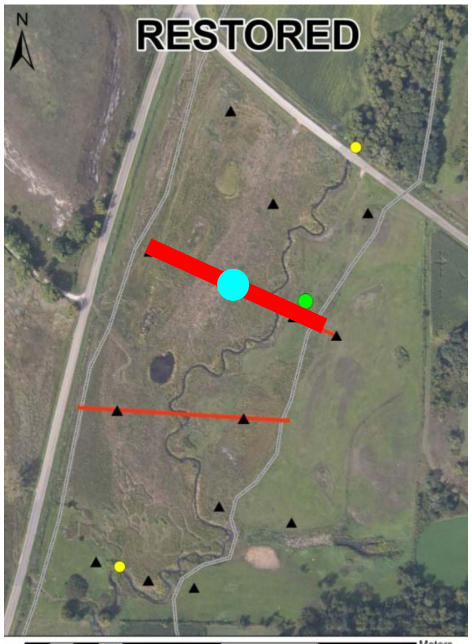
- Smaller amount of storage (soil removed in restored case) is depleted quicker if no groundwater is available to replenish

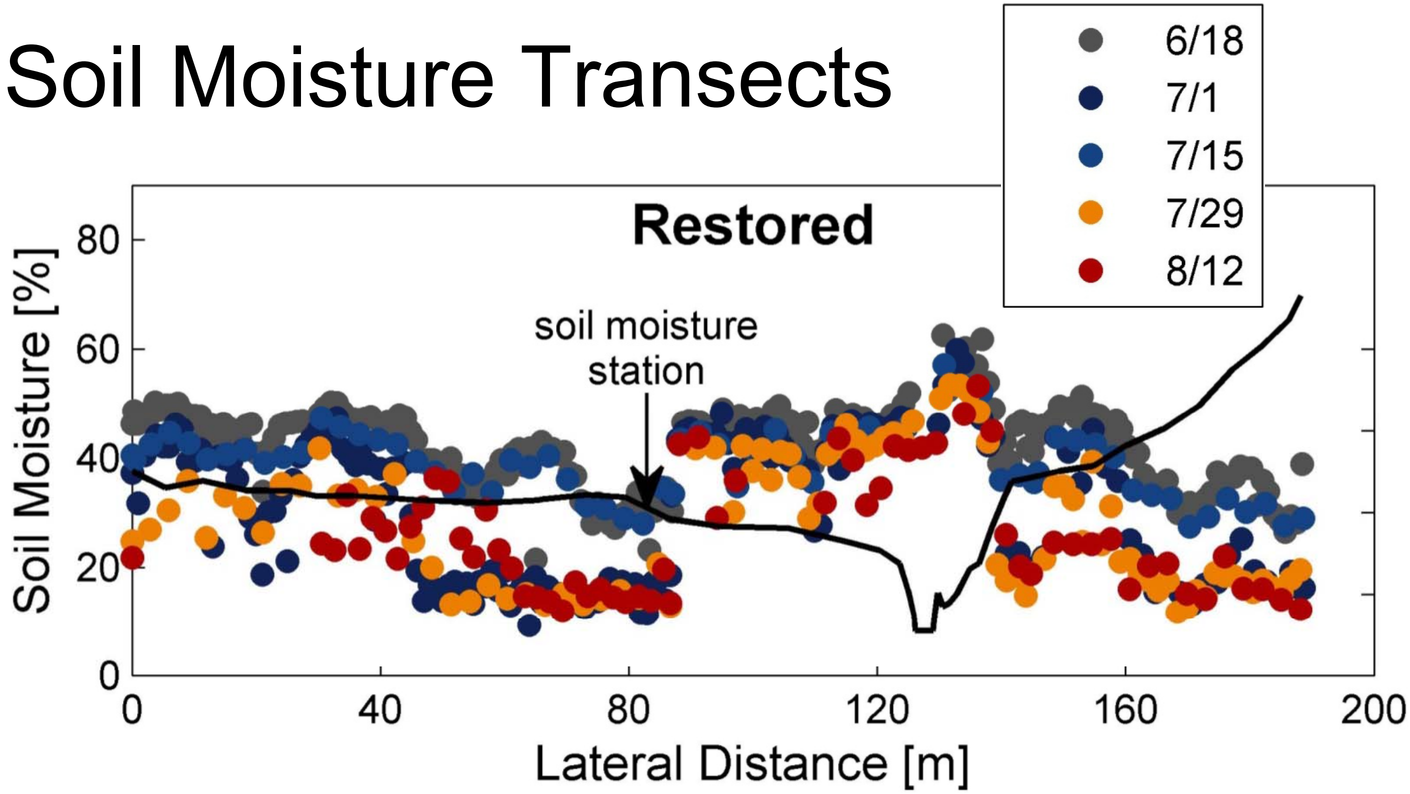
- Difference in vegetation – facultative wetland vegetation is adapted to wet conditions → therefore the restored site uses more water for transpiration and becomes drier

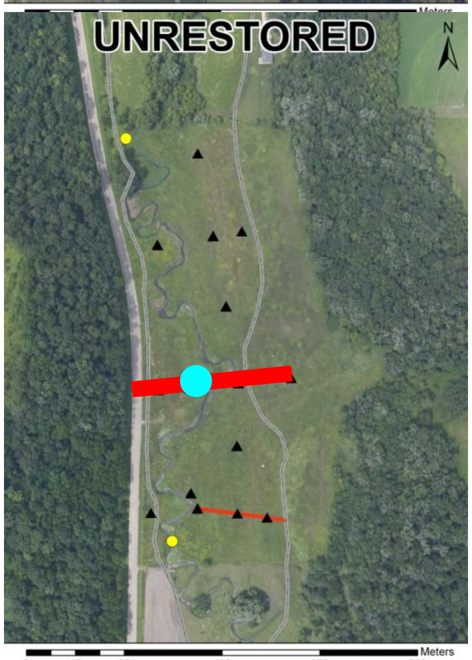
Soil Water Regime
Major take-home points

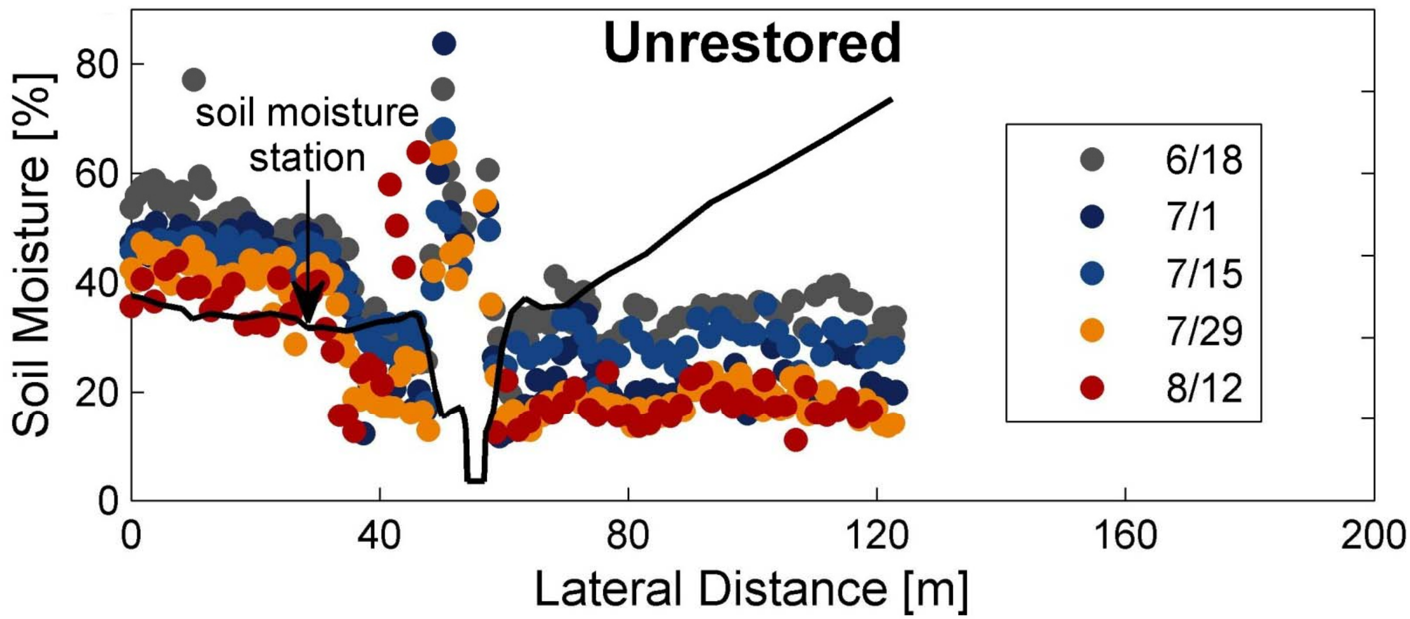
1. Shallow monitoring wells may not be able to express the water table and the root zone water regime in some situations
2. Choice of plant water stress function can have a large impact on soil moisture regime
3. Geomorphic history of floodplain needs to be considered
4. Where confining layer is present, restoration may lead to lower soil moisture

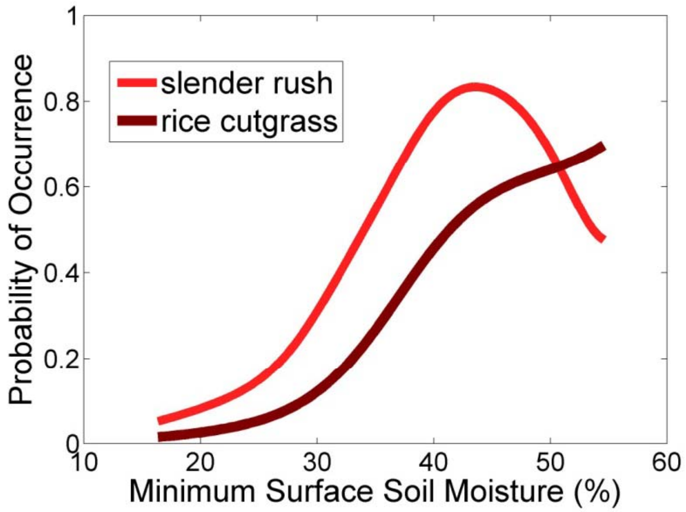
Soil Moisture Transects



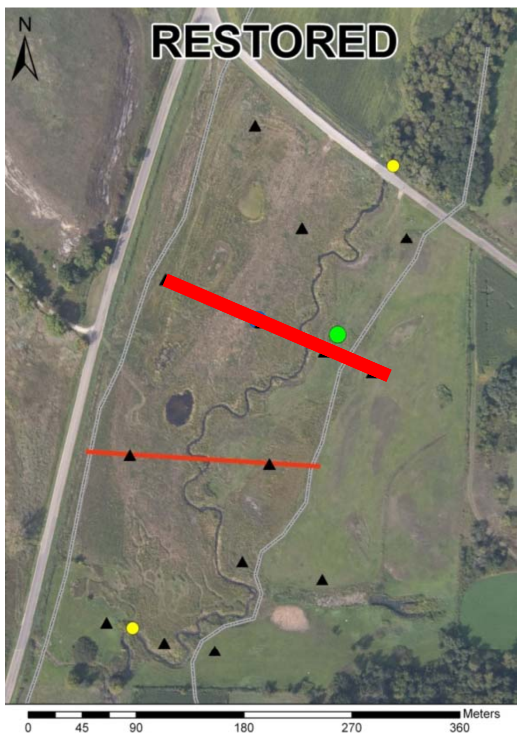


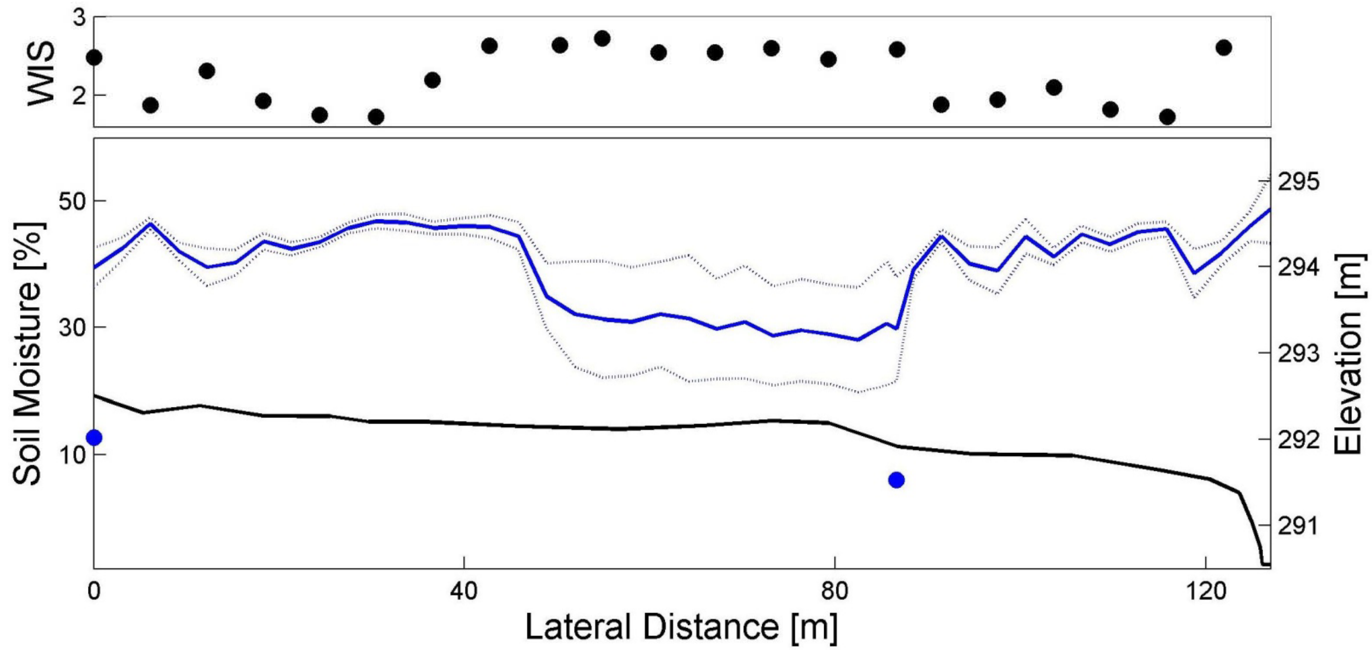




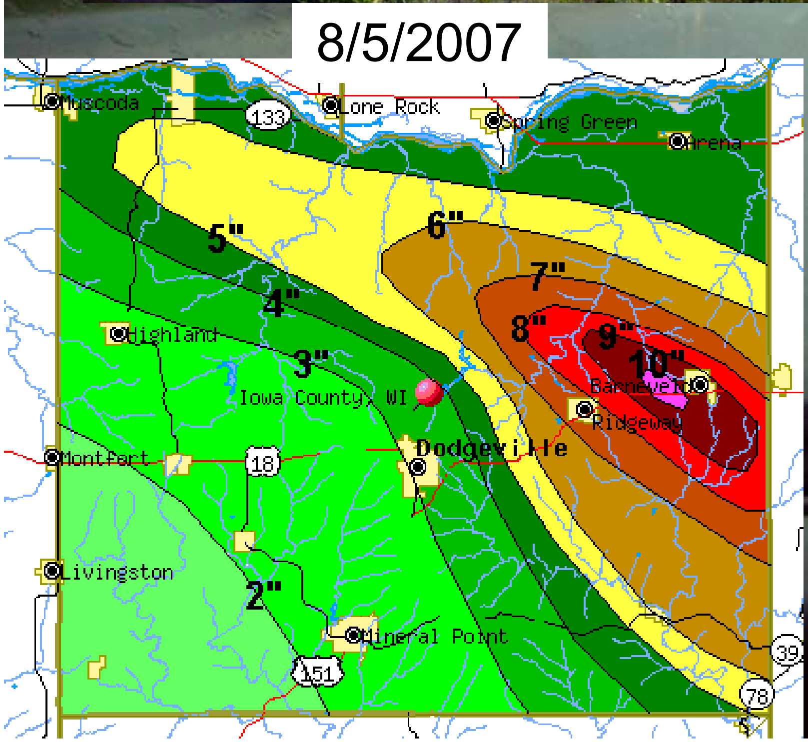


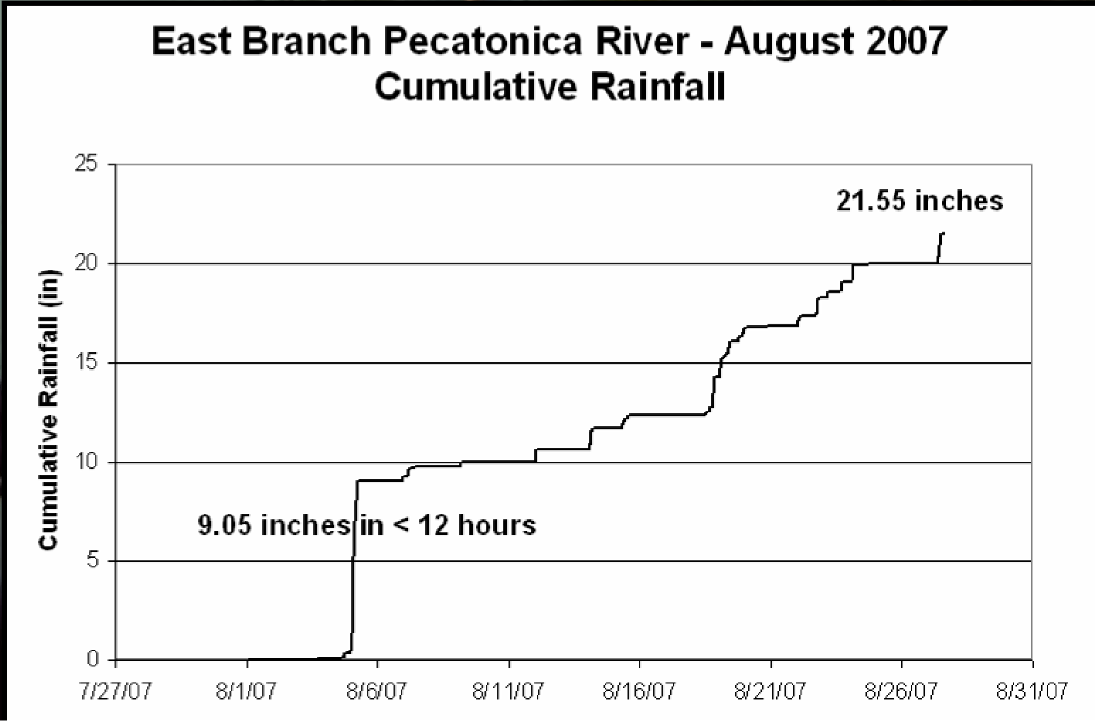
So what does this mean for making a predictive relationship between hydrology and vegetation?





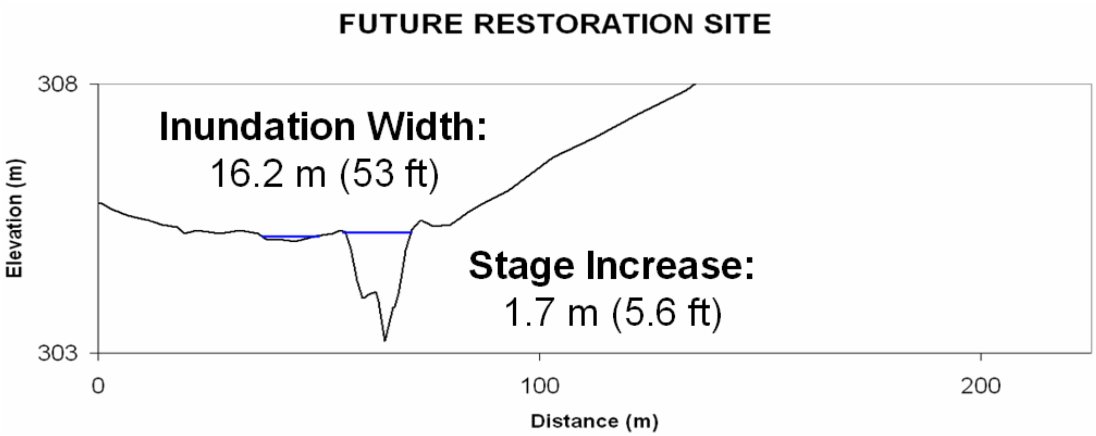
Record August 2007 Rainfall

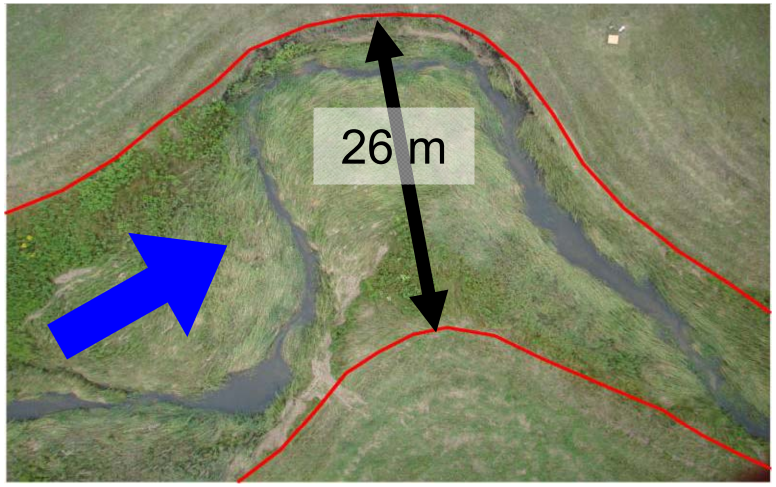




UNRESTORED SITE

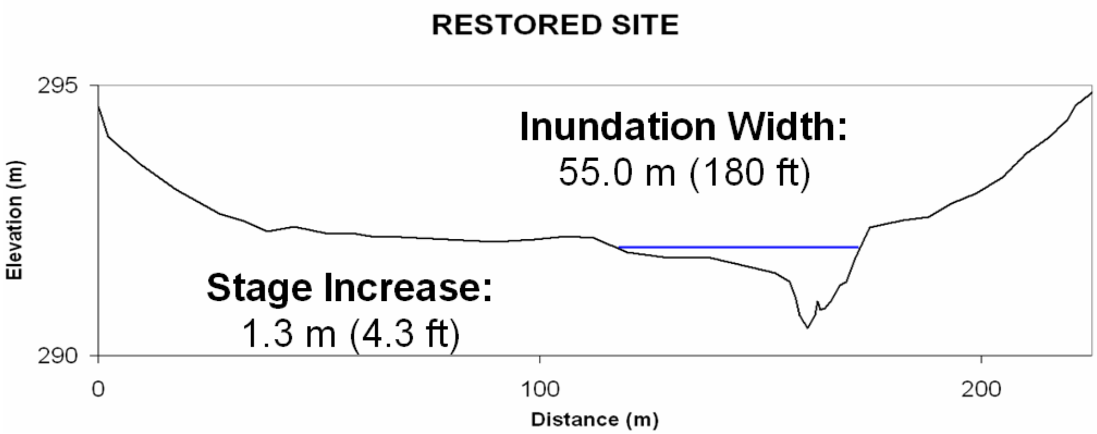
Flow confined to narrow meander belt, higher stream velocities, some bank erosion

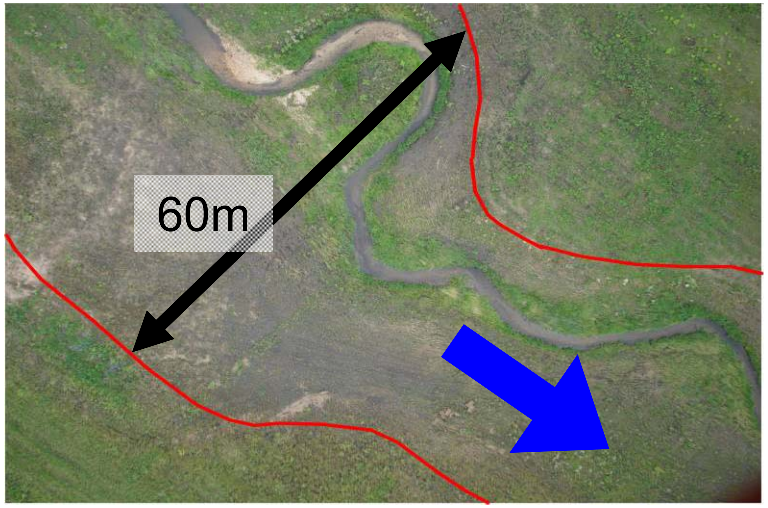




RESTORED SITE

Flow spread out over large extent, lower stream velocities, sediment deposition

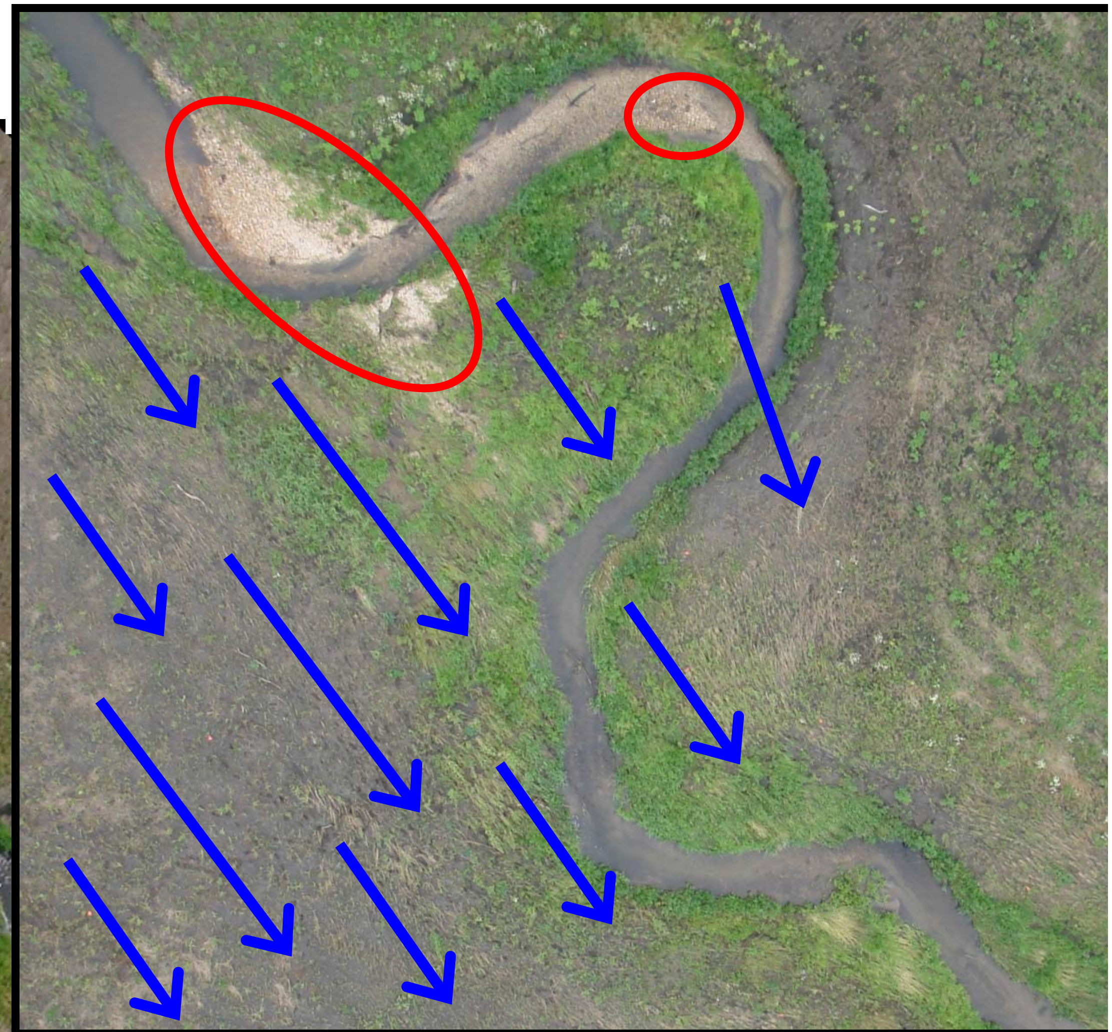




RESTORED SITE

PRE-FLOOD

August 1, 2007



POST-FLOOD

August 8, 2007 stage: +15 cm

August ‘07 floodplain deposition

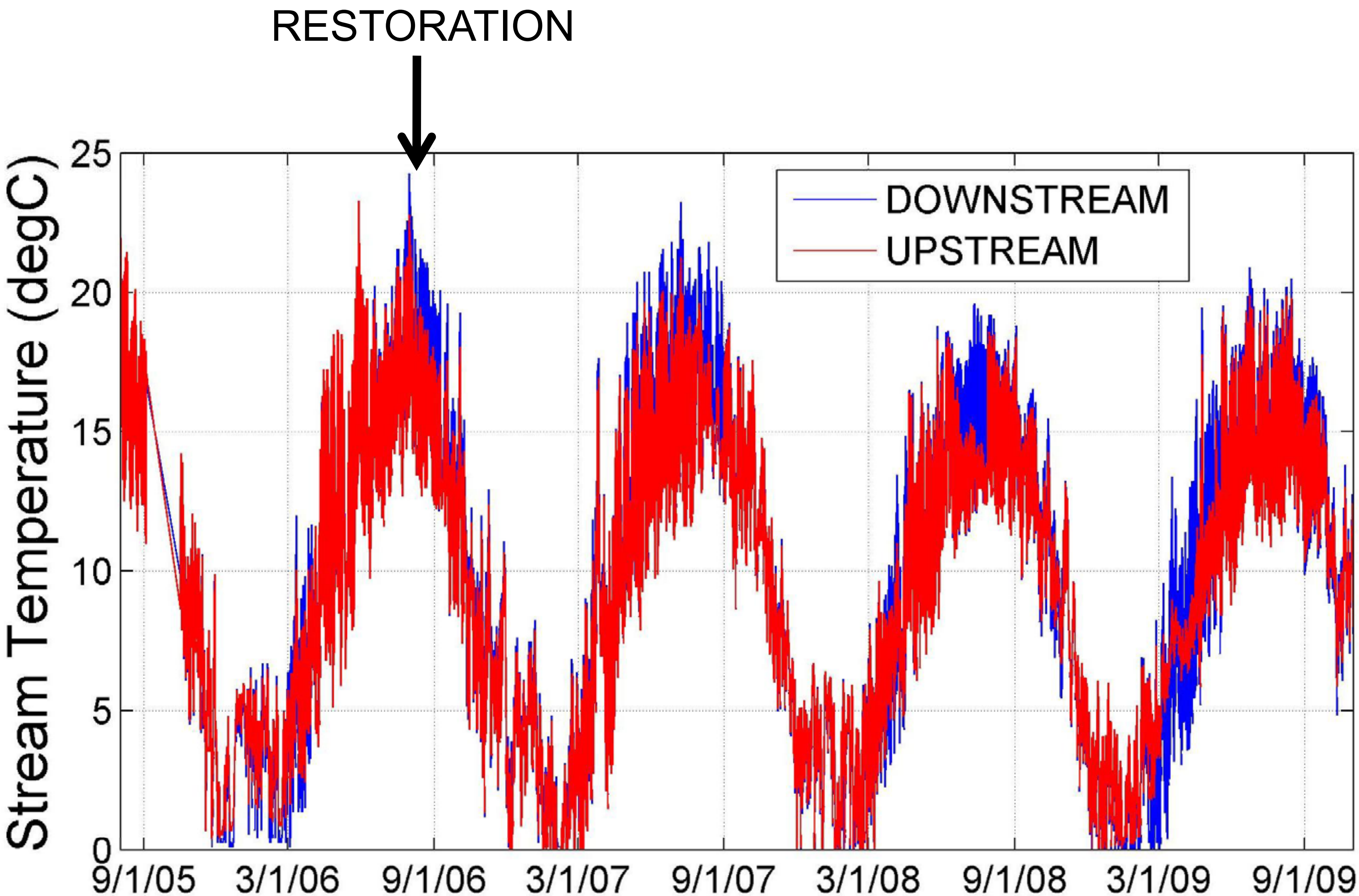
- ~5 mm on the lower floodplain surfaces

Channel width adjustments

- Channel margin deposition following removal of large-woody debris

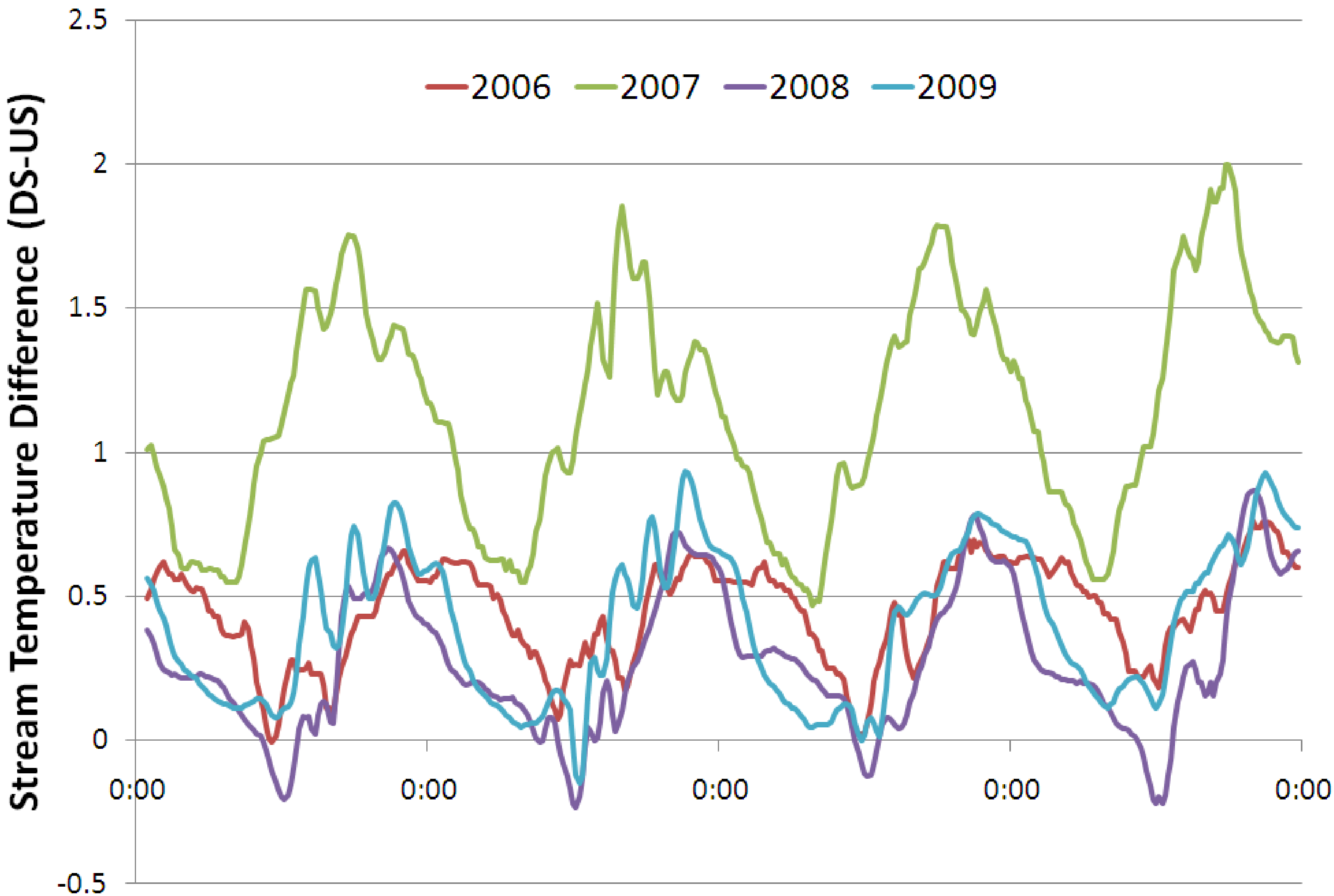
- Coir logs can accelerate adjustment

Stream Temperature



Heating over restored reach

- 4 representative clear summer days per year



Final summary

- What we have learned so far
  - Complex hydrologic response in floodplain soil
  - Near-surface soil moisture may effectively predict vegetation
  - Response to floods was positive at restored site
  - Channel narrows following LWD removal
    - stream temperature effects largely negligible?
- Limitations
  - Cannot expect entire floodplain to be a wetland following restoration
  - Sedimentation can be an issue in larger or more stressed watersheds

Visit our website

http://hydroecology.cee.wisc.edu/EBP/

Acknowledgements

Jim Knox, Emily Stanley, Ken Potter, Phil Townsend, Randy Hunt, Kira Langree, Chanel Kass, Julia Ferguson, Noah Lottig, Bob Hansis, Steve Richter, Rich Deitchman, Hans Wildebush, Nathan Braun, Alex Bilgri, Bill Selbig, Arlen Striegl, WDNR aviation

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Wisconsin Department of Natural Resources

National Science Foundation

References:

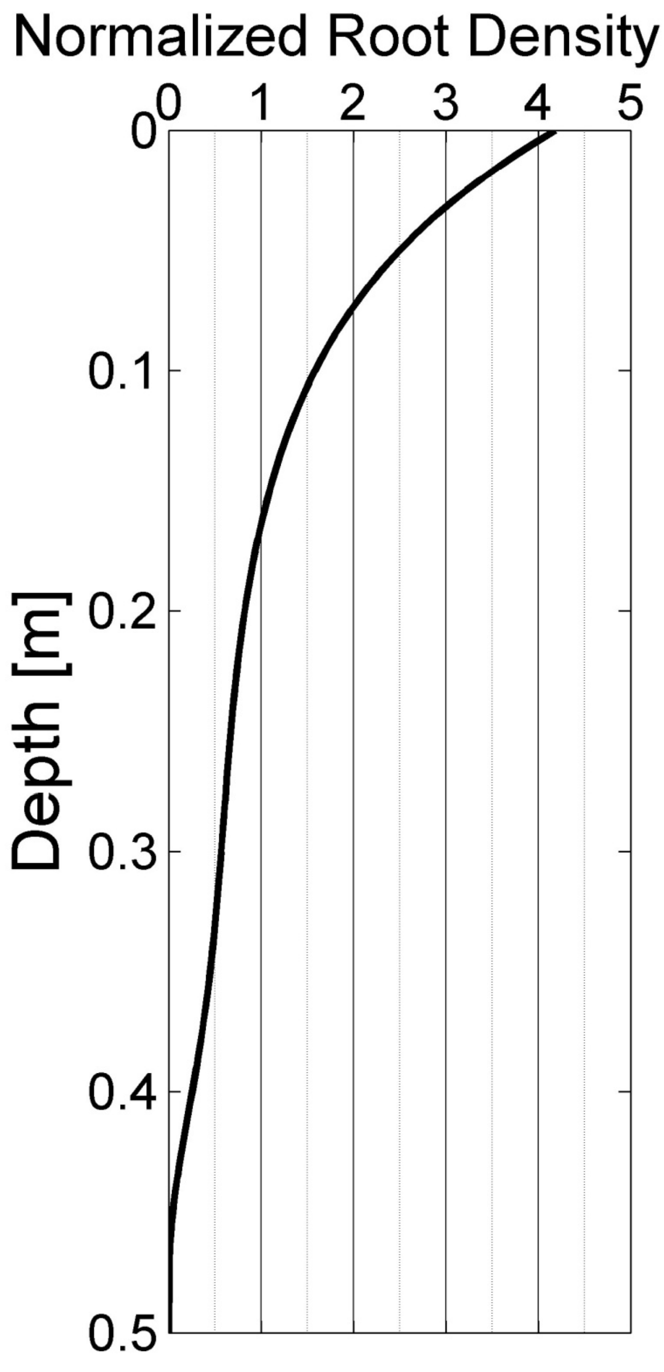
Allen, R., Pereira, L.S., Raes, D. and Smith, M., 1998. Crop evapotranspiration: Guidelines for computing crop requirements, FAO, Rome, Italy.

Bartholomeus, R.P., Witte, J.P.M., van Bodegom, P.M., van Dam, J.C. and Aerts, R., 2008. Critical soil conditions for oxygen stress to plant roots: Substituting the Feddes-function by a process-based model. Journal of Hydrology, 360(1-4): 147-165.

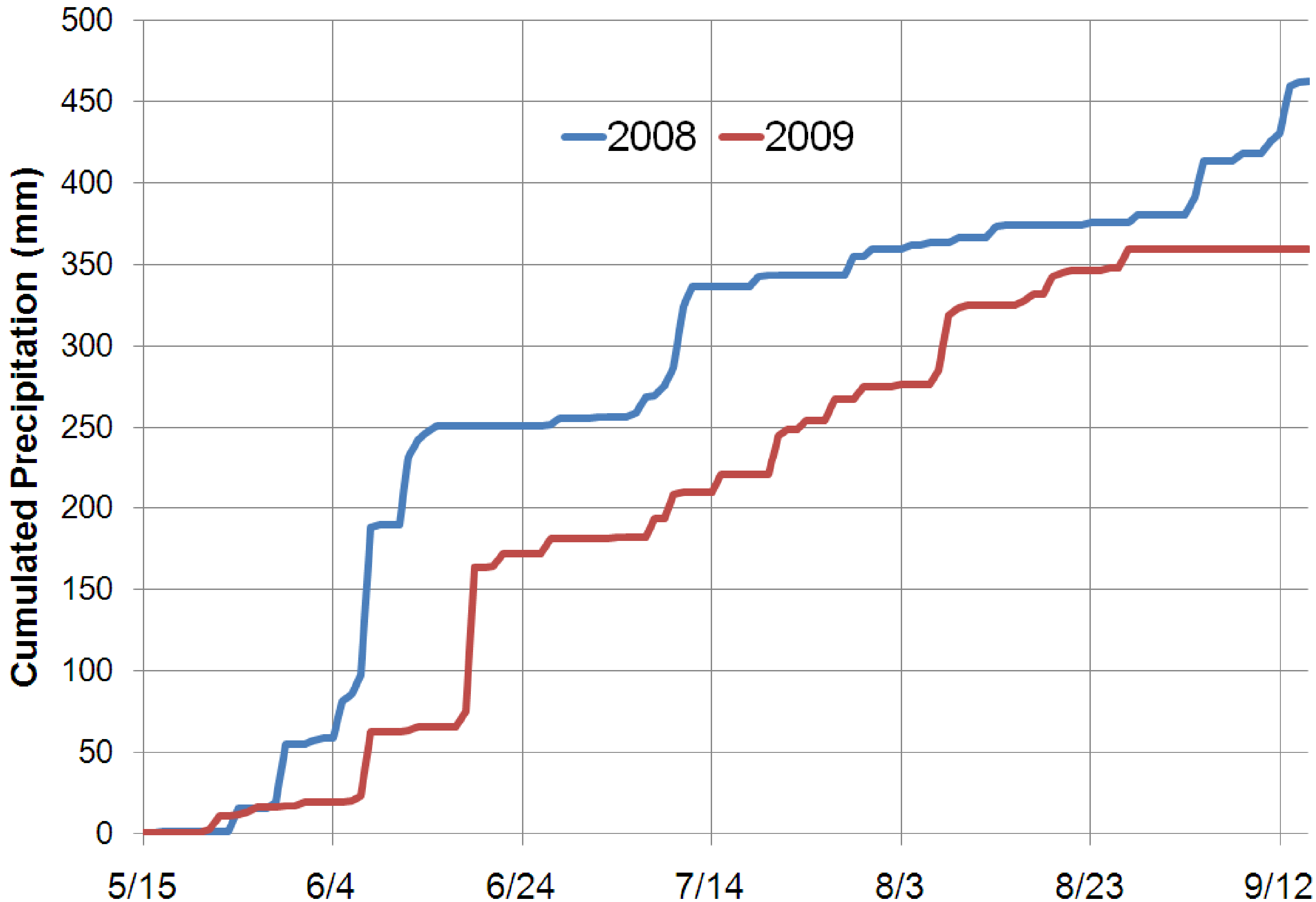
Booth, E, Loheide, S., (in review). Effects of evapotranspiration partitioning, plant water stress response, and topsoil removal on the soil moisture regime of a floodplain wetland: Implications for restoration. Hydrological Processes

Feddes, R.A., Kowalik, P.J. and Zaradny, H., 1978. Simulation of Field Water Use and Crop Yield. John Wiley and Sons, New York, NY.

EXTRA SLIDES

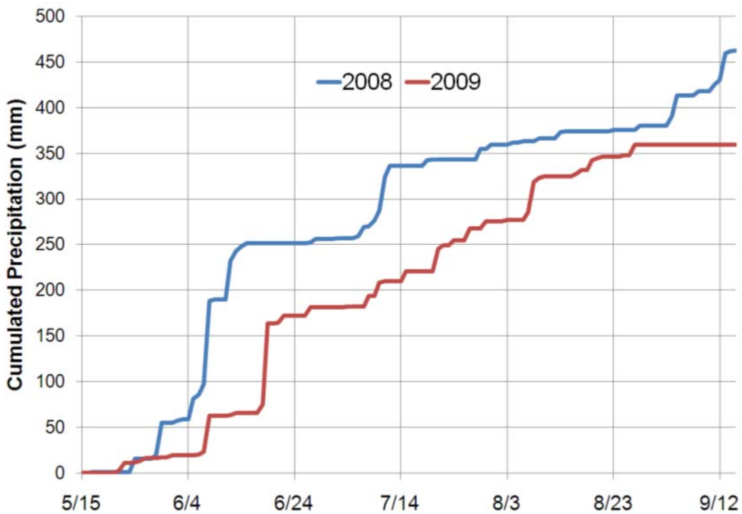

Normalized Root Density
0
1
2
3
4
5
0
0.1
0.2
0.3
0.4
0.5
Depth [m]

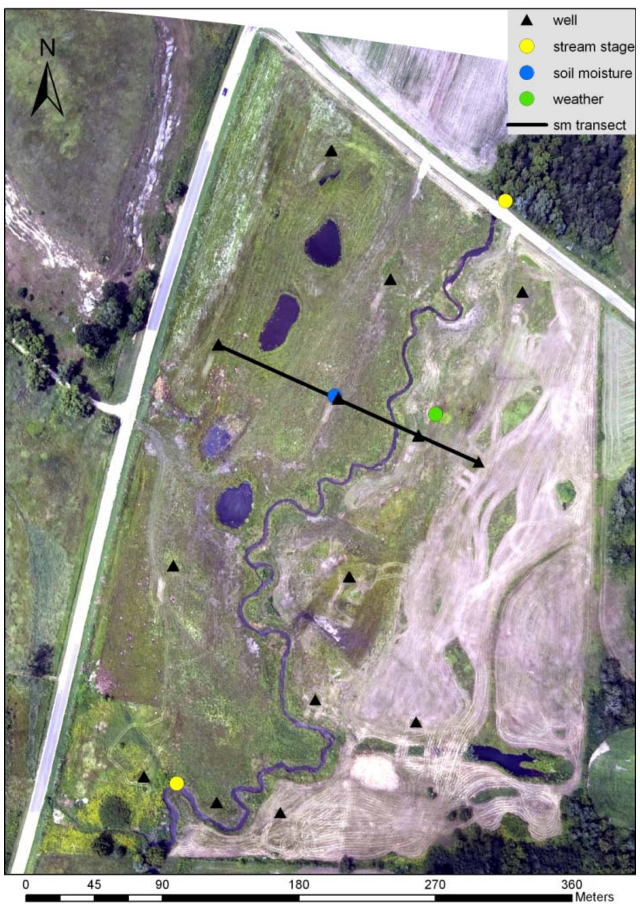
Growing Season Rainfall (2008 & 2009)

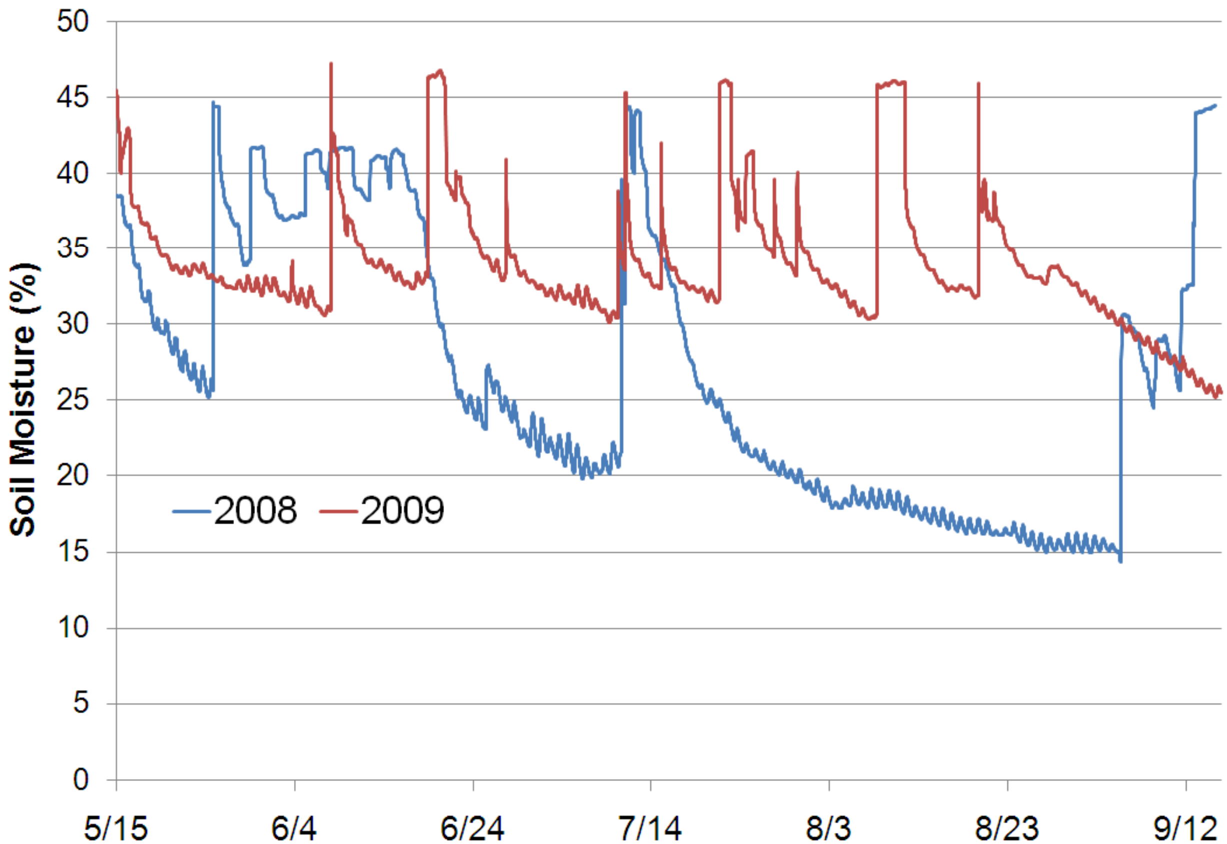


EBP06 site

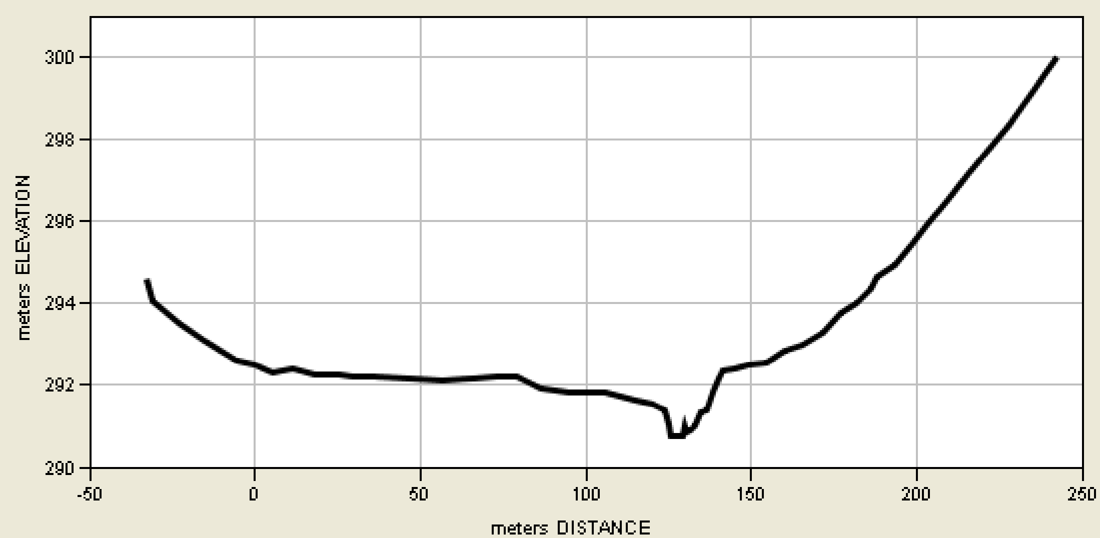
soil moisture at 10 cm

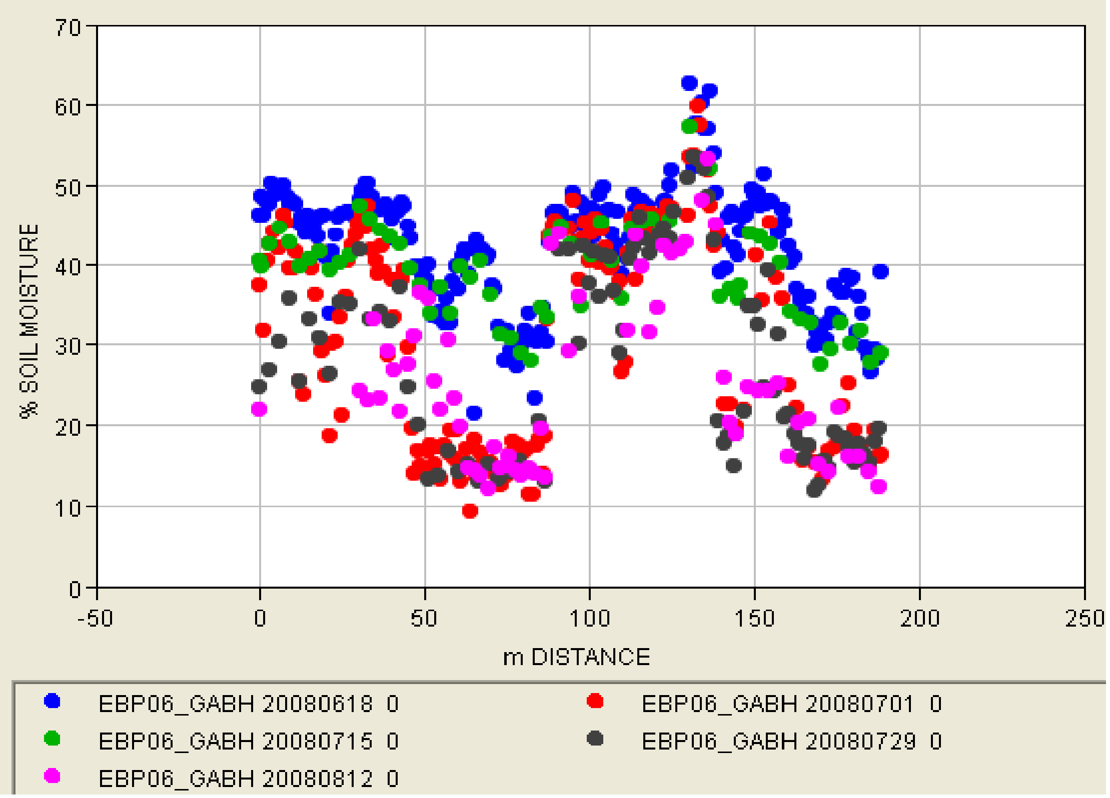


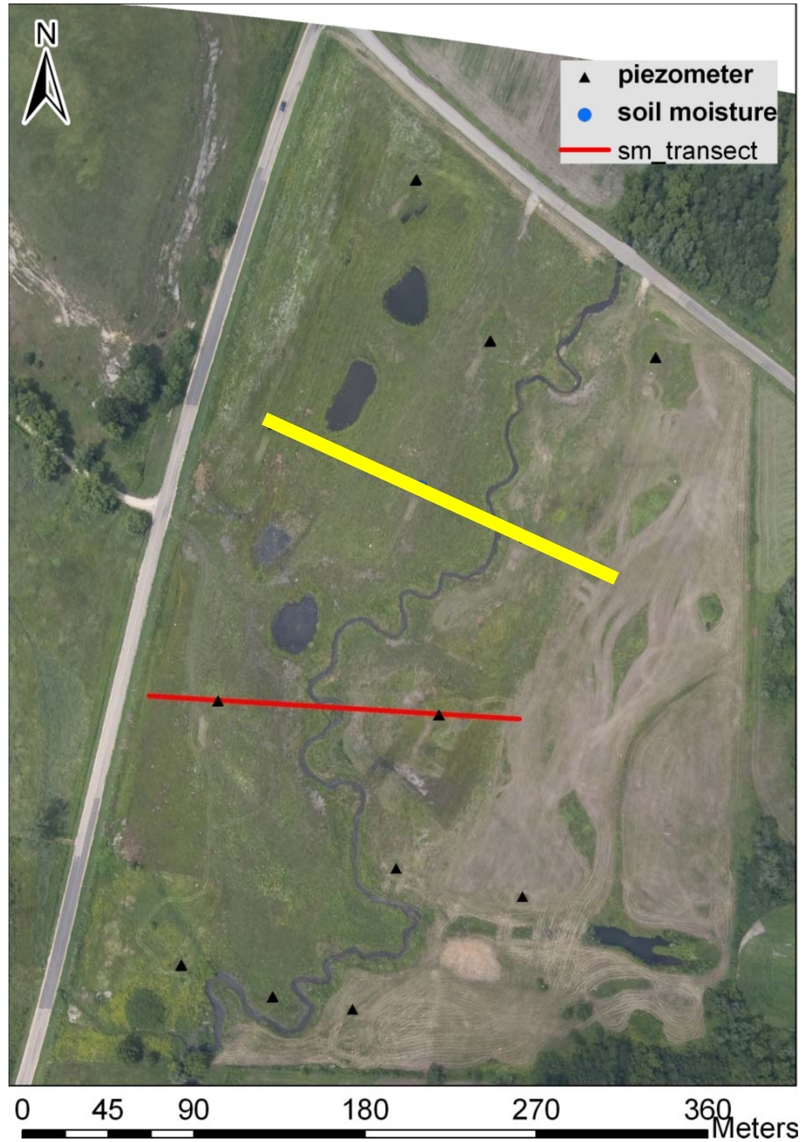




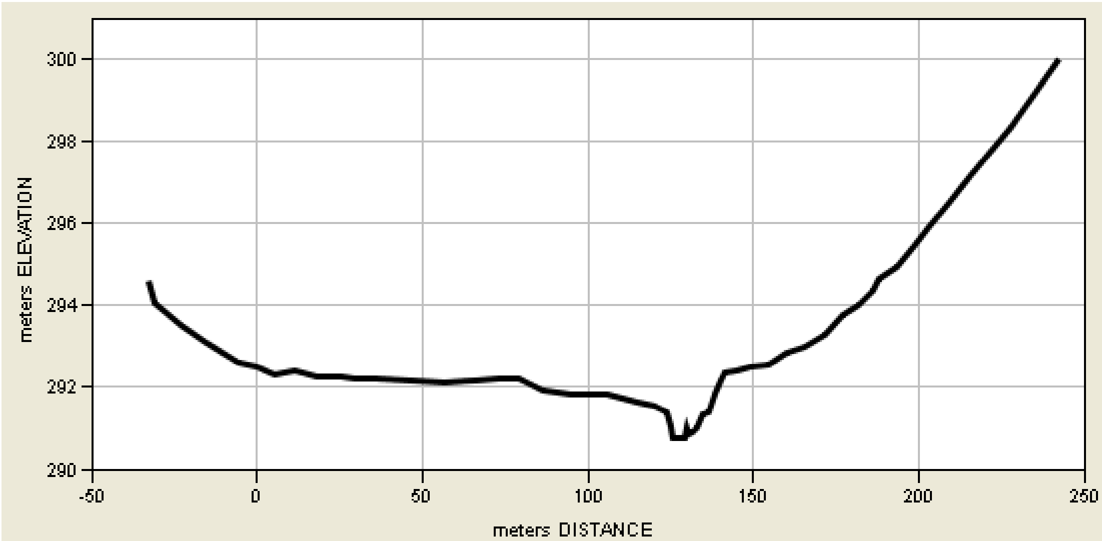
EBP06-GABH 2008

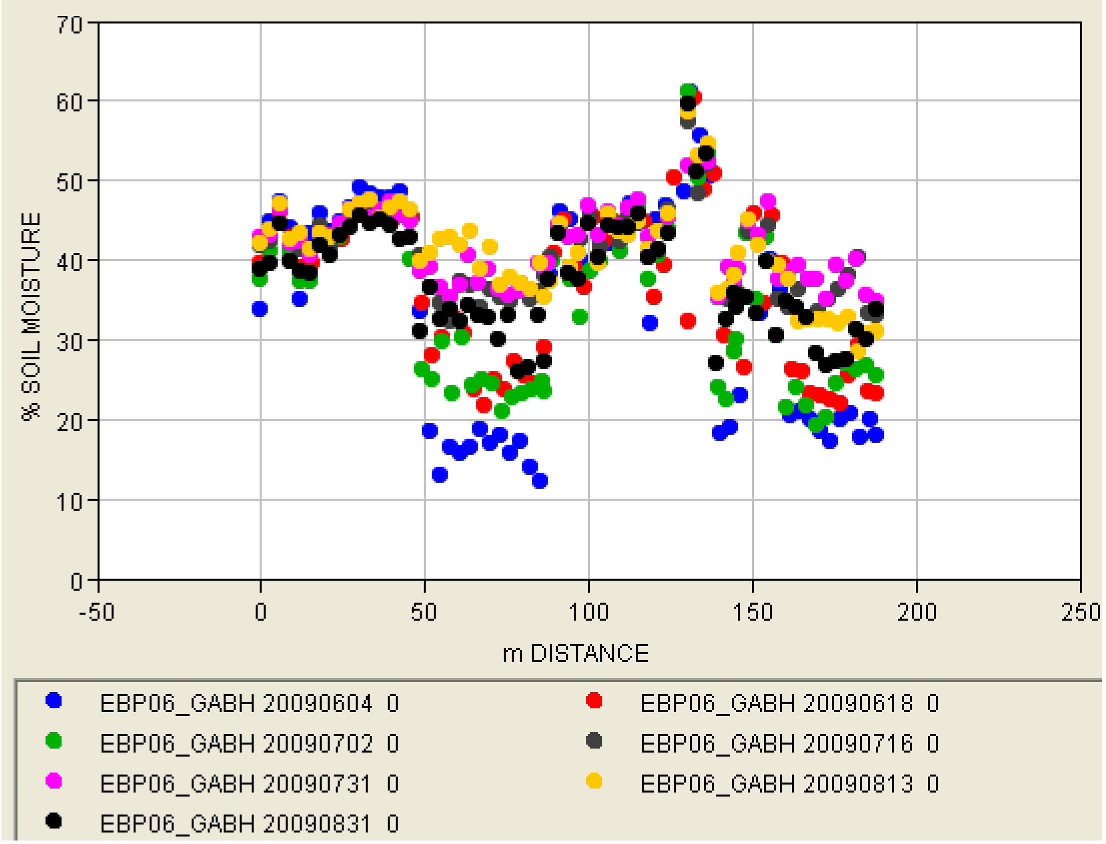


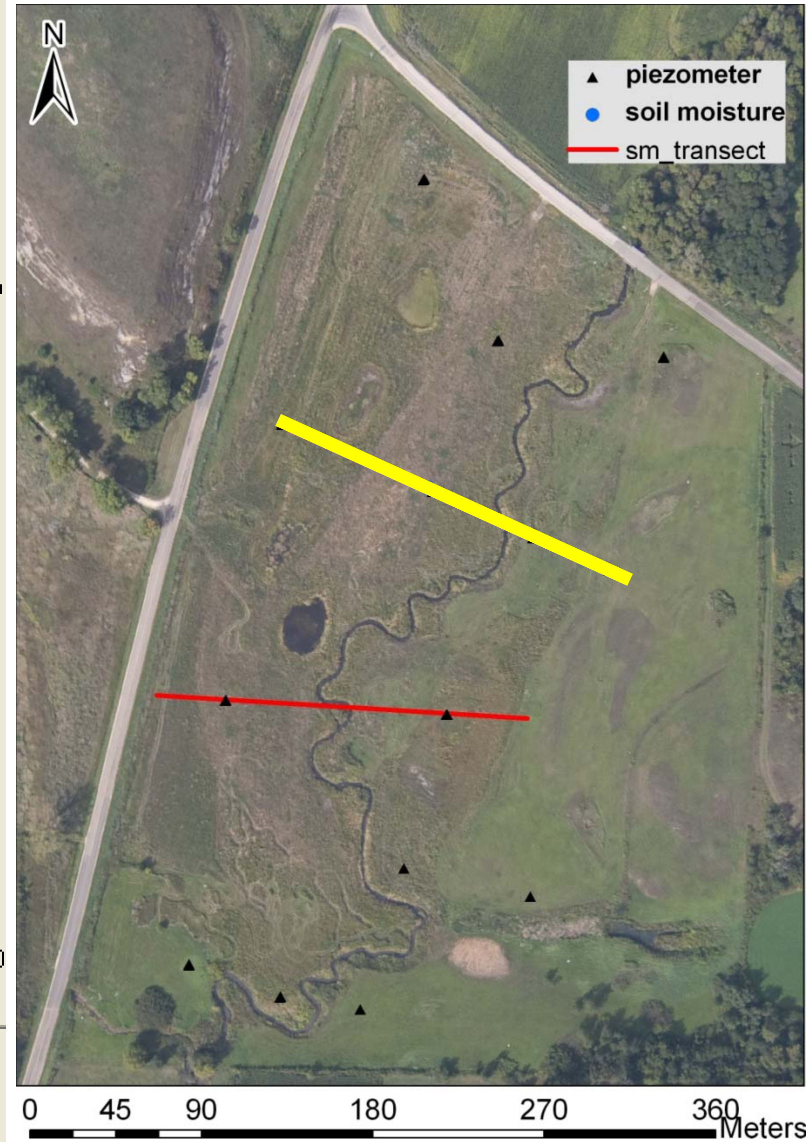




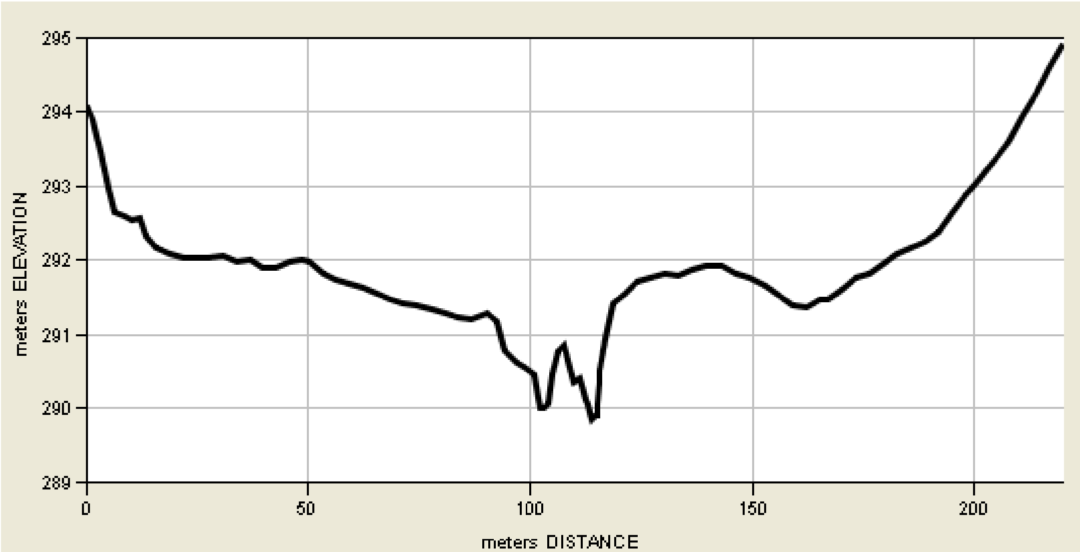
EBP06-GABH 2009

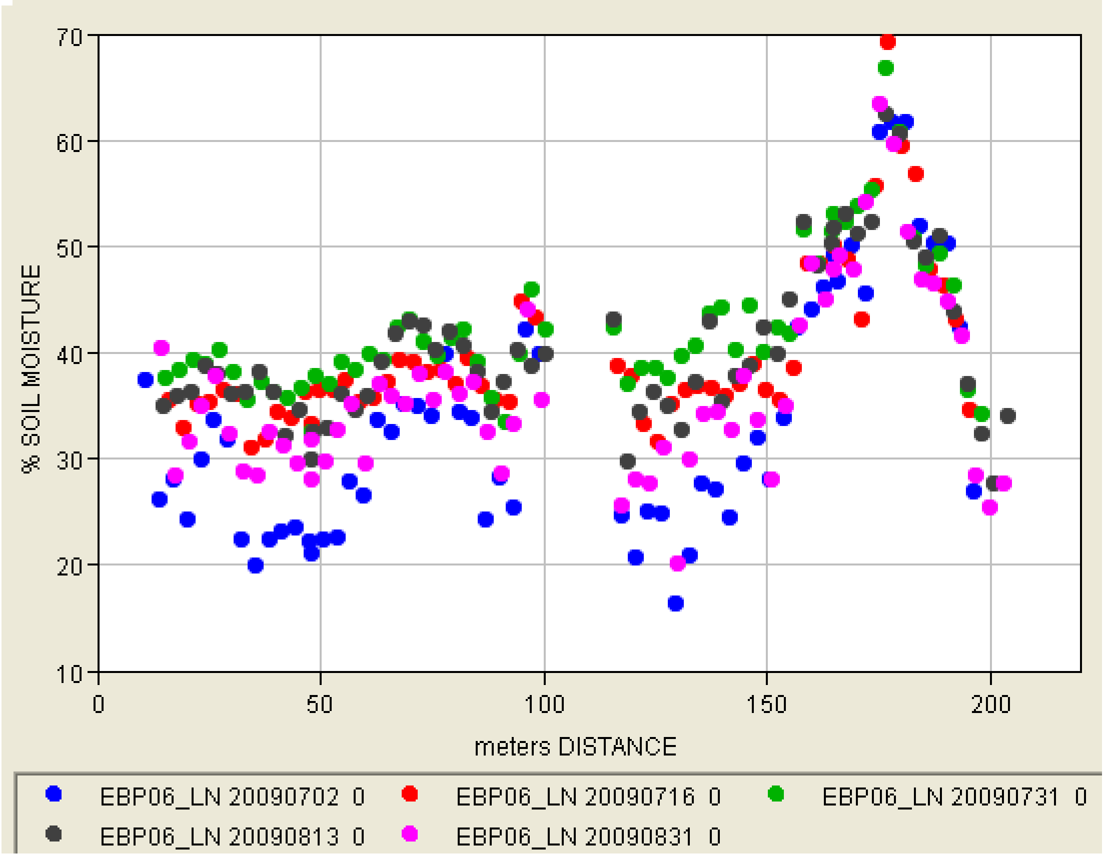


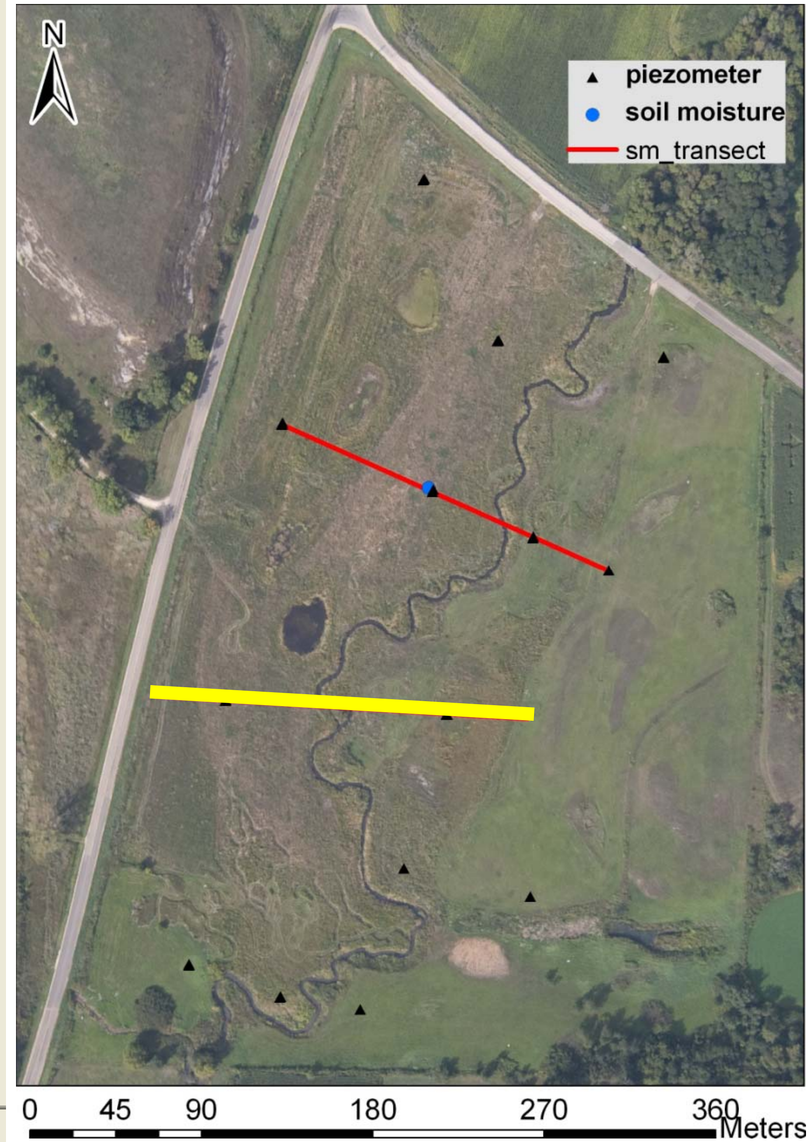




EBP06-LN 2009

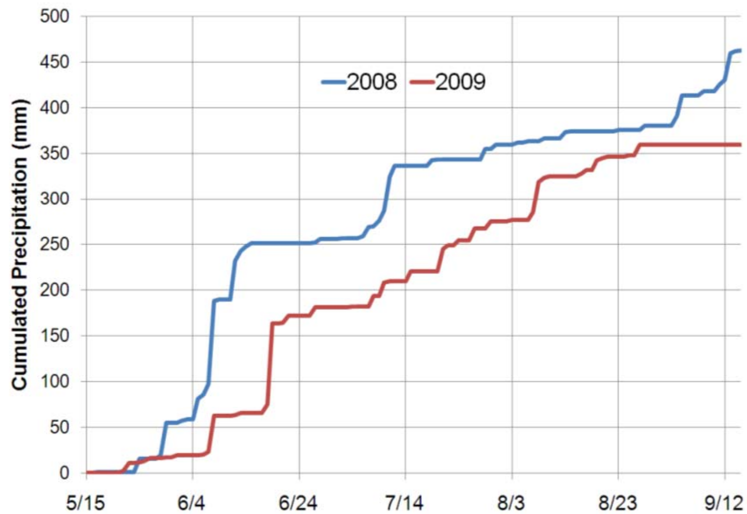


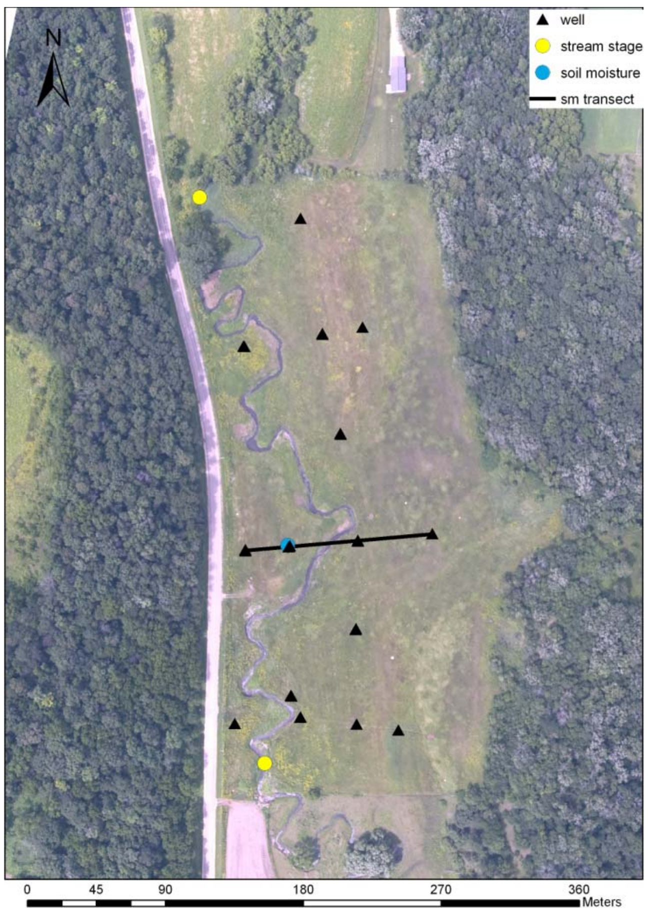


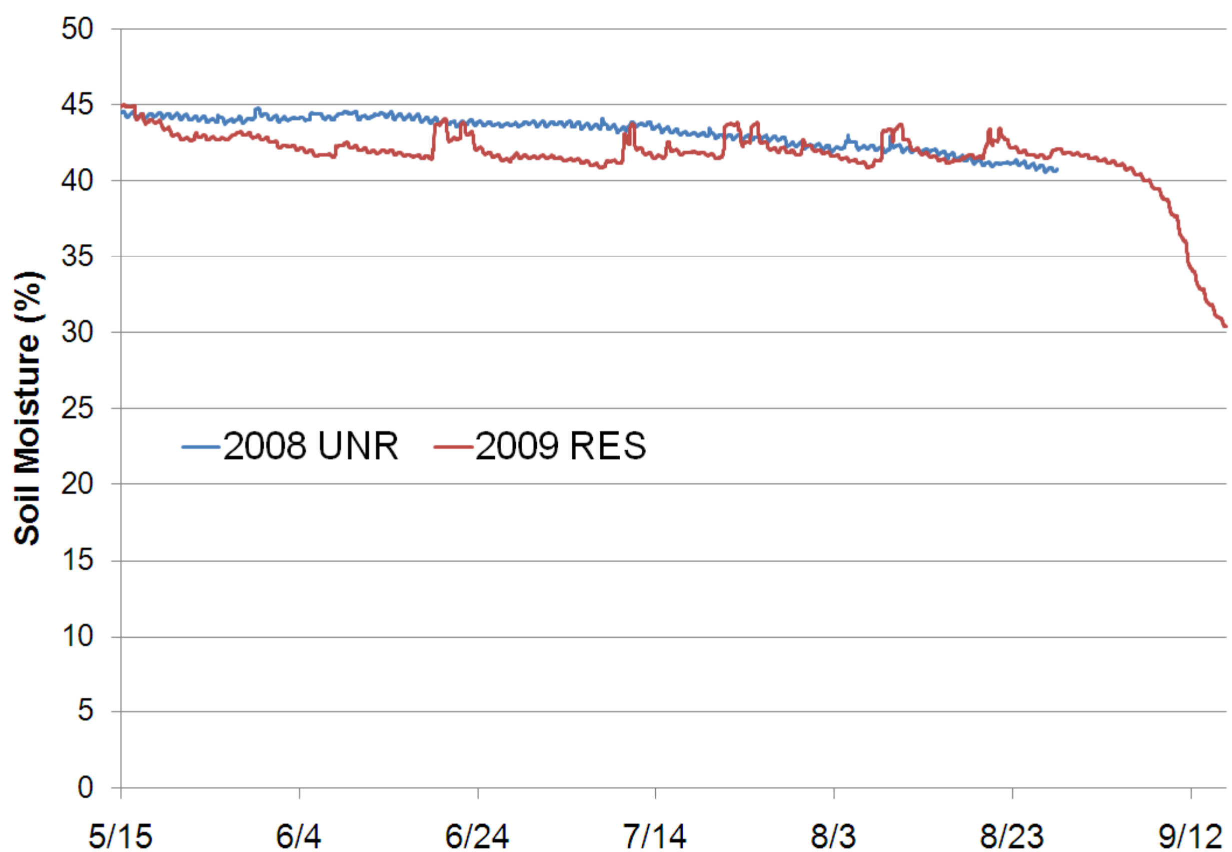


EBP08 site

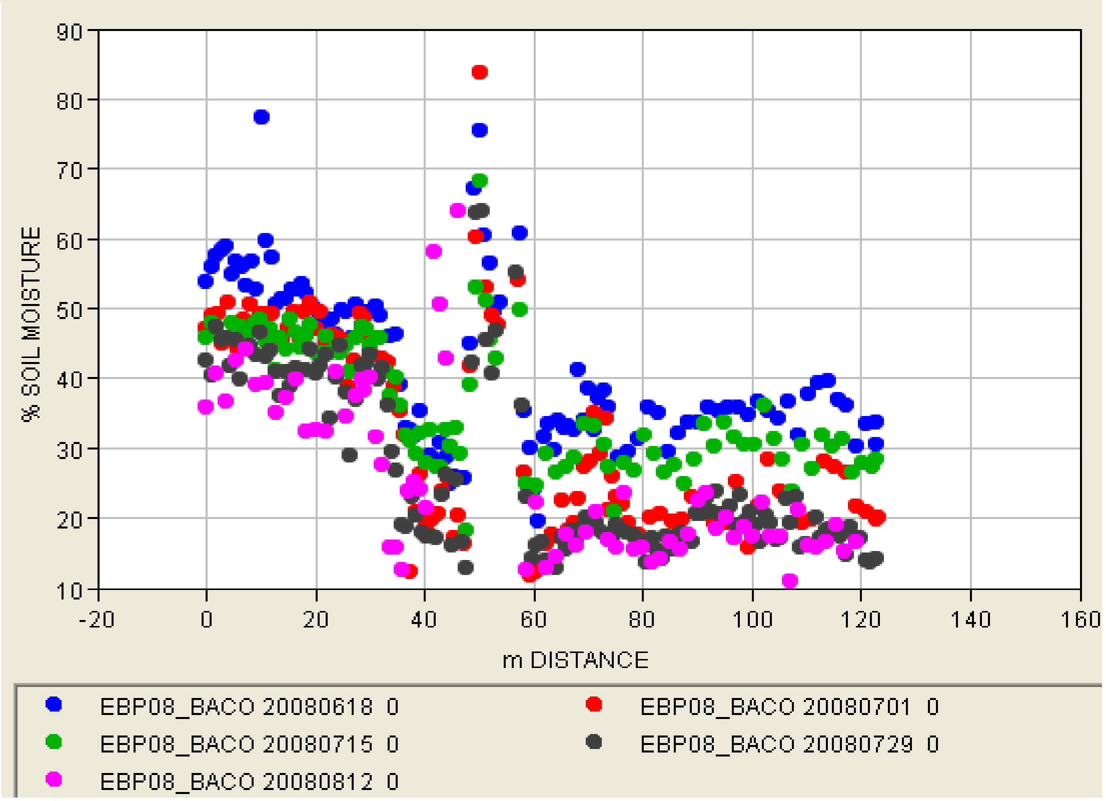
soil moisture at 10 cm

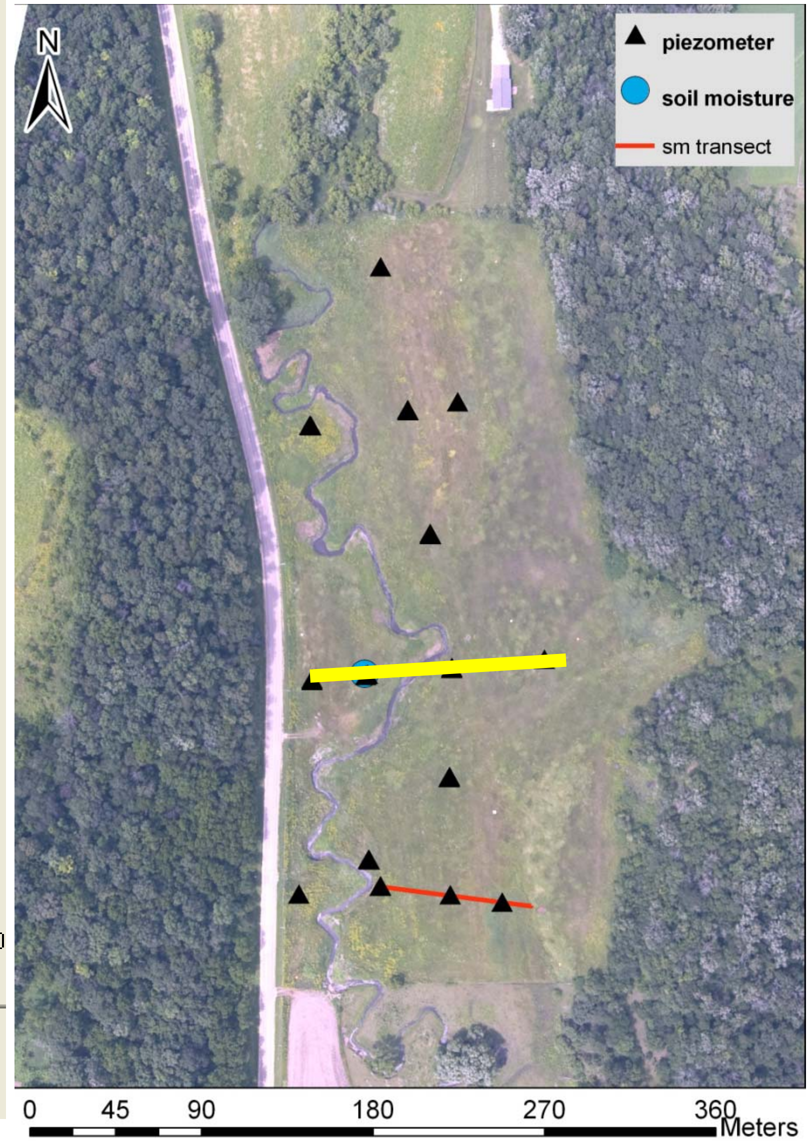




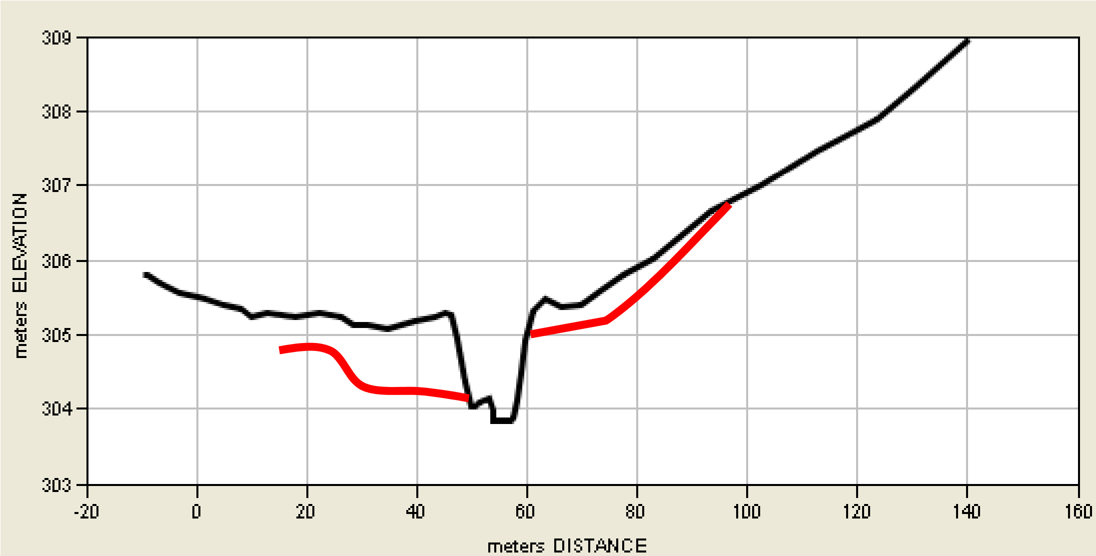


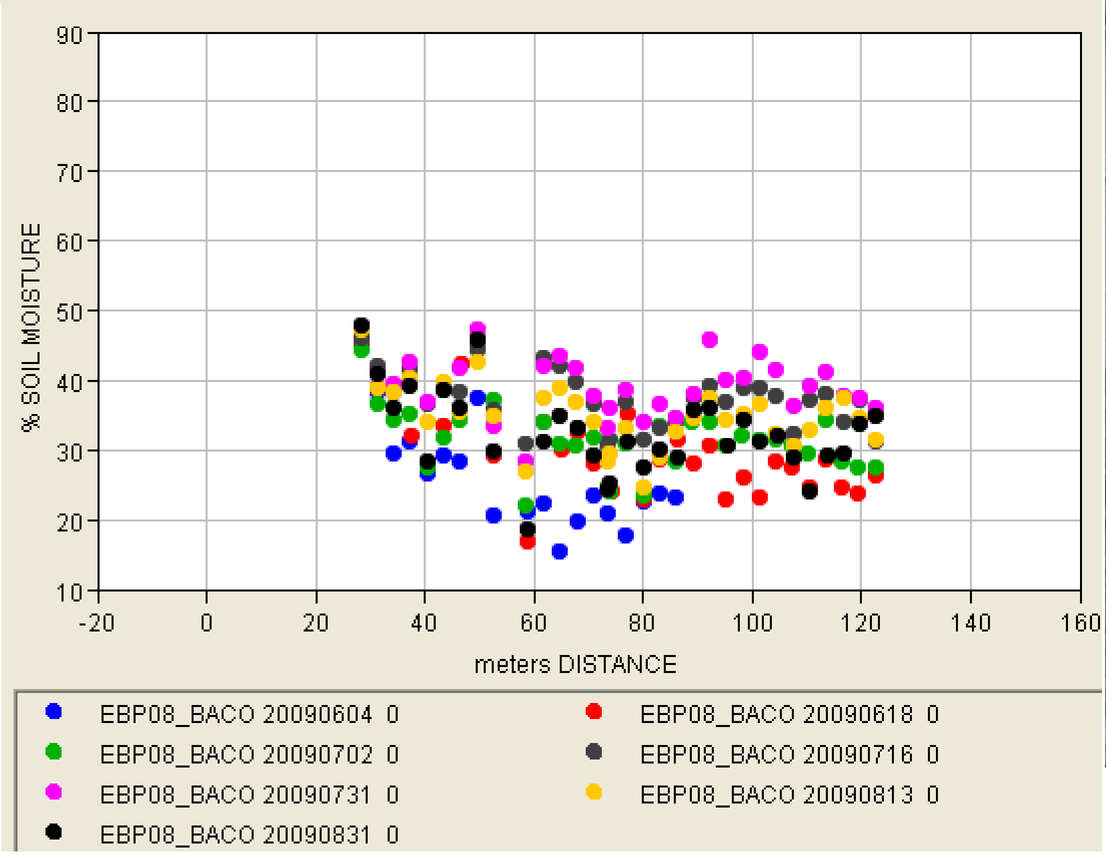
EBP08-BACO 2008

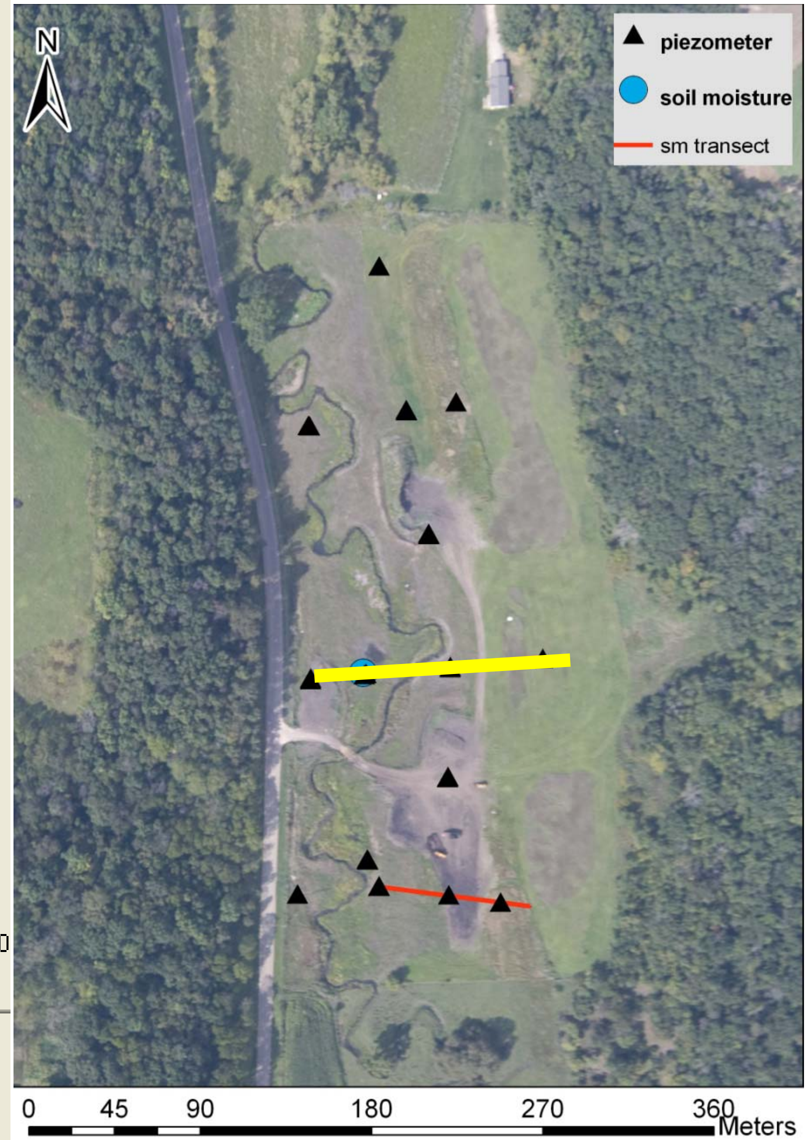




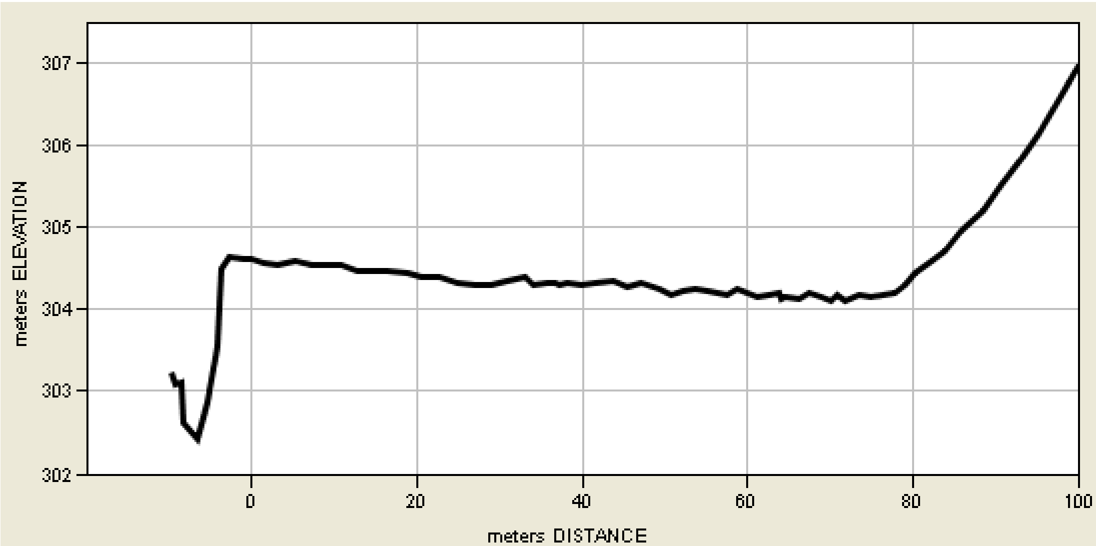
EBP08-BACO 2009

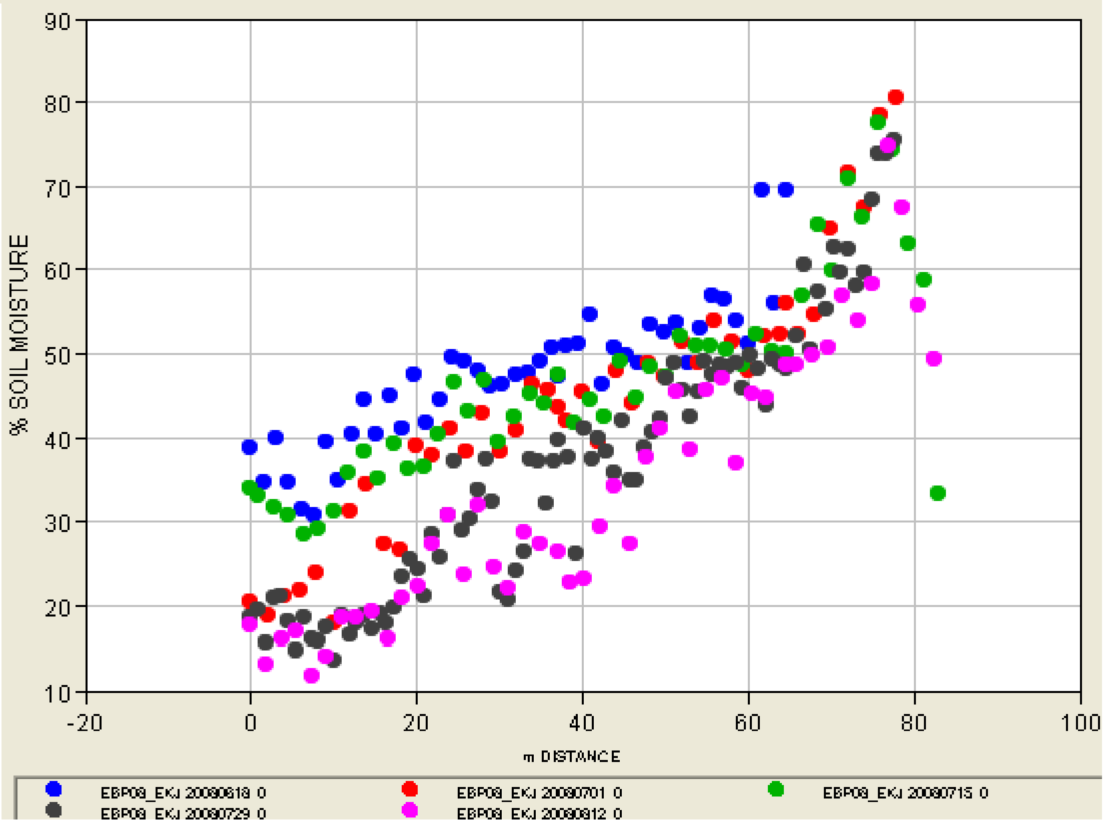


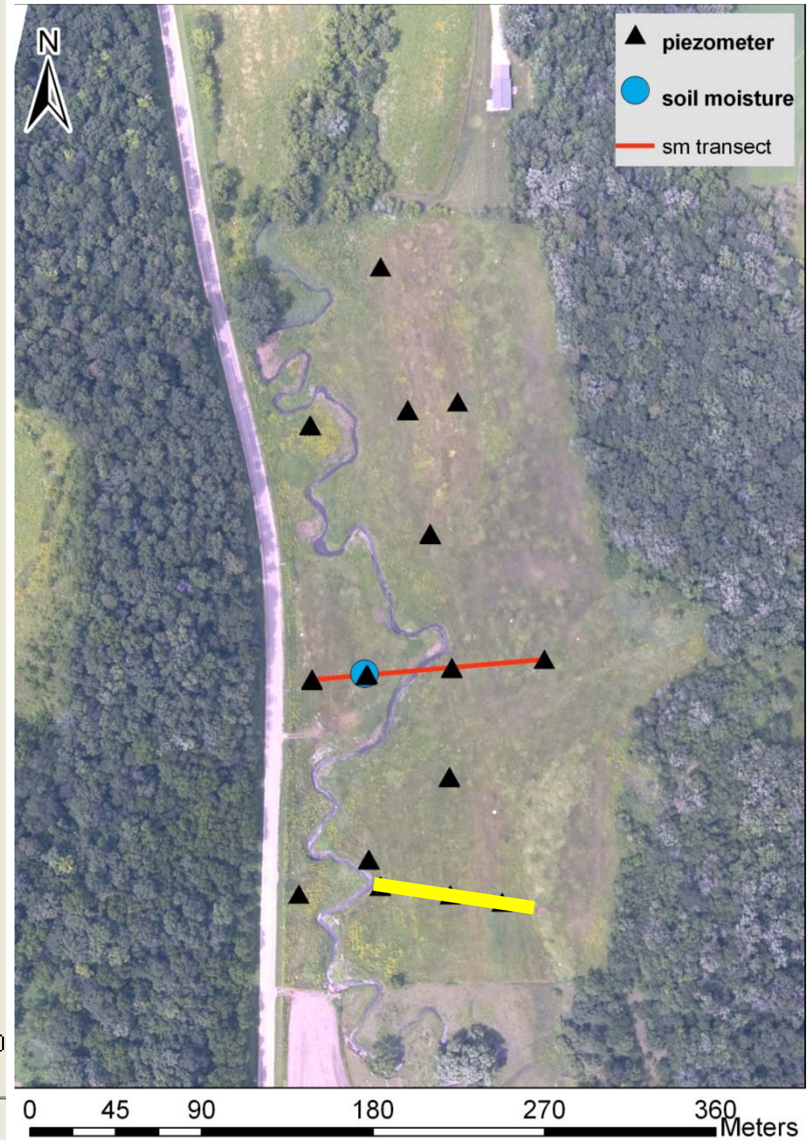




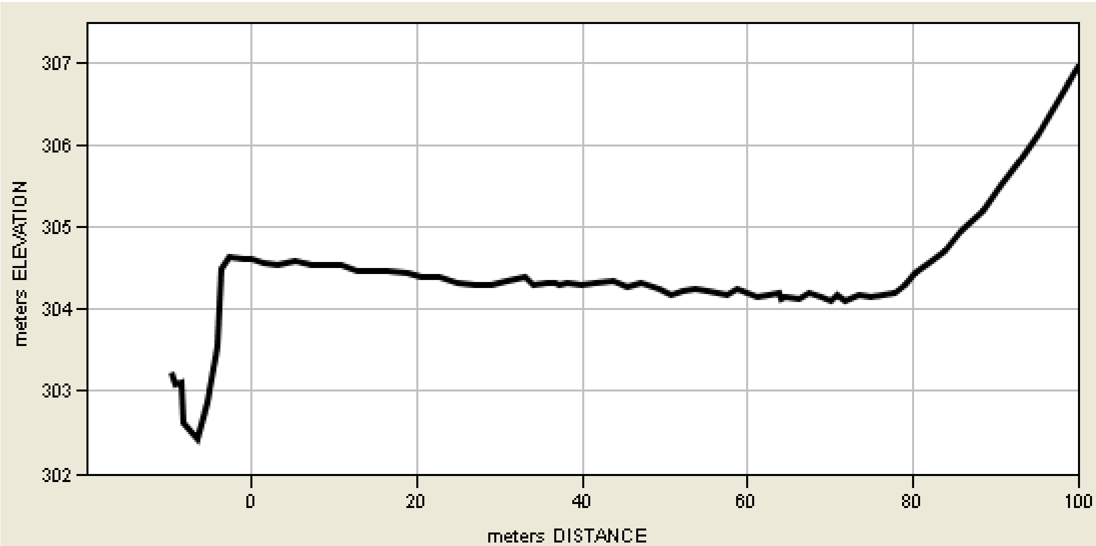
EBP08-EKJ
2008

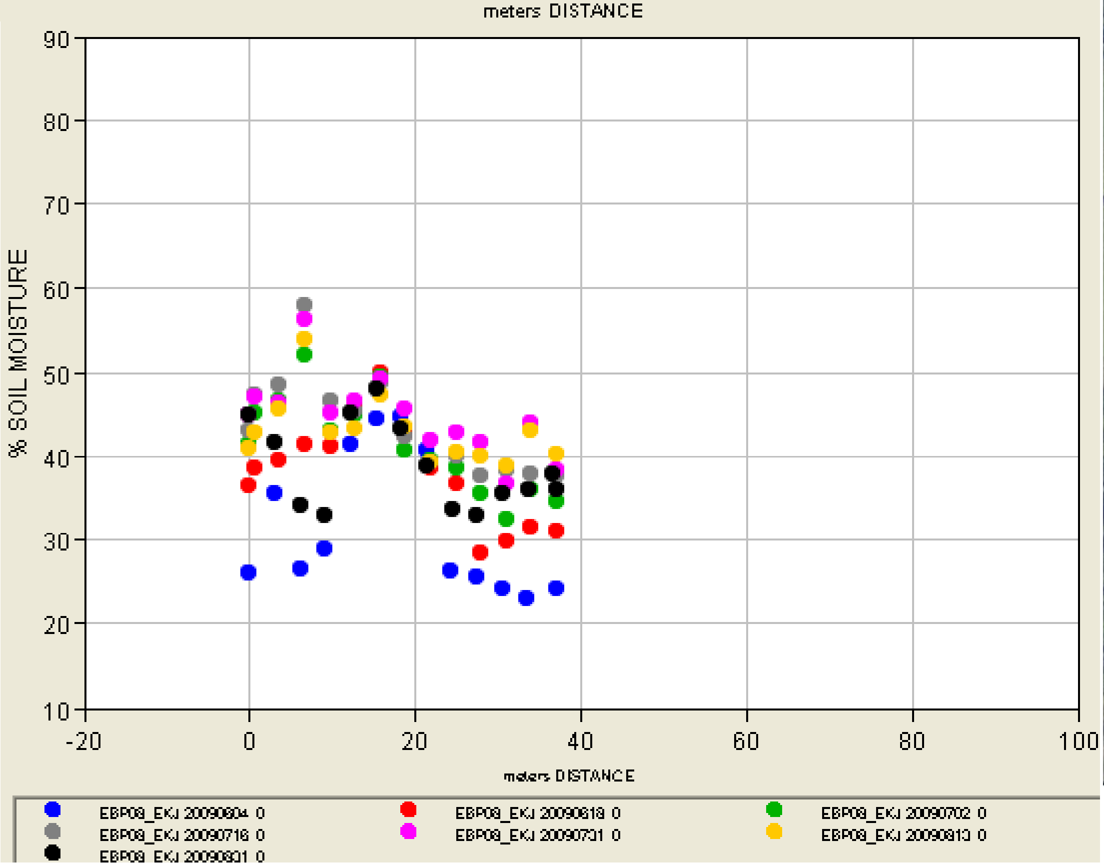


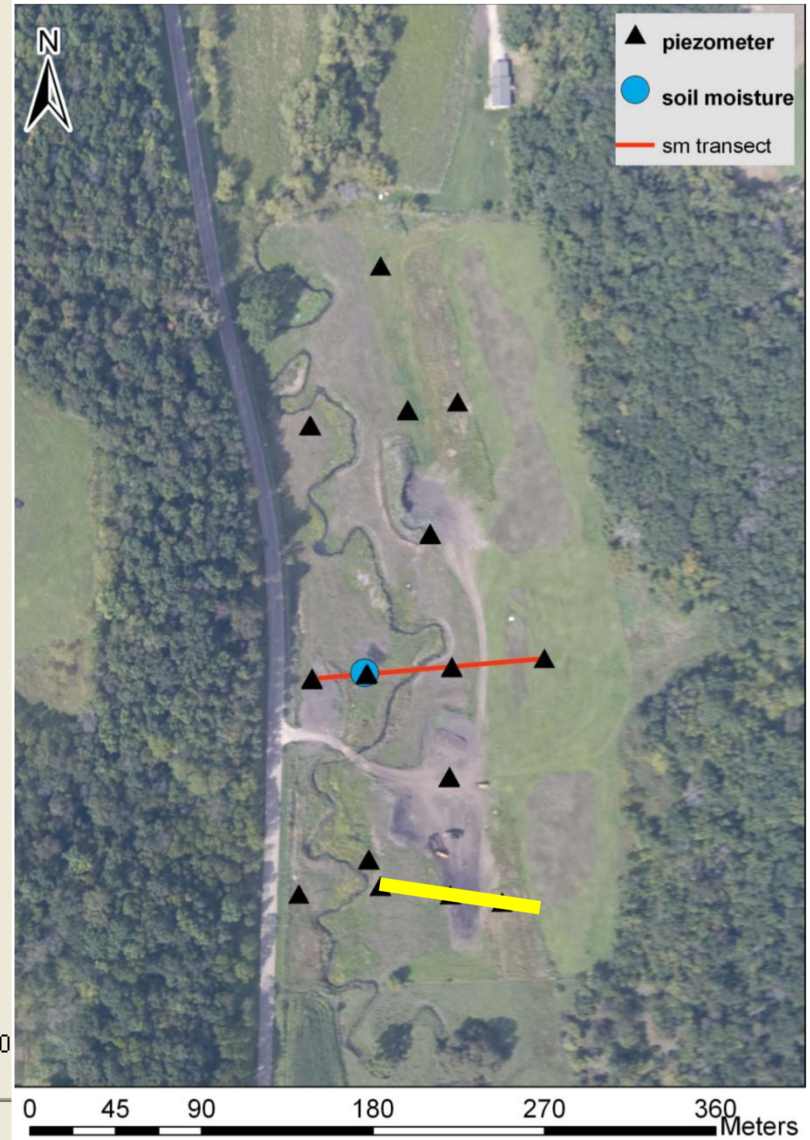




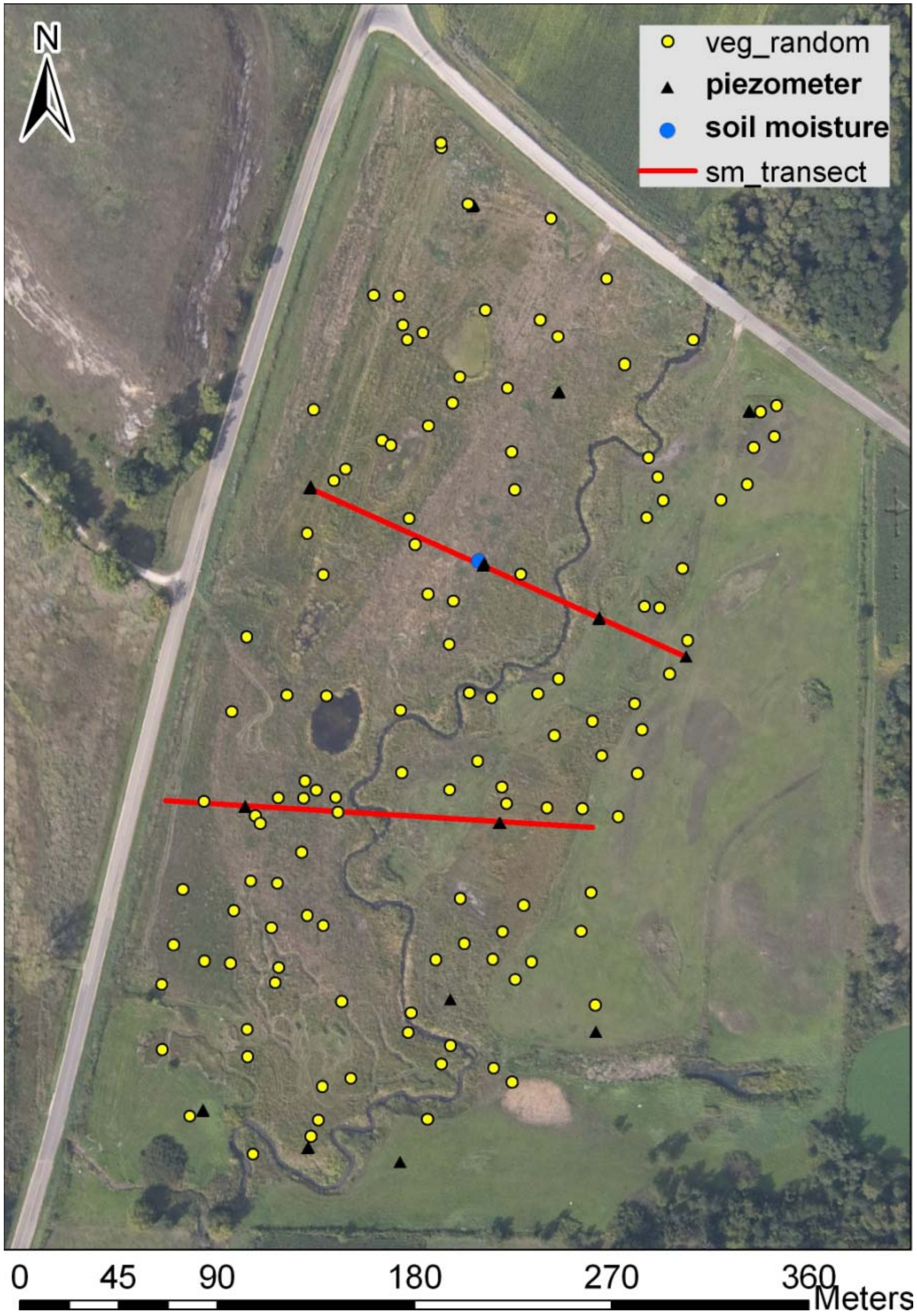
EBP08-EKJ 2009





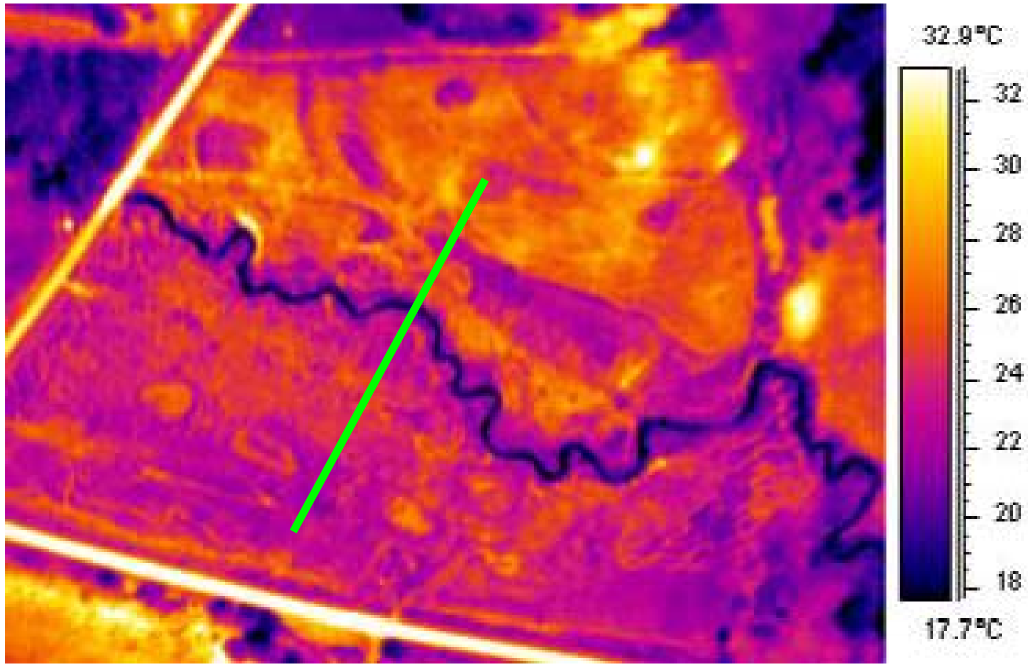


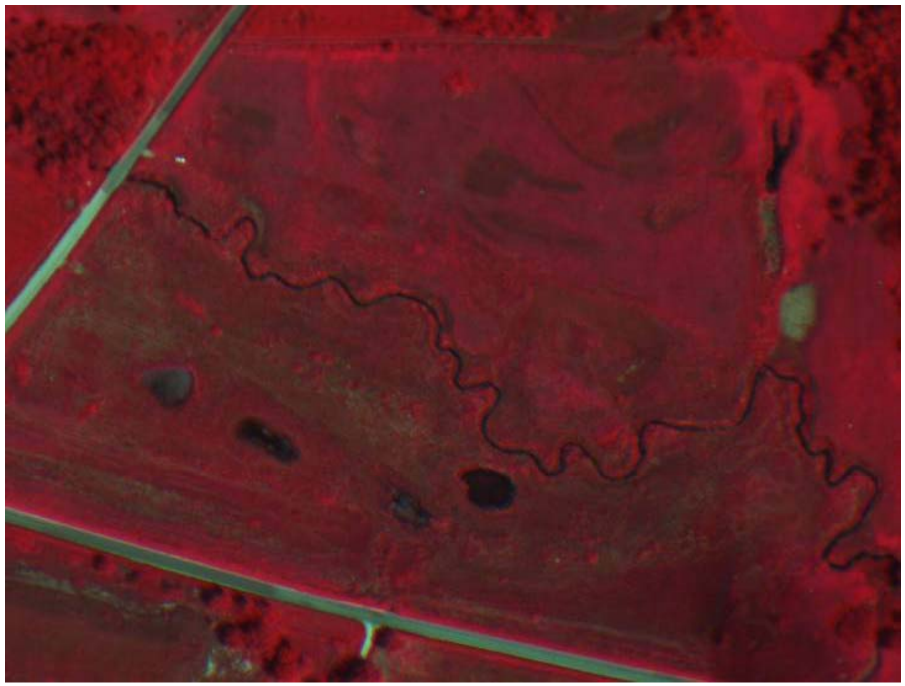
- Vegetation surveys
  - % cover estimates
    - wells
    - along transects
    - random points
  - 240 sample locations
  - 102 species identified

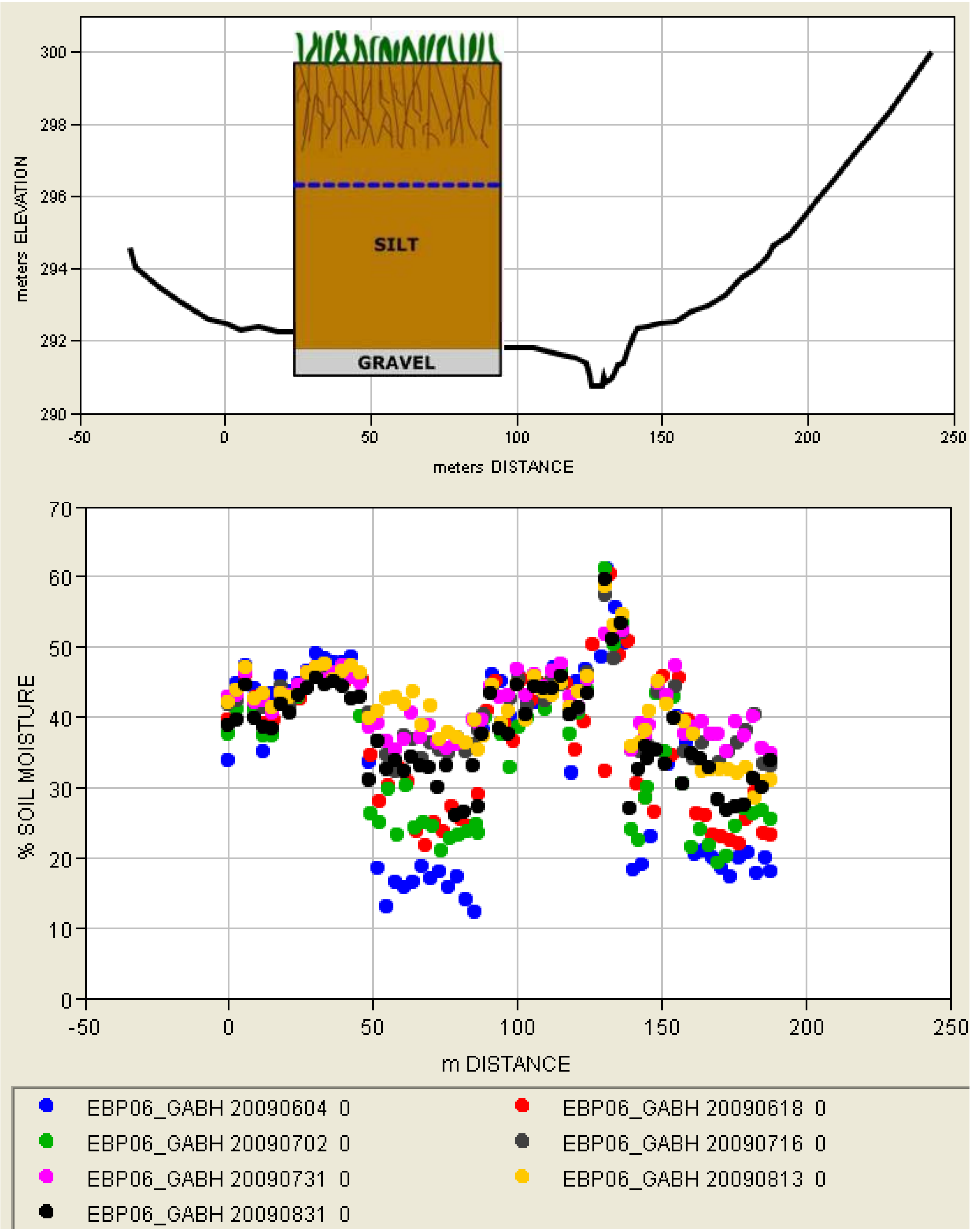


Remote Sensing

- Thermal
  - evapotranspiration estimates (model calibration)
- Near-Infrared
  - vegetation monitoring
  - estimate stress, LAI





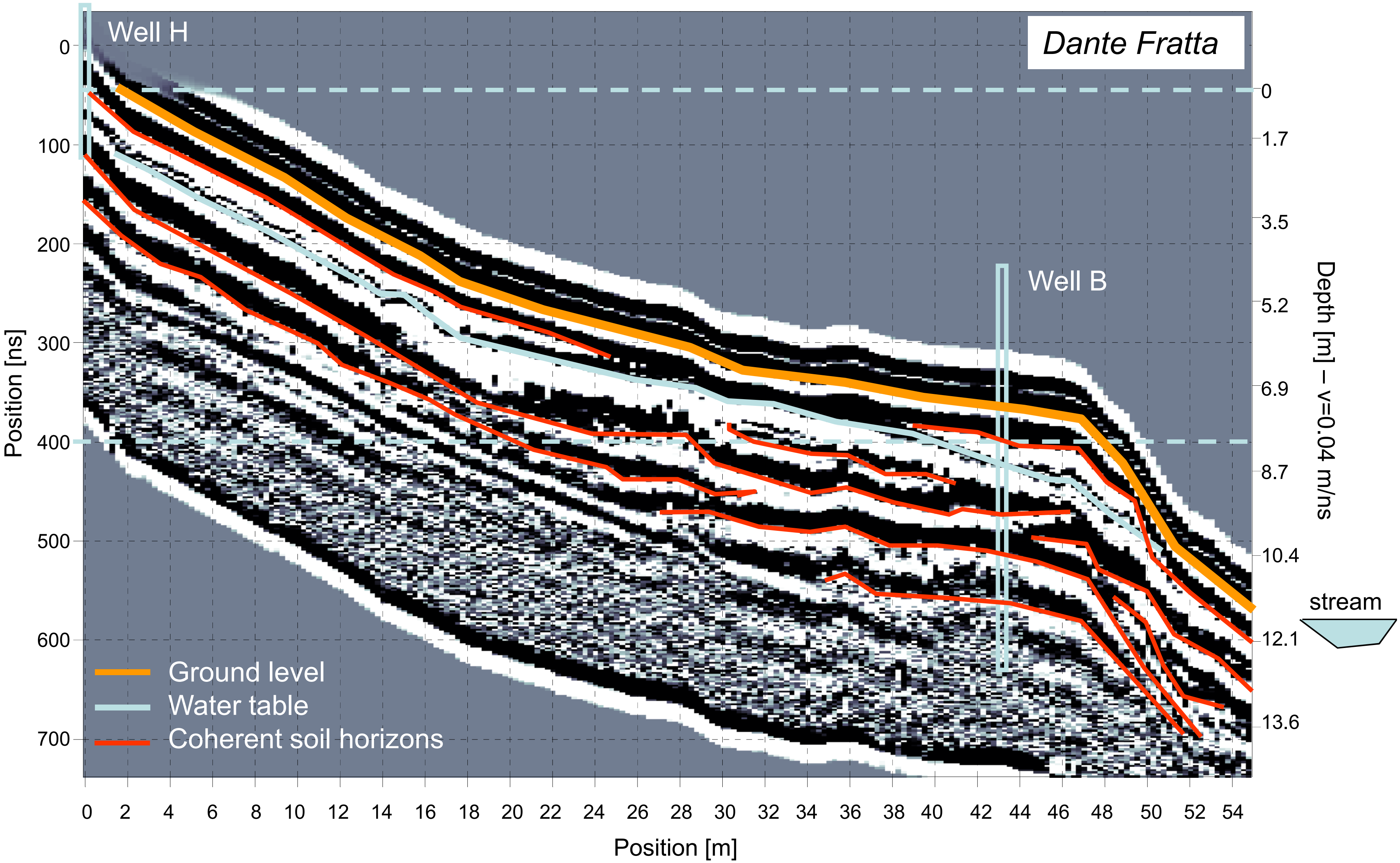


Extend 1-D numerical model across transects

- Interpolate between wells and stream to obtain the specified head in the gravel layer
- Eventually, simulate gravel aquifer across entire floodplain

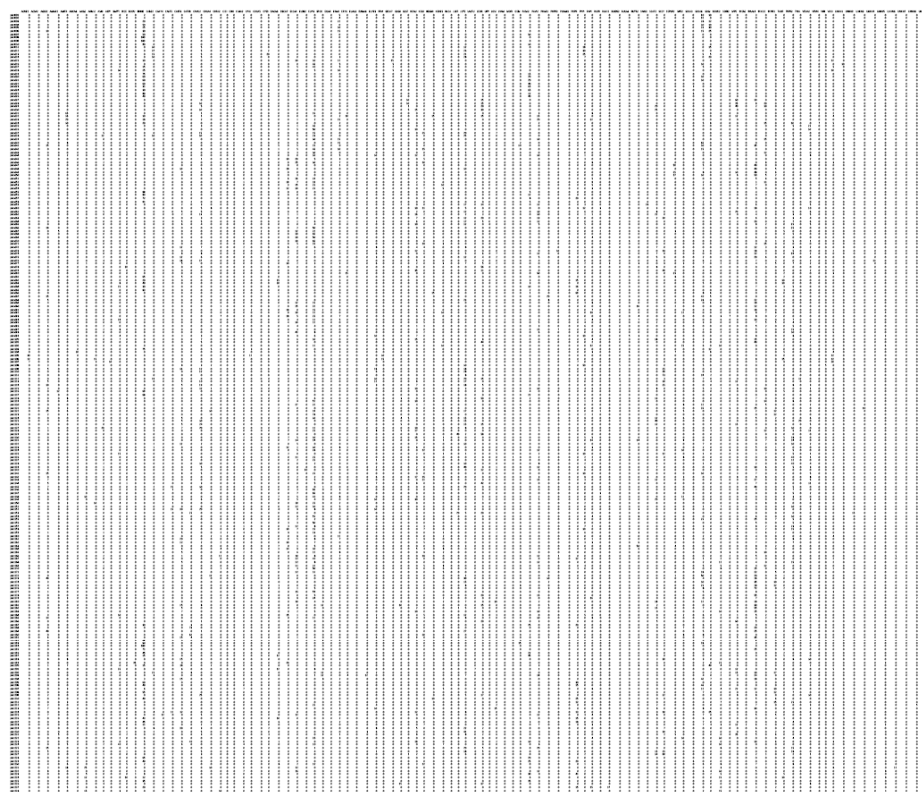
Geophysical methods - GPR

- Estimate extent and continuity of confining layer
- Augment with more soil cores



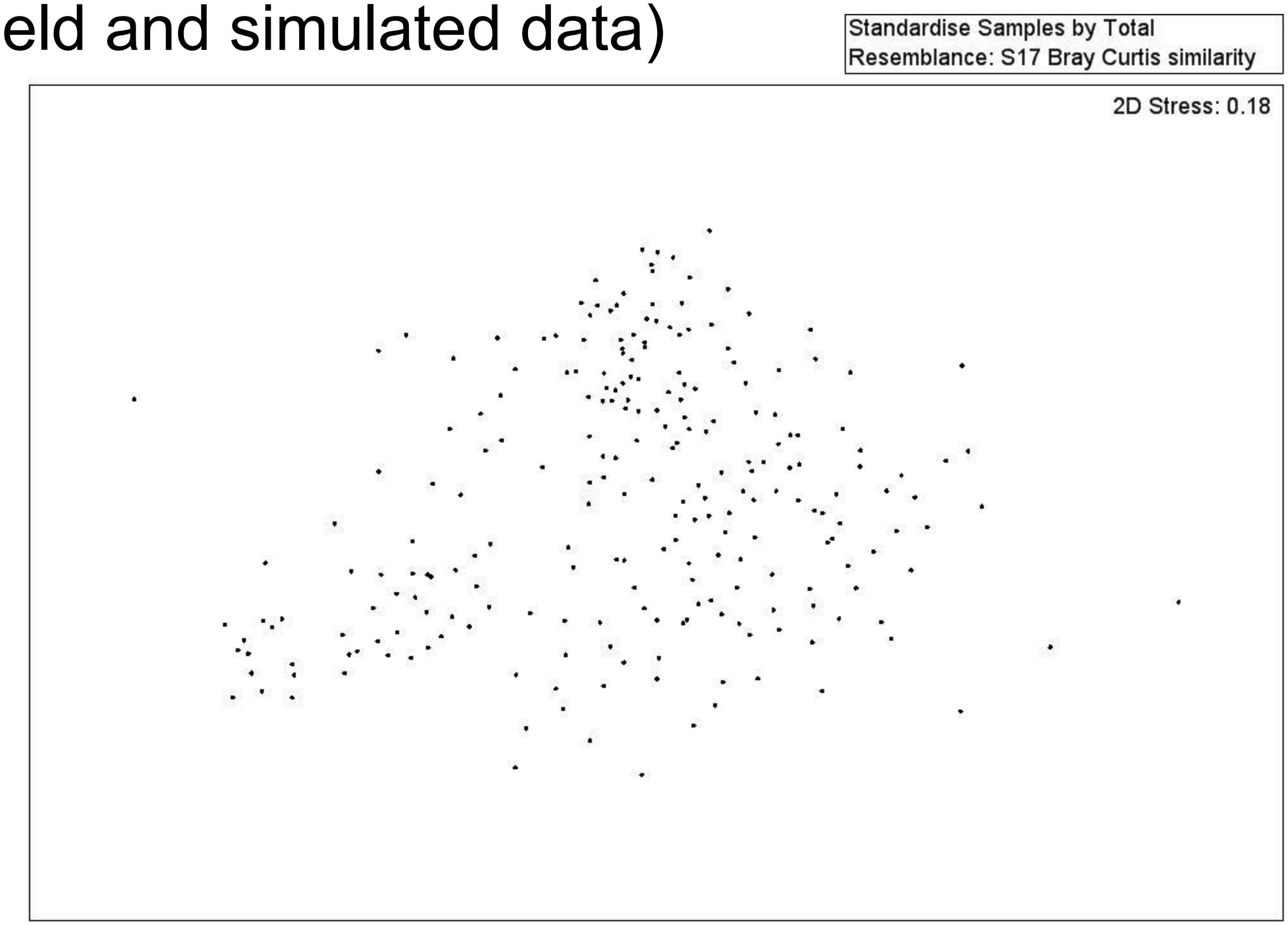
Plant Species Ordination

- Data matrix : species abundance vs plot
- Calculate a distance metric
  - How close are two plots in multi-dimensional space?



Plant Species Ordination

- Determine synthetic axes that explain the most variation between sample plots
- Correlate the synthetic axes with soil water regime metrics (field and simulated data)



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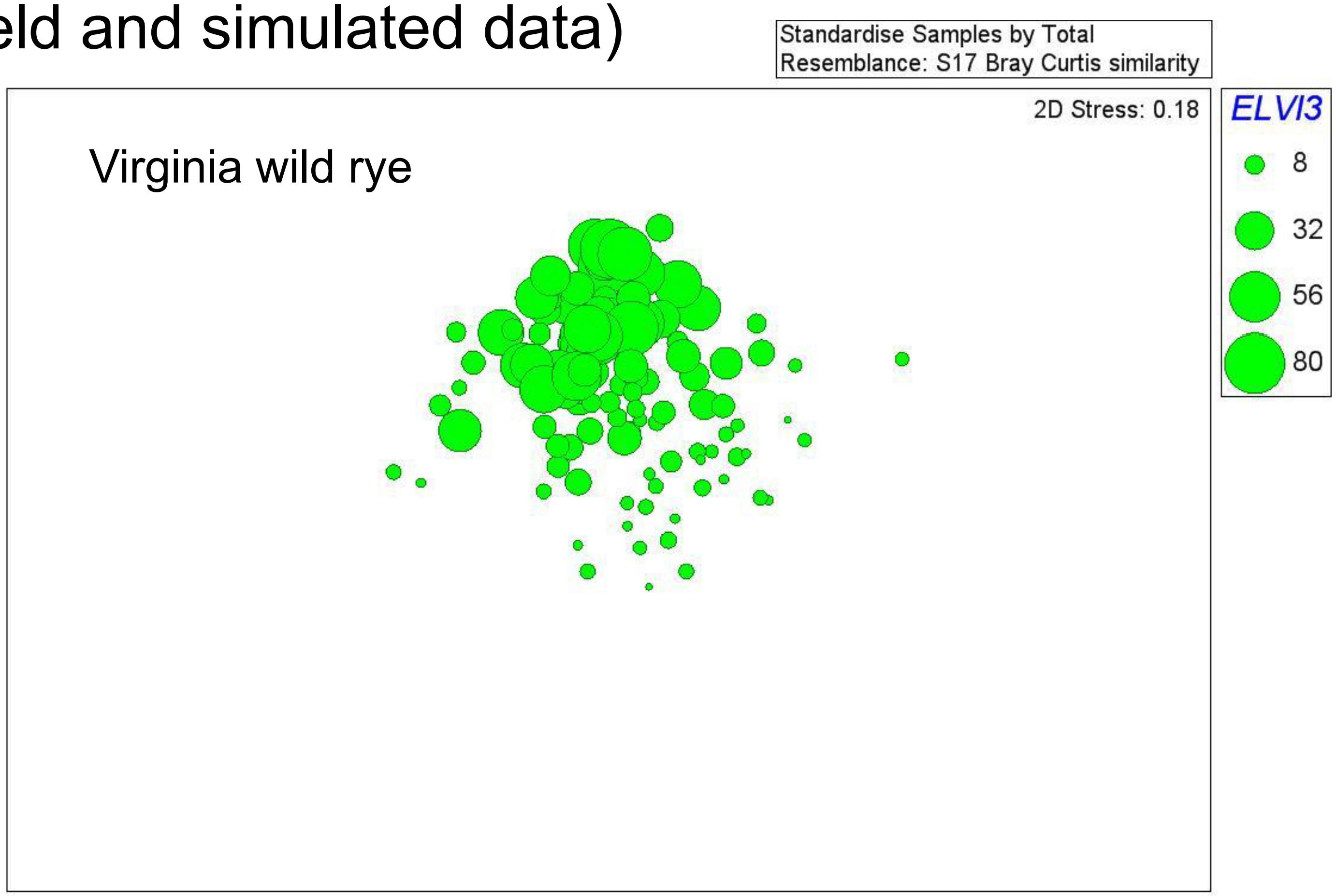

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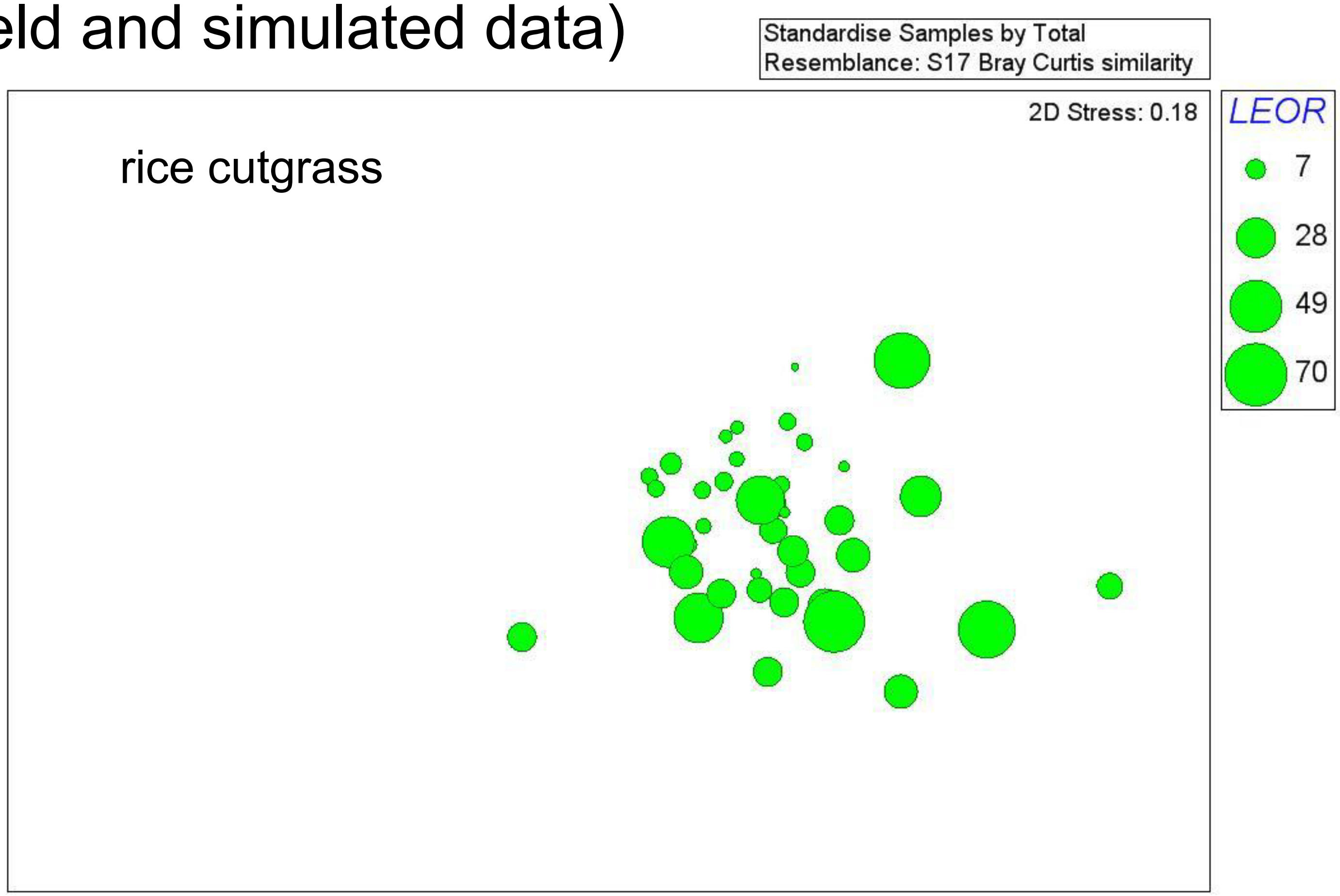


Plant Species Ordination

- Ultimately, determine the regime metrics that best predict plant species composition

- Create a statistical model to predict species abundance based on simulated data

Questions?

Extra slides

Floodplain Hydrologic Model

- 1-D transient, variably-saturated groundwater flow model

Richards Equation

$$\frac{\partial \theta}{\partial t} = C(\psi)\frac{\partial \psi}{\partial t} = \frac{\partial}{\partial z}\left[K(\psi)\left(\frac{\partial \psi}{\partial z}+1\right)\right]+Q_s(t)$$

Darcy's Law

$$q_x = K_s \frac{\partial h}{\partial x}$$

$$\frac{\Delta storage}{\Delta time} = \left(FLUX_{IN} - FLUX_{OUT}\right) + Q_S$$

C(ψ) *= ∂θ/∂ψ (1/L) – soil moisture characteristic function*

θ*: volumetric water content (L^3/L^3)*

ψ*: pressure head (L)*

K(ψ)*: unsaturated hydraulic conductivity (L/T)*

z*: elevation (L)*

Q_s *: source/sink term (1/T) – transpiration*

Soil Moisture Characteristic & Hydraulic Conductivity Functions

van Genuchten

$$S_e = \left(1 + |\alpha\psi|^n\right)^{-m}$$

where ***m*** *= 1-1/n*

$$K = K_s S_e^{\,L}\left[1 - (1 - S_e^{\,1/m})^m\right]^2$$

effective saturation

$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r}$$

θ_r : *residual θ*

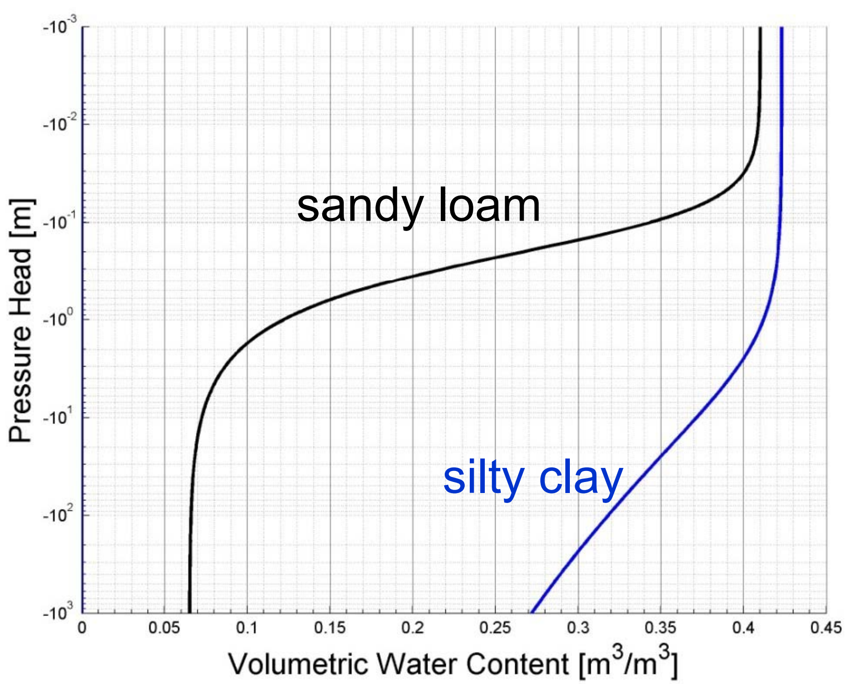
θ_s : *saturated θ*

α,n,L : *fit parameters*

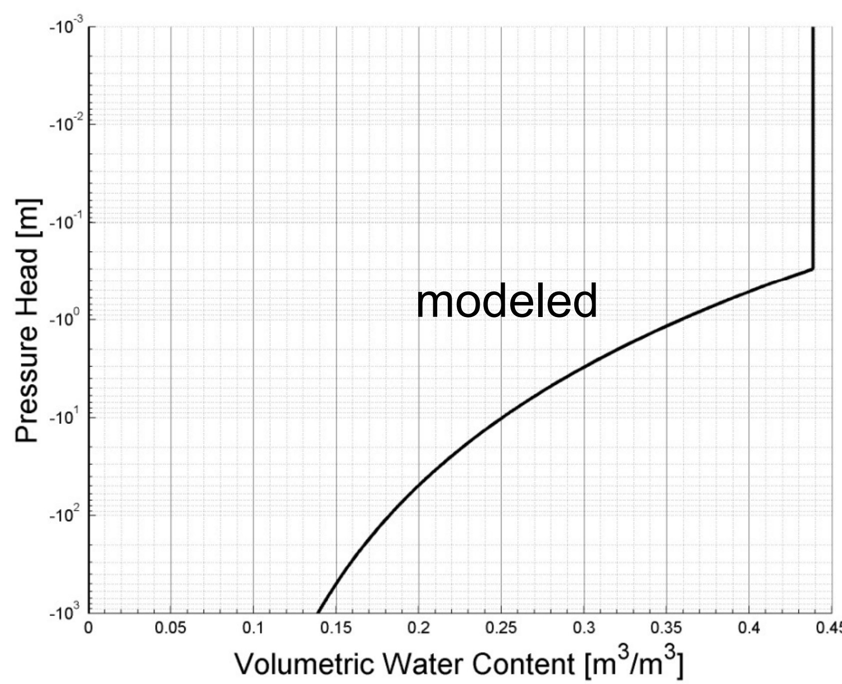
Brooks & Corey

$$S_e = \begin{cases} |\alpha\psi|^{-n} & \psi < -1/\alpha \\ 1 & \psi \geq -1/\alpha \end{cases}$$

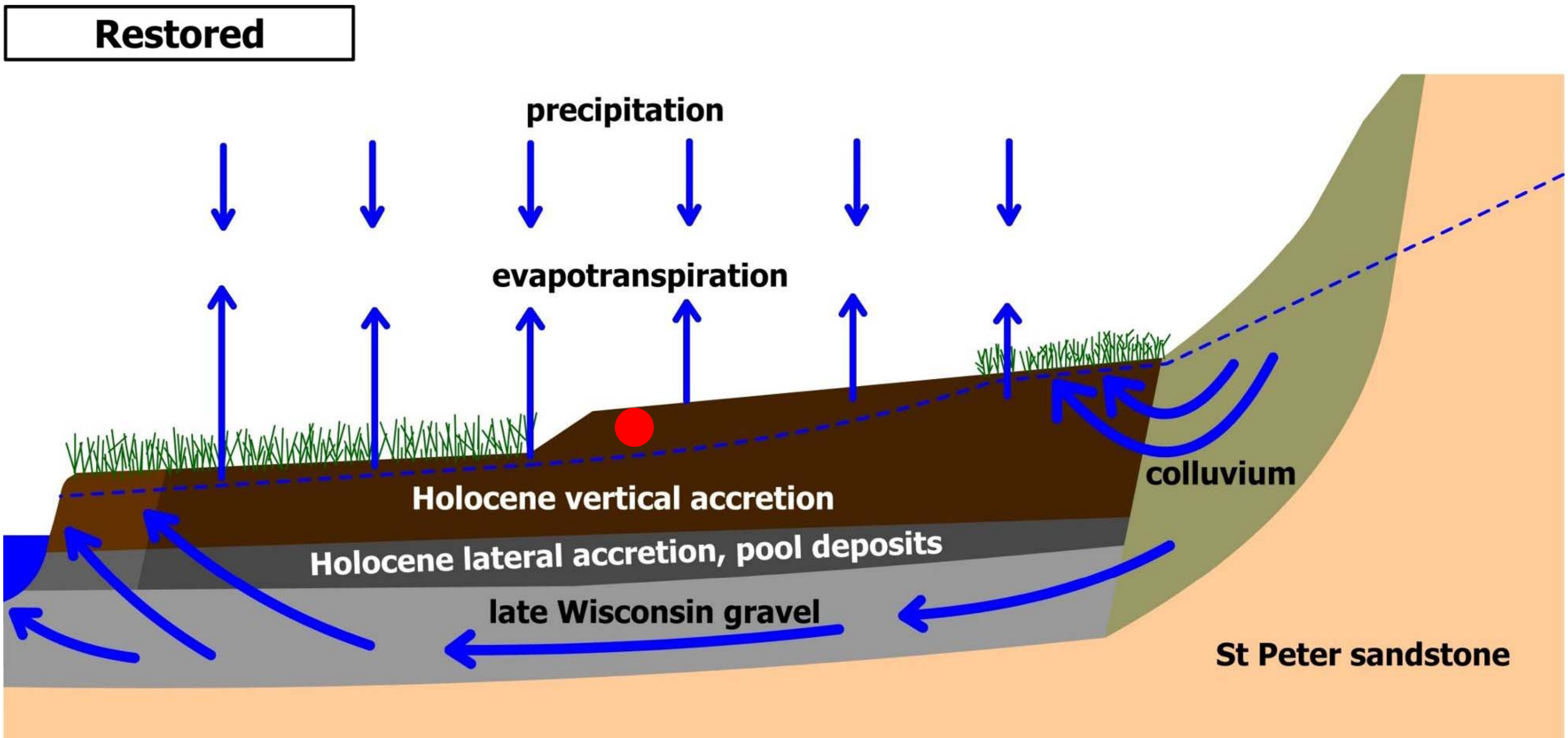
$$K = K_s S_e^{\left(2/n + L + 2\right)}$$



← MORE SUCTION

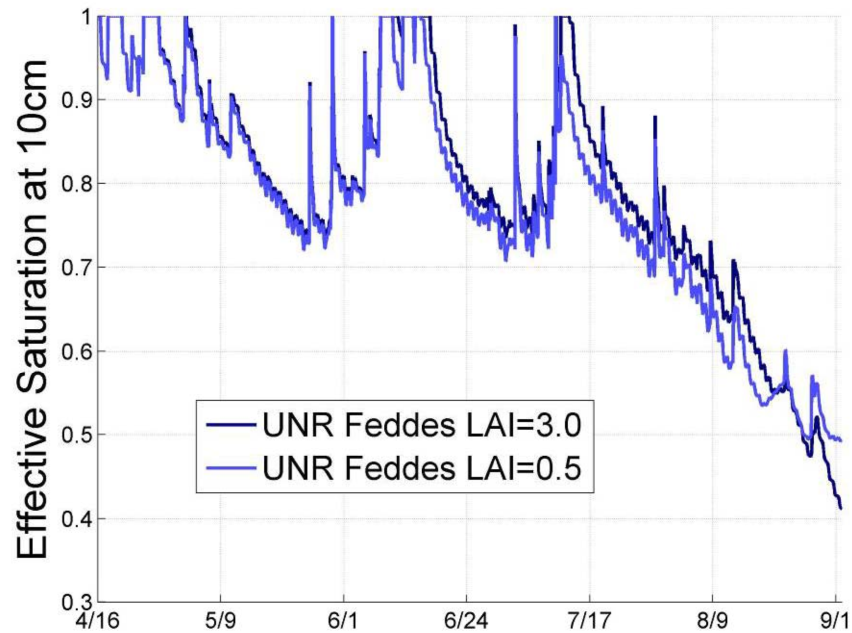


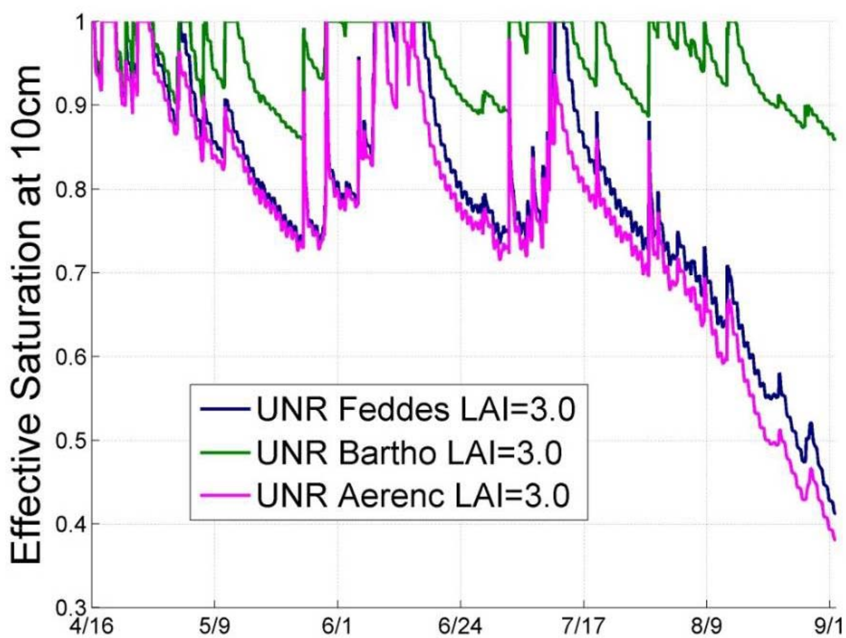
Implications for restoration

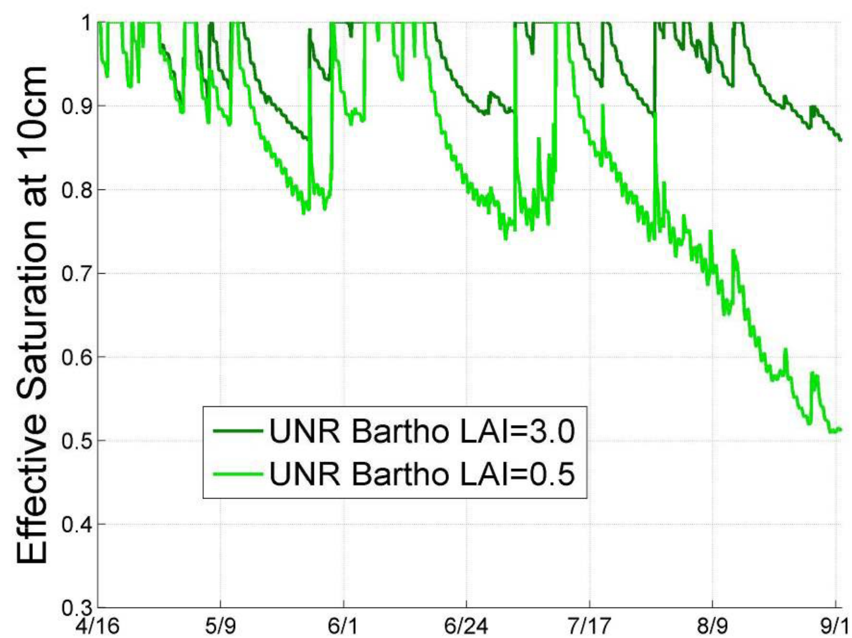


Unrestored Simulations

- ↑T, ↓E ↑E, ↓T
- Bartholomeus strongly limits transpiration
- Higher evaporation lowers soil moisture → allows for transpiration to turn ‘on’







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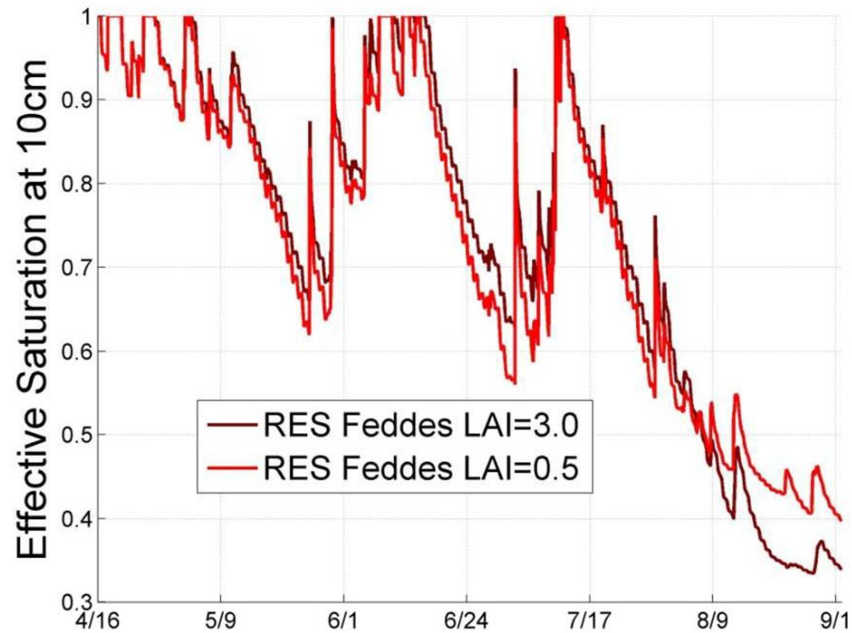
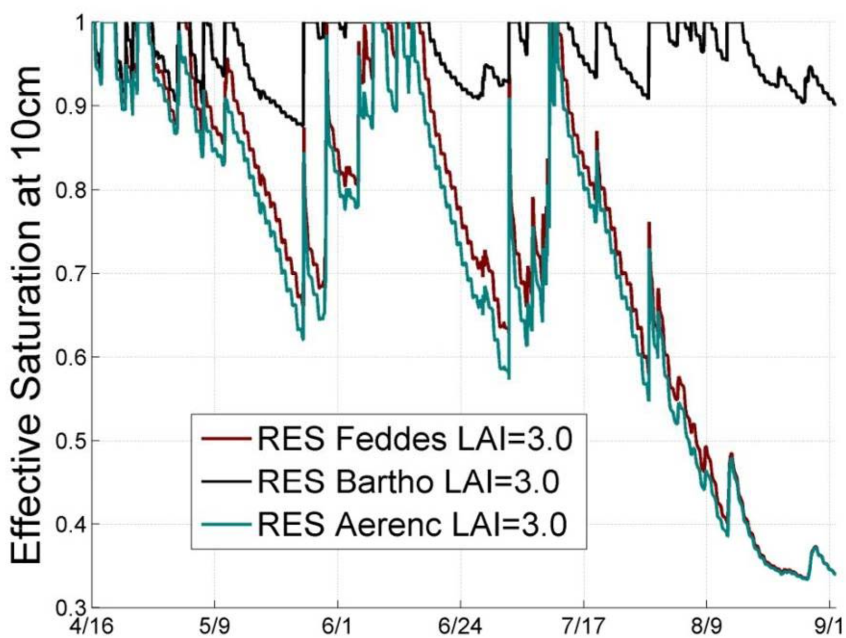
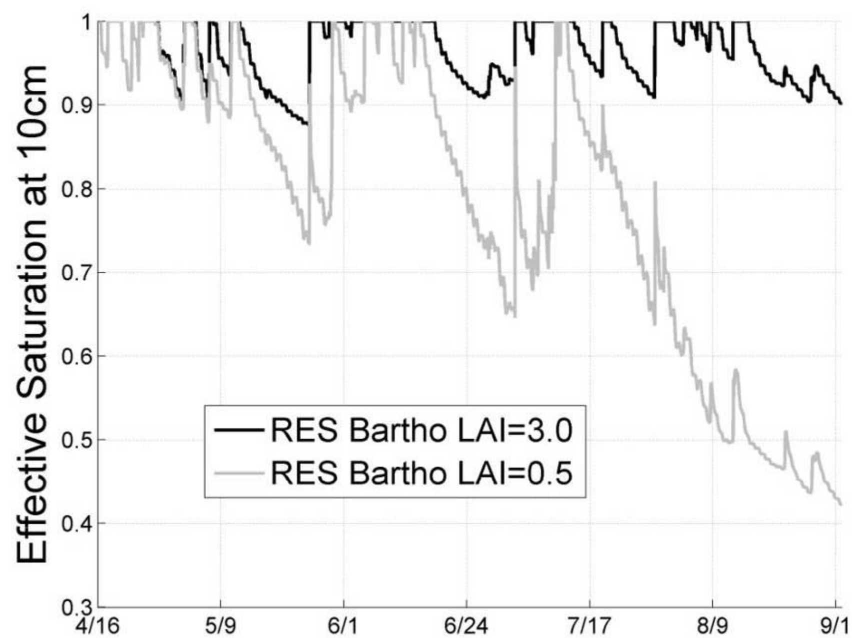
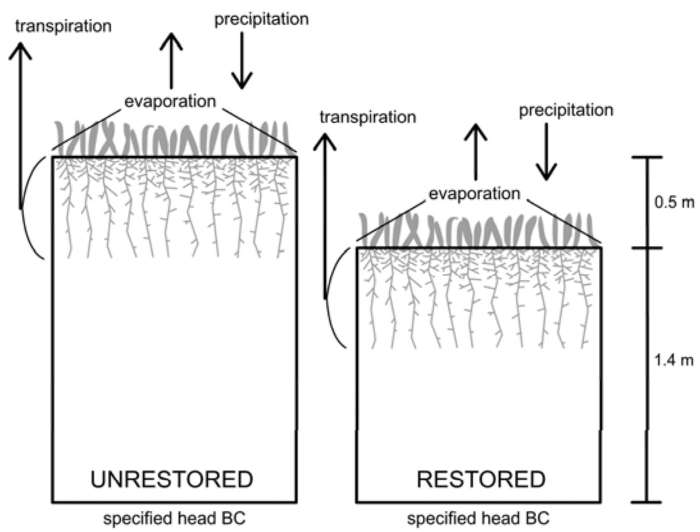


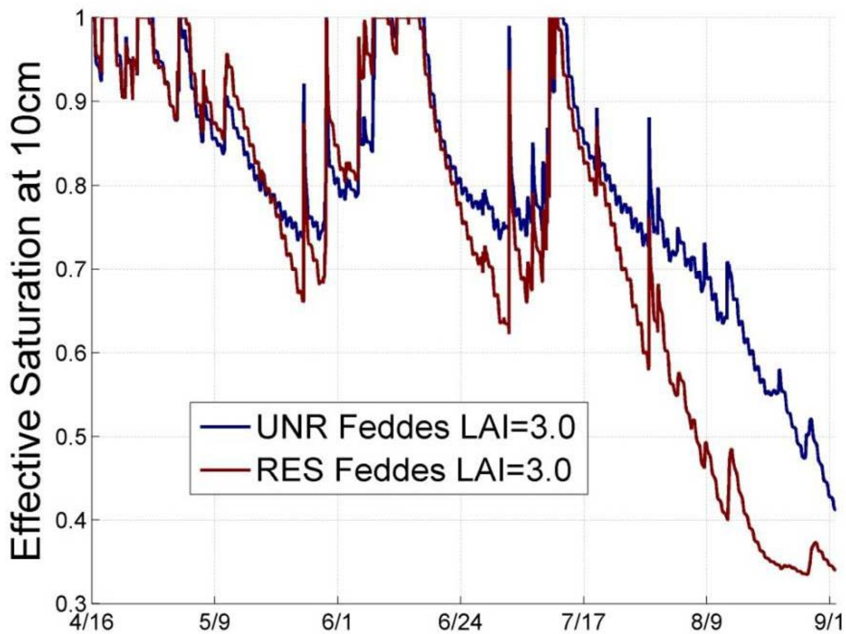


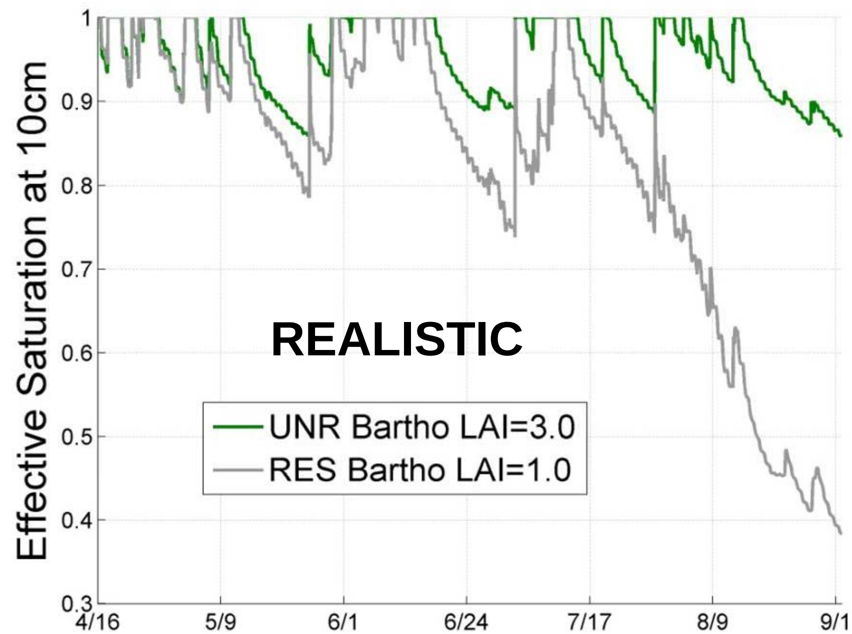


Unrestored vs Restored

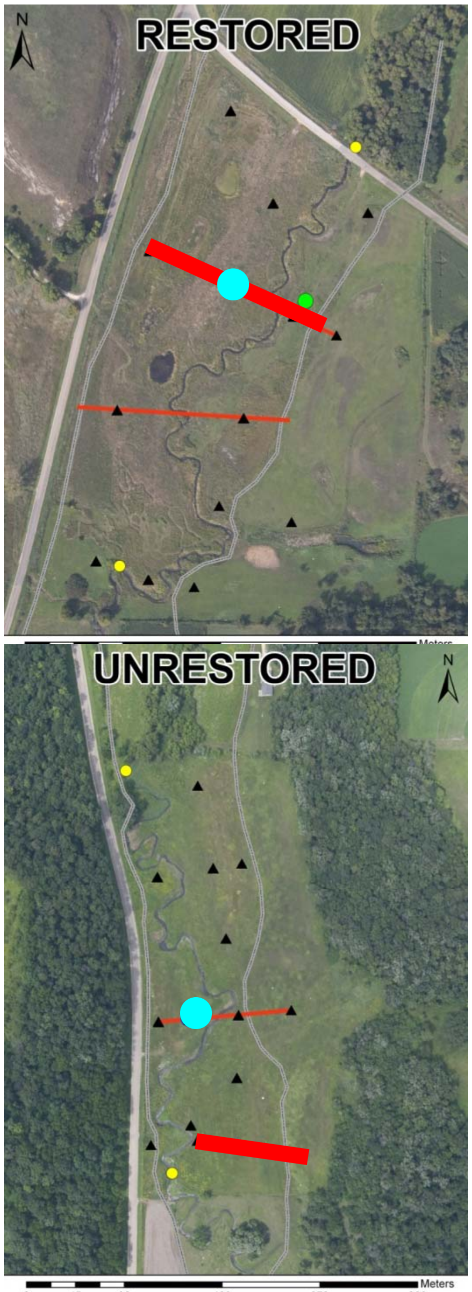
- Smaller amount of storage (restored)
  - depleted quicker if no groundwater is available to replenish

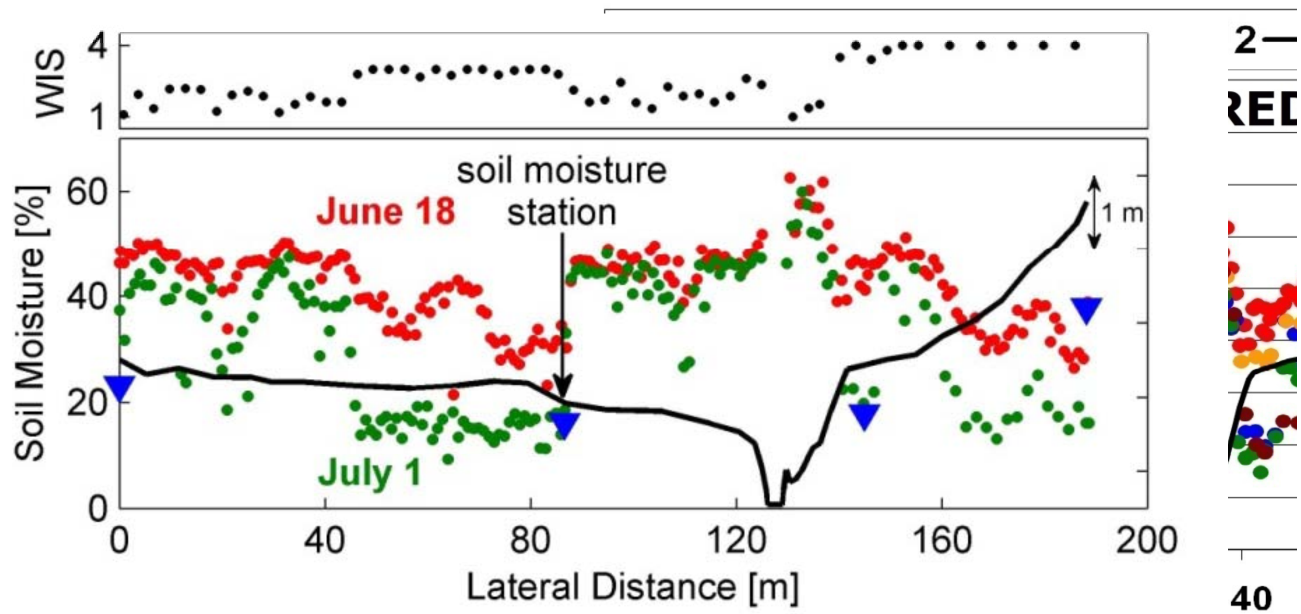


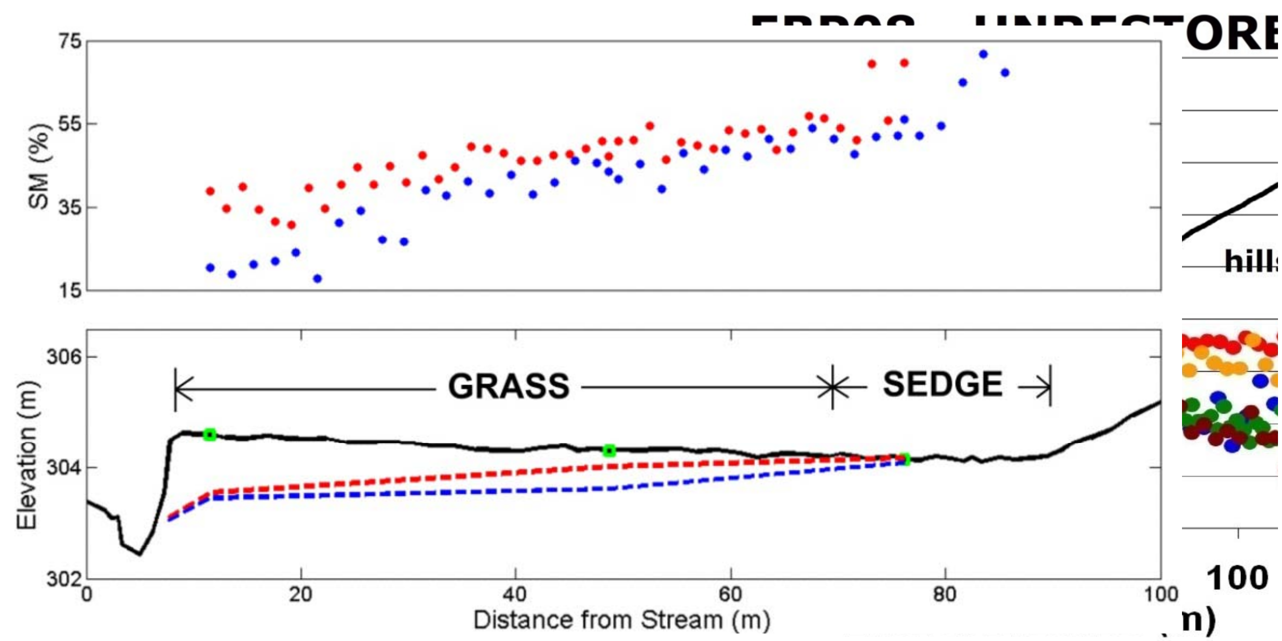




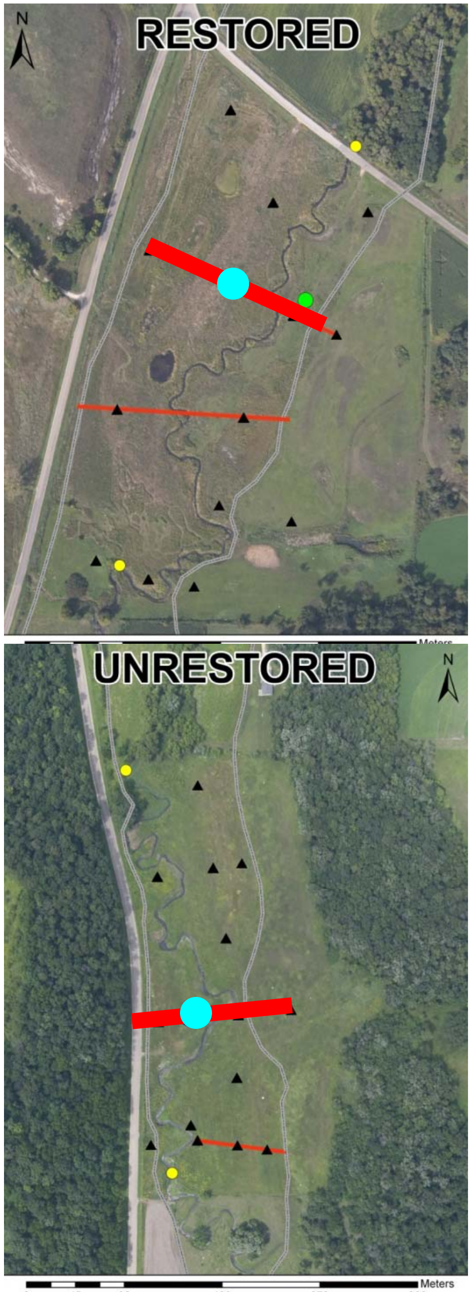
Soil Moisture and Vegetation Transects

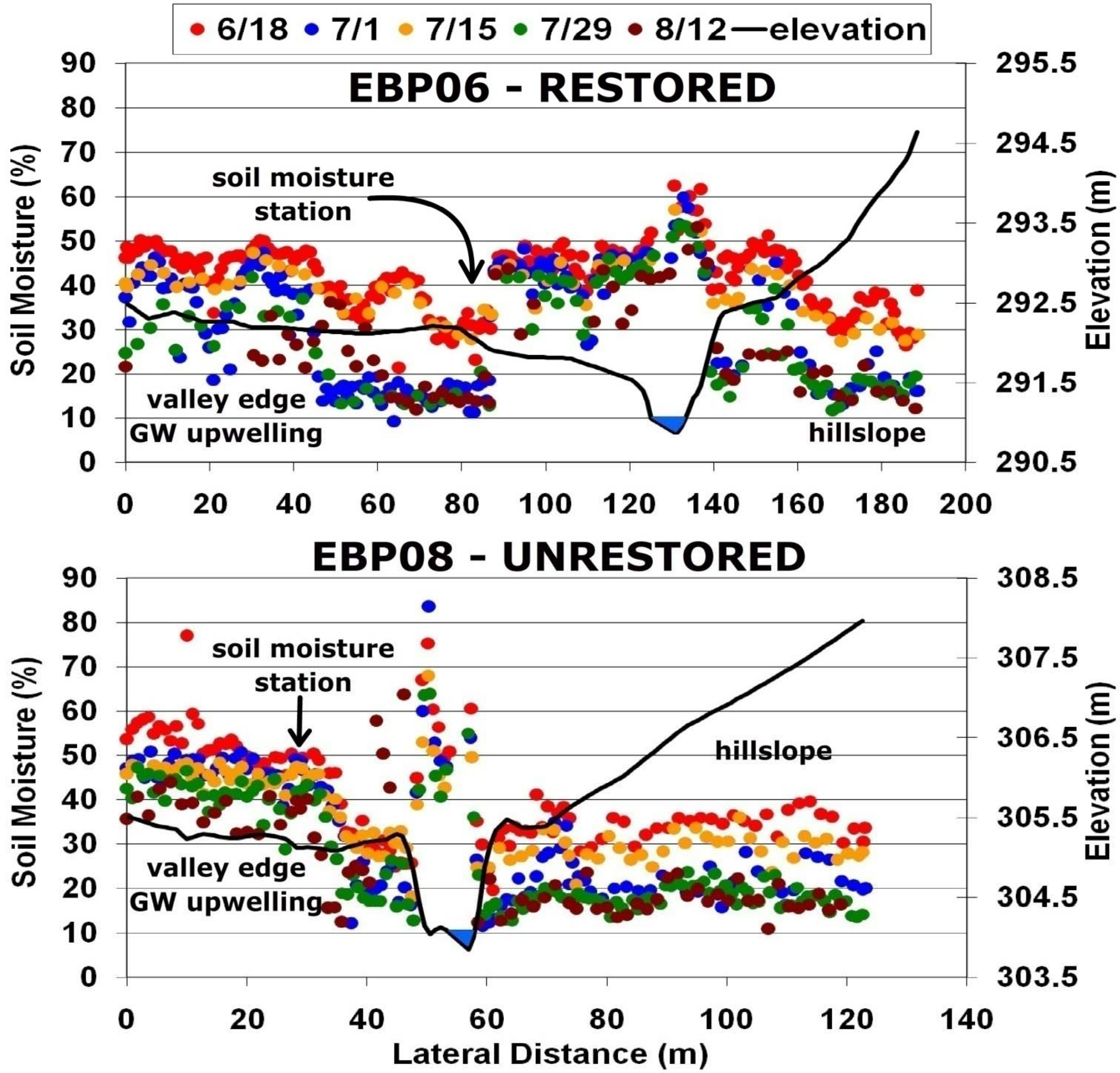




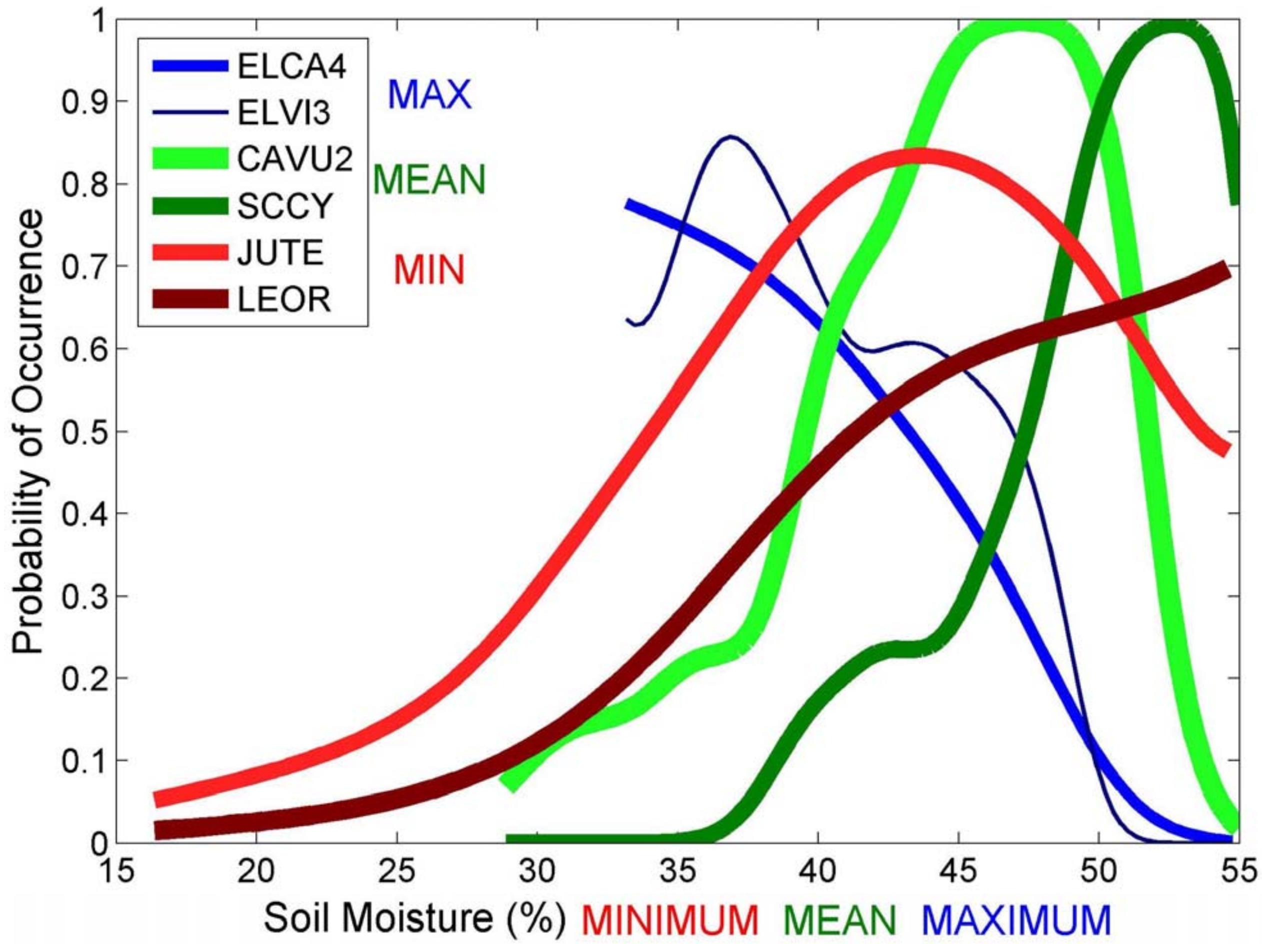


Soil Moisture Transects

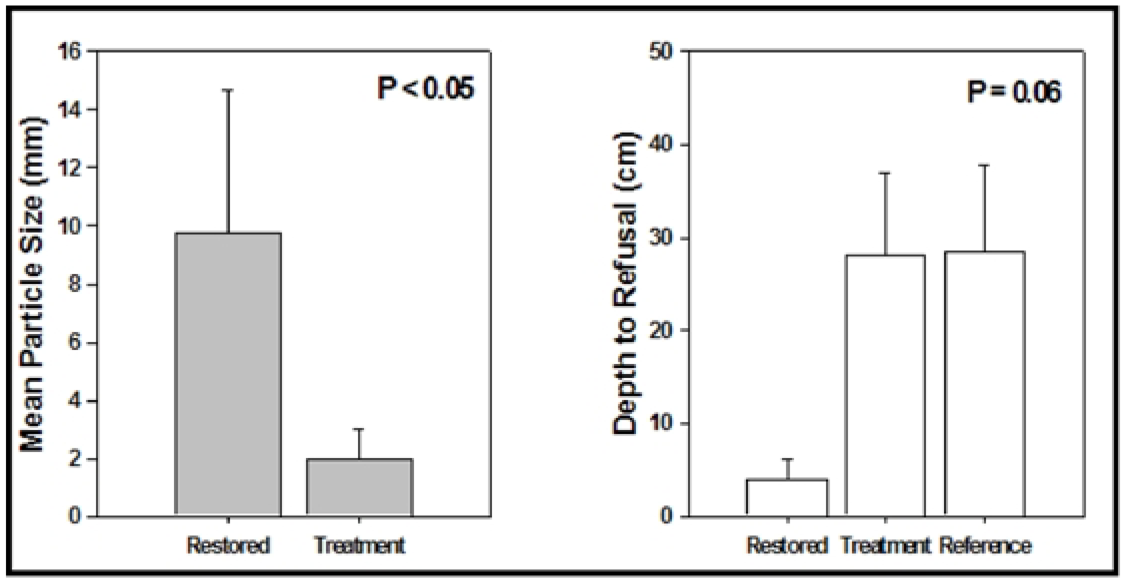




Predictive Vegetation Models

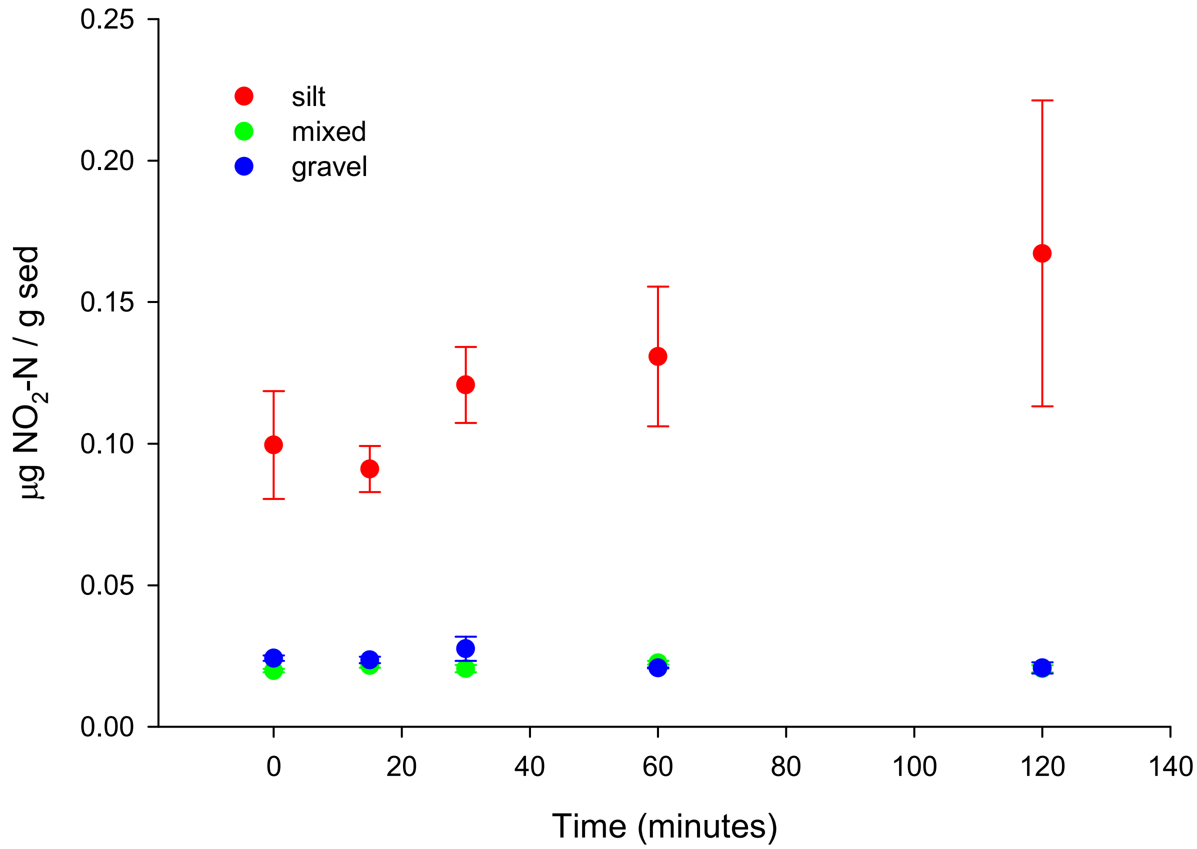


Streambed substrate and biogeochemistry



Production of Nitrite – NO_2

- potent toxin
- affects growth, respiration, reproduction, and survival of sensitive aquatic biota



Restored Site - April 25, 2008 flood

~2.0 inches on saturated watershed

Restored Site – April 25, 2008 flood

- Still a fair amount of sediment moving through this watershed
- Channel geometry: starting to narrow

Un-restored site – April 25, 2008

- Not as much erosion as August 2007 event