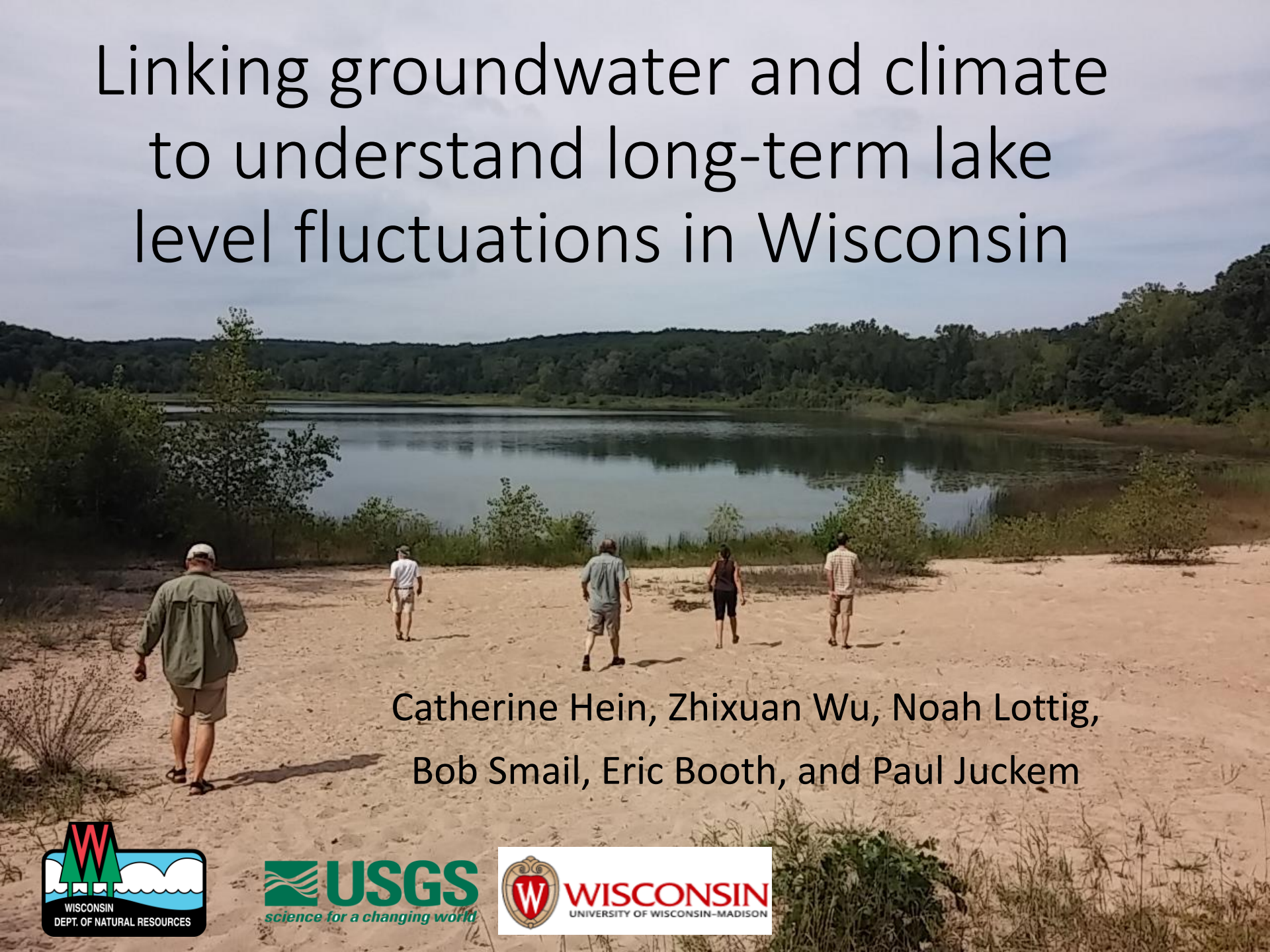
Linking groundwater and climate to understand long-term lake level fluctuations in Wisconsin



Catherine Hein, Zhixuan Wu, Noah Lottig,

Bob Smail, Eric Booth, and Paul Juckem

WISCONSIN DEPT. OF NATURAL RESOURCES

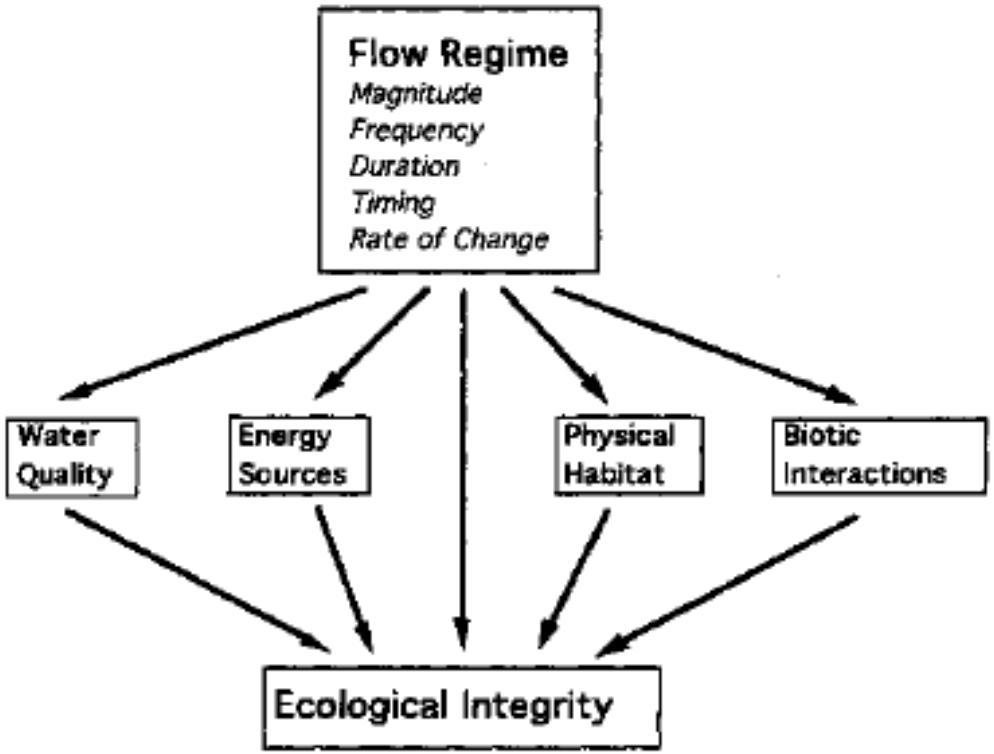
USGS science for a changing world

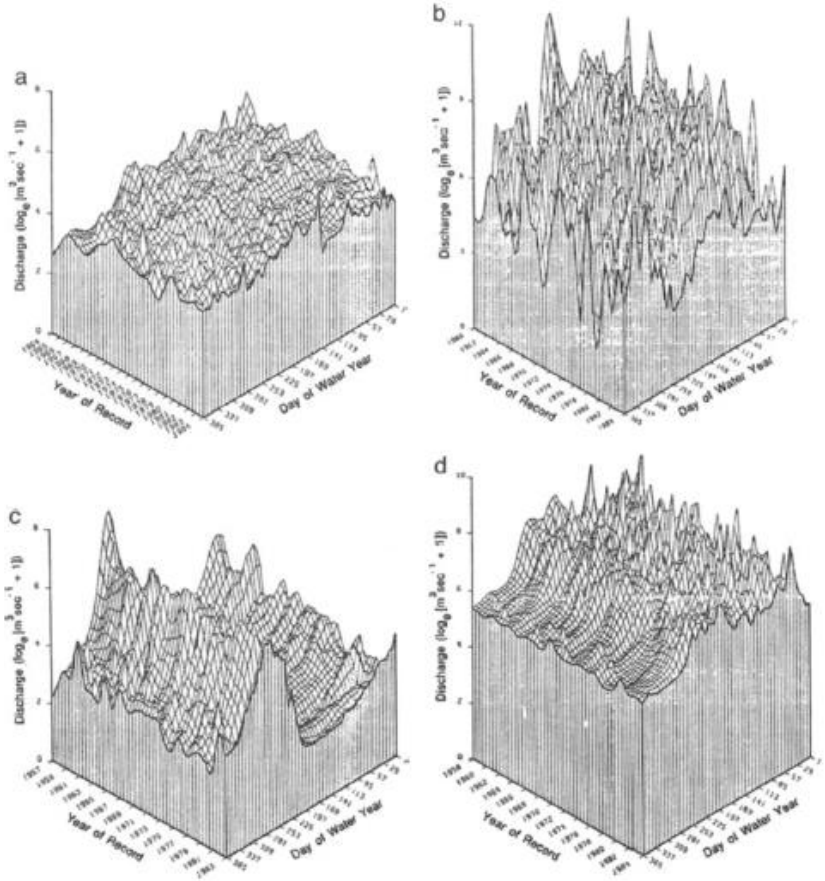
WISCONSIN UNIVERSITY OF WISCONSIN–MADISON

The Natural Flow Regime

A paradigm for river conservation and restoration

N. LeRoy Poff, J. David Allan, Mark B. Bain, James R. Karr, Karen L. Prestegaard,
Brian D. Richter, Richard E. Sparks, and Julie C. Stromberg



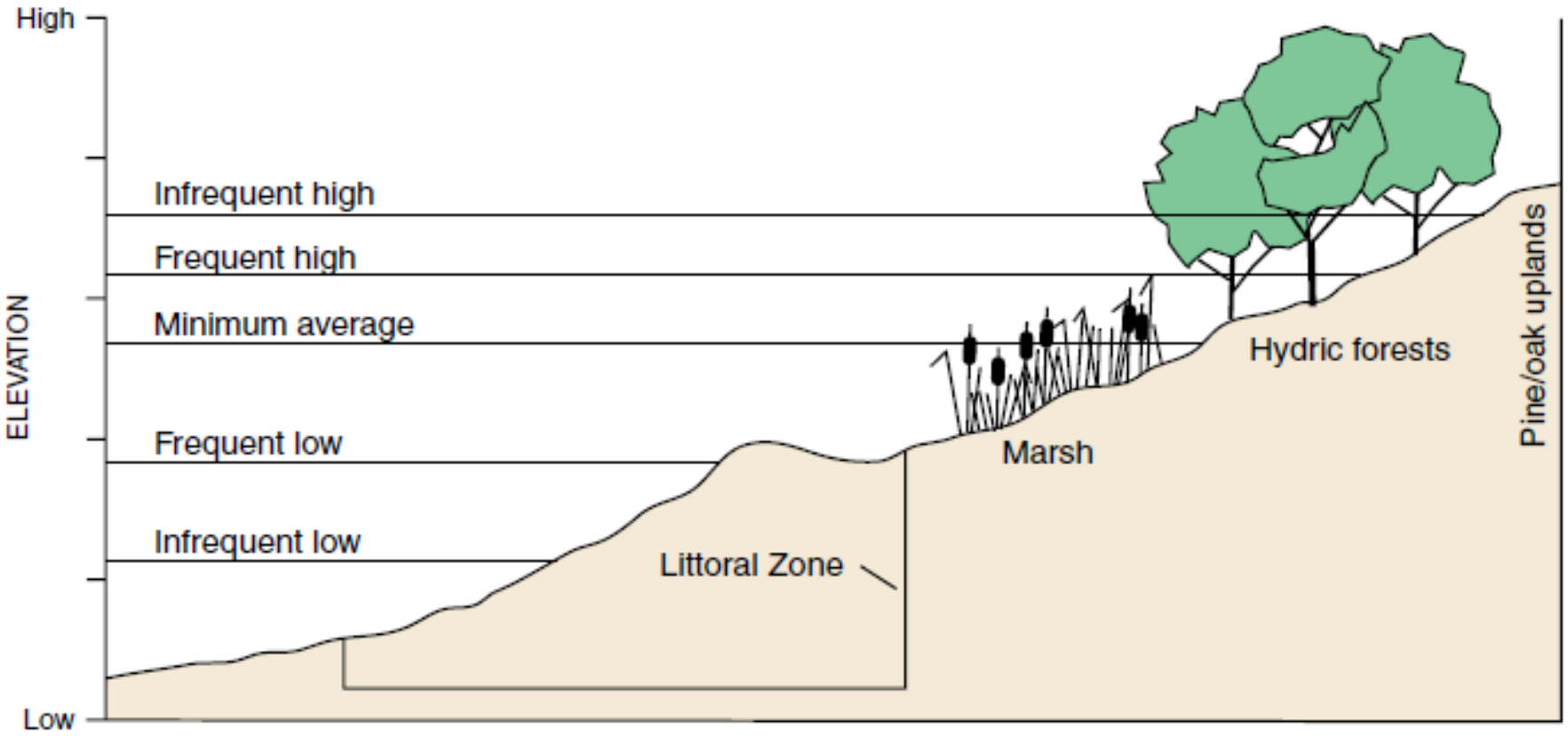


1997 BioScience

Lake Levels Fluctuate Too

Robertson et al. 2009 USGS Report 2009–5077

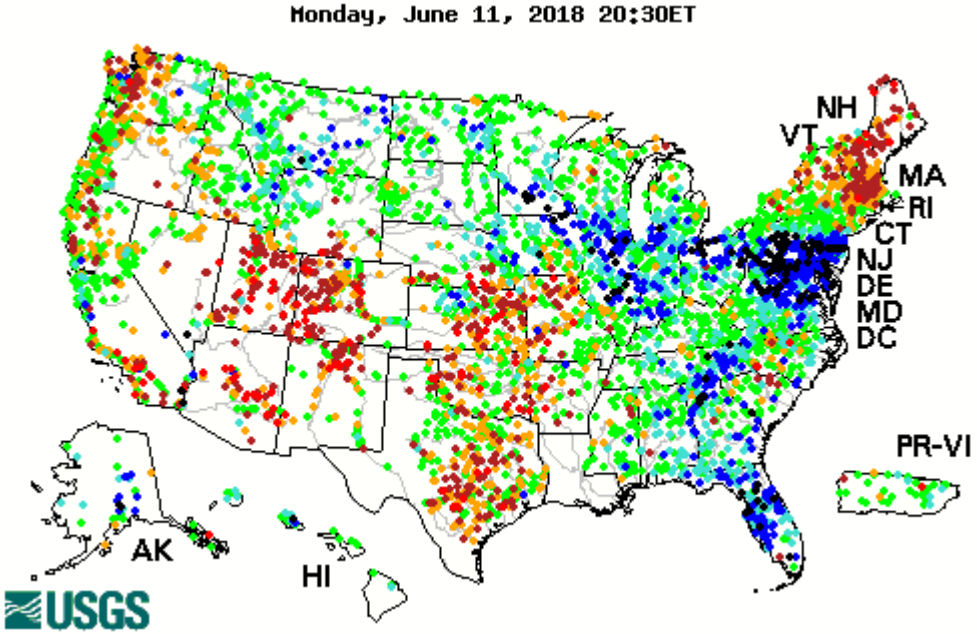
Natural Lake Level Regime



modified from McGrail et al. 1998

Long-term lake level records sparse compared to streams

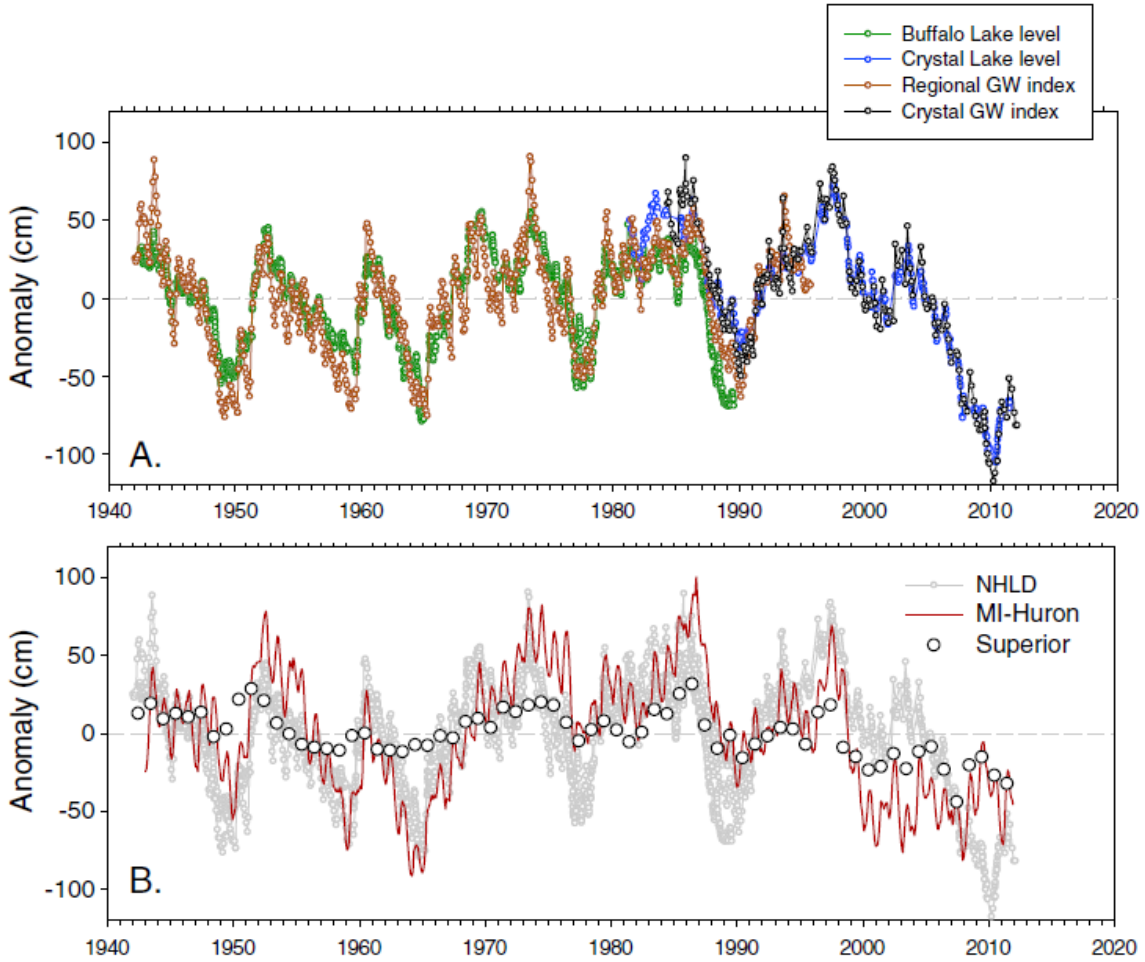
Daily Streamflow Data



Lake Staff Gauge

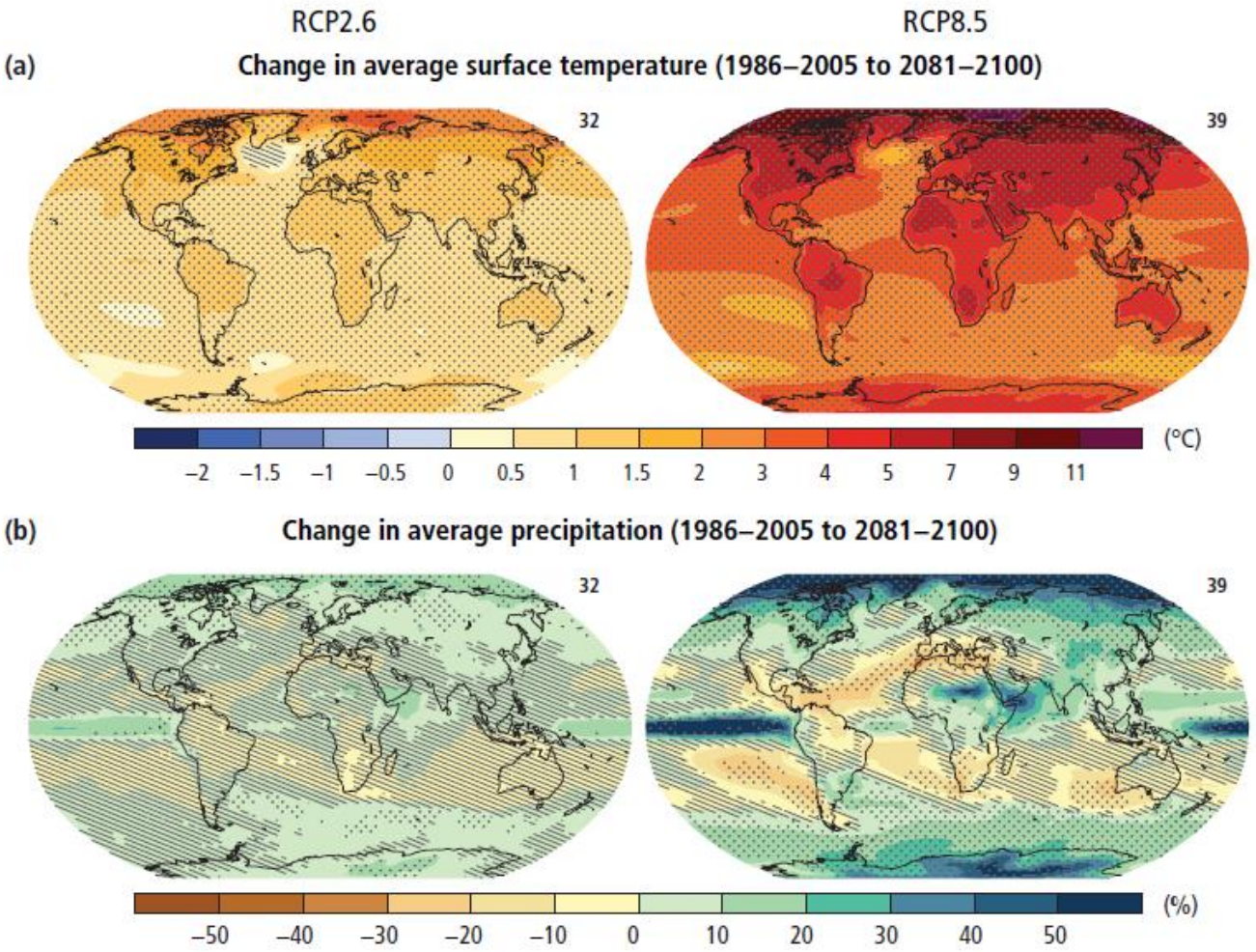
Stream Gauging Station

Coherent, near decadal cycle in lake and groundwater levels



Watras et al. 2014 Geophysical Research Letters

Climate Change & Water Use



IPCC 2014 Synthesis Report

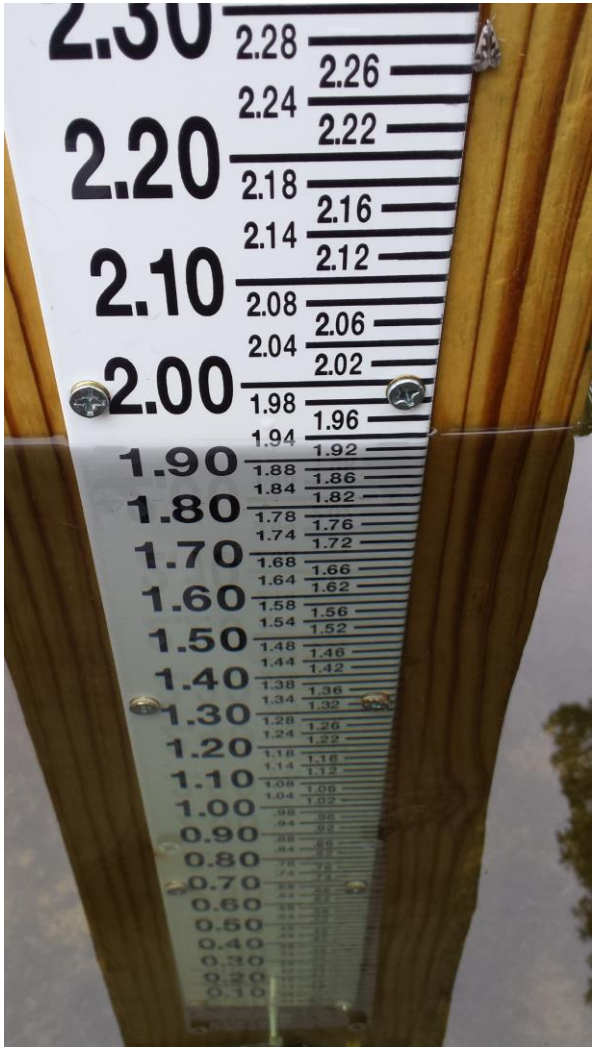
Lake Ecology & Management

- Recreation
- Navigation
- Water quality
- Habitat
- Biological Community
- Fisheries

Research Goal

Understand how groundwater and climate influence the spatial and temporal variability of water level fluctuations in Wisconsin's seepage lakes

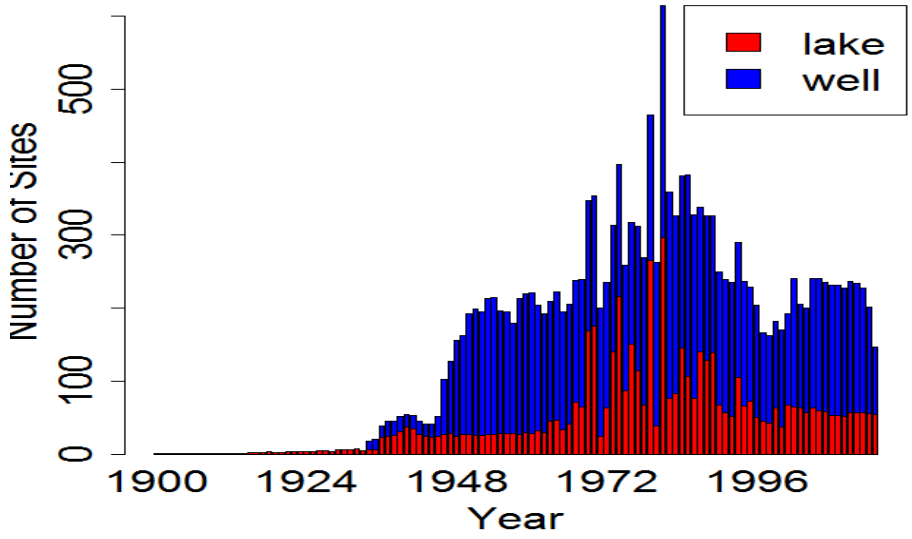
Objectives

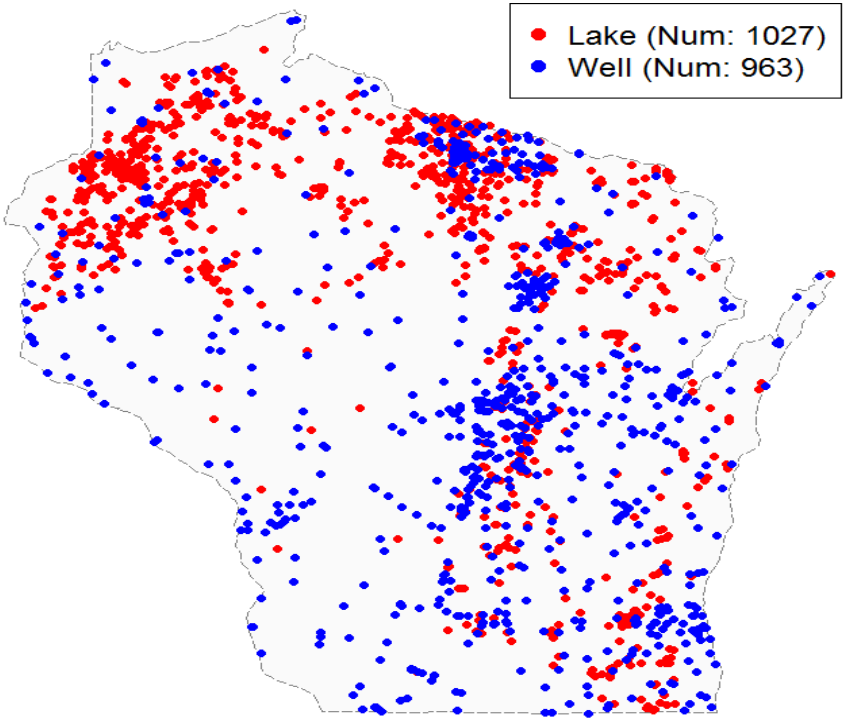


1. Build a database of groundwater and lake levels
2. Quantify ground and lake water level coherence
3. Quantify linkages between groundwater, climate, and seepage lakes
4. Characterize the hydrologic regime for seepage lakes across Wisconsin

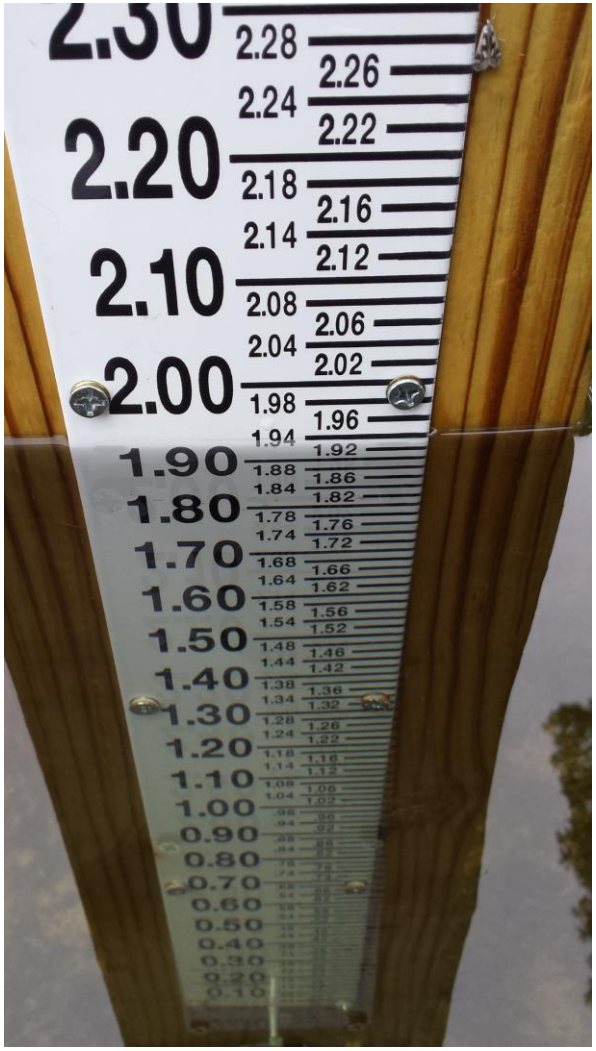
Groundwater and Lake Level Database

- ~1000 lakes and ~1000 wells from 1900-2015
- Data published on Environmental Data Initiative
- Eight agencies





Objectives



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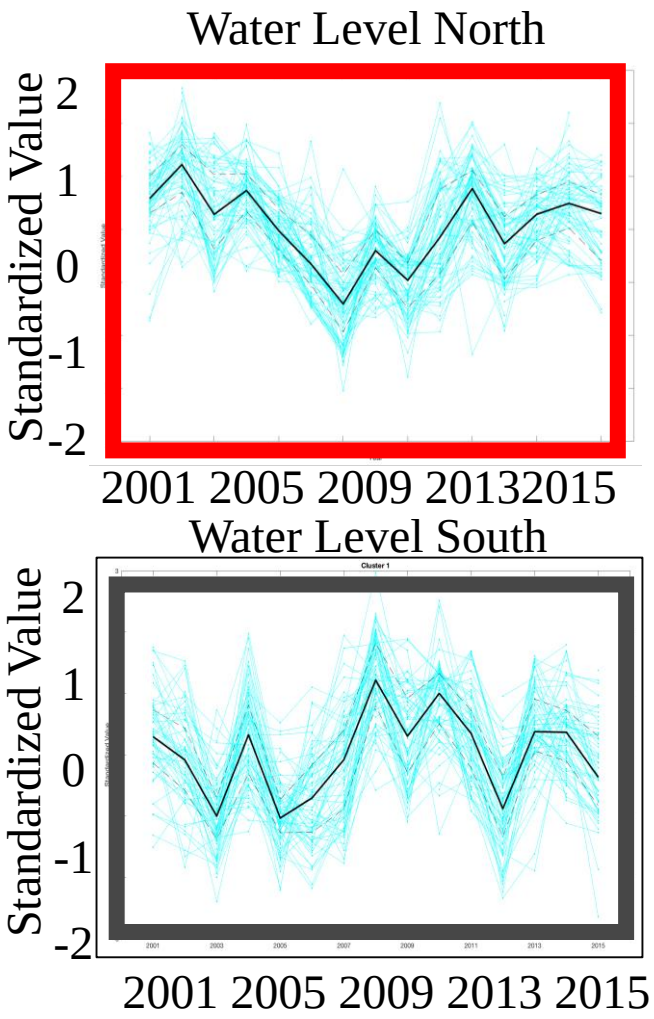
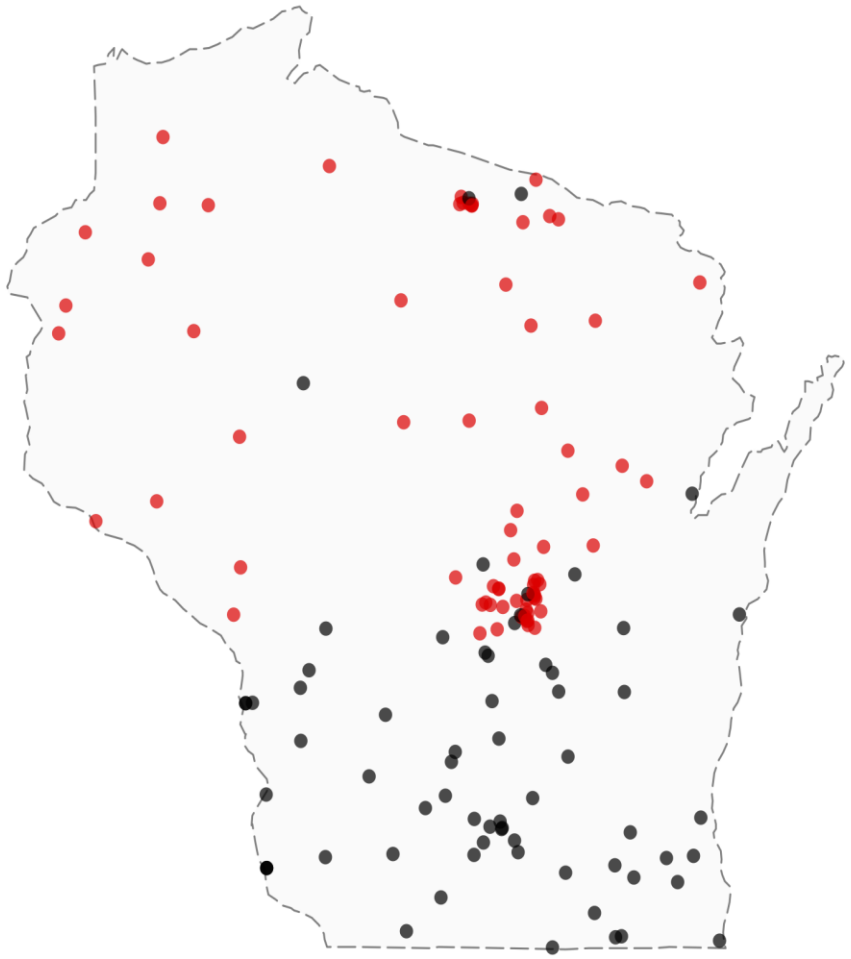
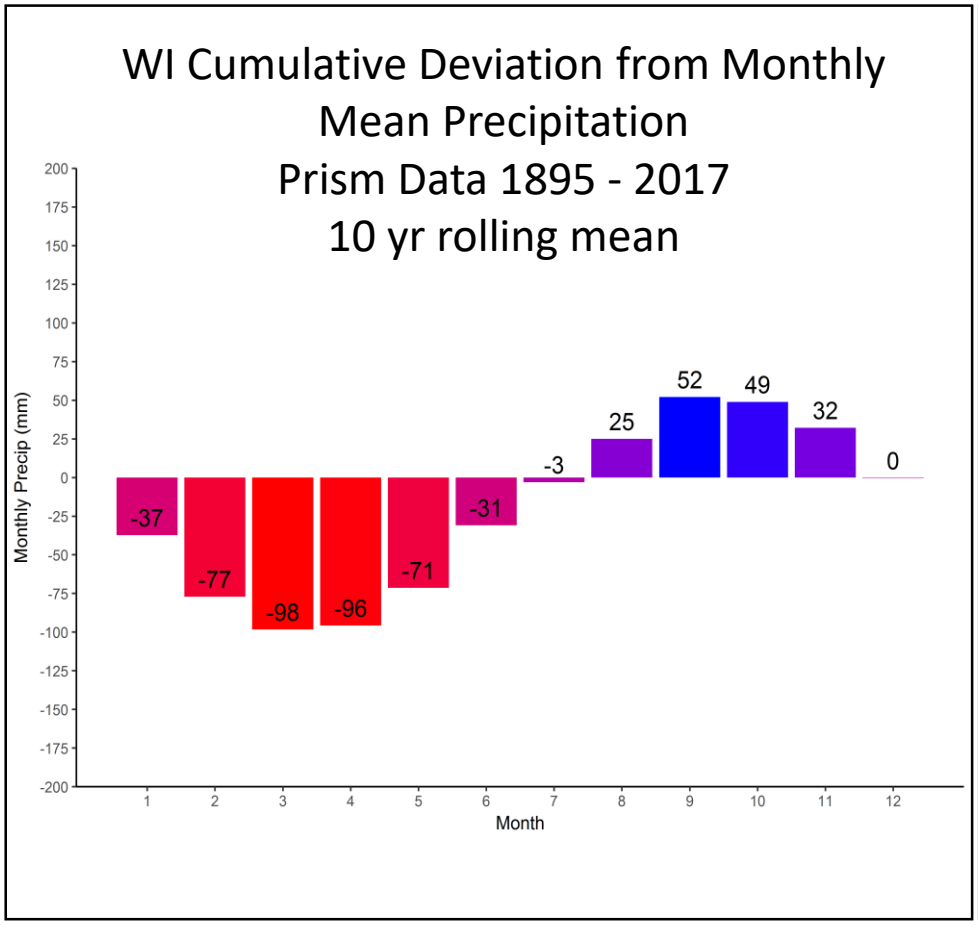
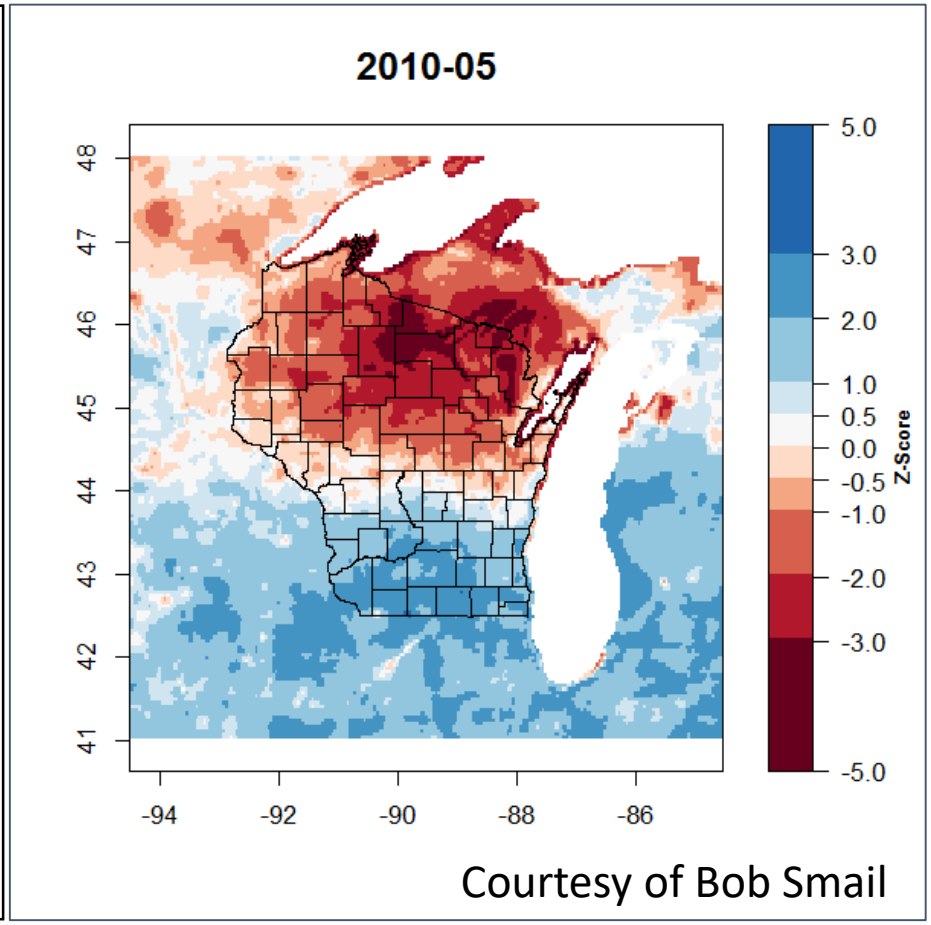
Regional patterns in groundwater and lake level coherence





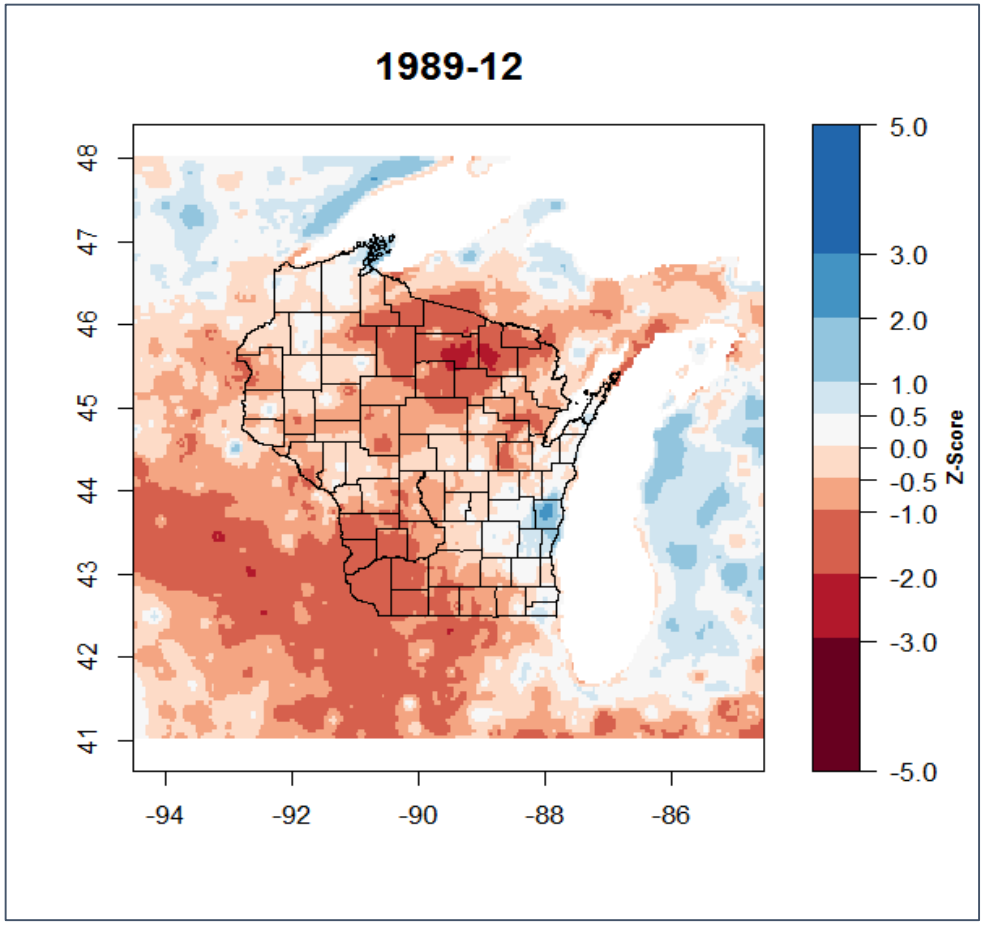
Precipitation best explains north-south divide in water levels

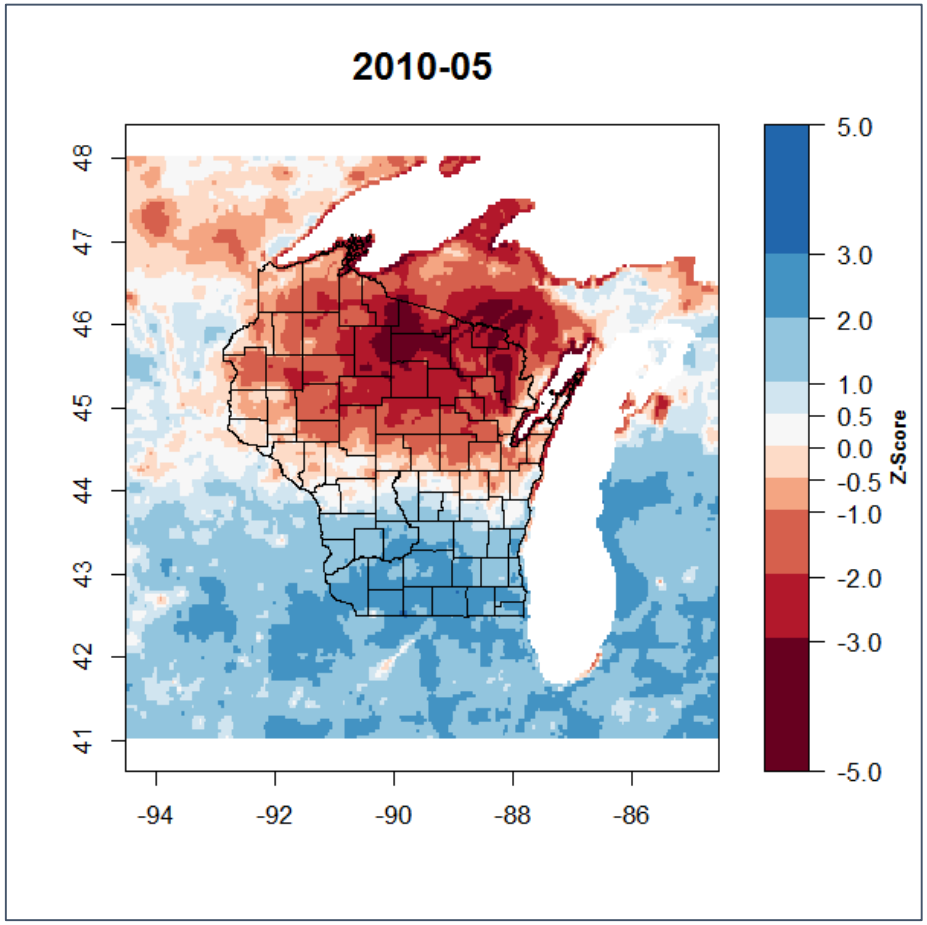




Courtesy of Bob Smail

But regional precipitation patterns change over time





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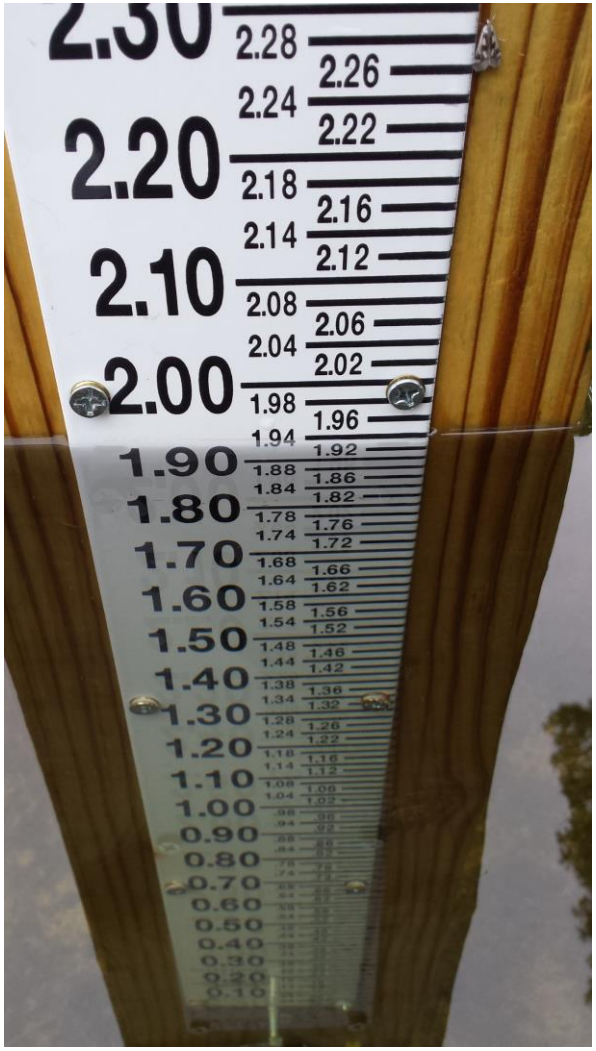

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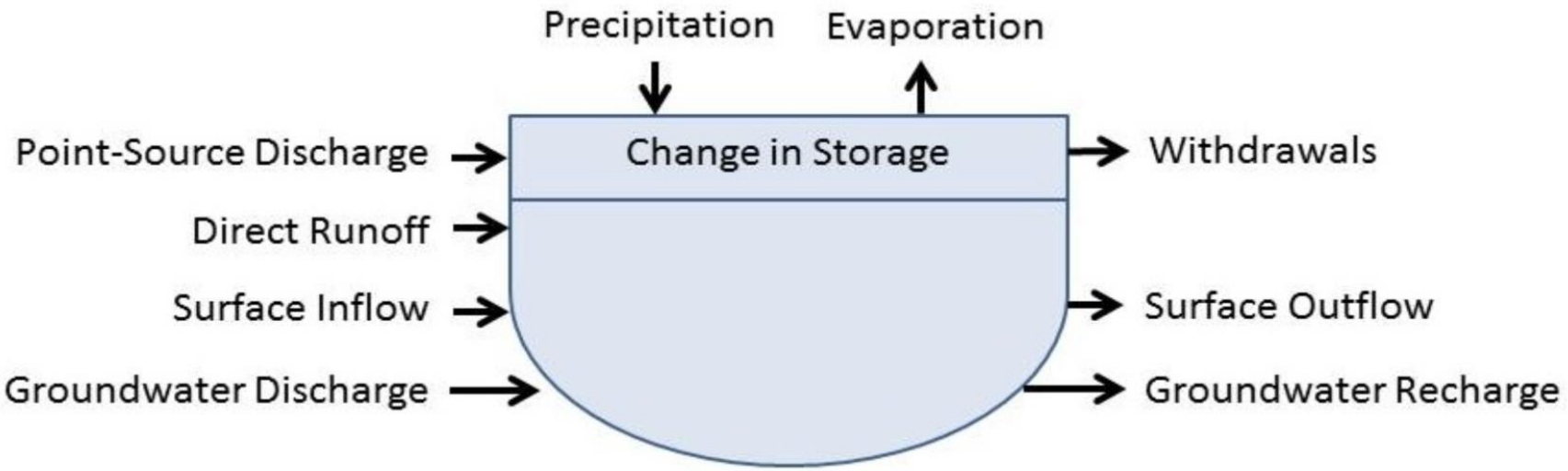
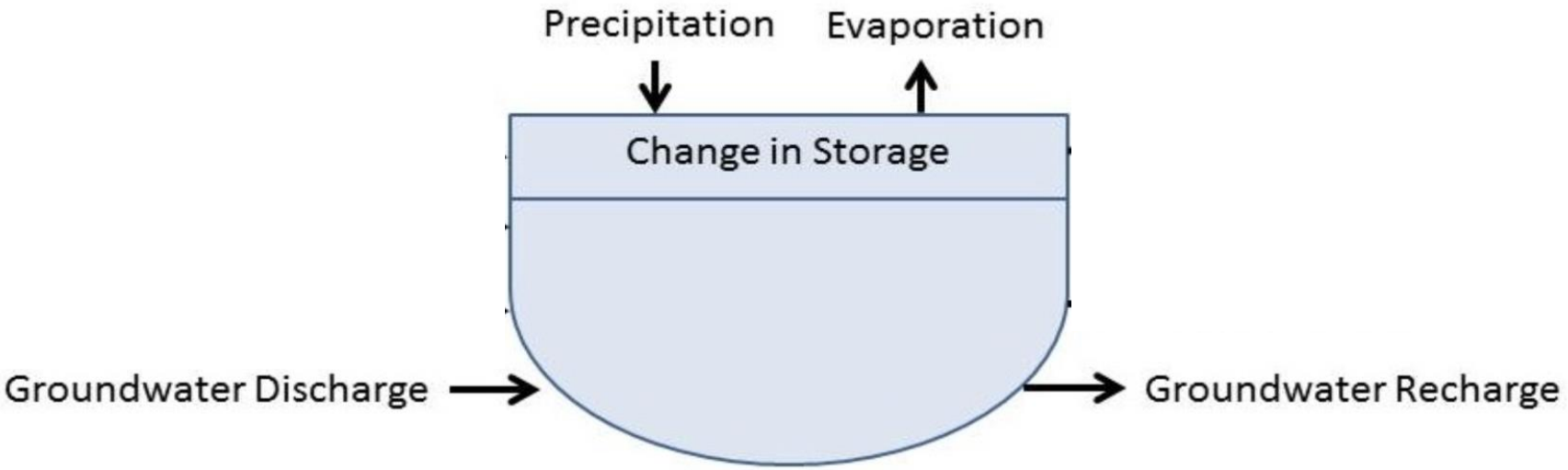
Process-Based Bayesian Hierarchical Model



Process-Based Bayesian Hierarchical Model

- Water level data (10+ day interval)
- Precipitation (PRISM)
- Evaporation (modeled, USGS – Jordan Read)



$$\Delta S = (P - E) + (G_{in} - G_{out})$$

Process-Based Bayesian Hierarchical Model

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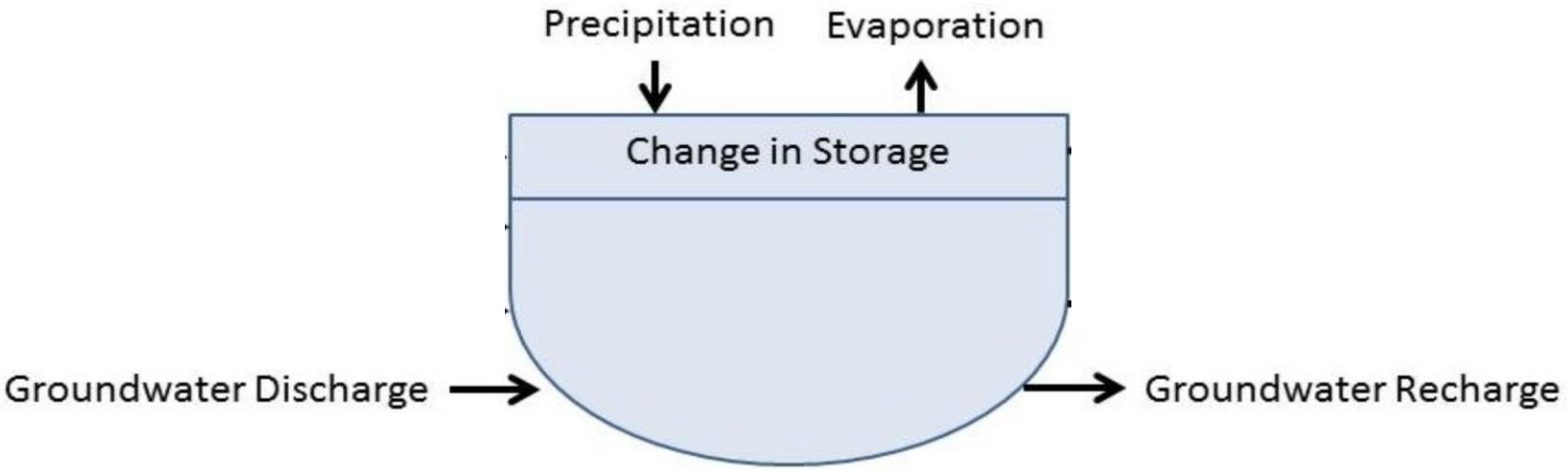
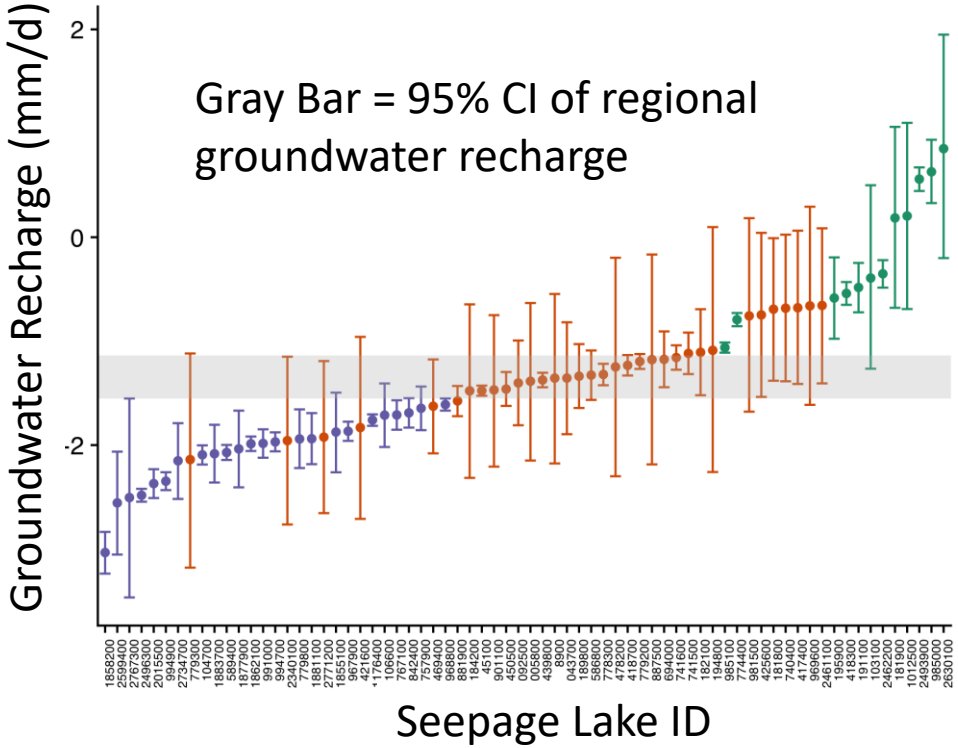


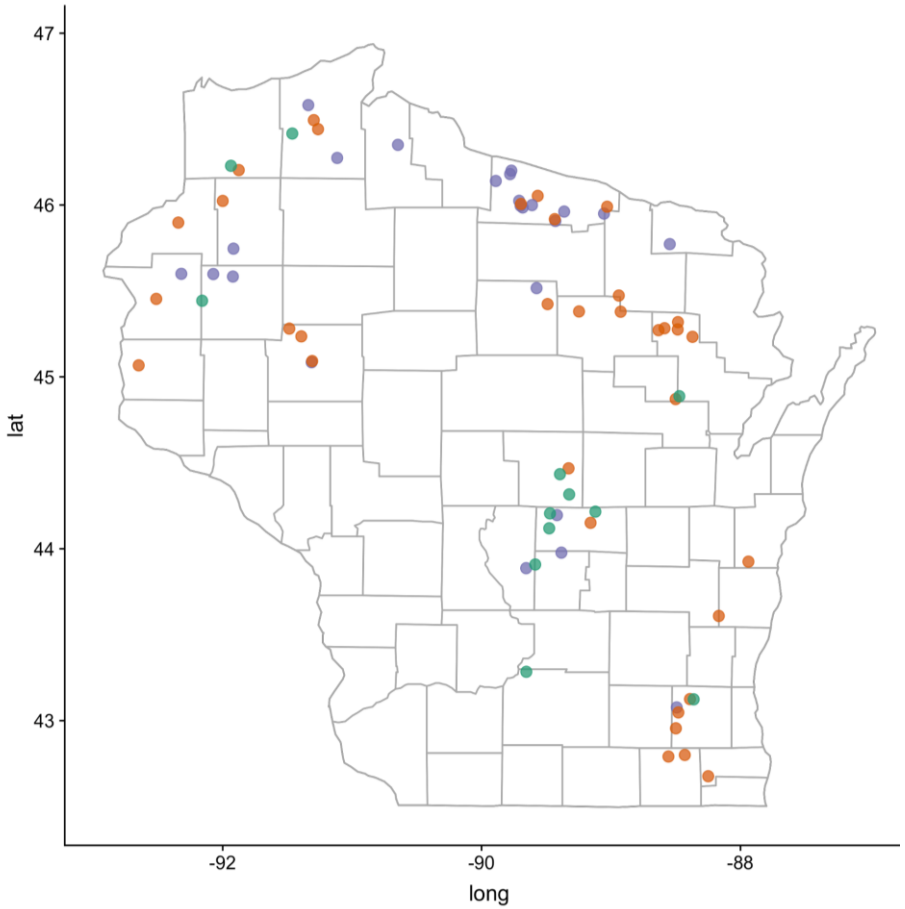
$$\Delta S = (P - E) + (G_{in} - G_{out})$$

$$G_{net} = \Delta S - (P - E)$$

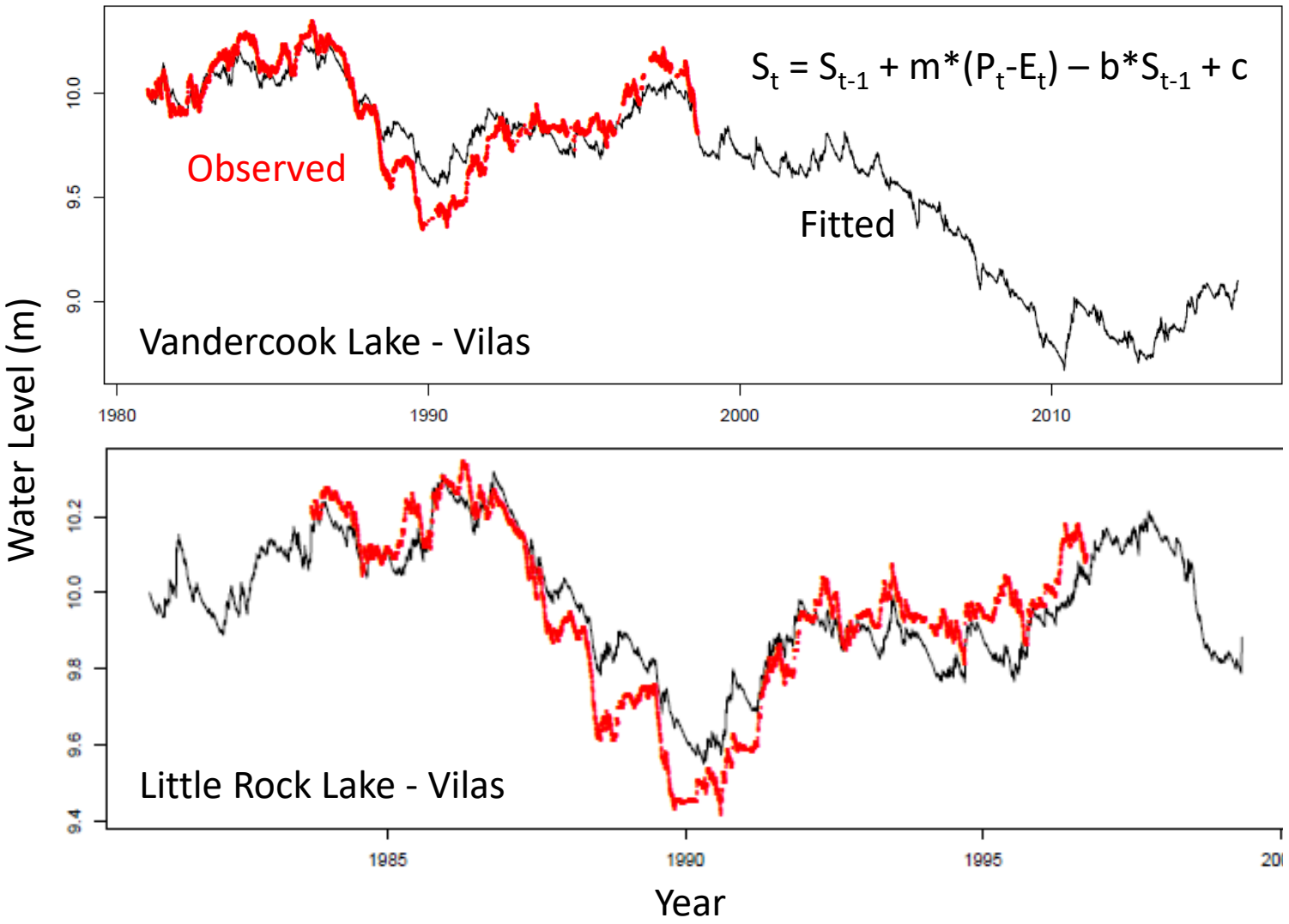
Net Groundwater Exchange in Seepage Lakes

- Net Groundwater Exchange -1.41mm/d (-51.1 cm/y)
- Evaporation ~3 mm/d (~54.4 cm/y)
- Similar Gnet in 60% of seepage lakes





Lake-specific process models perform well



Empirical Bayesian Hierarchical Model

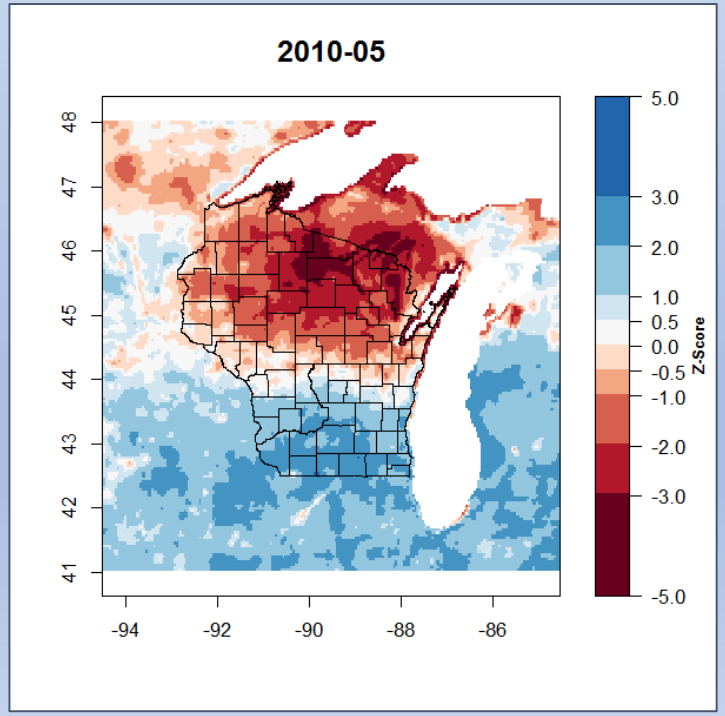
Lake Level = $\alpha + \beta$*Cumulative Deviation from 8-year Rolling Mean Precipitation

Seepage lakes with:

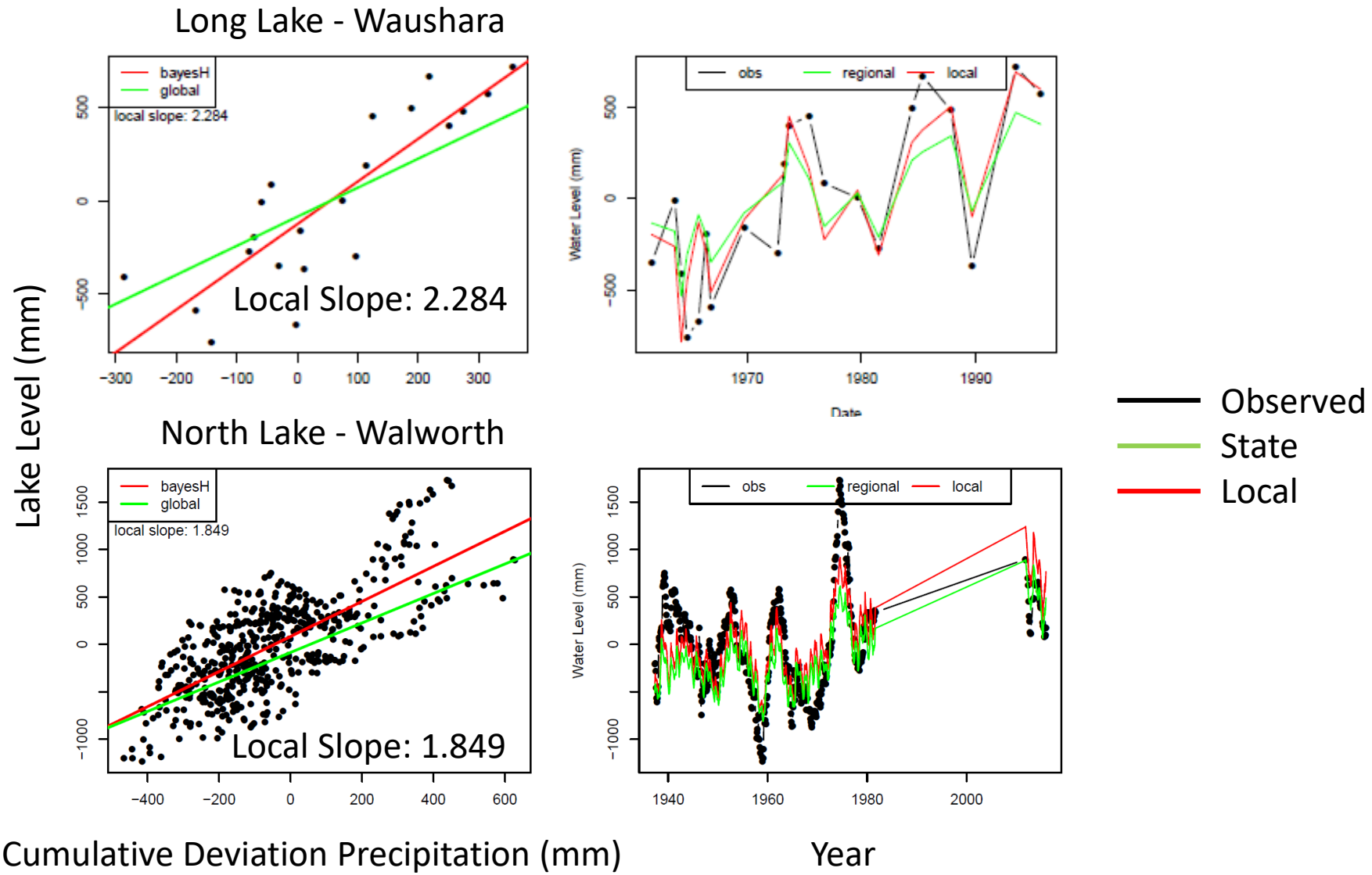
- 8+ years of data
- Groundwater withdrawals < 10,000,000 gals/year
- Observed precipitation range ≥ q85-q15

Discarded seepage lakes with:

- Negative slopes
- Suspect data

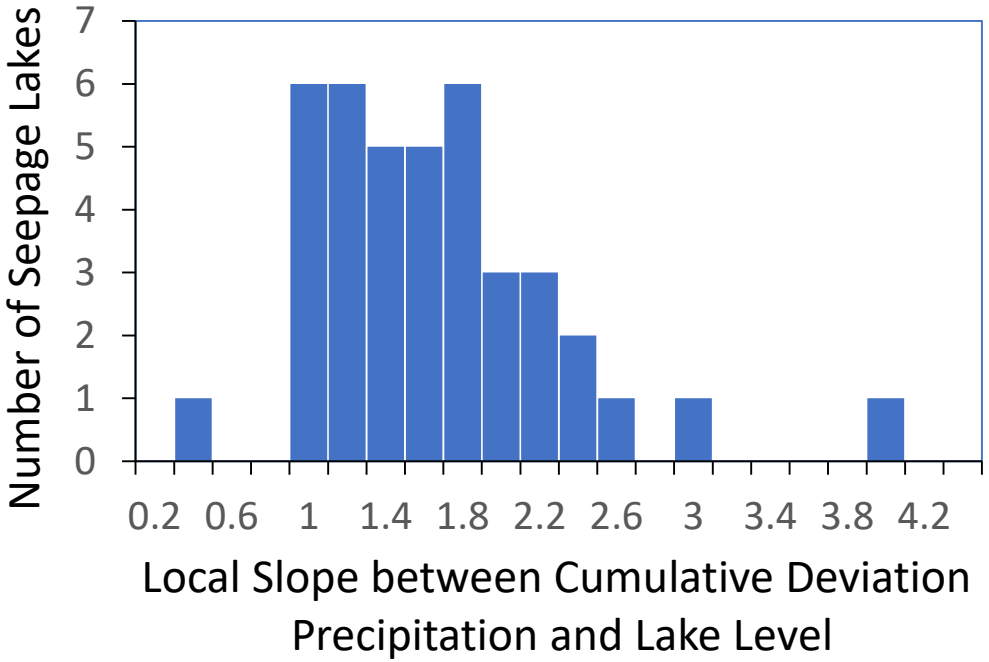


State & local empirical models perform well



What drives variation in local slopes?

β = land cover + geology + hydrology + landscape position + lake chemistry + lake morphology

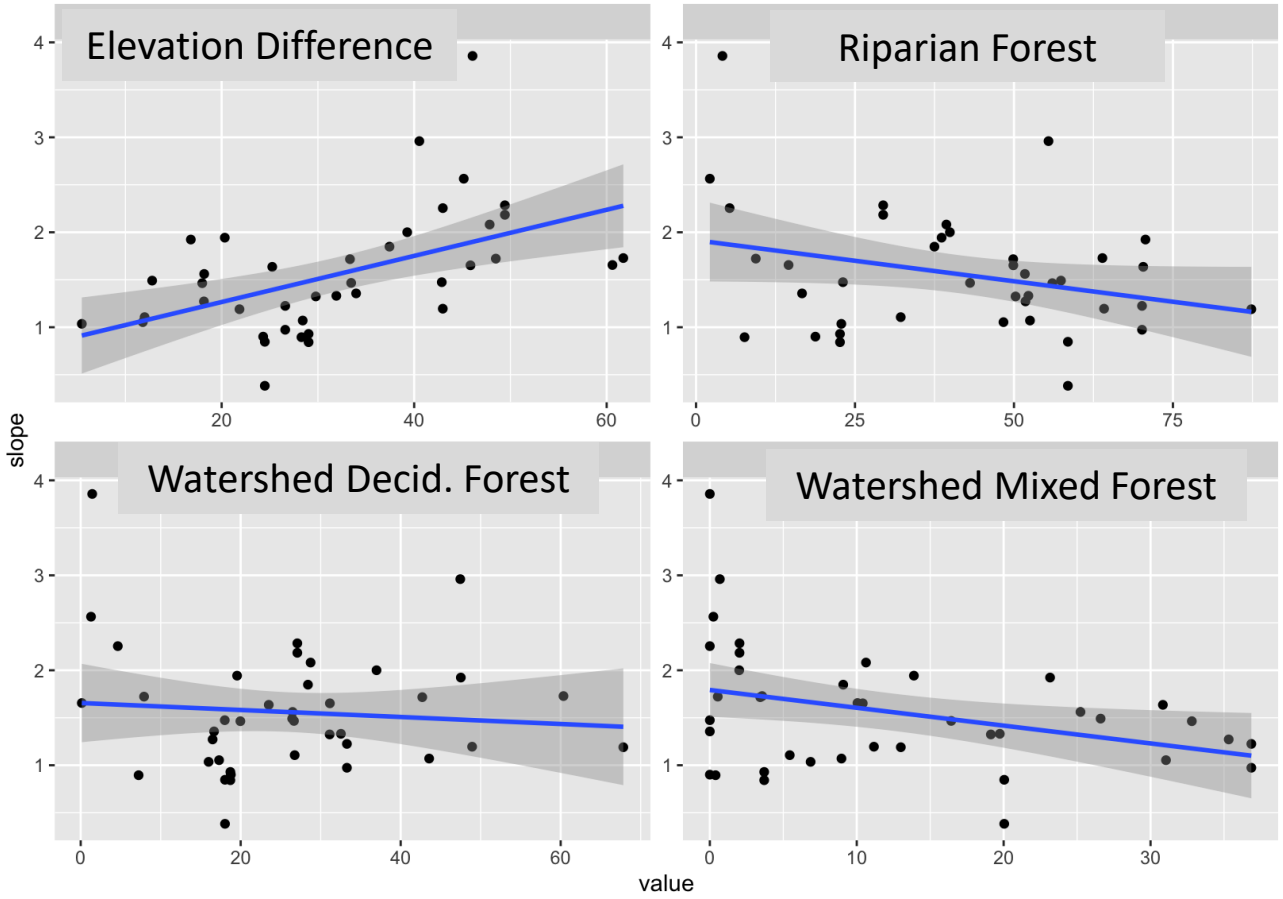


Landscape position and forested land explain some variation in slope

$\beta = \alpha$ + elevation difference – riparian forest – watershed mixed forest

Adj $R^2 = 0.217$

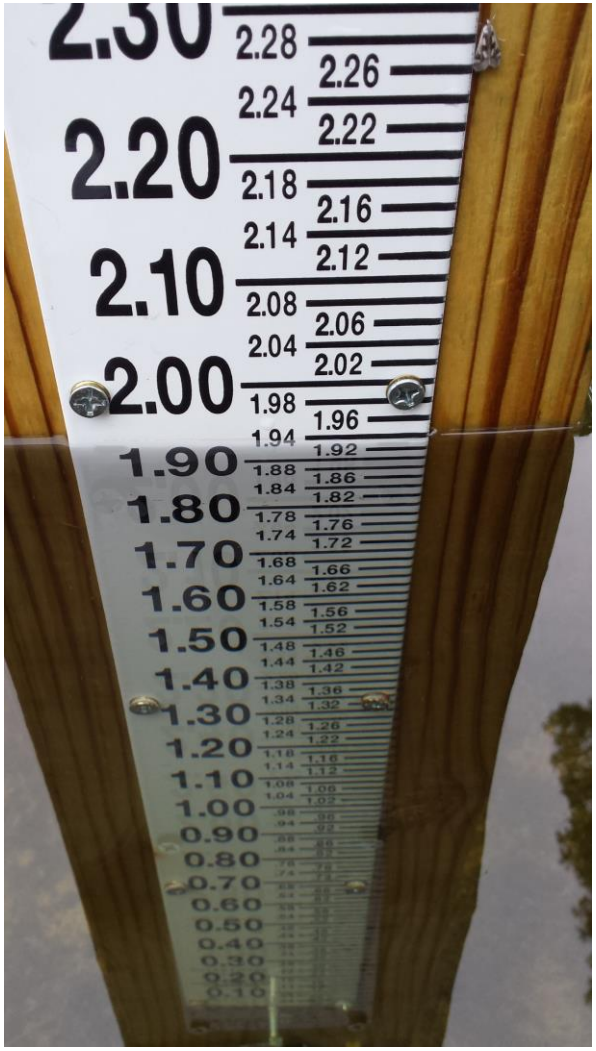
p-value = 0.0079



Predicting and Understanding Lake Levels

- Precipitation drives seepage lake level fluctuations
- Little variation in estimated net groundwater flux
- Lake levels can successfully be predicted using:
  - Process based models that quantify precipitation and evaporation
  - Empirical models using the 8-year cumulative deviation in precipitation
- Statewide model approximates lake level fluctuations, but may need to collect lake level data to parameterize local model
- Promising patterns for classifying how a lake will respond to precipitation, but highly variable

Objectives



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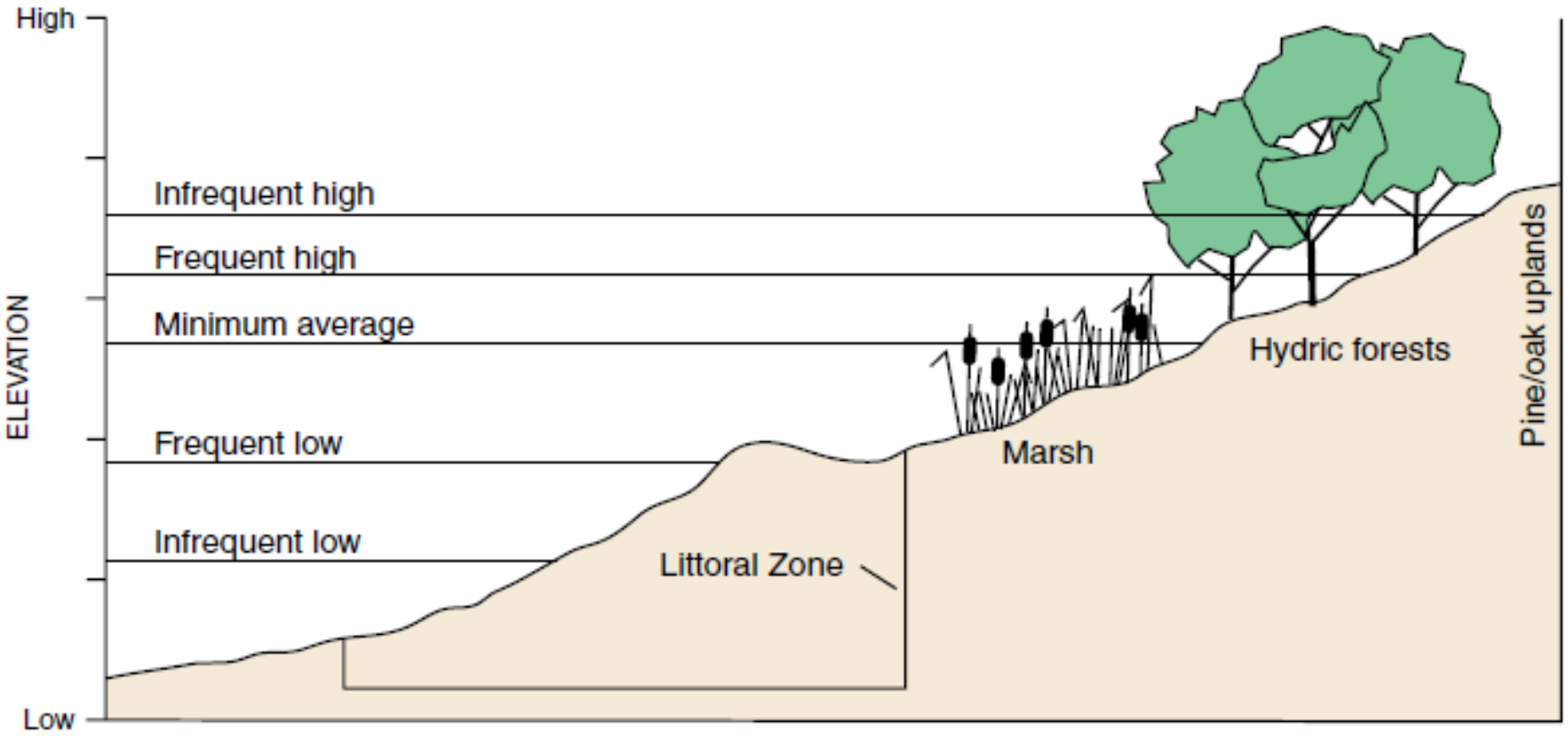
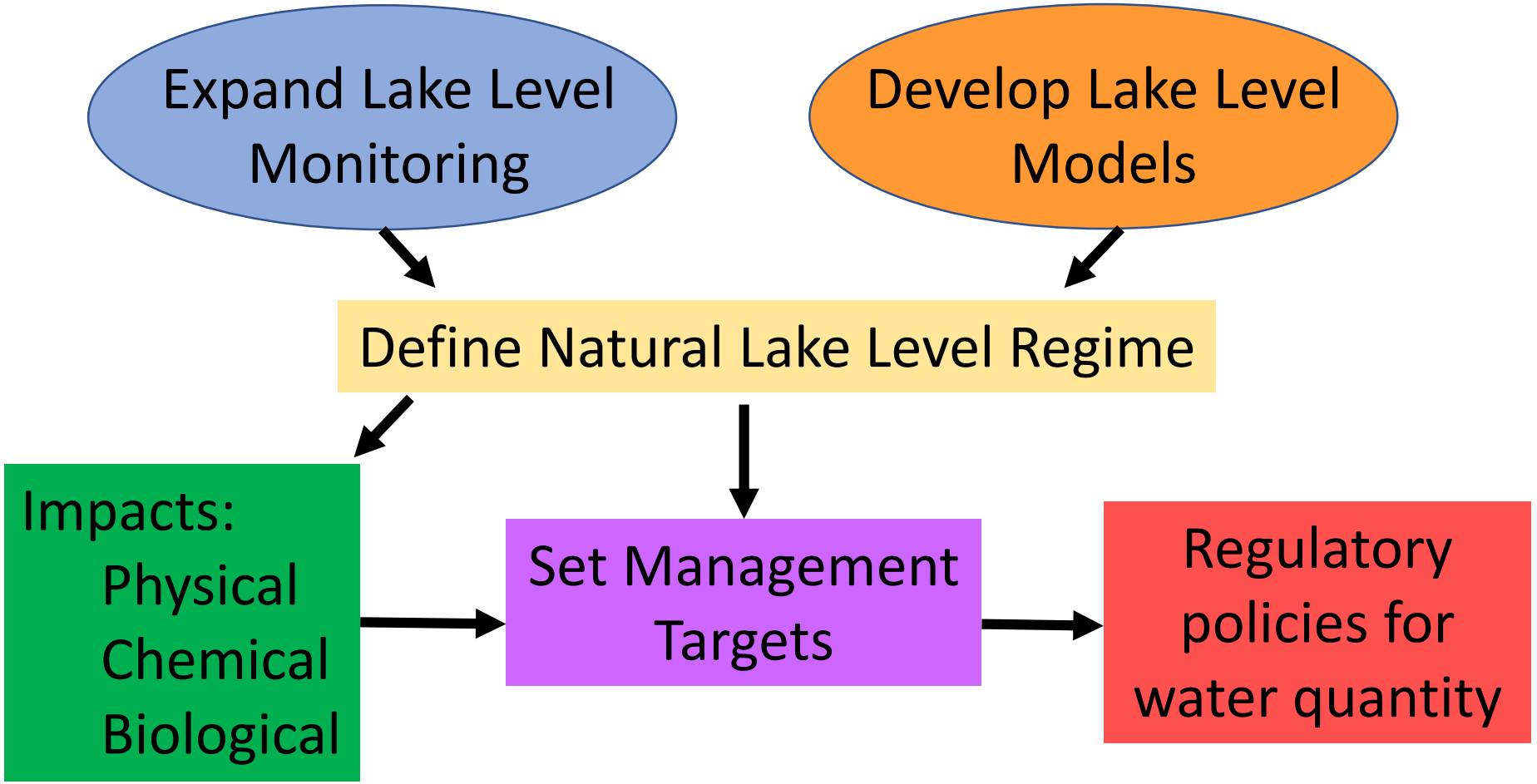
Natural Lake Level Regime



modified from McGrail et al. 1998

Future for Lake Level Research & Management



Acknowledgements

Collaborators:
Andrew Rypel, Bob Smail, Matt Diebel (WDNR)
Eric Booth, Emily Stanley, Corinna Gries, Kang Huang (UW)
Paul Juckem, Jordan Read (USGS)

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City of Shell Lake, North Lakeland Discovery Center, North Temperate Lakes Long Term Ecological Research, United States Geological Survey, Waushara County, Wisconsin Department of Natural Resources, Citizen Volunteers from Wisconsin

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