MAKING SENSE OF NOISY ENVIRONMENTAL SYSTEMS: CHARACTERIZING AND QUANTIFYING VARIABILITY

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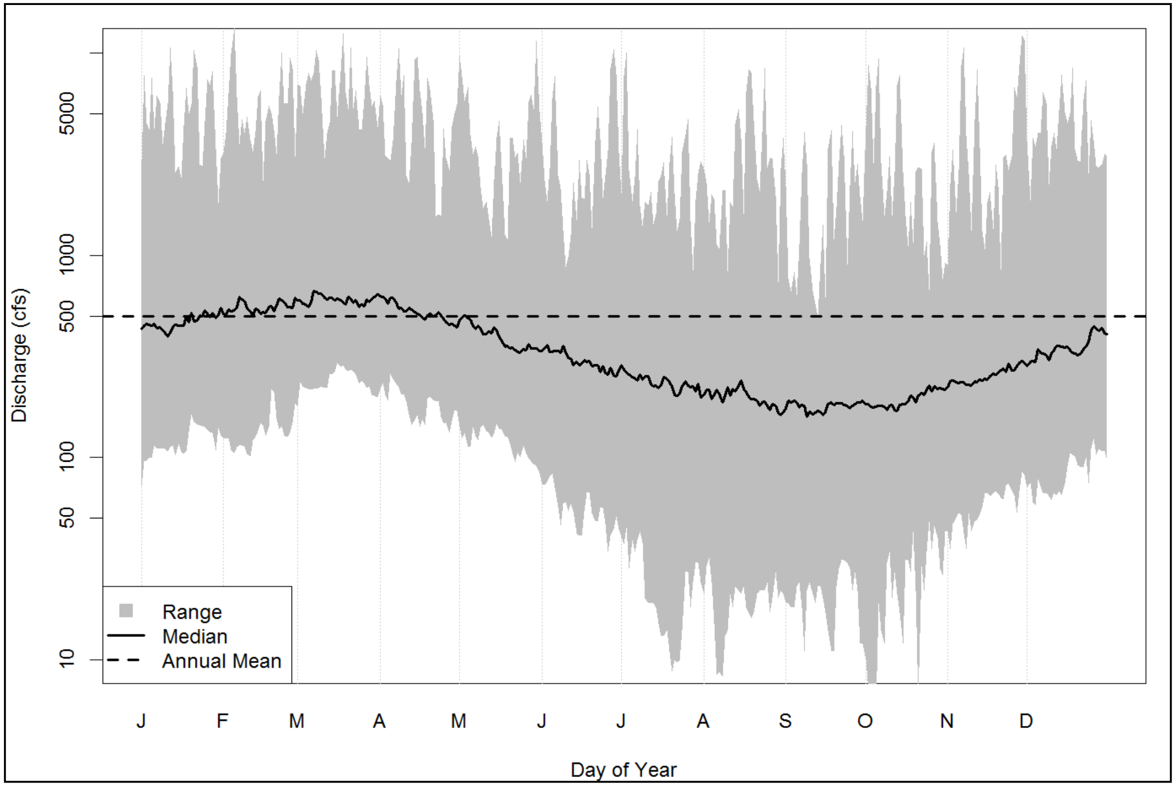
Variability in Water Resource Management

Aquatic systems are noisy places!

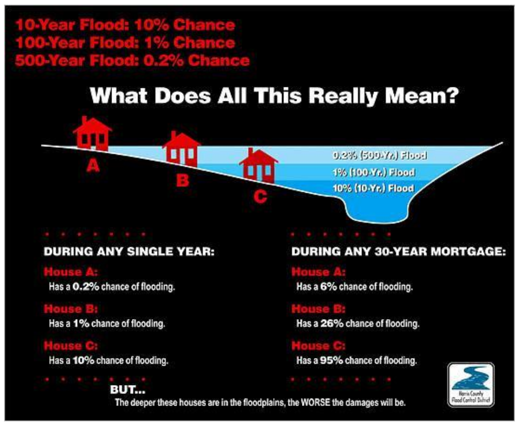
- Multiple sources of environmental variability
- Variability impacts "performance" of environmental, engineering, and socio-economic systems



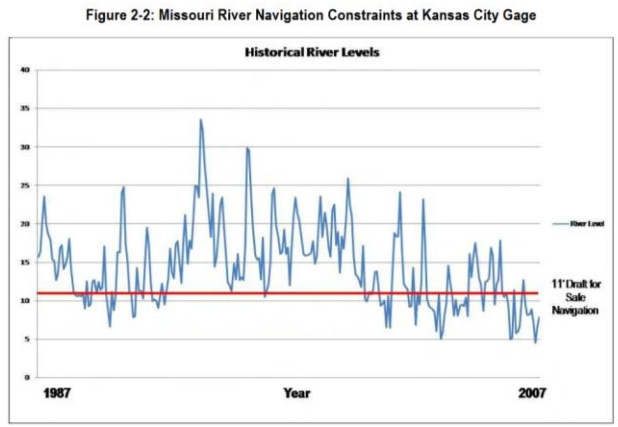
River hydrograph
Middle Oconee River
Athens, Georgia

Environmental variability affects (and/or is affected by) all USACE business lines

Flood Risk Management

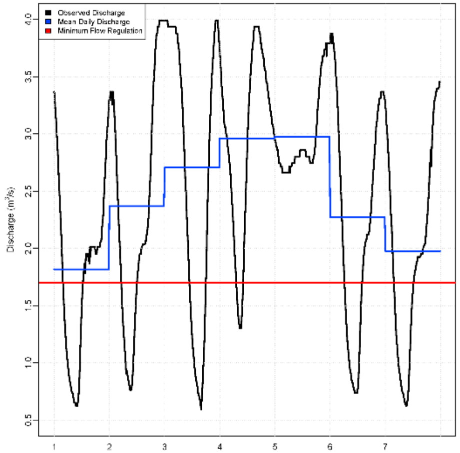


Navigation



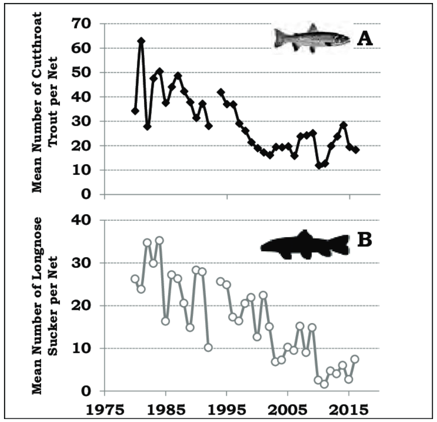
Water Supply

Hydropower



Recreation

Ecosystem Restoration



Figures: Harris County, Gehman et al. (2008), USACE-SPA, Oconee River near Penfield, Lake Lanier, Koel et al. (2017)

Project Goals

Provide a roadmap to understanding and quantifying the effects of variability on the ecosystem restoration business line.

- Key terms and concepts related to variability
- Structuring an analysis of variability
- Example of quantifying variability
  - Case study: Middle Oconee River

Key terms and concepts

Overcoming the maze of terminology!

Tipping Points

Disturbance Regime

Fluctuation

Thresholds

Black swans

Stochastic Simulation

Variability

Non-Stationarity

Time Series Analysis

Periodicity

Cyclical Behavior

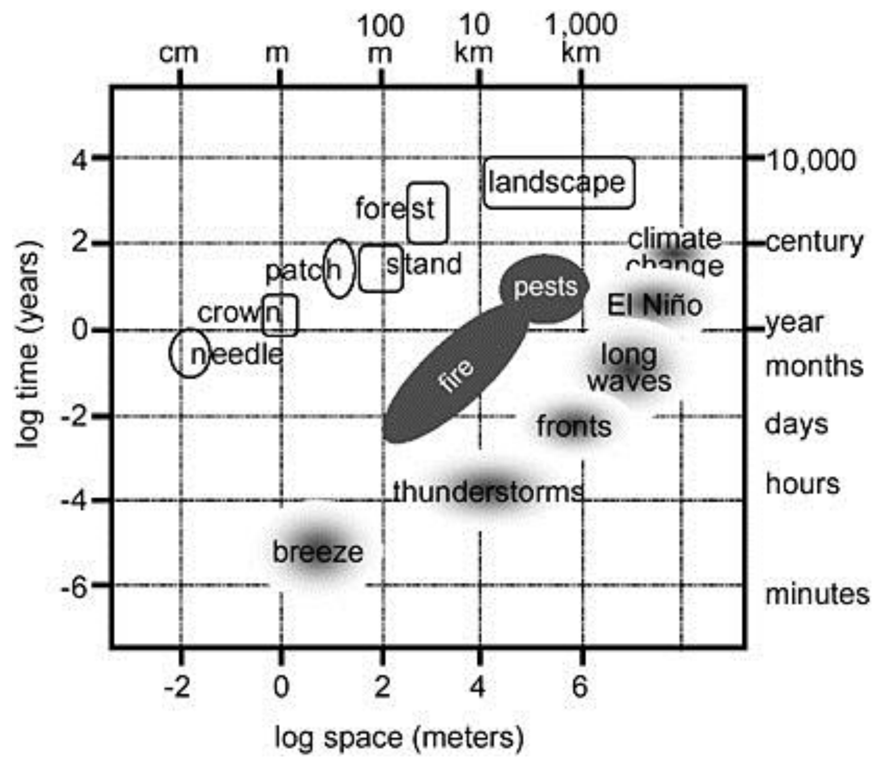
Hazard

Growth of “temporal ecology”

- Ecosystems are often acknowledge as varying in time and space
- Landscape ecology emerged to address spatial variability
- Temporal ecology remains an “emergent” field of study (Wolkovich et al. 2014, *Ecology Letters*)
  - Growth of long-term data sets
  - Increasingly sophisticated analytical techniques
  - Global change

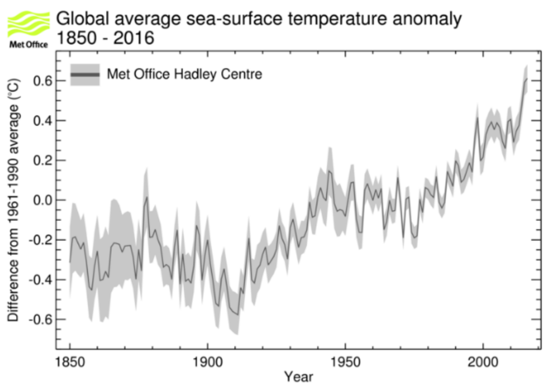
Example of Ecological Hierarchy

(NRC 2005, Assessing and Managing the Ecological Impacts of Paved Roads)

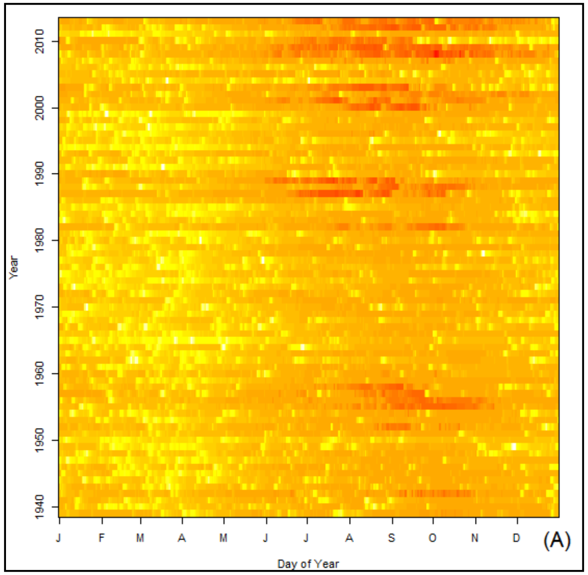


Environmental regimes come in all shapes and size, but they all fluctuate

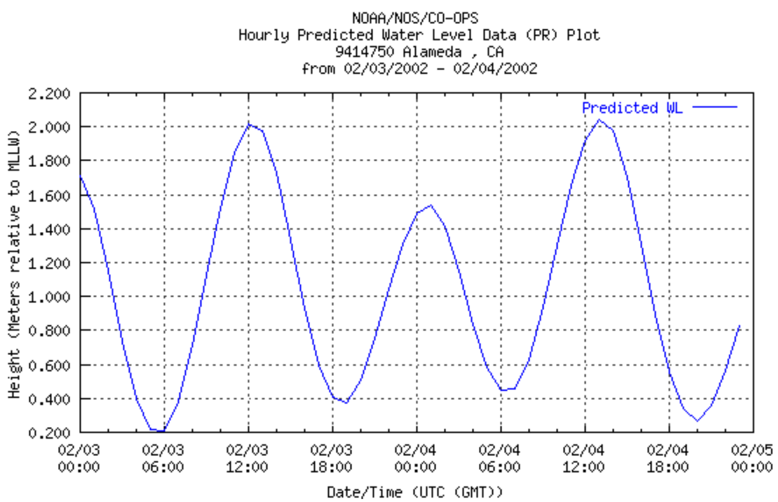
Temperature



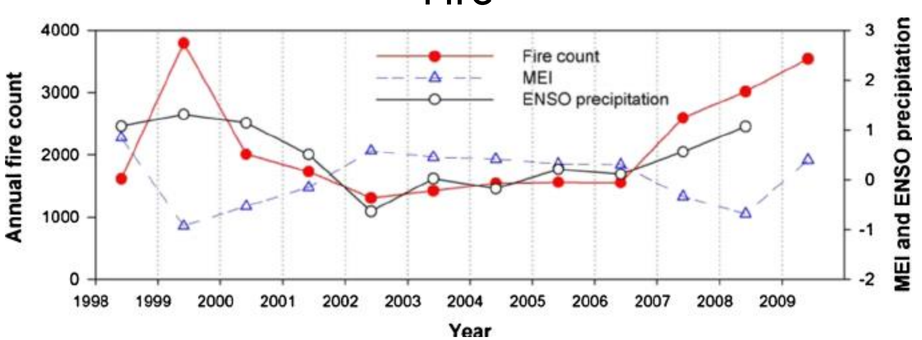
River Discharge



Tides

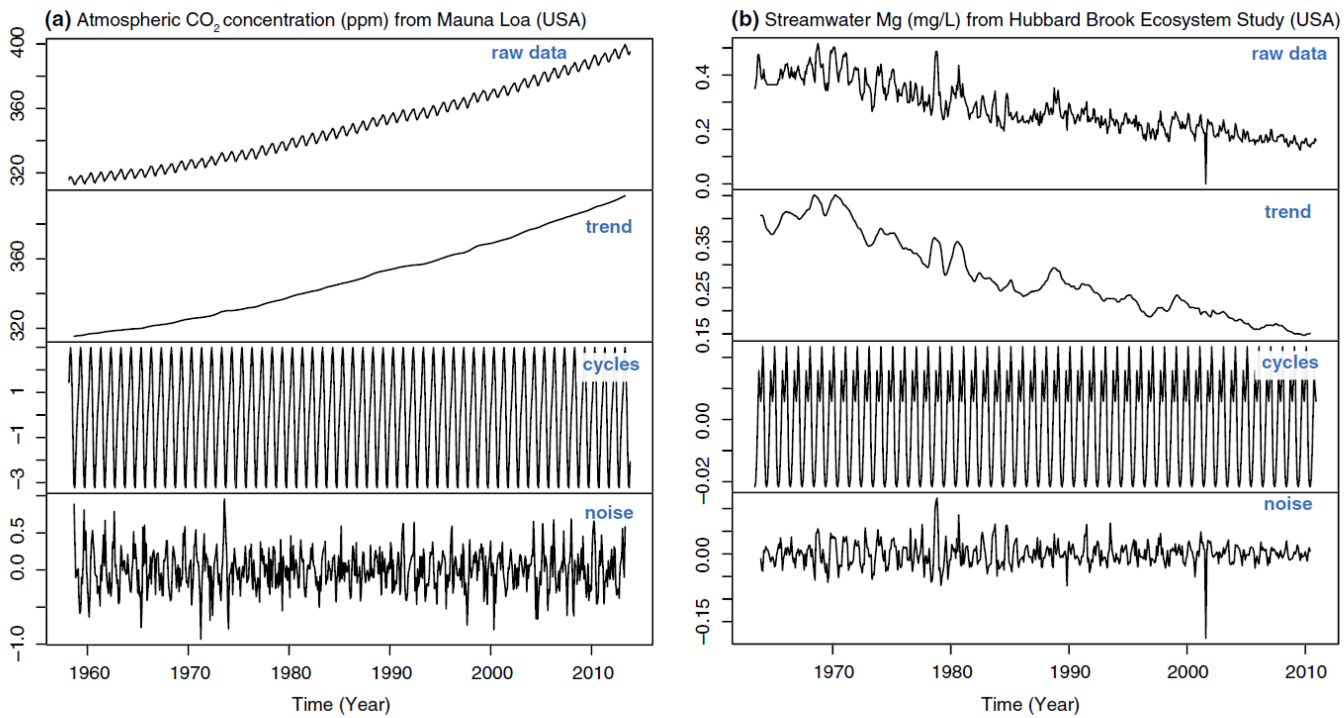


Fire



How do fluctuations manifest?

- Stochastic
- Periodic
- Catastrophic
- Trending
- (Non) Linearly
- All of the above?

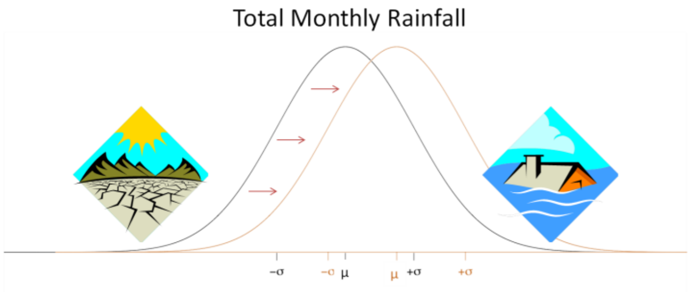


Wolkovich et al. (2014)

Disturbance Regimes

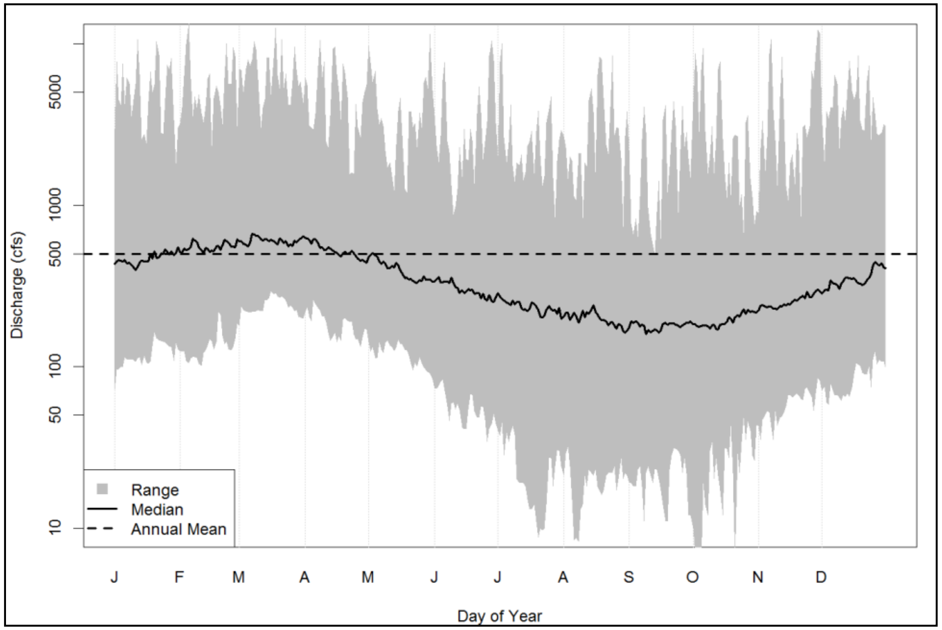
- What natural disturbances govern the system?
  - Pulses (discrete events) vs. Presses (slowly escalating events) vs. Ramps (slowly changing conditions)
- What is the disturbance regime?
  - i.e., magnitude, frequency, duration, timing, and rate of change (sensu, Poff et al. 1997)
- Are disturbance regimes changing (i.e., "stationary")?

Disturbance Type	Natural	Anthropogenic
Pulses	Earthquake Floods / coastal storms Fire	Terrorist attack Construction impact Oil spill
Presses	Landslides Drought Eutrophication	Economic recession Refugee crisis Land use change
Ramps	Sea level rise Ocean acidification Climate change	Legacy sediment Population growth Shifting value systems



Translating variability into ecological or socio-economic outcomes

- What is the risk associated with variability?
  - Probability * Consequence
  - Thresholds
- What is the resilience of the system?
  - How often does performance need to be satisfactory?
  - How fast can the system return to full performance?



Structuring an analysis of variability

Proposing an Analytical Framework

Topic	Guiding Questions
Understanding a disturbance regime	• What is the source of environmental variation? • What does a time series look like? Which parts of the time series most affect function? • What is the magnitude, frequency, duration, timing, and rate-of-change of the disturbance regimes? Are multiple regimes in play?
Assessing system performance requirements	• What are key thresholds in performance across the range of variability? • How often does "success" need to be achieved? • Are their goals related to variability (e.g., achieve this much outcome X% of time, avoid this outcome Y% of time)?
Designing around variability	• How will the project design react to historical disturbance trends, future disturbance trends, sequential disturbances, catastrophic disturbances? • How much adaptive capacity exists within the project design for coping with a changing (or unexpected) disturbance regime?
Operating for and with variability	• Are operations a fluctuating or static target? Where is the "wiggle room" in the system? • What are the sources of seasonal or periodic variability? How will the system be operated in these times? • What are the sources of catastrophic variability and plans for response? • Are data being collected to guide performance through time?

Case study:
Middle Oconee River

Examples from:

McKay S.K. *Forthcoming*. Meaningless means discharge for environmental flow management. Submitted to *Aquatic Conservation*.

Bhattacharjee N.V., Willis J.R., Tollner E.W., and McKay S.K. *Forthcoming*. Habitat provision associated with environmental flows. EMRRP-TN.

Middle Oconee River in Athens

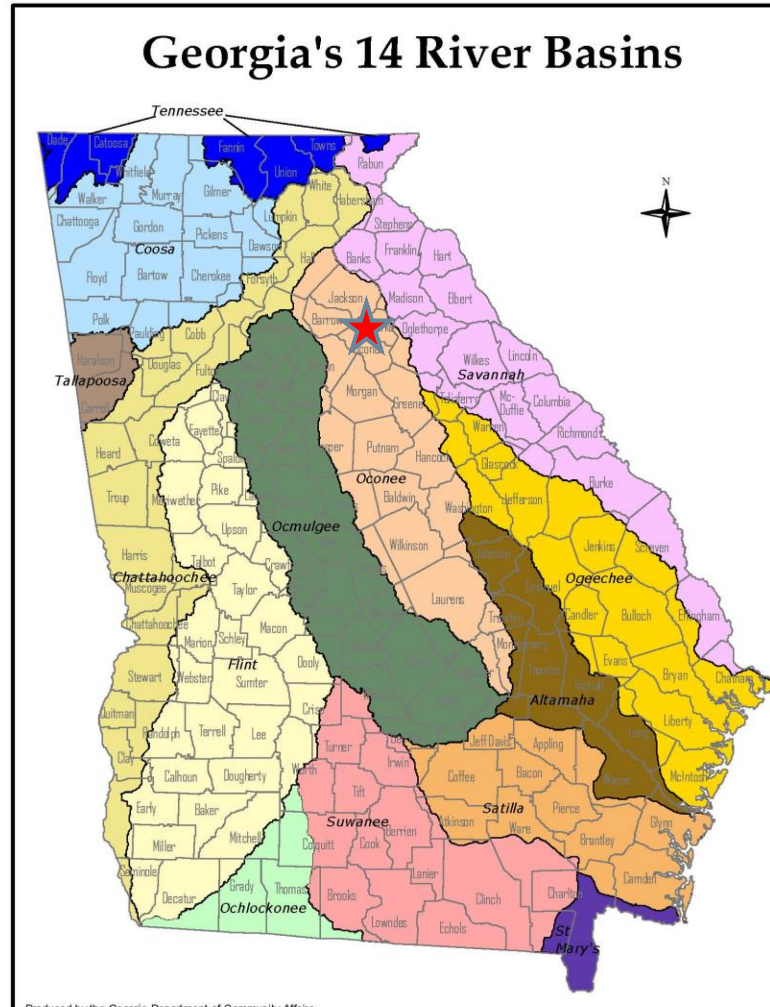
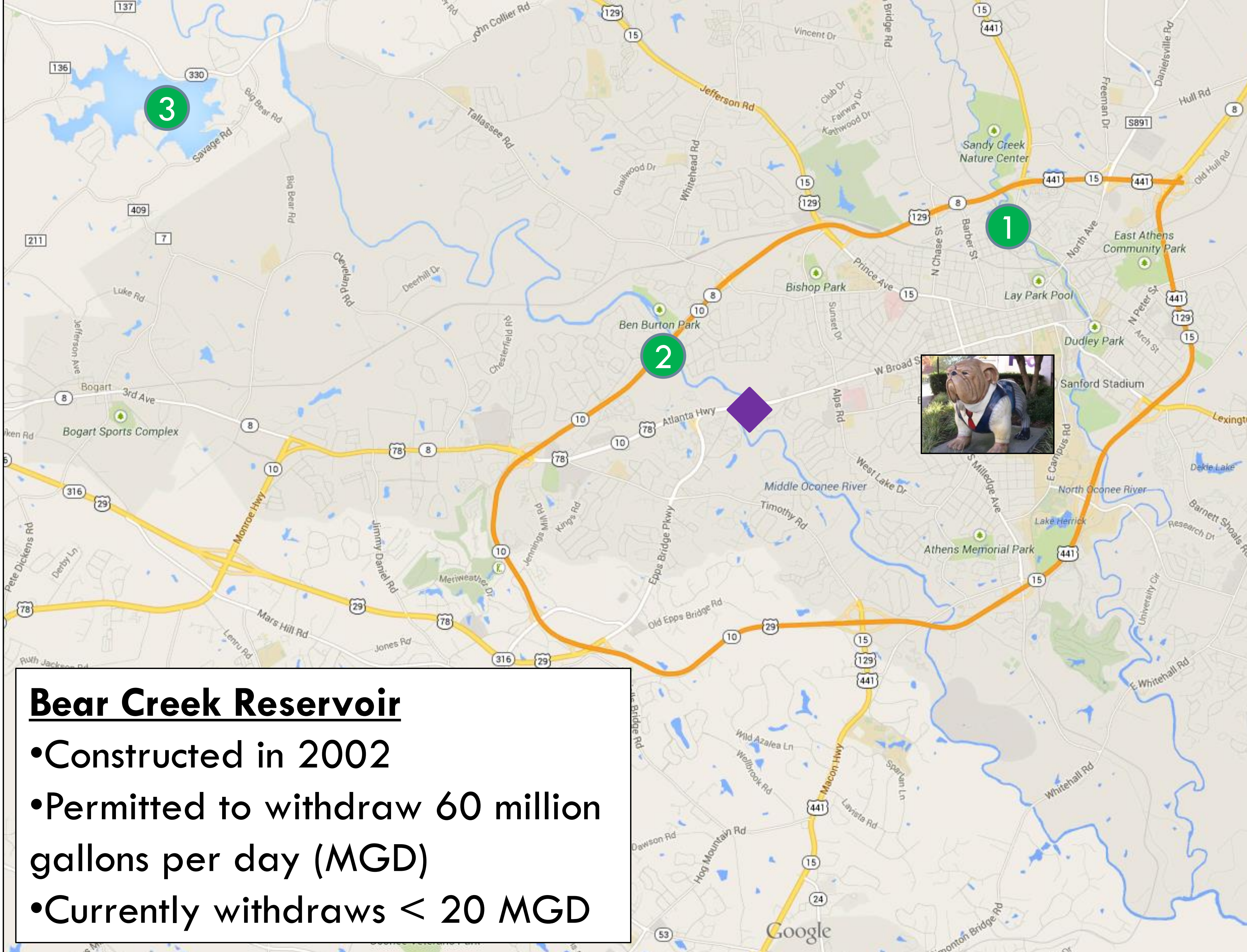


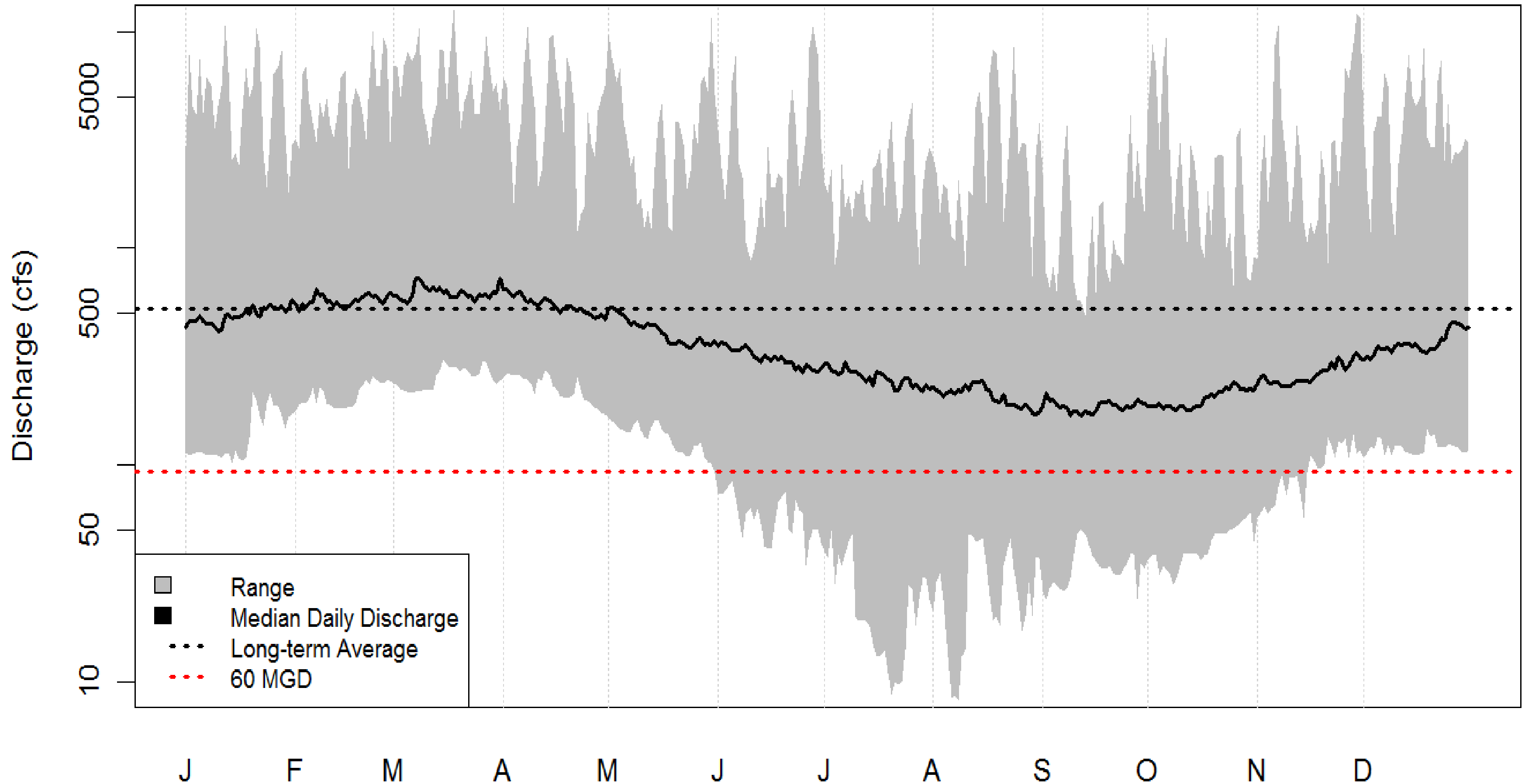
Figure: Georgia Department of Community Affairs



Bear Creek Reservoir

- Constructed in 2002
- Permitted to withdraw 60 million gallons per day (MGD)
- Currently withdraws < 20 MGD

Is 60MGD a lot of water?



Problem statement

- How much water can the city take from the river?
- How much water does the river need to maintain a vibrant ecosystem?
- Can we withdraw the same volume of water with less environmental impact?
- Confounding challenges
  - Hydrologic variability
  - Many ecological outcomes

Working through the proposed process

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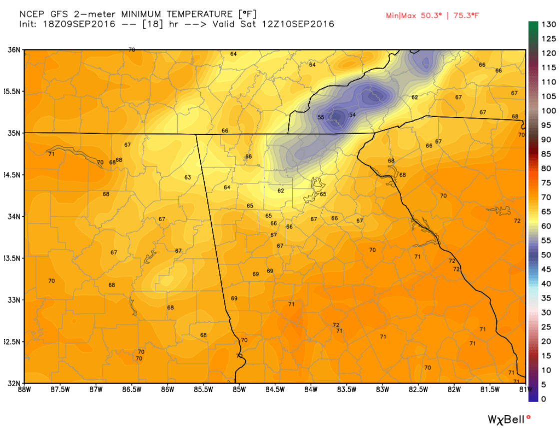
1-Understanding the disturbance regime:

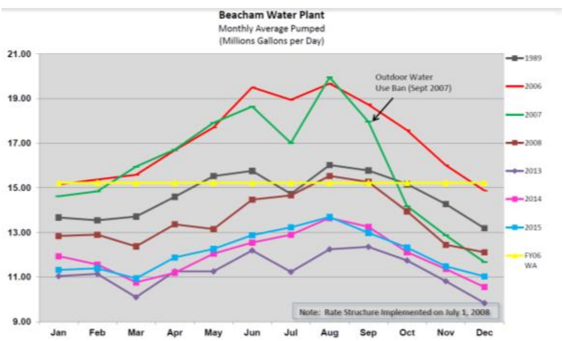
What is the source of environmental variation?

- While multiple processes are involved, one or a few regimes often become the focus of an analysis

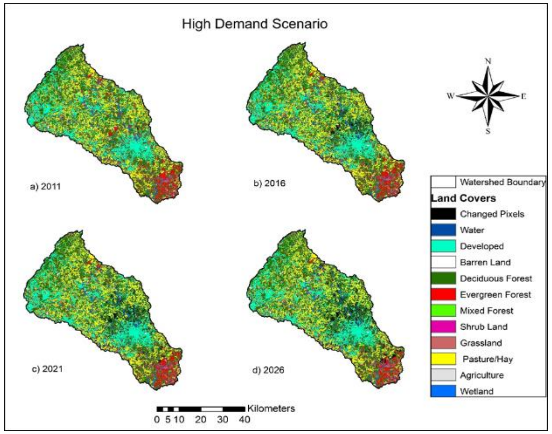
Precipitation and Temperature

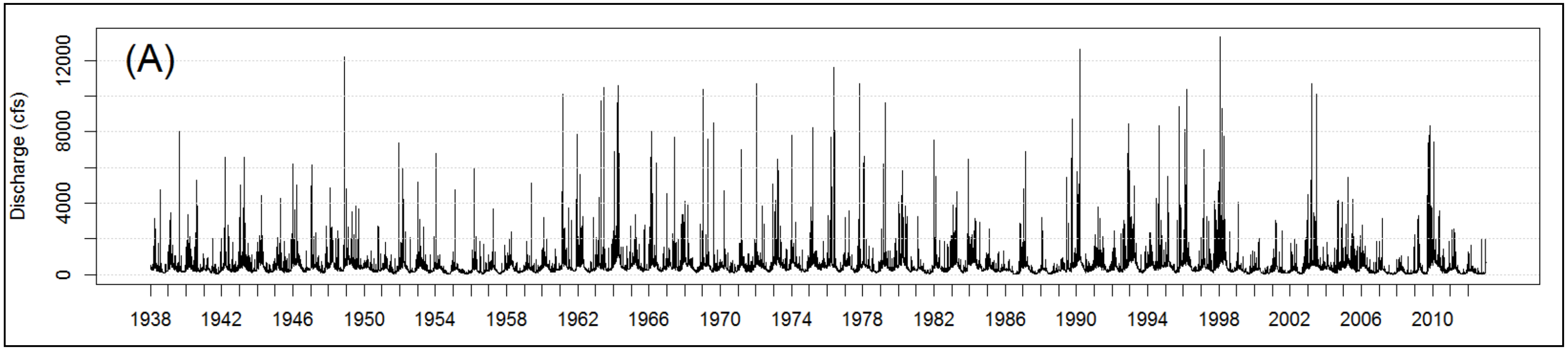


Water Use



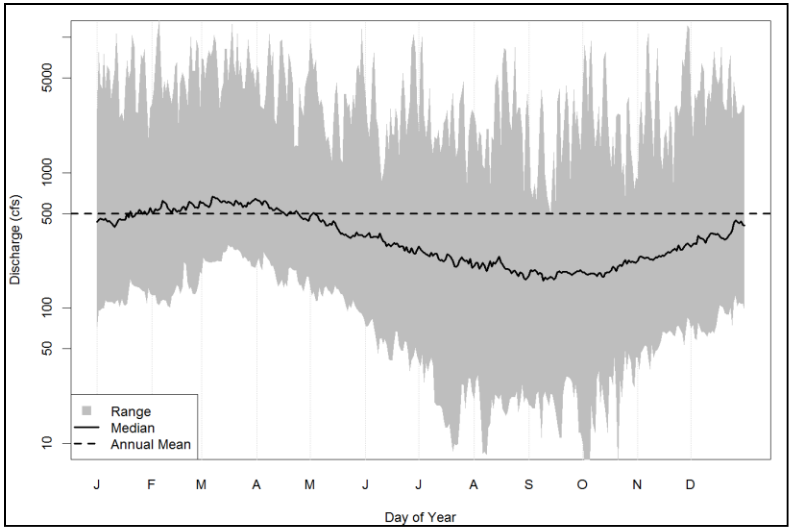
Land Use

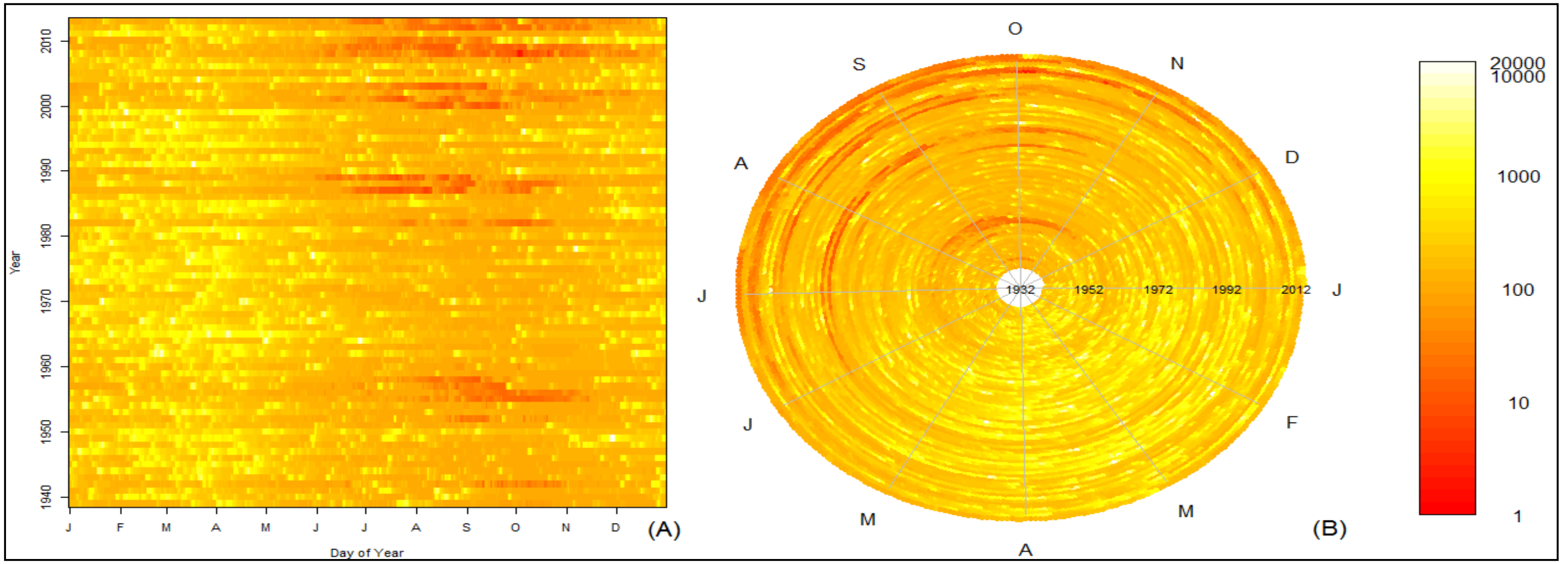




1-Understanding the disturbance regime:
Conceptualizing the time series

- Visualization is an invaluable tool for facilitating understanding
  - Highlighting different aspects
  - Providing reference points
  - Re-scaling axes
  - Using multiple visualizations





1-Understanding the disturbance regime:
What aspects of the time series matter?

What are the take-home lessons about discharge variability to carry forward?

- Mean discharge is meaningless!
- Most year provide plenty of water, but dry years are very dry (periodic drought)
- Seasonality is a strong influence in this system (particularly late summer low flows)
- High flows should be expected any time

2-Assessing system performance:
Thresholds and targets for performance

- What are the targeted aspects of system performance?
- How often does "success" need to be achieved?
- Are their goals related to variability (e.g., achieve this much outcome X% of time, avoid this outcome Y% of time)?

General Goal	Objectives	Key Thresholds
Provide for municipal water supply	Maximize water withdrawal	• Must be able to provide water all of the time (minimum withdrawal) • Regularly meet permit volume (average withdrawal)
Maintain a vibrant river ecosystem	Maximize habitat availability	• Regulatory minimum flow level • Avoiding ecological tipping points

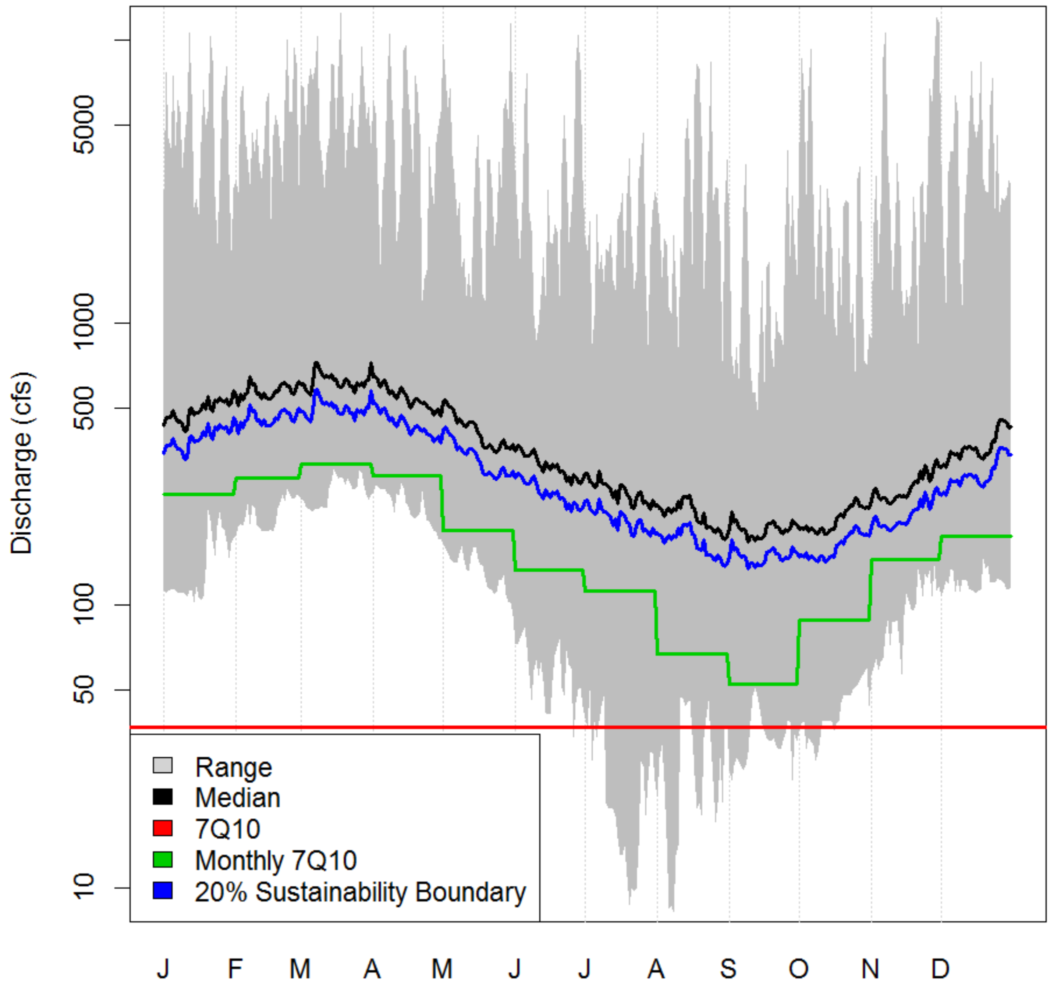
2-Assessing system performance:
What alternatives are available?

Minimum Flows

- Annual minimum flows
  - e.g., 7Q10 (old state reg)
- Monthly minimum flows
  - e.g., monthly 7Q10 (new reg)

Sustainability Boundaries

- Percentage based withdrawal
- e.g., TNC's "presumptive standard" of 20% limit (Richter et al. 2011)



2-Assessing system performance:
Assessing consequences of alternatives

Objectives

Water withdrawal
Habitat availability

Consequences

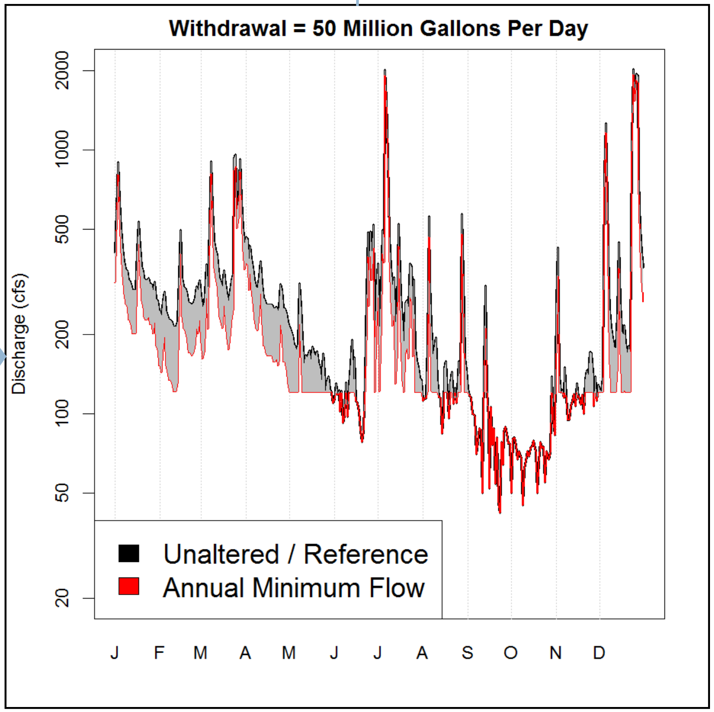
Using ecological models to assess each objective relative to each alternative (i.e., an altered flow regime)

Alternatives

Environmental flows
(e.g., minimum flows)

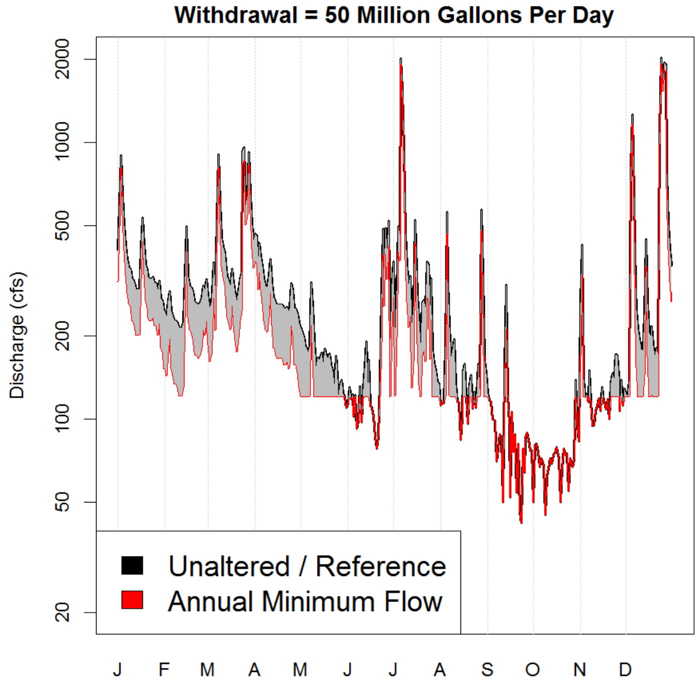
Period of Analysis

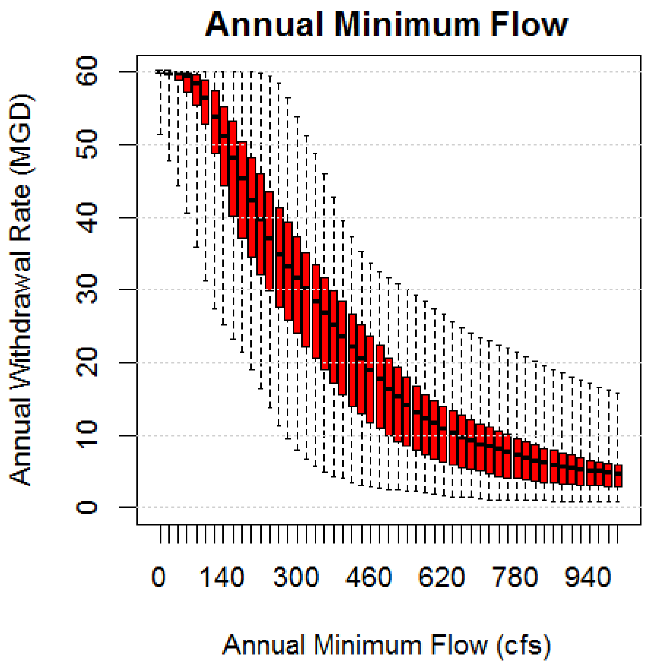
Historical Flow Regime
(1938-1997 gage data)



2-Assessing system performance:
Assessing consequences – Water withdrawal

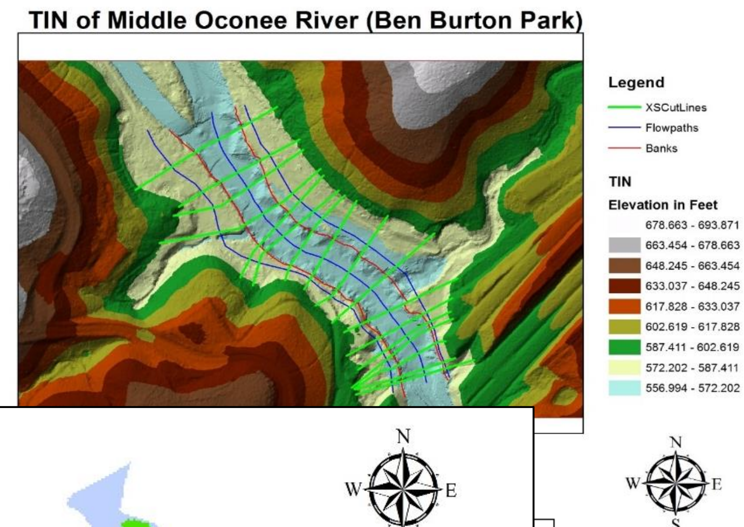
- 60 year historical record (1938-1997)
- Modify based on flow regime alternatives
- Compute **MINIMUM** withdrawal rate for each

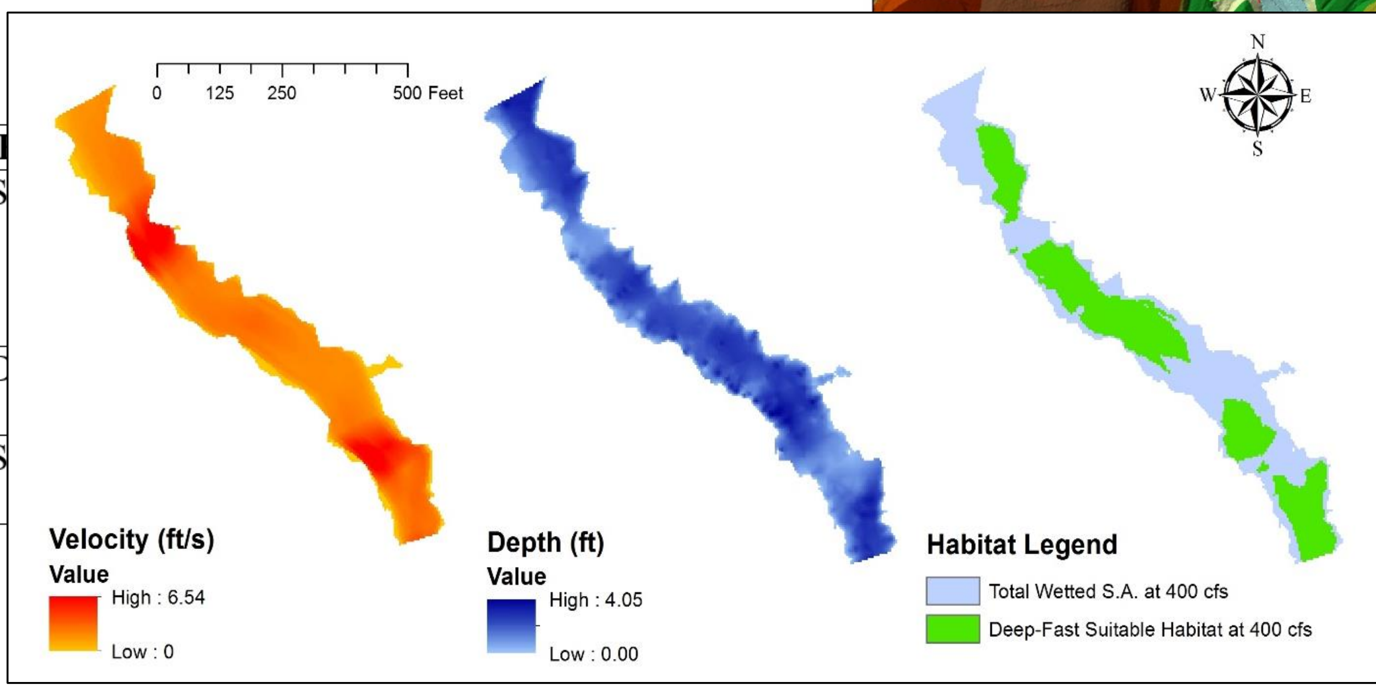




2-Assessing system performance:
Assessing consequences – Habitat

- Hydraulic model (HEC-RAS)
- Coupled with generic habitat requirements for the region (Freeman et al. 1997)

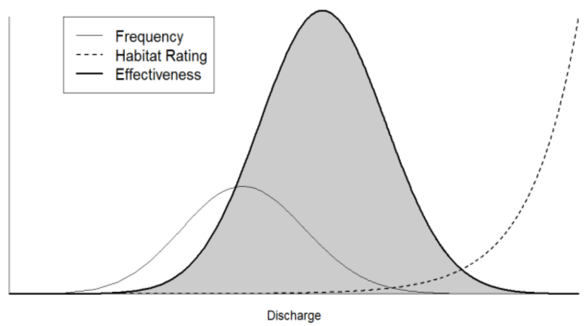


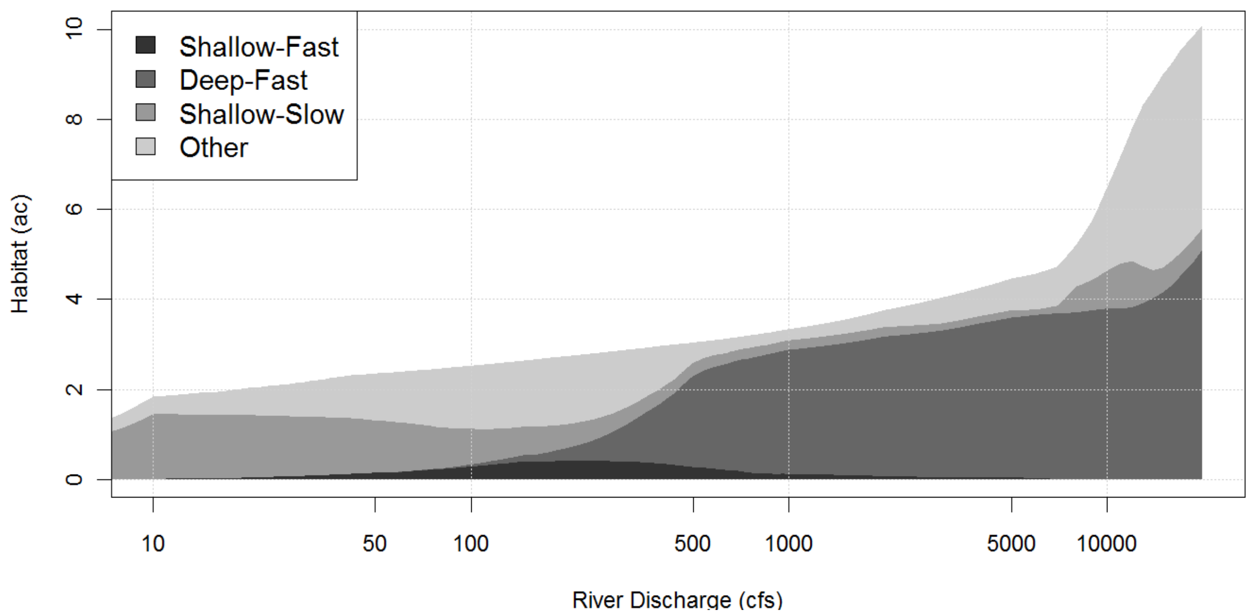


2-Assessing system performance:

Assessing consequences – Habitat

- Habitat assessed over the range of observed discharge
- Effectiveness analysis to couple magnitude and frequency



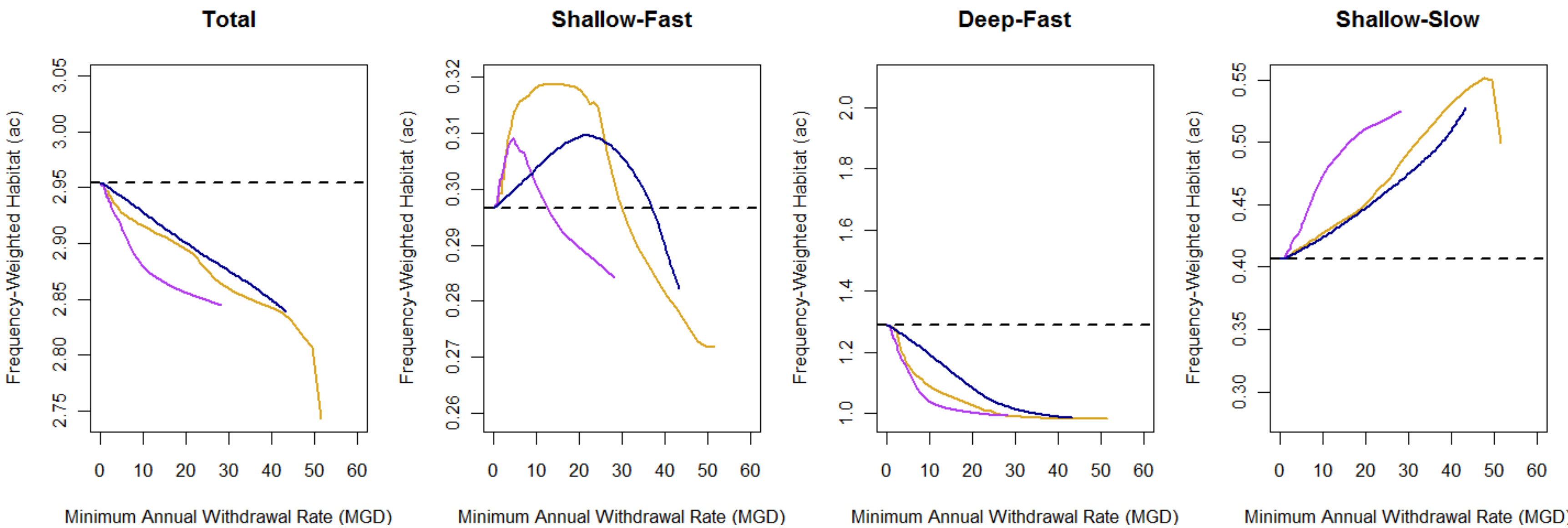


2-Assessing system performance:

Assessing consequences – Habitat

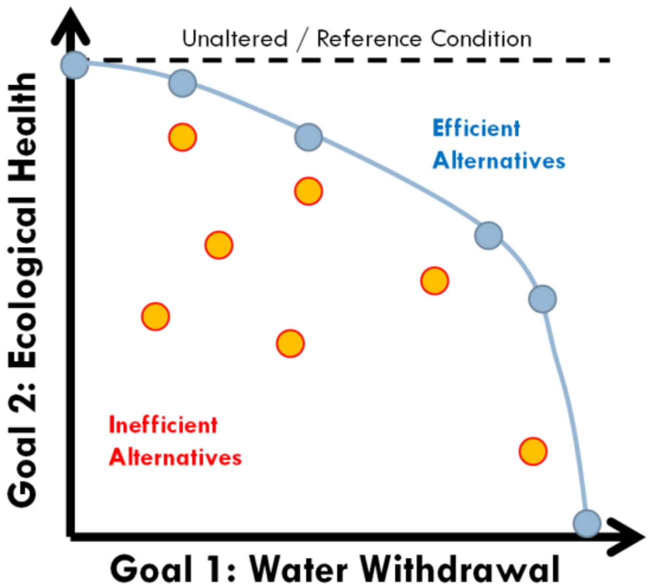
- Compute frequency-weighted habitat availability for all flow regimes
- Differential effects across habitat types

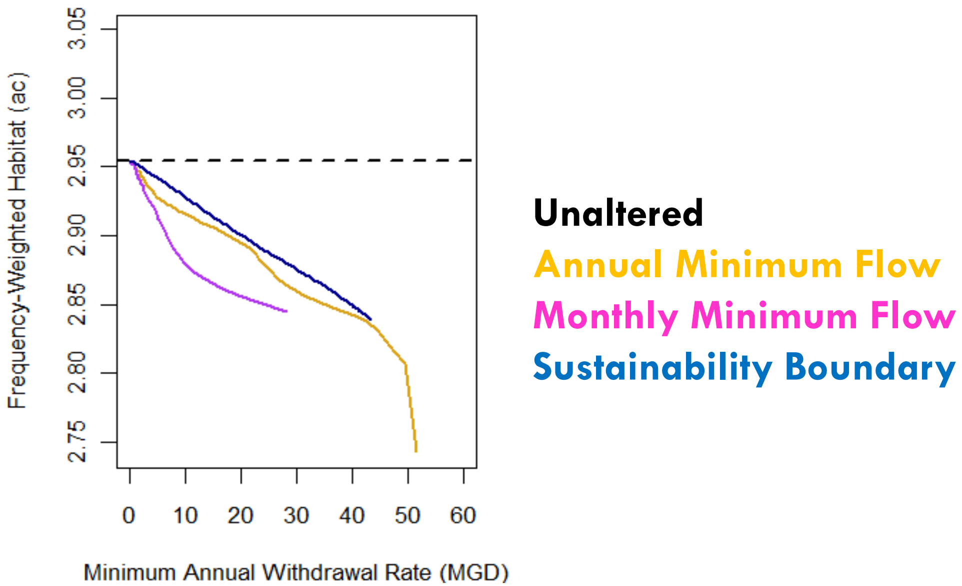
Unaltered
Annual Minimum Flow
Monthly Minimum Flow
Sustainability Boundary



2-Assessing system performance:
Summarizing key findings relative to variability

- Sustainability boundaries are consistently better relative to BOTH objectives (water supply and ecosystem integrity)
- Minimum withdrawal rates vary significantly across regimes
- Variability-oriented flow alternatives (sustainability boundaries) respond more consistently with fewer thresholds





3-Designing around variability:
How can design plan for variability?

How will the project design react to disturbances?

- Intakes designed to cope with range of flow rates (high flow scour and low flow submergence)

How much adaptive capacity exists within the project design for coping with a changing (or unexpected) disturbance regime?

- Initially, flat rate pumps were installed
- Variable speed pumps subsequently added
- Multiple municipal intakes provide further adaptability

4-Operating for and with variability:
Operational assessment of variability

Are data being collected to guide performance?

- Long-term USGS discharge data provides pre- and post-intake comparison
- Detailed water withdrawal and use rates for the four-counties

Are operations a fluctuating or static target? Where is the “wiggle room” in the system?

- Off-channel configuration is unique opportunity
- Massive intra- and inter-annual variability may facilitate opportunistic reservoir filling

4-Operating for and with variability:
Operational planning for variability

What are the sources of seasonal or periodic variability and plans for response?

- Reservoir filling typically occurs during wet season

What are the sources of catastrophic variability and plans for response?

- Drought is always a threat. Alternate withdrawal patterns and water use restrictions provide crucial management levers.
- Four-county management authority receives weekly reports on drought status (even during wet periods) and meets quarterly for reservoir planning.

Parting thoughts

Does variability matter?

- Variability is not a new phenomenon in water management. However, the growing toolkit allows for a revised approach to assessment.
- Mean values are often meaningless in aquatic systems, and disturbance regimes are the path to understanding and coping with variability.
- This assertion is supported in the broader trend in agency planning for risk, resilience, and reliability.
- This project focuses on developing an analytical framework and demonstrating these concepts in the context of ecological outcomes and restoration

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Forthcoming Report

Touzinsky K.F. and McKay S.K. *Forthcoming*. Conceptualizing and managing variability in ecosystem restoration. EMRRP-TN.