How much model complexity is needed to make environmental flow recommendations?

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Ecosystem Management and Restoration Research Program (EMRRP) Webinar Series

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Overview

- Comparing ecological models
  - Trading-off complexity, information, uncertainty, & resources

- Environmental Flow Case Study
  - Middle Oconee River, Georgia

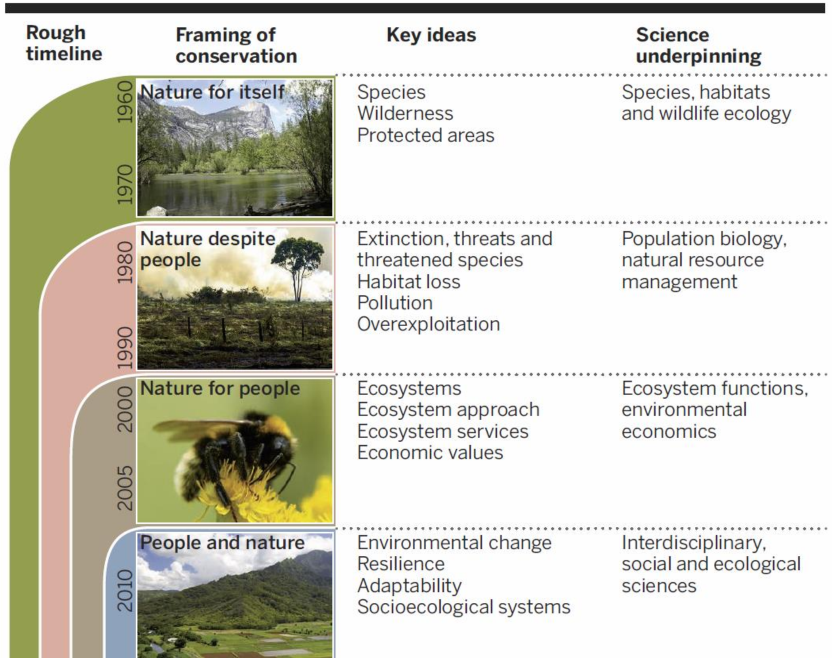
- Emerging lessons in model complexity
  - How much model do you need?

Comparing Ecological Models

Ecosystem Restoration

Environmental Flows

Conservation



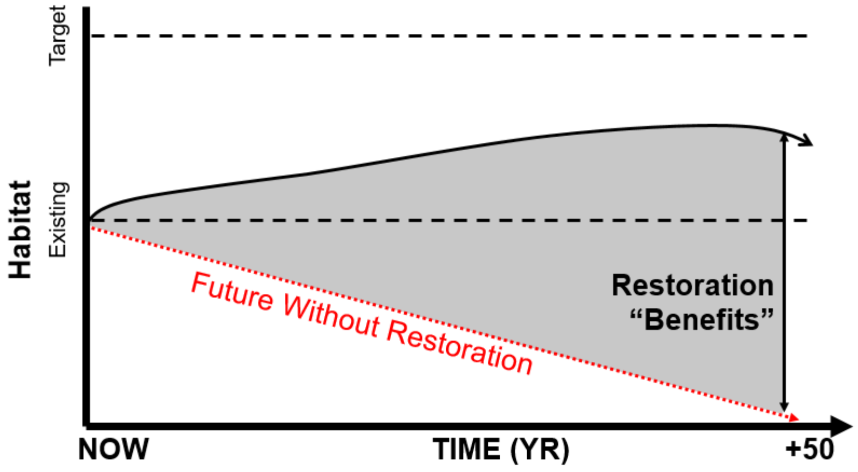
Rough timeline	Framing of conservation	Key ideas	Science underpinning
1960–1970	Nature for itself	Species Wilderness Protected areas	Species, habitats and wildlife ecology
1980–1990	Nature despite people	Extinction, threats and threatened species Habitat loss Pollution Overexploitation	Population biology, natural resource management
2000–2005	Nature for people	Ecosystems Ecosystem approach Ecosystem services Economic values	Ecosystem functions, environmental economics
2010	People and nature	Environmental change Resilience Adaptability Socioecological systems	Interdisciplinary, social and ecological sciences

Mitigation

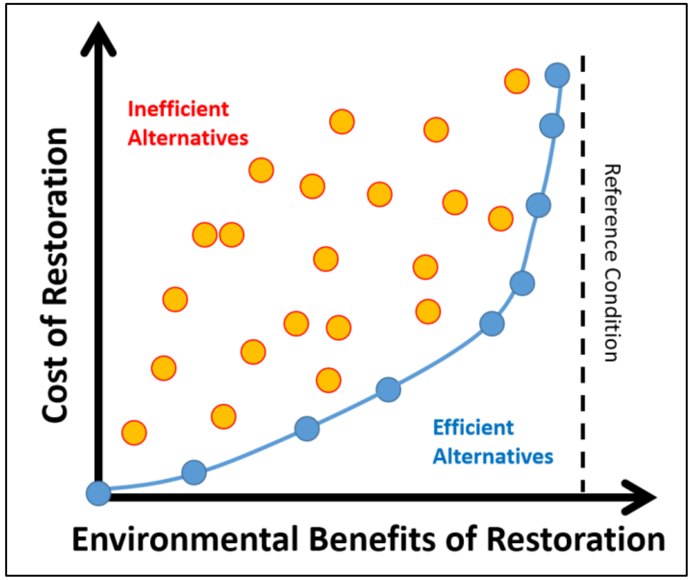
Figures:
Nate Richards,
Mace (2014),
USACE Savannah,
Dr. Tosin Sekoni

Ecosystem management and restoration benefit from the ability to predict (i.e., they need models)

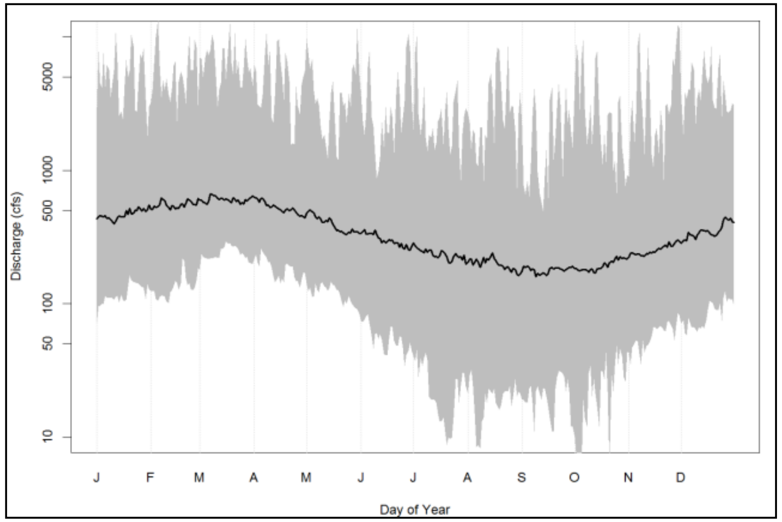
To forecast futures with and without projects



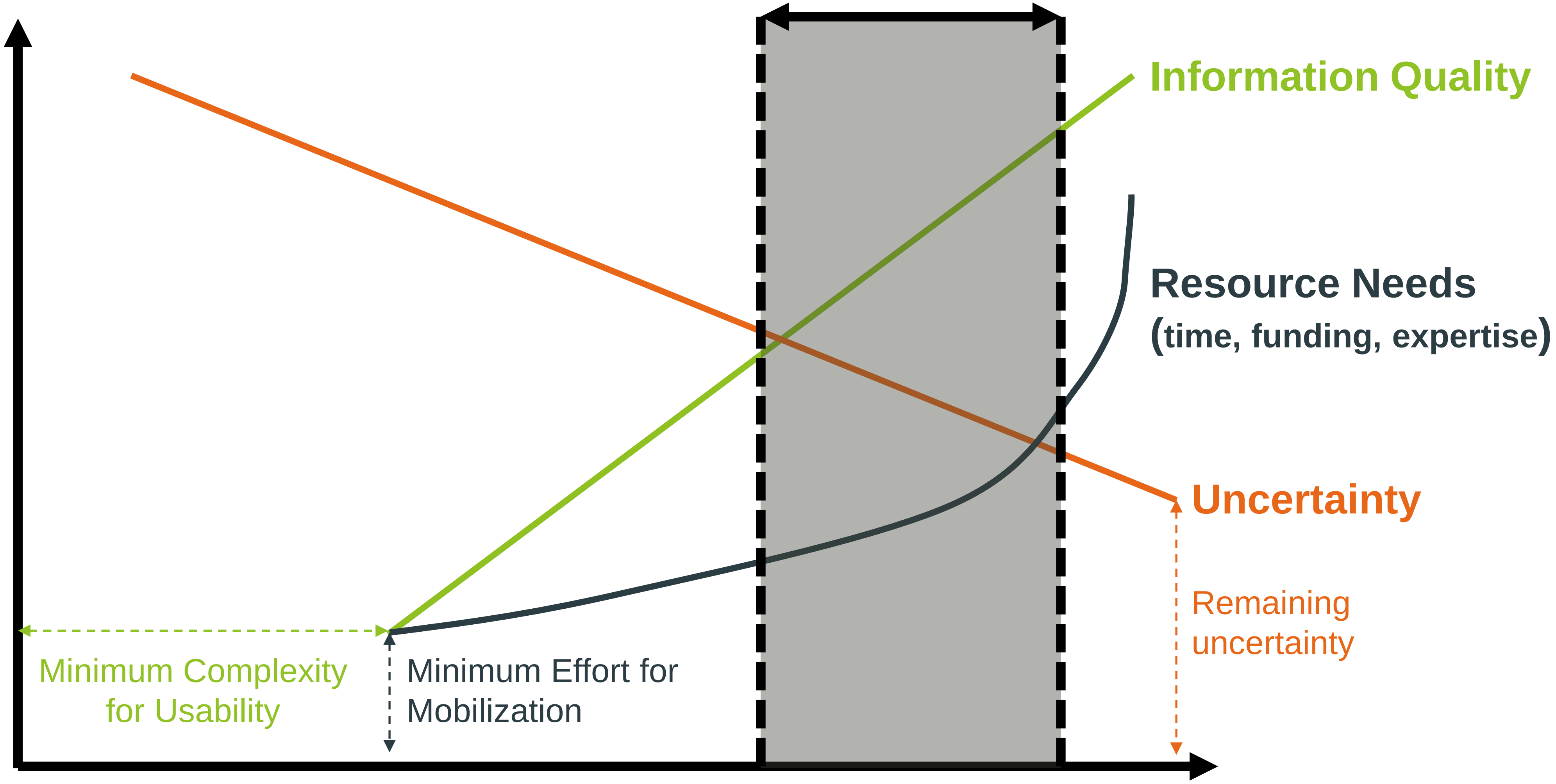
To assess benefits and costs of actions



To quantify and manage uncertainty



Is it worth it?



Model Complexity

Model complexity is a key issue for risk-informed planning

- How much model do I need to make a decision?
- Should I gather more input data?
- Does my model capture system dynamics?
- Do assumptions affect decisions?
- Do I need multiple models?
- Can we afford to “buy more model”?

Guiding questions driving our research

- What is the return-on-investment of “more model”?
- Is the agency making the “right” decision regardless of model complexity?

Overarching Research Project on Model Comparison

Within Model Comparison	Between Model Comparison	Best Practices for Comparing Ecological Models
• Data resolution • Parameter sensitivity • Environmental variability	• Models for the same outcome • Models for similar outcomes • Models for different outcomes	• Within model comparison • Between model comparison • Trade offs between level-of-effort and return-on-investment
• Middle Oconee River • Rio Grande	• H&H modeling of arid streams • Oyster reef harvest • Watershed connectivity for migratory taxa of Puerto Rico • Middle Oconee River	• Use prior case studies • Compile examples from USACE studies and published literature

Environmental flow analysis on the Middle Oconee River near Athens, Georgia

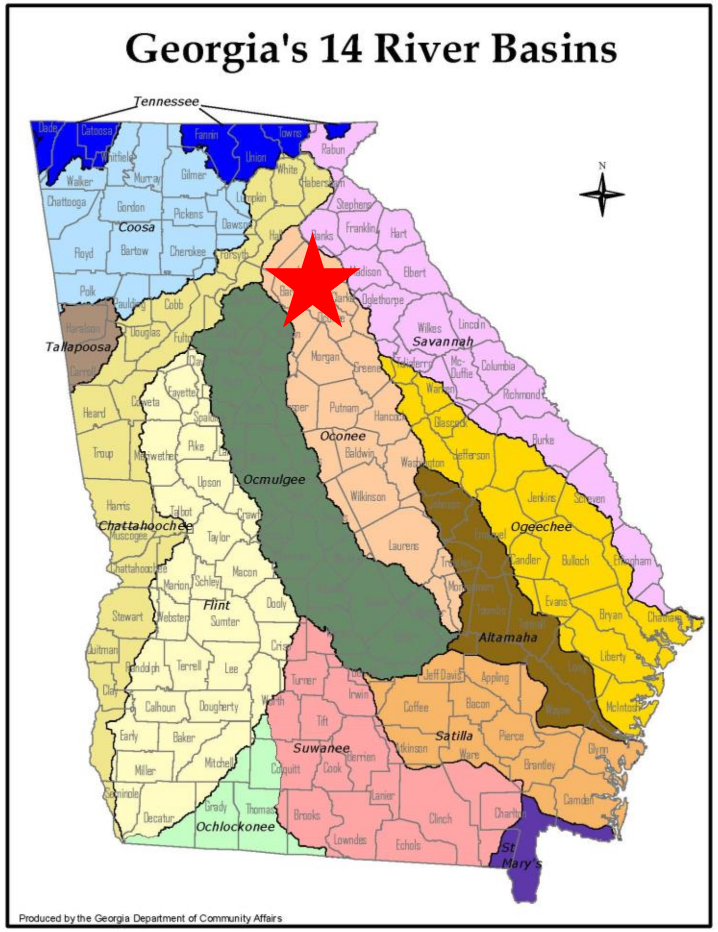
(Led by Caitlin Conn, Tyler Keys, and Mary Freeman)

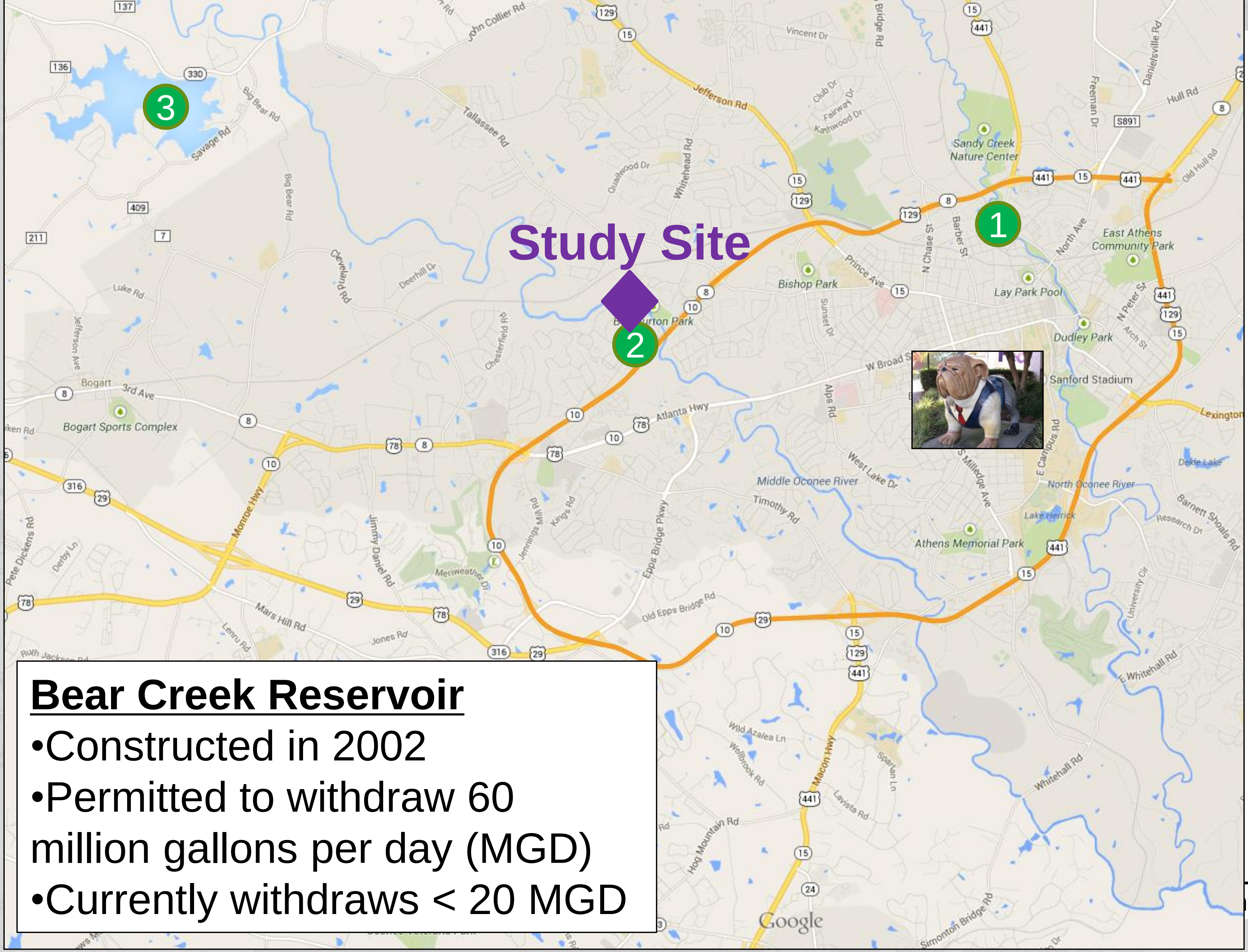
Preliminary results subject to change.

Bhattacharjee, Willis, Tollner, and McKay. 2019. Habitat provision associated with environmental flows. ERDC/TN-EMRRP-SR-85. U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Conn, Keys, Freeman, and McKay. Comparing river management recommendations with varying model resolution. In preparation for *Ecological Engineering*.

Middle Oconee River near Athens, Georgia





Bear Creek Reservoir

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

Problem Statement: Can the same volume of water be withdrawn with less environmental impact?

ter

Objectives

Water withdrawal

Habitat availability

…

Consequences

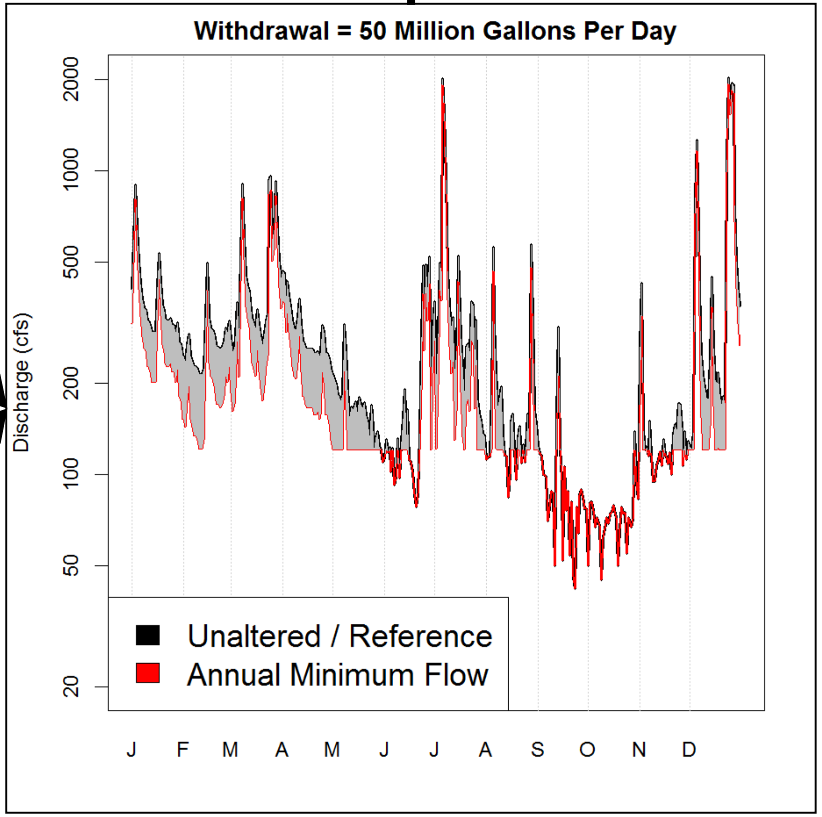
Using models to assess objectives for each alternative

Alternatives

Environmental flows (e.g., minimum flows)

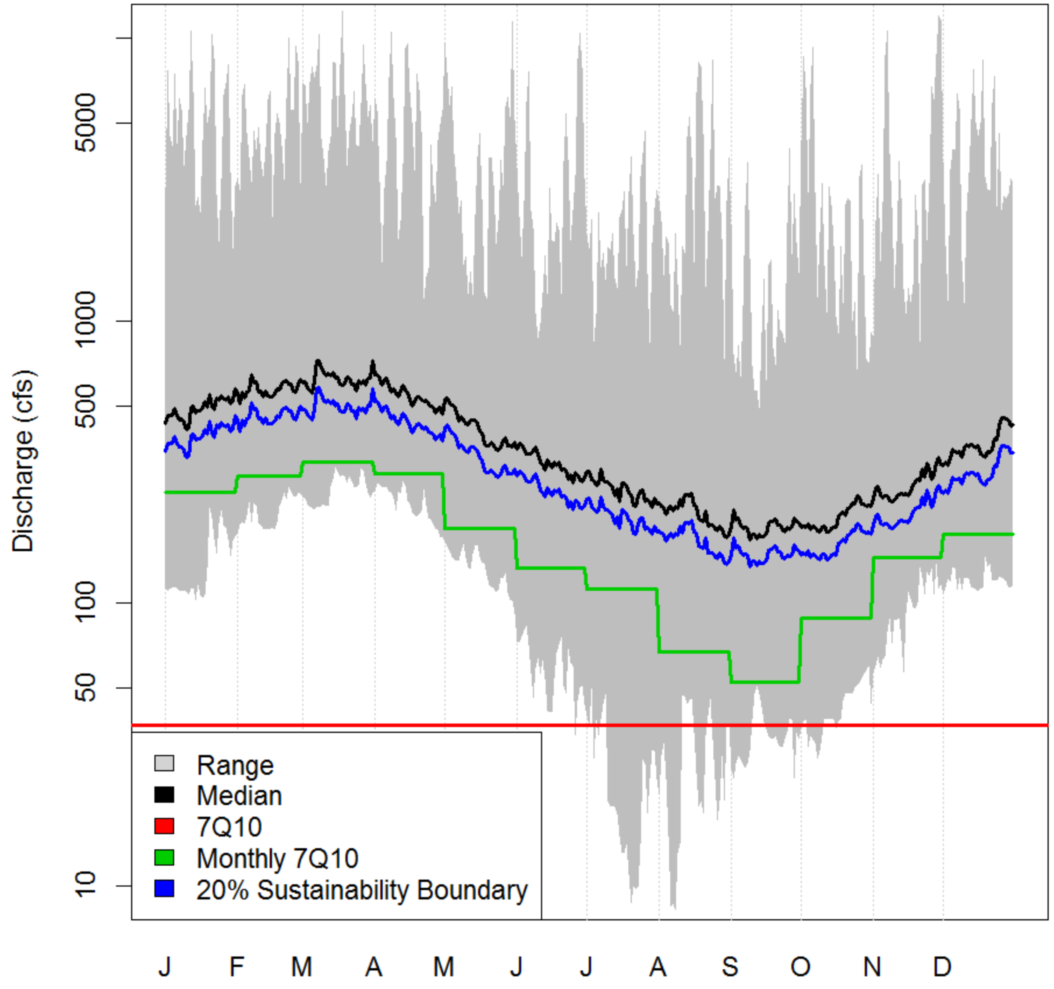
Period of Analysis

Historical Flow Regime (1938-1997 gage data)



Alternatives: Environmental flow options

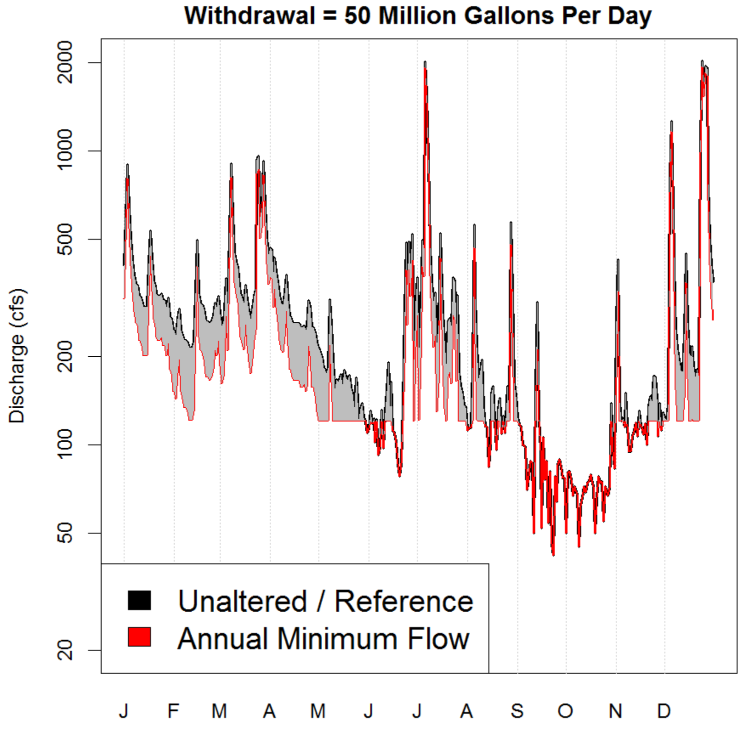
- Unaltered flow regime
  - “No action” alternative
- Annual minimum flows
  - e.g., 7Q10 (old state reg)
- Monthly minimum flows
  - e.g., monthly 7Q10 (new reg)
- Percent-of-flow
  - TNC’s “Sustainability Boundaries”

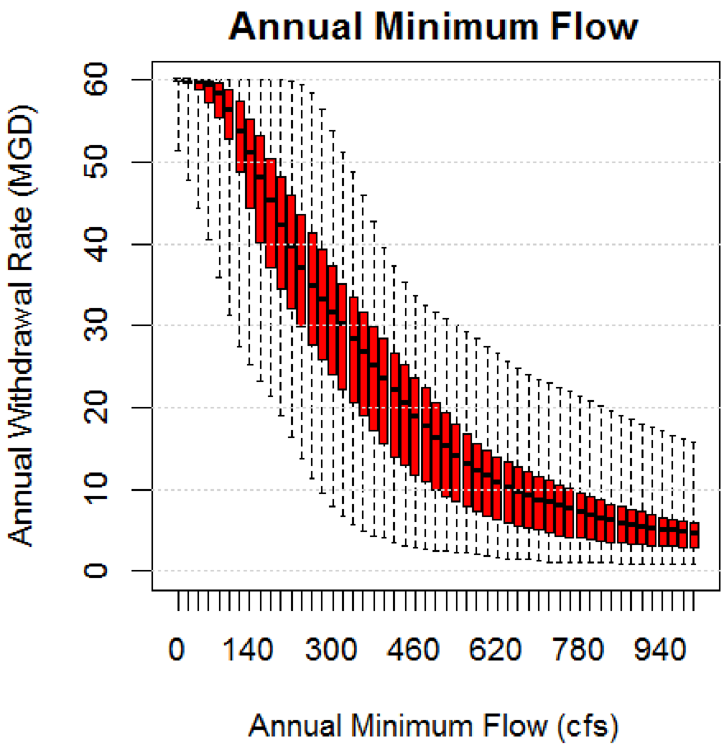


Consequences: Water withdrawal

- 60-year historical record
- Modify based on flow regime alternatives

- Compute withdrawal rate for each year
- Minimum annual withdrawal rate as a conservative metric of water supply

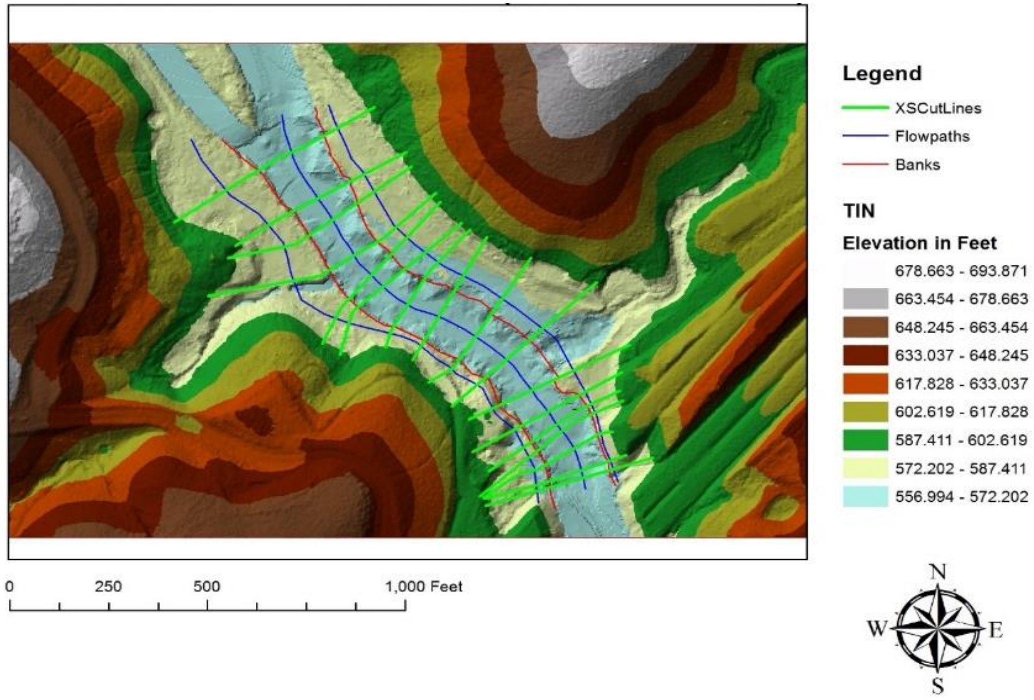


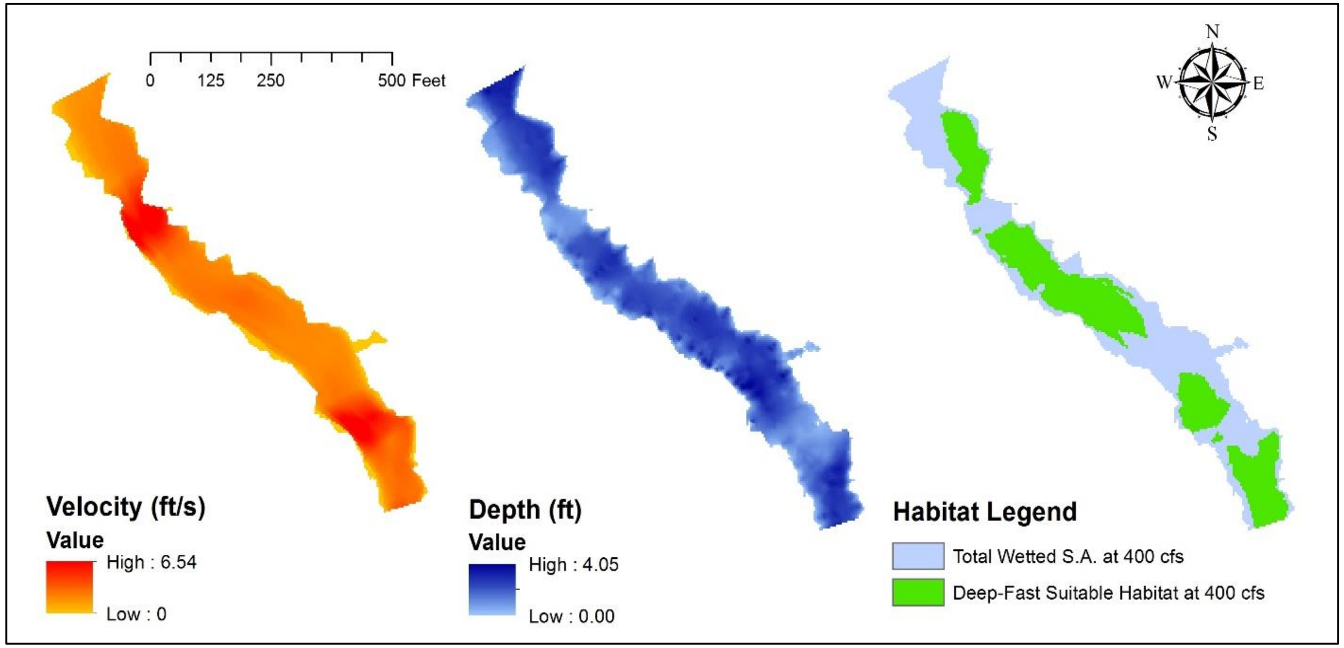


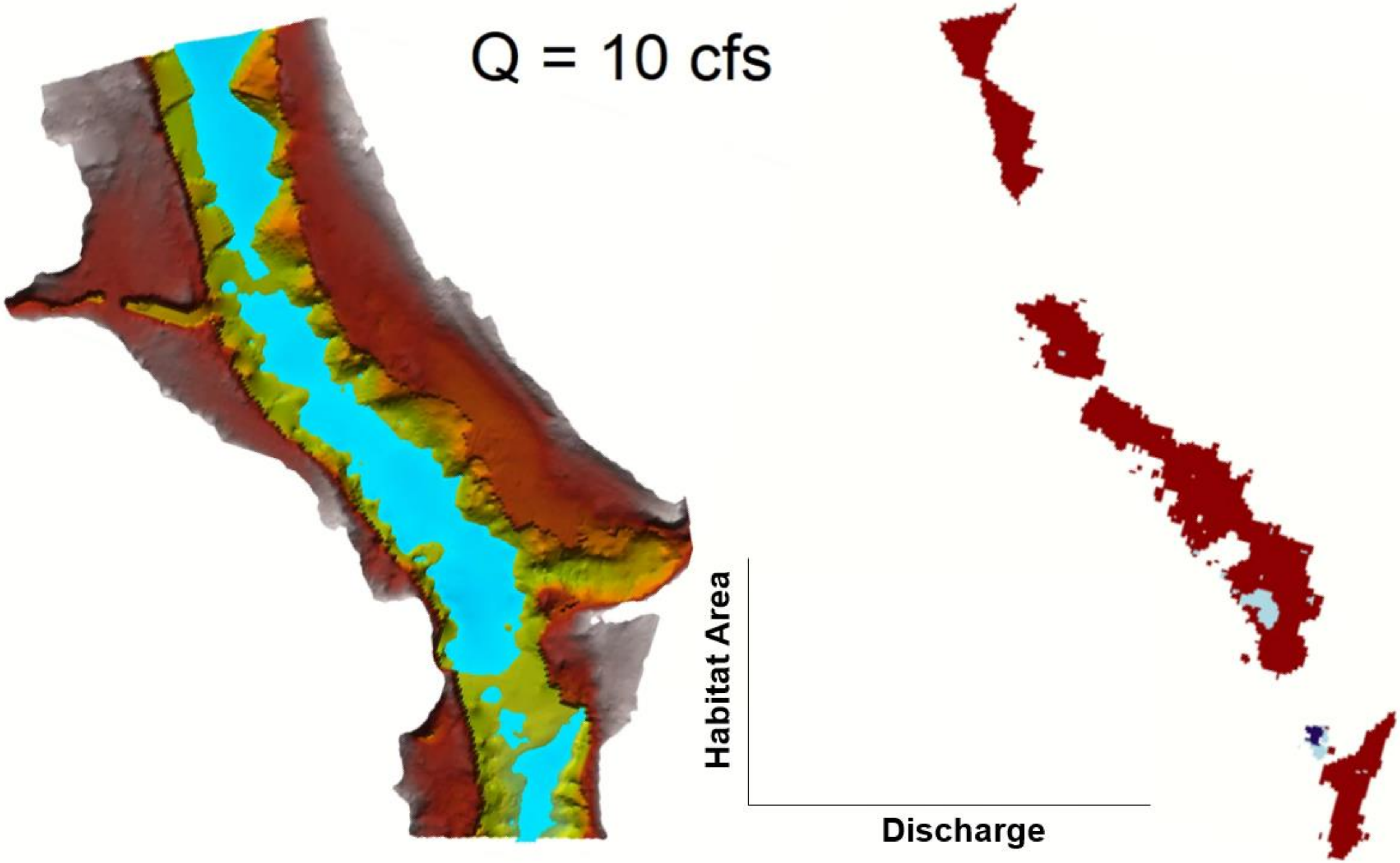
Consequences: Habitat availability

- Hydraulic model (HEC-RAS)
- Coupled with generic habitat requirements (Bain et al.)

Key Habitat	River Depth	Flow Velocity	Representative Taxa
1. Shallow – Fast	≤ 35 cm (≤ 1.15 ft)	≥ 55 cm/s (≥ 1.8 ft/s)	*Nocomis leptocephalus* (bluehead chub) *Notropis hudsonius* (spottail shiner)
2. Deep – Fast	≥ 35 cm (≥ 1.15 ft)	> 45 cm/s (> 1.48 ft/s)	*Micropterus Salmoides* (largemouth bass)
3. Shallow – Slow	< 35 cm (< 1.15 ft)	< 35 cm/s (< 1.15 ft/s)	*Lepomis* (bluegill and sunfish)







Habitat Types

Shallow-fast

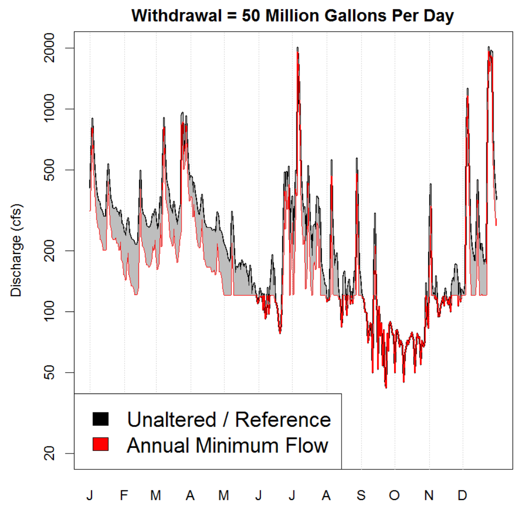
Deep-fast

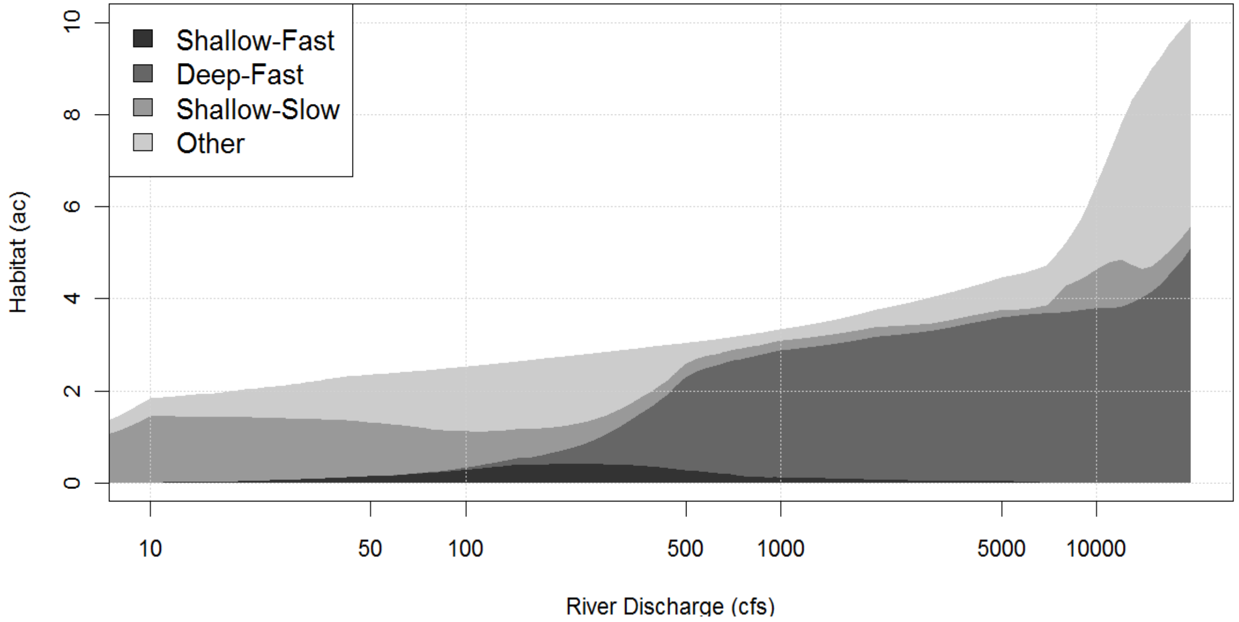
Shallow-slow

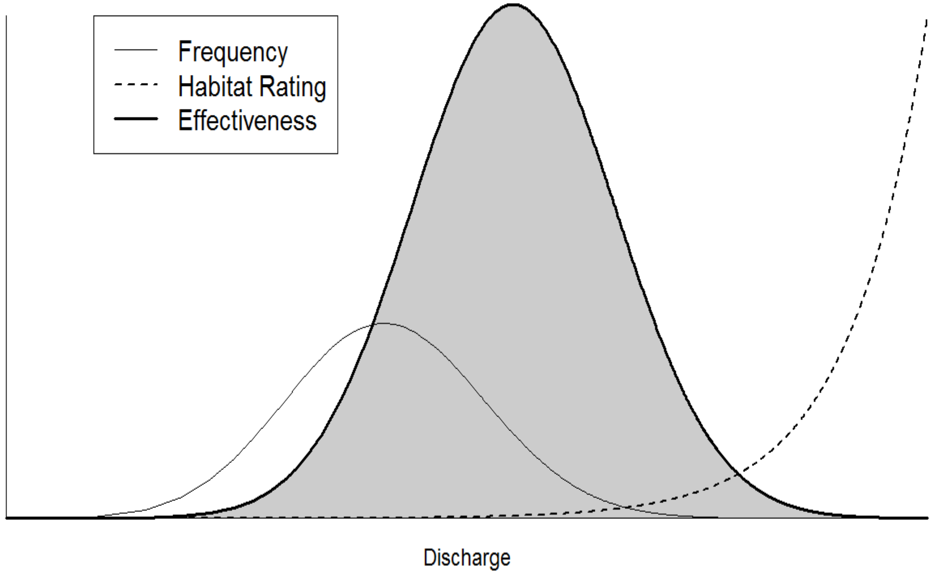
Other

Consequences: Habitat availability

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



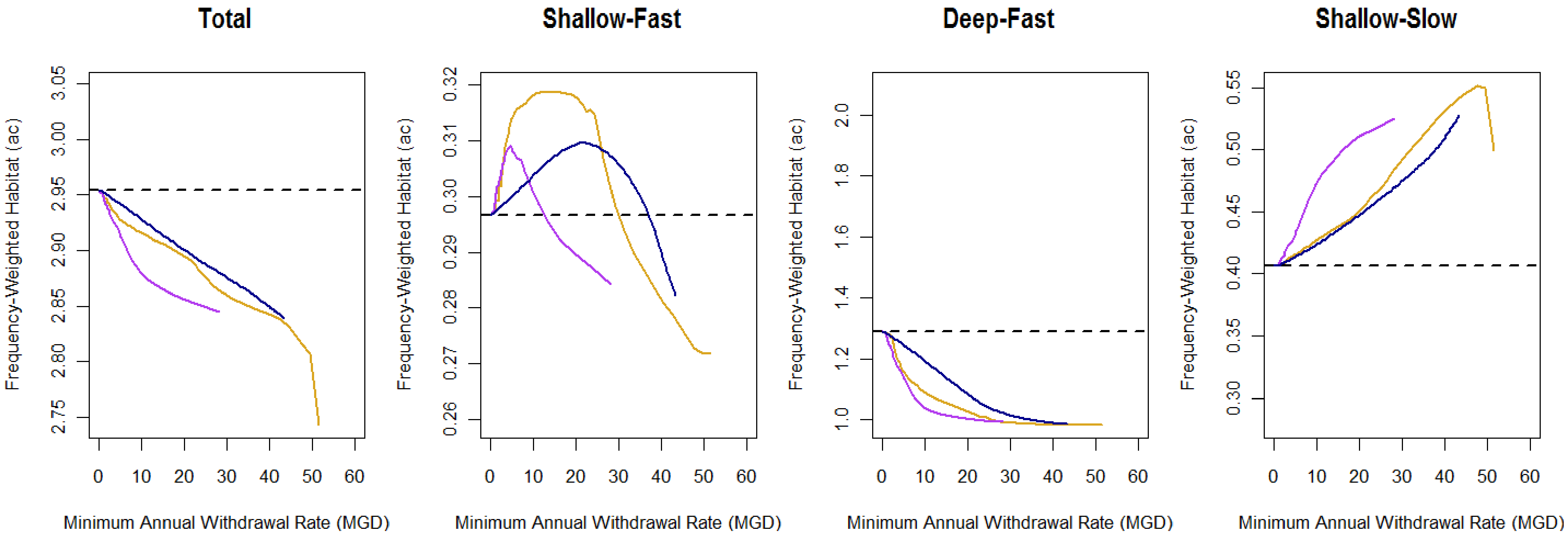




Trade-offs: Habitat availability

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

Unaltered
Annual Minimum Flow
Monthly Minimum Flow
Percent of Flow



Research Questions and Experimental Design

Overarching Issue

How does model complexity influence recommendations?

Testable Research Questions

1. How does input data resolution affect outcomes?
   - Varied the number of channel cross-section from 17 to 9 to 5

2. Does sampling design influence model complexity?
   - Cross-sections selected randomly vs. stratified by channel slope

3. Does hydraulic model dimensionality affect habitat?
   - Executed HEC-RAS in both one- and two-dimensional setups

Key Assumptions

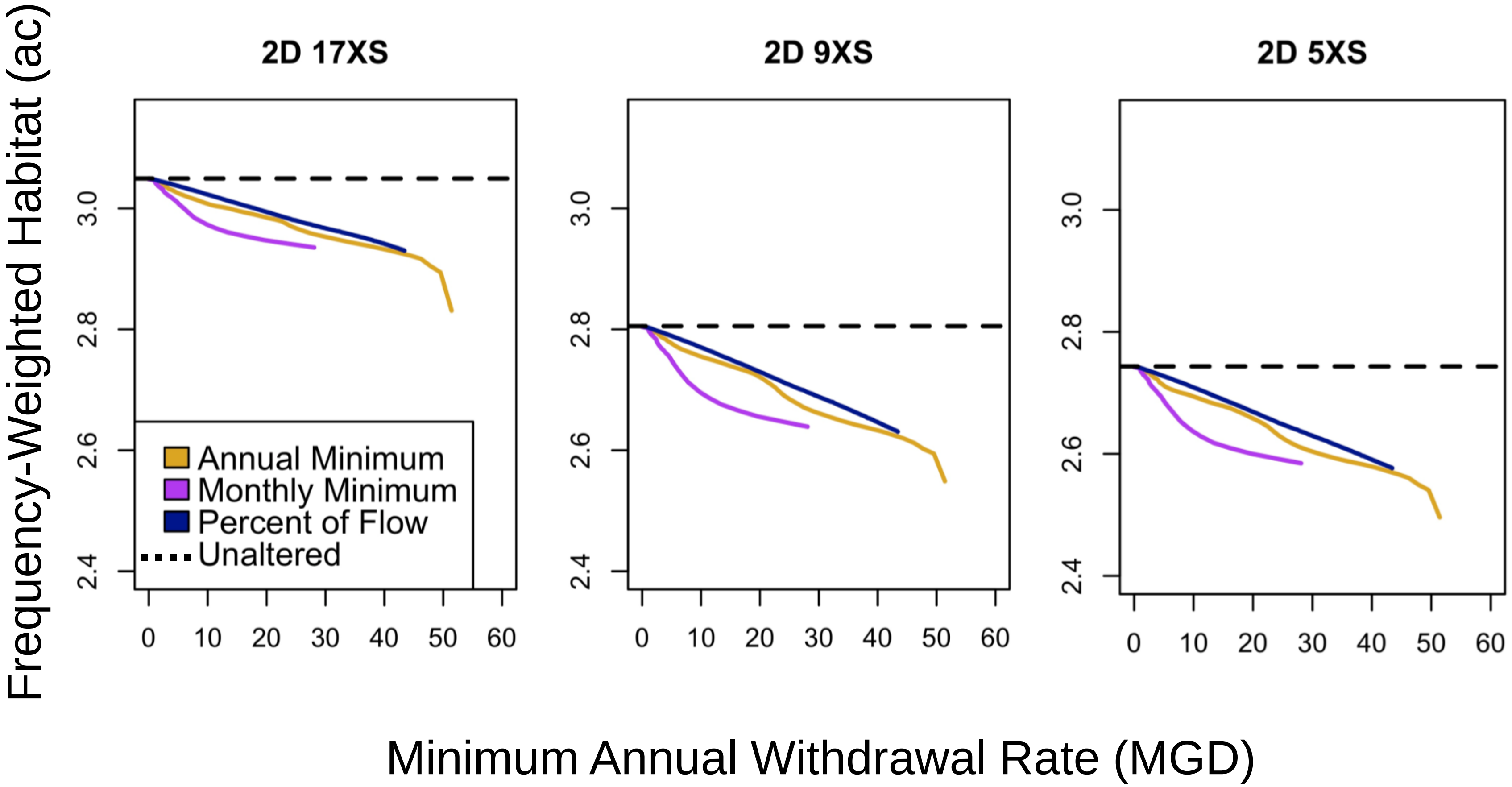
- The highest resolution model is the most accurate.
- Total habitat area is a meaningful metric.

Q1: How does input data resolution affect outcomes?

Varied the number of channel cross-section from 17 to 9 to 5

Observations

- Differences in the magnitude of habitat
- Shape of response curves is similar
- Relative ranking of eflow alternatives remains consistent

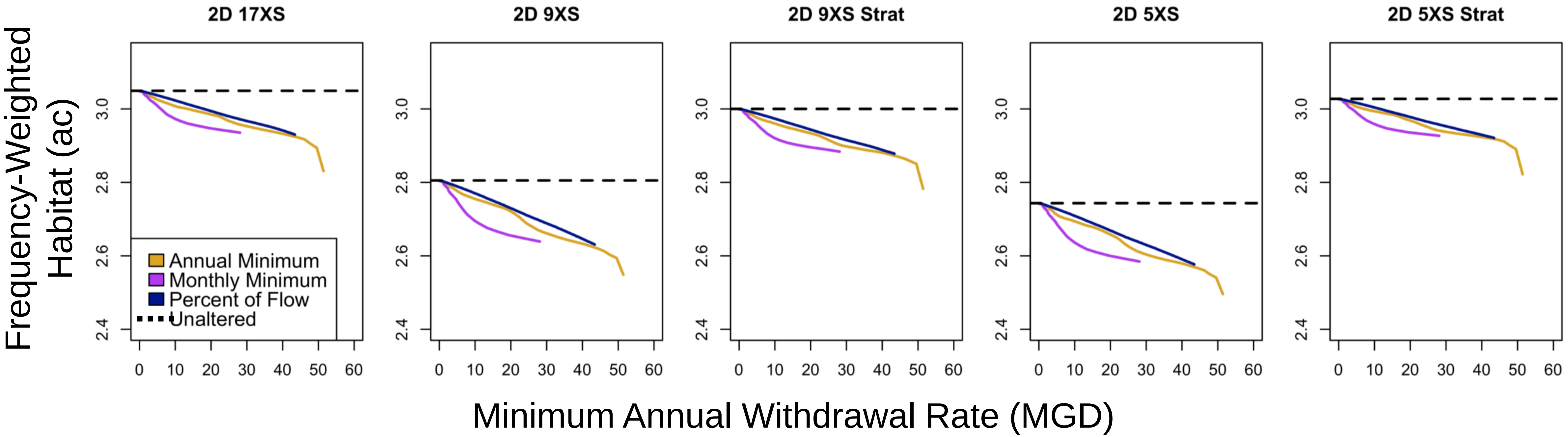


Q2: Does sampling design influence model complexity?

Cross-sections selected randomly vs. stratified by channel slope

Observations

- Bed-slope stratified surveys better capture habitat dynamics (relative to magnitude)
- Relative ranking of eflow alternatives remains consistent

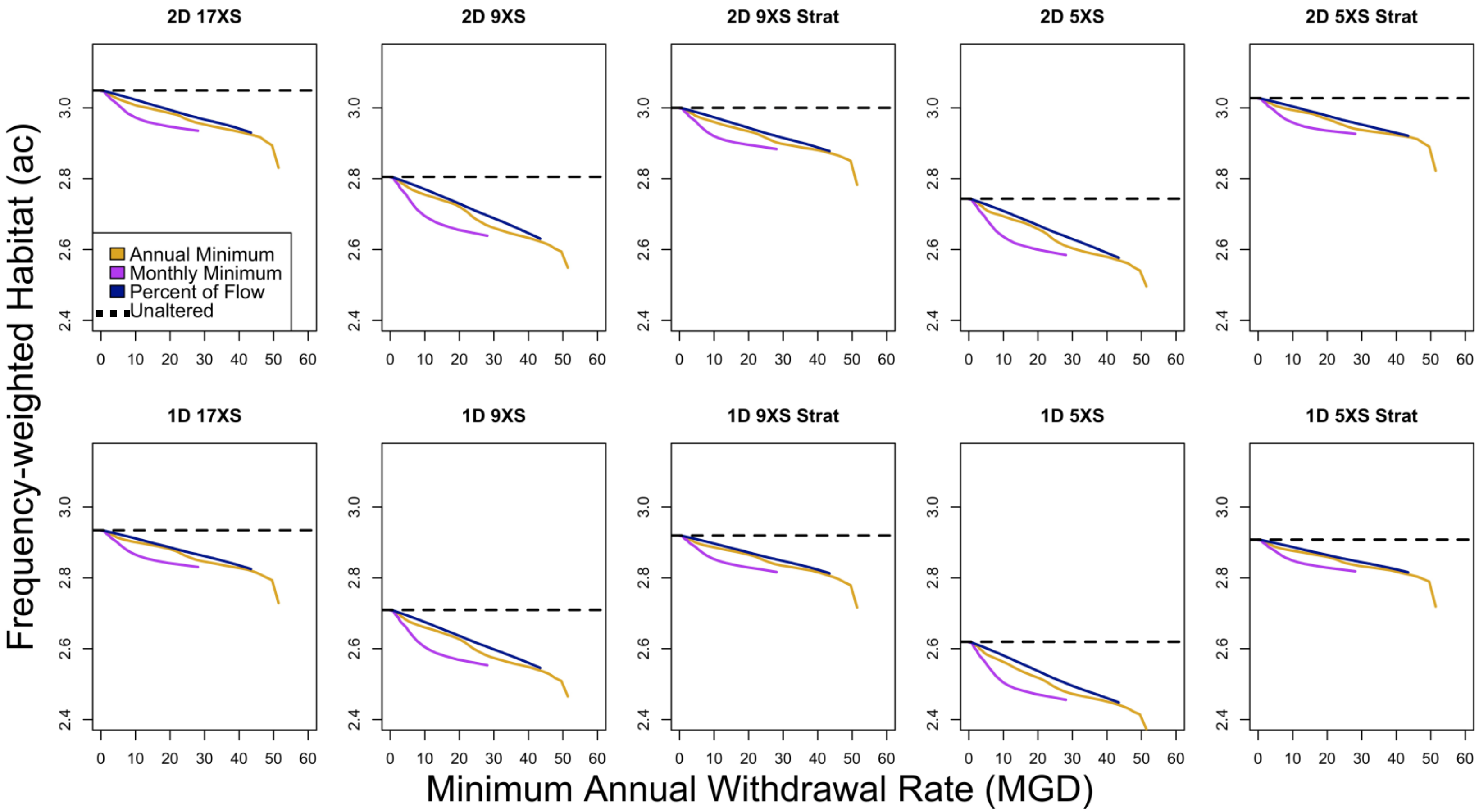


Q3: Does hydraulic model dimensionality affect habitat?

Executed HEC-RAS in both one- and two-dimensional setups

Observations

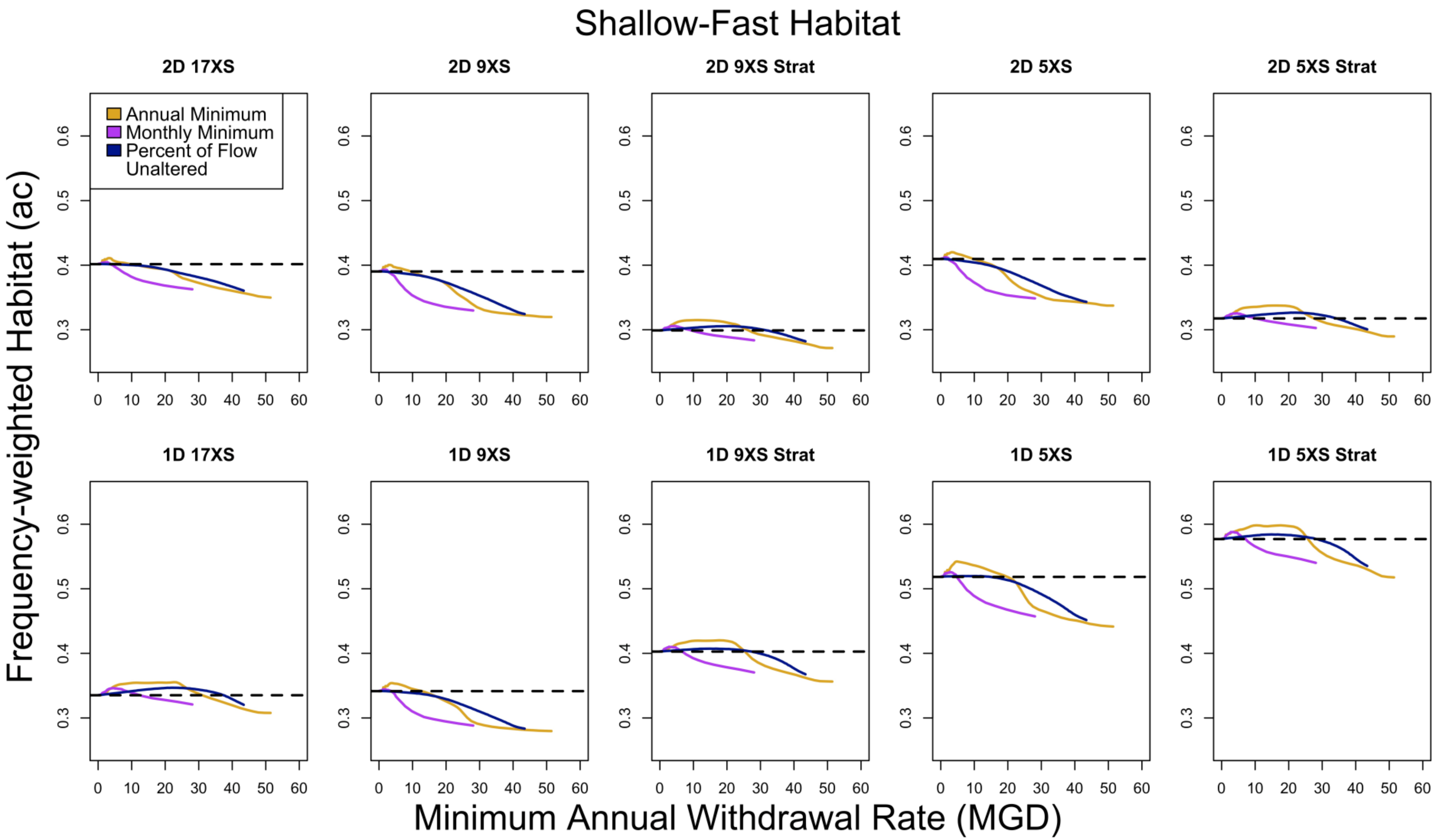
- Strong effect from xsec selection
- 2D models generally closer in magnitude
- Relative ranking of eflow alternatives remains consistent



Preliminary Findings Relative to Model Comparison *(at this site in the Middle Oconee River)*

- *Relative* ranking of eflow alternatives remains consistent
  - Consistent ranking leads to confidence in recommendation
- *Absolute* predictions of habitat vary quite a lot
  - Is your goal comparing two alternatives or prediction?
- Bed-slope stratified surveys better capture habitat dynamics (relative to magnitude)
  - Judgment- or analytically-based selection of cross-sections may be important
  - Not just random or even interval cross-sections
- 2D models generally closer in magnitude
  - Smaller effect than we might have thought

WARNING: Results may vary by habitat type (stay tuned)



WARNING: Results may vary by river

Rio Grande case study (Aubrey Harris, Jonathan AuBuchon, Michael Porter, and John Hickey)

- Hydrologic analysis
  - Duration of hydrologic seasons
  - Selection of hydrologic metric
- Hydraulic simulations
  - 1D vs. 2D HEC River Analysis System
  - Three representative flow years
  - Steady-state vs. unsteady
- Ecological analysis
  - HEC Ecosystem Function Model
  - Functional Data Analysis (FDA) comparing empirical population data to scenarios

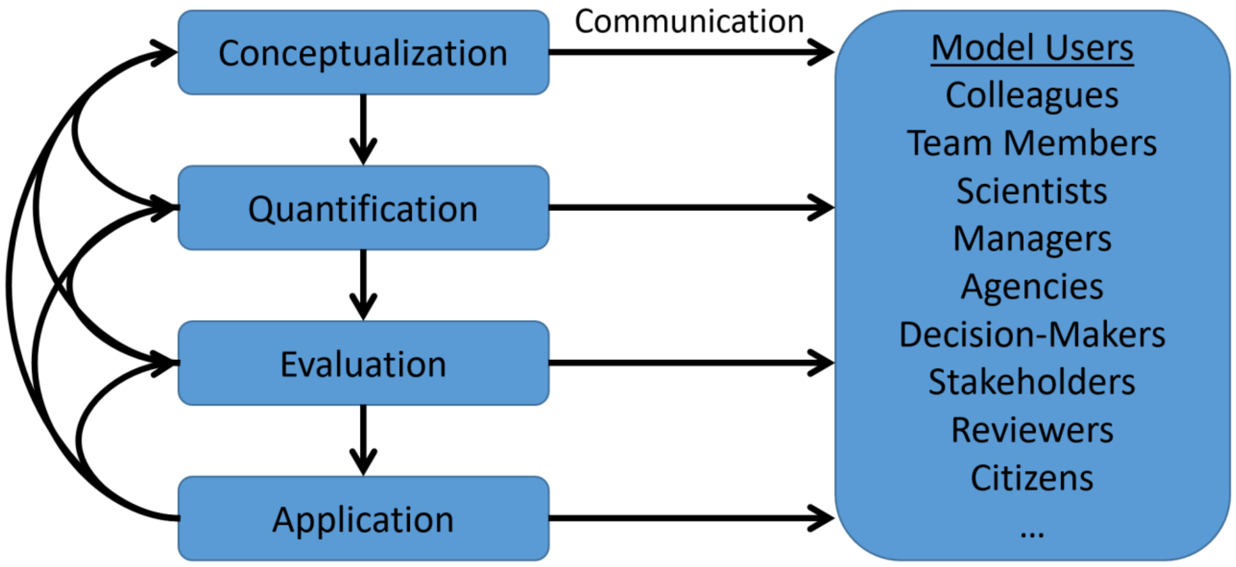
Photo credit: Jennifer Bachus (USBR 2016)

Emerging lessons in model complexity

(Contributions by Nate Richards and Todd Swannack)

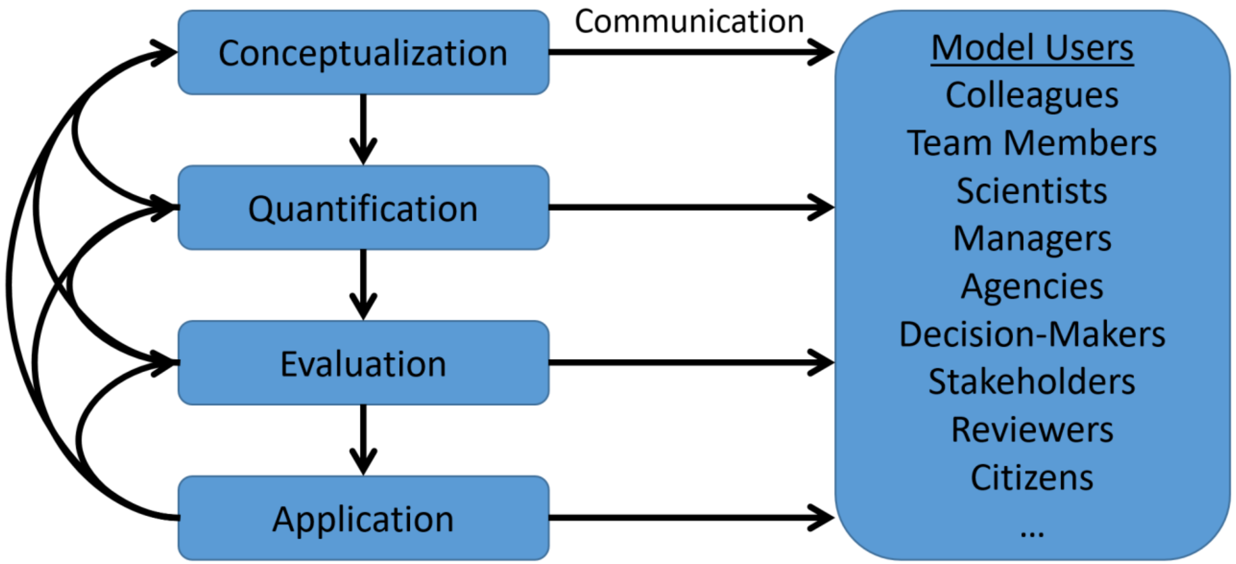
Adding Complexity: Ecological Model Development Process

- Conceptualization
  - Adding processes and mechanisms
  - Refining conceptual model with technical experts
  - Refining conceptual model with stakeholders
- Quantification
  - Adding parameters
  - Exploring alternative model assumptions (e.g., linear vs. logarithmic relationships)
  - Changing spatial or temporal grain or extent



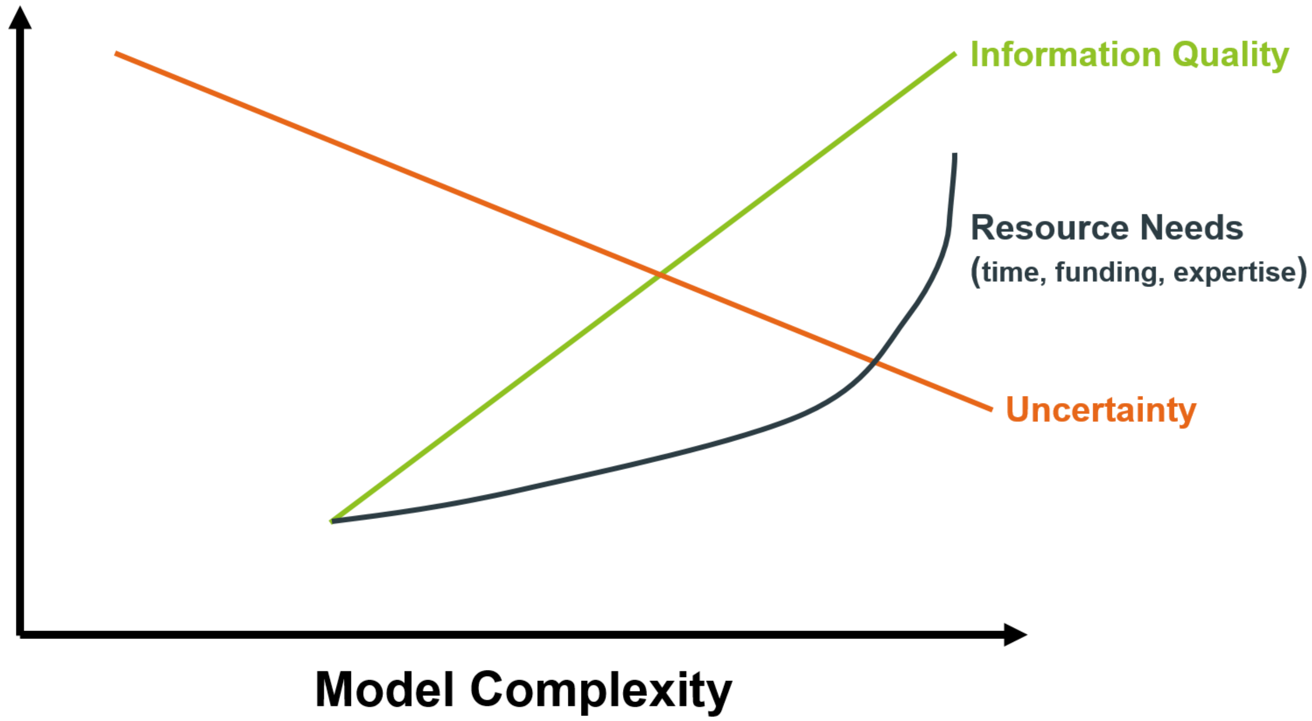
Adding Complexity: Ecological Model Development Process

- Evaluation
  - Exploring model sensitivity
  - Understanding your model to inform choices about the next level of investment
- Application
  - Conducting scenario analyses (last week's webinar by Hernandez-Abrams and Carrillo)
  - Incorporating stochasticity
- Communication
  - Using novel visualization mechanisms
  - "Telling a better story"



Value-of-Information

- Information comes at a cost (time, funding, bandwidth,…).
- We can't learn everything .
- More information doesn't guarantee certainty.



Are there definable and repeatable Levels of Effort (LoE) for modeling?

LoE	Ecological Modeling Goals and Features	Alignment with USACE Planning?
0	Building a conceptual foundation Conceptual modeling	Problems and opportunities Objective setting
1	Qualitative (or semi-quantitative) comparison of sites or alternatives Reliant on professional judgment (e.g., scoring spreadsheets)	~Alternatives Milestone
2	Capable of screening multiple sites or alternatives with different concepts Simple models with easy-to-use data Meets threshold of model certification	~Tentatively Selected Plan (TSP) Milestone
3	Capable of distinguishing “scales” of an alternative Methods withstand rigorous peer review Higher resolution / better data sources Typically tightly integrated with other models (H&H, WQ, etc.)	~Agency Decision Milestone
…	Capable of distinguishing operational and adaptive management options Typically needed for controversial or large scale projects Typically multiple modeling types (e.g., pop, habitat, WQ) Almost always integrated with multiple models (H&H, WQ, ResSim) or data	Often occurs post-planning (e.g., reservoir operations)

Thank you for your time!

Take-home messages

- Are the modeling goals relative comparison or absolute prediction?
- Model complexity should vary relative to the level of information needed to make a decision (and tolerable uncertainty).
- We're always looking for case studies and collaborators to join us in investigating these subjects!

Acknowledgements

- Middle Oconee Team: Caitlin Conn, Tyler Keys, and Mary Freeman
- Rio Grande Team: Aubrey Harris, Jonathan AuBuchon, Michael Porter, and John Hickey
- Model Comparison Team: Mike Scuderi and Mick Port, Todd Swannack, Nate Richards, Sarah Miller, Darixa Hernández-Abrams
- Thanks to EMRRP for supporting this work!

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Future assessments of <u>between</u> model comparison

- Outcomes beyond habitat
  - <u>Ecological</u>: hydrologic change, sediment transport, organic matter transport, primary production, fish recruitment
  - <u>Socio-economic</u>: water supply resilience, recreational kayaking
- Between model comparison
  - Models for similar outcomes (e.g., habitat type trade-offs)
  - Models for different outcomes (i.e., weight-of-evidence, decision confidence, reliability)
  - Uncertainty ranges in all models