Valuing Improvements in the Ecological Integrity of Local and Regional Waters Using the Biological Condition Gradient

Christian A. Vossler, U. Tennessee
Christine L. Dolph, U. Minnesota
Jacques C. Finlay, U. Minnesota
David A. Keiser, U. Massachusetts
Catherine L. Kling, Cornell U.
Daniel J. Phaneuf, U. Wisconsin

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Motivation: A pressing policy issue

- Clean Water Act establishes regulatory structure for surface waters in the U.S., with safety-based standards set for most water bodies to achieve "fishable and swimmable" uses.
- On balance, small gains have been achieved over the last 50 years.
  - Increases in non-point water pollution have offset gains achieved by point sources.
  - Over half of surface waters "impaired"; disturbing recent trends.

Motivation: Evidence suggests we should spend money elsewhere

Benefits and Costs of Federal Regulations

	Surface water (1)	*Drinking water* (2)	*Air* (3)	*Greenhouse gases* (4)	*All other* (5)	*All* (6)
A: Total US expenditures (trillions of 2017 dollars)						
1970 to 2014	2.83	1.99	2.11	–	–	–
1973 to 1990	0.94	0.49	0.85	–	–	–
B: Estimated benefits and costs of regulations analyzed in years 1992–2017						
Total benefits / total costs	0.79	4.75	12.36	2.98	1.97	6.31
Mean benefits / mean costs	0.57	8.26	15.18	3.64	21.79	16.17
Share with benefits < costs	0.67	0.20	0.08	0.00	0.19	0.15

Source: Keiser and Shapiro (*J. Econ. Perspectives*, 2019)

Motivation: Missing values and need for new methods

- Benefit-cost analyses often leave unquantified important sources of benefits.
- We need stated preference (SP) surveys to quantify total economic value (use and non-use values).
- SP approaches and case studies have not kept pace with policy needs.

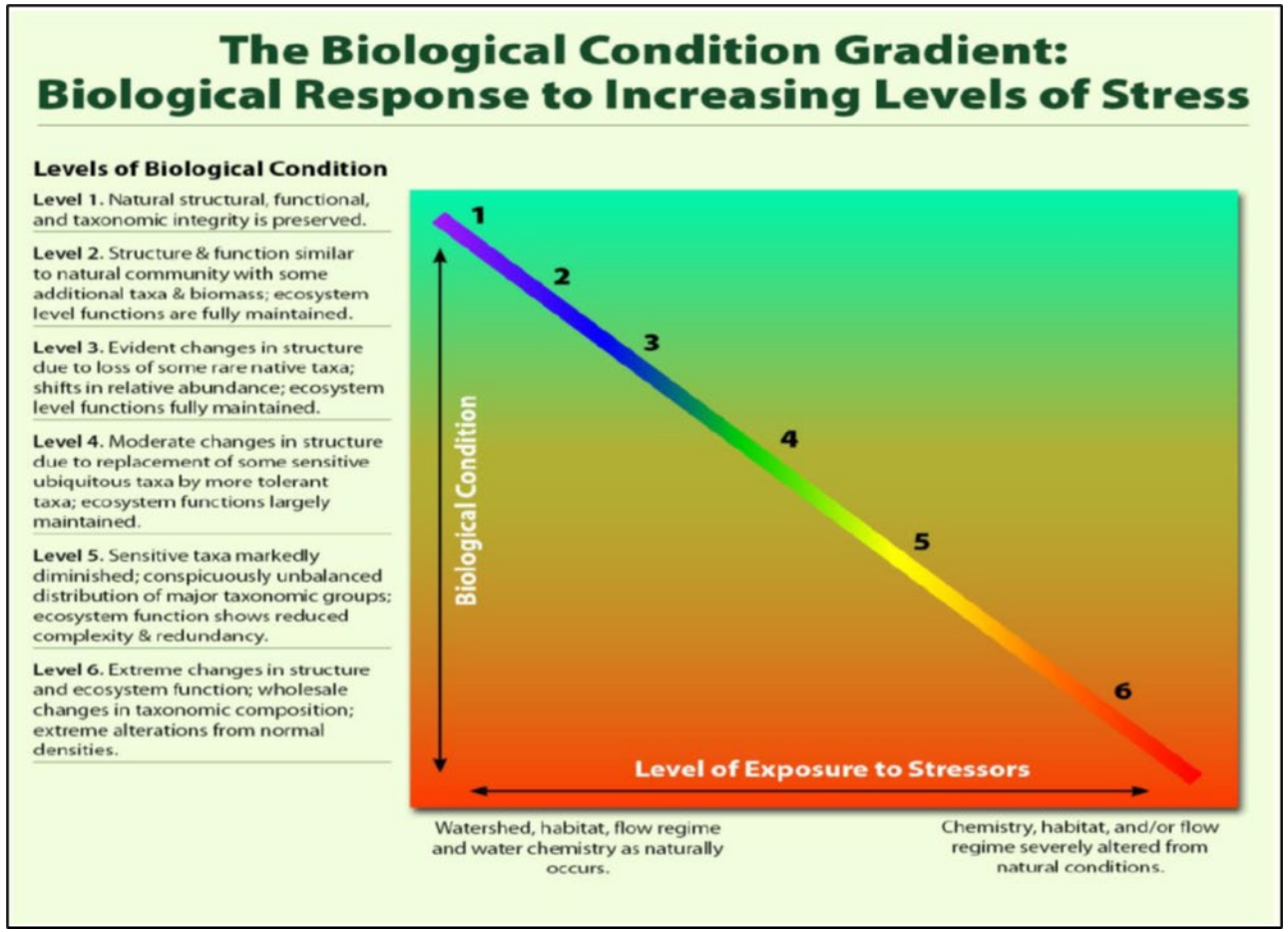
This study

- We develop a simple and generalizable framework based on a biological index for estimating use and non-use values associated with changes in ecosystem services.
- We obtain estimates for a large geographic area that account for spatial variation, are spatially scalable, and amenable to policy analysis.

Measuring water quality

- Several states have independently developed a biological index that measures ecosystem condition relative to a "natural" reference condition.
- Recently, the EPA has sought to unify approaches through the Biological Condition Gradient (BCG).
  - Systematic, predictive framework for biological changes expected to result from human influence
  - Allows assessment of incremental progress
  - Provides a common framework to allow for comparability of results across states and programs.

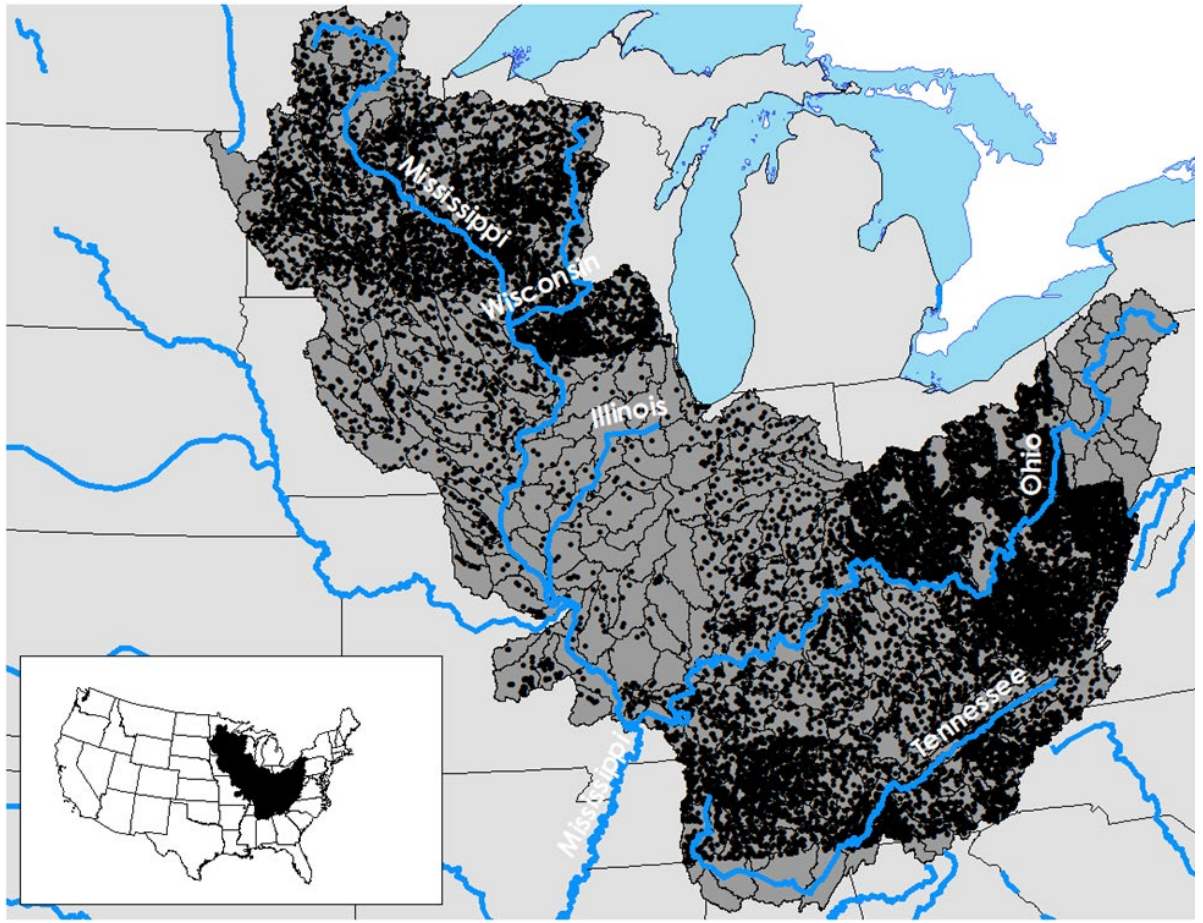
Measuring water quality



Source: U.S. EPA (2016)

Measuring water quality

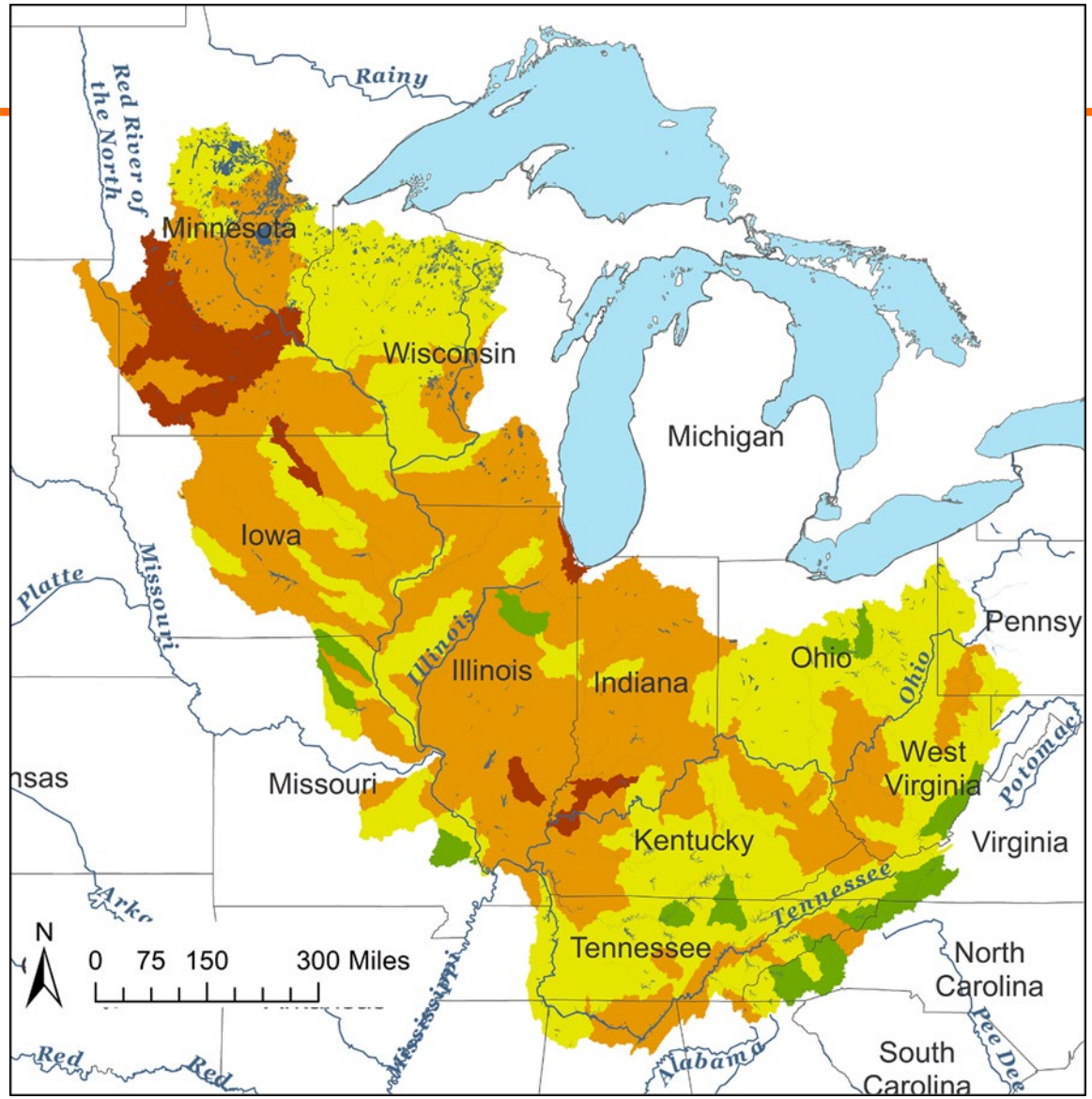
- Data from over 19,000 monitoring sites.
- BCG scores estimated for each of the 268 sub-watersheds in the region.
- Four states use BCG scores. For the remainder, biological index scores or other measures used to determine BCG scores.



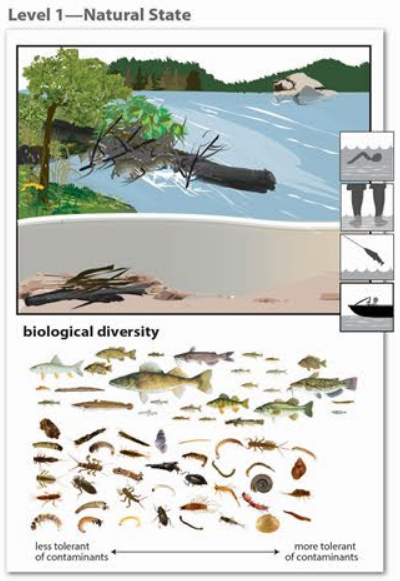
Source: Dolph and Finlay (2021)

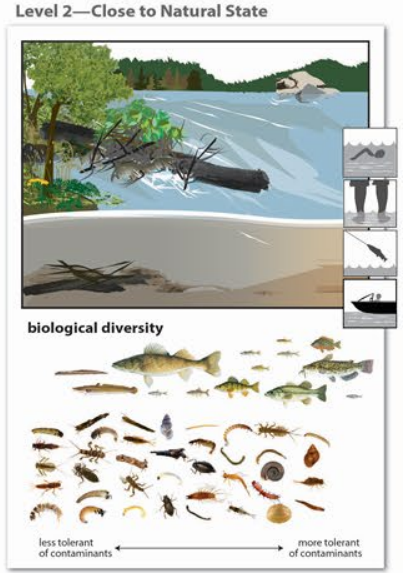
Measuring water quality

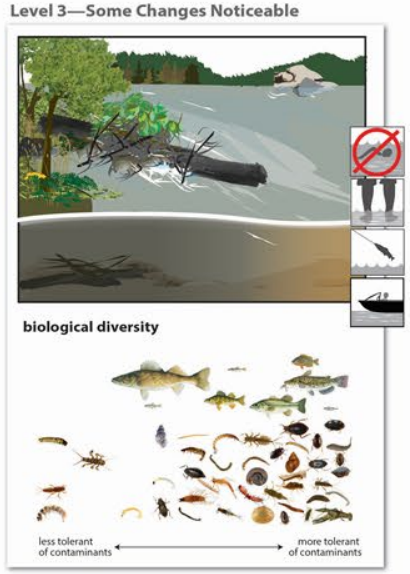
- Baseline water conditions.
- Level 2 (“green”) meets all designated use standards.
- Level 3 (“yellow”) meets biological standard but not swimmable.
- Level 4 (“orange”) meets fishable standard.
- Level 5 (“red”) good for boating only.

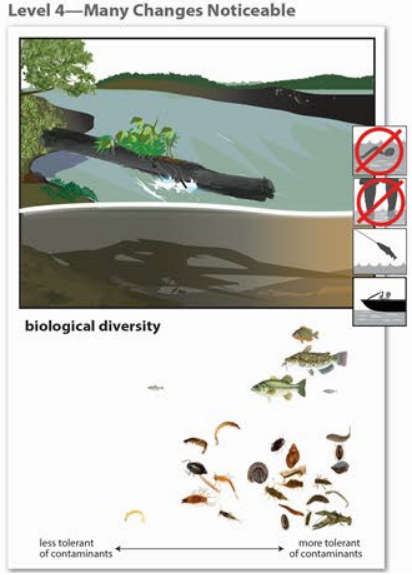


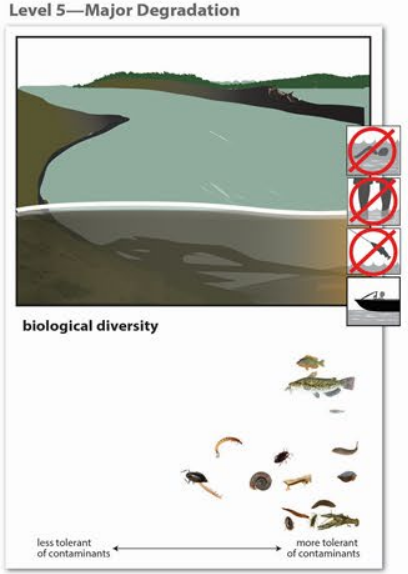
Describing water quality: Graphics for each WQ level



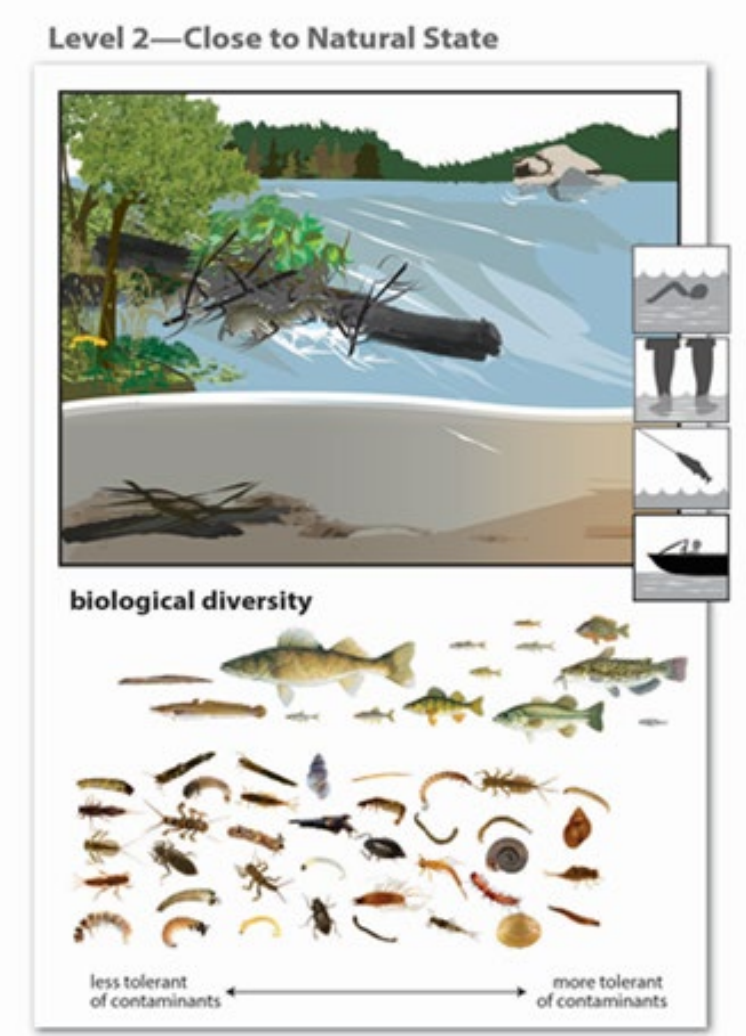


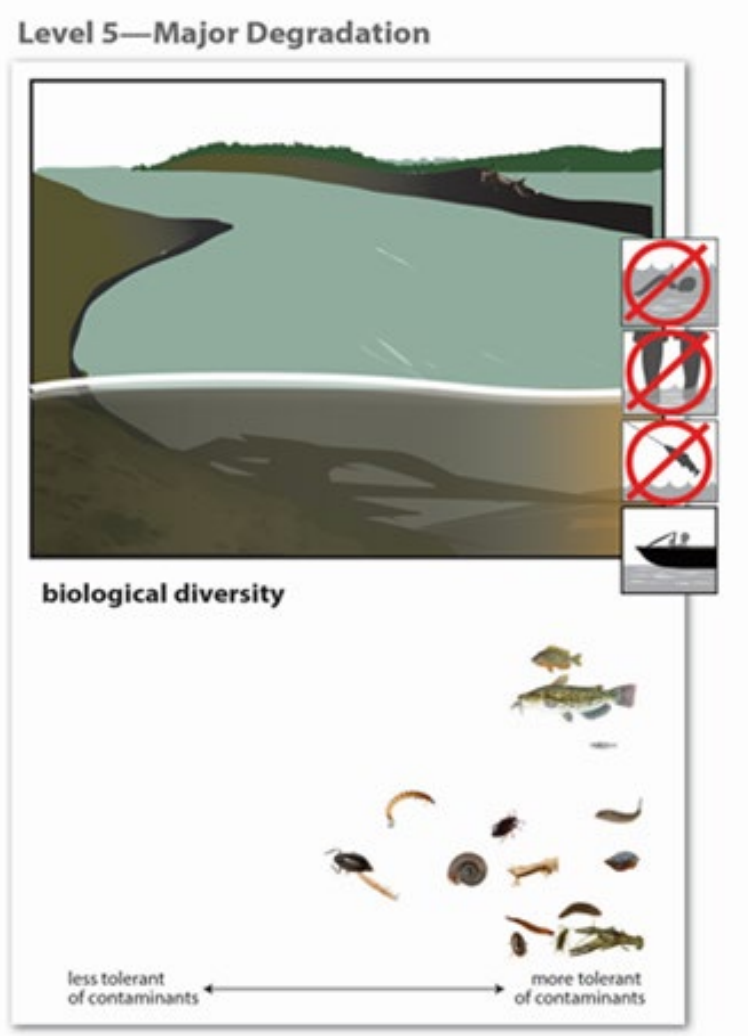




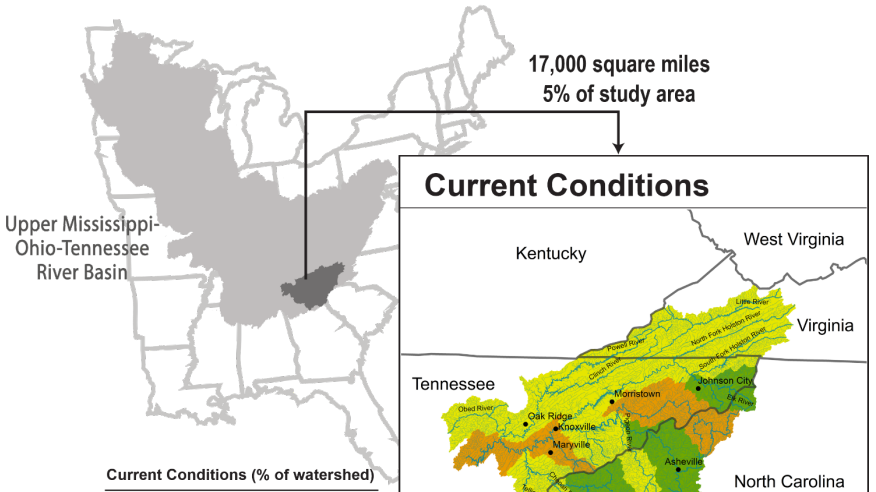


Graphics: Graphics for each WQ level

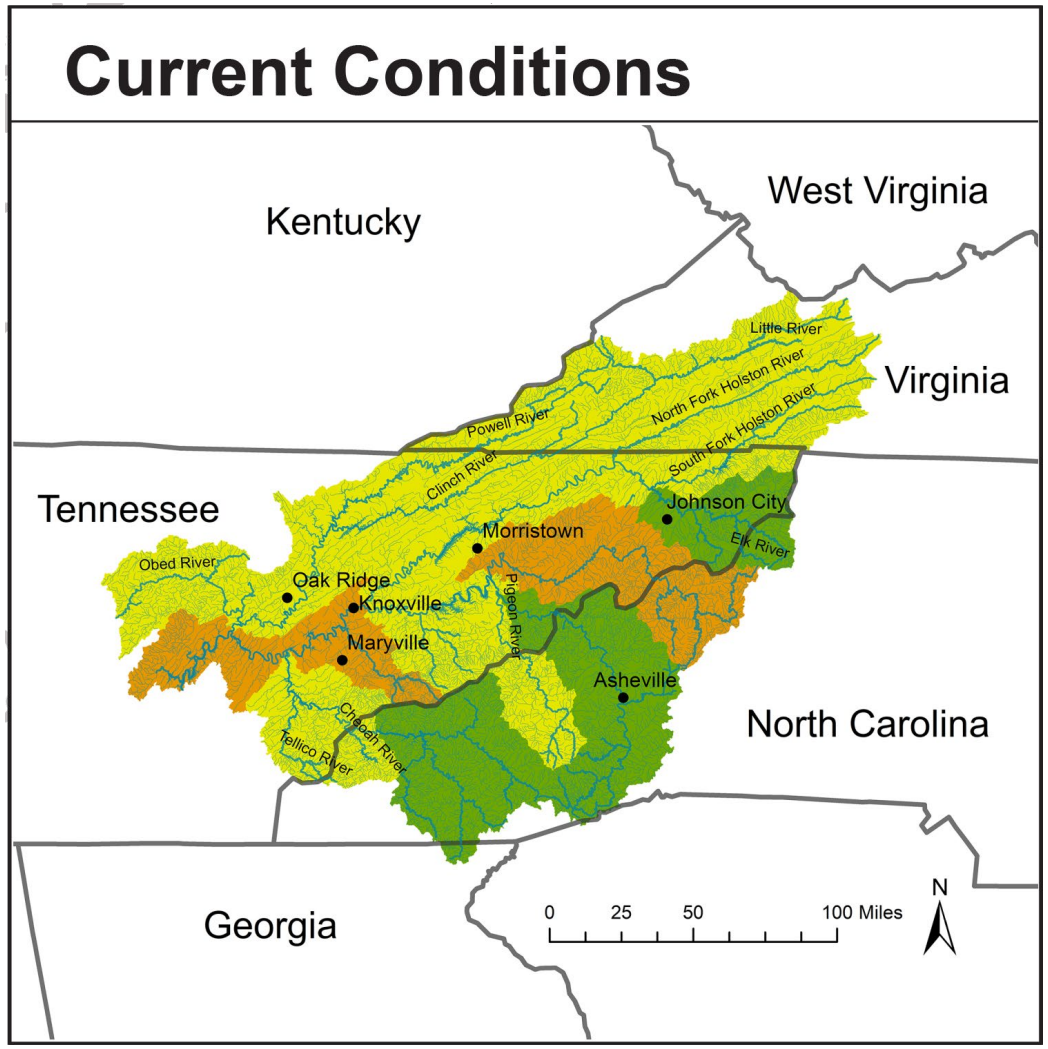




Describing water quality: spatial distribution



Current Conditions (% of watershed)	
Level 1 Natural State	0%
Level 2 Close to Natural State	25%
Level 3 Some Changes Noticeable	57%
Level 4 Many Changes Noticeable	18%
Level 5 Major Degradation	0%
Level 6 Extreme Degradation	0%
Average Level	2.93

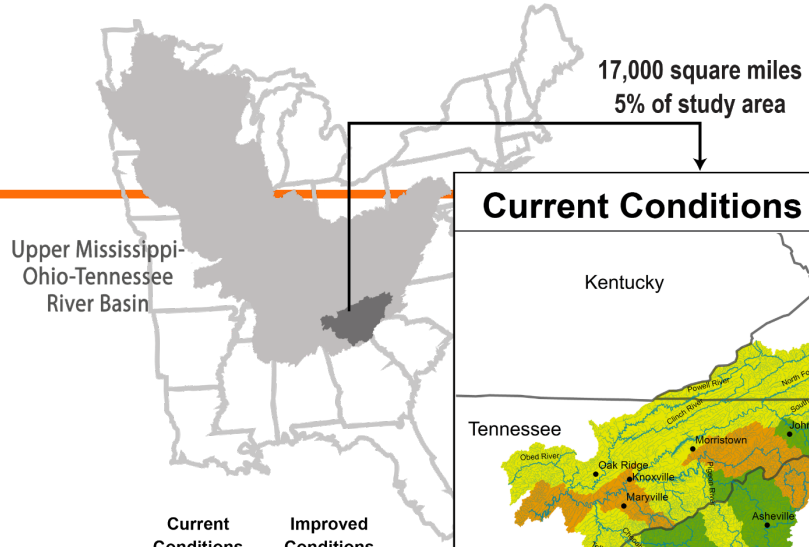


Describing possible policies

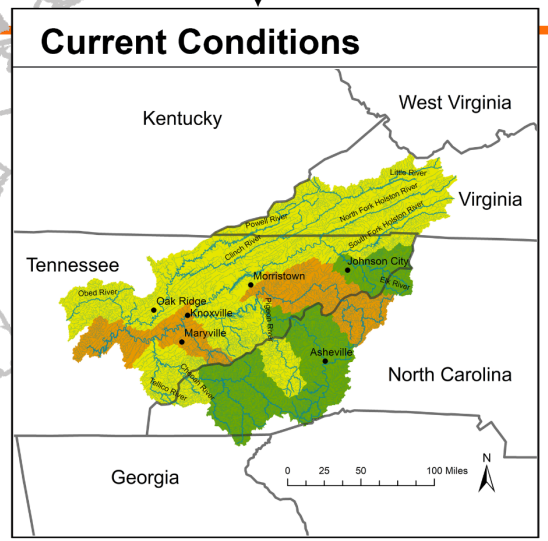
Policy proposal

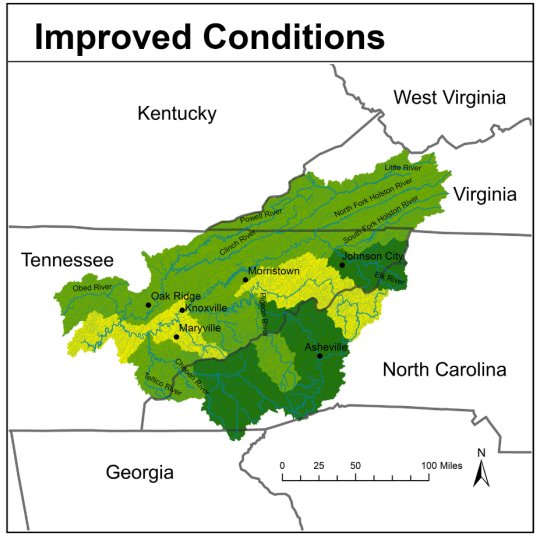
The water quality changes described below would occur only in the highlighted policy region on the maps.

Improvements would occur gradually, reaching the new conditions by about 2026, and then remain at the new levels. The tax increase would last 5 years, and be in place from 2022 to 2026.



	Current Conditions	Improved Conditions
	(% of watershed)	
Level 1 Natural State	0%	25%
Level 2 Close to Natural State	25%	57%
Level 3 Some Changes Noticeable	57%	18%
Level 4 Many Changes Noticeable	18%	0%
Level 5 Major Degradation	0%	0%
Level 6 Extreme Degradation	0%	0%
Average Level	2.93	1.93





Describing possible policies

Policy Summary

Description of policy region: Your **local** watershed.
Size of policy region: 17,000 square miles.

	No policy (current conditions)	Proposed policy (improved conditions)
Description of change	None	All areas within region improve by one level
Water quality near your home	Level 4 – Many Changes Noticeable	Level 3 – Some Changes Noticeable
Water quality throughout region (average)	2.93	1.93
Increase in taxes to your household (per year, for the next 5 years)	None	$50

Table 1. Valuation scenario attribute levels

Attributes	Levels
Spatial scale	A single watershed Three contiguous watersheds Full study region
BCG change scenario	One-level BCG improvement in all sub-watersheds Minimum BCG Level 2 Minimum BCG Level 3 Change all BCG Level 3 sub-watersheds to Level 2
Location	Policy area includes home watershed (local) Policy area does not include home watershed (non-local)
Annual tax increase, in effect for five years	$20, $50, $75, $100, $150, $200, $250, $350, $500, $750

Notes: A watershed corresponds with a 4-digit hydrologic unit code address (HUC4), as defined by the US Geological Survey. The full study region includes the Upper Mississippi, Ohio, and Tennessee River Basins (see Figure 1).

Survey overview

- Links household to sub-watershed (HUC-8) based on zip code
- Part 1: Ask about perceptions of local water quality
- Part 2: Describe water quality and test for understanding
- Part 3: Valuation tasks
  - Describe general aspects of water quality policies
  - Information scripts randomly assigned (the topic of a separate paper)
  - 6 to 10 valuation scenarios for each respondent
    - Framed as advisory referenda; coercive payment vehicle
  - Follow-up questions to understand motivations, gauge consequentiality, gauge attribute (non-)attendance
- Part 4: some demographics; recreation activities; questions about the pandemic

Survey development and implementation

- Development
  - Extensive focus group and classroom testing of information materials and survey instrument
  - Feedback from EPA personnel, other research teams
  - Three pilot tests using online Qualtrics survey with convenience samples (MTurk)
  - Pilot sample, drawing from population of interest.
- Implementation
  - Probability sample of 2000 households across study region.

Econometric framework

- Assume individual i's indirect utility from option $j = 0,1$ in voting scenario k can be expressed as:

$$V_{ijt} = -\alpha_i c_{ijt} + \mathbf{x}_{ijt}\boldsymbol{\beta}_i + u_{ijt}$$

$\mathbf{x}$ vector of attributes (BCG score x spatial unit x local/non-local; ASC)
c is the amount of the tax increase
u error term (Type I extreme value)

- Mixed logit model in utility space; assume coefficients vary across individuals, follow normal distributions

Table 2. Willingness-to-pay for selected water quality improvement scenarios

	Local Changes				Non-Local Changes	
Scenario	Sub-Watershed (HUC8)	Watershed (HUC4)	3 Watersheds (3 HUC4s)	Study Region	Watershed (HUC4)	3 Watersheds (3 HUC4s)
One-level BCG improvement	$152 (16)	$316 (13)	$302 (12)	$300 (12)	$165 (11)	$186 (12)
Minimum BCG Level 2 ("swimmable")	$237 (24)	$492 (21)	$470 (19)	$463 (18)	$225 (15)	$261 (18)
Minimum BCG Level 3 ("biological")	$119 (14)	$217 (10)	$209 (9)	$207 (9)	$95 (9)	$112 (9)

Notes: Table entries indicate the mean household willingness-to-pay (in 2021 dollars), per year over a period of five years, for a policy defined by the water quality improvement and the spatial scale. Standard errors in parentheses. A 'local' policy is one that improves water quality in the watershed where the household lives and a 'non-local' policy does not include the household's resident watershed. 'Study Region' refers to the Upper-Mississippi, Ohio, and Tennessee River Basins. Estimates are derived from Model 1, as described in the *SI Appendix*.

Unit of measurement: Household WTP per year for five years

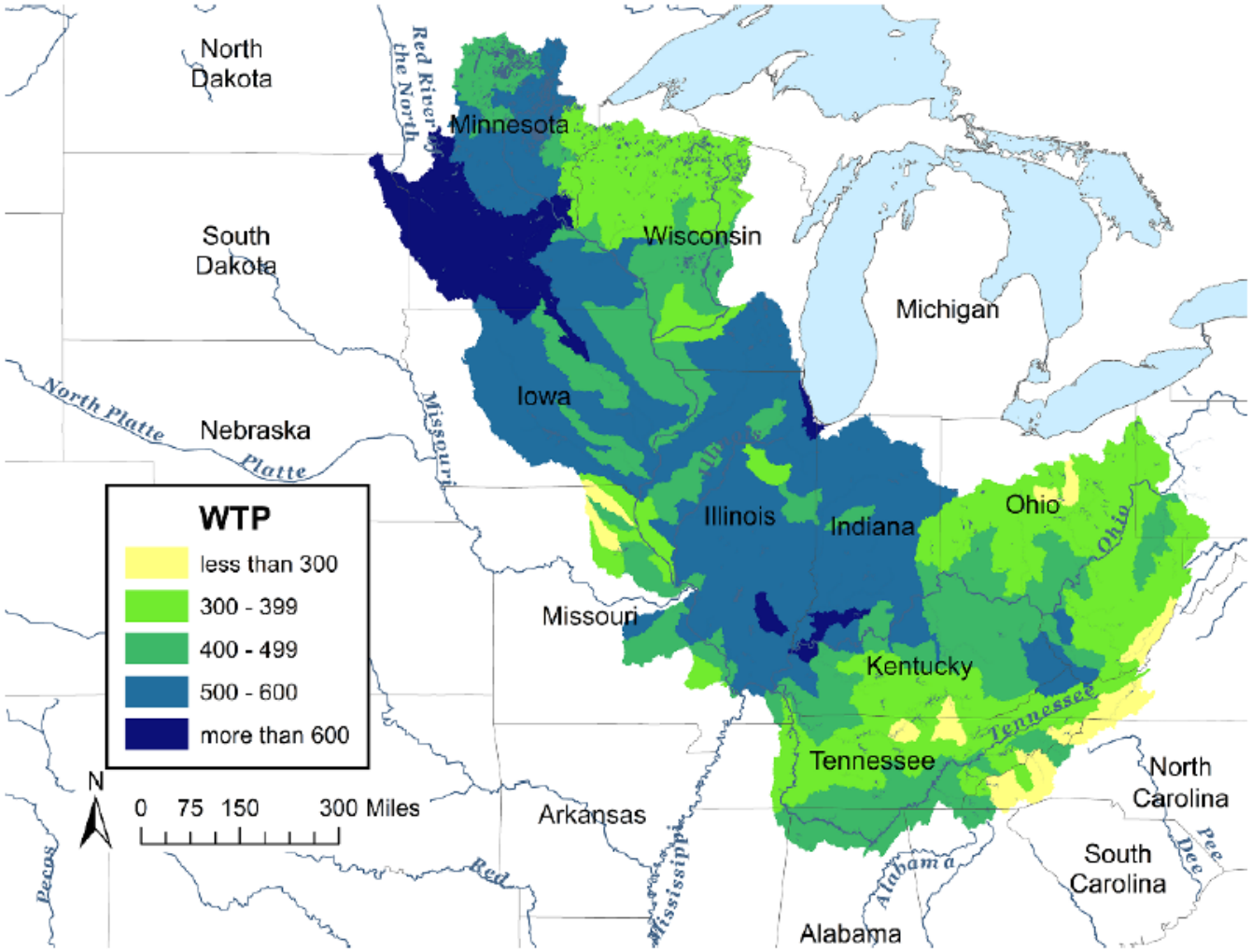


Figure 5. Spatial distribution of local willingness to pay for a minimum BCG Level 2 policy ($ per household in the affected watershed, annual payment for five years)

Table 3. Willingness-to-pay for water quality improvement scenarios based on percentage of impacted area located in-state

Scenario	Local policy: impact area 100% in-state	Local policy: impact area 25% in-state	Non-local policy: impact area 25% in-state	Non-local policy: impact area 0% in-state
One-level BCG improvement	$356 (18)	$274 (17)	$228 (19)	$159 (12)
Minimum BCG Level 2 ("swimmable")	$513 (23)	$432 (27)	$301 (22)	$232 (16)
Minimum BCG Level 3 ("biological")	$268 (20)	$187 (13)	$142 (19)	$72 (12)

Unit of measurement: Household WTP per year for five years

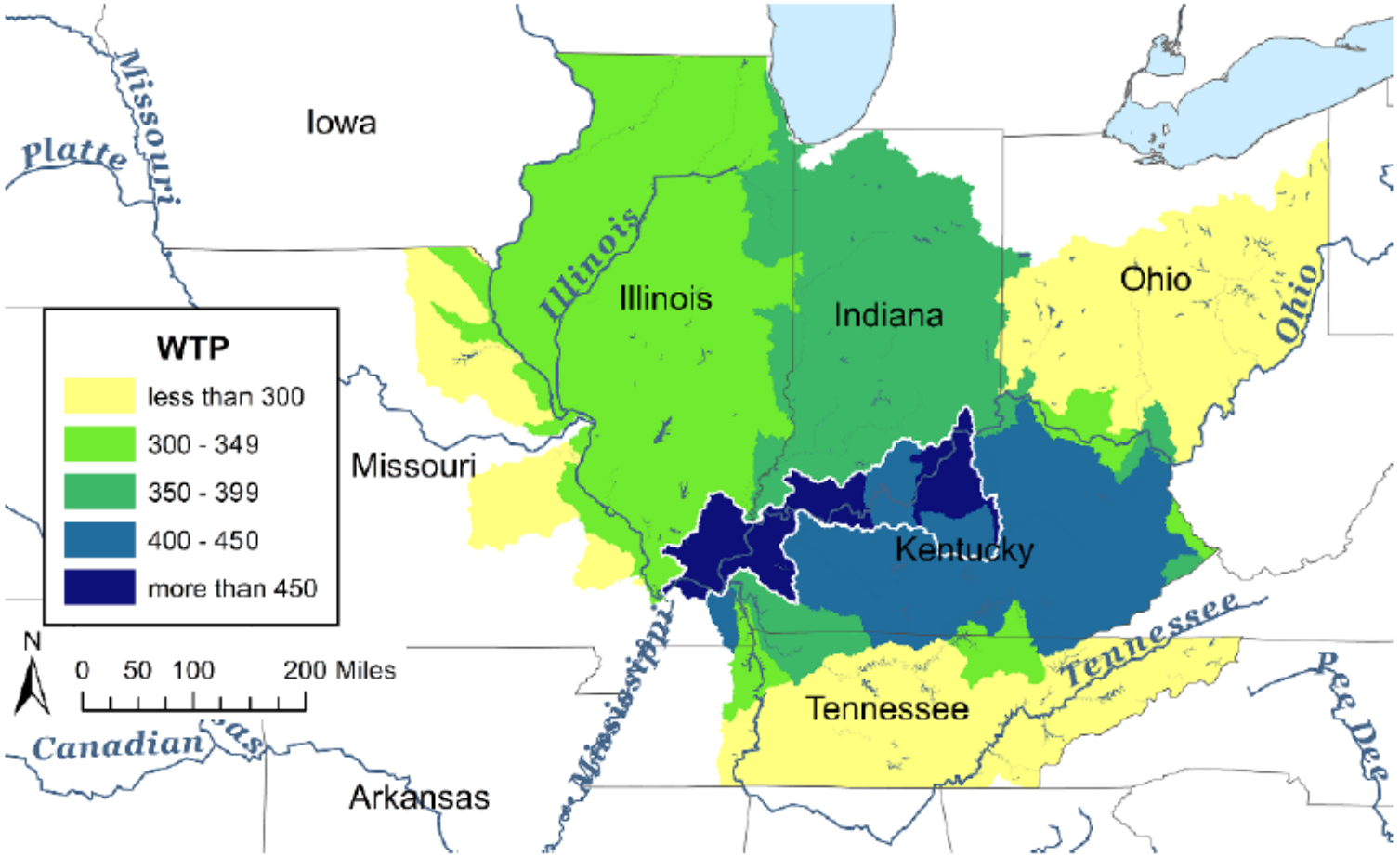


Figure 6. Spatial distribution of willingness to pay for BCG Level 2 in a single watershed (highlighted with a white border) ($ per household, annual payment for five years)

Other findings

- Effects of socio-economic characteristics
  - WTP for a policy decreases with age.
  - WTP increases with education, income.
  - No effect of household size, race/ethnicity, urban versus rural, other stuff

- Scaling up to the population
  - Bringing the entire study region to level 2 would yield **$10.5 billion** in economic benefits, annually for five years.

Related work in progress

- Through the same survey, we develop and test information scripts that have the potential to enhance the validity of stated preference surveys.
- Implement a second survey in same study region, using similar methods, but:
  - Focus on smaller spatial units
  - Better understand the relative importance of recreation
- Integrated Assessment Model (IAM) to estimate the economic benefits of counterfactual policy scenarios.

Thank you for listening!

Comments and questions are most welcome (especially when directed to my coauthors).

Email: cvossler@utk.edu

Website: https://volweb.utk.edu/~cvossler/