Spatial Dimensions of Water Quality Value in New England River Networks

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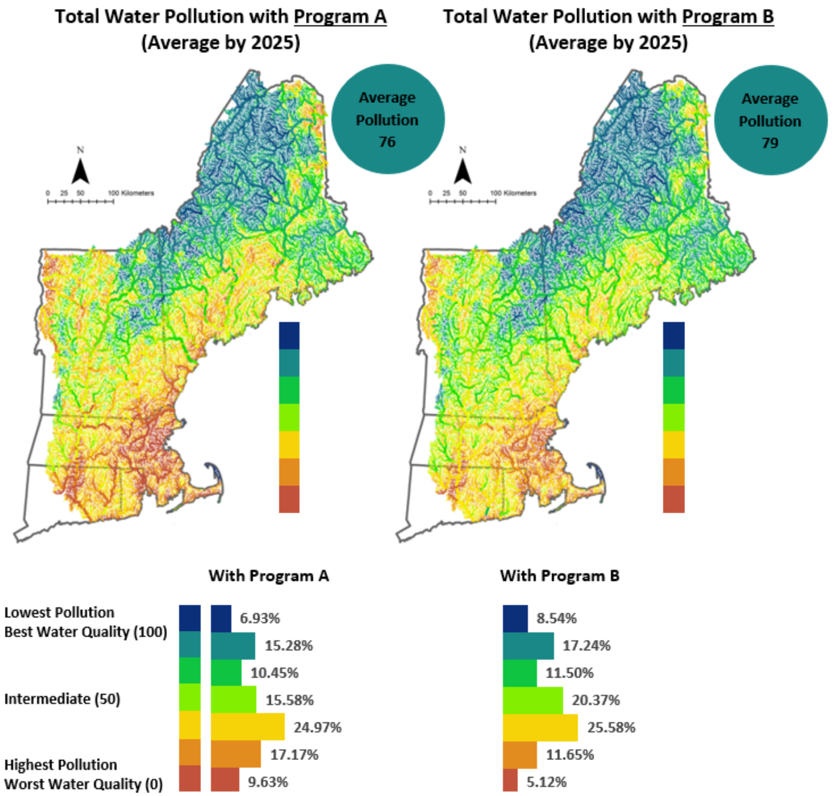
Spatial Dimensions of Stated Preference (SP) WTP

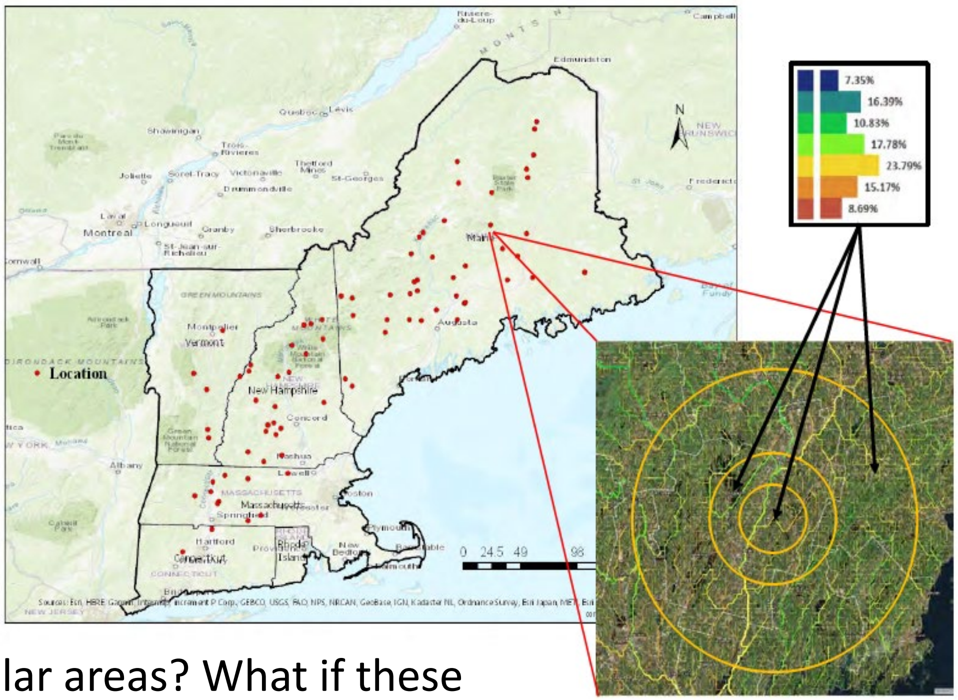
- Willingness to pay (WTP) for environmental change is often influenced by geospatial dimensions (Glenk et al. 2020).
  - Particularly salient for applications such as spatially complex/heterogeneous water quality change.
- Economists’ ability to model these effects is constrained by:
  - Simplified ‘matrix’ scenarios in typical choice experiments.
  - Surveys that provide little for respondents to engage with maps or explore conditions in areas relevant to them.
  - Complex effects modeled using simple approaches, e.g., distance to closest affected waterbody.

What Matters? And To Whom?



Percentage of Rivers and Streams in Each Total Water Pollution Category
(Program A versus Program B)

Typical choice experiments might present this complex change as a single number – from an average quality of 76 → 79.



What if people care about changes in particular areas? What if these areas are not anticipated by researchers?

Study Design / Overview

- Study integrates a water quality model and map-based, interactive choice experiment to estimate WTP for water quality improvements.
  - Choice experiment designed to capture the spatial richness of policy scenarios.
  - Questionnaire interface that elicits geospatial information for model estimation (e.g., through map tracking).
  - Bayesian econometrics that incorporate a richer and more heterogeneous set of spatial effects.
- Goal is an improved understanding of geospatial dimensions.
- Let the respondents (and the data) tell us what is important.

Choice Experiment Structure

- Many one-shot, binary referendum questions that convey spatially explicit policy effects under different policy scenarios.
- Each scenario reflects an actual, spatially explicit prediction of water quality changes over multiple indicators.
  - Entire river network, including small streams
- Scenarios illustrated using color-coded maps, bar charts and numerical information.
- Each respondent votes yes/no for one detailed, incentive compatible policy scenario.
- There is no fixed attribute matrix – respondents can attend to whatever information is relevant to them.

Case Study Application

- Application to water quality improvements over a case study area in Connecticut, Massachusetts, Rhode Island, Vermont, New Hampshire and Maine (New England, USA).
- 95,800 miles of rivers and streams; 71,992 sq. miles of land.
- Study sample drawn from the same six-state area.
- Design informed by 7 focus groups, 20 cognitive interviews, and 4 pilot tests (Mturk, N=200, 136; Qualtrics N=336 and 60).

Three Water Quality Indicators

- Valuation scenarios defined over three water quality indicators.
  - Total water pollution (quality index for all modeled pollutants) - WQ
  - Water safety - WS
  - Aquatic life support - AL
- Linked to underlying pollutants (DIN, chloride, fecal coliform).
- Illustrated using maps and charts
- Levels binned into 7 categories, from worst to best in New England.

Aquatic Life Today

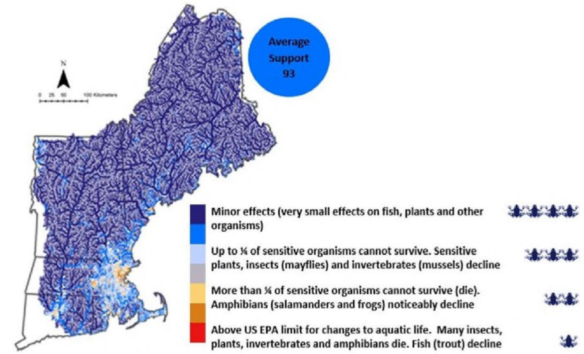
The following map shows current ability of New England rivers and streams to support **aquatic life**. This is affected by some types of pollution, including chemicals like road salt.

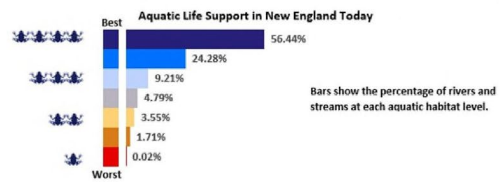
Species sensitive to pollution include (a) some fish caught by people, such as **brook trout**, (b) other fish such as **minnows**, and (c) organisms such as **freshwater mussels**, **mayflies**, **frogs** and other animals that are part of the food chain. **These species begin to disappear as pollution increases.**

The **Average Support** number in the colored circle shows average aquatic life support across New England, measured on a 0 to 100 scale.

Later, you will be shown possible programs that change aquatic life support.

Support for Aquatic Life in New England Today





Percentage of Rivers and Streams in Each Category of Aquatic Life Support (Current Condition)

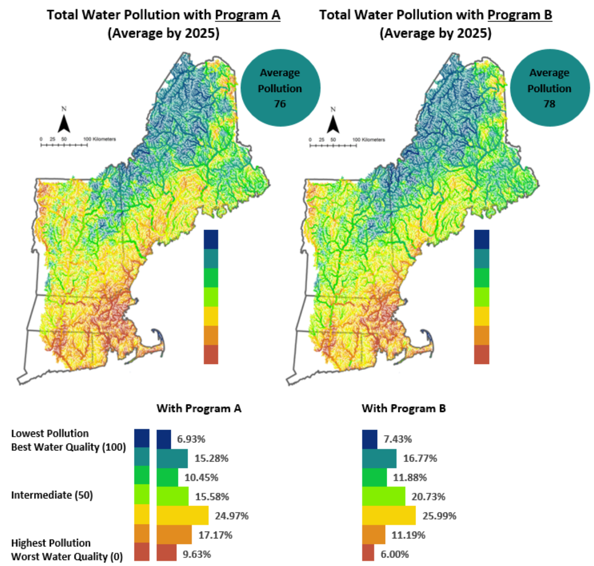
Clicking on the link below will bring up a new page where you can zoom to any location, if desired. This map requires several seconds to load and adjust after zooming.

Click Here for Map.

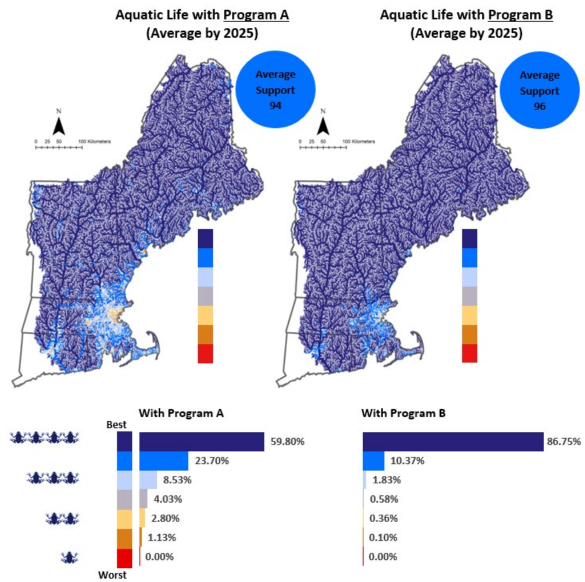
Scenario and Experimental Design

- Scenarios are outputs of spatial policy outcomes simulated via FrAMES (Framework for Aquatic Modeling of the Earth System).
- Predicted outcomes as of 2025 across the river network.
- Scenarios defined using full factorial (36) of policy drivers affecting water quality, bounded by minimum and maximum feasible levels.
  - Riparian buffers (0%, 90% of rivers in agricultural and developed land).
  - WWTP upgrades (50%, 90% from secondary to tertiary treatment).
  - Storm water retention (0%, 65%, 90% urban rain infiltration)
  - Road salt application (700, 4000, 7600 $g/mm/m^2$ snowfall)
- Plus 6 interventions in northern/southern states only.
- Each has distinct effects on the three water quality indicators.
- Bid levels: $30, $60, $120, $240, $480, $720, $960, $1200.

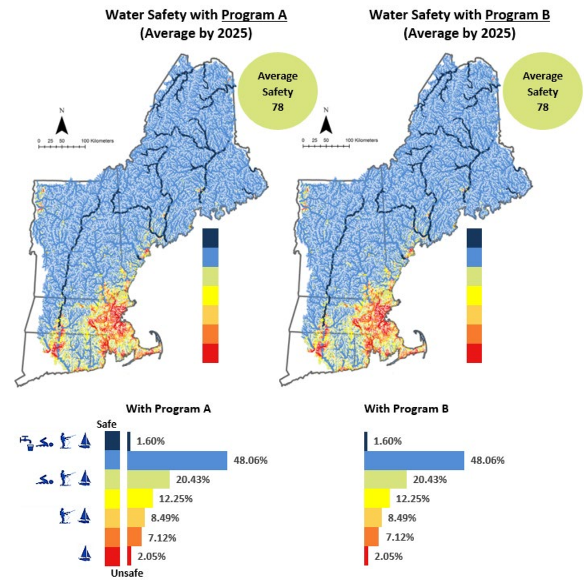
Example Scenario (#2 with $720 bid)



Percentage of Rivers and Streams in Each Total Water Pollution Category (Program A versus Program B)



Percentage of Rivers and Streams in each Category of Aquatic Life Support (Program A versus Program B)



Percentage of Rivers and Streams in Each Water Safety Category (Program A versus Program B)

Given the annual cost to your household and projected changes in total water pollution, water safety, and aquatic life support shown above, would you vote for **Program A** or **Program B**? (Please select one)

If you wish to explain the reason for your vote, you may do it below.

I would **vote for Program A** at an additional cost of **$0 per year**.

I would **vote for Program B** at an additional cost of **$720 per year**.

Interactive ArcGIS Maps for all Scenarios (9 maps)

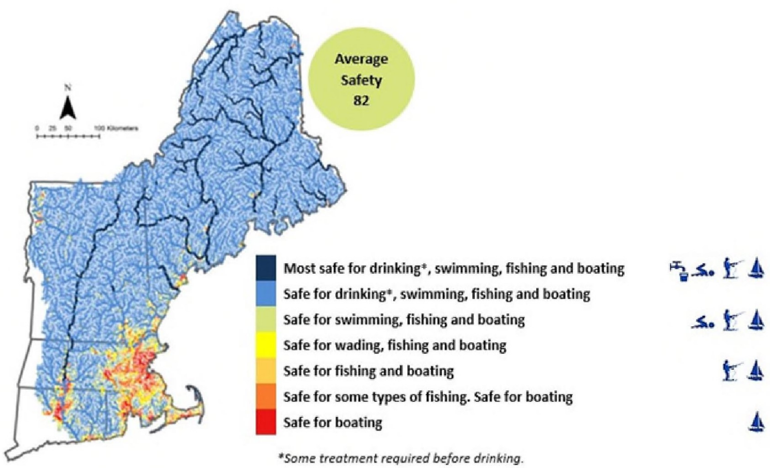
Water Safety Today

The following map shows current **water safety** for human uses. This is influenced by some types of pollution such as bacteria from septic systems and sewers.

Later, you will be shown possible programs that change this level of safety.

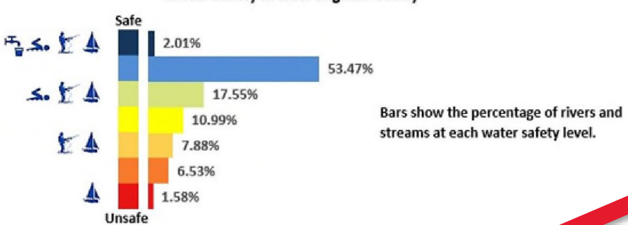
Water in the top two categories is drinkable with only minor treatment. The **Average Safety** number in the colored circle shows average water safety across New England, measured on a 0 to 100 scale.

Water Safety in New England Today



Some treatment required before drinking.

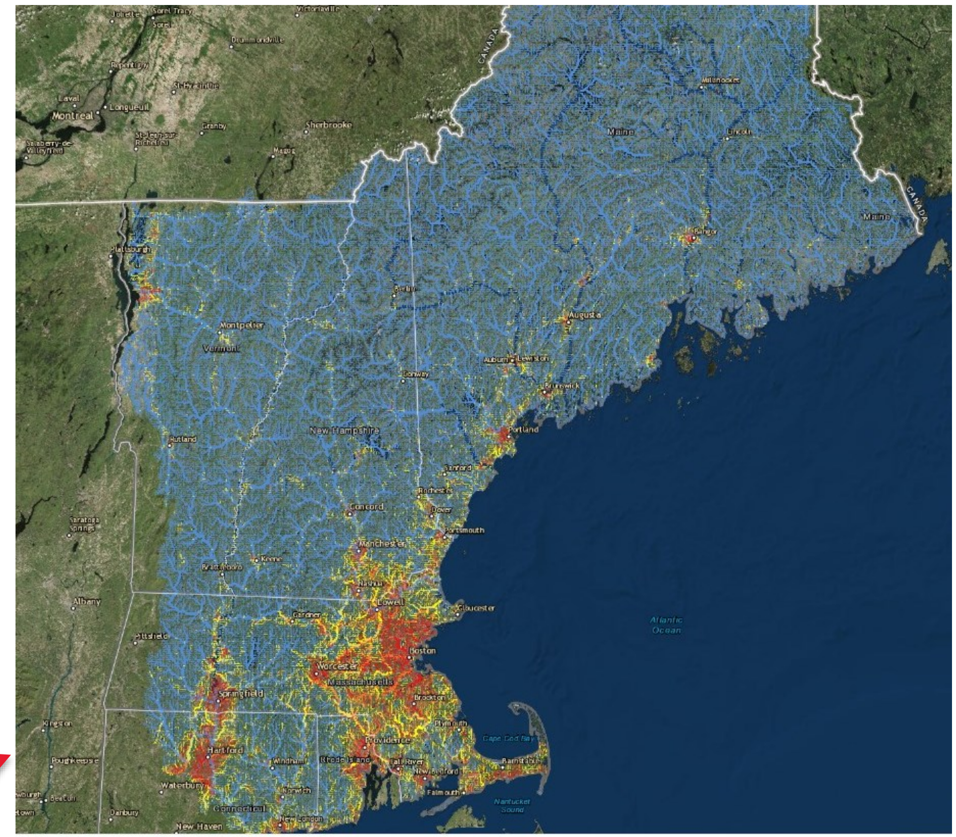
Water Safety in New England Today



Percentage of Rivers and Streams in Each Water Safety Category (Current Conditions)

Clicking on the link below will bring up a [illegible] page where you can zoom to any location, if desired. This map requires several seconds to load and adjust after zooming.

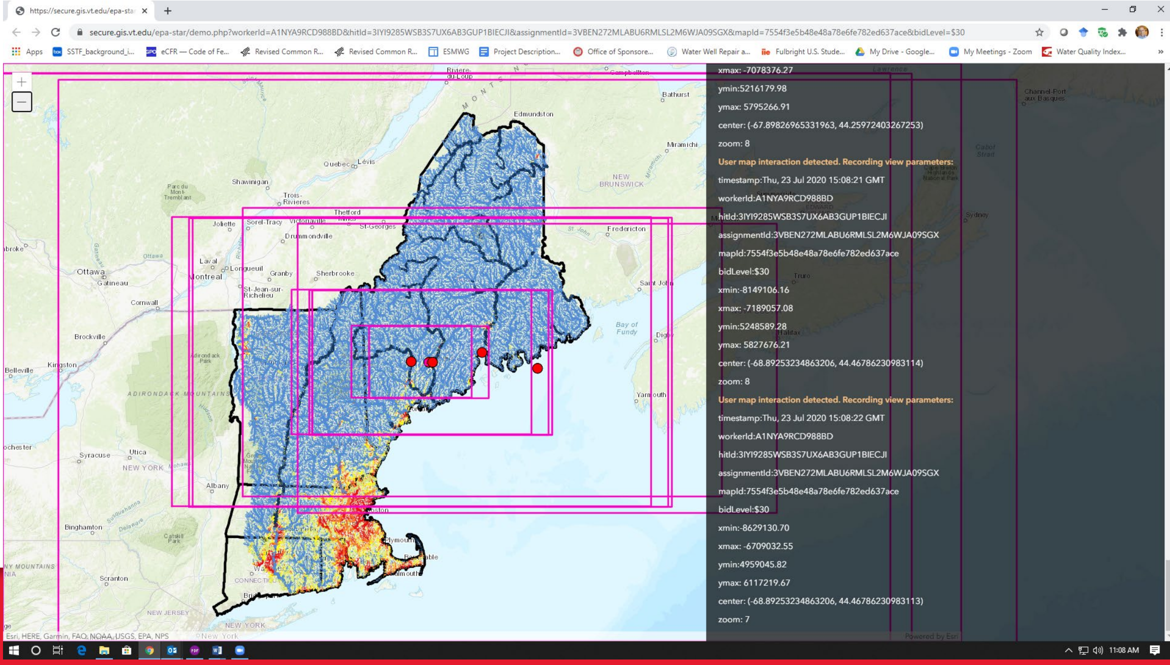
Click Here for Map.



Respondent can "pan and zoom" to any area.

Map Interaction Database

- All map interactions (e.g., zooming, panning) captured and recorded automatically using ESRI JavaScript API, linked to each survey response.
  - Record each area viewed on screen and length of view.
- Following prior studies that use survey engagement metrics to specify choice models (e.g., eye-tracking, response time), we use map-interaction data to infer locations where water quality might be salient.
- We also geocode home locations from mailing addresses.



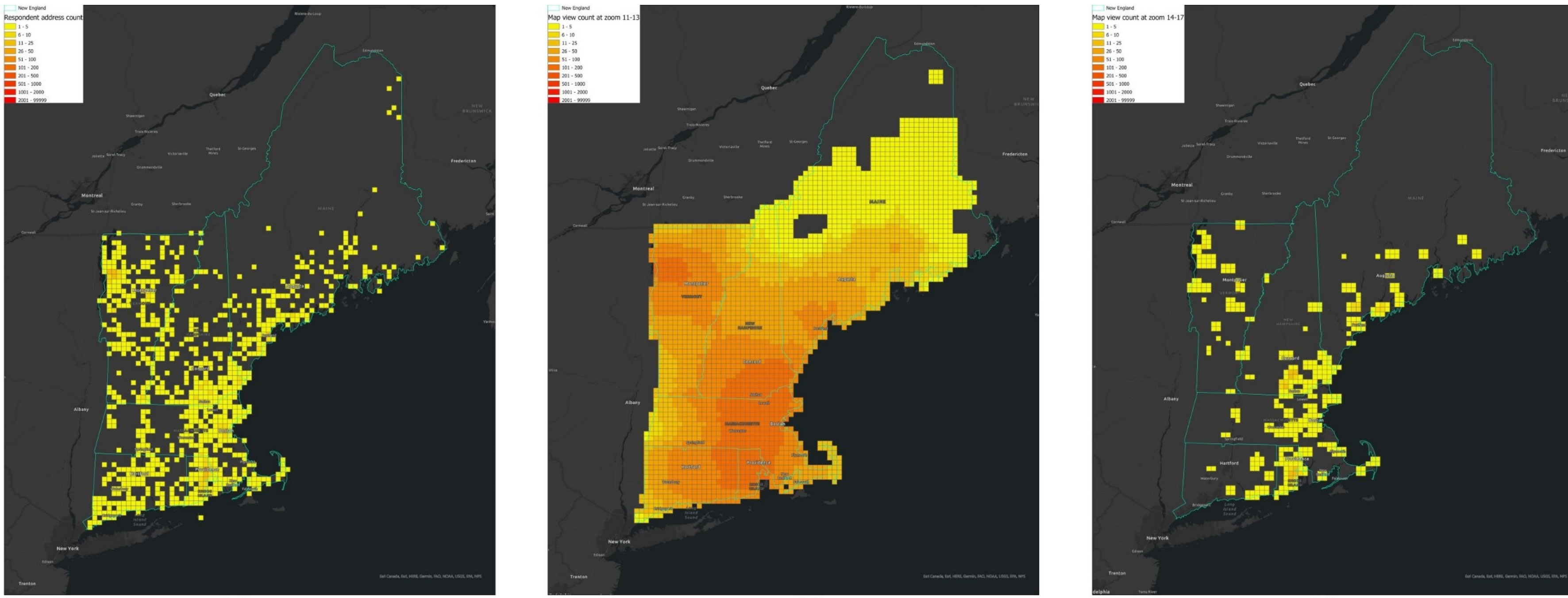
The Data

- Survey implemented May - June 2021 using an address-based push-to-web sample.
- Personalized invitation letters mailed to 7,167 random households in each state followed by two reminder mailings.
  - Screened to single-family households with physical addresses.
- Of 42,979 deliverable invitations, 2,203 total responses received.
- 1,698 answered the complete survey and had an identifiable home location in or close to the study area.
- Primary model estimated using data from 1,239 respondents who interacted with at least one map and lived within 10 miles of study area (allowing surrounding water quality to be identified).

Screened Map Interaction Data

- Database screened to eliminate map frames viewed for <2 seconds or >5 minutes.
- Remaining 31,771 frames screened to identify the longest-looked 3 frames for each of 9 map types in the survey.
- Identified a maximum of 27 “most salient” frames for each respondent (3 longest frames for each of 9 maps), represented by the areas given longest attention.
- Further categorized by zoom level (6-10, 11-13, 14-17).
  - Levels 6-10 represent entire study domain (*little new information beyond maps on main survey screens*).
  - Levels 11-13 represent communities, neighborhoods and major roads.
  - Levels 14-17 display smaller streets and structures.

Where Did People Look?
Map-Interaction Results



(a) Home Addresses

(b) Views/grid (zoom levels 11-13)

(c) Views/grid (zoom levels 14-17)

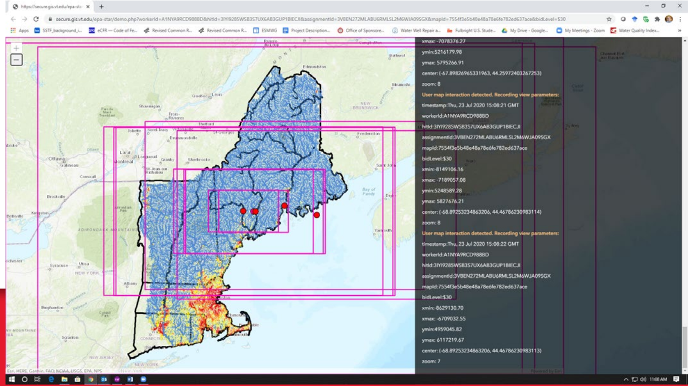
- **56.8%** of views at levels 11-13 included the respondent's home.
- **35.2%** of views at levels 14-17 included the respondent's home.

Econometric Estimation

- Logit models estimated in WTP-Space.
- Bayesian model search/averaging (BMS) to identify what matters.
- Understand influence of spatial dimensions
  - Does map-tracking provide information relevant to WTP?
  - To what extent is WTP determined by changes surrounding people's homes?
  - Do these effects vary across different quality measures?
  - Or improvements to the "best" versus "worst" areas?
- Multiple specifications estimated to evaluate robustness

Independent Variables

- WQ_i, WS_i and AL_i: mean domain-wide changes in percentage points.
- $WQbot3$, $WSbot3$, $ALbot3$, $WQtop3$, $WStop3$, and $ALtop3$: changes in percent of river miles ($\pm$ 0 to 100) within highest three (“top3”) and lowest three (“bot3”) binned quality levels over the domain.
- $WQXXbot3$, $WSXXbot3$, $ALXXbot3$, $WQXXtop3$, $WSXXtop3$, and $ALXXtop3$ (XX = {10,25}): same but in a 10- or 25-mile radius of each respondent’s home.
- $F1\_WQbot3$, $F1\_WSbot3$, $F1\_ALbot3$, $F1\_WQtop3$, $F1\_WStop3$, $F1\_ALtop3$: same but within the geographical extent of the **longest-looked map frame** (area) for each respondent.
  - Only available via map-interaction data – could be anywhere.



BMS Logit Results: Non-Spatial Effects

Explanatory variable	Variable definition and units	Parameter mean	Parameter std. dev.	p>0	p(in)	Signal
Mean index differences, entire policy domain						
WQ_i **(total pollution)**	Difference in index points (±0-100), policy domain	12.221	10.760	0.741	0.783	
WS_i **(water safety)**	Diff. in index points, policy domain	**27.823**	**8.596**	**0.995**	**0.996**	***
AL_i **(aquatic life)**	Diff. in index points, policy domain	6.310	9.215	0.529	0.625	
Top and bottom level differences, entire policy domain						
WQtop3	Diff. in % of river mi. in top 3 WQ levels (±0-100)	6.282	9.191	0.528	0.624	
WQbot3	Diff. in % of river mi. in bottom 3 WQ levels	**-20.774**	**10.666**	**0.009**	**0.936**	***
WStop3	Diff. in % of river mi. in top 3 WS levels	16.840	10.265	0.877	0.893	
WSbot3	Diff. in % of river mi. in bottom 3 WS levels	**-9.727**	**10.169**	**0.057**	**0.719**	**
ALtop3	Diff. in % of river mi. in top 3 AL levels	8.322	9.916	0.607	0.680	
ALbot3	Diff. in % of river mi. in bottom 3 AL levels	**-3.407**	**7.991**	**0.145**	**0.546**	*
Constant	-	5.416	9.951	0.707	-	
Scale	-	789.591	81.497	1.000	-	-

BMS Logit Results: Spatial Effects

Explanatory variable	Variable definition and units	Parameter mean	Parameter std. dev.	p>0	p(in)	Signal
Top and bottom level differences, 25-mile radius of respondent's home						
WQ25top3	Diff. in % of river mi. in top 3 WQ levels (±0-100)	1.296	7.052	0.303	0.502	
WQ25bot3	Diff. in % of river mi. in bottom 3 WQ levels	**-10.664**	**9.862**	**0.043**	**0.755**	***
WS25top3	Diff. in % of river mi. in top 3 WS levels.	3.330	6.904	0.409	0.531	
WS25bot3	Diff. in % of river mi. in bottom 3 WS levels	**-4.466**	**7.523**	**0.099**	**0.562**	**
AL25top3	Diff. in % of river mi. in top 3 AL levels	5.680	8.778	0.506	0.606	
AL25bot3	Diff. in % of river mi. in bottom 3 AL levels	**-3.438**	**7.903**	**0.141**	**0.542**	*
Top and bottom level differences, 10-mile radius of respondent's home						
WQ10top3	Diff. in % of river mi. in top 3 WQ levels (±0-100)	0.759	6.919	0.280	0.497	
WQ10bot3	Diff. in % of river mi. in bottom 3 WQ levels	**-9.852**	**9.614**	**0.049**	**0.739**	***
WS10top3	Diff. in % of river mi. in top 3 WS levels	2.662	6.149	0.377	0.501	
WS10bot3	Diff. in % of river mi. in bottom 3 WS levels	**-7.083**	**8.133**	**0.060**	**0.668**	**
AL10top3	Diff. in % of river mi. in top 3 AL levels	12.440	10.154	0.766	0.800	
AL10bot3	Diff. in % of river mi. in bottom 3 AL levels	**-6.860**	**9.152**	**0.083**	**0.642**	**
Top and bottom level differences, longest-looked map frame by each respondent						
F1_WQtop3	Diff. in % of river mi. in top WQ 3 levels (±0-100);	3.636	7.922	0.415	0.551	
F1_WQbot3	Diff. in % of river mi. in bottom 3 WQ levels	**-7.108**	**8.843**	**0.071**	**0.651**	**
F1_WStop3	Diff. in % of river mi. in top 3 WS levels	1.882	5.836	0.330	0.476	
F1_WSbot3	Diff. in % of river mi. in bottom 3 WS levels	**-8.255**	**8.496**	**0.048**	**0.705**	***
F1_ALtop3	Diff. in % of river mi. in top 3 AL levels	2.275	7.105	0.350	0.515	
F1_ALbot3	Diff. in % of river mi. in bottom 3 AL levels	-1.029	6.889	0.207	0.498	

Key Findings & Conclusions

- First evidence that individualized map interactions convey systematic information related to choices and WTP.
- WTP influenced by changes close to each respondent's home and in locations identifiable via each respondent's map interactions.
  - Distance decay modeling alone will not capture these patterns.
- WTP depends on spatial dimensions of water quality change that were only visible on maps.
  - Strong WTP signal for mean (non-spatial) regionwide change only found for water safety (WS).
- Spatial effects pertinent solely for improvements to rivers at low baseline quality.
- Patterns of this type cannot be estimated using standard choice experiment architectures.

Key Findings & Conclusions

- More sophisticated choice experiment architectures may be required to identify how and where people value water quality.
- There are potential advantages to eliciting choices using actual, spatially explicit predictions of environmental change rather than "ecologically artificial" experimental designs.
- We are just beginning to explore modeling possibilities with spatial data of this type. Examples of future work :
  - Modeling map interactions as endogenous.
  - Different areas salient for different measures of water quality?
  - Population-level benefit estimation.
- New USDA AFRI project will allow us to advance these methods further, for a Virginia case study (stay tuned).

QUESTIONS OR COMMENTS?

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