Estimating the Benefits of Stream Water Quality Improvements in Urbanizing Watersheds

Roger H. von Haefen, NC State

Social Cost of Water Workshop

September 2022

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Research Team

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  - George Van Houtven
- UMD & UMN:
  - Melissa Kenney
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Research Area

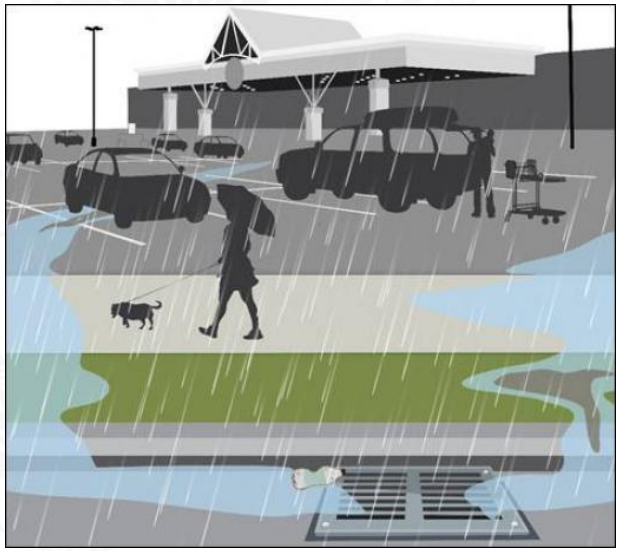
North Carolina

Research Focus

Urban Stream Syndrome

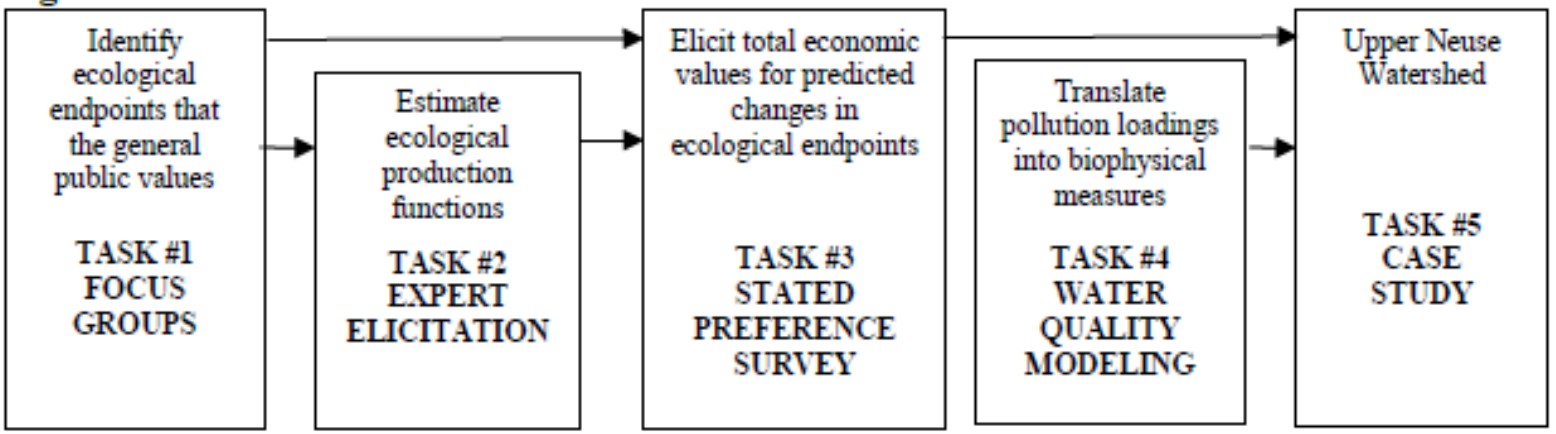
Causes

- Sediment erosion & surface runoff



Research Plan

Figure 1. Plan of Work



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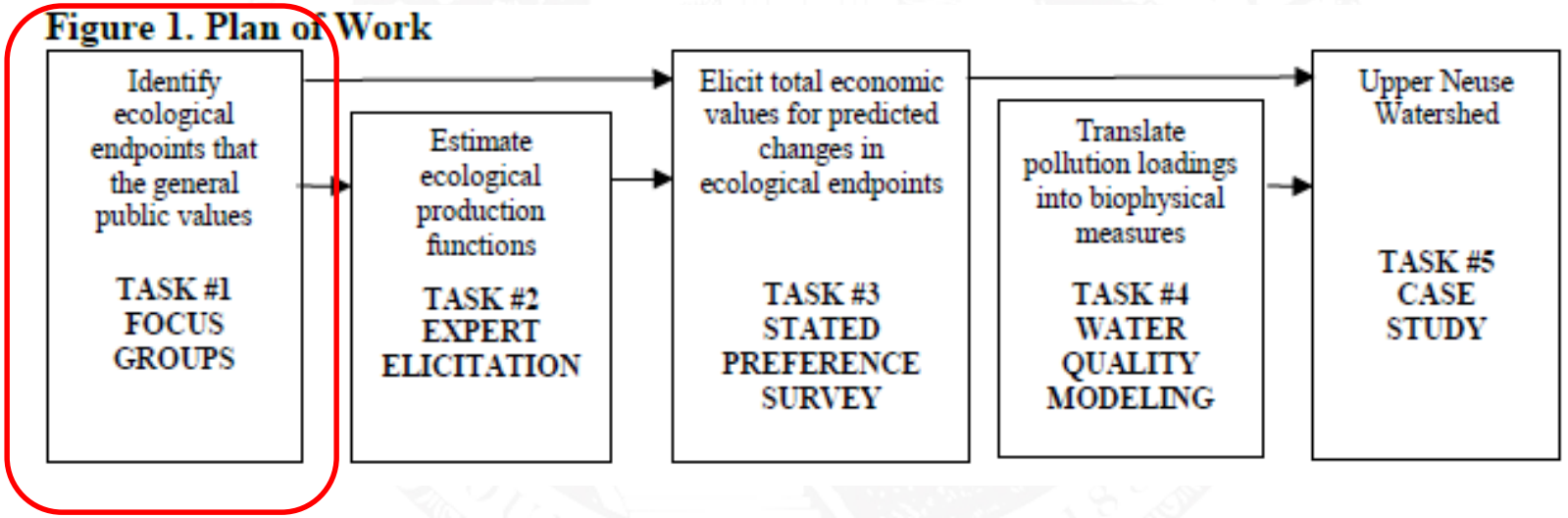

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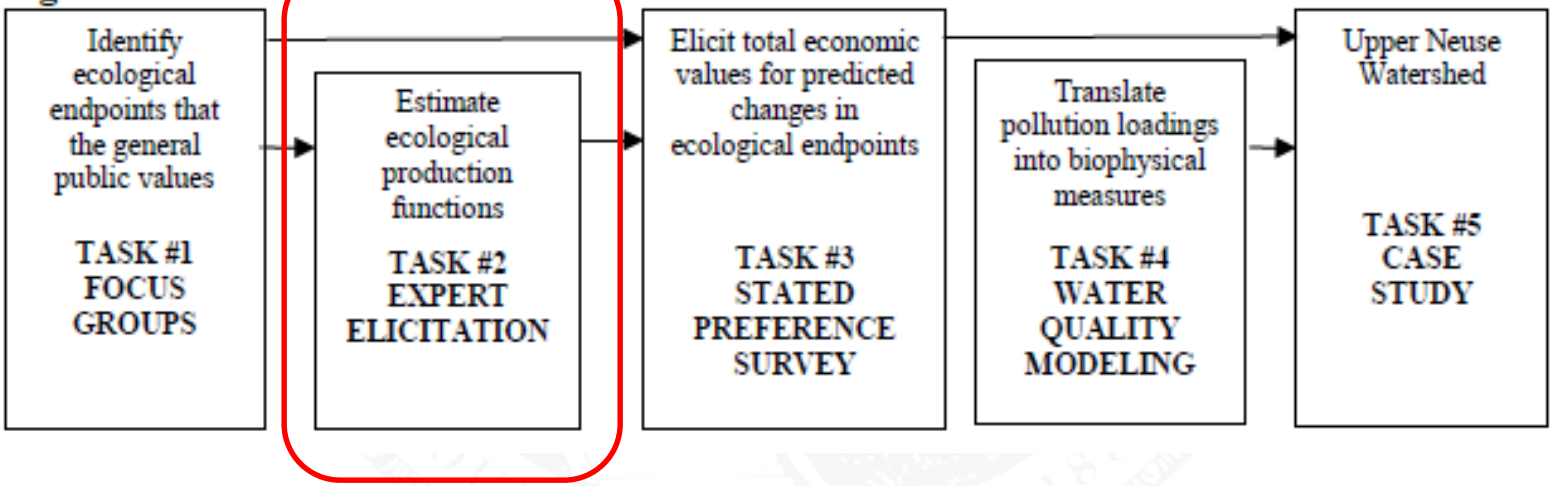

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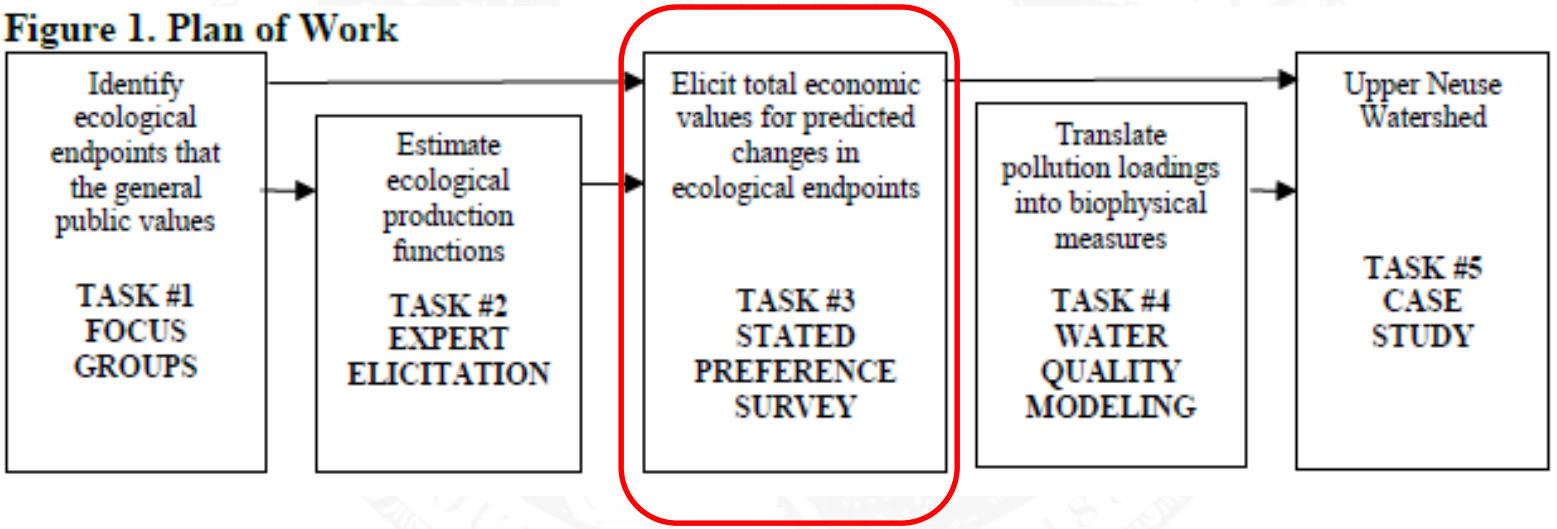

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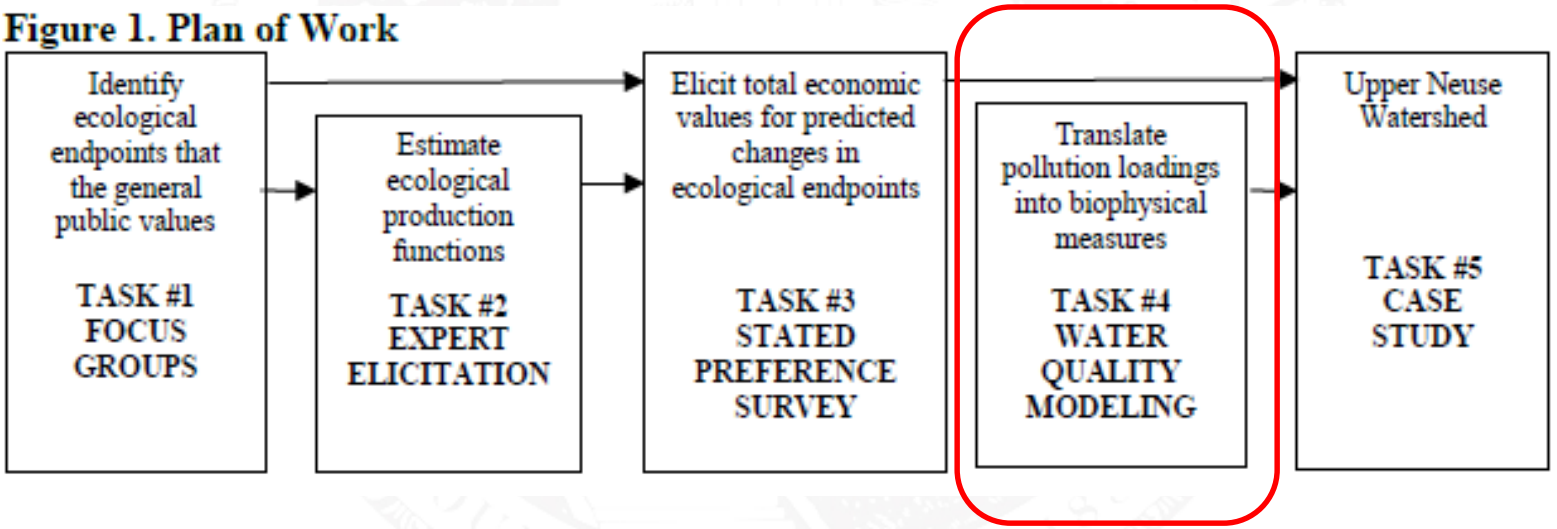

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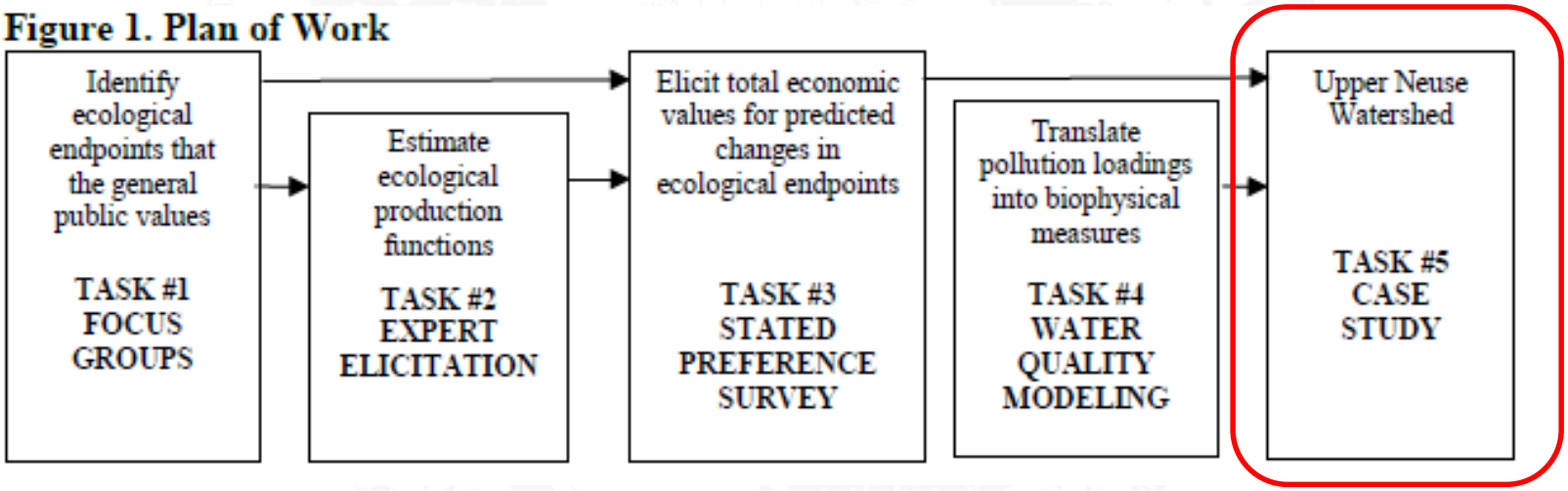
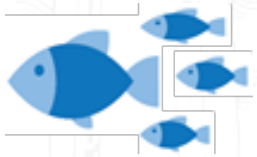


Endpoints

Harm to stream ecosystem conditions:



More bacteria in streams => human health risks

More murky water days

Ecosystem Condition

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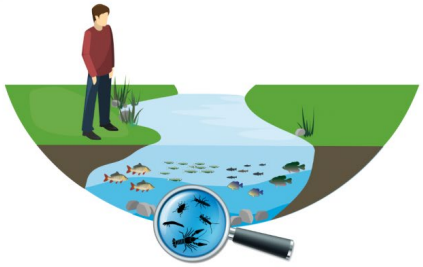
Categories of Stream Ecosystem Condition

Scientists often rely on indicators to measure ecosystem conditions. For streams, the two main indicators are fish and bottom dwellers. Fish feed on smaller organisms on stream bottoms. The quantity and diversity of these bottom dwellers can affect fish populations and overall ecosystem conditions.

Using these indicators, county streams can be divided into the following three categories:

1. GOOD ecosystem condition



Fish: Many different types and ages of fish like minnows, darters, and sunfish.

Bottom dwellers: Many different types of underwater bugs like mayflies, stoneflies, and crayfish.

2. FAIR ecosystem condition

Fish: Fewer but hardier species like crappie, carp and sunfish present. Some have shorter lifespans.

Bottom dwellers: Fewer types of bugs present; hardier types like dragonflies, beetles and crayfish present.

3. POOR ecosystem condition

Fish: Only a few very hardy species like sunfish present, which tend to be relatively small and young.

Bottom dwellers: Aquatic worms, leeches and snails dominate.

Human Health Risk

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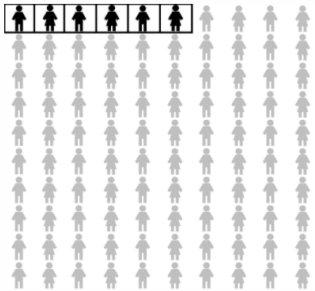
Categories of Increased Health Risk

Because children are more likely than adults to wade in streams, our categories are based on risks to children (less than 15 years old) of getting stomach illness from streams.

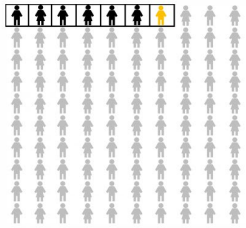
We describe these risks by comparing them with risks to children who do not wade in streams.

In a typical month, about **6 percent** of children who do not wade in streams get stomach illnesses that keep them home from school. They get these illnesses in many ways, especially from contact with other kids. This "**background**" risk of illness is represented by the six boxed kids in the graph of 100 children below.



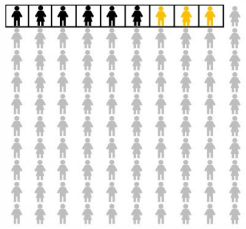
So to categorize each stream based on health risks, we ask the following question:

1. LOW health risk



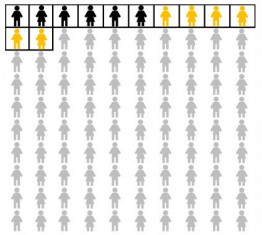
Because bacteria levels are low, wading in this type of stream increases a child's risk of a stomach illness from the background risk (6 percent) to on average **7 percent**.

2. MEDIUM health risk



Wading in this type of stream increases a child's risk of a stomach illness from background risk (6 percent) to on average **9 percent**.

3. HIGH health risk



Wading in this type of stream increases a child's risk of a stomach illness from background risk (6 percent) to on average **12 percent**. So, the higher bacteria levels would on average double the child's risk of a stomach illness.

Murky Water Days

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More Murky Water Days

When streams receive significant sediment erosion, the water becomes murky, making it hard to see the stream bottom.

CLEAR streams

MURKY streams

To be more specific, if you stand in one foot of murky water, you cannot see your feet. With clear water, you can.

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Number of Murky Water Days

County streams can generally be divided into three murky water day categories:

1. LOW number of murky water days

This type of stream is murky **less than 20 percent of the time** (less than 20 out of every 100 days).

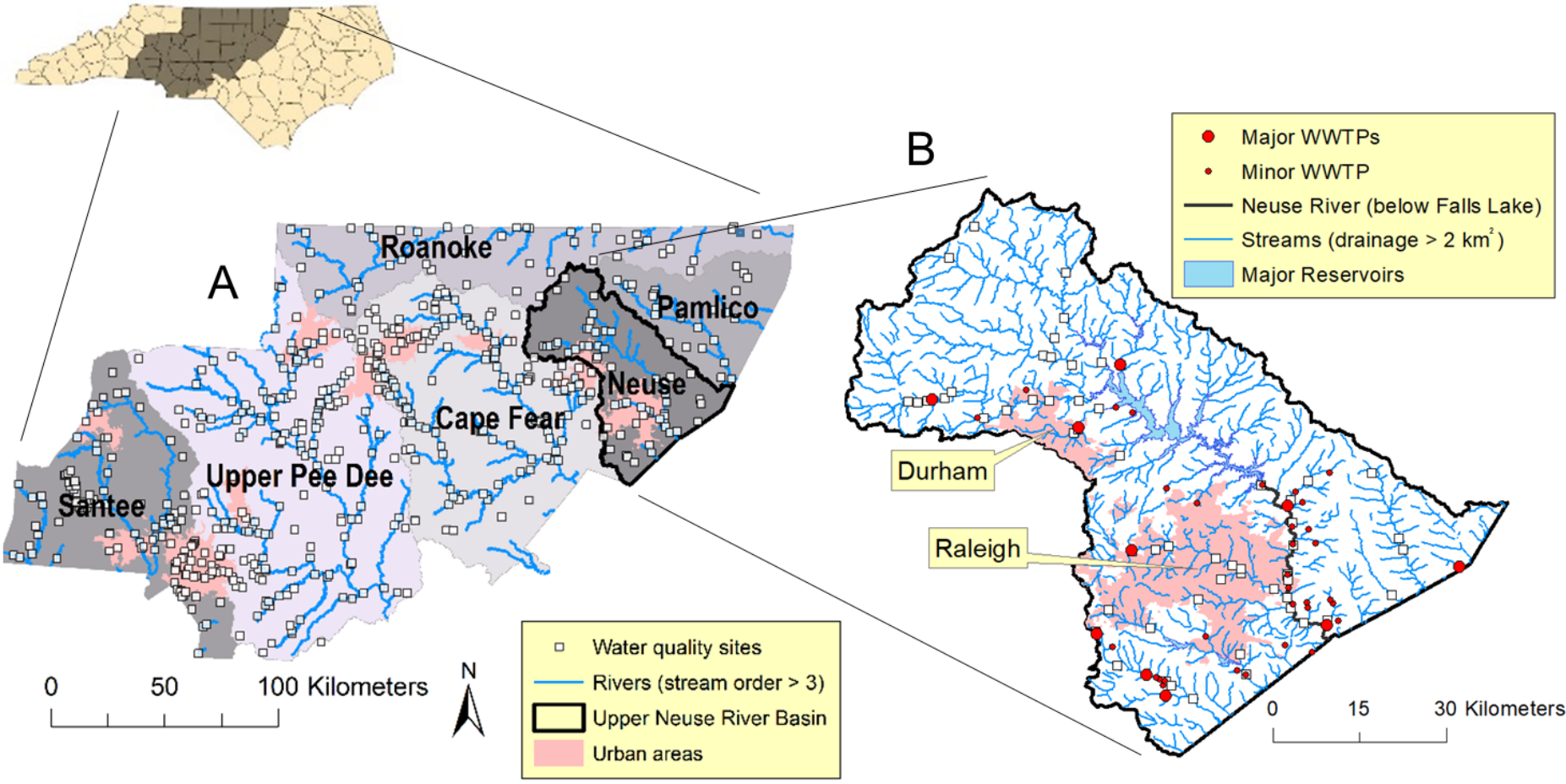
2. MEDIUM number of murky water days

This type of stream is murky **between 20 to 40 percent of the time** (between 20 and 40 out of every 100 days).

3. HIGH number of murky water days

This type of stream is murky **more than 40 percent of the time** (more than 40 out of every 100 days).

NC Piedmont/ Upper Neuse River Basin



Water quality modeling

1) Identify stressors for important water quality indicators:

- **BI**- Biotic index
- **TDU**- turbidity
- **TN**- total nitrogen
- **FC**- fecal coliform
- **SC**- specific conductance
- **TP**- total phosphorus

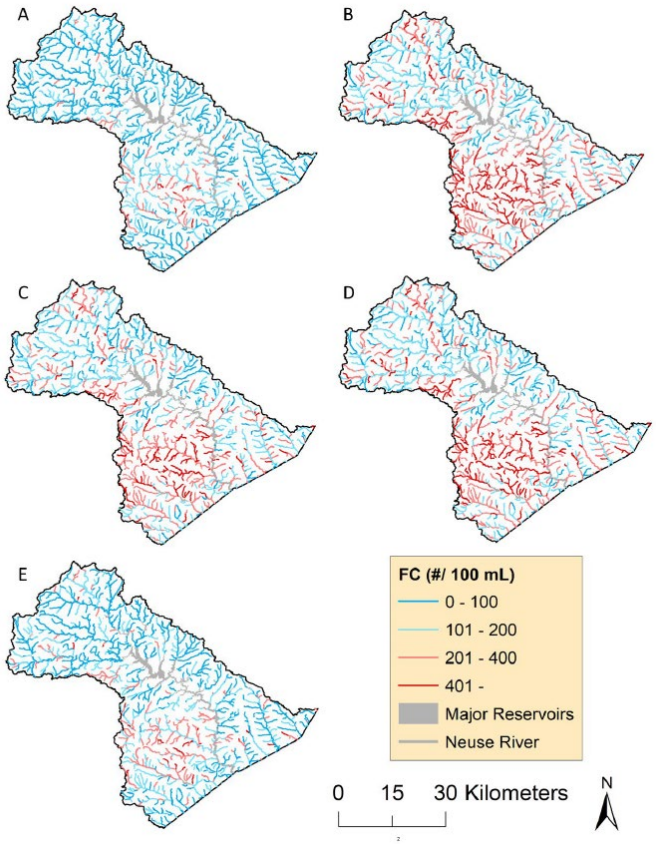
2) Assess potential water quality improvements

- Forecast indicators throughout the Upper Neuse River Basin
- Compare potential management scenarios

Scenarios

	Management Scenario	Candidate predictor variables affected
1	Increase canopy cover in stream buffers (50%)	Canopy Loss (buffer)
2	Decrease effect of IC (25%)	IC (basin, buffer) IC (recent) IC (age)
3	Decrease effect of WWTP (25%)	WWTP (loadings; #; spatial proximity)
4	Combination of scenarios #1-3	Canopy Loss (buffer) IC (basin, buffer) IC (recent) IC (age) WWTP (loadings; #; spatial proximity)
5	Mitigate positive site and basin random effects (25%)	Site random effects Basin random effects

Projections



Expert Elicitation

Ecological Measurement Data:

Biotic Index	Fecal Coliform (cfu/100mL)	Specific Conductance (uS/cm)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Turbidity (NTU)
7.86	150.7	80.5	0.43	0.035	6.97

Stream Ecosystem Condition:

What is the *most likely* condition of the wadeable urban stream for this endpoint?

Good

Fair

Poor

How many of the 100 streams will fall into each category of ecosystem condition?

0 10 20 30 40 50 60 70 80 90 100

Good 0

Fair 0

Poor 0

Expert Elicitation

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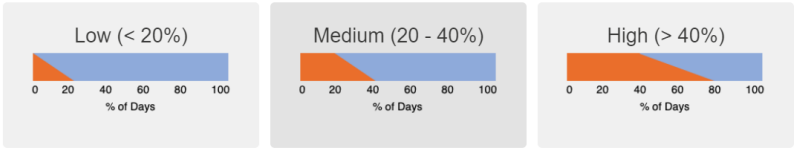
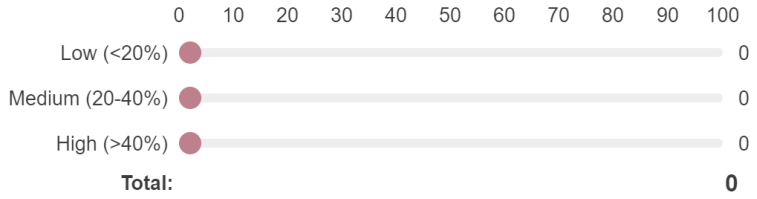
Murky Water Days:

What is the *most likely* condition of the wadeable urban stream for this endpoint?



How many of the 100 streams will fall into each category of murky water frequency?

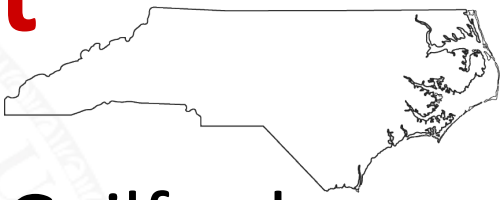


Expert Elicitation

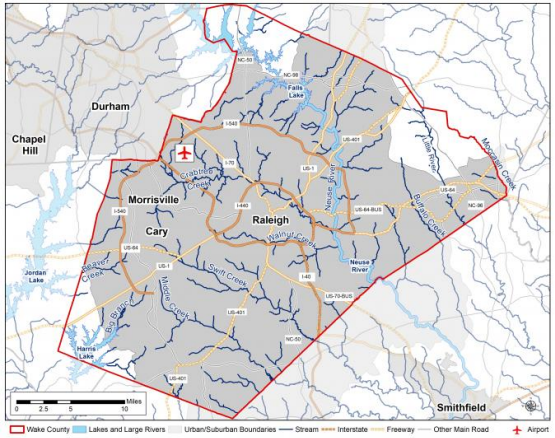
Human health risk

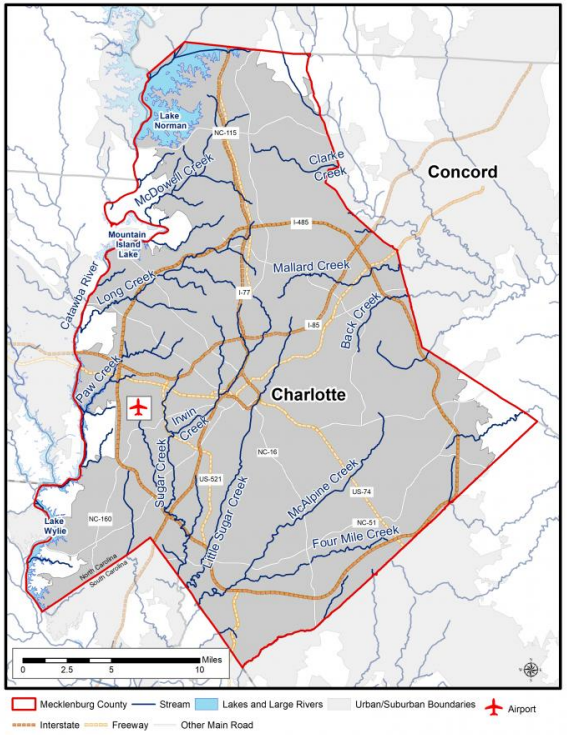
- We have data for fecal coliform; EPA standards are for E-Coli
- Standards are for adults, risks are for kids
- Regional heterogeneity

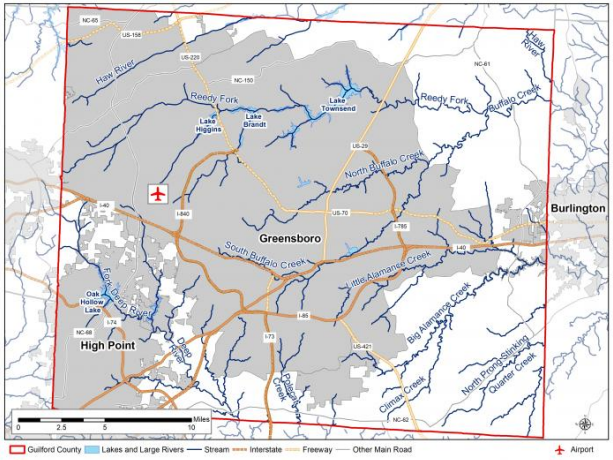
Survey Instrument



- Targets Wake, Mecklenburg and Guilford counties in NC







Stated Preference Survey

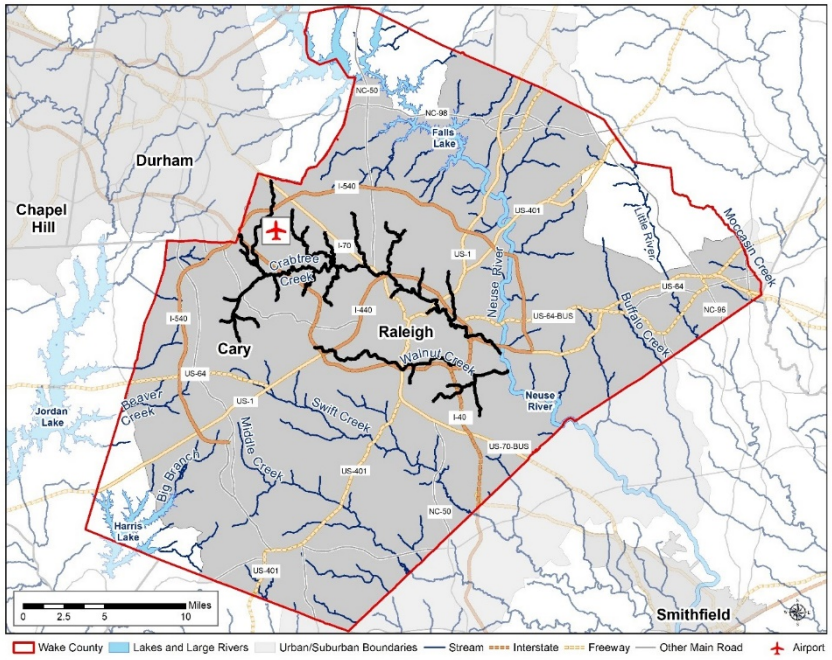
- Initial stakeholder meeting
- 13 focus groups
- 8 cognitive interviews
- A complete on-line survey instrument
- 2 Qualtrics panel pretests (N = 730, 420)
- Primary data collection w/ push-to-internet design (N = 2,511)

Survey Instrument

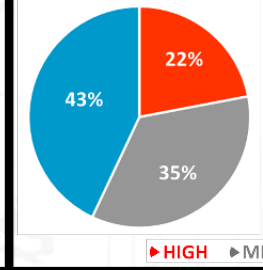
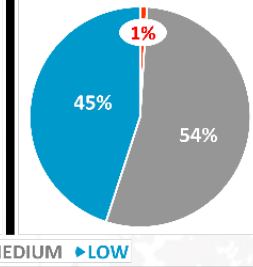
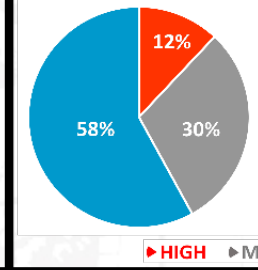
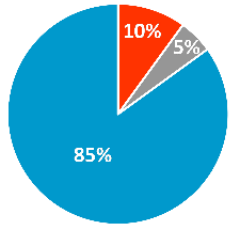
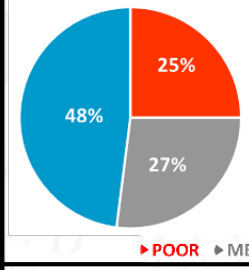
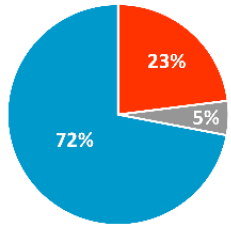
- Programmed in Qualtrics with extensive pictures, graphics
- Accessible by computer & phone
- 4 choice experiment tasks
- Experimental design includes 10 blocks (Ngene)
- Attributes presented in one of two randomly assigned orders

Choice Experiments

- Center around action plans that improve water quality in about 25% of stream miles (~100 miles) in each county



Choice Experiments

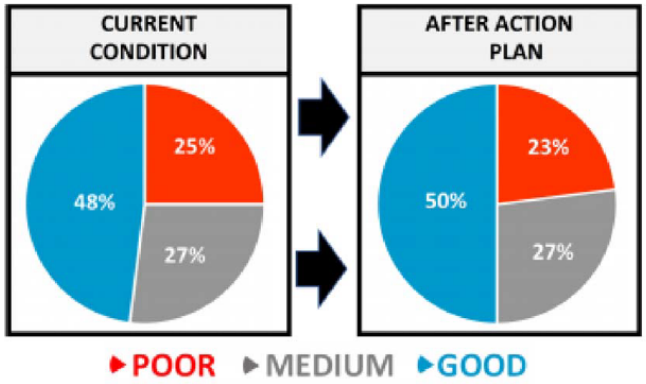
	CURRENT CONDITION	AFTER ACTION PLAN
MURKY WATER DAYS 		
HEALTH RISK 		
ECOSYSTEM CONDITION 		
ADDITIONAL MONTHLY FEE $	$0 per month	$32 per month ($384 per year)

- 3 water quality attributes, each having 3 levels
- Monthly stormwater fee

Choice Experiments

Improvements in Ecosystem Condition

- The percent of stream miles in **POOR** ecosystem condition would <u>decrease</u> from **25%** to **23%**.



- The percent of stream miles in **GOOD** ecosystem condition would <u>increase</u> from **48%** to **50%**.
- The percent of stream miles in **MEDIUM** ecosystem condition would <u>remain</u> at **27%**.

Demographics

Variable	Obs	Mean	Std. Dev.	Min	Max
male	2,511	.4752197	.4838155	0	1
age	2,511	51.14356	16.14859	18	90
income	**2,511**	**99130.84**	**61630.62**	**10000**	**225000**
fulltime	2,511	.5644826	.4808435	0	1
retired	2,511	.2393877	.4138101	0	1
own_home	**2,511**	**.751213**	**.4191645**	**0**	**1**
hs_diploma	2,511	.9902641	.0952711	0	1
college	**2,511**	**.7237811**	**.4338343**	**0**	**1**
adults	2,511	2	.8845735	1	10
kids	2,511	.5873789	.99405	0	10
asian	2,511	.0497099	.2105026	0	1
black	**2,511**	**.1574137**	**.3529555**	**0**	**1**
white	2,511	.7395972	.4254164	0	1

Raw Data

(all four choice experiments)

Cost	Obs	% Yes
cost = 4	2,208	76.4%
cost = 9	1,960	64.1%
cost = 18	2,227	51.3%
cost = 32	3,443	32.9%

Mixed logit model in WTP space

Number of obs = 15,168
Wald chi2(12) = 1117.51
Log pseudolikelihood = -3238.9405 Prob > chi2 = 0.0000

ce	Coef.	Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
Mean						
dummy	15.50642	3.324751	4.66	0.000	8.990023	22.02281
male	-1.565309	1.740209	-0.90	0.368	-4.976057	1.845438
age	-.1601189	.0516024	-3.10	0.002	-.2612577	-.0589801
college	4.213073	1.750302	2.41	0.016	.7825437	7.643603
white	-5.362919	2.068736	-2.59	0.010	-9.417566	-1.308271
ec_g	**.3201667**	**.061378**	**5.22**	**0.000**	**.1998681**	**.4404653**
ec_p	**-.2791668**	**.0646916**	**-4.32**	**0.000**	**-.4059599**	**-.1523736**
hr_g	**.2664616**	**.0583058**	**4.57**	**0.000**	**.1521842**	**.3807389**
hr_p	**-.6585985**	**.1781734**	**-3.70**	**0.000**	**-1.007812**	**-.3093852**
md_g	**.1536107**	**.0392421**	**3.91**	**0.000**	**.0766976**	**.2305237**
md_p	**-.144874**	**.0756479**	**-1.92**	**0.055**	**-.2931412**	**.0033932**
mcost	-1.98824	.11808	-16.84	0.000	-2.219672	-1.756807
SD						
ec_g	.8710257	.1951971	4.46	0.000	.4884464	1.253605
ec_p	.451598	.260568	1.73	0.083	-.059106	.962302
hr_g	.5087469	.1062016	4.79	0.000	.3005955	.7168983
hr_p	1.838725	.9041197	2.03	0.042	.0666832	3.610767
md_g	.4717708	.1353872	3.48	0.000	.2064167	.7371249
md_p	1.001095	.1363579	7.34	0.000	.7338383	1.268351
mcost	.1265296	.3916451	0.32	0.747	-.8941399	.6410808

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[illegible]	[illegible]	[illegible]	[illegible]	0.010	-9.417566	-1.308271
ec_g	.3201667	.061378	5.22	0.000	.1998681	.4404653
ec_p	-.2791668	.0646916	-4.32	0.000	-.4059599	-.1523736
hr_g	.2664616	.0583058	4.57	0.000	.1521842	.3807389
hr_p	-.6585985	.1781734	-3.70	0.000	-1.007812	-.3093852
md_g	.1536107	.0392421	3.91	0.000	.0766976	.2305237
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hr_p	1.838725	.9041197	2.03	0.042	.0666832	3.610767
md_g	.4717708	.1353872	3.48	0.000	.2064167	.7371249
md_p	1.001095	.1363579	7.34	0.000	.7338383	1.268351
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md_g	.1536107	.0392421	3.91	0.000	.0766976	.2305237
md_p	-.144874	.0756479	-1.92	0.055	-.2931412	.0033932
mcost	-1.98824	.11808	-16.84	0.000	-2.219672	-1.756807
SD						
ec_g	.8710257	.1951971	4.46	.000	.4884464	1.253605
ec_p	.451598	.260568	1.73	.083	-.059106	.962302
hr_g	.5087469	.1062016	4.79	.000	.3005955	.7168983
hr_p	1.838725	.9041197	2.03	.042	.0666832	3.610767
md_g	.4717708	.1353872	3.48	.000	.2064167	.7371249
md_p	1.001095	.1363579	7.34	.000	.7338383	1.268351
[illegible]	[illegible]	[illegible]	[illegible]	.747	-.8941399	.6410808

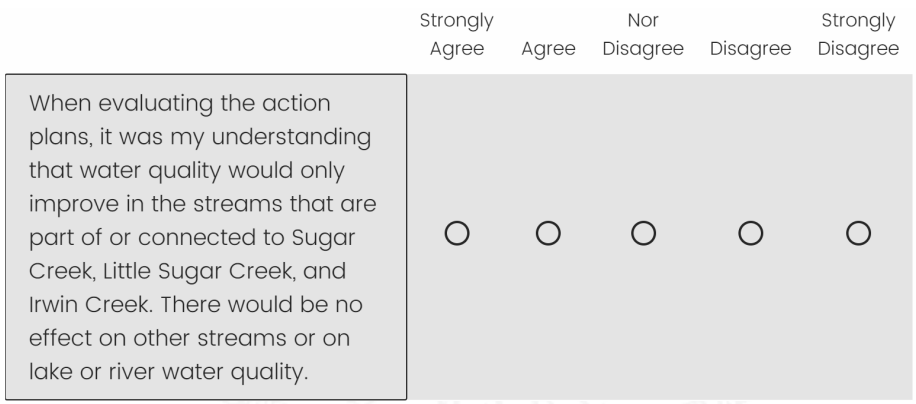
WTP Estimates

(all four choice experiments)

From baseline model	WTP to move 1 stream mile from ___ to ___.
Ecosystem Condition	
Med to Good	$3.84
Poor to Med	$3.35
Health Risk	
Med to Low	$3.20
High to Med	$7.90
Murky Water Days	
Med to Low	$1.84
High to Med	$1.74
Per Household WTP to move lowest quality stream mile to highest quality stream mile	**$21.87**
# of Adults in Wake County	**400,172**
Total WTP	**$8,753,578**

Debrief Results

- Generally encouraging
  - Respondents thought survey was balanced (75%), provided enough info (83%), was price and policy consequential (88% and 61%)
  - People did express some doubts about county gov't being able to achieve quality changes (41%)
- Health Risk & Ecosystem Conditions = most important



88% Agree or Strongly Agree

Trap Question

	Strongly Agree	Agree	Neither Agree Nor Disagree	Disagree	Strongly Disagree
I have doubts that the county government will be able to improve stream water quality as described in the action plans.	○	○	○	○	○
Please select "disagree" here. Thank you for reading carefully.	○	○	○	○	○
I am opposed to higher taxes, no matter what they are used for.	○	○	○	○	○

91% selected disagree

COVID effects?

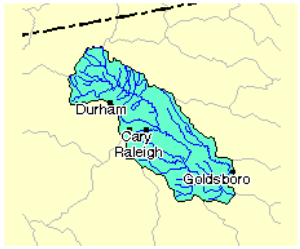
NC STATE UNIVERSITY

Thinking back on your votes for or against the various action plans to improve stream water quality, would you say that the current coronavirus pandemic and its effects made you:

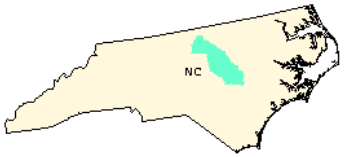
○ More likely to vote for the action plans.	18%
○ Less likely to vote for the action plans.	6%
○ Had no effect on how you voted.	73%

Additional Models

- Analyze initial CE only
- Different ordering of attribute presentation
- County-specific results
- Distance decay models
- All responses
- Latent class models



Case Study

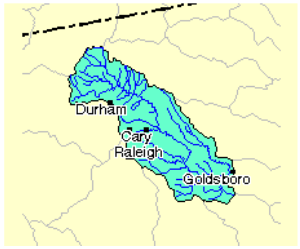


Upper Neuse River Basin

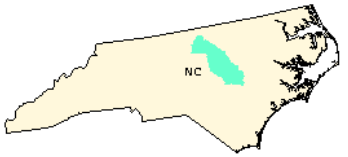
- **Scenarios**
  - a 25 percent increase in canopy cover combined with a 25 percent decrease in the negative effects of impervious cover.
  - a 25 percent reduction in the site and random effects.

Table 5.2. Ecological Endpoints (percentage of watershed stream miles in each category)

Sub-watershed	Scenario	Eco. Cond. Good	Eco Cond. Fair	Eco. Cond. Poor	Health Risk Low	Health Risk Medium	Health Risk Low	Murky Water Days Low	Murky Water Days Medium	Murky Water Days High
Crabtree & Walnut	Baseline	9.83	57.02	33.15	64.89	30.37	4.74	73.39	25.04	1.57
Middle & Swift	Baseline	15.11	60.54	24.35	67.00	28.80	4.20	75.33	23.32	1.35
Crabtree & Walnut	#1	19.18	61.21	19.60	69.92	26.57	3.51	78.44	20.53	1.03
Middle & Swift	#1	25.13	60.33	14.53	71.22	25.55	3.23	79.56	19.50	0.93
Crabtree & Walnut	#2	11.94	58.91	29.16	66.84	28.93	4.24	75.31	23.34	1.35
Middle & Swift	#2	17.96	61.15	20.89	68.90	27.35	3.74	77.24	21.61	1.15



Case Study



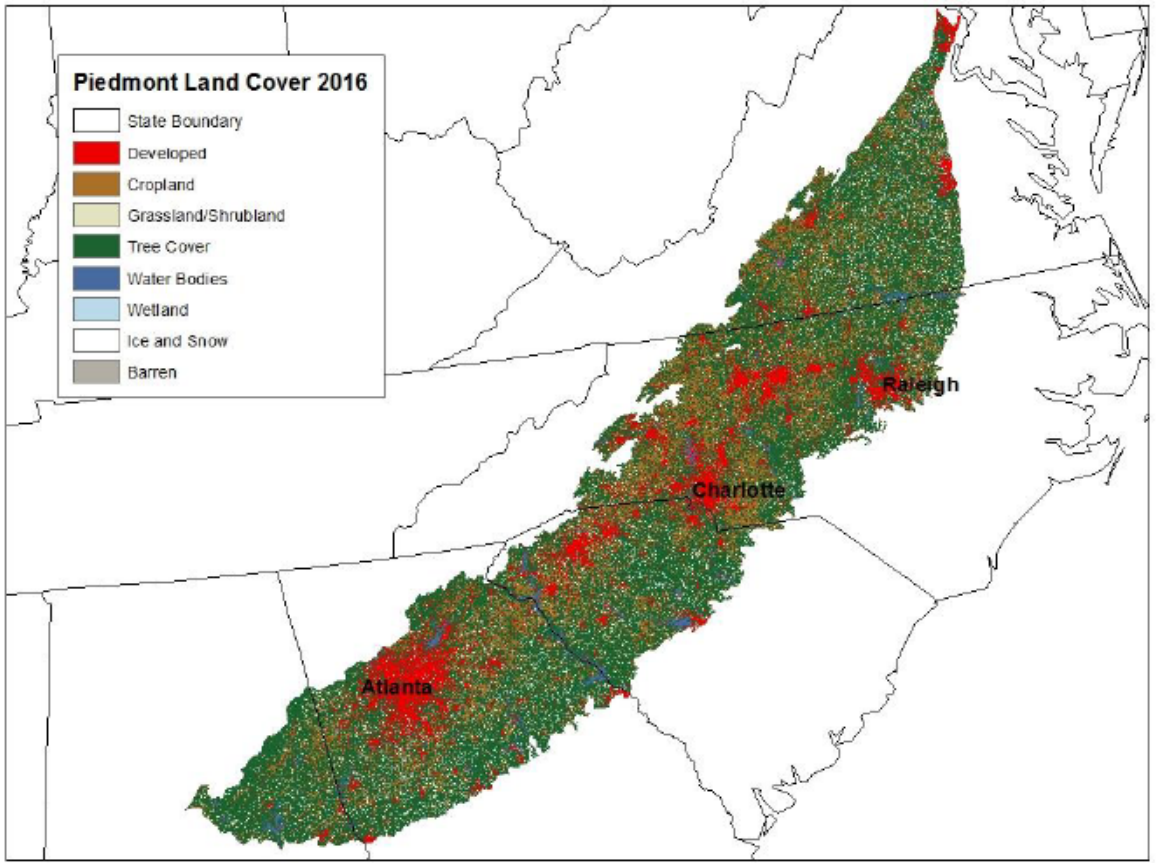
Upper Neuse River Basin

- **Scenarios**
  - a 25 percent increase in canopy cover combined with a 25 percent decrease in the negative effects of impervious cover.
  - a 25 percent reduction in the site and random effects.

Table 5.3. Annual Willingness to Pay Measures

	Per Household WTP		Aggregate WTP (millions)	
Sub-watersheds	Scenario #1	Scenario #2	Scenario #1	Scenario #2
Crabtree & Walnut	$126.48	$39.01	$50.6	$15.6
Swift & Middle	$86.33	$31.44	$34.5	$12.6

Piedmont Region



Thank you!

Questions or comments? Send to

roger_von_haefen@ncsu.edu