Quantifying the social benefits and costs of reductions in phosphorus loading under climate change

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Social Costs of Water Pollution Workshop
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GUND INSTITUTE FOR ENVIRONMENT

The UNIVERSITY of VERMONT

Research Questions

1) What are the social benefits and costs associated with reductions in phosphorus loading?

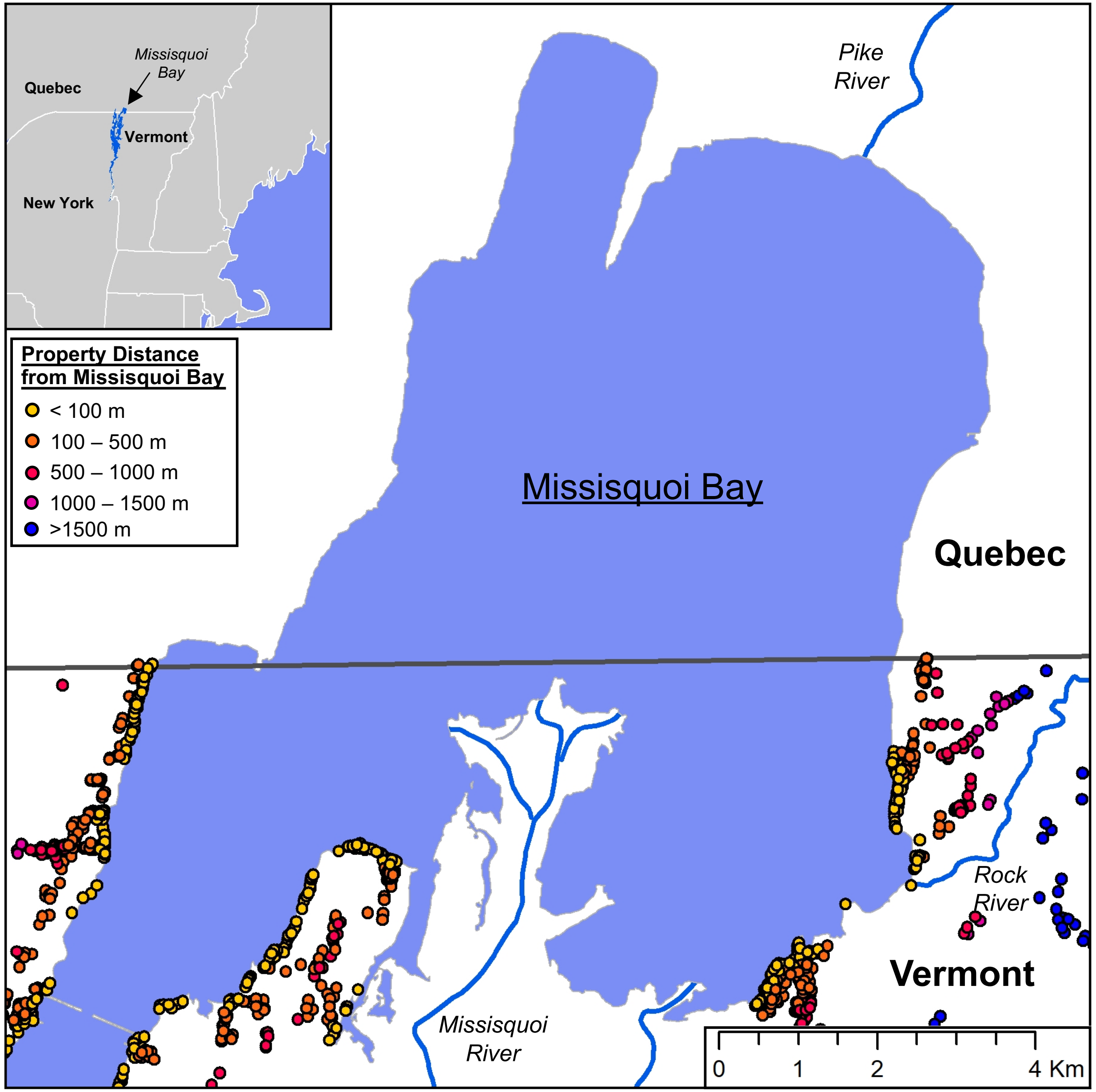
2) How do these benefits and costs vary over time?

3) How do the applied discount rate and time horizon of analysis affect the estimated benefits of improvements in water quality?

4) Do benefits of water quality improvements outweigh costs associated with P reductions?

Study Area – Lake Champlain, Vermont USA

- Rural, agricultural watershed, populated by small and mid-sized dairy farms
- Population = 19,000;
  Annual tourism = $5.9 million
- Increasing frequency and severity of harmful algal blooms, driven by phosphorus (P) loading
- EPA TMDL (2016) requires 64% reduction in P loading by 2038
- Cost of P abatement are closely tracked, but benefits are unknown

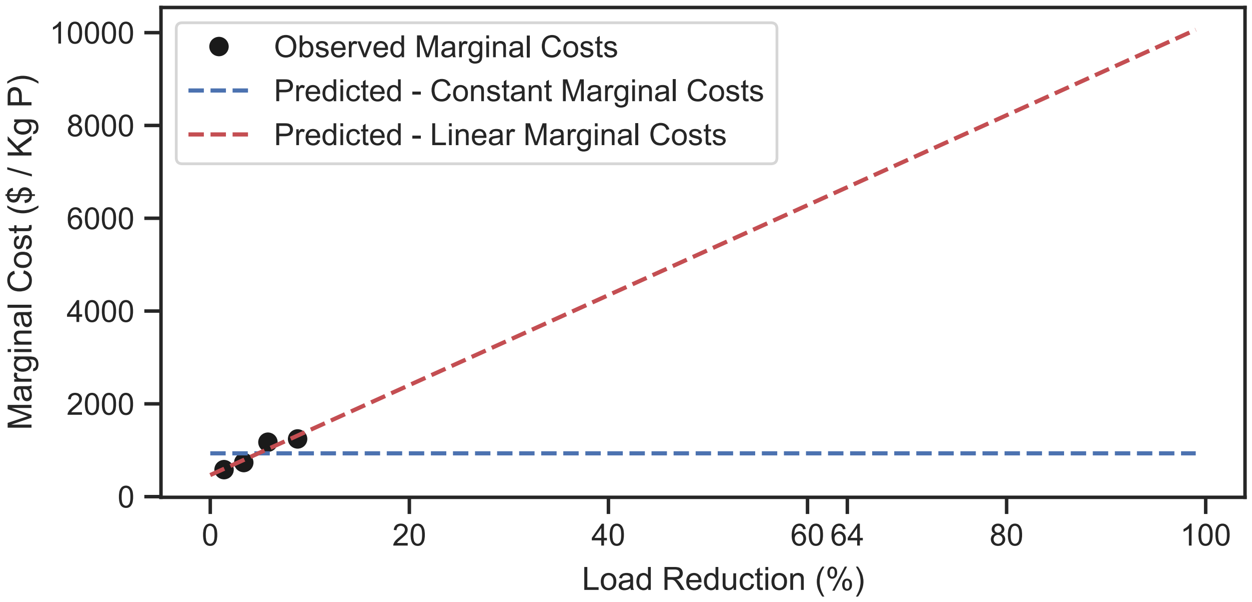


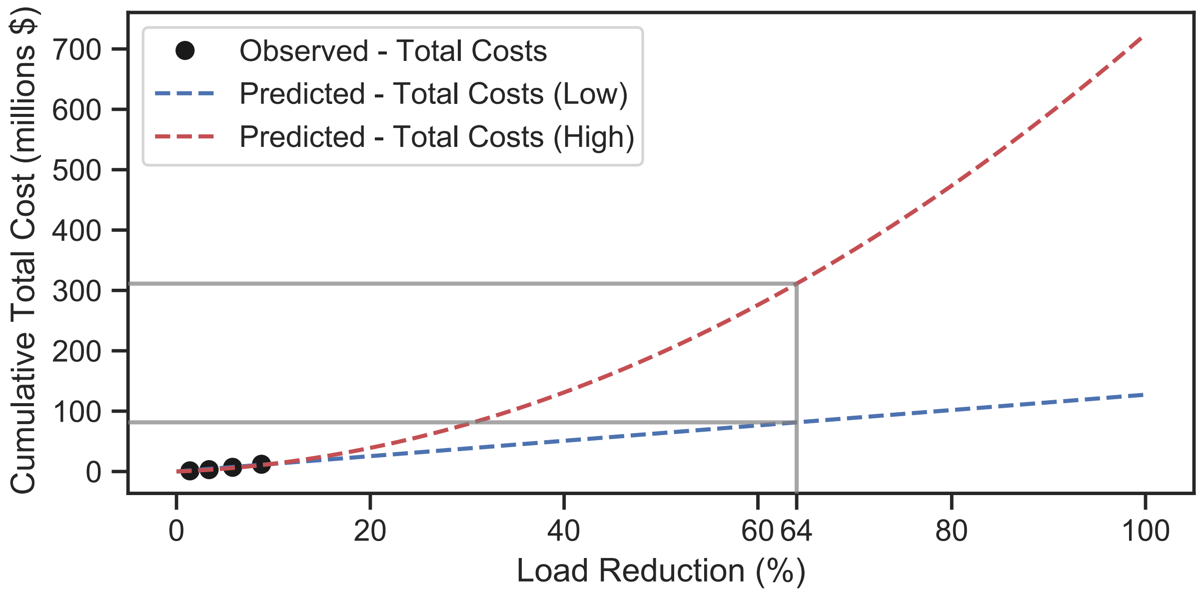
Costs of reductions in phosphorus loading

VERMONT CLEAN WATER INITIATIVE 2019 PERFORMANCE REPORT

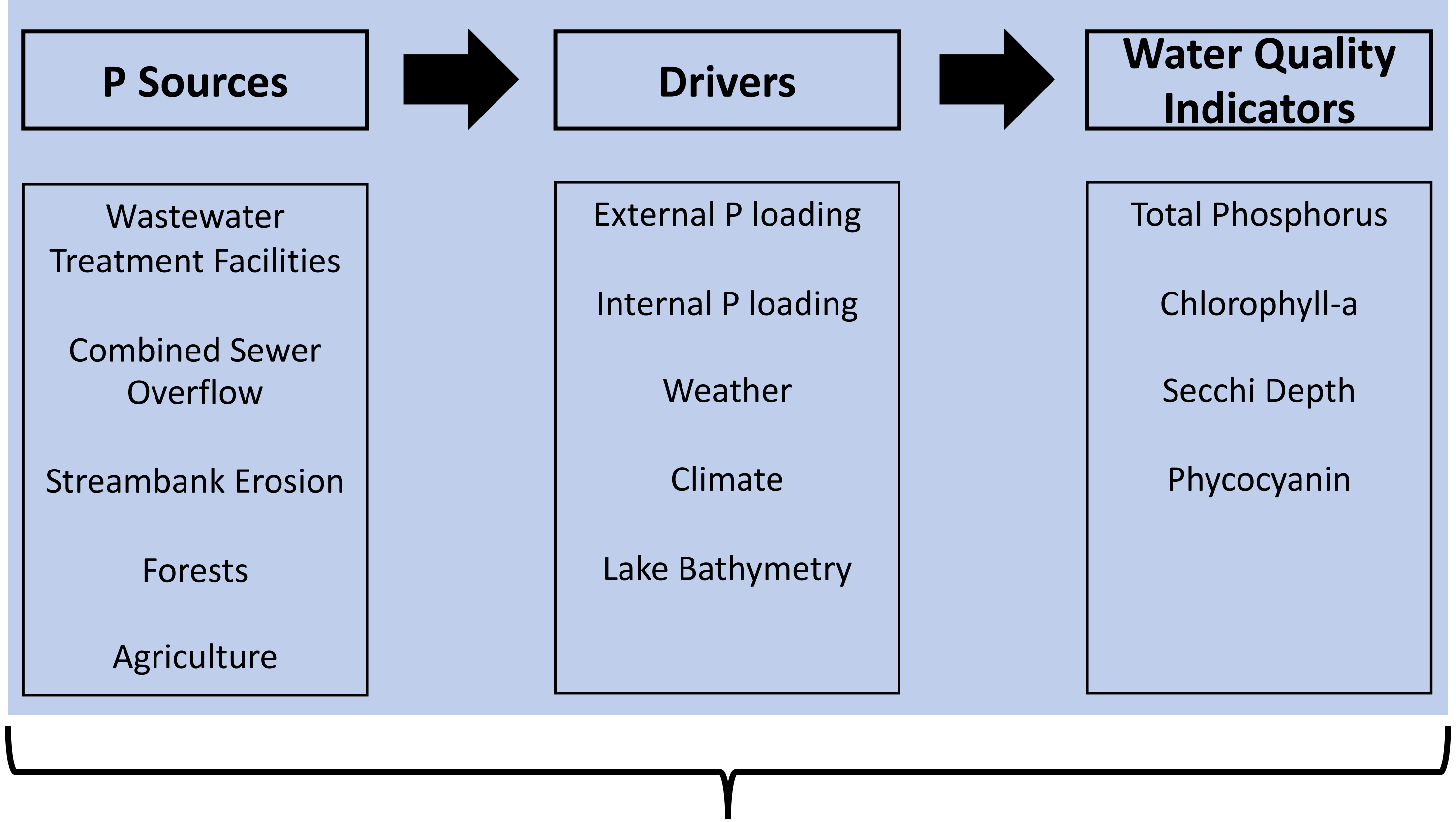
Submitted by the Vermont Agency of Administration

	Load Reduction (Kg P · yr-1)	Annual Cost ($ · yr-1)	Annual Marginal Cost ($ · Kg P)	Cumulative Load Reduction (Kg P)	Cumulative Load Reduction (%)	Cumulative Cost ($)
2016	1889.4	$ 1,099,962	$ 582	1889.4	1.4	$ 1,099,962
2017	2700	$ 1,983,629	$ 735	4589.4	3.4	$ 3,083,591
2018	3307.5	$ 3,881,430	$ 1,174	7896.9	5.8	$ 6,965,021
2019	4064.9	$ 5,055,451	$ 1,244	11961.8	8.8	$ 12,020,472





Conceptual Framework – Linking P and human well-being



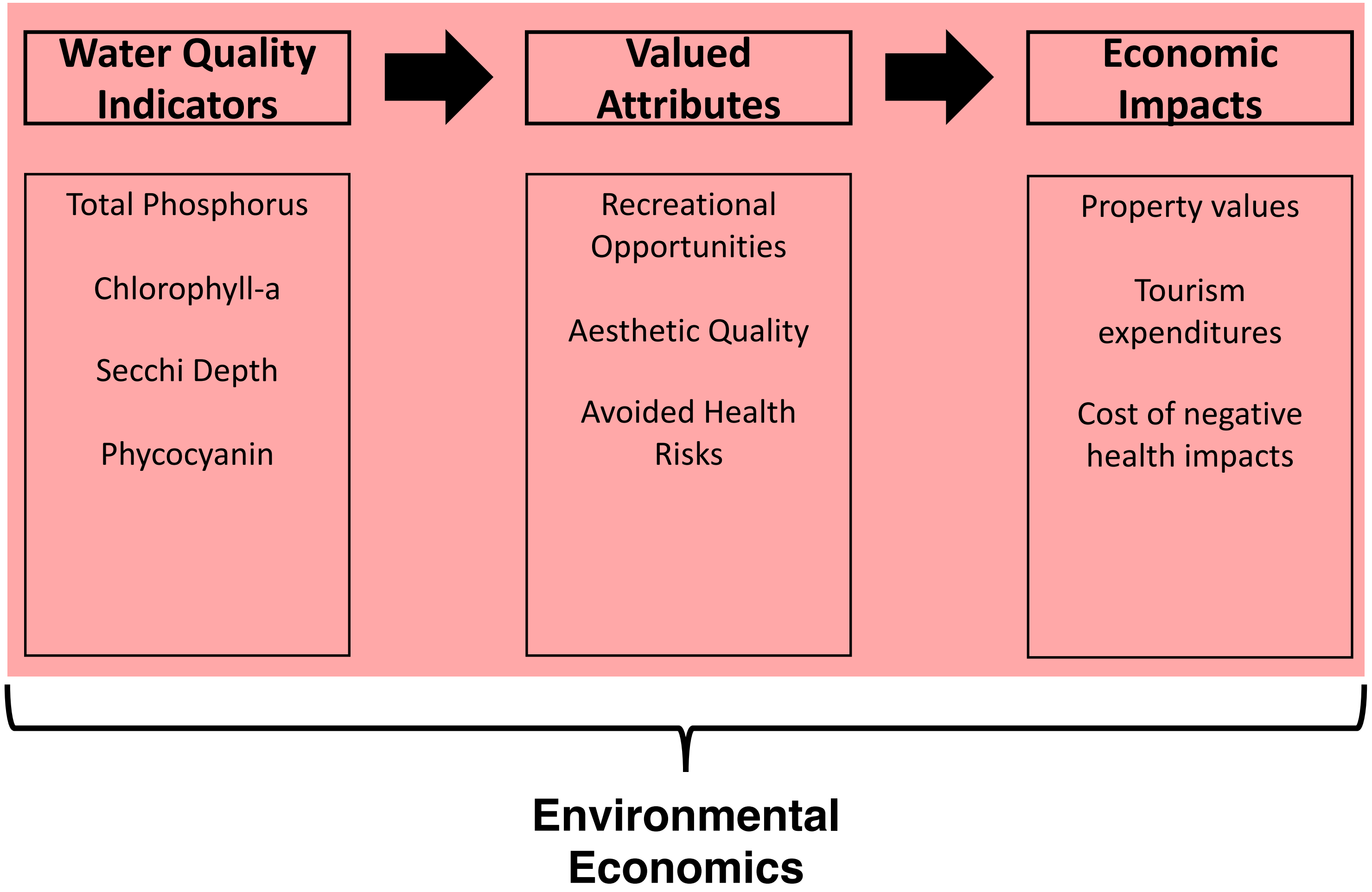
Ecology

Hydrology

Biogeochemistry

Limnology

Conceptual Framework – Linking P and human well-being



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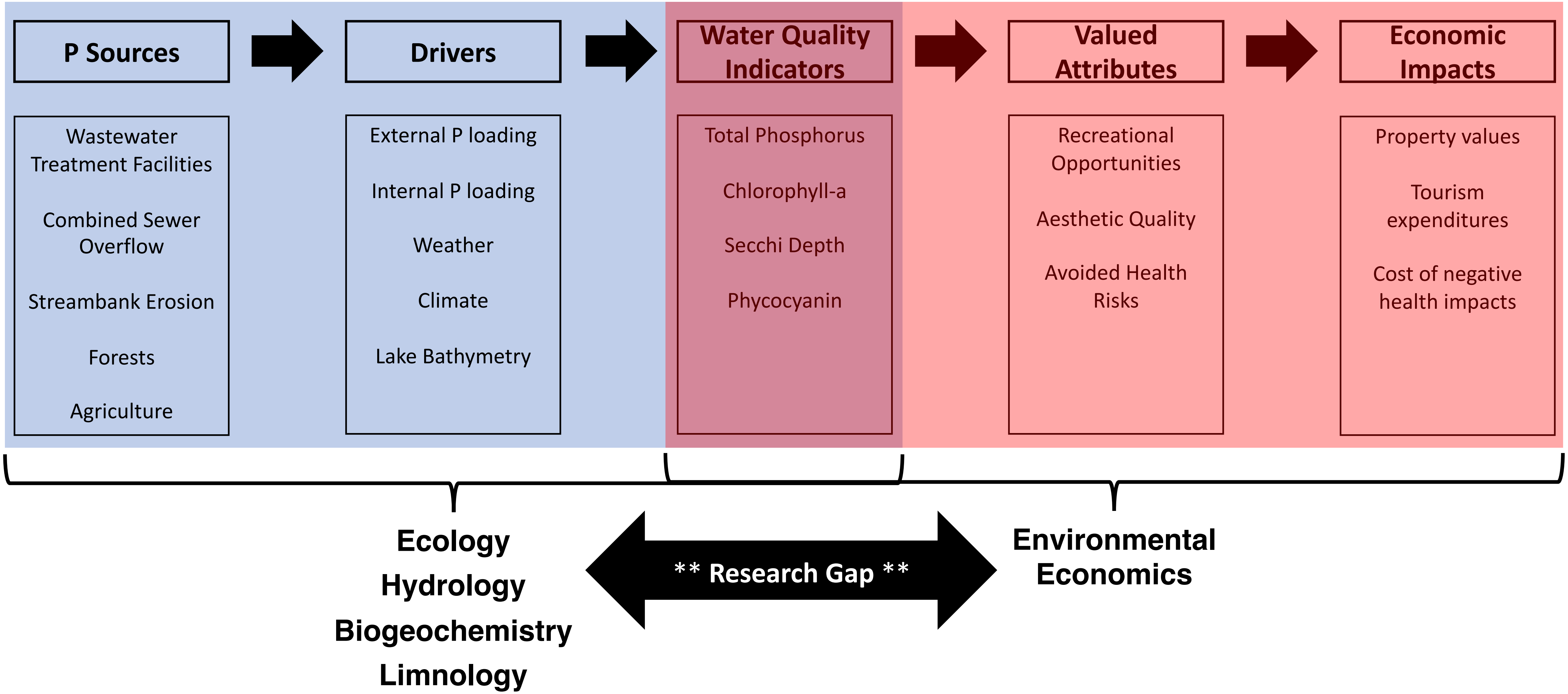

Water Quality Projections, 2016 – 2050


CrossMark

OPEN ACCESS

RECEIVED
12 August 2016

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25 October 2016

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28 October 2016

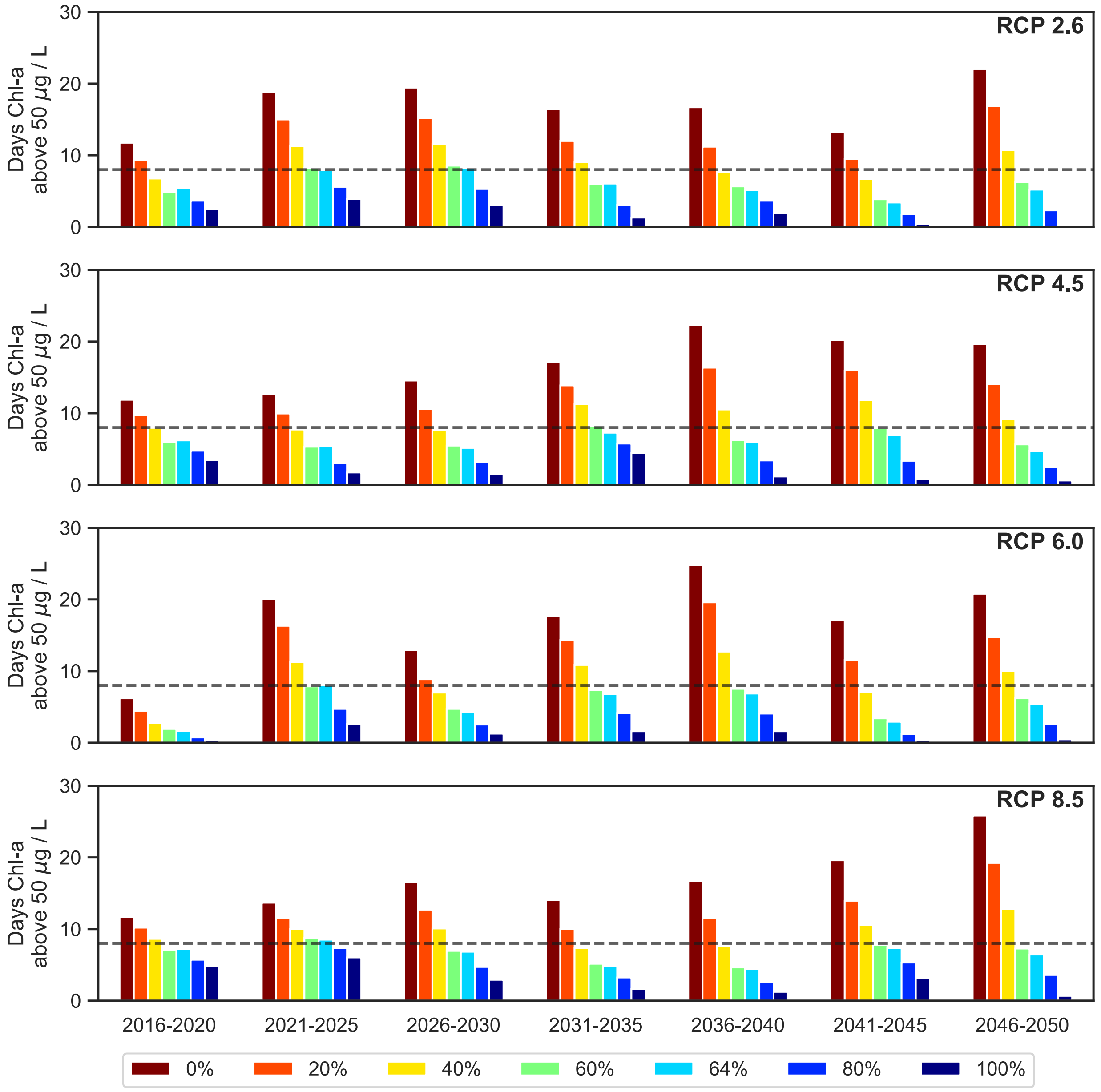
PUBLISHED
17 November 2016

LETTER

Coupled impacts of climate and land use change across a river–lake continuum: insights from an integrated assessment model of Lake Champlain's Missisquoi Basin, 2000–2040

Asim Zia[1,2,3,4], Arne Bomblies[4,5,6], Andrew W Schroth[7], Christopher Koliba[1,4], Peter D F Isles[8], Yushiou Tsai[6], Ibrahim N Mohammed[6], Gabriela Bucini[6], Patrick J Clemins[2,6], Scott Turnbull[6], Morgan Rodgers[6], Ahmed Hamed[6], Brian Beckage[9], Jonathan Winter[10], Carol Adair[8], Gillian L Galford[4,8], Donna Rizzo[4,5] and Judith Van Houten[6,10]

- Integrated assessment model linking P loading, climate, and water quality
- Daily time-step, 2016 – 2050
- Assumes P reductions occur 2016
- RCP outputs averaged across 5 GCMs



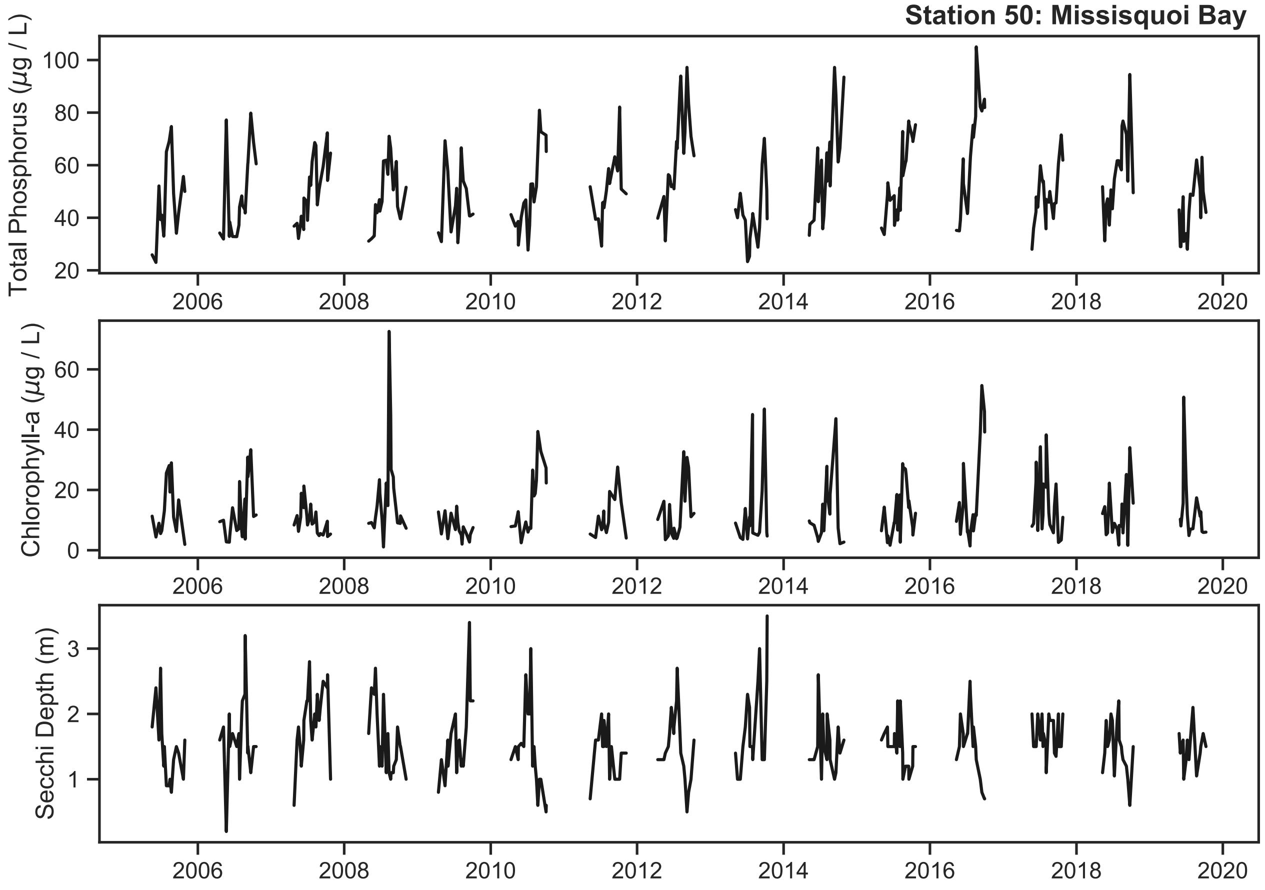
Observed Benefits of Improving Water Quality

Key Independent Variable:

Observed bi-weekly water quality (TP, Chl-a, SD)

Value of residential property transactions

- Dependent variable: Property sales 2010-2020 within 10km of the lakeshore
- OLS log-linear hedonic price model
- WQ variable: mean Chl-a 1-month prior to sale
- Properties <100m from lake: 3% increase in sale price associated with unit (ug/L) decrease in Chl-a
- Properties 100-500m from lake: 1.2% increase in sale price associated with unit (ug/L) decrease in Chl-a
- Properties >500m from lake: no effect of water quality on sale price



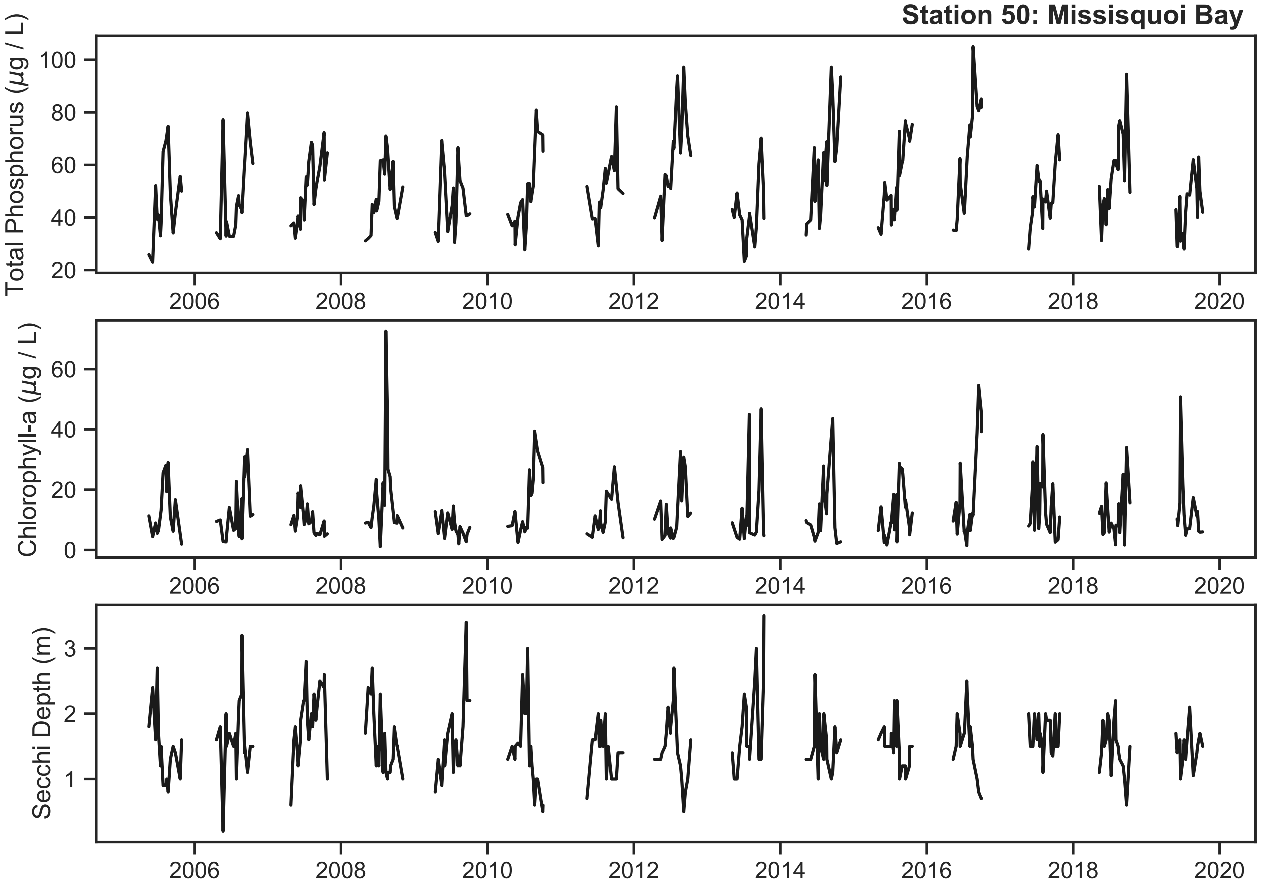
Observed Benefits of Improving Water Quality

Key Independent Variable:

Observed bi-weekly water quality (TP, Chl-a, SD)

Value of tourism expenditures

- Dependent variable: Monthly expenditures on meals, rooms, and alcohol reported by Vermont towns
- Mixed effects lin-log model
- WQ variable: max Chl-a 3-month prior to expenditures
- Town of Swanton: $9,800 increase in monthly expenditures associated with 1% decrease in Chl-a



Observed Benefits of Improving Water Quality

<u>Key Independent Variable:</u>

Estimated phycocyanin concentrations

<u>Value of avoided incidence of ALS</u>

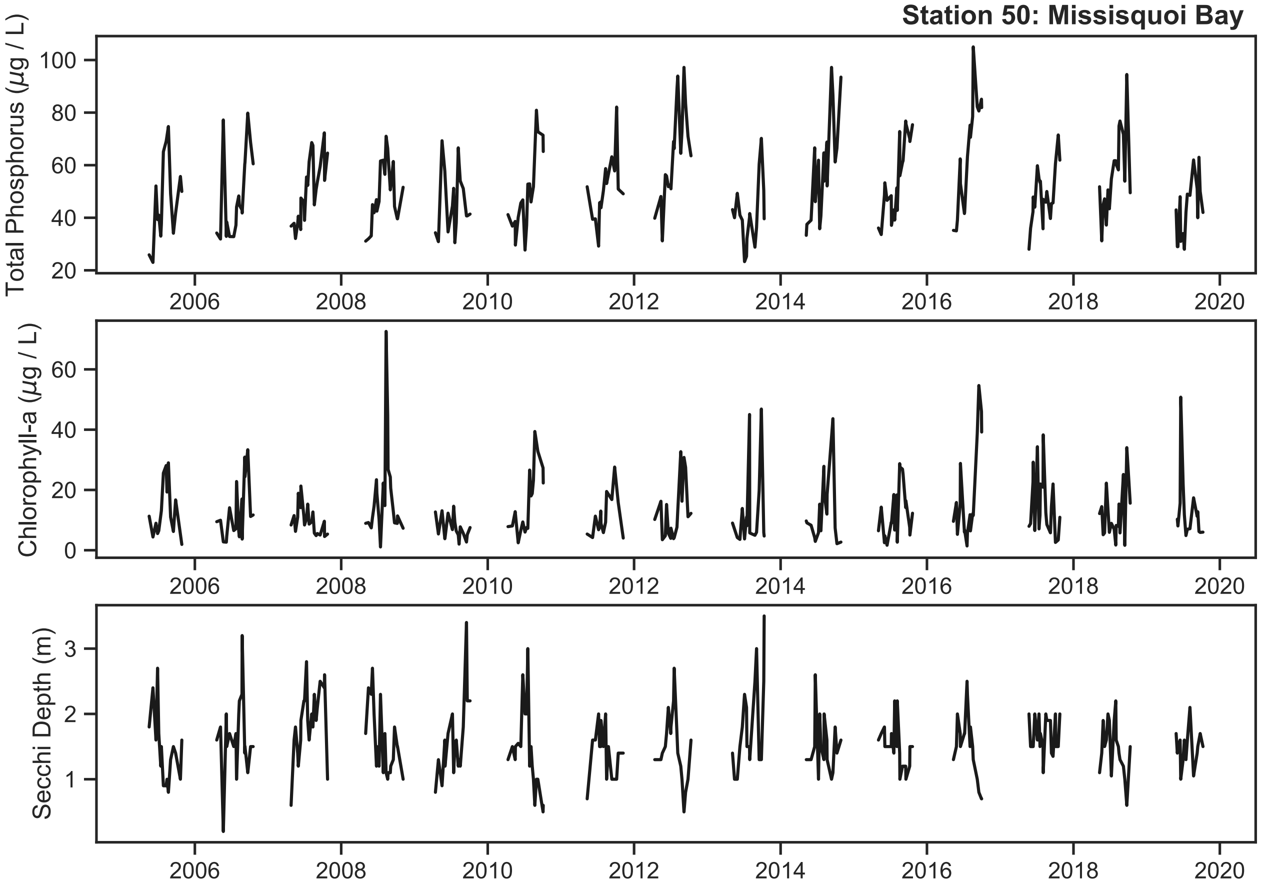
- Elevated exposure to BMAA (b-methylamino-L-alanine) is associated with increased risk of ALS (amyotrophic lateral sclerosis; Lou Gehrig's disease)

- Exposure to aerosolized BMAA may result from living near waterbodies with frequent algal blooms

- Relative risk (RR) of ALS increases by ~40% for individuals living near lakes with average phycocyanin (PC) levels greater than 100 µg / L (Torbick et al. 2018)

- Value of change premature mortalities = RR * Inc * (Pop / 100,000) * VSL

- VSL = $9.2 million



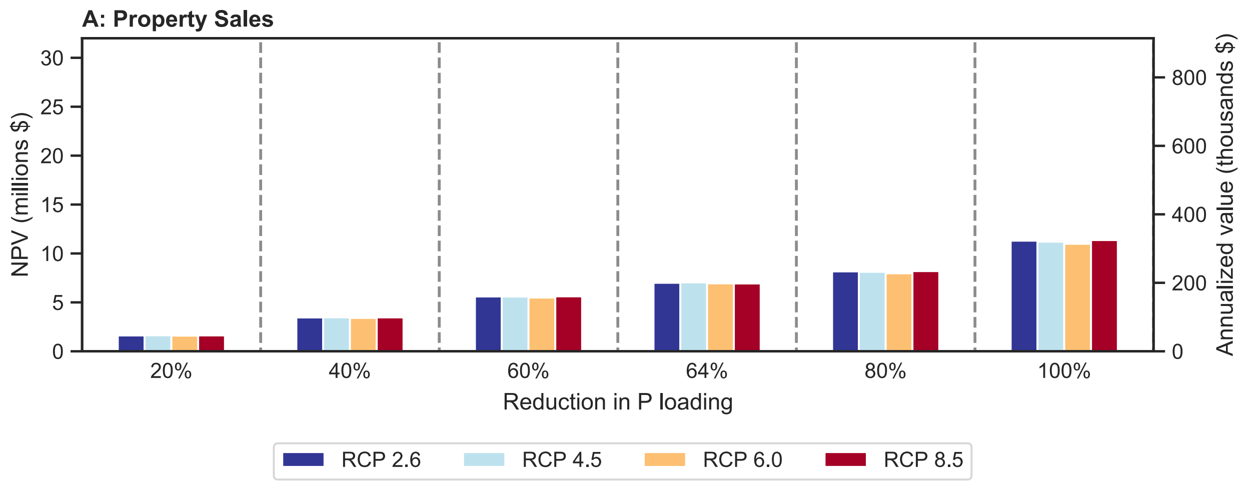
Net Present Value of Predicted Benefits, 2016 – 2050

Increase in NPV of Property Sales

20% reduction: *$1.6 million*

64% reduction: *$7.0 million*

100% reduction: *$11.2 million*



** Discount Rate = 3% **

Net Present Value of Predicted Benefits, 2016 – 2050

Increase in NPV of Property Sales

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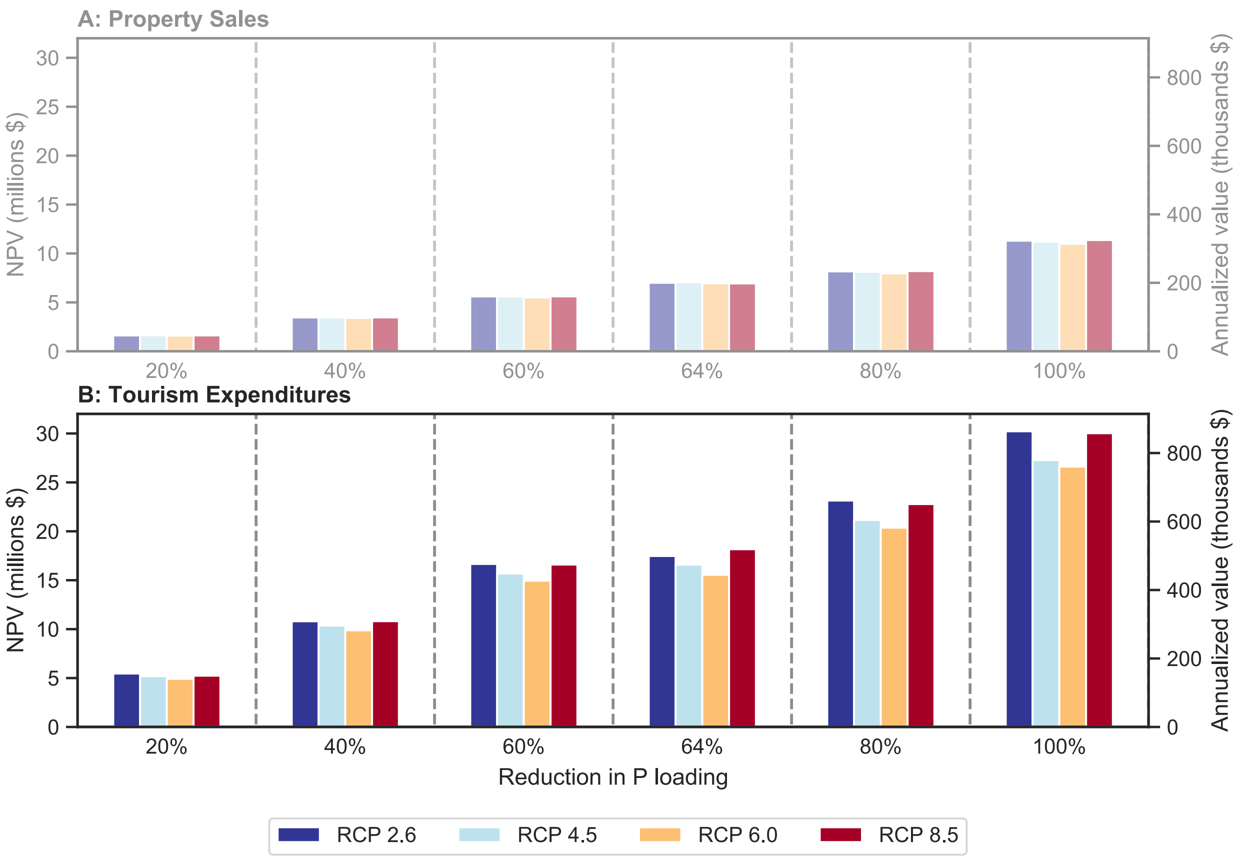
100% reduction: $11.2 million

Increase in NPV of Tourism Expenditures

20% reduction: $5.2 million

64% reduction: $16.9 million

100% reduction: $28.5 million



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Net Present Value of Predicted Benefits, 2016 – 2050

Increase in NPV of Property Sales

20% reduction: $1.6 million

64% reduction: $7.0 million

100% reduction: $11.2 million

Increase in NPV of Tourism Expenditures

20% reduction: $5.2 million

64% reduction: $16.9 million

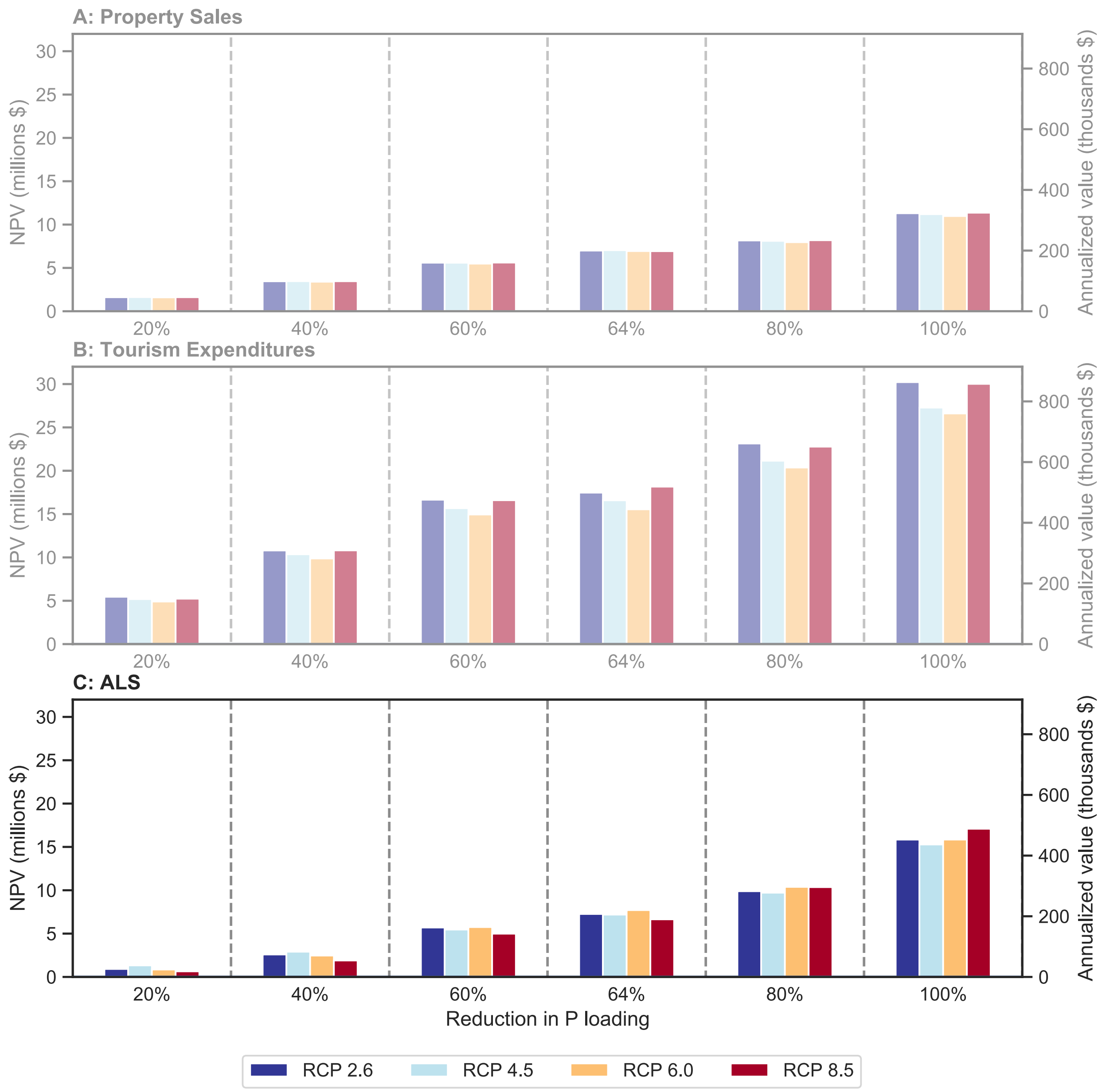
100% reduction: $28.5 million

NPV of Avoided ALS Incidence

20% reduction: $0.9 million (0.2 cases)

64% reduction: $7.3 million (1.4 cases)

100% reduction: $15.8 million (3.1 cases)



** Discount Rate = 3% **

Annual Benefits Increase Over Time

Lag in water quality response to reductions in P loading result in increasing annual benefits between 2016 and 2050

<u>64% Reduction</u>

<u>2020:</u> $1.1 million

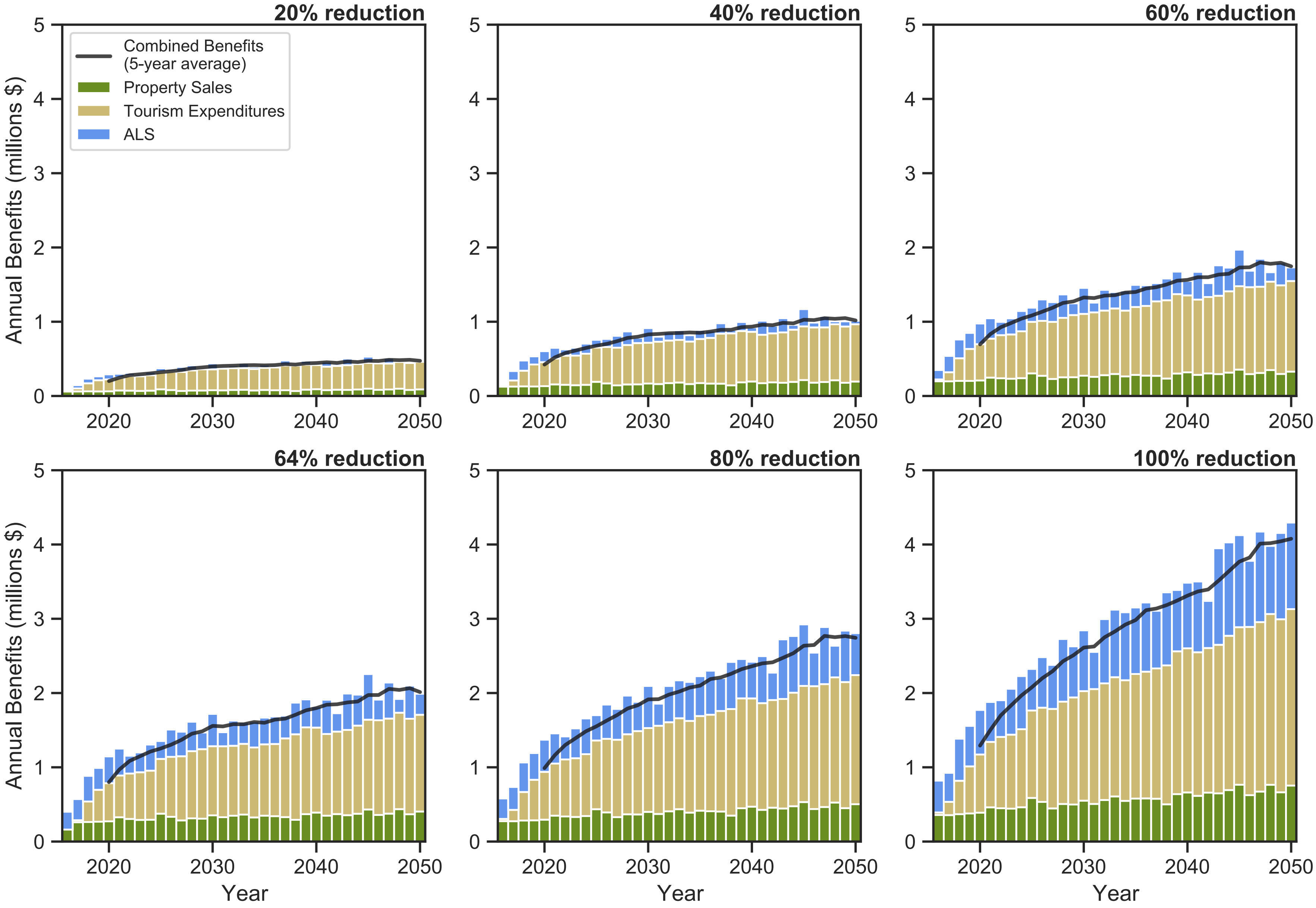
<u>2050:</u> $2.0 million

<u>100% Reduction</u>

<u>2020:</u> $1.8 million

<u>2050:</u> $4.3 million

** Discount Rate = 0% **

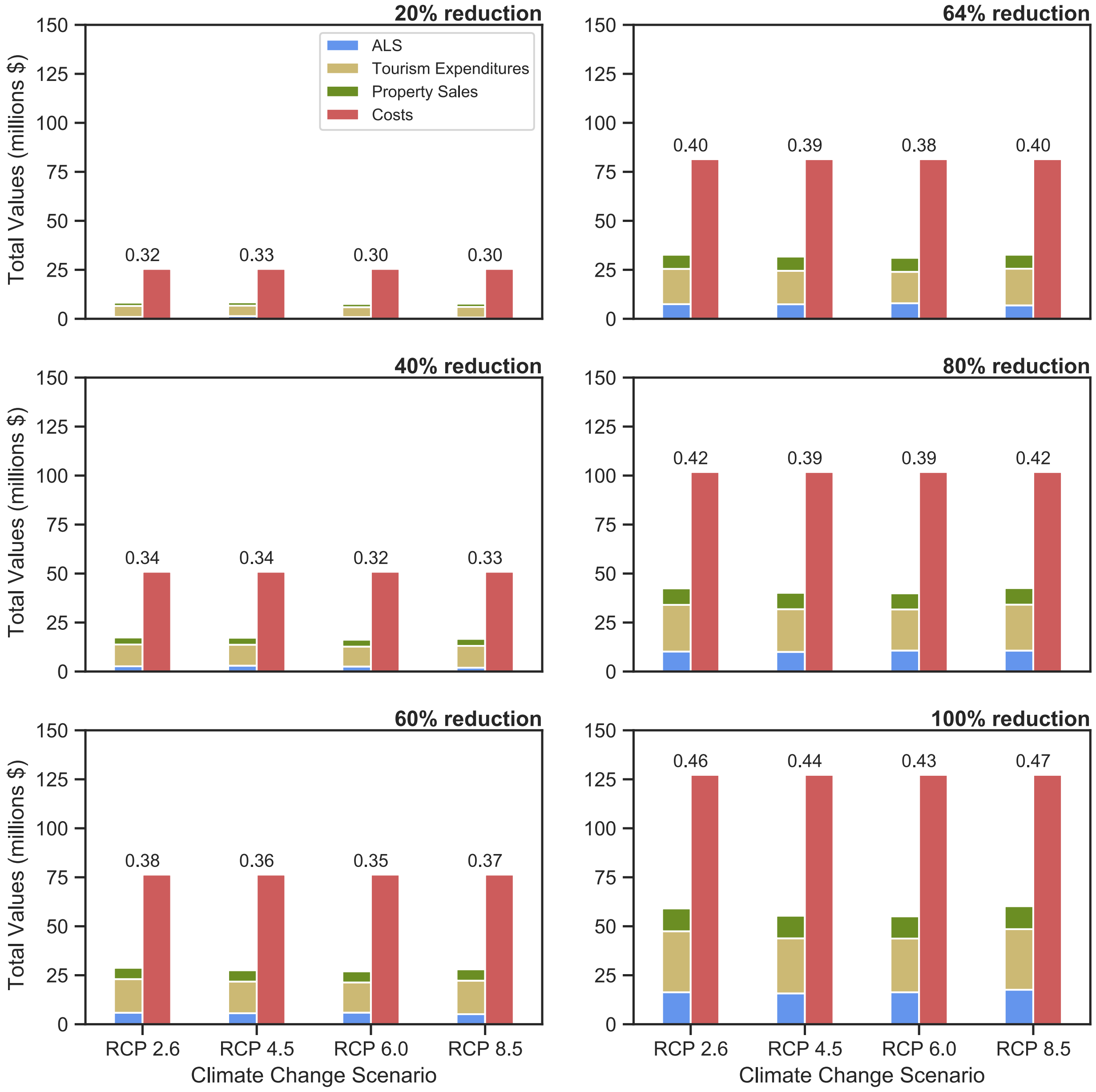


Combined benefits do not exceed costs over 35-yr time horizon

<u>20% Reduction</u>
Average Benefits: $8.0 million
Lower-Bound Costs: $25.5 million
Benefit-Cost Ratio: 0.31

<u>64% Reduction</u>
Average Benefits: $32 million
Lower-Bound Costs: $81.5 million
Benefit-Cost Ratio: 0.39

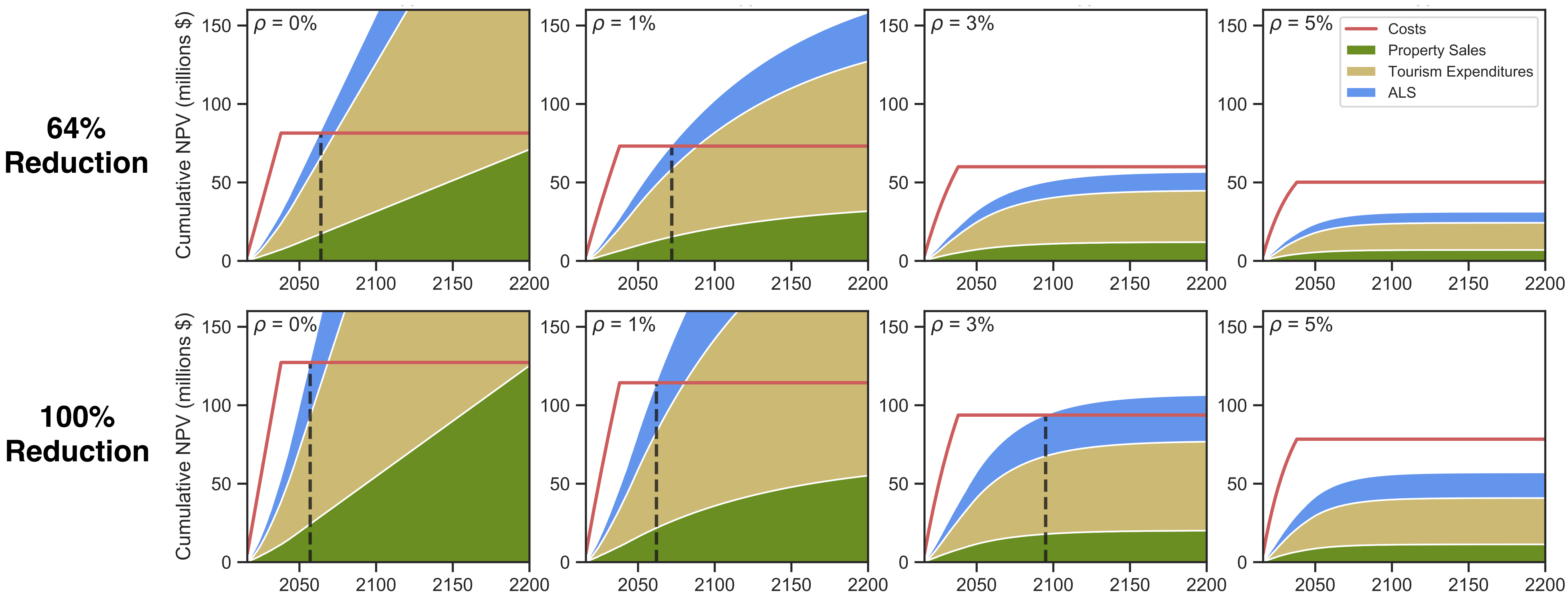
<u>100% Reduction</u>
Average Benefits: $57.4 million
Lower-Bound Costs: $127.3 million
Benefit-Cost Ratio: 0.45



** Discount Rate = 3% **

Sensitivity to time horizon and discount rate

- Benefits may exceed lower-bound costs if…
  - Time horizon extends to 2100, or beyond
  - Applied discount rate is less than or equal to 3%



Limitations and Future Research

<u>Limitations leading to under-estimation of benefit-cost ratios</u>

- Do not account for other benefits associated with improved water quality
  - e.g., recreational fishing, other health impacts, non-use values
- Do not include any stated preference valuation approaches
- Do not account for benefits accrued along Quebec shoreline

<u>Limitations leading to over-estimation of benefit-cost ratios</u>

- Do not account for costs of P reduction incurred by Quebec

<u>Other areas of future research</u>

- IAM modeling beyond 2050
- Modeling and valuation for other areas of Lake Champlain
- Cost effectiveness of interventions to reduce P loading

Final Thoughts

- Advancements in Integrated Assessment Modeling support water quality economics and governance

- Over the 35-year time horizon, the combined benefits do not exceed even the low-bound costs under any scenario
  - Benefit-cost ratios for this time horizon align with those found by Keiser et al. (2019)
  - However, this may change if the time horizon is extended to 2100 or beyond and the applied discount rate is less than 3%

- Uncertainty in water quality valuation & policy implications
  - Cost > Benefits: Investments in water quality are unjustified
  - Benefits > Costs: Underestimation of benefits & the Water Value Paradox (Keeler 2020)

- Distribution of benefits and costs to stakeholder groups

- Potential for Payment for Ecosystem Services program

Thank you

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*** Publication forthcoming in the Journal of Environmental Management ***

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