# EPA SNEP PROJECT

## Integrating Ecosystem Services Functions and Values into Land-Use Decision Making in the Narragansett Bay Watershed

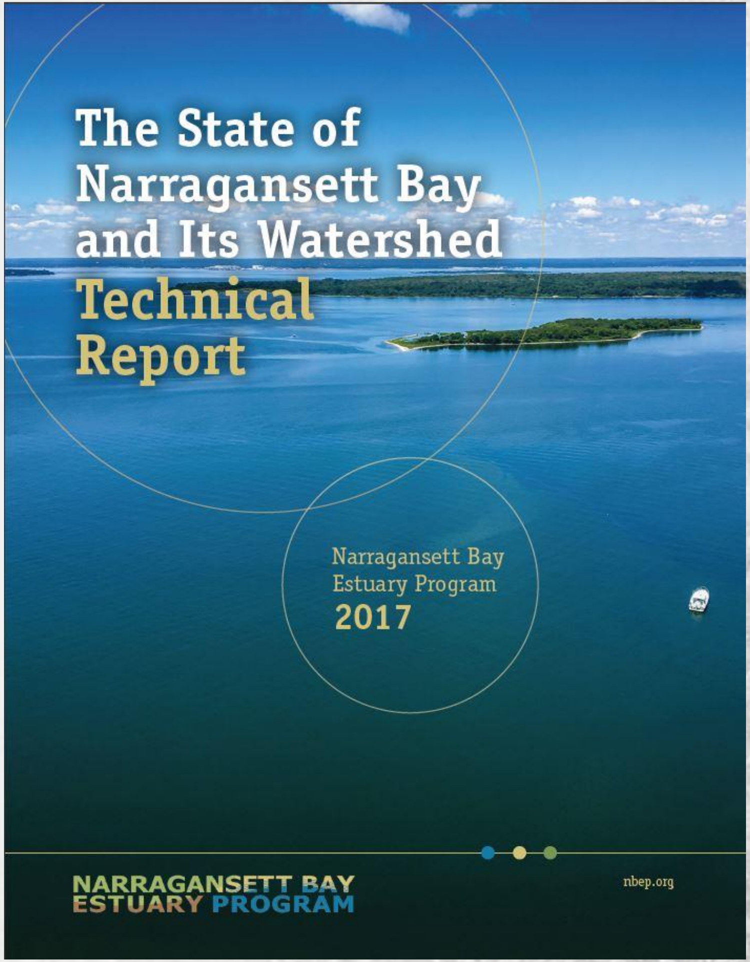
# Recent change in Narragansett Bay watershed

2.2% population increase

Urban land use up 8.5%
Forest land cover down 4%
2011 overall – Forest 39%, Urban 35%, Ag 6%

WWTF upgrades
    Nitrogen load down 55%
    Phosphorous load down 45%

Limited dam removal - at least 353 dams in watershed



# OUTREACH

“**Long and short term benefits** framing is important” *Resilient Taunton Watershed Network* “RI Statewide Planning is looking to get more involved in proposals versus long range planning.” *Rhode Island Statewide Planning*

“How much will **open space/forests contribute** to water quality in the Bay?” *Narragansett Bay Estuary Program*

“Build out analysis should include **environmental regs**, not just zoning” *Rhode Island Rivers Council*

“**Scale** is important to be relevant to decisions. Have a **bi-state picture** (*Sen. Whitehouse*), but also a per-acre view if possible. Municipal scale is also relevant as these are where decisions are often made.” *RISP, RTWN, Blackstone River Data Team*

“There is tremendous value in **stating the obvious**” *Blackstone River Data Team*

“Stormwater investments - what interventions get the most bang for the buck? **Where should we prioritize limited money?** Cost-benefit analysis.” *BDT* “Anything that can **tie to dollars and cents** would be really useful.” *Sen. Whitehouse*

# RESEARCH QUESTIONS

***Narragansett Bay Case Study***

**What was the change (2001 – 2011) in WQ and WTP from changes in land use and point source pollution**? **How has that changed spatially** across the Narragansett Bay watershed and across different water quality contaminants?

Under current conditions, what is the contribution to **changes in WTP from development/conservation** by forested areas? Where are priority areas to preserve/conserve?

**How will WQ and WTP change into the future** using Harvard Forest derived land use scenarios out to 2060?

***Integrated Assessment Modeling for WQ***

**Can we model a broader set of water quality attributes** than typically included in IAMs?

**What are the potential consequences of using a reduced set** of water quality attributes?

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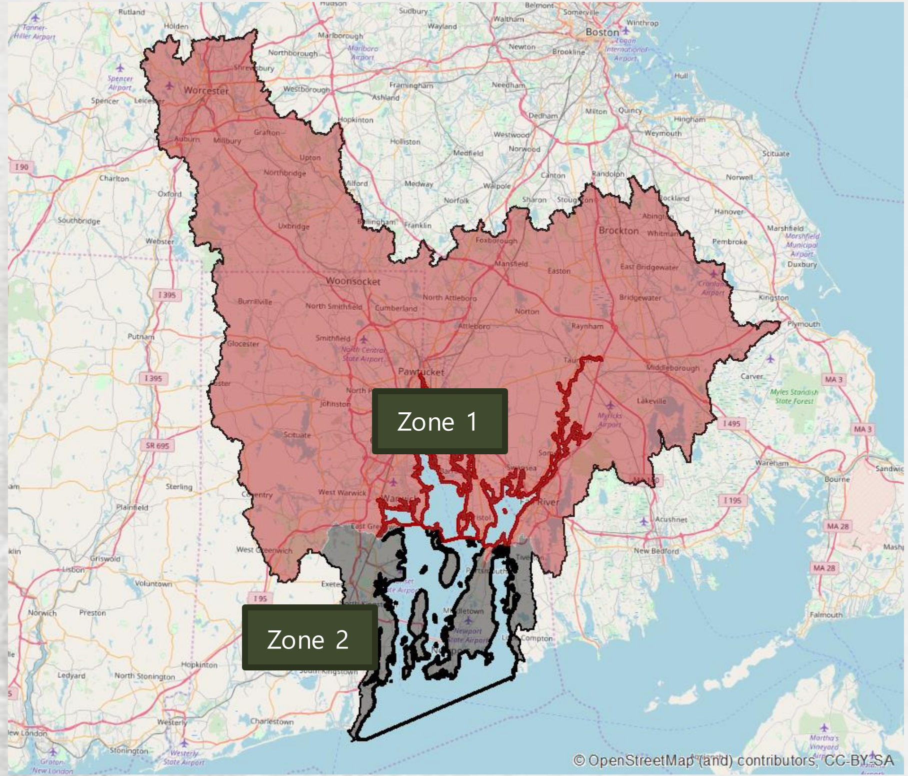
# PROJECT SCOPE



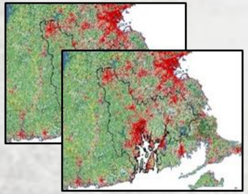

*Characteristics of decision space*

- Focal resource is Narragansett Bay
- Link decisions to benefits via ecosystem/policy change (scenarios)
- Outputs explicitly spatial (watersheds)
- Point v. non-point source contributions
- Output as physical changes or benefit relevant indicators (WTP)
- Bay modeled as two zones with independent watersheds
- Annual average values (WQ/WTP)

# INTEGRATED ASSESSMENT MODEL

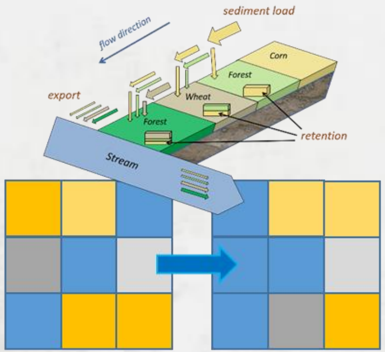
Decision → Ecology → Service → Well-being

Land use change



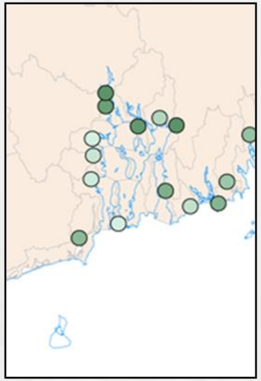
MRLC Consortium NLCD

Retention and export




Hamel et al (2017); Sharp et al. (2017)

Concentration at tributaries



Cortes and Schmidt (2017); Reis (1990)

Water Quality Index

| Pollutant | Units | WQI (0 – 100) |
|---|---|---|
| Dissolved Oxygen | # Mg/L | # |
| Enterococcus | cfu/100mL | # |
| Total Nitrogen | # Mg/L | # |
| Total Phosphorous | # Mg/L | # |
| Total Suspended Solids | # Mg/L | # |
| Chorophyll *a* | # µg/L | # |

Vaughan (1981), Cude (2001), EPA (2009)

Benefit Transfer Function

$$\boldsymbol{WTP_i = f(WQ, GEO, DEM_i, \overline{RES})}$$

*WTP* – Willingness to pay/year (+ change)
*i* - household
*WQ* – water quality index
*GEO* – geospatial env variables
*DEM* – demographic variables
*RES* – research vars (assumed fixed)

Johnston et al. (2005; 2017), EPA (2009)

EPA, 2009; EPA, 2010; Meehan et al., 2013; EPA, 2015; Johnson et al., 2016; Corona et al., 2019

# WATER QUALITY INDEX

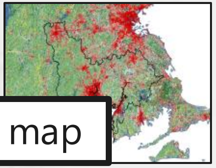
$$WQ = \prod_{i=1}^{6} Q_i^{W_i}; \quad 0 \le WQ \le 100$$

| Pollutant (Qi) | Unit | Weight (Wi) |
|---|---|---|
| **Dissolved Oxygen** | # Mg/L | .26 |
| **Enterococcus** | # Lbs/100mL | .25 |
| **Total Nitrogen** | # Mg/L | .15 |
| **Total Phosphorous** | # Mg/L | .15 |
| **Total Suspended Solids** | # Mg/L | .11 |
| **Chorophyll-a** | # µg/L | .08 |

- Sediment
- Nitrogen
- Phosphorous
- Chlorophyll A
- Dissolved oxygen
- Enterococcus

# INVEST MODELING

## Inputs



NLCD map

Parameter table

DEM

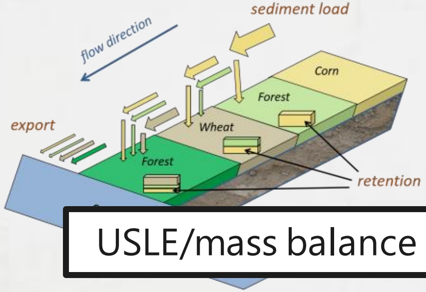
Watersheds

Erodibility

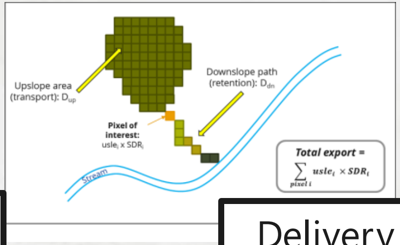
Erosivity/runoff

Calibration

## Model

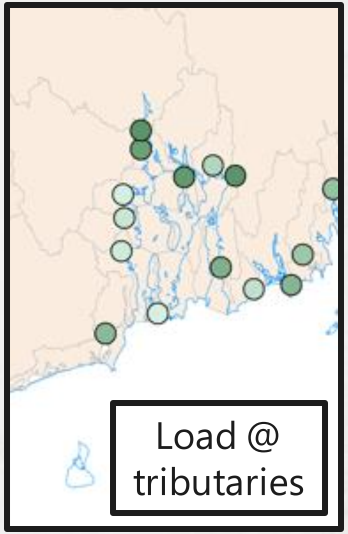



USLE/mass balance




Delivery ratio

## Output

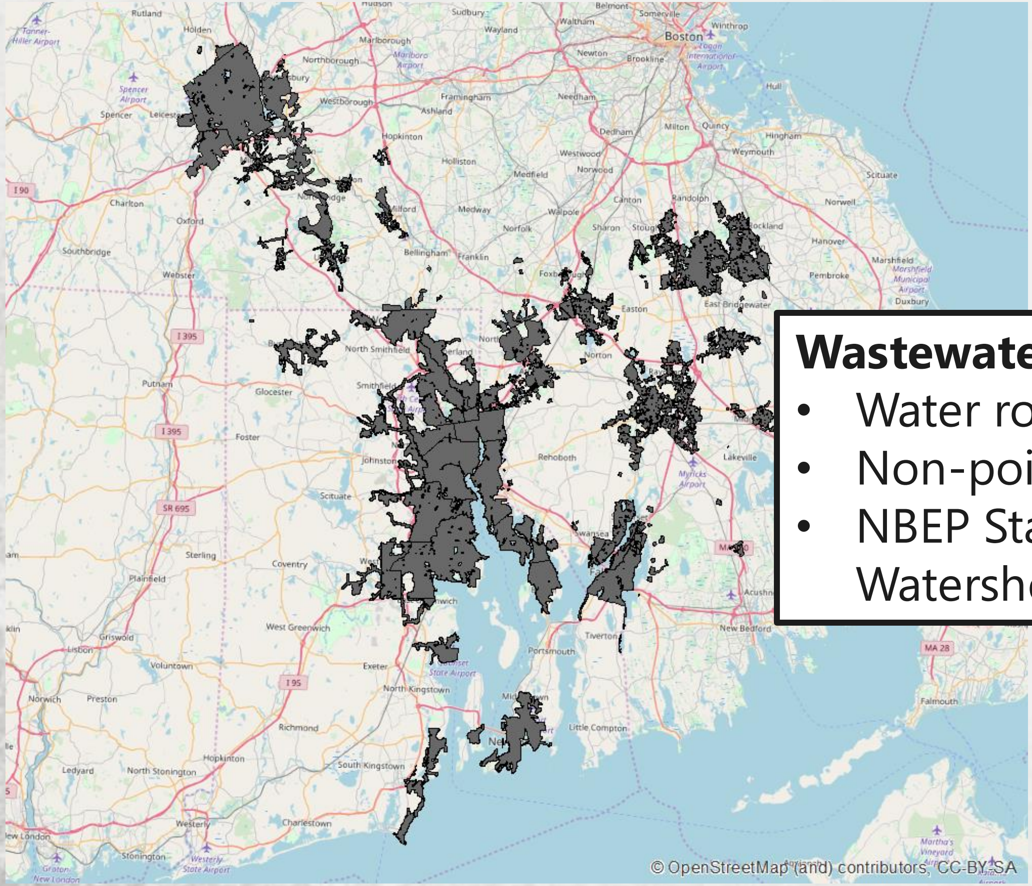


Load @ tributaries

- Sediment
- Nitrogen
- Phosphorous
- Chlorophyll A
- Dissolved oxygen
- Pathogenic bacteria

Sharp et al. (2017), Redhead et al. (2017), Hamel et al. (2015), Terrado et al (2014)

# WASTEWATER TREATMENT

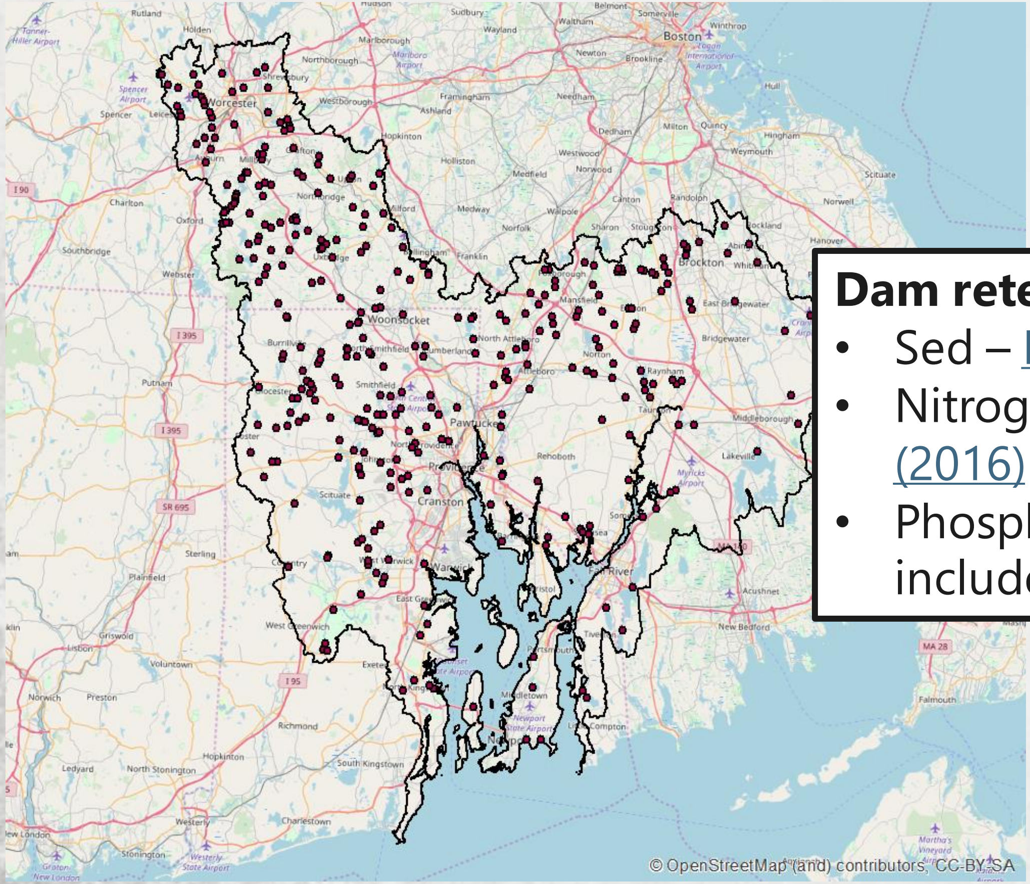



**Wastewater treatment**

- Water routing/retention
- Non-point source analysis
- NBEP State of the Watershed report ([Ch. 7](#))

- Sediment
- Nitrogen
- Phosphorous
- Chlorophyll A
- Dissolved oxygen
- Pathogenic bacteria

# DAMS

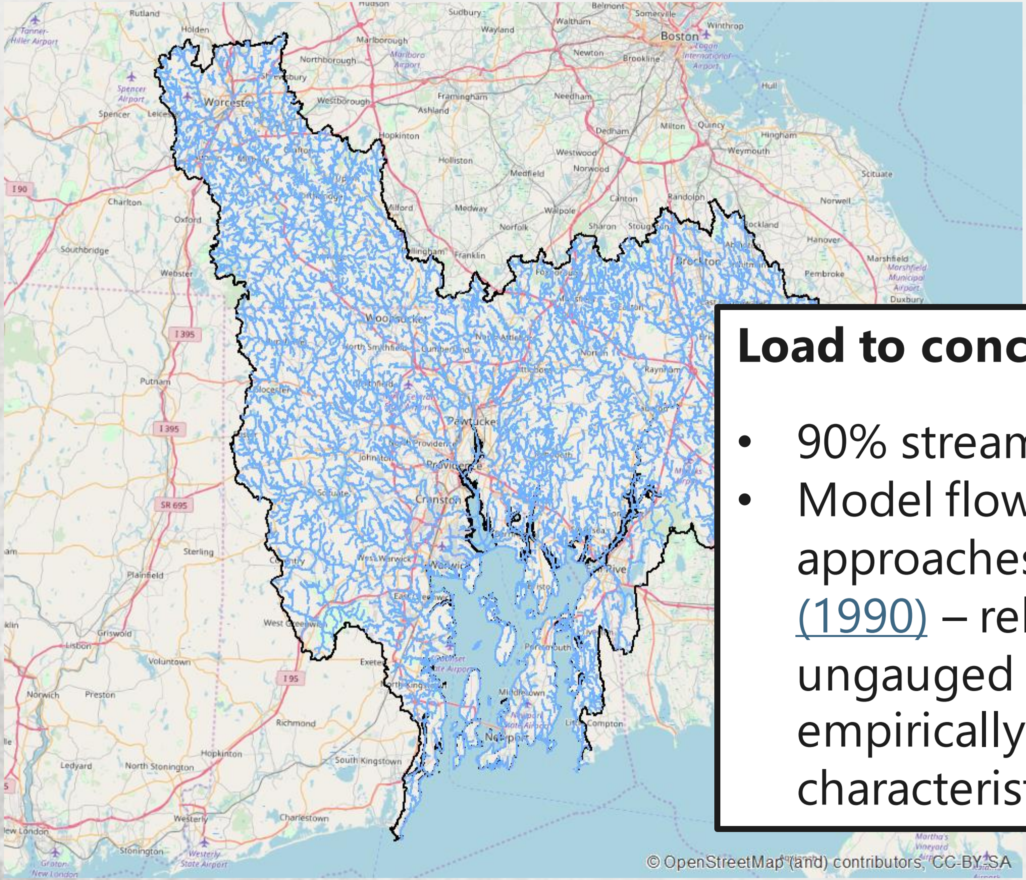



**Dam retention**

- Sed – Brune fn (1953)
- Nitrogen – Gold et al. (2016)
- Phosphorus – Not included

- Sediment
- Nitrogen
- Phosphorous
- Chlorophyll A
- Dissolved oxygen
- Pathogenic bacteria

# ANNUAL FLOW

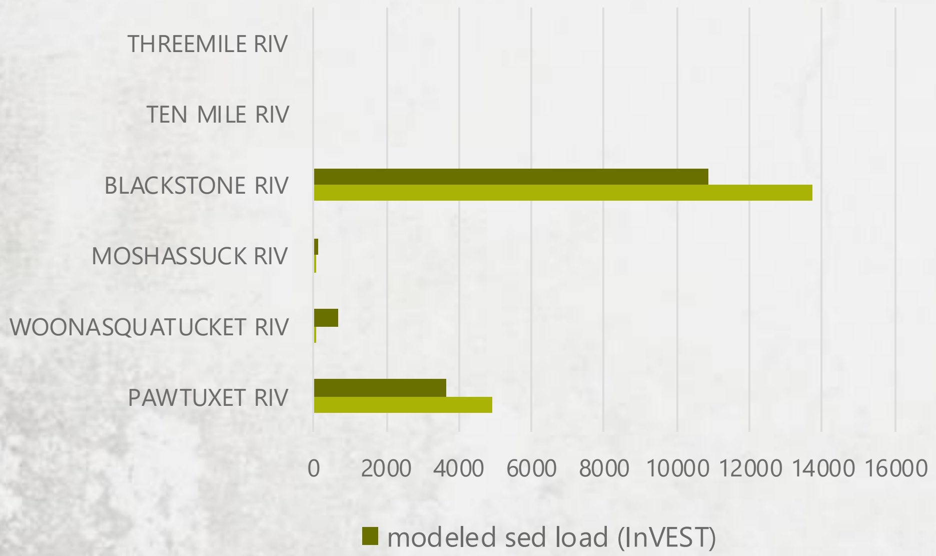



**Load to concentration**

- 90% streams ungauged
- Model flow based on approaches from [Reis (1990)] – relate flow at ungauged streams empirically to watershed characteristics

- Sediment
- Nitrogen
- Phosphorous
- Chlorophyll A
- Dissolved oxygen
- Pathogenic bacteria

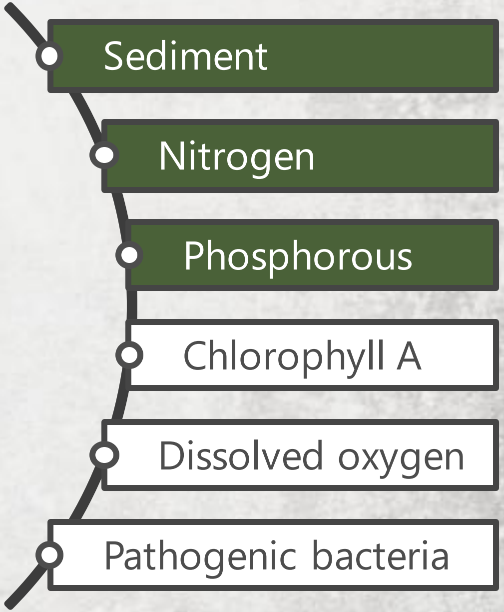
# MODEL CALIBRATION




Point/non-point

Sediment – USGS

Nutrients - NBEP



# EMPIRICAL MODELS

**Concentration related to environmental variables**

- Prediction vs correlation/causality
- Links to N and P estimates
- No need for calibration, streamflow
- Data from Narr Bay (USGS, Narragansett Bay Commission, RI DOH)

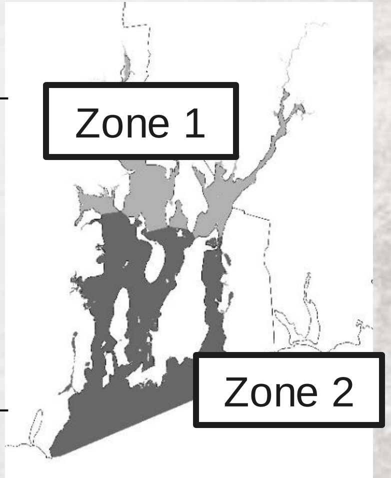
$$WQ^{C} \approx f(X, \beta)$$

$$X = \{N, P, NP, Z\}$$

- Sediment
- Nitrogen
- Phosphorous
- Chlorophyll A
- Dissolved oxygen
- Pathogenic bacteria

# RESULTS
## RETROSPECTIVE WATER QUALITY

| | 2001 | | 2011 | |
|---|---|---|---|---|
| | **Zone 1** | **Zone 2** | **Zone 1** | **Zone 2** |
| Total Nitrogen (mg/l) | 28 (2.8) | 47 (1.6) | 48 (1.6) | 58 (1.2) |
| Total Phosphorus (mg/l) | 38 (0.21) | 40 (0.20) | 58 (0.14) | 39 (0.20) |
| Sediment (mg/l) | 100 (17.5) | 67 (52.6) | 100 (19.5) | 65 (54.2) |
| Dissolved Oxygen (mg/l) | 84 (7.9) | 97 (9.7) | 99 (10.2) | 100 (10.4) |
| Chlorophyll-A (ug/l) | 10 (60.9) | 19 (16.2) | 31 (21.0) | 36 (18.5) |
| Enterococcus (cfu/100ml) | 98 (37.8) | 98 (19.8) | 97 (56.3) | 98 (24.4) |
| Overall | **57** | **64** | **75** | **70** |



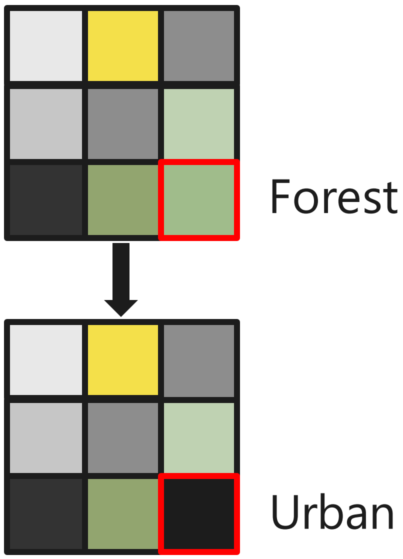
# RESULTS
## WILLINGNESS TO PAY

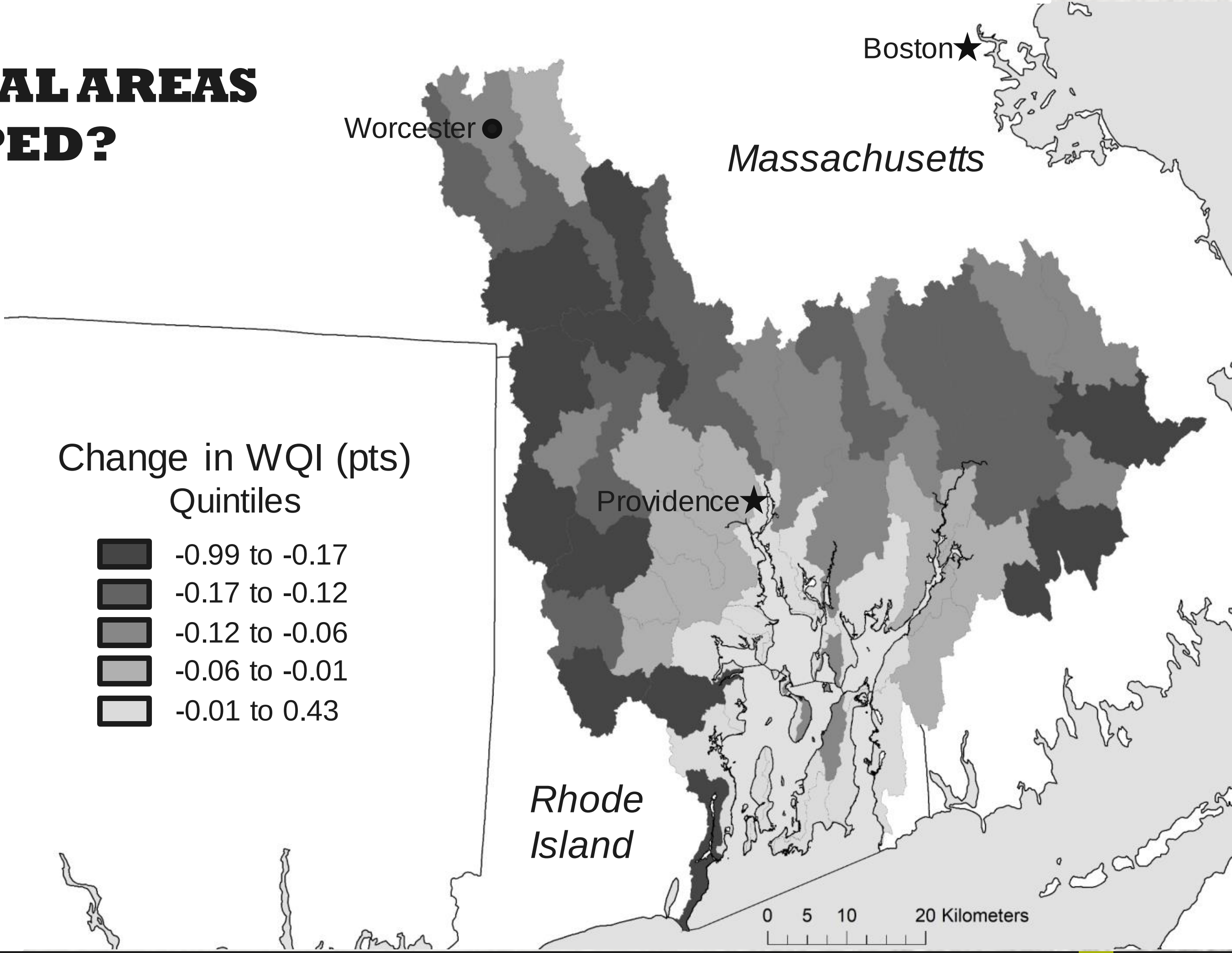
| Scenario | Zone | Baseline WQ (100 pt scale) | Water Quality Change (pt) | Annual WTP per Household ($) | Total WTP ($Mil/yr) |
|---|---|---|---|---|---|
| 2001 – 2011 | 1 | 56.5 | 18.1 | 59.6 | 50.6 |
| | 2 | 64.4 | 5.4 | 44.8 | 38.0 |
| Remove all dams 2011 | 1 | 74.6 | -6.3 | -45.7 | -38.8 |
| | 2 | 69.8 | -2.5 | -36.3 | -30.8 |

848,735 households; 2016 USD

# WHAT IF NATURAL AREAS WERE DEVELOPED?

**Marginal values map**
Ricketts and Lonsdorf (2013)



# CAVEATS

- Large integrated models
- Conducted calibration, some sensitivity analysis, model selection – still significant uncertainty, not easily quantified
- Subsurface leaching effect not well understood
- Oceanographic mixing through the bay, overestimation
- Benefit transfer function and small changes in WQI
- Matching demand and supply spatially
- Did not account for effect on lakes/ponds
- Only one of many services provided by ecosystems

# TAKEAWAYS

- Minor effects from modeled non-point source pollution from retrospective and future land use patterns
  - High existing water quality, cumulative dam retention, WWTF retention adjacent to bay, land use mix
- WWTF upgrades major change in WQ and well-being via WTP
- Dams provide some protection over Narragansett Bay water quality
- Challenges/opportunities in NB
  - Monitoring needed, sediment in particular
  - EPA creating an open source tool to automate BT effort
  - Pathogenic bacteria modeling – reasonably good data, could build on several efforts to advance science and prediction