Use of Output from the New England SPARROW Model to Estimate Concentrations of Total Nitrogen in Estuaries

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Purpose of This Work

- Link USEPA Estuary Nitrogen Model (ENM) to SPARROW Model for Application to:
  - National Coastal Assessment
  - Development of TMDLs for Estuaries
  - Development of Nutrient Criteria for Estuaries

Presentation Outline

Background

Description of Estuary Nitrogen Model (ENM)

Discuss Compatibility of SPARROW Model & ENM

Application of SPARROW & ENM to:

- Narragansett Bay
- Boston Harbor
- Great Bay Estuary

Summary

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The Estuary Nitrogen Model.

Dettmann (2001)

$$\frac{dN}{dt} = L_{land} + L_{sea} - E - \alpha N$$

N Loading (L_{land}, L_{sea})

Export (E)

Internal Losses (αN)

Assumptions:

Model deals with long-term (e.g. annual or multi-year averages.

Approximate steady state at scale of yearly cycle, i.e.

$$\frac{dN}{dt} = 0$$

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The Estuary Nitrogen Model.

Dettmann (2001)

Final Equations:

$$F_{ex} = \frac{1}{1 + \alpha\tau}$$

$$[N] = \left(\frac{L_{land}\tau}{V} + [N_{sea}]\right)\frac{1}{1+\alpha\tau}$$

τ = freshwater residence time

$\alpha \simeq 0.3\ \text{mo}^{-1}$ *(nonlinear least squares estimate for 11 estuaries)*

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Nitrogen Budgets for 11 Estuaries. Internal N Losses are Function of Residence Time

Export

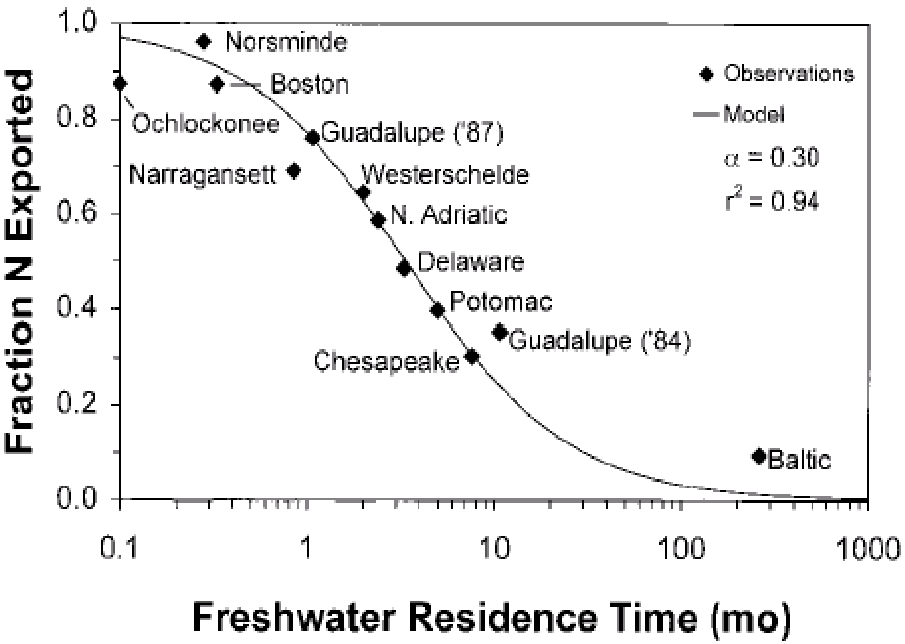

Fig. 2. The fraction of upland nitrogen input that is exported from 11 estuaries versus freshwater residence time (logarithmic time scale).

Denitrification

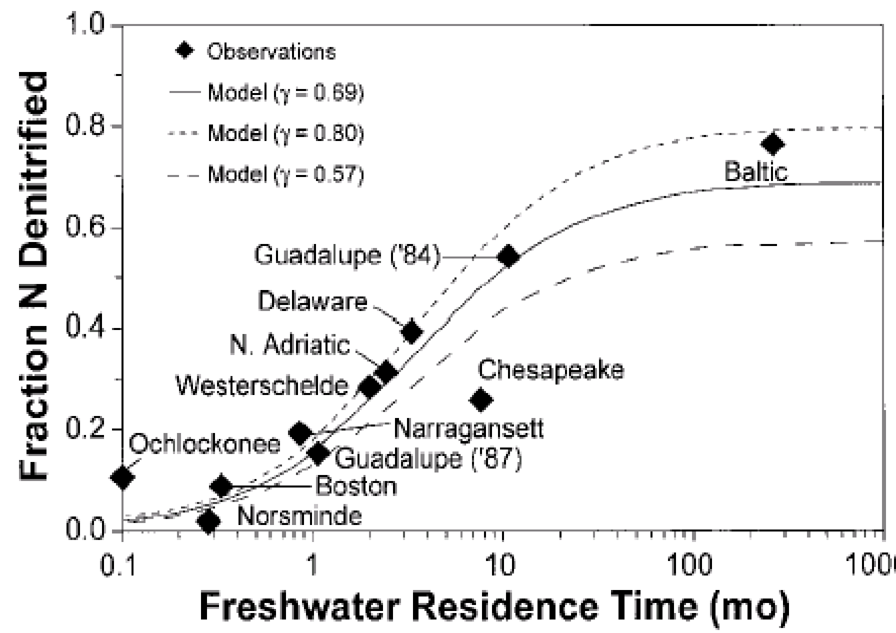

Fig. 3. The fraction of upland nitrogen input that is denitrified versus freshwater residence time. The solid model line ($\gamma = 0.69$, $r^2 = 0.85$) is the fit to all the data. The dashed model lines correspond to the 95% confidence limits for γ (0.57 and 0.80). If Chesapeake Bay is excluded from the fit (see text), the model line ($\gamma = 0.76$, $r^2 = 0.97$) lies between those for $\gamma = 0.69$ and $\gamma = 0.80$.

Dettmann (2001)

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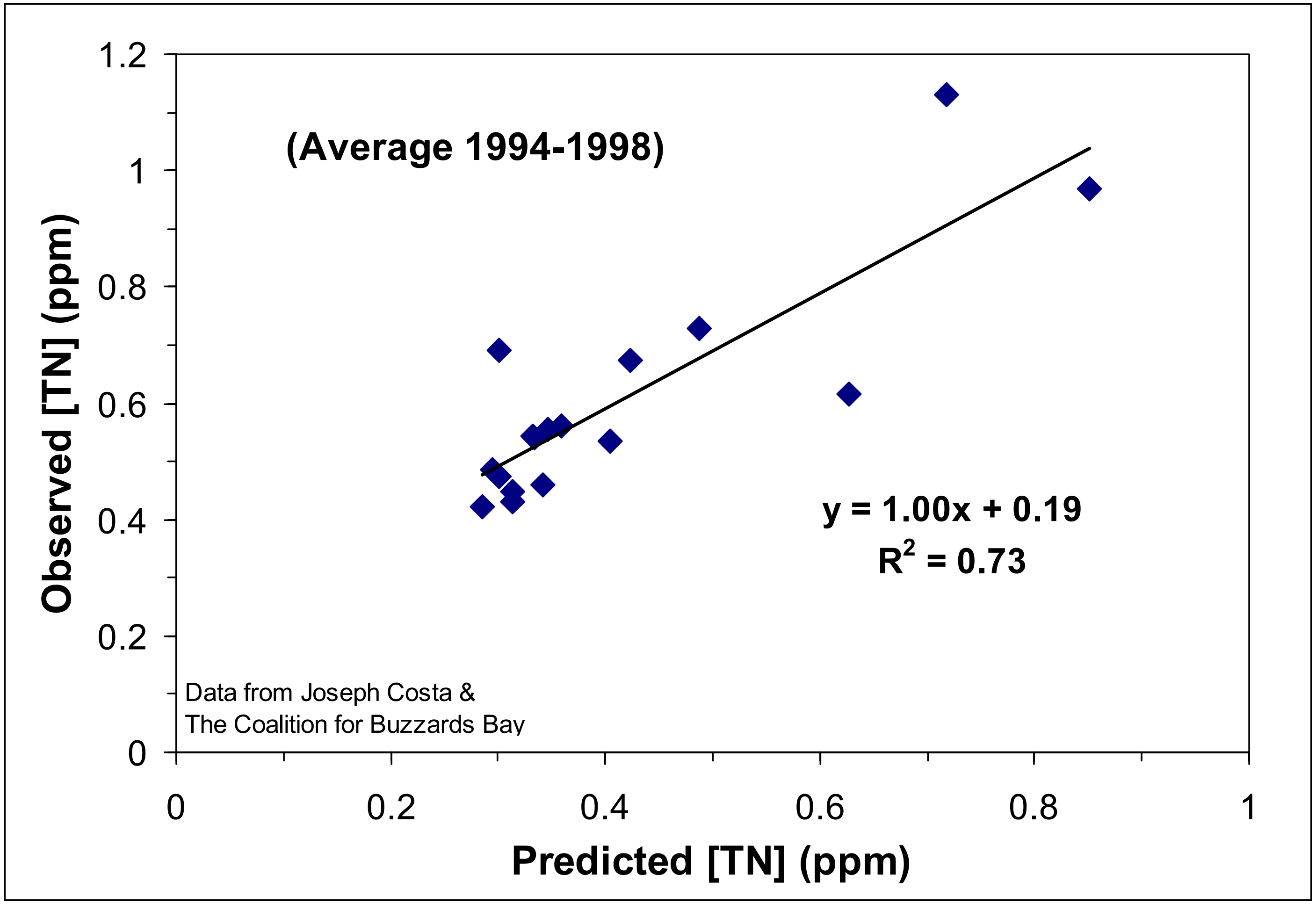
Predicted vs. Observed [TN] for 17 Side-Embayments of Buzzards Bay



Characteristics of Nitrogen Output from Sparrow Model

Annual Loads Only

TN Only (No Components)

Loads Only to Nontidal Streams

Loads Can Be Partitioned by Source Category

Sources of Riverine TN Loading

$\simeq$ 68% of loading to Narragansett Bay

	% TN / yr
• Atmospheric:	17.4%
• Urban:	18.4%
• Agriculture:	2.6%
• Point Sources:	61.2%

(point sources discharging directly into estuary not included)

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Summary of Data Requirements of the Estuary Nitrogen Model

Annual Loads of Total Nitrogen to Estuary from:

- Watershed
- Atmosphere
- Point sources

Average Annual Freshwater Residence Time (τ)

Estuary Volume

Background Nitrogen Concentration from Transport Across Seaward Boundary ($[N_{sea}]$)

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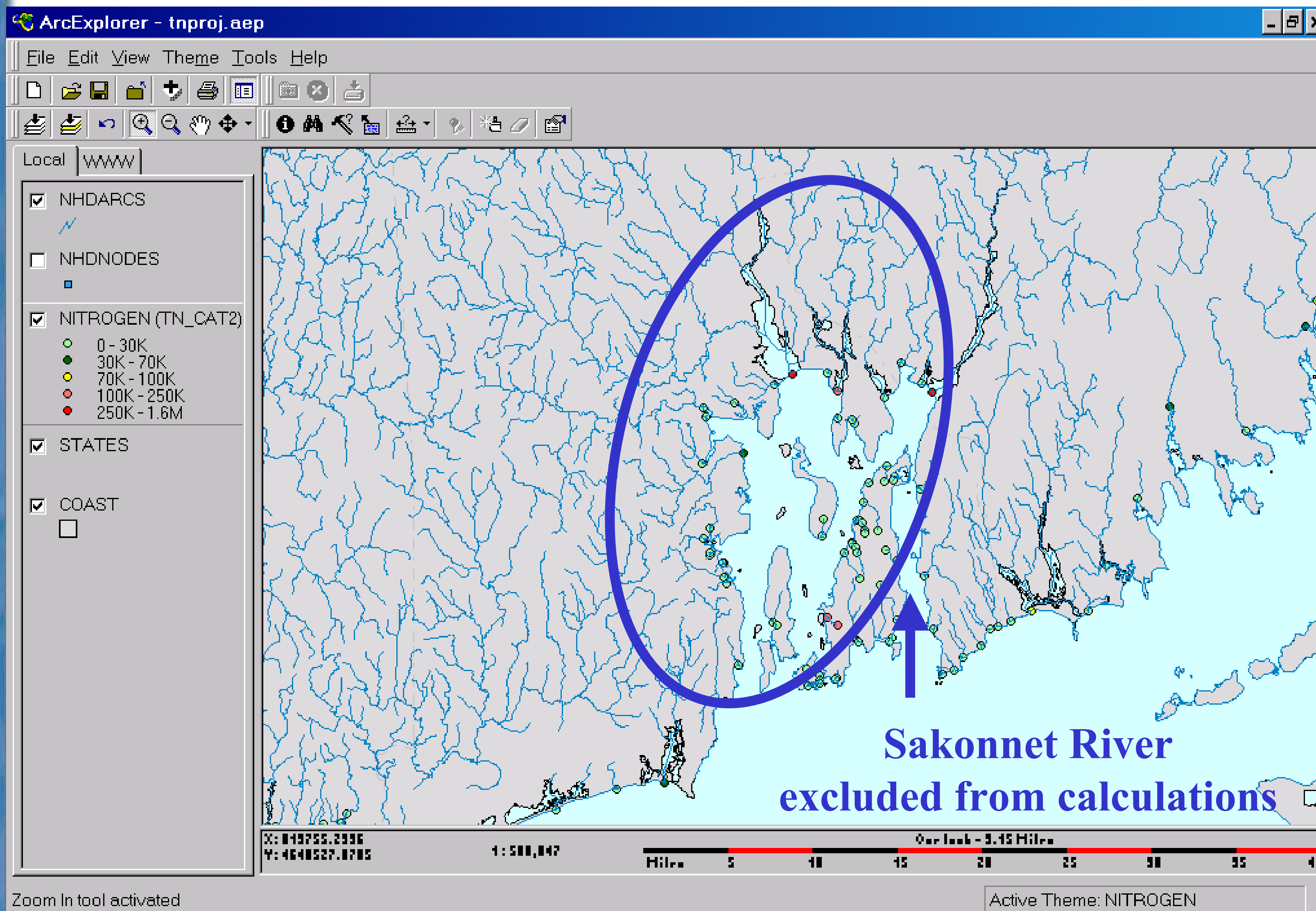
Estimated TN Input to Narragansett Bay from Rivers & Streams

(NE SPARROW Model)



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TN Loading to Narragansett Bay

	kg N y^{-1}
Sparrow (30 tributaries)	6,227,261
Nixon et al. (1995)	6,120,928

TN loading from SPARROW	6,227,261
Direct Atmospheric Deposition*	420,201
Sewage Treatment Plants*	2,563,226
Total TN Loading	9,210,688

*(Nixon et al., 1995)

Riverine TN loading to Narragansett Bay from New England SPARROW Model is 68% of total.

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Measured [TN] (1985—1986 SINBADD Cruises)

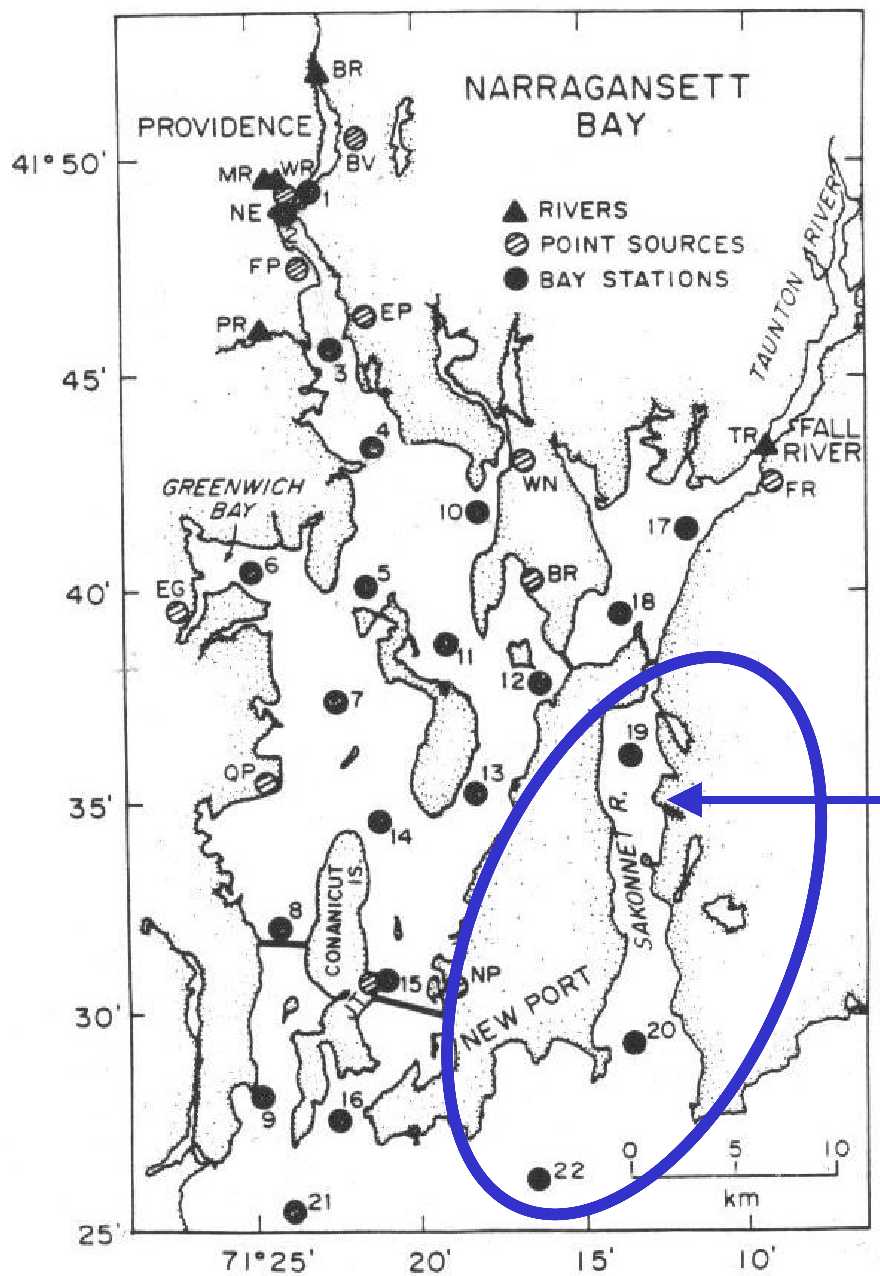

Figure adapted from Hunt et al. (1987a)

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Average TN Concentration in Narragansett Bay

L_{land} = 766,766 kg N mo^{-1}

τ = 26 d = 0.855 mo

V = 2.821 x 10^{9} m^{3}

V_{sw} = 2.584 x 10^{9} m^{3}

$[N_b]$ = 0.201 mg L^{-1}

$[N_{sea}]$ = 0.184 mg L^{-1}

$\alpha = 0.3$ mo^{-1} *(permanent loss to denitrification & burial)*

$$[N] = \left(\frac{L_{land}\,\tau}{V} + [N_{sea}] \right) \frac{1}{1 + \alpha\tau}$$

Model-Calculated [TN] = (0.232 + 0.185)/1.2565 = 0.332 mg L^{-1}

Measured [TN] (1985—1986 SINBADD Cruises)* = 0.358 mg L^{-1}

*(estimate, based on weighted average of TN, (Hunt et al., 1987)

Calculated [TN] is within 7.3% of measured concentration.

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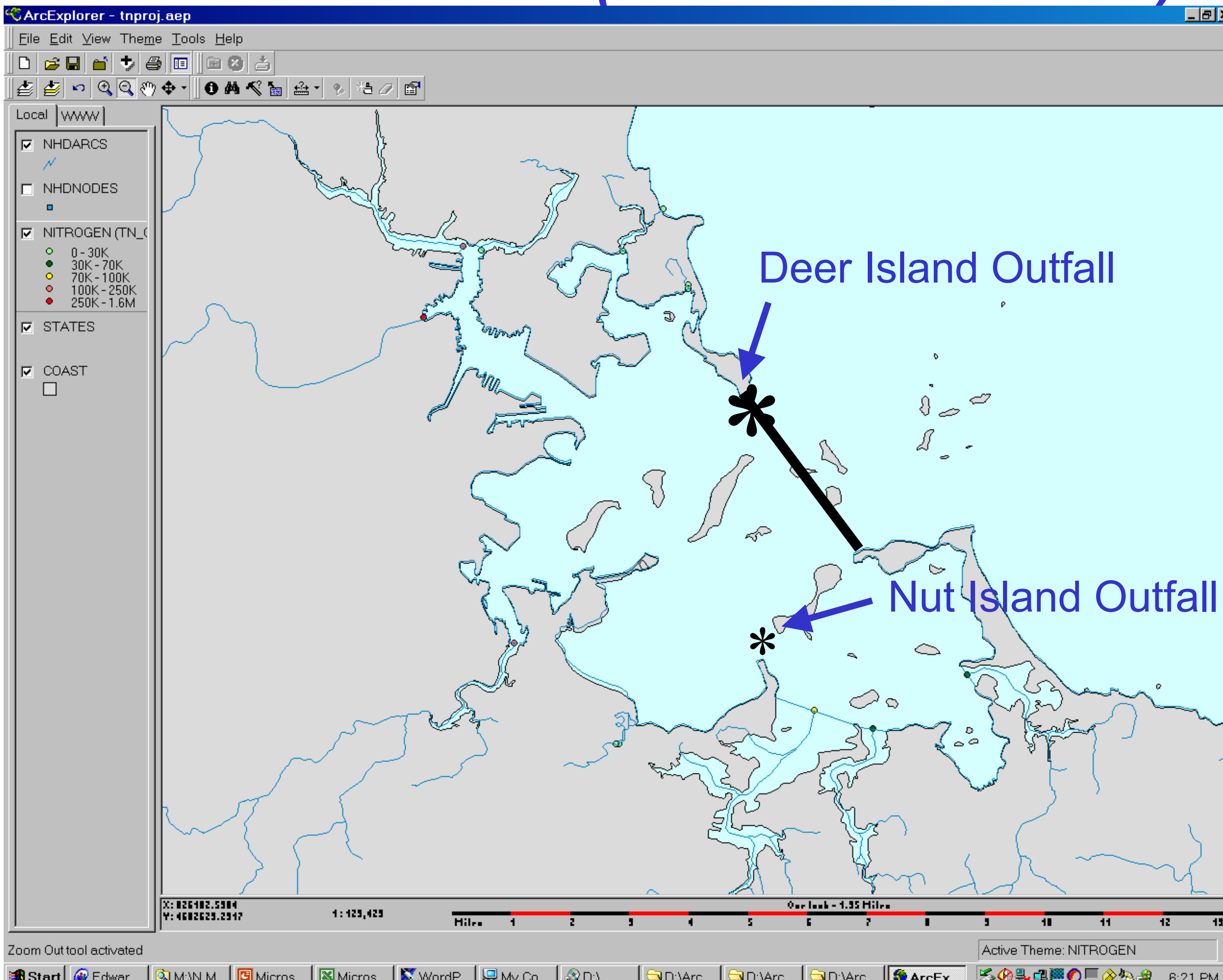
Estimated TN Input to Boston Harbor from Rivers & Streams (NE SPARROW Model)



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TN Loading to Boston Harbor Early 1990s (prediversion)

	$kg\ N\ y^{-1}$
Sparrow (all tributaries)	1,305,245
All rivers and urban runoff *	893,000
TN loading from SPARROW	1,305,245
Direct Atmospheric Deposition*	307,000
Sewage Treatment Plants*	11,350,000
Groundwater*	93,000
Total TN Loading	13,055,345

*Alber and Chan (1994)

Riverine TN loading to Boston Harbor from New England SPARROW Model is 10% of total.

Complicating Factors

Largest source of TN is on the seaward boundary.

Residence time for TN discharged by Deer Island WWTF is smaller than that of Boston Harbor as a whole.

Average TN Concentration in Boston Harbor (prediversion)

L_{land} = 108,770 kg N mo^{-1}
V = 612.5 x 10^6 m^3
V_{sw} = 603.9 x 10^6 m^3

$[N_b]$ = 0.233 mg L^{-1}
$[N_{sea}]$ = 0.230 mg L^{-1}
τ = 10 d = 0.33 mo
α = 0.3 mo^{-1}

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Calculated [TN] (model with full loading and τ = 10 d for Deer I. effluent) = 0.745 mg L^{-1}

Calculated [TN] (model with reduced loading and τ = 5 d for Deer I. effluent) = 0.481 mg L^{-1}

Measured [TN] (mean of MWRA data) = 0.475 mg L^{-1}

Calculated [TN] is within 1.3% of measured concentration.

Average TN Concentration in Boston Harbor (postdiversion)

L_{land} = 142,104 kg N mo^{-1}
V = 612.5 x 10^6 m^3
V_{sw} = 603.9 x 10^6 m^3

$[N_b]$ = 0.233 mg L^{-1}
$[N_{sea}]$ = 0.230 mg L^{-1}
τ = 10 d = 0.33 mo
α = 0.3 mo^{-1}

- -

Calculated [TN] (model with no loading from WWTFs) = 0.295 mg L^{-1}

Measured [TN] (rough estimate of mean of MWRA data) = 0.280 mg L^{-1}

This is within 5.4% of measured concentration.

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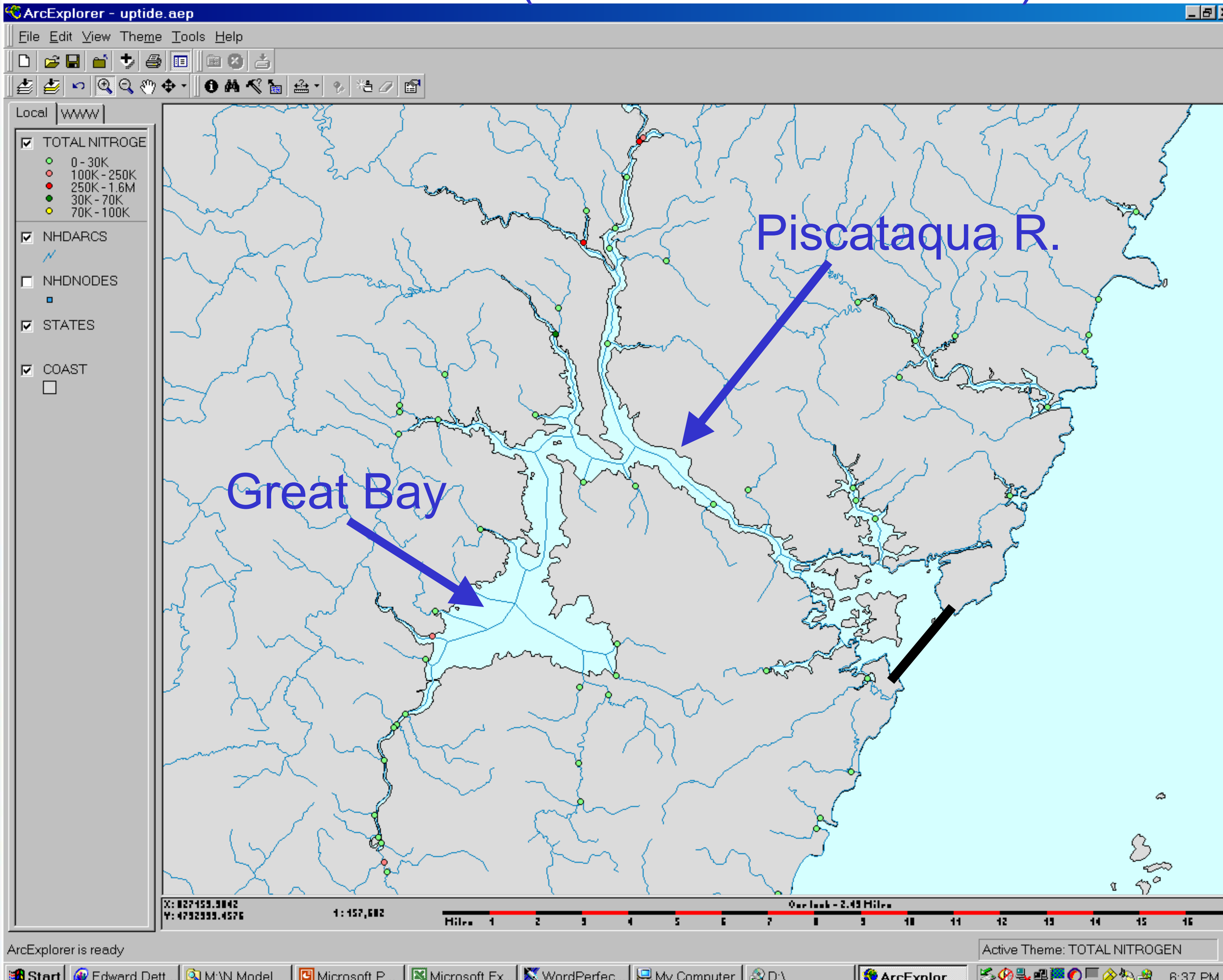
Estimated TN Input to Great Bay Estuary from Rivers & Streams (NE SPARROW Model)



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TN Loading to Great Bay Piscataqua Estuary

	kg N y^{-1}
Sparrow (all tributaries)	1,268,612

TN loading from SPARROW	1,268,612
Direct Atmospheric Deposition*	69,853
Sewage Treatment Plants into Estuary*	172,982
Total TN Loading	1,511,447

*Jones (2000)

Riverine TN loading to Great Bay/Piscataqua Estuary from New England SPARROW Model is 84% of total.

Average Calculated [TN] in Great Bay/Piscataqua Estuary

L_{land} = 125,954 kg N mo^{-1}
V = 198 x 10^6 m^3 *
V_{sw} = x 10^6 m^3 *
α= 0.3 mo^{-1}

$[N_b]$ = 0.19 mg L^{-1}
$[N_{sea}]$ = 0.16 mg L^{-1}
τ = 22 d = 0.72 mo *
For lower estuary,
τ = 1 d = 0.033 mo *

* Brown & Arellano (1980)

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Calculated [TN] = (0.001 + 0.354 + 0.133) mg L^{-1} = 0.488 mg L^{-1}

Portsmouth & Kittery (0.001) | All Other Loads (0.354) | Background (0.133)

Summary & Conclusions

- SPARROW Model TN loads are directly useable by the Estuary Nitrogen Model
- SPARROW loads must be supplemented with other loads to the estuary (e.g. point sources, atmospheric deposition, etc.)
- Three tests of this approach calculated TN concentrations that agree to within a few percent with measured values

Summary & Conclusions (cont.)

- This approach calculates annual average nitrogen concentrations, although it may be possible to infer seasonal values

- This approach readily permits analysis of the relative magnitudes of nitrogen loading from individual source classes

Acknowledgment

- Wendy Leo - MWRA

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Backup Slides

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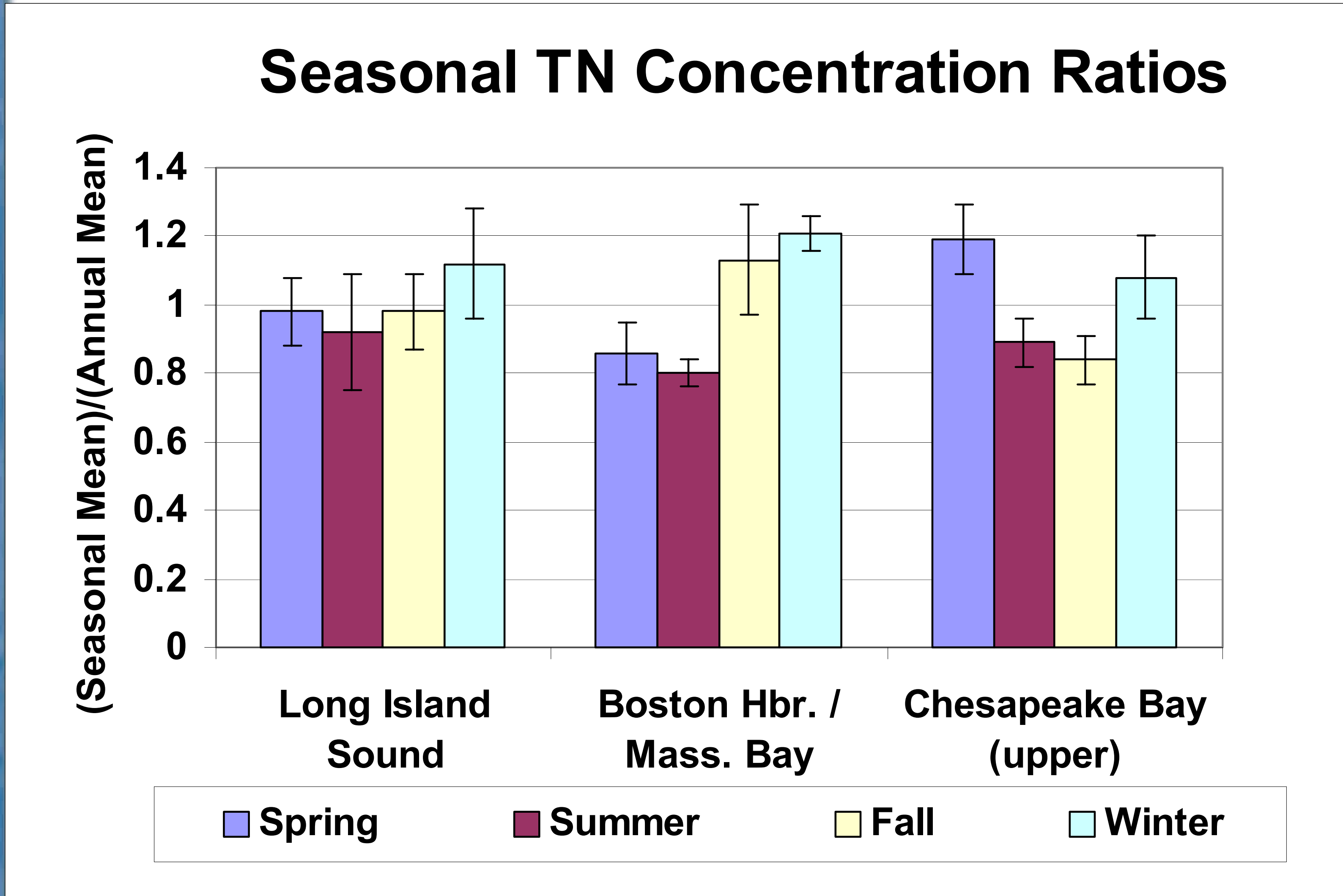

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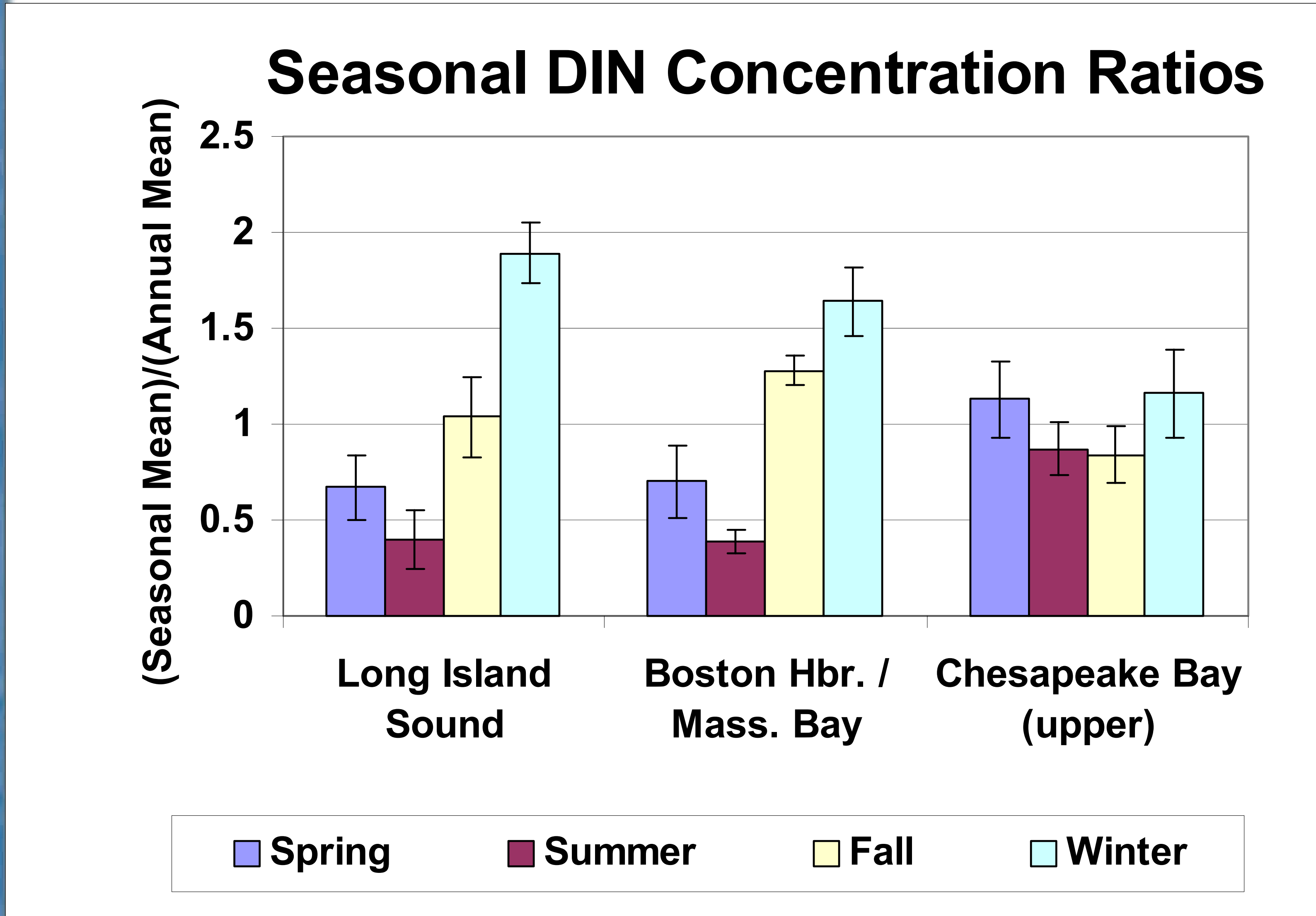

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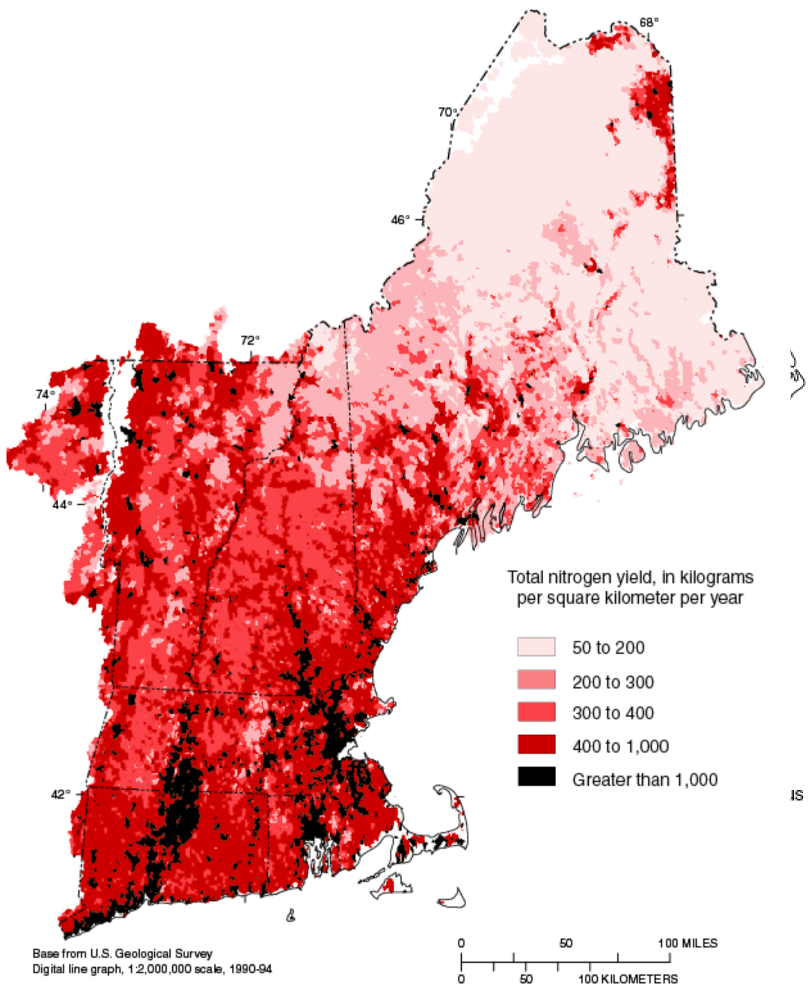
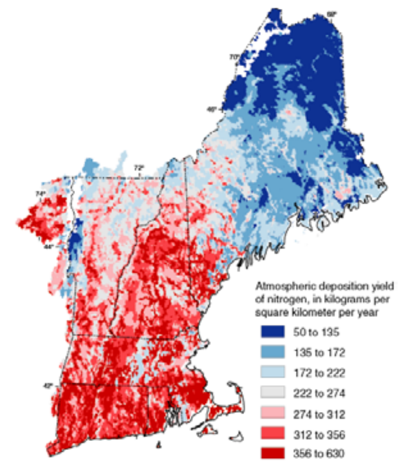
Predicted Nitrogen Yield

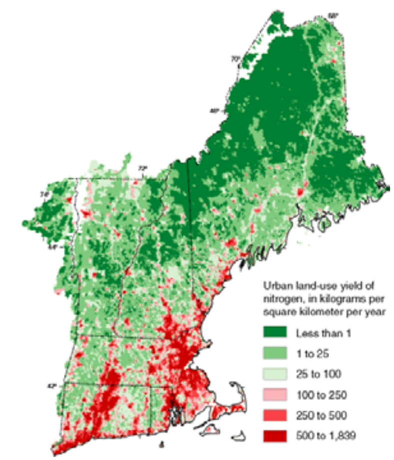
New England SPARROW Model



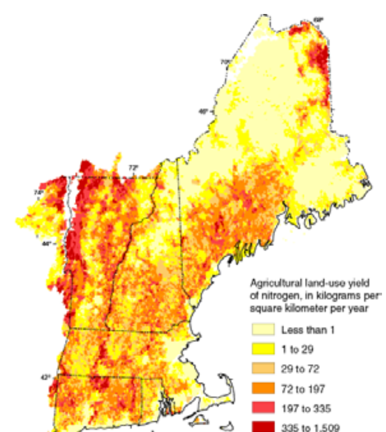
Sources of Nitrogen



Atmospheric



Urban



Agriculture

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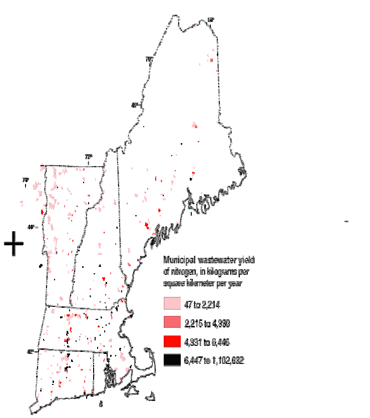

Point Source