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

Edward H. Dettmann¹, Richard B. Moore², Keith W. Robinson², Henry A. Walker¹, and Jaime B. Palter³

¹U.S. Environmental Protection Agency (USEPA), ORD, National Health and Environmental Effects Research Laboratory, Atlantic Ecology Division, Narragansett, Rhode Island

²U.S. Geological Survey (USGS), New Hampshire/Vermont District, Pembroke, New Hampshire

³Duke University, Department of Environment and Earth Sciences, Division of Earth and Ocean Sciences, Durham, North Carolina

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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:
  o Narragansett Bay
  o Boston Harbor
  o Great Bay Estuary

Summary
The Estuary Nitrogen Model.

\[
\frac{dN}{dt} = L_{\text{land}} + L_{\text{sea}} - E - \alpha N
\]

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

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

\[
\frac{dN}{dt} = 0
\]
The Estuary Nitrogen Model.  

Dettmann (2001)

Final Equations:

\[ F_{ex} = \frac{1}{1 + \alpha \tau} \]

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

\( \tau = \text{freshwater residence time} \)

\( \alpha \approx 0.3 \text{ mo}^{-1} \) (nonlinear least squares estimate for 11 estuaries)
Nitrogen Budgets for 11 Estuaries. Internal N Losses are Function of Residence Time

Denitrification

Export

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

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 $\gamma$ (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)
Predicted vs. Observed [TN] for 17 Side-Embayments of Buzzards Bay

(Average 1994-1998)

\[ y = 1.00x + 0.19 \]

\[ R^2 = 0.73 \]

Data from Joseph Costa & The Coalition for 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

~, 68% of loading to Narragansett Bay

\[\% \text{ TN / yr}\]

- Atmospheric: 17.4%
- Urban: 18.4%
- Agriculture: 2.6%
- Point Sources: 61.2%

(point sources discharging directly into estuary not included)
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 ($\tau$)

Estuary Volume

Background Nitrogen Concentration from Transport Across Seaward Boundary ($[N_{\text{sea}}]$)
Estimated TN Input to Narragansett Bay from Rivers & Streams (NE SPARROW Model)

Sakonnet River excluded from calculations
### TN Loading to Narragansett Bay

<table>
<thead>
<tr>
<th>Source</th>
<th>TN Loading (kg N y⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sparrow (30 tributaries)</td>
<td>6,227,261</td>
</tr>
<tr>
<td>Nixon et al. (1995)</td>
<td>6,120,928</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>TN loading from SPARROW</td>
<td>6,227,261</td>
</tr>
<tr>
<td>Direct Atmospheric Deposition*</td>
<td>420,201</td>
</tr>
<tr>
<td>Sewage Treatment Plants*</td>
<td>2,563,226</td>
</tr>
<tr>
<td><strong>Total TN Loading</strong></td>
<td><strong>9,210,688</strong></td>
</tr>
</tbody>
</table>

*(Nixon et al., 1995)*

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

Figure adapted from Hunt et al. (1987a)

Average TN Concentration in Narragansett Bay

$L_{\text{land}} = 766,766 \text{ kg N mo}^{-1}$
$\tau = 26 \text{ d} = 0.855 \text{ mo}$
$V = 2.821 \times 10^9 \text{ m}^3$

$V_{\text{sw}} = 2.584 \times 10^9 \text{ m}^3$

$[N_b] = 0.201 \text{ mg L}^{-1}$
$[N_{\text{sea}}] = 0.184 \text{ mg L}^{-1}$

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

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

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

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

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

Calculated $[TN]$ is within 7.3% of measured concentration.
Estimated TN Input to Boston Harbor from Rivers & Streams (NE SPARROW Model)

- Deer Island Outfall
- Nut Island Outfall
TN Loading to Boston Harbor
Early 1990s (prediversion)

<table>
<thead>
<tr>
<th>Source</th>
<th>kg N y⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sparrow (all tributaries)</td>
<td>1,305,245</td>
</tr>
<tr>
<td>All rivers and urban runoff *</td>
<td>893,000</td>
</tr>
<tr>
<td>TN loading from SPARROW</td>
<td>1,305,245</td>
</tr>
<tr>
<td>Direct Atmospheric Deposition*</td>
<td>307,000</td>
</tr>
<tr>
<td>Sewage Treatment Plants*</td>
<td>11,350,000</td>
</tr>
<tr>
<td>Groundwater*</td>
<td>93,000</td>
</tr>
<tr>
<td>Total TN Loading</td>
<td>13,055,345</td>
</tr>
</tbody>
</table>

*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)

\[ L_{\text{land}} = 108,770 \text{ kg N mo}^{-1} \]
\[ V = 612.5 \times 10^6 \text{ m}^3 \]
\[ V_{\text{sw}} = 603.9 \times 10^6 \text{ m}^3 \]

\[ [N_b] = 0.233 \text{ mg L}^{-1} \]
\[ [N_{\text{sea}}] = 0.230 \text{ mg L}^{-1} \]
\[ \tau = 10 \text{ d} = 0.33 \text{ mo} \]
\[ \alpha = 0.3 \text{ mo}^{-1} \]

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

Calculated [TN] (model with reduced loading and \( \tau = 5 \text{ d} \) 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)

\[ L_{\text{land}} = 142,104 \text{ kg N mo}^{-1} \]
\[ V = 612.5 \times 10^6 \text{ m}^3 \]
\[ V_{\text{sw}} = 603.9 \times 10^6 \text{ m}^3 \]

\[ [N_b] = 0.233 \text{ mg L}^{-1} \]
\[ [N_{\text{sea}}] = 0.230 \text{ mg L}^{-1} \]
\[ \tau = 10 \text{ d} = 0.33 \text{ mo} \]
\[ \alpha = 0.3 \text{ mo}^{-1} \]

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

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

- TN loading from SPARROW: \( 1,268,612 \)
- Direct Atmospheric Deposition*: \( 69,853 \)
- Sewage Treatment Plants into Estuary*: \( 172,982 \)

Total TN Loading: \( 1,511,447 \)

*RJones (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

\[
L_{\text{land}} = 125,954 \text{ kg N mo}^{-1}
\]
\[
V = 198 \times 10^6 \text{ m}^3 *
\]
\[
V_{\text{sw}} = x 10^6 \text{ m}^3 *
\]
\[
\alpha = 0.3 \text{ mo}^{-1}
\]

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

* Brown & Arellano (1980)

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


- Hunt, CD et al. 1987a-d. Narragansett Bay water quality monitoring and source strength measurements (Four volumes describing SINBADD Cruises 1-4). Marine Ecosystems Research Laboratory, Graduate School of Oceanography, University of Rhode Island, Narragansett, RI 02882.


Backup Slides
Seasonal TN Concentration Ratios

Seasonal mean divided by annual mean for different locations and seasons.

- Long Island Sound
- Boston Hbr. / Mass. Bay
- Chesapeake Bay (upper)

Seasons:
- Spring
- Summer
- Fall
- Winter
Seasonal DIN Concentration Ratios

(Seasonal Mean)/(Annual Mean)

- Long Island Sound
- Boston Hbr. / Mass. Bay
- Chesapeake Bay (upper)

- Spring
- Summer
- Fall
- Winter
Predicted Nitrogen Yield
New England SPARROW Model