Sources and fate of Nitrogen in coastal watersheds at regional and local scales

Neil D. Bettez
Cary Institute of Ecosystem Studies

Summit Meeting
Role of Nutrient Management in Urban and Suburban Landscapes in Nutrient Loading of Surface and Ground Waters
Nitrogen Sources:
1. Lightening strikes
2. Fixation by plant-associated and soil bacteria

Nitrogen Fluxes:
3. Denitrification by bacteria
4. Atmospheric deposition
5. Watershed runoff

* A flux is the movement of nitrogen from one component of the ecosystem to another.
Relative increase in the creation of reactive N

(Howarth et al. 2002)
Human alterations of the Nitrogen cycle

- Total reactive N
- Industrially fixed (mainly fertilizer)
- N-fixing crops
- Fossil fuel combustion

(Galloway et al. 2004)
Impacts of additional N

Air quality impacts:
~ Elevated ground-level ozone
~ Increased particles in the air
~ Reduced visibility
~ Increased acid rain and nitrogen deposition

Forest impacts:
~ Increased acidity of forest soils
~ Nitrogen saturation of forest ecosystems
~ Ozone damage to forests

Water quality impacts:
~ Elevated acidification of lakes and streams
~ Groundwater contamination
~ Over-enrichment of coastal ecosystems

Other impacts:
~ Increased production of greenhouse gases contributing to global climate change
~ Adverse human health effects from particulate matter and ground-level ozone

(Driscoll et al. 2003)
Nitrogen Sources:
1. Imported food and feed
2. Vehicle emissions
3. Powerplant emissions
4. Fertilizer imports
5. Fixation in croplands
6. Agricultural emissions

Nitrogen Fluxes:*
7. Atmospheric deposition
8. Wastewater from septic tanks and treatment plants
9. Agricultural runoff
10. Forest runoff
   Urban runoff

*A flux is the movement of nitrogen from one component of the ecosystem to another.

(Driscoll et al. 2001)
But huge regional variation in sources of reactive nitrogen, both naturally and from human activity.

Nitrogen Emissions (NO$_x$, NH$_3$, and nitrogen particles) move through atmosphere on scales of only meters to 100s or 1000s of kilometers.

Reactive N moves in rivers and ocean currents at similar scales.

In order to understand human alteration of nitrogen cycle it is important to work at the watershed and regional scale.
SCOPE N Project Characterized variation in sources and sinks of N at regional scale

Mass balance approach

Inputs of anthropogenic N
- fertilizer
- deposition
- food & feed imports

Outputs of N
- river fluxes

(Howarth et al. 1996)
North Atlantic Ocean region: human inputs of N are related to riverine N export

(Howarth et al. 1996)
North Atlantic Ocean region: human inputs of N are related to riverine N export

Note intercept... \(~ 100 \text{ Kg N km}^{-2} \text{ year}^{-1}, \text{ if no human inputs}\)
Increase in nitrogen flux in rivers due to human activities for key contrasting regions of the world:

- Labrador & Hudson’s Bay: no change
- Southwestern Europe: 3.7-fold
- Great Lakes/St. Lawrence basin: 4.1-fold
- Baltic Sea watersheds: 5.0-fold
- Mississippi River basin: 5.7-fold
- Yellow River basin: 10-fold
- Northeastern US: 11-fold
- North Sea watersheds: 15-fold
- Republic of Korea: 17-fold

“Dead zones,” or hypoxic areas – major global problem

Oxygen Depleted Coastal zones

- Persistent
- Annual
- Episodic
- Periodic

(UNEP, March 2004)
A closer look at the US....

Highest rate of NO$_x$ emissions per capita in the world.

Highest rate of inorganic N fertilizer use per capita in the world.

Second highest rate of meat consumption per capita in the world.

The US mobilization rate is ~4.5x natural
In the US we mobilize ~28.5 Tg N/yr

Energy Production

Food Production

An additional 4.2 Tg is created for industrial use

5.7 Tg N
(~20%)

18.6 Tg
(~65%)

(US EPA 2009)
Status of US Estuaries

Level of Eutrophic Conditions

Estuaries impaired: 40% high, 25% moderate, 35% low

(Bricker et al. 1999)
Sources of N in Coastal Watersheds

The questions

• *What are the sources of N in coastal watersheds?*

• *How much N is retained in the watershed?*

Two studies

• *The Northeast (16 watersheds)*

• *Eastern US (34 watersheds)*
Anthropogenic nitrogen sources and relationships to riverine nitrogen export in the northeastern USA
Watershed nitrogen inputs

- Net import in feed
- Net import in food
- Fertilizer use
- Agricultural N2 fixation
- Net atmospheric deposition
- Forest N2 fixation

Nitrogen, kg/km²/yr

(Boyer et al. 2002)
Nitrogen Sources in Coastal Watersheds

Source of Anthropogenic N across all 16 watersheds

- Natural fixation in forests (5%)
- Fertilizer use (15%)
- Fixation in agricultural lands (24%)
- Net imports of N in food and feed (25%)
- Net atmospheric deposition (31%)

However, the combined effect of fertilizer use, fixation in crop lands, and animal feed imports makes agriculture the largest overall source of N.

(Boyer et al. 2002)
Watershed nitrogen inputs and outputs

Outputs are 25% of inputs (retention is ~75%)
Sources of Nitrogen to Estuaries in the Eastern United States

(Castro et al., 2000)
Nitrogen Sources in Coastal Watersheds

Differences in anthropogenic N sources for the watersheds

• Atmospheric Deposition was the largest source in three watersheds.

• Urban areas (mainly in the Northeast) were the largest source in 11 watersheds.

• Agricultural activities were the major source 20 watersheds.
Nitrogen Sources in Coastal Watersheds

Average N inputs across all watersheds

- 9% (2.9 kg N ha\(^{-1}\) yr\(^{-1}\)) due to feed ( -5.1 – 14.8 kg N ha\(^{-1}\) yr\(^{-1}\))
- 12% (3.7 kg N ha\(^{-1}\) yr\(^{-1}\)) due to N fixation ( 0.3 – 10 kg N ha\(^{-1}\) yr\(^{-1}\))
- 19% (6.2 kg N ha\(^{-1}\) yr\(^{-1}\)) due to food ( -1 – 50 kg N ha\(^{-1}\) yr\(^{-1}\))
- 22% (4.8 kg N ha\(^{-1}\) yr\(^{-1}\)) due to deposition ( 4.1 – 11.7 kg N ha\(^{-1}\) yr\(^{-1}\))
- 38% (12 kg N ha\(^{-1}\) yr\(^{-1}\)) due to fertilization ( 0.5 – 48 kg N ha\(^{-1}\) yr\(^{-1}\))

(Castro et al. 2000)
Nitrogen Retention by Coastal Watersheds

Watersheds retained on average ~57% of total N input

- *Forests retained 85% to 95% of total N input (mostly atmospheric)*
- *Crop lands retained ~79% of total input.*
- *Urban lands retained ~21 to 60% of total N input*

(Castro et al. 2000)
Sources of N in Coastal Watersheds

The questions

• What are the sources of N in coastal watersheds?

• How much N is retained in the watershed?

The answers

• Mostly agriculture but it varies depending on land use.

• Most of the N is retained but it can vary by land use. Also, the more you put in the more get out.
Baltimore Ecosystem LTER

Input – Output Budgets

Inputs
- Deposition
- Fertilizer

Outputs
- Stream flow

Retention
- Forested 95%
- Agricultural 77%
- Suburban 75%

(Groffman a et al. 2004)
Forest Response to increased N Loading

---

**Whole Ecosystem Manipulations**

Added or removed N from whole Ecosystems.
Amount usually 3 - 10 x ambient deposition levels.
The longest one has been going on for 15 years.

---

**Transect Studies**

Transects span natural deposition gradients in the US and in Europe.
Transects are hundreds of meters to thousands of km in length.

---

(Ollinger et al. 1993)
Results across NITREX Sites

 Outputs in relation to Inputs

< 10 kg ha yr\(^{-1}\) all inputs were retained

> 25 kg ha yr\(^{-1}\) outputs increased significantly

\[\text{(Dise and Wright 1995)}\]
Results across NITREX Sites

*Outputs in relation to soil pH*

- As soil pH decreases, outputs increase

*(Dise and Wright 1995)*
Results across NITREX Sites

Outputs in relation to Forest floor C:N

Likelihood of NO$_3^-$ leaching

>30 - Low

25 → 30 - moderate

< 25 - High

(Gunderson et al. 1998)
Precipitation Collectors

Bulk Collectors (wet + some dry)

Throughfall Collectors (wet + more dry)
At two sites from 2003-2006

- No difference in Bulk with distance from the road at either site in any year
- Throughfall at forest edge always higher than forest interior

N Inputs

TDN mg m\(^{-2}\) day\(^{-1}\)

Distance (meters)
**Forest Floor pH**

- Forest floor pH is significantly lower near the road than at sites farther away.

- pH is ~0.4 pH units lower at 10 m than at 150 meters.

P < .05
Forest Floor C:N

- Forest floor C:N ratio is significantly lower near the road than at sites farther away.
- C:N ratio is 5 units lower at 10 meters than at 150 meters.
- Using current deposition estimates it would require ~38 years to cause this change.
Watershed Leaching

**Resin Leaching**

- Leaching near roads through out the watershed is elevated

- Leaching near the road is ~2 x that of sites farther away

![Graph showing NO$_3^-$ concentration versus distance from roads.](chart.png)
Forest N retention

Retention Rate away from a Roadway:

- Retention rate away from the road was similar to other estimates of retention.

- Areas near roadways receiving chronic low level N deposition had lower retention.

- Retention is 15% lower near the road than farther away.

<table>
<thead>
<tr>
<th>Distance (meters)</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>58%</td>
</tr>
<tr>
<td>50</td>
<td>73%</td>
</tr>
<tr>
<td>100</td>
<td>69%</td>
</tr>
<tr>
<td>150</td>
<td>73%</td>
</tr>
</tbody>
</table>
Why should I care how much is retained?

<table>
<thead>
<tr>
<th>Nitrogen Source</th>
<th>Loading to Watershed</th>
<th>Watershed losses</th>
<th>Estuary Loading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deposition</td>
<td>56%</td>
<td>89%</td>
<td>30%</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>14%</td>
<td>79%</td>
<td>15%</td>
</tr>
<tr>
<td>Wastewater</td>
<td>27%</td>
<td>65%</td>
<td>48%</td>
</tr>
</tbody>
</table>

(Valiela et al. 1997)
Distance to Nearest Road

(Watts et al. 2007)
Deposition Monitoring

Network of 87 sites located to represent major physiographic, agricultural, aquatic and forested areas within a region

Inorganic N wet deposition in USA

Site location
- Power plants: 10-20 km
- Urban area: 10 - 20 km
- Feed lots: 500 m
- Roads: 100 m
- Parking lots: 100m
- Grazing animals: 20 m

(Bigelow et al 2001, NADP 2006)
Waquoit Bay Watershed

- 5,444 ha in size
- 307 km of roads

Percentage of Watershed within
10 m = 13.5%
20 m = 22.5%
50 m = 44.3%