Water Residence Time and Nitrogen Loss in a Mississippi River Delta: A Modeling Approach

Ben Branoff
Department of Oceanography and Coastal Sciences
Louisiana State University
Baton Rouge, LA
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Impetus

Eutrophication is the number one coastal pollution problem in the U.S.
- NRC, 2000

Uncertainty in wetland nitrogen cycling, especially pertaining to prograding deltaic landscapes.
- Burgin and Hamilton, 2007; Brock, 2001; Kroeze et al., 2003

Major sediment diversions planned for the Louisiana coast
- LACPRA, 2012
The delta cycle

Delta Area (to ~ 15000 km²)

- Fluvially-Dominated
  - Increasing Discharge and Sediment Flux
- Steady State
  - Delta Maintenance
- Marine-Dominated
  - Decreasing Discharge and Sediment Flux

Time (~ 1000-2000 Years)

(Adapted from Roberts 1997 by G. Snedden)
Soil formation during delta development

![Graph showing soil formation during delta development](image)

- **Phosphorus**
- **Carbon + Nitrogen**

**Equilibrium N:P**

**N Limitation**

**P Limitation**

Young - Old

(Adapted from Walker and Syers 1976 by A. Bevington)
Sediment Diversions

2012 LA Master Plan for a Sustainable Coast

- $3.8 billion to sediment diversions
- Projected 777 km² of new land
- Up to 50% of the River’s peak flow
- 8% of Miss. R. flow for each project
Sediment Diversions

1963:
30% of Mississippi flow diverted down Atchafalaya

30-45% of Atch. diverted to Wax Lake Outlet

=10-15% of Mississippi flow
Atchafalaya and Wax Lake Deltas

2-3 km² yr⁻¹ land building rate (Roberts et al., 2007)

41% to 47% decrease in Atchafalaya River NO₃ concentrations (Lane et al., 2002).

"...the role denitrification plays in removing nitrate from the system is still under debate; there is some evidence that river nitrate is transformed and stays within coastal ecosystems." (Twilley et al., 2009).
Hypotheses and Objectives

Hypotheses

• Denitrification is the primary mechanism of nitrate removal from the Wax Lake Delta.
• Nitrogen removal efficiency is proportional to the residence time in the estuary.
• Temperature thresholds influence the balance of nitrogen transformations in this river delta.

Objectives

• Develop a biogeochemical model to more clearly define the nitrogen cycle process.
• Evaluate the fate of nitrogen in the Wax Lake Delta according to ecological parameters.
Mike Island

Martin and Reddy, 1997

How is nitrogen processed in this system?
What role does denitrification play?
What role do the various wetland properties play?
Methods: The Model

Martin and Reddy, 1997

Modifications

Visual Basic

Nitrogen assimilation from the surface water

Dissimilatory Nitrate Reduction to Ammonium
Field Site: Mike Island

- Surface and pore water quality
- Daily Temperature
- Daily Water Levels
- Depths
- Vegetation Coverage
- Soil Core Experiments
Methods: Calibration

Soil core incubation experiments

Optimize model parameters to fit observed results

Graph showing fluxes of Nitrate (NO₃) and Ammonium (NH₄), with observed and modeled data compared.
Methods: Calibration

Soil core Incubation experiments

Optimize model parameters to fit observed results
Methods: Spatial Simulation

Martin and Reddy, 1997

Inputs

Layer
- Water column
- Aerobic
- Anaerobic 1
- Anaerobic 2
- Anaerobic 3
- Anaerobic 4
- Anaerobic 5

Total height: 60

Cell 1 Cell 2 Cell 3 Cell 4 Cell 5 Cell 6 Cell 7

Daily horizontal exchange of water and N between vertical cells through the water column.

Vertical exchanges of N between model layers
Hydrodynamic Modeling

Mike Island via Kriging Interpolation

Quadric: \( z = ax^2 + by^2 + cxy - dx - ey + f \)

Elevations to NAVD88
-0.5-0  0-0.5  0.5-1
Hydrodynamic Modeling

- Basins compare excellently with respect to water elevation and total volume.
- Quadric is a good approximation of the site bathymetry.
Hydrodynamic Modeling

Compartmentalize the Landscape
• Averaged Depths
• Equal Volumes
Surface Water Nitrogen Simulations
Surface Water Nitrogen

March

- Observed NH4
- Observed NO3
- Model

NH4 & NO3

Distance From Creek (m)

uM
Surface Water Nitrogen

April

- Observed NH4
- Observed NO3
- Model

Distance From Creek (m)

NH4

NO3

μM
Pore Water Nitrogen Simulations
Pore Water Nitrogen

September

- Observed NH4
- Observed NO3
- Model

Depth (cm)

NH4 uM

NO3 uM
Results: Annual Rates

Averaged rates based on cumulative results of all cells

- DNRA > Denitrification
- Rates = \frac{\text{Core Measurements}}{10}
- In the process of validating these results in the lab
Results: Annual N Export

% Exported

y = 0.0254x - 962.61
Results:

N Export and Temperature

\[ y = -0.1779x + 84.015 \]
Results:
N Export and Residence Time

\[ y = -0.4512x + 81.975 \]
Results: Annual N Export

Dettman, 2001

Where is the Wax Lake Delta operating?

How will it change with time?
Conclusions

- Ecosystem Rates = \( \frac{\text{Core Incubation Rates}}{10} \)

- Vegetation uptake is the dominant process of the nitrogen cycle within the model
  - Denitrification plays a secondary role with DNRA

- Nitrogen export increases throughout the year from January to December
  - Residence time has little to do with this
  - Temperature is highly correlated
Questions?
What’s Next?

- Evaluate mass transfer rates and comparisons to other systems

Speieles & Mitsch, 1999


