Using Geospatial Data to Extend Site Specific N Analysis to the Watershed Scale

Research Coordination Meeting:
Strategic Placement and Area-wide Evaluation of Conservation Zones in Agric. Catchments

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Watershed Mass Balance Studies → considerable disappearance of N (60-90%) in landscape sinks

- **Hot Spot Hypothesis:** Denitrification focused in select, localized settings with:
  - Extended residence time
  - Pools of labile C

- Can we identify potential sinks along the flow path between source areas and large river systems?
Recent GIS tools enable us to track flow paths from source areas to watershed sinks (like riparian zones)

USGS Watershed Analyst
Raindrop Tracker generates flow paths from source areas (1:24,000 Topography)

Agricultural field

Origin of Raindrops
Questions / Challenges

- Can we use our riparian zone research, spatial data and GIS tools to guide local management of watershed N:
  - Where to target source controls?
  - Where to focus riparian protection/restoration efforts?
- What landscape features relate to high riparian N removal?
- What factors generate uncertainty in our estimates?
- Research funding is limited: Can available geospatial data provide guidance for local management?
How to extend from the site to the watershed scale?

Approach- Relate riparian N removal capacity to “mappable” site features including:

• Hydric status
• Geomorphic setting
• Stream Morphology (Rosgen Classification)
Riparian ecosystems: Hotspot for N cycling?

Streamside areas
Transition zones from upland to surface waters
Interface between groundwater and surface waters

N cycling varies with setting, season, vegetation, hydrology
• Can Reduce Water Borne Nitrate
• May Be a Source of N₂O

Other potential values:
• Pollutant retention (P, sediment)
• Stream temperature regulation
• Bank stabilization
• Woody debris - aquatic habitat
Available high resolution spatial data: USA

- Nat’l Wetland Inventory - 1:24,000
- SSURGO county scale digital soil surveys - 1:15,840
  - Soil wetness (hydric soils)
  - Geomorphology
- Land use
  - 1995 Anderson Level III - 1:24,000
- Topography & hydrography – 1:5,000 to 1:24,000
  - Flow patterns, watershed boundaries
  - Stream Networks

SSURGO
Status:
NE U.S.
March 2007
Example 1: Hydric soil status to explain variation in riparian N removal?

- Groundwater denitrification potential increases in hydric soils
  - The water table comes closer to the surface
  - Anaerobic conditions develop
  - Organic matter increases
  - Groundwater nitrate removal is often observed
Pawcatuck Catchment
Rhode Island, USA

Characteristics:
- Size: 850 km²
- Glaciated deposits
- Riparian study sites predominately mature red maple forests
Groundwater dosing experiment: Layout of dosing trenches and sampling wells
Non-hydric Field
location:
DO: 7.0 mg/L
WT: 70 cm

Non-Hydric Soil
D.O. 7.0 mg/l
WT: 90 cm

Time from application (days)
NO\textsubscript{3}-N (mg/L)
NO\textsubscript{3}-N (mg/L)

Nitrate

Bromide

NO\textsubscript{3}-N (mg/L)
Br (mg/L)
What is the removal mechanism?

Hydric Field location:
- DO: 1.5 mg/L
- WT: 10 cm
- 1:1 Dosing Ratio of N:Br
Nitrate-N Removal

Dissolved Oxygen

Nitrate-N Removal Rate (µg kg \(^{-1} \text{ d}^{-1}\) )

Dissolved Oxygen (mg L \(^{-1}\) )

Hydric Soils
(n = 6 sites)

Nonhydric Soils
(n = 4 sites)
Moving beyond mass balance studies: Assessing groundwater denitrification

$\text{NO}_3^- \rightarrow \text{NO}_2^- \rightarrow \text{NO} \rightarrow \text{N}_2\text{O} \rightarrow \text{N}_2$

- Anaerobic
- Heterotrophic (requires organic C)

• Expect high rates in wetland soils.

• Is it a key component of the water quality maintenance function of riparian zones
1. Pump groundwater
2. Amend with $^{15}$NO$_3^-$ and Br$^-$
3. Lower DO to ambient levels with gaseous SF$_6$
4. Push (inject) into well
5. Incubate
6. Pull (pump) from well
7. Analyze samples for $^{15}$N$_2$ and $^{15}$N$_2$O (products of microbial denitrification)

(Addy et al. 2002, JEQ)
Groundwater amended with $\text{NO}_3^{-}$-N, Br$^-$, and SF$_6_6$
High Nitrate Removal Setting

Nitrate removal >80% in PD and VPD
Low Nitrate Removal Setting: Incised Stream Channel

Nitrate removal <30% throughout
Example II: Can geomorphological map units depict groundwater flow paths?

Does nitrate-enriched groundwater bypass organically enriched media or interact with buried organic fluvial deposits?
Can geomorphology help explain observed variation in riparian N removal?

- **Organic/Alluvial**: deposits created by wetland conditions or riverine action
- **Glacial Outwash**: stratified sands, high permeability
- **Glacial Till**: unstratified sand and silt, moderate to low permeability
Does Geomorphology Affect Depth of Denitrification in Hydric Riparian Zones?

Sites: 2 mapped outwash
       2 mapped alluvial

At each site:
1. Pits dug below water table and analyzed for distribution, genesis and lability of organic deposits
2. In situ “push-pull” denitrification
   -Spring and Fall
   -3 depths (3 reps per depth)
3. Additional field surveys of buried organic deposits at 25 hydric riparian sites
Site Sampling Design: Cross-Section of Riparian Zone

Mini-piezometers for “Push-Pull” incubations (3 reps/depth)

General direction of groundwater flow

Nested mini-piezometers for site characterization
Field results: Geomorphic setting not related to vertical pattern of groundwater denitrification in hydric soils.
C deposits below the water table:
Found Up to 3 m depth near stream in hydric soils, regardless of “mapped” geomorphology

C Sources
• Buried surface horizons (17/18 “outwash” sites)
• Buried stream deposits
• Roots
• Windthrows

Blazejewski et al., 2005; J. SSSA
Some flat river valleys function like engineered denitrification walls

Buried carbon intercepts groundwater

Adapted from Schipper and Vojvodic-Vukovic 1998 and Downes et al. 1997
Groundwater Denitrification Rates with Distance from Stream

Depth = 150 cm

Stream channel within broad, flat river valley

Kellogg et al. 2005; JEQ
Geomorphology did relate to groundwater seeps

- Seeps found at 29/34 hydric till sites during field reconnaissance
- Expect reduced groundwater N removal potential in till

Rosenblatt et al., 2001; JEQ
We can relate buried alluvial/organic deposits to stream valley morphology.

Rosgen Classification: E4
Stream Type: Gentle slopes in broad riverine valley
Original scale of geospatial data can alter catchment scale assessment of riparian dynamics.

Proportion of stream length bordered by riparian hydric soils:
- 5%
- 75%

STATSGO
Original scale 1:250,000

SSURGO
Original scale 1:15,840

Legend:
- Green: hydric soils
- Yellow: nonhydric soils
- Blue: water
- Black: rivers and streams
Can geospatial data account for other catchment N sinks?

- Wet soils - wetlands
- Land-water interface (riparian zones, shorelines)
- Transient streams
- Headwater streams
- Reservoirs and lakes
Scale/type of spatial data can mask or display pathways and sinks
(data: Kingston Quad-RI)
National Wetland Inventory (1:24,000) displays potential sinks

Streams (1:24,000)
Ponds (1:24,000)
Forest / Open Space
Agriculture
Residential (low density)
Residential (med density)
Res. (med high density)
Institutional
Gravel pits
NWI Wetlands (1:24K)
SSURGO Hydric Soils suggest wetlands and transient streams connect source to stream.

Streams (1:24,000)
Ponds (1:24,000)
Forest / Open Space
Agriculture
Residential (low density)
Residential (med density)
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Institutional
Gravel pits
NWI Wetlands
Hydric soils (SSURGO) (1:15,840)
High resolution stream data and hydric soils display an active biogeochemical landscape.
High resolution hydrography data displays a marked increase in potential landscape sinks

State of RI = 2,600 km$^2$ sinks

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<thead>
<tr>
<th></th>
<th>1:5,000</th>
<th>1:24,000</th>
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<tbody>
<tr>
<td>Stream Length (km)</td>
<td>4850</td>
<td>1819</td>
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<tr>
<td>Drainage Density</td>
<td>1.19</td>
<td>0.45</td>
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<td>Number of Water Bodies</td>
<td>3600</td>
<td>3100</td>
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<td>Surface Water Area (km$^2$)</td>
<td>130</td>
<td>100</td>
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What if high resolution is lacking?

Coarse topographic data (Digital Elevation Models) can generate finer scale flow networks via **Flow Accumulation Grids – GIS Tool**

Flow accumulation for a given point:
The number of points whose flow paths eventually pass through that point
A. Flow Accumulation Map  
B. Distribution of Critical Contributing Areas

Summary/Challenges

• Can we design site specific research studies to explore how landscape features relate to catchment functions?

• Can we employ a suite of spatial data and GIS tools to guide local decisions regarding:
  – Prioritizing source controls in catchments
  – Prioritizing lands for protection
  – Prioritizing lands for restoration?

• Can we extend high resolution studies to other areas with similar geomorphic/landscape complexes?

• Can we capture the uncertainty associated with map scale and site variability to focus future research?
N Saturation of Riparian Zones?

• Will long-term N loading overwhelm nitrate removal functions in riparian zones?

• The fate of N between plants and denitrification may be the critical determinant of saturation.
Practical Applications

• Improve estuarine assessment tools which model sources and sinks of watershed nitrogen
• Target high N removal riparian sites for restoration and protection
Great uncertainty surrounds the fate of N in coastal watersheds across a wide spectrum of scales.

70-90% of the net inputs do not reach the outlet.

(Howarth, et al., 1996)