In-stream Denitrification: Pilot Studies and Site Characteristics on a Headwater Stream

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Goal of this study

- Does the constant rate injection method have the resolution necessary to evaluate in-stream N removal rates in the settings and conditions found within lower-order streams in southern New England?
- How sensitive is this method to seasonal variation?
- What is the extent of intra-seasonal variation?

Study site

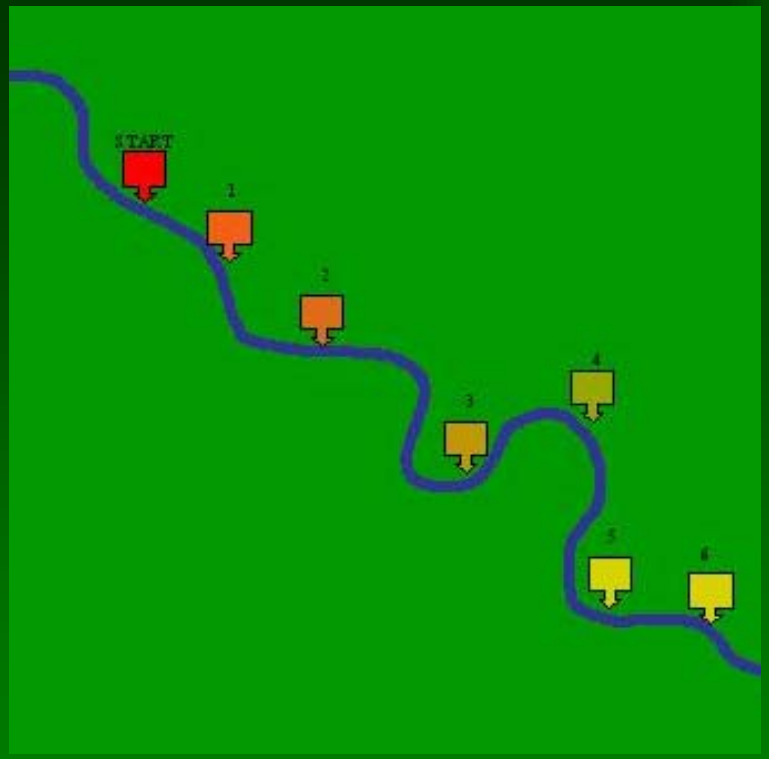
- 500 meter reach of a first/second order tributary
- Red maple swamp riparian area
- Located on sandy outwash with glaciofluvial deposits
- Forested watershed with some agricultural land use
- Representative of many streams in southern New England

Overview of Constant Rate Injection Method

- Isotopically enriched nitrate (^{15}N-KNO_3)
- Couple with gas tracer (SF_6) and a solute tracer (Br^-)
- Inject the solution into stream at steady, slow pace to create a plateau of concentration
- Comparison of downstream concentrations relative to tracer and measurement of ^{15}N indicate N removal

Using the constant rate injection method

- Whole reach study (series of sampling stations along 500 m reach)
- In-stream cycling and groundwater N inputs
- Transport and removal processes
- Does not artificially elevate ambient NO_3-N…1st order kinetics



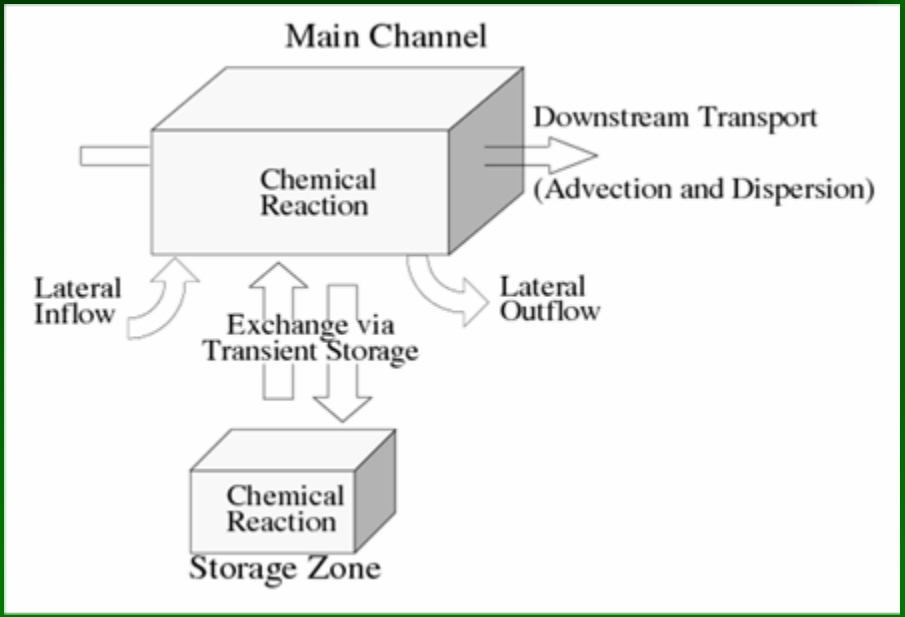
Replication and Sampling

- 3 replicate trials in the summer (August)
- 3 replicate trials in the fall (November)
- Sample prior to dosing and twice during the plateau
- At first and last stations, took samples every 5 min

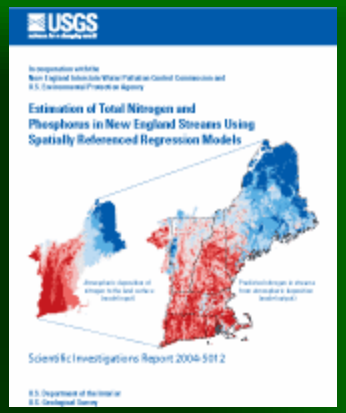
  - assess rising and falling concentrations
  - quantify hydrologic processes with USGS model (dispersion, storage in the hyporheic zone or in slow moving pockets)

Stream Solute Transport Model (OTIS)

- **O**ne dimensional **T**ransport with **I**nflow and **S**torage
- Downstream Br^- data
- Estimates where the solute/water is being held up



SPARROW model



- **SPA**tially **R**eferenced **R**egressions **O**n **W**atershed attributes
- Utilizes physical stream properties (flow & depth)
- Predicts:
  - uptake length (average distance traveled by a nitrate molecule before it is denitrified in a stream reach)
  - fraction of N delivery downstream

Results: Ambient characteristics

	Upstream Discharge ($L\ s^{-1}$)	Downstream Discharge ($L\ s^{-1}$)	Mean Stream Depth (m)	Time of Travel (hours)	Average Reach Velocity ($m\ s^{-1}$)
Summer 2006	4.3 (0.37)	5.3 (0.48)	0.06 (0.42)	**1.30** (0.01)	**0.11 (0.01)**
Fall 2006	28 (1.48)	49 (8.26)	0.14 (0.48)	**1.24** (0.01)	**0.11 (0.01)**

Data is mean for all three trials (SE)

Denitrification rate calculation

1. NO_3^- disappearance (Downstream NO_3-N : Br^- ratios)
2. ^{15}N gas flux (corrected for evasion using SF_6)
3. $^{15}NO_3$-N mass balance (corrected using Br^-)

Results: ^{15}N gas flux

	Mass Removal		Percent Removal	Uptake lengths (km)
	g day^{-1}	µmoles/m^2/hr		
Summer				
8/7/2006	0.12 (0.08)	0.7	< 0.1	2510
8/9/2006	0.03 (0.01)	0.2	< 0.1	9030
8/11/2006	1.82 (1.33)[a]	10.8	< 0.1	180
Fall				
11/7/2006	0.08 (0.01)	0.5	< 0.1	7340
11/10/2006	1.31 (0.91)	7.8	< 0.1	340
11/15/2006	1.41 (0.71)	8.4	< 0.1	340

Results: The Models

- SPARROW predicted that uptake length was > 170 km (agreeing with our observations)
- OTIS model indicates **minimal** stream storage zone area and hyporheic exchange in summer and fall

Runkel USGS

Results: GIS analysis of RI landscape

- Our stream's features were representative of many RI streams
- Headwater streams account for 70% of RI drainage network
- 36% of streams in RI similar to study stream
- Average length of RI headwater streams is about 1.4 km (100 fold less than uptake length)

Results: Seasonal variation

- Removal rates remained consistent
- Discharge, DOC, temp…no affect on removal rates
- No major difference between seasons in ambient NO_3-N and stream reach retention times (1st order kinetics)

Results: Within-season variation

- Discharge variable in the fall
- Downstream ambient NO_3-N variable in the summer
- No notable impacts on removal rates

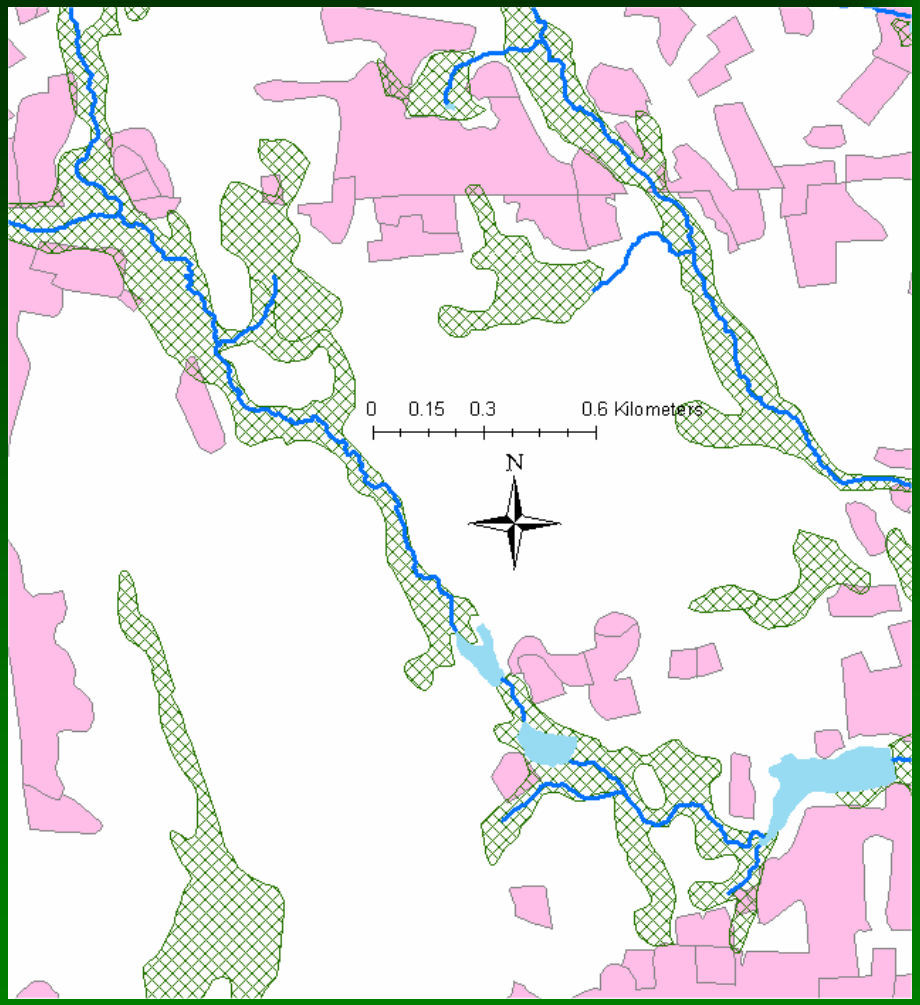
Study Site	Mean Depth (m)	Ambient NO_3-N (mg l^{-1})	Denitrification Uptake Length (km)
Sugar Creek (Bohkle et al., 2007)	0.19	0.99	17,950
Walker Branch (Mulholland et al., 2000)	0.05	0.02	0.5
Walker Branch (Mulholland et al., 2004)	0.03	0.03	0.217
Illinois agricultural stream (Royer et al., 2004)	0.31	7.78	166- >200
Rhode Island stream (Milliman)	0.10	0.90	176-9,030

"What-if scenarios" based on Mulholland et al. (2000) denitrification rates

	Ambient NO_3-N (mg l^{-1})	Velocity (m s^{-1})	Denitrification rate (μmoles/m^2/hr)	Denitrification Uptake length (km)
Summer				
Actual Upper Rate	**1.1**	**0.11**	**10.8**	**176**
Hypothetical	**1.1**	**0.11**	**123.3**	**15**
Fall				
Actual Upper Rate	**0.7**	**0.11**	**8.4**	**338**
Hypothetical	**0.7**	**0.11**	**123.3**	**23**

Take home messages

- Average headwater stream length in RI is substantially less than uptake lengths.
- Residence time and ambient NO_3-N conditions (1st order kinetics) important
- ^{15}N enrichment studies are costly

Future work

- Focus on settings with extended retention times and benthic interactions
- Impoundments and streams connected to swamps and ponds
- Review constant rate injection method for these studies- high costs associated with long retention times