Evaluating In-Stream Denitrification: Pilot Studies and Site Characterization

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Background

Our research seeks to understand the role of streams and rivers in reducing nitrate losses in coastal watersheds. The export of nitrogen (N) from coastal watersheds can degrade estuaries by promoting harmful algal blooms, hypoxia, fish kills, and destruction of critical spawning habitat. Estuaries are receiving substantially more N from rivers draining agricultural and rural lands than in the past.

Although N inputs to watersheds from fertilization and animal waste have increased greatly, as much as 80% of this nitrogen does not reach coastal waters. One of the major advances in watershed science over the last 25 years has been the realization that certain areas of the landscape have a capacity to function as "sinks" for N. In sink areas, biogeochemical processes transform inorganic N, especially nitrate, into organic N in plant and/or microbial biomass or into N gases (NO, N_2O, N_2) via denitrification, preventing movement of N into receiving waters.

The SPARROW (Spatially Referenced Regressions on Watershed Attributes) model has been used to estimate of the amount of in-stream N concentrations and yields, sources and the variation in downstream movement among the watersheds (Figure 1).

Recently, a number of studies have suggested that in-stream processing – removal that occurs while nitrate (NO_3^-) is being transmitted through river networks to coastal waters may be an important sink for watershed NO_3 (Alexander et al. 2000; Bohkle et al. 2004; Mulholland et al. 2004). However, streams vary markedly in their capacity for NO_3^- removal. Small, shallow streams with forested banks appear to generate the most removal, while stream and watershed disturbance, such as channelization and artificial drainage, may be important factors that curtail in-stream nitrate processing. In-stream nitrate processing is an emerging research area with extensive unanswered questions. The current state of knowledge warrants hypothesis-based research to examine how natural landscape features couple with current and prior land management to influence in-stream N removal.

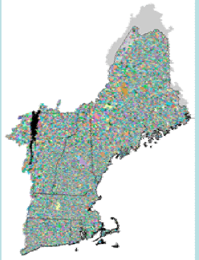

Fig.1 The SPARROW model of New England demonstrates the variation in risk of N delivery to coastal areas from each stream reach's catchment. The increase in risk of N export is not related to distance from the shore but rather it is based on other factors such as stream size, watershed land use and other site characteristics.

Objective

We will develop techniques and establish experimental sites that will advance the study and management of N removal potential within streams in rural New England to further our capacity to manage lands in ways that restore and improve our coastal waters.

Using the Reach-Scale Isotope Tracer Method

- Whole reach study
- Integrates N dynamics over a range of settings, such as debris dams, microbial biofilms and hyporheic zones
- Can serve to validate ecosystem behavior predicted by site specific and process level studies
- Increasing number of reach scale-studies have employed the reach-scale isotope tracer method (Figure 2).
- Isotopically enriched nitrate (^{15}N) and conservative tracers, bromide (Br^-) and sulfur hexafluoride (SF_6), are added to a stream
- Measure the changes in the distribution of the isotopes within different N forms as the nitrate moves downstream
- Accounts for important in-stream cycling and groundwater N inputs as well as provides information about transport and removal processes

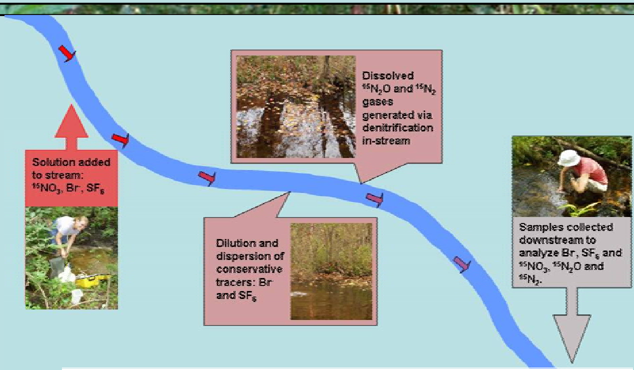

Fig. 2 Schematic of using the reach- scale isotope tracer method. Samples were collected at 6 stations along a 500m reach of stream.

Why use Isotopes?
Using previously accepted reach-scale methods of comparing N to conservative tracer ratios, such as Br^-, do not provide us with the necessary resolution to analyze the denitrification potential within our stream (Figure 3). This study will determine whether isotopic enrichment provides the adequate determination of in-stream denitrification in a small, New England stream.

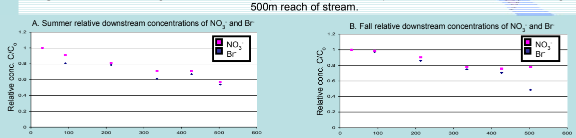

Fig. 3 Relative concentrations of NO_3^- and Br^- that were added to the stream in the (A) summer and (B) fall. C is the downstream concentration, and C_0 is the original concentration at the first sampling station. The relative concentrations decrease with increasing distance downstream. In the summer, the NO_3^- decreased quicker than the Br^-, giving an indication of removal. Even so, the resolution necessary to determine if this indication of N removal is due to denitrification cannot be achieved using NO3- and a conservative tracer alone. Using ^{15}N as a tracer will provide greater resolution in the data, and will help discriminate between denitrification, N uptake by plants and N that is retained within the stream sediments.

Progress to date

Our study site is:
- 500 meter reach of a first/second order tributary in the Wood-Pawcatuck River Watershed, RI (Figure 4)
- Red maple swamp riparian area
- Located on outwash with glaciofluvial deposits
- Forested watershed with some agricultural land use
- Representative of many streams we have examined in this watershed.

Before the study:

- Injected a slug of rhodamine in the first and last 10 m of the reach three times in summer and fall 2006 (Figure 5)
- Assessed initial velocity and discharge along the entire stream reach using steady-state injections of rhodamine one week before the ^{15}N study (Figure 6)
- Collected ambient data from the stream reach (Figure 7):
  NO_3^-
  ammonium (NH4)
  bromide (Br^-)
  dissolved oxygen (DO)
  pH
  temperature

Reach-scale isotope tracer method used:
- 3 replicate dosings summer 2006
- 3 replicate dosings fall 2006
- Samples are being analyzed for ^{15}N analysis of the NO_3^-, N_2 and N_2O.

Fig. 4 The study site is a 1st and 2nd order stream in a forested section of the Wood-Pawcatuck River Watershed in Kingston, RI. The land surrounding the stream is mostly red maple swamp.

Fig. 5 Rhodamine slug in stream to acquire initial discharge estimates

Fig. 6 Steady-state injection of rhodamine to acquire more precise discharge estimates

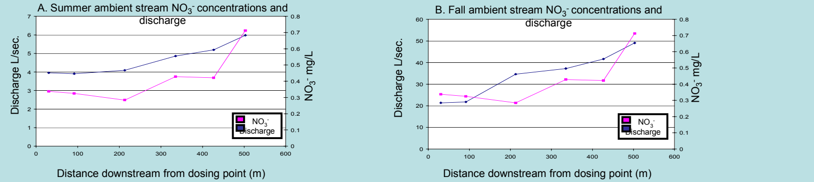

Fig. 7 Ambient stream NO_3^- and average discharge of the 500m stream reach. Data collected in the (A) summer and (B) fall of 2006. This stream is a gaining stream, as it receives groundwater inputs along the stream bank. NO_3^- loading to the stream increases with the discharge, implying that nitrate is entering the stream via groundwater from surrounding upland sources.

Applications and Future Work

- Continue working towards establishing whether the reach-scale isotope method will provide us with the necessary resolution to assess in-stream denitrification.
- Assess the capability of the reach-scale isotope method on multiple streams in an attempt to locate areas within the landscapes that act as substantial N sinks (Figure 8). We predict that lower water systems on outwash materials with greater amounts of woody debris will exhibit the greatest potential for denitrification.
- Improve management by targeting lower water systems that have high N removal potential thereby improving watershed scale BMPs and N budgets.

References
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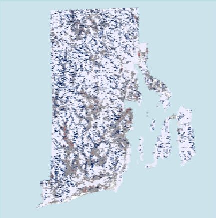

Fig. 8 Possible future reach scale isotope method sites: Low order streams of Rhode Island.