Nutrient Processing and Floodplain Connectivity Following Restoration in Urban Streams

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Stream Restoration & Field of Dreams Hypothesis

- Current restoration goals AND practices focus on improved channel stability and reduced sediment transport
- Natural Channel Design includes morphology adjustments and engineered structures to achieve stability, grade control and bank stabilization.
- *How do these physical changes influence ecosystem processes?*

Pristine

Impaired

Restored?

1. Can we achieve any measurable improvements in water quality with current design and construction practices?
2. Identify those restoration features (both in the stream and adjacent floodplains) that enhance nutrient transformations.

Stream Restoration in Urban Watersheds

Challenges:
- Flashy hydrology, channel incision
- Increased nutrient, sediment and contaminant transport

Solutions:
- Low impact development, stormwater control measures, stream restoration

Constraints:
- Existing infrastructure, competing project goals, funding

__764__ stream restoration projects in NC

Total cost of __$488,209,460__[1]

Little Sugar Creek, Charlotte, NC: Greenway and stream restoration (CMSWS, 2010)

[1]North Carolina Ecosystem Enhancement Program (NCEEP)

Stream restoration & nutrient retention

Retention = Hydrologic Retention × (Biological Retention + Physical/ Chemical Retention)

Mass | **Residence time** | **Flux (mass/time)**

Restoration →

- Floodplain reconnection
- Meanders
- 2-stage channel
- Bed complexity

- Assimilation
- Mineralization
- Production/ respiration

?

- Sorption
- Dissolution

Key stream-floodplain features

Restoration Age

Geomorphic Complexity

Hydrologic Connectivity

Restoration age: riparian vegetation, soil development

Geomorphic complexity: flowpath variability, microbial stability, retention time

Hydrologic connectivity: flood frequency, retention time

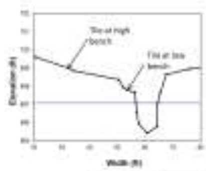
Methods: nutrient biogeochemistry

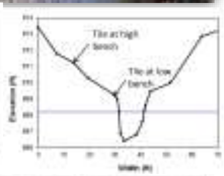
- Reach-scale uptake
  - Nutrient spiraling approach (Stream Solute Workshop 1990)
  - Short-term solute (NO_3^-, PO_4^{3-}) release with Cl^- tracer until steady state

- Denitrification
  - Ambient rates: Denitrification (acetylene + chloroamphenicol) and N_2O flux
  - Potential rates: Denitrification enzyme activity (DEA) assay using acetylene block (Groffman, 1999)
- Net N & P mineralization rates
  - In situ cores deployed for 30 days
  - Net flux (NH_4^+, NO_3^-, SRP) in soil anion/cation resin surrounding the soil core (Noe 2011)

Methods: hydrology and loading

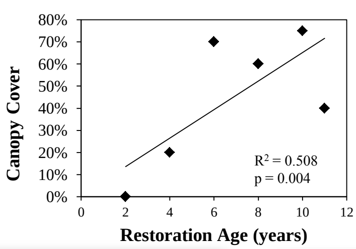
- Sediment & nutrient loading
  - Triplicate plots in floodplain
  - Monthly sedimentation rates via tile deposition (Noe and Hupp, 2009)
  - Monthly DIN/DIP loading via modified anion/cation resin bags (Binkley and Hart, 1989)
- Hydrologic connectivity
  - Stage gages installed at each site
  - Detailed survey to determine flooding frequency

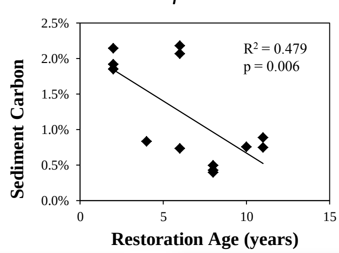




Effect of restoration age on instream retention

Newly restored sites with high autochthonous production -> increased sediment carbon and water temperature





AGE

McMillan, S. K., A. K. Tuttle, G. D. Jennings, and A. Gardner (2013). "Influence of restoration age and riparian vegetation on reach-scale nutrient retention in restored urban streams". Journal of the American Water Resources Association, In Press.

Effect of age + geomorphic complexity

Reach-scale uptake velocity, V_f =
efficiency of nutrient removal from water column

	NITRATE	PHOSPHATE
Predictor variable	R^2 = 0.82; p<0.001	R^2 = 0.73; p=0.006
Channel complexity	+	
Canopy cover	+	-
Temperature	+	
Sediment carbon		+
Nutrient Concentration		+
Velocity x depth	+	

- MLR variables tested: nutrient concentration, canopy, temperature, sediment carbon, channel complexity and velocity x depth

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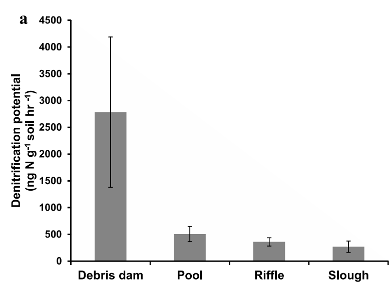
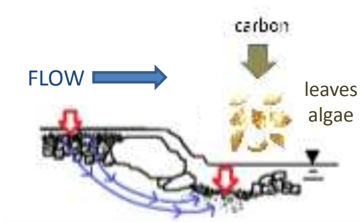
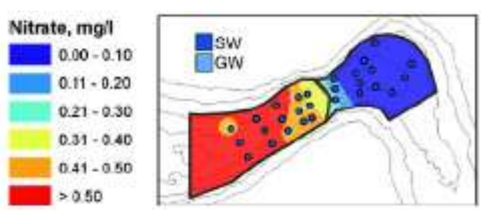
Effect of geomorphic complexity

- Pool: anoxic conditions, high retention times; high denitrification rates and nitrate removal leading to low concentrations
- Riffle: oxic conditions, low retention times; high nitrification increasing nitrate concentration
- Weir: high vertical head gradients, low retention times; transport dominated

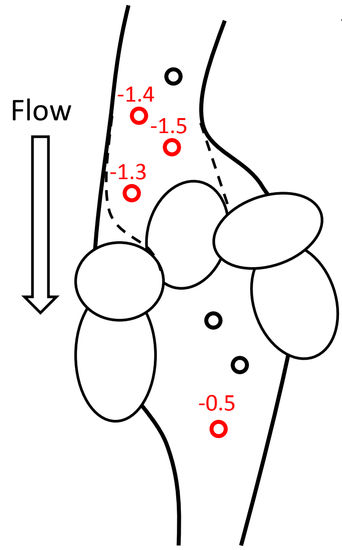


Harrison et al., 2012, Ecol. Engr.



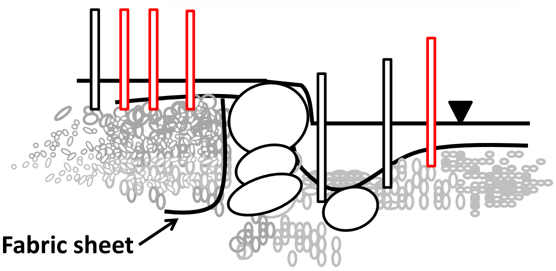


Lautz, and Fanelli 2008, Biogeochemistry

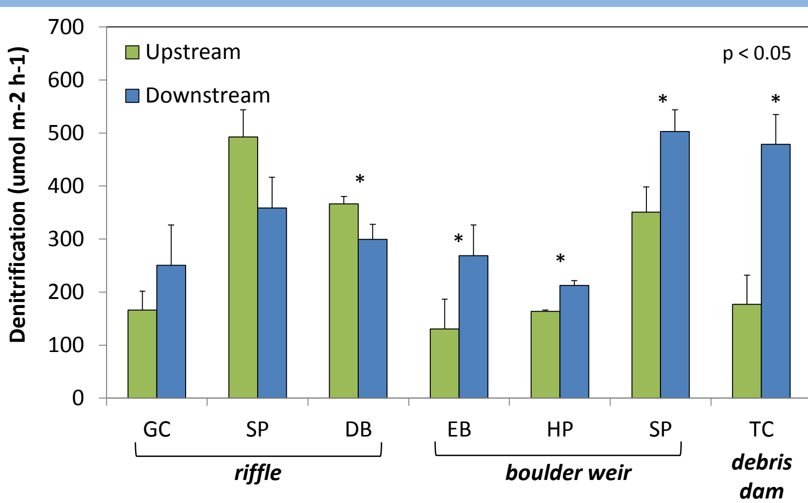


Sedgefield Park (SP)
7/21/2010

<u>Approach</u>: Measure denitrification rates (acetylene block) and head gradients (piezometers in stream bed) upstream and downstream of instream features

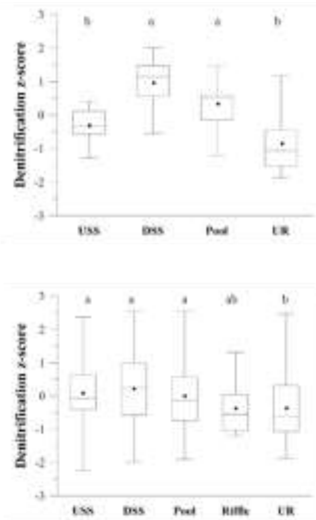


Geomorphic complexity increased denitrification



- Lower head gradients than expected near weir structures with changes in water surface profile
- **Higher DNF in pool downstream** of weir boulder structure

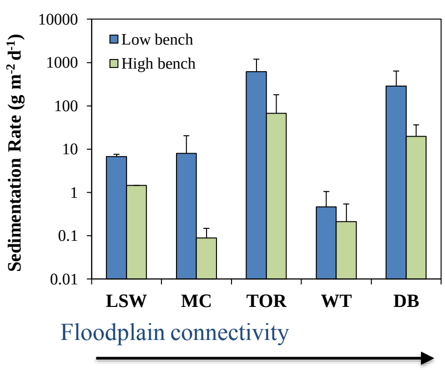
Influence of Channel Complexity + Restoration

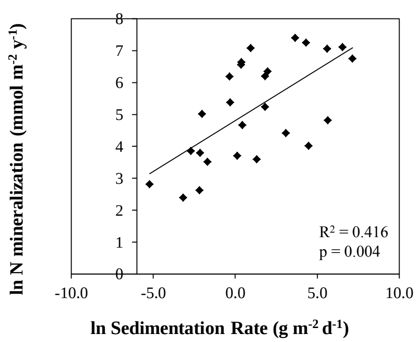


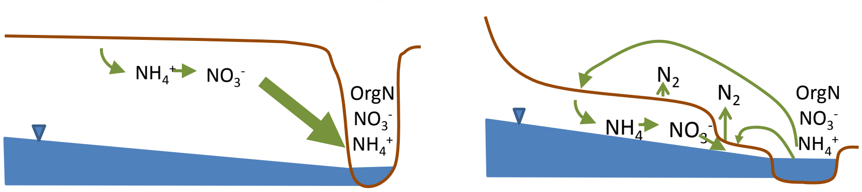
- Channel complexity increased rates of denitrification (p=0.014)
- Higher denitrification rates in restored streams (p=0.0006)
- Locations of greater DNF reflected design and construction practices

Tuttle, A. K., McMillan, S. K., A. Gardner and G. D. Jennings. "Geomorphologic Drivers of Denitrification Rates in Restored and Natural Urban Streams". Ecological Engineering, In Review.

Effect of hydrologic connectivity







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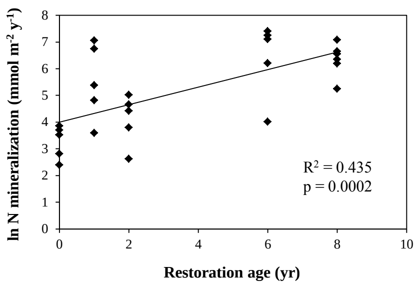
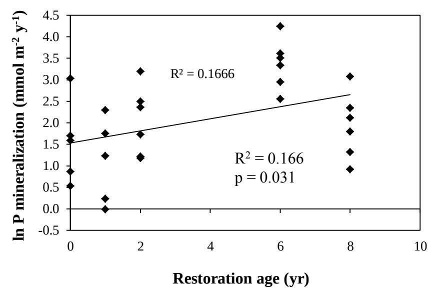
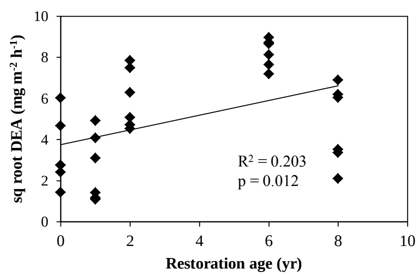
Effect of restoration age on N/P transformations







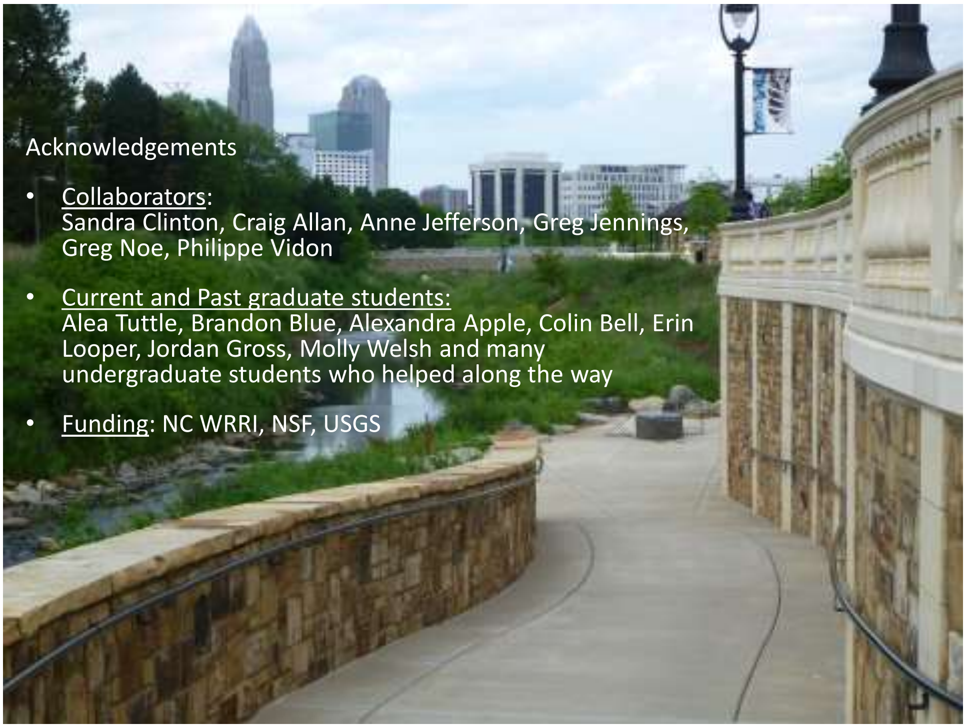
- In-situ mineralization rates of N and P increased with age
- Potential denitrification rates increased with age
- Lower DEA and P-min at oldest site with low connectivity
- Future work to integrate multiple controlling variables (age, connectivity, nutrient loading)

Key stream-floodplain features

RESTORATION AGE:
- Carbon inputs change as canopy cover matures
  - Instream = greater retention in newly restored streams by highly productive autotrophs
  - Floodplains = greater mineralization as sites mature and carbon pools build up

GEOMORPHIC COMPLEXITY:
- Greater diversity of flowpaths increase N/P retention (increase both retention time + microbial activity)

HYDROLOGIC CONNECTIVITY:
- Floodplains that flood frequently AND retain sediment have the greatest sediment carbon and greatest N/P processing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