

NM WRRI Student Water Research Grant Final Report

How does nutrient processing change along a river continuum?



Student Researcher

Vanessa Garayburu-Caruso

Faculty Advisor

Dr. Ricardo González-Pinzón

Department of Civil Engineering, University of New Mexico, Albuquerque, NM
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Research problems and objectives

Eutrophication is one of the main causes of water impairment in the U.S. (Naiman et al. 1995, Carpenter et al. 1998). High loads of nitrogen and phosphorus from point (wastewater treatment plants) and distributed sources (agriculture and urban runoff) stimulate bacterial metabolism and algal growth, often causing episodes of hypoxia (low level of dissolved oxygen) due to the subsequent demand of oxygen for organic matter decomposition. The Rio Grande basin supports 121 fish species, 69 of which are found nowhere else on the planet (Revenge et al. 2000). To preserve this biodiversity and other important recreation uses along the Rio Grande, a deeper understanding of the transport and fate of nutrients along the Rio Grande continuum is needed.

The transport and fate of nutrients is typically described by the dynamic coupling of physical and biochemical processes. Isolating each of these processes and determining their contribution to the whole system is challenging due to the complexity of the physical, chemical and biological domains. As a result, nutrient transport and processing have been primarily studied in headwater streams (Gonzalez-Pinzon et al., 2015) because they are more tractable and, therefore, our current understanding of nutrient processing in larger river systems (> 4th order streams) relies on the unconstrained (and untested) extrapolation of metrics developed in small streams through modeling and/or meta-analyses.

The objectives of my research are to:

- 1) Characterize spatial and temporal differences in nutrient processing in riverbed sediments along the Rio Grande continuum (i.e., from 1st to 8th order streams).
- 2) Characterize uptake limitations by limiting nutrients.
- 3) Understand how natural and anthropogenic influences affect microbial populations and metabolic activity along the Rio Grande continuum.

Methodology

I conducted column experiments to understand nutrient spiraling in shallow sediment-water interactions along representative sites of the Jemez River-Rio Grande continuum (eight stream orders), in New Mexico. I studied one representative site for each stream order (Figure 1, Table 1), with the exception of the 7th stream order where I selected two sites to characterize the high incidence of anthropogenic influences originating from the Albuquerque metropolitan area (i.e., discharges from wastewater treatment plants and irrigation channels).

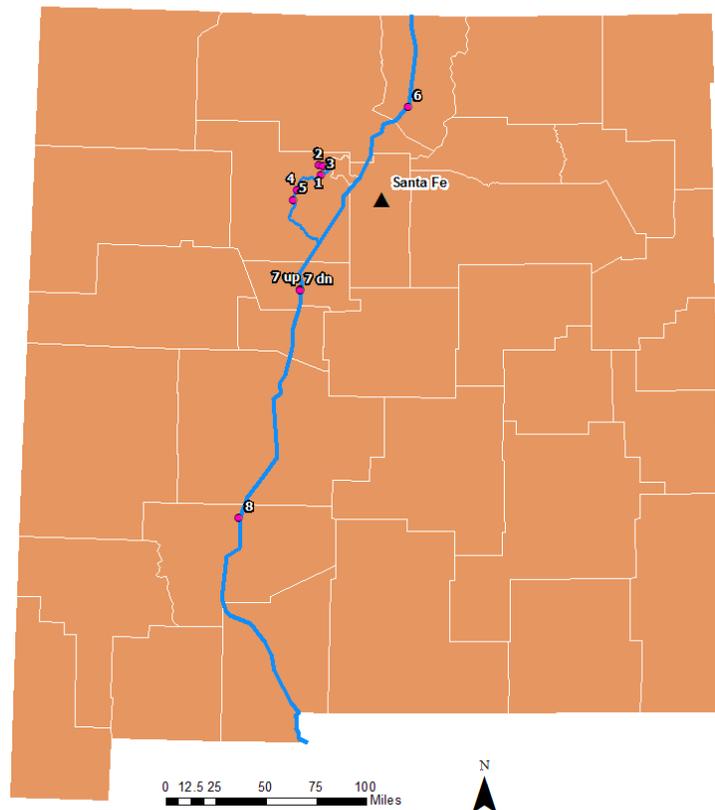


Figure 1. Representative study areas along the Jemez River-Rio Grande Continuum

Site	Location	Significance	Background NO ₃ (ppm)
1	Jaramillo Creek Valles Caldera National Park (VCNP)	Headwaters, uninfluenced.	0.28
2	Jaramillo Creek-VCNP	Headwaters, uninfluenced.	0.28
3	Jemez River-East Fork	Domestic water supply.	0.26
4	Jemez River-The Bluff fishing area	Recreational area. Human influence. Geothermal inputs from Soda Dam.	0.64
5	Jemez River-Diversion Dam	City/Human influence. Geothermal inputs from Soda Dam.	0.14
6	Rio Grande-Taos	Recreational area. Human influence.	0.68
7 up	Rio Grande-Albuquerque upstream WWTP	Human/Agricultural influence. Metropolitan area.	0.29
7 dn	Rio Grande-Albuquerque downstream WWTP	Human/Agricultural influence. Treated effluent.	2.17
8	Rio Grande-Elephant Butte	Agricultural influence.	0.37

For each site, I deployed a set 6 PVC columns (50 cm length, 7 cm diameter) packed with 3 different sediments, i.e., silica cone density sand ASTM D 1556 (0.075-2.00 mm), gravel (2–4mm) and native sediments. The top 10 cm of the column were made of clear acrylic to allow sunlight to stimulate primary production, and the bottom 40 cm of the column with white PVC to reproduce the dark conditions present in the buried sediments. The columns were deployed in December to begin the three month incubation period that will allow natural biological communities to colonize the sediments inside the columns (Figure 2).



Figure 2. Columns design, packing and deployment configurations

In March, after the incubation period was completed, I brought the columns to the lab and performed the following experiments (Figure 3):

- *Nitrate and conservative tracer additions (Nitrate injection)*: I added a short-term pulse of filtered river water with sodium nitrate ($[\text{NO}_3] = 25 \text{ ppm}$) and the conservative tracer sodium bromide ($[\text{Br}] = 65 \text{ ppm}$).

- *Nitrate, phosphate, and carbon additions (Redfield injection):* In a second set of experiments, I injected labile carbon (potassium acetate), sodium nitrate ($[\text{NO}_3] = 25 \text{ ppm}$) and sodium phosphate monohydrated ($[\text{PO}_4] = 2.5 \text{ ppm}$) following the Redfield's ratio (106 C: 16N: 1P).

The pulse was added using a Masterflex peristaltic pump operating at a constant rate of $\sim 6 \text{ mL/min}$ for $\sim 40 \text{ min}$. I collected ~ 40 samples for each column experiment from an intermediate sampling port after the clear acrylic and from the outflow port of the column. The samples were filtered using $0.45 \mu\text{m}$ nylon filter (SCP science) and analyzed using Dionex Ion-Chromatography (ICs-1100) with a $100 \mu\text{L}$ injection loop. A total of 108 column experiments will be run in my research, i.e., 3 columns per stream order, 8 stream orders (with 1 additional experiment in the 7th order), 2 set of experiments, and 2 seasons. Currently I completed the tests for the winter season.

Finally, I determined nutrient uptake dynamics using the Tracer Additions for Spiraling Curve Characterization method (TASCC; Covino et al., 2010). Briefly, this method increases the information content derived from my experimental design with respect to previous methods (e.g., plateau nutrient additions) by a factor that is directly proportional to the number of samples collected.



Figure 3. Experimental set up. Laboratory tracer test experiments

Results and Discussions

The concentrations of NO_3 in all the experiments varied from 40–15000 $\mu\text{g L}^{-1}$, Br ranged between 10–44400 $\mu\text{g L}^{-1}$ and PO_4 varied from 30-1500 $\mu\text{g L}^{-1}$. The ratio of NO_3 :Br in the injection was kept constant at 0.4. The ratio between the consumption of the reactive vs the conservative tracer throughout all the experiments varied from 0.01–0.4, these ratios represent differential transport of NO_3 relative to Br. Higher ratios were observed close to the peaks, these represent a more conservative transport of nitrate; lower ratios were present on the tails and they demonstrate stronger nitrate uptake.

Dynamic uptake metrics were calculated as a function of concentration using TASC for each substrate, injection and stream order. With this method I calculated and plotted key parameters for characterizing nutrient spiraling (i.e. nutrients uptake length (S_w), uptake velocity (V_f) and areal uptake rate (U)) from ambient to saturation concentrations. S_w represents the mean distance traveled as a dissolved inorganic solute before immobilization and removal from the water column. V_f corresponds to the theoretical speed at which a nutrient moves toward a sink and normalizes for the system's flowrate and U quantifies the mass of nutrient immobilized per area per unit time (Stream Solute Workshop 1990, Earl et al, 2006). Among these parameters, I will mainly focus on uptake velocity. V_f reflects nutrient uptake relative to concentration, hence it can be used to determine nutrient uptake efficiency (Davis and Minshall 1999). Figure 4 presents the results from both tracer injections (and for all stream orders) on columns packed with native sediments, similar trends were observed for the others substrates but only native sediments findings are fully described on this report.

By analyzing the resulting plots of uptake rate vs total nitrate concentration it can be suggested that the biological uptake follows saturation kinetics (e.g. Michealis–Menten enzyme kinetics). At lower nitrate concentrations, the uptake rate seems to be increasing linearly following a 1st order kinetic model, U increases proportionally until certain nitrate concentration where U remains around the same interval. Although it is expected that at higher nitrate concentration U would arrive to saturation (constant U with increasing nitrate concentrations), this stage was not reached experimentally, with the exception of the 1st order Redfield injection. Non saturation conditions allow the system to remain as nutrient limited, preventing poor nitrate uptake due to higher nutrient levels.

The results show that for the most part, under the same hydrologic and chemical conditions, uptake values do not vary significantly along the river continuum. This behavior could suggest that microbial species composition do not influence biological nutrient uptake. DNA extraction and bacteria sequencing of the sediments is required in order to verify the above statement, possible variations in processing could be also attributed to community structure, diversity and oxygen consumption.

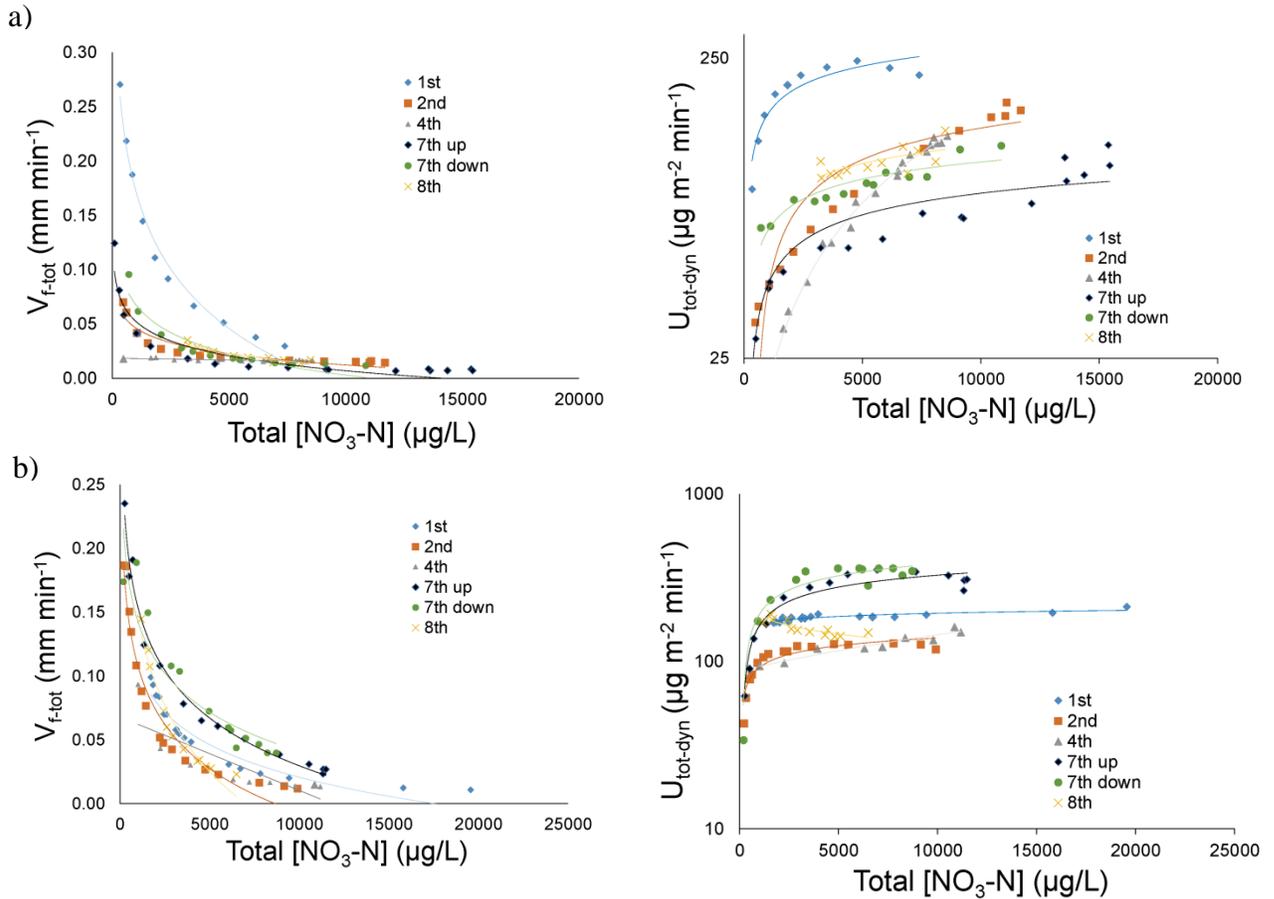


Figure 4. (a) Nutrient uptake kinetics for all stream orders, native sediments, nitrate injection. (b) Nutrient uptake kinetics for all stream orders, native sediments, Redfield injection

Figure 5 compares uptake velocities for nitrate and Redfield injections by stream order. Based on these trends, it can be seen that biological nutrient processing is limited by nitrate in headwater streams and by phosphate and carbon in larger stream orders. By increasing N:P ratio (16:1), some microorganisms show an increased demand for N relative to P (nitrate affinity is greater when phosphate is abundant), which explains by nutrient limitation theory why nitrate uptake is higher in larger stream orders for Redfield. However, the fact that nitrate uptake remains invariable for headwaters indicate that N can also be the limiting nutrient since autotrophic and heterotrophic communities exhibit different nutrient limitation: N may limit autotrophs, heterotrophs may be simultaneously limited by P or N.

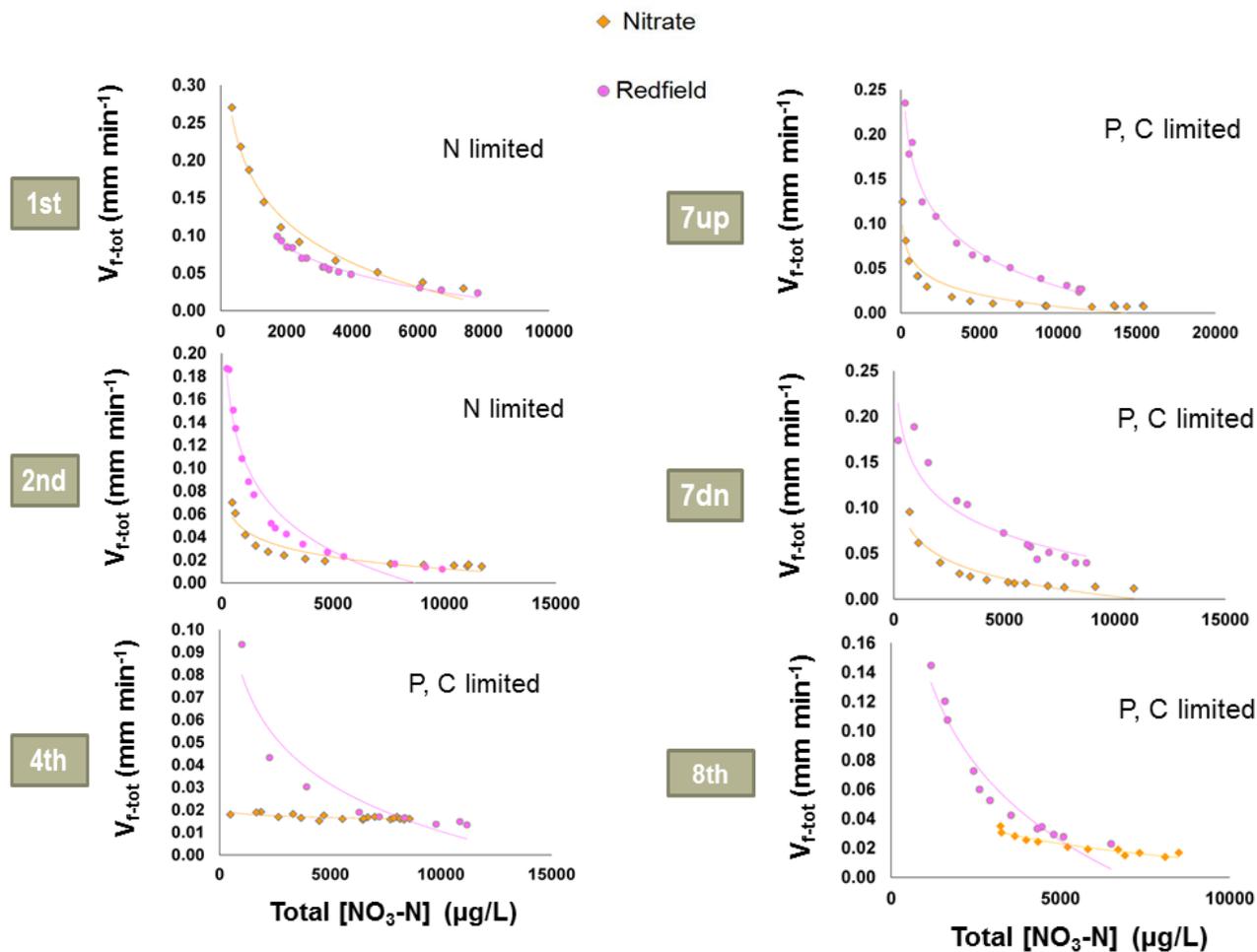


Figure 5. Uptake velocity for all stream orders. Nitrate injections represented in orange and Redfield injections in pink.

Finally, Figure 6 compares uptake velocity for the two locations in the Albuquerque metropolitan area (7th stream order, upstream and downstream the waste water treatment plant (WWTP)). The results expose no significant difference between the two locations regardless of the type of injection. This suggests that anthropogenic influences associated with wastewater treatment plant discharge do not affect biological nutrient processing.

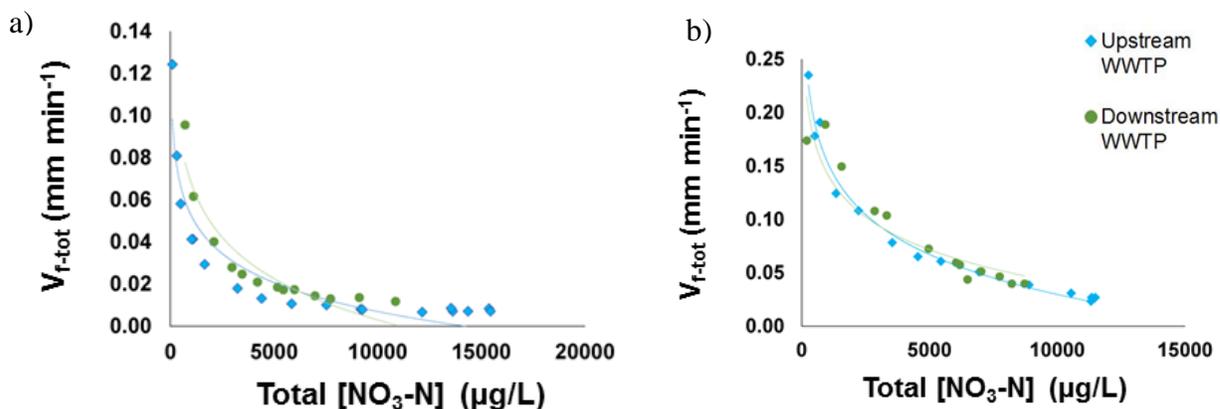


Figure 6. Uptake velocity, 7th stream order, upstream and downstream WWTP orders. (a) Native sediments, nitrate injection. (b) Native sediments, Redfield injection.

Conclusions

- Nutrient processing along the river continuum follows Michealis–Menten enzyme kinetics.
- Nutrient biological uptake might not be directly influenced by species composition.
- NO₃ uptake velocity in larger streams demonstrates a biotic nutrient limitation for phosphate and carbon, while headwater streams showed nitrate limitation.
- Large streams exhibited more efficient NO₃ uptake at high N:P ratio. But the processing in the headwaters remained the same.
- Anthropogenic influences associated with wastewater treatment plant discharge do not significantly affect biological nutrient processing.

Acknowledgements

I would like to acknowledge the New Mexico Water Resources Research Institute 2016 Student Grant and the National Science foundation for supporting this research.

Provide a paragraph on who will benefit from your research results. Include any water agency that could use your results.

With these experiments I will be able to determine for the first time how natural changes in bacterial communities and sediment composition occurring seasonally along the river continuum define nutrient processing, as well as the relationship between biofilm formation and riverbed sediment diversity. This work will support the development of a new generation of field and lab experiments to quantify nutrient processing in large rivers where only about 5% of all reported tracer experiments have been conducted. Also, my research will provide valuable insight into managing impaired reaches along the Rio Grande basin.

Describe how you have spent your grant funds.

I have spent my grant funds on the following:

- Laboratory supplies and column building materials (i.e. silica sand, PVC pipes and fittings, silicone, PVC glue, hose clamps)
- In state travel needed to complete field work related to column deployment.
- Poster printing.
- Travel costs associated with AGU conference and poster printing.
- In state travel needed to complete field work related to retrieving the columns from the river.
- Laboratory supplies needed for collecting, filtering and analyzing samples (digitubes, vials and caps for Ion Chromatography, 0.45 µm filters).

List presentations you have made related to the project.

I have presented a poster on the following conferences:

- NM WRRI 60th Annual New Mexico Water Conference. Taos, NM. (10/15)
- Mexican American Engineers & Scientists (MAES) Symposium. Las Vegas, NV. (10/15)
- American Geophysical Union (AGU) Fall Meeting. San Francisco, CA. (12/15)

I have performed an oral presentation on the following conference:

- Association for the Sciences of Limnology and Oceanography (ASLO) Summer Meeting. Santa Fe, NM. (6/15)

List any other students or faculty members who have assisted you with your project.

Faculty

- Dr. David Van Horn
- Dr. Timothy Covino

Students

- Jacob Mortensen
- Betsy Summers
- Cameron Herrington

Provide special recognition awards or notable achievements as a result of the research including any publicity such as newspaper articles, or similar.

- First place on the Mexican American Engineers & Scientists (MAES) Symposium 2015 Research Poster Competition in Las Vegas, NV.

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