Hydrologic effects on nitrate loading and transformation in backwater lakes of the Upper Mississippi River.

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Abstract

Floodplain backwater lakes (BWL) are biogeochemically active and potentially able to remove significant portions of transported nitrate (NO_3^-) from the Upper Mississippi River (UMR) ecosystem. We explored NO3- transformations in BWL receiving high NO3- water under natural flooding and controlled inflow conditions to determine: 1) patterns of NO3- loss; 2) biogeochemical processes affecting NO3- transformation; and 3) effect of loading rate on removal capacity. In a large (300 ha) BWL, floodwater NO3- concentrations dropped from 6.5 to < 0.5 mg-N· L^{-1} in 12 d, with a total loss of ~18 tons-N. Under controlled inflow another BWL (Third Lake, 15 ha) exhibited high rates denitrification (22 µg-N · cm-2 · d^{-1}), limited by NO3- loading and tightly coupled with nitrification. Nitrate retention was linear to load (r^2=0.95), with greatest retention occurring in late June. Mass balance suggested an average of 48 kg · d^{-1} NO3- was removed from Third Lake (~ 43 % of the total load), ~ 30 % via denitrification. These results show backwater lakes of the UMR have tremendous potential for NO3- removal, a potential that is directly related to river-flood plain connectivity. Managed reconnection of backwaters to main channels could reduce downstream flux of NO3- while also restoring other ecologic functions and meeting multiple management goals.

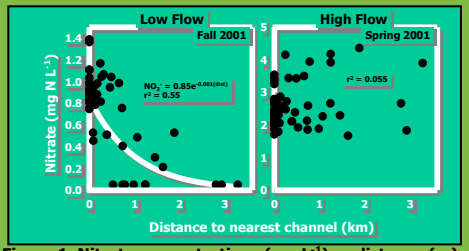


Figure 1. Nitrate concentrations (mg L^{-1}) vs distance (m) from main channel, in Nav. Pool 8 during low flow and high flow (flood); floods tend to homogenized nitrate concentrations across river pools

Background

Flooding redistributes solutes, homogenizing concentrations across floodplains (Fig.1). Nitrate concentrations are largely controlled by an interaction between river discharge and flood plain geomorphology (e.g., connectivity).

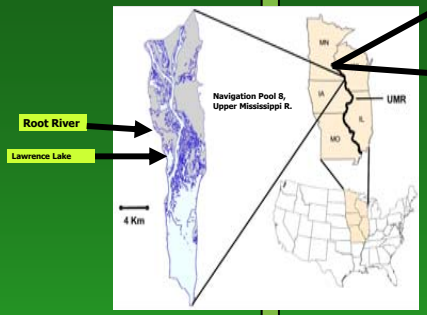
Questions

1. What is the pattern of nitrate dissipation after flooding in backwater lakes?
2. With controlled loading what are the spatial and temporal patterns of nitrate dissipation and processing in flood plain lakes?
3. What the limits to nitrate removal by flood plain lakes?

Natural flooding of flood plain lakes: Lawrence Lake

High nitrate flood waters from the Root River inundate **Lawrence lake**, a 300 ha backwater lake of the UMR. Rapid loss of nitrate after flooding is a common feature of backwater lakes.

Figure 2. Lawrence Lake; vegetation includes *Nelumbo*, *Ceratophylum*, *Myriophylum*, and *Phalaris*; with 50 – 90% coverage of lake surface.,



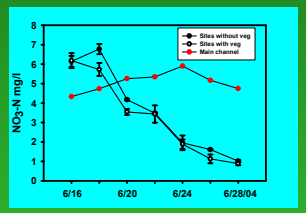


Figure 3. Rapid depletion of [NO_3^-] in Lawrence Lake following flood, 16 June to 30 June 2004. Note: [NO3] in Main Channel of Mississippi River for reference.

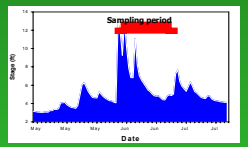


Figure 4. Discharge of Root River resulting in flooding of Lawrence Lake. Sampling period from 12 June to 30 June, 2004.

Summary

Flood plain lakes tend to have low [NO3-] in summer; flooding (either tributaries or Mississippi River) can increase [NO3-] to 6 - 8 mg L^{-1}. Ambient denitrification is low (< 0.1 ug-N cm^{-2} d^{-1}) except after flooding; sediment pore water [exchangeable NHx] tends to be high (~20 mg-N L^{-1}), promoting coupled nitrification-denitrification (Strauss et al, 2004, Richardson et al 2004).

Following flooding by the Root River, [NO3-] in Lawrence Lake reached maximum (6.7 mg L^{-1}) on 18 June; within 12 days [NO3] was <1 mg L^{-1}. [NO3-] in macrophyte beds tended to be lower than open water.

Nearly 18 tons NO3-N was removed from this flood plain lake in the 12 d post flood.

Controlled flows to flood plain lakes: Finger Lakes system - Third Lake

Upper Navigation Pool 5: Finger Lakes. Upstream end of each lake with a gated culvert to control flows from Pool 4 into each Finger Lake

Figure 5. Water column sampling sites in the Finger Lakes. Third Lake is outlined in red. Weekly sampling of nutrients and discharge at inflow and outflow of each lake. NO3, NH4, TN, soluble P, total organic carbon.

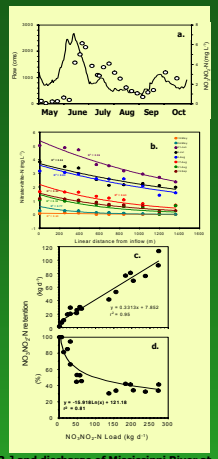


Figure 6. [NO3-] and discharge of Mississippi River at Finger Lakes (a) from May to October – note large increase in [NO3] in late June following flood; (b) longitudinal change in [NO3] along axis of Third Lake – note increasing NO3 depletion with increased inflow concentration; (c) NO3 retention v NO3 load (kg/d); (d) retention rate asymptotes at loading >200 kg/d to ~40 % retention, a function of decreasing water residence time with increasing inflow rate.

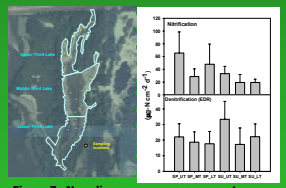


Figure 7. N-cycling process measurements (sediment nitrification, denitrification) were made in May (=SP) and July (=SU), at 6 random sites (yellow dots) in each of three regions of Third Lake (UT, MT, LT). Nitrification was high but did not vary by date or lake region. Denitrification was highest in July and the near inflow area.

Table 1. NO3 budget for Third Lake

Variables		Flux (kg d^{-1})
Measured inputs	Culvert loading	113
	Nitrification	51
Measured outputs	Denitrification	32
	Discharge	65
Difference	Gross retention	97
	Net retention	48

Conclusions

1. Nitrate concentrations in flood plain backwaters of the UMR are determined by flood loading and uptake processes. 2. Denitrification is an important loss (~30% in Third Lake); temporary storage (assimilation) accounts for >60 of loss. 3. NO3 removal capacity is limited by lake retention time and NO3 delivery. 4. Restoration of backwater – main channel connectivity would result in increased nitrate retention in the UMR.

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