Response of N-cycling variables to flow and water level manipulations in Navigations Pools 5 and 8, Upper Mississippi River

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Focus of talk:

1. Pattern of nitrate loss from sediments as a result of water level management.
   (drawdown of Pool 8)

2. Patterns of nitrate removal in a flow-controlled backwater lake – with implications for management of nitrate.
   (Finger Lakes example)

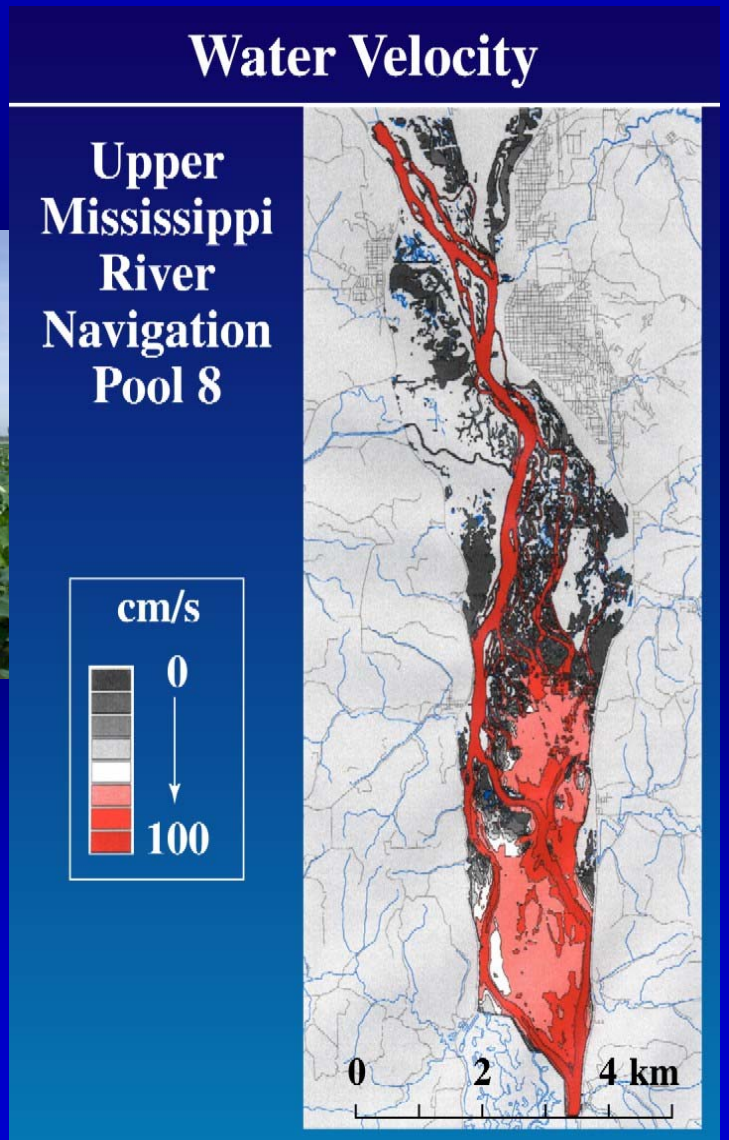
3. Ongoing and future planned research:

   Pool 5 drawdown (role of macrophytes on N flux;
   Periphyton assimilation of NO3 in Finger Lakes;

Management Issues: What can be done *on the flood plain* to reduce local effects of nitrogen enrichment and reduce downstream loss of N?

1. Water level management

2. Alternate flow management



Water level management:

1. Attempt to simulate a more natural hydrograph;

   - by reducing summer water depth in a given navigation pool;

   - facilitated by operation of the lock and dam system.

2. Expected outcomes:

   - sediment drying: compaction, aeration, seed germination.

   - increase depth of photic zone to promote plant growth.

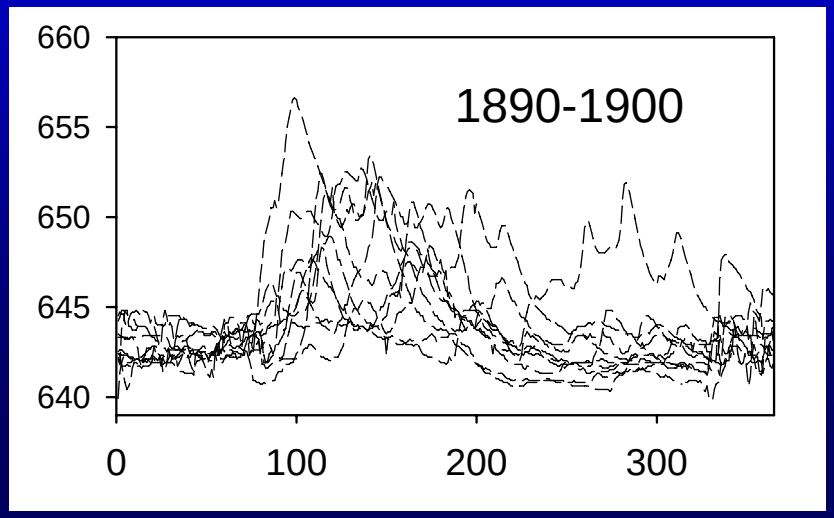
   - increase upper trophic production (e.g., fish & ducks) by increasing plant production and diversity.

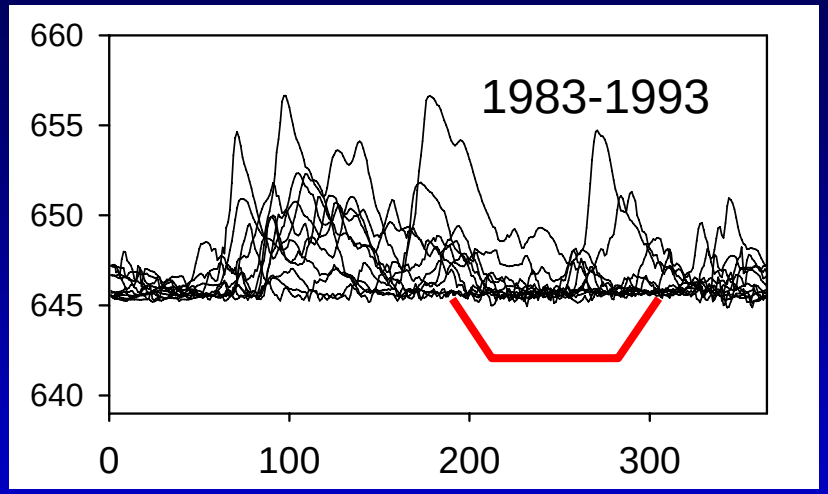
   - decrease sediment organic carbon and nitrogen through alternating oxic (drying) and anoxic (hydrating) conditions.

3. Sites: Pool 8; summer 2001 (40 days, variable depth, mixed duration) and 2002 (90 days, 0.5 m); Pool 5: summer 2005 (50+ d, ~0.5 m)

Effect of water management for navigation: Water elevation at Winona, Minnesota

Elevation (ft)





Daily River Stage: 1890-1900

Mean stage: 645, but variation extreme.

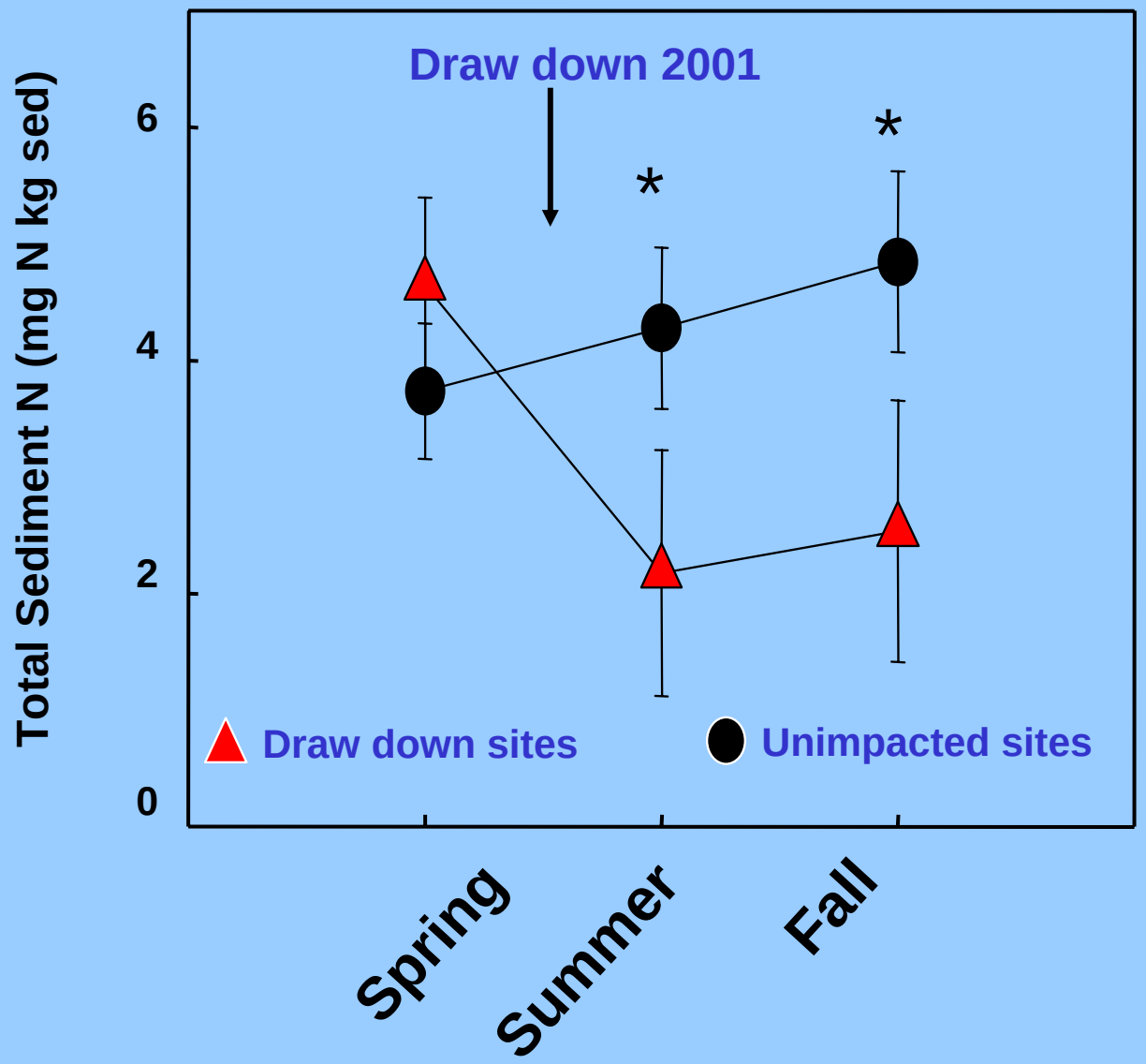
Resulted in more dynamic channel form, more variable light penetration, variable sediment wetting and drying.

Daily River Stage: 1983-1993

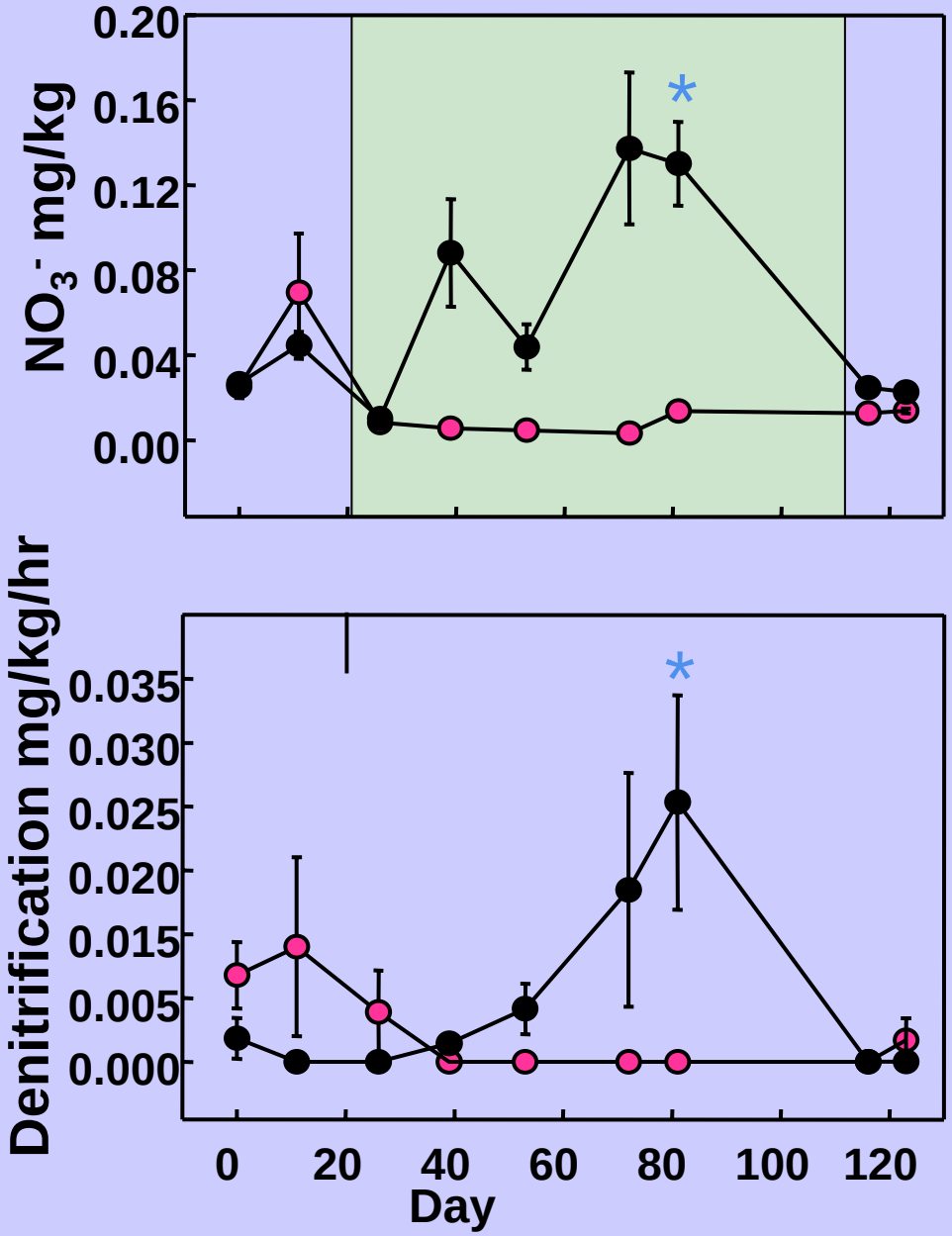
Mean stage: 648, but low end of hydrograph truncated

"Water level management"
Designed to simulate historical low summer river stage.

Preliminary results (low sample size): Total sediment nitrogen during 2001 drawdown of Pool 8



Effect of drawdown on sediment nitrogen in 2002 (more extensive study)



= Sed. remained wet

= Dried and re-wet

Plant growth during study:

Start of study: 0 g/m^2

End of study 500 g/m^2

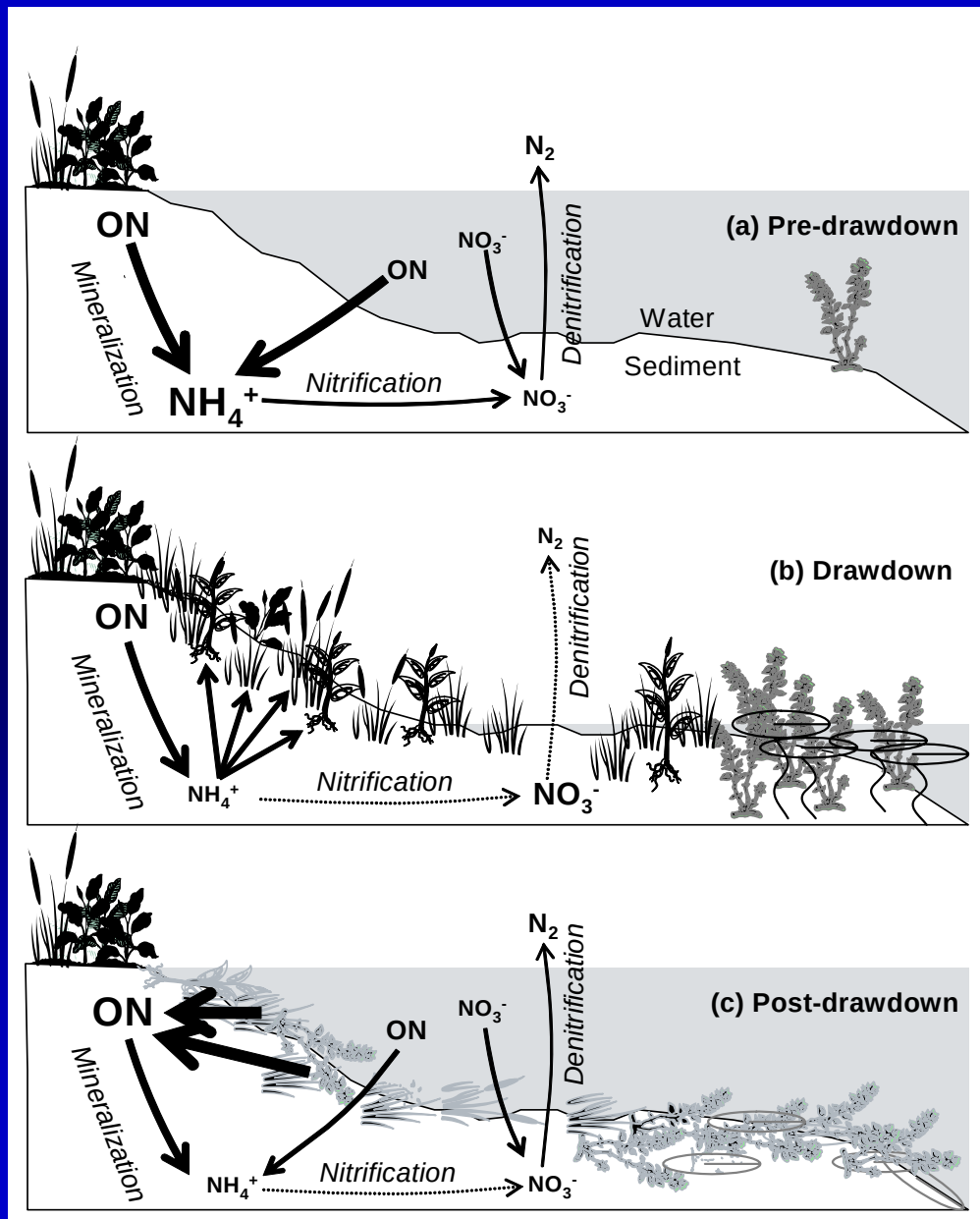
Total N contained in plant biomass: 19 g/m^2

Summary of drawdown effect on N loss.

(a) Pre-drawdown: Coupled Den-Nitr important in organic sed. of backwaters and impoundments; mineralization of ON drives NH4-nitrification dynamics.

(b) Drawdown: Den. Minimal; nitrification slowed; macrophyte-N dynamics increased – temporarily resulting in NHx decrease in sediment; senescence and mineralization likely release N for downstream flux in fall and spring floods.

(c) Re-wetting: recovery of microbial processes is slow; role of mineralization, plant senescence, organic N loss is unknown.



Water Level Manipulations: conclusions

1. Positive response from emergent macrophytes (biomass, seed bank).

2. Effect on nitrogen dynamics:

   Significant reduction of sediment porewater ammonium (UMR);

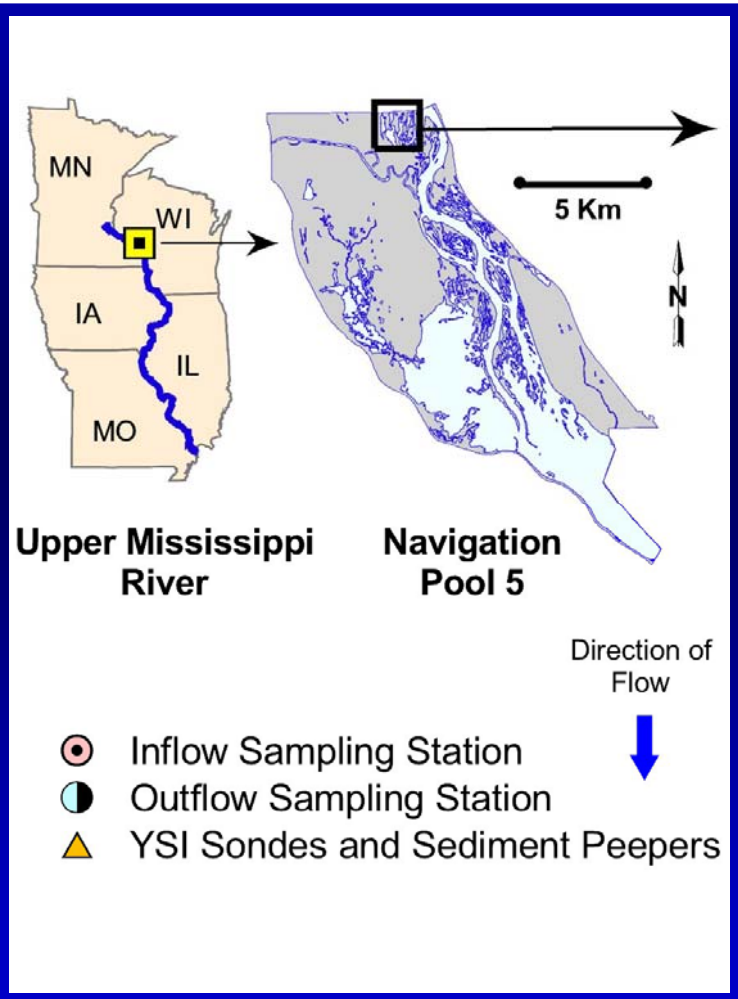
   Some reduction in total sediment N (UMR).

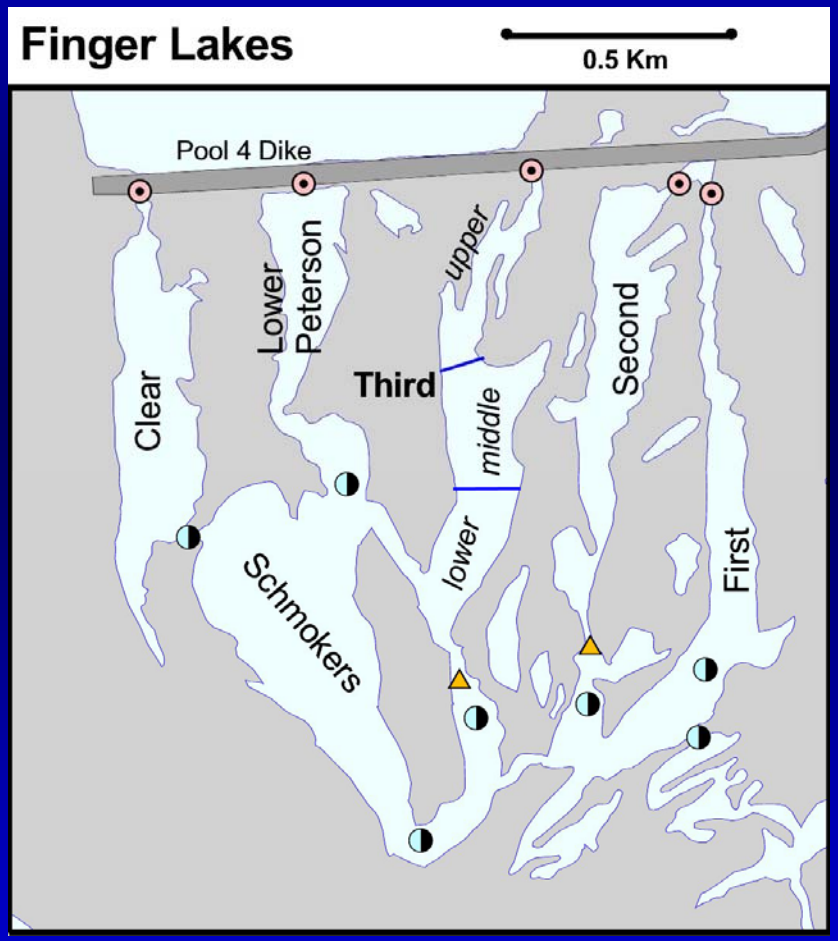
   Emergent macrophytes likely key to understanding N dynamics.

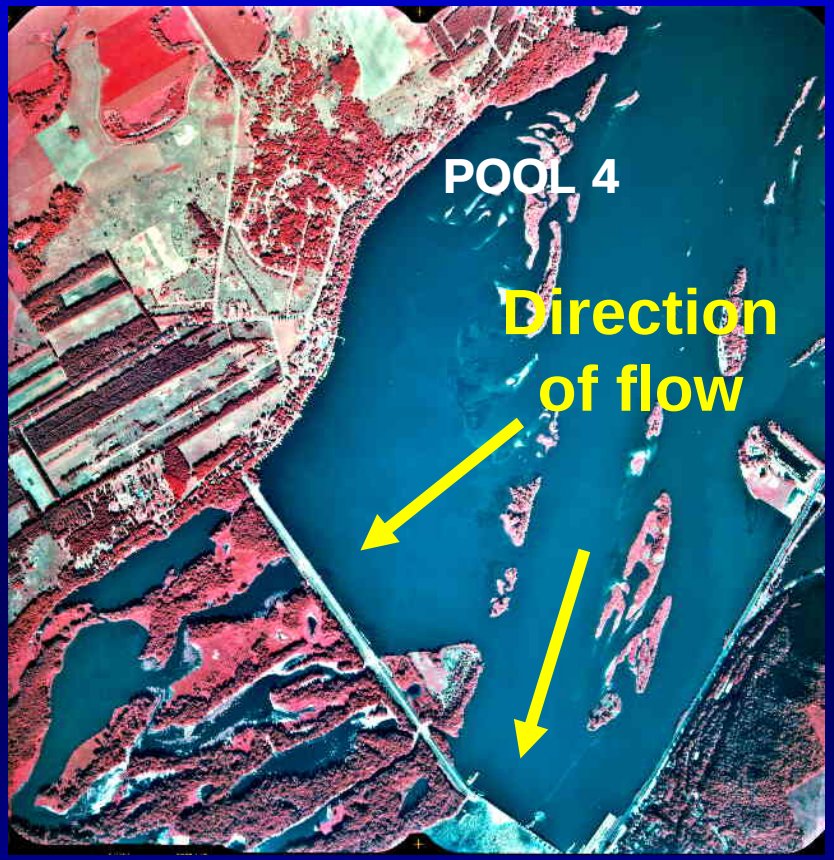
3. Lack of water delivery to bioreactive sediments prohibits denitrification except that coupled with nitrification.

4. Effective N management tool? If combined with macrophyte harvest might see significant effect.

Nitrate in flow-through backwater lake: The Finger Lake system, Navigation Pool 5







Flow regulation via valved culverts at upper end of each lake; inflow ~1.0 m^3s^{-1}, max = 1.6 m^3s^{-1}).

Upstream culvert

Upstream dike

Upper Third Lake

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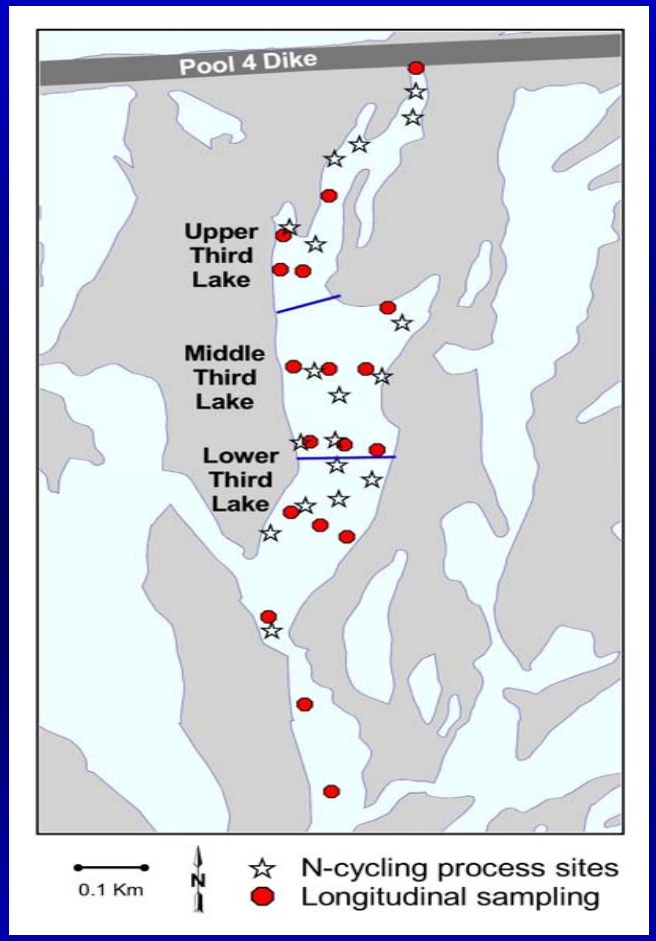
Third Lake (2004)



Area = 15 ha, max depth = 2m, mean = 0.6m, volume=93,000m^3

Biweekly sampling

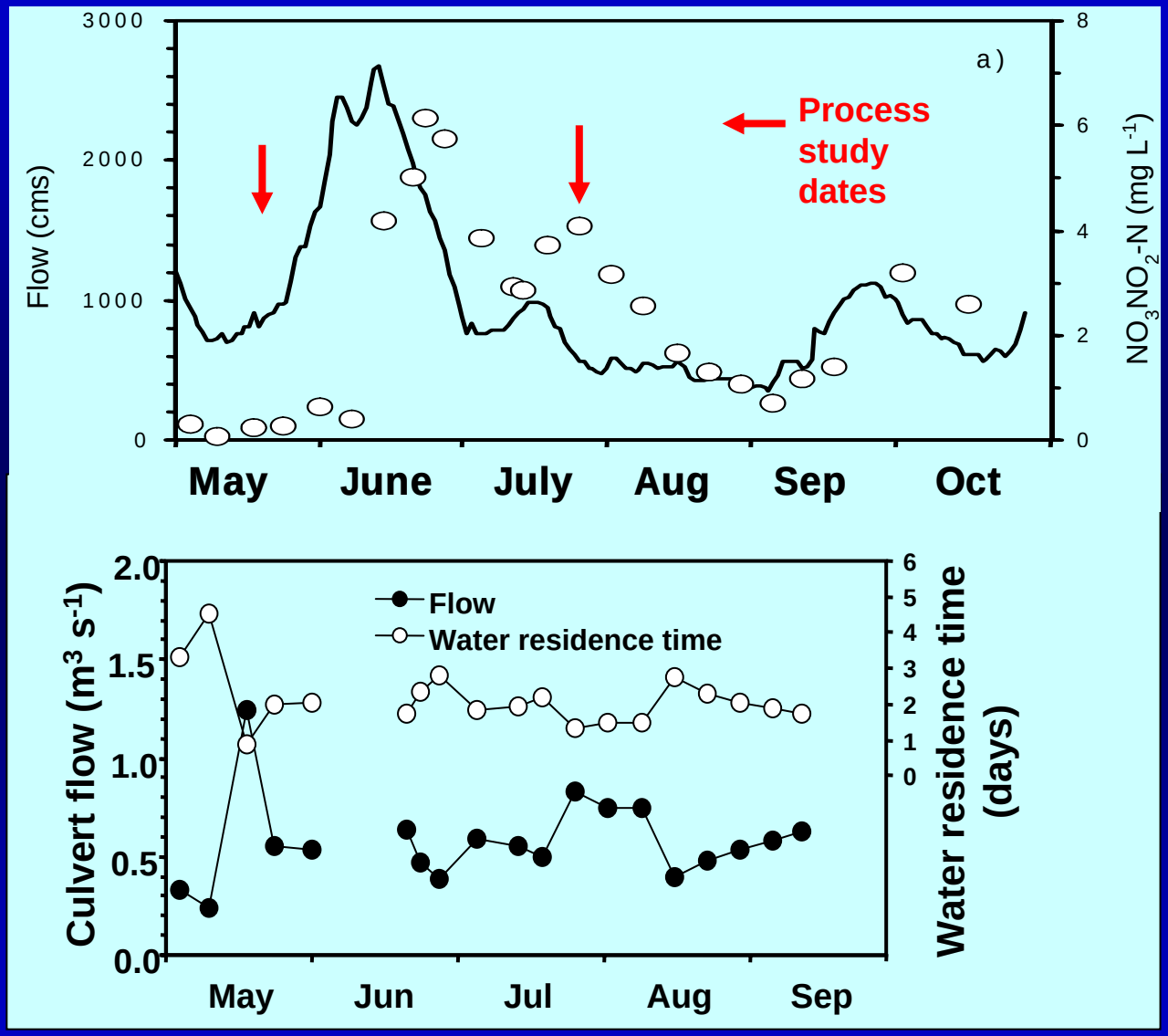
Inflow/outflow, longitudinal
TN, NO3, NH4, POC

Sediment process sampling

Denitrification (acetylene block), N+C limitation assays, nitrification (nitrapyrin method), water column NO3-, NH4+,

Sampled 18 locations, low NO3 load (spring), high NO3 load (summer)

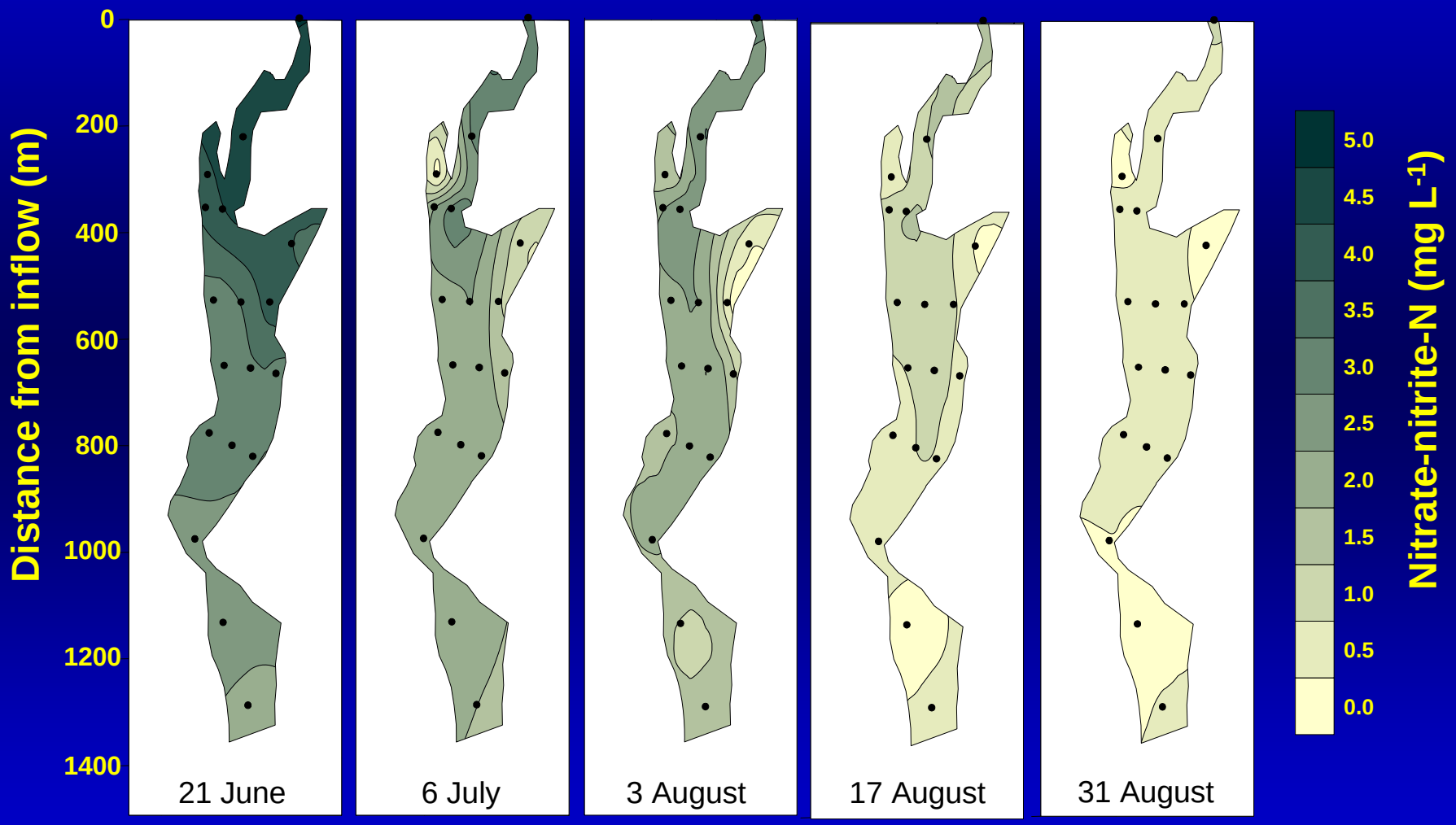
Source water nitrate, inflow rates, and resident times



River source water [NO3] low until June flood, increasing from <0.5 mg/l to 6 mg/l.

Water residence time ranged from 1 to 5 d

Spatial variation of nitrate concentration in Third Lake through time



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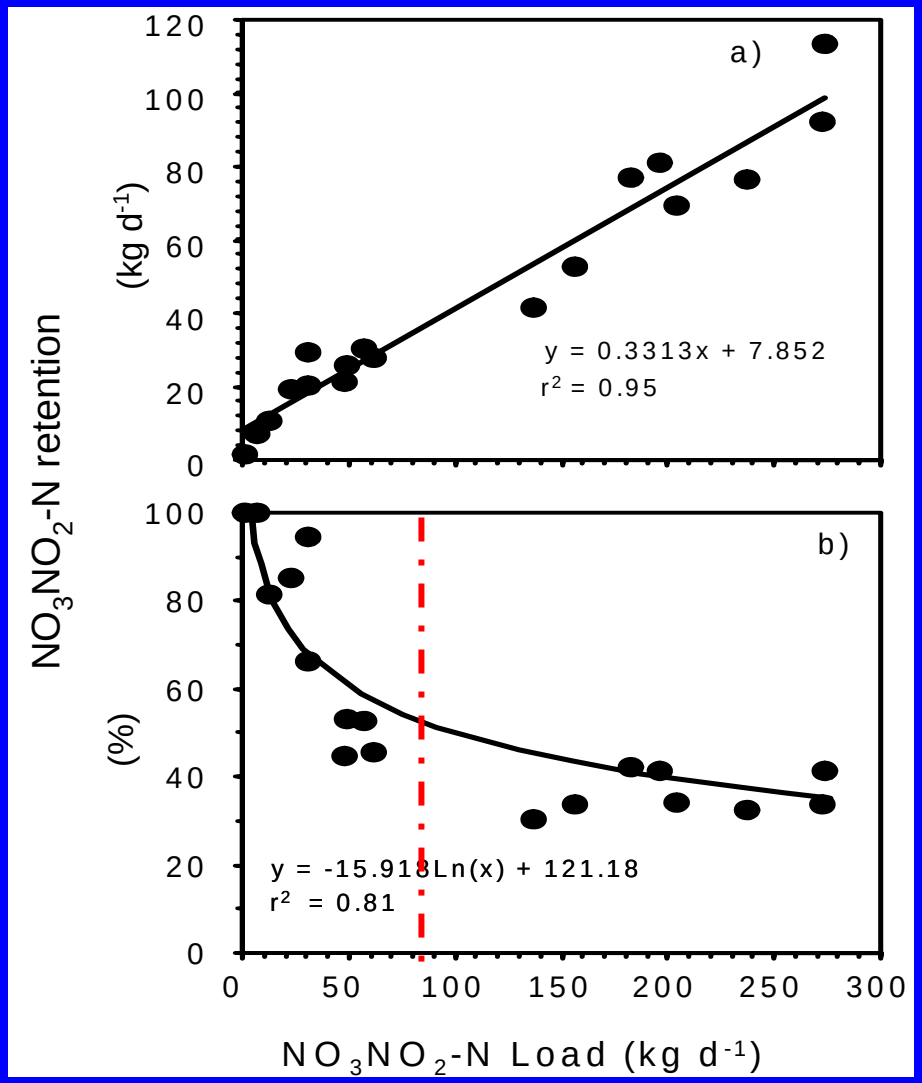
Nitrate retention capacity of Third Lake

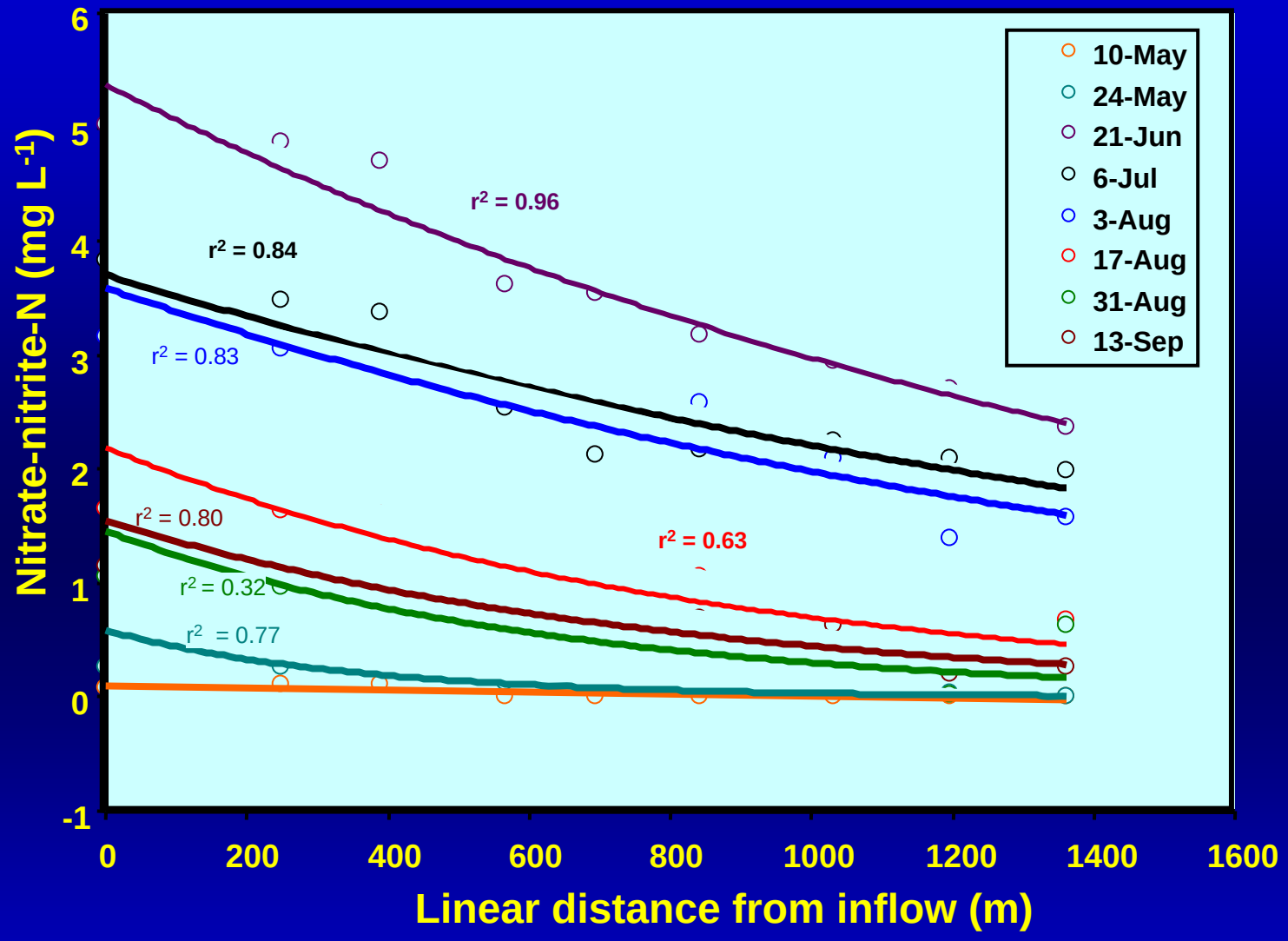


Nitrate retention on a mass basis (kg/d) increased linearly with load.

Average retention: ~ 3.5 kg/ha/d.

Nitrate retention, as a percent of load, declined at loads > ~75 kg/d to 40 %.

Loss of retention capacity likely a result of overshooting uptake length (>1500 m, with load > 200 kg/d).



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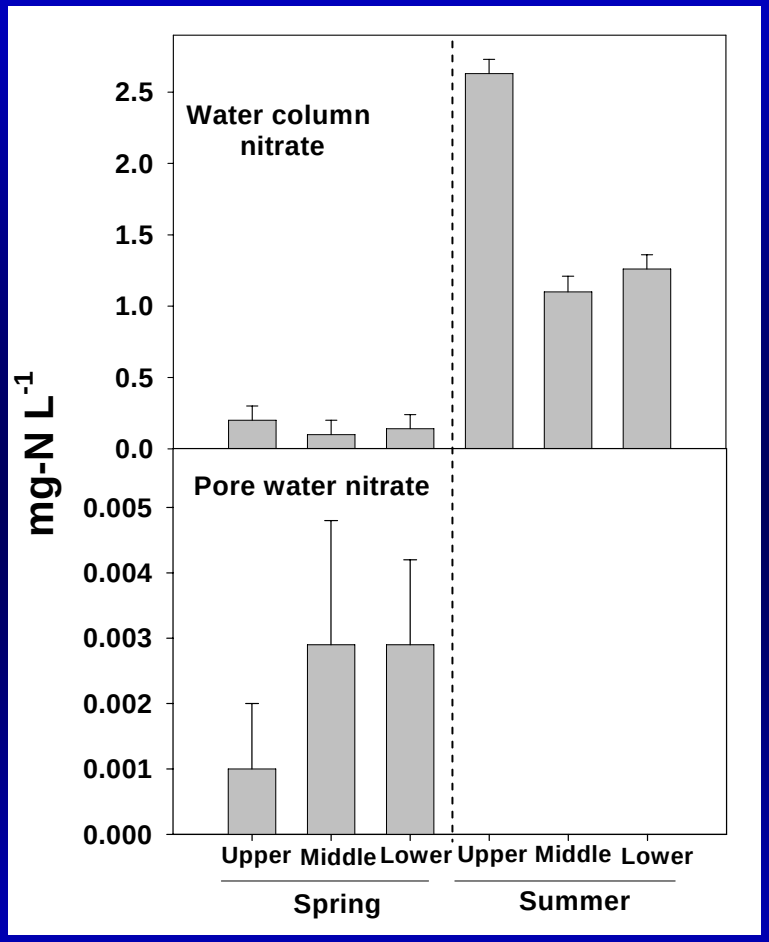
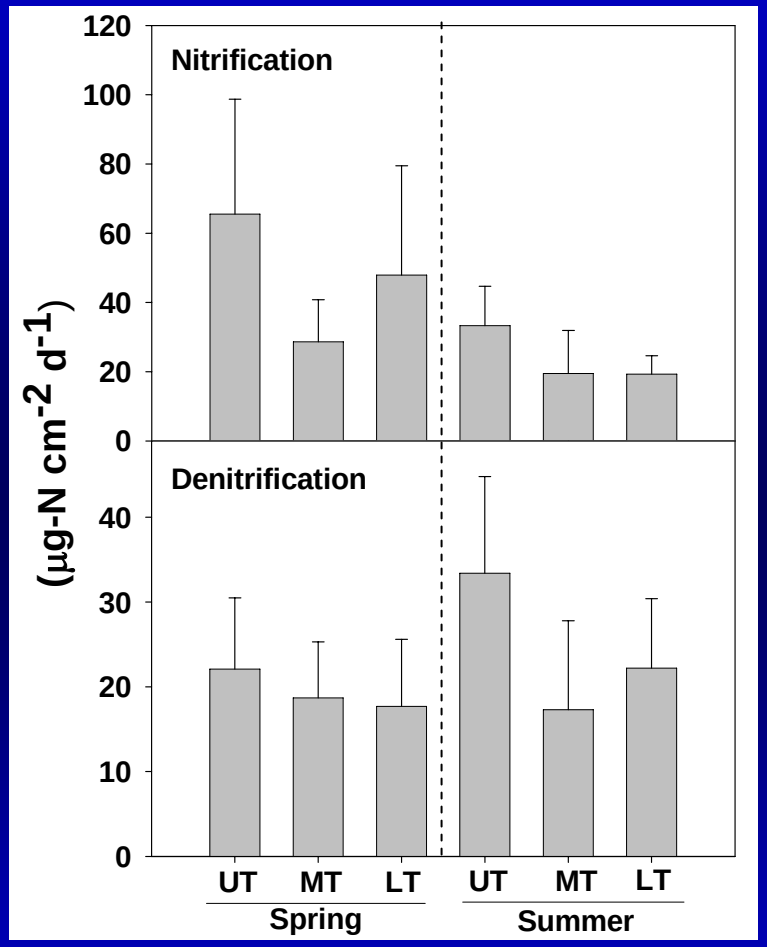
Process estimates:

spring v summer, low v high nitrate load





Water column nitrate significantly higher in summer, higher in upper end of lake in summer; Porewaer nitrate higher in spring, no spatial variation.

Nitrification: higher in spring, little spatial variation; Denifiication: higher in summer, higher in upper part of lake.

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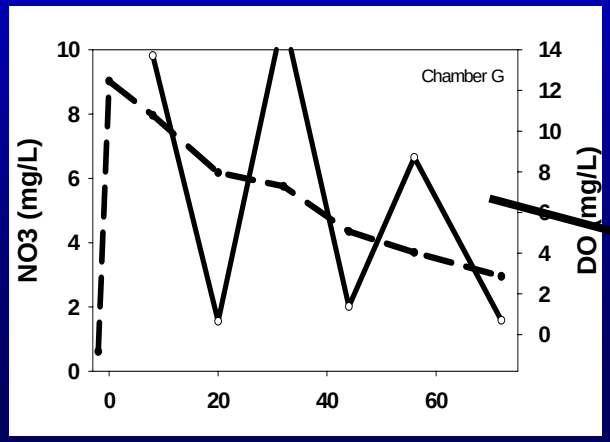
Conclusions

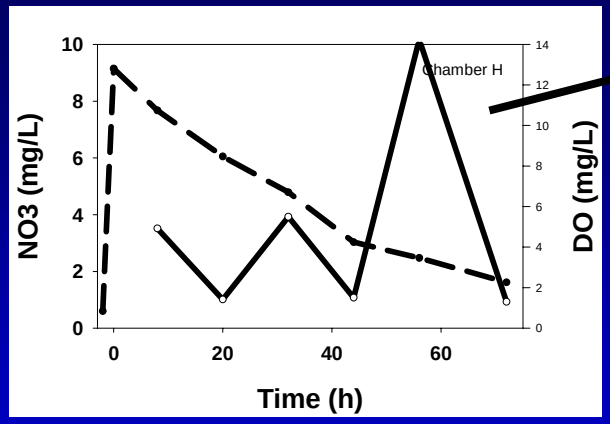
- Nitrate losses in two floodplain lakes loaded by flooding or controlled inflow during summer was ~ 3 to 5 kg/ha/d.
- Denitrification accounted for roughly 10 - 30% the nitrate retention in Third Lake.
- Assume assimilation accounts for ~70 - 90% of nitrate retention. Long term fate of assimilated N currently unknown.
- Controlled inflows to backwater lakes could function to reduce nitrate movement downstream while also improving fisheries and wildlife habitat.

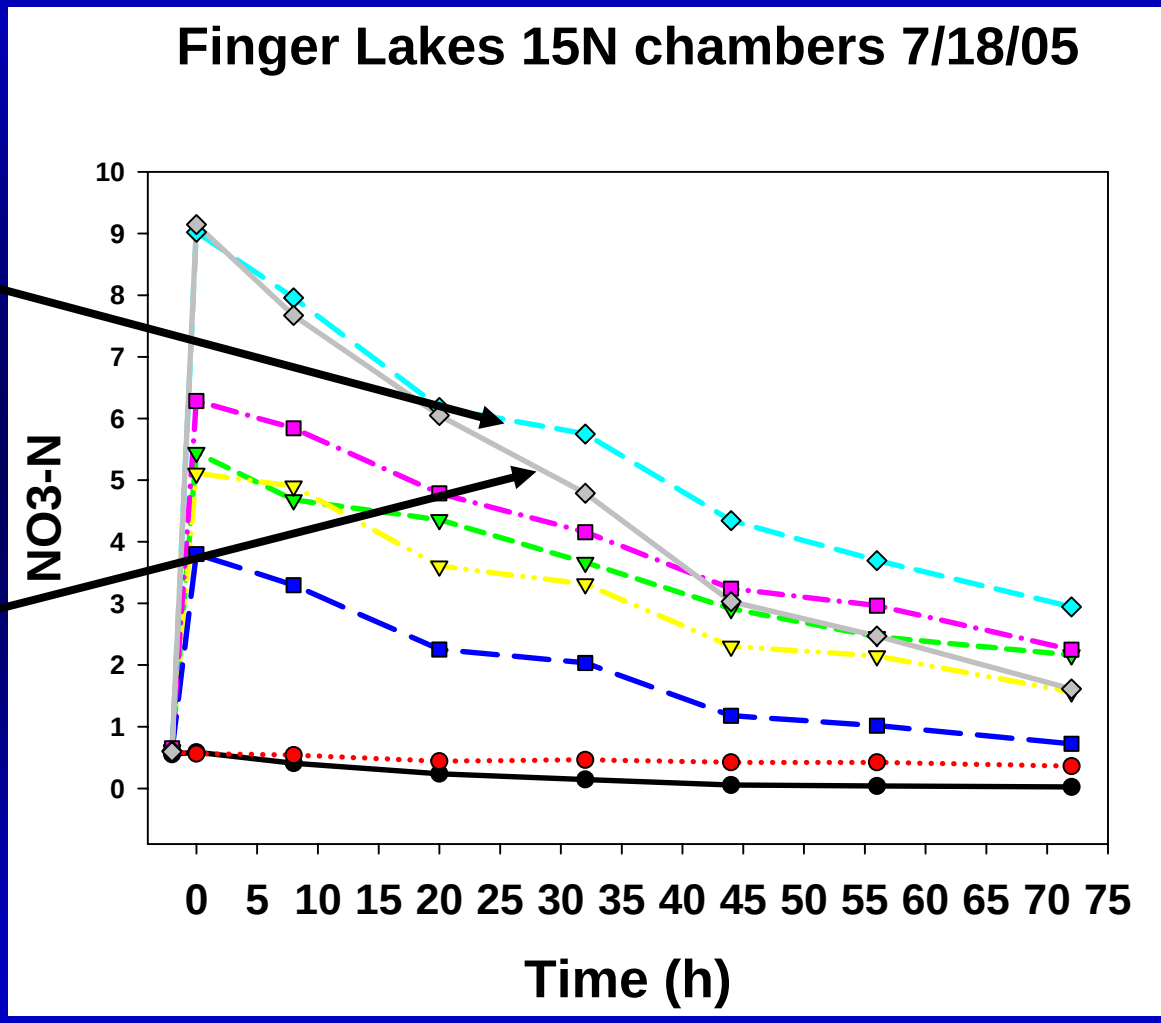
Current work in Finger Lakes:

1. Determine assimilation of NO3-N by periphyton using *in-situ* ^{15}N tracer + NO_3 uptake experiments in Finger Lakes.
2. Will relate assimilation estimates to loss via denitrification and mass flux of total N through backwater lakes.
3. Build simple models linking hydraulic function (N loading and flow paths) and biogeochemical processes.

Preliminary results: NO3 uptake in plant beds of Third Lake







2005 6 27

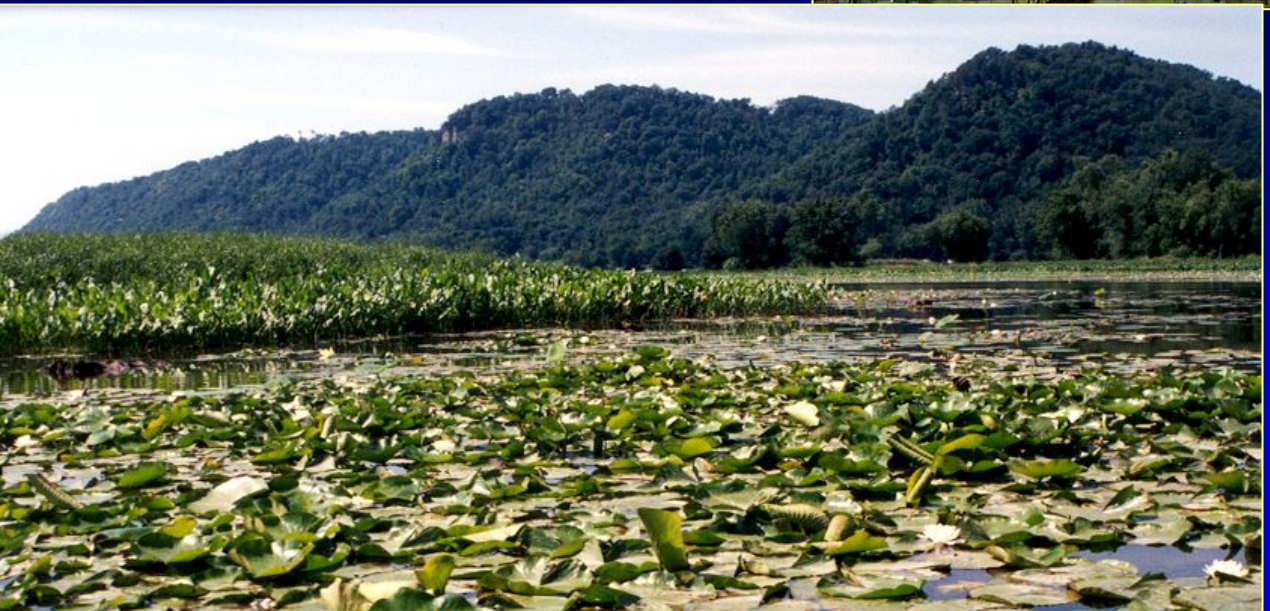
2005 6 28

2005 6 27

2005 6 27

2005 6 27

Current work on Pool 5 drawdown:



Habitat characteristics of "Navigation Pools"

Low
C &N

Sediment C & N Gradient

High
C & N

Main channel

high NO_3^-

low PW NH_4

Off-channels

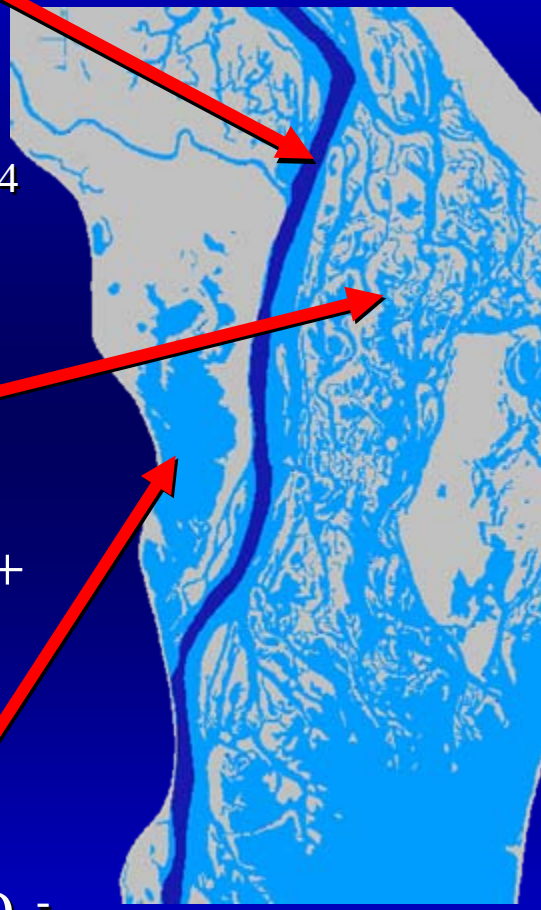
variable NO_3^-

variable NH4+

Backwaters

low WC NO_3^-

high Sed NH_4^+



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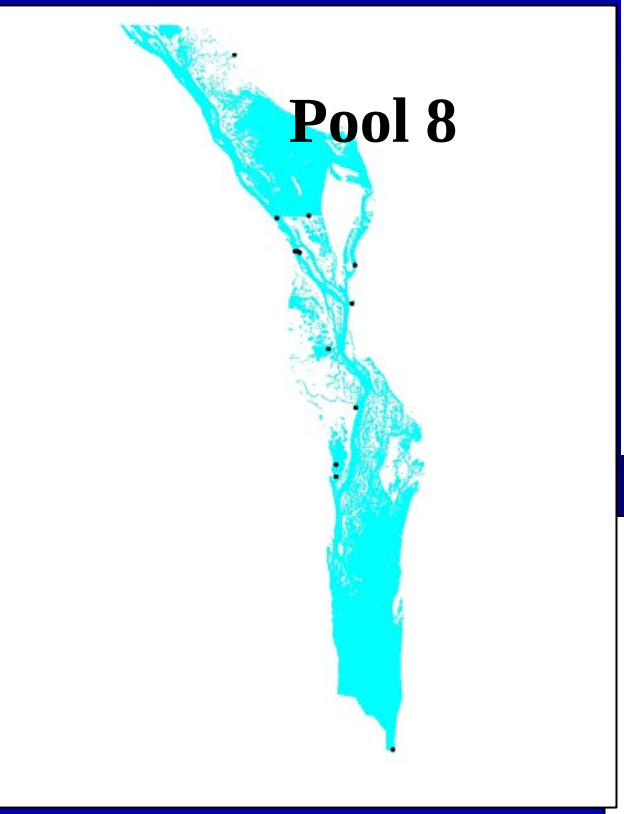
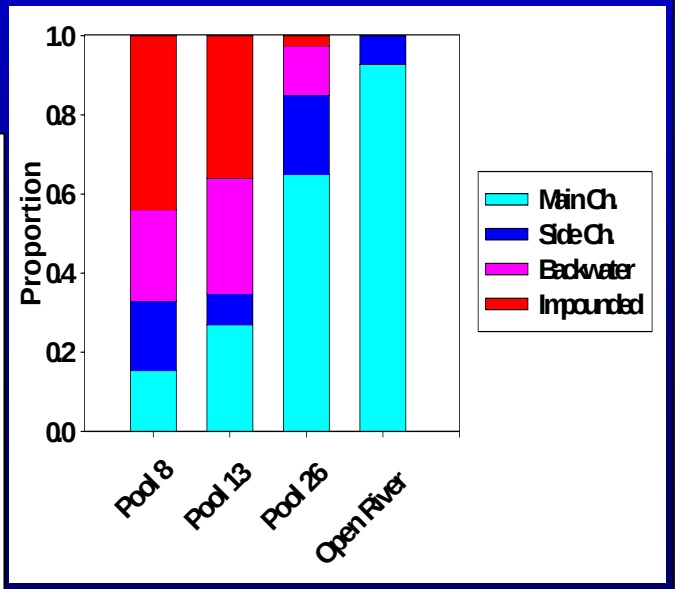
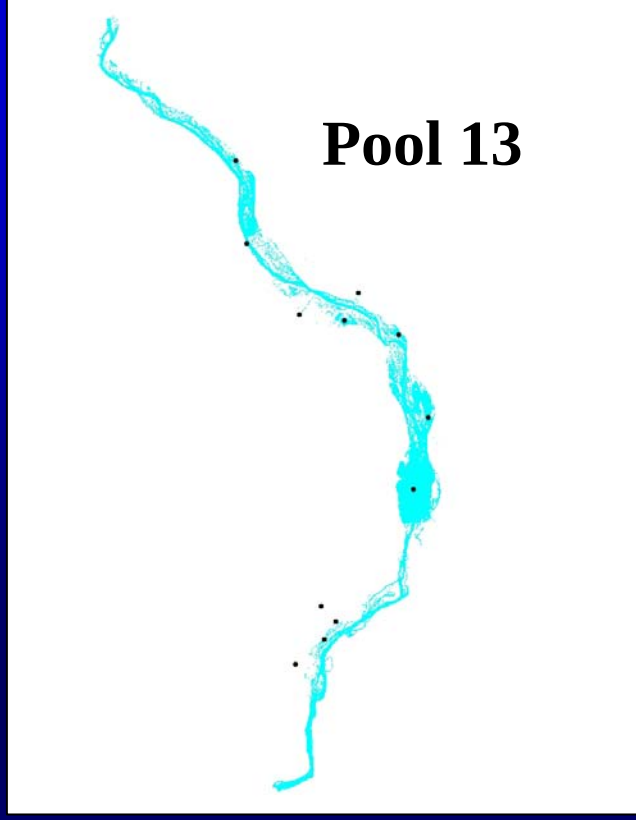
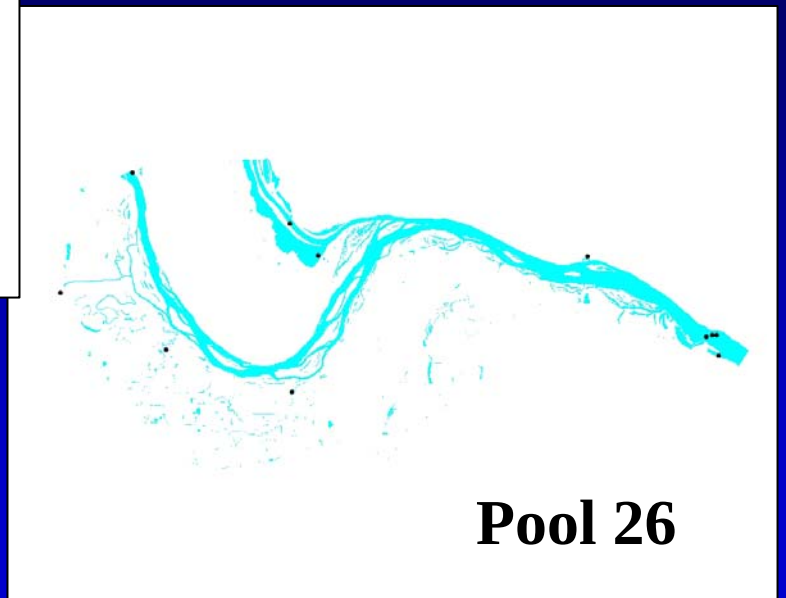
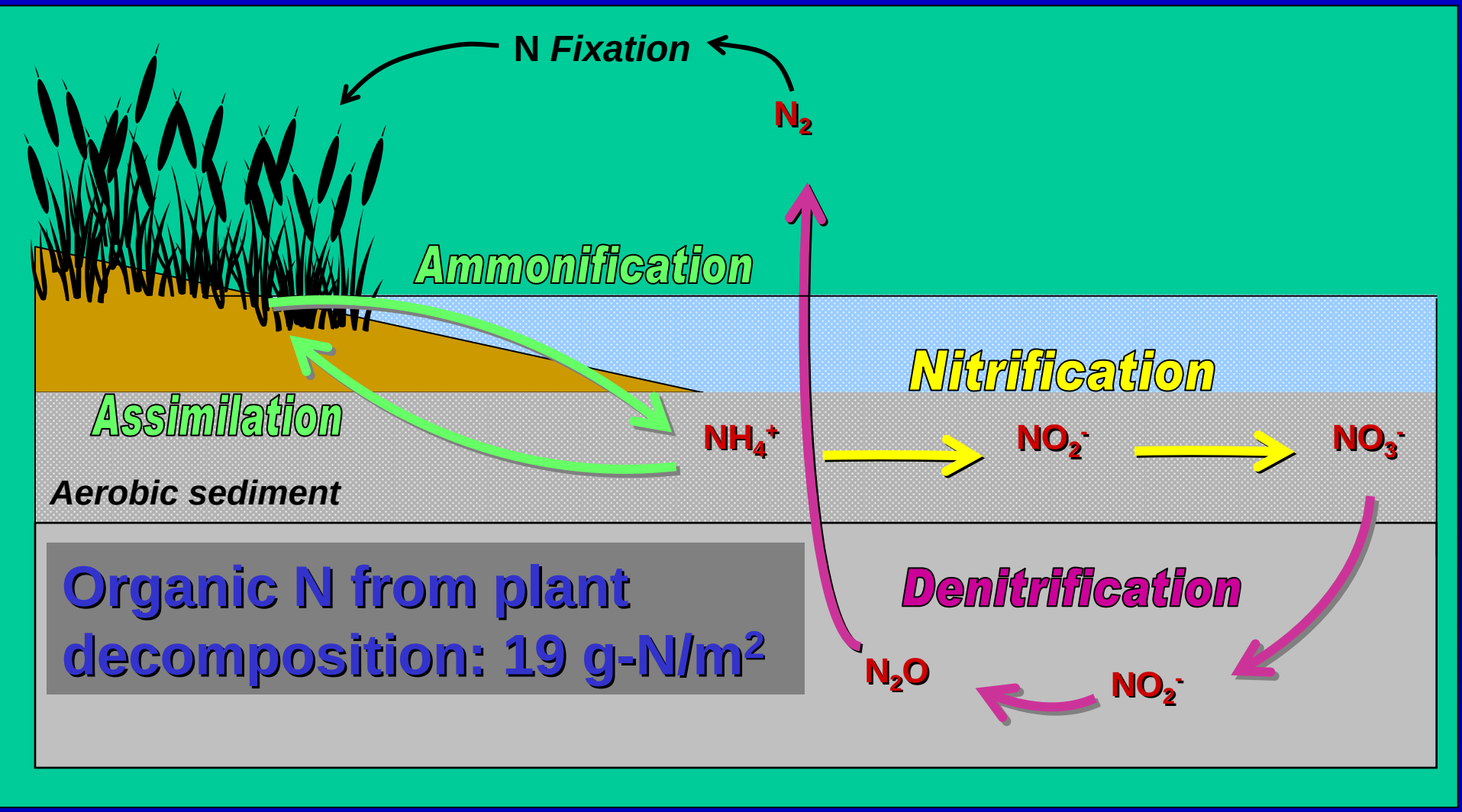

Pool 8


1.0
0.8
0.6
0.4
0.2
0.0
Proportion
Pool 8
Pool 13
Pool 26
Open River
Main Ch.
Side Ch.
Backwater
Impounded

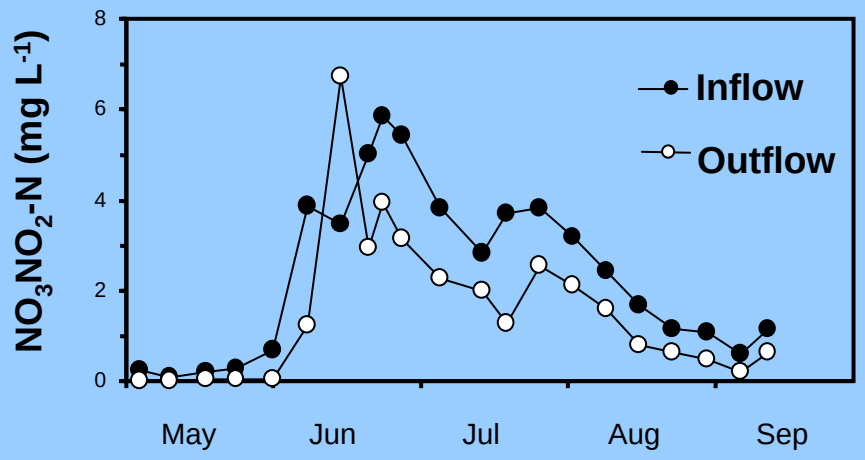

Pool 13


Pool 26



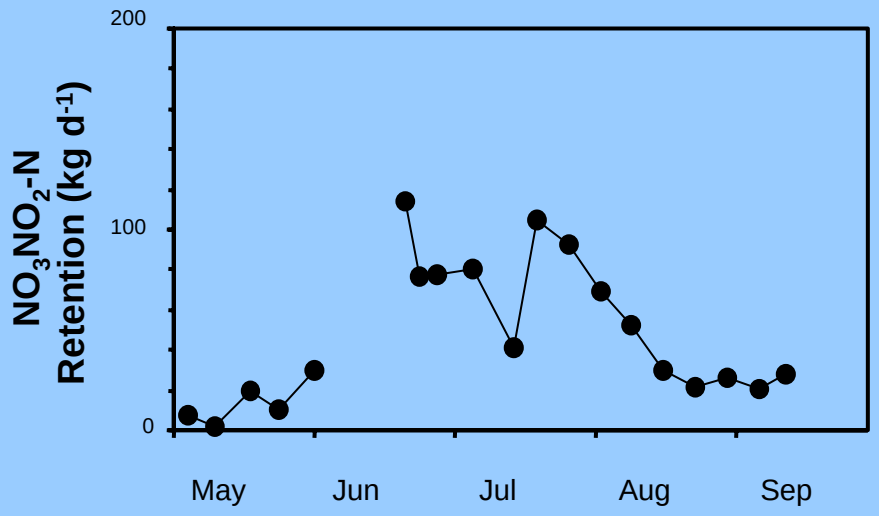
Organic N from plant decomposition: 19 g-N/m^2

Nitrate inflow-outflow, loading, and retention in Third Lake



Nitrate concentrations in Third Lake are dependent on inflow concentrations.

Elevated outflow concentrations due to backflooding from downstream.



Nitrate load dramatically increase with early summer flood; load elevated until August when River concentrations drop.

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Natural flooding of a flood plain lake: Root River and Mississippi River flooding into Lawrence Lake

Pool 8: Lawrence Lake

Aerial of Lawrence Lake here

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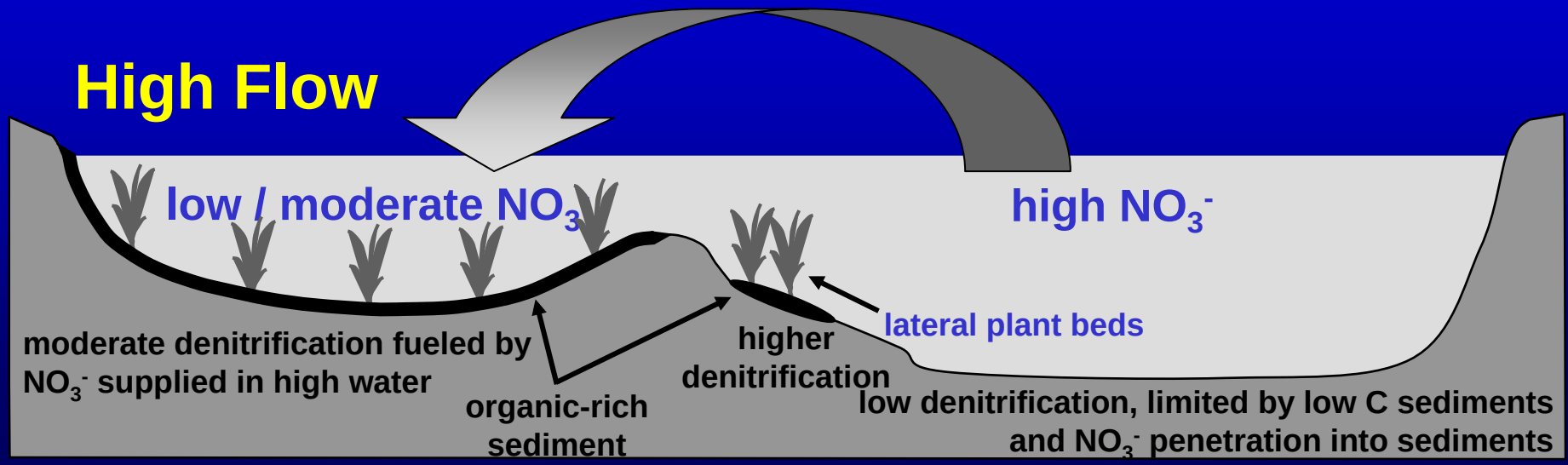
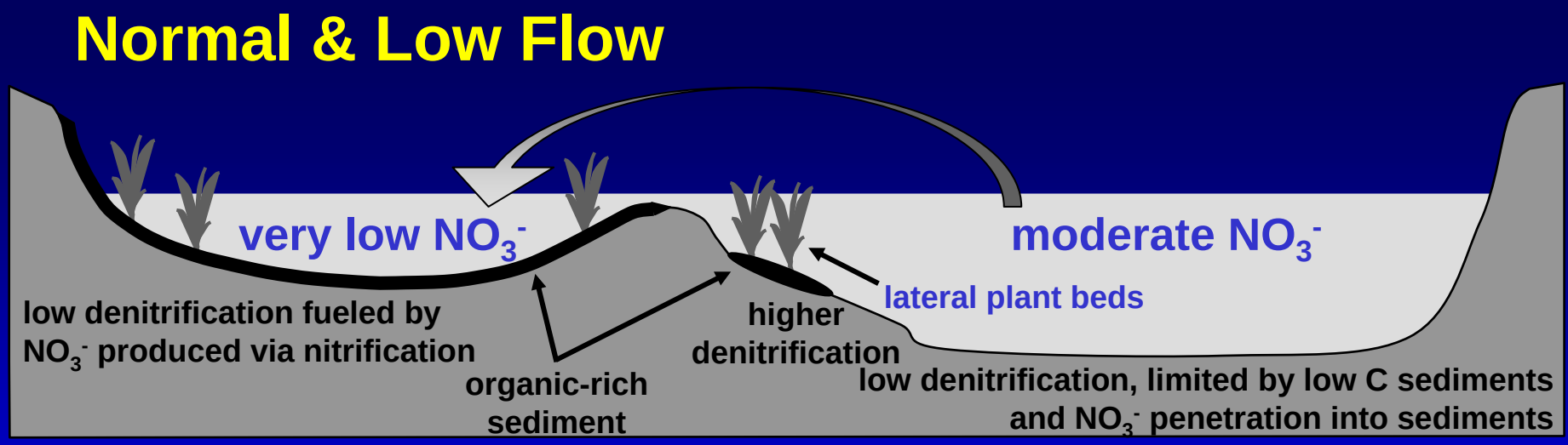
Current working model for hydrologic control of nitrate cycling in the UMR





Backwaters **Main Channel**

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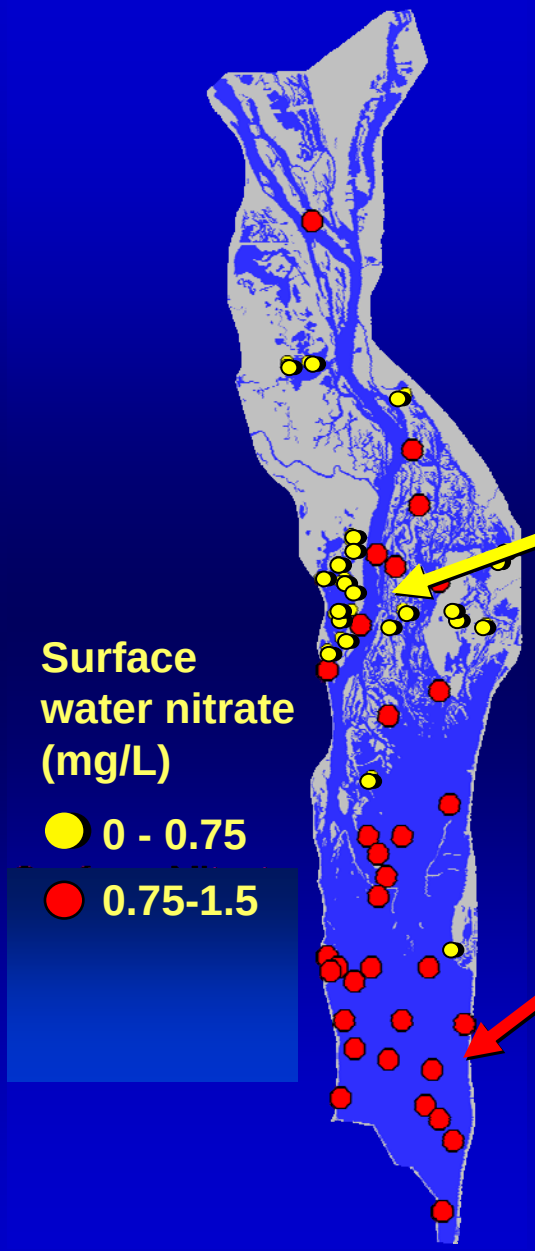
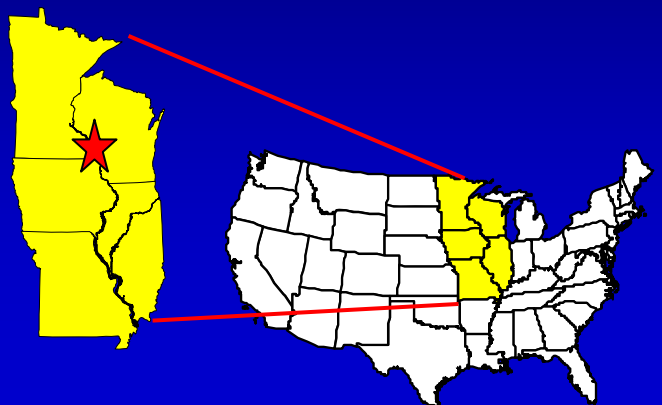
Spatial Distribution of Nitrate at Base Flow



Navigation Pool 8, Fall 1999

Nitrate concentrations are lower in backwaters with aquatic macrophytes

Nitrate concentrations are high in the main channel or side channel areas



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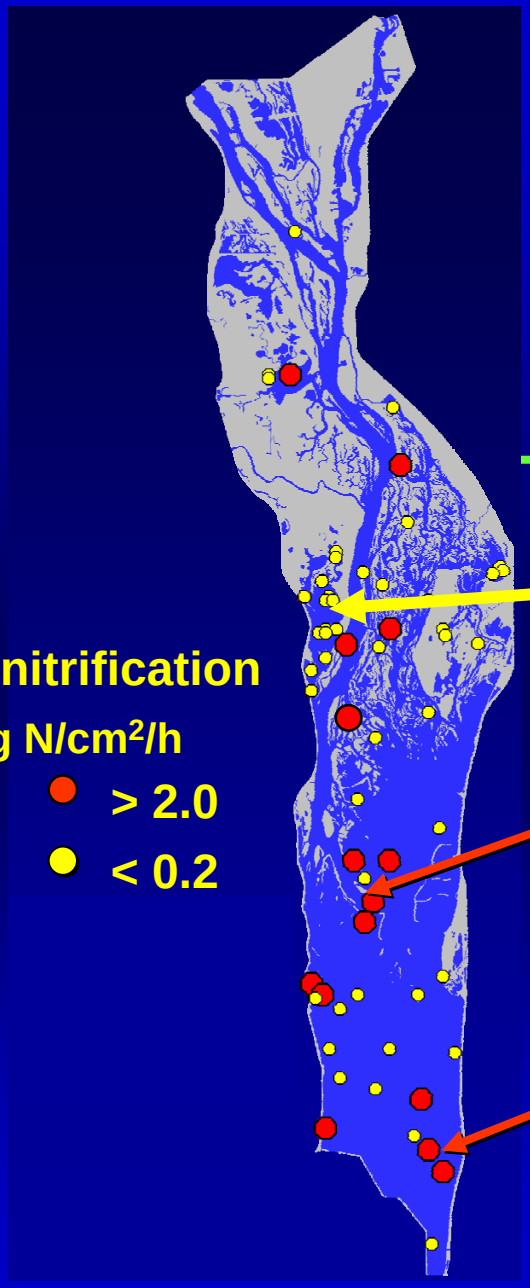
Upper Mississippi River: Flood plain river ecosystem with much connection remaining between main channels and floodplain lakes and wetlands.

Backwater nitrate concentrations increase with flooding, concentrations tend to decline rapidly with falling hydrograph.

Backwater lakes typically contain low concentrations of water column nitrate, with high potential for denitrification and assimilation, and high sediment ammonium.

Nitrate removal (denitrification) is linked to the spatial distribution of nitrate.



Low rates in backwaters

High rates near main channel

High rates in zebra mussel beds

Navigation Pool 8, Fall 1999

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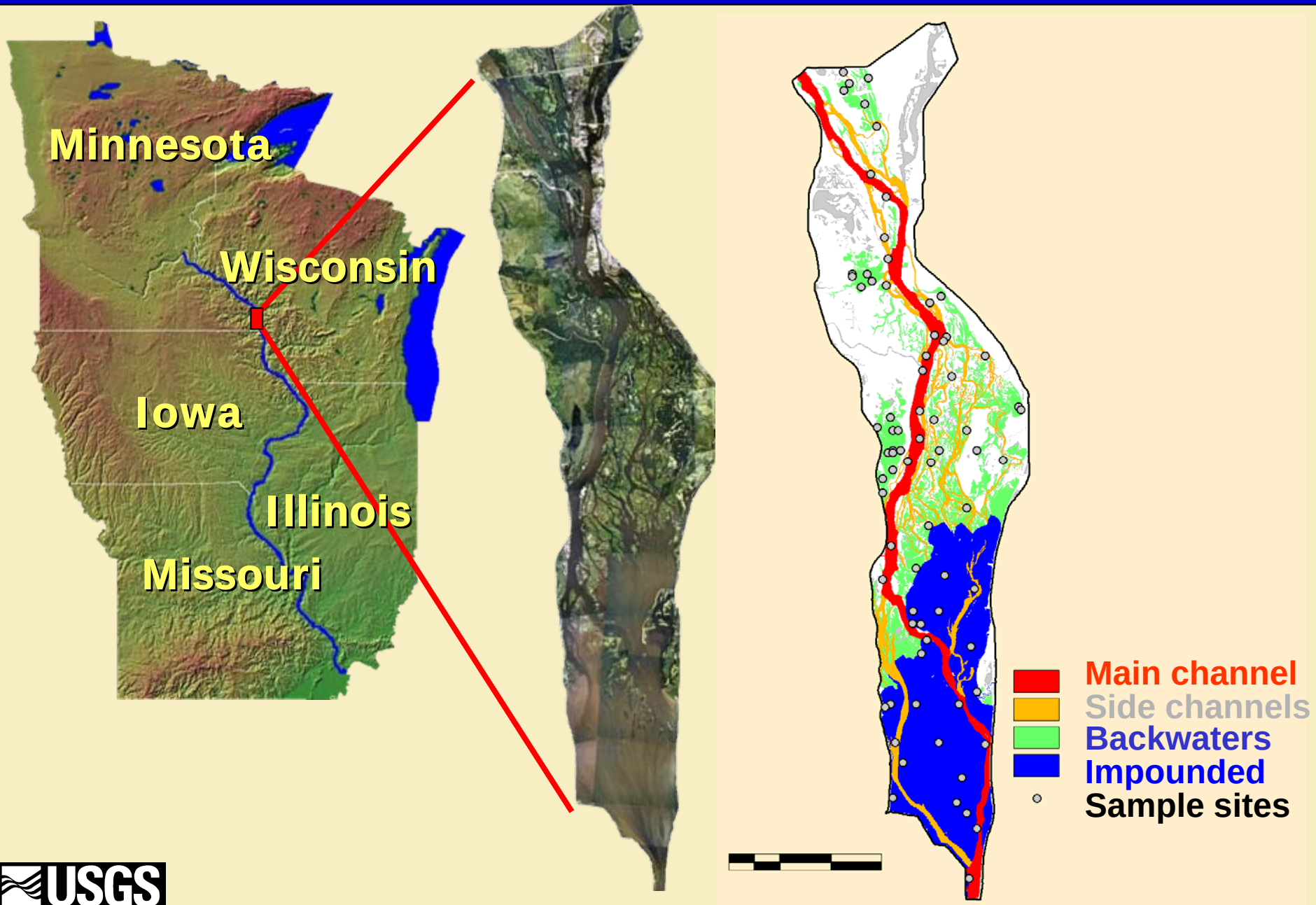
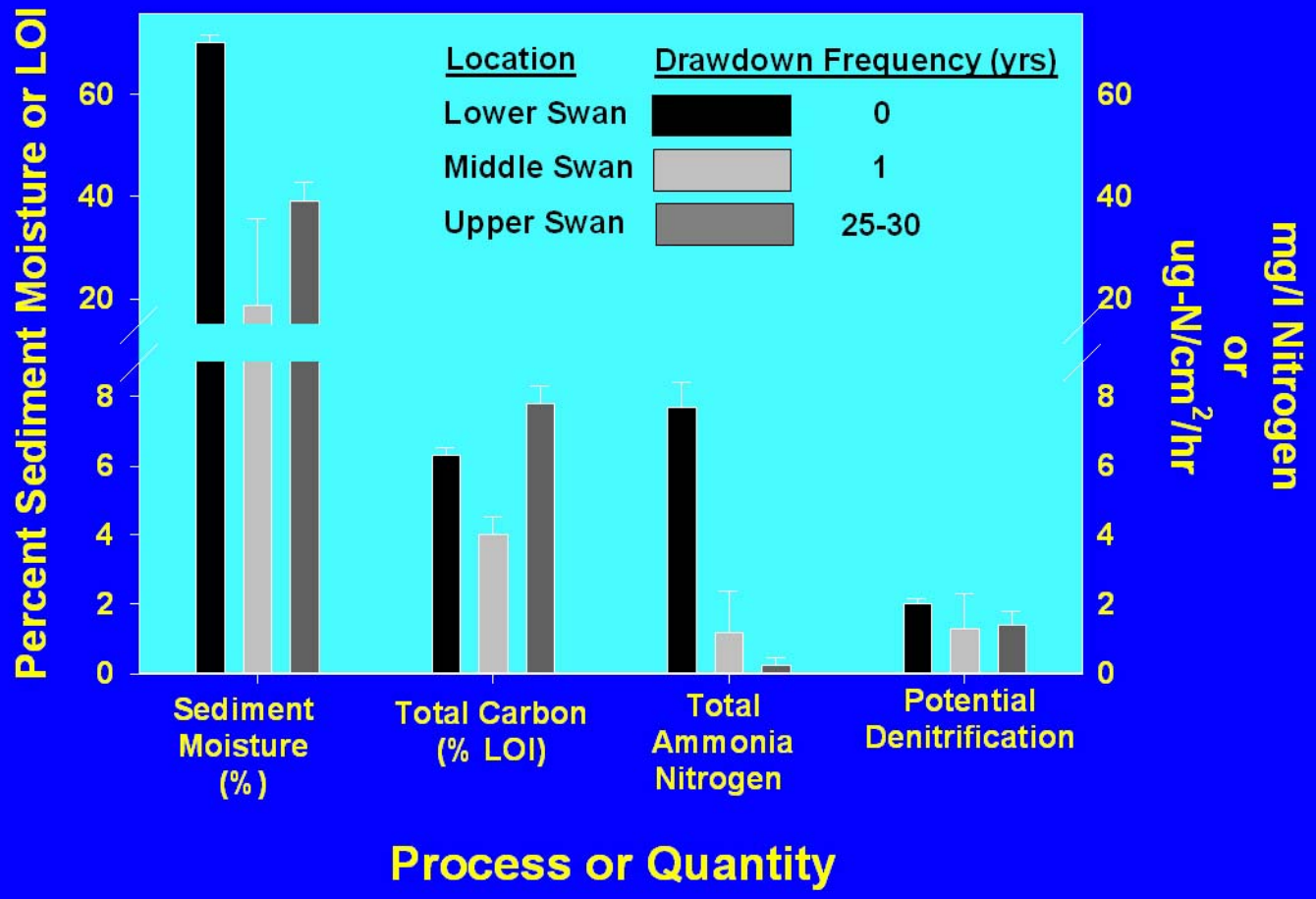
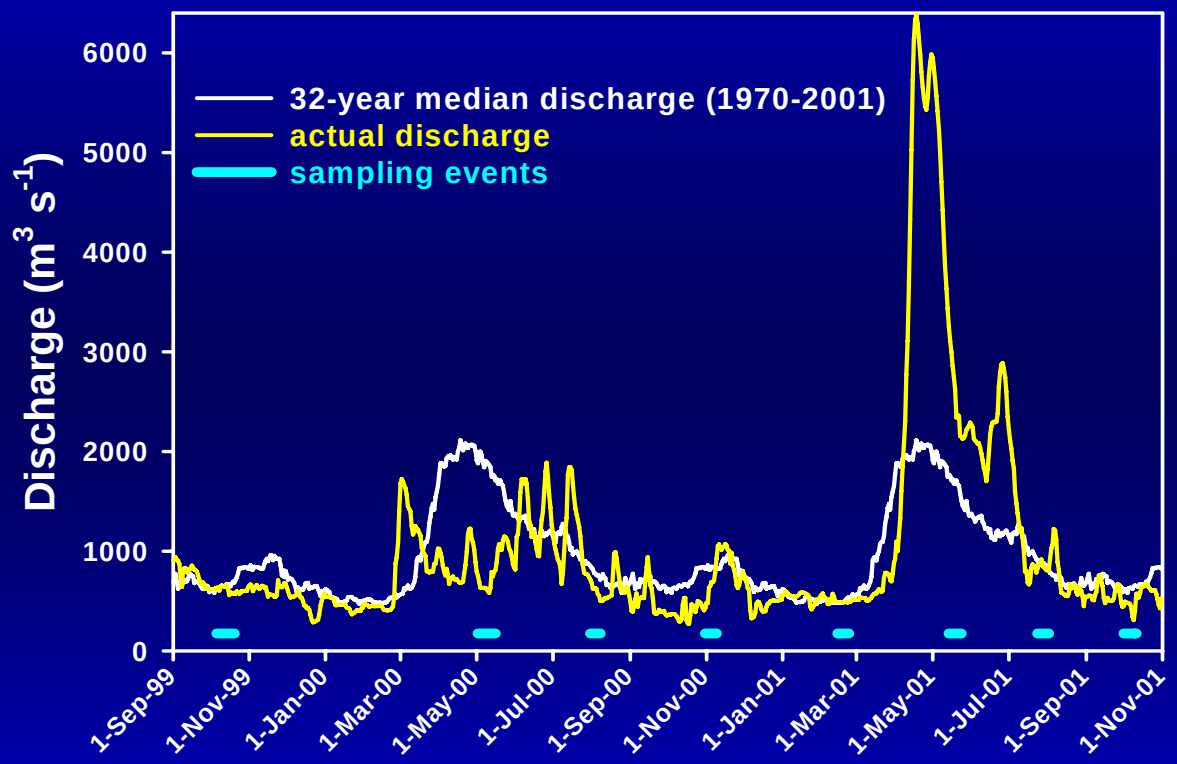
Study location and setting: Upper Mississippi River



Swan Lake,
Two Rivers National Wildlife Refuge



Variation in Mississippi River discharge at La Crosse, WI



Base flow
(~ 900 $m^3 s^{-1}$)

Flood
(6500 $m^3 s^{-1}$)

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