Overview of Nitrogen Cycling Rates and Controls in the Upper Mississippi River

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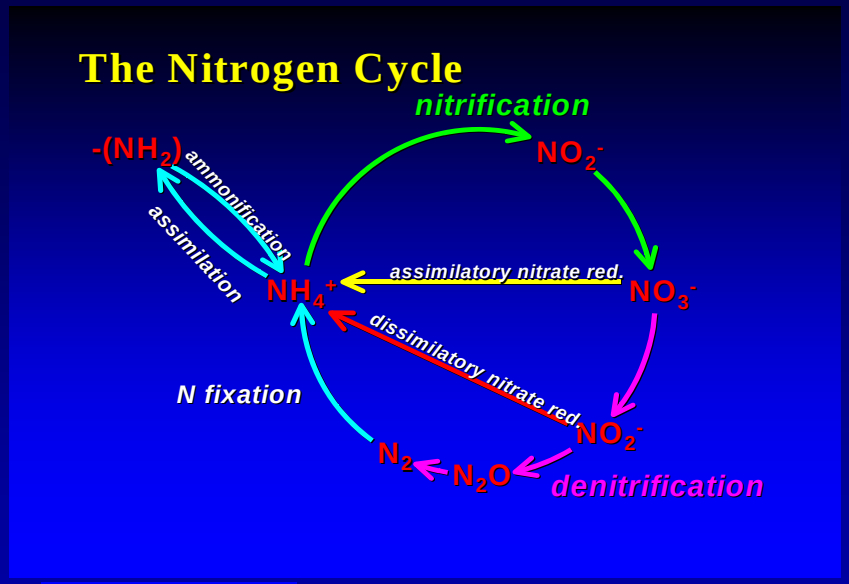

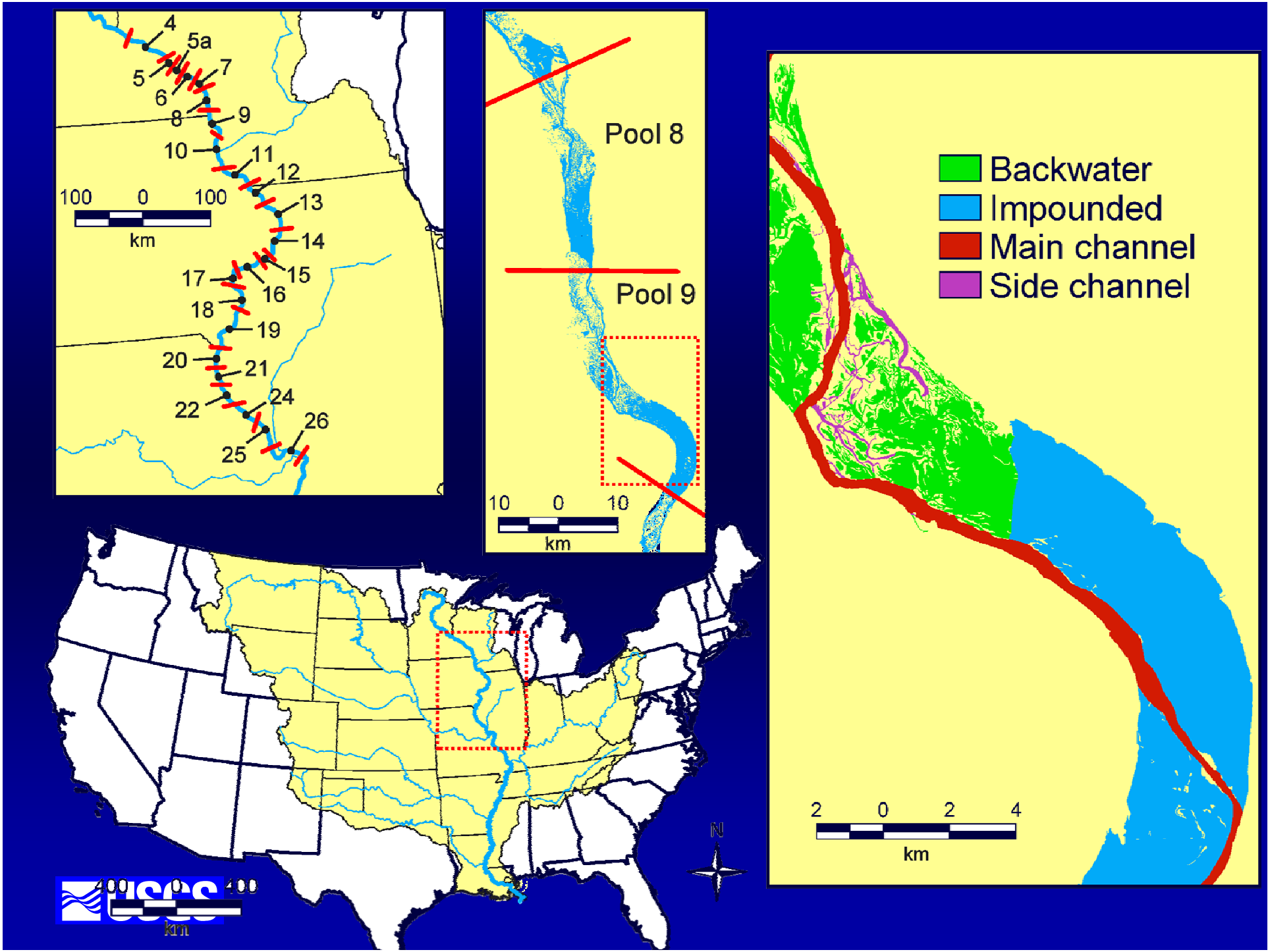
4
5a
5
7
6
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
24
25
26
100 0 100
km
Pool 8
Pool 9
10 0 10
km
Backwater
Impounded
Main channel
Side channel
2 0 2 4
km
N
400 0 400
km

Take Home

- **Floodplain rivers have huge potential to process and remove nitrogen, but capacity is overwhelmed by N load.**
- **N-cycling is tightly linked to river hydrology and geomorphology.**
- **Management options to control N are limited, but possible, on the floodplain.**

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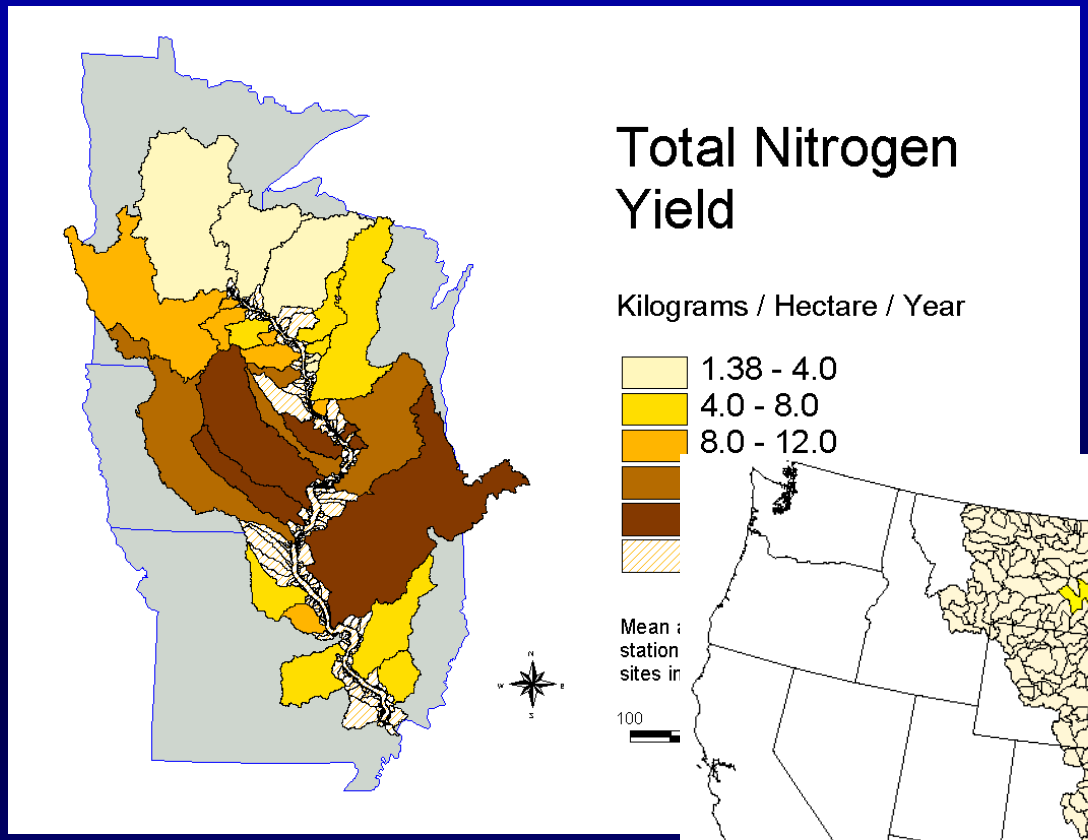
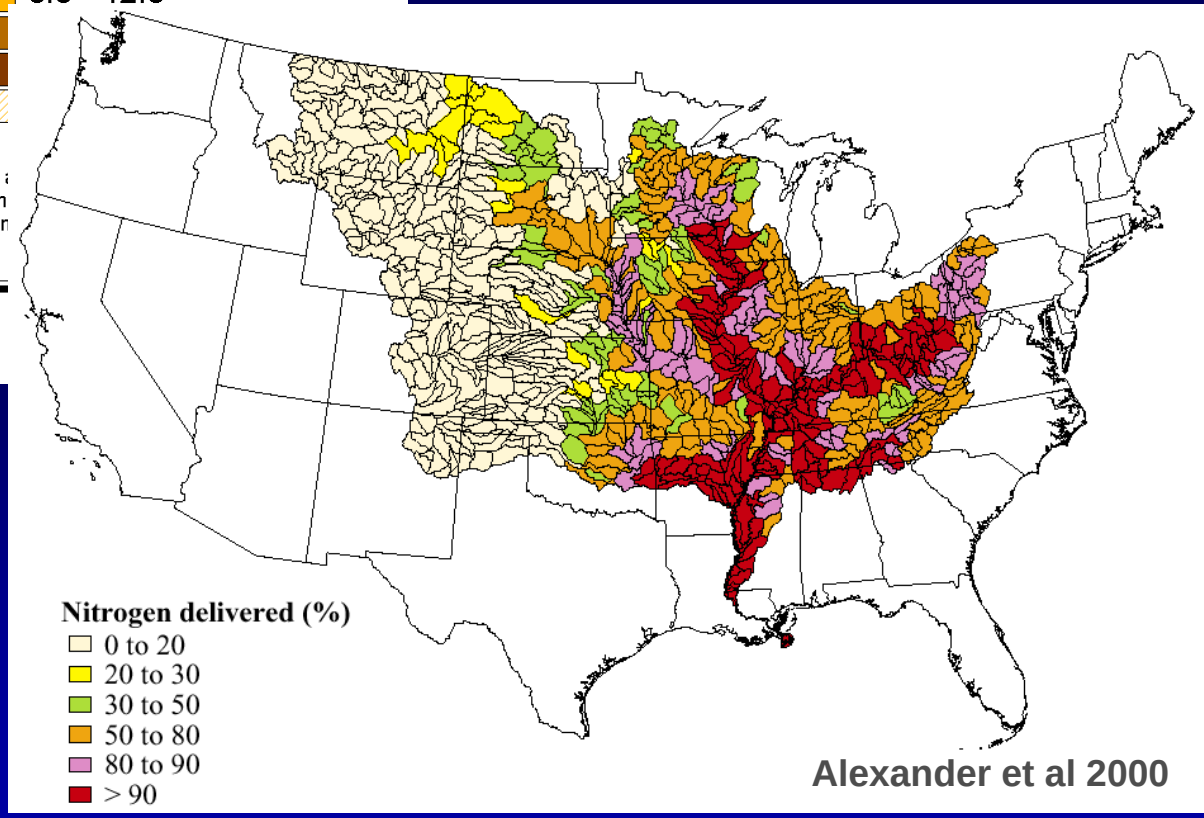


Where in the basin does N come from?



Alexander et al 2000

What percent actually arrives at the Gulf of Mexico?

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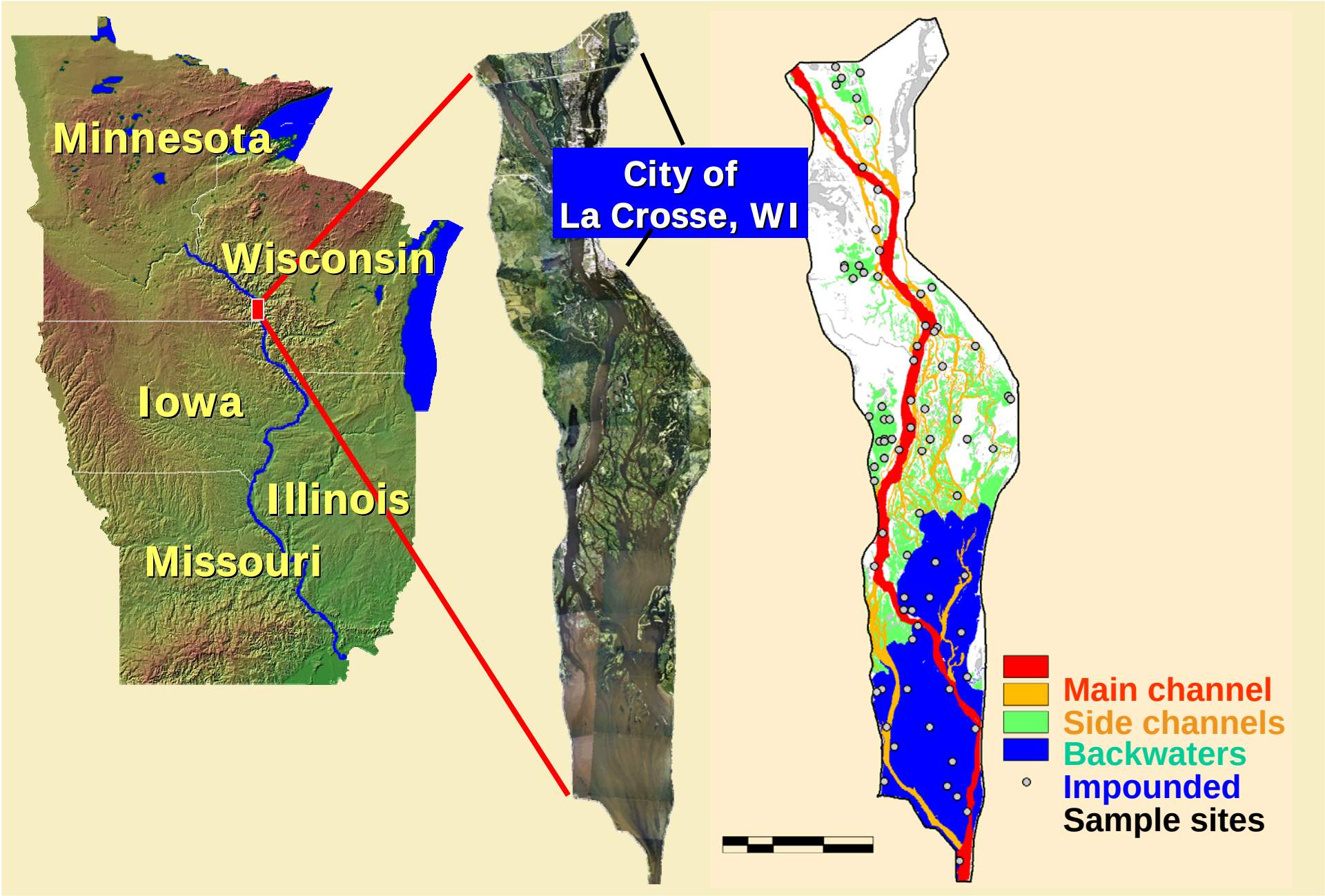
Minnesota
Wisconsin
Iowa
Illinois
Missouri
City of
La Crosse, WI
Main channel
Side channels
Backwaters
Impounded
Sample sites

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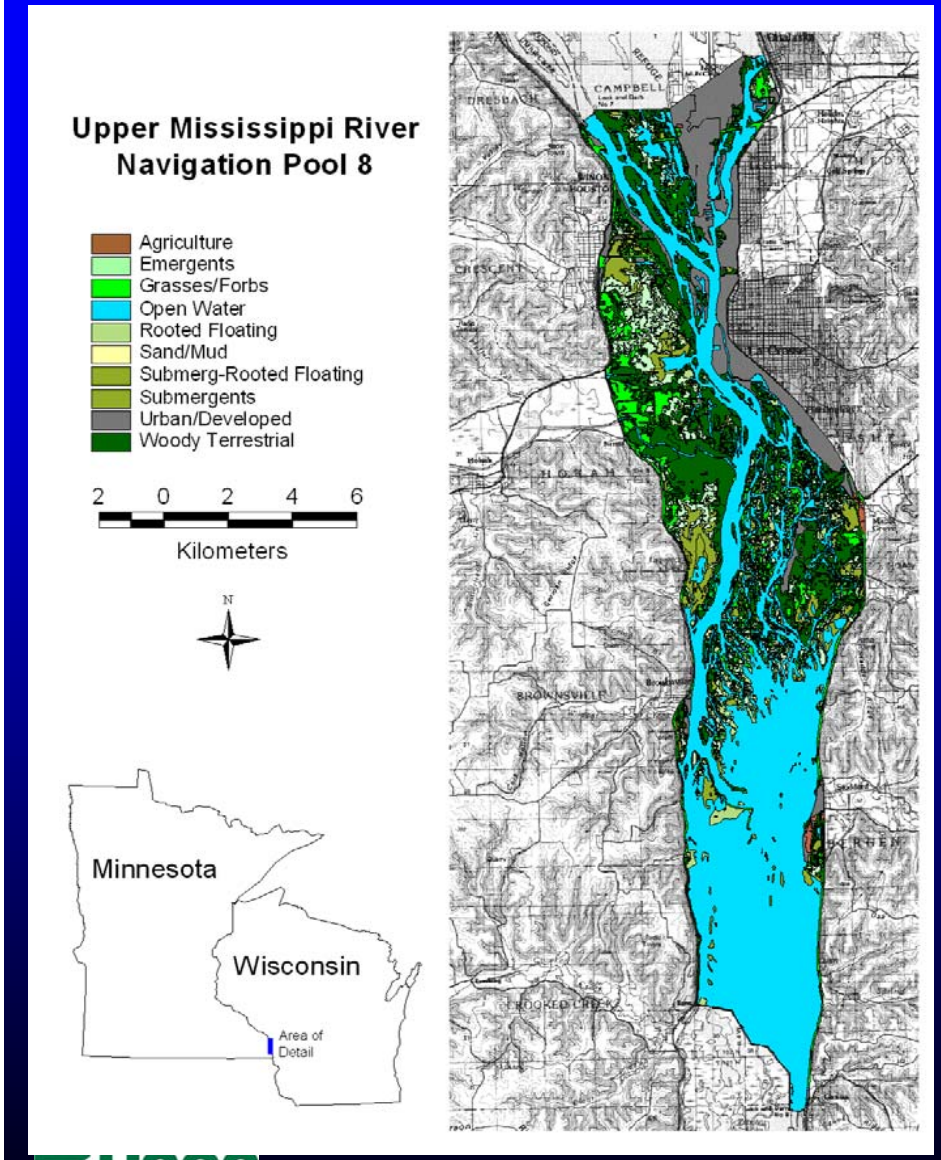
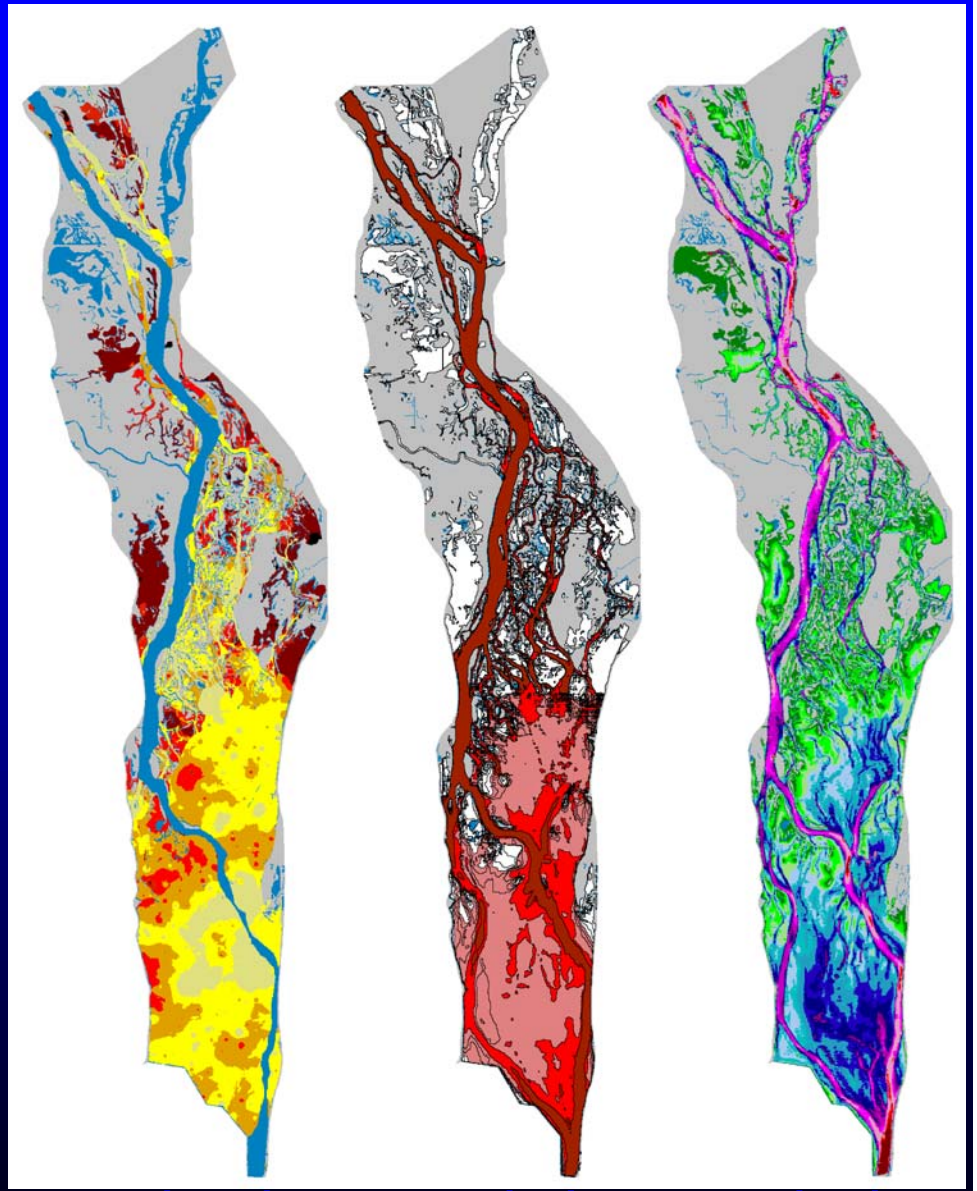
Spatial Heterogeneity – UMR Pools





sed. carbon velocity depth

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Habitat characteristics in pool 8

Low
C &N

Sediment C & N Gradient

High
C & N

Main channel

high NO_3^-

low NH_4^+

Off-channels

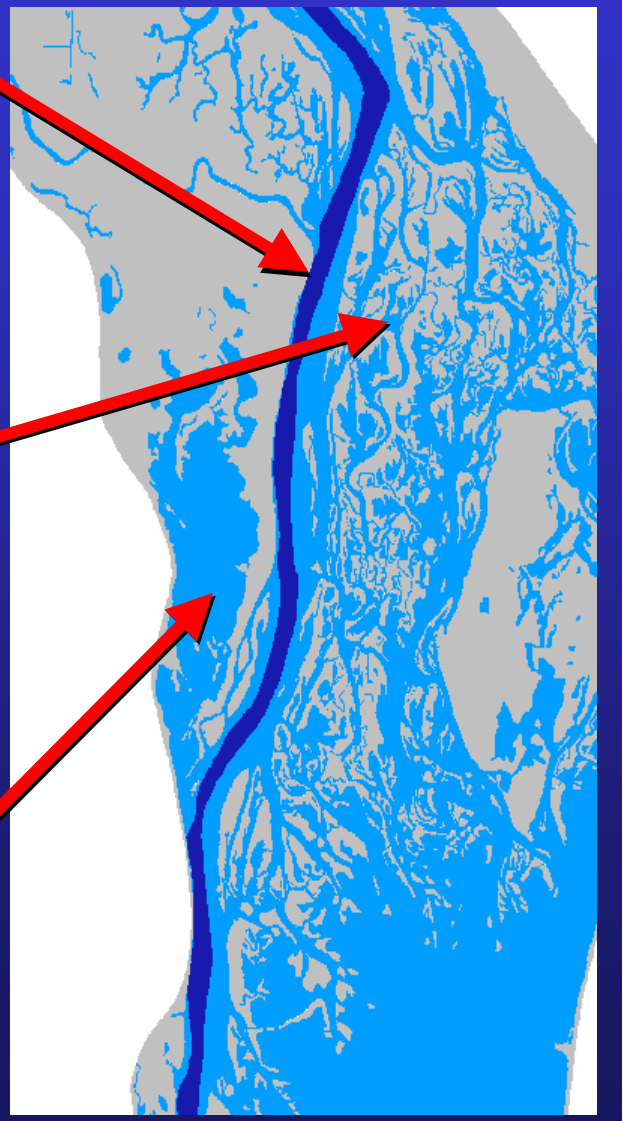
variable NO_3^-

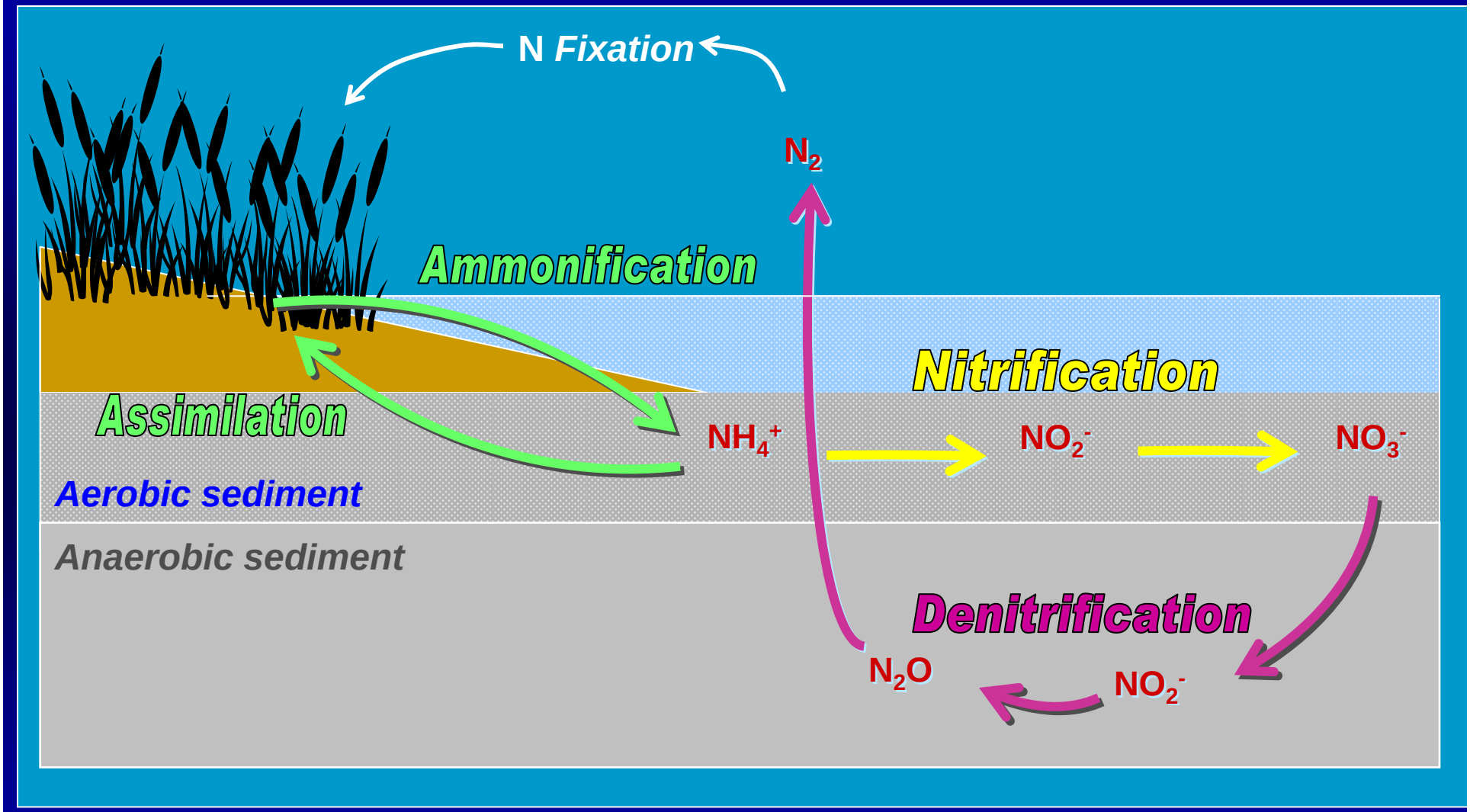
low NH_4^+

Backwaters

low NO_3^-

low NH_4^+




N Fixation
N_2
Ammonification
Nitrification
Assimilation
NH_4^+
NO_2^-
NO_3^-
Aerobic sediment
Anaerobic sediment
Denitrification
N_2O
NO_2^-

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River floodplains are ideal sites for bacterially mediated nitrogen removal:

Sediments tend to be highly organic, moist, and combination of aerobic and anaerobic conditions.

Connections with main channel water can replenish nitrate in backwater wetlands.

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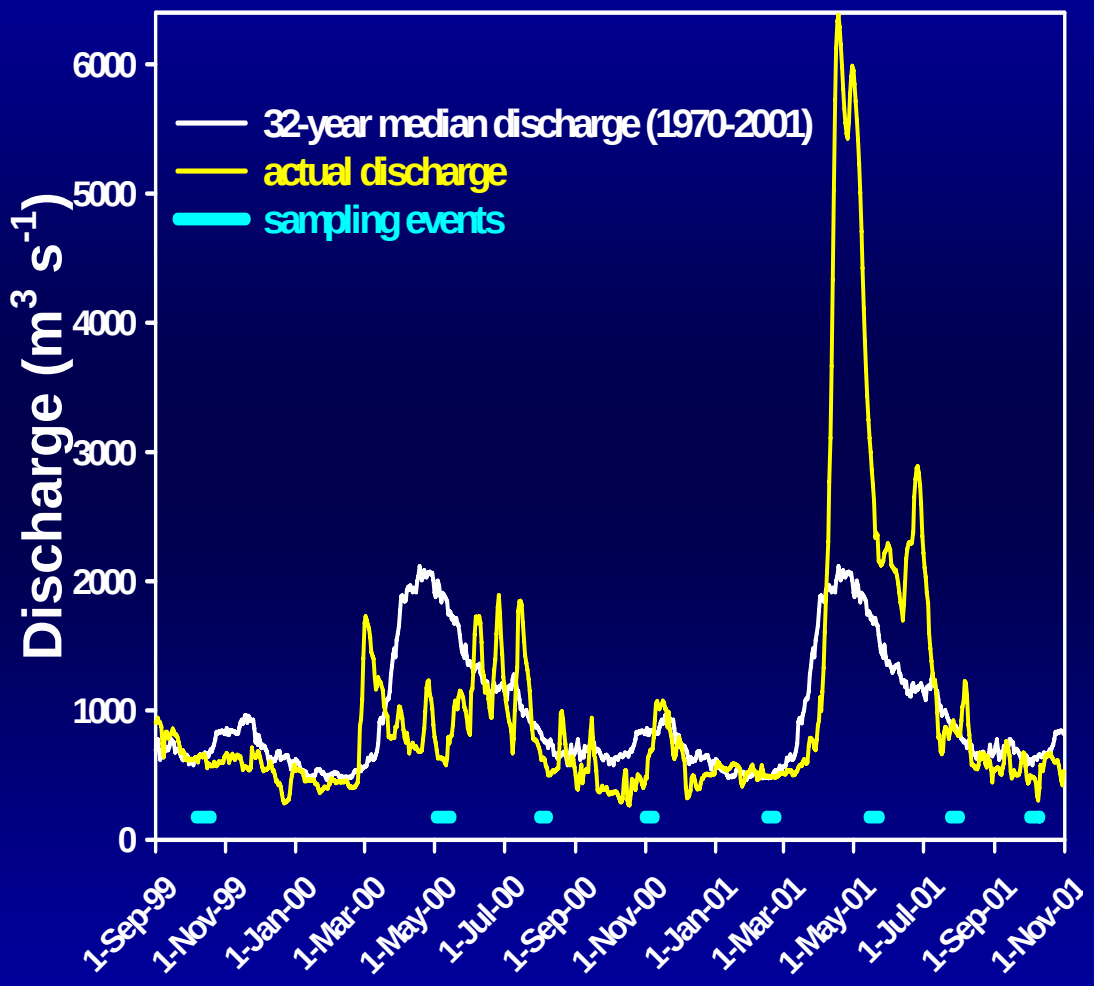
Variation in river discharge

1. Redistribution of nitrogen, oxygen and sediment throughout the flood plain.

2. Sediment moisture, oxygen, and redox dynamics.

3. Plays a role in temperature dynamics.



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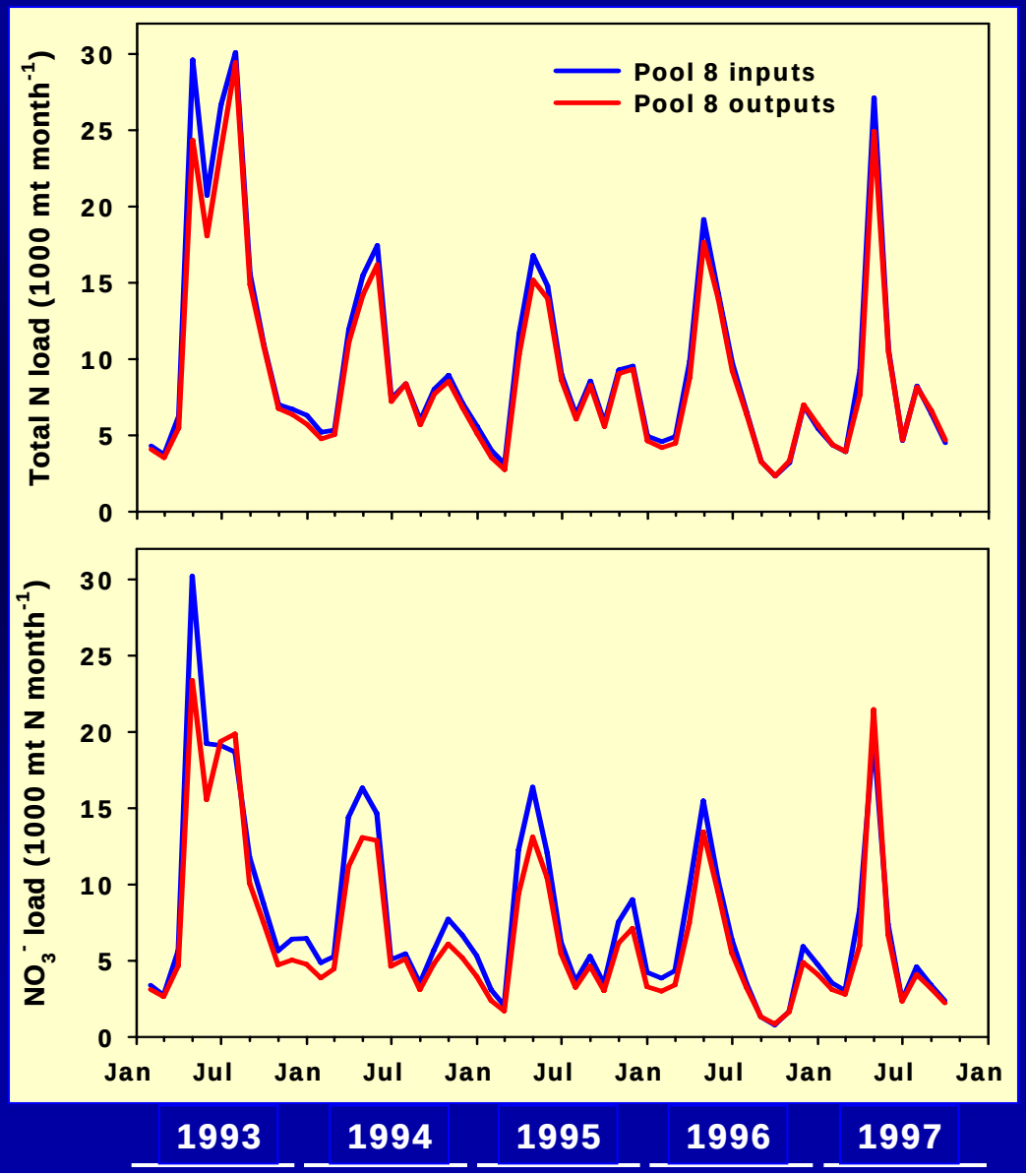
Nitrate and total N loading to Pool 8 (1993 – 1997; LTRMP data)

Variation in discharge determines loading patterns.

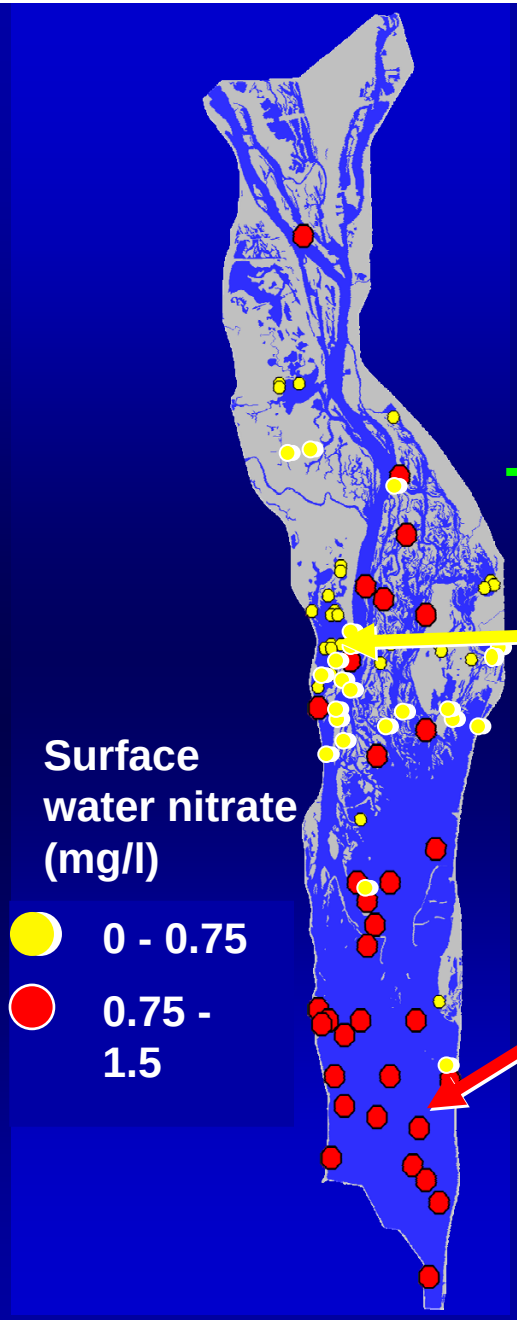
Some nitrate is retained in Pool 8 during floods.

Pattern suggests either nitrate uptake or deposition increases during floods.

Pattern also suggests some nitrate management potential on the floodplain.



Nitrate concentrations have a distinct spatial distribution during base flow

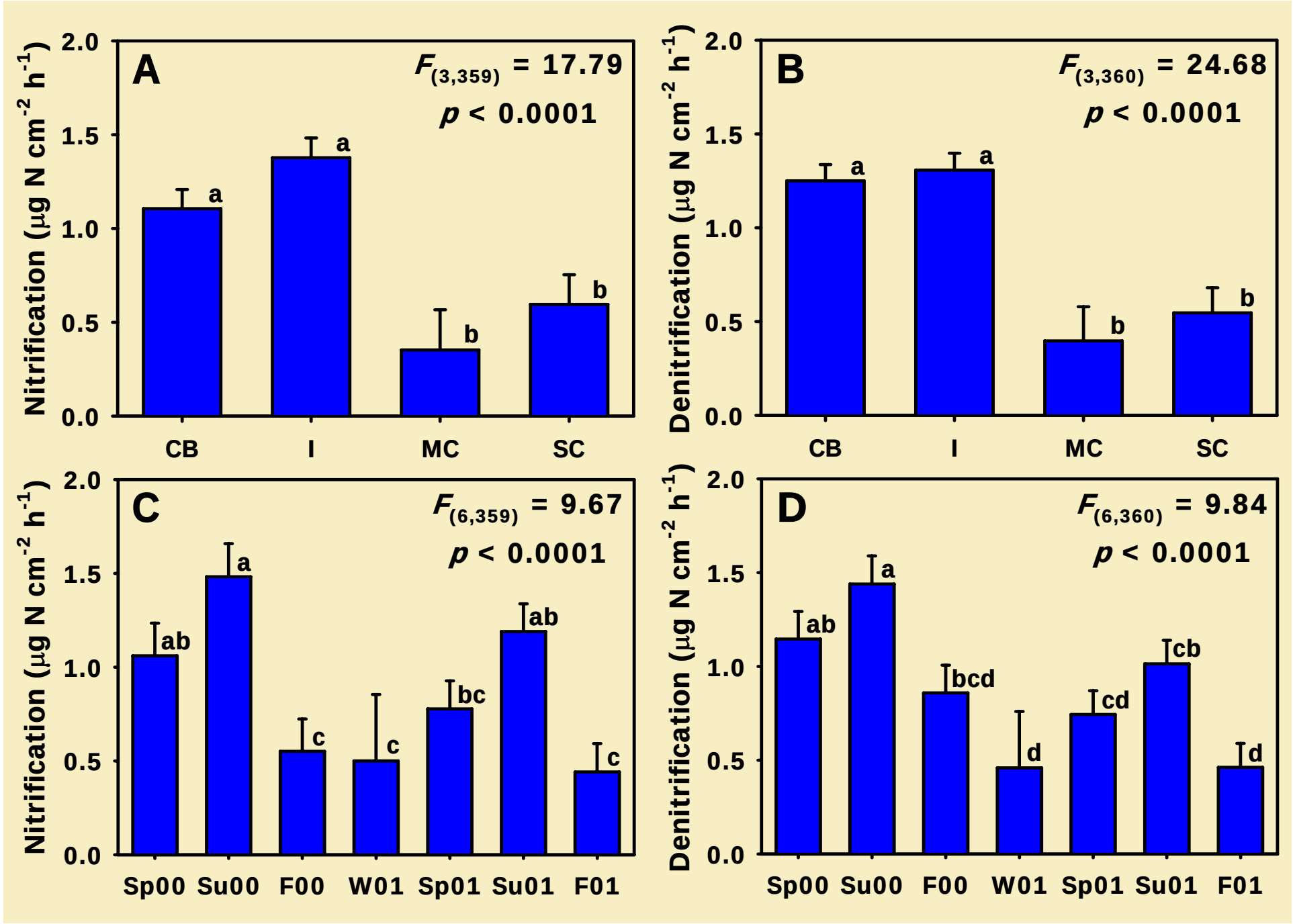


Nitrate concentrations extremely low in backwaters

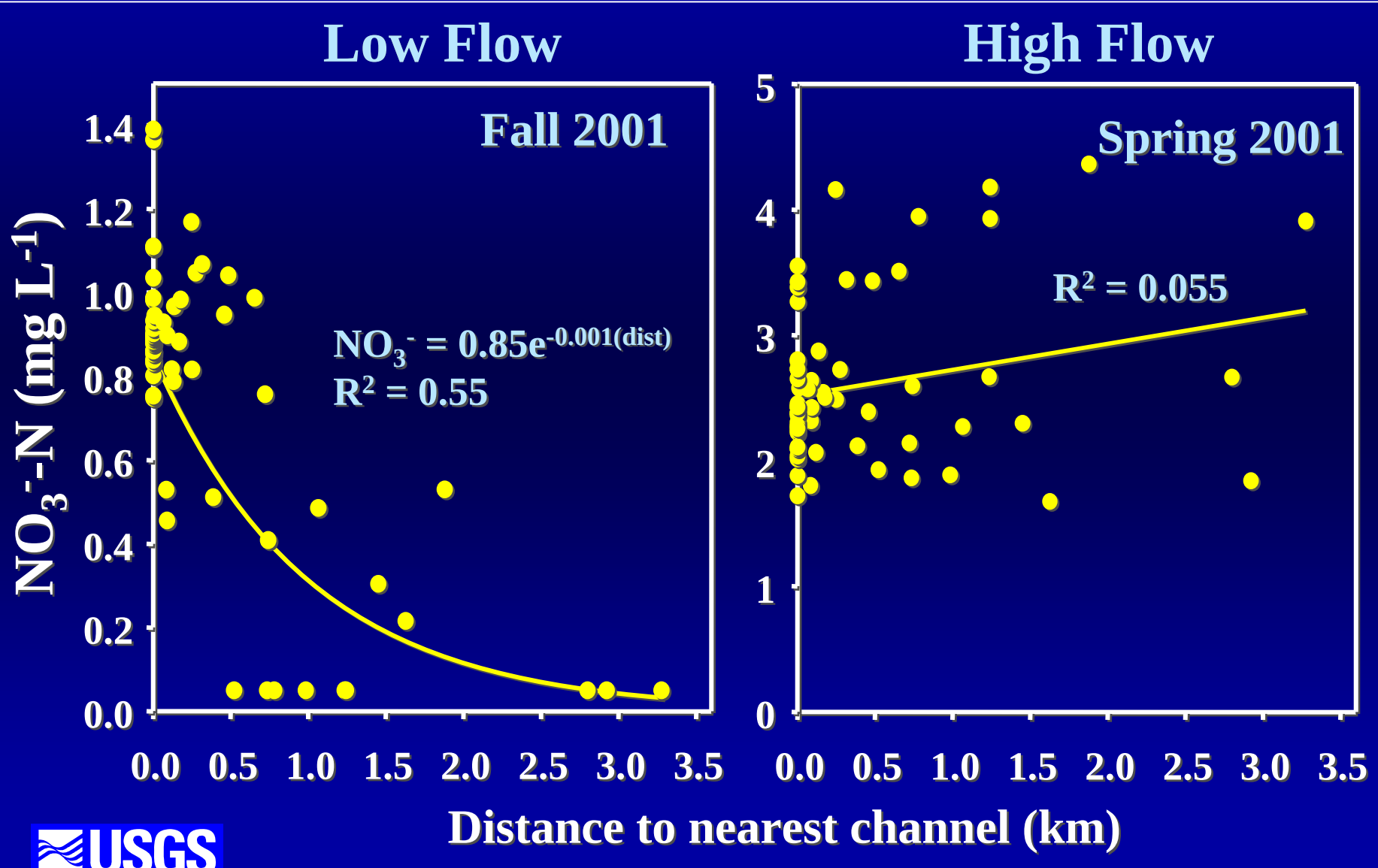
Nitrate concentrations high in main channel and flowing areas

Navigation Pool 8, Fall 1999

USGS


A
$F_{(3,359)}$ = 17.79
p < 0.0001
Nitrification (μg N cm^{-2} h^{-1})
2.0
1.5
1.0
0.5
0.0
a
a
b
b
CB
I
MC
SC
B
$F_{(3,360)}$ = 24.68
p < 0.0001
Denitrification (μg N cm^{-2} h^{-1})
a
a
b
b
CB
I
MC
SC
C
$F_{(6,359)}$ = 9.67
p < 0.0001
Nitrification (μg N cm^{-2} h^{-1})
ab
a
c
c
bc
ab
c
Sp00
Su00
F00
W01
Sp01
Su01
F01
D
$F_{(6,360)}$ = 9.84
p < 0.0001
Denitrification (μg N cm^{-2} h^{-1})
ab
a
bcd
d
cd
cb
d
Sp00
Su00
F00
W01
Sp01
Su01
F01

Linking discharge and spatial variability of nitrate concentrations



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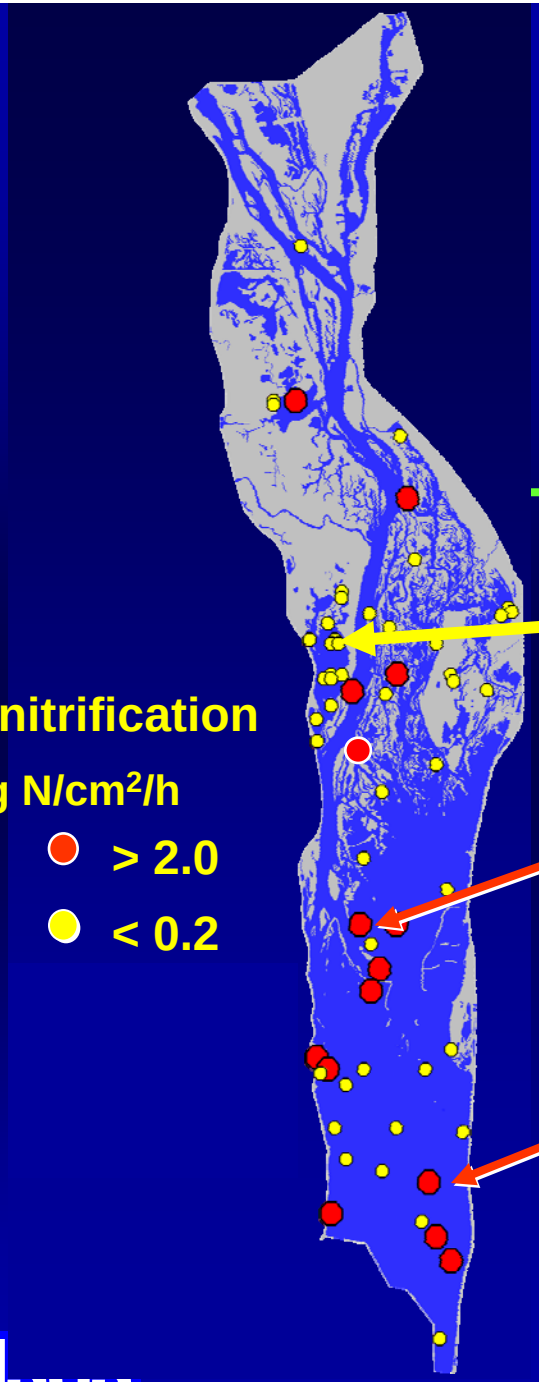
Nitrate removal (denitrification) is linked to the spatial distribution of nitrate.

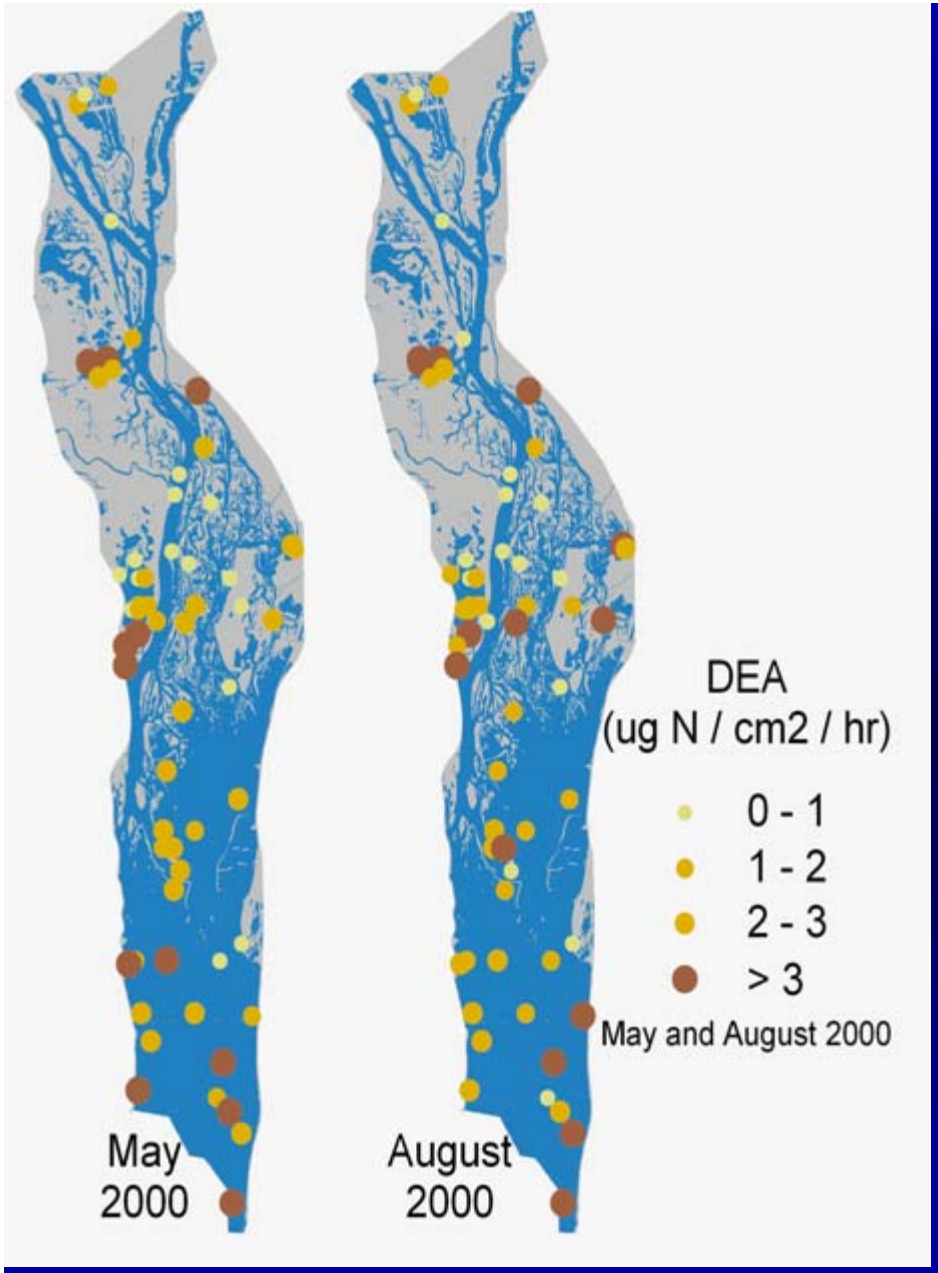


Low rates in backwaters

High rates near main channel

High rates in zebra mussel beds

Navigation Pool 8, Fall 1999



Denitrification Enzyme Activity (DEA)

Estimate of potential denitrification under optimal conditions (excess NO_3^-, C, anaerobic water saturated sediments).

Backwaters and impounded areas with high DEA (longer retention times, high sediment C, relatively low nitrate).

Channels with generally low DEA (short retention times, low C sediments, but high nitrate).

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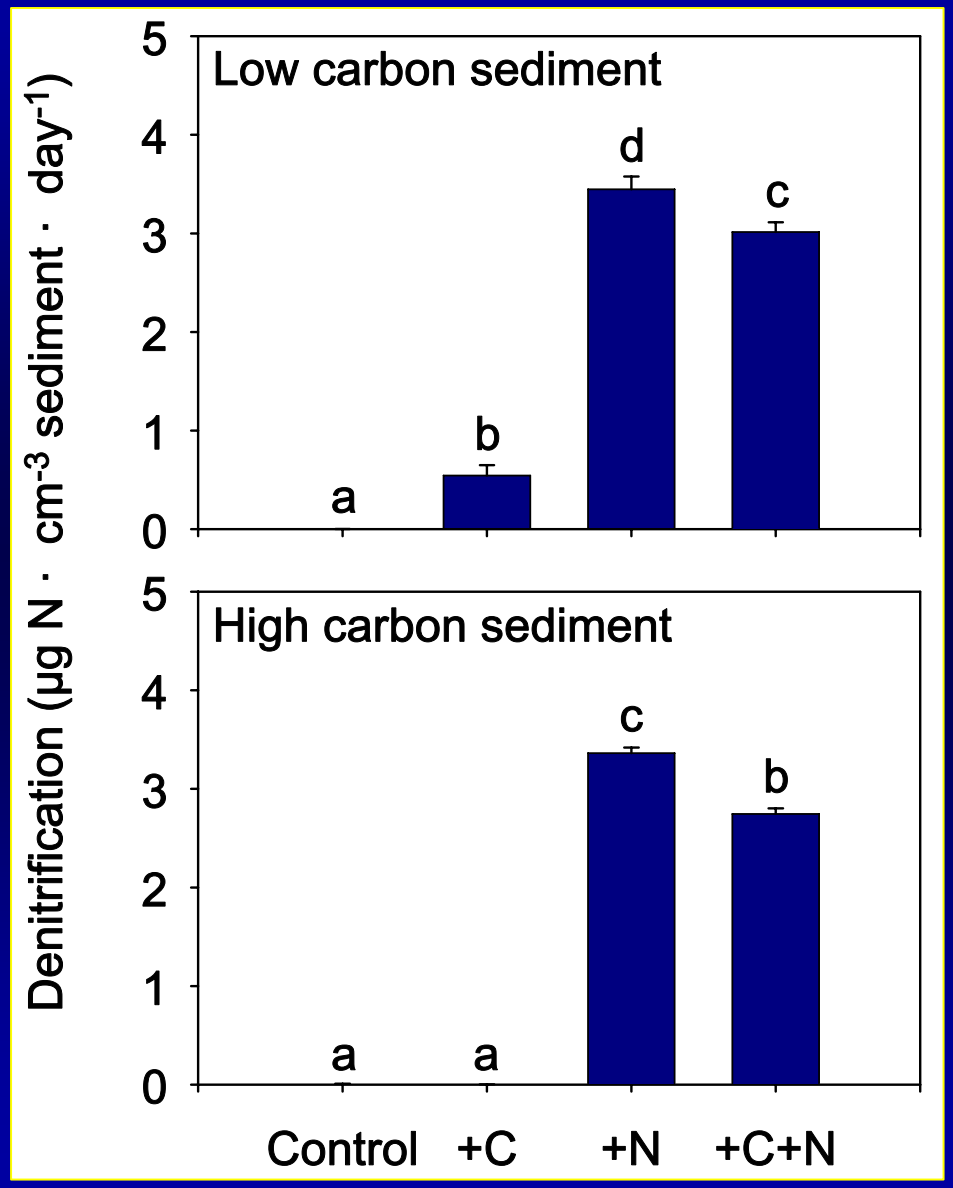
What limits denitrification in the UMR?

Experimental evaluation of carbon and nitrate limitation:

Carbon addition (10 mg/l – glucose) had little effect on denitrification rates except in low carbon sediments.

Nitrate additions (2 mg/l) resulted in dramatic increases in denitrification in all sediments.

Supports "nitrate delivery" hypothesis.



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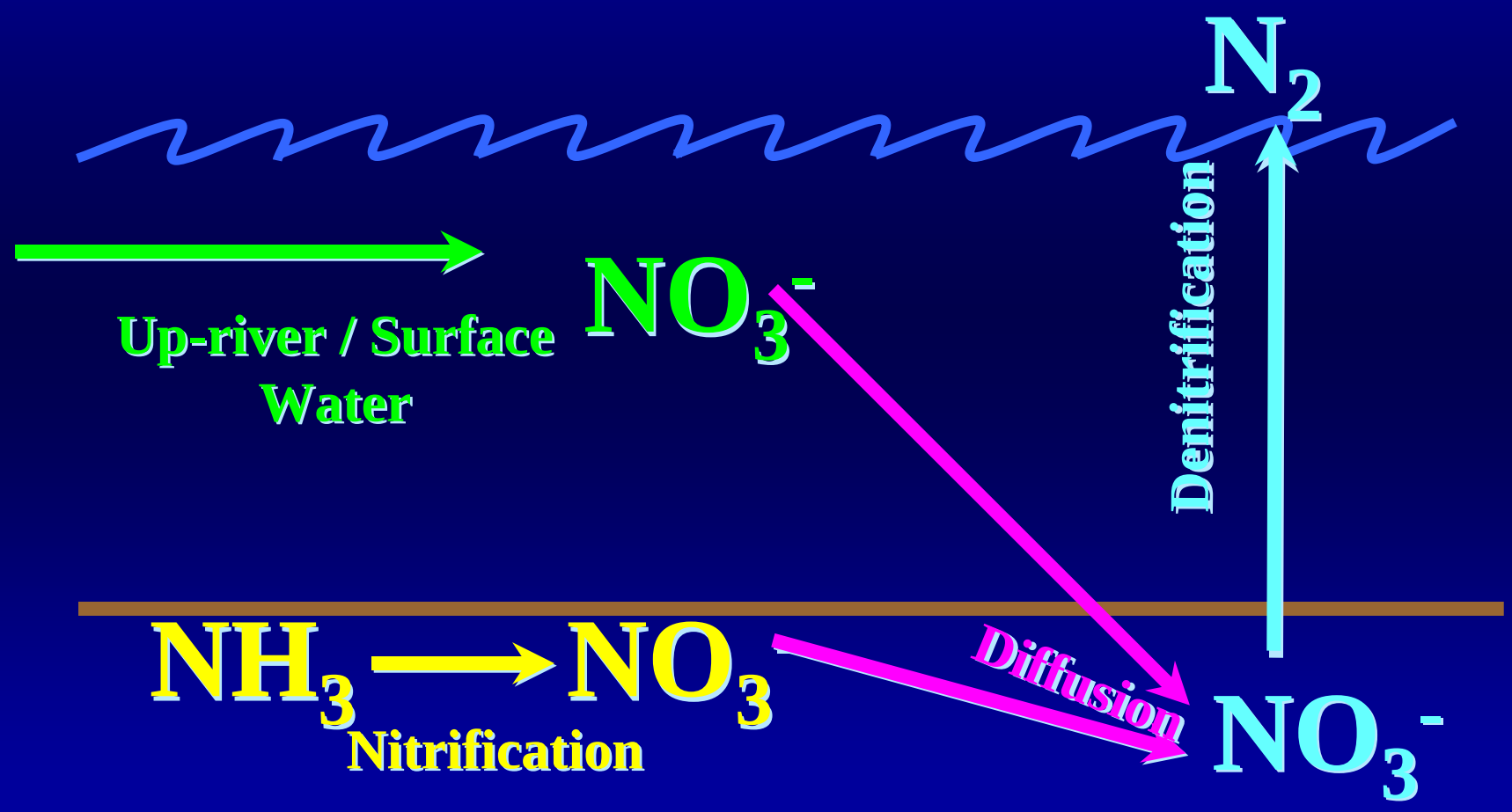
Coupled nitrification-denitrification: Nitrification as a source of nitrate for denitrification during low flows in backwaters and impounded areas



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Major points:

Pool-wide: 20 % gross removal of nitrate.

Nitrate generation via nitrification nearly balanced losses via denitrification

13% of nitrate loss unaccounted: assimilation, burial, temporary storage in plant mass.

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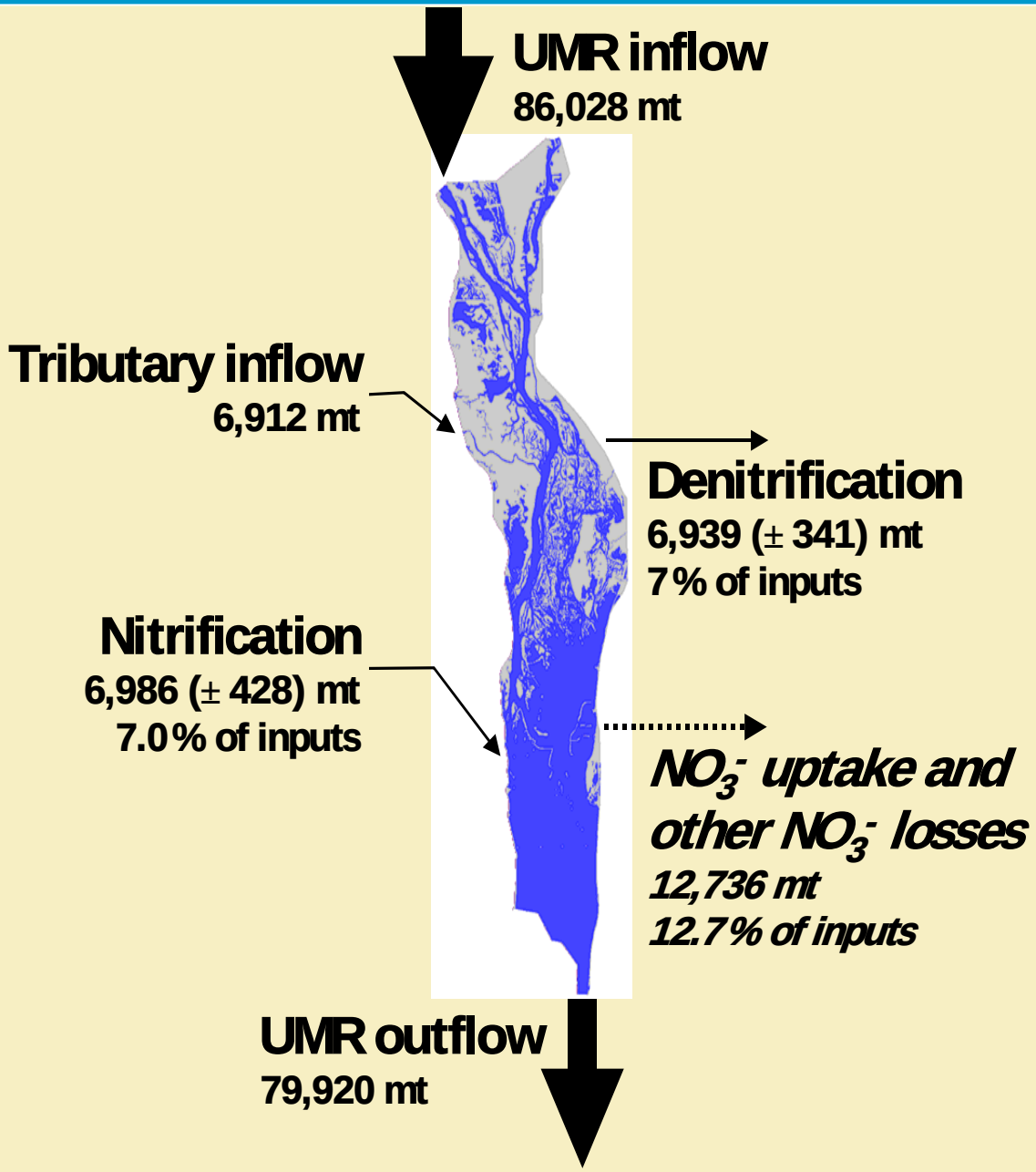
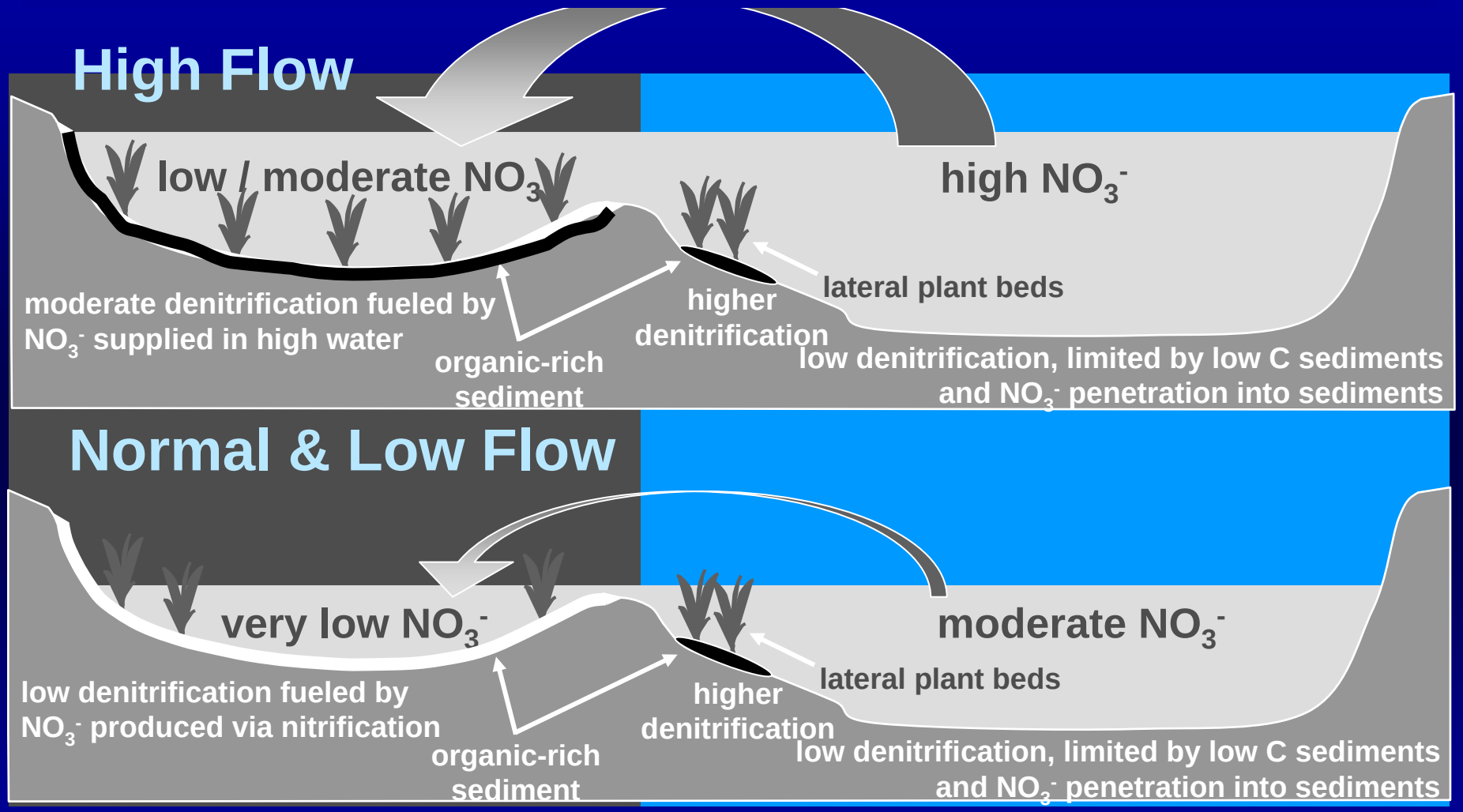
Annual nitrate budget



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



Backwaters

Main Channel

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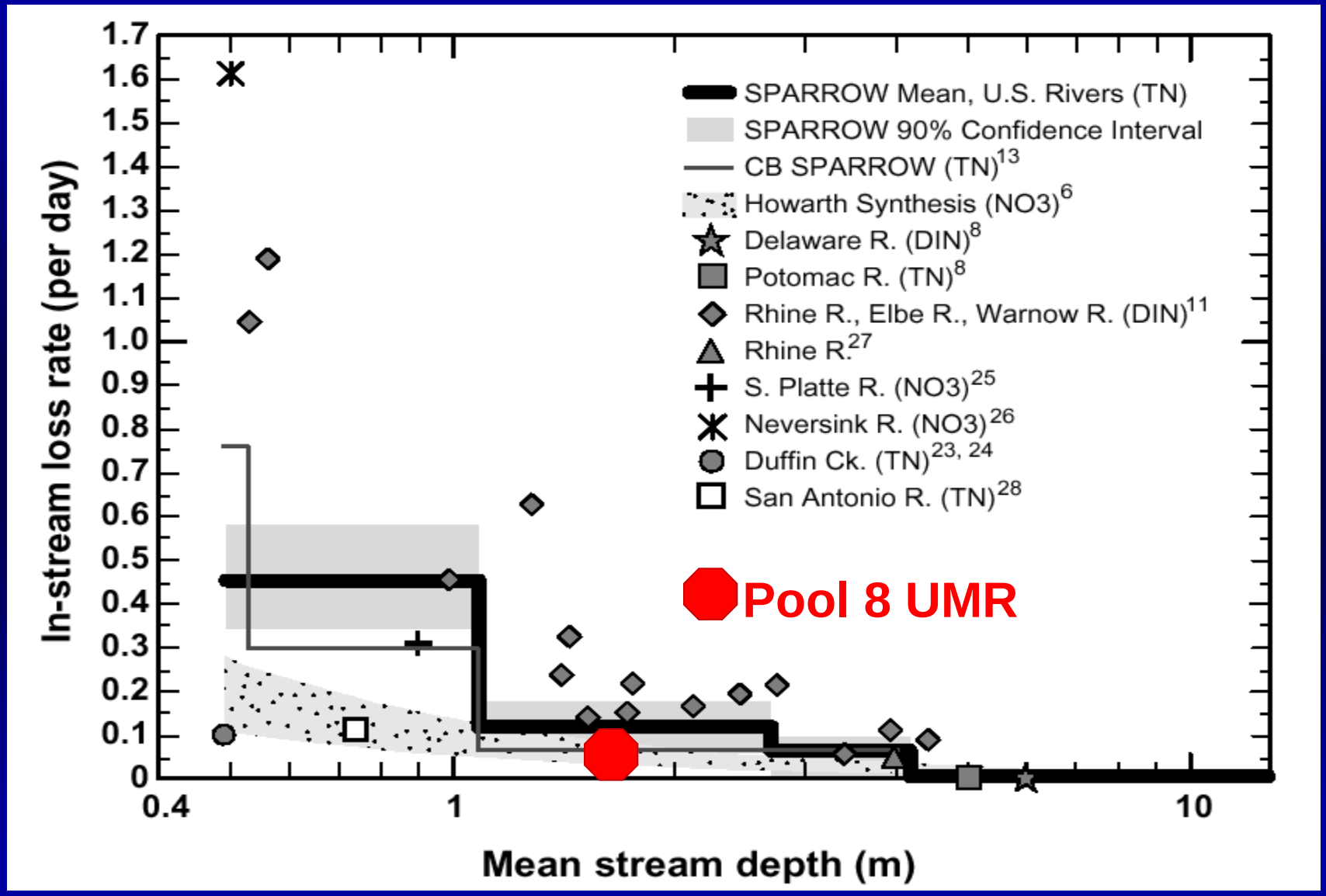
N loss rate of lotic systems



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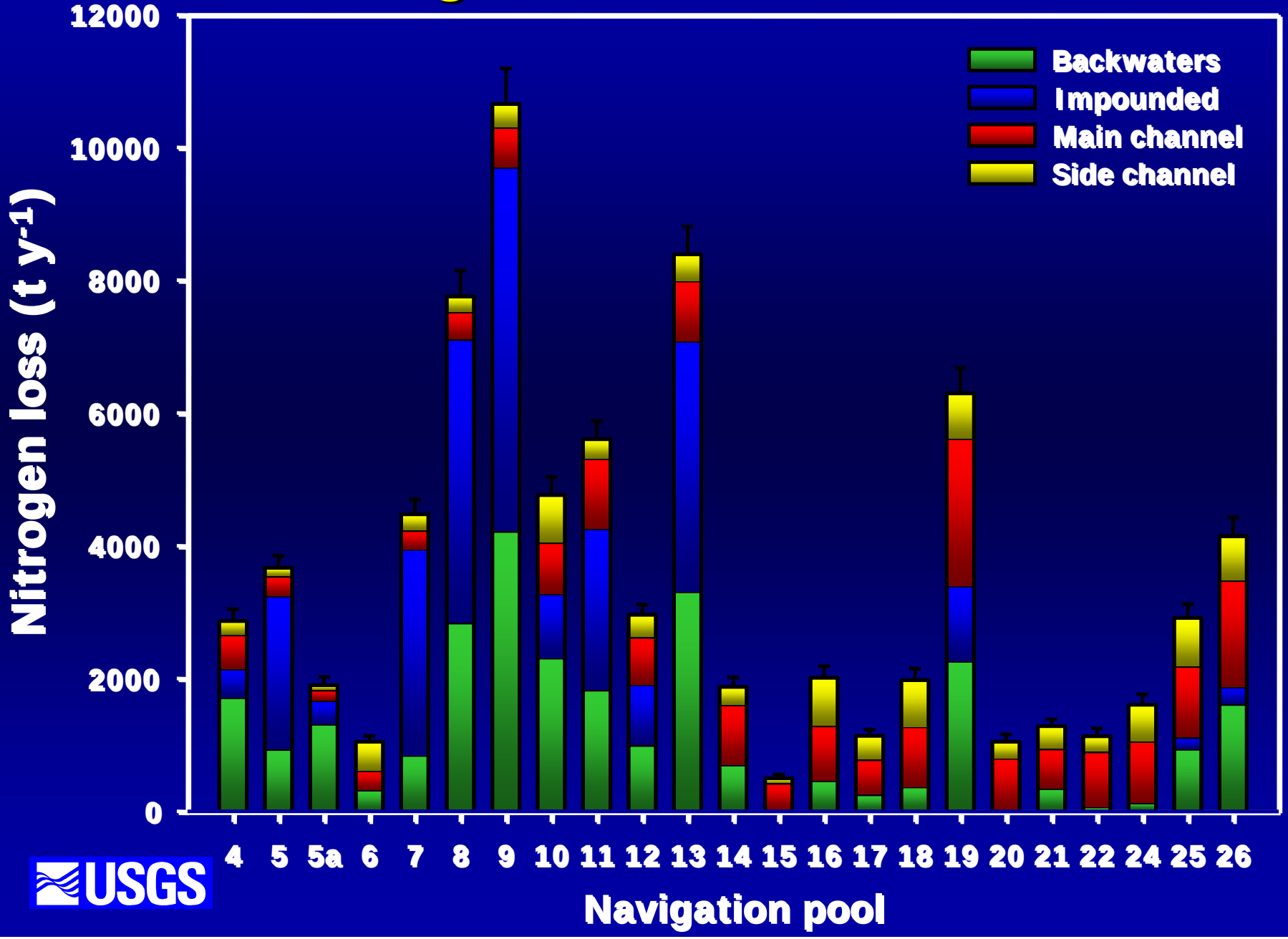
Alexander et al. (2000)

Nitrogen loss in the UMR



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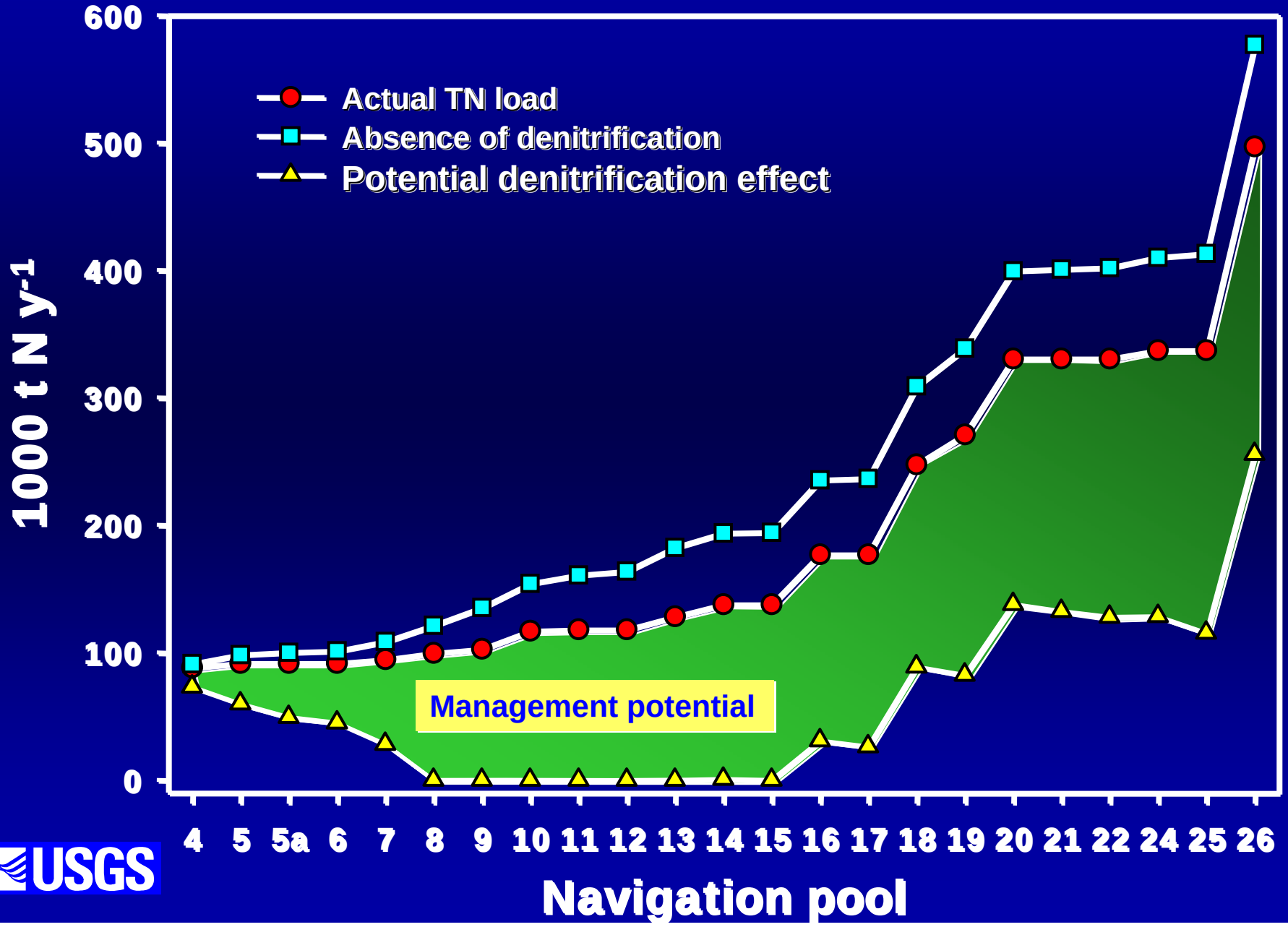
Effect of denitrification potential



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Conclusions:

1. Rates of NO3 removal in the UMR are limited by NO3 delivery to carbon rich areas of the flood plain.

2. Coupling of nitrification-denitrification is important during base-flow periods.

3. With current river management, NO3 load overwhelms the capacity of the river-flood plain ecosystem to remove more than ~ 10% of total N load.

4. There may be some greater capacity to promote N removal through manipulation of N-rich water to C-rich backwaters and impounded areas.

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Future Direction of Nutrient Research in the UMR

1. **Determine the role of assimilation, plant scenescence, and mineralization in nitrogen flux in flood plain rivers.**
2. **Develop linked hydraulic-biogeochemical process models to better predict nutrient and carbon dynamics.**
3. **Determine linkages between primary production and loading of N & P.**
4. **Develop models predicting effectiveness of river management actions on N removal and biologic responses.**

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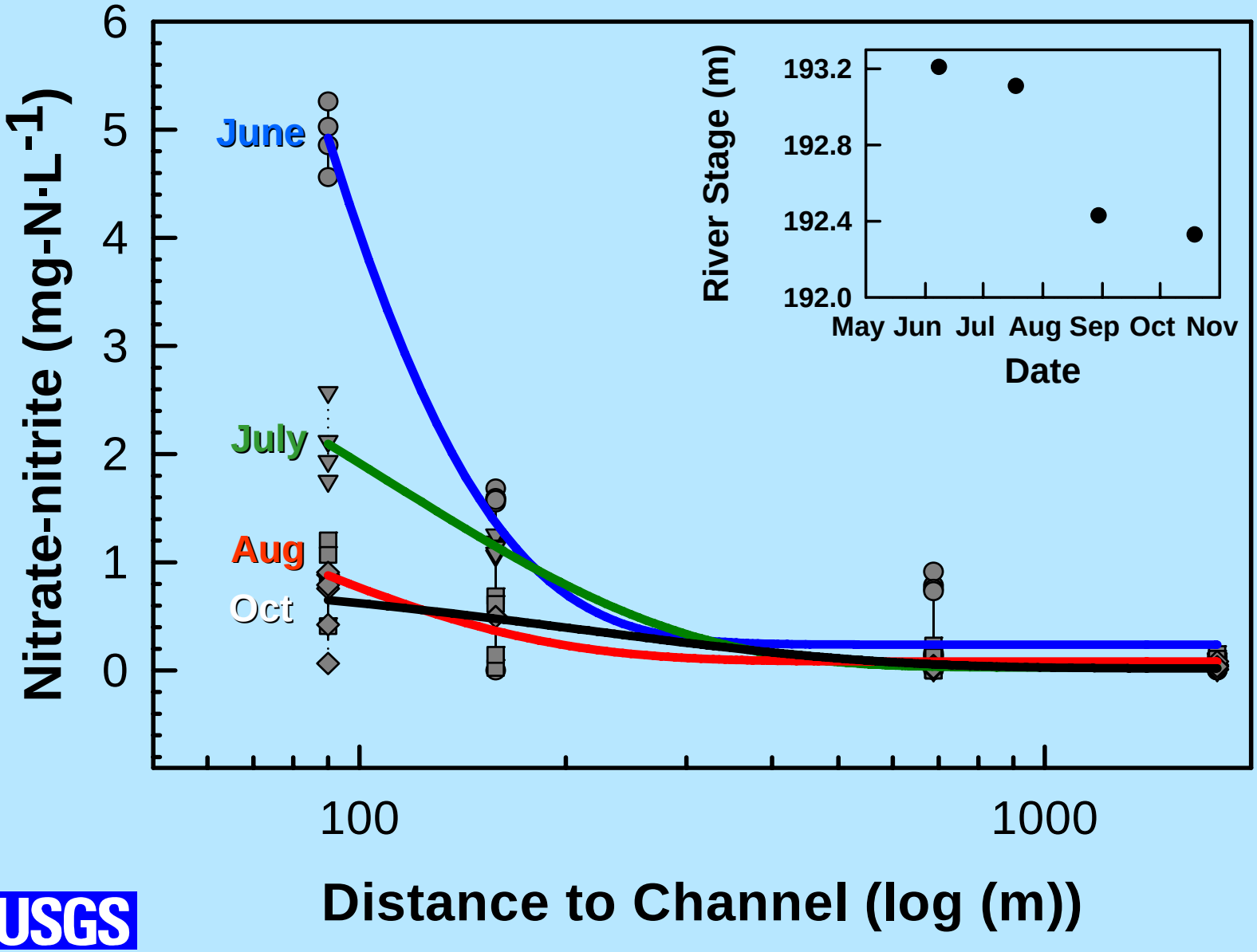
END of TALK

Nitrate Depletion



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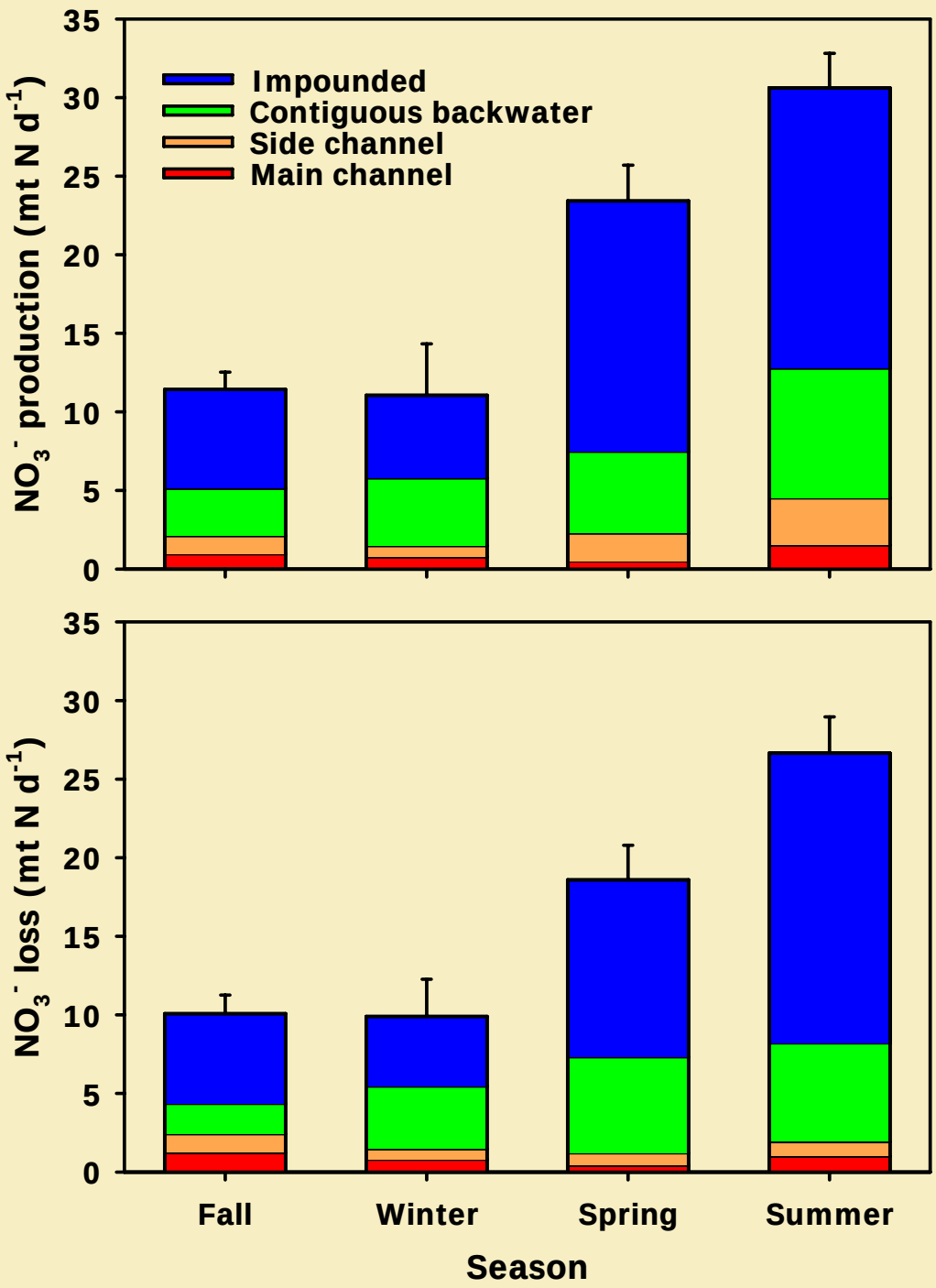
Impounded
Contiguous backwater
Side channel
Main channel
NO_3^- production (mt N d^{-1})
NO_3^- loss (mt N d^{-1})
0
5
10
15
20
25
30
35
Fall
Winter
Spring
Summer
Season

Minnesota
Minneapolis
La Crosse, WI
Wisconsin
Chicago
Iowa
Illinois
St. Louis
Missouri

USGS

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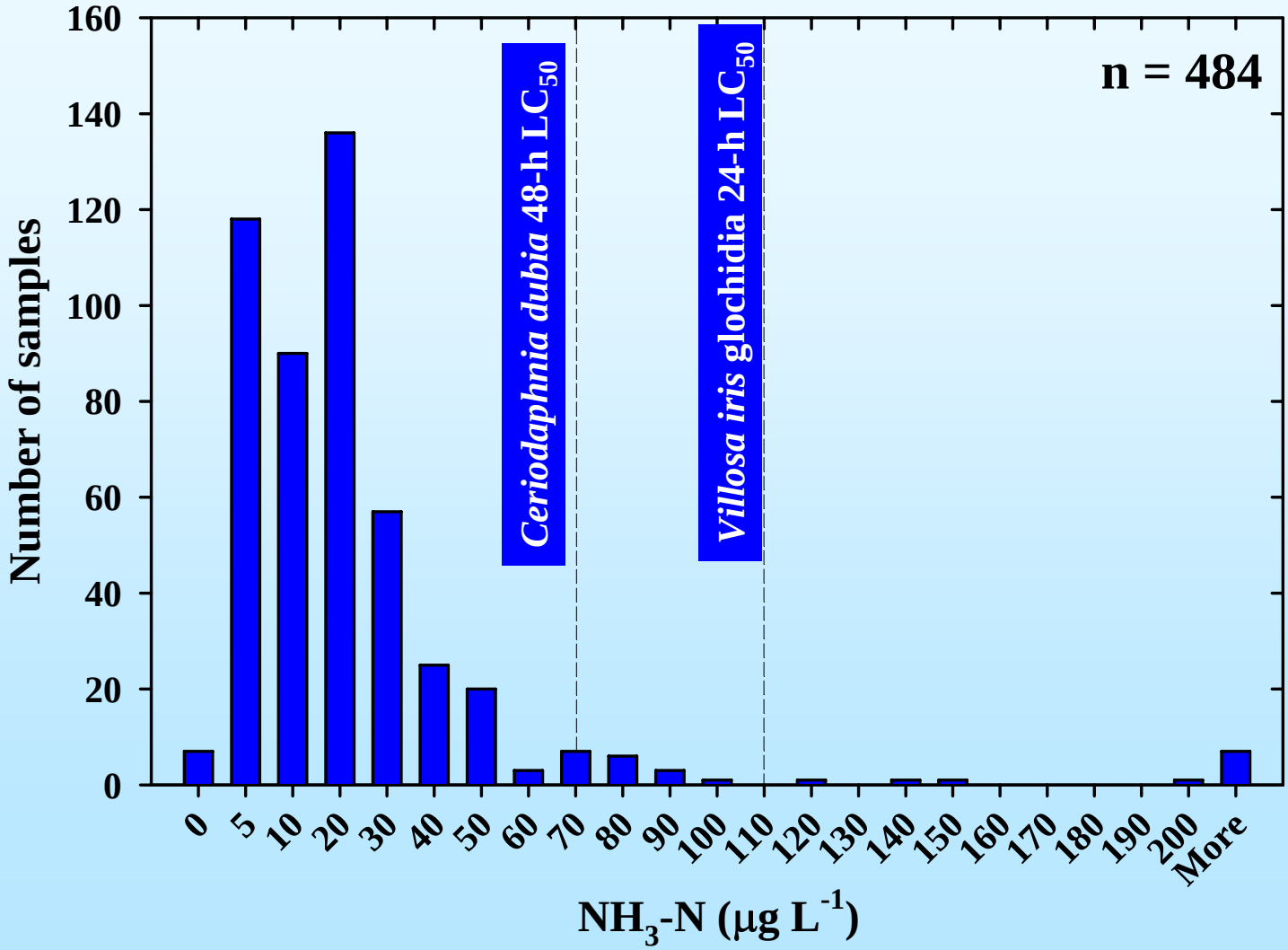
Unionized ammonia concentrations in sediment porewater of Pool 8



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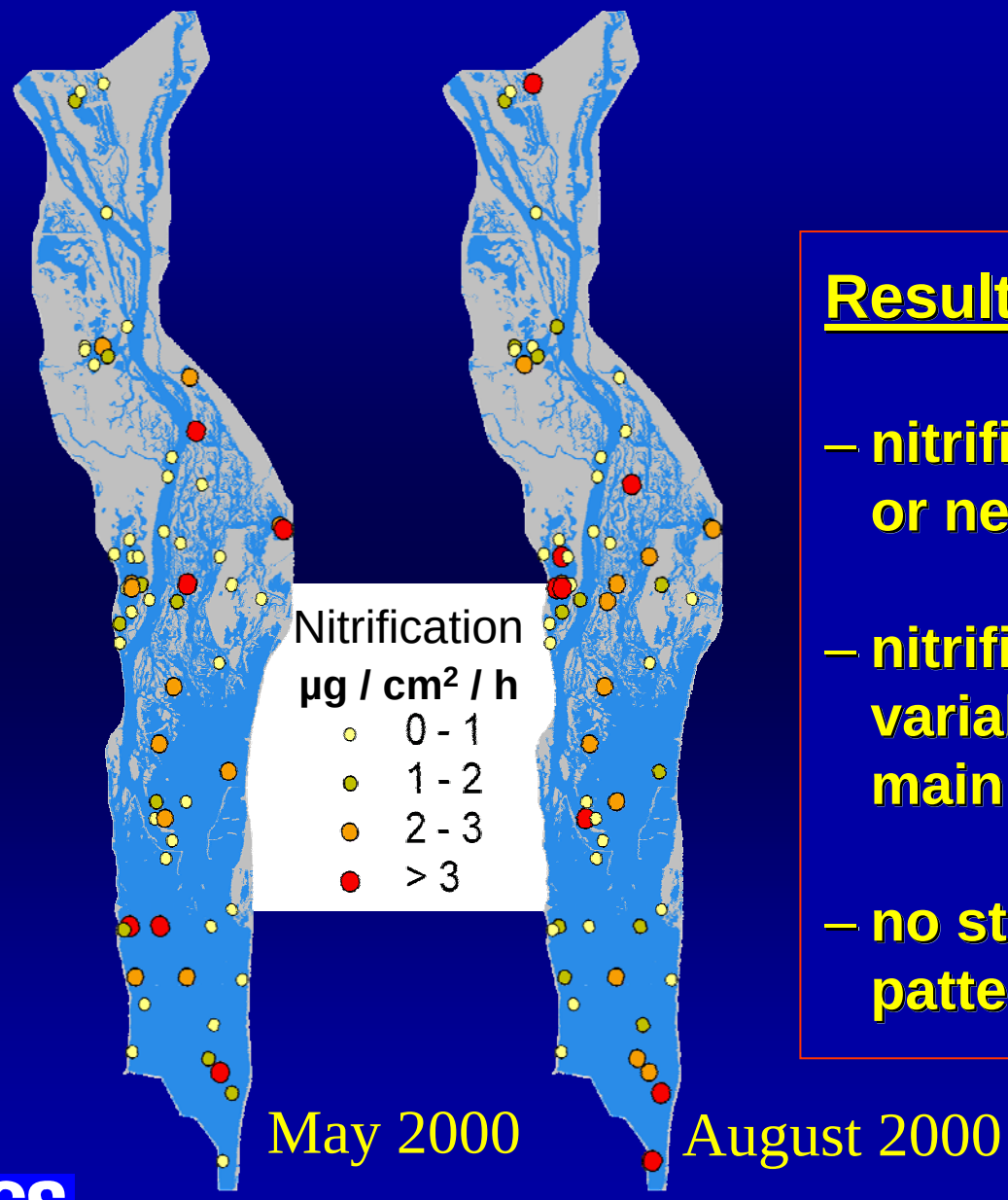
Nitrification in Pool 8



Results

- nitrification was low in or near main channel
- nitrification was variable away from main channel
- no strong seasonal pattern

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Nutrients in large rivers

Local stimulatory effects

Local inhibitory effects

Downstream effects

N v P cycling

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