Patterns of nutrient distributions in the St. Croix and Upper Mississippi Rivers: Preliminary evaluation of variation among channels, flowing backwaters and isolated backwaters

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Flood plain river characteristics of interest:

Main Channels
- high water column (wc) nutrient concentrations
- short hydraulic retention time
- low sediment carbon concentrations
- high sediment oxygen concentrations

Flowing backwaters (side channels)
- intermediate wc nutrient concentrations
- intermediate hydraulic retention times
- intermediate sediment carbon
- variable sediment oxygen concentrations

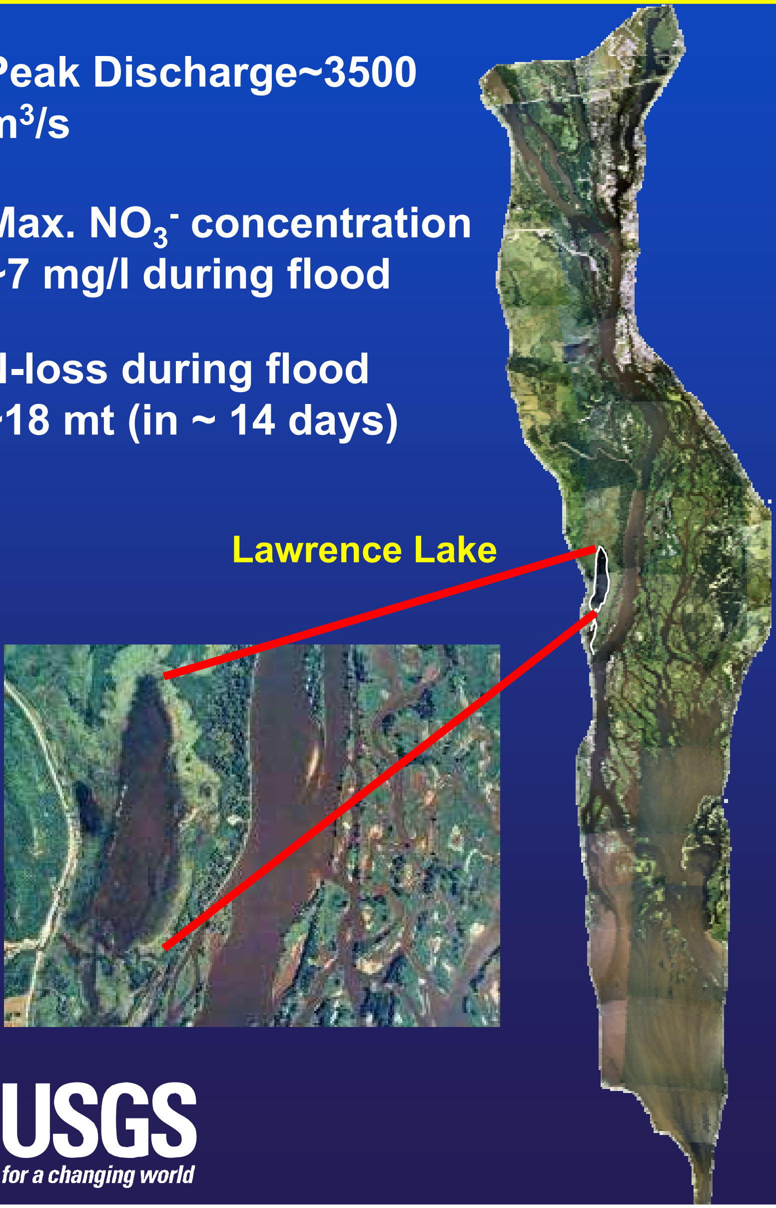
Isolated backwaters
- potentially depleted wc nitrogen/potentially elevated phosphorus concentrations via internal cycling processes
- long hydraulic retention times
- elevated sediment carbon
- low sediment oxygen concentrations

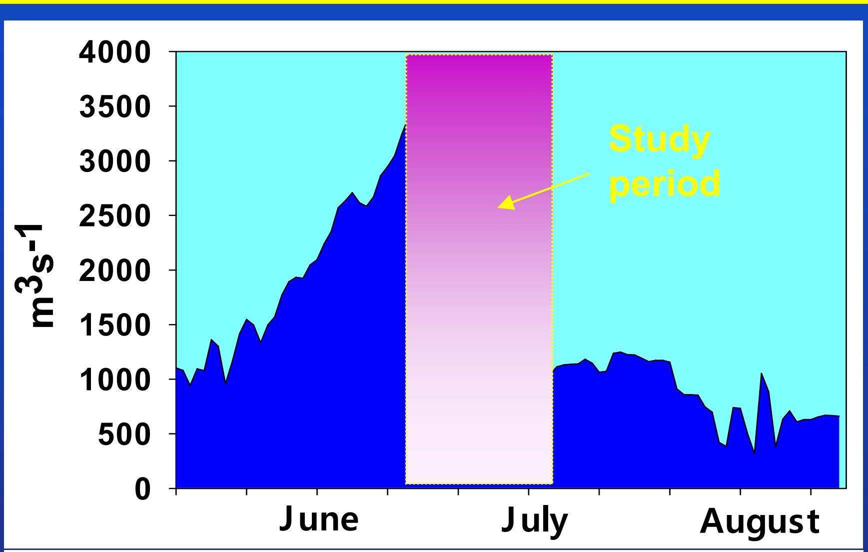
Lawrence Lake, Pool 8, flooded in summer 2004 with Mississippi River water.

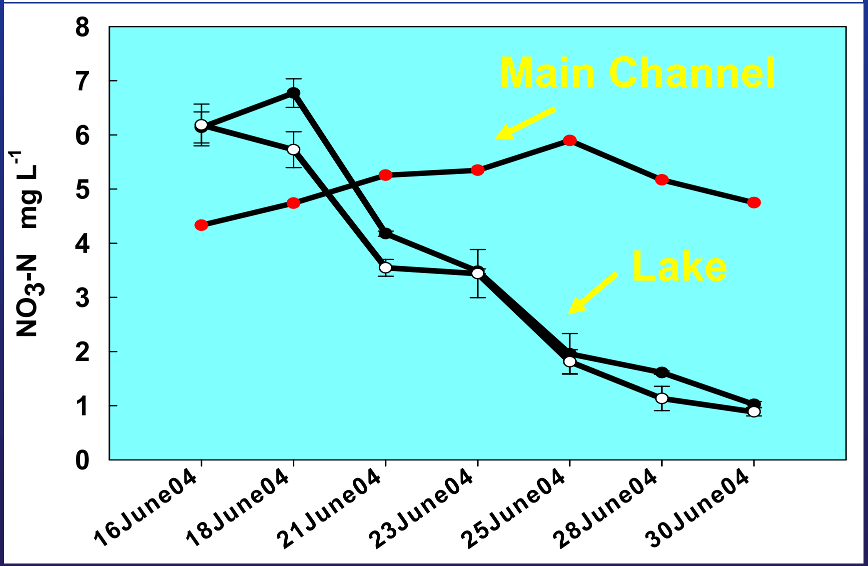
Peak Discharge~3500 m^3/s

Max. NO_3^- concentration ~7 mg/l during flood

N-loss during flood ~18 mt (in ~ 14 days)







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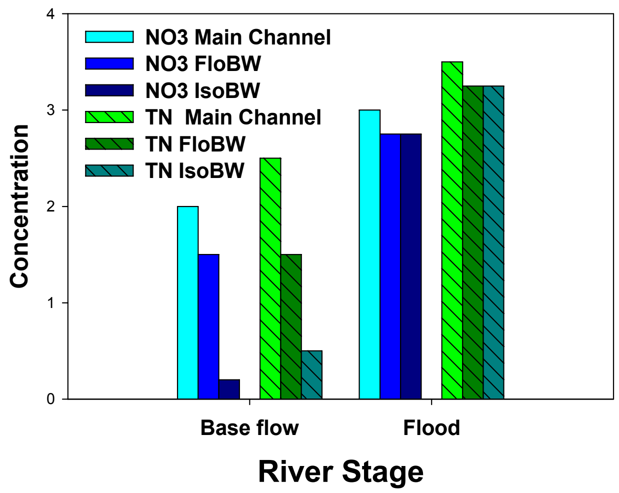
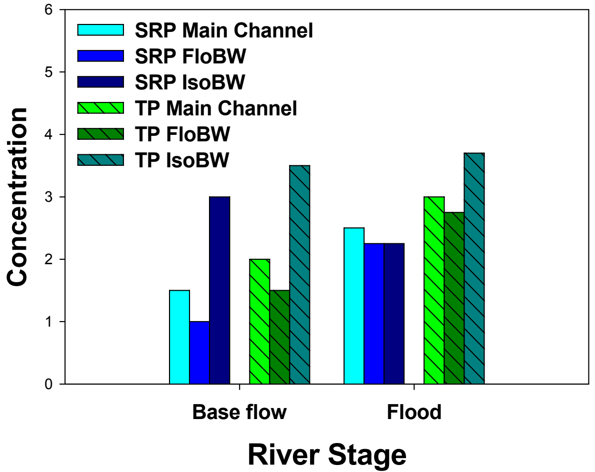
Hypothetical spatial distribution of N and P across the floodplain at base and flood stage

Hypthetical Nitrogen Concentrations



Hypothetical Phosphorus Concentrations



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

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

UMR Pool 8, 2001

Base flow phytoplankton

Project Goals – 3 yr study, 2007 – 2009

- In the St Croix (clean river) and Upper Mississippi (not so clean river).

- In Main Channels, Isolated backwaters, Flowing backwaters:

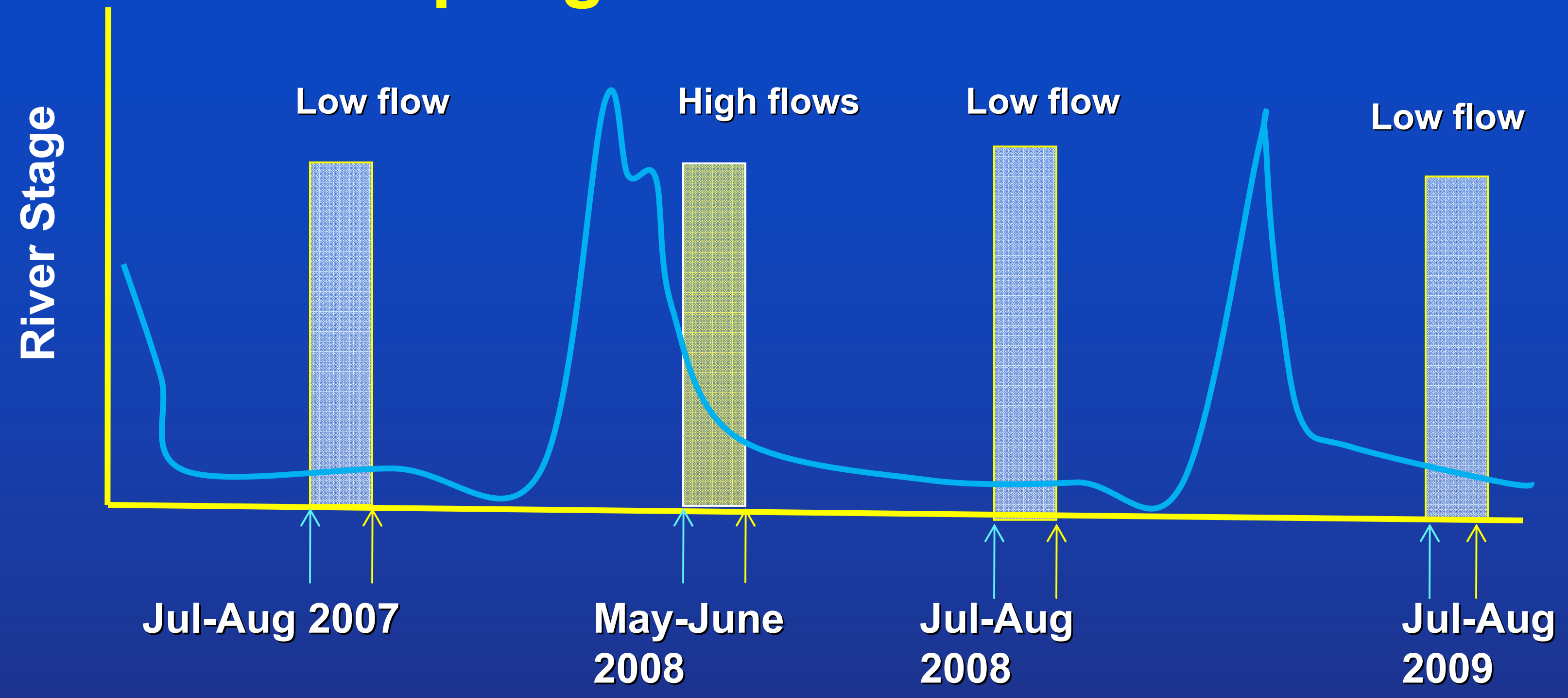
1. Characterize nutrient conditions at sites in SACN and MISS.

2. Investigate biogeochemical processes affecting nitrogen cycling (sed. ammonia accumulation, denitrification, nitrification, mineralization, NO_3^- uptake [chambers and flow path]).

3. Explore spatial differences in nutrient concentrations and cycling in main channel versus backwater habitats.

4. Quantify effects of nutrient enrichment on key indicator biota and ecological processes (nutrient diffusing substrates, juv. mussel growth, community metabolism).

Sampling time line and tasks



2007 (low flow only)
- Site selection
- Nutrient diffusing substrates
- N & P concentrations

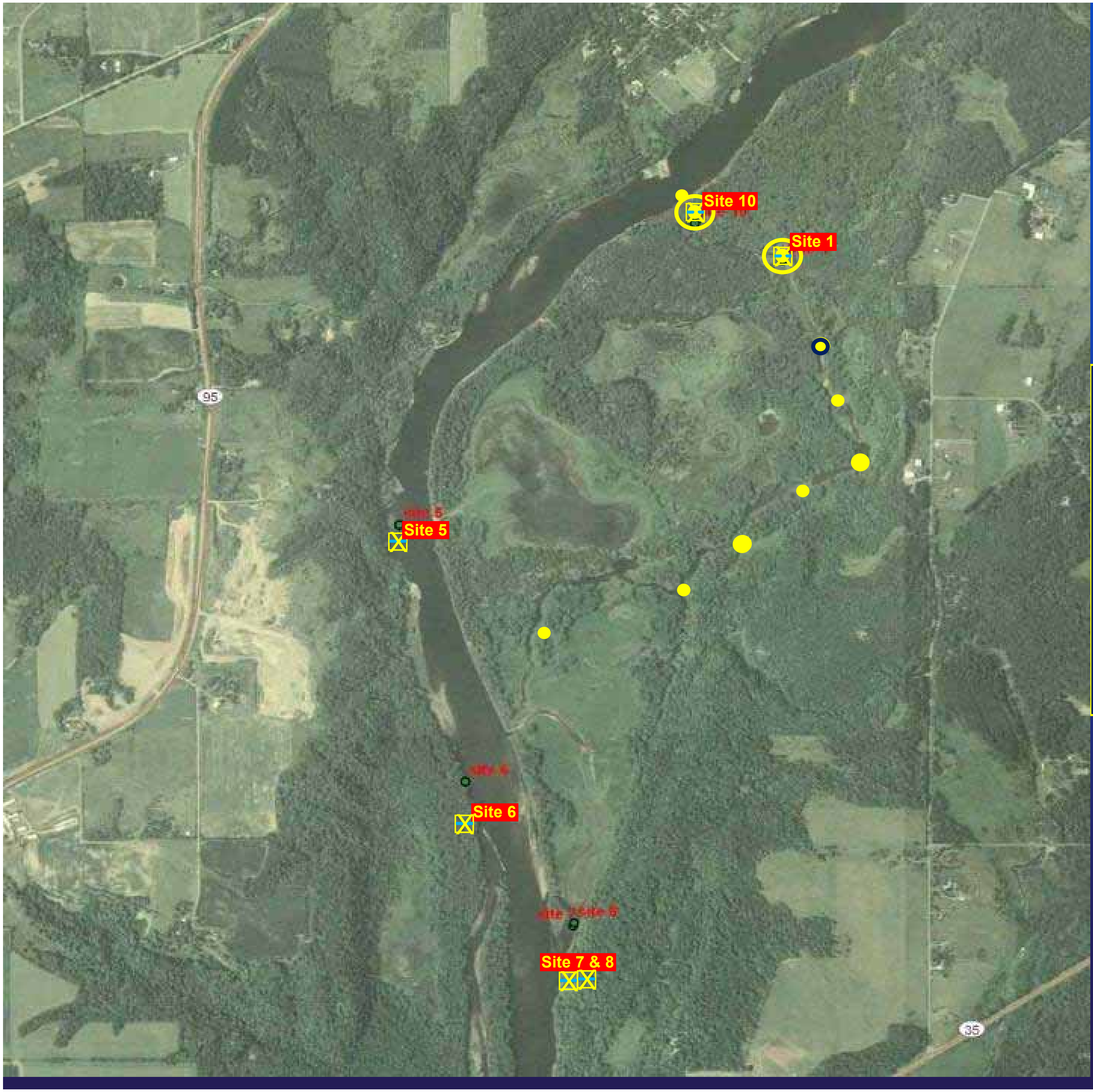
MN WRD team
-Metabolism
-Instantaneous loads (nutrients & sediment)
-Chlorophyll

2008 (high and low flow)
- N & P concentrations
- N-Biogeochem
- NO3 uptake (chambers)
- NO3 uptake (flowpath)
-Nutrient Diffusing substrates
-Mussel growth chambers

MN WRD team
-Metabolism
-Instantaneous loads
-Chlorophyll

2009 (low flow only)
- N & P concentrations
- N-Biogeochem
- NO3 uptake (chambers)
- NO3 uptake (flowpath)
-Nutrient Diffusing substrates
-Mussel growth chambers

MN WRD team
-Metabolism
-Instantaneous loads
-Chlorophyll



SACN Study Sites

FY08 Design

- 2 non-flowing BW (Sites 7&8);
- 2 flowing BW (Sites 1&10),
- 2 main channel (Sites 5 & 6)

Samples

○ NO_3 uptake chambers

● NO_3 depletion

X Biogeochemistry

□ NDS samplers

— Mussel cages

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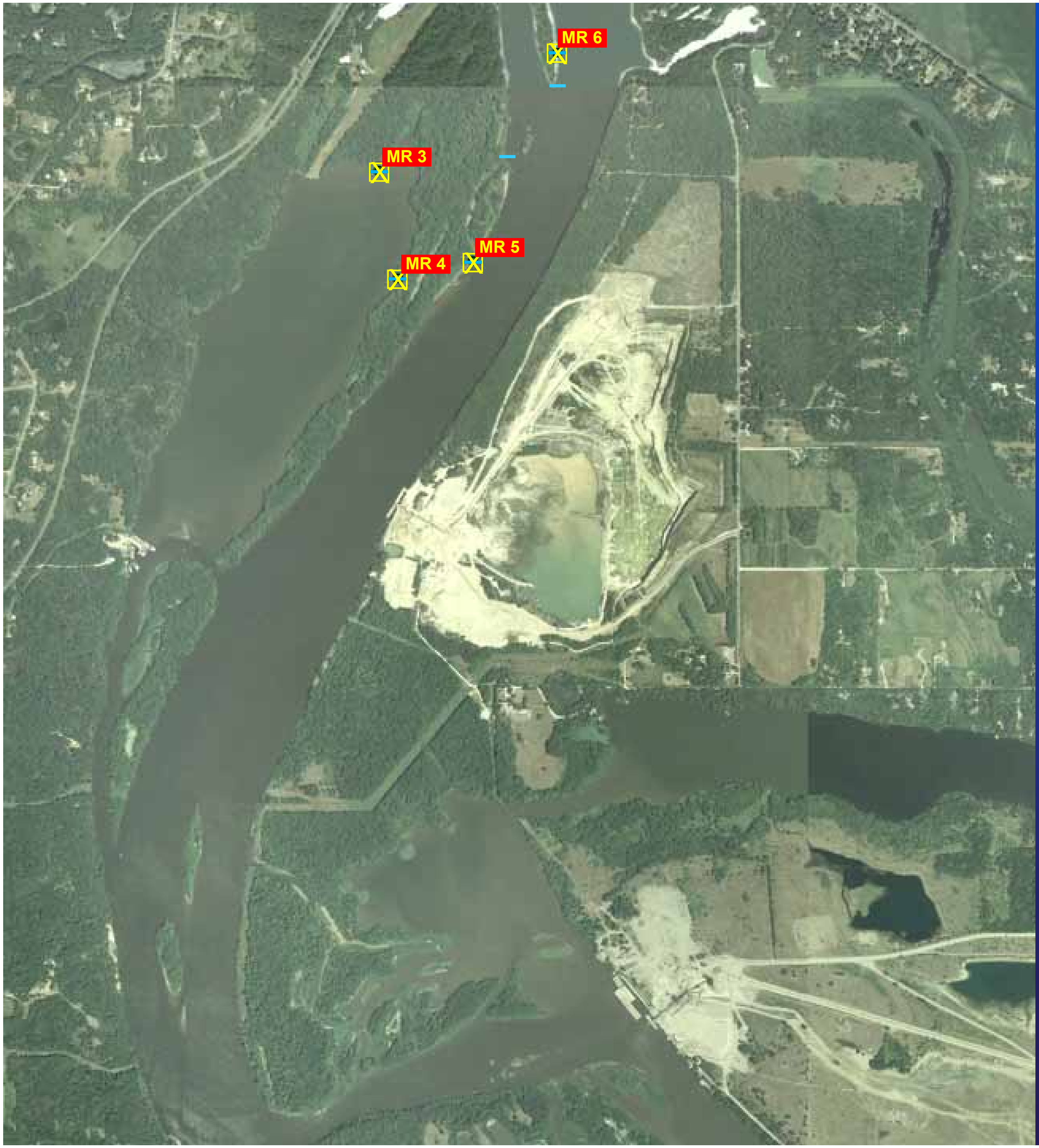


MNRA Study Sites

FY08 Design

- 2 non-flowing BW
(Sites 3&4);

-2 flowing BW
(Sites 8&9),

-2 main channel
(Sites 5 & 6)

Samples

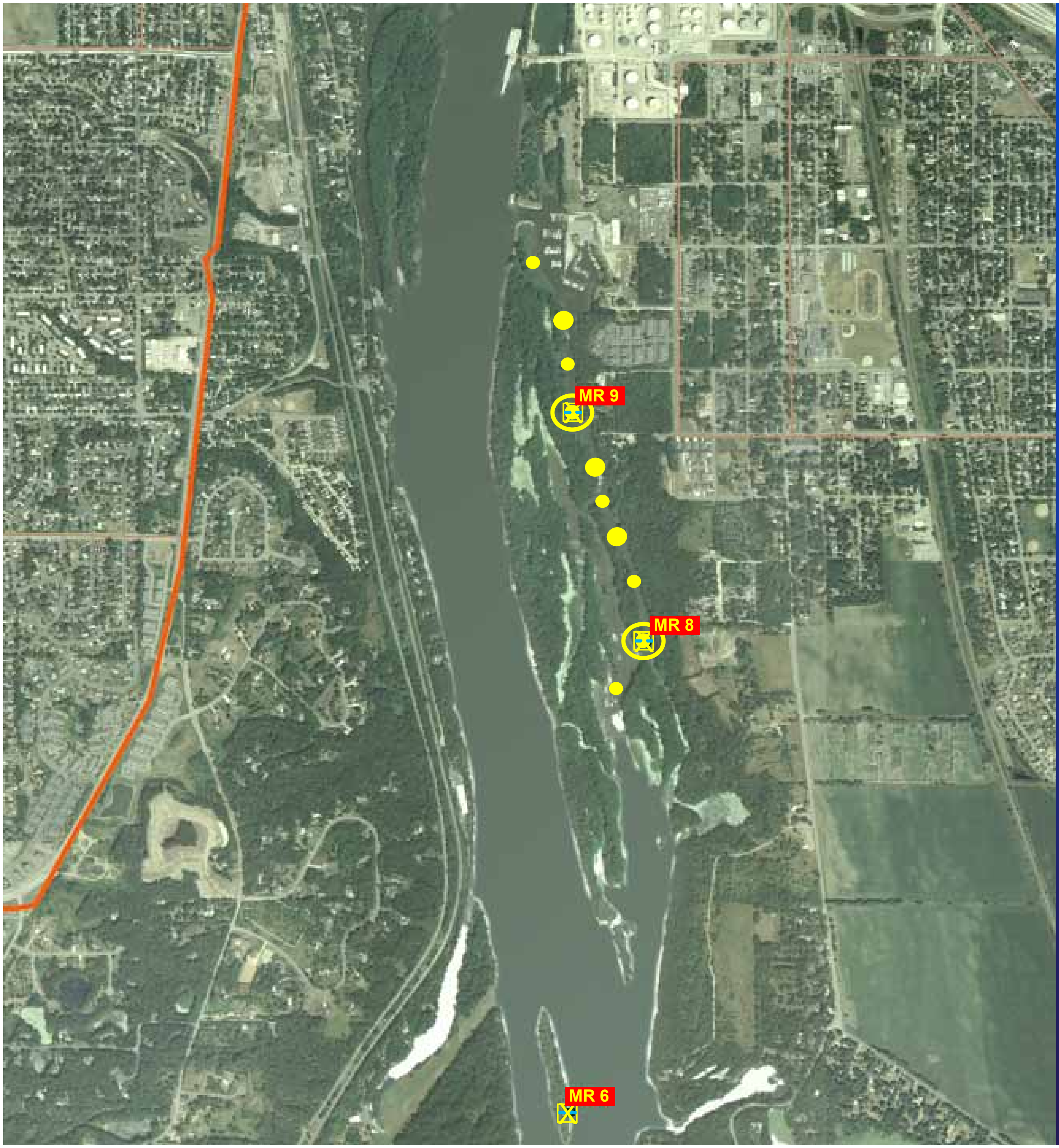
○ NO$_3$ uptake chambers

● NO$_3$ depletion

X Biogeochemistry

□ NDS samplers

— Mussel cages



MNRA Study Sites

FY08 Design

- **2 non-flowing BW (Sites 3&4);**

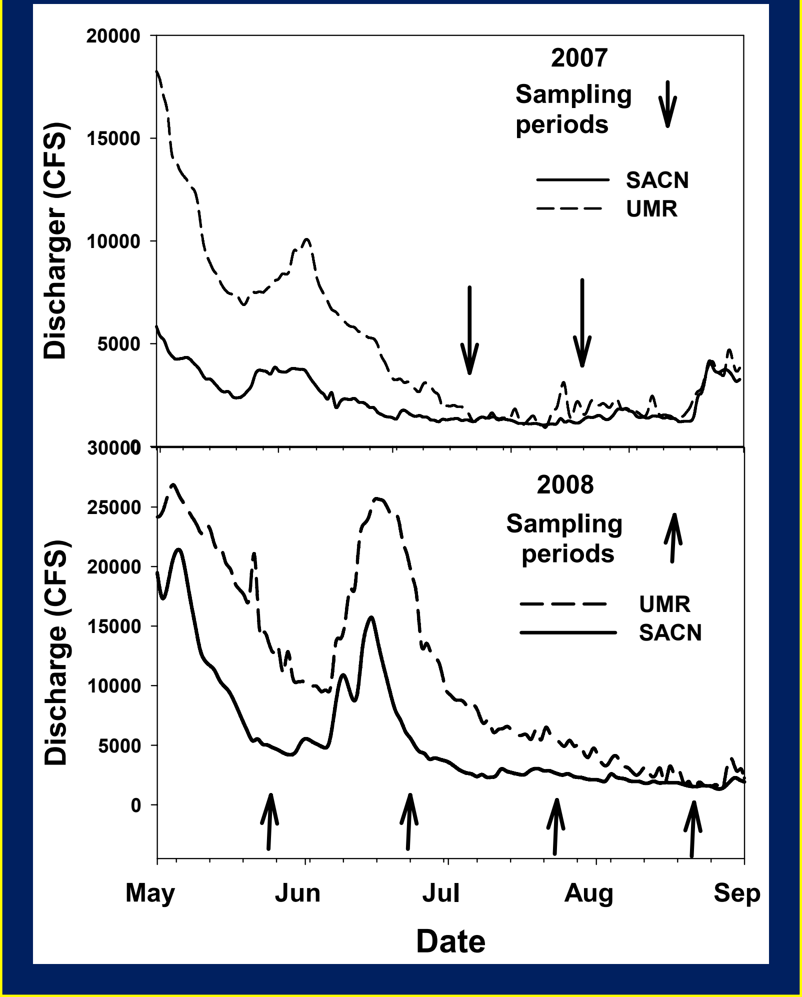
-2 flowing BW (Sites 8&9),

-2 main channel (Sites 5 & 6)

Samples

- ○ **NO_3 uptake chambers**
- ● **NO_3 depletion**
- X **Biogeochemistry**
- □ **NDS samplers**
- — **Mussel cages**

Sampling events and river discharge



2007

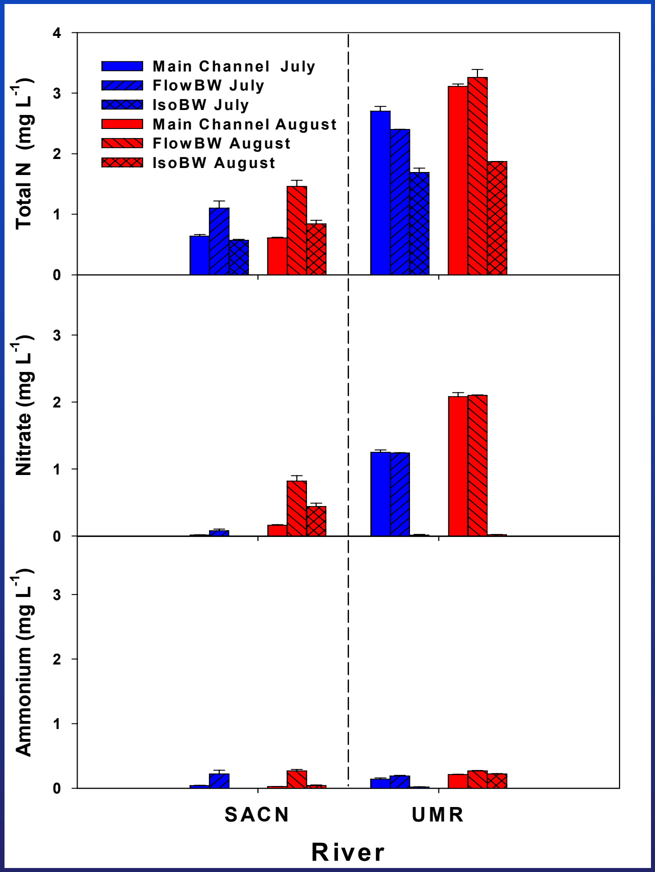
July 23-26 -> SACN 1410 cfs, UMR1399 cfs
August 23-25 -> SACN1440 cfs, UMR 2217 cfs

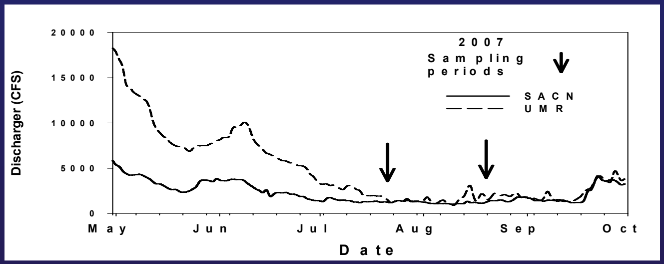
2008

May 26-28 -> SACN 4260 cfs, UMR 11070 cfs
July 27-30 -> SACN 2430 cfs, UMR 5420 cfs
August 24-27 -> SACN 1340 cfs, UMR 1607 cfs

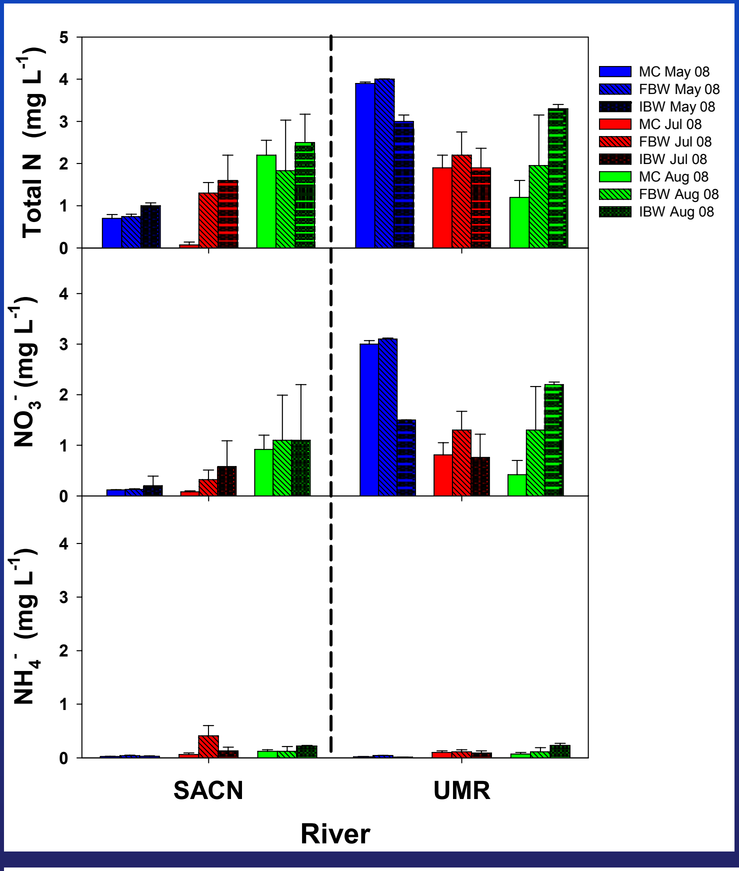
Nitrogen

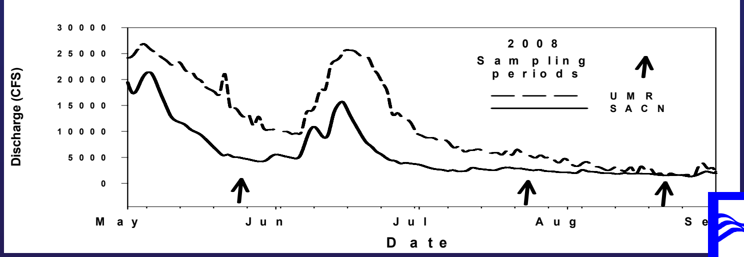
July and August 2007





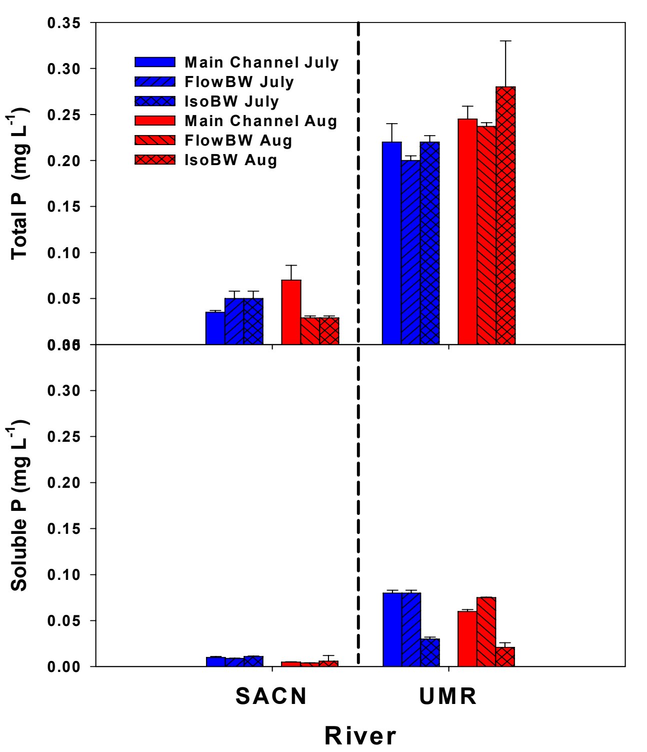
May, July and August 2008



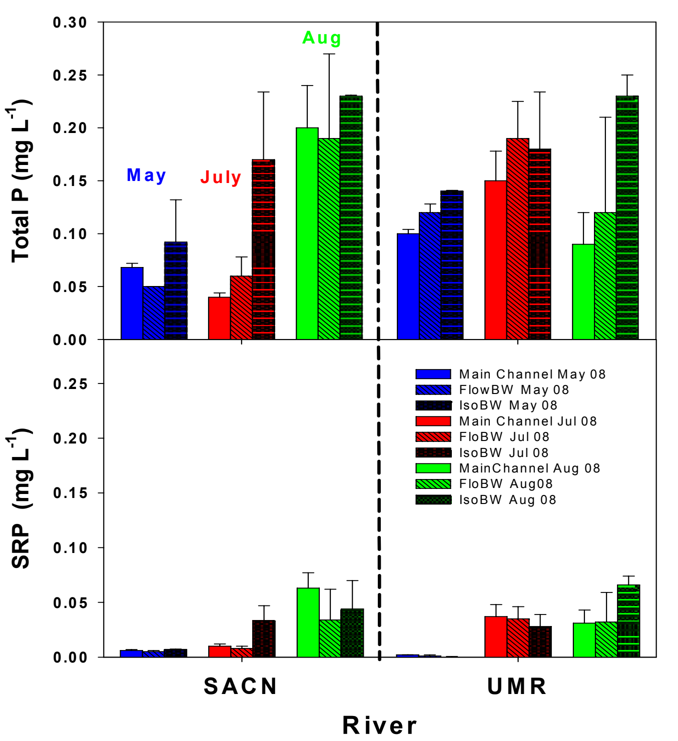


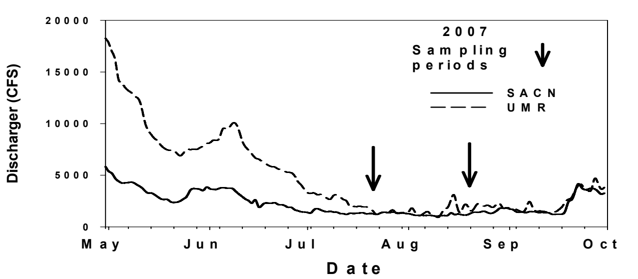
Phosphorus

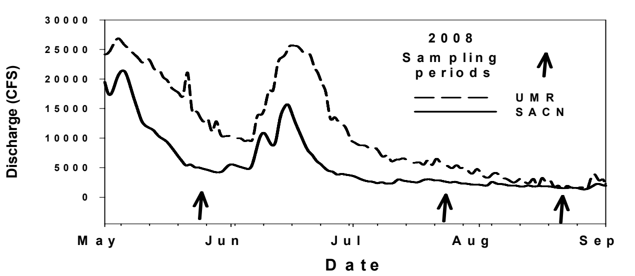
July and August 2007



May, July and August 2008



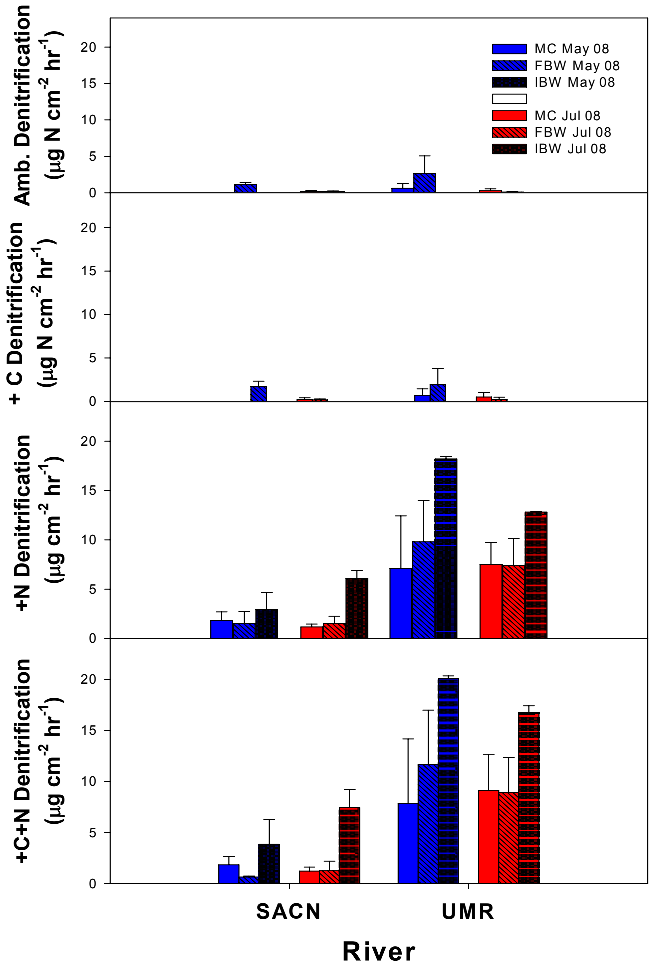




Sediment Denitrification

($NO_3^- \rightarrow N_2O, N_2$)

May and July 2008



Ambient denitrification low in all habitats

Carbon (glucose) additions have little effect

Nitrate additions strong effect, esp. in IsoBW, esp. Miss. River

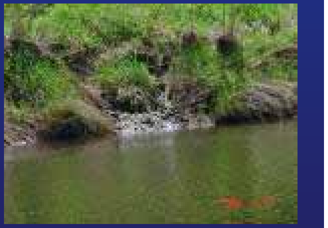
Addition of both C and N not greater response than nitrate alone (no interaction effect)

Summary (mid-study arm waving)

- Nutrient concentrations across the flood in the St.Croix not as expected; Upper Mississippi conformed better to the expected nutrient patterns.

- River discharge over-rides habitat-specific variation in nutrient dynamics

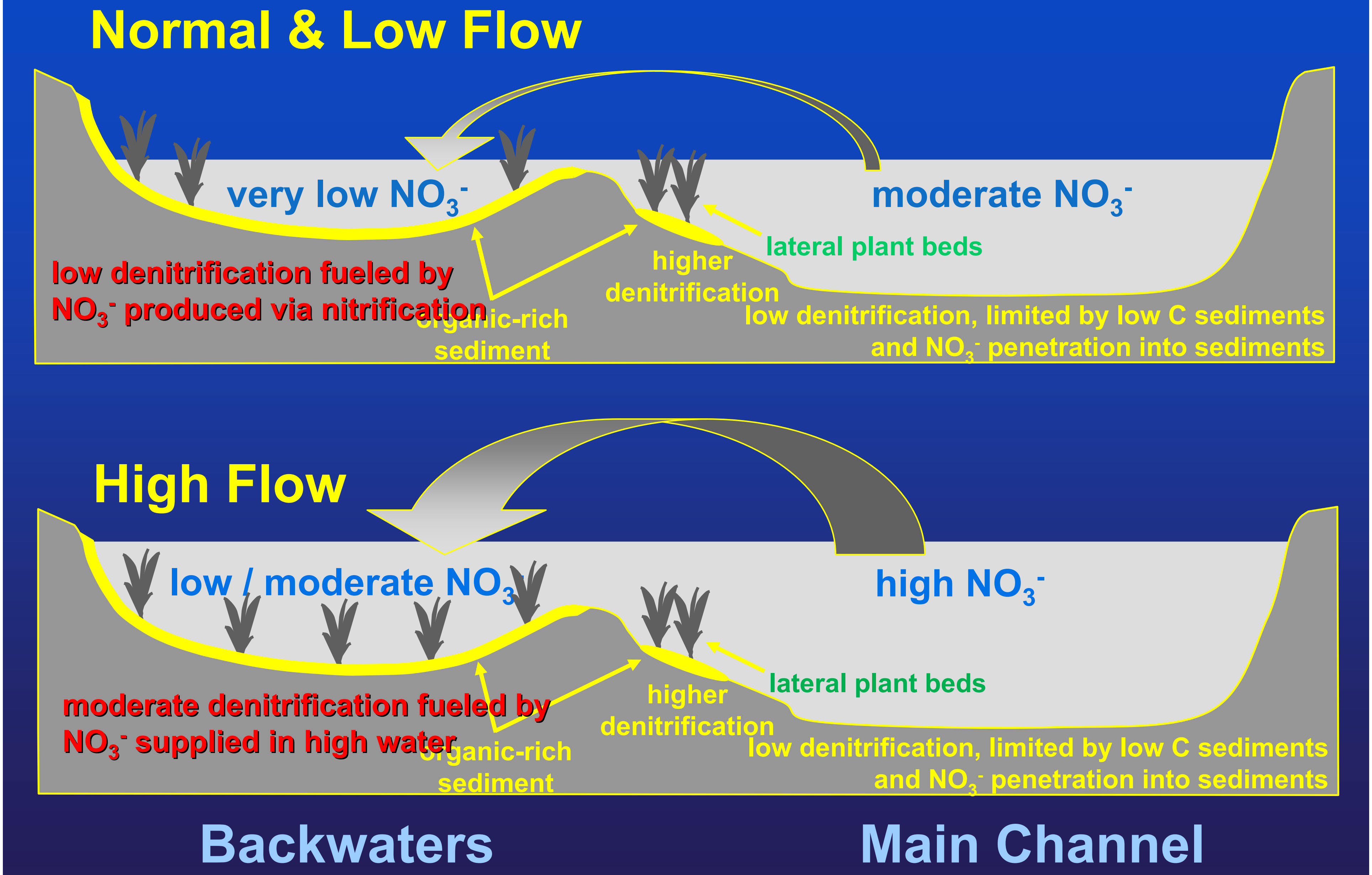
- Local nutrient inputs (groundwater) may play major role in backwater/side channel nitrogen dynamics



- Primary production and oxygen dynamics likely plays secondary role in nitrate and soluble phosphorus dynamics in backwaters.

Questions?

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



Normal & Low Flow

very low NO_3^-

moderate NO_3^-

lateral plant beds

higher denitrification

low denitrification fueled by NO_3^- produced via nitrification

organic-rich sediment

low denitrification, limited by low C sediments and NO_3^- penetration into sediments

High Flow

low / moderate NO_3^-

high NO_3^-

lateral plant beds

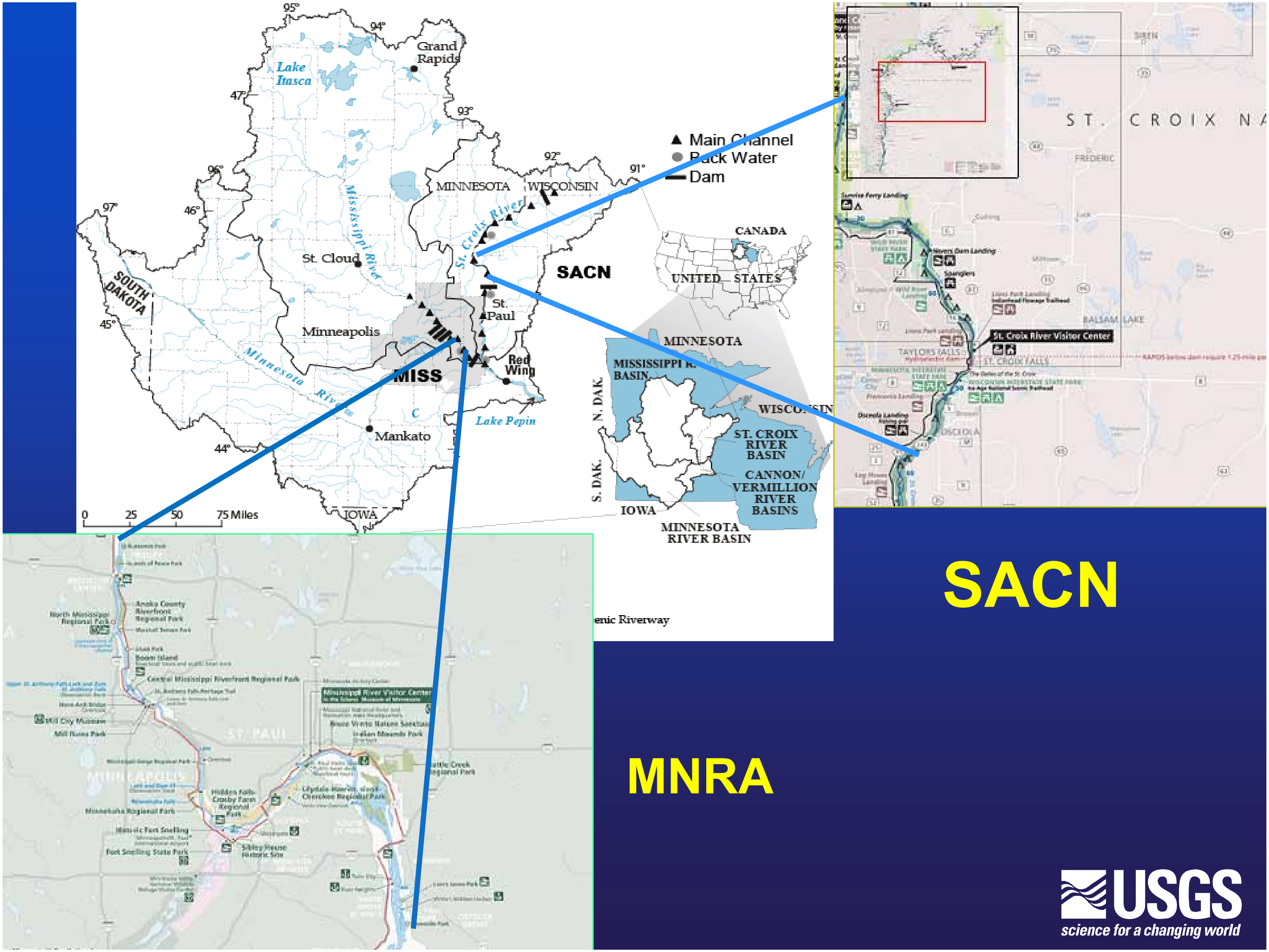
higher denitrification

moderate denitrification fueled by NO_3^- supplied in high water

organic-rich sediment

low denitrification, limited by low C sediments and NO_3^- penetration into sediments

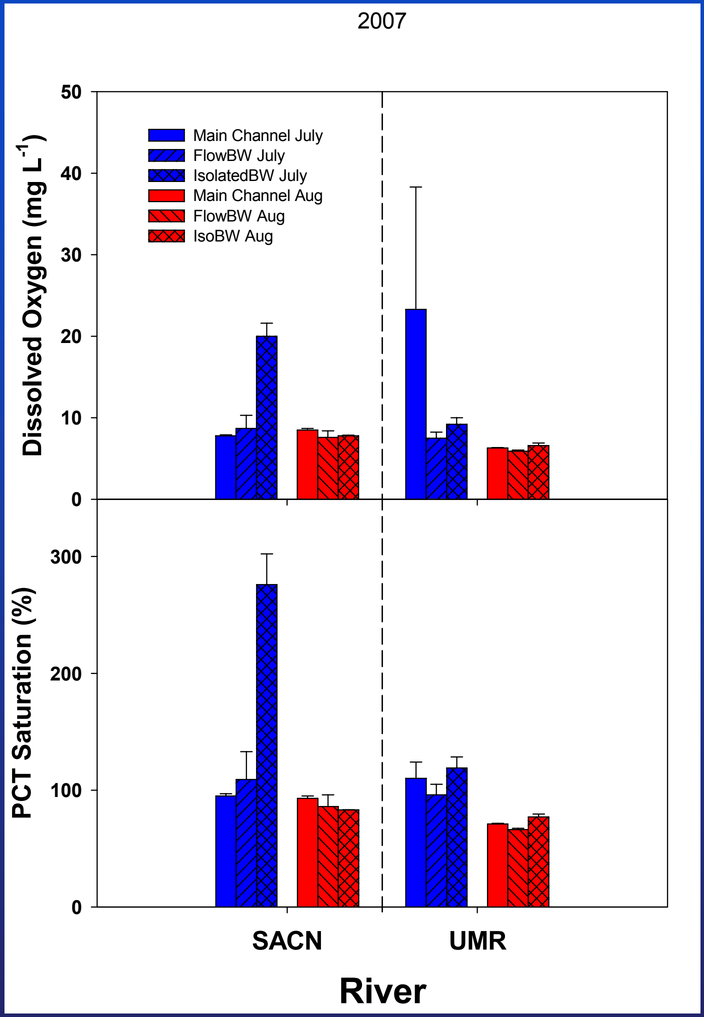
Backwaters **Main Channel**

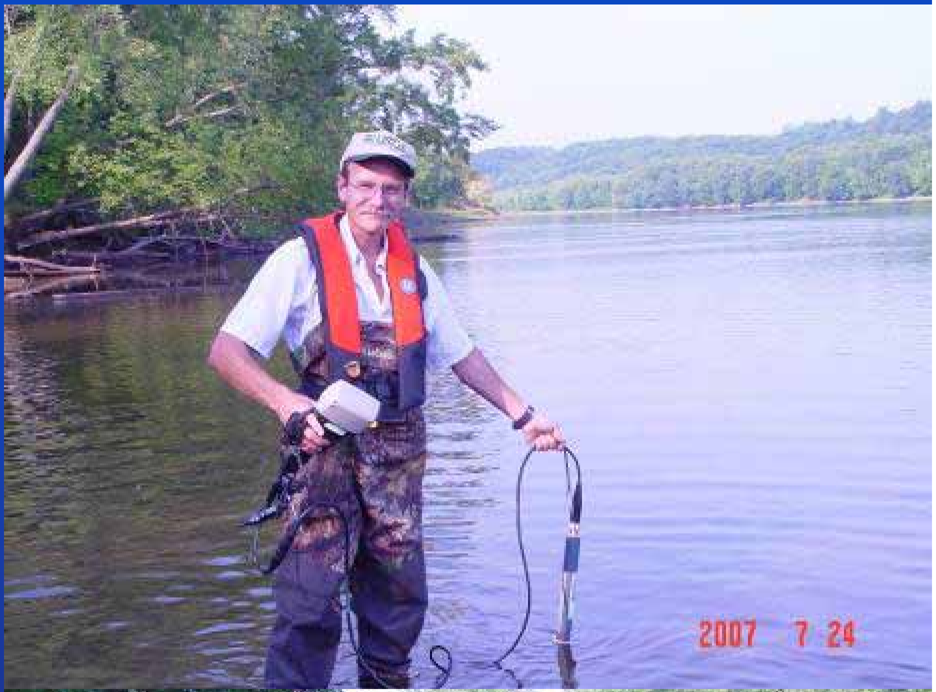


95°
94°
Grand Rapids
Lake Itasca
47°
93°
92°
91°
96°
97°
46°
45°
44°
MINNESOTA
WISCONSIN
St. Croix River
Mississippi River
St. Cloud
Minneapolis
St. Paul
Red Wing
Lake Pepin
Mankato
Minnesota River
SOUTH DAKOTA
IOWA
SACN
MISS
▲ Main Channel
● Back Water
▬ Dam
0 25 50 75 Miles
CANADA
UNITED STATES
MINNESOTA
MISSISSIPPI R. BASIN
WISCONSIN
N. DAK.
S. DAK.
IOWA
ST. CROIX RIVER BASIN
CANNON/ VERMILLION RIVER BASINS
MINNESOTA RIVER BASIN
enic Riverway
ST. CROIX NA
FREDERIC
SIREN
BALSAM LAKE
St. Croix River Visitor Center
TAYLORS FALLS
ST. CROIX FALLS
OSCEOLA
Mississippi River Visitor Center
ST. PAUL
MINNEAPOLIS

SACN

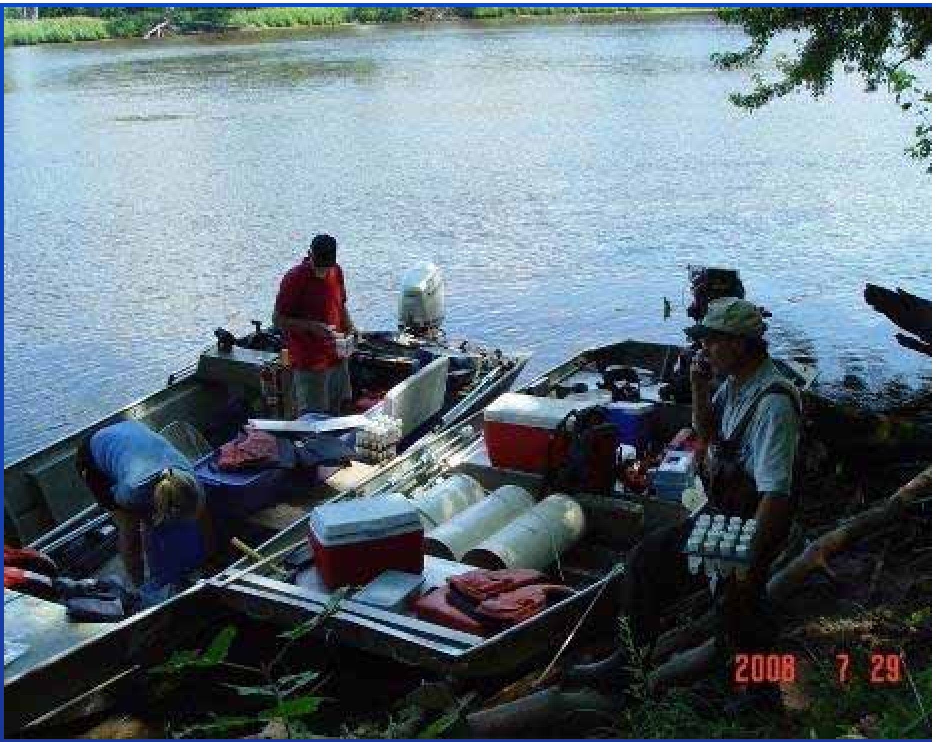
MNRA


2007
50
40
30
20
10
0
Dissolved Oxygen (mg L^{-1})
Main Channel July
FlowBW July
IsolatedBW July
Main Channel Aug
FlowBW Aug
IsoBW Aug
300
200
100
0
PCT Saturation (%)
SACN
UMR
River


2007 7 24


2007 7 24


2008 7 29


2008 7 29


2008 5 27


2008 5 27


2007 7 25


2007 7 24

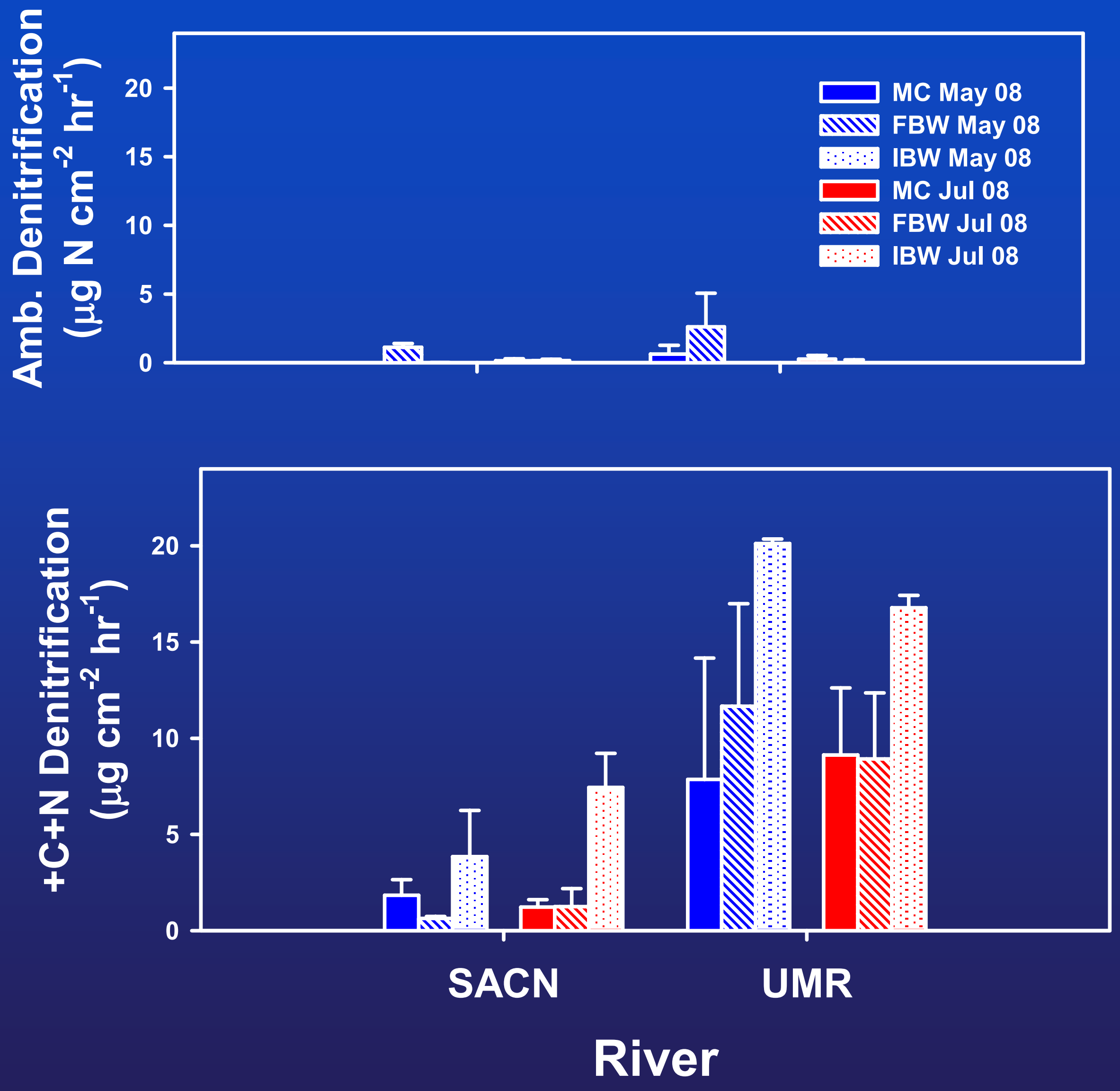

2007 7 25

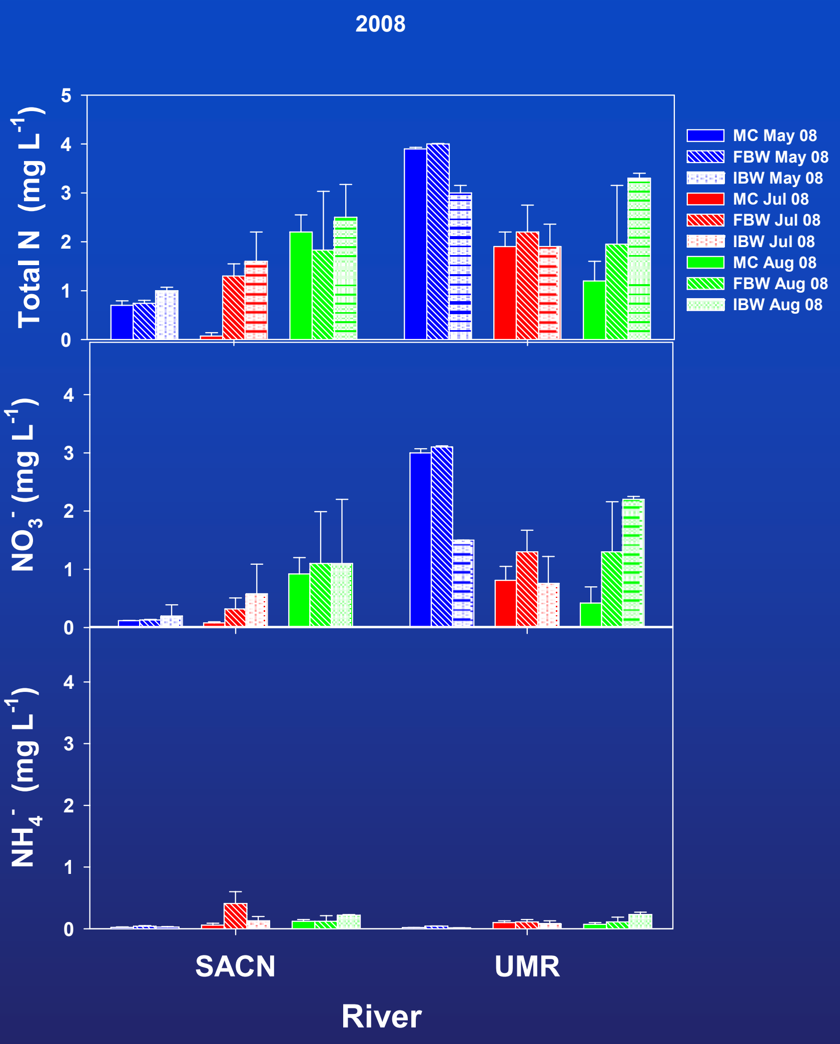
27

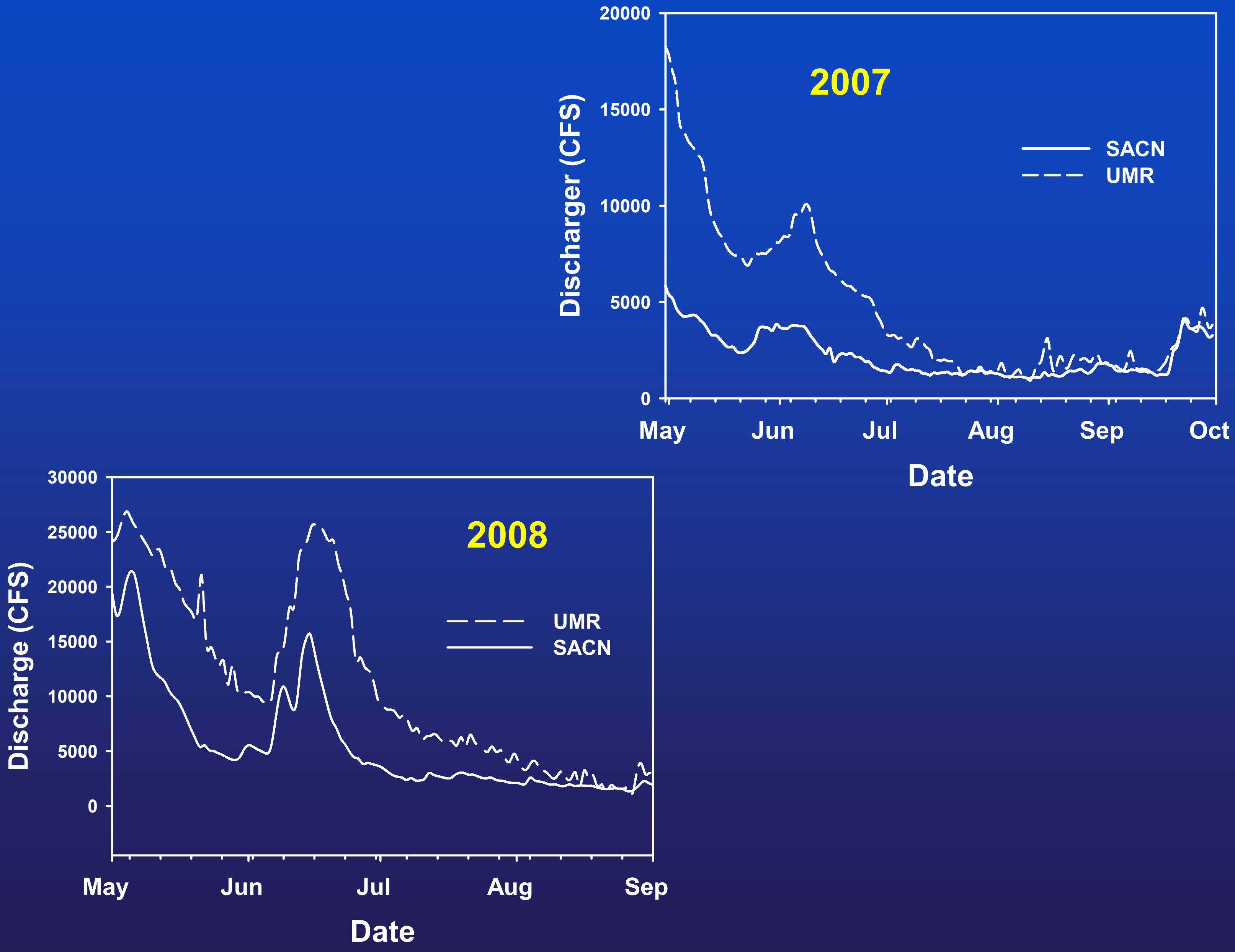
2007

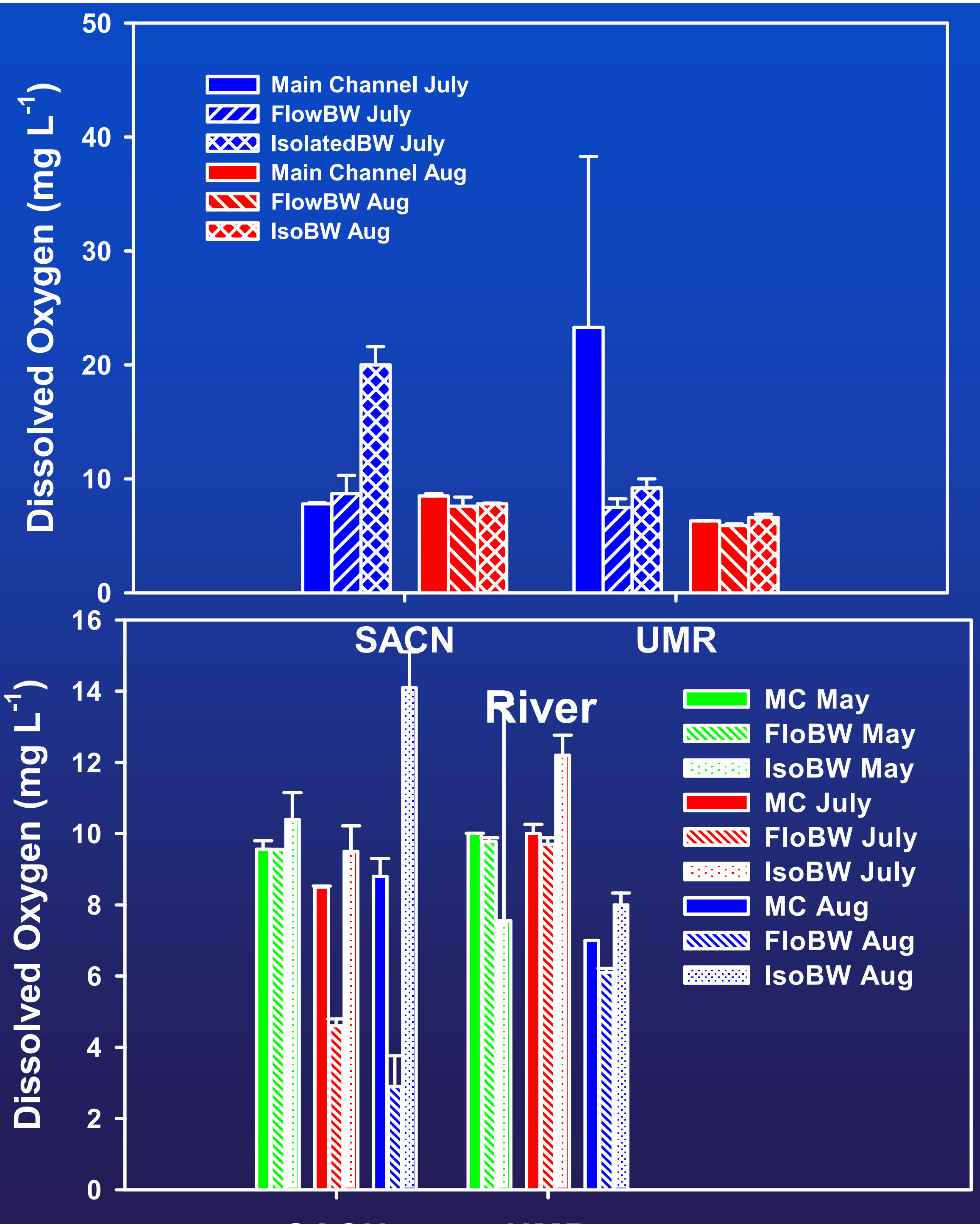
2008 5 29

2008 5 28


Amb. Denitrification
(µg N cm-2 hr-1)
+C+N Denitrification
(µg cm-2 hr-1)
0
5
10
15
20
MC May 08
FBW May 08
IBW May 08
MC Jul 08
FBW Jul 08
IBW Jul 08
SACN
UMR
River

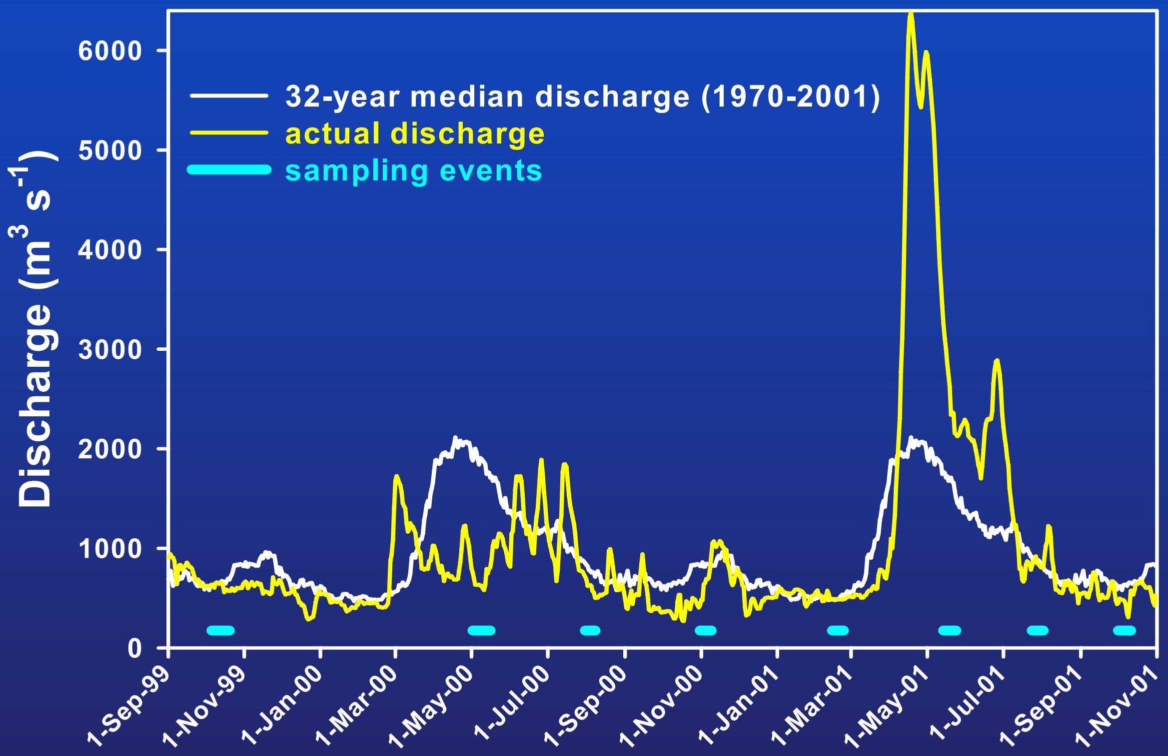

2008
Total N (mg L-1)
NO3- (mg L-1)
NH4- (mg L-1)
0
1
2
3
4
5
MC May 08
FBW May 08
IBW May 08
MC Jul 08
FBW Jul 08
IBW Jul 08
MC Aug 08
FBW Aug 08
IBW Aug 08
SACN
UMR
River


2007
Discharger (CFS)
20000
15000
10000
5000
0
May
Jun
Jul
Aug
Sep
Oct
Date
SACN
UMR
2008
Discharge (CFS)
30000
25000
20000
15000
10000
5000
0
May
Jun
Jul
Aug
Sep
Date
UMR
SACN



Dissolved Oxygen (mg L-1)
50
40
30
20
10
0
Main Channel July
FlowBW July
IsolatedBW July
Main Channel Aug
FlowBW Aug
IsoBW Aug
SACN
UMR
River
Dissolved Oxygen (mg L-1)
16
14
12
10
8
6
4
2
0
MC May
FloBW May
IsoBW May
MC July
FloBW July
IsoBW July
MC Aug
FloBW Aug
IsoBW Aug

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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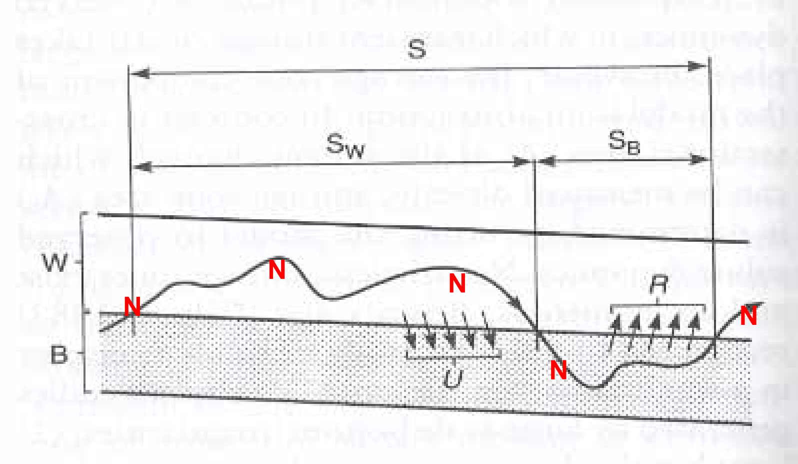
Nutrient “Spiraling” in Streams (a cycle moving downstream)

Two compartment nutrient spiraling model:



Atom of nutrient (N, P, C) is transported downstream until uptake (and assimilation) by biota.

Upon release (excretion, dissociation) atom continues movement downstream until re-assimilated (Newbold, 1992).

Biologically diverse and productive streams have shorter spiraling lengths (Sw).

Streams with fast water velocity generally have longer Sw.

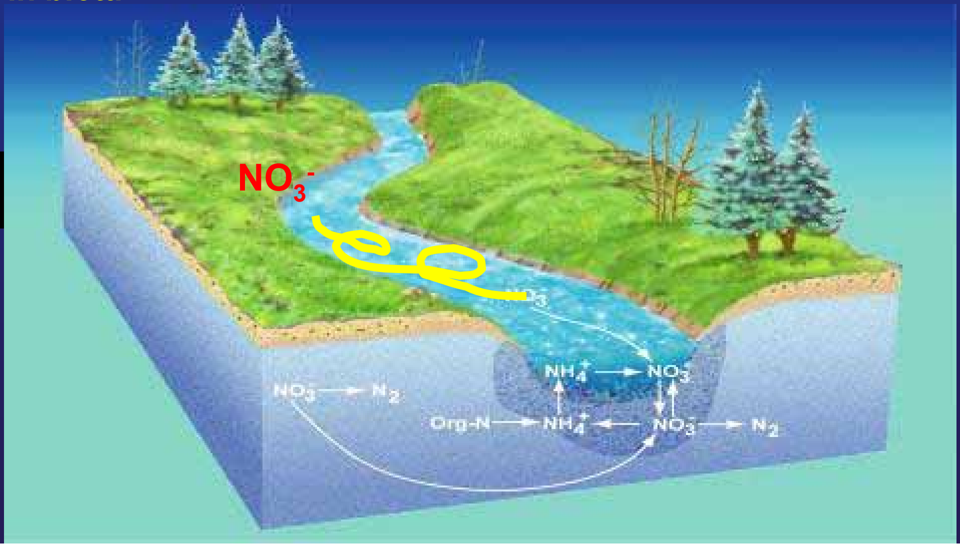
S = spiral length: average distance nutrient atom travels downstream in 1 “cycle”.

Sw = transport distance in water

SB = transport distance in biota

U = uptake

Nitrate example



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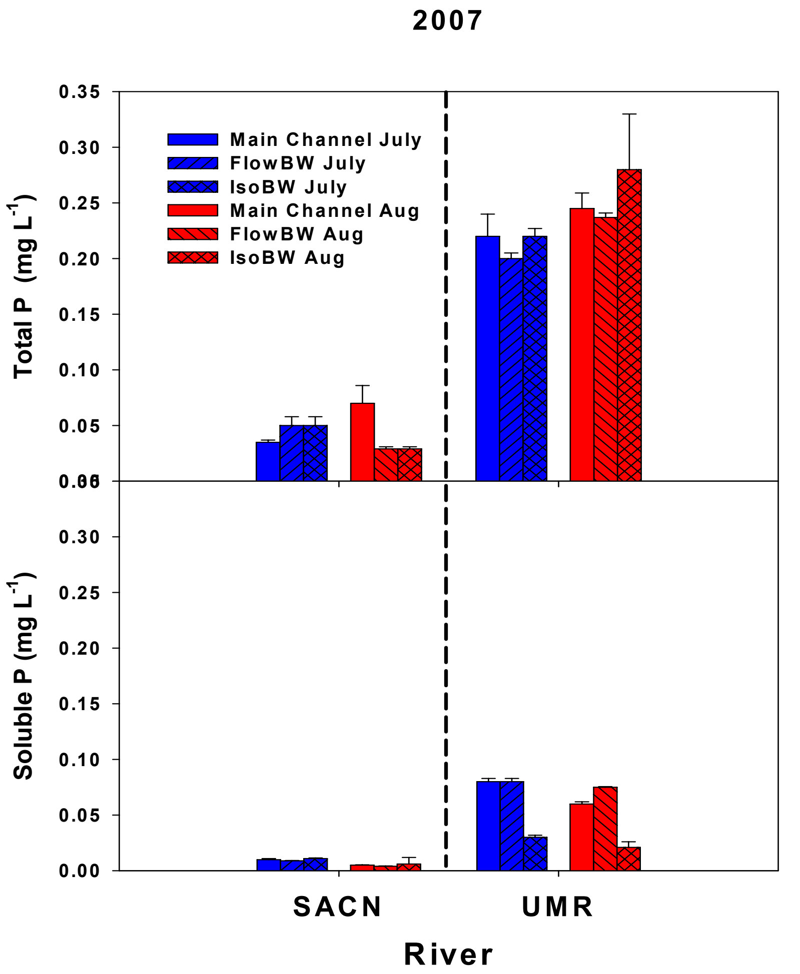
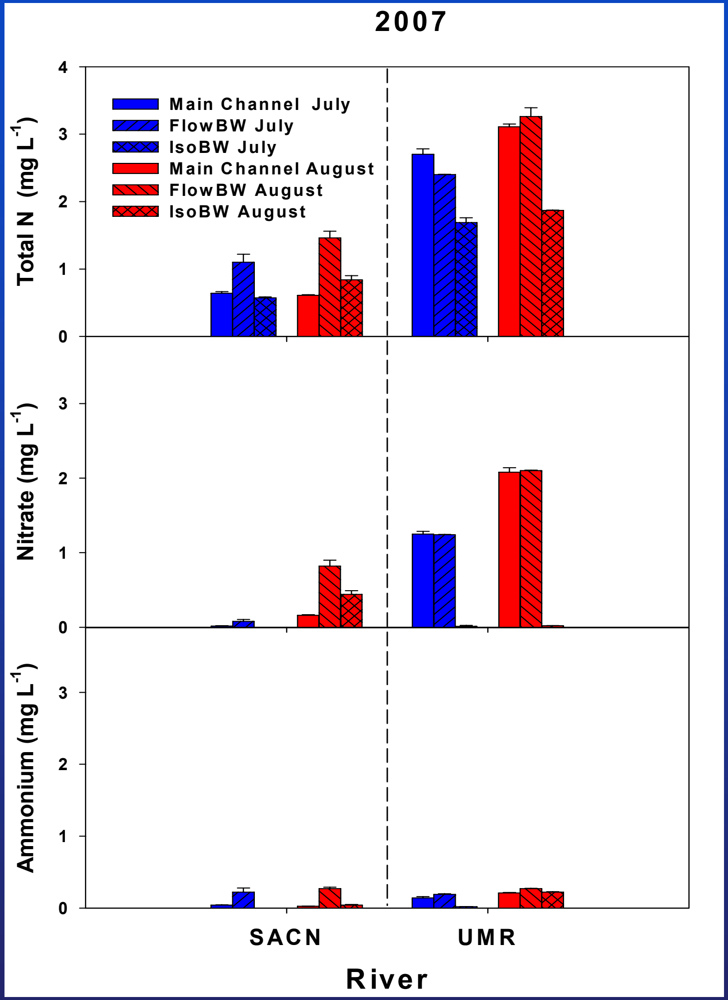
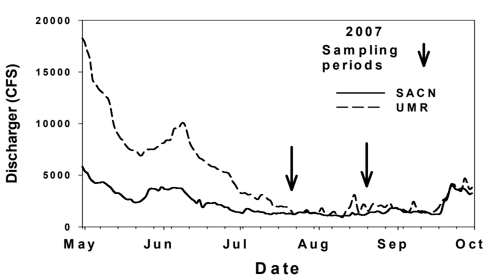
Phosphorus

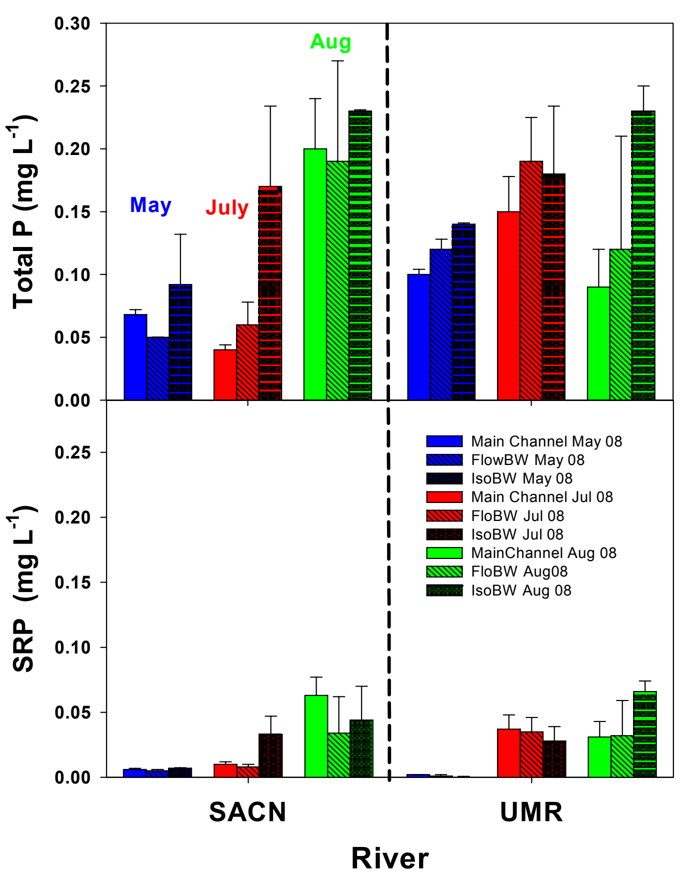


Nitrogen

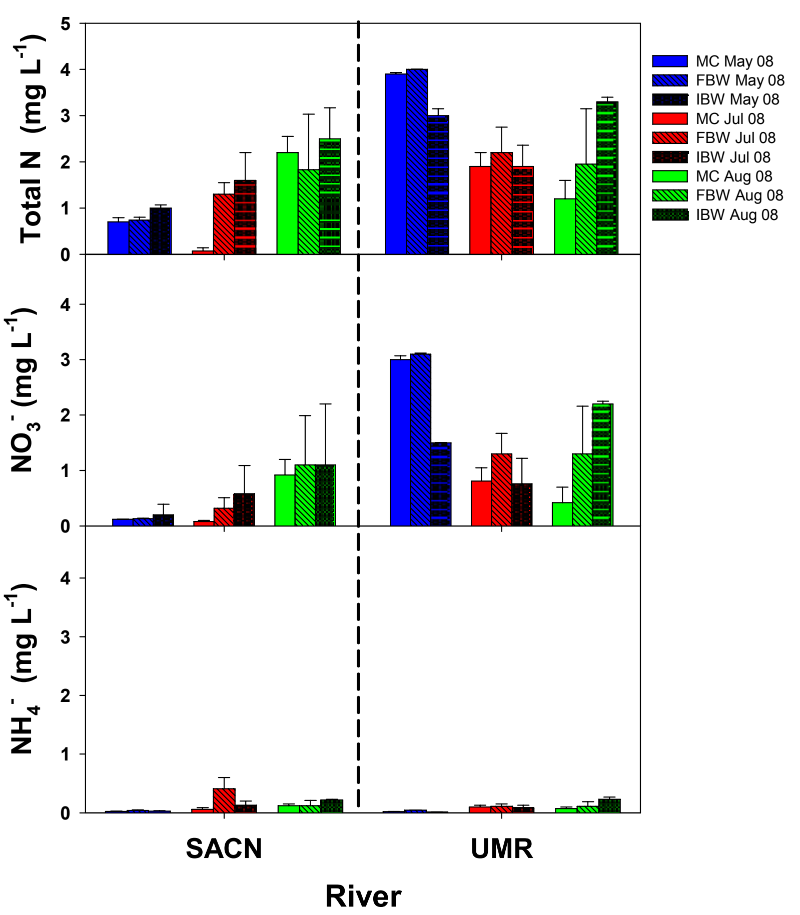


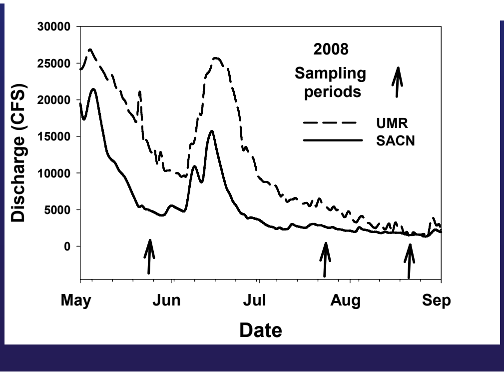


Phosphorus



Nitrogen






2008 5 30


2008 5 30


2008 5 30


2008 5 30

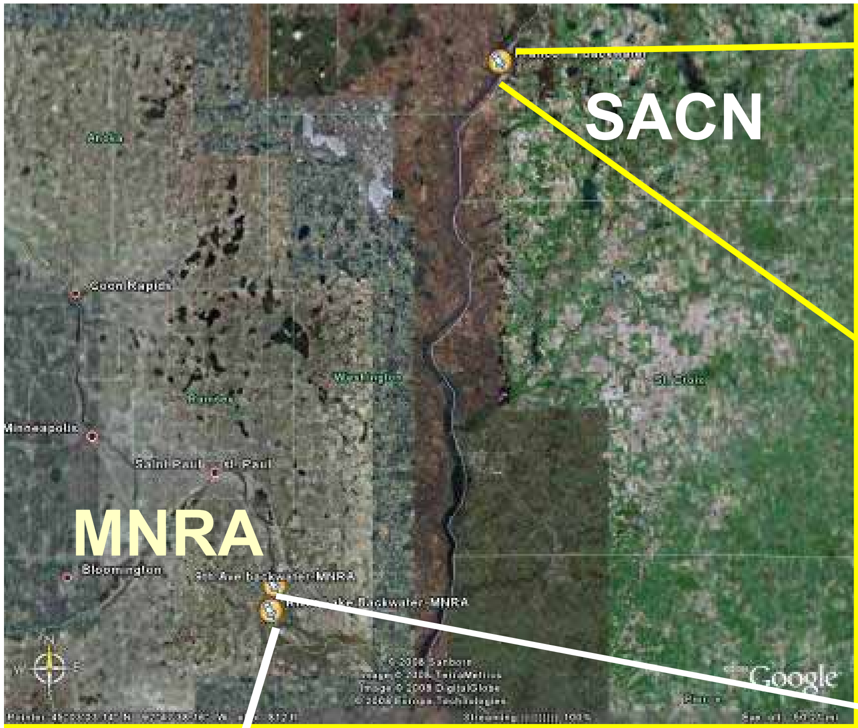
Phosphorus in rivers –

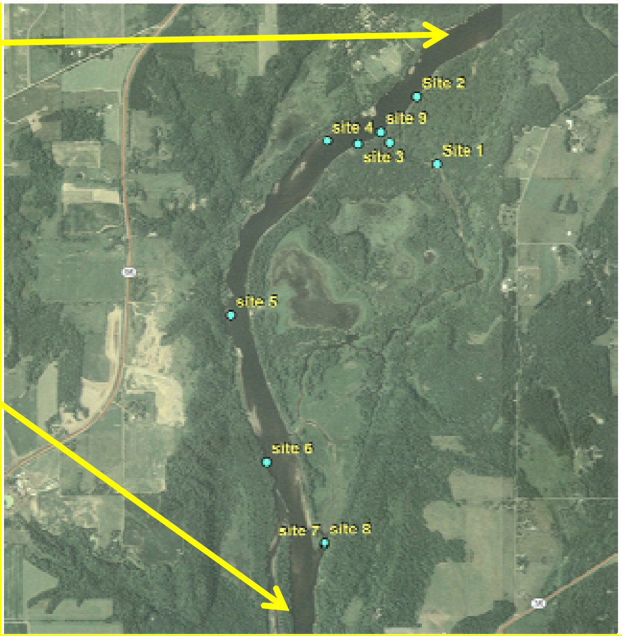
Distribution tends to be tightly linked to delivery of sediment particles

Backwater concentrations likely determined by sediment oxygen dynamics and redox conditions

Release of soluble P under anoxic conditions
 - backwater sediments as source of soluble P esp. during low flow conditions.


2008 7 29



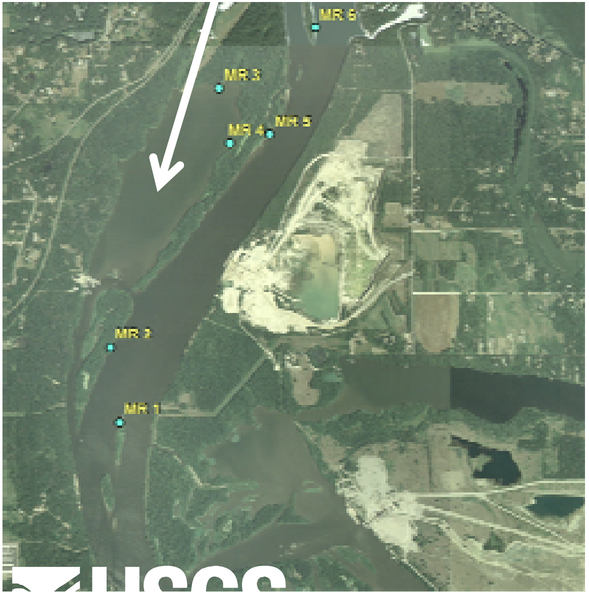


SACN Nutrient Diffusing Substrate emplacement sites SU 2007

Original Design:

- 2 non-flowing backwater (Sites 7&8);
- 4 flowing backwaters (Sites 1,3,4,5).
- 3 main channel sites (Sites 2,6, 9)

Note: Sites 7 & 8 were planned for Peasley Lake (non-flowing backwater), but the Lake was completely dry (7/24/2007). The current location of 7 & 8 was nearly stagnant, with much filamentous algae – as close to a non-flowing backwater as could find.



MNRA Nutrient Diffusing Substrate emplacement sites SU 2007 (River Lake section)

Design:

- 2 non-flowing backwaters (Sites 3&4);
- 2 flowing backwater (Sites 5&6).
- 4 main channel sites (Sites 1, 2, 5-7, 10)

MNRA Nutrient Diffusing Substrate emplacement sites SU 2007 (3rd Street Landing section)

Design:

- 2 non-flowing backwater (Sites 8&9);
- 2 flowing backwaters (Sites 5&6).
- 4 main channel sites (Sites 1, 2, 6-7, 10)

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Channel – flood plain connectivity: role of floods

-Replenishment of consumed solutes (esp. nitrate)

-Redistribution of sediments and associated nutrients (esp. soluble and sediment sorbed P)

-Redistribution of lipid-rich food particles

Aerial view of the Missouri River flooding on July 30, 1993, in the vicinity of Cedar City and Jefferson City Memorial Airport immediately north of Jefferson City, Missouri, looking south (photography from the Missouri Highway and Transportation Department).

www.lbl.gov/Science-Articles/Archive/Nov-15-2002/flood_corn.jpg