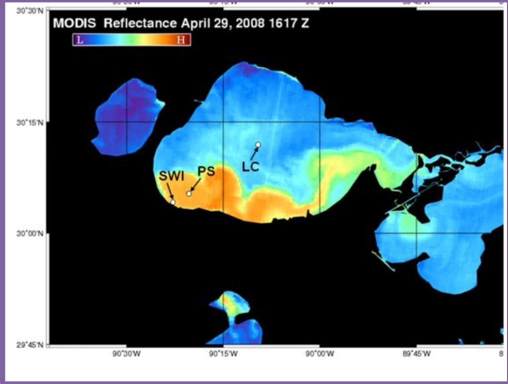
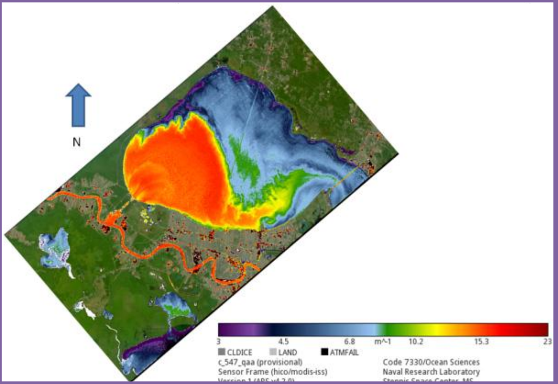
Nutrient Dynamics at the Estuarine Sediment-Water Interface during Large Pulses of High Nitrate Mississippi River Water

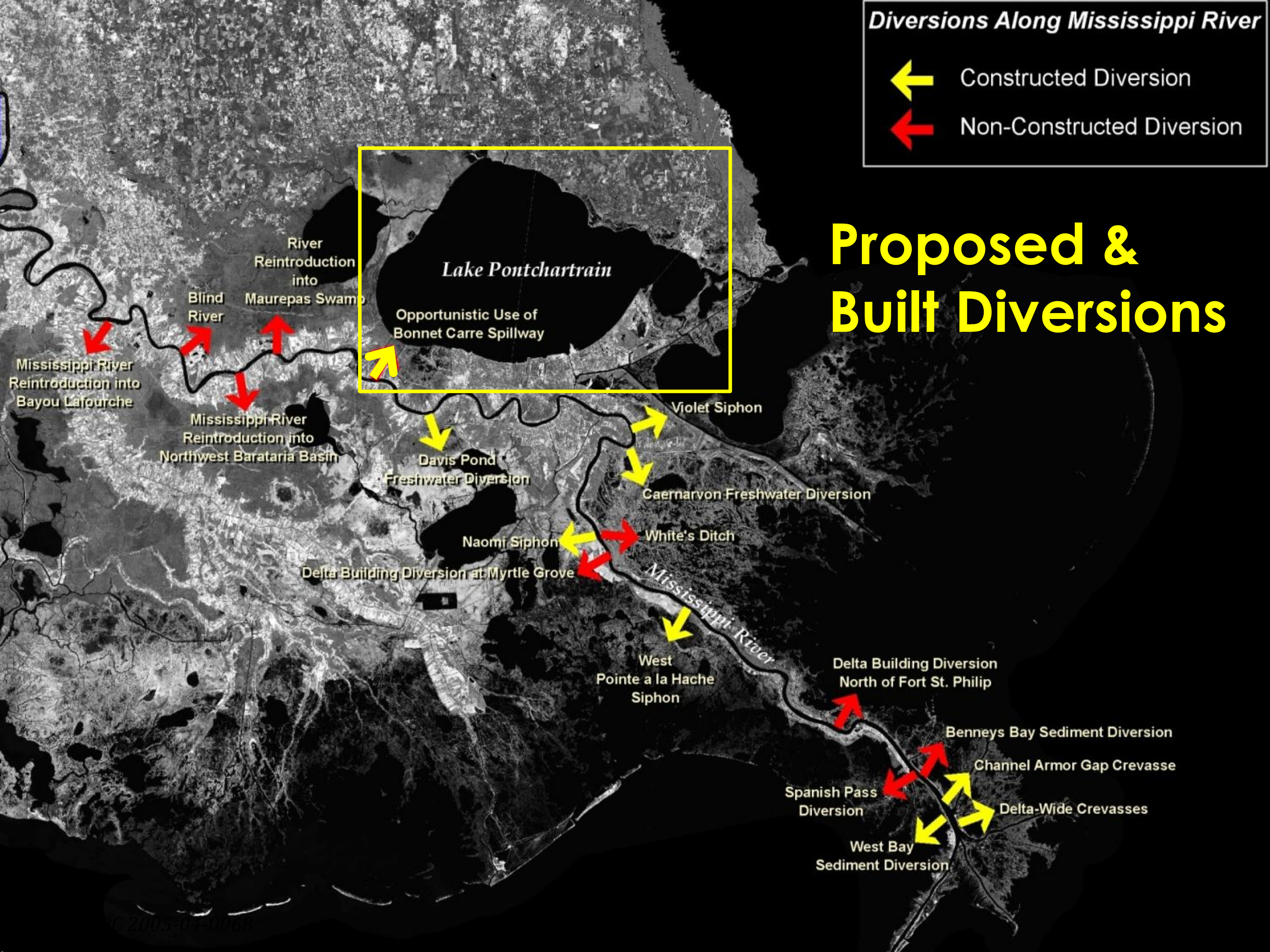




<u>ERIC ROY</u>, JOHN WHITE, SIBEL BARGU,
EMILY SMITH, & NATHAN NGUYEN
LOUISIANA STATE UNIVERSITY
Wetland & Aquatic Biogeochemistry Lab
Department of Oceanography & Coastal Sciences
School of the Coast & Environment

Ancient Courses of the Mississippi River
Images by Fisk (US Army Corps)

Proposed & Built Diversions



The Mississippi River has Changed

- More nutrients, Less sediment
- For flood diversions, this results in a potential trade-off of ecosystem services: flood protection vs. water quality

Lake Pontchartrain:

An Experiment in Nutrient Pulsing

Bonnet Carré Spillway:

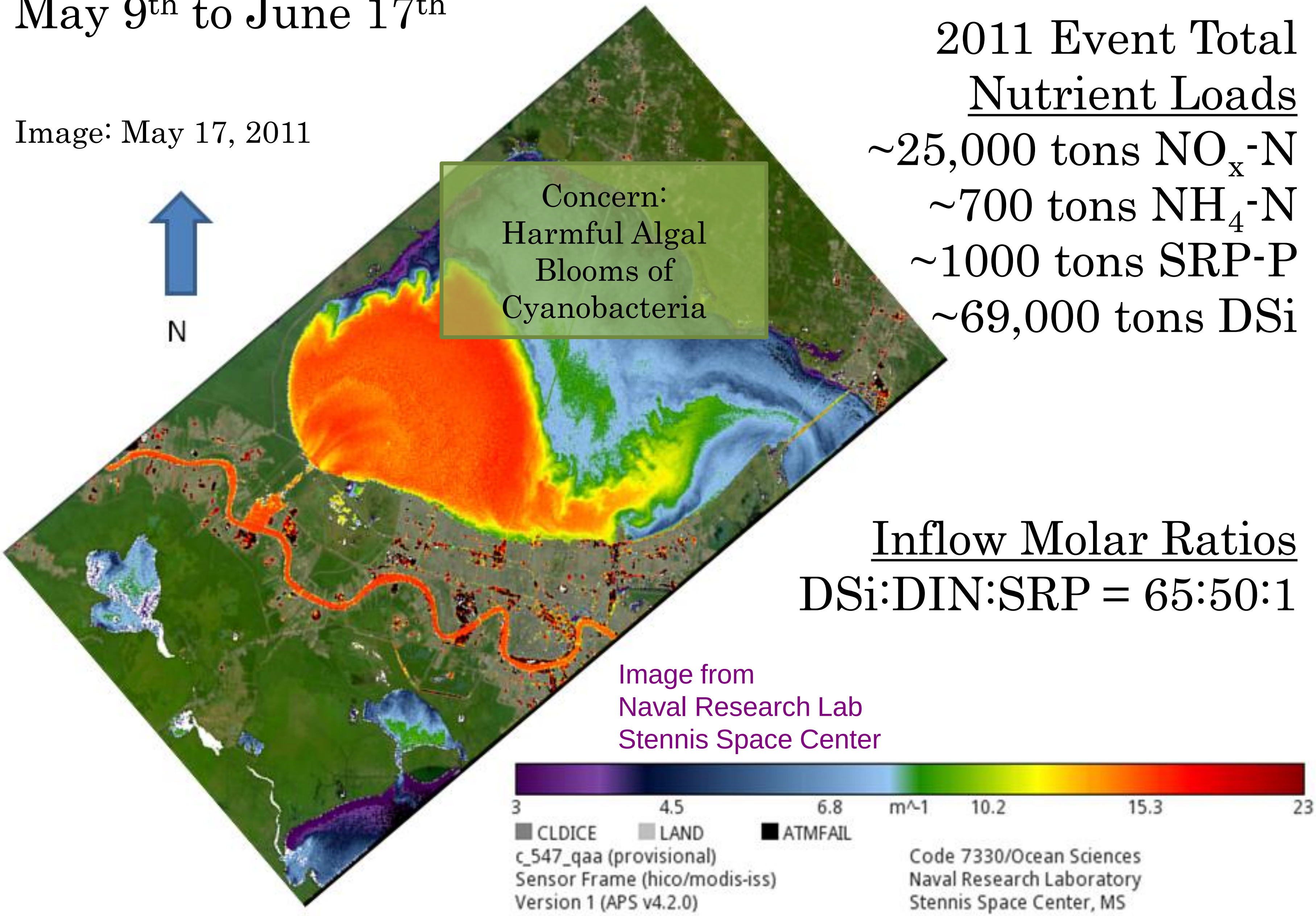
Peak Flow = 250,000 cfs (~20.8% of river "design flood")

Recent openings: 1997, 2008, 2011

2011 Bonnet Carré Spillway Opening:

May 9th to June 17th

Image: May 17, 2011



2011 Event Total
Nutrient Loads

~25,000 tons NO_x-N
~700 tons NH_4-N
~1000 tons SRP-P
~69,000 tons DSi

Inflow Molar Ratios

DSi:DIN:SRP = 65:50:1

Image from
Naval Research Lab
Stennis Space Center

N-Limited Conditions (DIN:DIP < 16)

Can favor N-fixing cyanobacteria

Large External Pulse of N-Rich Freshwater

→

P-Limited Conditions (DIN:DIP >> 16)

Can favor diatoms, other unharmful species, or non-N fixing cyanobacteria

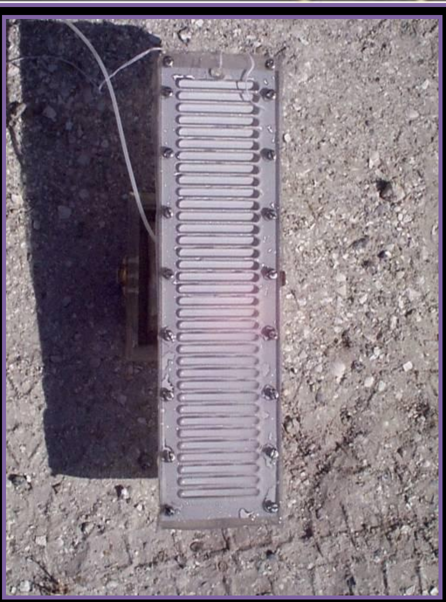
Key Question:

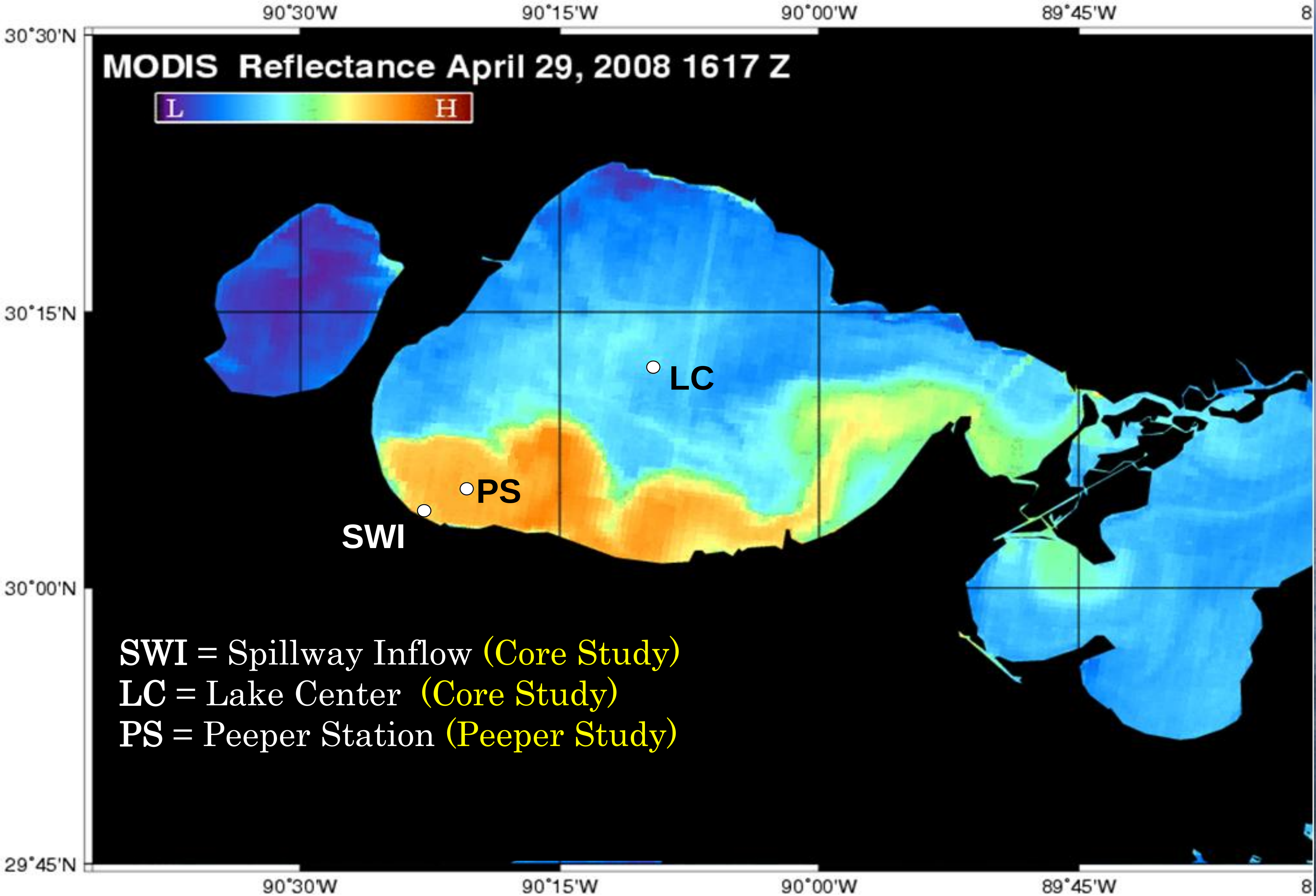
Where does all the nitrate go?

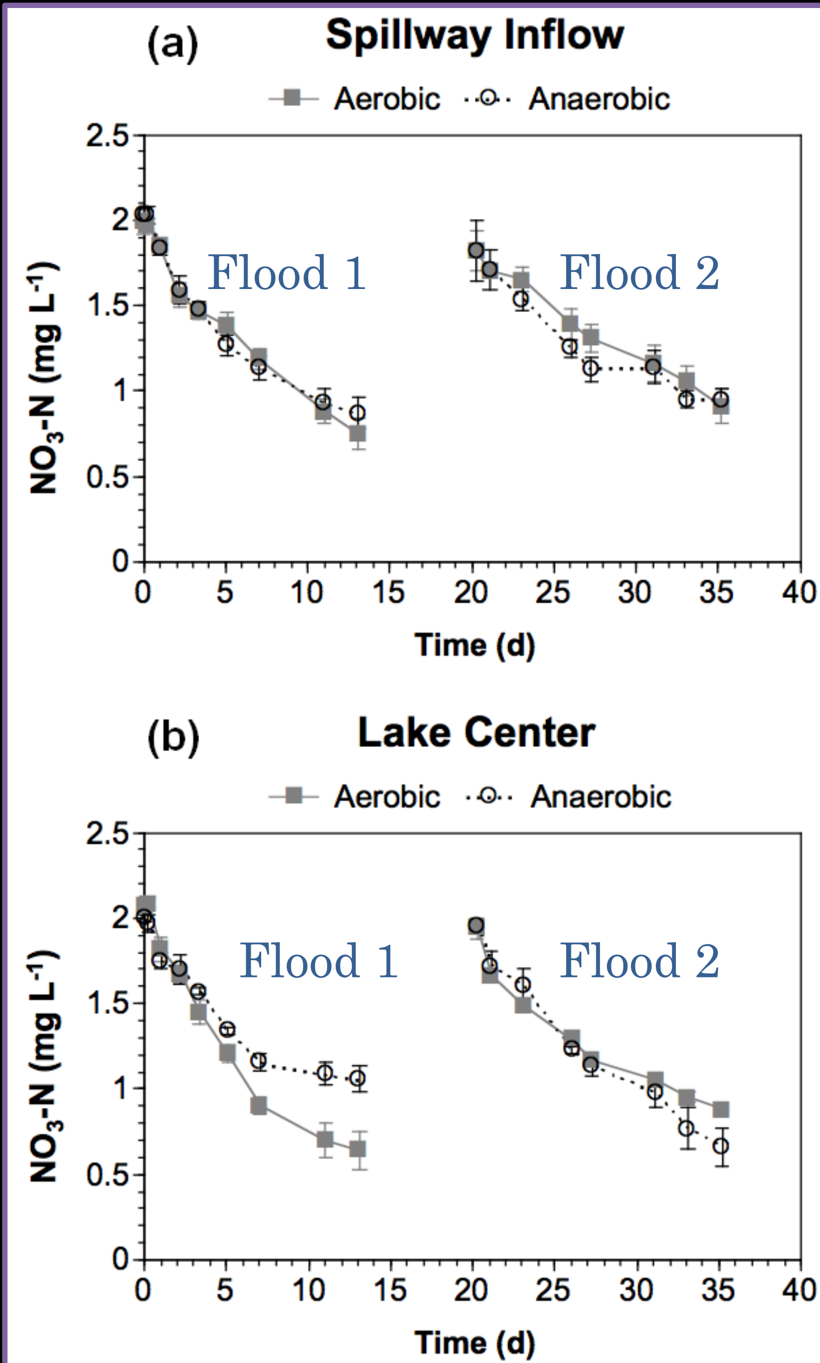
Methods Applied to Investigate Nitrate Flux into Sediments

1. **Lab Experiment:**
   Nitrate Flux in Intact Sediment Cores during Aerobic & Anaerobic Incubations (n = 3-4 at 2 sites)

2. **2011 Field Measurement:**
   Porewater Profiles at Sediment-Water Interface using Peepers (n = 2 at one site)




MODIS Reflectance April 29, 2008 1617 Z
L
H
90°30'W
90°15'W
90°00'W
89°45'W
30°30'N
30°15'N
30°00'N
29°45'N
LC
PS
SWI
SWI = Spillway Inflow (Core Study)
LC = Lake Center (Core Study)
PS = Peeper Station (Peeper Study)



Nitrate Flux Into Sediments: Intact Core Experiment Results

Flux Rate based on Mass Transfer (for 1.4 mg NO_3-N L^{-1}) = **-21.0** mg NO_3-N m^{-2} day^{-1}

Aerobic Flux = Anaerobic Flux Indicates:

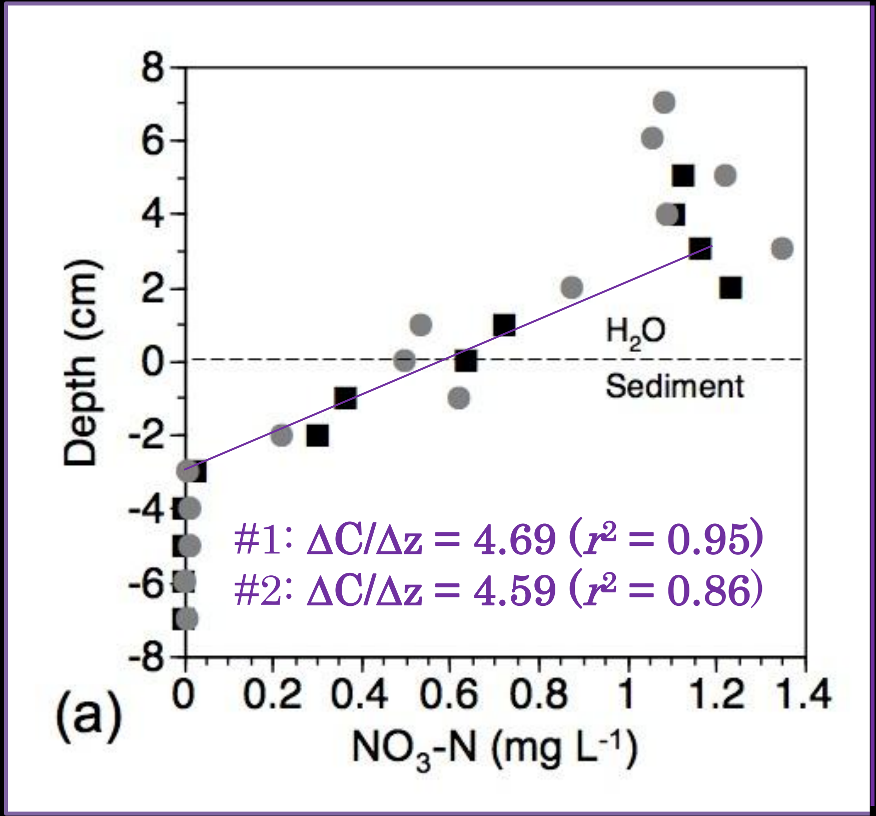
Nitrification of sediment NH_4 not a significant source of NO_x

The most likely pathway in sediment is denitrification

O_2 in Lake P bottom waters does not limit denitrification

Roy et al. In Press. JEQ

Nitrate Flux into Sediments : Peeper Results



Mean Fickean Diffusive Flux Rate = **-29.7** mg NO_3-N m^{-2} day^{-1}

Flux Rate based on Mass Transfer = **-21.0** mg NO_3-N m^{-2} day^{-1}

Modeled 2008 Spillway NO_3^- Loss by Denitrification
≈ **300-420 tons or 3.0-4.2% of total load**

iss.2011137.0517.131328.L1B.Lake_Pontchartrain.v03.6Tue May 17 13:13:41 2011
Beam attenuation at 547 nm, QAA algorithm v5

2011 Field Sampling:

13 Transect Runs

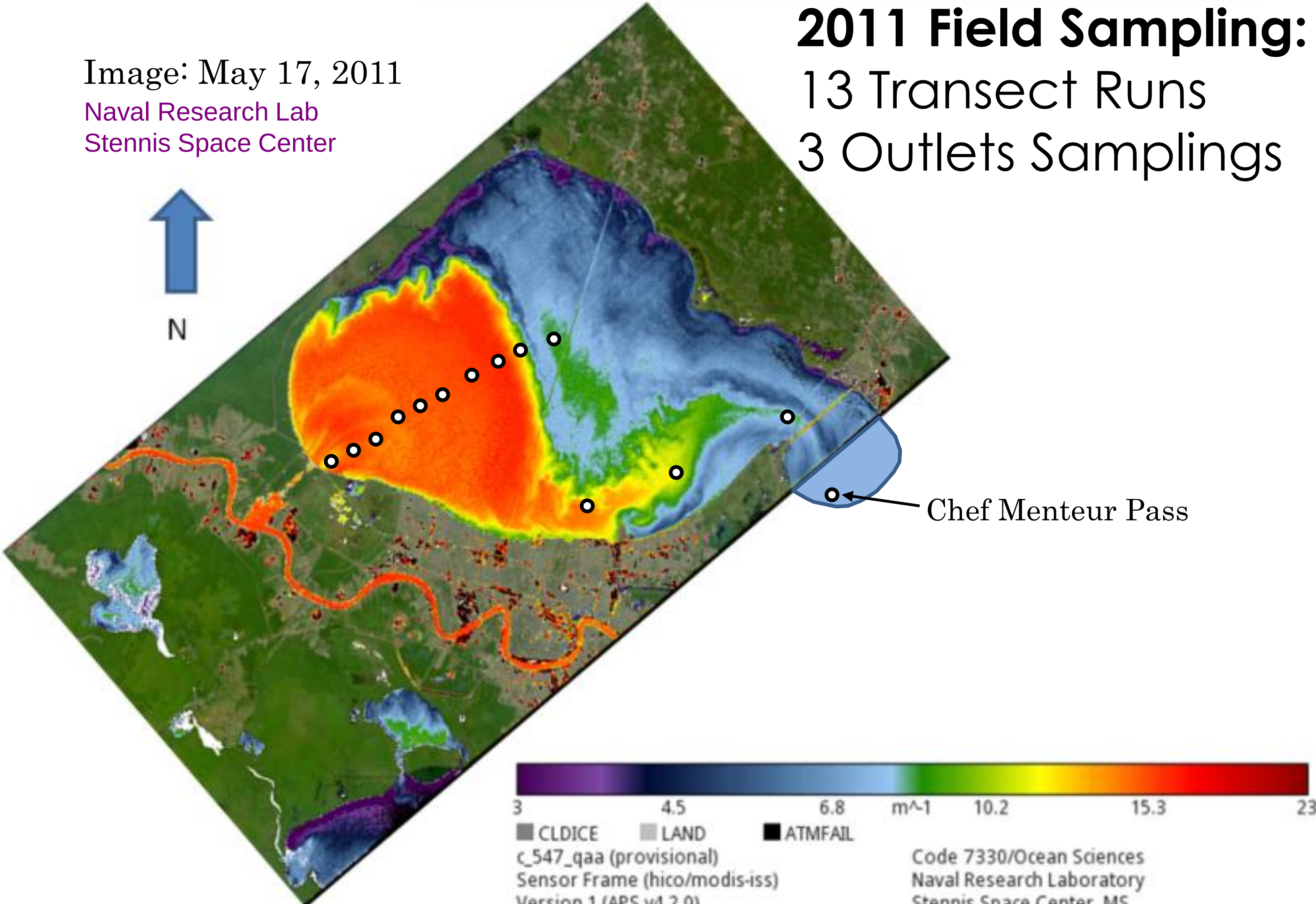
3 Outlets Samplings

Image: May 17, 2011

Naval Research Lab

Stennis Space Center

N

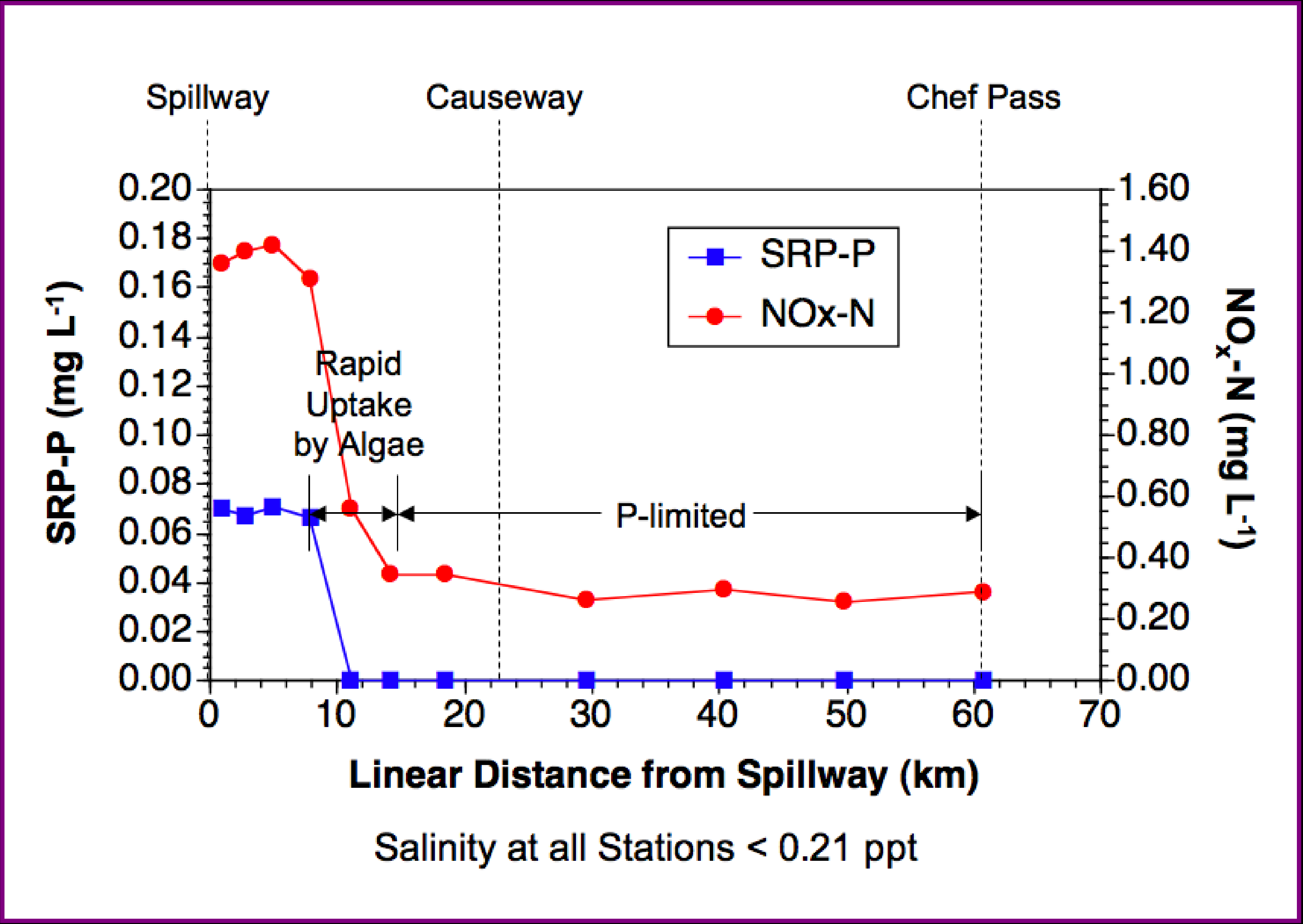


CLDICE LAND ATMFAIL

c_547_qaa (provisional)
Sensor Frame (hico/modis-iss)
Version 1 (APS v4.2.0)

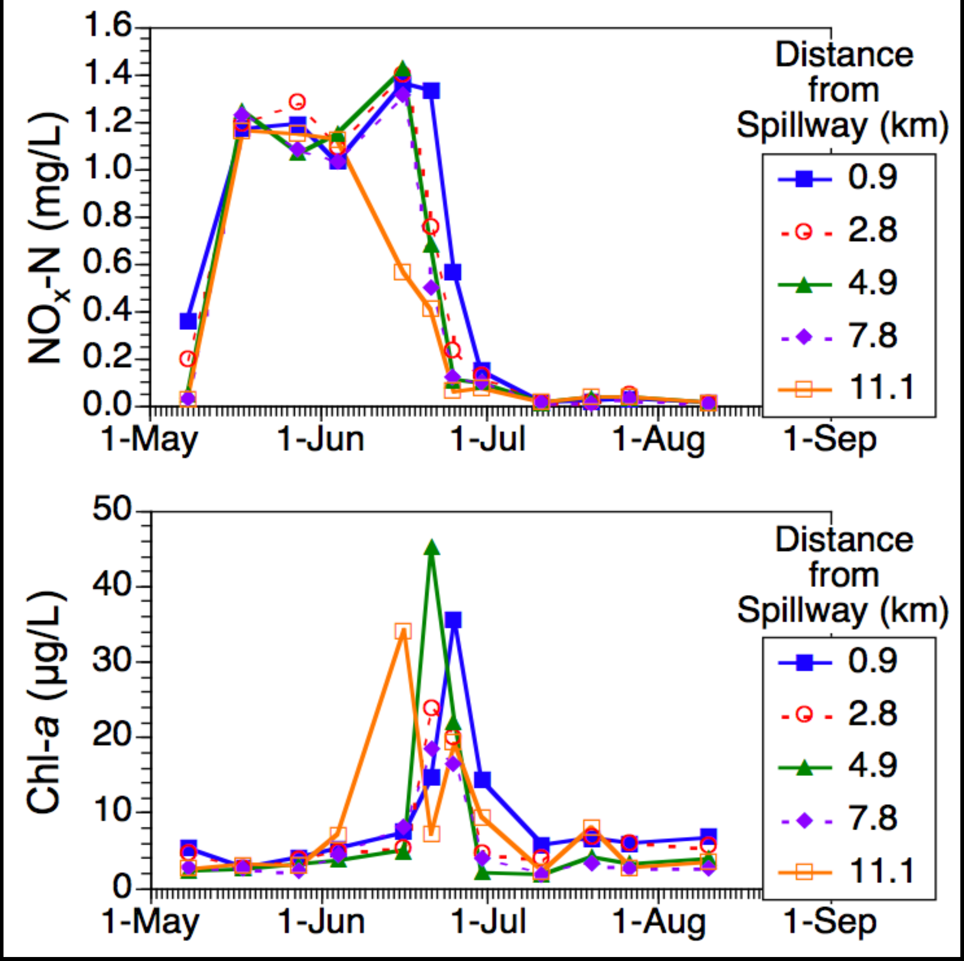
Code 7330/Ocean Sciences
Naval Research Laboratory
Stennis Space Center, MS

June 15th & 16th, 2011



2011 Nitrate and Phytoplankton Dynamics:

-Rapid Collapse (~21 days) following Spillway Closure
-Collapse corresponds to Chl *a* spike
-Phytoplankton community never dominated by a single species
-No harmful algal bloom of cyanobacteria observed



NO_x-N Concentration Balance

Uptake by Phytoplankton

0.36 – 1.06 mg L^{-1} (32 – 76 %)

Spillway Inflow

1.14 – 1.40 mg L^{-1}

Lake P Water Column

Chef Pass (corrected for salinity)

0.28 – 0.74 mg L^{-1} (20 – 65 %)

Flux into Sediment

0.04 – 0.06 mg L^{-1} (3 – 4 %)

Based on

Measured Nitrate Flux into Sediments

Transect Observations on June 16th

Outlets Measurements for June 8th, 15th, and 25th

N-Limited Conditions (DIN:DIP < 16)
Can favor N-fixing cyanobacteria

→ **Large External Pulse of N-Rich Freshwater** →

P-Limited Conditions (DIN:DIP >> 16)
Can favor diatoms, other unharmful species, or non-N fixing cyanobacteria

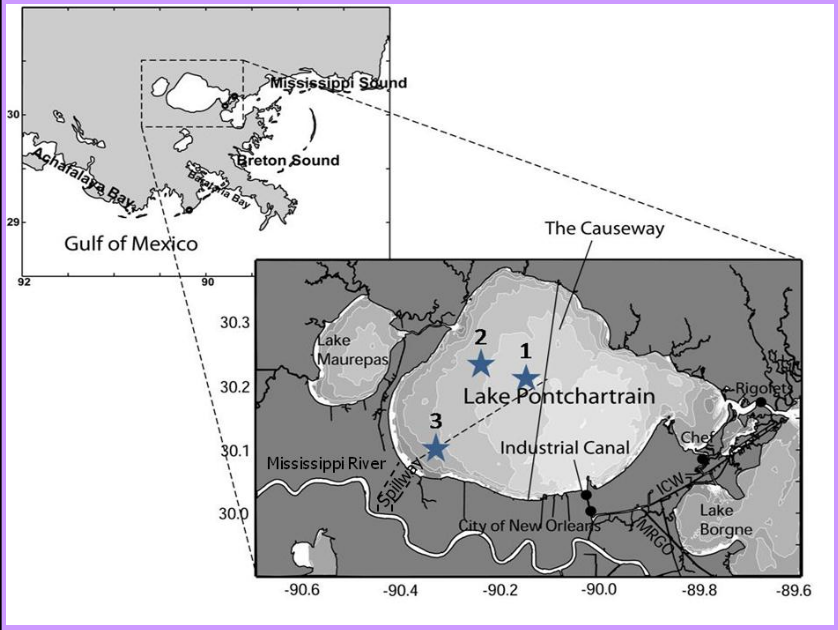
→ **Rapid Nutrient Uptake by Phytoplankton given Favorable Environmental Conditions** (NO_x depleted in ≤ 3 weeks) →

N- and P-Depleted Conditions

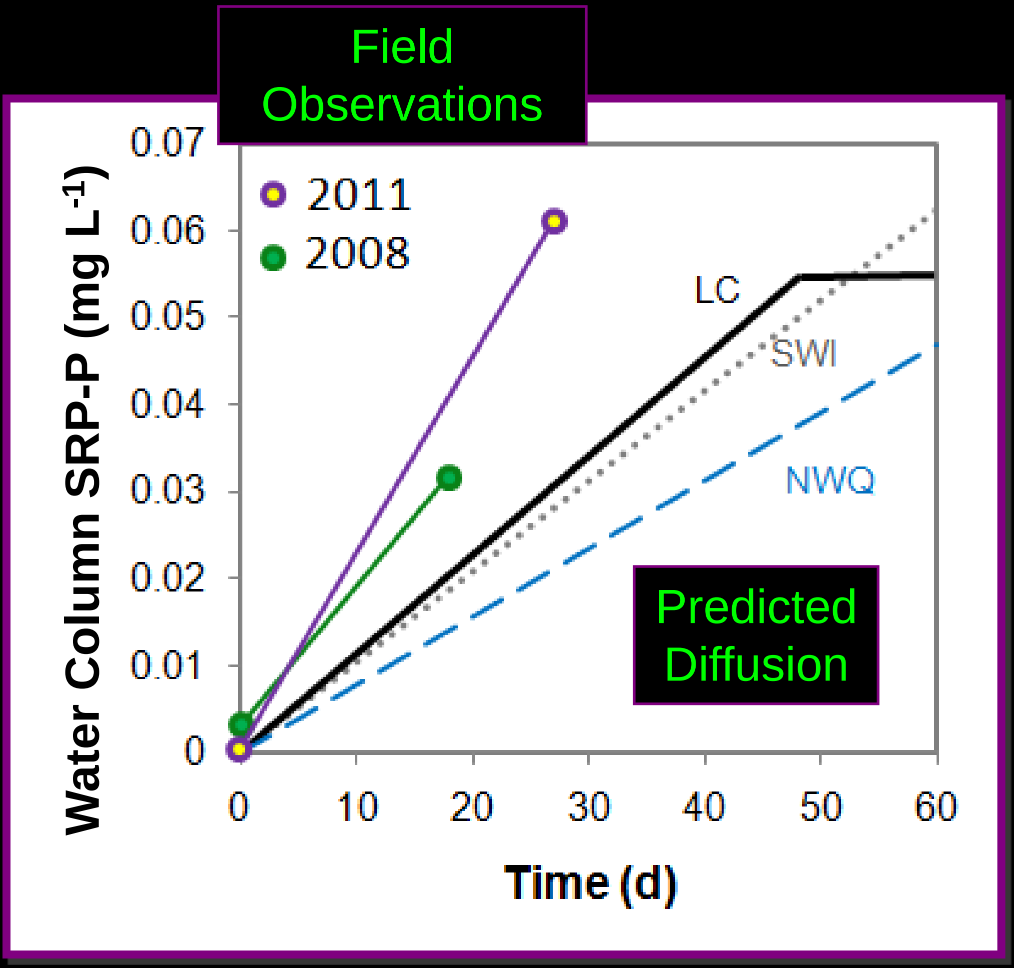
Key Question:
Are sediments a significant source of P under P-depleted conditions?

Methods Applied to Investigate Phosphorus Flux out of Sediments

1. Lab Experiment:
   Phosphorus Flux in Intact Sediment Cores during Aerobic & Anaerobic Incubations (n = 3 at 3 sites)



P Flux from Sediments:
Intact Core Experiment Results



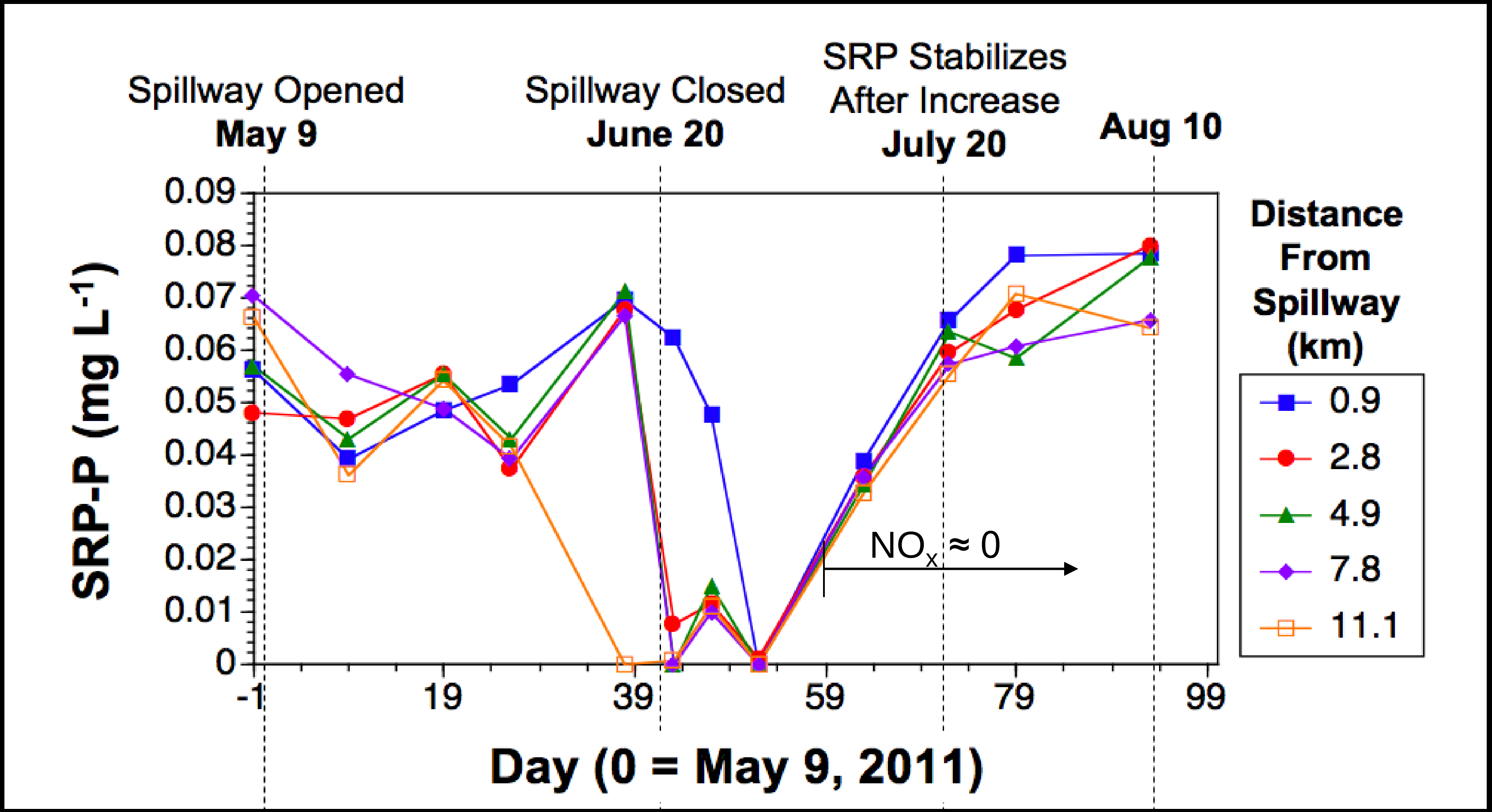
Measured maximum rates of water column SRP increase in anaerobic intact cores:

Lake Center
= 4.2 mg SRP-P m^{-2} d^{-1}

Northwest Quadrant
= 2.9 mg SRP-P m^{-2} d^{-1}

Spillway Inflow
= 3.9 mg SRP-P m^{-2} d^{-1}

Roy et al. 2012. Hydrobiologia 684: 69-82.



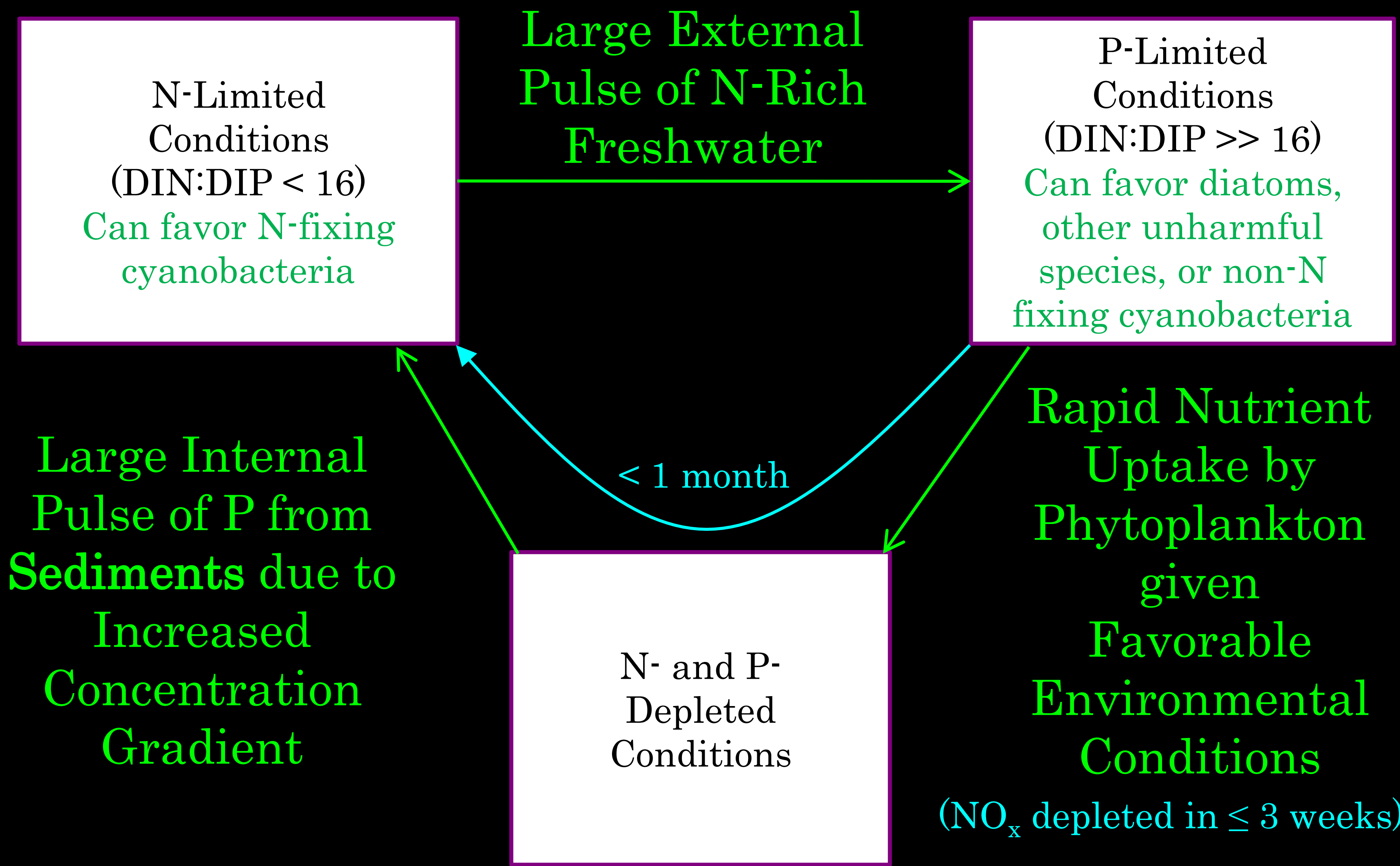
SRP-P for Transect Stations
0.9-11.1 km from Spillway Inflow

Conclusions :

Nutrient Dynamics @ the Sediment-Water Interface

Significant denitrification during diversion events
(300-420 tons NO_x-N in 2008)
Relatively minor role (~3-4%) in the transformation of the very large amount of nitrate received at these times.
[Algal uptake & transport to coastal ocean dominate NO_x loss]

Lake Pontchartrain sediments are a significant source of P under P-depleted water column
& can restore N-limited conditions rapidly following Spillway events



Roy et al. 2012. Hydrobiologia 684: 69-82.
Bargu et al. 2011. Hydrobiologia 661: 377-389

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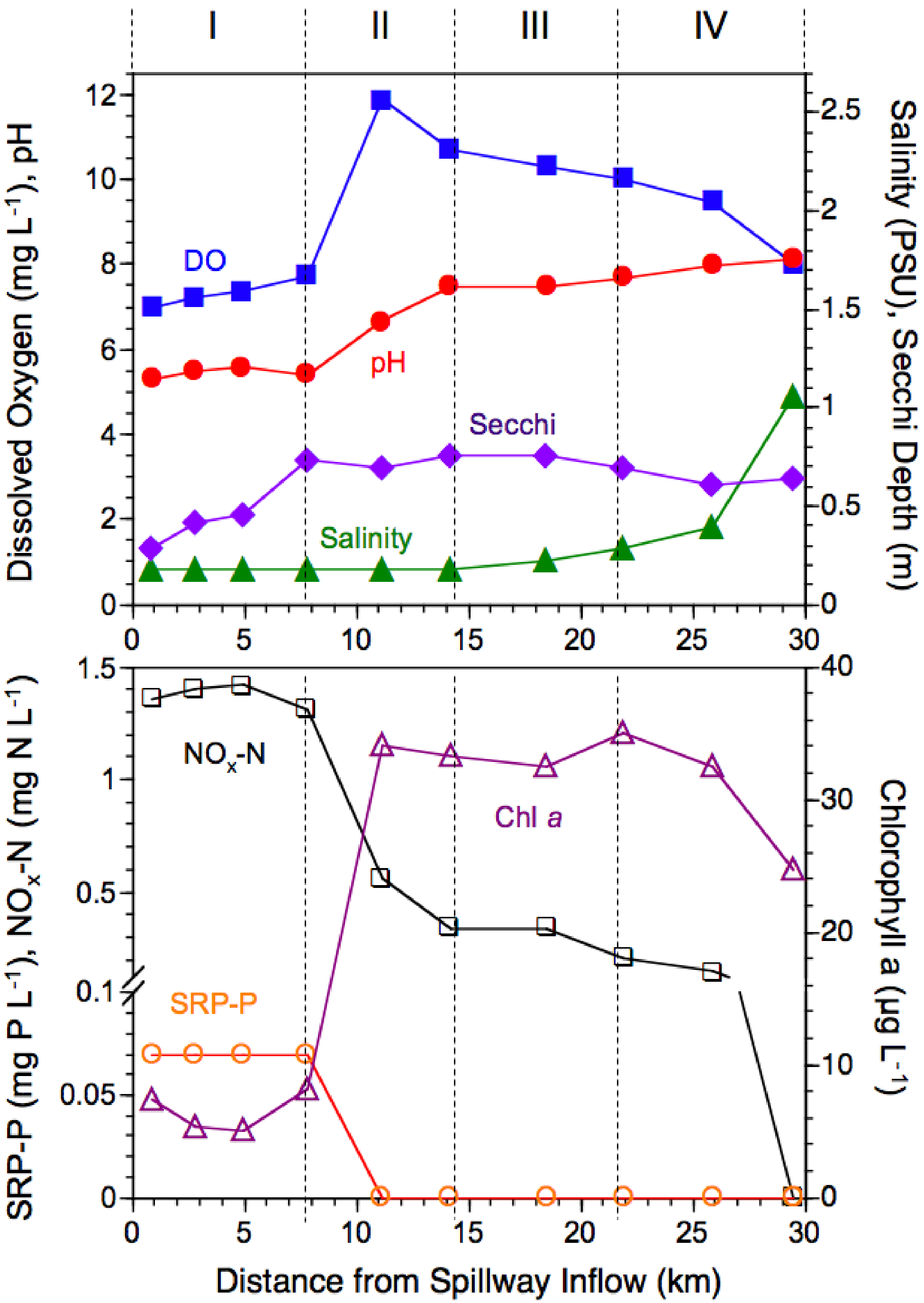
QUESTIONS?

EXTRA SLIDES



June 16th Transect

Plume Region I

Higher nitrate & SRP,
pH < 6, lower water clarity

Plume Region II

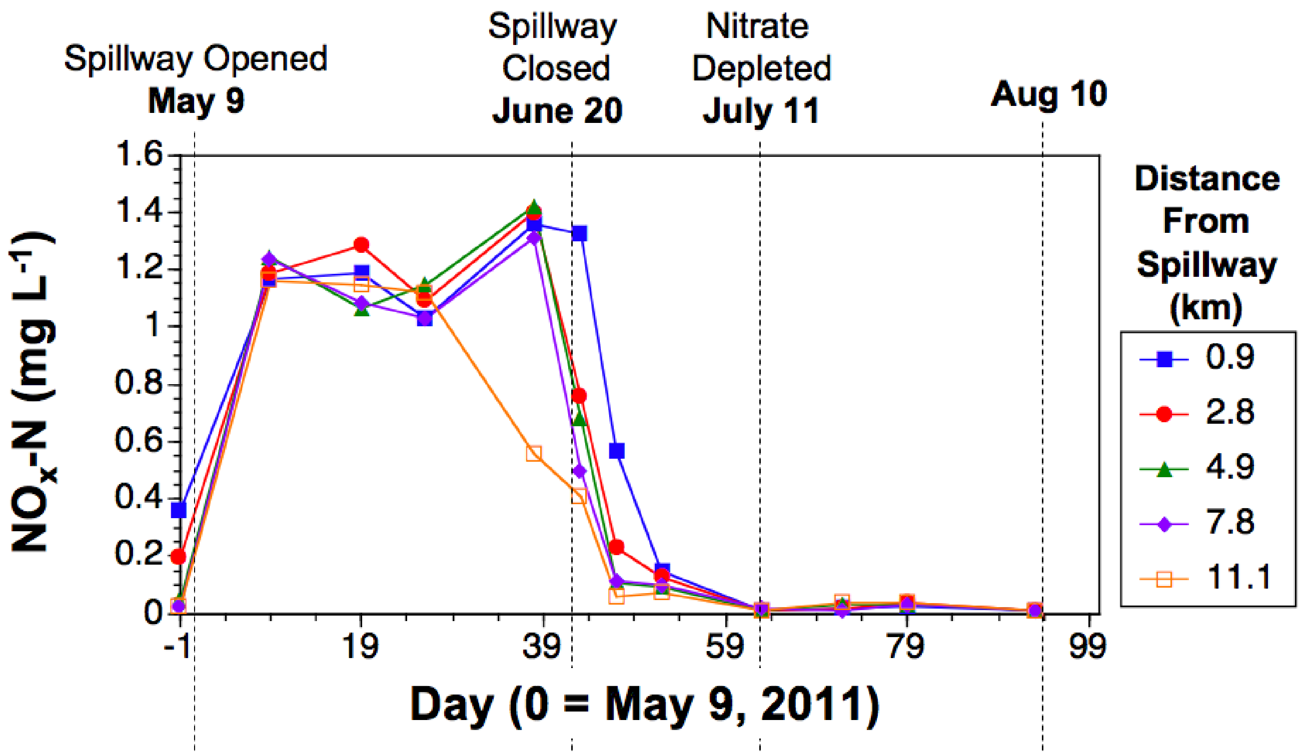
Secchi > 0.5 m
Rapid uptake of nutrients by algae, DO spike, pH > 6

Plume Region III

P-limited

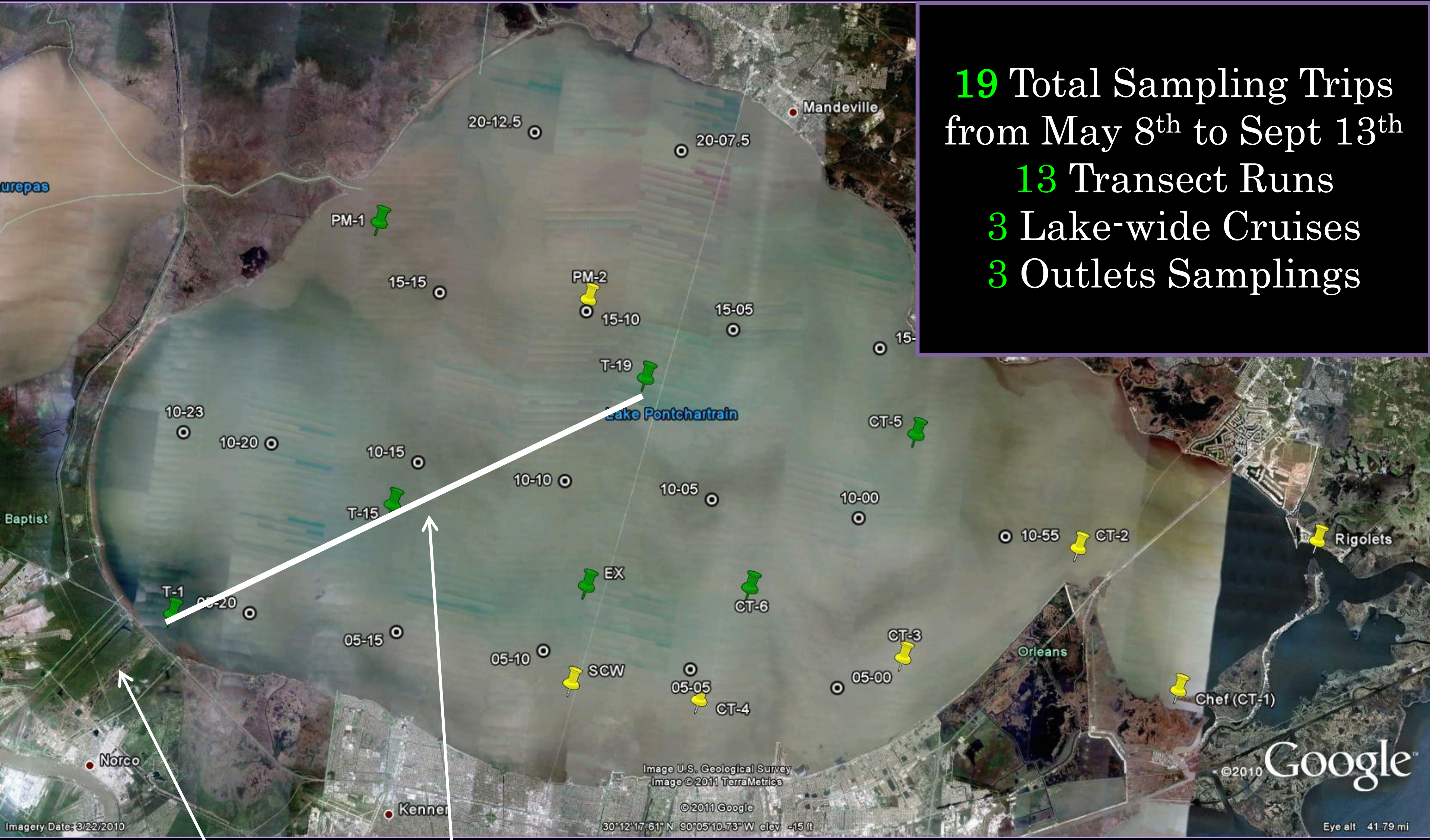
Plume Region IV

Dilution zone impacted by saltier, nutrient-poor estuarine water



NO_x-N for Transect Stations
0.9-11.1 km from Spillway Inflow

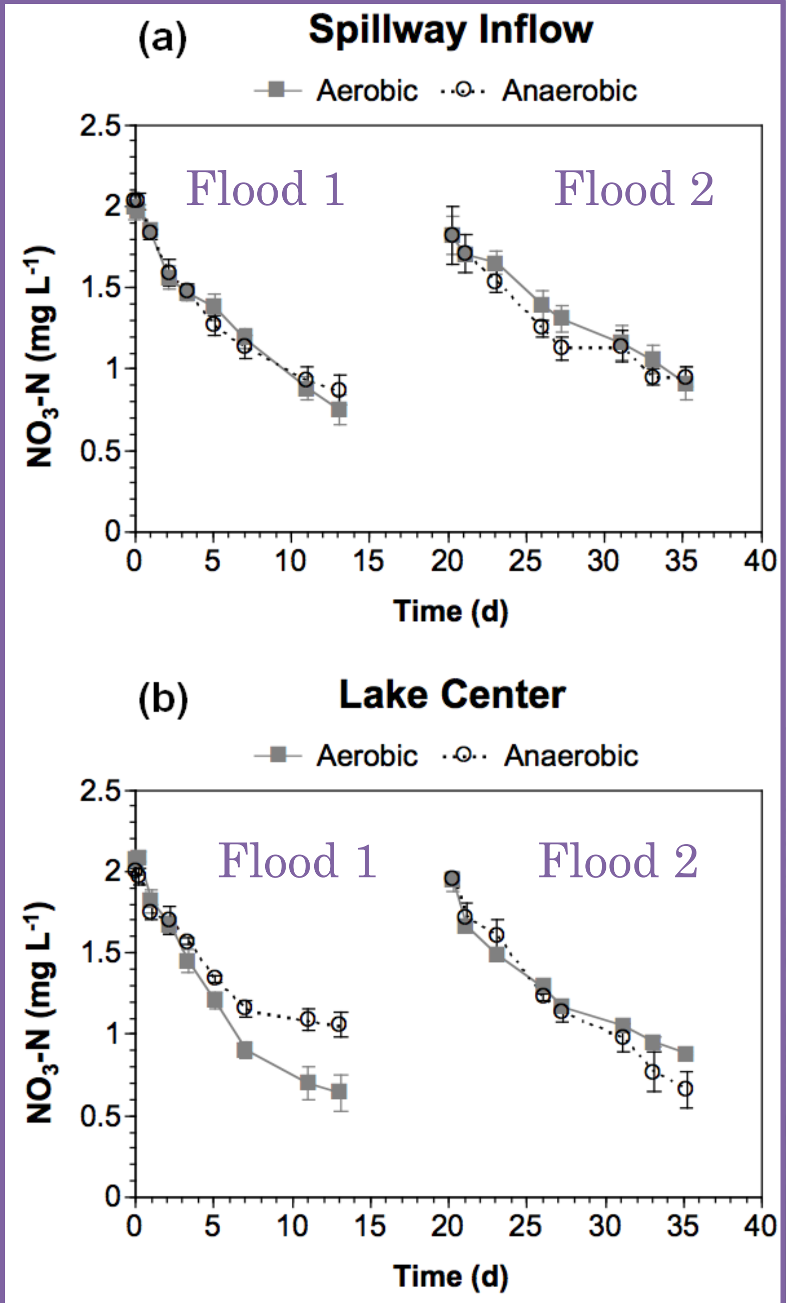
2011 Bonnet Carré Spillway Event Field Sampling



19 Total Sampling Trips from May 8th to Sept 13th
13 Transect Runs
3 Lake-wide Cruises
3 Outlets Samplings

Spillway

30 km 10-station transect



Exponential trendlines were determined for each core.

$C(t) = C(0) * e\text{^}[(p / h)*t]$

p = mass transfer coefficient
= -0.015 m day^{-1}

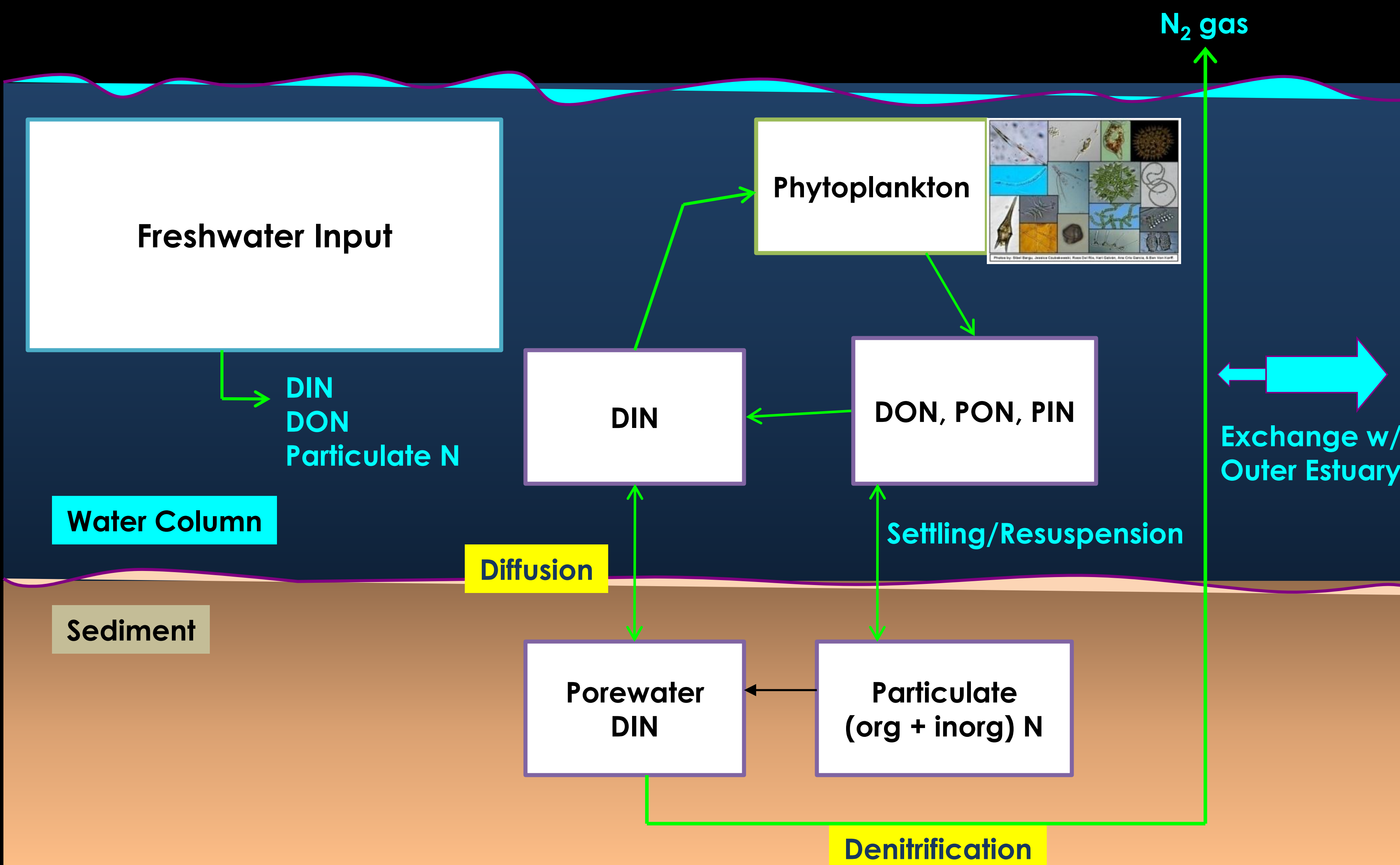
F = rate of nitrate flux into sediment

$F = p * C$

$F = -0.015(1.4\ mg\ L^{-1} *1000)$

$F = -21.0$ mg NO_3-N $m^{-2}\ day^{-1}$

Nitrogen
Biogeochemistry & Eutrophication



TOTAL SPILLWAY LOADS

	1997	2008	2011	2011/1997	2011/2008
Mississippi River Water Influx (km^3)	11.7[a]	7.5[b]	21.9	1.9	2.9
% of Lake Volume	176[a]	113[b]	330	1.9	2.9
Nitrate+Nitrite (tons NO_x-N)	13110[c]	9714[b]	25395	1.9	2.6
Ammonia (tons NH_4-N)	330[d]	224[b]	690	2.1	3.1
DIN (tons N)	13440	9939[b]	26085	1.9	2.6
DIP (tons P)	526[e]	400[e]	1122	2.1	2.8
DSi (tons Si)	35258[f]	19347	69017	2.0	3.6
DSi:DIN:DIP Inflow Molar Ratio[g]	74:57:1	57:59:1	65:50:1	-	-

a Perret et al. 2007, **b** White et al. 2010, **c** Turner et al. 2004, **d** Based on mean NOx-N to NH4-N ratio in 2008 and 2011 of ~40, **e** Roy et al. 2012, **f** 1997 DSi concentration is estimated based on mean concentrations measured at the Spillway inflow in Lake Pontchartrain in 2008 and 2011, as well as measurements made by Lane et al. (2004) in 2001. **g** Based on mean concentrations measured in Spillway inflow water for 2008 and 2011. 1997 values are based on USGS measurements in the Mississippi River at Baton Rouge.

2008 Bonnet Carré Spillway Opening

Total nitrate load = ~10,000 metric tons NO_3-N over 49 days

Mass NO_3-N denitrified = sum[A(t) * F * 10^{-9}] for $0 \leq t \leq 49$

A(t) = freshwater plume area

F = flux rate of nitrate into the sediment = -29.7 mg NO_3-N m^{-2} d^{-1}

Mass NO_3-N denitrified

= 420 metric tons NO_3-N

= ~4% of total load