Assessing Risk of Watershed Nitrogen Export: The Role of Landscape Sinks

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NOWRA Nitrogen Symposium
April 7, 2008

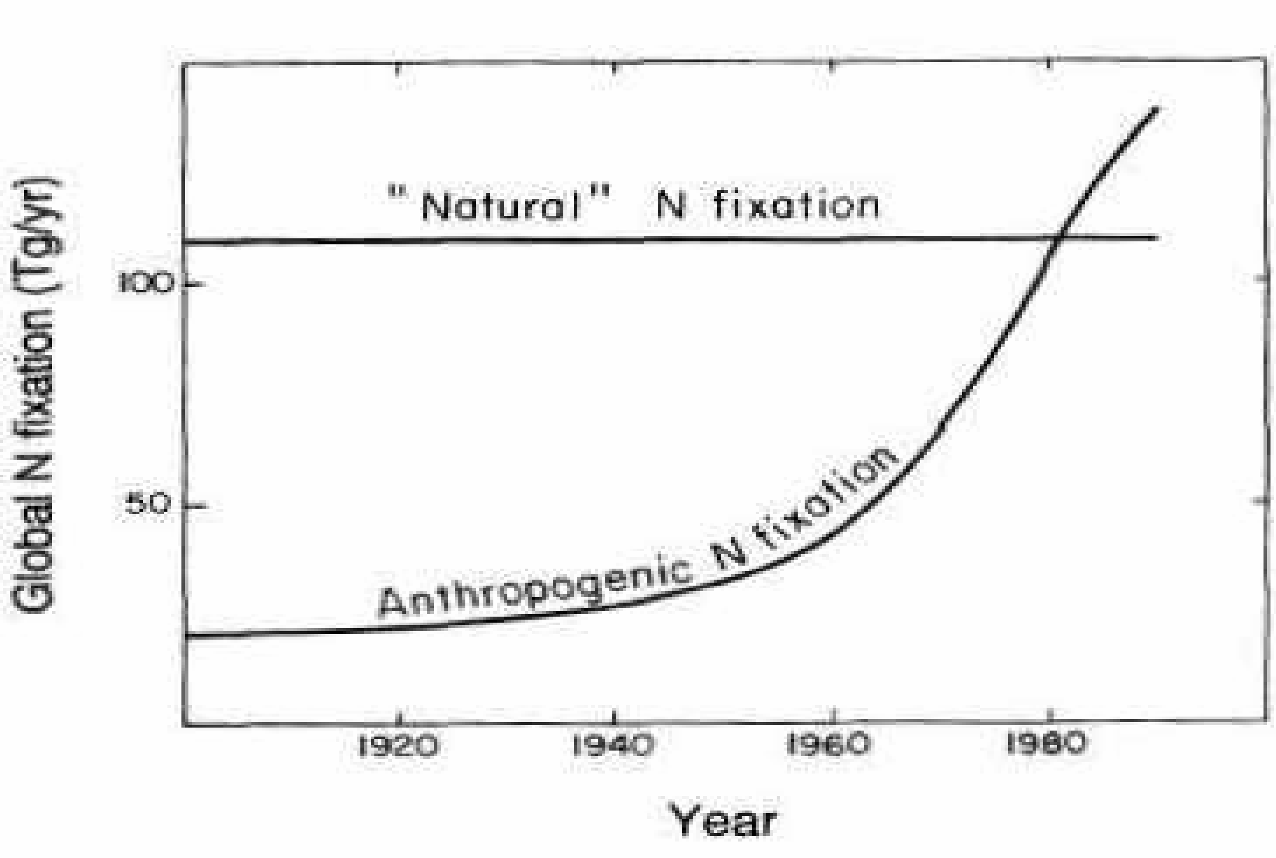
Applying knowledge to improve water quality
New England
Regional Water Program
A Partnership of USDA CSREES
& Land Grant Colleges and Universities

NRCS Natural Resources Conservation Service

Topics

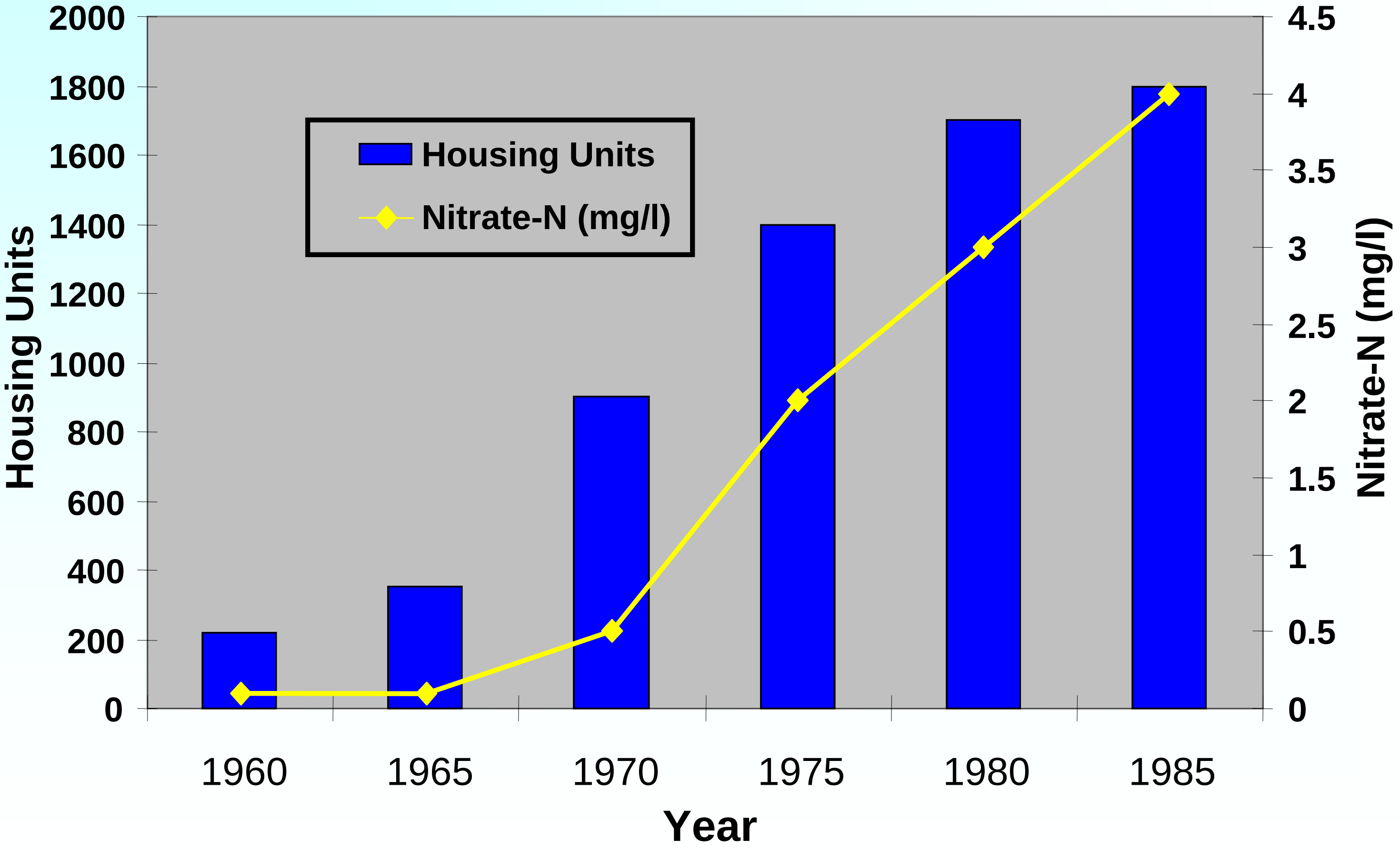
1. Brief review of sources and effects of N loading
2. The disappearing N question: What happens to watershed N inputs?
3. The hotspot hypothesis: Select landscape features remove watershed N
4. Risk management options: Can we identify watershed sinks to prioritize high risk N export locations?

“Fixed” N has doubled in past 60 years



Cause and Effect

Unsewered Housing Density Increases Groundwater Nitrate
Yarmouth, MA: Community Well



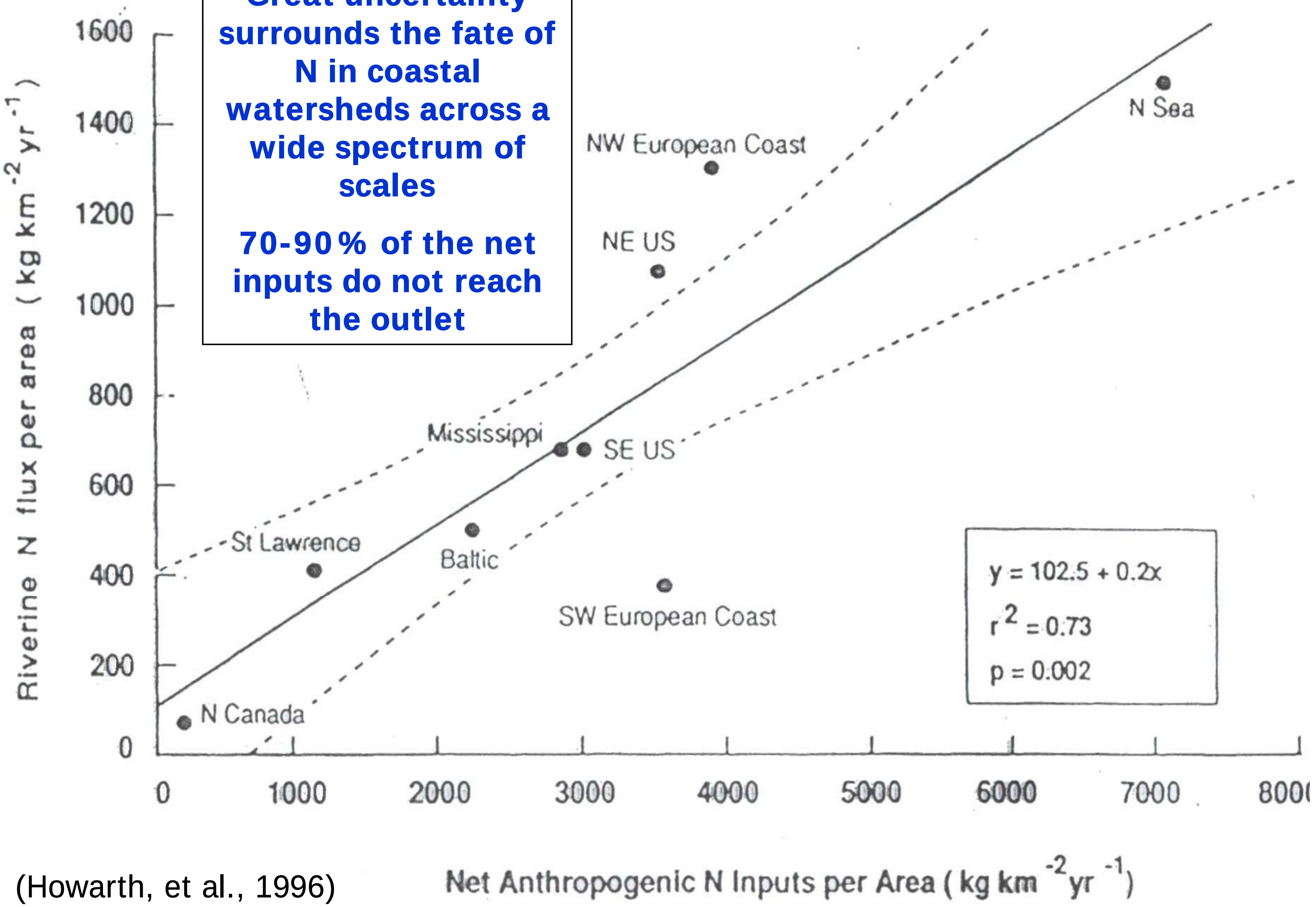
Adapted from Nelson et al. 1988

Dead Zones:
Attributed to increased N & P inputs

Gulf of Mexico Dead Zone: 7,000 sq miles
EPA SAB, 2007

Great uncertainty surrounds the fate of N in coastal watersheds across a wide spectrum of scales

70-90% of the net inputs do not reach the outlet



(Howarth, et al., 1996)

Groundwater Nitrate-N Loading Sources: Research

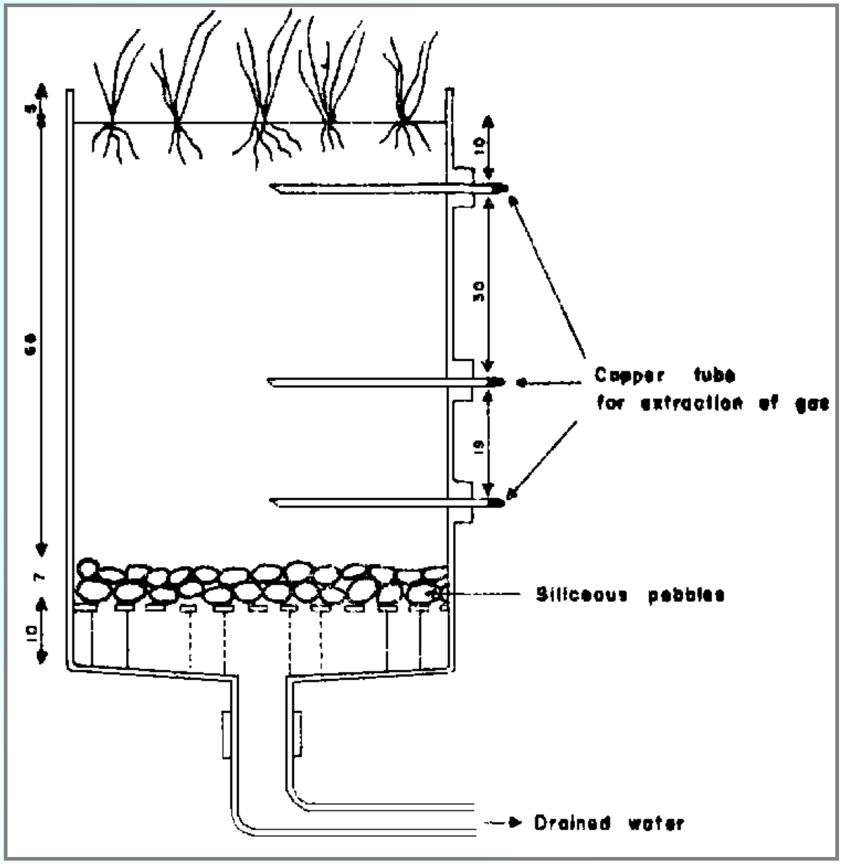
Septic Systems
80% Leaching, 21 lbs/home/yr;
½-1 acre zoning: 21- 42 lbs/yr

Lawn Fertilizer
Application: 175 lbs N/ac/yr
6% leaching, 10 lbs/ac/yr,

Lawn Fertilizer, High Irrigation
20% Leaching, 35 lbs/ac/yr

Unfertilized Area
1.2 lbs N/ac/yr

Tilled Cropland
Application: 215 lbs N/ac/yr,
28% Leaching, 60 lbs N/ac/yr



Atmospheric Deposition
5-20 lbs/acre/yr; high yield in urban areas

(Adapted from Gold et al., 1990; Morton et al., 1988; Howarth et al., 2000)

How does watershed N disappear?
Denitrification in watershed sinks

Seitzinger et al. 2006. Biogeochemistry – Global Estimates

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$$

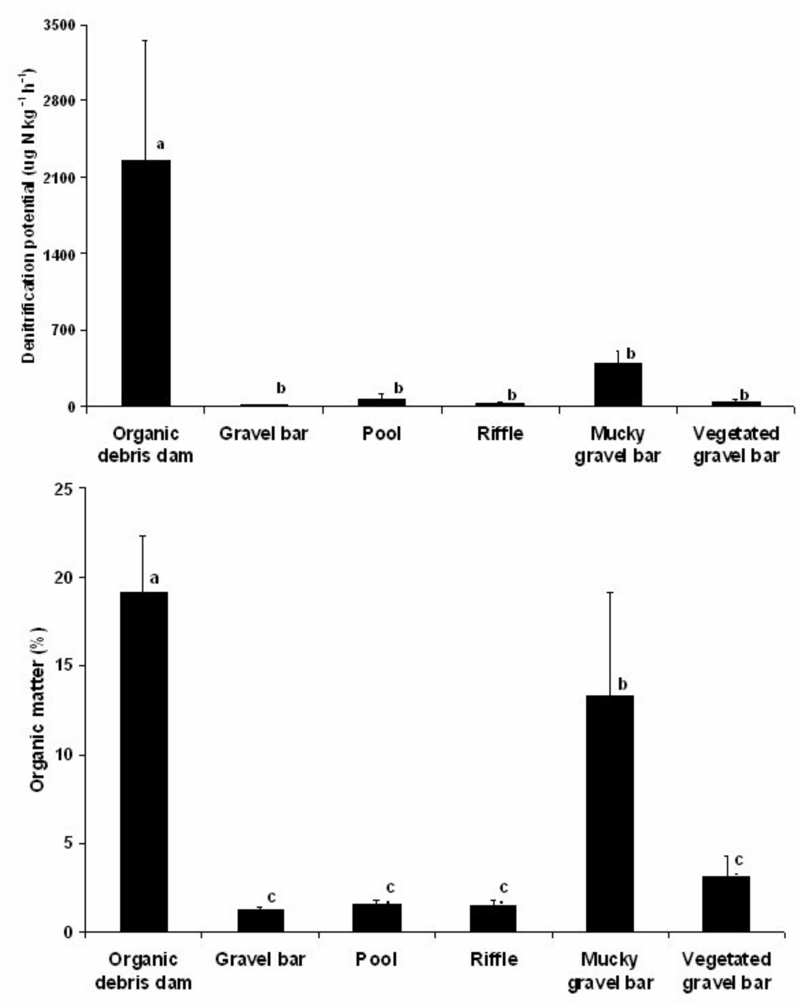
Sink	% Denitrification of Terrestrial N	
	"Best Guess"	Range
Surface Soils*	46%	24-65%
Groundwater	16%	0-51%
Lakes/Reservoirs	11%	7-16%
Rivers	13%	7-13%

* Conventional Septic Systems bypass surface soils

Problem: Denitrification varies widely within groundwater, rivers and lakes

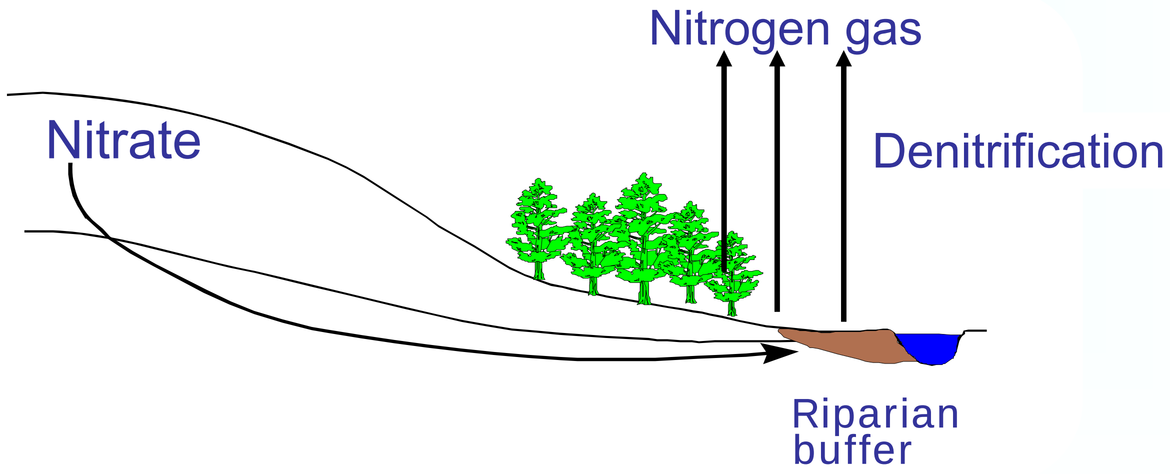
- Hot Spot Hypothesis: Denitrification is focused in select, localized settings with:
  - Extended residence times
  - Pools of labile C

- Can we identify potential sinks along the flow path between source areas and large river systems?



Hot "Spots" for Denitrification

- Anaerobic, pyrite-rich aquifers
- Riparian wetlands
- Small, headwater streams
- Reservoirs and lakes w/long retention



Groundwater: Nitrate can move great distances with minimal removal

Robertson et al., 1991. Groundwater

High Risk:

- Aerobic Aquifers
- High Hydraulic Conductivity
- Low Labile C
- **Close Proximity to Surface Water**
- Brief Retention Times
  - Sandy, water table aquifers
  - Limestone aquifers

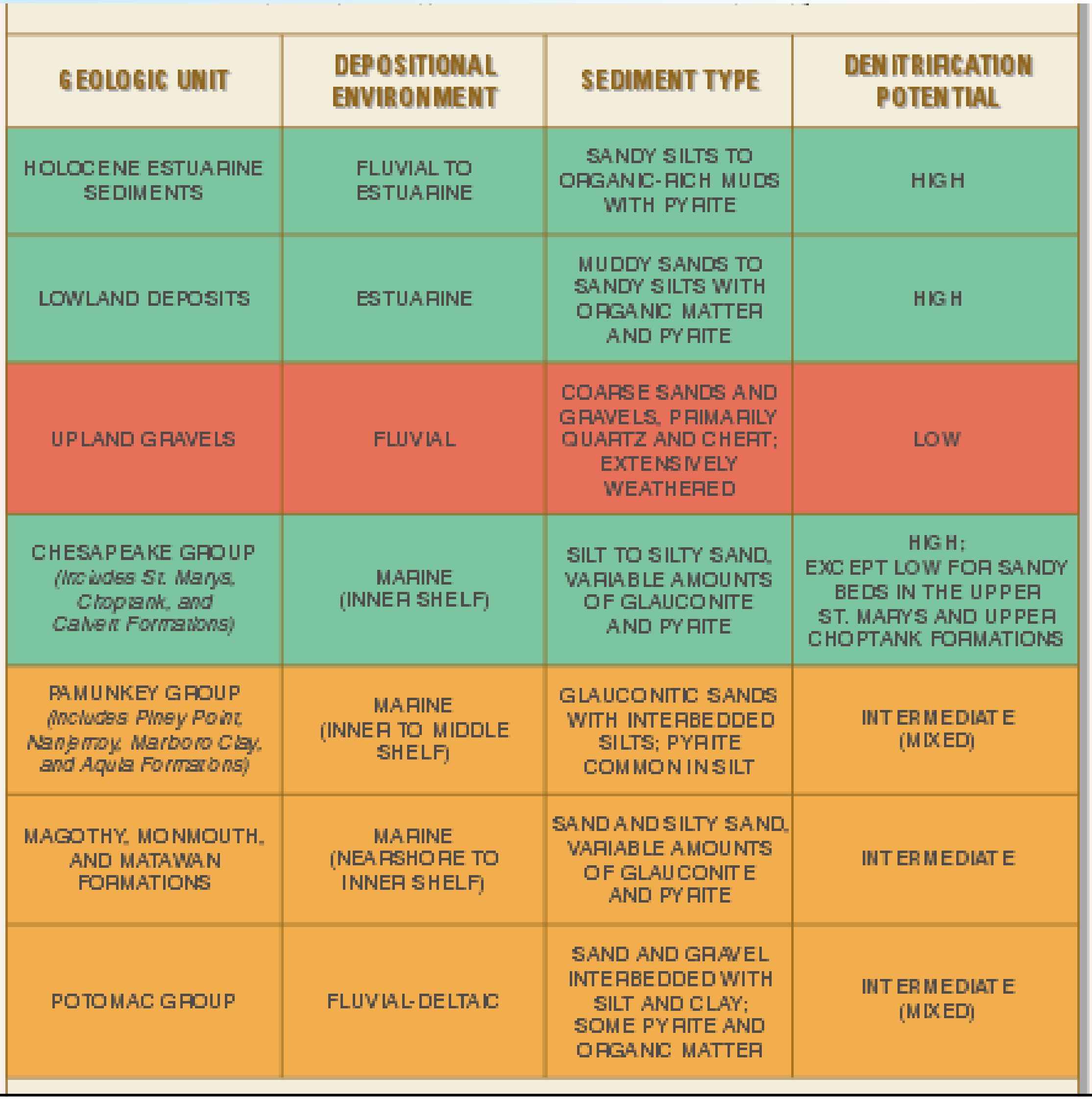
In Contrast: Pyrite Rich Aquifers Generate Denitrification (Delmarva Peninsula)

Pyrite (FeS_2) Reaction

$5FeS_2 + 14NO_3 + 4H$

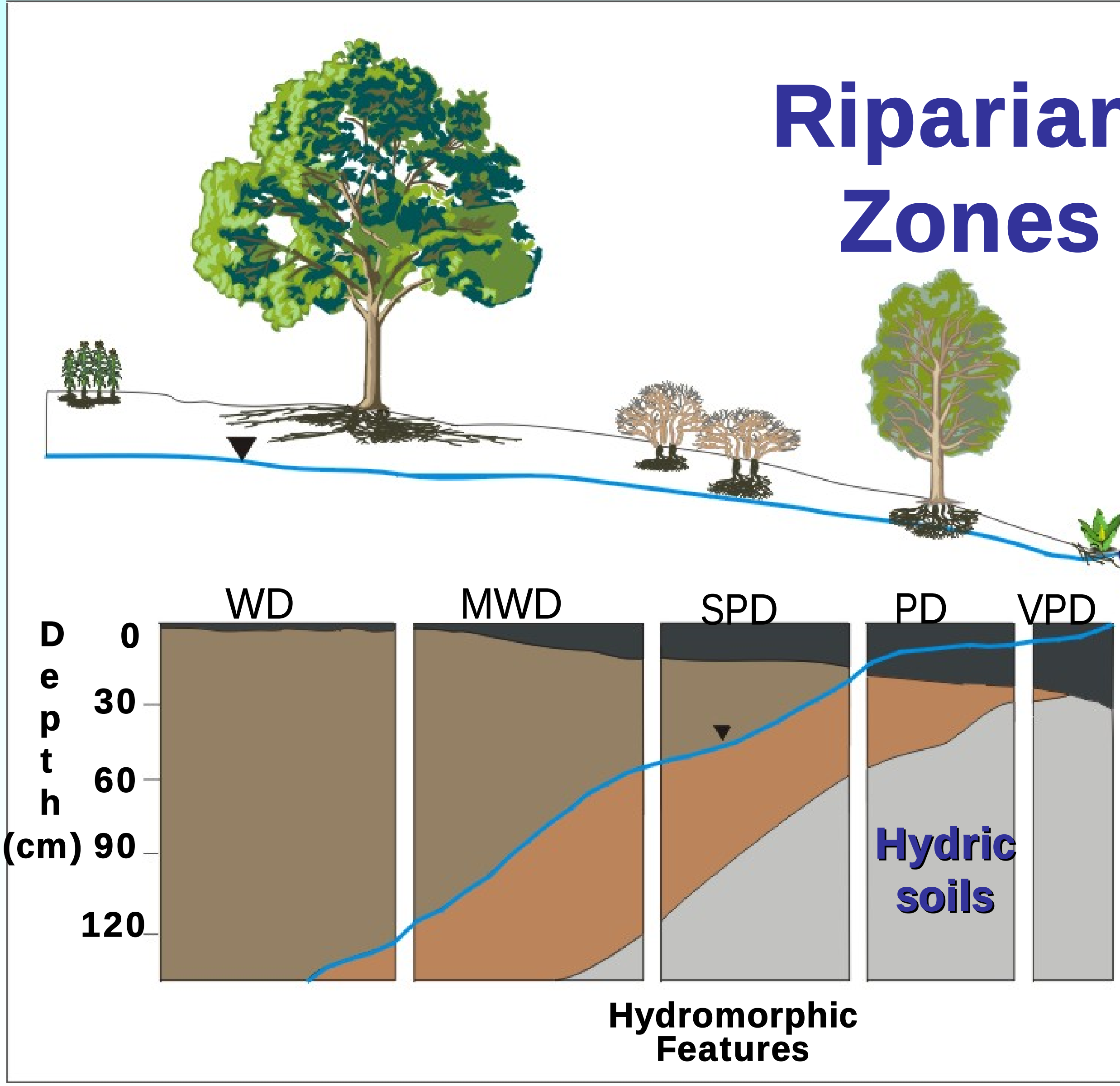
$\longrightarrow$

$7N_2 + 10SO_4 + 5Fe$
$+ 2H_2O$



GEOLOGIC UNIT	DEPOSITIONAL ENVIRONMENT	SEDIMENT TYPE	DENITRIFICATION POTENTIAL
HOLOCENE ESTUARINE SEDIMENTS	FLUVIAL TO ESTUARINE	SANDY SILTS TO ORGANIC-RICH MUDS WITH PYRITE	HIGH
LOWLAND DEPOSITS	ESTUARINE	MUDDY SANDS TO SANDY SILTS WITH ORGANIC MATTER AND PYRITE	HIGH
UPLAND GRAVELS	FLUVIAL	COARSE SANDS AND GRAVELS, PRIMARILY QUARTZ AND CHERT; EXTENSIVELY WEATHERED	LOW
CHESAPEAKE GROUP *(Includes St. Marys, Choptank, and Calvert Formations)*	MARINE (INNER SHELF)	SILT TO SILTY SAND, VARIABLE AMOUNTS OF GLAUCONITE AND PYRITE	HIGH; EXCEPT LOW FOR SANDY BEDS IN THE UPPER ST. MARYS AND UPPER CHOPTANK FORMATIONS
PAMUNKEY GROUP *(Includes Piney Point, Nanjemoy, Marlboro Clay, and Aquia Formations)*	MARINE (INNER TO MIDDLE SHELF)	GLAUCONITIC SANDS WITH INTERBEDDED SILTS; PYRITE COMMON IN SILT	INTERMEDIATE (MIXED)
MAGOTHY, MONMOUTH, AND MATAWAN FORMATIONS	MARINE (NEARSHORE TO INNER SHELF)	SAND AND SILTY SAND, VARIABLE AMOUNTS OF GLAUCONITE AND PYRITE	INTERMEDIATE
POTOMAC GROUP	FLUVIAL-DELTAIC	SAND AND GRAVEL INTERBEDDED WITH SILT AND CLAY; SOME PYRITE AND ORGANIC MATTER	INTERMEDIATE (MIXED)

Riparian Zones

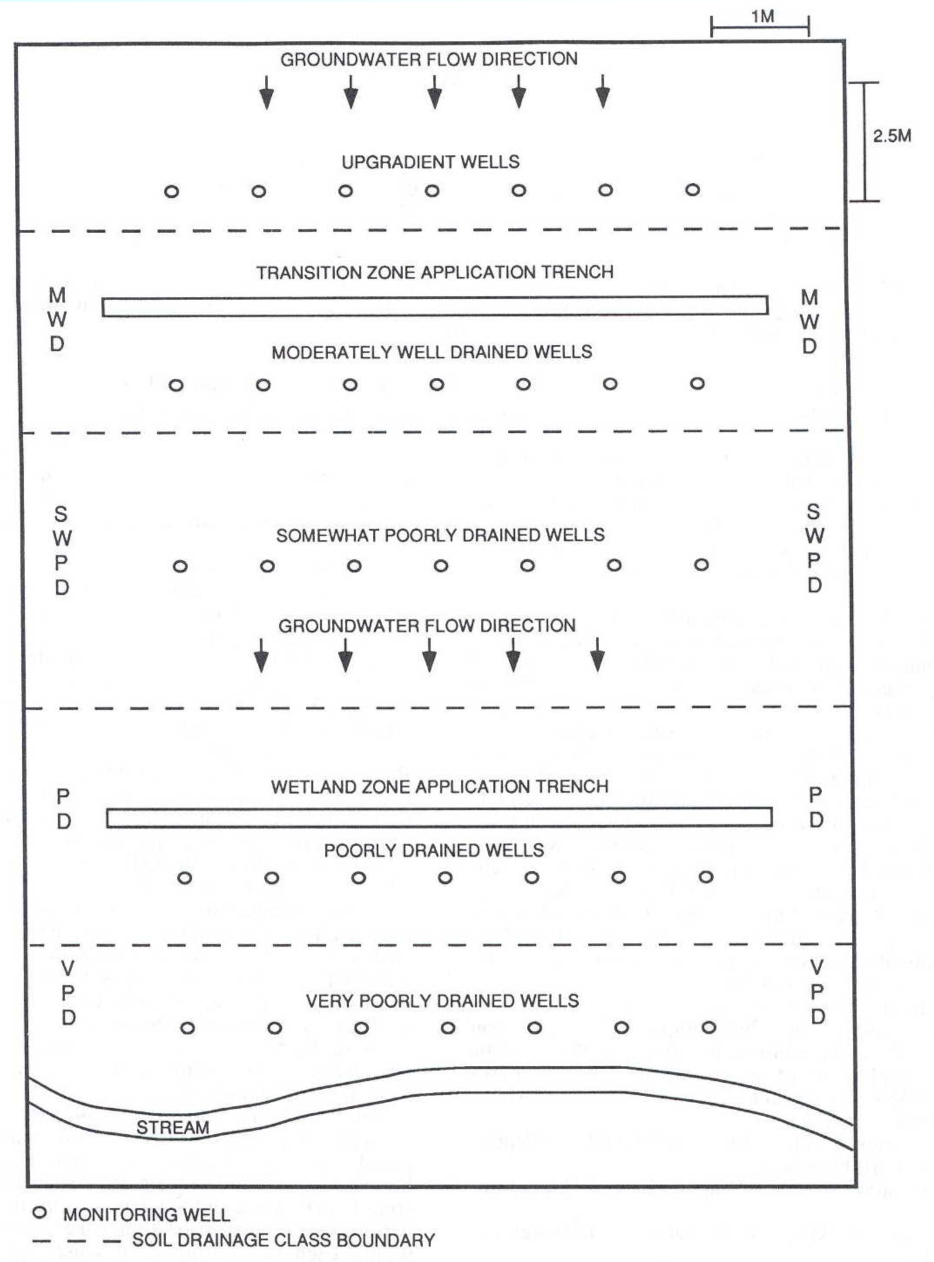


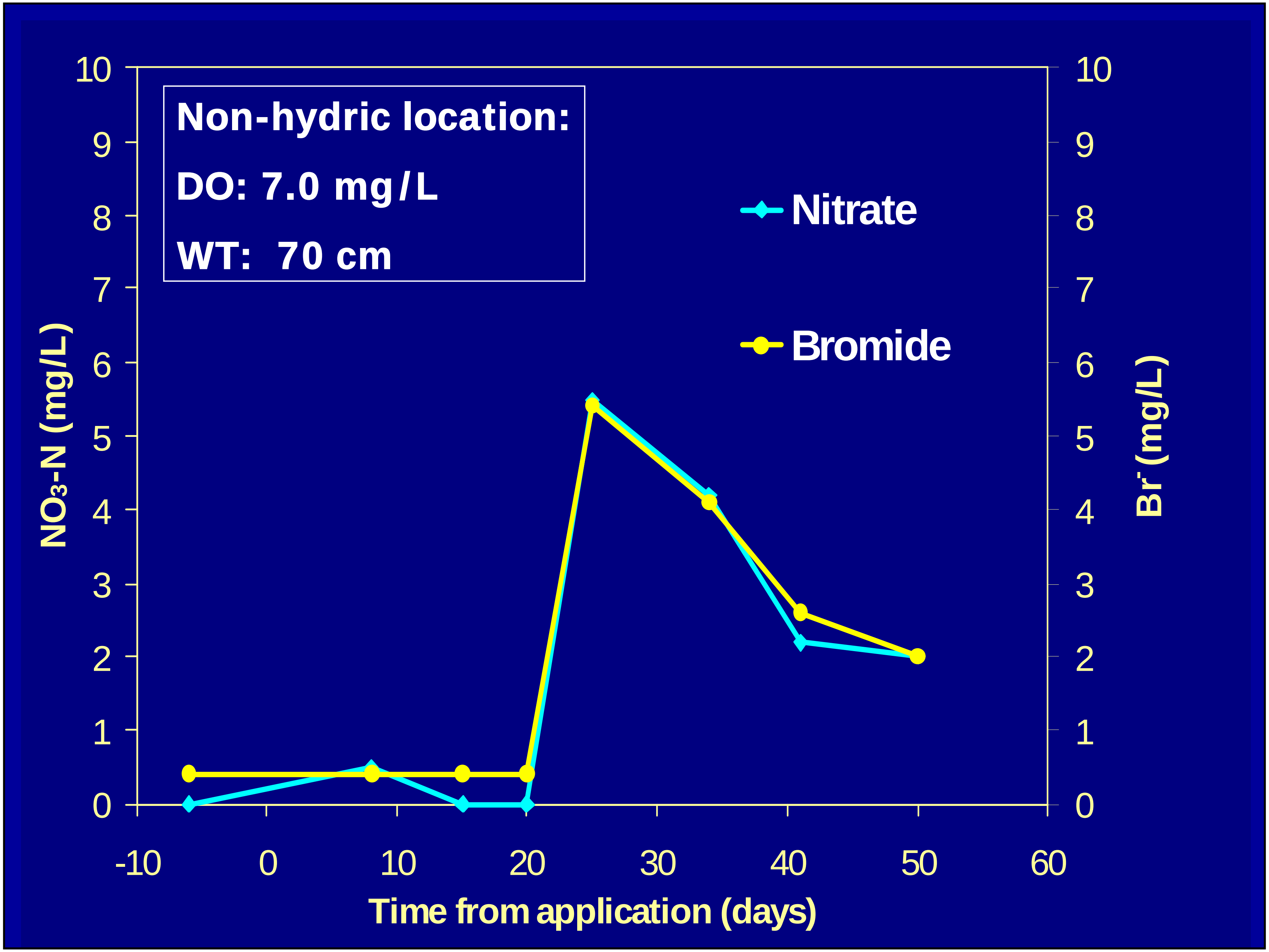
Groundwater denitrification potential increases in hydric soils

- **The water table comes closer to the surface**
- **Anaerobic conditions develop**
- **Organic matter increases**
- **Groundwater nitrate removal is often observed**

Riparian Groundwater Experiment: Dosing Trenches and Sampling Wells

Simmons, Gold,Groffman. JEQ

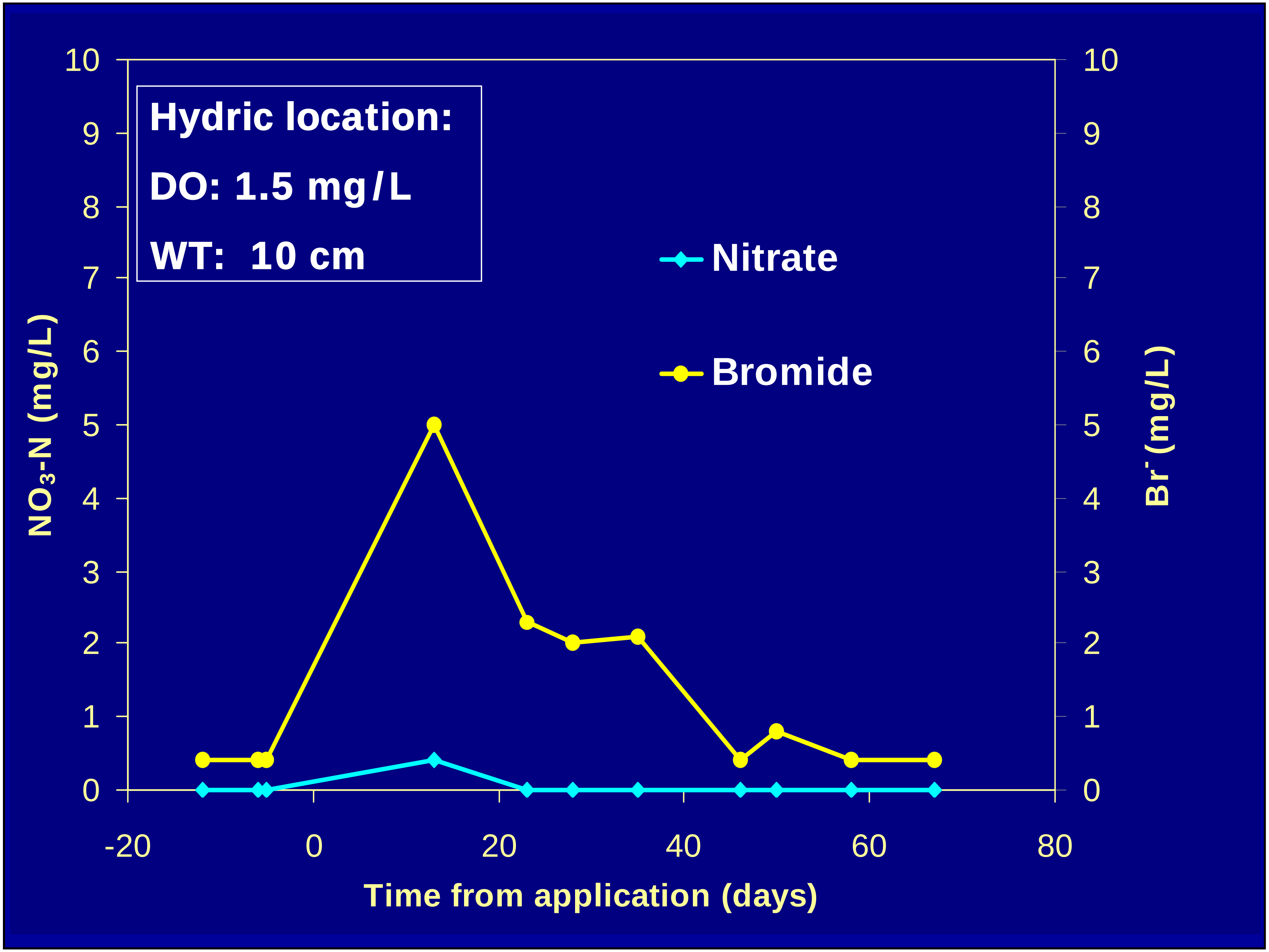


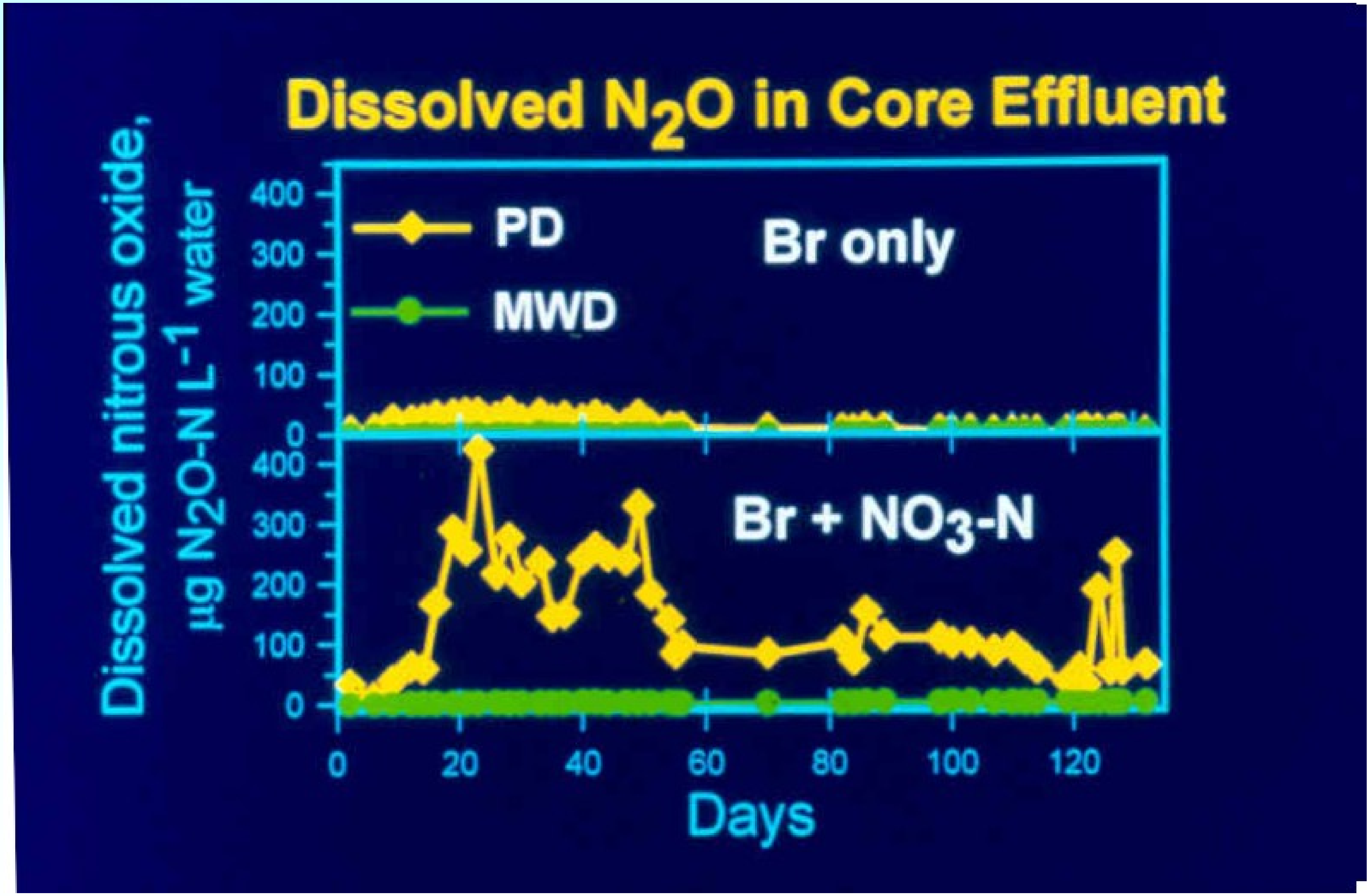


Non-hydric location:

DO: 7.0 mg/L

WT: 70 cm

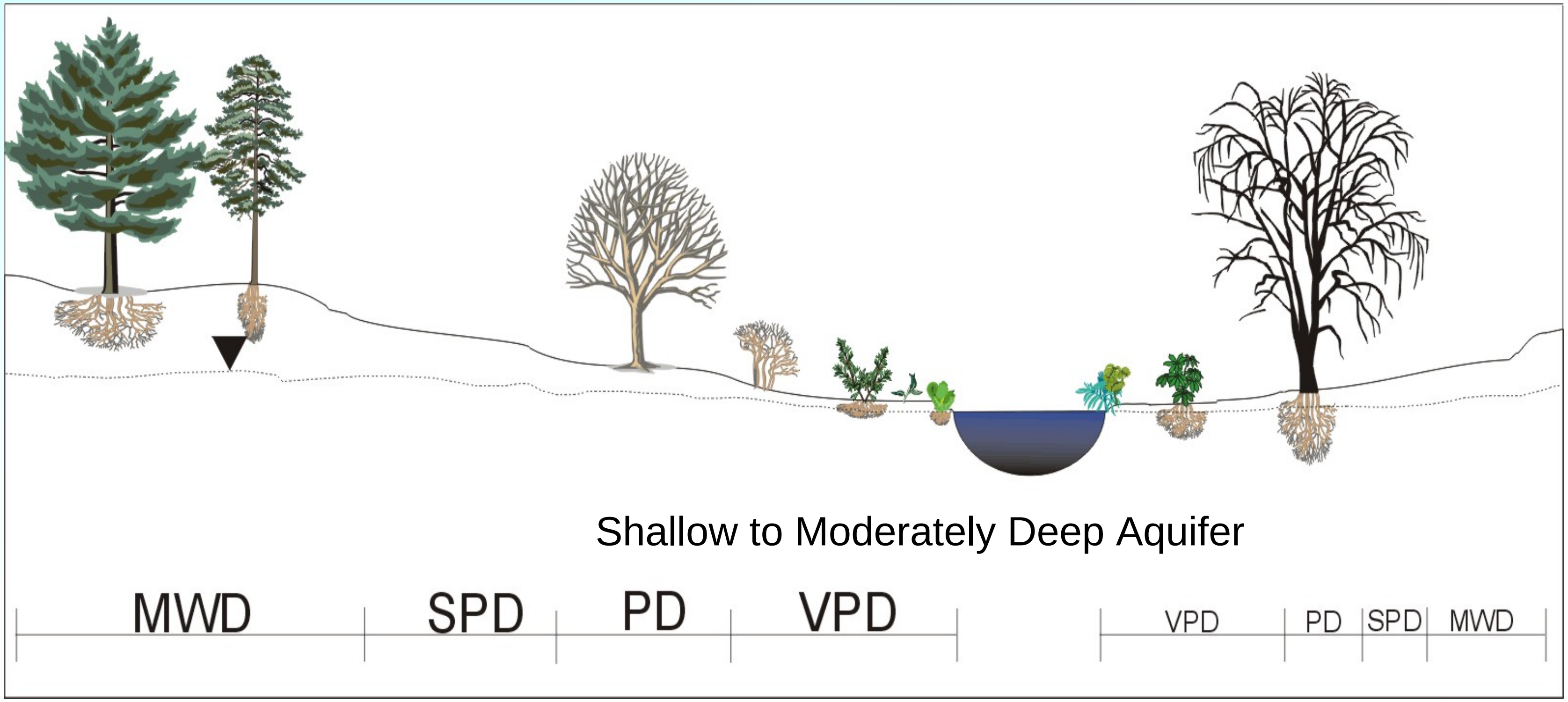

Hydric location:
DO: 1.5 mg/L
WT: 10 cm
Nitrate
Bromide
NO3-N (mg/L)
Br- (mg/L)
Time from application (days)
0
1
2
3
4
5
6
7
8
9
10
-20
0
20
40
60
80



Dissolved N_2O in Core Effluent

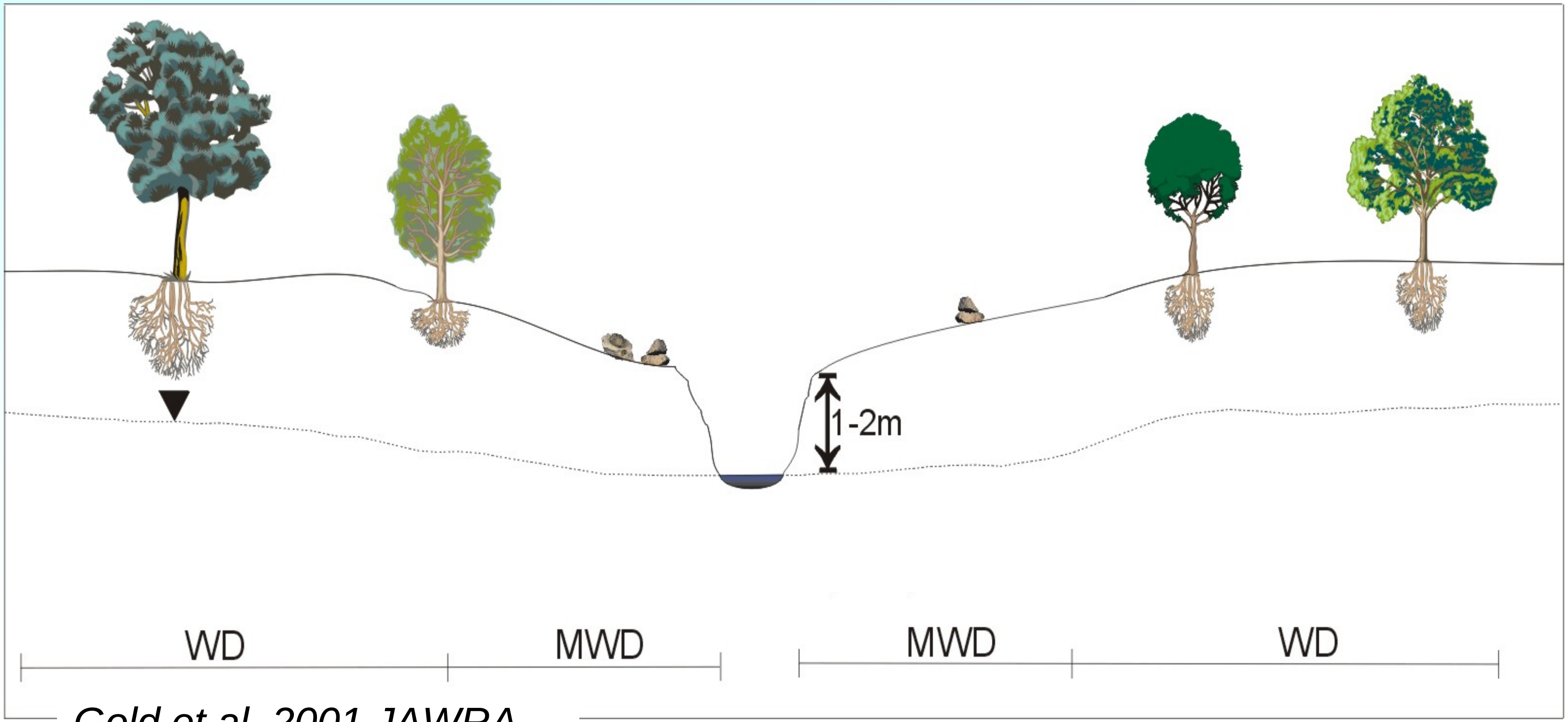
High Nitrate Removal Setting

Nitrate removal >70% in Hydric PD and VPD Soils



Low Nitrate Removal Setting: Incised Stream Channel: No Hydric Soils

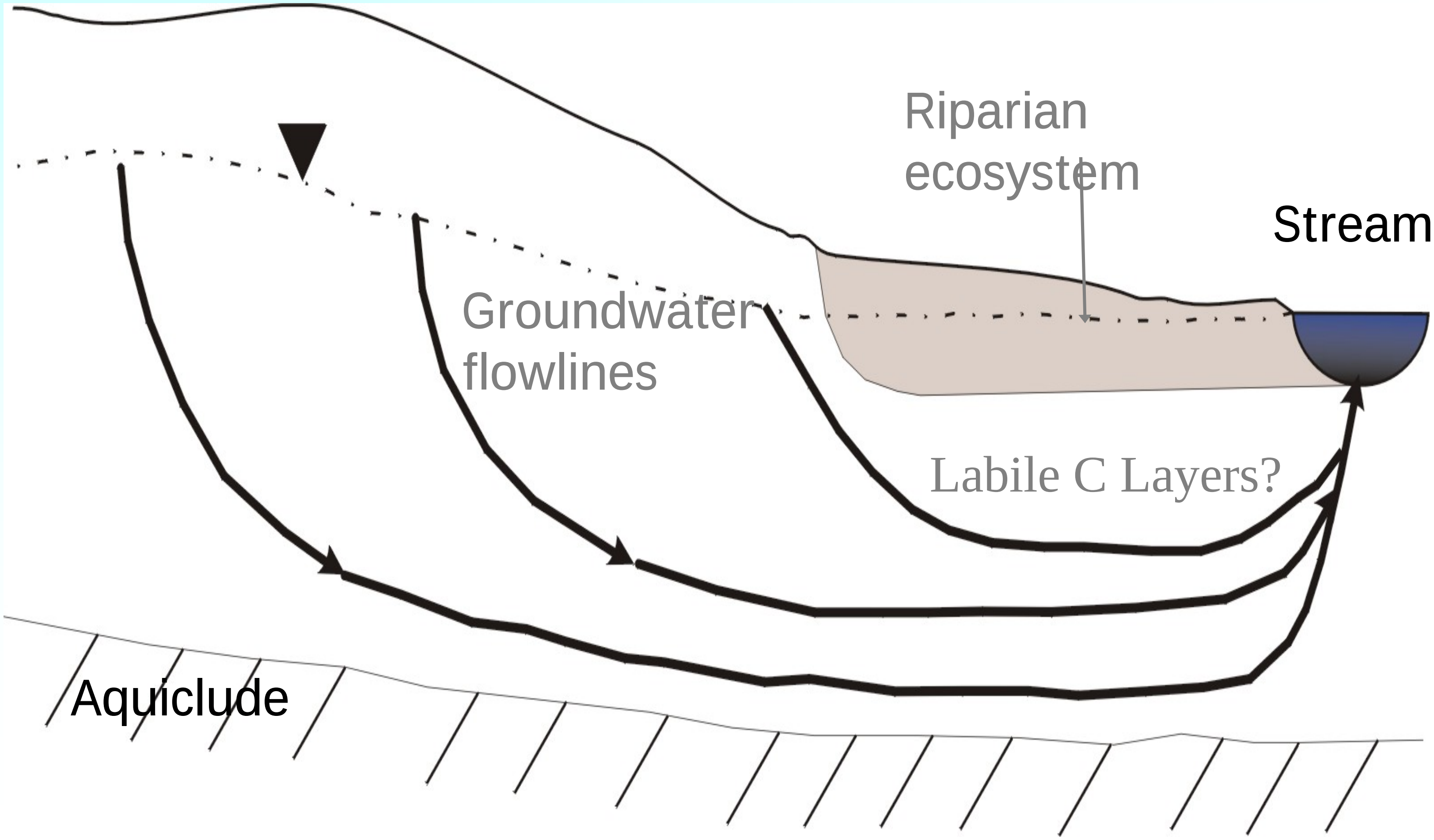
Nitrate removal <20% throughout



Gold et al. 2001 JAWRA.

Deep Groundwater Flowpaths

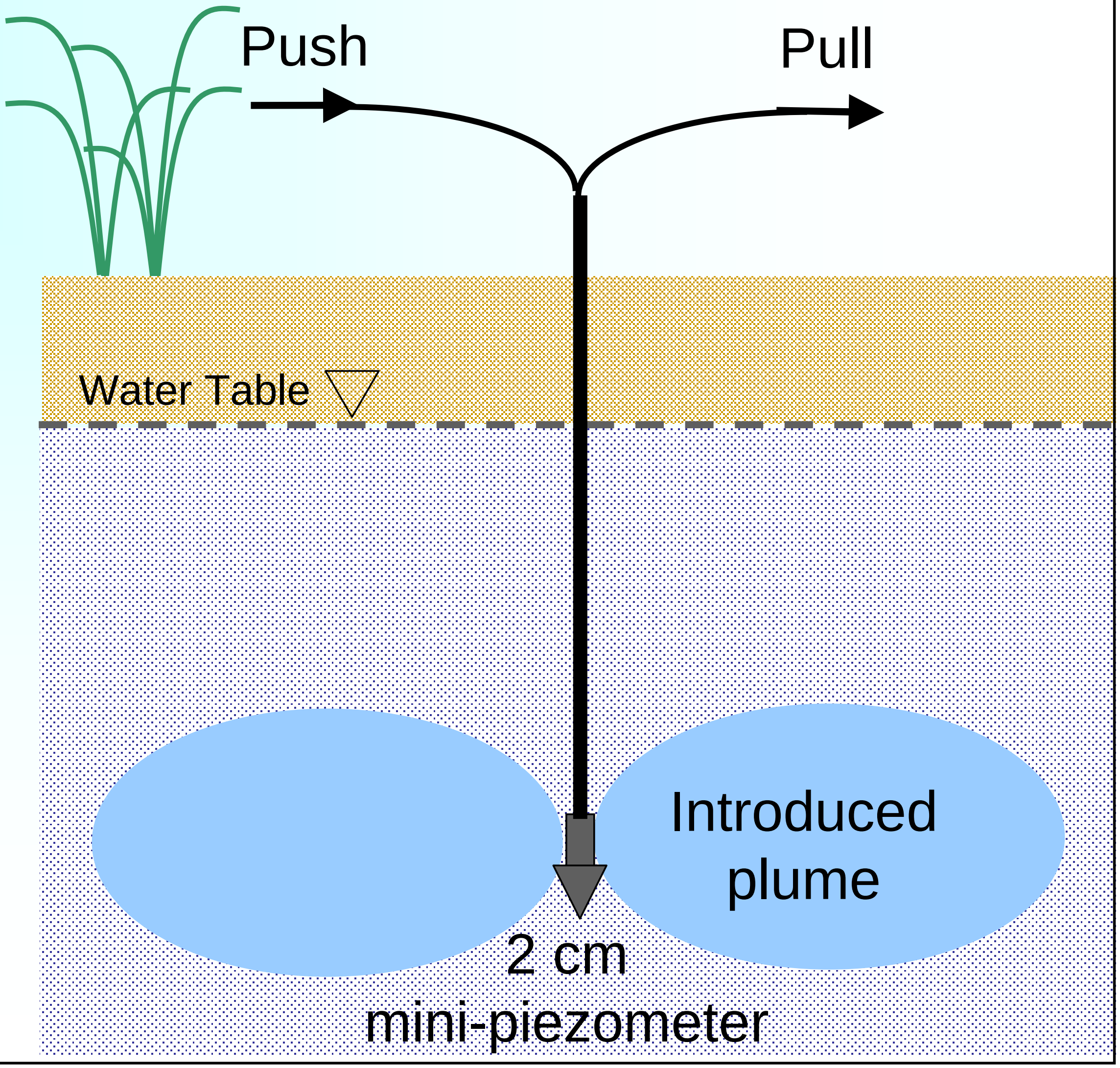
Bypassing organically enriched media or interacting with buried organic fluvial deposits?



Push-Pull Method: In Situ Denitrification Capacity

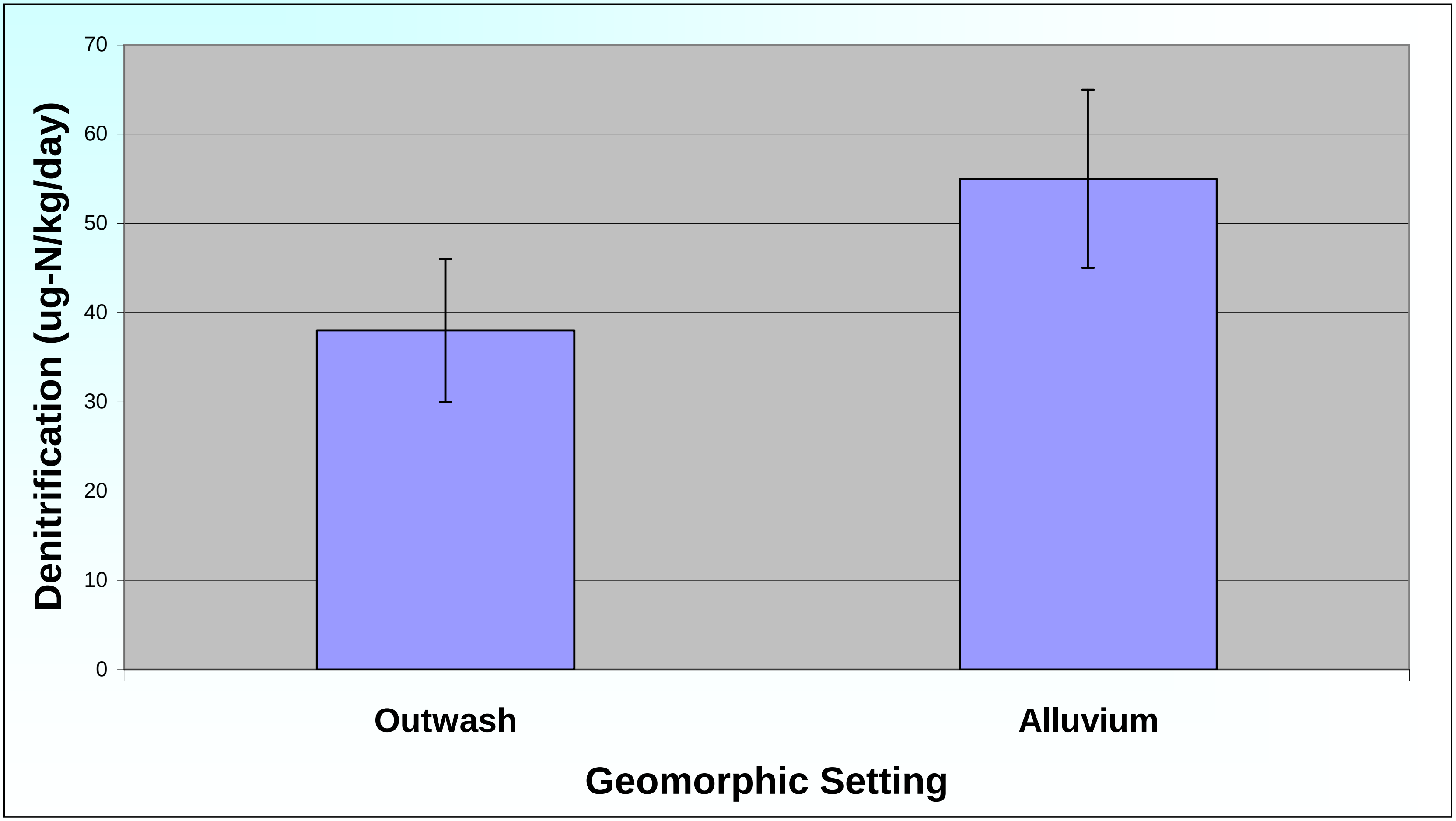
1. Pump groundwater
2. Amend with $^{15}NO_3^-$ and Br^-
3. Lower DO to ambient levels with gaseous SF_6
4. Push (inject) into well
5. Incubate
6. Pull (pump) from well
7. Analyze samples for $^{15}N_2$ and $^{15}N_2O$ (products of microbial denitrification)

(Addy et al. 2002, JEQ)



Groundwater Denitrification in Outwash and Alluvium:

High Removal Rates 1.5 m below Ground Surface



Kellogg et al., 2005; JEQ

C Deposits Below The Water Table:

<u>Found Up to 3 m depth</u>
near stream in hydric Soils,
regardless of “mapped”
geomorphology

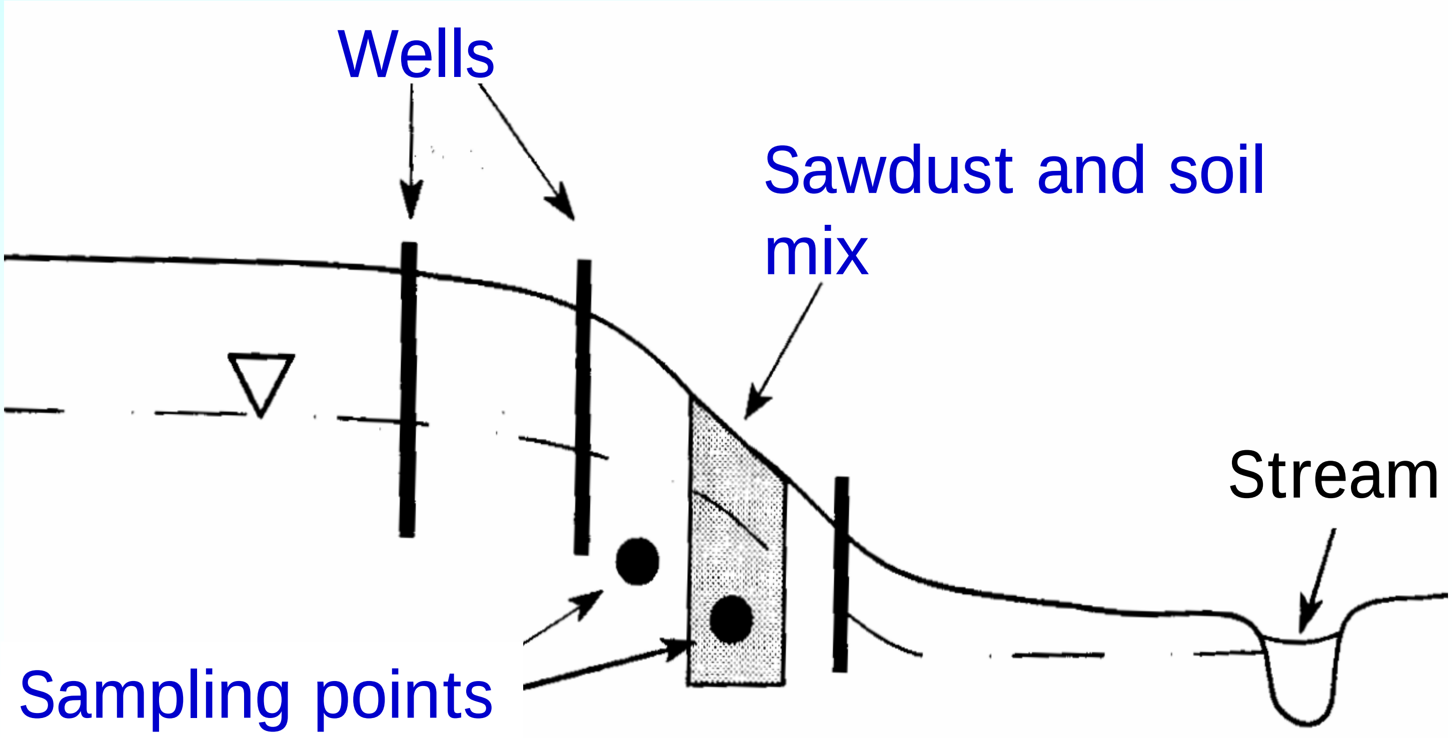
C Sources

- Buried surface Horizons (17/18 “outwash” sites)
- Buried stream deposits
- Roots
- Windthrows

Blazejewski et al., 2005; J. SSSA

Some Flat River Valleys Function Like Engineered Denitrification Walls

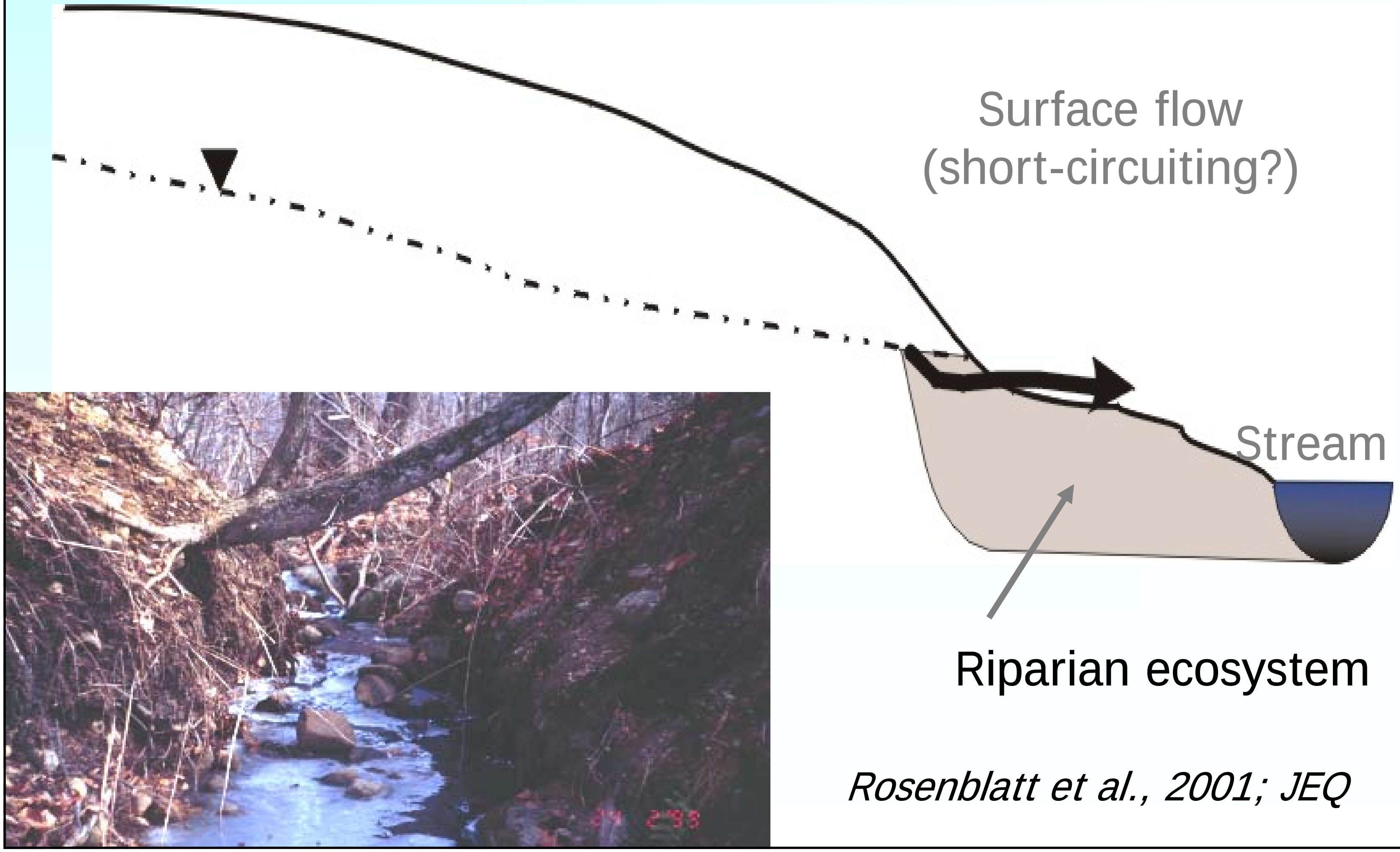
Buried Carbon Intercepts Groundwater



Adapted from Schipper and Vojvodic-Vukovic 1998 and Downes et al. 1997

Groundwater Seeps and Geomorphology

- Seeps found at 29/34 hydric till sites during field reconnaissance
- Expect reduced groundwater N removal potential in till



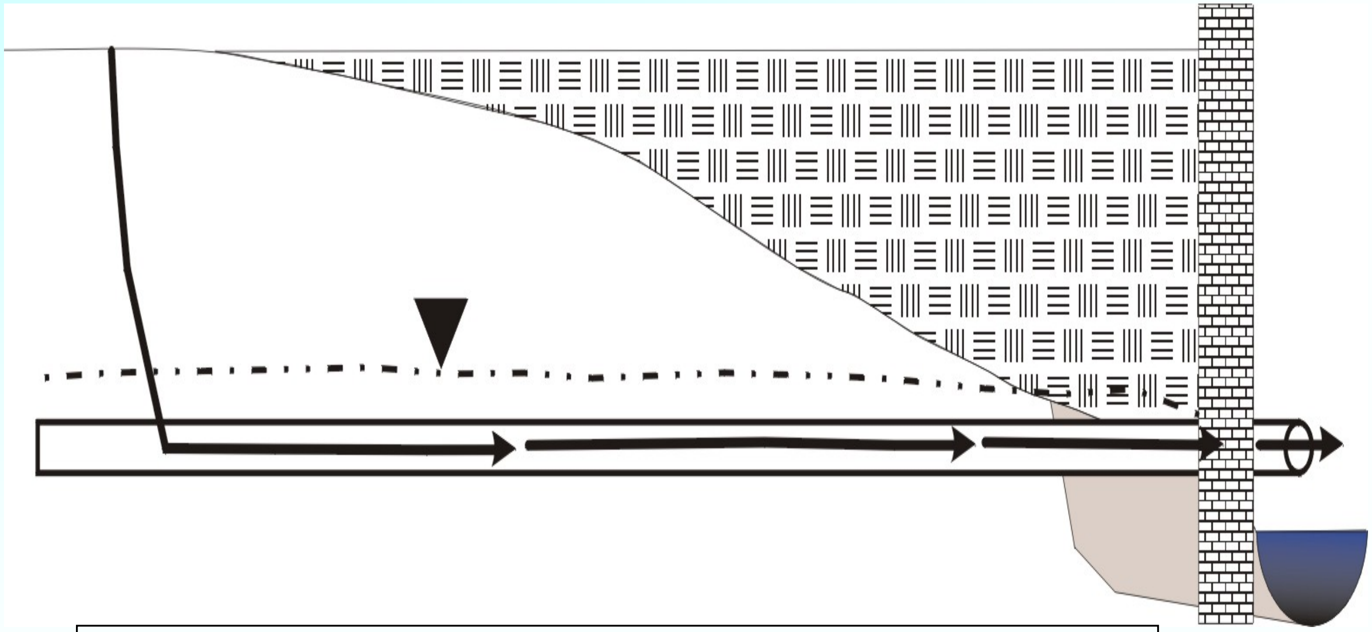
Surface flow (short-circuiting?)

Stream

Riparian ecosystem

Rosenblatt et al., 2001; JEQ

Human disturbance in shoreline areas reduces the N removal function of vegetated buffers

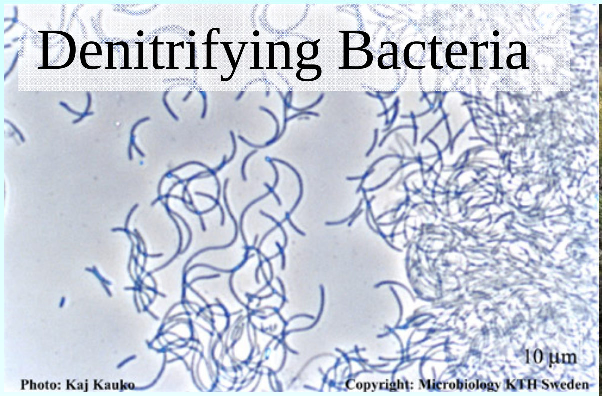


Bulkheads, drainage and fill lower the water table and *short-circuit* flowpaths that may have intercepted denitrification zones

Vegetated buffers also fail if the upland generates concentrated flows

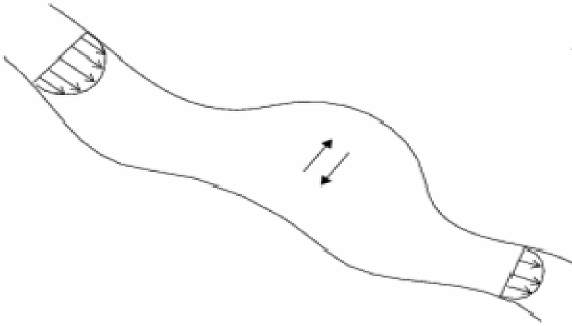
Site reshaping and infiltration “rain gardens” promote buffer functions

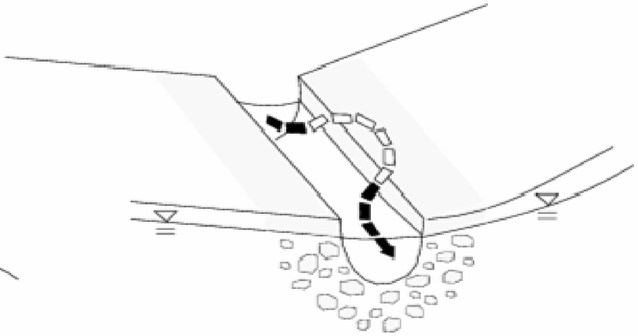
Role of Streams:
Potential Denitrification Pathways


Denitrifying Bacteria


Woody debris
Biofilms


Algal mats
Biofilms


Surface water storage


Hyporheic exchange

Stream denitrification?
Active area of research

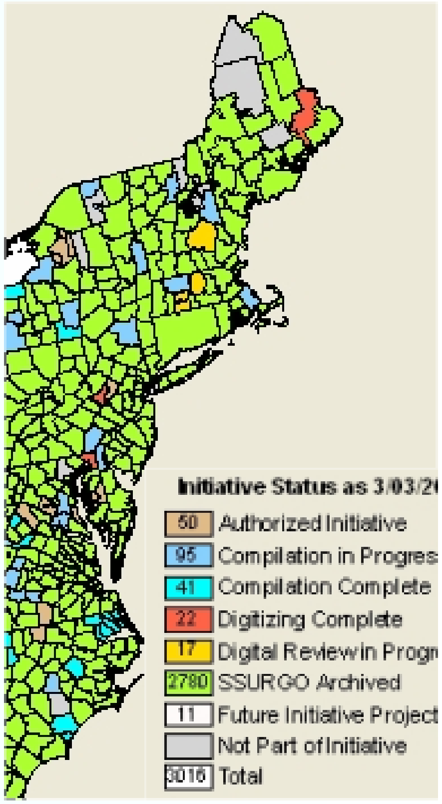
- Slow, shallow streams can be important denitrification sinks (Alexander et al. 2000)
- Minimal denitrification within larger streams (Mulholland et al. 2004)
- Nitrogen removal in agricultural headwater streams is low and is significant only during brief periods in summer (Herrman et al. 2007)

In-stream Wetlands, Lakes and Reservoirs

- 25 to 50% of N load removed with extended retention times (> 4 months): *David et al., 2006 Ecol. Applic*.
- In-stream wetlands have yielded high denitrification rates with retention times of 1 week to 1 month. Mixing is critical *Kovacic et al. 2000. JEQ*
- State of Illinois: Wetlands and reservoirs remove 20% of total river flux of N

How to identify sinks? High resolution spatial data

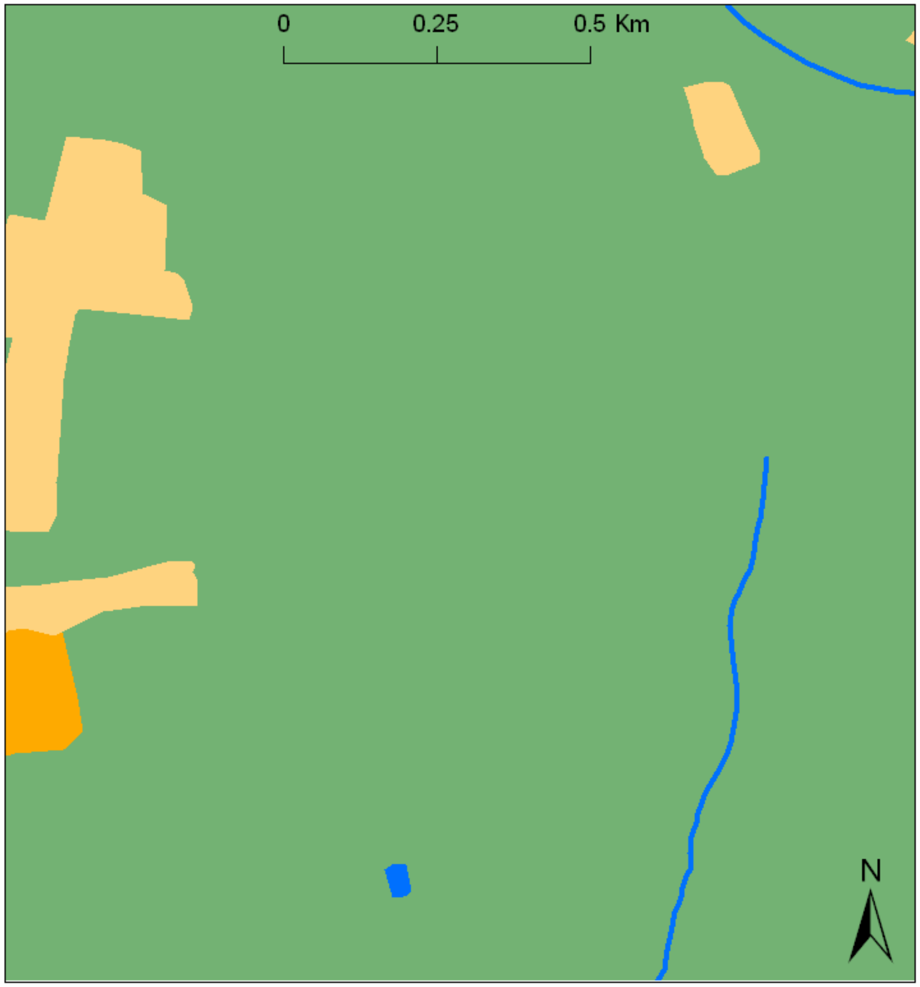
- Nat’l Wetland Inventory: 1:24,000
- SSURGO County Scale Digital soil surveys: 1:15,840
  - Soil wetness (hydric soils)
  - Geomorphology
- Land use
  - 1995 Anderson Level III (1:24,000)
- Topography & hydrography (1:5,000 to 1:24,000)
  - Flow patterns, watershed boundaries
  - Stream Networks



SSURGO
Status:
NE U.S.
March 2007

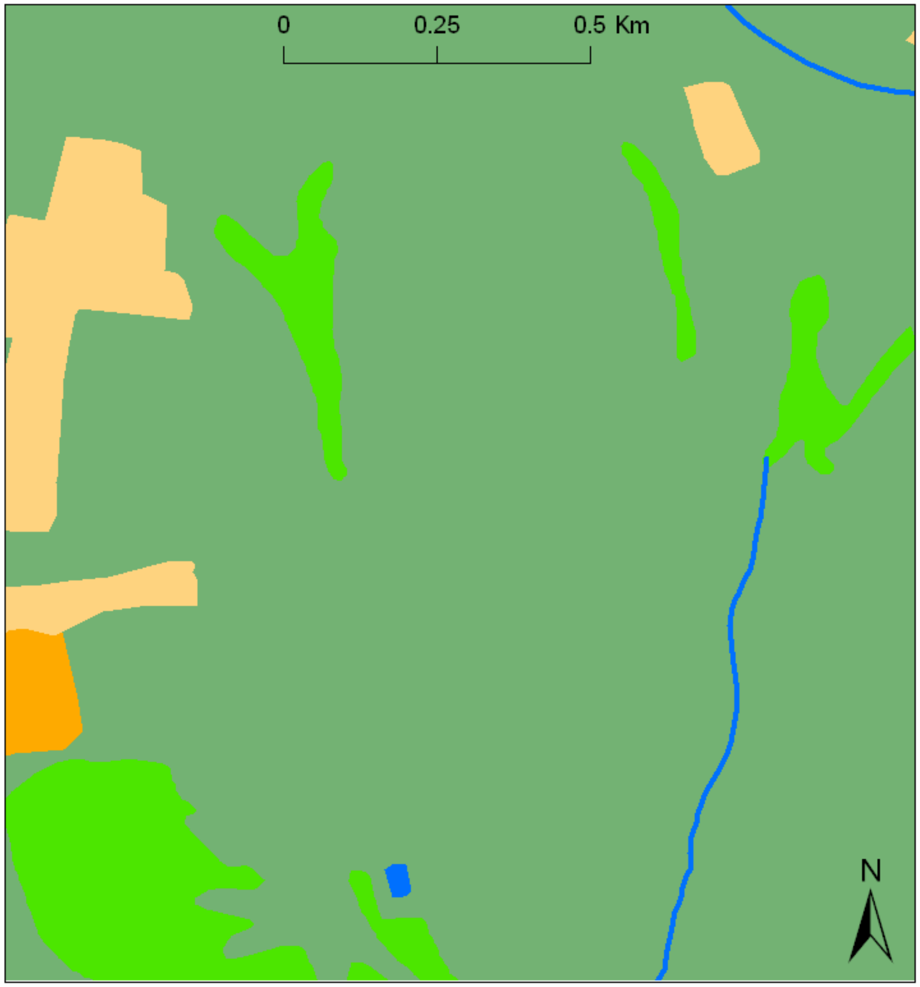
The choice of spatial data can either mask or display potential pathways and sinks

(data from 5 km^2 area of Kingston Quad- RI)



- ∿ **Streams (1:24,000)**
- 🟩 Forest / Open Space
- 🟦 Water
- 🟨 Residential (med density)
- 🟧 Residential (high density)

National Wetland Inventory (1:24,000) displays potential sinks



🟧 HD Residential

🟨 MD Residential

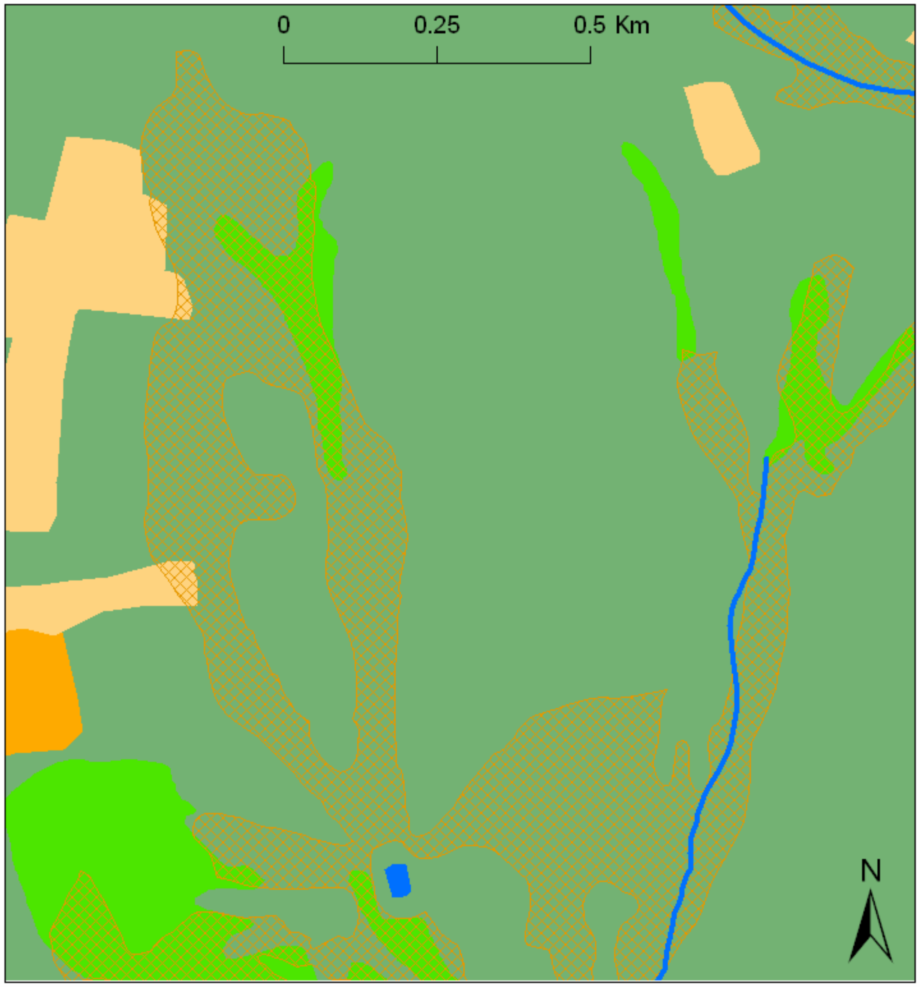
🟩 Forest / Open Space

🟩 **NWI Wetlands**

🟦 Water

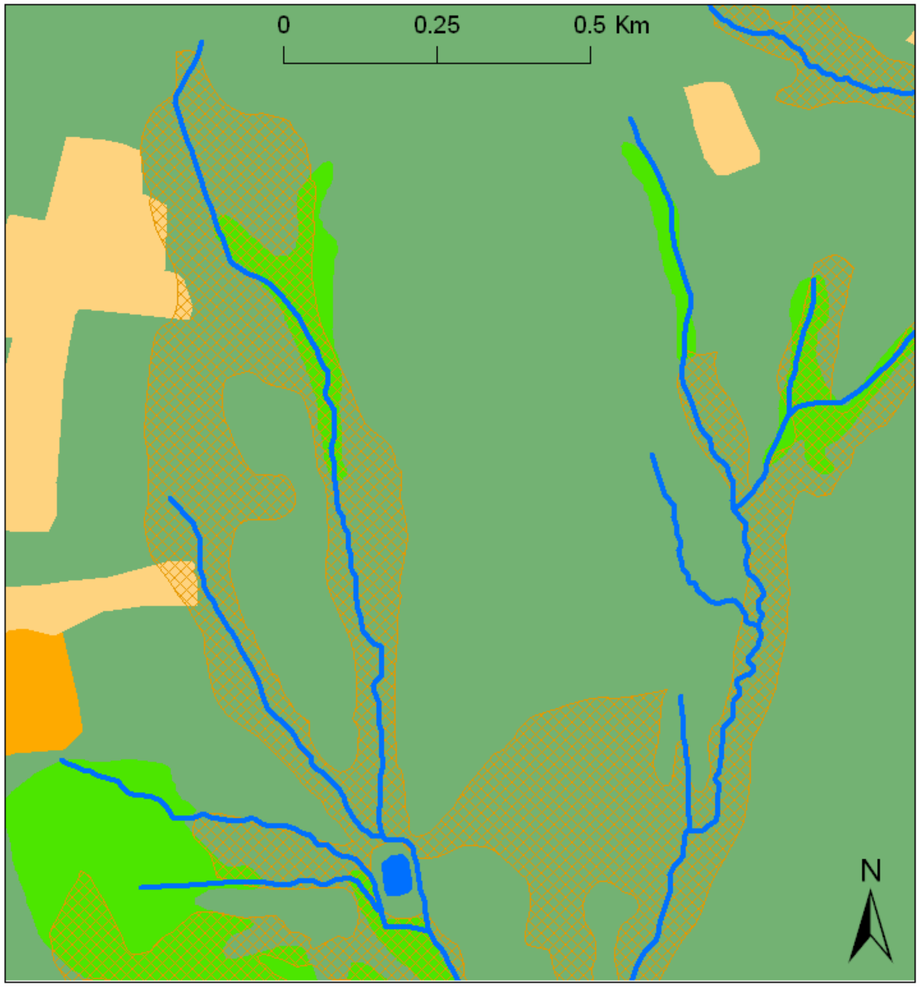
∿ Streams (1:24,000)

SSURGO Hydric Soils suggest wetlands and zero order streams connect source to stream



- 🟧 HD Residential
- 🟨 MD Residential
- 🟩 Forest / Open Space
- 🟩 NWI Wetlands
- ▨ **Hydric Soils (SSURGO)**
- 🟦 Water
- 〰 Streams (1:24,000)

High resolution stream data and hydric soils display an active biogeochemical landscape



🟧 HD Residential

🟨 MD Residential

🟩 Forest / Open Space

🟩 NWI Wetlands

▨ **Hydric Soils (SSURGO)**

🟦 Water

∿ **Streams (1:5,000)**

Why Identify and Research N Sinks?

- We can employ a suite of spatial data and GIS tools to guide local decisions regarding:
  - Source controls: When sinks are absent from downgradient flow paths, source area controls (e.,g. N removal systems) are more critical
  - Protection/restoration: When sinks intercept sources of nitrate, those areas are priorities for protection and restoration.

Resources:

URI Watershed Hydrology Lab

www.uri.edu/cels/nrs/whl

New England Water Quality Program

www.usawaterquality.org/newengland

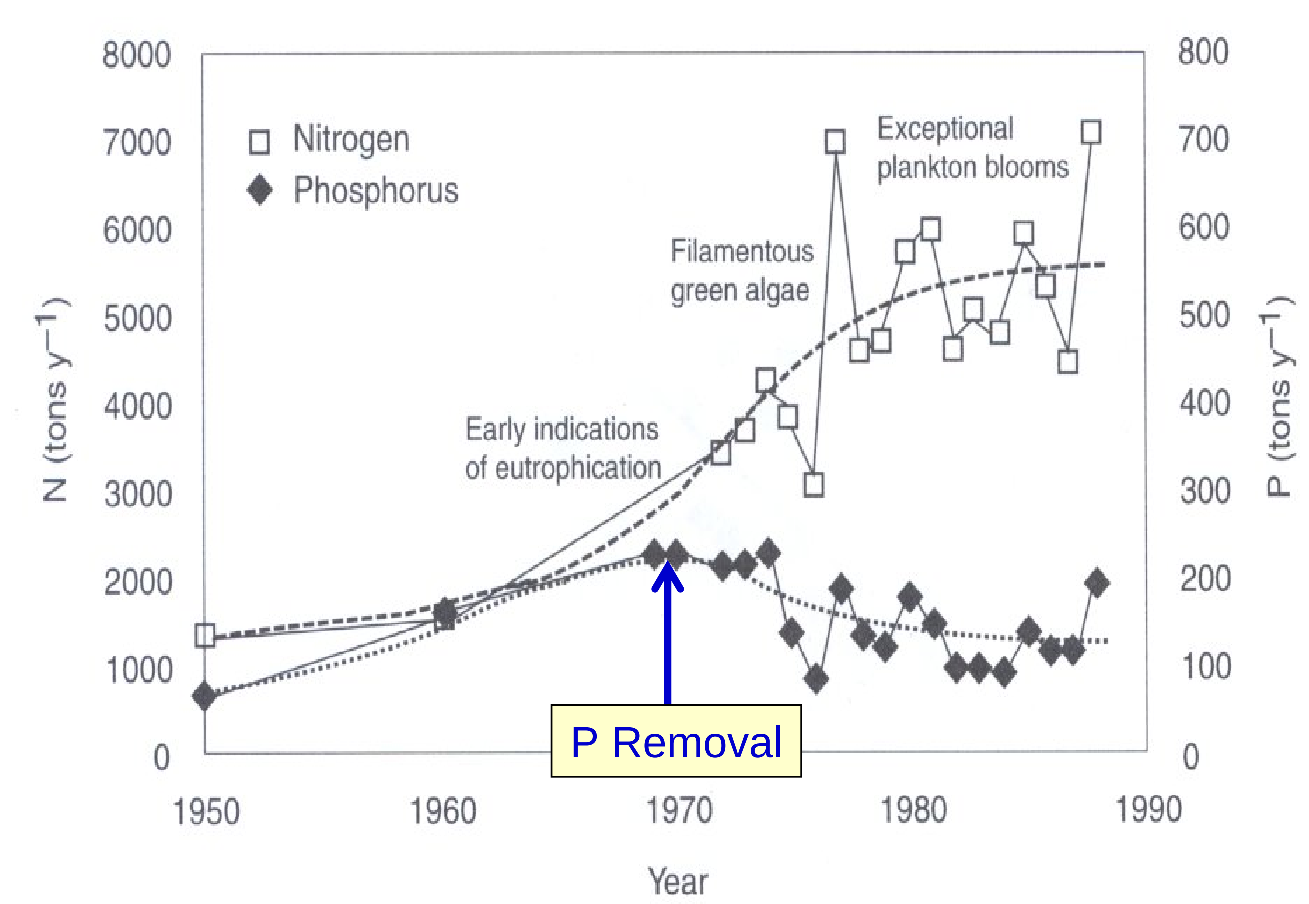
NEW ENGLAND Regional Water Program

NRCS Natural Resources Conservation Service

University of Rhode Island NEMO

N Inputs Degrade Coastal Waters:

Swedish Estuary Study: Algal blooms related to N inputs, not P inputs of wastewater effluent



P Removal

- **Howarth RW et al. (2000)** ***Clean Coastal Waters:***
National Academy Press

Does Geomorphology Affect Depth of Denitrification in Hydric Riparian Zones?