Water Quality Trends and Conditions

The Continuing Saga of Chesapeake Bay Restoration

Phase 2 Presentation

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(and many friends)

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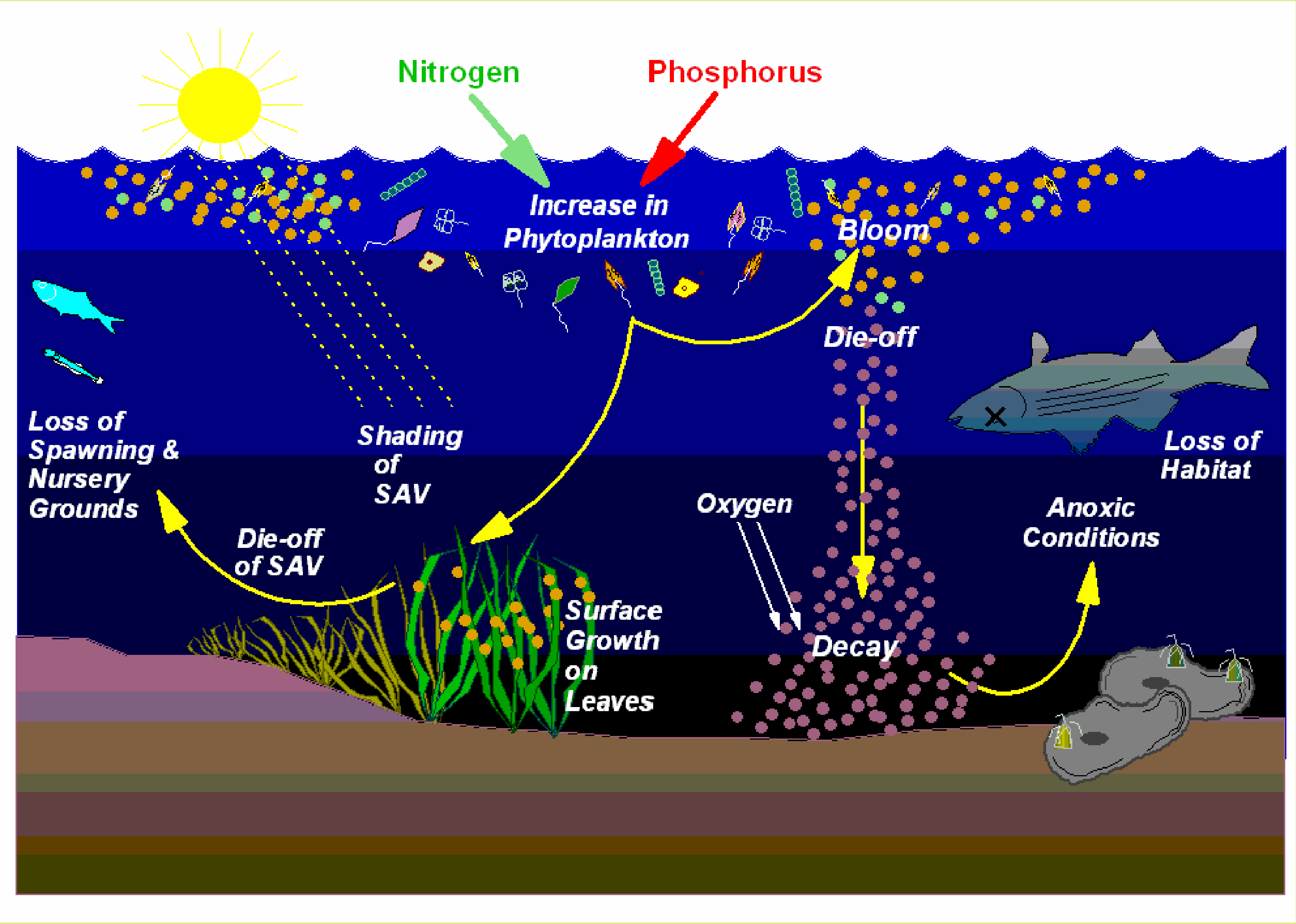
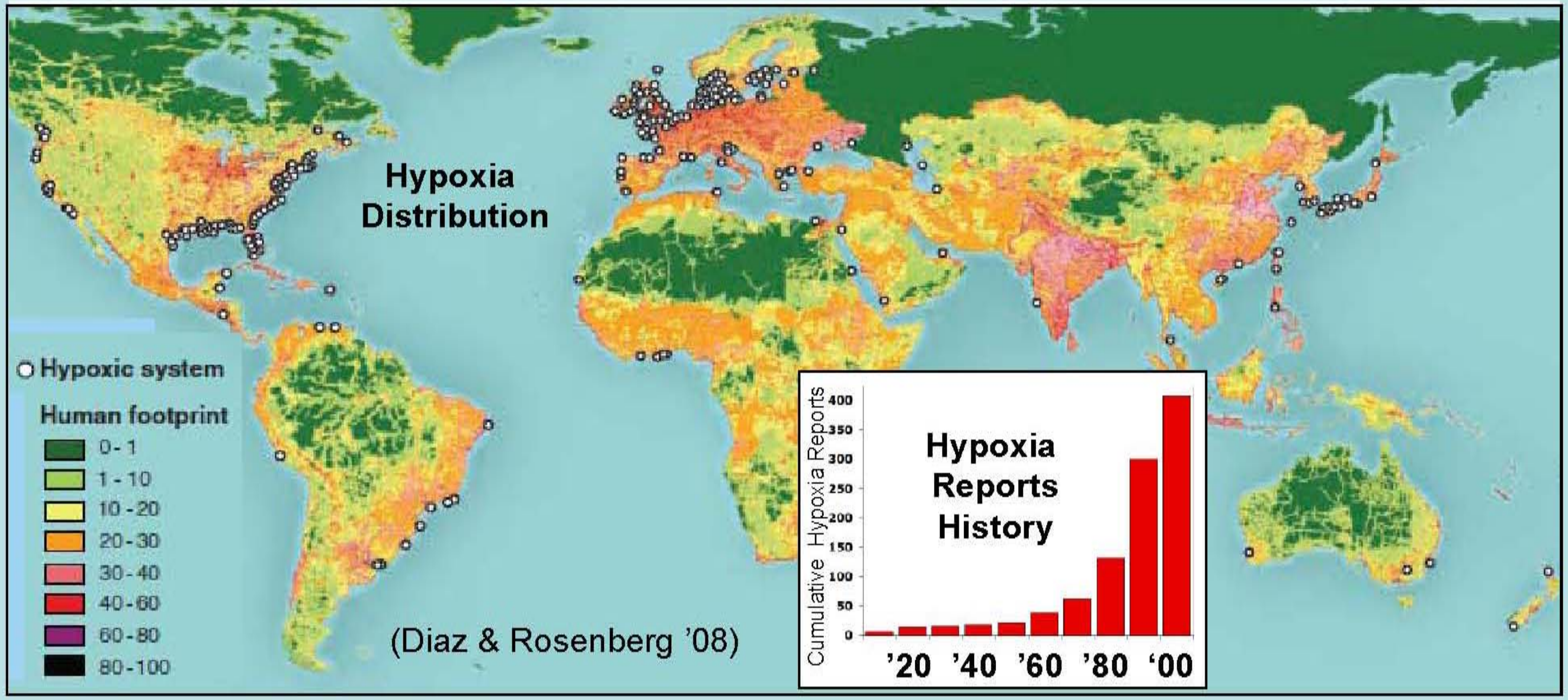
Topics for Today

- A Brief Eutrophication Primer
- Nutrient Loads and WQ Trends in the Potomac (+ and -)
- A Natural "Hot Spot" for Nutrient Losses…the Diffuse Source Term
- Major Nutrient Loss Terms, Thresholds, and Restoration Activities
- Some Concluding Thoughts

Eutrophication Cartoon

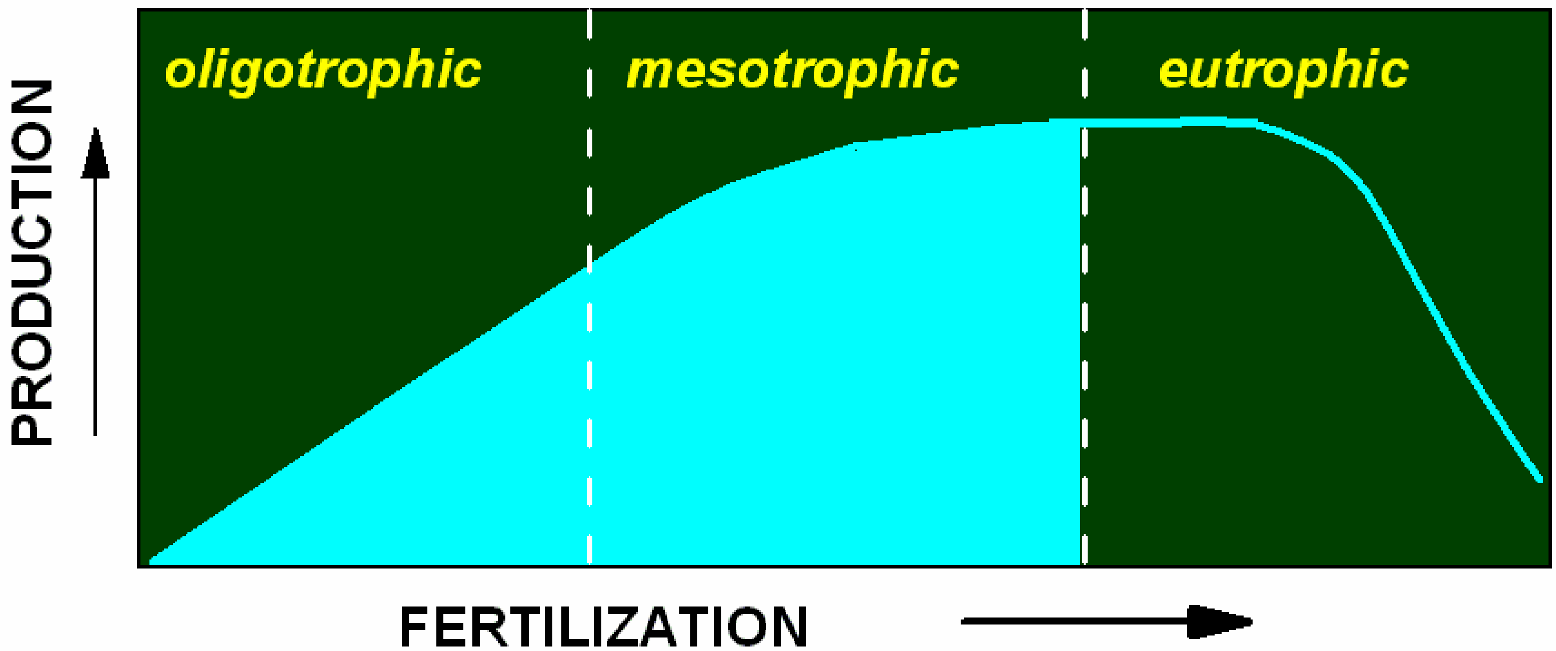


Global-Scale Spread of Coastal Hypoxia



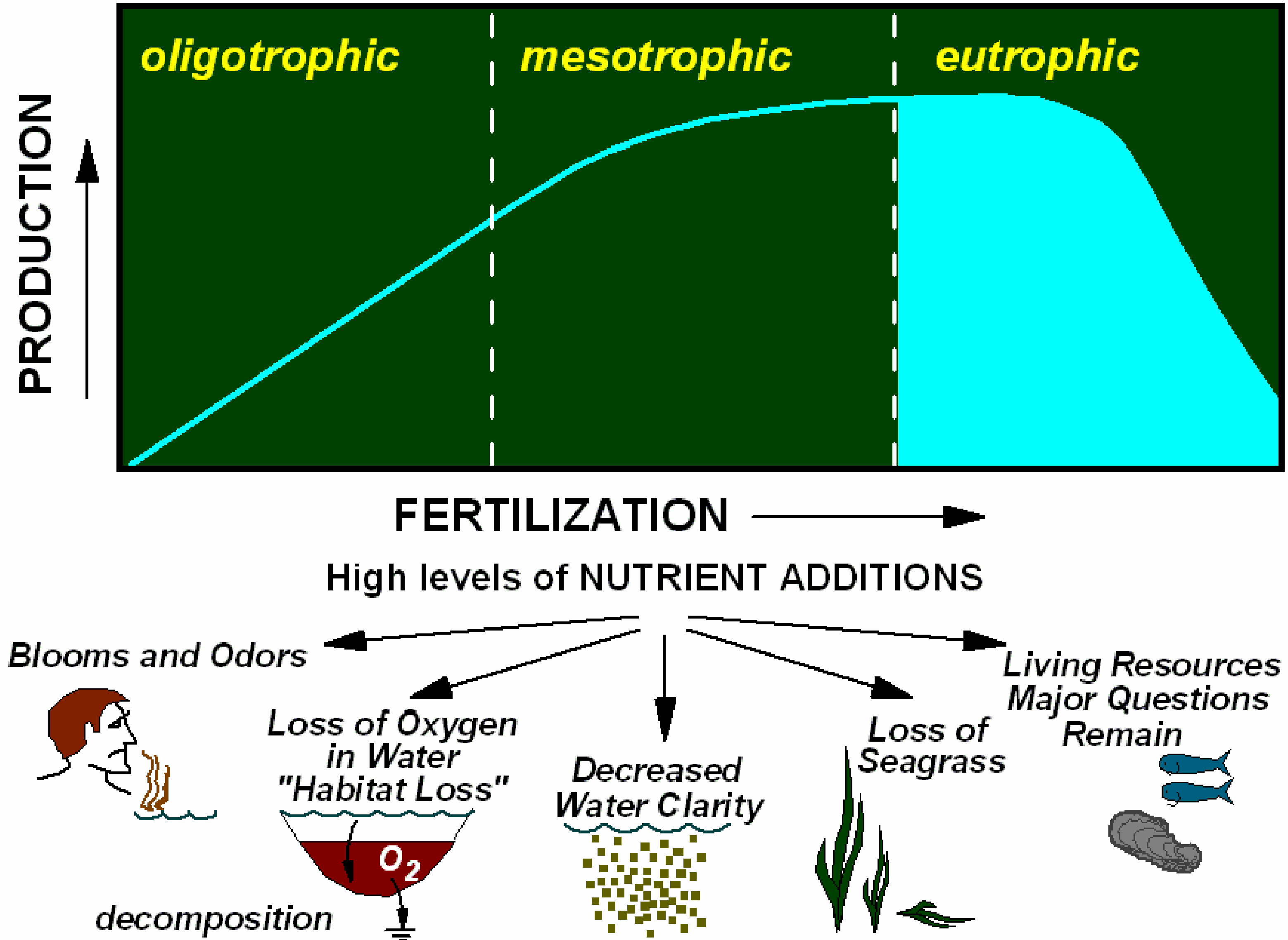
- Global distribution of coastal hypoxia
- Hypoxia concentrated near intense human activities
- Global spread of hypoxia related to eutrophication
- Other processes (e.g., climate change) also important

POSITIVE EFFECTS



- Essential for plant growth. In most estuaries and the open ocean microscopic plants provide the basic food supply.
- Within limits, increased fertilization increases food supply and production of other organisms.

Negative Effects…Nutrient Obesity



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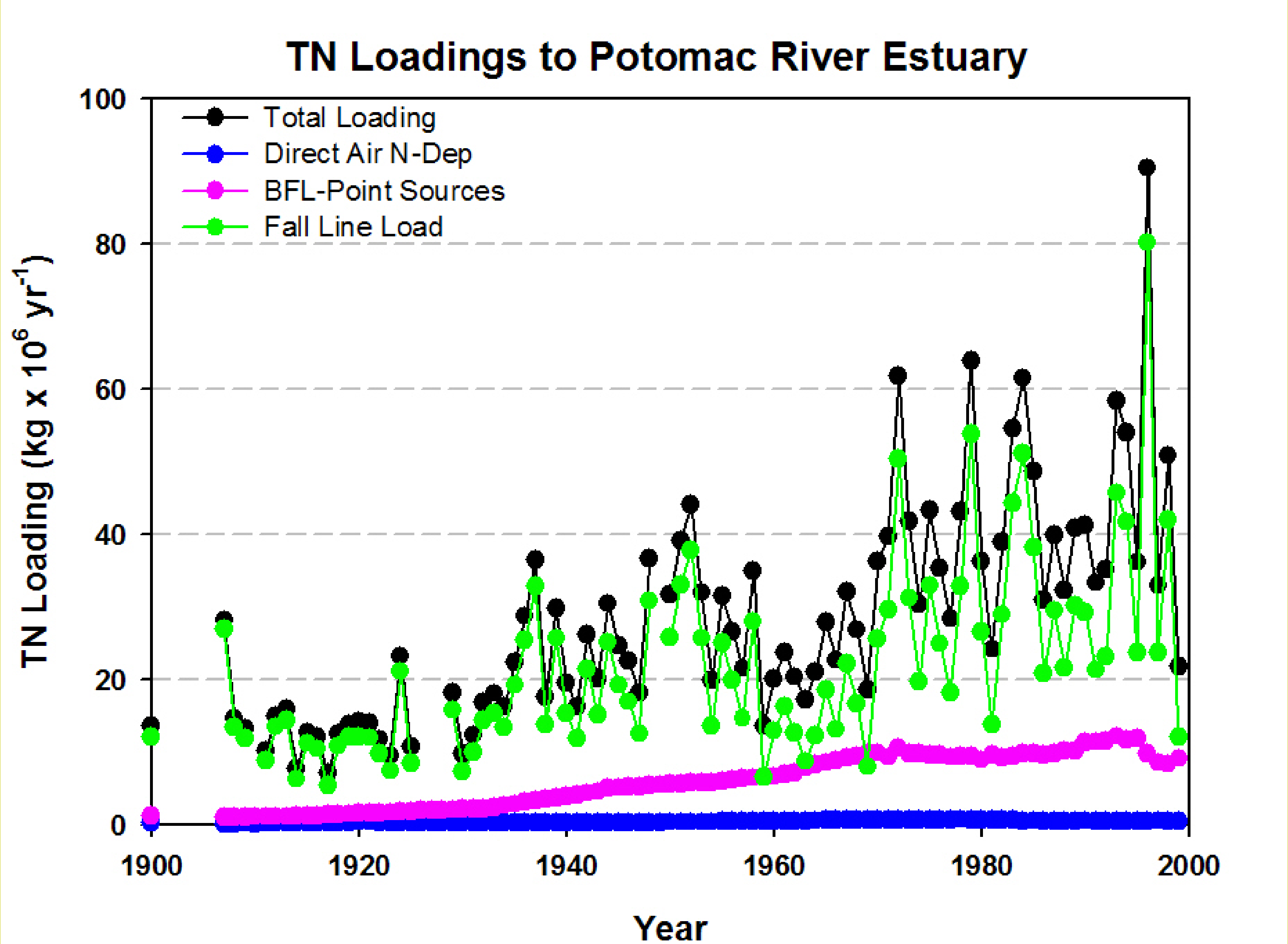
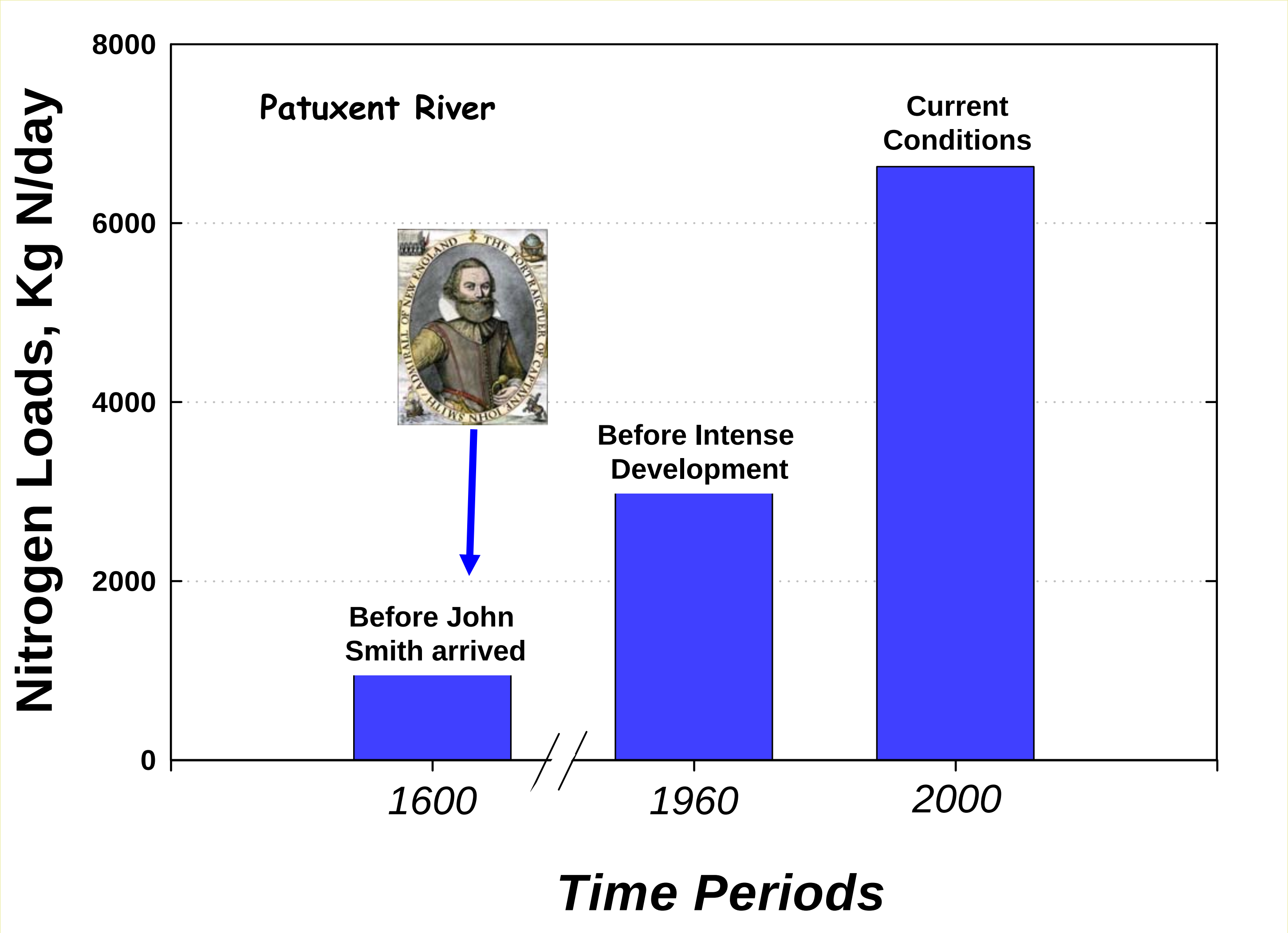


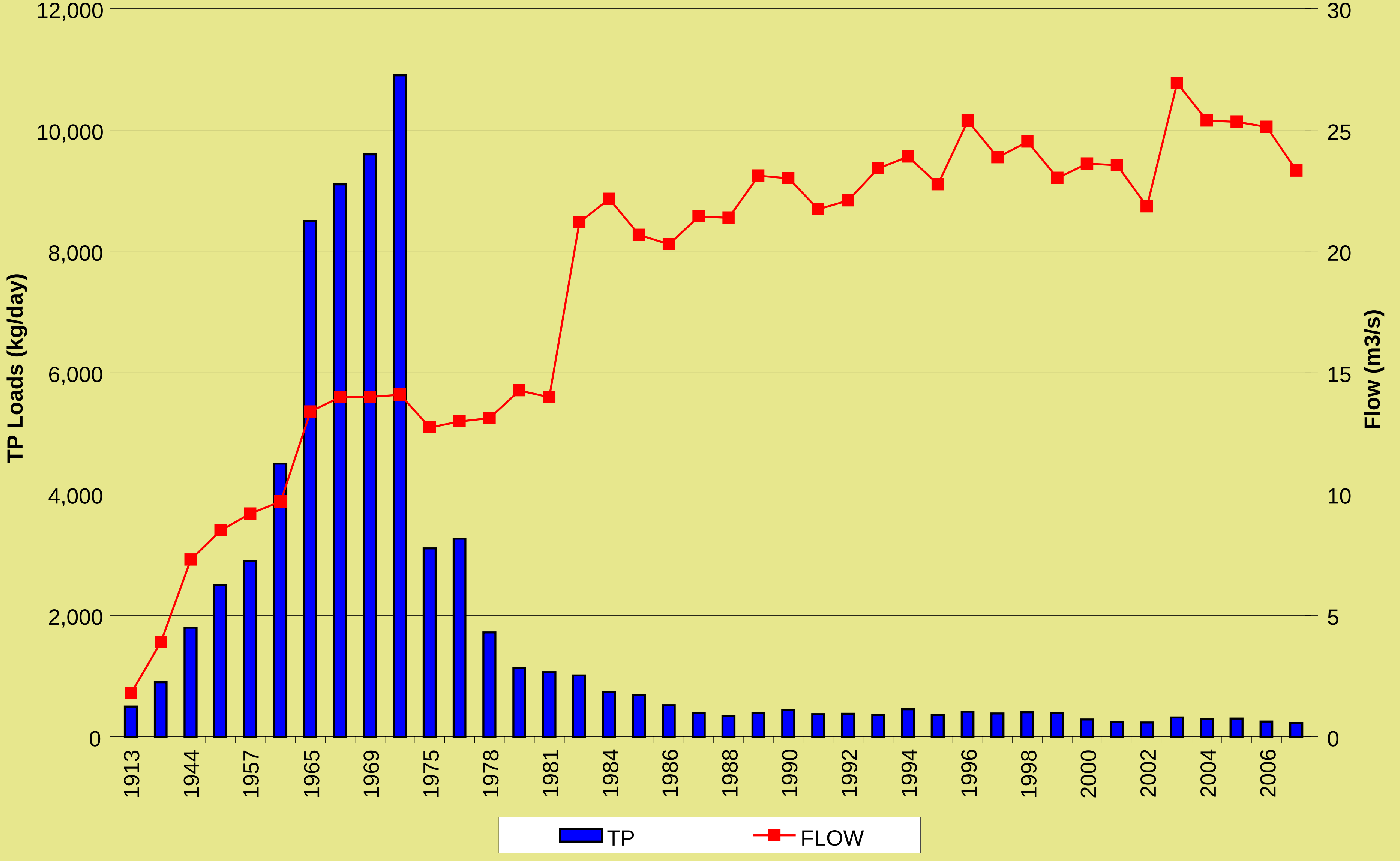
(N. Jaworski 2007)

Historical Increases in Bay Nitrogen Loading

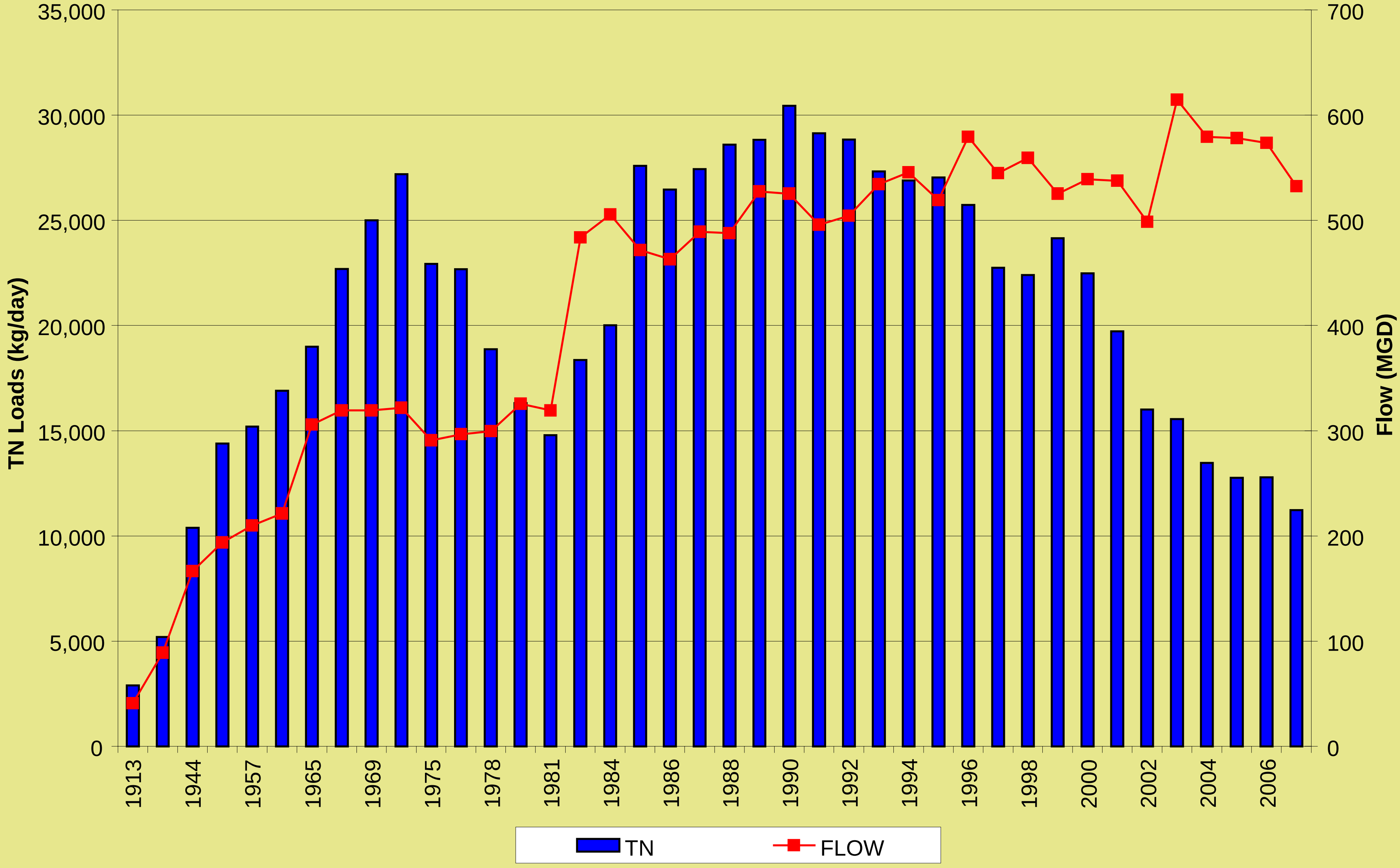


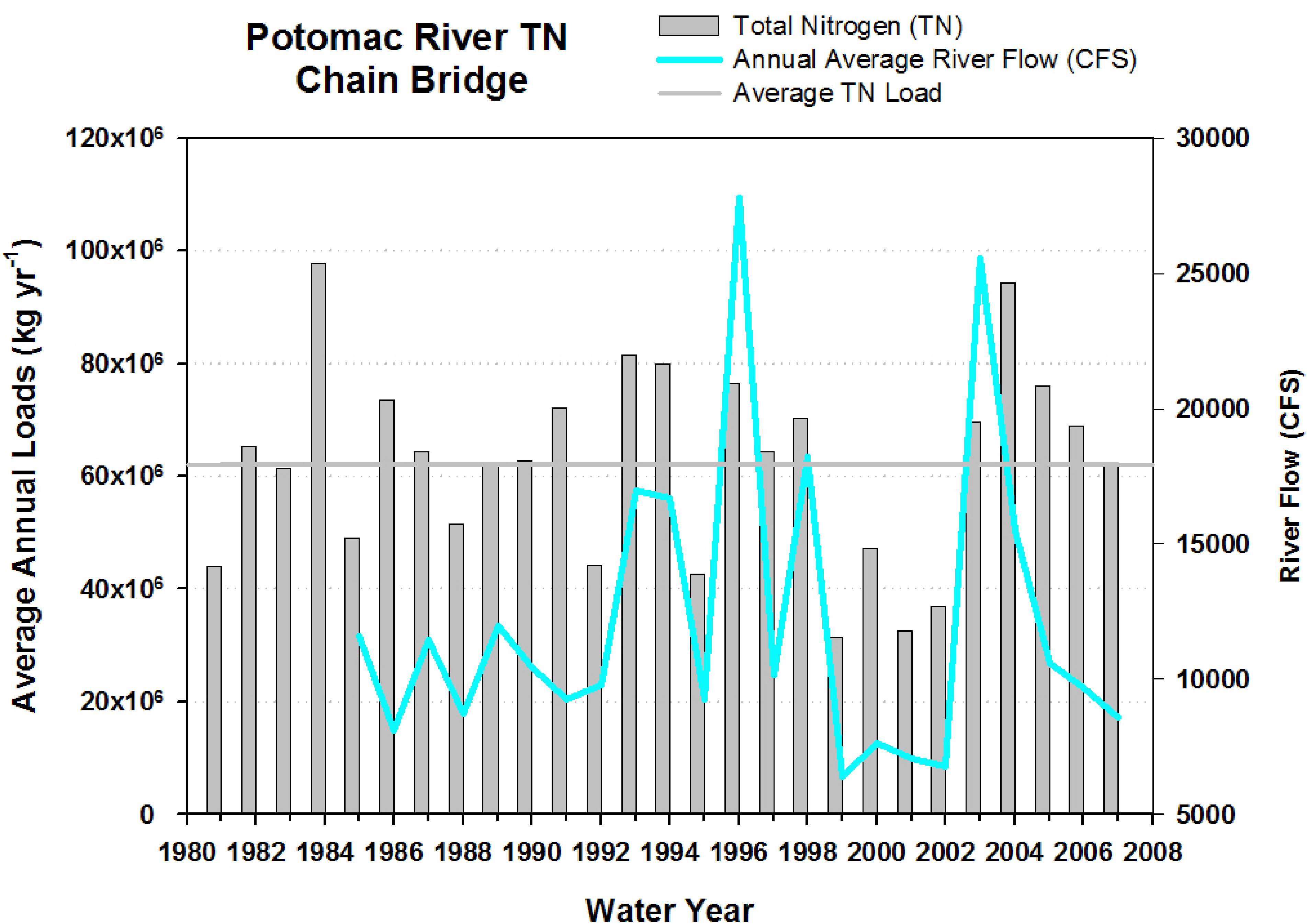
- 7-Fold Increase since John Smith's arrival to Bay Area
- 50% Increase during first 360 yrs & 50% increase in last 40 yrs

Annual Total Phosphorus Loads From Regional WWTPs



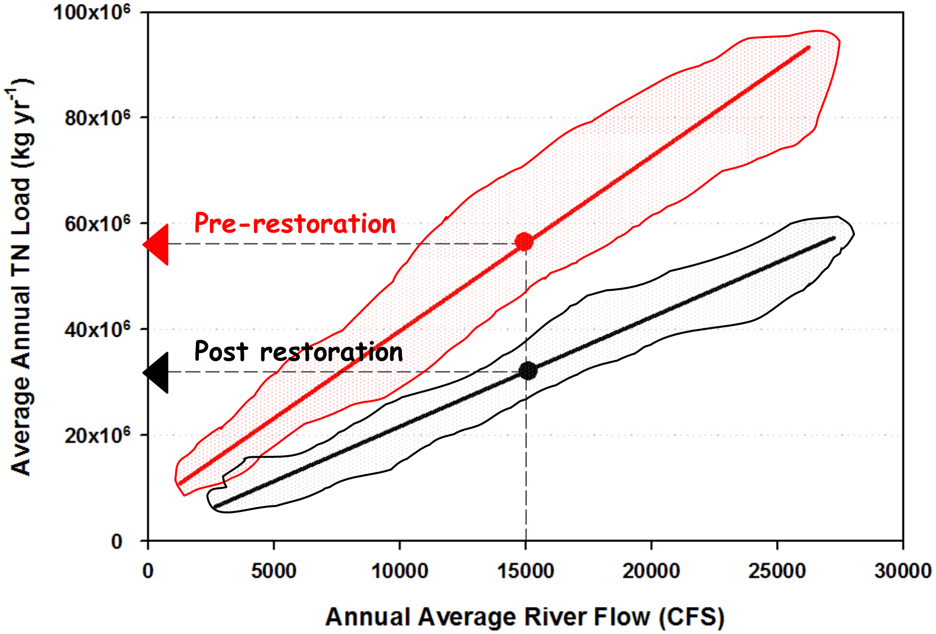
Annual Total Nitrogen Loads From Regional WWTPs



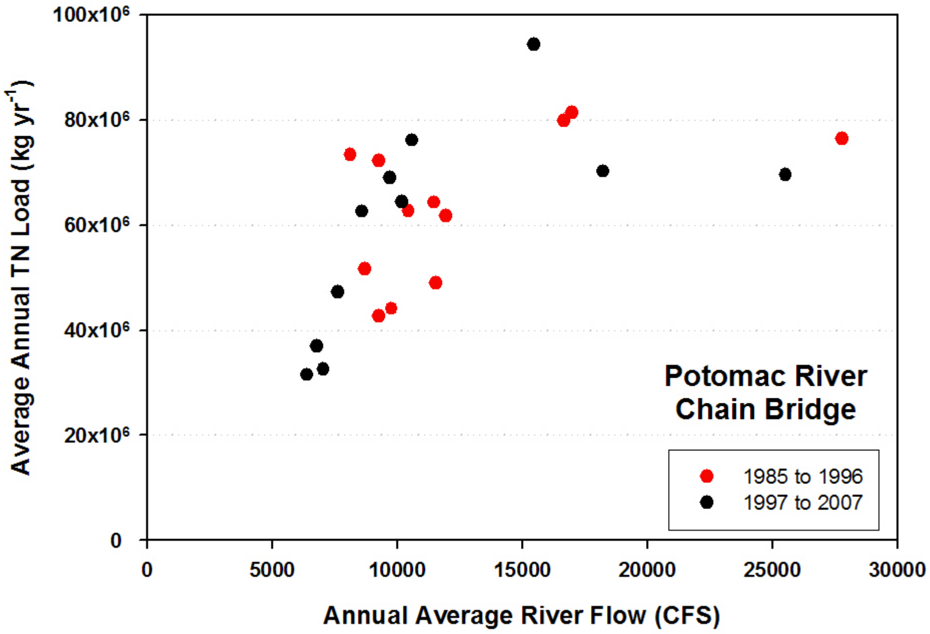

Potomac River TN
Chain Bridge
Total Nitrogen (TN)
Annual Average River Flow (CFS)
Average TN Load
Average Annual Loads (kg yr-1)
120x10^6
100x10^6
80x10^6
60x10^6
40x10^6
20x10^6
0
River Flow (CFS)
30000
25000
20000
15000
10000
5000
1980 1982 1984 1986 1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008
Water Year

Potomac River Load-Flow Patterns

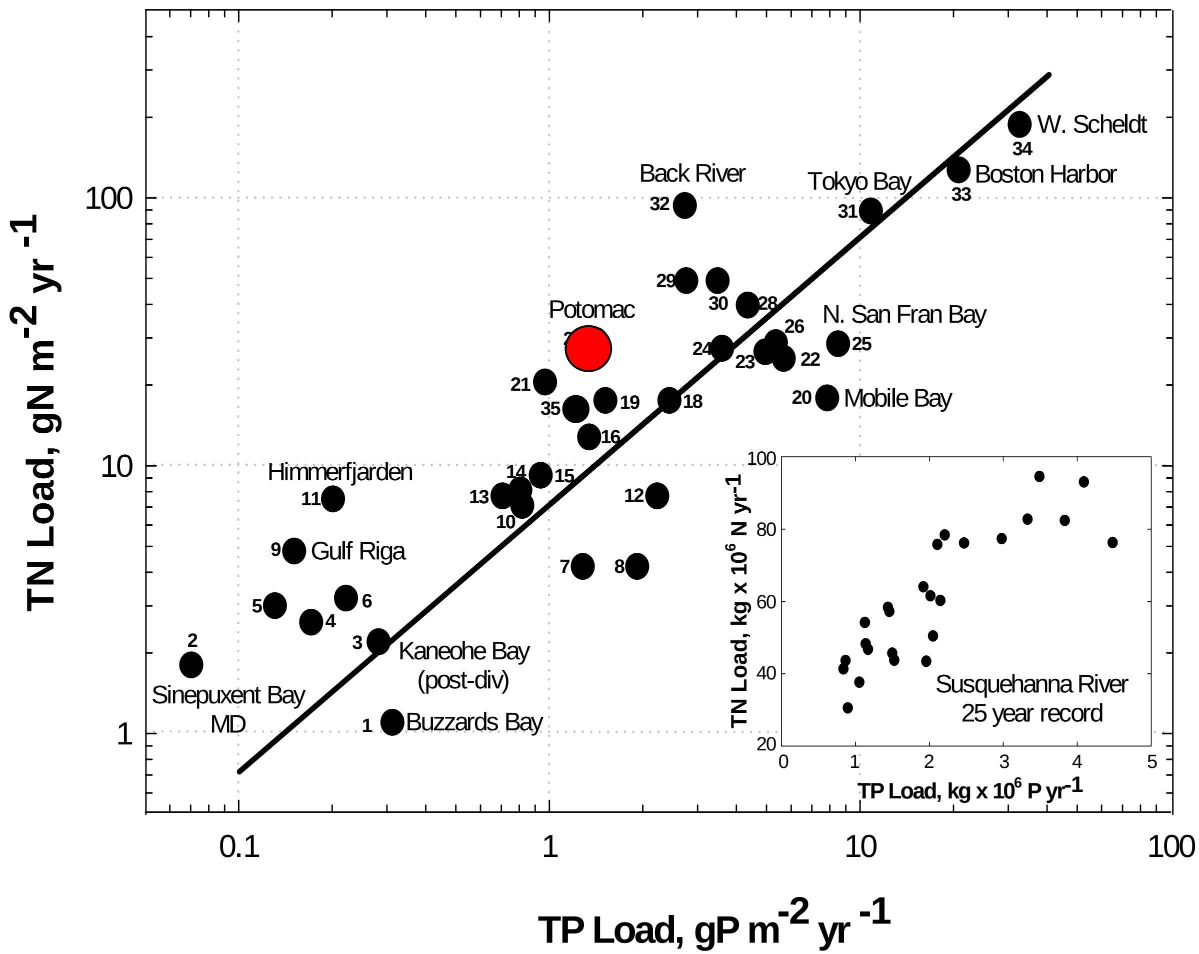
Expected Conditions



Actual Conditions

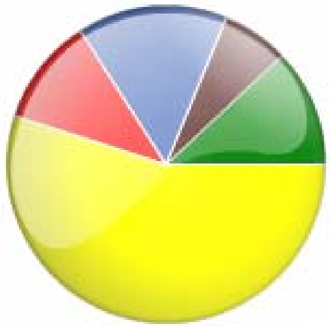


N and P Loading Rates for Estuarine Systems

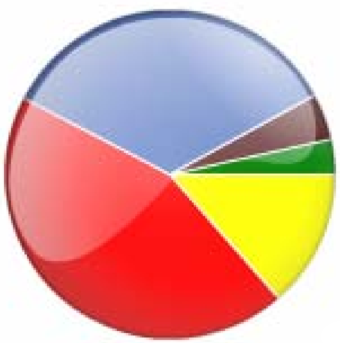


- Potomac has high loads…but not super high
- Loads tend to be "N-Rich" relative to P
- Loads alone do NOT determine degree of eutrophication

Potomac River Maryland Nitrogen Sources



Upper

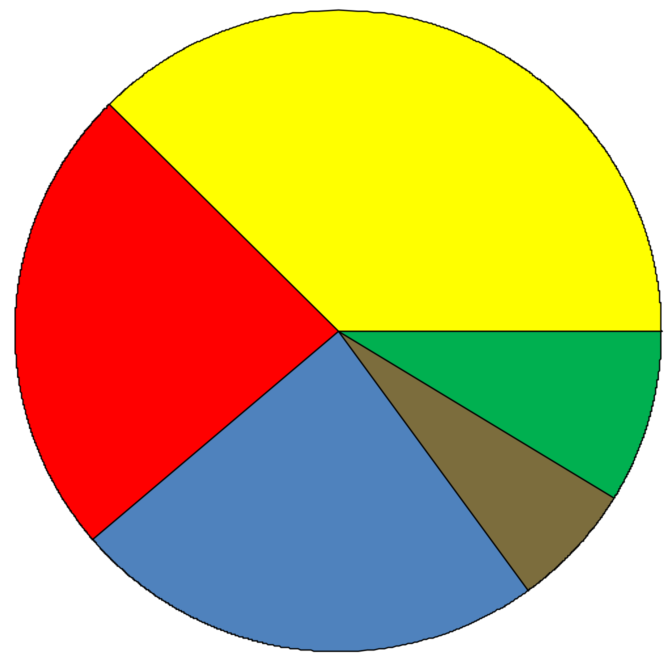


Middle

Lower

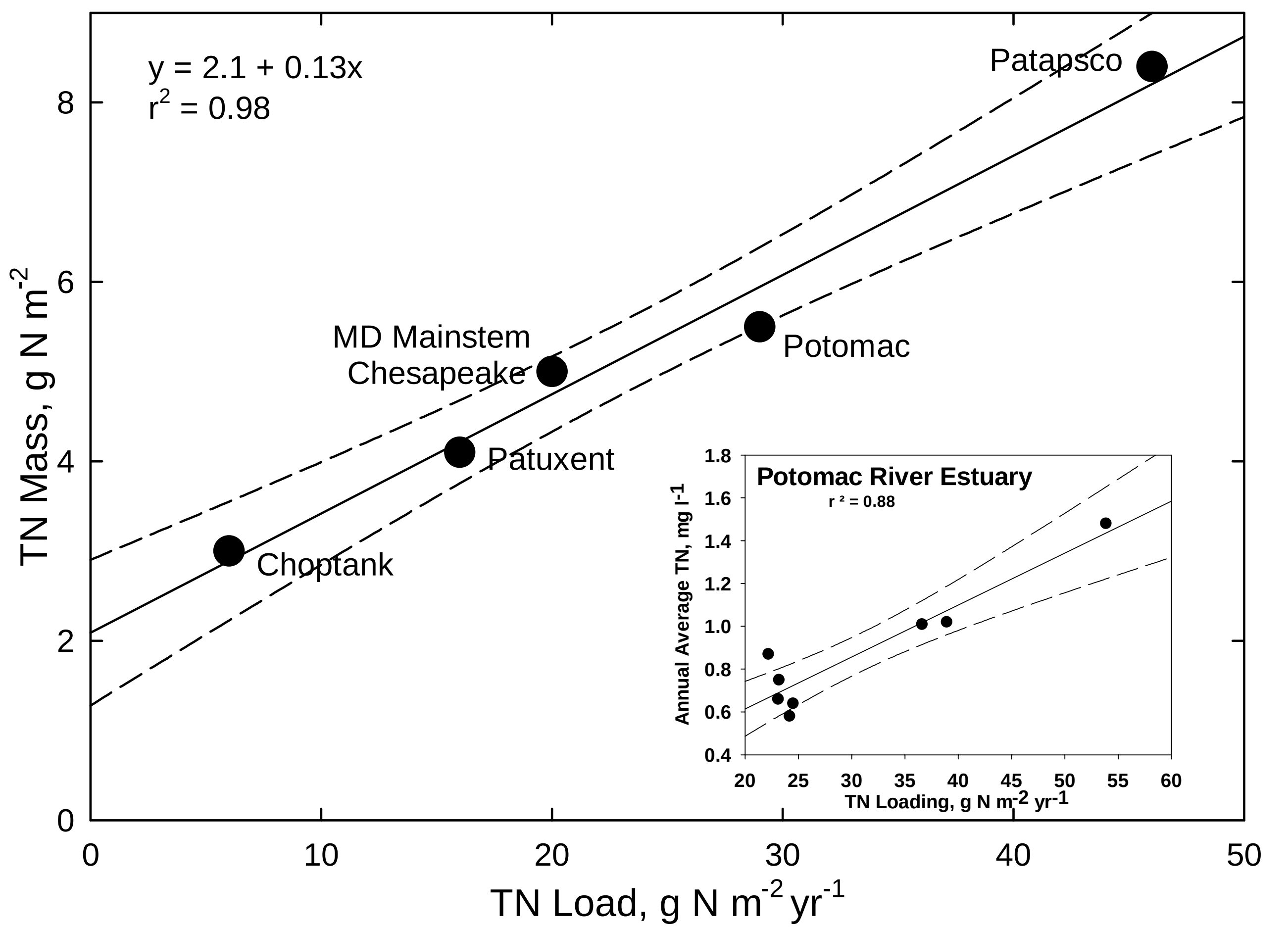
(x 10^6 kg $year^{-1}$)

	Farms	WWTP	Stormwater Runoff	Septic Systems	Forests
Upper	2.1	0.4	0.6	0.3	0.5
Middle	0.4	1.2	0.9	0.1	0.1
Lower	0.5	0.3	0.4	0.1	0.2
Total	**3.0**	**1.9**	**1.9**	**0.5**	**0.7**

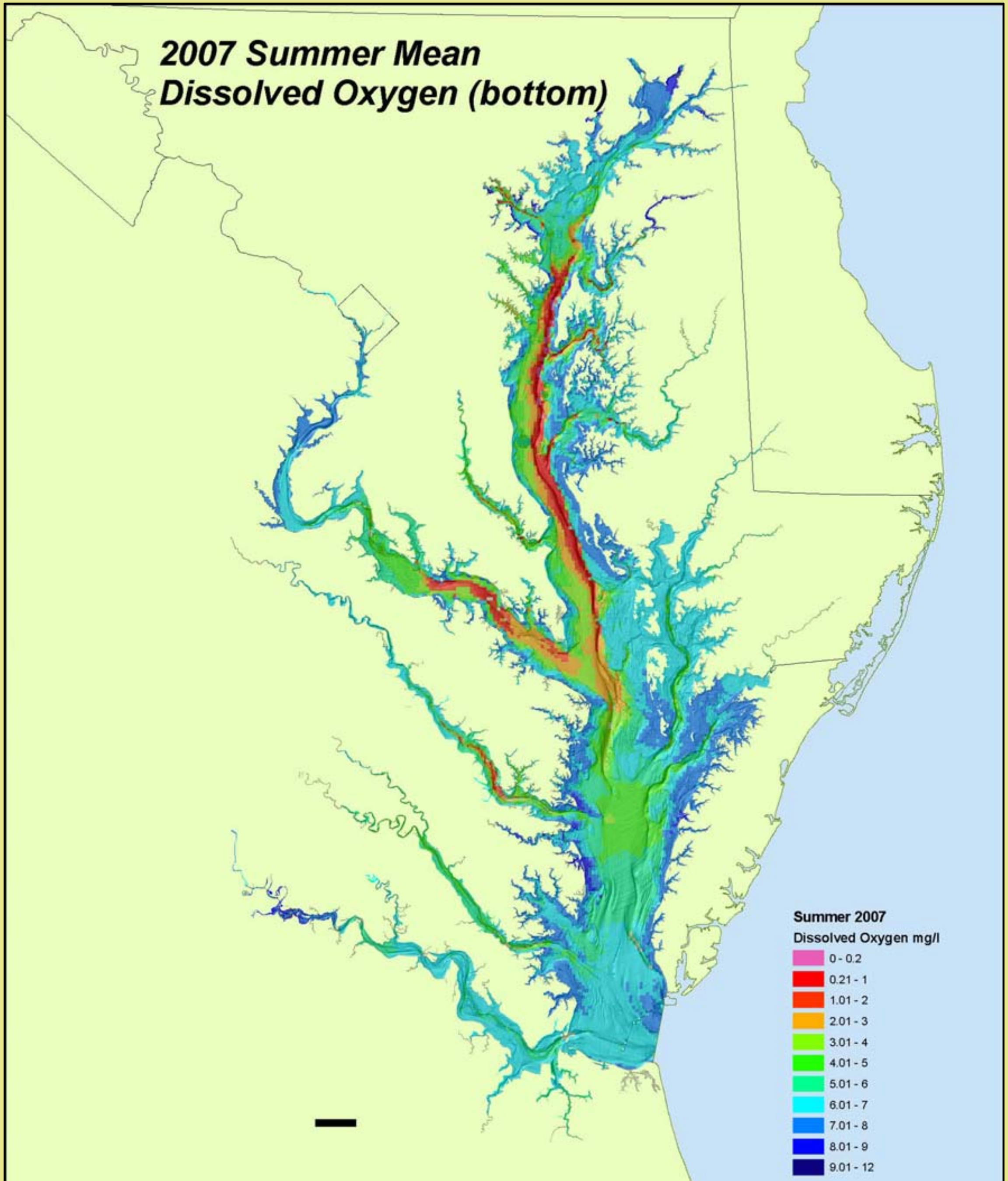


Total

N Load and Concentration Relationship

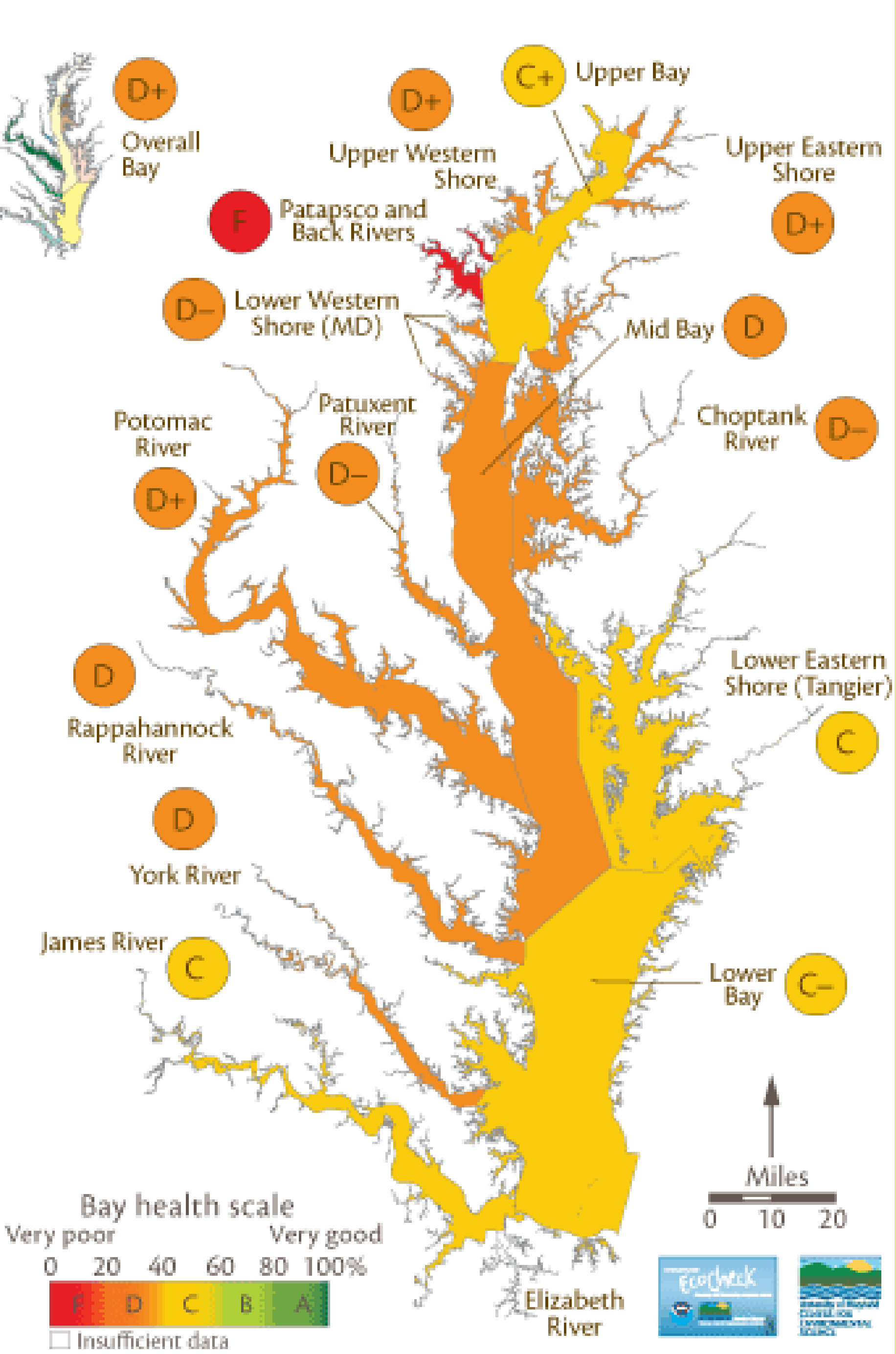


- We can see, reflected in concentrations, the effect of loads
- Linear across Chesapeake Bay systems
- Similar result in Potomac Time-Series data

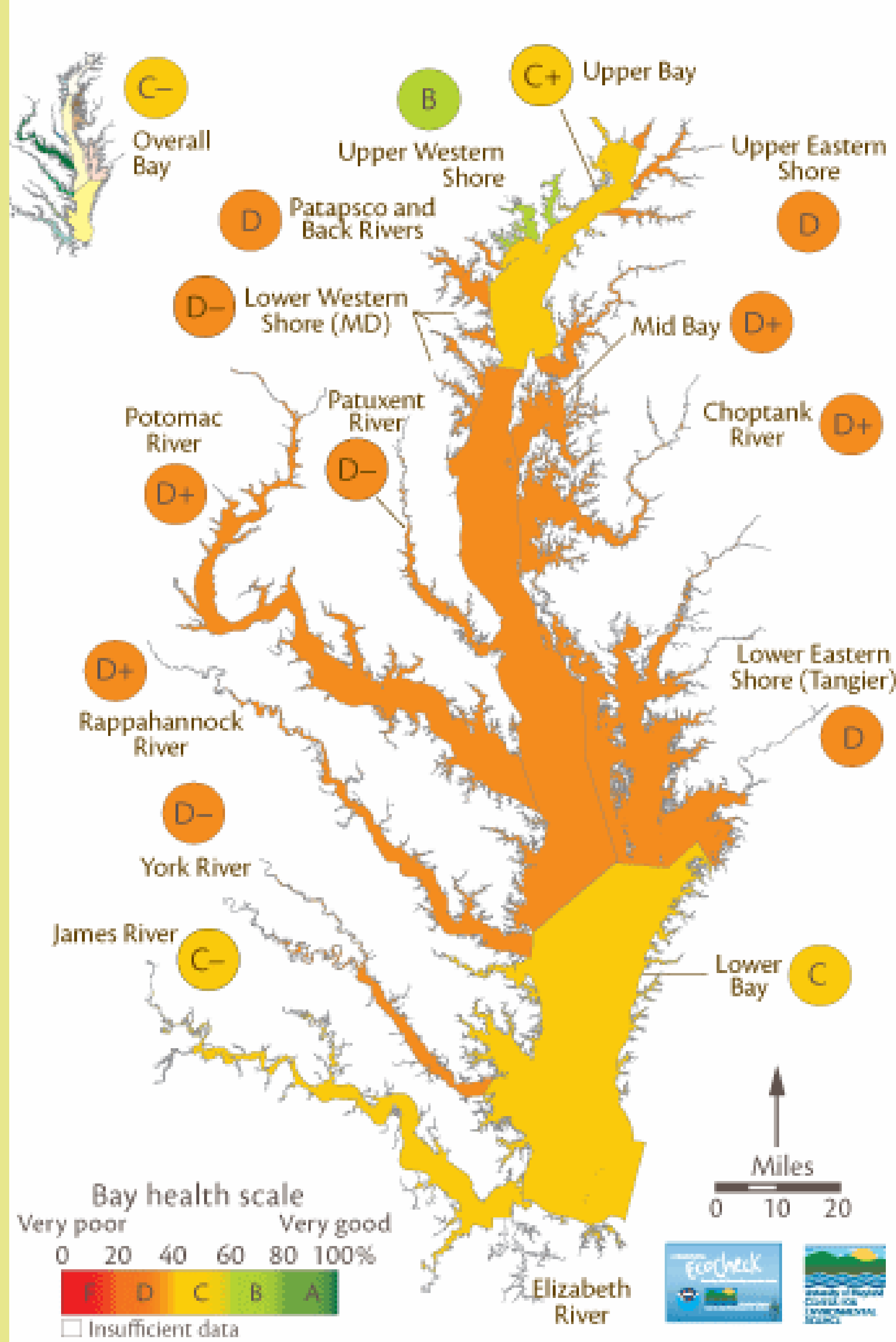


- Hypoxia in 2007 was not particularly severe…but not good
- Potomac one of the large hypoxic zones of the Bay system
- Note the disconnect between the Bay and Potomac low DO waters…suggesting that the Potomac generates its own hypoxia

Bay Health Index 2006



Bay Health Index 2007



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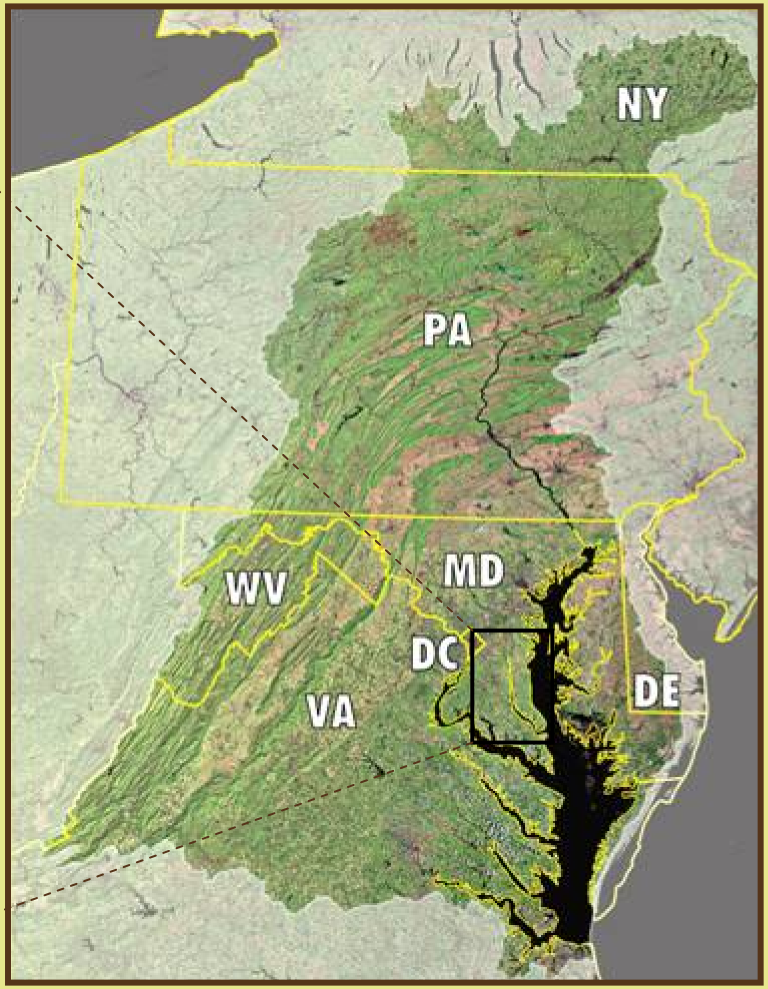
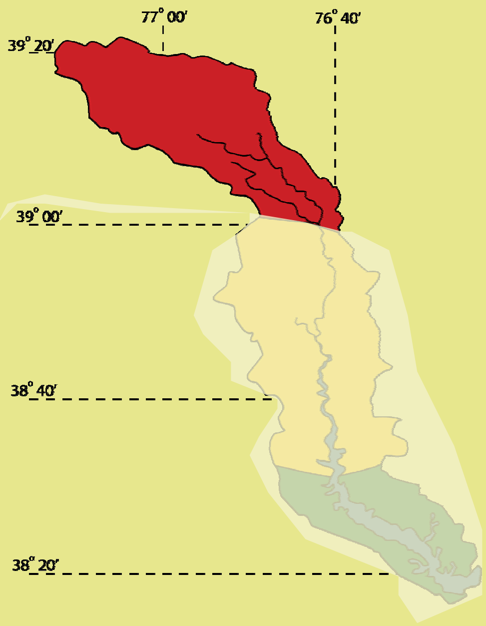
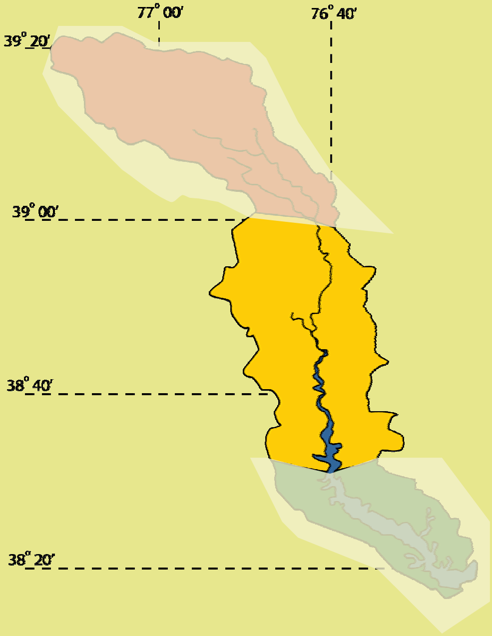
Patuxent River in the context of Chesapeake Basin and Bay



The upper Patuxent River has multiple tributaries, is narrow, has “flashy flow”, is a water supply source and is rapidly developing.

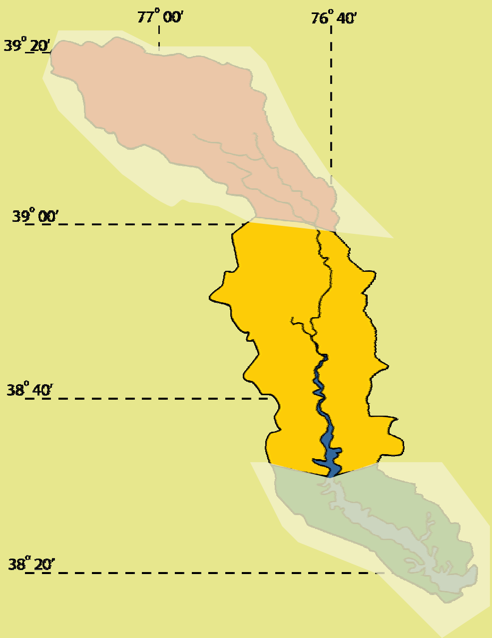


The mid-Patuxent is tidal and has more marsh than open water…a key element in the nutrient economy of this estuary



Jug Bay - University of Maryland

The tidal marshes of the mid-Patuxent are productive and keeping pace with sea level rise



Nutrient Budget Conceptual Model

- Basic components include inputs, internal losses and exports
- Internal storages and selected recycle processes also included
- Data averaged for multiple years
- Large number of data sources including:

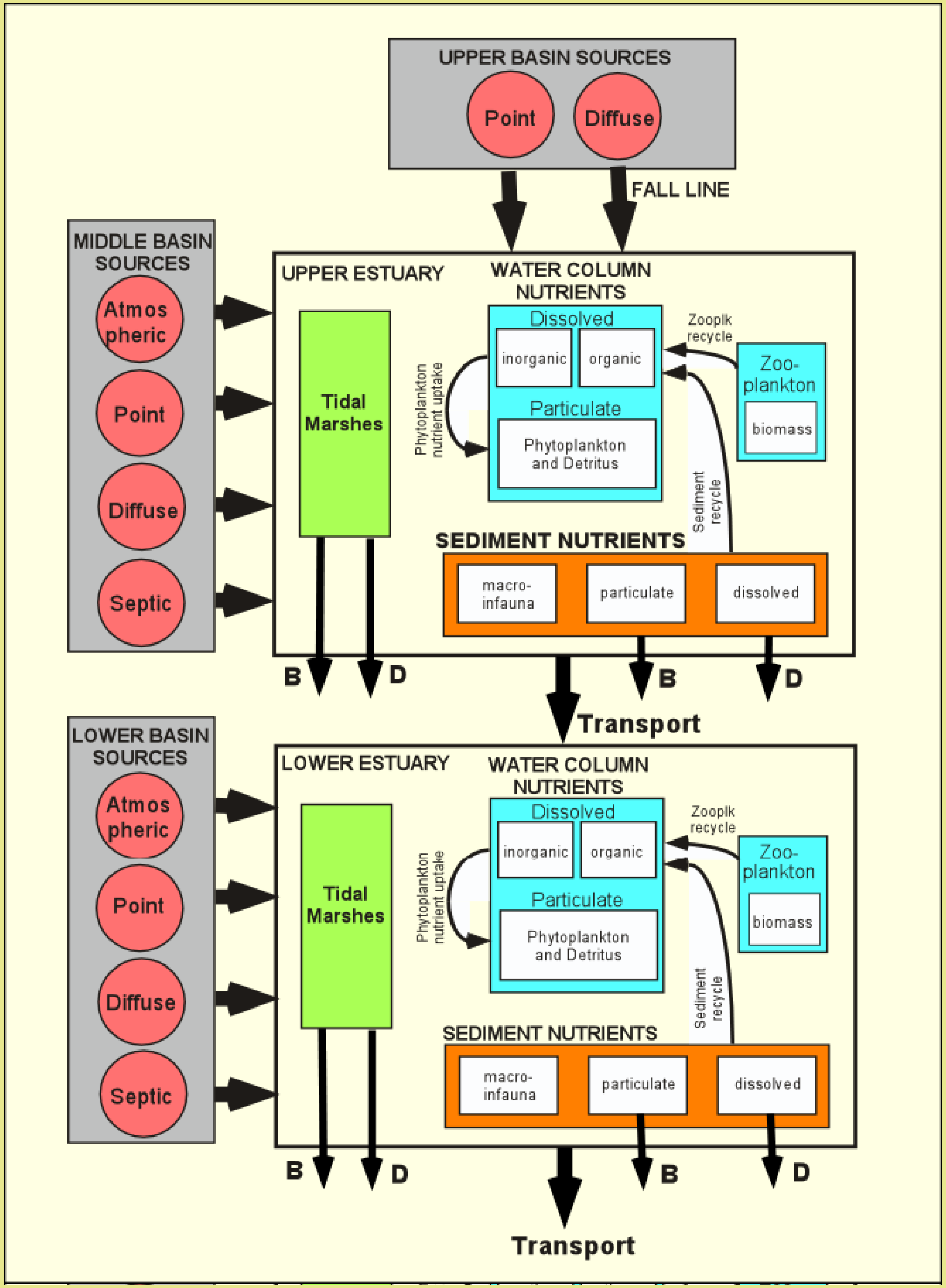
    USGS river monitoring

    Landscape model output

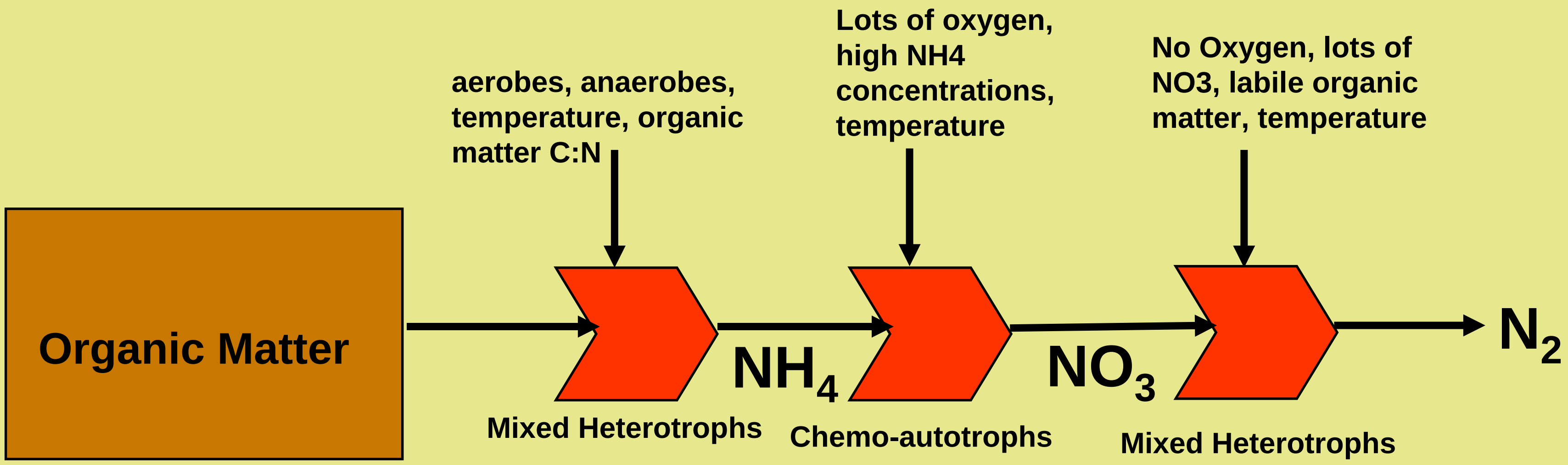
    Estuary monitoring data

    Atmospheric deposition monitoring

    Field Studies…lots of them



Denitrification Sequence



Detailed reaction sequence

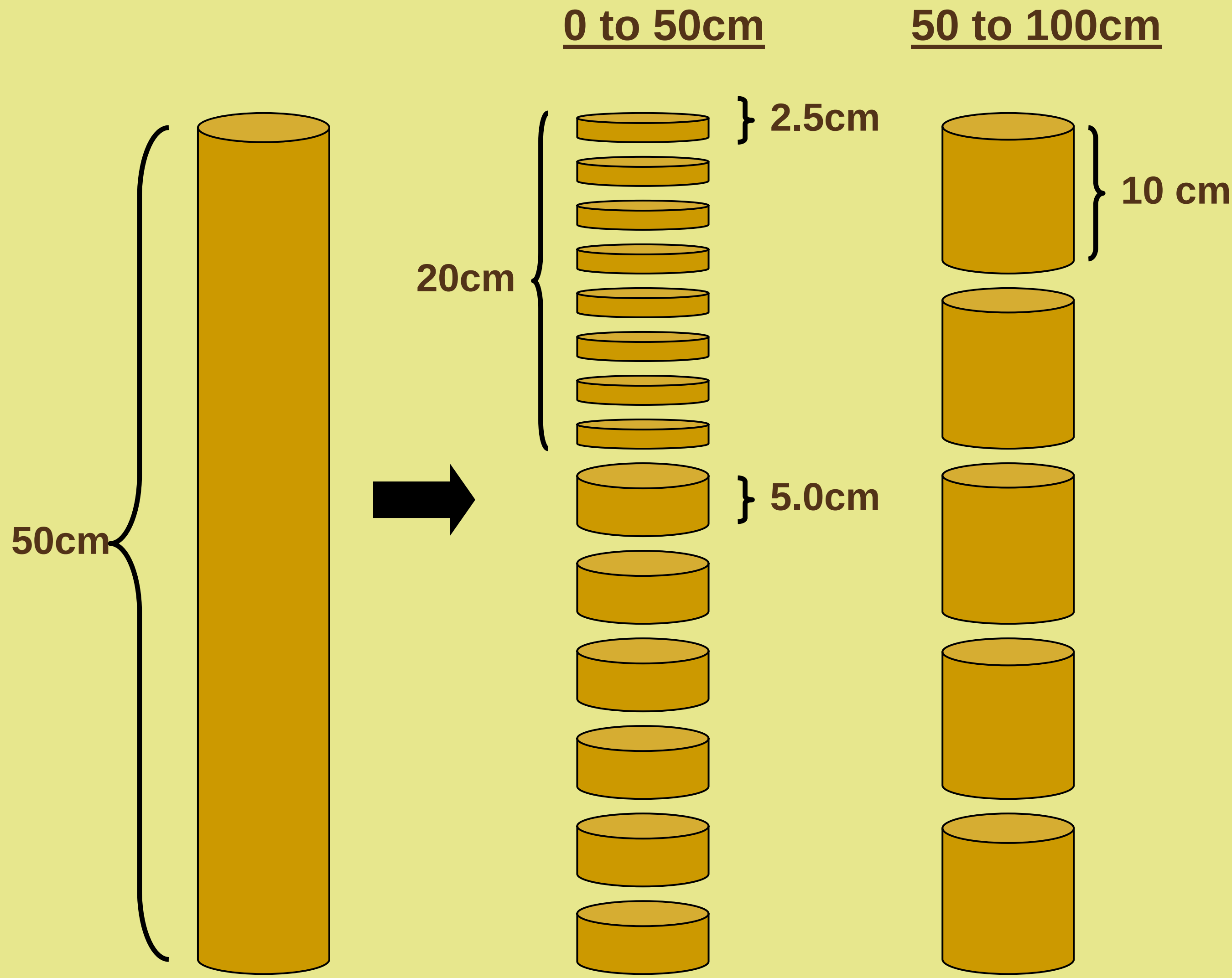
$NO_3 \rightarrow NO_2 \rightarrow NO \rightarrow N_2O \rightarrow N_2 \rightarrow$

Data Collection for Denitrification

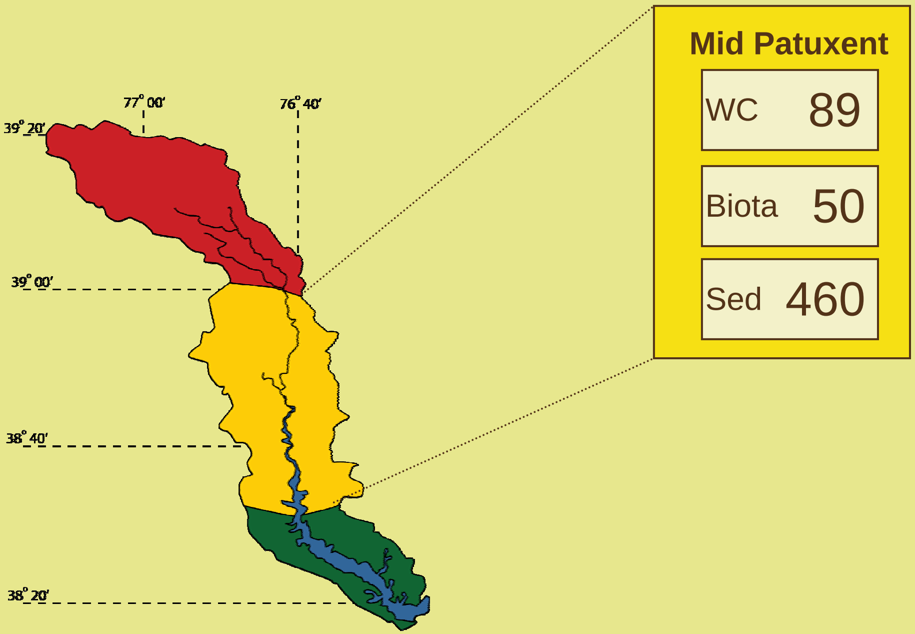
Cores taken by hand from high, mid and low marsh.

Marsh creek cores taken with a pole corer.

Sediment Cores were used for making Nutrient Burial Estimates



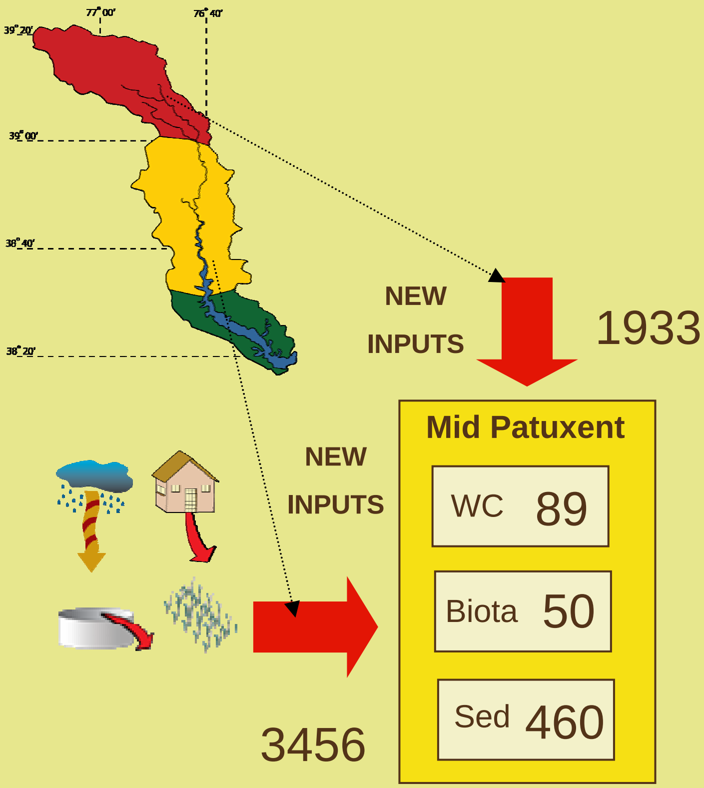
Total nitrogen inputs, transport, and losses in the Mid-Patuxent estuary



Mid Patuxent	
Inputs	?
Denitrification	?
Burial	?
Export	?
Net	?

Flows kg N day^{-1}
Stocks kg x10^3 N

Total nitrogen inputs, transport, and losses in the Patuxent estuary

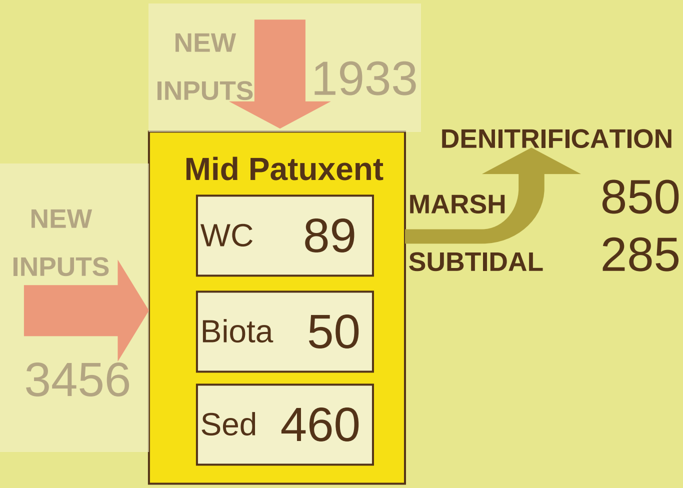


Mid Patuxent	
Inputs	5389
Denitrification	?
Burial	?
Export	?
Net	?

Flows kg N day^{-1}

Stocks kg x10^3 N

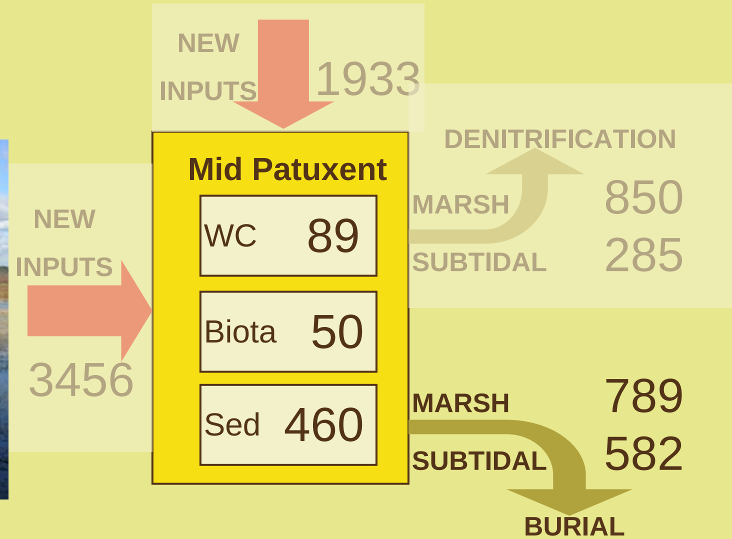
Total nitrogen inputs, transport, and losses in the Patuxent estuary



Mid Patuxent	
Inputs	+5389
Denitrification	-1135
Burial	?
Export	?
Net	?

Flows kg N day^{-1}
Stocks kg $x10^{3}$ N

Total nitrogen inputs, transport, and losses in the Patuxent estuary

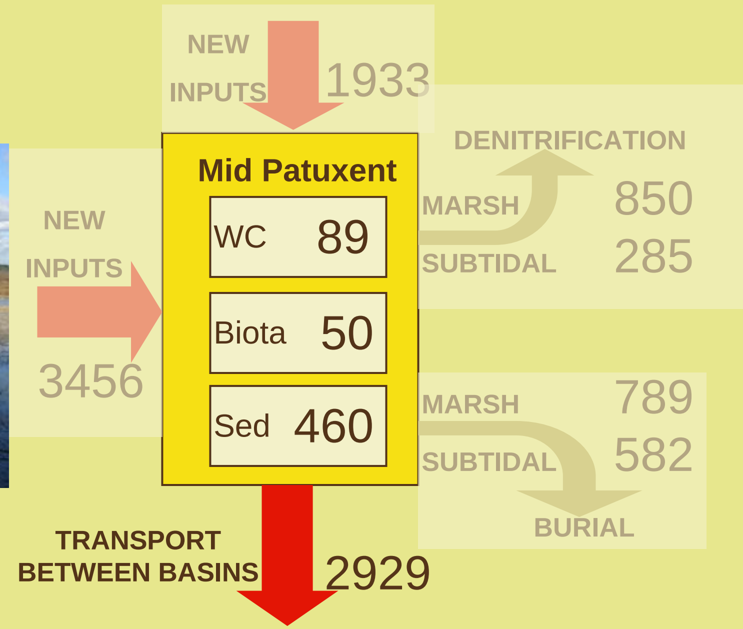


Mid Patuxent	
Inputs	+5389
Denitrification	-1135
Burial	-1371
Export	?
Net	?

Flows kg N day^{-1}

Stocks kg x10^{3} N

Total nitrogen inputs, transport, and losses in the Patuxent estuary

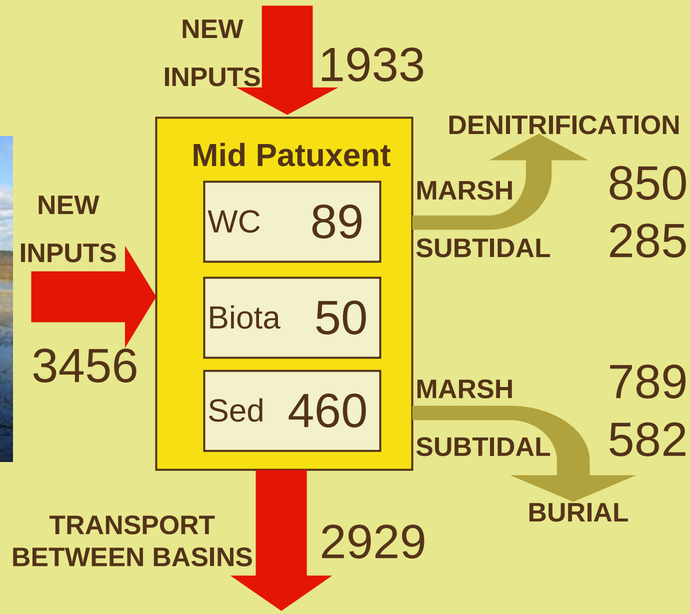


Mid Patuxent	
Inputs	+5389
Denitrification	-1135
Burial	-1371
Export	-2929
Net	?

Flows kg N day^{-1}

Stocks kg $\times 10^3$ N

Total nitrogen inputs, transport, stocks and losses in the Patuxent estuary

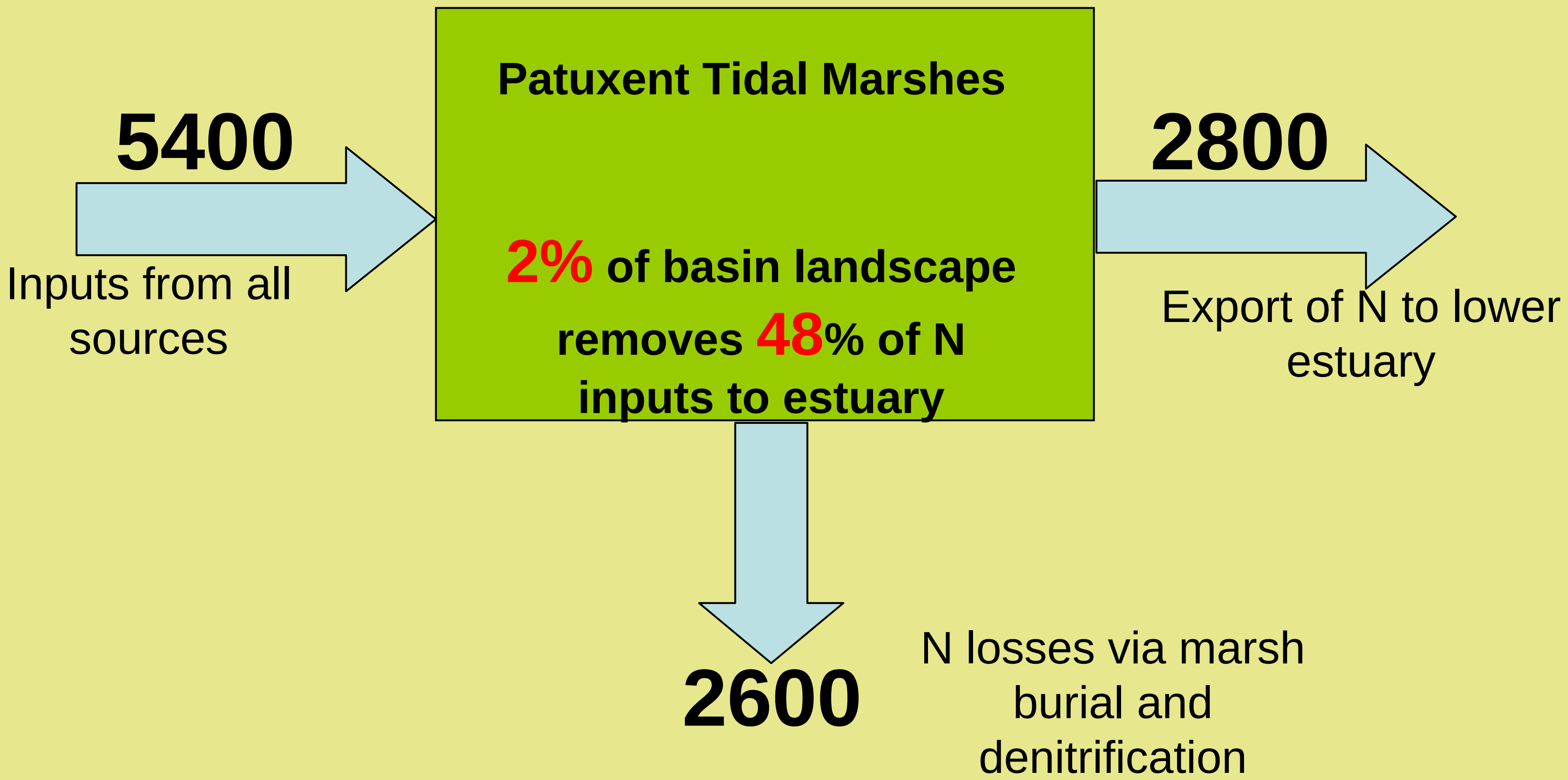


Mid Patuxent	
Inputs	+5389
Denitrification	-1135
Burial	-1371
Export	-2929
Net	46

Flows kg N day^{-1}

Stocks kg $\times 10^3$ N

Tidal Marshes: *Hotspot* in the Landscape



Units = Kg N/day

Treatment Plants vs. Tidal Marshes

- Wastewater Treatment Plant N Removal via Denitrification **= 0.8 million Kg/year**

- Tidal Marsh N Removal via N burial and denitrification = **0.9 million Kg/year**

- **Both important…need to promote denitrification in the landscape!**

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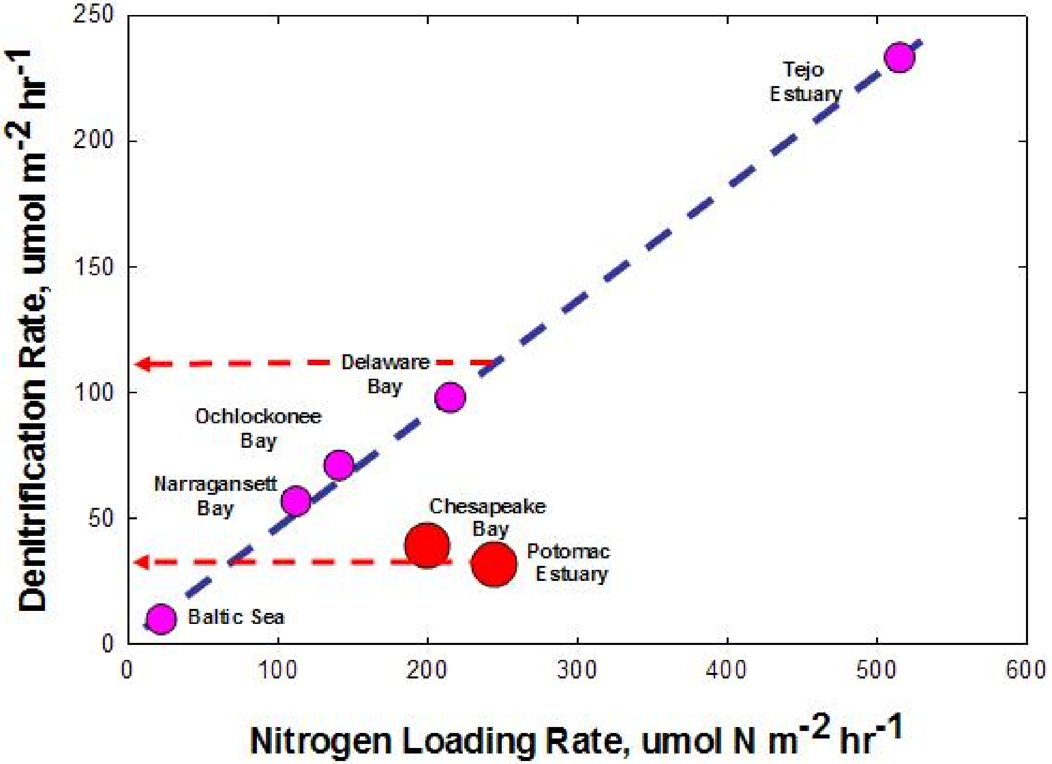
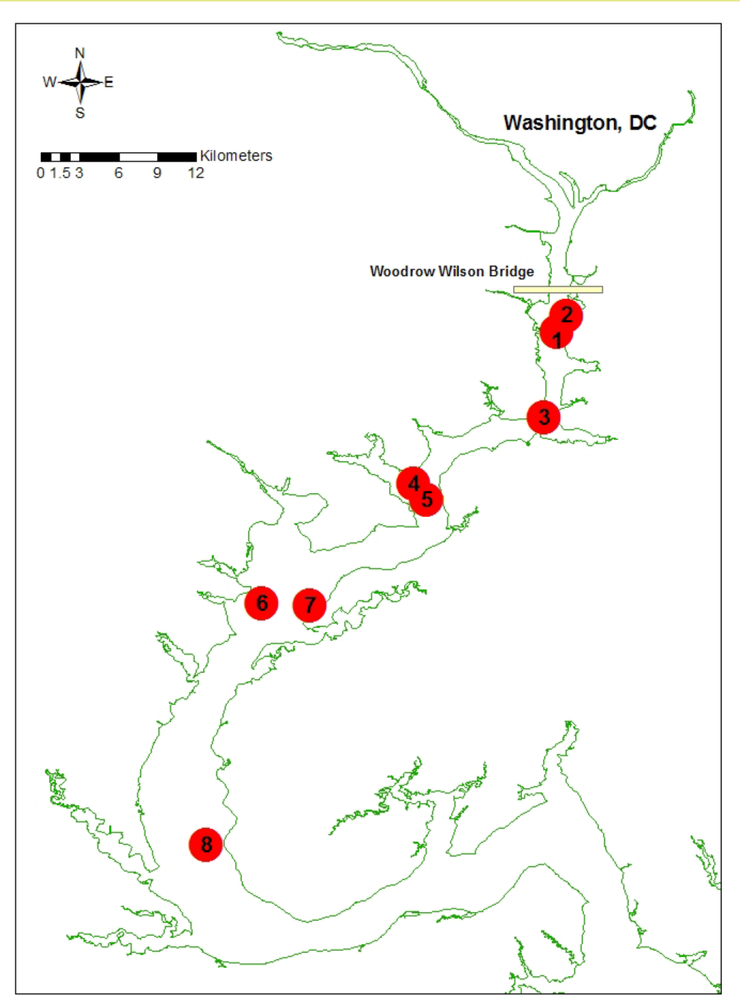
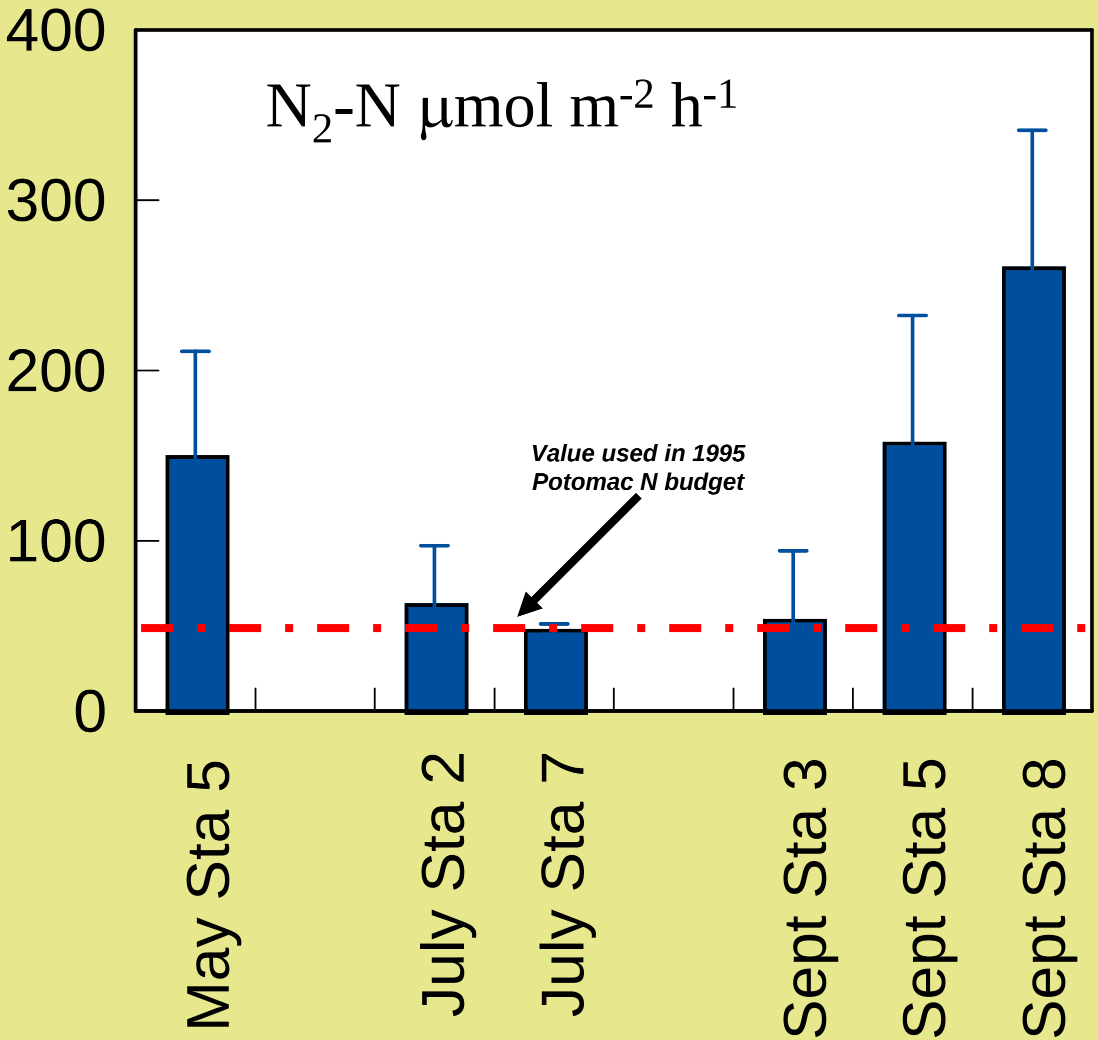
Nitrogen Losses via Denitrification… The big N- purging process

- Denitrification removes biologically active N from the system (to atmosphere)
- In NON_HYPOXIC systems about 50% of N entering estuary leaves as N2 gas
- Chesapeake systems have much lower N-removal rate likely because of so much hypoxia
- So, increase bottom water DO concentrations!!!!!



Potomac River Denitrification Rates

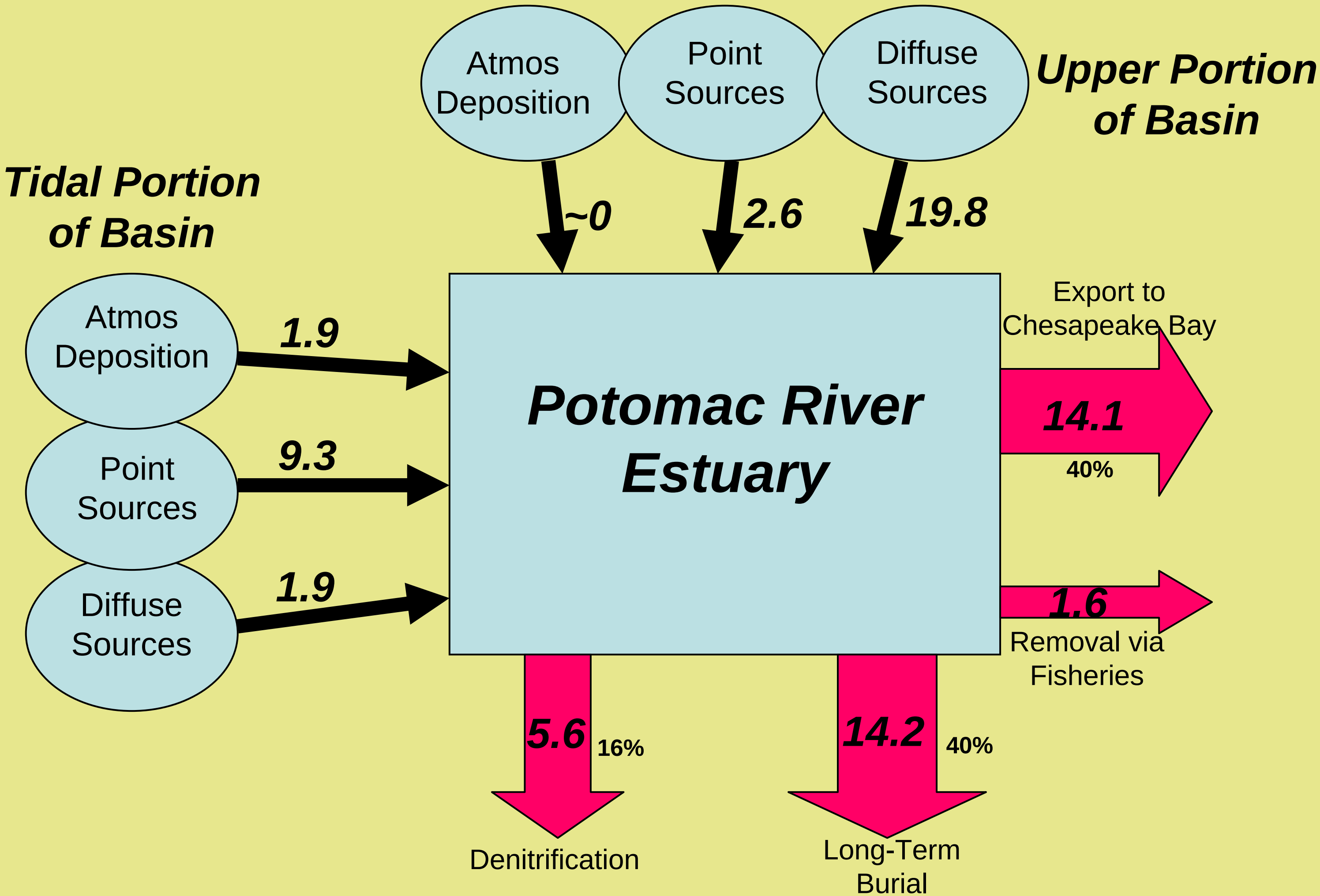




Measurements used N_2:Ar technique
Dr. J. Cornwall HPL-CES

Potomac River Estuary Nitrogen Budget

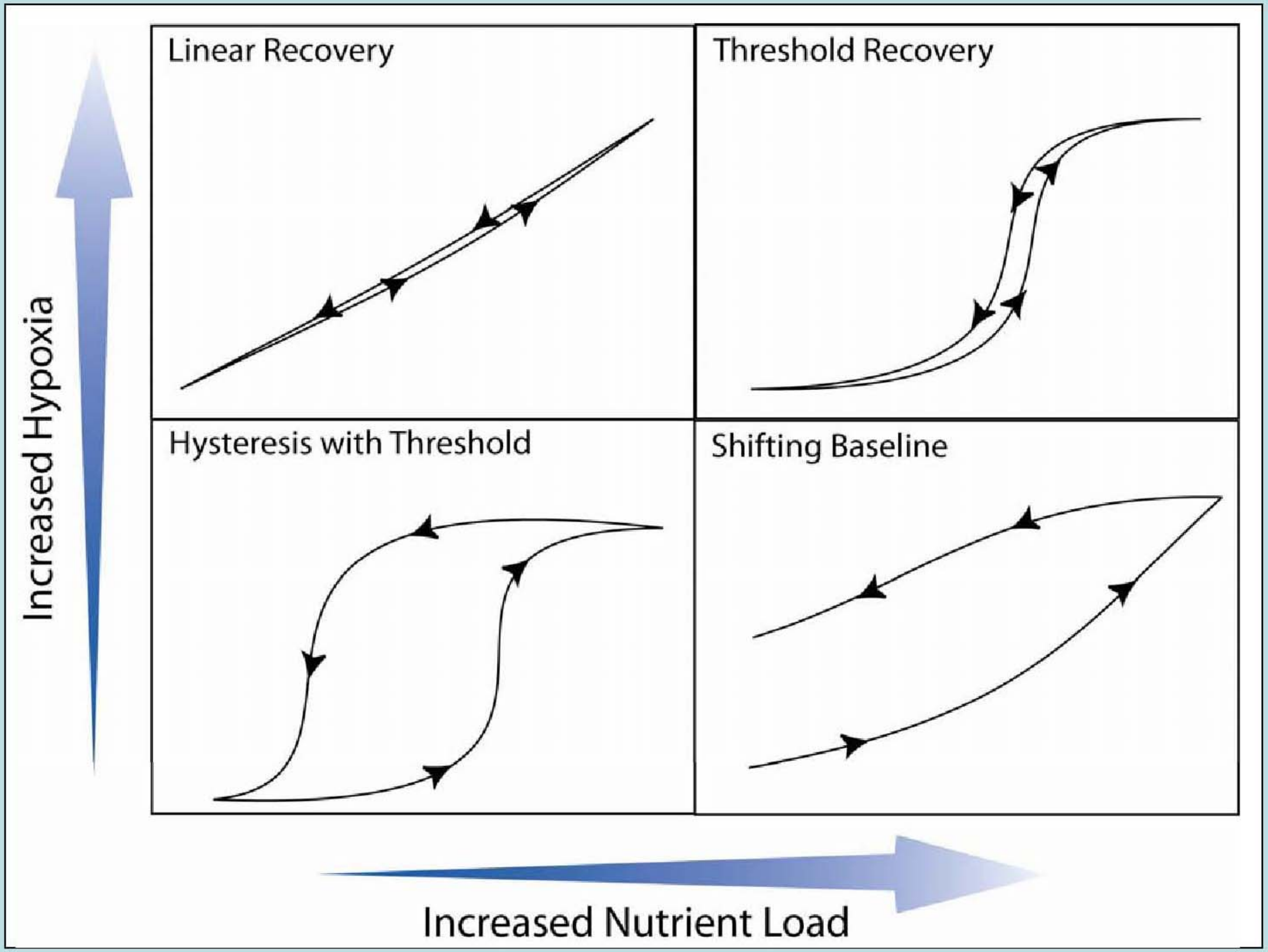
(1985-1986)



(Boynton et al. 1995)

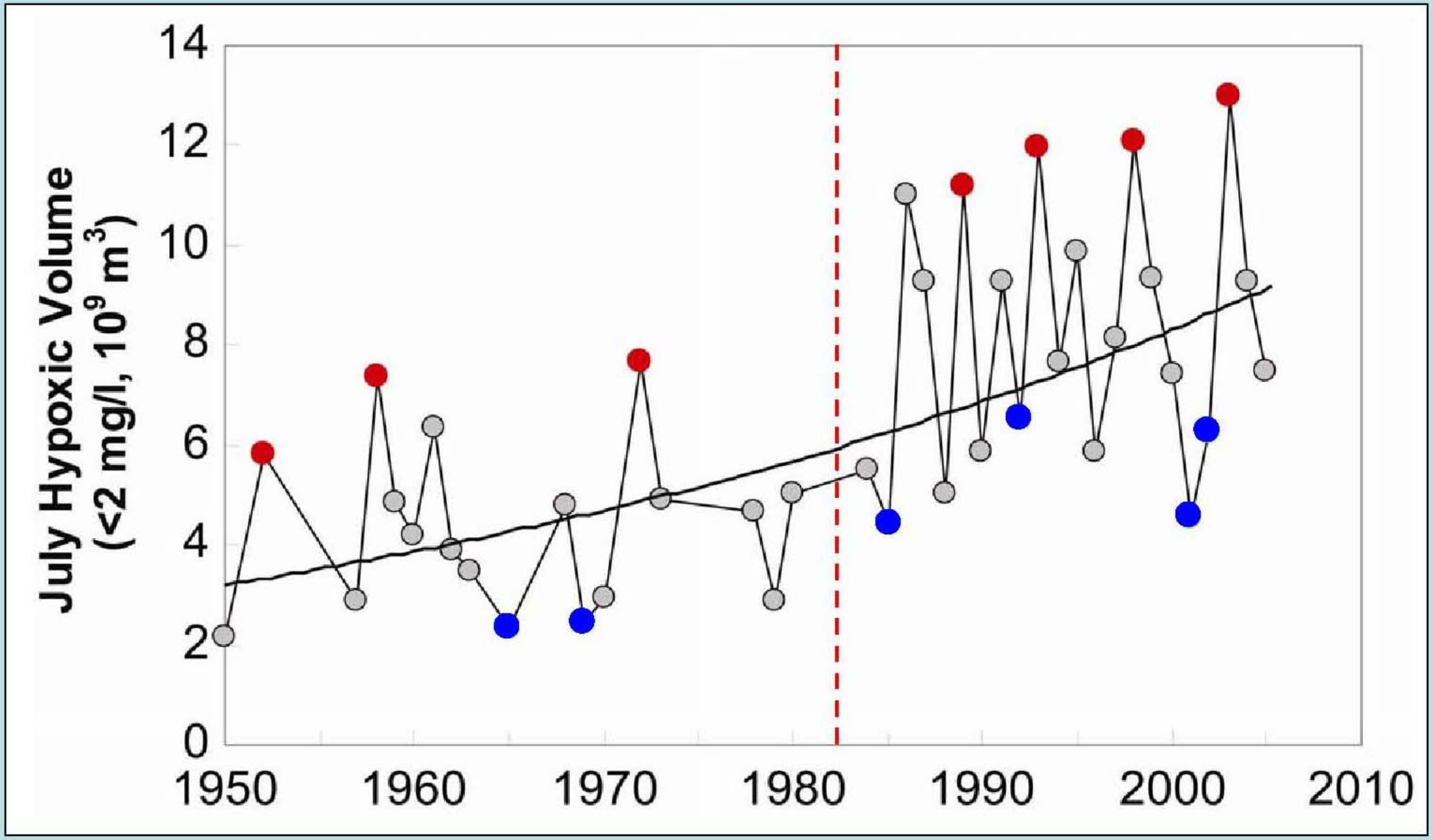
Total Load = 30-35 g m^{-2} yr^{-1}

Response of Hypoxia to Nutrient Remediation?



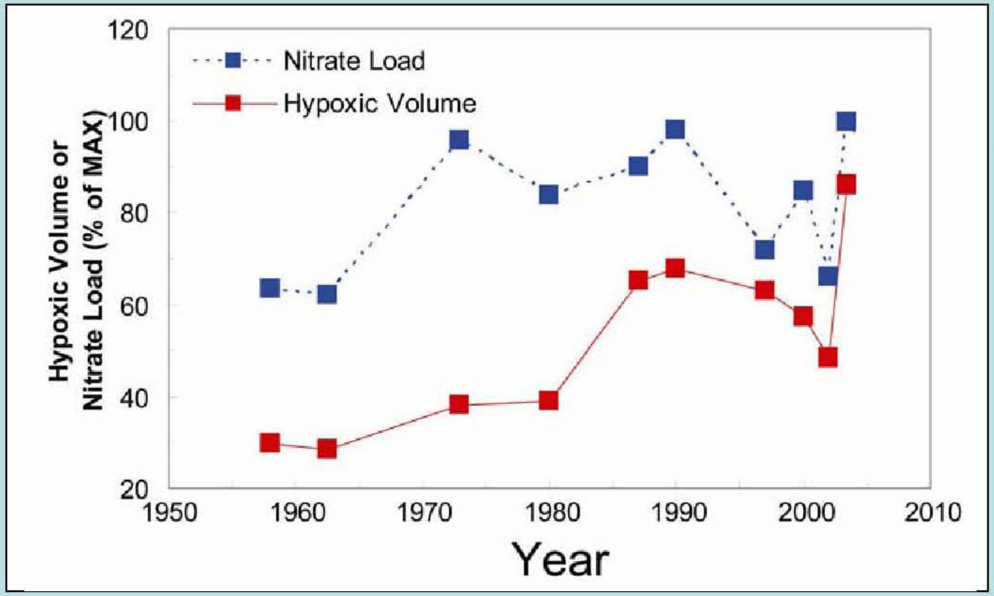
(modified after Duarte et al. 2008)

Trend in Bay Summer Hypoxia Volume (1950-2004)

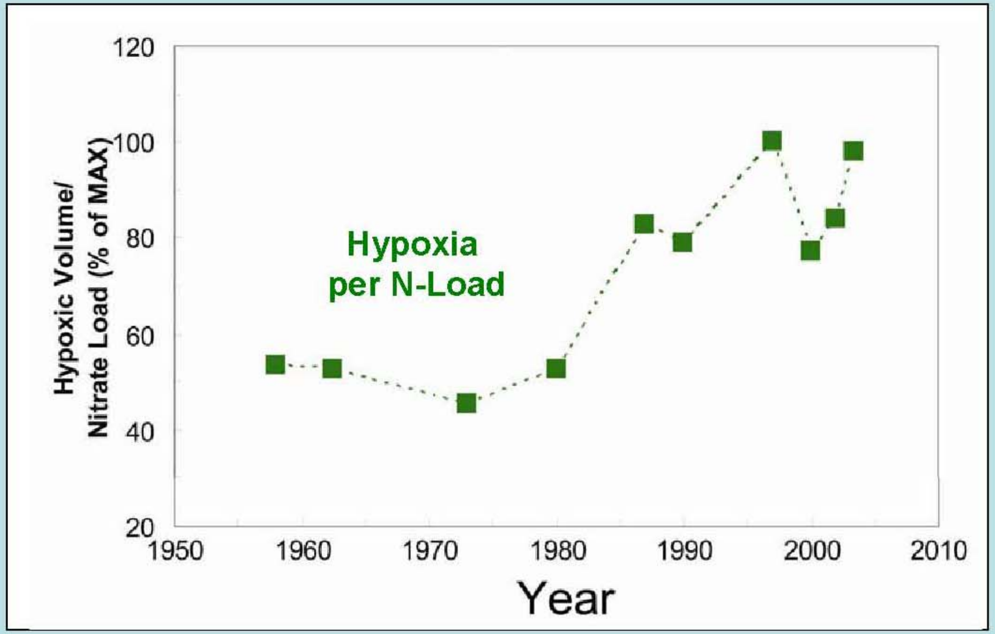


- Exponential increase, w/ strongest change since 1980
- Interannual variability driven by **high** and **low** river flow

Focusing on Years of Intermediate River Flow

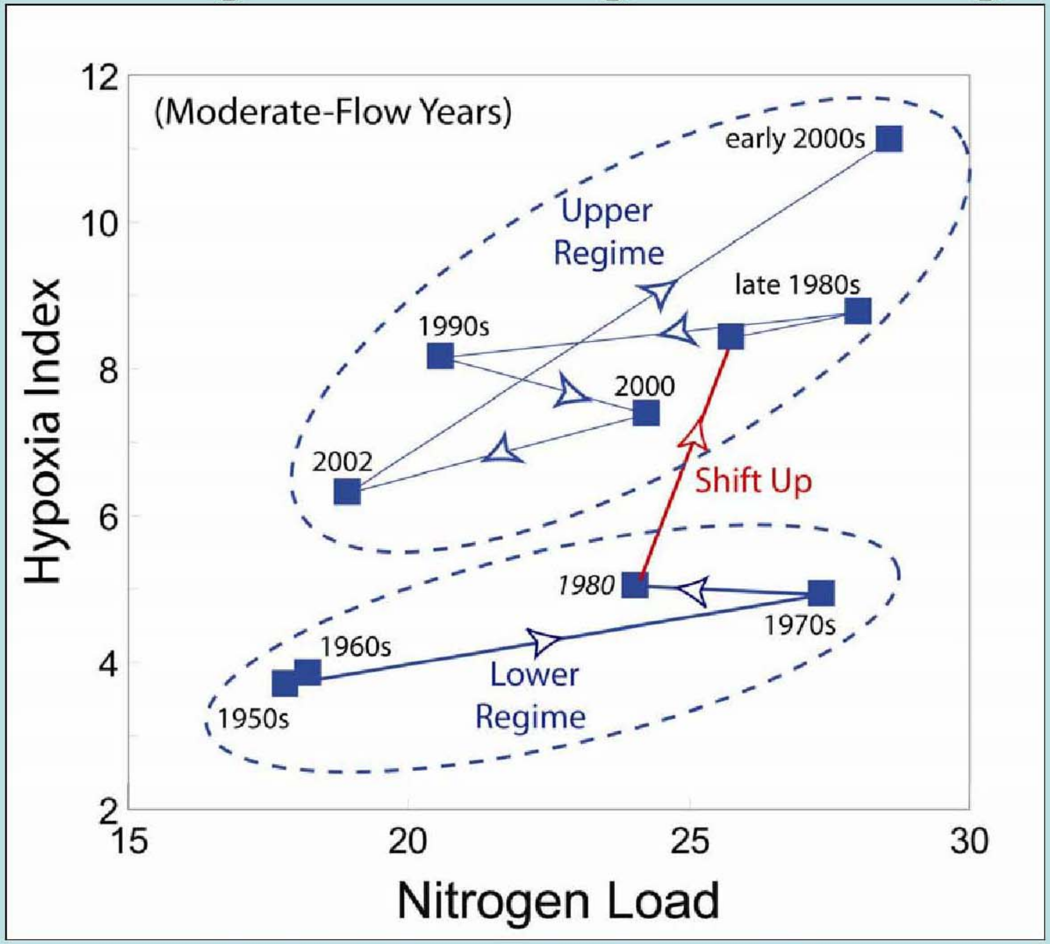


- To reduce inter-annual variance, we analyzed only years with intermediate flow (mean ± SE).
- From 1960–2006, both NO_3-Load and Hypoxia increase steadily
- Hypoxia increases more rapidly than NO_3-Loading



- Hypoxia volume per NO_3-Load relatively constant until 1980.
- Shifts-up in mid-1980's and remains high through early 2000s

Bay Hypoxia Response Trajectories for Changes in Nitrogen Loading

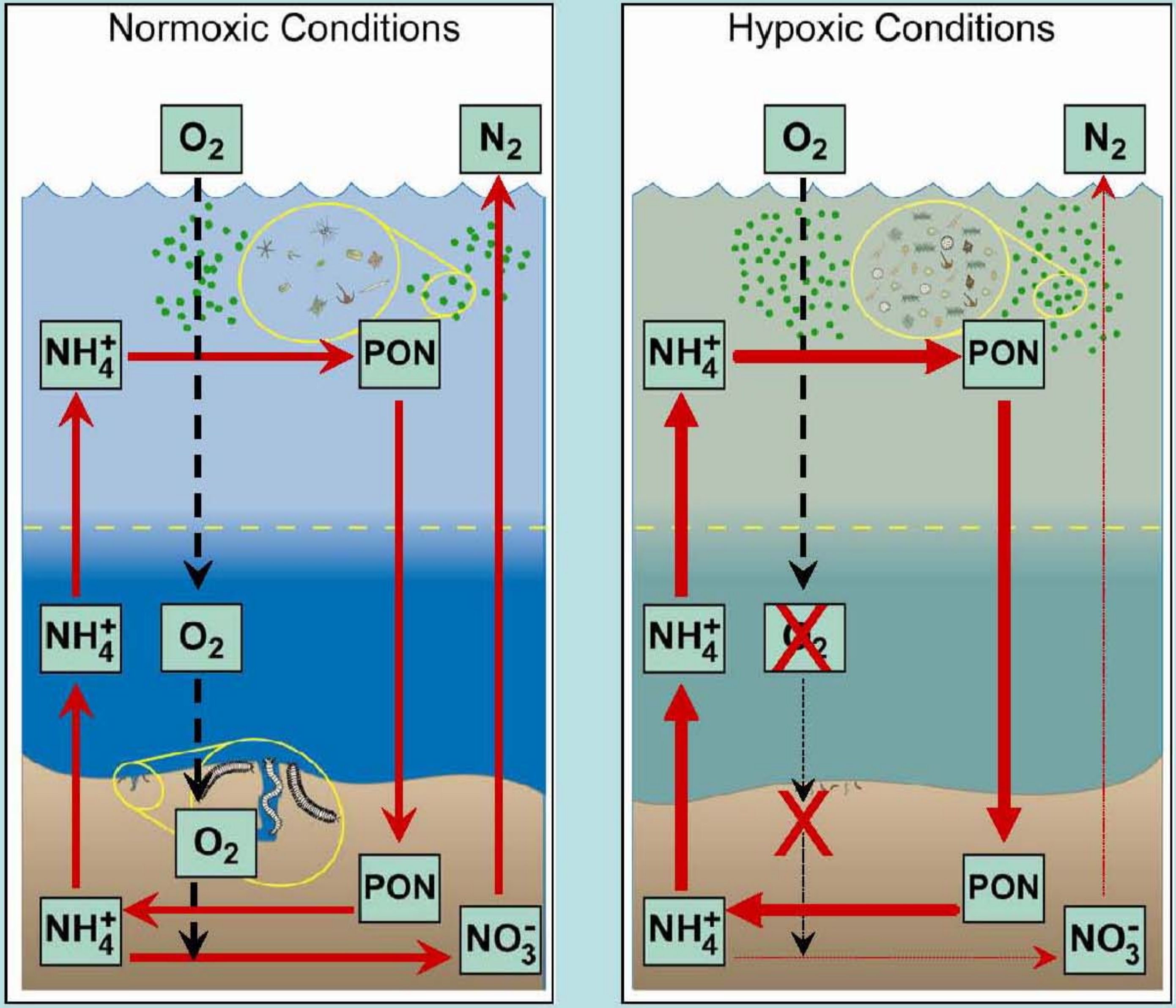


- **Visualize response trajectories and regime shifts**
- **Shift-up to new *Upper Regime* in 1980 with more Hypoxia per N-Load**
- **Recent apparent down-shift to *Lower Regime* (initial recovery?)**

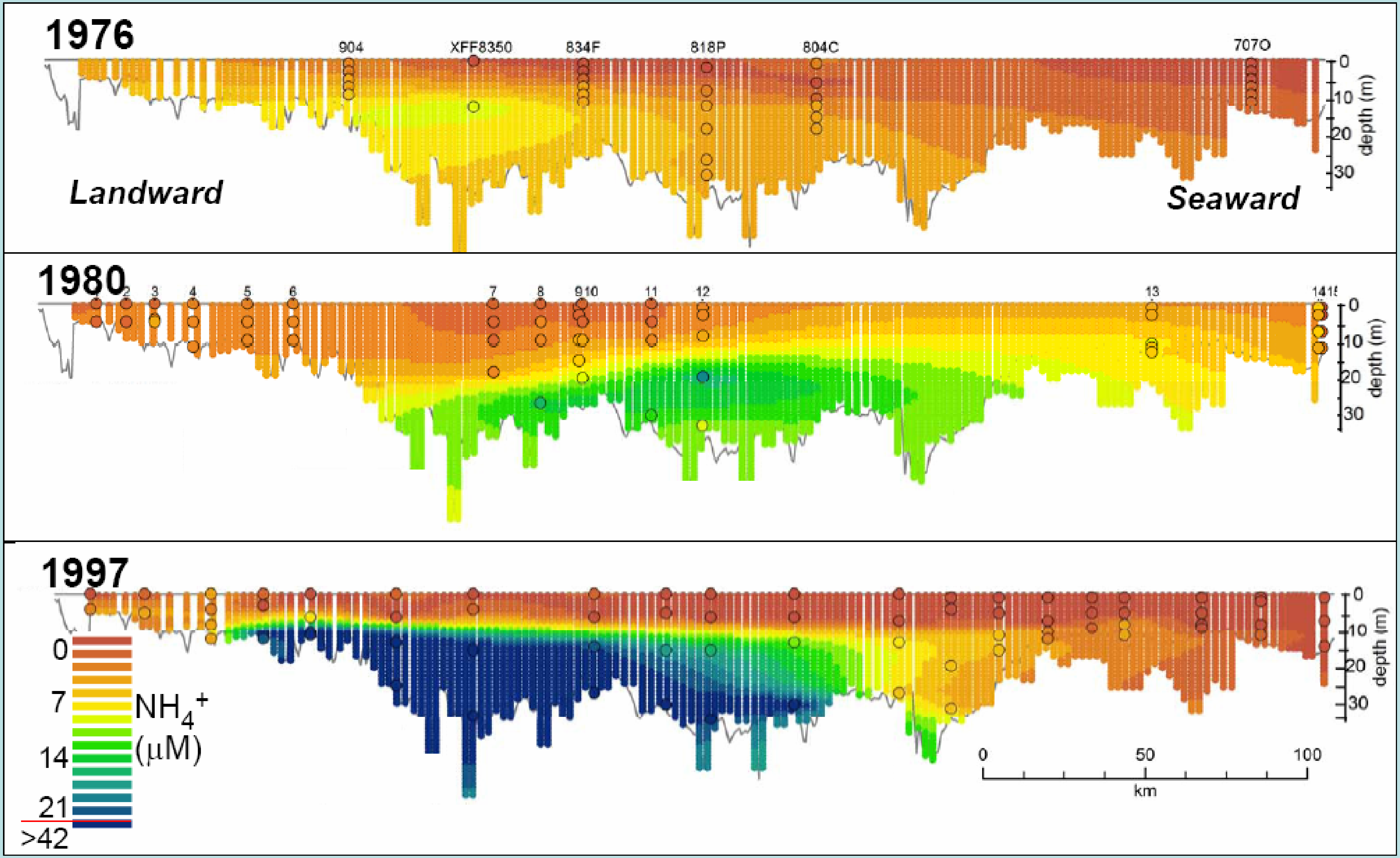
Potential Explanations for Observed Shift in Relationship between Hypoxia & N-Loading

- Loss of oyster grazing on phytoplankton
- Loss of seagrass & marsh “nutrient trapping”
- Climate-induced changes (temperature, circulation)
- Enhanced nutrient recycling efficiency under low O_2

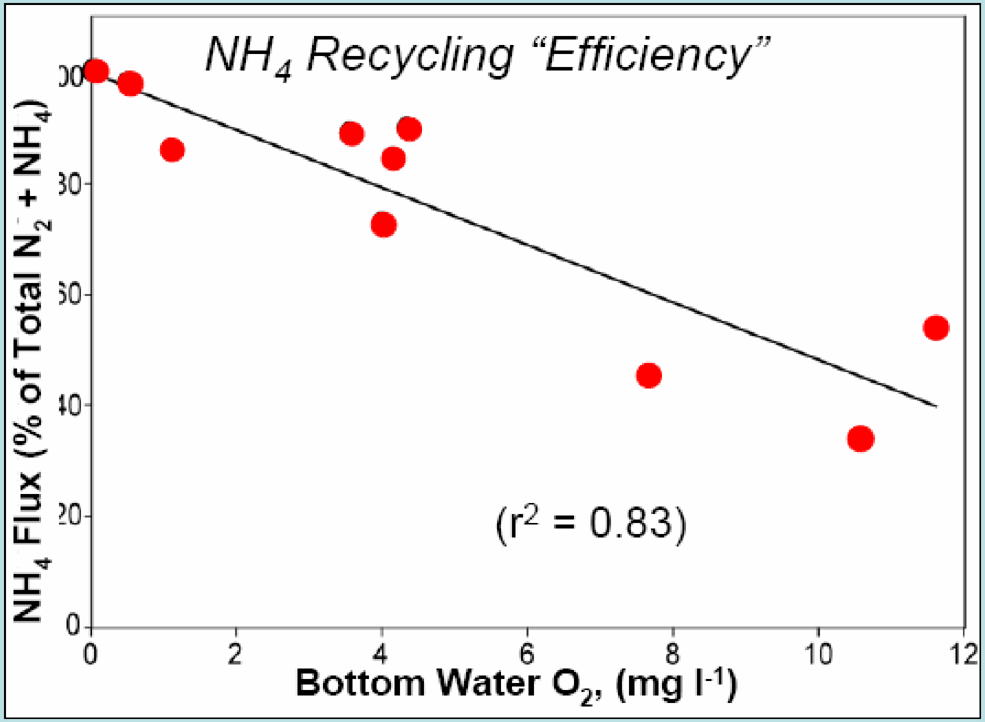
Conceptual Model of O_2 Interactions with N-Cycle



Decadal Change in July Distribution of $[NH_4^+]$



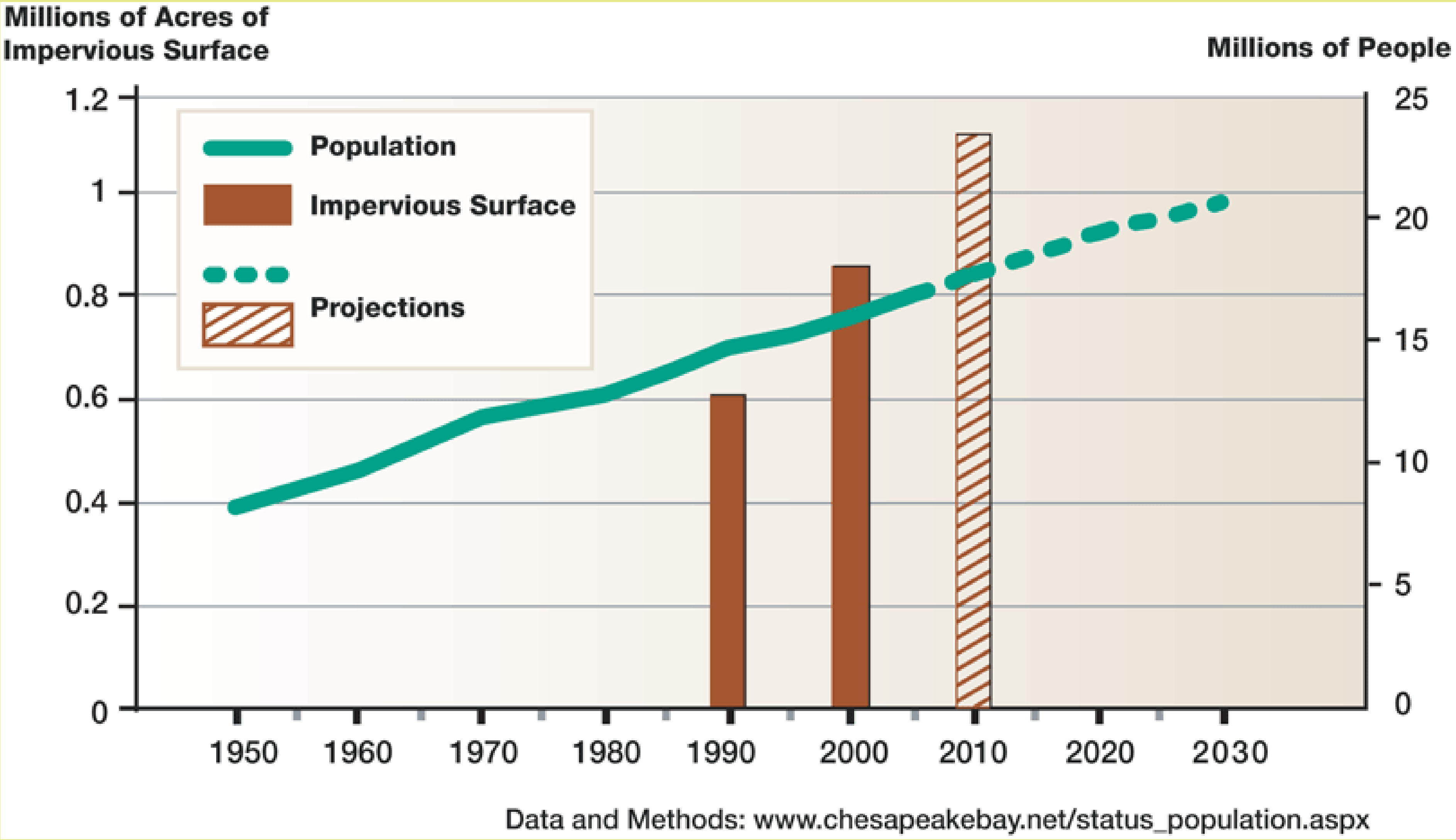
Hypoxia Enhancement of Benthic Nutrient (NH_4^+) Recycling Efficiency



- DIN 'Recycling Efficiency' (NRE) is flux ratio (DIN/(DIN + N_2))
- NRE increases w/ decreasing O_2 because of nitrification inhibition
- Thus, DIN recycling higher under hypoxic conditions.

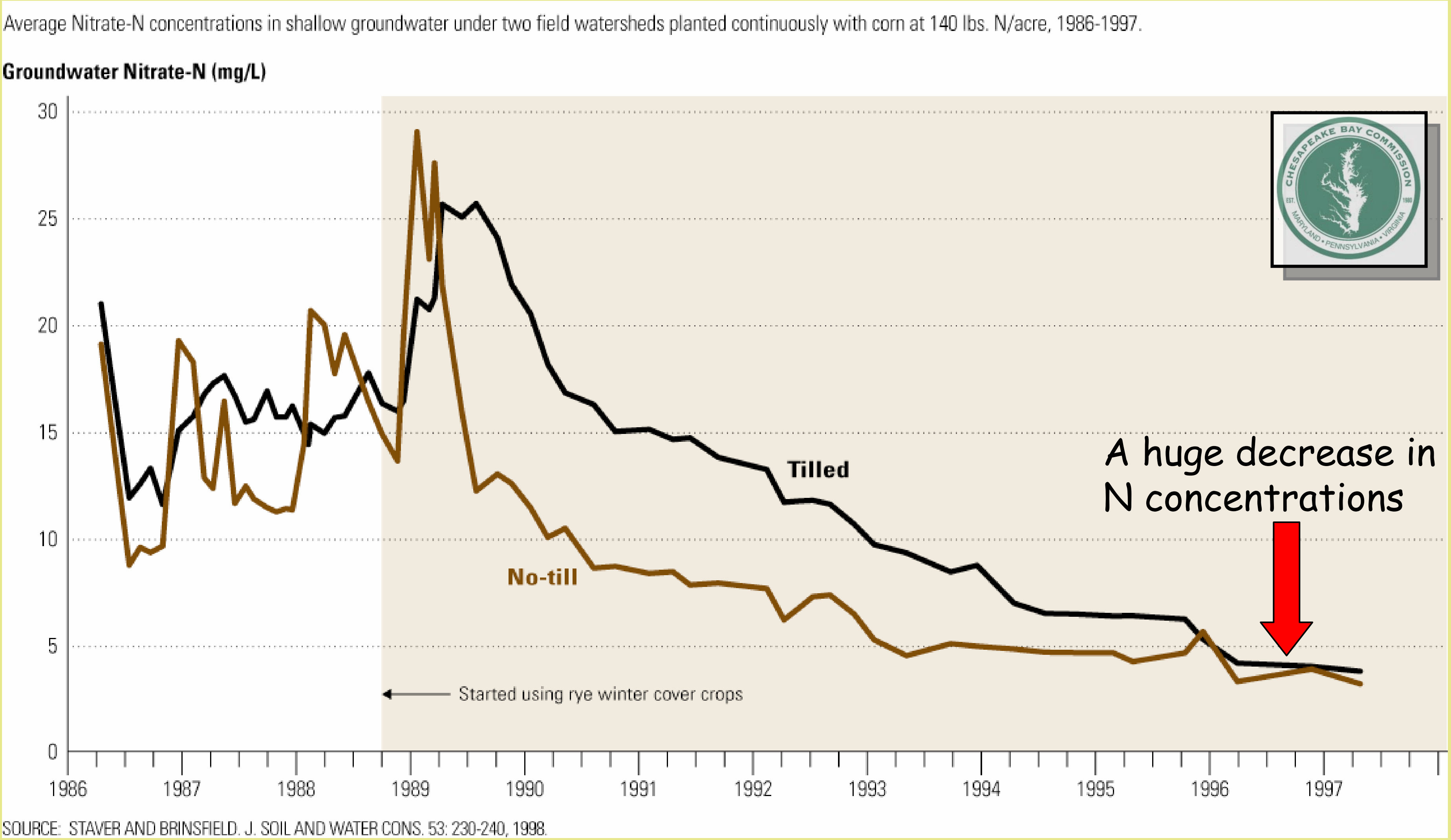
(J. Cornwell data from Kemp et al. 2005)

Bay Watershed Population and Impervious Surface



Development and Land Use Change Still Going Strong

Conservation Practices Deliver Water Quality Benefits



Storm Water Management: Wet Pond Example

Pollutant Removal Efficiencies:
TSS: 46%
TP: 46%
TN: 32%

There have been many of these constructed in the Patuxent Basin…HOW or IF they work is largely unknown.

We need effective SWM systems…the new Federal administration (ECOLOGICAL) infra-structure initiative

Some Ideas from Paleoecologists

(From Brush 2008)

- Pre-colonial landscape covered with forests and MANY WETLANDS
- In past 300 years (especially last 50 years) nutrient loads have diversified and INCREASED about 6-8 fold.
- Pre-colonial N cycle maintained by balance of N-fixation and denitrification…for >1000 years.
- Deforestation and wetland loss led to loss of landscape sites for denitrification
- BEAVERS were important for denitrification sites…likely 5 million of these busy rodents in pre-colonial watershed (~1940 human population)
- Restore the pre-colonial wet and marshy condition…mimic the beavers coupled with other more conventional approaches…
- This is a huge effort and results will take time because of lags in groundwater transport.

Concluding Thoughts

- Restoration in the face of high growth rates is tough…it has largely not worked for diffuse sources or just managed to "hold the line"…total loads have remained high
- The Potomac is a typical "OVER-ENRICHED" estuary…too much of a good thing
- Diffuse sources dominate, need serious attention and will likely be expensive…creativity is needed up in the basin.
- There is a need to focus on basin "hot spots" both for preservation (tidal marshes and other wetlands) and restoration (adding "ecological plumbing") to urban and suburban areas