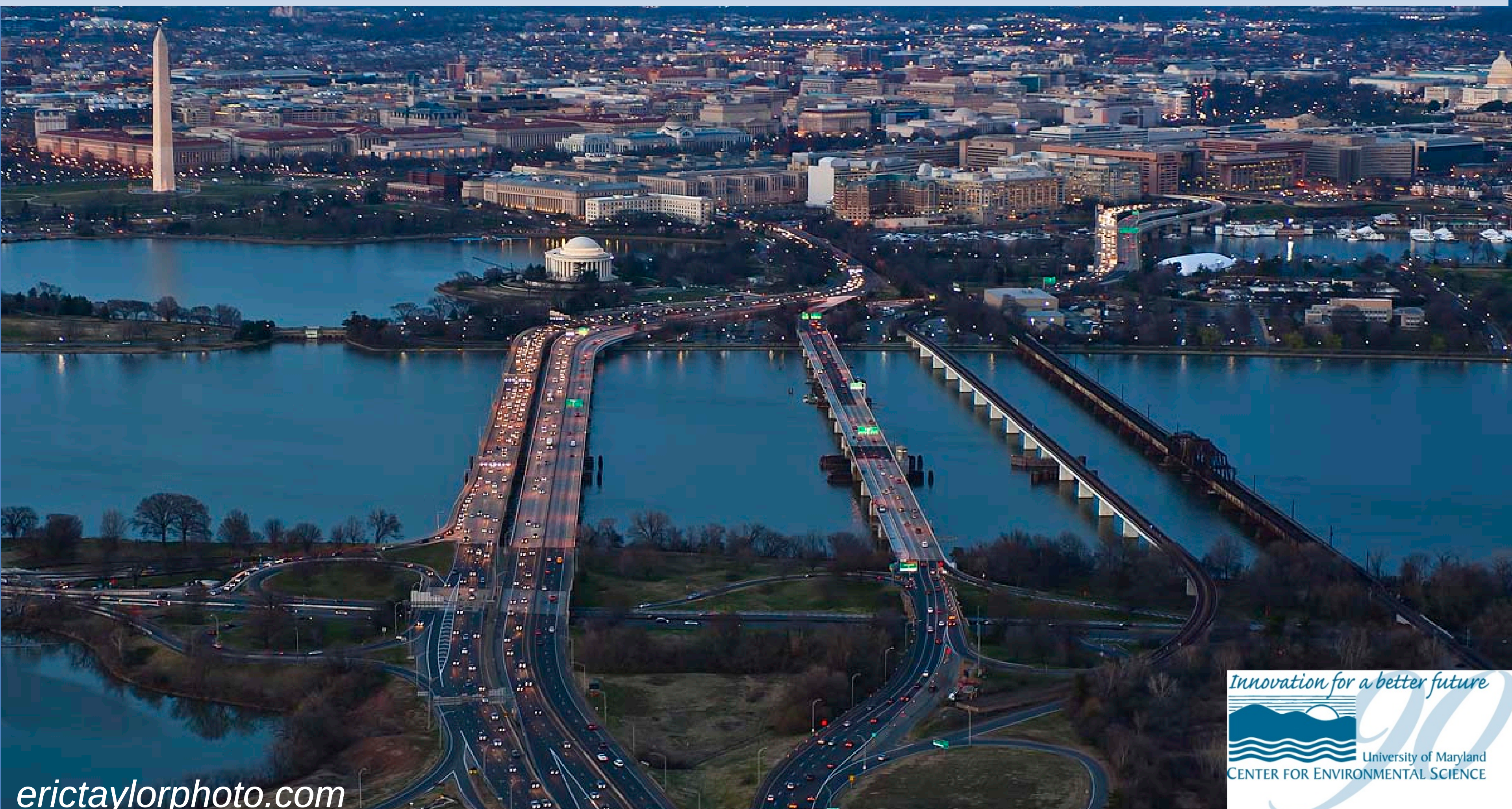
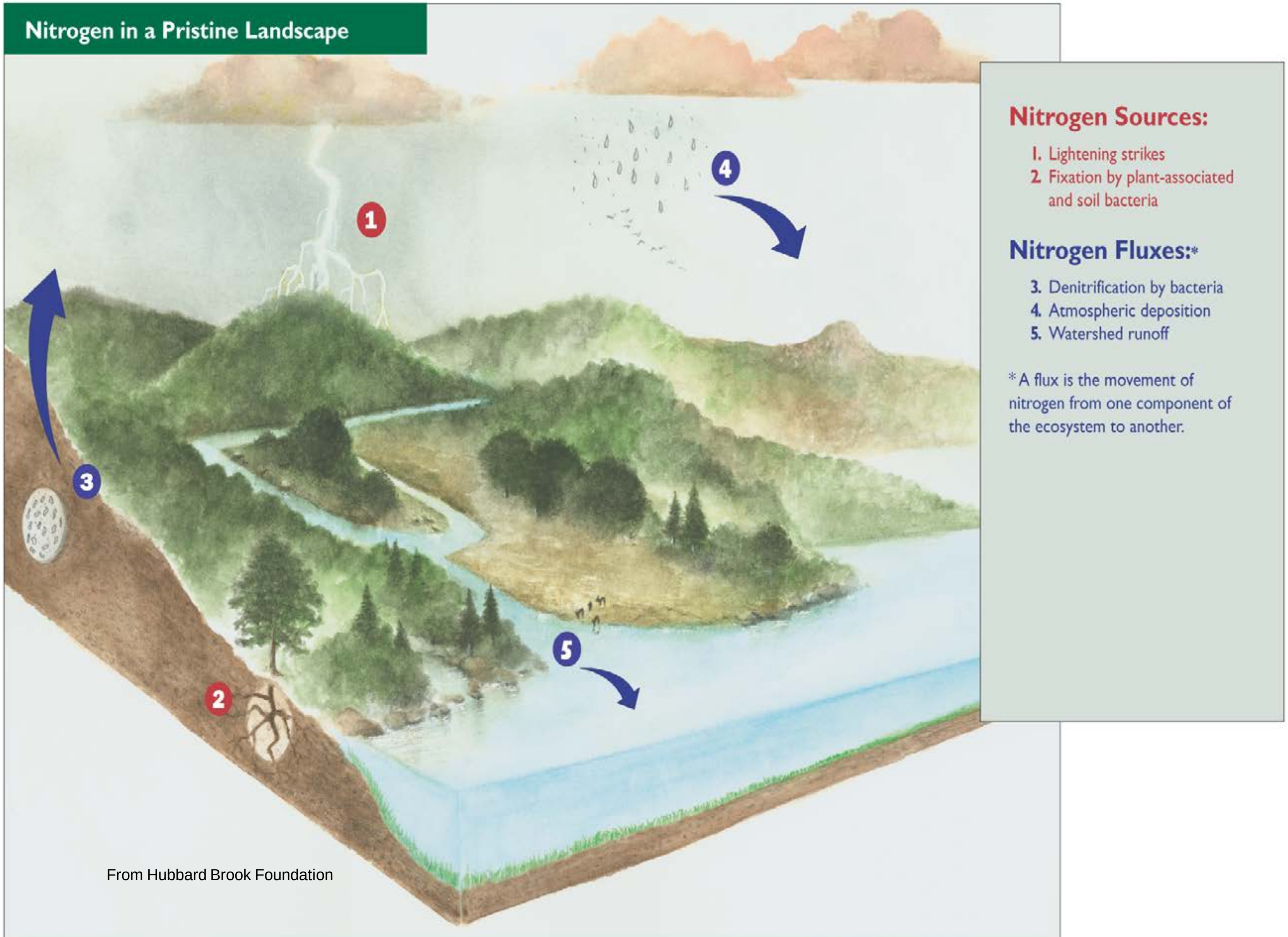
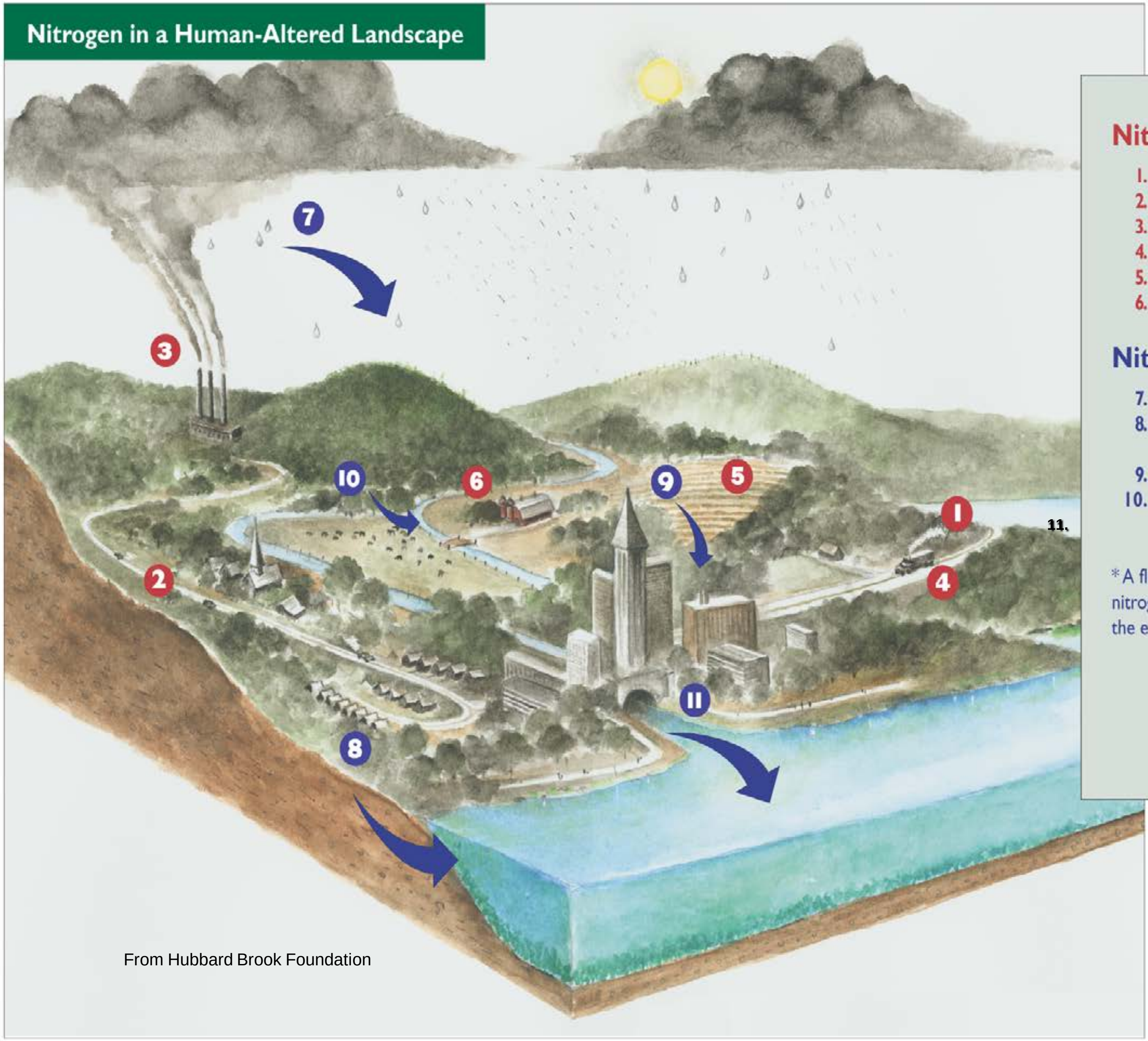
# Documenting Impacts of Climate, Clams, and a Changing Watershed on the Potomac Estuary

Lora Harris, UMCES-CBL




Innovation for a better future
University of Maryland
CENTER FOR ENVIRONMENTAL SCIENCE


Nitrogen in a Pristine Landscape
1
2
3
4
5
Nitrogen Sources:
1. Lightening strikes
2. Fixation by plant-associated and soil bacteria
Nitrogen Fluxes:*
3. Denitrification by bacteria
4. Atmospheric deposition
5. Watershed runoff
* A flux is the movement of nitrogen from one component of the ecosystem to another.
From Hubbard Brook Foundation




## Nitrogen Sources:

1. Imported food and feed
2. Vehicle emissions
3. Powerplant emissions
4. Fertilizer imports
5. Fixation in croplands
6. Agricultural emissions

## Nitrogen Fluxes:*

7. Atmospheric deposition
8. Wastewater from septic tanks and treatment plants
9. Agricultural runoff
10. Forest runoff

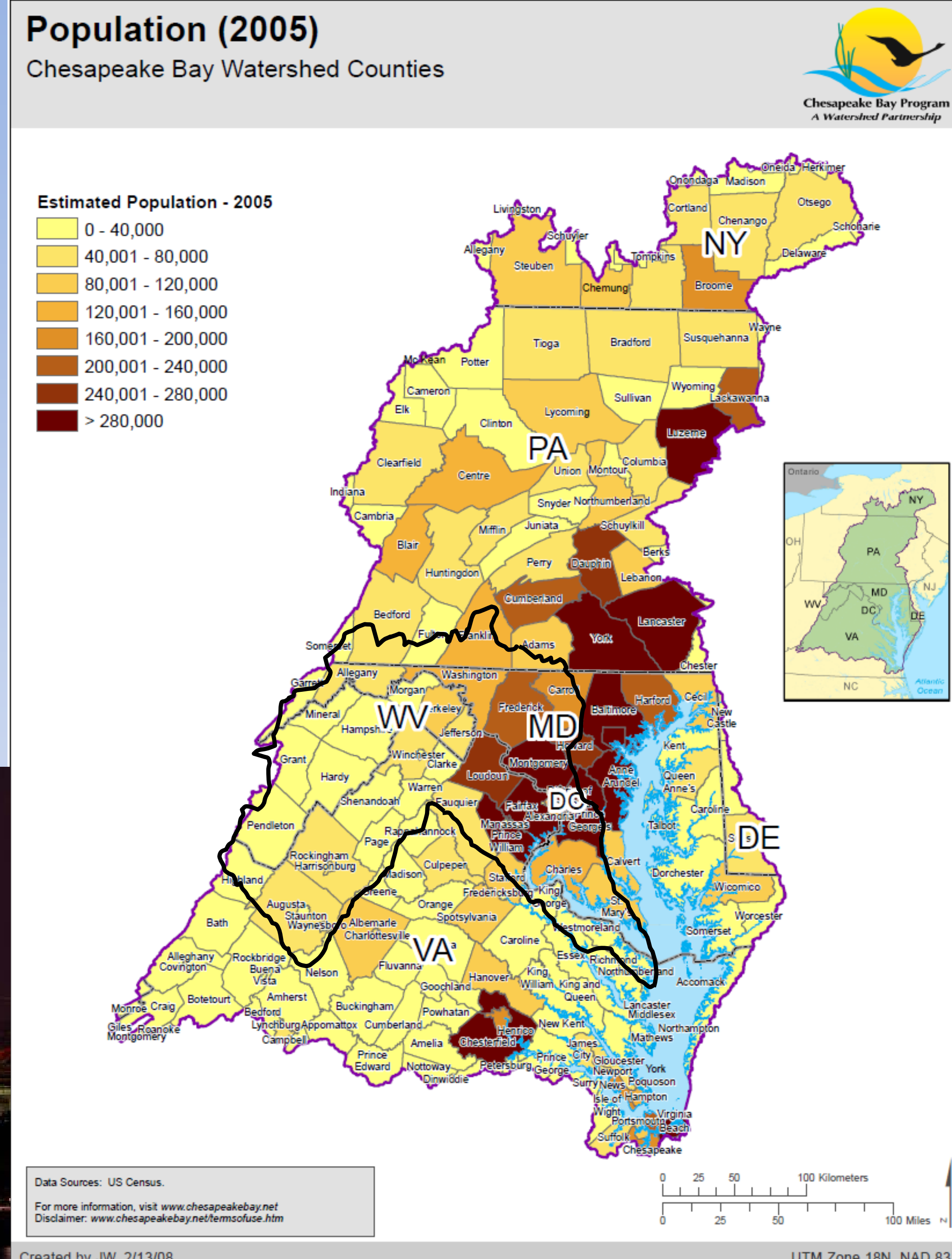
    Urban runoff

*A flux is the movement of nitrogen from one component of the ecosystem to another.

From Hubbard Brook Foundation

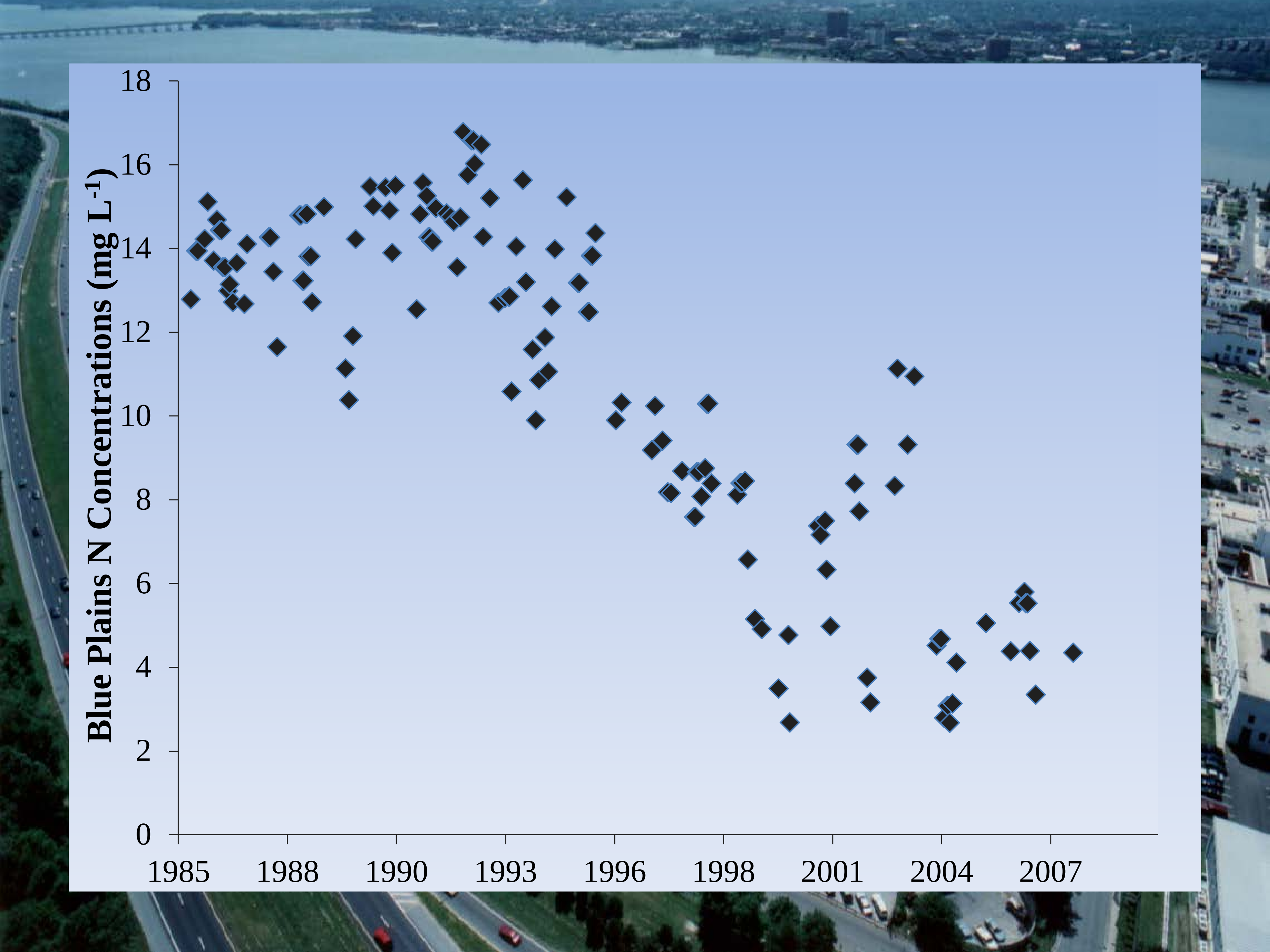
# POTOMAC ESTUARY

- Largest Tributary of CBay
- Watershed covers four states and Washington, DC
- Lower Population Density in Mesohaline portion of estuary



# Major Historical Acts in Water Quality Monitoring

- **1870s**: First sewers built
- **1894**: US Public Health Service began sanitary surveys in DC
- **1897**: USGS conducted first water quality survey of entire Potomac
- **1965**: Water Quality Act enacted establishing water quality standards for interstate waters
- **1972**: Clean Water Act establishing National Pollutant Discharge Elimination System (NPDES)
- **1983, 1987**: Chesapeake Bay Agreement enacted; goal to reduce nutrient loads

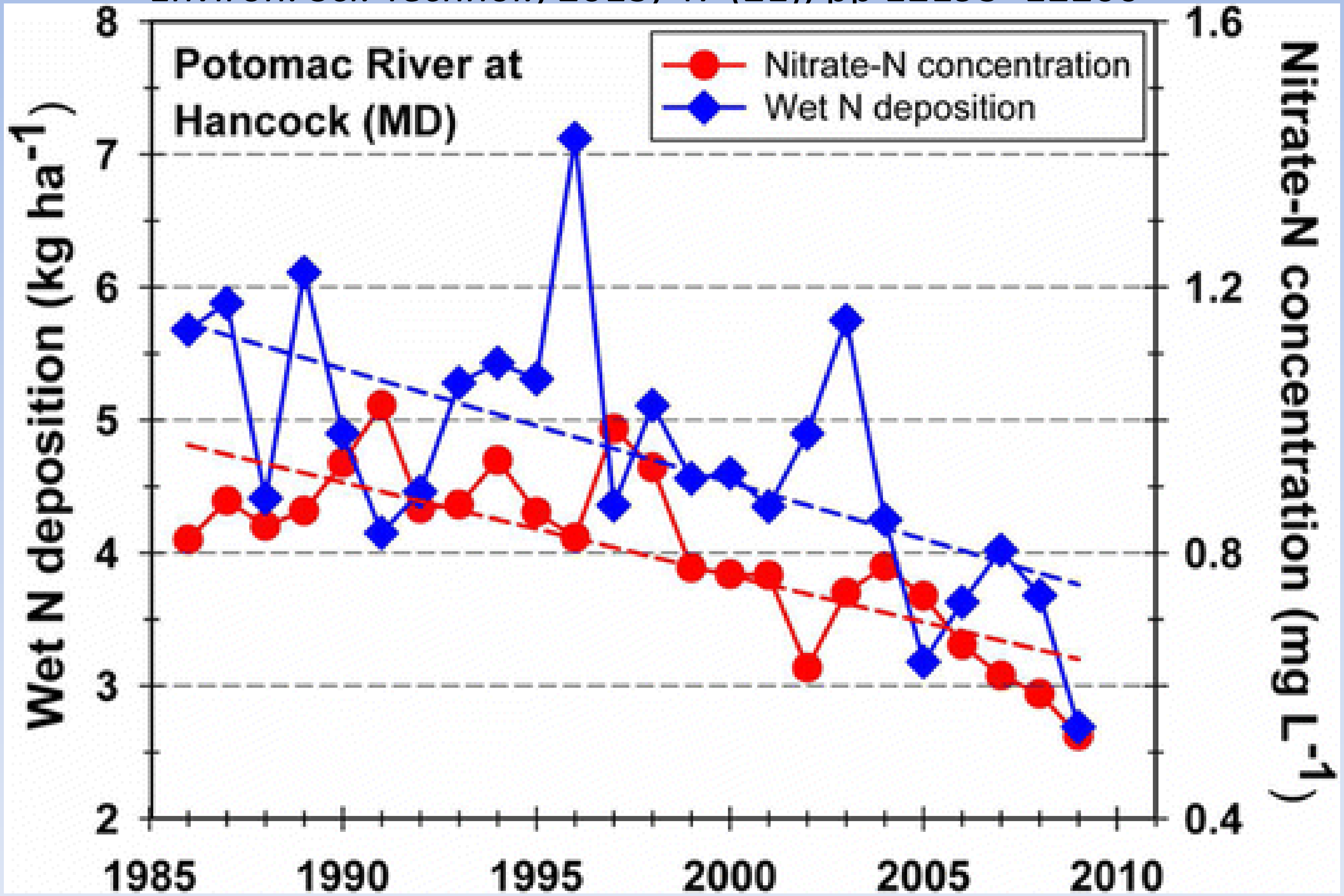


Blue Plains N Concentrations (mg L-1)
0
2
4
6
8
10
12
14
16
18
1985
1988
1990
1993
1996
1998
2001
2004
2007

# Surface Stream Water Quality Is Improving due to Declining Atmospheric N Deposition

Keith N. Eshleman*, Robert D. Sabo, and Kathleen M. Kline

†*Environ. Sci. Technol.*, 2013, 47 (21), pp 12193–12200

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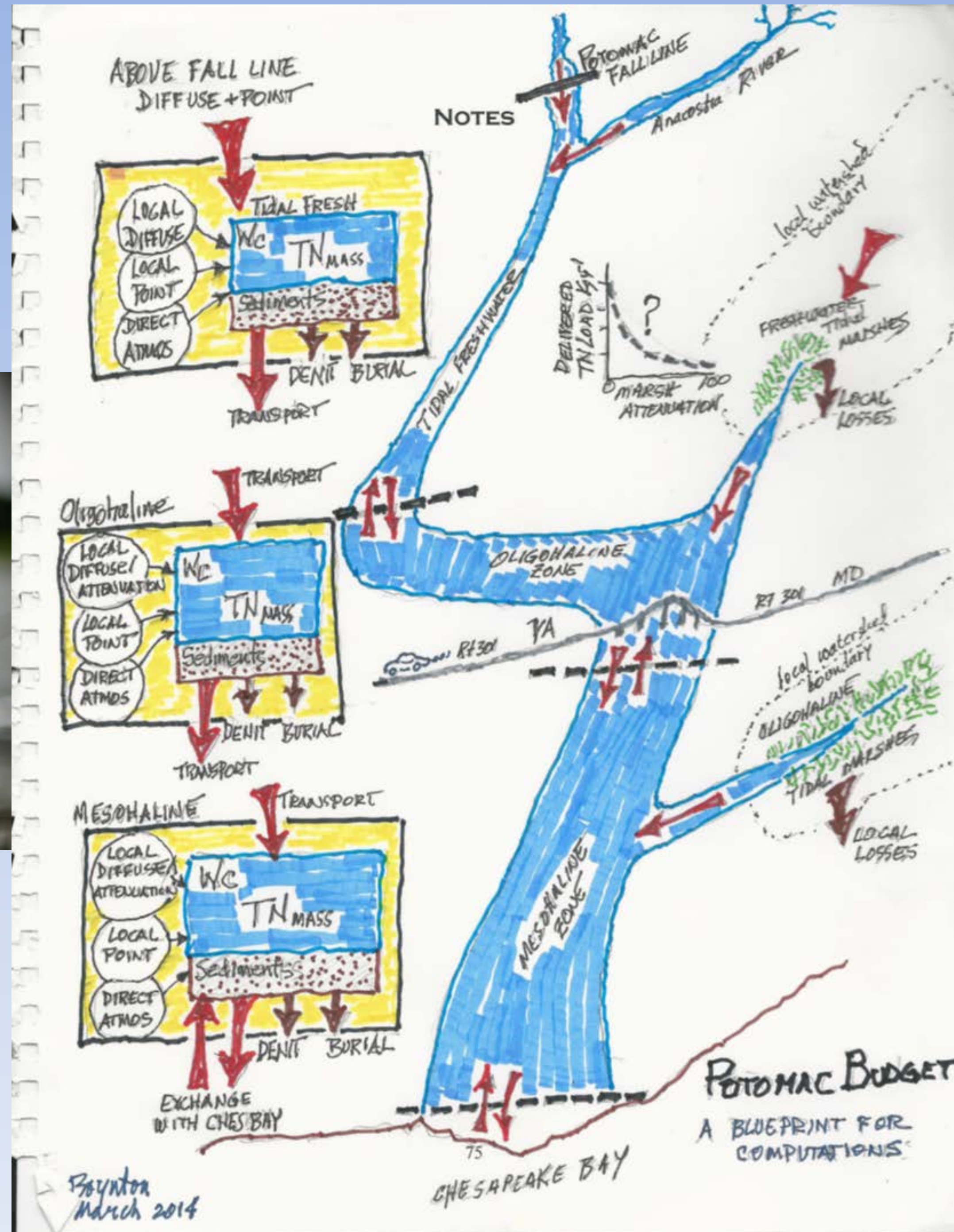
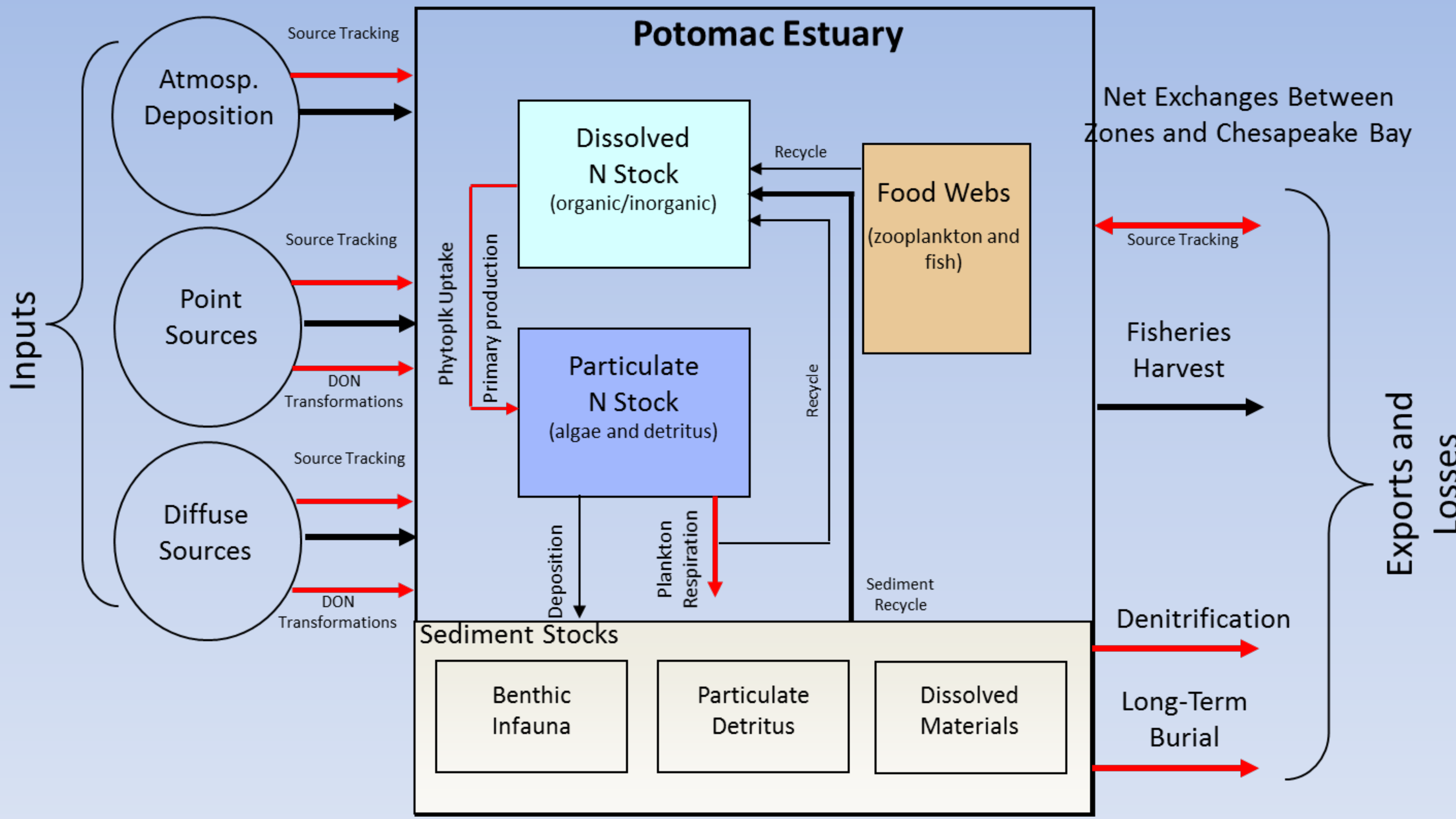
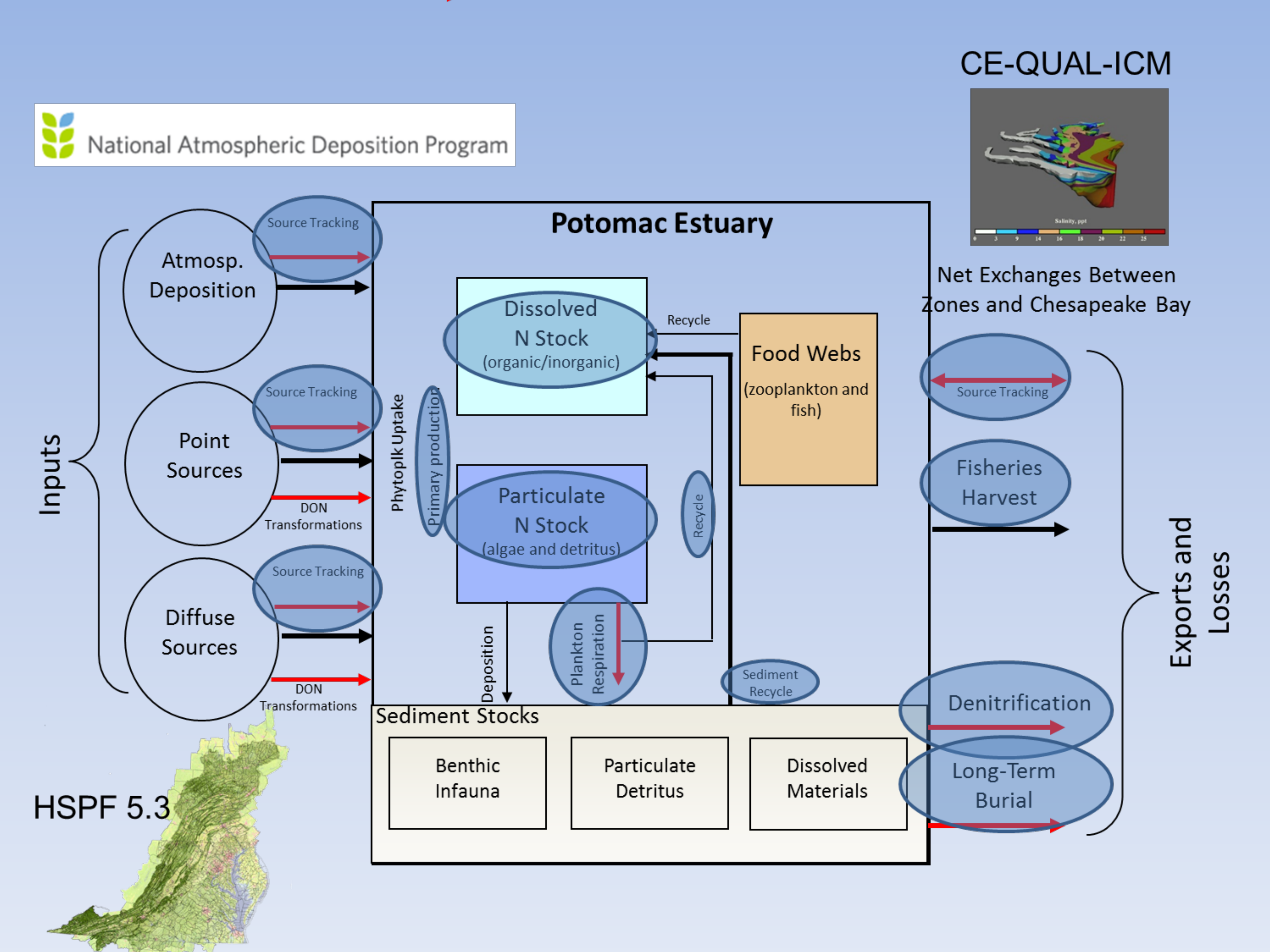

NOTES
ABOVE FALL LINE
DIFFUSE + POINT
POTOMAC FALL LINE
Anacostia River
TIDAL FRESH
LOCAL DIFFUSE
LOCAL POINT
DIRECT ATMOS
WC
TN MASS
Sediments
DENIT
BURIAL
TRANSPORT
TIDAL FRESHWATER
DELIVERED TN LOAD
?
MARSH ATTENUATION
100
local watershed boundary
FRESHWATER TIDAL MARSHES
LOCAL LOSSES
Oligohaline
TRANSPORT
LOCAL DIFFUSE/ ATTENUATION
LOCAL POINT
DIRECT ATMOS
WC
TN MASS
Sediments
DENIT
BURIAL
TRANSPORT
OLIGOHALINE ZONE
MD
Rt 301
VA
local watershed boundary
OLIGOHALINE TIDAL MARSHES
LOCAL LOSSES
MESOHALINE
TRANSPORT
LOCAL DIFFUSE/ ATTENUATION
LOCAL POINT
DIRECT ATMOS
WC
TN MASS
Sediments
DENIT
BURIAL
EXCHANGE WITH CHES BAY
MESOHALINE ZONE
POTOMAC BUDGET
A BLUEPRINT FOR COMPUTATIONS
75
CHESAPEAKE BAY
Boynton
March 2014

# Our Role: Develop Nitrogen Mass Balance for Potomac Estuary





CE-QUAL-ICM
Salinity, ppt
National Atmospheric Deposition Program
Potomac Estuary
Inputs
Atmosp. Deposition
Source Tracking
Point Sources
Source Tracking
DON Transformations
Diffuse Sources
Source Tracking
DON Transformations
Phytoplk Uptake
Primary production
Dissolved N Stock (organic/inorganic)
Recycle
Food Webs (zooplankton and fish)
Particulate N Stock (algae and detritus)
Recycle
Deposition
Plankton Respiration
Sediment Recycle
Sediment Stocks
Benthic Infauna
Particulate Detritus
Dissolved Materials
Net Exchanges Between Zones and Chesapeake Bay
Source Tracking
Fisheries Harvest
Denitrification
Long-Term Burial
Exports and Losses
HSPF 5.3

Three Cruises:

*Spring*

High nitrate 16-92 $\mu$M

Temperature ~17 $^{o}$C

DO low near mouth

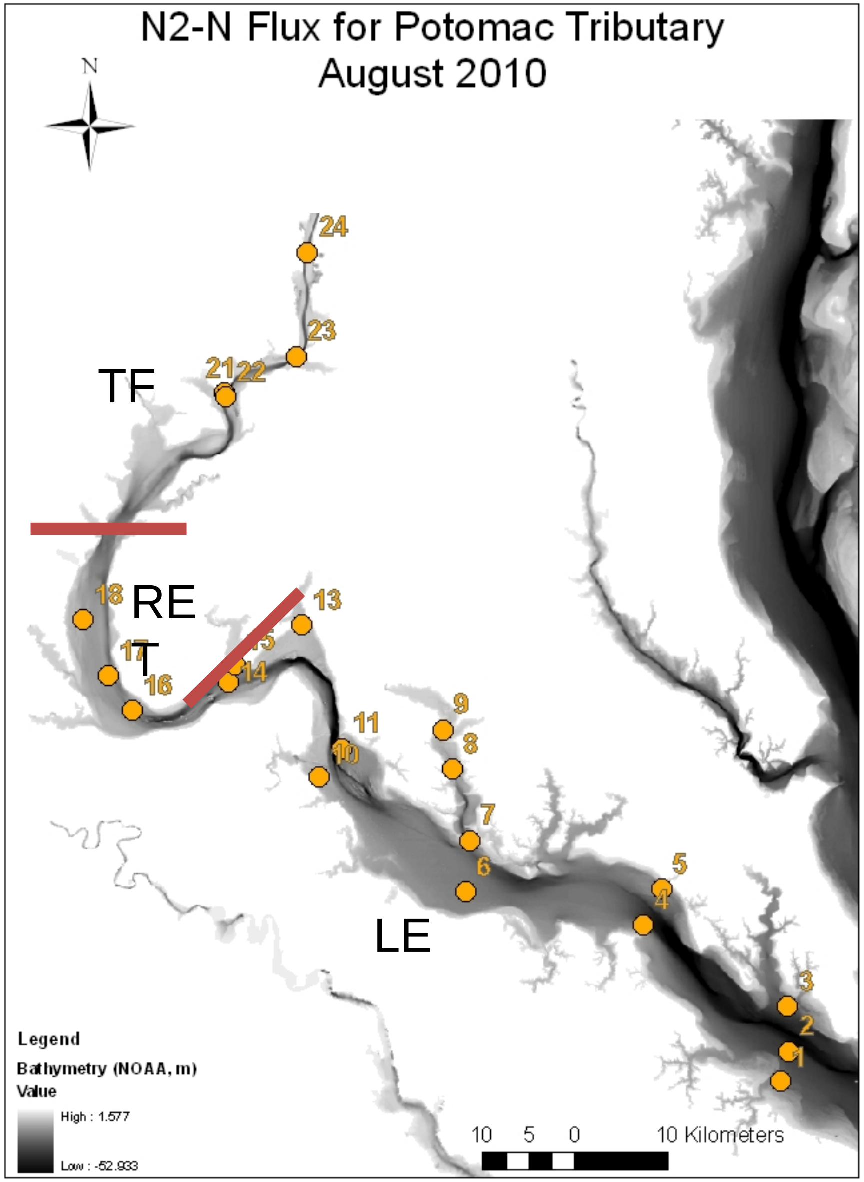
*Summer*

Low nitrate 1.0-7.5 $\mu$M

High temperature ~27 $^{o}$C

Anoxic near mouth

*Sediments - spring*



## Estimates of Denitrification

1. Rate measurements of N2-N fluxes interpolated across lower Potomac

2. Raster dataset exported fromArcGIS, predictions summed to estimate total denitrification rate for Potomac.

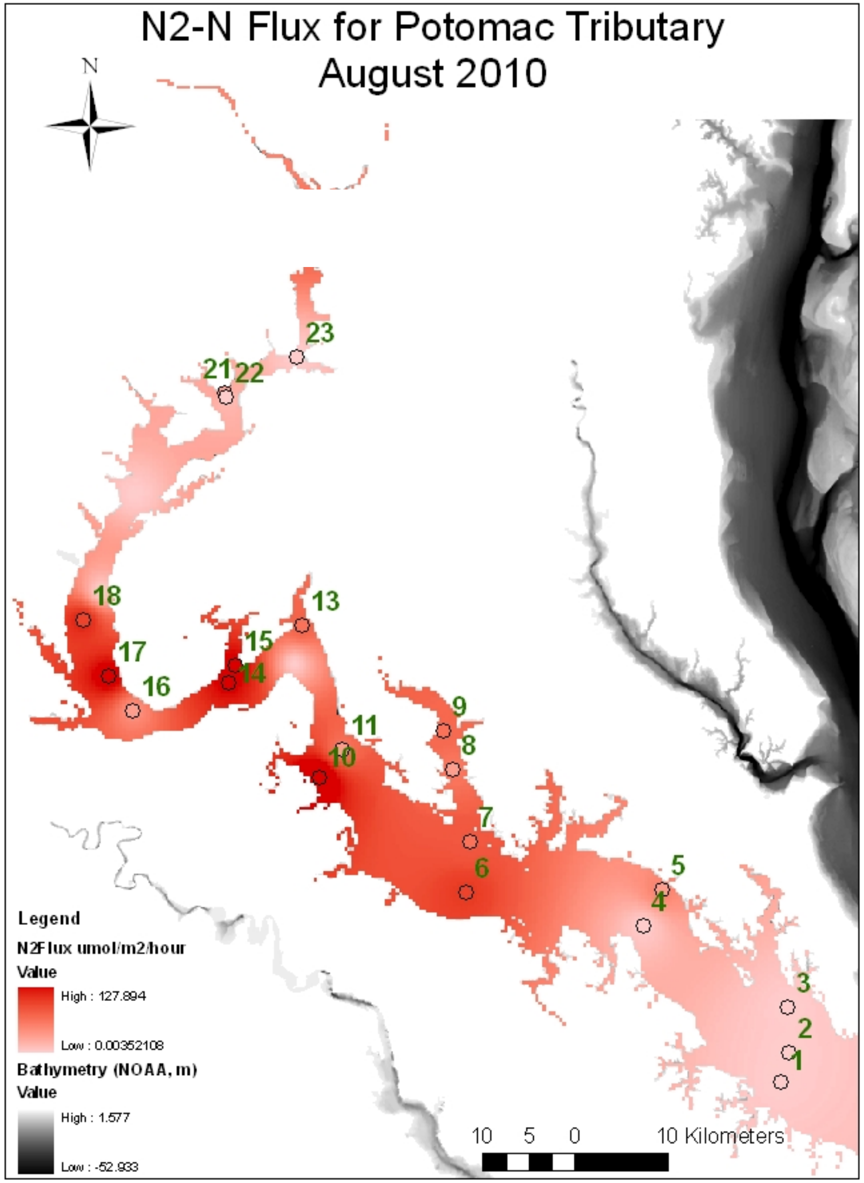
   ~15,900 kg N per day

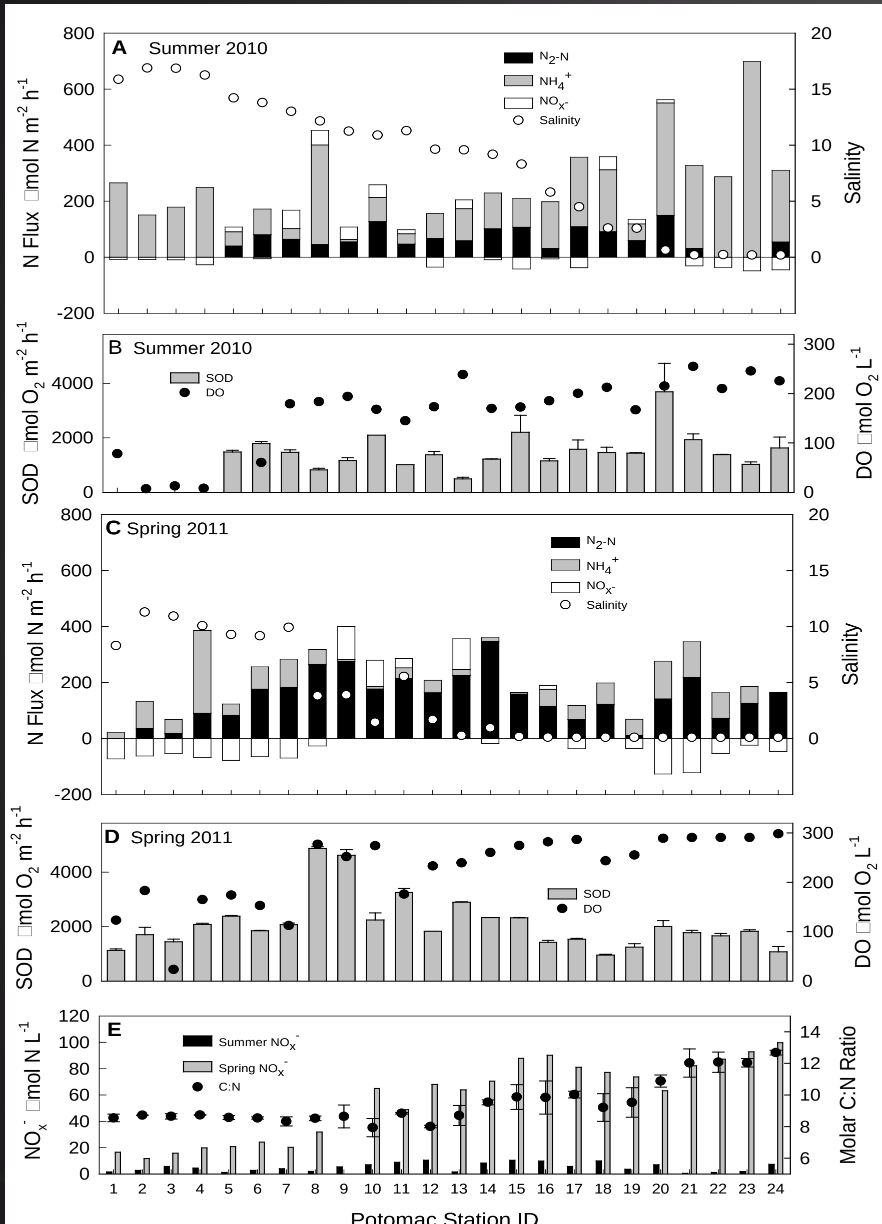
3. Inputs of N from upper Potomac averaged for July and August, 2009

   8695 kg N per day

4. Inputs of N from Blue Plain averaged for July and August, 2007

   6976 kg N per day






Journal of Coastal Research | 32 | 4 | 776–787 | Coconut Creek, Florida | July 2016

**Sediment-Water Nitrogen Exchange along the Potomac River Estuarine Salinity Gradient**

Jeffrey C. Cornwell[†]*, Michael S. Owens[†], Walter R. Boynton[‡], and Lora A. Harris[‡]

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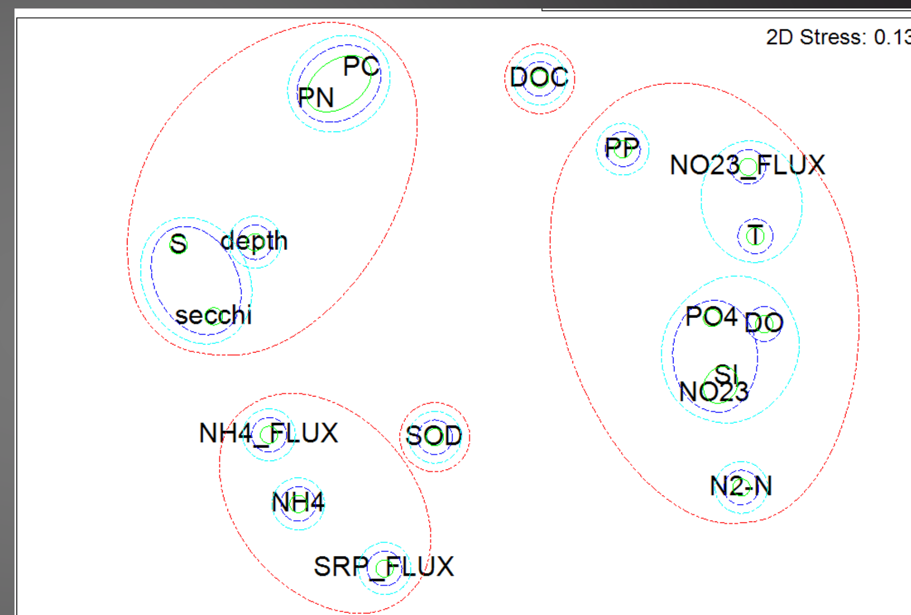
University of Maryland Center for Environmental Science
Cambridge, MD 21613, U.S.A.

[‡]Chesapeake Biological Laboratory
University of Maryland Center for Environmental Science
Solomons, MD 20688, U.S.A.

www.cerf-jcr.org




*"…our observations are not consistent with direct effects of salinity controlling $N_2$-N effluxes…we believe the whole range of controls must be considered."*

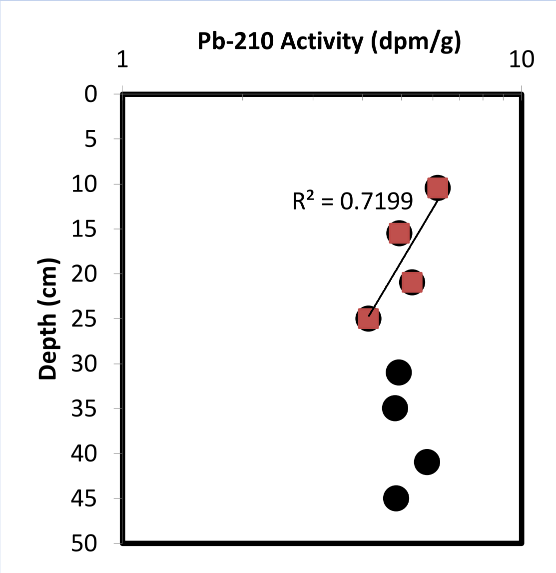
Burial Rates

Measured by estimating sedimentation rates using Pb-210 activity

Nutrient concentration in sediments concurrently measured in 5 cm increments.

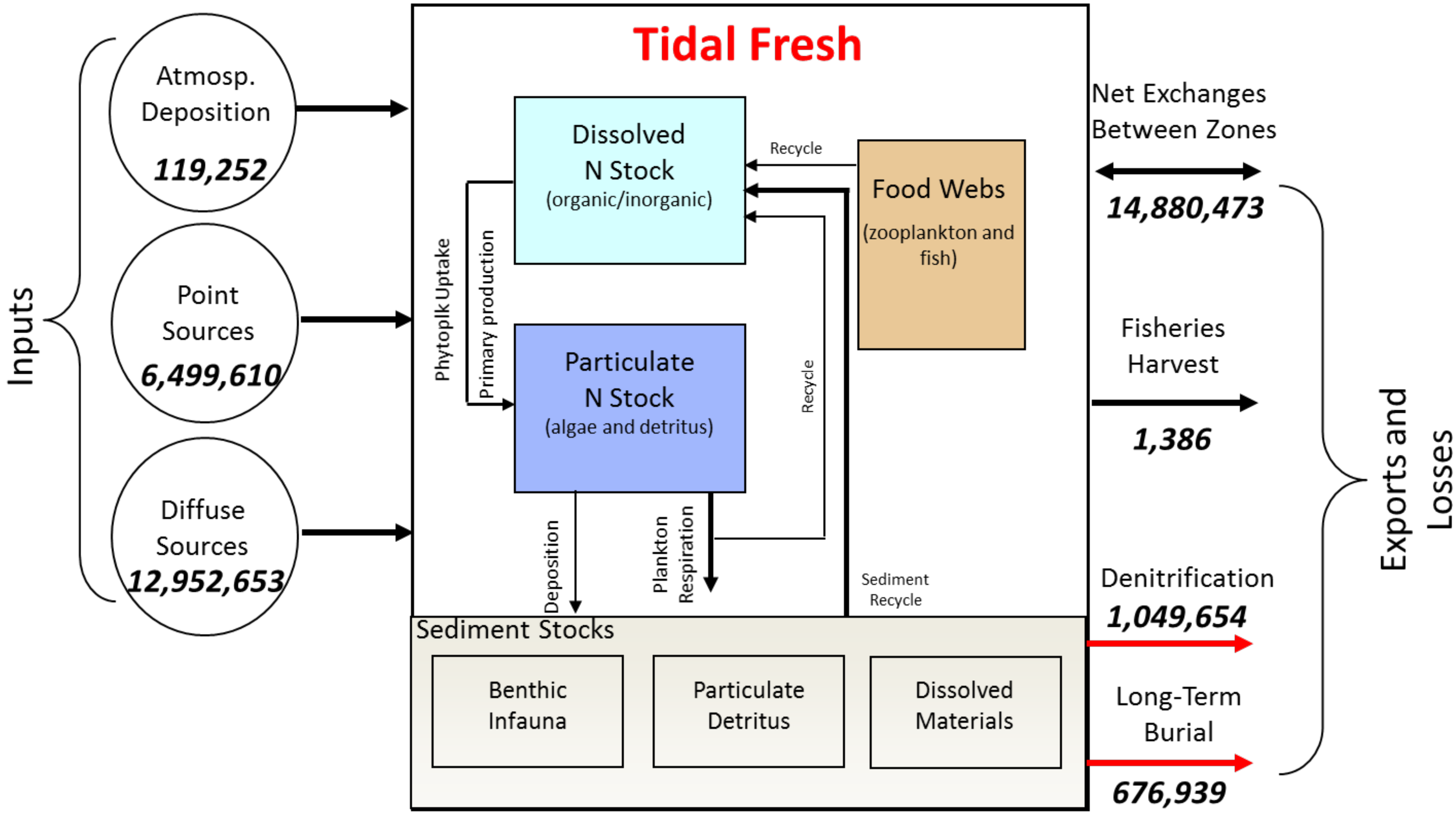
Ranged from 2.1-11.2 mm $year^{-1}$

Nitrogen Burial 0.2-2.0 mg $cm^{-2}$ $yr^{-1}$



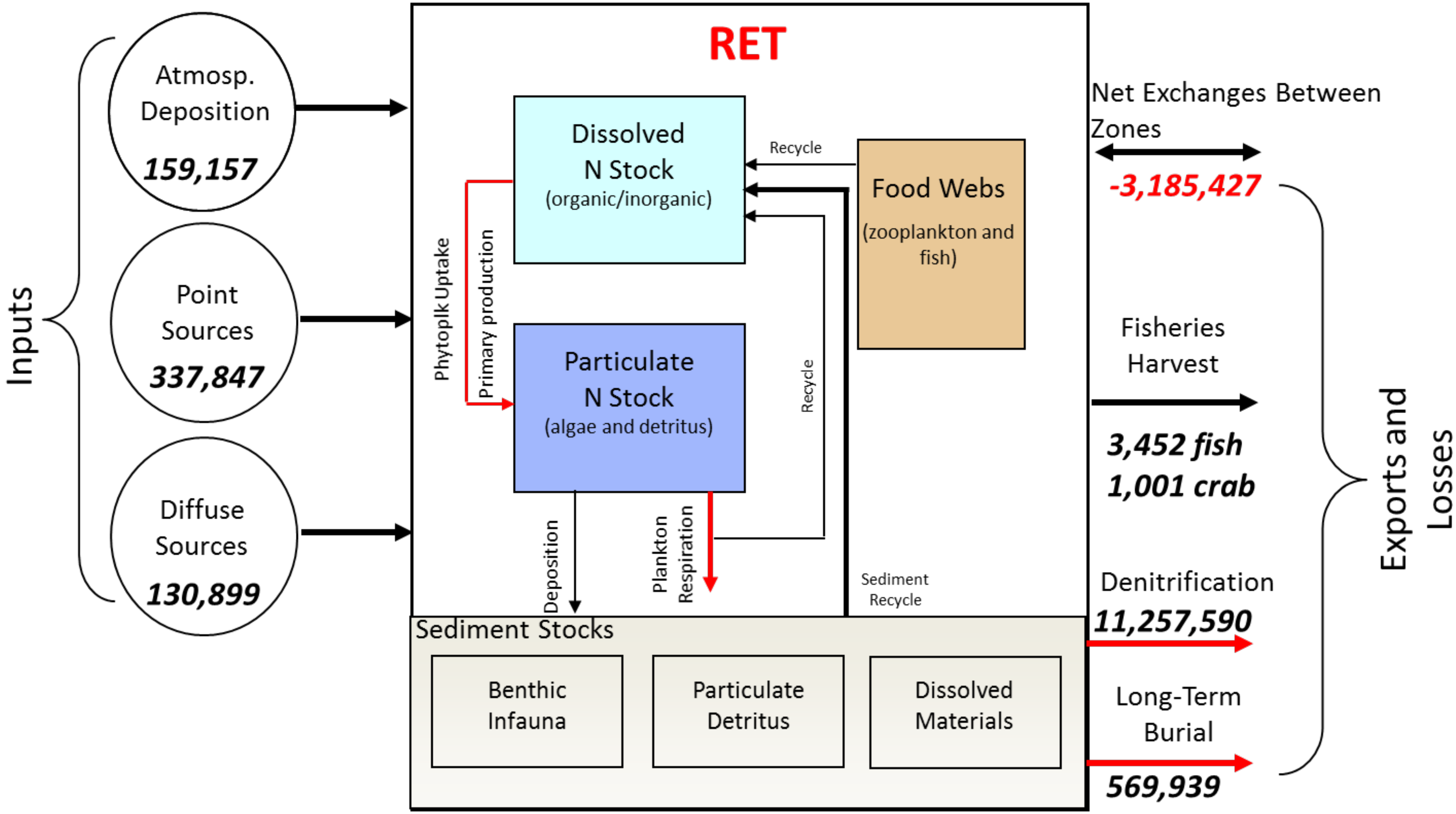

| Inputs | Losses | Mass Balance | % Difference |
|---|---|---|---|
| 19,571,515 | (16,608,453) | 2,963,062 | 15% |

# POST-BNR



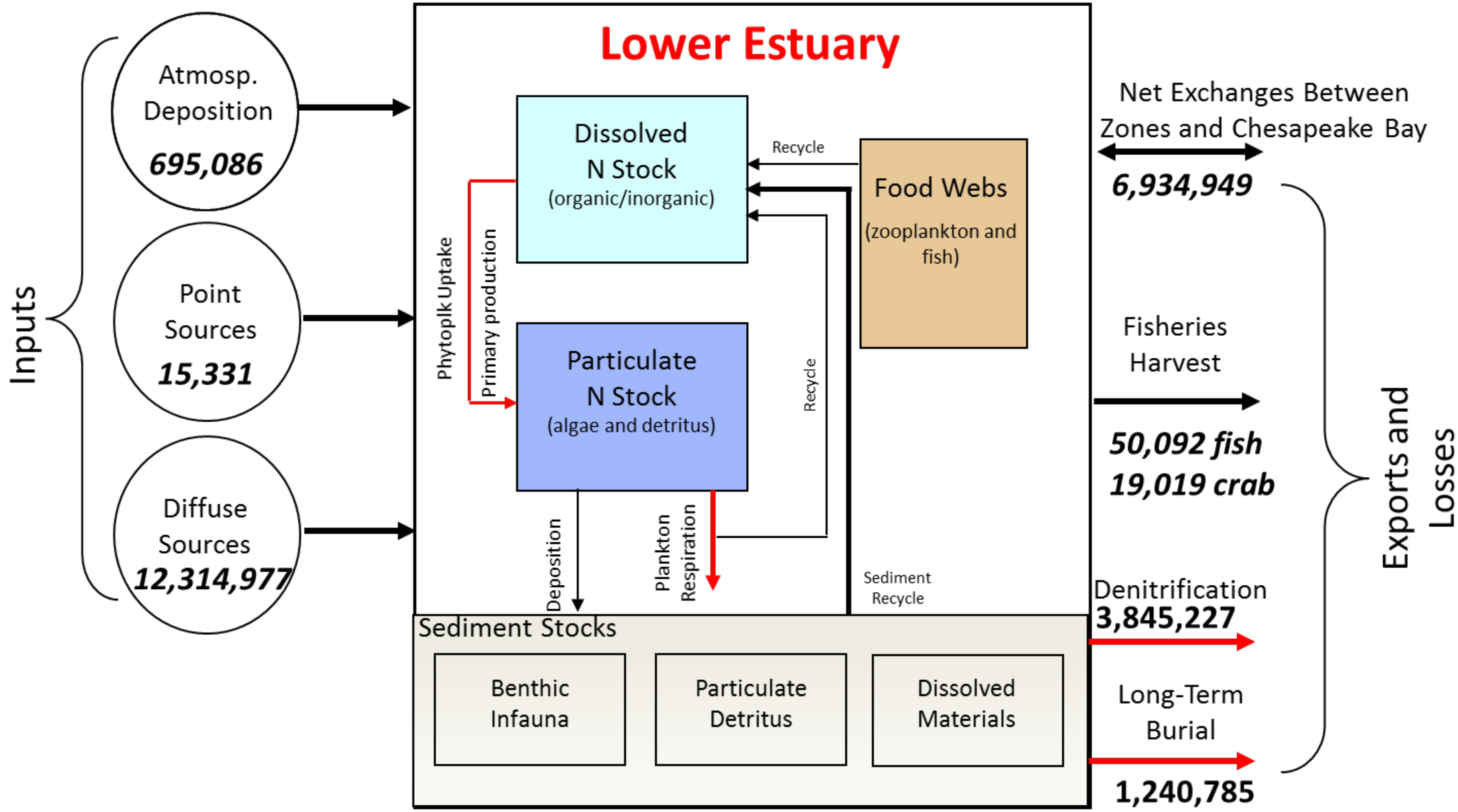
| Inputs | Losses | Mass Balance | % Difference |
|---|---|---|---|
| 15,508,377 | (13,544,369) | 1,964,007 | 13% |

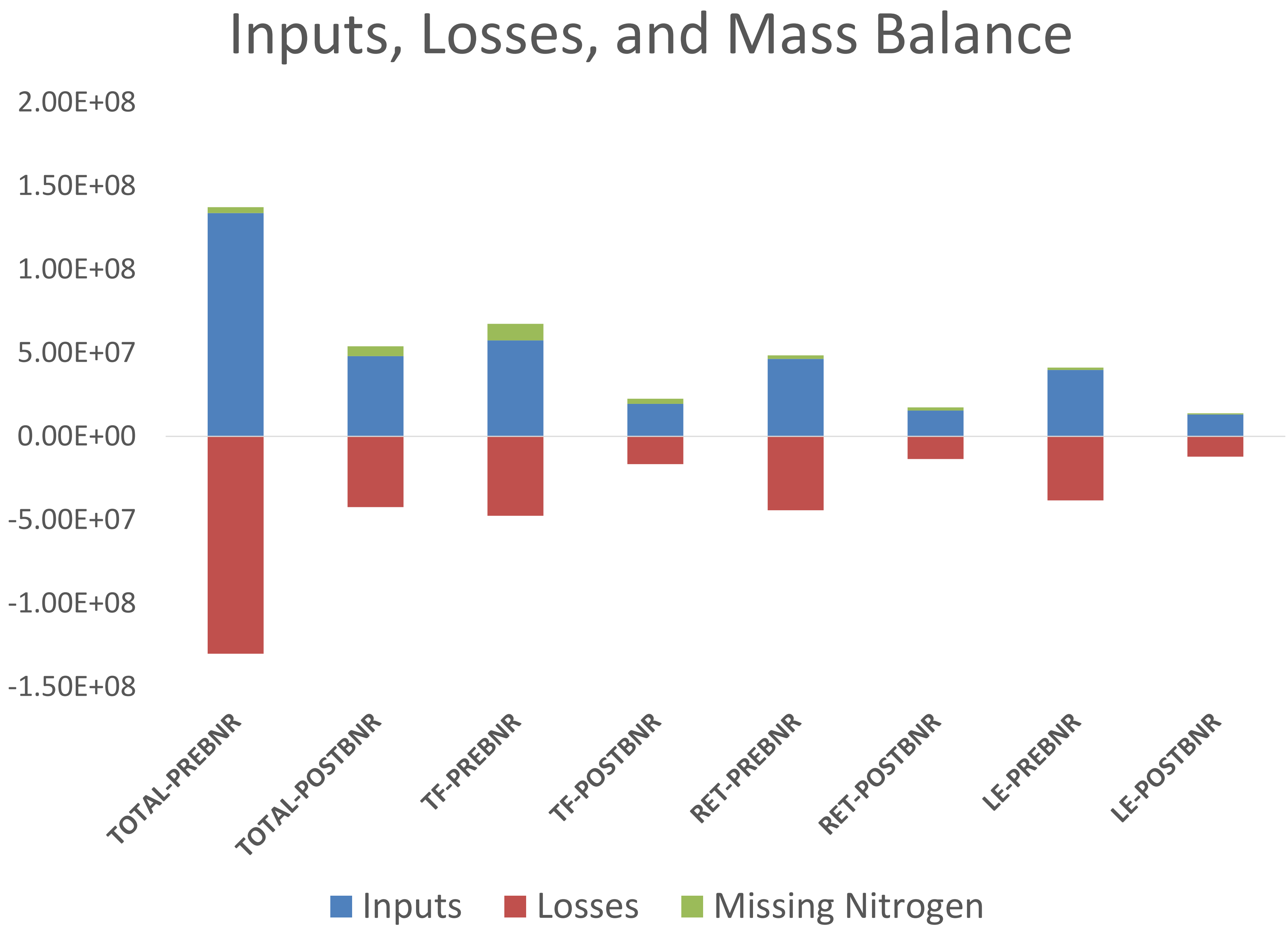
# POST-BNR



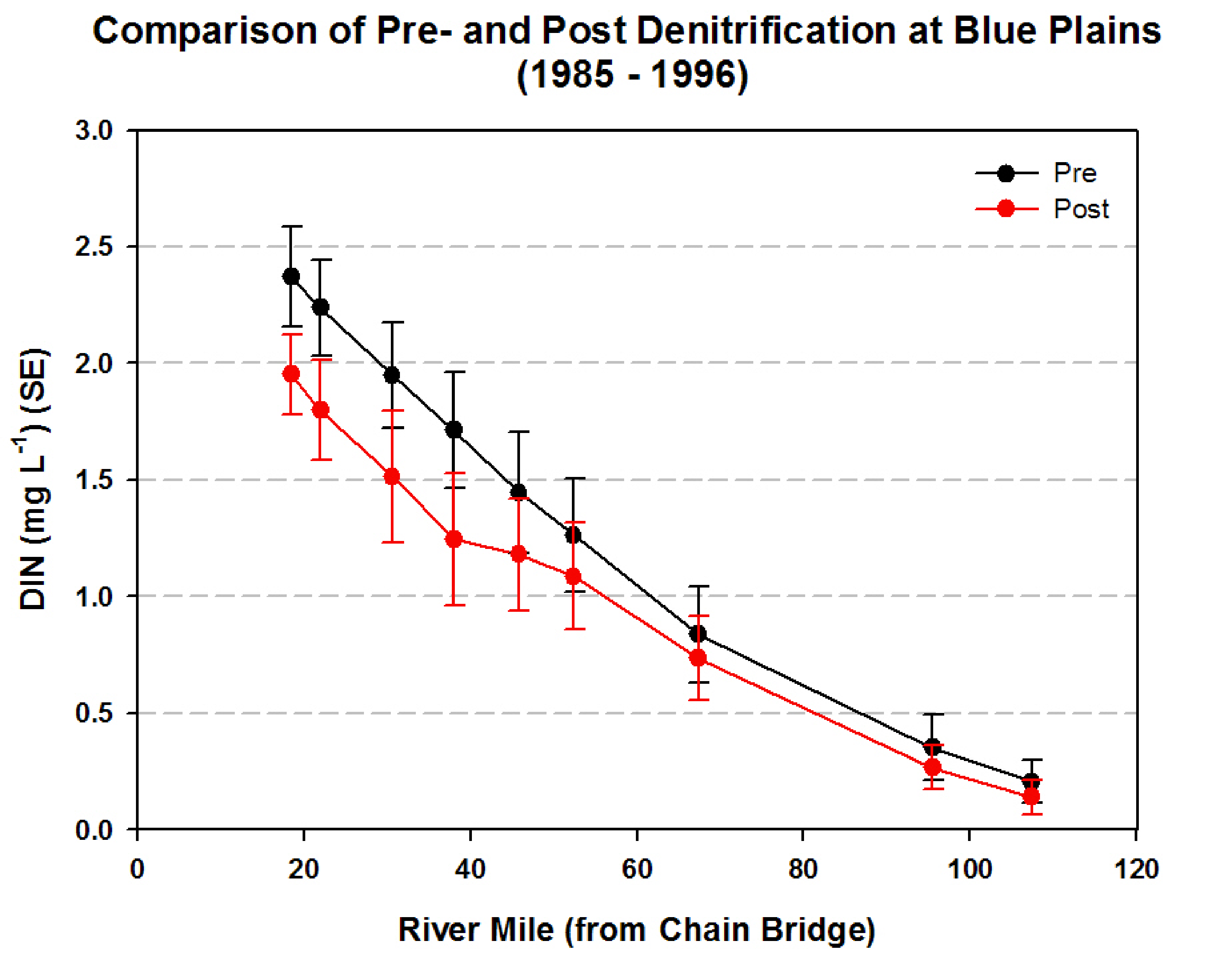
| Inputs | Losses | Mass Balance | % Difference |
|---|---|---|---|
| 13,025,395 | (12,090,072) | 935,322 | 7% |

# POST-BNR



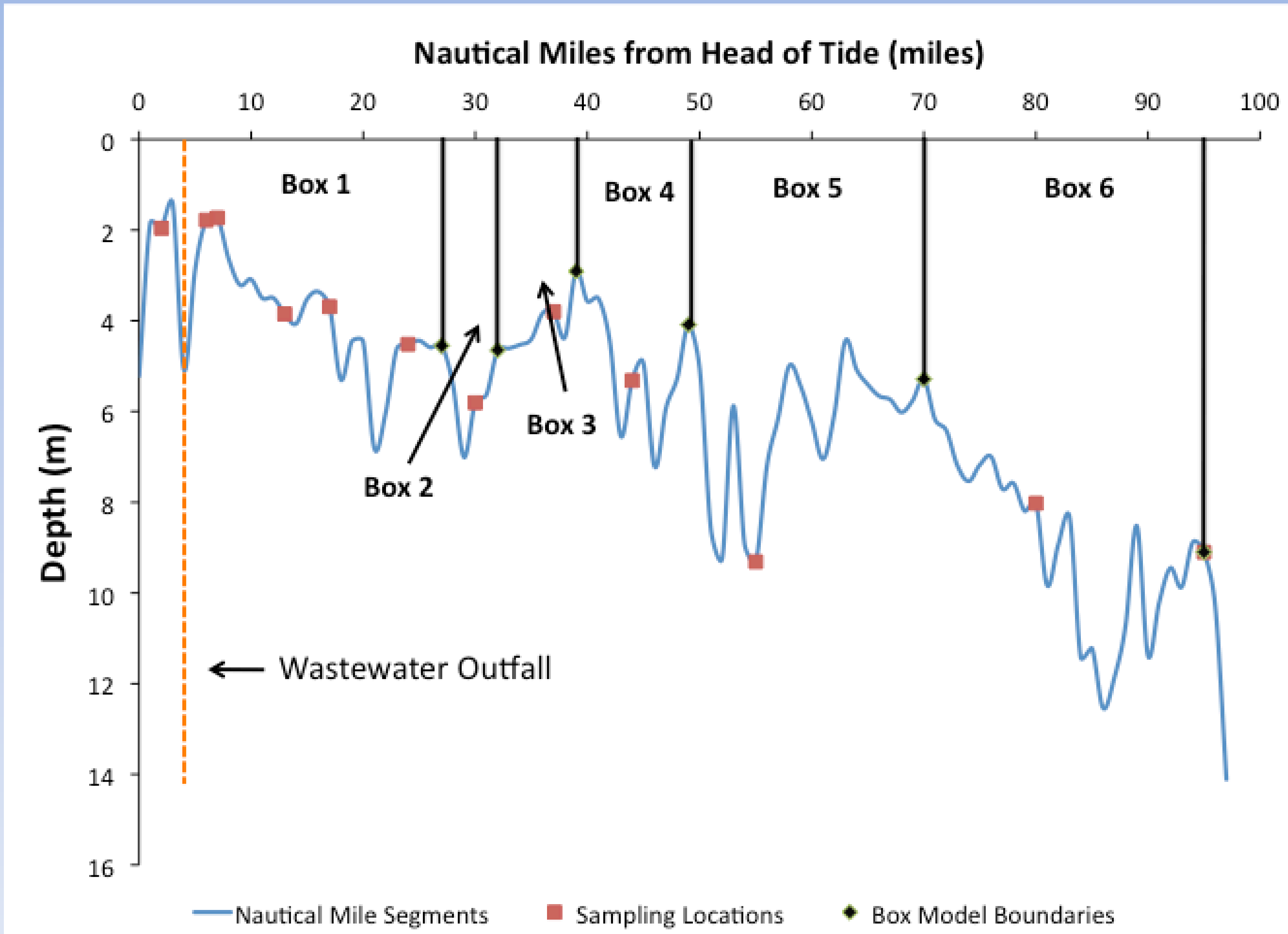


Inputs, Losses, and Mass Balance
2.00E+08
1.50E+08
1.00E+08
5.00E+07
0.00E+00
-5.00E+07
-1.00E+08
-1.50E+08
TOTAL-PREBNR
TOTAL-POSTBNR
TF-PREBNR
TF-POSTBNR
RET-PREBNR
RET-POSTBNR
LE-PREBNR
LE-POSTBNR
Inputs
Losses
Missing Nitrogen




Attribution to Claire Buchanan?

# Box Model Boundaries



<u>Source Tracking</u>

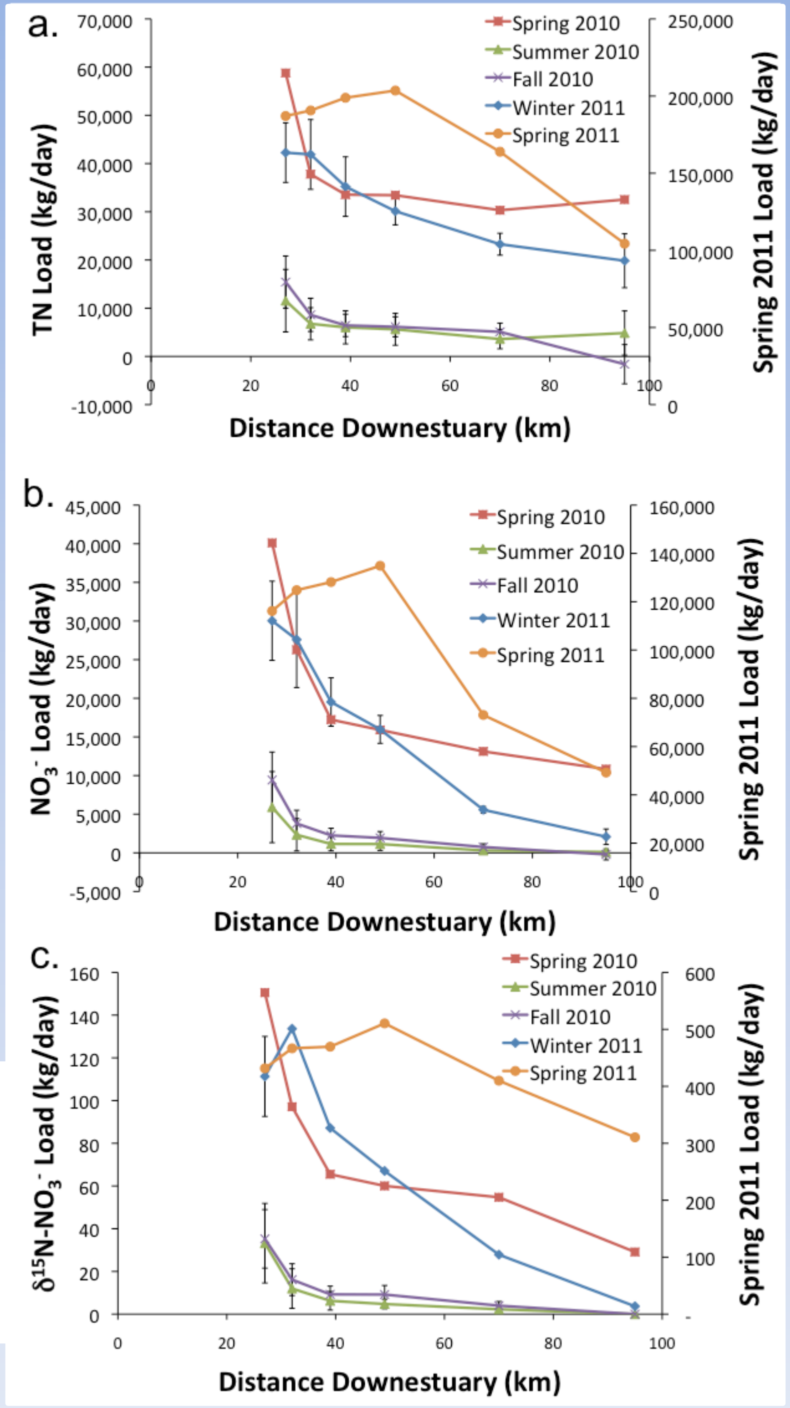
Modeled N loads decreased down estuary.

Depending on the season, export of wastewater effluent to the Chesapeake Bay main stem characteristic of the Blue Plains treatment plant ranged from 1-30% of inputs.

Remineralization of N inputs was evident in changed ratio of *δN15 and δO18* isotopes of nitrate.

Values estimated using this approach similar to direct flux measurements.

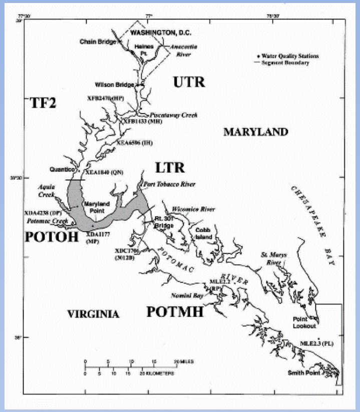
| | Total Inputs (kg/day) | % of Inputs from Blue Plains* | Net Export (kg/day) | % of Blue Plains Inputs Exported |
|---|---|---|---|---|
| Winter | 49,150 ± 30,323 | 10 ± 13 | 19,844 ± 13,728 | 3.7 ± NA |
| Spring | 13,5317 ± 14,614 | 8 ± 0.8 | 68,431 ± 48,060 | 71 ± 20 |
| Summer | 13,888 ± 596 | 38 ± 3 | 4,853 ± 8,326 | 19 ± 11 |
| Fall | 15,334 ± 3,700 | 47 ± 13 | -1,613 ± 12,124 | 18 ± 10 |

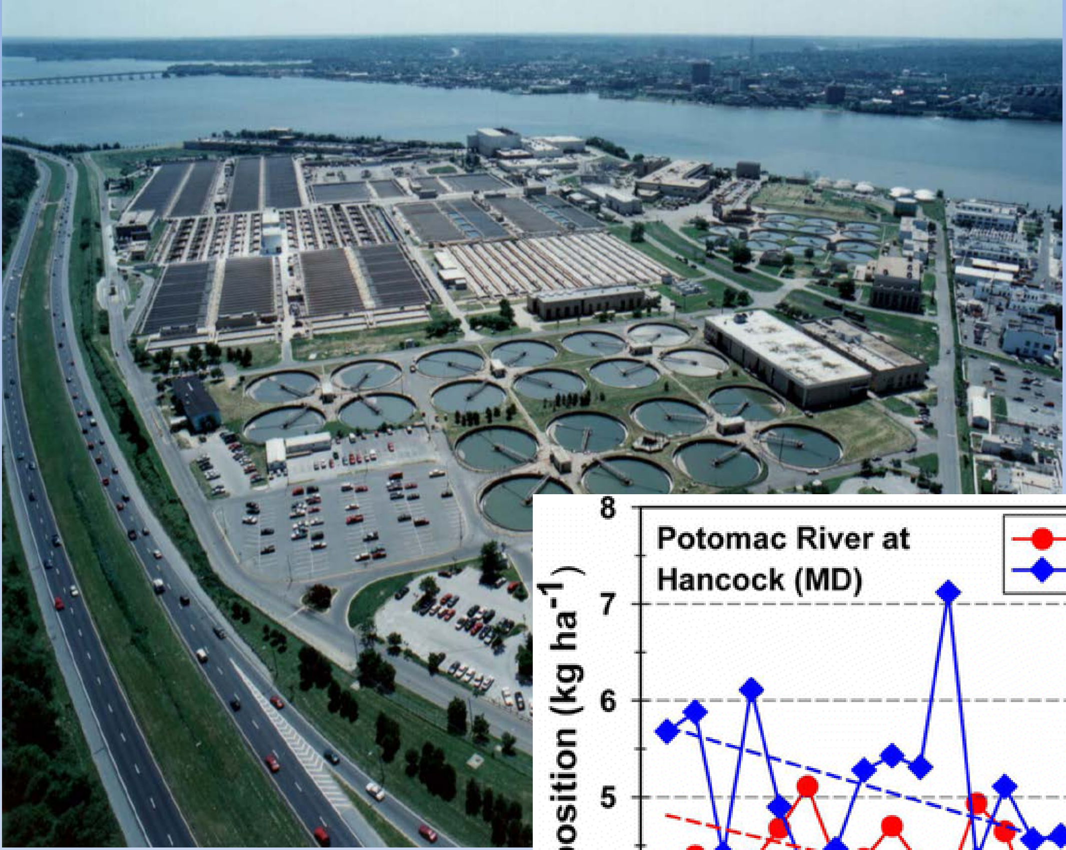


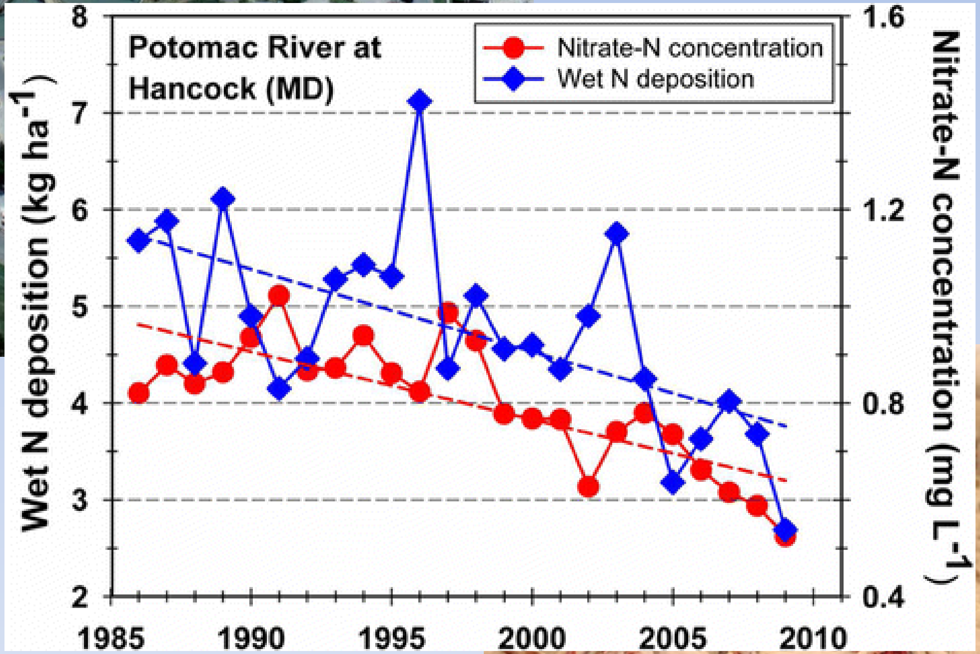
# The Mid-Point Assessment: Integrated Trends and Analysis Team

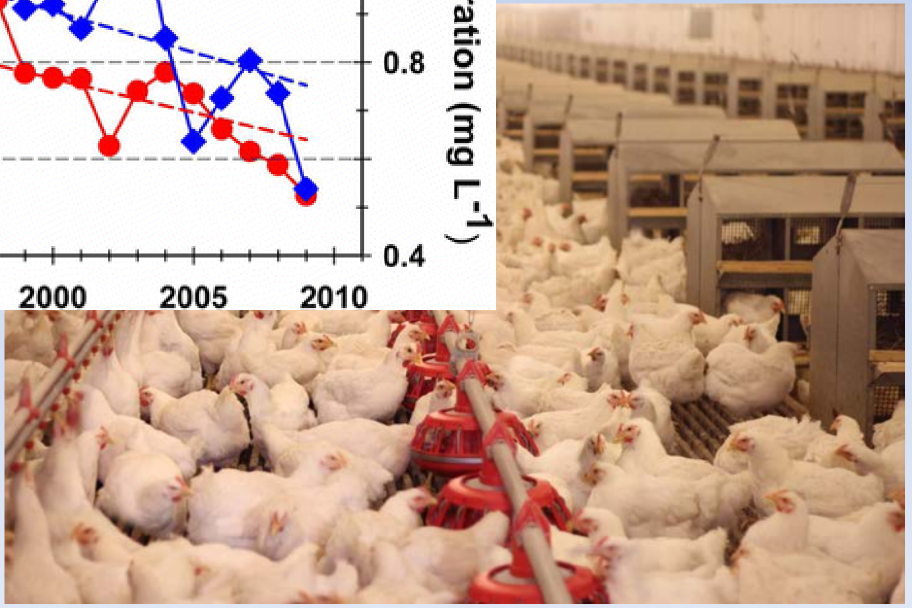
Chesapeake Bay Program

*Science. Restoration. Partnership.*


WASHINGTON, D.C.
Chain Bridge
UTR
TF2
MARYLAND
LTR
POTOH
VIRGINIA
POTMH
CHESAPEAKE BAY
POTOMAC RIVER

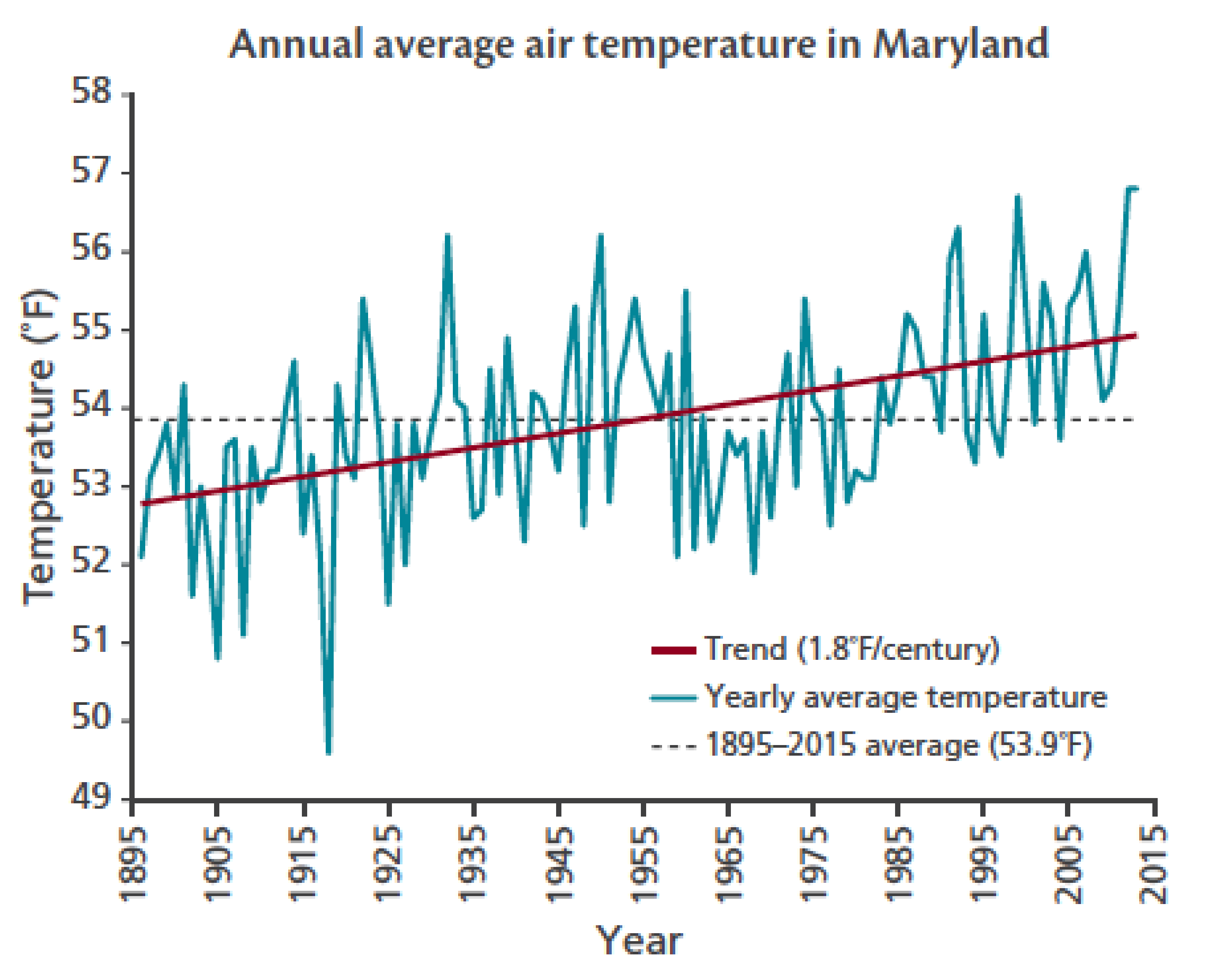



Potomac River at
Hancock (MD)
Nitrate-N concentration
Wet N deposition
Wet N deposition (kg ha-1)
Nitrate-N concentration (mg L-1)
8
7
6
5
4
3
2
1.6
1.2
0.8
0.4
1985
1990
1995
2000
2005
2010



# Climate Indicators Show Impacts on Chesapeake Region

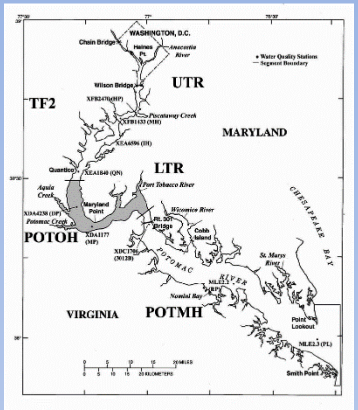
National Climatic Data Center
from http://climatechange.maryland.gov/science/



# Analytical Approach:
# *The Watershed*

- Examine fall line loads and trends
- Determine sources contributing to fall line loads
- Use source analysis to assess role of inputs

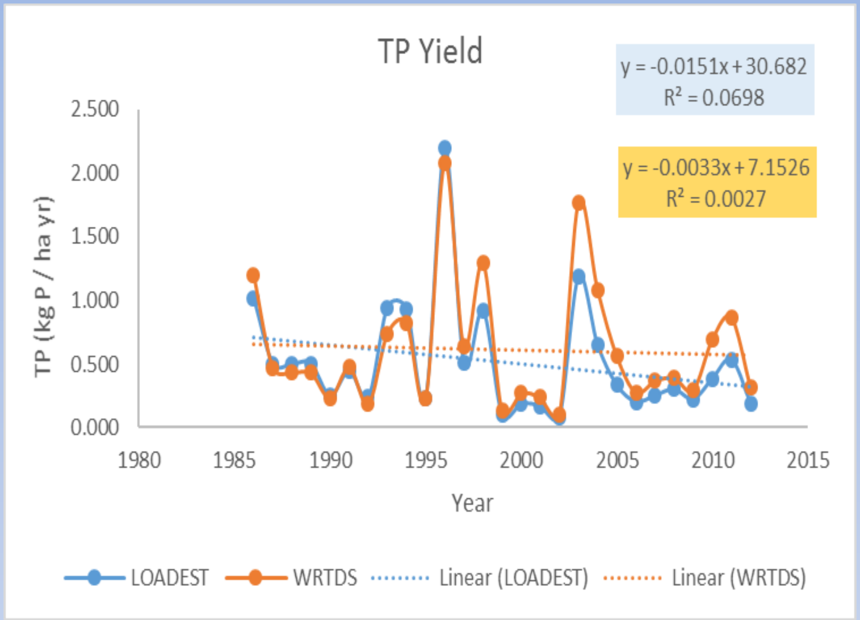
# Analytical Approach:
# *The Estuary*

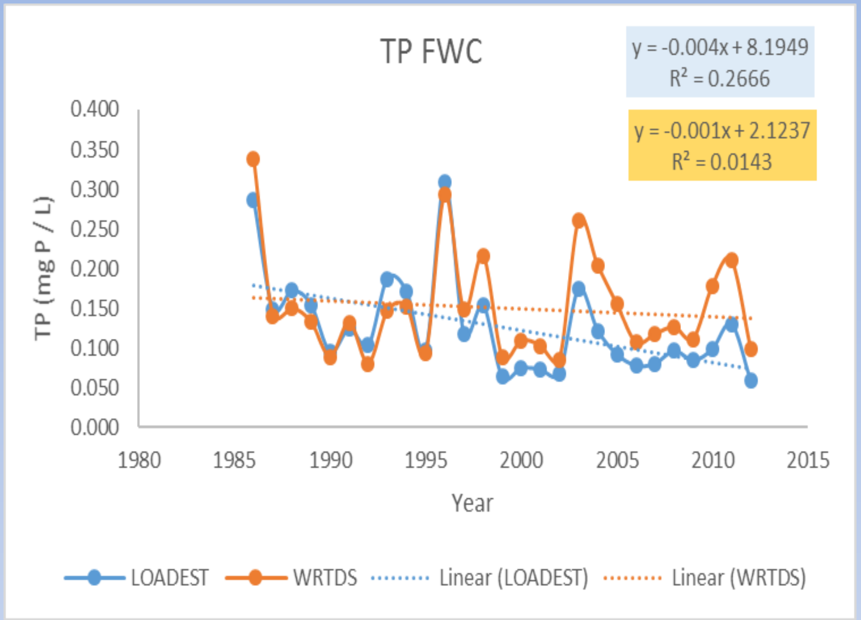


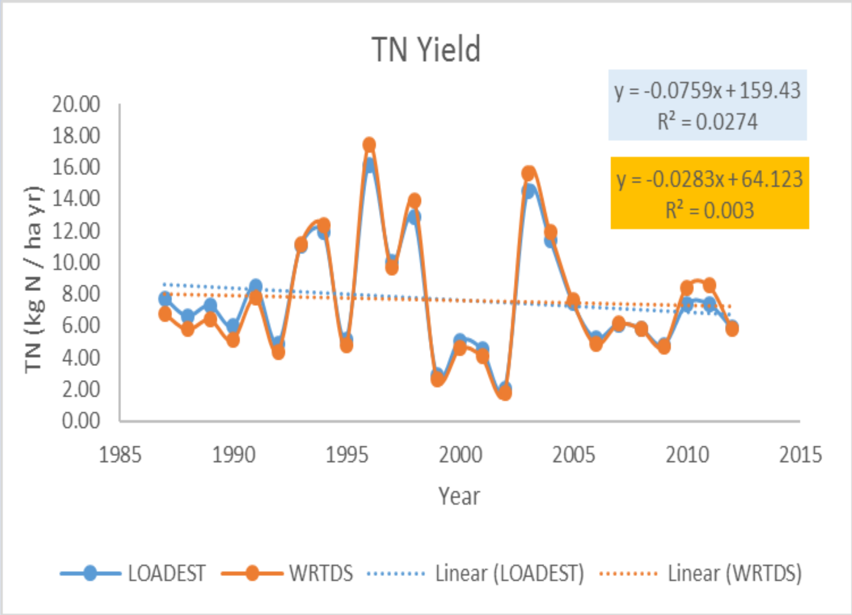

- Test explanatory models related to water quality variables of interest (GAMs)
- Tidal fresh vs Mesohaline
- Think outside the box for explanations

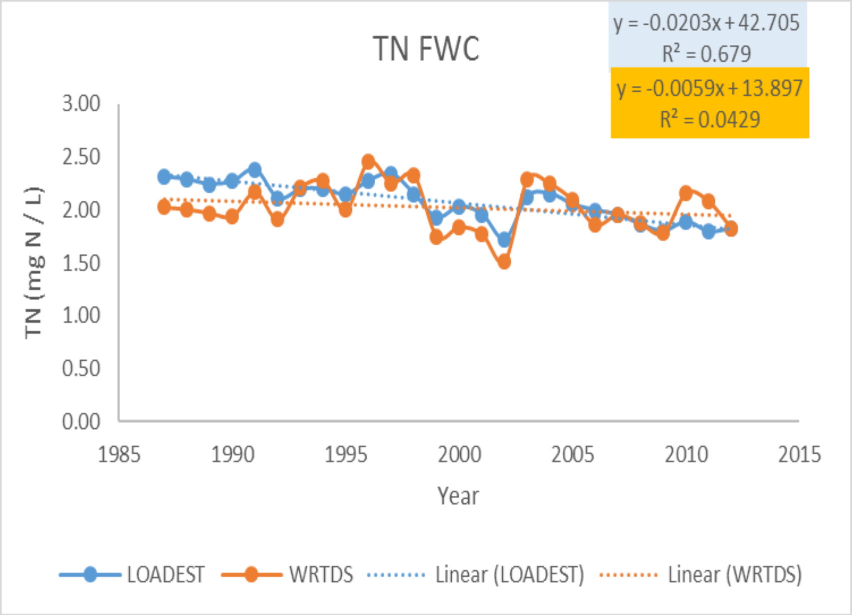


# The Watershed

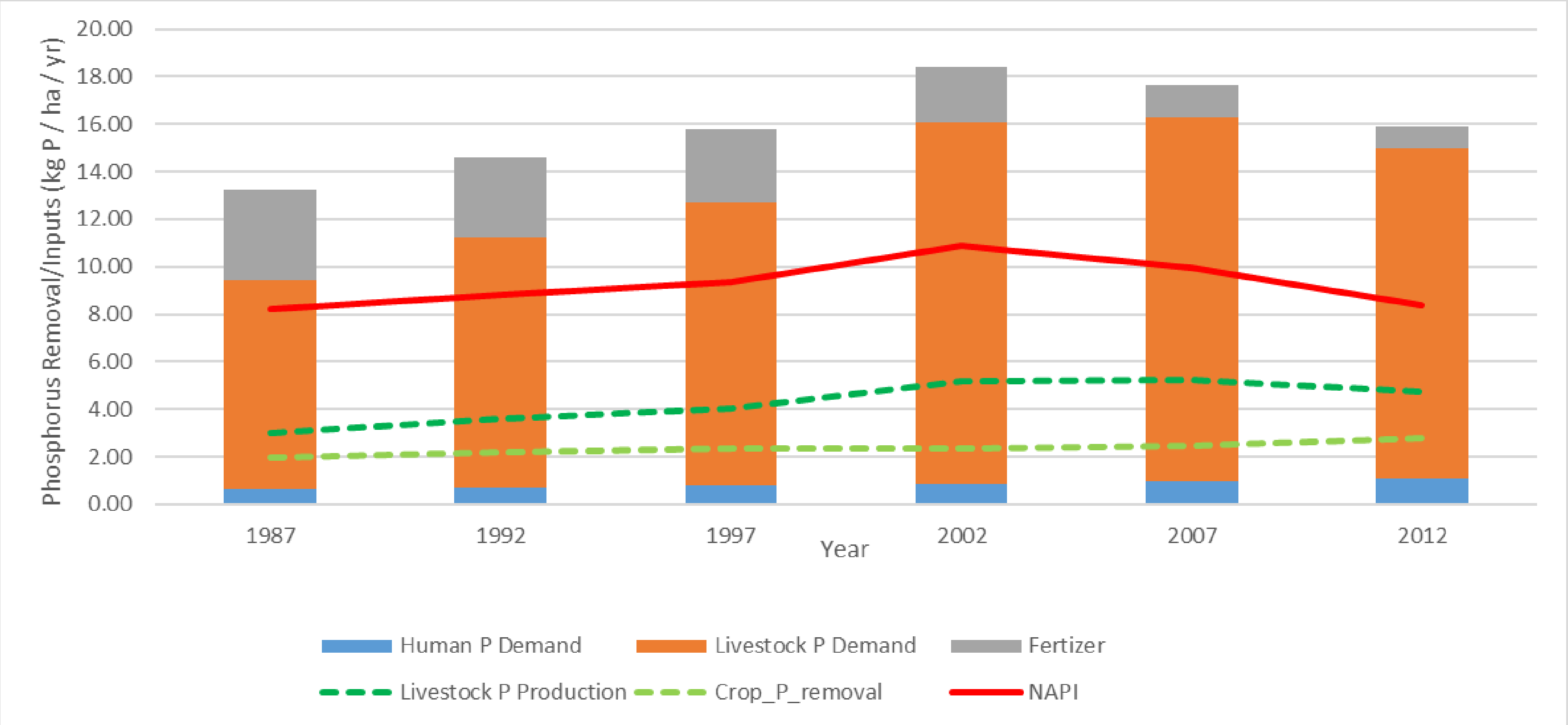


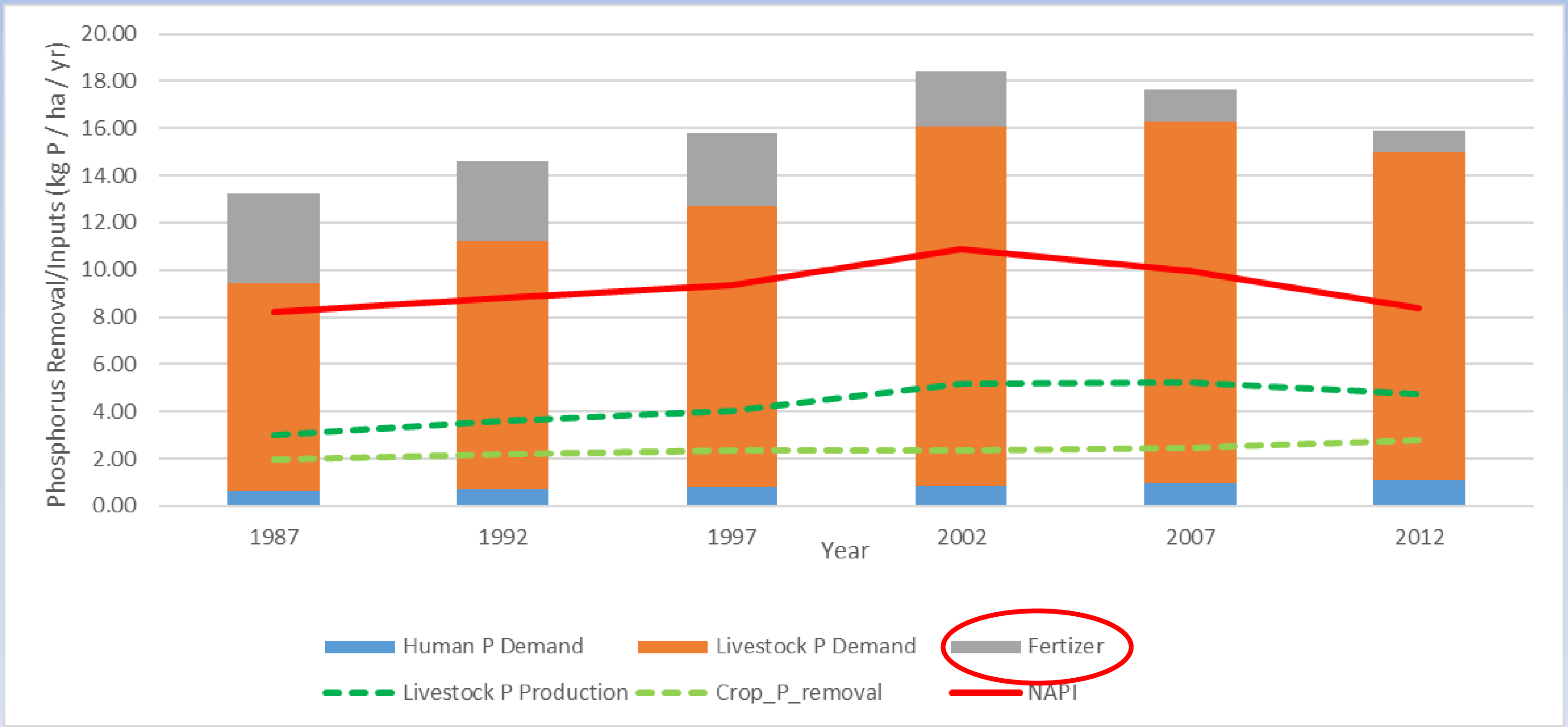



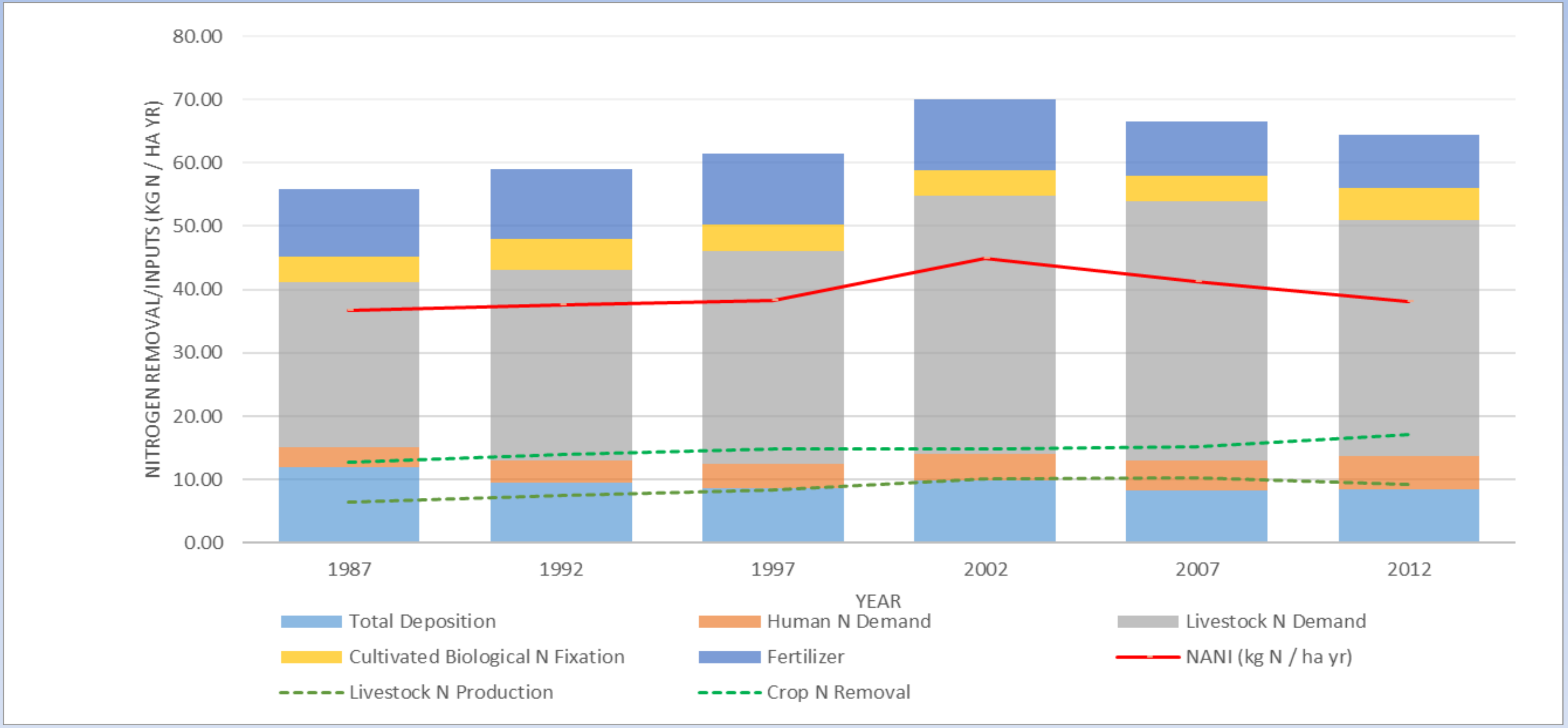
# Net Anthropogenic Inputs - Phosphorus



# Net Anthropogenic Inputs - Phosphorus



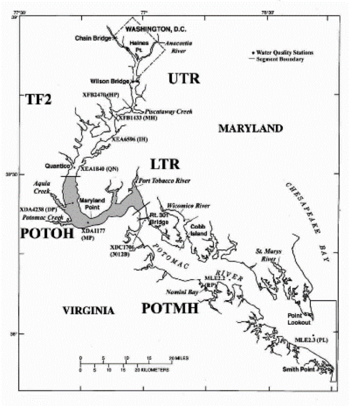
# Net Anthropogenic Inputs - Nitrogen



# Net Anthropogenic Inputs - Nitrogen

| | MANN KENDALL | LINEAR REGRESSION | | | GAM | | |
|---|---|---|---|---|---|---|---|
| | Tau | Δ(abs) (kg N $ha^{-1}$ $yr^{-1}$) | 95% C.I. of Δ(abs) | | Δ(abs) (kg N $ha^{-1}$ $yr^{-1}$) | 95% C.I. of Δ(abs) | |
| **LIVESTOCK N CONSUMPTION** | **0.73** | **15.05** | **11.80** | **18.31** | **14.92** | **13.61** | **16.47** |
| **AGRICULTURAL N FIXATION** | -0.24* | -0.23 | -0.75 | 0.29 | -0.19 | -0.67 | 0.20 |
| **LIVESTOCK N PRODUCTION** | **0.73** | **3.76** | **2.95** | **4.58** | **3.75** | **3.36** | **4.14** |
| **FERTILIZER N APPLICATION** | **-0.41** | **-3.64** | **-4.94** | **-2.35** | **-3.63** | **-4.59** | **-2.80** |
| **CROP N PRODUCTION** | **0.80** | **2.56** | **1.38** | **3.75** | **2.41** | **0.99** | **3.51** |
| **HUMAN N CONSUMPTION** | **1.00** | **2.13** | **2.08** | **2.18** | **2.12** | **1.93** | **2.28** |
| **POINT SOURCE TN LOADS** | **-0.81** | **-0.45** | **-0.55** | **-0.36** | **-0.45** | **-0.50** | **-0.40** |
| **TOTAL N DEPOSITION** | **-0.48** | **-3.64** | **-5.65** | **-1.64** | **-3.40** | **-5.30** | **-1.73** |
| **NANI** | 0.26* | 3.33 | -0.76 | 7.43 | 3.36 | 0.74 | 6.23 |

# Analytical Approach: *The Estuary*




- Freshwater:

chla ~ seas + s(doy, bs = "cc") +s(flow,by=seas) + s(PAR,by=seas) + s(wtemp,by=seas) +s(bivalves,by=seas)+s(WWtn,by=seas) +s(RIM-TN,by=seas)+s(RIM-TP,by=seas)

- Mesohaline:

chla ~ seas + s(doy, bs = "cc") +s(stratification,by=seas) + s(PAR,by=seas) + s(wtemp,by=seas) +s(main-TN,by=seas)+s(main-TP,by=seas) +s(RIM-TN,by=seas)+s(RIM-TP,by=seas)

# Trends in Global Cloud Cover in Two Decades of HIRS Observations

Donald Wylie

*Space Science and Engineering Center, University of Wisconsin—Madison, Madison, Wisconsin*

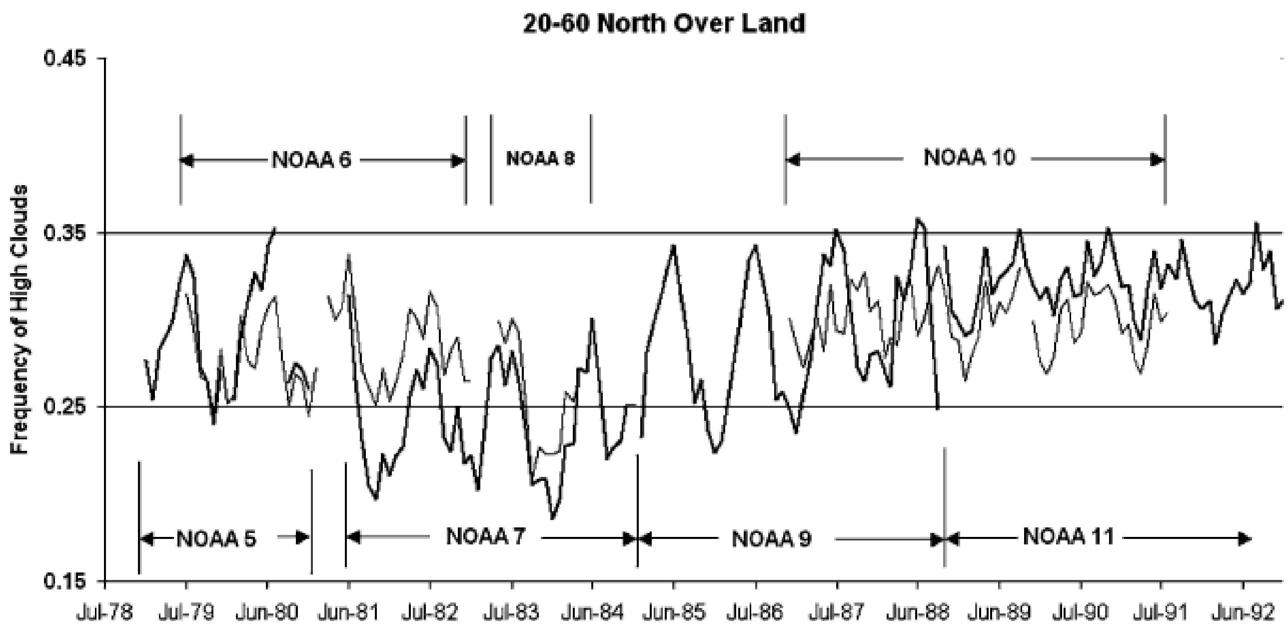
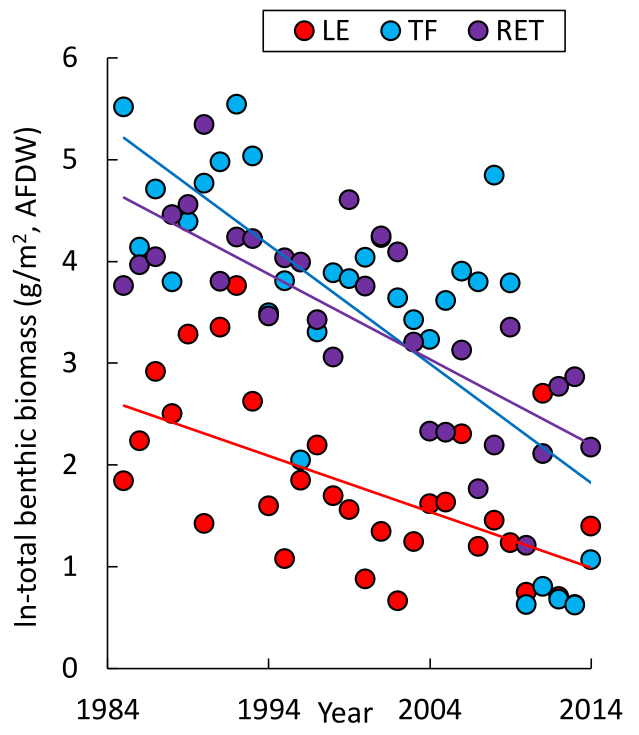
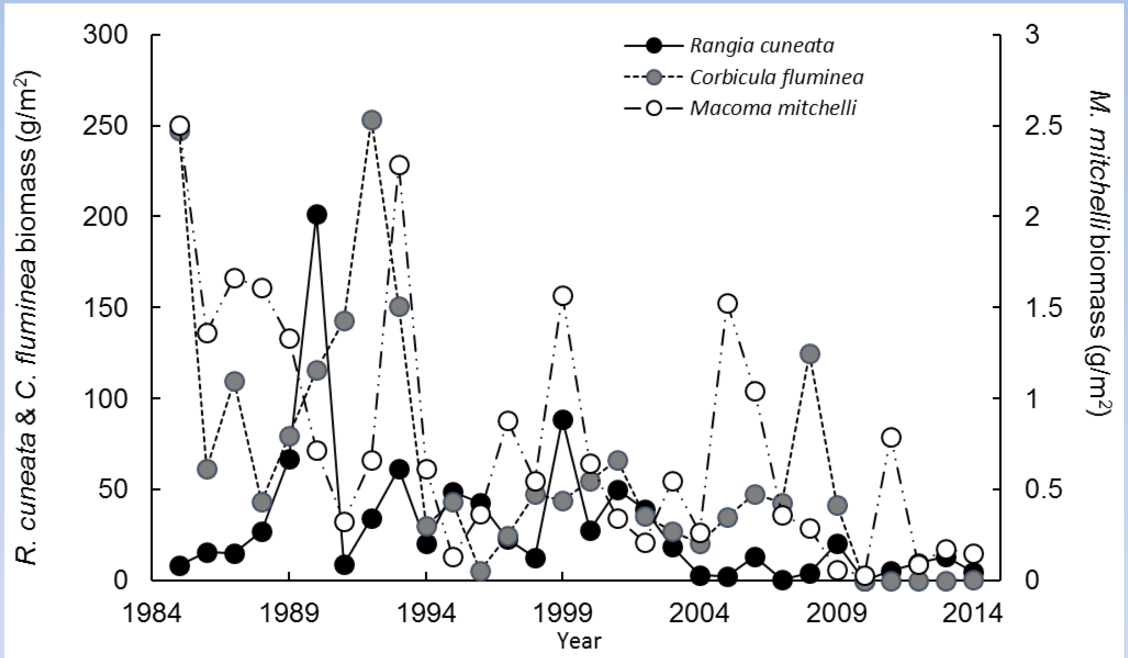


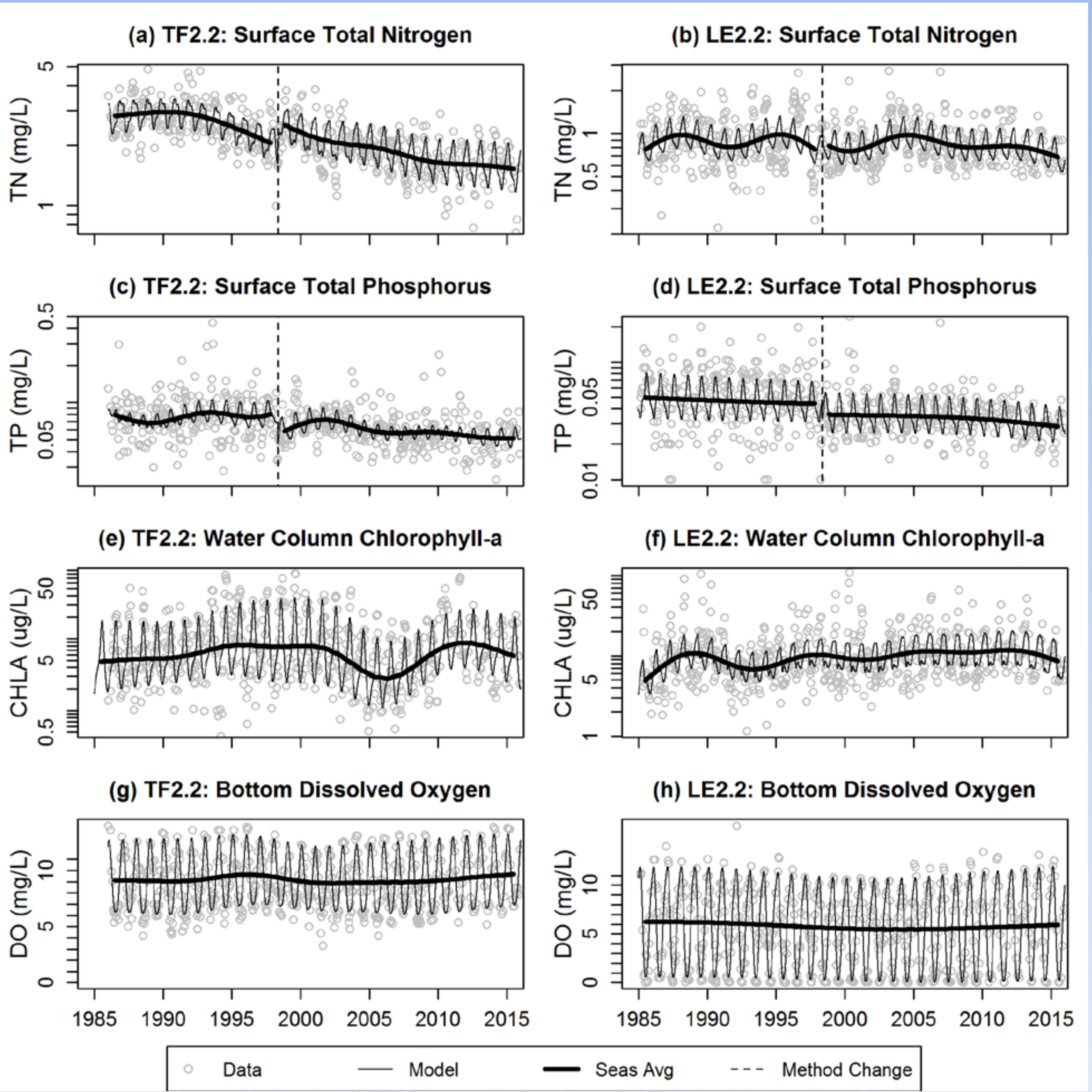

FIG. 3. The monthly average frequency of high clouds from 20° to 60°N showing the time period of individual satellites.

# Clams Tell A Story…

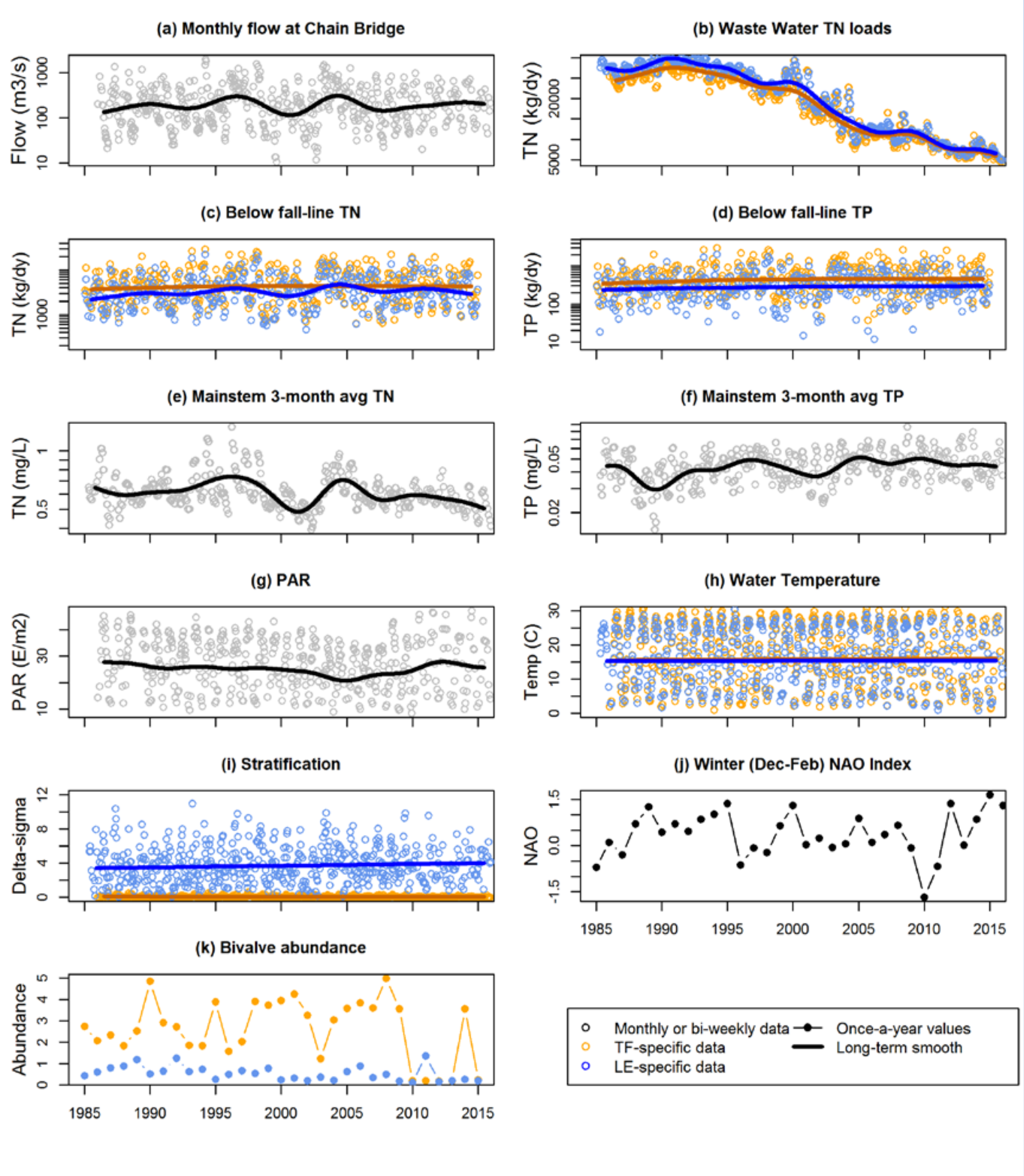


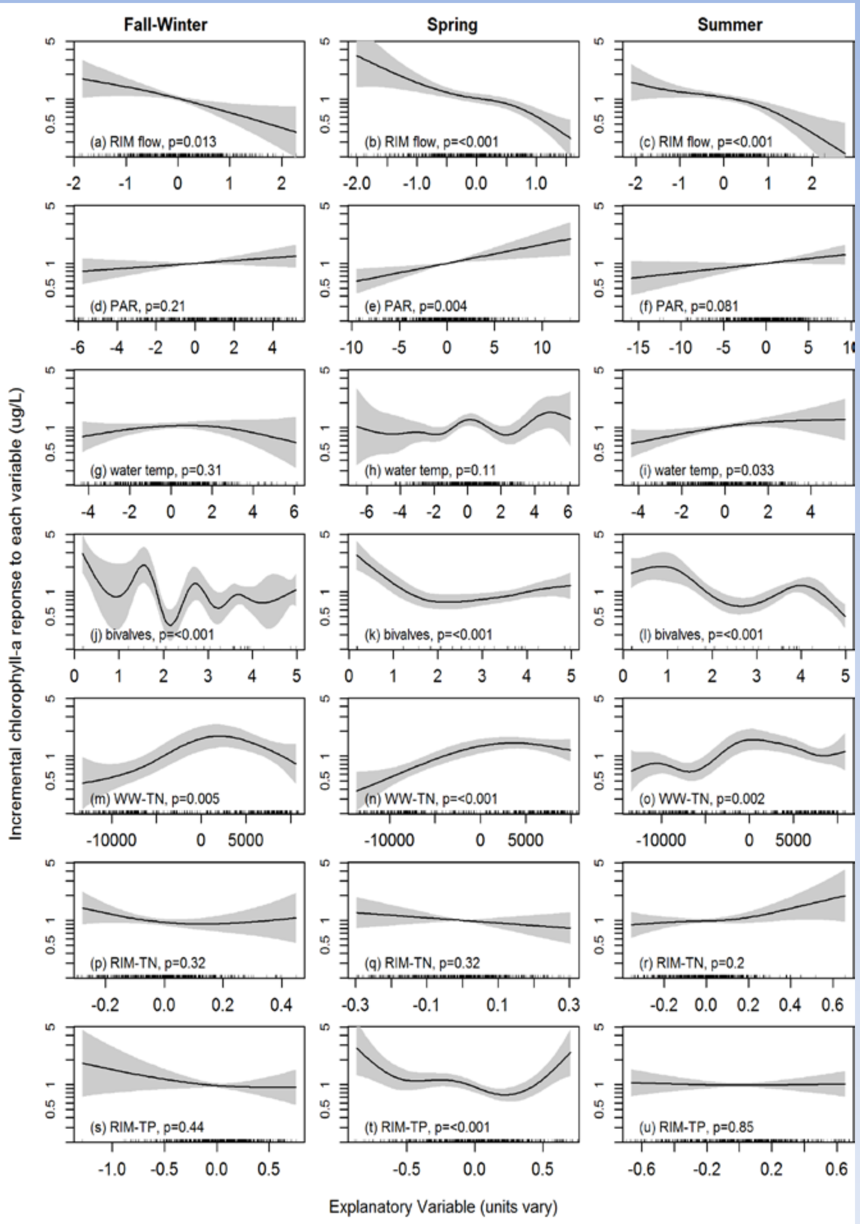
# Response Variables

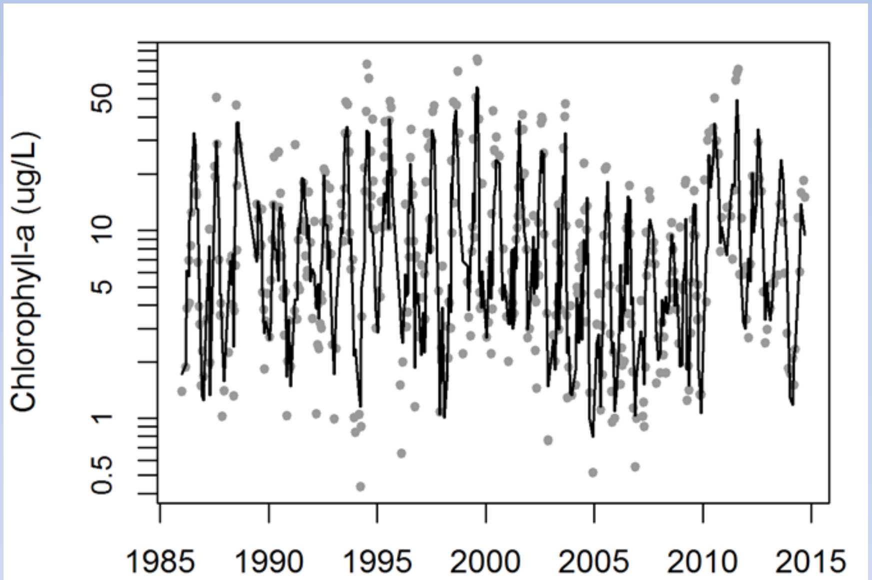


# Explanatory Variables

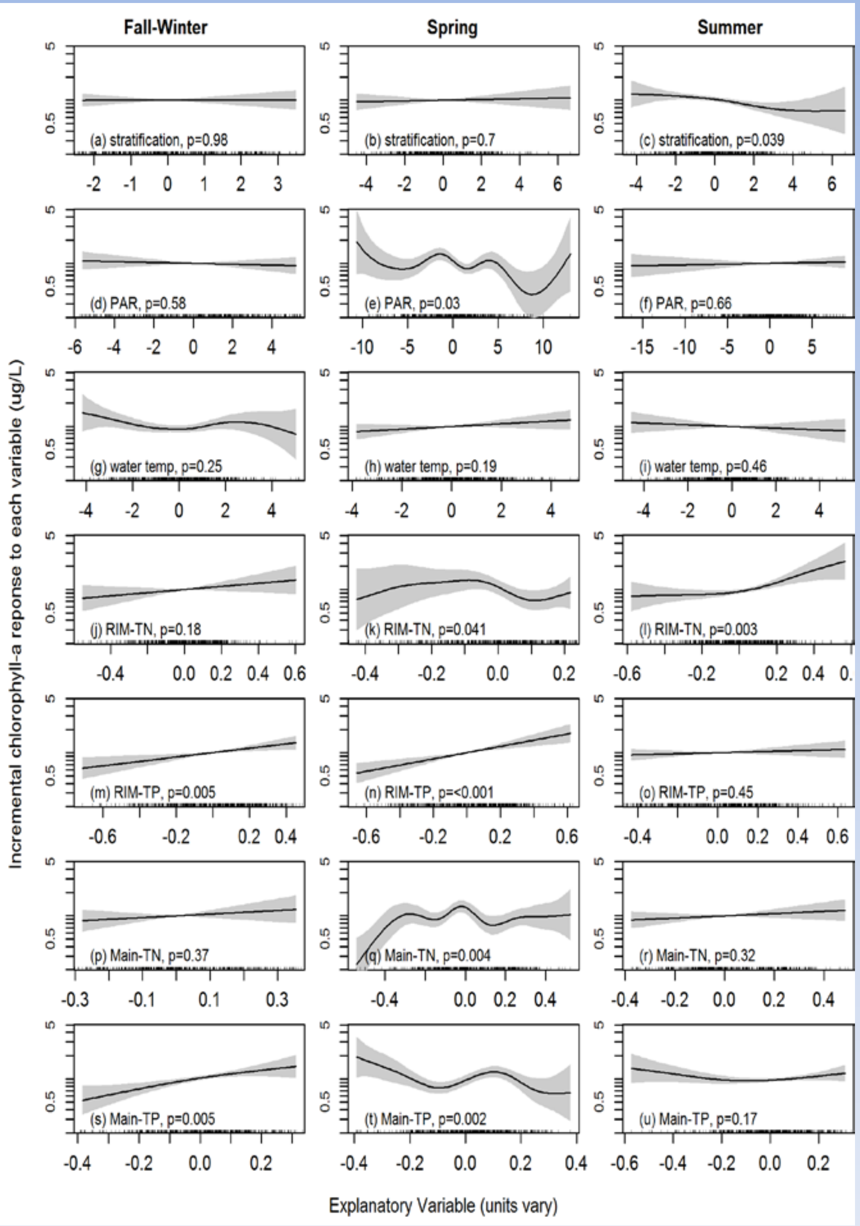


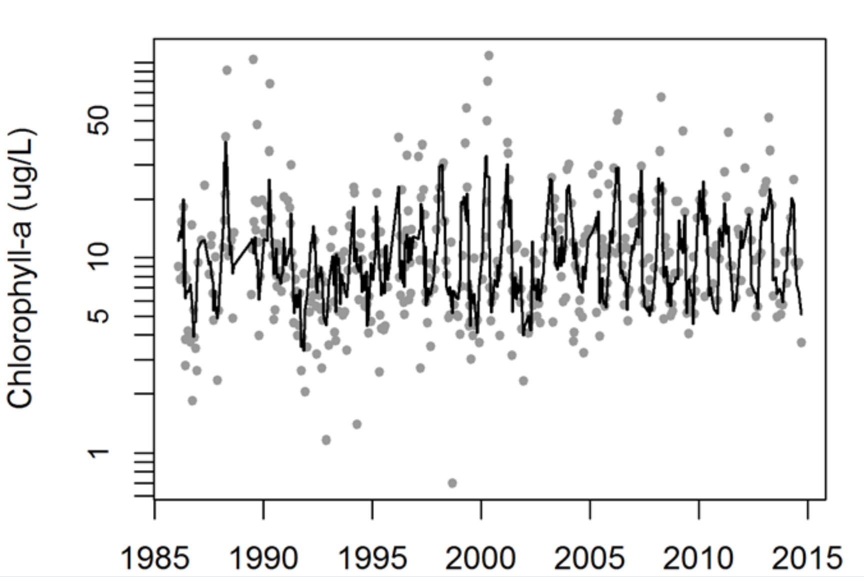
# Fitted GAM components - FW



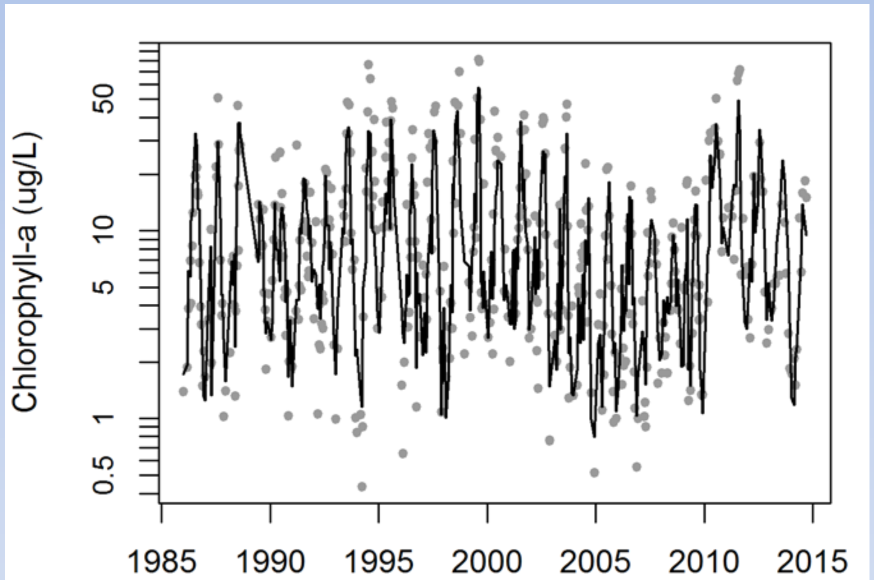



# Fitted GAM components - MESO

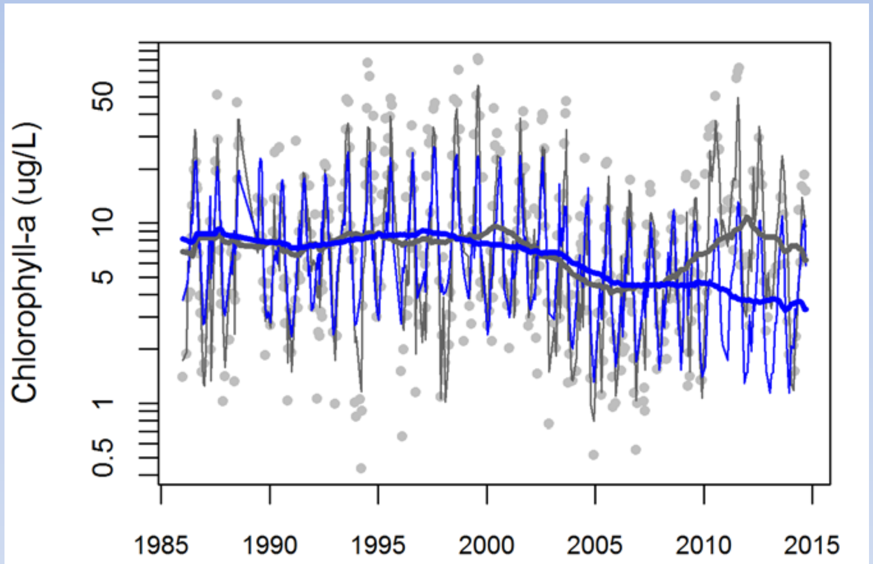


# Fun with GAMs:
# *What would Chl look like in a less variable world?*

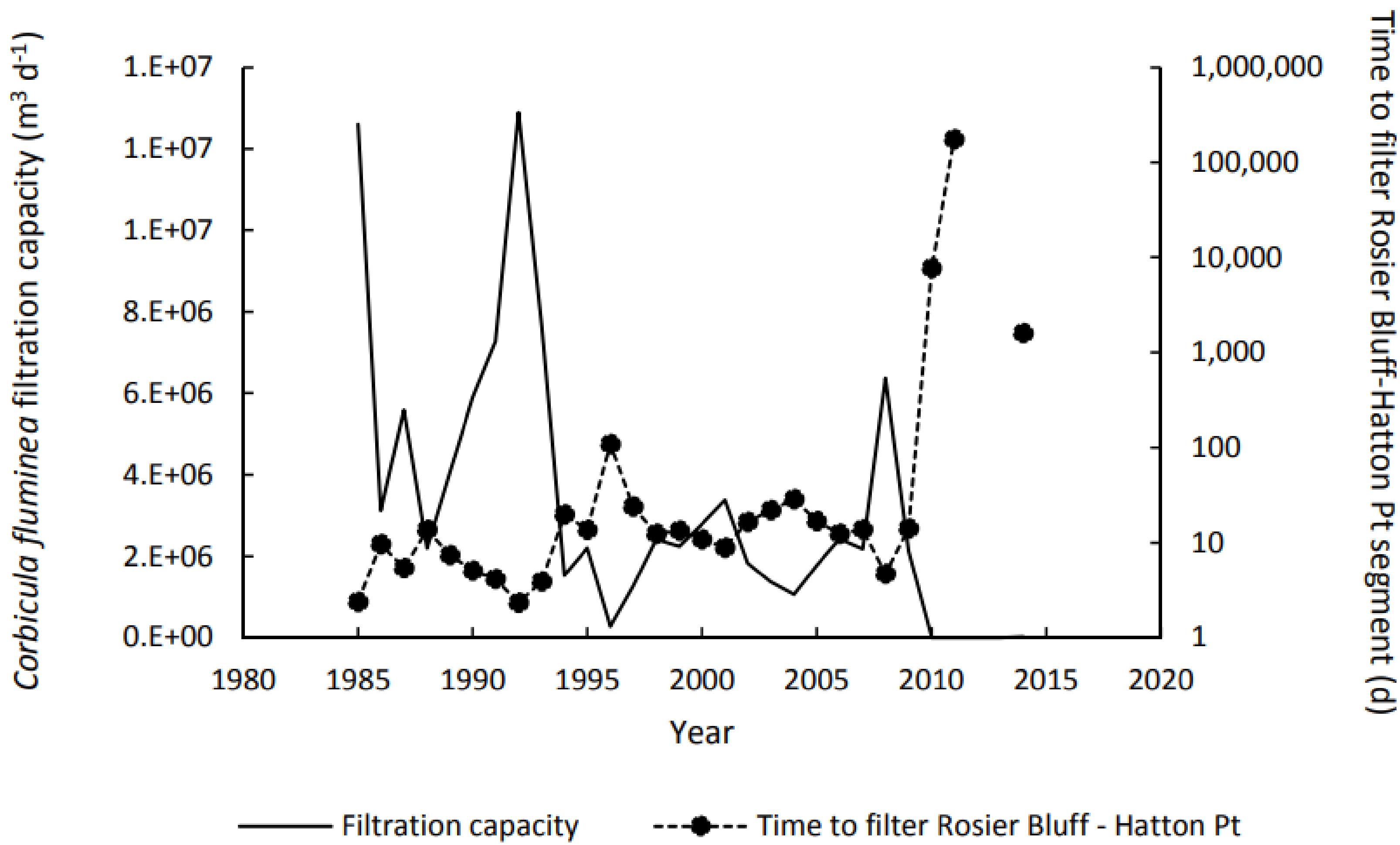



With time series untouched….

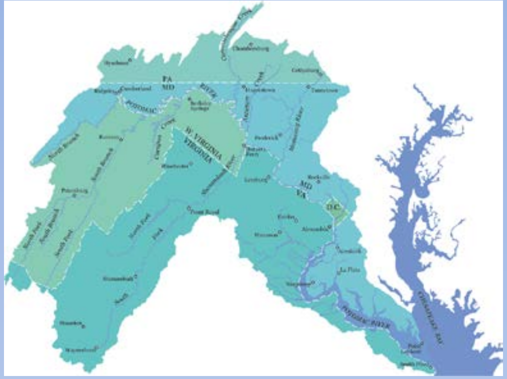



Manipulating Clams and Climate

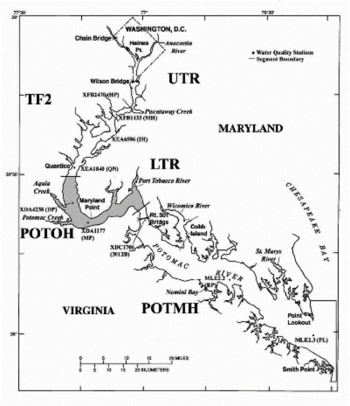
# *Corbicula!*



*Corbicula fluminea* filtration capacity (m3 d-1)
1.E+07
1.E+07
1.E+07
8.E+06
6.E+06
4.E+06
2.E+06
0.E+00
1980
1985
1990
1995
2000
2005
2010
2015
2020
Year
1,000,000
100,000
10,000
1,000
100
10
1
Time to filter Rosier Bluff-Hatton Pt segment (d)
Filtration capacity
Time to filter Rosier Bluff - Hatton Pt



# Conclusions




- **Quantifying** management effects is possible from empirical data
- **Changing** agricultural practices mask some declines in nutrient sources
- **Climatic** factors & **Ecological** considerations helpful in understanding lack of expected response
- Potomac Estuary water quality responsive to different factors in **tidal fresh versus mesohaline**

# With Gratitude:

Chesapeake Bay Program

*Science. Restoration. Partnership.*

Melinda Forsyth, Jeff Cornwell, Walter Boynton, Jeremy Testa, Cindy Palinkas, Casey Hodgkins, Michael Pennino

Versar Environmental Services

DC WATER





# Net Anthropogenic Inputs - Phosphorus

| | MANN KENDALL | LINEAR REGRESSION | | | GAM | | |
|---|---|---|---|---|---|---|---|
| | Tau (%) | Δ(abs) (kg P $ha^{-1}$ $yr^{-1}$) | 95% C.I. of Δ(abs) | | Δ(abs) (kg P $ha^{-1}$ $yr^{-1}$) | 95% C.I. of Δ(abs) | |
| HUMAN P CONSUMPTION | 0.74 | 0.43 | 0.42 | 0.44 | 0.43 | 0.39 | 0.46 |
| LIVESTOCK P CONSUMPTION | 0.74 | 6.84 | 5.48 | 8.19 | 6.80 | 6.31 | 7.43 |
| LIVESTOCK P PRODUCTION | -0.92 | 2.33 | 1.87 | 2.79 | 2.32 | 2.13 | 2.49 |
| FERTILIZER P APPLICATION | 0.82 | -3.02 | -3.51 | -2.53 | -2.93 | -3.74 | -2.10 |
| CROP P PRODUCTION | -0.90 | 0.48 | 0.29 | 0.67 | 0.44 | 0.19 | 0.62 |
| POINT SOURCE TP LOADS | 0.45 | -0.13 | -0.15 | -0.11 | -0.13 | -0.14 | -0.12 |
| NAPI | 0.74 | 1.45 | 0.38 | 2.53 | 1.51 | 0.76 | 2.10 |