USGS
science for a changing world

Non-tidal network – nutrient trend results

Robert M. Hirsch
Research Hydrologist

September 13, 2016

U.S. Department of the Interior
U.S. Geological Survey

Acknowledgements

- **Load and Trend Analysis** Team Lead: Doug Moyer

  Jeff Chanat, Joel Blomquist, Mike Mallonee, Gavin Yang, Ken Hyer, Many Others!!, Mike Langland, Bob Hirsch

- **Water-Quality Monitoring Partners**

U.S. Environmental Protection Agency
NY State Dept. of Env. Conservation
Susquehanna River Basin Comm.
DE Dept. Natural Resources and Env. Control
VA Dept. of Env. Quality
U.S. Geological Survey (All Bay States)
PA Dept. of Env. Protection
DC Dept. of the Environment
MD Dept. of Natural Resources
WV Dept. of Env. Protection
WV Dept. of Ag.

USGS

Starts with water quality samples at the 117-station nontidal network

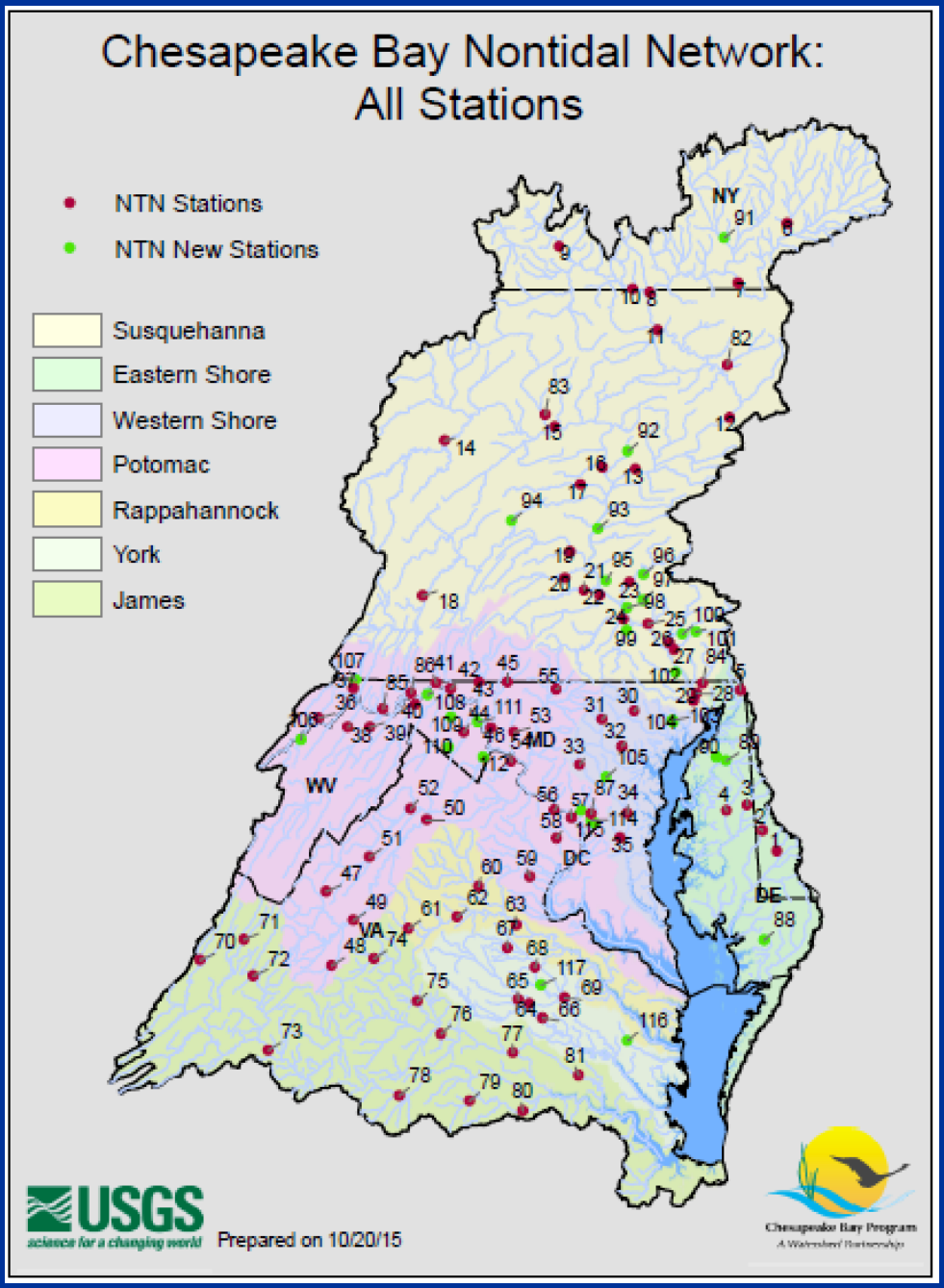
At each station annually:
12 routine and 8 stormflow samples

Total samples collected across NTN = 2,340 annually

Plus daily discharge data at all sites

USGS

Chesapeake Bay Nontidal Monitoring Network



How are nitrogen, phosphorus, and suspended-sediment loads responding to restoration activities, and changes in land use, waste-water treatment, population, and other factors?

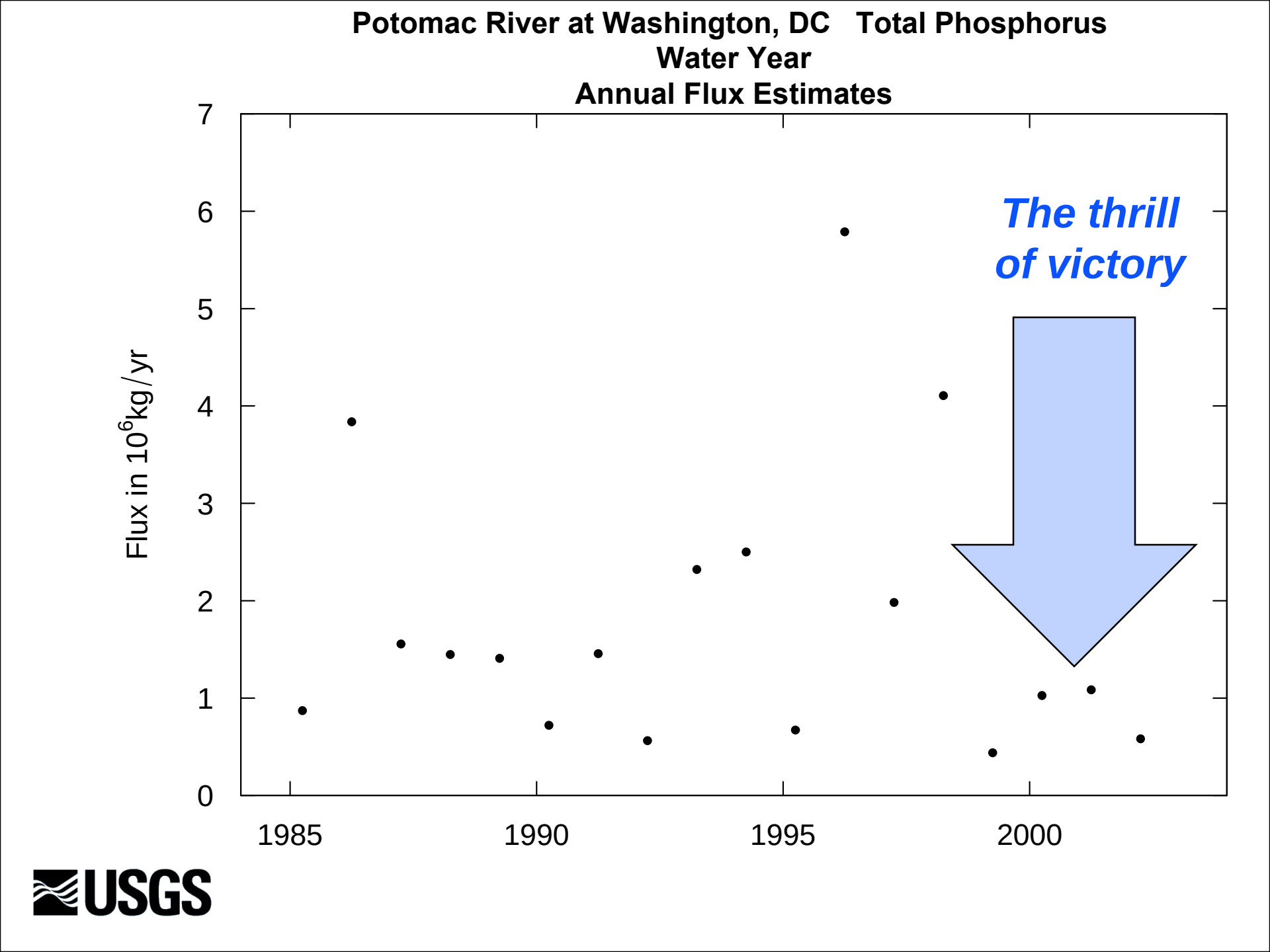
Focus here is on loads but the same analysis method can be applied to looking at trends in concentration.

Analysis issues

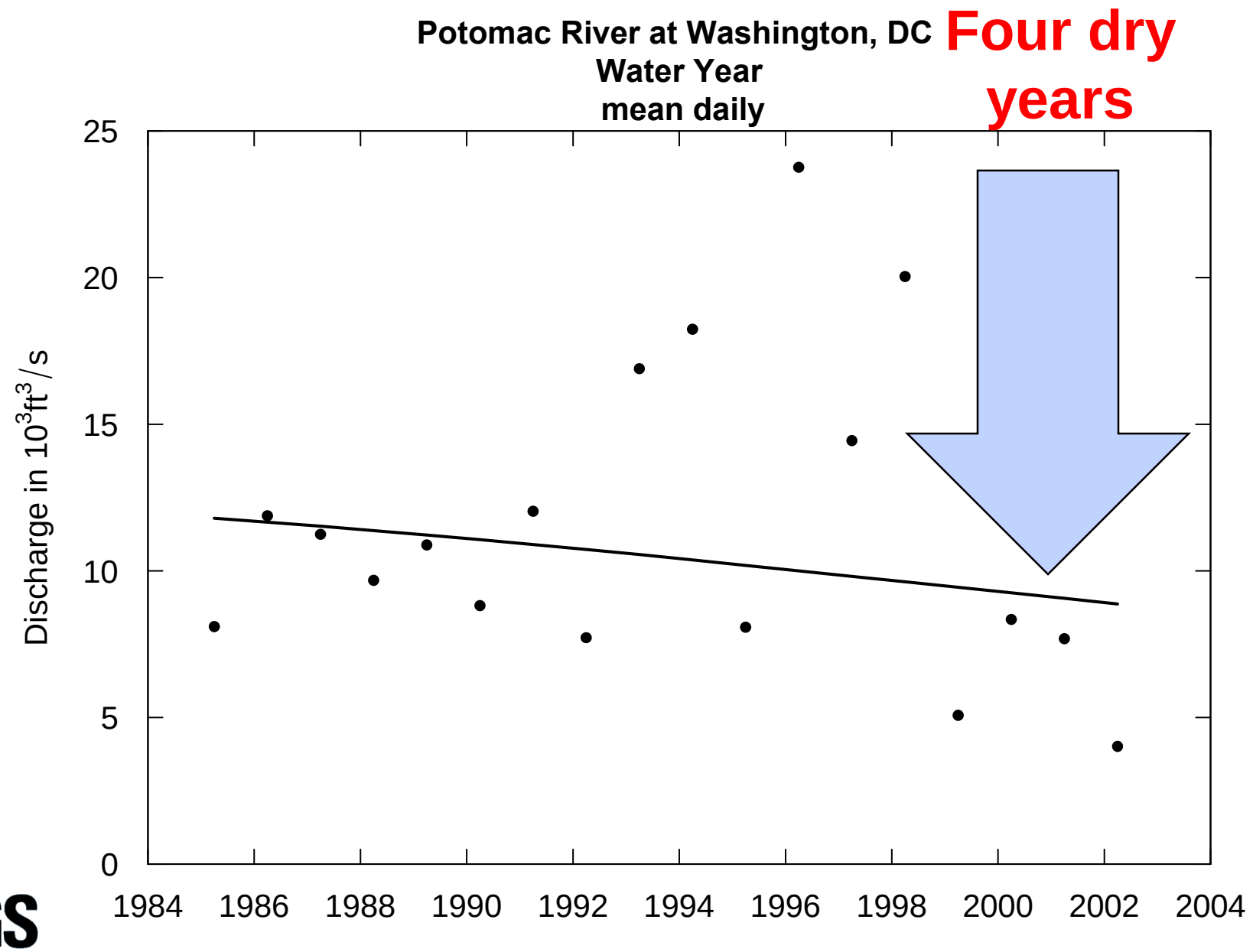
- Highly related to streamflow and season
- Highly skewed
- Sometimes censored

- Assessements of progress can be easily obscured by the random, but persistent, patterns of wet and dry years
- I call this: **“The thrill of victory, the agony of defeat”**

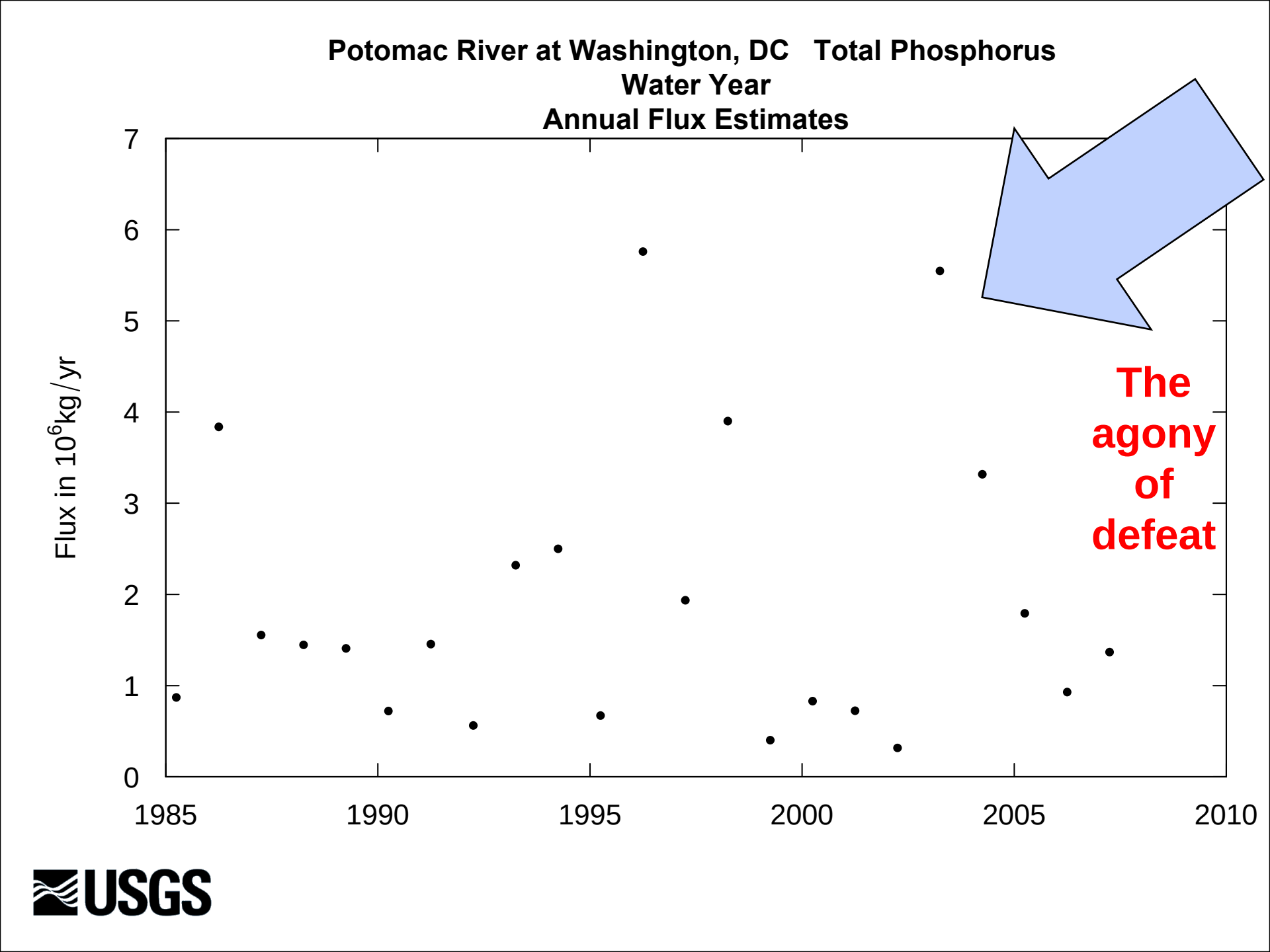
USGS

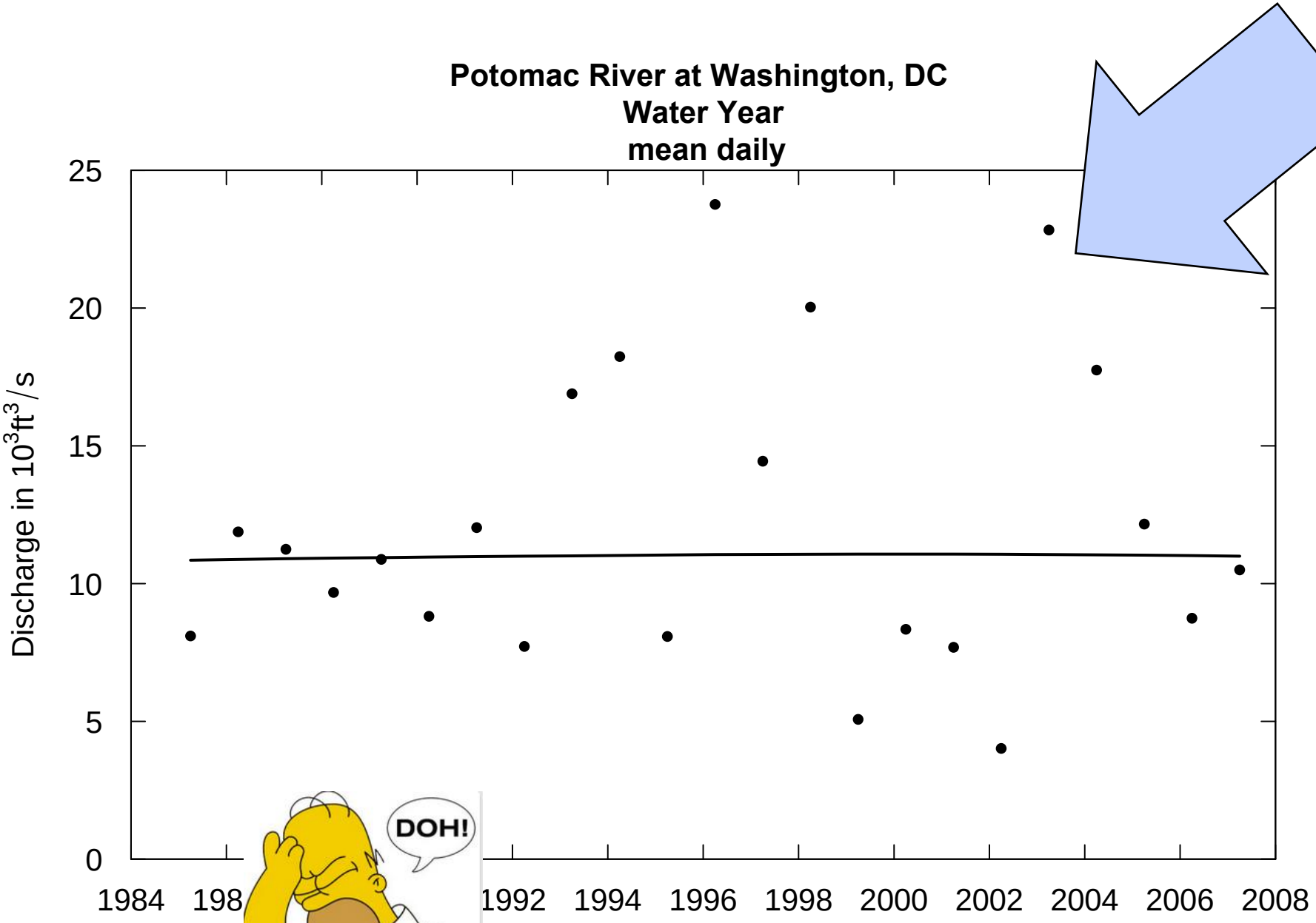

Potomac River at Washington, DC Total Phosphorus
Water Year
Annual Flux Estimates
Flux in 10^6kg/yr
0
1
2
3
4
5
6
7
1985
1990
1995
2000
The thrill of victory
USGS

Look at the discharge record



USGS


Potomac River at Washington, DC Total Phosphorus
Water Year
Annual Flux Estimates
Flux in 10^6kg/yr
0
1
2
3
4
5
6
7
1985
1990
1995
2000
2005
2010
The agony of defeat
USGS



USGS

It's all about the flow!

What's my point here?

- The history of loadings can be very useful to the ecologist trying to understand the drivers of the receiving water body
- But, it is not useful for assessing progress in the watershed.
- We are smarter than Homer! We can deal with the influence of flow.

USGS

Analysis issues

- Trends can be different across seasons
- Trends can be different across flows
- Trends shouldn’t be restricted to be linear or monotonic
- We want a highly flexible model of how daily concentration varies as a function of time, discharge, and season

USGS

Approach

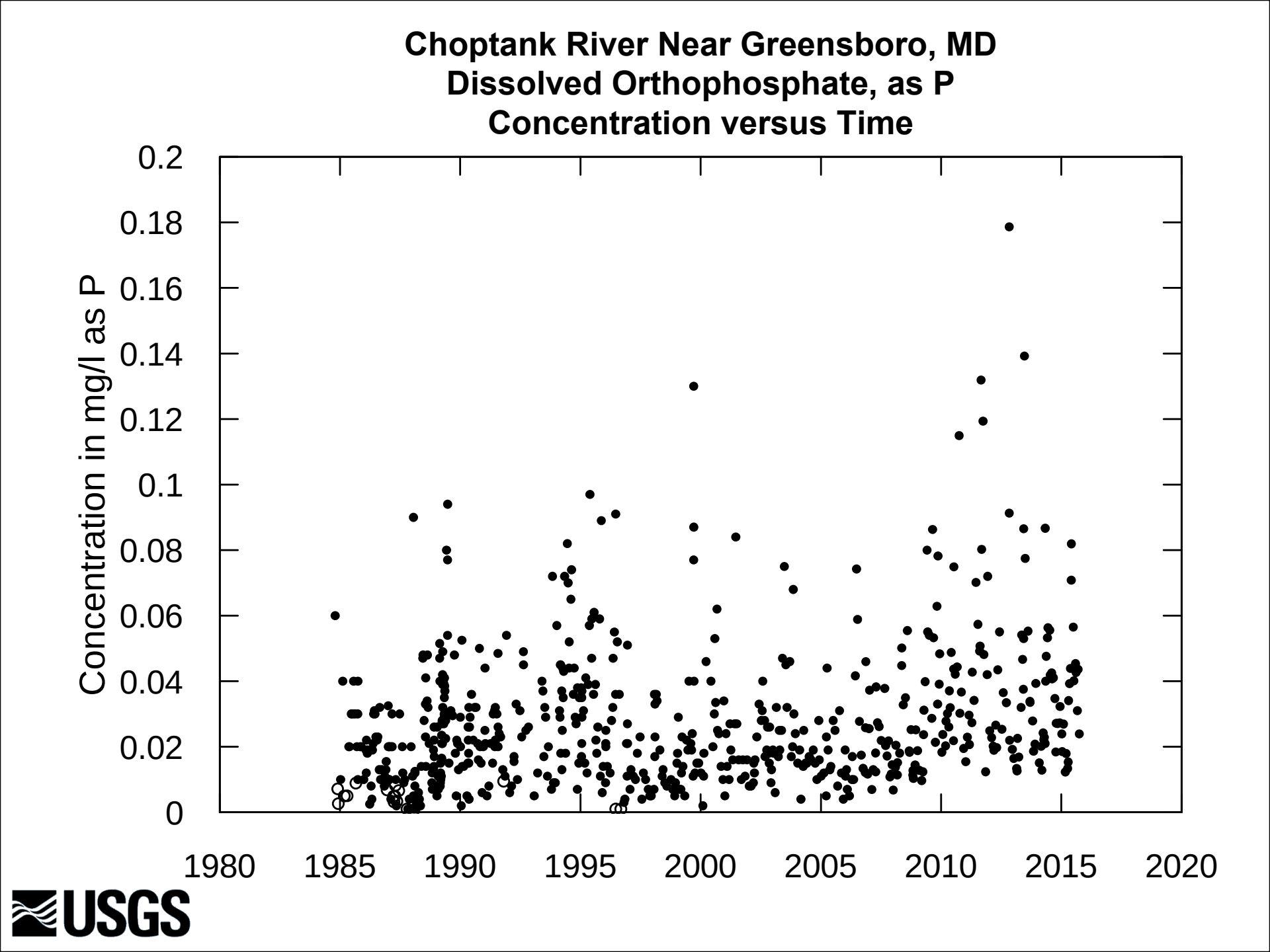
- Flexible statistical model to determine the expected value of concentration for any possible combination of date and discharge during the period of record.
- E[flux] = E[Concentration] * Discharge

USGS

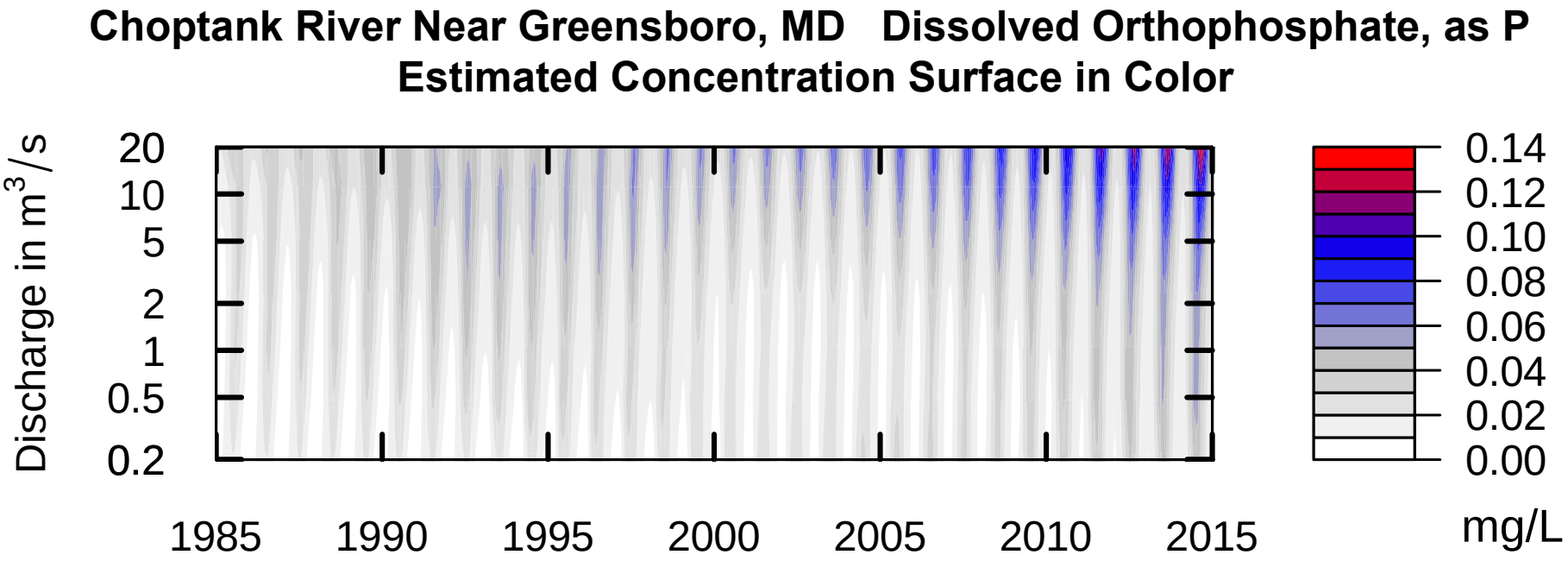
Analysis method

- **Uses Weighted Regressions on Time, Discharge and Season (WRTDS) (Hirsch and others, 2010)**
- **WRTDS bootstrap test for uncertainty analysis (Hirsch and others, 2015)**
- **Software is open source, in R, the EGRET package (Exploration and Graphics for RivEr Trends), available from CRAN**

USGS


Choptank River Near Greensboro, MD
Dissolved Orthophosphate, as P
Concentration versus Time
Concentration in mg/l as P
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1980
1985
1990
1995
2000
2005
2010
2015
2020
USGS

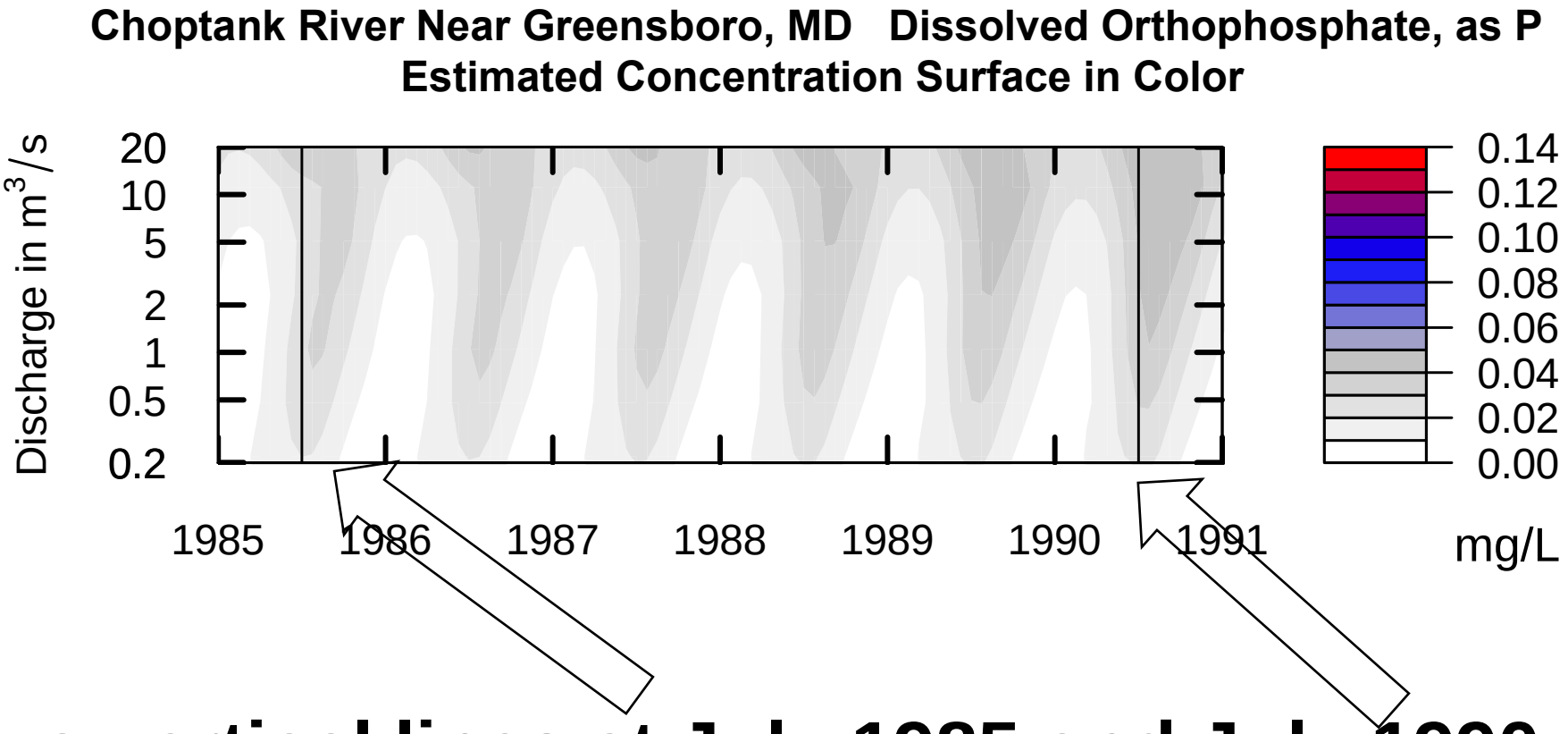
WRTDS characterizes the evolving relationship of concentration to season and discharge



Let's zoom in on parts of this plot

USGS

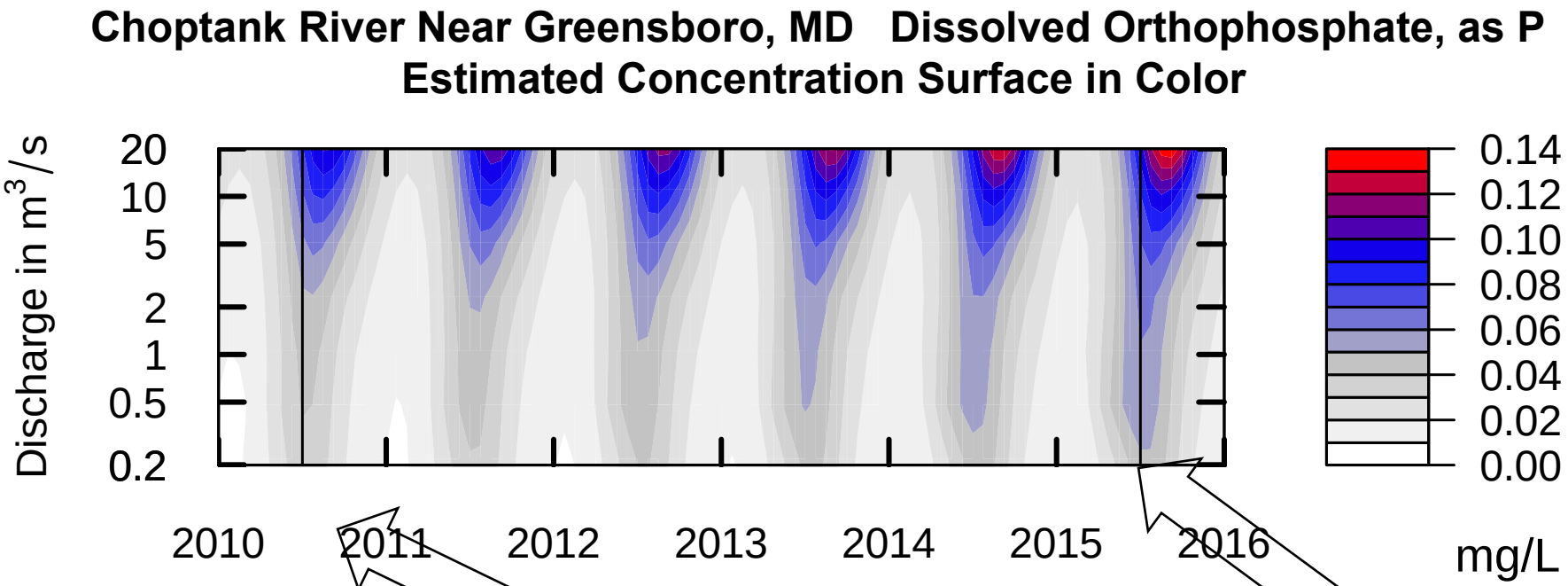
First 6 years of the model



Two vertical lines at July 1985 and July 1990

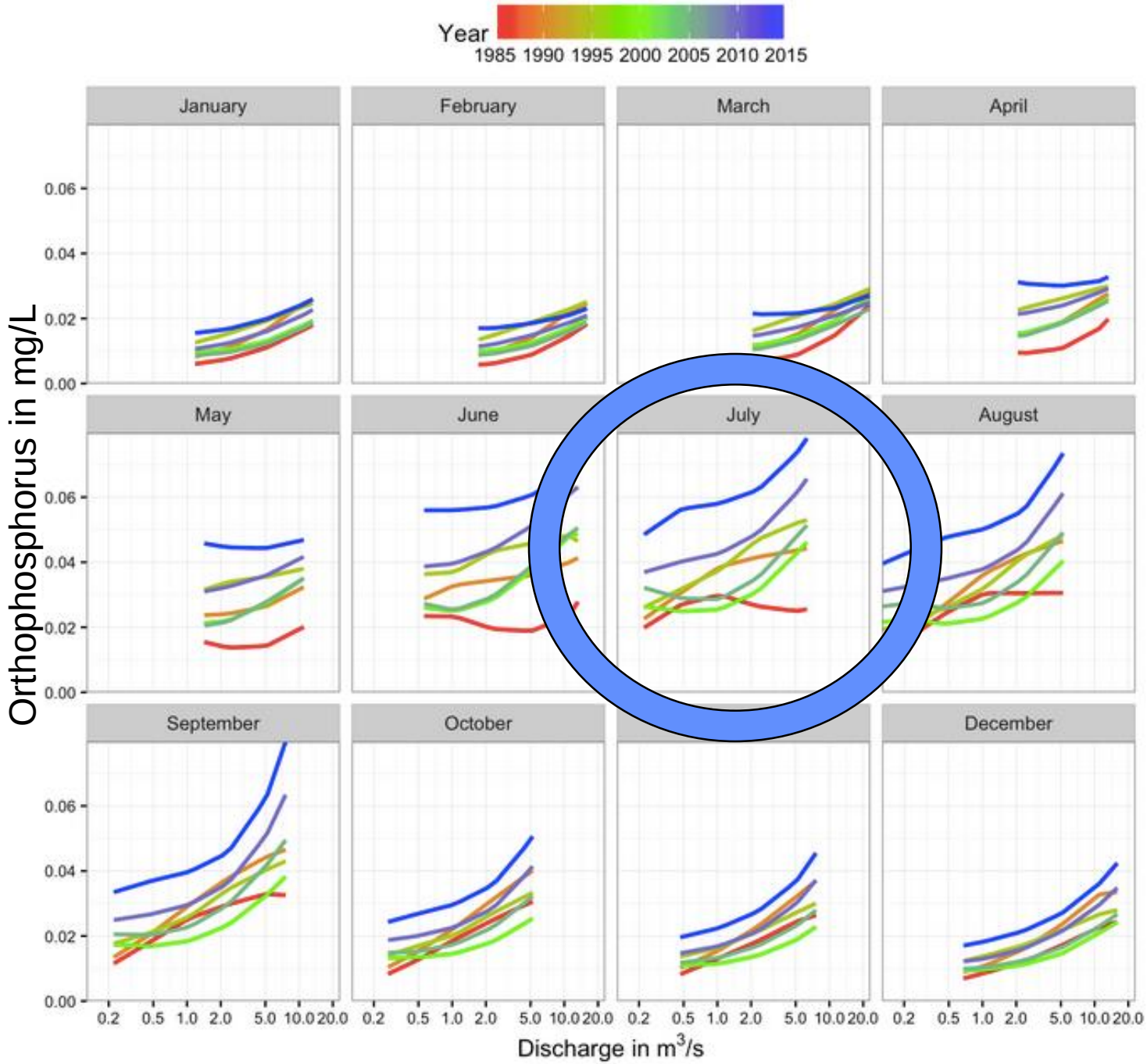
USGS

Last 6 years of the model



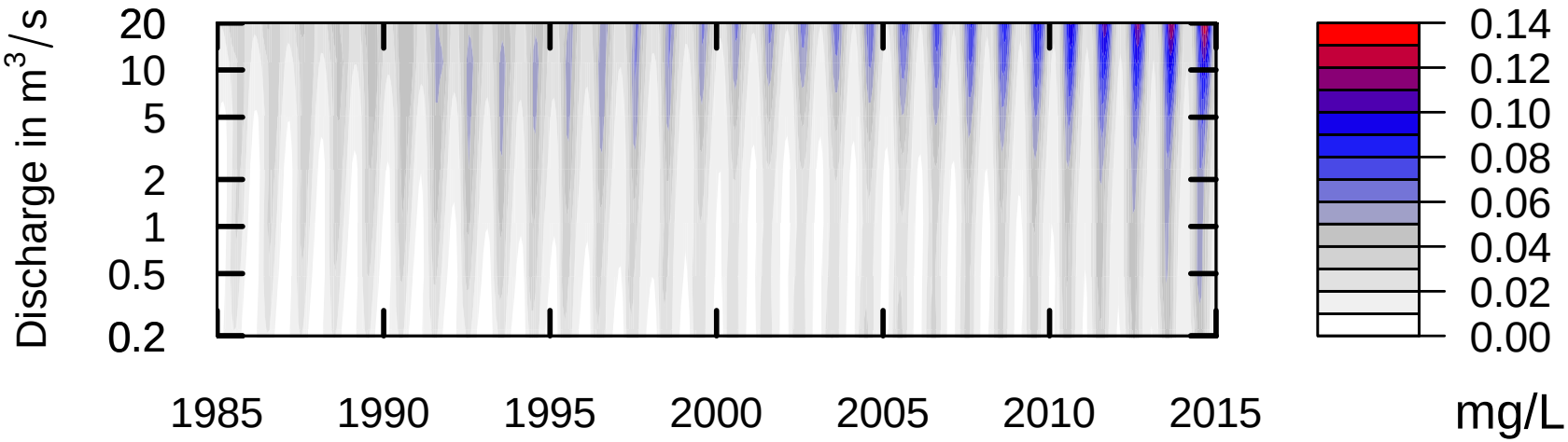
Two vertical lines at July 2010 and July 2015

USGS

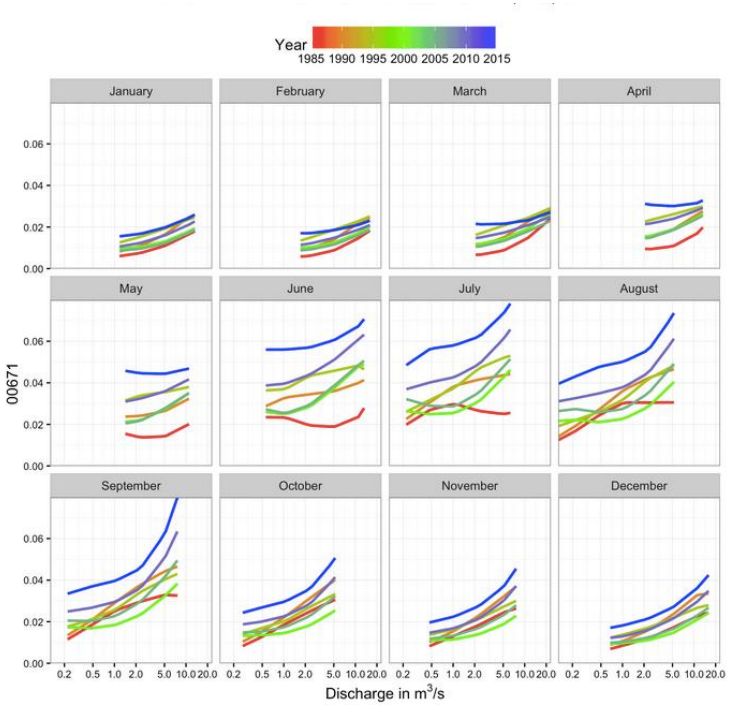

Year
1985 1990 1995 2000 2005 2010 2015
January
February
March
April
May
June
July
August
September
October
December
Orthophosphorus in mg/L
0.00
0.02
0.04
0.06
0.2 0.5 1.0 2.0 5.0 10.0 20.0
Discharge in m3/s

USGS

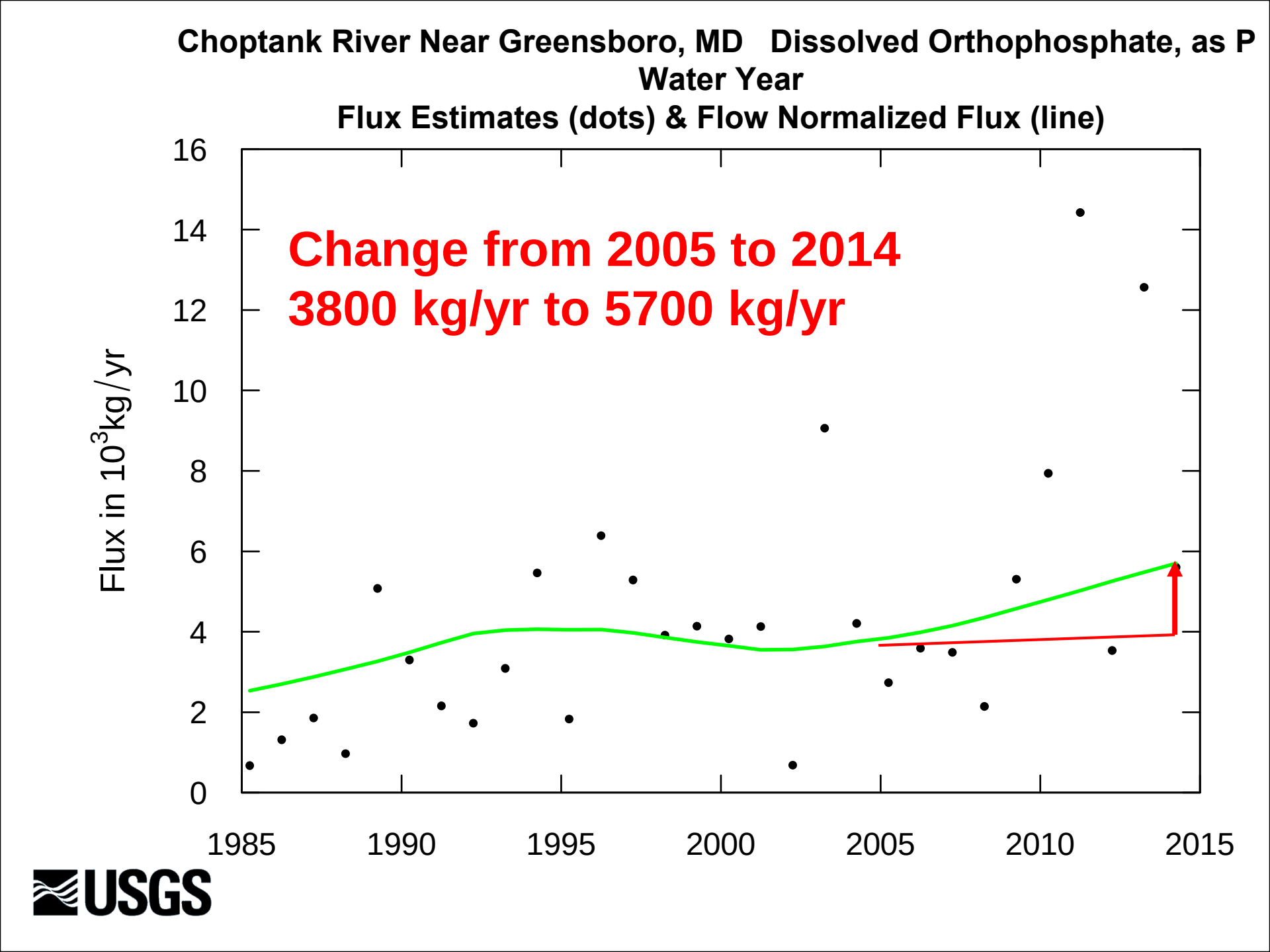
Choptank River Near Greensboro, MD Dissolved Orthophosphate, as P
Estimated Concentration Surface in Color



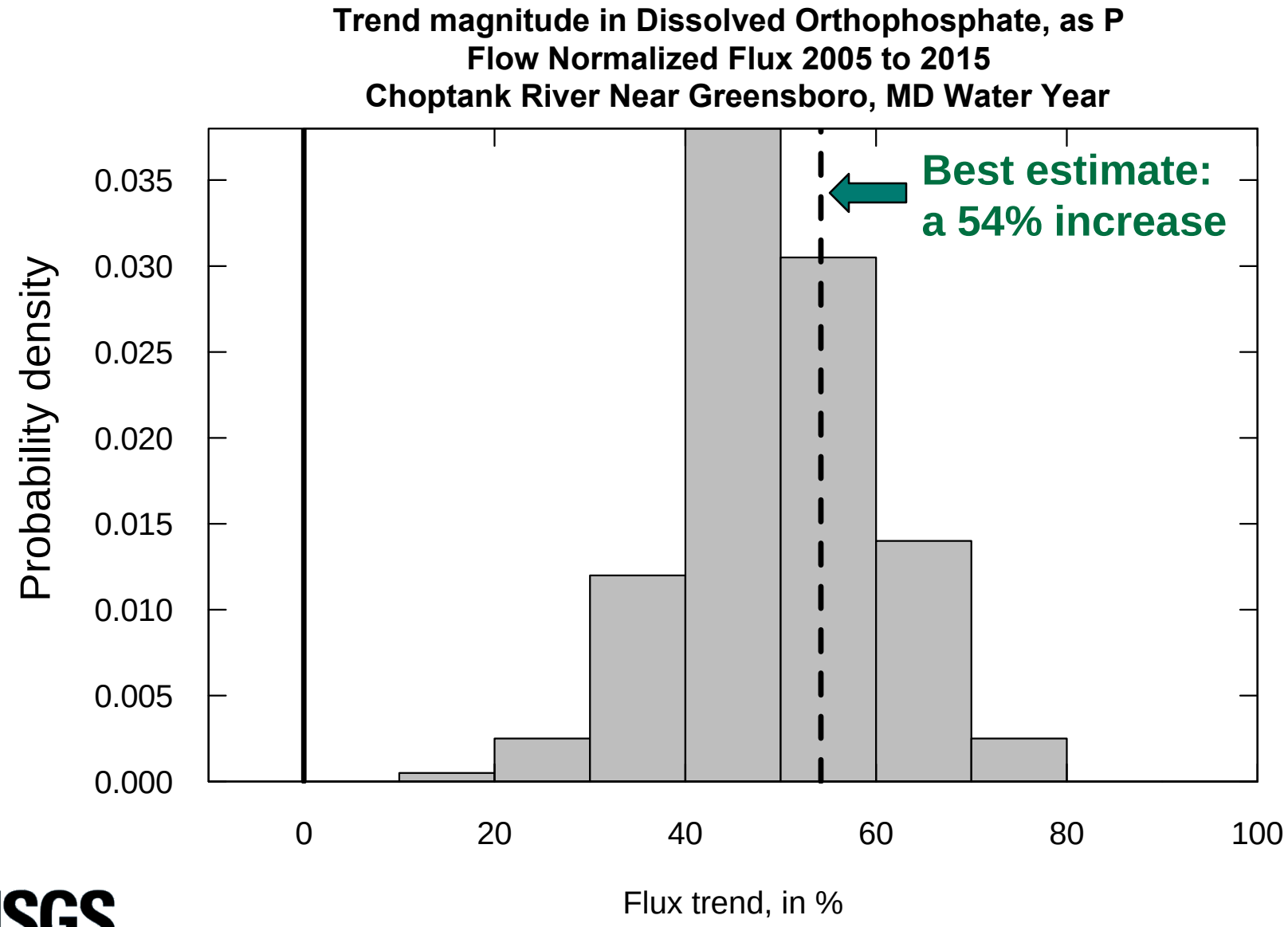
- **Lots of detail. Can provide insights on the nature of the change.**
- **But we can also boil it down to a history annual load, not influenced by the year-to-year variations in flow**
- **Integrate this surface over the seasonal frequency distribution of discharge.**
- **We call the result the “Flow-normalized annual flux.”**



USGS

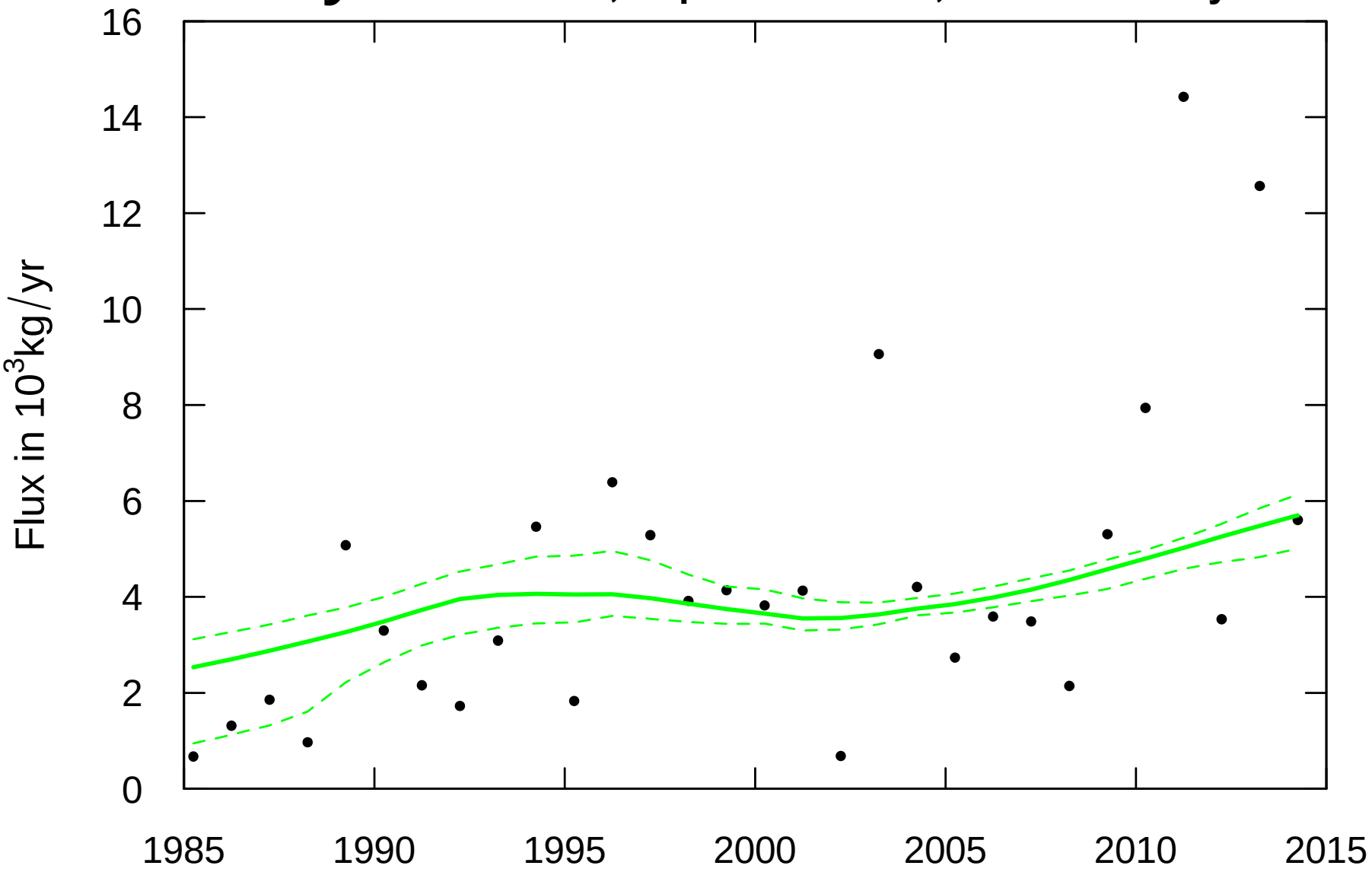

Choptank River Near Greensboro, MD Dissolved Orthophosphate, as P
Water Year
Flux Estimates (dots) & Flow Normalized Flux (line)
Change from 2005 to 2014
3800 kg/yr to 5700 kg/yr
Flux in 10^3kg/yr
0
2
4
6
8
10
12
14
16
1985
1990
1995
2000
2005
2010
2015
USGS

Measures of uncertainty



USGS

Uncertainty: 90% Confidence Interval



USGS

That's the method -- now some results

- Total Nitrogen
- Total Phosphorus
- Dissolved Orthophosphorus

USGS

Total Nitrogen Yields

Total nitrogen loads range from 1.19 to 33.4 lbs/ac with an average load of 7.33 lbs/ac

3 Categories of Loads:

(1) Low =

≤ 6.88 lbs/ac

52 of 81 stations

(2) Medium =

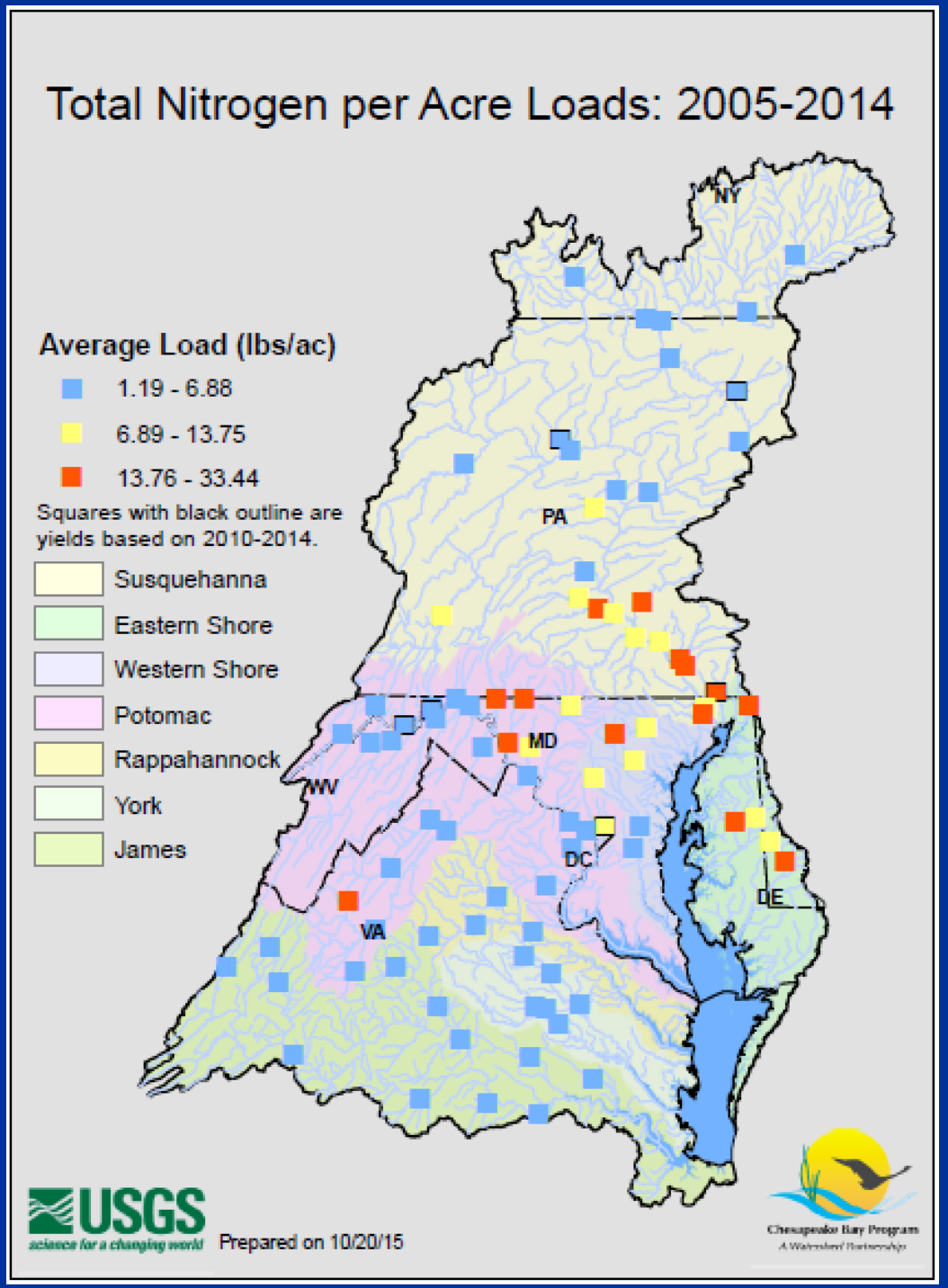
> 6.88 to ≤ 13.75

15 of 81 stations

(3) High Yields = ≥ 13.76

14 of 81 stations

USGS



Total Nitrogen Yields and Trends: 2005-2014

Improving Trends = 44 of 81 (54%)
Degrading Trends = 22 of 81 (27%)
No Trend = 15 of 81 (19%)

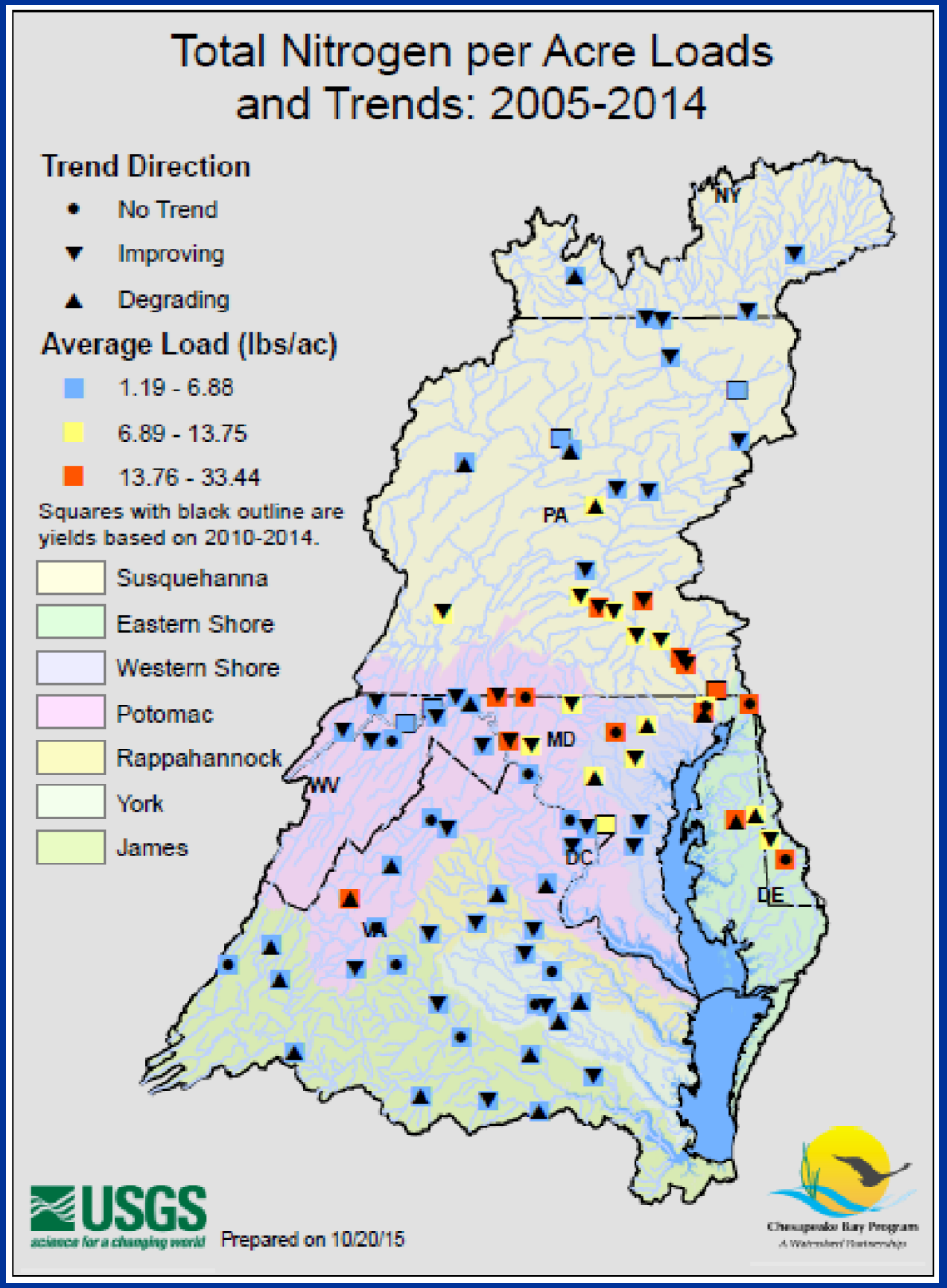
5 largest % improvements

- Susquehanna R. at Conklin, NY
- Wills Creek, Cumberland, MD
- Georges Creek, Franklin, MD
- Susquehanna R. at Waverly, NY
- Opequon, Martinsburg, WV

5 largest % degradations

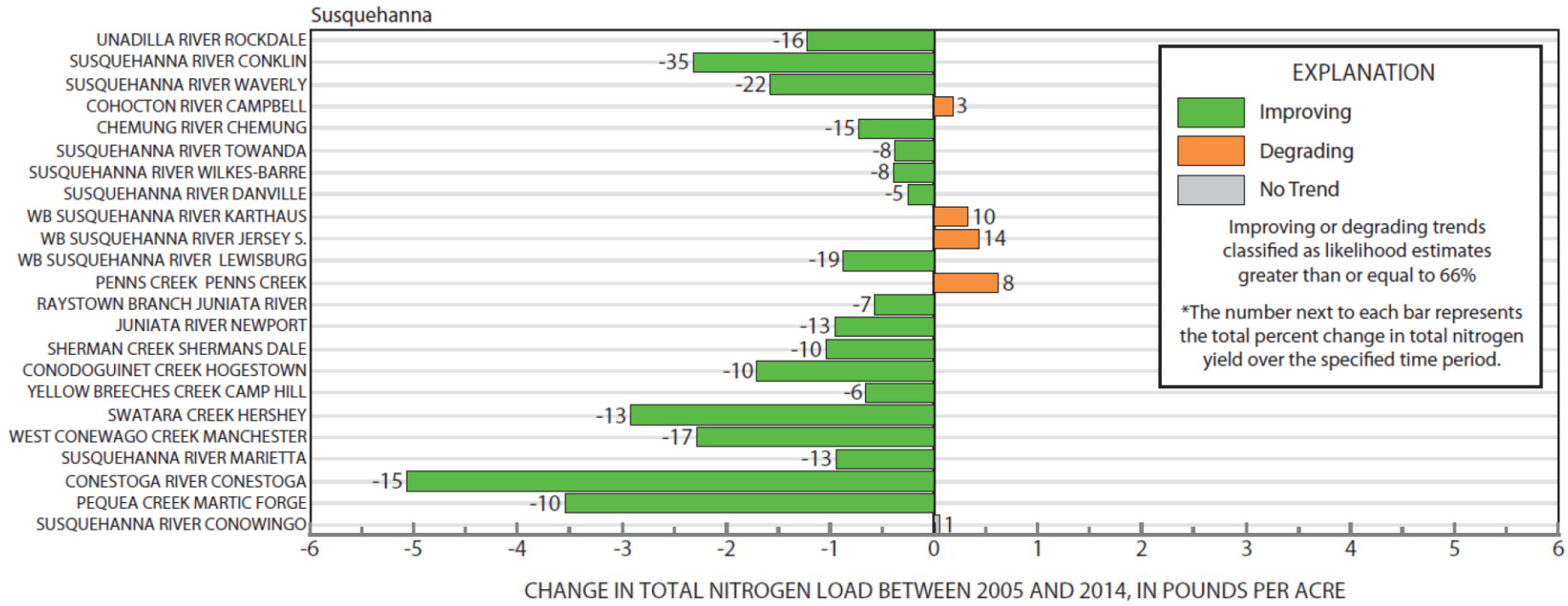
- SF Quantico, Ind. Hill, VA
- Rappahannock, Remington, VA
- James R., Richmond, VA
- Appomattox, Farmville, VA
- WB Susquehanna, Jersey S, PA

USGS



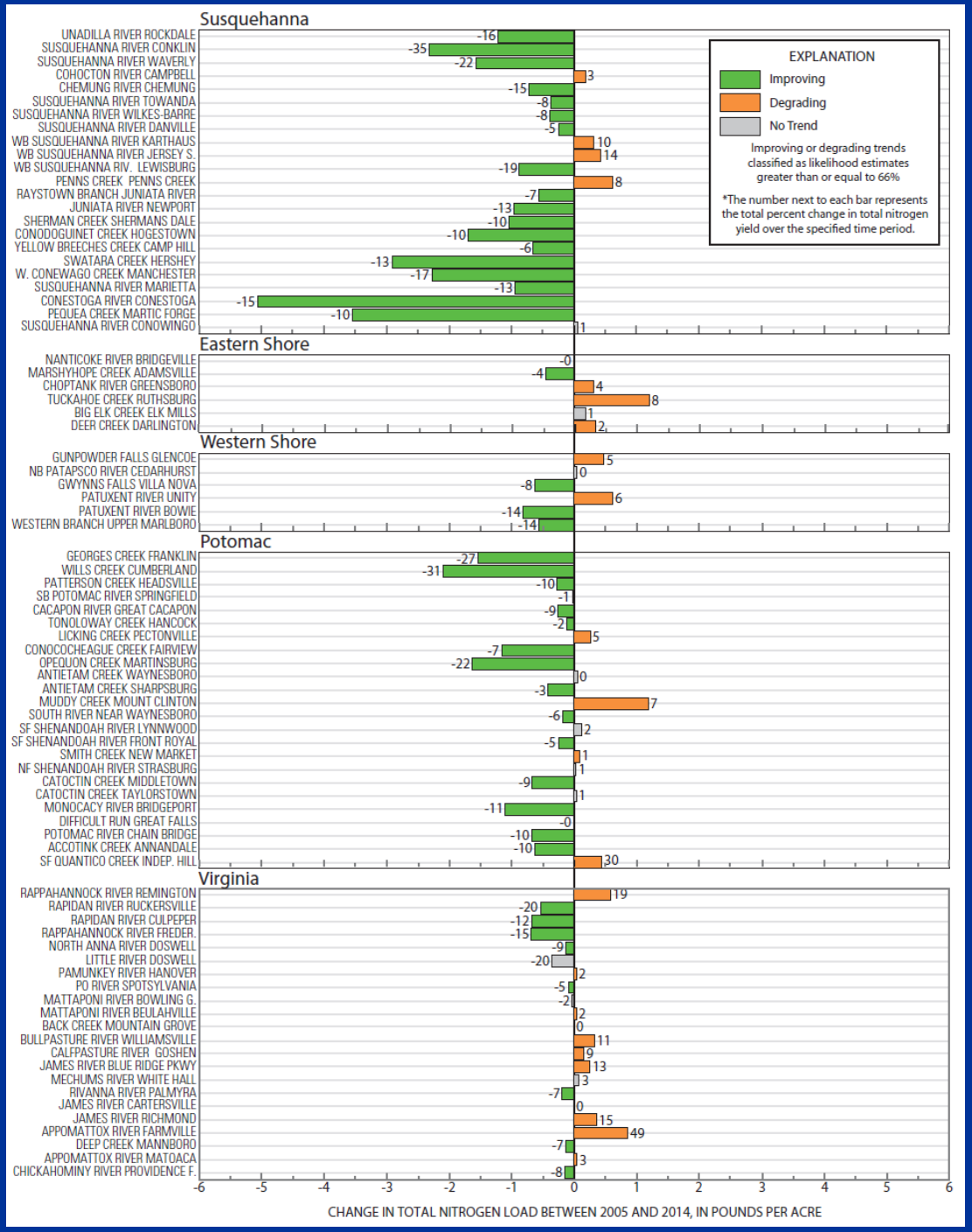
Changes in Nitrogen per Acre Loads: 2005-2014

Example from the Susquehanna Watershed



USGS

Changes in Total Nitrogen Yield: 2005-2014



Download figure:
http://cbrim.er.usgs.gov/maps.html

USGS

Total Phosphorus Yields & Trends: 2005-2014

Improving Trends = 41 of 60 (68%)
Degrading Trends = 12 of 60 (20%)
No Trend = 7 of 60 (12%)

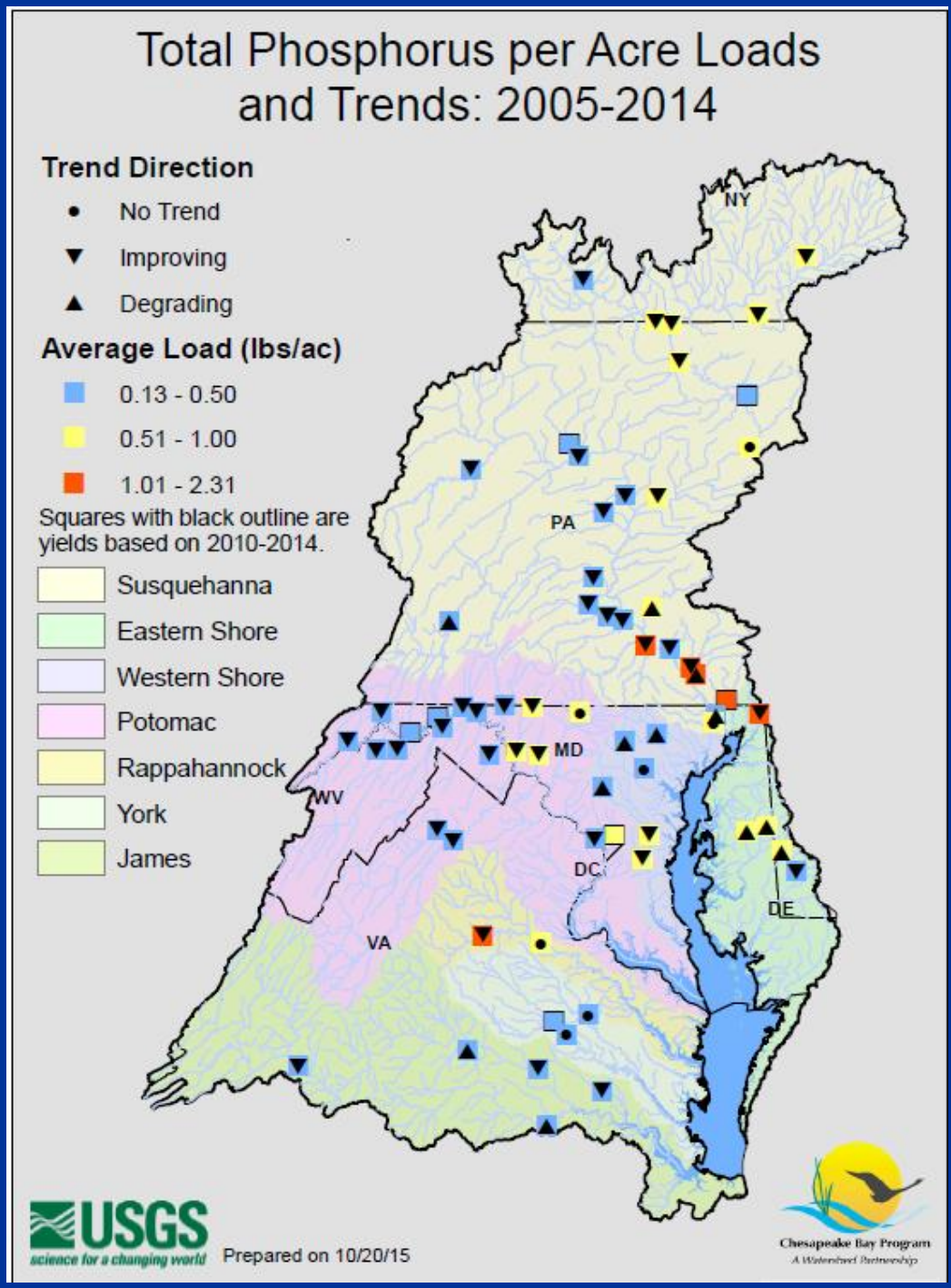
5 largest % improvements:

- Opequon, Martinsburg, WV
- Antietam, Waynesboro, MD
- Rapidan, Culpeper, VA
- Susquehanna, Conklin, NY
- SB Potomac, Springfield, WV

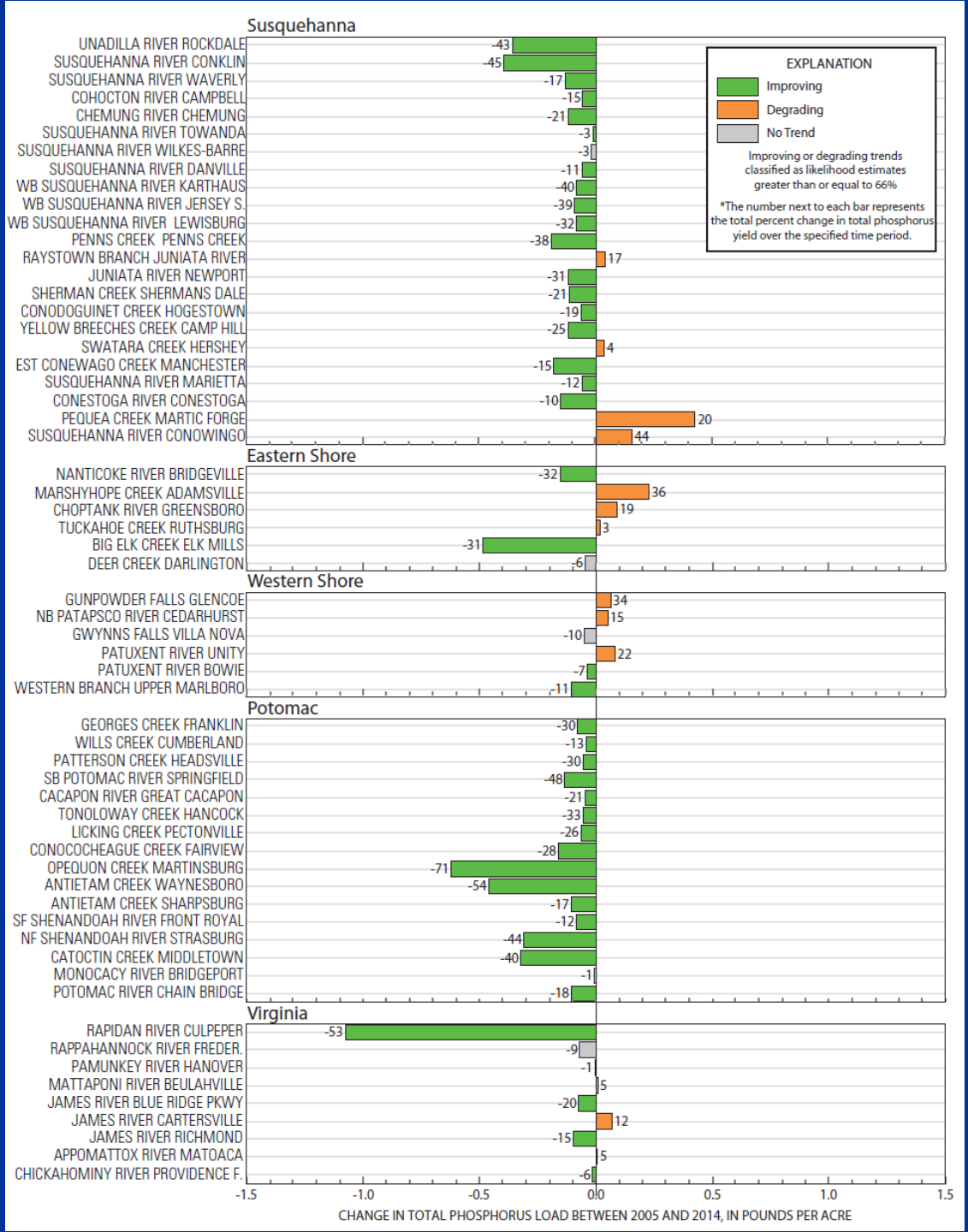
5 largest % degradations:

- Susq. River, Conowingo, MD
- Pequea Cr., PA
- Marshyhope Cr., DE
- Gunpowder R., MD
- Patuxent R., Unity, MD

USGS



Changes in Total Phosphorus Yield: 2005-2014



USGS

Orthophosphate Trends: 2005-2014

Improving Trends = 31 of 52 (60%)

Degrading Trends = 13 of 52 (25%)

No Trend = 8 of 52 (15%)

5 largest % improvements are:

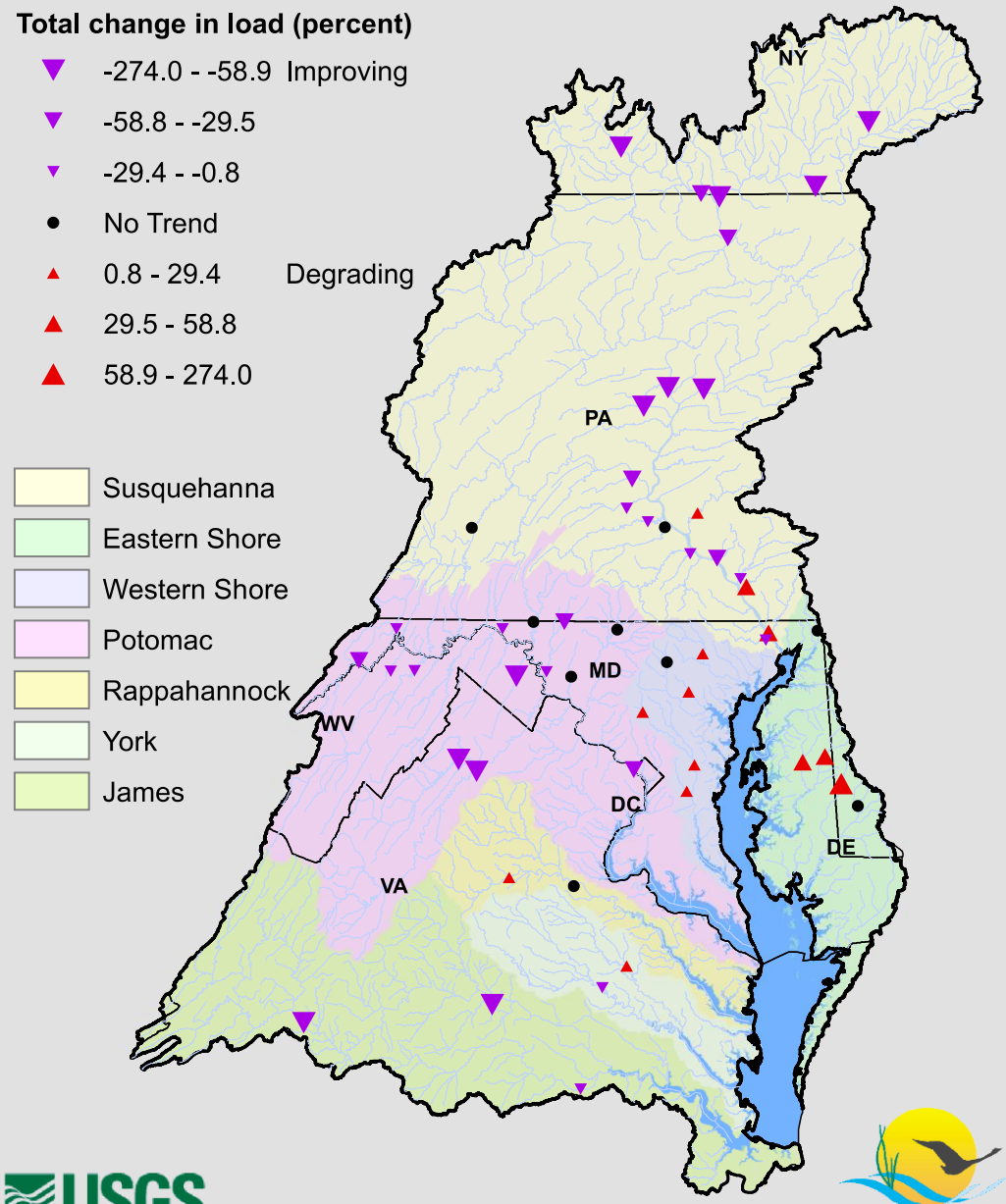
- Unadilla River, NY
- Susq. at Conklin, NY
- W. Br. Susquehanna, PA
- S. Fk. Shenandoah, VA
- N. Fk Shenandoah, VA

5 largest % degradations are:

- Marshyhope Creek, DE
- Choptank River, MD
- Pequea Creek, PA
- Susq. at Conowingo, MD
- Tuckahoe Creek, MD

USGS

Change in Orthophosphorus in Percent: 2005-2014

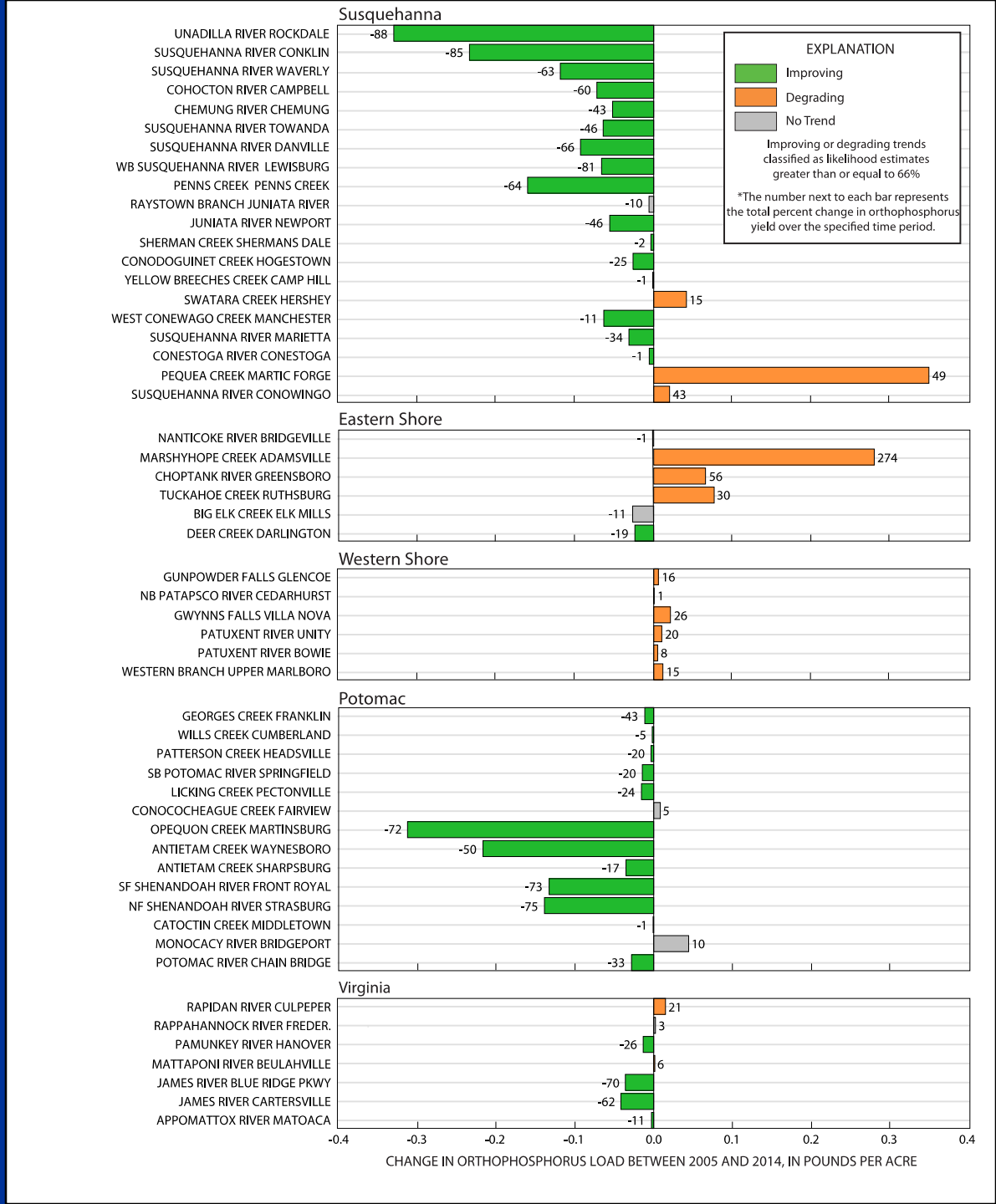


USGS science for a changing world

Prepared on 10/20/15

Chesapeake Bay Program
A Watershed Partnership

Changes in Orthophosphate Yield: 2005-2014



Download figure:
http://cbrim.er.usgs.gov/maps.html

USGS

There are many things to learn from these data sets and the WRTDS model derived from them:

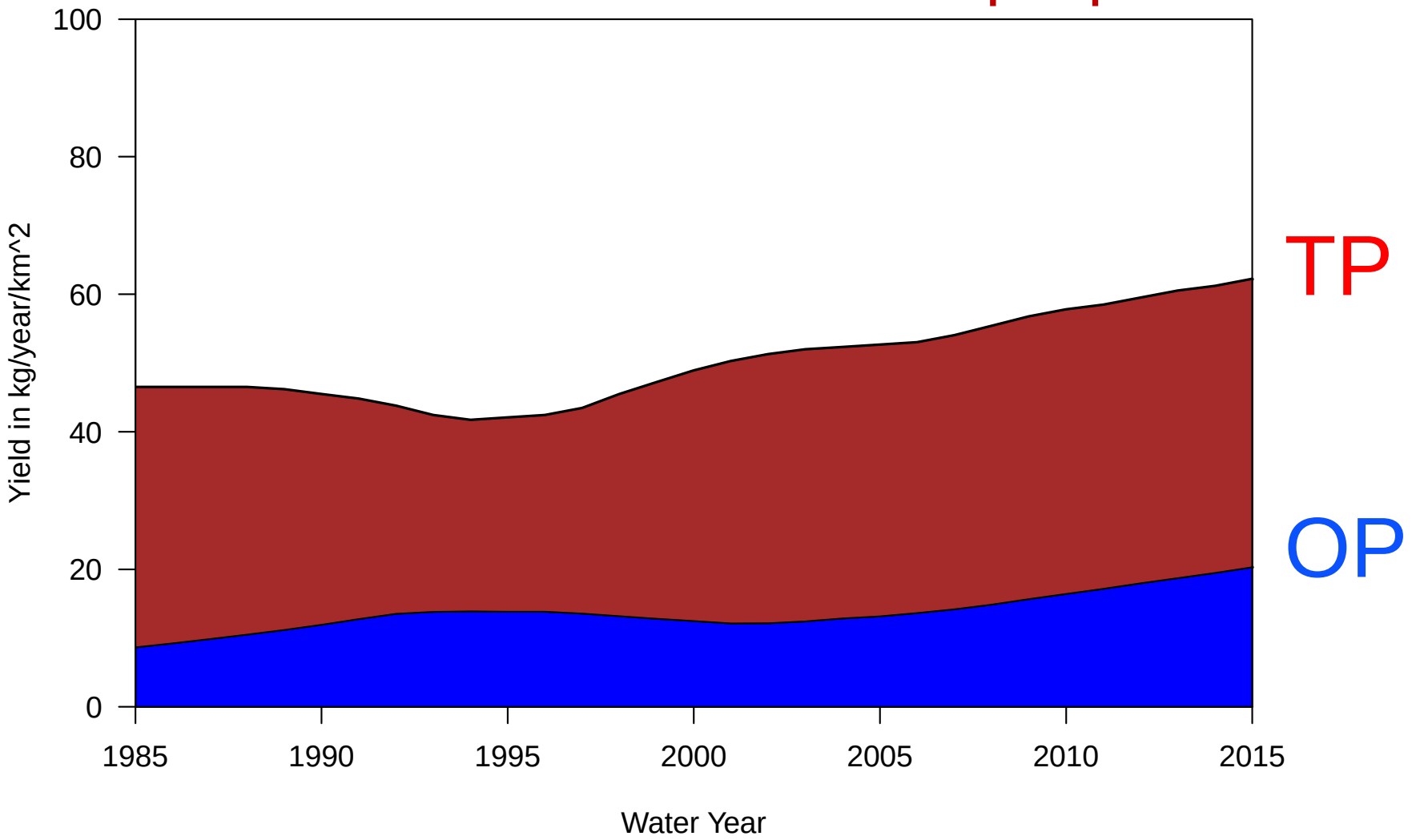
- Compare analytes at a site
- Compare across sites
- Compute N:P or TP:SS ratios
- Relate NTN trends to trends in the Bay

Need to have a dedicated effort of "Forensic Water Quality Trend Analysis"

USGS

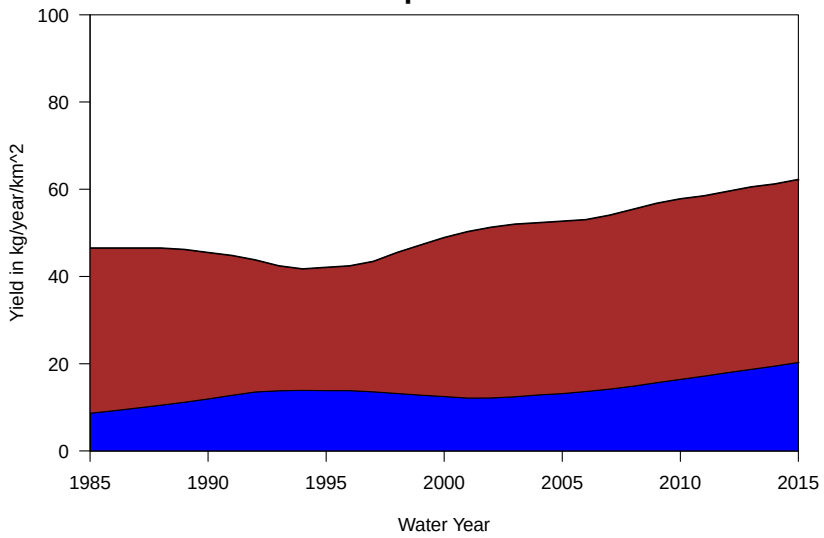
Flow Normalized Yields, Choptank River near Greensboro, MD

Blue shaded area is dissolved orthophosphorus,
Red shaded area is all other forms of phosphorus

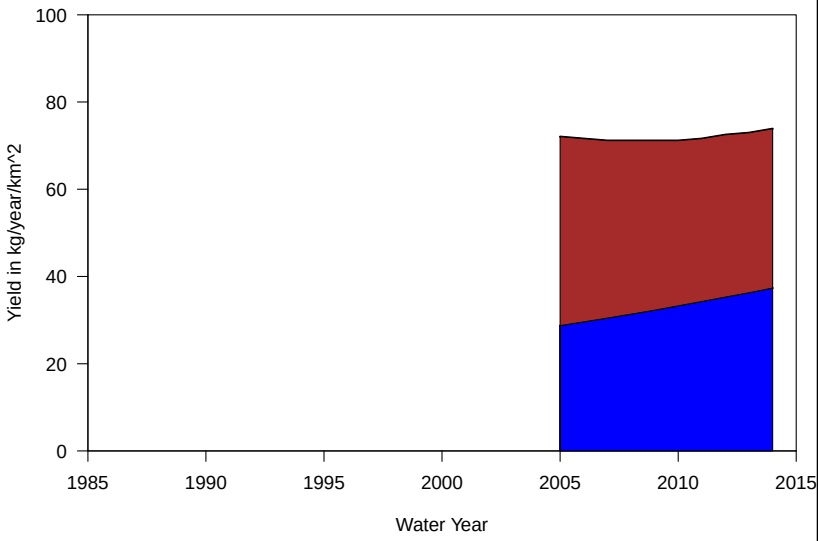


USGS

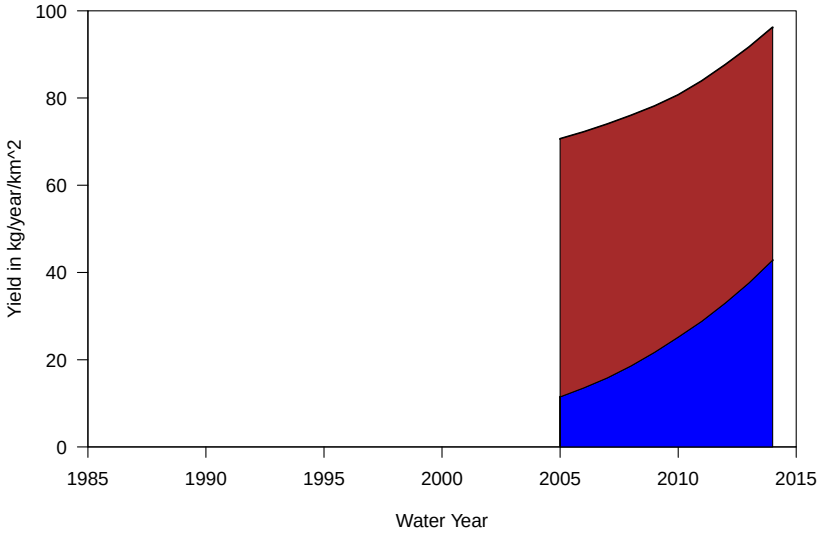
Choptank



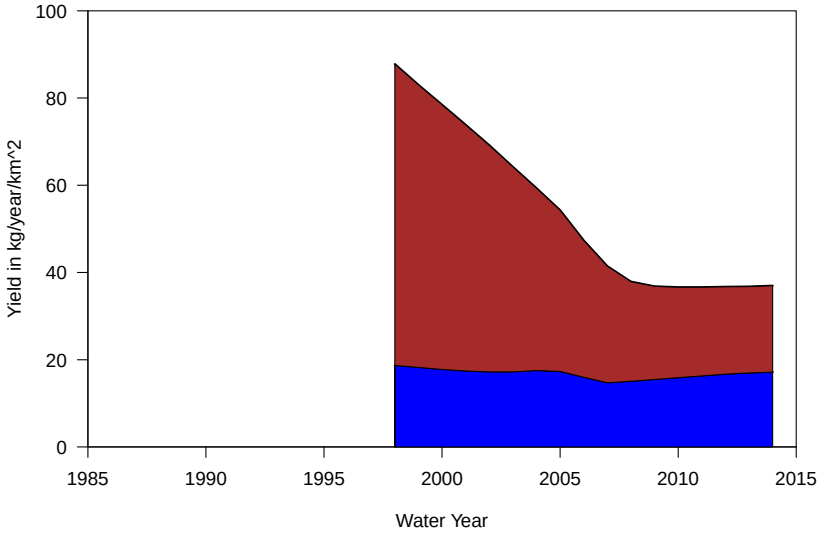
Tuckahoe



Marshyhope

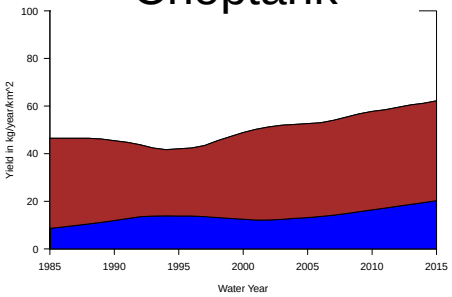


Nanticoke

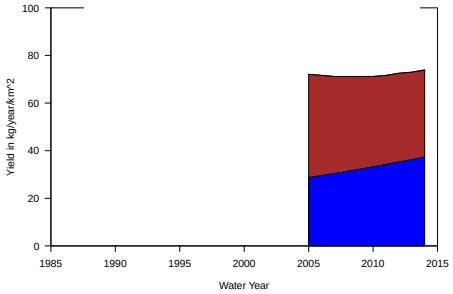


USGS

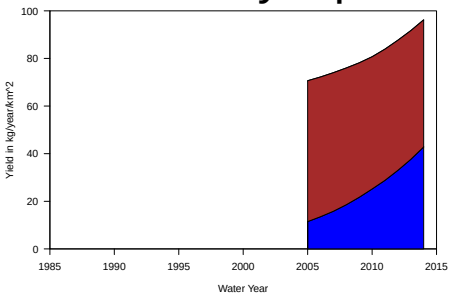
Choptank



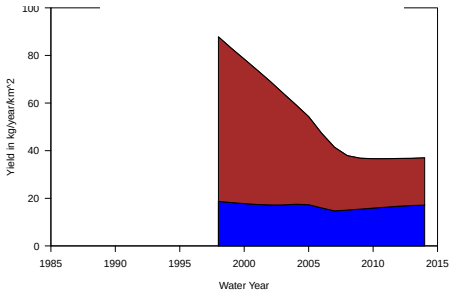
Tuckahoe



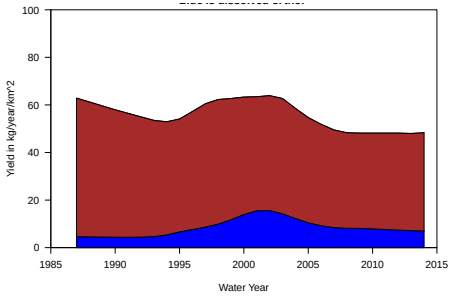
Marshyhope



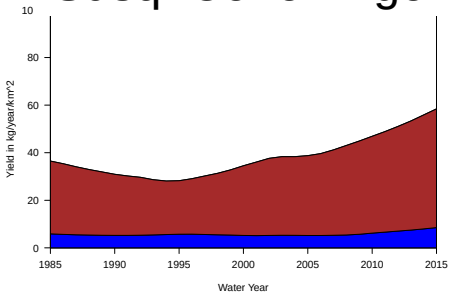
Nanticoke



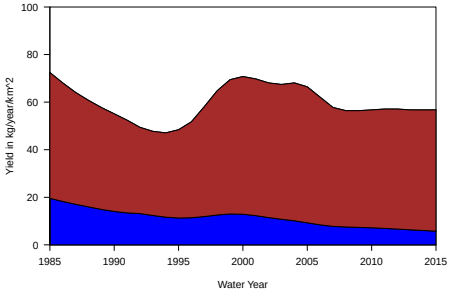
Susq. Marietta



Susq. Conowingo



Potomac



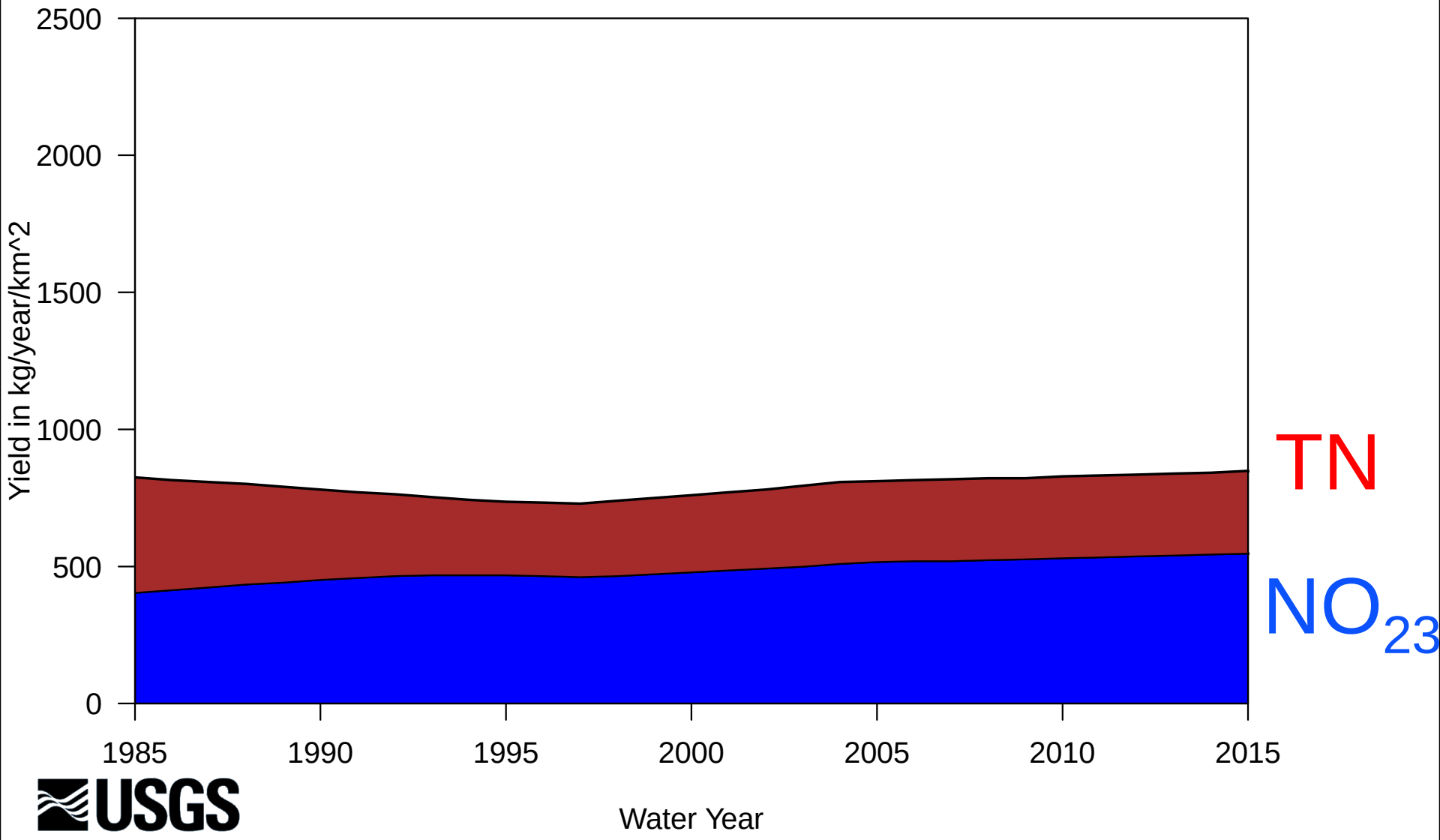
- OrthoP yields much higher on Delmarva than Susquehanna or Potomac
- OrthoP falling at Marietta and Potomac, Rising at Conowingo
- Delmarva sites, TP increases largely due to OrthoP increases
- Bump after 1996 at Marietta and Potomac may be due to 1996 flood
- TP yields on Delmarva bracket those of Susquehanna and Potomac

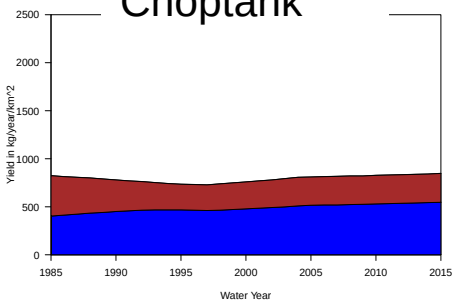
USGS

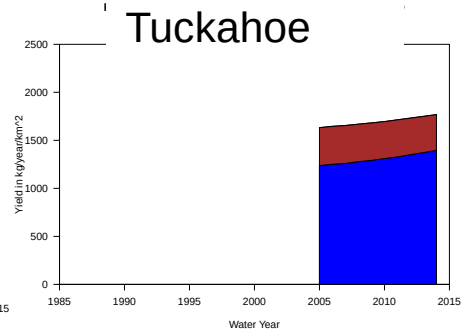
Flow Normalized Yields, Choptank River near Greensboro, MD

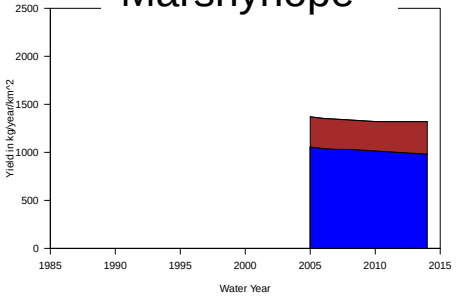
Blue shaded area is dissolved nitrate plus nitrite

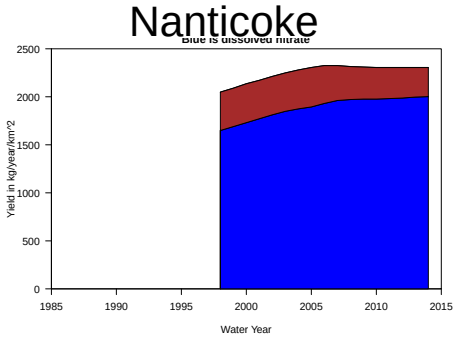
Red shaded area is all other forms of nitrogen

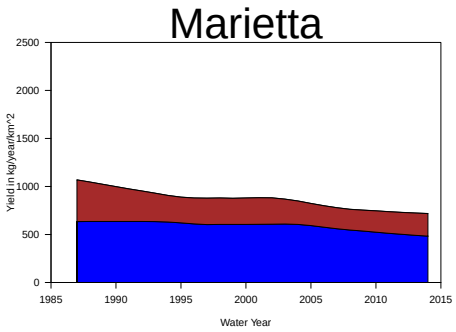


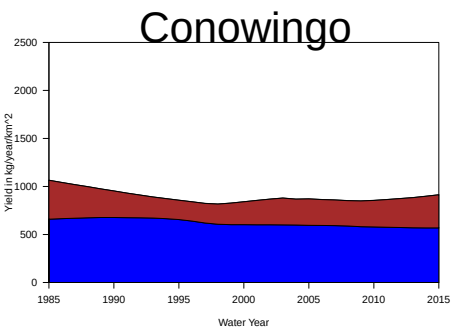


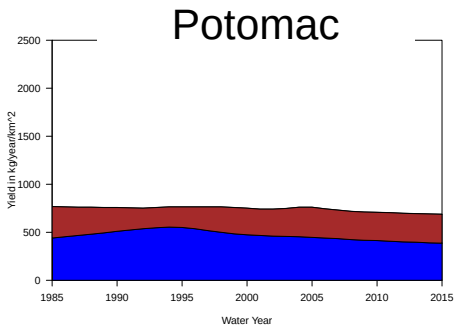












- NO_{23} mostly rising on Delmarva and falling on Susquehanna & Potomac
- NO_{23} yields generally higher on Delmarva than Susq. or Potomac
- Most Delmarva sites have higher TN yields than Susq. or Potomac
- The only site where non-NO_{23} forms are rising is Conowingo

USGS

Changing TN:TP ratios

Site	1987	2005	2014
Choptank	**38**	**34**	**30**
Tuckahoe		**50**	**53**
Marshyhope		**43**	**30**
Nanticoke		**94**	**138**
Susquehanna at Marietta	**38**	**33**	**33**
Susquehanna at Conowingo	**66**	**50**	**36**
Potomac	**26**	**25**	**27**

USGS

Changing TN:TP ratios

Site	1987	2005	2014
Choptank	38	34	30
Tuckahoe		50	53
Marshyhope		43	30
Nanticoke		94	138
Susquehanna at Marietta	38	33	33
Susquehanna at Conowingo	66	50	36
Potomac	26	25	27

USGS

Orange indicates strong decrease

Green indicates strong increase

General trends 2005-2014

- **TN improved at majority of sites. Exceptions in: Delmarva, and Susquehanna at Conowingo, but Susquehanna above Conowingo generally improved.**
- **TP improved at majority of sites. Exceptions in: Delmarva, other parts of coastal plain and piedmont, and Susquehanna at Conowingo, but Susquehanna above Conowingo generally improved.**
- **Orthophosphorus improved at majority of sites. Exceptions in: most sites in coastal plain and piedmont, and Susquehanna at Conowingo, but Susquehanna above Conowingo generally improved.**

USGS

These results are being used to:

- explain change
- enhance models
- measure progress
- inform strategies

It is built on a 3-decade effort with many partners.

USGS

Partners

- US Environmental Protection Agency (US EPA)
- Maryland Department of Natural Resources (MD DNR)
- Virginia Department of Environmental Quality (VA DEQ)
- Pennsylvania Department of Environmental Protection (PA DEP)
- West Virginia Department of Environmental Protection (WV DEP)
- Delaware Department of Natural Resources and Environmental Control (DNREC)
- New York State Department of Environmental Conservation (NYSDEC)
- Susquehanna River Basin Commission (SRBC)
- District Department of the Environment (DDOE)