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science for a changing world

Using the WRTDS (Weighted Regressions on Time, Discharge, and Season) to describe water quality trends

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The challenge

How do we come to understand what is happening to water quality in our watersheds.

Is it getting better or worse?

Can we relate the trends and their timing to causative factors?

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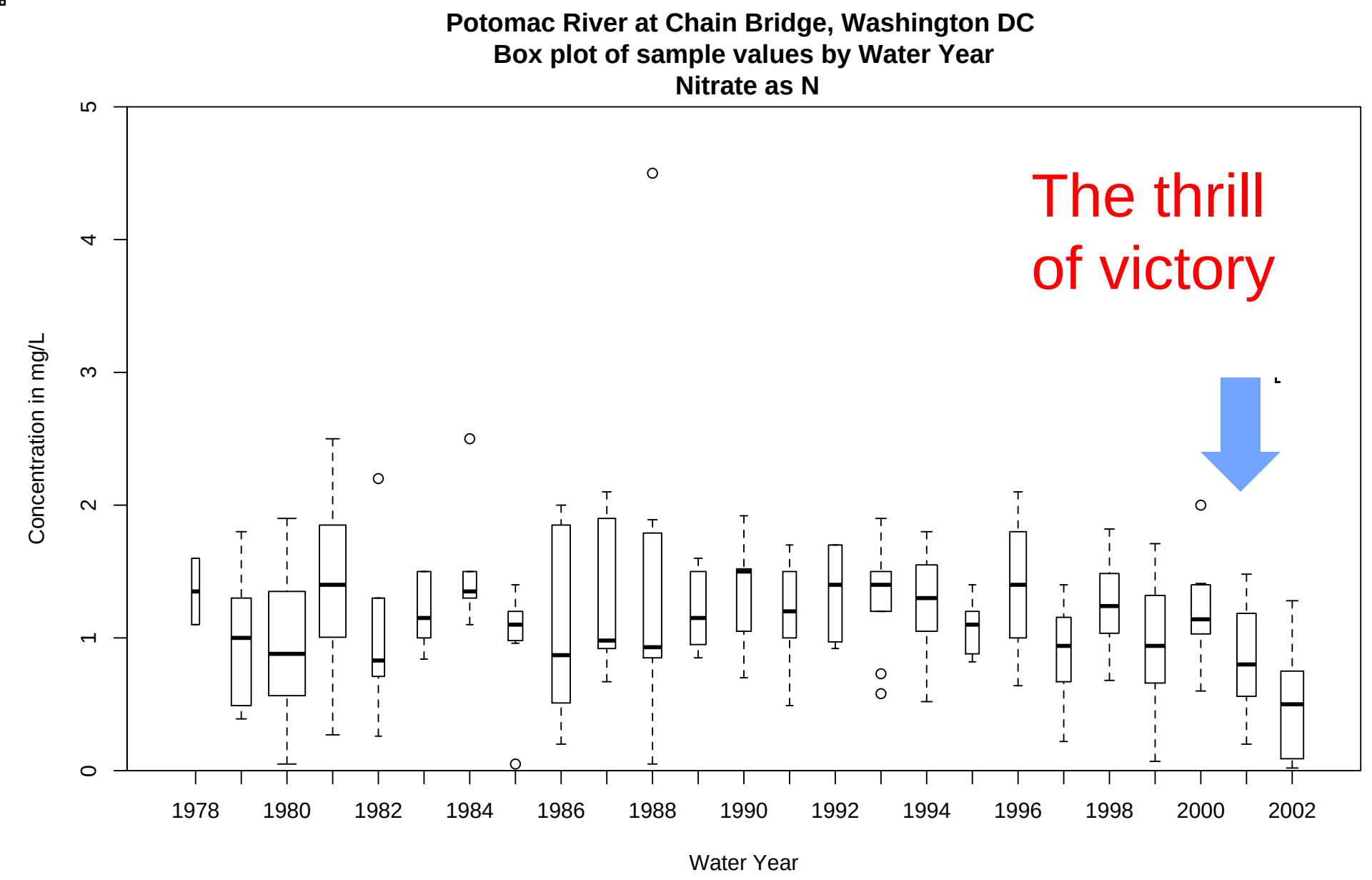
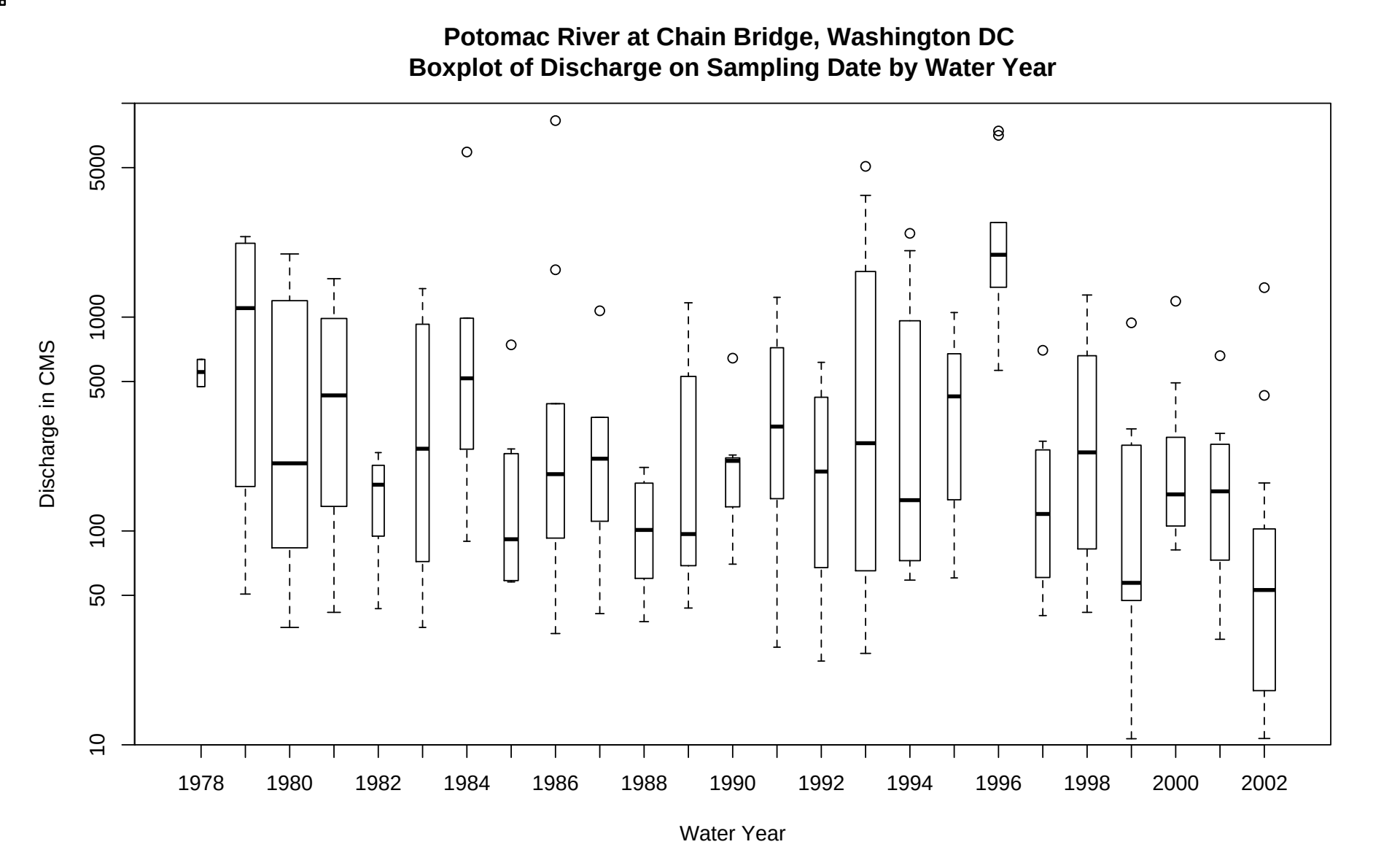
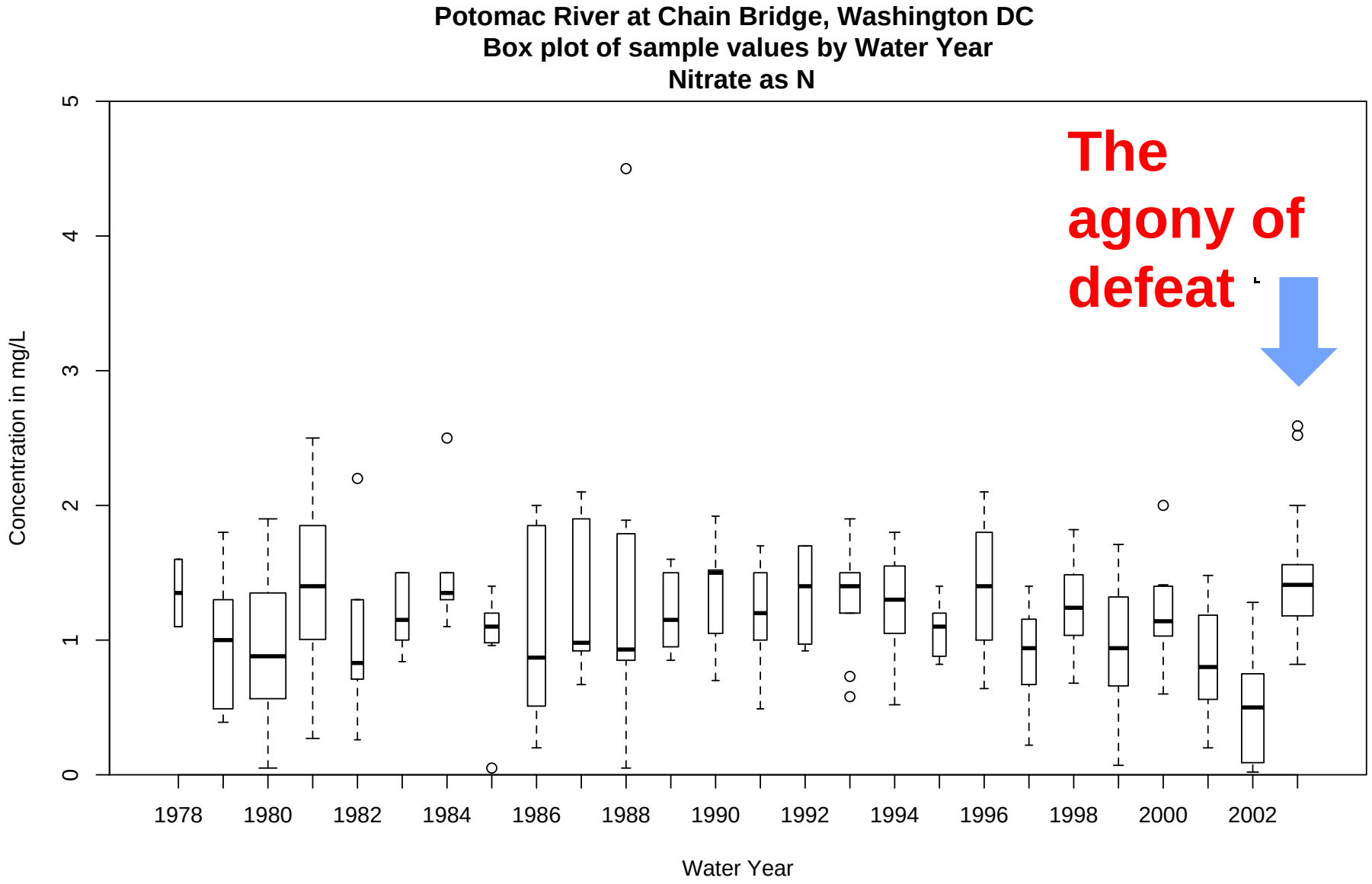
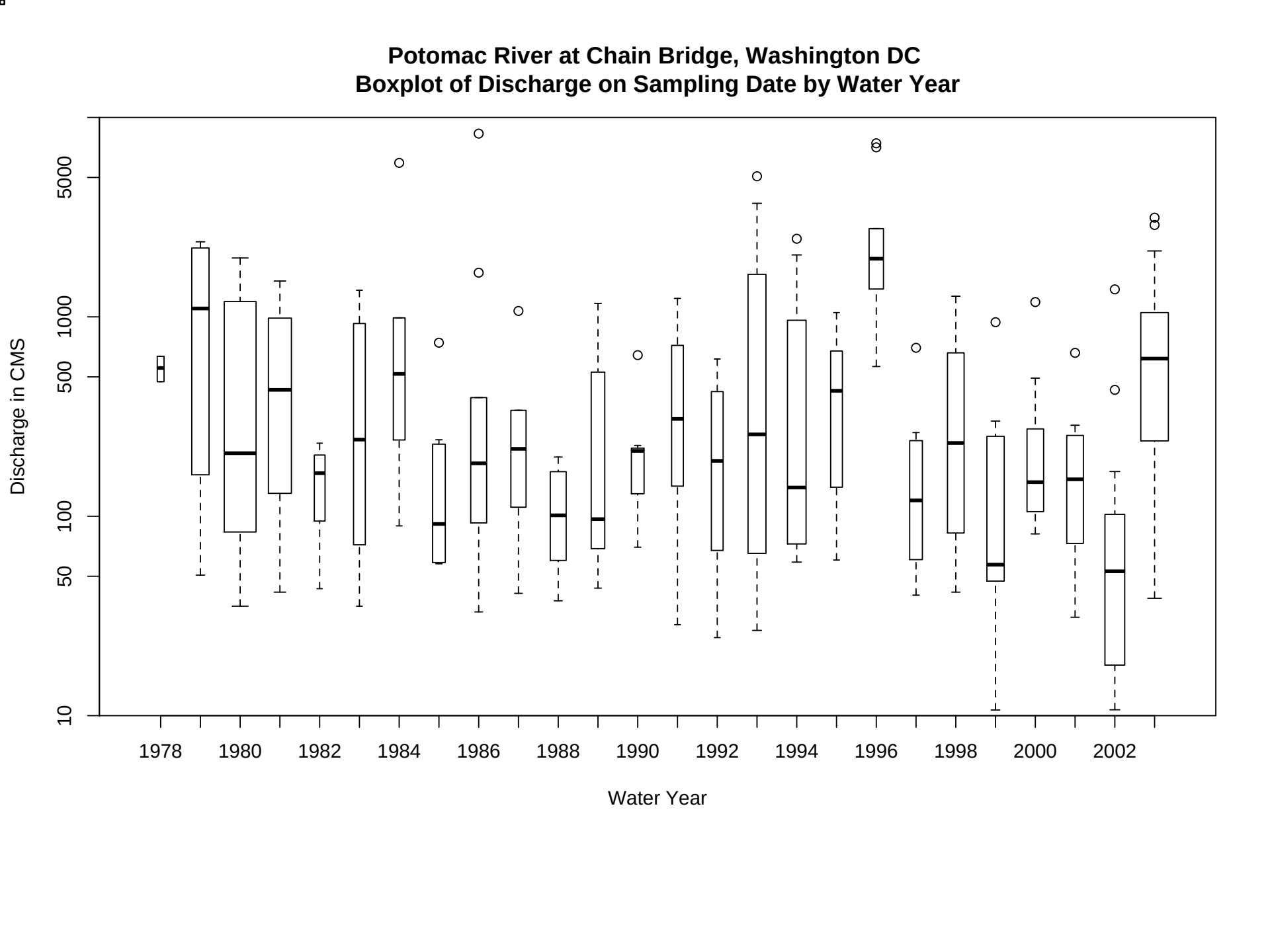


Data through September 2002


Potomac River at Chain Bridge, Washington DC
Boxplot of Discharge on Sampling Date by Water Year
Discharge in CMS
10
50
100
500
1000
5000
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
Water Year



Data through September 2003


Potomac River at Chain Bridge, Washington DC
Boxplot of Discharge on Sampling Date by Water Year
Discharge in CMS
10
50
100
500
1000
5000
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
Water Year

Motivations for the method

- Describe the evolving behavior of the watershed. No mathematical straight-jacket!!
- Estimate both concentration & flux (averages as well as trends).
- Estimate the actual history but also a flow-normalized history.
- Be quantitative but also exploratory.

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Data requirements

- Low intra-day variability (not flashy)
- Requires a complete discharge record
- Intended for >200 samples, but has been used for some purposes with as few as 60 samples
- Water quality samples cover most of the discharge range
- For trend studies: 10+ years
- For average flux computations: 5 years.

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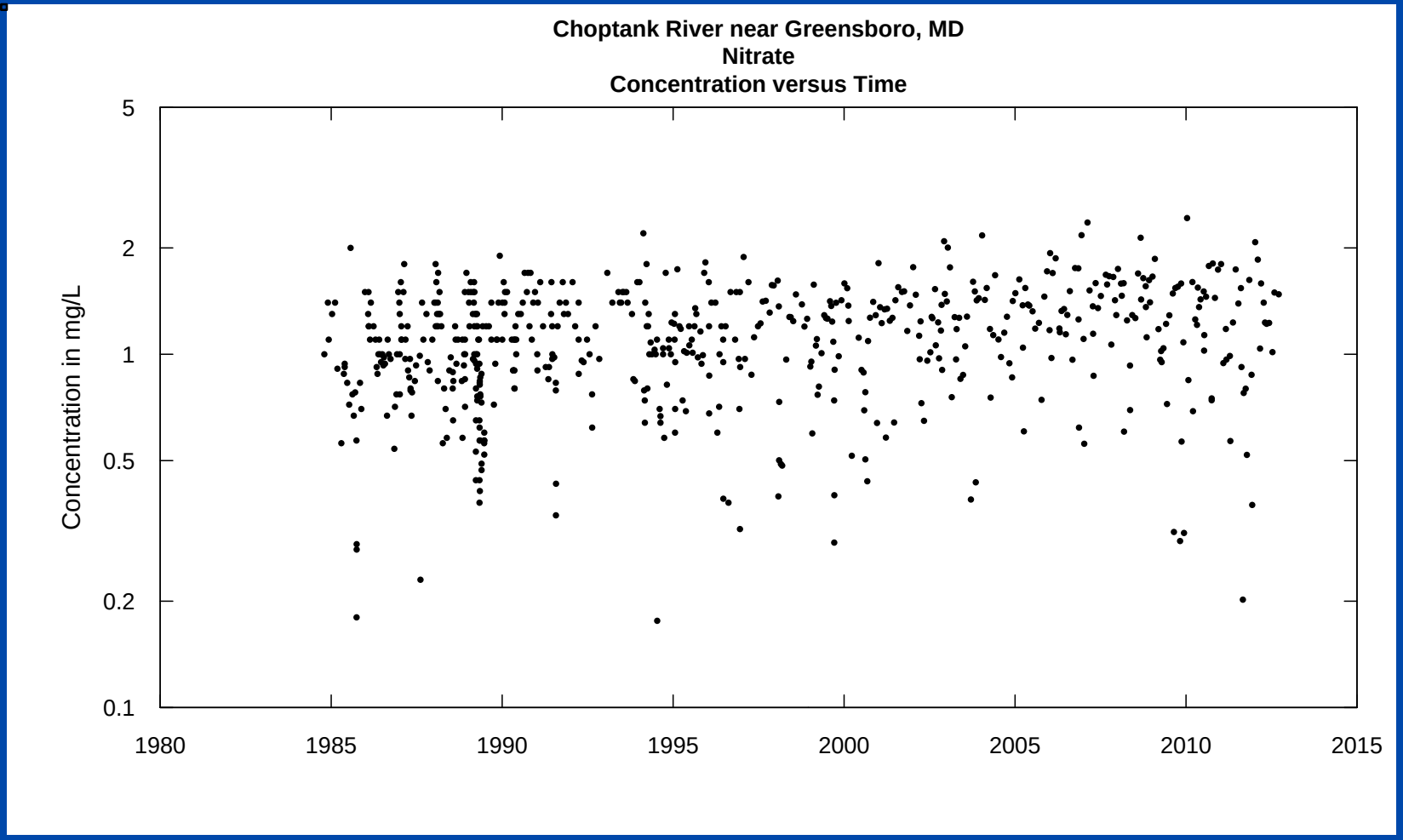
“Data without models are chaos, but models without data are fantasy”

Nesbit, Dlugokencky and Bousquet, Science, 31 January 2014, pp. 493-495



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Use the data and a simple, highly-flexible smoothing model to decompose the data into 4 components.

1)Time trend

2)Discharge

3)Seasonal cycle

4)Random component

Weighted Regressions on Time, Discharge and Season (WRTDS)

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Locally Weighted Regression

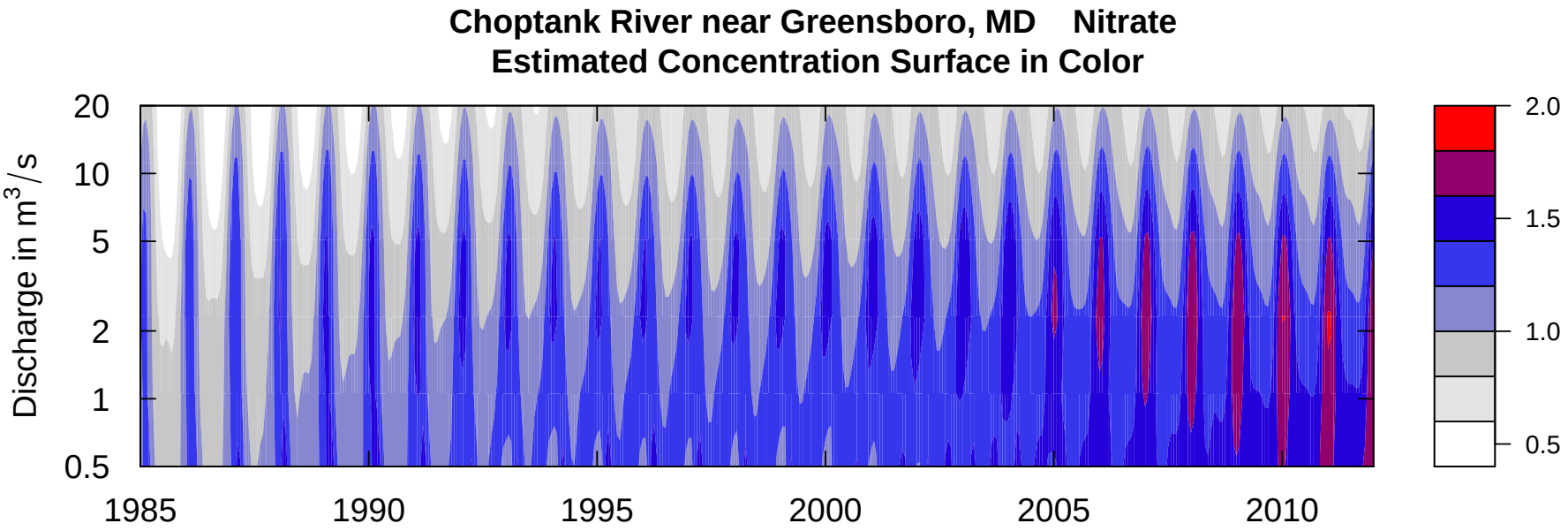
For any location in time - discharge space (*t* and *Q*) we assume that concentration (*c*) follows this model

$$\ln(c) = \beta_0 + \beta_1 \bullet t + \beta_2 \bullet \ln(Q) + \beta_3 \bullet \sin(2\pi t) + \beta_4 \cos(2\pi t) + \varepsilon$$

But the coefficients should be smoothly changing as we move through the space

Use weighted regression at many points in that space. The weight on each sample is determined by its "relevance" to that particular point in the space.

WRTDS view of the evolving behavior of nitrate



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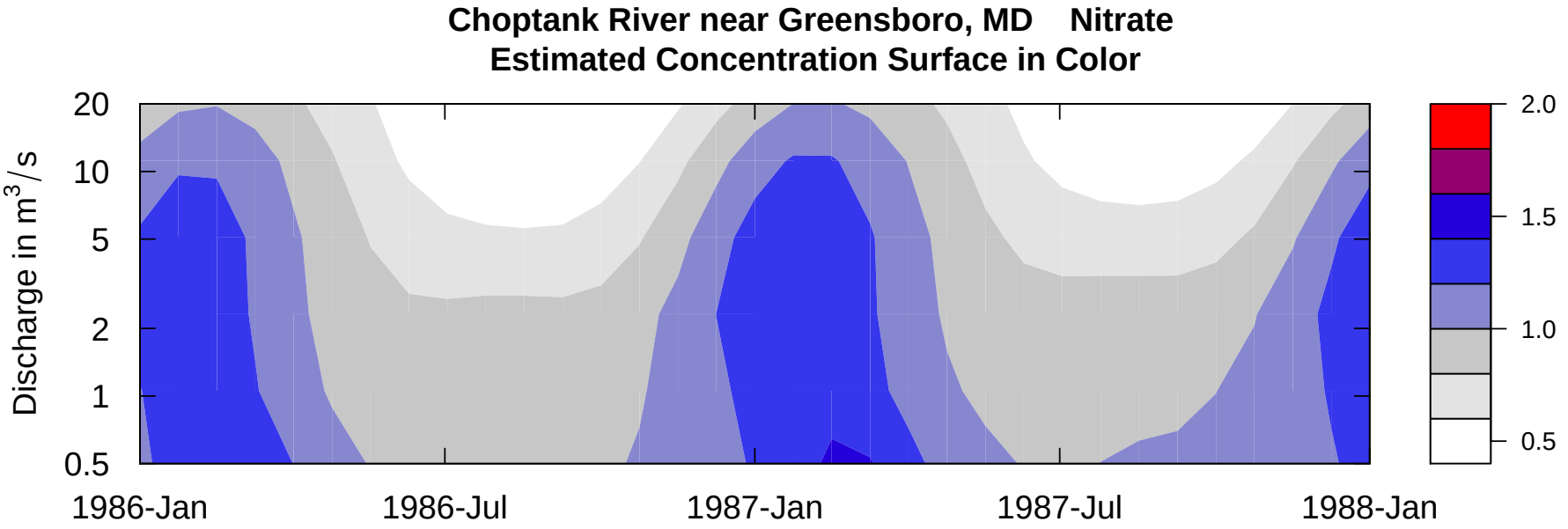
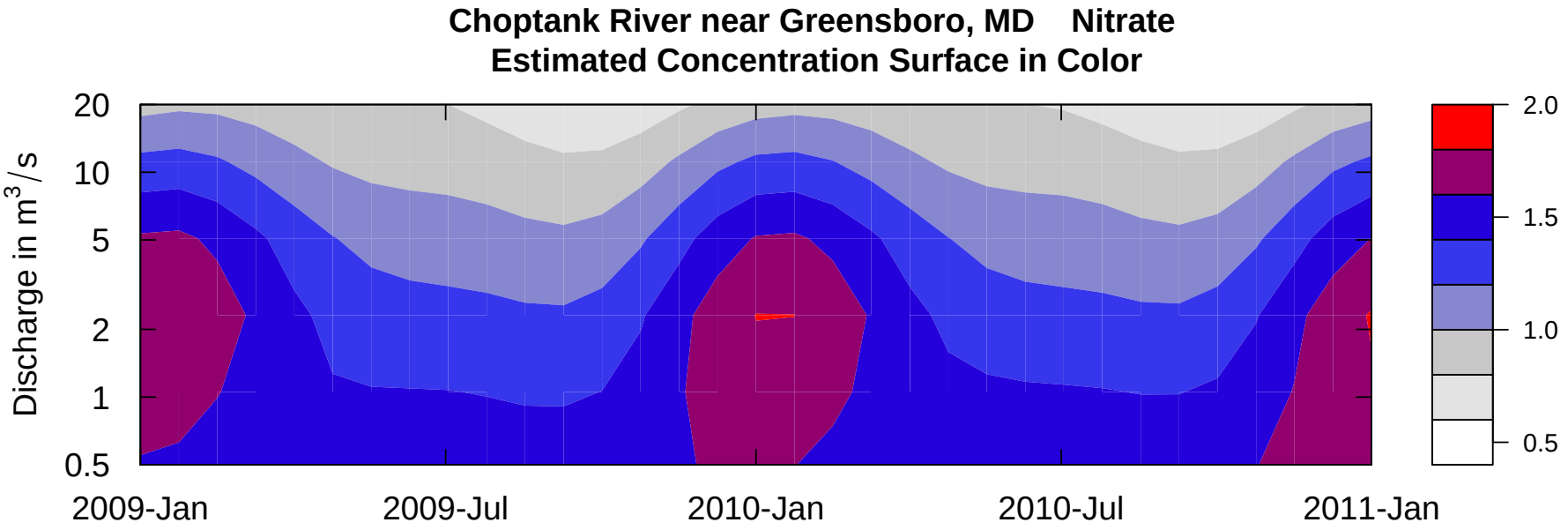
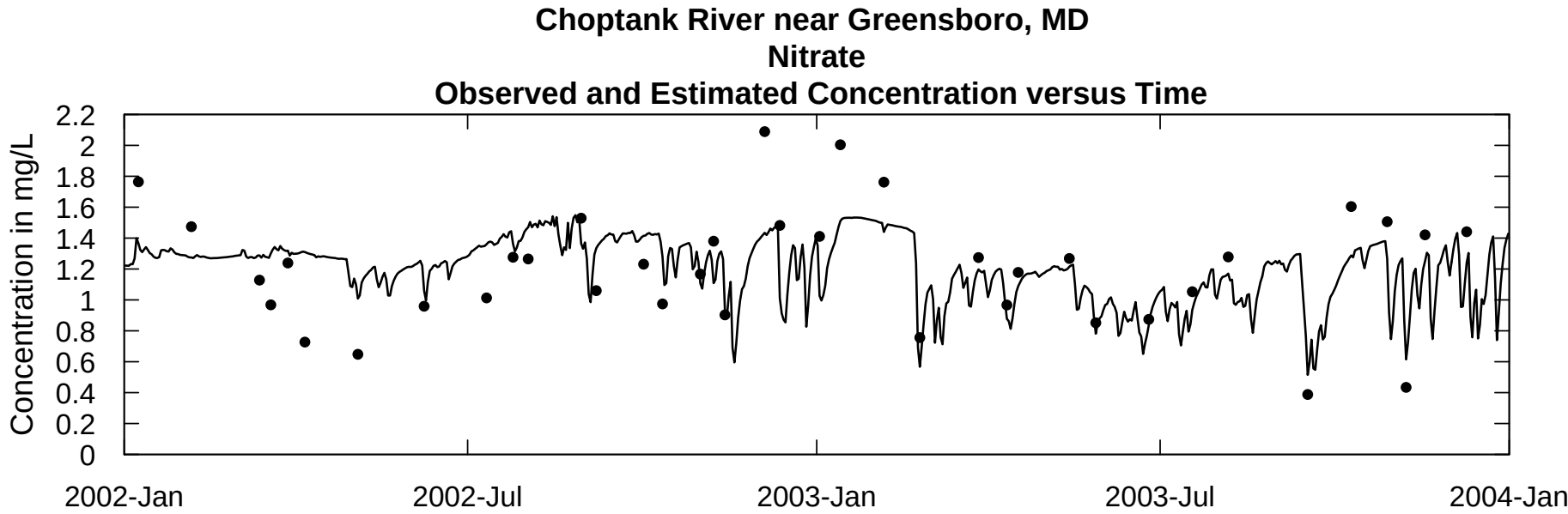
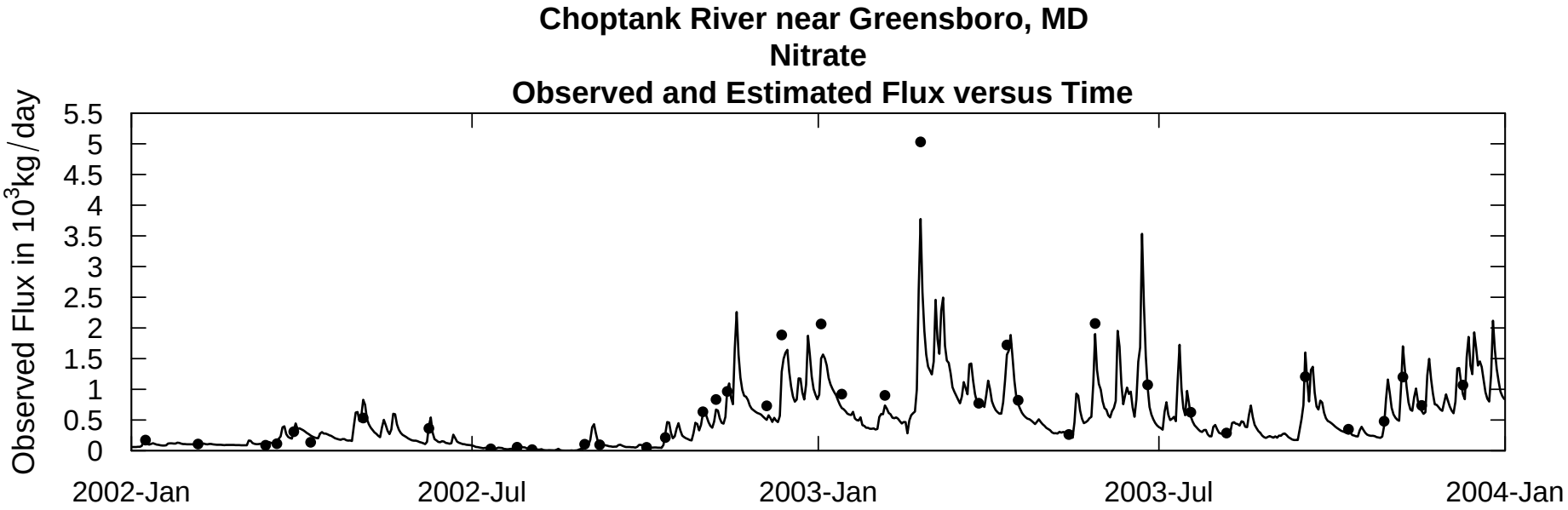
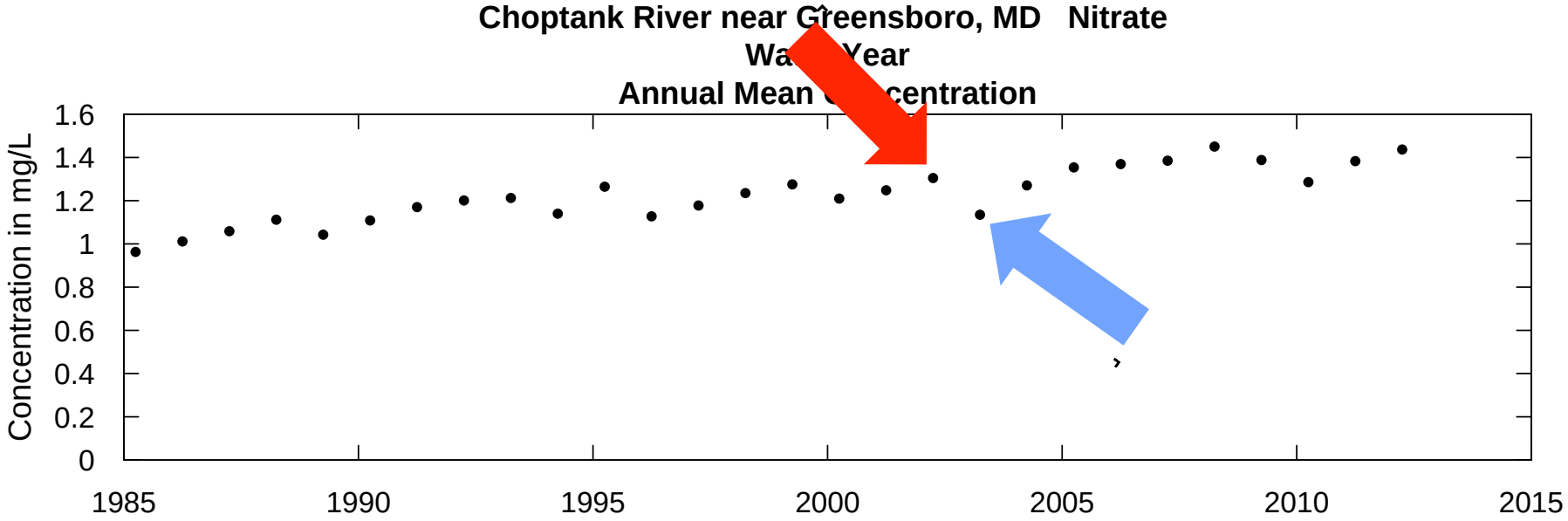
WRTDS view of the evolving behavior of nitrate

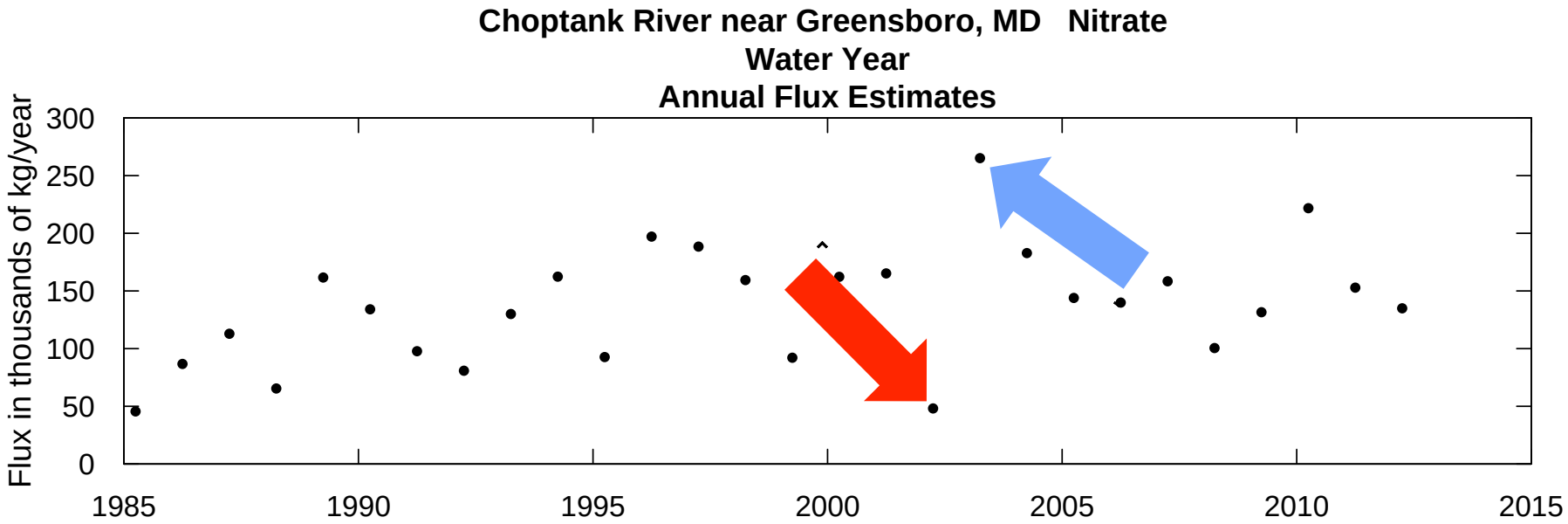


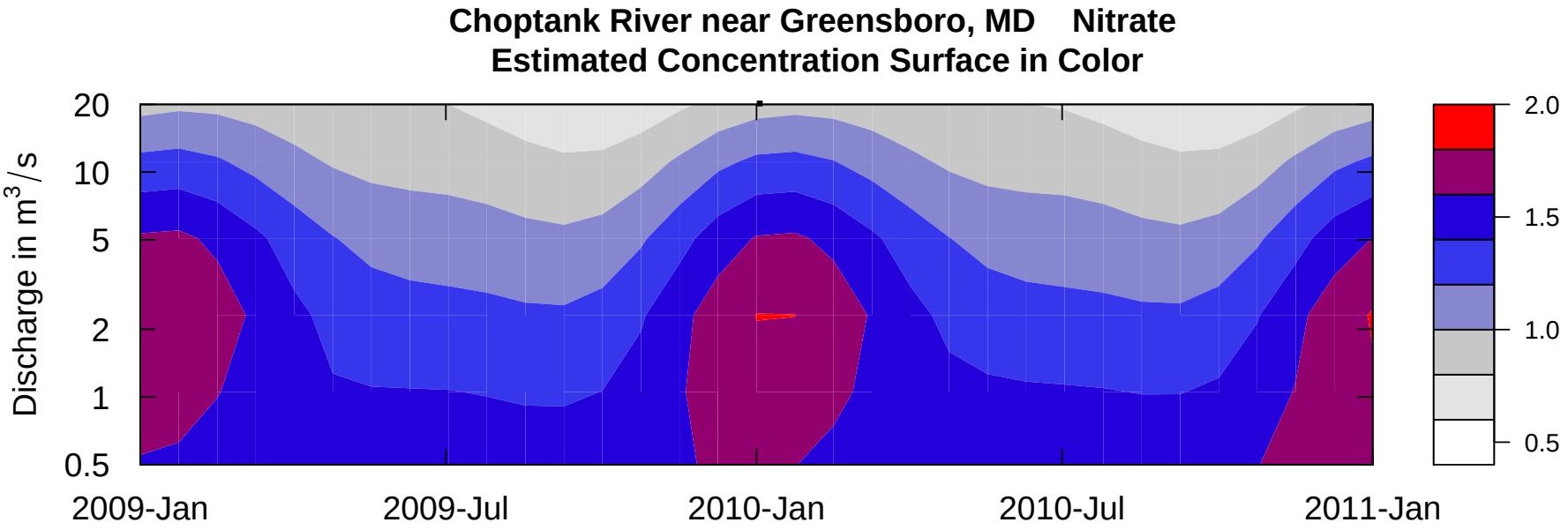



Choptank River near Greensboro, MD
Nitrate
Observed and Estimated Concentration versus Time
Concentration in mg/L
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
2002-Jan
2002-Jul
2003-Jan
2003-Jul
2004-Jan


Choptank River near Greensboro, MD
Nitrate
Observed and Estimated Flux versus Time
Observed Flux in 10^3kg/day
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
2002-Jan
2002-Jul
2003-Jan
2003-Jul
2004-Jan


Choptank River near Greensboro, MD Nitrate
Water Year
Annual Mean Concentration
Concentration in mg/L
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1985
1990
1995
2000
2005
2010
2015

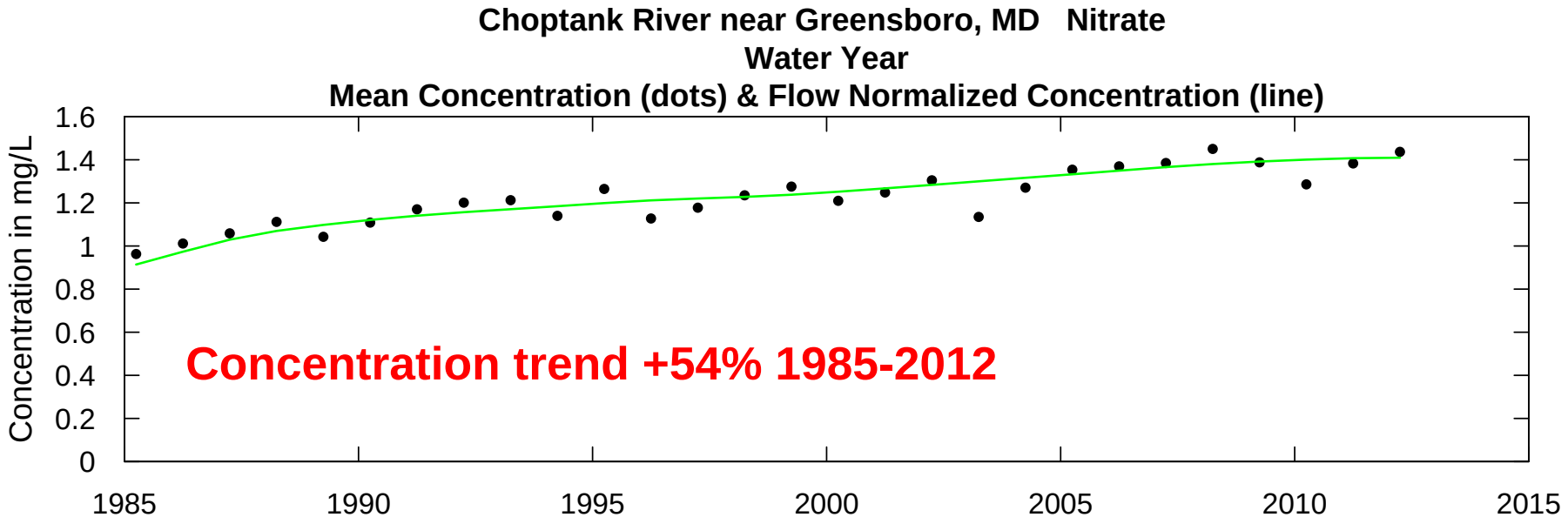

Choptank River near Greensboro, MD Nitrate
Water Year
Annual Flux Estimates
Flux in thousands of kg/year
300
250
200
150
100
50
0
1985
1990
1995
2000
2005
2010
2015

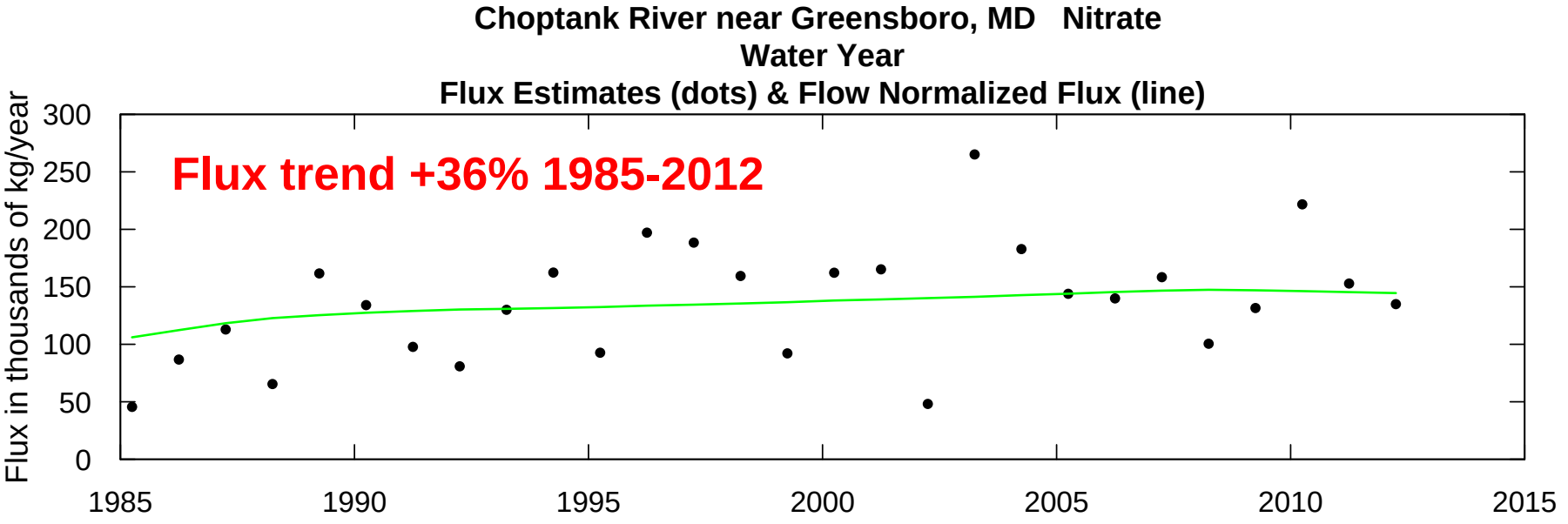


The “flow normalized concentration” on any given day is: c=f(Q,T) integrated over the probability distribution of Q for that day of the year.

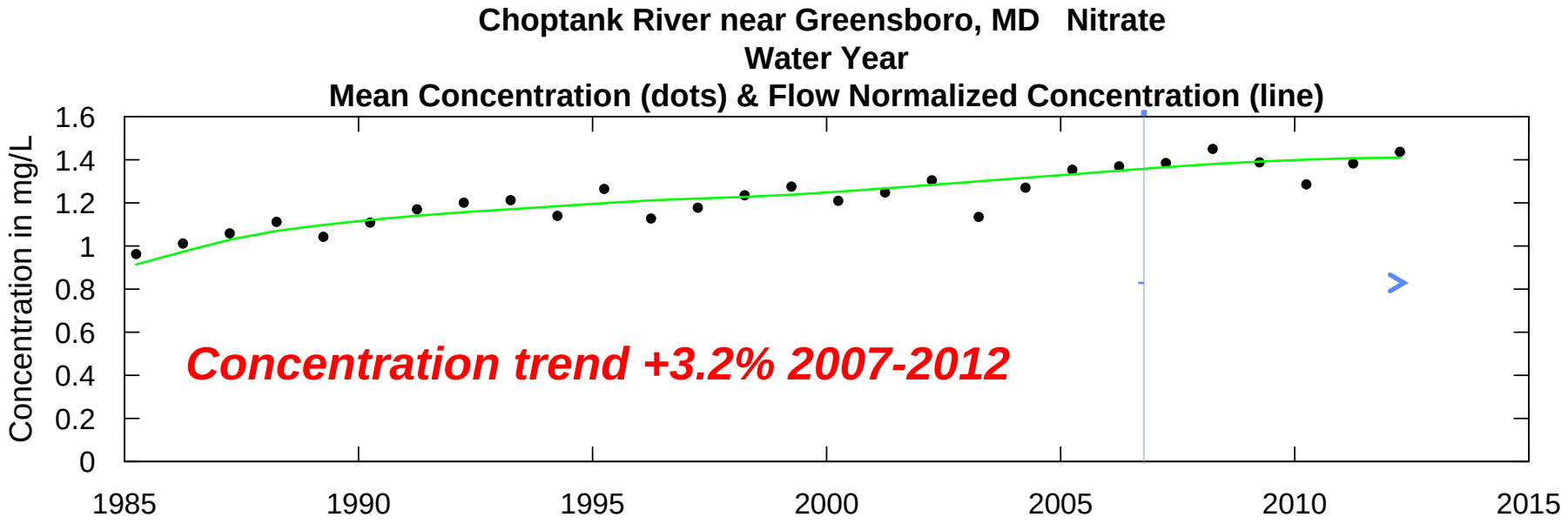
Flow normalized flux is just c x Q integrated over discharge.

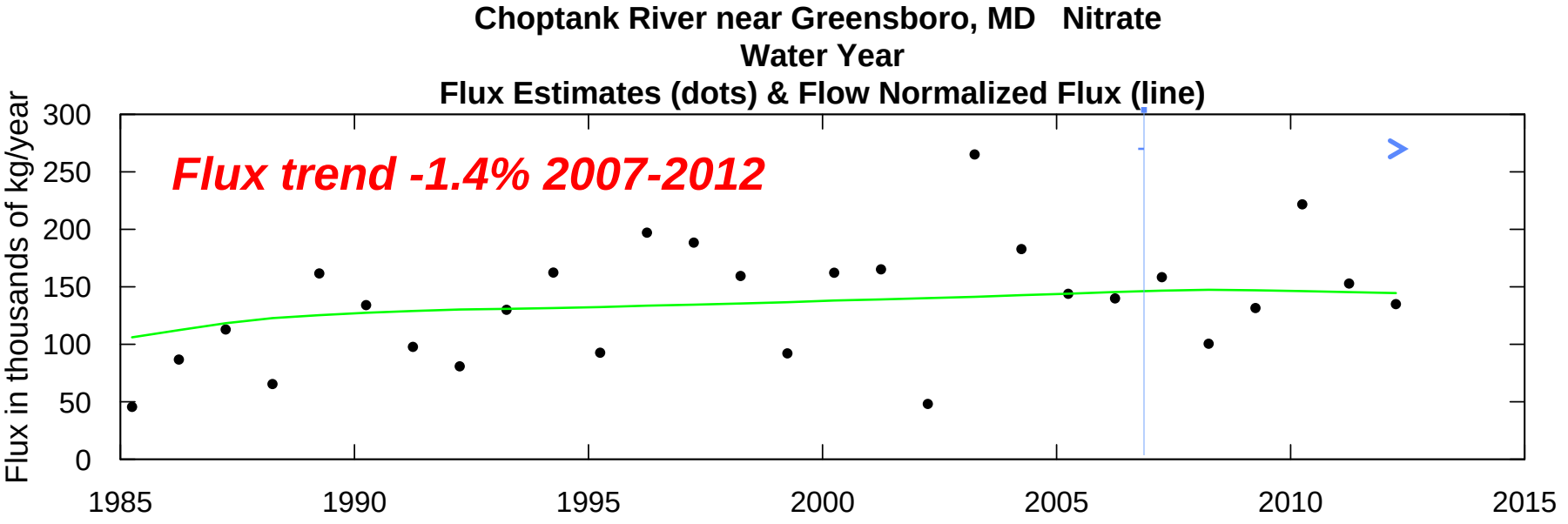
Sum those over the year to get annual flow-normalized mean concentration and flux.





Preliminary, unpublished results

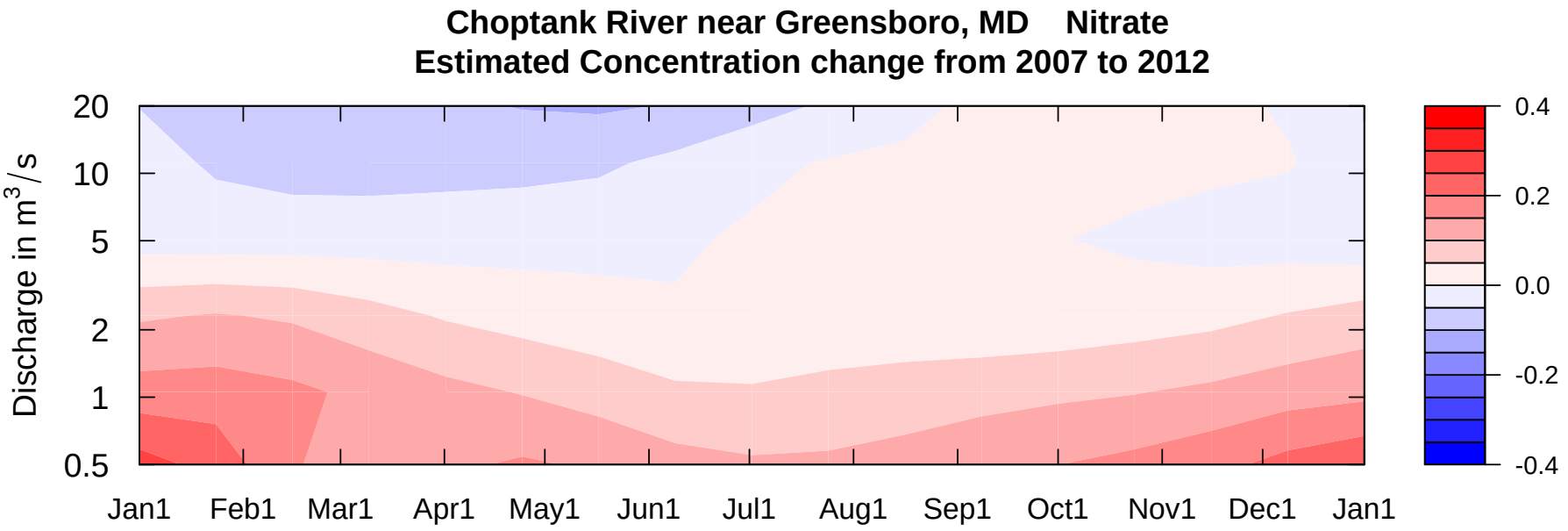




Preliminary, unpublished results

Look at changes in just the last few years.

This is a graphic of differences 2007 to 2012



A plausible hypothesis: Cover crops are helping at higher flows particularly in the winter. Low flows are still responding to legacy of nitrate enriched groundwater.

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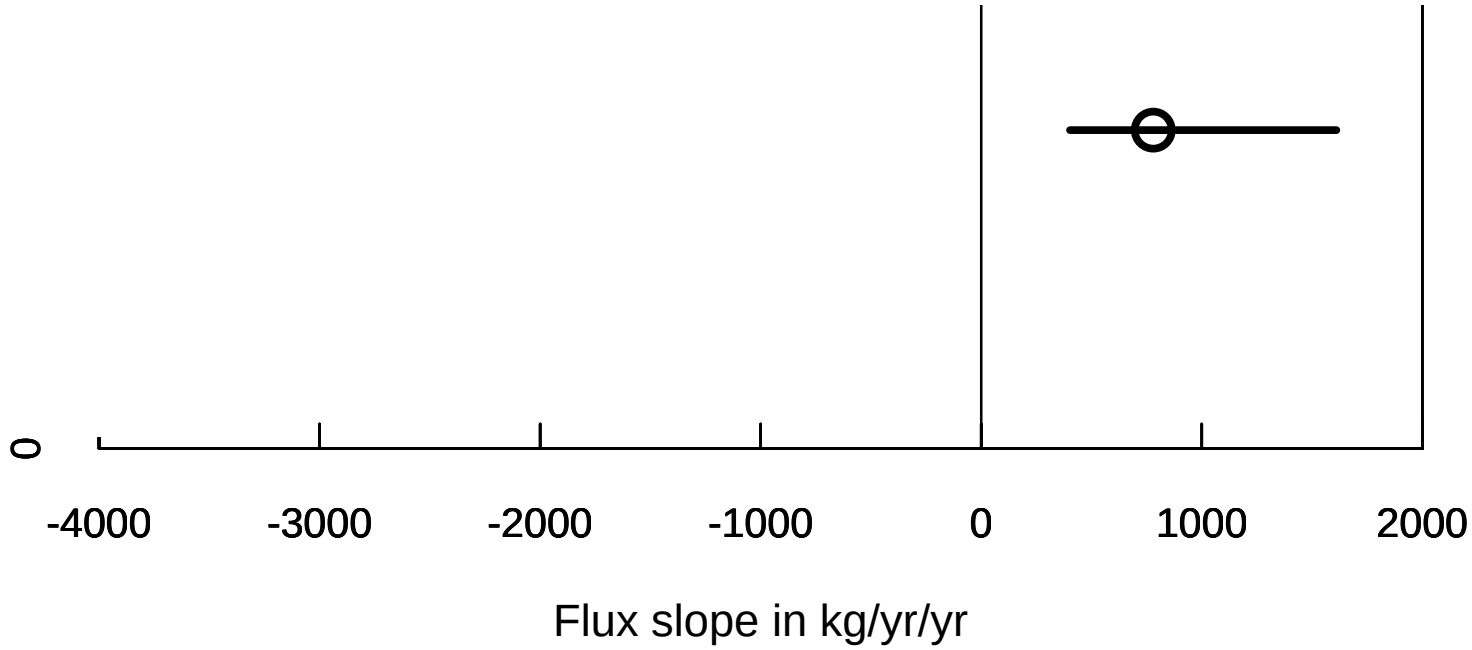
Can we state our uncertainty about the changes? Here are some preliminary results, still in the experimental stage.

Trend in nitrate 1990 – 2007,
circle is our best estimate,
bar is 90% confidence interval



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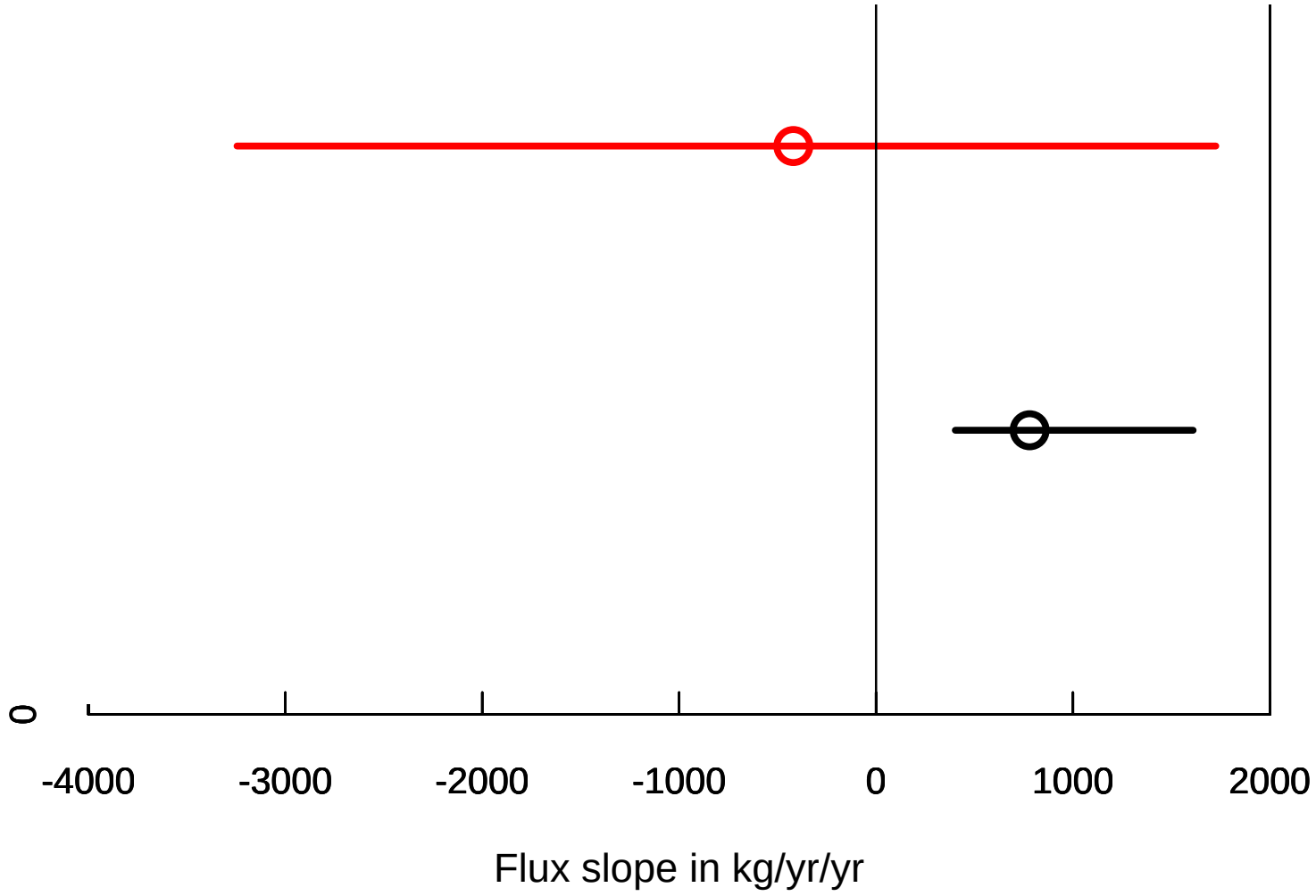
Red bar is CI for trend slope from 2007 – 2012. Best estimate is negative, but the 90% CI is very wide and overlaps the 1990 – 2007 CI.



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Why all this complexity?

Different products for different purposes

- **Concentration versus flux**
- **Actual history versus flow-normalized history**

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For understanding impact on the estuary ecosystem

Estuary

Watershed

Streamgage & Sampling Location

Tidal River

We want the flux history

For understanding progress in the watershed

Estuary

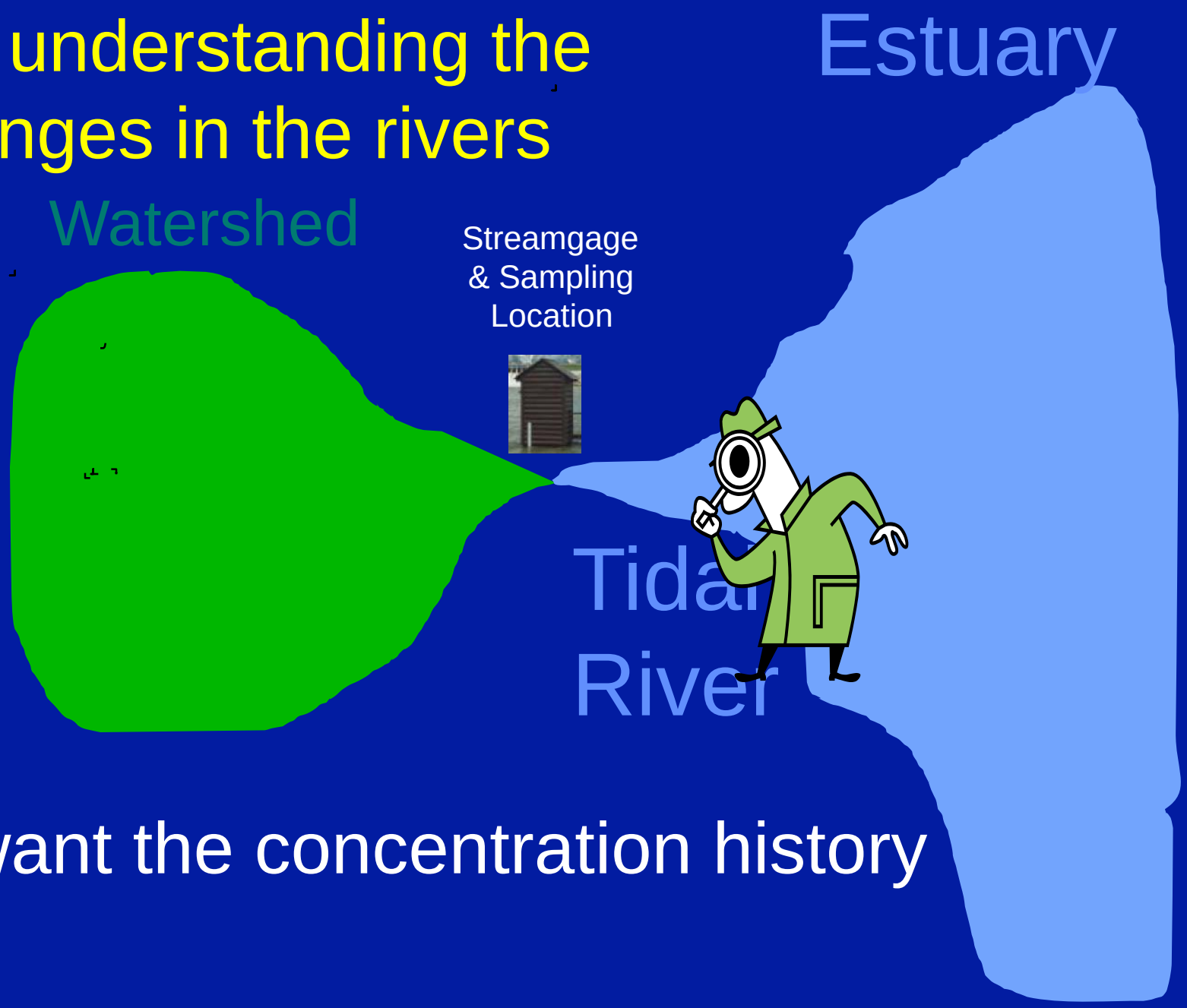
Watershed

Streamgage & Sampling Location

Tidal River

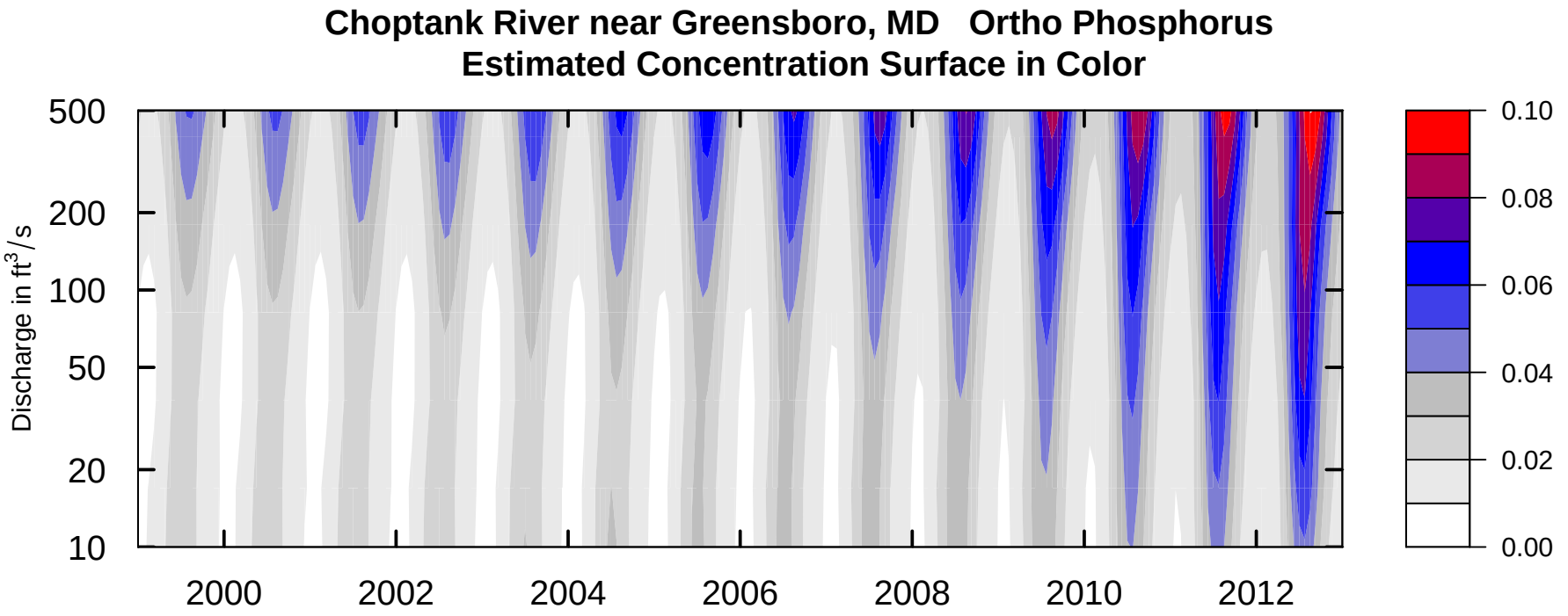
We want the flow-normalized flux history

For understanding the changes in the rivers

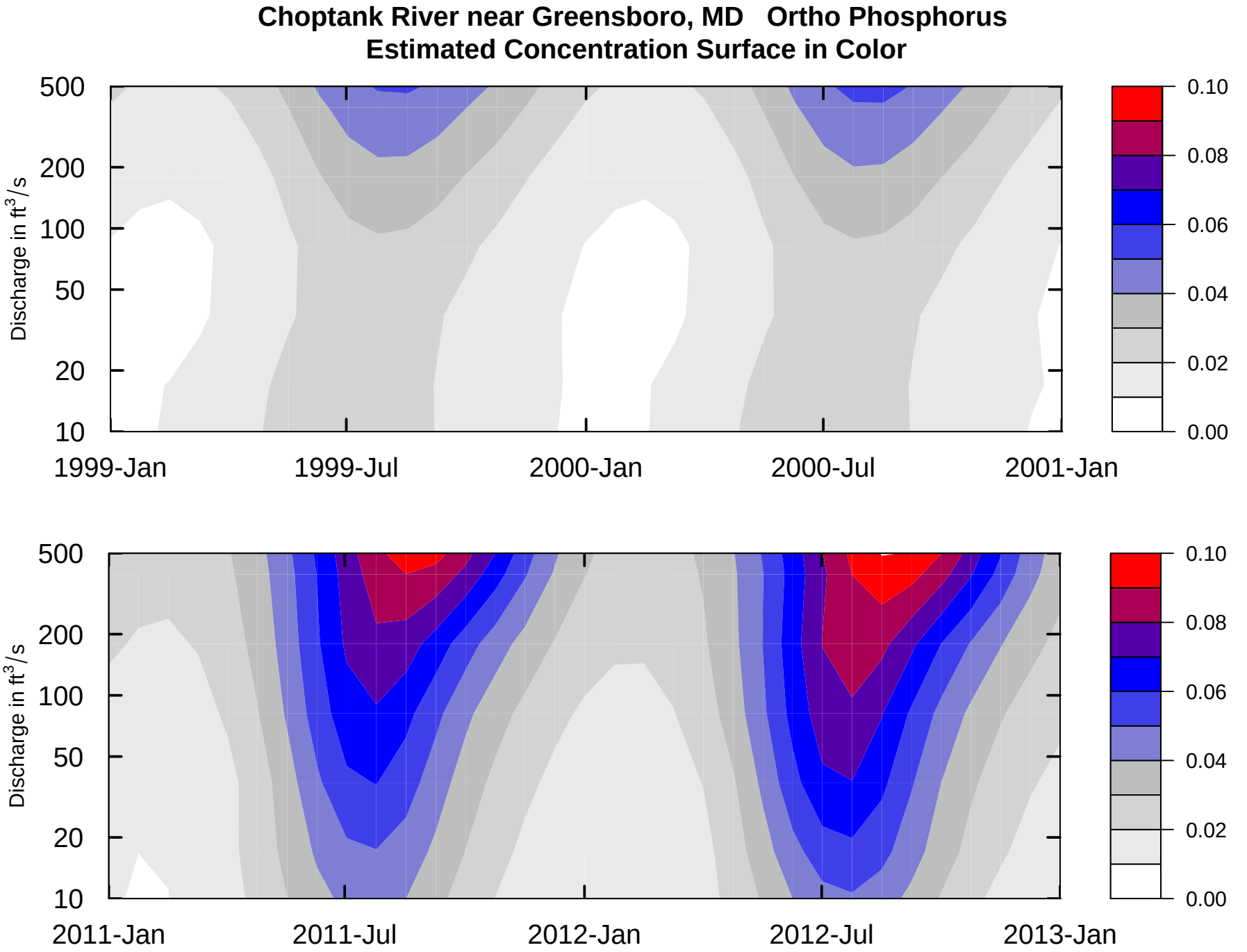


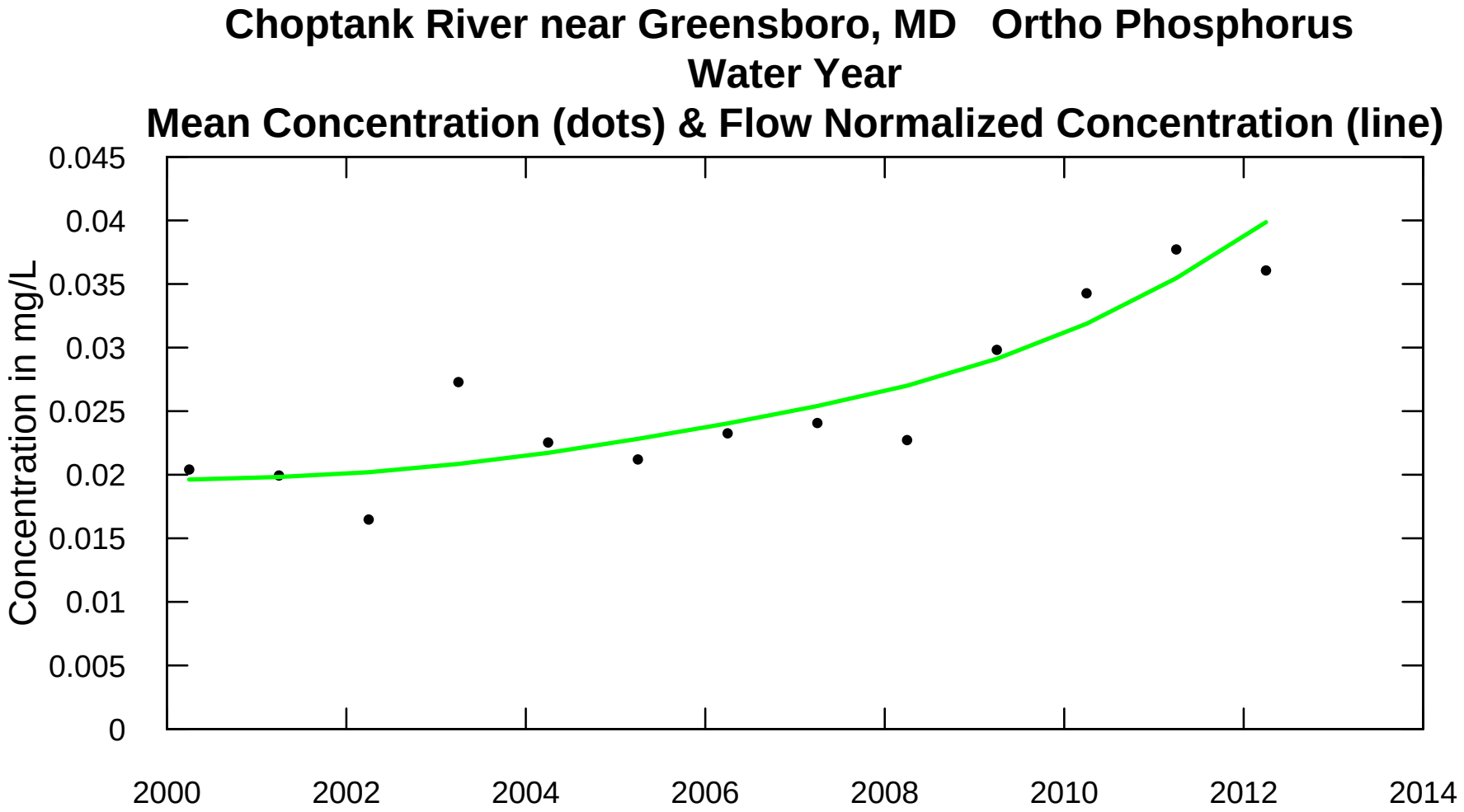
We want the concentration history

Let’s look at ortho-phosphorus for the Choptank



Preliminary, unpublished results


Choptank River near Greensboro, MD Ortho Phosphorus
Estimated Concentration Surface in Color
Discharge in ft3/s
500
200
100
50
20
10
1999-Jan
1999-Jul
2000-Jan
2000-Jul
2001-Jan
0.10
0.08
0.06
0.04
0.02
0.00
Discharge in ft3/s
500
200
100
50
20
10
2011-Jan
2011-Jul
2012-Jan
2012-Jul
2013-Jan
0.10
0.08
0.06
0.04
0.02
0.00



Concentration up 103%
Flux up 69%

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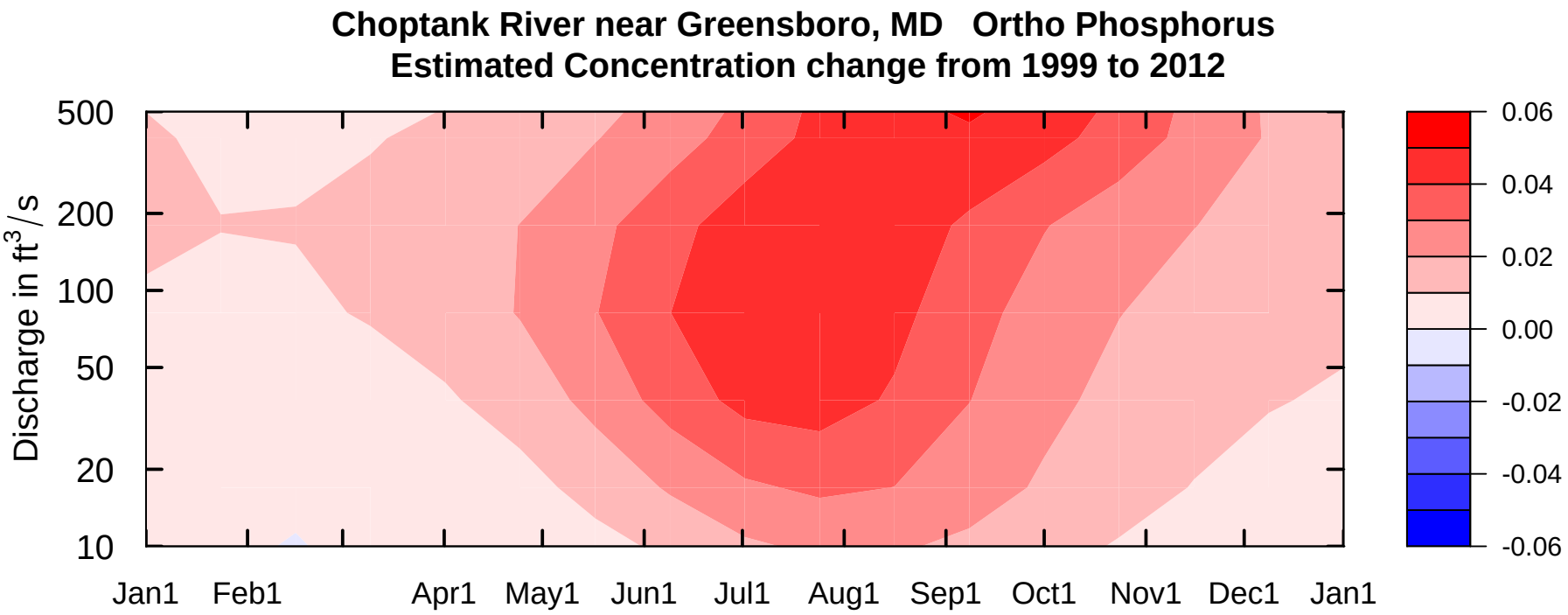
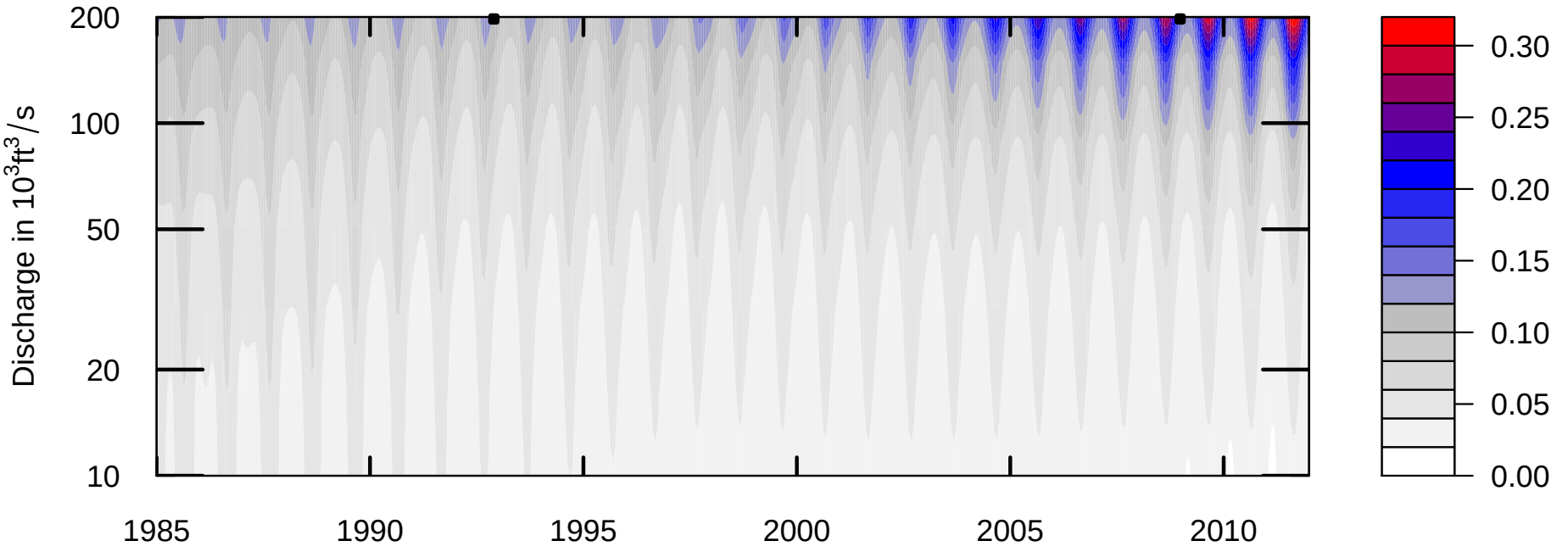
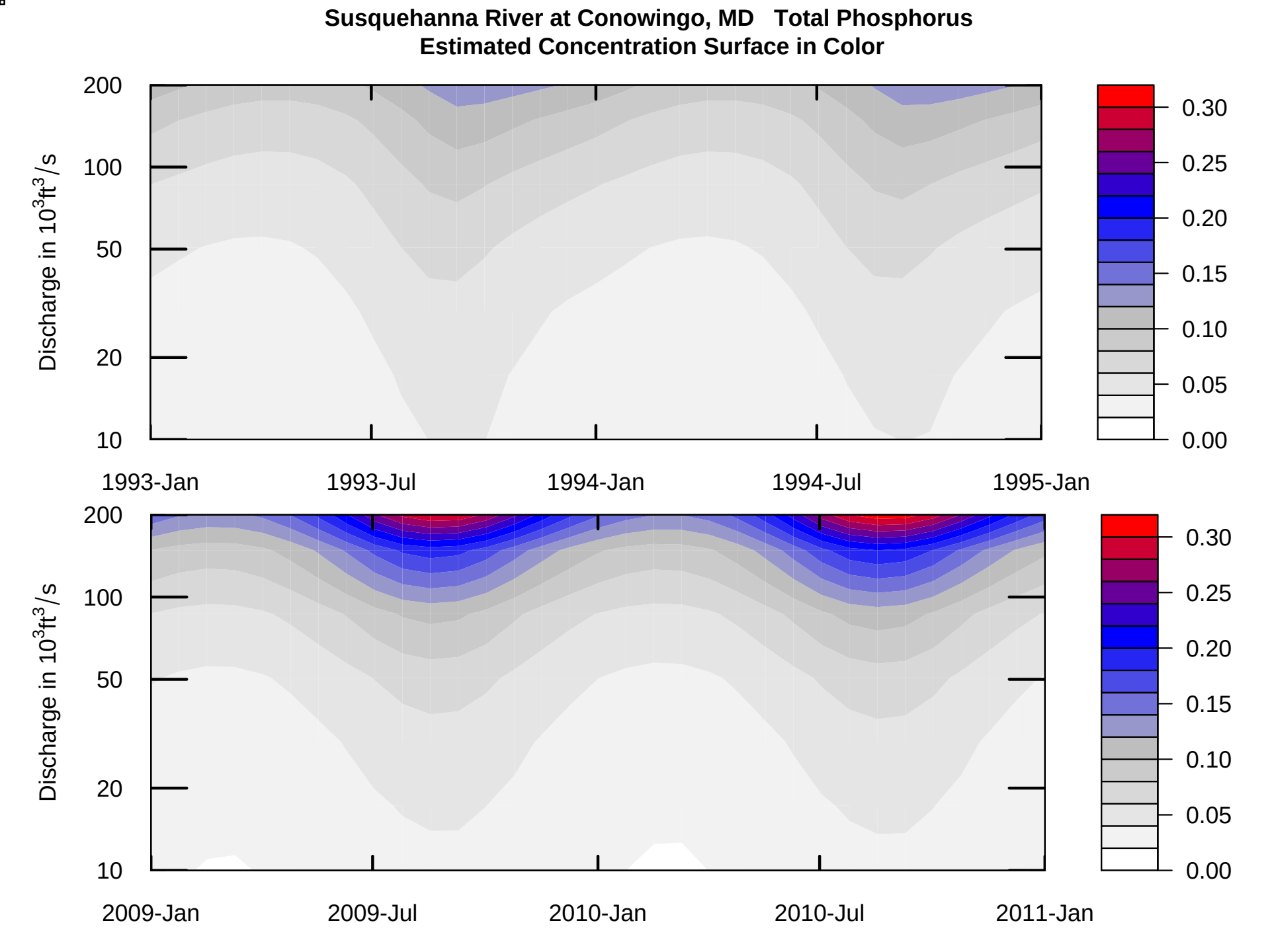
Preliminary, unpublished results

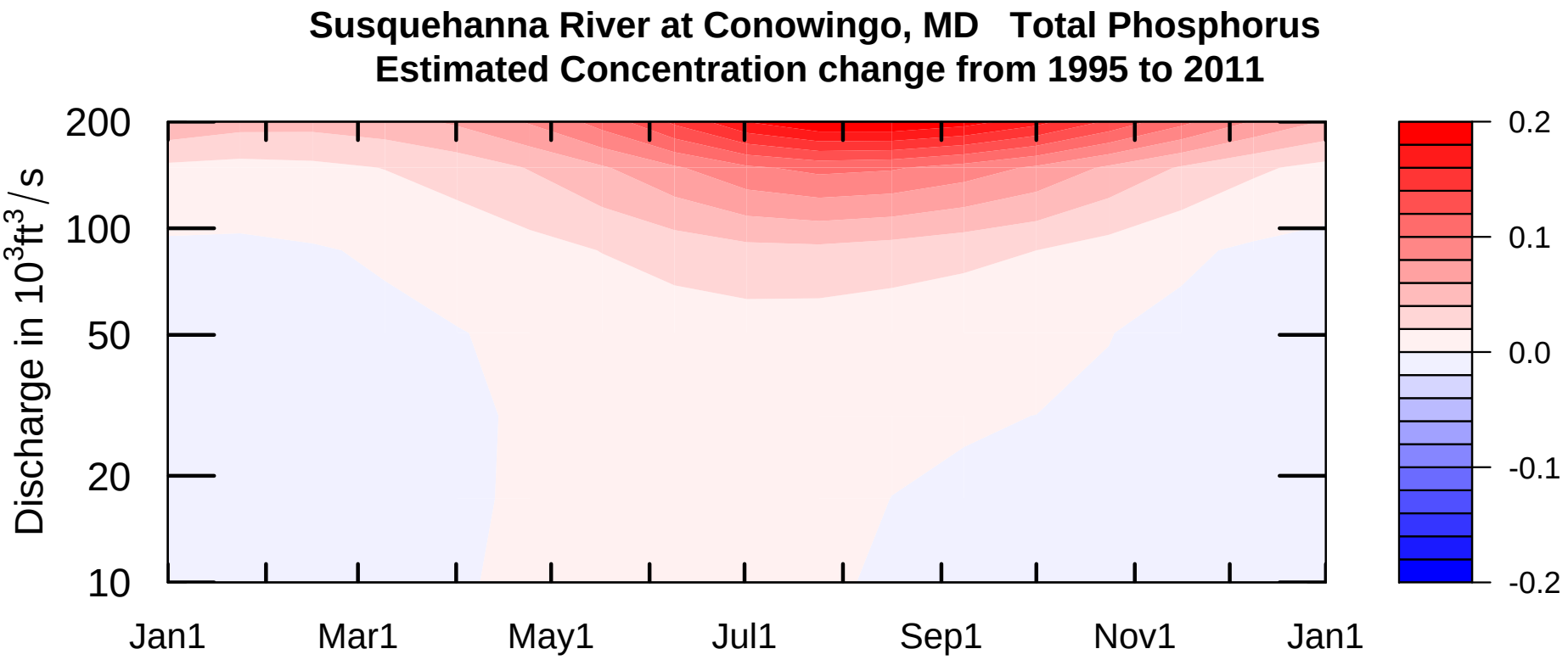


Preliminary, unpublished results



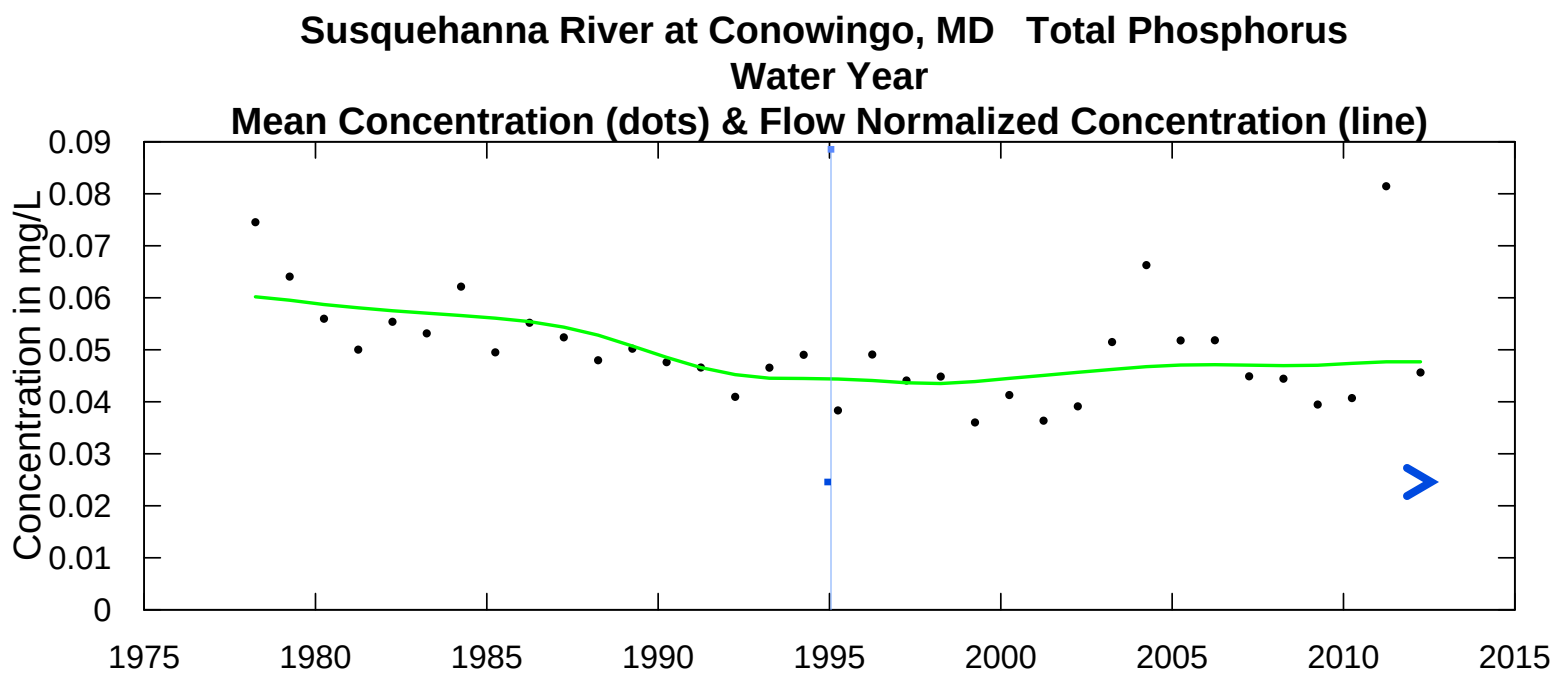
Conowingo Dam during Tropical Storm Lee, September 2011, Reservoir is rapidly filling, Trap efficiency in decline


Susquehanna River at Conowingo, MD Total Phosphorus
Estimated Concentration Surface in Color
Discharge in $10^3 ft^3/s$
200
100
50
20
10
1993-Jan
1993-Jul
1994-Jan
1994-Jul
1995-Jan
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Discharge in $10^3 ft^3/s$
200
100
50
20
10
2009-Jan
2009-Jul
2010-Jan
2010-Jul
2011-Jan
0.30
0.25
0.20
0.15
0.10
0.05
0.00

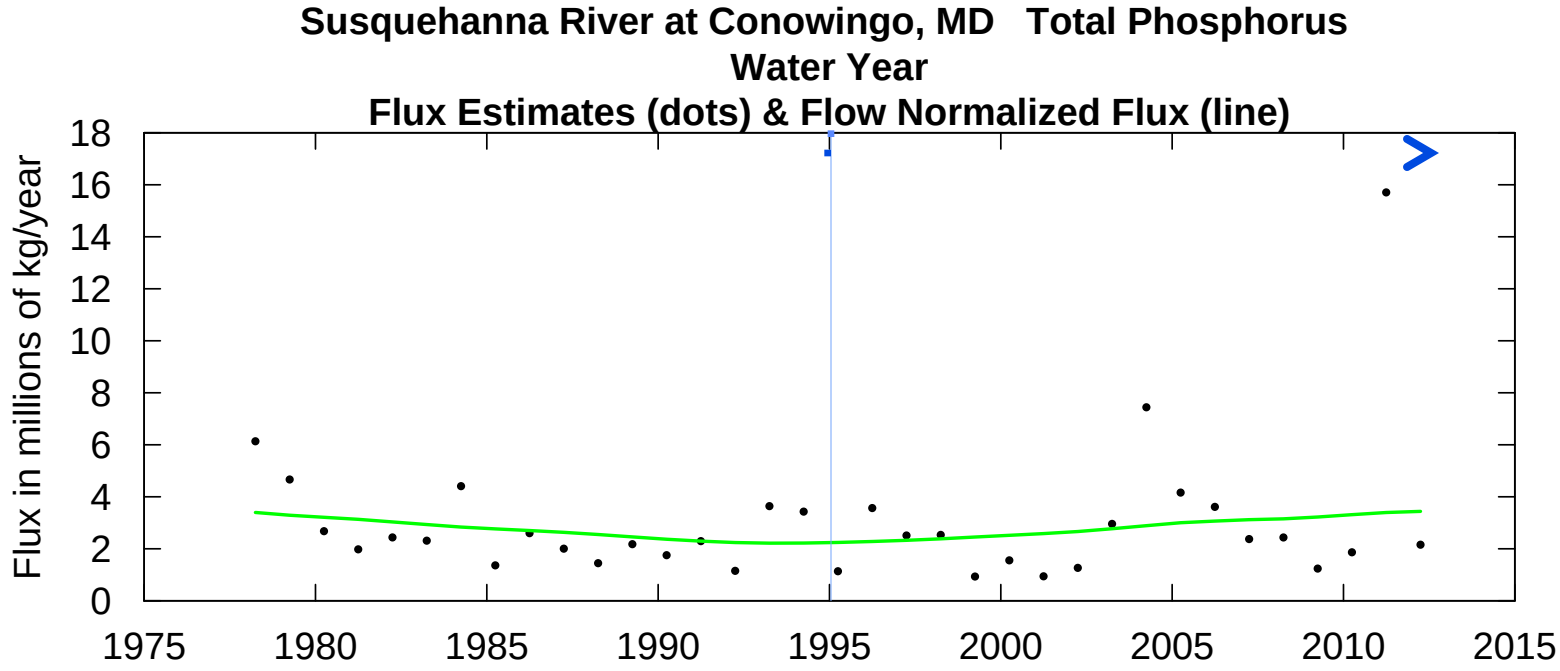

Susquehanna River at Conowingo, MD Total Phosphorus
Estimated Concentration change from 1995 to 2011
Discharge in $10^3 ft^3/s$
200
100
50
20
10
Jan1
Mar1
May1
Jul1
Sep1
Nov1
Jan1
0.2
0.1
0.0
-0.1
-0.2

Change from 1995-2012

0.4%/yr



3.1%/yr



Temporal Questions

- Does the trend differ across flows?
- Does the trend differ across seasons?
- Is it significantly different from zero?
- Has it changed in slope over time?
- How do any of these things relate to changes in practices?
- What's the trend at the time of year critical to the ecosystem?

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Multi-site Questions

- How do trends in concentrations or yields compare across watersheds?
- How do these relate to changes in:
  - Population
  - Point source controls
  - Urban runoff BMPs
  - Atmospheric deposition
  - Agricultural practices – BMPs
  - Declines in BMP effectiveness

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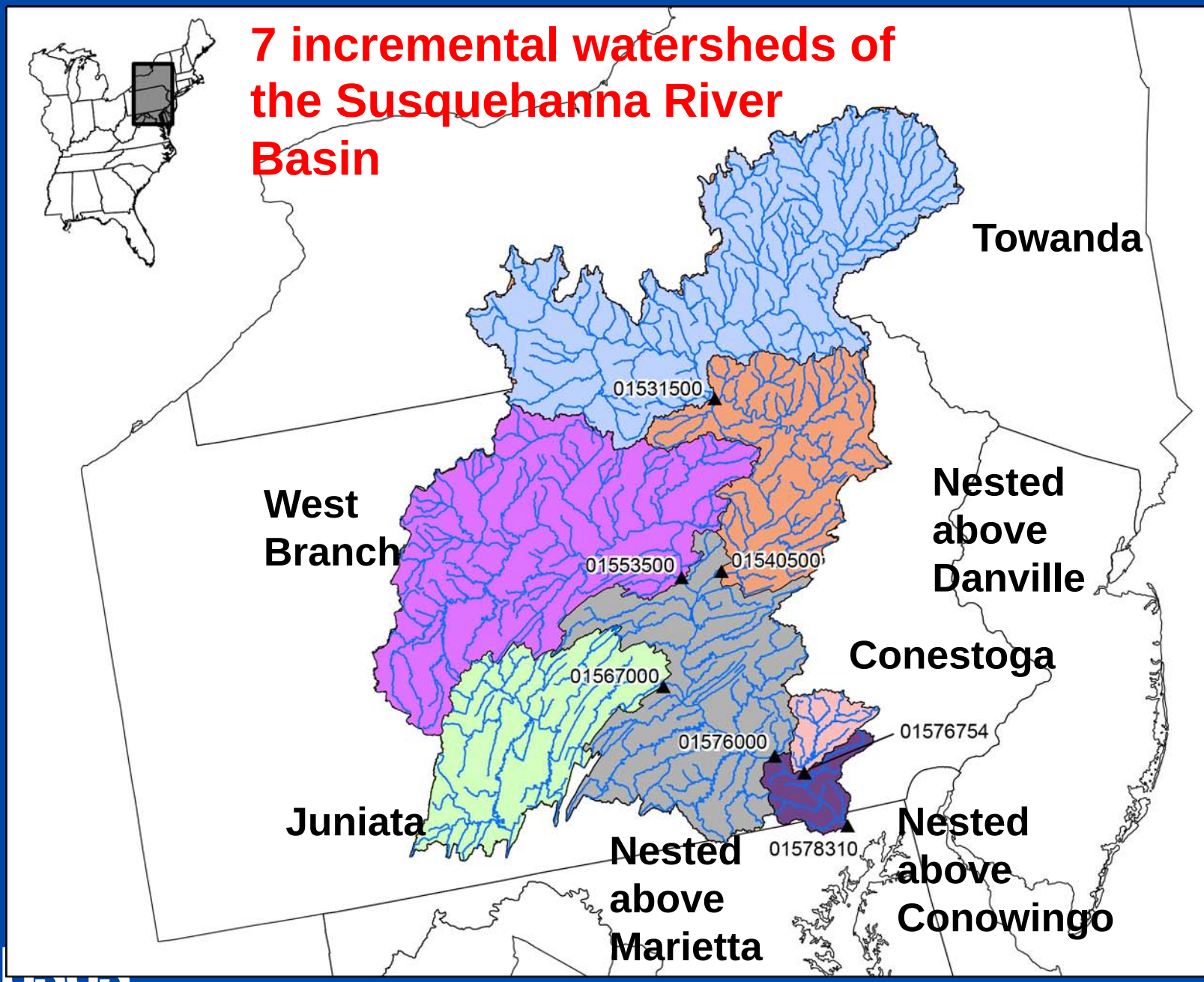
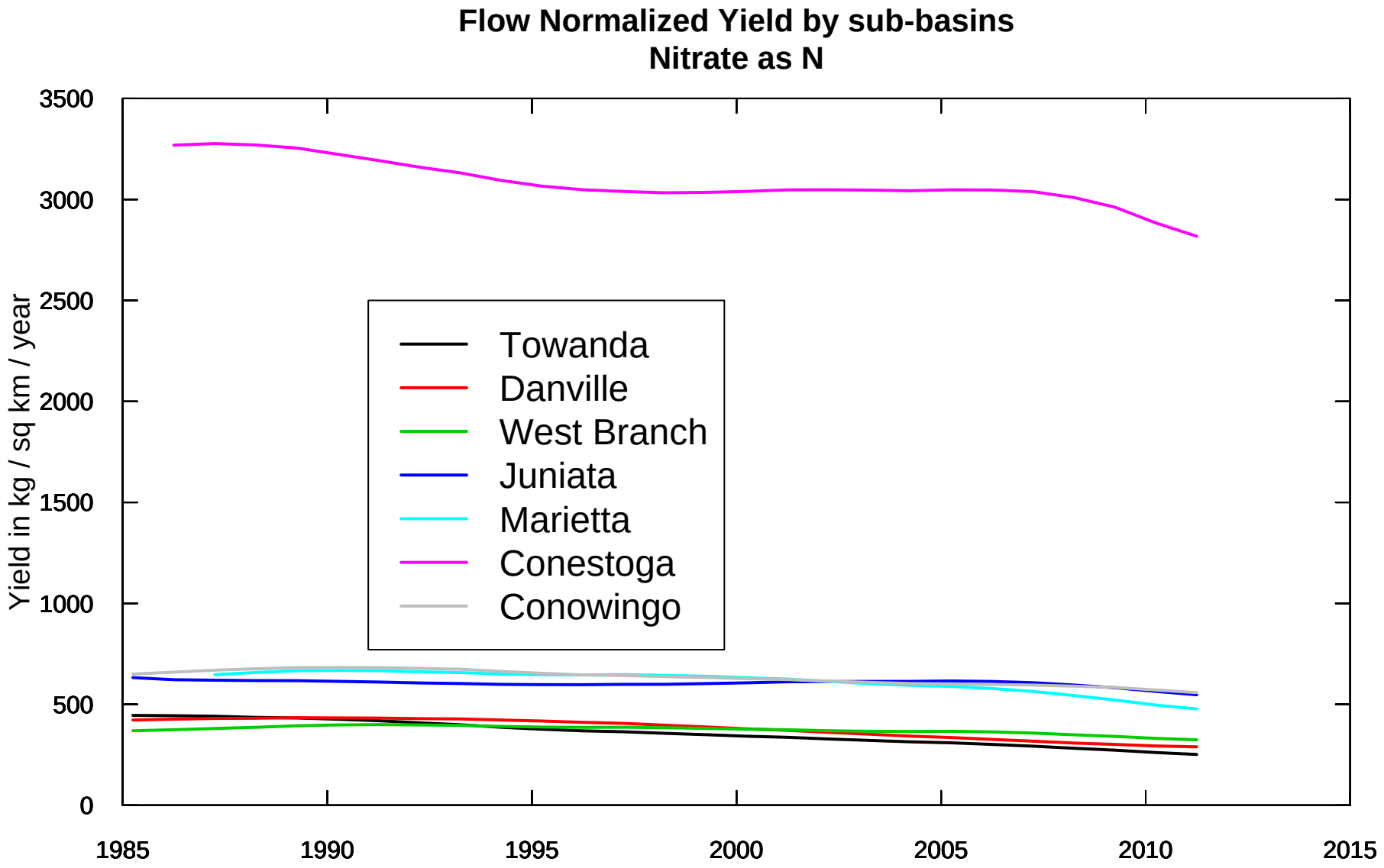

7 incremental watersheds of the Susquehanna River Basin
Towanda
01531500
West Branch
01553500
01540500
Nested above Danville
Conestoga
01567000
01576754
01576000
Juniata
Nested above Marietta
01578310
Nested above Conowingo

Preliminary, unpublished results



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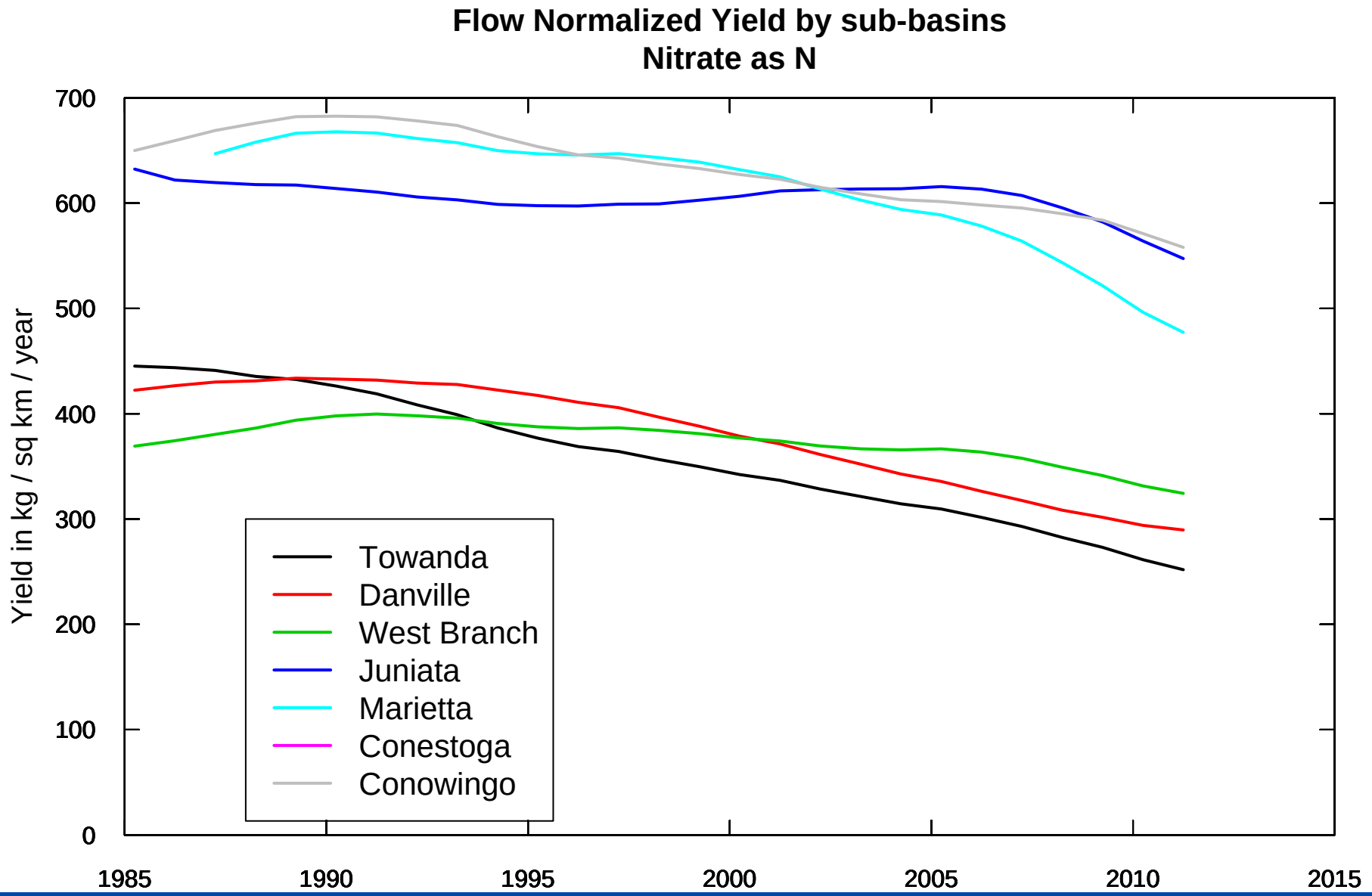
Focus in on the six lower yield sites

Preliminary, unpublished results



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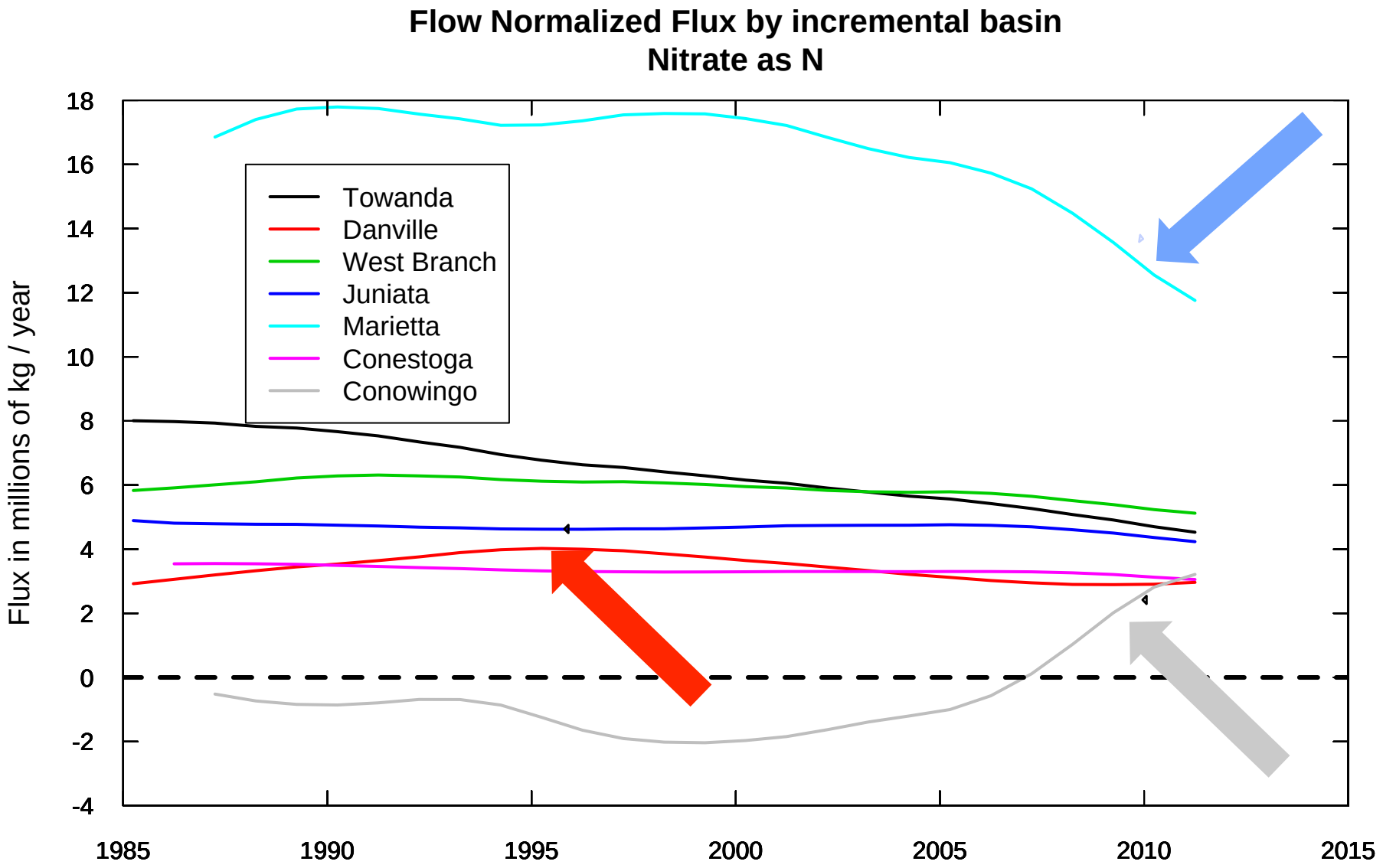
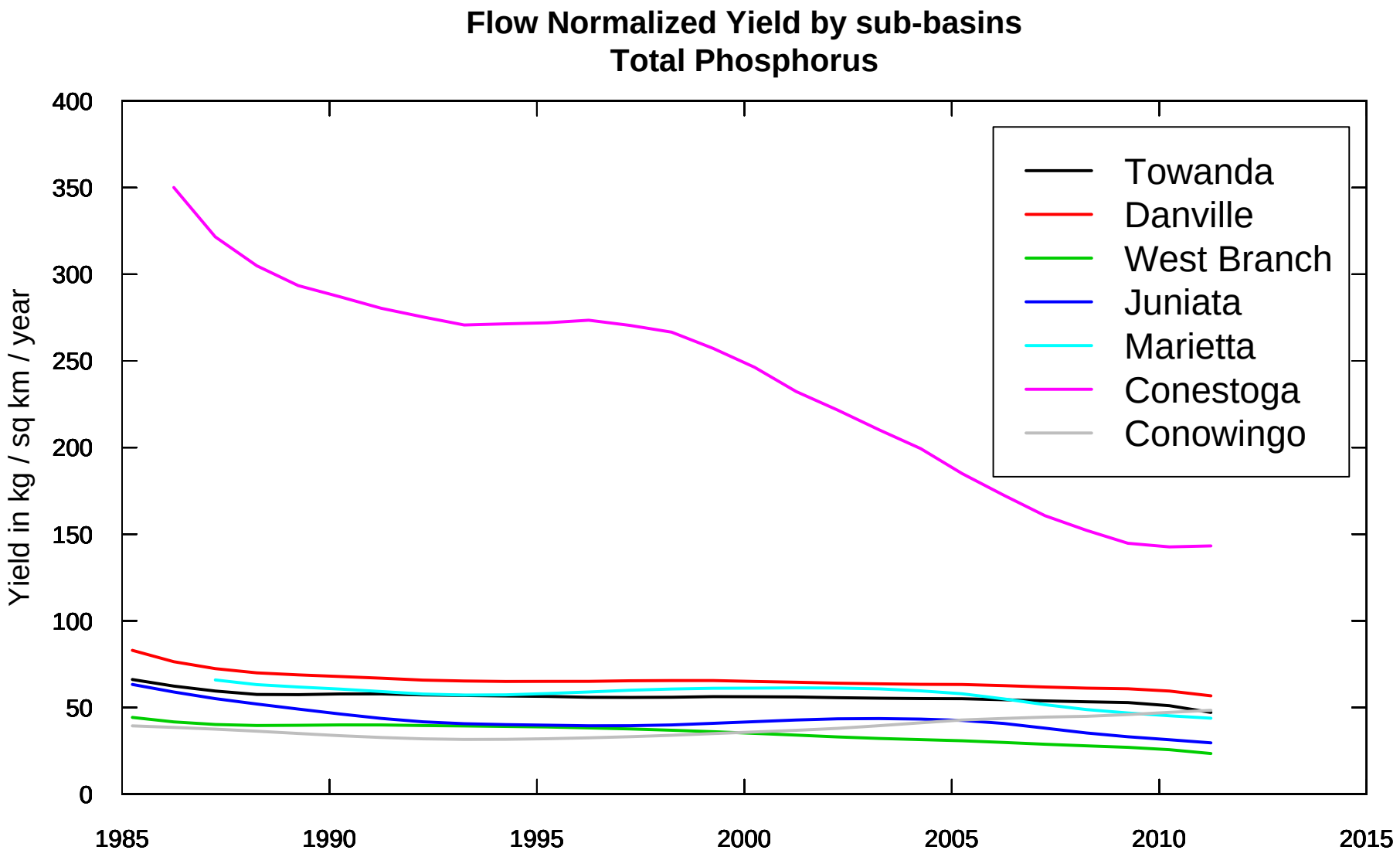
Now look at trends in output minus input?

Preliminary, unpublished results



Danville, Marietta, and Conowingo incremental watersheds??

Preliminary, unpublished results



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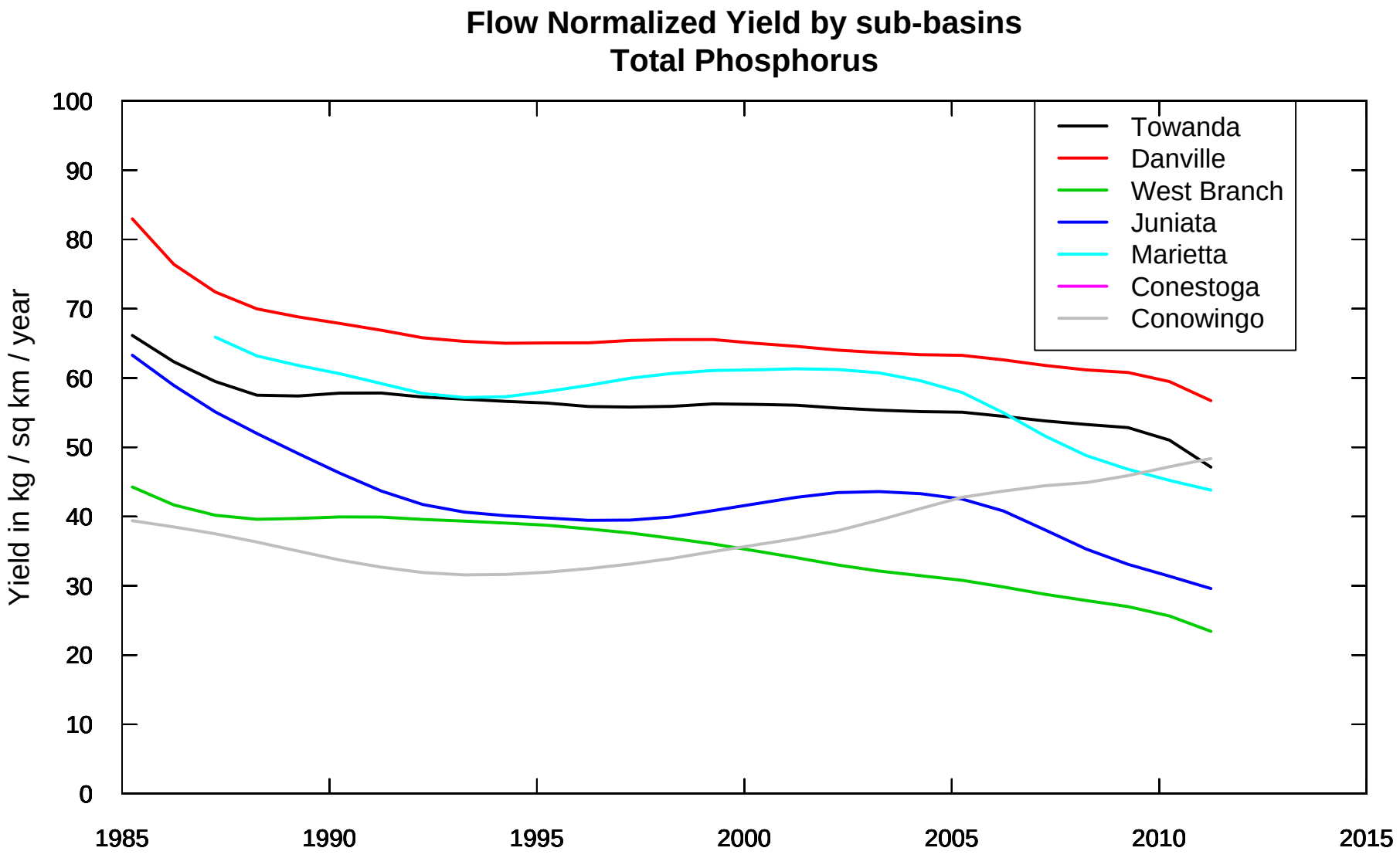
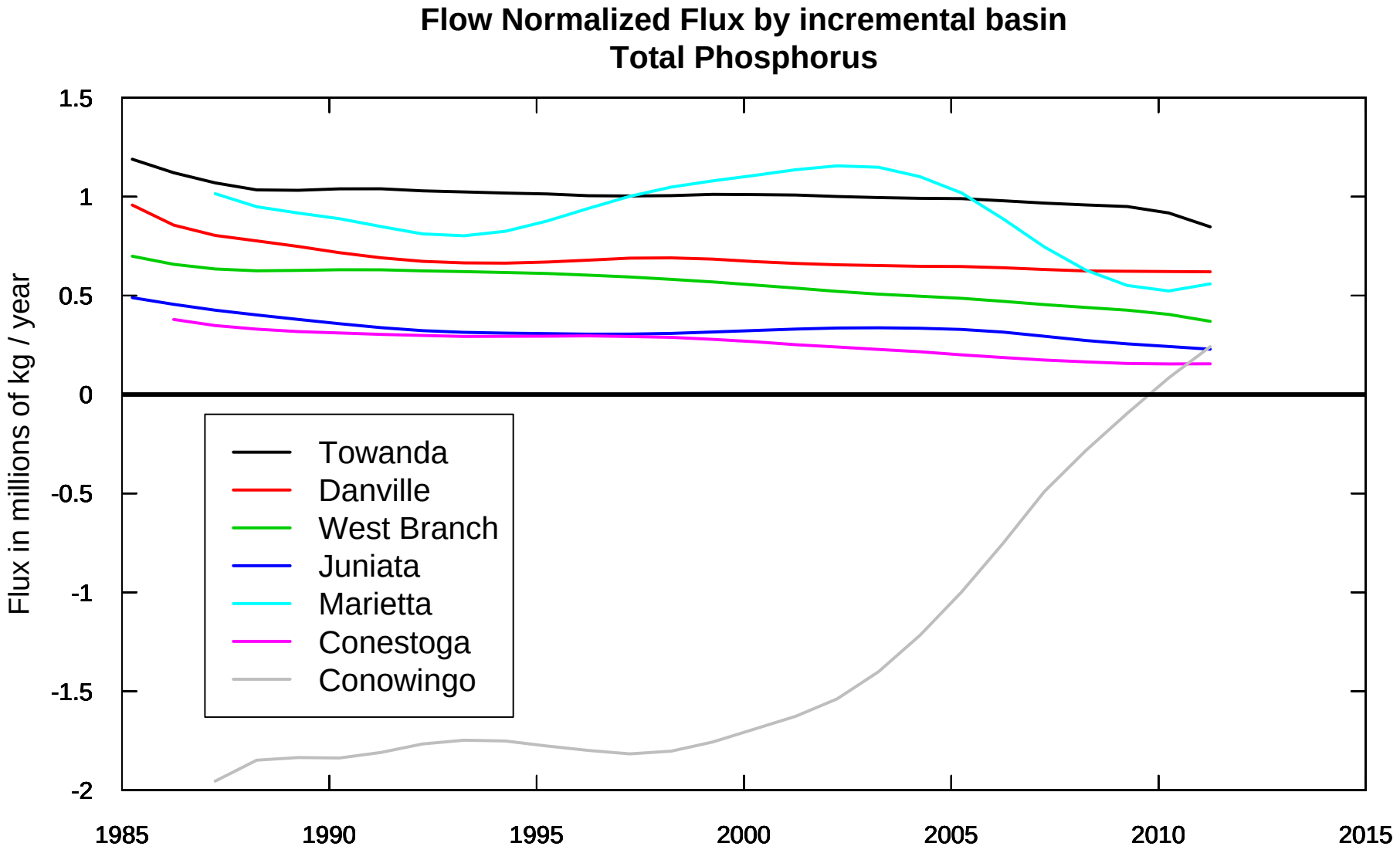
Success almost everywhere



Preliminary, unpublished results

Preliminary, unpublished results



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Conowingo, was a large sink, now a small source

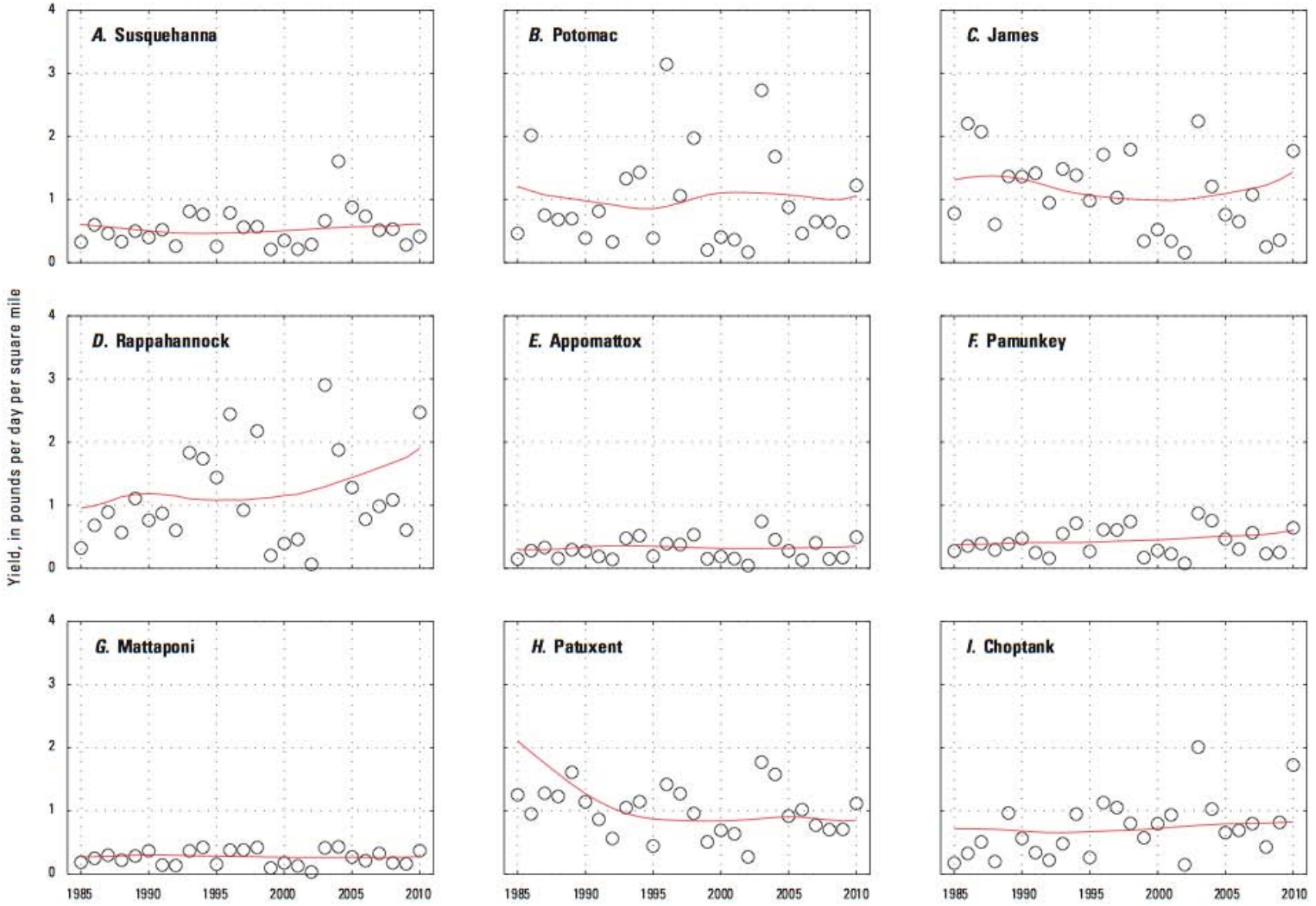

Figure 20. Total phosphorus yields (black circles) and flow-normalized yields (red line) for the nine RIM stations using the WRTDS method.

Overview of WRTDS interpretations

- At any given site, most of the variability is due to the random variations in streamflow (random variations in weather)
- Seasonality is a large component of variability
- The non-stationary portion (trend) can be rather subtle, and in WRTDS is assumed to be rather gradual
- The changes in human drivers are mostly gradual and their impacts on downstream water quality can also have long lag times

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Where do we go next?

- Quantification of uncertainty of WRTDS results
- WRTDS can generate characterizations of change and help us consider hypotheses about the drivers of change.
- The challenges are:
  - How to test the linkages between cause and effect
  - How to have results feed-back to the watershed model

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