Recent history of Conowingo Reservoir Infill:

In the broader context of trends in Nitrogen and Phosphorus Fluxes to the Chesapeake Bay

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A series of questions

- How big is the change in TN and TP input to Bay?
- How sure are we about it?
- Is this just an artifact of Tropical Storm Lee?
- Is this a result of climate change?
- Watershed sources vs. change in net trapping?
- Implications for the watershed model?
- Importance in a total Chesapeake Bay context?

How big is the change?

- Analysis uses Weighted Regressions on Time, Discharge, and Season
- Accounts for changing response to flow and season
- Flow-normalized flux integrates out the influence of season and flow variation
- Results expressed here in terms of % change per year over two periods: 1995-2014 and 2005-2014.

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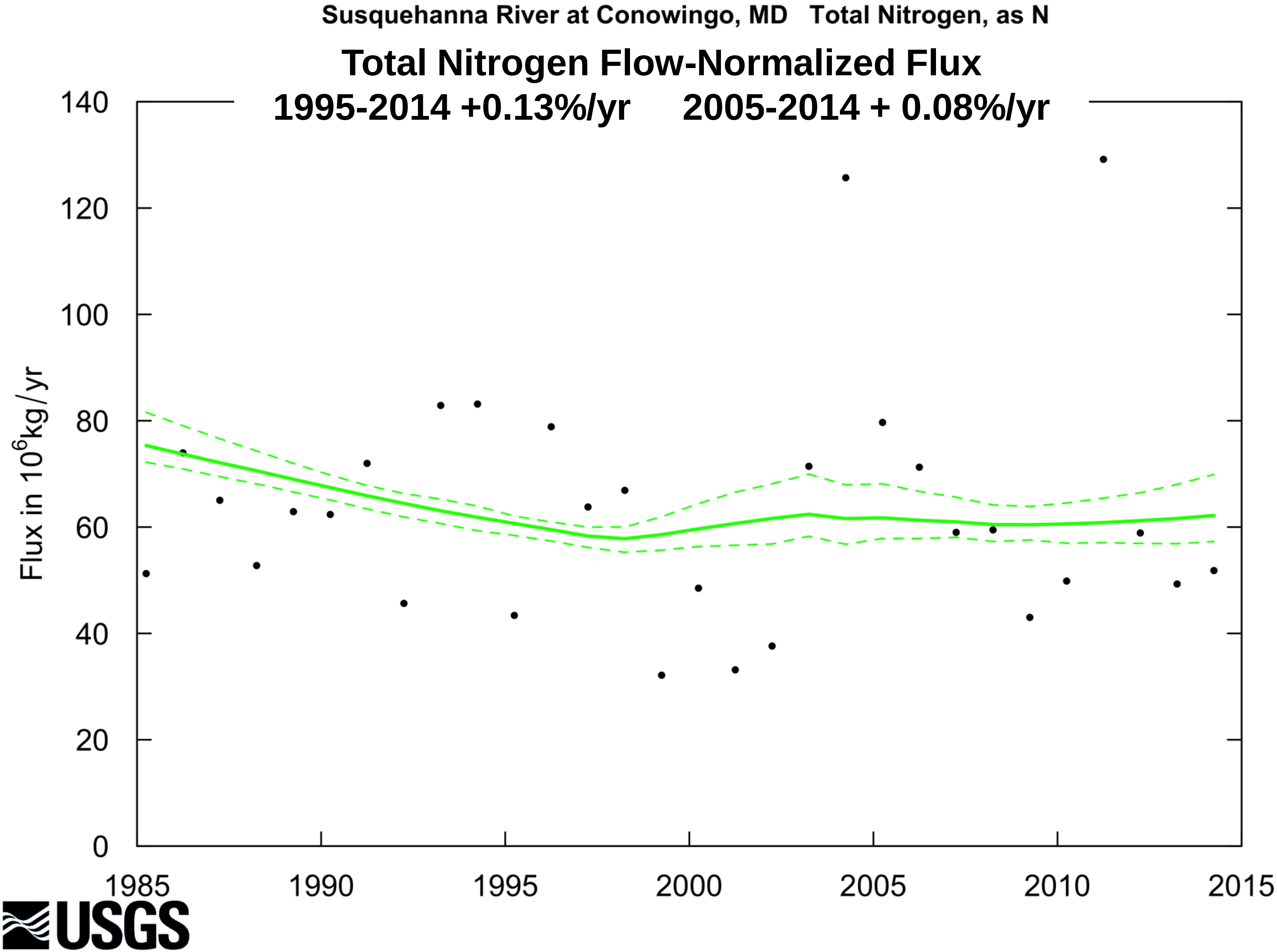
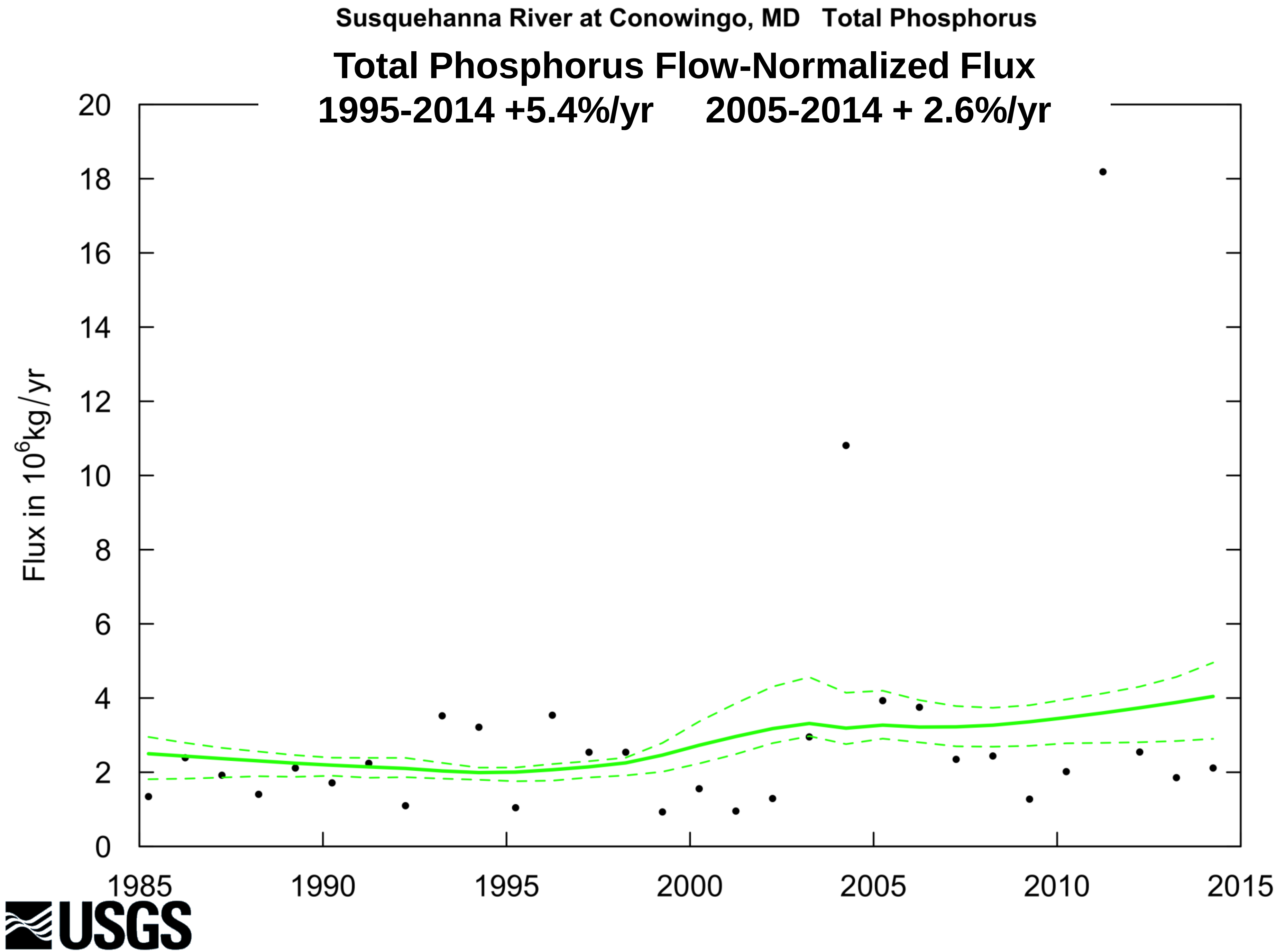

Susquehanna River at Conowingo, MD   Total Nitrogen, as N
Total Nitrogen Flow-Normalized Flux
1995-2014 +0.13%/yr   2005-2014 + 0.08%/yr
Flux in 10^6 kg/yr
0
20
40
60
80
100
120
140
1985
1990
1995
2000
2005
2010
2015
USGS


Susquehanna River at Conowingo, MD Total Phosphorus
Total Phosphorus Flow-Normalized Flux
1995-2014 +5.4%/yr 2005-2014 + 2.6%/yr
Flux in 10^6kg/yr
0
2
4
6
8
10
12
14
16
18
20
1985
1990
1995
2000
2005
2010
2015
USGS

Uncertainty? Using the WRTDS Bootstrap Test*

	1995-2014	2005-2014
	Total Nitrogen Results	
p-value	0.62	0.94
Change in 10^6 kg / yr	+1.5	+0.44
90% CI on change	(-6.0,9.7)	(-6.3,9.1)
	Total Phosphorus Results	
p-value	0.08	0.49
Change in 10^6 kg / yr	+2.04	+0.77
90% CI on change	(0.27,2.68)	(-0.87,1.28)

* Hirsch, et al. 2015, Journal of Environmental Modelling and Software

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Is it possible that one big event, Tropical Storm Lee, fooled us into thinking that a major change is happening?

No. We could see the change in our previous published work, before T.S. Lee happened

Hirsch, Moyer, and Archfield, 2010, JAWRA, TP analysis through water year 2008

TABLE 4. Changes in Total Phosphorus Flux for the Nine RIM Sites for Two Periods: 1978-2008 and 2000-2008.

River	1978-2008		2000-2008	
	Slope (% per year)	Flux Change (kg/day)	Slope (% per year)	Flux Change (kg/day)
Susquehanna	−0.4	−990	+1.9	+970
Potomac	−0.3	−530	−2.0	−940
James	+0.5	+480	+2.5	+590
Rappahannock	+4.0	+780	+8.4	+580
Appomattox	−0.2	−10	+0.8	+12
Patuxent	−2.5	−400	+0.2	+2
Pamunkey	+1.2	+64	+1.1	+19
Mattaponi	+0.7	+12	+0.1	+0
Choptank	+0.3	+3	+1.9	+5

Flux change is the flow-normalized annual flux estimate at the end of the period minus the flow-normalized annual flux estimate at the beginning of the period. The slope is this flux change per year expressed in percentage terms over the period.

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Moyer, Hirsch, and Hyer, 2012, USGS Scientific Investigations Report, 2012-5244
TP results presented in table 5. Based on data through water year 2010.

RIM station	WRTDS flow-normalized yield			
	1985 to 2010		2001 to 2010	
	Total change (%)	Slope (%/yr)	Total change (%)	Slope (%/yr)
Susquehanna	1.9	0.1	18.4	2.0
Potomac	–12.4	–0.5	–5.0	–0.6
James	9.4	0.4	46.0	5.1
Rappahannock	99.8	4.0	62.0	6.9
Appomattox	16.1	0.6	11.5	1.3
Pamunkey	60.5	2.4	31.2	3.5
Mattaponi	1.2	0.0	3.6	0.4
Patuxent	–59.7	–2.4	0.2	0.0
Choptank	14.7	0.6	11.6	1.3

latest estimate, 2001-2014, trend is 2.8% / yr

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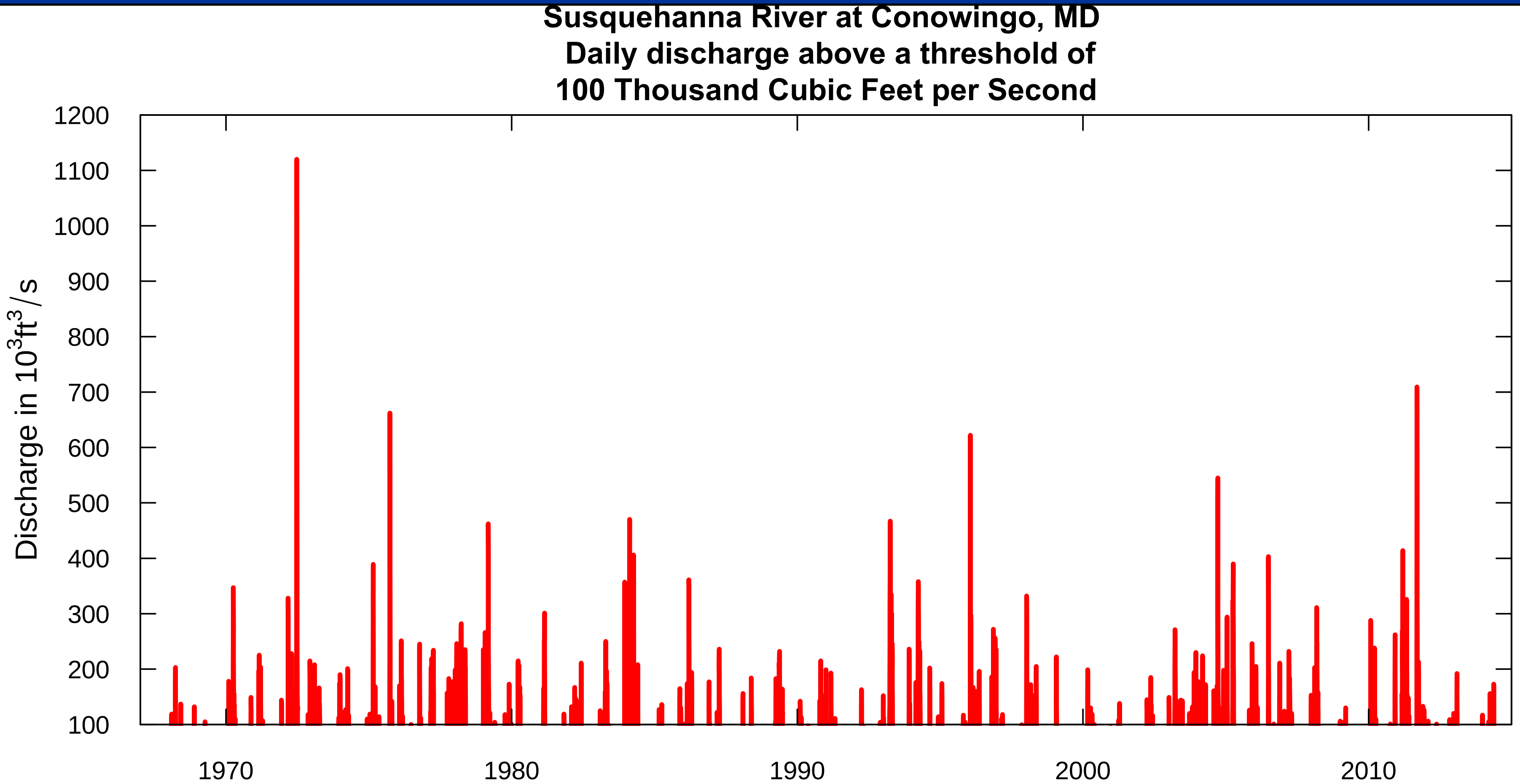
Is this a result of climate change:
More frequent high flows, bigger high flows?
Look at the flow record for the last half century



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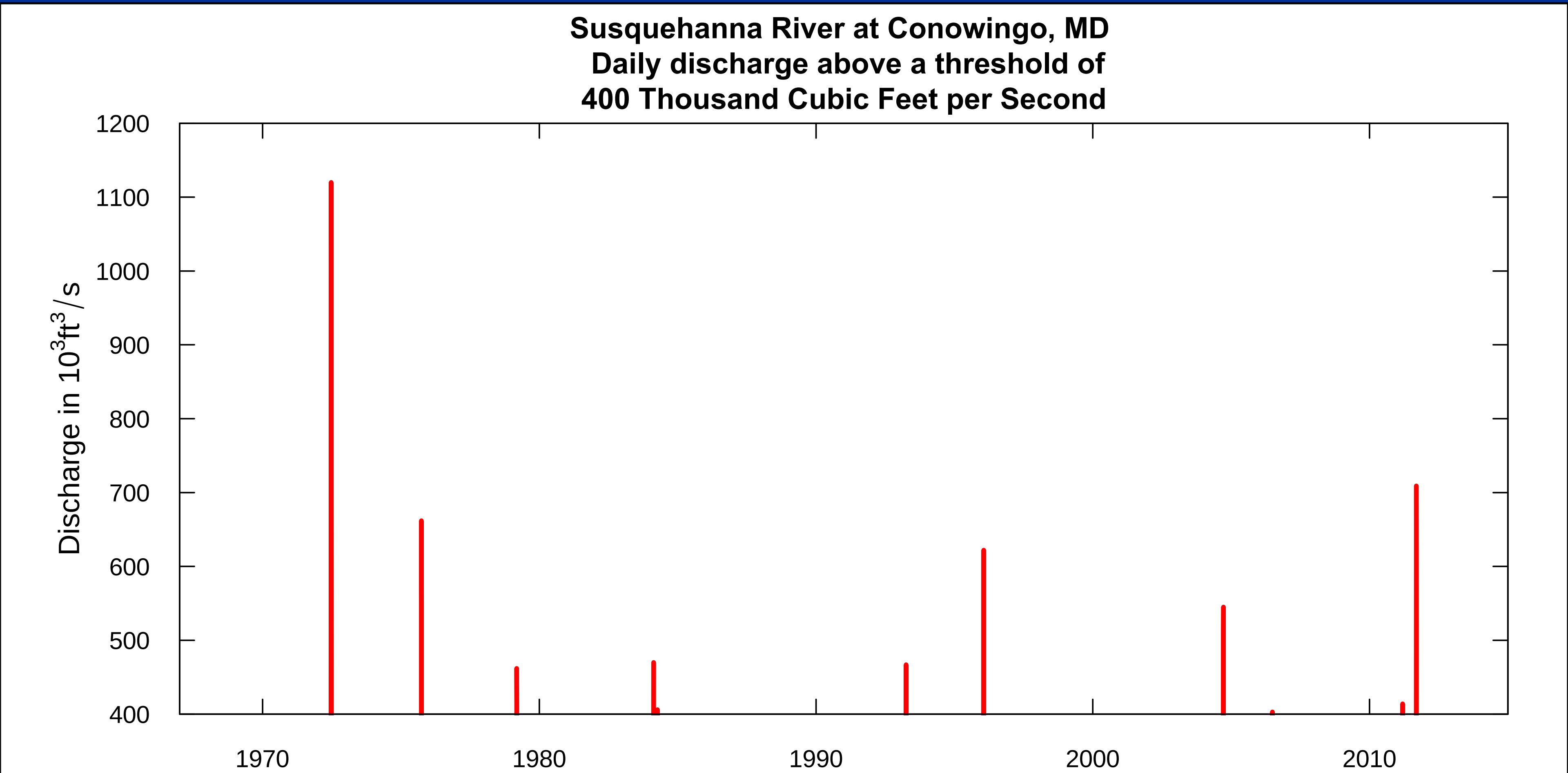
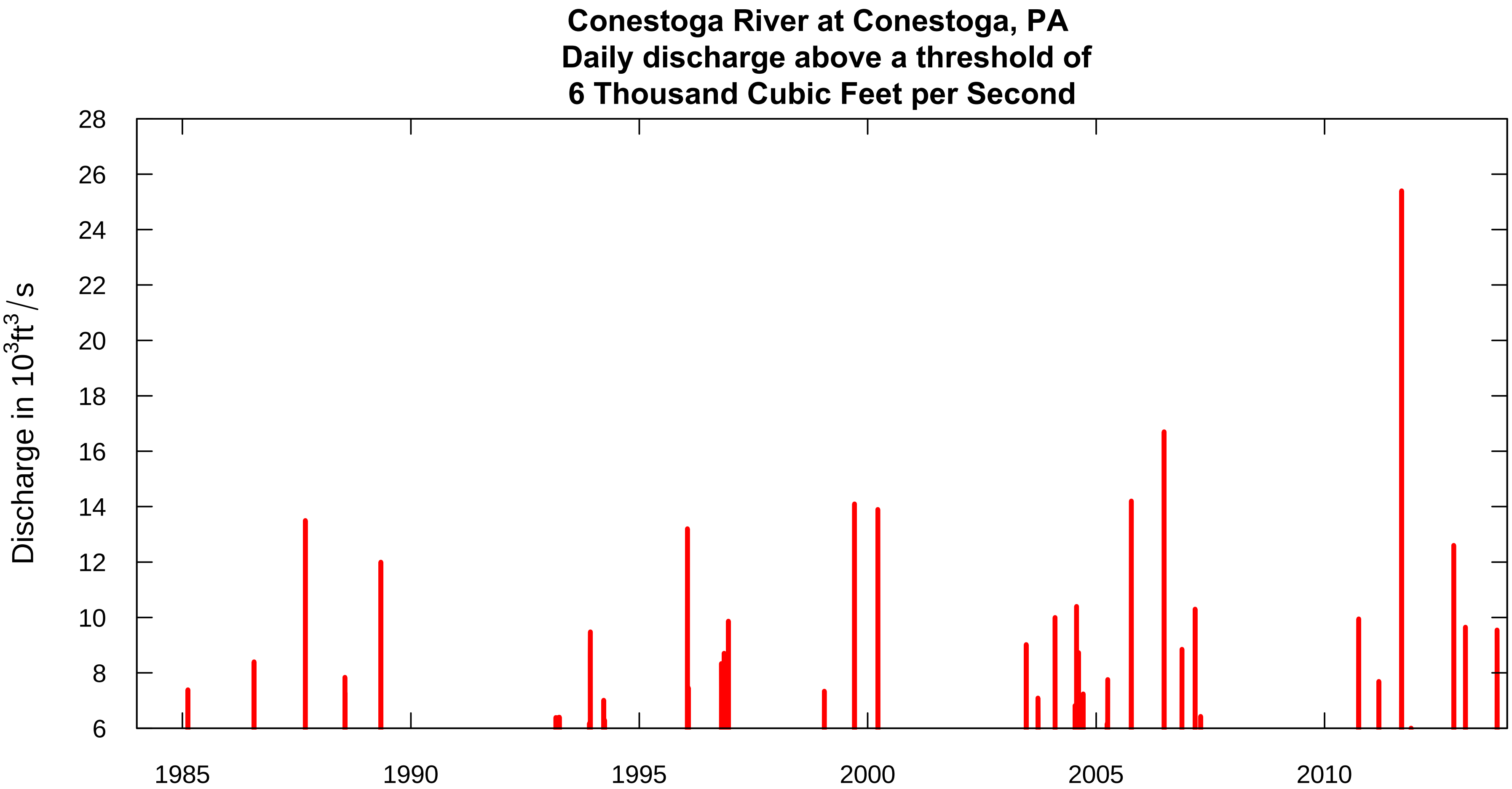
What if we pick a higher threshold: 400,000 cfs, the “scour threshold”



What about a smaller watershed: More responsive to shorter events



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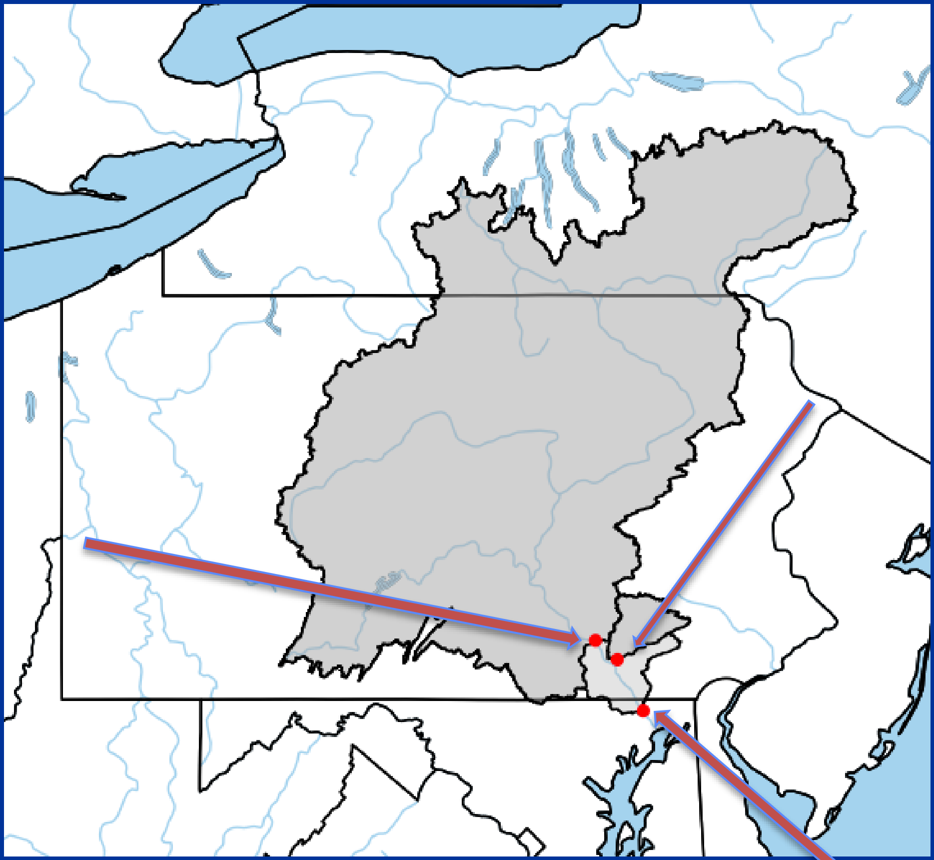
Mass Balance on reservoir reach



Susquehanna River at Marietta, PA
drainage area = 25,990 mi^2

Conestoga River at Conestoga, PA
drainage area = 470 mi^2

Susquehanna River at Conowingo, MD
drainage area = 27,100 mi^2

The mass balance calculations use 2.36 x Conestoga flux as an estimate of the flux for watershed area below Marietta and above Conowingo. (Drainage area ratio).

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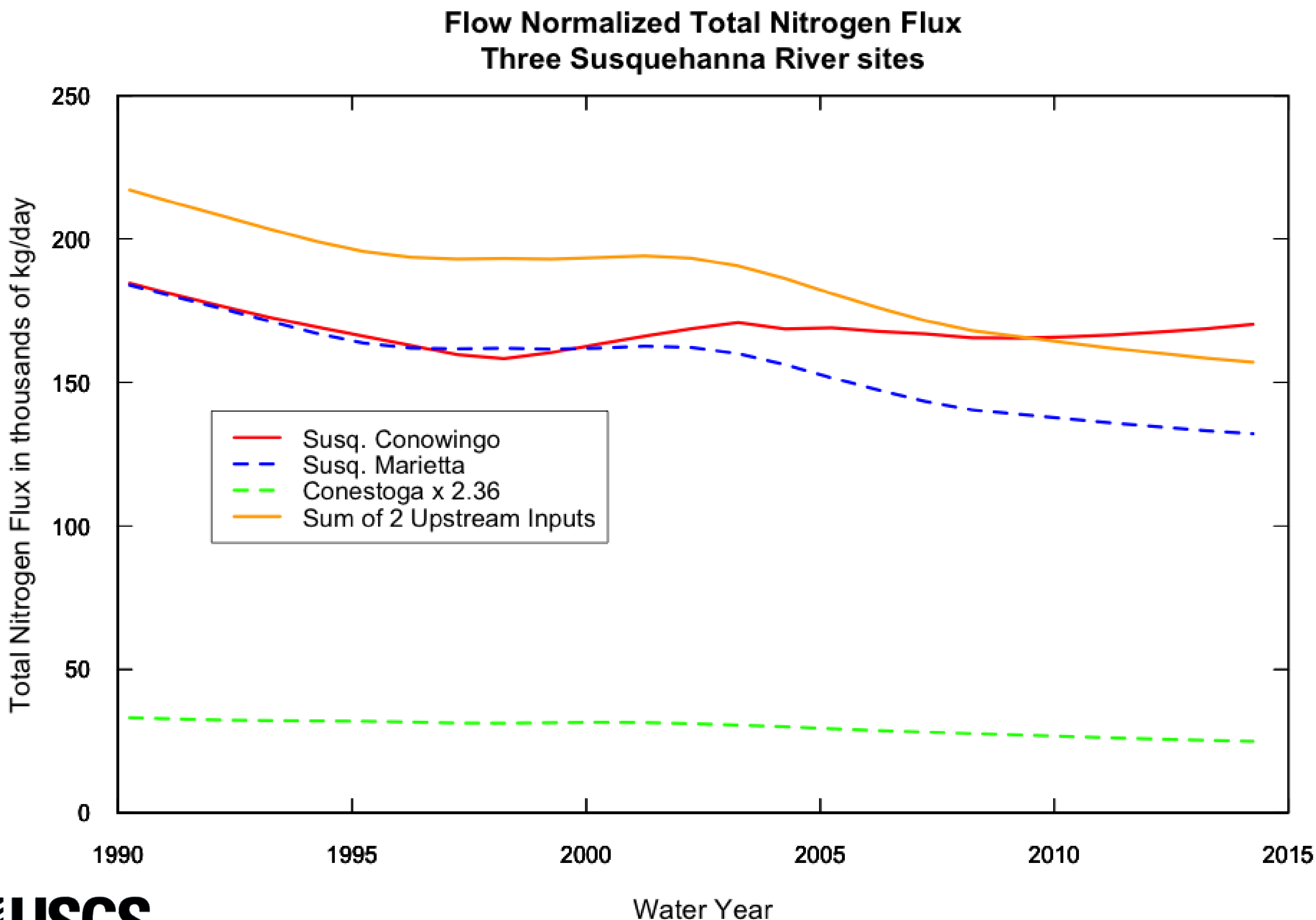
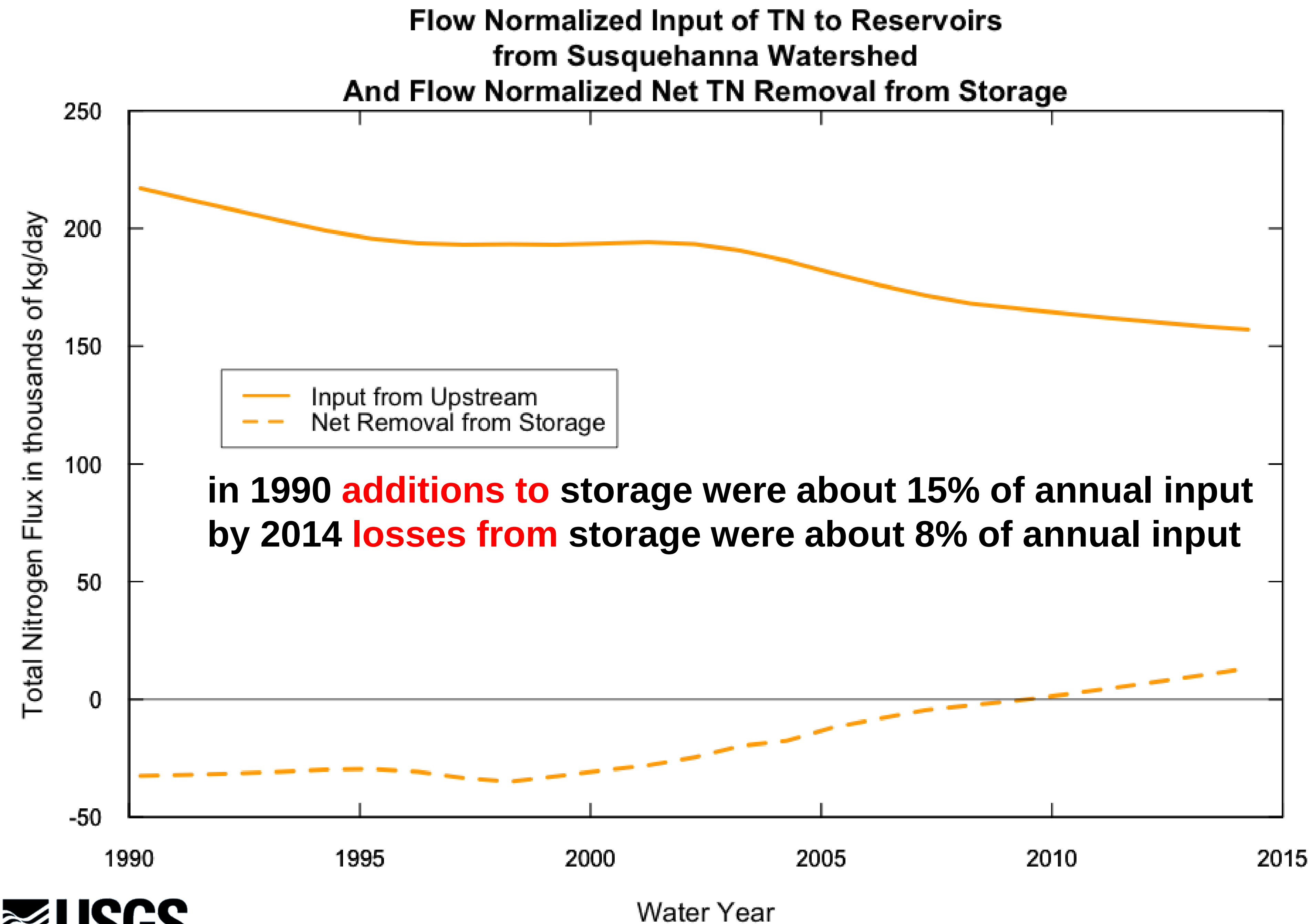
Total Nitrogen mass balance




Flow Normalized Input of TN to Reservoirs
from Susquehanna Watershed
And Flow Normalized Net TN Removal from Storage
250
200
150
100
50
0
-50
Total Nitrogen Flux in thousands of kg/day
Input from Upstream
Net Removal from Storage
in 1990 additions to storage were about 15% of annual input
by 2014 losses from storage were about 8% of annual input
1990
1995
2000
2005
2010
2015
Water Year

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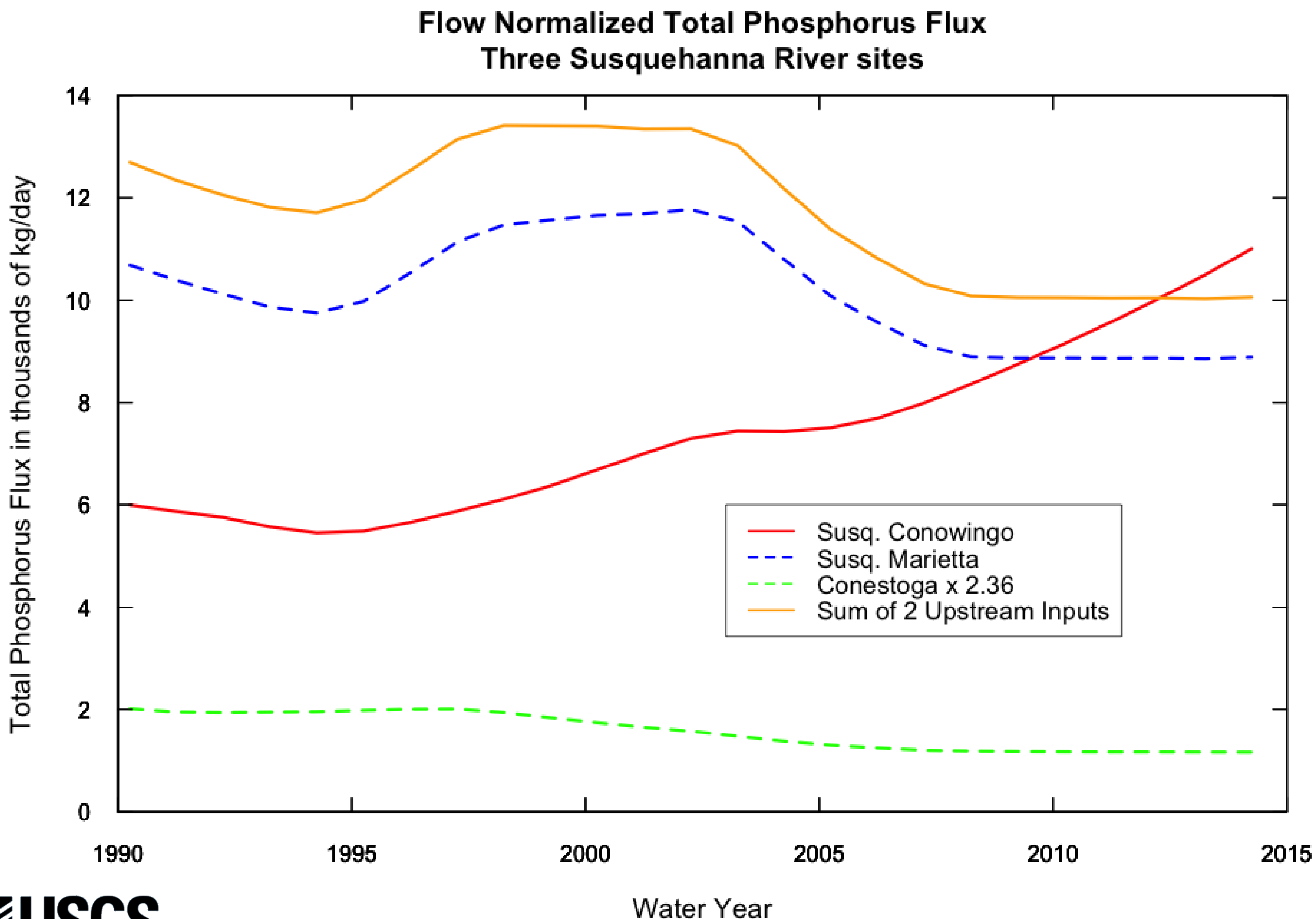
Total Phosphorus mass balance



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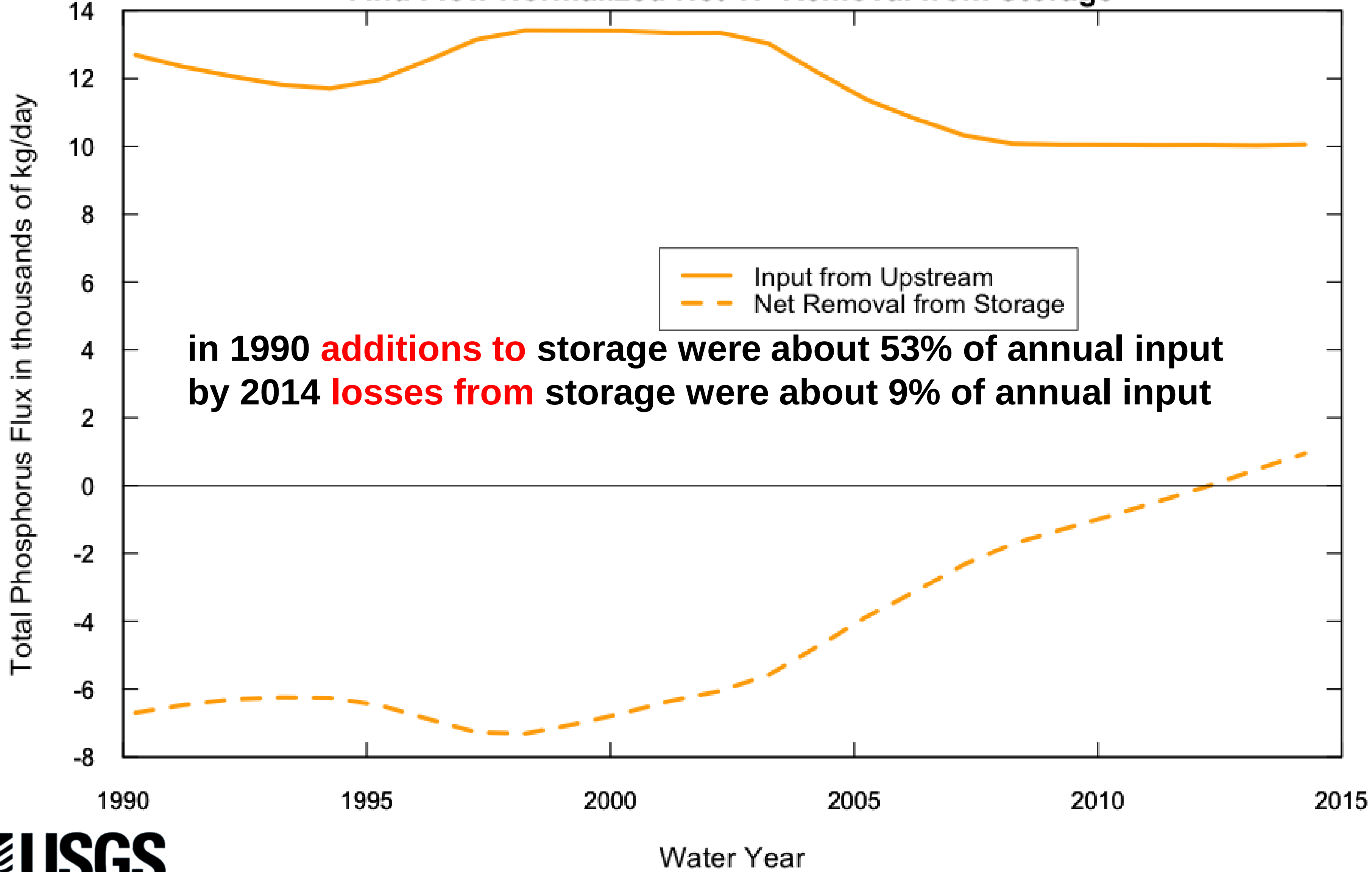
Flow Normalized Input of TP to Reservoirs from Susquehanna Watershed And Flow Normalized Net TP Removal from Storage



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Implications for the watershed model

- TN: the reservoir sink was an average of about 30,000 kg/day in the 1990's. Now it is a source of near 10,000 kg/day.
- TP: the reservoir sink was an average of about 7,000 kg/day in the 1990's. Now it is a source of about 1,000 kg/day.
- The model must represent this behavior recognizing that it varies greatly as a function of discharge and season.
- The model must credibly simulate the 1990's condition, the recent condition, and the likely future condition.

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Now: place this in a Bay-wide context

- Susquehanna is just one river (the largest).
- Need to consider all major rivers (the RIM network).
- Must also consider inputs from:
  - WWTP below the RIM sites
  - Non-point sources below the RIM sites
  - Atmospheric deposition on tidal waters

- The analysis uses published summaries from the CBPO and USGS
- Treats the whole Bay as if it were a single, well-mixed body of water
- Ignores variations by season
- Ignores variations between wet & dry years
- But, these issues of spatial and temporal variation can be dealt with in the suite of models used by the Bay Program
- This analysis has some “big picture” value in terms of describing changing inputs.

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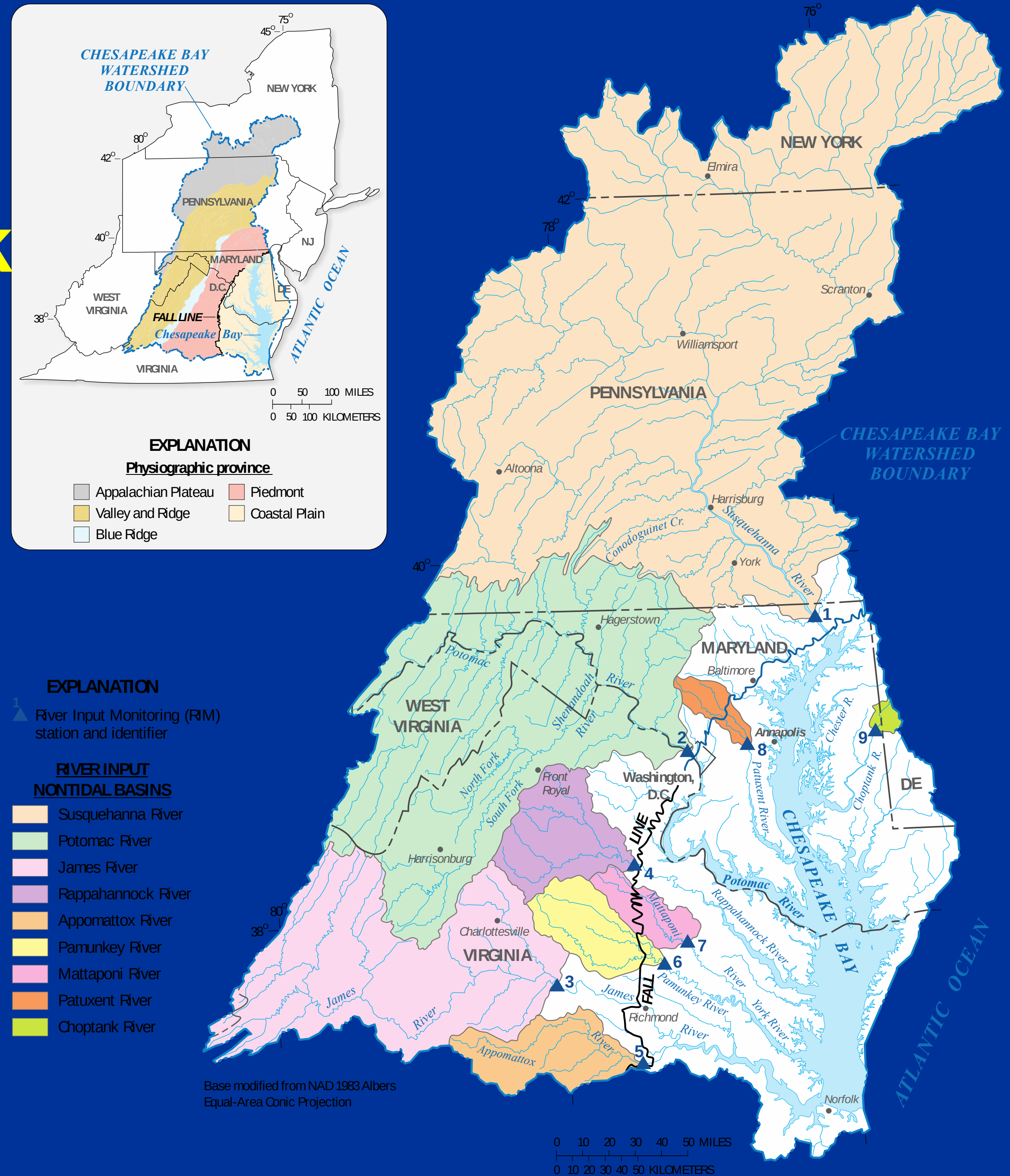
River Input Monitoring (RIM) Network

Collectively, it covers 78% of the Bay watershed

Susquehanna
Potomac
James
Rappahannock
Appomattox
Pamunkey
Mattaponi
Patuxent
Choptank



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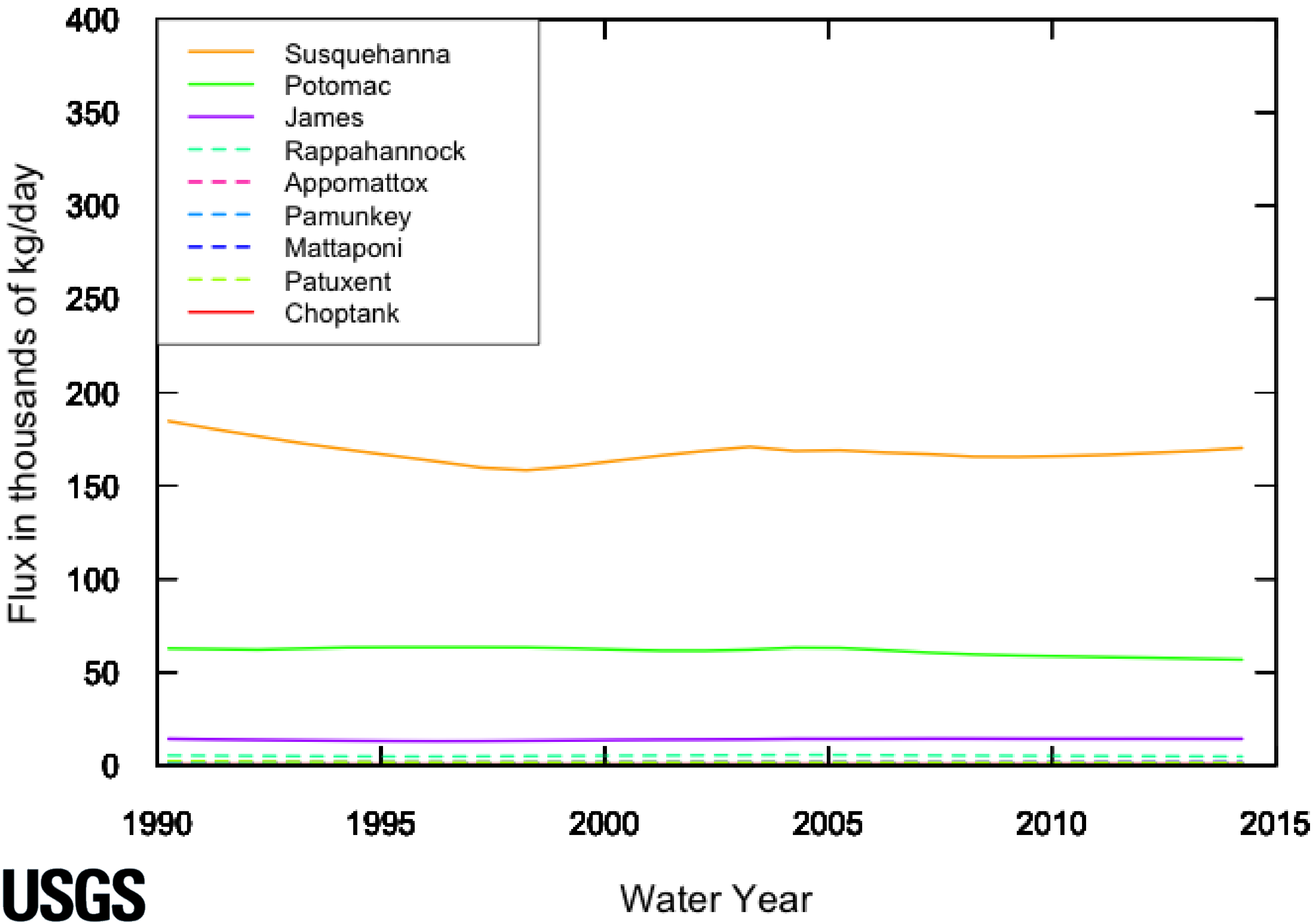
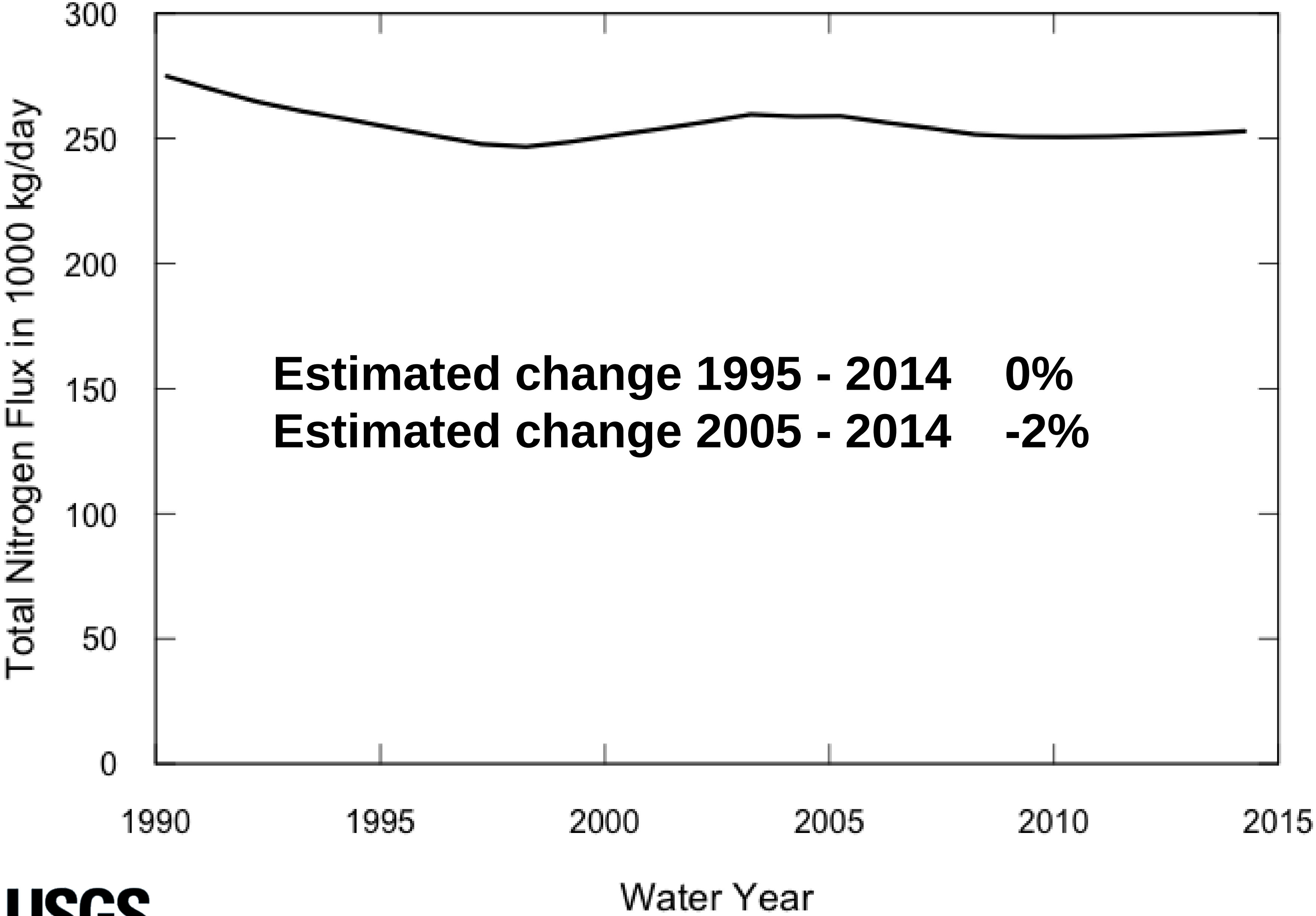
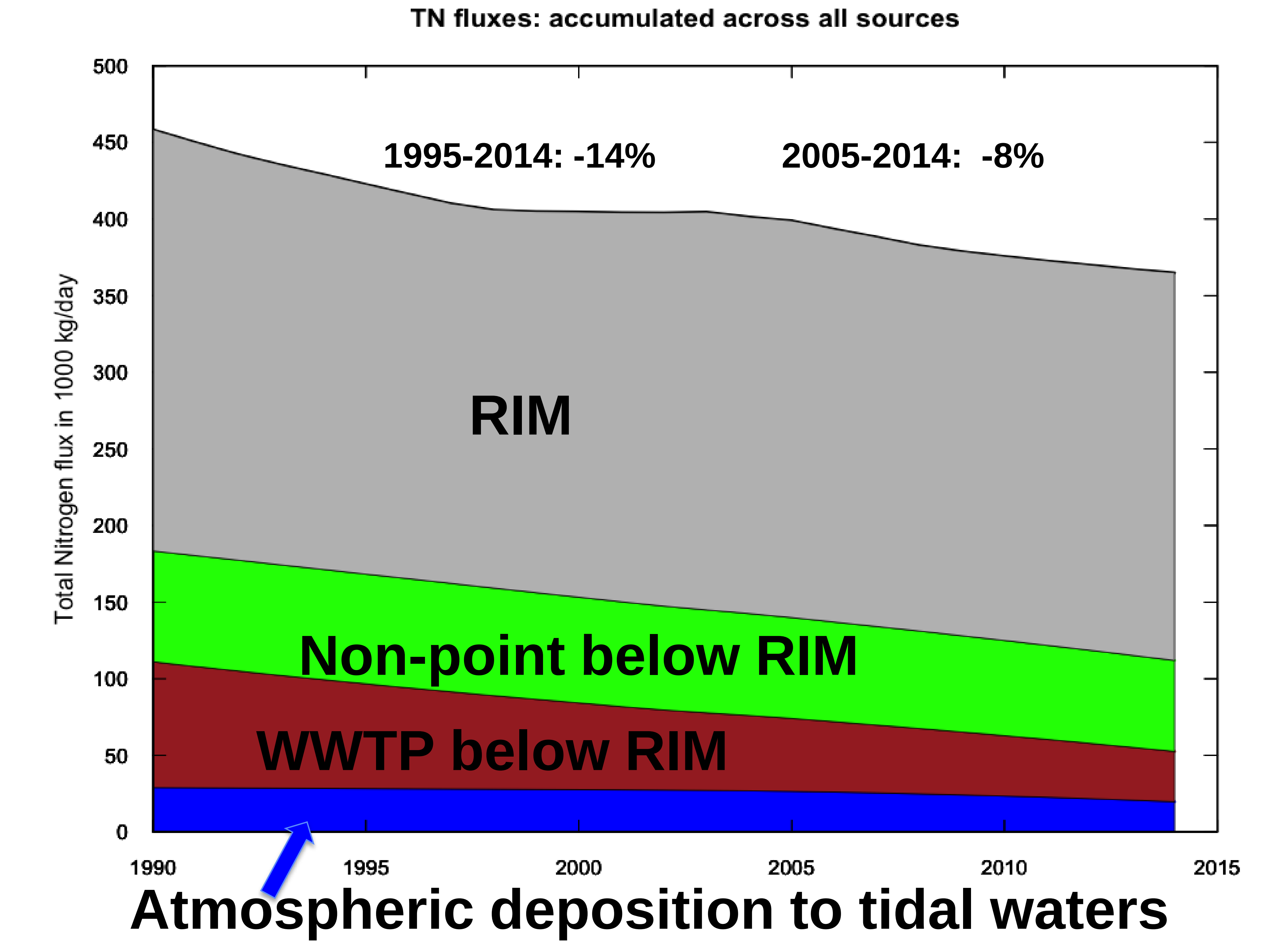
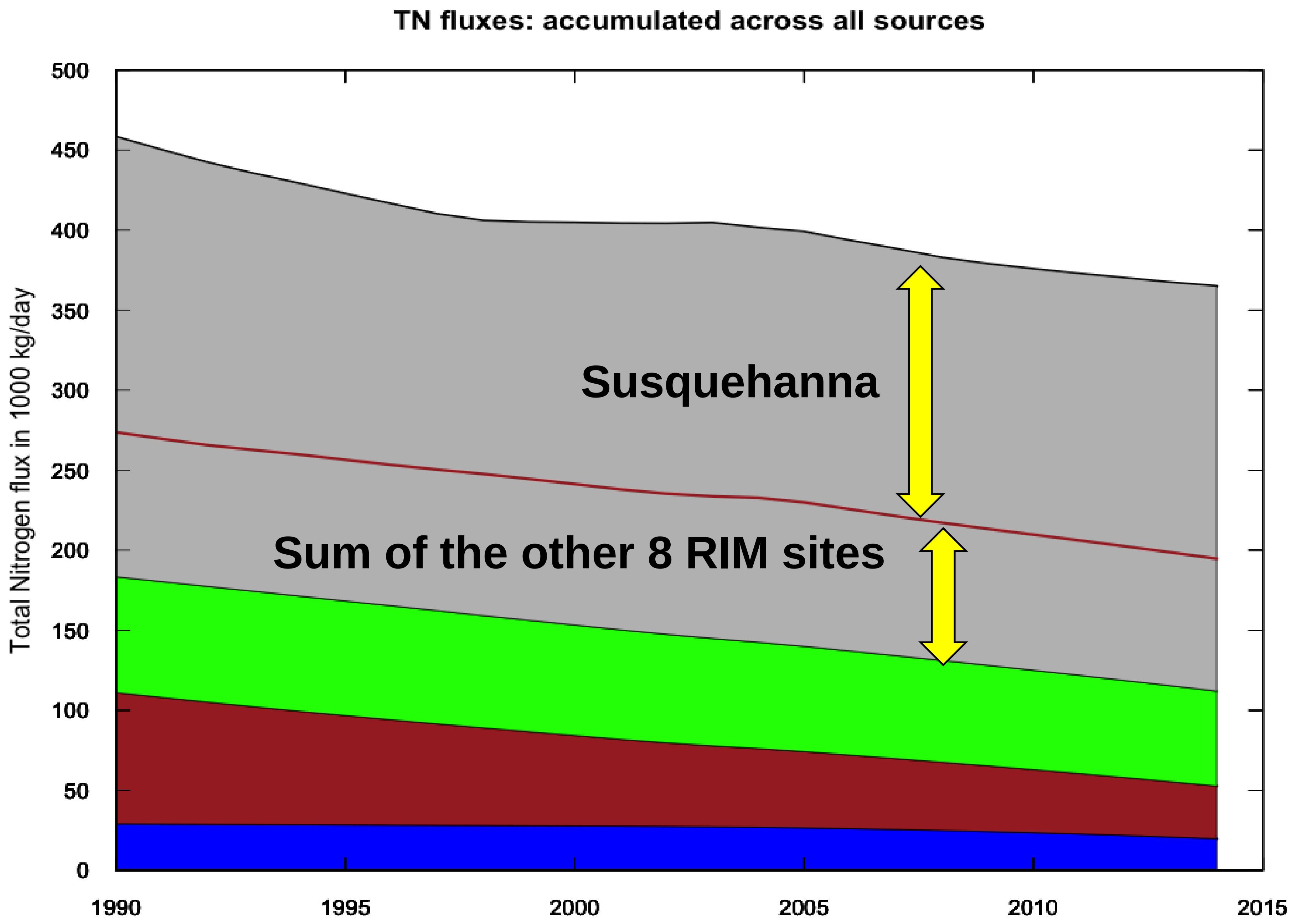
Individual river contributions of Total Nitrogen loads to the Bay



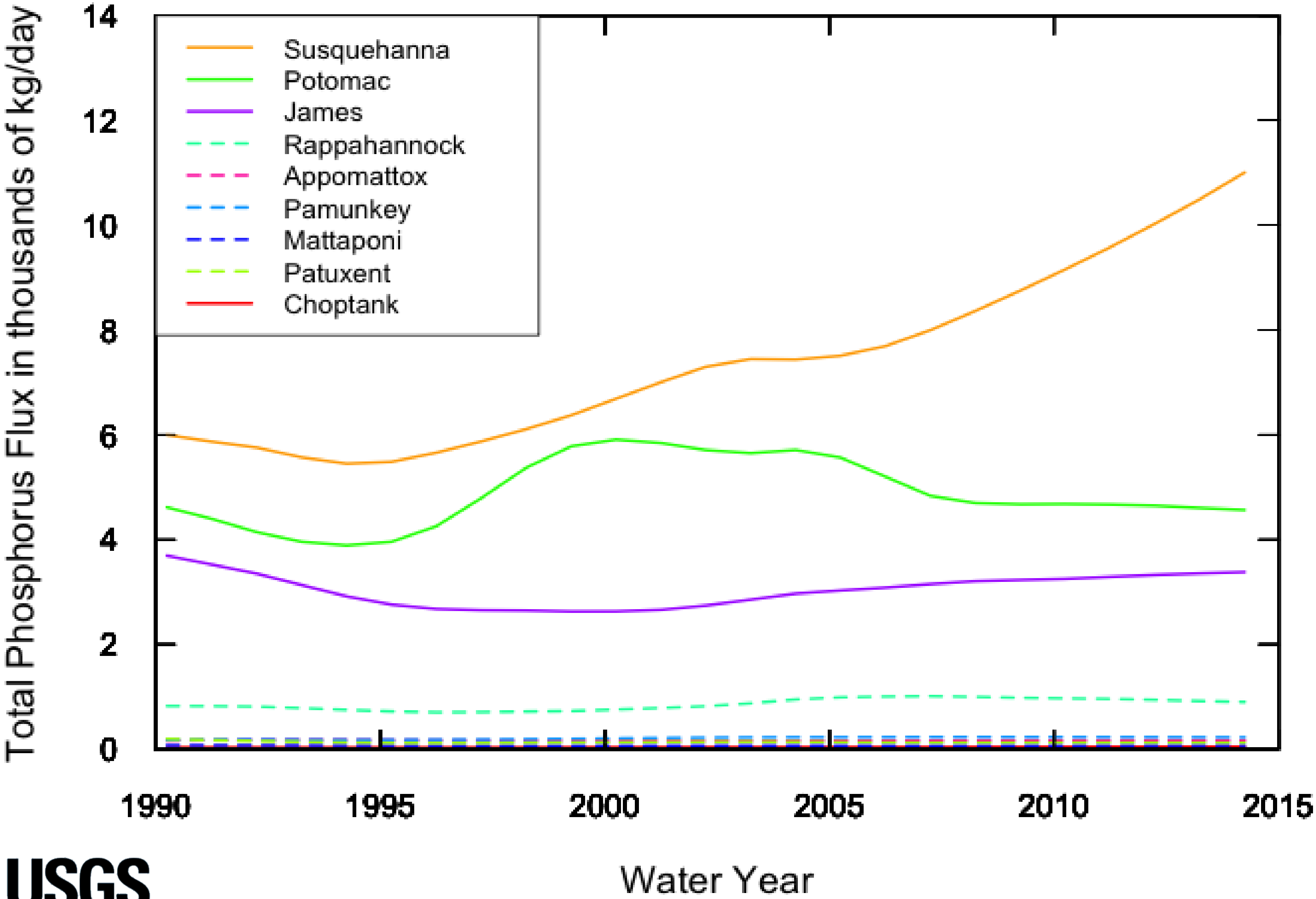
Sum of Flow Normalized Nitrogen Flux for all 9 RIM sites




TN fluxes: accumulated across all sources
Total Nitrogen flux in 1000 kg/day
0
50
100
150
200
250
300
350
400
450
500
1990
1995
2000
2005
2010
2015
1995-2014: -14%
2005-2014: -8%
RIM
Non-point below RIM
WWTP below RIM
Atmospheric deposition to tidal waters


TN fluxes: accumulated across all sources
Total Nitrogen flux in 1000 kg/day
500
450
400
350
300
250
200
150
100
50
0
1990
1995
2000
2005
2010
2015
Susquehanna
Sum of the other 8 RIM sites

Individual river contributions of TP loads to the Bay



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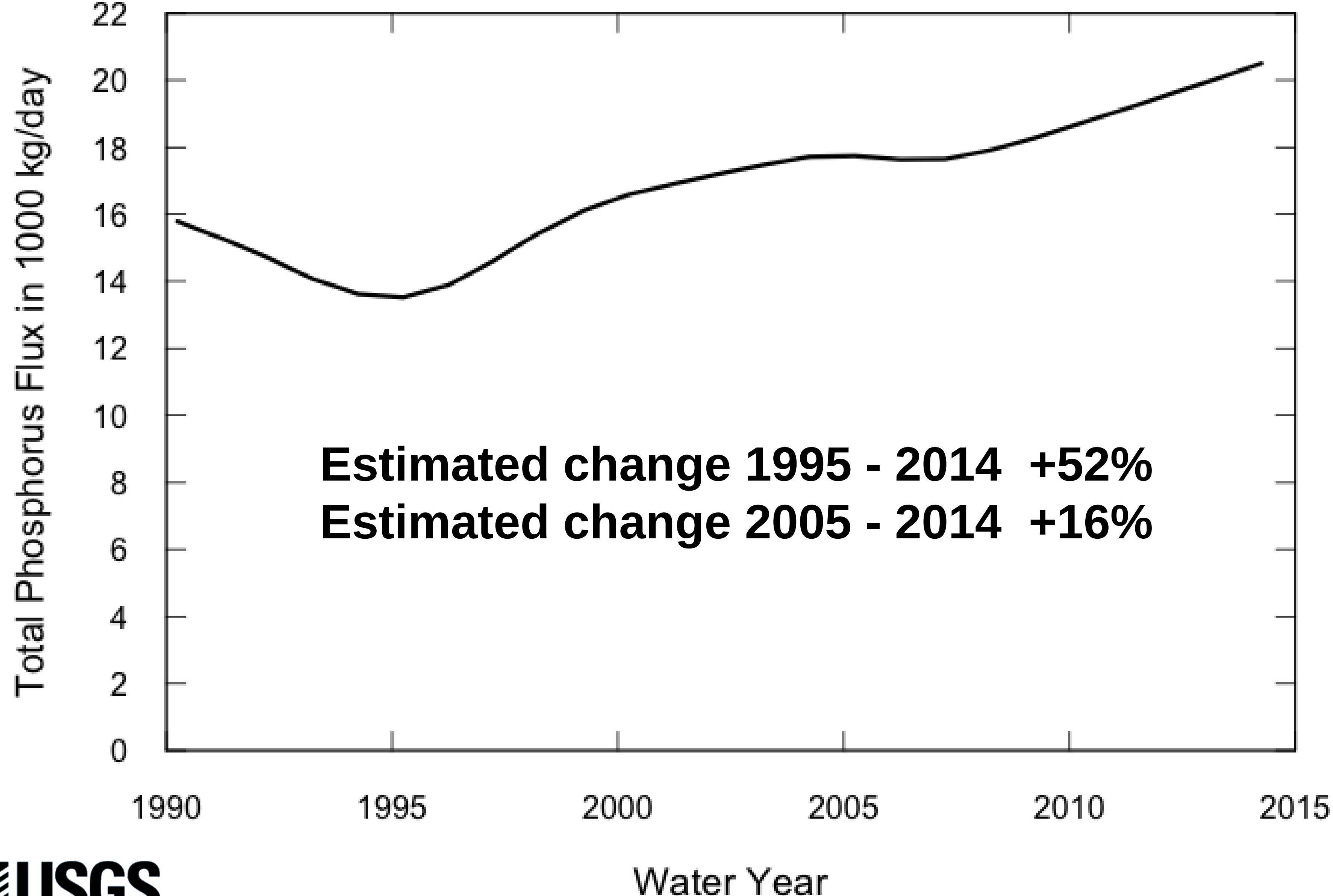
Sum of Flow Normalized Phosphorus Flux for all 9 RIM sites



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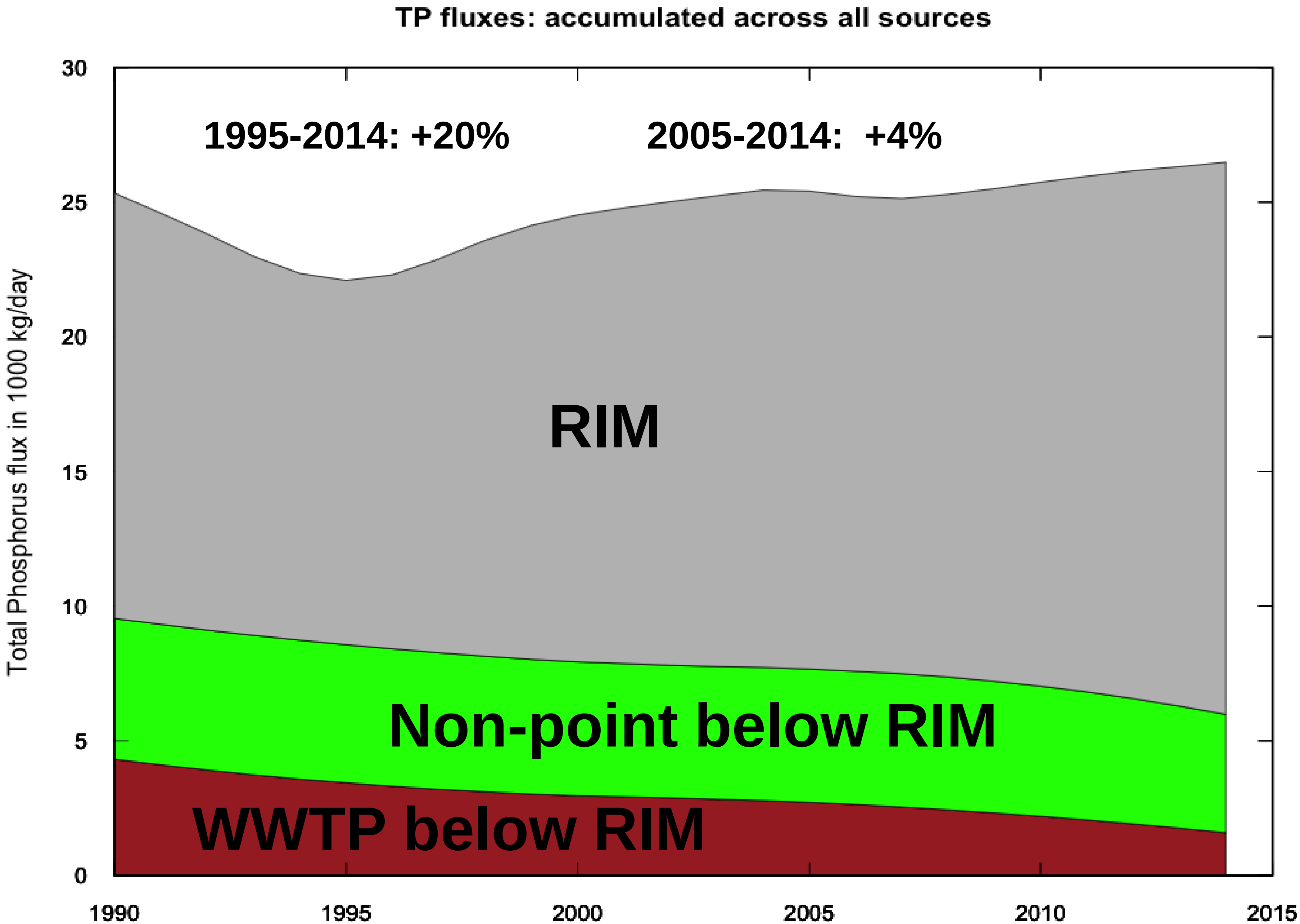
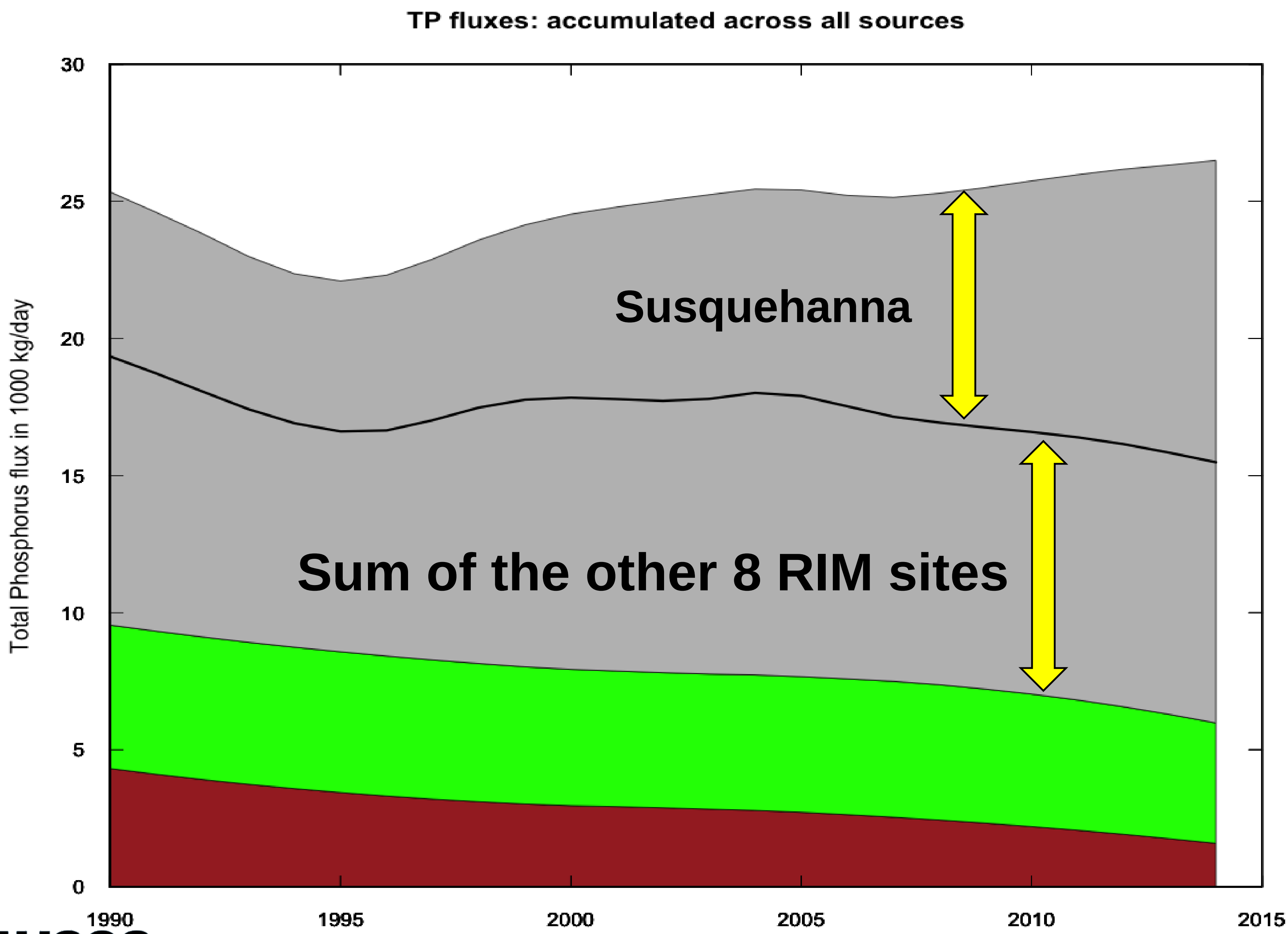

TP fluxes: accumulated across all sources
1995-2014: +20%
2005-2014: +4%
RIM
Non-point below RIM
WWTP below RIM
Total Phosphorus flux in 1000 kg/day
0
5
10
15
20
25
30
1990
1995
2000
2005
2010
2015

USGS



TP fluxes: accumulated across all sources
Total Phosphorus flux in 1000 kg/day
30
25
20
15
10
5
0
1990
1995
2000
2005
2010
2015
Susquehanna
Sum of the other 8 RIM sites

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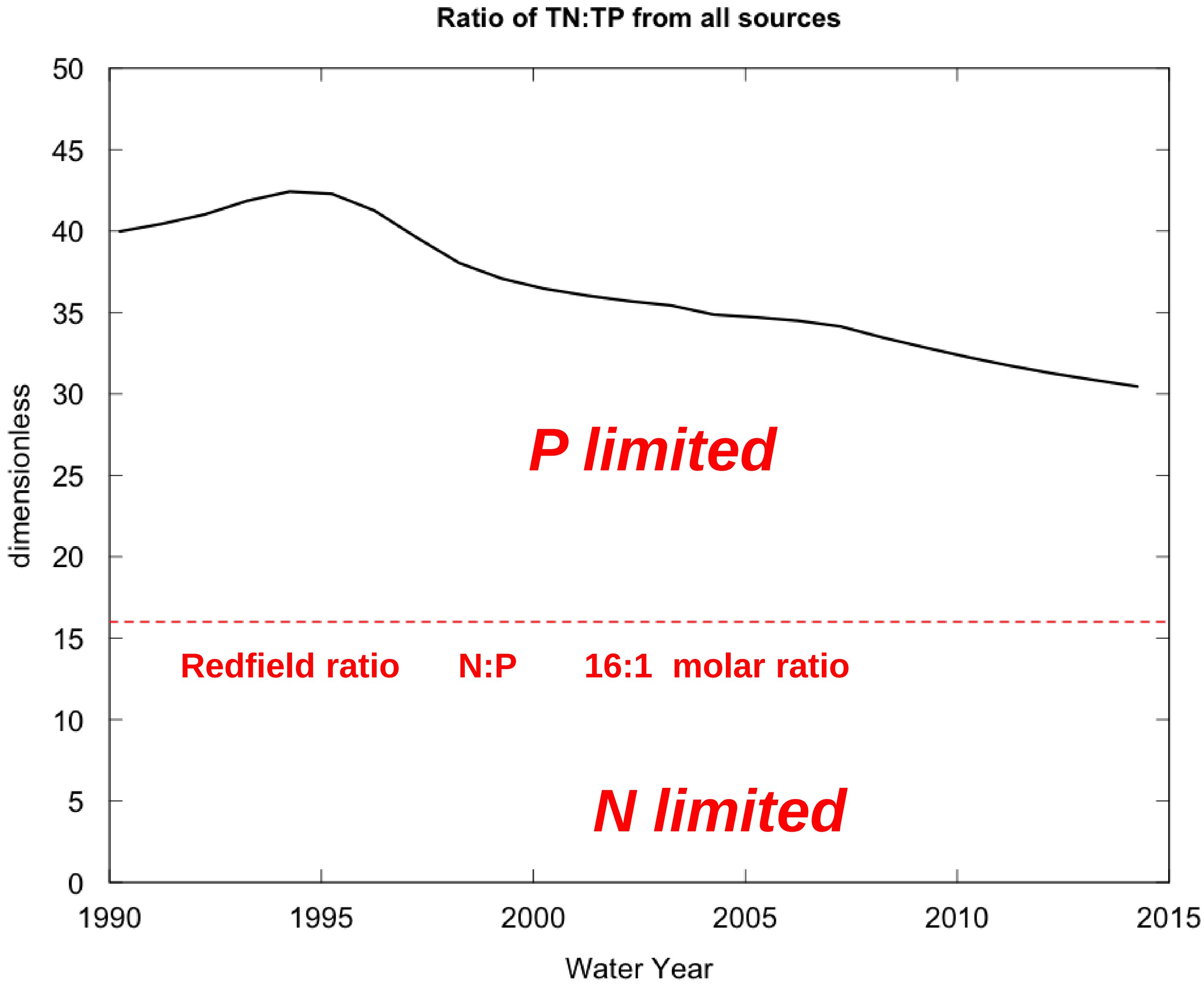
1995-2014 decline from 42 to 30

A decrease of 28%

Is this ratio change important ecologically?



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Take away messages: 1

- Susquehanna nutrient inputs are important to the Bay, they are currently:
  - 47% of TN
  - 41% of TP
- Reminder: The Bay is not a simple well-mixed body of water. Local inputs matter a great deal.
- Predicting inputs to the Bay from the Susquehanna depend on
  1. a model of what comes off the landscape
  2. a model of how the reservoir system modulates the inputs from upstream

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Take away messages: 2

- This analysis can help constrain process-based models of how the reservoirs modulate the inputs. The processes include:
  - Additions to storage (sediment deposition)
  - Losses from storage to the Bay (scour, diffusion, biology?)
  - Losses from storage to the atmosphere (denitrification)
- The future behavior of this reservoir system will not be like the past
- Ongoing measurements of the mass balance of sediment, N, and P are crucial
- Need to see if the chemistry and ecology of the Bay are responding to the change in the input mix of TN:TP
- Analysis needs to be on-going and adaptive – there is no “cook book” on the issue.

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