Chesapeake Bay Program
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University of Maryland
CENTER FOR ENVIRONMENTAL SCIENCE

USGS
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CBP STAC Water Clarity Workshop
Solomons, MD, 02/06/2017

Long-term Riverine Inputs from Major Tributaries to Chesapeake Bay Relevant to Water Clarity

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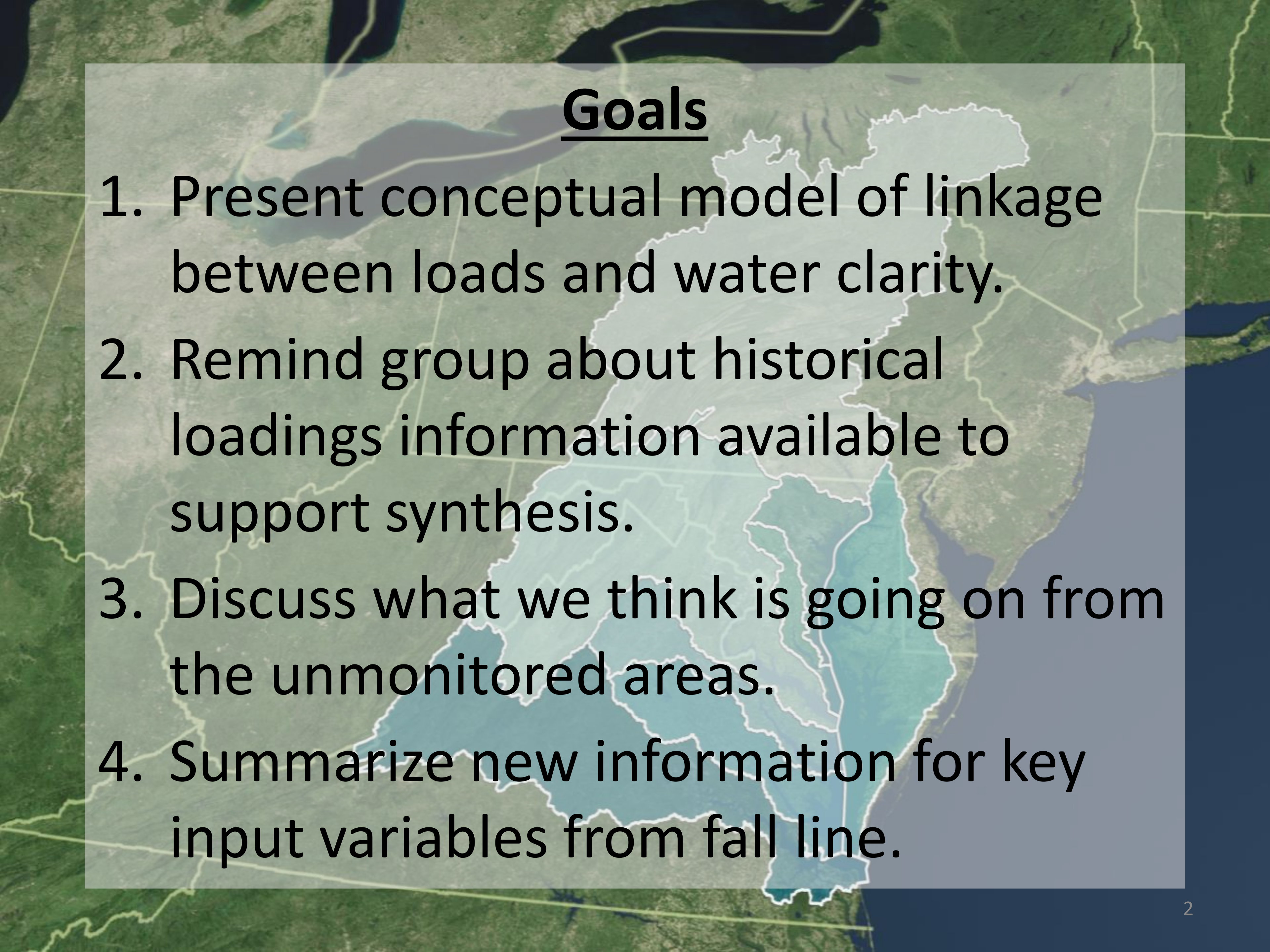
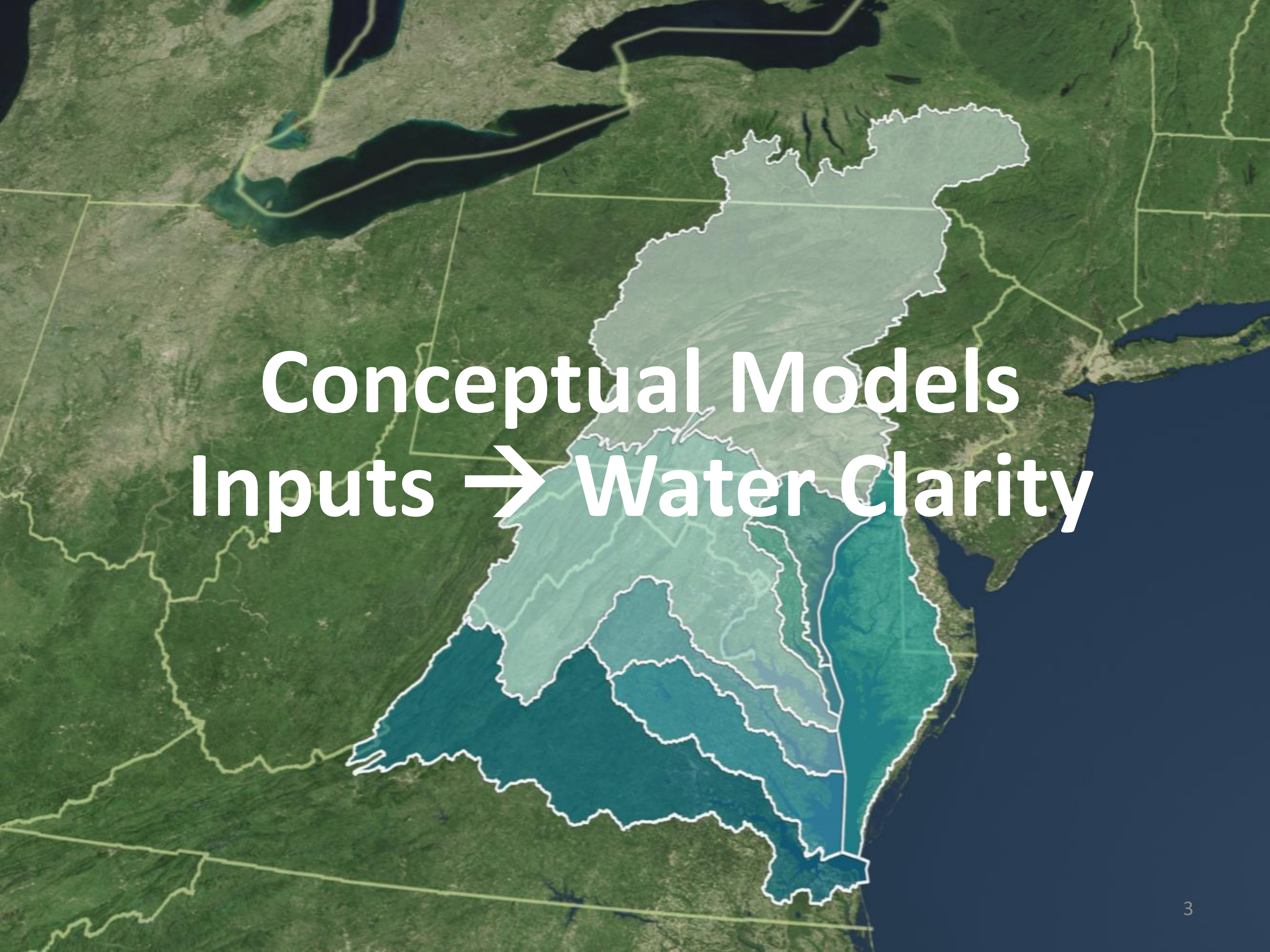
Preliminary Information - Subject to Revision.

Not for Citation or Distribution.



Goals

1. Present conceptual model of linkage between loads and water clarity.
2. Remind group about historical loadings information available to support synthesis.
3. Discuss what we think is going on from the unmonitored areas.
4. Summarize new information for key input variables from fall line.



Conceptual Models
Inputs → Water Clarity

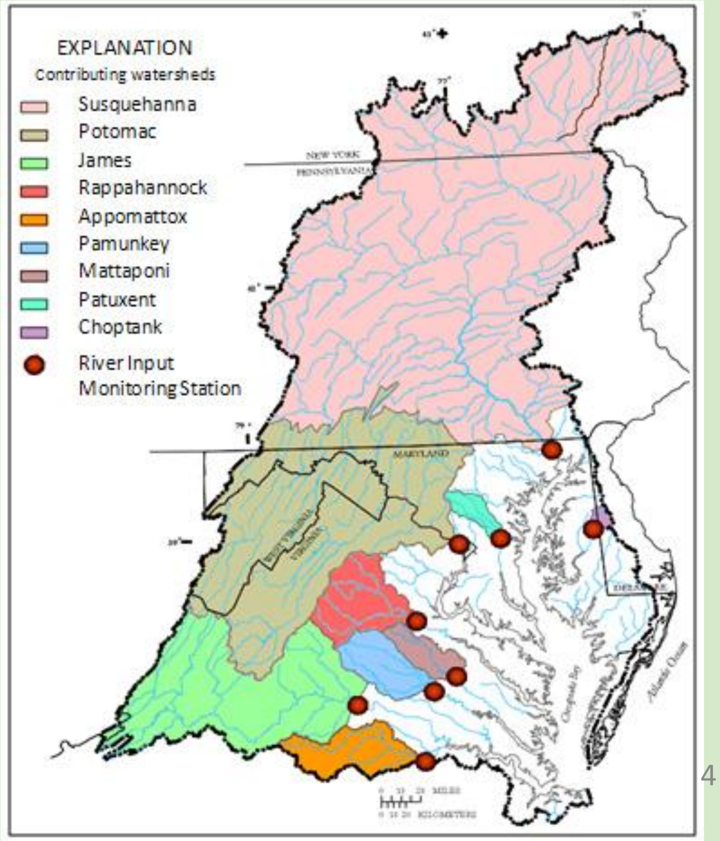
River Input Monitoring (RIM)

Traditional constituents

- Fresh Water Flows
- Nitrogen
  - Total Nitrogen
  - Nitrate
- Phosphorus
  - Total Phosphorus
  - Dissolved Orthophosphate
- Suspended Sediment

New Constituents

- Fine Sediment
- Chlorophyll A
- Organic Carbon



Causes, controls, and processes governing water clarity

- Physical processes that cause of impaired light penetration in the water column
  - Diffraction
  - Diffusion
  - Absorption
- Material that control these processes in aqueous systems
  - Water
  - Particulate mineral sediments
  - Particulate organic material
  - Dissolved organic material
  - Algae, zooplankton, and bacteria
- Sources and processes that control the amount of these materials
  - Allochthonous causes
    - Watershed delivery of mineral sediments and organic material that directly affect light penetration.
  - Estuarine responses and processes
    - Primary productivity and subsequent cycles
    - Resuspension of previously deposited material
  - Autochonous processes?

Conventional Conceptual Models of water clarity drivers (1)

- **Streamflow**
  - Large flows change salinity gradient
  - Reshapes the salt wedge
  - Relocates the turbidity maximum zone? – Temporarily
  - Freshwater flushing may relocate water with diminished clarity
- **Suspended sediment**
  - Suspended particles impair light transmittal
  - Large fluxes relative to estuary and sub-estuary volumes can limit light transmittal for large areas.
  - Large fluxes during critical periods can have a severe impact on aquatic ecology for subsequent periods
  - Deposited sediments are stored, mixed and resuspended in subsequent periods.

Conventional Conceptual Models of water clarity drivers (2)

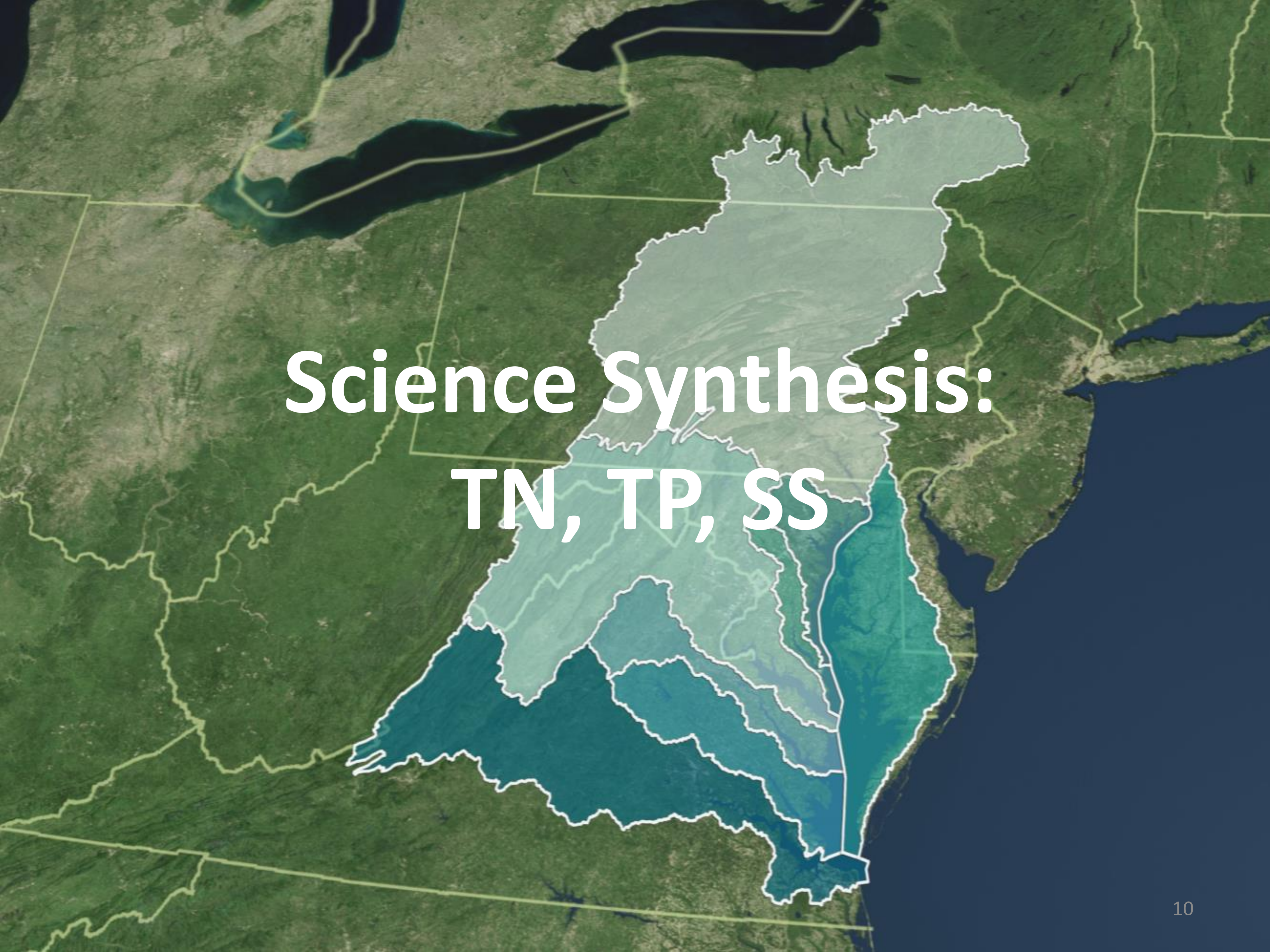
- **<u>Nitrogen and phosphorus</u>**
  - Fuels primary productivity, and subsequent zooplankton communities which absorb and diffuse light transmittal.
    - Large fluxes promote widespread blooms and massive increases in primary productivity.
    - Bacteria communities respond with some breakdown of organics on surface or water column.
  - Nitrate may be more important to water clarity (than other forms of N) due to availability in the water column
    - Particulate N and organic N may be of lesser importance to water clarity – as they may be more tied to benthic processes
  - Dissolved phosphorus may hove a more immediate impact on productivity than about particulate P, which may lag.
  - Successive breakdown of algae, zooplankton, and related bacteria in the water column generate dissolved and particulate organic molecules that may impact clarity beyond the organisms life cycle.

Conceptual Models of additional drivers of water clarity NEW

- **Fine particulate suspended sediment**
  - Sand probably plays no role in decreasing light transmittal in the estuary because it settles quickly.
  - Silt, and particularly, clay can remain in suspension for a long time which may be one source of degraded light transmittal
  - Silt and clay remain in suspension in a thin layer of fresh water across the estuarine surface, this may only affect light transmittal for a very limited depth.
  - Silt and clay deposits are more easily resuspended by wave action.

Conceptual Models of additional drivers of water clarity NEW

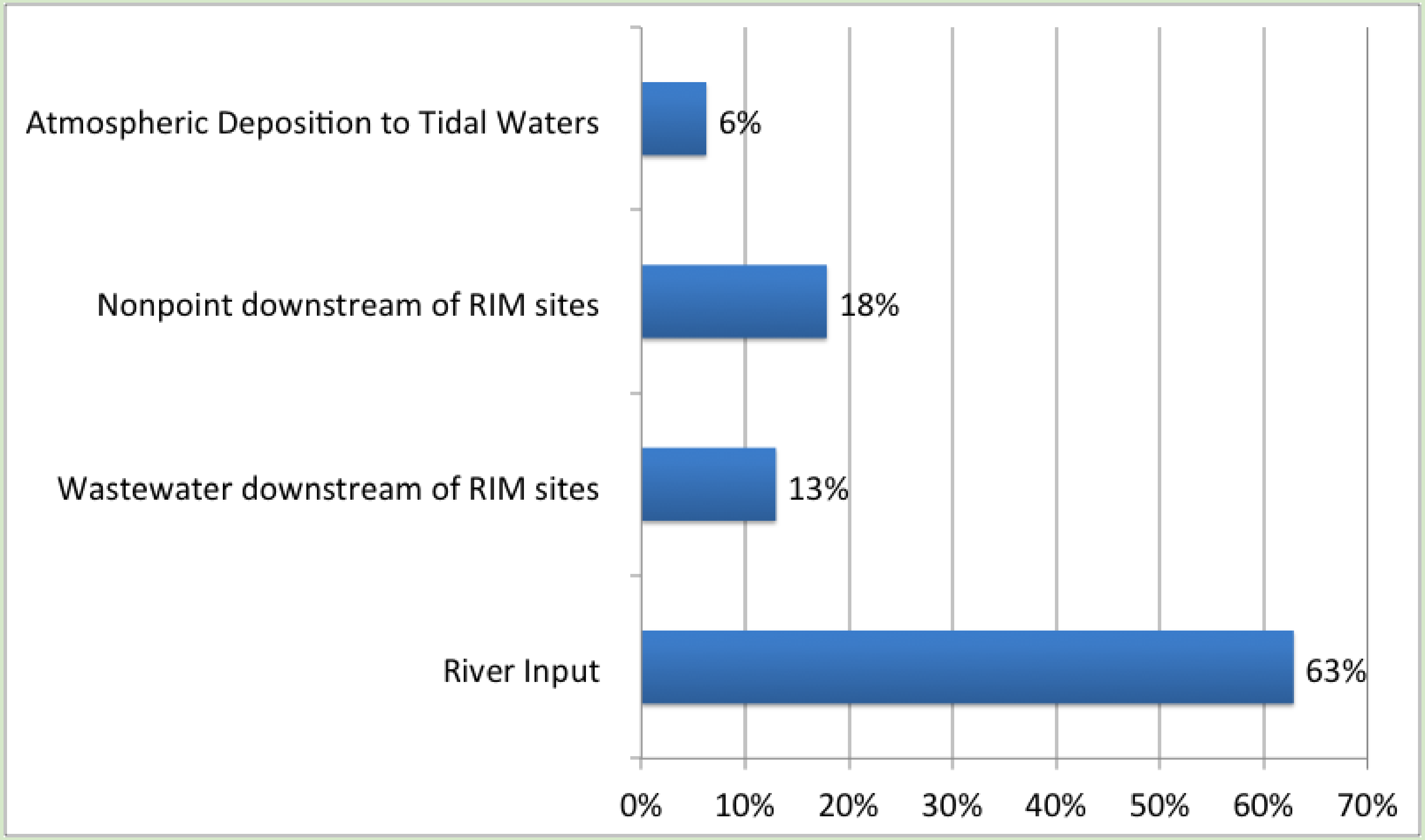
- **Chlorophyll-a**
  - Riverine inputs may account for a significant proportion of phytoplankton which can decrease light transmittal
  - Riverine inputs of phytoplankton may seed colonies in tidal fresh estuaries and sub-estuaries
- **Organic carbon**
  - The native organic carbon content of influent water may have light diffraction properties, and these properties may differ among tributaries.
  - Organic Carbon can fuel BOD processes in the estuary, which may be large
  - Particulate and Dissolved Carbon can have very different light absorption and diffraction properties



Science Synthesis: TN, TP, SS

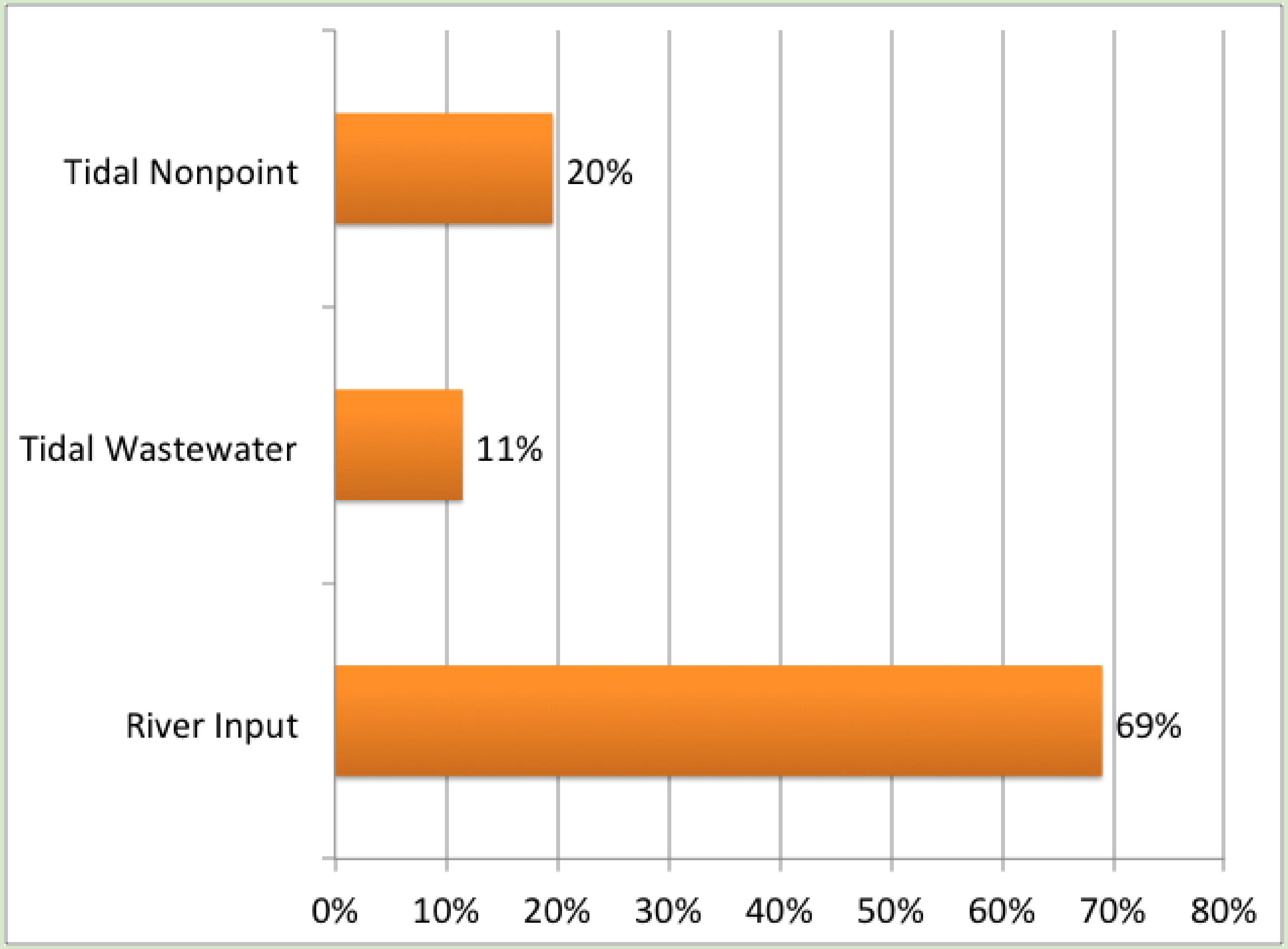
TN input

Measured and Modeled Nitrogen Sources to Chesapeake Bay

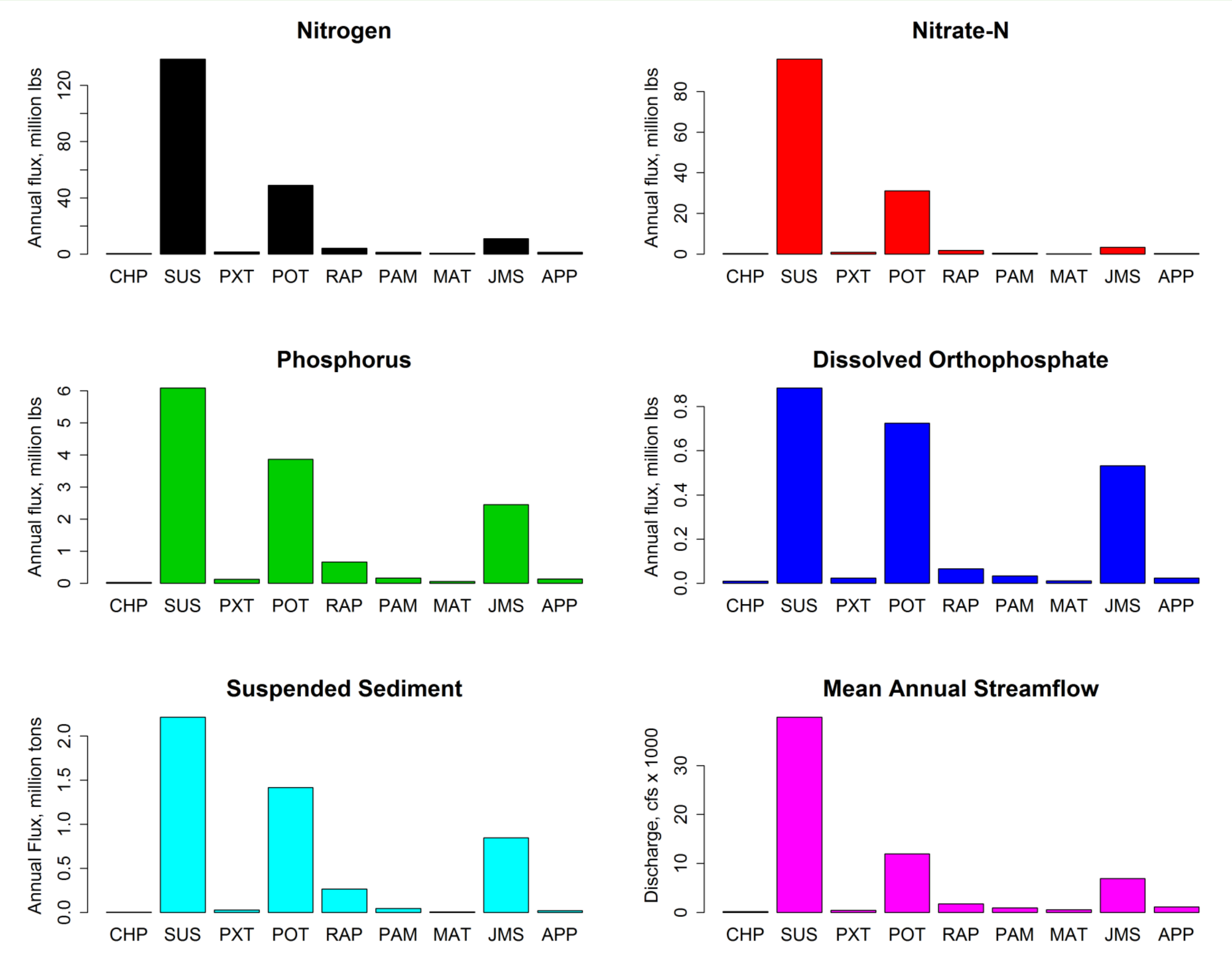


TP input

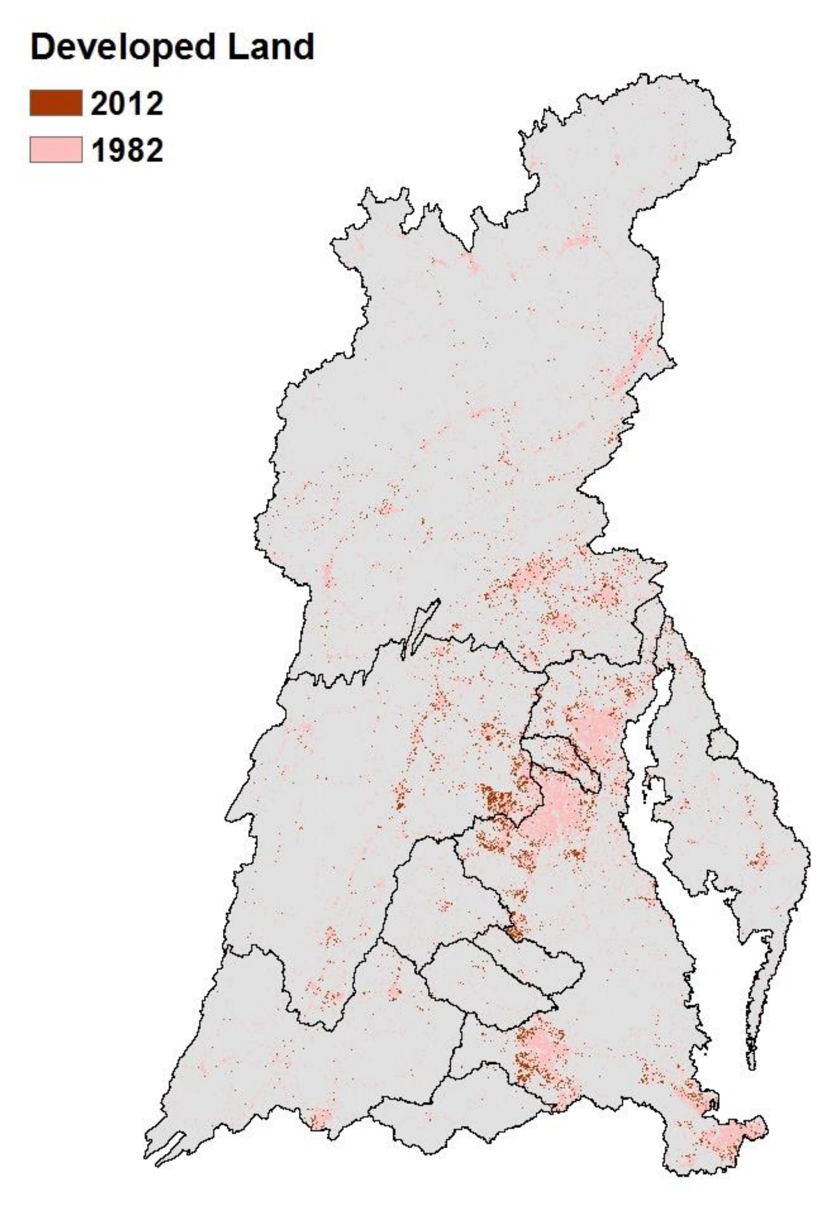
Measured and Modeled Phosphorus Sources to Chesapeake Bay



RIM inputs

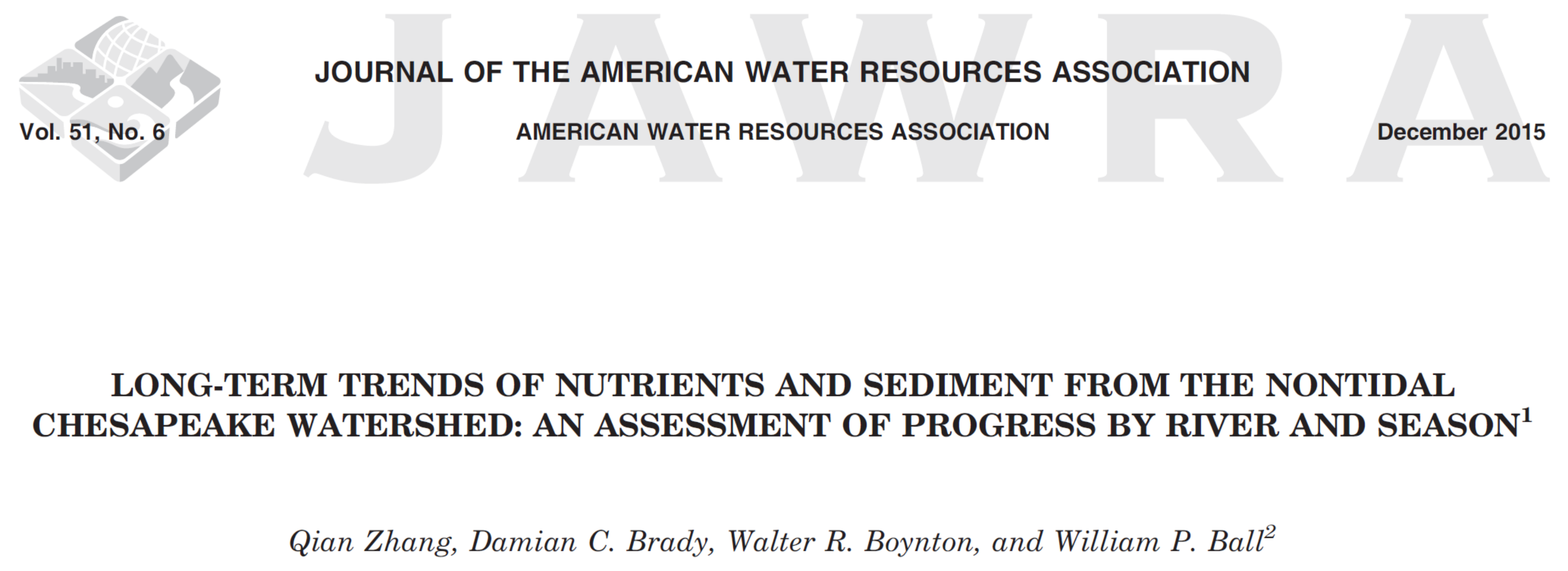

Nitrogen
Annual flux, million lbs
0
40
80
120
CHP
SUS
PXT
POT
RAP
PAM
MAT
JMS
APP
Nitrate-N
Annual flux, million lbs
0
20
40
60
80
CHP
SUS
PXT
POT
RAP
PAM
MAT
JMS
APP
Phosphorus
Annual flux, million lbs
0
1
2
3
4
5
6
CHP
SUS
PXT
POT
RAP
PAM
MAT
JMS
APP
Dissolved Orthophosphate
Annual flux, million lbs
0.0
0.2
0.4
0.6
0.8
CHP
SUS
PXT
POT
RAP
PAM
MAT
JMS
APP
Suspended Sediment
Annual Flux, million tons
0.0
0.5
1.0
1.5
2.0
CHP
SUS
PXT
POT
RAP
PAM
MAT
JMS
APP
Mean Annual Streamflow
Discharge, cfs x 1000
0
10
20
30
CHP
SUS
PXT
POT
RAP
PAM
MAT
JMS
APP

Below-fall-line inputs



SOURCE: U.S. Conterminous Wall-to-Wall Anthropogenic Land Use Trends (NWALT), 1974–2012

Non-tidal Chesapeake Bay Watershed (NTCBW)



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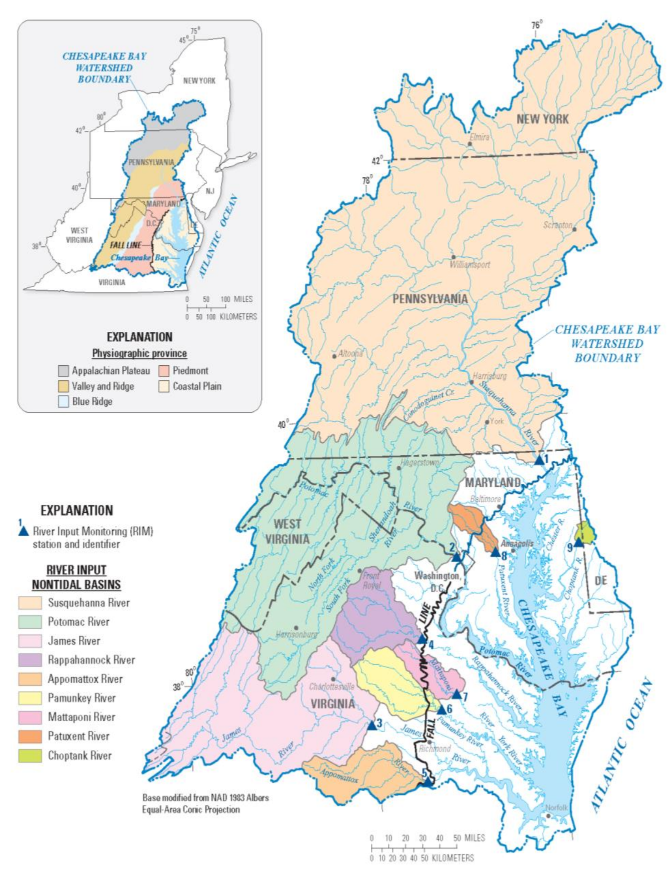
LONG-TERM TRENDS OF NUTRIENTS AND SEDIMENT FROM THE NONTIDAL CHESAPEAKE WATERSHED: AN ASSESSMENT OF PROGRESS BY RIVER AND SEASON[1]

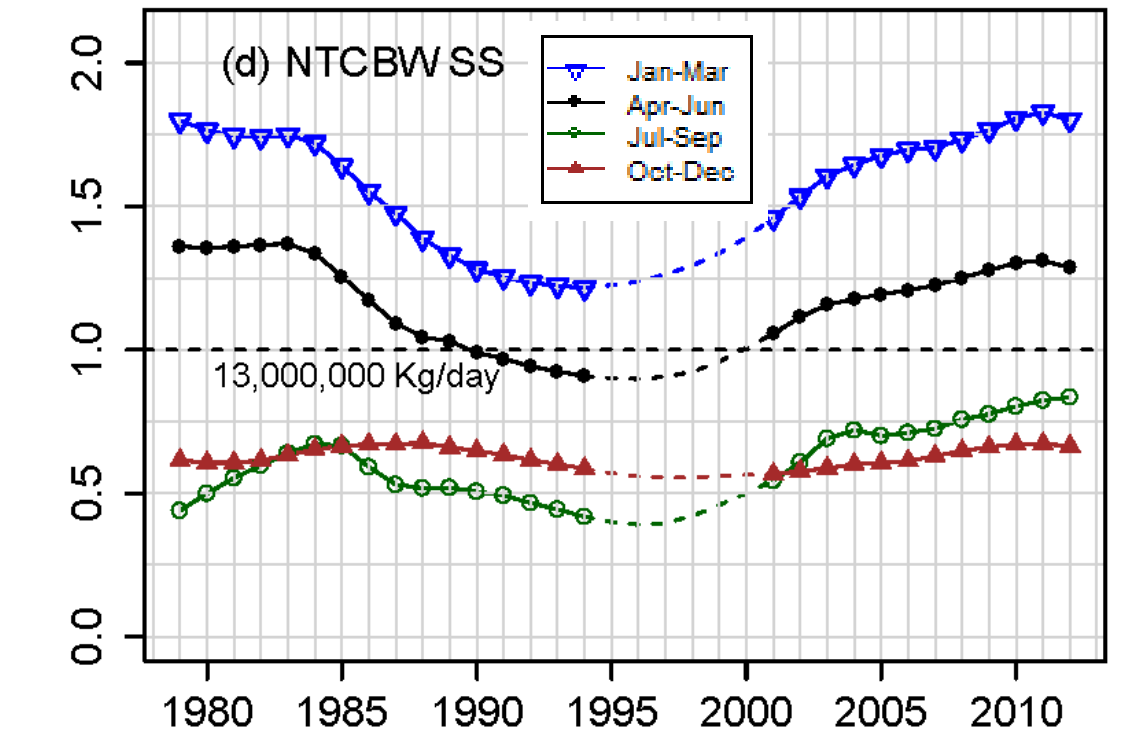
Qian Zhang, Damian C. Brady, Walter R. Boynton, and William P. Ball[2]

Zhang, Qian, Damian C. Brady, Walter R. Boynton, and William P. Ball, 2015. Long-Term Trends of Nutrients and Sediment from the Nontidal Chesapeake Watershed: An Assessment of Progress by River and Season. Journal of the American Water Resources Association (JAWRA) 51(6): 1534–1555. DOI: 10.1111/1752-1688.12327

NTCBW SS

NTCBW SS Load = Sum of Loads at 9 RIM Stations

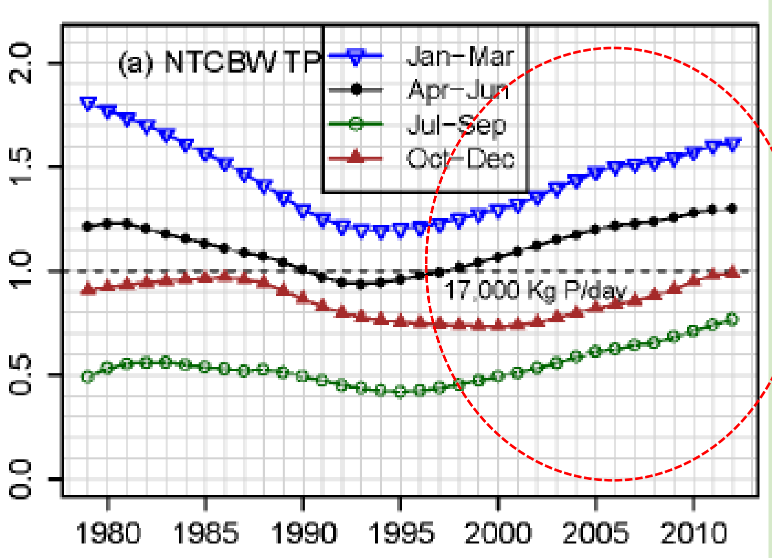




(1.0 = long-term <u>*annual*</u> *median* load; color = season)

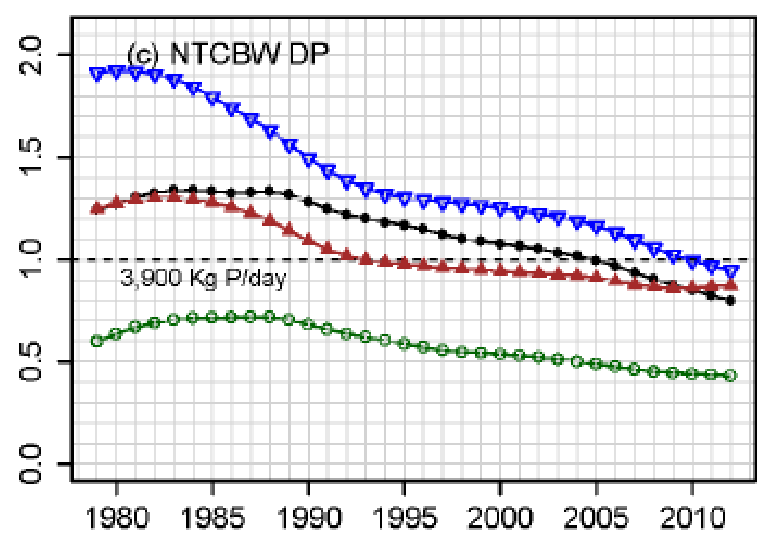
NTCBW P

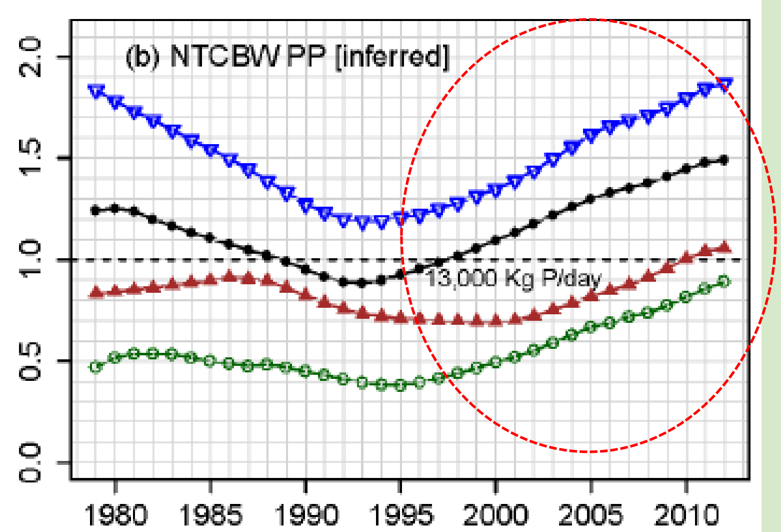
TP: Total Phosphorus
DP: Dissolved Phosphorus
PP: Particulate Phosphorus



Rising TP and PP
in last decade

Steady decline
in DP loading since 1985

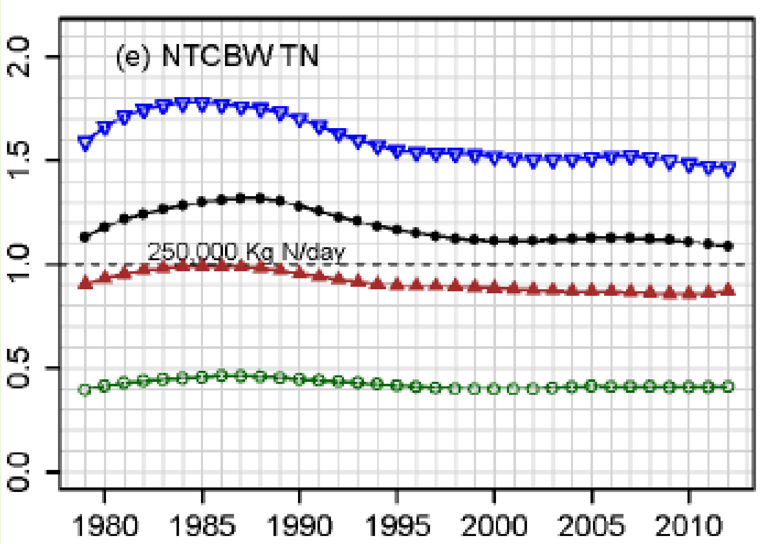


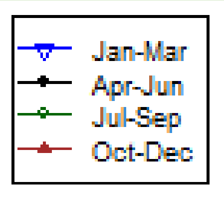


NTCBW N

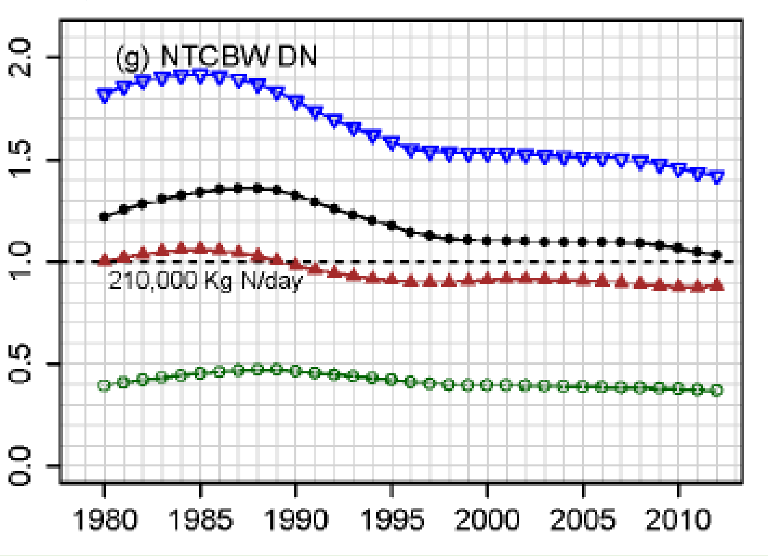
TN: Total Nitrogen
DN: Dissolved Nitrogen
PN: Particulate Nitrogen

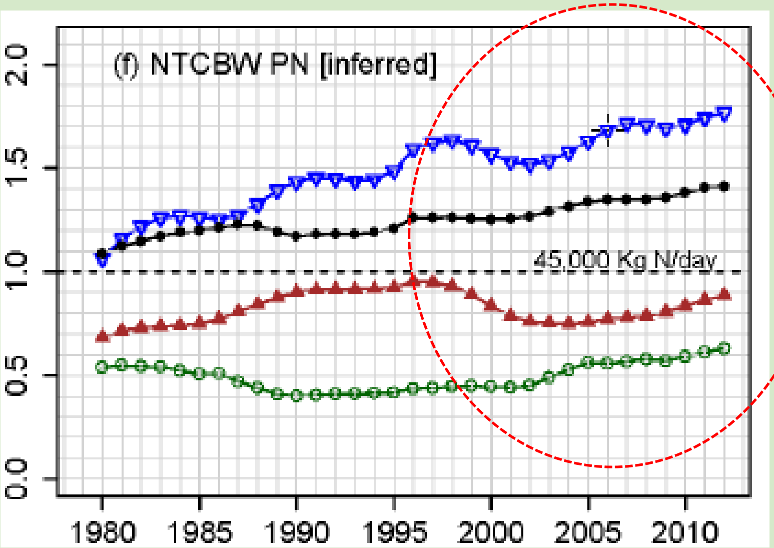
Steady but lessening decline in TN and DN loading since 1985



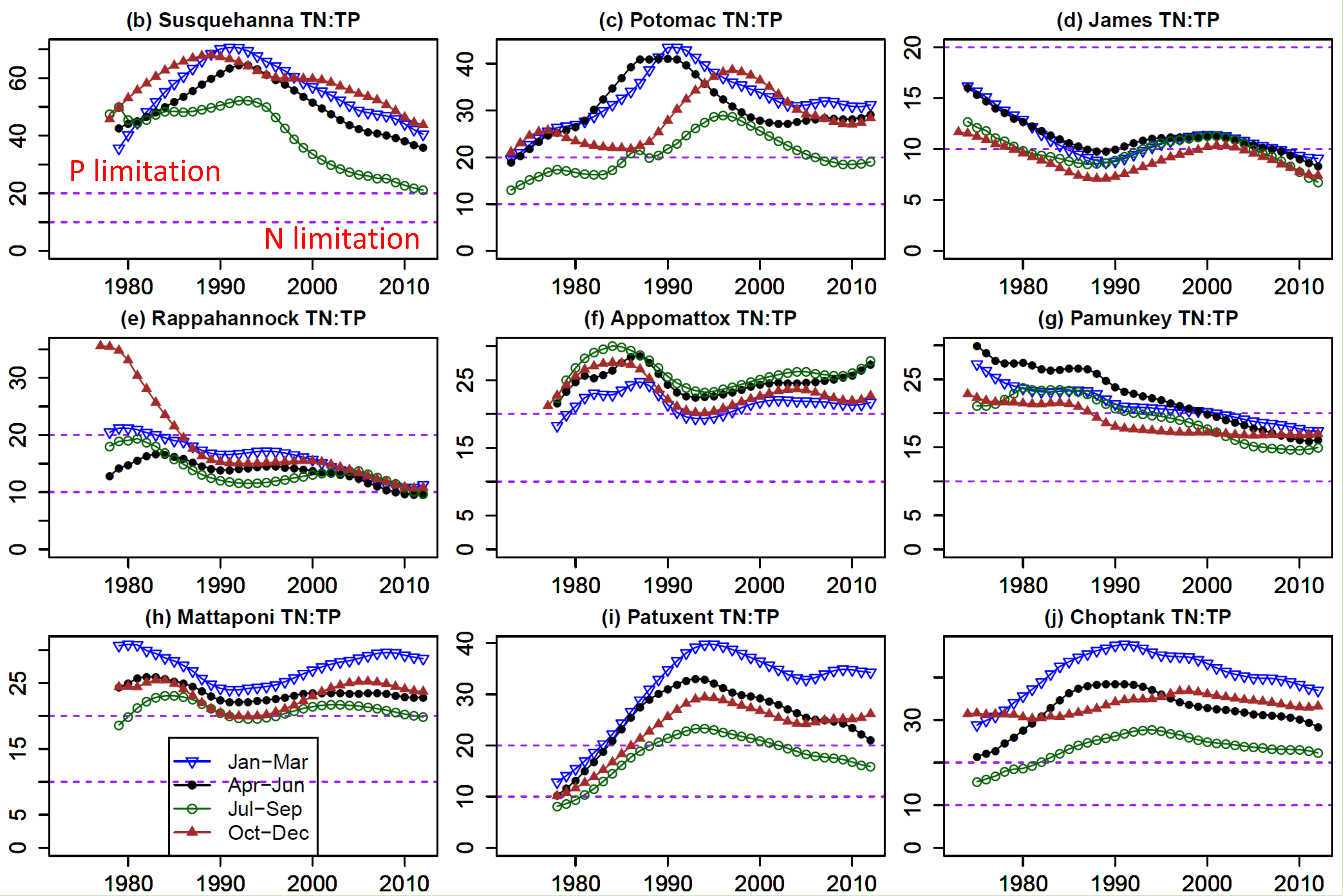


Rising PN in recent decades?? (small diff of large numbers





Seasonal trends in TN:TP molar ratios



Summary

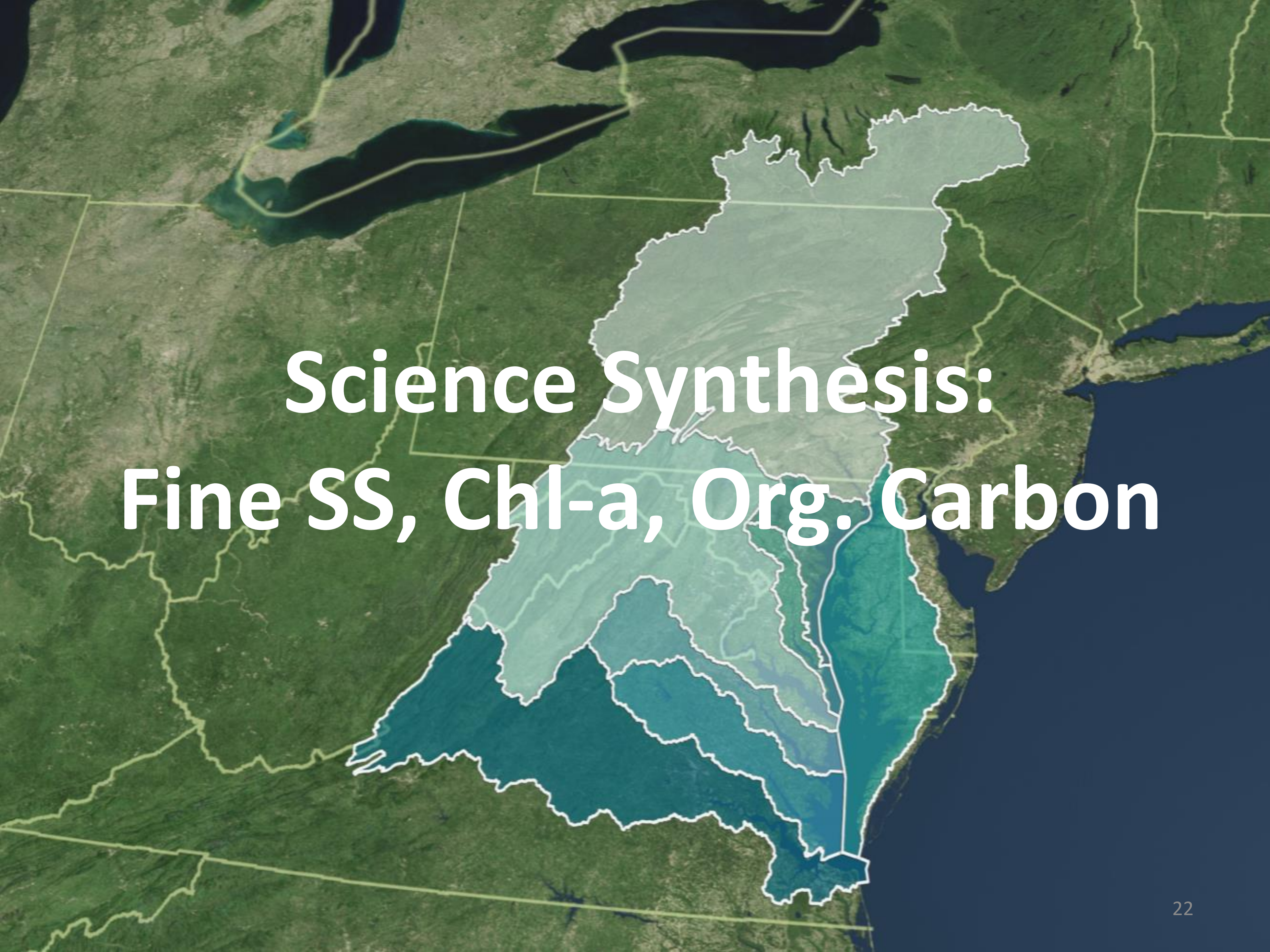
- **Have loadings of particulate species (SS, PP, PN) declined in the NTCBW and the tributaries?**
  - Particulate species (SS, PP, PN) loads from the NTCBW have risen since 1995, due in large part (but **not 100%!)** to diminished trapping within the Conowingo Reservoir on Susquehanna River.

- **How about dissolved species (DN, DP)?**
  - Dissolved nutrients (DN, DP, TN) loads from the NTCBW and most tributaries have declined, likely due to effects of management (e.g., detergent ban, WWTP upgrades, Clean Air Act).

Summary

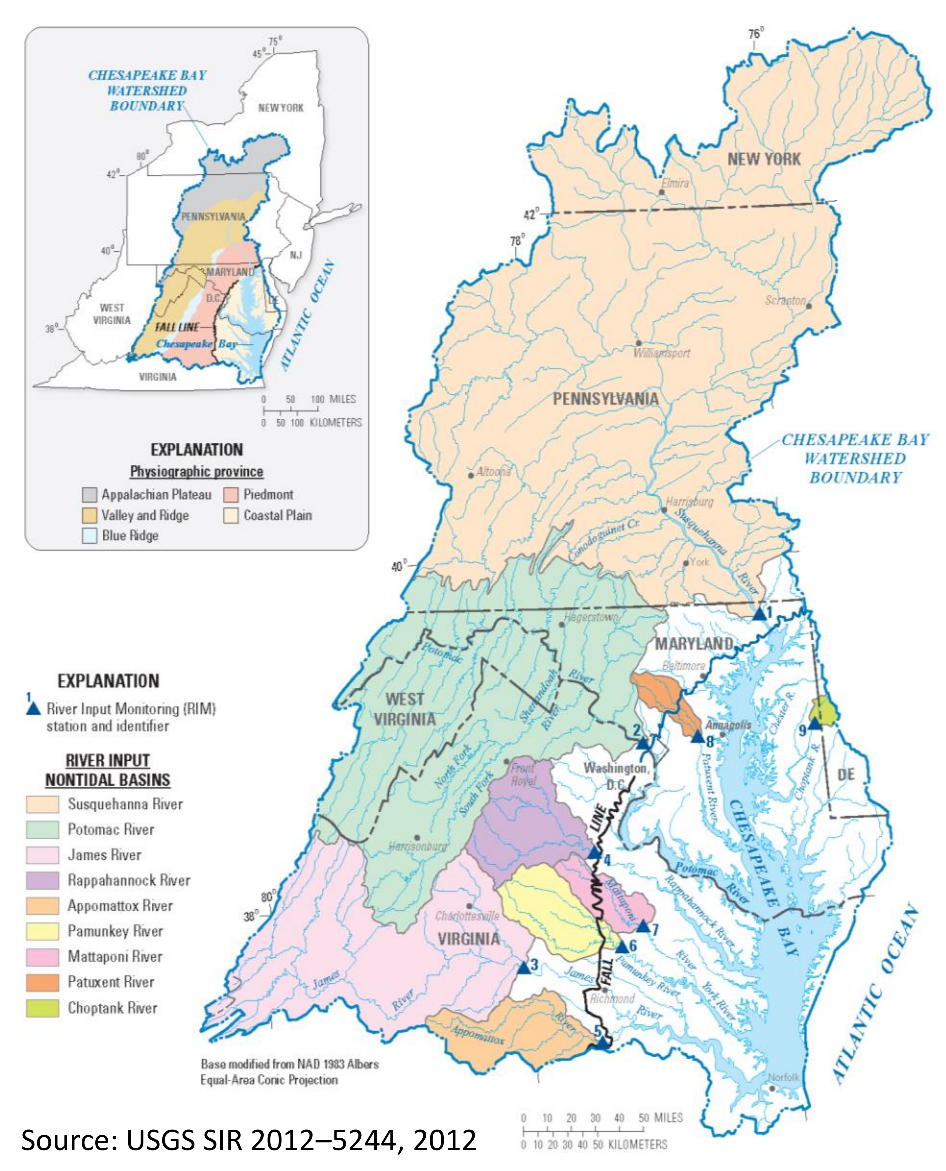
- **Have Coastal Plain and upland (piedmont-and-above) tributaries shown similar trends?**
  - The Coastal-Plain watersheds showed lack of reduction in TN loads (also DN and DP), likely reflecting lagged subsurface transport of nutrient inputs. In comparison, the 7 upland watersheds have shown consistent declines in TN load.

- **Have TN:TP molar ratios been changing over time?**
  - TN:TP ratios have declined in most rivers, suggesting the potential for changes in nutrient limitation in the estuaries.



Science Synthesis:
Fine SS, Chl-a, Org. Carbon

Study sites & data



Source: USGS SIR 2012–5244, 2012

- USGS RIM sites: ~77% of total fresh water from the entire Bay watershed.

Sediment (mg/L)

- SS concentration (USGS parameter **P80154**); since the 1980s.
- Fine suspended sediment fraction (< 0.0625mm) data (USGS P70331); since the 1980s. (SS_{fine} = **P70331** x SS / 100.)

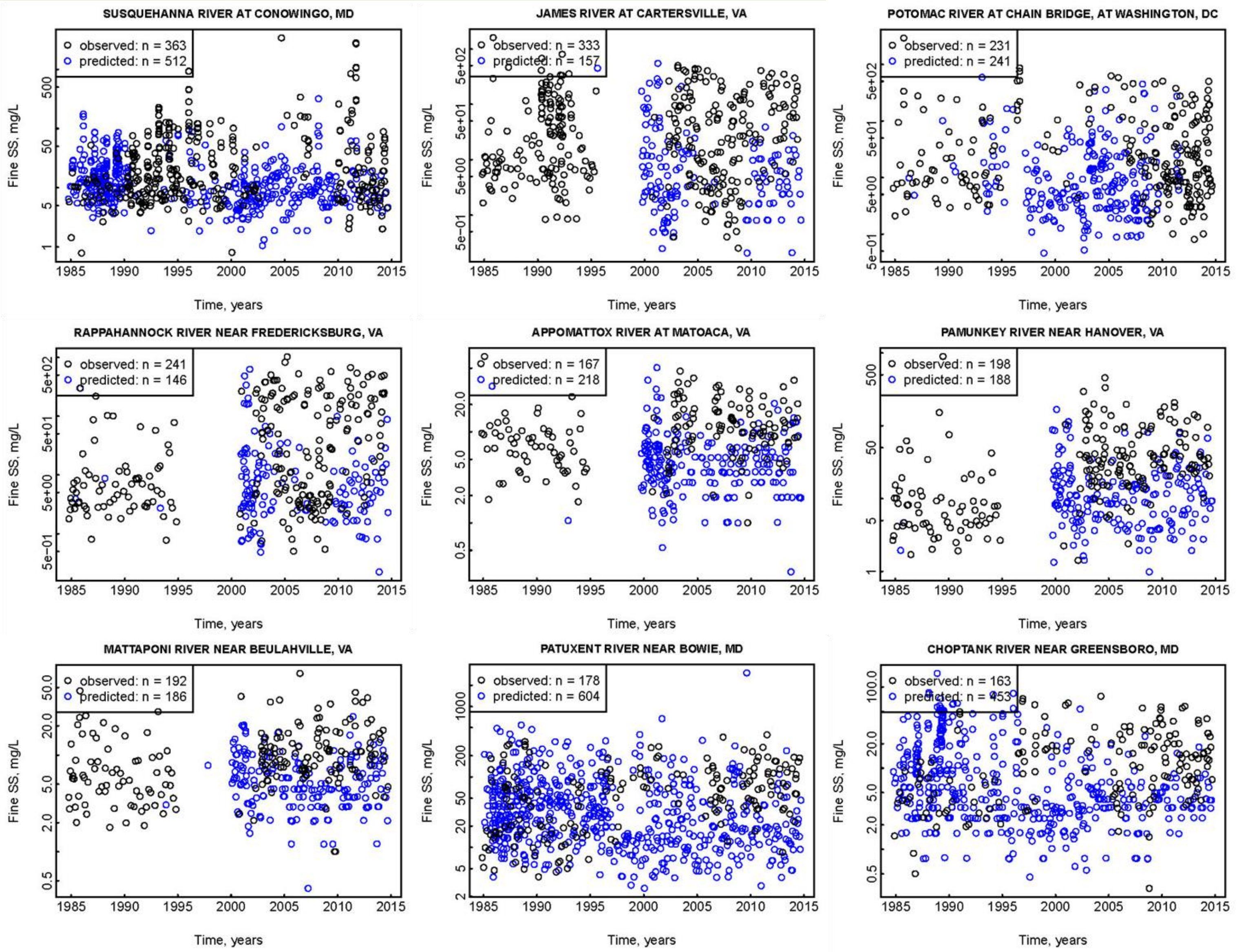
Chl-a (ug/L)

- MD sites: USGS parameter **P32211** (spectrophotometric acid method)
- VA Sites: USGS parameter **P70953** (chromatographic-fluorometric method)

Organic Carbon (mg/L)

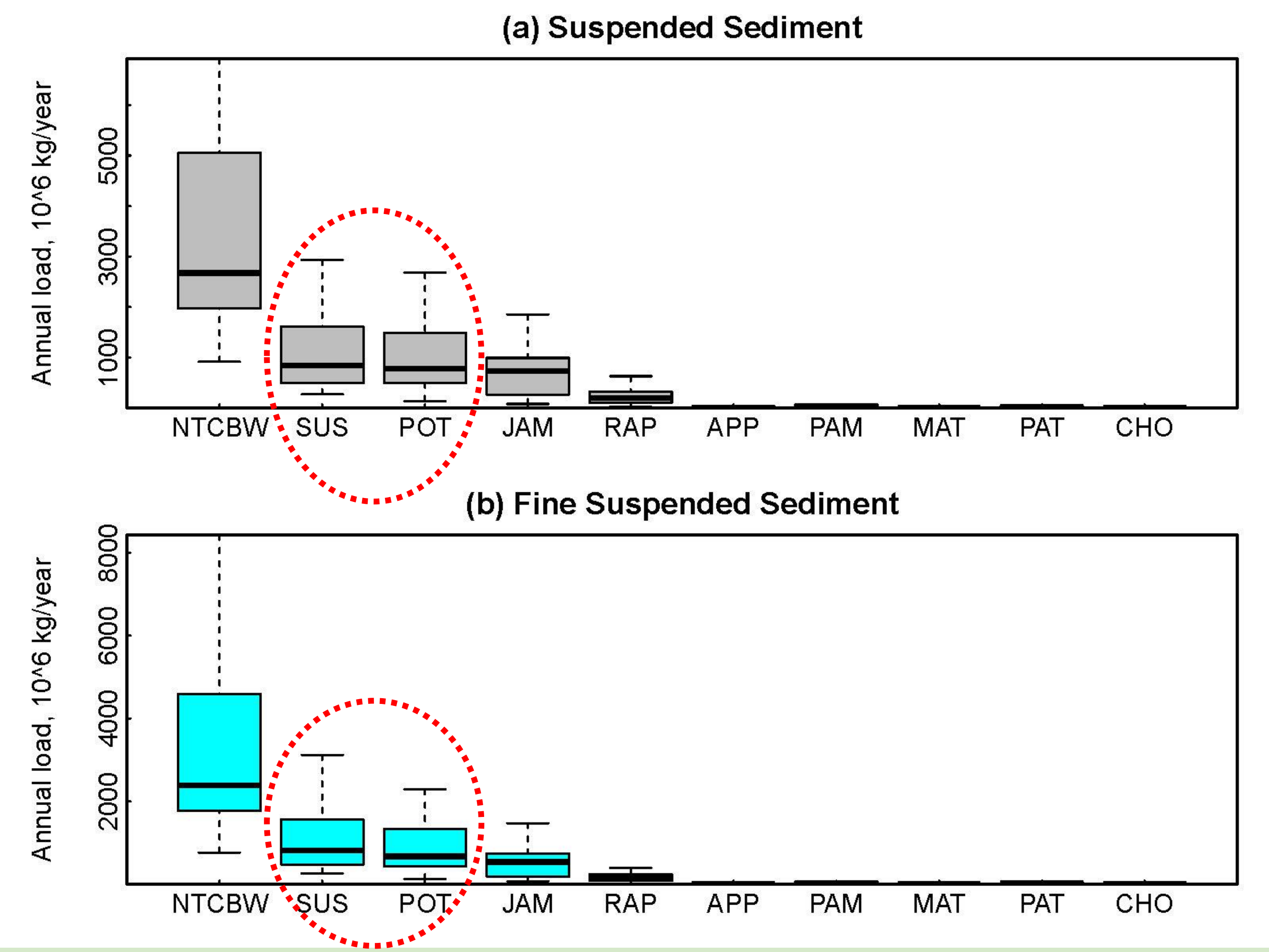
- TOC: USGS parameter **P00680**
- DOC: USGS parameter **P00681**
- POC: USGS parameter **P00689**

Temporal availability of SS_{fine} data



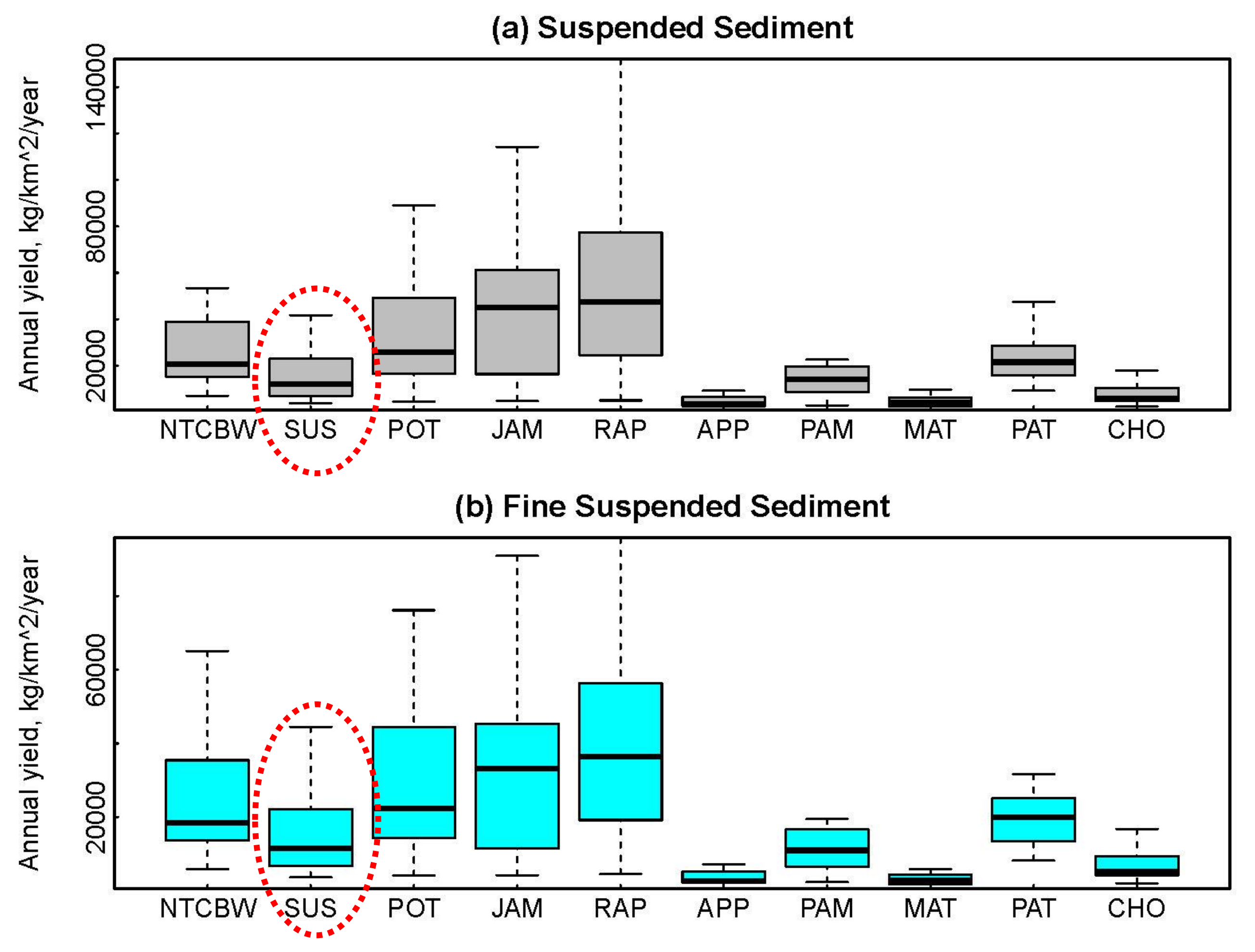
1. The reconstructed SS_{fine} records at the nine sites have values ranging 378-875 in total number (13-29/year), with Maryland sites generally have more values.

Spatial patterns of SS and SS_{fine} export



1. The annual loads of SS and SS_{fine} are dominated by the three largest rivers.
2. The similar magnitude between Susquehanna and Potomac loads is likely related to historical trapping in the lower Susquehanna reservoirs.
3. The smaller tributaries have low loads but can be important locally.

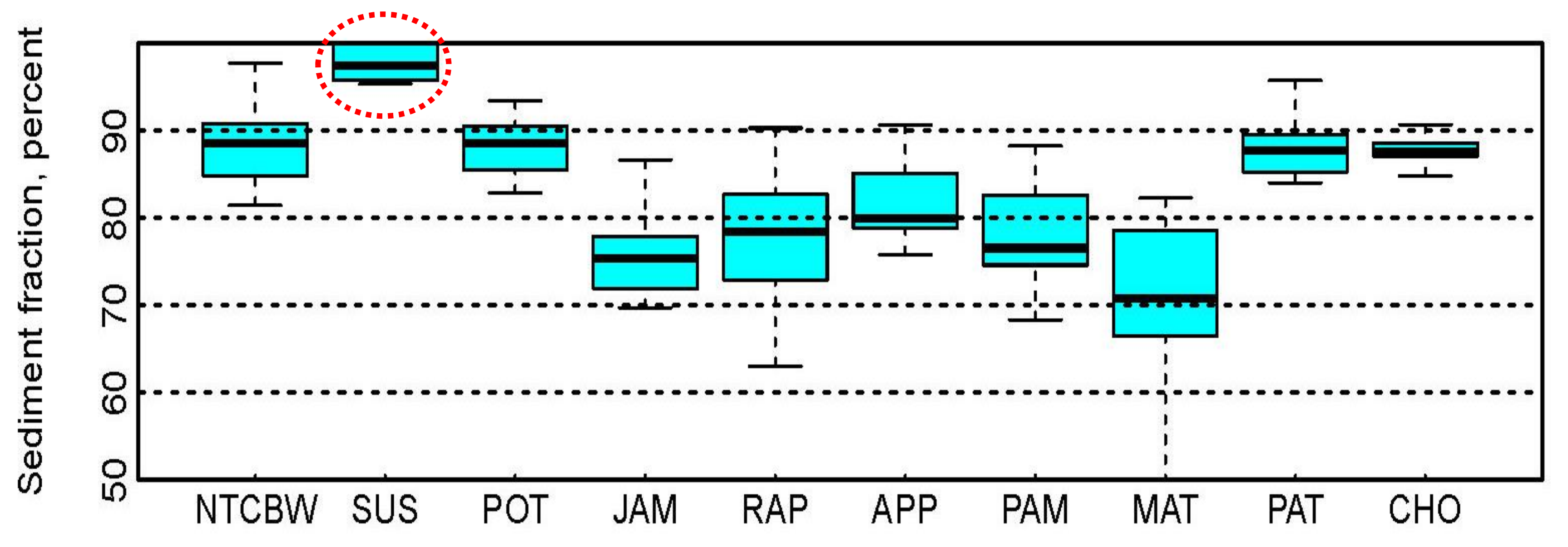
Spatial patterns of SS and SS_{fine} export



1. The annual yield (flux/unit area) of SS and SS_{fine} exhibits the following general order: Rappahannock > James > Potomac > Patuxent > NTCBW> Pamunkey > Susquehanna > Choptank > Appomattox, Mattaponi.

2. The larger tributaries generally have higher yields except the Susquehanna where yield is small due to reservoir trapping.

Spatial patterns of SS and SS_{fine} export

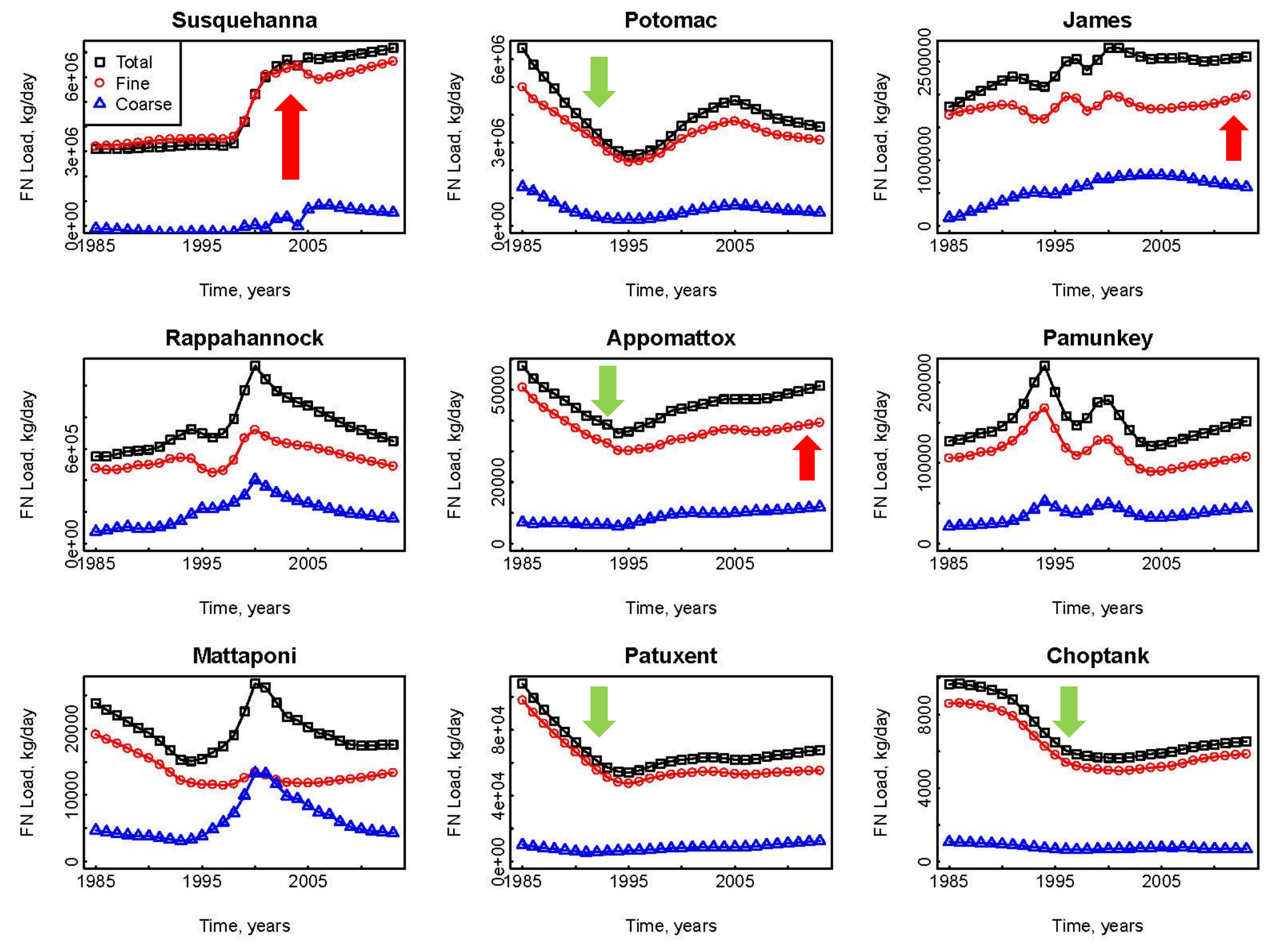


1. SS_{fine} is always the dominant fraction (>50%) of SS in all tributaries.

2. The fraction of fine sediment exhibits the following general order: Susquehanna (~95%) > NTCBW, Potomac, Patuxent, Choptank (~90%) > Virginia rivers (~70%-80%).

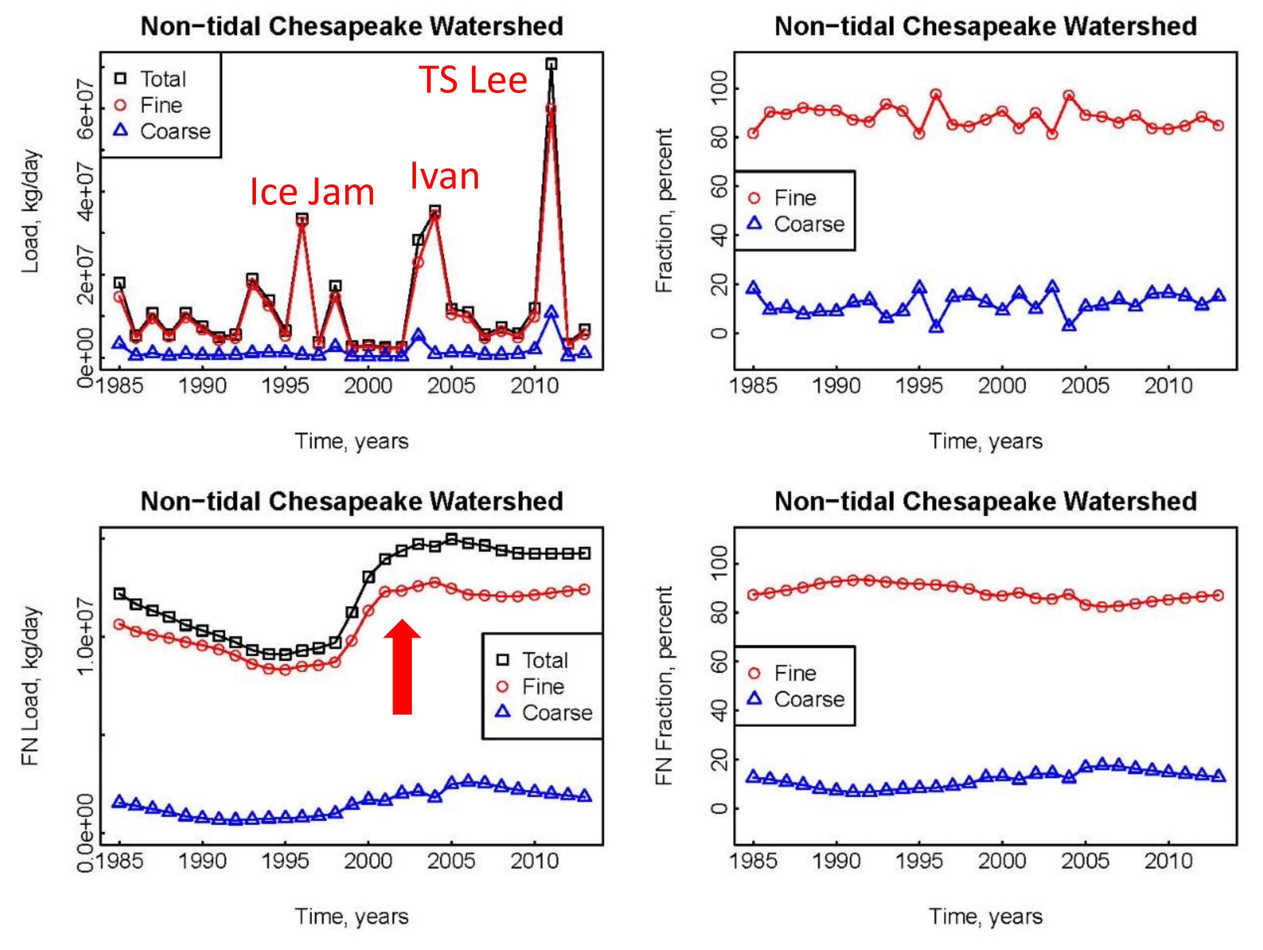
3. The dominance of fine sediment in Susquehanna @ Conowingo strongly indicates reservoir modulation of sediment sizes.

Temporal patterns of SS and SS$_{\text{fine}}$ fluxes



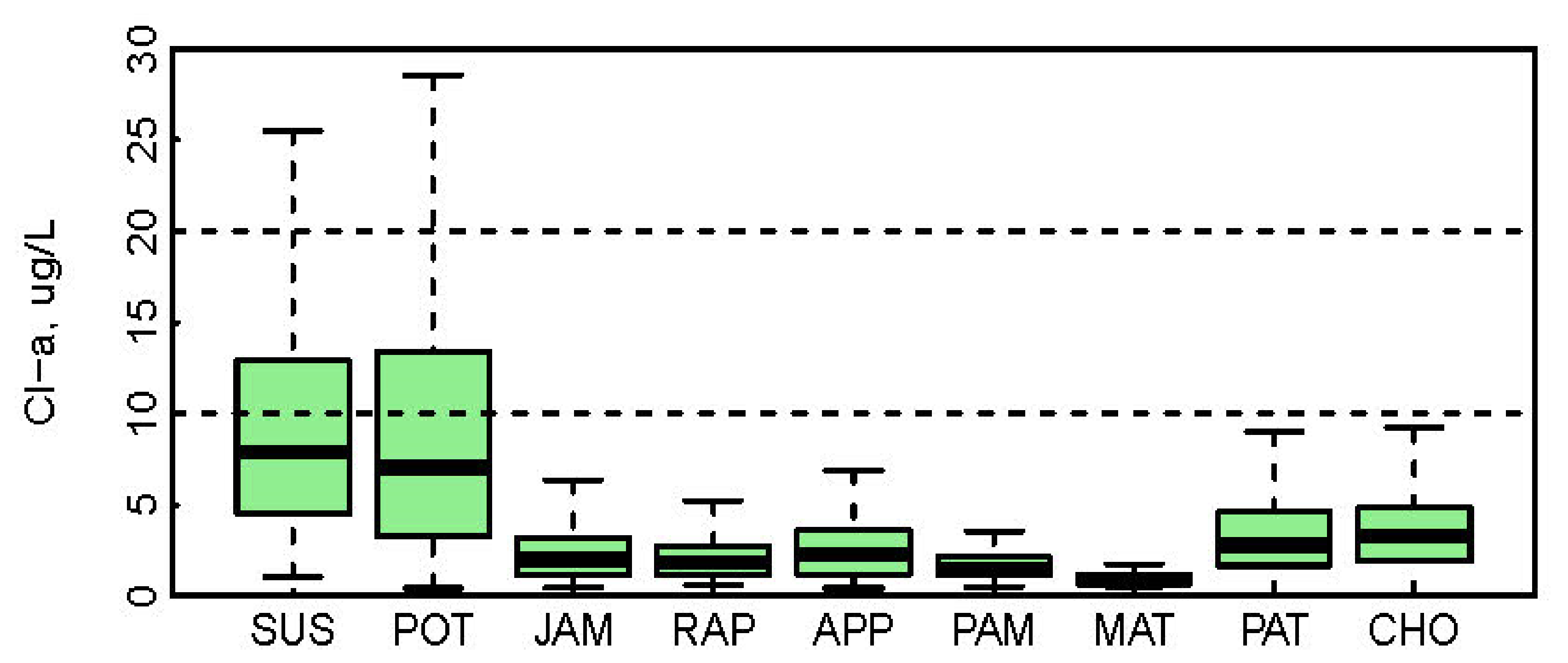
1. SS flux shows ***recent increase*** in Susquehanna, James & Appomattox.
2. SS flux shows ***early decline*** in Potomac, Appomattox, Patuxent & Choptank.
3. SS$_{\text{fine}}$ flux trend closely follows SS trend in all tributaries except Mattaponi.
4. In most rivers, the long-term trends and variability in SS flux is largely controlled by changes in SS$_{\text{fine}}$ in these rivers.

Long-term export of SS and SS_{fine} from the NTCBW



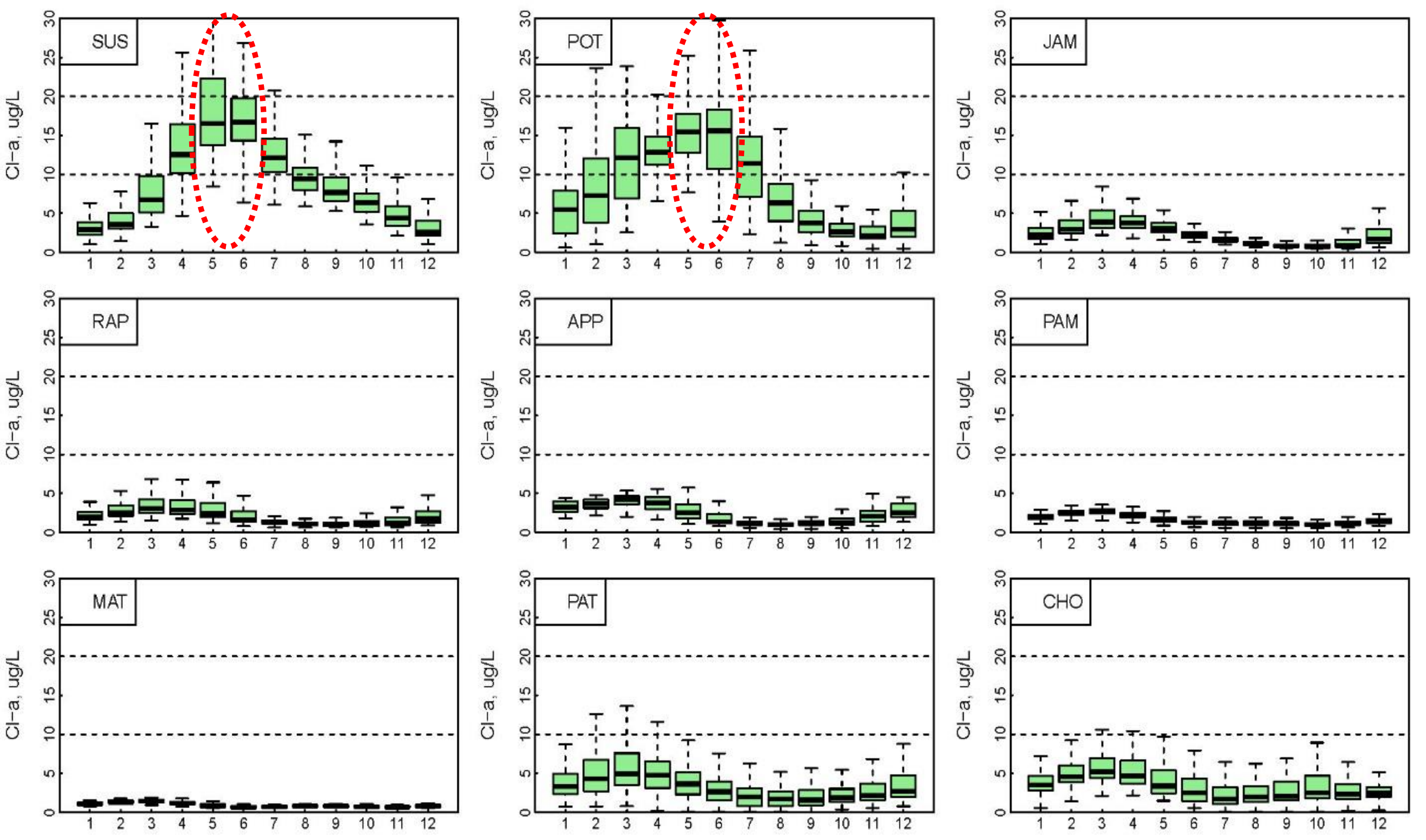
1. NTCBW SS flux is heavily affected by Susquehanna input: all SS fractions reached maximum in 2011 (TS Lee), 2004 (Ivan) & 1996 (ice jam).
2. In terms of ***relative fraction***, both true-condition and flow-normalized data indicate relatively constant contributions by SS_{fine} (~90%) and SS_{coarse} (~10%).
3. In terms of ***temporal trend***, SS, SS_{fine}, and SS_{coarse} all exhibit increasing trend since around 1995, which is largely related to Susquehanna reservoirs.

Spatial patterns of Chl-a concentration



1. Chl-a concentration exhibits the following general order: Susquehanna, Potomac > Choptank, Patuxent > Appomattox > James, Rappahannock, Pamunkey > Mattaponi.

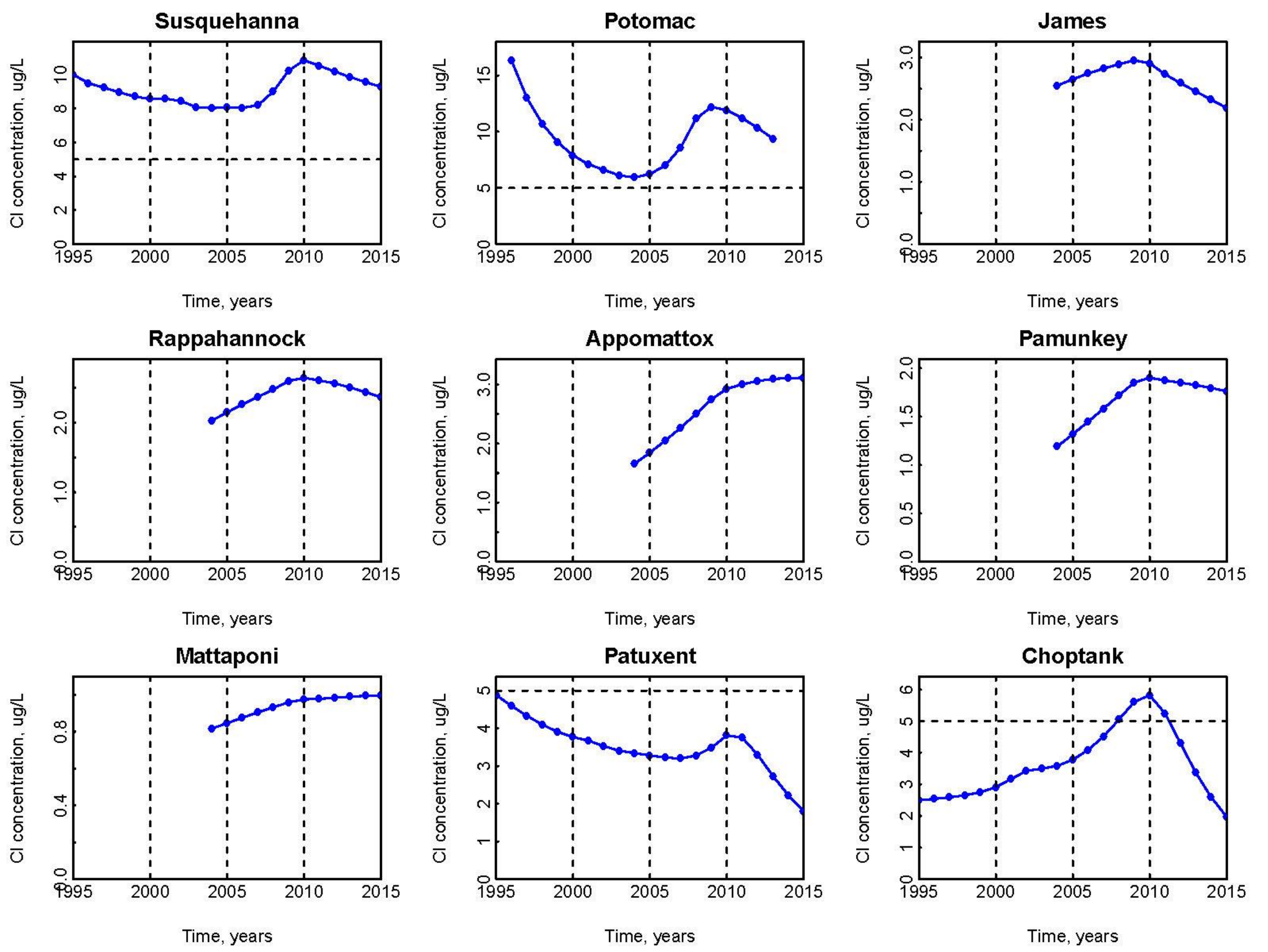
Seasonal patterns of Chl-a concentration



1. Grouped by month, the highest median concentration is observed with *May – June* in Susquehanna and Potomac (the two largest tributaries), as compared with *March – May* in the other (smaller) tributaries.

2. For Susquehanna and Potomac, there appears to be a seasonal switch in terms of their dominance, with Susquehanna having a higher (lower) median concentration in *May – November* (December – April).

Temporal patterns Chl-a concentration

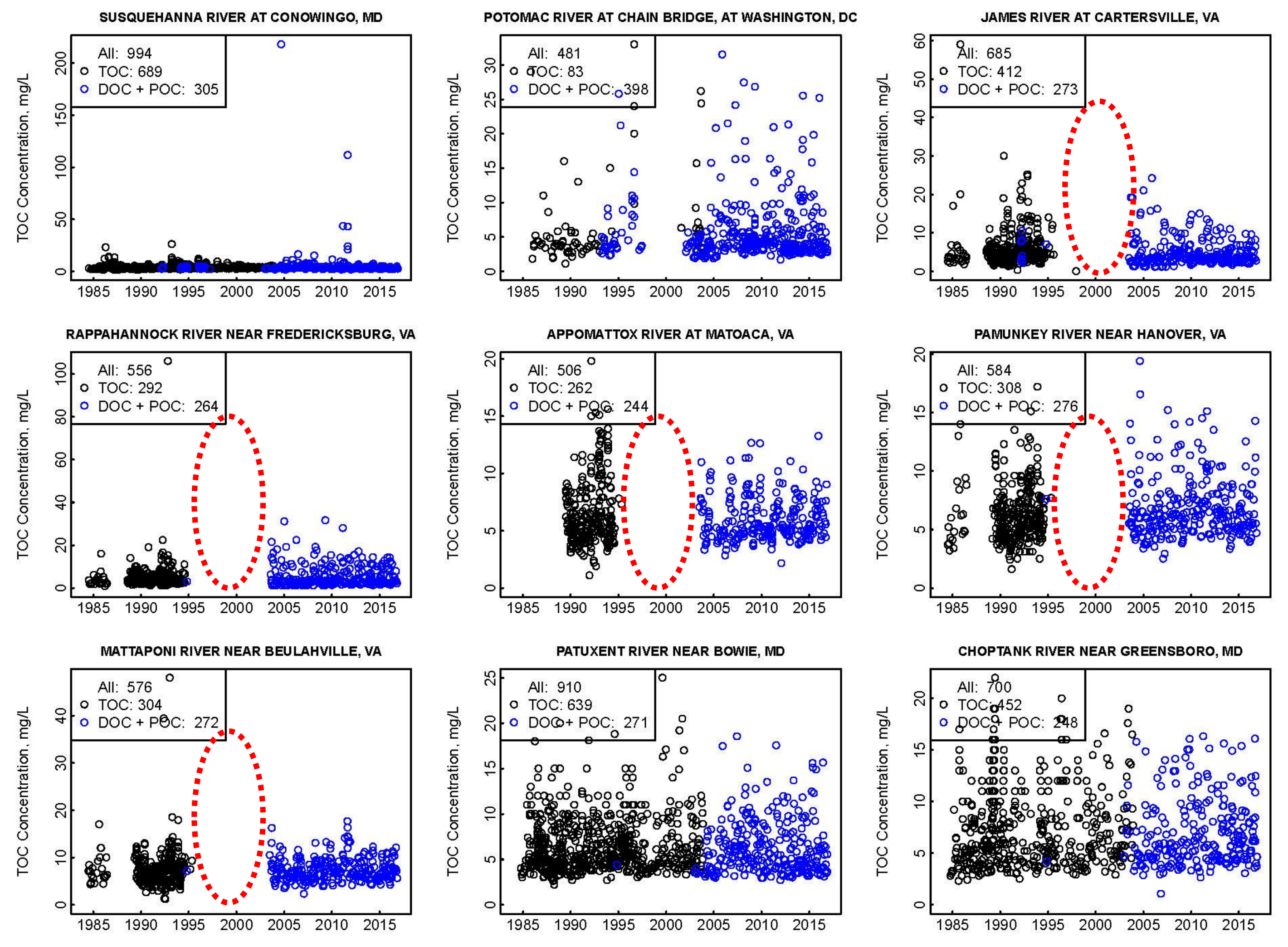


1. WRTDS FN concentration shows period-of-record ***downward*** trends in Potomac, James, Patuxent & Choptank.

2. WRTDS FN concentration shows period-of-record ***upward*** trends in Rappahannock, Appomattox, Pamunkey & Mattaponi.

3. A dramatic decline in chl-a concentration occurred in Patuxent (ENR?)

Temporal availability of TOC data

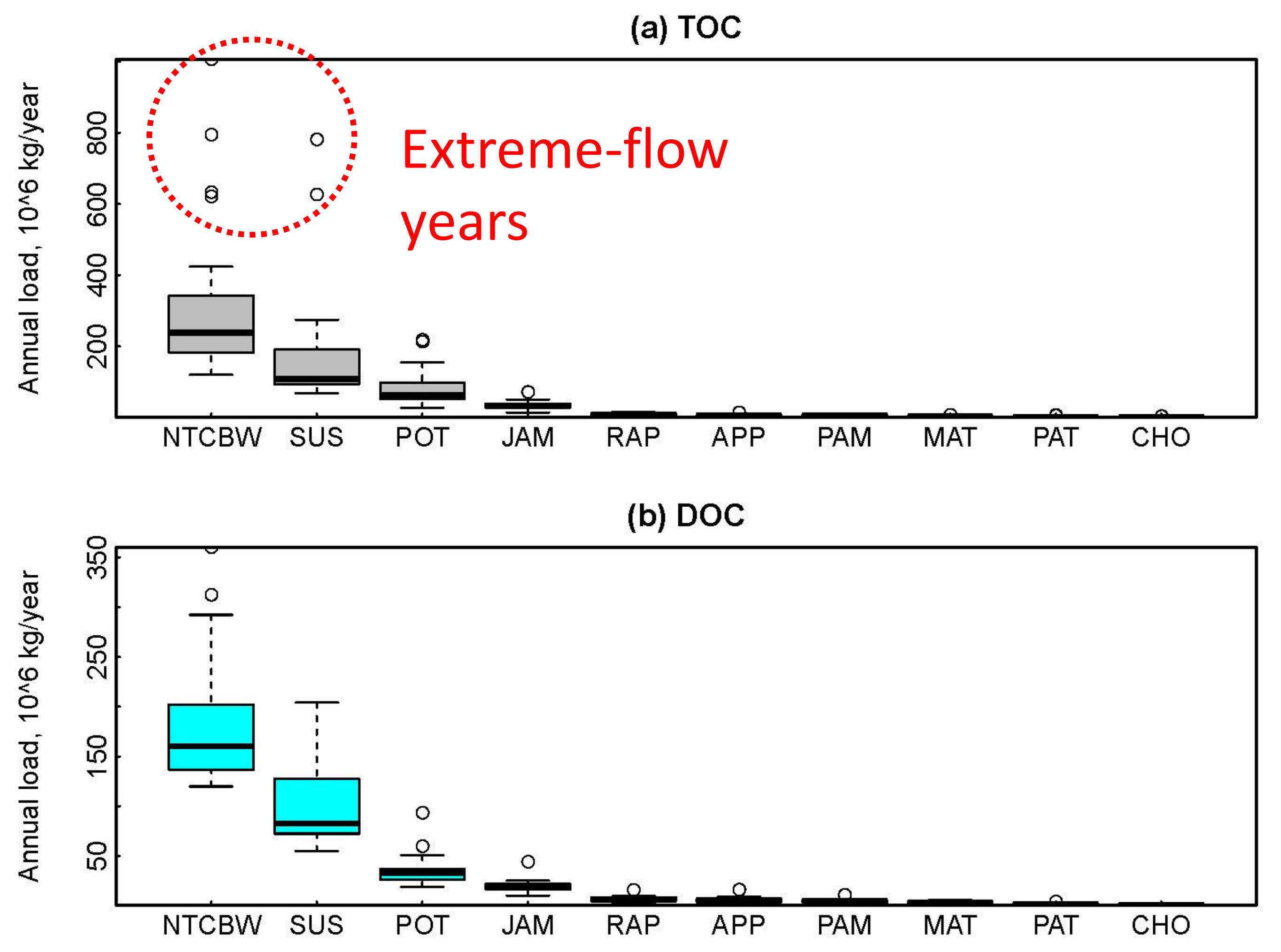


1. TOC has been monitored in the early years; POC and DOC in later years.

2. Gap existed for TOC in 1995-2004 at all five Virginia sites (similarly for SS).

3. Susquehanna has the largest # of TOC observations (~ 30/year).

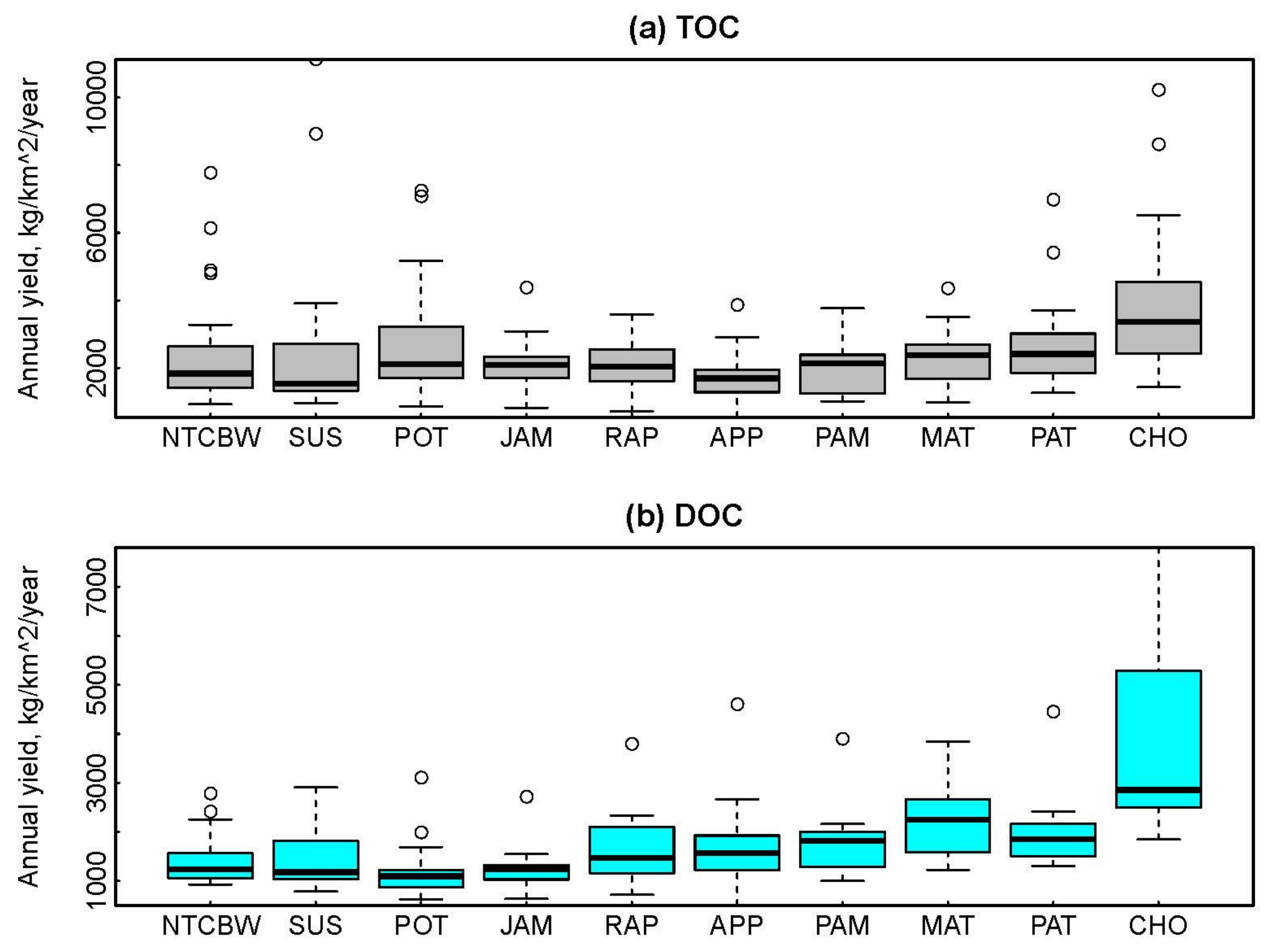
Spatial patterns of TOC and DOC export



1. The annual load of TOC and DOC both show strong dominance by the three largest tributaries, *i.e.*, Susquehanna, Potomac, and James.

2. The smaller tributaries have low loads but can be important locally.

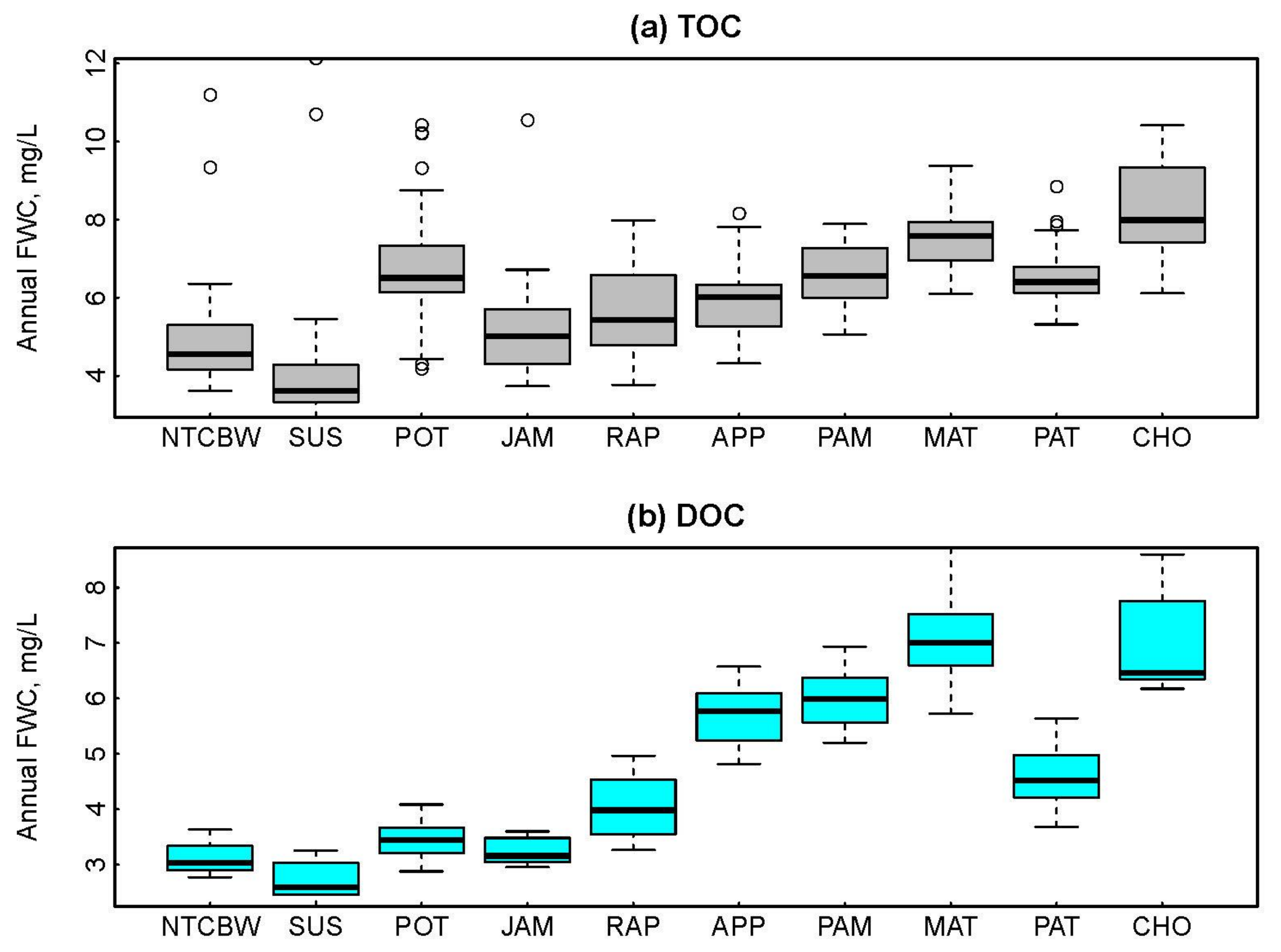
Spatial patterns of TOC and DOC export



1. The annual yield (flux/unit area) of TOC and DOC is fairly consistent among the various tributaries, which is in strong contrast with sediment.

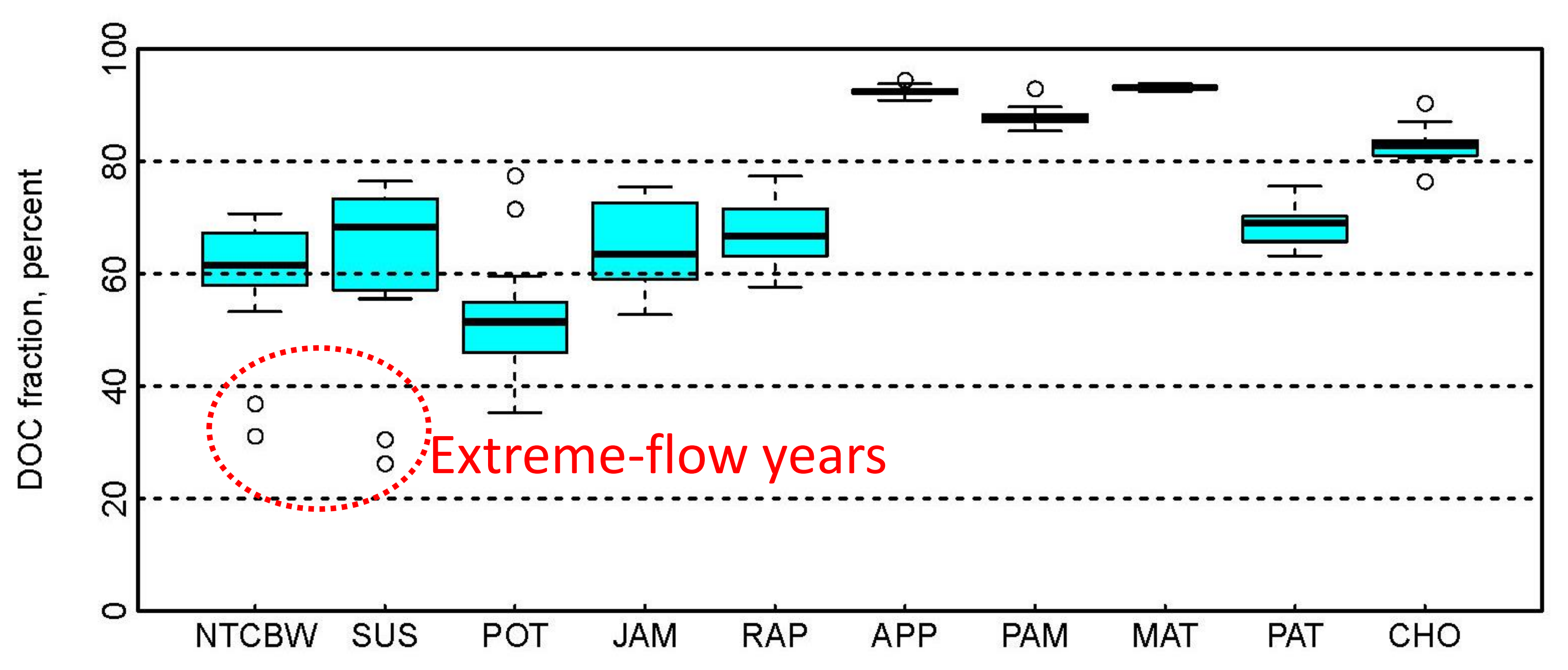
2. The Choptank appears to have the largest yields for both TOC and DOC.

Spatial patterns of TOC and DOC export



1. The annual flow-weighted concentration (FWC) of TOC and DOC appear to be smaller at the largest tributaries, particularly Susquehanna.

Spatial patterns of DOC fraction

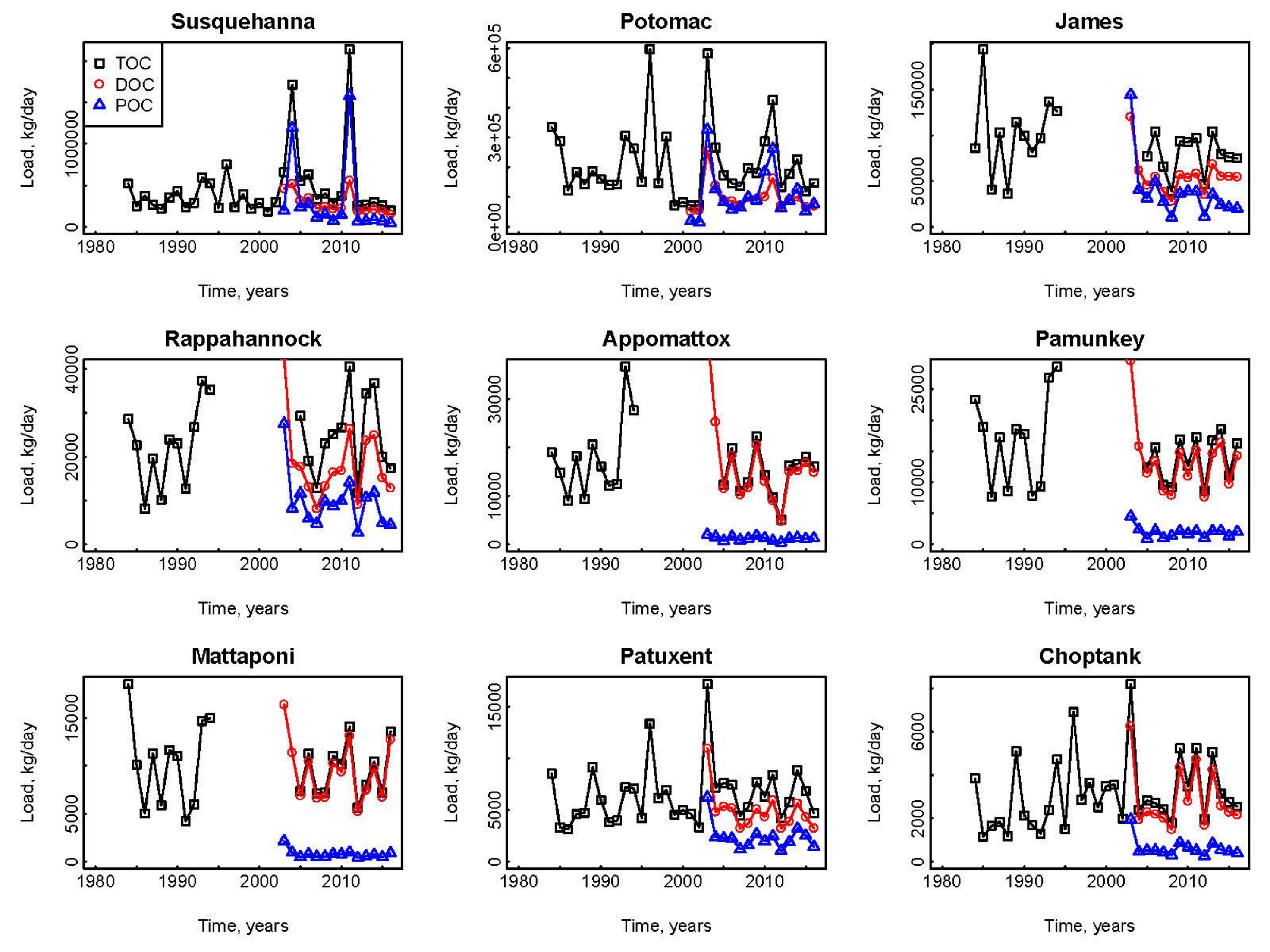


1. In general, DOC is the dominant fraction in relative to POC.

2. In extreme event years (2004 and 2011), Susquehanna and Potomac show increased dominance of POC.

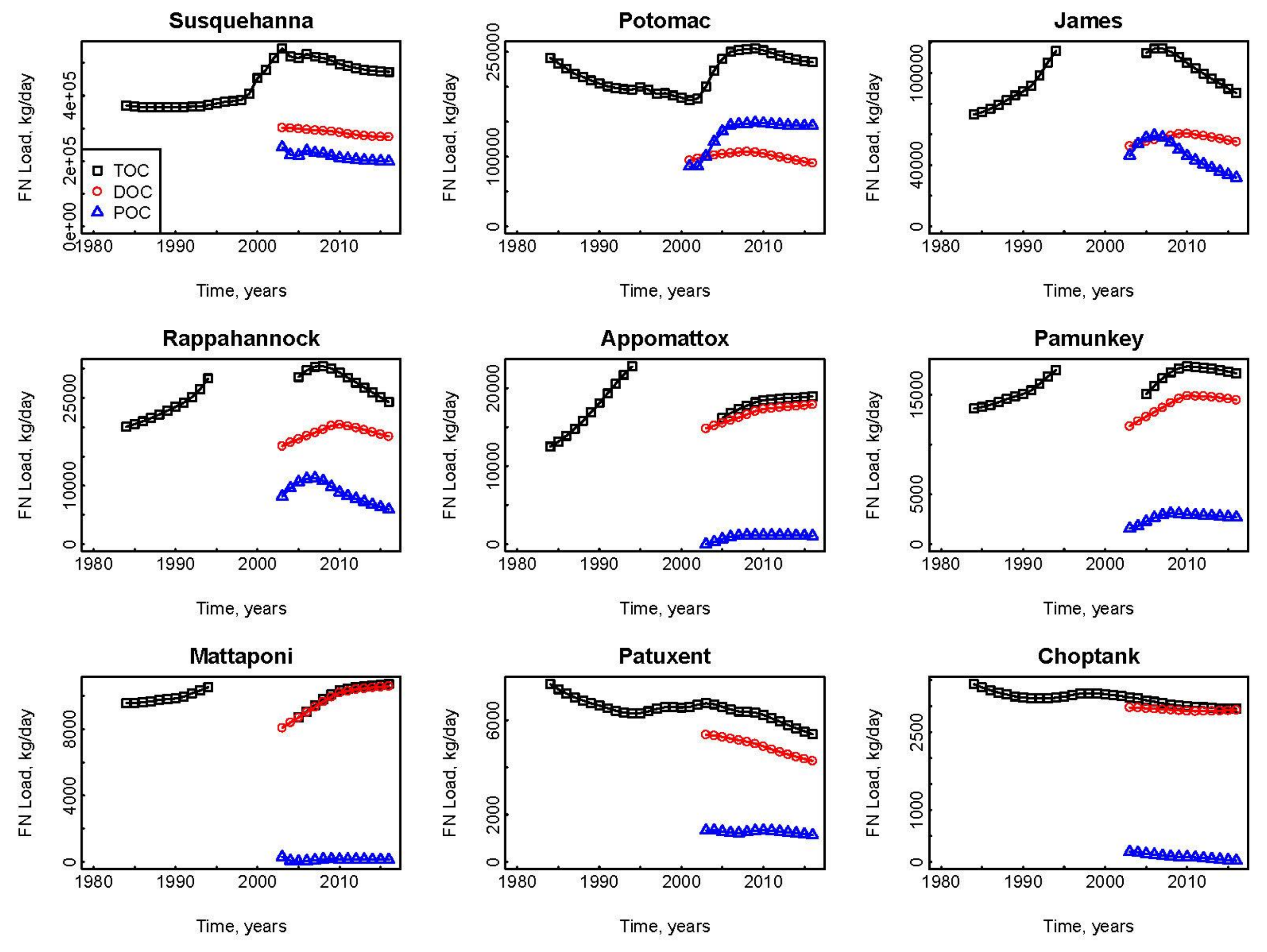
3. The smaller rivers show highest DOC fractions, particularly the VA rivers (~90%; and without much variation) and Choptank.

Temporal patterns of TOC and DOC fluxes



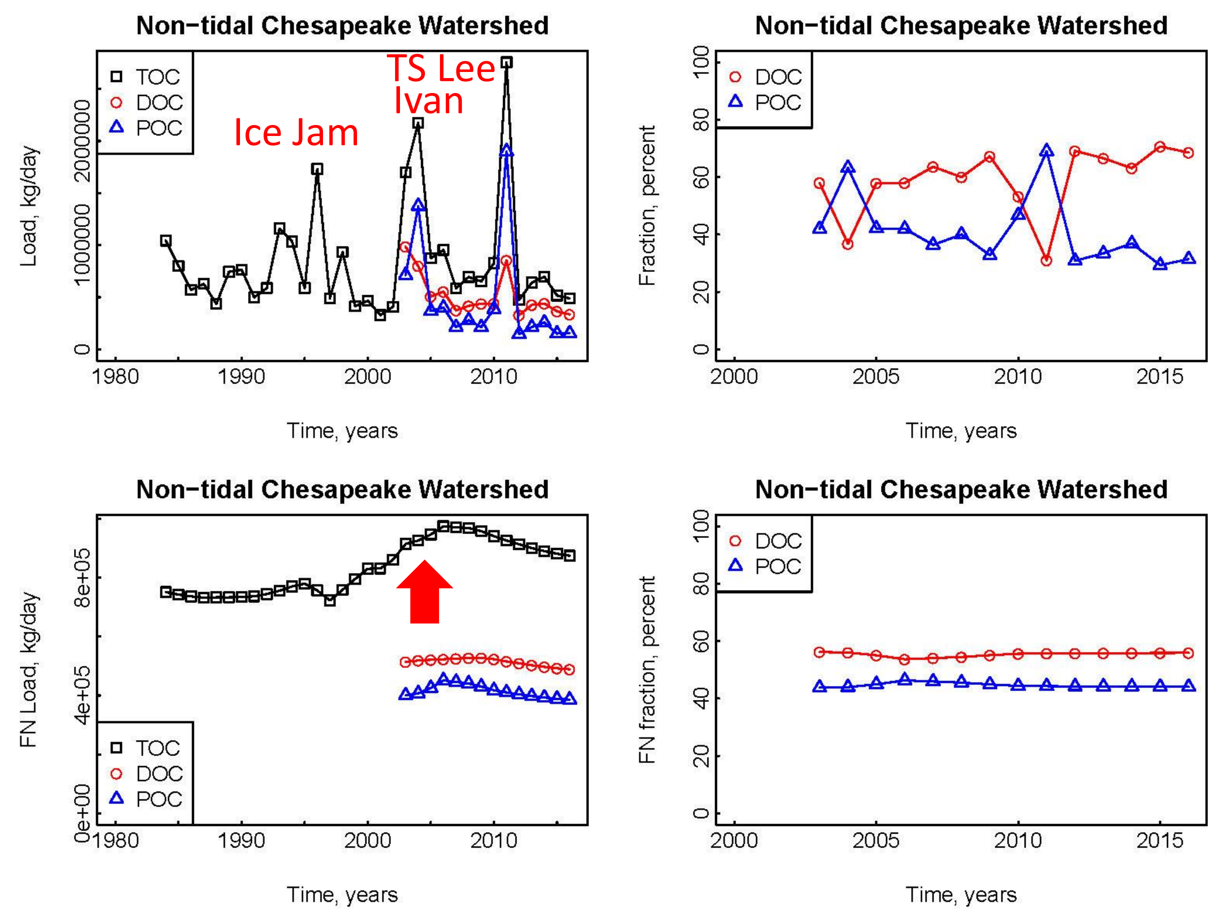
1. All fluxes show strong inter-annual variability due to variability in streamflow. In particular, peaks have been coherent among the nine rivers, notably including 2011 (Tropical Strom Lee), 2004 (Hurricane Ivan), and 1996 (a major ice jam event).

Temporal patterns of TOC and DOC fluxes



1. VA rivers show discontinued TOC trends due to lack of monitoring.
2. MD rivers show strong recent TOC rise in Susquehanna (*reservoir?*) and Potomac (*dam removal?)* but steady TOC decline in Patuxent (*WWTP?*) and Choptank (*conservation?*).

Long-term export of TOC and DOC from the NTCBW

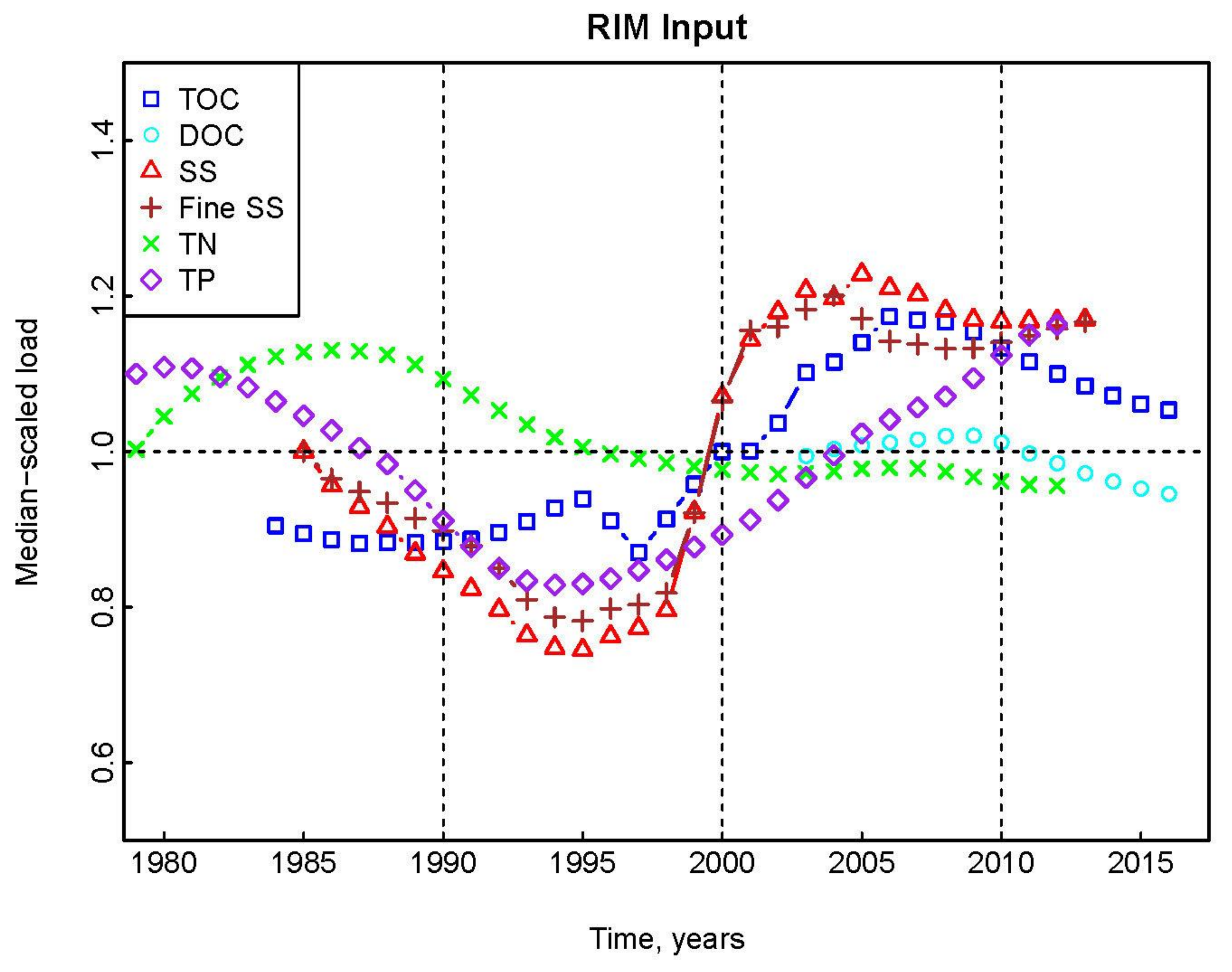


1. NTCBW carbon flux is heavily affected by Susquehanna input: true-condition fluxes all reached maximum in 2011 (TS Lee), 2004 (Ivan) & 1996 (ice jam).

2. In terms of ***temporal trend***, TOC has been increasing since the late 1990s.

3. In terms of ***relative fraction***, flow-normalized data indicate relatively constant contributions by DOC (~55%) and POC (~45%); but true-condition data indicate strong dominance of POC in extreme event years (2004 and 2011).

Summary of RIM inputs



Next steps

- To further quantify inputs from the below-fall-line areas.
- To establish linkage between riverine input and water clarity in the estuary.
- To establish possible linkage between fall-line chl-a concentration to changes in N and P availability & N:P ratios in the rivers.

Thank You!