Comparison of two Regression-Based Approaches for Determining Nutrient and Sediment Loads and Trends in the Chesapeake Bay Watershed

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Conclusions

- The USGS has a new method for quantifying trends in nutrient and sediment loads.
- The new trend in load information:
  - Improves the relevancy of the information we provide to our local, state, and federal partners
  - Enhances the existing information for trend in concentration
- Trend in load and trend in concentration together provide a more complete understanding of how changes in watershed characteristics (e.g. land use) and the implementation of BMPs influence resulting water-quality conditions.

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Presentation Topics

- Provide background information on a new approach that the USGS has developed to determine trends in nutrient and sediment loads
- Present trends in total nitrogen, total phosphorus, and suspended sediment loads
- Compare “new” trends in loads and “historical” trends in concentration
- Thoughts on next steps

Paradigm Shift for Trend Reporting

- Historically, long-term changes in riverine water-quality conditions were represented as a trend in concentration.
- We now have the analytical ability to represent long-term changes in water-quality conditions as both trends in concentration and load.
- This shift allows for a more holistic view of changes in water-quality conditions and better aligns with nutrient and sediment reduction goals.

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Trend in Concentration vs. Trend in Load

- Trend in concentration provides information on how BMPs have influenced in-stream concentrations at a given point.
  - Great information for local water quality condition
  - Determined based on patterns in the majority of observed water-quality data (often low to intermediate Q); most influenced by baseflow, groundwater, point-source inputs
- Trend in load *(concentration x discharge)* provides information on how BMPs have influenced the downstream transport of nutrients and sediment.
  - Relevant for managers trying to reduce the mass delivered to the tidal portions of the Bay (TMDL)
  - Determined based on patterns in the highest load samples (~10 percent of the observations); most influenced by wet-weather inputs (nonpoint sources)

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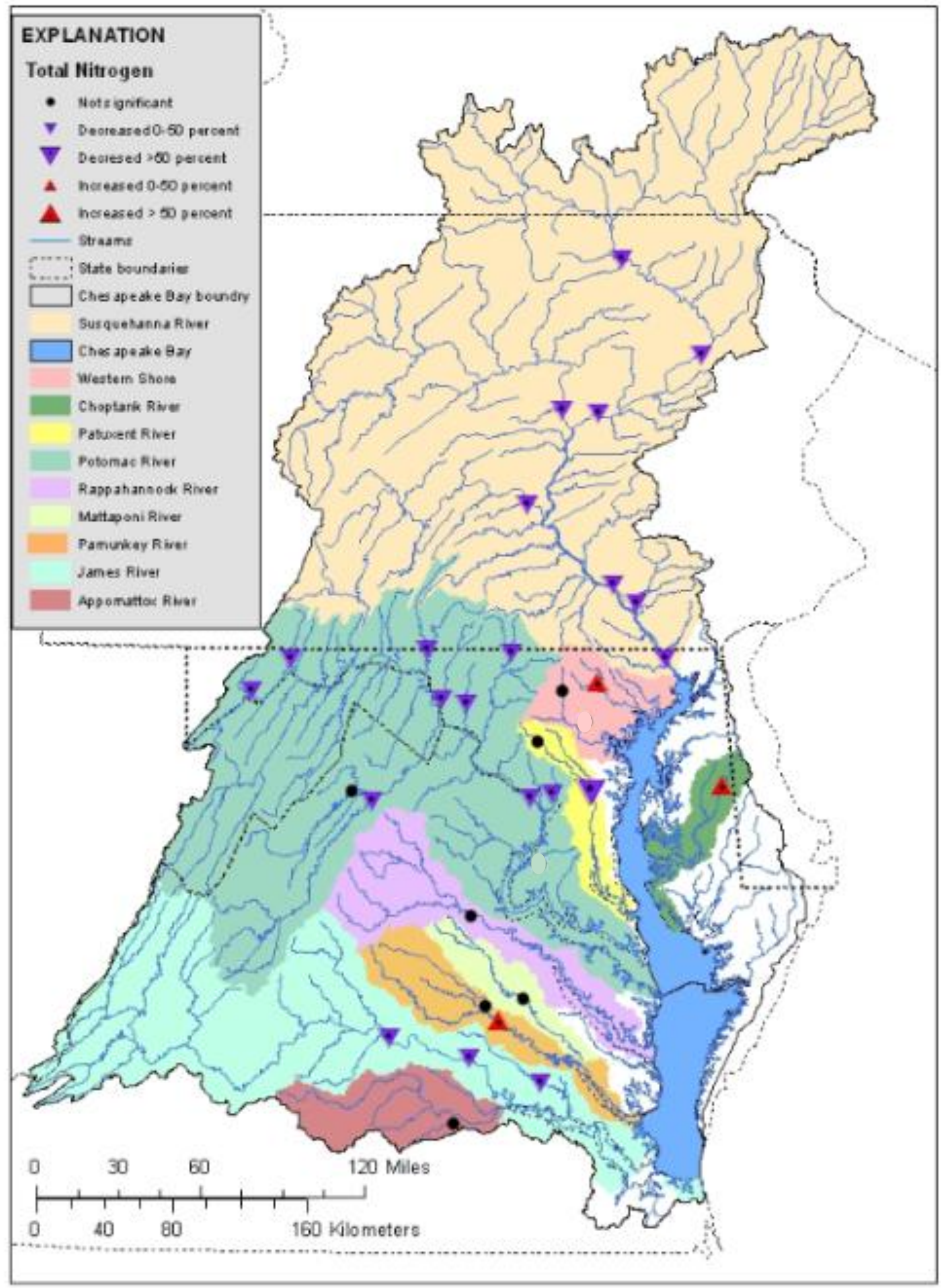
Trends in Flow-Adjusted Concentration

Example: Total nitrogen for the period 1985 to 2011

ESTIMATOR is the approach used to determine trends in flow-adjusted concentration across nontidal network.

Problem with the trend in flow-adjusted concentration is that it has been/is commonly used as a surrogate for trend in load.



Flow-adjusted trends for total nitrogen for 31 sites in the Chesapeake Bay Watershed, 1985-2011.

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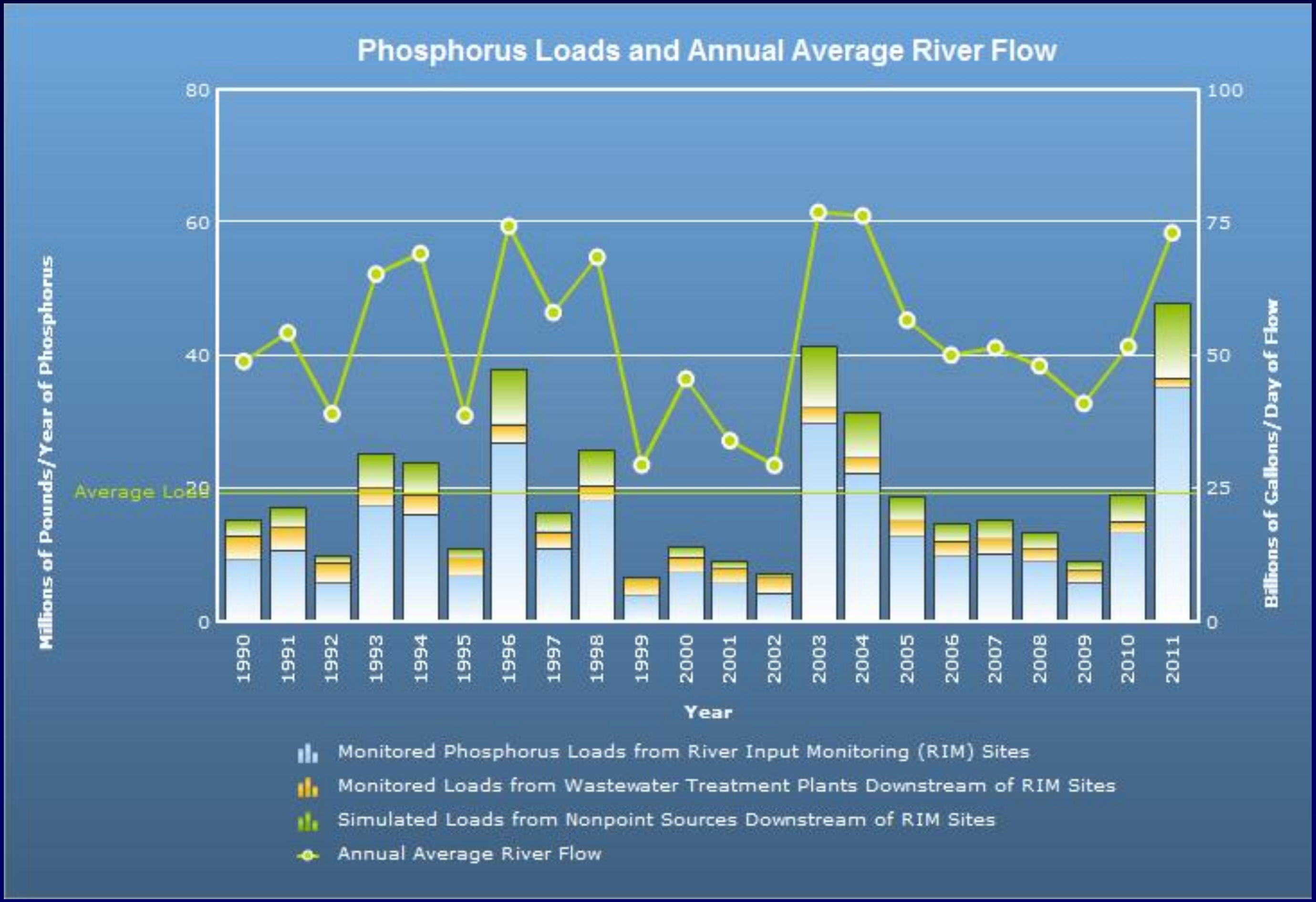
MANAGEMENT CONCERNS

- Can we report a measure of trend in ANNUAL LOAD of nutrients and sediment delivered to the Chesapeake Bay that is indicative of changes in the watershed (e.g. BMPs, land conversion, …) and not influenced by random year-to-year variations in streamflow?



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NEW METHODOLOGY

Weighted Regression on Time, Discharge, and Season (WRTDS)

Is a new statistical approach that now allows us to determine:

- Trends in annual loads that have been adjusted to account for the year-to-year variation in flow
- Nutrient and sediment loads with greater accuracy for locations with complex concentration-discharge relations

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WEIGHTED REGRESSIONS ON TIME, DISCHARGE, AND SEASON (WRTDS), WITH AN APPLICATION TO CHESAPEAKE BAY RIVER INPUTS[1]

Robert M. Hirsch, Douglas L. Moyer, and Stacey A. Archfield[2]

ABSTRACT: A new approach to the analysis of long-term surface water-quality data is proposed and implemented. The goal of this approach is to increase the amount of information that is extracted from the types of rich water-quality datasets that now exist. The method is formulated to allow for maximum flexibility in representations of the long-term trend, seasonal components, and discharge-related components of the behavior of the water-quality variable of interest. It is designed to provide internally consistent estimates of the actual history of concentrations and fluxes as well as histories that eliminate the influence of year-to-year variations in streamflow. The method employs the use of weighted regressions of concentrations on time, discharge, and season. Finally, the method is designed to be useful as a diagnostic tool regarding the kinds of changes that are taking place in the watershed related to point sources, groundwater sources, and surface-water nonpoint sources. The method is applied to datasets for the nine large tributaries of Chesapeake Bay from 1978 to 2008. The results show a wide range of patterns of change in total phosphorus and in dissolved nitrate plus nitrite. These results should prove useful in further examination of the causes of changes, or lack of changes, and may help inform decisions about future actions to reduce nutrient enrichment in the Chesapeake Bay and its watershed.

(KEY TERMS: monitoring; computational methods; statistics; time series analysis; nonpoint-source pollution; nutrients; point-source pollution.)

Hirsch, Robert M., Douglas L. Moyer, and Stacey A. Archfield, 2010. Weighted Regressions on Time, Discharge, and Season (WRTDS), With an Application to Chesapeake Bay River Inputs. *Journal of the American Water Resources Association* (JAWRA) 46(5):857-880. DOI: 10.1111/j.1752-1688.2010.00482.x

INTRODUCTION

Given the importance of water quality to the national and global environment and the efforts being made to improve water quality, there is great value in developing and using data analysis methods aimed at deriving the greatest possible amount of information from the data that are collected, particularly related to changes in water quality over time. Furthermore, it is imperative that the results from these analyses be used to help communicate the water-quality changes that are taking place so that the best information possible is used to guide decisions about future efforts to protect and restore water quality.

[1]Paper No. JAWRA-10-0082-P of the *Journal of the American Water Resources Association* (JAWRA). Received May 18, 2010; accepted July 30, 2010. © 2010 American Water Resources Association. This article is a U.S. Government work and is in the public domain in the USA. Discussions are open until six months from print publication.
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Current Study: Moyer, Hirsch, & Hyer

OBJECTIVE:

Evaluate the performance of ESTIMATOR and WRTDS in reproducing nutrient and sediment concentrations and loads and determine which model ultimately ensures the highest level of accuracy in annual load estimates provided to the Chesapeake Bay Program.

QUESTIONS:

1. What are the differences in functional form and model construction?
2. Which model reproduces discrete observations with the greatest accuracy and least bias?
3. How different would the historical estimates of load been had WRTDS been used instead of ESTIMATOR?
4. What are the trends in annual nutrient and sediment loads and how do they compare to ESTIMATOR concentration trends?

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Chesapeake Bay: River Input Monitoring Stations

Stations:

- Susquehanna
- Potomac
- James
- Rappahannock
- Appomattox
- Pamunkey
- Mattaponi
- Patuxent
- Choptank

Why these stations:

- Greater than 75% of the land area
- Vast majority of the total discharge from the nontidal areas passes these stations
- Robust datasets: nearly 30 years of monitoring with total observations ranging from 600 to 1,400

Constituents:

- Total Nitrogen
- Nitrate
- Total Phosphorus
- Orthophosphorus
- Suspended Sediment

Therefore 9RIM * 5 Constituents = 45 possible analytical combinations

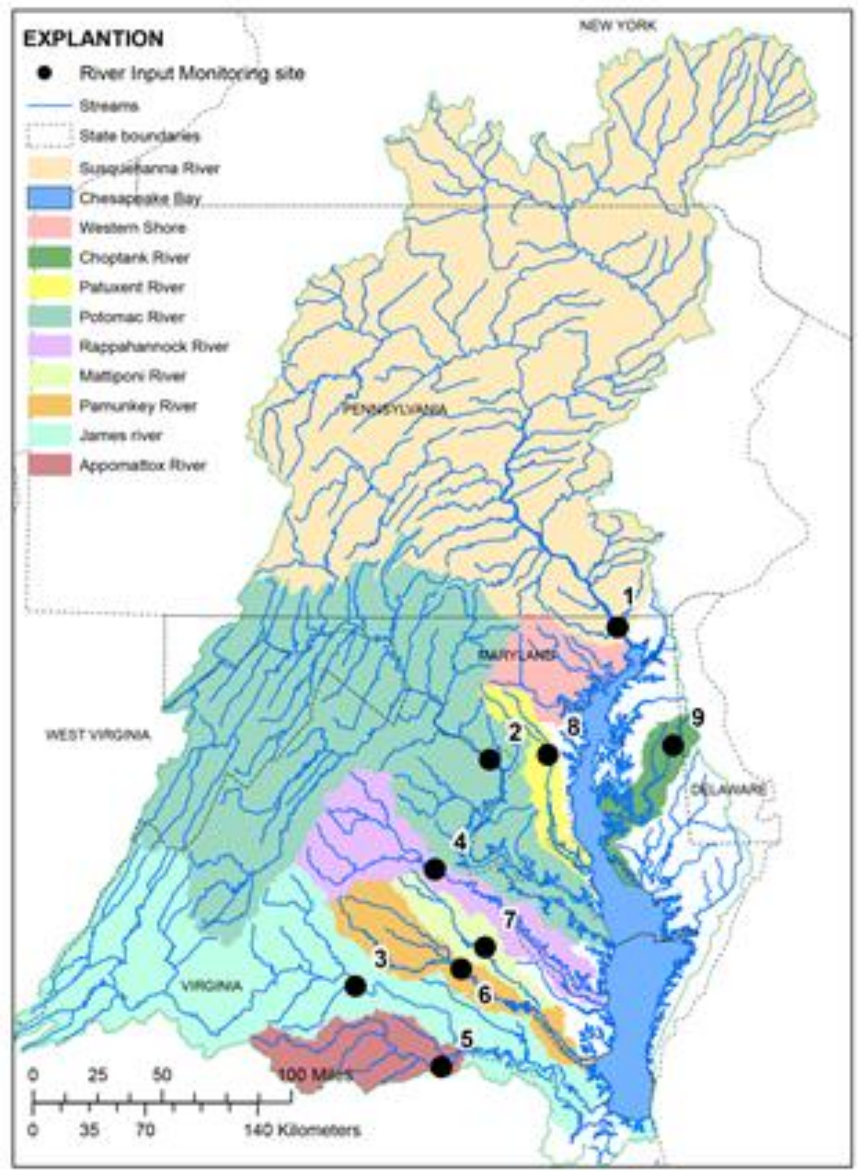

Figure 1. Map showing the location of the 9 River Input Monitoring (RIM) stations in the Chesapeake Bay watershed.

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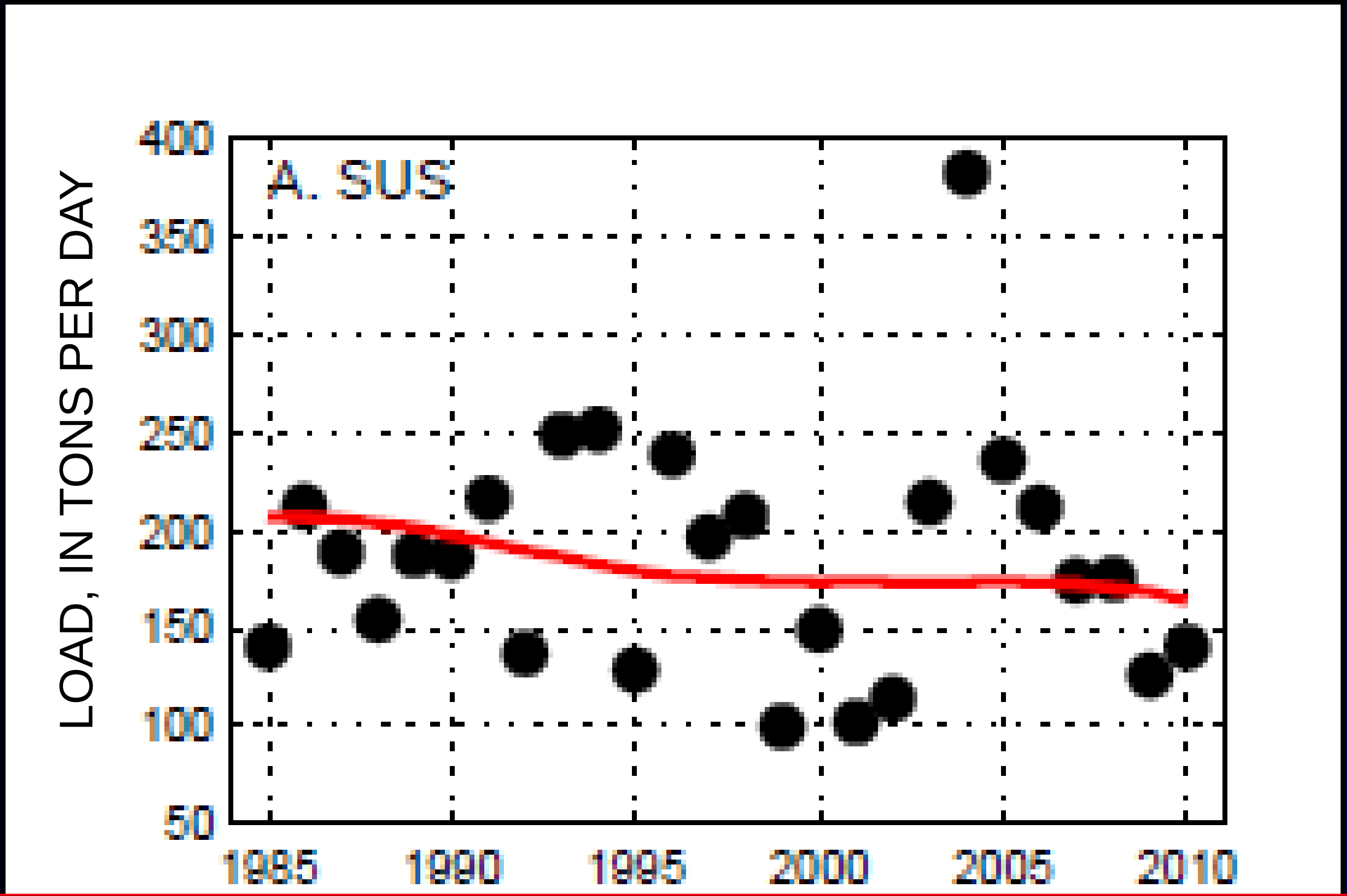
Trends in Total Nitrogen Annual Load

Total Nitrogen Load: Susquehanna (RIM)

- Influence of year-to-year variation in flow

With WRTDS, we now can communicate how annual loads have changed once the year-to-year variation in Q has been removed



Trend in load for:
1985 to 2010 = Total reduction of 21% at a rate of -0.8% per year
2001 to 2010 = Total reduction of 6% at a rate of -0.6% per year

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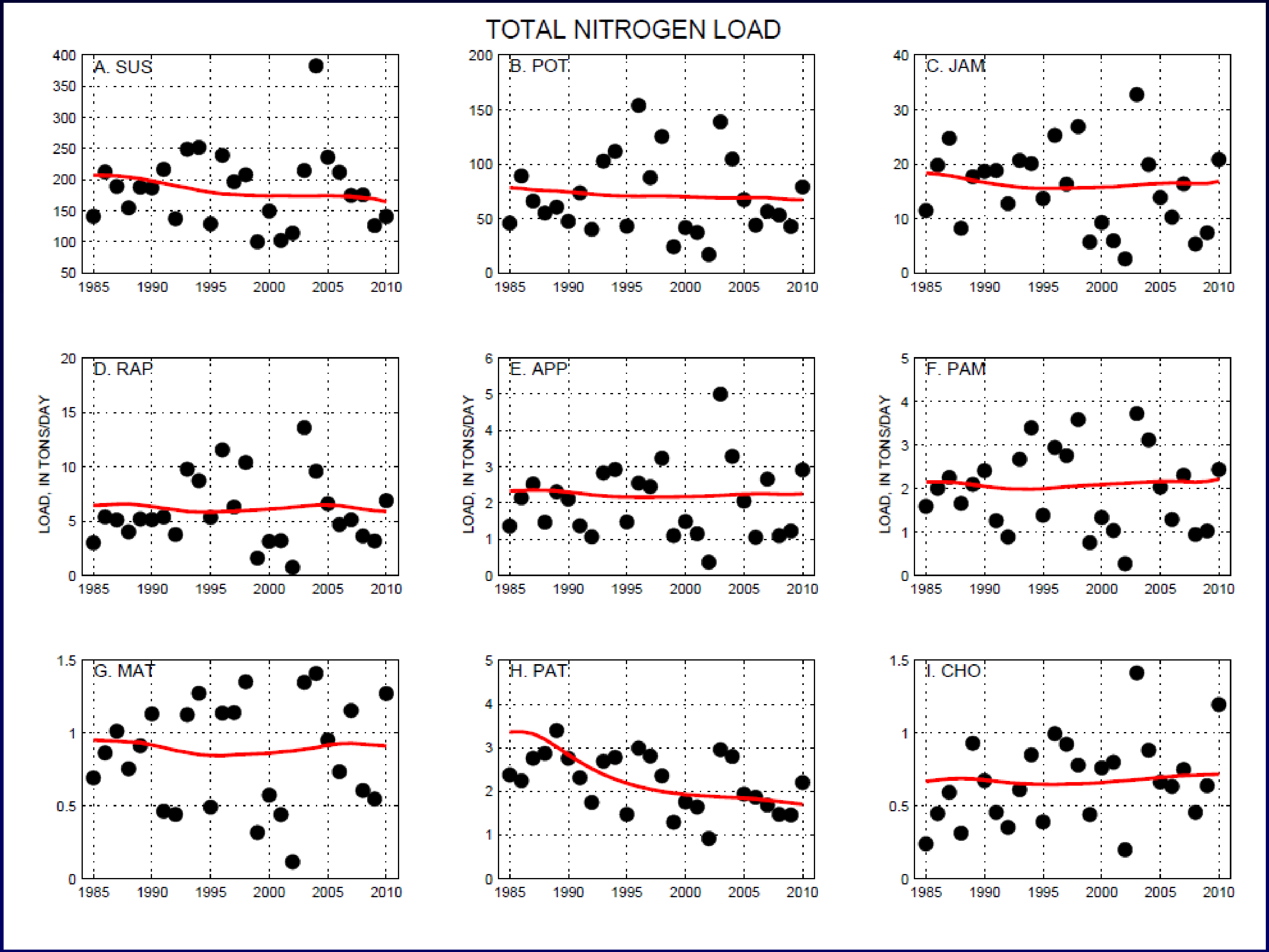
Black Dots = Annual Load Red Line = Flow Normalized Load

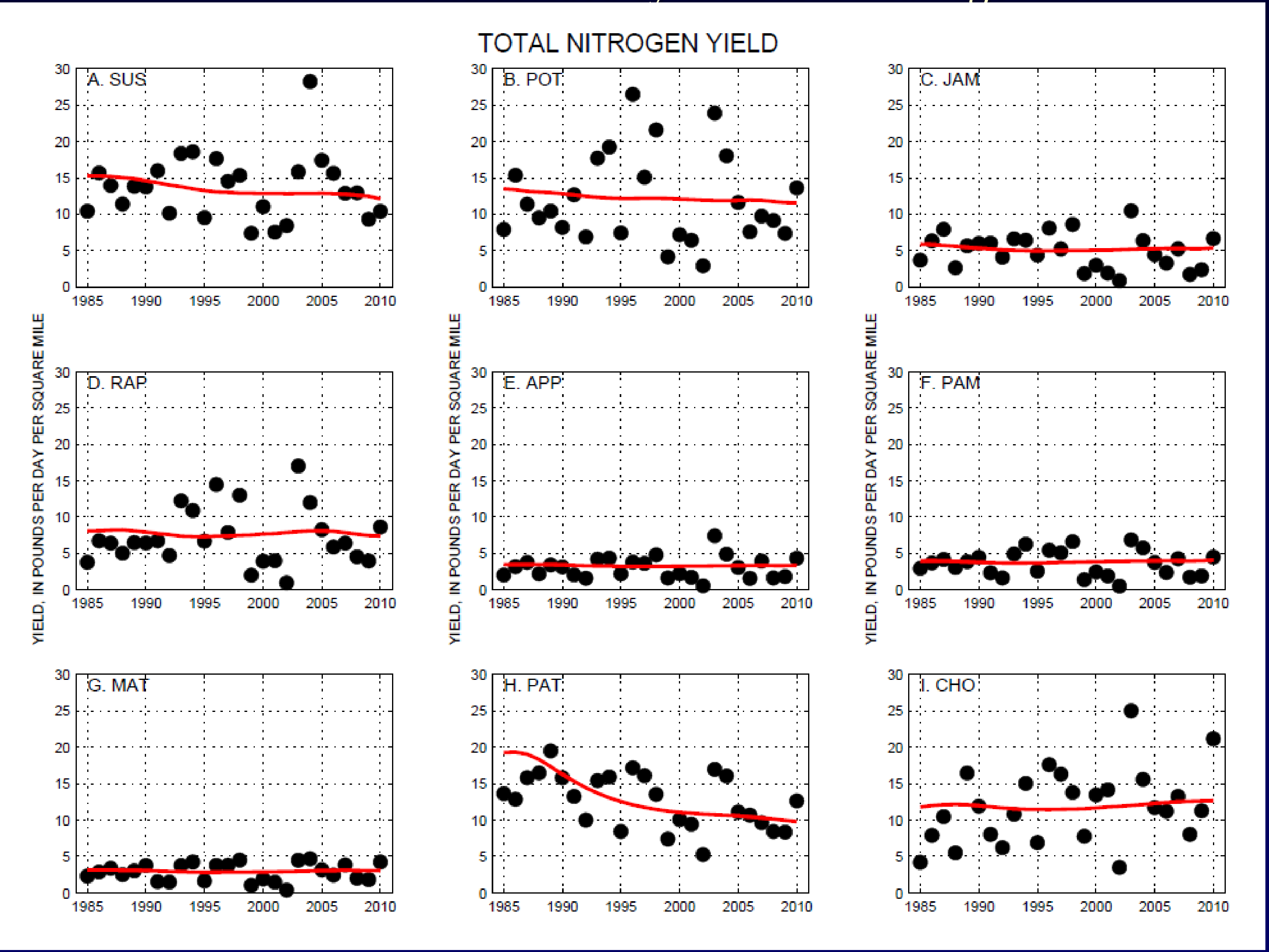
Trends in Total Nitrogen Load



Black Dots = Annual Load Red Line = Flow Normalized Load

Trends in Total Nitrogen Yield

Yield = Load divided by the Basin Drainage Area



Black Dots = Annual Yield   Red Line = Flow Normalized Yield

Trends in Total Nitrogen Load

Station	Long-Term Trend (1985-2010)	Short-Term Trend (2001-2010)
Susquehanna	Improving	Improving
Potomac	Improving	Improving
James	Improving	Degrading
Rappahannock	Improving	Improving
Appomattox	Improving	Degrading
Pamunkey	Degrading	Degrading
Mattaponi	Improving	Degrading
Patuxent	Improving	Improving
Choptank	Degrading	Degrading

Light shaded boxes = total change less than or equal to |10%|

Dark shaded boxes = total change greater than |10%|

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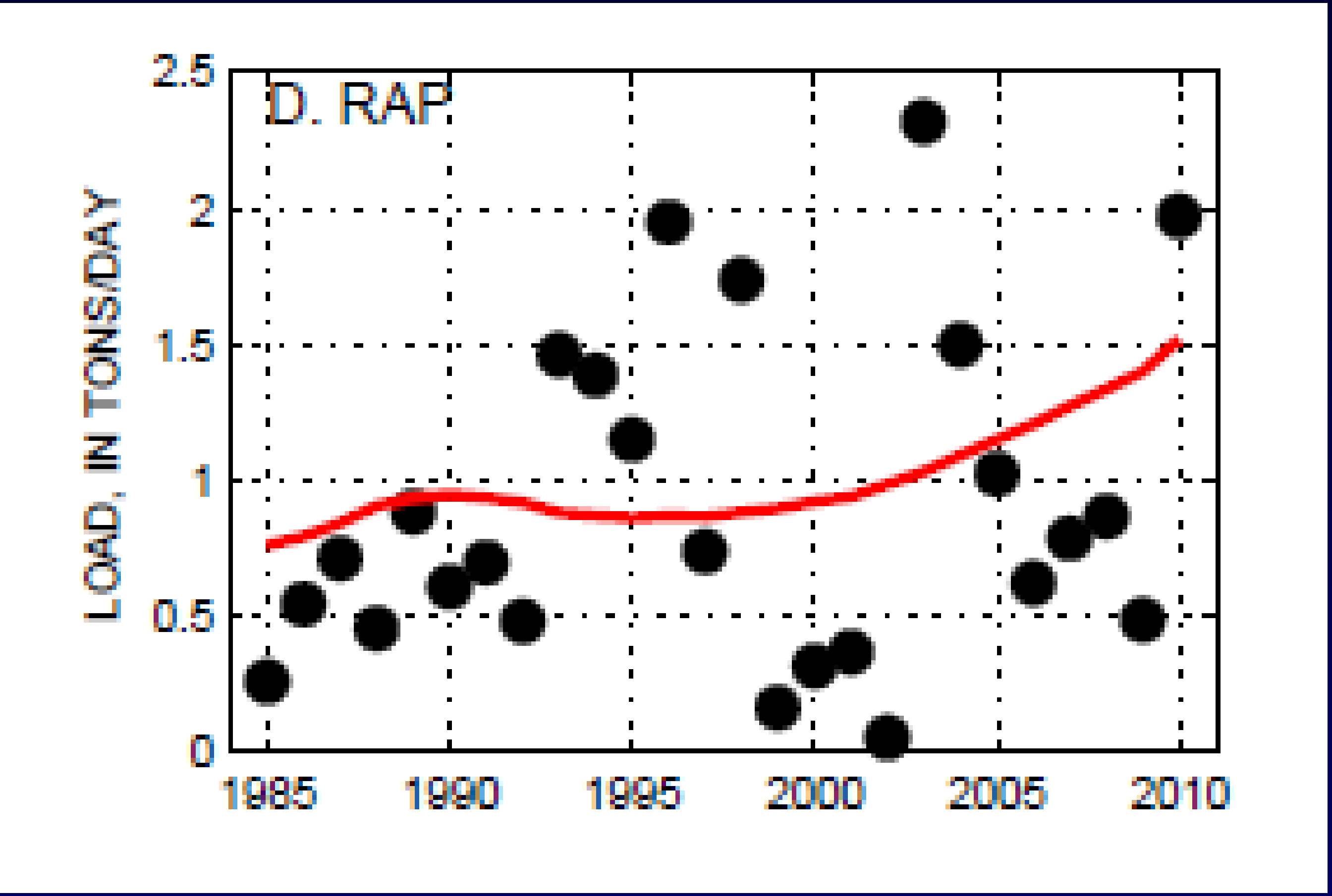
Trends in Annual Phosphorus Load

Total Phosphorus Load: Rappahannock (RIM)

- Influence of year-to-year variation in flow



Trend in load for:
1985 to 2010 = Total increase of 99% at a rate of 3.8% per year
2001 to 2010 = Total increase of 62% at a rate of 6.2% per year

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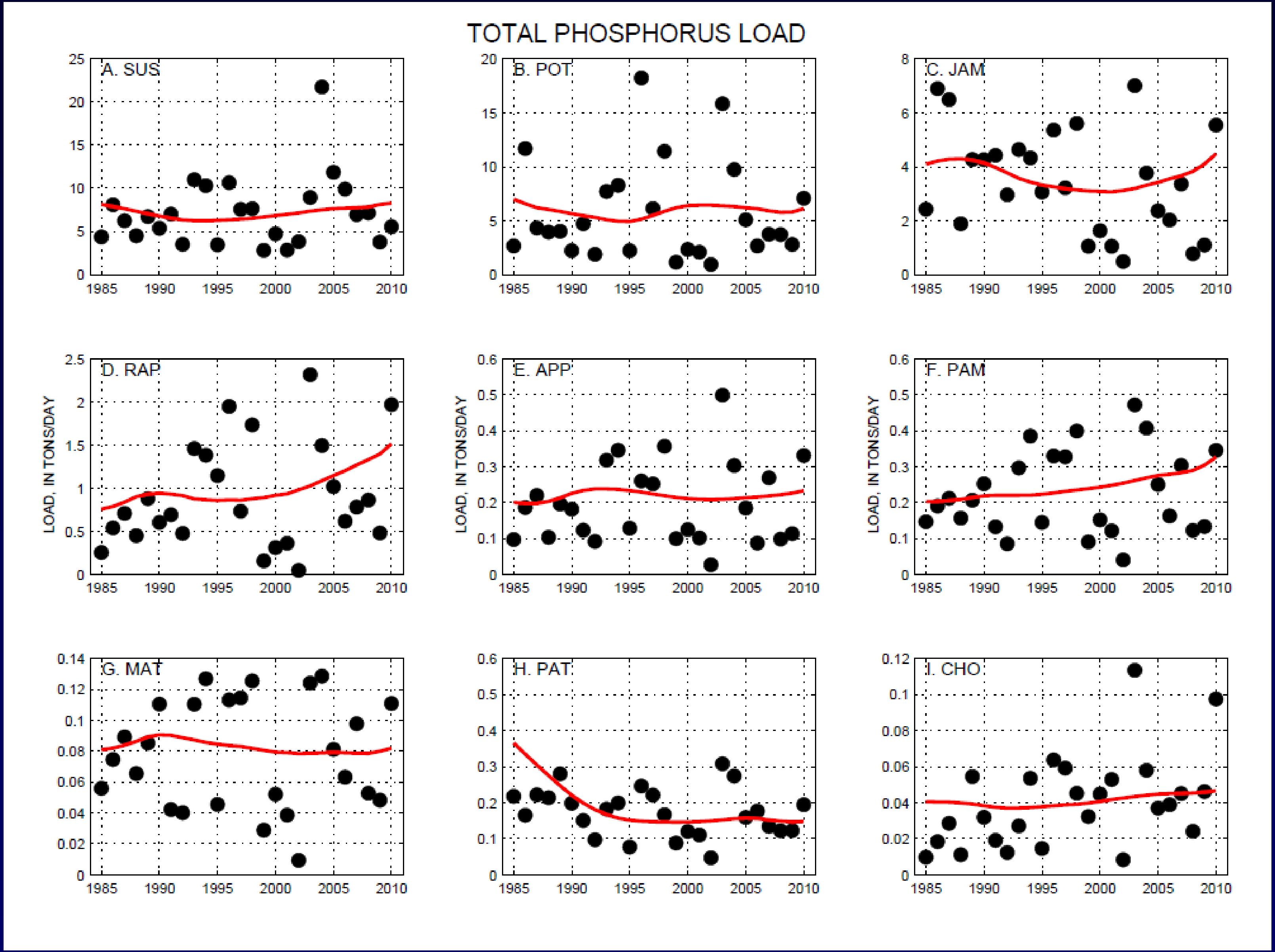
Black Circles = Annual Load Red Line = Flow Normalized Load

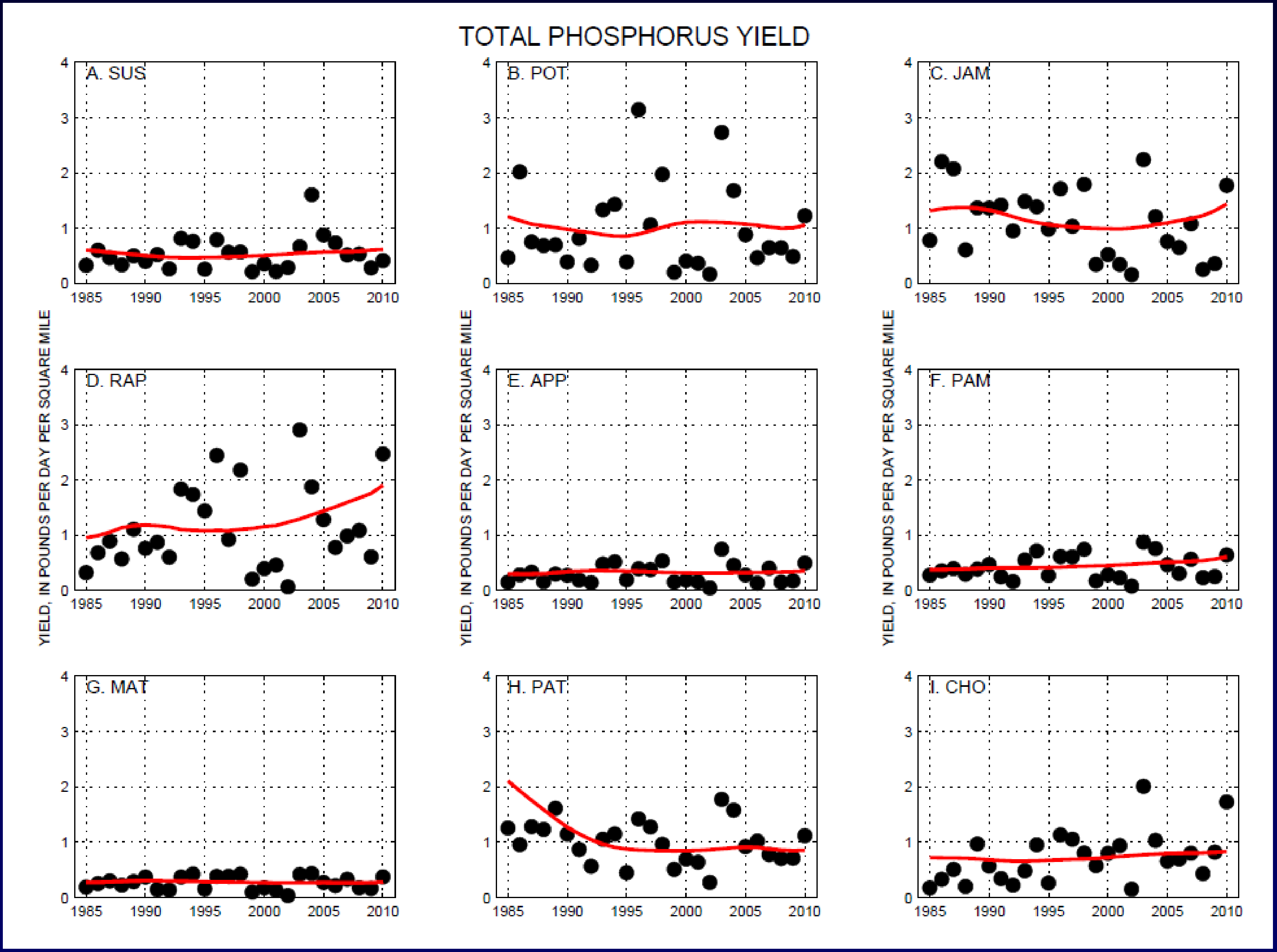
Trends in Total Phosphorus Load



Black Dots = Annual Load   Red Line = Flow Normalized Load

Trends in Total Phosphorus Yield

Yield = Load divided by the Basin Drainage Area



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Black Dots = Annual Yield Red Line = Flow Normalized Yield

Trends in Total Phosphorus Load

Station	Long-Term Trend (1985-2010)	Short-Term Trend (2001-2010)
Susquehanna	Degrading	Degrading
Potomac	Improving	Improving
James	Degrading	Degrading
Rappahannock	Degrading	Degrading
Appomattox	Degrading	Degrading
Pamunkey	Degrading	Degrading
Mattaponi	Degrading	Degrading
Patuxent	Improving	No Trend
Choptank	Degrading	Degrading

Light shaded boxes = total change less than or equal to |10%|

Dark shaded boxes = total change greater than |10%|

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Trends in Suspended Sediment Load

Station	Long-Term Trend (1985-2010)	Short-Term Trend (2001-2010)
Susquehanna	Degrading	Degrading
Potomac	Degrading	Degrading
James	Not Available	Degrading
Rappahannock	Not Available	Degrading
Appomattox	Not Available	Degrading
Pamunkey	Not Available	Degrading
Mattaponi	Not Available	Improving
Patuxent	Improving	Degrading
Choptank	Improving	Degrading

Light shaded boxes = total change less than or equal to |10%|

Dark shaded boxes = total change greater than |10%|

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Interpreting Trend in Load Results

How do these “new” trend in loads compare to the “historical” trend in concentrations?

What does it mean when the trend in load and the trend in concentration are in different directions?

Trend in Concentration vs. Trend in Load: All 9 Chesapeake Bay RIM Stations

TIME PERIOD	TRENDS IN SAME DIRECTION	TRENDS IN OPPOSITE DIRECTIONS	RIM Stations
TOTAL NITROGEN			
1985 to 2010	9	0	
2001 to 2010	9	0	
TOTAL PHOSPHORUS			
1985 to 2010	7	2	JAM/MAT
2001 to 2010	6	3	JAM/PAM/PAT
SUSPENDED SEDIMENT			
1985 to 2010	2	2	SUS/POT
2001 to 2010	9	0	

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Trend in Concentration vs. Trend in Load

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Trends Agree

Example where trend in concentration and trend in load are in the same direction (Susquehanna Nitrate)

Categorize water-quality observations based on 3 discharge conditions:

- High
- Intermediate
- Low

ESTIMATOR trend in concentration indicates improving conditions (total reduction of approx. 16%)

WRTDS trend in load indicates improving conditions (total reduction of approx. 16%)

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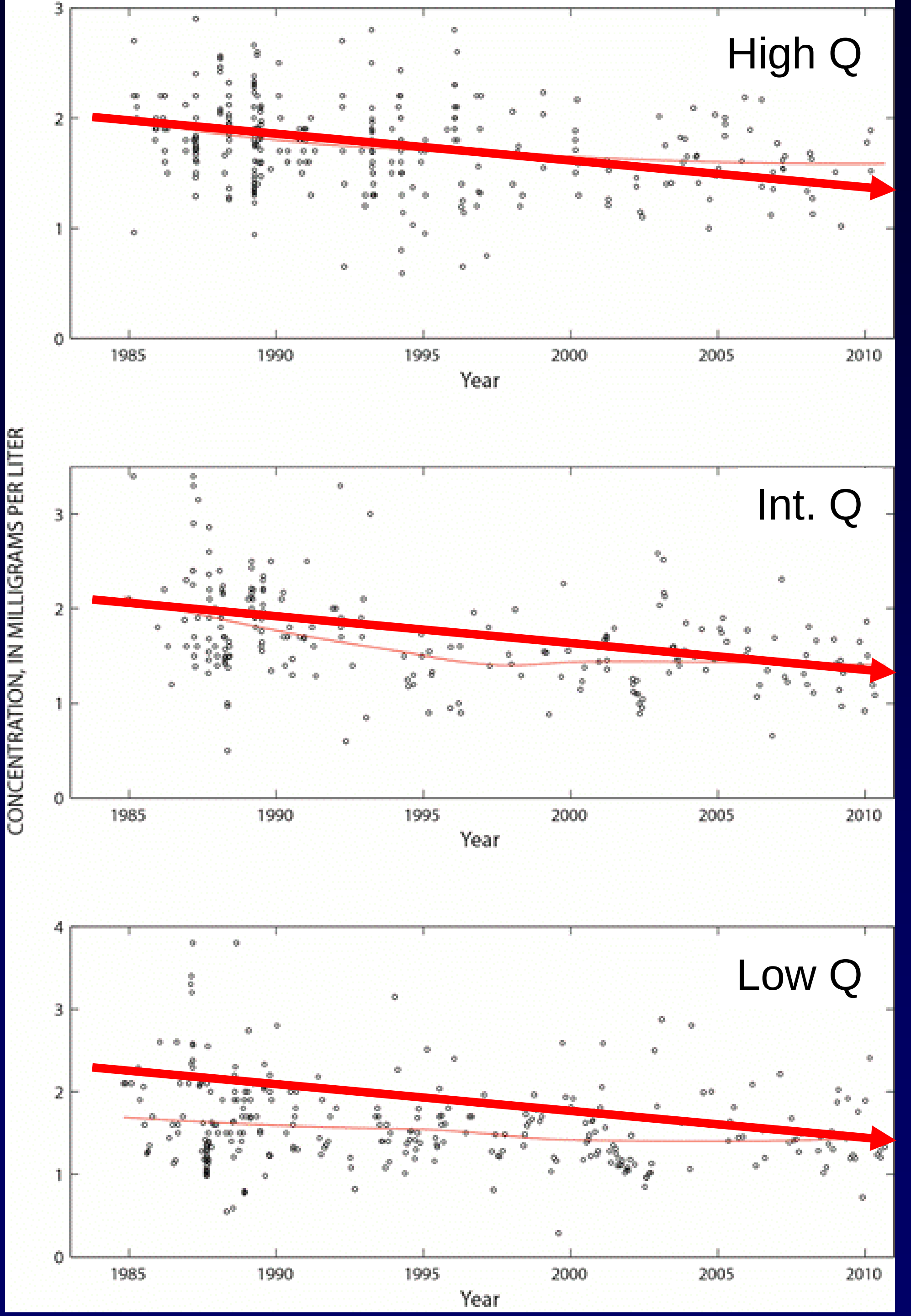
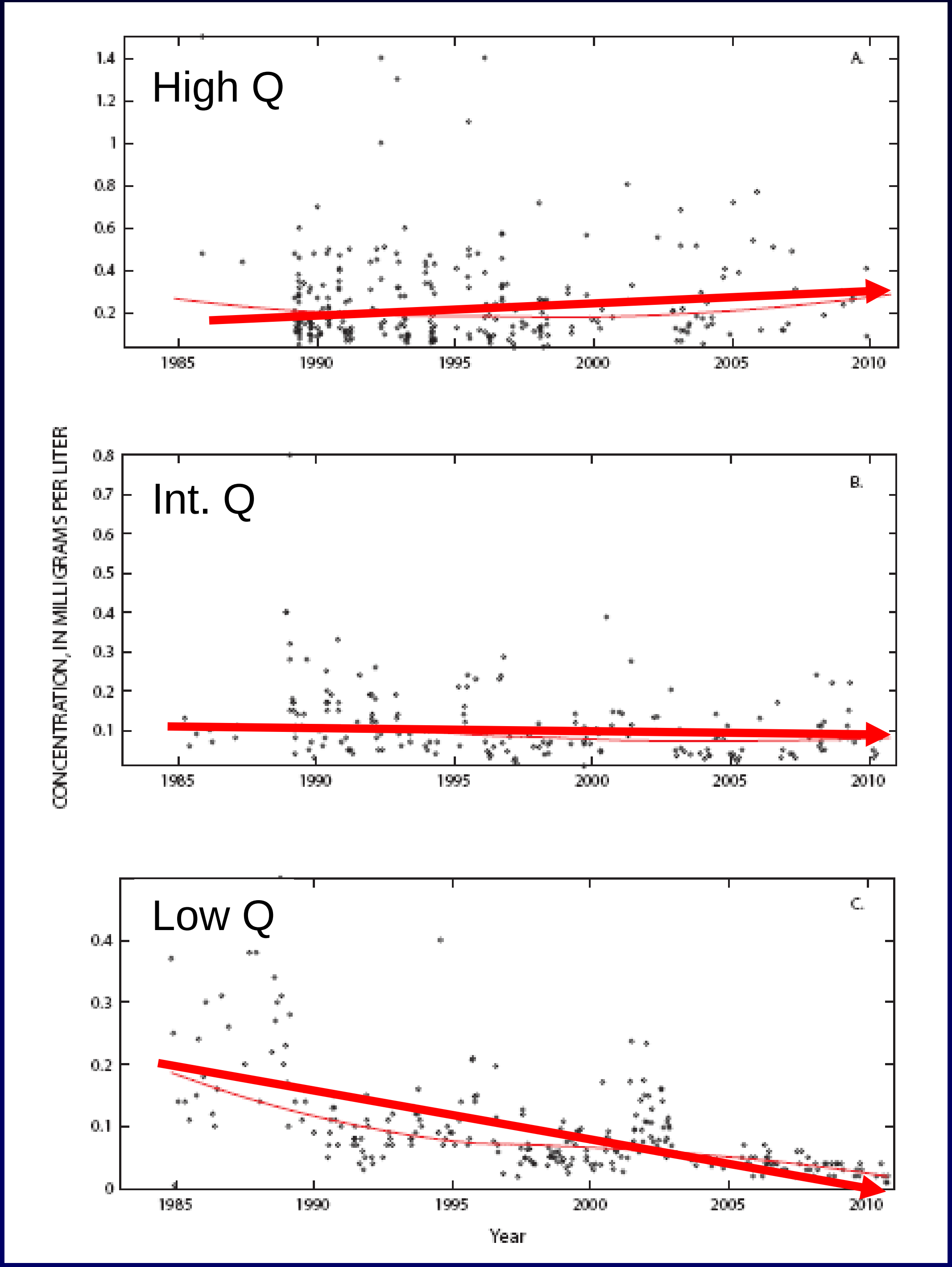


Trends Disagree

Example where trend in concentration and trend in load are in opposite direction (James River Total Phosphorus)

ESTIMATOR trend in concentration indicates improving conditions (total reduction of approx. 60%)

WRTDS trend in load indicates degrading conditions (total increase of 10%)



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Conclusions

- The USGS has a new method for quantifying trends in nutrient and sediment loads.
- The new trend in load information:
  - Improves the relevancy of the information we provide to our local, state, and federal partners
  - Enhances the existing information for trend in concentration
- Trend in load and trend in concentration together provide a more complete understanding of how changes in watershed characteristics (e.g. land use) and the implementation of BMPs influence resulting water-quality conditions.

Publication

Draft report has been reviewed, approved, and is currently being prepared for printing and dissemination.

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Report Series XXXX–XXXX

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

Communication

- Present trend in load results to cooperators and concerned partners (VA, MD, NY, PA, WV, COG, EPA, NRCS)
- Report release Mid-December
- USGS Science Summary of trend results
- Other Ideas?

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Next Steps

- Compare WRTDS load and flow normalized results from the 9 RIM stations to CB Watershed Model results. Link WRTDS results to CBP nutrient and sediment goals (2012-2013)

- Apply WRTDS methodology to other long-term stations in the watershed (e.g. Potomac and Susquehanna)

- Work with CBP to better integrate nontidal nutrient and sediment load and trend results into the current tidal-waters assessment methodology

Questions and Discussion

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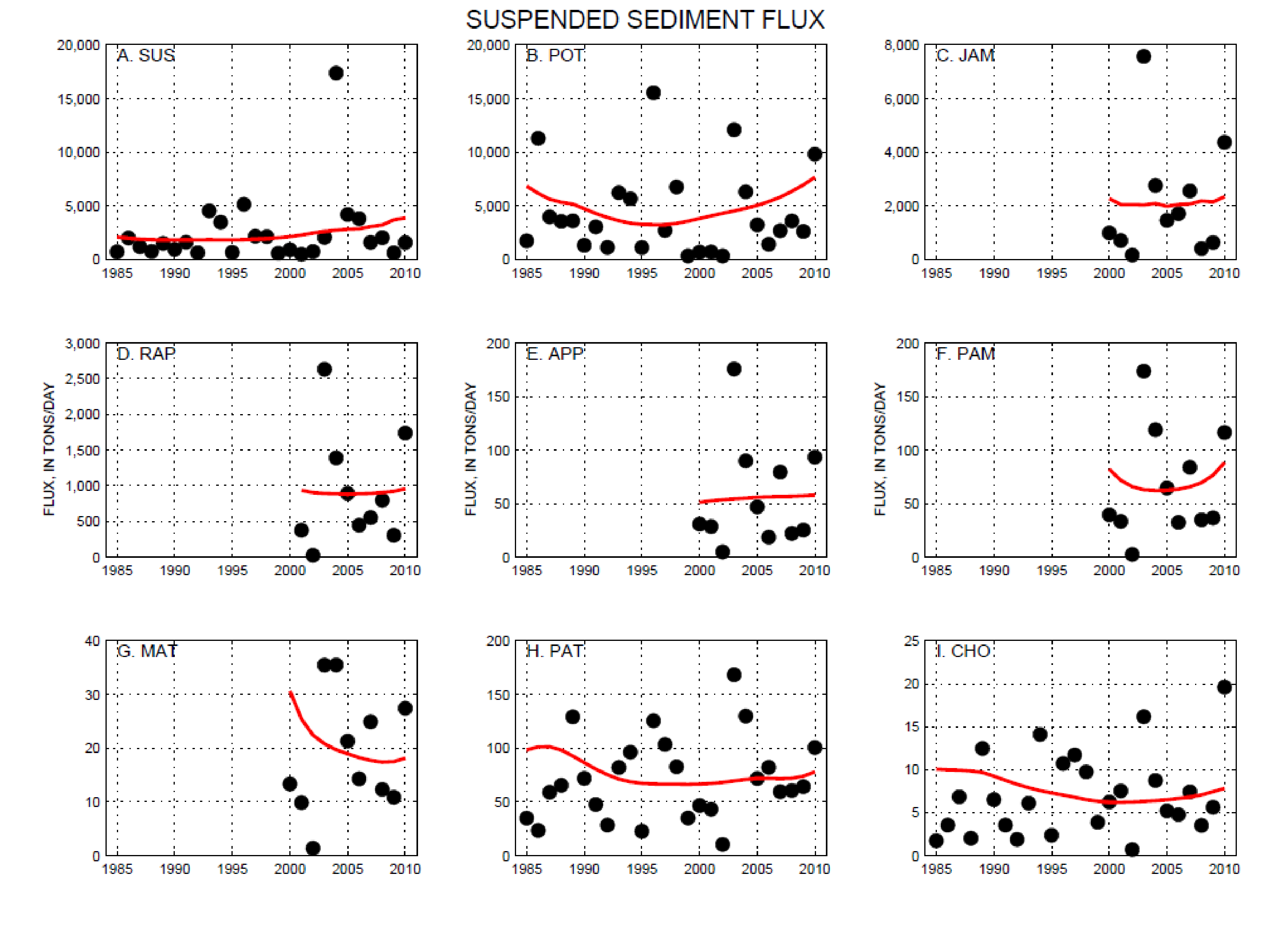
Trends in Suspended Sediment Load



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