Effects of Reservoir Filling on Sediment and Nutrient Removal in the Lower Susquehanna River Reservoir System: An Input-Output Analysis based on Long-Term Monitoring

Photo of Conowingo Dam from www.chesapeakeboating.net

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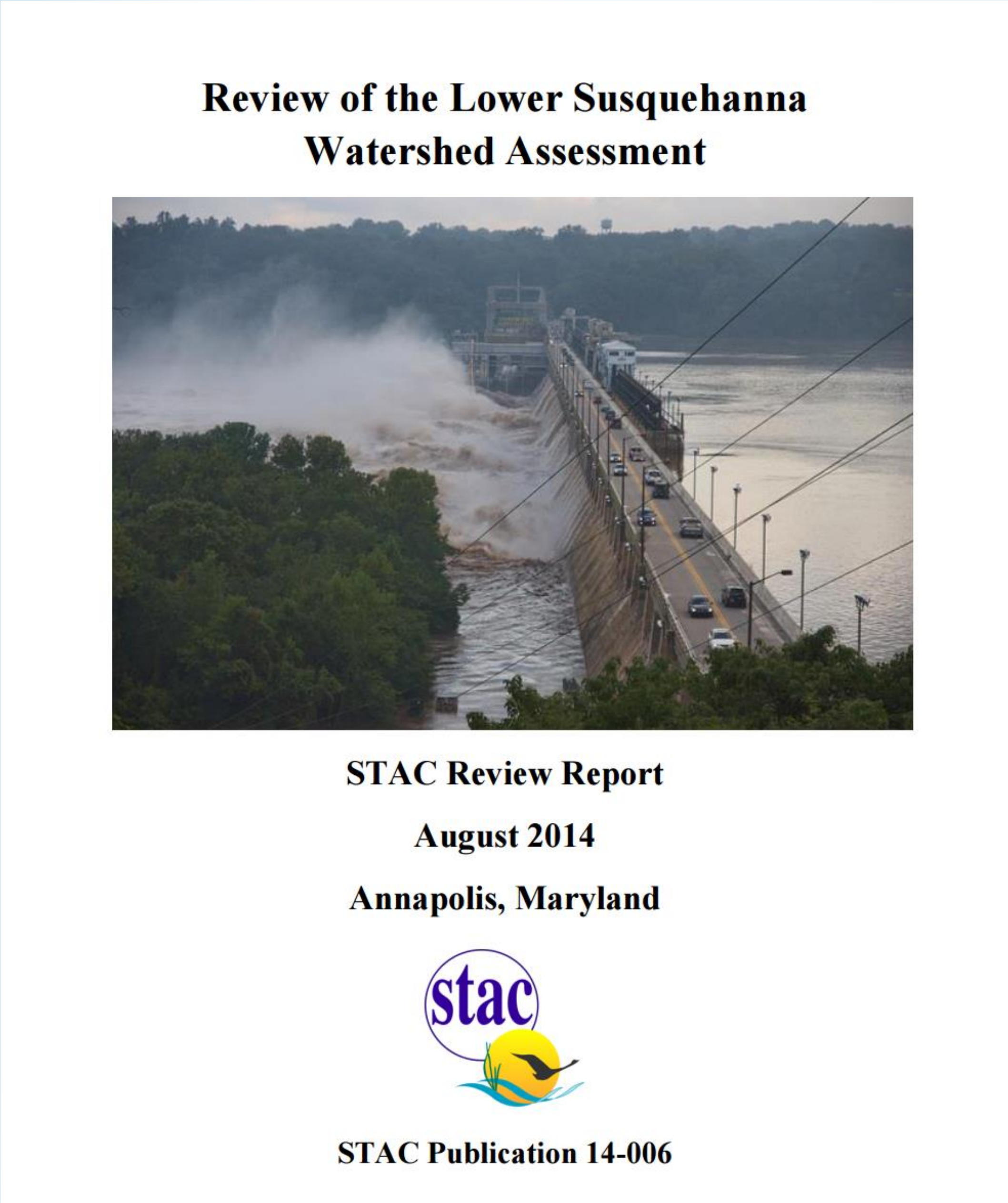
STAC Workshop, January 13, 2016

Background



Review of the Lower Susquehanna Watershed Assessment

STAC Review Report

August 2014

Annapolis, Maryland

stac

STAC Publication 14-006

STAC Review Report on LSRWA (No. 14-006)

Section "Reduced deposition associated with reservoir infilling has been neglected"

"Net trapping efficiency is the sum of increases in average annual scour and decreases in average annual deposition. However, the simulations and calculations in the study only considered the increase in scour … Without having the model simulate the full range of changes due to the loss of trapping efficiency, the report's authors have introduced a large uncertainty into the results … This issue underlies a significant weakness in the report, which is that ***it focuses its inquiry on the impact of large, but infrequent, scour events rather on the total impact of the change in trapping efficiency of the reservoir system****."*

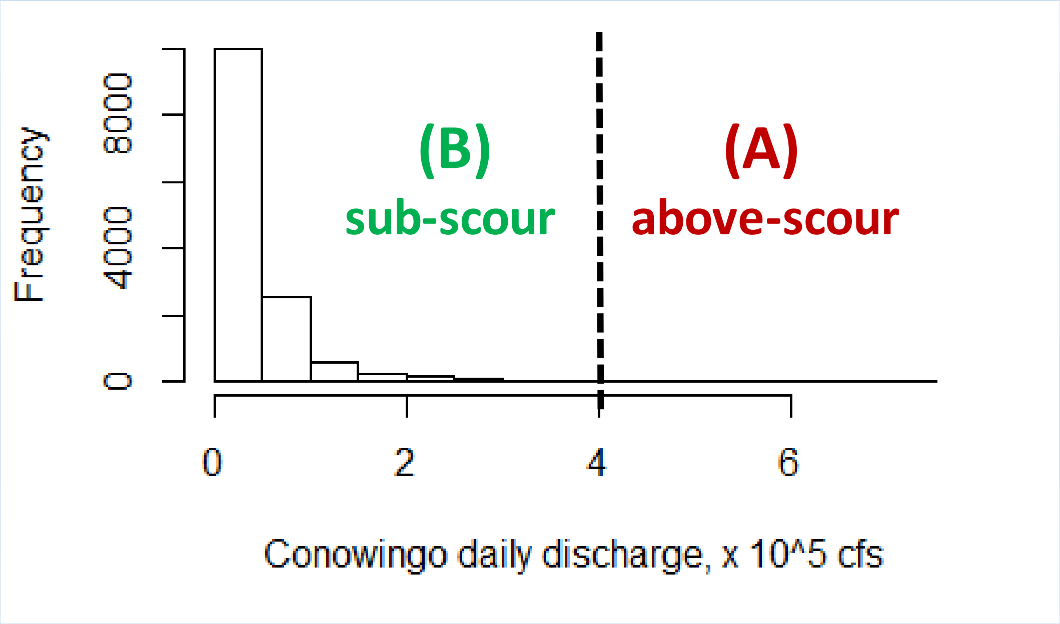
Background

- Need to quantify the broad changes in the reservoir performance based on available data.

- Need to explore the ***relative importance*** of:

  (A) ***Infrequent events at very high flows*** *(> 400,000 cfs or ~11,000 m^3/s) vs.*

  (B) ***Frequent events at moderate and high flows*** *(sub-scour levels).*



Objectives

To provide new insights on sediment and nutrient processing within the reservoir system in the monitored period of 1986-2013 (~30 years)

1
- Identify temporal change in system function: *C vs. Q*
  Graphical analysis of "raw" *C*, *Q* data to obtain *C*, *Q* relationships

2
- Evaluate trends in particulate loadings above and below the reservoir
  WRTDS analysis of *C*, *Q* data to obtain "flow-normalized" trends

3
- Conduct input-output analyses across the reservoir (net deposition) *
  WRTDS analysis of *C*, *Q* data to obtain "true-condition" estimates

4
- Isolate effects of the temporally-varying regression surface: $C(Q, t_{season})$
  Application of "stationary" *C(Q, t) surfaces* to the same long-term *Q* data

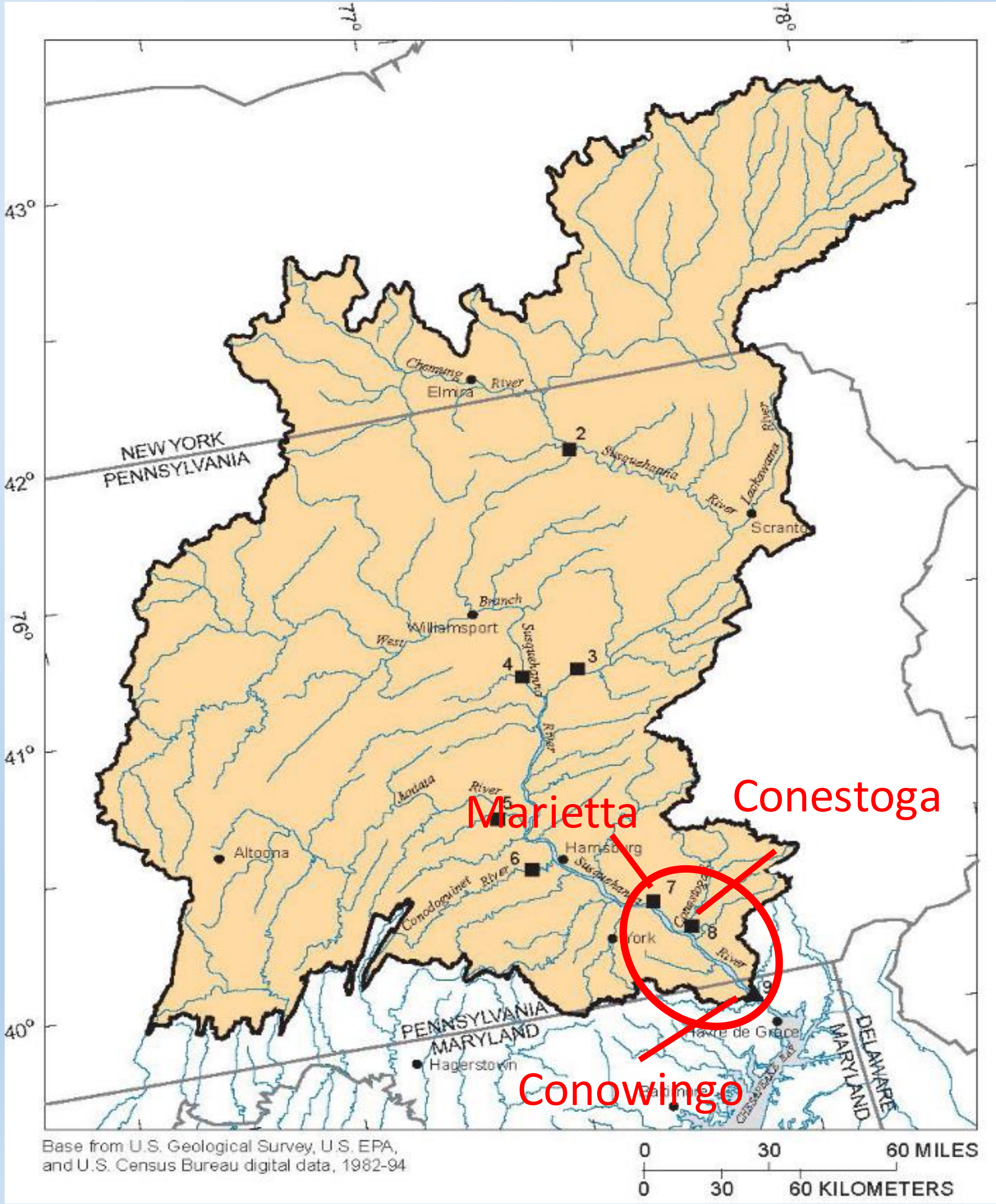
Study sites and data

Monitoring sites:

- Above reservoir:
  Marietta + Conestoga
  (~97% of SRB drainage area)
- Below reservoir:
  Conowingo
  (99% of SRB drainage area)

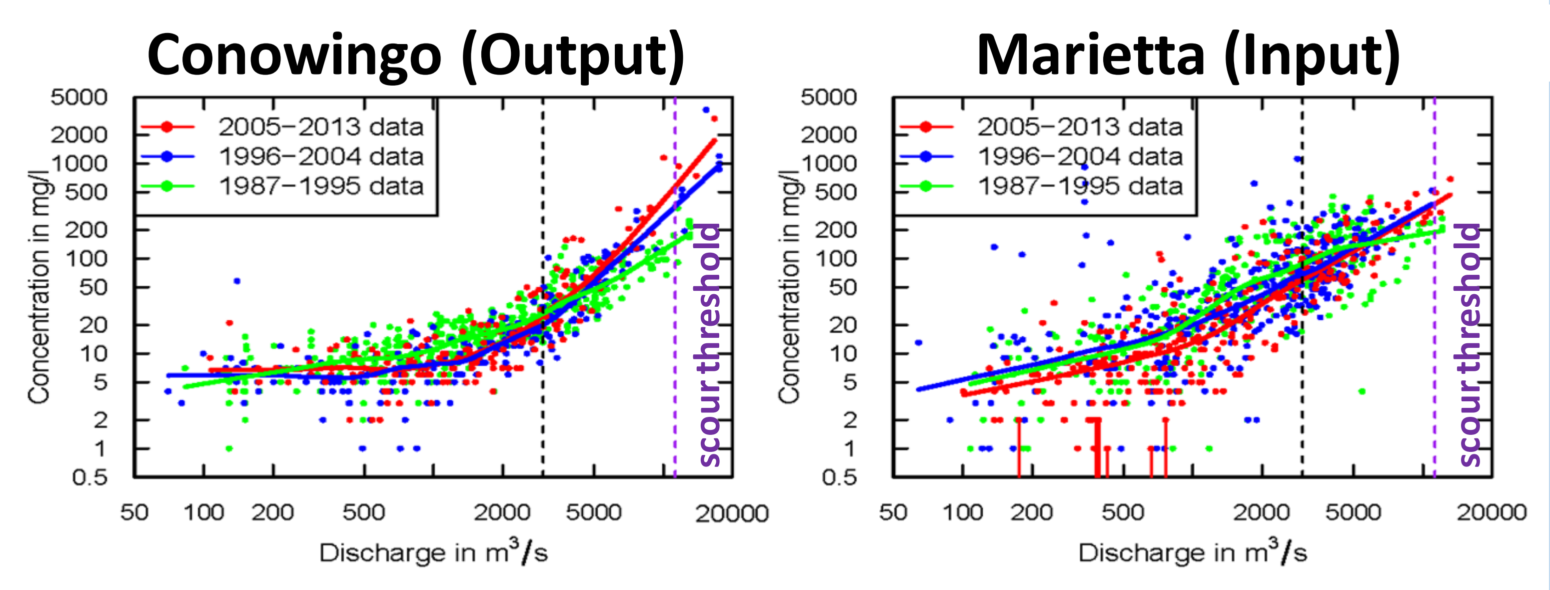
Available Data (all sites):

- Daily discharge data;
- **SS**, **P**, and **N** data (25-40 sampled days per year)



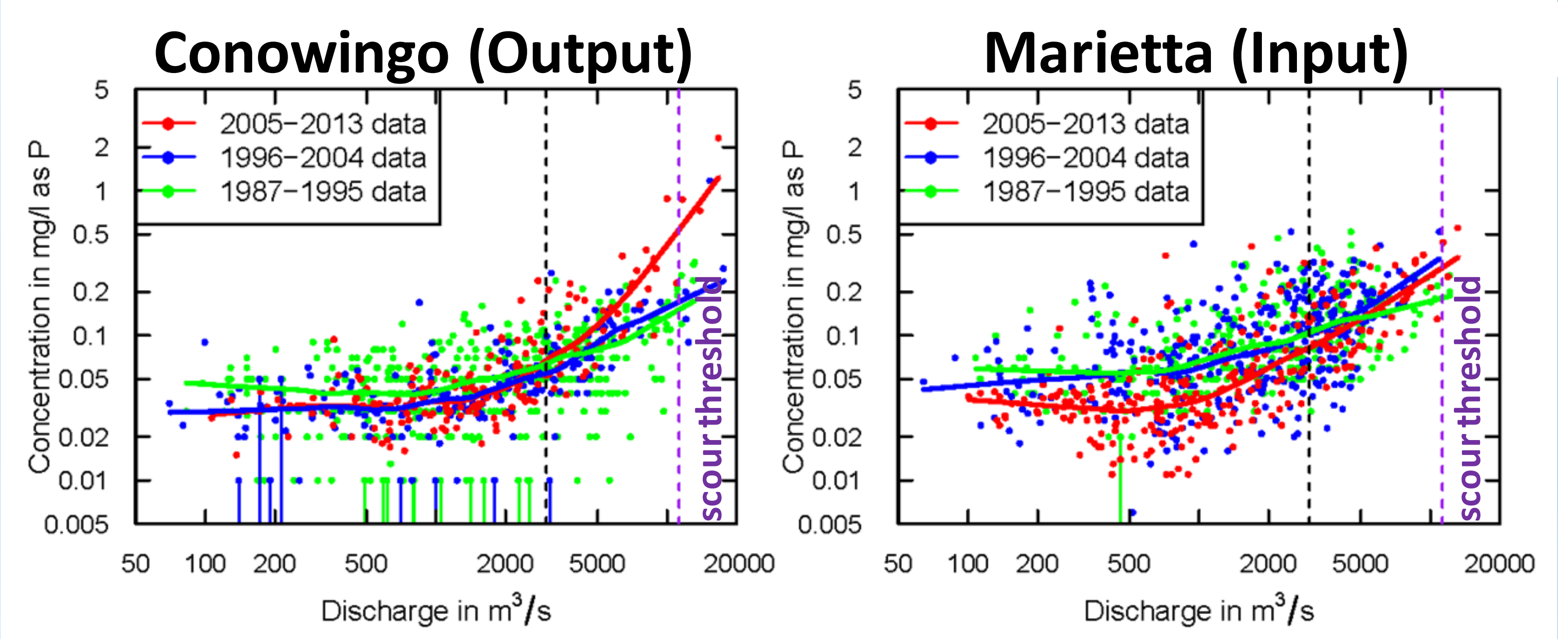
1. Temporal changes in *C-Q* relationships above & below LSRRS

Suspended Sediment (SS)



* LOWESS curves fitted to C-Q data in periods of 1987-1995, 1996-2004, and 2005-2013

Total Phosphorus (TP)



2. Flow-normalized trends in particulate loadings above & below LSRRS

Marietta + Conestoga (26,460 mi²)

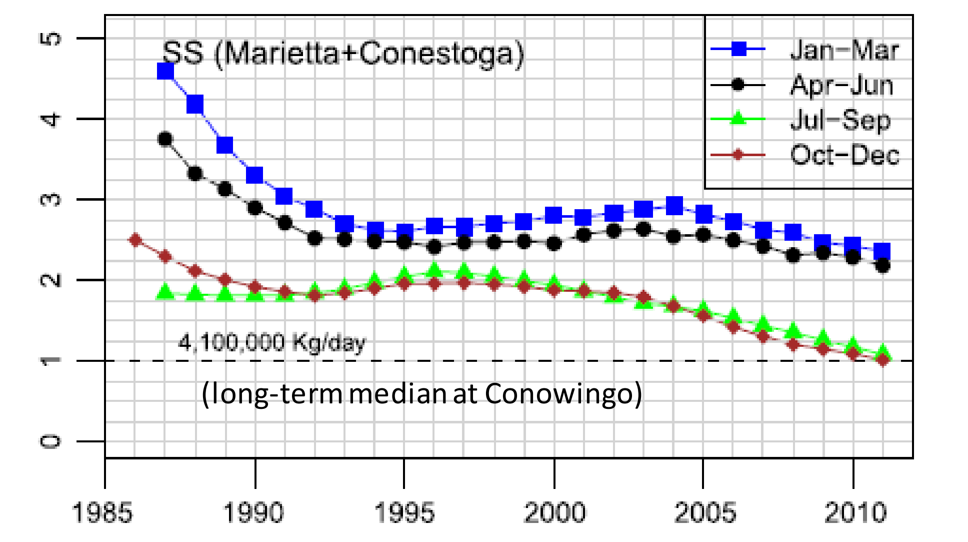
LSRRS

Conowingo (27,100 mi²)

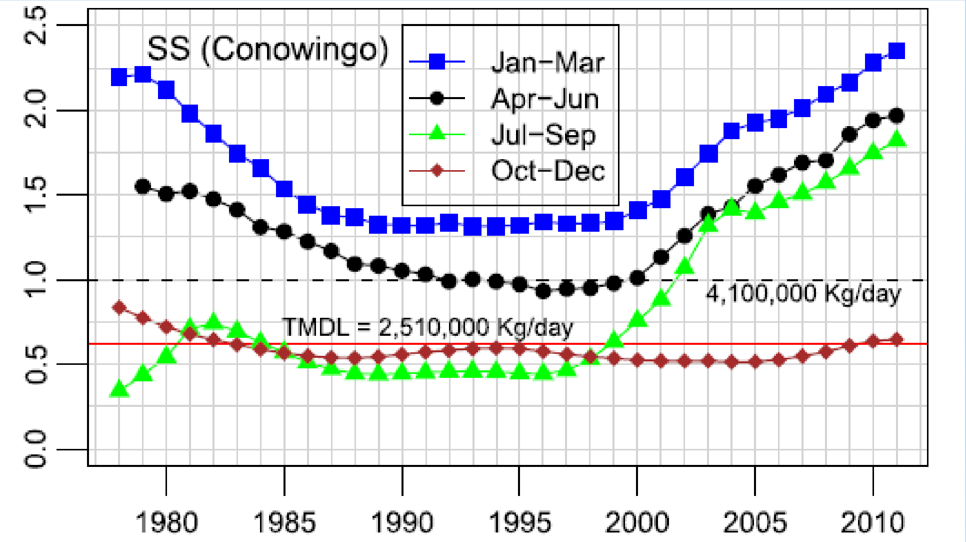
(Zhang *et al.*, *STOTEN*, 2013)

Suspended Sediment (SS) loadings

"Flow-Normalized" Estimates by Season of Year



Reservoir Input

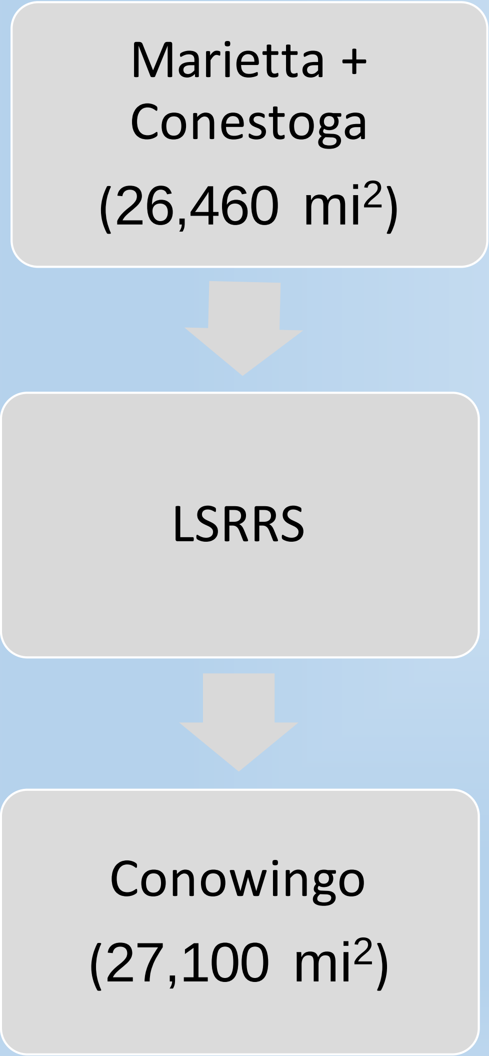


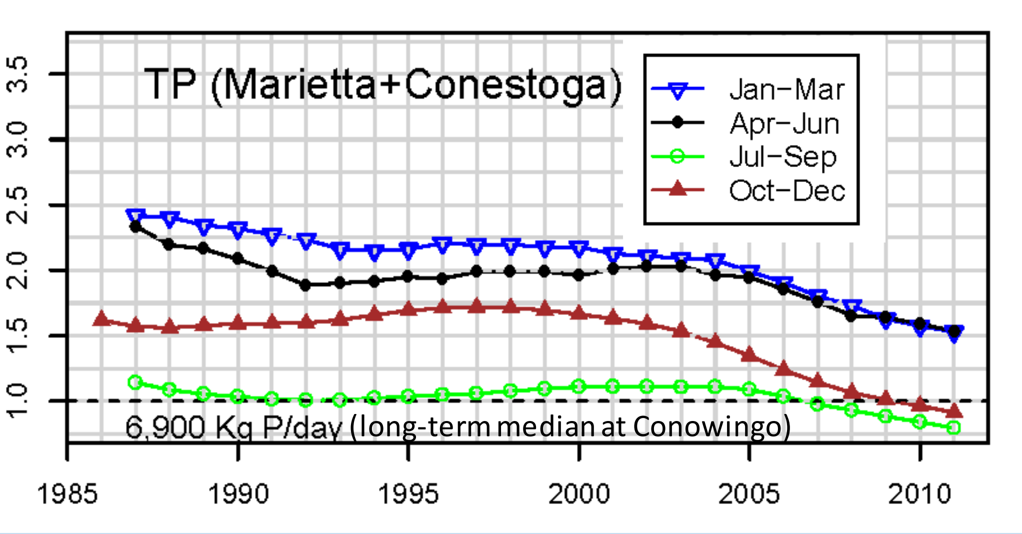
Reservoir Output

2. (cont'd) **Flow-normalized trends in particulate loadings above & below LSRRS**

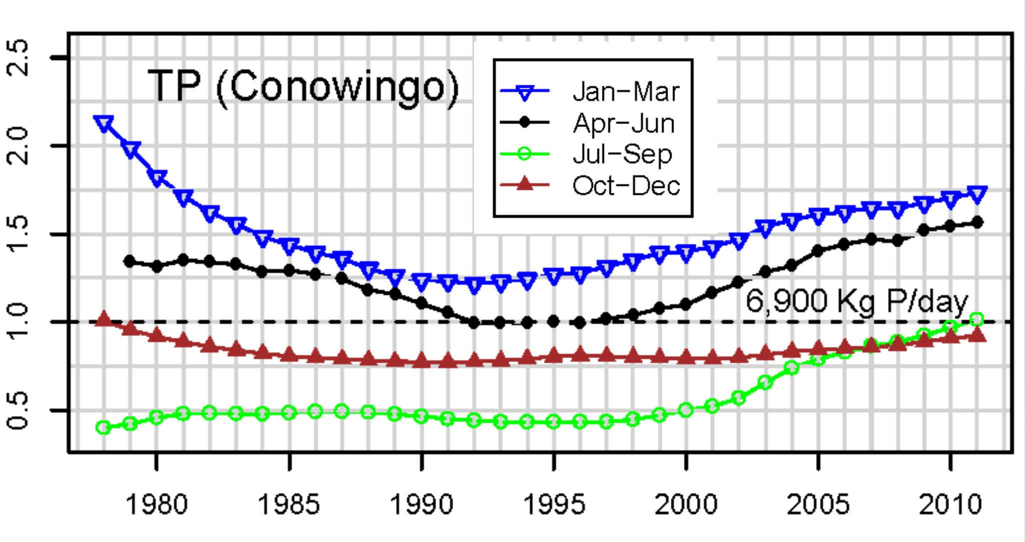
Total Phosphorus (TP) loadings

"Flow-Normalized" Estimates by Season of Year





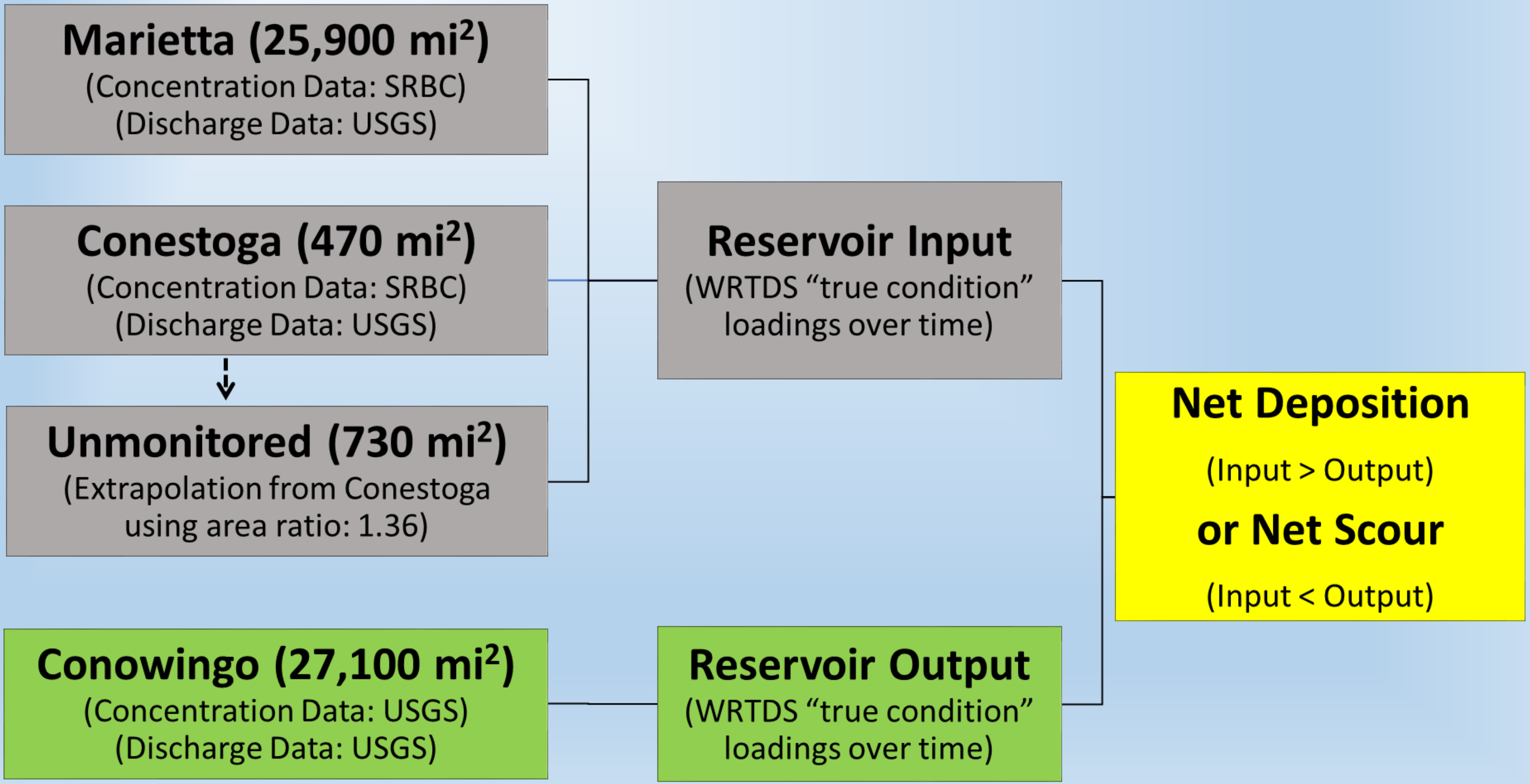
Reservoir Input



Reservoir Output

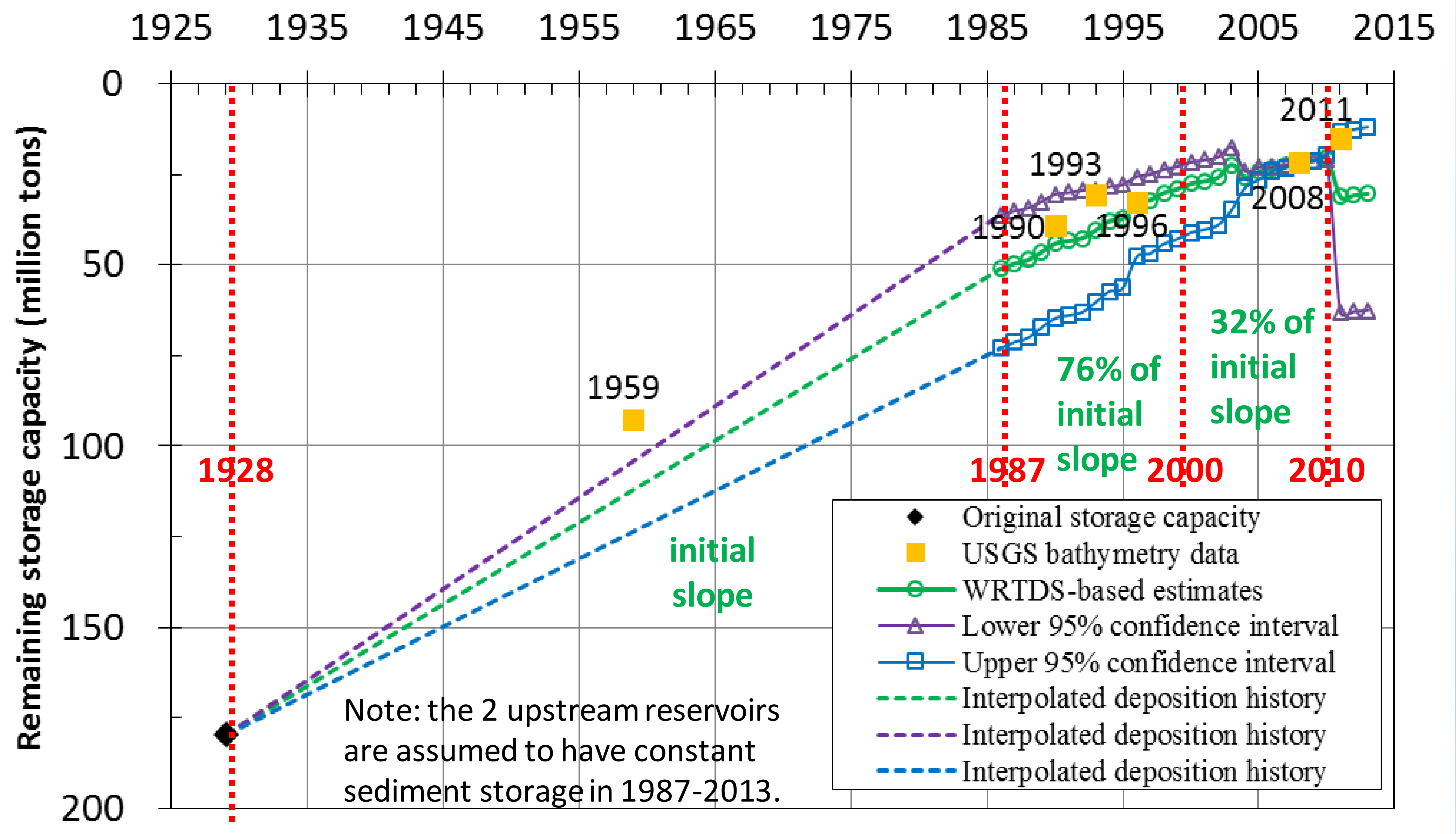
(Zhang *et al.*, *STOTEN*, 2013)

3. Input-output analyses: net deposition in the reservoirs over time

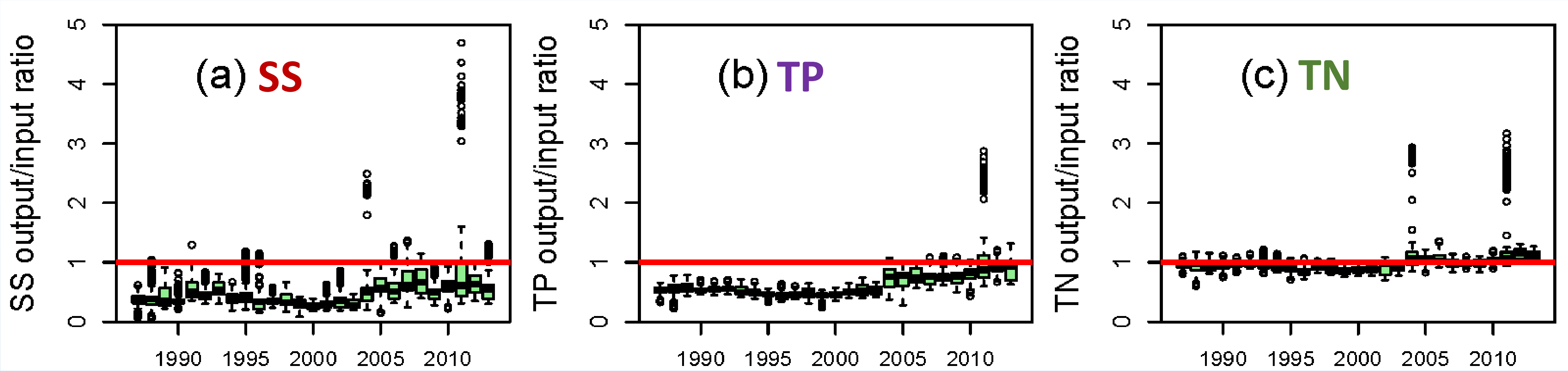


3. (cont'd) **Input-output analyses: cumulative sediment storage (1929-2013)**

Q: What is the broad trend in average net deposition rate?



3. (cont'd) Input-output analyses: output/input ratios (1987-2013)



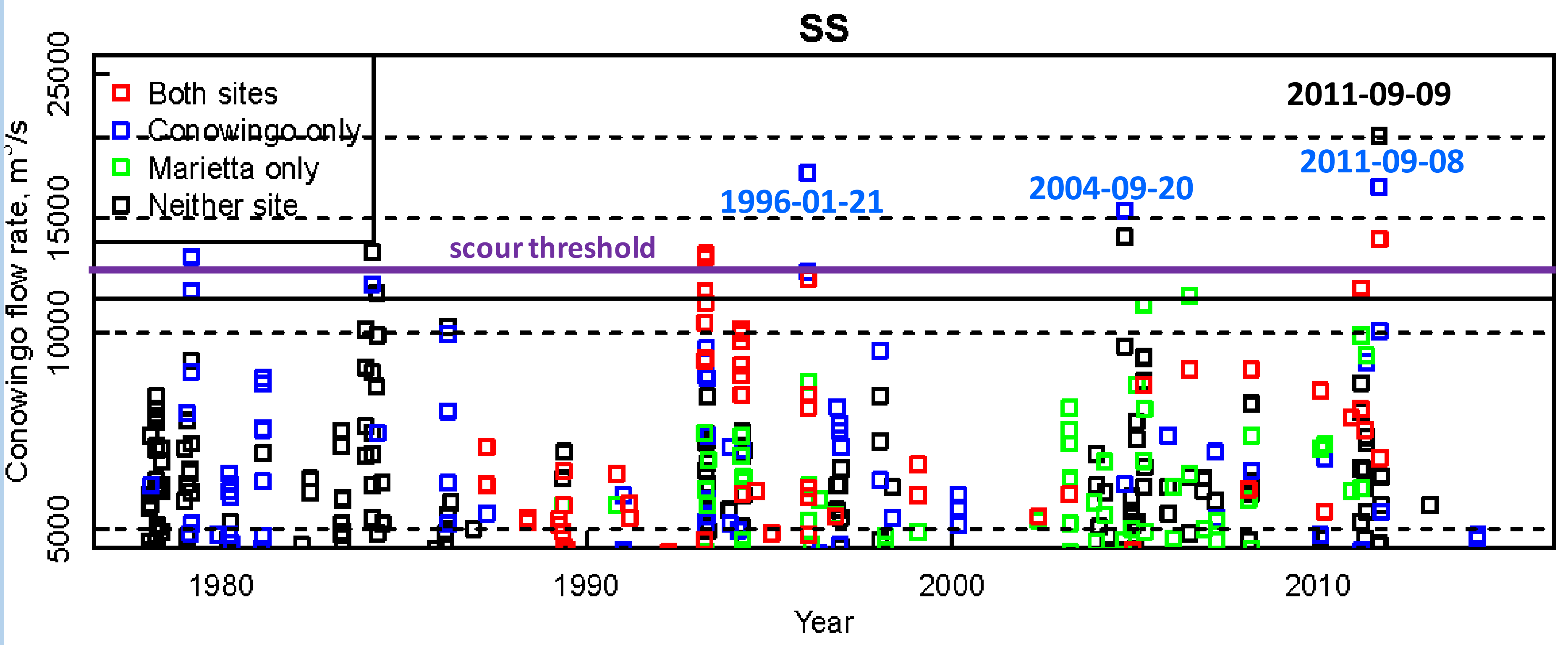
- Boxplots for daily O/I ratios for each year in 1987-2013.
- O/I ratio < 1 → net deposition.
- Travel time: we used 35-day moving averages of both input and output to calculate O/I ratios for mitigating effects of travel time across the reservoir system. (Results insensitive to selection of averaging time.)
- SS and TP O/I ratios have increased in recent years.

Notes:

- **TP** dominated by **PP**
- **TN** dominated by **DN**

3. (cont'd) **Input-output analyses: sensitivity to differential highflow sampling**

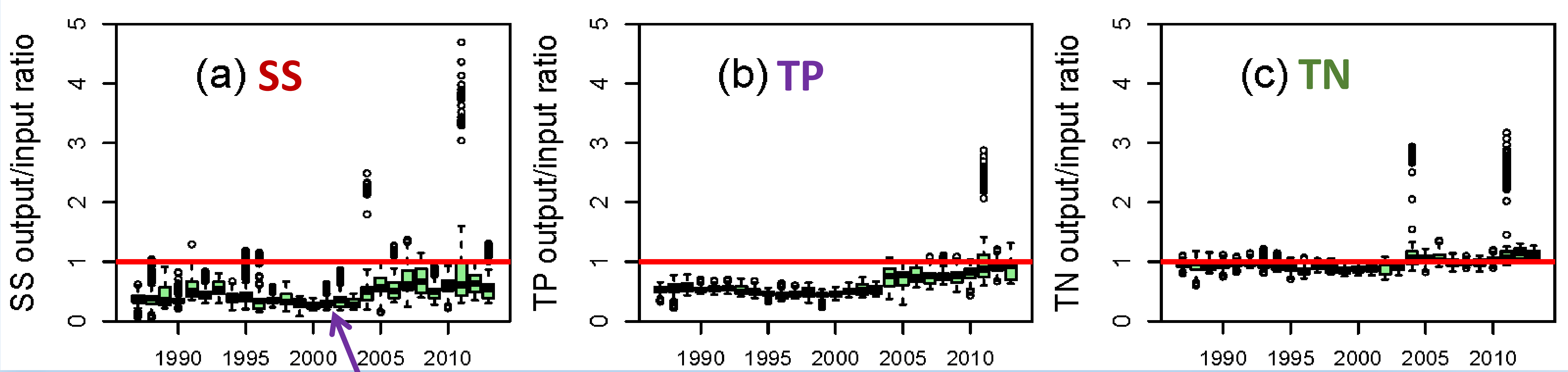
Q: Are trends in O/I ratio biased by the differential highflow sampling at Marietta and Conowingo?



- **Major distinction in sampling**: **15,000-20,000 m³/s** -- 3 dates were sampled at Conowingo but not Marietta (*i.e.*, **1996/01/21, 2004/09/20, and 2011/09/08**).
- **Sensitivity analysis**: We re-examined Marietta and Conowingo data by using only those samples with **Q < 15,000 m³/s**. O/I trend results are consistent with those with all samples.

3. (cont'd) **Input-output analyses: uncertainty analysis on O/I ratio**

Q: What are the uncertainties in the O/I ratio trends?

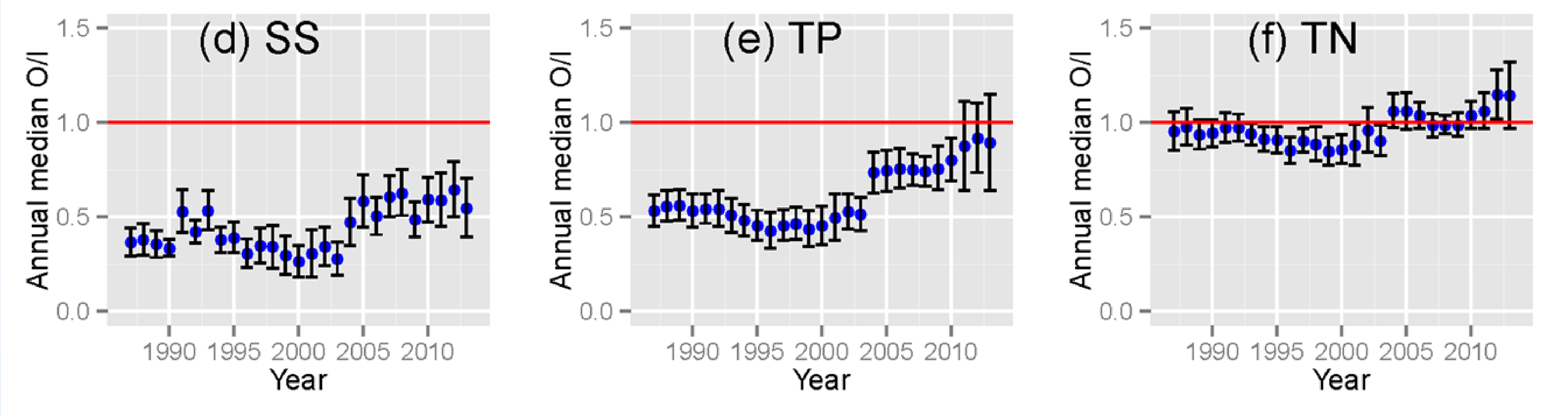


"Centerline" formed by
the annual median of 365 daily ratios
in each year from 1987 to 2013

3. (cont'd) **Input-output analyses: uncertainty analysis on O/I ratio**

"Centerline": annual median of daily O/I ratios

Averages (blue dots) & the 95% confidence intervals (black error bars) (based on estimation with 100 realizations of representative data sets)



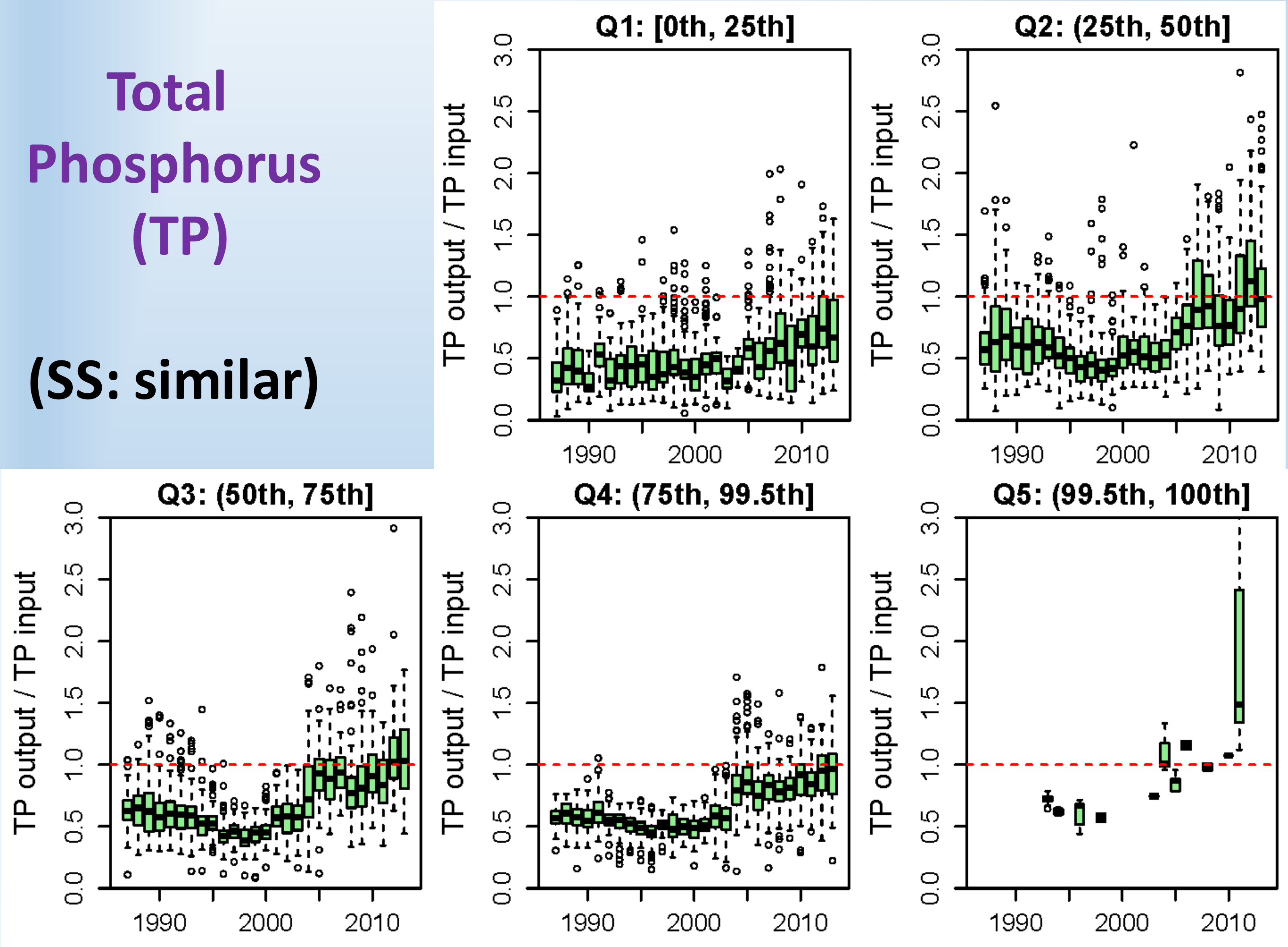
- **Trends in annual median O/I**: qualitatively maintained based on the 100 runs.
- **TP ratio > SS ratio**: decreasing retention in recent years is more pronounced for the finer (and more P-enriched) sediments.
- **Slight rise in TN ratio**: an increasingly larger quantity and fraction of **PN** in the reservoir output that deserves further study and management consideration.

3. Input-output analyses: O/I ratios by five flow class

Q: Is the O/I trend associated with highflow only?

Total Phosphorus (TP)

(SS: similar)



Conowingo Flow Classes

Q_1: 25~396 m^3/s;

Q_2: 399~787 m^3/s;

Q_3: 790~1,464 m^3/s;

Q_4: 1,467~7,646 m^3/s;

Q_5: 7,674~20,077 m^3/s.

Q_{scour}: ~ 11,000 m^3/s

Conowingo Dam on 9/12/2011, 3 days after peak discharge following Tropical Storm Lee (9/1 to 9/5)

REF: pubs.usgs.gov/sir/2012/5185/

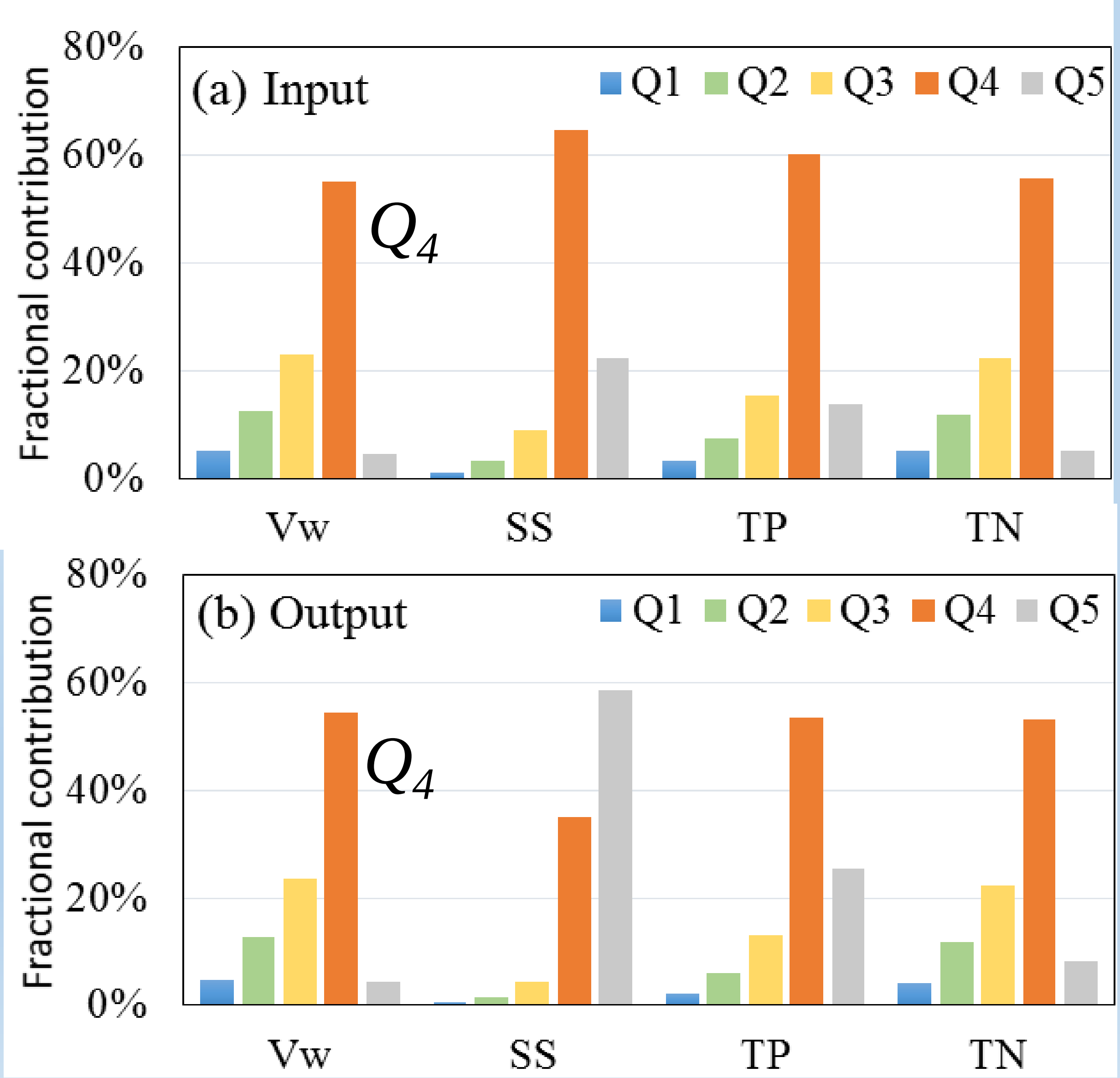
3. (cont'd) Input-output analyses: % contributions of loads by five flow classes

Q: What flow class has contributed the most of mass delivery?

Conowingo Flow Classes

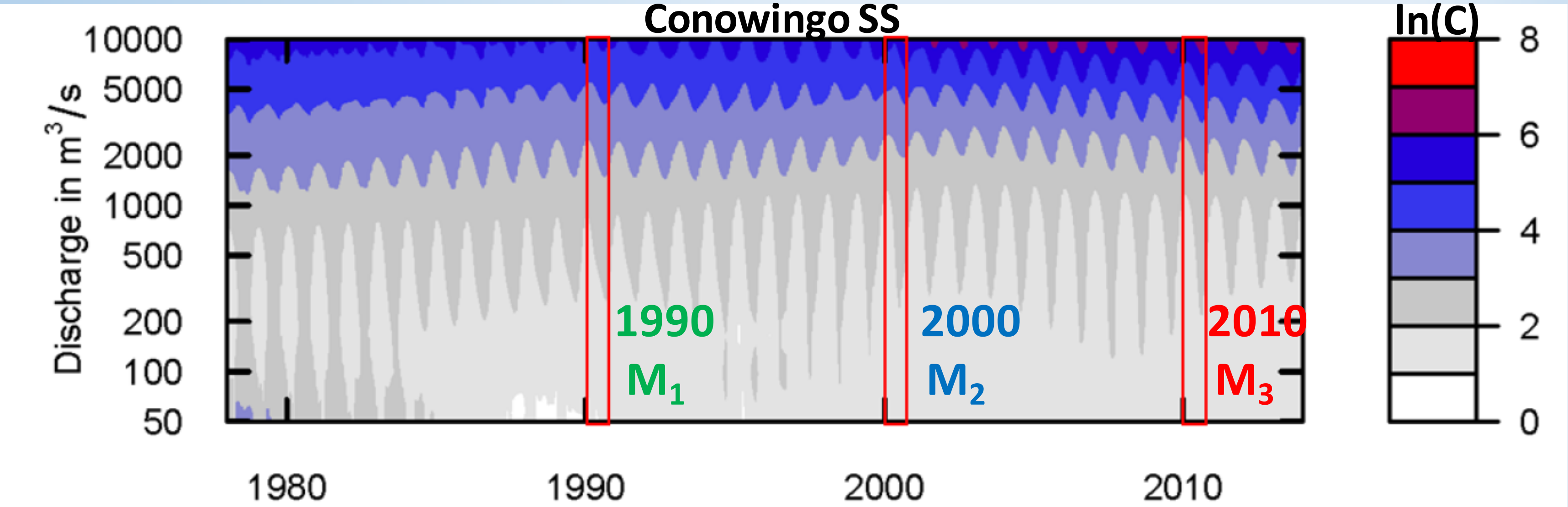
Q_1: 25~396 m^3/s;
Q_2: 399~787 m^3/s;
Q_3: 790~1,464 m^3/s;
Q_4: 1,467~7,646 m^3/s;
Q_5: 7,674~20,077 m^3/s.
Q_{scour}: ~ 11,000 m^3/s

- Q_4 has dominated the absolute mass delivery of **Vw**, **TN** and **TP** through the system despite its sub-scour status.
- Q_4 has also had a major contribution to **SS** delivery.



4. Stationary-model analyses: effects of changing $C(Q, t_{season})$ surface

- Inter-annual comparisons of WRTDS true-condition loadings are influenced by:
  - **(A) the particular history of flows occurred in a given year** and
  - **(B) changes in the concentration regression surface, *i.e.*, *C(Q, tseason)*.**

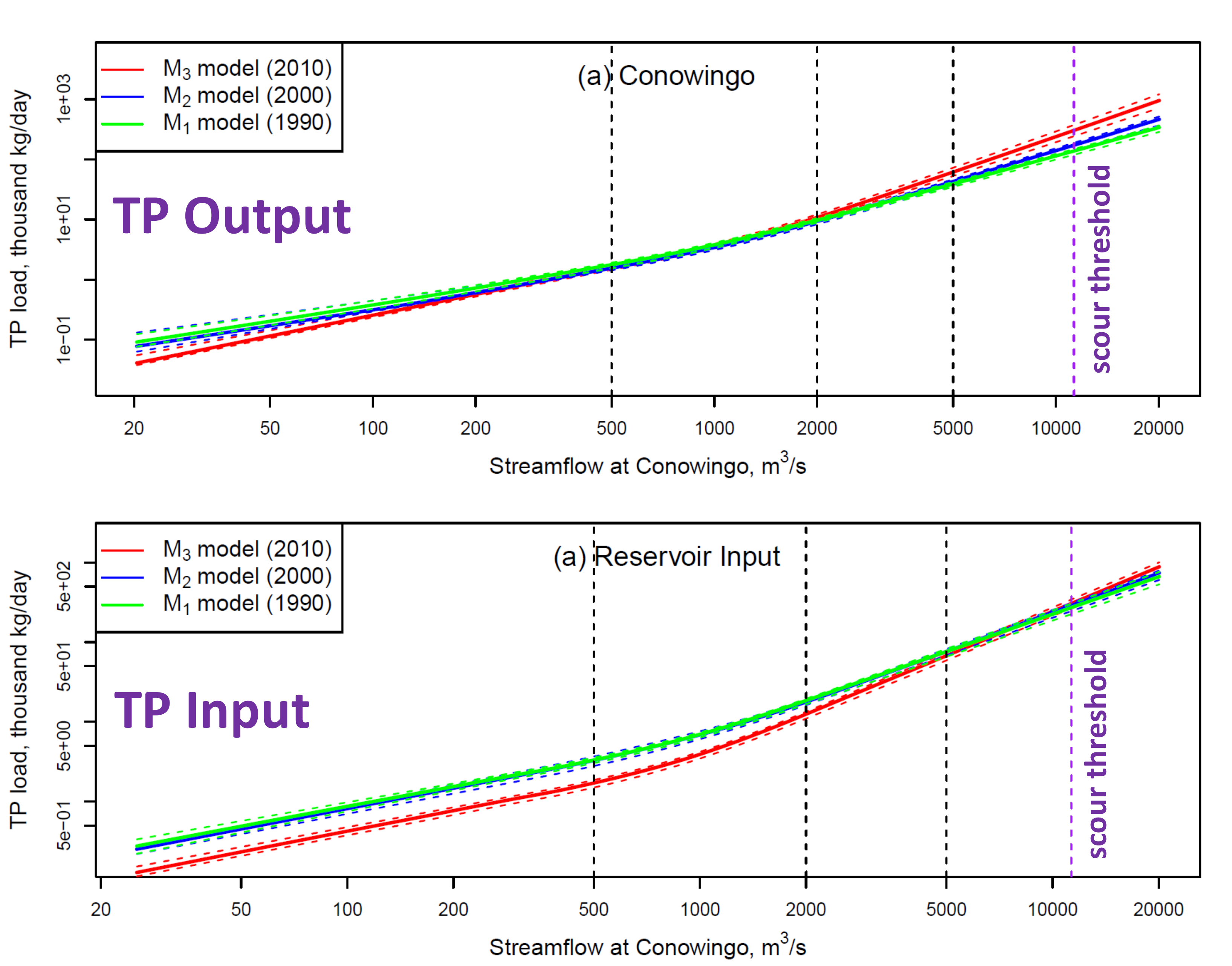


- To isolate the effects of **(B)**, we developed **3 "stationary" WRTDS models** that represent historical conditions in 3 different years -- **1990**, **2000**, **2010**.
- Repeat each 1-year surface over the full record to obtain "stationary" surfaces and apply these to the ***same, actual flow history*** to estimate loadings.
- Differences in loading estimates reflect the differences in the "stationary" surfaces, ***i.e.*, changes in reservoir system function**.

4. (cont'd) Stationary-model analyses: load vs. Q under 3 reservoir conditions

Differences in *TP loading vs. flow* among 3 scenarios of stationary surface representing 1990, 2000, and 2010 reservoir conditions

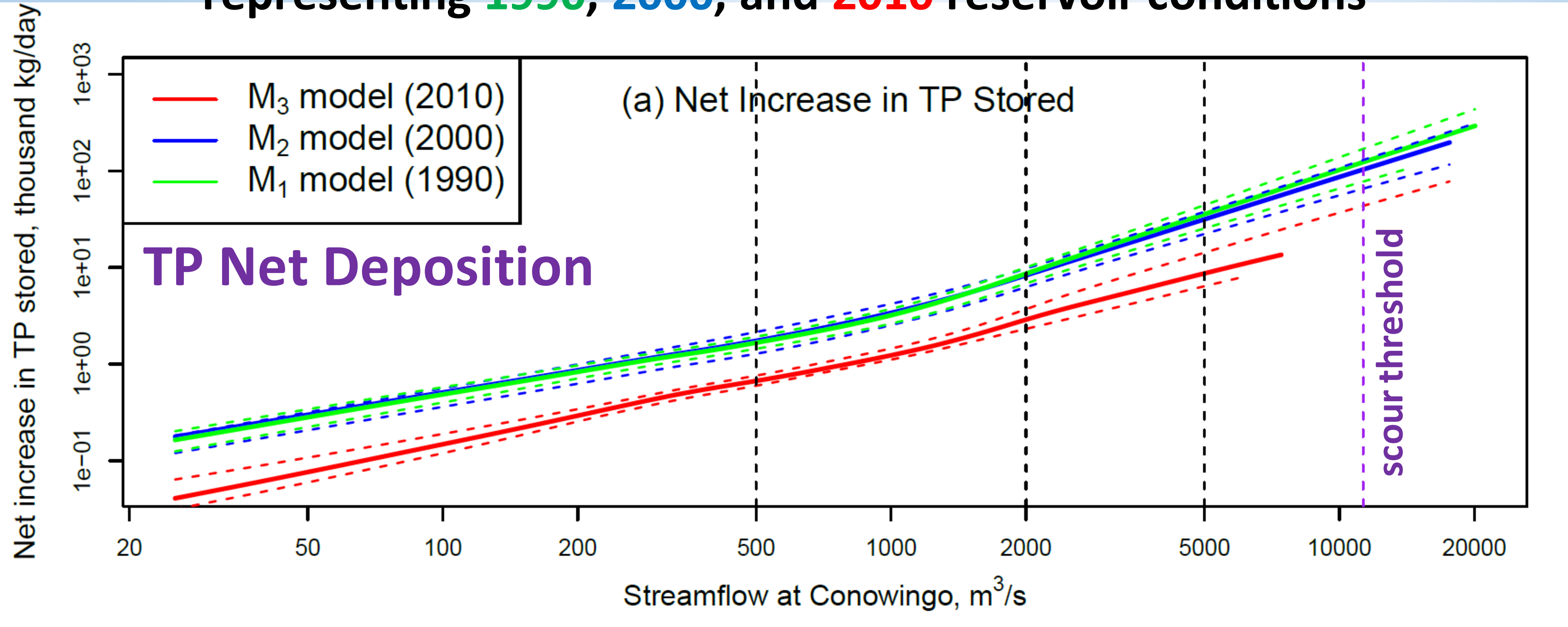
(SS results: similar)



Note: these modeled relationships are more uncertain at extremely high discharges due to the scarcity of monitoring data for input & output

4. (cont'd) **Stationary-model analyses: load vs. Q under 3 reservoir conditions**

Differences in *net deposition rate vs. flow* among 3 scenarios of stationary surface representing 1990, 2000, and 2010 reservoir conditions

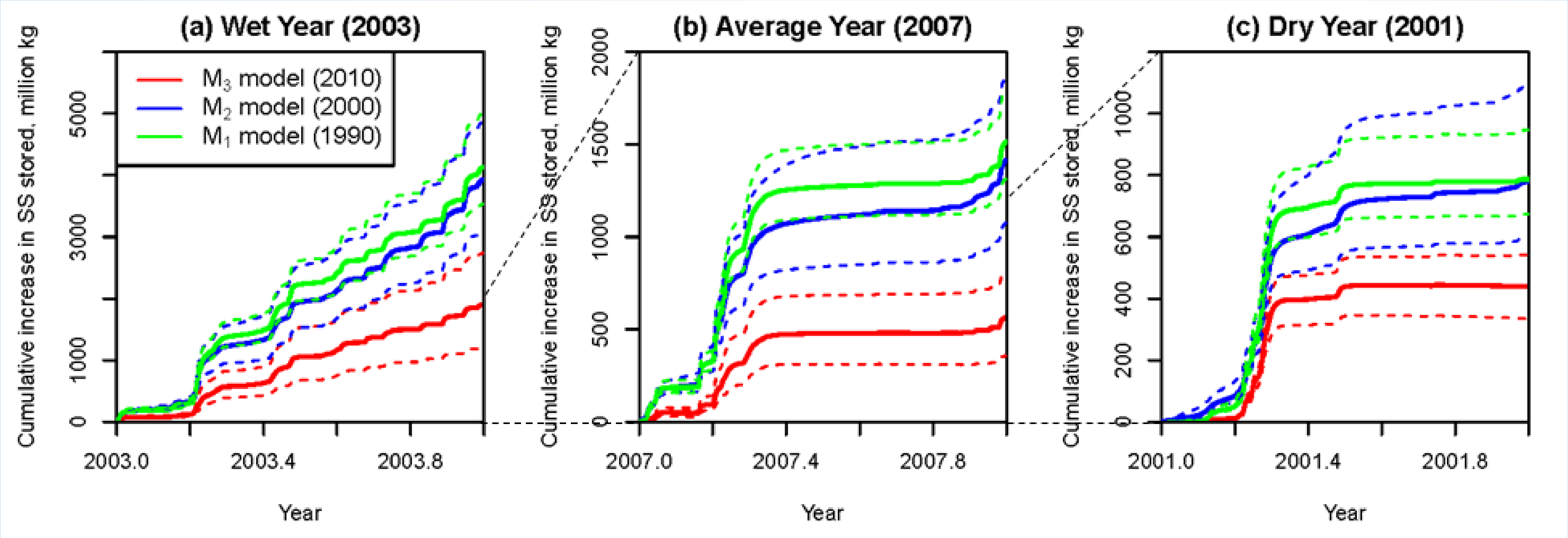


- Diminished net trapping of **TP** and **SS** (not shown; but similar patterns) has occurred under a range of flow conditions, including Q << "scour threshold".

Note: This slide was modified from its original form as presented at the Conowingo Infill Workshop. Moreover, these results are subject to further revisions and therefore are not for attribution or distribution. Final version should be available in the published work cited on Slide 23 of this document.

4. (cont'd) **Stationary-model analyses: storage under 3 reservoir conditions**

Predictions of ***cumulative SS net deposition*** for a ***Wet (2003)***, an ***Average (2007)***, and a ***Dry Year (2001)*** by **3 scenarios of stationary surface representing 1990, 2000, and 2010 reservoir conditions**



Decreased net deposition under the 2010 reservoir condition for all three cases

Note: This slide was modified from its original form as presented at the Conowingo Infill Workshop. Moreover, these results are subject to further revisions and therefore are not for attribution or distribution. Final version should be available in the published work cited on Slide 23 of this document. (The original slide can be found at the end of this document but is not for attribution or distribution.)

Summary

Major Findings

- This retrospective study has evaluated reservoir performance in the last 30 years using different modeling approaches, all of which consistently show decreased net deposition of SS and TP in Conowingo Reservoir.
- Decreased reservoir trapping has occurred under a wide range of flow conditions, including sub-scour levels. The moderately high flows (75^{th}~99.5^{th} percentile of flow at Conowingo) has dominated the absolute mass of delivery through the reservoir.
- Moreover, the recent rise in TN O/I ratio may reflect an increasingly important role of particulate N that deserves further study.
- These broad changes in net deposition are:
  a) robust based on uncertainty analysis and
  b) not sensitive to the differential highflow sampling at Marietta and Conowingo.

Summary (cont'd)

Management Implications

- Future progress in Bay restoration will depend on accurate predictions of how upstream inputs to the reservoir system will be modulated by reservoir processes.
- Our analyses can help constrain and inform the development of improved predictive models of reservoir performance, and particularly the (possible) incorporation of such models in the ongoing upgrade of the Chesapeake Bay Watershed Model.
- **This retrospective study (1986-2013) does NOT speak for the issue of future reservoir conditions.**
- Additional monitoring and modeling of the reservoir is critically needed, including at least:
  - a) Input & output sampling,
  - b) Bathymetry measurements,
  - c) N & P distributions in bottom sediments, and
  - d) N & P transport and fate under different flows.

Acknowledgements

- Bob Hirsch (USGS) and Bill Ball (JHU, CRC) for their contributions to the work
- Joel Blomquist (USGS) for his review comments
- MD Sea Grant, USGS, and MD Water Resources Research Center for funding

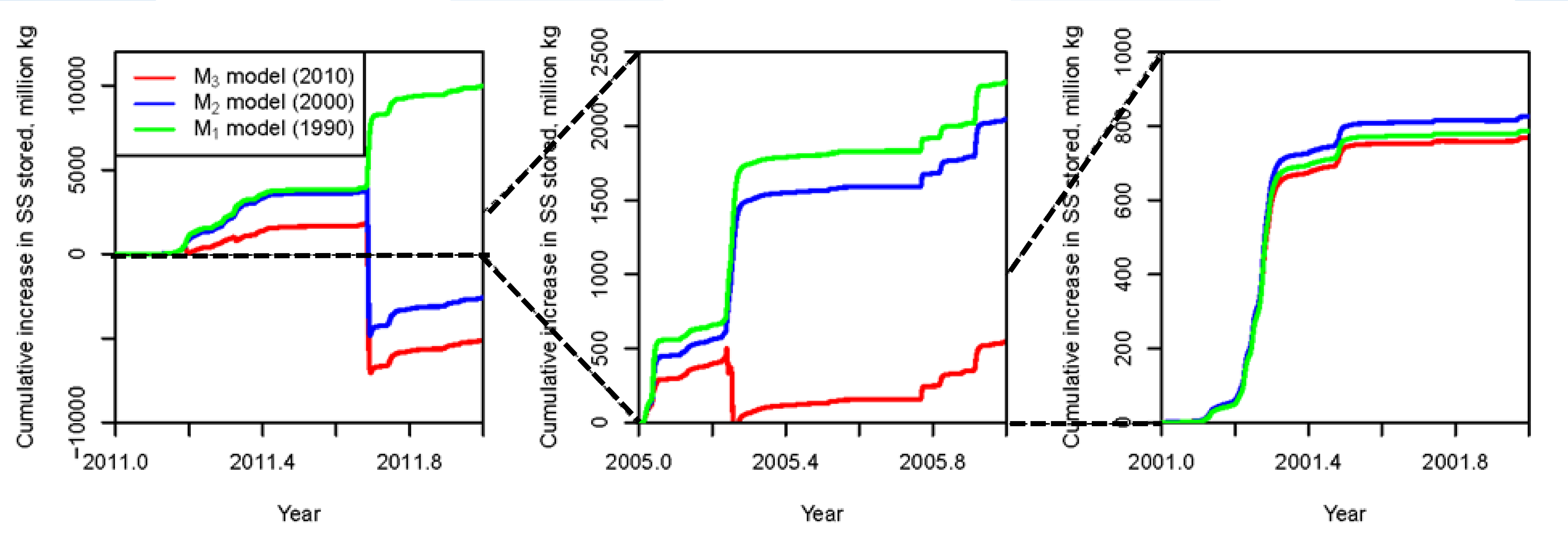
Documents in mySTAC WorkZone:

- Zhang, Hirsch, Ball, 2016, *Environ. Sci. Technol.*, in press, doi: 10.1021/acs.est.5b04073.
- Zhang, Brady, Ball, 2013, *Sci. Total. Environ.*, 452-453, doi: 10.1016/j.scitotenv.2013.02.012.

QUESTIONS?

4. (cont'd) **Stationary-model analyses: storage under 3 reservoir conditions**

Predictions of ***cumulative SS net deposition*** for a ***Wet (2011)***, an ***Average (2005)***, and a ***Dry Year (2001)*** by **3 scenarios of stationary surface representing 1990, 2000, and 2010 reservoir conditions**



Note: Not for distribution or attribution. 2011 estimates are highly uncertain at the extreme discharges due to data scarcity.

Wet Year (2011)

No net scour if TS Lee had occurred under the 1990 reservoir condition

Normal Year (2005)

No net scour if the high flow had occurred under the 1990 and 2000 reservoir conditions

Dry Year (2001)

(Mildly) reduced net deposition even for the dry-year scenario