Evaluation of Results from the HDR Conowingo Sediment Transport Model

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With contributions from **Gopal Bhatt, Gary Shenk, and Lewis Linker** (CBPO)

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Phase 6 Conowingo Simulation Strategy

Multiple models and lines of evidence

- Direct Use
  - HDR
  - WRTDS
- Supporting Evidence
  - Langland studies
  - LSRWA
  - Observations

Phase 6 Conowingo Simulation Strategy

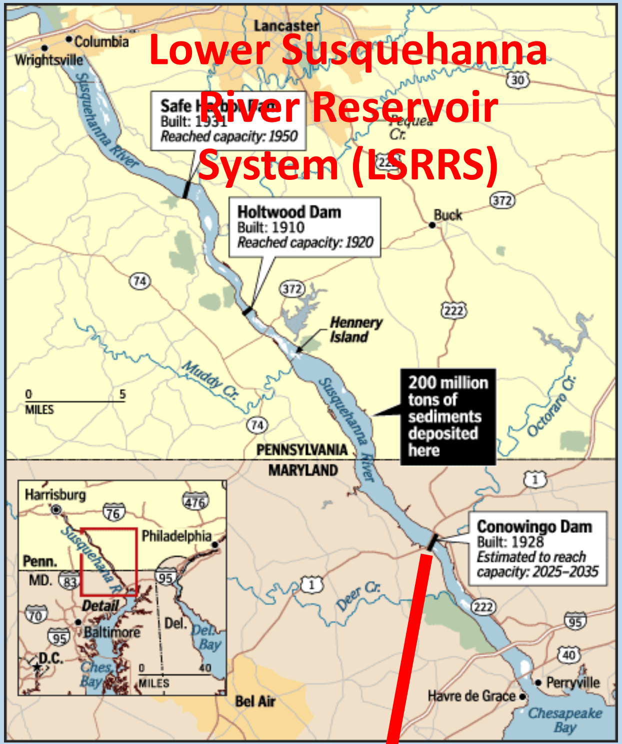
Questions

- How does the scour and deposition change with bathymetry?
- How does the Output/Input ratio change with nutrient reductions?
- What are the fractions of G1/G2/G3 organics?

Objective

To evaluate the results from the HDR Sediment Transport Model, with focus on comparison with water quality observations (SS, TP, TN) at Conowingo.

1. Comparison of C-Q evolution among (a) observations, (b) WRTDS, and (c) the HDR model – ***long-term overall patterns***;
2. Comparison of flux during major storm events (i.e., Sep 2004, Jun 2006, Mar 2011, and Sep 2011) among (a) observations, (b) WRTDS, and (c) the HDR model – ***short-term episodic patterns***.
3. Evaluation of reservoir response to changes in nutrient input and dynamics of G1/G2/G3 classes.

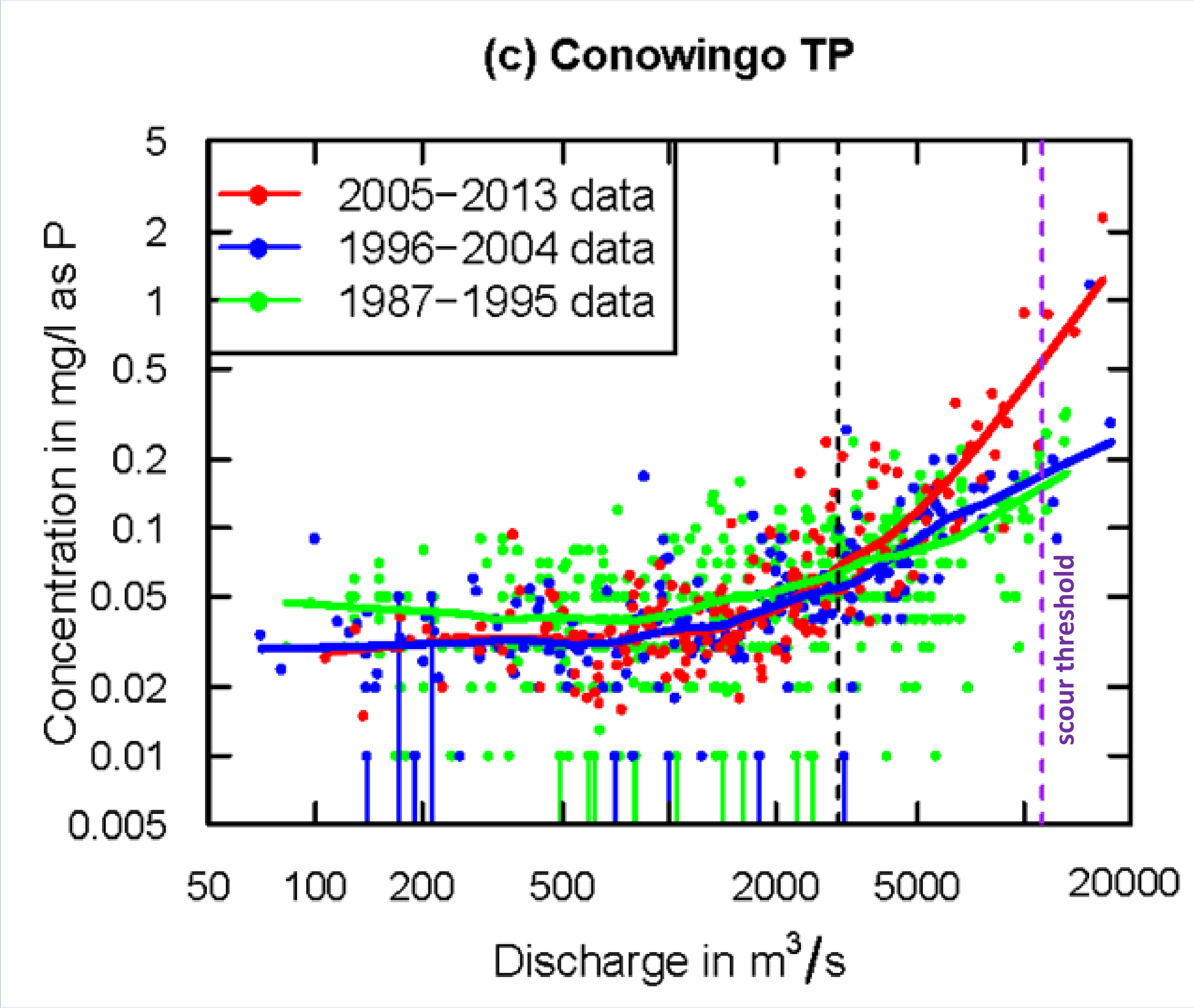


HDR Model: Scenarios

Bathymetry	Nutrient Factor	Sediment Factor	Sediment Model	Flux Model
97-14	1	1	Conowingo_Sediment_Discharge _1997-2014_28Dec2016	FOR_EPA_C1
97-14	0.5	1		FOR_EPA_P1
97-14	0.85	1		FOR_EPA_P2
97-14	1.2	1		FOR_EPA_P3
14+	1	1	Conowingo_Sediment_Discharge _SCENARIO_0_31Dec2016	FOR_EPA_C2
14+	0.5	0.65	Conowingo_Sediment_Discharge _SCENARIO_1_31Dec2016	FOR_EPA_P4
14+	0.85	0.895	Conowingo_Sediment_Discharge _SCENARIO_2_31Dec2016	FOR_EPA_P5
14+	1.2	1.14	Conowingo_Sediment_Discharge _SCENARIO_3_31Dec2016	FOR_EPA_P6

I. C-Q Analysis

Temporal Evolution of *C-Q* Relationships



(fitted lines are **LOWESS curves**)

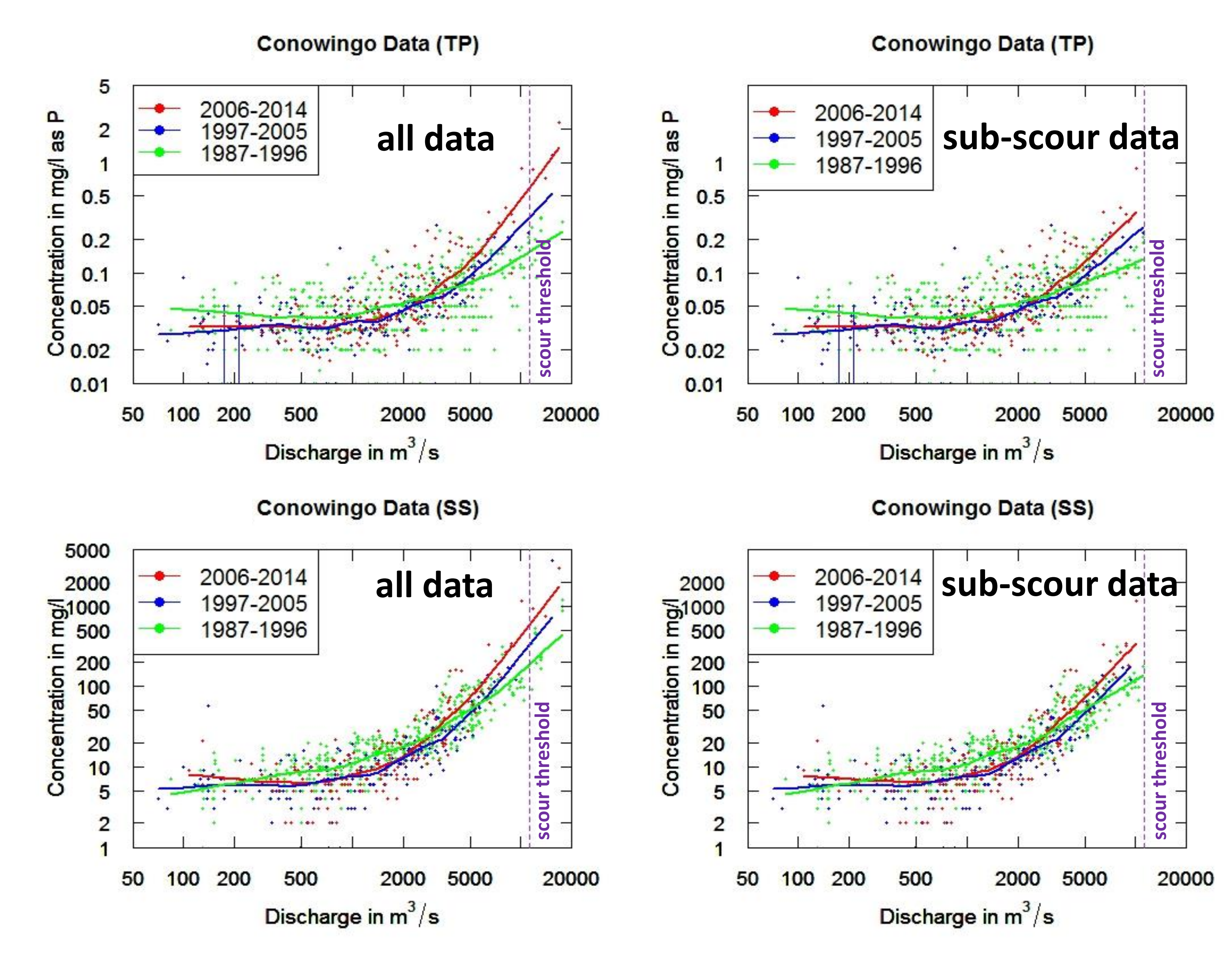
(Zhang, Hirsch, Ball, ES&T, 2016)

LOWESS 101

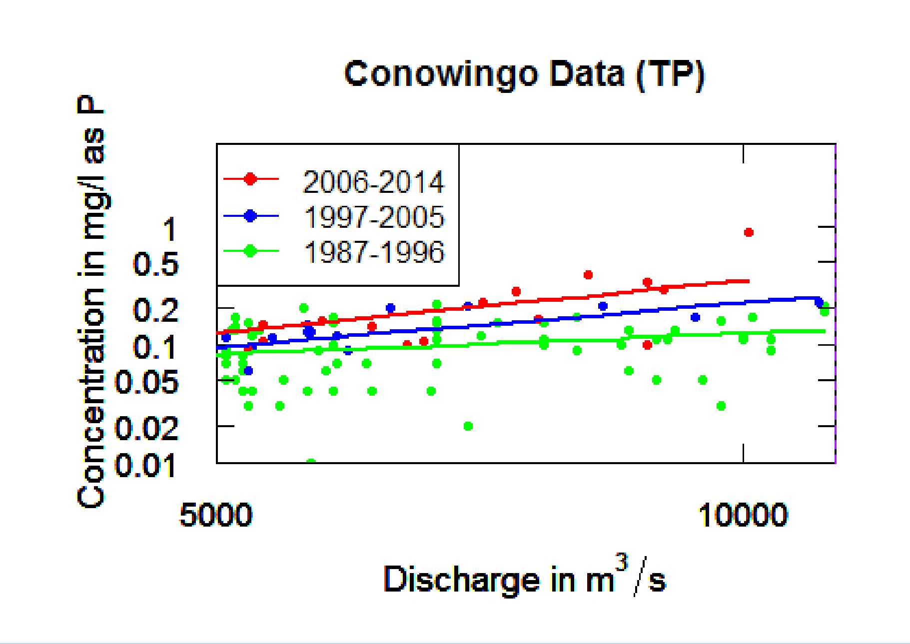
LOcally WEighted Scatterplot Smoothing

- Originally proposed by Cleveland (1979)
- Nonparametric (not assuming linearity)
- Locally fits polynomials and then joins them
- Sensitive to the smoothing parameter:
  - → 1.0: inefficient use of data; over-smoothed; large bias; more prone to outliers or edge effect
  - → 0.0: insufficient data; lots of noise; large variance
  - Guideline: always compare the fit with data

Temporal Evolution of *C-Q* Relationships



Temporal Evolution of *C-Q* Relationships

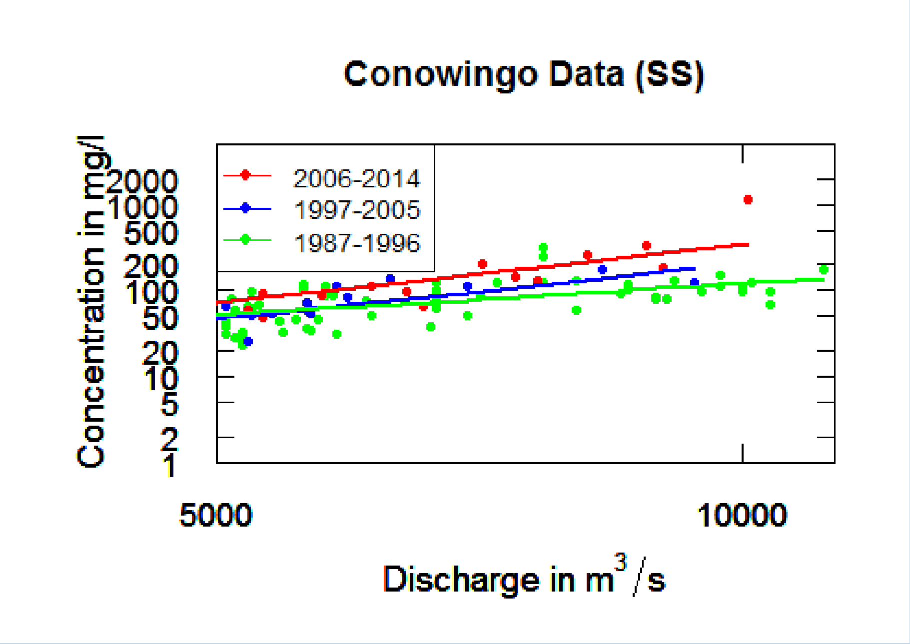


Wilcoxon rank-sum test for TP

5,000 cms to 11,300 cms

(17,5000 cfs to 400,000 cfs)

Test	W	p-value
T1 < T2	302.5	0.008
T1 < T3	244.5	0.0001
T2 < T3	79.5	0.09



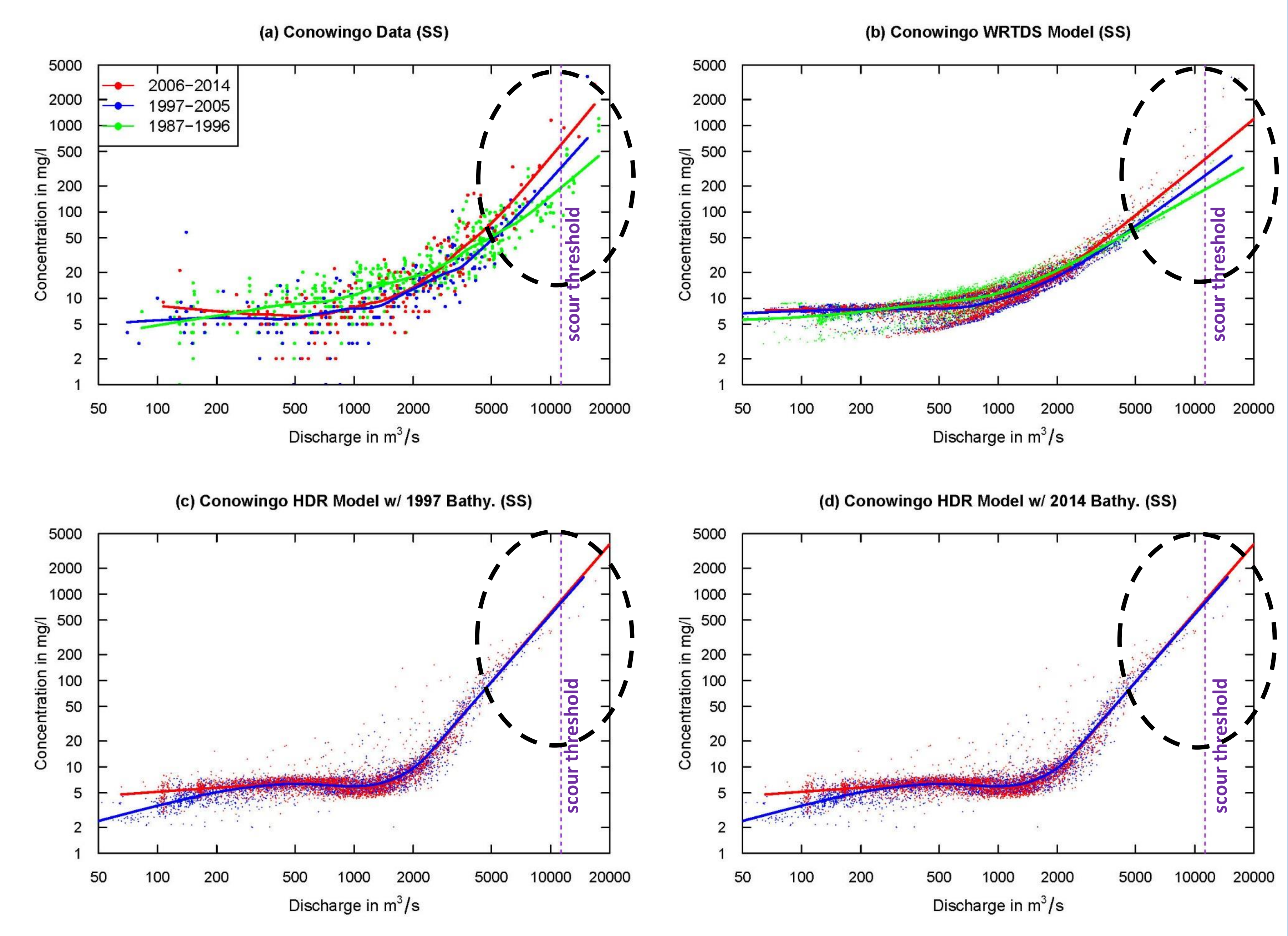
Wilcoxon rank-sum test for SS

5,000 cms to 11,300 cms

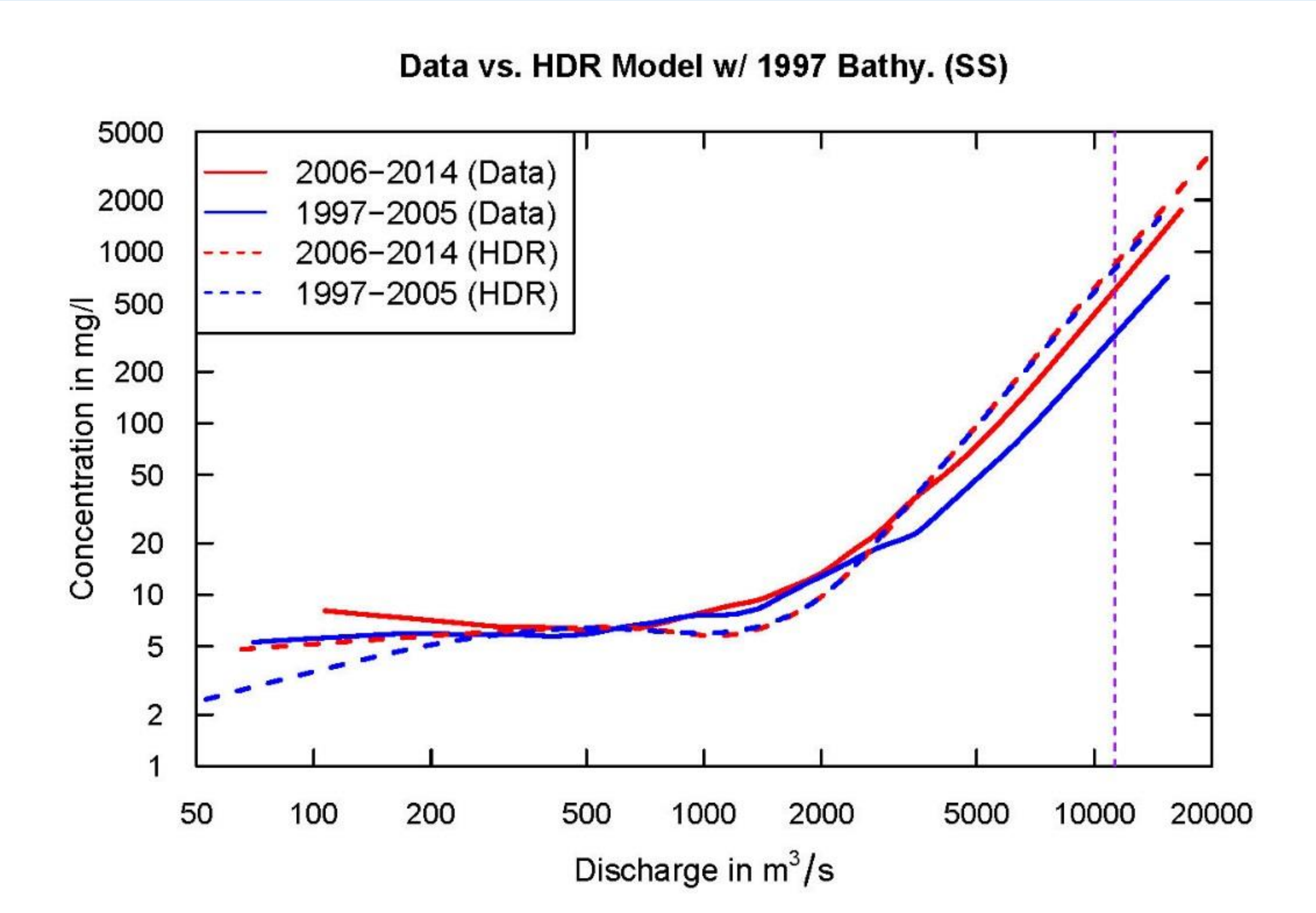
(17,5000 cfs to 400,000 cfs)

Test	W	p-value
T1 < T2	430	0.27
T1 < T3	249.5	0.00015
T2 < T3	50	0.0086

Temporal Evolution of *C-Q* Relationships: SS

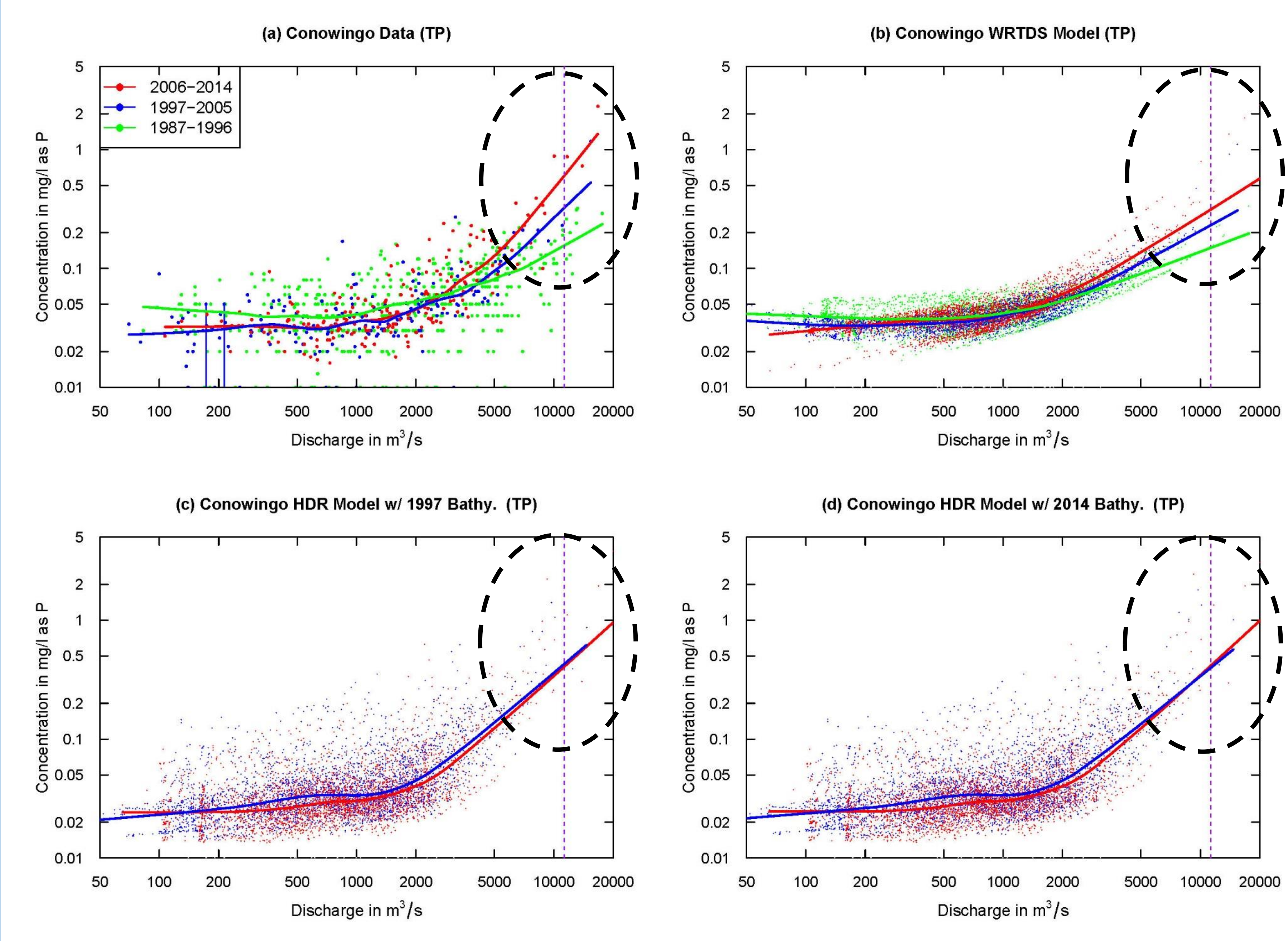


Temporal Evolution of *C-Q* Relationships: SS

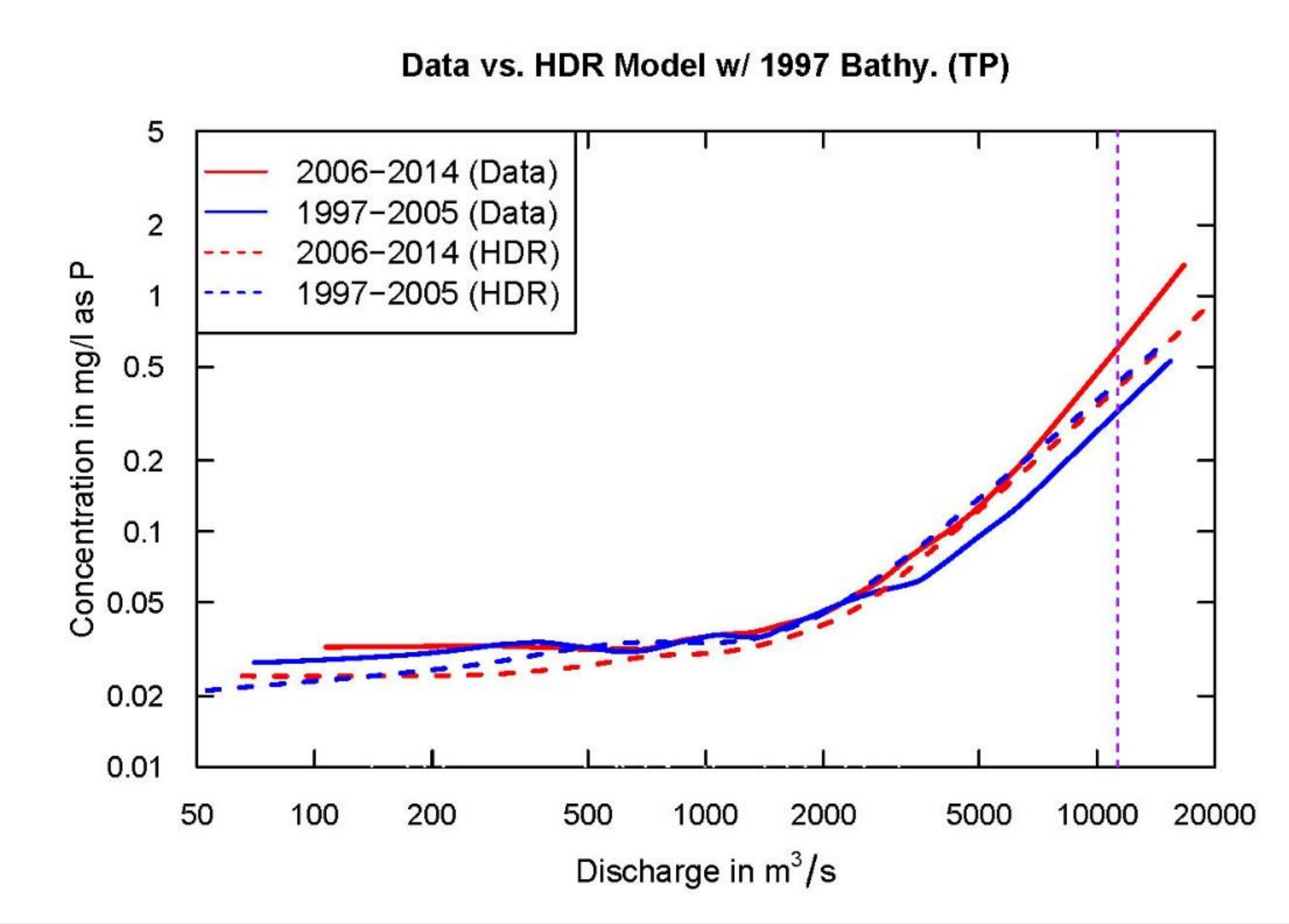


1. The HDR model is able to capture the general shape of the C-Q curve very well.
2. It does not capture the evolution of C-Q relationship, as compared with data.

Temporal Evolution of *C-Q* Relationships: TP

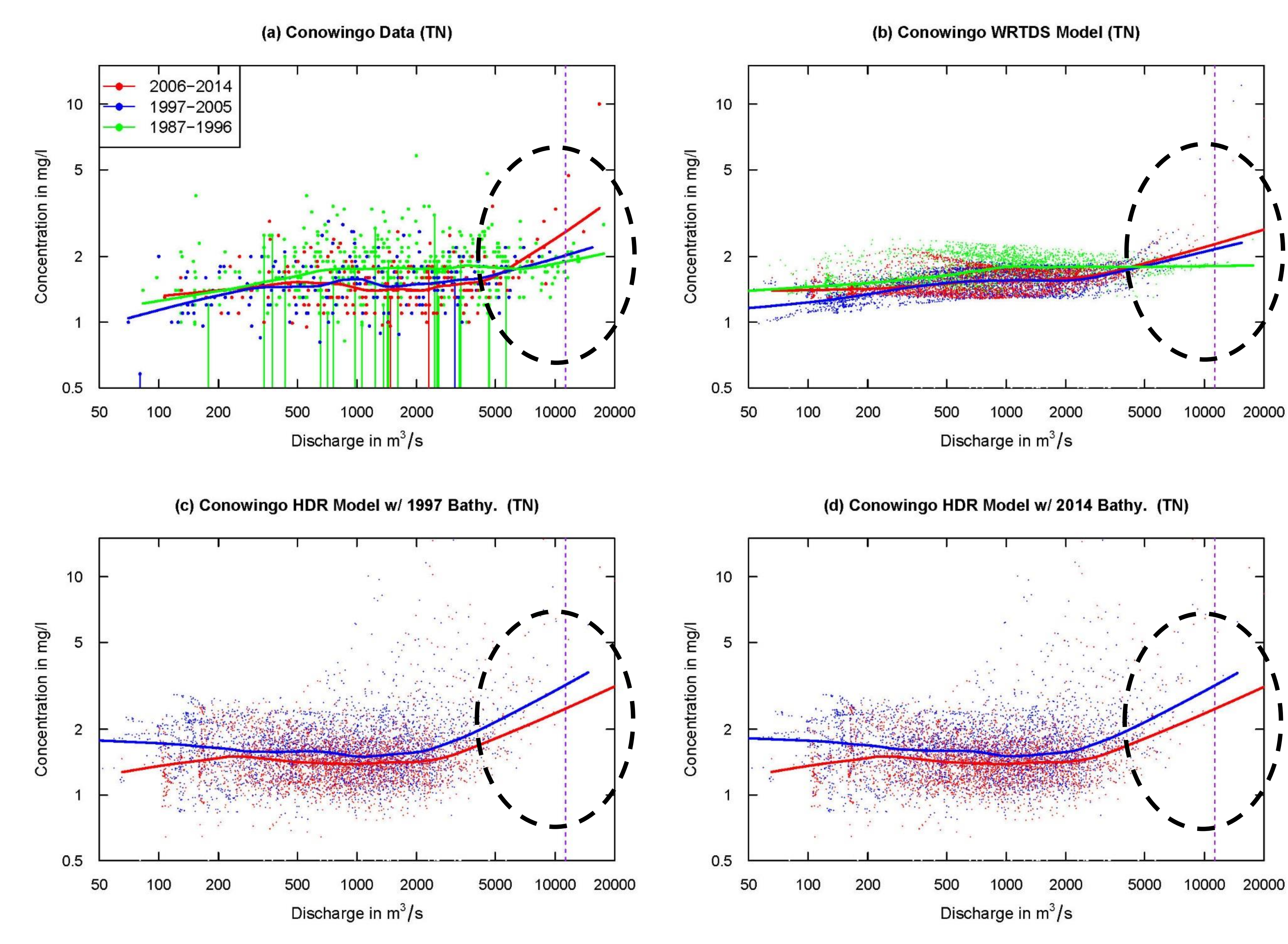


Temporal Evolution of *C-Q* Relationships: TP

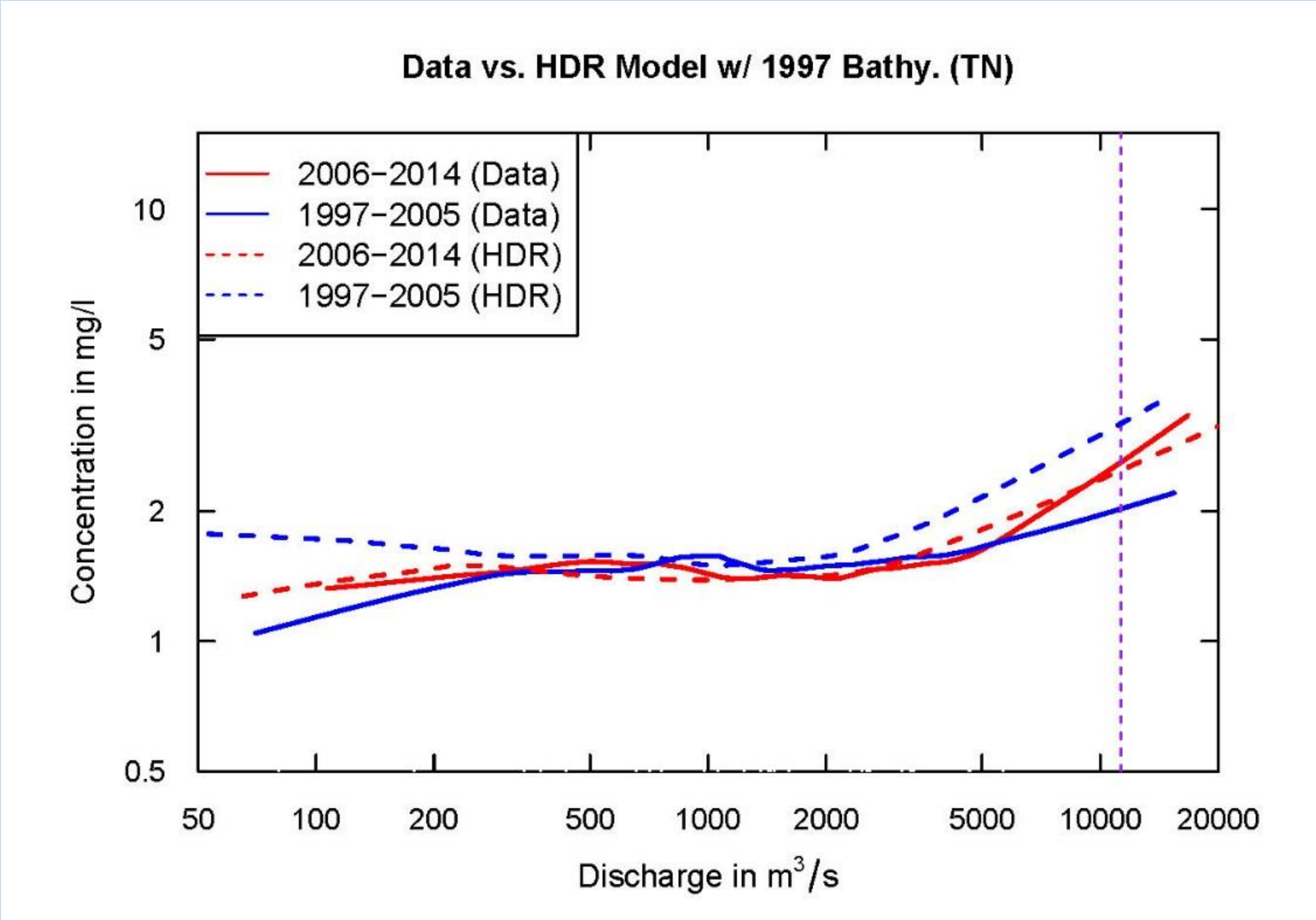


1. The HDR model is able to capture the general shape of the C-Q curve very well.
2. It does not capture the evolution of C-Q relationship, as compared with data.

Temporal Evolution of *C-Q* Relationships: TN



Temporal Evolution of *C-Q* Relationships: TN



1. The HDR model is able to capture the general shape of the C-Q curve very well.
2. It does not capture the evolution of C-Q relationship, as compared with data.

II. Storm Flux Analysis

Uncertainty Issue

Storm	Date	Daily flow (m^3/s)		Sampled (Y/N)?	
		Mar	Cono	Mar	Cono
Storm 1	1993/4/1	10,760	11,610	Y	Y
	1993/4/2	12,176	13,224	Y	Y
	1993/4/3	12,205	13,054	Y	Y
Storm 2 *(Ice Jam)*	1996/1/20	12,205	12,431	N	Y
	1996/1/21	15,744	17,613	N	Y
	1996/1/22	10,987	12,120	Y	Y
Storm 3 *(Ivan)*	2004/9/20	14,073	15,433	N	Y
Storm 4	2006/6/29	11,412	11,412	Y	N
Storm 5	2011/3/12	11,978	11,723	Y	Y
Storm 6 *(TS Lee)*	2011/9/8	14,866	16,764	N	Y
	2011/9/9	17,443	20,077	N	N
	2011/9/10	13,224	13,960	Y	Y

Uncertainty Issue

Table S3. Comparison of SS load estimates during six storm events in 1986-2014 under three sampling scenarios.

Storm	Date	Daily flow (m^3/s)		Sampled (Y/N)?		SS fractional difference			
		Mar	Cono	Mar	Cono	$(M_2-M_1)/M_1$	$(M_3-M_1)/M_1$	$(C_2-C_1)/C_1$	$(C_3-C_1)/C_1$
						Sub-scour only (-47 samples) [a]	Artificial data (+7 samples) [b]	Sub-scour only (-60 samples) [a]	Artificial data (+1 sample) [b]
Storm 1	1993/4/1	10,760	11,610	Y	Y	-13%	12%	-28%	0%
	1993/4/2	12,176	13,224	Y	Y	-15%	13%	-33%	0%
	1993/4/3	12,205	13,054	Y	Y	-15%	13%	-32%	0%
Storm 2 *(Ice Jam)*	1996/1/20	12,205	12,431	N	Y	-10%	15%	-46%	0%
	1996/1/21	15,744	17,613	N	Y	-10%	17%	-63%	0%
	1996/1/22	10,987	12,120	Y	Y	-10%	15%	-45%	0%
Storm 3 *(Ivan)*	2004/9/20	14,073	15,433	N	Y	54%	147%	-75%	-12%
Storm 4	2006/6/29	11,412	11,412	Y	N	-3%	21%	-69%	-13%
Storm 5	2011/3/12	11,978	11,723	Y	Y	13%	0%	-12%	0%
Storm 6 *(TS Lee)*	2011/9/8	14,866	16,764	N	Y	16%	142%	-80%	-4%
	2011/9/9	17,443	20,077	N	N	11%	164%	-81%	-4%
	2011/9/10	13,224	13,960	Y	Y	22%	120%	-77%	-3%

[a] For the flow-censored data scenario, all samples from flows above 11,300 m^3/s and all samples collected during the entire hydrographs of the six storm events were removed at both locations.

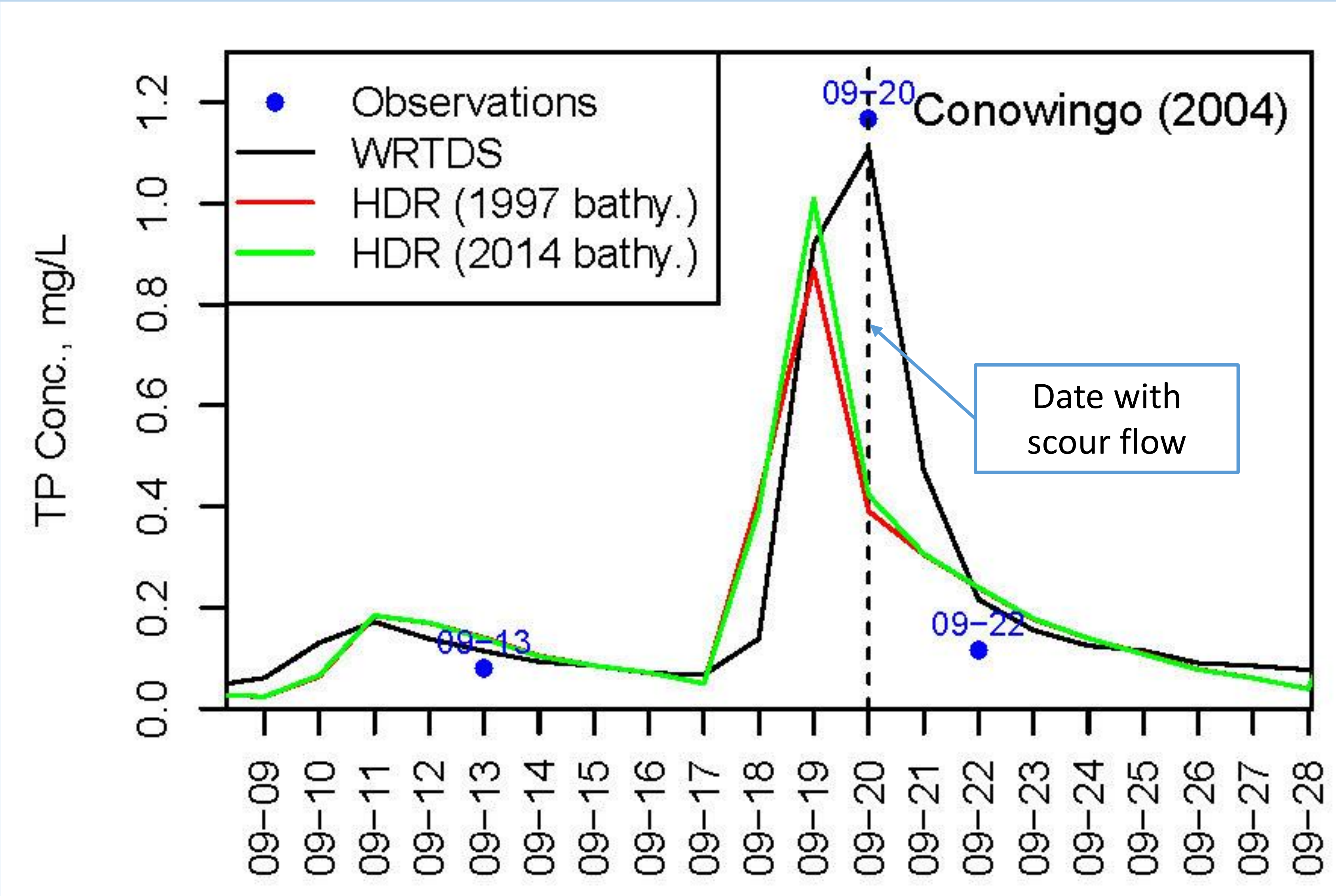
[b] For the artificial data scenario, artificial samples were inserted at the non-sampled or "N" location of highlighted dates.

Uncertainty

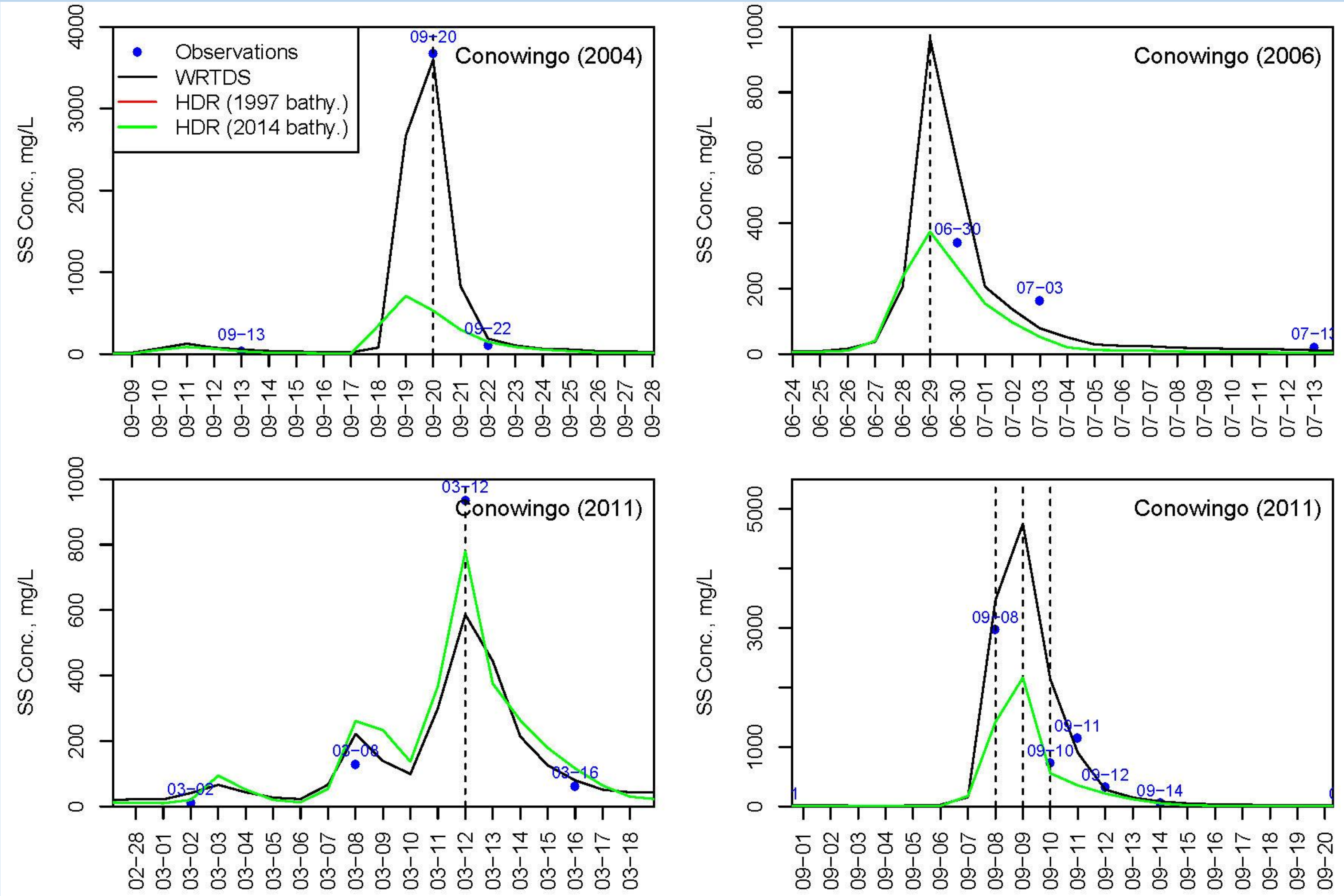
Quantity & quality of observations during the full hydrograph

Statistical approaches for concentration and flux estimation

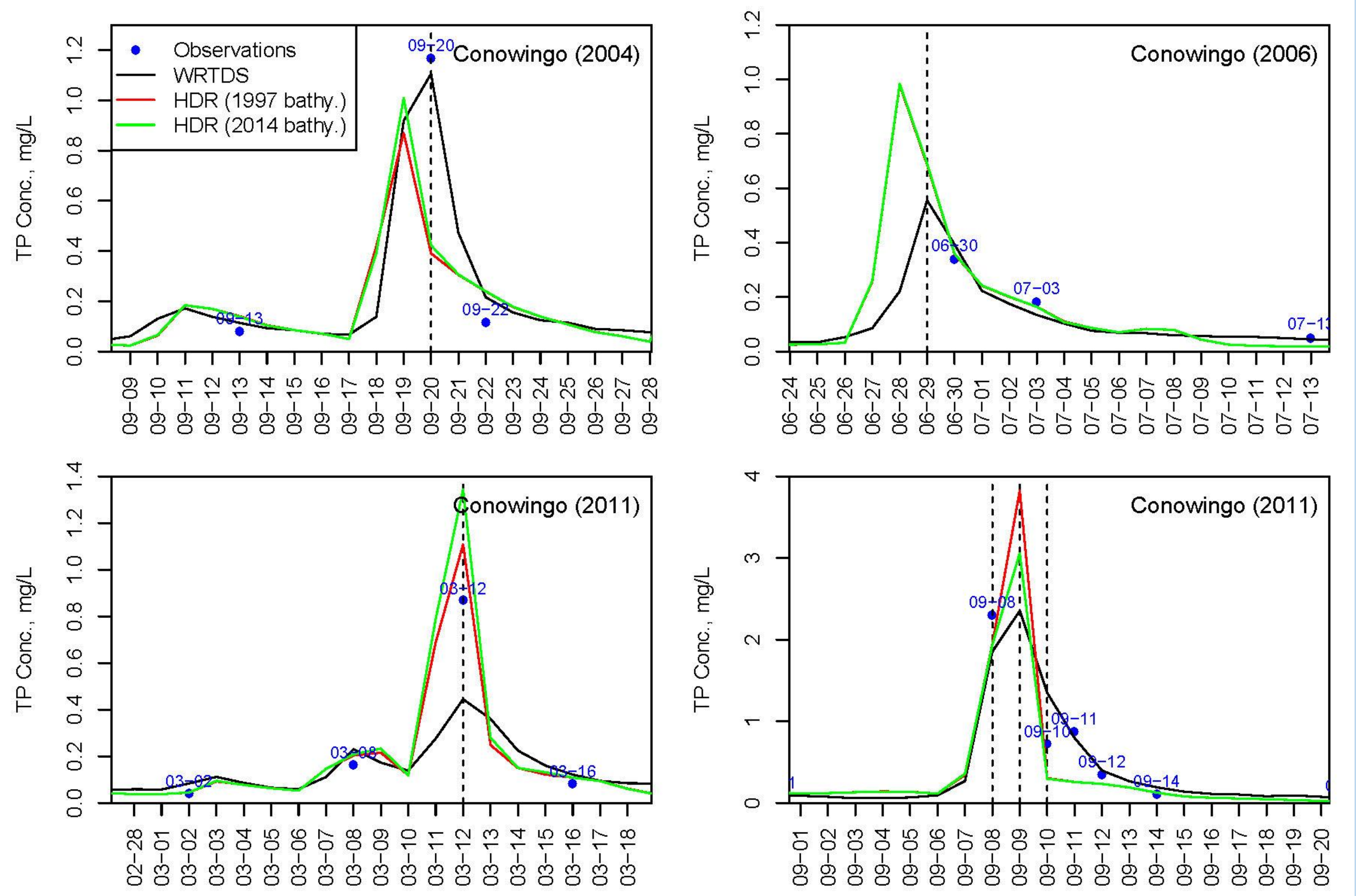
Flux during Major Storm Events



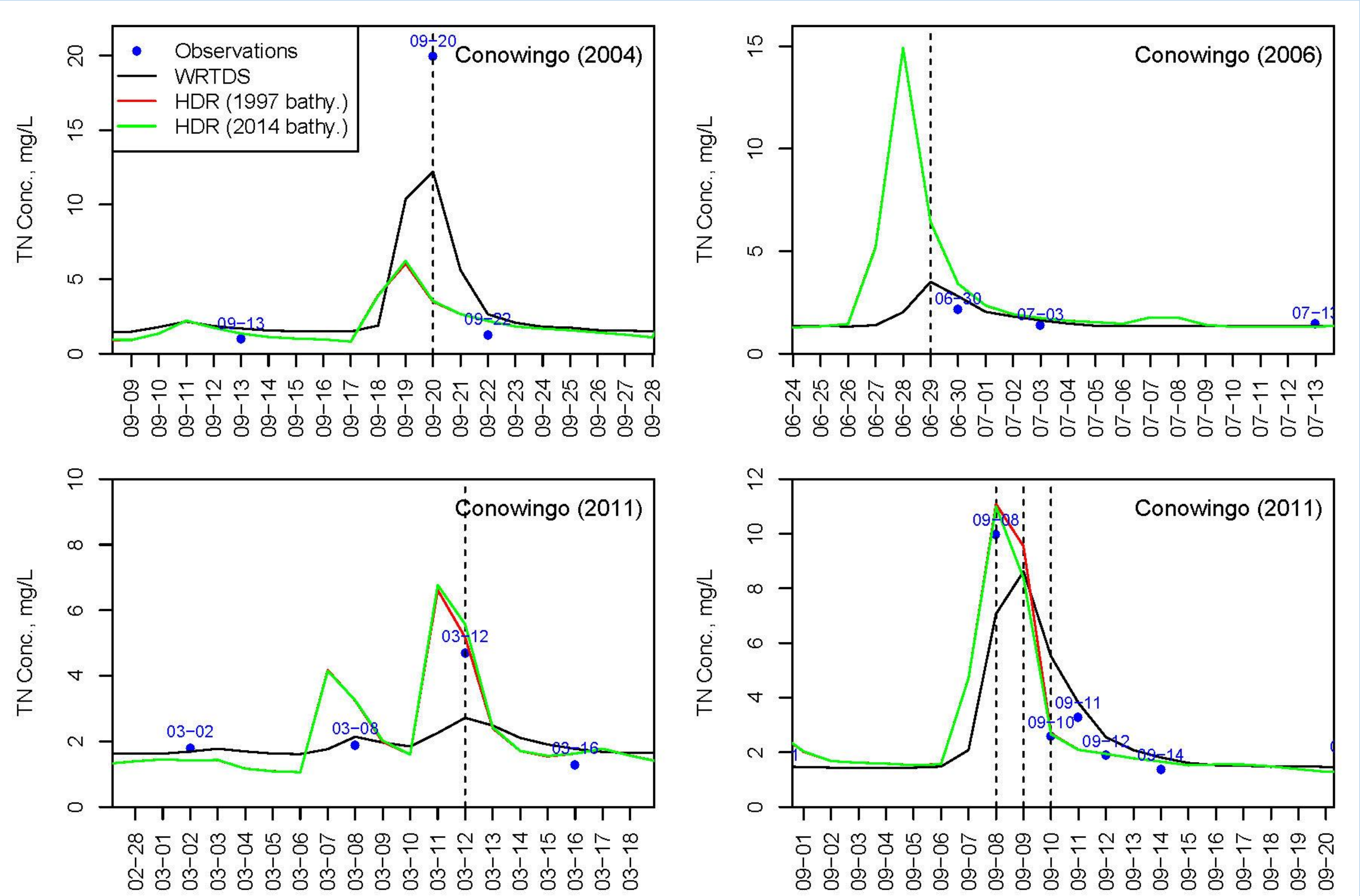
Flux during Major Storm Events: SS



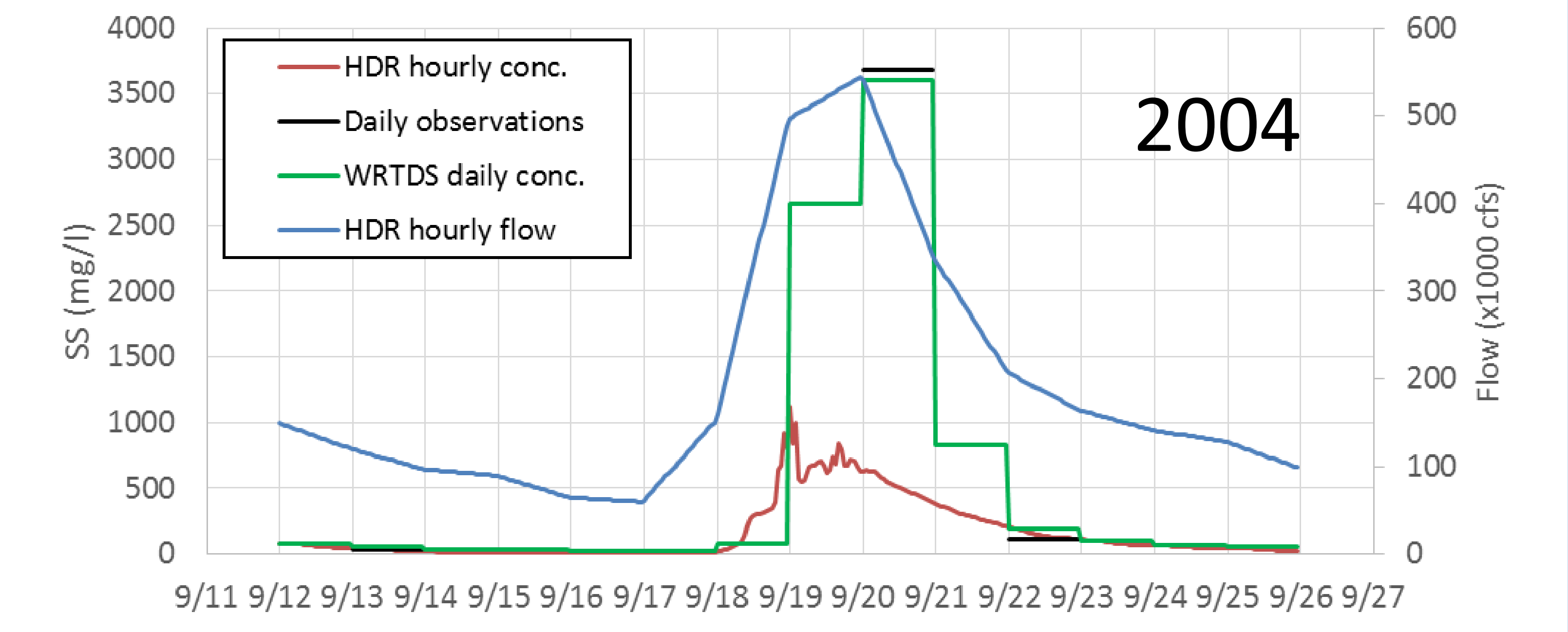
Flux during Major Storm Events: TP

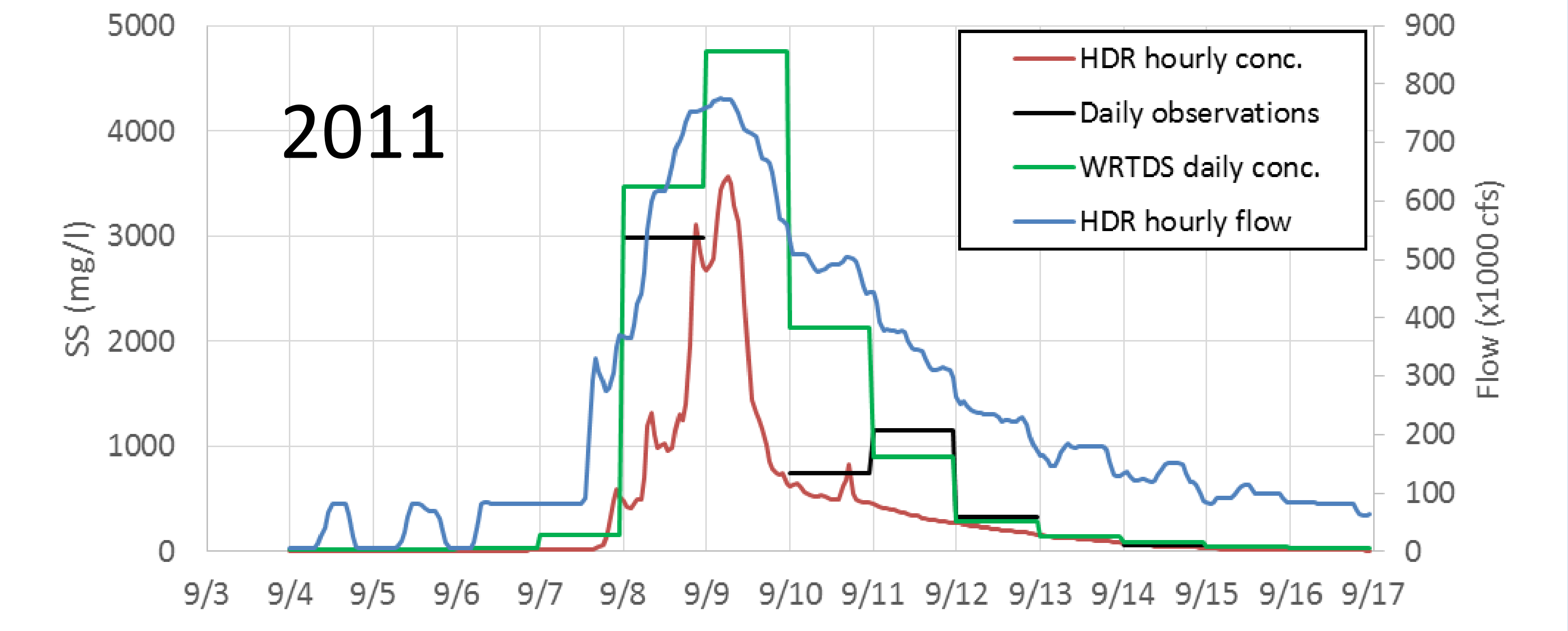


Flux during Major Storm Events: TN



Flux during Major Storm Events: SS



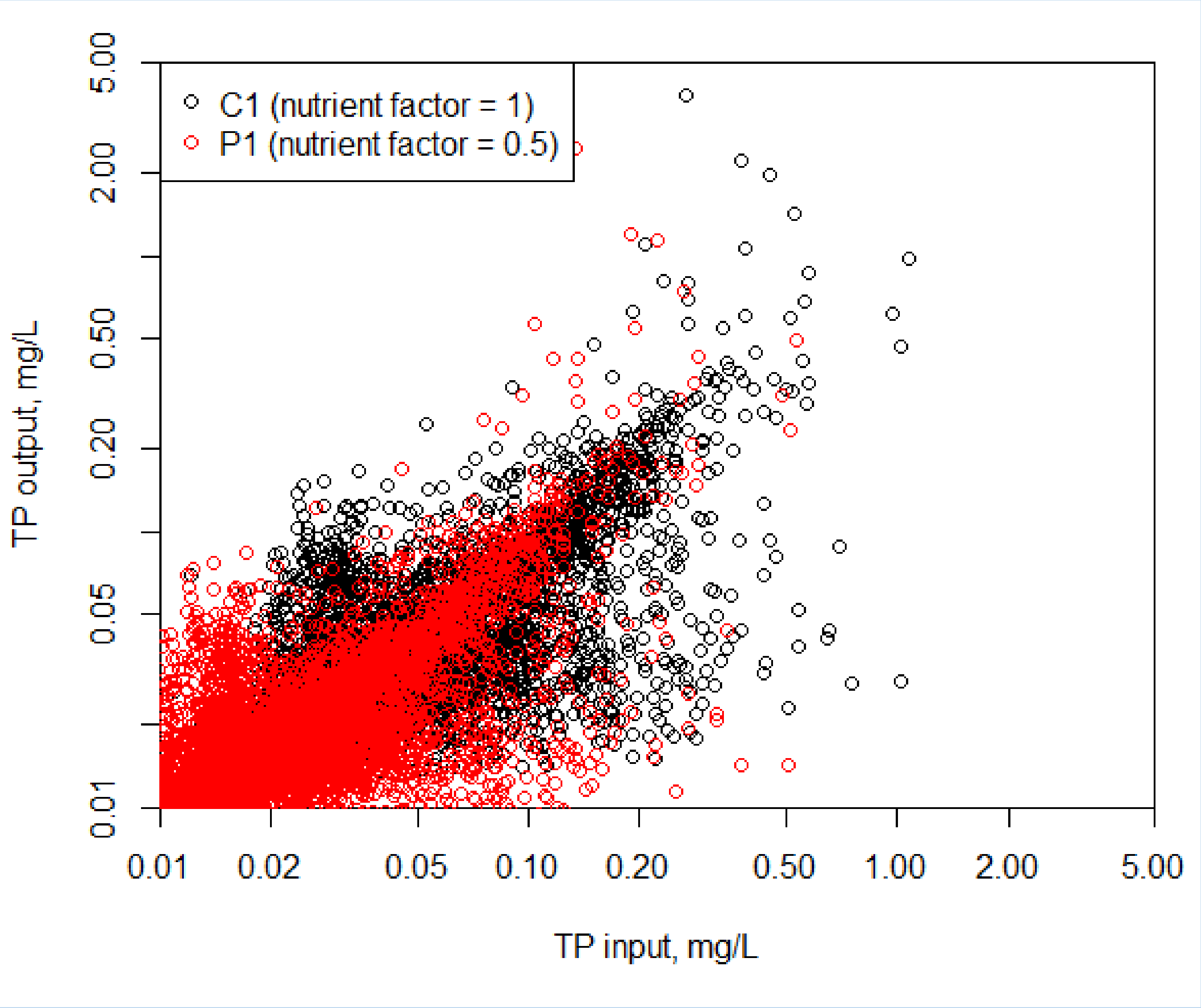


III. Input Scenario and G1/G2/G3 Analysis

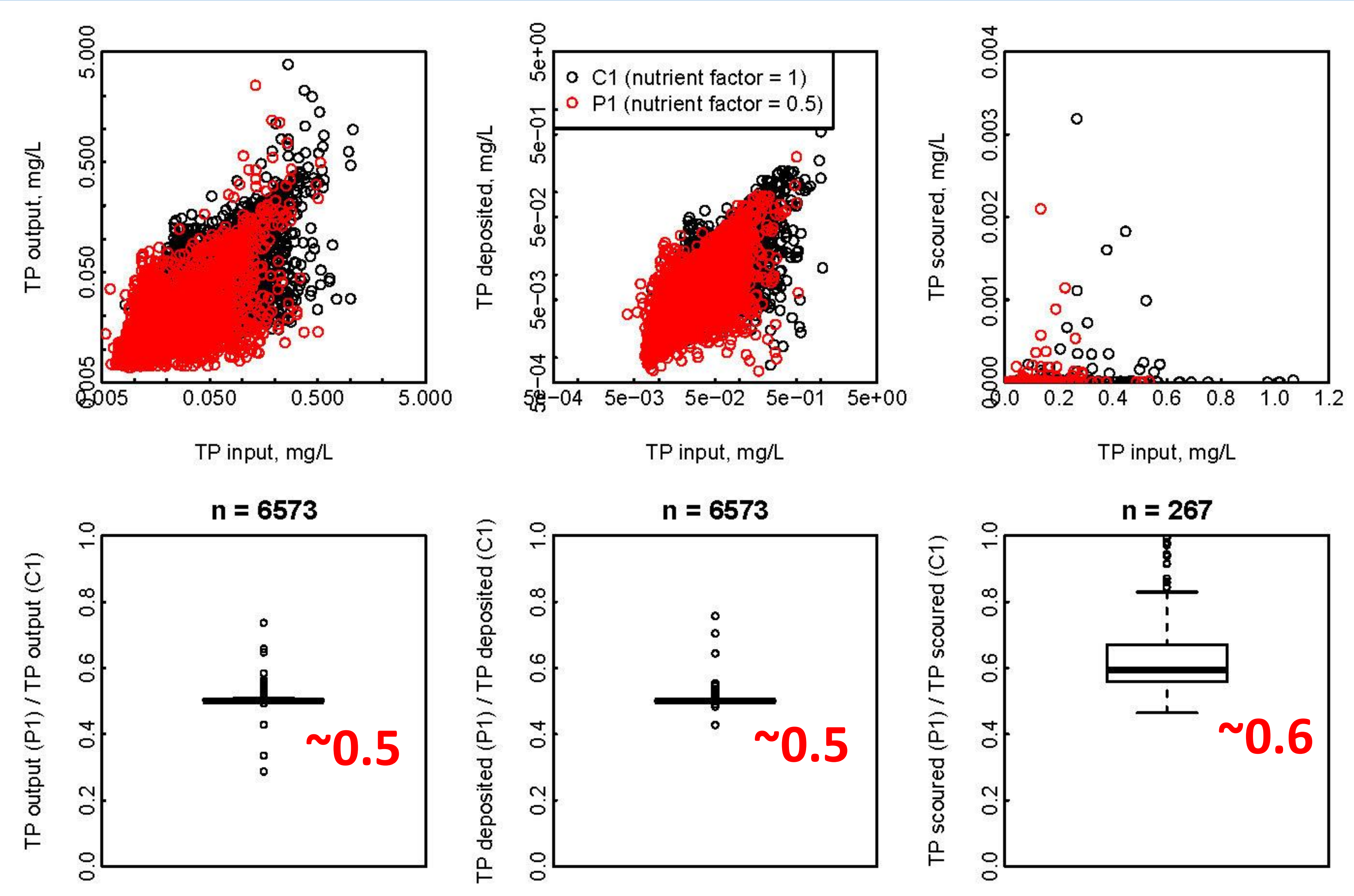
HDR Model: Scenarios

Bathymetry	Nutrient Factor	Sediment Factor	Flux Model
97-14	1	1	C1
97-14	0.5	1	P1
97-14	0.85	1	P2
97-14	1.2	1	P3
14+	1	1	C2
14+	0.5	0.65	P4
14+	0.85	0.895	P5
14+	1.2	1.14	P6

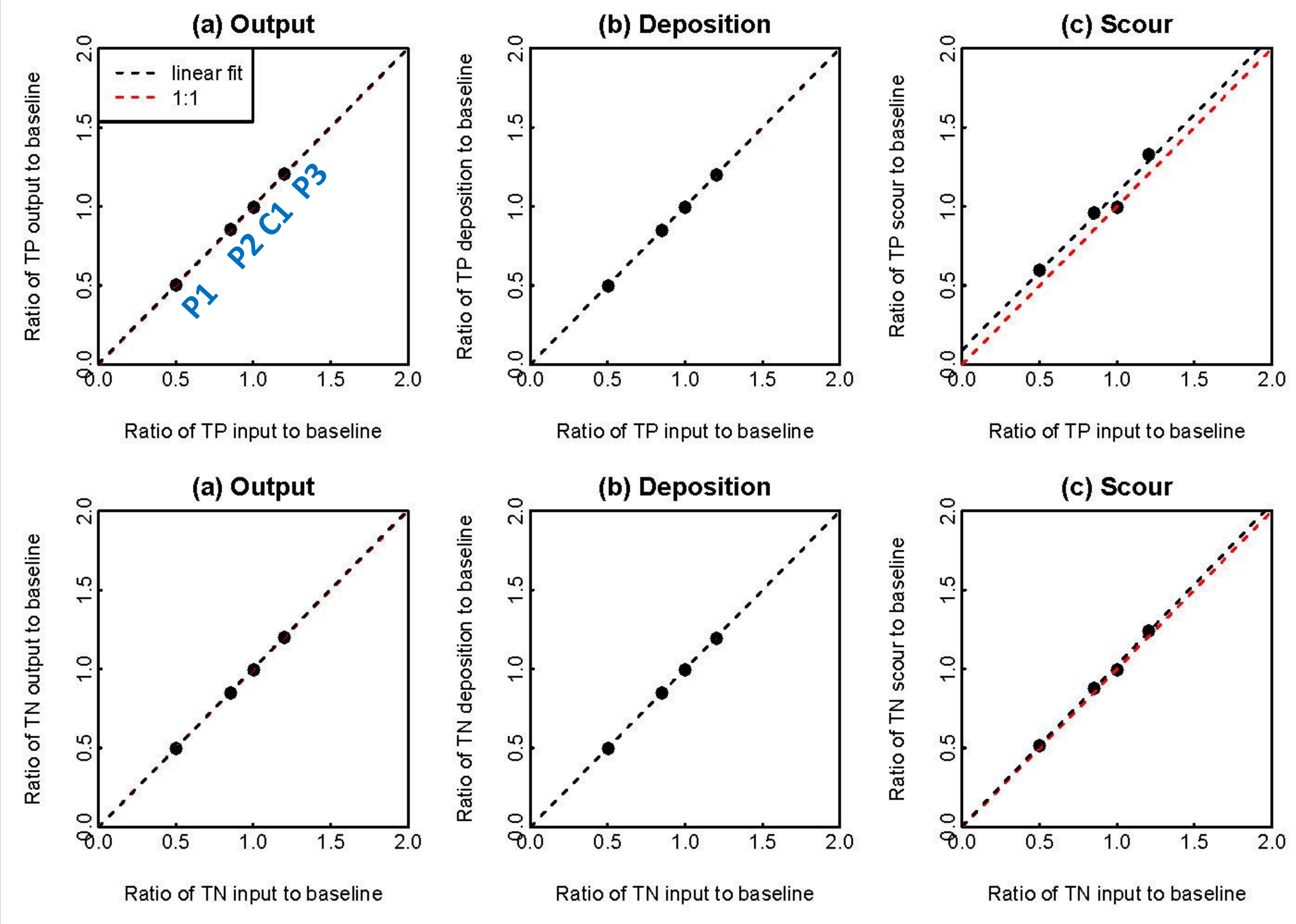
HDR Model: Output vs. Input



HDR Model: Output, Deposition, Scour



HDR Model: Output, Deposition, Scour

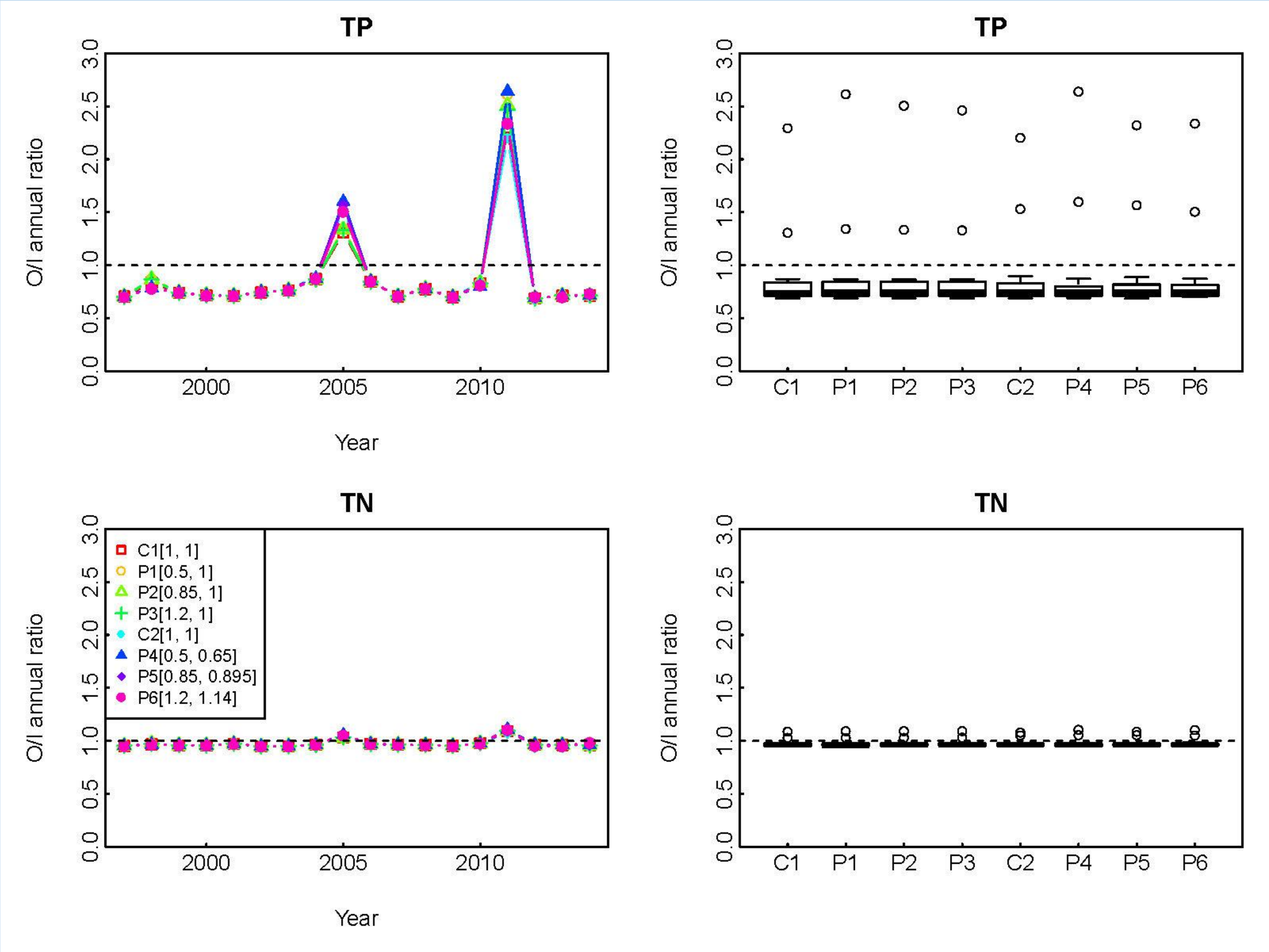


HDR Model: Scenarios

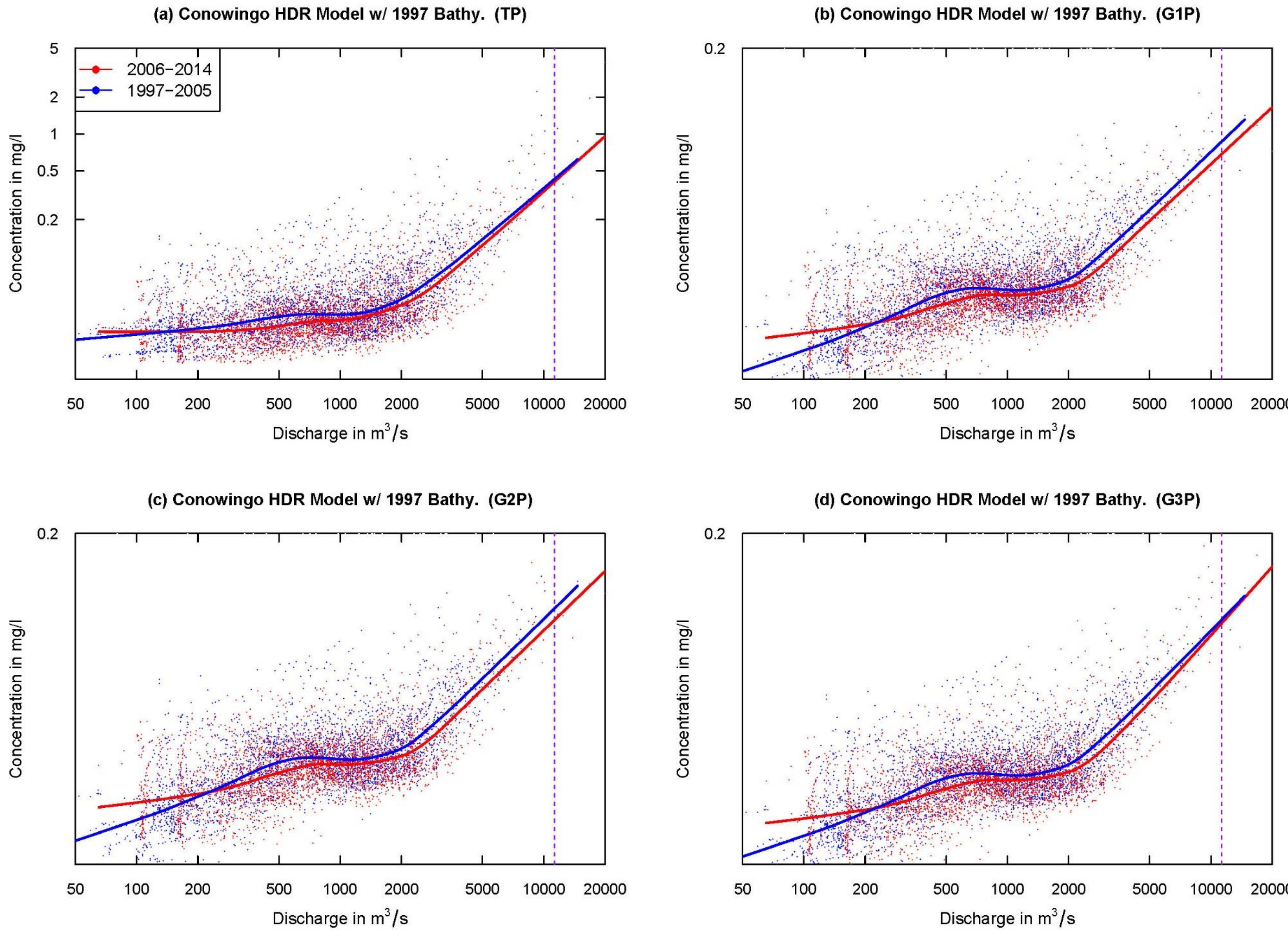
Bathy metry	Nutrient Factor	Sediment Factor	Flux Model	TN Output, x 10^6 lb/yr	TN Input, x 10^6 lb/yr	**TN O/I**	TP Output, x 10^6 lb/yr	TP Input, x 10^6 lb/yr	**TP O/I**
97-14	1	1	C1	151	153	**0.98**	7.6	7.4	**1.03**
97-14	0.5	1	P1	75	77	**0.98**	4.0	3.7	**1.08**
97-14	0.85	1	P2	128	131	**0.98**	6.6	6.3	**1.06**
97-14	1.2	1	P3	181	184	**0.98**	9.4	8.9	**1.05**
14+	1	1	C2	151	153	**0.98**	7.6	7.4	**1.03**
14+	0.5	0.65	P4	76	77	**0.98**	4.1	3.7	**1.10**
14+	0.85	0.895	P5	128	131	**0.98**	6.6	6.3	**1.05**
14+	1.2	1.14	P6	176	179	**0.98**	8.7	8.6	**1.02**

1. **Based on the O/I ratio (~1.0), the HDR model started at dynamic equilibrium in 1997 and does not change between the 97-14 and the 14+ scenarios.**
2. **The O/I ratio remains essentially the same among different scenarios of input (indicating linearity).**

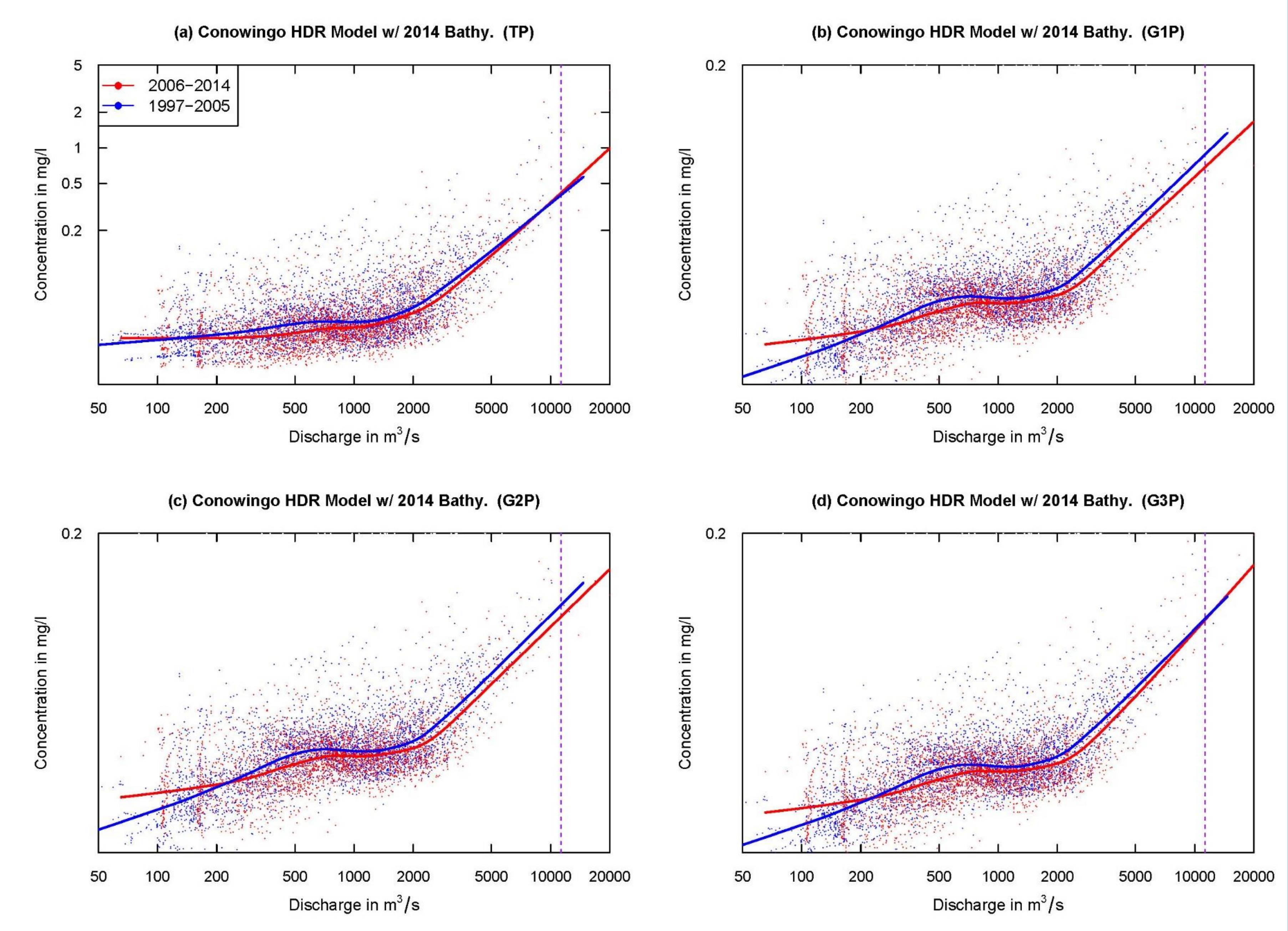
HDR Model: O/I Ratio by Year



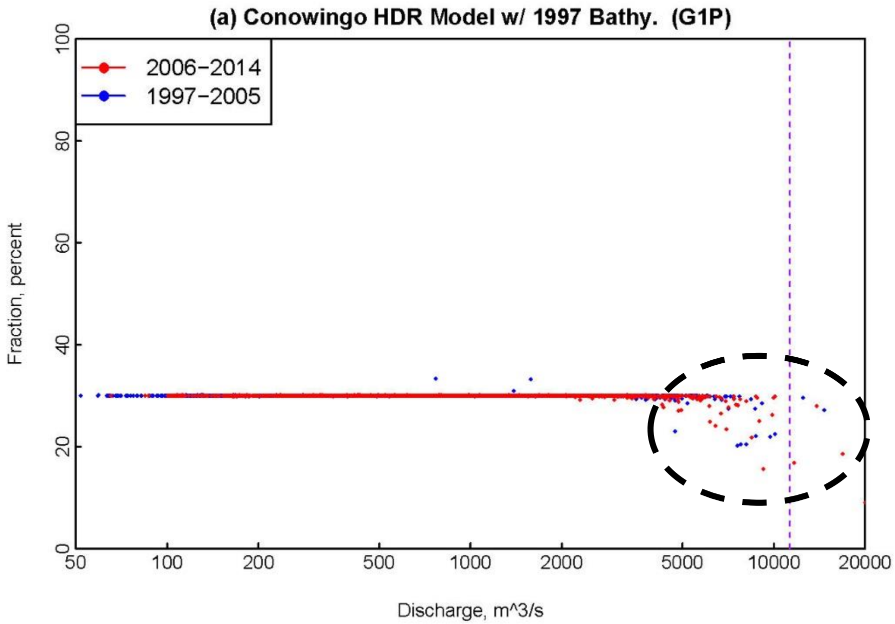
HDR Model: G1P/G2P/G3P (1997 Bathy.)

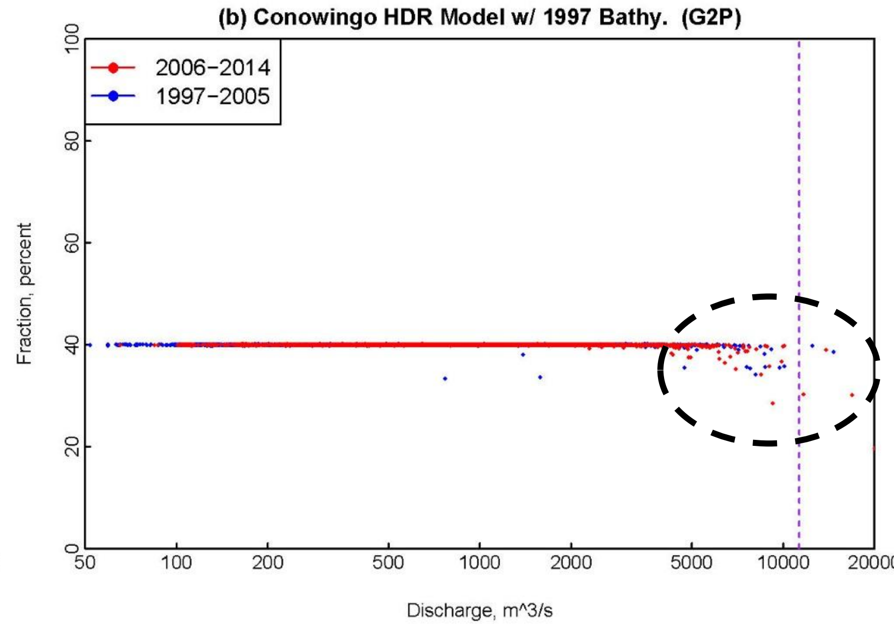


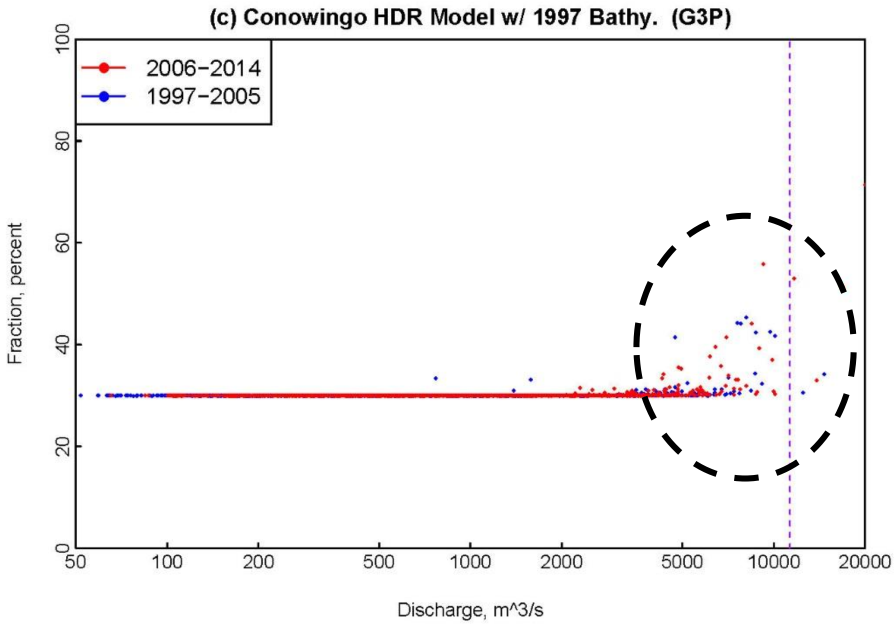
HDR Model: G1P/G2P/G3P (2014 Bathy.)



HDR Model: G1P/G2P/G3P (1997 Bathy.)

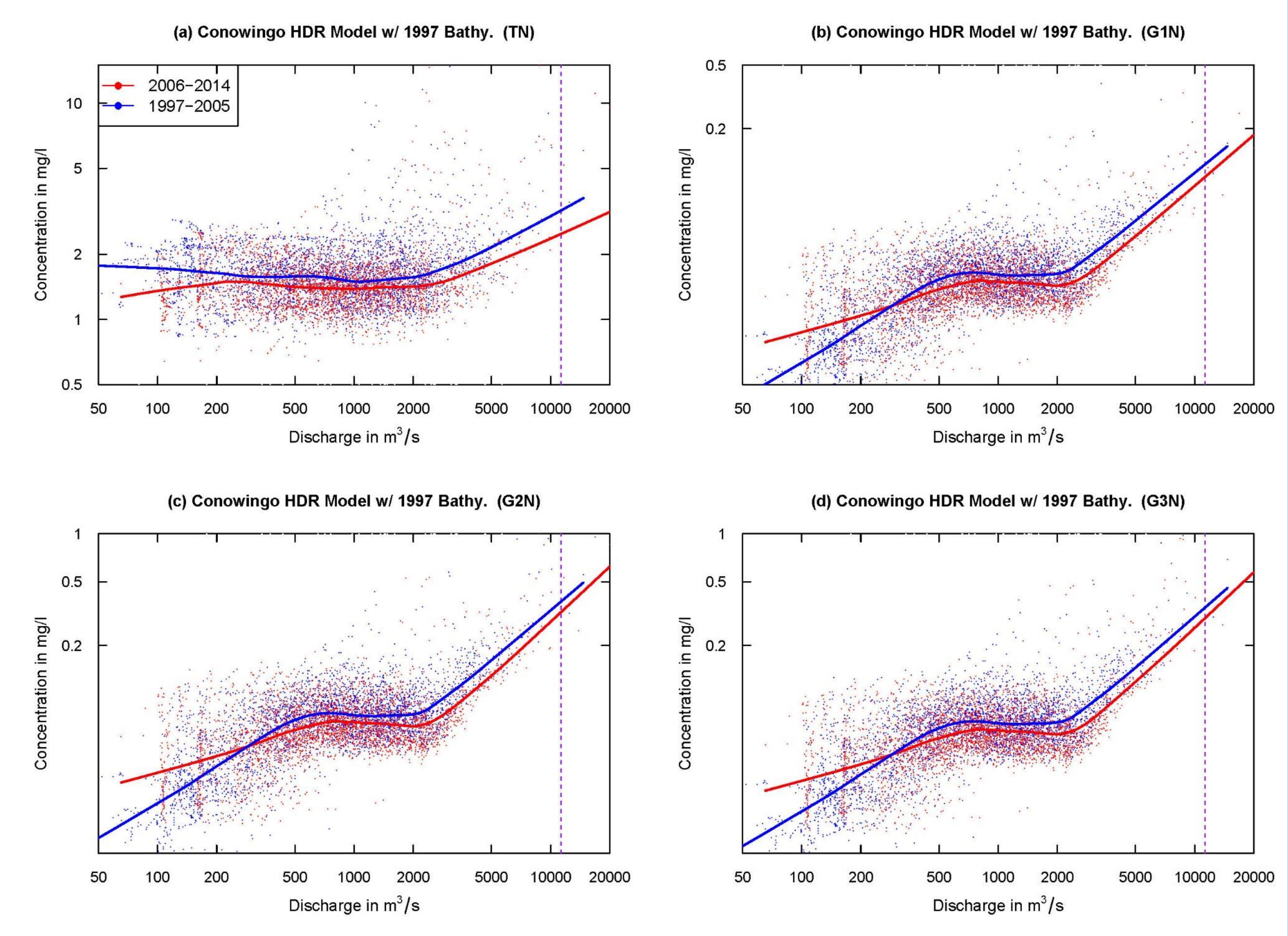




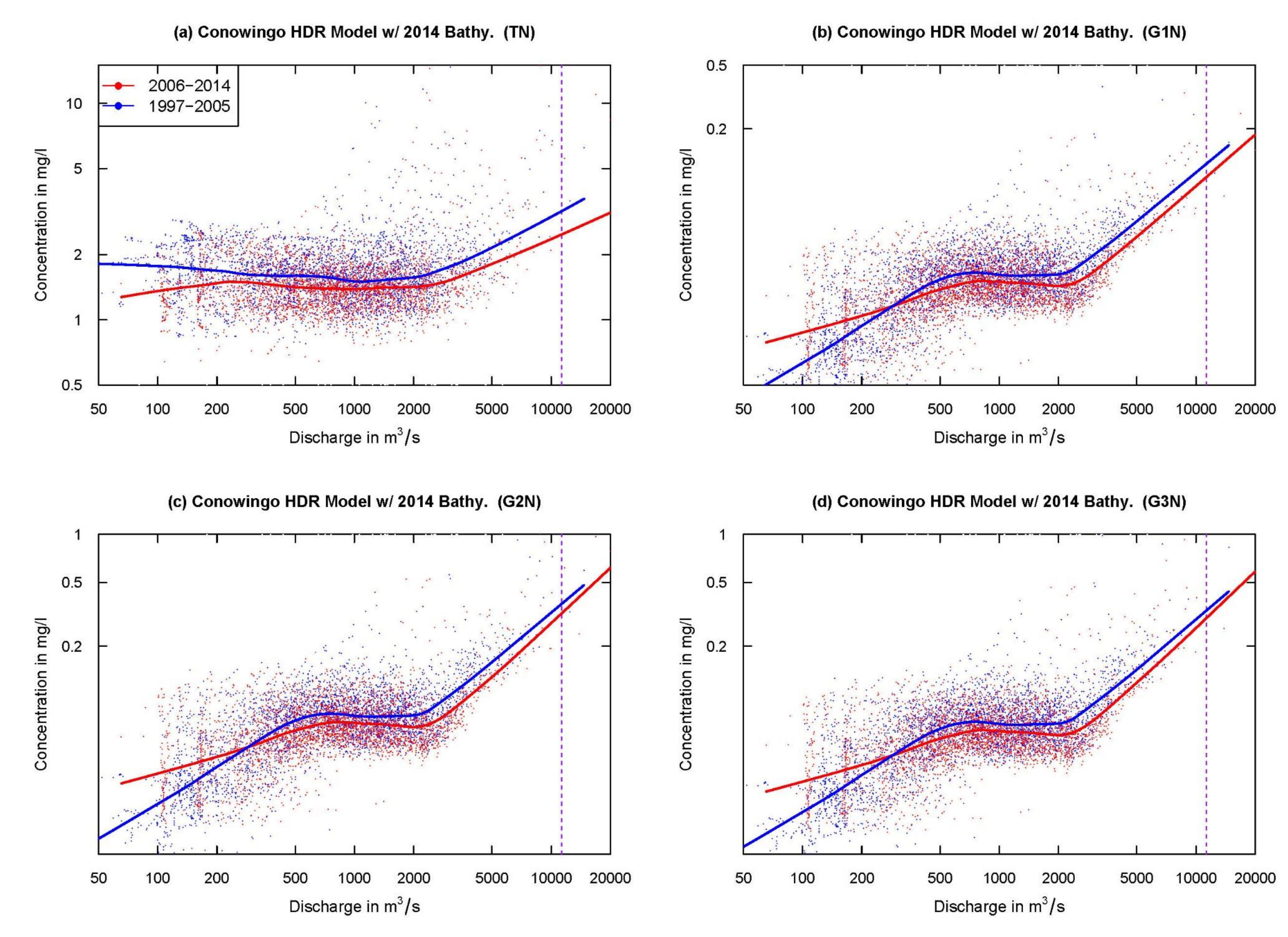


G1/G2 fractions decrease at high flows
G3 fraction increases at high flows

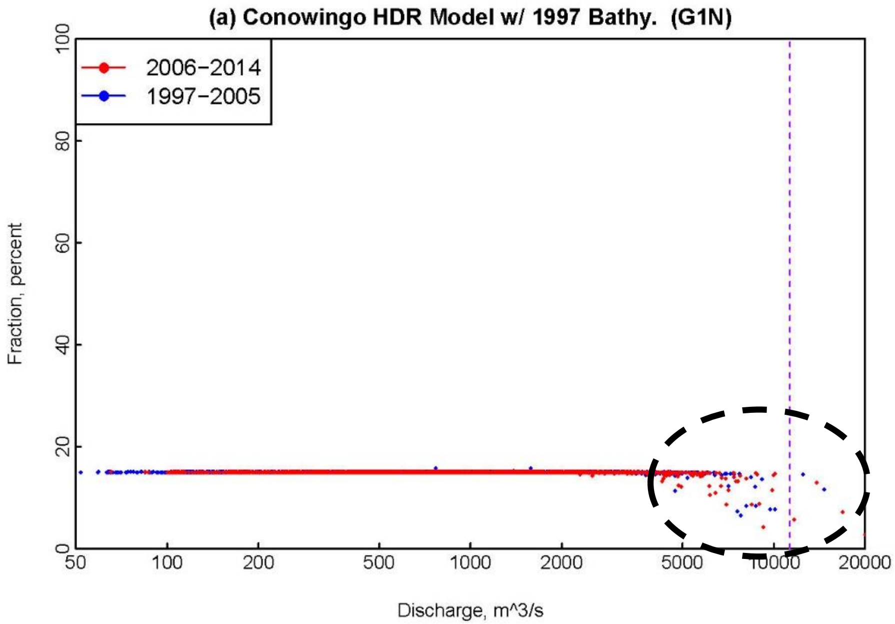
HDR Model: G1N/G2N/G3N (1997 Bathy.)

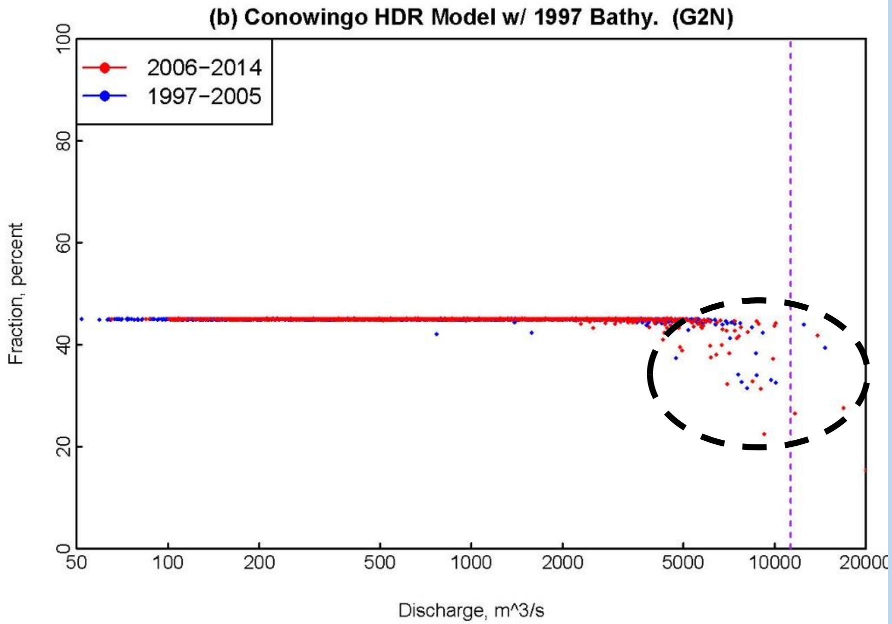


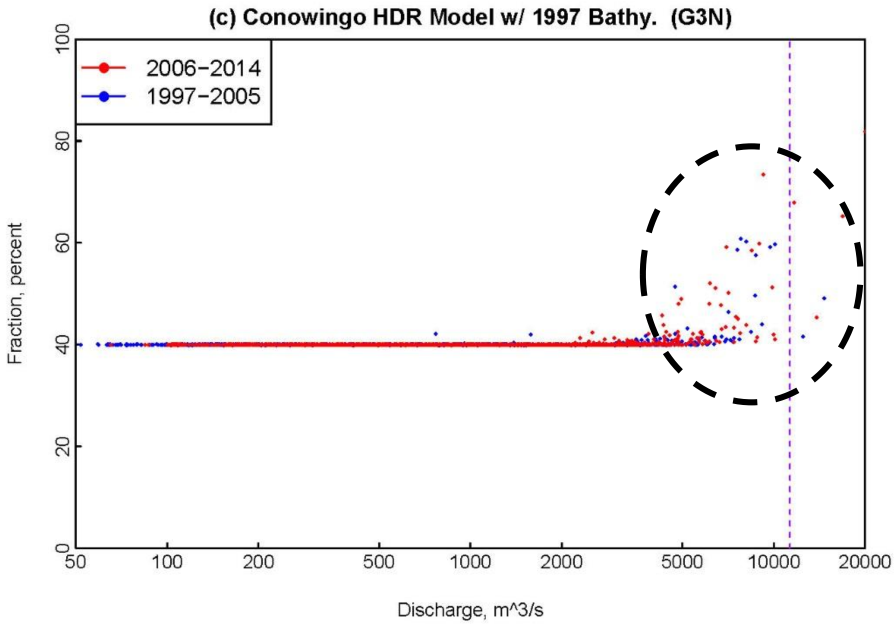
HDR Model: G1N/G2N/G3N (2014 Bathy.)



HDR Model: G1N/G2N/G3N (1997 Bathy.)







G1/G2 fractions decrease at high flows
G3 fraction increases at high flows

Summary (I)

- The HDR model and the WRTDS analysis were compared to observational data.
- **<u>Concentration-discharge analysis</u>**: Both WRTDS and the HDR model appear to represent the overall structure of the concentration discharge relationship, indicating that both methods simulate the reservoir dynamics reasonably well. WRTDS is able to capture the temporal evolution of the concentration-discharge relationship, but HDR appears not adequate in this regard.
- **<u>Storm-flux analysis</u>**: It remains vague which model (HDR or WRTDS) better captures extreme events due to lack of monitoring data for the full hydrograph. *<u>These results are associated with higher uncertainties due to the limited quantity and unknown quality of observations</u>*.

Summary (II)

- **<u>Input scenario analysis</u>**: The HDR model indicates virtually identical change in output and deposition compared with the level of change in input, supporting the method used in previous CBP watershed models. The change in scour amount appears to differ slightly from the level of change in input, this may be due to a short spin-up time.
- **<u>G1/G2/G3 analysis</u>**: The HDR model provides new information on the dynamics of G1, G2, and G3 in terms of change in C-Q relationship and in terms of flow effects (*i.e.*, higher G3 fraction but lower G1 and G2 fractions at extreme flows). Such new and unique information might be used to inform the WSM.

Phase 6 Conowingo Simulation Strategy

Multiple models and lines of evidence

- Direct Use
  - HDR
  - WRTDS
- Supporting Evidence
  - Langland studies
  - LSRWA
  - Observations

Questions
CBPO-proposed Answers

- How does the scour and deposition change with bathymetry?
  - WRTDS
- How does the Output/Input ratio change with nutrient reductions?
  - HDR
- What are the fractions of G1/G2/G3 organics?
  - HDR

Beta 4 Estimated Infill Influence on Deep Chanel DO

Scenario Start Cbseg	Description End State	**Base Calibration** 1993-1995 Deep Channel DO	**Base Calibration w/ Conowingo Infill** 1993-1995 Deep Channel DO	**WIP2** 1993-1995 Deep Channel DO	**WIP2 w/ Conowingo Infill** 1993-1995 Deep Channel DO
CB3MH	MD	16.0%	17.5%	0.1%	0.1%
CB4MH	MD	46.0%	47.6%	6.8%	8.1%
CB5MH	MD/VA	14.2%	15.8%	0.0%	0.0%
CHSMH	MD	37.4%	37.4%	8.7%	8.7%
POTMH	MD/VA	20.2%	21.6%	0.0%	0.0%
POMMH	MD	20.4%	21.7%	0.0%	0.0%
RPPMH	VA	19.0%	24.2%	0.0%	0.0%
EASMH	MD	25.4%	26.7%	3.9%	5.4%
MD5MH	MD	21.7%	23.1%	0.0%	0.0%
VA5MH	VA	4.5%	6.2%	0.0%	0.0%
PATMH	MD	24.8%	26.1%	0.0%	0.5%