September 30, 2014

Phase 6 Watershed Model Prototype:

calibration, sensitivity, & key scenarios using Breakthrough Curve Approach (PQUAL Strategy)

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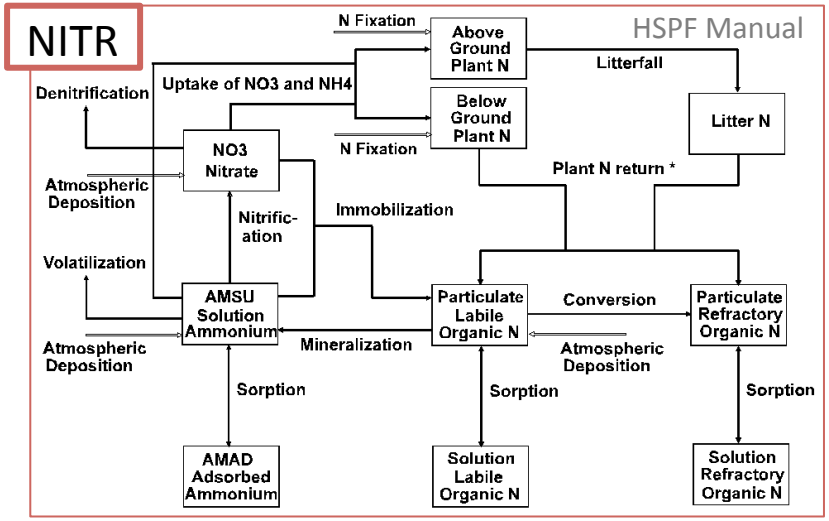
Outline …

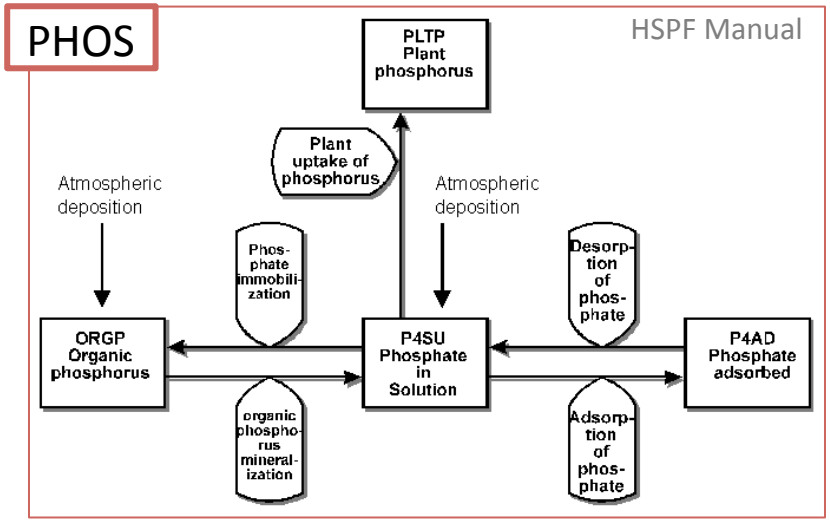
- Overview of Breakthrough Curve (BTC) Approach
  - A refined PQUAL strategy using breakthrough curves
- Calibration and Scenario Modes of Nutrient Simulation
  - Land nutrient export calibration to EOF targets
  - Brief overview of sensitivity
  - Procedural details of sensitivities in model & prototype
  - Key management scenarios using draft sensitivities
- Refinements to Nutrient Calibration: Land – River Linkage
  - Parameterization of the breakthrough curves

Overview of Breakthrough Curve Approach

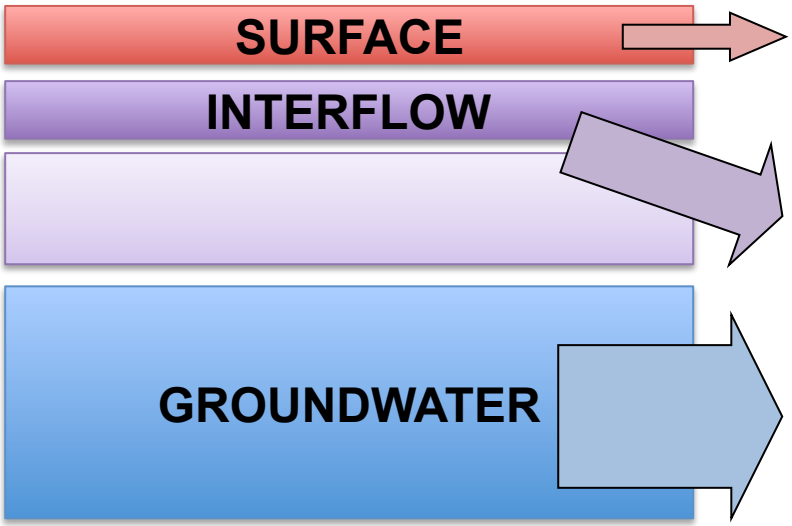
NITR



PHOS



PQUAL



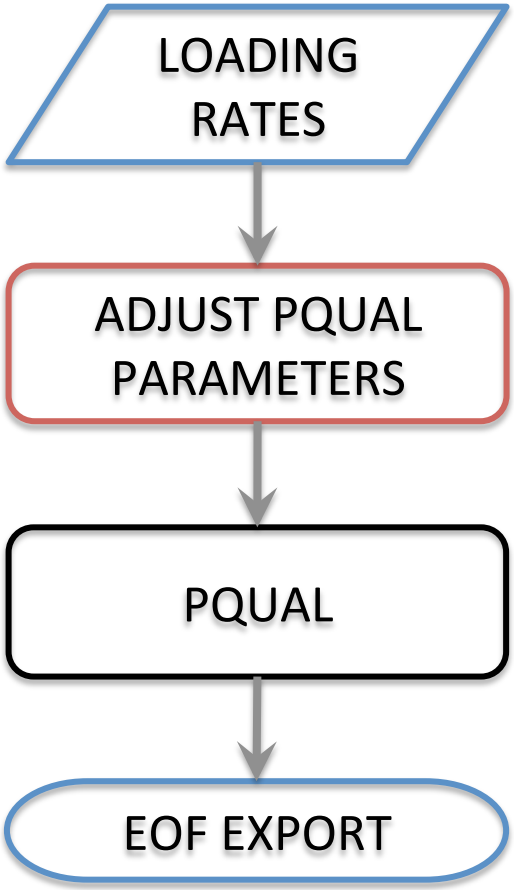
NH3 = Flow x Conc.
+ Sed x factor

NH3 = Flow x Conc.

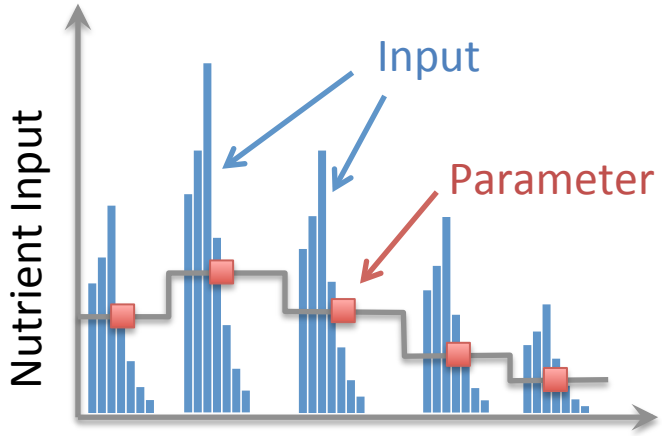
NH3 = Flow x Conc.

Adapted from Shenk, 2009

Land Simulation using PQUAL

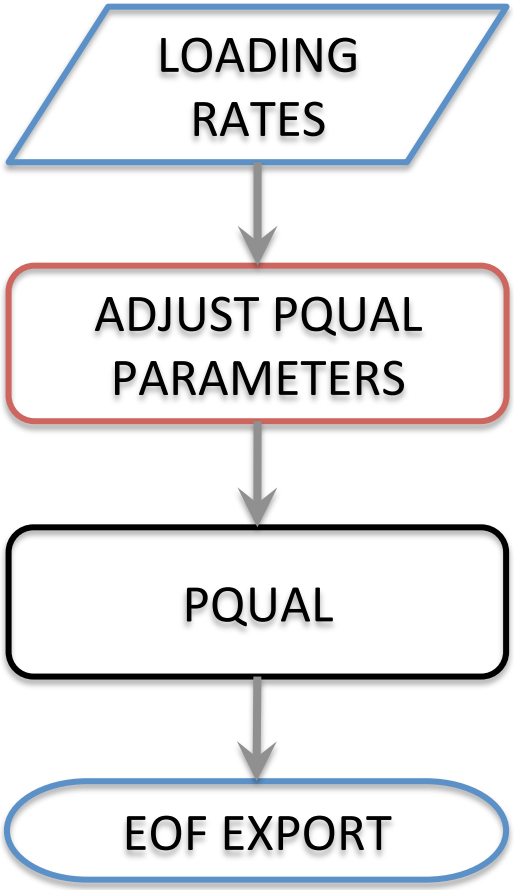


During calibration average PQUAL parameters are annually varied based on annual input loads.



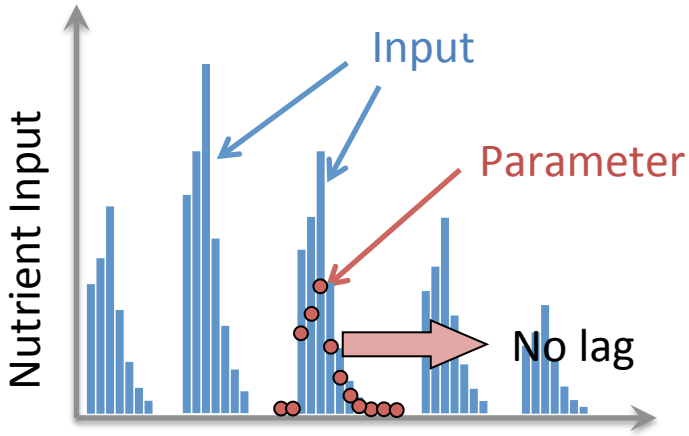
This acts as a mechanism to translate inter annual variability in inputs (e.g. atmospheric deposition, fertilizer, manure) to model output (EOF Export).

Land Simulation using PQUAL



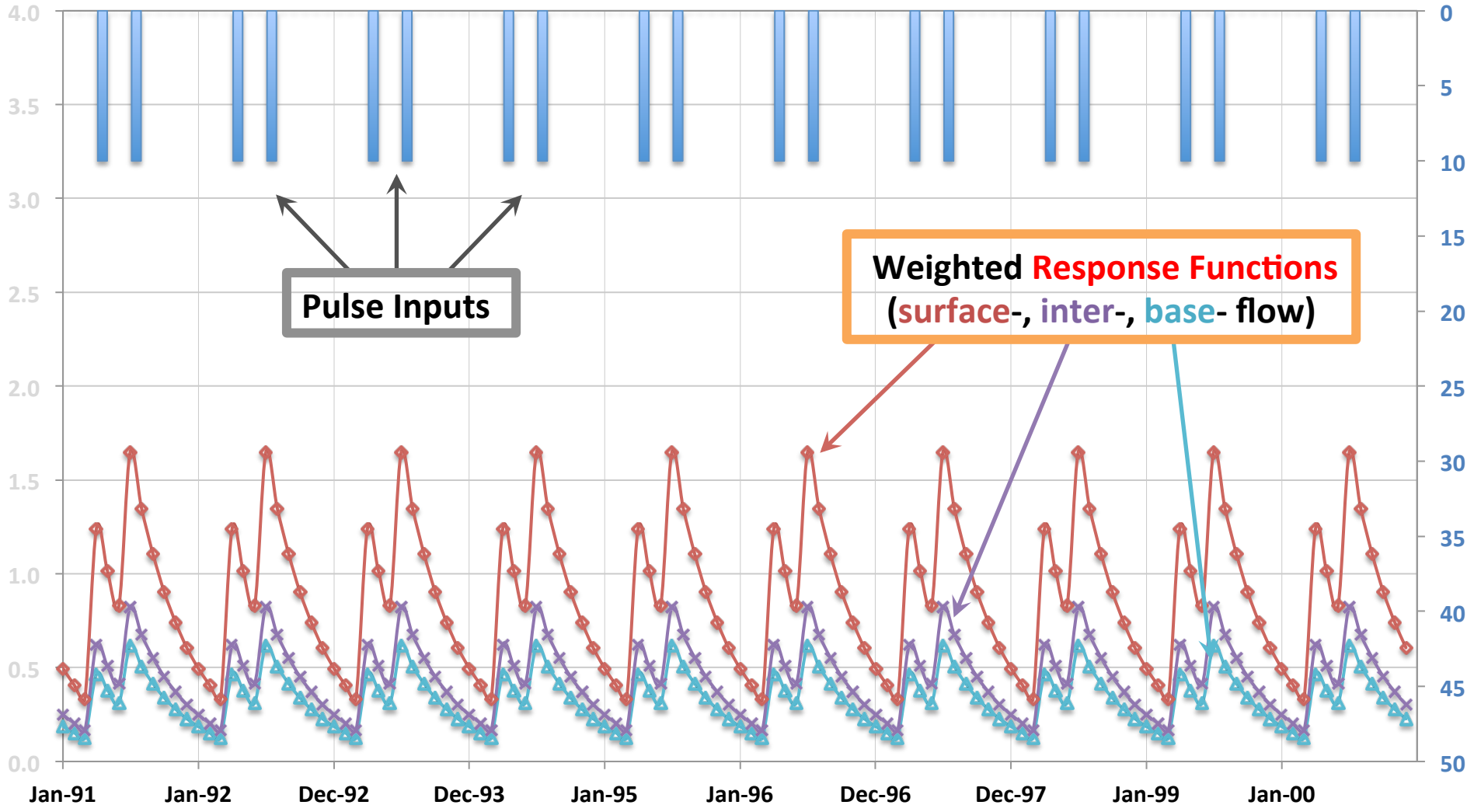
As a result, simulated response do not see any intra-annual variability in input.

Shortening the time-scale (e.g., month) would help but we would not be able to account for lag in response.



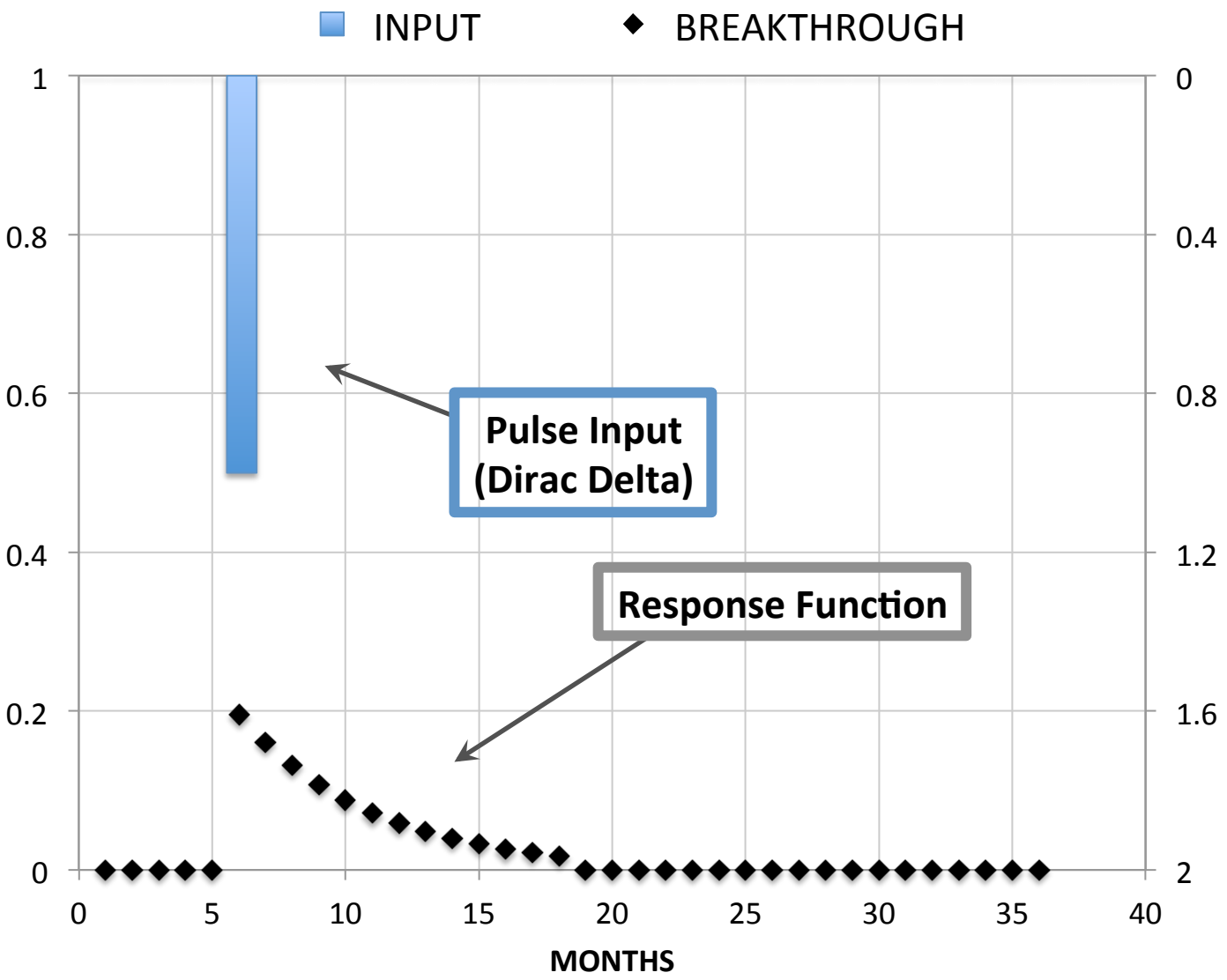
We need a new strategy!

A Simple Spreadsheet based Example …

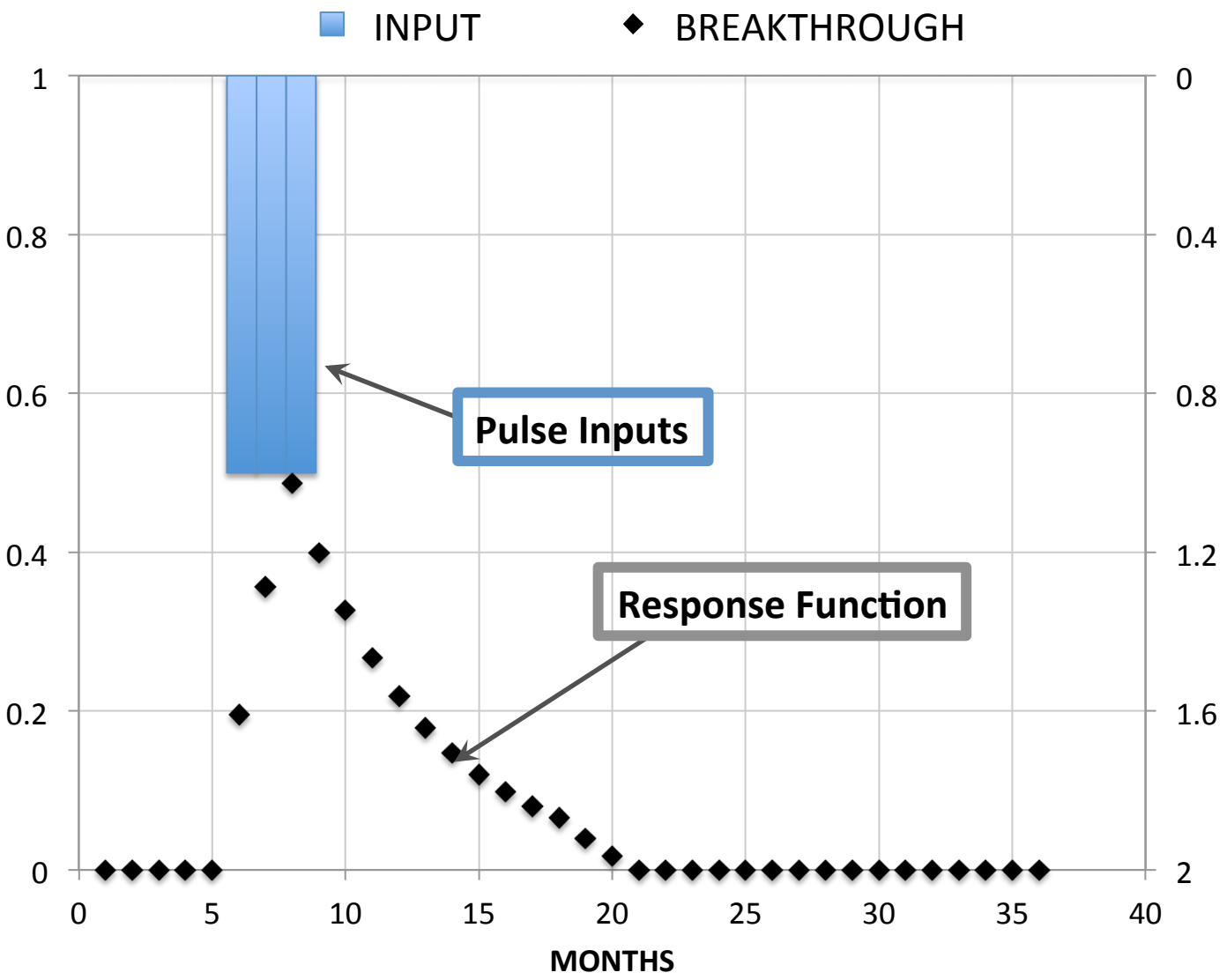


Note: Response functions are analogous to PQUAL concentrations.

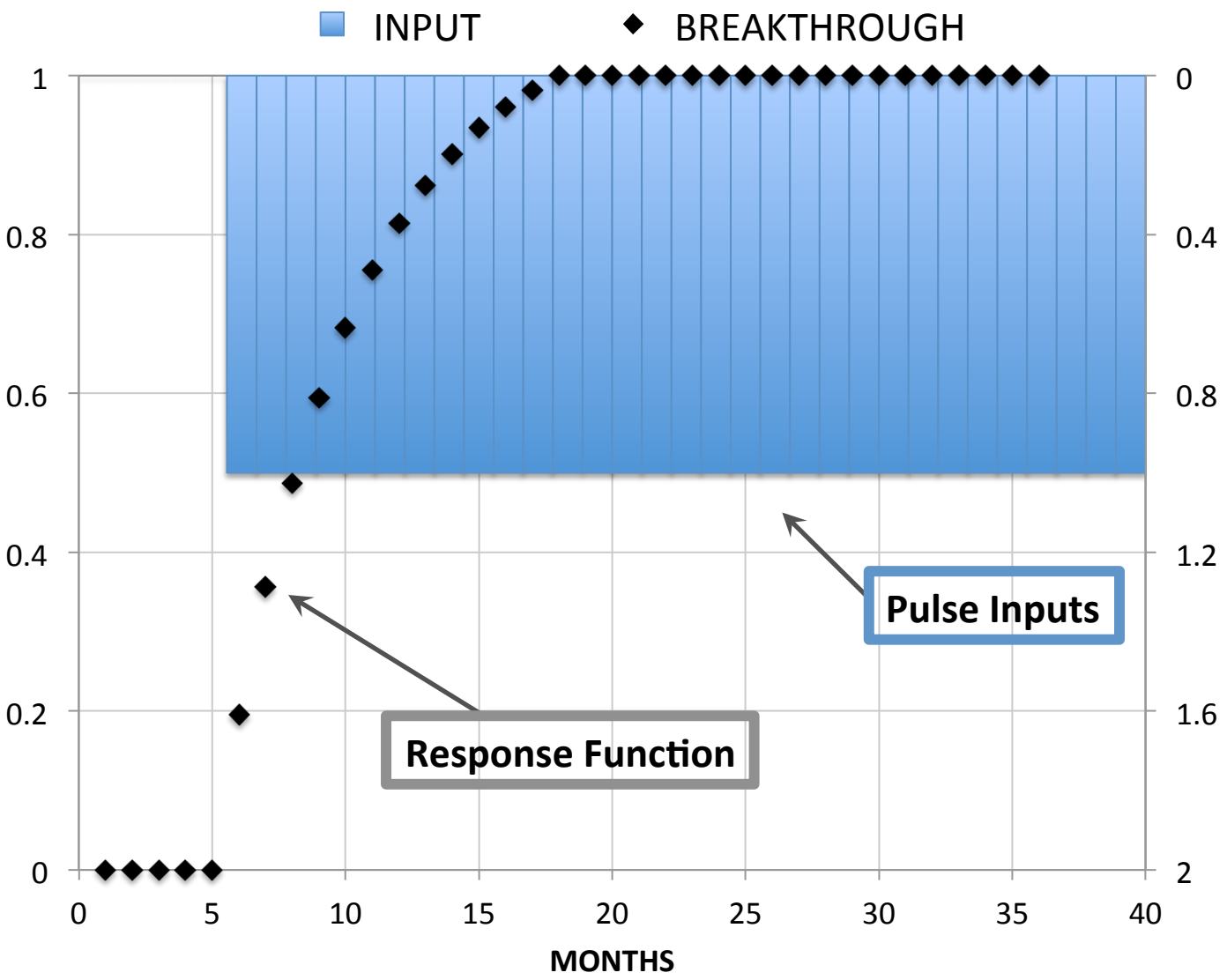
Development & Testing of Refinements to Nutrient Simulation

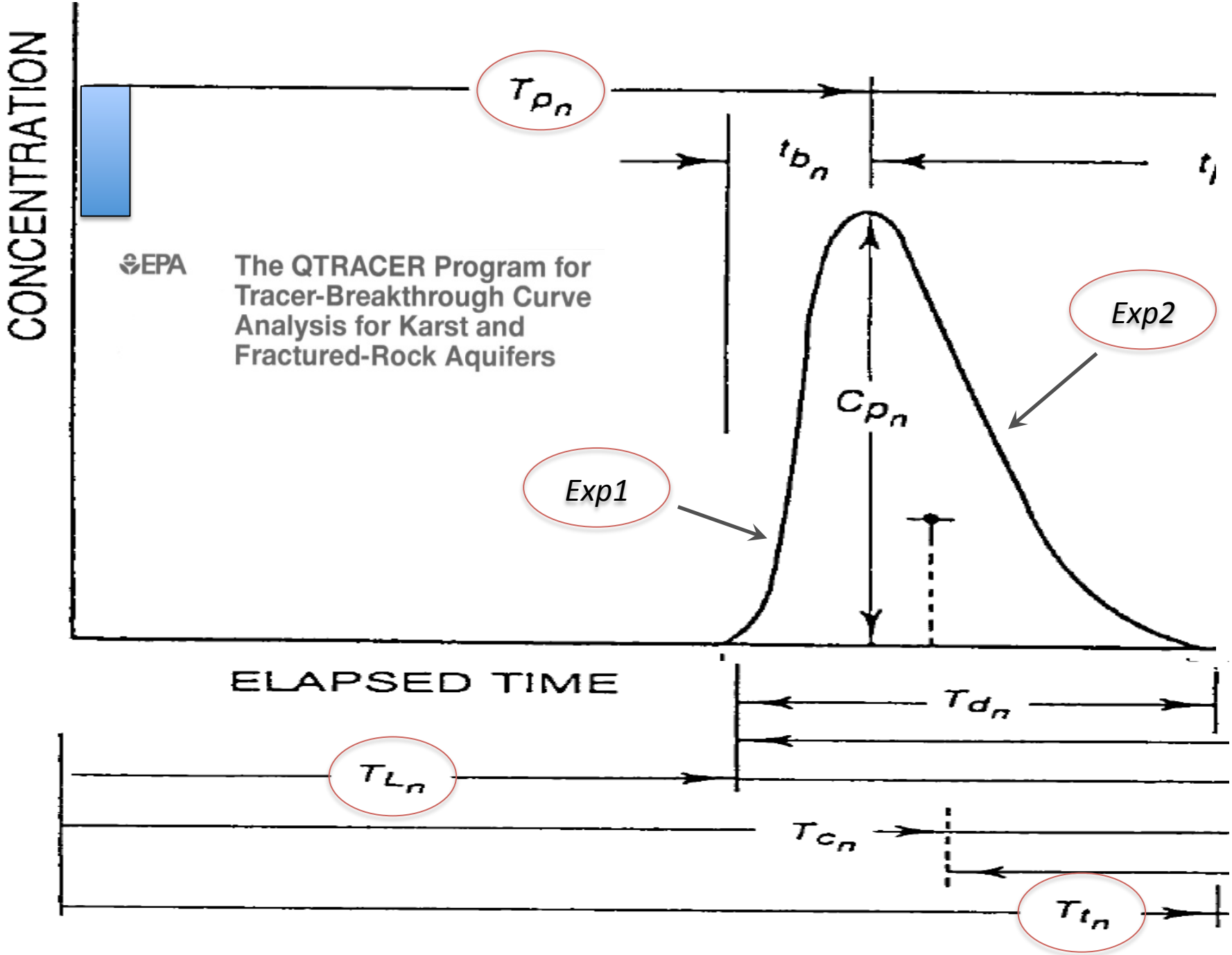


Development & Testing of Refinements to Nutrient Simulation



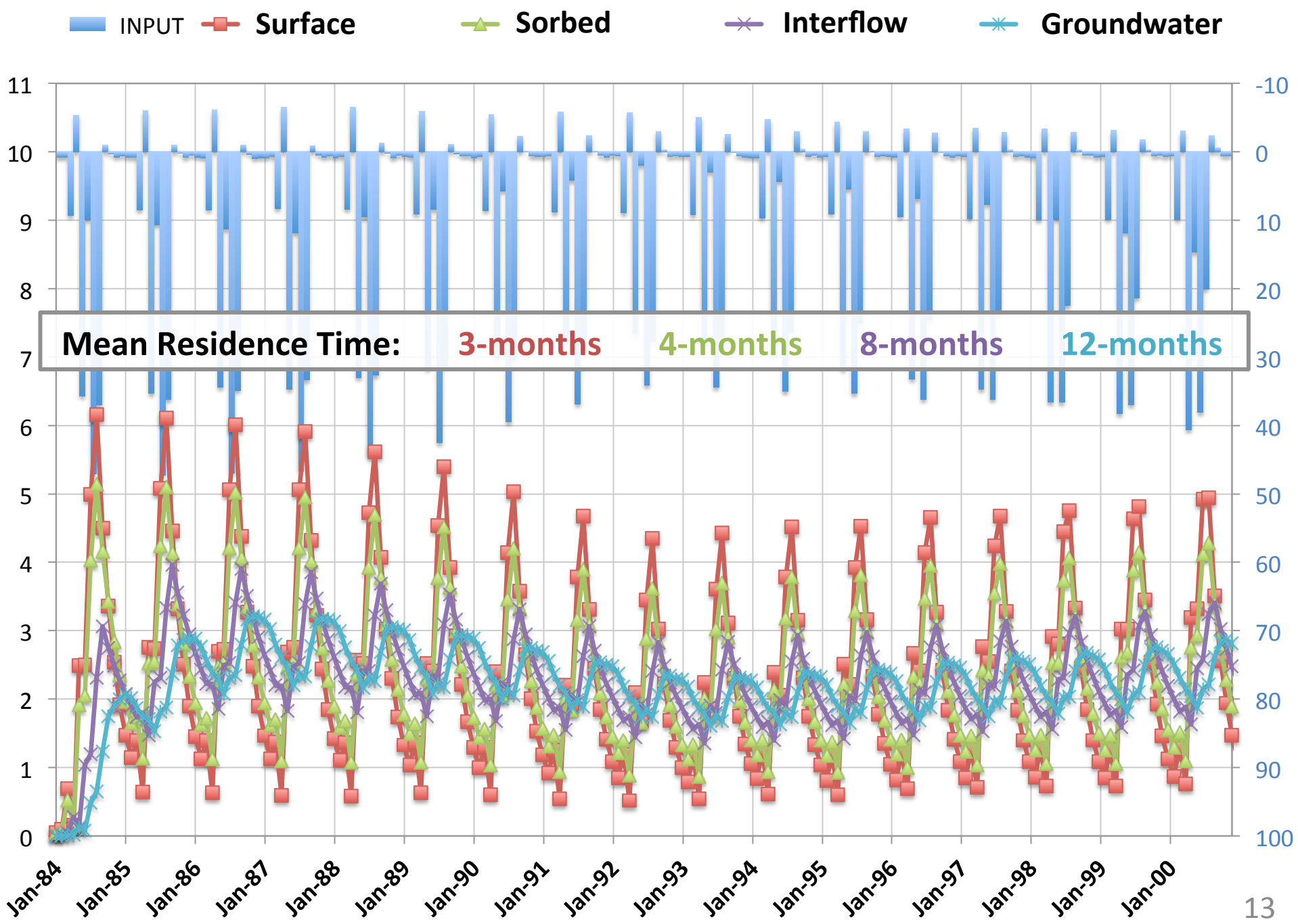
Development & Testing of Refinements to Nutrient Simulation





http://www.epa.gov/ncea/pdfs/qtracer/qtracerch03.pdf

Calibration and *Scenario* Modes of Nutrient Simulation

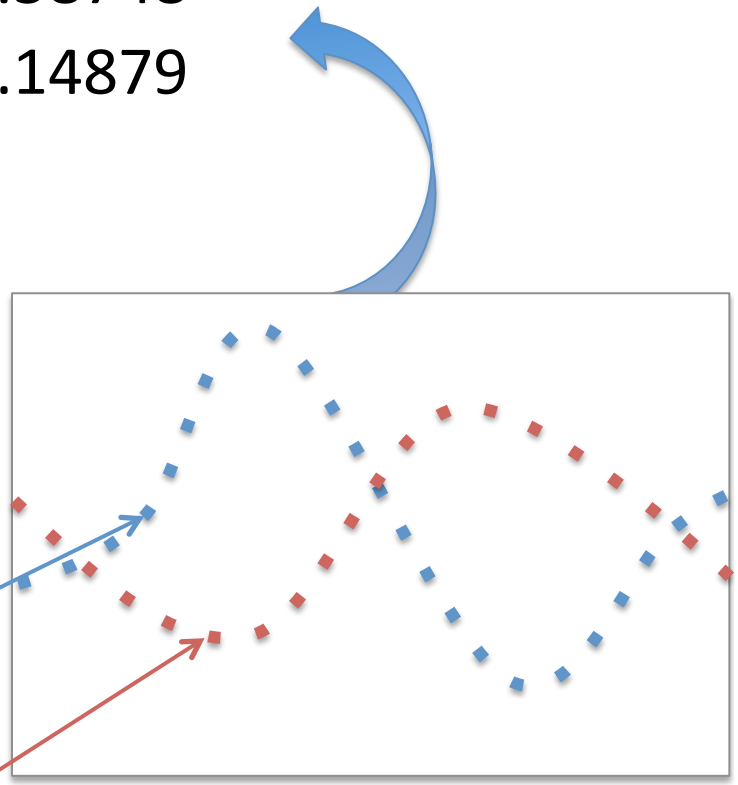

INPUT
Surface
Sorbed
Interflow
Groundwater
Mean Residence Time:
3-months
4-months
8-months
12-months
11
10
9
8
7
6
5
4
3
2
1
0
-10
0
10
20
30
40
50
60
70
80
90
100
Jan-84
Jan-85
Jan-86
Jan-87
Jan-88
Jan-89
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Jan-00

Land nutrient export calibration to EOF targets

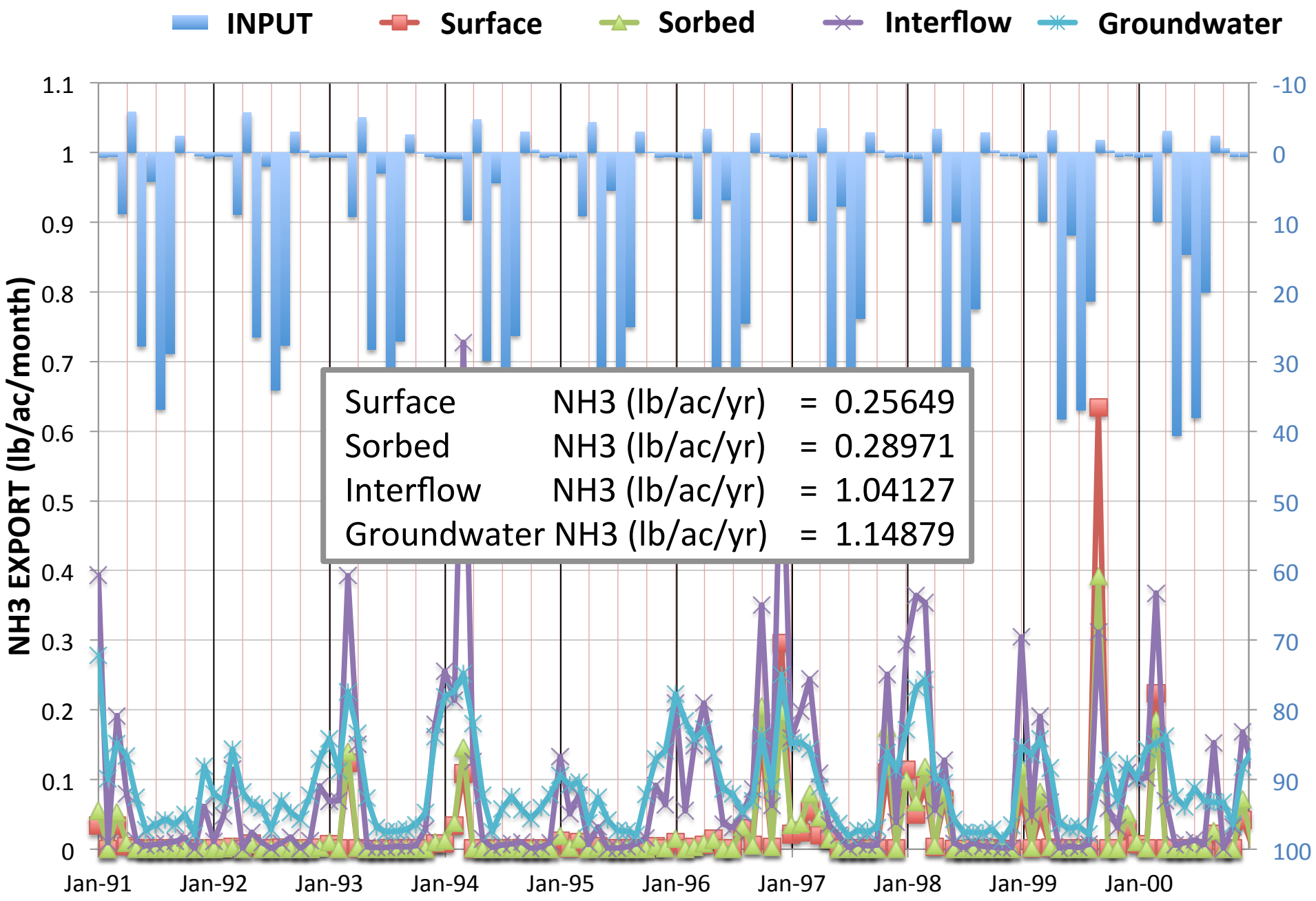
E.g. Calibration : : A10001 HOM (**h**igh till w/**o** **m**anure)

- EOF Export Targets:
  - **Stormflow** **NH3** (lb/ac/yr) = 1.58748
  - **Baseflow** **NH3** (lb/ac/yr) = 1.14879

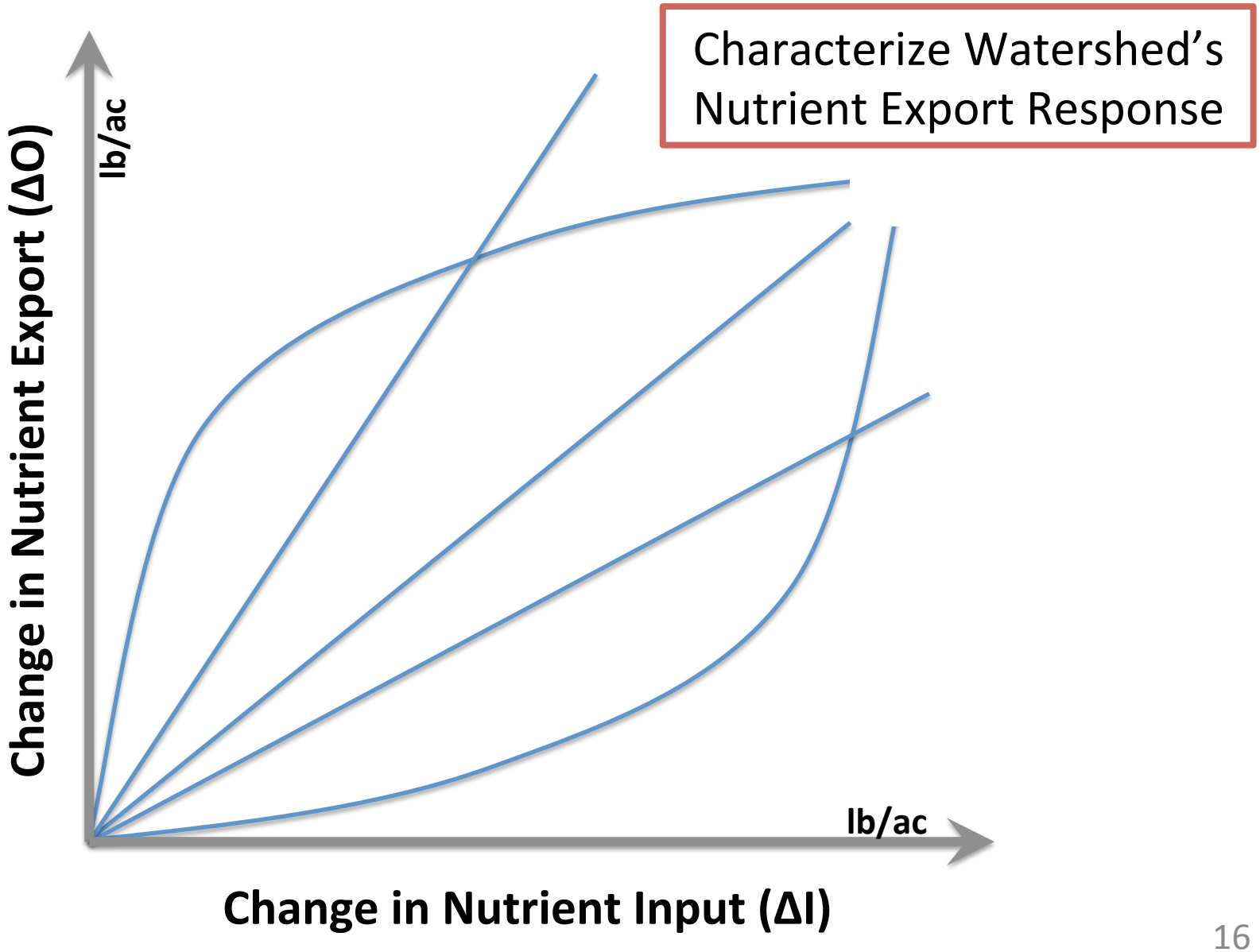
- Flow (PWATER):
  - SURO (in/ac/yr) = 1.07687974
  - WSSD (tn/ac/yr) = 3.18039107
  - IFWO (in/ac/yr) = 3.50402546
  - AGWO (in/ac/yr) = 9.32850075

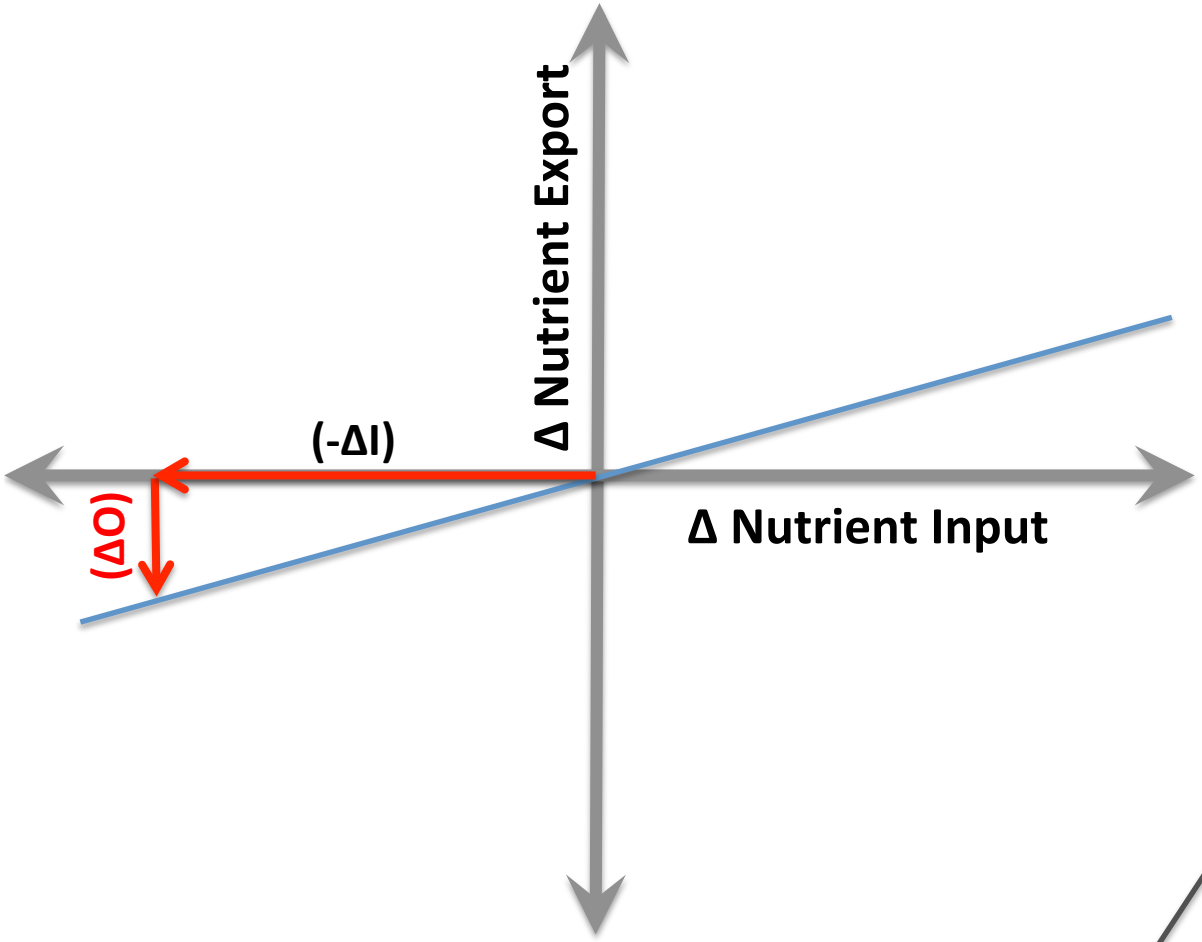


- **Export (hr) = Flow (hr) x Response Function (hr)**

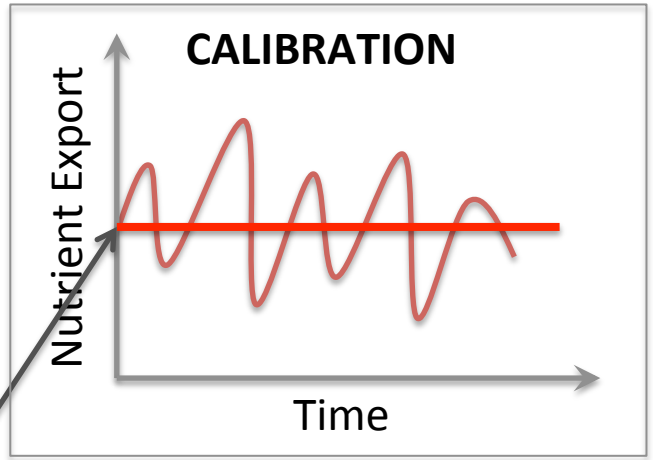

INPUT
Surface
Sorbed
Interflow
Groundwater
NH3 EXPORT (lb/ac/month)
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-10
0
10
20
30
40
50
60
70
80
90
100
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Jan-00
Surface NH3 (lb/ac/yr) = 0.25649
Sorbed NH3 (lb/ac/yr) = 0.28971
Interflow NH3 (lb/ac/yr) = 1.04127
Groundwater NH3 (lb/ac/yr) = 1.14879

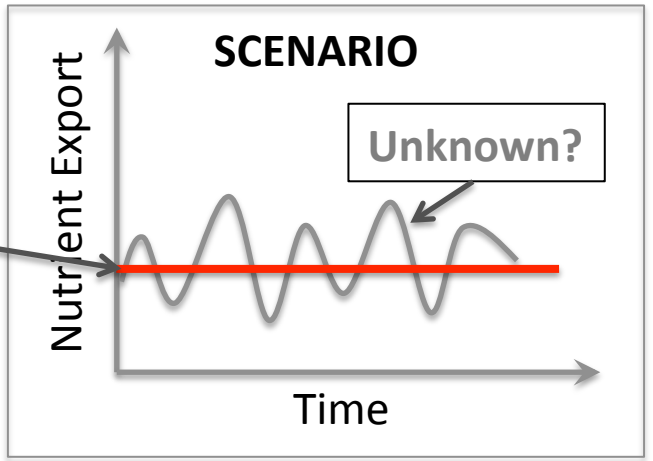
Watershed Model Nutrient Export "Sensitivity"





ΔO is Long-term Change in Nutrient Export (*average annual* change during 1991-2000)





Procedural details of sensitivities in model & prototype

E.g. Scenario : : A10001 HOM

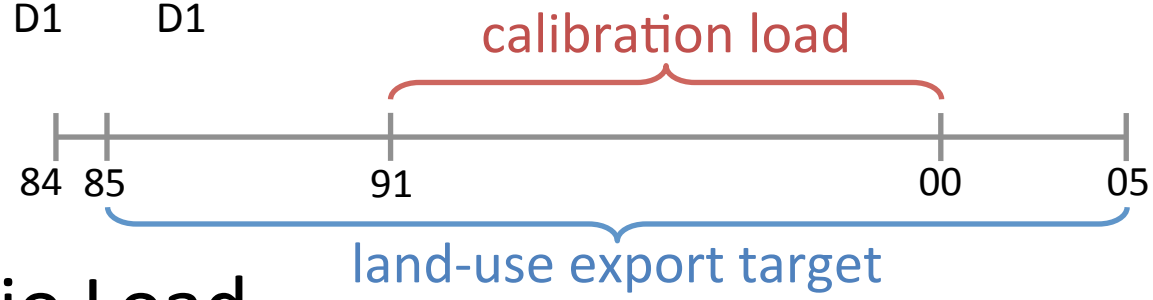
- Read Monthly Inputs for CALIB & SCEN
  - as (AppType, AppSpecies, YY, MM)

- Read Nutrient Export Sensitivities
  - hom_atdep_sensitivity.csv

Sensitivites: A10001

	NH3	NO3	LON	RON	PO4
Sen :	0.43	0.43	0.012	0.012	0.1
Grp :	1	1	2	2	3
Mtd:	D1	D1	D1	D1	D1

Change in Export **ΔO** (lb/ac)



- Calculate Scenario Load

Validation Step 1: EOF Export Calib to Scen

Hand Calculation

Cal Atdep 91-00	1.1109E+02
Sce Atdep 91-00	1.3886E+02
Del (lb/ac/yr) i.e. **ΔI**/10	**2.776486**

2.776486 x **0.430**	**1.1938890**
2.776486 x **0.012**	**0.0333178**

inorganics & organics

LU 5 = hom

QUALS = NH3, NO3, LON, RON, PO4

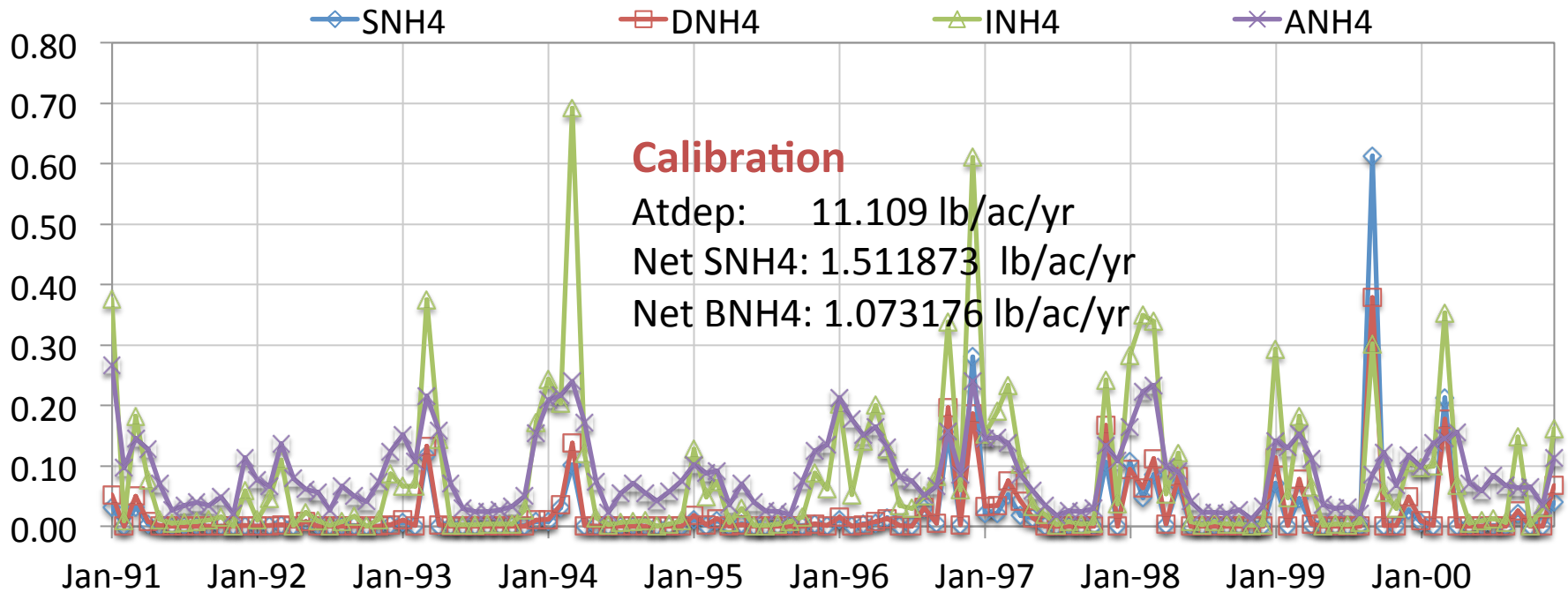
Sensitivity Model

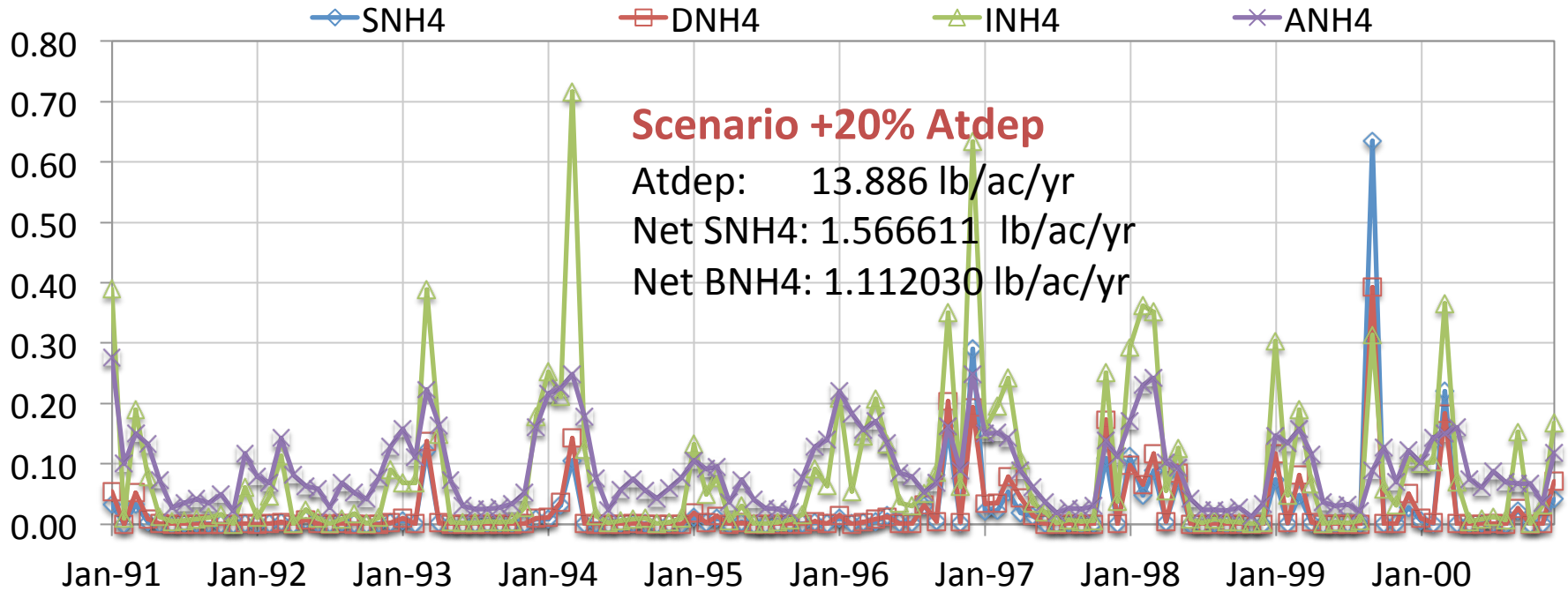
NH3

Surface & Baseflow

LU	QUAL	LoadCal	DelLoad	LoadScen
5	1s	1.5119E+00	5.4741E-02	1.5666E+00
5	1b	1.0732E+00	3.8857E-02	1.1120E+00
5	2s	7.7023E+00	2.7888E-01	7.9812E+00
5	2b	2.2686E+01	8.2141E-01	2.3508E+01
5	3s	2.9496E-01	1.5107E-03	2.9647E-01
5	3b	2.9547E-01	1.5133E-03	2.9698E-01
5	4s	2.9489E+00	1.5103E-02	2.9640E+00
5	4b	2.9658E+00	1.5190E-02	2.9810E+00
5	5s	7.3123E-01	0.0000E+00	7.3123E-01
5	5b	1.1469E-02	0.0000E+00	1.1469E-02

1.1938880
0.0333170


SNH4
DNH4
INH4
ANH4
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Calibration
Atdep: 11.109 lb/ac/yr
Net SNH4: 1.511873 lb/ac/yr
Net BNH4: 1.073176 lb/ac/yr
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Jan-00


SNH4
DNH4
INH4
ANH4
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Scenario +20% Atdep
Atdep: 13.886 lb/ac/yr
Net SNH4: 1.566611 lb/ac/yr
Net BNH4: 1.112030 lb/ac/yr
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Jan-00

Validation Step 2: Simulated Scenario Loads

Adjusted Targets for Scenario

LU	QUAL	LoadCal	DelLoad	LoadScen
5	1s	1.5119E+00	5.4741E-02	**1.5666E+00**
5	1b	1.0732E+00	3.8857E-02	**1.1120E+00**
5	2s	7.7023E+00	2.7888E-01	7.9812E+00
5	2b	2.2686E+01	8.2141E-01	2.3508E+01
5	3s	2.9496E-01	1.5107E-03	2.9647E-01
5	3b	2.9547E-01	1.5133E-03	2.9698E-01
5	4s	2.9489E+00	1.5103E-02	2.9640E+00
5	4b	2.9658E+00	1.5190E-02	2.9810E+00
5	5s	7.3123E-01	0.0000E+00	7.3123E-01
5	5b	1.1469E-02	0.0000E+00	1.1469E-02

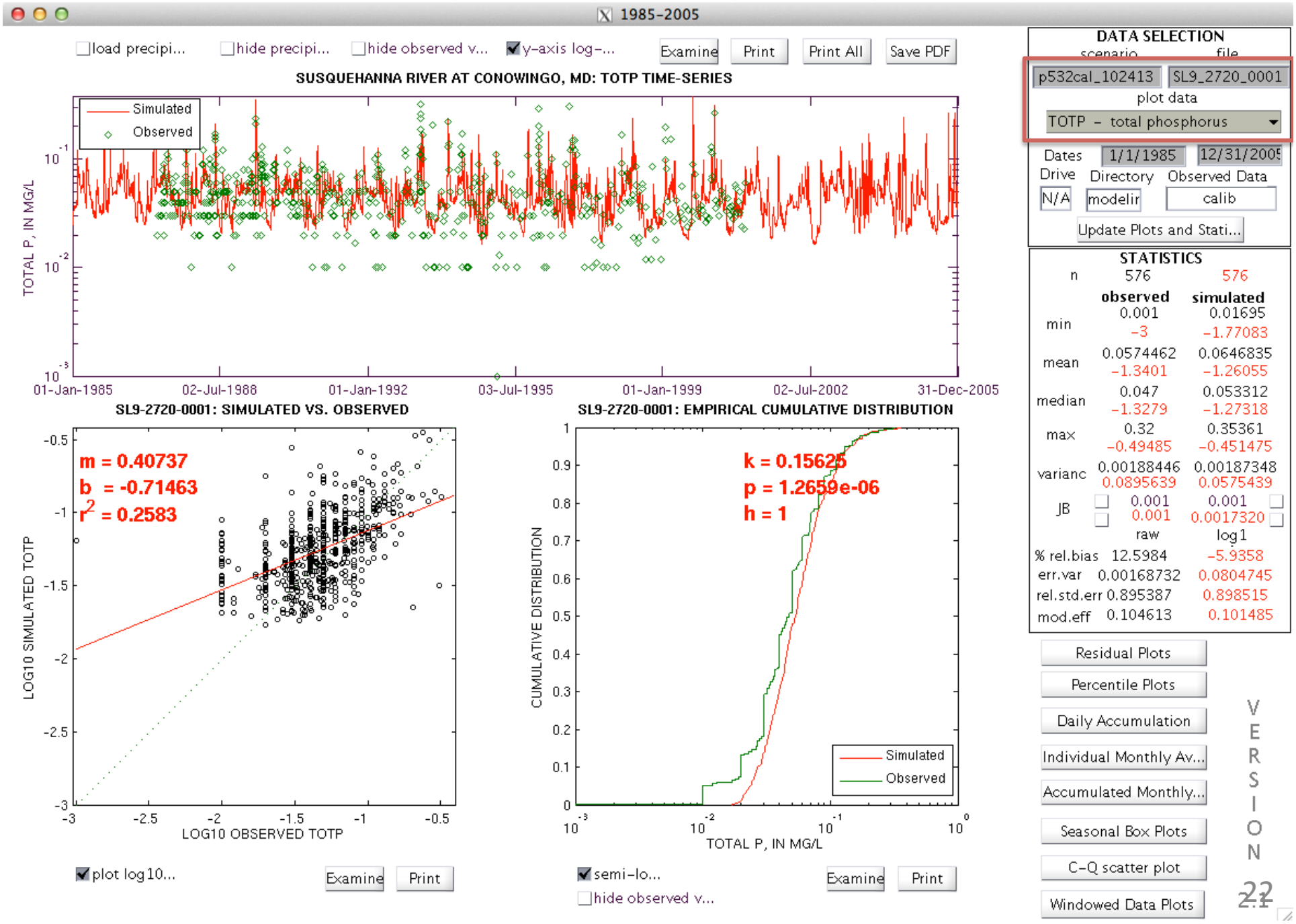
After Simulation EOF Scenario *

SNH3	1.566611
BNH3	1.112030

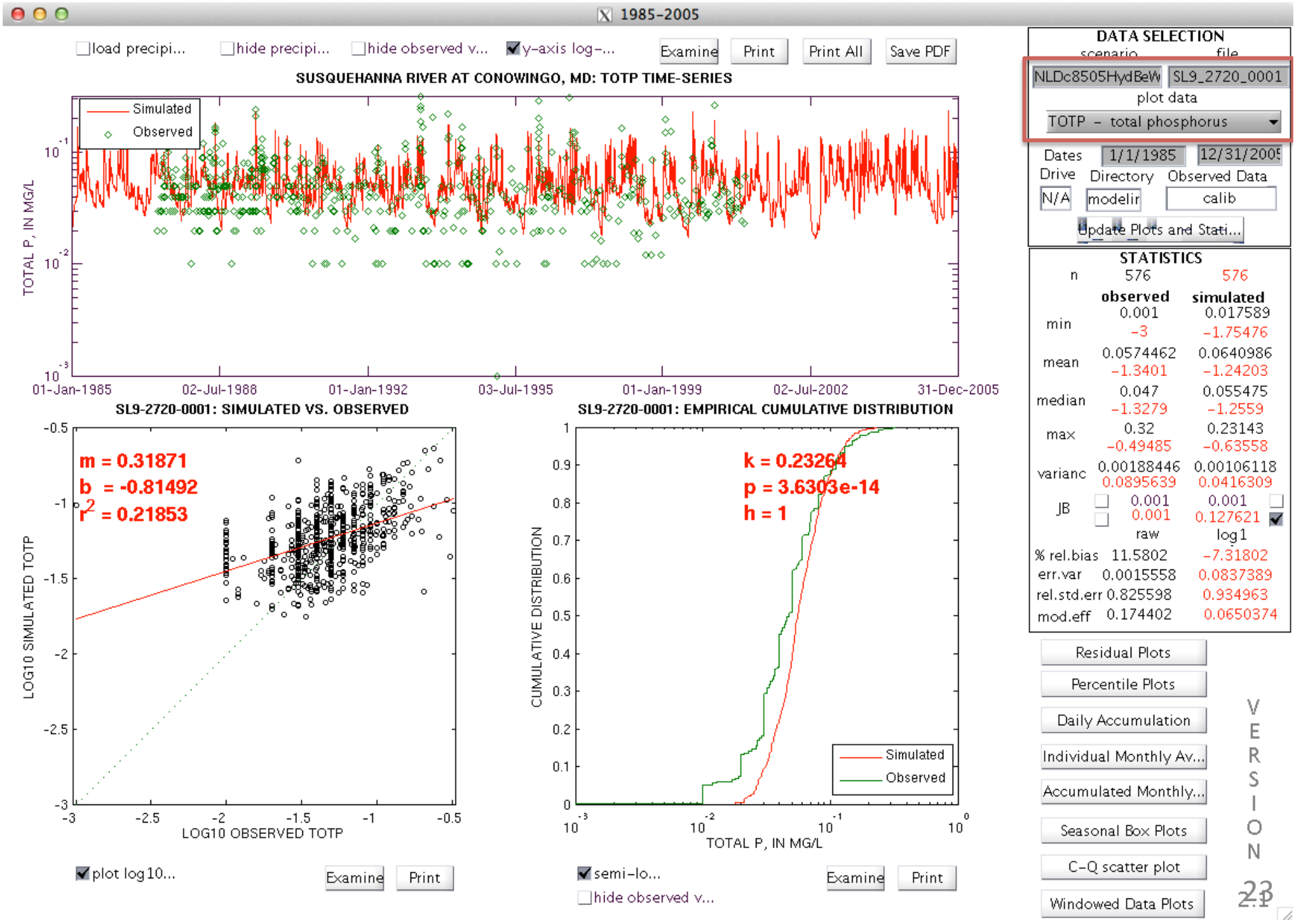
* from WDM file with hourly EOF loads

Precise match between load estimated from *sensitivity* to the WSM simulated load

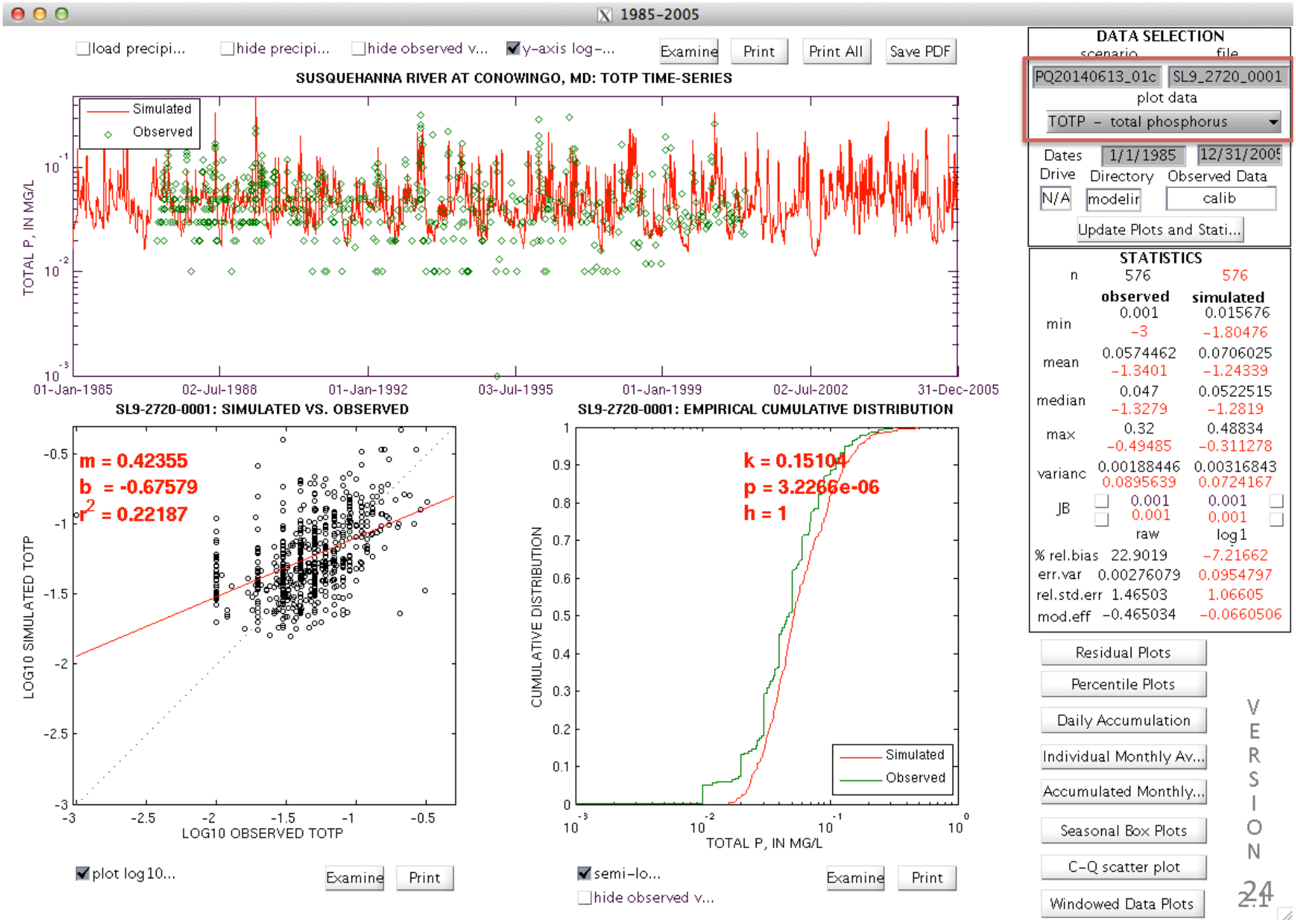
Phase 532: Total Phosphorous Susquenahanna at Conowingo



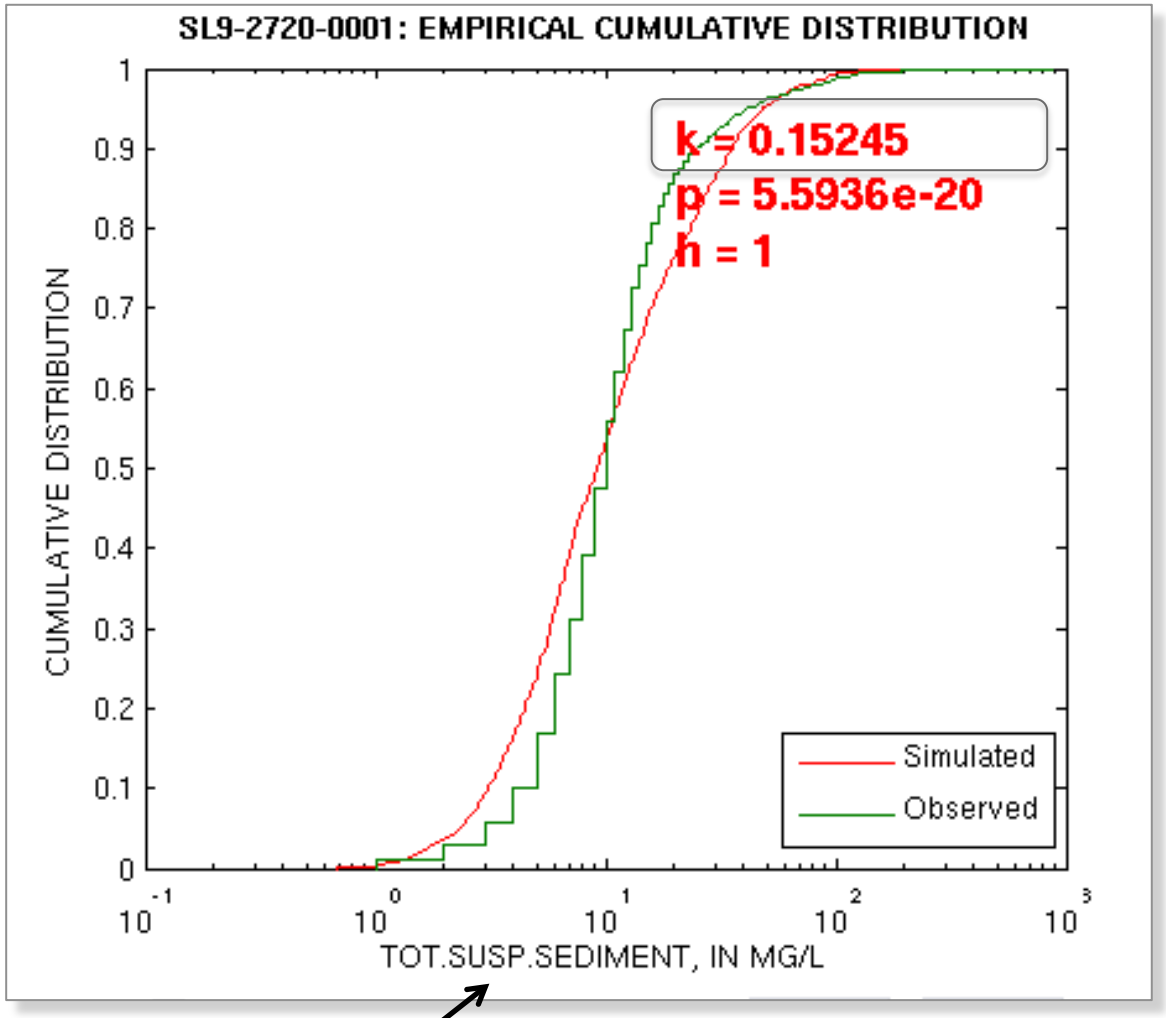
Phase 6 PQUAL: Total Phosphorous Susquenahanna at Conowingo



Phase 6 BTC: Total Phosphorous Susquenahanna at Conowingo

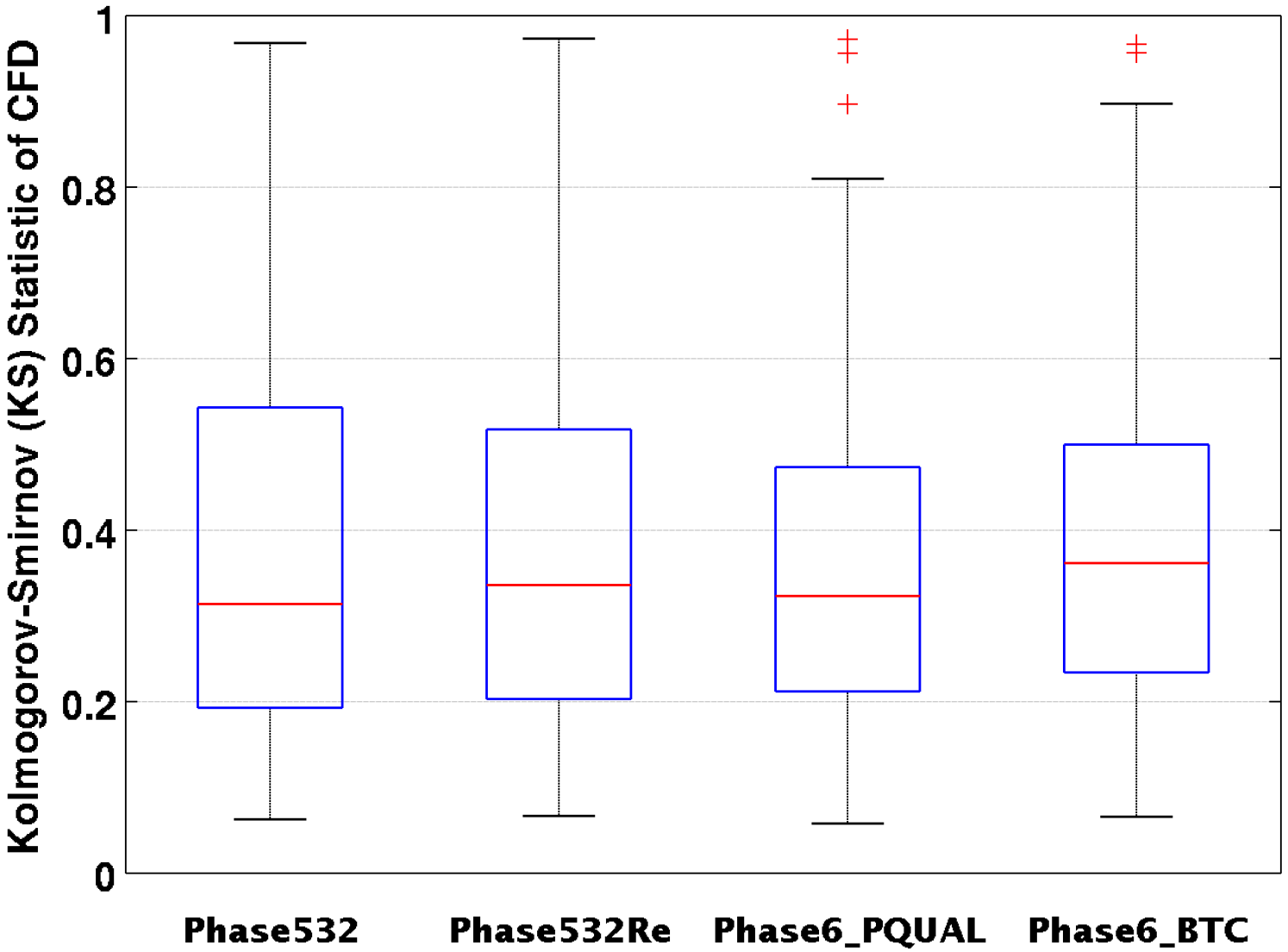


River Water Quality Calibration Approach

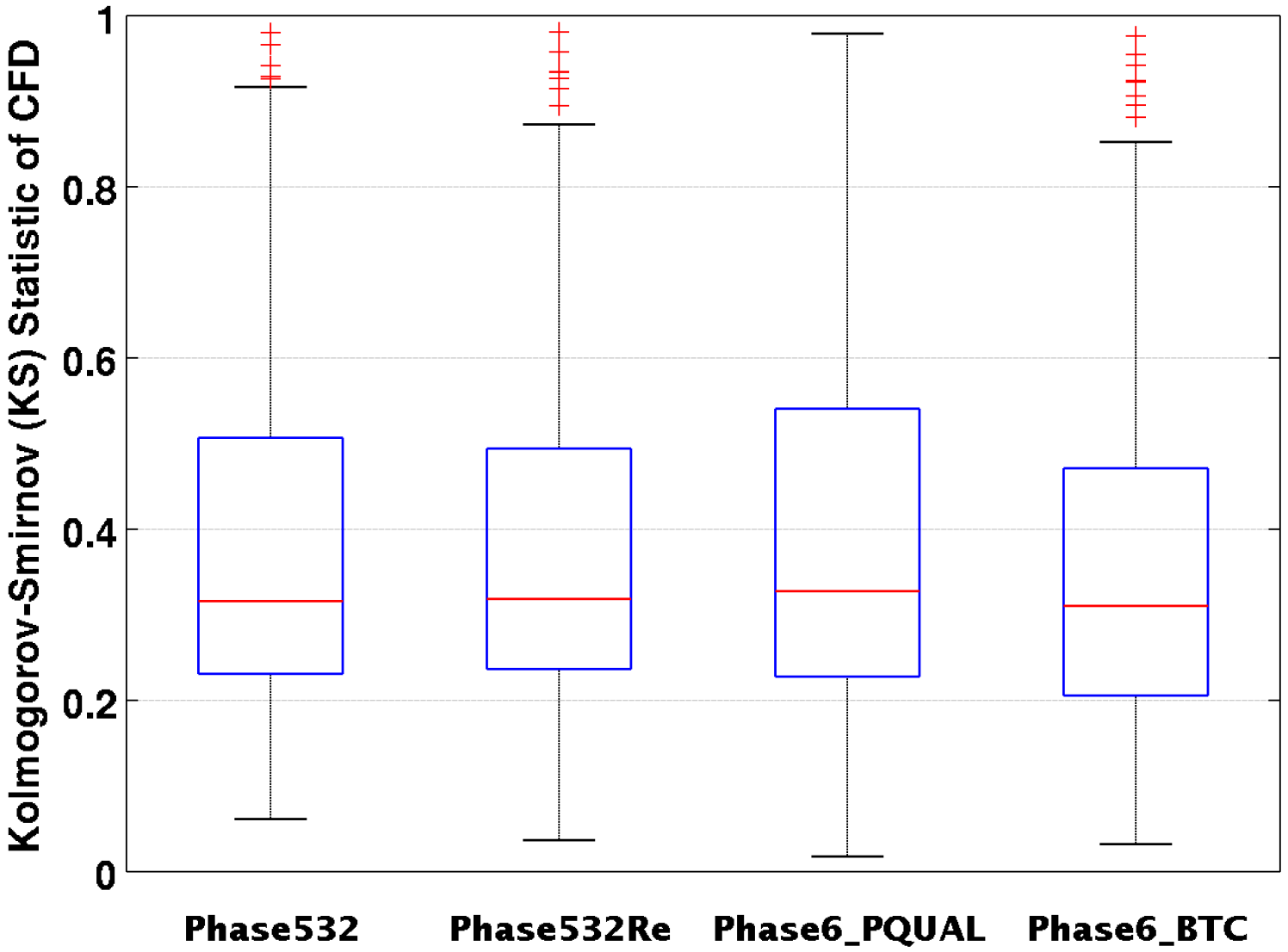


Concentration

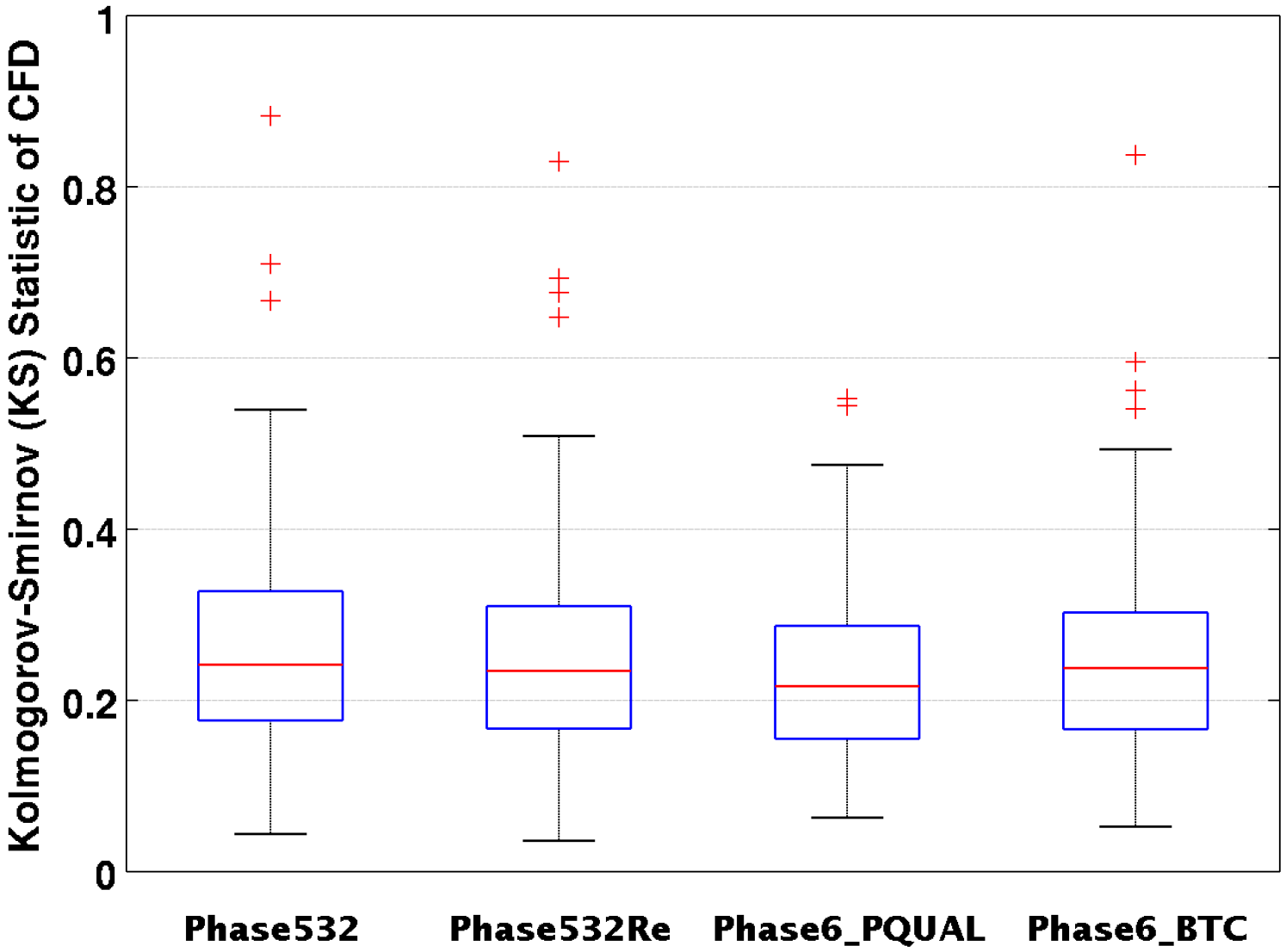
Total Nitrogen (TOTN) at 149 Monitoring Stations



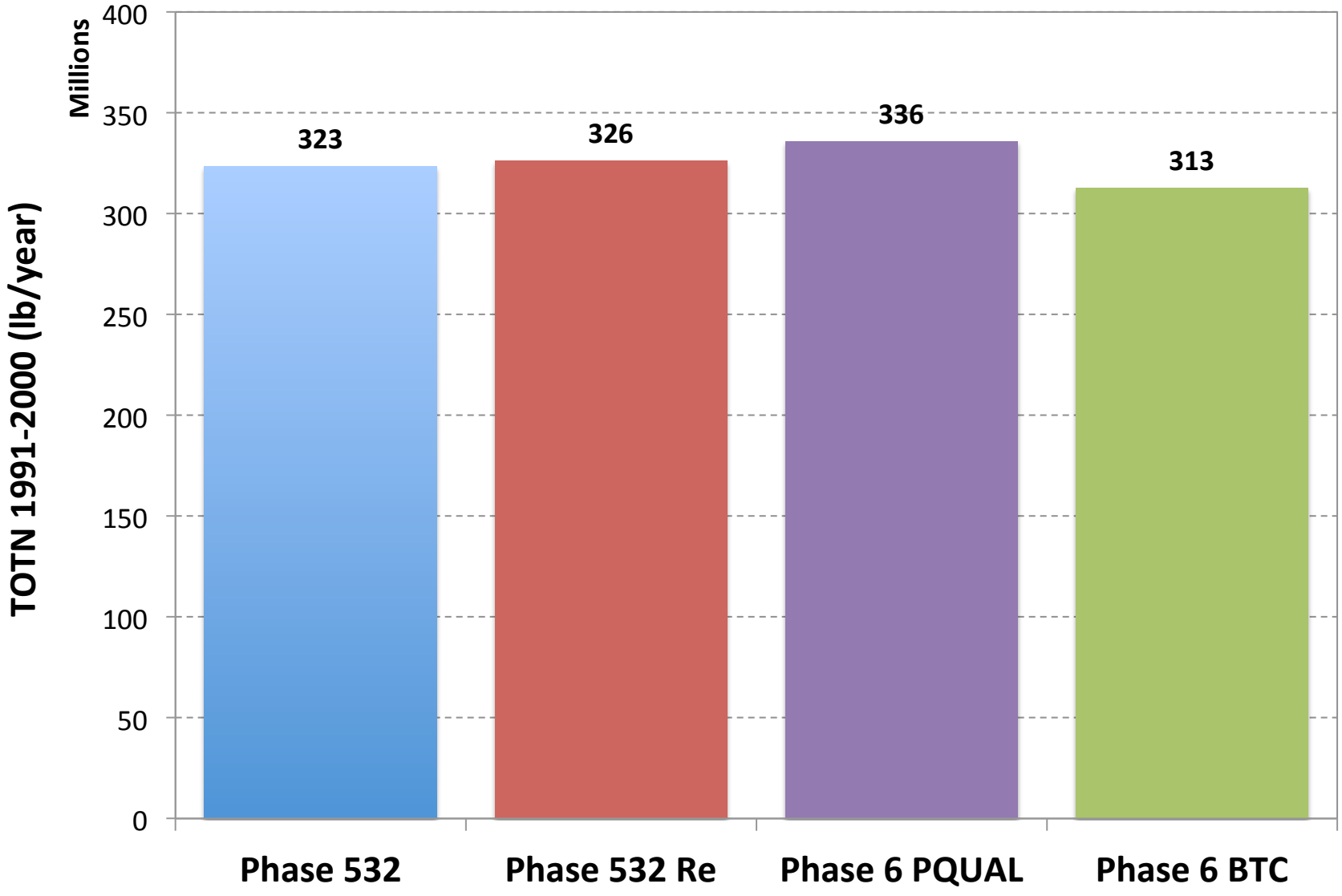
Total Phosphorous (TOTP) at 209 Monitoring Stations



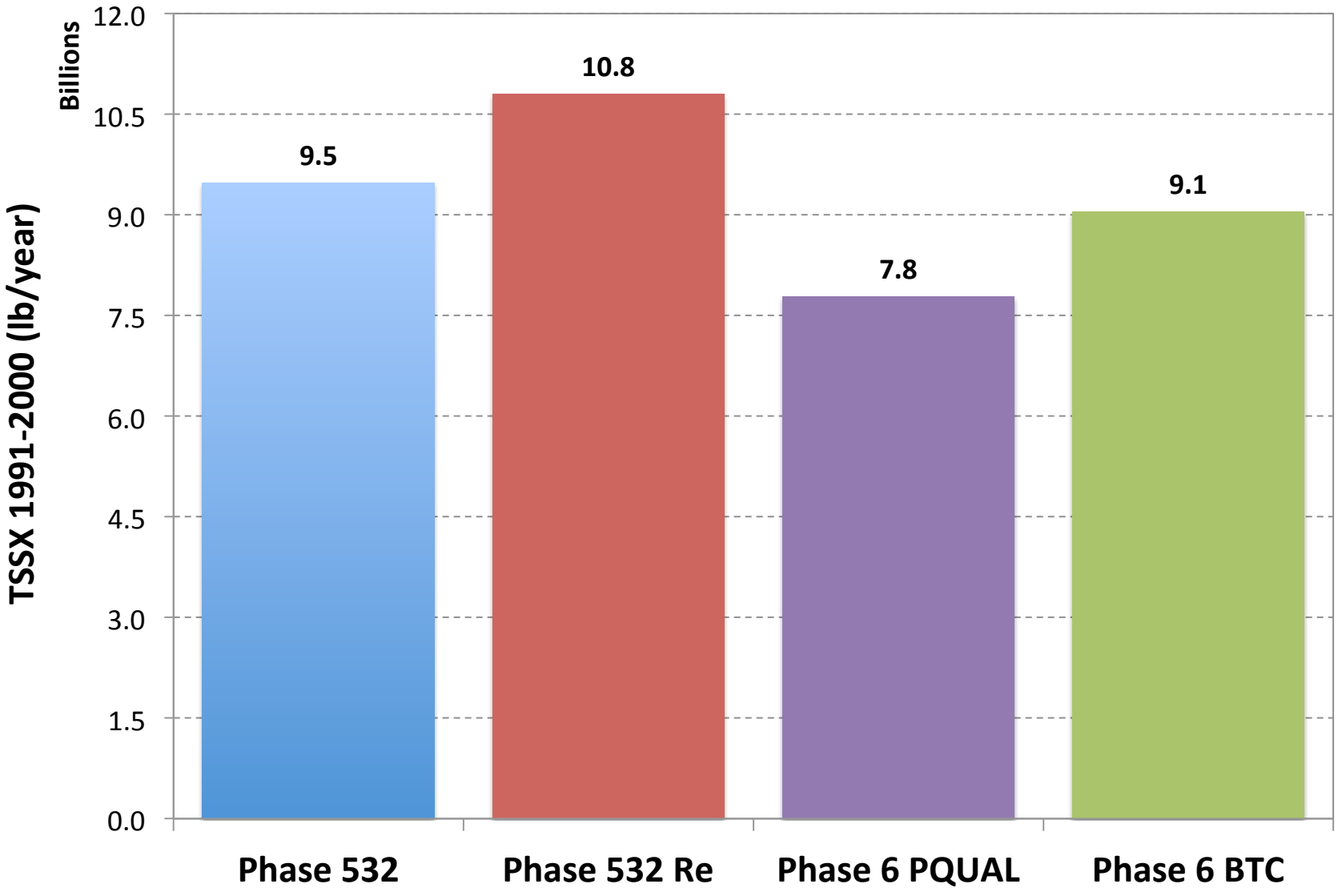
Total Sediment (TSSX) at 193 Monitoring Stations



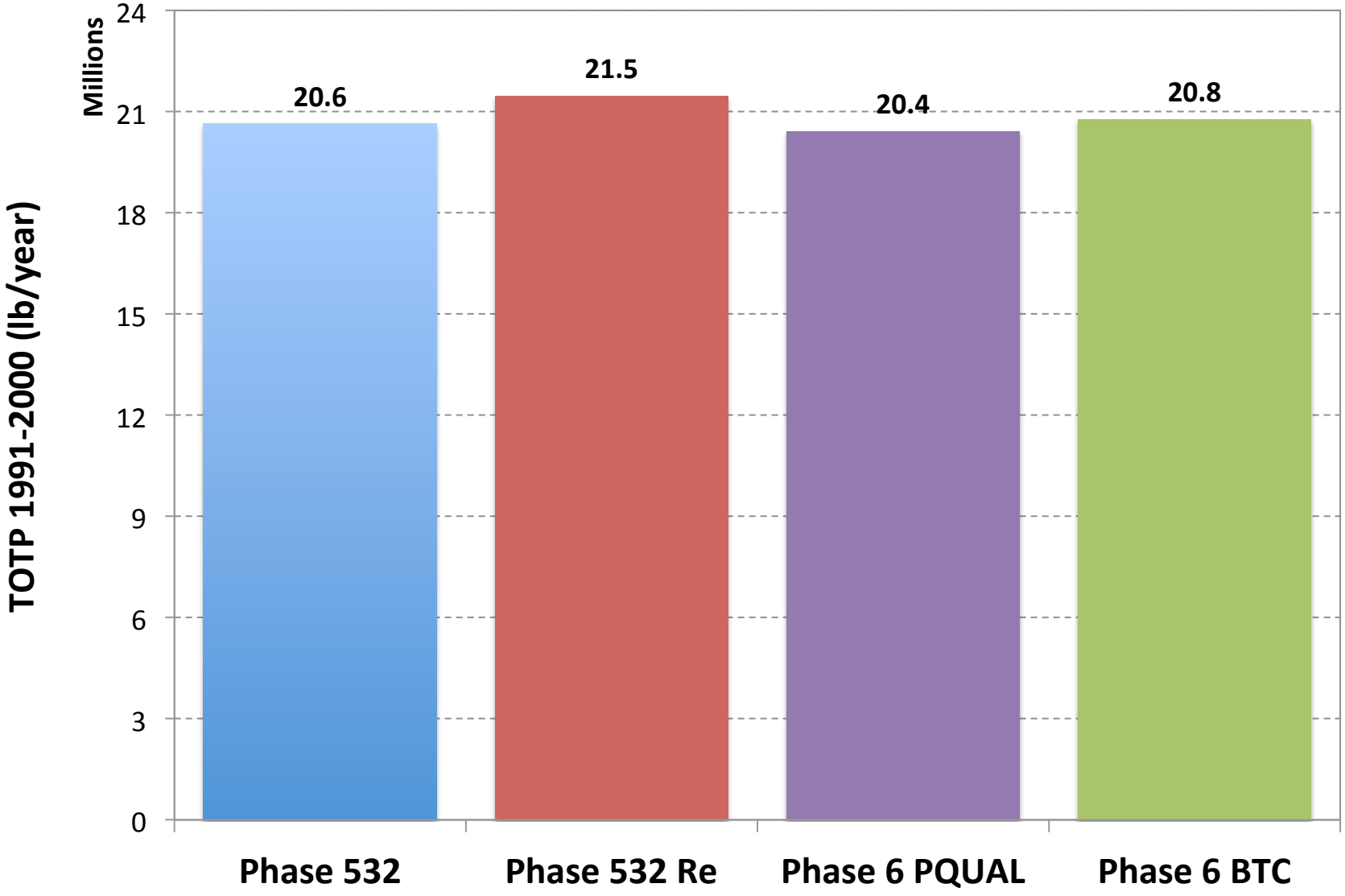
Total Nitrogen Delivery from the Watershed



Total Sediment Delivery from the Watershed



Total Phosphorous Delivery from the Watershed



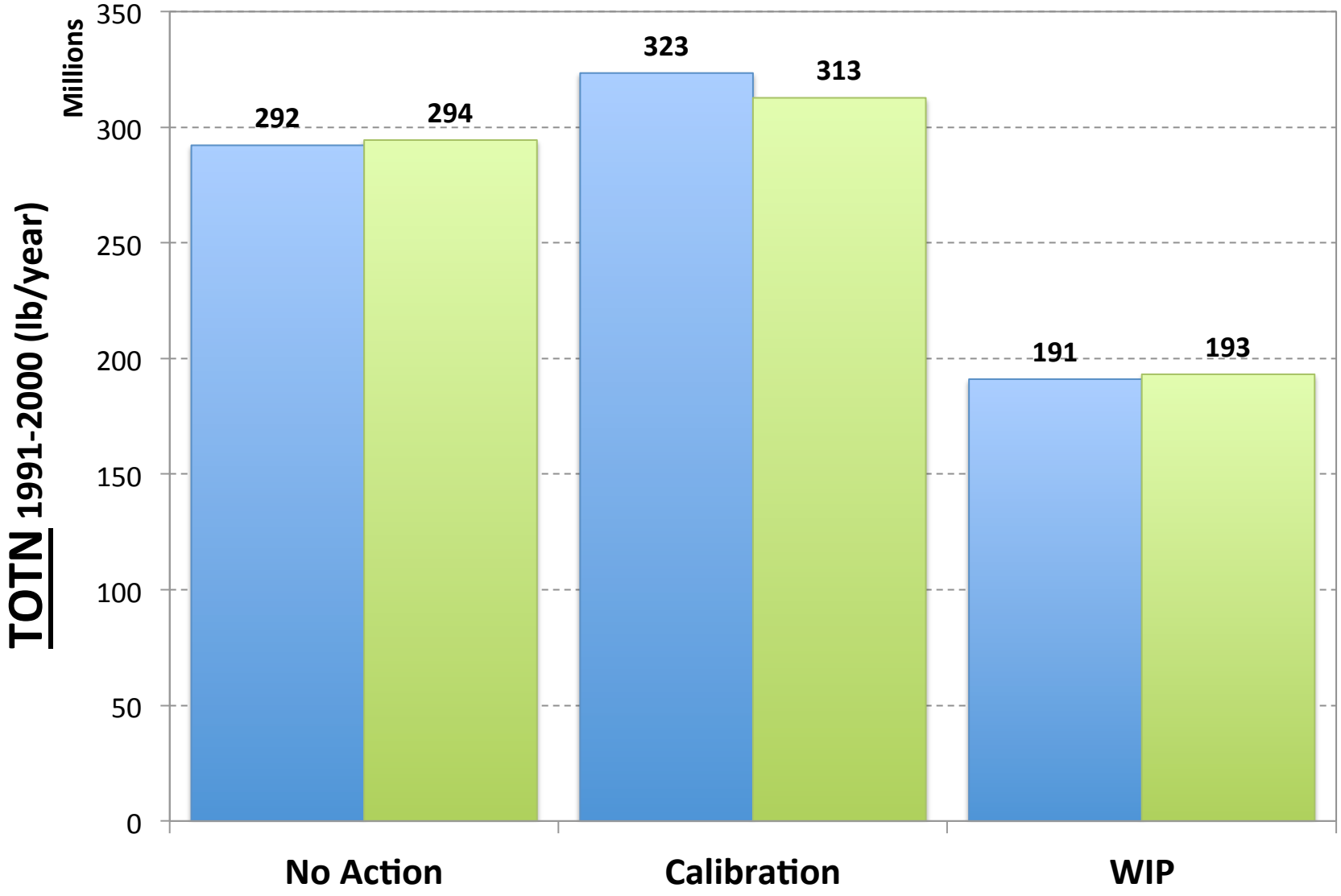
Key Management Scenarios using Draft Sensitivities

- Three key management scenarios (No-Action, Calibration, and WIP) were analyzed to evaluate operational aspects of Phase 6 prototype.

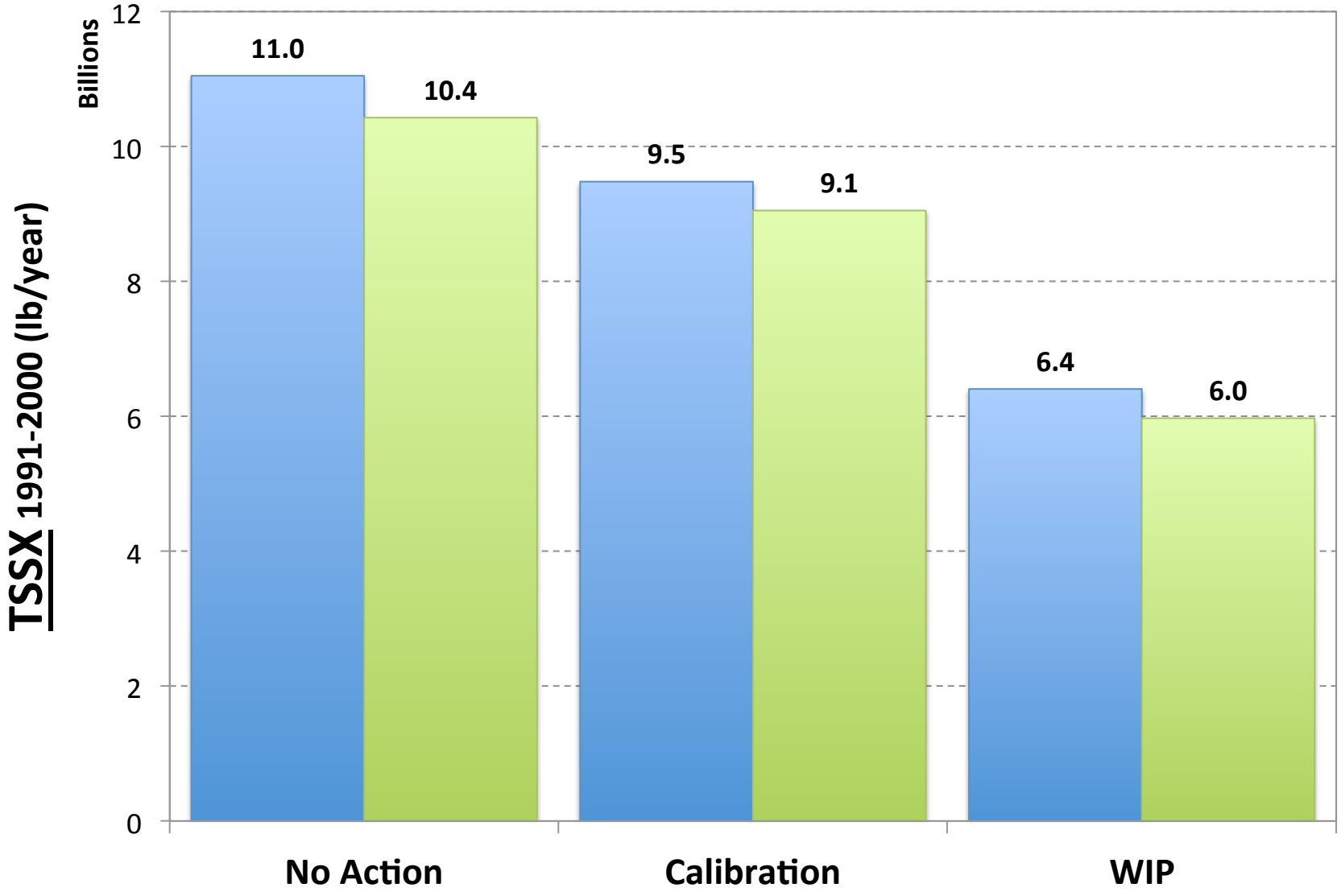
- Scenarios were run using draft sensitivities for 9 land-uses (*Tian et al., Sept 2013*), and assuming reasonable sensitivities for the rest 21 land-uses.

Tian R., Yactayo, G., Shenk, G., Linker, L., Wang, P., Bhatt, G., Pruzinsky, A., Sept 2013. Sensitivity analysis of HSPF AGCHME Model.

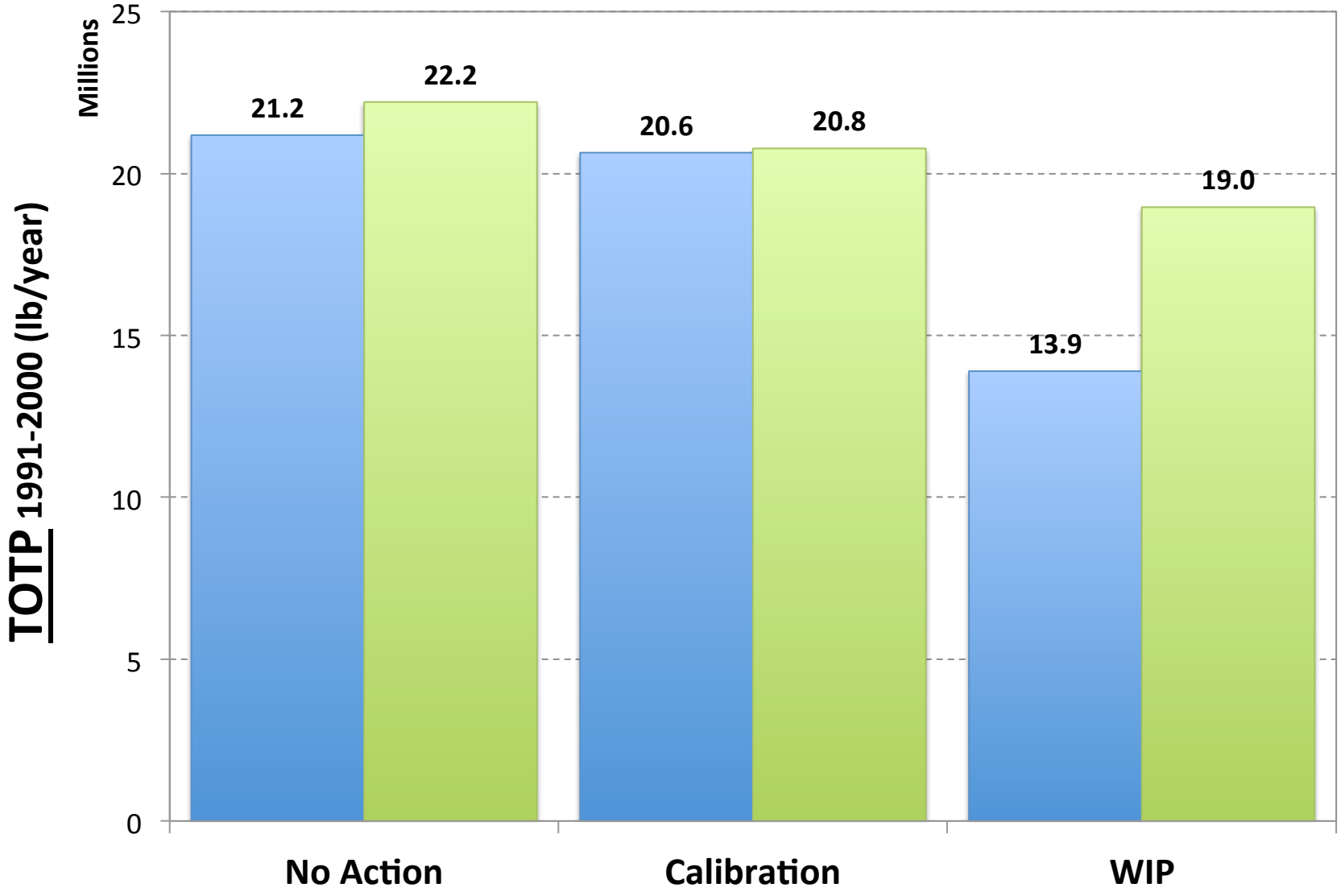
Key Management Scenarios: Phase 532 vs. Phase 6*



Key Management Scenarios: Phase 532 vs. Phase 6*



Key Management Scenarios: Phase 532 vs. Phase 6*



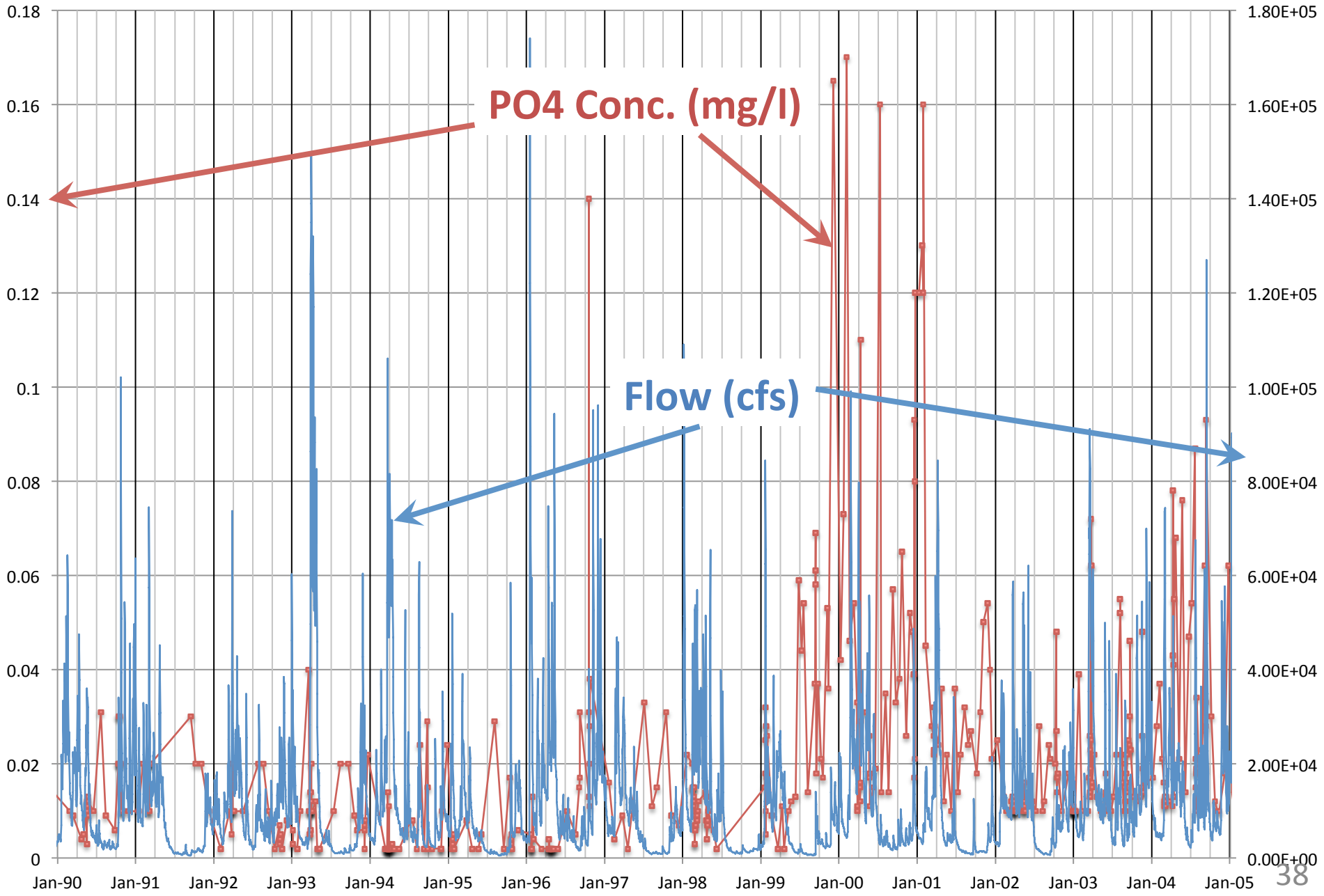
Refinements to Nutrient Calibration: Land–River Linkage

- Parameterization of breakthrough curve parameters such that it closely represents the watershed response has potential to improve model performance.

- Model provides ability to assign breakthrough curve parameters separately for transport processes (surfaceflow, sediment, groundwater flow) at land-segment : : land-use scale.

- The seasonality of river water quality concentration observations as a basis to characterize land uses and parameterization of breakthrough curves.
  - major land-use classes?

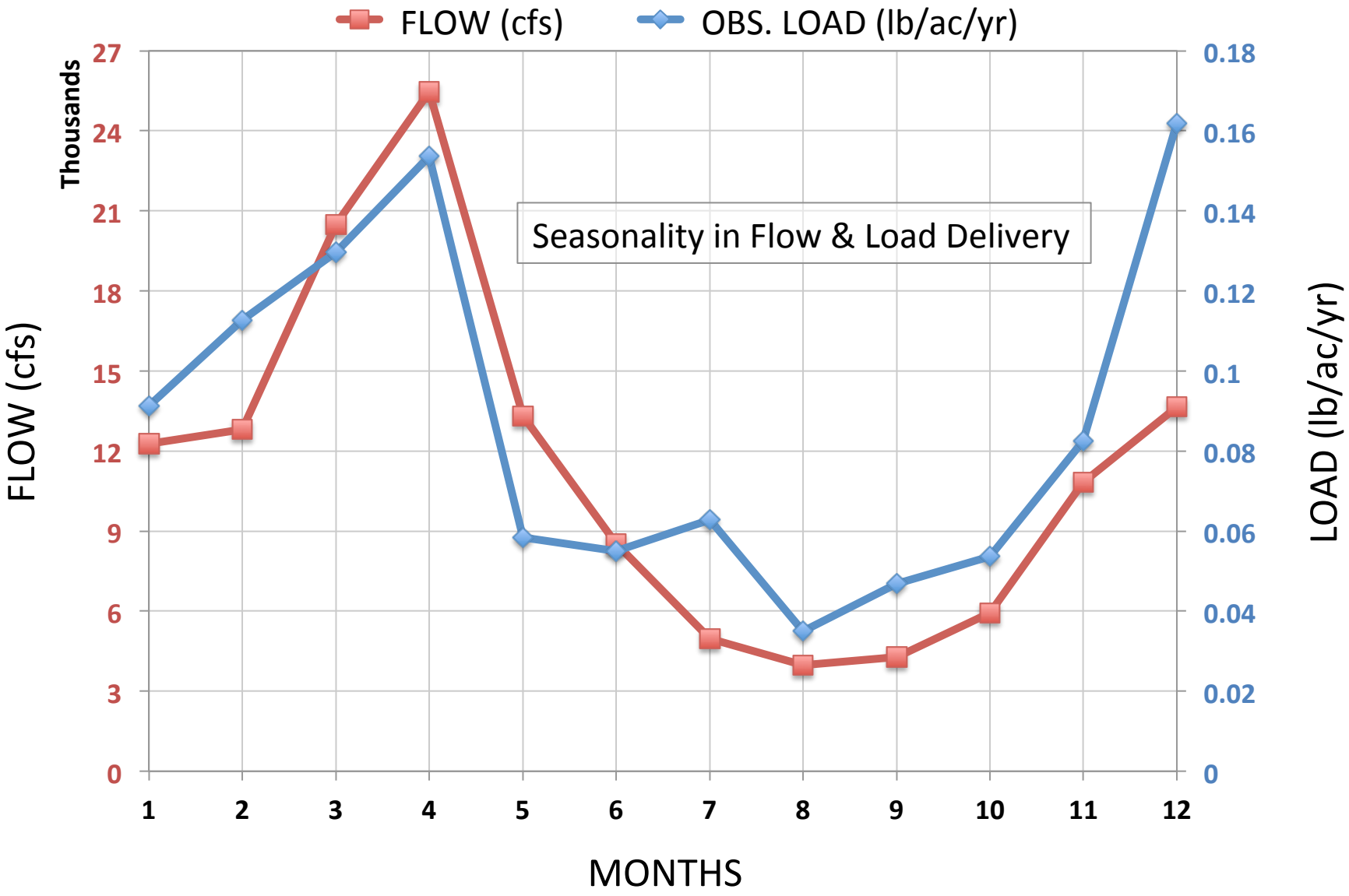
SU7_0850_0730: 4,983,225 ac (0.815%); 70% for; 4% hwm; 5% hyw; 4% alf; 7% pas;

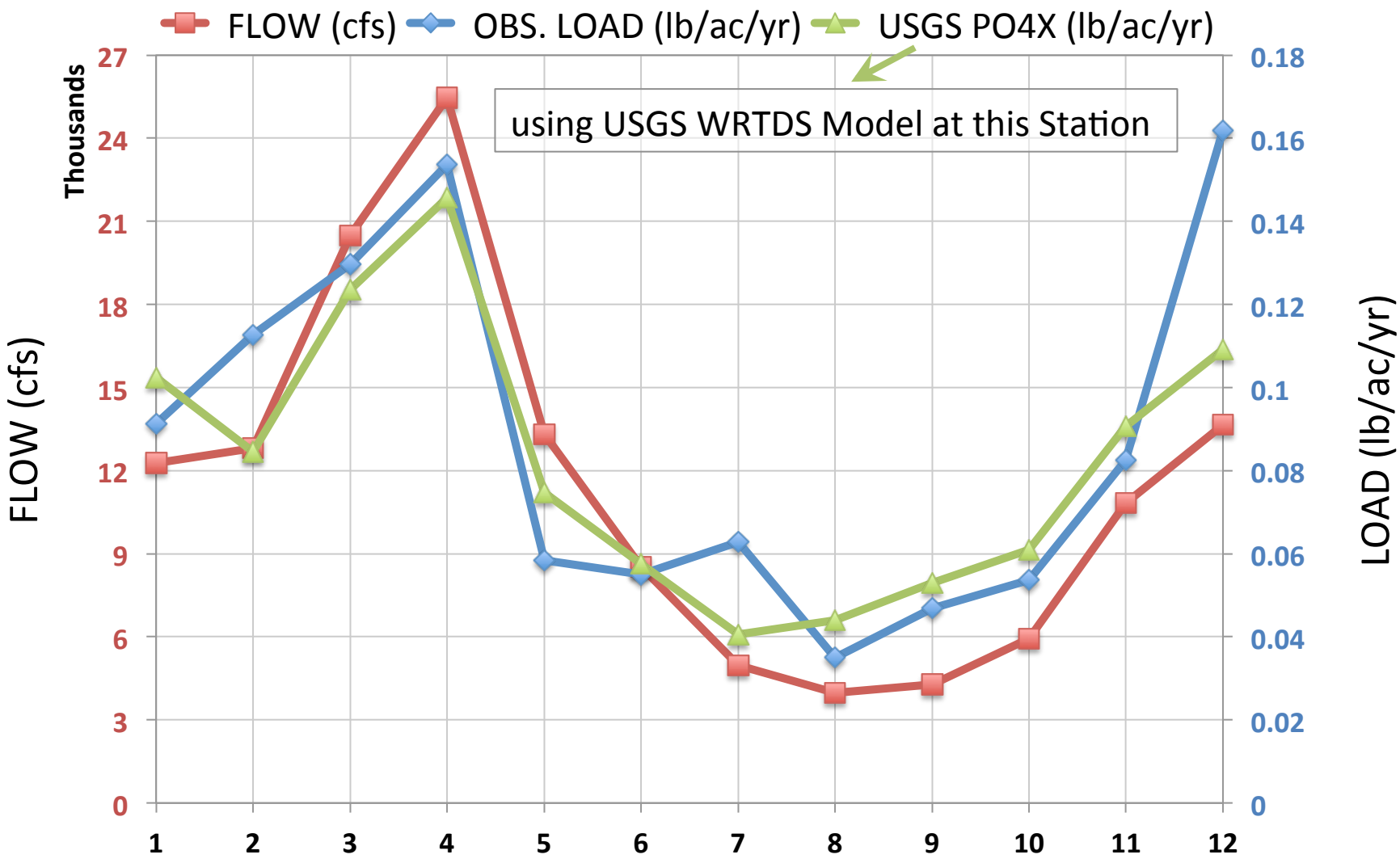


Synthesis from long-term observation

Months	PO4X (mg/l)	FLOW (cfs)	OBS. LOAD (lb/ac/yr)
JAN	0.01881	12278	0.0913
FEB	0.02228	12814	0.1128
MAR	0.01600	20510	0.1296
APR	0.01527	25467	0.1536
MAY	0.01110	13318	0.0584
JUN	0.01633	8528	0.0550
JUL	0.03200	4969	0.0628
AUG	0.02226	3978	0.0350
SEP	0.02767	4280	0.0468
OCT	0.02295	5924	0.0537
NOV	0.01933	10813	0.0826
DEC	0.03006	13644	0.1620

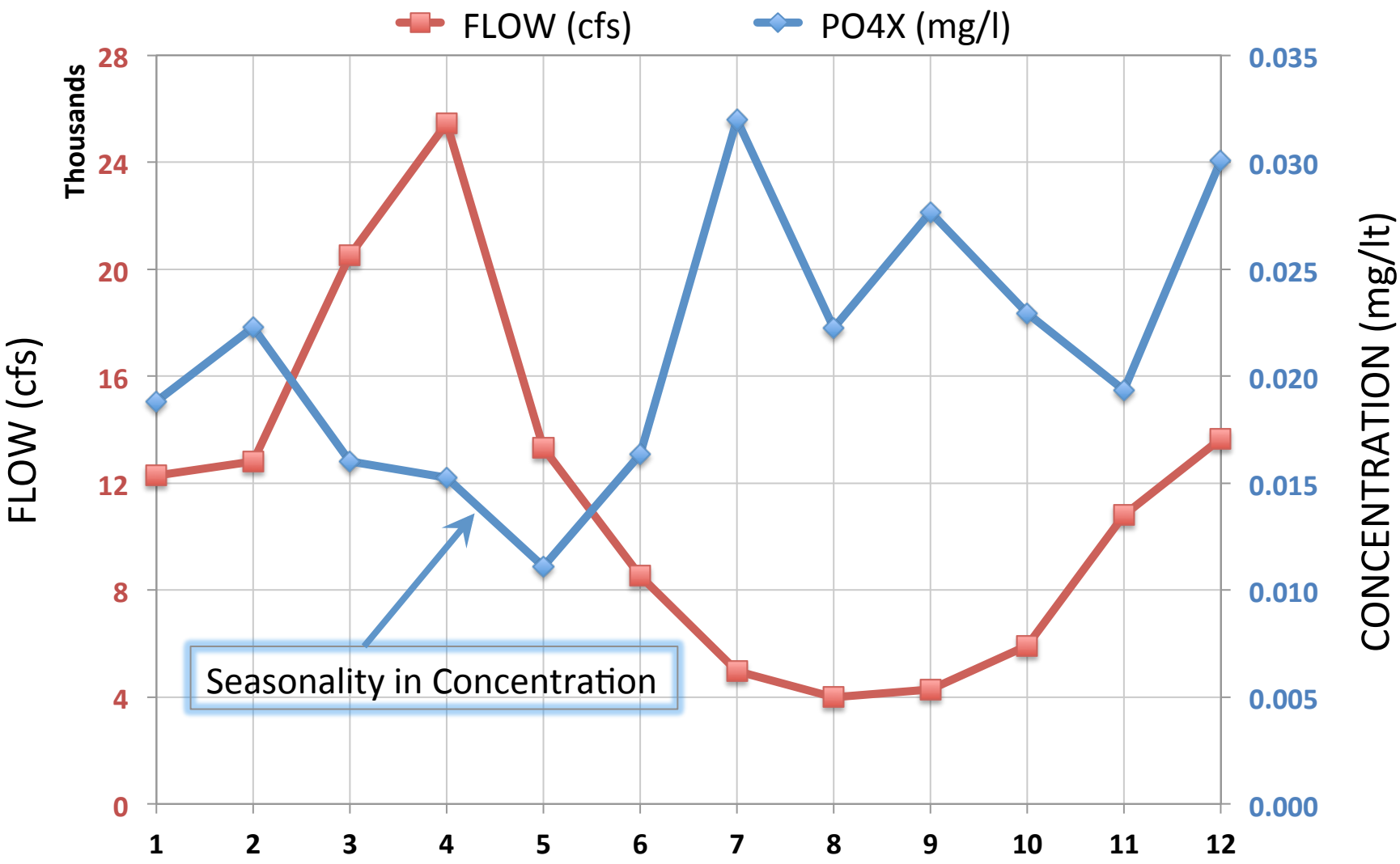
SU7_0850_0730: 70% forest

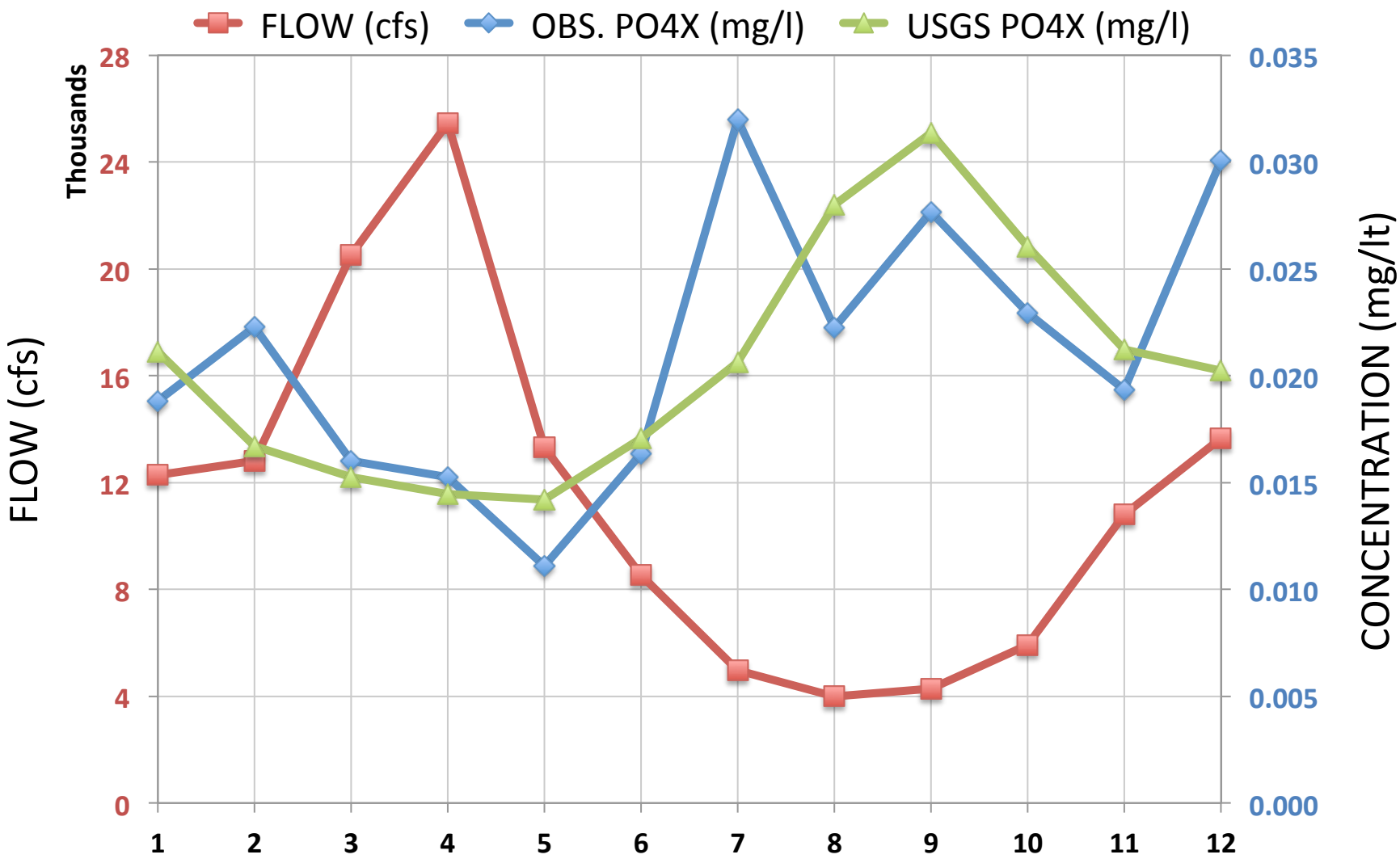




USGS Analysis using WRTDS or ESTIMATOR: http://cbrim.er.usgs.gov/monthly_loads_query.html

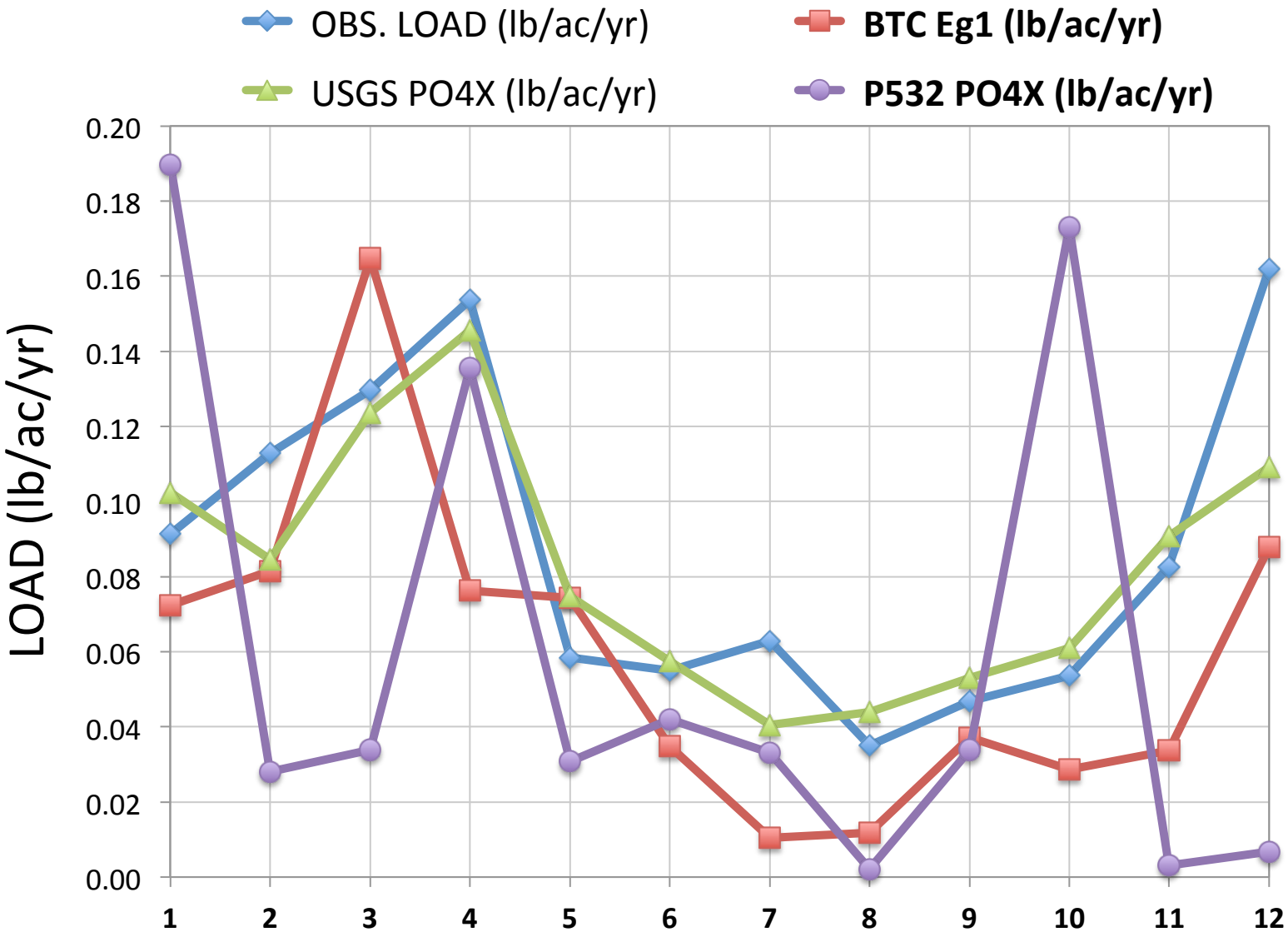
SU7_0850_0730: 70% forest



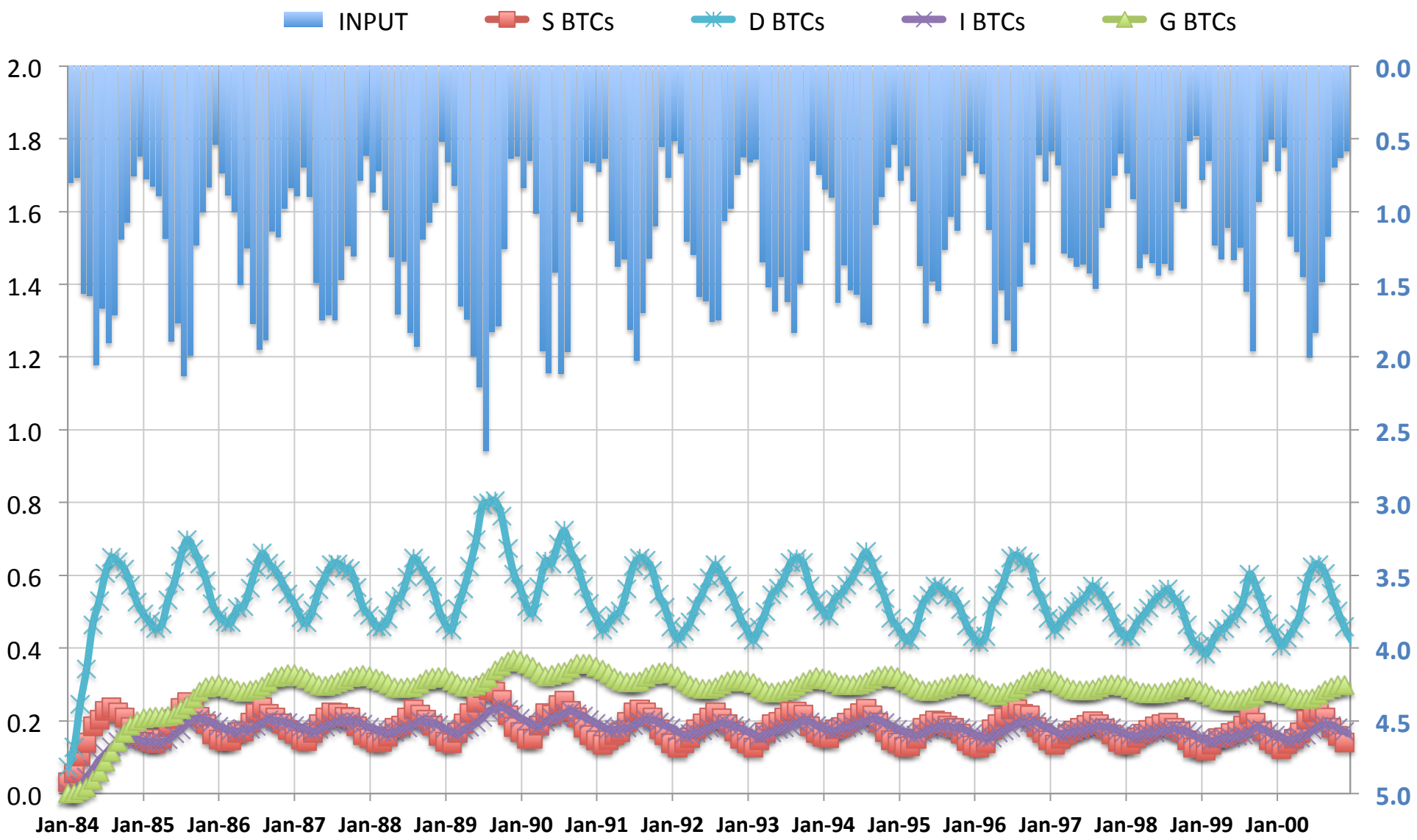

FLOW (cfs)
OBS. PO4X (mg/l)
USGS PO4X (mg/l)
Thousands
FLOW (cfs)
CONCENTRATION (mg/lt)
28
24
20
16
12
8
4
0
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
1
2
3
4
5
6
7
8
9
10
11
12

SU7_0850_0730: 70% forest vs. A10001 forest

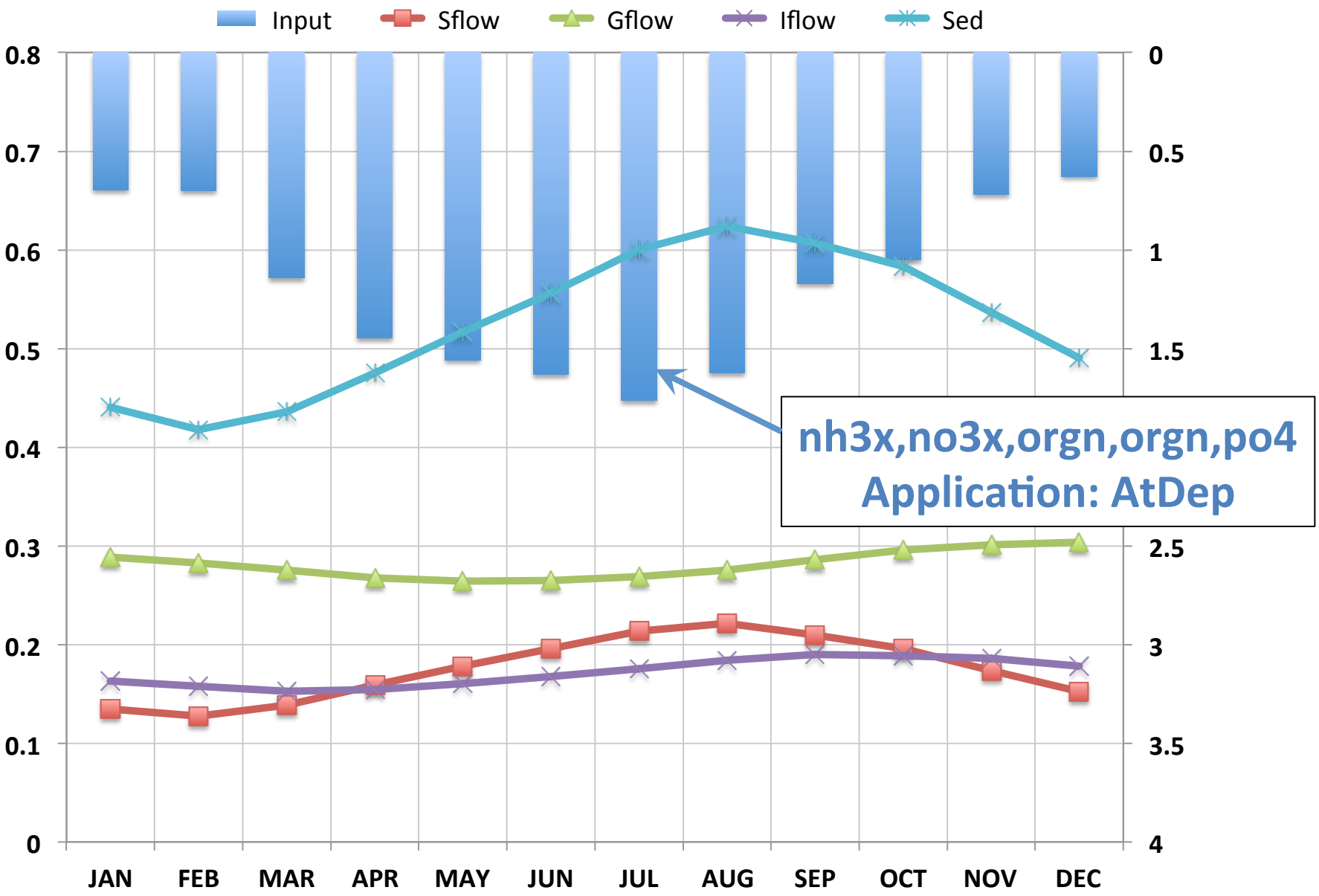
Seasonality in forest response from Observation vs. Model



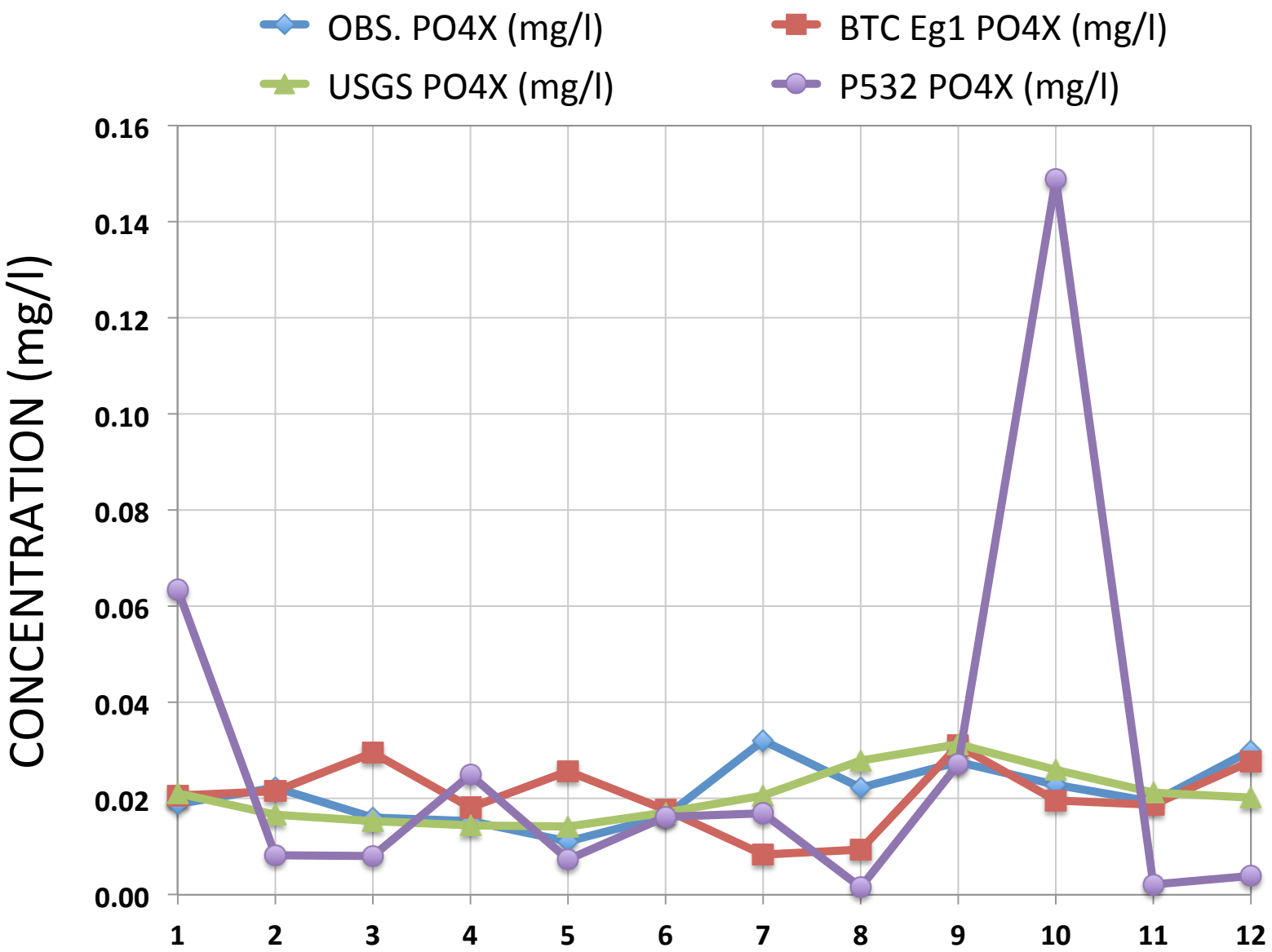
A10001 Forest: Breakthrough Curves (PO4X)



SU7_0850_0730: 70% forest vs. A10001 forest



Seasonality in forest response from Observation vs. Model

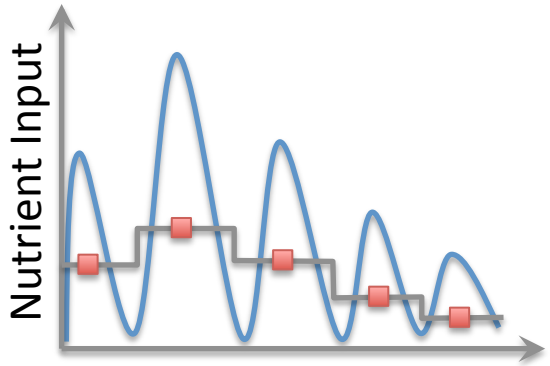


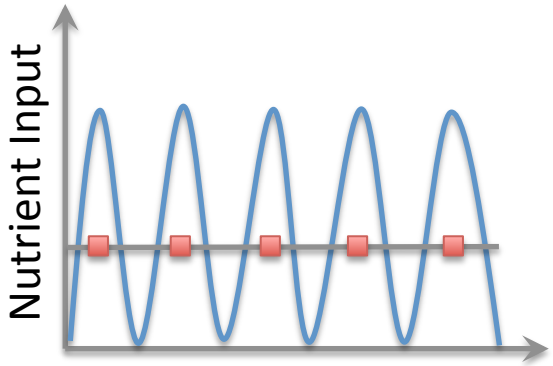
Next Steps …

- Parameterize Breakthrough Curve parameters to capture seasonality:
  - possibly for three major land-use categories (i.e. forest, agriculture, urban)
  - do so for total nitrogen and total phosphorous load. Break them out further if evidence points that way.
- Revise model draft sensitivities to incorporate other sources.
  - E.g., APLE
- Incorporate (labile and refractory) organic P in the framework.

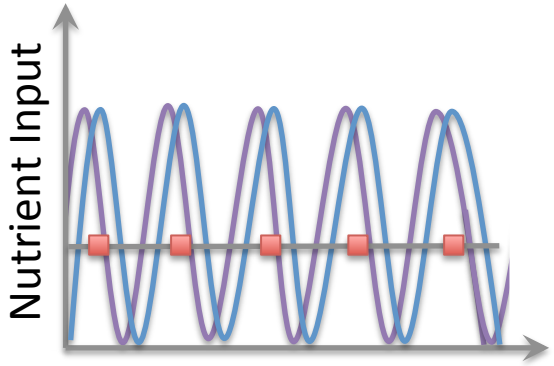
Limitations of the Framework …

- Currently PQUAL calibration does not account for seasonality of input (+/-)





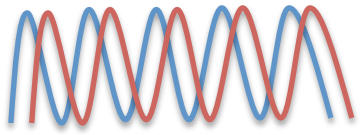
- Export estimated from 'sensitivities' using this method would <u>not</u> be able to account for changes in input pattern, if any.



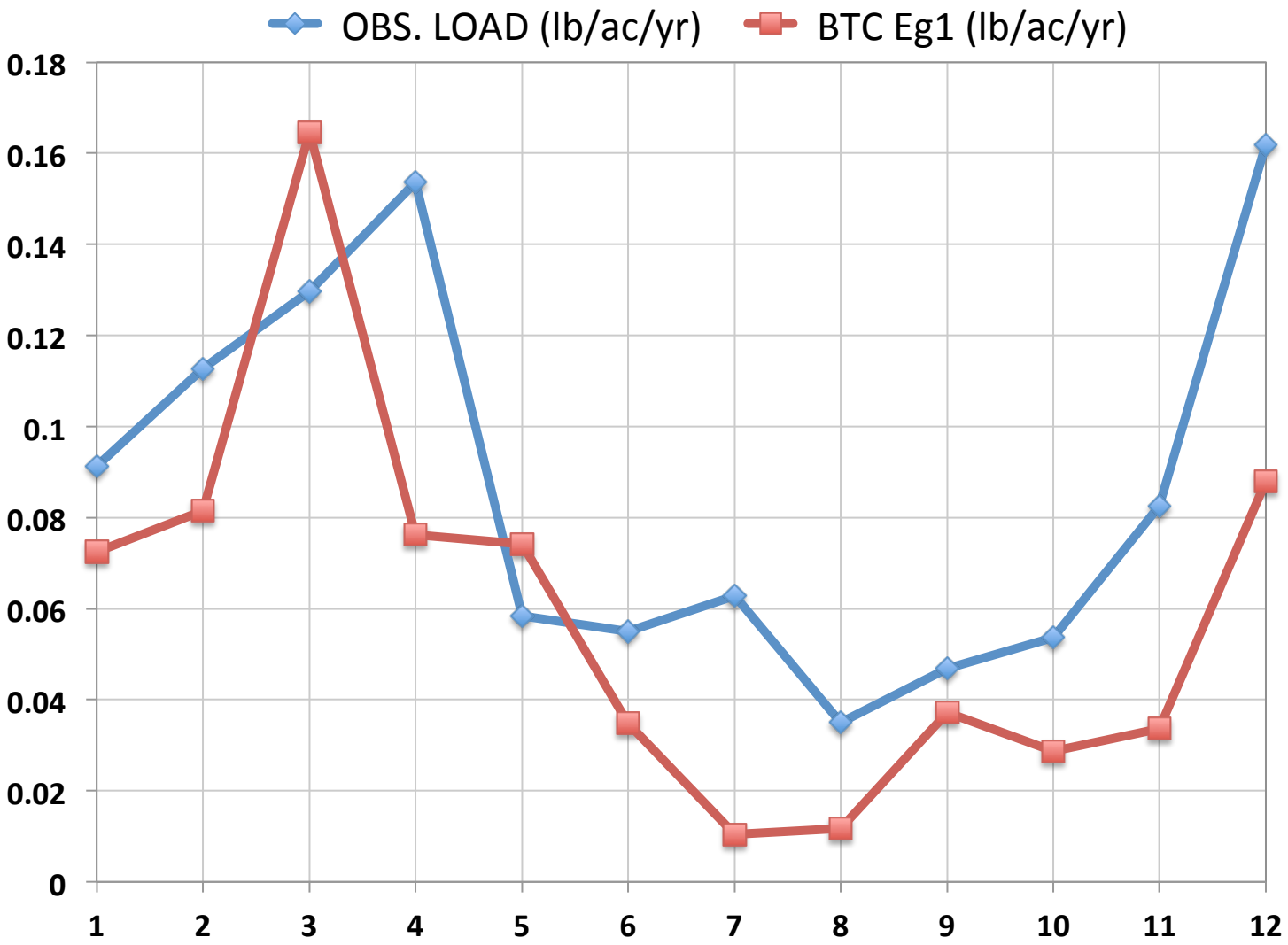
E.g., Fertilizer application in April vs. June

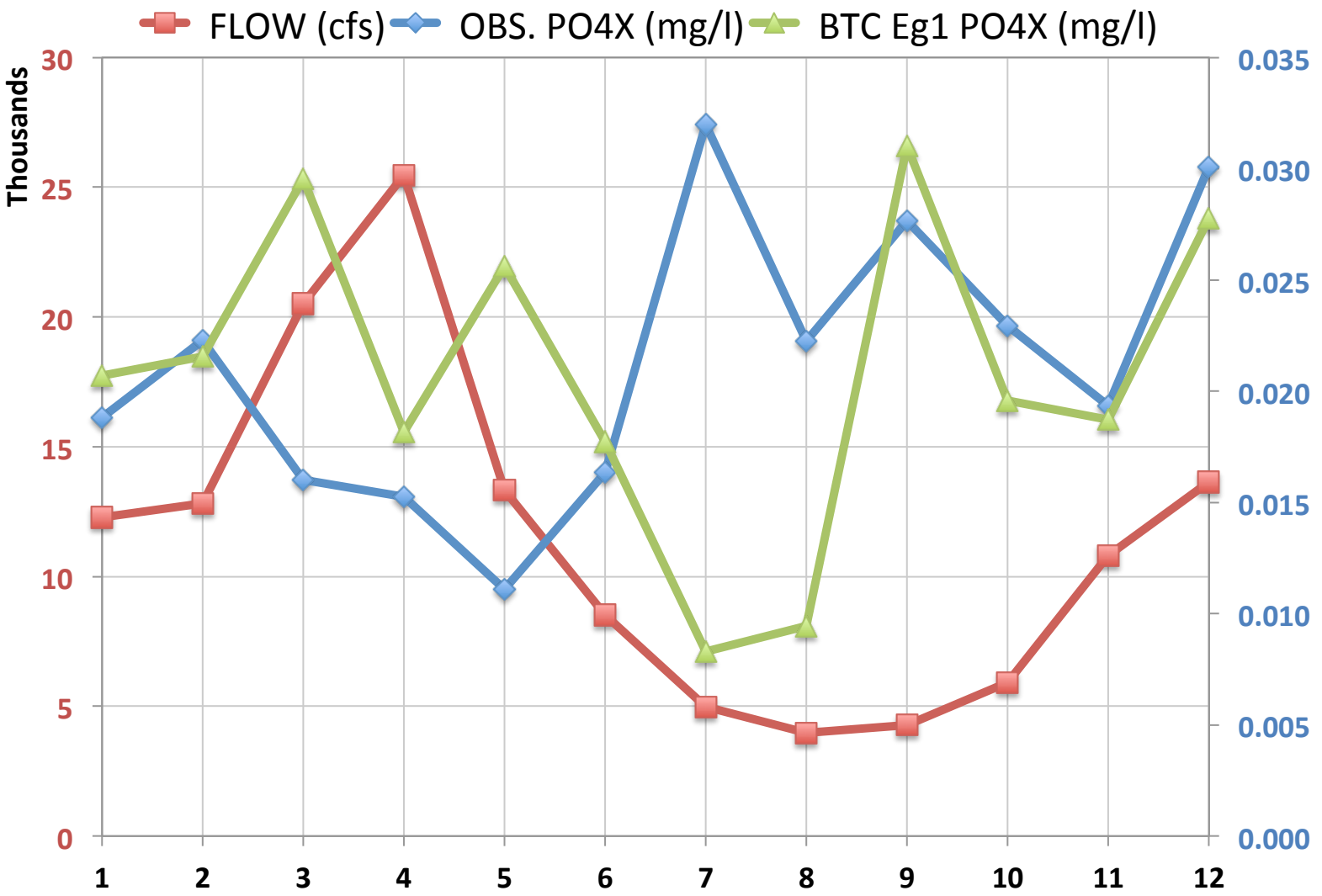
Advantages …

- Proposed framework is simple, easy to understand; and offers accounting of management scenarios.
- Offers ability to incorporate evidence based understanding of the watershed response.
  - E.g., Sensitivity, Residence time
- Framework ensures consistency between long-term export estimated from 'sensitivity' and export from hourly outputs.
- Framework is directly related to inputs. It provides ability to handle scenarios with not only changes in application rate, but application pattern.



SU7_0850_0730: 70% forest vs. A10001 forest




FLOW (cfs)
OBS. PO4X (mg/l)
BTC Eg1 PO4X (mg/l)
Thousands
30
25
20
15
10
5
0
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
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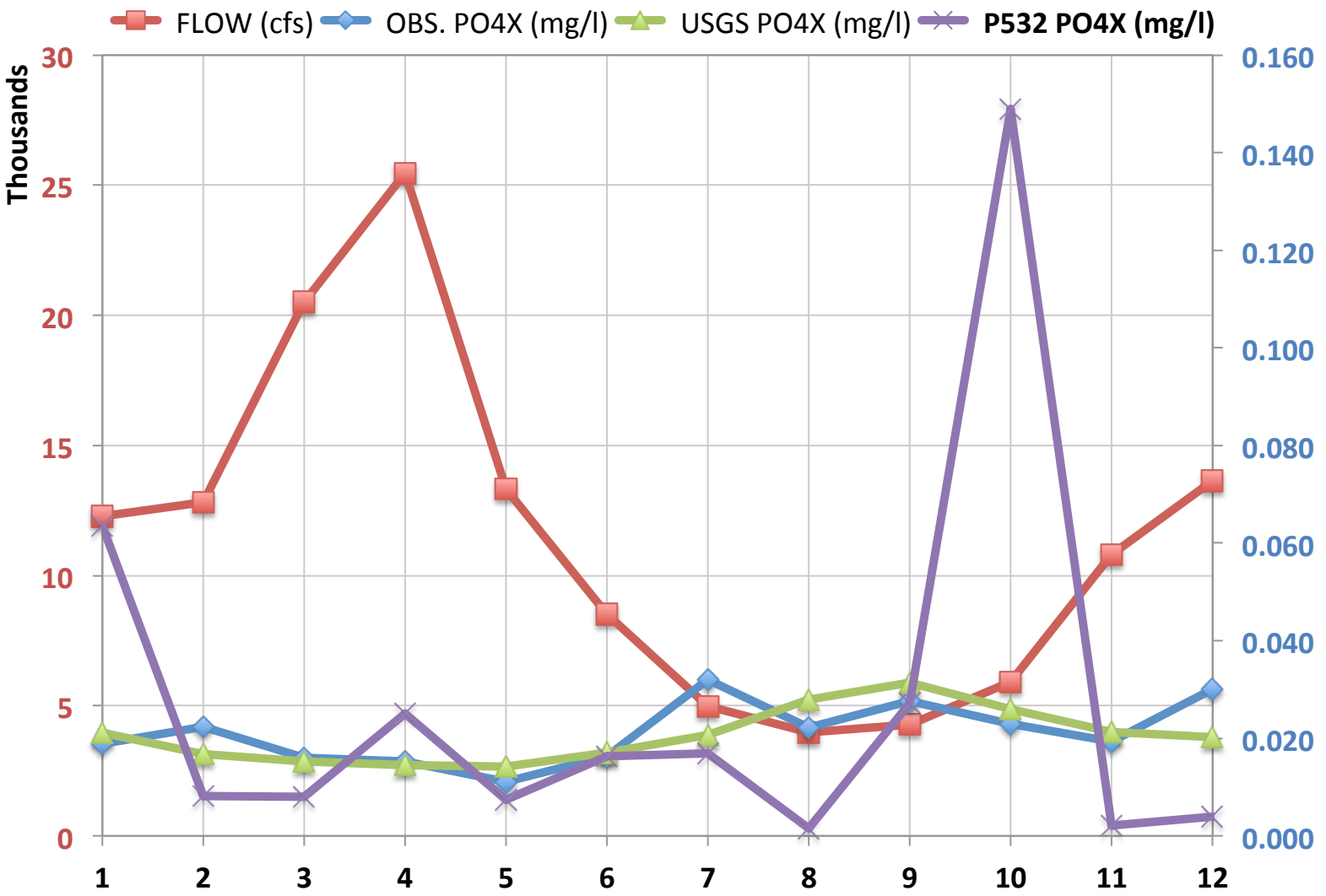
FLOW (cfs)
OBS. PO4X (mg/l)
USGS PO4X (mg/l)
P532 PO4X (mg/l)
Thousands
30
25
20
15
10
5
0
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
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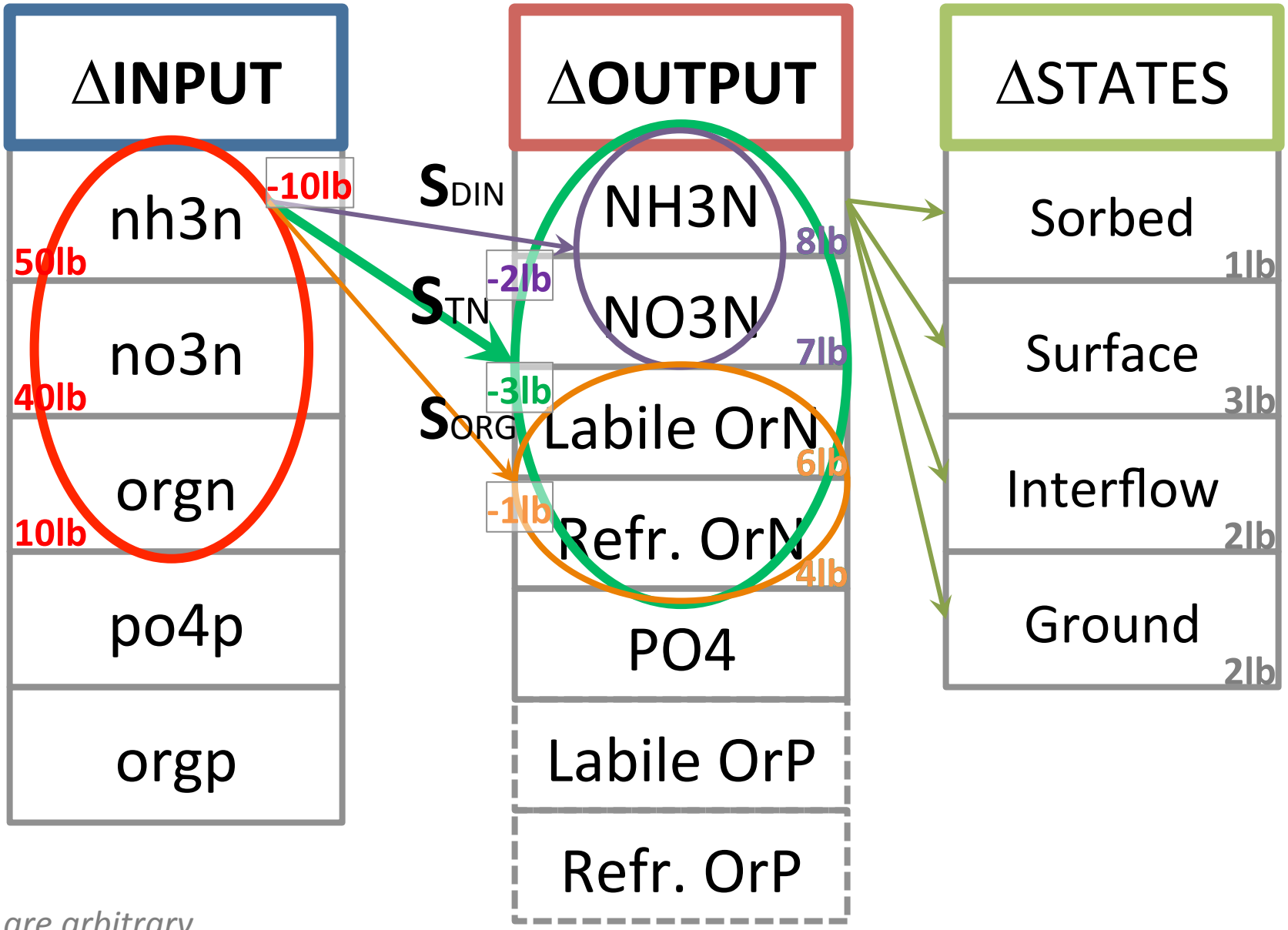
Step 2: Apply Sensitivities to *Baseline*



loads are arbitrary