PHOSPHORUS LOADING PROCEDURES AND RESULTS

2013 Cayuga Lake Study

Technical Briefing (CLTAC)
Cayuga Lake Modeling Project
May 19, 2014
Albany, NY

Goals and Analysis Components

- develop representative estimates of the magnitude and apportionment of external loads of bioavailable phosphorus (BAP_L) to Cayuga Lake
  - components of analysis
    - algal bioassays of key inputs to quantify bioavailability
    - monitoring of forms of P, runoff event based sampling of tributaries
    - development of P concentration-driver relationships
    - loading estimates and apportionment
  - point sources and tributaries considered

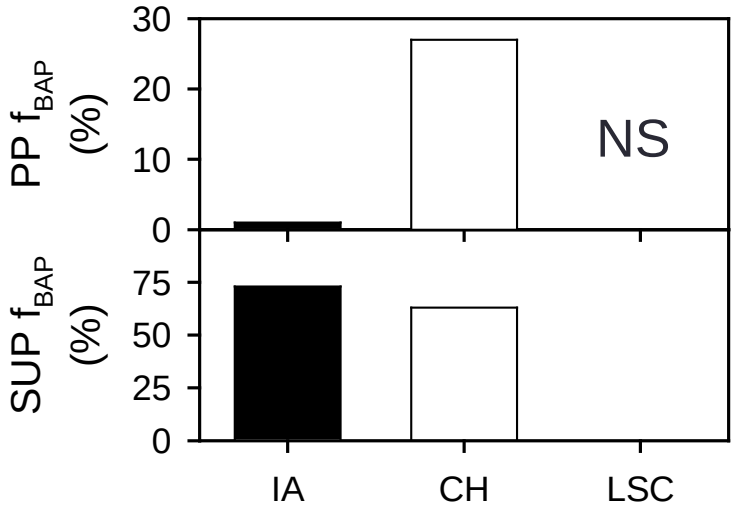
Bioavailability

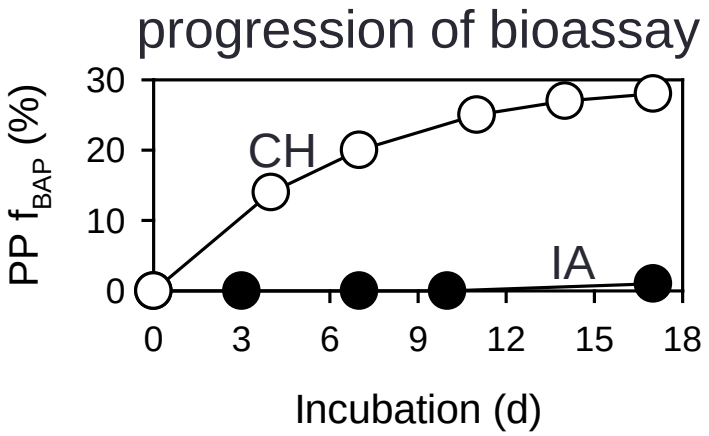
- Bioassays used to determine fraction of P actually usable by algae
- Particulate and dissolved fractions
- Algal P uptake measured over 30 d incubation
- Fraction of P used by algae determined (f_{BAP})

Bioavailability: Point Sources

-f_{BAP} (%)

- low for PP at IAWWTP
  - characteristic of micro-sand ballasted flocculation treatment
- same as Metro in Syracuse
- similar results for SUP f_{BAP}
- LSC
  - lake hypolimnion water



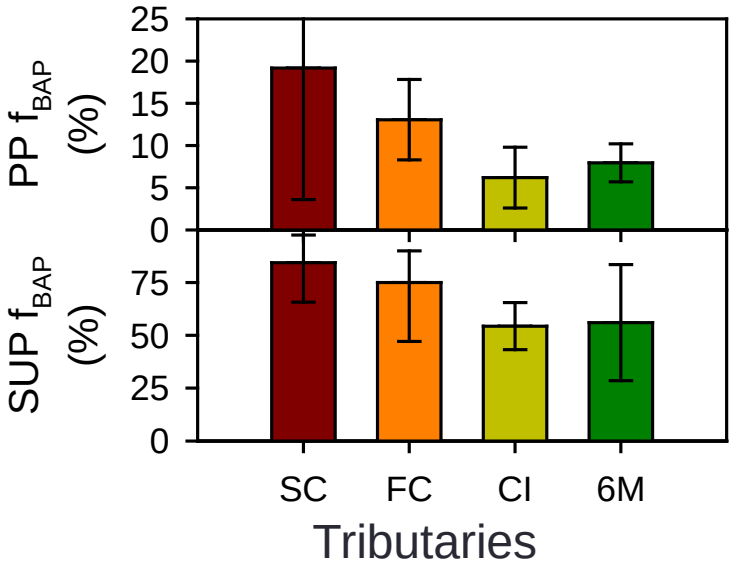


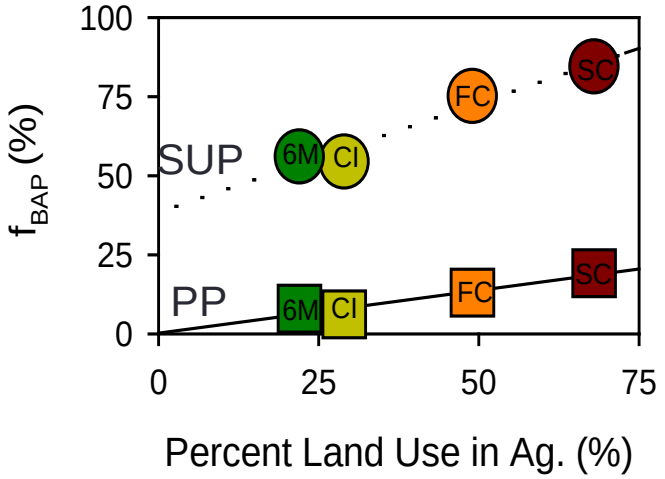
Bioavailability: Tributaries

-f_{BAP} (%)

- SRP (not shown)
  - ~ 100% bioavailable
  - consistent for all sources
- PP
  - only 5-20% bioavailable highly correlated to land use
- SUP
  - from 55-84% bioavailable
  - % SUP bioavailable highly correlated to land use
- Assay results used to estimate "available" P (BAP_L) loading

- f_{BAP} (%) highly correlated to agricultural land use (r > 0.95)

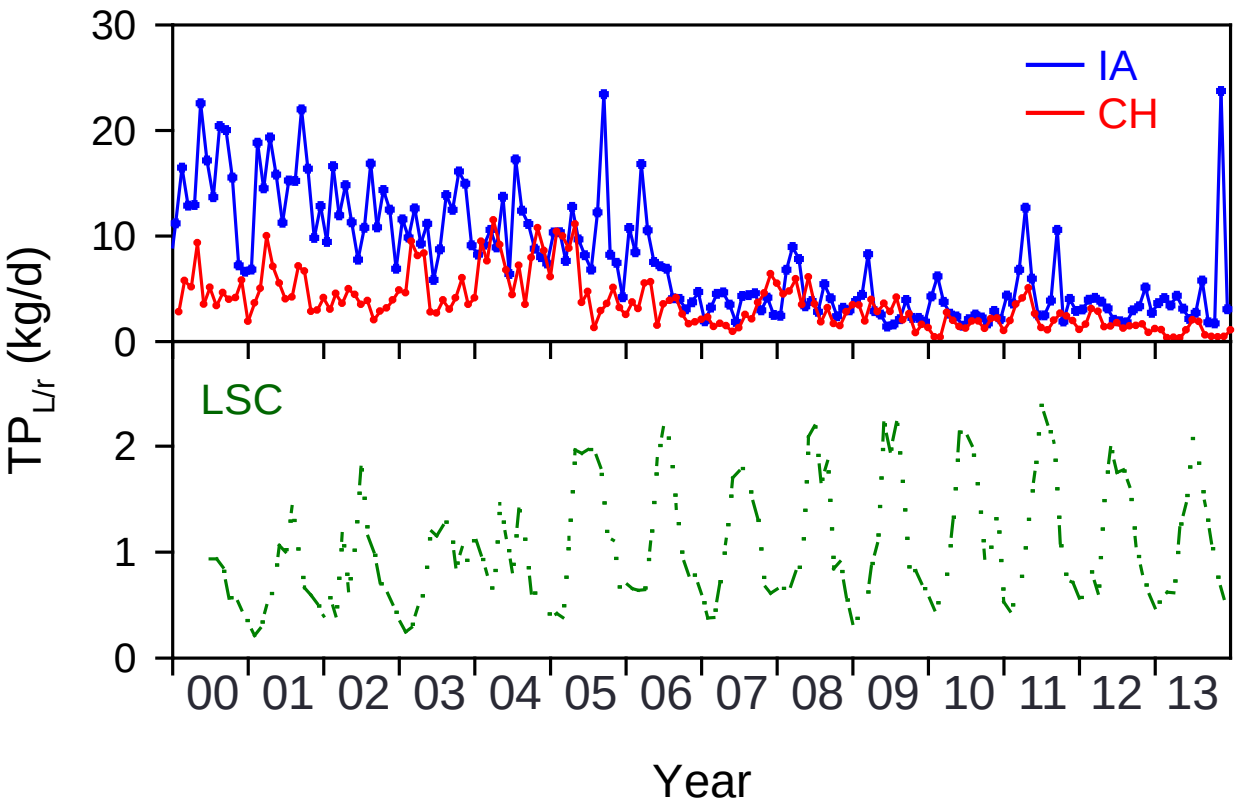




2013 Point Source Load Estimation

- Monthly DMR reports from NYS DEC
- Forms of P not routinely available, only TP_L were calculated
- TP_L calculated as the product of monthly average TP conc. (mg/L) and monthly average flow (MGD) and number days per month (d)
- Assumptions were made regarding P fractions, bioavailability for minor point sources and prior to 2013

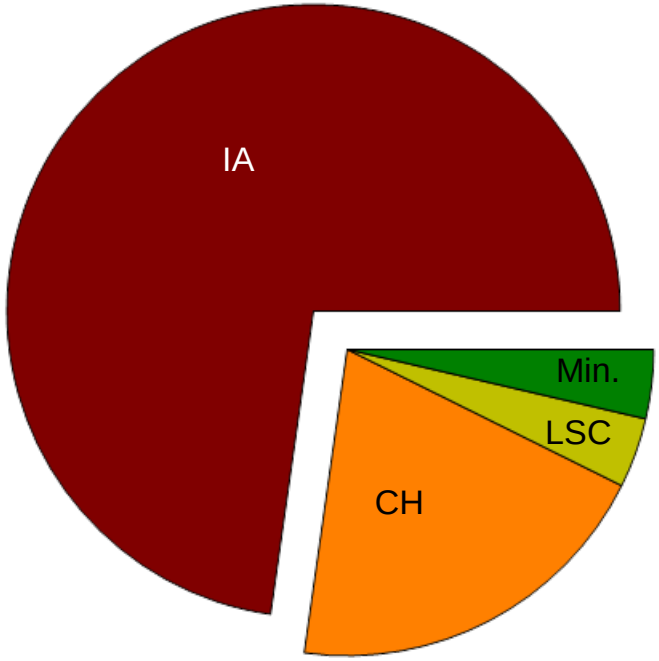
Recent History of Point Source Loading to the Shelf



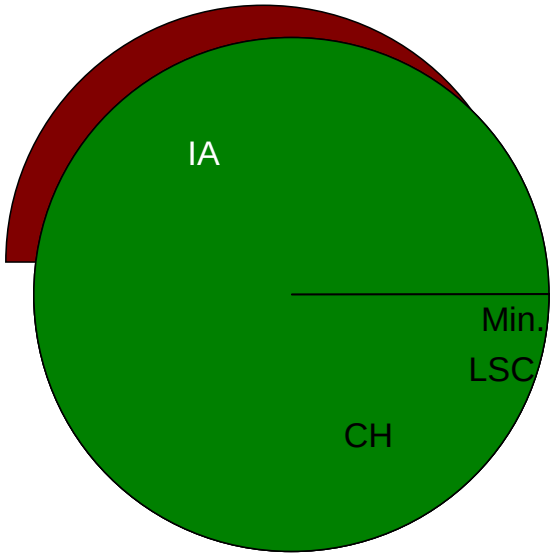
- IAWWTP
  - large decreases since ~ 2005
  - implementation of enhanced treatment
- CHWWTP
  - decreases since 2000
- LSC
  - seasonal – max load during summer
  - overall increases since 2000
    - increases in conc. and flow

Partitioning Contributions: Shift from Treatment Upgrades

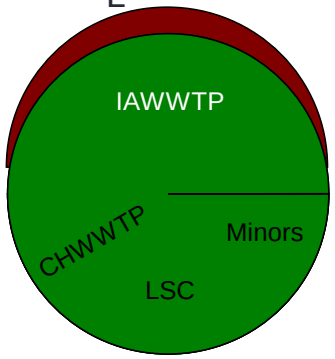
TP_L 5.2 mt



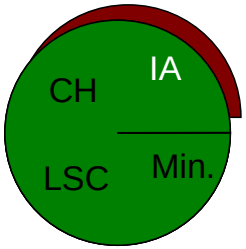
BAP_L 3.6 mt



TP_L 1.4 mt

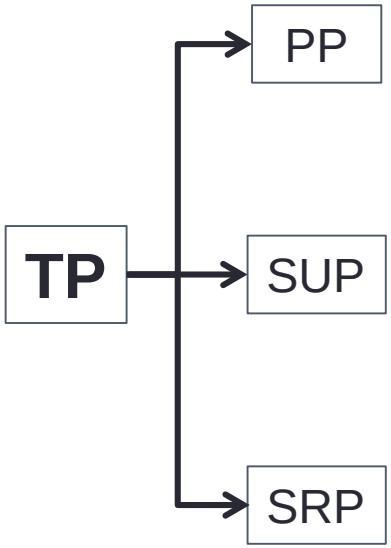


BAP_L 0.7 mt



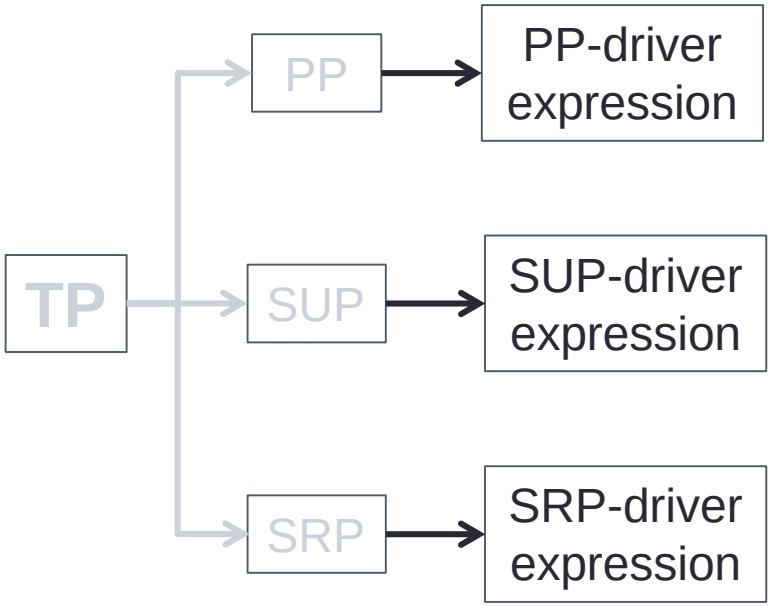
- 2000
  - estimates of BAP_L uncertain, assumptions about P conc. and f_{BAP}
  - historic context
- 2013
  - only ~ ½ TP_L is bioavailable
  - since 2000
    - ~ 73 % reduction in TP_L
    - ~ 81 % reduction in BAP_L
  - IA contribution largest decrease since 2000
  - LSC contribution increased since 2000

Strategy to Develop Tributary P Loads



concentrations
runoff event
based sampling

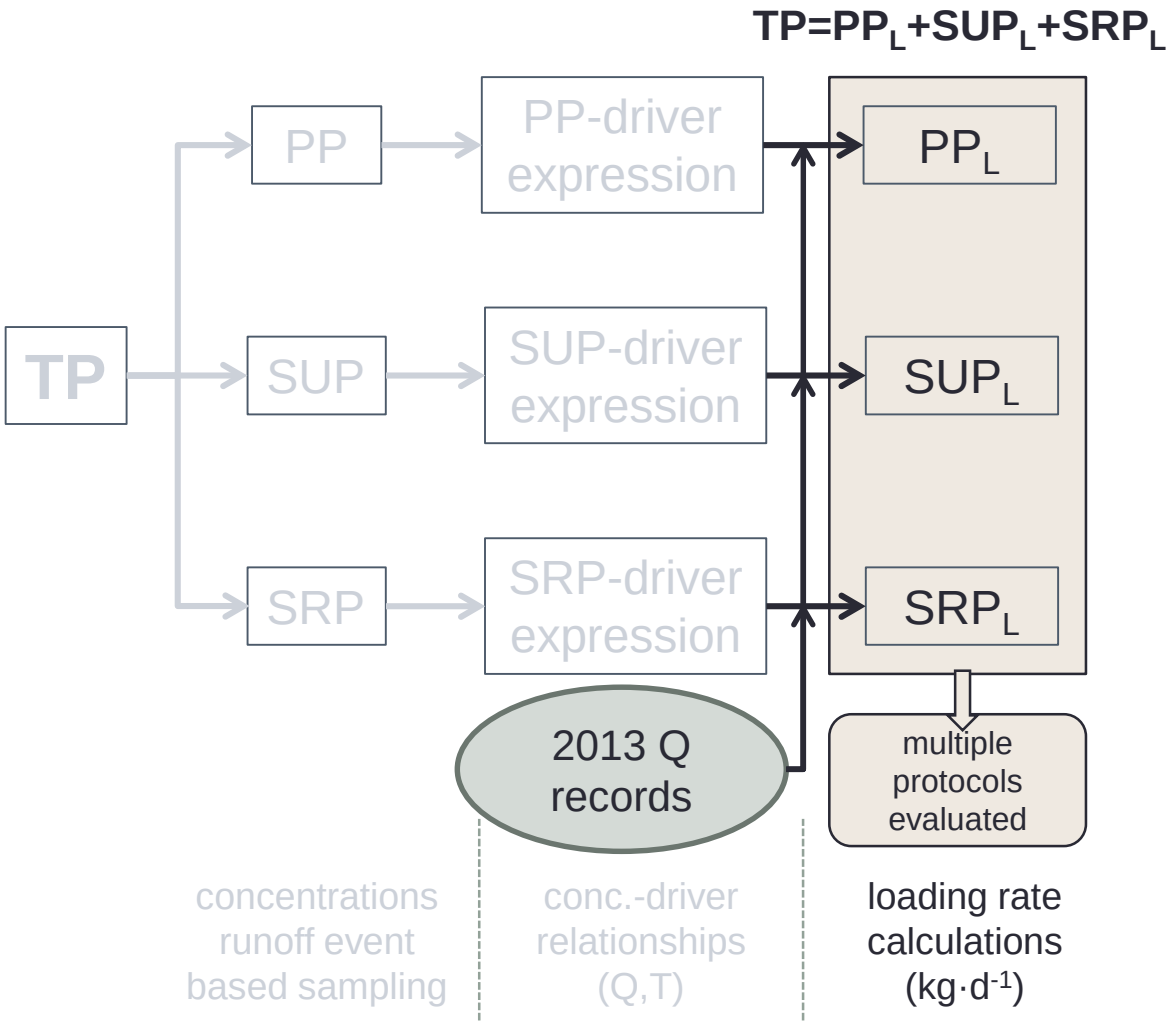
Strategy to Develop Tributary P Loads



concentrations runoff event based sampling

conc.-driver relationships (Q,T)

Strategy to Develop Tributary P Loads



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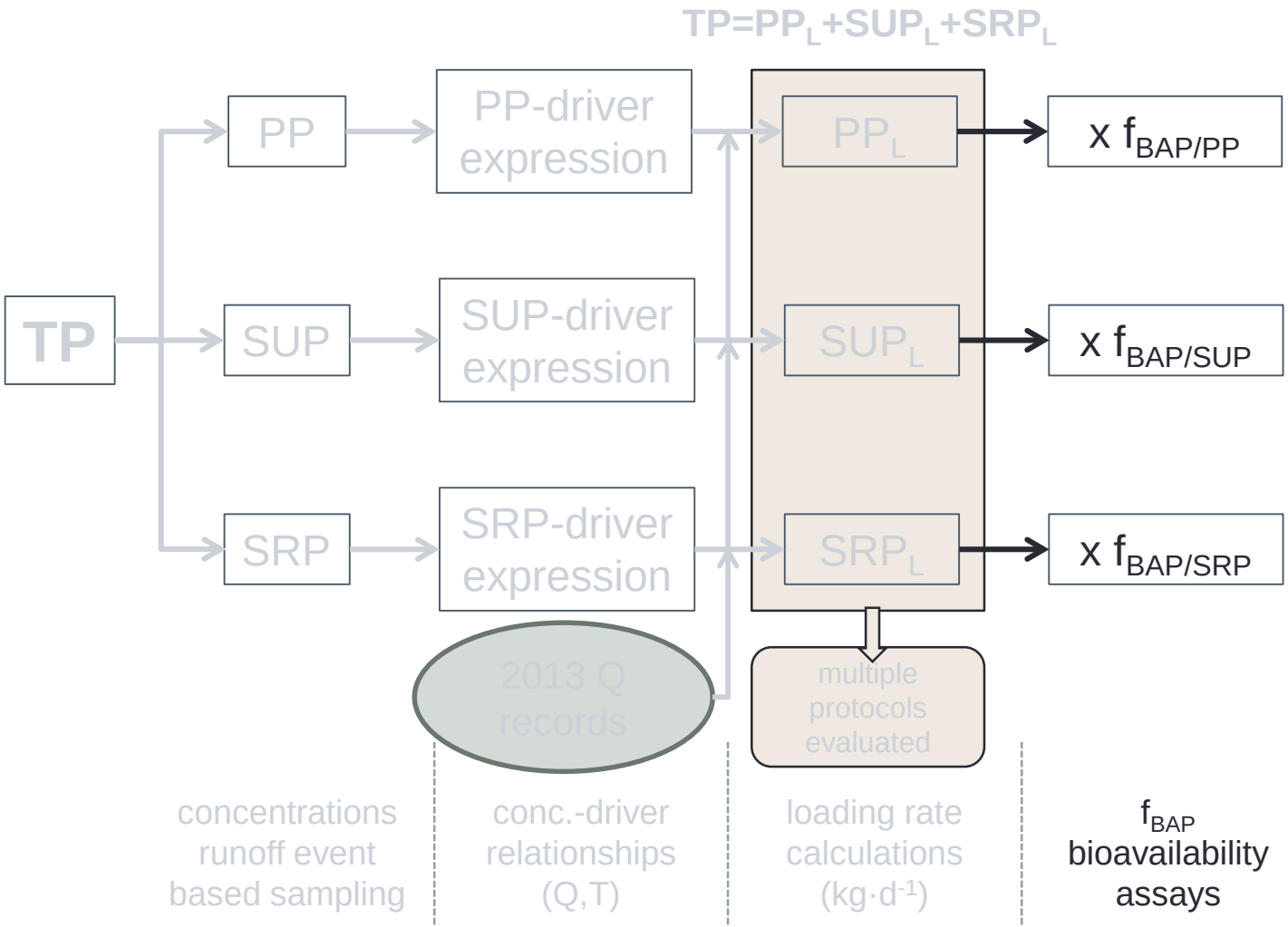

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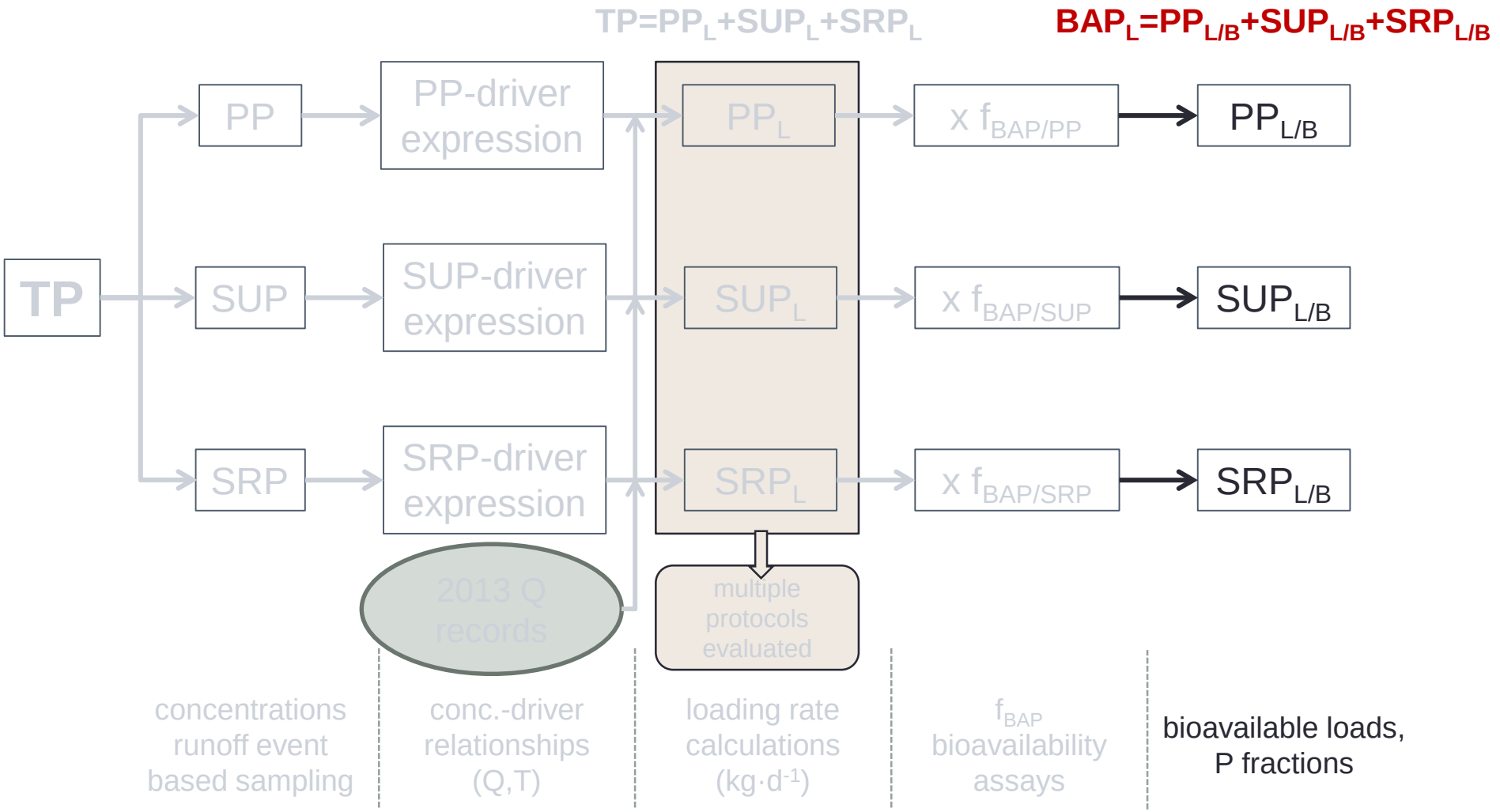

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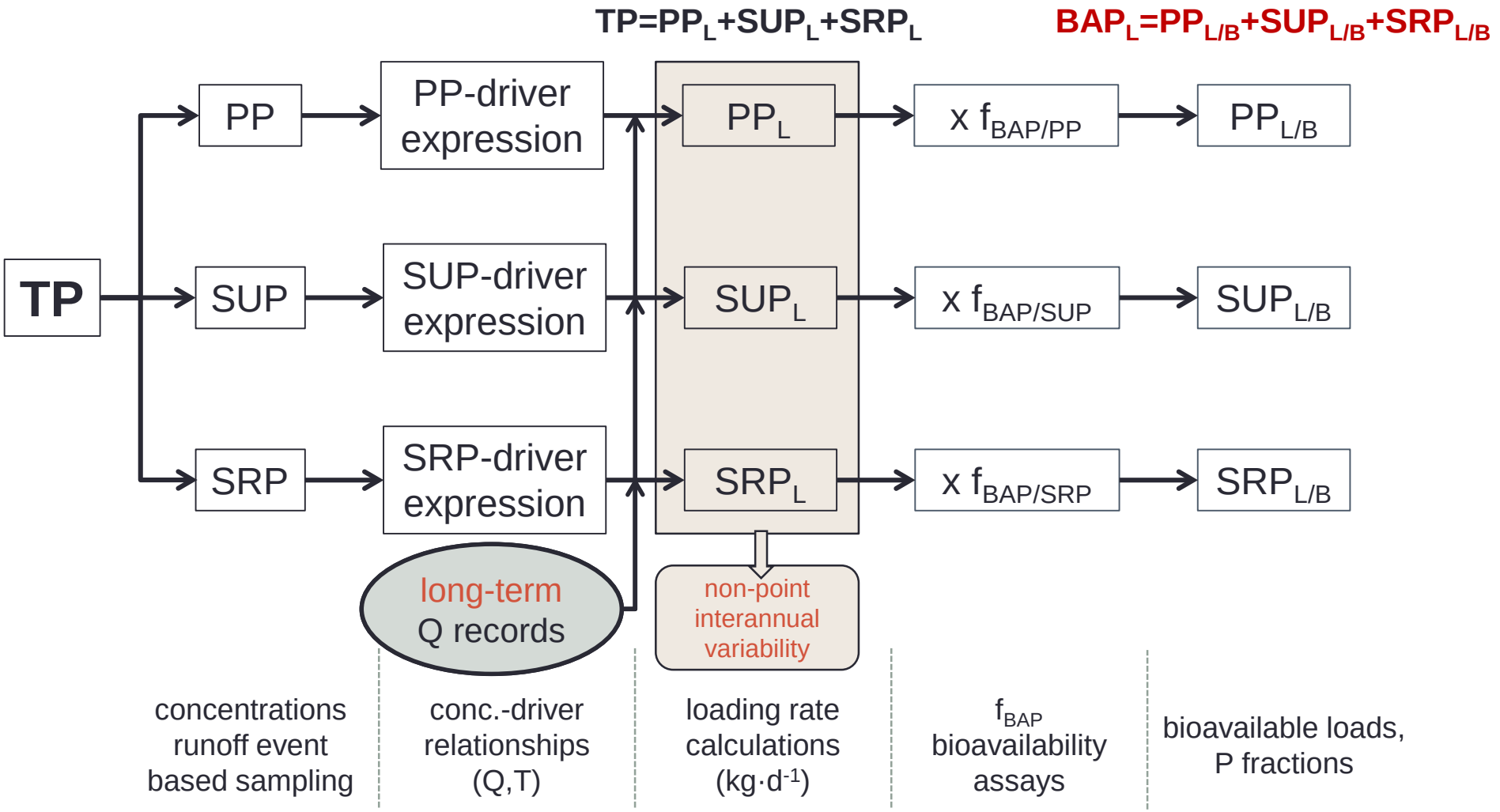
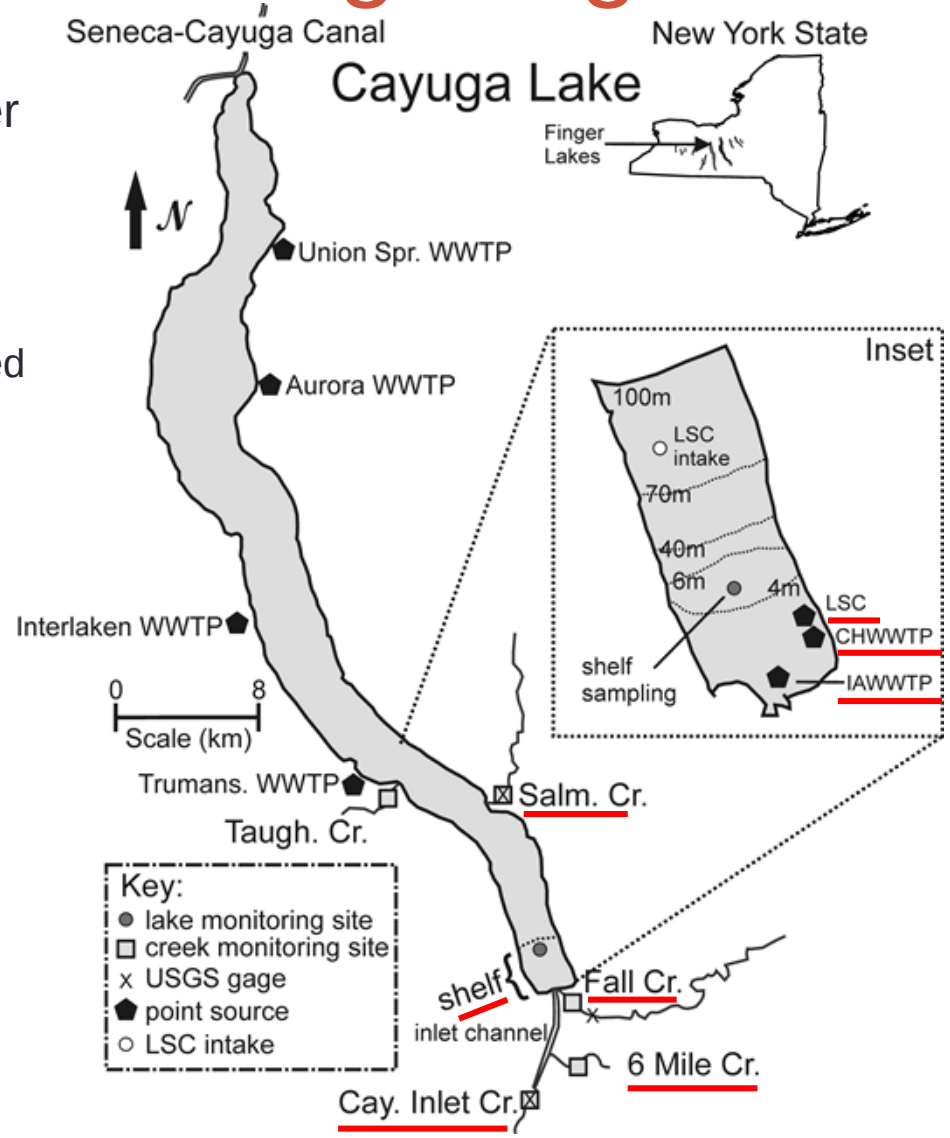


2013 Tributary Monitoring Program

- Mid-March through mid-November
  - biweekly, fixed frequency
  - runoff events targeted
- Monitored 4 gauged tribs, 1 ungauged trib
  - Seneca-Cayuga Canal not considered
- Gauged:
  1. Fall Cr.
  2. Cayuga In.
  3. Salmon Cr.
  4. Six Mile Cr.
- Ungauged:
  1. Taughannock Cr.
- Parameters:
  - forms of phosphorus, dissolved nitrogen, DOC, suspended solids, turbidity, silica
- Focus of this presentation
  - forms of phosphorus

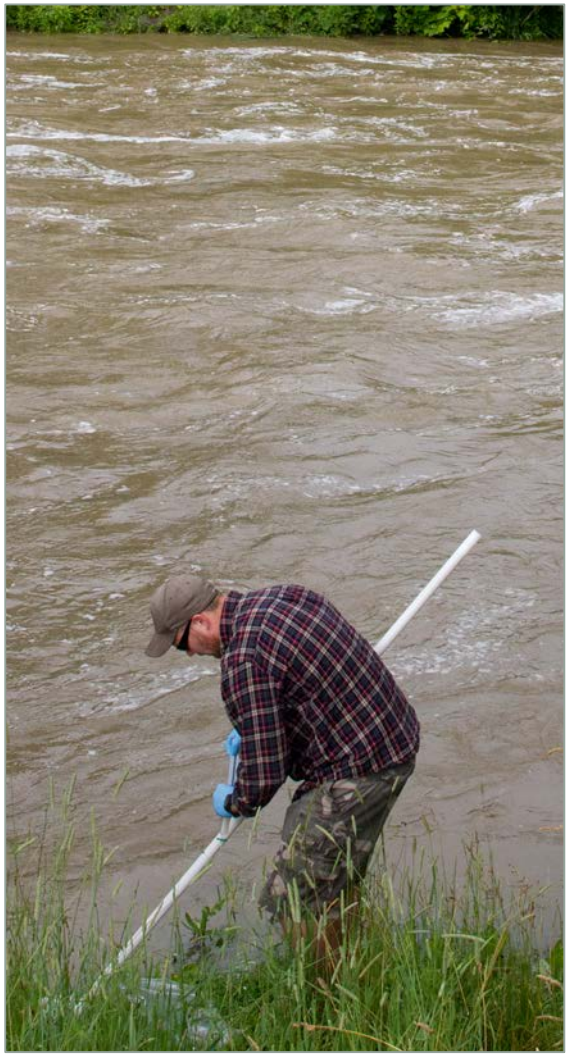


Tributary Monitoring: Sampling Coverage

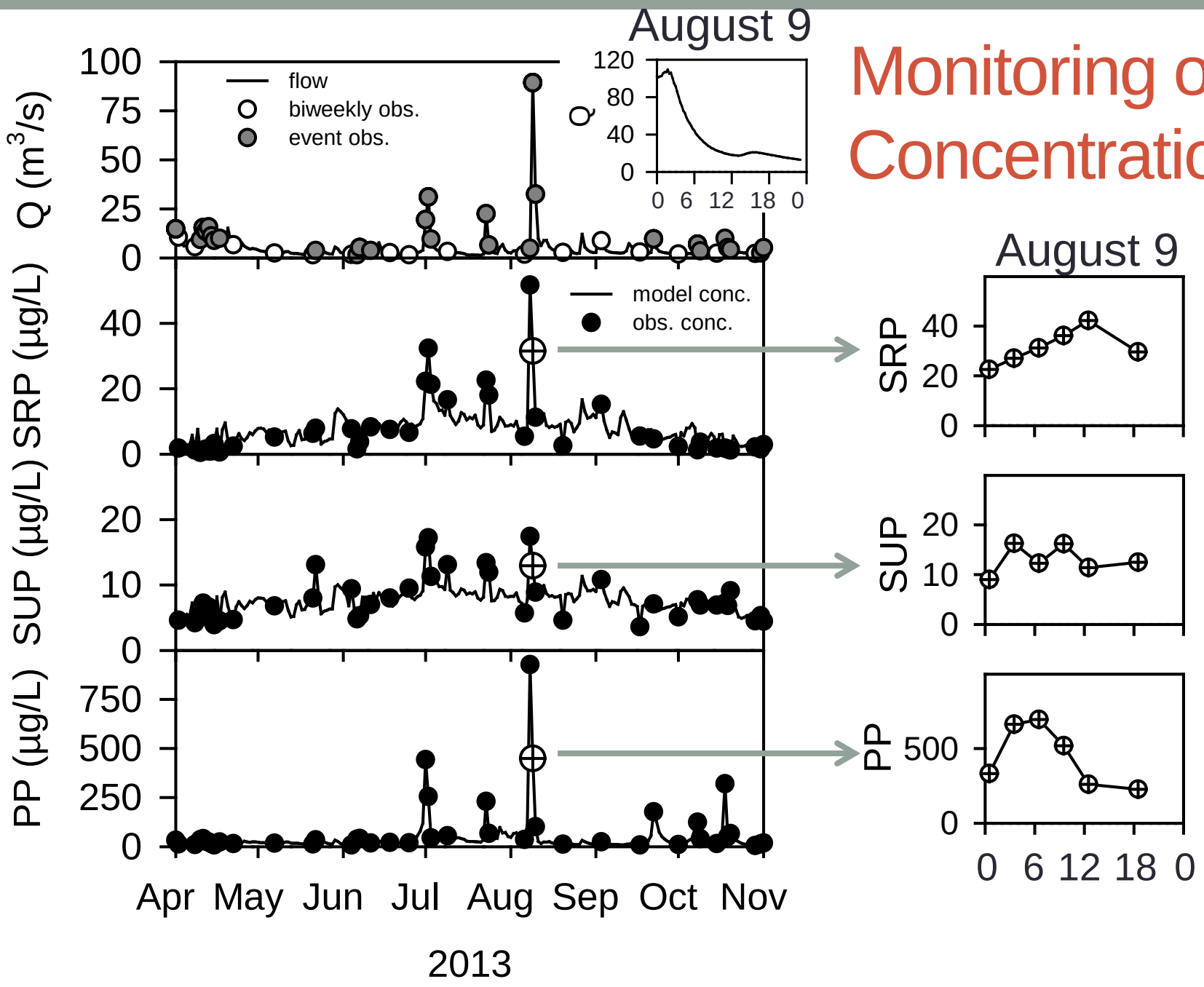
April through October (214 days)

Stream	No. Samples	No. Days Samples	No. Events Monitored
Fall Cr.	87	43	11
Cayuga In.	63	34	6
Salmon Cr.	88	47	9
Six Mile Cr.	62	34	7
Taugh. Cr.[1]	18	18	0
Total	**318**	**176**	**-**

[1] biweekly sampling only



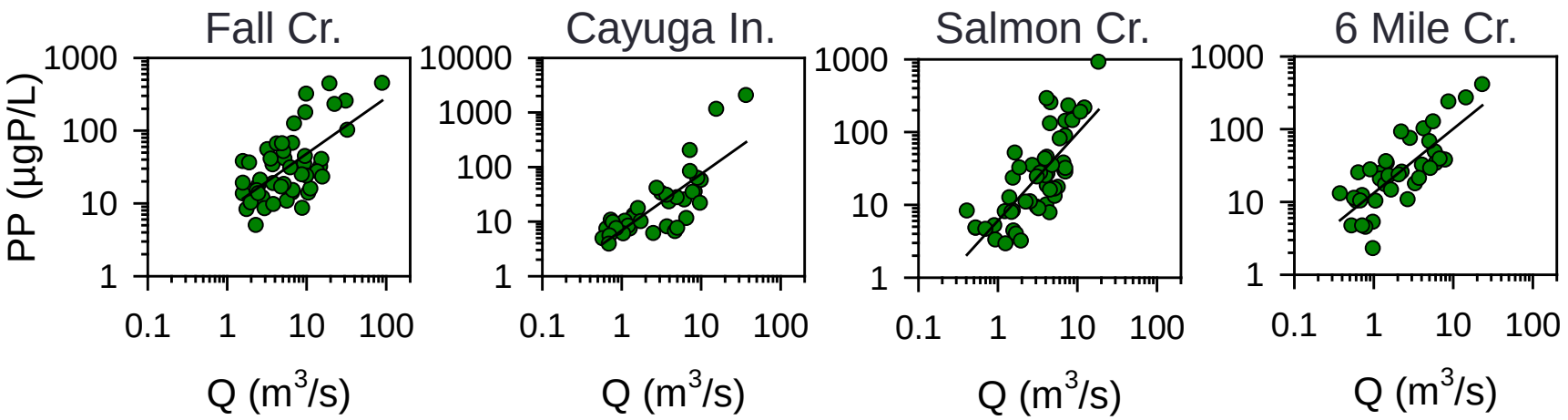
Monitoring of P Concentrations



Concentration-Flow Relationships, PP

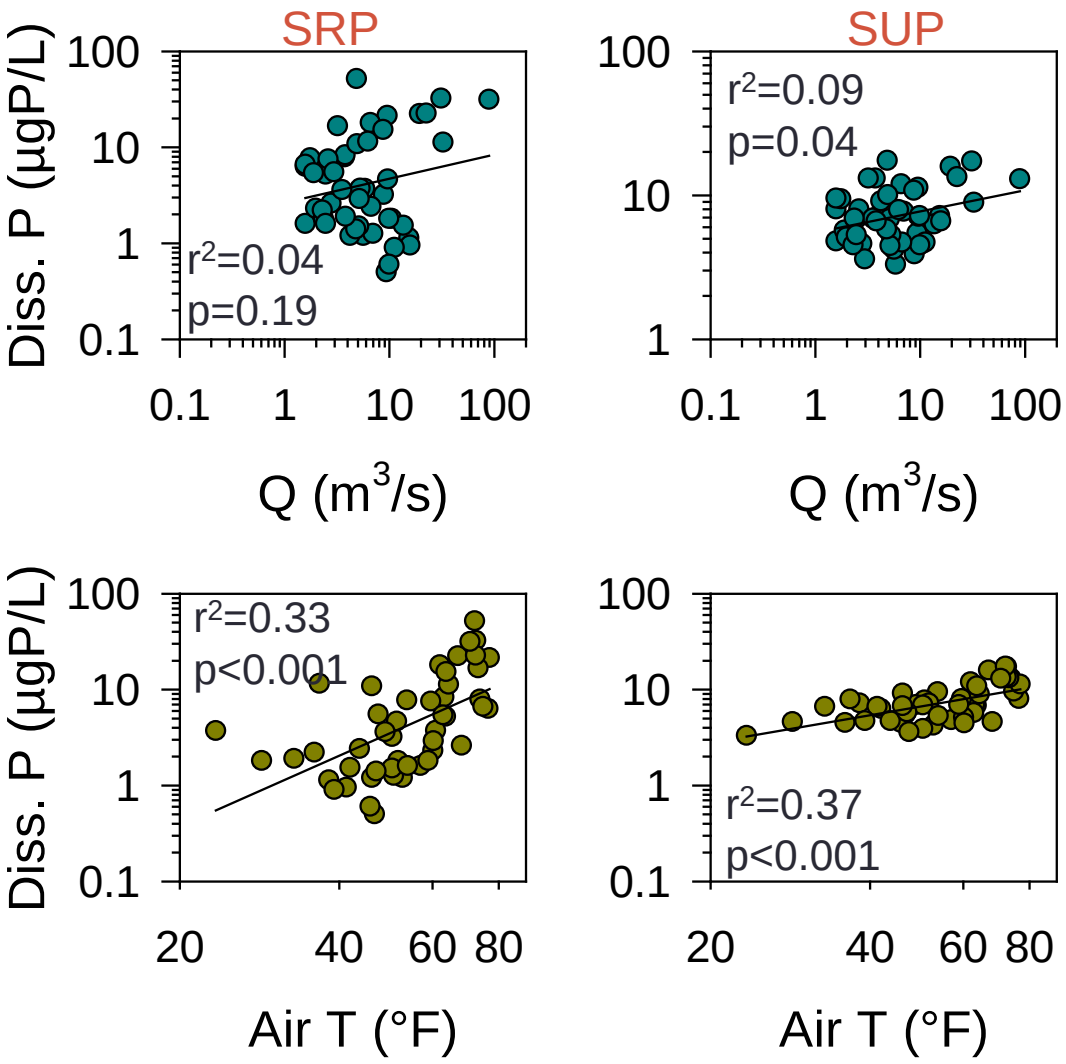
Flow-Particulate P

Tributary	Abbrev.	PP-Q Equation	Model Fit	Significance
Fall Cr.	FC	$PP=8.20 \cdot Q^{0.768}$	$r^2=0.39$	$p < 0.001$
Cayuga In.	CI	$PP=6.87 \cdot Q^{1.035}$	$r^2=0.62$	$p < 0.001$
Salmon Cr.	SC	$PP=6.04 \cdot Q^{1.205}$	$r^2=0.57$	$p < 0.001$
Taugh. Cr.	TC	$PP=6.23 \cdot Q^{0.378}$	$r^2=0.19$	$p = 0.07$
Six Mile Cr.	6M	$PP=13.2 \cdot Q^{0.883}$	$r^2=0.62$	$p < 0.001$



Concentration-Driver Relationships, Dissolved P

Fall Creek



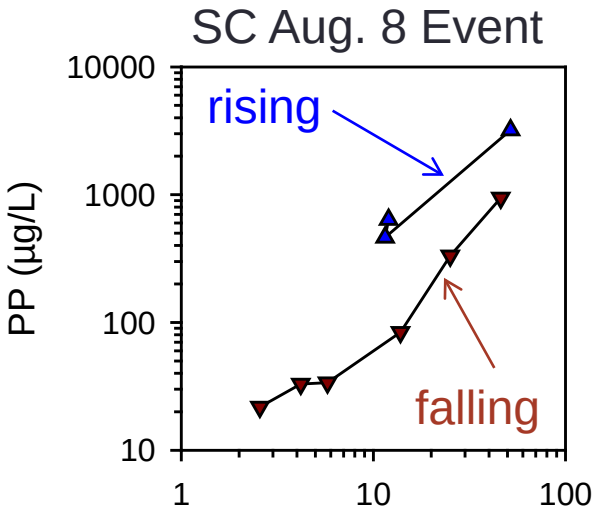
- Neither SRP nor SUP exhibited strong concentration-flow relationships

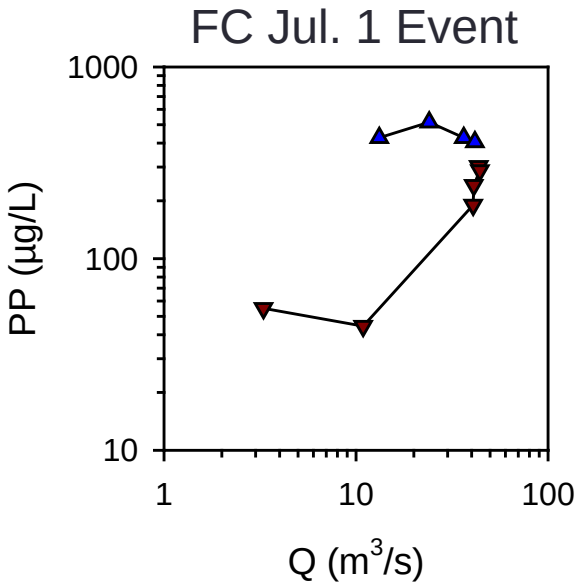
- concentrations, f (Q, air T) by multiple linear regression
- highly significant, good fit

- Both SRP, SUP had strong, significant relationships with air temperature

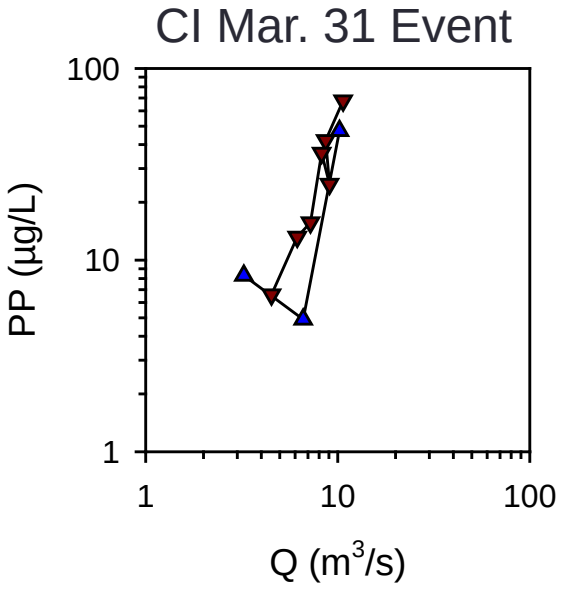
Hysteresis: Differences in Rising/Falling Limbs

- Certain events demonstrated strong hysteresis patterns
- Examples:
  - Salmon Cr. Aug. 8
  - Fall Creek Jul. 1





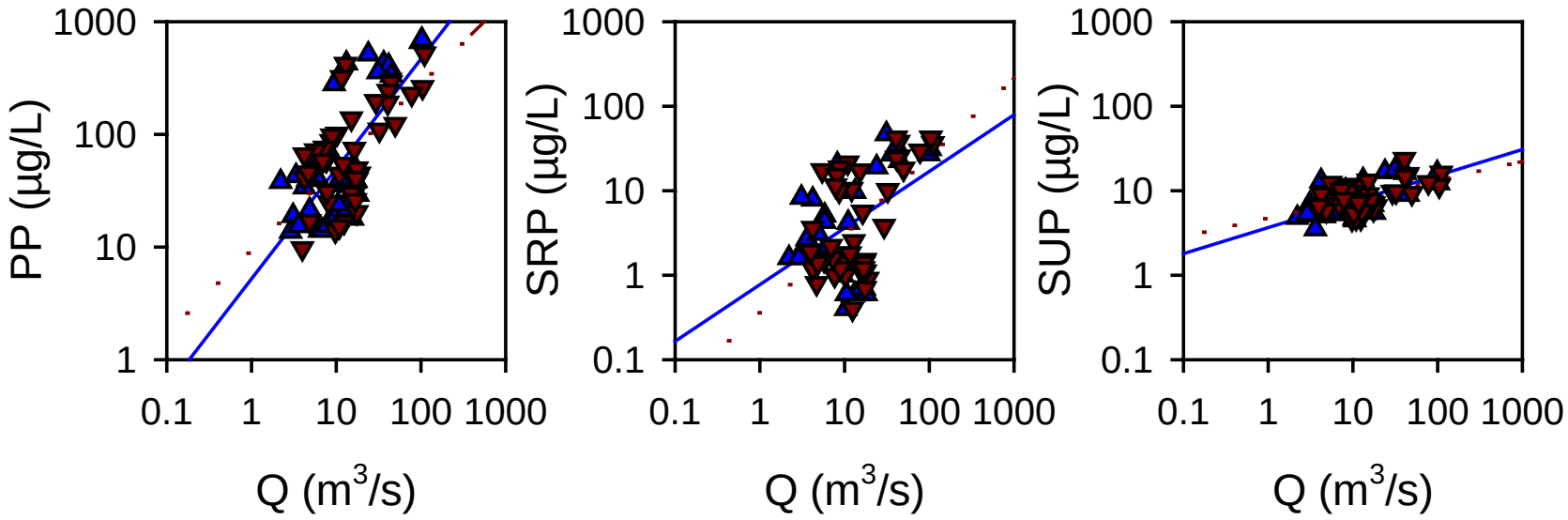
- Other events had less distinct differences on rising/falling limb concentrations
  - Cayuga Inlet Mar. 31



Hysteresis: Differences in Rising/Falling Limbs

- Taken as a whole (all measurements), differences between flow-concentration slopes on rising and falling limbs were generally not significant

- Example: Fall Creek P fractions



2013 Tributary Load Estimation Protocols

1. FLUX32 Methods

   LN transformed, daily averaged flows, samples

   1. flow-conc. regression, method 6, 2 flow strata at mean flow with interpolated residuals
   2. flow-conc. regression, method 6, 2 flow strata at mean flow
   3. 2 additional regression methods , 2 flow strata at mean flow
   4. flow-conc. regression, method 6, hydrograph separation (steady flow, rising, falling)

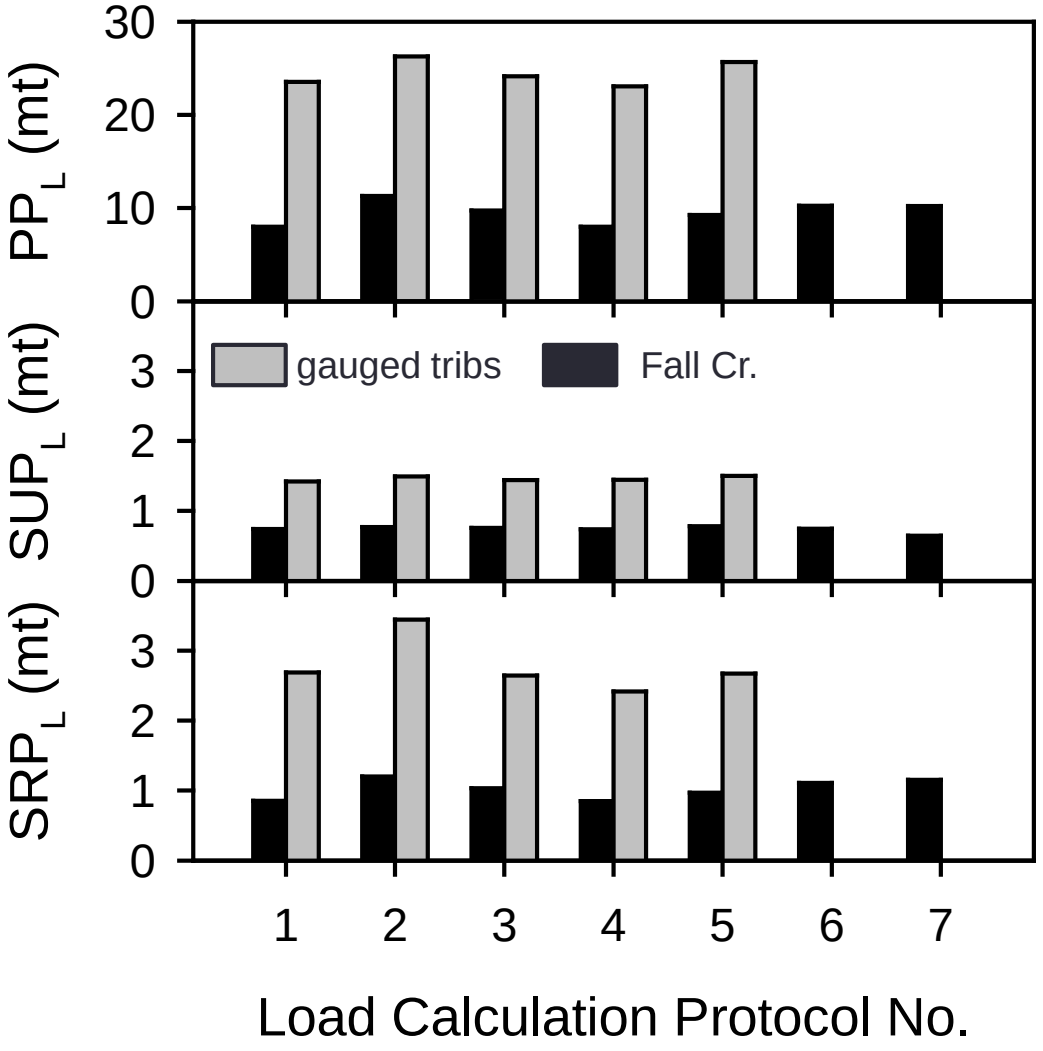
2. Manual Methods

   LN transformed, 15 min flows, original observations

   5. multiple linear regression, Q and Air T, no flow stratification, dissolved P only
   6. flow-conc. regression on 15min flows, original observations, 2 flow strata at mean flow (Fall Creek only)
   7. flow-conc. regression on 15 min flows, , 2 flow strata at mean flow with event load estimates (Fall Creek only)

P Load Estimates, According to Multiple Estimation Protocols

- Generally, good agreement between protocols
- Differences between methods not uncommon in load estimation
- Fall Creek:
- PP_L range of predictions:
  - 8-11.2 mt
  - CV = 6%
  - fairly precise estimates
- SUP_L range of predictions:
  - 0.65-0.79 mt
  - CV = 2%
  - very precise estimates
- SRP_L range of predictions:
  - 0.85-1.2 mt
  - CV = 14%



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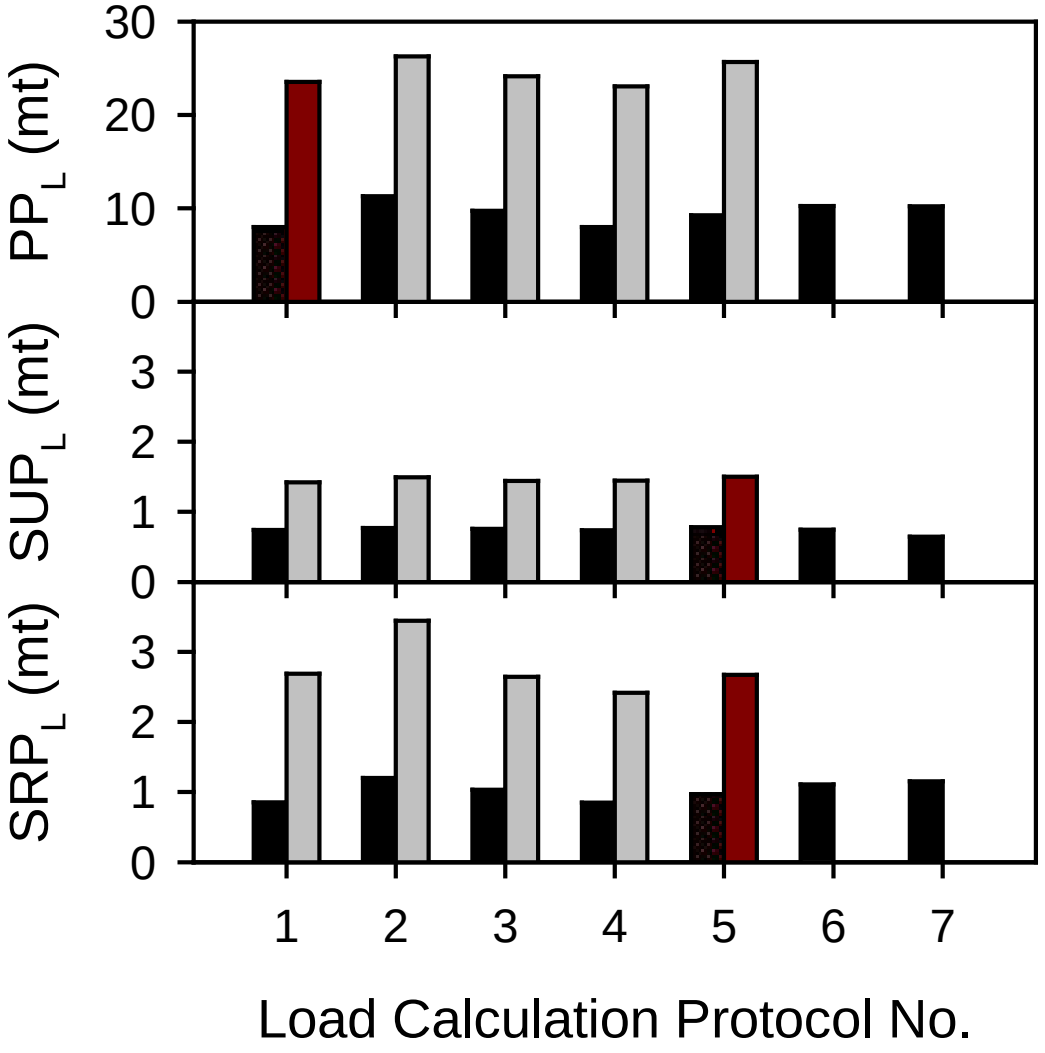


Method Selection

- Table represents a summary of method selection criteria for each parameter (SRP, SUP, PP)
- Number represents, the best method per criteria

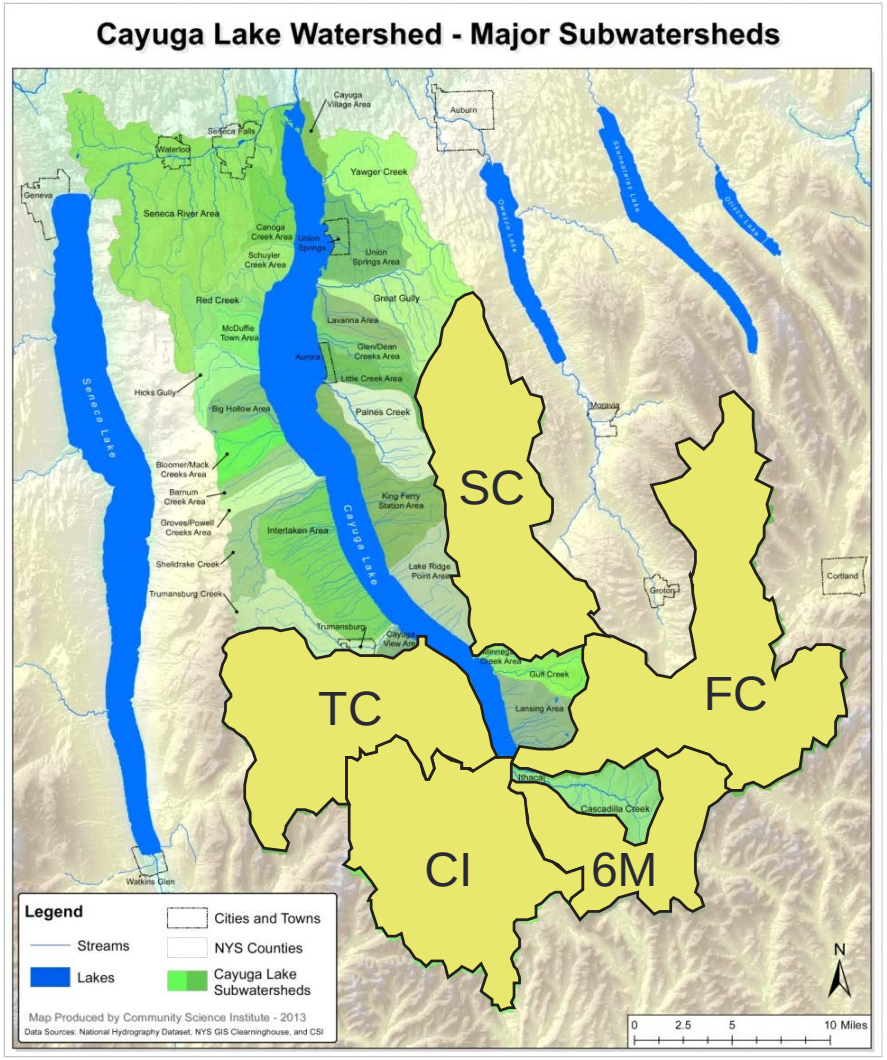
Parameter	Fit (r^2)	Method (p-value)	Method Uncertainty (mse)	Does the Method Make Sense?	Use of Actual Meas.	Certainty in Load Estimates
SRP	5	5	5	5	5	5
SUP	5	5	5	5	5	5
PP	1	1	1	1	1	3

- Best P loading protocols:
  - Dissolved P (SRP, SUP), method 5, the multiple linear regression model using stream flow and air T
  - Particulate P, method 1, the 2 strata concentration-flow with interpolation in FLUX32

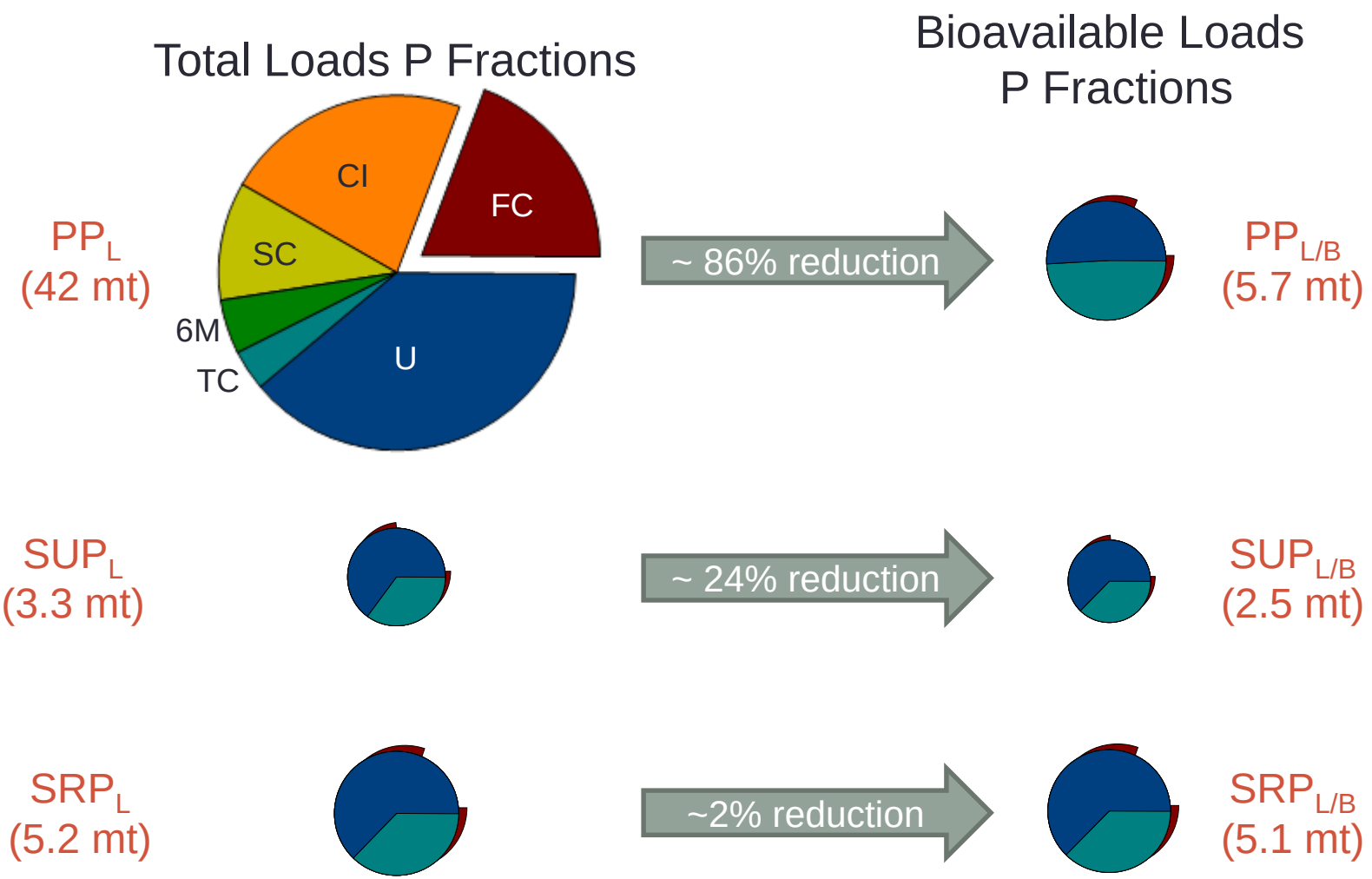
Unmonitored Tributaries: Load Estimation

~40% unmonitored

- Monitored Watershed
  - 5 largest tribs, ~60% of watershed area
  - assumed 60% of hydrologic inflow
  - FC, CI, SC, TC, 6M (yellow)
- Unmonitored Watershed
  - 40 % of lake's watershed
  - many small streams (each < 3.5% of lake's watershed)
  - assumed unmonitored area ∝ to unmonitored inflow
- Unmonitored Load Estimates
  - prorated monitored loads to whole-lake watershed loads based on ratio of monitored:unmonitored watershed areas



2013 Tributary Loading Estimates: Apr. – Oct.

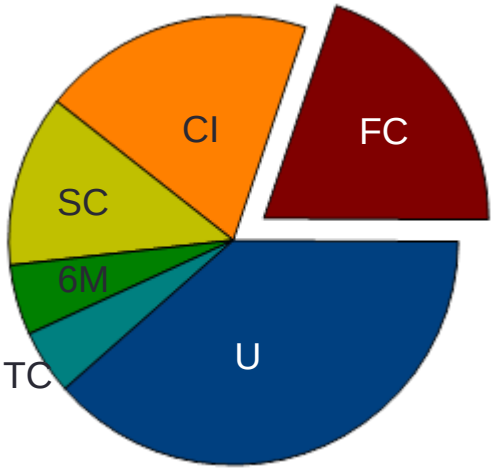


2013 Tributary Loading Estimates: Apr. – Oct.

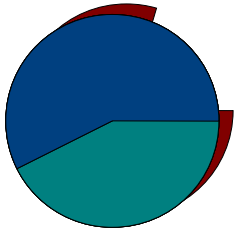
Total Loads P Fractions

Bioavailable Loads P Fractions

TP_L (51 mt)



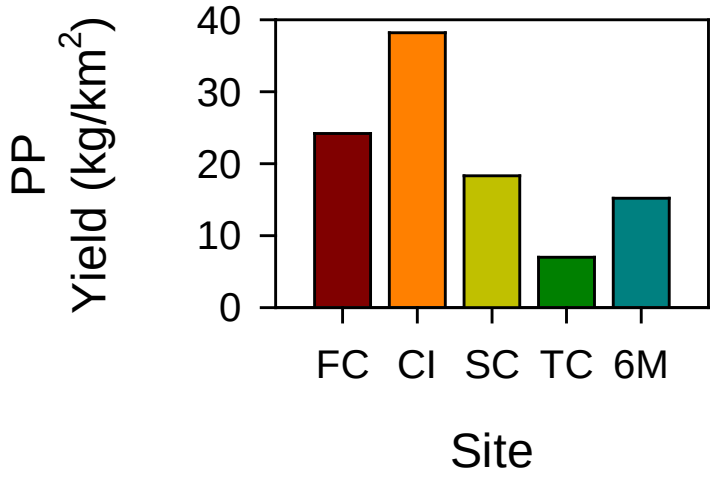
~ 75% reduction



BAP_L (13 mt)

2013 Raw and Bioavailable P Loading Estimates as Yields: PP

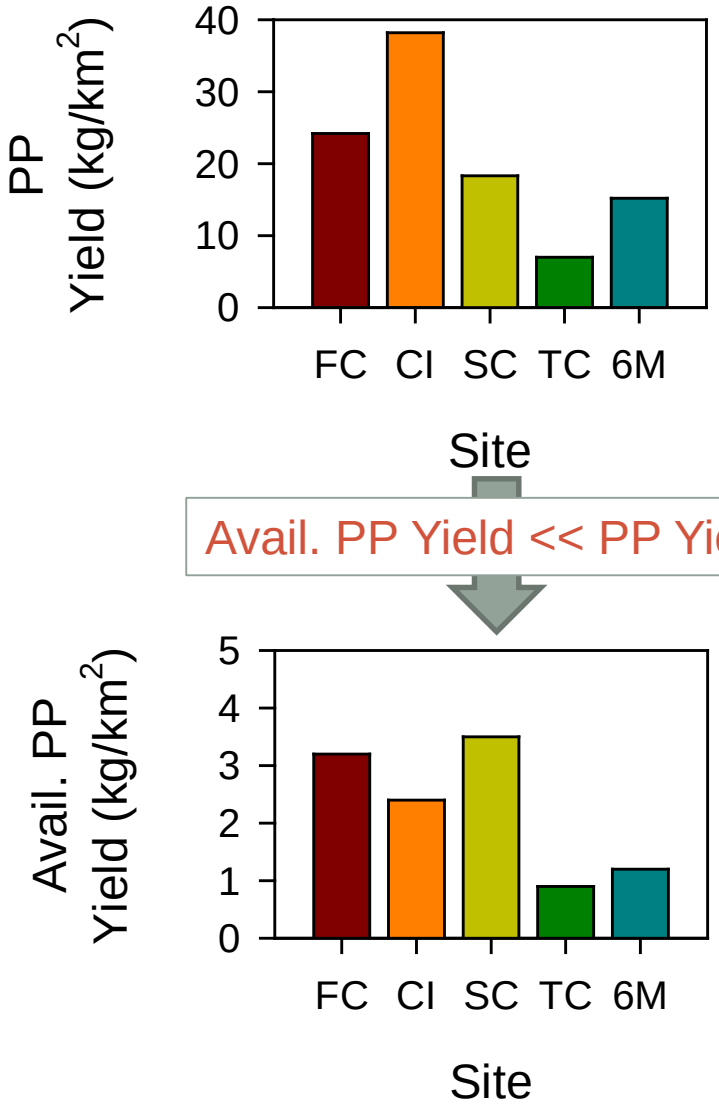
- Tributary yields
  - P load ÷ watershed area
- Cayuga In.
  - largest PP yield



2013 Raw and Bioavailable P Loading Estimates as Yields: PP

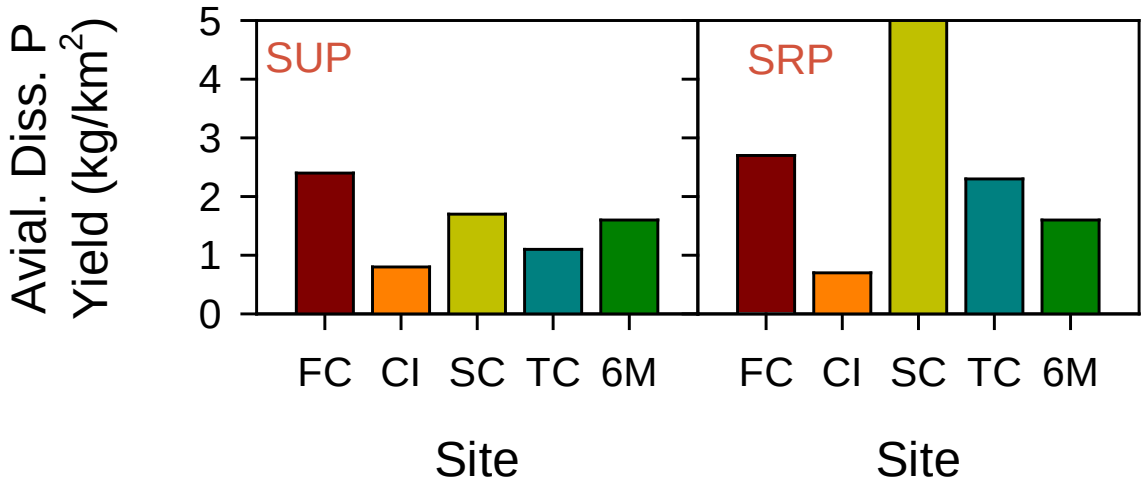
- Tributary yields
  - bioavailable P load ÷ watershed area
  - potency of sources

- Fall Cr., Cayuga In., Salmon Cr. watersheds
  - Important sources of $PP_{L/B}$
  - Salmon Cr. dominates $PP_{L/B}$

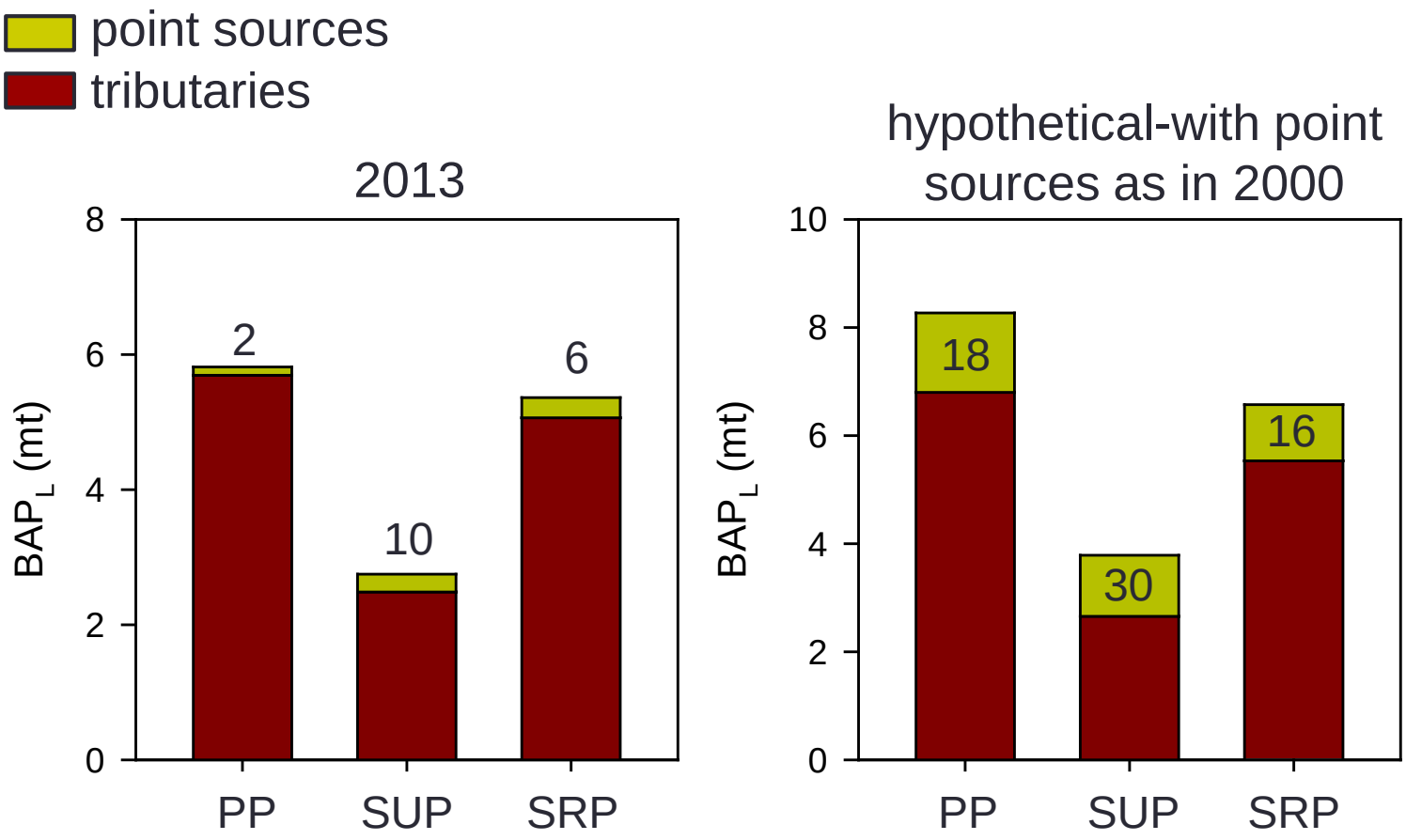


2013 Bioavailable P Loading Estimates as Yields: Dissolved P

- Tributary yields
  - bioavailable P load ÷ watershed area
  - potency of sources
- Salmon Cr. $SRP_{L/B}$ yield high, conspicuously enriched
  - Fall Cr., Taugh. Cr. also important sources



Contributions to Point Sources to BAP_L



#s represent % contribution from point sources

Apportionment of External Loads, 2013

	Percent Contribution (%)									
Source	**Q (%)**		**PP_L**	**SUP_L**	**SRP_L**	**TP_L**		**$PP_{L/B}$**	**$SUP_{L/B}$**	**$SRP_{L/B}$**	**BAP_L**
Fall Cr.	18.6		16.3	20.9	16.2	16.5		18.7	21.9	16.0	18.2
Cayuga In.	7.9		18.7	5.0	2.8	16.2		16.5	4.7	2.8	8.6
Salmon Cr.	9.3		8.7	10.3	20.5	10.0		15.1	11.8	20.5	16.7
Six Mile Cr.	6.0		4.1	3.8	5.0	4.2		2.2	3.0	5.1	3.6
Taugh. Cr.	10.8		3.3	10.2	6.3	4.1		2.9	9.9	6.3	5.7
Unmon. Tribs.	41.5		47.4	39.8	44.2	46.6		41.9	38.9	44.2	42.3
summed (%)	***94.1***		***98.5***	***90.2***	***95.0***	***97.6***		***97.4***	***90.2***	***95.0***	***95.0***
IAWWTP	1.0		0.9	6.2	0.6	1.2		0.1	6.3	0.6	1.5
CHWWTP	0.2		0.3	0.7	0.3	0.3		1.4	0.7	0.3	0.8
minor WWTP	0.1		0.1	1.6	3.3	0.5		0.4	1.6	3.3	1.8
LSC	4.6		0.2	1.3	0.8	0.3		0.8	1.2	0.8	0.9
summed (%)	***5.9***		***1.5***	***9.8***	***5.0***	***2.4***		***2.6***	***9.8***	***5.0***	***5.0***
summed (%)	***100***		***100***	***100***	***100***	***100***		***100***	***100***	***100***	***100***

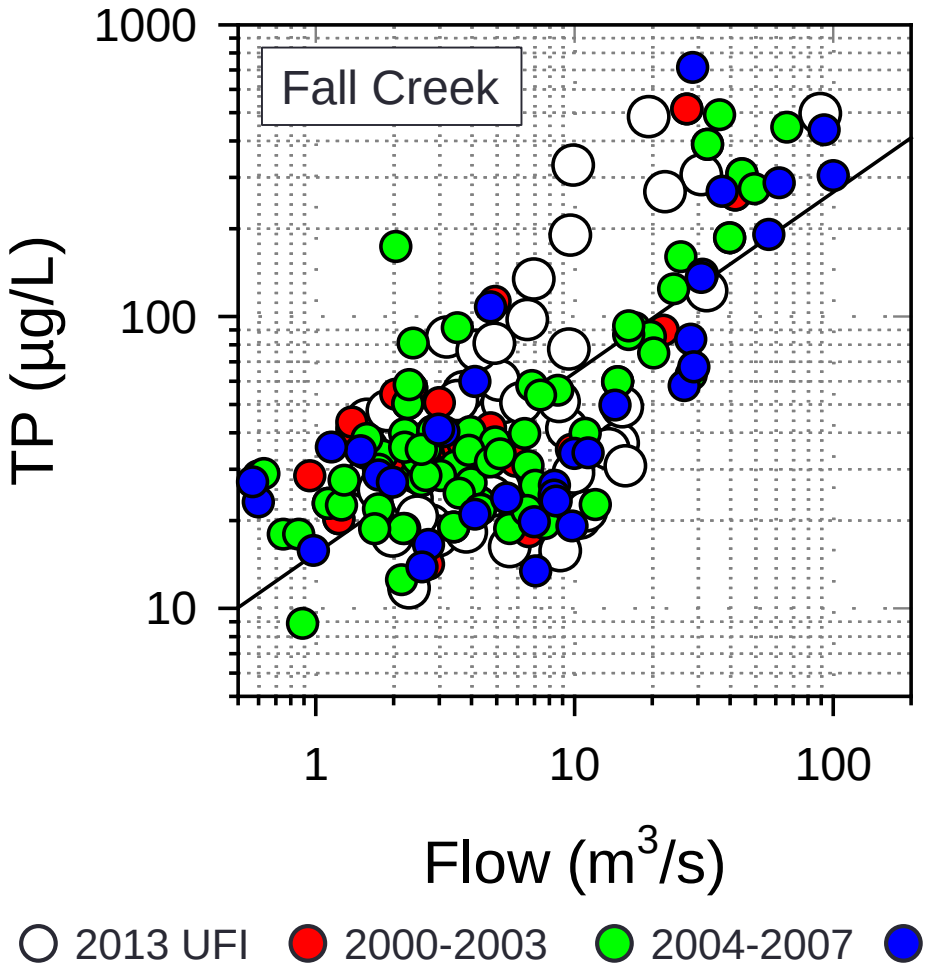
Apportionment of External Loads, 2013

	Percent Contribution (%)					
Source	**Q (%)**		**$PP_{L/B}$**	**$SUP_{L/B}$**	**$SRP_{L/B}$**	**BAP_{L}**
Fall Cr.	18.6		18.7	21.9	16.0	18.2
Cayuga In.	7.9		16.5	4.7	2.8	8.6
Salmon Cr.	**9.3**		15.1	11.8	20.5	**16.7**
Six Mile Cr.	6.0		2.2	3.0	5.1	3.6
Taugh. Cr.	10.8		2.9	9.9	6.3	5.7
Unmon. Tribs.	41.5		41.9	38.9	44.2	42.3
summed (%)	***94.1***		***97.4***	***90.2***	***95.0***	***95.0***
IAWWTP	1.0		0.1	6.3	0.6	1.5
CHWWTP	0.2		1.4	0.7	0.3	0.8
minor WWTP	0.1		0.4	1.6	3.3	1.8
LSC	4.6		0.8	1.2	0.8	0.9
summed (%)	***5.9***		***2.6***	***9.8***	***5.0***	***5.0***
summed (%)	***100***		***100***	***100***	***100***	***100***

Apportionment of External Loads, 2013

	Percent Contribution (%)
Source	**BAP_L**
Fall Cr.	18.2
Cayuga In.	8.6
Salmon Cr.	**16.7**
Six Mile Cr.	3.6
Taugh. Cr.	5.7
Unmon. Tribs.	42.3
summed (%)	***95.0***
IAWWTP	1.5
CHWWTP	0.8
minor WWTP	1.8
LSC	0.9
summed (%)	***5.0***
summed (%)	***100***

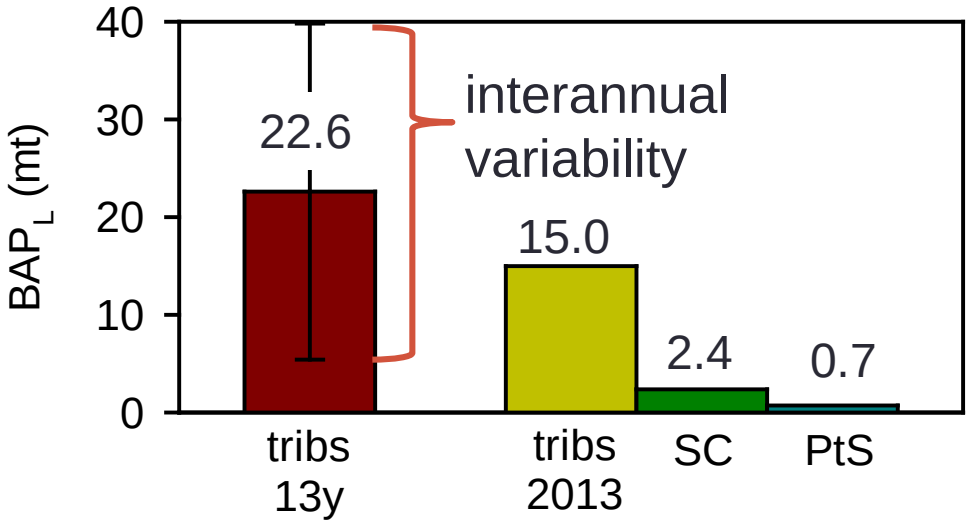
Using 2013 Conc.-Driver Relationships for 2000-2012 Loading Estimates



- no statistical differences in Q-TP relationship (slopes) between 2013 and other sources, previous years (CSI, DEC, UFI ‘03-’06),
  - guided by community data
- similar results for other tributaries

Load Estimates for the 2002-2012 Period: Magnitudes and Interannual Variability

- 2013 conc.-driver relationships applied
- comparison to 2013 estimates
  - total, Salmon Cr., summed point sources



- 2013 close to long-term mean
- interannual variability large (± 1 std. dev.)
  - > Salmon Cr.
  - > summed point sources
- context – reasonable expectations for management actions

Uncertianties/Caveats

1. Uncertainties

	Upside
a. incomplete temporal coverage	runoff event-based monitoring
b. variance in conc.-driver relationships	reasonably strong relationships
c. other loading calculation protocols?	robust array evaluated, good closure
d. unmonitored tribs.	many small streams, practical limitations

2. in context – a strong representation for a challenging system

3. other future potential systematic modifications of $PP_{L/B}$
   a. particulate budget around the Inlet Channel; e.g. could modify Six Mile and Inlet Loads
   b. “effective” $PP_{L/B}$, could diminish within lake associated with deposition vs. release rates (model)

application of the total phosphorus guidance value (20 µg/L) on the South “Shelf” of Cayuga Lake in the context of bioavailability findings

presented previously ❖

PARTITIONING THE CONTRIBUTIONS OF MINEROGENIC PARTICLES AND BIOSESTON TO PARTICULATE PHOSPHORUS AND TURBIDITY*

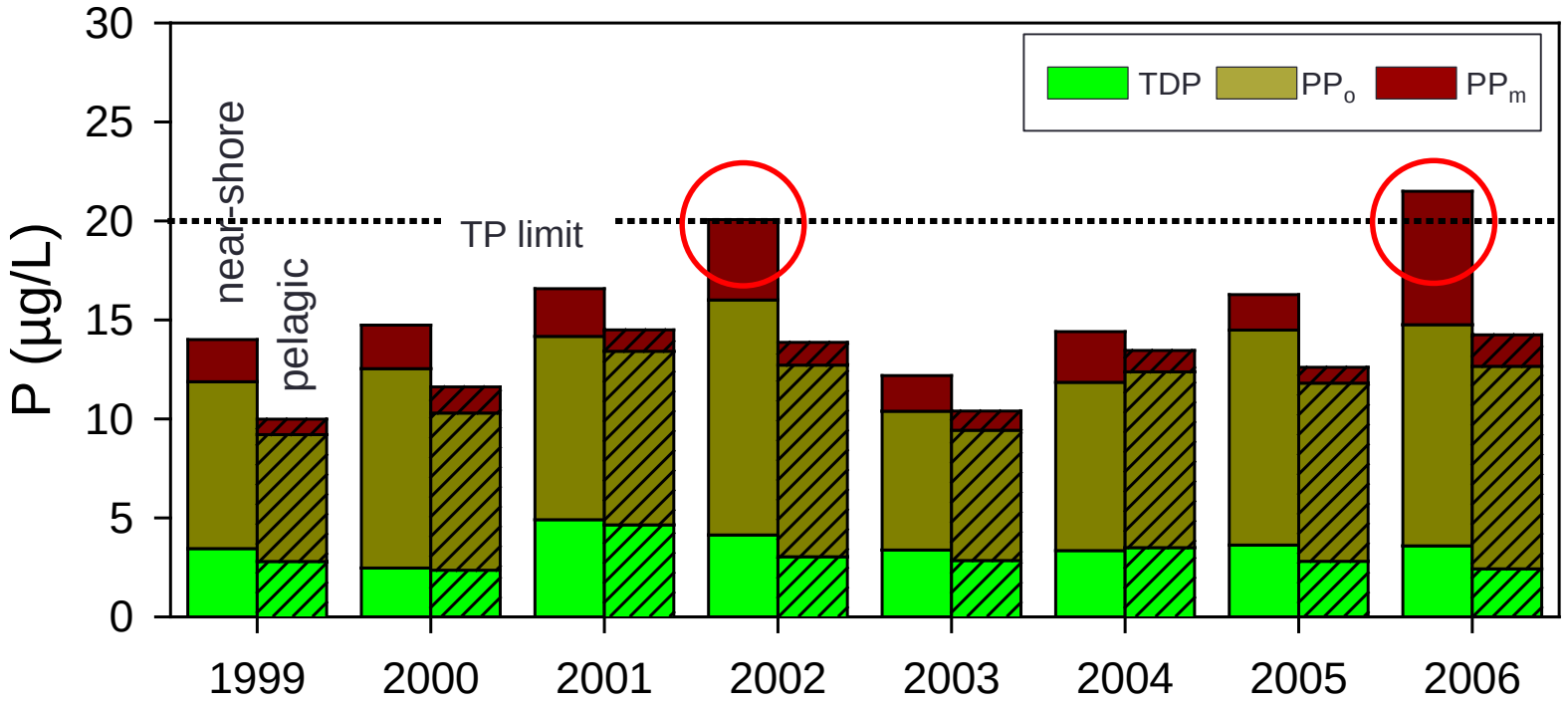
Steven W. Effler,
Anthony R. Prestigiacomo,
Feng Peng,
Rakesh Gelda, and
David A. Matthews

Effler et al. 2014. Inland Waters 4:179-192

presented previously ❖

Application of the 2-Component Models: Implications for the TP Guidance Value

- components of TP (TDP, PP_o, PP_m) for near-shore and pelagic sites for study years
- total P (TP) guidance value (June-September average) – 20 µg/L



- approach to, and exceedance of, TP guidance values (near-shore only) in 2 years of the highest minerogenic PP (PP_m)

presented previously ❖

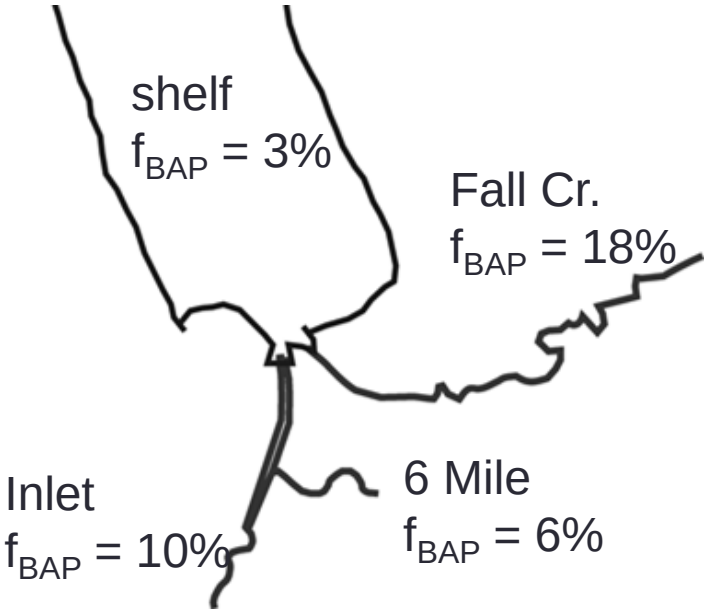
Management Implications

- if the bioavailability of PP_m is low:

> ". . . TP, (which is) driven by year-to-year and spatial differences in PP_m, is not a reliable indicator of changes or differences in trophic state in Cayuga Lake."

Low Bioavailability of Runoff Event PP: Tributaries and the Shelf

- runoff event of July 1, 2013
- f_{BAP} – fraction of PP bioavailable



Site	PP (µg/L)
Fall Cr.	444
6 Mile Cr.	271
Cay. In.	202
Inlet Channel	104
shelf	46

- demonstrated: shelf PP (post-runoff event) is essentially unavailable to support algae growth; i.e., uncoupled from trophic state
- implications: these features are not supportive of the inclusion of post-runoff event TP observations for assessment of trophic state status

Summary

1. External BAP_L's developed and apportioned according to sources
   a. BAP_L only ~ 25 % of TP_L
   b. representative loading estimates
   c. critical inputs/drivers for forthcoming water quality model
   d. particularly critical, P limiting nutrient
2. A comprehensive application of the bioavailability concept
   a. algal bioassays of 3 P fractions, multiple sources
   b. event-based monitoring gauged tributaries
   c. concentration-driver relationships developed
   d. loading calculations – multiple protocols tested, 2013 estimates and apportionment implications, natural variations in Q

Summary

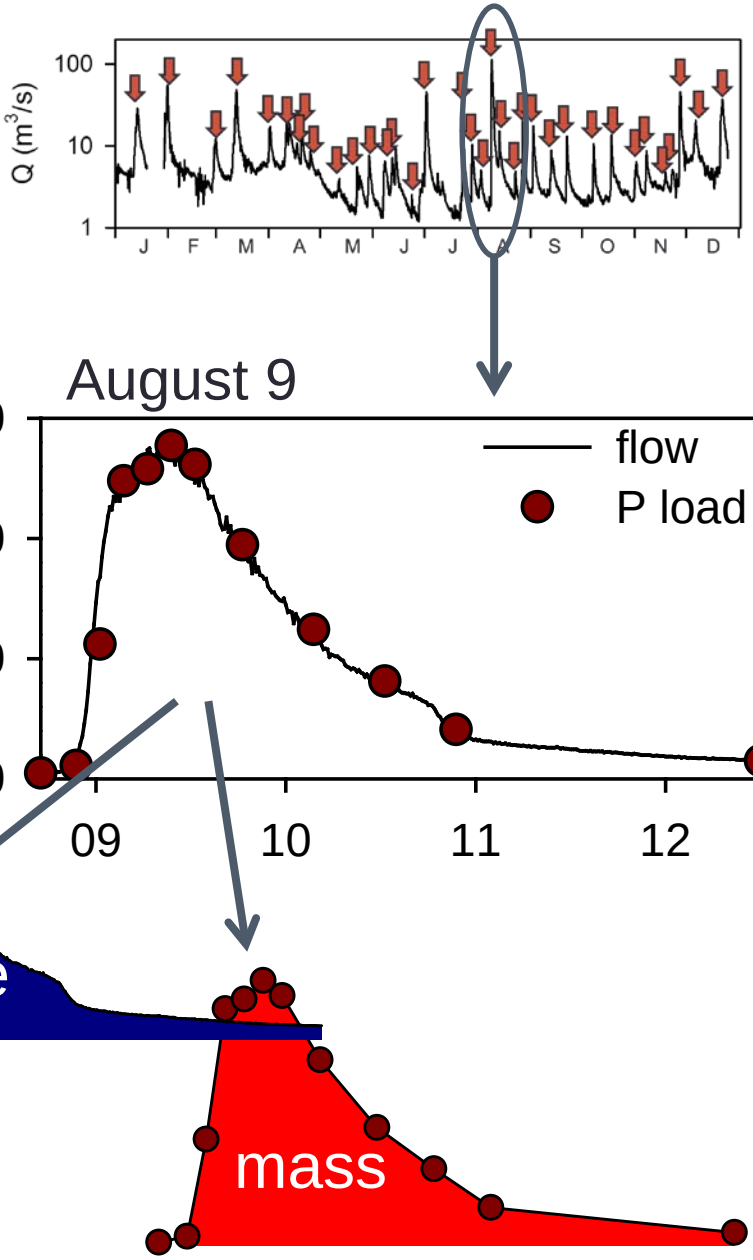
3. Selected salient findings
   a. bioavailability – SRP completely, SUP - mostly, PP - low
   b. runoff event-based sampling necessary
   c. tributary P-driver relationships reasonably strong
   d. good convergence of load estimates from multiple protocols
   e. source-specific differences in P bioavailability
      - PP low at IAWWTP, attributes of particular treatment
      - tributaries: positive dependence on % agriculture
   f. Salmon Creek's contribution to BAP_L is high relative to that for total inflow
   g. low f_{BAP} for tributaries and in-lake shelf sample – not supportive of inclusion of post-runoff event shelf TP observations in assessment of trophic state or application of guidance value

Questions

Event Load Estimates

Protocol No. 7; Fall Creek

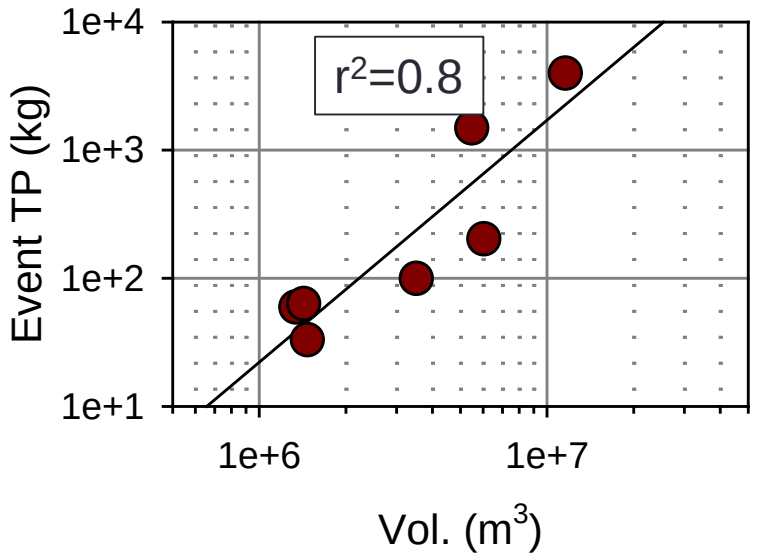
- Delineated 2013 hydrograph
- August 9 Example
  - hydrograph integrated, flow volume (m^3) calculated
  - pollutagraph integrated, event load (mass, kg) calculated
- Relationships between event volume and event mass from all 11 events developed for all P fractions



Event Load Estimates

Protocol No. 7; Fall Creek

Event TP (kg) vs. Event Volume (m^3)

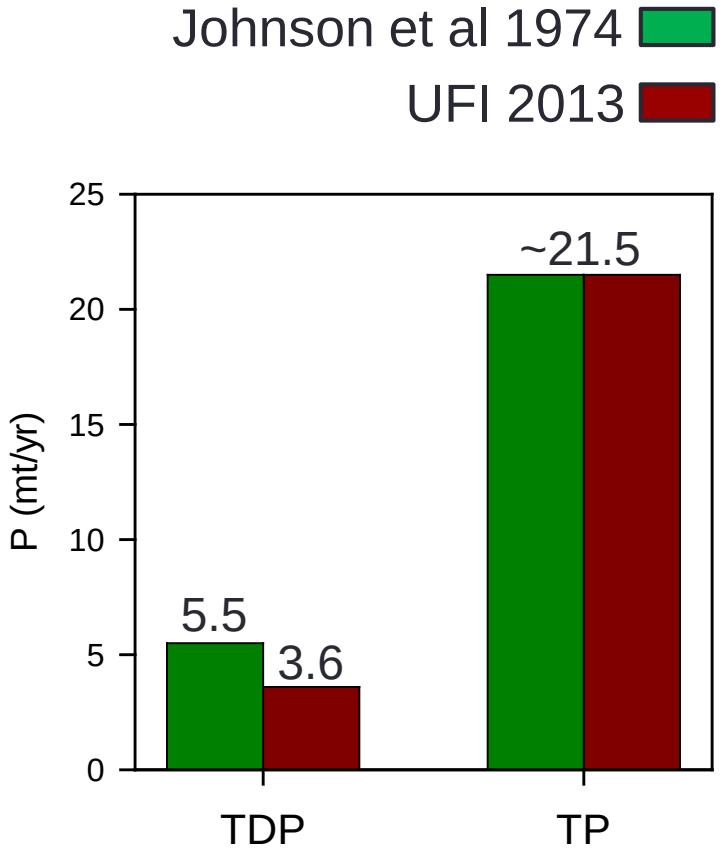


$$\text{Event TP (kg)} = 4.61E^{-5} \cdot \text{Event Vol}^{1.889}$$

- Relationships used to predict event loads from all 35 delineated events
  - all P fractions
- Non-event intervals predicted from flow-conc. regression on 15min flows, original observations, 2 flow strata at mean flow (method 6)

P Loads, 1970s vs 2013

- Johnson et al. 1974a Fall Creek P Study
- Similarities with current study
  - measured dissolved P and total TP
  - preferentially monitored runoff events
- Similar P loading results



P Loads, 1970s vs 2013

Source	Supporting Data	Tributaries Monitored	TPD_L (mt/yr)	TP_L (mt/yr)
Likens, 1974 Tech. Reports	weekly, biweekly	25 tributaries (unmonitored estimated)	67	104
Haith, 2009	GWLF model, land use coefficients, sediment nutrient content	na	58	98
UFI 2013	biweekly, events	Fall Cr., Cayuga In., Salmon Cr., 6 Mile Cr., Taugh. Cr. (unmonitored estimated)	25	137