Tributary Monitoring

2013 Cayuga Lake Study
Technical Briefing (CLTAC)
Cayuga Lake Modeling Project
Nov. 5, 2014

Outline

1. Goals and Analysis Components
2. Monitoring
3. Constituent Concentrations
4. Concentration-Driver Relationships
5. Load Estimation Techniques and Best Methods
6. 2013 April – October Load Estimates
7. P bioavailability and Loads
8. 2000-2012, Loading and Magnitudes of Interannual Variability
9. Inlet Channel Effects: Case for Inlet Load Adjustments
10. Summary

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Goals and Analysis Components

1. review of tributary program
2. provide critical analyses of relationships
3. develop constituent loads that will support the water quality model

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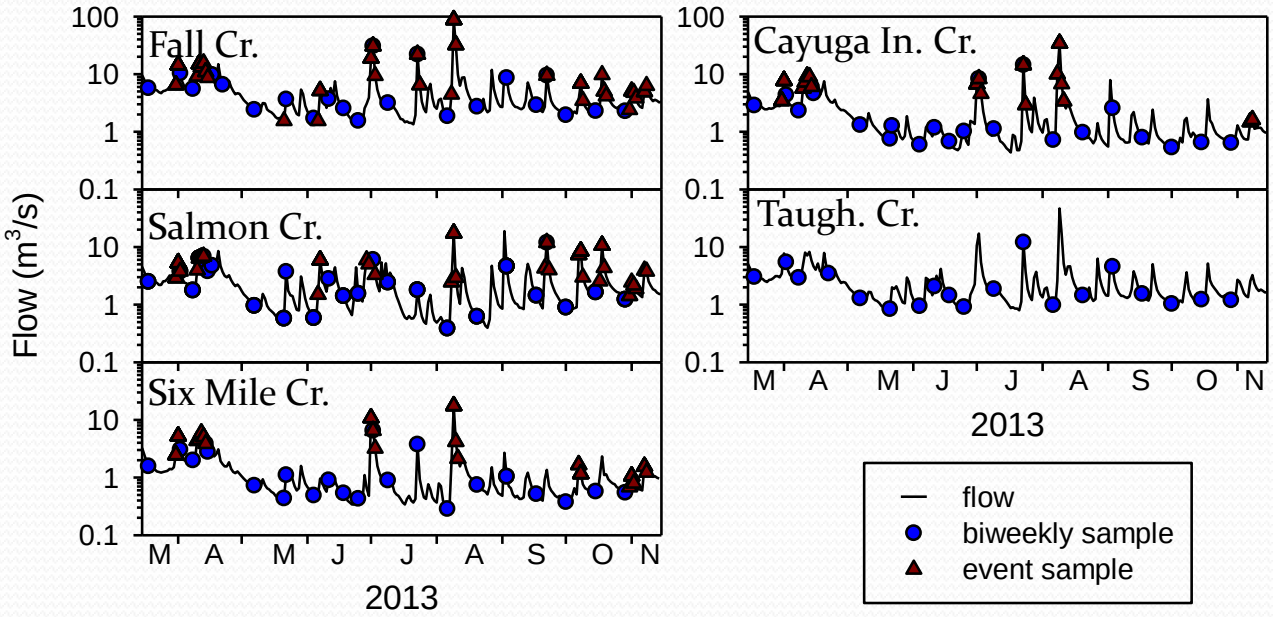
Monitoring: Sample Counts

- according to constituent and tributary

Tributary	TP (µg/L)	PP (µg/L)	TDP (µg/L)	SRP (µg/L)	SUP (µg/L)	Tn (NTU)	TSS (mg/L	FSS (mg/L	VSS (mg/L	t-NH_3 (µg/L)	NO_X (µg/L)	DOC (mg/L)	Si (mg/L
Fall Creek	97	96	97	88	87	93	63	63	63	66	62	57	57
Cayuga Inlet Creek	72	72	73	63	63	71	47	47	47	47	46	47	47
Salmon Creek	96	96	97	87	87	91	56	56	56	61	62	54	54
Taughannock Creek	18	18	19	19	19	19	10	10	10	10	10	10	10
Six Mile Creek	79	79	80	70	70	78	46	46	46	49	50	48	47
Totals	362	361	366	327	326	352	222	222	222	233	230	216	215

meets or exceeds QAPP requirements

Monitoring: Temporal Coverage



- Fall Cr., Cayuga In. Cr., Salmon Cr., Six Mile Cr.
  - biweekly and event samples
  - 12-22% of days monitored during study interval (constituent dependent)
  - 32-44% of tributary inflow monitored

robust monitoring coverage

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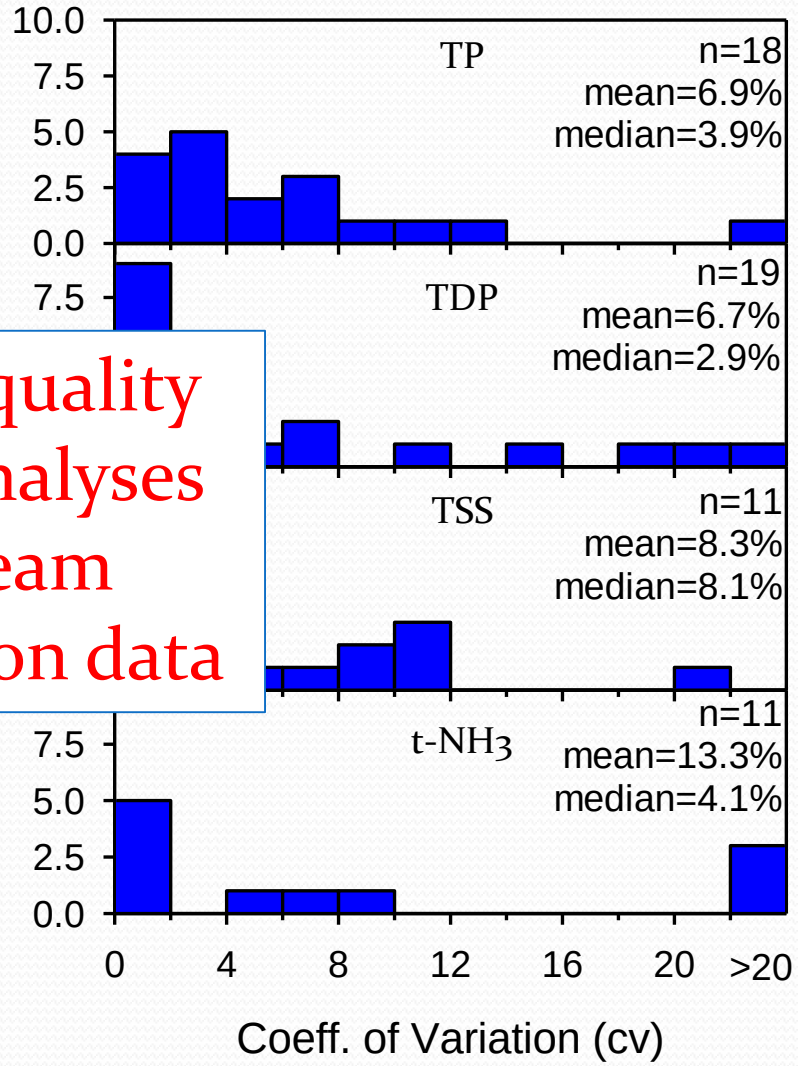
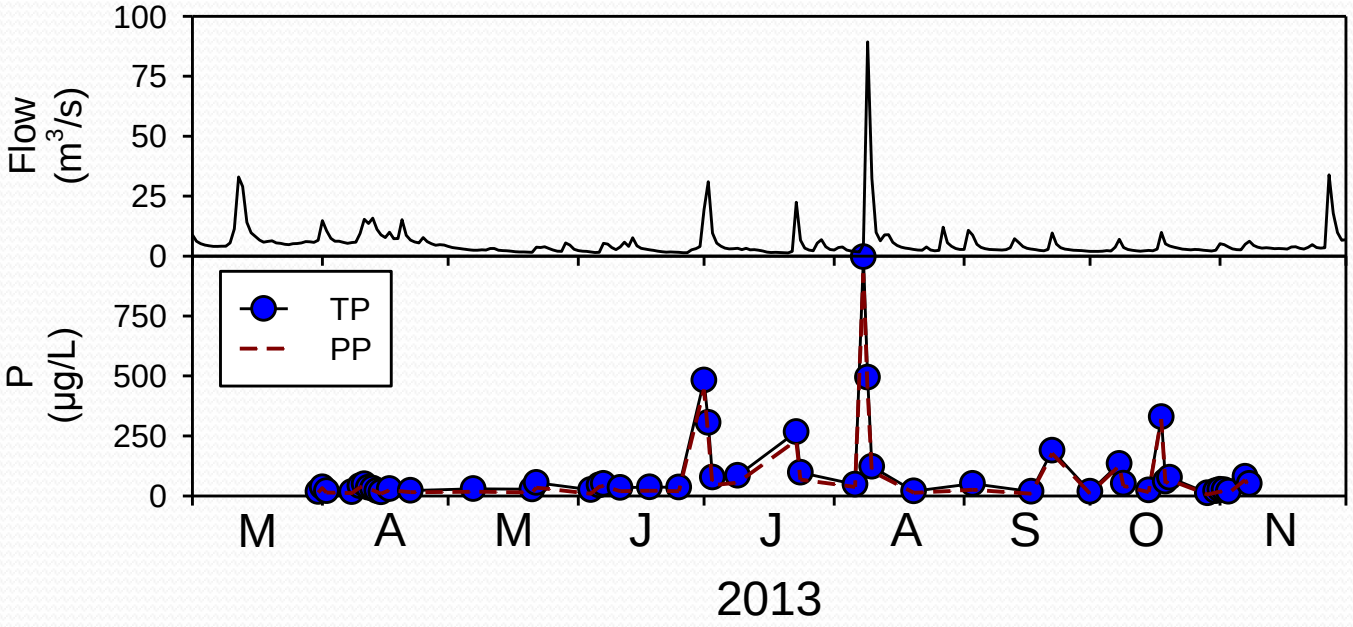
Data Quality for Constituent Concentrations

- triplicate water quality samples collected at Salmon Cr. mo
- precision of tri
(as coefficients
variation, cv) u
metric of data
- average cv for all constituents were less than 15% (shown for TP, TDP,TSS)



good data quality supports analyses with stream concentration data

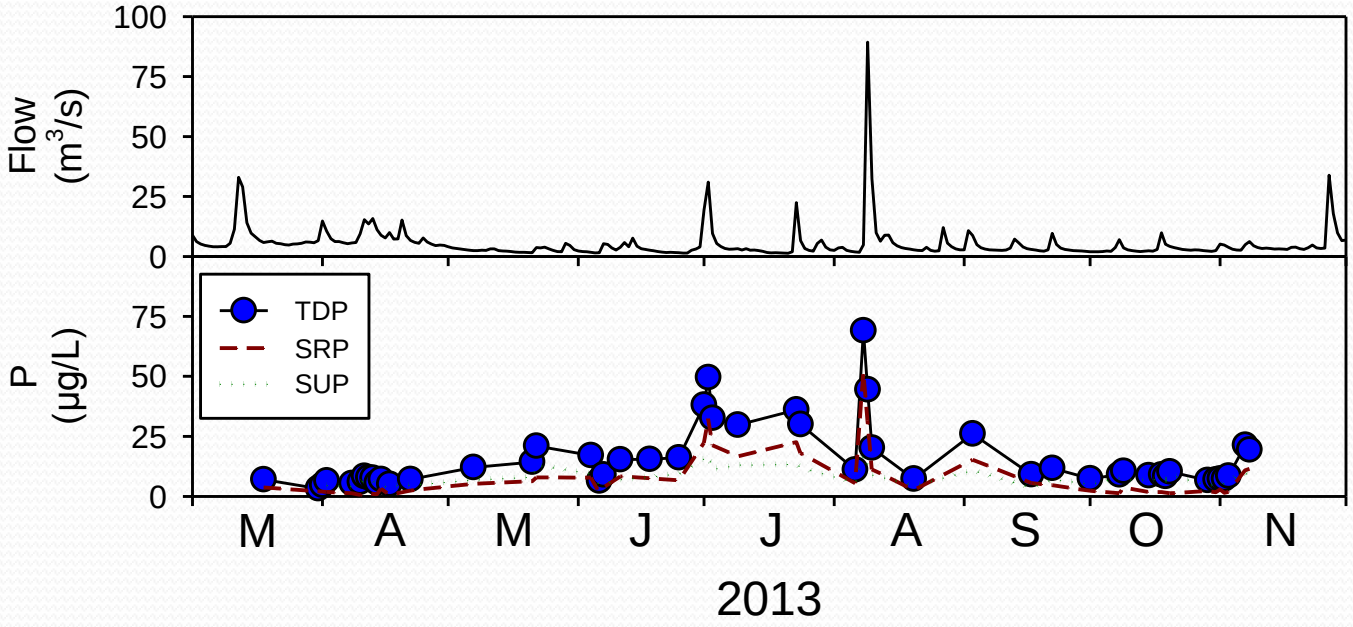
Constituent Concentrations: Fall Creek Time Series for TP, PP



- TP dominated by PP
- PP increased dramatically during periods of high flow (see three largest events monitored : June 30, July 21, and August 8-9)
  - peak TP and PP concentrations were 996 and 927 µg/L, respectively

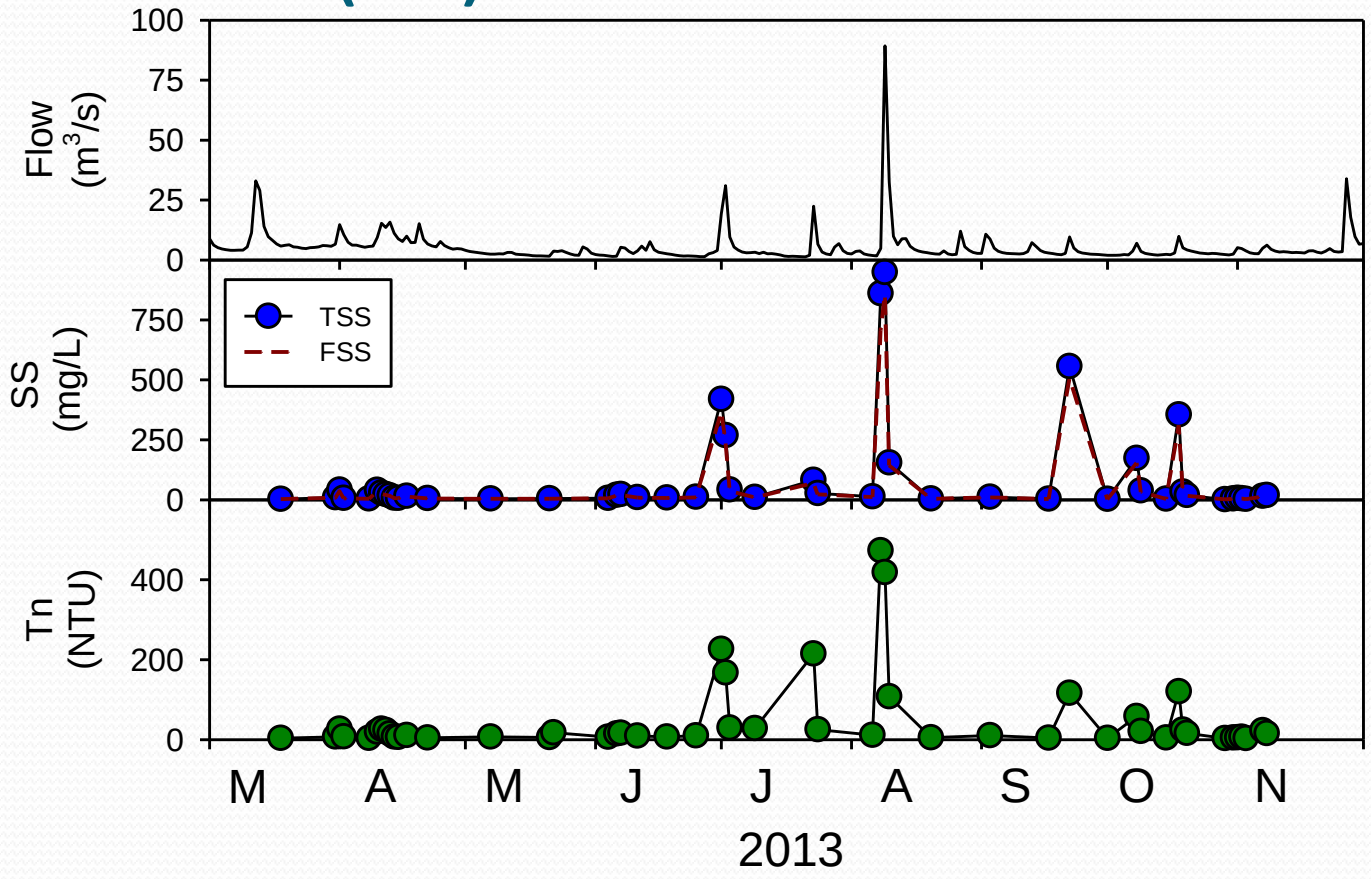
Fall Creek During High Flow

Constituent Concentrations: Fall Creek Time Series for Dissolved P



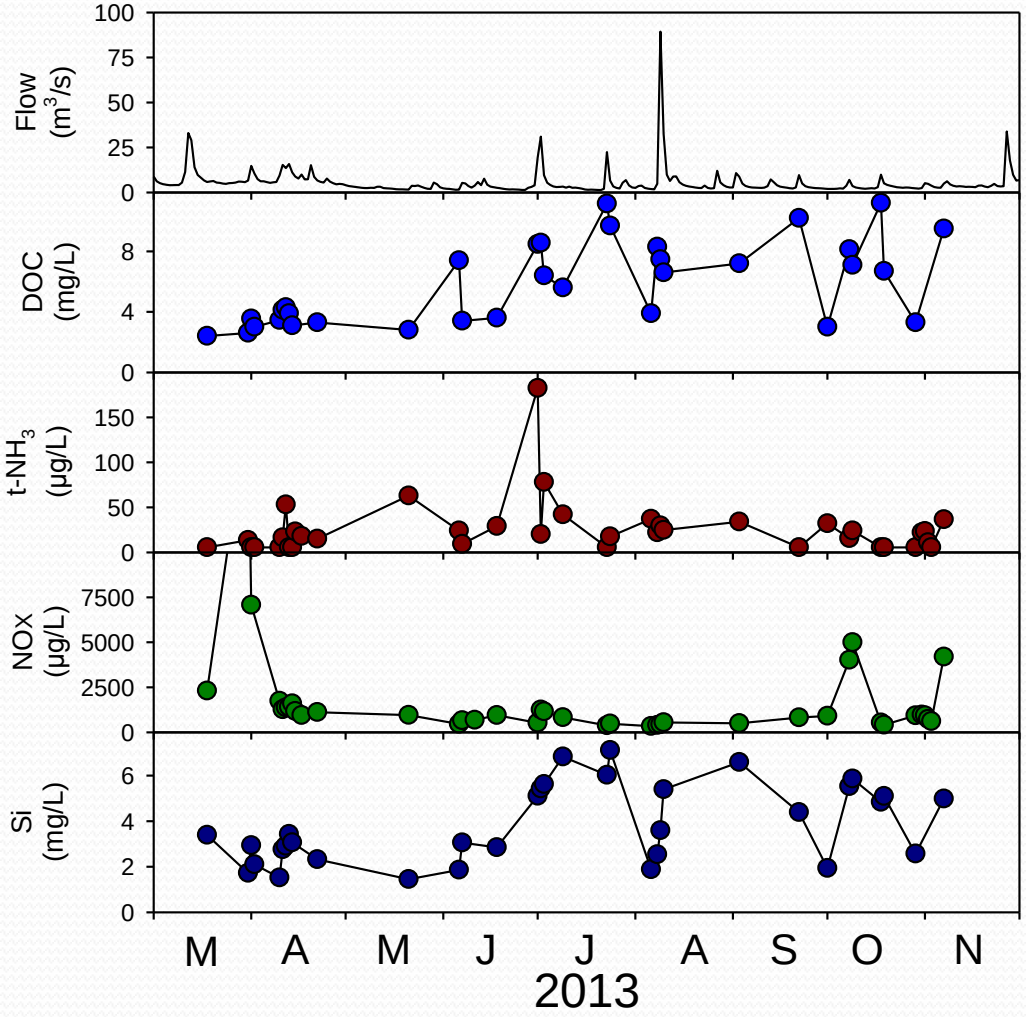
- SRP, SUP demonstrated some seasonality
- SRP, SUP were generally lowest during periods of low flow and increased during runoff events
  - increases observed were less substantial than for particulate constituents

Constituent Concentrations: Fall Creek Time Series for Suspended Solids (SS) and Tn



- forms of SS were generally low during low flow
- TSS dominated by FSS
- TSS was lowest in spring and fall, increased during periods of high flow
  - 70-fold increase from Aug 6 to Aug 8
- patterns of Tn similar to SS

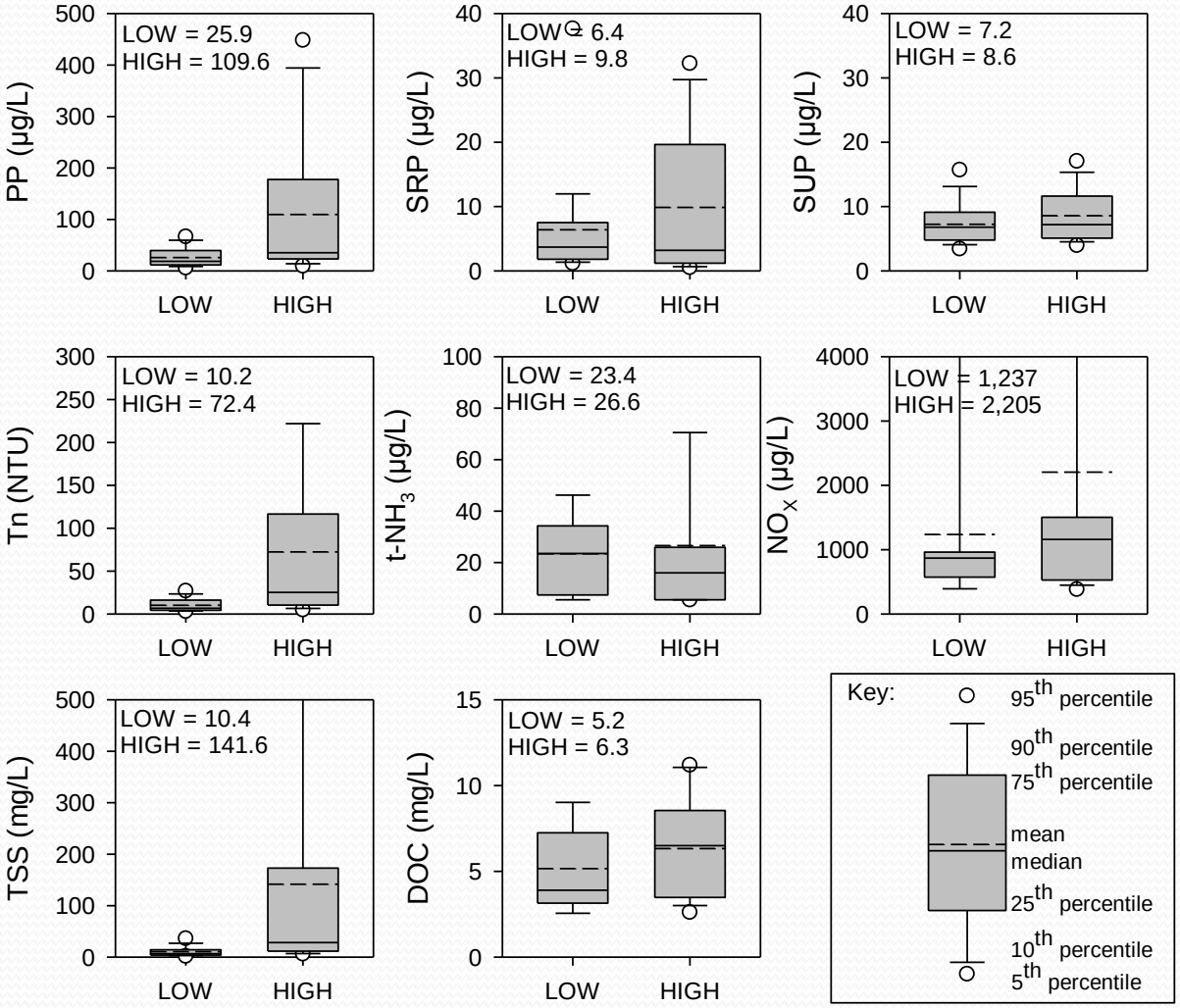
Constituent Concentrations: Time Series for Fall Creek



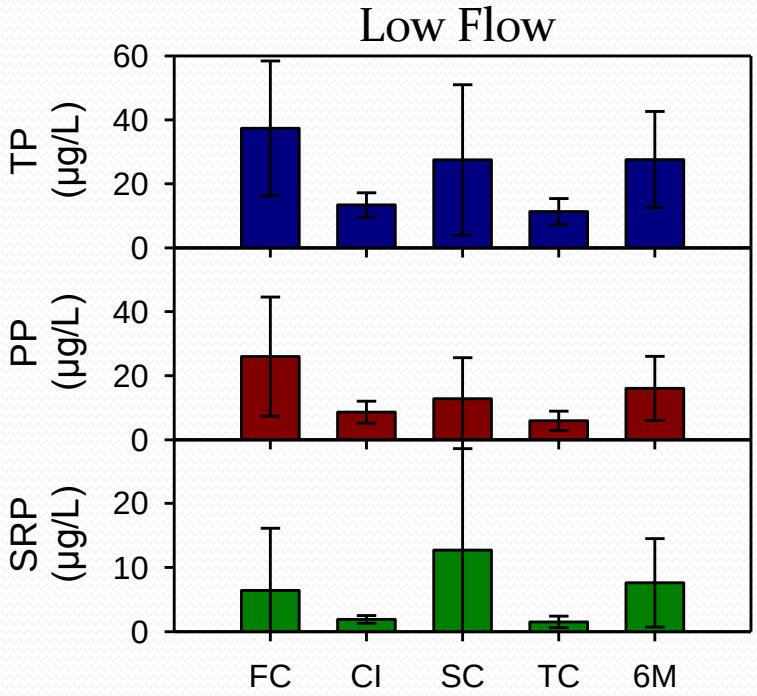
- other dissolved constituents (DOC, t-NH_3, Si) similar to dissolved P
  - generally lowest during periods of low flow and increased during runoff events
  - increases during high flow, less substantial than for particulates
- NO_X highest in spring and fall
  - dominant form of dissolved N

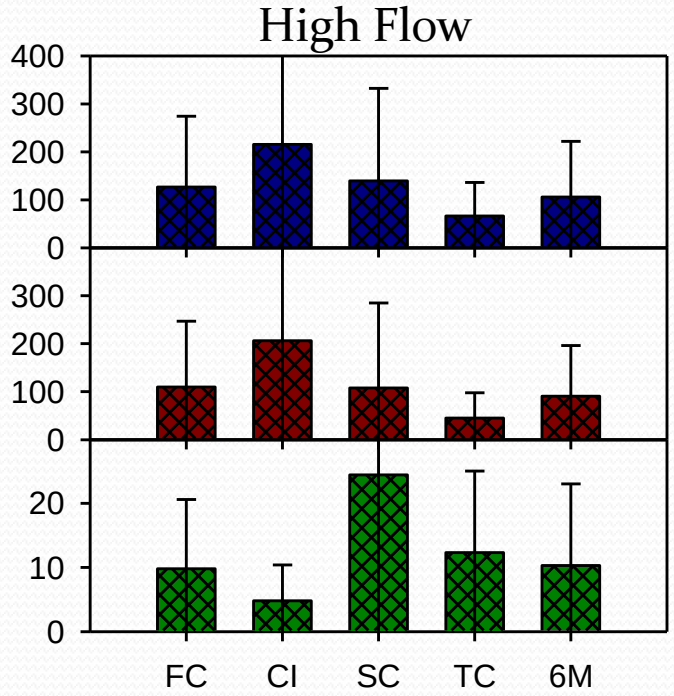
Constituent Concentrations: Example Box-Whiskers for Low Flow vs. High Flow for Fall Creek

- large increases in mean concentration between low and high flow for particulates
- dissolved constituents showed increases from low-to-high flow but less substantial than for particulates
- Fall Creek patterns (not necessarily magnitudes) were similarly demonstrated in other streams



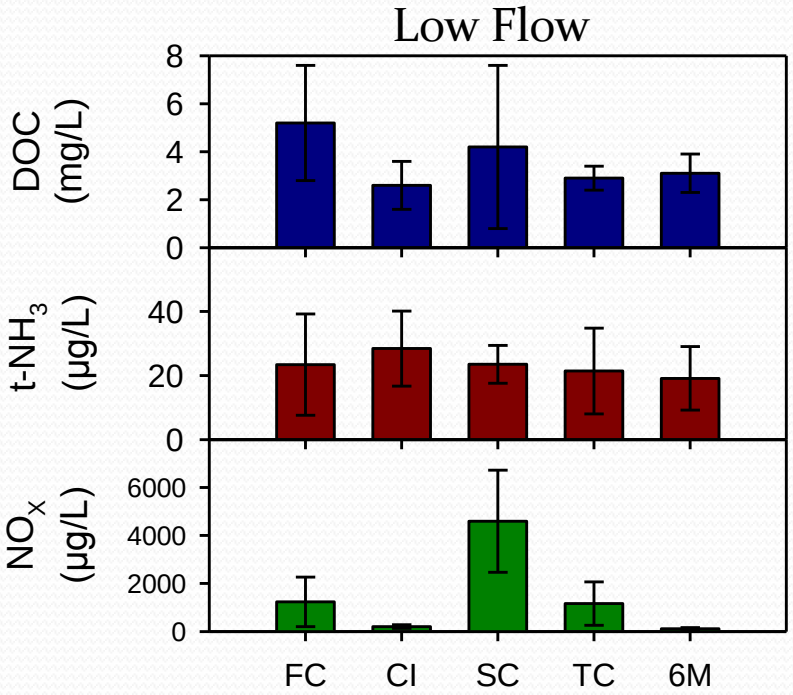
Constituent Concentrations: Comparisons Between Tributaries

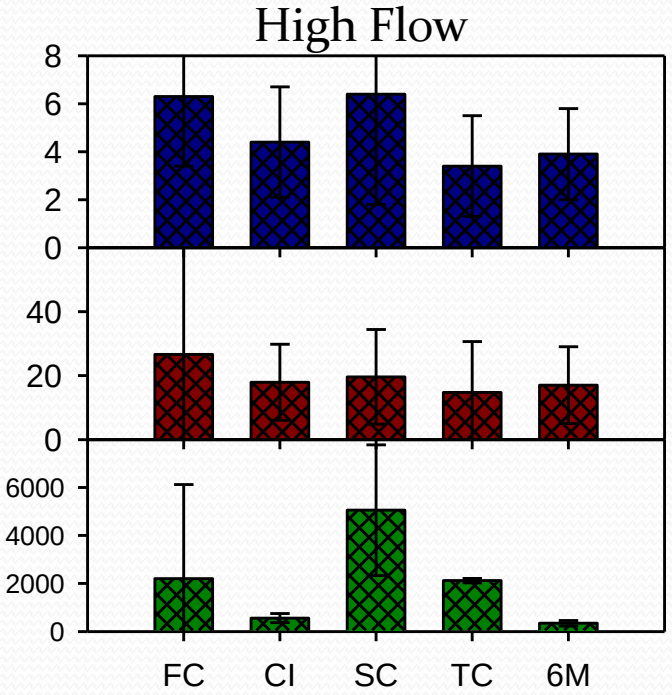




- At low flow:
  - TP, PP highest average in Fall Creek
  - Tn, SS similar to PP
  - SRP highest for Salmon Creek
- At high flow:
  - TP, PP highest average in Cayuga In. Creek
  - SRP highest for Salmon Creek

Constituent Concentrations: Comparisons Between Tributaries





- At low flow:
  - DOC highest in Fall Cr. and Salmon Cr.
  - $t\text{-}NH_3$ similar for all streams
  - NO_X highest for Salmon Creek
- At high flow:
  - high flow conditions similar to low flow conditions
  - NO_X >> $t\text{-}NH_3$

Constituent Concentrations: Phosphorus Ratios

- TP
  - dominated by PP for Fall, Cayuga In. Cr., Six Mile Cr., and Taugh Cr. at low and high flow
  - at low flow Salmon Cr. had the lowest PP:TP ratio (i.e., Salmon Cr. TP dominated by TDP)
  - PP:TP ratio increased with increasing flow for all tribs
- TDP
  - dominated by SUP for Fall Cr. and Cayuga In. Cr.
  - dominated by SRP for Salmon Cr. and Six Mile Cr.
  - bioavailability implications
  - SRP:TDP increased slightly with increasing flow (all but Six Mile Cr.)

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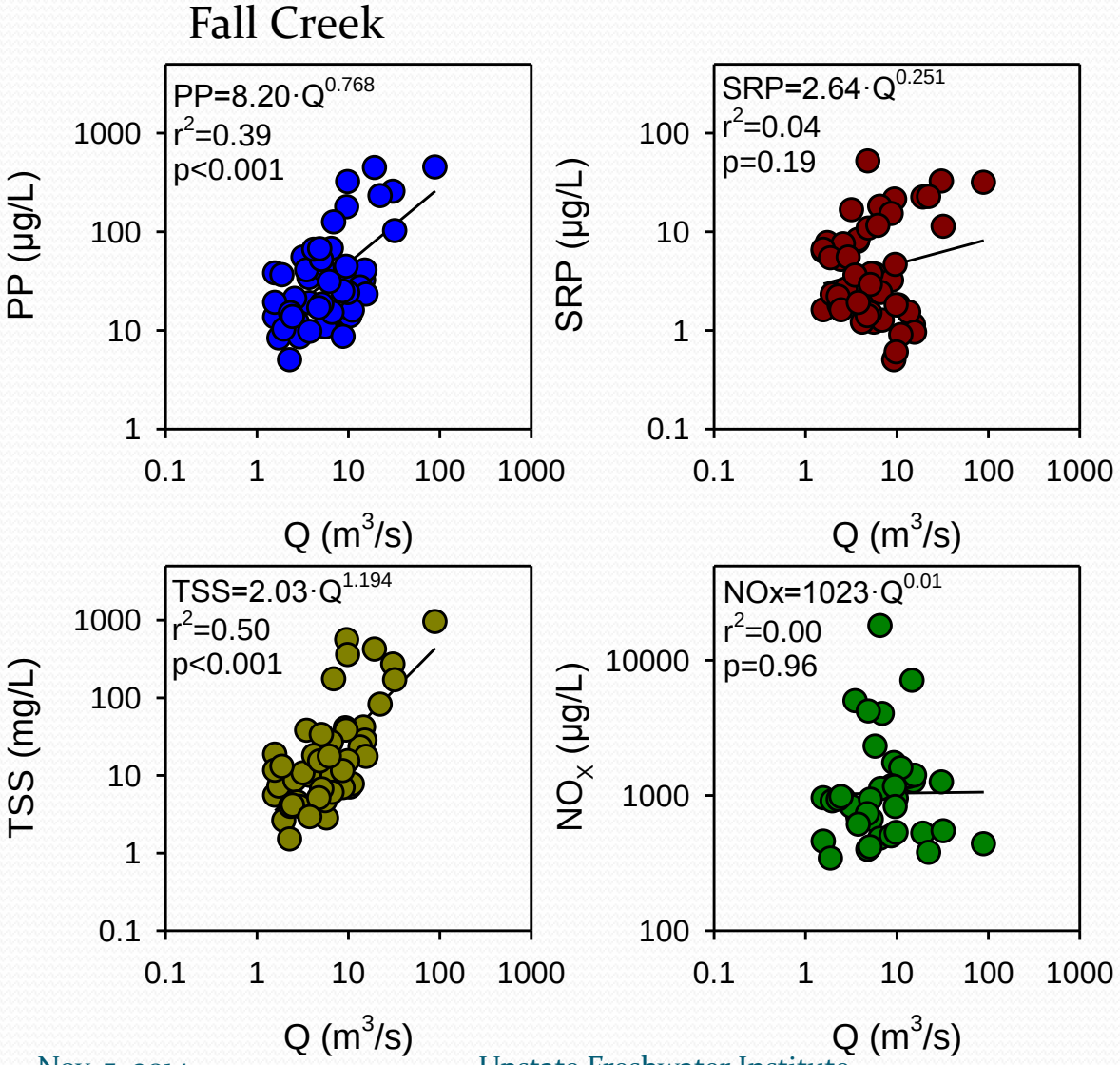
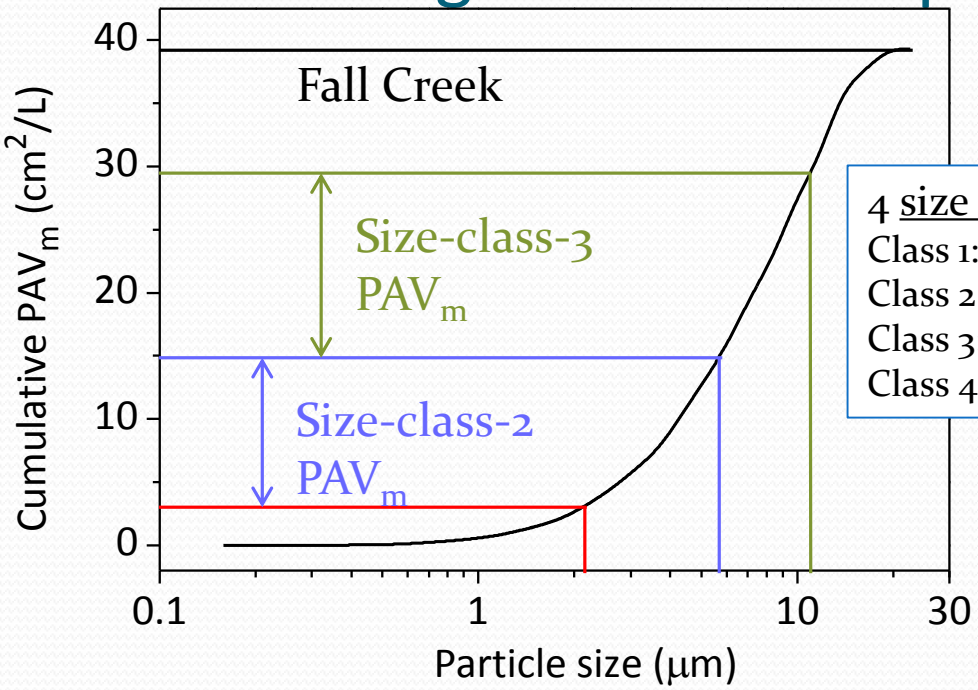
Concentration-Driver Relationships: Concentration-Flow

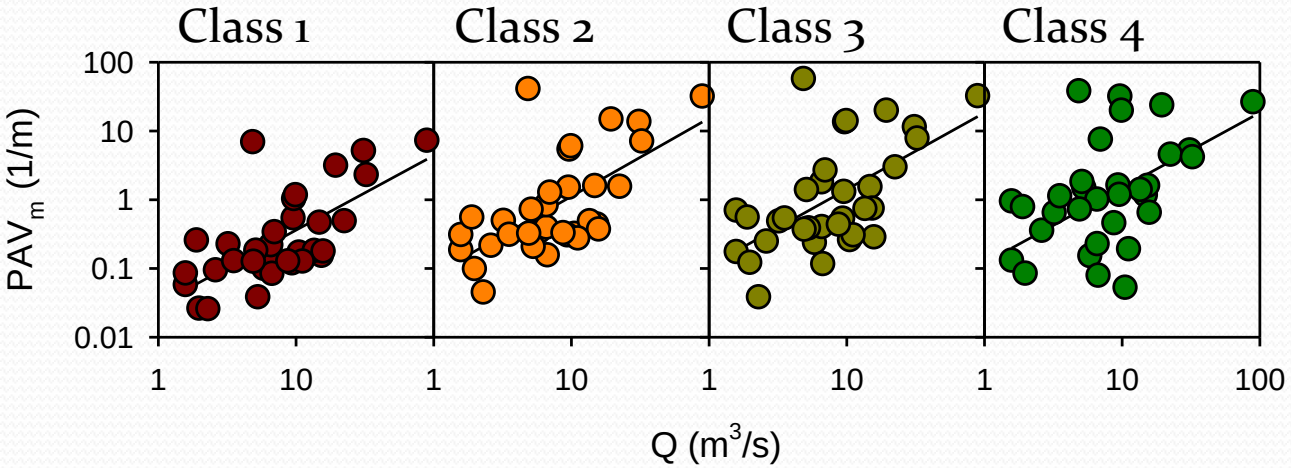


- conc.-Q relationships were stronger for particulates than for dissolved constituents
  - significance, strength of fit varied between parameters, streams

Concentration-Driver Relationships: Flow-Projected Area Minerogenic Particles per Unit Volume (PAV_m)

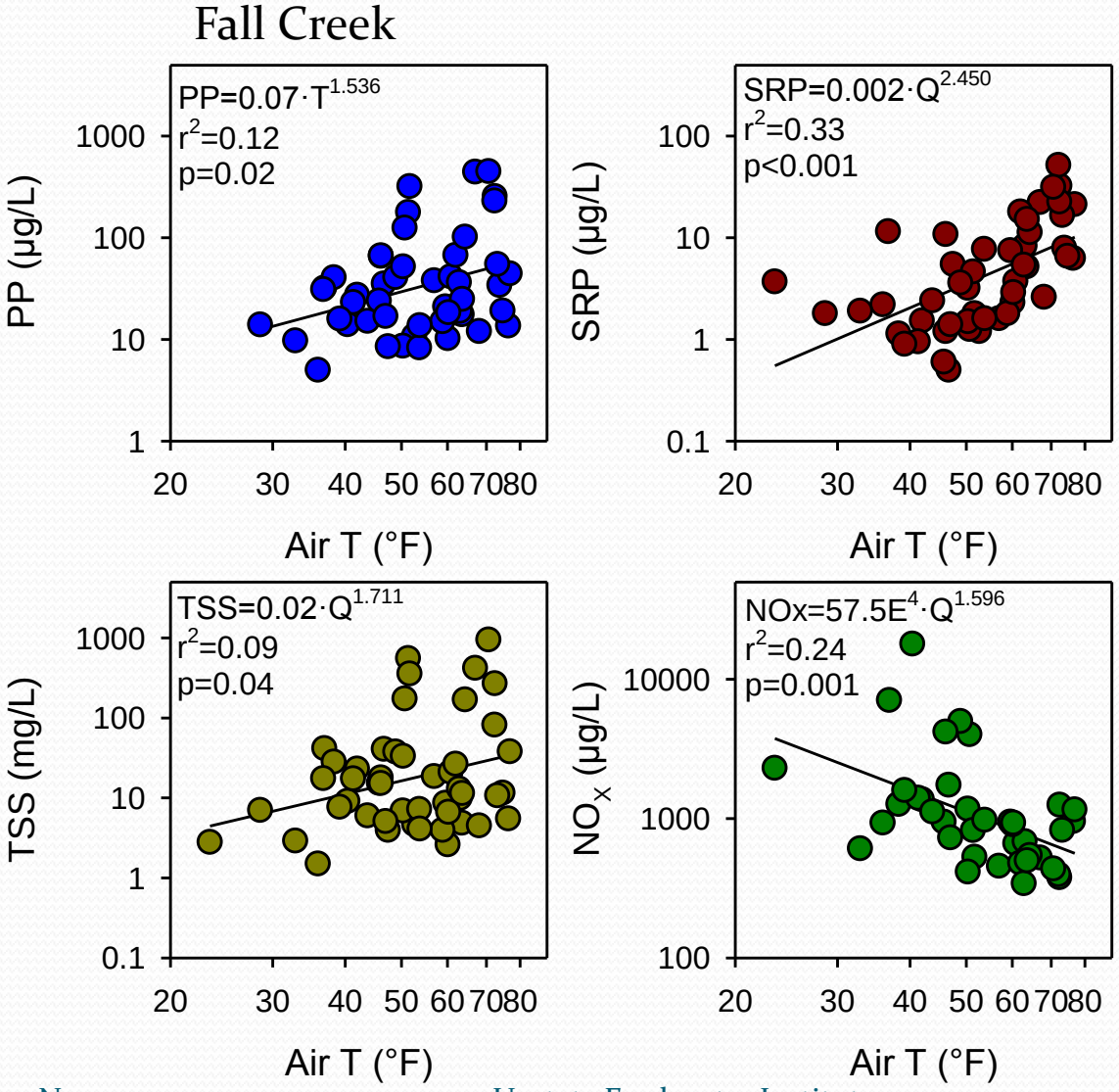


- valuable metric for P and optical impacts of inorganic (mineral) particles
- 4 size classes support modeling of fate of minerogenic particle inputs to lake



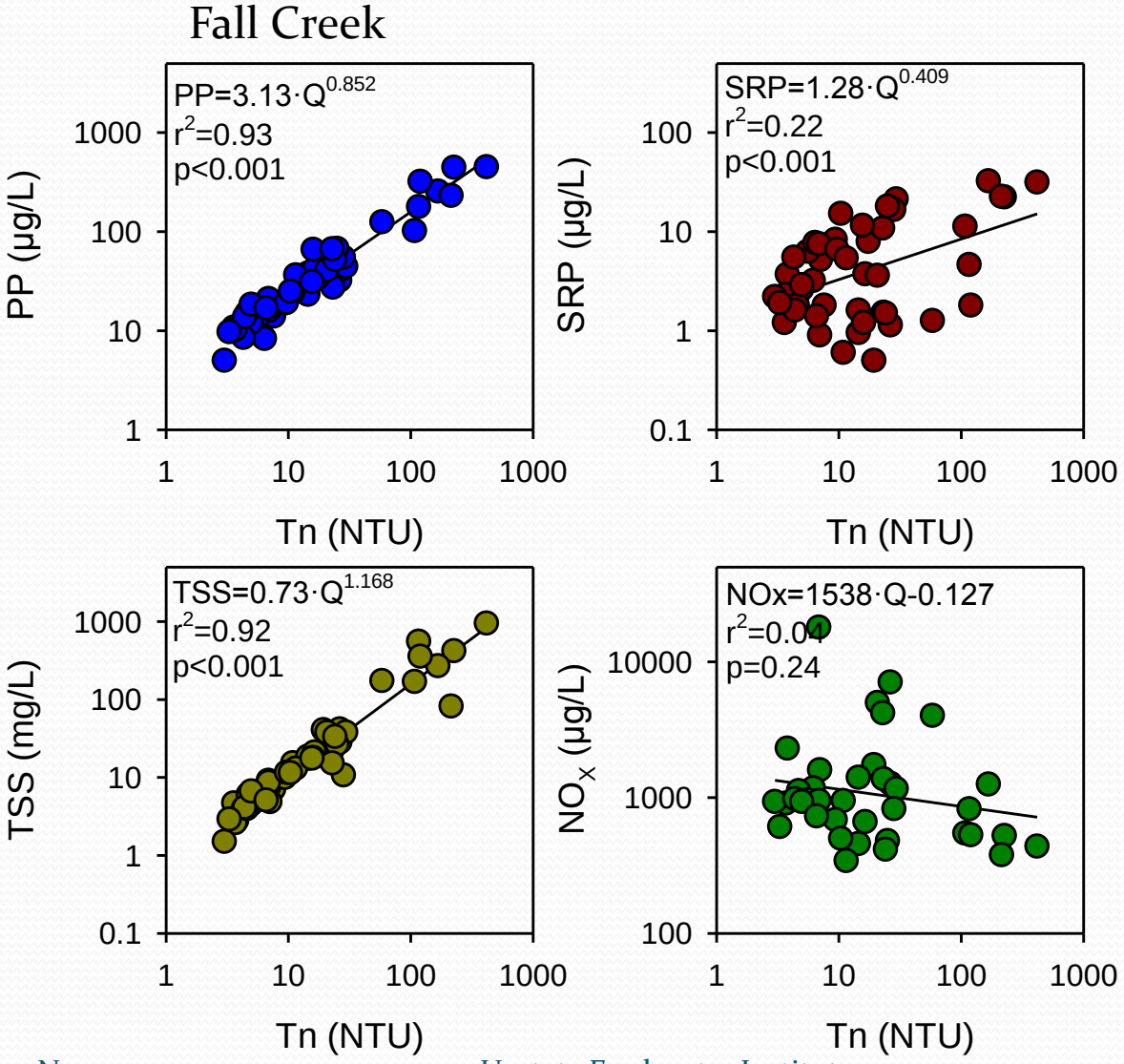
- positive dependency on Q

Concentration-Driver Relationships: Concentration-Air Temperature



- conc.-air T relationships not significant for particulates
  - exception Fall Cr.
- conc.-air T significance, strength of fit better for dissolved constituents than for particulates
  - better predictor than flow for most parameters, streams

Concentration-Driver Relationships: Concentration-Turbidity



- exploratory
- conc.-Tn relationships very strong for particulates
  - $r^2>0.8$
  - $p<0.001$
- conc.-Tn results varied between parameters, streams for dissolved constituents
  - good predictor for some parameters, streams

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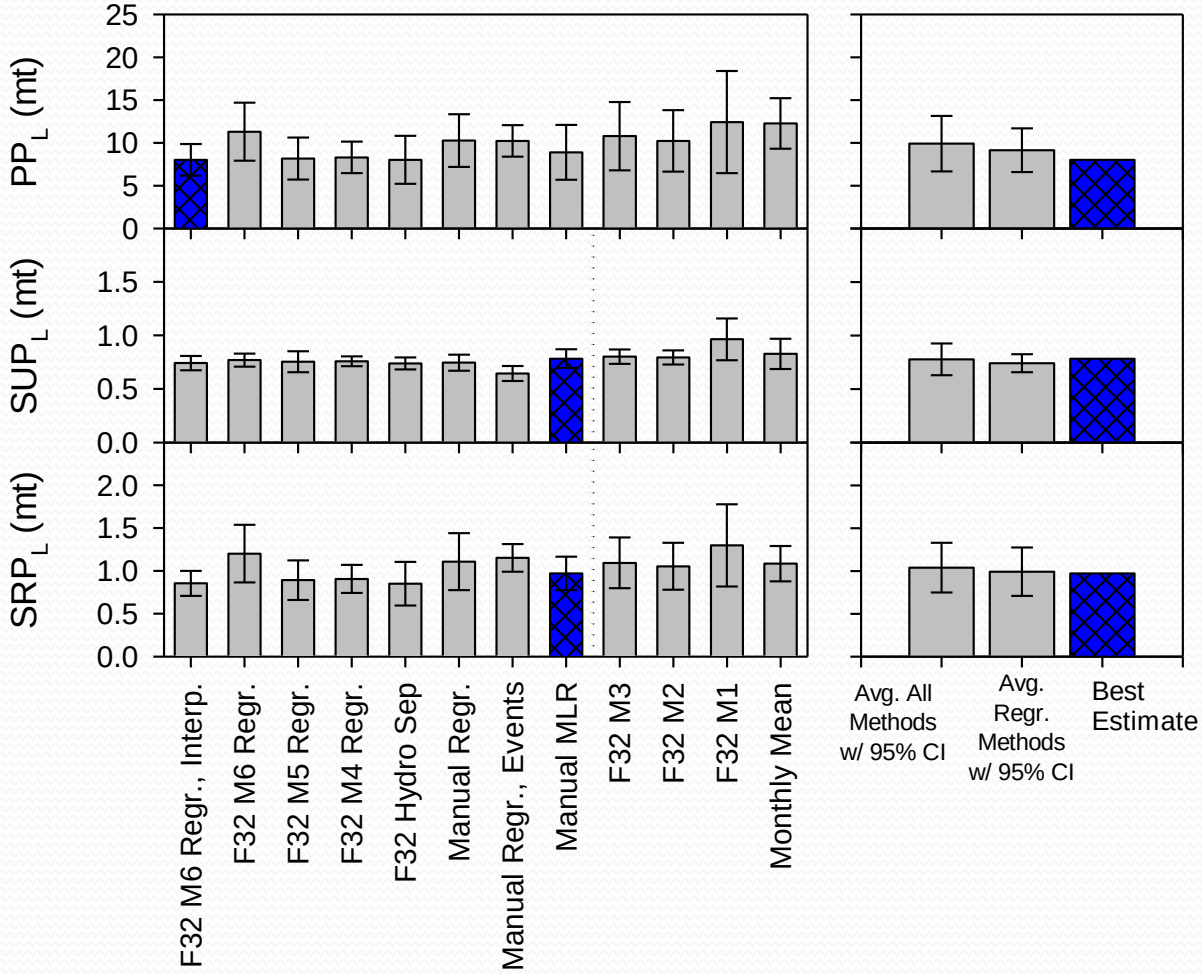
Load Estimation Techniques Adopted

- FLUX32 (F32) Load Estimation Software
  - Regression Methods
    - 5 methods
  - Non-regression methods
    - 3 methods
- Manual Methods
  - Multiple linear regression with flow, air T
  - C/Q regression using instantaneous flow (Fall Cr. only)
  - C/Q regression using instantaneous flow with event load estimates (Fall Cr. only)
  - Monthly mean method

Load Estimation Results for Fall Creek: All Methods, April-October

Method	PP Load (kg)	SUP Load (kg)	SRP Load (kg)
F32 method 6 C/Q interpolated	8,010	742	855
F32 method 6 C/Q	11,289	770	1,202
F32 method 5 C/Q adj.	8,156	755	893
F32 method 4 C/Q flow wtd. adj.	8,300	759	907
F32 Rising/Falling limb	8,008	739	850
Manual regr.	10,251	746	1,108
Manual regr. with events	10,223	645	1,153
Multiple Linear Regression	8,896	784	971
F32 method 3 Beale's Ratio Estimator	10,778	802	1,095
F32 method 2 flow weighted conc.	10,223	794	1,055
F32 method 1 average load	12,425	964	1,298
Monthly mean	12,259	828	1,085
---regression methods (range)	**8,008-11,289**	**739-770**	**850-1,202**
---non-regression methods (range)	**10,223-12,259**	**794-828**	**1,055-1,095**

Load Estimation Results for Fall Creek Using Different Methods, April-October



- PP_L
  - okay agreement, regression methods within 10-22% of best method
- SUP_L
  - strong agreement, regression methods within 1-6% of best methods
- SRP_L
  - okay agreement, regression methods within 7-20% of best method

this level of uncertainty is not uncommon in load estimation

Best Methods for Load Estimation

- Particulate Constituents
  - FLUX32 C/Q Regression, Interpolation
    - daily time step
    - significant relationships between concentration and flow
    - stratified by flow regime supported by differences in C/Q slopes between low and high flow
    - allows smooth interpolation between observations using defined C/Q relationship estimates
    - air T generally not significantly related to particulate concentration
    - usually less uncertainty than non-regression methods
- Dissolved Constituents
  - Multiple Linear Regression with Q, air T as drivers
    - daily time step
    - flow generally not strong, rarely significant predictor of concentration
    - concentration-air T significant in most cases
    - multiple regression model better than C/Q alone

Best Methods for Load Estimation: Unmonitored Tributaries

~40% unmonitored

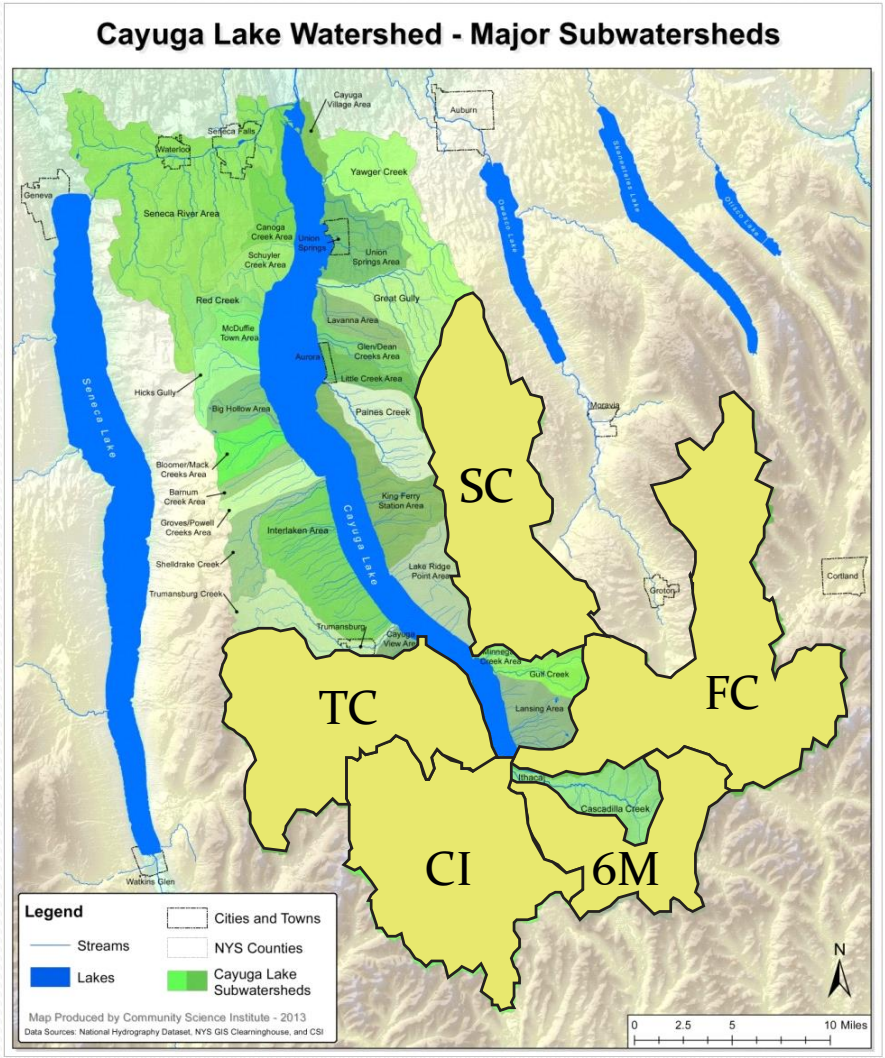
Monitored Watershed

- 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
- consistent with land use information



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2013 April-October Loading Estimates: Primary Constituents

Tributary	TP (kg)	PP (kg)	TDP (kg)	SRP (kg)	SUP (kg)	Tn (NTU·m^3)
Fall Creek	9,765	8,010	1,755	971	784	5.86E+09
Cayuga Inlet Creek	9,564	9,208	356	167	189	1.04E+10
Salmon Creek	5,792	4,171	1,621	1,234	387	3.02E+09
Taugh. Creek	4,931	3,639	1,291	813	479	4.96E+09
Six Mile Creek	2,500	2,036	464	321	143	2.77E+09
Unmonitored	22,157	18,422	3,735	2,387	1,349	1.84E+10
Point Sources	1,415	745	669	302	368	-
Total Watershed	56,124	46,232	9,892	6,194	3,698	4.54E+10

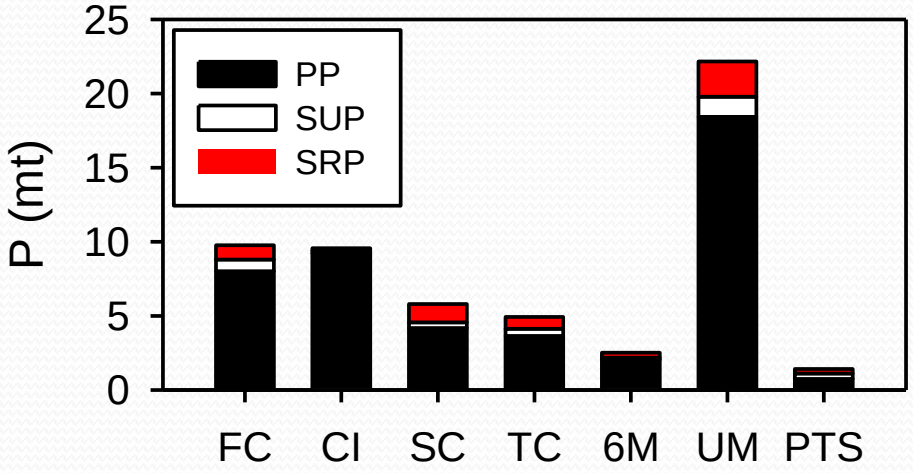
sum of daily estimates

2013 April-October Loading Estimates: Secondary Constituents

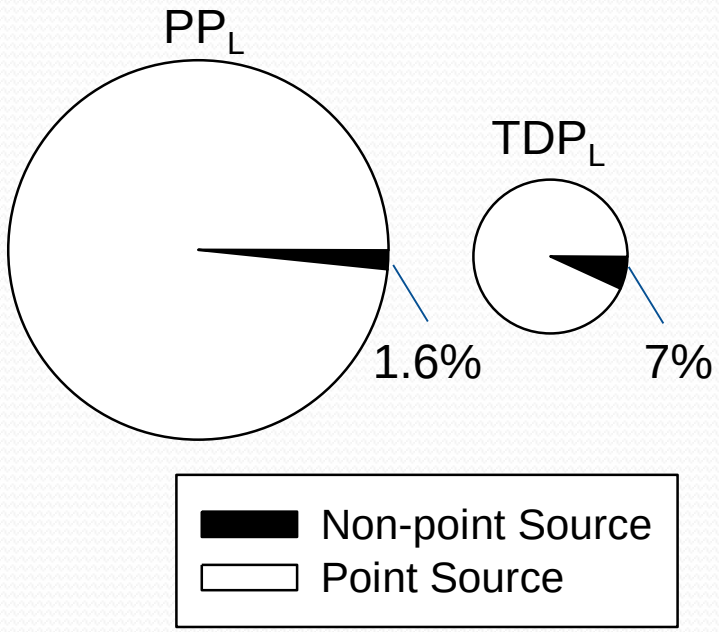
Tributary	TSS (kg)	FSS (kg)	VSS (kg)	t-NH_3 (kg)	NO_X (kg)	DOC (kg)	Si (kg)
Fall Creek	11,196,214	10,040,965	1,155,249	2,755	110,606	551,300	343,068
Cayuga Inlet Creek	10,429,918	9,640,675	789,243	889	15,656	154,949	230,061
Salmon Creek	2,866,144	2,493,251	372,893	1,179	225,205	266,865	231,276
Taugh. Creek	3,227,723	3,003,859	223,864	1,514	65,289	264,981	343,492
Six Mile Creek	2,738,443	2,456,535	281,908	584	6,663	109,585	125,778
Unmonitored	20,731,759	18,810,156	1,921,602	4,711	288,203	917,309	866,936
Point Sources	-	-	-	-	-	-	-
Total Watershed	51,190,201	46,445,441	4,744,760	11,631	711,621	2,264,989	2,140,611

sum of daily estimates

2013 April-October Loading Estimates: Phosphorus

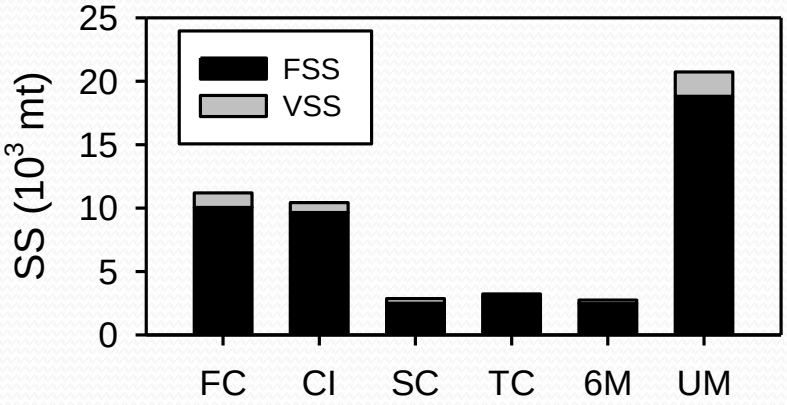


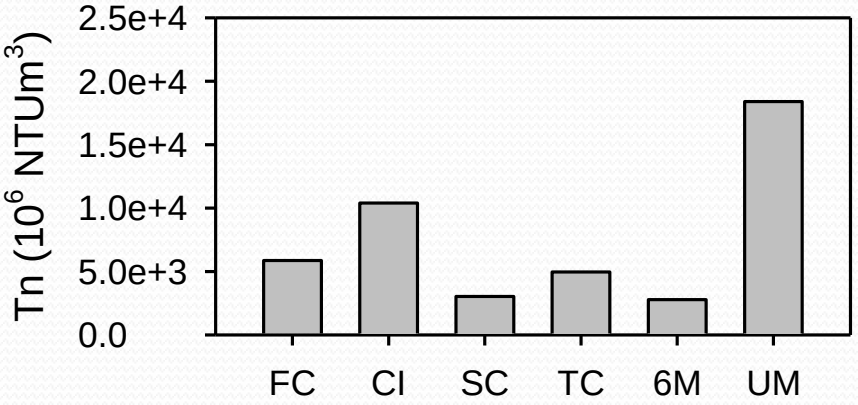
- TP_L dominated by PP_L
- Fall Cr. and Cayuga In. – largest individual contributors of PP_L
  - Fall Cr. – 8.0 mt (17.3%)
  - Cayuga In. – 9.2 mt (20%)
- Fall Cr. and Salmon Cr. – largest contributors of TDP_L
  - Fall Cr. – 1.8 mt (17.7%)
  - Salmon Cr. – 1.6 mt (16.4%)



- Cayuga Lake PP_L and TDP_L is dominated by non-point sources

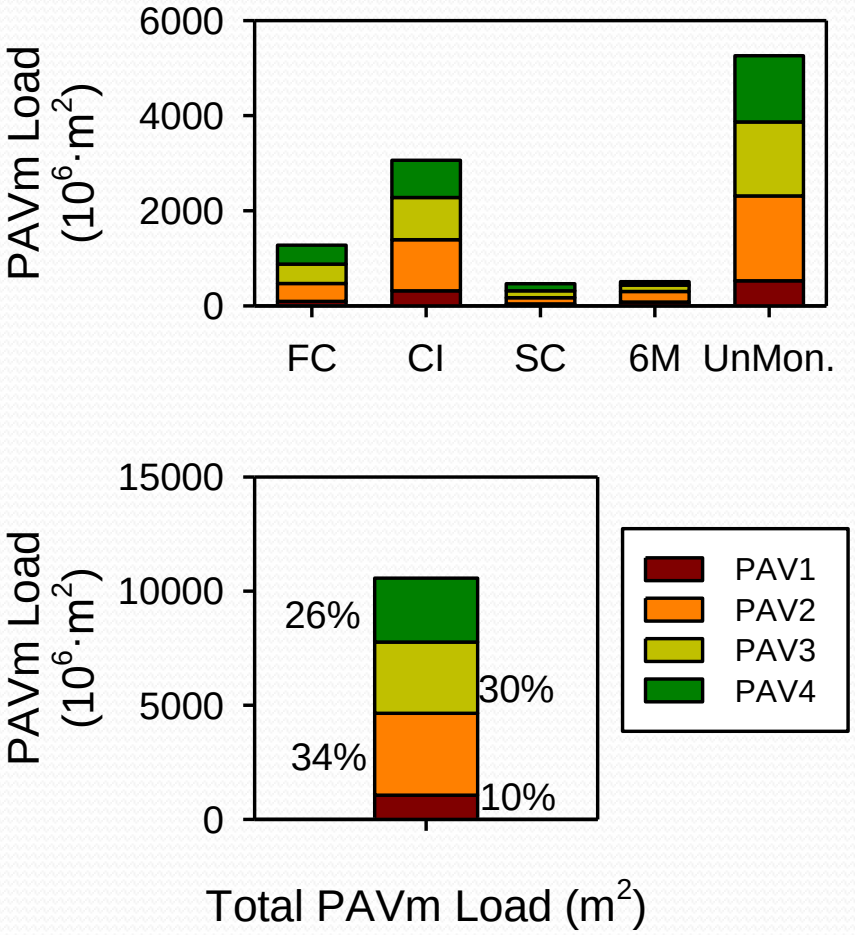
2013 April-October Loading Estimates: Turbidity and Forms of SS





- TSS_L dominated by FSS_L (minerogenic particles)
  - 87-93%
- Fall Cr. and Cayuga Inlet Cr. – largest individual sources
- Tn_L patterns were similar to TSS_L

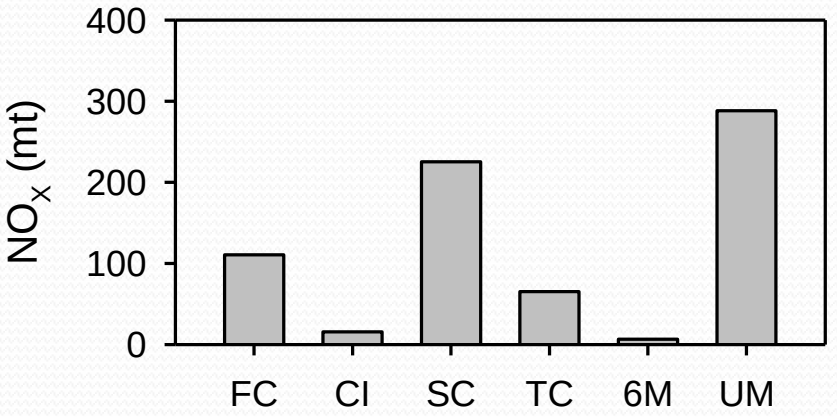
2013 April-October Loading Estimates: PAV_m



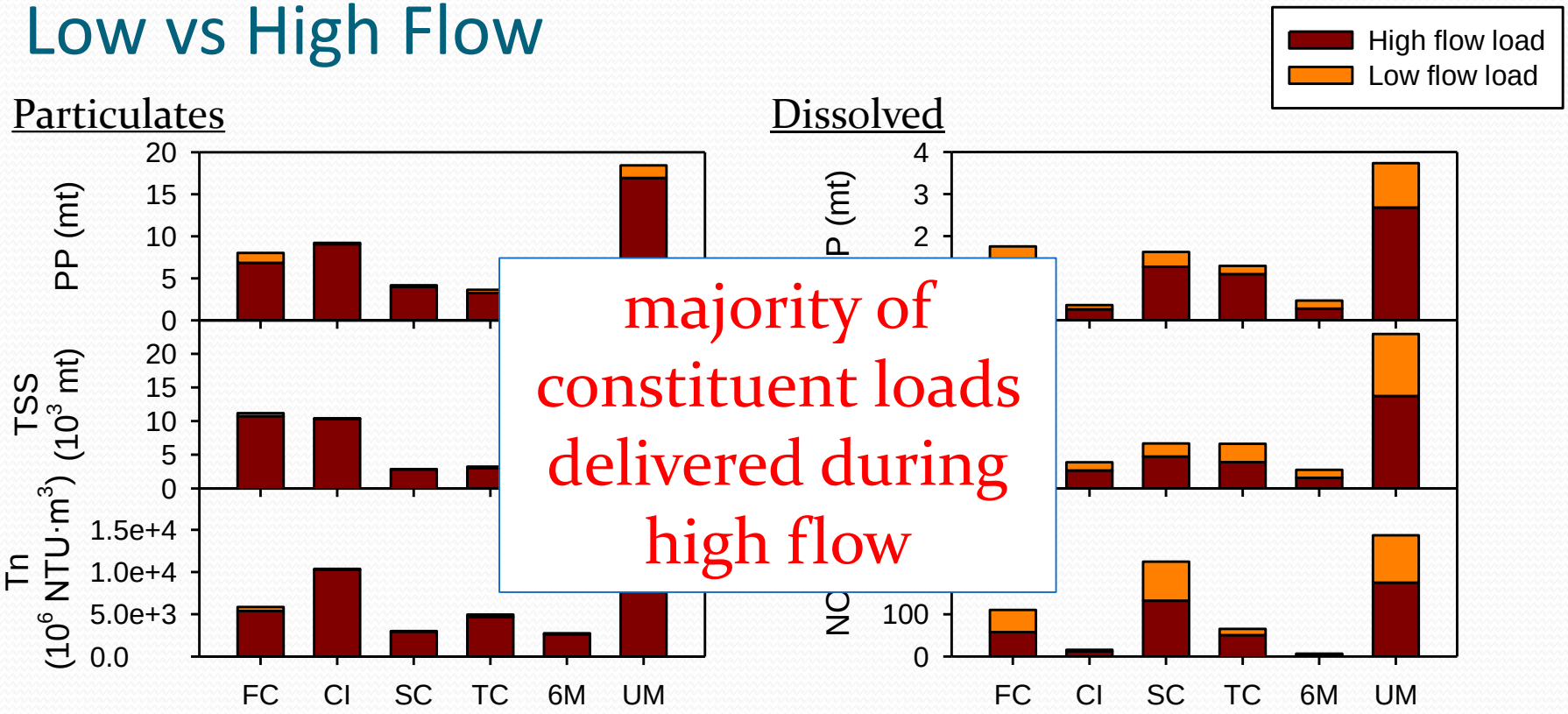
- apportioned according to 4 size classes
- size class 2 contributes the most (34%)
  - smallest size class (PAV1) contributes the least
- general similarity to SS and Tn patterns

2013 April-October Loading Estimates: NO_X

- Salmon and Fall Cr. largest individual sources
- NO_{XL} >> than t-NH_{3L}



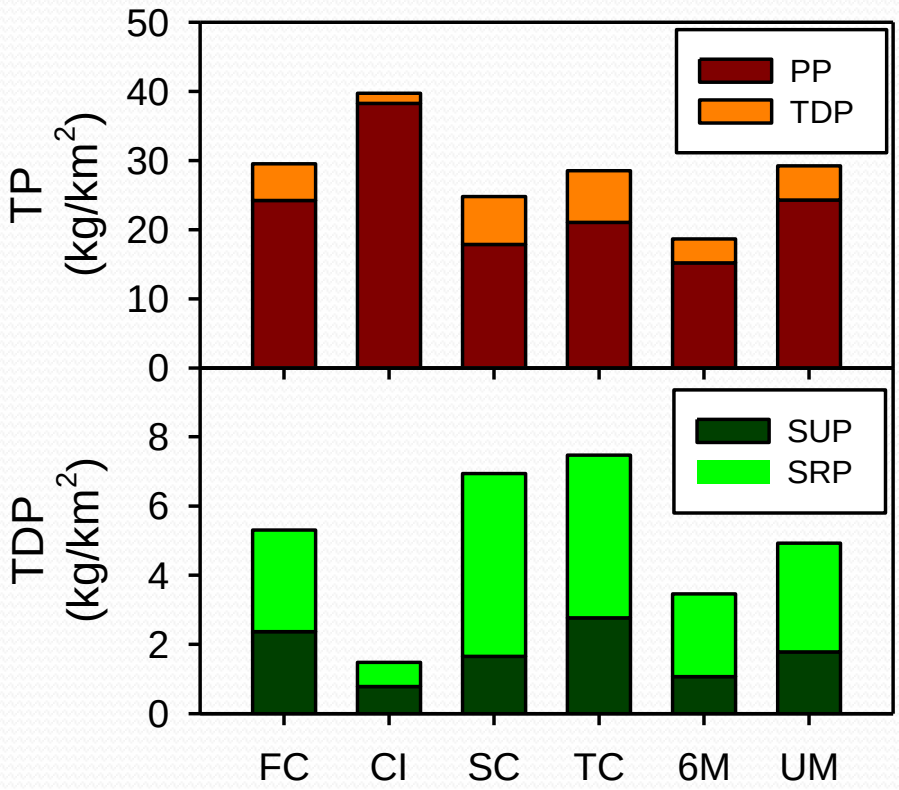
2013 April-October Loading Estimates: Low vs High Flow



- delivered during high flow
  - 18% of days for Fall Cr. during study
- 91% of PP_L and Tn_L
- 97% of TSS_L
  - other particulates similar

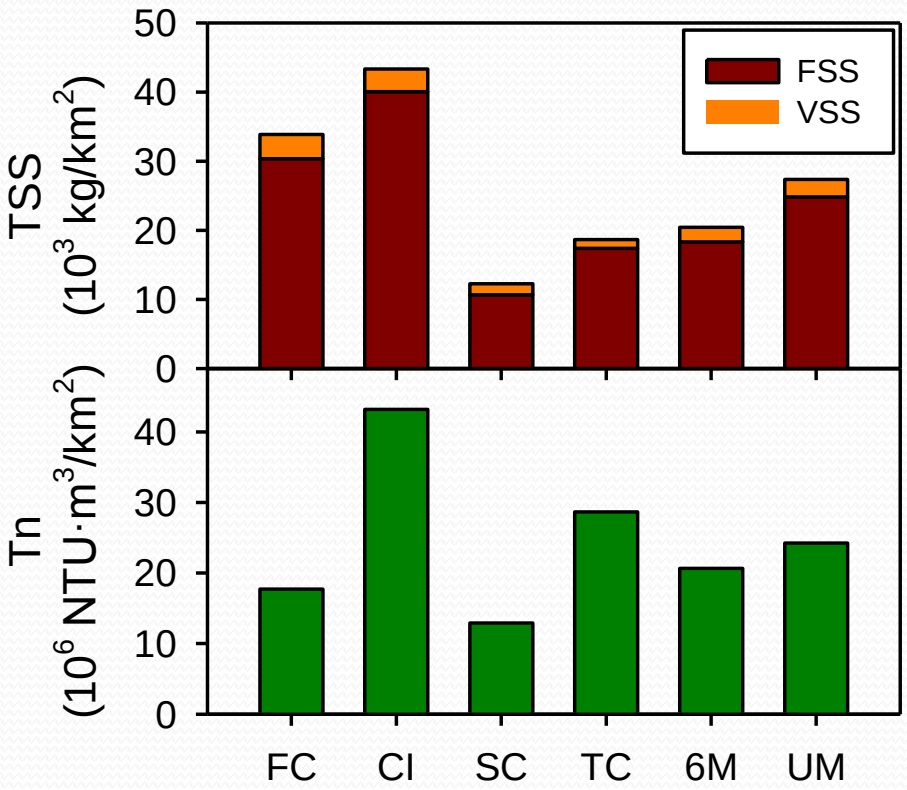
- delivered during high flow
- 70% of TDP_L
- 61 % of DOC_L
- 65 % of NO_{XL}

2013 April-October Loading Estimates: As Yields (kg/km^2)



- yield = load ÷ watershed area
- to indicate potency of individual sources
- TP yield was dominated by PP
- Cayuga Inlet had the largest TP yield
  - 40 kg/km^2
- TDP yield was dominated by SRP
  - Taugh Cr. and Salmon Cr. ~ 7 kg/km^2

2013 April-October Loading Estimates: As Yields (kg/km^2)



- TSS yield was dominated by FSS
- Cayuga Inlet had the largest TSS yield
  - $43.3 \cdot 10^3$ kg/km²
- Fall Cr. was second highest for TSS yield
  - $33.8 \cdot 10^3$ kg/km2
- Tn similar to TSS patterns
  - Taugh. Cr. and Six Mile Creek ranked 2nd and third
    - 20.4 and 18.7 kg/km²

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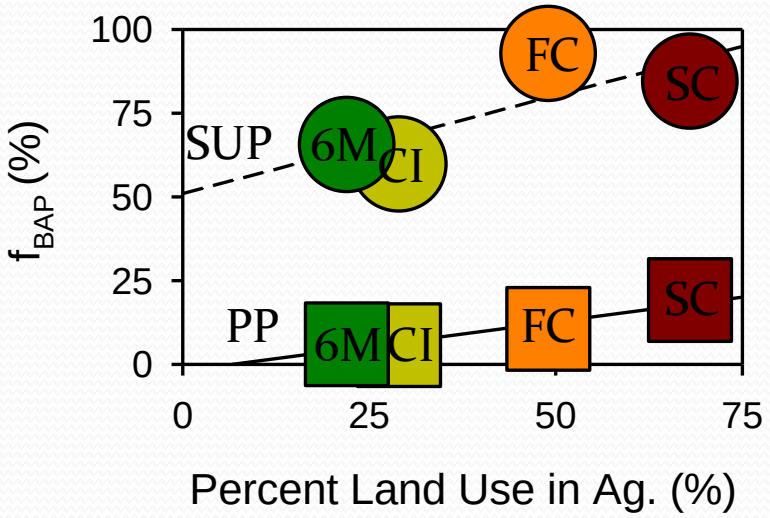
Phosphorus Bioavailability

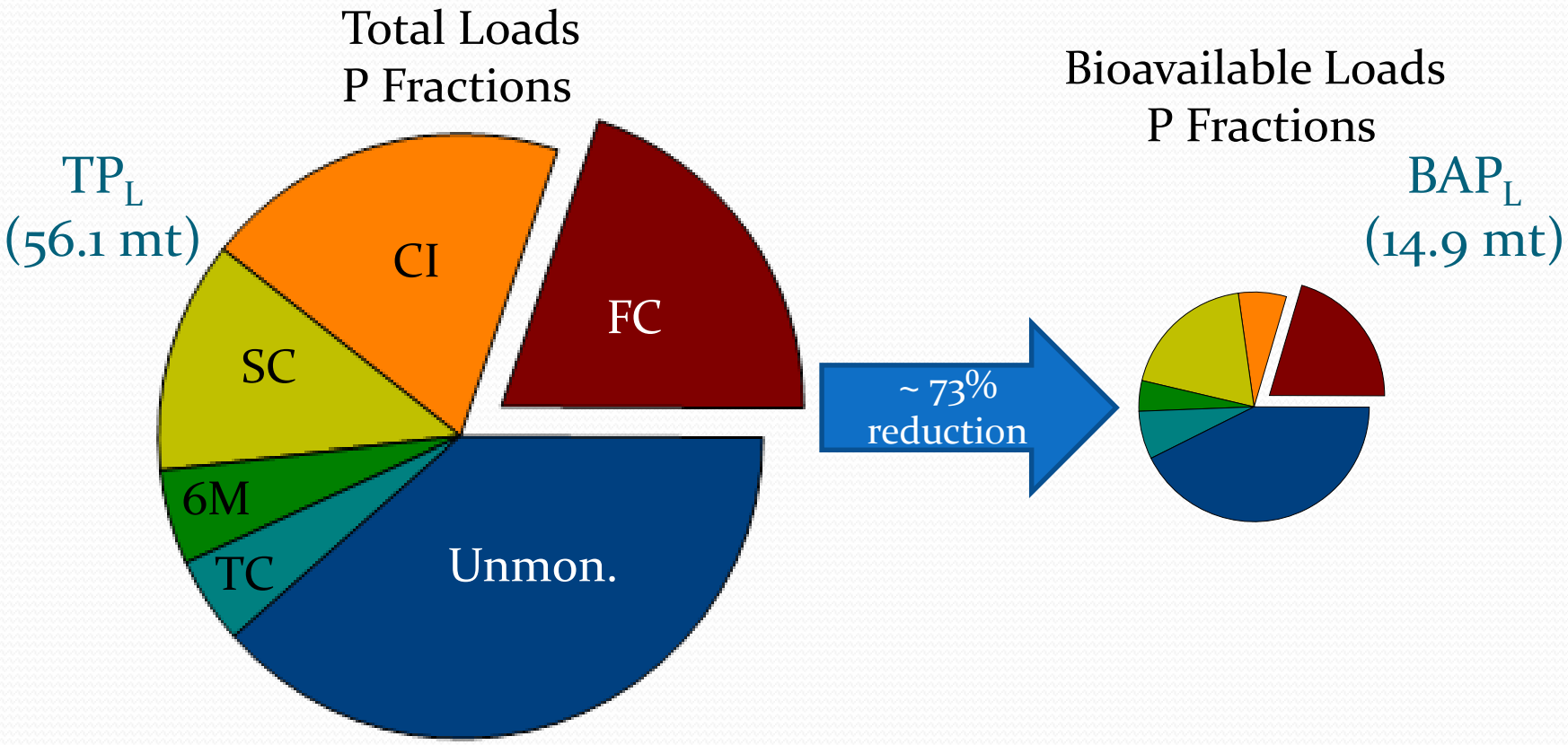
Tributary	mean PP f_{BAP} (%)	CV	mean SUP f_{BAP} (%)	CV
Fall Cr.	10.6	60	92.7	7
Cayuga Inlet Cr.	5.7	64	59.7	24
Salmon Cr.	19.2	70	84.4	20
Six Mile Cr.	6.0	69	65.5	49
CHWWTP	25.4	11	62.7	16
IAWWTP	1.2	83	73.2	29
LSC	-	-	8.2	141



- f_{BAP} – fraction of P bioavailable
- PP was least bioavailable
- SUP was mostly bioavailable
- SRP (not shown) was nearly completely available (> 93%)

- f_{BAP} found to be watershed specific, correlated to % watershed in agriculture
  - %Ag-PP f_{BAP}, r =0.97
  - %Ag-SUP f_{BAP}, r = 0.78

2013 Tributary Loading Estimates: Bioavailable P, April – October



Apportionment of BAP Loads, 2013

	Percent Contribution (%)
Source	**BAP_L**
Fall Cr.	16.9
Cayuga In.	5.3
Salmon Cr.	**15.8**
Six Mile Cr.	3.5
Taugh. Cr.	10.7
Unmon. Tribs.	43.4
summed (%)	***95.7***
IAWWTP	1.4
CHWWTP	0.5
minor WWTP	0.9
LSC	1.5
summed (%)	***4.3***
summed (%)	***100***

non-point sources

point sources

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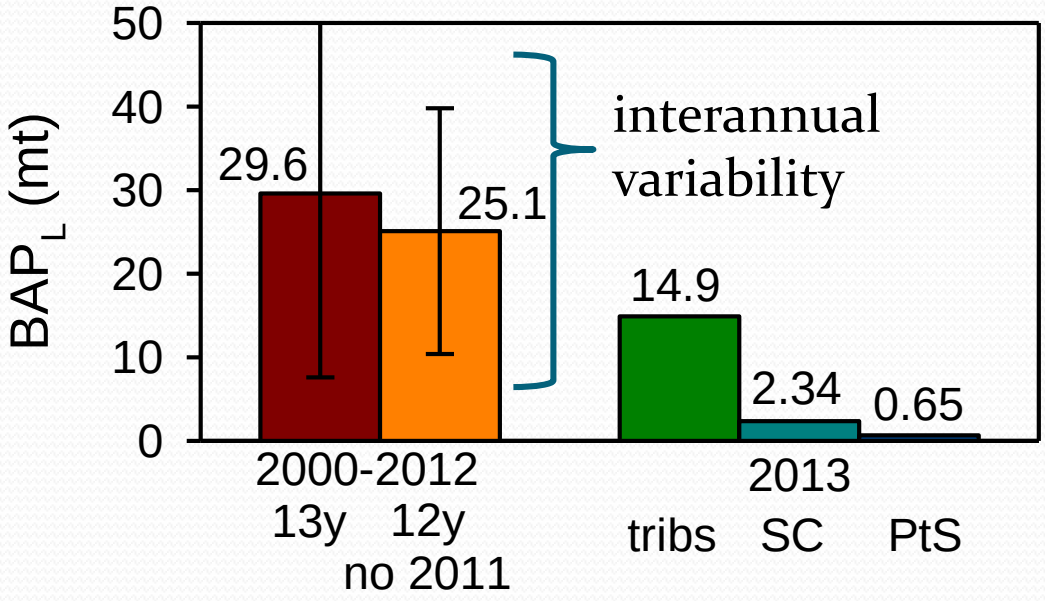
Load Estimates for the 2002-2012 Period: Magnitudes and Interannual Variability

- 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
- important for reasonable expectations for management actions

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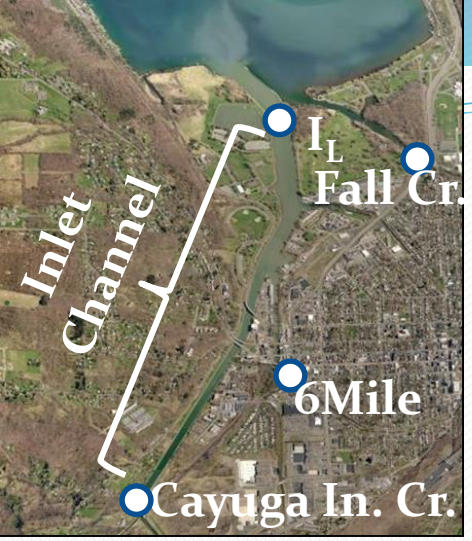
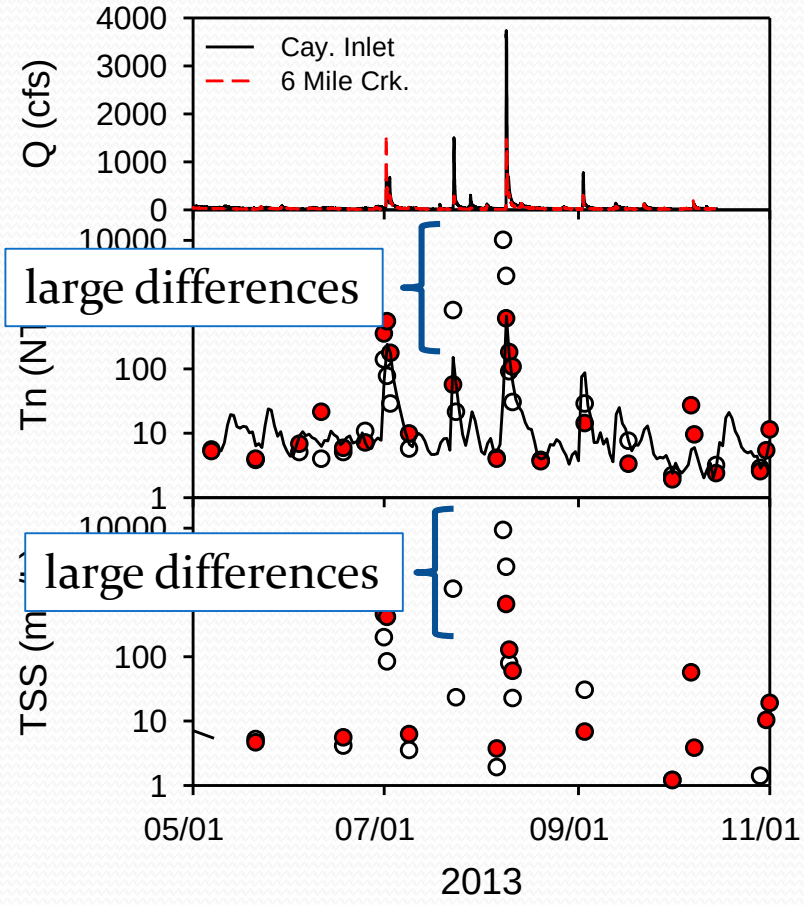


Adjustments in P/Suspended Solids Loading from Effects of Inlet Channel Necessary

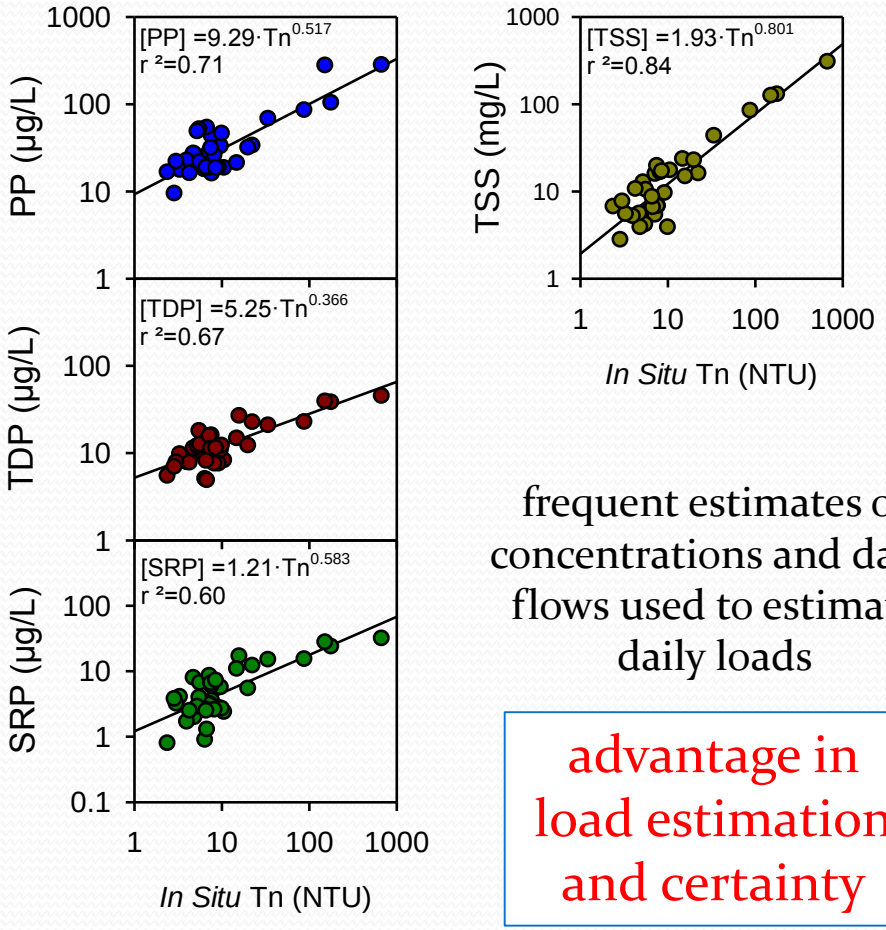
- strong evidence that the P and SS loads delivered to the lake from the inlet channel are lower than the sum of tributary inputs (2013 example)
  - in-channel deposition
- instrument deployments together with conc-Tn relationships will be used to estimate the effective loading (subsequently)
- development of adjusted loads is necessary to support realistic predictions for the shelf



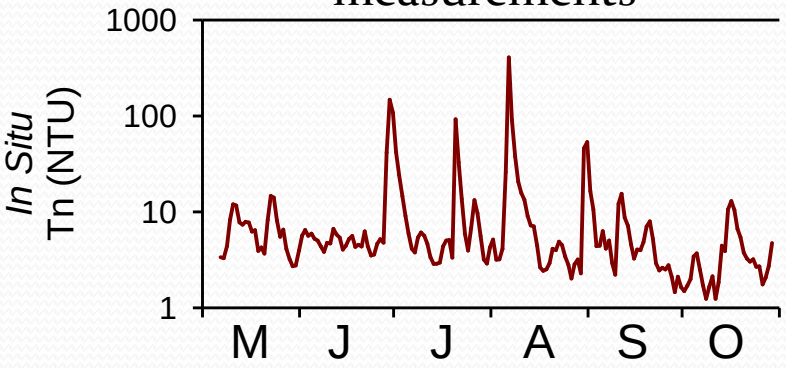
Estimation of Constituent Concentration Using In Situ Deployments

Instrument deployments

Concentration-driver (Tn) relationships



Frequent (>> daily) Tn (driver) measurements



frequent estimates of concentrations and daily flows used to estimate daily loads

advantage in load estimation and certainty

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Summary

- comprehensive event-based monitoring of major tributaries conducted in 2013
- constituent concentrations increased during high flow, particularly metrics of particulates
- concentration-driver relationships developed to estimate conditions on non-monitored days
  - Q and T, relationships of varied strengths
- loading estimates made (daily time step) to support modeling for multiple constituents
  - multiple protocols, reasonable closure
  - majority of loads delivered during high flow intervals
  - sediment loads mostly inorganic
  - apportioned according sources

Summary

- adjustments of constituent loading from tributaries entering the Inlet Channel are required because of depositional losses
- bioavailability of P forms and development of BAP_L's
  - PP – limited, SUP – mostly, SRP ~ completely
  - BAP_L ~ 25% of TP_L for the lake
  - point source contributions are minor (< 5%)
  - interannual variations (driven by Q) are large relative to individual source contributions

Questions