C. Minerogenic particles and the sediment issue

—SAX and a lake model

Part I: Outline

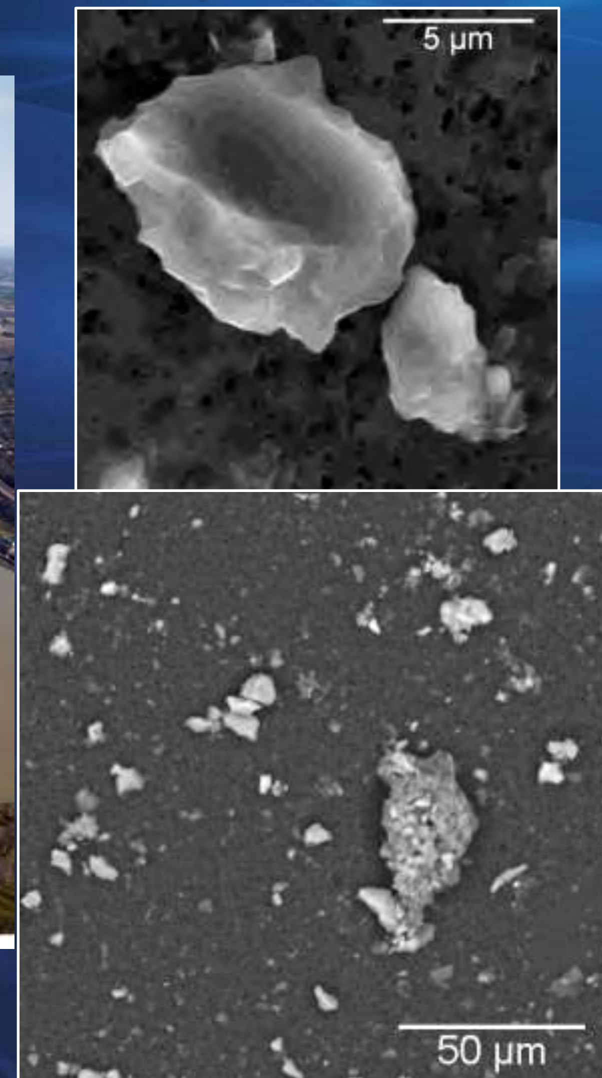
1. system-specific issues; limitations of conventional approach
2. SAX: technical details, advantages, and applications
3. Cayuga Lake 2013 water quality studies
   a. tributaries
   b. lake dynamics
   c. assessments of water quality impacts
4. model framework and summary

Selected related issues, Cayuga Lake

aerial photo of the southern shelf during a high runoff event

April 5, 2005 CAYUGA LAKE view north from Ithaca photo by Bill Hecht

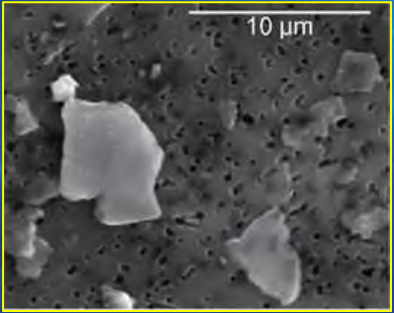
clay mineral particles



Selected related issues, Cayuga Lake

stream bank erosion

Minerogenic particles and sediment: Importance to lakes and origins



- importance
  - transport, cycling, and apportionment of forms of nutrients and contaminants
  - levels of light scattering and absorption and thereby optical metrics of water quality (optics sub-model) and remote sensing signal (NASA projects)
  - metabolic activity and composition of biological communities
  - net sediment accumulation
- origins
  - terrigenous (allochthonous, particularly runoff events)
  - resuspension (internal)
  - autochthonous (internal; $CaCO_3$ precipitation)

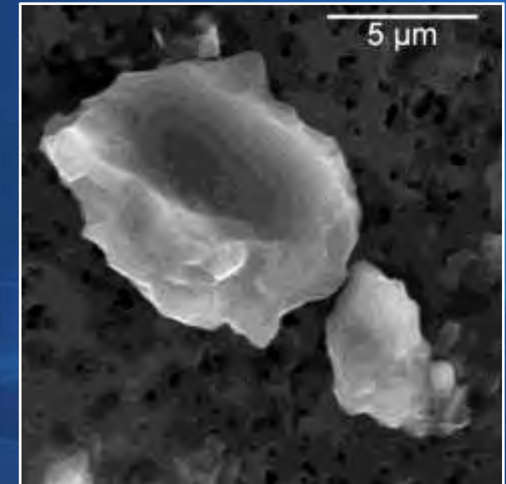
History of sediment measurements

- gravimetric—mass per unit vol. of water; unit in mg/L, for example
- suspended particulate material (SPM, or TSS)
  - organic and inorganic components (VSS and FSS)
- SPM = OSPM + ISPM (TSS = VSS + FSS)
  organic + inorganic
  - operationally defined, burn temperature
- ISPM an attempt to represent minerogenic particles
- streams/rivers vs. lakes/reservoirs
  - higher vs. lower concentrations
  - composition differences, terrigenous vs. lacustrine components

problems

Features of natural minerogenic particle populations

—influence transport, fate and impacts



- features
  - number concentration —*N* (i.e., number per unit volume of water)
  - particle size distribution (PSD)
  - elemental composition of individual particles
  - particle shape (least important)

Cannot be done from ISPM

- points to be expanded upon
  - strong linkage between the common term "sediment" and minerogenic particle populations; e.g., Cayuga Lake
  - limitations of older sediment measurement protocols
  - superior capabilities of SAX—scanning electron microscopy interfaced with automated image and X-ray analyses

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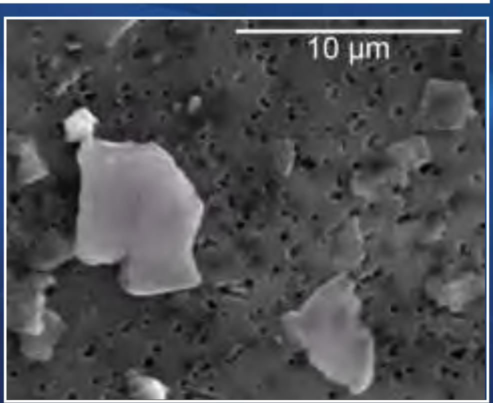
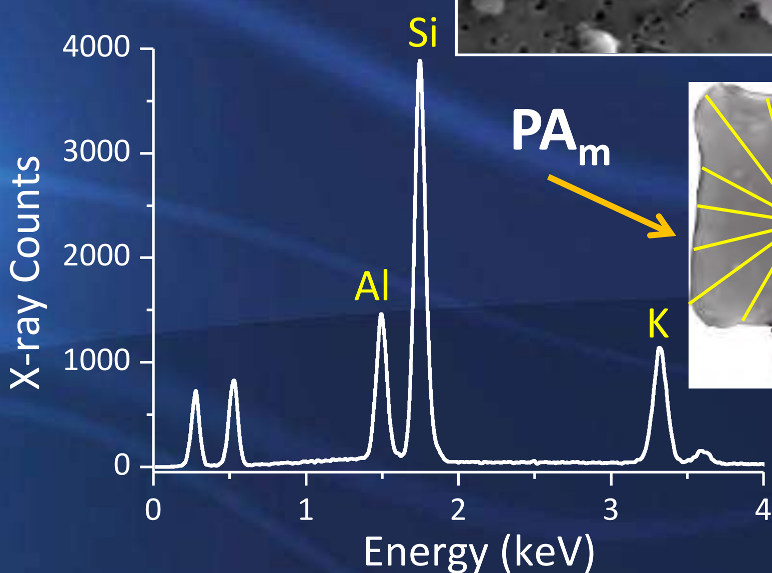
SAX

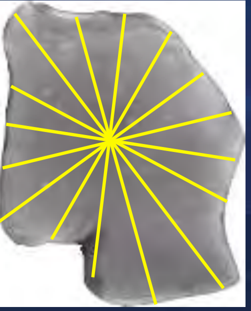
—Scanning electron microscopy coupled with Automated image and X-ray analyses

- **morphology and composition analyses for individual mineral particles**
  - **a platelet clay mineral particle**
    —dominant form in many systems, including Cayuga Lake



- **PA_m—projected area of a minerogenic particle**
- **PAV_m—total projected area of minerogenic particles per unit volume of water (m^{-1})**
  —a powerful summary metric

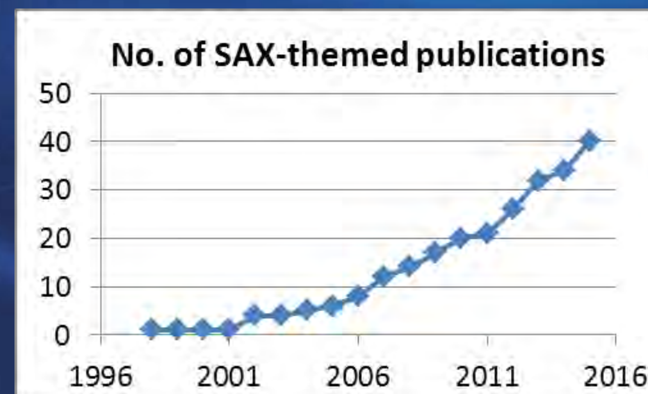


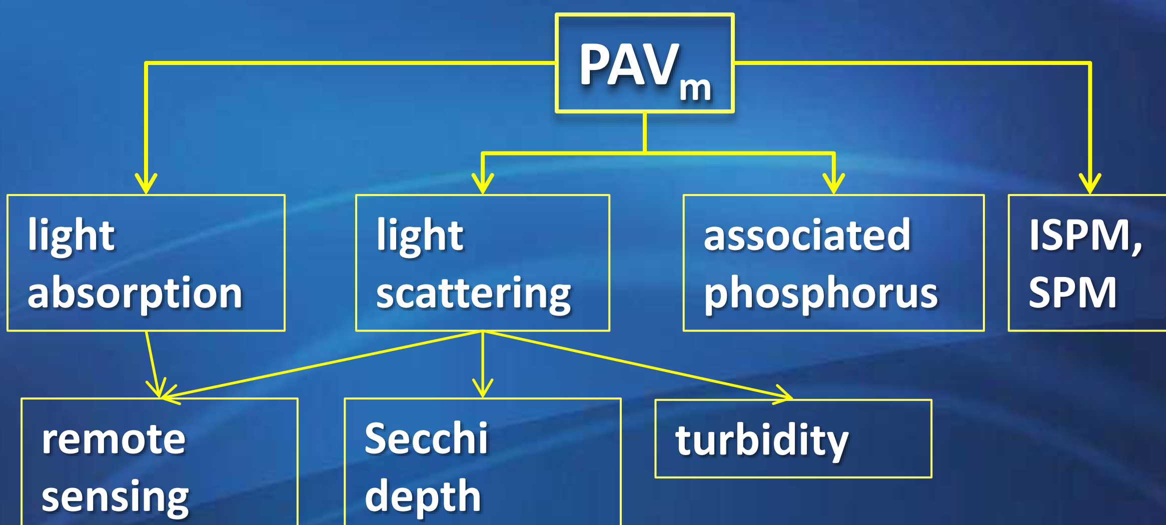


The 'new' measurement capabilities for minerogenic particles by SAX

—recognized to be established and powerful

- started in NYC watershed turbidity studies (late 1990s)
- expanded through NY and Great Lakes
- multiple key water quality issues quantitatively connected
- documentation in peer-reviewed literature
  - — cumulative growth
- central role and value of the PAV_m metric





PAV_m—total projected area of minerogenic particles per unit volume of water (i.e., area conc., m^{-1})

Demonstration of credibility and value of SAX–PAV$_m$ information

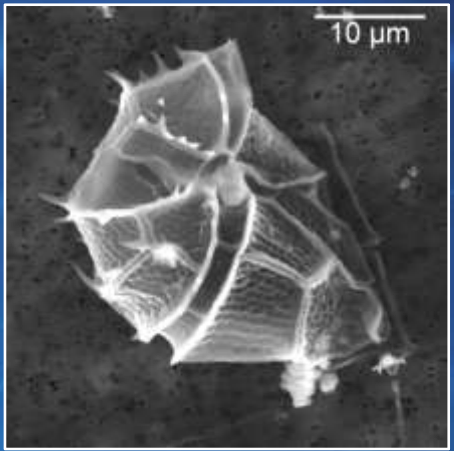
—systems and water quality topics listing; Table 2 in Peng and Effler (2015)

Table 2. Summary of closure or consistency demonstrated by SAX-based approach (PAV$_m$) for North America Fresh Waters.

System	**Closure (✓) or Consistency (×)**						**No. of Compo -nents**	**Reference**
	b_p	b_{bp}	a_{NAP}	T_n or SD^{-1}	PP_m	SPM or ISPM		
New York City (NYC) Reservoir Systems (9)				×		×	1	Peng et al. (2002, 2004)
Finger Lakes (NY)				×			2	Peng and Effler (2005)
Schoharie Creek (NY)				×		×	1	Effler et al. (2007)
Schoharie Reservoir and Schharie Creek (NY)	✓			×			1	Peng and Effler (2007)
Central NY lakes (4) and a river	✓ ×	×					2	Peng et al. (2007)
Lake Superior	✓	✓	✓				2	Peng et al. (2009a), Effler et al. (2010a)
NYC Reservoir Systems (6)				×			1	Peng et al. (2009b)
Lake Erie	✓	✓		×			1	Peng and Effler (2010)
Lake Ontario	✓	✓		×			2	Peng and Effler (2011)
Onondaga Lake (NY)	✓						2	Effler and Peng (2012)
Ashokan Reservoir and Esopus Creek (NY)	✓					✓	1	Peng and Effler (2012)
Great Lakes (3) and Central NY lakes (4)		✓						Effler et al. (2013)
Lake Erie			✓			✓	1	Peng and Effler (2013a)
Skaneateles Lake (NY)	×			×			3	Peng and Effler (2013b)
Cayuga Lake (NY)	✓			×			2	Effler and Peng (2014)
Cayuga Lake (NY)				✓	✓		2	Effler et al. (2014)
Great Lakes			×					Peng and Effler (2015)

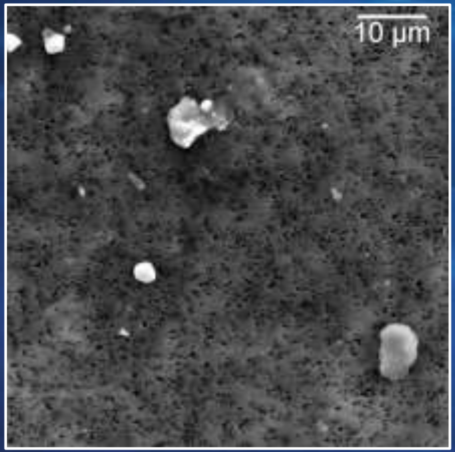
SAX separates minerogenic particles from phytoplankton

- example micrographs from scanning electron microscopy



phytoplankton
(greens)
– organic

phytoplankton
(diatoms)
– mixed organic
inorganic (Si)



minerogenic
clay minerals, quartz, etc.
– inorganic

produced in lakes

watershed

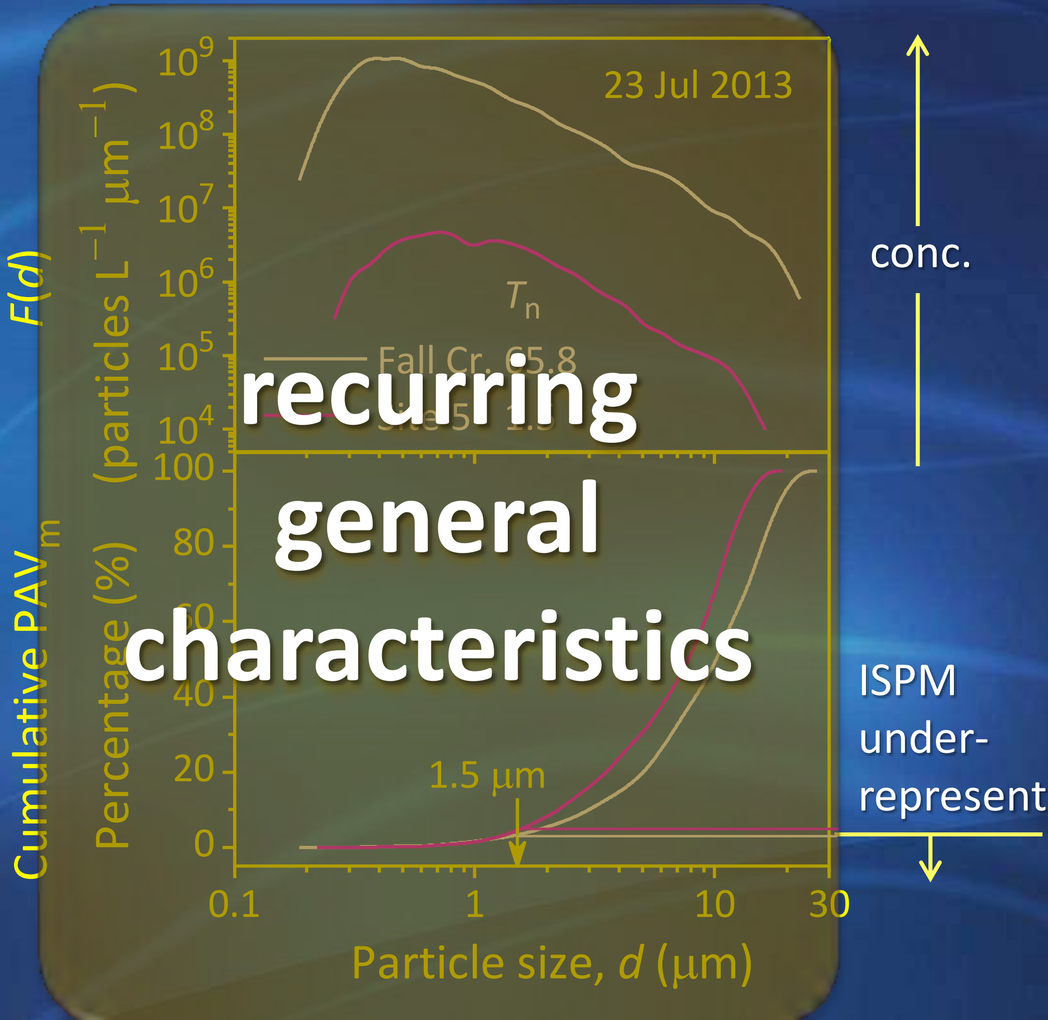
inorganic

- particle origins and impacts central to management issues
  * phosphorus and trophic state metrics
  * optics—Secchi depth, turbidity, remote sensing

a problem for ISPM in lakes

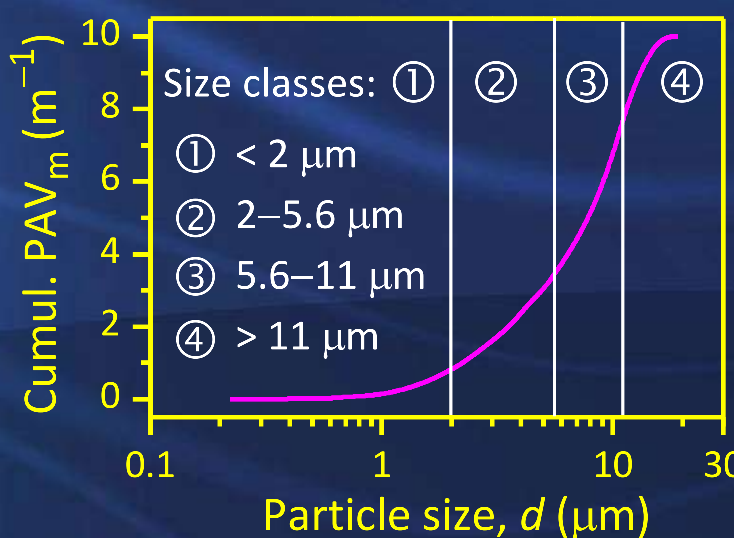
Particle size distributions (PSDs) of minerogenic assemblages from SAX

—natural polydispersed particle populations



recurring general characteristics

- **multiple sized particles observed**
- **broad size range(s) contribute**
  - ∗ **1–14 μm in lake**
  - ∗ **1–20 μm in stream**
- **behavior and impact reflect multiple sizes**
  - **basis for four broad size classes**



Advantages of PAV_m, disadvantages of ISPM, to represent minerogenic particles

Feature	PAV_m (SAX)	ISPM
(1) analytical precision, lakes	good	poor
(2) representation of sizes of impacts	complete	none
(3) minerogenic particles successfully isolated	yes	no, variable contributions of diatoms
(4) resolve contributions of different sizes	yes	no
(5) resolve contributions of different geochemical types	yes	no
(6) theoretical and demonstrated consistency with impacts	yes, projected area	no, mass

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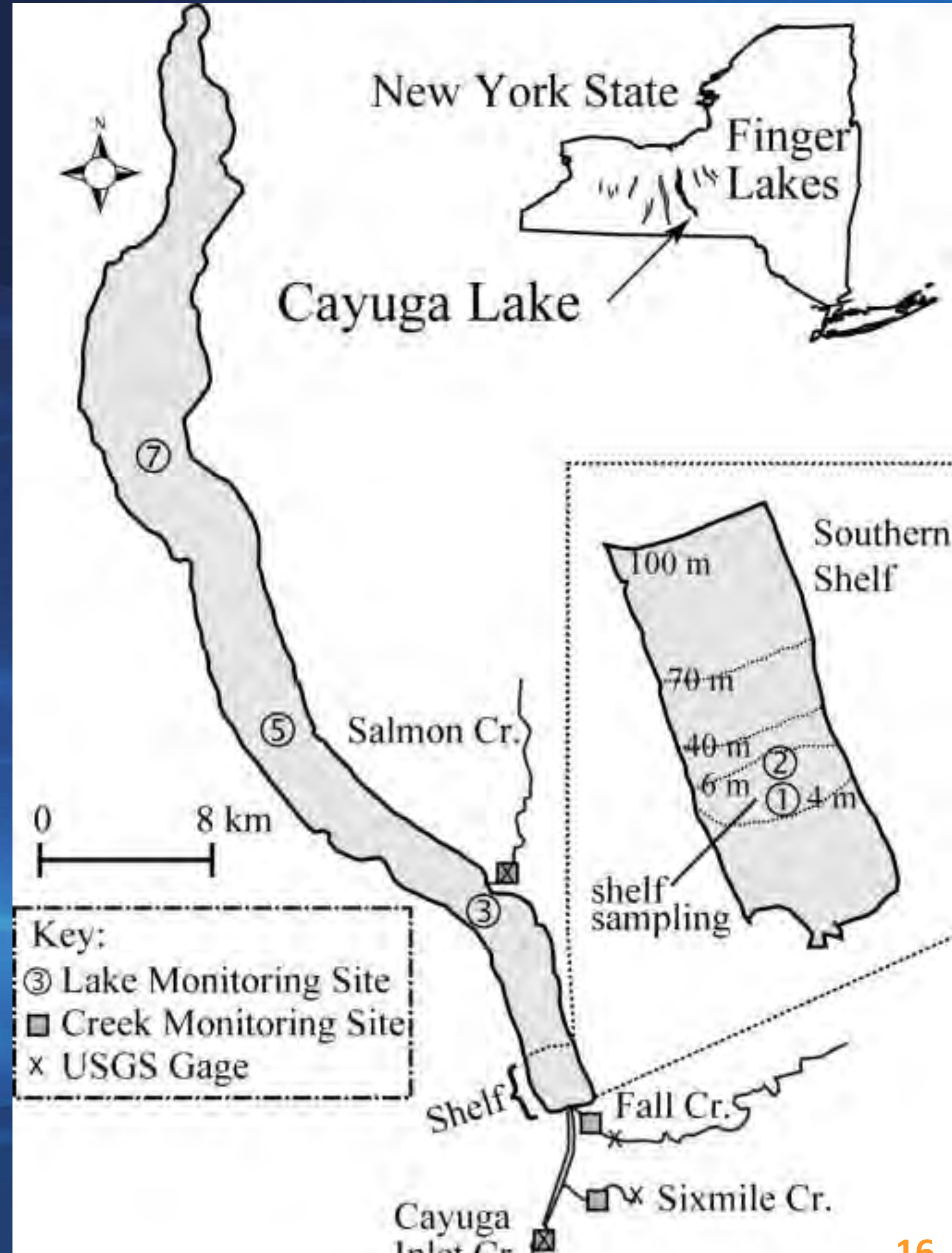
Cayuga Lake 2013 water quality studies
—phosphorus, clarity

- intensive sampling: lake and major tributaries

- >400 SAX samples
- ~350 SAX samples, 1999–2006



SAX characterizations

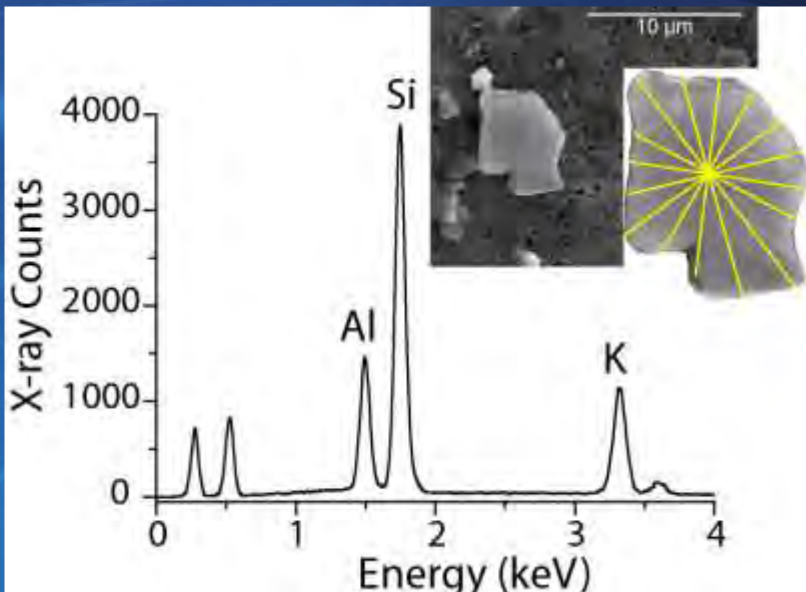


Image analysis

– projected area (PA)

– size (area equivalent diameter, *d*)

X-ray microanalysis

– elemental X-ray composition

– particle types: clay minerals, calcite, quartz

- Summary results
  - ➢ PAV_m (particle projected area conc.)
    - size and generic geochemical type distributions
    - related to turbidity, Secchi depth, PP_m
  - ➢ PVV_m (particle volume conc.; mm^3/L or ppm), clay platelets
    - mass loading, consistency testing

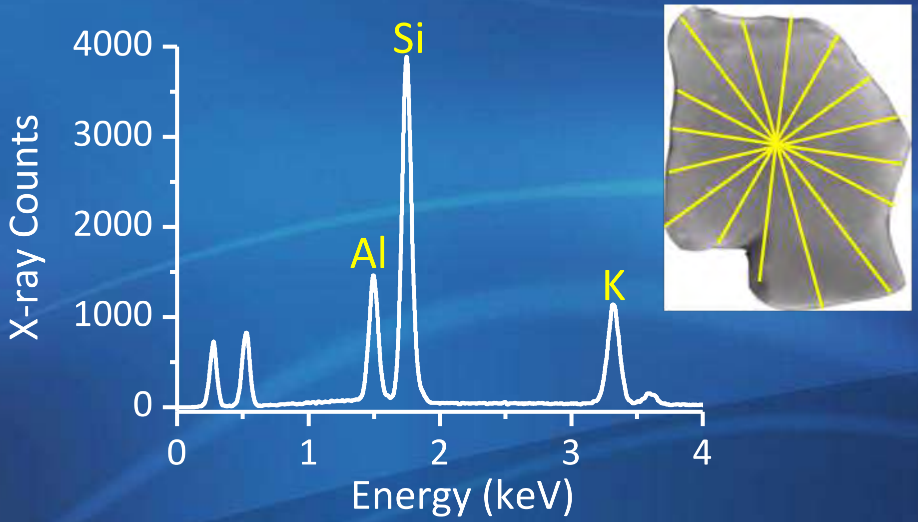
Sediment delivery to Cayuga Lake: Where and when?

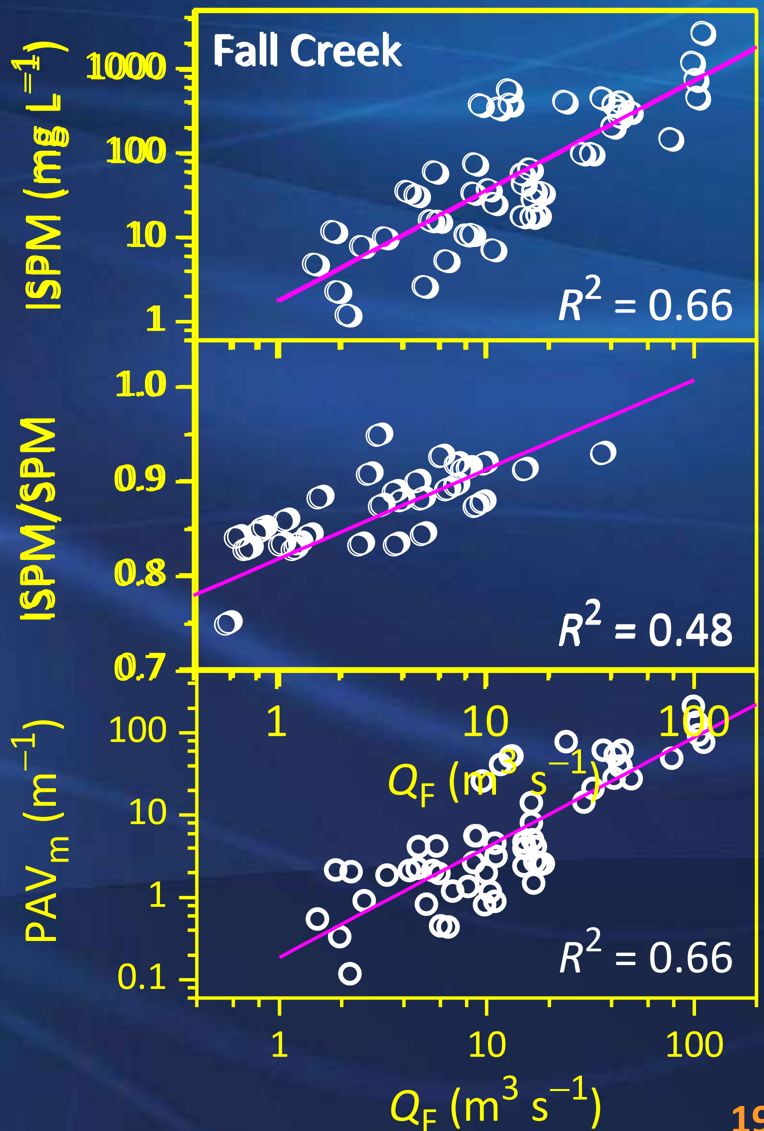
1. reception from the watershed
2. localization at southern end—enters the shelf
3. mostly from runoff events
   — conspicuous visual signatures

4. estimates of external loads supported by focus on runoff events (NYSDEC)

Positive dependencies of minerogenic sediment metrics on stream flow (Q_F) for Cayuga tributaries

1. traditional gravimetric measurements
   - ISPM—mostly minerogenic
   - ISPM : SPM dominance, increasingly as Q_F increased
2. SAX characterizations
   - composition and size

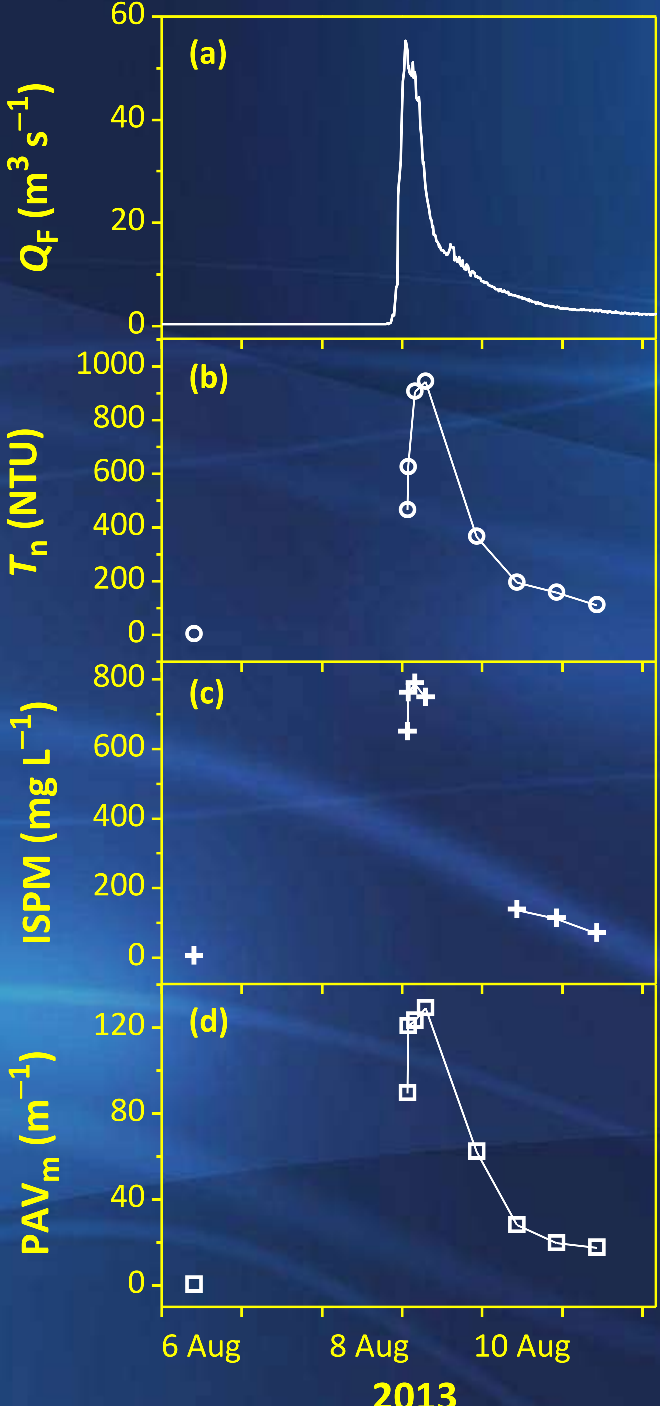




   - clay minerals dominate PAV_m

Increased minerogenic sediment input (i.e., PAV_m) from tributaries during runoff event

- example for Six Mile Creek
- also clearly manifested in PAV_m dynamics



* flow event

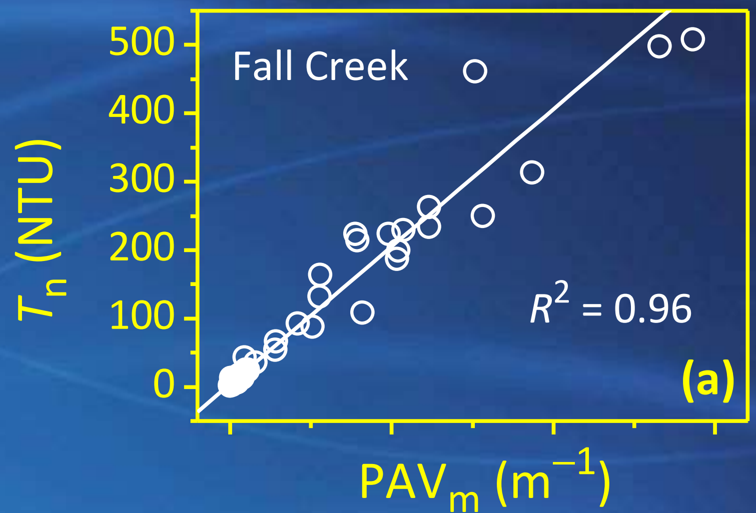
* increases in T_n (turbidity)

* increases in ISPM (inorganic sediment mass)

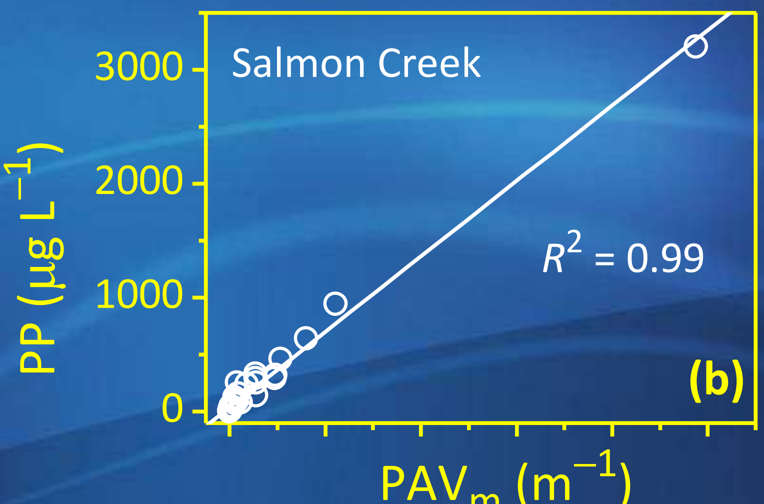
* increases in PAV_m

SAX–PAV_m tributary dependencies with other particulate metrics of water quality (2013 observations)

—driven by runoff event sampling (NYSDEC)



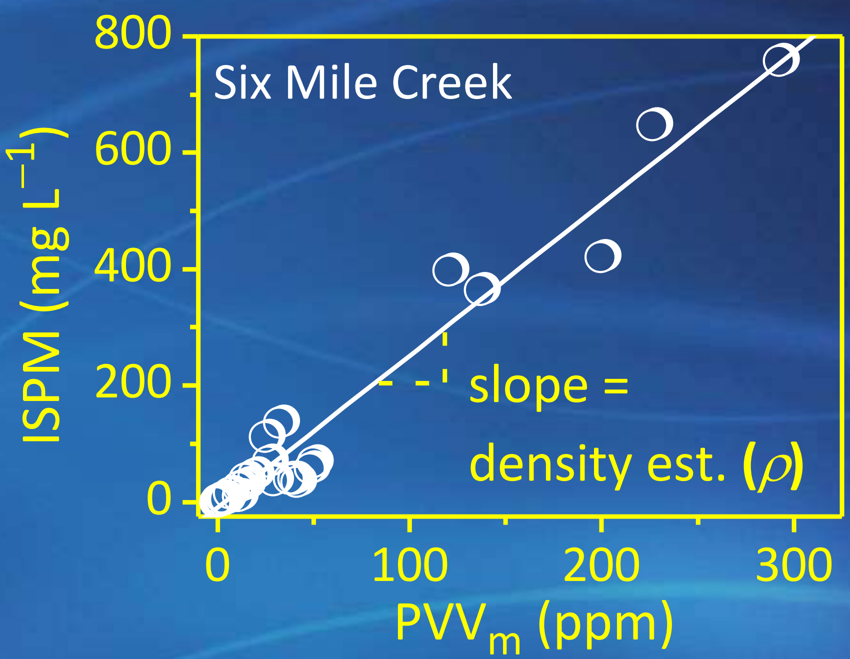
- T_n—turbidity
- strong dependencies
- linkage of PAV_m to an optical metric of quality



- PP—particulate P (= TP – TDP)
- strong dependencies
- linkage to a trophic state metric

Sediment delivery to Cayuga Lake : Mass consistency of ISPM and SAX observations

—Cayuga Lake tributaries



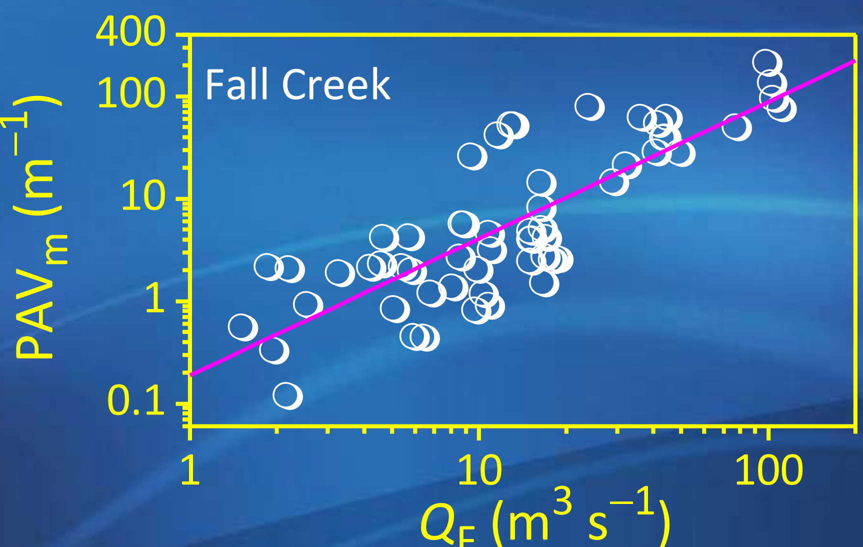
- PVV_m—minerogenic particle volume per unit volume of water (i.e., volume conc.)
  - from SAX
  - calculated from PAV_m/PVV_m ratios (priori) or individual particle volumes
- slope value→density (2.6×10^3 kg m^{-3})

- apparent densities (ρ) consistent with clay mineral values (e.g., kaolinite 2.60×10^3 kg m^{-3})
  - ∗ Peng and Effler (2015)—Cayuga tributaries
  - ∗ Peng and Effler (2012)—NYC reservoir and tributary

SAX–PAV$_m$ tributary dependencies on flow (2013 observations): Support for tributary load estimates

—benefits of runoff event sampling

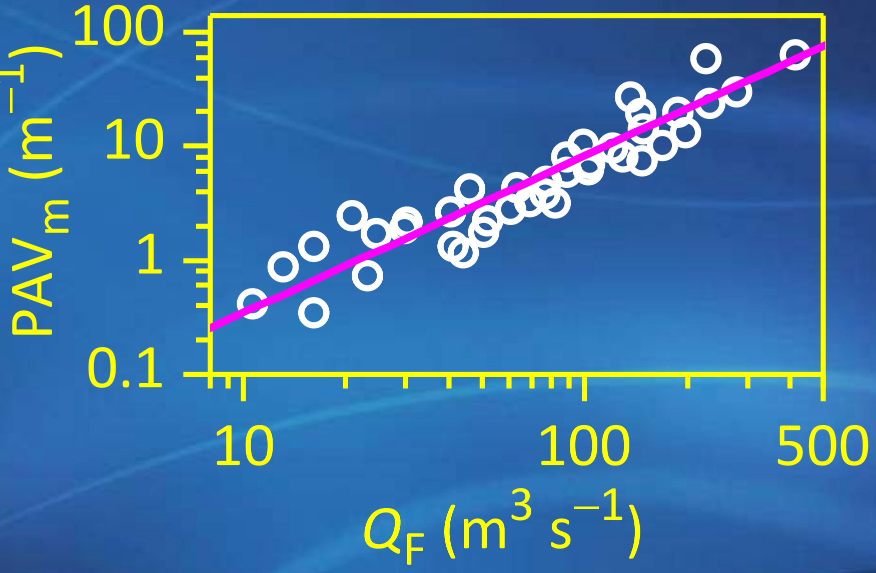
- positive, reasonably strong (power law, PAV$_m$= $A \times Q_F^B$) dependencies



- associated loads would increase with increased runoff events and severity of the events
- however, noteworthy variance in relationships, as with other particulate constituents—consider origins

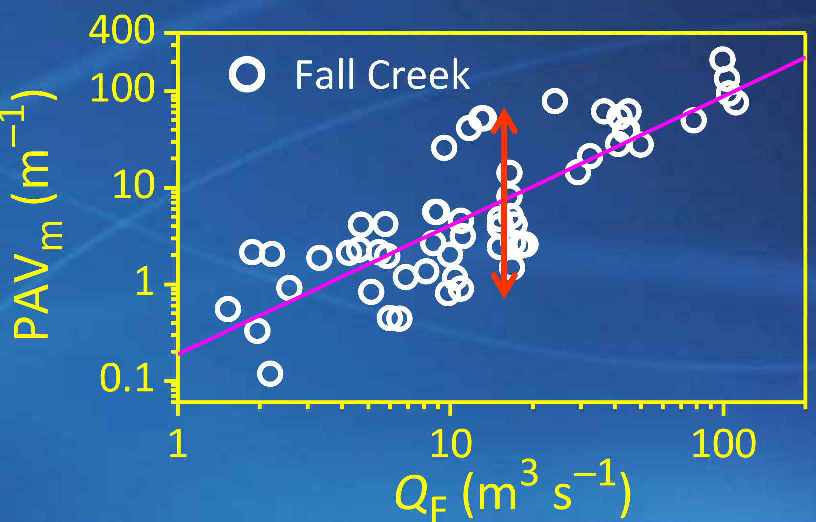
SAX–PAV_m tributary dependencies on flow (2003 Schoharie Cr., NYC Reservoir System)

NYC Reservoir System, Catskill region:
Stream bank erosion—a problem



Aerial photo of Ashokan Reservoir, NY

SAX–PAV$_m$ tributary dependencies on flow (Fall Creek 2013)



Fall Creek:
Stream bank erosion

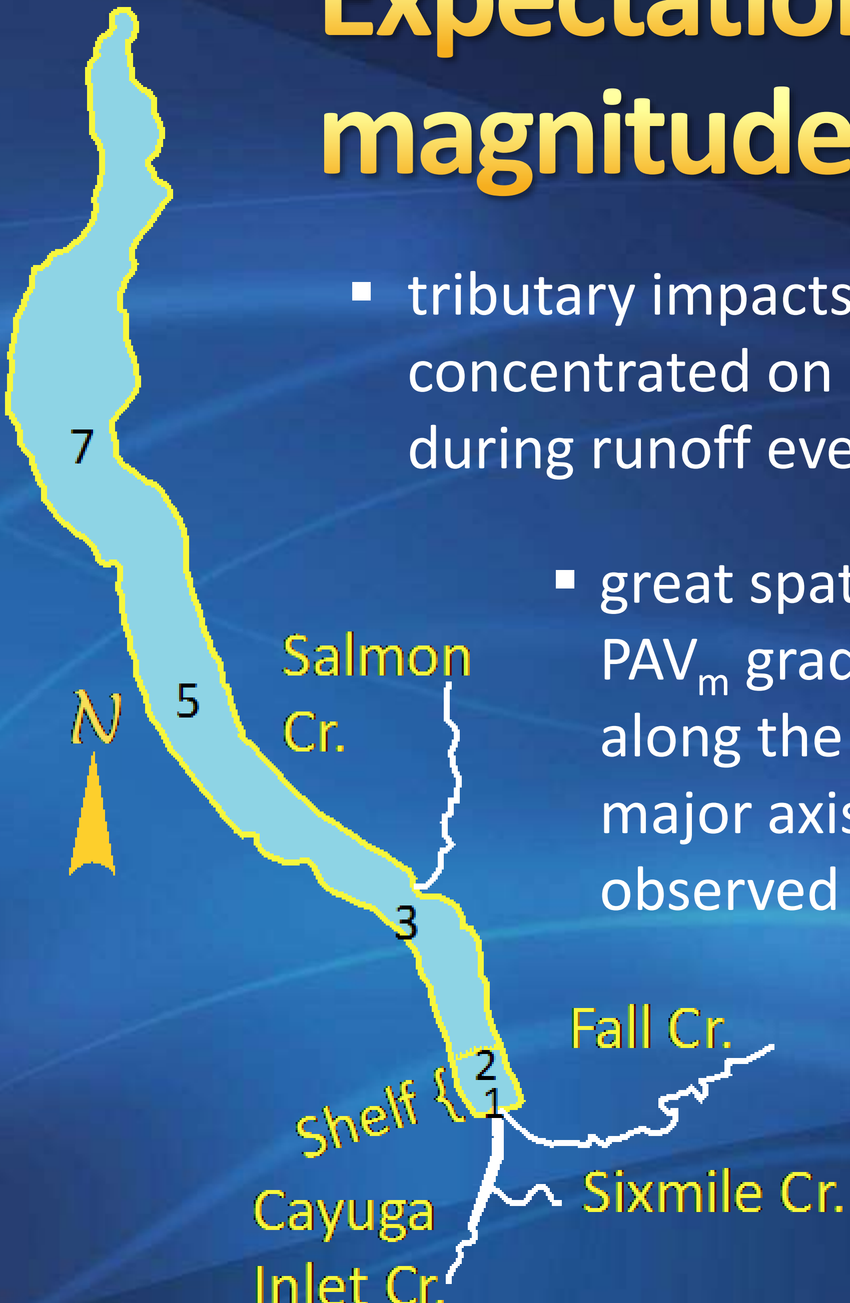
- importance of stream bank erosion for sediment inputs from certain Cayuga streams, and sources of variance

Nagle, G. N., T. J. Fahey, J. C. Ritchie, and P. B. Woodbury. 2007. Variations in sediment sources and yields in the *Finger Lakes and Catskill* regions of New York. Hydrol. Process. 21: 828–838.

Expectations for lake PAV_m magnitudes and patterns

- tributary impacts concentrated on shelf during runoff events

- great spatial PAV_m gradient along the lake's major axis observed



Selected SAX–PAV_m results for 2013

Table 4. Minerogenic particle population characteristics, in terms of contributions to PAV_m by geochemical and size classes, for Cayuga Lake tributaries and lake sites in 2013 (Peng and Effler 2015)

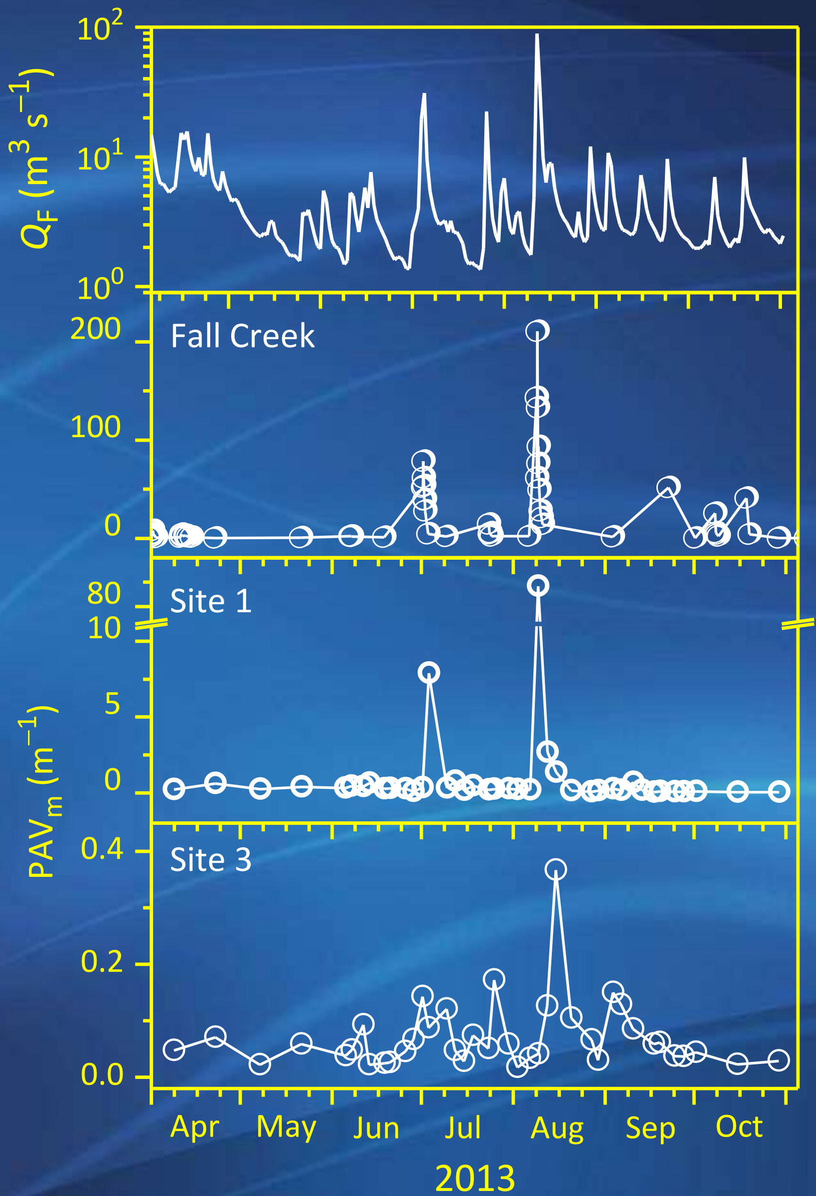
Stream or Lake Site	Avg. PAV_m	% Contributions by Particle Types to PAV_m						% Contributions by Size (µm) Classes			
Site 2	0.35	82.5	6.4	2.9	4.1	0.5	3.7	18.8	44.0	28.2	9.0
Site 3	0.071	74.6	5.4	8.7	6.1	0.5	4.7	18.5	44.6	27.5	9.4
Site 5	0.053	70.7	5.6	11.9	6.9	0.5	4.5	18.0	42.6	27.2	12.3
Site 7	0.058	67.1	5.5	10.2	9.8	0.8	6.6	19.2	43.4	28.0	9.4

Key features:

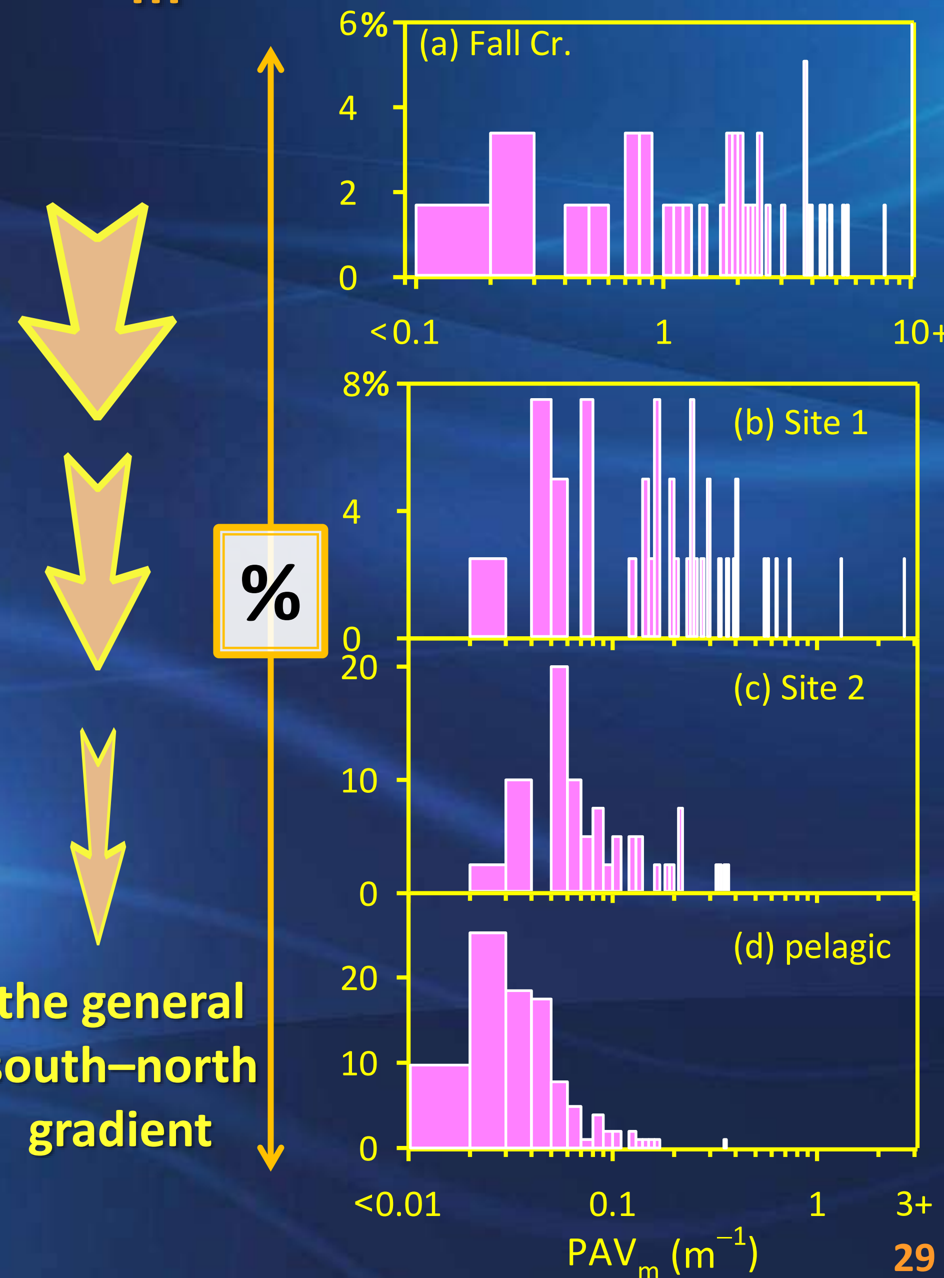
1. PAV_m gradient: southern tribs→shelf→pelagic
2. clay dominance, calcite secondary for pelagic
3. shift in PSD from tribs to lake—larger to smaller particles

Example distributions of PAV_m observations in 2013

- runoff event driven dynamics



- the general south–north gradient



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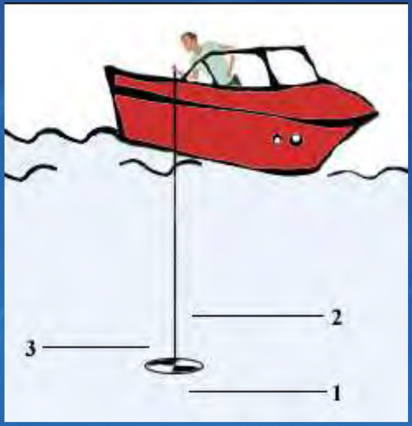
Impacts of minerogenic particles on water quality: PAV_m-based, optics

- optical metrics—regulated through light scattering
  - (1) Secchi depth (SD)



$SD^{-1} \propto b_p$ (b_p: particulate scattering coeff. , m^{-1})

$b_p = b_m + b_o$ (minerogenic and organic components)

$b_m = \langle Q_{b,m} \rangle \times PAV_m$

scattering efficiency factor = 2.3 (±5%)

b_o—estimated from chlorophyll-*a* or POC-based empirical models

  - (2) turbidity (T_n; side-scattering)
  - (3) backscattering (b_b)
- conceptually sound; well documented
  – *see* PAV_m-themed reference list
- ISPM is not a legitimate alternative

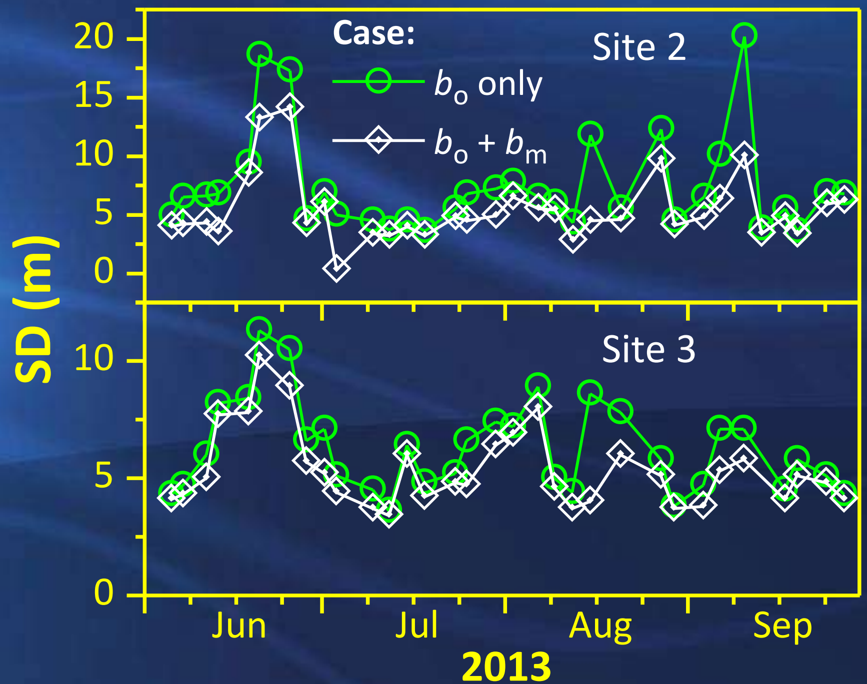
Impact assessments of minerogenic particles on water quality metrics in Cayuga Lake, 2013: Secchi depth (SD) predictions

- **based on empirical system-specific relationships**

$$SD^{-1} \propto b_p \qquad \left[b_p\text{: particulate scattering coeff.} \right]$$

$$b_p = b_m + b_o \qquad \left[\begin{array}{ll} \text{minerogenic component:} & b_m = 2.3 \times PAV_m \\ \text{organic component:} & b_o = f\,(\text{Chl-}a) \end{array} \right]$$

- **temporal patterns of SD for b_o only, and for ($b_o + b_m$)**
  - **b_m (i.e., PAV_m) caused lower SD compared with b_o (phyto) only cases, from contributions to b_p**
  - **effect greater on shelf than pelagic waters**
    - † **27% greater on shelf without minerogenic particles**
    - † **15% greater in pelagic waters**

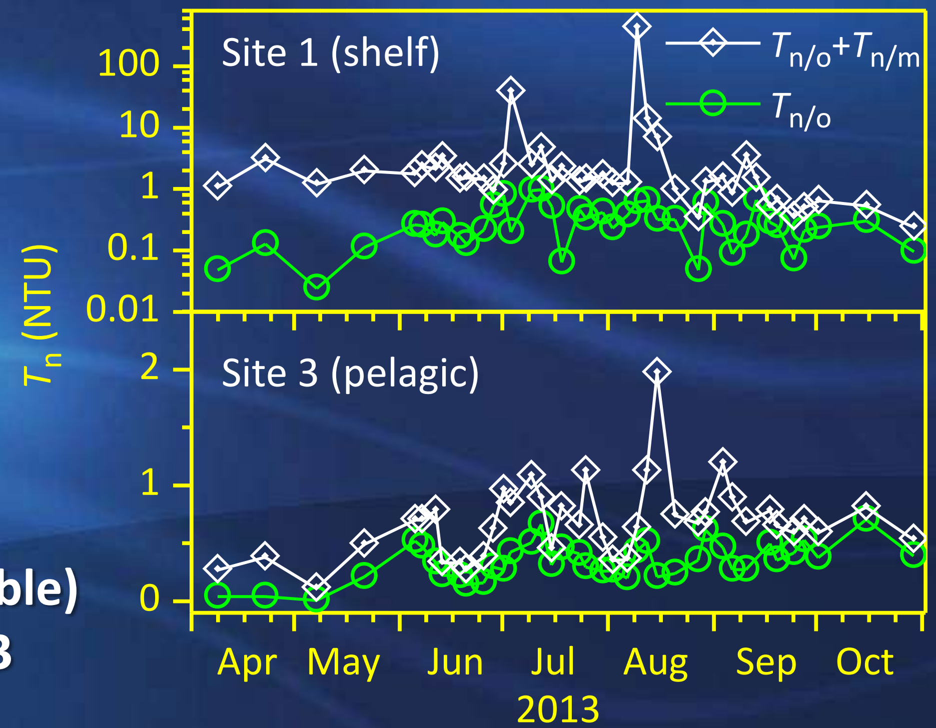


Impact assessments of minerogenic particles on water quality metrics in Cayuga Lake, 2013: Turbidity (T_n) predictions

- based on two component partitioning (Effler et al. 2014, Inland Waters)—Chl-*a* and PAV_m as drivers
- temporal patterns of T_n
  - 'org' contribution only
  - 'org' + 'min' contributions
- higher T_n values because of added $T_{n/m}$; larger effect than on SD
- effect greater on shelf than in pelagic waters
  - † log- vs. linear scale
  - † $T_{n/o}$ max. on shelf <1 NTU (negligible)
  - † $T_{n/m}$ 48% of T_n on average at Site 3

Organic: $T_{n/o}$: Chl-*a* = 0.08

Minerogenic: $T_{n/m}$: PAV_m = 4.80



Impacts of minerogenic particles on water quality: PAV_m-based

- associated phosphorus, a particulate form—PP_m
- published for the Cayuga Lake case in the peer-reviewed literature
  - Effler et al. (2014) Partitioning the contributions of minerogenic particles and bioseston to particulate phosphorus and turbidity. Inland Waters 4: 179–192.
- first presented on this project (TAC meeting, Jan 2014, Ithaca), reviewed here
  - $PP = \underbrace{\underbrace{(PP_o : Chl\text{-}a)}_{\text{stoichiometry}} \times Chl\text{-}a}_{\text{organic component}} + \underbrace{\underbrace{(PP_m : PAV_m)}_{\text{stoichiometry}} \times PAV_m}_{\text{minerogenic component}}$

unavailable fraction of PP_m ($PP_{m/u}$) dominates, subsequently

- ISPM is not a legitimate alternative to support this analysis

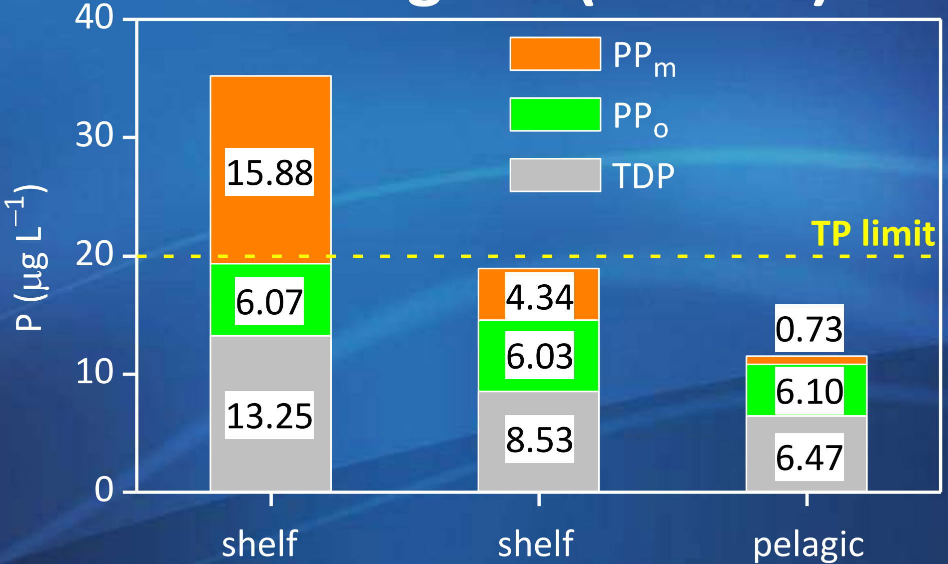
Impact assessments of minerogenic particles on water quality metrics in Cayuga Lake, 2013: Particulate phosphorus (PP)

- based on empirical system-specific model of Effler et al. (2014); paired measurements of PP, PAV_m, and Chl-*a*

$$PP = (PP_o : \text{Chl-}a) \times \text{Chl-}a + (PP_m : PAV_m) \times PAV_m$$

  - PP_m and PP_o are the minerogenic and organic (phyto) particle components

- summer avg. TP (and PP) concentrations partitioned



  - 20 µg/L NYS guidance value
  - higher PP_m concentrations primarily cause of higher shelf TP levels
  - negative implications for listing and application of guidance value

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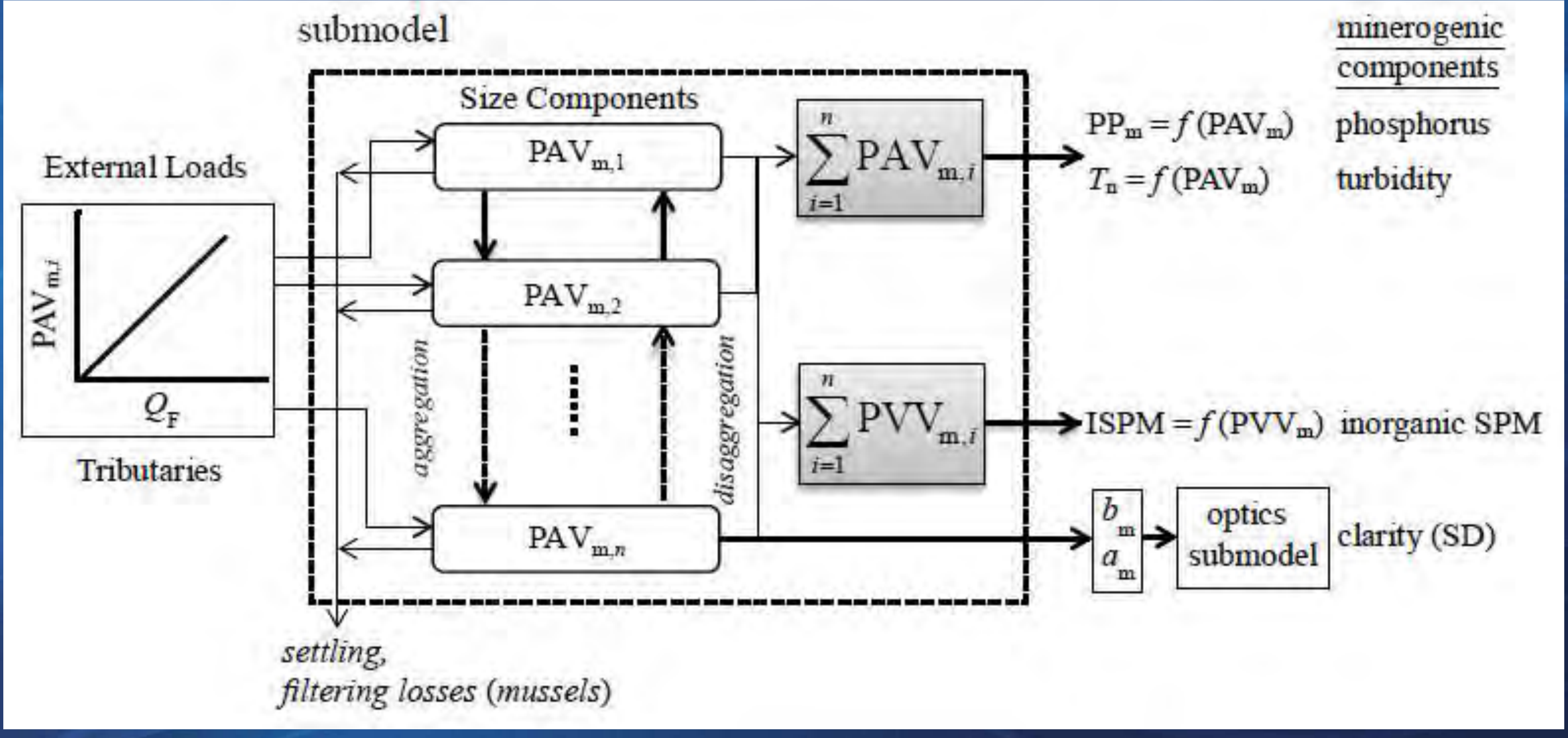
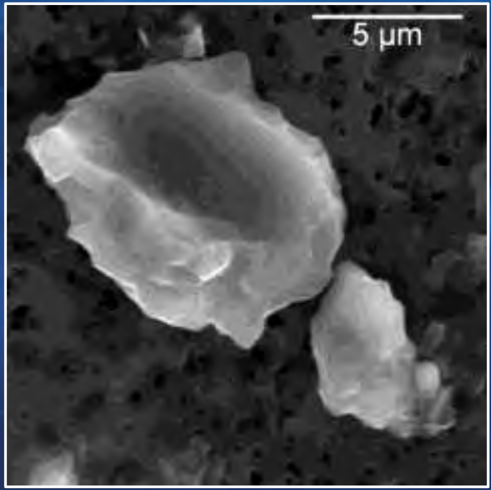
A conceptual model for minerogenic particles in a lake

Peng, F., and S. W. Effler. 2015. Quantifications and water quality implications of minerogenic particles in Cayuga Lake, New York, and its tributaries. *Inland Waters*, 5: 403–420.



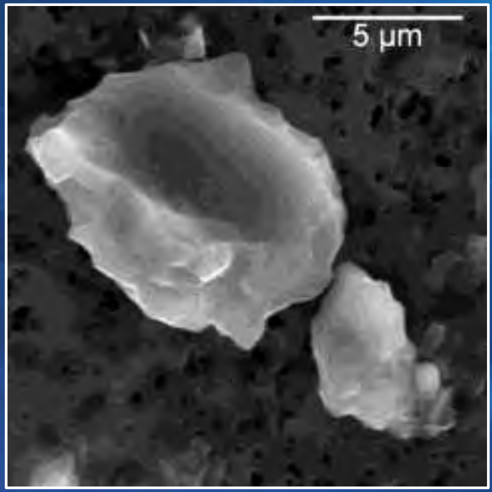
Summary: SAX–PAV_m and Cayuga Lake

Peng, F., and S. W. Effler. 2015. Quantifications and water quality implications of minerogenic particles in Cayuga Lake, New York, and its tributaries. *Inland Waters*, 5: 403–420.



- SAX was applied to characterize minerogenic particles of Cayuga Lake and primary tributaries
- SAX–PAV_m applied to quantify their effects on common metrics of water quality
- PAV_m the primary summary metric
- PAV_m is linearly related to the minerogenic particle components of PP (PP_m), T_n ($T_{n/m}$), light-scattering coefficient, and inversely related to SD

Summary: SAX–PAV_m and Cayuga Lake



- SAX supports partitioning PAV_m into multiple particle size (i.e., polydispersed populations) and composition classes
- PAV_m was higher on shelf than in pelagic areas following runoff events because of elevated inputs from local tributaries
- coupled degradations in water quality included higher PP_m, $T_{n/m}$, and lower SD, on the shelf; though diminished quality in pelagic waters was also resolved for the largest events
- PAV_m information is superior to ISPM for this important particle group, particularly in lacustrine systems
- a conceptual model for PAV_m behavior in the lake was presented

Mass-balance type model for sediment input, transport, and fate

—PAV_m based

Gelda, Effler, Prestigiacomo, Peng, and Watkins. 2015b. "Simulation of minerogenic particle populations in time and space in Cayuga Lake, New York, in response to runoff events", submitted to *Inland Waters*


April 5, 2005 CAYUGA LAKE view north from Ithaca photo by Bill Hecht

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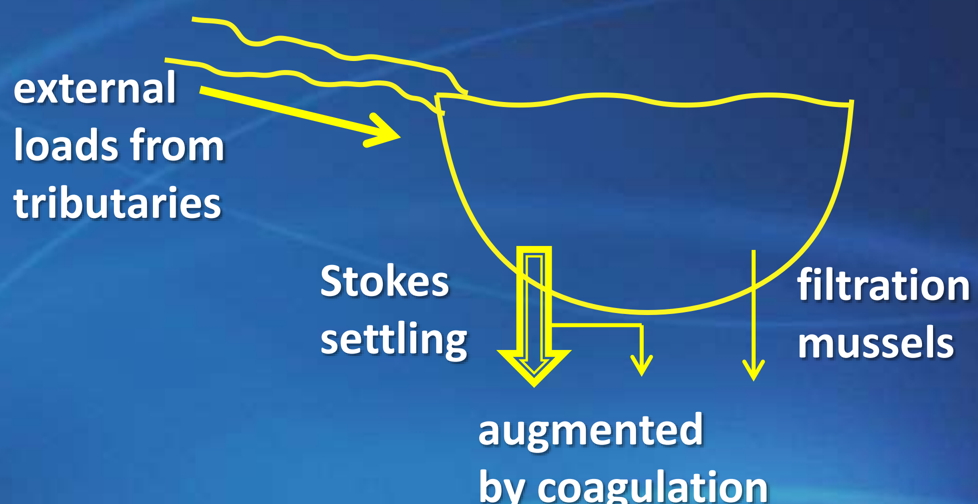
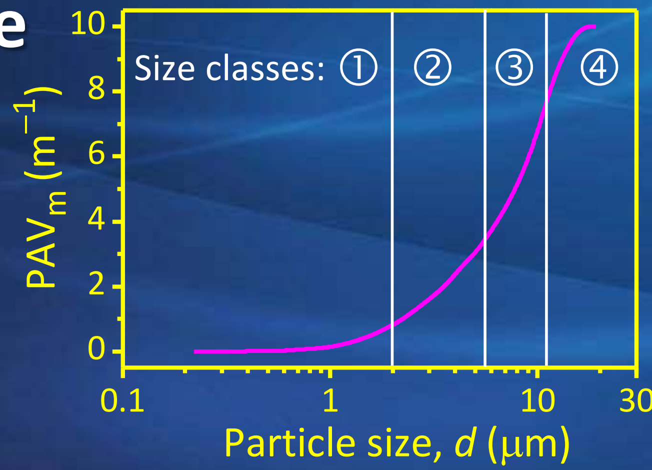
A first mechanistic mass balance type model for minerogenic particles in a lake

- drivers
  - ∗ demonstrate importance for multiple water quality metrics (T_n, PP_m, SD)—shelf vs. pelagic waters
  - ∗ value/implications for 'listing' of water quality issues—phosphorus and sediment
  - ∗ rich data sets of SAX–PAV_m measurements for lakes and tributaries

Conceptual model for PAV_m model

- model state variables—multiple size classes of PAV_m, $PAV_{m,n}$, $n = 4$
- sources and sinks





- size class contributions

$PAV_{m,4}$
$PAV_{m,3}$
$PAV_{m,2}$
$PAV_{m,1}$

$$\sum_{i=1}^{n} PAV_{m,i} = PAV_m$$

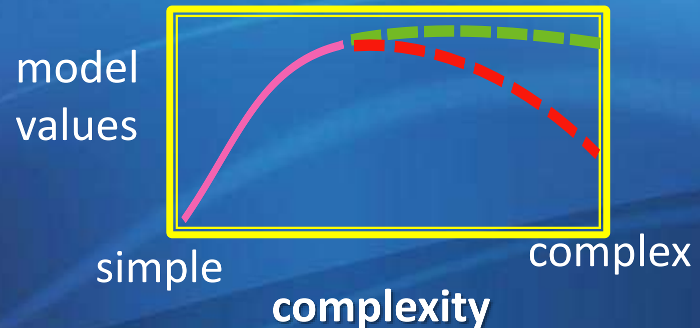
- parsimonious approach
  - complex feature, $PAV_{m,n}$, but necessary
  - simplifying, number of sink processes and size classes

Post runoff event: Shelf

April 5, 2005 CAYUGA LAKE view north from Ithaca photo by Bill Hecht

Parsimonious choices for PAV_m model structure: An appropriate approach

Model structural features	model complexity		
	simple	intermediate	complex
(1) particle size classes (*n*)	1	4	>> 4
(2) dimensions, transport submodel	1D	2D (W2/T)	3D
(3) aggregation	no	yes, simple M-M kinetics	yes, many coefficients
(4) filtration loss(es)	no	mussels, dry wt., survey	mussels, size classes, zooplankton
(5) internal production $CaCO_3$	no	specify from measurements	model kinetics, $CaCO_3$



* **intermediate choices made**

model values:

performance, management
utility, credibility

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Model loss processes for PAV$_m$: Three represented (1)–(3)

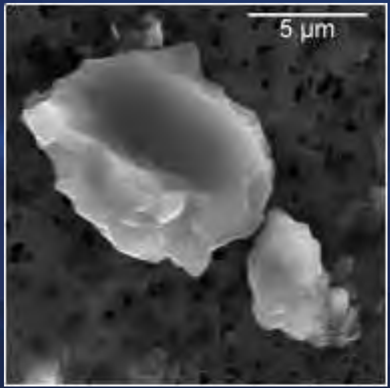
- **the summation of the effects of three loss processes, for 4 size classes**

$$S_i = \underset{(1)}{S_{i,\text{settling}}} + \underset{(2)}{S_{i,\text{aggregation}}} + \underset{(3)}{S_{i,\text{grazing}}}$$

- **setting loss of PAV$_{m,i}$ (1), projected area conc. of one of the size classes**

$$S_{i,\text{settling}} = -v_i \frac{\partial c_i}{\partial z}$$

v_i —settling velocity of the i^{th} size class
c_i —PAV$_m$ of the i^{th} size class
z—vertical dimension



- $$v_i = \frac{\alpha g(\rho_p - \rho_w)}{18\mu} d_i^2$$ **(Stokes' Law)**

a—shape factor (platelet) = 0.5
g—gravitational constant
ρ_p *and* ρ_w—densities, particles and water
d_i —particle diameter for i^{th} size
μ—water viscosity

Model representation of enhanced deposition from particle aggregation

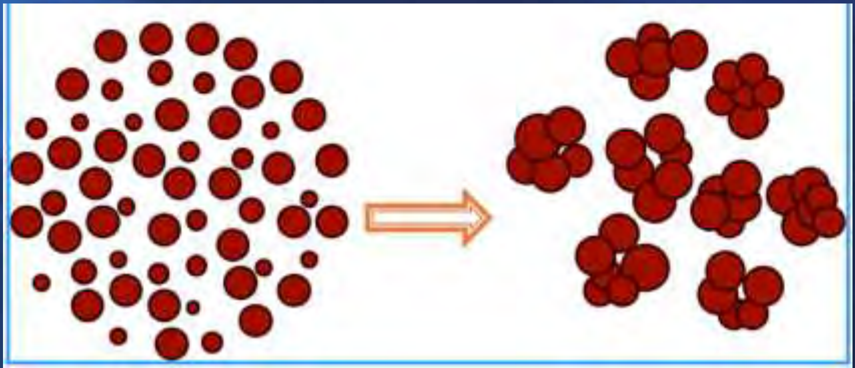
- **parsimonious approach—the three smallest of those size classes are subject to aggregation, through conversion to the largest, most rapidly settling size class**

for i = classes 1, 2, 3 $$S_{i,\text{aggregation}} = -k_{c,i}\left(\frac{c_i}{c_i + K}\right)c_i^2$$

for class 4 $$S_{4,\text{aggregation}} = \sum_{i=1}^{3} k_{c,i}\left(\frac{c_i}{c_i + K}\right)c_i^2$$

$k_{c,i}$ = 0.5 m·d^{-1}, aggregation rate constant for the i^{th} PAV$_m$ size class (i = 1, 2 and 3)
K = 0.05 m^{-1},Michaelis-Menten constant

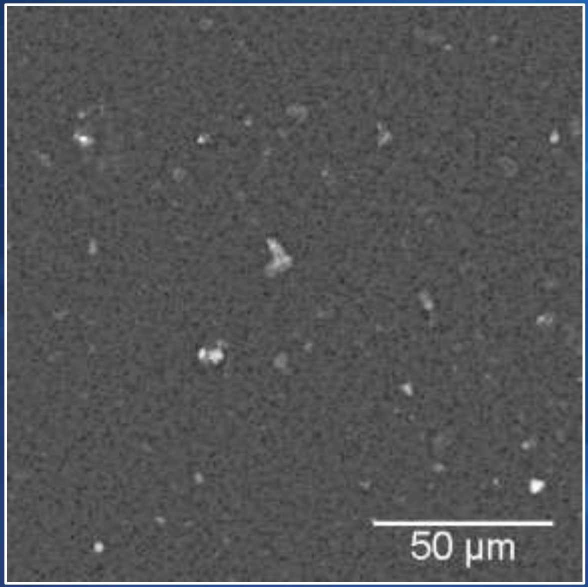
  - **positively dependent on particle concentrations, from increased collisions**



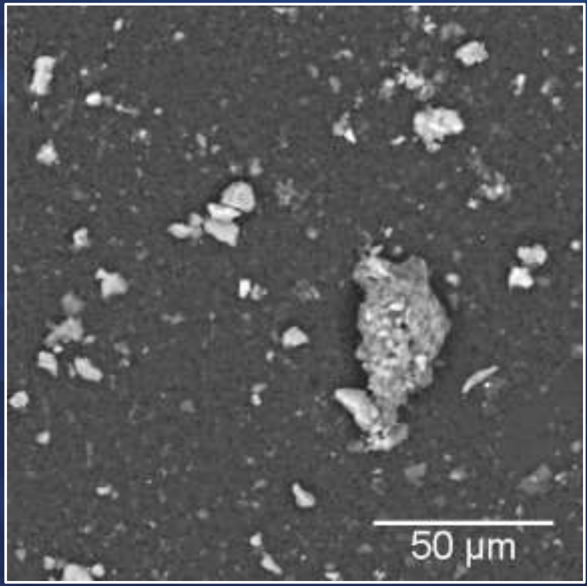
The aggregation process: SAX provides definitive supporting observations

- aggregates—multiple particle combinations
- defined by SAX observations
- advances beyond strictly model calibration support
- particle concentration dependence
  - low, dry weather
  - high, post runoff events

dry

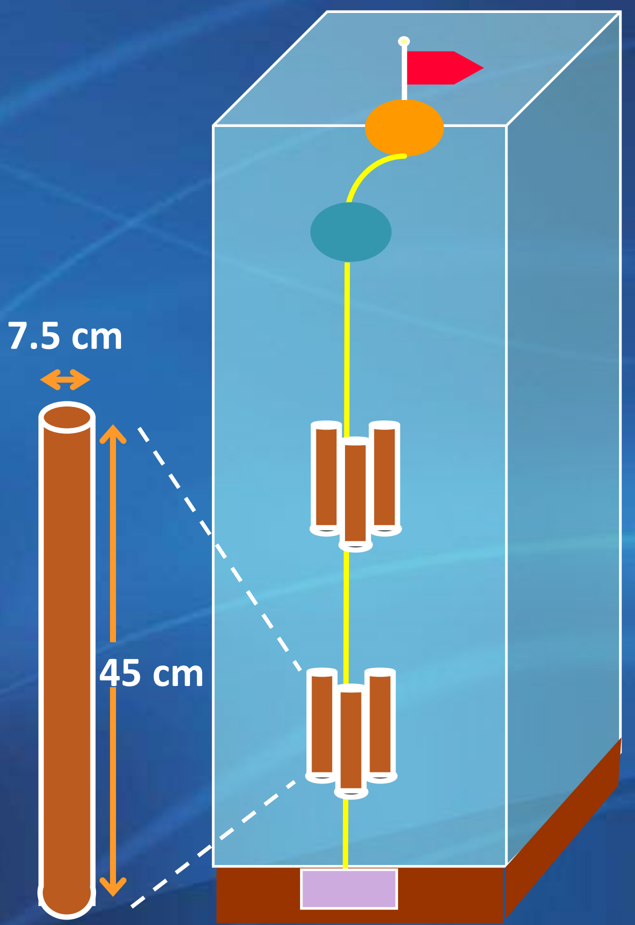


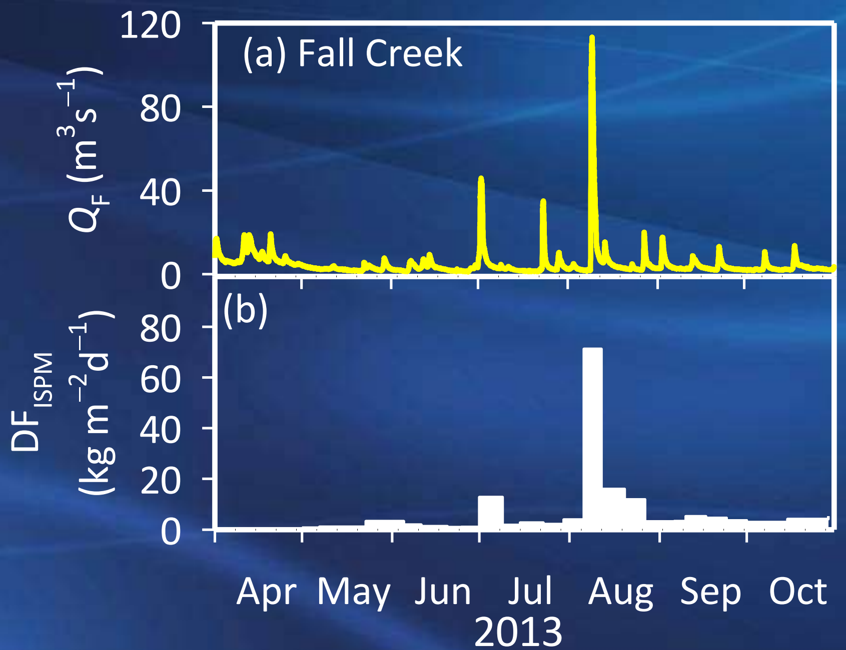
runoff event



Sediment traps: Support for testing model simulation of shelf deposition from runoff events

- trap design
  - —size, shape, DF (g m^{-2} d^{-1})





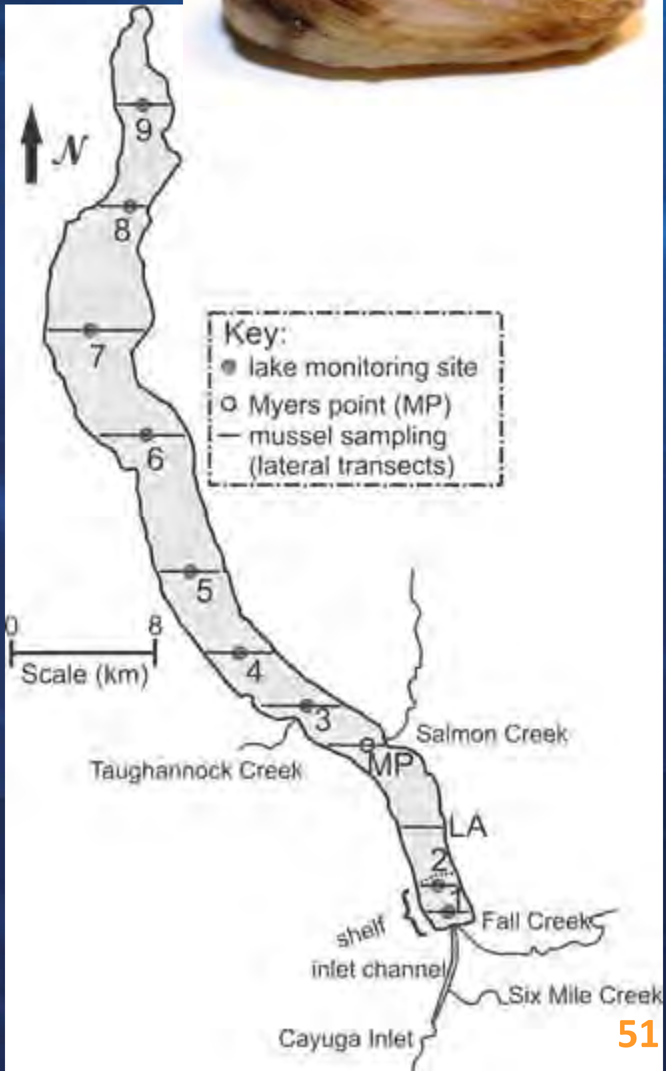
- conspicuous ISPM deposition signature from August event
- opportunity to support PAV_m model performance

PAV_m → particle volume deposited → mass (ISPM) deposited

↑ density

Filtration losses by dreissenid mussels: Supporting measurements

- benthic bivalves, non-selective filter feeders, including important minerogenic particle sizes
- invaded lake in mid-1990s zebra initially, guagga dominate now
- dense populations in 2013 survey (279 samples from 11 lateral transects) for pelagic waters (~85 gDW·m^{-2}), diminished on shelf (~9 gDW·m^{-2})
- potential for substantial impact on lake metabolism, including loss pathway for particles



Filtration losses by dreissenid mussels: Model representation

- **benthic areal filtration rates (k_f, $m^3 \cdot m^{-2} \cdot h^{-1}$)**

$$k_f = f_r M_a \theta^{(T-20)}$$

f_r —biomass-specific filtering rate ($m^3 \cdot gDW^{-1} \cdot h^{-1}$, at 20 °C); θ —T coefficient

M_a —areal biomass of quagga mussels ($gDW \cdot m^{-2}$), from surveys, according to model cell from interpolation process

- **sink term for PA_m, for i^{th} size class ($S_{i,grazing}$, $m \cdot s^{-1}$)**

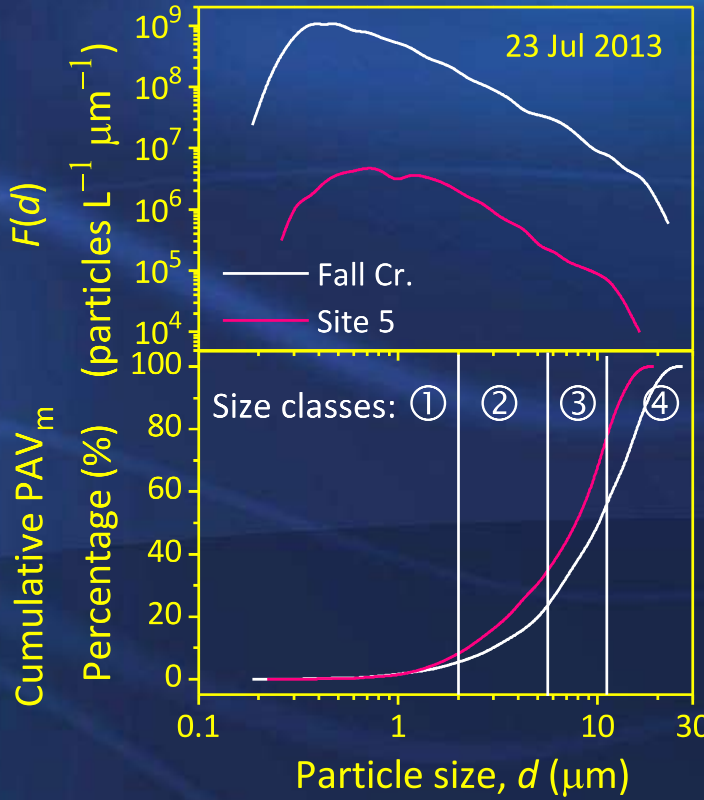
$$S_{i,\text{grazing}} = -k_f c_i \frac{A_{\text{sed}}}{V}$$

A_{sed} —sediment surface area (m^2)
V —computational cell volume (m^3)

- **potential grazing effect of mussel grazing large during high lake turbulence—effect limited otherwise from boundary layer effects**

A mass balance type model for PAV_m for Cayuga Lake (Gelda et al. 2015b)

- a necessary major advancement for addressing the effects of minerogenic particles, beyond being based on mass measurements (ISPM)
  - behavior of polydispersed (i.e., multiple size classes) particle populations cannot be represented by such a single state variable
- also, a necessary building block to support predictions of PP_m (PP associated with minerogenic particles)
  - ➢ PAV_m model has four size classes, guided by PSDs and contributions of the size classes to PAV_m



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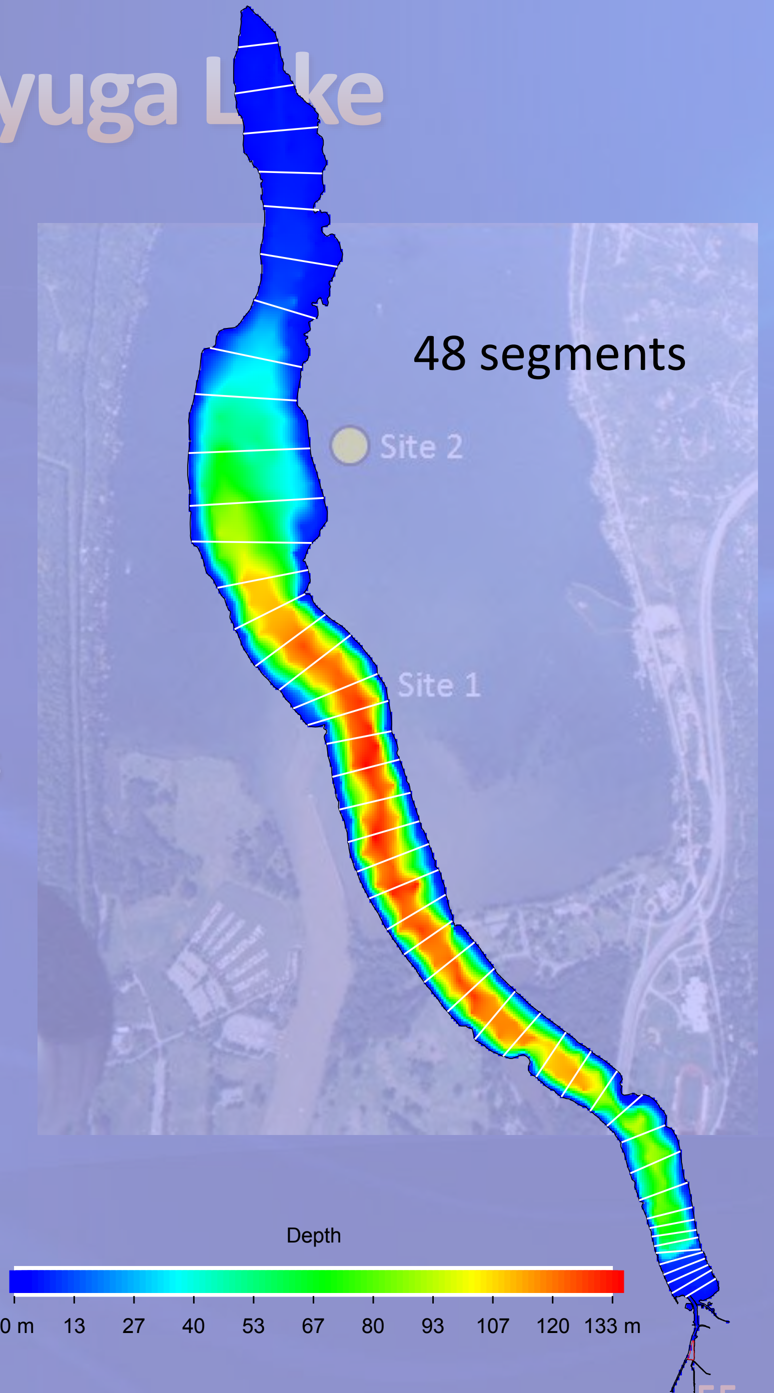
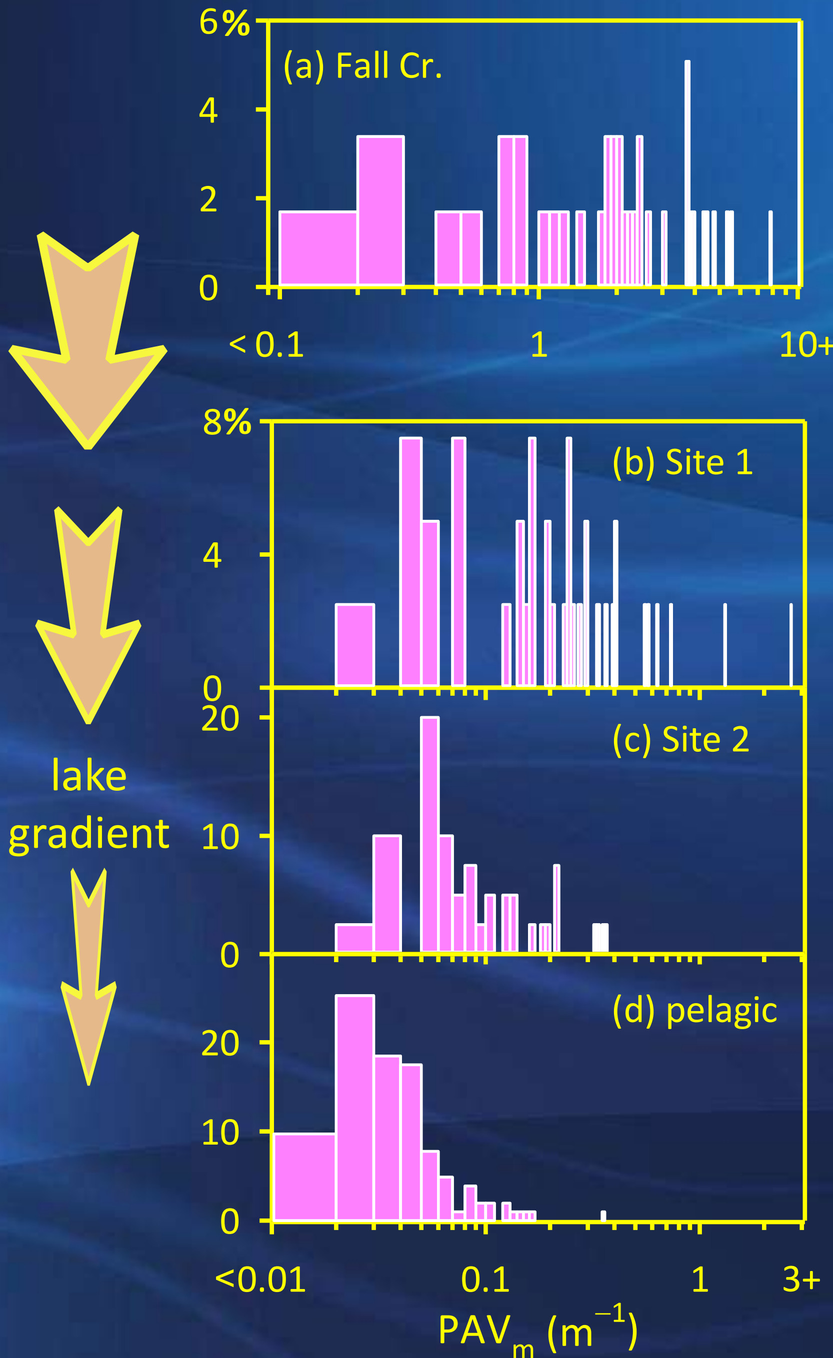
Performance targets for Cayuga Lake PAV$_m$ model

- higher PAV$_m$ levels on shelf compared with in pelagic waters in response to runoff events
- dependency of shelf response on magnitude of a runoff event
- extent of lake-wide effects from events
- increases in minerogenic particle deposition on the shelf from local inputs of the events
- independently validated two-dimensional (W2/T) serves as the hydrothermal/transport submodel (Gelda et al. 2015a)



Performance targets: Simulate distributions and patterns of PAV_m observations on the shelf and in Lake

- **narrowing of distributions**
- **decreases in central metrics**



PAV$_m$ model performance target: Historic shelf observations

- runoff events were not specifically targeted in LSC monitoring
- however, 16 events were in part encountered in that monitoring program for the shelf
  - features of the historic events in the table →

Table 2. Features of selected Fall Creek runoff events and subsequent PAV$_m$ monitoring observations for the shelf of Cayuga Lake, NY for the 2000–2013 period.

Event No.	Sampling Date	Peak Q_F (m^3/s)	Δt (hr)	PAV$_m$ (m^{-1})	T_n (NTU)
1	15-Jun-2000	41.6	74	1.01	1.3
2	28-Jun-2001	51.0	107	0.98	11.7
3	18-Apr-2002	35.1	84	0.90	4.4
4	16-May-2002	72.8	63	2.60	15.4
5	05-Jun-2003	34.3	94	0.60	2.2
6	06-May-2004	21.7	71	0.55	3.7
7	14-Apr-2005	175	272	0.95	7.2
8	29-Jun-2006	65.7	32	7.63	42.4
9	01-May-2007	15.5	120	0.28	2.9
10	16-Apr-2008	10.6	92	0.20	2.0
11	11-Aug-2009	17.7	7	0.08	2.2
12	20-Apr-2011	51.5	75	2.03	13.7
13	27-Apr-2011	38.2	89	4.47	18.8
14	03-Jul-2013	20.3	37	1.98	46.1
15	09-Aug-2013	113	12	86.02	374
16	12-Aug-2013	113	86	2.67	9.1

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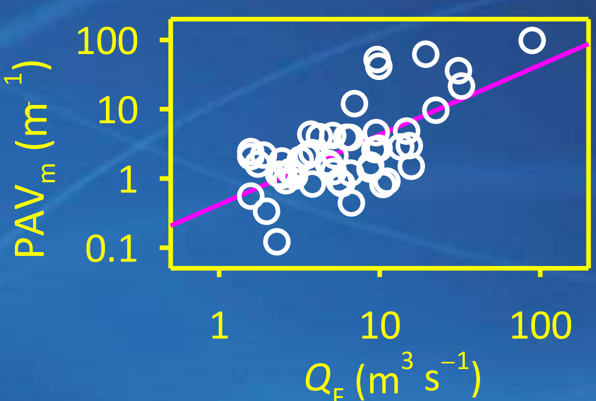
Good performance of PAV_m model for Cayuga Lake: General spatial patterns

- **predicted distributions for Sites 1, 2, and 3 in 2013 were generally similar to those formed from observations**
  - driving conditions: Fall Creek



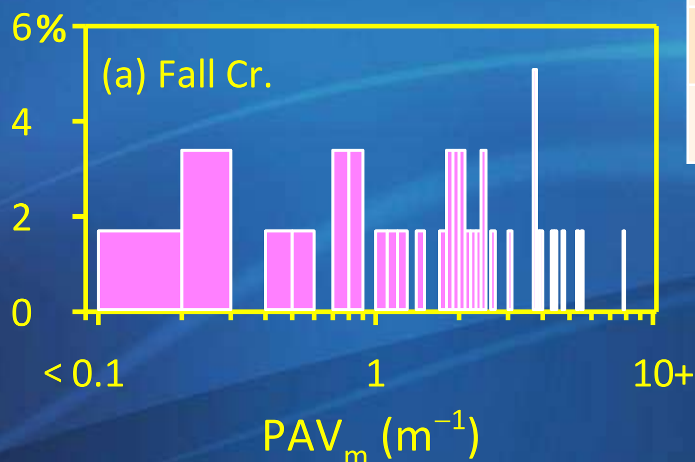
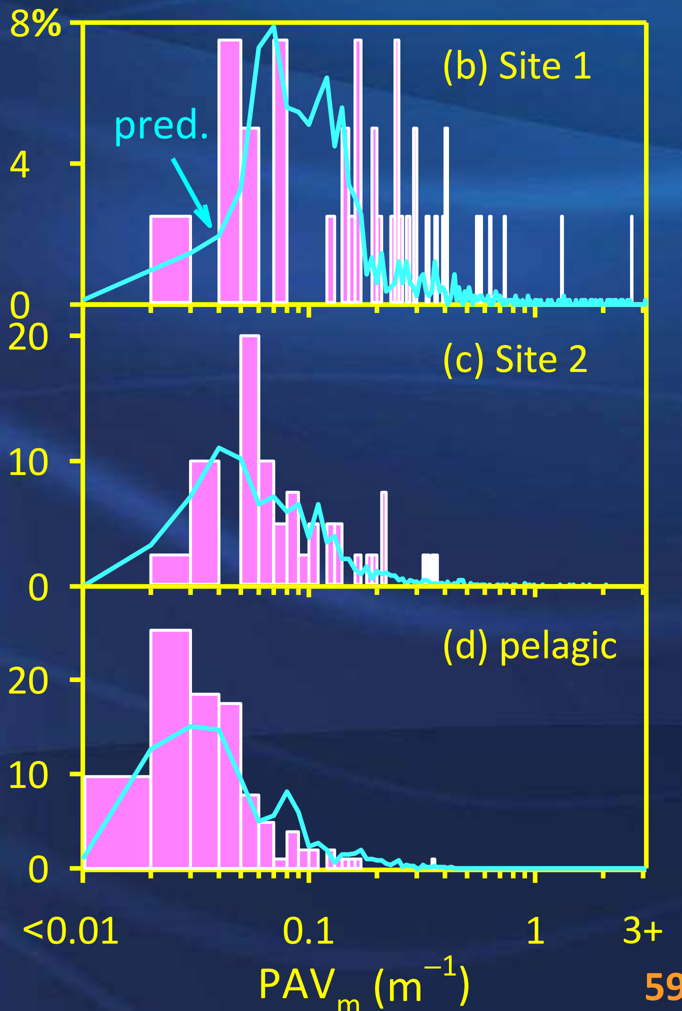
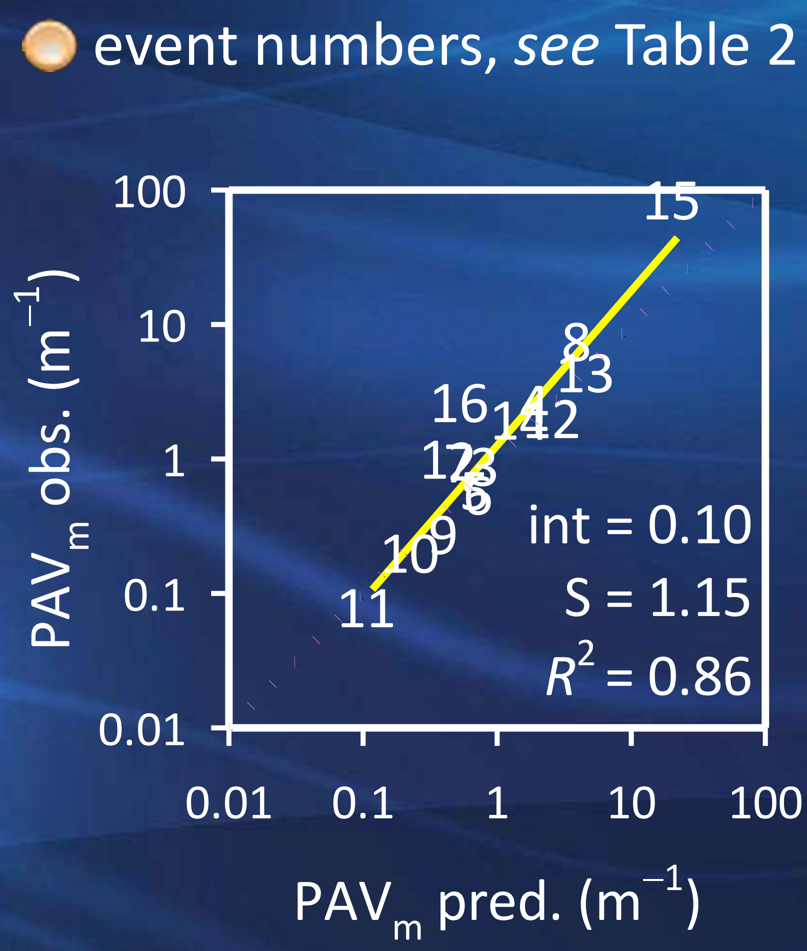


Fig. ID	n	med.	med_p
(a)	59	3.8	
(b)	40	0.24	**0.17**
(c)	40	0.08	**0.08**
(d)	102	0.04	**0.05**



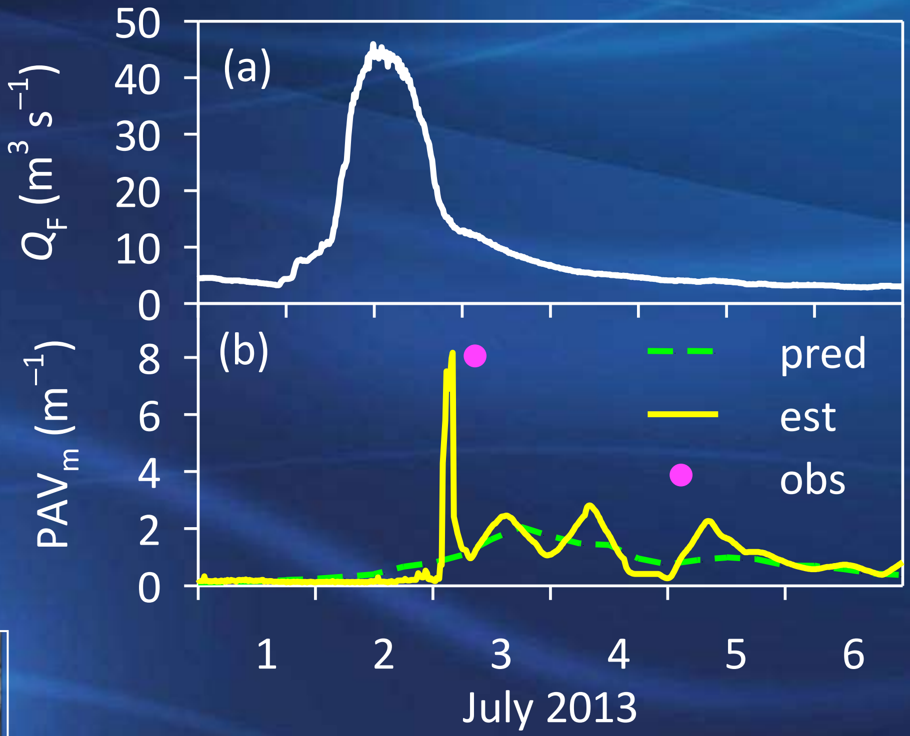
Good performance of PAV_m model for Cayuga Lake, shelf: Historic observations

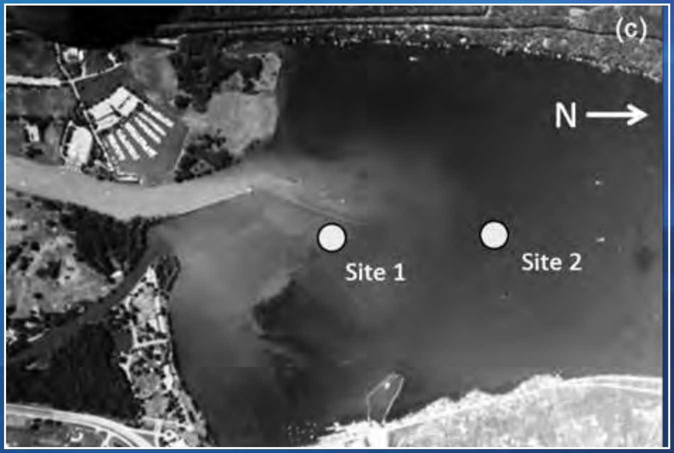
- **16 runoff events captured during LSC monitoring program for the shelf**
- **good performance across the wide range of events**



Good performance of PAV_m model for shelf for a July (2013) runoff event

- well defined major runoff event, early July
- model performed reasonably well for the subsequent interval
- variable short-term trajectories of turbid plumes for streams contribute to deviations
  - illustrated in aerial photo

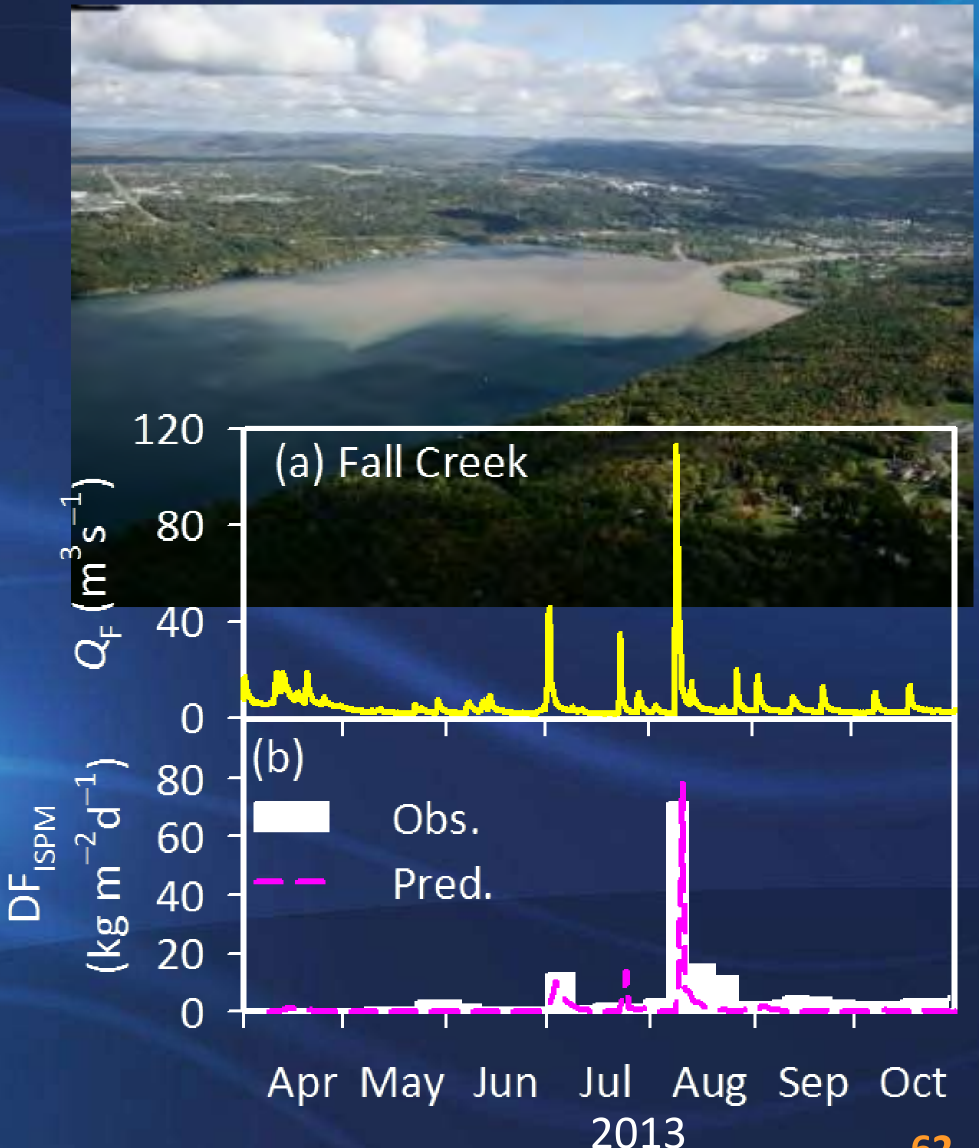




- lateral differences

Good PAV_m model performance for shelf—enhanced local deposition from runoff events

- comparisons of simulations of deposition of minerogenic particles to observations with sediment traps
  - observations and predictions were both elevated for the major runoff events
  - semi-quantitative support, given the variable operation and trajectories of the turbid shelf plumes



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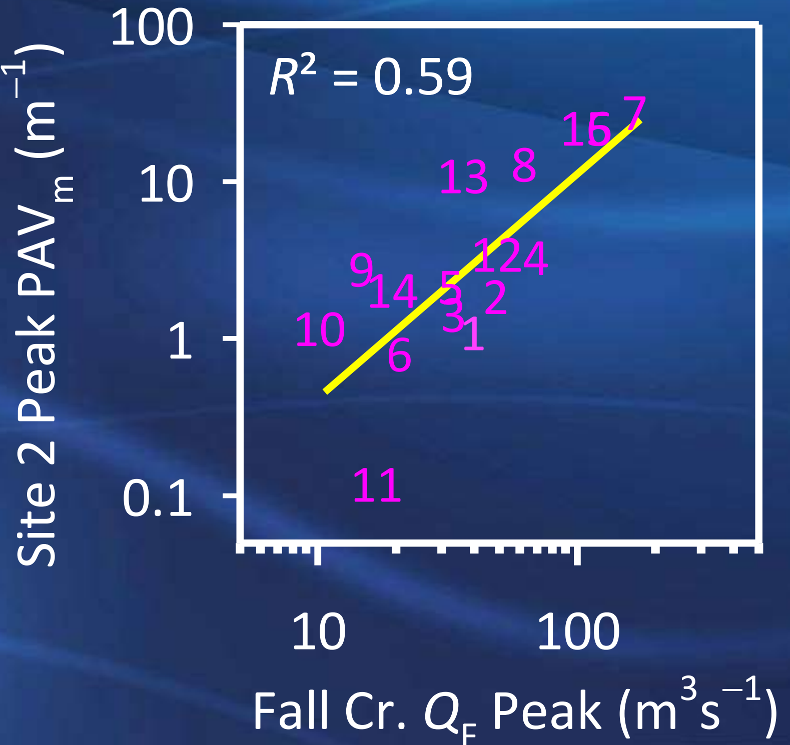
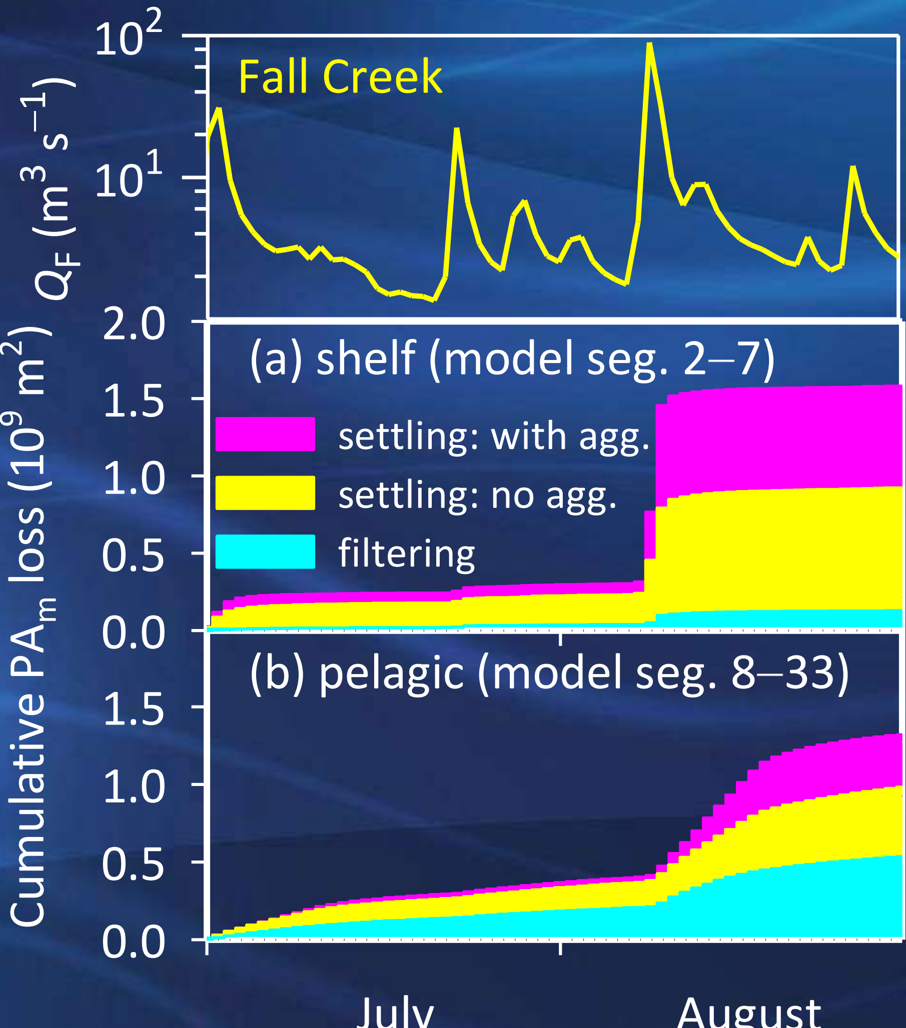
Application of the PAV_m model: Dependence of shelf response on runoff event magnitude

- Fall Creek peak Q_F for the earlier runoff events
- corresponding predicted peak PAV_m at Site 2 on shelf
- strong, positive dependency on event magnitude
- sources of variance—variations in ambient mixing, limitations in peak Q_F defining external loads



Application of the PAV_m model: Loss pathways for PAV_m for shelf vs. pelagic waters

- the dominance of runoff events, particularly in early Aug., in timing of loads and losses
- mussel filtration minor (maybe less) on shelf, but more important in pelagic waters
- abrupt and large short-term minerogenic sediment losses on shelf (i.e., more than lake-wide)
- aggregation process(es) contributes importantly to overall settling (or deposition) losses



Application of the PAV_m model: Predictions of related water quality attributes, PAV_m and Chl-*a* contributions

- **predictions of spatial differences in the contributions of minerogenic vs. organic (phyto.)**
- **water quality attributes**
  - ∗ b_p—overall scattering coefficient, related to Secchi depth
  - ∗ b_{bp}—backscattering coefficient, related to remote sensing
  - ∗ T_n—turbidity
  - ∗ $PP_{m/u}$ —unavailable minerogenic particulate P
- **summations; e.g., $PP = PP_{m/u} + PP_o$**

Table 3. Equations to estimate the contributions of PAV_m-based minerogenic vs. Chl-*a*-based organic particles to bulk water quality metrics in Cayuga Lake, NY, 2013.

Equations	Reference
b_p(660)	
$b_m = 2.34 \times PAV_m$	Peng and Effler 2015
$b_o = 0.267[\text{Chl-}a]^{0.6}$	Huot et al., 2008
b_{bp}(660)	
$b_{b,m} = 0.063 \times PAV_m$	Peng and Effler 2015
$b_{b,o} = 0.0017[\text{Chl-}a]^{0.618}$	Huot et al., 2008
T_n	
$T_{n/m} = 4.8 \times PAV_m$ $T_{n/o} = 0.08[\text{Chl-}a]$	Effler et al., 2014
PP	
$PP_{m/u} = 7.1 \times PAV_m$ $PP_o = 1.53[\text{Chl-}a]$	Effler et al., 2014

Application of the PAV$_m$ model: Predictions of spatial differences in dependent water quality attributes

- means, medians, and ranges for Sites 1, 2, 3
  - four differences between minerogenic and organic components

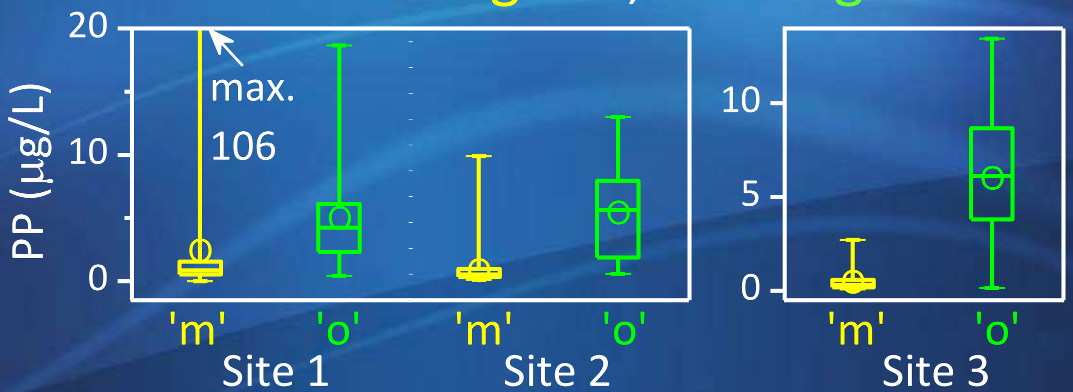
(1) spatially uniform organic

(2) greater minerogenic particle effects on shelf

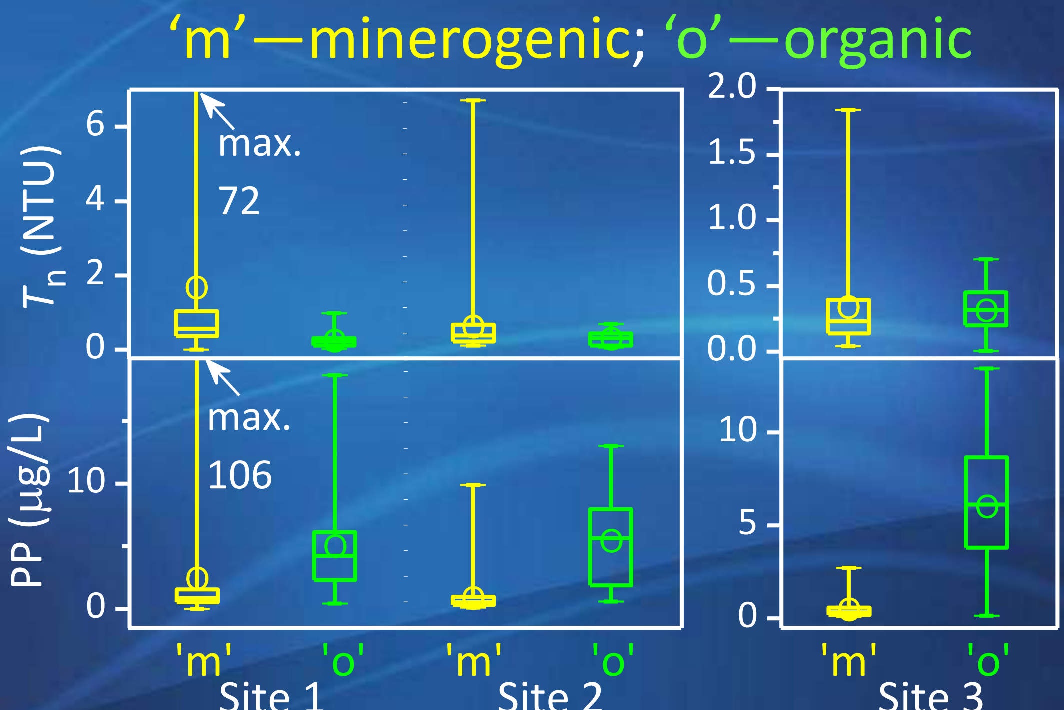
(3) extreme degradations on shelf associated with runoff events

(4) metric-based differences in relative effects of minerogenic particles

‘m’—minerogenic; ‘o’—organic



Application of the PAV$_m$ model: Predictions of spatial differences in dependent water quality attributes



- means, medians, and ranges for Sites 1, 2, 3
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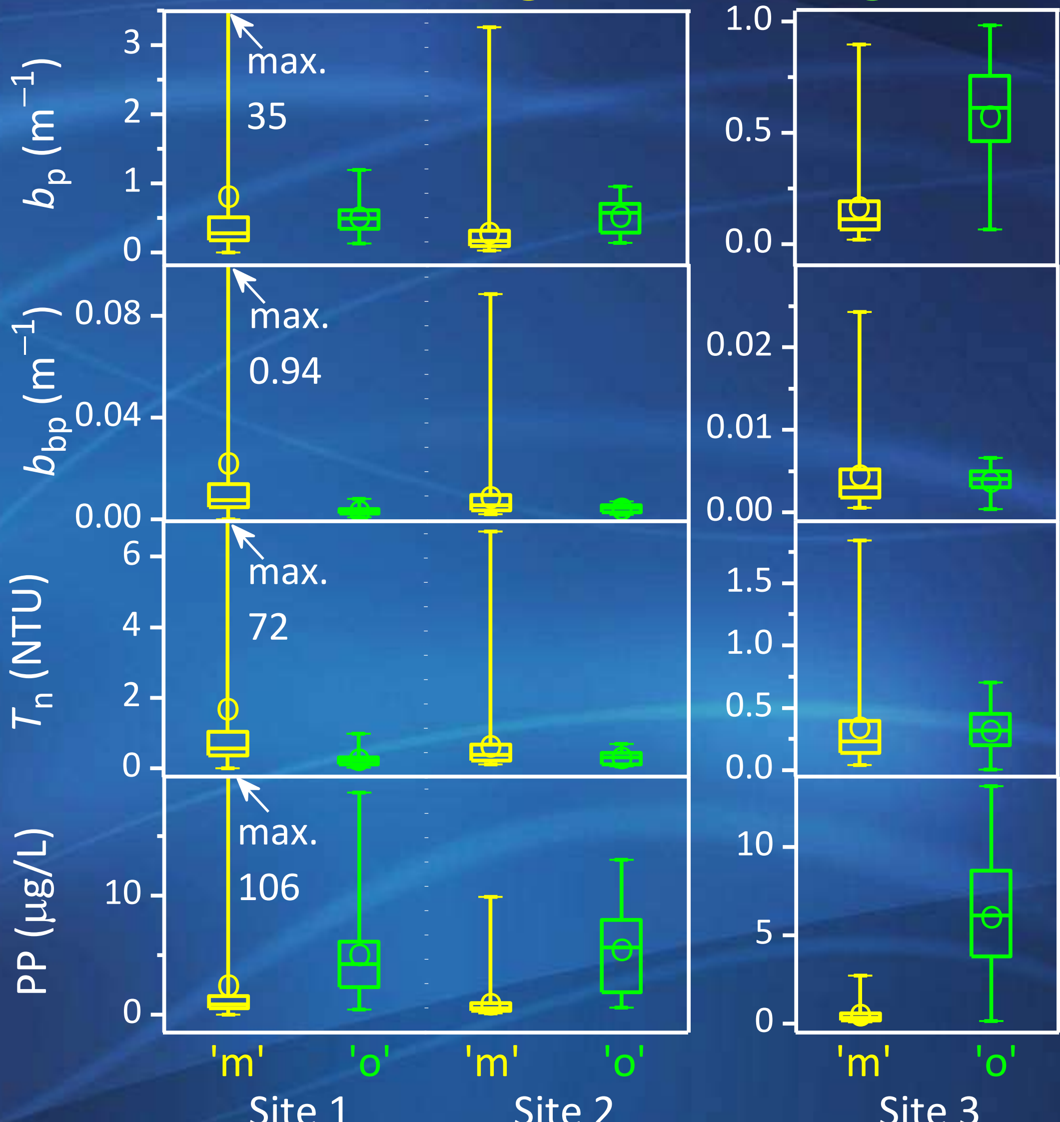
Application of the PAV$_m$ model: Predictions of spatial differences in dependent water quality attributes

'm'—minerogenic; 'o'—organic



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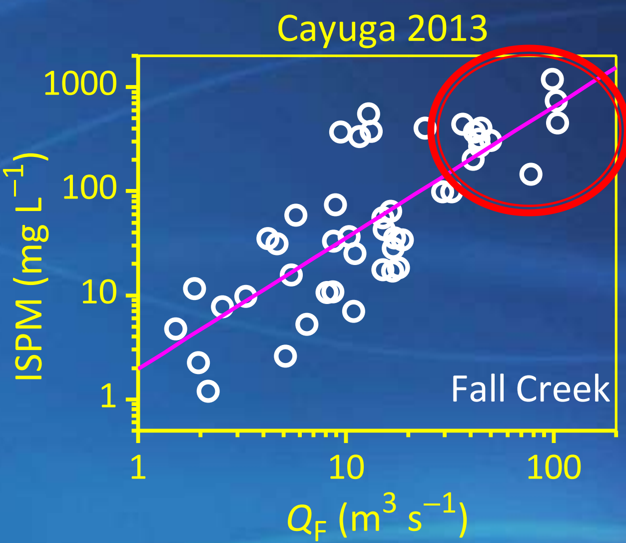
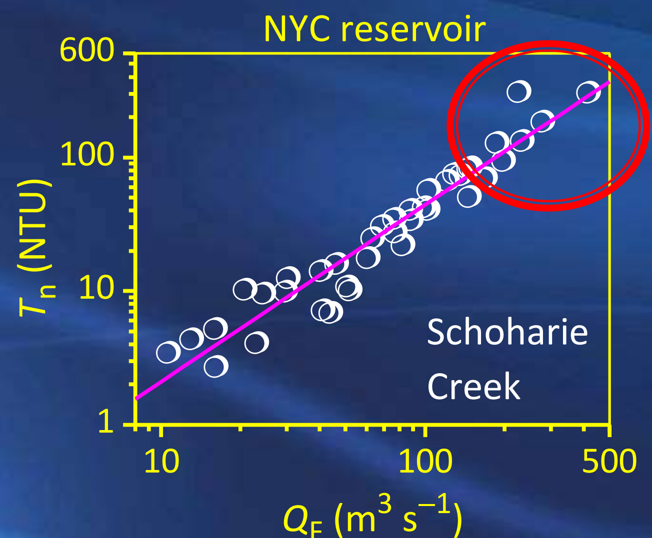
(4) metric-based differences in relative effects of minerogenic particles

Potential applications: Climate change and expectations for future sediment loading

- observations for the Cayuga Lake system and elsewhere demonstrate the positive dependence of sediment loading on stream flow (Q_F)





- systematic increases expected in response to predicted climate change in this region, increases in occurrence and severity of runoff events (NOAA, 2013)
- in-lake impacts from increased sediment loading and in-lake PAV_m could be pursued with the model

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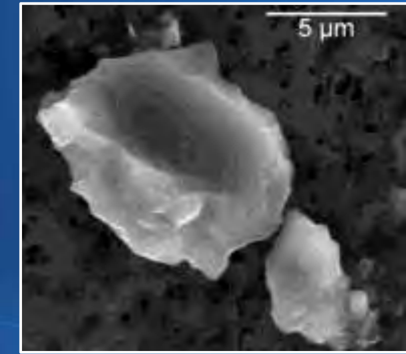
Summary: Mass balance type model for PAV_m for Cayuga Lake

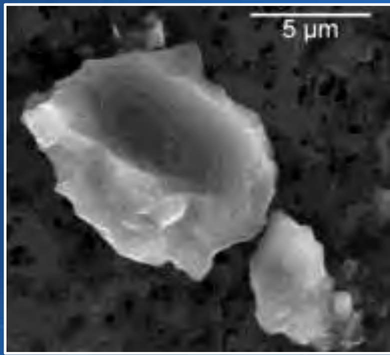


See Abstract:

Gelda, Effler, Prestigiacomo, Peng, and Watkins. 2015b. "Simulation of minerogenic particle populations in time and space in Cayuga Lake, New York, in response to runoff events", submitted to *Inland Waters*

- mass balance type model for PAV_m, partitioned into four size class contributions, has been developed and successfully tested for Cayuga Lake
- supported by long-term monitoring of PAV_m in the lake, shorter-term for the tributaries
- sources of PAV_m—inputs from tributaries, primarily during runoff events
- sink processes (n = 3) represented: (1) settling, (2) enhancement from aggregation, and (3) grazing by mussels

Summary: Mass balance type model for PAV_m for Cayuga Lake



- localized external loads of minerogenic sediment and increases from runoff events were well simulated, including:
  1) higher PAV_m levels on the shelf following events
  2) positive dependence of the shelf increases on magnitude of the event
  3) shelf deposition predictions consistent with sediment trap observations
- settling/aggregation losses large for PAV_m on the shelf for major runoff events
- protocols to use PAV_m predictions to quantify the important effects of these particles on optical and P water quality metrics, particularly for the shelf, are demonstrated