Scope of Work for: Cayuga Lake Study to Support a Phosphorus TMDL*

modified from Cayuga Lake
QAPP Workshop (Jan 30, 2013)

Cornell University

Project Phasing

Phase 1 (2013 – 2014)

- lake monitoring
- stream monitoring
- bioavailability studies
- limnological analyses
- mass balance analyses
- biological community characterizations
- lake hydrothermal model setup and testing
- watershed model testing
- report summarizing study findings
- recommendations for Phase 2 water quality model

Phase 2 (≥ 2015)

- in-lake water quality model development
- in-lake water quality model testing

Field Water Quality Measurements

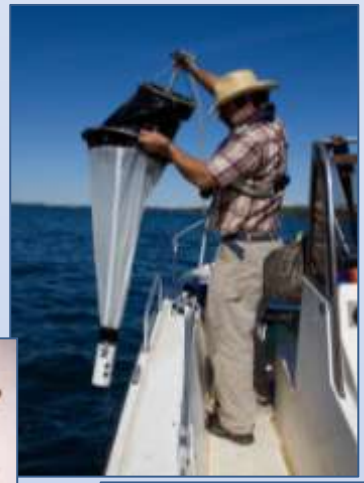
- rapid profiling instruments
- Secchi disc measurements
- stream sonde measurements

Sampling and Laboratory Analysis

stream and lake samples

Biological Sampling

- phytoplankton sampling
- zooplankton sampling
- dreissenid mussel sampling

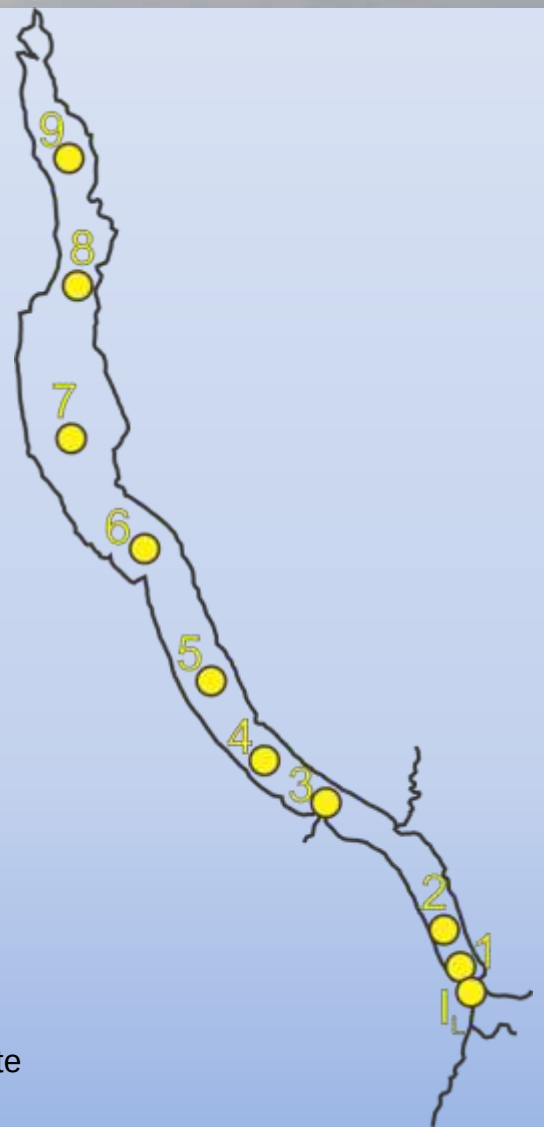


In-Lake Sampling

Whole Lake Monitoring Sites

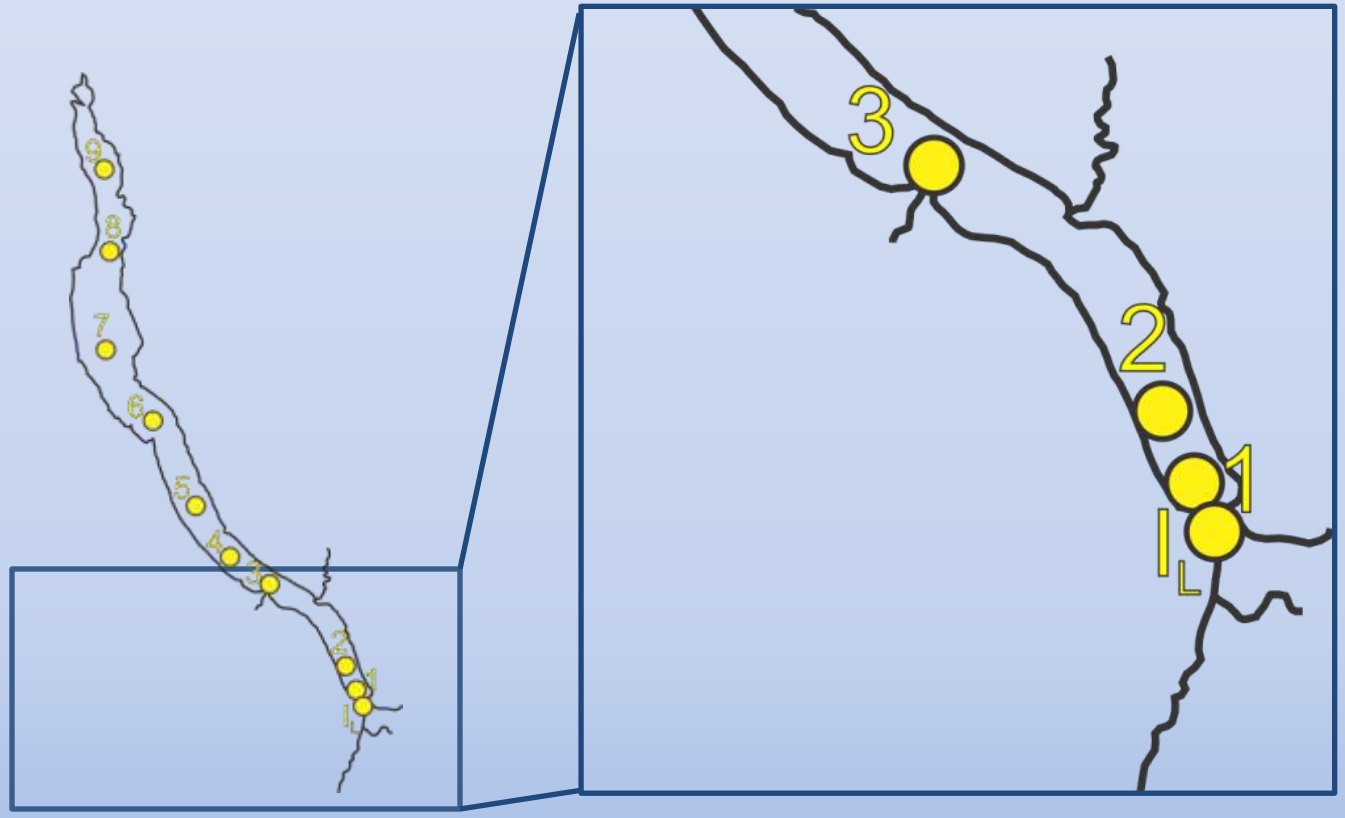
- 9 in-lake sites
- 1 site in inlet near mouth
- 2 times per month, April-October

- field measurements
- water collection
- phytoplankton sampling
- zooplankton sampling



More Frequent South Monitoring Sites

- field measurements
- water collection (less parameters)

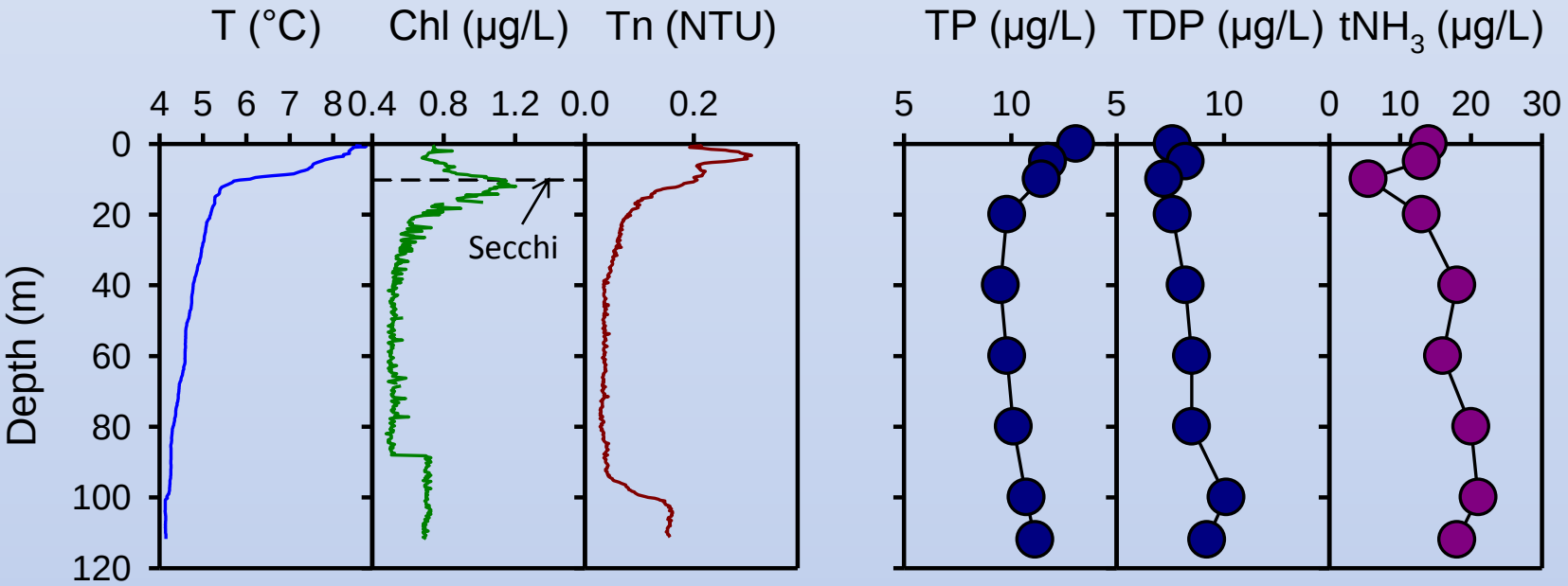


In-Lake Instrumentation Measurements

No.	Parameter	Abbrev.	Utility
1	temperature	T	thermal stratification, important model input
2	specific conductance	SC	conservative tracer
3	field beam attenuation coefficient	$\mathbf{C}_{660_f}$	surrogate of Tn, light scattering coefficient and TSS
4	field turbidity	Tn_f	surrogate of “sediment” (e.g., suspended particulate material (SPM)), and light scattering coefficient
5	field chlorophyll a	Chl_f	trophic metric, proxy for phytoplankton biomass
6	scalar irradiance	PAR	light penetration

In-Lake Instrumentation Measurements

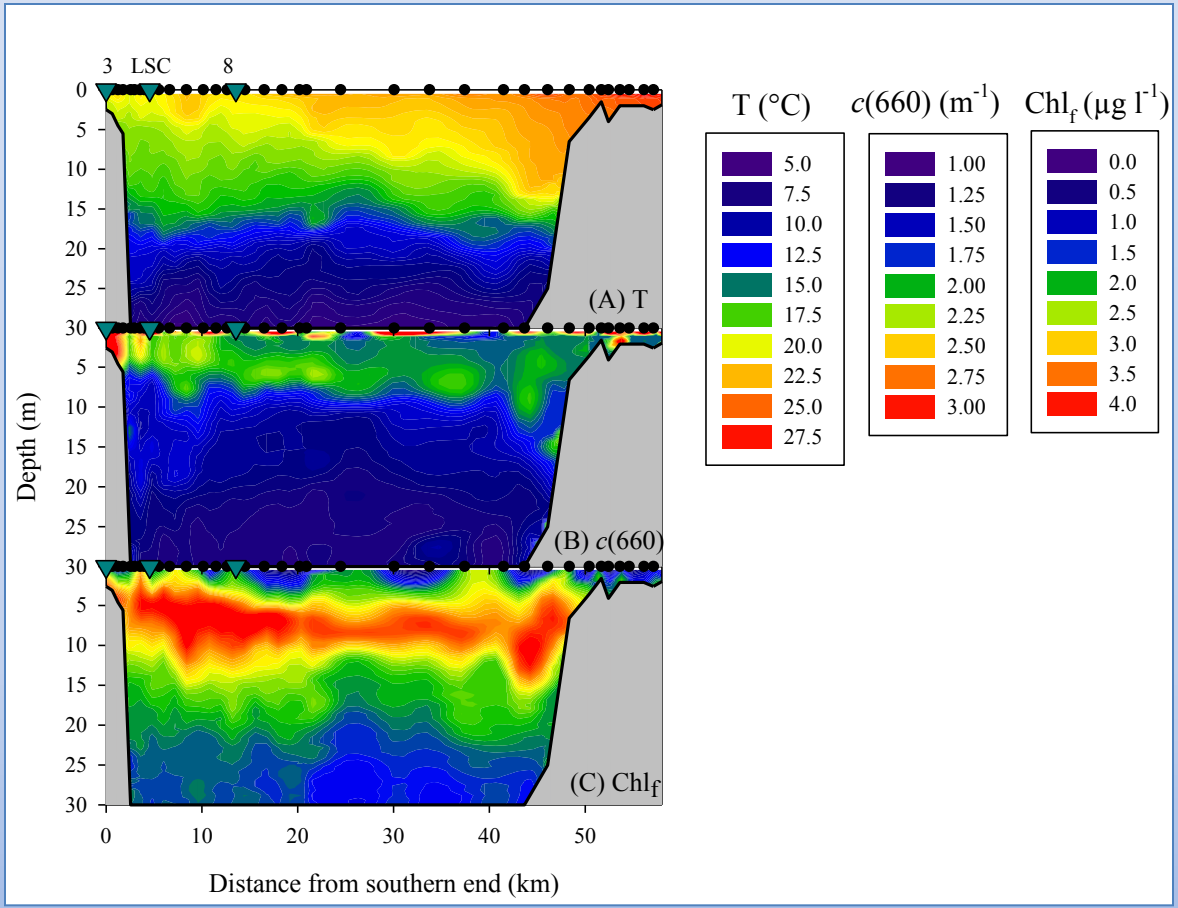
- example data from Site 5 on May 7



  - delivered within 48 h of collection to interested stakeholders

Multiple Site Profiles Can Support Spatial Contour Representations

Earlier example from 1996 survey



Laboratory Measurements on Lake Samples

phosphorus (P)

No.	Parameter	Abbrev.	Utility
1	total phosphorus	TP	trophic state metric, liming nutrient, quantifies the P pool
2	total dissolved phosphorus	TDP	available nutrient for phytoplankton
3	soluble reactive phosphorus	SRP	immediately available nutrient for phytoplankton growth
4	total inorganic phosphorus	TIP	inorganic phosphorus measured to calculate other pools of phosphorus

Laboratory Measurements on Lake Samples

nitrogen (N)

No.	Parameter	Abbrev.	Utility
5	nitrate + nitrite	NO_X	used along with NO_2 to calculate NO_3 a phytoplankton nutrient
6	nitrite	NO_2	used along with NO_X to calculate NO_3 a phytoplankton nutrient
7	total ammonia	t-NH_3	phytoplankton nutrient
8	total nitrogen	TN	quantifies the overall N pool
9	total dissolved nitrogen	TDN	quantifies the overall dissolved N pool

Laboratory Measurements on Lake Samples

carbon/phytoplankton

No.	Parameter	Abbrev.	Utility
10	dissolved organic carbon	DOC	quantify dissolved organic C pool
11	particulate organic carbon	POC	representation of phytoplankton biomass
12	chlorophyll **a**	Chl	trophic metric, proxy for phytoplankton biomass
13	silica	DRSi	phytoplankton nutrient (diatoms)
14	light attenuation at a wavelength of 254 nm	UV_{254}	surrogate of precursors for disinfection by-product

Laboratory Measurements on Lake Samples

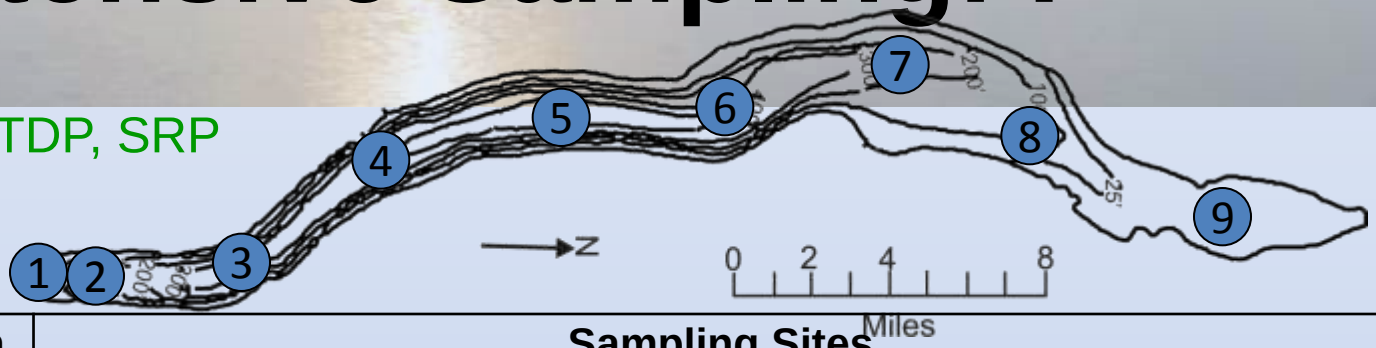
clarity/tracer

No.	Parameter	Abbrev.	Purpose
15	turbidity	Tn	surrogate of “sediment” (e.g. suspended particulate material (SPM)) and the light scatting coefficient
16	beam attenuation coefficient	$\mathbf{c}_{660}$	surrogate of Tn, light scattering coefficient and TSS
17	total suspended solids	TSS	gravimetric measure of total sediments
18	fixed suspended solids	FSS	gravimetric measure of inorganic sediment
19	projected area per unit volume	PAV_m	inorganic particles contribution to turbidity
20	chloride	Cl	tracer

Intensive Sampling: P

X = TP, TDP, SRP

O = TIP



Features

April – Oct (1 year)

bi-weekly (13 trips)

9 sites

Depth (m)	Sampling Sites								
	1	2	3	4	5	6	7	8	9
0	X, O	X, O	X, O	X, O	XXX, OOO	X, O	X, O	X, O	X, O
5			X	X	X	X	X	X	
10			X, O	X, O	X, O	X, O	X, O	X, O	
20			X		X				
40			X		X				
60			X	X	X	X			
80			X		X				
100				X	X	X			
120					X				
bottom					X				

Less Intensive Sampling

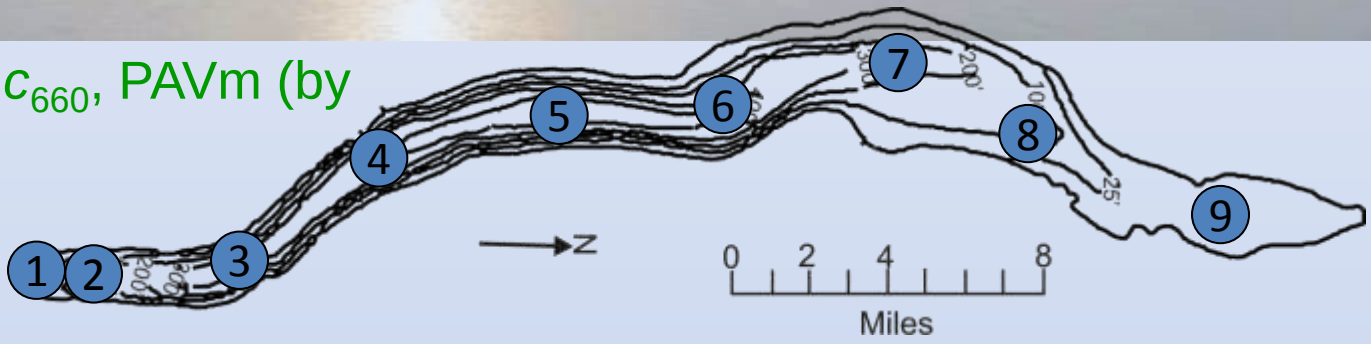
X = TDN, TN, Tn, c_{660}, PAVm (by SAX)

Features

April – Oct (1year)

bi-weekly (13 trips)

9 sites



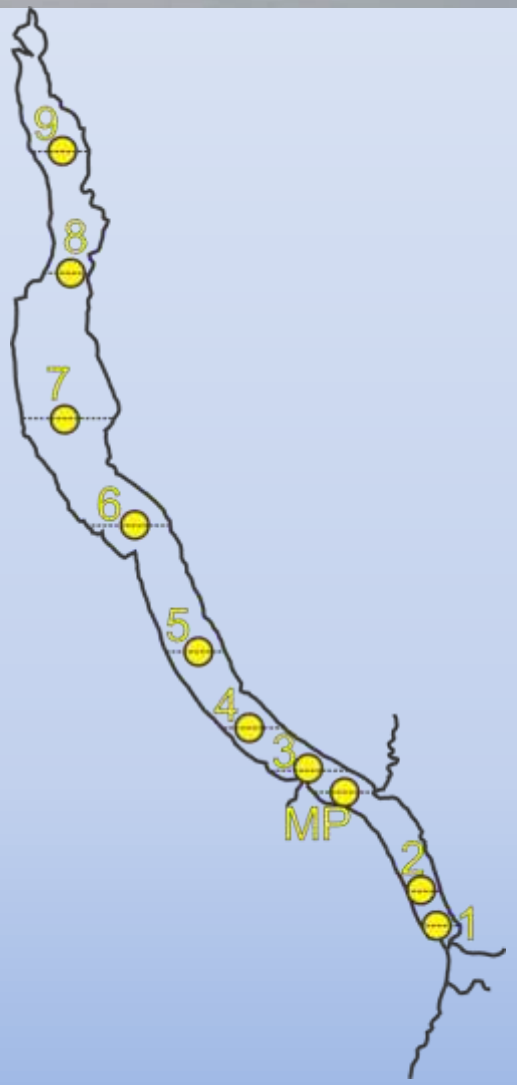
Depth (m)	Sampling Sites								
	1	2	3	4	5	6	7	8	9
0	X	X	X		XXX		X		X
5									
10									
20									
40									
60									
80									
100									
120									
bottom									

Whole Lake
Dreissenid Mussel Sampling Sites

- 100 in-lake sites
- positioned along 10 transects

Zebra Mussel
(*Dreissena polymorpha*)

Quagga Mussels
(*Dreissenia rostriformis bugensis)*

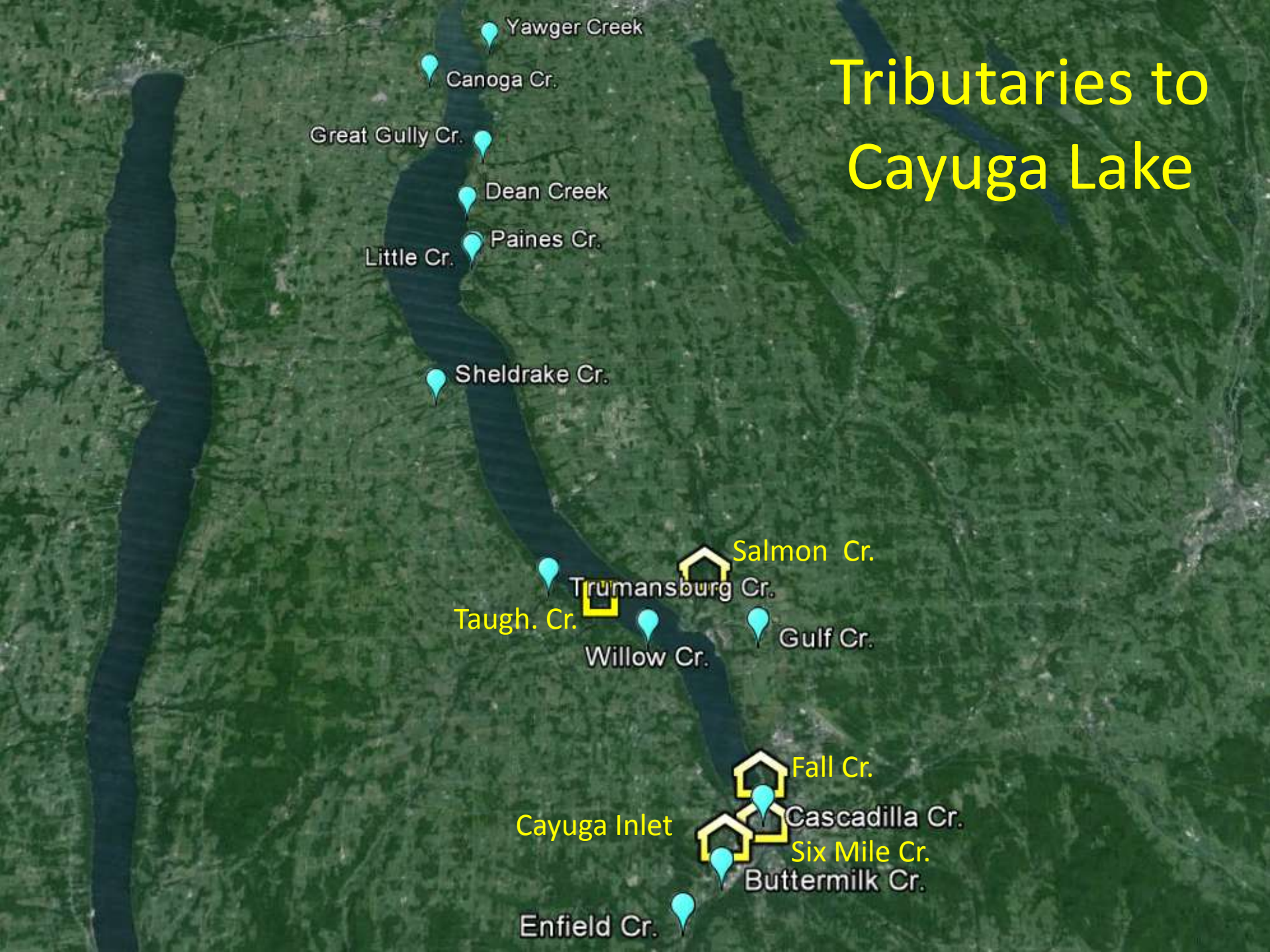


Biological Monitoring

- phytoplankton – Professor N. Hairston's lab
  - collections: epilimnion samples – 5 sites, below thermocline – 3 sites; duplicates
  - preserved
  - subset analyzed, guided by chl *a* data
- zooplankton – Professor N. Hairston's lab
  - collections at same sites as phytoplankton, vertical hauls
  - preserved
  - subset analyzed
- dreissenid mussles – J. Watkins and L. Rudstam
  - Watkins et al. (2012) surveys, 2006
  - lake-wide benthic survey, 2013
  - laboratory excretion rate experiments

Stream Sampling

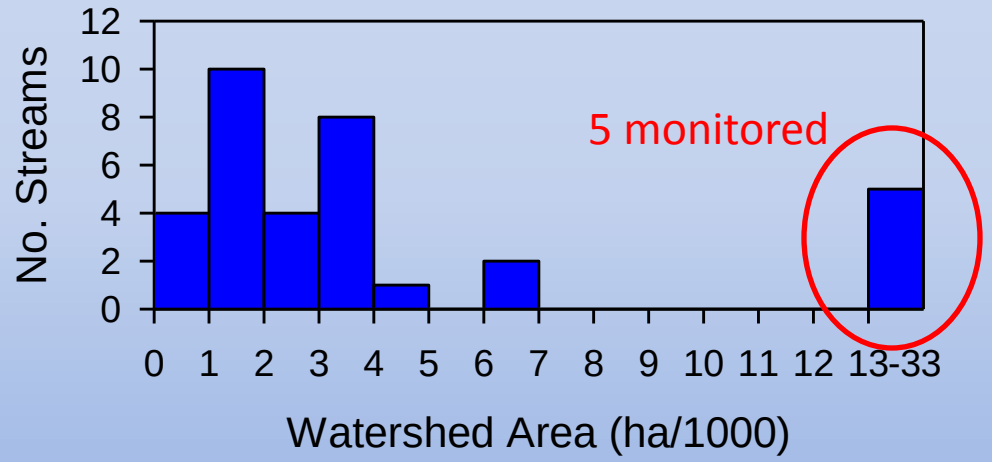
5 streams


Tributaries to Cayuga Lake
Yawger Creek
Canoga Cr.
Great Gully Cr.
Dean Creek
Paines Cr.
Little Cr.
Sheldrake Cr.
Salmon Cr.
Trumansburg Cr.
Taugh. Cr.
Willow Cr.
Gulf Cr.
Fall Cr.
Cascadilla Cr.
Cayuga Inlet
Six Mile Cr.
Buttermilk Cr.
Enfield Cr.

The Selection of Five Streams

Selected Streams	WS Area Rank	Event Based Sampling	Gaged
Fall Cr.	1	✓	✓
Cayuga Inlet	2	✓	✓
Salmon Cr.	3	✓	✓
Six Mile Cr.	5	✓	✓
Taughannock Cr.	4		

- fractions of total watershed monitored
  - 5 streams – 60%
  - 4 streams (event based) – 50%

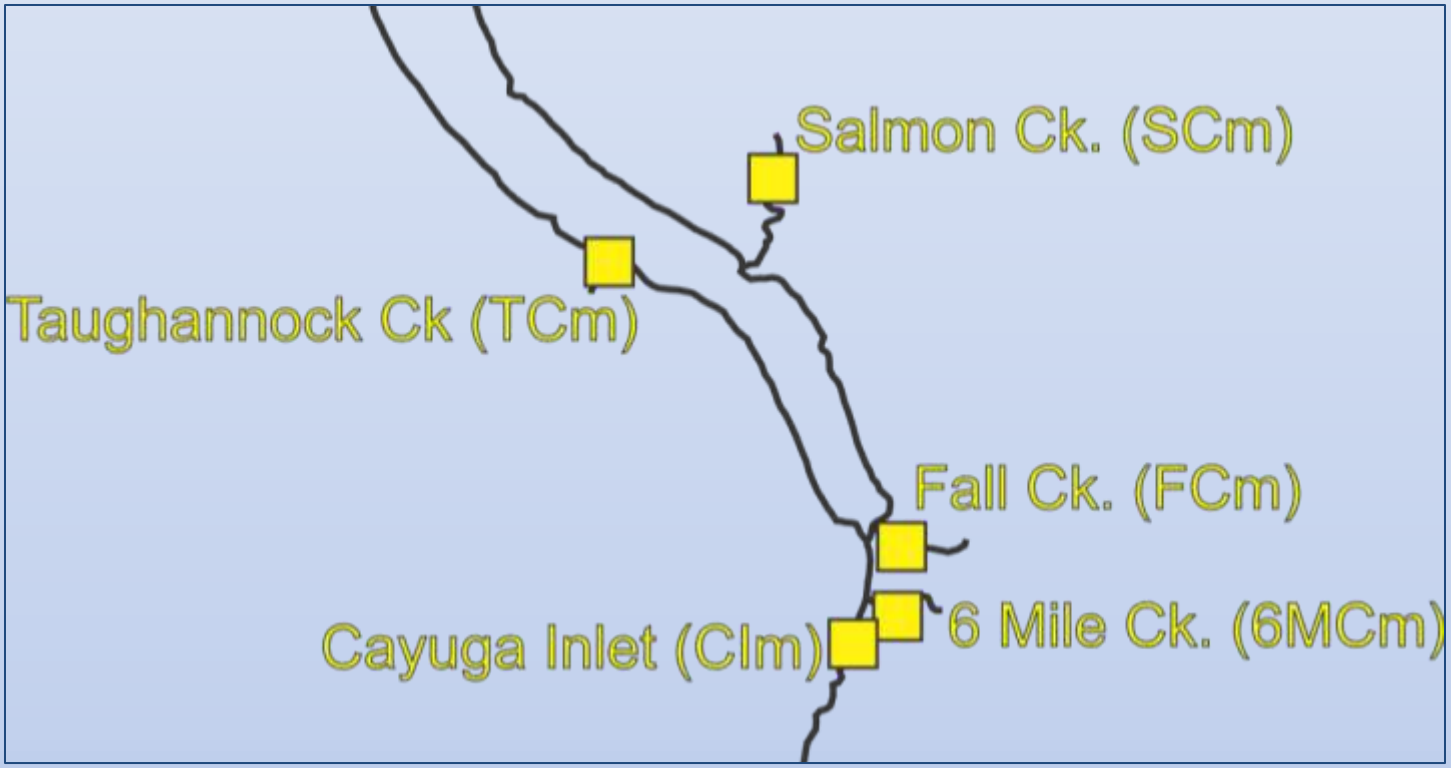


- 34 separate watersheds
- threshold for inclusion of 5 for reasonable program scope self-evident
- consistent with TMDL focus on shelf

Stream Sampling Types

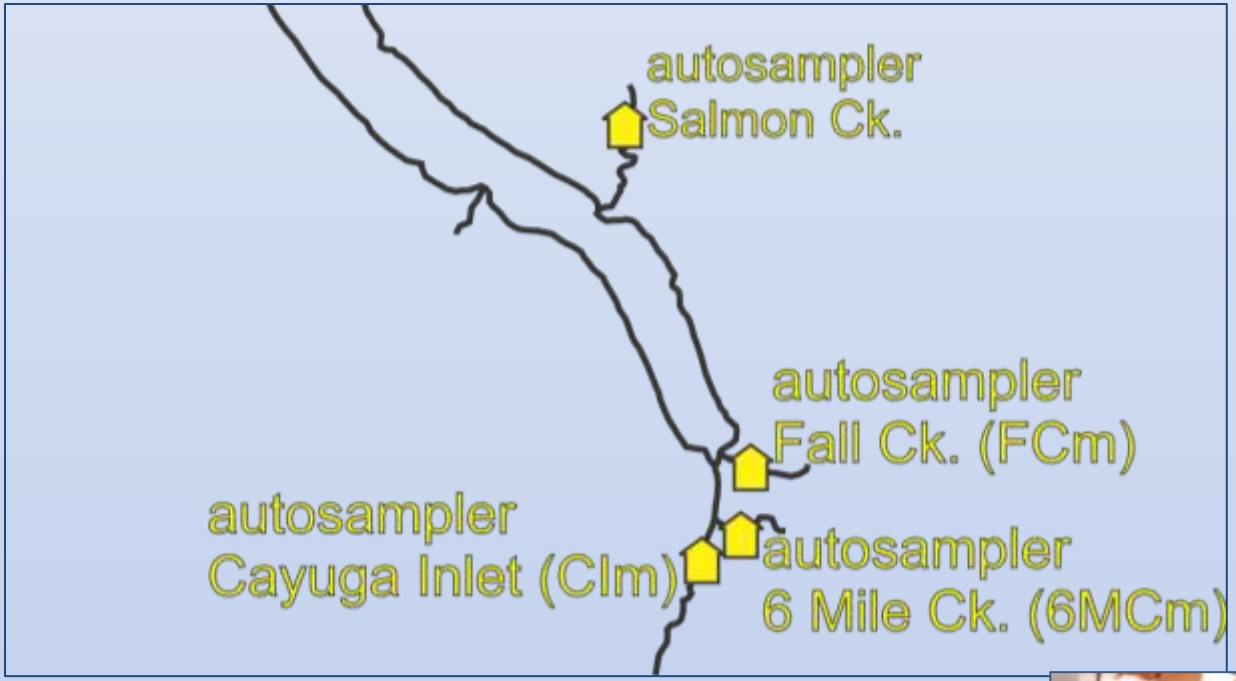
- fixed frequency (FF) near mouth of stream
- runoff event (E) sampling using autosamplers near mouth
- upstream synoptic surveys (SE), selected streams (Fall Creek and Salmon Creek), two events
- bioavailability

Fixed Frequency Stream Sampling



- twice a month at mouth of Creek
- grab samples

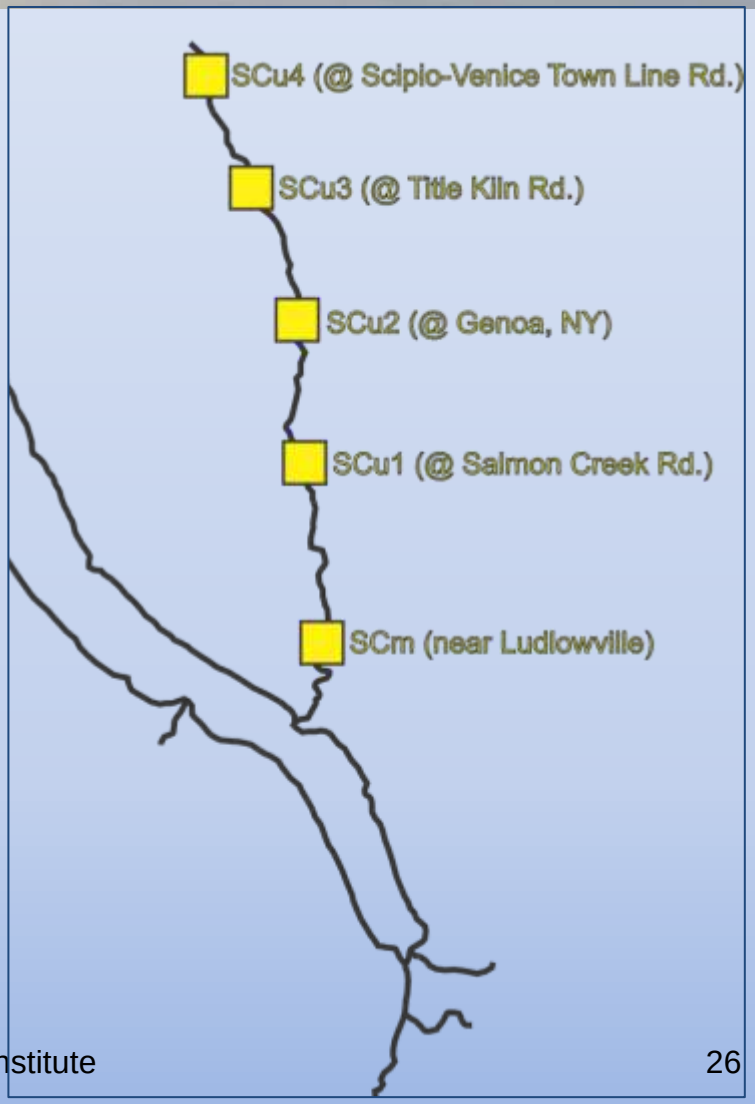
Event Stream Sampling



- at mouth of 4 gaged streams
- auto sampler inside an enclosure
- 4 events

Upstream Synoptic Survey

- mouth site and four upstream sites Salmon Ck.
- 1 dry weather and two wet weather events
- five samplings cycles per event



Stream Sampling

No.	analyte	Stream											
		Fall Ck.			Cayuga Inlet		Salmon Ck.			Six Mile Ck.		Taughann. Ck.	
		FF	E	SE	FF	E	FF	E	SE	FF	E	FF	E
1	TP	X	X	X	X	X	X	X	X	X	X	X	
2	TDP	X	X	X	X	X	X	X	X	X	X	X	
3	SRP	X		X	X		X		X	X		X	
4	TIP	X	X		X	X	X	X		X	X	X	
5	NO_x	X	X	X	X	X	X	X	X	X	X	X	
6	$t\text{-}NH_3$	X	X	X	X	X	X	X	X	X	X	X	
7	DOC	X	X		X	X	X	X		X	X	X	
8	UV_{254}	X	X		X	X	X	X		X	X	X	
9	DRSi	X	X		X	X	X	X		X	X	X	
10	Tn	X	X	X	X	X	X	X	X	X	X	X	
11	TSS	X	X	X	X	X	X	X	X	X	X	X	
12	FSS	X	X	X	X	X	X	X	X	X	X	X	
13	PAV_m	X	X		X	X	X	X		X	X	X	
14	Cl	X	X	X	X	X	X	X	X	X	X	X	

Special Efforts on Phosphorus

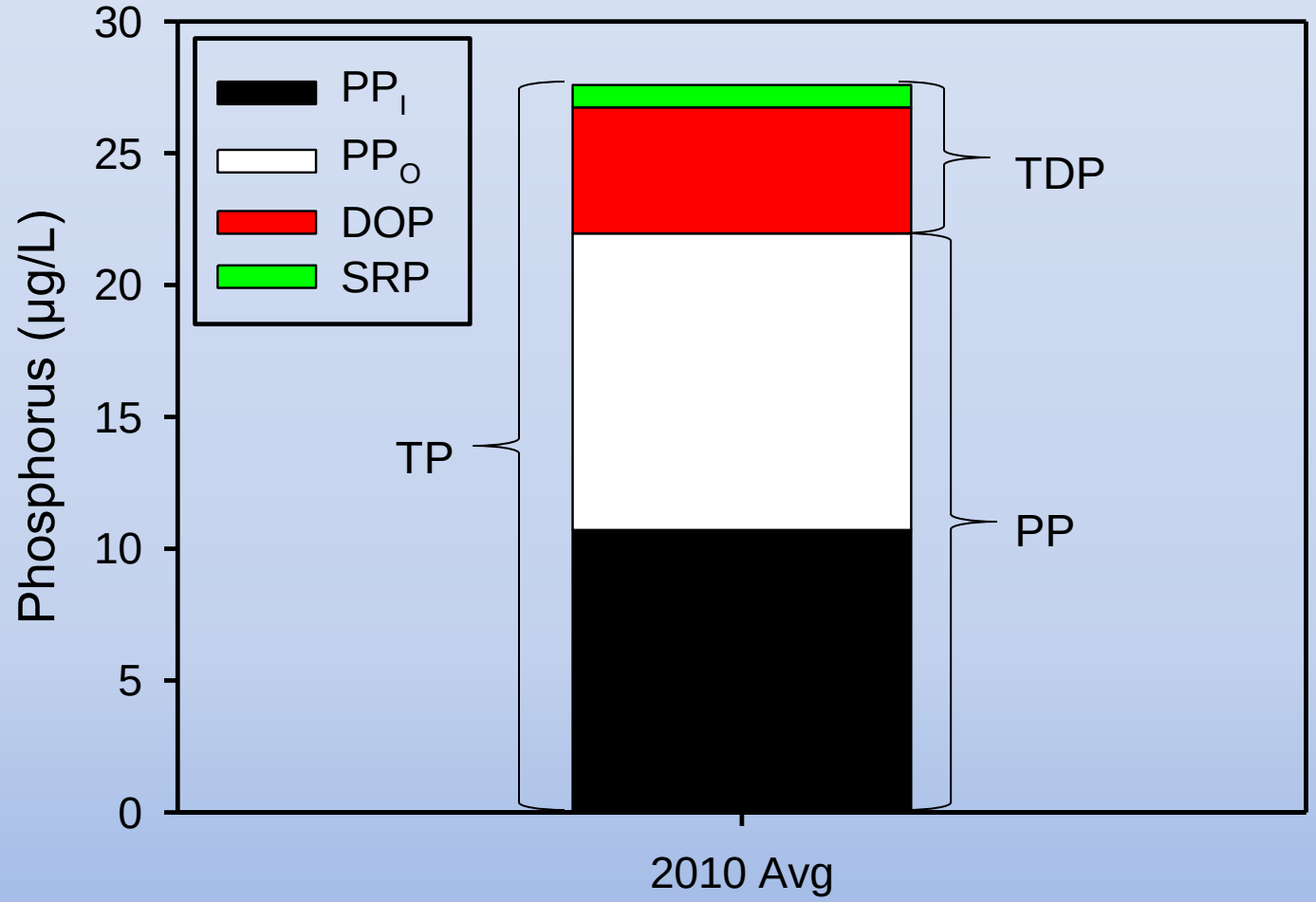
Forms of Phosphorus (P)

✓ frequently measured
✓✓ less frequently measured
❍ rarely measured

	No.	Parameter	Abbrev.	determined	relationships
✓	1	total P	TP	measured	TP = TDP +PP TP = TOP + TIP
✓✓	2	total dissolved P	TDP	measured	TDP = DOP +SRP
✓	3	soluble reactive P	SRP	measured	
❍	4	total inorganic P	TIP	measured	
	5	dissolve organic P	DOP	calculated by difference	DOP = TDP - SRP
	6	total organic P	TOP	calculated by difference	TOP = TP –TIP TOP = DOP + PP_O
	7	particulate P	PP	calculated by difference	PP = TP - TDP
	8	particulate organic P	PP_o	calculated by difference	PP_O = TOP -DOP
	9	particulate inorganic P	PP_i	calculated by difference	PP_I = PP - PP_O

Example of P Partitioning

upper waters Onondaga Lake, Syracuse , NY



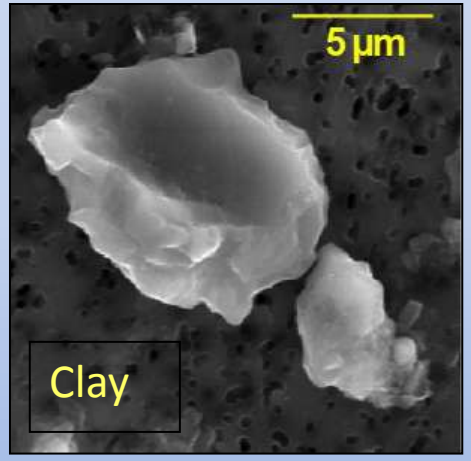
Bioavailability of Forms of Phosphorus

SRP – immediately and completely available

DOP – delayed and mostly available

PP – variable, uncertain, subject to deposition; where PP is an substantial fraction of tributary TP, the associated uncertainty in bioavailability is an important issue

clay particles



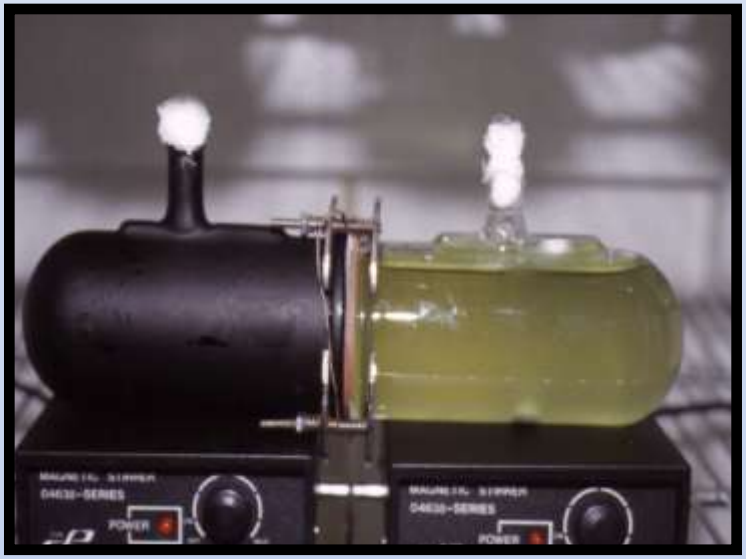
<u>Fractions of PP</u>

PP_O – available through decomposition pathways

PP_I – often low bioavailablity; sorption/ desorption process

Bioavailability Algal Assays

- dual culture diffusion apparatus (DCDA)
  - DePinto (1982), Auer et al. (1998), Effler et al. (2012)
- features – semi-permeable membrane separates chambers, mobilized P taken up by P-starved algae
- sampling 4 streams (Fall Ck., Cayuga Inlet, Six Mile Ck., Salmon Ck.)
- sampling 2 WWTP (Cayuga Heights, Ithaca Area WWTP)
- 1 dry weather and two wet weather events



- assays being conducted in laboratory of M. T. Auer, Michigan Technol. University

Special Efforts on Inorganic Particles

important to

- phosphorus (PP_i), above
- water clarity (Secchi disc, SD)

  $SD \propto 1/b_p$

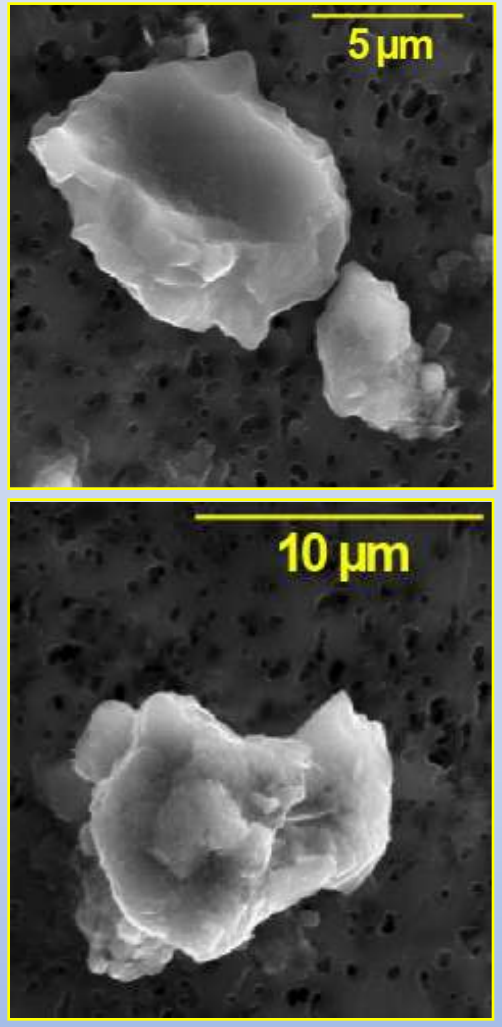
  b_p – particle scattering coeff.

  $= b_o + b_m$

  phytoplankton (algae) + inorganic particles

  $b_m \propto PAV_m$

- based on system-specific information



Turbidity Plumes

Draft Work Schedule

No.	Component Description	Phase 1												Phase 2
		2012				2013				2014				2015
		1	2	3	4	1	2	3	4	1	2	3	4	
1	develop QAPP			→										
2	review available system information						→			→				
3	tributary monitoring program a). routine b). event c). tributary analysis d). loading calculations e). bioavailable particulate P estimates						→	→	→		→			
							→	→	→	→	→			
4	lake monitoring program a). lake monitoring b). limnological analysis c). mass balance analysis						→	→	→		→	→	→	
5	setup and testing of 2-D transport/hydrothermal model								→	→	→	→	→	
6	setup and testing of a watershed model a). develop database b). tier-one model c). tier-two model						→	→	→	→	→	→	→	
								→	→	→	→	→	→	
7	Phase 1 report – summary of a). data analysis b). hydrothermal modeling c). watershed modeling d). recommended validation data sets e). recommendations for Phase 2										→	→	→	
											→	→	→	
												→	→	
												→	→	
												→	→	
8	develop QAPP Phase 2													→
9	Setup and test a phosphorus/eutrophication model													starts

Incorporation of Other Data Sets

- philosophy statement, page 96 of 495
  - “The intent is to utilize data collected as part of local research and monitoring efforts to the extent possible”

- stream data acquisition and review
  - T. Walter’s group at Cornell
  - secondarily, UFI
- lake data acquisition and review by UFI
- potential direct involvement of NYSDEC in critical data set decisions
- stakeholder input on data acquisition and descriptions
  - completeness

Acquisition of Other Data Sets

- Data Sources and Ongoing Analysis
- LSC Monitoring
- Dr. David Bouldin
- CSLAP
- Seneca County (Dr. J. Makarewicz) – lake, North
- CSI
- IAWWTP – effluent, tribs, lake
- CHWWTP – effluent
- NYS DEC

Photo by William Warmus http://www.warmus.com/cayuga_lake_views.htm

Value Added Activities*

*not specified in QAPP

Value Added Activity: Automated Water Quality Platform

- Site 2
  - measuring temperature, specific conductance, and turbidity at 15 min intervals
  - in collaboration with T. Cowen (Cornell Univ.)

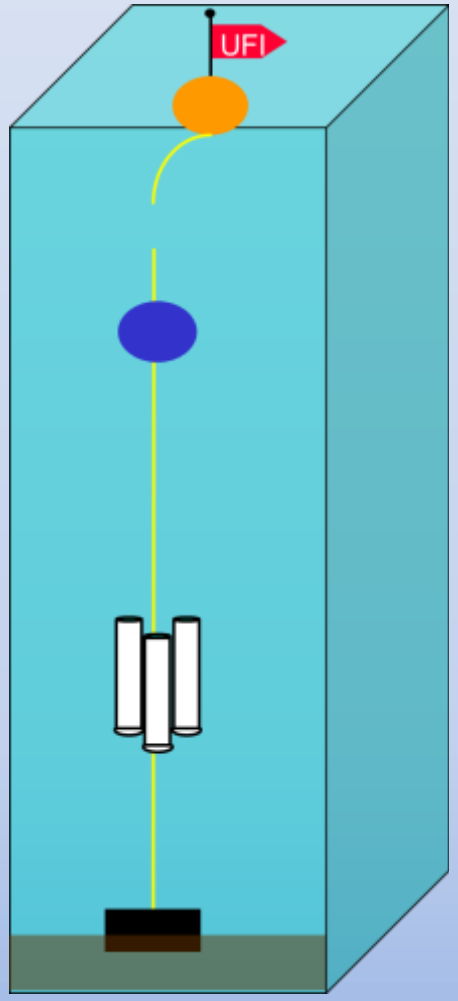
Value Added Activity: Instrument Deployments at Mouth of Inlet

- data sonde
  - measuring temperature, specific conductance, and turbidity at 15 min intervals
- ADCP
  - paired with Cornell's flow meter will assess turbidity loads to the lake
  - together with sonde data to support Tn loading
  - potential differences with upstream gage sampling site

in collaboration with T. Cowen (Cornell Univ.)

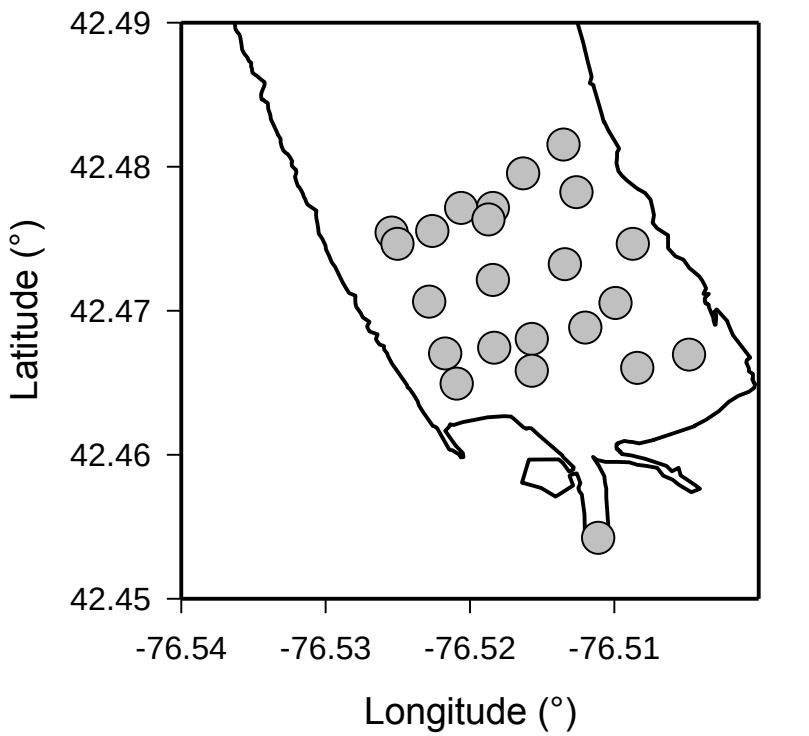
Value Added Activity: Analysis Sediment Trap Collections

- deployed May 1, 2013 at Site 2
- for determining downward flux and settling velocity
- collected weekly
- samples archived, will be analyzed for:
  - TP, TIP, TSS, FSS, Ca, Chla, POC



Value Added Activity: Shelf Monitoring, July 3 2013

- shelf region monitored in response to July 1 rain event
- 25 SeaBird profiles collected in a “grid” pattern
- elevated turbidity levels were observed in the inlet and in the entire southern shelf
- bioavailability sample collected during this survey



Small Creeks Survey, June 11, 2013

Value Added Activity: Small Stream Survey, June 11, 2013

- UFI conducted a survey of 18 tributaries to Cayuga Lake on June 11, 2013 to characterize nutrient and turbidity inputs for ungauged sources
  - field data, phosphorus and nitrogen data were collected
- the 5 main tributaries were sampled along with 13 small tribs around the lake's perimeter

Value Added Research Activities in Optics

- successful proposal to NASA by UFI
  - “Parameterizing spectral characteristics of optically active constituents in inland waters for improved satellite retrievals”
  - program: NASA ROSES 2012, A. 32 Remote Sensing of Water Qualilty 2.3 Improving description of the link between optical and biogeochemical properties
- funding delayed until summer 2014 (sequestration)
- seeks to advance remote sensing capabilities of water quality for inland waters through mechanistic algorithm approaches
- requires detailed optical characterization of various test systems (researcher choice – Cayuga Lake chosen)

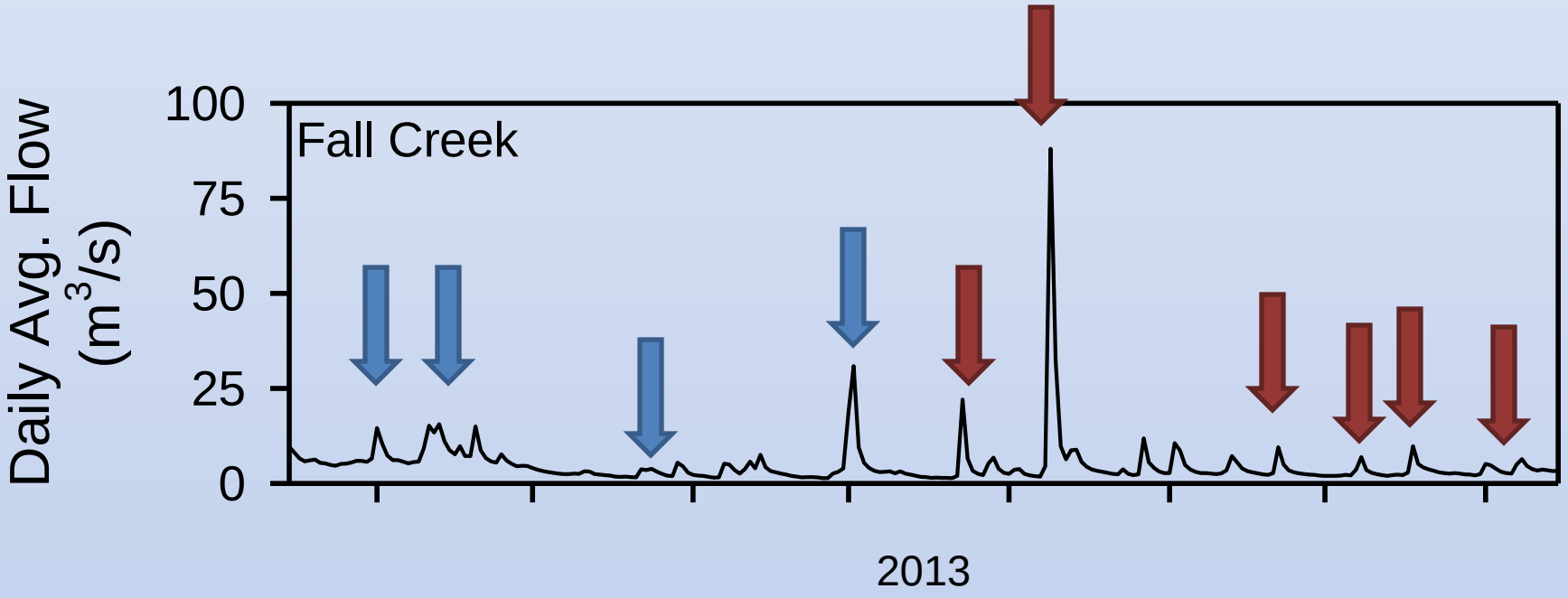
Added Measurements from Optics Program

Metrics

Field	Laboratory
absorption coefficient (**a**(λ))	CDOM absorption (($\mathbf{a}_{CDOM}(\lambda)$)
scattering coefficient (**b**(λ))	particle absorption ($\mathbf{a}_{P}(\lambda)$)
beam attenuation coefficient (**c**(λ))	phytoplankton absorption ($\mathbf{a}_{\varphi}(\lambda)$)
backscattering coefficient ($\mathbf{b}_{b}(\lambda)$)	non-algal particulate absoprtion ($\mathbf{a}_{NAP}(\lambda)$)
remote sensing reflectance ($R_{rs}(\lambda)$)	
CDOM fluoescence ($CDOM_{f}$)	

- lake sites 2,3 and 5, upper waters focus
- 4 tributaries, $\mathbf{a}_{CDOM}$ only
- anticipate some synergy with TMDL study

Value Added Activity: Additional Stream Sampling for Events



- sampling conducted beyond the 4 required events