A Novel Approach to Estimating Nutrient Transport and Its Applications

Presentation to the Water Quality Management Agency of Cayuga County

May 5, 2022

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The Novel Approach in Three Parts

(Described in 4/1/2021 presentation to WQMA, available on CSI website)

Part 1: Nutrient loads in monitored gauged streams

Samples collected by volunteers over multiple years are used to calculate loads with e.g. LOADEST software from USGS

Part 2: Nutrient loads in monitored ungauged streams

Loads are extrapolated from streams with calculated loads by comparing a) mean stormwater nutrient concentration in samples collected by volunteers over multiple years (from CSI database), and b) drainage basin area

Part 3: Nutrient loads in unmonitored ungauged streams

Loads are approximated by multiplying the drainage area by nutrient yields extrapolated from known yields in similar drainages

Part 1: Nutrient Transport in Gauged Streams Monitored by Volunteers

- **Nutrient Load** (*mass/time*) **= Nutrient Concentration** *(mass/volume)* **x Stream Discharge** *(volume/time)*

Conventionally, an autosampler is used to collect stream samples under a range of flow conditions **in a single year** and analyze for nutrients

Software (e.g., LOADEST from USGS) is used to estimate and sum nutrient concentrations over all the flows recorded by the gauging station across the entire year.

Unconventional approach: Volunteers collect samples under a range of flow conditions **over multiple years**.

Remainder of protocol is the same.

Unconventional Approach, Part 1, Works Well:
TP Loading Estimates for Southern Cayuga Lake Agree With Cayuga Lake Modeling Project/Draft TMDL

Draft TMDL Comment Table 1

Comparison of CSI and Draft TMDL Total Phosphorus Loading Estimates for "Impaired Southern End" Tributary Streams

Stream	**Drainage Area (mi^2)**	**Community Science Institute (short tons/year)[a]**	**Draft TMDL, Table 16 (short tons/year)[b]**	
Fall Creek	129	19.56[c]	21.6	
Six Mile Creek @ Bethel Grove	39	5.69[c]	6.28	
Cascadilla Creek	13.7	1.07	1.56	
Cayuga Inlet	92.4	8.13	9.12	
Total "Impaired Southern End" TP Load	**274**	**34.45**	**38.56**	

Part 2: Nutrient Transport in Ungauged Streams Extrapolated from Gauged Streams

Nutrient load (mass/time) = **Index Load of Gauged Stream** (mass/time) x **Stormwater Nutrient Ratio** (ungauged/gauged) x **Drainage Basin Ratio** (ungauged/gauged).

Demonstration of concept using Fall Creek and Six Mile Creek

- Calculated annual Fall Creek SRP load ("Index Load") = 3.81 tons/year
- Stormwater SRP ratio (Six Mile Creek/Fall Creek) (from CSI database) = 22.6 ug/L / 24.8 ug/L
- Drainage basin ratio (Six Mile Creek (Bethel Grove)/Fall Creek) = 39 mi^2 / 126 mi^2

Six Mile Creek SRP Load = 3.81 x (22.6/24.8) x (39/126) = 1.07 tons/year

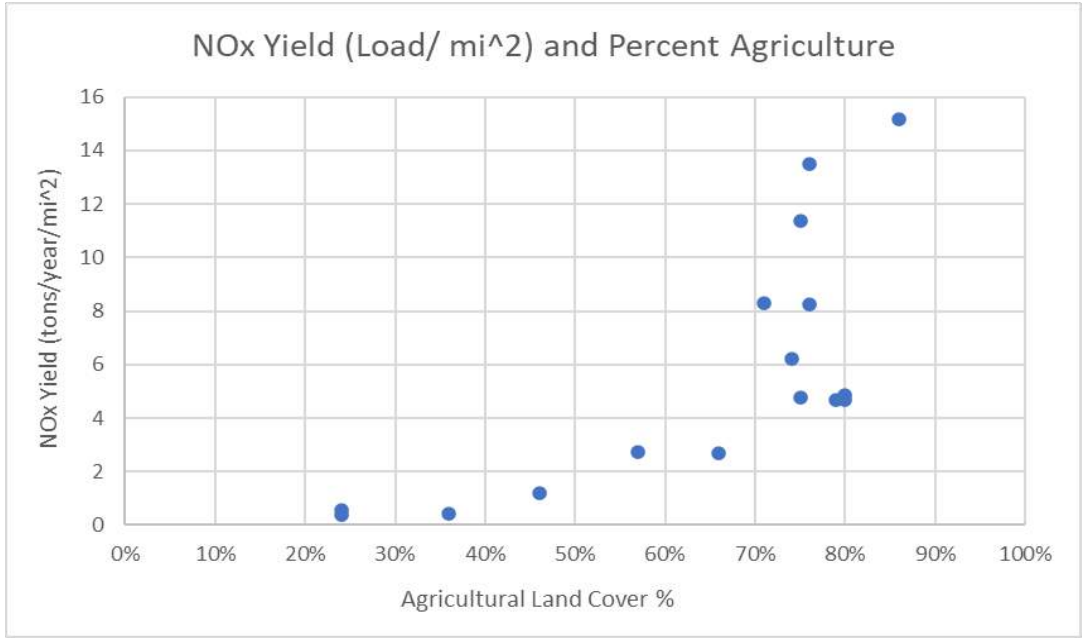
Six Mile Creek SRP Load calculated using LOADEST software = 0.85 tons/year

Approximated Nutrient Loads in 14 Monitored, Ungauged Cayuga Lake Tributary Streams

Monitored Drainage Areas within Cayuga Lake Watershed			Two Sets of Nutrient "Index Loads" and Yields in Gauged Streams							
Watershed	Drainage Area (mi^2)	Percent Agriculture	Average SRP Load (tons/ year)	SRP Yield (tons/year/mi^2)	Average TP Load (tons/year)	TP Yield (tons/year/mi^2)	Average NOx Load (tons/ year)	NOx Yield (tons/year/mi^2)	Average TKN Load (tons/ year)	TKN Yield (tons/year/mi^2)
Fall Creek	129	46%	3.81	0.030	19.56	0.15	156	1.21	124.8	0.97
Six mile Creek @ Bethel Grove	39	24%	0.85	0.022	5.69	0.15	21.8	0.56	28.5	0.73
					Average Approximated Loads and Yields (based on two "Index Loads," above)					
Cayuga Inlet	92.37	36%	1.63	0.02	8.13	0.09	39.87	0.43	49.27	0.53
Cascadilla Creek	13.7	24%	0.55	0.04	1.07	0.08	5.40	0.39	7.58	0.55
Taughannock Creek	66.8	57%	1.89	0.03	7.90	0.12	183.39	2.75	57.82	0.87
Trumansburg Creek	13.07	66%	0.56	0.04	0.94	0.07	35.21	2.69	11.71	0.90
Salmon Creek	89.2	71%	6.33	0.07	15.34	0.17	740.83	8.31	121.19	1.36
Town Line Creek	1.7	75%	0.17	0.10	0.24	0.14	19.34	11.38	1.91	1.13
Mill Creek	1.4	86%	0.19	0.14	0.41	0.29	21.27	15.19	1.45	1.04
Paines Creek	15.3	76%	2.02	0.13	2.73	0.18	126.01	8.24	15.40	1.01
Deans Creek	3.2	76%	0.89	0.28	1.00	0.31	43.21	13.50	5.80	1.81
Burroughs Creek	3.7	74%	0.75	0.20	1.35	0.36	23.00	6.22	8.34	2.25
Williamson Creek	1.4	80%	0.22	0.16	0.54	0.39	6.53	4.66	2.63	1.88
Great Gully Creek	15.56	79%	2.88	0.18	4.44	0.29	72.54	4.66	29.60	1.90
Canoga Creek	5.83	75%	0.78	0.13	1.50	0.26	27.70	4.75	9.27	1.59
Yawger Creek	24.91	80%	3.87	0.16	8.34	0.33	120.86	4.85	60.26	2.42

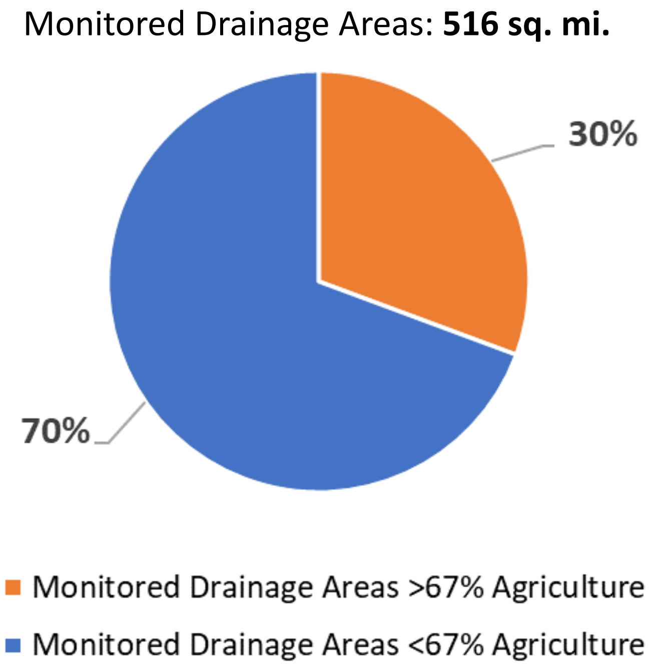
Part 3: Nutrient Transport in Unmonitored, Ungauged Drainages Estimated from Yields in Monitored Drainages

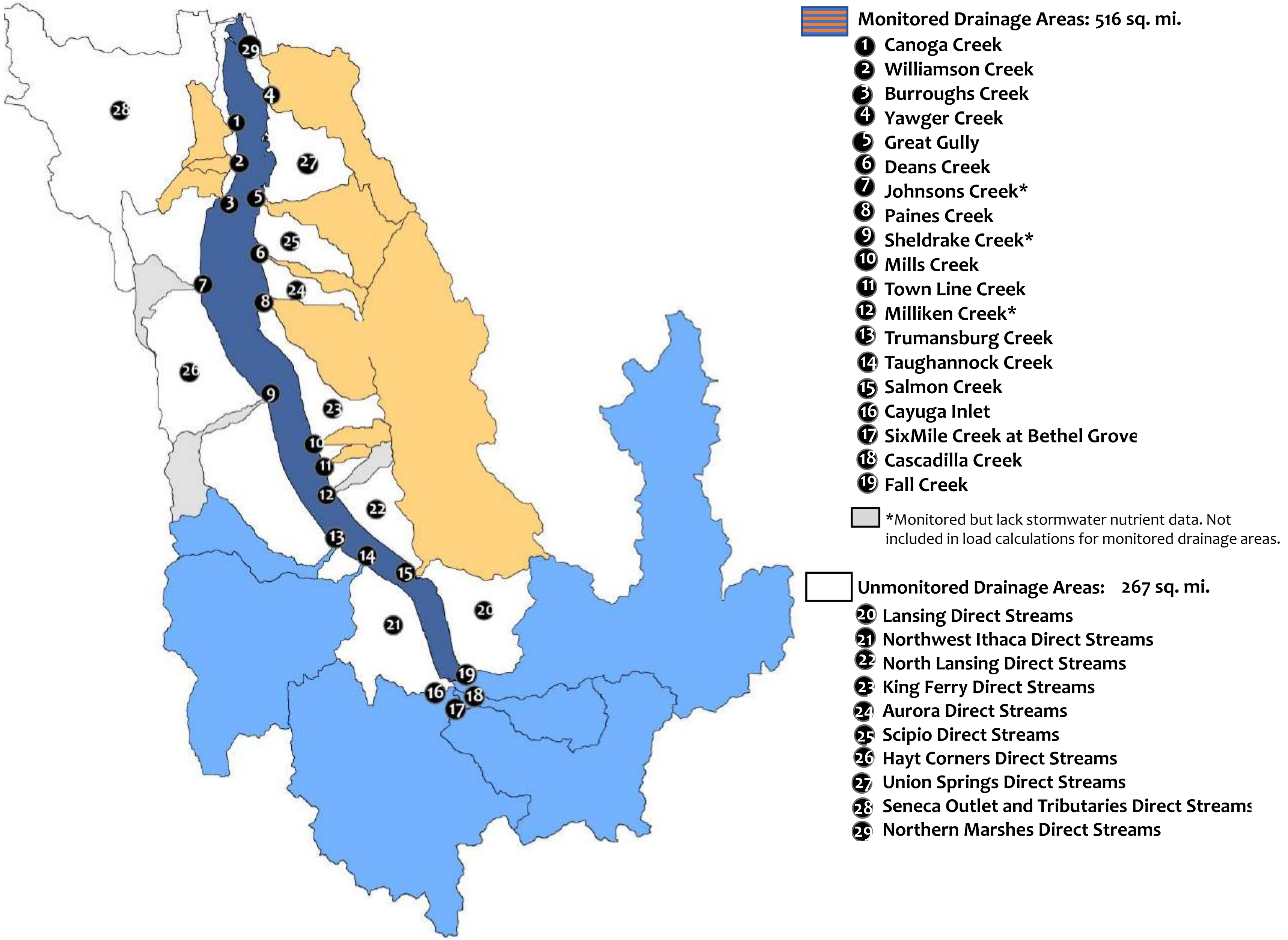
- Nutrient yields (tons/year/mi^2) in monitored drainages are characteristically biphasic: <67% agriculture, they are ~flat; >67% agriculture, they rise sharply. The reason(s) is (are) unknown. However, average yields <67% and >67% agriculture can be used to estimate loads.



Example: Drainage Area >67% ag (mi^2) x Avg Yield (tons/year/mi^2) = Load (tons/year)

Monitored Drainage Areas in the Cayuga Lake Watershed Grouped by Two Agricultural Land Cover Categories





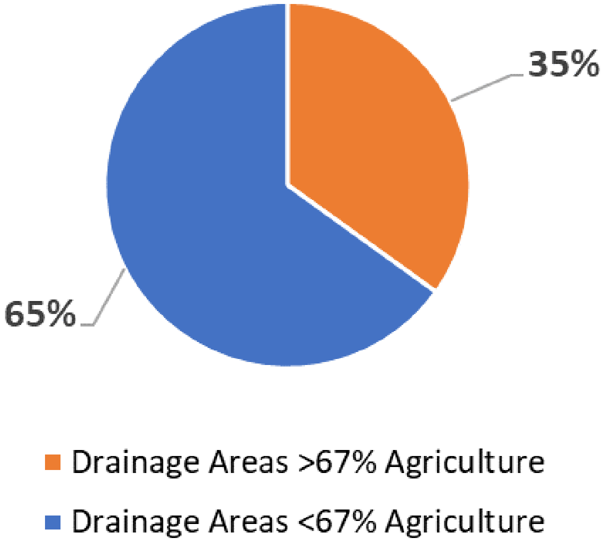
Approximated Nutrient Loads in Unmonitored Drainages in the Cayuga Lake Watershed

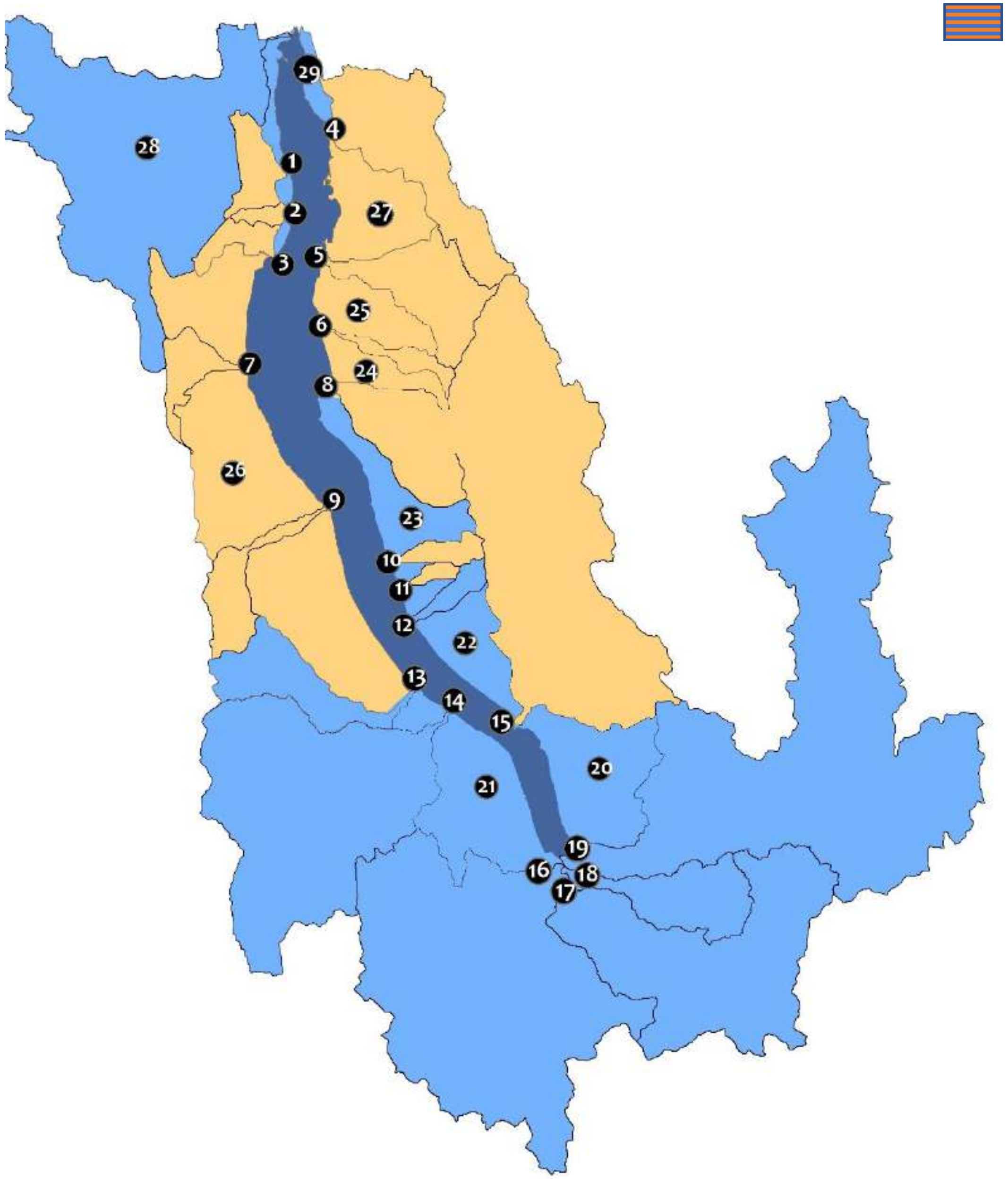
Unmonitored Drainages within Cayuga Lake Watershed			Approximated Loads (drainage area x average yield in monitored drainages for either <67% or >67% agriculture category)			
Watershed	**Drainage Area (mi^2)**	**Percent Agriculture**	**SRP Load (tons/year)**	**TP Load (tons/year)**	**NOx Load (tons/ year)**	**TKN Load (tons/year)**
Lansing Direct Streams	19.66	36%	0.59	2.14	26.32	14.90
Northwest Ithaca Direct Streams	23.5	56%	0.71	2.56	31.46	17.81
King Ferry Direct Streams	14.29	64%	0.43	1.56	19.13	10.83
North Lansing Direct Streams (includes Milliken Creek)	15.8	61%	0.47	1.72	21.15	11.97
Aurora Direct Streams	9.21	73%	1.43	2.34	75.30	15.09
Scipio Direct Streams	7.74	76%	1.20	1.97	63.28	12.68
Union Springs Direct Streams	14.44	76%	2.24	3.67	118.06	23.66
Northern Marshes Direct Streams	6.95	44%	0.21	0.76	9.30	5.27
Seneca Outlet and Tributaries	75.21	65%	2.26	8.20	100.69	56.99
Hayt Corners Direct Streams (includes Johnsons Creek and Sheldrake Creek)	80.00	74%	12.41	20.34	654.08	131.09

Monitored and Unmonitored Drainage Areas in the Cayuga Lake Watershed Grouped by Two Agricultural Land Cover Categories

Monitored and Unmonitored Drainage Areas in the Cayuga Lake watershed: **782 sq. mi.***

***sum of monitored and unmonitored drainage areas listed in the tables**





Monitored Drainage Areas: 516 sq. mi.

1. Canoga Creek
2. Williamson Creek
3. Burroughs Creek
4. Yawger Creek
5. Great Gully
6. Deans Creek
7. Johnsons Creek*
8. Paines Creek
9. Sheldrake Creek*
10. Mills Creek
11. Town Line Creek
12. Milliken Creek*
13. Trumansburg Creek
14. Taughannock Creek
15. Salmon Creek
16. Cayuga Inlet
17. SixMile Creek at Bethel Grove
18. Cascadilla Creek
19. Fall Creek

* Monitored but lack stormwater nutrient data. Not included in load calculations for monitored drainage areas.

Unmonitored Drainage Areas: 267 sq. mi.

20. Lansing Direct Streams
21. Northwest Ithaca Direct Streams
22. North Lansing Direct Streams
23. King Ferry Direct Streams
24. Aurora Direct Streams
25. Scipio Direct Streams
26. Hayt Corners Direct Streams
27. Union Springs Direct Streams
28. Seneca Outlet and Tributaries Direct Streams
29. Northern Marshes Direct Streams

Pause to Consider the Value of this “Bootstrapping”of Loading Estimates from Volunteer Monitoring Data

- These “bootstrap” estimates address a yawning void in data-driven assessments of phosphorus and nitrogen loading throughout much of the Cayuga Lake watershed.
- These estimates are made possible by dedicated teams of volunteers who collect stream samples year after year, building long-term data sets that reliably characterize nutrient concentrations under diverse flow conditions.
- These estimates of phosphorus and nitrogen loading are not perfect, but the picture they provide has valuable applications, even though that picture might be slightly out of focus.

Application 1: Correction of TP and SRP Loading Estimates in Draft Cayuga Lake TMDL

- Draft TMDL relied on SWAT model to estimate phosphorus loading
- SWAT model was calibrated using data from southern Cayuga Lake tributary streams, and it was validated using CSI data for Fall Creek
- As shown in earlier slide, CSI and Draft TMDL/SWAT loading estimates agree well for southern streams where nutrient data were collected
- Draft TMDL applied SWAT model to estimate phosphorus loading across the entire Cayuga Lake watershed <u>without collecting nutrient data to validate the model in northern tributary streams</u>
- CSI-volunteer stream monitoring partnerships have collected samples and documented high dissolved nutrient concentrations in northern streams beginning in 2009, contrary to SWAT model predictions

Draft TMDL Underestimates Total Cayuga Lake SRP Loading by a Factor of 3 Compared to CSI and Two Other Estimates

Draft TMDL Comment Table 3					
Comparison of TMDL with Three Independent Estimates of Dissolved Phosphorus[a] Loading (short tons/year)					
Watershed	Draft TMDL, Table 17 (2021)	CSI (2021)[b]	Haith et al (2012)[c]	Likens (1970-71)[c,d]	
Fall Creek	2.06	3.81	11.2	10.9	
Combined Cayuga Inlet[e]	3.14	3.03	10.4	29.2	
Salmon Creek	4.26	6.33	8.7	5.8	
Taughannock Creek	1.28	1.89	4.7	3.7	
Great Gully	0.82	2.88	--	--	
Cayuga Lake	**17**	49	64	74	
		Mean CSI, Haith et al, Likens = **62 +/- 13** (SD) short tons dissolved phosphorus/year			

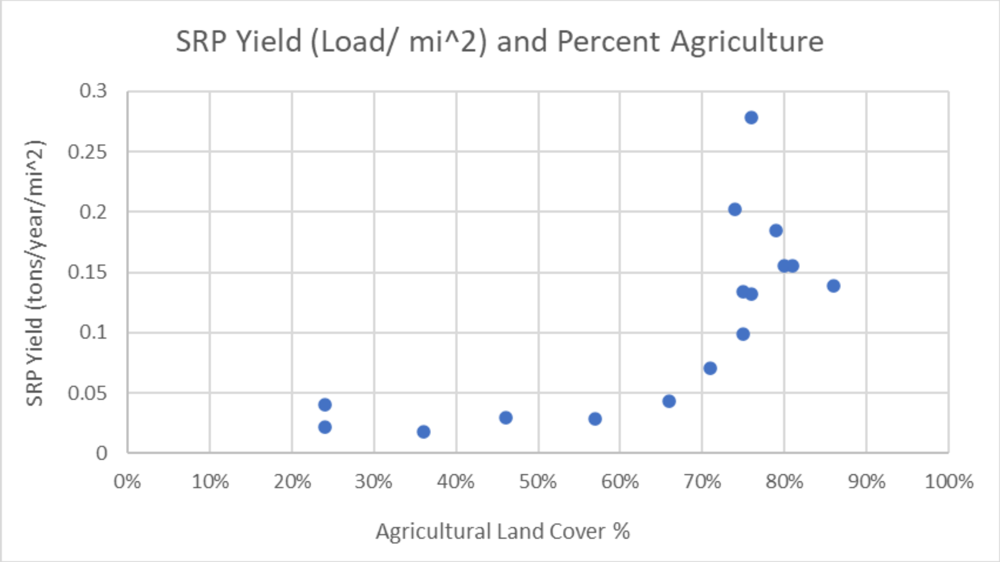
Draft TMDL Overestimates Total Cayuga Lake TP loading by a Factor of 2 Compared to CSI and Two Other Estimates

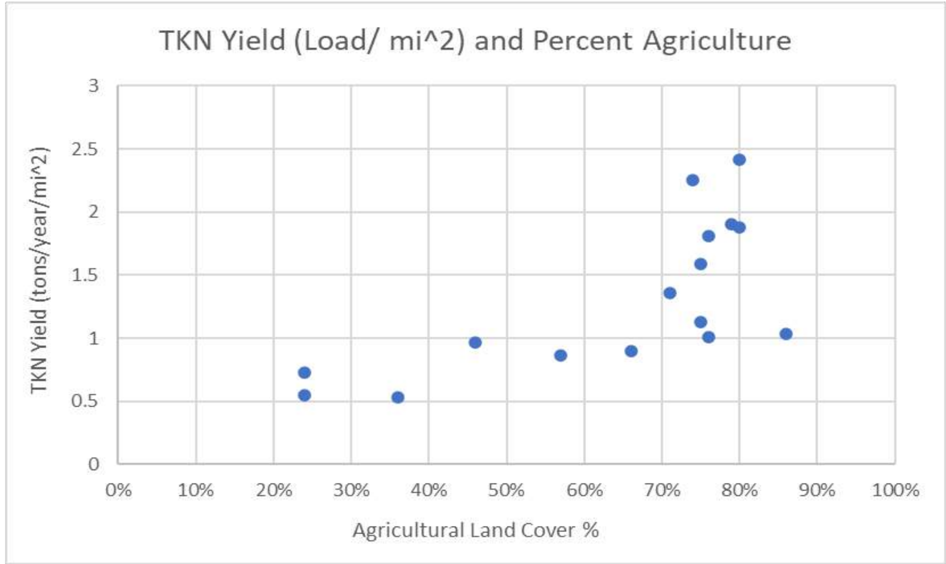
Draft TMDL Comment Table 2						
Comparison of Draft TMDL with Three Independent Total Phosphorus Loading Estimates (short tons/year)						
Watershed	Draft TMDL, Table 16 (2021)		CSI (2021)[a]	Haith et al (2012)[b]	Likens (1970-71)[b,c]	
Fall Creek	21.6		19.6	18.6	22.8	
Combined Cayuga Inlet[d]	17.0		14.9	20.0	37.6	
Salmon Creek	39.9		15.3	14.6	11.0	
Taughannock Creek	10.9		7.9	7.9	5.6	
Great Gully	17.9		4.4	--	--	
Cayuga Lake	**207**		124	108	114	
			Mean CSI, Haith et al, Likens = **115 +/- 8.1** (SD) short tons TP/year			

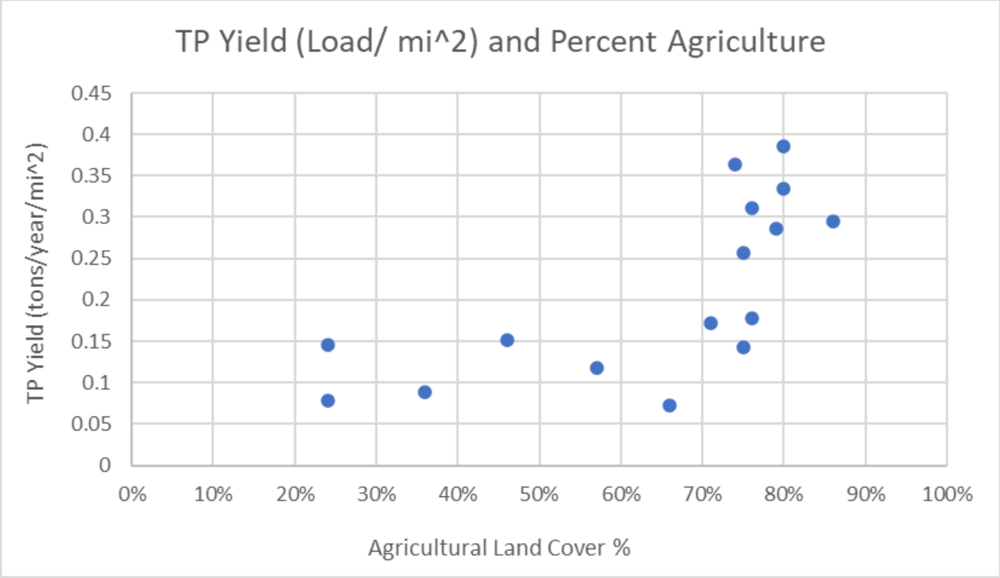
Application 2: Estimating Nutrient Loading <u>Within Specific Jurisdictions</u> in the Cayuga Lake Watershed

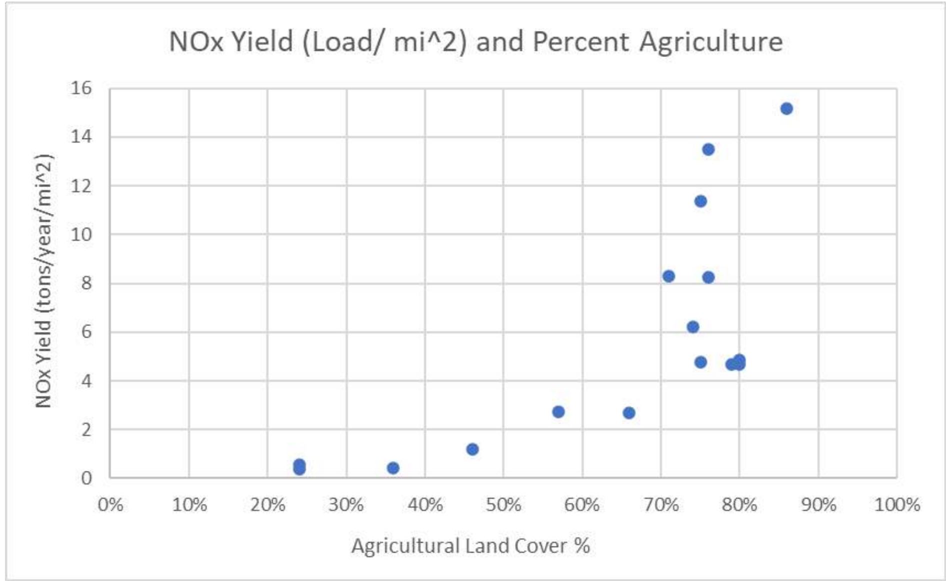
- As we have seen, nutrient loading is correlated with agricultural land use as defined by the National Land Cover Database
- In addition to the number of acres in agriculture, nutrient loading is impacted by the <u>percent of a stream's drainage area being farmed</u>
- When the percent of agricultural land in a stream's drainage area exceeds approximately 67%, the nutrient concentration in runoff, i.e., the nutrient yield, increases sharply
- Where are the drainages that load disproportionately large amounts of nutrients to Cayuga Lake?
- What are the implications for managing nutrient loading?

Dependence of Nutrient Yield on % Agricultural Land Cover









Cayuga Lake Watershed Land by County

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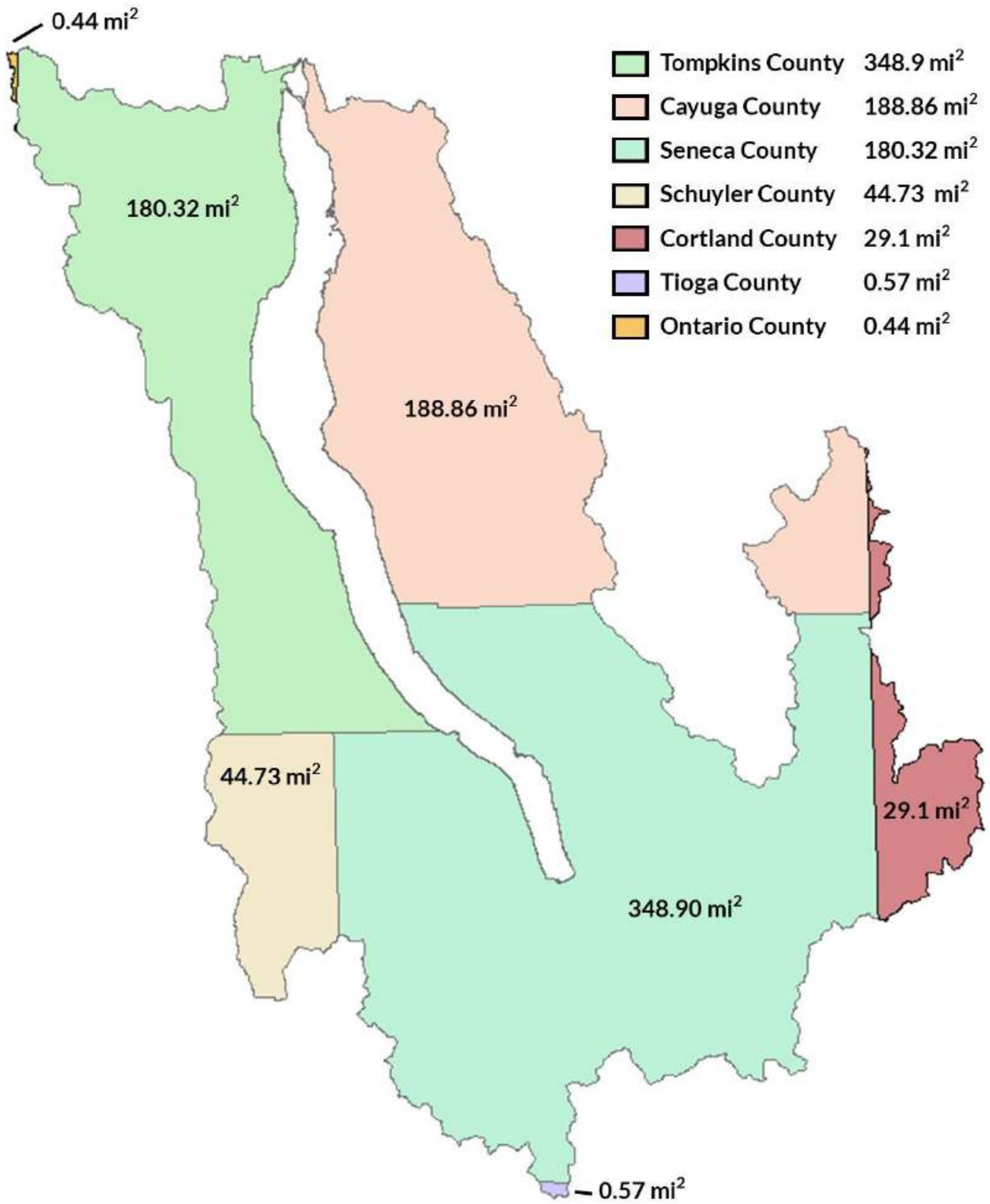
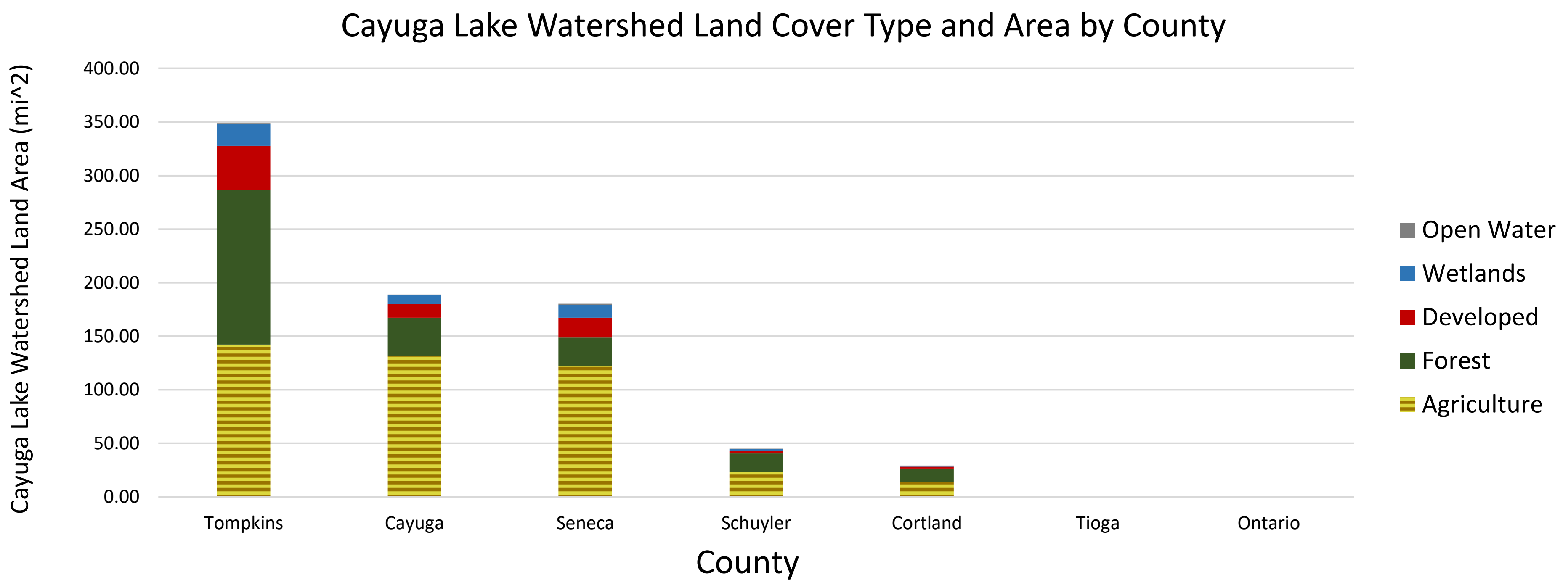
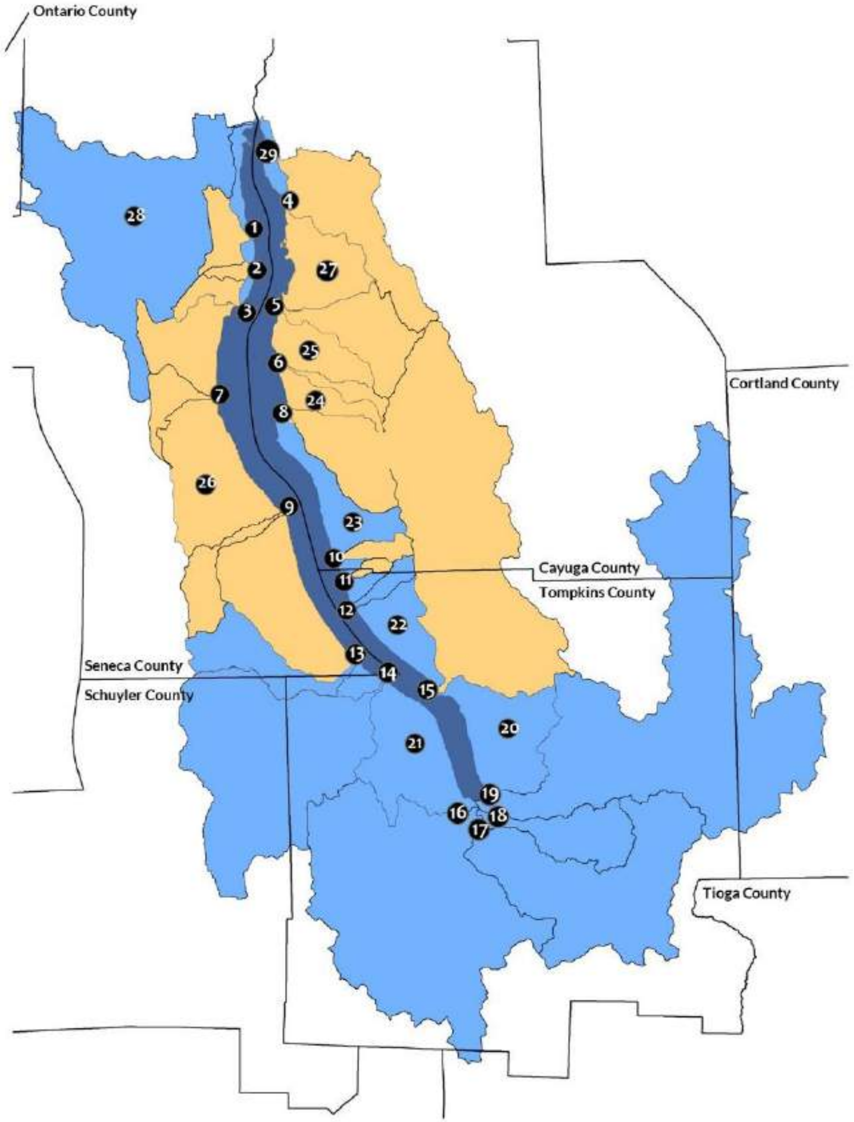


Cayuga Lake Watershed (CLW) Land Cover Type and Area by County												
County	Total Land (mi^2)	Percent of CLW Total Land	Agricultural Land (mi^2)	Percent of CLW Agricultural Land	Forested Land (mi^2)	Percent of CLW Forested Land	Wetlands (mi^2)	Percent of CLW Wetlands	Developed Land (mi^2)	Percent of CLW Developed Land	Open Water (mi^2)	Percent of CLW Open Water
Tompkins	348.9	44%	142.17	33%	144.53	61%	20.05	47%	41.19	54%	0.97	40%
Cayuga	188.86	24%	131.51	30%	35.82	15%	8.42	20%	12.69	17%	0.41	17%
Seneca	180.32	23%	122.28	28%	26.56	11%	12.17	28%	18.36	24%	0.94	39%
Schuyler	44.73	6%	23.10	5%	17.37	7%	1.47	3%	2.74	4%	0.05	2%
Cortland	29.1	4%	13.80	3%	12.71	5%	0.82	2%	1.73	2%	0.04	2%
Tioga	0.57	0%	0.08	0%	0.40	0%	0.07	0%	0.01	0%	0.01	0%
Ontario	0.44	0%	0.07	0%	0.25	0%	0.06	0%	0.06	0%	0.00	0%
Total:	**792.92**		**433.01**		**237.64**		**43.06**		**76.79**		**2.42**	

Source: National Land Cover Dataset, 2019. Retrieved from https://www.mrlc.gov/





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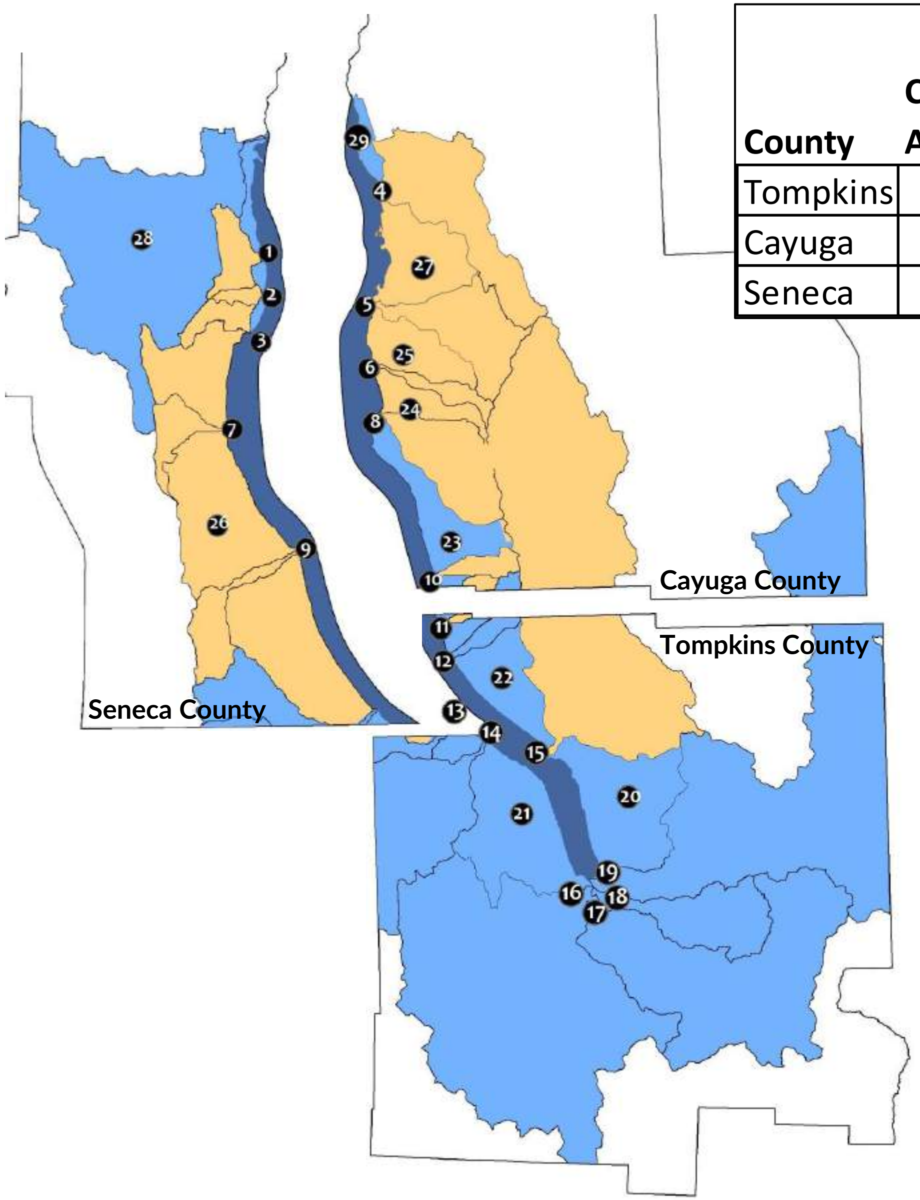

County	CLW Drainage Area	Total Drainage Area <67% Agriculture	Percent of County CLW Drainage Area	Total Drainage Area >67% Agriculture	Percent of County CLW Drainage Area
Tompkins	349	314	90%	35	10%
Cayuga	189	41	22%	148	78%
Seneca	180	86	48%	94	52%

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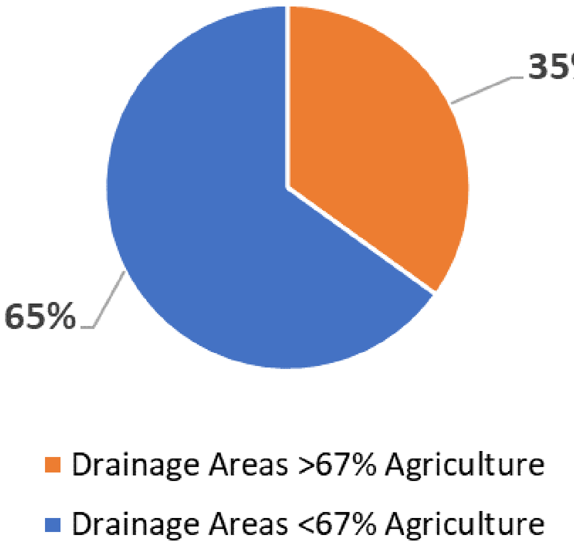
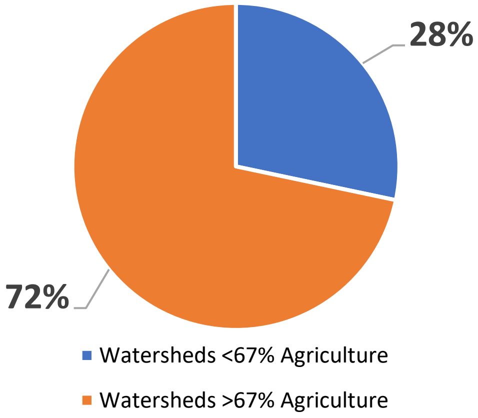
Total Cayuga Lake Watershed Nutrient Loads from Two Agricultural Land Cover Categories

Monitored and Unmonitored Drainage Areas in the Cayuga Lake watershed: **782 sq. mi.***

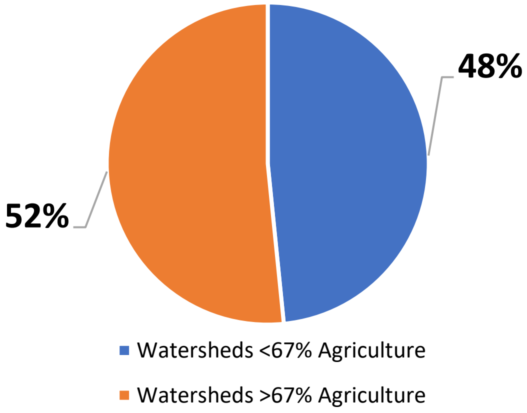
***sum of monitored and unmonitored drainage areas listed in the tables**



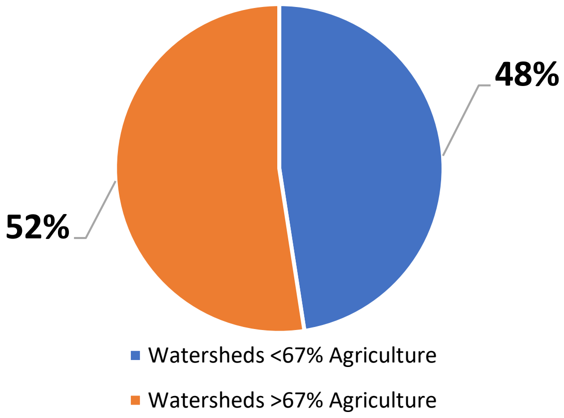
Total Watershed SRP Load: **49 tons/ year**



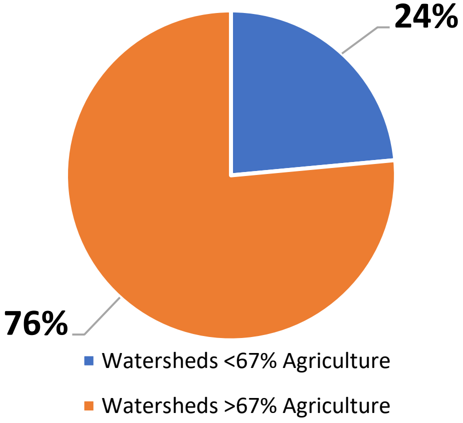
Total Watershed TP Load: **124 tons/ year**



Total Watershed TKN Load: **836 tons/ year**

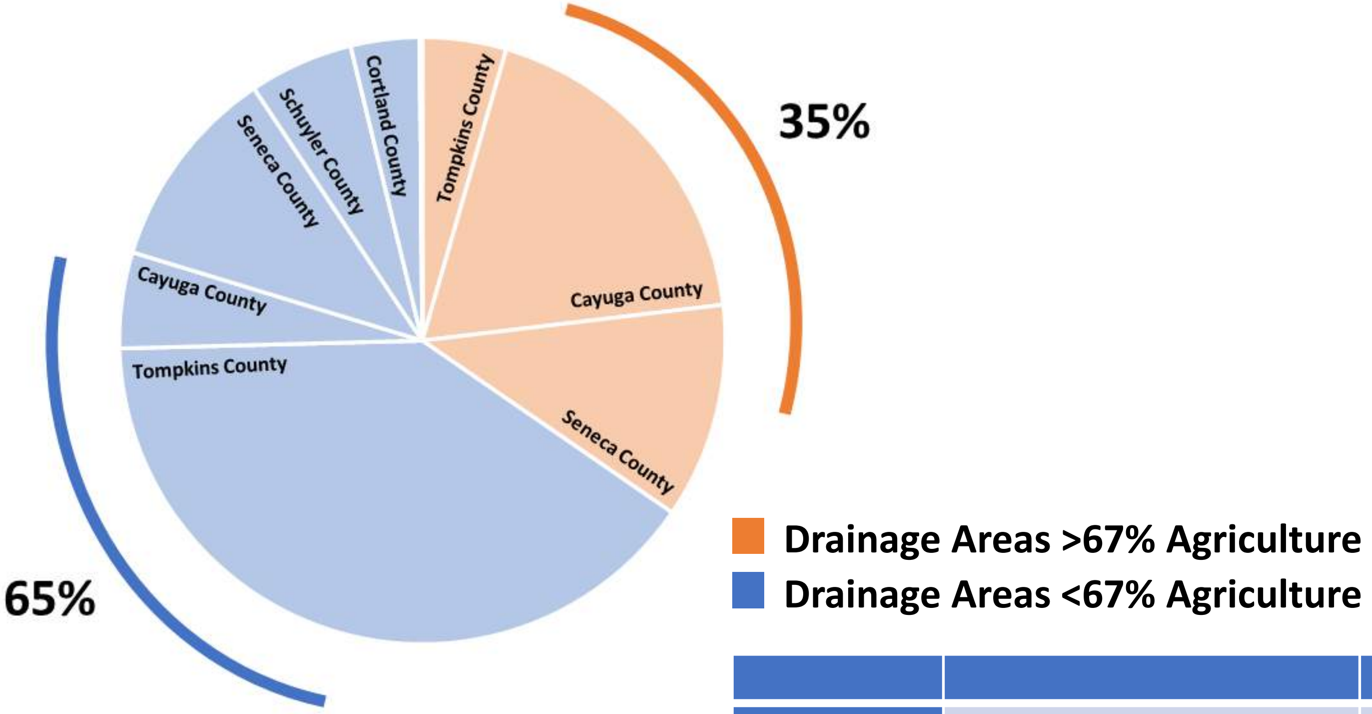


Total Watershed NOx Load: **2,761 tons/ year**



Monitored and Unmonitored Drainage Areas in the Cayuga Lake watershed: 782 sq. mi.*

*sum of monitored and unmonitored drainage areas listed in the tables



		Counties' Nutrient Loads and Yields							
		Nutrient Load (tons/year)				Nutrient Yield (tons/year/mi^2)			
County	Drainage Area within Cayuga Lake Watershed	SRP Load	SRP Yield	TP Load	TP Yield	NOx Load	NOx Yield	TKN Load	TKN Yield
Tompkins	349	14	0.04	50	0.14	734	2.1	340	0.97
Cayuga	189	20	0.11	40	0.21	1,182	6.3	269	1.42
Seneca	180	15	0.08	34	0.19	841	4.7	225	1.25

Conclusions

- Stream monitoring partnerships with volunteer groups have generated long-term nutrient data sets in drainages comprising 65% of the Cayuga Lake watershed
- These nutrient data sets make it possible to obtain reasonably accurate “ball park” estimates of phosphorus and nitrogen loading to Cayuga Lake
- In a surprising discovery, we find that nutrient yields increase dramatically when agriculture comprises more than about 65-70% of the land use in a stream’s drainage
- The basis for this biphasic relationship between nutrient yield and % agricultural land use is not known
- One speculative possibility is that the capacity of soil to sequester nutrients may become saturated

Conclusions (cont'd)

- The SRP and TP loading estimates in the Draft TMDL are incorrect based on CSI's results and two published sets of values
- Nutrient loading is effectively a function of agriculture in a stream's drainage basin and is determined by a) The <u>total number of agricultural acres</u>, and b) The <u>fraction of acres</u> in agriculture in the drainage
- Tompkins County has twice the land area of Cayuga County, however, it loads only about 2/3 as much dissolved phosphorus and nitrogen as Cayuga County, where most drainages have high percentages of their land area in agriculture
- Due to the high agricultural percentages in its drainages, Cayuga County as a whole loads 2x to 3x more dissolved nutrients per acre than Tompkins County

Conclusions (cont’d)

- Nutrient yields in Seneca County are intermediate between Cayuga and Tompkins County yields, consistent with about half of Seneca County land being located in stream drainages with high agricultural land use
- Tompkins County loads greater amounts of Total Phosphorus (TP) and Total Kjeldahl Nitrogen (TKN) than either Cayuga or Seneca County
- TP and TKN include soil-bound as well as dissolved forms of nutrients
- Measurements of Total Suspended Solids (TSS) concentrations are roughly similar in streams across the Cayuga Lake watershed (see CSI database)
- This implies that the particulate fraction of nutrients may be roughly equally distributed among all drainages, and that differences in TP and TKN yields and loads are mainly a reflection of their dissolved components.

Acknowledgements

- Nate Launer, CSI’s Director of Outreach, helped with the calculations and also made all the maps and tables
- Noah Mark is Technical Director of CSI’s certified lab (ELAP ID# 11790) and responsible for maintaining the high quality of the data in this report

- Please welcome Dr. Grascen Shidemantle, who will replace me as CSI Executive Director in July