Long Term Data Sets and Nutrient Management: Bootstrapping Approximations of Phosphorus and Nitrogen Loading to Cayuga Lake

Presentation to the Water Resources Council – Cornell University Monitoring Partnership

August 9, 2022

Stephen Penningroth, Founder

Community Science Institute

What We Need in Order to Manage Nutrients

- Certified measurements of phosphorus and nitrogen concentrations in streams under diverse flow conditions
- Estimates of nutrient loading based on these certified concentration measurements and on flows
- Ability to distinguish between dissolved (100% bioavailable) and soil-bound (poorly bioavailable) nutrient fractions
- Ability to distinguish anthropogenic and natural sources
- Implementation of nutrient-appropriate BMPs by local governments and stakeholders
- “Trust but verify” BMPs and discard if ineffective

Bootstrapping Loading Estimates, in Three Parts

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

Part 1: Monitored, gauged streams with long-term nutrient data sets

Certified nutrient data collected with volunteer groups over multiple years are used to calculate loads with e.g. LOADEST software from USGS

Part 2: Monitored, ungauged streams with long-term nutrient data sets

Part 1 loads are used to approximate Part 2 loads based on ratios of stormwater nutrient concentrations and drainage basin areas

Part 3: Unmonitored, ungauged streams lacking long-term nutrient data sets

Loads from Parts 1 and 2 are used to extrapolate average yields in unmonitored drainages. Extrapolated average yield is multiplied by the area of each unmonitored drainage to approximate load.

Bootstrap Part 1: Nutrient Transport in Gauged Streams Monitored with 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 season** 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.

Bootstrap approach: Volunteers collect certified nutrient data under a range of flow conditions **over multiple years**.

Remainder of protocol is the same.

Bootstrap, 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**	

Bootstrap Part 2: Nutrient Transport in Monitored, Ungauged Streams Pro-Rated from Part 1 Streams

Bootstrap Part 2 pro-rated 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 to pro-rate Six Mile Creek SRP load

- Bootstrap Part 1 annual Fall Creek SRP load ("Index Load") = 3.81 tons/year
- Long-term (17-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

Bootstrap Part 2 pro-rated Six Mile Creek SRP Load = 3.81 x (22.6/24.8) x (39/126) = 1.07 tons/year

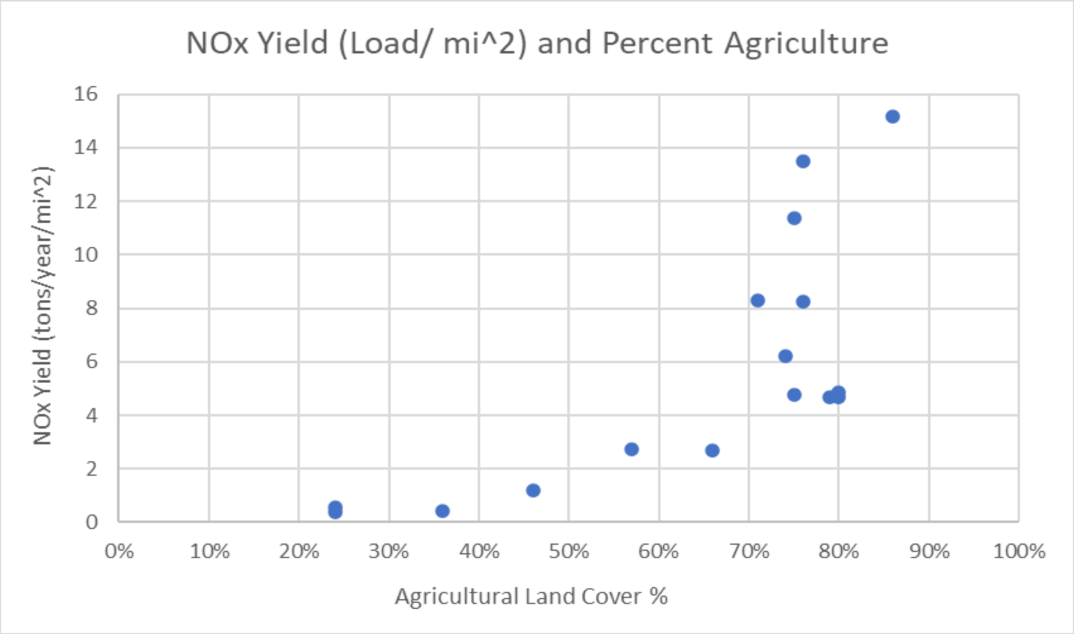
Bootstrap Part 1 Six Mile Creek SRP Load calculated using LOADEST software = 0.85 tons/year

Bootstrap Part 2: Pro-Rated Nutrient Loads in 14 Monitored, Ungauged Cayuga Lake Tributary Streams with Long-Term Data Sets including Stormwater Concentrations

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

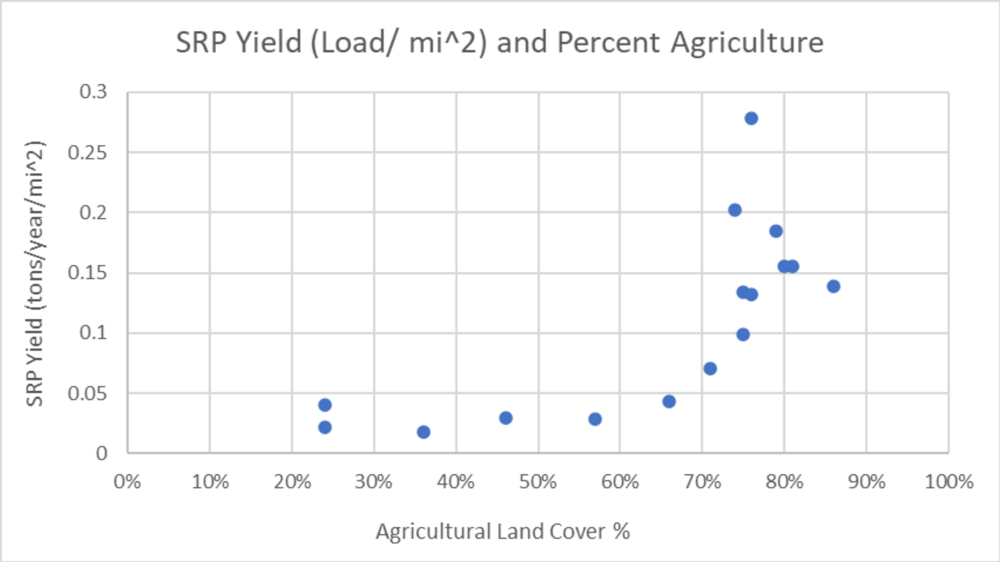
Bootstrap Part 3: Nutrient Loads in Unmonitored, Ungauged Drainages Based on Extrapolated Yields

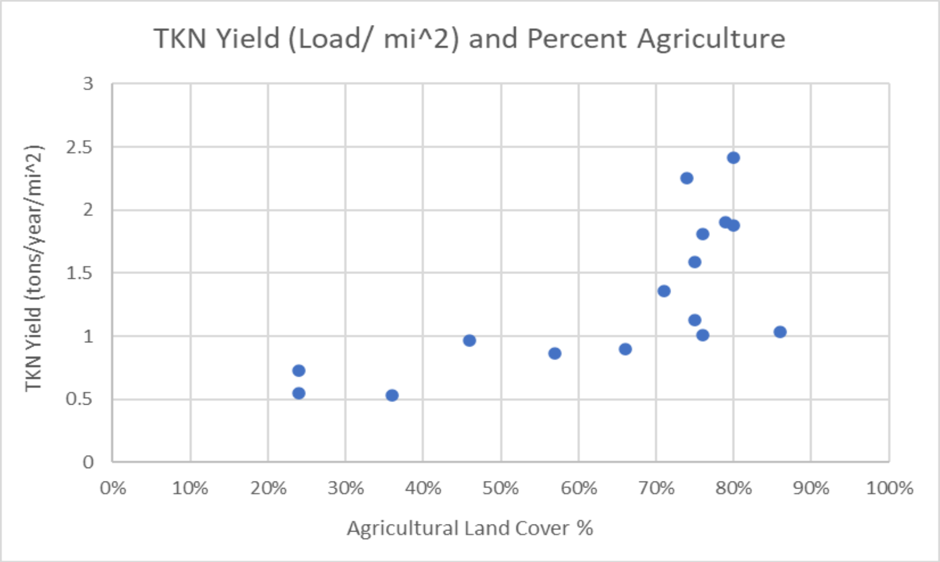
- Surprisingly, nutrient yields in Bootstrap Part 1 and 2 streams are biphasic with respect to % ag land use: <67% agriculture, they are almost flat; >67% agriculture, they rise sharply. This empirical observation of ~order-of-magnitude differences in yield provides an opportunity to estimate loads for drainages <67% and >67% ag.

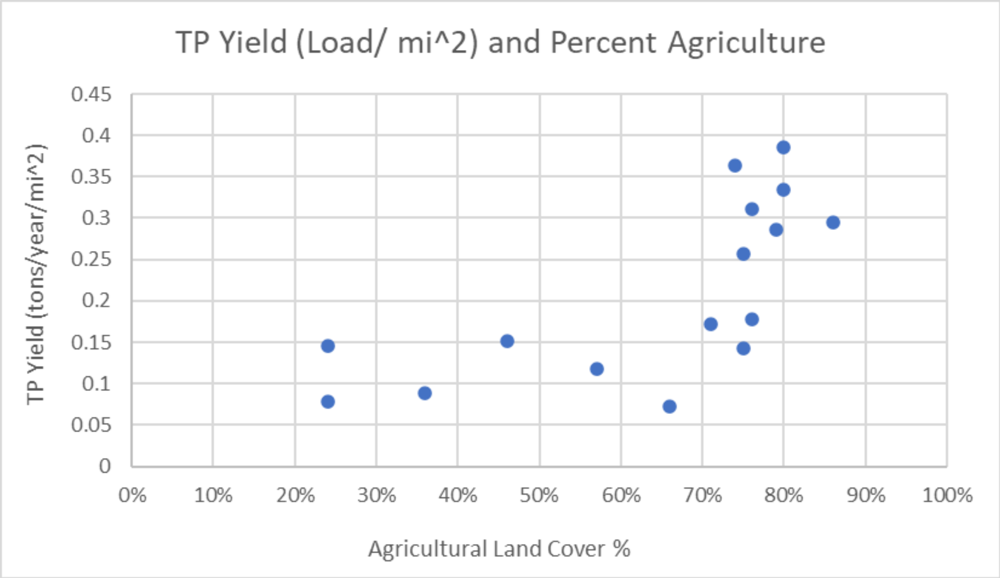


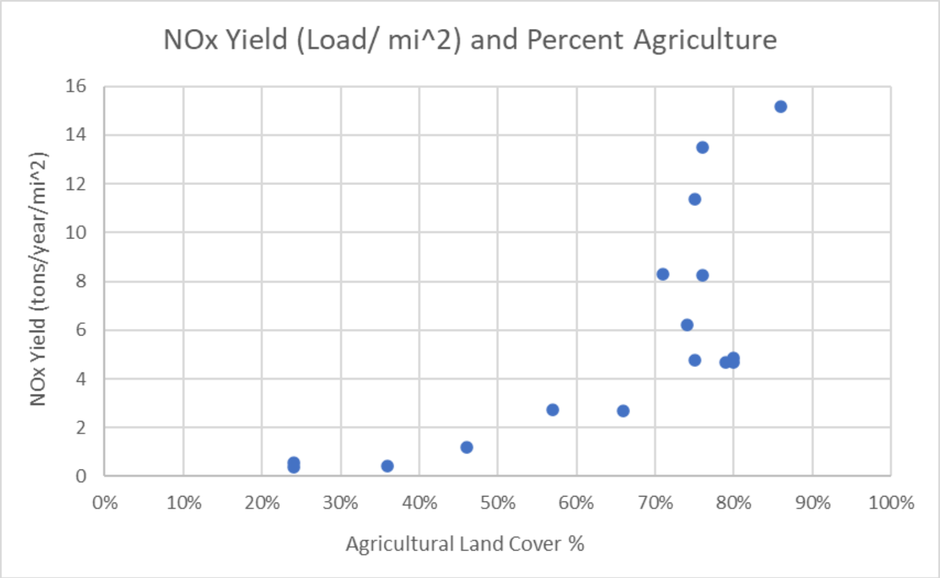
Example: Drainage Area >67% ag (mi^2) x Avg Nutrient Yield in Part 1 and 2 streams with >67% ag (tons/year/mi^2) = Approx. nutrient load (tons/year)

"Tipping Point" in Nutrient Yield if Agricultural Land Cover >~65-70%

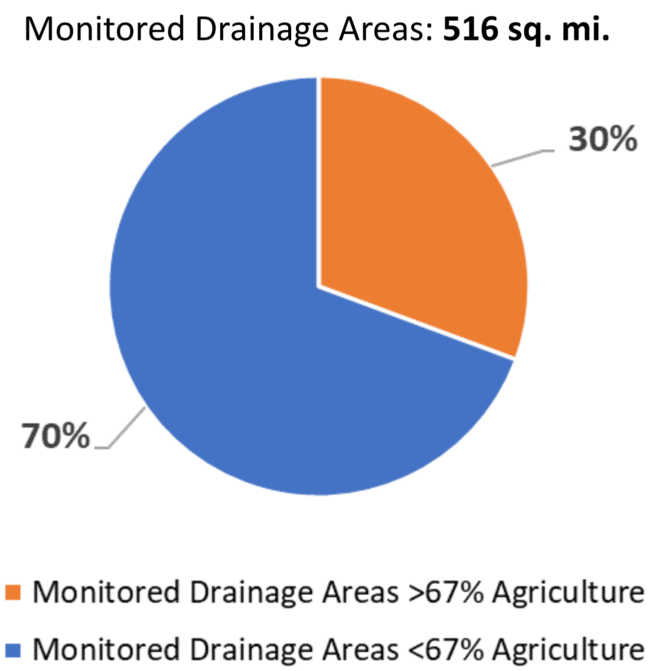


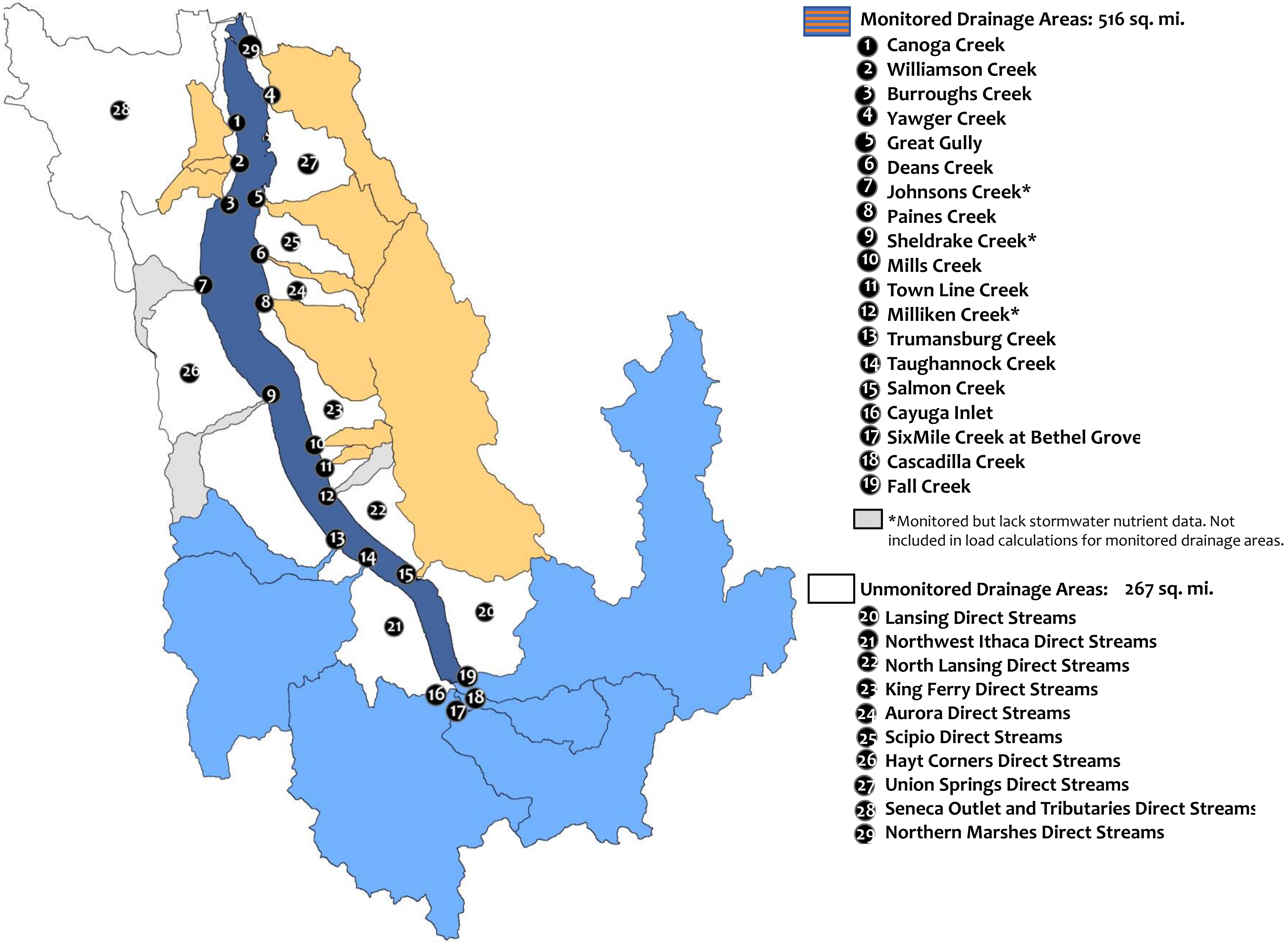






Drainage Areas in the Cayuga Lake Watershed Monitored by CSI Volunteers and Grouped by Two Agricultural Land Cover Categories based on NLCD





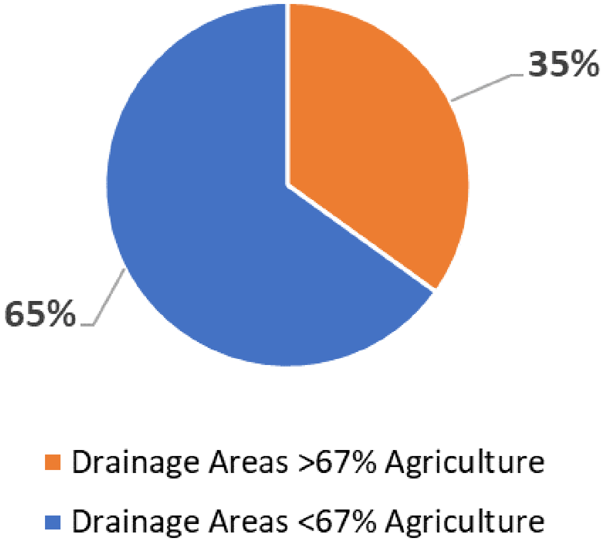
Approximated Nutrient Loads in Ungauged, Unmonitored Drainages Based on Yields Extrapolated From Bootstrap Parts 1 and 2 Monitored Drainages

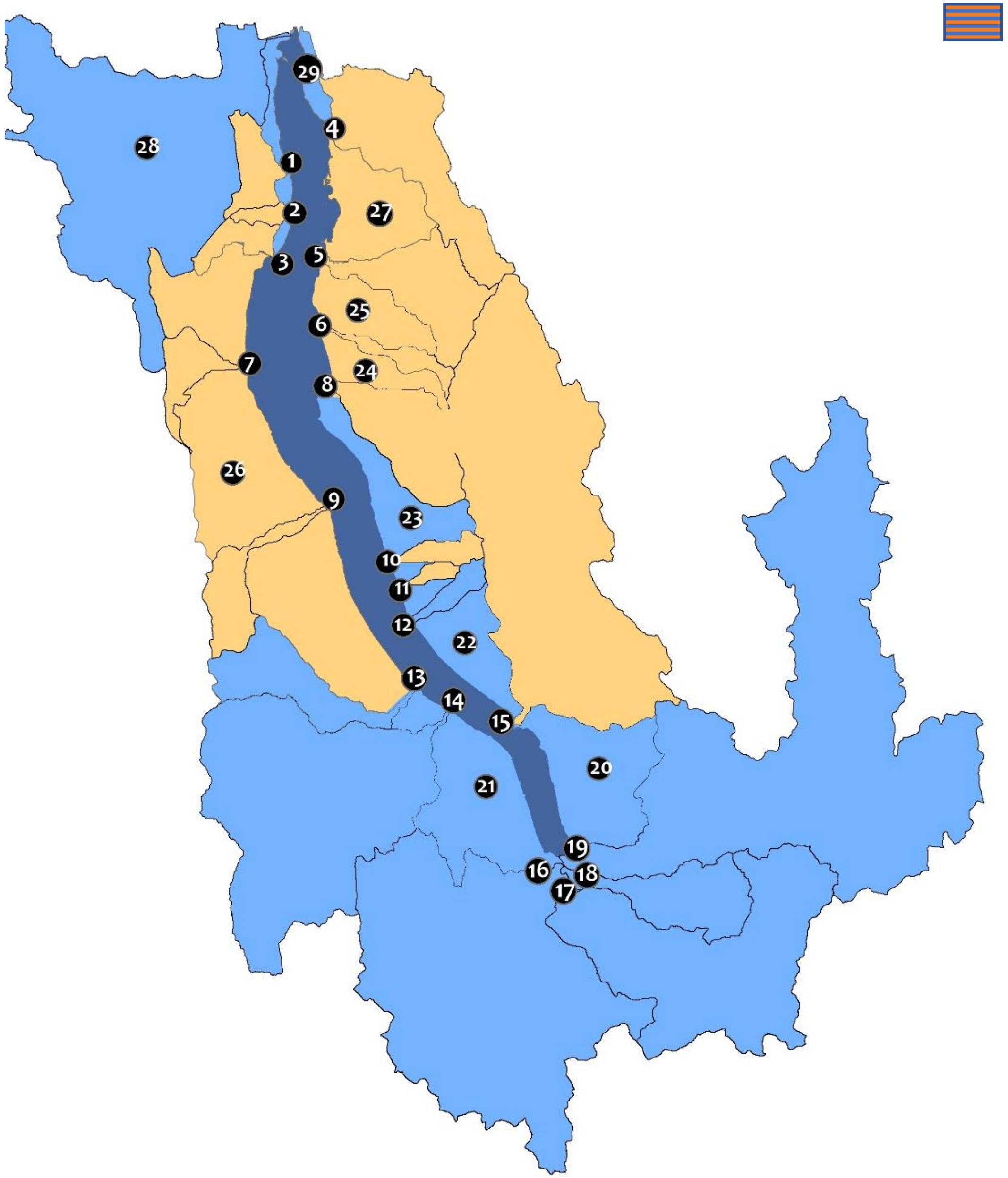
Unmonitored Drainages within Cayuga Lake Watershed			**Approximated Loads (drainage area x average yield in monitored drainages for either <67% or >67% agriculture category)**			
Watershed	**Drainage Area (mi^2)**	**Percent Agriculture**	**SRP Load (tons/year)**	**TP Load (tons/year)**	**NOx Load (tons/ 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 in NLCD

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 Power of Long-term Nutrient Data Sets Collected with Dedicated Volunteer Partner Groups

- Long-term nutrient data sets covering 16 sub-watersheds and 2/3 of the Cayuga Lake drainage make it possible to leverage approximations of phosphorus and nitrogen loading that would otherwise not be possible.
- “Bootstrap estimates” based on long-term certified nutrient measurements fill a huge data void while empowering community volunteers to become stewards of their local water bodies.
- “Bootstrap estimates,” while unconventional, nevertheless provide loading estimates that are sufficiently accurate to encourage future modeling efforts and support nutrient management strategies.

Bootstrap Impact 1: Correct SRP and TP 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 this same SWAT model to estimate phosphorus loading across the entire Cayuga Lake watershed <u>without collecting actual 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 and loading 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

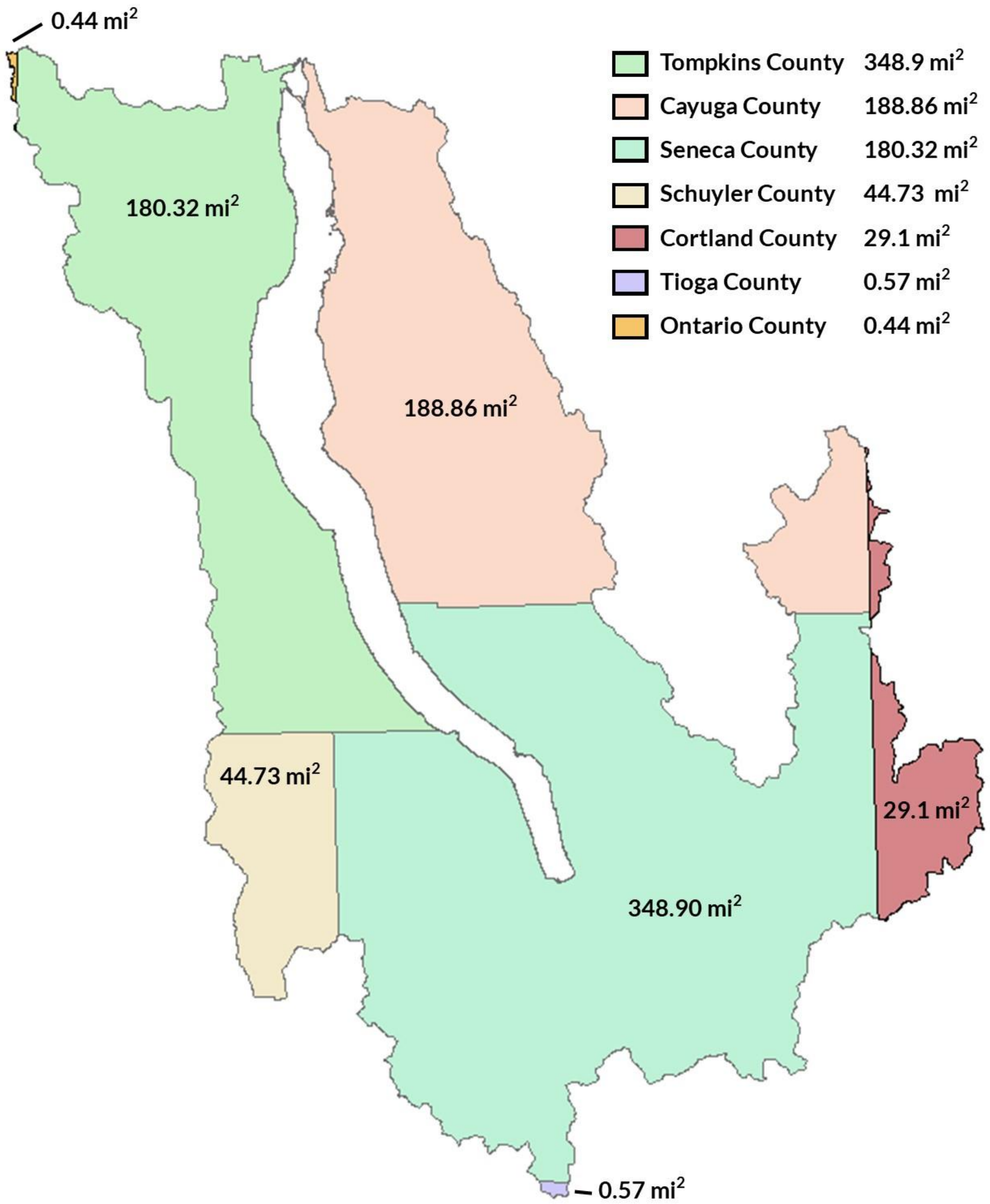
Draft TMDL Comment Table 2						
Comparison of Draft TMDL with Three Independent Total Phosphorus Loading Estimates (short tons/year)						
Watershed	Draft TMDL, Table 16 (2021)		CSI (2021)[a]	Haith et al (2012)[b]	Likens (1970-71)[b,c]	
Fall Creek	21.6		19.6	18.6	22.8	
Combined Cayuga Inlet[d]	17.0		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			

Bootstrap Impact 2: Apportioning Nutrient Loading to Counties Bordering Cayuga Lake

- As we have seen, nutrient loading is correlated with agricultural land use as defined by the National Land Cover Database
- In addition to the absolute number of acres in agriculture, nutrient loading is impacted by the percent of a stream's drainage area in agriculture, as defined by the NLCD
- When the percent of agricultural land in a stream's drainage exceeds approximately 67% based on the NLCD, the nutrient concentration in runoff, i.e., the nutrient yield, reaches a "tipping point" and rises sharply
- How are these high yield drainages distributed in counties around Cayuga Lake?

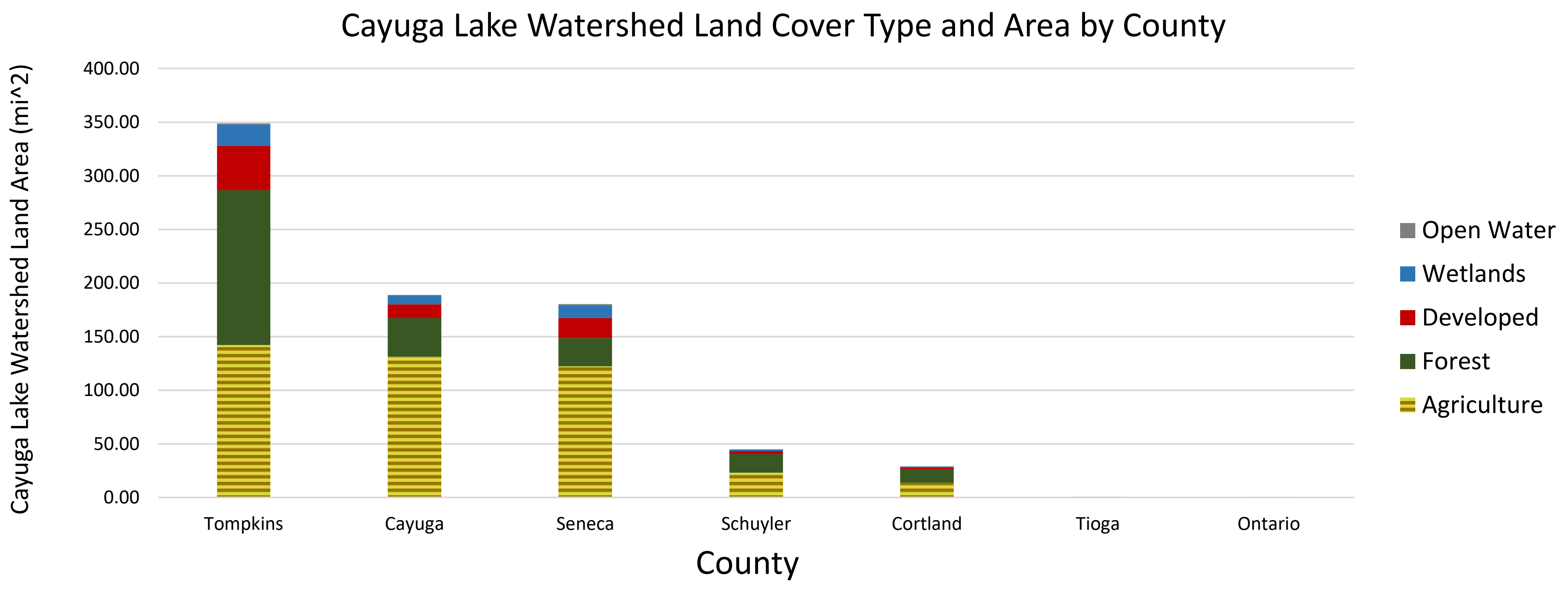
Cayuga Lake Watershed Land by County

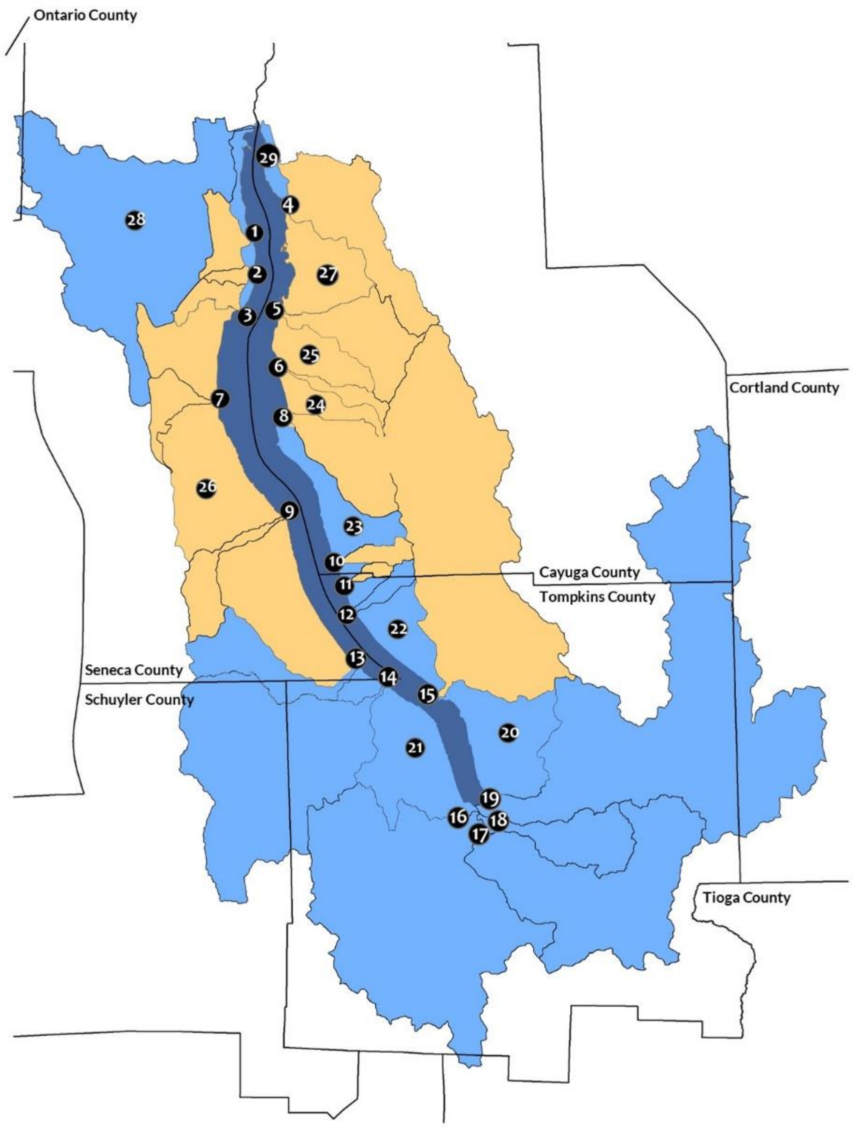
Community Science Institute • www.communityscience.org • info@communityscience.org



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/





Monitored Drainage Areas: 516 sq. mi.

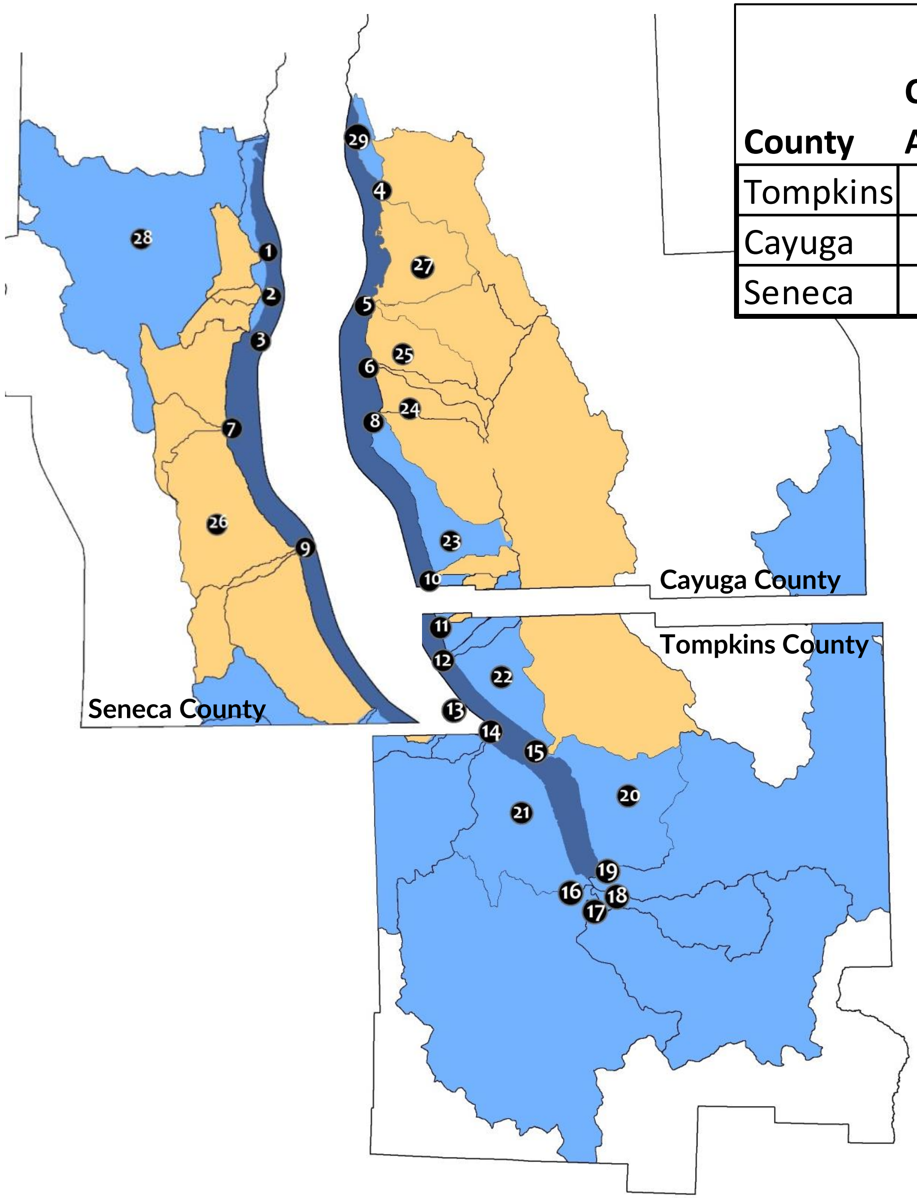
1. Canoga Creek
2. Williamson Creek
3. Burroughs Creek
4. Yawger Creek
5. Great Gully
6. Deans Creek
7. Johnsons Creek*
8. Paines Creek
9. Sheldrake Creek*
10. Mills Creek
11. Town Line Creek
12. Milliken Creek*
13. Trumansburg Creek
14. Taughannock Creek
15. Salmon Creek
16. Cayuga Inlet
17. SixMile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

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%



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.

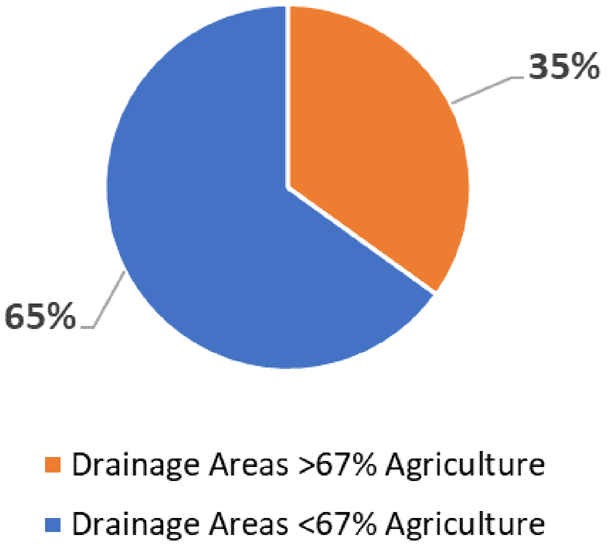
Unmonitored Drainage Areas: 267 sq. mi.

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

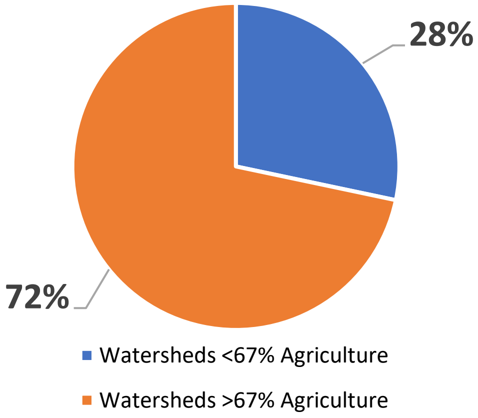
Total Cayuga Lake Watershed Nutrient Loads from Two Agricultural Land Cover Categories

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

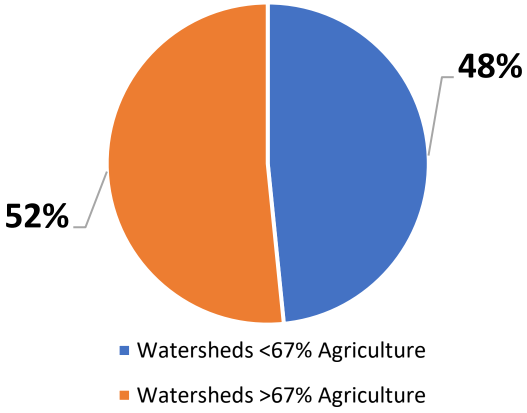
***sum of monitored and unmonitored drainage areas listed in the tables**



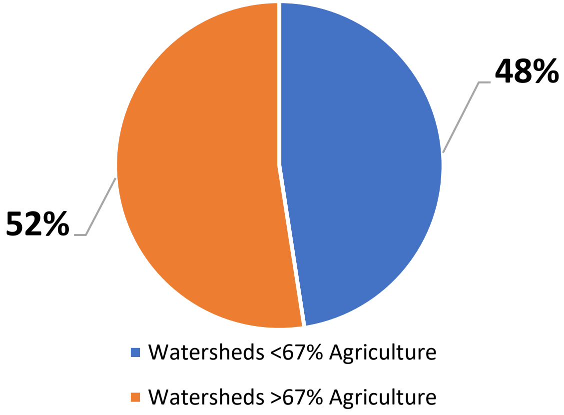
Total Watershed SRP Load:
49 tons/ year



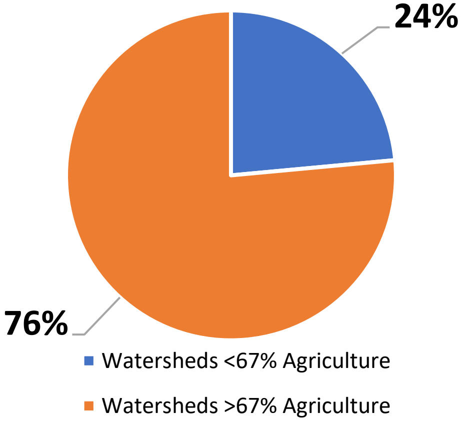
Total Watershed TP Load:
124 tons/ year



Total Watershed TKN Load:
836 tons/ year

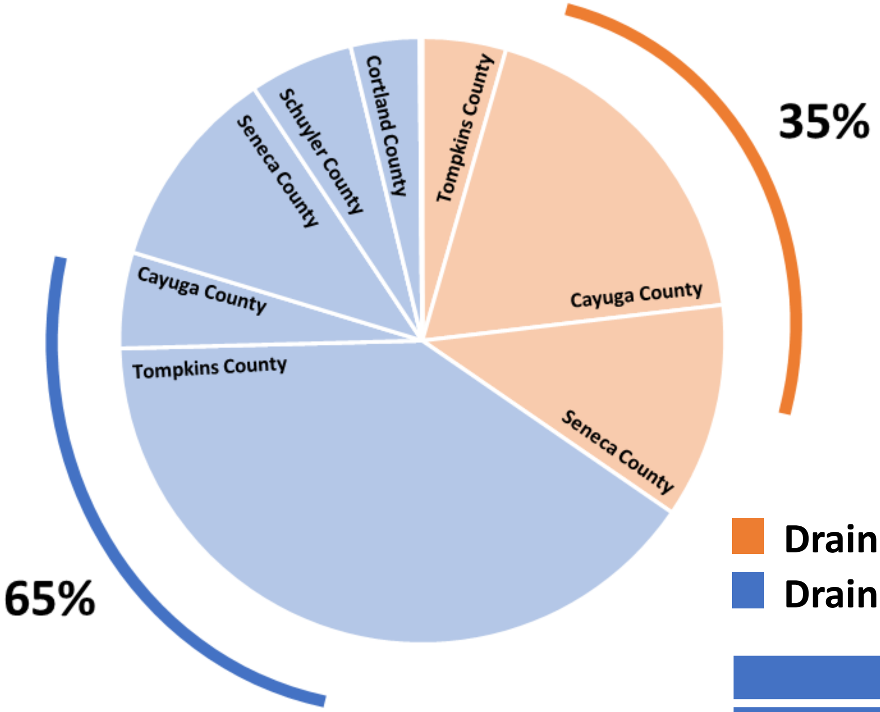


Total Watershed NOx Load:
2,761 tons/ year



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

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



Drainage Areas >67% Agriculture

Drainage Areas <67% Agriculture

		Counties' Nutrient Loads and Yields							
		Nutrient Load (tons/year)				Nutrient Yield (tons/year/mi^2)			
County	Drainage Area within Cayuga Lake Watershed	SRP		TP		NOx		TKN	
		Load	Yield	Load	Yield	Load	Yield	Load	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

Summary and Conclusions

- Stream monitoring partnerships with volunteer groups have generated long-term certified nutrient data sets in 16 drainages comprising 2/3 of the Cayuga Lake watershed
- These comprehensive, long-term data sets make it possible to leverage useful approximations of phosphorus and nitrogen loading to Cayuga Lake including SRP, TP, NOx and TKN
- Agriculture impacts nutrient loading in two ways: a) By total number acres, and b) By the fraction of a drainage in agriculture, i.e., <> 67%
- The Draft TMDL underestimates SRP loading 3x and overestimates TP loading 2x based on CSI’s results and two published reports

Summary and Conclusions (cont'd)

- Tompkins County has roughly twice as much land area in the Cayuga Lake watershed as either Cayuga County or Seneca County
- All three counties have approx. equal amounts of land in agriculture
- Tompkins County loads significantly less dissolved phosphorus and dissolved nitrogen to Cayuga Lake than Cayuga County and roughly the same amount as Seneca County, apparently because its drainages are <67% agriculture and nutrient yields are lower
- Tompkins County loads greater amounts of TP and TKN, which are nutrient forms that have a significant soil-bound component

General Recommendations

- In Tompkins County, consider prioritizing erosion control in order to manage soil-bound nutrients
- In Cayuga and Seneca Counties, consider prioritizing reduction of fertilizer and manure runoff to manage dissolved nutrients
- Investigate “hot spots” of soil erosion and nutrient runoff using CSI’s public online database to guide additional investigative sampling by volunteer teams
- Incorporate volunteer-CSI nutrient monitoring programs into best management practices (BMPs)
- Discontinue any BMP where monitoring shows nutrient levels are not reduced

Nine Element Plan for Cayuga Lake

- The long-term certified nutrient data sets in the CSI database can be used to initiate development of one or more Nine Element Plans for managing phosphorus and nitrogen loading from southern and northern tributary streams of Cayuga Lake
- CSI data for tributaries of Seneca and Keuka Lakes have previously been used to launch a Nine Element Plan for the Keuka-Seneca Lake Watershed
- Alternatively, CSI data can be used to improve the draft TMDL with respect to a) Phosphorus loading estimates, and b) The equitable allocation of SRP and TP load reductions among county and municipal governments and stakeholders

Acknowledgements

- Nate Launer, CSI’s former Director of Outreach, assisted 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 succeeded me as CSI Executive Director last month