

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

Presentation to the Water Resources Council
of Tompkins County

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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 concentration measurements and flows
- Distinguish between dissolved (100% bioavailable) and soil-bound (less bioavailable) nutrient fractions
- Distinguish between anthropogenic and natural sources of nutrients
- Implementation of BMPs by local governments and stakeholders
- Monitor nutrient reduction and discard ineffective BMPs

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 estimate 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

Parts 1 and 2 loads are used to extrapolate yields to unmonitored drainages. Drainage basin area is multiplied by yield 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.

Bootstrapping 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 (mi²)	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 mi² / 126 mi²

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

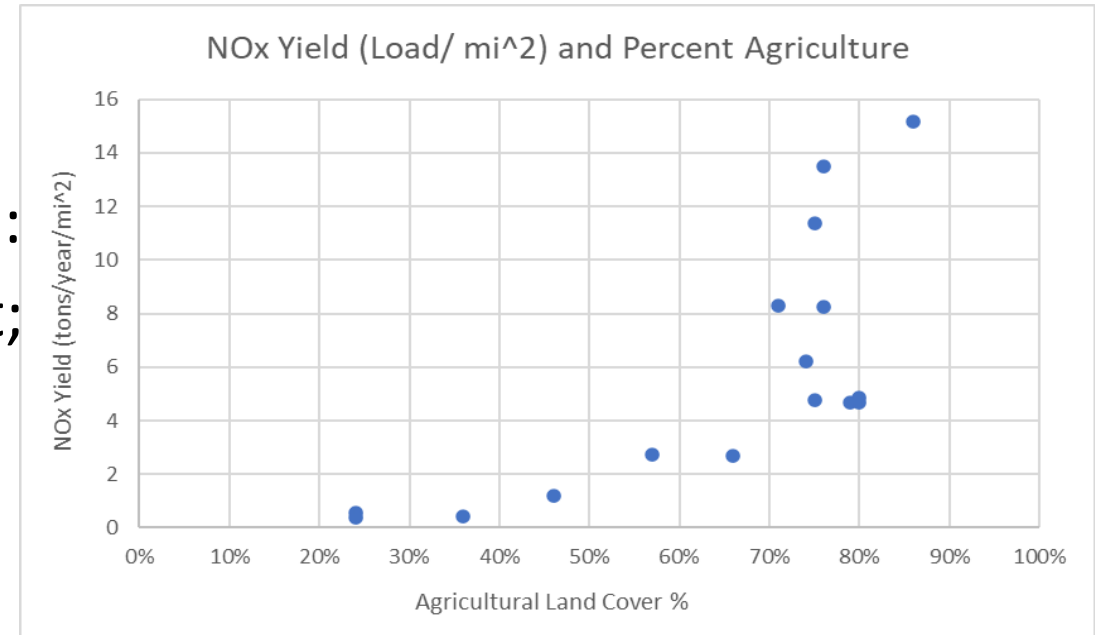
**Bootstrap Part 1 Six Mile Creek SRP Load calculated using LOADEST software =
0.85 tons/year**

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 Approximated Yields

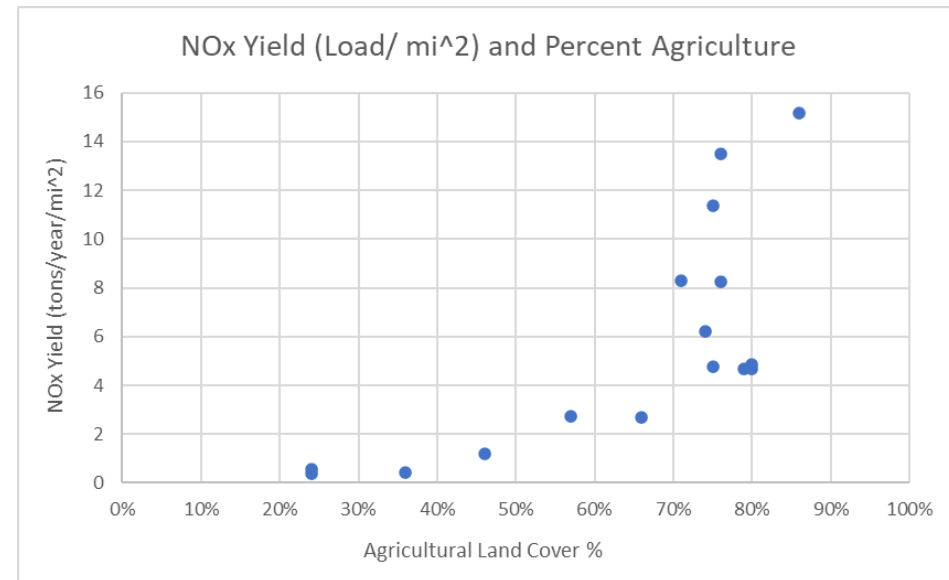
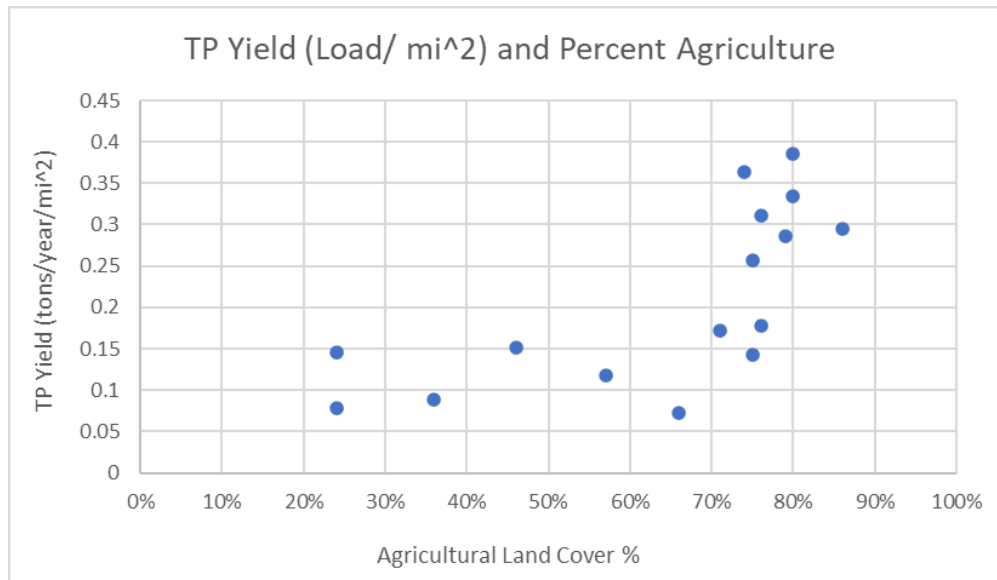
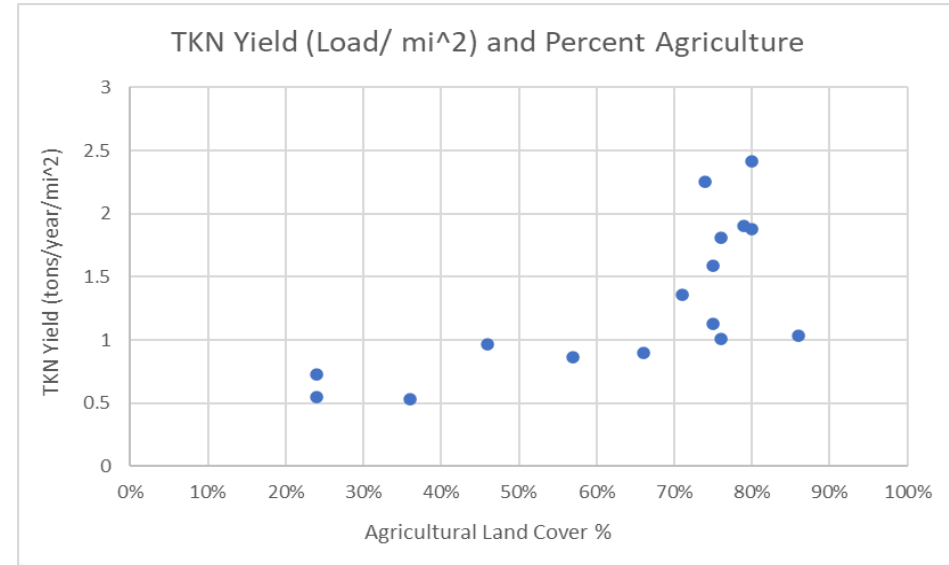
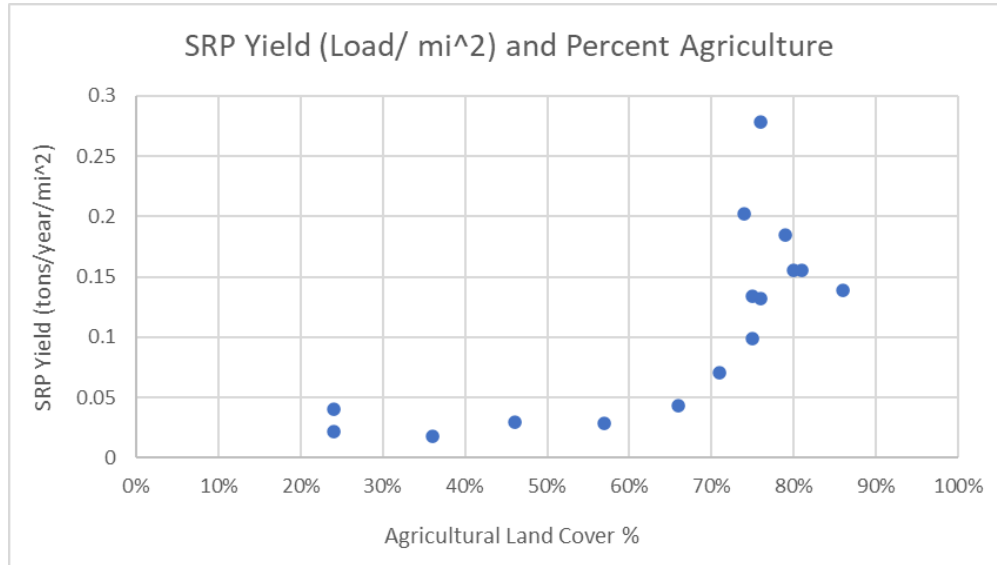
- Surprisingly, nutrient yields in Bootstrap Part 1 and 2 streams are biphasic with respect to % ag land use: <67% agriculture, they are almost flat; >67% agriculture, they rise sharply. This empirical observation of ~order-of-magnitude differences in yield



provides an opportunity to estimate loads for drainages <67% and >67% ag.

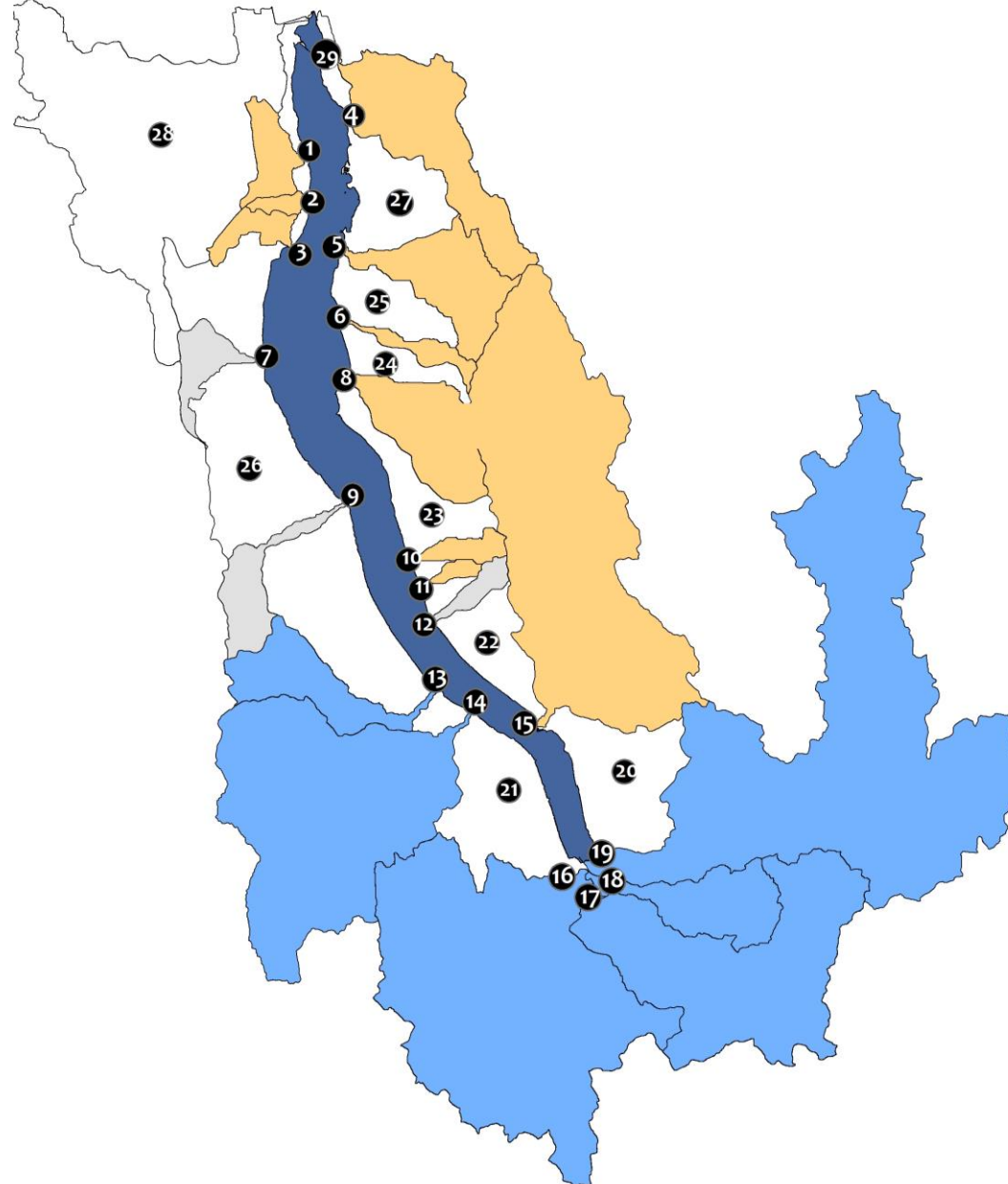
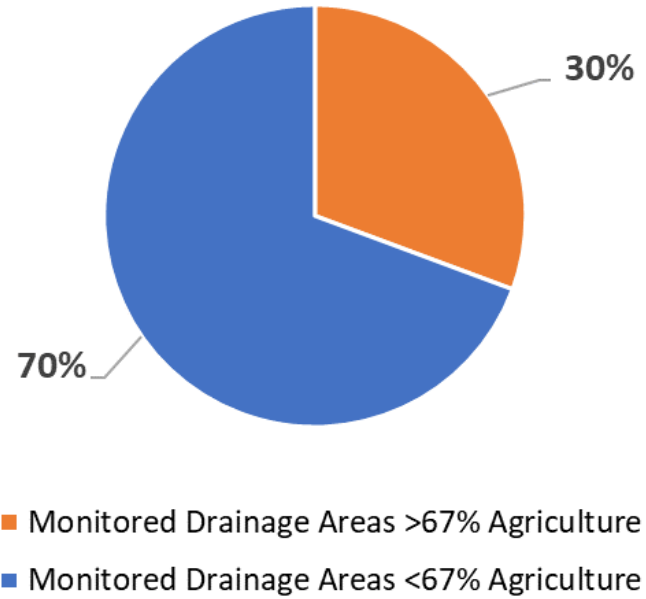
Example: Drainage Area >67% ag (mi²) x Avg Nutrient Yield in Part 1 and 2 streams with >67% ag (tons/year/mi²) = Approx. nutrient load (tons/year)




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



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

Monitored Drainage Areas: **516 sq. mi.**



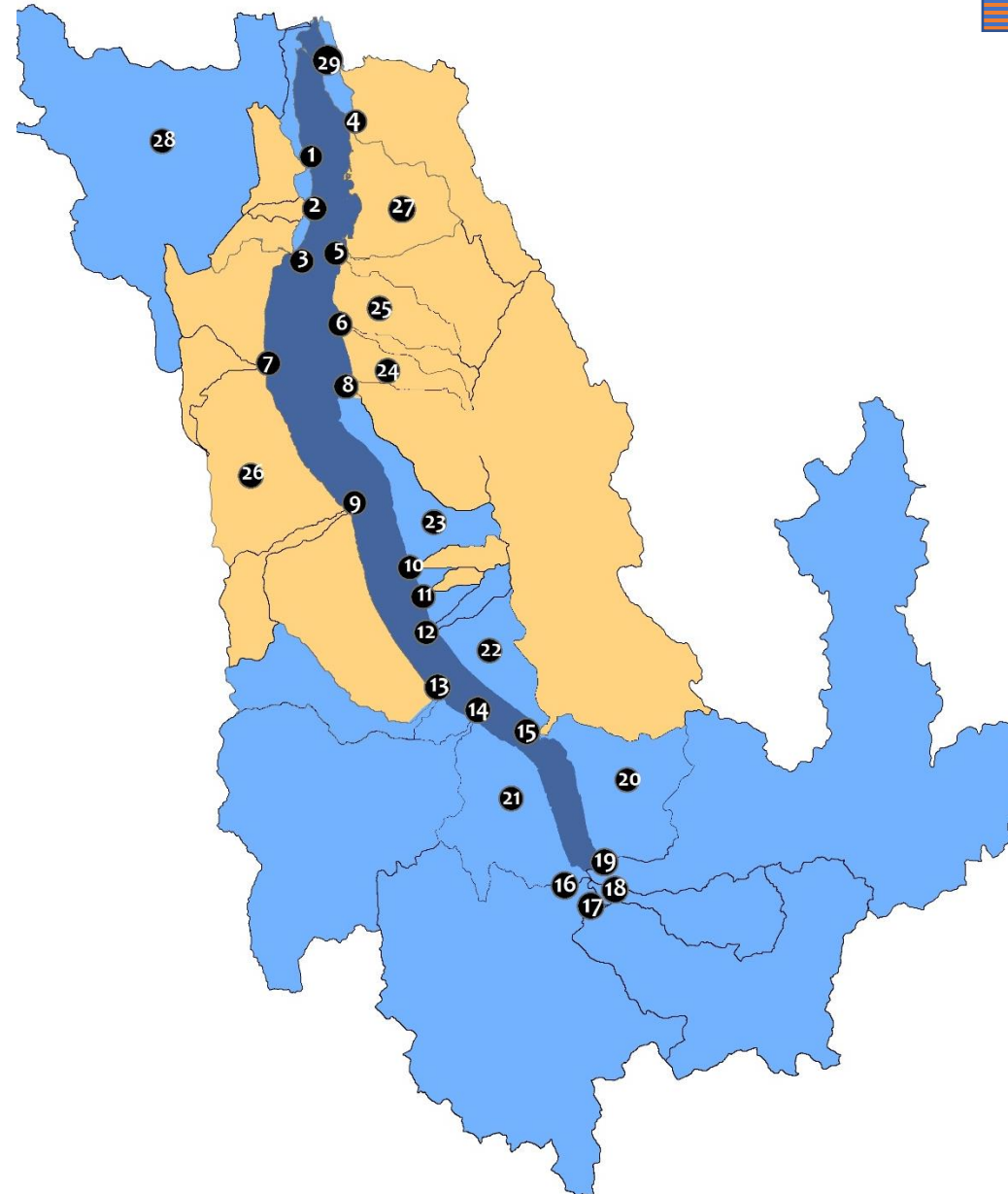
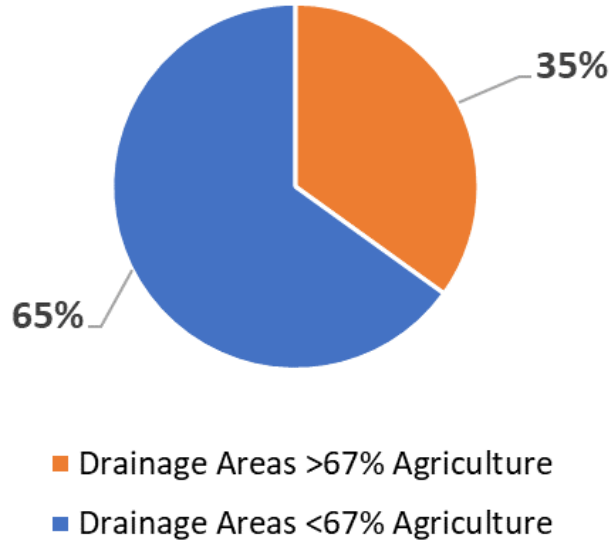
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 - 2** Williamson Creek
 - 3** Burroughs Creek
 - 4** Yawger Creek
 - 5** Great Gully
 - 6** Deans Creek
 - 7** Johnsons Creek*
 - 8** Paines Creek
 - 9** Sheldrake Creek*
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 - 14** Taughannock Creek
 - 15** Salmon Creek
 - 16** Cayuga Inlet
 - 17** SixMile Creek at Bethel Grove
 - 18** Cascadilla Creek
 - 19** Fall Creek
 -  **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
-  *Monitored but lack stormwater nutrient data. Not included in load calculations for monitored drainage areas.

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	TP Load	NOx Load	TKN Load				
			(tons/year)	(tons/year)	(tons/ year)	(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*
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- ⑮ Salmon Creek
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- ㉙ Northern Marshes Direct Streams

Pause to Consider the Value of “Bootstrapping” Loading Estimates on the Basis of Long-term Nutrient Data Sets Collected with Dedicated Volunteer Partner Groups

- Bootstrap estimates address a yawning void in data-driven assessments of phosphorus and nitrogen loading in the northern half of the Cayuga Lake watershed.
- Bootstrap estimates empower community volunteers who collect stream samples year after year, building data sets that reliably characterize nutrient concentrations under diverse flow conditions.
- Bootstrap estimates, while imperfect and unconventional, nevertheless provide estimates of phosphorus and nitrogen loading in Cayuga Lake tributary streams that are sufficiently accurate to guide nutrient management strategies

Bootstrap Guidance 1: Correct 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 without collecting nutrient data to validate the model in northern tributary streams
- 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				

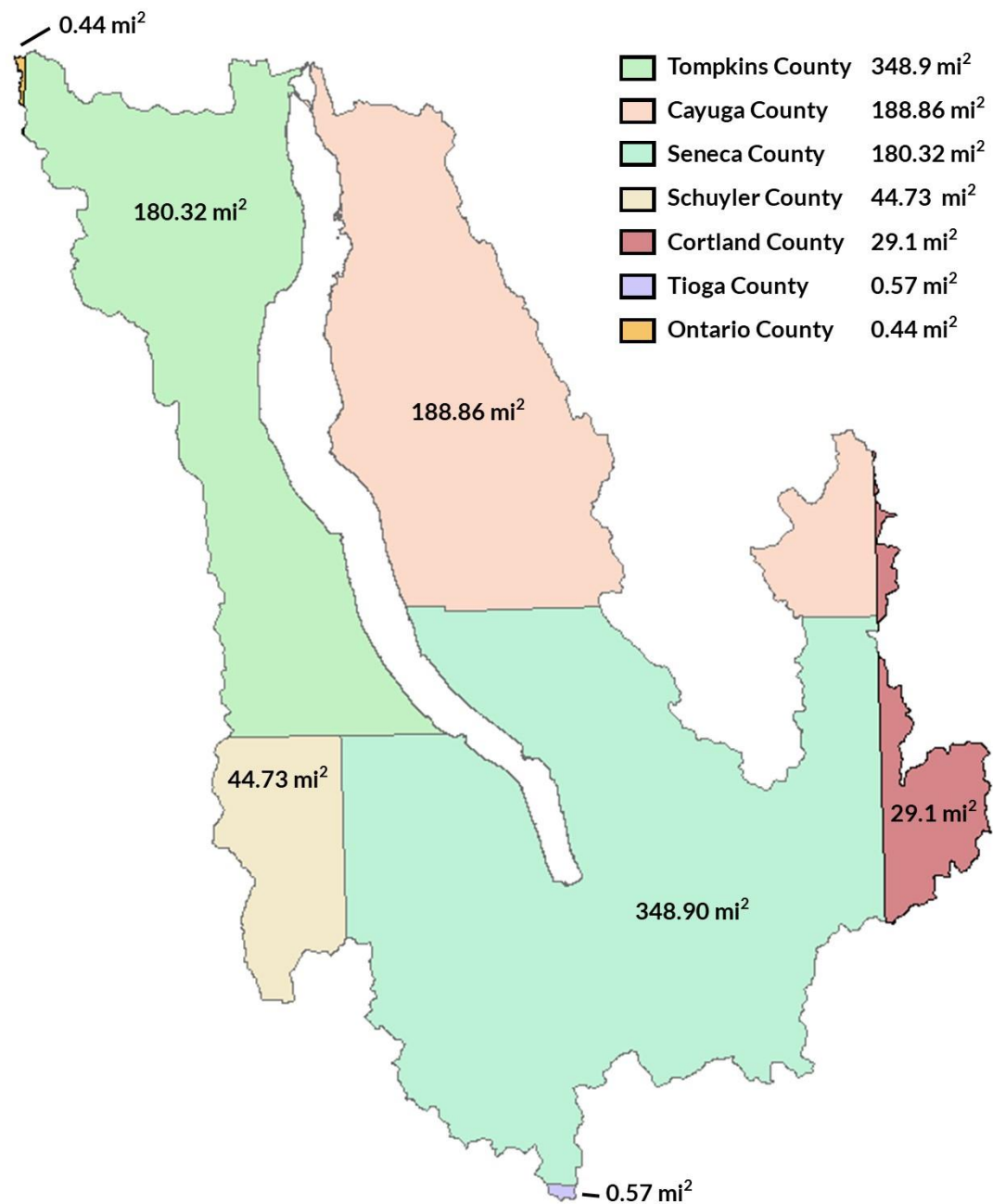
Bootstrap Guidance 2: Allocating Nutrient Loading in Counties Bordering Cayuga Lake

- 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 the high yield drainages distributed in counties around Cayuga Lake?



Cayuga Lake Watershed Land by County

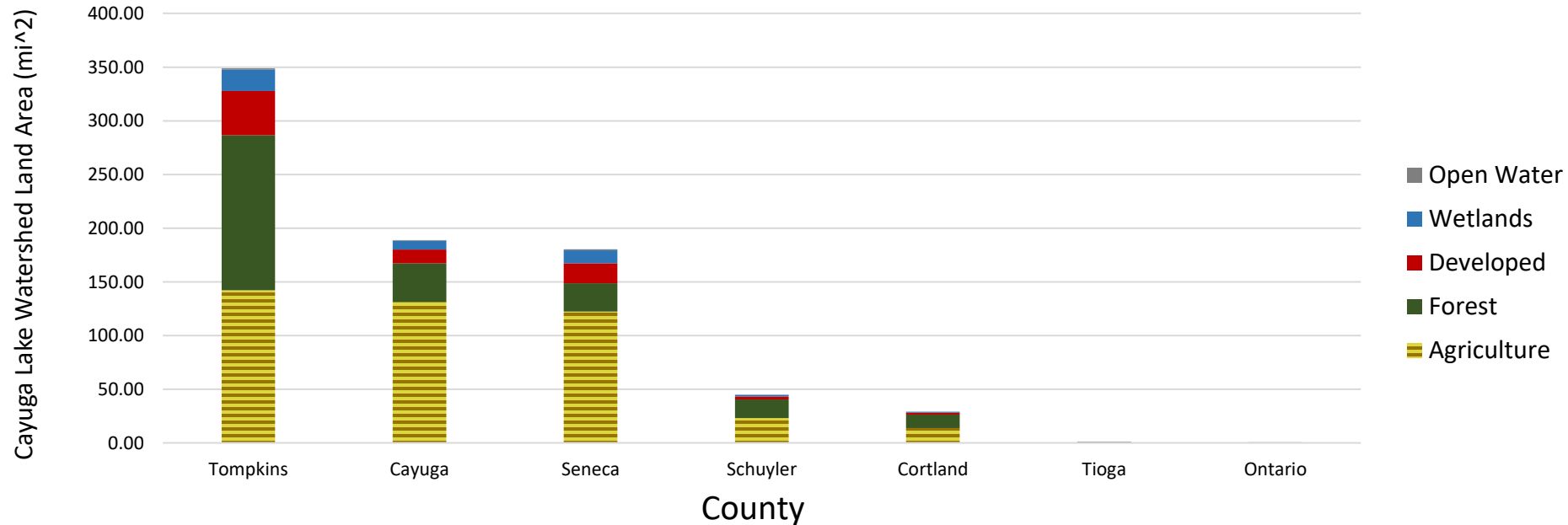
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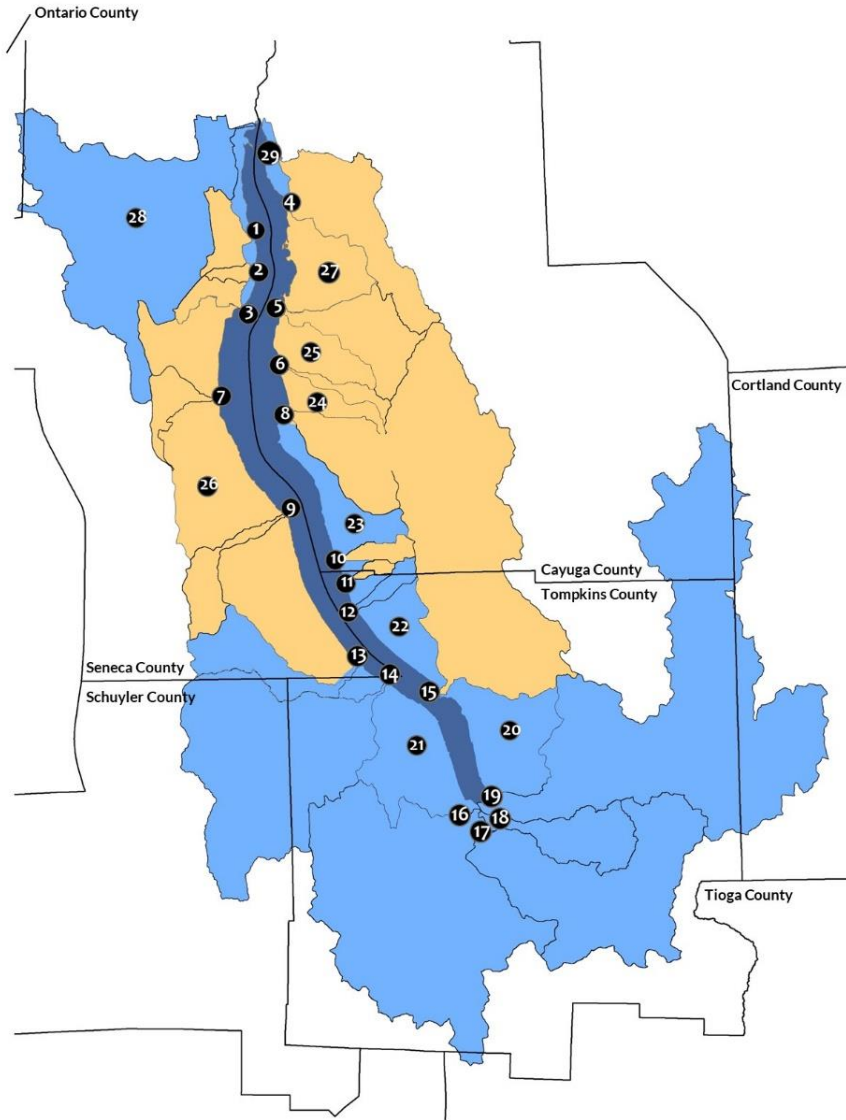


Cayuga Lake Watershed (CLW) Land Cover Type and Area by County												
County	Total Land (mi ²)	Percent of CLW Total Land	Agricultural Land (mi ²)	Percent of CLW Agricultural Land	Forested Land (mi ²)	Percent of CLW Forested Land	Wetlands (mi ²)	Percent of CLW Wetlands	Developed Land (mi ²)	Percent 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/>

Cayuga Lake Watershed Land Cover Type and Area by County





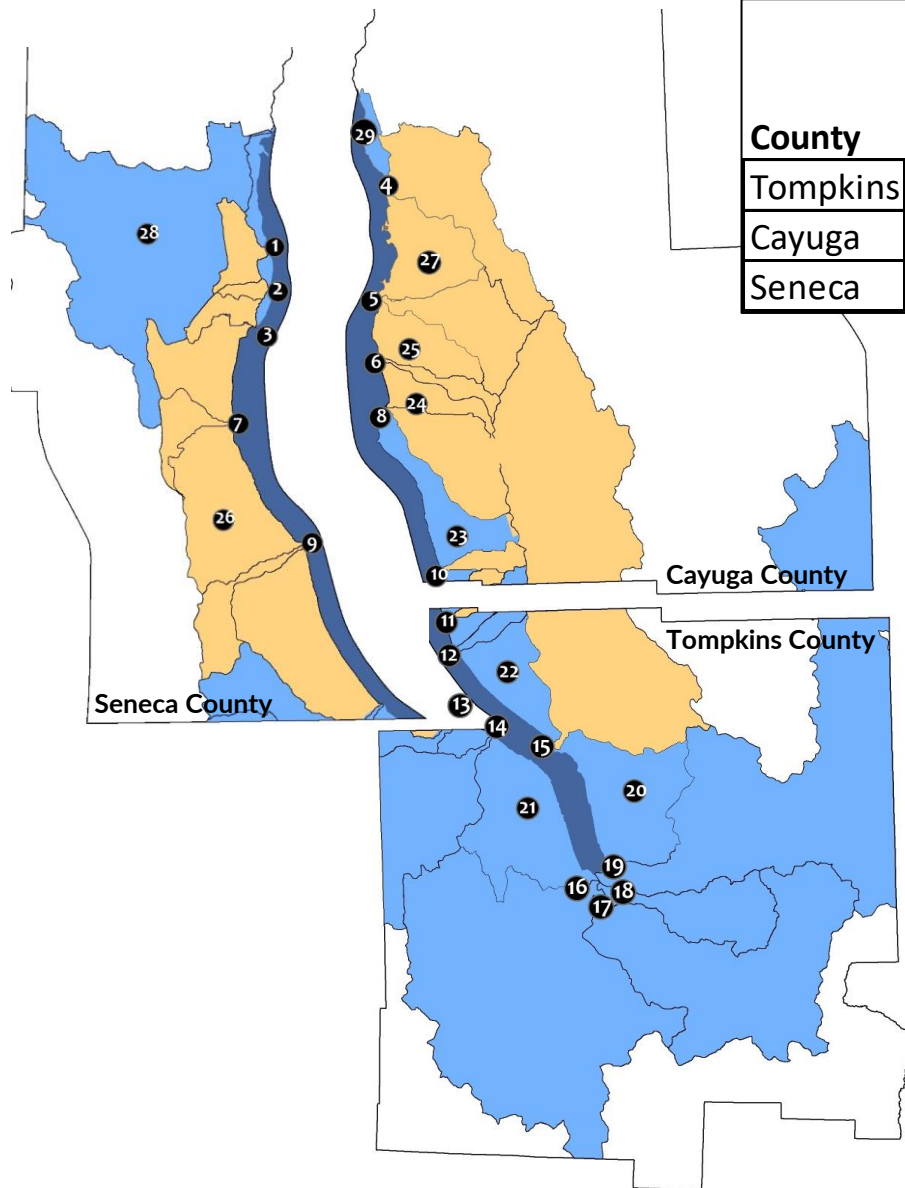
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- 29 Northern Marshes Direct Streams



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.

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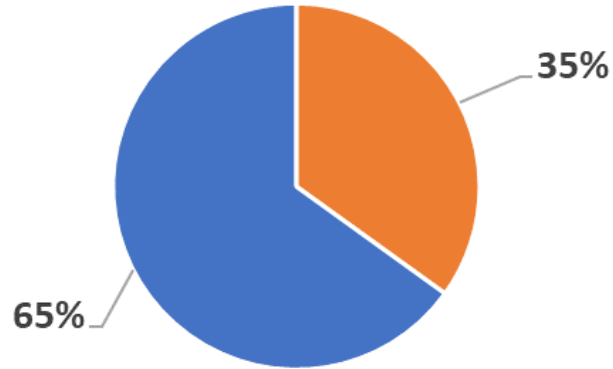
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Total Cayuga Lake Watershed Nutrient Loads from Two Agricultural Land Cover Categories

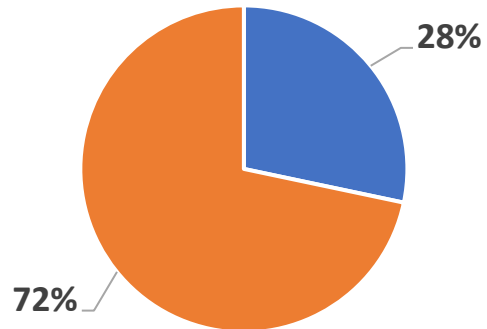
Monitored and Unmonitored Drainage Areas in the Cayuga Lake watershed: **782 sq. mi.***

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



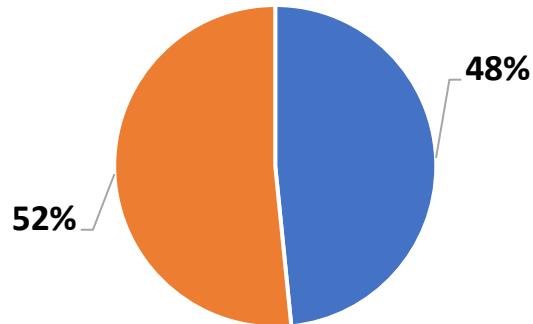
- Drainage Areas >67% Agriculture
- Drainage Areas <67% Agriculture

Total Watershed SRP Load:
49 tons/ year



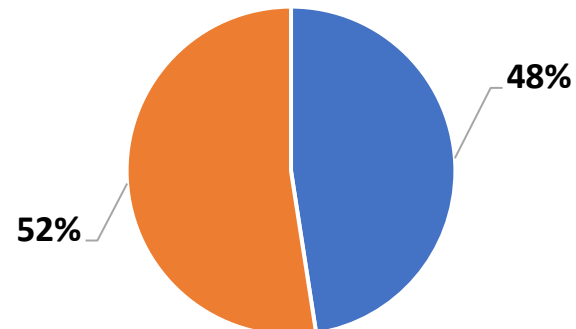
- Watersheds <67% Agriculture
- Watersheds >67% Agriculture

Total Watershed TP Load:
124 tons/ year



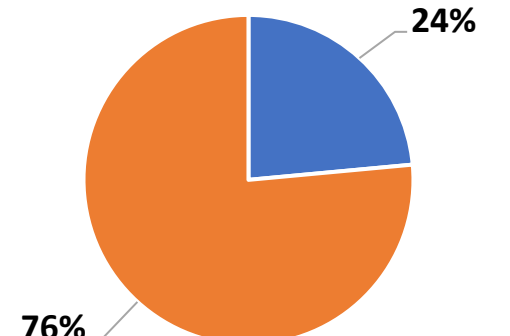
- Watersheds <67% Agriculture
- Watersheds >67% Agriculture

Total Watershed TKN Load:
836 tons/ year



- Watersheds <67% Agriculture
- Watersheds >67% Agriculture

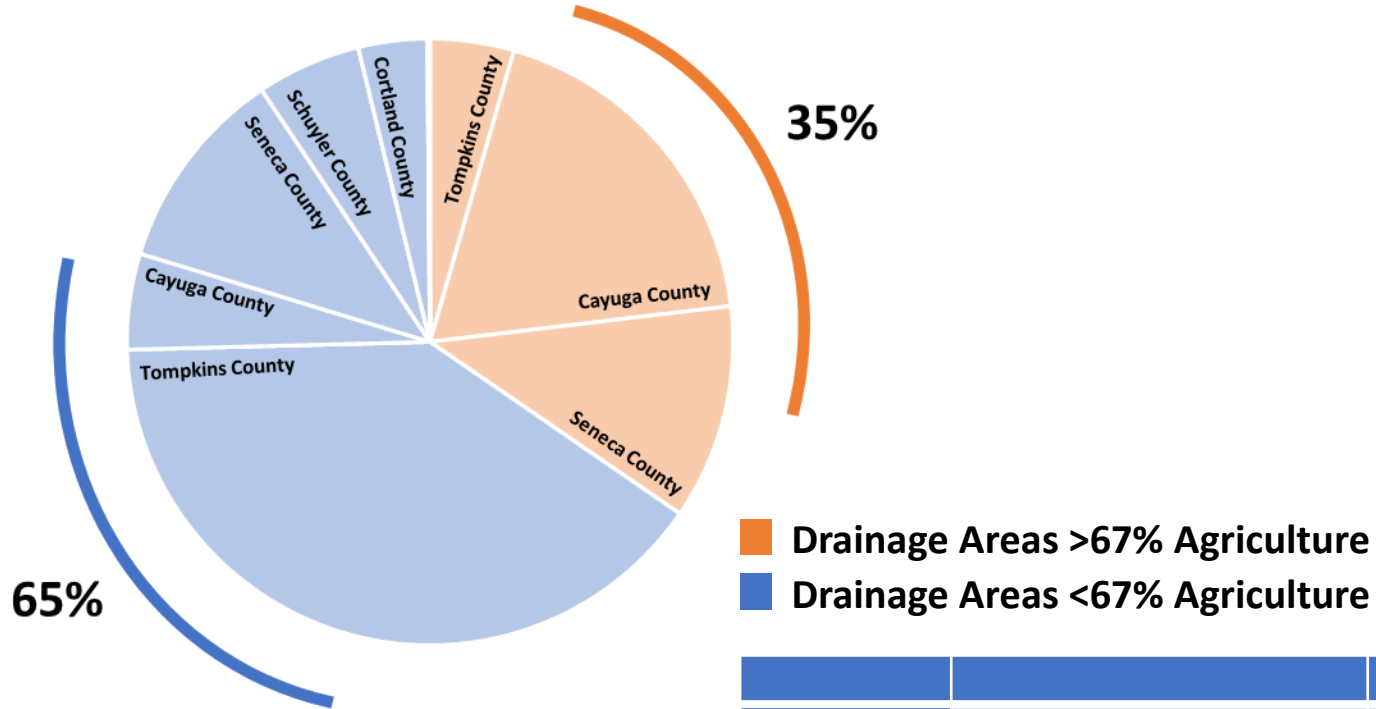
Total Watershed NOx Load:
2,761 tons/ year



- Watersheds <67% Agriculture
- Watersheds >67% Agriculture

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		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 nutrient data sets in drainages comprising 65% of the Cayuga Lake watershed
- These comprehensive, long-term data sets make it possible to obtain credible, useful estimates of phosphorus and nitrogen loading to Cayuga Lake including SRP, TP, NO_x and TKN
- Agriculture contributes to nutrient loading in two ways: a) The total number acres, and b) The fraction of a drainage in agriculture
- The Draft TMDL underestimates SRP loading 3x and overestimates TP loading 2x based on CSI's results and two published reports for the Cayuga Lake watershed

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 less dissolved phosphorus and dissolved nitrogen to Cayuga Lake than either Cayuga or 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 sampling by volunteers
- Include in best management practices (BMPs) the monitoring of nutrient levels
- Discontinue BMP if monitoring shows nutrient levels are not reduced

Nine Element Plan for Cayuga Lake

- The long-term 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
- 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 jurisdictions

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