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Photo: Finger Lakes Land Trust, Cayuga Lake Aug. 2, 2017, 4PM. FLLT Facebook post Aug 3.

The HABs – Nutrient Connection: Might Nitrogen Play a Central Role?

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HABs and Non-Point Source Pollution in the Finger Lakes:
Strategies for Addressing the Threat
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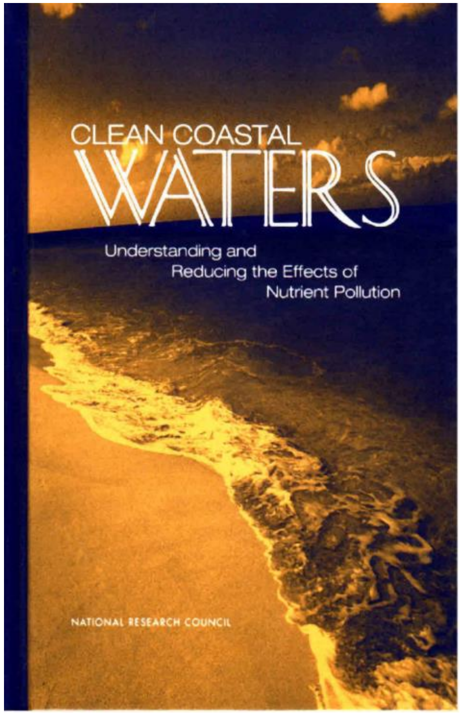
Management paradigm for eutrophication (excess phytoplankton growth, degrading water quality) **over the past several decades:**

Phosphorus is the key for freshwater lakes (since early 1970s).

Nitrogen is the key for estuaries and coastal marine ecosystems (since ~ 2000).

Important to keep in mind: Strategies for controlling non-point pollution differ for phosphorus and nitrogen.

Until 2009, I totally agreed with this paradigm, and in fact was central in developing the nitrogen control idea for coastal marine ecosystems over the past 35 years as distinct from what is needed for lakes.



Chair of National Academy of Science committee on coastal ocean water quality (2000)

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Briefing by Robert Howarth for the White House Office of Science and Technology Policy November 3, 2006

Science AAAS

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Controlling Eutrophication: Nitrogen and Phosphorus

Improvements in the water quality of many freshwater and most coastal marine ecosystems requires reductions in both nitrogen and phosphorus inputs.

Daniel J. Conley,[1]* Hans W. Paerl,[2] Robert W. Howarth,[3] Donald F. Boesch,[4] Sybil P. Seitzinger,[5] Karl E. Havens,[6] Christiane Lancelot,[7] Gene E. Likens[8]

The need to reduce anthropogenic nutrient inputs to aquatic ecosystems (eutrophication) in order to protect drinking water supplies and to reduce proliferation of harmful algal blooms (*1*) and "dead zones" in coastal marine ecosystems (*2*) has been widely recognized. However, the costs of doing this are substantial; hence, developing the appropriate nutrient management strategy is very important. Nitrogen (N), needed for protein synthesis, and phosphorus (P), needed for DNA, RNA, and energy transfer, both are

in the Experimental Lakes Area, Canada (*5*). These and other results (*6*) led to widespread reductions in P loading to North American and European lakes and consequent improvements in water quality (*7*). On the basis of lake examples, P controls were prescribed by environmental regulatory agencies for estuarine and coastal marine ecosystems as well (*8*). P-reduction programs improved water quality in many lakes, but broader water- and ecological-quality goals were not achieved, particu-

larly in estua nd coastal marine ecosystems. This le e general recognition of the need to con input to coastal waters (*9*).

In lake key symptom of eutrophication is cy cteria blooms. Planktonic N_2-fixing c acteria bloom in fresh waters when P plete and N availability is low. Such ms are undesirable, because cyano ria can be toxic, cause hypoxia, and d food webs (*1*, *10*). N_2 fixation by cyan teria also can help to alleviate N sho and hence maintain a lake in a P-

"Improvements in the water quality of many freshwater and most coastal marine ecosystems requires reduction in both nitrogen and phosphorus inputs."

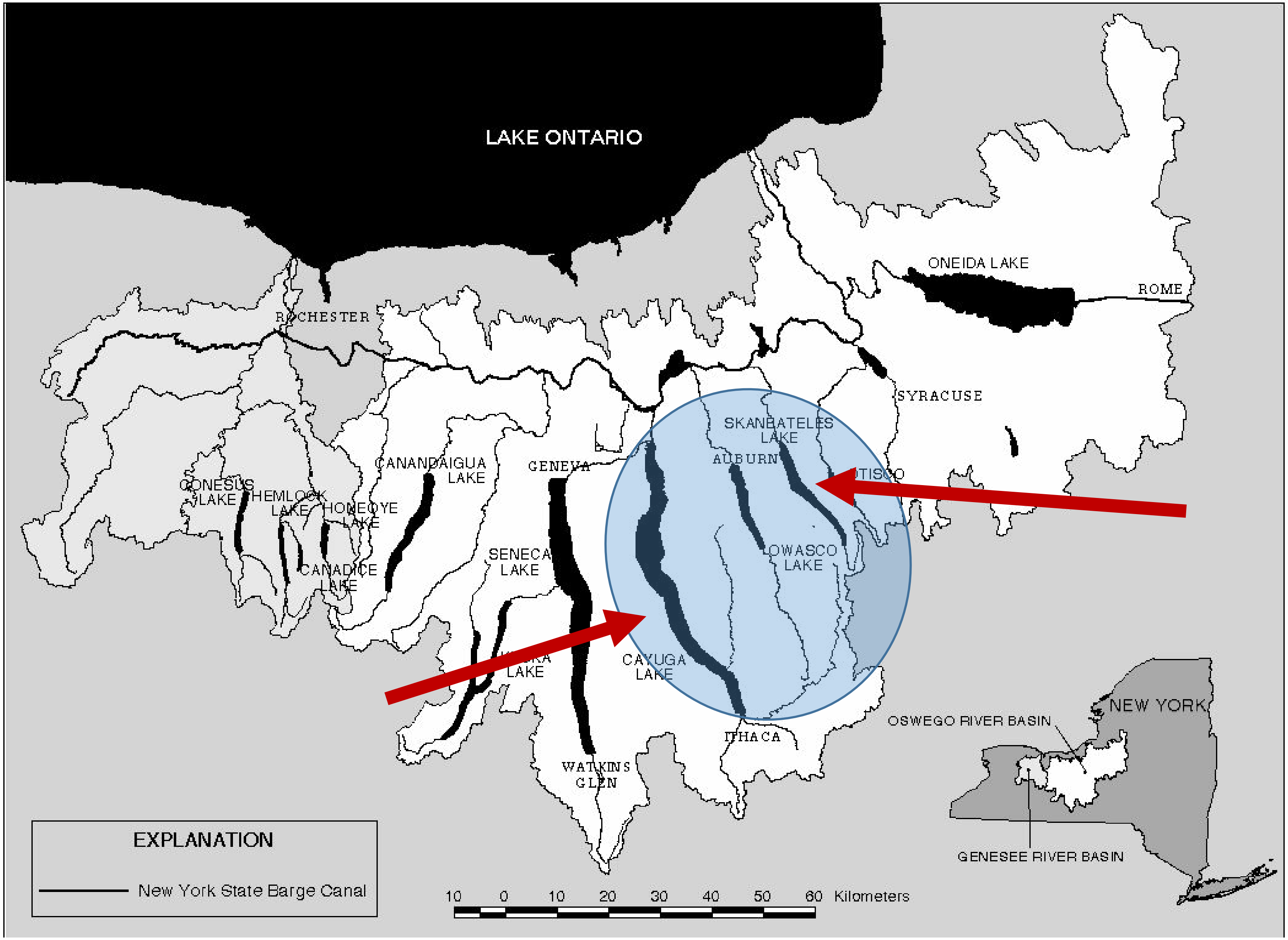
The first ever HABs in 2017 Cayuga and Skaneateles do not well fit the paradigm of phosphorus as culprit in freshwater.

Photo: Finger Lakes Land Trust, Cayuga Lake Aug. 2, 2017, 4PM. FLLT Facebook post Aug 3.

My tentative conclusion:

Eutrophication in lakes is a phosphorus problem, but these HABs (toxic cyanobacteria) are probably not tied to eutrophication.

We may need to control both phosphorus and nitrogen.


LAKE ONTARIO
ONEIDA LAKE
ROME
ROCHESTER
SYRACUSE
SKANEATELES LAKE
AUBURN
OTISCO
GENEVA
CANANDAIGUA LAKE
CONESUS LAKE
HEMLOCK LAKE
HONEOYE LAKE
CANADICE LAKE
SENECA LAKE
OWASCO LAKE
KEUKA LAKE
CAYUGA LAKE
ITHACA
WATKINS GLEN
NEW YORK
OSWEGO RIVER BASIN
GENESEE RIVER BASIN
EXPLANATION
New York State Barge Canal
10 0 10 20 30 40 50 60 Kilometers

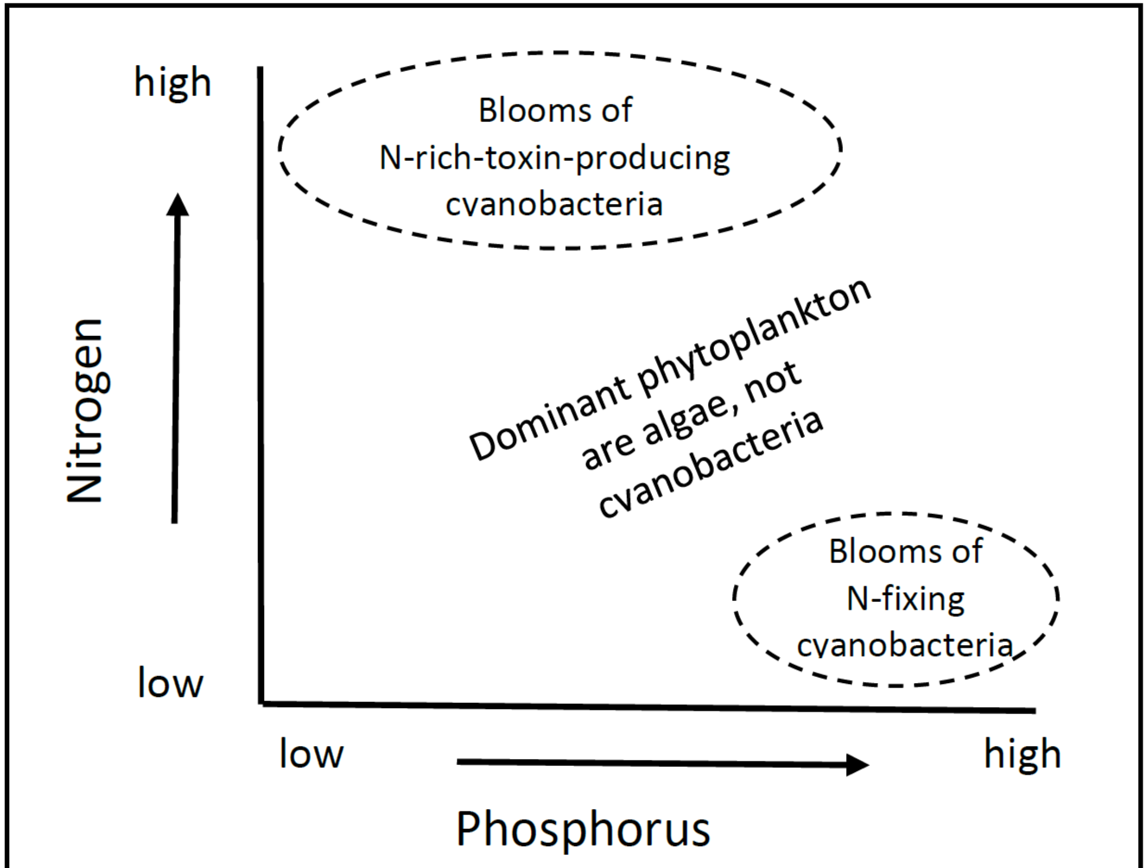
Skaneateles has been well protected against eutrophication from phosphorus for past 30 years.

Unfiltered drinking water supply for Syracuse, approved by NY State DOH because of this phosphorus protection (thanks to quality staff such as Ron Entringer).

The protection has worked well, and Skaneateles is far from eutrophic (phytoplankton production is low enough to classify the lake as oligotrophic, and is regulated by phosphorus and not be nitrogen; Brian Roberts, Cornell Ph.D. thesis, 2004.)

2017 HAB bloom in Cayuga a little less surprising than in Skaneateles, but not by much:

- Cayuga is not eutrophic (rather, mesotrophic).
- Both lakes have high N:P ratios, conditions not conducive to nitrogen-fixing cyanobacteria (which are often the bloom-forming phytoplankton elsewhere).
- Blooms tend to be favored by warm water and long sunny periods, yet 2017 blooms were in unusually cold water, and following long period of rain and clouds.



Conceptual diagram illustrating that bloom-forming cyanobacteria may have two ecological sweet spots, one with high P and low N inputs that favors N_2 fixation, and another of high N inputs that favors toxin production. Currently, water-quality management strategies focus only on the blooms by N_2-fixing cyanobacteria. This proposal focuses on the toxin-forming blooms.

Howarth et al. 2018 ACSF proposal

Production of microcystin toxin by cyanobacteria in mesocosm experiments in reservoirs in Arkansas dependent on N:P ratio

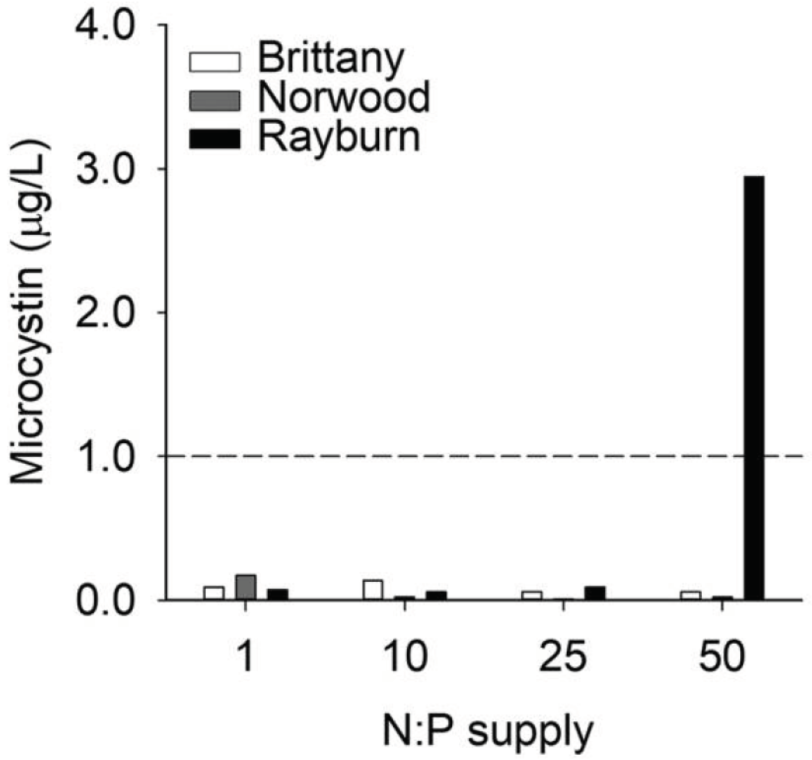
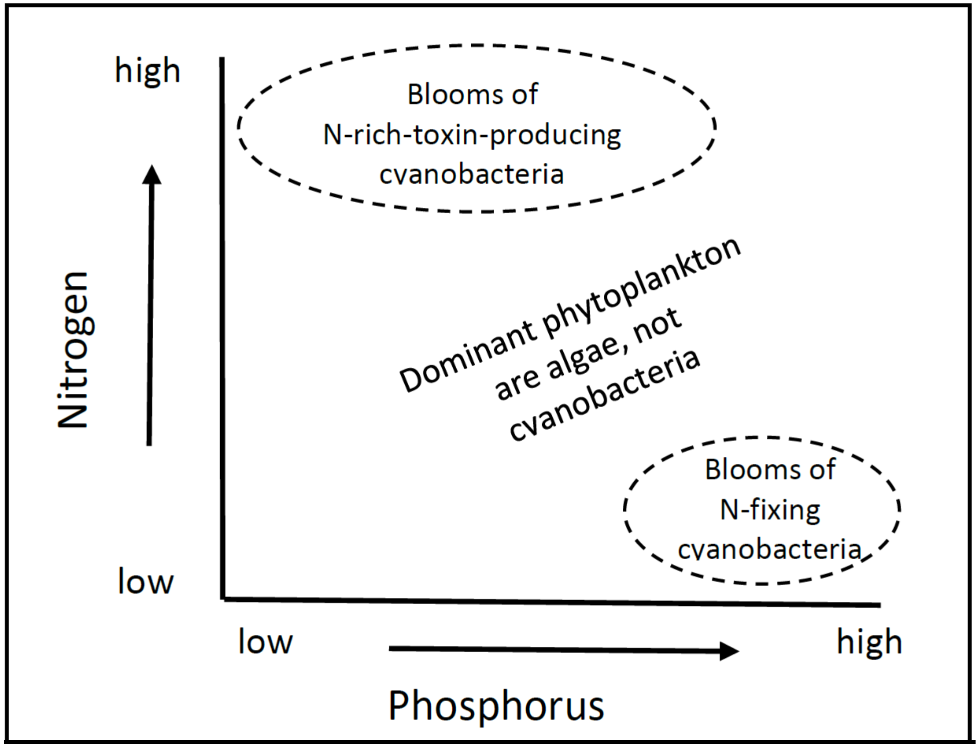


Figure 6. Microcystin measured from a subsample collected from a treatment composite sample (samples from all 3 mesocosms from that treatment combined) in each reservoir. Horizontal dashed line represents the World Health Organization's provisional guideline of 1 µg/L, above which concentrations are considered unsafe for human health.

Baker et al. 2018

The high nitrogen allows cyanobacteria to produce nitrogen-rich toxins which protect them from grazing by zooplankton.

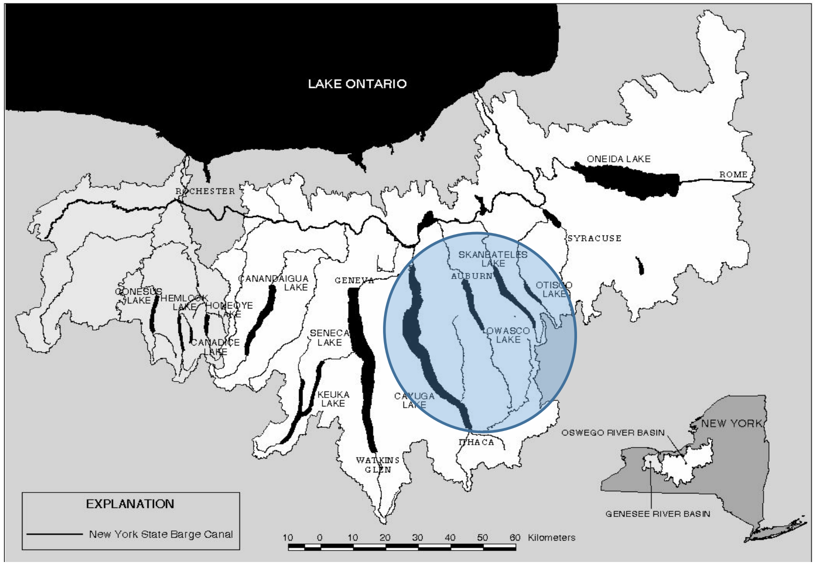
Even if they grow slowly (as in low-productivity lakes such as Skaneateles), they can bloom if they are not being grazed.



Howarth et al. 2018 ACSF proposal

So if nitrogen is the culprit, what happened in 2017?

- **2016 was an extremely dry year.**
- **Nitrogen built up in the landscape in 2016 as a result.**
- **Wet spring and summer in 2017 flushed this nitrogen into the lakes at unprecedented level.**



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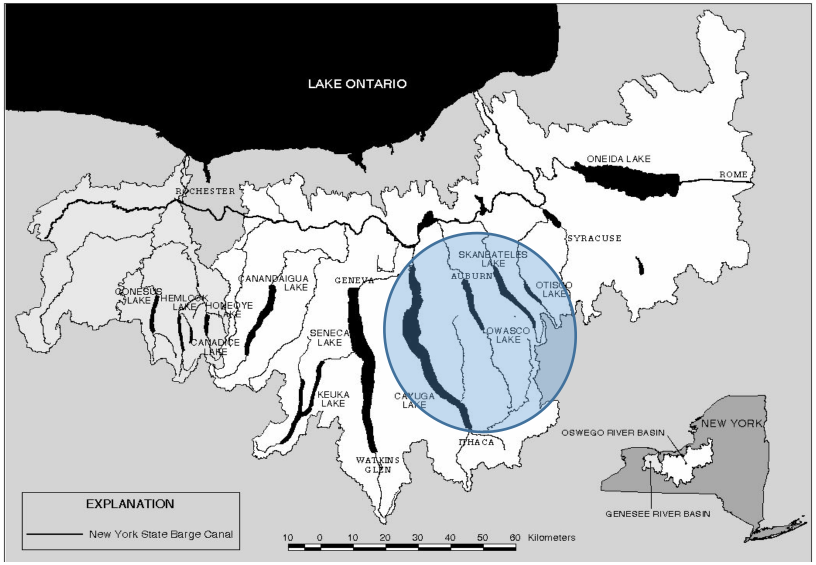
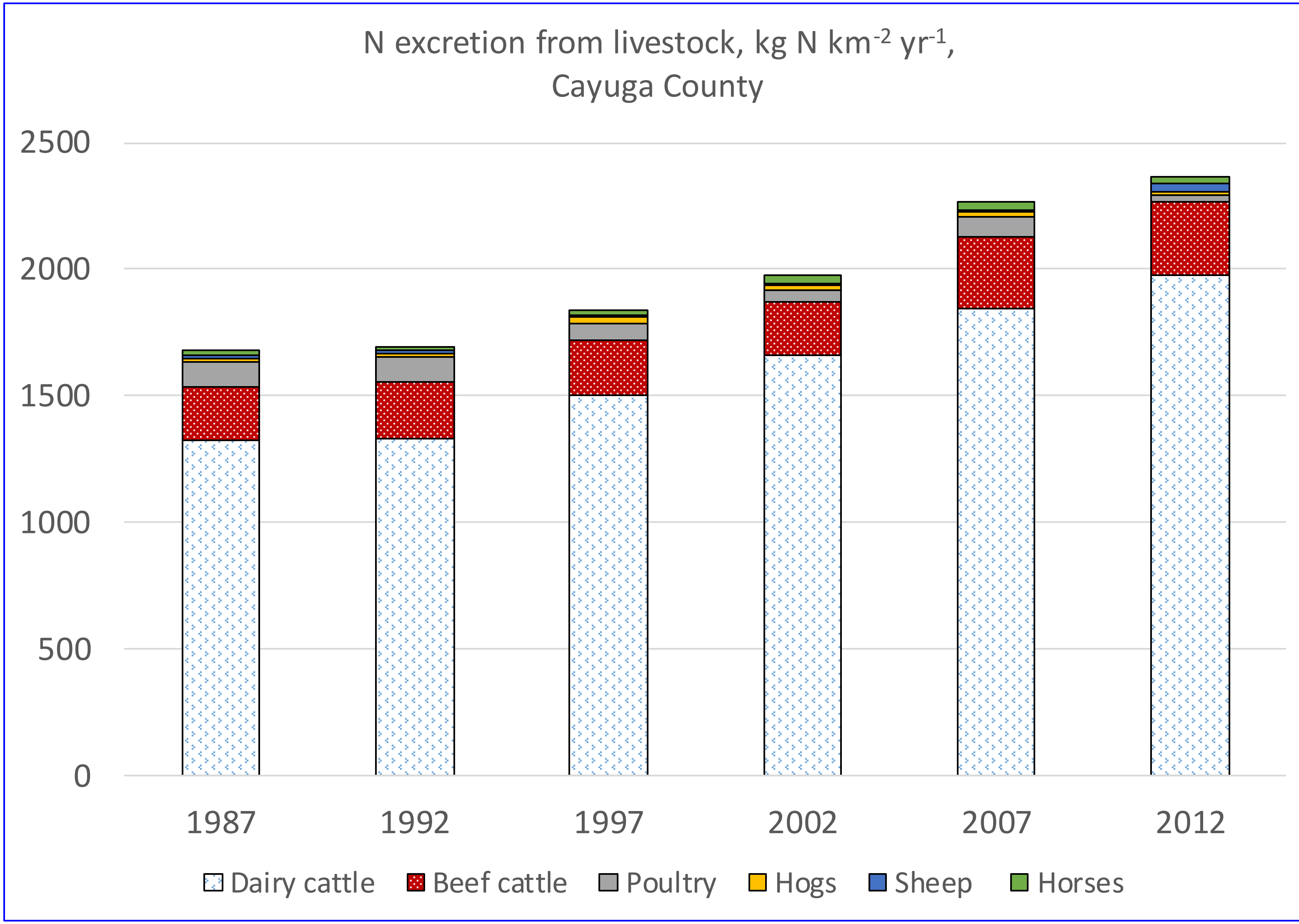
So these greater extremes in climate were a major contributor.

With climate change, this may become prevalent pattern.

Note that less of an influence on phosphorus (storage in dry years is less important).



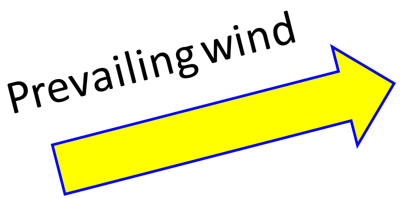
Another driver: Increased animal agriculture in the watersheds & airsheds over the past few decades.

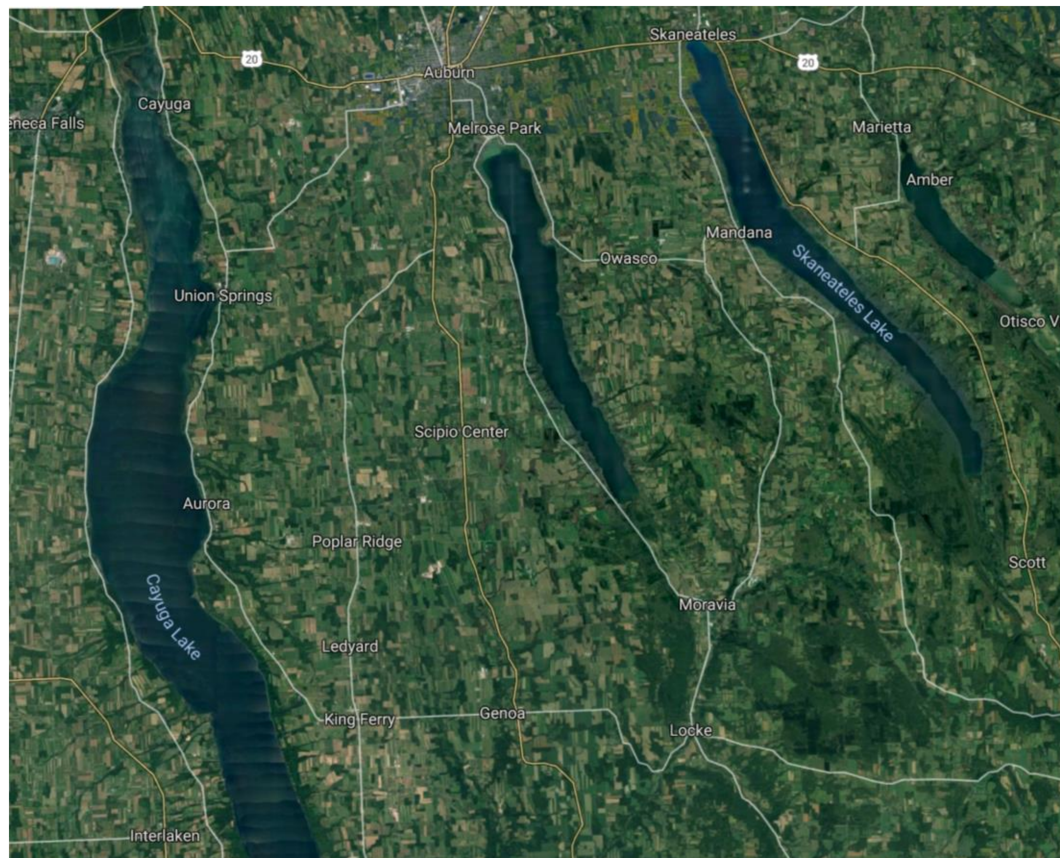


Swaney & Howarth, unpublished

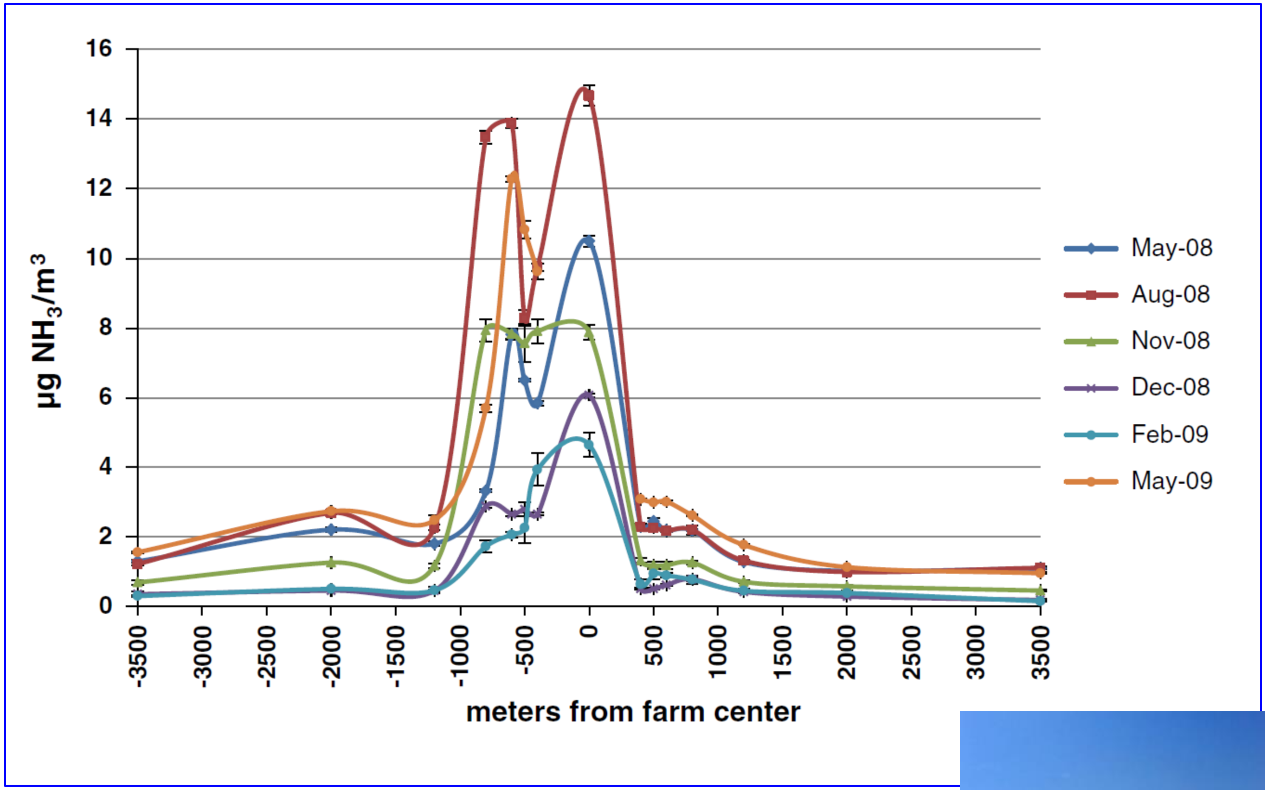
For nitrogen, protecting just within the watershed boundaries is not enough.

Must protect the airshed, and consider movement of nitrogen as ammonia gas through the atmosphere across watershed boundaries.





Atmospheric ammonia gas at and near Harford Farm



Butler et al. 2015

Effectiveness of management practices for Reducing N and P:

	phosphorus	nitrogen
No-till agriculture	very effective	not effective
Winter cover crops	effective	very effective
Perennial cropping systems	effective	very effective
Buffer strips along streams	effective	variable

Howarth et al. 2005

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For nitrogen, atmospheric transport of ammonia gas becomes very important, perhaps necessitating improved handling and use of manure? (manure smell is not simply an "unpleasantness," but a real threat to water quality and public health).

Conclusions:

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- Toxic cyanobacteria blooms (HABs) can occur in oligotrophic lakes (Skaneateles), so traditional phosphorus controls are not enough.
- Increased nitrogen inputs are best explanation for 2017 blooms in Cayuga and Skaneateles (so far).
- Increase in animal agriculture over time a likely contributor to increased nitrogen pollution (and phosphorus).
- Climate change probably also a major contributor: dry 2016 stored nitrogen, which was flushed into the lakes in wet 2017.
- Climate effect on nitrogen much greater than for phosphorus, in part because ammonia gas emissions and movement across watershed boundaries greater during dry periods, and because stored nitrogen is readily flushed in wet years (no equivalent storage of phosphorus, where flux is dependent just on erosion).
- We need to control both nitrogen and phosphorus.
- And best management practices (BMPs) for nitrogen are not the same as those for phosphorus.