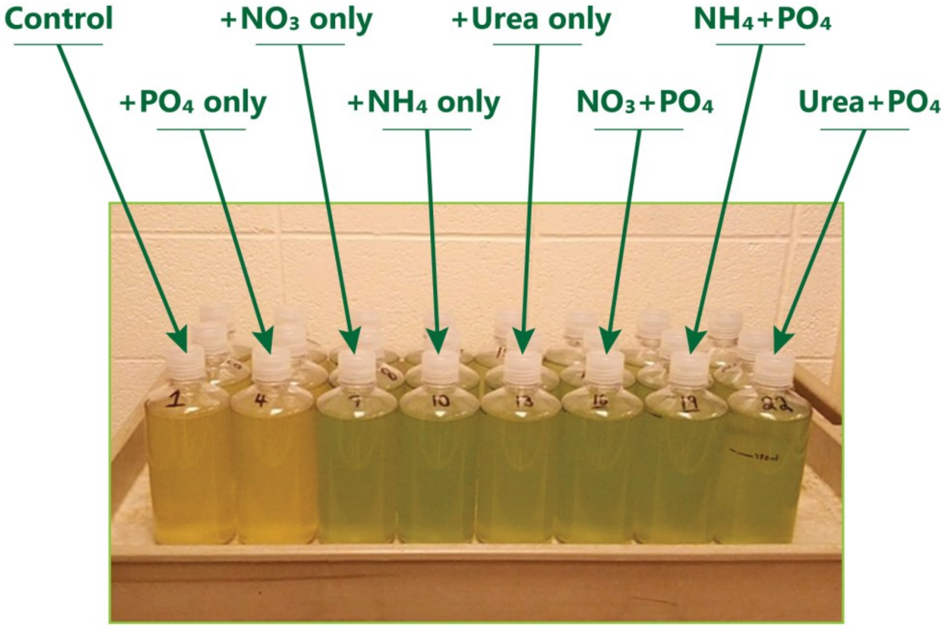
Great Lakes HABs Collaboratory

Linking Science and Management to Reduce Harmful Algal Blooms

How Does Nitrogen Affect Harmful Algal Blooms?

Harmful algal blooms (HABs) are a global water quality issue and are the result of increased nutrient loading and a changing climate. In certain areas of the Great Lakes, such as the western basin of Lake Erie, annual HABs degrade water quality, deter recreation, and reduce property values. Lake Erie provides drinking water for an estimated 11 million residents and supports a large tourism industry. As such, protecting this valuable resource is important for the region. Research conducted in Lake Erie has linked phosphorus (P) loading to HABs; thus, management strategies focused on reducing P loading to minimize HABs. However, emerging research shows that nitrogen (N) is much more important to HABs than originally thought, both in Lake Erie and around the world. This document summarizes the current knowledge related to the role of N in HAB formation and bloom toxicity.

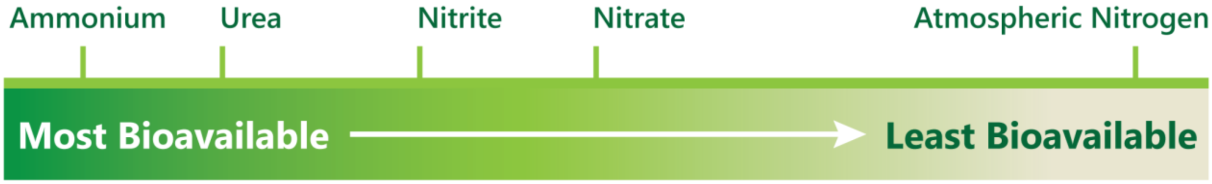
Nitrogen dynamics in aquatic systems play a role in understanding HAB biomass trends and potential toxicity. For example, in lab tests both *Microcystis* and *Planktothrix* (the species of cyanobacteria that make up HABs in Lake Erie) often respond quickly to additions of N by increasing both biomass and toxicity with and without additional P (e.g., Davis et al. 2015, see below). *Microcystis* and other cyanobacteria can produce microcystins, which are potent liver cyanotoxins. The molecular makeup of microcystin is N-rich, so toxin production requires a lot of N. Nitrogen additions can increase biomass and toxin production in *Microcystis* blooms, but at different rates depending on the form of N. (Harke et al. 2016).



Nutrient additions to *Planktothrix* bloom samples from Sandusky Bay show that nitrogen affects algae growth (Davis et al. 2015). Water samples that appear green indicate more algal growth than samples that appear yellow. The type of nutrient addition, if any, is shown above each column of water samples: the yellow bottle on the far left is the control (i.e., no nutrient addition), the second yellow bottle was spiked with phosphorus only, and the six green bottles on the right are spiked with either nitrogen or both nitrogen and phosphorus.

What are the different forms of nitrogen and why is this important?

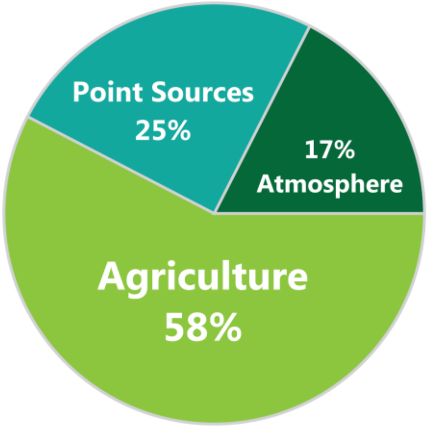
In water, N occurs in several different dissolved forms. These N forms influence communities of algae and cyanobacteria in different ways, based largely on their abilities to convert the different N forms into biomass and compete with other organisms. Regardless of the N form, cyanobacteria must convert N to ammonium (NH_4^+) within the cell before they can use it for biomass or toxin production. Ammonium is also the easiest N form for primary producers to acquire and transport into the cell. Nitrate and nitrite (NO_3^-/NO_2^-) must be actively transported into the cell and converted to ammonium, which, in turn, requires energy and micronutrients, such as iron. For atmospheric nitrogen gas (N_2) gas fixation performed by some HABs, this energy requirement is severe and can limit bloom size and toxicity. A depiction of the differences in N bioavailability can be seen below.



Depiction of the bioavailability of different forms of N to cyanobacteria.
Ammonium (NH_4+) is the most efficient and does not require substantial effort to by cyanobacteria to make N bioavailable for use in biomass or toxicity production. By contrast, atmospheric nitrogen (N2) requires considerable energy before N is bioavailable.

How does nitrogen enter the Great Lakes?

The primary sources of N to the Great Lakes are agricultural runoff, municipal wastewater treatment plant effluent, and atmospheric deposition (see below). Agricultural runoff of fertilizer and manure, as well as other agricultural sources (N fixation, mineralization of organic matter in soil, and residue from plant decay), are the largest sources of N entering Lake Erie. Most N that enters Lake Erie from tributaries, especially in areas with a high proportion of agriculture, is in the soluble form, nitrate (NO_3^-; Bullerjahn et al. 2016). Studies of agricultural runoff show that much of the N leaving farm fields as nitrate does so through subsurface drainage pipes, rather than by surface runoff. In fact, nitrate losses from farm fields are often correlated with subsurface drainage intensity in the Midwest. In addition to N inputs, N recycling within the Lake helps sustain the annual summer bloom.



Sources of N to Lake Erie based on the USGS SPARROW model (Robertson and Saad 2011).
For more information, visit: https://water.usgs.gov/nawqa/sparrow/mrb/3.html.

Strategies to reduce nitrogen loading

Since the source of most N entering HAB-impacted areas of the Great Lakes is agricultural runoff (including groundwater), the most effective reductions in N will result from the implementation of agricultural best management practices (BMPs). To date, the most effective practices to reduce N include improved nutrient management practices and adhering to the 4Rs of fertilizer application (right rate, right place, right time, right source) for each crop. Additionally, instead of leaving field bare, non-target crops grown in the off-season, known as cover crops, are very good at allowing farmers to apply less N, retain N over the winter months, and reduce water runoff from fields. The utilization of cover crops has resulted in notable decreases in N runoff from agricultural fields. Edge-of-field buffers, floodplains, and wetlands are also efficient BMPs to reduce nutrient loads to the Great Lakes. Point sources are still a sizable input to the Great Lakes, and efforts should continue to be made to reduce N in wastewater through improved wastewater treatment.

Finally, reductions in atmospheric N loading have been ongoing since the 1970s via industrial controls (e.g., scrubbing smokestacks), however, some of these reductions have been offset by increases in agricultural sources (especially N from manure). More efforts should be spent to reduce atmospheric N by increasing industrial controls and controlling atmospheric losses in animal dominated agriculture.

Future directions for nitrogen research

- **What is the N budget for Lake Erie?** That is, where does N come from, how is it transformed within the lake, and ultimately how much and which forms are exported to the lake?
- **How does N leave the land and enter the water?** How important are groundwater vs. surface inputs to riverine systems? How do N forms transform and recycle from the field to the river to the lake?
- **What should the target N reduction be to reduce the extent and toxicity of HABs?**
- **What is the link between N loading and toxicity?** Can toxicity of HABs be forecasted by N concentration?
- **Will BMPs aimed at reducing P also reduce N?** Which BMPs are most effective at reducing N runoff? For any scenario, an adaptive management approach should be followed whereby the effectiveness of any practice is evaluated and the magnitude of response from the lake is monitored.

References

Bullerjahn, G.S., McKay, R.M., Davis, T.W., Baker, D.B., Boyer, G.L., D'Anglada, L.V., Doucette, G.J., Ho, J.C., Irwin, E.G., Kling, C.L., Kudela, R.M., Kurmayer, R., Michalak, A.M., Ortiz, J.D., Otten, T.G., Paerl, H.W., Qin, B., Sohngen, B.L., Stumpf, R.P., Visser, P.M., and Wilhelm, S.W. (2016). Global solutions to regional problems: collecting global expertise to address the problem of harmful cyanobacterial blooms. A Lake Erie case study. *Harmful Algae*, 54, 223-238.

Davis, T.W., Bullerjahn, G.S., Tuttle, T., McKay, R.M., and Watson, S.B. (2015). Effects of Increasing Nitrogen and Phosphorous Concentrations on Phytoplankton Community Growth and Toxicity During *Planktothrix* Blooms in Sandusky Bay, Lake Erie. *Environmental Science & Technology*, 49(12), 7197-7207.

Harke, M.J., Steffen, M.M., Gobler, C.J., Pttem. T.G., Wilhelm, S.W., Wood, S.A., and Paerl, H.Q. (2016). A review of the global ecology, genomics, and biogeography of the toxic cyanobacterium, *Microcystis* spp. *Harmful Algae*, 54, 4-20.

Robertson, D.M. and Saad. D.A. (2011). Nutrient Inputs to the Laurentian Great Lakes by Source and Watershed Estimated Using SPARROW Watershed Models. *Journal of the American Water Resources Association*, 47(5), 1011-1033.
