Controlling Harmful Cyanobacteria Blooms **in the Face of Climate Change**

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What's manageable and what's not?

The nutrient-harmful cyanobacterial bloom connection

Freshwater lakes and reservoirs are experiencing an unprecedented proliferation of harmful (toxic, food-web altering, hypoxia-generating) cyanobacterial blooms (CyanoHABs), driven largely by excessive inputs of the macronutrients nitrogen (N) and phosphorus (P) (Paerl and Otten 2013); and in lakes where there has been a long history of excessive nutrient inputs, also by re-mobilization of nutrients from lake sediments by physical, chemical and biological processes (Cooke et al. 1993). To decelerate and reverse the trend of CyanoHAB proliferation, reductions of both N and P are needed in most cases (Paerl and Otten 2013). The necessary proportions and amounts of N and P reductions are system-specific and highly dependent on watershed and airshed sources and loads as well as system geomorphological and hydrodynamic features (Grantz et al. 2014; Russell and Shogren 2012).

Impacts of climate change

Complicating the need to develop system-specific nutrient reductions is climate change, specifically warming and greater variability in temperature, evapotranspiration, and precipitation/runoff regimes (IPCC 2012). In some instances, more extreme climatic conditions, including changes in frequency, intensity, and duration of storms and droughts can strongly modulate and even override the impacts of human nutrient enrichment on eutrophication and CyanoHABs (c.f., Paerl 2014). Yet the effects on any particular lake are varied and unpredictable. Examples are provided in Figure 1.

First, consider a prolonged drought followed by a period of high flow of water that is just sufficient to partially

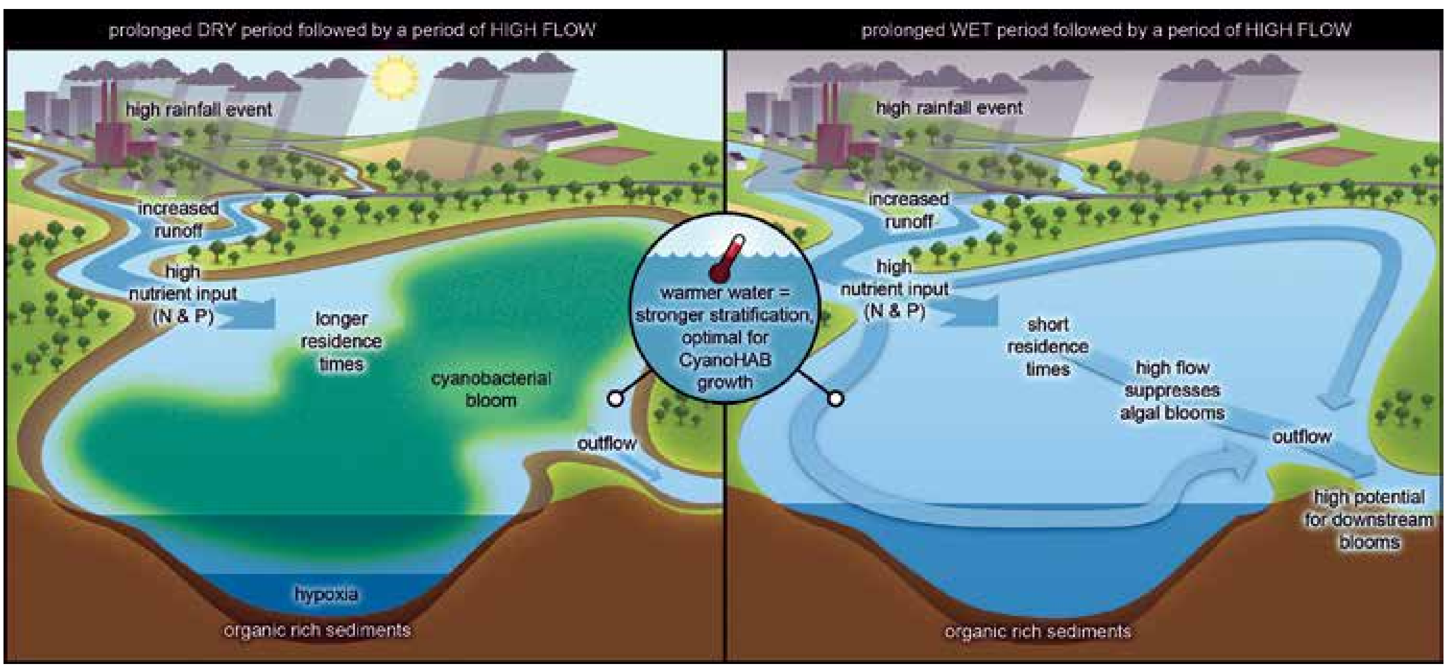

Figure 1. Examples of the interactive, and sometime counteracting, impacts of human- and climatically induced changes on eutrophication and harmful cyanobacterial bloom potentials of lakes and reservoirs. Two contrasting scenarios are presented for a lake basin receiving anthropogenic nutrient loads; (left) moderate loads, followed by drought conditions, which lead to blooms due to poor flushing and relatively long water residence times, and (right) elevated storm and precipitation events, which while leading to larger nutrient loads, also shorten the water residence times enough to flush bloom organisms downstream.

fill a eutrophic lake in an agricultural watershed that had very low water levels. Nutrient inputs from the watershed are likely to be high, and the lake is expected to respond with CyanoHABs.

Second, consider the same lake in a year when water levels already are high and the same extreme rainfall event occurs in summer that rapidly flushes the lake. In this second case, despite a delivery of N and P, the short residence time might actually suppress blooms. While this outcome might help temporarily ameliorate the CyanoHAB problem, it also increases the potential for CyanoHABs and other blooms to expand into downstream impoundments and even estuaries, especially if they are large enough (long residence times) to retain these loads: e.g., Lake Ponchartrain (Bargu et al. 2011) and Barataria Sound (Roy et al. 2013), LA; Neuse River Estuary, NC (Piehler et al. 2004), Potomac River Estuary, VA-MD-DC (Harding et al. 2013), and St John's River system, FL (Moisander et al. 2008).

Effects of climate change also can be expected to differ between deep and shallow lakes (Jeppesen et al. 2014). In shallow lakes, particularly eutrophic lakes with a high biomass of benthivores and flocculent sediments, water quality is likely to severely deteriorate in times when climate change results in prolonged droughts. For any given amount of wind blowing across the lake surface, there will be greater shearing stress on the sediments and more re-suspension of sediments, N, and P. This could fuel blooms of cyanobacteria that can tolerate what might be low light conditions due to high levels of abiotic seston. Low water levels also mean a smaller volume for nutrient loads to enter, resulting in increased nutrient concentration and again, a greater likelihood of blooms. High internal P loading due to physical resuspension by storms is well-documented in large shallow lakes including Lake Arreso, Denmark (Kristensen et al. 1992), shallow lakes in New Zealand (Hamilton and Mitchell 1997) and China (Zhu et al., 2014), and biological transport of P by fish sometimes can exceed external loads (Schaus and Vanni 2000).

One scenario that could happen in the future, if shallow eutrophic lakes experience prolonged periods of lower water, is a switch from species that prefer some level of stability and form surface blooms, e.g., *Microcystis*, to species that bloom in the water column, e.g., *Cylindrospermopsis*. Havens and Steinman (2015) recently identified that this situation of prolonged low water is a likely future condition of Lake Okeechobee, the largest lake in the southeastern USA.

In deeper lakes, the effects of variations in rainfall may be less pronounced, although even those systems are known to respond to changes in rainfall driven by climate variability (Van Cleave et al. 2014).

These are some speculations about how climate change could affect lakes, based on our experience with CyanoHABs, and they are areas in need of research.

Changes in temperature, including warming and more extremes, also can modify phytoplankton community by (1) favoring cyanobacteria, which are able to take advantage of warmer conditions (Paerl and Huisman 2009; Kosten et al. 2012), (2) causing earlier ice-out and later ice-on (favoring multiple groups, including diatoms, cyanobacteria and flagellates), and (3) increasing extremes (favoring fast-growing taxa and also some cyanobacterial bloom species, especially during heat waves and extensive droughts). Therefore, climate change poses an additional challenge to formulating nutrient-based bloom thresholds as part of a strategy for controlling CyanoHABs. It seems likely that with warmer water, achieving a desired low level of CyanoHABs in the future will require greater reductions in the inputs of N and P to lakes than is needed under the current climate conditions (Paerl and Huisman 2009).

Additional factors

If these issues do not present a big enough challenge, consider trying to control CyanoHABs in a system that has a long legacy of nutrient loading, internal storage, and cycling of previously loaded nutrients, and is also impacted by warming and more hydrologically-extreme conditions, including protracted record droughts and an increase in tropical cyclone activity. A well-studied example is Lake Okeechobee, where a watershed with decades of agricultural activity contains enough P in its surrounding soils and wetlands to maintain P loads of 500 metric tons per year to the lake for the next 20-50 years (Reddy et al. 2011). The sediments of the lake also contain a huge storage of P that periodically is entrained into the water column by hurricanes (Havens et al. 2007).

Considering the examples provided above, each lake or reservoir must be judged individually with regard to its ability to benefit from CyanoHAB control strategies of varying cost and longevity in a future with climatic changes. Conditions could sometimes be so unwieldy that no currently-available management strategy can handle either the synergistic or antagonistic effects of human nutrient enrichment. Available nutrient reduction strategies sometimes may be overwhelmed by climatic events impacting the system. While it is clear that nutrient management strategies aimed at controlling CyanoHAB outbreaks and persistence must adapt to short- and long-term climate changes, there may come a time where such changes exceed the ability of managers to fulfill societal demands for creating permanent CyanoHAB-free conditions.

Mitigation Options

There is a range of physical/engineering manipulations available for CyanoHAB mitigation, including: diverting water through impacted systems to promote flushing, enhancing circulation and vertical mixing, use of ultrasound, and utilizing flocculation techniques to sediment CyanoHABs to the bottom (c.f. Paerl 2014) (Figure 2).

Most of these techniques offer short-term fixes and simply hide problems temporarily, while not compensating for excessive nutrient loading and in many instances legacy nutrient issues (Jarvie et al. 2013) – the root causes of CyanoHAB expansion and persistence. Then there is sediment dredging, which can be an effective means of removing nutrients in relatively small impoundments, but is highly disruptive to the benthic habitat and benthic-pelagic interactions, and the dredge spoils must be deposited outside the drainage basin. Whichever option becomes the method or approach of choice, it will still need

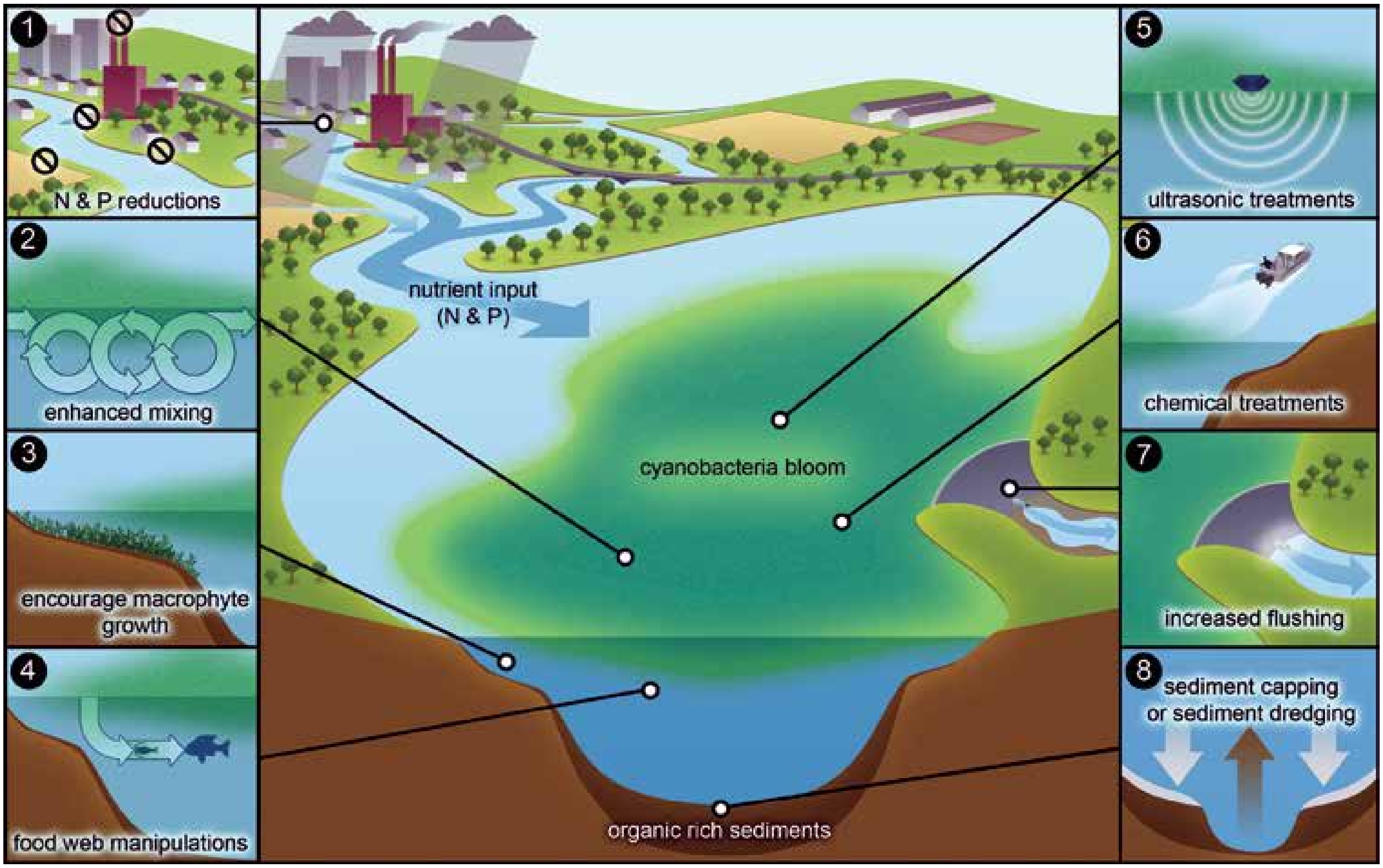

Figure 2. Approaches currently in use to control CyanoHABs, including control measures in the watershed and within the ecosystem. (1) Point and non-point source nutrient (N & P) input reductions. (2) Mechanical mixing. Increasing flushing rates (decreasing water residence times). (3) Establishing submersed and emergent aquatic vegetation for localized nutrient attenuation and removal. (4) Food web manipulation to encourage filtering and consumption of CyanoHABs. (5) Ultrasonic cell disruption. (6) Application of algaecides, including copper salts, hydrogen peroxide. (7) Enhanced flushing. (8) Dredging and capping of bottom sediments to trap nutrients and reduce sediment-water column nutrient exchange.

to be accompanied by comprehensive watershed nutrient input reductions, and it must be adaptive to climate changes impacting CyanoHAB-sensitive systems, including more extreme temperature fluctuations and greater hydrologic variability.

Chemical treatments, including precipitation and immobilization of phosphorus in bottom sediments, application of algaecides (Cu compounds, H_2O_2, permanganate, etc.), as well as biological controls, such as the introduction of invertebrate to fish grazers, lytic bacteria, and viruses, may temporarily halt the advance of CyanoHABs (Robb et al. 2003; Pan et al. 2006; Matthijs et al. 2012). However, most of these options do not provide permanent solutions, they require continuous applications, are expensive, often have unpredictable unintentional secondary effects and consequences, and may not allow a system to return to a state that is socially acceptable and representative of pre-CyanoHAB conditions.

Final thoughts

One of the most difficult decisions a manager must make when faced with spending public or private funds on efforts to mitigate CyanoHABs and other nuisance blooms is to determine whether there is a realistic, achievable chance that bloom-free conditions can be achieved for a specific systems in question. Can public expectations of bloom-free conditions be met, given hydrologic, morphometric, and eco-physiological constraints of the system, and in the face of predicted climate change scenarios? Is it ecologically and economically feasible to restore a specific system to CyanoHAB-free conditions? Are there novel physical, chemical, and biological approaches worth pursuing to achieve this goal? How might we change our current control strategies and realistically, can we determine what is likely to be our maximal ability to control CyanoHABs short of some new unknown approaches being discovered?

In situations where human and specific ecological requirements are not critical and approaches are impractical and/or costs prohibitive, the most realistic and preferred routes may be to curtail mitigation and management efforts, leaving the CyanoHABs to their own devices. After all, they were the pioneer microbes (2+ billion years ago) that created the environmental conditions (specifically an oxygen-rich world) needed for biotic diversification and ultimately the establishment of mankind. Now they're simply reclaiming waters that we failed to preserve and protect during our short time on Earth. While this may be an increasingly realistic option in a warmer future, there likely will be tremendous pressure to pursue actions to reduce CyanoHABs where clean water is necessary for drinking purposes or as a supply for downstream restored ecosystems. Whether the desired outcomes can be achieved remains to be seen. In virtually all cases, having effective decision-making tools requires a more thorough understanding of the interactions between nutrient dynamics and climate change.

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Next Issue – Winter 2015 *LakeLine*

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