Planktonic:

In-water Prevention Strategy
Limited Supporting Field Data

Benthic:

In-water Prevention Strategy
Limited Supporting Field Data

The acidification of freshwater aquatic systems, either by surface discharge or by precipitation, has been noted as an issue of increasing environmental concern (Graham, Arancibia-Avila, and Graham 1996). In normal freshwater systems, an average pH is usually between 6.5 and 9.0 (USEPA 1986). Aquatic organisms, including cyanobacteria that cause HCBs, exist in a variety of environments over wide pH ranges. However, these organisms have a tolerance that, once a pH shift occurs, may impact their ability to function and survive. Ecologists who have surveyed acidified lakes noted that cyanobacteria are often absent in benthic habitats where the pH is less than 4.0 and mildly acidic lakes with pH ranges of 5.0–6.0 (Brock 1973). Researchers proposed that shifting the pH into an acidic environment could control or eliminate cyanobacterial blooms (Klemer et al. 1996). In a recent review (Triest, Stiers, and Van Onsem 2016), data from mesocosm experiments indicated that the addition of CO_2 to a pH around 7.0 kept cyanobacterial biomass low (Tessier et al. 2011 in Triest, Stiers, and Van Onsem 2016). Similarly, following biomanipulation of Lake Vesijärvi in Finland, Keto and Tallberg (2000) suggested that low pH may have prevented cyanobacterial dominance, and listed low pH as one parameter that limits cyanobacterial growth in hypereutrophic ponds (Peretyatko et al. 2012).

Evidence of acidification occurring naturally has been reported. Planktonic species of cyanobacteria disappeared from the epilimnion (upper layer of water) in Little Rock Lake, Wisconsin, as the pH fell to 5.2 (Klemer et al. 1996). In controlled studies, blooms in experimental lakes remained dominated by cyanobacteria until the pH dropped below 5.2, at which point filamentous green algae became most abundant for a limited time (Turner et al. 1995). This pattern of acidification does not seem to be universal, however, as succession in the same lake showed a shift of *Anabaena* spp. and *Lyngbya* spp. to colonial species of *Merismopedia* and *Chroococcus*. This shift in species is consistent with other field observations that low pH seems to select for cyanobacteria that do not regulate their buoyancy by gas vesicles: As pH decreased from 5.9 to 5.1, the abundance of cyanobacteria that form gas vesicles decreased, while abundance of those without gas vesicles increased (Findlay and Kasian 1986).

There is limited applied data (see Teissier et al. 2011 mesocosm results above) to suggest that artificially acidifying water will prevent or control an ongoing HCB. Experimental acidification has been studied in a number of benchtop and laboratory assays that used bubbled CO_2 to artificially lower the pH while the cells were growing under optimal conditions. These studies had results similar to the field data above—growth of targeted species of cyanobacteria was adversely affected starting at pH <6.0 (Wang et al. 2011).

While the exact method of action is not known, acidification could physiologically inhibit cyanobacteria growth or adversely affect any number of biological processes the cyanobacteria use. Some laboratory observation data have highlighted that low pH inhibits important cellular functions, such as CO_2-concentrating mechanisms. It has also been observed that low pH causes cyanobacterial cells to expend high levels of energy to maintain optimal intracellular pH range for metabolic processes and that low pH causes cells to build up carbonic acid, which can interfere with photosynthesis (Mangan et al. 2016).

PLANKTONIC AND BENTHIC
EFFECTIVENESS • Water body type: Pond, lake/reservoir • Depth: Shallow • Any trophic state • Any mixing regime • Any water body use
NATURE OF HCB • Cyanobacteria species that use gas vesicles to regulate buoyancy • Unknown interaction with cyanotoxins • Prevention strategy

ADVANTAGES • Field observations note that potentially problematic cyanobacteria species are absent in acidified environments. • Limited experimental data show that artificially lowering pH causes gas-vesicle-dominated cyanobacteria to die.
LIMITATIONS • There are few full-scale studies (on entire ecosystem impact) on artificially lowering pH. • Limited field data noted that while gas-vesicle-forming species disappeared, species that do not form gas vesicles were able to grow in their place. • Laboratory studies that bubbled CO_2 were conducted on pure cultures under non-field conditions. • May affect all aquatic organisms

Adding CO_2 to a water body will not necessarily shift the pH adequately to prevent or disrupt blooms of cyanobacteria, as pH depends on a variety of ambient conditions. Previous studies on acidification have pumped CO_2 into vats of sample water using tanks of liquid CO_2, which can be readily acquired from various vendors. The cost of this method will depend partly on whether the multiple bubble lines spanning a lake are derived from one tank or from multiple tanks. For larger waterbodies, multiple tanks can be evenly spaced with individual bubblers.

COST ANALYSIS PER GROWING SEASON: ACIDIFICATION

ITEM	**Relative Cost Per Growing Season**
Material	$$
Personal protective equipment	$
Equipment	$
Machinery	$
Tools	$
Labor	$
O & M Costs	$$
Delivery	$
Overall	**$$**

REGULATORY AND POLICY CONSIDERATIONS

Implementation of acidification equipment may require installation of temporary tubing as well as investment in infrastructure to maintain and support the tools and supplies needed to maintain and monitor the supply of the bubbling system. Monitoring lake pH should be embedded in the treatment, as there is no known quantified relationship between the volume of gas added and the response of small lakes. Off-target effects are possible to fish and other aquatic life that may be impacted by the sudden shift in pH. Additional concerns about mobilization and immobilization of various metals should be considered and will depend on the chemistry of the water body and sediment. Various regulatory entities may prohibit shifts in pH more than 1 unit above or below typical background levels to minimize off-target effects of treatment. Applicable state water quality criteria must also be considered.

REFERENCES

Brock, Thomas D. 1973. “Lower pH limit for the existence of blue-green algae: evolutionary and ecological implications.” *Science* 179 (4072):480-483. doi: https://doi.org/10.1126/science.179.4072.480.

Findlay, D. L., and S. E. M. Kasian. 1986. “Phytoplankton community responses to acidification of lake 223, experimental lakes area, northwestern Ontario.” *Water, Air, and Soil Pollution* 30 (3):719-726. doi: https://doi.org/10.1007/BF00303337.

Graham, James M., Patricia Arancibia-Avila, and Linda E. Graham. 1996. “Effects of pH and selected metals on growth of the filamentous green alga Mougeotia under acidic conditions.” *Limnology and Oceanography* 41 (2):263-270. doi: https://doi.org/10.4319/lo.1996.41.2.0263.

Keto, Juha, and Petra Tallberg. 2000. “The recovery of Vesijärvi, a lake in southern Finland: water quality and phytoplankton interpretations.” *Boreal Environmental Research* 5.

Klemer, Andrew R., John J. Cullen, Michael T. Mageau, Kathryn M. Hanson, and Richard A. Sundell. 1996. “Cyanobacterial buoyancy regulation: the paradoxical roles of carbon.” *Journal of Phycology* 32 (1):47-53. doi: https://doi.org/10.1111/j.0022-3646.1996.00047.x.

Mangan, N. M., A. Flamholz, R. D. Hood, R. Milo, and D. F. Savage. 2016. “pH determines the energetic efficiency of the cyanobacterial CO2 concentrating mechanism.” *Proceedings National Academy of Sciences USA* 113 (36):E5354-62. doi: https://doi.org/10.1073/pnas.1525145113.

Peretyatko, Anatoly, Samuel Teissier, Sylvia De Backer, and Ludwig Triest. 2012. “Classification trees as a tool for predicting cyanobacterial blooms.” *Hydrobiologia* 689 (1):131-146. doi: https://doi.org/10.1007/s10750-011-0803-4.

Triest, Ludwig, Iris Stiers, and Stijn Van Onsem. 2016. “Biomanipulation as a nature-based solution to reduce cyanobacterial blooms.” *Aquatic Ecology* 50 (3):461-483. doi: https://doi.org/10.1007/s10452-015-9548-x.

Turner, M. A., D. W. Schindler, D. L. Findlay, M. B. Jackson, and G. G. Robinson. 1995. “Disruption of littoral algal associations by Experimental Lake acidification.” *Canadian Journal of Fisheries and Aquatic Sciences* 52 (10):2238-2250. doi: https://doi.org/10.1139/f95-815b.

USEPA. 1986. “Quality Criteria for Water, 1986 *EPA 440/5-86-001*.” Washington, D. C.: U. S. Environmental Protection Agency, Office of Water. https://www.epa.gov/sites/production/files/2018-10/documents/quality-criteria-water-1986.pdf.

Wang, X., C. Hao, F. Zhang, C. Feng, and Y. Yang. 2011. “Inhibition of the growth of two blue-green algae species (Microsystis aruginosa and Anabaena spiroides) by acidification treatments using carbon dioxide.” *Bioresour Technol* 102 (10):5742-8. doi: https://doi.org/10.1016/j.biortech.2011.03.015.