EPA Region 10 Harmful Algal Blooms Workshop
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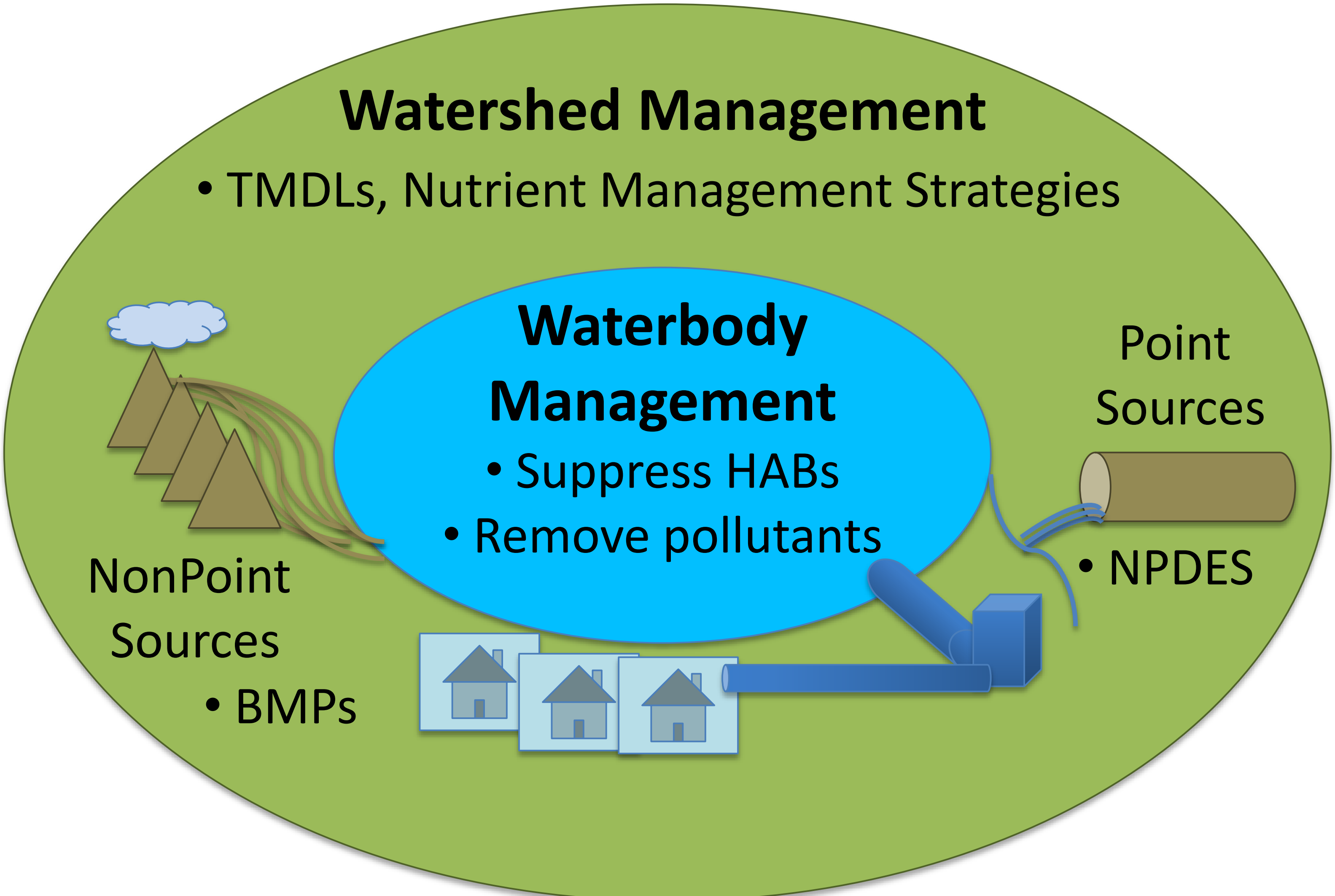
Waterbody Management Approaches for HABs

Mario R. Sengco
U.S. EPA Office of Water
Office of Science and Technology
Washington, D.C.

What is Waterbody Management?



Hudnell, K. H., "A Systems Approach to Freshwater Management: Waterbody Treatments", U.S. EPA Webinar, May 14, 2014.

Disclaimer

The purpose of this presentation is to provide information and to describe various approaches for managing harmful algal blooms (HABs) as they are reported in the literature and other publications.

The EPA has not conducted any systematic, scientific review or technical analysis of these approaches. Therefore, the EPA does not endorse or recommend any particular approach.

Waterbody Management Approaches

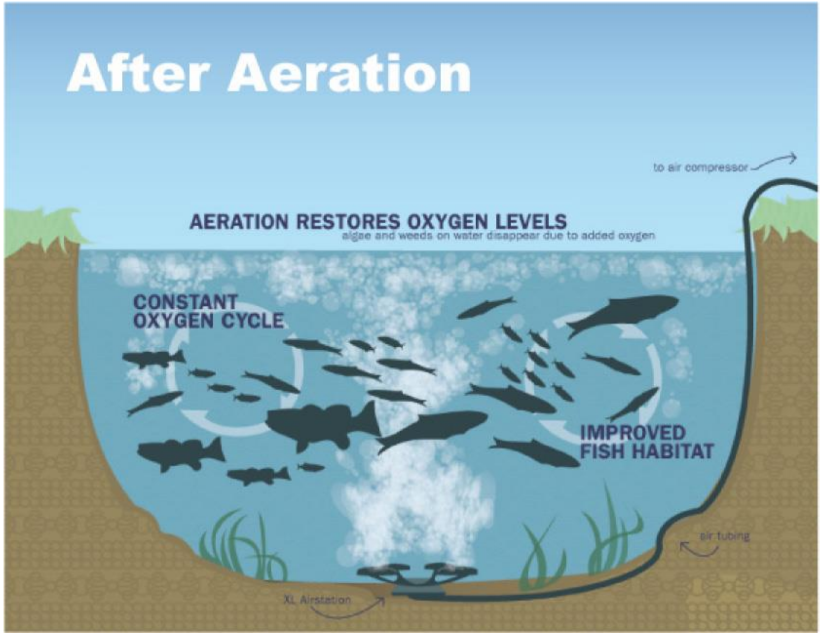
http://www2.epa.gov/nutrient-policy-data/control-and-treatment

Waterbody Management Method	Description	Benefits/Effectivenes	Limitations
Physical Controls			
Aeration F	Aerators operate by pumping air through a diffuser near the bottom of the waterbody, resulting in the formation of plumes that rise to the surface and create vertical circulation cells as they propagate outwards from the aerator. This mixing of the water column disrupts the behavior of cyanobacteria to migrate vertically in addition to limiting the accessibility of nutrients.	Successfully implemented in small ponds and waterbodies. Proven effectiveness in several field studies. May also provide more favorable growth conditions for competing organisms.	Generally more efficient in deeper water columns. Also highly dependent upon the degree of stratification and the air flow rate.
Hydrologic manipulations F	Low flow conditions in waterbodies can lead to stratification of the water column, which aids cyanobacterial growth. Particularly in regulated systems, the inflow/outflow of water in the system can be manipulated to disrupt stratification and control cyanobacterial growth.	Easy to implement in controlled systems (i.e., reservoirs, dams, treatment facilities).	Requires sufficient water volume and the ability to control flow. Oftentimes can be expensive. Unintended consequences for other aquatic organisms are likely.
Mechanical mixing (circulation) F	Mechanical mixers are usually surface-mounted and pump water from the surface layer downwards or draw water up from the bottom to the surface layer. This mixing of the water column disrupts the behavior of cyanobacteria to migrate vertically in addition to limiting the accessibility of nutrients.	Successfully implemented in 350+ waterbodies in the U.S. Also used in other countries.	Individual devices have limited range; areas further away may remain stratified and provide a suitable environment for growth.

F = freshwater; M = marine

Aeration and Oxygenation

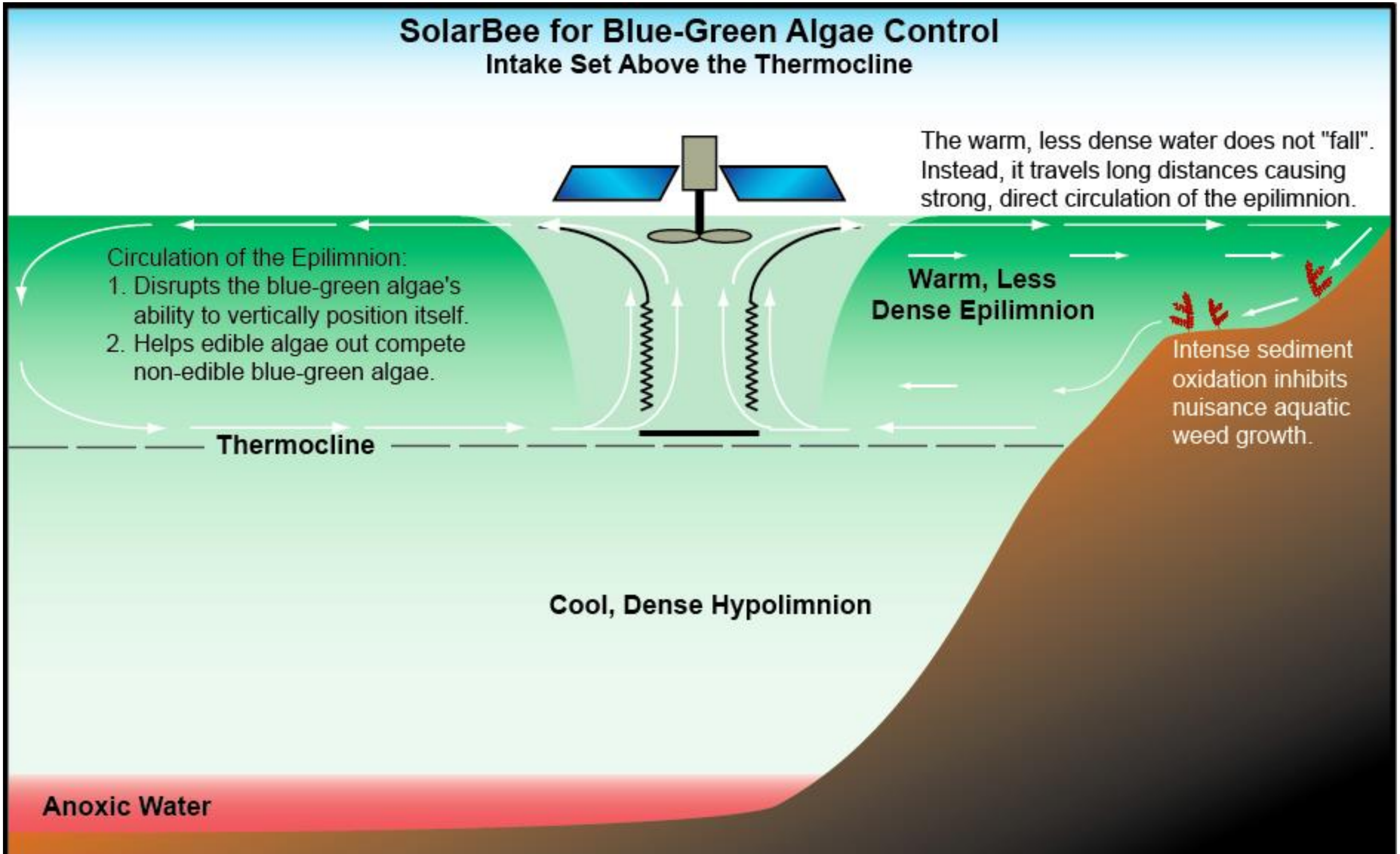
http://www.vertexwaterfeatures.com/sites/default/files/imagecache/billboard_frontpage_aeration/billboard-frontpage/billboard_A1.jpg



Bahia Del Mar Lake, St Petersburg, FL

http://www.vertexwaterfeatures.com/sites/default/files/bdm_both.jpg

Mechanical Mixing (Circulation)



http://www.vitalbodies.com/blog/wp-content/uploads/2009/04/solarbee_bga2.jpg

Physical Controls (continued)

Reservoir drawdown/dessication F	In reservoirs and other controlled waterbodies, can draw down the water level to the point where cyanobacteria accumulations are exposed above the waterline. Subsequent dessication and/or scraping to remove the layer of cyanobacteria attached to sediment or rock is required, in addition to the reinjection of water into the system.	Easy to implement in controlled systems (i.e., reservoirs, dams, treatment facilities).	Can have a significant impact on other aquatic organisms in the system. Often times is expensive and requires a significant input of resources.
Surface skimming F/M	Cyanobacterial blooms often form surface scums, especially in the later stages of a bloom. Oil-spill skimmers have been used to remove cyanobacteria from these surface scums. Often times this technique is coupled with the implementation of some coagulant or flocculant.	Useful method for blooms that are in later stages and have formed surface scums. Successful results seen in field studies in Australia.	This technique cannot be effectively employed until the later stages of a bloom, at which point many of the harmful aspects of a bloom have materialized. Requires proper equipment prior to implementation.
Ultrasound F	An ultrasound device is used to control HABs by emitting ultrasonic waves of a particular frequency such that the cellular structure of cyanobacteria is destroyed by rupturing internal gas vesicles used for buoyancy control.	Successfully implemented in ponds and other small waterbodies. A single device can cover up to 8 acres. Non-chemical; inexpensive.	Also disrupts cellular functioning of green algae. Effectiveness are dependent upon waterbody geometry and cyanobacteria species. Further research of method is required.

F = freshwater; M = marine

Mechanical Removal

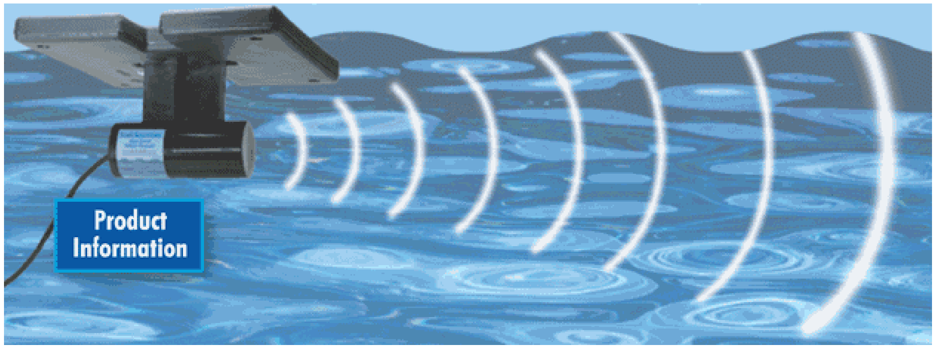
Skimming

Plant Removal

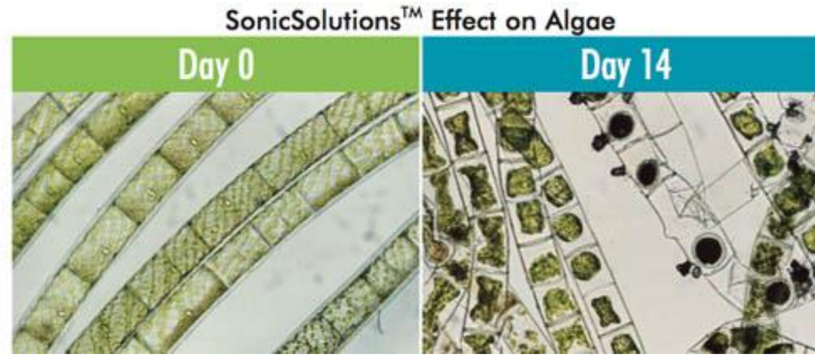
Filtration/Sieving

Lake Sediment Removal

Ultrasonics



http://www.sonicsolutionsllc.com/images/SonicAnimat630pxforDisc%20-%20Optimized.gif



http://cdn2.hubspot.net/hub/227988/file-201537022-jpg/images/effectsOfAlgae.jpg?t=1371692499000

http://www.marylandbiochemical.com/images/WildingAcres.jpg

http://www.smokytroutfarm.com/Sonic%20Solutions%20Ultrasound%20Algae%20Control.jpg

Chemical Controls			
Algaecides F/M	Algaecides are chemical compounds applied to a waterbody to kill cyanobacteria. Several examples are: • Copper-based algaecides (copper sulphate, copper II alkanolamine, copper citrate, etc.) • Potassium permanganate • Chlorine • Lime	Wide range of compounds with a history of implementation. Relatively rapid and well-established method. Properties and effects of compounds are typically well-understood.	Risk of cell lyses and the release of toxins. Thus, is often used at the early stages of a bloom. Certain algaecides are also toxic to other organisms such as zooplankton, other invertebrates, and fish.
Barley straw F/M	Barley straw bales are deployed around the perimeter of the waterbody. Barley straw, when exposed to sunlight and in the presence of oxygen, produces a chemical that inhibits algae growth. Field studies suggest significant algistatic effects. Several causes for the observed effects have been suggested; however, the exact mechanism of this process is not well understood.	Studies have shown that decomposed barley straw inhibits the growth of cyanobacteria Microcystis sp. Successfully implemented in many reservoirs and dams in the United Kingdom with positive results.	Does not kill existing algae, but inhibits the growth of new algae. May take anywhere from 2 to 8 weeks for the barley straw to begin producing active chemical. Potential to cause fish kills through the deoxygenation of the waterbody due to decay.
Coagulation F	Coagulants are used to facilitate the sedimentation of cyanobacteria cells to the anoxic bottom layer of the water column. Unable to access light, oxygen, and other critical resources, the cells do not continue to multiply and eventually die.	Several studies have shown that cells can be coagulated without damage; however, further research is required. Successfully implemented in several treatment facilities.	Subject to depth limitations. Coagulated cells become stressed over time and lyse, releasing toxins to the waterbody.

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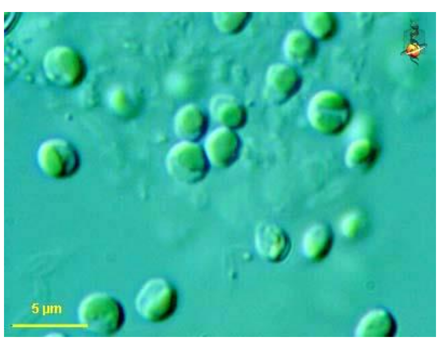
Algaecides (Kill or inhibit cells)

Inorganic chemicals

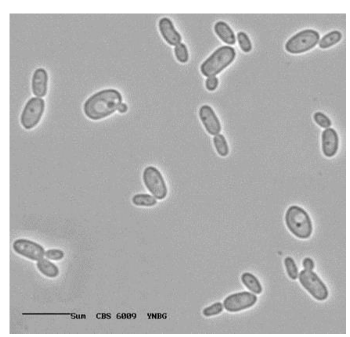
- $KMnO_4$, $FeCl_3$, chlorine, alum, flocculants
- NaOCl (bleach from electrified seawater)
- Hydrogen peroxide

Organic chemicals

- Aponin (from alga *Nannochloris* sp.)
- Sophorolipids (from fungus *Candida bombicola*)
- Phlorotanins (from brown alga *Ecklonia kurome*)
- Barley straw bales and extract



Nannochloris sp.



Candida bombicola

Ecklonia kurome

Barley Straw

Tommy's Pond, Metuchen, NJ

England

http://aquatic-solutions.co.uk/wp-content/uploads/2012/04/Barley-Straw.jpg

http://www.metuchenmatters.com/IMG_3585.JPG

http://www.mankysanke.co.uk/assets/images/autogen/a_Barley_straw_reservoir.jpg

Chemical Controls (continued)

Flocculation F/M	Flocculants are used to facilitate the sedimentation of nutrients to the anoxic bottom layer of the water column, thereby limiting nutrient levels in the waterbody and inhibiting cyanobacterial growth.	Successfully implemented in larger lakes and ponds (e.g., Florida DEP, Lake Hilaman).	Subject to depth limitations.
Hypolimnetic oxygenation F	Techniques used to achieve hypolimnetic oxygenation include: airlift pumps, side stream oxygenation and direct oxygen injection. The primary goal of this method is to increase the oxygen concentration in the hypolimnion in order to prevent or reduce the release of nutrients from the sediment while maintaining water column stratification. This serves to limit upper level nutrient levels thereby inhibiting cyanobacterial growth.	Maintains water column structure (thermocline, pycnocline, etc.).	Techniques are relatively expensive. Requires a significant understanding of system in order to determine effectiveness.

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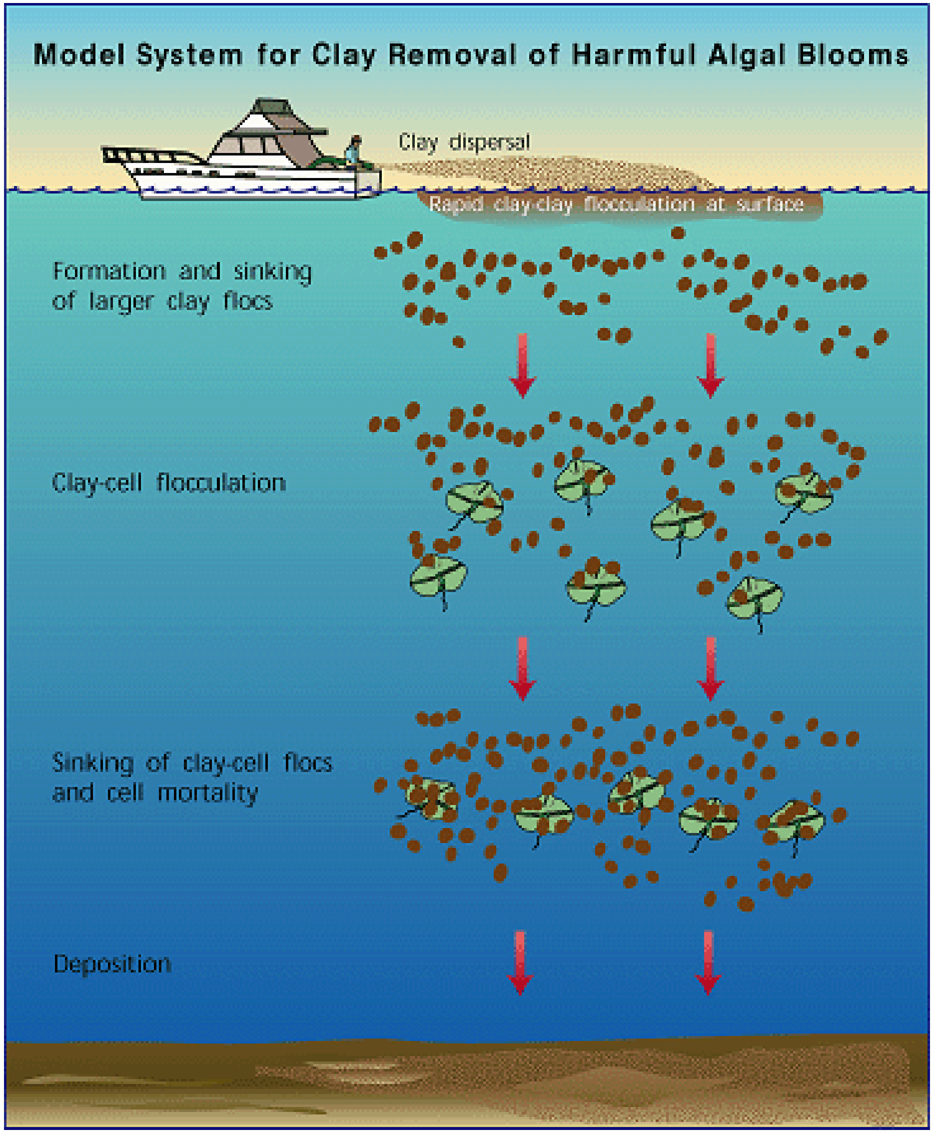
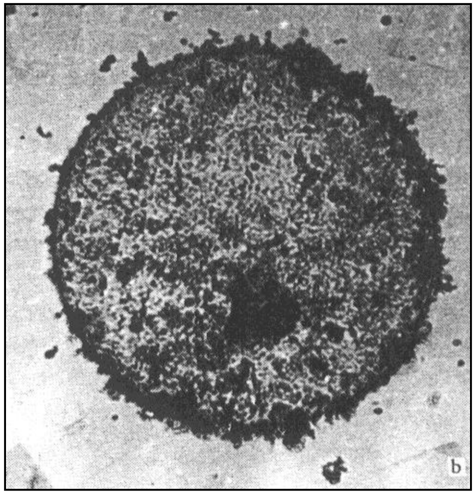
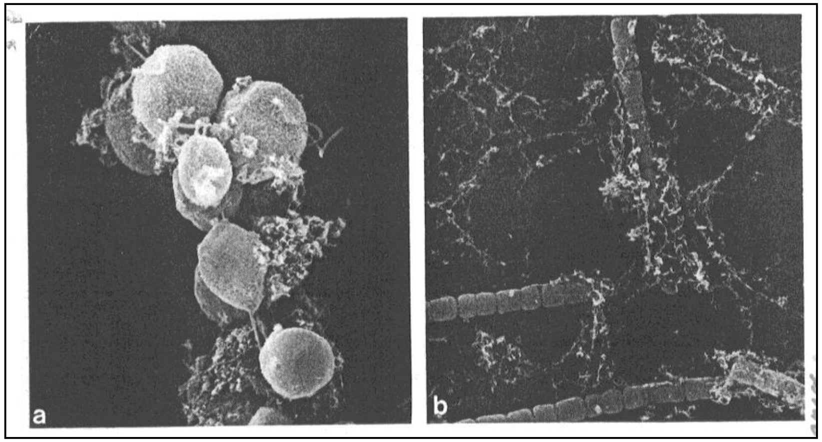
Clays (bind, aggregate and sink)







Clay treatment

South Korea

China

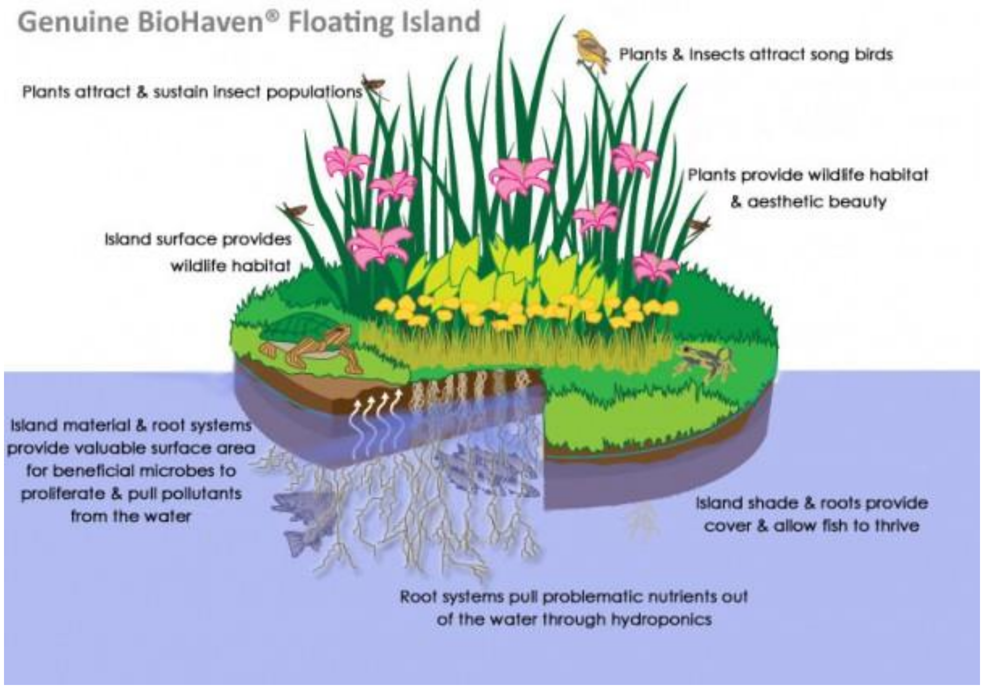
http://www.gangpan-environment.com/kindeditor/attached/image/20130514/20130514100056_3017.jpg

Sarasota Bay, FL

Biological Controls (Biomanipulation)			
Floating artificial wetlands F	Artificial wetlands are constructed using floating mats and placed in a waterbody. As the plants grow, they function as a sink for excess nutrients such as phosphorous and nitrogen. Periodic harvesting of mature plants is conducted to prevent the stored nutrients from re-entering the aquatic ecosystem, which helps to mitigate the risk of cyanobacterial blooms by keeping nutrient levels in balance.	Implemented in small waterbodies with limited success.	Often dependent upon the amount of input (i.e., the number of plants and mats). Also subject to depth limitations.
Increasing grazing pressure F	Various measures can be introduced to encourage the growth of zooplankton, benthic fauna, and other aquatic organisms that feed on cyanobacteria, thereby limiting the proliferation of cyanobacteria populations. Techniques include: • The removal of fish that feed on zooplankton and other benthic fauna or the introduction of predators to these fish, and • The development of niches to encourage the growth of beneficial organisms.	Biomanipulation has fewer direct detrimental effects on other aquatic organisms when compared to chemical and physical methods.	Unintended consequences may arise related to the deliberate modification of the biodiversity of the system. Requires constant monitoring. Increasing resource competition has only proven effective in shallow water bodies with moderate nutrient levels
Increasing resource competition F	The introduction of other primary producers such as macrophytes can limit the available phosphorus and therefore limit cyanobacterial growth. An example of this technique is the introduction of floating wetlands (see above).		

F = freshwater; M = marine

Floating Islands



http://www.prlog.org/11132852-biohaven-floating-island.jpg

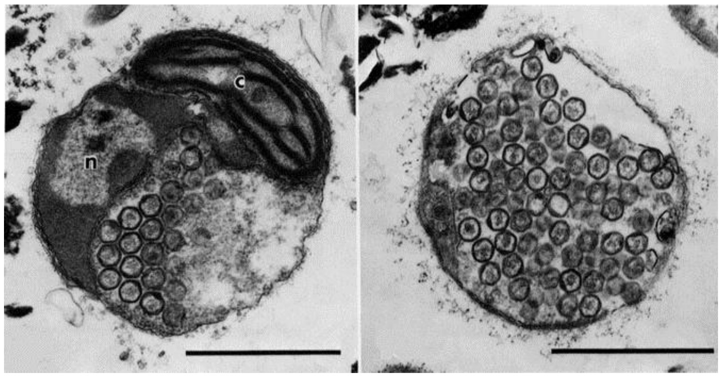
http://www.lowtechmagazine.com/images/2008/11/12/floating_island_rhizome_collective.jpg

http://lake-savers.com/wp-content/uploads/2013/03/feature-floating-island.jpg

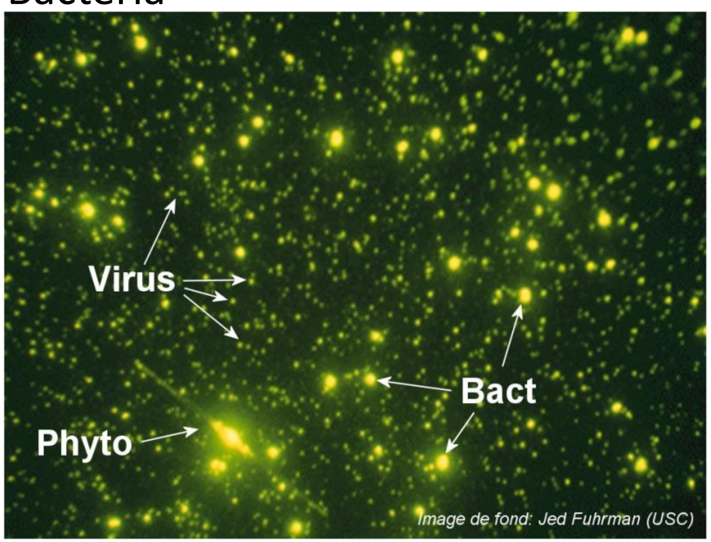
http://www.wef.org/assets/0/86/108/668/773/6442452995/6442453001/1cf66293-bbae-4476-8f88-5d76eaef71fc.jpg

Biological Control and Biomanipulation

Viruses



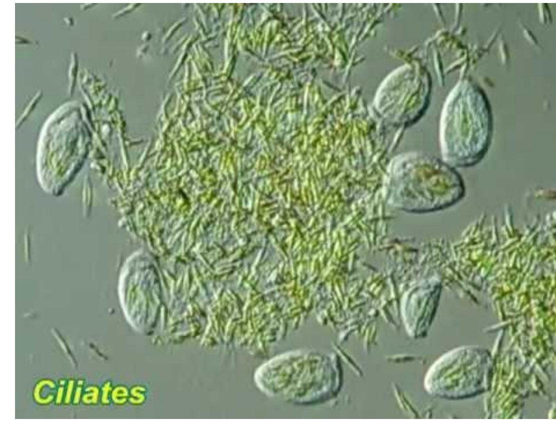
Bacteria



http://www.quebec-ocean.ulaval.ca/_images/Marine_microbe_A._Comeau_Jed_Furrman.jpg

Parasites

Grazers



http://wilsonlab.com/images/daphnia.jpg

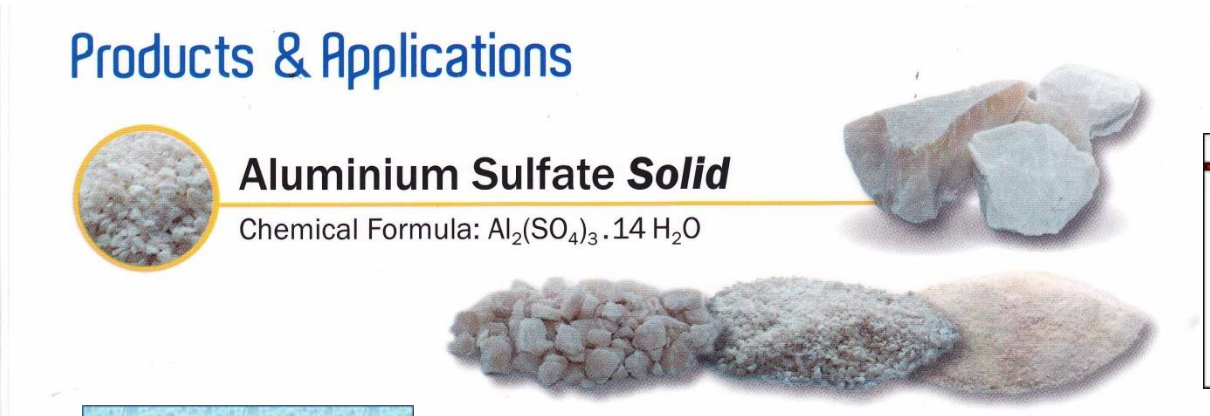
Competitors
(including allelopathy)

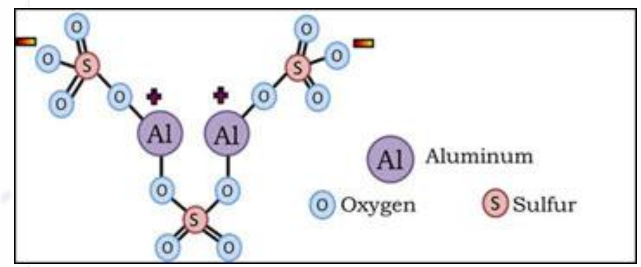
http://cfb.unh.edu/phycokey/Choices/Prymnesiophyceae/PRYMNESIUM/Prymnesium_02_600x448_nies.go.jp.nies-1397.jpg

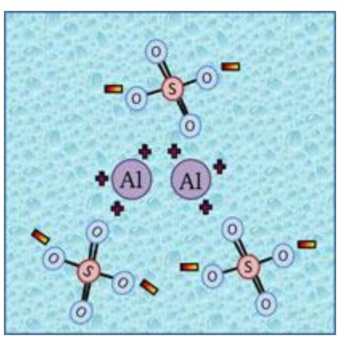
Direct Nutrient Removal

Chemical flocculants (bind, aggregate and sink)

Chemical flocculants (dissolved and particulates)
- aluminum sulfate (alum)
- polyaluminum chloride (PAC)
- polymeric flocculants

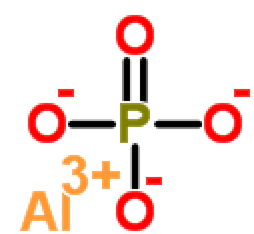






Aluminum hydroxide
$Al(OH)_3$
"Floc"

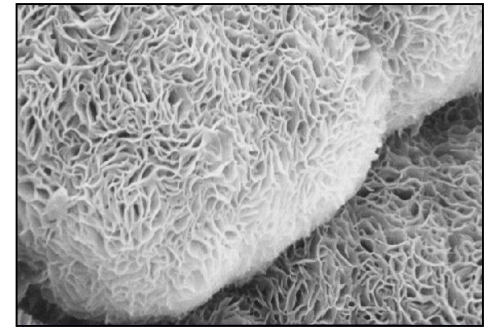
+ phosphates

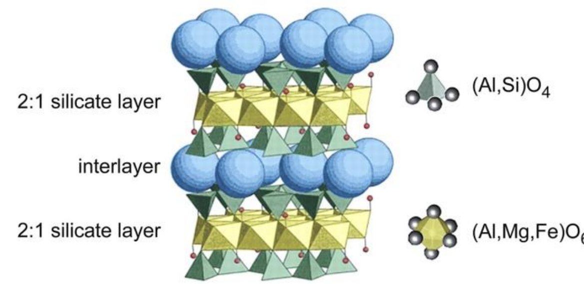


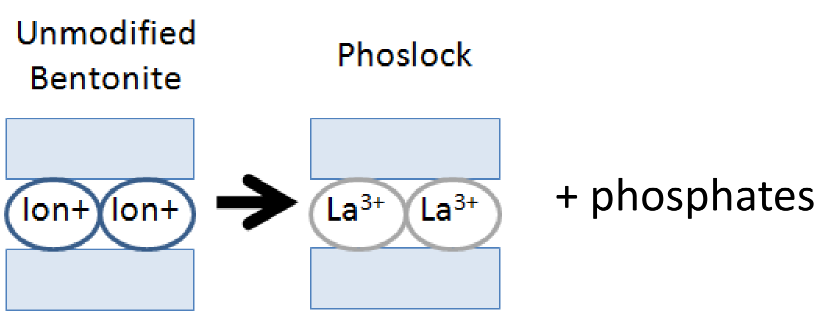
http://www.chemspider.com/ImagesHandler.ashx?id=58204&w=200&h=200
http://sinarindahcentral.files.wordpress.com/2011/11/aluminium-sulfat-solid1.jpg
http://www.teachengineering.org/collection/usf_/lessons/usf_flocculant/usf_flocculants_lesson01_figure3web.jpg

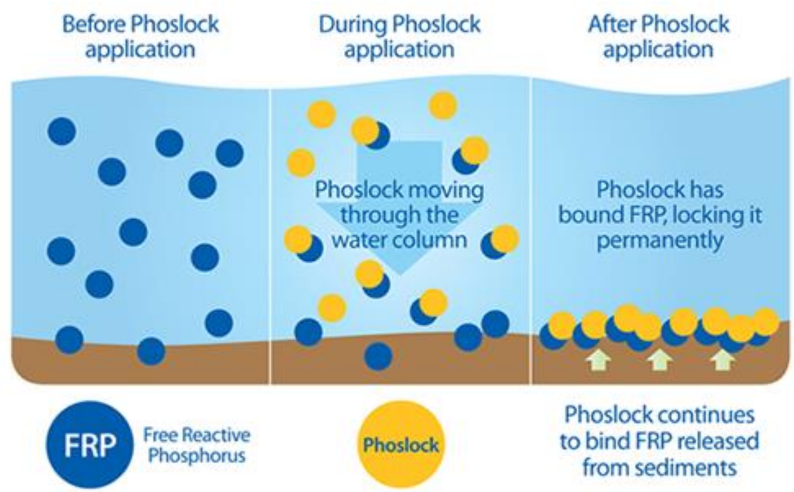
Alum Treatment in Lake Stevens (WA)

http://aquatechnex.com/wp-content/uploads/2013/06/IMG_5531.jpg









http://www.cygnetenterprises.com/ftp/productimages/Pics/Phoslock%2055lb%20bag_300x375.jpg
http://www.sepro.com/phoslock/images/HowPhoslockWorks.png
http://www.phoslock.eu/en/phoslock/about-phoslock/
http://elements.geoscienceworld.org/content/5/2/99/F2.large.jpg

Phoslock Treatment

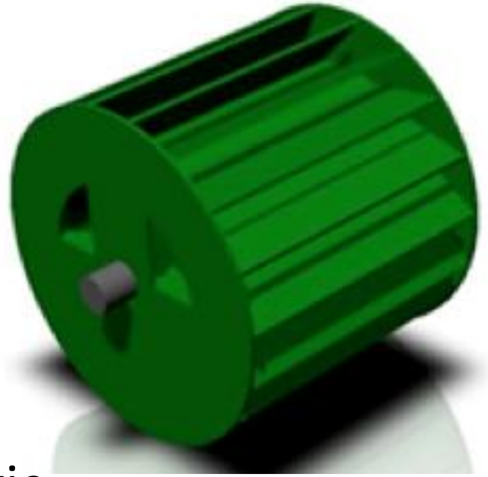
The Netherlands

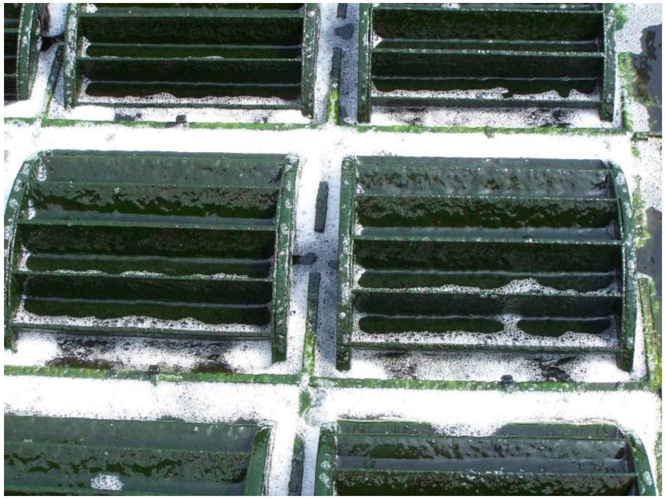
Lake Lorene, WA

http://www.sepro.com/phoslock/images/PhoslockSideBySide.jpg

AlgaeWheel

ONE water
ONE SOLUTION





Input: high nutrient water with natural algae & bacteria, sunlight, air/CO_2

Output: clean water, nontoxic algae for biofuel, other

Waterbody Management

Pros

- Prevents/Limits the impacts of nutrient pollution in short term (especially human health, drinking water, and local economies);
- Allows time for criteria development and implementation, including policy challenges;
- Cost effective approach (relative to watershed management).

Cons

- Benefits may be temporary;
- Treatments may need to be repeated or maintained over time;
- Cost effectiveness can distract from addressing the problem itself (i.e., sources);
- Implemented in small scales. Some technologies untested for larger scales.