Harmful Algae

HOW TO STAY AHEAD OF THE BLOOM

Let's Solve Water

Harmful Algae:
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It's the call no water treatment plant superintendent wants to receive, especially not while on vacation. Andy McClure, Superintendent of Toledo, Ohio's Collins Park Water Treatment Plant, answered his phone to hear his head of operations report that the level of microcystin in the finished water was high, caused by a large harmful algal bloom (HAB) that was impacting the plant's Lake Erie intake.

Microcystin is a common and very potent toxin created by blooms of cyanobacteria, also known as blue-green algae. At 2.5 µg/L, the level was more than double the 1.0 µg/L concentration the World Health Organization (WHO) has recommended as a safe limit for drinking water. McClure kept in close contact with his staff, as he prepared to return to the plant the next day. By midnight, they had confirmed the levels. A few hours later, in the early hours of August 2, 2014, and after consulting with state officials, the Mayor of Toledo issued a do-not-drink advisory to the consumers of Toledo's water. Approximately 500,000 Ohio and Michigan residents awoke to the news that their water was not safe. The advisory warned of possible health impacts of consuming the water, including abnormal liver function, diarrhea, nausea, vomiting, dizziness and numbness. The advisory would remain in effect for three days, as the City of Toledo's water department worked to bring the toxin levels down and flush the system[1,2,3].

Cyanotoxins Cause Illness, Even Death

Microcystin, the toxin detected in Toledo's system, is a hepatotoxin, which attacks the liver. Hepatotoxins are the most commonly occurring and geographically widespread of the three classes of cyanotoxins produced by cyanobacteria. Other toxins attack the nervous system, while still others affect the skin and mucus membranes (see Table 1). Bottom line, cyanotoxins can be lethal and water utilities must ensure that they are kept out of the water supply.

Table 1: Cyanobacteria Metabolites – Toxins and Taste & Odor Compounds

Toxin Type	Affects	Examples	Comments
Hepatotoxins	Liver and kidney	Microcystin, Nodularin, Cylindrospermopsin	Most common, can be fatal
Neurotoxins	Nervous system	Anatoxin-a, saxitoxin	Seizures
Dermatoxins	Skin lesions, eye, ear and mucus membrane irritants	Microcystin-LR	
Taste and Odor			
Terpenoids	Musty, earthy smells and tastes	Geosmin, 2-Methylisoborneol (2-MIB)	May be present with or without toxins

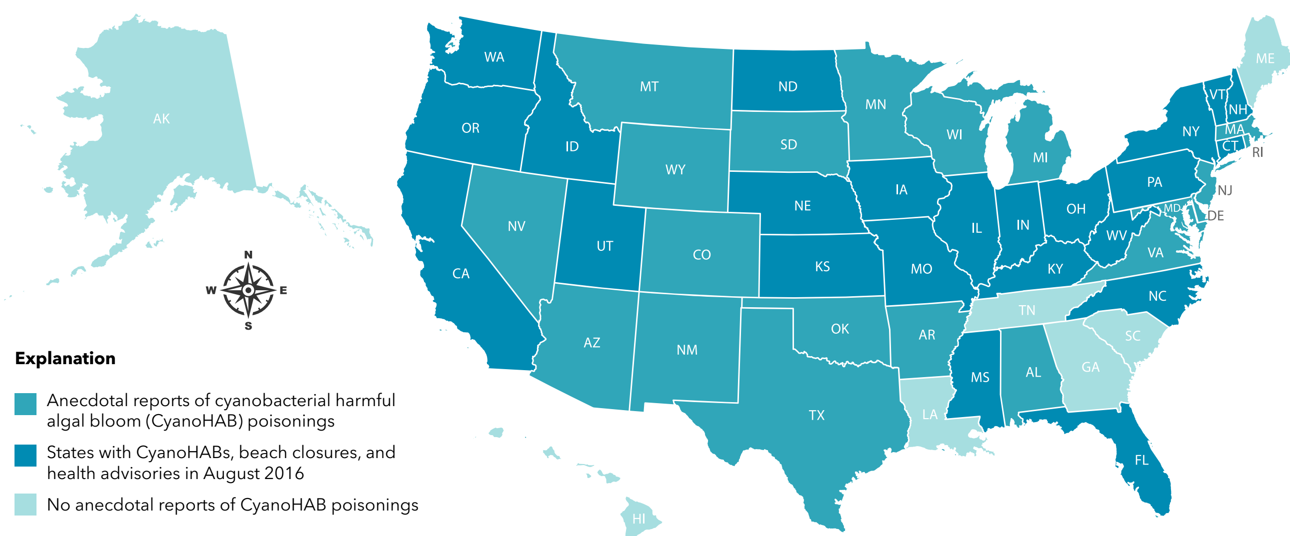
Taste and odor also caused by HABs – leading cause of customer complaints

Even without the looming toxicity concerns, HABs can be a public relations nightmare for your utility due to taste and odor. Some cyanobacteria that create toxins also create Geosmin and 2-Methylisoborneol (2-MIB), causing earthy, musty smells detectible at very low levels – 30 ng/L for Geosmin and 5 ng/L for 2-MIB. Like most cyanotoxins, these compounds are released when the algal cells die. Also like cyanotoxins, these compounds are not removed through conventional filtration. Though not technically harmful, taste and odor compounds are the leading cause of customer complaints, causing your customers to question if the water produced is "clean" and safe.

Widespread but largely unregulated – for now

Many types of algae can cause HABs in both freshwater and marine systems, but the freshwater cyanobacteria HABs (CHABs) have the highest potential to adversely impact drinking water systems. A survey conducted by UNESCO and published in 2005 confirmed that cyanobacteria occur throughout all regions of the world and in all the countries surveyed[4]. In the US, the USGS cites anecdotal reports of CHABs in 43 states in August 2016, leading to many health advisories and/or beach closings (Figure 1)[5].

Figure 1: USGS reported CHABs August 2016[5]



As with other Contaminants of Emerging Concern (CECs), most countries have not yet placed regulatory limits on cyanotoxins, though both categories are on the regulatory radar and being studied for possible enforcement. Wise utilities will consider other treatment objectives in addition to reducing cyanotoxins, and explore treatment options that may also address these CECs. The good news is that many treatment processes that destroy cyanotoxins are also effective against difficult to remove CECs, such as personal care products (PCPs), pharmaceutical residuals, and endocrine disrupting compounds (EDCs).

In the United States, cyanotoxins are not regulated under the Safe Drinking Water Act (SDWA). However, the EPA has published the Drinking Water Health Advisory for the Cyanobacterial Microcystin Toxins[6], which provides guidance on levels of two common cyanotoxins (Table 2), though not yet carrying the weight of regulation. In this Drinking Water Health Advisory, the EPA reported that eighteen countries and three states (Minnesota, Ohio and Oregon) have issued guidelines for microcystin as of June 2015[6].

Table 2: World-wide guidance on cyanotoxins

	Cylindor-spermopsin	Microcystin - LR	Microcystin (total)	Saxitoxin (total)	Nodularin
EPA Health Advisory					
Adults	3 µg/L		1.6 µg/L		
Bottle Fed Infants and Preschool-aged Children	0.7 µg/L		1.6 µg/L		
World Health Organization (WHO)		0.7 µg/L			
Health Canada			1.5 µg/L		
Australia	1 µg/L		1.3 µg/L	3 µg/L	3 µg/L

A listing of other countries can be found in the Global Water Research Coalition, International Guidance Manual for the Management of Toxic Cyanobacteria, 2009[7]. In addition, the EPA has added three cyanotoxins, Microcystin-LR, Anatoxin-A, and Cylindrospermopsin, to the Third Contaminant Candidate List (CCL3). The Fourth Unregulated Contaminant Monitoring Rule, UCMR 4, also requires monitoring for ten cyanotoxins at all large (more than 10,000 retail customers) and 800 randomly selected small Public Water Systems with surface water sources or groundwater under the direct influence of surface water.

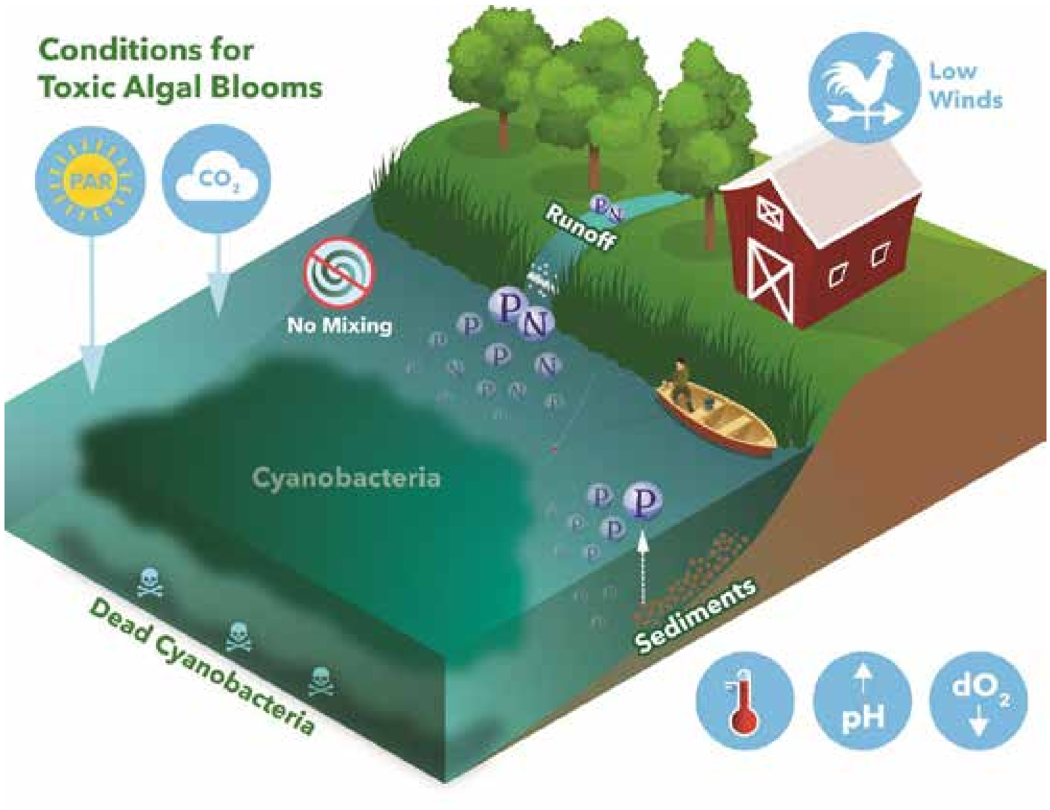
But first, how do you know if your water supply is at risk?

Factors favoring HABs

Conditions favoring HABs occur seasonally in fresh water bodies and reservoirs and include:

- Nutrient load – nitrogen and phosphorus
- Sunlight
- Temperature – warmer temperatures favor growth
- Higher CO2 levels
- Lack of wind, turbulence
- Sediment release and biological interactions

Figure 2: Factors contributing to HABs



The concentration and duration of HABs will likely increase, as temperatures and carbon dioxide levels rise due to climate change and watershed development increases nutrient loadings. Through transport of toxins released into the water, a HAB may impact a utility that is far from the actual bloom.

Which raises the all-important question:

How do you stay ahead of algal blooms? What are your management options?

Management Options

The utility has three types of management options to control HABs impact on their utility:

1. Source controls
2. Intake modifications
3. Treatment modifications

To the extent practical, it is always advantageous to keep algae out of the treatment plant through source control or intake modifications. This reduces the risk of toxins being released into the raw water from the algal cells via lysing (rupturing of the algal cell wall). Once toxins are released, treatment options required to remediate them tend to be more complex.

Source Controls

Depending upon the source water, several options (Table 3) might inhibit the algal growth. However, once a bloom has taken hold of a water body it is hard to fully eliminate it, and source control methods usually require repetitive action. It is extremely difficult to remove or prevent the growth of all algal cells. Preventing the entrance of excess nutrients into the system is also very challenging, especially when they may be flowing in from outside, uncontrollable sources.

Table 3: Source Controls

Potential Action	Benefits	Challenges	Relative Cost
Reduce nutrient load (Point-source and non)	Limits occurrence of algae and byproducts at the source	• Difficult implementation • Long timeframes	Low
Bio-manipulation		• Fish/wildlife side effects	Low
Block sunlight (Floating Covers)		• Loss of recreation • Service life	Medium
Mixing and aeration		• May not work on large or deep sources • Operating cost unless solar powered	Medium
Dredging		• Permitting, disposal • Does not remove algae or toxins in water	High
Chemical Phosphorus Precipitation		• Recreational use • Fish/wildlife side effects	High
Algicides		• Recreational use • Kills algae - release of toxins	High

Case Study: Thames Water – Using Reservoir Profiler to Maximize Water Quality, Reduce Algal Load and Costs

- Queen Mother Reservoir, built in 1976.
- Drought between November 2004 and July 2006 required an increased focus on water use efficiency and one part of the solution was to install profile samplers to inform water withdrawal decisions.
- The vertical profiler system samples and analyzes water throughout the depth of the reservoir, allowing operators to know the depth of the best quality water.
- Algae is one of the parameters the profiler analyzes.
- Advanced intake allows water to be withdrawn at different depths.
- Terry Bridgman, Field Scientist in the water quality team stated, "For example, if we are able to ensure that the algal load in water supplied to the drinking water treatment plants remain low, we can save costs by optimizing the treatment process."
- Thames Water also suppresses algal growth through active mixing within the reservoir using jets and aeration. The profiler allows them to employ mixing only when needed, saving energy and reducing costs.
- Operating since 2006.
- Thames water has added vertical profilers to other systems as well as upgrading to newer monitoring technologies.

Intake Modifications

For some utilities, intake modifications (Table 4) might keep algal cells and toxins from entering the treatment system. Vertical profiling and good data on the biochemistry of the source water is key to intelligent decision making when looking for a new source or making modifications to an intake.

Table 4: Intake Modifications

Potential Action	Benefits	Challenges	Relative Cost
Alter Inlet Depth	Avoid algae intake at specific depths	• Deep reservoirs only • Permitting and construction costs	Low
Move Inlet Location	Avoid algae intake at new location	• Large reservoirs only • Changing environmental conditions can bring algae to any location	Medium
Riverbank Filtration	Removes algae without a waste stream	• Rivers or canals only • Depends on soil conditions	Medium
New Source(s)	Avoid algae at new source	• May require other treatment barriers • New pipelines and rights-of-way • Water rights	High

Treatment Modifications

For many utilities, source controls or intake modifications are either not practical, or are not capable of ensuring that no algae or toxins enter the system. For those, treatment modifications provide the only viable options.

For algae and its toxins, a two-pronged approach may be required.

Algae cells and their metabolites – your treatments must deal with both. Most (though not all) of the metabolites from algae remain inside the living cells. Therefore, if the cells can be removed intact, without lysing, less of the compounds need to be removed by advanced treatment. Once the cell dies though, the cell membrane breaks down and the compounds are released into the water. Since some cells have died in every bloom, these compounds will be present regardless of how careful you are to remove intact cells. The goal of removing the intact cells is to minimize the concentrations of toxins.

Once released into the water, the toxins and T&O compounds are difficult to remove, requiring ozone, ozone-Biologically Activated Carbon (BAC), advanced oxidation processes (AOPs) or adsorption with activated carbon. These processes require ongoing lifecycle costs (LCC), so it is often more economical to reduce the size of and loading on these processes by first removing intact cells, thereby reducing the concentrations in the water as much as possible. Processes for cell removal, particularly Dissolved Air Floatation (DAF), may have lower LCC than destruction or adsorption of the toxins and T&O compounds. Treatment modifications should be viewed in this two-prong approach of cell removal and treatment (Table 5).

Table 5: Treatment Modifications

Option	Algae Removal	Taste & Odor	Algal Toxins	Details	Significant Impacts to Operations
Dissolved Air Flotation (DAF)	✔			• Avoids lysing • Proven high removal rates • Piloting is key for best lifecycle cost	• Chemical • Energy
Clarifiers or Plate Settlers	✔			• May grow algae • Uncertain removal rates • Large footprint requirement	• Chemical
Micro-strainers	✔			• Significant headloss • May lyse cells • Uncertain removal rates	• Energy
Ozone - BAC	✔	✔	✔	• Destruction of CECs an additional benefit • Piloting is key	• Energy • Liquid Oxygen supply (LOX)
Ozone		✔	✔	• Proven effectiveness • Potential for disinfection byproducts	• Energy • LOX
UV AOP		✔	✔	• Log removal credits for Cryptosporidium and/or Giardia • CECs destruction is an additional benefit	• Energy • Chemical
Ozone AOP		✔	✔	• CEC destruction is an additional benefit	• Energy • Chemical • LOX
Activated Carbon (GAC, PAC)		✔	✔	• May also adsorb CECs	• Energy • Transportation • Labor

Cell Removal Methods:
When evaluating removal options, keep in mind the algae's natural buoyancy. This makes removal through settling processes more difficult, requiring more chemical to force the algae to settle. Also, with algae's sticky texture, it can quickly blind strainers and filters. Because of these properties, DAF is often the best alternative as it takes advantage of the buoyancy and can remove the algae without lysing or blinding.

Compound Removal Methods:
In most cases, removal of the algae alone will not remove the toxins or taste and odor compounds, all of which are difficult to break down with standard disinfection. As Table 5 shows, additional treatment is usually needed. These treatments use ozone, advanced oxidation processes (using hydrogen peroxide and either ozone or ultraviolet light), ozone - BAC, or adsorption using Granular Activated Carbon (GAC) or Powdered Activated Carbon (PAC). Clearly, keeping these compounds to a minimum by removing as much intact algae as possible reduces the costs of these treatments.

Every source water, every utility is unique, and the exact capital and operating costs will also be unique, based on the source water quality and other treatment objectives. As Table 5 indicates, many of the treatments to adsorb or destroy toxins and T&O compounds are also effective for CECs. The overall analysis should consider future treatment objectives and anticipate future regulation to the extent possible. Keep in mind that HAB impacts can be seasonal in nature, so a complete analysis would consider turndown capabilities and the associated savings for an accurate LCC. A comprehensive evaluation should consider all these factors and develop a low to high LCC ranking for a specific plant based on the range of treatment options and objectives.

How do you know when to begin treatment? Monitoring is the first line of defense.

Recent advances in monitoring technology can help you stay ahead of algal blooms. By knowing if the conditions are right, and if the algae in your surface water supply is indeed cyanobacteria, you can take steps to mitigate the impacts and minimize liability – at a minimal cost by not treating when you don't have to, or if there is a bloom, possibly using technology to locate and access raw water with lower concentrations of algae.

So, what should you monitor? The best monitoring strategy is two-fold: Both in the water and out.

Out of the water (Table 6), monitor for conditions that favor algal blooms, and cyanobacteria.

Table 6: Out-of-water monitoring

Monitor this…	Because…
Temperature	High temperatures favor cyanobacteria
Barometric Pressure	Affects dissolved gasses, especially CO_2, at water's surface
Wind direction and speed	Blooms can migrate with wind patterns
Sunlight, particular wavelengths	Photosynthetically Active Radiation (PAR) is the energy source of blue-green algae

Case Study: Waco Texas – Tackling Taste and Odor with DAF and Ozone

- Lake Waco source water feeds two water treatment plants.
- Warm climate, and high nutrient loads from agricultural operations create algal impacts on water quality.
- Residents were vocal in complaints about taste and odor, the problem continued for years.
- A single pretreatment plant was constructed at the reservoir site, using DAF followed by ozone.
- DAF removes intact cells without lysing, reducing the loading on the ozone system. Ozone then breaks down the taste and odor compounds, as well as any CECs, into inert compounds.
- From the pretreatment plant, the water flows to two existing water treatment plants where it is filtered prior to final disinfection and distribution.
- Eliminated use of PAC.
- Piloting of DAF system provided information for fine tuning final design, demonstrating that the DAF could deliver 2.5-log removal of algae cells, while also reducing turbidity.
- The full-scale DAF consistently reduces turbidities from 10 to 70 NTU (after a storm) to less than 0.5 to 0.7 NTU.
- Finished water DPBs were cut in half, and geosmin was reduced to less than 9 parts per trillion.
- With 0.7 NTU of turbidity coming from the full-scale DAF system, filter runs improved to over 100 hours per run.
- The full-scale DAF has been effective for Cryptosporidium and Giardia removal, with 3.5 to 4+ log removal, increasing the overall resiliency of the WTP.
- Commissioned in July 2010.

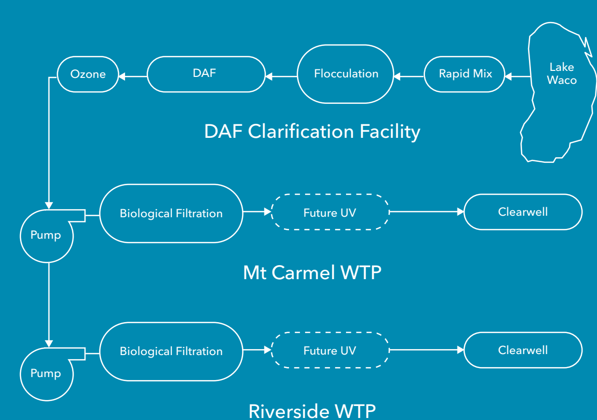


Table 7: In water monitoring

Monitor this…	Because…
Chlorophyll	Found in almost all algae
Phytocyanin	Found specifically in blue-green algae
Temperature	High temperatures favor cyanobacteria
pH	Rising pH due to high growth; makes carbon dioxide more bioavailable
Turbidity	Surrogate for increased biomass; may be indicative of nutrient-bearing suspended solids
Dissolved Oxygen	Decreases during a bloom; may lead to fish kills
Conductivity	Blue-green algae generally thrive in lower conductivity waters
Algae identification	Determine whether pigments/turbidity are due to potentially toxic (PTOX) blue-green algae
Microcystin toxin	Hazardous to human and animal health
Nitrogen and Phosphorus	Growth-limiting nutrients that stimulate blooms when in high concentrations (eutrophic waters)

Many of these parameters are self-explanatory, monitoring conditions that either favor algal formation or may be indicative of the beginning of a bloom. Remember that timing is critical, so in-situ monitoring is essential – you must know what is happening in real time. One vital link is determining if an algal bloom is indeed blue-green algae. Thanks to advances in sensor technology, which measure fluorescence to distinguish between green and blue-green algae, this determination can now be made in real time. Real time identification allows you to be proactive in your response to a bloom, rather than waiting days for test results.

In addition to alerting you to potential problems, ongoing monitoring allows you to look for trends and correlations between specific parameters. These are very site specific, so knowing how YOUR water supply responds to changing conditions yields huge benefits in being proactive, and maintaining control.

Multiple parameters for HAB monitoring can be bundled in the most advanced sensors by YSI.

Case Study: Sung-Nam Water Treatment, Korea – Advanced Oxidation of Ozone + Peroxide Eliminates Algal Taste and Odor

- Serves 300 million people plus a beverage industry producing 45,000 bottles per day.
- Algal blooms upstream in the Han-River cause seasonal taste and odor from 2-MIB.
- The distance between upstream reservoirs where the blooms are occurring, and the WTP, made source and intake options impossible, necessitating an investment in advanced treatment to target taste and odor compounds, along with any potential toxins.
- Piloting determined optimal AOP system was an ozone-hydrogen peroxide system. This is typical for systems with high flowrates, where ozone-based AOPs tend to be more cost effective than UV- based AOPs.
- The AOP system is also effective for the removal of CECs, an additonal concern for this facility.
- Ozone dose of 2 mg/L with H_2O_2 dose of 0.5 mg/L achieves 0.5 log removal of 2-MIB
- Operating since 2012.

Putting it all together – the four-point plan.

Step 1: Protect and Gather

- Protect your watershed from nutrients: Engage stakeholders such as agricultural producers to avoid over-fertilization. Regulate development to minimize nutrients in stormwater discharges, septic systems in rural areas, and upstream wastewater plants and other point-source dischargers. These options are often beyond a utility's direct control, but can be much more economical than future investments to address blooms.

- Gather information: Implement a monitoring program to gather data on water and environmental conditions in and around your water source. Having a strong set of baseline water quality data on your source will allow for intelligent and informed decision making in the future if algal blooms develop.

Step 2: Assess Options

- Partner with a proven consulting team to develop a feasibility study of available options.

- Evaluate source and intake options: The study should encompass a thorough review of all relevant source and intake options on a lifecycle cost basis, in addition to consideration of recreational, environmental and other relevant factors.

- Assess and compare treatment options: Within the treatment plant, available options should be assessed and compared on a basis of Total Cost of Ownership, from identification and procurement, all the way through decommissioning and renewal.

- Narrow viable options for additional study: All options, from source through intake and into treatment, should be compared on relevant criteria, and the recommended option(s) should be identified for more detailed study.

Step 3: Test and Verify

- Partner with proven equipment manufacturers offering needed pilot systems to confirm performance, fine tune and finalize design parameters, and verify Total Cost of Ownership.

Step 4: Finalize, Budget and Implement

- Finalize the necessary investments needed to protect your water users from Harmful Algal Blooms.

- Budget and obtain funding for the needed capital and operations investments.

- Continue the monitoring program. Integrate it into the overall water system database and operational analysis system, to provide information and trend analysis for operation and optimization of treatment systems, and to verify the function of any other measures implemented to manage blooms.

Algal blooms are going to increase in range, intensity and length of season, as nutrient levels increase due to development, and climate change push the temperature and carbon dioxide levels higher. It is simply good management to be proactive, to assess your risk. Then, if blooms might be in your water plant's future, develop a plan.

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1) The tissue in plants that brings water upward from the roots;
2) a leading global water technology company.

We're a global team unified in a common purpose: creating advanced technology solutions to the world's water challenges. Developing new technologies that will improve the way water is used, conserved, and reused in the future is central to our work. Our products and services move, treat, analyze, monitor and return water to the environment in public utility, industrial, residential and commercial building services settings. With its October 2016 acquisition of Sensus, Xylem added smart metering, network technologies and advanced data analytics for water, gas and electric utilities to its portfolio of solutions. In more than 150 countries, we have strong, long-standing relationships with customers who know us for our powerful combination of leading product brands and applications expertise, and a sharp focus on developing comprehensive, sustainable solutions.

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Xylem, Inc.
14125 South Bridge Circle
Charlotte, NC 28273
Tel 704.409.9700
Fax 704.295.9080
855-XYL-H2O1 (855-995-4261)
www.xyleminc.com