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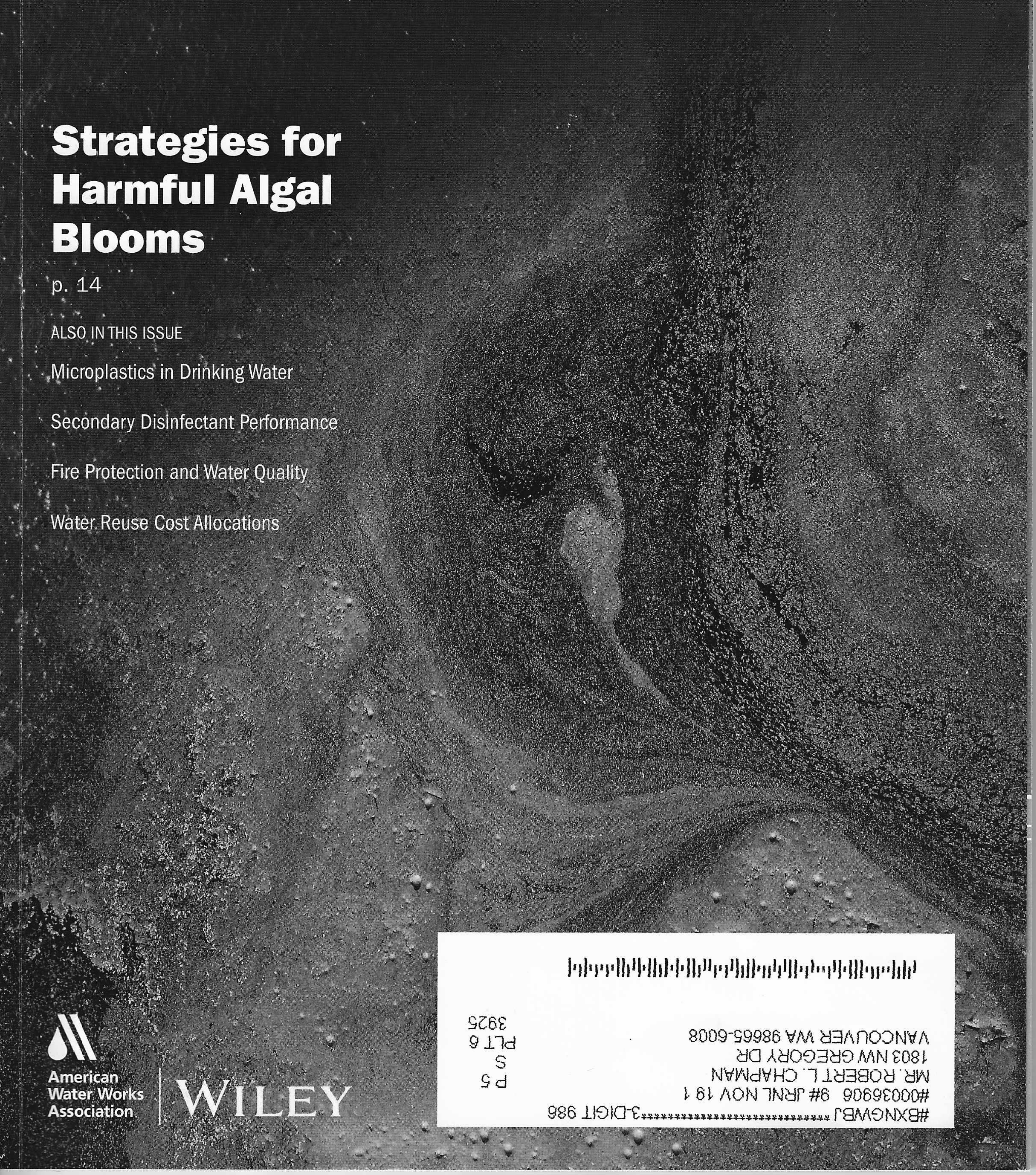

## Strategies for Harmful Algal Blooms

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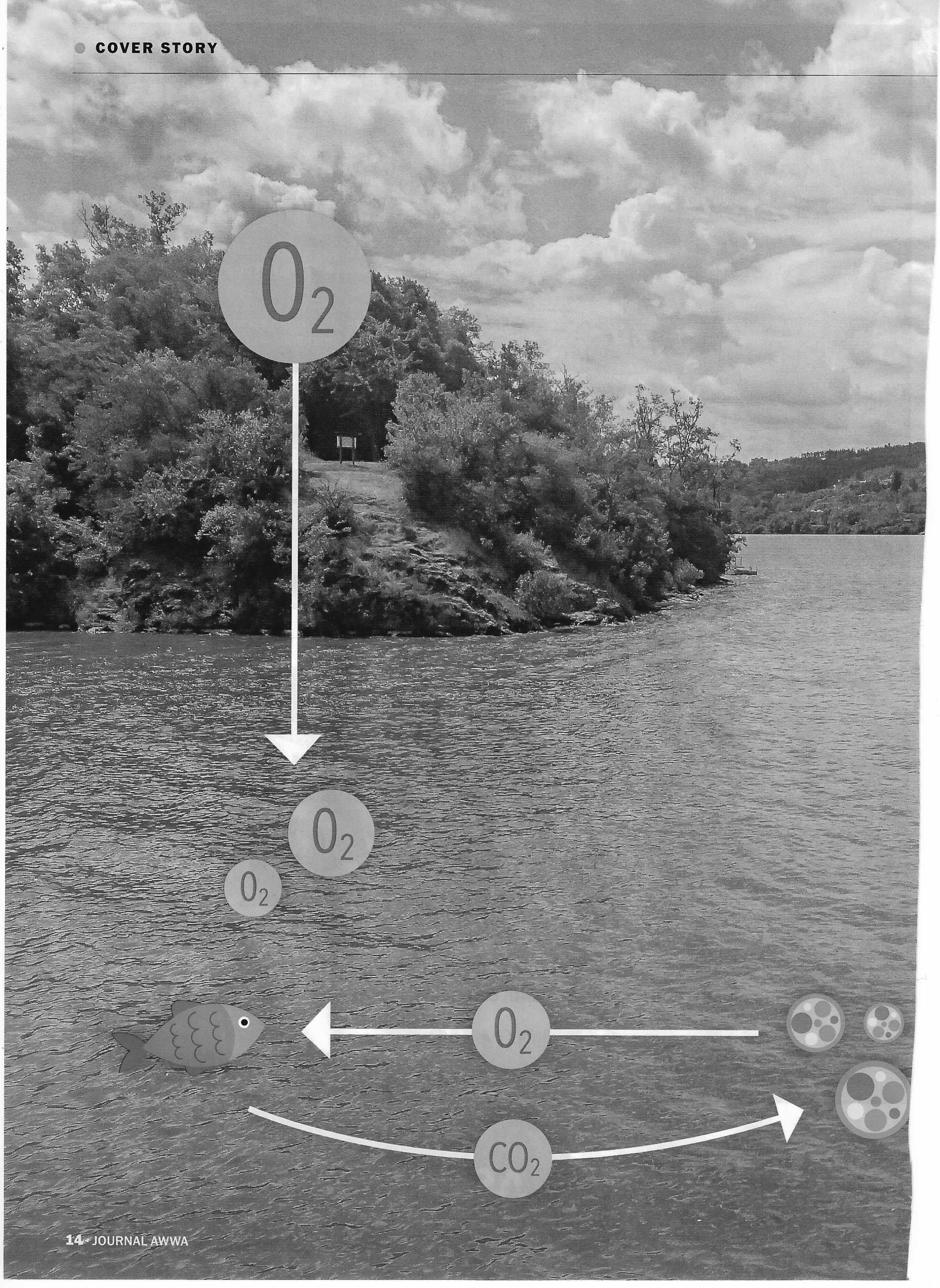
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# Beyond Toxins: A Source-to-Treatment Strategy for Harmful Algal Blooms

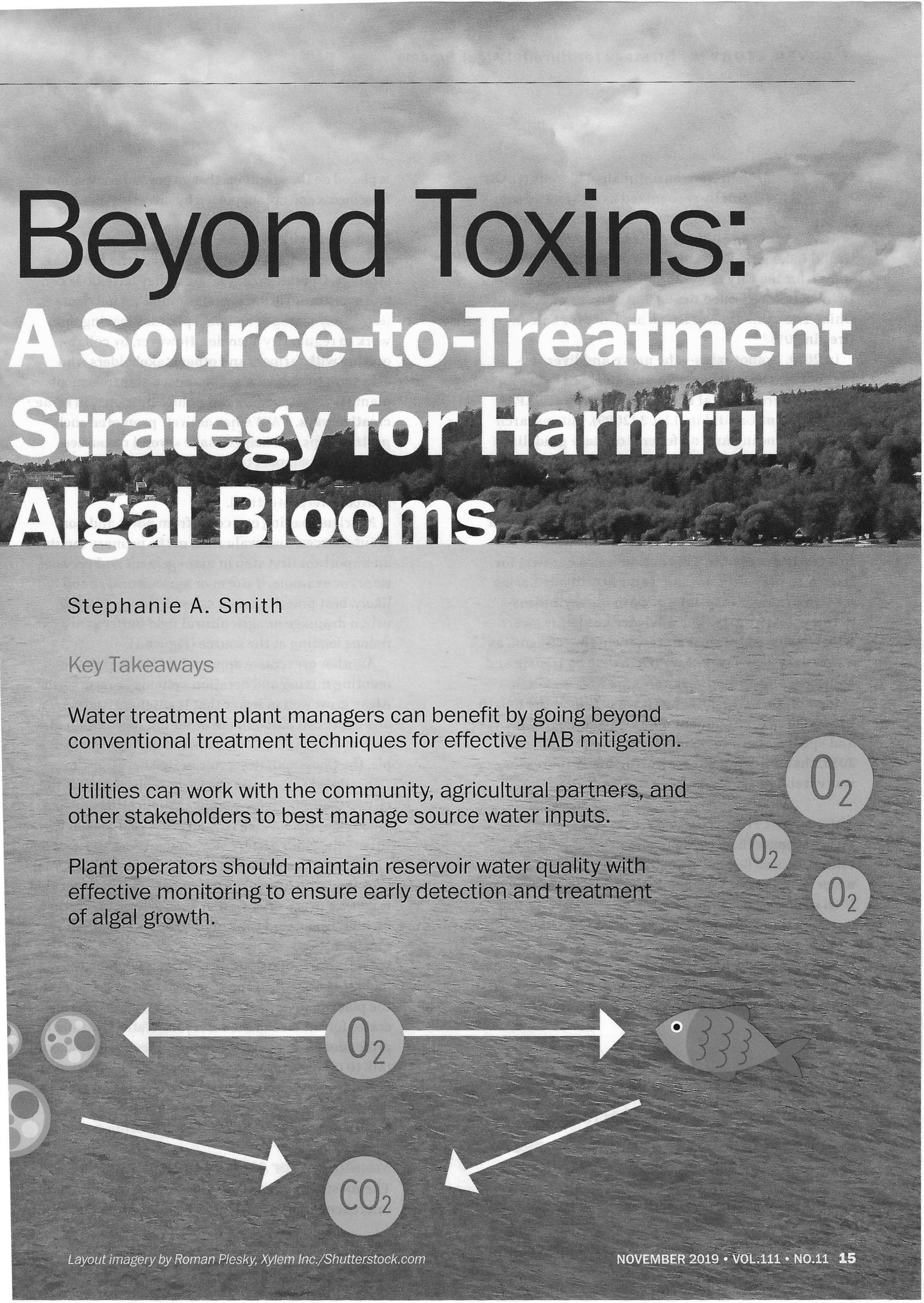
Stephanie A. Smith

## Key Takeaways

Water treatment plant managers can benefit by going beyond conventional treatment techniques for effective HAB mitigation.

Utilities can work with the community, agricultural partners, and other stakeholders to best manage source water inputs.

Plant operators should maintain reservoir water quality with effective monitoring to ensure early detection and treatment of algal growth.



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When were harmful algal blooms (HABs) finally recognized as a threat to safe drinking water in the United States? In 2010, with the beach closures at Grand Lake–St. Mary's, the primary drinking water source for the City of Celina, Ohio? The 2014 Do Not Drink advisory issued to 500,000 citizens of Toledo, Ohio? The same Do Not Drink advisory for Salem, Ore., in 2018?

In 2010, cyanotoxins—the nerve and liver toxins that can be produced during an HAB—were on the US Environmental Protection Agency (USEPA) Contaminant Candidate List 3 (2009), but research was still pending and no federal or state guidelines were yet in place. By 2014, Ohio EPA was prepared to enforce a Do Not Drink advisory for Toledo based on World Health Organization cyanotoxin exposure guidelines (available since the early 2000s) and implemented statewide guidelines that would lead to a testing program. This action was a catalyst for USEPA to provide drinking water health advisories for two cyanotoxins—microcystin and cylindrospermopsin—in 2015. The advisory guidelines were widely adopted by most states, including Oregon, as a February 2017 *Journal AWWA* article by Henrie and colleagues described. Cyanotoxins were again included on CCL 4 in 2016, but it wasn't until the fourth Unregulated Contaminant Monitoring Rule (UCMR 4), and specifically a revision published in December 2016, that assessment monitoring for cyanotoxins was established.

## Three-Part HAB Strategy

The challenges that HABs pose for drinking water sources go well beyond cyanotoxins. It's important for water treatment professionals to establish a three-part HAB strategy model:

- Management at the source
- Monitoring for algal growth
- Mitigation through treatment

For each critical action, this article discusses technologies that are helpful for dealing with HABs. Emphasis is placed on those options that go beyond conventional treatments and are supported by successful use.

> **Water treatment professionals considering aeration technology should talk to other plant managers about their experiences and recommendations.**

## Management at the Source

Preventing or limiting algal growth is the best HAB strategy. Operators may assume they have little control over the influx of algae-stimulating nutrients (especially nitrogen and phosphorus), leaving that work to regulatory agencies. However, by collaborating with farmers and other stakeholders who also want to reduce algal blooms, water treatment plant (WTP) managers can reduce nutrients in some creative ways. AWWA has actively promoted such partnerships and helped make several resources available to support these initiatives as part of the recently enacted 2018 Farm Bill (see www.awwa.org/sourcewaterprotection).

Nutrient loading can come from point and nonpoint sources, and evaluation of the primary inputs is an important first step in management and prevention. For example, if storm or agricultural runoff is likely, best practices such as establishing filtered urban drainage or agricultural field buffer zones can reduce loading at the source (Figure 1).

Another preventive approach to HABs is implementing mixing and aeration systems in reservoirs. Algae grow well in water that is stagnant and warm, and algae can outcompete other microbes when dissolved-oxygen (DO) levels start to decline. For example, the Chessman Reservoir in Helena, Mont., experienced algal blooms in the early 2000s that cost the city $5,500/month for chemical applications during bloom months. In 2007, the city invested $110,000 in three solar- and battery-powered mixing and aeration systems and built onsite facilities for housing them in the off-season (the mixers cannot be left in water that might ice over). This system had a seven-year return on investment and continues to enjoy low maintenance costs.

There are limitations of aeration technologies, including the size of the area a mixer can treat, and the placement and circulation pattern the mixer generates for the size of the reservoir. Water treatment professionals considering aeration technology should talk to other plant managers about their experiences and recommendations. Mixing and aeration technology can be further improved when paired with a multiparameter water quality monitoring system.

## Monitoring for Algal Growth

The most common algae monitoring tools include microscopy, toxin testing, and laboratory-based

**Improvements to Address Urban or Agricultural Runoff**

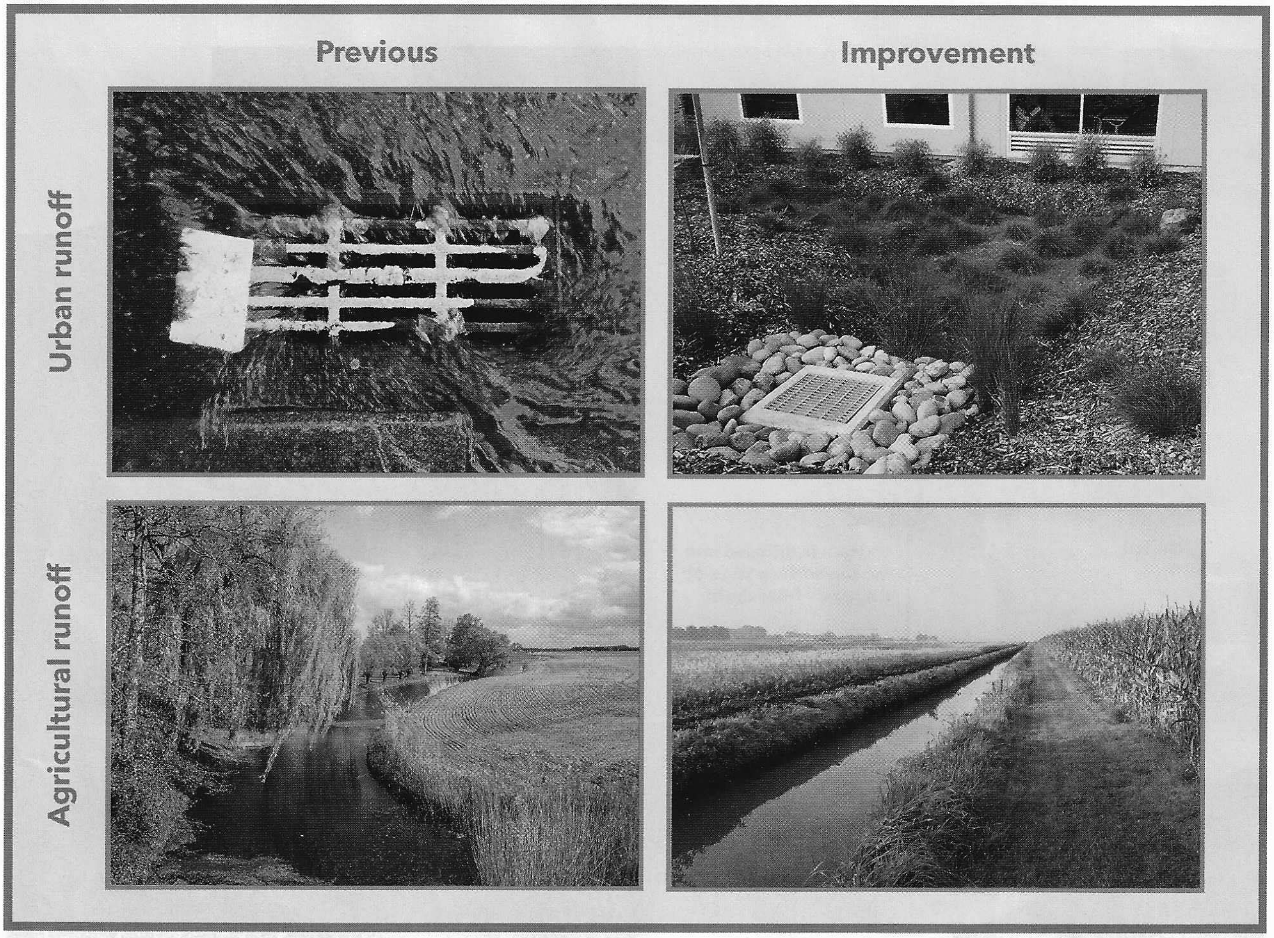


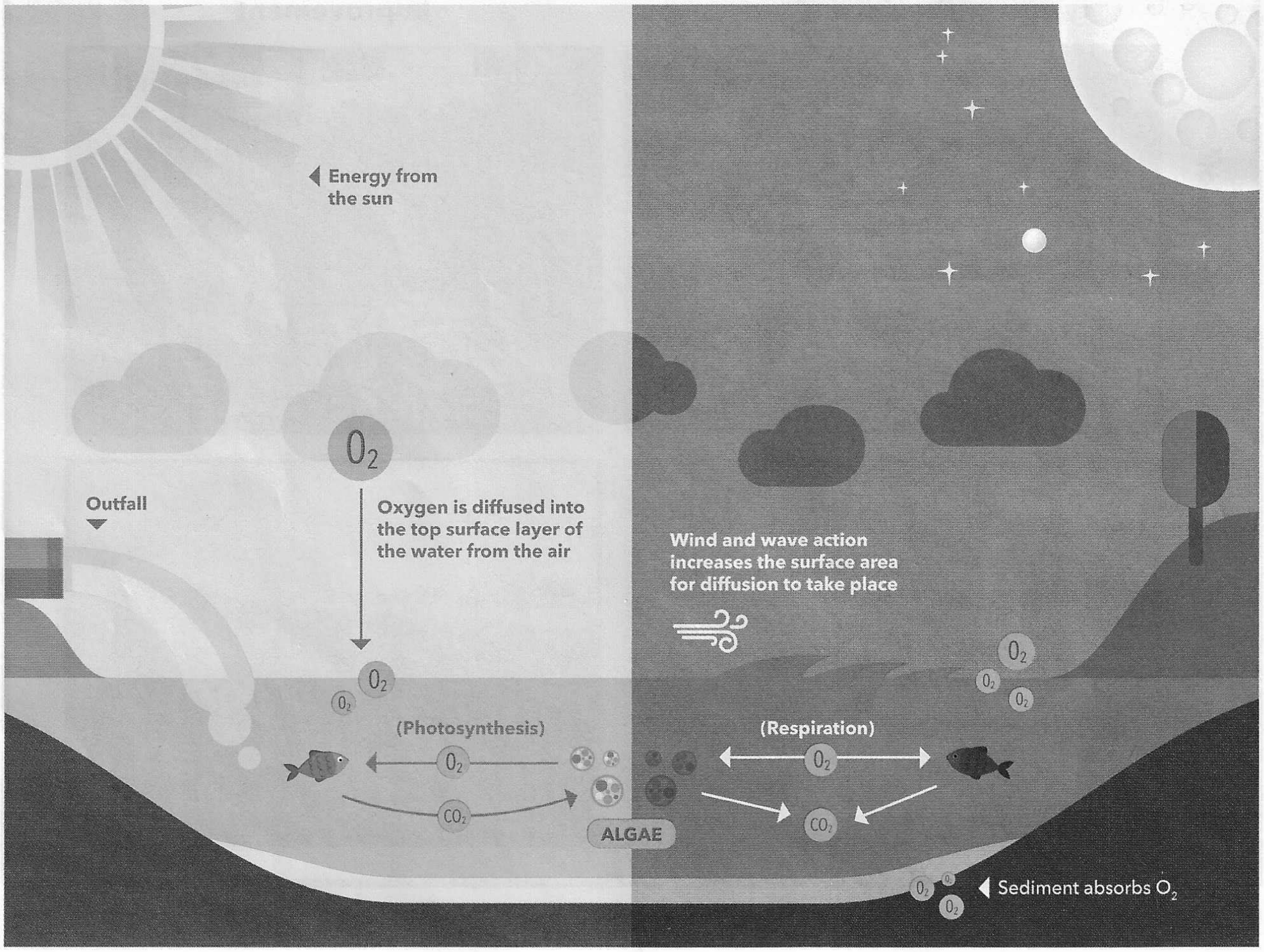
**Figure 1**

methods for measuring algal pigments, chlorophyll, and phycocyanin. The biggest limitation of these tools is the time elapsed from the point of sample collection to that of the end result. Early detection can make in-reservoir amendments and water treatment more effective and less expensive, especially when complemented by an understanding of the baseline water quality of a system. For early detection, pigments can be detected with sensors directly in the source, which should be accompanied by at least three fundamental water quality parameters in a multiparameter platform: temperature, DO, and pH.

### Temperature

In most cases, warm water favors the proliferation of HABs. Unlike DO and pH, temperature affects the growth of algae but doesn't respond to the algae, so monitoring provides an understanding of when the temperature is conducive to algal growth. Contrary to popular belief, HABs can occur in cooler waters, and in fact some algae can bloom under ice. Many WTP managers deal with both spring and fall blooms of different types of algae. The goal of temperature monitoring is thus to determine the conditions favored by the algae in a specific source water as well as seasonal, spatial, and temporal temperature patterns that may affect HAB cycles.

**Dissolved Oxygen Levels Affected by Algae via Photosynthesis and Respiration**



**$CO_2$—carbon dioxide, $O_2$—oxygen**

**Image courtesy of Xylem Inc.**

**Figure 2**

### Dissolved Oxygen (DO)

Dissolved oxygen is one of the most important and misunderstood indicators of healthy water quality. DO levels are affected by other water quality parameters as follows:

- Temperature: as temperature increases, DO decreases
- Barometric pressure: as pressure decreases, DO decreases
- Salinity: as salinity increases, DO decreases

For instance, seawater (high salinity) holds approximately 20% less oxygen under the same temperature and atmospheric pressure as freshwater.

DO is expressed in different units, but most often in milligrams per liter or percent saturation, which refers to the equilibrium point for gases to naturally dissolve in water. At sea level and 25 °C (77 °F), there is 100% oxygen saturation and a DO of ~8 mg/L in most lakes (the effects of salinity are generally negligible in freshwater). As a point of reference, fish typically require DO greater than

**The treatment challenges of HABs include clogged intake screens and filters, excessive HAB biomass in clarifiers that must be removed and disposed of, and—most upsetting to customers—taste and odor issues.**

5 mg/L, where concentrations below that put most aquatic life under significant stress.

Algae have interesting effects on DO. Oxygen is a product of photosynthesis, and in a balanced diurnal cycle of photosynthesis and respiration, algae generate and consume oxygen, respectively. Algae also consume oxygen during the day, but not nearly as fast as it's produced via photosynthesis. In a healthy system, oxygen concentrations rise throughout the day when photosynthesis is active and decline at night when respiratory activity consumes that oxygen (Figure 2).

With an HAB, this balance is disrupted. During the early and peak growth phases of an HAB, DO can increase significantly in the vicinity of the bloom because of exceedingly high photosynthetic activity during the day. More oxygen is generated than can be consumed by either the algae or other organisms, day or night. This can lead to supersaturation, wherein percent saturation conditions will be in excess of 100%, signaling that high photosynthetic activity is occurring.

As the bloom fades and dies, the algae become food for bacteria and other heterotrophs that consume oxygen via cellular respiration. At this stage, DO levels can drop precipitously, leading to hypoxia, or levels of DO below 2 mg/L. A common misperception is that cyanotoxins kill fish in drinking water reservoirs but in reality, hypoxia induced by high system respiratory activity is most often the cause.

The size of the bloom relative to the size of the water body, proximity of a DO sensor to the bloom or the oxygen-consuming organisms, and mixing in the system can all affect one's ability to observe DO patterns and use them to manage a reservoir. Aerators can help to combat hypoxia during this late stage of a bloom and may have the added benefit of preventing blooms by encouraging the growth of competing organisms and promoting mixing in the system, as described in the "Management at the Source" section above.

### pH

Like DO, pH responds to the growth of algae because of the balance between photosynthesis, which consumes dissolved carbon dioxide, and respiration, which generates carbon dioxide (Figure 2). One of the primary forms of carbon dioxide dissolved in water is carbonic acid ($H_2CO_3$), which dominates at low pH. It's in equilibrium with other carbon forms, notably bicarbonate ($HCO_3^-$) and carbonate ($CO_3^-$). Bicarbonate is formed when $CO_2$ from the air dissolves into the water's surface; however, it's also generated during respiration, as shown in Figure 2. The flux of carbon dioxide affects the equilibrium among all other carbon types that buffer the water against wide fluctuations in pH, protecting the physical and biological components of the aquatic system (Figure 3).

When photosynthetic activity is very high, algae consume $CO_2$ faster than it's generated by respiration, such that even at night, when no photosynthesis occurs, the respiratory generation of $CO_2$ can't keep up with the day's consumption. This throws off the natural buffering system, which becomes dominated by less acidic carbon types, causing the pH to rise. A system normally at pH 6 or 7 can reach a pH of 9 or 10 during severe HABs. Thus, pH can be a highly useful indicator of both the rise and decline of an algal bloom, making it one of the most effective ways to monitor for HABs.

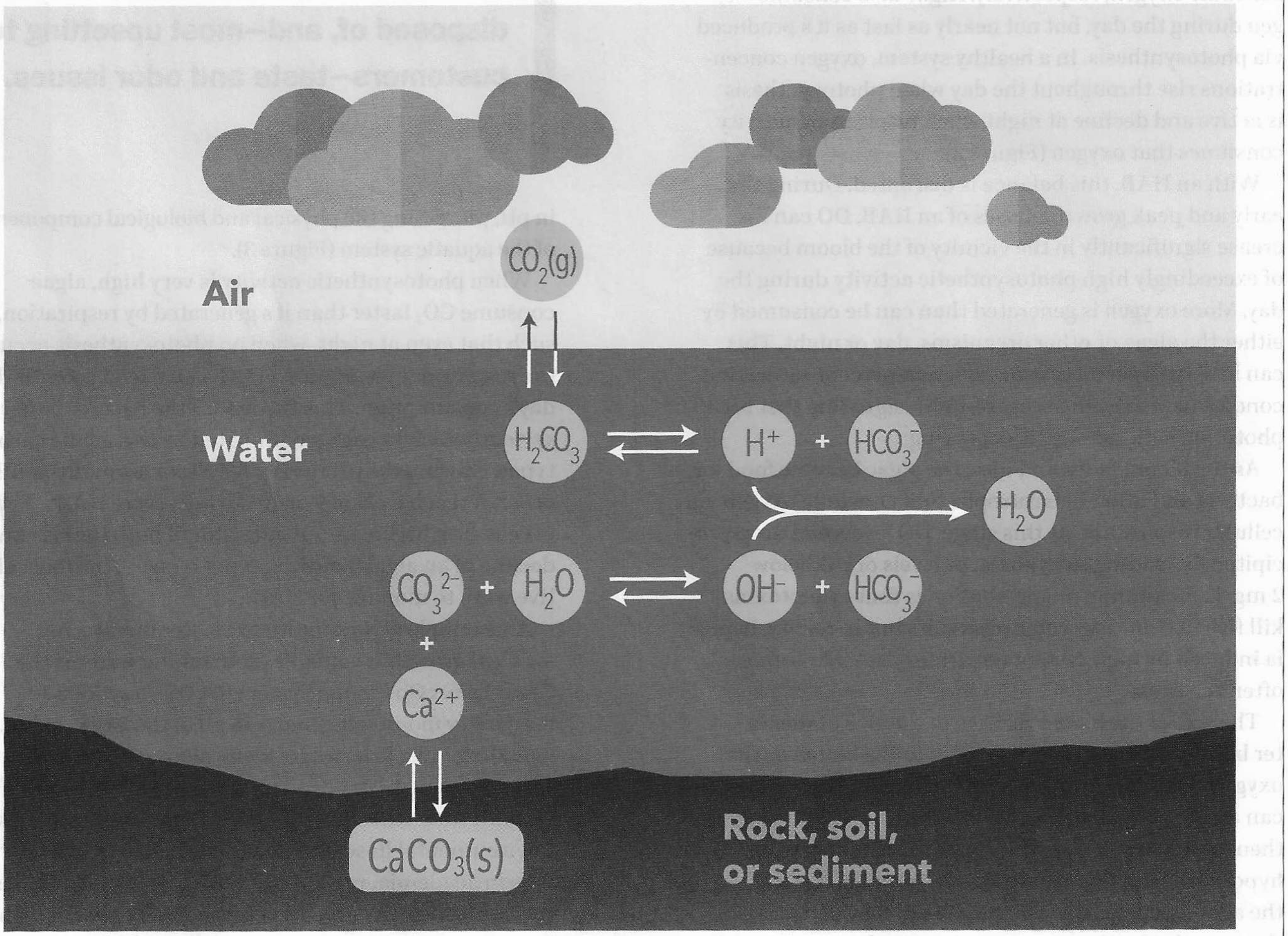
An example of how multiparameter monitoring for algal growth is valuable for drinking water is the Great Lakes Observing System (GLOS), a set of water quality monitoring buoys in all of the Great Lakes, including Lake Erie, where algae blooms are now a recurring event. Managed primarily by the National Oceanic and Atmospheric Administration's Great Lakes Environmental Research Lab (GLERL) but also by partners in academia, private industry, and municipalities, the Lake Erie buoy system is leveraged by several drinking water managers to try to understand what goes on near treatment plant water intakes. Data can be tracked online at the GLOS buoy portal, and plant managers often directly contact the buoy managers for continuous, reliable monitoring.

This type of early-warning system enables managers to prepare and respond, preventing finished-water contamination with toxins or taste and odor compounds. Their response is optimized by having the right technologies ready to bring online, as described in the next section.

## Mitigation Through Treatment

Conventional treatment systems can be overwhelmed by HABs, especially without management at the source or monitoring for algal growth. Even with those elements, however, the treatment challenges of HABs include clogged intake screens and filters, excessive HAB biomass in clarifiers

## The Carbonate System in Natural Waters



**$Ca^{2+}$—calcium ions, $CaCO_3(s)$—calcium carbonate (solid), $CO_2(g)$—carbon dioxide (gas), $CO_3^{2-}$—carbonate ions, $H^+$—hydrogen ions, $H_2O$—water, $H_2CO_3$—carbonic acid, $HCO_3^-$—bicarbonate ions, $OH^-$—hydroxyl ions**

**Image courtesy of Xylem Inc.**

**Figure 3**

that must be removed and disposed of, and—most upsetting to customers—taste and odor issues. To combat these issues, whole cell removal and advanced oxidation processes (AOPs) are two options worth considering.

### Whole Cell Removal

Whole cell removal refers to removing algal cells while preventing cell lysis, or the process of cells breaking open. Some cyanotoxins are retained in very high concentrations within algal cells, and cell lysis releases these water-soluble toxins. Generally, harmful algal toxins are more difficult to remove than simply removing the intact algae.

A dissolved air flotation (DAF) system is a cost-effective way to remove a high volume of low-density solids like algal cells. Like a conventional settling process, DAF starts with a coagulant—alum, polyaluminum chloride, or ferric—to neutralize anionic particles in the water and encourage them to flocculate together.

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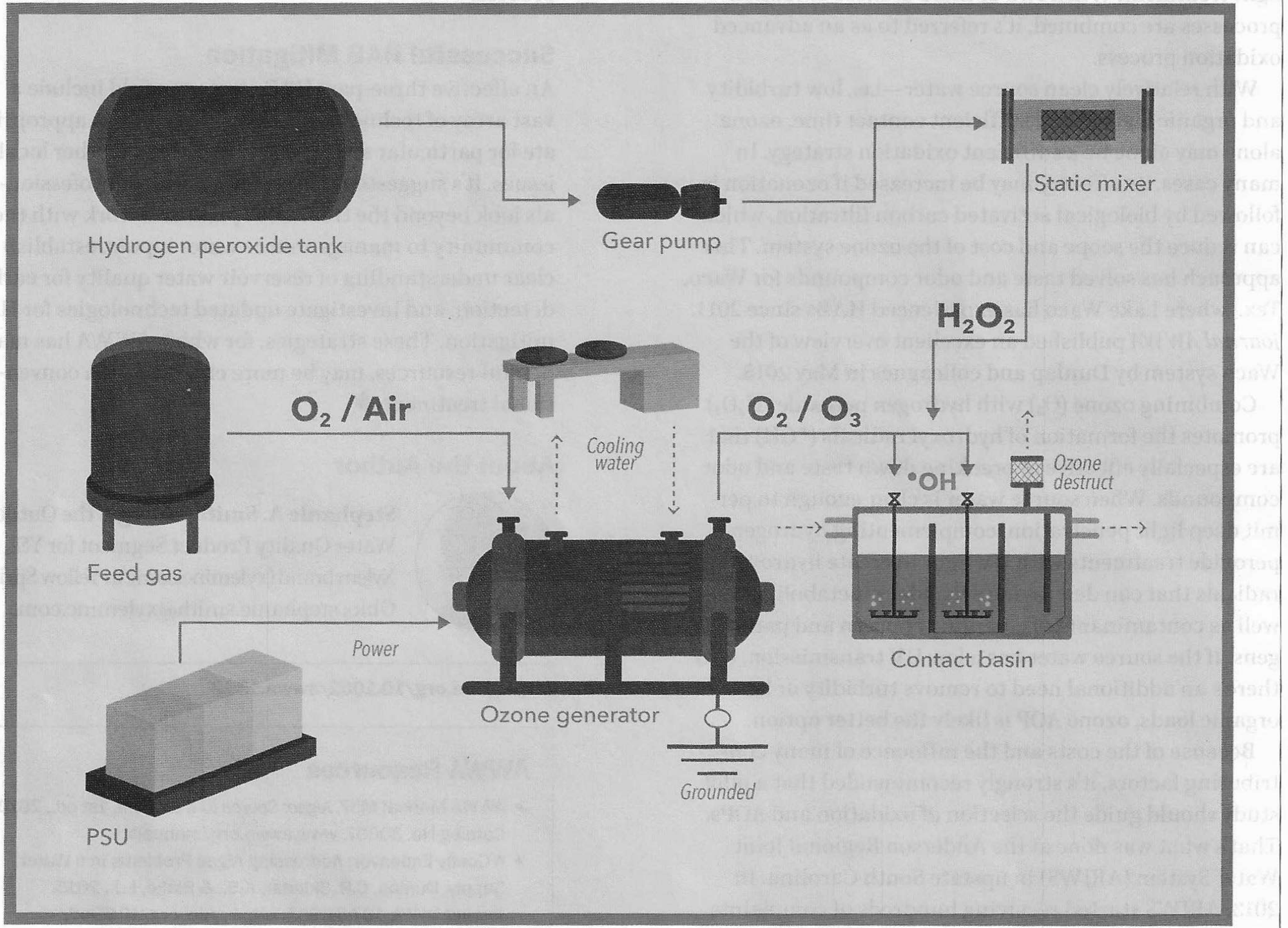
## Overview of the Advanced Oxidation Process at Anderson Regional Joint Water System



**$H_2O_2$—hydrogen peroxide, $O_2$—oxygen, $O_3$—ozone, •OH—hydroxyl radicals, PSU—power supply unit**

**Image courtesy of Xylem Inc.**

**Figure 4**

However, instead of relying on the floc to settle, microbubbles propel the floc to the surface of the tank where it's removed by a reciprocating skimmer. DAF can reduce the potential exposure time where algae could naturally break down by 75% or more, and the risk of chemical or physical lysis are lessened because chemicals like permanganate aren't used and the shear forces are gentler than those of conventional mixing. DAF can remove 90%–99% of algae and algae particles.

While DAF is great for whole cell removal, it's possible that lysis can occur before the DAF process. In that case, DAF treatment is still valuable for removing whole and fragmented dead cellular matter from the water; however, taste and odor compounds are continuously released into the water by algae. Even if whole cell removal is 100%, there is potential for some cyanotoxins to be present in the water. DAF won't remove these small molecules, referred to here as secondary metabolites.

### Secondary Metabolite Removal

Secondary metabolites will almost always be present at some concentration in HAB-affected waters, but they can be effectively neutralized via oxidation, where treatment options include ozone, peroxide, and ultraviolet (UV) light treatment. When two or more of these oxidation processes are combined, it's referred to as an advanced oxidation process.

With relatively clean source water—i.e., low turbidity and organic loads—and sufficient contact time, ozone alone may alone be a sufficient oxidation strategy. In many cases, its efficacy may be increased if ozonation is followed by biological activated carbon filtration, which can reduce the scope and cost of the ozone system. This approach has solved taste and odor compounds for Waco, Tex., where Lake Waco has experienced HABs since 2011. *Journal AWWA* published an excellent overview of the Waco system by Dunlap and colleagues in May 2015.

Combining ozone ($O_3$) with hydrogen peroxide ($H_2O_2$) promotes the formation of hydroxyl radicals ($^\bullet OH$) that are especially effective at breaking down taste and odor compounds. When source water is clear enough to permit deep light penetration, complementing hydrogen peroxide treatments with UV light to create hydroxyl radicals that can destroying secondary metabolites as well as contaminants of emerging concern and pathogens. If the source water has a low UV transmission, or if there's an additional need to remove turbidity or heavier organic loads, ozone AOP is likely the better option.

Because of the costs and the influence of many contributing factors, it's strongly recommended that a pilot study should guide the selection of oxidation and AOPs. That's what was done at the Anderson Regional Joint Water System (ARJWS) in upstate South Carolina. In 2013, ARJWS started receiving hundreds of complaints each week of musty-smelling and bad-tasting water. The water quality issues resulted from HABs in Lake Hartwell, the area's primary drinking water source. Initially, ARJWS officials tried various practices, such as copper- and peroxide-based algaecides for in-lake treatment. Adding powder activated carbon and chlorine dioxide within the treatment plant to adsorb and oxidize the objectionable compounds was also met with limited success. When conventional treatment methods did not resolve the ongoing taste and odor issues, officials at ARJWS explored advanced treatment technologies.

Four treatment options were explored in pilot tests. These included ozone, either alone or as part of AOPs with hydrogen peroxide and/or UV light. In the end, ARJWS selected ozone and peroxide in an AOP like that shown in Figure 4. Over a 20-year period, this ozone AOP was projected to be the least costly option, at $12.5 million in capital costs and $378,000 for annual operation and maintenance. ARJWS officials have since noted operational efficiencies to the media filtration system, as outlined in a 2019 *Water & Wastes Digest* article, and have found other ways to reduce the chemicals needed in the process.

### Successful HAB Mitigation

An effective three-part HAB strategy could include a vast array of technologies and approaches as appropriate for particular source water quality and other local issues. It's suggested that water treatment professionals look beyond the treatment plant and work with the community to manage source water inputs, establish a clear understanding of reservoir water quality for early detection, and investigate updated technologies for HAB mitigation. These strategies, for which AWWA has many helpful resources, may be more effective than conventional treatment.

### About the Author

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### AWWA Resources

- AWWA Manual M57, *Algae: Source to Treatment,* 1st ed., 2010. Catalog No. 30057. www.awwa.org/manuals.
- A Costly Endeavor: Addressing Algae Problems in a Water Supply. Dunlap, C.R. Sklenar, K.S., & Blake, L.J., 2015. *Journal AWWA,* 107:5:E255. https://doi.org/10.5942/jawwa.2015.107.0055.
- Occurrence and State Approaches for Addressing Cyanotoxins in US Drinking Water. Henrie, T.; Plummer, S.; Roberson, J.A., 2017. *Journal AWWA,* 109:2:40. https://awwa.onlinelibrary.wiley.com/doi/10.5942/jawwa.2017.109.0022.
- Cyanotoxins: Practical Solutions Needed. Roberson, J.A. & Carpenter, A.T., 2015. *Journal AWWA,* 107:10:12. https://awwa.onlinelibrary.wiley.com/doi/10.5942/jawwa.2015.107.0158.
- Source Water Protection. AWWA Resource Topics. www.awwa.org/sourcewaterprotection.
- A Cyanotoxin Primer for Drinking Water Professionals. Westrick, J.A. & Szlag, D., 2018. *Journal AWWA,* 110:8:E1. https://awwa.onlinelibrary.wiley.com/doi/10.1002/awwa.1088.

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