Successfully Detecting and Mitigating Algal Blooms and Taste and Odor Compounds

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Key Takeaways

After receiving hundreds of complaints, the City of Wichita Falls, Texas, developed a plan for monitoring harmful algal blooms to detect and mitigate taste and odor (T&O) compounds and cyanotoxins.

The plan uses sensory analysis, genus-level or functional-group identification, gas chromatography–mass spectrometry/electron capture detector, data sondes, and quantitative polymerase chain reaction to monitor blooms for T&O issues and cyanotoxins before they become problems.

When blooms are detected, mitigation efforts include source-switching, pretreatment, oxidation, and adsorption, which have eliminated customer complaints following more than 60 years of unmitigated T&O cycles.

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Volatile and semivolatile organic compounds are classes of chemicals commonly responsible for taste and odor (T&O) events in surface waters. They are metabolites produced by algae and cyanobacteria during harmful algal blooms (HABs); they also can be produced by other types of bacteria, some plants, and during the decomposition of organic material (Pepper et al. 2015).

T&O problems are not considered risks to human health, but they sometimes serve as indicators that cyanobacteria are present in sufficient quantities to create a toxin event as well. Drinking-water aesthetic quality problems can occur in many cities, and consumers often mistakenly perceive T&O as a measure of drinking water safety. T&O events can be a costly nuisance to water systems. Analytical detection of T&O compounds can be difficult because of their varying chemistry, the different required sampling techniques and source water management, and the subjectivity of methods (Nollet & De Gelder 2014).

> **The most effective method for forecasting challenges is a multifaceted approach in which data generated over time are used as a baseline to understand "normal" conditions for individual reservoirs.**

T&O events can create a public relations nightmare within a matter of hours for water systems, so it is important to proactively handle customer complaints for systems with regular issues (Burlingame 1999). Appropriately categorizing complaints can improve a utility's response, and systematically grouping complaints builds a record of seasonal water quality variations (Dietrich & Burlingame 2021). Customer contact information should be recorded, as well as information about the complaint, the duration of the problem, the location of occurrence, and any other factors that can aid in complaint investigation and determination (Dietrich 2006). Proactively addressing T&O issues reduces the number of complaints and builds confidence with consumers.

HABs are indicative of some degree of ecosystem imbalance and exemplify the tenacious ability of algae and cyanobacteria to exploit their environment. Blooms most often occur in eutrophic systems, but they are difficult to forecast because environmental conditions during bloom and non-bloom periods can be similar—i.e., light, temperature, dissolved oxygen, nutrient loading, etc. (Dodds & Whiles 2010). There is no complete catalog for compounds produced by specific taxa, and it can be difficult to link a single T&O compound to a single taxon.

Many common T&O compounds have been identified and categorized on the basis of taste, odor, and chemical structure on the T&O wheel in Suffet et al. (1995), then in *Standard Methods* (2017), and on a modified biological T&O wheel (Lin et al. 2019). Dynamic variables make it impractical and ineffective for a water system to rely on a single analysis to manage T&O issues (Buerkens et al. 2020). Proactive monitoring can save time and work while speeding up recovery to affected customers, bolstering credibility and system reliability (Chowdhury 2021).

To overcome the challenges associated with the complexity of detecting and mitigating T&O compounds in surface and drinking waters, the City of Wichita Falls Cypress Environmental Laboratory (Texas) developed a monitoring plan that merged analyses from its microbiological and analytical laboratories while optimizing the water system's existing treatment technologies (Southard et al. 2016). To do this, the laboratory uses analytical approaches to determine when treatment changes are needed and where to focus testing until T&O events subside.

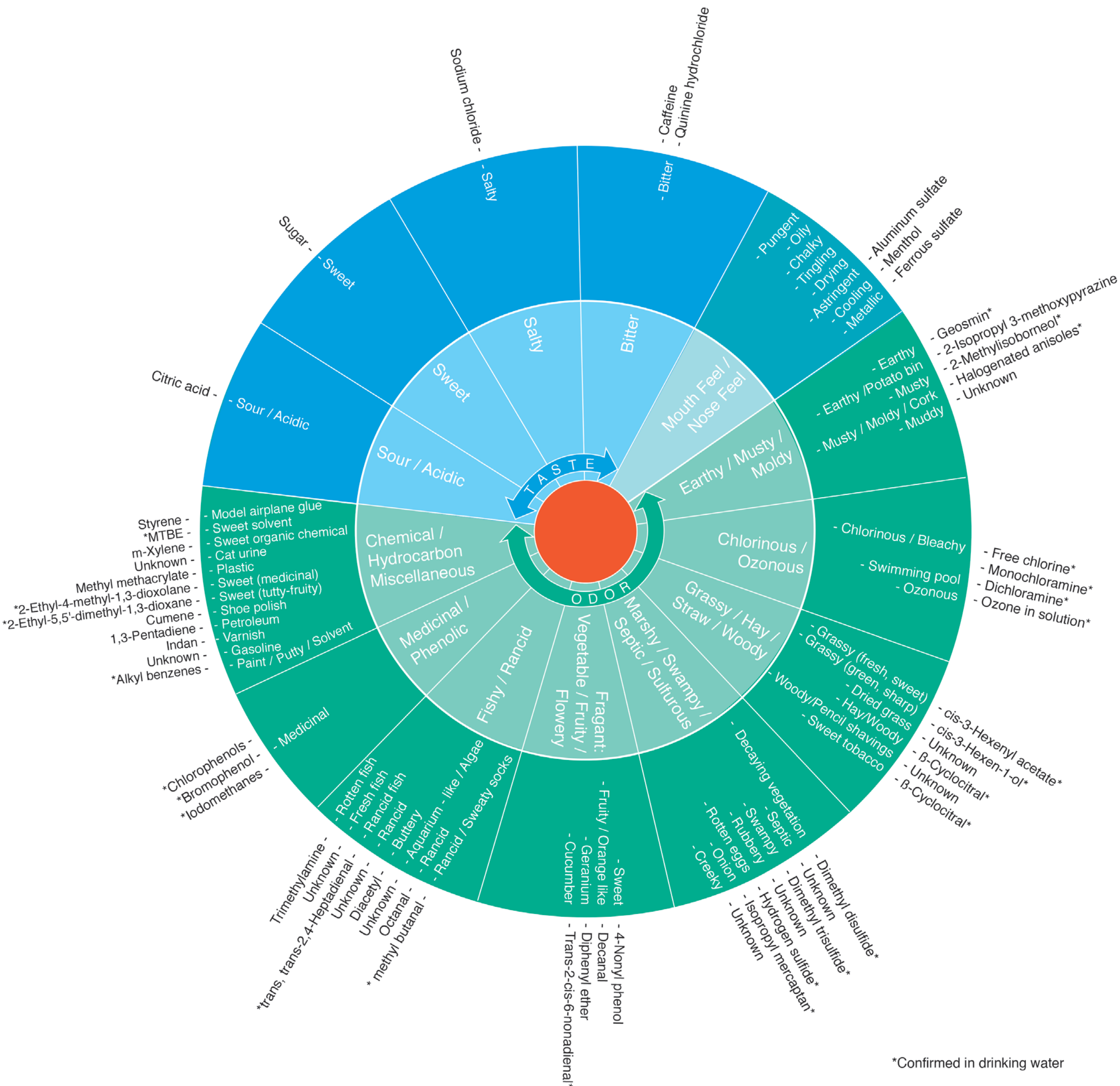
Monitoring for T&O Issues

Benthic and planktonic cyanobacteria should be monitored during T&O events because both groups can produce T&O compounds during growth and senescence. However, the chemistry of T&O compounds is complex and the problems they create can be subjective, making their detection difficult, especially at trace levels (Burlingame & Doty 2018). Threshold levels for detection in water span several orders of magnitude, depending on the type of compound.

The T&O compounds are grouped into four taste categories and eight odor categories (Figure 1). The descriptors loosely reflect chemical compositions, which help explain why certain treatments are more effective for a particular group of odors (Mallevaille & Suffet 1987). Quantitative measurements are always reasonable estimates of the analyte but involve some level of uncertainty, so it is essential to use standards of the highest purity to ensure quantitative precision (Taylor 1987).

The most widespread and problematic compound category for water systems is the earthy/musty/moldy category, including geosmin, 2-methylisoborneol (MIB), pyrazines, and halogenated anisoles. The grassy/hay/straw/woody category includes semiochemicals like esters, alcohols, and fragrant apocarotenoids. The fishy/rancid category consists of aldehydes and amines that are produced by taxa with high cellular polyunsaturated fatty acids. The compounds in the marshy/swampy/septic/sulfurous category are rarely produced by cyanobacteria during normal conditions, but they are major constituents produced in anaerobic decomposition of HABs and other organic material.

Drinking Water Taste and Odor Wheel



Source: Suffet et al. 1995. Adapted with permission. © AWWA Research Foundation and AWWA.

Figure 1

The medicinal/phenolic category odors are commonly described as pesticides, herbicides, and disinfectants. The fragrant/vegetable/fruity/flower category compounds are not typically nuisance compounds but can be disinfection byproducts (DBPs)—e.g., produced by ozonation. The chemical/hydrocarbon category also includes compounds not normally found in surface waters, but they can be present because of spills or the introduction of sewage. Like the previous category, the chlorinous/bleachy category includes compounds not normally found in surface waters. This class consists of constituents used as disinfectants in the treatment of surface water, such as free chlorine, monochloramine, and dichloramine.

Cyanobacteria and algae can bloom within hours, making them difficult to track. However, advances in monitoring technologies have made it possible to expand the size and scope of monitoring programs without significantly increasing labor. Rapid detection over multiple sample locations allows timely and effective decision-making. Comprehensive monitoring should begin in the field and then move to the laboratory, which is made possible through the use of an analytical approach like using gas chromatography–mass spectrometry/electron capture detector (GC–MS/ECD); with the addition of multiparameter sondes; semiautomated, flow-imaging microscopes with image-recognition; and molecular-based assays.

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Multiparameter Sondes

Multiparameter sondes are used in the field for remote deployment or discrete sampling. Sondes are customizable with interchangeable probes that allow for detection of the following important HAB-related parameters:

- **Water temperature.** Temperatures can align with seasonal, spatial, and temporal bloom patterns and can be an early indicator of lake stratification.
- **Dissolved oxygen (DO).** As blooms grow, photosynthetic activity increases, and DO can rapidly increase; this is followed by a rapid DO depletion as the growth phase ends and as blooms die.
- **pH.** Increased pH can indicate bloom growth as DO levels drop; as blooms grow, increased photosynthetic activity depletes dissolved carbon dioxide faster than it is generated from cellular respiration.
- **Chlorophyll and phycocyanin concentrations.** Fluorescence-based pigment detection can reveal concentrations that lead to an estimate of the abundance of algae versus cyanobacteria since chlorophyll a is found in both types of organisms, but phycocyanin is found only in cyanobacteria.

DO and pH have diurnal variations that are related to the extent of a bloom or other biological activity—i.e., photosynthesis versus cellular respiration in diurnal cycles, where greater variation corresponds to greater biological activity (Smith 2019).

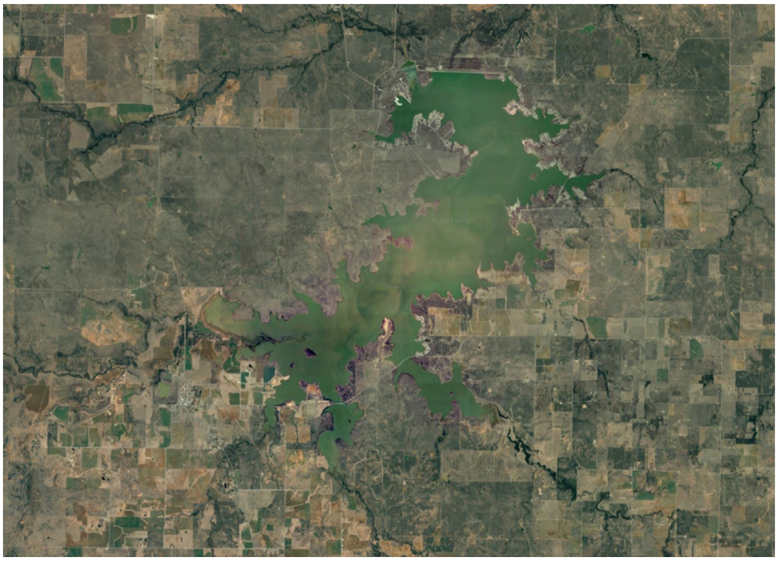
Flow-Imaging Microscopes

Semiautomated, flow-imaging microscopes can provide rapid imaging, identification, and enumeration of cyanobacteria and nuisance algae. Water systems rarely have the need or staff to make species-level identification for the purposes of treatment decisions. Genus-level or functional-group identification offers a practical approach to processing samples. While nothing completely replaces traditional microscopic identification methods, this is a highly effective tool. Samples can be processed in less than 10 minutes, with cyanobacteria, diatoms, and algae automatically sorted on the basis of pigment excitation. Digital images are saved along with a comma-separated-values report of the count, concentration, and size of the organisms, enabling technicians to quickly spot known problem organisms. It can take time to build image recognition parameters that allow the instrument and software to automatically sort and classify the microscopic images of concern, but the process is relatively simple. The result of implementation is actionable data backed by a repeatable, scalable, and user-friendly method, which helps utilities facing staff turnover or with limited microscopy and taxonomy skill sets.

Molecular-Based Assays

While sondes track analyte concentration levels and flow-imaging microscopes determine cell counts, molecular-based assays can measure the genetic fingerprint of organisms in a sample. Molecular-based technology can measure the 16S rRNA gene found in all cyanobacteria, quantitatively measuring the amount of gene copies present by quantitative polymerase chain reaction (qPCR). There is no established correlation between cell counts and gene copy numbers, but fluctuations in either are indicative of the size of a bloom and scope of its growth (McKindles et al. 2013). Assays also are available for cyanotoxin-producing gene determination, and work is being done to map T&O-production pathways. Technicians can determine if cyanobacteria are present and assess the risk for toxins or T&O problems within hours using gene detection.

Google Maps Image of Lake Arrowhead in April 2020 During an *Anabaena* Bloom



Map data © 2020 Google

Figure 2

Forecasting Challenges

Forecasting HABs involves assimilating data from a variety of sources to make predictions of the likelihood of bloom occurrence. This incorporates data from analyses described previously, with the addition of more advanced technologies that are used in Great Lakes forecasting, such as satellite imagery data (Figure 2). The most effective method is a multifaceted approach in which data generated over time are used as a baseline to understand "normal" conditions for individual reservoirs. Only then can determinations be made with relative accuracy and precision.

Treatment Technologies

Water systems must remove algae and their metabolites from the source water while meeting all applicable regulations. This can be done early in the process by aerating the water near reservoir intakes, alternating intakes, adjusting the pH to deter pH-sensitive organisms, and by using algaecides such as copper sulfate. Most systems incorporate a multibarrier approach, combining reservoir management strategies with physical pretreatment, physical removal, conventional treatment, biological treatment, oxidation, and/or adsorption (Waer 2006).

Oxidation

Chemical oxidation is used to destroy algae and their metabolites. Potassium permanganate ($KMnO_4$) is commonly used early in treatment processes to maximize contact time. $KMnO_4$, unlike many other oxidants, produces little to no DBPs, and it also helps demobilize algal cells and settle them out prior to contact with a disinfectant, preventing cellular lysis and the release of intracellular compounds into the water. However, it is not as effective at removing geosmin and MIB as other oxidants. Care should be taken to use the correct dosage because elevated concentrations can cause a pink/red discoloration in finished tap water.

Chlorine dioxide (ClO_2) is a preoxidant that is more effective at removing geosmin and MIB than $KMnO_4$, but it has more management requirements because it usually is generated onsite and the DBP chlorite must be closely monitored to ensure regulatory compliance.

Chlorine (Cl_2) is minimally effective at oxidizing T&O compounds, and formation of halogenated DBPs is a concern at high doses. Ozone (O_3) is very effective at oxidizing T&O compounds, but system construction and management costs are high and ozonation-produced DBPs—including bromate, aldehydes, and ketones—can be problematic.

Advanced oxidation processes (AOP) combine O_3 with ultraviolet (UV) light or hydrogen peroxide (H_2O_2), or UV with H_2O_2. These can be expensive to build and operate, but they are effective at eliminating T&O compounds, and DBP formation potential can be reduced when combined with biofiltration before disinfection.

Biofiltration

Some water systems use the microbiology of their source water to their advantage. Each source water has a unique community and can be "cultured" in existing plant filters so that they degrade organic compounds as they pass through the media. Combinations of preoxidation, such as AOP with biofiltration, are an effective way to mitigate T&O compounds. Biological activated carbon filters can combine biological removal with adsorption.

Technicians can determine if cyanobacteria are present and assess the risk for toxins or T&O problems within three hours using gene detection.

Adsorption

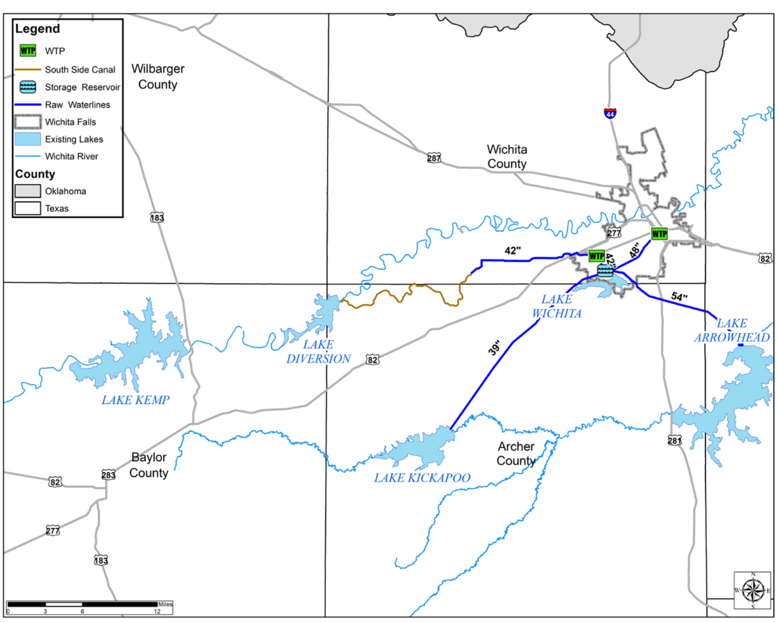
Adsorption is a highly effective treatment method that typically uses powdered activated carbon (PAC) or granular activated carbon (GAC). Feeding PAC early in the treatment process allows time for organic compounds to adsorb onto the carbon particles and settle out as they become heavier during coagulation. PAC is also commonly used with $KMnO_4$. The PAC dosage can be adjusted as needed depending on T&O concentration fluctuations.

GAC is commonly used in place of sand and/or anthracite filter media. GAC effectiveness lessens over time as the active sites become filled with adsorbed organic material, so the media must ultimately be replaced or regenerated. GAC effectiveness can lessen quickly when source water organic levels are high.

Early Warning and Prevention

The City of Wichita Falls, Texas, has a surface water system with adjudicated rights to five water sources, four of which are used primarily for treatment: Lake Arrowhead, Lake Kickapoo, and the Lake Kemp/Lake Diversion system. The system has two water treatment facilities—Cypress Water Treatment Facility, which has one advanced and three conventional treatment plants, and Jasper Water Treatment Facility, which has two conventional treatment plants—and includes a water distribution system (Figure 3). The water system experienced two extreme T&O events in February and August 2016. Hundreds of customer complaints were received in a two-week period in August 2016. To mitigate this problem, the City of Wichita Falls Cypress Environmental Laboratory designed and implemented a comprehensive monitoring program using sondes, traditional threshold odor number (TON) and modified flavor profile analysis (FPA), a single quadrupole GC-MS/ECD system, flow-imaging microscopy, and qPCR (Adams et al. 2018). Existing water system oxidation and adsorption processes were evaluated and optimized. Since this program was put in place, the city has not received any additional T&O-related customer complaints.

City of Wichita Falls Water System Map



WTP—water treatment plant

Figure 3

Thirteen T&O events in the source waters were detected over the past five years, spanning a total of 19 months. Eleven of the events were narrowed down to a specific cyanobacteria taxon. The largest event in terms of duration and concentration occurred February–May 2020 when an *Anabaena* bloom reached >1,500 chains/mL and geosmin levels exceeded 15,000 ng/L (Figure 4). More recent blooms in July 2020 allowed the laboratory to test each facet of its monitoring program to determine effectiveness (Figure 5). Each episode was detected and mitigated before water was distributed to the public.

Figure 4

***Microcystis* and *Anabaena* Bloom in a Lake Arrowhead Tributary in July 2020**

Effectiveness of Response Treatments and Tools

Source lakes, a holding reservoir, and both water treatment plants are monitored on a seasonal schedule. Warmer summer months are scheduled for sampling three to five days per week, while colder winter months are only sampled one day per week. When a T&O event is detected, it is important to systematically collect high-quality data to guide mitigation. The city's plan has been effective because with more frequent monitoring, the laboratory has been able to detect and address small problems before they become big blooms.

When an algae event is detected, the utility superintendent is notified and testing frequency increases. If the event worsens, the utility can switch sources to a lake without the bloom. If blooms occur in multiple lakes, then treatment at the plant is increased to include ClO_2 as a primary disinfectant of raw water, $KMnO_4$ in the plant lagoons and clarifiers, and PAC in the clarifier mixing zone to adsorb and settle out T&O compounds during treatment. During this time, the laboratory increases testing and chemical addition in the plant or source waters until the bloom subsides.

Treatment of a bloom in its nascent stages is critical because large blooms are difficult to treat, and any compounds in algal cells, like toxins and T&O, can be released at high levels.

Treatment of a bloom in its nascent stages is critical because large blooms are difficult to treat, and any compounds in algal cells, like toxins and T&O, can be released at high levels. Spot treatments work in many cases, but only for blooms up to a certain size or cell count. Overtreatment—i.e., killing all algal and cyanobacteria cells upon detection—creates an imbalanced ecosystem that is even more vulnerable to the invasion of a large cyanobacteria bloom. *Anabaena* and *Microcystis,* two globally pervasive cyanobacteria, can dominate an entire body of water in just a few days. The goal is to achieve control at the source through proactive monitoring. For this to work, utilities must understand the limnology of local lakes and reservoirs as well as the infrastructure that links the components of their storage and conveyance systems (Taylor et al. 2006).

Multiparameter sondes are used to monitor temperature, DO, pH, chlorophyll a, and phycocyanin pigments.

FlowCam Images of *Microcystis* (A) and *Anabaena* (B) From a Sample of Lake Arrowhead in July 2020

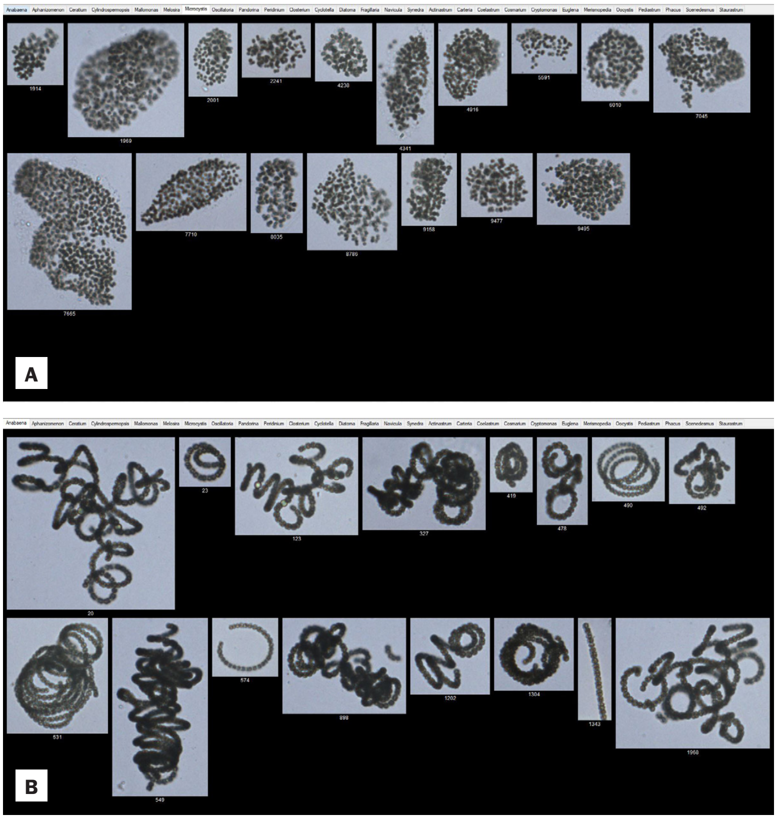


Figure 5

A semiautomated, flow-imaging microscope (FlowCam) is used to identify and enumerate algae and cyanobacteria, and to sort them into groups such as T&O-producers and filter-cloggers. Knowing which taxa are present helps to determine whether a T&O or cyanotoxin event is likely. Chemical analysis can indicate if T&O or cyanotoxin compounds are already present in the water column, while identification of organisms indicates that heightened monitoring is prudent even if the compounds have not been detected.

The presence of a cyanobacteria bloom does not mean that the organisms are toxic or producing T&O compounds. However, the absence of toxins or T&O compounds does not mean that a problem is not emergent (Westrick & Szlag 2018). T&O compounds can be detected and quantified by selected ion monitoring (known as SIM) using GC–MS methods described by Adams and colleagues (2020).

Since many of the region's most problematic cyanobacteria are known to produce cyanotoxins, qPCR (using CyanoDTec) was included to determine presence and abundance of cyanobacteria and cyanotoxin-producing genes. Positive qPCR detections are followed up by analytical confirmation by a third-party laboratory using liquid chromatography with tandem mass spectrometry, and these data have shown direct correlations with the qPCR results.

Lake intakes are profiled monthly at every foot of depth to determine if reservoir stratification is occurring. Pigment concentrations also can be used to determine the likelihood of higher cell counts of cyanobacteria versus algae.

After sample preparation, traditional TON testing is performed in accordance with method 2150B (*Standard Methods* 2017) to determine the magnitude of a T&O event, while a modified FPA in accordance with method 2170 (*Standard Methods* 2017) is performed to determine what type of odor is present using olfactory detection instead of taste. Just as no single analytical method can detect all chemical contaminants in water, no single sensory method can provide all the answers to T&O questions (Dietrich et al. 2003). The TON and FPA results allow technicians to bridge this gap and choose which GC–MS/ECD method to run to determine T&O compound concentrations.

Continued Monitoring

The Cypress Environmental Laboratory continues to monitor source water samples for T&O compounds to ensure that the tap water remains issue-free. Important research on T&O compounds has been conducted in the last several decades, but many questions remain. Aesthetic quality and perception of T&O remain some of the biggest deterrents to customers drinking tap water. By integrating biological and chemical methods, the Cypress Environmental Laboratory has been able to proactively monitor for both algae and cyanobacteria and the T&O compounds and cyanotoxins they produce. After more than 60 years of experiencing unmitigated blooms, the City of Wichita Falls has used this approach to completely address T&O issues before they become T&O problems.

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AWWA Resources

- **Eliminate Taste-and-Odor Events With Cost-Effective Algae Control. Buerkens F, Kilgore T, Adams H. 2020. *Opflow*. 46:11:16. https://doi.org/10.1002/opfl.1454**
- **Biological Pretreatment: An Innovative Approach to Addressing Taste and Odor. Brown J, Nyfennegger J, Ang Y, et al. 2020. *AWWA Water Science*. 2:2:e1173. https://doi.org/10.1002/aws2.1173**
- **A Tale of Two Utilities: Cyanotoxin Response Plans. Hayden A, To P, Gorzalski AS, et al. 2020. *Journal AWWA*. 112:10:24. https://doi.org/10.1002/awwa.1592**
- **Understanding the Basics of Tap Water Taste. Burlingame GA, Dietrich AM, Whelton AJ. 2007. *Journal AWWA*. 95:5:100. https://doi.org/10.1002/j.1551-8833.2007.tb07930.x**

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