Aerial photograph of Woodland Reservoir and surrounding area. *Syracuse Water Department*

Ultrasonic Units and Diffused Aeration Replace Decades of Applying Copper Sulfate in an Open Drinking Water Reservoir

by Rich Abbott *(Published previously in the Winter 2020 issue of* Lakeline *[NALMS])*

A combined ultrasonic algal control and diffused aeration systems added to Woodland Reservoir has eliminated the need to add algaecide (copper sulfate) for algal control and has paid for itself in two years while improving the quality of the water for a capital investment of $26,056.

Records dating back to 1975 documented that copper sulfate pentahydrate ($CuSO_4 \cdot 5H_2O$) was applied for 44 consecutive years to Woodland Reservoir to control algal growth. As diffused aeration systems and advanced ultrasonic units were positioned in the reservoir, daily algal cell counts decreased to levels where treatment was not necessary in 2019 and 2020. Cell counts of consistently dominant cyanobacteria (blue-green algae) – *Chroococcus* Type I, *Cyanobium* and *Polycystis* – decreased by 96%, 94% and 77%, respectively, from 2014 to 2020. For residents dependent on the reservoir as their primary drinking water source, the $26,056 capital investment in diffused aeration systems and advanced ultrasonic units has resulted in a major improvement to water quality during the summer and fall months. At an average annual material cost for copper sulfate of $16,110 (2004-2015) the payback period for the City of Syracuse was less than two years.

Background

Woodland Reservoir is a 126-million-gallon (460,000-cubic-meter) constructed reservoir that serves as a drinking water supply for the City of Syracuse, New York, population 142,327 *(US Census 2019)*. The reservoir's water surface area is approximately 14 acres with a maximum depth of 35 feet. The reservoir bottom is lined with concrete and the side walls are faced with rubble masonry laid in cement. Completed in 1894, it is at the receiving end of 19 miles (30 kilometers) of conduits conveying water from Skaneateles Lake, which is an unfiltered water supply located in New York's Finger Lakes Region.

To control algal populations, two approaches have been used:

- Reservoir manipulation.
- Application of algaecide.

Reservoir manipulation is conducted during the summer and early fall months; these manipulations include increasing flow to maximize turnover rate and drawing down the reservoir to expose periphytic growth on the reservoir walls. Adjustments within the water distribution system allow for reductions in flow to covered water storage tanks and the diversion of a higher volume of Syracuse's daily water demand into the reservoir. Maximum daily discharges recorded at the reservoir for July through September typically average 24 to 27 million gallons per day (MGD) allowing for a residence time of approximately five to six days. Average discharges for spring and winter months range between 13 and 16 MGD.

Algaecide has been applied regularly to the reservoir from May through October to suppress algal growth. As water temperatures increase, algal cell counts, periphytic growth on reservoir walls, turbidity, water color and clarity are all carefully monitored. Conditions that warrant algaecide treatment include exceedance of established algal threshold levels or indications of deteriorating water quality based on visual inspection of the reservoir.

The method of algaecide application is dependent on whether the growth is planktonic or periphytic. For attached growth on reservoir walls, the treatment method consists of city employees dispensing medium crystal copper sulfate from 50-pound burlap bags into the reservoir, either by dragging the bags around the perimeter of the reservoir or towing the bags along the entire reservoir surface by boat.

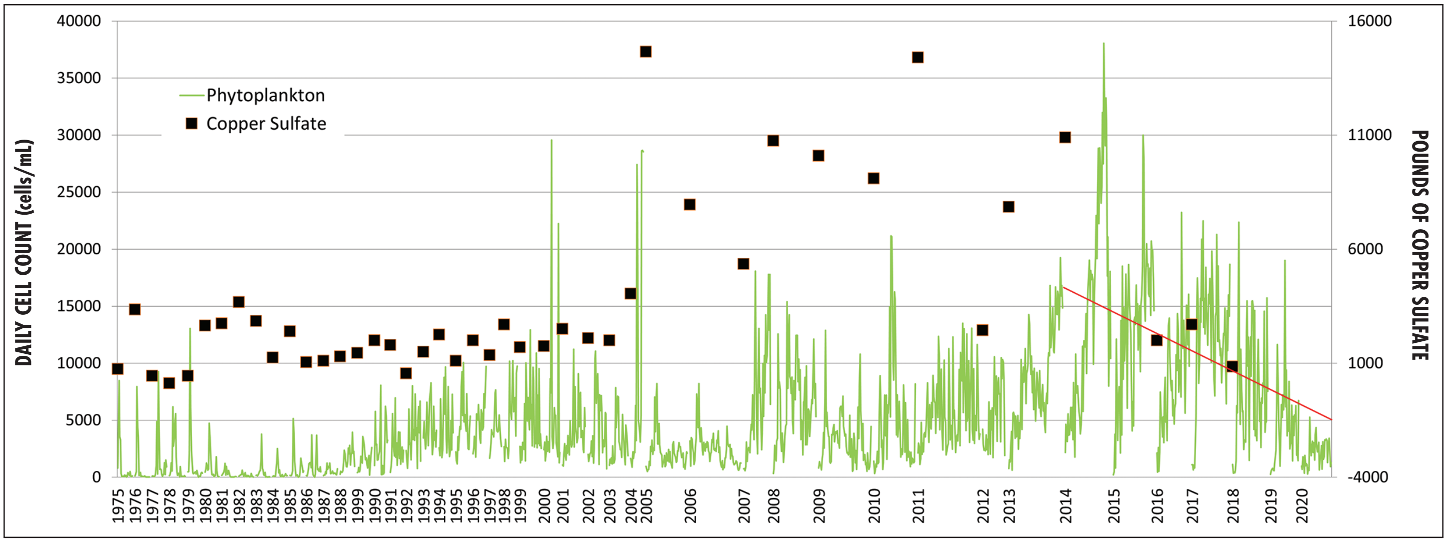

Figure 1. Daily algal cell count totals and annual pounds of copper sulfate, 1975 through 2020. *Rich Abbott*

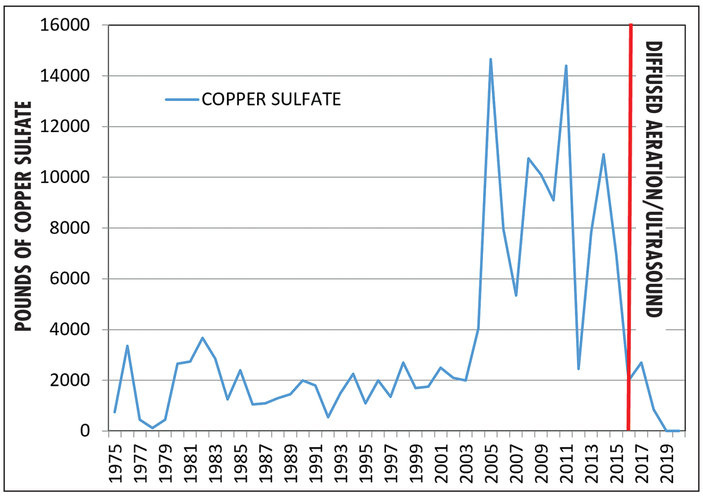

Figure 2. Copper sulfate annual applications. *Rich Abbott*

Copper Sulfate Treatments over Time

From 1975 through 2018, at least one copper sulfate treatment was recorded each year. A total of 266 treatments were recorded during this 43-year period, averaging six per year. The annual volume of copper sulfate applied ranged from 125 pounds (1978) to 14,650 pounds (2005). ***Figure 1*** illustrates cell counts and corresponding annual copper sulfate treatments dating back to 1975. From 2004 through 2015, the reservoir was treated with copper sulfate on 112 occasions, averaging 8,708 pounds per year. Annual copper sulfate treatments exceeded 4,000 pounds throughout this time frame except for 2012, when the reservoir was drained for the season July 19, 2012, as part of an infrastructure project.

Figure 2 illustrates the dramatic increase in total pounds of copper sulfate applied annually beginning in 2004 because of elevated cell counts of cyanobacteria and their apparent resistance to established treatment amounts. Average annual copper sulfate treatments increased from 1,755 pounds (1975 through 2003) to 8,708 pounds (2004 through 2015). ***Figure 2*** also illustrates the significant decrease in total pounds of copper sulfate applied annually following the initiation of diffused aeration and advanced ultrasonic units in 2016.

Treatment effectiveness has varied considerably depending on environmental conditions, algal species targeted, cell counts and how uniformly the product was dispersed. Of the 78 treatments recorded from 2007 through 2018, 22% resulted in an actual increase in targeted species cell counts (two to four days following pre-treatment counts). Of the 17 targeted treatments for *Chroococcus* Type I during this time frame, post-treatment cell counts exceeded pre-treatment counts 35% of the time within two to four days of treatment.

Unmanageable Algal Cell Counts

In August 2004, *Chroococcus* Type II (Cyanobacteria, family; Chroococcaceae) cell counts increased from 3,000 cells per milliliter of water (cells/mL) to more than 28,000 cells/mL within a six-day period despite several copper sulfate treatments. The reservoir was taken offline and follow-up treatments of copper sulfate and a liquid, chelated copper formulation were not effective in improving water quality. The reservoir was ultimately drawn down and not put back into service until colder water temperatures resulted in a significantly reduced cell count.

Elevated *Chroococcus* Type II cell counts continued to be problematic in 2005 and 2006 accounting for 43% and 26% of the annual cell counts, respectively. Copper sulfate was applied to the reservoir on 15 occasions in 2005 totaling 14,650 pounds, which is the highest annual amount on record. In early August 2006, 1,500 gallons of an acidified, copper-based algaecide was applied to the reservoir over a two-day period as an alternative to copper sulfate. As *Chroococcus* Type II cell counts increased rapidly in late August, exceeding 3,200 cells/mL, the reservoir was treated with three copper sulfate applications totaling 5,200 pounds within a seven-day period.

A New Approach – Ultrasonics

A new strategy employing ultrasonic algal control devices was employed in 2007 in an effort to suppress *Chroococcus* Type II growth. The devices work by emitting soundwaves from a transducer head positioned just under the water surface, converting electrical energy into sound (mechanical) energy with the sound projected into the water body. Soundwaves at the same frequency of algal cell structures reach Critical Structural Resonance (CSR) causing internal wall damage or ruptured gas vesicles depending on the type of algae.

The internal wall damage compromises cell pressure and inter-

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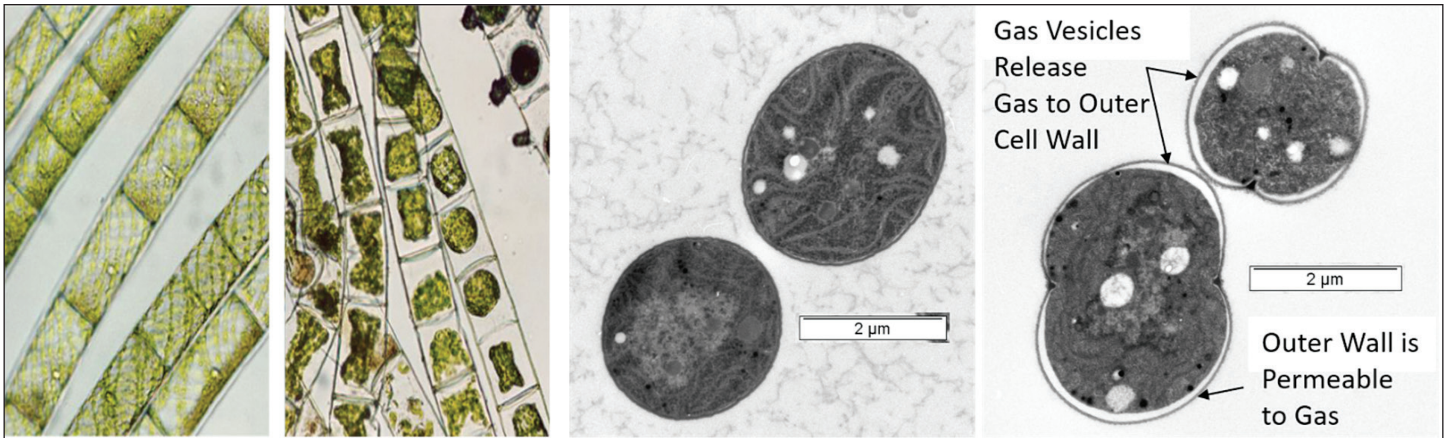

Figure 3. ***Spirogyra*** **(left) and** ***Microcystis aeruginosa*** **(right) before and after ultrasonic treatment. Scanning electron microscopy of** ***Microcystis aeruginosa*** **was prepared by Dr. Paul Zimba of Texas A&M University, Corpus Christi.** *SonicSolutions Algae Control, LLC*

nal fluid flow in green algae and most diatoms (Bacillariophyceae). When the inner cell wall (plasmalemma) is torn, internally pumped fluid flow and internal pressure is disturbed causing collapse of the inner cell wall and loss of nutrient transfer. It also compromises the cell's defense mechanism ultimately allowing bacteria to invade and begin digesting the algae. The damaged algal cells begin to float after about three weeks due to collection of digestion gases caused by internal bacterial attack.

The Research

The Centre for Aquatic Plant Management demonstrated with light microscopy how ultrasonic waves result in separation of plasmalemma from cell walls of green algae *Spirogyra* and *Selenastrum* under controlled conditions. Ultrasound exposure times for *Spirogyra* and *Selenastrum* were three weeks and eight weeks, respectively. The investigation summarized that ultrasound exposure caused irreversible structural damage to the cells, loss of chlorophyll and loss of viability *(CAPM 2004)*. The ultrasonic effect on algae is illustrated in ***Figure 3***.

Spirogyra, a green filamentous type of algae, is damaged by the inner cell wall or plasmalemma being torn from the contractile vacuole pumping mechanism such that it collapses inside the stronger outer cell wall. *Microcystis aeruginosa,* a cyanobacteria, loses buoyancy when the extremely small gas vesicles are internally broken and the gas that they hold is slowly diffused through the unbroken outer cell wall over a period of three to four days. Gas vacuoles are made up of stacks of cylindrical gas vesicles which are closed by conical ends *(Bowen and Jensen, 1965; Walsby, 1994)*. Lee et al. (2001) investigated the concept of using ultrasonic radiation to damage gas vacuoles of algal cells, causing them to sink within the water column and reducing their access to sunlight. Transmission electron microscopy of the cells showed that the gas vacuoles were intact before sonication and collapsed after sonication *(Lee et al., 2001)*. As water depth increases, ultrasonic technology becomes more effective in controlling cyanobacteria. Both types of damage indicated above occur due to CSR that can occur when the natural resonance frequencies match the ultrasonic frequencies being emitted by the device.

Deployment in the Reservoir

Five ultrasonic units of type model SS600 manufactured by SonicSolutions Algae Control, LLC, were installed around the reservoir perimeter. The original SS600 sonic heads each created 18 frequencies with an average difference between frequencies of 1.3% or 580 hertz (Hz) and a range of about 9.4 kilohertz (kHz), centered on 42.2 kHz. The estimated maximum green algae (Chlorophyta) control range for this device was 850 feet, covering up to 6.5 acres. In 2009, the SS600 model frequency set was increased to 79 frequencies, the range was about 40 kHz and was centered on 44 kHz with the difference between frequencies at 1.4% or about 525 Hz on average. This was the first attempt at increasing the frequency density to increase the odds of hitting CSR frequencies of more species.

Although the model SS600 units initially appeared to be effective in controlling *Chroococcus* Type II cell counts, a new form of cyanobacteria, identified as *Cyanobium,* became dominant in the reservoir in the summer and fall of 2007. The model SS600 units and copper sulfate treatments were not effective in controlling *Cyanobium* growth. Monthly cell counts for the summer/fall 2007 season averaged 6,210 cells/mL (July), 6,306 cells/mL (August) and 11,997 cells/mL (September). Post examination of these units by AlgaeControl.US, a distributor of the SonicSolutions products, indicated that the piezos (high frequency sound emitters) had cracked, causing the sound output to be substantially diminished.

From 2007 through 2015, 77 copper sulfate treatments were applied, totaling 77,850 pounds. *Cyanobium* was consistently the dominant form throughout this period, ranging from 34.1% to 76.4% of annual cell counts. Elevated cell counts persisted throughout summer and fall seasons, with maximum cell counts for individual months totaling 14,240 cells/mL (July 26, 2008), 17,074 cells/mL (Aug. 11, 2010) and 18,223 cells/mL (Sept. 15, 2014).

Transforming Algal Control

From 2016 through 2020, a different approach in algal control was implemented using a combination of diffused aeration and improved ultrasonics.

Diffused Aeration

In 2016 two Robust-Aire Diffused Aeration systems (RA3XL model) were installed in the reservoir. Robust-Aire systems pump compressed air from a shore-mounted compressor through self-weighted tubing to diffuser stations on the reservoir bottom. The diffusers continuously release microbubbles that are typically two millimeters in diameter and rise at 1 foot per second through

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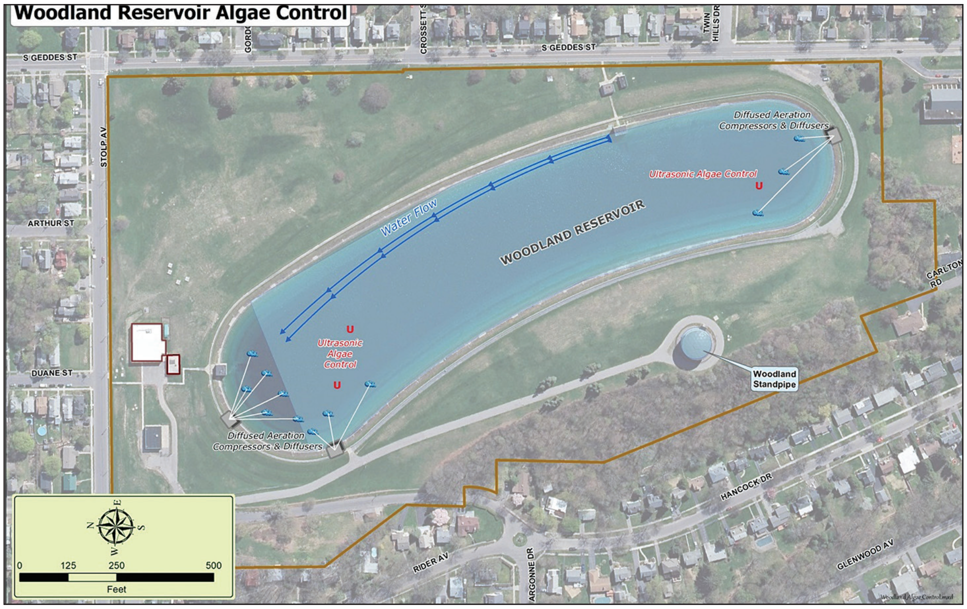

Figure 4. Orthoimagery of Woodland Reservoir showing algal control stations. *Rich Abbott*

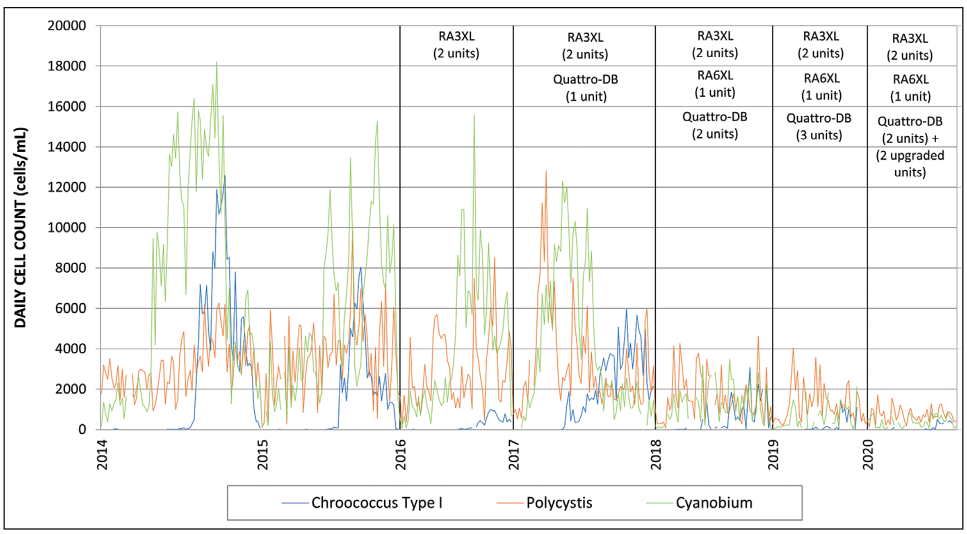

Figure 5. Dominant cyanobacterial algal forms, 2014 through 2020. *Rich Abbott*

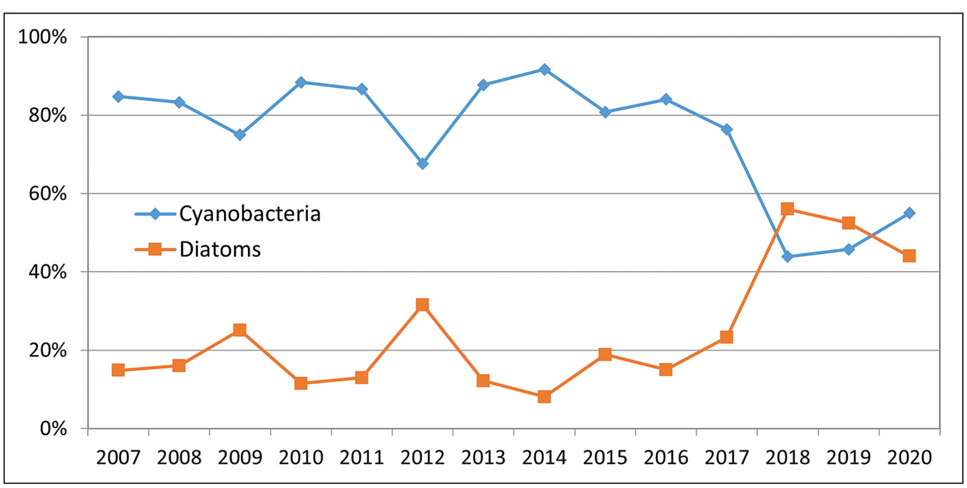

Figure 6. Percent of algal total cell count. *Rich Abbott*

the water column to the surface. As the bubbles rise, they push and drag large volumes of water from the reservoir bottom to the surface allowing for beneficial water movement and mixing. Exchanging gases with the atmosphere induces oxygen transfer and allows gases such as carbon dioxide to be expelled. Continued mixing of the reservoir allows for uniform chemical and physical properties including temperature and pH. Since cyanobacteria require extended photoperiods and warmer water, continuously mixing the reservoir disrupts cyanobacteria's ability to dominate the upper water column. Cyanobacteria cells traveling up and down through the water column encounter a mixture of dark and light environments and cooler water conditions, both of which discourage their ability to proliferate in the reservoir.

The two RA3XL diffusers were positioned at depths of 25 to 35 feet, each displacing approximately 16.7 MGD, totaling approximately 100 MGD. Due to the reservoir's kidney shape and location of the inlet and outlet, flow studies, water quality observations and cell counts indicated that stagnant zones form within the reservoir. Since the inlet is located along the southeast perimeter and the outlet's location is at the north end, influent water short-circuits along the east side of the reservoir. To enhance mixing, the RA3XL models were placed along the northwest and south sections of the reservoir ***(Figure 4)***. An additional unit (RA6XL model) was installed in 2018 in the north basin of the reservoir.

Ultrasonic Boost

In July 2017, a Hydro BioScience Quattro-DB ultrasonic algal control unit was installed in the reservoir's north basin. The unit generates over 1,582 different frequencies in two separate bandwidths:

- The lower bandwidth has a range of 34 kHz centered on 41 kHz with an average difference between frequencies of 0.053% or 22 Hz. There are 1,565 unique frequencies in this lower bandwidth.
- The upper bandwidth has a range of 10 kHz centered on 200 kHz with an average difference between frequencies of 0.31% or 625 Hz. The upper bandwidth was installed to target cyanobacteria like *Microcystis*. It produces 17 frequencies that are repeated 27

times each per 34-minute cycle for 459 generated frequencies.

In all, there are 2,024 frequencies generated at one per second for 34 minutes. The high number of frequencies assures that CSR can occur within the operating frequency ranges. A 0.6 second pause is included between each pulse, added to improve biofilm control in water treatment facilities. The Quattro-DB has the same coverage area as about three of the SS600 units due to having the sound emit from four emission points. All the SS600 and Quattro-DB units were purchased to be used with 120-volt AC power.

The coverage area for this device includes up to 17 acres for green algae and diatoms (radial range of 150 meters) and up to 120 acres for cyanobacteria (radial range of 400 meters). Another Quattro-DB unit was installed in 2018 within the south basin, and in 2019 an additional Quattro-DB was installed in the north basin.

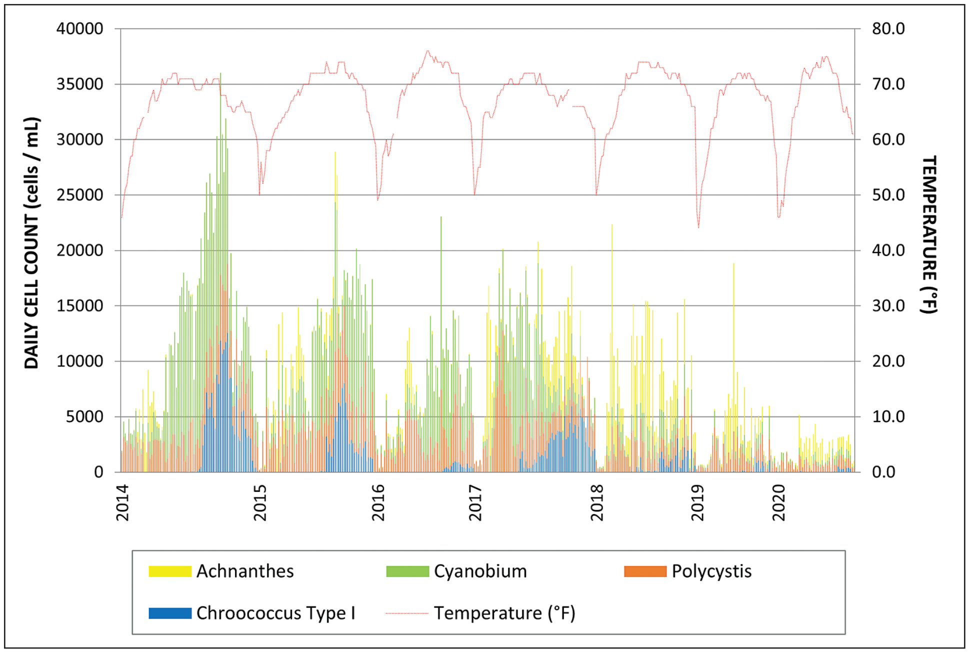

Figure 7. Dominant algae, 2014 through 2020. *Rich Abbott*

Results

Installation of Robust-Aire Diffused Aeration systems and Quattro-DB units from 2016 through 2020 resulted in an exponential decline in algal cell counts. Before the initial Robust-Aire Diffused Aeration system installations in 2016, maximum cell counts exceeded 30,000 cells/mL in 2014 and 2015. The highest cell count recorded in 2020 was 5,261 cells/mL. Average cell counts totaled 13,752 cells/mL (2014) and 13,008 cells/mL (2015), compared to 2019 and 2020 counts of 4,330 cells/mL and 2,127 cells/mL, respectively.

The impact of expanding and upgrading devices has been most pronounced in the reduction of dominant forms of cyanobacteria. ***Figure 5*** illustrates the steep decline in cell counts of *Chroococcus* Type I, *Cyanobium* and *Polycystis,* corresponding to additional Robust-Aire Diffused Aeration systems and Quattro-DB units. *Chroococcus* Type I, *Cyanobium* and *Polycystis* have decreased by 96%, 94% and 77%, respectively, from 2014 to 2020.

Figure 6 illustrates a significant shift in algal dominance beginning in 2018. Cyanobacteria accounted for 82% of the annual average cell count from 2007 through 2017, whereas diatoms accounted for just 17%. From 2018 through 2020, annual average cell counts of cyanobacteria remained suppressed, accounting for only 48% of cell counts. Diatoms exceeded cyanobacteria as the dominant phylum during this period, accounting for 51% of the annual average cell count.

The steep decline in *Cyanobium* cell counts from 2014 to 2020 and transition from *Cyanobium* dominance to *Achnanthes* dominance in 2018 is apparent in ***Figure 7****. Cyanobium* average cell counts declined from 7,175 cells/mL to 397 cells/mL. For the same period, *Chroococcus* Type I average cell counts declined from 2,440 cells/mL to 136 cells/mL. Note the elevated cell counts of *Cyanobium* and *Chroococcus* Type I in 2014, despite seven copper sulfate applications totaling 9,650 pounds targeting the two cyanobacteria.

Time and Material Savings

At a contract price of $92.50 per 50-pound bag of medium crystal copper sulfate, the material cost from 2004 to 2015 averaged $16,110 per year, with a total cost of $193,325. Staffing and miscellaneous costs, although difficult to quantify, were a significant seasonal expense, involving a three- to four-person crew necessary to transport, bag and apply the product. Applying copper sulfate in ideal conditions (i.e., full sunlight and a dedicated crew available during the peak vacation season) frequently posed operational challenges. Continuous monitoring of the reservoir's water quality through visual observations, cell counts and physical parameters (temperature and turbidity) accounted for numerous hours, especially in the late summer and fall months.

To reach the goal of eliminating copper sulfate treatments in the reservoir, Syracuse invested $26,056 in diffused aeration units and advanced ultrasound algal control devices from 2016 through 2019. The average annual algal control material cost throughout the four-year transition phase was $9,081, divided as follows:

- Diffused aeration and ultrasound units: $6,514.
- Copper sulfate: $2,567.

Employing additional and improved units and devices within the reservoir has allowed for consistently exceptional water quality, suppressed daily cyanobacteria cell counts and consecutive years (2019 and 2020) of no copper sulfate applications following 44 years of treatment. As a result of lower cell counts and improved water quality, algal monitoring and cell counting have been gradually reduced from 67 days in 2014 to 44 days in 2020.

Seasonal operation and maintenance of the Quattro-DB 120-volt AC powered ultrasonic algal control units involves approximately a half-day of installation in the spring, monitoring and removal of biofilm and mineral deposits on the transducers in the summer/fall and a half-day removing and cleaning units in the fall. Basic maintenance of the Robust-Aire Diffused Aeration systems consists of cleaning or replacing air filters and cleaning the compressor cabinets. Following two or three seasons of operation or if reduced air flow or preferential air flow is observed between diffusers, additional maintenance includes replacing compressor

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piston cups. Head compressor rebuild kits supplied by the manufacturer are serviced in the field. The kits include cups, cylinder, gaskets/O-rings and valves.

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