2024 TECHNICAL UPDATE

Case Study: Algae Prevention and Mitigation

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Technical Update, September 2024

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NOTE

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ACKNOWLEDGMENTS

EPRI prepared this report based on work conducted by a member.

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This report describes research conducted by EPRI.

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ABSTRACT

A facility located in the southeastern United States experienced elevated total suspended solids (TSS) concentrations in its cooling pond, which were believed to be related to a persistent algal bloom which began in tandem in July 2021. An investigation of this persistent algae bloom included regular algae counts which determined that the algae consisted of an overgrowth of the cyanobacteria *Limnothrix sp.*, the predominant contributor to the observed elevated TSS. Algae counts and other water quality data were acquired while the facility used various algaecides to combat the algae in 2021, 2022, and 2023. Comprehensive water chemistry and nutrient sampling took place in 2023, when algal populations were lower and more diverse. Nutrient data demonstrated enriched nitrogen concentrations at many sampling points within the plant, and enriched phosphorus concentrations at cooling tower blowdown and unit sump sampling locations. Usage of different cooling tower maintenance chemicals was reviewed in terms of content (potential nutrient and/or carbon source for algal growth) and periods of use. The elevated phosphorus concentrations from the cooling tower blowdown likely fed the 2021–2022 algal blooms. This conclusion is drawn from the temporal correlations observed between the onset and subsequent reduction of TSS and algae challenges, and the use of a cooling tower maintenance chemical. This chemical, which contained phosphonic acid, was in use until its elimination in 2023. Thus, it is probable that the chemical contributed to the increase in phosphorus concentrations seen prior to 2024.

It is likely that part of the resolution of this algae bloom was the discontinuation of the phosphate-based additive which reduced nutrients that previously fed significant algal growth and elevated TSS. Additional work will be required to confirm this outcome and utilize it for ongoing algae control and prevention. The station will implement a quarterly nutrient sampling plan along with ongoing algal counts which will be helpful in reducing wastewater nutrient loadings and enable the facility to anticipate problematic algal blooms.

Keywords

Algae
Eutrophication
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Phosphonic acid
Phosphorus
Total suspended solids (TSS)

EXECUTIVE SUMMARY

Deliverable Number: 3002030493

Product Type: Technical Update

Product Title: Case Study: Algae Prevention and Mitigation

Primary Audience: Utility technical staff, such as personnel in plant operations and environmental compliance

Secondary Audience: Utilities that have on-site cooling impoundments, that utilize municipal effluent, as well as those that experience problematic, unexpected algal blooms, specifically for the treatment of cyanobacteria *Limnothrix sp*.

KEY RESEARCH QUESTION

This work aimed to explain the potential causes of elevated TSS and algal blooms at the member facility. Additionally, it investigated potential short- and long-term strategies that could be utilized to prevent a recurrence and mitigation strategies that can be employed in the event the problem reemerges.

RESEARCH OVERVIEW

In July 2021, a facility in the southeastern United States began experiencing elevated total suspended solids (TSS) concentrations in its cooling pond. This was believed to be connected to a persistent algal bloom that started around the same time. Regular algae counts determined that the algae consisted of an overgrowth of *Limnothrix sp.*, the predominant contributor to the observed elevated TSS. The 2021–2022 algal blooms likely fed on excess residual nutrients from water treatment additives. This work investigated the potential root causes for the algae bloom. It also identified potential nutrient source controls and key water quality monitoring necessary to inform future strategies to manage or prevent a recurrence.

KEY OUTCOMES

- Elevated phosphorus was observed within the station's cooling tower blowdown waste stream. These elevated phosphorus levels may be correlated to use of a maintenance chemical which contained phosphonic acid. Phosphorus levels were also elevated at most major sumps on-site for the duration of data provided to EPRI. Eliminating the use of this maintenance chemical coincided with lower TSS and algal counts.
- Elevated nitrogen was observed sitewide and was pronounced at the various major sumps on site. A sump which primarily receives wastewater from a carbon burnout operation, was especially high in nitrogen.

- The Redfield Ratio – the mass ratio of carbon: nitrogen: phosphorus in algal cells – was identified as a useful tool to determine whether algal growth was limited by nutrient availability over time.
- Solids management may play a role in limiting nutrient inputs to wastewater. Utilities evaluating a suspected nutrient issue should pursue targeted TSS and dissolved phosphorus analyses along with comprehensive analysis of controlling parameters such as pH, oxidation-reduction potential, etc.
- An understanding of baseline water quality is useful when unexpected conditions such as algae blooms arise.

WHY THIS MATTERS

Facilities experiencing algal growth may experience a host of problems, including (but not limited to) blocked water conveyances, challenges to filter operations, difficulty meeting wastewater quality permit limits, and potential toxicity issues. Understanding contributing factors can allow utility operators to identify potential operational changes that (for example) can minimize ongoing nutrient additions, reducing the likelihood of prolonged algae growth and the cascading challenges that result.

HOW TO APPLY RESULTS

The process for evaluating nutrient issues applied here and lessons learned may be useful to other facilities experiencing similar difficulties and may allow for improved efficiency in determining potential nutrient sources.

LEARNING AND ENGAGEMENT OPPORTUNITIES

- EPRI's Program 238 (Water Treatment Technologies) provides research that includes treatment of waters at power facilities. Program 240 (Water Quality and Effluent Guidelines) provides research on water quality. These programs collaborate to facilitate the EPRI Pond and Landfill User Groups that enable members to share best practices concerning ponds, landfill operation, and facility housekeeping.

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PROGRAMS: Water Treatment Technologies, Program 238; Water Quality and Effluent Guidelines, Program 240

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1 INTRODUCTION: ALGAE AT GENERATING STATION IN SOUTHEASTERN UNITED STATES

Site Introduction

This case study occurred at a member generating station with four coal units which entered commercial operation from the mid-1970s to the early 1980s, for a station capacity of about 1100 MW. The station is equipped with forced oxidation flue gas desulfurization (FGD) scrubbers and operates with a full suite of selective catalytic reduction and electrostatic precipitation systems. The station uses a closed cycle cooling system, with makeup water coming from a distant freshwater source. All station wastewaters mix in the facility's 400-acre cooling pond for temperature regulation, solids settling, and treatment prior to discharge.

The station has undergone changes to comply with current environmental statutes. For compliance with the 2013 Coal Combustion Residual (CCR) rule, the station began closure by removal (ongoing as of this writing), an effort which involves CCR impoundment dewatering and excavation as well as construction of new landfill cells within the footprints of two former impoundments. As such, the remaining impoundments are sources of contact stormwater as they undergo closure, and the landfills are sources of contact stormwater (via chimney drains) and leachate. In compliance with the 2015 Steam Electric Power Generating Effluent Limitations Guidelines (ELG) rule the station ceased discharge of fly ash and bottom ash sluice water in the spring of 2020 and ceased discharge of other station wastewaters to CCR impoundments in April 2021. These changes resulted in rerouting other station wastewaters as low volume waste (LVW) to two new lined low volume wastewater ponds (West LVW and South LVW ponds).

As of this writing (summer 2024), the facility continues to operate under an administratively continued wastewater discharge permit. Under that permit, allowable total suspended solids (TSS) concentrations at the final point of discharge are approximately 20 and 60 mg L^{-1} (monthly average and daily maximum, respectively). A new draft permit on the state environmental agency's website indicates that future limits may be elevated to roughly 30 and 95 mg L^{-1} (monthly average and daily maximum, respectively). An additional constraint involves the facility's temperature limitation, which forces intermittent periods of no-discharge under the current permit, especially in early fall when the limit is reduced.

Timeline

The facility has experienced periodic elevated algae levels within the station cooling pond throughout the history of the station, normally emerging with pH fluctuations in the spring, which have previously resolved following treatment with Hydrothol. However, in August of 2021, elevated TSS levels (above 19.5 mg L^{-1}) alerted the station to an algal bloom which ultimately did not respond to Hydrothol application. Algae counts indicated high levels of *Limnothrix sp.* (Figure 1), generally ranging above 1×10^6 cells mL^{-1}, with few other algae species present. The pond was well-mixed, with *Limnothrix sp.* equally distributed at upper-, mid-, and lower-depths and with under-developed gas vacuoles (also called gas vesicles or aerotopes). The algae's uniform distribution throughout the water column suggests that they were well-mixed and able to obtain essential nutrients without the need for vertical movement. After application of a peroxide-based algaecide, TSS declined to acceptable levels but within two months again exceeded the monthly average TSS limit. A lengthy period of no discharge began in November 2021 with limited data collection. When discharge resumed in April 2022, TSS levels were low but swiftly rose well over the monthly average TSS limit approximately one month later. A no-discharge condition was reinitiated, and application of a copper-based algaecide during this period was not effective. However, when discharge resumed in early 2023, TSS levels were within the typical range for this facility.

In 2023, the facility initiated a comprehensive water chemistry and nutrient sampling program with corresponding monthly algal counts. Algal counts remained below 500,000 cells mL^{-1}, with much more algal diversity, and TSS concentrations remained below the monthly average limit through late April 2024. The facility's initial sampling plan is presented in Appendix A.

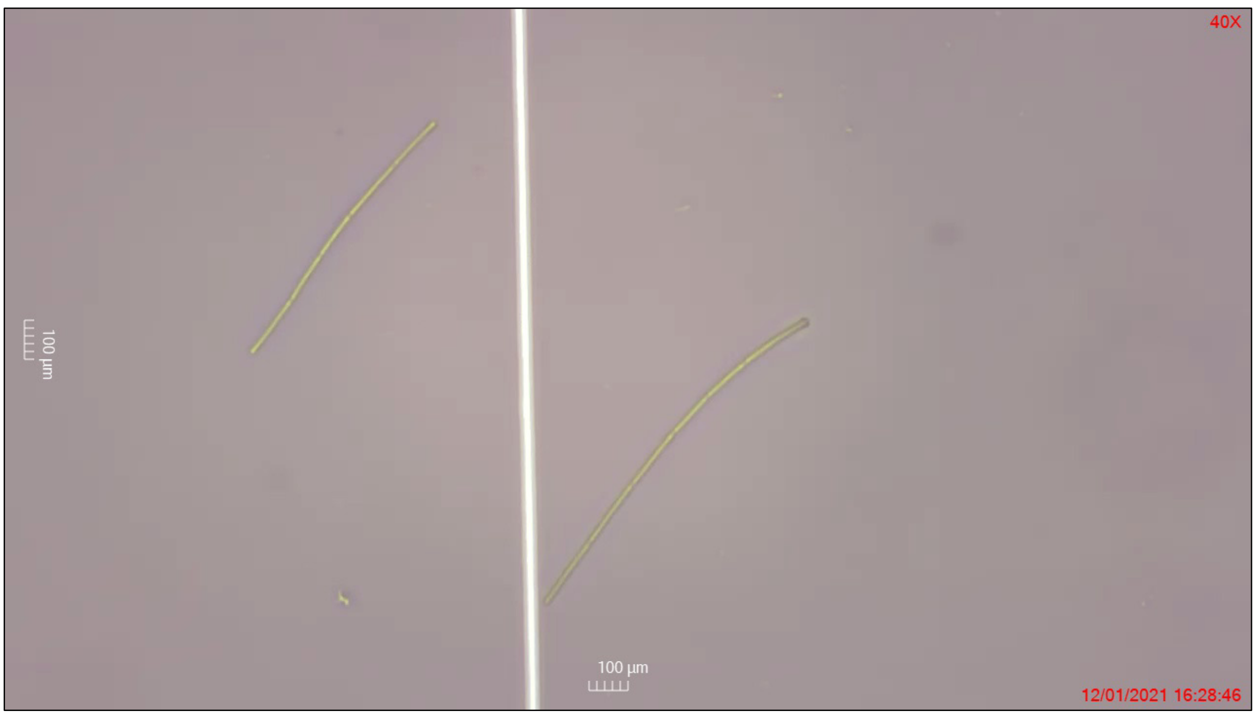

Figure 1. *Limnothrix sp.* identified (December 1, 2021)

Data Sampling Plan

In its comprehensive sampling plan, the facility had sought to sample approximately 25 locations from the intake reservoir to the station's discharge pumps. Not all locations were sampled since some discharge intermittently. After six months, sampling was reduced to quarterly at seven locations. Analysis consisted of chloride, fluoride, sulfate, nitrite, nitrate, Total Kjeldahl Nitrogen (TKN), total nitrogen, and total phosphorus (TP). Available data collected through early 2024 were reviewed for trends, correlations, and quality assurance; values below detection were filtered as equal to detection limits; the filtered data were plotted with respect to time and position within the facility's wastewater system.

In addition, mass ratios of TKN:TP were calculated and compared to the Redfield ratio. The Redfield Ratio of 106:16:1 is the mass ratio of carbon: nitrogen: phosphorus in algal cells. Carbon is generally widely available, so algal growth is unlimited as long as environmental concentrations of nitrogen: phosphorus are roughly 16:1. When nutrient concentrations are outside that ratio, the environment limits continued algal growth. So, a ratio of < 16:1 would be said to be nitrogen limited, and a ratio > 16:1 would be considered phosphorus limited.

Algae Counts and Total Suspended Solids Concentrations

The observed dataset of total suspended solids concentrations was compared to the dataset of algae counts for many different genera and species. TSS concentrations were higher when algae concentrations exceeded 500,000 cells mL^{-1} and *Limnothrix sp.* dominated. These data are plotted in Figures 2 and 3. It is noteworthy that in the cases where *Limnothrix sp*. was predominant, green algae was minimally observed.

Simplified Model of the Wastewater System

A simple wastewater model was constructed which placed each sampled location within the wastewater system in the following "bins" for further analysis:

- Bin 1 – Station clearwell, consisting of raw water from source stream
- Bin 2 – Sumps, ponds and area drains which received rainwater only, but whose discharge was likely contaminated after interacting with industrial areas of the plant. Some drain to the west low volume waste pond, others drain directly to cooling pond.
- Bin 3 – Sumps and drains which receive a combination of intake water from the clearwell, rainwater, recycled cooling water, and industrial wastewater. Most notably, this bin includes cooling tower blowdown.
- Bin 4 – Fines thickener supernate from the FGD wastewater system. Located downstream of Bin 3 because the plant uses cooling tower blowdown in the FGD scrubber systems.
- Bin 5 – Forebay entrance to the west low volume waste pond. This bin represents mixed wastewaters from the entire plant before settling within the wastewater pond.
- Bin 6 – Discharge from the west low volume waste pond, draining directly to the cooling pond
- Bin 7 – Cooling pond

The model is depicted in Figure 4, and was used to screen data to analyze in fine detail and to sort data in a way that allowed for visual interpretation.

Total Phosphorus Concentrations

Total phosphorus concentrations were analyzed in terms of contributions to effluent streams. Data were plotted by date for the cooling pond and component direct discharges to the cooling pond (Bins 2, 6, and 7) as shown in Figure 5. Although some sample locations were intermittently sampled, available data were relatively consistent with time for most locations. The west low volume waste pond was the outlier within this set. Data from this location were erratic and more concentrated than other locations in this dataset, and with one unusually high value detected in the spring of 2023.

In Figure 6, phosphorus data were plotted by bin across the entire station. Bin 3 (sumps and drains which discharge to the west low volume waste pond) and Bin 6 (the west low volume waste pond discharge) demonstrated excess phosphorus compared to other locations around the plant. Notably, Bin 4 (FGD wastewater) did not have elevated phosphorus concentrations. Note that the samples collected from the entrance to the west low volume waste pond also did not demonstrate elevated concentrations of phosphorus compared to other locations around the plant – an unexpected finding that may warrant further study.

Total Kjeldahl Nitrogen Concentrations

TKN concentrations were plotted by date for the cooling pond and its direct contributors (in a similar fashion as phosphorus) and shown as Figure 7. TKN was observed to be consistent with time (primarily < 6 mg L^{-1}) but had the highest presence in the west low volume waste pond. There were observations showing a short-term increase of higher nitrogen concentrations in the spring of 2023.

In Figure 8, data were plotted by bin across the entire station. As with phosphorus, Bin 3 (sumps and drains which discharge to the west low volume waste pond) and Bin 6 (the west low volume waste pond discharge) demonstrated excess nitrogen compared to other locations around the plant. Bin 4 (FGD wastewater) did not have elevated nutrient concentrations, but the single coal pile runoff sample from Bin 2 did demonstrate elevated nitrogen. As with phosphorus, samples from the entrance to the west low volume waste pond did not demonstrate elevated concentrations of TKN compared to other locations around the plant.

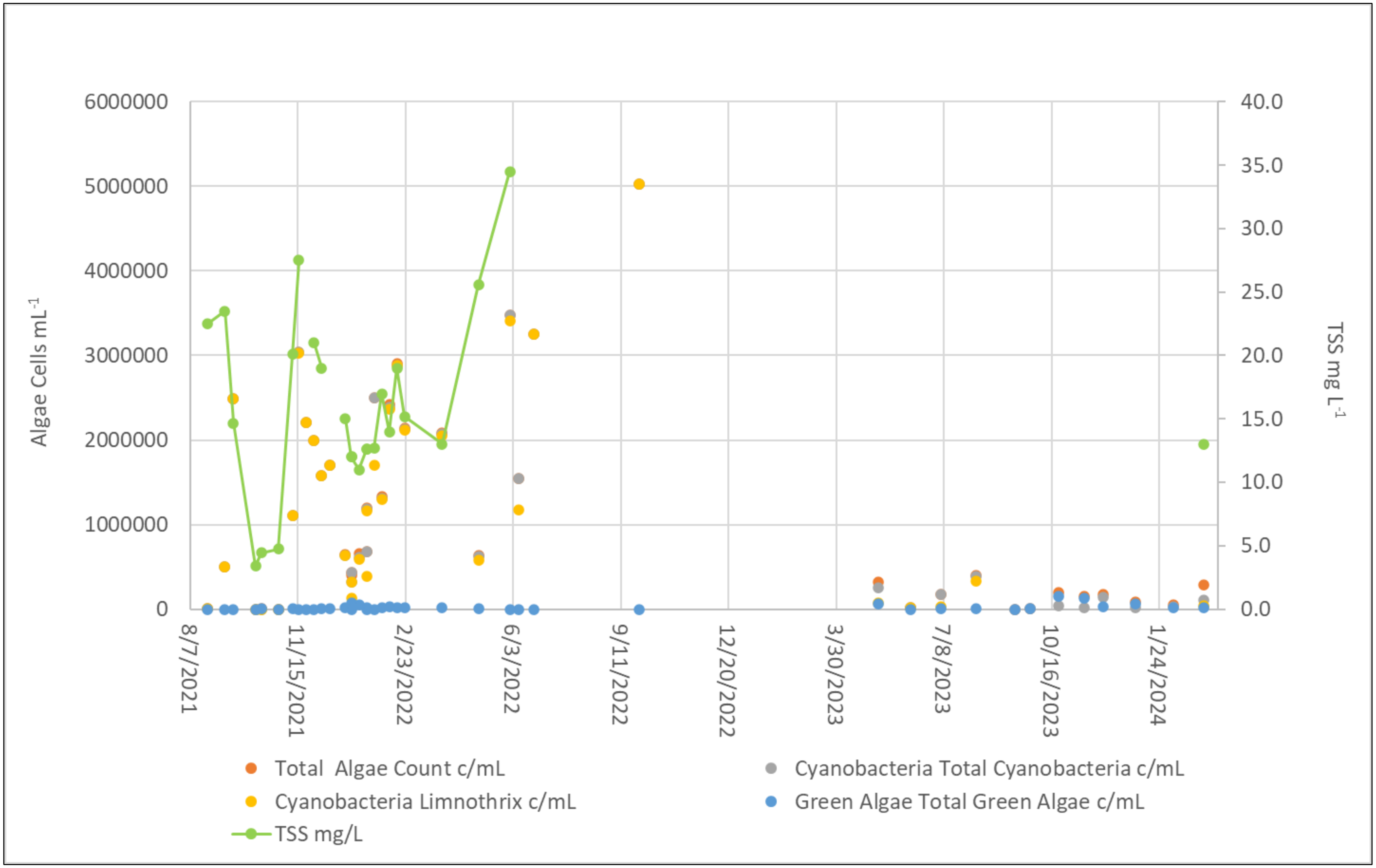

Figure 2. Algal counts versus total suspended solids (TSS) concentrations, August 2021 – March 2024

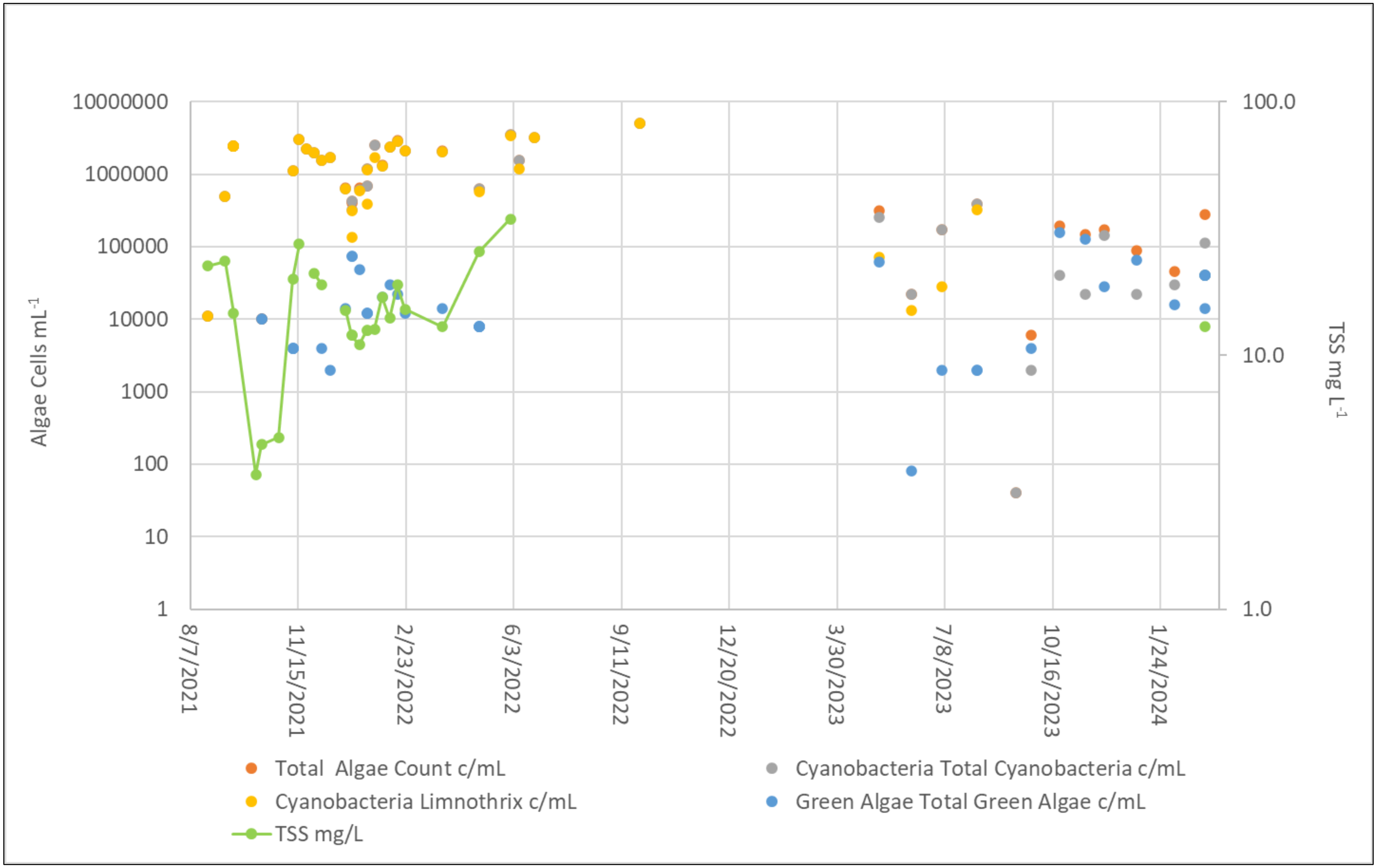

Figure 3. Algal counts versus total suspended solids (TSS) concentrations, August 2021 – March 2024, logarithmic scale

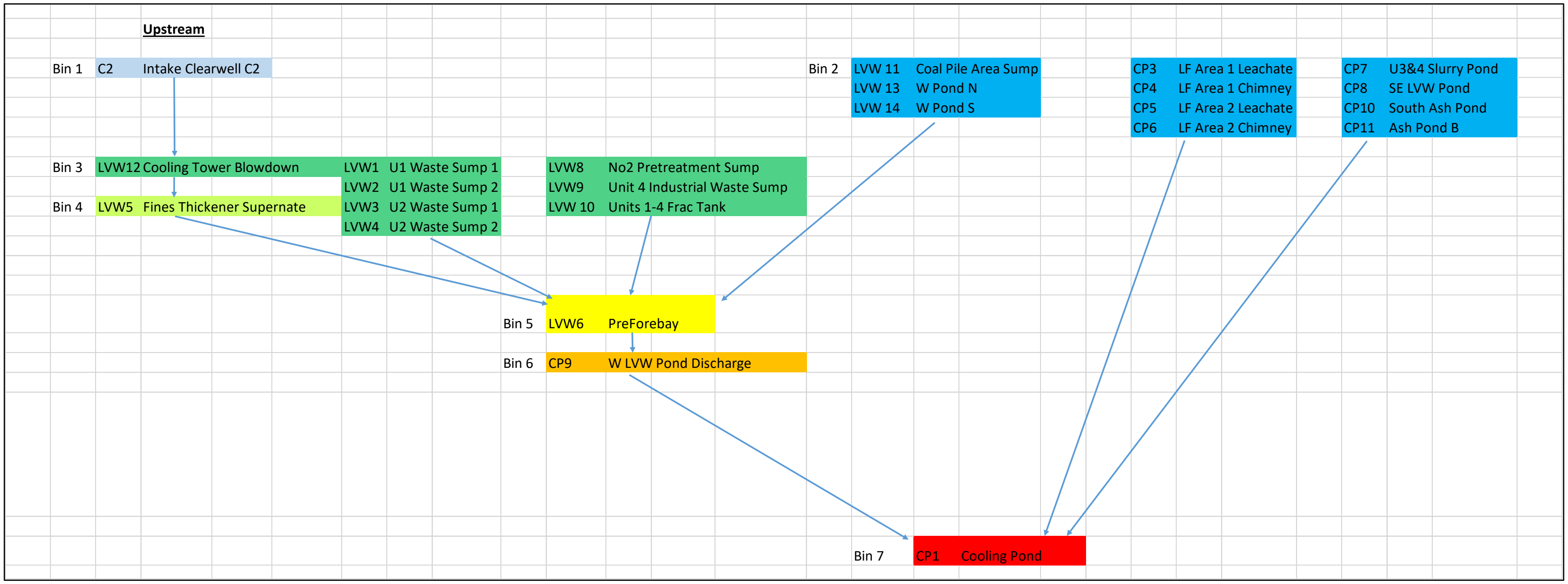

Figure 4. Model positions within station wastewater system

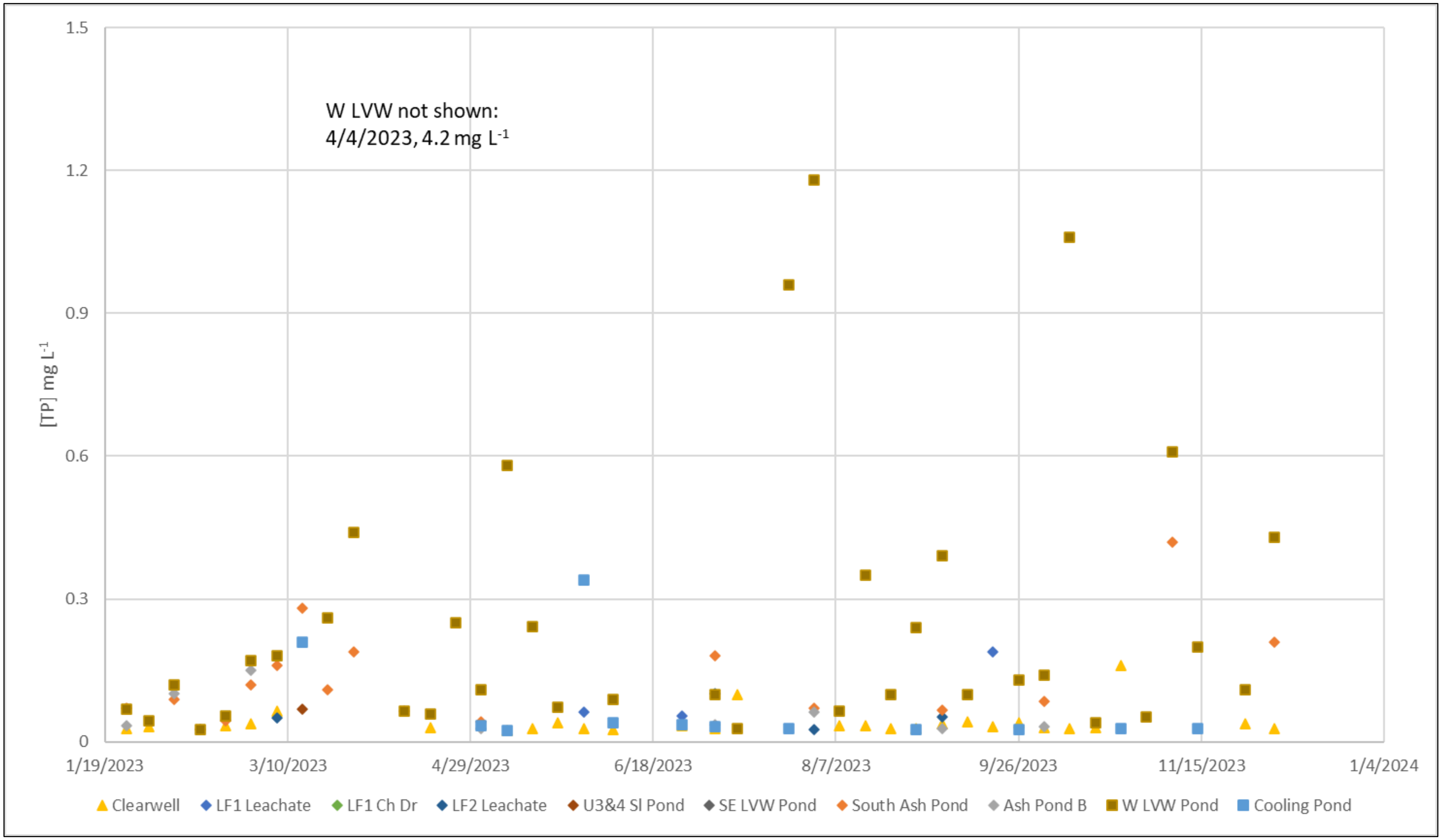

Figure 5. Total phosphorus concentrations, cooling pond and direct discharges to cooling pond, January 25 – December 5, 2023. Values below detection limit (0.05 and 0.025 mg L^{-1}) not shown.

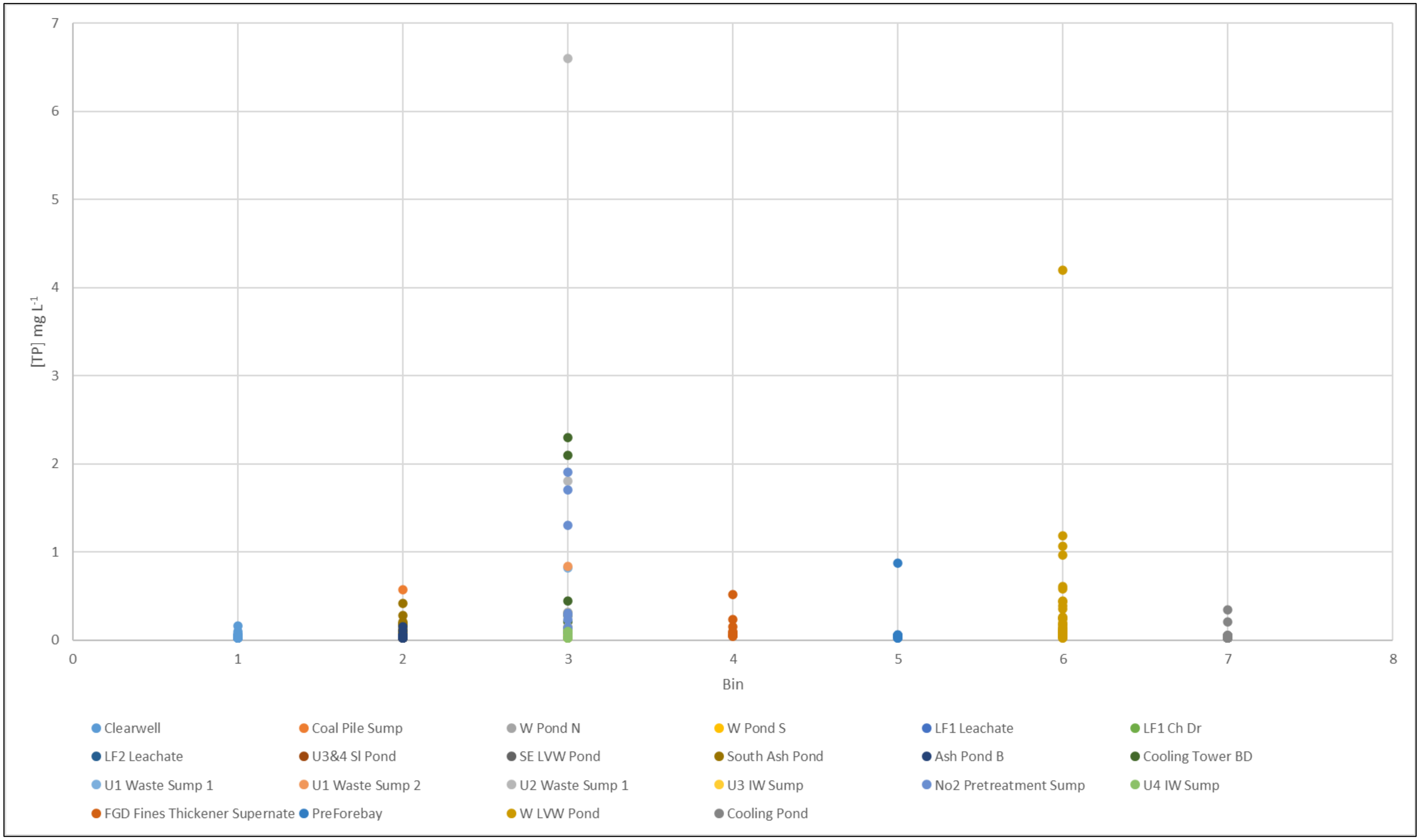

Figure 6. Phosphorus occurrence, station wide (values below detection limit set to detection limit)

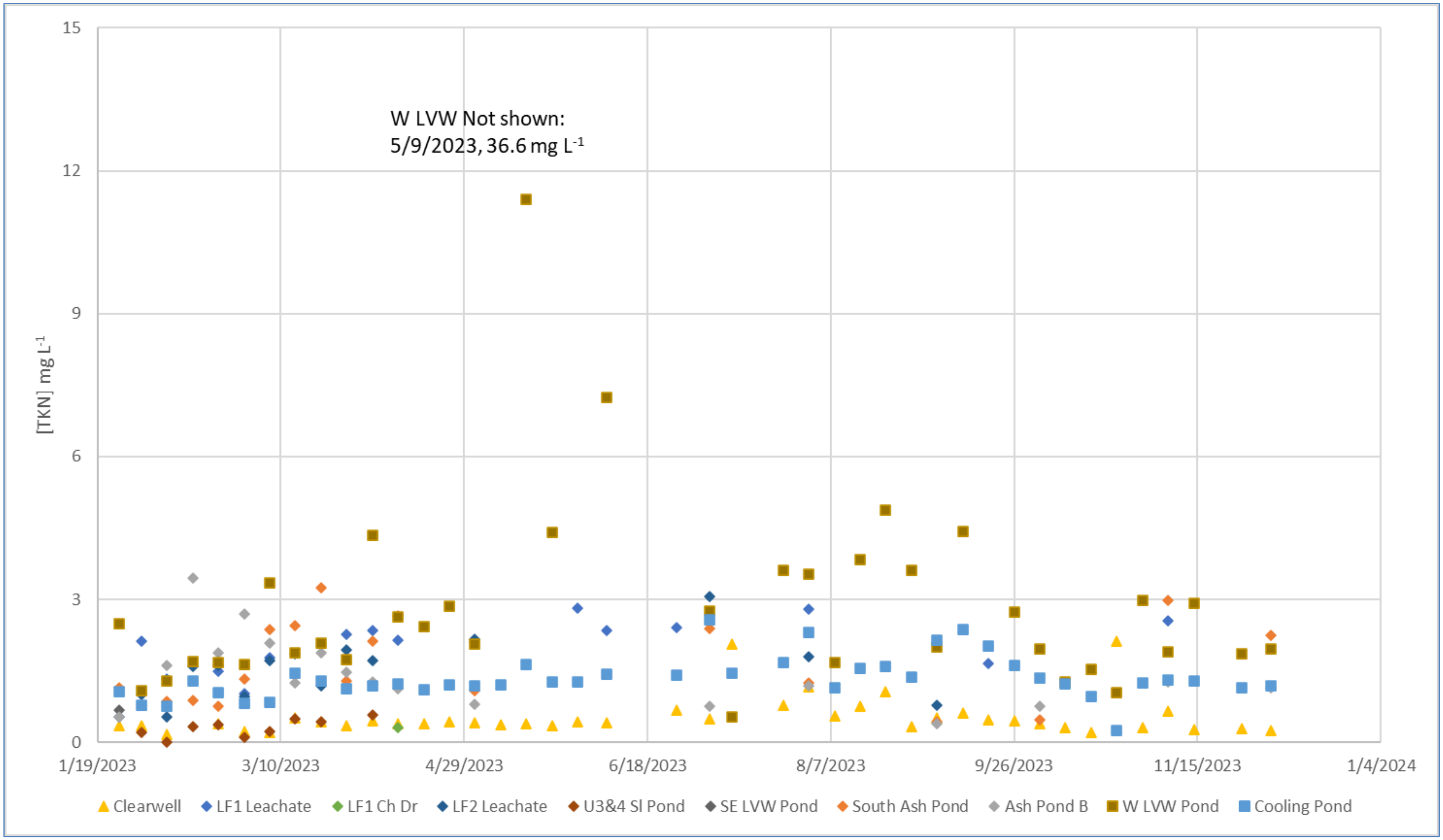

Figure 7. Total Kjeldahl nitrogen concentrations, cooling pond and direct discharges to the cooling pond, January 25 – December 5, 2023

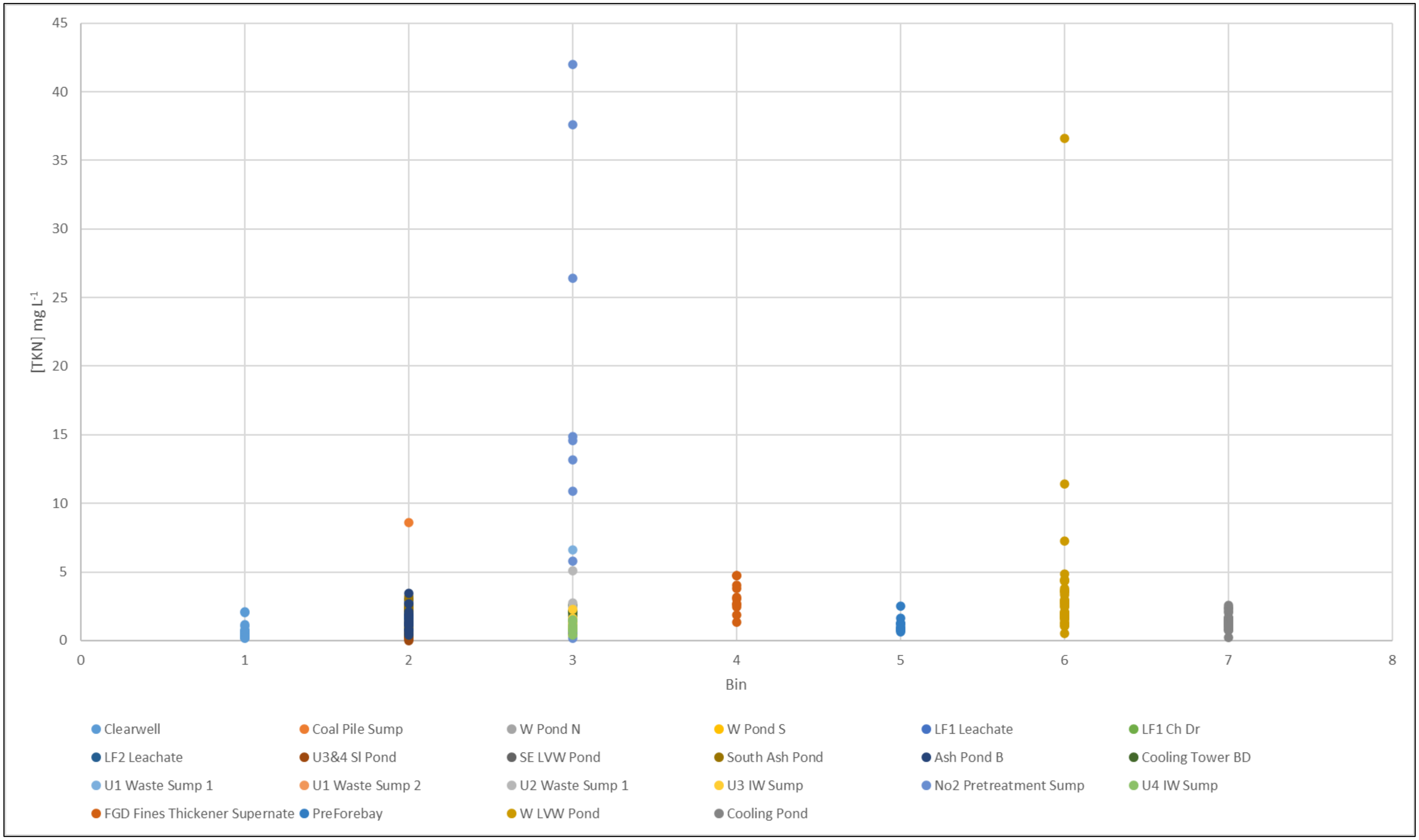

Figure 8. Total Kjeldahl nitrogen occurrence, station wide (values below detection limit set to detection limit)

Results and Discussion

Data collected revealed potential areas where nutrients were added to the system. Total Kjeldahl Nitrogen is high throughout the entire system, with the exception of the site's FGD slurry pond. TP is high mostly at the discharge of the West LVW (WLVW) pond. The WLVW pond receives wastewater from several sumps across the site, and these sumps seem to be the primary original sources of TP to the station cooling pond. The WLVW pond also receives cooling tower blowdown (CTBD), the other notable source of nutrients. TKN was highest from a sump which drains the site of a former pretreatment water plant. Although this operation is no longer present, this portion of the site does receive wastewater from a co-located carbon burnout facility owned and operated by a tenant. Ash is known to leach ammonia, so it is possible that wastewater or stormwater exposed to ash at the carbon burnout facility may be contributing to elevated nitrogen levels in this sump. Notably, the data do not indicate that the facility's landfill leachate or contact stormwater drains are providing significantly elevated contributions of either nutrient.

Several observations can be made from the 2023–2024 study results:

- Phosphorus appears to be the limiting nutrient in the cooling pond. Due to the stoichiometry of algal metabolism and growth, TP is often the limiting nutrient (USEPA, 2023). In this case, TP averaged about 0.07 mg L^{-1}, excluding sampling events for which TP was below the detection limit. Estimates of eutrophication-inducing TP thresholds differ, but some are as low as 0.012 mg L^{-1}. In Lake Okeechobee, the threshold has been estimated at between 0.05–0.10 mg L^{-1} (Yang et al., 2008).
- The Redfield Ratio compares the ratio of carbon: nitrogen: phosphorus in terms of mass units (not molar units) based on an empirically derived C:N:P ratio of 106:16:1 for algae in seawater. The significance of the ratio is that it reveals which nutrient is limiting in a given scenario. For instance, if N:P is above 16:1, phosphorus limits algal growth and metabolism; if below, nitrogen limits (Yang et al., 2008). Although metabolism and biomass each differ among algal species, the 16:1 ratio is a reasonable threshold for many purposes, especially considering high chlorides and sulfate concentrations within the cooling pond. For the samples for which TP was detectable, the TKN:TP ratio of the cooling pond ranged from 3.7–83, with an average of 40.9, strongly suggesting that TP is the limiting nutrient.
- The cooling pond also has high nitrogen concentrations, ranging from 0.26 mg L^{-1} – 2.58 mg L^{-1} TKN, with an average concentration of 1.34 mg L^{-1}. Waters are often considered eutrophic for nitrogen at 1 mg L^{-1} and hypereutrophic above 2 mg L^{-1} (Yang et al., 2008).
- Cyanobacteria are equipped with metabolic flexibility (*Nat. Geosc.* editorial, 2014; Lima et al., 2018), which may have equipped them to thrive where other algal species could not. High concentrations of nitrogen seen in the cooling pond may have allowed *Limnothrix sp*. to out-compete algae which fix nitrogen from the atmosphere (Xie et al., 2012).

- Generally, TP is associated with solids, adsorbed to the surface of particles. Nitrogen species are normally thought of as aqueous nitrates and nitrites, but EPRI has observed that ammonia often leaches from fly ash. Ammonia would be expected to be most pronounced in freshly generated ash, rather than in ash that has been recovered from closing ash ponds. Nevertheless, these observations indicate that solids management may have a role to play with respect to preventing problematic algal blooms through nutrient reductions in the cooling pond.

2 REACTIVE MEASURES: CONTROLLING ALGAE DURING A WATER QUALITY EXCURSION

The utility has employed a number of algaecide applications over the past several years to mitigate excess algae. Learnings from these activities are summarized below, along with information and suggestions that could be developed into an action plan for prevention and reactive treatment of future algae blooms.

EPRI (2024) has reviewed past work (a review of different proactive and reactive treatment options for algae blooms, titled *Algae Present in Power Plant Operations: A Review of Remediation Options*, 3002028869) and recent developments in treatment technologies to prepare an overview of reactive technologies for the utility to consider when forming its reactive algae treatment plan for the facility's 400-acre cooling pond. It is suggested that preventative care (such as nutrient control) be the first line of defense against potential algae blooms.

Potential reactive treatments are presented in Table 1.

Table 1. Reactive treatment technologies that could potentially be deployed at facility

Treatment Technology	Response Type	Applicability
Copper-based algaecide	Reactive	SeClear, a combined copper-/alum-based algaecide was utilized, but did not show benefit to algae concentration (applied 6/2022). Copper-based algaecides work by binding to algae cells, damaging them and destroying the algae. Consistent dosing is required, leading to higher cost and potential risk to aquatic life/discharge permits. While copper-based algaecides have been proven acceptable to use for most wildlife, ongoing use of copper algaecides can result in high loading within pond beds, affecting the bacteria found in the sludge. Benthic organisms can be inhibited by copper due to its anti-microbial properties. With lower levels of benthic organism activity, organic matter—including the destroyed algae—can accumulate quickly at pond bottoms since there is less bacteria present to break down the material. Increased organic matter may eventually lead to increased algae blooms due to excess nutrients and insufficient aerobic bacteria to digest them.

Table 1 (continued). Reactive treatment technologies that could potentially be deployed at facility

Treatment Technology	Response Type	Applicability
Peroxide-based herbicide	Proactive/ Reactive	Proactive/Reactive: PAK-27, a peroxide-based algaecide, showed promising treatment potential but only temporarily corrected the issue (applied 9/2021), where *Limnothrix* re-appeared 2 weeks after application. The active ingredient in PAK-27 is sodium carbonate peroxyhydrate (SCP). When exposed to water, SCP forms inactive carbonates and hydrogen peroxide. After the hydrogen peroxide reacts with the algae, it breaks down into water and oxygen, with the final byproduct being sodium carbonate, also known as soda ash. SCP is unique as an algaecide because it targets cyanobacteria (USDA, 2014) over green algae when dosed in small quantities. It is reported to be able to treat current algae growth and prevent future algae growth. Application is recommended early in the season, before increased algae growth begins, or as soon as algae growth is observed (Biosafe Systems, 2023). Reactive: Oximycin (peroxide) is another potential algaecide option evaluated. The utility, as of August 2023, reported that it can be used if needed.
Endothall-based herbicide	Reactive	At this facility, Hydrothol 191 was traditionally used to control algae, but it did not prove successful in treating the *Limnothrix* bloom (applied 3/2021 and 8/2021). Hydrothol 191's active ingredient is an endothall salt. Endothall can eliminate growing algae, but does not prevent future algal growth. Like copper-based algaecides, Endothall is not long-acting and requires consistent dosing.

In the event of an algal bloom, the facility has several controls that can be used. Beyond the use of algaecides, one of the potential controls the facility currently has available in the event of an algae bloom is to maintain fresh water in the cooling pond. Based on previous experience, Hydrothol 191 should only be applied after completion of an algae count to ensure that resistant species (such as *Limnothrix sp.)* are not predominant. After an algaecide treatment, the facility should liberally pump in fresh water and discharge treated water out of the system to flush as much phosphorus from the lysed algal cells as possible. Even then, ready access to PAK-27, found to be effective on the previous *Limnothrix sp.* bloom, should be ensured if eliminating competing algae species via Hydrothol dosing allows *Limnothrix sp.* to achieve dominance. Pumping should be maintained after algaecide application to ensure as much TP and TN are removed from the system as possible. Careful pumping versus unit dispatch, rainfall, and phosphorus and pond level monitoring may allow the facility to dilute nutrient levels successfully while ensuring compliance with the 316(b) rule for a pond which is part of a facility's cooling system; over pumping would violate the 316(b) rule and must be prevented.

3 PROACTIVE MEASURES: CONTROLLING WATER QUALITY TO REDUCE THE PROBABILITY OF PROBLEMATIC ALGAL BLOOMS

Utilities should consider implementing the following proactive steps to monitor and address problematic water constituents, such as nutrients that may lead to algae blooms. EPRI (2024) has reviewed past work (a review of different proactive and reactive treatment options for algae blooms, titled *Algae Present in Power Plant Operations: A Review of Remediation Options*, 3002028869) and recent developments in treatment technologies to prepare an overview of preventive technologies for a utility to consider when forming its algae control and management plan for their affected impoundment or pond. Such preventative care (such as nutrient control) can be a powerful first line of defense against potential algae blooms.

Treatment technologies were evaluated based on how useful they are for a large waterbody. Potential proactive treatments are categorized in Table 2:

Table 2. Preventative and proactive algae management technologies and practices that could be adopted for managing algae at facility

Treatment Technology	Response Type	Applicability
Nutrient removal/ sequestration	Proactive	The removal or sequestration of nutrients from water, such as phosphorus or nitrogen, is a proactive treatment option aimed at addressing nutrients that already exist within the waterbody. The usage of two different nutrient-based technologies – PhosLoc for the sequestration of phosphorus, and filter bags/nutrient socks for the sequestration of phosphorus can be considered. PhosLoc use could further contribute to station TSS issues if it does not promptly settle in turbulent conditions. To best mimic these conditions, a jar test with the subject water in turbulence can determine if PhosLoc settles quickly in turbulent water. Disc filters or filter bag technology may be suitable to remove particulates if solids do not settle rapidly. However, filter bags become heavy and difficult to maneuver and are potential waste disposal items. A potential alternative to PhosLoc may be to apply alum to the cooling pond. Alum treatment has been demonstrated to provide effective short-term treatment of water column phosphate and effective long-term mitigation of “internal” phosphorus loading - that is, release from sediments under anoxic conditions (Xie et al., 2008; Groves, 2021). Other suggested technologies for the removal or sequestration of nutrients from the cooling pond include the following: • Artificial floating wetlands • Nutrient recovery (Ostara, Gross-Wen) • Nutrient removal (DEMON, ANITA, SAGR, AquaDisk)

Table 2 (continued). Preventative and proactive algae management technologies and practices that could be adopted for managing algae at facility

Treatment Technology	Response Type	Applicability
Watershed Management and Onsite Good Management Practices	Proactive	The prevention of excess nutrients from entering the waterbody is a proactive option aimed at addressing nutrients that have not yet made it into the waterbody. If ongoing sampling indicates that excess nutrient loading is from external sources, then watershed management can be considered as a proactive measure to prevent algae blooms. During conversations with the utility, EPRI determined that good management practices for keeping solids out of station wastewater systems may be effective. Some suggested Good Management Practices (GMPs) for preventing CCP exposure to stormwater or introduction into wastewater include: • Inlet protection around storm drains (e.g., silt fences, sediment tubes, hardware cloth and pea gravel) • A roof over the carbon burnout (CBO) facility storage area, or improvements to CBO wastewater • Additional focus on station housekeeping • Evaluation of solids control strategies for ponds undergoing closure and continued ongoing maintenance. • Temporary or permanent cover of landfills • Implementation of additional construction stormwater GMPs around landfill construction. • Utilization of check dams in ditches One possible side-benefit of improved CCP housekeeping would be the reduction in sediment management in the ponds.
Fish species	Proactive	Fish species, such as tilapia or grass carp, could be considered for the use of algae control. For *Limnothrix*, tilapia may be considered as they are filter/planktonic feeders. Several studies have utilized tilapia for control of toxic algae species including *Limnothrix* (Triest et al., 2016; Semyalo et al., 2011). Consumption of cyanobacteria may be dependent on water clarity, as tilapia prefer mobile insects when the water is clear enough to make them visible.

Table 2 (continued). Preventative and proactive algae management technologies and practices that could be adopted for managing algae at facility

Treatment Technology	Response Type	Applicability
Aeration	Proactive	Proactively, aeration of a stratified waterbody may aid in its destratification, i.e., mixing of the deeper/cooler and shallower/warmer layers. Destratification of a waterbody can potentially prevent pond turnover during colder weather (decreasing nutrient release from sediment) and mineralize nutrients currently present in the waterbody column via increased DO levels. Destratification may also aid in the growth of beneficial aerobic bacteria present in the pond sludge, allowing for increased nutrient removal. Reactively, aeration has the potential to disrupt algae migration throughout the water column. *Limnothrix* contains gas vacuoles called aerotopes that allow for water column migration, rising to the surface during the day for photosynthesis, and sinking at night to absorb nutrients present in the pond sediment. The introduction of aeration could disrupt the natural movement of vesicle-containing algae and deter their growth in a stratified pond. However, where lack of aerotope development has been noted, it may indicate that the pond is already well-mixed, in which case strategies are unlikely to be effective. The potential for pond stratification may be worthy of additional study. Bathymetry of the pond should be considered if deciding whether to use surface or diffused aeration, as waterbodies deeper than 8 feet may be better suited for diffused aeration. A concurrent EPRI project has demonstrated that a pond of secondary treated effluent is well mixed when aerated and less mixed when not; results will be presented in a future report.
Ultrasound	Proactive	Ultrasonic treatment may prevent excess algae growth by inhibiting gas vesicle-containing algae species, such as *Limnothrix*, from migrating throughout the water column, unless the pond is already well-mixed. Ultrasound waves disrupt the gas vesicles and limit vertical movement in the water column (LG Sonic, 2017; Park et al., 2017), preventing the algae from accessing adequate sunlight or nutrients. While EPRI is aware of the successful use of ultrasonic buoys for algae treatment in enclosed spaces like clarifiers, there has not been any EPRI or EPRI member-documented evidence proving the efficacy of ultrasound for use in larger reservoirs[1] or cooling ponds. These have, however, been successfully utilized in open-topped round tanks and clarifiers. As with aeration, bathymetry of the pond should be considered if deciding whether to use ultrasonic treatment or not, as it is less effective in deeper ponds (>8 feet) and can be blocked by large objects such as fallen trees, boulders, or columns. Ensuring adequate coverage is essential for this technology to be successful. Generally, ultrasonic treatments currently in use are more effective in smaller waterbodies that allow for an echo effect or recycling of the ultrasonic waves.

[1] Previously, a member reported that no improvement was observed when using ultrasonic technology on a 45-acre pond while tracking several algae groups, including cyanobacteria (algae gas vacuole/aerotope presence was not specified).

Table 2 (continued). Preventative and proactive algae management technologies and practices that could be adopted for managing algae at facility

Treatment Technology	Response Type	Applicability
Light-blocking	Proactive	Light-blocking technologies may aid in reducing algae growth. Without light, algae cannot efficiently perform photosynthesis and will not thrive, even in nutrient-rich water. The size of the facility cooling pond limits the use of dyes or covers, but more flexible light-blocking options, such as floating balls, floating tiles, or floating solar panels, may be applicable. Floating balls and plates are efficient at blocking out sunlight (EPRI, 2014, 3002004203), providing up to 91% coverage and 99% coverage, respectively (AWTT, published 2017). However, one limitation to note is that due to the near full coverage of the water surface, air-water interactions are limited. This may impact several things, including oxygen exchange, water chemistry, and cooling capacity of the pond. Floating solar panels (FPVs) are another modular light-blocking option that combine traditional solar panels with HDPE pontoons to suspend them over water. FPVs do not block light as extensively as the floating balls/plates, but they have been shown to successfully reduce algae with a majority surface area coverage. While dependent on the design of the FPV pontoon, those suspended above the water restrict the air-water interface less than floating balls or plates, while still blocking out light. This may aid in algae reduction while lessening impacts on oxygen exchange/cooling capacity. Floating solar is the topic of an ongoing project which will be described in "*Floating Photovoltaics: Potential Implications for Water Quality and PV Performance at Generation Stations, #3002028898*," anticipated to be published by EPRI in late 2024.
Peroxide-based herbicide	Proactive/ Reactive	Proactive/Reactive: PAK-27, a peroxide-based algaecide, showed promising treatment potential but only temporarily corrected the issue (recall, it was applied in this case study), where *Limnothrix* re-appeared 2 weeks after application. The active ingredient in PAK-27 is sodium carbonate peroxyhydrate (SCP). When exposed to water, SCP forms inactive carbonates and hydrogen peroxide. After the hydrogen peroxide reacts with the algae, it breaks down into water and oxygen, with the final byproduct being leftover sodium carbonate, also known as soda ash. SCP is unique as an algaecide in that it targets cyanobacteria (USDA, 2014) over green algae when dosed in small quantities. It is reported to be able to treat current algae growth and prevent future algae growth. Application is recommended early in the season, before increased algae growth begins, or as soon as algae growth is observed (Biosafe Systems, 2023).

It is good practice to proactively manage nutrient levels in station impoundments below eutrophic thresholds, ideally <0.05 mg L^{-1} TP and <1 mg L^{-1} TKN, through a combination of careful pumping (see section 2) and source reduction. Ideally, based on station data in this case, the facility should be able to meet the TSS limit given a diverse algal population and a total concentration of <500,000 cells mL^{-1}.

For proactive measures to be effective, facilities should review operating and maintenance chemical programs station-wide and ensure that additional sources of phosphorus or nitrogen being injected into the system are documented, replaced if possible and minimized if not. Source control efforts should be considered for "hotspots" around the station. Improvements might be achieved through improved solids management for TP, and by minimizing the potential for ammonia leaching from fly ash for TKN. Additional TSS and nutrient improvements might also be realized in landfill and pond areas, but these seem to be lower sources of nutrients in this case study.

Ongoing station sampling and analysis programs will help monitor the progress of source reduction efforts, establish an operational baseline, and potentially provide an early warning of an impending algal bloom. Quarterly nutrient sampling of targeted locations is reasonable, unless a bloom is in progress, in which case an expanded list of sampling points is advisable on a more-regular basis. This is especially true at the bloom's initiation, as it may provide a clue to the source of additional nutrients. Also recommended are limited analyses for dissolved and total phosphorus, which may suggest additional solids control strategies to minimize nutrient enrichment. Quarterly algal counts of cooling pond samples should also be maintained. A suggested revised nutrient sampling plan is contained in Appendix B.

4 CONCLUSIONS AND SUGGESTIONS FOR ADDITIONAL WORK

This case study highlighted the result of reactive management of algae through algaecide applications in the presence of excess nutrient loadings over several years. It was observed that during this period, *Limnothrix* established overgrowth and dominance through algaecide-induced reduced competition. In the absence of nutrient treatment, prevention of a recurrence will require disrupting the nutrient cycle or the light that *Limnothrix* requires to thrive. Although other opportunities for improvement exist, site data suggest source control strategies centering on operating chemistry should be a primary means of prevention.

Among reactive technologies, algaecide remains the most applicable strategy in the absence of data which demonstrate pond stratification. Additionally, strategic volume management via pumping may play a role in maintaining lower nutrient levels within the pond.

Additional learnings may be determined through the examination of more data such as:

- Dates of outage washes and air heater washes
- Maintenance chemical application logs
- Additional TSS, temperature, chlorides, conductivity, DO, ORP, and pH data dating through periods of interest, including process data from periods when the Cooling Pond wasn’t discharging
- Daily intake and discharge data
- Landfill leachate and contact stormwater data shared with EPA
- Owner engineer reports on station water quality before and after the low volume waste pond construction project

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A ORIGINAL 2023 SAMPLING PLAN

Cooling Pond Sampling Plan (Provided by Member)

Sampling Locations:

All inflows to the Cooling Pond will be sampled. This will include all pipes flowing into the West Low Volume Waste Pond as well as pipes or stormwater flowing into the cooling pond system. Sample location IDs are listed below.

Sample ID Sample Location Descriptions

LVW 1 Unit 1 Low Volume Waste Sump #1
LVW 2 Unit 1 Low Volume Waste Sump #2
LVW 3 Unit 2 Low Volume Waste Sump #1
LVW 4 Unit 2 Low Volume Waste Sump #2
LVW 5 Fines Thickener Supernate Pumps

LVW 6 PreForebay Discharge

LVW 7 Unit 3 Industrial Waste Sump
LVW 8 No. 2 Pretreatment Sump
LVW 9 Unit 4 Industrial Waste Sump
LVW 10 Units 1,2,3, and 4 Frac Tank
LVW 11 Coal Pile Area Sump Pump
LVW 12 Cooling Tower Blowdown and Storm Water Pumping Station
LVW 13 West Ash Pond North Pump
LVW 14 West Ash Pond South Pump

CP 1 Cooling Pond
CP 2 Clearwell

CP 3 Area 1 Leachate Pumps
CP 4 Area 1 Chimney Drain
CP 5 Area 2 Leachate Pumps
CP 6 Area 2 Chimney Drain
CP 7 Units 3 and 4 Slurry Pond Floating Pump Station
CP 8 SE LVWP Forwarding Pumps
CP 9 W LVWP Forwarding Pumps
CP 10 South Ash Pond Discharge Point
CP 11 B Ash Pond Discharge Point

Sampling Frequency:

Samples will be collected on a weekly basis, every Tuesday. Samples should be collected at approximately the same time of day each week. Ambient temperature, pond temperature, and which units are online should all be documented during each sampling event.

Sample Collection & Analysis:

Each sample location will be analyzed for Total Nitrogen, Total Kjeldahl Nitrogen, Total Phosphorus, Nitrate, Nitrite, Chloride, Fluoride, and Sulfate. This will require 3 sample bottles be filled at each sample point. Bottles should be labeled with the following information:

Sample ID
Sample Date & Time
Sample Collector
Sample Analysis to be performed

Once collected, sample bottles must be kept in a cooler with ice so that their temperature reaches $<6^oC$.

Sample Delivery:

Nitrate & Nitrite have a 48 hour hold time. As a result, samples must be delivered to the Central Lab the same day they are collected. A chain of custody must be completed to accompany the samples. The samples must remain on ice during transport and arrive at the Central Lab having a temperature of $<6^oC$.

Proposed Updated Sampling Plan – 4/17/23

Sampling History:

Weekly sampling of all above -listed sampling points has been done for 12 consecutive weeks. The results for the first 10 weeks of samples are available and have been compiled into a spreadsheet with graphs.

Recommendations:

Based on the 10 weeks of data available, the following is recommended:

1. Eliminate all LVW sample points- LVW 5 (Fines Thickener Supernate Pumps) and LVW 8 (former pretreatment area sump) seem to be the main contributors of chlorides and nitrogen into the West Low Volume Waste Pond. However, all sample locations flowing into the West Low Volume Waste Pond contribute to the eutrophic atmosphere with nitrogen greater than 1 ppm. Because of this, I believe that cutting out these individual sampling points and focusing on the sample that is leaving the West Low Volume Waste Pond (CP 9) and flows into the Cooling Pond will give us sufficient nutrient data going forward.
2. Continue sampling at CP 9, CP1, and CP 2 weekly (every Tuesday) – CP 9 is the West Low Volume Waste Pond forwarding pump. This data point will capture all sources flowing into the WLVW pond once they are mixed and are being pumped into the cooling pond. CP 1 is the Cooling Pond. This sample point continues to monitor the nutrient level of the water we discharge through our NPDES permitted outfall. CP 2 is the Clearwell. Continuing to sample this will ensure the quality of the water entering the plant site from the source water.
3. Begin sampling remaining CP sample points of interest monthly – The first Tuesday of the month, in addition to CP 1, CP 2, and CP 9, samples from CP 3 (Area 1 Leachate), CP 5 (Area 2 Leachate), CP 10 (South Ash Pond), and CP 11 (B Ash pond) will be collected. These 4 sampling locations showed elevated levels of nitrogen during the initial sampling and should continue to be monitored as the temperatures increase.
4. Begin sampling Algae ID monthly – An algae ID sample will be pulled from the cooling pond on the first Tuesday of every month. This will be analyzed to monitor algae counts and types of algae present as temperatures rise.
5. Limit requested analysis to Total Phosphorus and Total Nitrogen – TP and TN are the main contributors to causing a eutrophic water body, ideal for algae growth. Although the cooling pond has not shown detectible levels of TP, I believe we should continue to monitor this as the temperatures increase into the summer months.

Proposed Updated Sampling Plan – 11/2/23

Weekly sampling of the updated/lessened sample points has been done for 6 full months. The results are available and have been compiled into a spreadsheet with graphs. There have been no excursions to note, and the cyanobacteria is no longer found in the pond. TSS is consistently less than 10 mg/L, and little algae has been found in the cooling pond over the past several months.

As a result, it is proposed that we discontinue weekly sampling, and begin the following quarterly monitoring program:

Frequency: Quarterly
Sample Points: CP 1, CP 2, CP3, CP5, CP 9, CP10, CP11.
CP 1 Cooling Pond
CP 2 Clearwell
CP 3 Area 1 Leachate Pumps
CP 5 Area 2 Leachate Pumps
CP 9 W LVWP Forwarding Pumps
CP 10 South Ash Pond Discharge Point
CP 11 B Ash Pond Discharge Point

Sample Analysis:

Total Phosphorus, Total Nitrogen – All sample points

TSS and pH will be analyzed weekly in the Cooling Pond and Clearwell by the station Results Lab.

If results of either TSS or pH begin to rise, increased sampling/analysis will be reestablished.

B SUGGESTED REVISED SAMPLING PLAN

A simplified, reduced sampling plan was developed and shared with the utility. It involves sampling for dissolved phosphorus twice per year to evaluate the degree to which solids management may improve cooling pond nutrient loading and a focus on ”hot spots” identified by the station's 2023 sampling efforts.

Full Sampling Plan - March and August

Rationale: It would be helpful to know conditions in pond preceding algal blooms. Historically algae treatments have been needed in the April/May timeframe, and the 2021 *Limnothrix sp.* issues started in August and September, which has also been when temperature-based discharge restrictions occur under the current permit. TSS and dissolved phosphorus analyses will help to determine the degree to which TP is solids-associated and help to determine where solids management improvements may be targeted.

Sample ID	*Sample Location Description*	*pH*	*ORP*	*Cond*	*TSS*	*TP*	*Dissolved TP*	*TKN*	
LVW 1	U1 LVW Sump 1	x	x	x	x	x	x	x	
LVW 2	U1 LVW Sump 2	x	x	x	x	x	x	x	
LVW 3	U2 LVW Sump 1	x	x	x	x	x	x	x	*only most active unit sump
LVW 4	U2 LVW Sump 2	x	x	x	x	x	x	x	
LVW 7	U3 Ind Waste Sump	x	x	x	x	x	x	x	
LVW 9	U4 Ind Waste Sump	x	x	x	x	x	x	x	
LVW 5	Fines Thickener Supernate Pumps	x	x	x	x	x	x	x	
LVW 6	PreForebay Discharge								
LVW 8	No. 2 Preatreatment Sump	x	x	x	x	x	x	x	
LVW 10	Units 1,2,3,4 Frac Tank								
LVW 11	Coal Pile Area Sump Pump	x	x	x	x	x	x	x	
LVW 12	CT Blowdown/Stormwater Pumping	x	x	x	x	x	x	x	
LVW 12A	Stormwater Pond Grab	x	x	x	x	x	x	x	
LVW 13	West Ash Pond North Pump	x	x	x	x	x	x	x	*only most active WAP pump
LVW 14	West Ash Pond South Pump	x	x	x	x	x	x	x	
CP 1	Cooling Pond	x	x	x	x	x	x	x	
CP 2	Clearwell	x	x	x	x	x	x	x	
CP 3	Area 1 Leachate Pumps								
CP 4	Area 1 Chimney Drain								
CP 5	Area 2 Leachate Pumps								
CP 6	Area 2 Chimney Drain								
CP 7	U3&4 Slurry Pond								
CP 8	SE LVWP Forwarding Pumps								
CP 9	W LVWP Forwarding Pumps	x	x	x	x	x	x	x	
CP 10	South Ash Pond Discharge	x	x	x	x	x	x	x	
CP 11	B Ash Pond Discharge	x	x	x	x	x	x	x	

Notes

1. Evaluate need for continued TSS/Dissolved P after completing first early spring/late summer collection cycle.
2. Collect at consistent depth, location, and time of day.
3. Recommend briefly returning to full sample plan in event of algal bloom and adjusting after first results are received.
4. Continue to record ambient temperature, cooling pond temperature, and number of units operating at time of collection.
5. Recommend pairing with algae sp. analysis of cooling pond.
6. Evaluate TKN:TP ratio of cooling pond and source waters over time. As long as ratio is ~16:1 or greater, TP likely limits.

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Reduced Sampling Plan - June and December

Rationale: Reduction in sampling to areas that have been historic hotspots for TP, which seems to have been limiting nutrient. Should provide indicator of degree to which solids mitigation strategies are helping to reduce TP discharge to the cooling pond.

Sample ID	Sample Location Description	pH	ORP	Cond	TSS	TP	Dissolved TP	TKN	
LVW 1	U1 LVW Sump 1	x	x	x		x		x	
LVW 2	U1 LVW Sump 2	x	x	x		x		x	
LVW 3	U2 LVW Sump 1	x	x	x		x		x	*only most active unit sump
LVW 4	U2 LVW Sump 2	x	x	x		x		x	
LVW 7	U3 Ind Waste Sump	x	x	x		x		x	
LVW 9	U4 Ind Waste Sump	x	x	x		x		x	
LVW 5	Fines Thickener Supernate Pumps	x	x	x		x		x	
LVW 6	PreForebay Discharge								
LVW 8	No. 2 Preatreatment Sump	x	x	x		x		x	
LVW 10	Units 1,2,3,4 Frac Tank								
LVW 11	Coal Pile Area Sump Pump	x	x	x		x		x	
LVW 12	CT Blowdown/Stormwater Pumping	x	x	x		x		x	
LVW 12A	Stormwater Pond Grab								
LVW 13	West Ash Pond North Pump								
LVW 14	West Ash Pond South Pump								
CP 1	Cooling Pond	x	x	x		x		x	
CP 2	Clearwell	x	x	x		x		x	
CP 3	Area 1 Leachate Pumps								
CP 4	Area 1 Chimney Drain								
CP 5	Area 2 Leachate Pumps								
CP 6	Area 2 Chimney Drain								
CP 7	U3&4 Slurry Pond								
CP 8	SE LVWP Forwarding Pumps								
CP 9	W LVWP Forwarding Pumps	x	x	x		x		x	
CP 10	South Ash Pond Discharge	x	x	x		x		x	
CP 11	B Ash Pond Discharge	x	x	x		x		x	

Notes

1. Collect at consistent depth, location, and time of day.
2. Recommend briefly returning to full sample plan in event of algal bloom and adjusting after first results are received.
3. Continue to record ambient temperature, cooling pond temperature, and number of units operating at time of collection.
4. Recommend pairing with algae sp. analysis of cooling pond.
5. Evaluate TKN:TP ratio of cooling pond and source waters over time. As long as ratio is ~16:1 or greater, TP likely limits. Should this ratio stabilize at a level significantly lower than 16:1, consider running TKN for all streams and target efforts to reduce nitrogen discharge.

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Water Treatment Technologies, Program 238
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