Lake Ketchum –
A restoration success story

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Lake Ketchum is a 26-acre lake in Washington State located about 50 miles north of Seattle, just a few miles from Puget Sound (Figure 1). There are about sixty homes located on this beautiful public lake and it is heavily used for swimming, fishing and boating. Lake Ketchum is also home to a variety of birds and wildlife including bald eagles and osprey. Until the 1940s, Lake Ketchum was largely undeveloped and served as a reserve drinking water source for the nearby City of Stanwood. Unfortunately, lake water quality markedly deteriorated and for the last several decades Lake Ketchum was the most polluted lake in Snohomish County and one of the worst in the state.

The problem

For several years, Lake Ketchum was plagued by severe blooms of cyanobacteria. Thick growths of algae formed unsightly scums that covered the lake for months at a time, severely impairing the public use and enjoyment of the lake. Even worse, the algal blooms were frequently toxic, threatening the health of people, pets, and wildlife. For much of the year the lake was posted with recreational warnings that discouraged most lake uses (Figure 2 a-c). The liver toxin, microcystin, reached over 400 µg/L in the few years prior to restoration, well above the state's current recreational guidance value of 8 µg/L (www.nwtoxicalage.org).

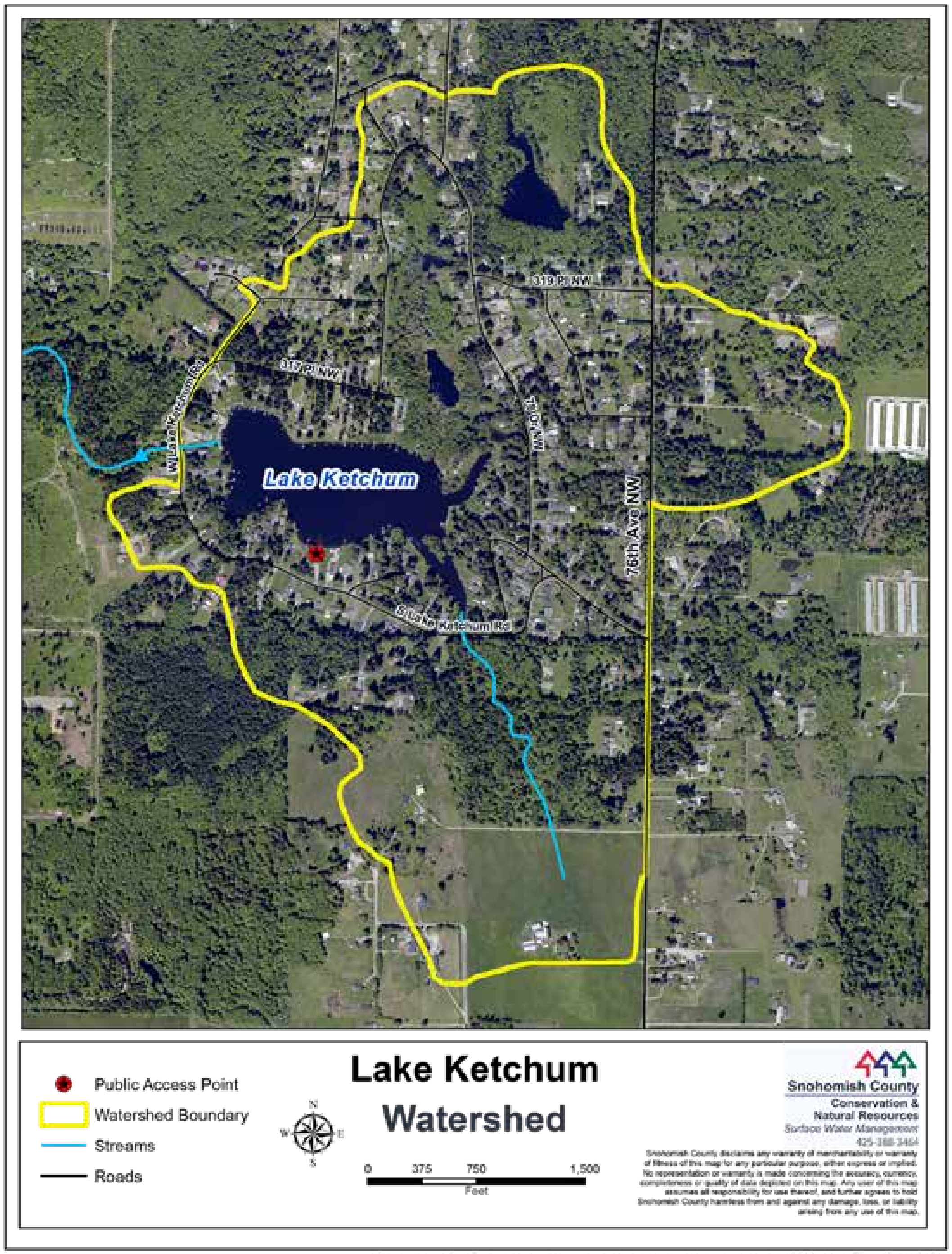

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Figure 1. Lake Ketchum Watershed.

< *Figure 2 (a) Typical cyanobacteria bloom at Lake Ketchum prior to restoration; (b) Sample collection of thick cyanobacteria bloom at Lake Ketchum prior to restoration; (c) Toxic Algae Warning sign at Lake Ketchum prior to restoration.*

Snohomish County had a long-term volunteer monitoring program at the lake. Using data collected through that program, the county was able to determine that the harmful algal blooms were fueled by extremely high phosphorus levels (Snohomish County 2012). The 1996-2011 epilimnetic (upper water layer) total phosphorus (TP) concentration averaged 277 µg/L (Snohomish County, 2012). These values were some of the highest in the state and were 13 times higher than the regional standard. The summer hypolimnetic (lower water layer) TP average was over an order of magnitude higher at 1,746 µg/L. Seasonal peaks in the hypolimnion sometimes had TP values as high as raw sewage.

Early county and community efforts to identify the source of the problem found that the original source of phosphorus to the lake was from a former dairy farm (Entranco, 1997). The farm is in the southern portion of the watershed. The seasonal inlet stream that drains to the lake originates on the farm. At one point in time, the dairy farm served as an annual waste depository, leaving the soils on the farm heavily saturated with phosphorus. Over time, phosphorus entering the lake from the farm accumulated in the lake bottom and became a major source of phosphorus loading to the lake.

The solution

Unfortunately, early attempts to reduce the phosphorus load into the lake were confounded by lack of funding and feasible options. With mounting concerns regarding the toxic blooms, the county was able to secure funding to conduct an intensive lake study which was used to develop the Lake Ketchum Algae Control Plan (Snohomish County, 2012). The primary goal of the Plan was to reduce frequent harmful algae blooms caused by excessive phosphorus pollution.

The plan included a water and nutrient budget showing that the internal loading, or recycling of the phosphorus from the lake sediments, accounted for 73 percent of the annual phosphorus inputs.

While the TP from the stream had decreased substantially (1,500 ug/L in 1994/1995 to 646 µg/L in 2010-2011) the inlet was still contributing 24 percent of the total annual phosphorus load to the lake. Around 2 percent was coming from runoff from the homes around the lake with minor amounts coming from precipitation and groundwater.

The data were used to develop a phosphorus model for the lake, from which multiple restoration options were modeled to determine their impact to the lake. Solutions included treating the toxic algae itself, several lake aeration options and whole-lake and continuous injection of phosphorus inactivation products. Using the model results coupled with preliminary cost estimates, the community decided on a final action plan that included five main elements as follows:

- **Large-scale aluminum sulfate (alum) treatment** to inactivate the legacy phosphorus in the lake sediments. An initial treatment was planned to inactivate the upper lake sediments with a potential follow-up treatment in year 6 for deeper sediments.
- **Small annual alum treatments** to neutralize the large inflow of phosphorus from the lake inlet or other sources plus any additional phosphorus released from the lake sediments each year.
- **Wetland protection** to ensure wetlands near the lake inlet are preserved as they are instrumental in removing some phosphorus from the farm field and may also be a source of legacy pollution if disturbed.
- **Reduce phosphorus from lake residents** by encouraging landowners to make changes in lawn and yard care, septic system care and shoreline management via the county's LakeWise outreach program (www.lakewise.org).
- **Monitoring & adaptive management** to provide the necessary information to assess the efficacy of the plan as well as to adaptively manage the annual dosing of alum treatments.

It should be noted that there were also significant prior efforts to make improvements on the farm to prevent further pollution. In the 1990s the farm ceased application of animal waste and converted the field from cattle to hay production. The farm soil remained contaminated, yet the landowner was unwilling to take any further action, precluding additional watershed management options from being included in the plan.

Implementing the plan

Following the completion of the Lake Ketchum Algae Control Plan, the community and county worked for two years to obtain funding which was ultimately comprised of a state toxic algae grant, direct county contributions and an annual fee imposed on the lake community by the county (per the community's request), to pay for implementation of management alternatives.

In 2014, implementation kicked off with a large-scale whole-lake alum treatment. The initial alum dose was calculated to remove phosphorus from the water column and inactivate the majority of the phosphorus stored in the top 10 cm of lake sediments (Brattebo et al., 2017). In May 2014, contractors applied over 13,400 gallons of liquid alum and 7,400 gallons of sodium aluminate (buffer). Unfortunately, the application methodology used caused short-term impacts to lake pH and the treatment was not fully completed.

A second large-scale alum treatment was completed in March 2015 with revised application methodology which improved the mixing of alum and sodium aluminate to prevent pH impacts. In March 2015, another 13,000 gallons of alum and 8,100 gallons of sodium aluminate were applied to the lake. The 2015 large-scale treatment was completed with no impacts to lake pH or fish health.

The planned small annual alum treatments began in 2016 and are conducted each year with doses varying slightly based on the winter precipitation and budget limitations (Table 1). Overall, 50,734 gallons of alum and 29,390 gallons of sodium aluminate have been applied to the lake through 2023. Note that the 2020 annual alum treatment was delayed until the second week in May due to the COVID-19 pandemic.

The community has strongly supported implementation of the Algae Control Plan and have taken on additional efforts to improve the lake, especially through strong participation in the LakeWise program. The community has contributed countless hours to volunteer lake monitoring and residents have also worked to ensure the wetlands remain protected.

Water quality improvements

The first large alum treatments in 2014 and 2015 exceeded expectations at both reducing phosphorus in the water column and preventing internal phosphorus loading. The plan goal was to

Table 1. Aluminum dose and quantities of aluminum sulfate and sodium aluminate applied to Lake Ketchum from 2014-2021.

Year	Date	Dose (mg Al/L)	Alum Applied	Buffer Applied
2014	5/21/2014	19.5	13,484	7,415
2015	3/4/2015	20.4	13,000	8,118
2016	4/27/2016	4.4	2,900	1,705
2017	4/26/2017	6.1	4,050	2,380
2018	4/25/2018	4.4	3,000	1,800
2019	4/10/2019	4.4	3,000	1,800
2020	5/7/2020	4.4	3,000	1,800
2021	4/9/2021	4.4	3,191	1,572
2022	3/30/2022	3.14	2,629	1,430
2023	3/21/2023	3.0	2,480	1,370

reduce summer (Jun-Sept) TP concentrations in the epilimnion to 40 µg/L or less. The summer average TP in surface waters decreased from 80 µg/L in 2013 to 11 µg/L in 2015 and has stayed consistently low, well exceeding the plan goal (Figure 3).

In 2014, sediment phosphorus release was essentially eliminated following the alum treatment, decreasing from an average rate of near 25 mg/m^2 per day to zero (negative rates). Summer hypolimnetic average total phosphorus decreased from 1,844 µg/L in 2013, to 158 µg/L in 2014, to 14 µg/L 2015 (Figure 4). Since then, total phosphorus in the bottom waters remains low indicating that internal loading of phosphorus has been largely eliminated.

The primary goal of the Algae Control Plan was to reduce the frequency and duration of potentially toxic algae blooms. Chlorophyll concentrations did not dramatically improve, as was the case for TP, following the first alum treatment in 2014. Summer average chlorophyll in the epilimnion in 2014 was 55 µg/L, driven by a heavy bloom in June. However, starting in 2015 summer average chlorophyll concentrations fell to 12 µg/L and have largely remained low (Figure5).

Most importantly, toxic algal blooms have been virtually eliminated in Lake Ketchum since implementation of the plan began. There have not been any blooms with toxins exceeding the state's recreational guideline since the start of the annual small alum treatments in 2016. There has only been one posting of the lake which occurred in May 2020, but the bloom did not have high toxins associated with it. The bloom likely occurred as a result of the alum treatment being delayed due to the Covid-19 pandemic. It quickly dissipated after the treatment was conducted.

Water clarity improved slightly following the 2014 treatment to a summer mean of 2.1 m (Figure 6). After the second alum treatment in 2015, water clarity almost doubled to a summer mean of 4.0 m, with the Secchi disk sometimes reaching the lake bottom. Increased water clarity often follows alum applications, however, the increase in summer water clarity was mostly due to the overall decrease in algae in the water column.

Overall, long-term results show that implementation of the Algae Control Plan is meeting and exceeding the plan goals. Phosphorus concentrations have dramatically decreased leading to substantial reductions in algal growth, significantly clearer water and even improved dissolved oxygen. Most importantly, toxic algal blooms have been virtually eliminated. The treatment approach at Lake Ketchum has shown that the successful inactivation of sediment

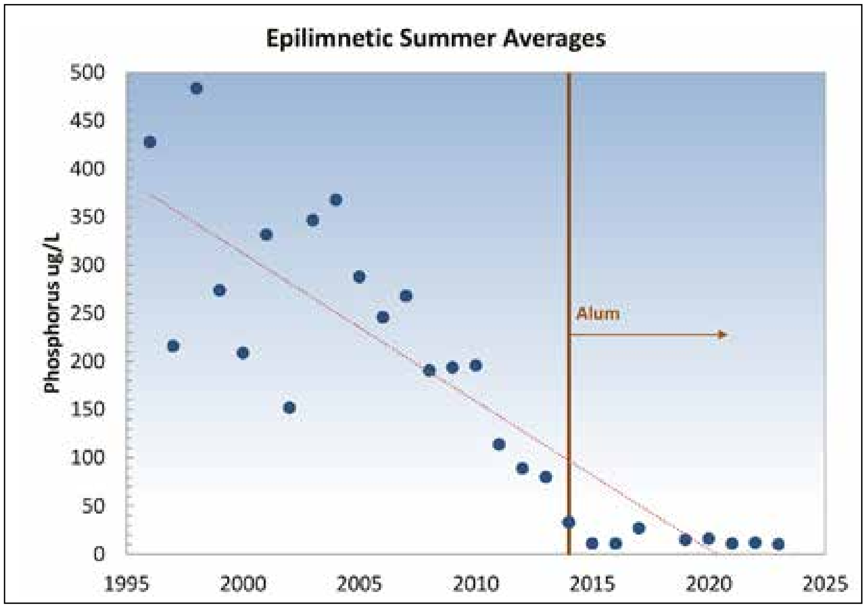

Figure 3. Lake Ketchum epilimnetic summer average TP, 1996-2023.

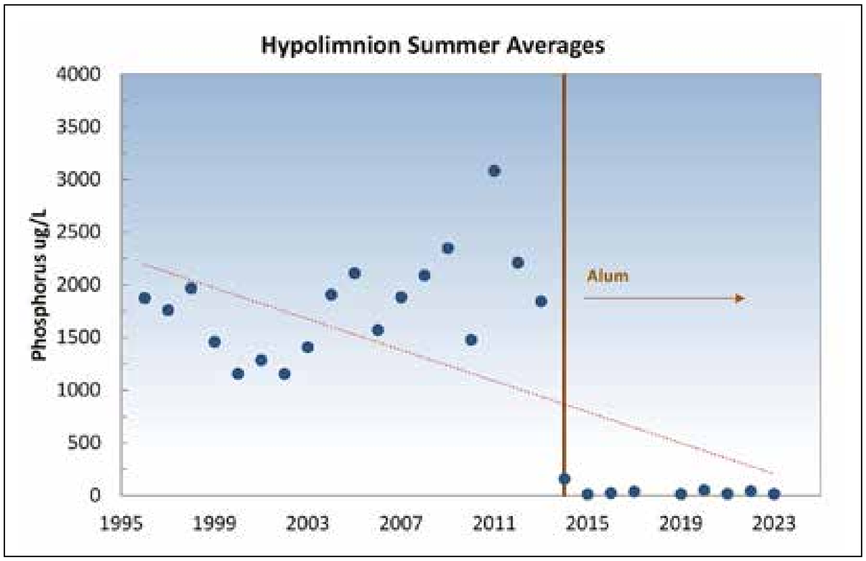

Figure 4. Lake Ketchum hypolimnetic summer average TP, 1996-2023.

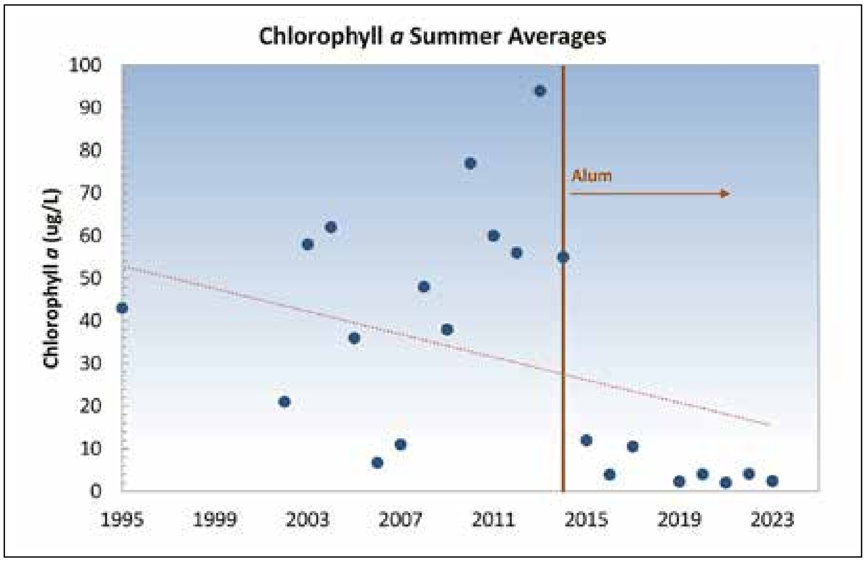

Figure 5. Lake Ketchum summer average chlorophyll, 1994-2023.

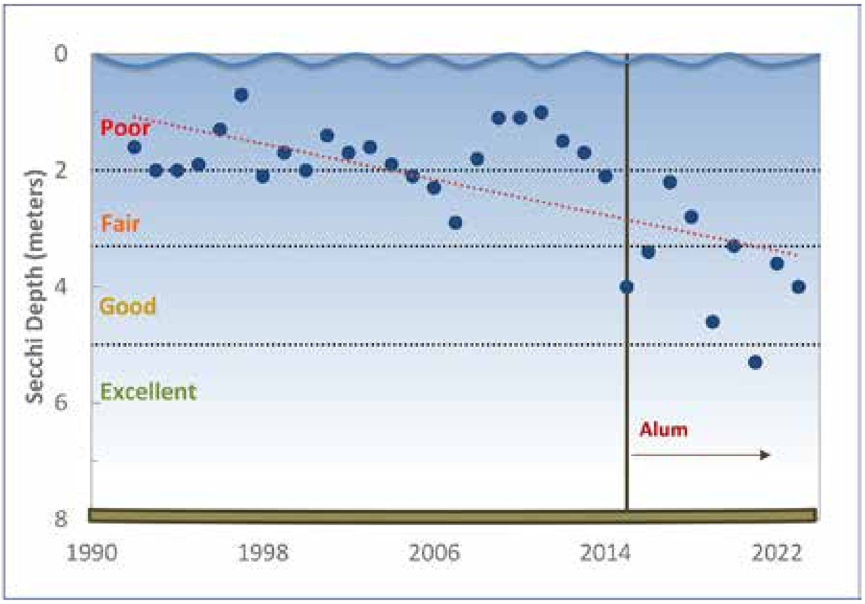

Figure 6. Lake Ketchum summer average water clarity, 1992-2023.

phosphorus using alum is both safe and effective.

Ecological improvements

Not only have toxic algae blooms disappeared from Lake Ketchum, but the overall food web dynamics of the lake have dramatically changed (Snohomish County 2024). Cyanobacteria are just one of several types of phytoplankton that form the base of the lake food chain. Compared to other phytoplankton species, cyanobacteria are largely inedible to zooplankton. Healthy zooplankton are important as they are the tiny animals consumed by fish and other aquatic organisms.

Since the alum treatments began, there has been a substantial reduction in cyanobacteria and a shift towards more desirable algal species (Snohomish County, 2024). The June to October average cell counts of cyanobacteria plunged from 25,547 cells/mL pre-treatment to 5,889 cells/mL in the first three years following treatment (Figure 7). In that same period phytoplankton diversity increased with the unique number of genera identified increasing from an average of 34.2 genera pre-treatment to 46.3 post-treatment. Overall, the phytoplankton community is more diverse with higher levels of desirable algae such as diatoms and green algae.

Changes in phytoplankton corresponded to a change in the zooplankton structure in the lake as well (Snohomish County 2024). While the pre-treatment data are limited to 2012-2013 for zooplankton, the lake was largely dominated by rotifers which rely heavily on organic particles and bacteria. Post-treatment the dominant zooplankton organisms transitioned to phytoplankton-grazers including copepods and cladocerans, which provide an important food source for fish.

Not only have restoration efforts improved the microscopic ecosystem, but also the lake's macrophyte community. Prior to the restoration efforts, the lake was a heavily algal dominated system with such heavy blooms that light was restricted, preventing the growth of most submergent aquatic plants. The state conducted a survey in 2010 and found only one small patch of rooted aquatic plants in the entire lake (https://apps.ecology.wa.gov/lakes). Even macroalgae such as Chara were absent. A follow up survey in 2019 showed the plant community had begun to rebound with four species of submergent plants found throughout the lake (Figure 8).

Unfortunately, there was not a pre-treatment survey to understand the impacts of the alum treatments on the fish community. However, not only has the zooplankton community improved, but summer dissolved oxygen conditions throughout the lake are more favorable for fish. Prior to alum treatments, much of the lake water column (any waters deeper

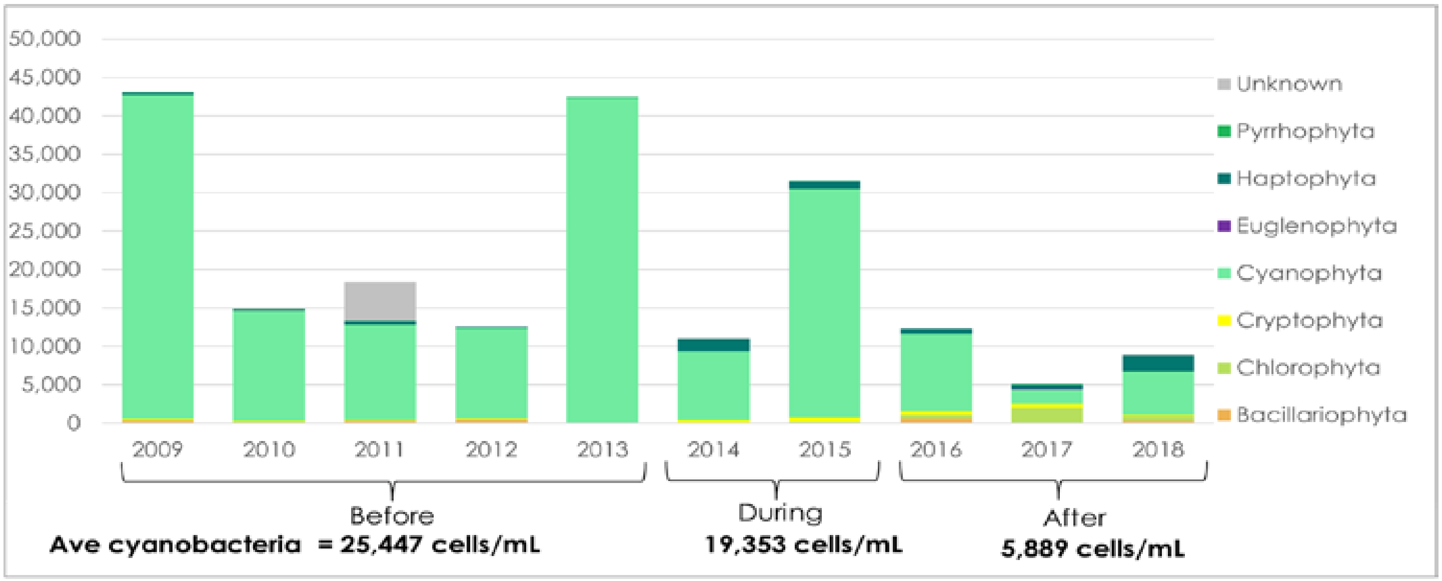

Figure 7. Lake Ketchum phytoplankton average annual cell count by algal group, 2009-2018 (June-October).

than 3 m) had very low dissolved oxygen concentrations and at times were completely anoxic. Much more telling is the happiness of anglers, which has certainly improved with the lack of constant toxic algae warnings.

Overall, the substantial changes in lake health have once again allowed residents and lake users to enjoy the lake for swimming, fishing, and boating throughout the summer. The lake community has significantly invested in this restoration program, both in time and direct financial contributions, and are seeing returns in their ability to enjoy the lake, increased property values and a closer lake community (Figure 9).

Future outlook and next steps

Despite the success of the Lake Ketchum restoration program, the work is not yet done. The inlet TP concentrations remain high causing annual winter spikes in lake phosphorus. Left untreated, the additional phosphorus each year is substantial enough to support frequent summer algal blooms as demonstrated in 2020 when the treatment was delayed. Without the annual alum treatments, it can be assumed that the chlorophyll concentrations in the lake would increase over the summer and there would be large, potentially toxic, blooms of cyanobacteria.

So, for now, the small annual alum treatments will continue into the foreseeable future. Someday, inlet concentrations may decrease enough to reduce the frequency or lower the dose of the annual treatments. A new landowner of the farm may also bring about future opportunities to work directly with the contaminated soils to reduce total phosphorus loading to the stream. In the meantime, there will be an ongoing financial commitment for the community, yet it is a comparatively small price to pay for a healthy toxin-free lake.

To learn more about the project visit https://snohomishcountywa.gov/2451/.

Figure 8. Resurgence of native aquatic plants following implementation of Algae Control Plan.

Figure 9. Lake Ketchum after implementation of Algae Control Plan.

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Washington State Toxic Algae Database. Washington State Department of Ecology (www.nwtoxicalgae.org)

Shannon Brattebo has been an environmental engineer and limnologist for Tetra Tech, Inc. in Washington State since 1999. Shannon's work has focused on lake and reservoir water quality, restoration, and management both in the Pacific Northwest and across the nation. Shannon has B.S. in Civil/ Environmental Engineering from Seattle University and an M.S.C.E in Civil/Environmental Engineering from the University of Washington. Shannon has been a member of NALMS since 2001 and is a current board member and past secretary of the Washington Lakes Protection Association (WALPA). Shannon is the current Treasurer of NALMS and was also a past Region 10 NALMS Director (2015 – 2018).

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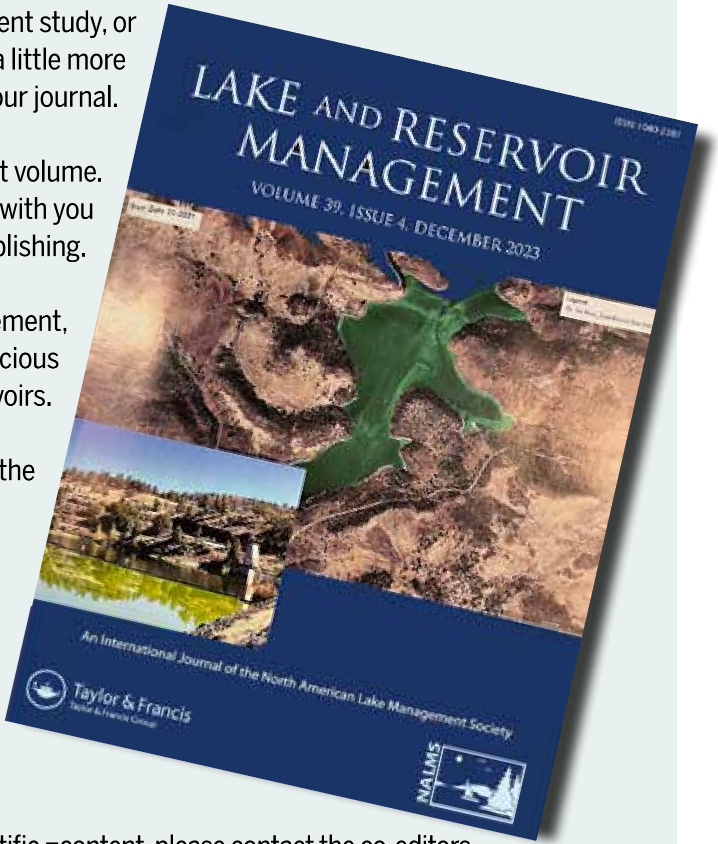

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