Restoring Water Quality in Bald Eagle Lake, Minnesota

Joe Bischoff, Matt Kocian, Brian Beck, and William F. James

Using adaptive watershed and lake management

Introduction

Lake restoration can be a frustrating endeavor, with managers and stakeholders spending countless hours and millions of dollars often achieving only small, incremental changes in their lake's water quality. Because of the often-undetectable changes in water quality during the restoration process, stakeholders routinely ask for examples of successful lake restorations to ensure they are on the right path. The restoration of Bald Eagle Lake is a success story where the perseverance and dedication of the Rice Creek Watershed District (RCWD), the Bald Eagle Area Association (BEAA), and local stakeholders paid off in immediate and significant improvements in water quality and lake ecology. The path to restoration for Bald Eagle Lake was not without its trials and tribulations, including high restoration costs and difficult decision points throughout the process. Some of the challenges included determining when watershed phosphorus load reduction opportunities were exhausted, deciding on the appropriate time to turn to in-lake management, and practicing patience, waiting to see results after spending millions of hard-earned dollars in restoration costs. The path to success required strong stakeholder support, a dedicated project sponsor, and innovative technical leadership to reach aggressive restoration goals. Years of hard work and dedication culminated in one of the premiere lake restoration success stories in the Twin Cities Metropolitan Area (TCMA).

Background

Bald Eagle Lake is a 1,071-acre recreational lake located in the northeast portion of the TCMA, about 10 miles north of the City of St. Paul (Figure 1). While Bald Eagle Lake is relatively deep with a maximum depth of 39 feet, over 60 percent of the lake area is littoral, expected to support significant aquatic vegetation. The lake is a key regional resource and is heavily used for open water and ice fishing, swimming, and boating. The lake is routinely stocked with walleye and muskellunge, making the lake a popular fishing destination in the TCMA.

Bald Eagle Lake and its 10,835-acre watershed reside in a rapidly developing part of the TCMA with approximately 37 percent of the watershed currently a mixture of residential and commercial developments. The remaining land use is a mix of low intensity agriculture and undeveloped land. Bald Eagle Lake has three primary drainage inputs including Judicial Ditch 1 (JD1), County Ditch 11 (CD11), and direct drainage through numerous stormwater pipes surrounding the lake. Both JD1 and CD11 drain large, hydrologically altered wetland complexes prior to discharging to the lake. CD11 also receives stormwater from downtown White Bear Lake, Minnesota.

Prior to restoration, Bald Eagle Lake had poor water quality dating back to the 1980s, with summer average total phosphorus (TP) concentrations around 72 µg/L. The lake was very productive during this period with chlorophyll-*a* concentrations averaging 29 µg/L. Late season cyanobacteria (blue-green algae) blooms were common in Bald Eagle Lake. Water clarity was relatively poor with a summer average Secchi depth around 1.4 meters.

Restoration planning and implementation

Being one of the premier recreational lakes in the northern TCMA, Bald Eagle Lake has long been a focus for management efforts by local stakeholders. In 1991, a Clean Water Partnership grant was used to evaluate the lake's phosphorus budget, which identified JD1 as a primary source of TP to Bald Eagle Lake. RCWD relied on these study results to pursue watershed and wetland restorations to reduce TP loading from JD1.

As RCWD and BEAA pursued watershed phosphorus load reduction projects, questions remained regarding the role of internal phosphorus loading in the lake's phosphorus budget. "Internal phosphorus loading" is a term used to describe phosphorus movement from lake sediment to the water column. Internal loading is primarily caused by the release of phosphorus from sediments under low oxygen (anaerobic) conditions. In Minnesota lakes, sediment phosphorus release is typically controlled by the reduction of iron during these anaerobic conditions, releasing mobile phosphorus into the porewater. Since anaerobic conditions regularly occur in Bald Eagle Lake during summer stratification, this process was expected to contribute phosphorus to Bald Eagle Lake. Rooted aquatic plants are also thought to translocate phosphorus from sediments during their growth phase releasing soluble phosphorus into overlying water during dieback. This process can be especially problematic with curly-leaf pondweed where senescence occurs in

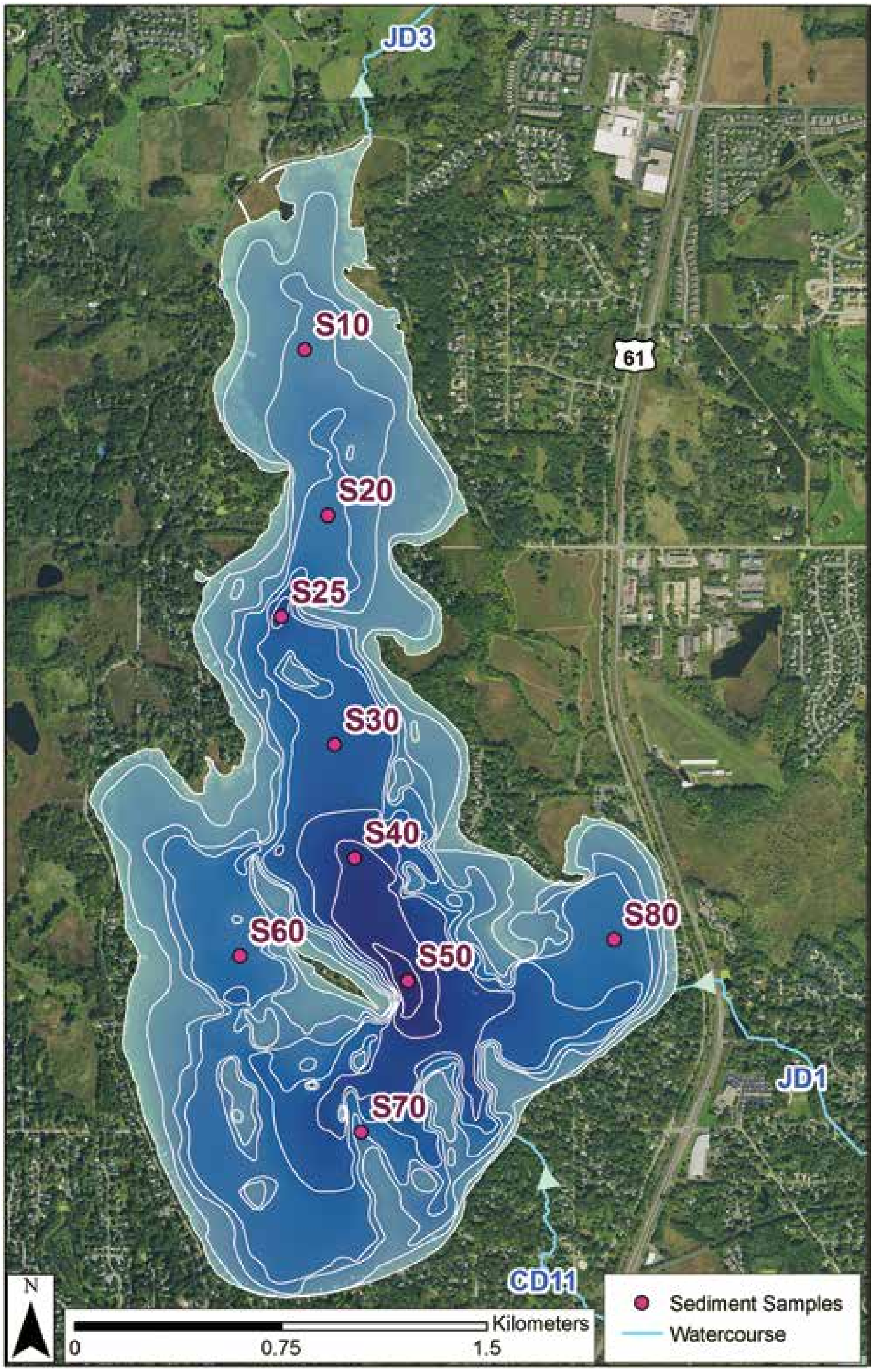

Figure 1. Bald Eagle Lake including sediment sampling sites.

the middle of the growing season. Finally, benthic feeding fish can cause internal loading by disturbing the sediments during feeding activities. These processes needed further investigation in order to guide critical in-lake management actions for Bald Eagle Lake.

Recognizing that internal loading may be an important source to the lake, RCWD pursued several phosphorus budget updates to quantify Bald Eagle Lake's internal load. In 1998, the nutrient budget was updated using literature values for sediment phosphorus release and general assumptions regarding the temporal and spatial extent of anaerobic conditions in the lake (Figure 2). The phosphorus budget was again updated in 2003, this time dividing the load between sediment phosphorus release, resuspension from carp, and phosphorus release from curly-leaf pondweed dieback that occurs in midsummer. It is important to note that the authors of that plan recognized the high level of uncertainty in those divisions. Finally, in 2007, RCWD decided to collect sediment cores from the deep area of the lake and measure sediment phosphorus release under anaerobic conditions as a part of a TMDL study. Results of the TMDL confirmed the role of internal loading in Bald Eagle Lake and solidified RCWD's desire to pursue an internal load control project while still addressing the watershed on an opportunistic basis.

Moving from the watershed and into the lake

As RCWD pursued watershed phosphorus load reduction projects and curly-leaf pondweed management, local stakeholders began to get frustrated with the lack of progress made in reducing TP concentrations in Bald Eagle Lake (Figure 3). Several high-priority watershed projects were already completed, including a large stormwater reuse project on a golf course, 10 neighborhood raingardens, and 6 shoreline stabilization projects with total costs exceeding $1,000,000. Stakeholders were concerned that future watershed practices would take a long time to implement. The District also continued its efforts to control curly-leaf pondweed in the hopes of decreasing TP concentrations in the lake, spending over $600,000 in targeted harvesting and herbicide applications. Recognizing that the return-on-investment for lower-priority watershed projects would not be favorable and that curly-leaf pondweed management was having minimal effect on TP concentrations, RCWD and BEAA decided to turn their focus to internal loading, specifically sediment phosphorus release.

To control sediment phosphorus release in Bald Eagle Lake, RCWD pursued an aluminum sulfate (alum) treatment to permanently bind mobile sediment phosphorus. Alum is applied to lakes as a liquid subsequently forming aluminum hydroxide, a solid precipitate that settles to lake sediments. Aluminum hydroxide attracts and permanently binds

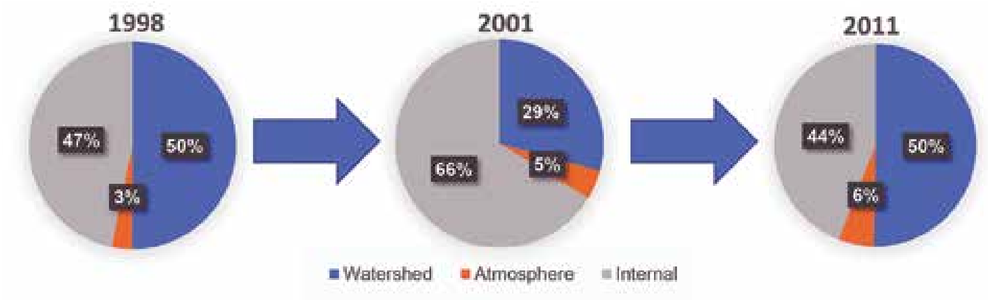

Figure 2. Evolution of the phosphorus budget for Bald Eagle Lake showing various attempts to quantify internal phosphorus loading. The 2011 budget included laboratory measurements of anaerobic sediment phosphorus release.

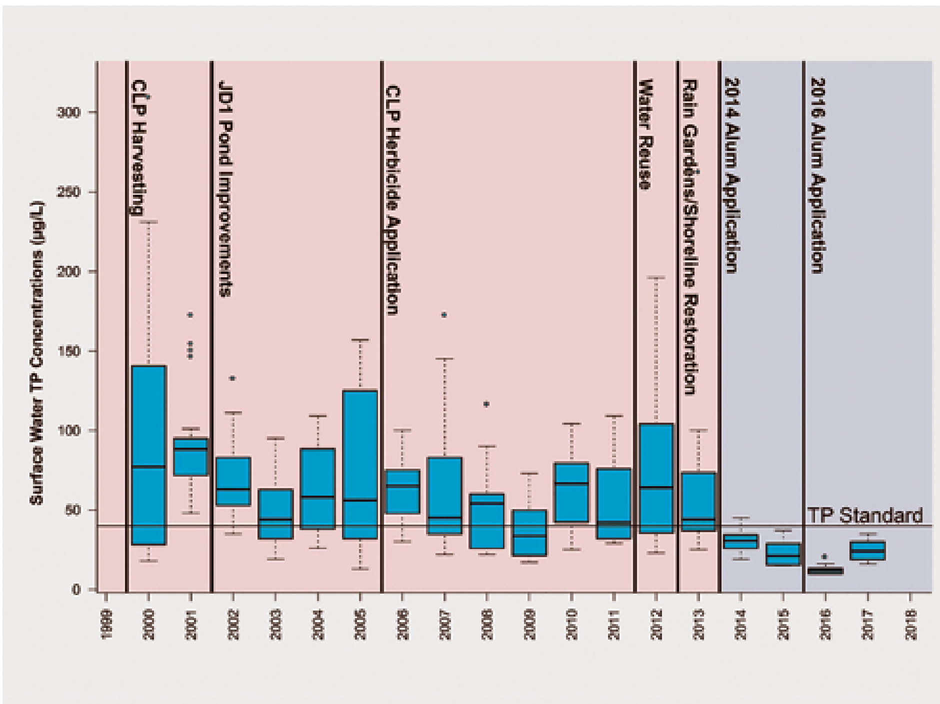

Figure 3. Epilimnetic total phosphorus concentrations during various stages of restoration of Bald Eagle Lake.

sediment phosphorus removing it from the internal phosphorus loading cycle. However, some questions remained regarding when to pursue an alum treatment, what it would cost, and whether it would be effective for the long term.

Alum Dose and Cost Determination

To estimate costs and evaluate the long-term effectiveness of an alum treatment, sediment cores were collected from eight sites in the lake to measure phosphorus that is mobile under anaerobic conditions (redox-P) to develop an alum dose for the lake (Figure 1). Sediments from each site were exposed to increasingly higher doses of alum in the laboratory until the measured mobile P (redox-P) was converted to aluminum-bound P (James 2011; James and Bischoff 2015). Two treatment zones were identified, prescribing 100 g Al/m^2 in areas greater than 15 feet deep and 50 g Al/m^2 in shallow areas demonstrating high mobile P in the sediment. This dose targeted a reduction in mobile phosphorus in the top 6 centimeters of sediments to control sediment phosphorus release. The cost for completing the alum treatment was estimated at just under $900,000.

Cost Effectiveness

Prior to investing in the alum treatment for Bald Eagle Lake, in-lake costs were compared to the cost of further watershed TP load reductions for other restoration projects in the TCMA. The 30-year life cycle cost for several types of watershed practices completed in the TCMA was compared to the cost of an alum treatment on a per pound of TP removal basis (Figure 4). Diffuse watershed practices such as rain gardens were the most expensive since they had relatively low impact on phosphorus loading. As practices increased in size and adopted the use of adsorption media such as iron enhanced sand filters, cost efficiencies increased significantly. The five alum projects reviewed for this comparison were by far the most cost-effective projects even though initial costs can be daunting. This analysis allayed the fears of spending such a large sum of money on the alum treatment as compared to spending more money on watershed practices.

Alum Longevity

As the District considered an alum treatment, there was a general concern from regulators that if watershed phosphorus loading wasn't sufficiently reduced, the alum treatment would get buried by new phosphorus, limiting the long-term effectiveness of the project. To address this concern, phosphorus sedimentation was estimated from the TMDL lake response model to estimate the amount of time expected to replace inactivated sediment phosphorus. Using this approach, it was estimated that without any reductions in watershed loading, the alum treatment could last as long as 22 years (Figure 5). An additional 25 to 75 percent reduction in watershed phosphorus loading could extend the life of the alum treatment between 7 and 40 years. The District had already achieved some reductions in watershed phosphorus loading suggesting the project would last longer than the typical 30-year life span of a watershed BMP at a lower cost per pound removed.

Adaptive alum application

Recent research and experience suggested that application of the entire alum dose at one time might not achieve established sediment targets. Furthermore, recent studies suggested that the alum could settle on top of the denser sediment surface instead of mixing into the sediment, limiting reaction between the alum and mobile phosphorus (James 2017). We used an adaptive application

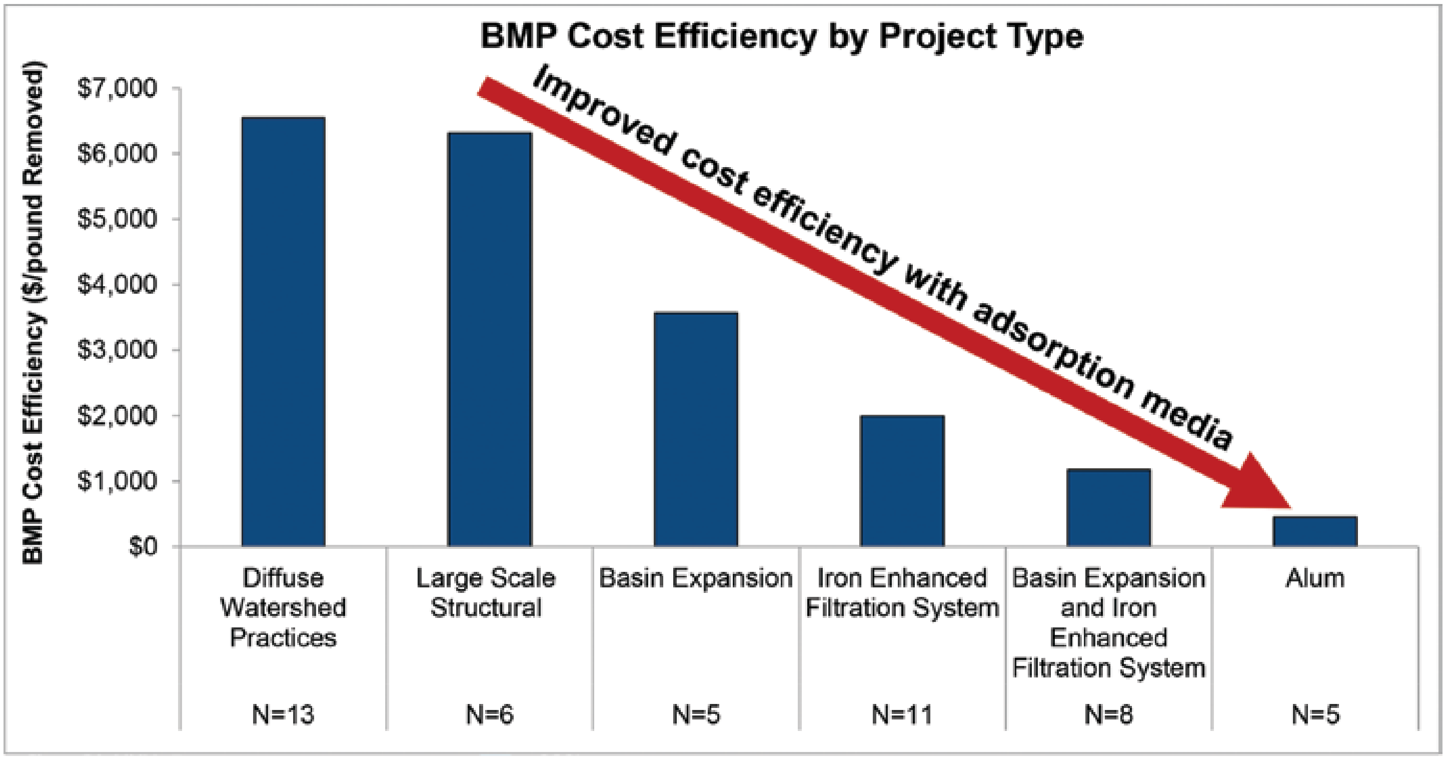

Figure 4. Project cost and phosphorus removal efficiency for watershed and in-lake Best Management Practices.

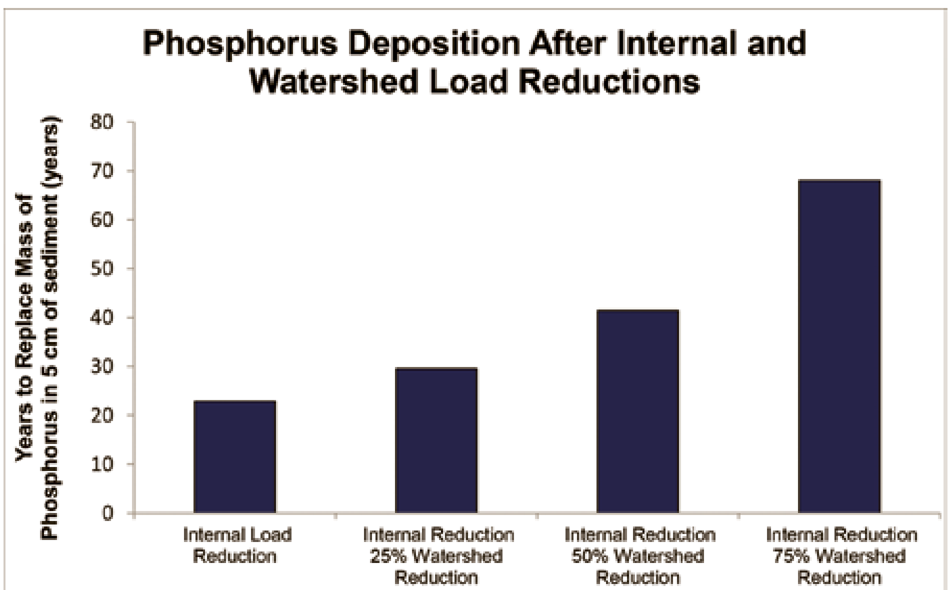

Figure 5. Estimates of the number of years it will take to replace mobile phosphorus inactivated through phosphorus deposition using the Canfield-Bachmann model. Estimates included lower sedimentation rates as watershed phosphorus loading is reduced.

approach, where the dose was split between two years, 2014 and 2016, with sediment monitoring one year following application of the initial half dose (Figure 6). The purpose of the split dose was to increase the reaction time of the alum with mobile phosphorus and to allow for application adjustments between the alum applications.

Half of the prescribed alum dose was applied in 2014 by HAB Aquatic Solutions using precise application software to ensure target doses were applied appropriately (Figures 7 and 8). Sediment cores were collected from 4 sites in 2015 to measure progress toward achieving sediment targets. Anaerobic sediment phosphorus release prior to the alum treatment ranged between 2 and 12.5 mg/m^2/day with the highest rates found in the deepest area of the lake (Figure 9). Following application of the initial half dose, anaerobic sediment phosphorus release was reduced between 12 and 91 percent with the greatest reductions occurring in the shallow areas of the lake. Phosphorus release in the deepest area of the lake where release rates were the highest, showed only a 12-percent reduction in phosphorus release. Wind and drift during application might have moved the aluminum floc out of this region during deposition even though records showed that the applicator had gone over this area and applied at the prescribed rates. Since release rates were reduced greater than expected in the shallow areas and less than expected in the deeper area, the application areas were adjusted to apply more alum in the deeper areas of the lake in 2016 (Figure 7). Some of the shallower areas that achieved their goals did not receive a second dose, while the alum dose for the deep area of Bald Eagle Lake was doubled to ensure mobile phosphorus immobilization in the targeted area.

The second alum application occurred in 2016 using the adjusted application areas and aluminum concentrations with

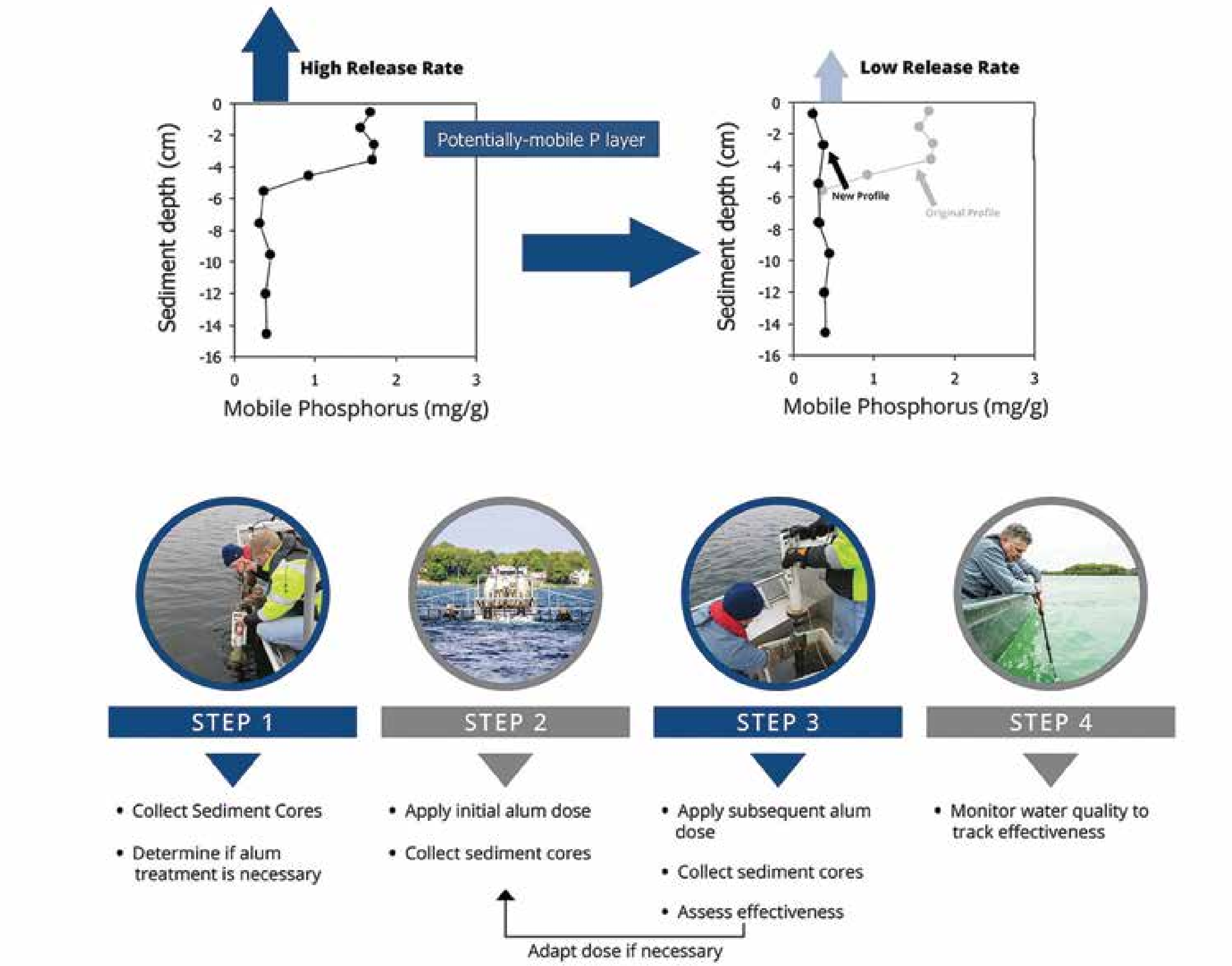

Figure 6. The adaptive alum application approach used in Bald Eagle Lake.

the continued goal of reducing sediment phosphorus release. Sediment cores were collected in 2017 and measured for anaerobic sediment phosphorus release. Release rates were reduced at all sites between 86 and 99 percent with the deep site (Station S50) demonstrating almost no phosphorus release (Figure 9). The reallocation of alum to target areas where sediment phosphorus release reductions were less than expected was a success. All of the sites had minimal sediment phosphorus release and essentially met the established goal of controlling sediment phosphorus release (Figure 9).

Water quality and vegetation response

Water Quality Response

Bald Eagle Lake responded to the alum applications extremely well and is now meeting Minnesota's deep lake eutrophication standard of 40 µg/L summer average total phosphorus for the first time in over 30 years (Figure 3). Epilimnetic total phosphorus concentrations were significantly reduced in Bald Eagle Lake following the initial alum application in Spring 2014, with summer average concentrations dropping from a long-term summer average of 73 µg/L to 25 µg/L. Maximum hypolimnetic phosphorus concentrations were reduced from a pre-alum average of 150 µg/L to 64 µg/L after the treatment, demonstrating that internal loading was significantly reduced. Average summer chlorophyll-a concentrations dropped from a long-term average of 31 µg/L to 9 µg/L and Secchi depth improved from a long-term average of 1.4 meters to 2.3 meters.

Changes in aquatic vegetation

Prior to the improvements in water clarity, annual aquatic plant surveys indicated limited species richness even with successful curly-leaf pondweed management, which reduced the distribution and density of the invasive species in Bald Eagle Lake. Herbicide treatments in the mid-2000s targeted 80-100+ acres while recent target areas (2014 to 2017) were reduced to 20-40 acres. Stem density within the treatment areas declined from about 600 stems/m^2 in 2003 to about 10 stems/m^2 in 2015. Floristic Quality Index (FQI) scores (Nichols 1999) for the vegetation community remained poor with the vegetation community dominated by invasive and tolerant species indicative of poor water quality (e.g. curly-leaf pondweed, coontail).

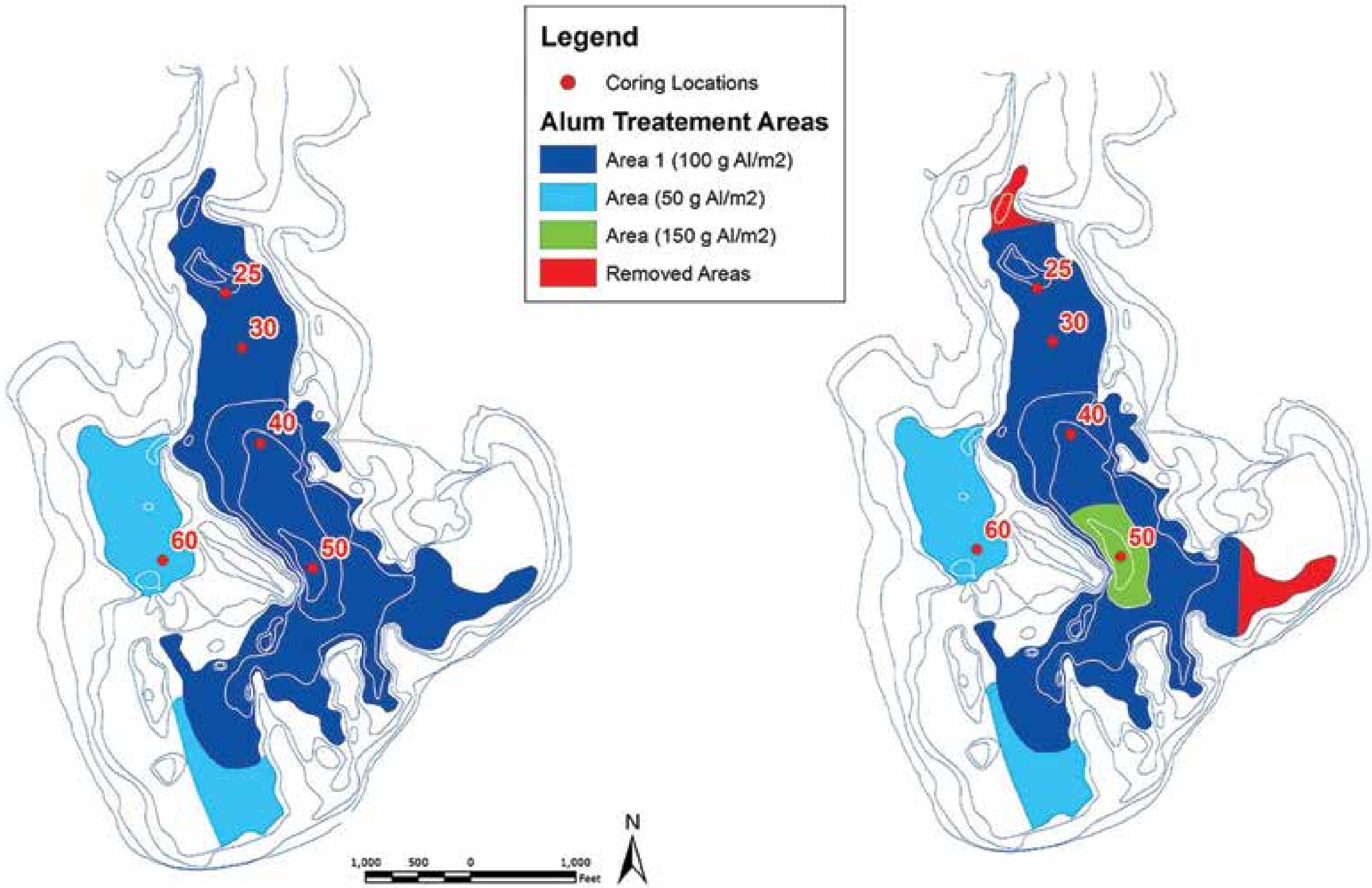

Figure 7. Alum application areas and rates used in the initial half dose applied in spring of 2014 and the adjusted half dose applied in spring of 2016.

Figure 8. HAB Aquatic Solutions' alum application vessel used to precisely apply alum to Bald Eagle Lake at the prescribed alum dose.

While the decline in curly-leaf pondweed did not improve lake water quality or species diversity, it did create an opportunity for increased growth of native plants following the alum treatment. Following the increase in water clarity, aquatic vegetation species richness improved from an average of about 16 species per plant survey to nearly 20. FQI scores increased from an average of 21, which was below the median score for Bald Eagle's ecoregion (Radomski and Perleberg 2012), to nearly 25, which is in the upper 3rd quartile for the ecoregion (Figure 10). Additionally, the spatial extent of higher species richness improved with more native taxa being found per sample point (Figure 11). Overall, the changes in aquatic plant communities indicate improvement in the overall health of the ecosystem.

Long-term management

While the alum treatment was successful in restoring water quality

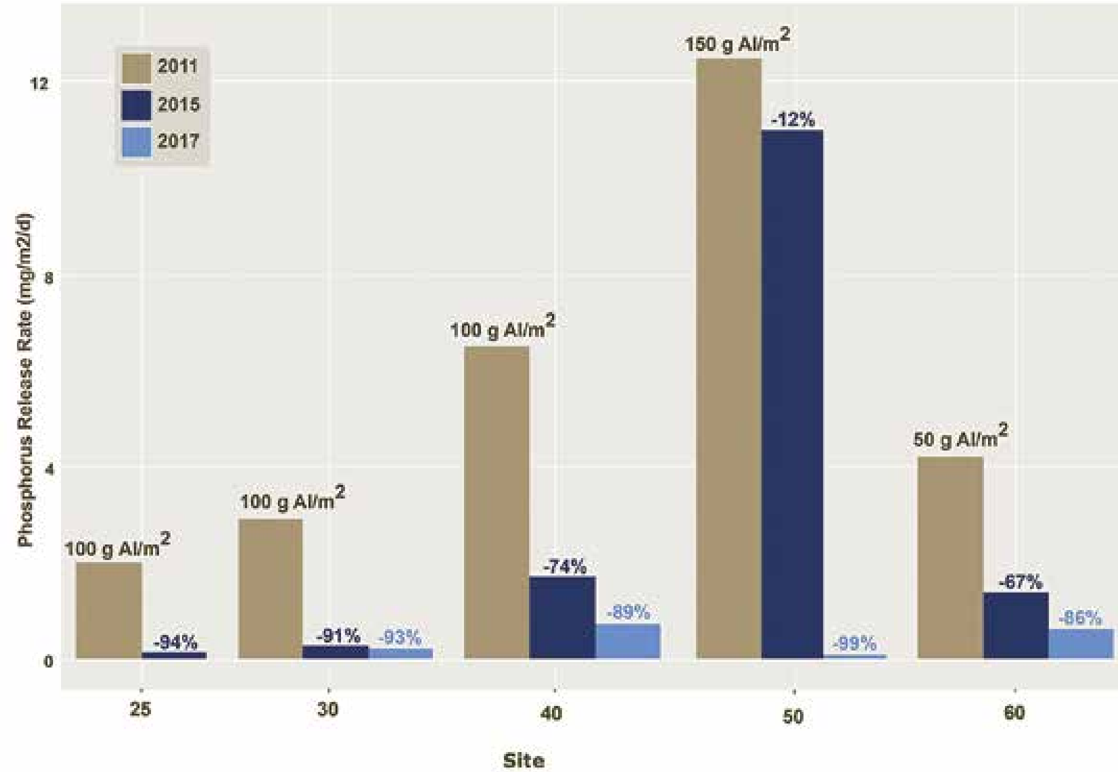

Figure 9. Laboratory measurements of anaerobic sediment phosphorus release rates (n=3) for monitoring sites prior to the alum treatment, following the initial alum application, and after the final alum application. Final alum doses (g-Al/m²) are included for reference.

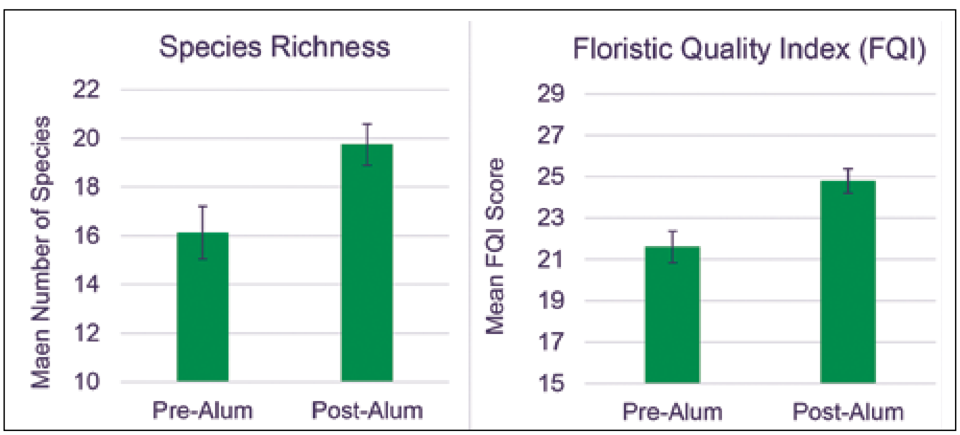

Figure 10. Mean species richness and Floristic Quality Index scores for Bald Eagle Lake before and after the alum treatment. Error bars indicate standard error. Pre-alum, n = 17 years; post-alum, n = 4 years.

in Bald Eagle Lake, several challenges remain to protect water quality for the long term. The primary tributary to Bald Eagle Lake flows through a large wetland complex, Schuneman Marsh, that has demonstrated periodic release of soluble phosphorus that can bypass settling ponds and cause algal blooms in the lake. Several urban subwatersheds still contribute untreated stormwater with high phosphorus concentrations. RCWD continues to work with the BEAA and other local partners to implement large-scale stormwater retrofit projects and small-scale stormwater treatment systems (i.e., raingardens). Continuing to decrease external phosphorus loads protects the investment in alum by increasing its longevity (Figure 5).

Acknowledgements

The authors wish to acknowledge Steve McComas, of Blue Water Science, for sharing aquatic plant survey data; Keegan Lund, April Londo, and Kylie Cattoor, of the Minnesota Department of Natural Resources, for sharing aquatic plant survey data; Terry Noonan, Louis Soukup, and John Manske, of Ramsey County Public Works, for providing water quality and phytoplankton data; Eric Macbeth, of the City of Eagan for providing project costs; and the Bald Eagle Area Association for providing critical local input and partial funding for the alum treatment.

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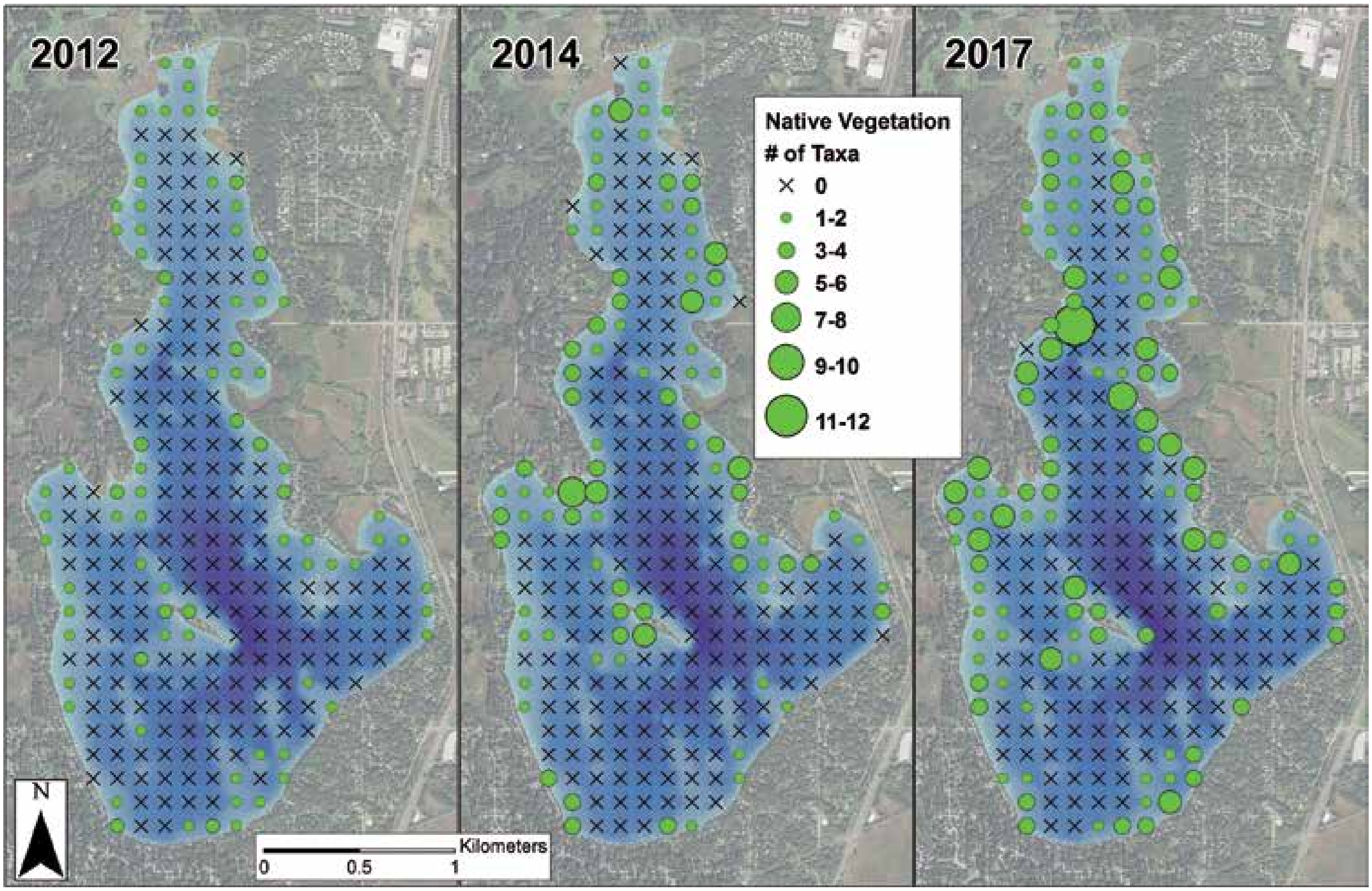
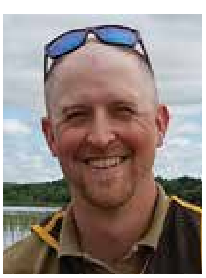


Figure 11. Spatial distribution and species richness of aquatic vegetation as the number of native taxa per sample point. Figure courtesy of Minnesota Department of Natural Resources.

Joe Bischoff is a principal limnologist with Wenck Associates, Inc. in Golden Valley, MN. Joe's work focuses on lake and reservoir restoration and management throughout the Upper Midwest. Specific areas of expertise include internal phosphorus loading, shallow lake restoration, and nutrient management. Joe is currently co-chair of the NALMS policy committee.



Matt Kocian is an aquatic ecologist for the Rice Creek Watershed District. He plans and implements a monitoring program to evaluate short- and long-term changes in aquatic ecosystems. He also manages lake and stream restoration projects.

Brian Beck is a geochemist with Wenck Associates in Golden Valley, MN. His work focuses on sediment geochemistry, water quality modeling, and contaminant fate and transport. Brian enjoys understanding how sediments impact water quality and developing innovative solutions to improve sediment quality.

William (Bill) F. James is a professor and research aquatic ecologist at the University of Wisconsin – Stout. His research interests are in lake and reservoir phosphorus cycling and eutrophication management. His career in limnology spans 38 years with over 50 peer-reviewed publications. He is also an associate editor for *Lake and Reservoir Management*.

Next Issue – Spring 2018: Dam Removal

Dam removal is becoming a more common event, and these projects are large, expensive and have many intended and unintended consequences.

This issue will explore various elements related to dam removal, including ecological, financial, technical, and regulatory aspects of such projects. Articles for this issue are due by February 15, with a publication timeline for late March.