AMENDMENT TO: Half Moon Lake Management Plan (2010)

25 January, 2017

Problem identification

Half Moon Lake and the surrounding Carson Park is an important recreational resource in the City of Eau Claire for swimming, fishing, and boating and provides critical aquatic habitat for waterfowl, song birds, fish, and native submersed and emergent vegetation (Figure 1). In recent decades, the lake has exhibited dense invasive curly-leaf pondweed growth that covers nearly the entire lake, recent invasion by Eurasian watermilfoil, and severe cyanobacterial blooms, necessitating the closure of the swimming beach. The lake was classified as hypereutrophic (trophic state index > 70; James et al. 2002) with mean summer total phosphorus concentrations > 100 µg/L and chlorophyll exceeding 300 µg/L. These patterns resulted in poor water transparency and low light penetration which limited native submersed macrophyte growth (James 2010). Anoxia developed in the bottom water of the lake throughout much of the summer, which exacerbated phosphorus flux from sediments and greatly increased the potential for algal uptake and growth.

Figure 1. Bathymetric map of Half Moon Lake, Eau Claire, WI

An extensive water quality, hydrological, and phosphorus budget analysis in 1999 targeted quantification of phosphorus loads to the lake for modeling evaluation of loading reduction scenarios to decrease phosphorus and algal biomass and increase water clarity for native submersed macrophyte re-establishment. Phosphorus inputs examined during the study were external sources from urban runoff and internal sources from leaching during curly-leaf pondweed senescence in June, flux of phosphorus from sediments, and resuspension of phosphorus from sediment during water skiing events. Many of these fluxes are not commonly quantified and incorporated into phosphorus budgets for evaluation.

The study found that external loading (i.e., storm, groundwater pumps, and direct precipitation) accounted for only 21% of the phosphorus budget to the lake (Figure

2). In contrast, internal sources originating from the sediment, curly-leaf pondweed (CLP) decomposition, and motor boat activity dominated phosphorus inputs and collectively represented 79% of the lake's phosphorus budget. Phosphorus flux from sediment represented most of the internal phosphorus load at 42%, while CLP decomposition and motor boat activity each accounted for ~ 20% of the internal input. Eutrophication modeling analysis projected that reduction of phosphorus sources from urban runoff, sediments, plants, and motor boat activity to the lake would result in a decrease in mean summer total phosphorus concentration from 109 µg/L to 38 µg/L, a decline in chlorophyll from

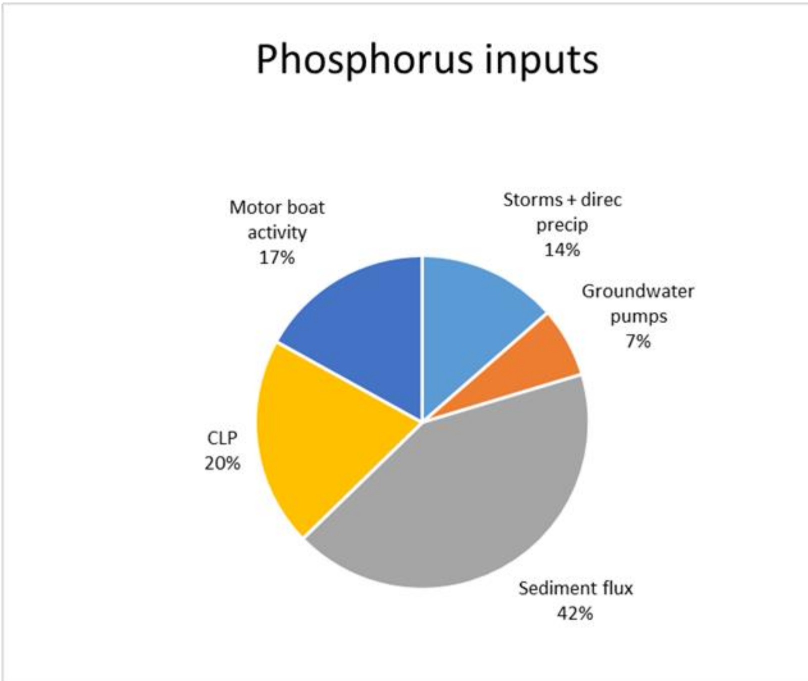

Figure 2. Summer phosphorus budget of Half Moon Lake (1999, James et al. 2002)

82 µg/L to 18 µg/L, and an increase in transparency from 1.1 m to 3.8 m.

Based on the eutrophication modeling projections, a robust phosphorus management plan was developed for implementation as outlined in the Half Moon Lake Implementation Taskforce (2010). This document outlined numerous recent efforts to improve WQ such as:

- CLP management
- Storm sewer diversion
- Construction of rain gardens and drainage swales to collected runoff from parking areas of Luther Hospital and the Lakeshore School area
- Gasoline-powered motorboat ban
- Conservancy zoning around the entire lake
- Fisheries survey and installation of aeration equipment
- TMDL development
- etc

The goals of these efforts have been to:

- Improve WQ (lower total P and chlorophyll and increase Secchi transparency)
- Reduce invasive aquatic plants (CLP and milfoil) and increase native plant biomass and diversity
- Improve fishery habitat
- Protect and improve shorelines
- Increase recreational opportunities (boating, fishing, swimming, hiking, bicycling)
- Reduce watershed runoff
- Minimize motor boat impacts
- Increase citizen awareness and education on the importance of Half Moon Lake as a natural resource to the City.

Urban runoff had previously been decreased substantially by rerouting storm sewer drainage. Additional street sweeping and installation of rain gardens and wetland detention ponds were implemented to further reduce urban runoff. The local ski club moved to a nearby reservoir in 2007 to minimize sediment phosphorus resuspension in the lake. To reduce phosphorus contributions to the lake by senescing CLP, a multi-year herbicide application program was started in 2009 and continuing through 2020. The goal of this management strategy has been to selectively target CLP via early spring, low-dosage endothal treatments over several years to reduce the turion seed bank in the sediment. By applying herbicide in this manner, impacts to native submersed macrophytes have been minimal and the lake submersed macrophyte community has shifted to elodea-dominance. Eurasian Watermilfoil was also successfully eradicated in 2009. Beach closures due to fecal coliform contamination have been successfully addressed by goose population management. Fish habitat has been improved by addition of woody structure in the form of nearly 100 felled trees along the entire shoreline of the lake.

To address the primary source of phosphorus to the lake, an alum treatment was conducted in 2011 to control phosphorus flux from the sediment. Dosage was based on the redox-sensitive P (i.e., redox-P; the sum of the loosely-bound and iron-bound P fractions) concentration in the upper 4-cm sediment layer but constrained by a financial budget. Redox-P concentrations were extraordinarily high in western arm sediments, ranging between 1 and 5 mg/g, and were an order of magnitude lower at ~ 0.15 mg/g in the east arm sediments. Approximately 150 g/m^2 of buffered aluminum sulfate-sodium aluminate, arguably one of the highest Al dosages applied to a lake as of 2015 (Huser et al. 2016), were applied to the west arm while the east arm was treated with 75 mg/g.

The community of the City of Eau Claire has been fully invested in management of Half Moon Lake to improve water quality (WQ). A survey conducted indicated that over 80% of the community believed that the lake was a vital resource to the City and supported management to improve and maintain a healthy ecosystem. The outcome of on-going management on use has been multifaceted. Beach attendance has increased tremendously. Recreational canoeing, kayaking, and fishing have increased. The lake now supports the swimming leg of the Eau Claire triathlon. The Dragon Boat Festival, sponsored by Mayo Health Care Systems to promote wellness and support hospice services, has grown in popularity and is expected to have over 50 teams paddling Hong Kong-style dragon boats along a 250-

m course on Half Moon Lake this August. Overall park attendance and usage has steadily increased in conjunction with management for improved WQ.

The overall WQ goal was to maintain total phosphorus and chlorophyll below 0.030 mg/L and 20 µg/L, respectively. These goals were achieved during the first 3 years after alum treatment (Figure 3). However, alum effectiveness in binding P derived from sediment P flux has diminished 5 years after application (Figure 4, James 2017). The native macrophyte community is clearly being impacted by high PAR attenuation, particularly in the west arm of the lake, due to the reemergence of cyanobacterial blooms in 2014-2016. The current working hypothesis suggests that porewater Fe and P have slowly diffused from deeper sediment layers into the surface Al floc layer over time. While the Al floc is sequestering some of this P, another portion is now coupled with Fe and can diffuse into the overlying water column under reducing conditions. More importantly, this P is directly available for uptake by cyanobacteria. Even though an adequate Al dosage was applied to inactivate the high sediment mobile P concentrations, the Al floc did not sink into the upper sediment due to higher bulk density characteristics of the original sediment interface. Thus, Al binding efficiency has decreased over time (de Vicente et al. 2008a and b), allowing for upward P diffusion through the Al floc and re-adsorption onto Fe~(OOH) (Lewendowski et al. 2003). This outcome is most apparent in west arm sediments, where mobile P concentrations were extraordinarily high in the original surface sediment layer. Although similar diffusional processes are occurring in east arm sediments, much less mobile P has accumulated in the surface Al floc layer due to lower mobile P concentrations in the original surface sediment layer.

Because mobile P concentrations were so high in the original sediment column and the Al floc could not sink into the sediment to sequester this P, upward P diffusion is likely to continue, reducing Al treatment success and longevity in Half Moon Lake. Thus, long-term Al management (i.e., over several years to decades) is required that involves applications every 2 to 5 years. Al dosage should target binding mobile P in the current Al floc layer (i.e., the upper 3 cm in the west arm and the upper 2 cm in the east arm). Because bulk densities are lower in these layers, addition of a new Al floc has a greater probability of sinking through these surface layers to bind mobile P. De Vicente et al. (2008b) similarly suggested that smaller Al doses spread out over several years might maintain higher P binding efficiencies.

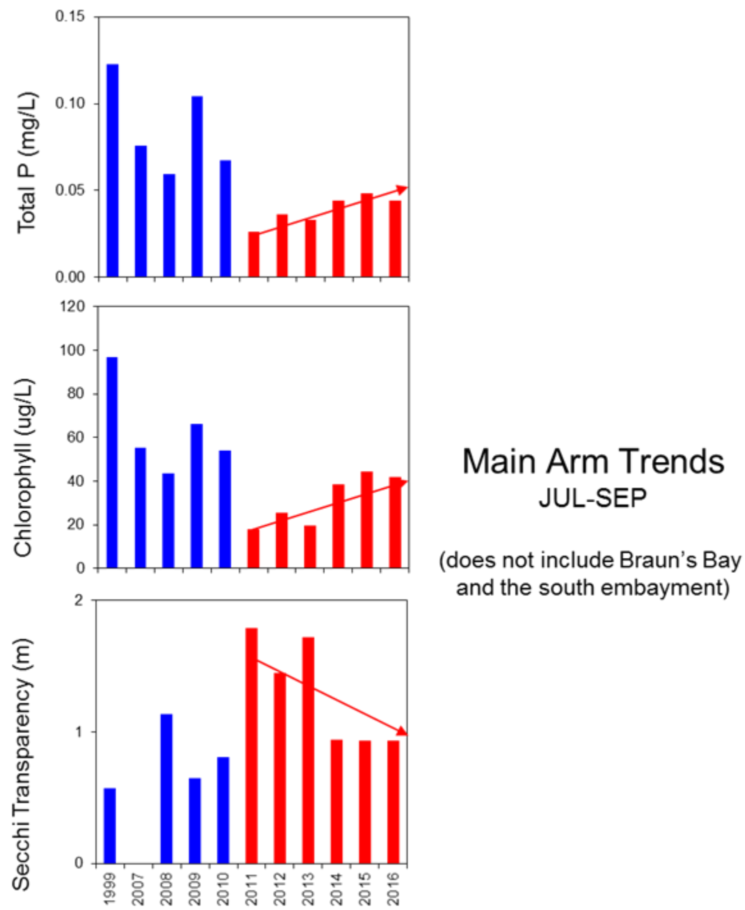

Figure 3. Mean summer WQ trends in Half Moon Lake before (blue bars) and after (red bars) alum treatment.

Additional Management

Location of the Al floc on the sediment surface and diminished P binding efficiency due to crystallization need to be considered in the management of internal P loading in Half Moon Lake. Application of multiple lower Al concentrations spread out over a period of years will be more effective in filling binding sites, lowering the Al:P binding ratio, and stabilizing polymerization for longer internal P loading control and at a lower overall cost. For Half Moon Lake, an adaptive management approach of applying lower Al concentrations spread out over a period of years (i.e., 2-5 year intervals) and monitoring lake response for future Al maintenance applications will lead to greater longevity and more effective control of internal P loading (James 2016). In contrast, the success and longevity of another large dose Al application depends on adding enough Al to sequester and control internal P loading while compensating for Al polymerization and P binding inefficiency. This management scenario will be more expensive, inefficient, and shorter-lived.

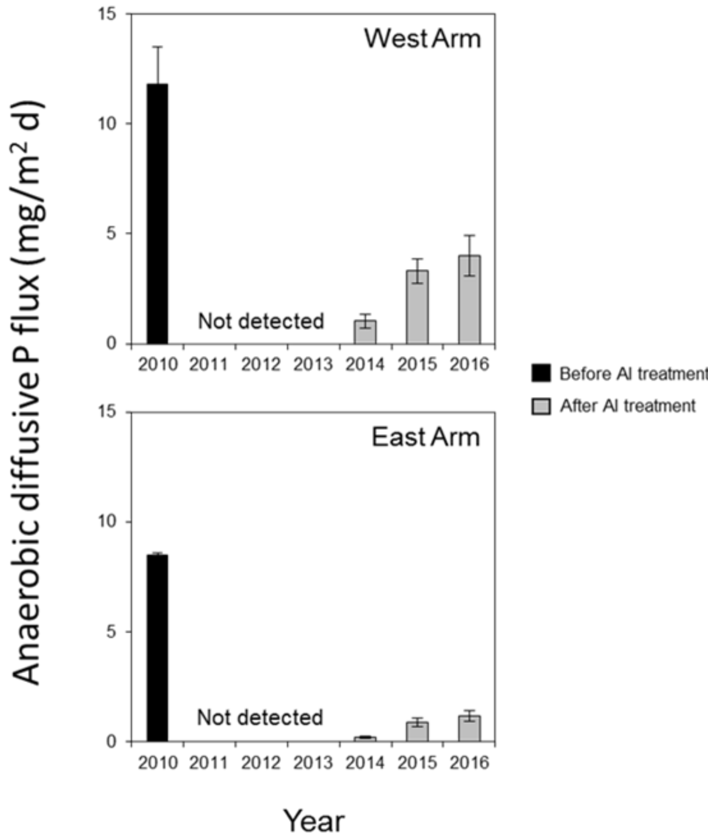

Figure 4. Changes in summer anaerobic diffusive phosphorus flux.

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Since the Al application in the west arm sediments has lost 40% of its P binding effectiveness, an additional Al treatment is recommended in that area of the lake in 2017. An Al dose of ~ 50 g/m^2 within the 10-ft contour is expected to provide internal P loading control over a period of at least 2-3 years (Table 8). Both west and east arm sediment will continue to be monitored for P binding efficiency and internal P loading control annually as part of an adaptive management plan to support decisions regarding additional lower Al dose applications in the future. It is anticipated that lower dose Al applications on the order to ~25 g/m^2 in the east arm and 50 g/m^2 in the west arm at 2 to 5 year intervals will be needed over a period of 10 to 15 years to completely control internal P loading in the lake (Table 9). This dosage and application scenario will be much more cost effective compared to another larger Al dose application as was conducted in 2011.

Table 8. Estimated Al dosage and application areas for future control of internal P loading in Half Moon Lake. Al application strategy is to apply lower Al dosages at 2 to 5 year intervals for up to 10 years (see Table 9). The goal with this strategy is to maximize P binding onto the Al floc, increase internal P loading control and longevity, and reduce overall costs.

	West arm	East arm
P flux through Al floc (g/m^2 y)	0.4	0.1
Control period (y)	2-3	4-5
Al dose (g/m^2)	50	25
Treatment area (m^2)	111,390	88,235
Depth contour (ft)	10	7.5
Cost per treatment ($)	~$50,000	< $12,000

Table 9. Example Al application strategy for Half Moon Lake. The west arm is treated every 3 years with ~ 50 g Al/m^2 while the east arm is treated every 5-6 years with 25 g Al/m^2 (see Table 8). Sediment and water chemistry are monitored to provide adaptive management and decision-making support for adjusting dosage and application strategy.

	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
West arm	■			■			■			■
East arm		■						■		

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