In-Lake Measures
For Phosphorus Control

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The most feasible and cost-effective solution for long-term management of water quality in urban lakes?

Imagine you are a lake manager with a limited budget and a lot of lakes to restore. Also envision that you could use your budget to restore a single lake, or to restore 50 lakes. To help you make your decision, here is some background: all the lakes are eutrophic, all have excess nutrient inputs from the surrounding watersheds, and all display signs of excess internal phosphorus (P) loading from the sediment. What would you do: restore just one, or try to restore as many as possible? Most, if not all lake managers would opt for the latter option but this decision in not always as easy as it may seem.

Anyone who has studied lake restoration has been taught that when it comes to managing nutrient-rich, eutrophic lakes, focus should first be placed on problems in the watershed. This makes sense, because even in lakes where nutrient inputs are dominated by a legacy of internal loading from lake sediment, this material came from outside the lake. Fixing problems in the watershed feels good, too; we are tackling what we have been taught is the source of the problem and we can actually see the restoration measures in action. There is this widespread feeling that there is a "correct" path to take when managing degraded lakes, and it starts in the watershed (external loading) and then moves to the lake (internal loading). But what if this path means you have only enough resources to restore one lake, instead of 50? A recent study looked at

The city of Minneapolis with Lake Calhoun in the foreground. Photo courtesy of the Minneapolis Park and Recreation Board.

the costs of both external and internal measures to reduce phosphorus in a chain of lakes in Minneapolis, MN, and the results, at least in this case, put into question the path we've all learned to take when managing water quality.

The Minneapolis Chain of Lake Clean Water Partnership Project

The Minneapolis Chain of Lakes, surrounded by a city of over 2 million people (Figure 1), receives approximately 6 million visitors a year. Thus, it is not only an important natural resource for locals, it is also important to the state for tourism. The lakes are surrounded by a fully developed 7,000-acre watershed, which has transported excess nutrients to the lakes since development started over a century ago. In addition to excess nutrient inputs from the watershed, all of the lakes in the chain displayed characteristic signs of elevated nutrient release from the sediment (internal loading) due to decades of P accumulation from sources in the watershed.

In response to the degraded water quality in the lakes, citizens and other stakeholders formed the Minneapolis Chain of Lakes Clean Water Partnership (CWP) in 1990. The CWP established nutrient reduction targets and then developed and implemented a plan to achieve these goals. Total funding for the project was $12.4 million, the bulk of which was spent on measures to reduce external P loading from the watershed, and the reminder was spent on education, new regulatory controls, enforcement efforts, and measures to reduce internal loading via aluminum (Al) application to the sediment.

Twenty-six years after the CWP formed and project work began, an analysis of the cost-effectiveness of the measures used to control P levels in the Chain of Lakes was published (Huser et al. 2016a). Watershed measures were generally installed first and the final restoration phase was Al treatment of lake sediment to reduce internal P loading. On average, constructed watershed measures were 50 times more expensive than internal measures for P removal when expressed as dollars spent per kilogram P removed or inactivated (Figure 2). The large difference in cost-effectiveness was mainly related to the efficiency of treating more diffuse sources of P in the watershed, versus managing the excess P once it had been concentrated at one place, the lake sediment.

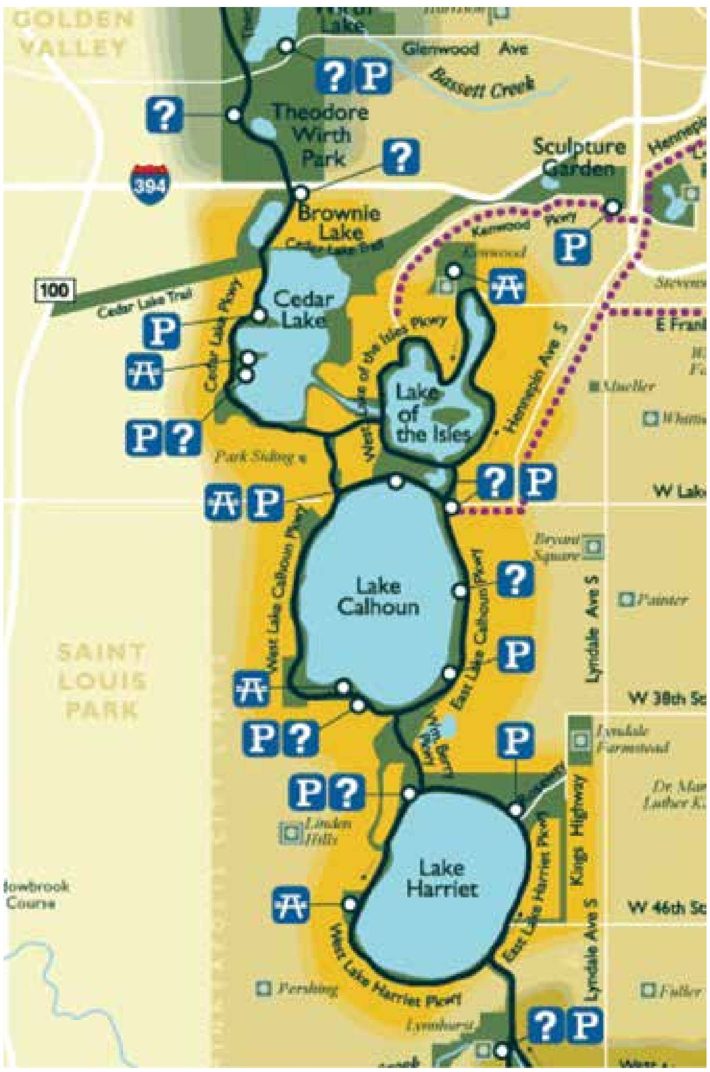

Figure 1. The Minneapolis Chain of Lakes. Water flows from Cedar Lake toward Lake Harriet. Graphic courtesy of the Minneapolis Park and Recreation Board.

How effective were different types of measures?

None of the four lakes in the project achieved water quality management goals until after Al treatment was used to control internal P loading from the sediment. Longevity of improved water quality, however, varied greatly. Lake of the Isles and Cedar Lake met surface water quality goals for 4 and 11 years after Al treatment respectively, although Al treatments in these lakes were based on outdated dosing methods. The treatment applied to Lake Harriet also reduced internal P loading and improved surface water quality for five years, but was designed to prevent migrating blue-green algae from utilizing phosphorus at the sediment surface in littoral areas. Therefore no improvements in water quality were expected besides a reduction in algal mat formation near the shoreline. The Al treatment in Lake Calhoun, based on improved dosing methodology, is expected to maintain improved water quality for approximately 20 years. Even though Al treatment works, internal loading will eventually return because continued P inputs from the watershed will resupply the sediment with phosphorus leading to elevated internal loading, exactly as it did in the other three lakes.

The greatest reduction to external loading was at Cedar Lake, where P loads from the main tributary creek were reduced by over 60 percent (excluding overflows, which were not measured). Overall external loading to Cedar Lake was reduced by 49 percent, by far the best result compared to the other three lakes where external reductions were between 1 and 13 percent. Nearly one metric ton of legacy phosphorus was permanently bound in the sediment via Al treatment as well. Continued external loading, even at roughly half of previous levels, has slowly led to a return of internal loading of P to near pre-treatment levels. In this case, however, the reduction of external loading likely doubled the expected longevity of the in-lake Al treatment (11 versus 5.3 years; Huser et al. 2016b).

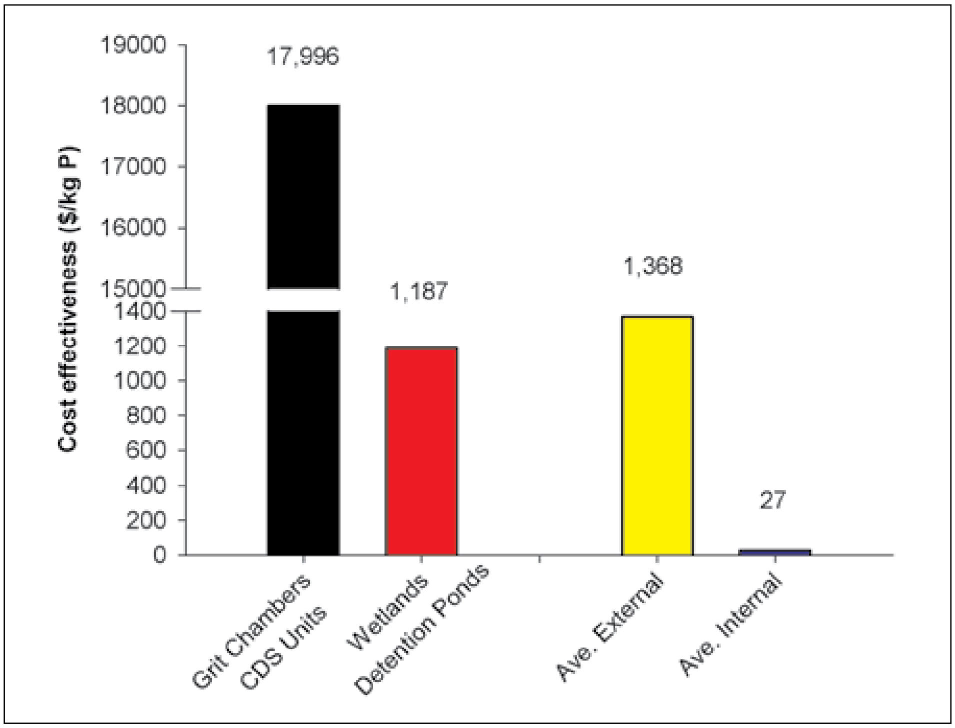

Figure 2. Average cost effectiveness of internal and external measures applied at the Minneapolis Chain of Lakes. Note the break in the y-axis between $1,400 and $15,000 per kg P removed.

But what did this extended improvement in water quality cost? The average cost efficiency for external measures was $1,368 per kg P removed (2001 dollars, Figure 2), whereas the average cost efficiency for Al treatment was $27 per kg P inactivated (a 50:1 ratio). To put it another way, if the money used for watershed measures was instead used to treat the P once it had reached the lake, Cedar Lake would have likely met water quality goals for approximately 270 years, instead of the 5.7 years gained via watershed management strategies. This is a somewhat oversimplified calculation but it is also conservative, as operation and maintenance costs (for example dredging of wetlands and removal of accumulated waste from continuous deflective separators (CDS) and grit chambers) were not included in the cost calculation for external measures.

It should be noted that focusing on internal measures to manage lake water quality will not work in all cases, especially when water residence time is short and external loading drives water quality, even if internal loading is high. In other cases, the main inflows to the lakes are themselves categorized as degraded due to excess nutrients, and they must be restored as well. The calculations are also based solely on P removed, and do not include any monetary benefits from improved ecosystem services. New technological developments may lead to improved methods to reduce the transport of pollutants to lakes and rivers, minimizing the cost of retrofitting in already built areas as well. But every method has a lifespan and must be continually renewed or replaced over time.

How can we improve cost-effective management of lakes?

As we move forward with lake management, a number of small steps would go a long way in helping to use limited resources in the best manner possible. For example, stormwater treatment has focused on traditional methods including detention ponds, which allow a major portion of the biologically available forms of P (most responsible for algal growth) to move through the system. To increase the removal of these forms of P, a shift towards measures that also promote biological uptake (for example, wetlands), has occurred. However, the space needed for efficient uptake often mean this method is impractical to use in the middle of urban areas where land prices are high and available space low. New technologies, such as iron-enhanced sand and spent lime filters (Figure 3), have shown promise for removing sediment and binding biologically available P (and even some heavy metals). Such innovative measures, especially those reusing material from other applications, could substantially increase the cost-effectiveness of external measures.

In order to even begin the discussion about which measures to use for improving water quality, however, we need concrete information about how cost-effective different measures actually are in terms of nutrient reduction. This information is non-centralized, hard to find, or generally lacking for many measures and is likely one of the main reasons why more than 50 percent of reported lake restoration cases have failed to achieve a long-term, sustainable recovery (Sondergaard et al. 2007; Gulati et al. 2008). Even with the excellent data provided for this study by the City of Minneapolis and the Minneapolis Park and Recreation Board, information such as maintenance costs for external measures was difficult to obtain. Monitoring of water quality (both in and outside the lake) is too often conducted for only a few years before and sometimes, but not always, for a few years after measures are applied. Rarely is monitoring conducted consistently for the common life span of many external measures (approximately 20 years). Monitoring of nutrients in sediment, especially the forms of P that can be released to the water, was generally neglected until recent advancements in Al treatment methodology occurred. Costs for measures (design, land acquisition, construction, and maintenance), can be even more difficult to obtain. Furthermore, as we saw at the Chain of Lakes, performance is often over estimated (CDS units and grit chambers) while maintenance is underestimated (dredging of wetlands/ponds was needed twice as often as expected).

Monitoring of water resources has improved recently, but far too often data needed for critical evaluation of restoration efforts are lacking. Even when monitoring is conducted, between watershed and lake type comparisons are made difficult, for example, by the measurement of different parameters or even different forms of P. A common

Figure 3. First-of-their-kind enhanced sand filter with 5 percent reused iron filings and spent lime filter (A) made of dried, drinking water treatment residual (B). Designed by Barr Engineering for the Ramsey-Washington Metro Watershed District in Minnesota. Photo A, Brian Huser; Photo B, Keith Pilgrim.

management plan, instituted at the federal (or state) level and required when using state and or federal funds for lake management, would lead to a dataset that could arguably be worth at least as much as the ongoing management work itself. This dataset could be used to develop a measures "library," where one could browse through different methods to reduce nutrient loading and select the most cost-effective measure(s) for a given situation. Monitoring costs money, but it is typically a fraction of the sum total of the measures needed to restore a lake. The cost may also be seen as diverting money from additional nutrient reduction measures. But this is one cost that should be paid, because the data provided will save money in the long run, helping lake managers choose the most cost-effective strategies for managing water quality, and reducing the risk for failures in the future.

Is it okay to turn natural resources into treatment systems?

Finally, a number of philosophical arguments can be made, both for and against managing P in the lake. For example, should we turn lakes with excess nutrient loading into what amounts to a treatment system, inactivating sediment phosphorus once every decade or two? On the other hand, should we take the last few natural features or recreational areas in urban environments, such as wetlands and parks, and turn them into treatment devices to reduce phosphorus in stormwater runoff? All of these resources are part of the commons, managed for individual and collective benefit. Obviously people will have different feelings towards the above questions depending on the value they place on different natural resources. But they are important questions to ask.

The Minneapolis Chain of Lakes restoration project is one project, and the results should be discussed in that context. By no means do we want to imply that reducing nutrients in the watershed should not be considered. But it is a fact that we have limited resources when it comes to managing surface waters. It is also a fact that the record of successful, long-term management of lake water quality has been poor. In order to succeed in the future, the management of surface waters should be based on maximizing water quality in the most cost-effective and scientifically sound manner possible. We may also need to change how we think about lake management in urban areas, with respect to both where we focus our resources, and the timescales we work to. We need to move from a single project mindset to an ongoing commitment to managing water quality in urban lakes. This holds true irrespective of whether internal, external, or a combination of both types of measures are applied.

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