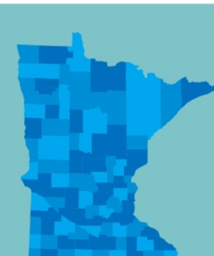
Lake management guide

August 2020

Minnesota State and Regional Government Review of Internal Phosphorus Load Control

An important option in the lake management toolbox.

MINNESOTA



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Foreword

This document is intended to serve as a reference for investigating different methods of reducing internal phosphorus loads, as there are many necessary considerations before making the most informed decision on lake management.

This provides an overview of the most common practices for internal lake phosphorus load control in Minnesota. These were reviewed by staff from Minnesota Pollution Control Agency (MPCA), Minnesota Department of Natural Resources (MDNR), Board of Water and Soil Resources, and the Metropolitan Council. The intended audience is state and local lake practitioners as well as agency staff issuing permits or reviewing grant proposals when considering the use of internal phosphorus load reduction practices.

For a more detailed examination of particular practices, costs, and general information on phosphorus loading, readers can look to the references provided in Appendix A.

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Introduction

Internal loading is the process in which phosphorus is released from sediment during anoxic conditions and mixed back into the water column by wind or wave action. It is often identified in Total Maximum Daily Load (TMDL) studies and lake management plans as a significant source of phosphorus to Minnesota lakes and a cause of poor water quality. Internal loading of phosphorus has been described as a “wicked problem” in aquatic science and management (Oriehl et al, 2017; Rittel and Webber, 1973) because it is ill defined and complex. The release of sediment bound phosphorus can result in high lake phosphorus concentrations even in the absence of significant external phosphorus loads.

The following conclusions have been agreed upon by the government agencies that authored the report.

- While external loads are the original source of excess phosphorus to a lake, internal loading is often identified as a significant source of phosphorus to Minnesota lakes;
- The State of Minnesota and the Metropolitan Council recognize that addressing sources of phosphorus within a lake’s basin is an appropriate and necessary part of many lake restoration plans and potentially some lake protection plans;
- There is no “one size fits all” formula that can be used to predict internal phosphorus load reductions achieved from application of control methods. Internal phosphorus loads depend on a multitude of factors including the physical, chemical, and/or biological attributes of a particular lake, on the size, depth and shape of the lake relative to its watershed, as well as the geographical location and associated land-use of the lake’s watershed. Lake-specific plans need to be developed to quantify the internal load reductions that could be expected from applying phosphorus reduction methods. Lake data and modeling will be critical to develop feasible and cost-effective management strategies;
- The State of Minnesota executive branch departments (hereafter referred to as the State) and/or other government units have regulatory authority over many of the actions or activities that would be part of an internal phosphorus load reduction plan. However, there may be multiple other partners that have a vested interest in what actions/activities are planned or phased over time. It is the State’s expectation that the planning process will be sufficiently broad-based to include the input of all interested partners;
- There are currently no specific thresholds that outline how external and internal phosphorus load reduction efforts should be balanced, timed, or sequenced for Minnesota lakes. As mentioned above, there are too many lake-specific factors as well as an insufficient history of in-lake treatment efforts in Minnesota to create such thresholds. The Board of Water and Soil Resources (BWSR) has solicited input from various consultants who develop/design internal phosphorus control management plans on how such thresholds might be designed and the State may develop specific criteria and/or thresholds in the future. Again, lake data and modeling will be critical to develop and justify how to phase and balance proposed internal vs. external load reduction efforts;
- Scientific literature suggests the duration of internal load control effectiveness can be variable, ranging from 1-20 years depending on the lake morphology, external loads and the phosphorus reduction method employed (Appendix A). Scaling the approach as appropriate for a particular lake (e.g. proper dosing of alum) and external nutrient control will increase the effectiveness and longevity of internal load control methods.

Planning considerations for internal phosphorus load controls

Lake managers should quantify their lakes' overall phosphorus budget prior to considering an internal phosphorus reduction plan. Some information such as a phosphorus source assessment and source reduction targets may be available if a TMDL has been developed. Additional investigations, such as the analysis of lake sediment will often be needed to directly measure and quantify the internal phosphorus load. If an internal load has been identified as a significant source of phosphorus, lake managers should consider incorporating measures to control internal phosphorus loading into an overall phosphorus reduction plan. The following are additional considerations when determining the appropriateness of employing internal phosphorus load reductions practices.

External vs. internal load

A lake is a reflection of its watershed as drainage area, land use, topography and geology impact the phosphorus budget of a lake. Where external loading is sufficient to cause water quality issues over the residence time of the lake, a significant proportion of the watershed phosphorus load will likely need to be reduced to achieve long-term water quality improvement. Unless external loading has been adequately addressed, in-lake treatment will have short-term benefits at best.

No threshold of external phosphorus reduction has been identified to trigger the use of internal load measures. Although there are estimated, unpublished guidelines suggesting 50% or greater internal loading will limit the efficacy of watershed management activities to reduce in-lake phosphorus (Ken Wagner, pers comm), the use of "rule of thumb" management decisions over simplifies the complex and unique nature of individual lakes and our relatively limited knowledge of the application of internal load controls. However, when proposing these phosphorus load controls, lake managers should be able to demonstrate through modeling or other means how the combined efforts of reducing external and internal loads will collectively achieve lake management goals.

Lake type

Lake type will influence the success of internal load control treatments. Depth, hydrologic connections, watershed: surface area ratio, and other factors influence the outcome and duration of treatments. For example, seepage lakes, maintained primarily by groundwater inflow, typically have small watersheds and consequently long residence times. Drainage lakes, fed by inflowing streams, have larger watersheds and shorter residence times. Drainage lakes are more difficult to manage for phosphorus than seepage lakes because inflowing streams will carry the nutrients and sediment of the entire watershed. Lakes with small watershed: surface area ratios are generally better suited for in-lake treatment.

Lake depth is also important to consider when choosing among internal load reduction strategies. Minnesota defines deep lakes as those with 15 feet or more depth or less than 80% littoral area. In general, lakes that maintain stratification during the summer months are deep lakes. In deep lakes, phosphorus is released from bottom sediments when the lake is stratified and oxygen at the water/lake bottom interface is depleted. Therefore, strategies preventing anoxic conditions or anoxic release of phosphorus could be effective in deeper lakes (e.g. alum, hypolimnetic aeration). Conversely, physical removal of phosphorus-laden sediments (dredging) or hardening of bottom sediments (drawdown), though impractical in deep lakes, may be effective in shallow lakes.

Stable state dynamics

Shallow lakes are known to resist shifts between clear (dominated by rooted vegetation) and turbid states (dominated by algae). Recent research shows that the turbid-water condition will dominate due to the difficulty to remove bottom disturbing fish and manage internal load. Attempts to shift to a clear state often have only short-term improvements (Hobbs et al. 2012, Ramstack-Hobbs et al. 2016).

Comprehensive lake management

Lakes are complex, connected ecological systems. As such, methods for reducing internal phosphorus load can impact aquatic plant and animal communities and abundance. For example, moving a lake from a turbid state to a clear state will result in increased vegetation. This is especially prevalent in shallow lakes with relatively large littoral areas. Therefore, it is important to propose or review internal phosphorus treatment plans within the context of a more comprehensive and customized lake management plan. This should incorporate the perspectives of watershed management, water quality, fisheries, recreational opportunities, public perception management, and development pressures.

Internal load reduction methods used in Minnesota lakes

Typical internal load reduction methods used in Minnesota lakes can be broken down into three main categories: chemical, physical and biological. Chemical methods generally involve the application of a substance that reduces or inactivates the release of sediment bound phosphorus in a lake making less phosphorus available for algal growth. Chemical applications can be applied to an entire lake or just those areas that have been identified as heavily laden with sediment bound phosphorus. Physical reduction methods vary from removal of phosphorus rich sediment (dredging) to hydrologic alterations such as lake level drawdowns and aeration. Dredging for the purpose of phosphorus control is generally limited to specific areas with phosphorus rich sediments as indicated by sediment cores. Hydrologic alterations act to reduce the availability of phosphorus through hardening of sediments or preventing anoxic release of phosphorus. Biological methods involve harvesting of vegetation to remove plant bound phosphorus in the lake and managing the fish community to reduce disturbance of phosphorus rich lake sediments by bottom disturbing fish. The tools or best management practices to reduce in-lake phosphorus can be adapted and used in combination or sequentially to meet management goals.

Table 1 lists many of the most commonly applied internal phosphorus load reduction methods used in Minnesota lakes. The reader can use the table to narrow down potential load reduction options for a particular lake based on its morphology and potential side-effects. Once readers have preferred treatment options, they may consult Appendix A where additional detail and links to case studies are provided for the different treatments. Table 1 does not include cost estimates, as these can be highly variable and only meaningful within the context of a specific lake. Lewtas et al. (2015) includes a range of cost estimates for most of the options presented in Table 1. This can be used to provide lake specific context such as cost per hectare, cost per pound of phosphorus reduced, cost per year, costs associated with equipment maintenance and costs of disposal of waste materials.

Table 1. Internal loading management options (see Appendix A for additional information on each treatment option).

Type of treatment	Treatment	Lake morphology	Longevity	Permits required*	Impacts to Biological community: x-direct, 0-indirect**, z-more study needed			Problems or considerations
					Fish	Invertebrates	Aquatic macrophytes	
Chemical	Aluminum additions	shallow/deep	4 - 21 years - stratified 1 - 11 years - shallow	MPCA (approval letter)	0 - Macroalgae is primary fish habitat. May impact community composition and abundance. Toxic to fish if pH decreased (acidified) resulting in toxic Al^{3+} ions.	x - Short term impacts related to the settling of the floc layer 0-macroalgae are habitat for invertebrates	x - Toxic to macroalgae if the pH decreases (acidified) resulting in release of toxic Al^{3+} ions.	To be effective might require pH buffering. Whole lake treatments generally limited to smaller basins (<500 acres). Larger lakes might require targeting of higher loading areas in the lake. Can also be added to tributary inflows.
	Iron filings	shallow/deep	Short term, iron tends to bind P only in the presence of O_2 so first anoxic period may release large quantity of bound P	MPCA (approval letter)	z	z	z	Used in low sulfate waters (sulfide competes with phosphate for precipitation with Fe). Aeration or artificial circulation may have to accompany applications to prevent the breakdown of the oxidized barrier.
	Ferric Chloride	deep	Variable effective time, O_2 depletion can limit longevity	MPCA (approval letter)	z	z	z	May work better combined with O_2 injection.
	Lanthanum	shallow	Unclear, but P inactivation treatments typically are not effective for more than 15 years	MPCA (approval letter)	z	x - Short term impacts related to the settling of the floc layer	z	Works well under anoxic conditions. Turbidity increases immediately after application - turbidity decreases after settling. Not as common as Alum or Iron.
Physical	Dredging	shallow	Depends on incoming loads and material removed	MDNR public waters work permit; MPCA management of dredge material permit	x - Impact community composition and/or abundance	x - Impact community composition and/or abundance	x - Impact community composition and/or abundance	Goal to remove high P sediments. High cost and placement of dredged materials. Potentially toxic materials such as trace elements and organic pesticides. Can also be used to increase depth for recreation.
	Drawdown	shallow	Depends on macrophyte community, area exposed, length of time, and reintroduction of bottom disturbing fish	ACoE Section 404 permit; MDNR public waters work permit, water appropriation permit and aquatic plant management permit; MPCA 401 certification, NPDES construction permit and management of dredge materials permit; MNDOT work in ROW permit	x - Impact community composition and/or abundance	x - Impact community composition and/or abundance	x - Impact community composition and/or abundance	Disposal of water from drawdown. Expensive, engineering costs. Manually remove accumulations of dead fish as basins are dewatered. Vegetation maintenance.
	Dilution	shallow/deep	Long term although not very practical, limited conditions where possible	MDNR public waters work permit; ACoE Section 404 permit	z	z	z	Costs for pumping or rerouting waters; effects of altering water sources and flows; generally limited to small lakes.
	Oxygen injection	deep	Continual treatment primarily during growing season	MDNR aeration permit	x - Impact community composition and/or abundance	0 - Could alter community composition/abundance by changing area of lake bottom that has higher D.O. levels	z	Costs for initial setup; sizing system to lake for desired effect. Maintenance and operation costs annually. Can create thin ice areas in winter months.
	Hypolimnetic withdrawal	deep	Depends on magnitude and duration of TP transport from hypolimnion	MDNR water appropriation permit and public waters work permit	z	0 - Could impact community composition and/or abundance depending on withdrawal severity and changes in D.O. and/or nutrient availability	z	Multiple options: withdrawal and return, withdrawal and discharge, withdrawal and treat and return; winter aeration causes ice instability.
	Hypolimnetic aeration	deep	Continual treatment	MDNR aeration permit	z	0 - May alter community composition and abundance	0 - May alter community composition and abundance	Goal to eliminate the loss of O_2, either by injecting O_2 or increasing mixing of water column. Can create thin ice areas in winter months.
	Circulation and aeration	shallow/deep	Continual treatment	MDNR aeration permit	x - Decreases winterkill, may alter community composition and abundance	0 - May alter community composition and abundance	z	Can create thin ice conditions in winter months; used to prevent winterkill.

Biological	Fish removal	shallow/deep	Depends on the re-introduction of bottom disturbing fish	MDNR permit	Disturbance of lake sediments and includes targeting bottom disturbing fish such as common carp; black and brown bullheads and/or complete fish community removal utilizing pesticides such as rotenone.	0 - Increasing bluegill numbers to eat common carp eggs can increase predation of invertebrates	0 - May alter community composition and abundance (for positive or negative)	Physical fish capture and disposal are the primary cost drivers. Creative alternatives to the capture and disposal of targeted fish species will reduce costs. Requires consideration of barrier installation to prevent reintroduction of problem species. Reintroduction of appropriate fish and other related aquatic species should be considered when whole community removal is attempted.
	Mechanical aquatic plant removal	shallow/deep	Continuous, multiyear obligation; removes nutrients directly from system	MDNR aquatic plant management permit	x - Direct mortality - Fish, amphibians are often unintended targets of harvesting 0 - May alter community composition and abundance - predator/prey and depending on scale of application - oxygen depletion could lead to fish kill	0 - May alter community composition and abundance	0 - May alter community composition and abundance	A relatively short-term solution and targets invasive aquatic plants. Risk in spreading invasive plants by fragmentation or seeds. Harvesting programs are typically developed for recreation purposes; increase lake access. Limited TP removal relative to the whole internal load.

* List of permit requirements not intended to be comprehensive. Permit requirements could vary by method and local jurisdiction. Please contact identified state and federal agencies as well as local authority to obtain required permits/approvals prior to beginning work.

** Successful treatments will result in less available nutrients in a waterbody increasing water clarity. Increasing water clarity will have indirect impacts on all aquatic biological communities. Submersed aquatic macrophytes will increase in abundance, which will expand habitat for invertebrates and provide additional food sources and cover for fish. Predator prey relationships may be altered as well as shifts in population composition and abundance.

Information for determining the most appropriate load control option

The following information should be considered by lake managers when determining the appropriateness of internal phosphorus load control options. This information would be included in a feasibility study, when required:

1) Internal load control vs external load reductions
    a. What information exists that is directing the desired goal?
    b. Has a model (e.g. BATHTUB, CE-QUAL-W2) been completed and validated?
    c. Has a TMDL been calculated?
2) History of projects completed in the watershed and in the lake
    a. What was done?
    b. Where was it done?
    c. What were the outcomes?
    d. Are there any other projects currently underway or proposed for this lake or watershed?
    e. What are the limitations to further reductions in the lake and watershed?
3) Cost benefit analysis of treatment options including the status quo option
    a. Estimated load reduction and treatment effectiveness longevity
    b. Decision making process to determine the best options
    c. Expected effects of treatment on the lake in addition to load reductions (e.g. increased vegetation, altered fish assemblage, thin winter ice)
4) Lake and watershed information
    a. Lake water quality data (chemistry data, trends, loading information)
    b. Watershed land use, especially on-going land use changes
    c. Watershed: lake surface area ratio
    d. Fish community (stocking history, changes to fish community, historic species control)
    e. Plant community (presence of invasive species, non-natives, and historic treatments)
5) Social dynamics
    a. Engagement of lake shore and watershed residents
    b. Presence of lake association
    c. Plan for educating public on possible outcomes

Managing expectations

An important aspect of any lake improvement project is managing the expectations of those involved, including lakeshore and watershed residents. As indicated in Table 1, phosphorus reduction treatments can have unintended consequences ranging from thin winter ice to increased vegetation to changing fish community composition. These possibilities should be clearly communicated to lake stakeholders prior to proceeding on a lake improvement project.

Factors influencing effectiveness and longevity of treatment

1. External phosphorus load – if external load is a major source of phosphorus, the effectiveness and longevity of internal reductions could be compromised.

2. Dosing of chemical treatments – using the proper dose of chemical treatment (e.g. alum) is important for limiting the availability of phosphorus for algal growth.
3. Watershed to lake area ratio – longevity of in-lake treatment effectiveness tends to be greater for lakes with a smaller watershed relative to lake surface area.
4. Lake morphology – treatment effectiveness and longevity tend to be greater for deep lakes and less for shallow lakes.
5. Connectivity or barriers – if fish removal is proposed, preventing reintroduction of bottom disturbing fish will be critical.
6. Abundance of bottom disturbing fish – large populations of bottom disturbing fish (e.g. carp) can stir up sediment releasing phosphorus into the water column.

Socio-economic considerations

1. Cost and long-term management – treatment costs can be significant and might need to be repeated to maintain improvements; cost analyses of treatment options should consider longevity of effectiveness.
2. Impaired water status – treatments, even if deemed successful, do not guarantee removal from the impaired waters list.
3. Timing of treatment – treatments will not likely provide immediate remedy for an active algal bloom.
4. Lakes as living ecosystems – improvements to water clarity will likely enhance aquatic plant growth.
5. Robust monitoring effort – a long-term pre and post-project monitoring effort will inform treatment requirements and effectiveness.
6. Urban vs. rural expectations – the geographic setting of the lake is often associated with different perceptions of clean water and responsibilities for implementing solutions.

Regulatory considerations

1. Permit/authorization requirements – the internal load treatments identified in this guidance require federal and/or state and/or local permits or authorizations; it is the responsibility of the local practitioner to obtain all necessary permits.
2. Wasteload allocation – internal load treatments do not count toward wasteload reductions assigned to a municipal stormwater permittee in a TMDL.

Summary/Conclusions

The unique circumstances of any particular lake dictate the appropriateness of utilizing internal phosphorus load controls. Lake morphology, lake phosphorus balance, watershed landuse, downstream impacts, budgetary restrictions, permitting requirements and public expectations are just some of the factors that need to be weighed when considering internal phosphorus control practices.

Methods to reduce internal loading should only be considered in the context of a comprehensive lake management plan. Ideally, lake management plans reflect the agreed upon goals of diverse stakeholders. The methods for protecting and/or restoring a lake, which could include internal phosphorus controls, are derived from those goals. A holistic approach to lake management that incorporates watershed and in-lake practices is more likely to lead to long-term success and sustainability.

Appendix A

Phosphorus budget and trophic state dynamics

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