ENHANCING WATER QUALITY THROUGH NUTRIENT INACTIVATION

Lake Morey Sediment Study & Management Recommendations

SŌLITUDE LAKE MANAGEMENT

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1 Project Understanding & Overview

SOLitude Lake Management (SLM) understands that improving current water quality and protecting against future degradation is of importance to the Lake Morey community and lake users. In particular, phosphorus (P) management is important to limit nutrient availability to the algal community, which in turn reduces algae, increasing clarity and generally improves water quality.

SLM further understands that Lake Morey (575-ac) is a relatively deep lake (maximum depth = 43 ft, mean depth = 28 ft) and experiences thermal stratification and anoxic bottom water during summer. Anoxia occurs during the summer months at depths greater than 26 ft, which suggests internal loading of P from the lakebed is likely an important source of P to the lake.

This Lake Morey Sediment Analysis study has two main objectives:

(1) Determine the pool of P in the lake sediments that is available for release into the overlying water column

(2) Assess management options to reduce the amount of P released from the sediments into the water column

(3) Determine the amount of nutrient inactivant (alum, lanthanum) required to inactivate sediment P and reduce internal P loading

This information is critical to understanding the sources P loads to the lake, the rates of P loading, and to design specific and focused approaches to controlling loads.

Total sediment P consists of multiple fractions (e.g., labile P, iron-bound P, aluminum-bound P, and biogenic P). These fractions define the pool of P available for release into the overlying water (internal loading) and measuring them reduces the uncertainty associated with estimating internal loading. We collected sediment samples and had them analyzed for separate P fractions. In collaboration with Dr. Ken Wager at Water Resource Services, this data is then used to determine the amount of alum and lanthanum required to inactivate the available P in the sediments, which reduces internal P loading.

The results of this study are presented in the remainder of this report.

2 Determination of Available Sediment Phosphorus Pool

2.1 Sediment Core Collection Methods

Sediment samples were collected from an anchored boat on November 29, 2022 from twelve locations at Lake Morey with an Eckman dredge. The locations were representative of the basin conditions and captured spatial variation in sediment chemistry across the probable deepwater internal loading zone of Lake Morey (Fig. 1). The top 10 cm of sediment was collected at each location and then delivered to the University of Wisconsin-Stout where they were analyzed for various P-fractionation concentrations.

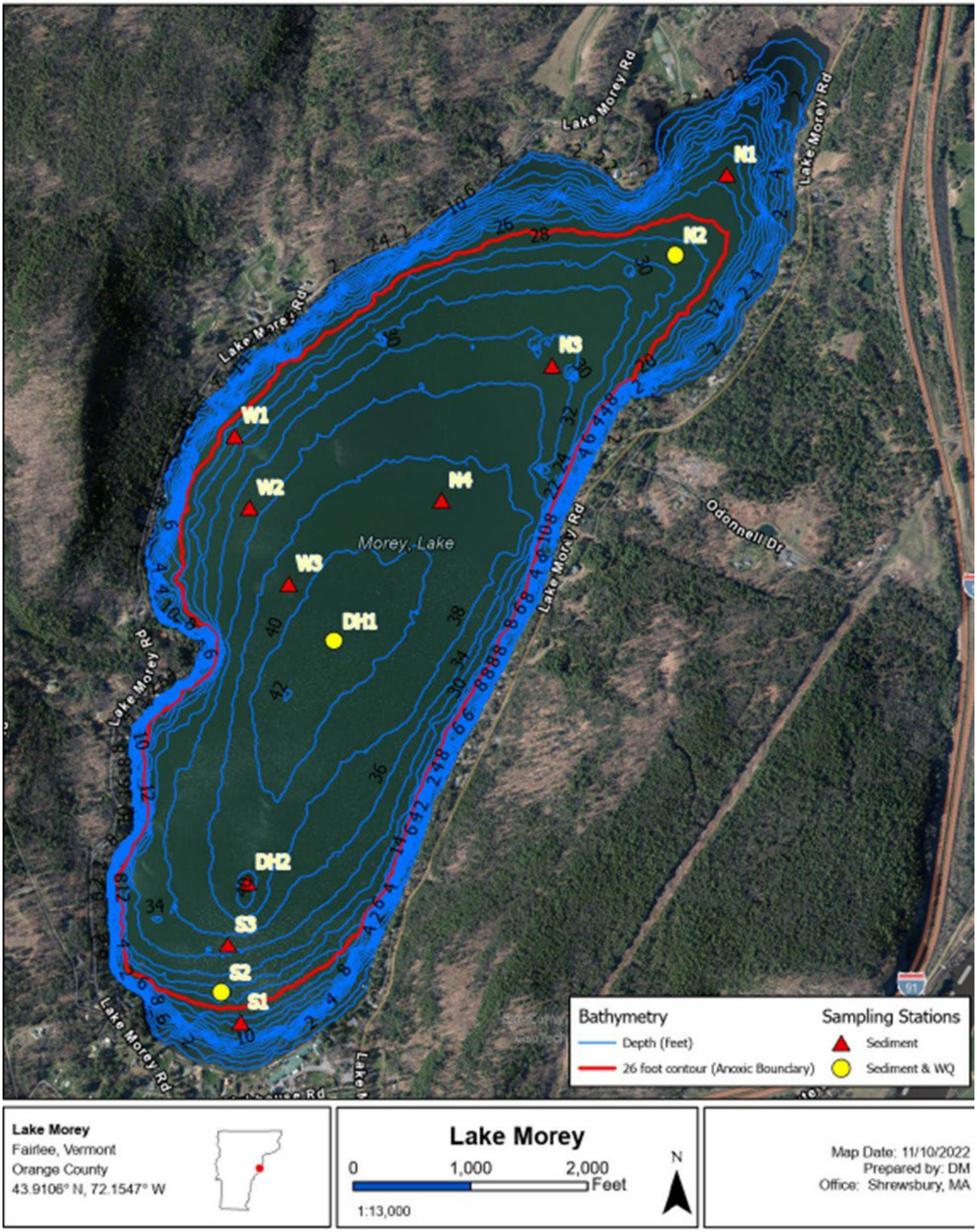

Figure 1. Lake Morey Sediment Coring Locations

2.2 Laboratory Testing

Sampling efforts resulted in 12 sediment samples for P-fractionation. UW-Stout Lab analyzed each sample for the following parameters:

- Percent Water & Percent Solids
- Phosphorus Fractions: Biogenic Phosphorus, Mobile Phosphorus (iron-bound phosphorus plus labile phosphorus), & Aluminum-bound Phosphorus

The labile and iron-bound P fractions are readily mobilized at the sediment-water interface as a result of anaerobic conditions that lead to desorption of P from sediment and diffusion into the overlying water column. The sum of the labile and iron-bound P fraction represents redox-sensitive P (i.e., the P fraction that is active in P release under anaerobic and reducing conditions; redox-P). In addition, biogenic organic P can be converted to soluble P via bacterial mineralization or hydrolysis of bacterial polyphosphates to soluble phosphate under anaerobic conditions. The sum of redox-sensitive P and biogenic P collectively represent the component of sediment P available for internal loading. This fraction is active in recycling pathways that result in exchanges of P from the sediment to the overlying water column and assimilation by algae. In contrast, aluminum-bound P is more chemically inert and subject to burial rather than recycling.

2.3 Results

Redox P concentrations indicate that a large pool of P exists in Lake Morey sediments and is available to contribute P to the water column via internal loading. The internal loading source of P from the sediments is twofold. The first internal loading source is the redox-sensitive P (sum of the labile and iron-bound P fraction). This source is controlled by stoichiometric redox chemistry and internally loading from this source generally occurs when the sediments and sediment porewater are anoxic. There is a large amount of redox sensitive P (primarily in the form of iron bound-P) in the Lake Morey sediments and it is an internal loading source of concern.

The second source is biogenic-P. The biogenic-P represents the portion of organic-P that is most readily available for dissolution into the water column and is often controlled by biological activity in the sediments. Biogenic-P in Lake Morey is an additional internal loading source of concern.

For Lake Morey, these two sediment sources of P (redox sensitive and biogenic) were combined to determine the amount of P available for internal loading events (i.e. the total sediment pool of available P). The depth integrated average across the eleven sites is 1.820 g/m^2. Using accepted dosing protocol, it was determined that an average of 33.50 g Al/m^2 is required to inactivate this pool of sediment P (Table 1).

Table 1. Available sediment phosphorus and aluminum dose by site. Results from site S1 were recognized as an outlier and excluded from the analysis.

Site	Available P (g/m^2)	Aluminum Dose (g/m^2)
S1	8.177	101.89
S2	1.664	38.15
S3	1.621	34.24
DH1	1.295	22.37
DH2	2.562	39.15
N1	1.897	32.49
N2	2.685	41.92
N3	1.997	38.48
N4	1.931	34.75
W1	1.707	31.86
W2	1.313	30.14
W3	1.346	24.95
Average (excludes S1)	**1.820**	**33.50**

3 Management Alternatives

The three proven ways to control internal P loading are dredging, oxygenation, and P inactivation.

- Dredging is technically challenging and very expensive. It focuses on removing the high P sediment, lowering oxygen demand and available P reserves, and resetting in-lake conditions. Funding and permitting are often major constraints.

- Oxygenation can be accomplished with or without breaking stratification, and there are multiple ways to increase deep water oxygen without disrupting thermal stratification as well as several ways to increase oxygen by mixing the lake with a circulation system.

- P inactivation is accomplished by adding a P binder that is resistant to P release under low oxygen conditions (note that much P is bound to iron, which is subject to P release under anoxia) and/or binds up P released from organic matter with decomposition (note that under oxic conditions, iron will often bind P released by decomposition, increasing sediment reserves subject to P release when anoxia occurs).

3.1 Dredging

Essential data for evaluating the potential for dredging at Lake Morey are not available, including information on sediment quantity and quality. However, given the extreme cost of dredging, this may not be an option worth pursuing. If the material was "clean", such that special disposal arrangements would not be required, and if just one foot of material was removed from the 379 acres of hypolimnetic area, that would equate to 1.8 million cubic yards of material. At a low end cost of $30/cy for removal, that would be $18+ million. While P concentration in the sediment declines with depth, there is no guarantee that 1 foot is enough removal to reach a low P stratum or to reduce oxygen demand. Considerably more analysis would be needed, but at the projected minimum cost, this may not be a viable alternative for further consideration.

3.2 Oxygenation

Getting more oxygen to the sediment-water interface is a valid approach, but it has to be a reliable system of sufficient size to meet the demand and recover from inevitable shutdowns. A reliable circulation system for a lake this size is likely to require many diffusers or pump ports with an extensive network of feed lines, something generally not ideal in a recreational lake with boating, anchors and other possible pitfalls.

An alternative is to use non-destratifying oxygenation, which can be accomplished several ways. Bubbling pure oxygen into the deep water can allow oxygen to be absorbed before bubbles reach the thermocline and cause mixing, but this requires a vertical run of about 20 ft and that is not available in Lake Morey (hypolimnetic thickness is <16 ft in all areas). Chambers into which air can be bubbled to increase oxygen content of deep water which is then returned to the deep zone have been used for many years. Such systems can be effective but are not efficient, as the oxygen content of air is limited (21%) and transfer efficiency is low (<3% per vertical meter traveled). While some are still in use, few new hypolimnetic aeration towers are installed these days with rising power costs.

Chambers in which pure oxygen can be added to water can be installed in the lake or on shore, and these have become the currently preferred approach where the hypolimnion is too thin to allow unconfined pure oxygen bubbles to work. Chambers in the lake have the advantage of a smaller shore-based footprint and can take advantage of natural pressure at depth to increase the saturation point for added oxygen. The water is oxygenated and sent back into the hypolimnion. Lateral mixing is substantial with little effort, a matter of concentration gradient. Chambers on shore can perform the same service and are easier to maintain, just with some increased footprint and efficiency loss. Oxygen demand calculations are needed, so sizing of such a system would involve significant lead-in work. No oxygen demand measurements have been made using in-situ chambers or incubated cores in the lab, and no oxygen profiles collected at weekly to monthly time intervals in spring appear available to make an empirical calculation of oxygen demand.

Oxygen demand between 1 and 2 g/m^2 per day could be reasonably expected over the 379-acre hypolimnetic area, but both the demand and the area involved need to be verified. Yet with these assumptions, a 1.53 million m^2 area consuming 1 $g/m^2/day$ would require oxygen input at about 1,530 kg/day, while at 2 $g/m^2/day$ it would be double that amount. Based on empirical values from other projects, the capital cost of such a system is about $1,000 per kg/day, so an estimated cost range of $1.53 to 3.06 million is derived. Operational costs can vary widely, but a cost near $1 per kg per day is offered. If run for 100 days, such a system would cost $153,000 to $306,000 per year to operate.

3.3 Phosphorus Inactivation

There are multiple P binders that can be used, including calcium and lanthanum, but the only one applied in New England for decades has been aluminum. Iron can be used in association with oxygenation systems but cannot hold P under low oxygen conditions. Lanthanum dosing is not as well understood as aluminum dosing and there is more uncertainty in its effectiveness and longevity, the application is less precise and there is a lack of larger lake case studies that would be similar to Lake Morey. When equivalent doses are compared (i.e., equal number of P binding sites), lanthanum applications are 1.5 to 2.5 more expensive than aluminum applications. SOLuitude uses lanthanum to manage phosphorus in many small ponds, but we have found that it is not the best option for larger lakes.

Aluminum has an imperfect but generally reliable track record and offers very flexible application options. It can be added in a single, large dose to inactivate P in the surficial sediment, a process that yielded 35 years of improved conditions at Lake Morey. As detailed in Section 4.0 below, the cost of P inactivation with aluminum is less expensive than the capital cost of oxygenation and with no ongoing operational cost, and an order of magnitude less expensive than dredging. Along with the flexibility of approach and successful track record, P inactivation is the normal choice for controlling internal P loading in recreational lakes.

4 Internal Load Control Recommendations – Sediment P Inactivation

4.1 Overview

Testing shows that a large pool of iron-bound P exists in Lake Morey. The iron to P chemical bond is unstable and breaks under the reducing conditions of anoxia. We recommend "inactivating" this iron bound P by the addition of aluminum to the sediments. P will preferentially bind to Al and, unlike the iron to P bond, the Al to P bond is very stable. Thus, P remains bound to the Al under both anoxic and oxic conditions. The Al addition effectively keeps the P in the sediments and also provides unfilled binding sites that intercept future P releases from both the redox sensitive and biogenic sediment P fractions.

We recommend applying aluminum sulfate combined with sodium aluminate (to buffer pH) using specialized equipment and a barge that ensure the precise placement of the material in Lake Morey. Upon mixing with the lake water, precipitate (floc) is formed and has active sites for P to bind. The resulting compound is insoluble in water and the bound phosphorus can no longer be used to fuel the algae. As the floc settles, phosphorus and particles are removed from the water column leaving the lake noticeably clearer. The floc then forms a thin layer on the bottom that binds the phosphorus as it leaches out of the bottom sediments during internal loading events. The floc layer keeps the phosphorus from entering the overlying water and makes it unavailable to the algae.

4.2 Aluminum Dose & Estimated Cost

SLM specifically recommends:

- Lakebed sediments in areas greater than 26 ft in depth experience summer anoxia and contribute P internally to the overlying water column. This area is 379-ac in size.

- Our study (in collaboration with Dr. Ken Wager at Water Resource Services) found that sediments in this 379-ac zone need to be supplemented with 33.50 g Al/m^2 via buffered alum application to inactivate available sediment P and reduce internal P release. To provide a margin of safety, the aluminum requirement was rounded up to 35 g Al/m^2. For purposes of comparison, the 1986 Lake Morey aluminum dose at Lake Morey was 44 g Al/m^2. The current dose is 20% lower indicating that there are likely some residual benefits from the previous alum application.

- This would require 105,330 gallons of alum and 52,665 gallons of sodium aluminate
- Cost estimate for this strategy is $740,000

- Cost estimate is lump sum and include all contractor costs associated with applying the alum and sodium aluminate (chemicals, delivery, application services, taxes, mobilization, demobilization, incidentals, etc.). Note that this is an estimate, not a quote from SLM.

4.3 Lanthanum Dose & Estimated Cost (Phoslock®)

Bentonite encapsulated Lanthanum (Phoslock®) was also considered as a P inactivate for Lake Morey. As recommended by Phoslock® staff, 558,400 lb of Phoslock® is required to the available sediment P. The lump sum cost estimate (chemicals, delivery, application services, taxes, mobilization, demobilization, incidentals, etc.) for this strategy is $1,655,000. Although SLM utilizes Phoslock® as a lake management tool, we are not recommending it for Lake Morey as:

- Alum is a more cost-effective option for inactivating the pool of available sediment P.

- SLM has the equipment and experience to moderate potential pH changes with sodium aluminate.

- Alum has proven to be a successful tool to address internal P loading at Lake Morey (the 1986 Lake Morey alum/sodium aluminate application of 44 mg Al/m^2 was effective for 35+ years).

4.4 Project Specific Considerations for Alum

4.4.1 Chemical Application Conditions

- The contractor must apply the alum and sodium aluminate in accordance with the following table:

Acreage	Al Dose (g/m2)	Aluminum Sulfate (gal/ac)	Sodium Aluminate (gal/ac)	Max Predicted Al (mg/L)	Max Allowable Al (mg/L)
379	35	278	139	9.55	4.25*

*Determined from EPA Aluminum Calculator using the following Lake Morey data collected on 11/29/22: Hardness = 68.9 mg/L; pH = 7.63; DOC = 2.47 mg/L.

- The contractor shall monitor, evaluate and adjust application rates to attain the target dose above.
- To maintain conditions below the maximum allowable Al concentration:
  - The contractor shall apply the first half dose over the entire 379-ac application zone.

  - The contractor shall apply the second half dose over the entire 379-ac application zone at least 24 hours after the first dose.

4.4.2 Other Application Conditions

Many states have expanded the permit requirements for alum applications. While these requirements are not a restriction for the use of alum, they do require a greater level of performance and requirements from the contractor. Although SLM feels that high expectation from the contractor have always been important, we are now making even stronger project specification recommendations. In addition to standard alum project specifications (available upon request) we endorse the following requirements.

- Project Experience/Recommendations with large-scale alum applications and experience with the permitting and reporting processes.
  - The contractor must have conducted whole-lake alum treatments in a minimum of three lakes that are 300 surface acres or more in size, within the last five years. Chemical application experience on these projects should include application of alum and sodium aluminate as nutrient inactivants. Provide brief project descriptions and client contact information for a minimum of three, but not more than five, such projects. Detail contractor experience with current state alum permitting process.
- Strict insurance requirements, including pollution liability insurance (example specifications available upon request).
- Responsible bidder form. The form asks for experience on similar projects, references, etc. Requires contractor to sign verifying that they are qualified/meet the qualifications. Provides a definition of a responsible bidder (example specifications available upon request).
- Project supervision. Contractor provides a skilled and experienced superintendent who will be onsite during the application and will not have multiple project responsibilities at the same time (example specifications available upon request).
- Project duration. Limit on the number of days the contractor has to complete the project. The estimated duration limit for the Lake Morey application is 10-20 days (example specifications available upon request).
- Safety. Recommend requiring an OSHA compliant contractor (example specifications available upon request).
- Ability to calculate jar test doses, conduct jar testing, collect hourly pH measurements in the alum application zone throughout the project, evaluate wind speed and direction effects on the application process.

5 Appendix A. P-Fractionation Lab Results

Station	Moisture content (%)	Dry bulk density (g/cm^3)	Wet bulk density (g/cm^3)	Organic content (LOI, %)	Loosely-bound P P (mg/g)	Iron-bound P P (mg/g)	Labile organic P P (mg/g)	Aluminum-bound P P (mg/g)
S1	53.6	0.649	1.377	4.0	0.025	0.101	0.062	0.045
S2	85.7	0.157	1.079	16.6	0.035	0.071	0.274	0.098
S3	88.7	0.121	1.060	18.2	0.043	0.091	0.298	0.130
DH1	92.1	0.083	1.042	17.6	0.036	0.120	0.227	0.151
DH2	89.8	0.109	1.055	17.7	0.107	0.128	0.249	0.530
N1	83.8	0.179	1.092	15.4	0.012	0.094	0.151	0.094
N2	85.6	0.157	1.080	16.2	0.022	0.149	0.192	0.119
N3	88.7	0.121	1.060	18.7	0.030	0.135	0.306	0.178
N4	90.7	0.099	1.049	18.6	0.082	0.113	0.312	0.343
W1	84.1	0.176	1.092	14.5	0.024	0.073	0.168	0.074
W2	90.1	0.105	1.051	20.7	0.055	0.070	0.324	0.177
W3	90.7	0.099	1.049	18.3	0.055	0.081	0.232	0.152