H2Ohio Technology Assessment Program (TAP)

Final Report

Assessment of Nutrient Management Technology Submission

Phoslock® Phosphorus Locking Technology

January 2022

TETRA TECH

EXECUTIVE SUMMARY

SePRO of Carmel, Indiana has submitted a technology proposal for Phoslock® Phosphorus Locking Technology to Ohio Environmental Protection Agency' (Ohio EPA's) H2Ohio Technology Assessment Program (TAP) for the purpose of addressing the Lake Erie algal blooms and associated nutrient loading. The TAP objectives addressed by Phoslock® are to reduce nutrient loading to rivers, streams, and lakes, reduce the toxicity of algal blooms, and to improve nutrient removal in wastewater treatment systems, specifically with small (e.g. lagoon) and decentralized systems. Phoslock®, when applied to surface waters, can inactivate both soluble reactive phosphorus (SRP) in the water column and releasable phosphorus in the sediment. Phoslock® can be applied to the surface water of a waterbody in its dry clay form or as a slurry, or it can be injected at the sediment-water interface to target reducing the sediment release of phosphorus (internal loading). According to SePRO, Phoslock® is most effective in SRP inactivation when applied to lentic waterbodies that have excessive SRP in the water column or nitrogen to phosphorus ratios that favors cyanobacteria growth. The use of Phoslock® in this manner is claimed to reduce water column SRP concentrations to less than 10 micrograms per liter (μg/L) within 24 hours of treatment. Phoslock® is also claimed to be exceptionally efficient at inactivating sediment iron-bound phosphorus that can be released under anoxic conditions, commonly observed in the summertime in waterbodies.

This report evaluates Phoslock® against a suite of criteria identified by the TAP using information provided by SePRO and obtained elsewhere. Tetra Tech determined that the active ingredient within Phoslock®, lanthanum, binds with SRP within the water column and reduces and/or prevents release of SRP from lake sediments with minimal impacts to the environment and aquatic life. There are numerous studies documenting reductions in lake phosphorus and chlorophyll concentrations following Phoslock® treatment. Phoslock® may also provide additional benefits such as stabilizing the sediment-water interface to reduce resuspension under turbulent conditions and reducing the germination of dormant cyanobacteria (akinetes) at the sediment-water interface. The primary limitation of Phoslock® appears to be its inability to react and inactive particulate forms of phosphorus within a waterbody. Therefore, Phoslock® should be applied to a waterbody during the fall or spring when no algal blooms are present and when SRP concentrations are high. The cost of Phoslock® has also been reported to be more expensive than other phosphorus inactivation products such as alum or buffered forms of alum. However, the comparison of costs between Phoslock® and alum is complicated due to the fact that alum removes both particulate P and SRP, whereas Phoslock® only removes SRP. Finally, it should be noted that most of the Phoslock® applications around the world have been on small waterbodies with surface areas less than 100 acres. There is limited post-application data available to assess the long-term effectiveness or success of larger treatments.

Tetra Tech's recommendation for the location of a technology demonstration would be a small to moderate sized waterbody within the Lake Erie basin where internal loading of phosphorus has been demonstrated to be the driver of cyanobacteria production and makes up over 85% of the total summer loading. Tetra Tech would recommend a demonstration treatment be conducted in the early spring and/or late fall when SRP concentrations in the water column would be at their highest to maximize binding with lanthanum.

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ACRONYMS/ABBREVIATIONS

Acronyms/Abbreviations	Definition
µg/L	micrograms per liter
ANSI	American National Standards Institute
CSIRO	Australian Commonwealth Scientific and Industrial Research Organization
DOC	Dissolved Organic Carbon
EC50	Half maximal effective concentration
HABs	Harmful Algal Blooms
lb.	pound
lbs.	pounds
LMB	lanthanum modified bentonite clay
mg/L	milligrams per liter
N	Nitrogen
NICNAS	National Industrial Chemical Notification and Assessment Scheme
NSF	National Sanitation Foundation
Ohio EPA	Ohio Environmental Protection Agency
OSHA	Occupational Health and Safety Administration
P	Phosphorus
QAPP	Quality Assurance Project Plan
REE	Rare earth element
RFT	Request for Technology
SRP	Soluble reactive phosphorus
SRTC	SePRO Research & Technology Campus
TAP	Technology Assessment Program
Tetra Tech	Tetra Tech, Inc.
TP	Total phosphorus
TSCA	Toxic Substances Control Act
USEPA	United States Environmental Protection Agency
WLEB	Western Lake Erie Basin

1.0 INTRODUCTION AND BACKGROUND

H2Ohio (http://h2.ohio.gov) is Ohio Governor Mike DeWine's comprehensive, data-driven water quality plan to reduce Harmful Algal Blooms (HABs), improve wastewater infrastructure, and prevent lead contamination. Governor DeWine's H2Ohio plan is an investment in targeted solutions to help reduce phosphorus runoff and prevent algal blooms through increased implementation of agricultural best management practices and the restoration of wetlands; improve wastewater infrastructure; replace failing home septic systems; and prevent lead contamination in high-risk daycare centers and schools.

HABs have been a concern in Lake Erie for decades, and the State of Ohio has a long history of developing solutions to address them. In support of these efforts, state agencies are often presented with new approaches for addressing HABs. These approaches often involve technologies and products that are typically innovative, proprietary, and span multiple scientific disciplines; the efficacy and feasibility of these proposals must be evaluated. To support this H2Ohio objective, the Ohio Environmental Protection Agency (Ohio EPA) worked with the Ohio Lake Erie Commission to create a public advisory council - the Technical Assessment Program (TAP) Team. The H2Ohio TAP Team is comprised of representatives from the private sector, public sector, trade associations, and non-profit companies. The H2Ohio TAP team is conducting an evaluation of technologies designed to treat, control, and reduce HABs in the Lake Erie watershed. H2Ohio initiated the TAP to solicit and evaluate technologies that support one or more of the following five goals:

1. Reduction of nutrient loading to rivers, streams, and lakes;
2. Removal of nutrients from rivers, streams, and lakes;
3. Reduction of the intensity or toxicity of algal blooms;
4. Recovery of nutrients from animal waste; and
5. Improvement of nutrient removal in wastewater treatment systems.

The H2Ohio TAP Team worked to solicit and prioritize technology proposals for further review. A Request for Technologies (RFT) was developed and issued by the Ohio EPA in November 2020 (H2Ohio TAP, 2020). The H2Ohio TAP conducted a thorough evaluation of the 40+ proposals received in response to the RFT and selected 10 technologies for further evaluation. The developers of these 10 technologies were given an opportunity to provide additional information and supporting data to allow an independent evaluation of their technology by a third party, Tetra Tech, Inc. (Tetra Tech).

As a contractor to the Ohio EPA ,Tetra Tech conducted an independent third-party evaluation of the 10 technologies selected by the H2Ohio TAP team. The goal of the evaluation was to provide a general assessment of the potential effectiveness, implementability, readiness, and cost of deploying each technology. Select technologies may eventually be demonstrated in the field under future H2Ohio programs.

2.0 PURPOSE

The primary purpose of the technology assessment and evaluations was to conduct a comprehensive scientific evaluation of the selected technologies to determine if and how they could be utilized to address HABs in Lake Erie.

Based on input from Ohio EPA and the H2Ohio TAP team Tetra Tech established primary (P1 & P2) and secondary (S1 & S2) objectives for the third-party evaluation program. The primary objectives are critical to the technology evaluation and involve conclusions regarding technology performance that are based on quantitative and semi-quantitative data. The primary objectives for the evaluations of the participating technologies are as follows:

- P1: Effectively assess the performance, cost-effectiveness, and reliability data gathered from each vendor with regard to one or more of the 5 H2Ohio goals:
    - Reduce nutrient loading to rivers, streams, and lakes:
    - Remove nutrients from rivers, streams, and lakes:
    - Reduce the intensity or toxicity of algal blooms
    - Recover nutrients from animal waste:
    - Improve nutrient removal in wastewater treatment systems, specifically with small (e.g. lagoon) and decentralized systems
- P2: Ensure that the evaluations are completed by appropriate personnel using a documented, consistent approach and level of detail, to include:
    - Proof of concept review
    - Fatal flaw analysis
    - Review of previous implementation of the technology or similar technologies
    - Review of data quality objectives
    - Review of quality assurance/quality control procedures and reports
    - Evaluation of scalability
    - Information gap evaluation
    - Evaluation of cost; both total and by unit, such as nutrient reduced/removed
    - Feasibility review for a proposed demonstration project
    - Feasibility review for full scale implementation
    - Statement of probability of success

The secondary objectives pertain to Tetra Tech's approach to assessing and presenting the information and thus support the primary objectives.

The secondary objectives for Tetra Tech's evaluation are as follows:

- S1: Prepare Comprehensive Scientific Assessment and Recommendations Reports for each technology that will support potential users' ability to make sound judgements on the applicability of the technology to a specific site and to compare the technology to alternatives.

- S2: Ensure that project deliverables follow consistent format and similar levels of detail. Each report will contain:
  - A summary of the technology and results of past uses of the technology;
  - Results of conceptual model review, fatal flaw analysis, and information gap evaluation;
  - A statement of probability of success and scalability of the project;
  - Verification of cost estimates at various implementation levels;
  - Results of the feasibility review for a potential demonstration project and full-scale implementation of the technology;
  - Verification of claims made by applicants.

The technology evaluation consisted of the (1) collection; (2) evaluation; and, (3) summarizing and reporting of data on the performance and cost of each technology. These data provided the basis for meeting the primary objectives.

Most data supporting these evaluations were provided by the technology developers and Tetra Tech attempted to verify it using independent sources, when available. Tetra Tech focused its verification efforts on key aspects of the technology (e.g., effectiveness, cost) as well as any claims that seemed questionable. Otherwise, Tetra Tech assumed information provided by the vendor to be accurate. Instances where Tetra Tech is unsure of a claim being made by the vendor are noted in the report. In some cases, information was also obtained from the peer-reviewed scientific literature. Tetra Tech worked with each developer to obtain the data necessary to meet the primary and secondary evaluation objectives.

Tetra Tech then completed an independent evaluation of the data provided by each developer and prepared separate reports for each technology evaluation, following a consistent report format. This report provides a summary of our review of Phoslock®.

3.0 TECHNOLOGY OVERVIEW

Phoslock® is a registered trademark of Phoslock® Environmental Technologies LTD, of which SePRO is the only authorized United States distributor. Phoslock® phosphorus (P) locking technology is designed to inactivate soluble reactive phosphorus (SRP), the most bioavailable form of phosphorus. Phoslock can bind SRP present in the water column and it can also prevent the release of SRP from the sediment. As many cyanobacteria are capable of nitrogen (N)-fixation, SRP is often the critical nutrient which regulates growth and proliferation. Furthermore, by reducing the abundance of bioavailable SRP in the water column, the N to P ratio increases and N-limitation is overcome, reducing the competitive advantage of N-fixation by toxic cyanobacteria, and leading to enhanced competition from non-toxic, beneficial algae. The use of Phoslock® in phosphorus rich waterbodies can result in a shift of phytoplankton assemblage from a dominance of toxin producing cyanobacteria to a more diverse assemblage that has a much lower potential for toxin production and can benefit food webs.

Phoslock® may also provide additional benefits such as stabilizing the sediment-water interface to reduce resuspension under turbulent conditions and reducing the germination of dormant cyanobacteria (akinetes) at the sediment-water interface (ongoing research). This ability to stabilize the sediment-water interface makes

Phoslock® an appropriate tool to reduce sediment P-release in shallow waterbodies that experience higher wind and wave mixing.

4.0 TECHNOLOGY EVALUATION

This section of the report addresses each of the criteria identified by Ohio EPA to be included in the independent evaluation process.

4.1 CONCEPTUAL MODEL REVIEW

Phoslock® is a highly specific and permanent phosphorus-binding agent that inactivates excess soluble phosphorus in waterbodies to reduce nutrients and restore water quality. SePRO is the only authorized United States distributor of Phoslock®, which is a registered trademark of Phoslock® Environmental Technologies LTD. Phoslock® is lanthanum modified bentonite clay (LMB) and was developed by the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO), an Australian government agency, in the 1990s.

The phosphorus locking technology of Phoslock® is designed to inactivate SRP within a waterbody, which is the most bioavailable form of phosphorus available for plant uptake. Phoslock® is also designed to prevent the release of SRP from the sediments of a waterbody. Phoslock® contains lanthanum (5%), which is a naturally occurring rare earth element (REE), embedded inside a modified bentonite clay matrix (~95%). Lanthanum has a very high binding affinity for SRP. When lanthanum binds with phosphorus the elements react to form rhabdophane ($LaPO_4 – nH_2O$) which is an inert and insoluble mineral resistant to dissolution under pH changes or anoxic conditions. The formation of rhabdophane essentially serves as a permanent sink for SRP, reducing water column SRP concentrations as well as the total mass of potentially releasable phosphorus in the sediment. Ageing of rhabdophane may lead to the formation of monazite ($LaPO_4$), which has an even lower solubility than rhabdophane (Copetti et al., 2016).

Phosphorus is often the limiting nutrient which regulates the growth and proliferation of phytoplankton and cyanobacteria in a waterbody. In waterbodies with large concentrations of phosphorus, nitrogen can become the limiting nutrient, however many species of cyanobacteria are capable of fixing atmospheric nitrogen to meet the demand. By reducing the concentration of SRP in the water column, the nitrogen to phosphorus ratio increases and nitrogen-limitation is overcome, reducing the competitive advantage of nitrogen-fixation by cyanobacteria. The use of Phoslock® in phosphorus rich waterbodies can result in a shift in the phytoplankton assemblage from a dominance of toxin producing cyanobacteria to a more diverse assemblage of diatoms, green algae, and others. This shift results in a much lower potential for toxicity as well as benefits to the food web.

According to SePRO's response to the H2Ohio RFT, the reaction between SRP and lanthanum is very thermodynamically favorable under a wide variety of environmental conditions – hard or soft waters, marine, brackish, or freshwaters, oxic or anoxic conditions, and throughout a range of pHs from approximately 4 to 10. During a laboratory-scale evaluation, however, it was found that lanthanum may be released from LMB if exposed to saline environments (Douglas et al., 2000). The results of this experiment have indicated that applications of LMB should be avoided in moderately saline environments (Copetti et al., 2016), although this would not be a limiting factor to application in Ohio. Several studies have also indicated a lanthanum to SRP binding ratio above the expected stoichiometric ratio of 1:1 suggesting interference in the rhabdophane formation (Copetti et al., 2016). Reitzel et al. (2013) found that LMB performed better in soft waters compared to hard waters, however a study using water from 16 Danish lakes did not show any correlation between alkalinity and the phosphorus binding capacity of LMB (Dithmer et al., 2016). Instead, this study found a significant negative correlation between dissolved organic carbon (DOC) concentrations and the SRP binding capacity of LMB and demonstrated that DOC interfered with the rhabdophane formation. This is also supported by several other studies (Douglas et al., 2000 and Lürling et al., 2014). However, given enough time it was found that SRP will eventually bind with the lanthanum, overcoming the interference by DOC (Dithmer et al., 2016). Lürling et al. (2014) suggests a DOC threshold of 10 mg/L. DOC concentrations at sites in Maumee Bay and Sandusky Bay, Lake Erie ranged from near 2.5 to 5.0 mg/L in 2009 (Moitra, 2012), lower than the suggested threshold in Lürling et al. (2014) and lower than most of the lakes in Dithmer et al. (2016b) that had lanthanum to phosphorus binding ratios greater than 1, indicating interference.

The bond between SRP and lanthanum is not impacted by anoxic conditions. Ross et al. (2008) found that LMB did not release phosphorus under anoxic conditions. Laboratory investigations on the effect of pH on the binding of SRP by LMB indicated maximum binding efficiency in a pH range of 5 to 7 with absorption capacity decreasing at pH higher than 9 (Ross et al., 2008; Haghseresht et al., 2009; Reitzel et al., 2013). However, exposing phosphorus saturated LMB to pH 9 did not lead to any significant release of phosphorus, confirming the stability of rhabdophane (Reitzel et al., 2013; Haghseresht et al., 2009).

Phoslock® does not impact vital waterbody characteristics such as pH, alkalinity, conductivity, or hardness and can be applied to a waterbody with minimal equipment. Figure 1 shows the typical equipment used to apply Phoslock® to a moderately-sized waterbody. It requires 100 pounds (lbs.) of Phoslock® to remove 1 pound (lb.) of phosphorus (equivalent to approximately 3 lbs. of SRP) from a waterbody. Phoslock® can be applied to the surface of a waterbody in its dry clay form or as a slurry – mixed with water from the treatment location. This appears to be the most common application method. Phoslock® can also be injected into the sediment-water interface. Phoslock® is primarily used to inactivate SRP in the water column and prevent the release of SRP from the sediment, however the SePRO proposal indicated that Phoslock® has recently been shown to be effective in reducing SRPs concentrations in a variety of additional settings, such as lagoons, dairy and municipal wastewater effluent, wetlands, holding ponds, and agricultural soils. Tetra Tech did not review any case studies of these types of applications in the scientific literature.

Phoslock® works to permanently remove potentially releasable SRP contained in the sediment of a waterbody and will continue to bind SRP until all of the active ingredient (lanthanum) has reacted and formed rhabdophane. According to the SePRO, one Phoslock® treatment can significantly reduce water column phosphorus concentrations and improve water quality for 10+ years without any operational or disposal requirements. The proposal also states that if watershed management leads to reduce inputs of phosphorus to a waterbody, then no future Phoslock® applications are required to maintain water quality benefits following the first application. However, if external phosphorus loading continues, then future Phoslock® applications may be required based on the total mass of phosphorus input into the waterbody.

Figure 1 - Example of a Moderate Sized Phoslock® Application

Phoslock® application at Ladybird Lake in Austin, TX. Photo obtained from EutroPHIX (a SePRO company).

SePRO claims that Phoslock® is much more effective than other phosphorus sequestration technologies in shallow or turbulent waterbodies due to the ability of the clay particles to enhance sediment stability and fill small pores in the surficial sediment. Egemose et al. (2010) found that the addition of Phoslock® to lake sediments in a laboratory-controlled experiment generated a high density layer on top of the sediment, compacting and consolidating the sediment, and therefore increased the erosion threshold. This study also determined that Phoslock® creates an active layer on top of the sediment which is able to bind phosphorus from the water column during/after resuspension events. Several resuspension events appeared to reduce the release of lanthanum from the treated sediments most likely due to the increased consolidated sediments and the additional binding of phosphorus left less lanthanum available for release (Egemose et al., 2010). Yin et al. (2016) also concluded that geoengineering materials (Phoslock®) can solidify surface sediments and make them more stable when subjected to wind disturbance. The results of several laboratory experiments indicated that the addition of Phoslock® can limit the mobility and supply of phosphorus in sediments under the disturbance of frequent resuspension events, and therefore, the flux of phosphorus across the sediment-water interface is reduced (Yin et al., 2016).

Copetti et al. (2016) stated in their review of eutrophication management in surface water using LMB that there is a scarcity of long-term studies and that the potential long-term impacts derived from LMB applications have so far been largely unexplored. According to Copetti et al. (2016) there are several cases that have been monitored for up to 7 years post LMB addition without any signs of ecosystem or community level deterioration and eutrophic lakes. These include two lakes in the Netherlands, Rauwbraken and De Kuil, which both showed strong expansion of submerged macrophytes and overall improved ecological structure following LMB addition.

4.2 FATAL FLAW ANALYSIS

Fatal flaws of Phoslock® are not apparent. Its primary limitation appears to be its inability to react and inactive particulate forms of phosphorus within a waterbody. Phoslock®, as stated in SePRO's proposal, selectively reacts with SRP to convert bioavailable phosphorus into a stable mineral that cannot be released under environmentally relevant conditions, therefore reducing the overall pool of phosphorus that can stimulate algal growth. There is a significant amount of phosphorus within a waterbody that is not in a soluble form but present in a particulate form. This includes phosphorus attached to suspended sediments within the water column or sediments entering a waterbody from the watershed, as well as any detritus or terrestrial material that may fall into a waterbody. A large portion of particulate phosphorus in a waterbody is also contained within the phytoplankton. During a large or moderate algal bloom, SRP concentrations will most likely be at their lowest concentration due to the active uptake of phosphorus by algae.

Particulate forms of phosphorus may not be bioavailable, or soluble, at a particular point in time, but changing environmental conditions within a waterbody can lead to changing bioavailability of phosphorus. For example, during a large or moderate algal bloom SRP concentrations in the water column may not be detectable but total phosphorus (TP) concentrations may be quite high due to the large amount of phosphorus contained within the algal cells. When the bloom collapses the phosphorus contained within the algal cells is then released into the water column as SRP. The TP concentration remains the same but there has been a shift in the form of phosphorus within the water column. For this reason, it has been strongly recommended that Phoslock® not be applied to a waterbody during an algal bloom when SRP concentration are low (Copetti et al., 2016). The efficiency of Phoslock® to bind with SRP also decreases markedly at pH higher than 9. Such high pH values are often associated with strong photosynthetic activity (due to both macrophytes and phytoplankton) within a waterbody, making the timing a crucial component of a Phoslock® application. SePRO recommends targeting April/May, before an algal bloom has started, or after the growing season (October/November) for a Phoslock® application. SePRO also recommends that Phoslock® be primarily implemented as a proactive strategy to prevent high SRP release from the sediments that can fuel algal blooms rather than a reactive strategy to reduce or treat blooms. However, it may have some utility in preventing secondary algae blooms because it can bind the SRP that is released after algal cells degrade following a bloom collapse.

4.3 REVIEW OF PREVIOUS IMPLEMENTATION OF PHOSLOCK®

Phoslock® has been applied to more than 300 eutrophic lakes across a wide geographic distribution including lakes in Europe, Australia and New Zealand, North America, Asia, Africa and South America. Closer to the Lake Erie basin, Phoslock® has been used in Swan Lake, near Toronto, Canada, Lac Bromont near Montreal, Canada, and by Princeton Hydro in a variety of Pennsylvania, New York, and New Jersey lakes. Most of the Phoslock® applications around the world have been on small waterbodies with surface areas less than 100 acres. There is very limited pre and post-application data available to assess the effectiveness of larger treatments.

The first full scale application of Phoslock® was conducted by Robb et al. (2003) in two impounded river sections in Western Australia, the Canning and Vasse Rivers. The authors found a marked reduction of SRP concentrations in the treated areas compared to untreated areas in both systems and a substantially reduced phosphorus outflow from the sediments during the course of the trial. The impact of phosphorus reduction on the phytoplankton growth was clearly evident in the Vasse River which was phytoplankton dominated but less clear in the alternating phytoplankton to aquatic plant dominated Canning River, which also is subject to external nutrient inputs (Robb et al., 2003).

Spears et al. (2016) assessed the responses of TP and SRP during the 2 years following LMB applications relative to pre-application conditions (2 years pre-application) across 18 different lakes. The 18 different lakes were located in the United Kingdom (5), The Netherlands (2), Germany (10), and Canada (1) and ranged in size from 2.2 to 158 acres with mean depths ranging from 0.8 to 8.8 meters (2.6 to 28.9 feet). The Phoslock® mass applied to the 18 lakes ranged from 4.7 to 230 tons. Across all lakes there was a general reduction in SRP concentrations to very low levels following application. The reduction in SRP concentrations was large in all seasons with median annual SRP concentrations decreasing from 19 µg/L to 5 µg/L. Median annual TP concentrations also decreased significantly across all lakes from 80 µg/L during the 24 months pre-application to 30 µg/L post-application. Spears et al. (2016) also found decreased chlorophyll *a* concentration (15 lakes) and increased secchi disk depths (15 lakes) following Phoslock® applications. Phosphorus concentrations following Phoslock® application varied across the lakes but were correlated positively with DOC concentrations. This suggests that DOC is a potential factor confounding the operational performance of LMB (Spears et al., 2016). The findings in Spears et al. (2016) indicate variable water quality responses across the multiple treated lakes, most likely due to multiple and interacting confounding processes operating within the different treated lakes and their watersheds. Because of this the authors stressed the need for comprehensive site-specific understanding of a waterbody to support the application of Phoslock® or similar management measures.

Epe et al. (2017) conducted a long-term study which examined the water quality characteristics of a polymictic, eutrophic, swimming lake in central Germany, Lake Bärensee, following the application of LMB. Lake Bärensee is a small (14.8 acre), artificial, excavated lake that suffered from frequent cyanobacteria blooms caused by nutrient enrichment, mostly from swimmers, runoff and phosphorus release from the sediments. Lake Bärensee was first treatment with LMB in 2007. Smaller reapplications of LMB were conducted in 2010 and 2013 when phosphorus concentrations exceeded a defined threshold as a result of the ongoing nutrient inputs, primarily by swimmers. Mean TP concentrations decreased from 61 µg/L in 2007 to 36 µg/L in 2008 – 2010 before reapplication of LMB. After the reapplication of LMB, mean TP was 32 µg/L in 2010 – 2013 and 41 µg/L in 2014 and 2015. Annual mean SRP concentrations decreased from 13 µg/L in 2007 to 5 µg/L (detection limit) in 2008 through 2014. Annual mean SRP increased to 16 µg/L in 2015. Chlorophyll *a* concentrations decreased from 35.9 µg/L in 2007 to 19.2 µg/L in 2008 – 2010. There was another large decrease in chlorophyll *a* following reapplication with annual mean concentrations of 11.7 µg/L in 2010 – 2013 and 10.1 µg/L in 2014 and 2015. According to Epe et al. (2017), local federal authorities visited the lake regularly and did not observe massive blooms of cyanobacteria. Swimming bans have not occurred since 2007.

Dithmer et al. (2016b) examined the behavior of LMB and its interactions with phosphate and other substances present in bed sediments across 10 lakes treated with LMB between 2006 and 2013. Specifically, the authors examined the responses in sediment characteristics including lanthanum and phosphorus fractions and binding forms, phosphorus adsorption capacity of discrete sediment layers, and pore water phosphorus concentrations. This study demonstrated that LMB treatment of the 10 lakes resulted in the sequestration of phosphorus in the form of rhabdophane. Lanthanum was distributed across the upper 10 cm of bed sediments in most of the lakes. Additionally, the study concluded that LMB was generally mixed vertically in the sediments at the deepest area of the lakes, which may have reduced phosphorus removal efficiency at the sediment water interface at the whole lake scale. At the time samples were collected, study results indicate that the lakes generally had a low SRP sediment flux, indicating that LMB, or other phosphorus binding properties of the sediments, controlled the release of phosphorus across the sediment-water interface. The two exceptions were Lake Het Groene Eiland and Lake Blankensee which showed significant release of phosphorus at the time of sampling. The lanthanum to phosphorus ratios in the sediments of the 10 lakes were generally above 1, which indicates that not all the lanthanum had reacted with the phosphorus (Dithmer et al., 2016). The lanthanum containing sediment layers did not display any increased SRP binding capacity and the excess lanthanum did not bind with excess SRP during a 24-hour incubation experiment. This indicates that not all of the lanthanum in the LMB can bind with SRP or that there were interactions with DOC or other chemical constituents of the waterbody that reduced the operational performance of the LMB (Dithmer et al., 2016).

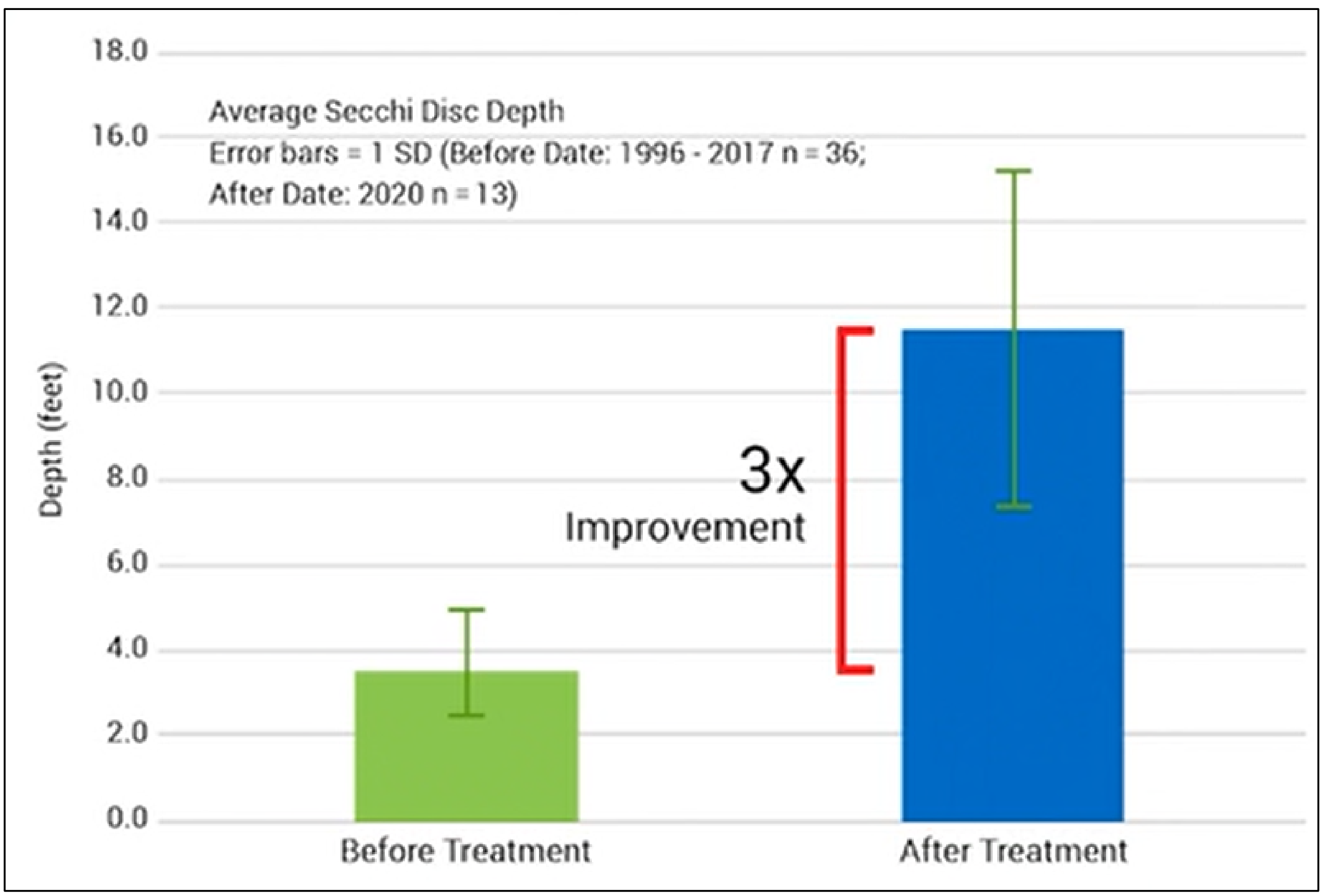
Nürnberg (2017) summarized the water quality results and predictions of the attempted management of cyanobacteria by Phoslock® in Canadian Lakes. At the time the paper was published, 4 systems had been treated with Phoslock® in Canada with a 5th waterbody planned for treatment in 2017. All of the lakes were treated due to recurrent cyanobacteria blooms. The first full Canadian lake Phoslock® application was in 2013 on a small (13.5 acre) urban lake, Swan Lake. There was a significant decrease in mean TP from 250 µg/L before application to 60 µg/L during the second post-treatment growing season. There was also a related decline in algal biomass (Nürberg, 2017). There was a lack of response in the algal biomass in the first treatment year which was attributed to the late application, after phosphorus had been released from the winter bottom sediments and already consumed by phytoplankton. Preliminary results at the time of publication indicated that despite successful management of resident geese in the summer of 2016, TP concentrations in Swan Lake were as high as they had been pre-treatment. Henderson Lake, an urban, highly eutrophic lake in Alberta was treated in April 2016. Preliminary TP data for 10 dates and 5 sites showed a significant decrease in TP, from 220 µg/L pretreatment to 24 µg/L in the growing season immediately following application (Nürnberg, 2017). Nürnberg (2017) concludes that for a successful application of Phoslock®, and any in-lake treatment, the external phosphorus load, especially SRP, should be much smaller than the internal load and all external sources, even less obvious ones (e.g. waterfowl, groundwater) must be evaluated. This is not the case for Lake Erie, as Anderson et. al. (2021) report that the upper estimate of internal phosphorus loading is comparable to the total load from the tributaries. Nürnberg (2017) also states that the timing of an application must coincide with a high bioavailable phosphorus level (SRP concentration) in the water column to ensure immediate and maximal response.

Phoslock® was applied to a portion (Landing Channel - 50 acres) of Lake Hopatcong, New Jersey's largest freshwater lake in June 2020. At the time this was the largest Phoslock® treatments to be conducted in the Northeast. Preliminary data show that the Phoslock® treatment reduced SRP concentrations in the bottom waters of Landing Channel and kept SRP at or below the detection limit through the 2020 growing season (Lake Hopatcong Foundation, 2020). Surface water SRP concentrations in Landing Channel did not appear to be impacted by the Phoslock® treatment and increased during the growing season. This could have been due to storm events and increased watershed loading (Lake Hopatcong Foundation, 2020).

Phoslock® was also applied to Kitsap Lake in Washington State in June 2020. Kitsap Lake is a 256-acre lake in the Puget Sound Region that in recent years has been plagued by HABs. Two Phoslock® applications were completed on Kitsap Lake in 2020, a water column stripping application in June and a second application in August to capture phosphorus that had been accumulating in the hypolimnion (AquaTechnex, 2021). This is believed to be the largest Phoslock® application in the United States. At this time there is limited data to assess the effectiveness of the Phoslock® treatments on SRP concentrations in Kitsap Lake. Available data suggest that the lake had a secchi disk transparency of 14 feet or greater during the summer of 2020 (AquaTechnex, 2021).

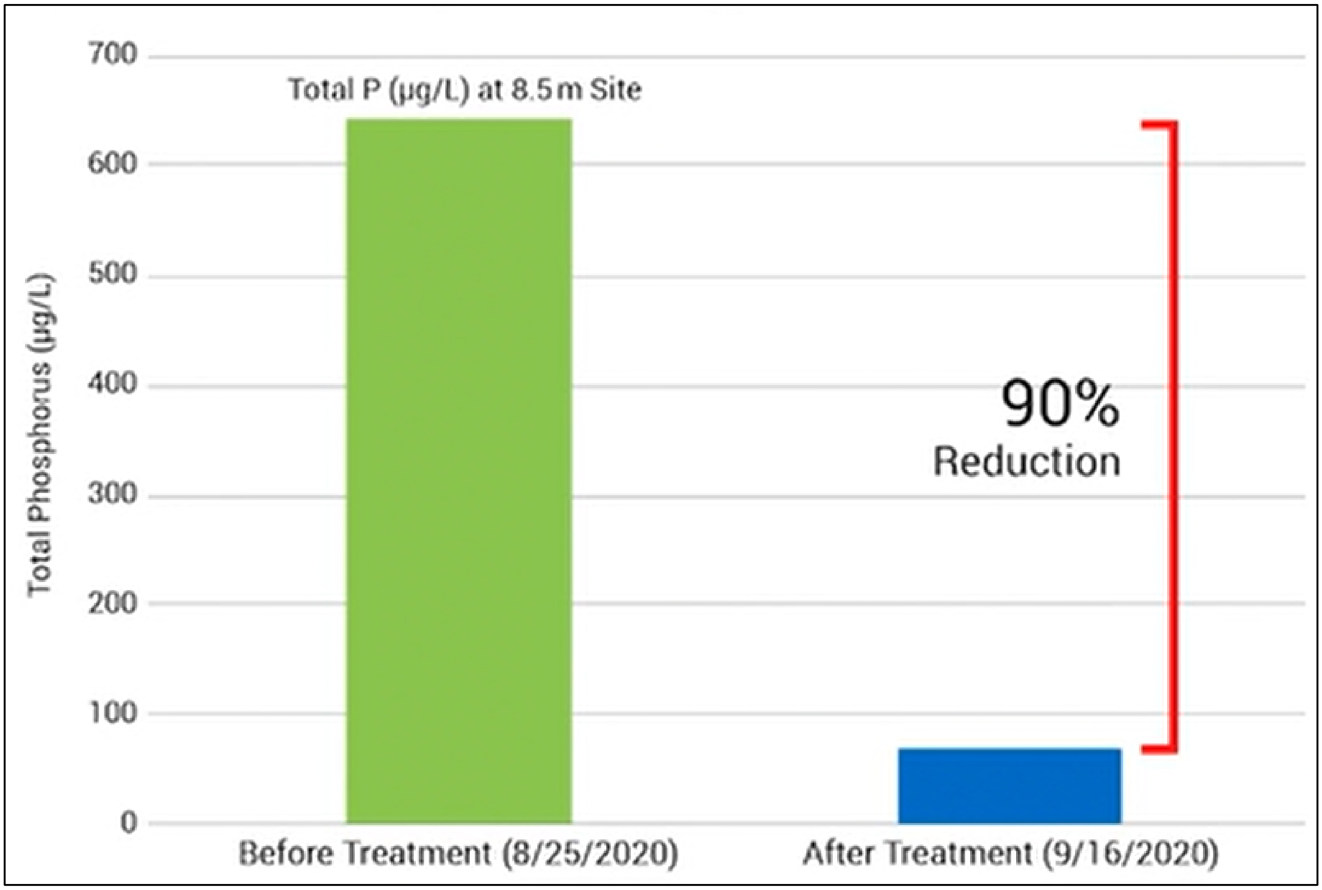
SePro provided two figures showing the short-term impacts on secchi disk (water clarity) and hypolimnetic TP in Kitsap Lake following the Phoslock® application in 2020. Water clarity improved from an average of slightly less than 4.0 ft (1.2 m) during 1996-2017 to an average of about 11.5 ft (3.5 m) in 2020 following treatment (Figure 2). Hypolimnetic TP in the deep zone of the lake decreased from around 640 µg/L in August 2020 before treatment to around 80 µg/L in September following treatment (Figure 3), which is about a 90% reduction. SePro did not provide any further data collected post-treatment (after September 2020 and 2021) to evaluate effectiveness.

Figure 2 - Kitsap Lake, WA Water Clarity Before and After Phoslock® Applications in 2020



Graphic Provided by SePRO.

Figure 3 - Hypolimnetic TP Concentrations in Kitsap Lake Before and After Phoslock® Application



Graphic Provided by SePRO.

4.4 COST EVALUATION

SePRO claims there are no operational, capital, maintenance, or decommissioning costs associated with Phoslock®. SePRO provided a range of $1.50 to $2.60 per pound of Phoslock®, with costs varying based on the scale of the project (i.e., larger projects have a lower unit cost). The application of Phoslock® to a waterbody usually requires a boat or barge, a staging area, and trained applicators. SePRO suggests the costs for equipment and applicators is generally 20-30% of the material costs at larger scales. Based on SePRO's required dosage of 100 lbs. of Phoslock® to permanently inactivate 1 lb. of phosphorus, the cost to inactivate 1 lb. of phosphorus (~3 lbs. of SRP) would generally cost between $150 and $250; refer to Table 1.

Using the cost information provided by SePRO in Table 1, Tetra Tech estimated the total cost to reduce the annual internal phosphorus load in Sandusky Bay, Lake Erie by 40% using Phoslock®. Sandusky Bay has a surface area of approximately 40,959 acres and an average annual internal phosphorus (SRP) load of 881,849 lbs. per year (Tetra Tech, 2021). Using the cost information in Table 1, provided by SePRO, the cost to mitigate or remove 1 lb. of TP in a large treatment area (>10,000 acres) is $152 per pound. SePRO also reports that inactivating 1 lb. of TP is equivalent to inactivating 3 lbs. of SRP. Therefore, the cost to reduce the SRP internal load in Sandusky Bay by 40%, or approximately 352,740 lbs., would be approximately $17,900,000.

The cost of Phoslock® can be more expensive than other phosphorus inactivation products such as alum or buffered forms of alum (Lürling et al., 2020, Lake Hopatcong Foundation, 2020; Lubnow et al., 2016; Copetti et al., 2016; Herrera Environmental Consultants Inc., 2018; Palli, 2105). Huser (2021 personal communication; Huser et al., 2016) calculated the cost of alum per mass of phosphorus removed for several lakes. Tabe 2 summarizes costs of each alum treatment per pound of TP removed, with an average cost of $134/lb of TP. This is similar to the low end of the range of costs provided in Table 1 for removal per pound of TP by Phoslock®. It should be noted that the comparison of costs between Phoslock® and alum is complicated due to the fact that alum removes both particulate P and SRP, whereas Phoslock® only removes SRP. Since the portion of TP that is SRP varies by lake and within a lake over time, there is no easy way to make a direct cost comparison.

Copetti et al. (2016) states in their review that the cost of using LMB in lake restoration may be a controlling factor due to the price of lanthanum being on the order of thousands of dollars per ton, or around one order of magnitude higher than the cost of aluminum products (e.g., alum).

Table 1 - Phoslock® Cost per Pound of Phosphorus Mitigated Based on Treatment Area

Treatment Area Size (acres)	Cost/Pound of Phosphorus Mitigated		
	Phoslock® Cost	Application Cost	Total Cost
>10,000	$130	$22	$152
5,000 to 9,999	$135	$28	$163
1,000 to 4,999	$140	$44	$184
500 to 999	$145	$59	$204
250 to 499	$150	$74	$224
100 to 249	$175	$78	$253

Table 2 - Summary of Alum Treatment Costs per Pound of Phosphorus Removed

Lake	Total Cost/Pound of TP Mitigated
Kohlman	$142.09
Bryant	$111.23
Rebecca	$121.87
Sunfish	$119.17
McCarron	$111.01
Spring	$169.65
Long	$170.61
Harriet	$39.72
Cedar	$200.39
Calhoun	$46.96
Isles	$247.74
Average	**$134.59**

*2014 costs as reported by Huser (Huser, 2021 - personal communication) were converted to 2021 dollars using the CPI Inflation Calculator on the US Bureau of Labor Statistics Website, CPI Inflation .Calculator (bls.gov)

4.5 SCALABILITY EVALUATION

Phoslock® was first implemented at field scale in the summer of 2001/2002 in Western Australia when a full-scale application was undertaken in impounded river sections of the Canning and Vasse Rivers (Robb et al., 2003). According to the SePRO proposal, Phoslock® has been successfully used at the field level scale in waterbodies ranging from less than 1 acre-ft to reservoirs larger than 1 million acre-ft. A review of the literature and information provided by SePRO indicates that Phoslock® has mostly been applied to small and moderate sized waterbodies, up to around 100 acres, or small portions of larger waterbodies (e.g. 50-acre Landing Channel in Lake Hopatcong).

There are a few of examples of larger Phoslock® applications including:

- Xingyun Lake – 8,500 acre hyper-eutrophic lake used for drinking water in China; 3,000 tons of Phoslock® applied in May 2019
- Lagoa de Pampulha - 470-acre artificial lake in Brazil; Phoslock® applications started in 2015
- Jezioro Goldap - 321-acre lake in northern eastern Poland; Phoslock® applications in December 2017 and May 2018
- Kitsap Lake – 256-acre lake in the Puget Sound Region of Washington State; two Phoslock® applications in 2020 with additional applications planned for 2021
- Lac Bromont – 119-acre lake near Montreal, Canada; Phoslock® applied in October 2017

There have not been any applications of Phoslock® to waterbodies on the scale of Lake Erie. For example, Anderson et al (2021) estimates that the area of Lake Erie that contributes to internal loading is 1.5 to 2.2 million acres.

The amount of Phoslock® required to inactivate SRP within the water column and sequester sediment phosphorus is directly related to the concentration of SRP within the waterbody and sediments. Therefore, scalability is straightforward for Phoslock® applications. However, larger applications may be limited by available equipment and application rates.

4.6 INFORMATION GAP EVALUATION

Based on SePRO's proposal and provided literature, as well as Tetra Tech's independent literature search and review, there is limited information regarding the effectiveness of Phoslock® applications in large waterbodies. Most of the available literature provides information regarding treatment effectiveness for small (100 acres or less) waterbodies. At this time limited pre- or post-treatment data has been provided for any of the 5 large applications referenced in the section above or the Lake Hopatcong treatment. It is very important to understand how Phoslock® has performed within larger waterbodies, as that would be the most applicable data to the Lake Erie basin.

SePro provided data regarding the effectiveness of the large treatment on Xingyun Lake in China where a small-scale pilot study was used to model the expected impact of a large-scale treatment. The model results were exceeded according to post-application monitoring data and a dramatic improvement in water clarity was observed. The TP concentration in Xingyun Lake decreased from 280 µg/L to 60 µg/L, which was the lowest value observed within the past 10 years.

There is also a lack of information regarding the long-term performance of Phoslock® and treatment longevity. Most available literature and studies evaluate post-treatment conditions for 24 months or less. Tetra Tech only found two studies that evaluated the impacts of Phoslock® for several years post application. Epe et al. (2017) examines nine years of phosphorus management with Phoslock® in a eutrophic, shallowing swimming lake in Germany – Lake Bärensee. Over the course of nine years, Phoslock® was applied to the lake a total of 3 times; an initial dose in June 2007 and two smaller applications in May 2010 and March 2013. Waajen et al. (2016) report long-term results of a combined LMB and iron(III) chloride ($FeCl_3$), $FeCl_3$ serving as a flocculant and LMB as the active phosphorus sorbent and ballast, treatment to Lake De Kuil in the Netherlands. This combination of a flocculant and LMB is referred to as the "Flock and Lock" method. The results of the study indicated that after the "Flock and Lock" treatment the water quality in Lake De Kuil rapidly and substantially improved. The treatment effectively precipitated a developing cyanobacteria bloom and shifted the trophic state of the lake from eutrophic to mesotrophic. This trophic state was maintained in Lake De Kuil for at least six years following treatment (Waagen et al., 2016). To our knowledge there has been no long-term (greater than 2 years) study conducted on a lake that received a one-time Phoslock® application. Copetti et al. (2016) also concluded that there is a scarcity of long-term studies following Phoslock® applications and that the potential long-term impacts derived from LMB applications have been largely unexplored.

4.7 FEASIBILITY FOR LARGE-SCALE TECHNOLOGY DEMONSTRATION

Based on discussions with SePRO representatives and information provided in their proposal, a large-scale technology demonstration with Phoslock® is possible within the Lake Erie basin. SePRO believes that Phoslock® can be applied to treat both phosphorus-rich lakes within the Lake Erie watershed to reduce phosphorus discharge into Lake Erie, as well as, within Lake Erie itself to remove excess phosphorus and prevent internal phosphorus release from the sediments. SePRO's recommendation for large-scale technology demonstration would be to apply Phoslock® to an isolated bay on the shoreline of Lake Erie. They believe this will result in a demonstration project with the highest probability of success due to the reduced potential for mixing of nutrient-rich water from the main body of Lake Erie. SePRO recommended Castaway Bay as a potential large-scale technology demonstration site. Castaway Bay is approximately 1,830 acres and is located just to the southeast of Sandusky Bay. It appears that Castaway Bay is almost completely isolated from the main waterbody of Lake Erie. However, it is unknown whether Castaway Bay has high SRP concentrations in the water column and sufficient phosphorus internal loading to drive cyanobacteria production. Prior to implementation of any large-scale technology demonstration, monitoring would need to be conducted to determine phosphorus (TP, SRP) concentrations, chlorophyll concentrations, and sediment phosphorus characteristics and the internal loading potential of the potential treatment area.

SePRO also recommended smaller options to demonstrate the potential benefit of a Phoslock® application, Mentor Harbor (~55 acres) and/or Veterans Memorial Park Lake (~25 acres). Both of these waterbodies are located in Mentor, Ohio, about 30 minutes northeast of Cleveland. SePRO believes these options would be less likely to show the intended benefit of Phoslock® because Mentor Harbor is not completely isolated from the main body of Lake Erie and Veterans Memorial Park Lake is small and does not appear to be significantly impacted by phosphorus loading.

Tetra Tech's recommendation for the location of a large-scale technology demonstration would be a small to moderate sized waterbody within the basin where internal loading of phosphorus has been demonstrated to be the driver of cyanobacteria production and makes up over 85% of the total summer loading. Tetra Tech would recommend a demonstration treatment be conducted in the early spring and/or late fall when SRP concentrations in the water column would be at their highest to maximize binding with lanthanum.

4.8 FEASIBILITY FOR FULL-SCALE IMPLEMENTATION

SePRO envisions that Phoslock® would initially be used within the Lake Erie basin to target bays and shorelines to benefit the water quality of recreational areas and benefit coastal residents. Once the smaller shoreline/bay Phoslock® projects have demonstrated substantial value and improved recreational use during critical periods, SePRO recommends that larger Phoslock® applications be completed targeting deeper sections of Lake Erie that demonstrate substantial phosphorus release due to anoxic conditions. SePRO believes these large applications could significantly reduce the total mass of phosphorus loading due to internal nutrient release. Their assumption is that this phosphorus reduction would likely have a synergistic impact on the food web, by increasing the N to P ratio which favors beneficial algae such as diatoms and greens over toxin producing cyanobacteria.

As stated earlier, Anderson et al (2021) estimates that the area of Lake Erie that contributes to internal phosphorus loading is roughly 1.5 to 2.2 million acres. Treating this large of an area with Phoslock® is most likely not feasible or practical and would have limited visible success. However, targeting areas with known high internal loading and severely degraded water quality (i.e., Maumee and Sandusky Bay) may be a feasible option. Maumee and Sandusky Bays are large areas and would be considerably larger than any Phoslock® application that Tetra Tech has reviewed and/or is aware of. However, a targeted application to Maumee or Sandusky Bay would have a better chance of showing improvement to water quality as well as a reduction in internal loading compared to an application to Lake Erie. Consideration would need to be made regarding the magnitude of external phosphorus loading to these Bays and how it would impact treatment effectiveness and longevity. Monitoring would need to be conducted pre and post treatment to determine the success of any application but specifically in terms of whether the Phoslock® ended up within the targeted treatment area and how effective it was at reducing internal loading.

4.9 PROBABILITY OF SUCCESS

Previous studies and information provided by SePRO show that Phoslock® applications have the opportunity for success in addressing nutrient loading issues that are contributing to the Lake Erie algal blooms if applications are well planned, designed, and implemented. Based on the available data and literature, it is evident that the active ingredient within Phoslock®, lanthanum, binds with SRP within the water column and reduces and/or prevents release of SRP from lake sediments with minimal impacts to the environment and aquatic life. However, the scale required of such an application within the Lake Erie basin, as well as the continuous source of nutrients coming into the lake from external sources, threatens the probability of success. Careful planning, design, and selection of an appropriate treatment location would increase the chances of success of a Phoslock® application. The high costs associated with a full-scale Phoslock® application may also be prohibitive.

4.10 FINANCIAL VIABILITY

SePRO corporation is located in Carmel, Indiana and is part of the Pesticide, Fertilizer, and Other Agricultural Chemical Manufacturing Industry. The SePRO corporation was founded in 1994 with the mission to provide plant protection and plant management products and services that fit specialized market needs (SePRO, 2021). According to their website, the SePRO corporation is dedicated to discovering and developing sustainable solutions. SePRO acquires, develops, manufactures, and markets value-added products and services that satisfy the unique needs of their customers. Additionally, SePRO has partnered with several of the top agricultural chemical companies to develop their chemistries for use in key markets. Central to that product innovation is the 410-acre SePRO Research & Technology Campus (SRTC) in Whitakers, NC. SePRO corporation has 115 total employees across all of its locations.

SePRO is the industry leader in aquatic herbicides and algaecides and just recently launched a new aquatic herbicide, ProcellaCOR. ProcellaCOR targets and provides long-term control for hydrilla, milfoil, crested floating heard, and other tough to control aquatic weeds. SePRO also recently established EutroPHIX, which is a Division of SePRO Corporation dedicated to “accelerating water resource restoration” by mitigating nutrient pollution and management HABs.

Tetra Tech is not aware of any financial viability concerns with SePRO.

4.11 QAPP

Most of the data that was evaluated as part of this assessment was obtained from peer-reviewed manuscripts and journal articles. The assumption can be made that data provided within peer-reviewed literature is reliable and suitable for purposes of this assessment. Tetra Tech does not have information regarding data quality and was not provided a Quality Assurance Project Plan (QAPP) by SePRO for pre and post treatment data collected at Kitsap Lake, Lake Hopatcong, or Xingyun Lake.

4.12 DATA VALIDATION

Since most of the data used to prepare this evaluation were provided by parties other than SePRO, the data are considered to be validated.

4.13 SUPPLY CHAIN

Phoslock® contains lanthanum (5%), a naturally occurring rare earth element (REE). Light REEs, such as lanthanum, are by far the most abundant of all REEs (Copetti et al., 2016). Lanthanum is similar to elements such as copper, cobalt, and lead in terms of average crustal abundance. REEs may be found in a range of rocks, sediments and soils, as well as, in terrestrial and aquatic biota. Sources of REEs are generally limited to two types, heavy mineral-enriched beach sands, or primary or secondary igneous pegmatite-hosted deposits (Copetti et al., 2016). A large REE deposit exists in Baotou, located in Inner Mongolia which has been estimated to contain approximately 75% of the world's known REE reserves (Copetti et al., 2016).

Phoslock is manufactured in China with bentonite also mined from China. The supply of bentonite clay is not likely to be a limiting issue as the worldwide production was more than 20 million metric tons in 2018 (Brown et al, 2020).

SePRO has indicated that they keep a large supply of Phoslock® on hand, enough material to supply a large project of up to around 1,000 acres. SePRO is able to ship Phoslock® anywhere in the United States within 3 to 10 days from the order and they expect it will generally take 3 to 5 days to arrive in the Lake Erie Basin. For projects larger than about 1,000 acres, SePRO would need 2 to 3 months lead time to acquire the material. This would be concurrent however with project pre-implementation monitoring and application logistics.

SePRO has indicated that based on scale and location, projects can be implemented in as early as two weeks and generally within 2 months. SePRO has a full-service laboratory and research campus with technical specialists available to assess sites and prescribe a Phoslock® dose. SePRO has a network of Phoslock® applicators stationed throughout the Ohio area and available for the application of Phoslock® to a waterbody. According to SePRO's proposal, if additional data is required for treatment design, water column and sediment samples can be collected for laboratory analysis of critical parameters, such as SRP and TP in the water column, and sediment phosphorus speciation. SePRO's team is quick to mobilize, and the laboratory has a rapid turnaround time, with the potential to have all necessary data ready within one week of project initiation. Additionally, sediment incubation laboratory experiments can be performed to further refine and improve dose calculations if necessary.

4.14 ENVIRONMENTAL RISKS

SePRO references several studies that have shown that Phoslock® is a safe product. SePRO indicates that lanthanum and the clay used in the formulation of Phoslock® are not listed on the United States Environmental Protection Agency (USEPA) Toxic Substances Control Act (TSCA) inventory list and that Phoslock® is NSF/ANSI (National Sanitation Foundation/American National Standards) Standard 60 certified for use in potable water supplies. Rhabdophane, the biproduct of the reaction of lanthanum and SRP, is a natural mineral that is chemically inert, non-toxic, and naturally integrates into the sediment following application.

It appears that the main environmental risk and concern associated with Phoslock® is the potential release of dissolved lanthanum into the waterbody following application. Spears et al. (2013) states that the incorporation of lanthanum into a bentonite carrier was deemed necessary to reduce the potential for adverse ecological effects associated with leaching of dissolved lanthanum from Phoslock®. Their study evaluated data from 16 case study lakes which Phoslock® had been applied and pre and post application total lanthanum and filterable lanthanum data existed. According to the study, the release of filterable lanthanum to the water column following a Phoslock® application was confirmed and was higher than the Dutch filterable lanthanum standard, 10.1 µg/L, (based on reproductive rates of *Daphnia magna*) within the first month post-application in the bottom waters of two lakes. In surface waters, five of the six monitored lakes would have had filterable lanthanum concentrations higher than the Dutch standard during application, but concentrations were below the standard 3 months post application (Spears et al., 2013). The study also determined that the maximum reported estimates of Phoslock® in the 16 receiving waterbodies did not exceed the Half maximal effective concentration (EC50) values reported for Phoslock® from laboratory-based ecotoxicology trials. Generally, the filterable lanthanum concentrations measured post Phoslock® application and the model predicted free lanthanum concentrations were higher in soft waters when compared to hard waters. In normal and high alkalinity waters (alkalinities of 0.8 mEq/L or higher [approximately 40 mg $CaCO_3$/L or higher]) maximum predicted concentrations of free lanthanum were substantially lower than the lowest reported EC50 concentration for daphnia species and no direct toxic effects of free lanthanum were likely (Spears et al., 2013). The authors suggest that the application of Phoslock® in very soft waters should be met with care. Ohio EPA data from various stations in Lake Erie, Sandusky Bay, Maumee Bay and the Maumee River in 2019 had measured alkalinities ranging from around 80 to 180 mg $CaCO_3$/L, which is well into the normal/high alkalinity range.

Lürling et al. (2014) observed a strong increase in filterable lanthanum in the presence of humic substances in laboratory-controlled experiments with Phoslock®. The observed concentrations (up to 273 µg/L in the presence of 10 milligrams per liter [mg/L] DOC) were in the same range as the monthly mean concentrations found in surface waters of 6 lakes (2 to 414 µg/L) following Phoslock® application (Spears et al., 2013). However, the DOC concentration in most of those lakes was not known. Regardless, Lürling et al. (2014) concluded that the presence of humic substances not only interferes with the binding efficiency of Phoslock® but also that the concentration of filterable lanthanum in the waterbody during and following application strongly increased in the presence of humic substances. Reported DOC concentrations for Maumee Bay, Sandusky Bay, and Lake Erie ranged from around 2.5 to 5.0 mg/L, which is lower than the suggested threshold of 10 mg/L, however, may be high enough at some locations to interfere with the lanthanum – SRP binding efficiency and release filterable lanthanum. Samples should be collected within any potential treatment location prior to treatment to determine DOC concentrations and evaluate any potential negative impacts.

Copetti et al. (2016) states that Phoslock® should not be used in saline environments due to the potential that substantial lanthanum may be released from Phoslock®. The concern is that a range of soluble lanthanum species would be released into the water column with the likelihood of significant ecotoxicological effects. The use of Phoslock® in moderately saline environments should be considered carefully and, on a case-by-case basis. Issues with the leaching of soluble lanthanum due to salinity are not a large concern within the Lake Erie Basin due to the low salinity of most waterbodies.

According to the review done by Copetti et al. (2016) lanthanum concentrations detected during or immediately following a Phoslock® application are generally below acute toxicological thresholds for various aquatic organisms, with the exception of some zooplankton species (e.g. *Daphnia magna* and *C. dubia*). Several studies show that there is a large range of ecotoxicological responses across a wide range of taxa for both lanthanum and LMB (Copetti et al., 2016; Table 2). This variability could be related to different media and experimental settings and to the presence of oxyanions or humic substances which impact the bioavailability of lanthanum. There is little information present in peer-reviewed literature on the potential effects of LMB applications on benthic invertebrates which may experience the highest turbidity and lanthanum concentrations following a treatment (Copetti et al., 2016). Benthic invertebrates are also directly exposed to LMB through ingestion and bioturbation of the sediments. There is also concern associated with the concentration of suspended sediments during an LMB application which Spears et al. (2013) estimated overlapped concentrations found to cause significant effects on a wide range of organisms. Even though suspended solids concentrations can reach pre-treatment concentrations quickly after an application the short-term duration of elevated concentrations are theoretically sufficient to impair productivity in macrophytes and algae or negatively impact young fish (Copetti et al., 2016). Copetti et al. (2016) suggests there is a need for further assessment of the physical effects of LMB applications on aquatic organisms, focusing on the exposure duration and frequency. Copetti et al. (2016) also states however that at the time of their review, there are no published examples of long-term negative ecotoxicological effects in LMB treated ecosystems.

A recent study by Alvarez-Manzaneda et al. (2019) found that Phoslock® did not inhibit algal (*R. subcapitata*) growth rates within the tested concentration range (< 2 grams/Liter) but did increase immobilization of *D. magna* with increasing concentrations and contact time. The study concluded that there was some risk for aquatic organisms during treatment of a lake with Phoslock® but it was most likely caused by physical effects of particles in the water. The authors go on to say that this risk may be acceptable on a case-by-case basis and no long term effects of Phoslock® in the pelagic areas of a waterbody are expected.

4.15 HEALTH & SAFETY

According to SePRO's, Phoslock® is not considered hazardous by the Occupational Health and Safety Administration (OSHA) (29 CFF 12910.1200). Regulatory bodies in Australia such as the National Industrial Chemical Notification and Assessment Scheme (NICNAS) have also considered LMB as a non-toxic product. The human health risks associated with LMB treated waterbodies appears to be negligible (Copetti et al., 2016). Phoslock® can be safely applied in bathing water and drinking water reservoirs as long as these waterbodies are not soft or acidic (Copetti et al., 2016). It appears unlikely that implementation of Phoslock® significantly poses risks to the health and safety of those conducting the applications. However, wearing personal protective equipment is likely required when applying Phoslock® to any waterbody.

4.16 COMMUNITY PERCEPTION & DISPROPORTIONATE IMPACT

SePRO anticipates that the local community will be very receptive and supportive of an environmentally friendly, novel solution, such as Phoslock®, that can improve water quality and therefore enhance the recreational uses of Lake Erie and waterbodies within the Lake Erie Basin. SePRO states in their proposal that the application of Phoslock® will likely benefit minority and low-income communities as poor water quality has been shown to disproportionality impact these communities (Evans and Kantrowitz, 2002). They go on further to state that minority and low-income communities are significantly more likely to rely on subsistence fishing as a means of providing food for their family and water quality issues can result in health advisories and closures that would reduce their ability to fish. Additionally, there is a risk of bioaccumulation of cyanotoxins in fish which have been shown to pose serious health risks upon ingestion (Ferrão-Filho and Kozlowsky-Suzuki, 2011).

SePRO does not anticipate any negative impacts or negative perceptions from the local community to the use of Phoslock® within the Lake Erie Basin. According to SePRO's proposal the use of Phoslock® has not resulted in any negative side effects in more than 300 waterbodies treated worldwide and negative impacts are not anticipated in any community.

4.17 WASTE/BY-PRODUCT MANAGEMENT REQUIREMENTS

It is unlikely that waste and/or by-product management requirements will impact the implementation of Phoslock®. According to SePRO's proposal, rhabdophane is a natural mineral and the biproduct of the reaction between lanthanum and SRP. Rhabdophane is chemically inert, non-toxic, and is naturally integrated into the sediment after Phoslock® reacts with SRP. Therefore there is no waste or by-product that would require management following a Phoslock® application.

5.0 FINDINGS AND OPINIONS

Based on our review of the available information and discussions with SePRO, Tetra Tech has reached the following conclusions regarding Phoslock®:

- Based on the available data and literature, it is evident that the active ingredient within Phoslock®, lanthanum, binds with SRP within the water column and reduces and/or prevents release of SRP from lake sediments with minimal impacts to the environment and aquatic life. There are numerous studies documenting reductions in lake TP, SRP, and chlorophyll concentrations following Phoslock® treatment.

- Phoslock® is a fully developed product and has been applied to more than 300 eutrophic lakes across a wide geographic distribution including lakes in Europe, Australia and New Zealand, North America, Asia, Africa and South America.

- Phoslock® may also provide additional benefits such as stabilizing the sediment-water interface to reduce resuspension under turbulent conditions and reducing the germination of dormant cyanobacteria (akinetes) at the sediment-water interface. This ability to stabilize the sediment-water interface makes Phoslock® an appropriate tool to reduce sediment P-release in shallow waterbodies that experience higher wind and wave mixing.

- The primary limitation of Phoslock® appears to be its inability to react and inactive particulate forms of phosphorus within a waterbody. Therefore, Phoslock® should be applied to a waterbody during the fall or spring when no algal blooms are present and when SRP concentrations are high.

- The cost of Phoslock® has been reported to be more expensive than other phosphorus inactivation products such as alum or buffered forms of alum. Costs provided by SePro, however, are similar to those reported by Huser (2021 personal communication; Huser et al., 2016) for alum treatments based on a pound of TP removed. The comparison of costs between Phoslock® and alum is complicated due to the fact that alum removes both particulate P and SRP, whereas Phoslock® only removes SRP. Since the portion of TP that is SRP varies by lake and within a lake over time, there is no easy way to make a direct cost comparison.

- It should also be noted that most of the Phoslock® applications around the world have been on small waterbodies with surface areas less than 100 acres. There is limited post-application data available to assess the long-term effectiveness or success of larger treatments.

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