



Lake Massapoag Sediment Coring and Nutrient Inactivation Dosing Study

Lake Massapoag, Sharon, Massachusetts

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Prepared For:

Lake Massapoag Advisory Committee

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Contents

1. Introduction.....	1
2. Approach.....	1
3. Results.....	4
4. Recommendations.....	5
5. References.....	9

Figures

Figure 1	Sediment Sampling Locations
Figure A	Willner-type Coring Device in Use
Figure B	Simplified Phosphorus Fractionation Scheme for Lake Bottom Sediments
Figure C	Concentrations of Fe-P at Core Depth

Tables

Table 1	Summary of Sediment Characteristics and Composition
Table 2	Estimated Internal Phosphorus Loading Rates from Fe-P and Org-P
Table 3	Calculated Full Dose and Recommended Dose for 25-ft Contour
Table 4	Calculated Full Dose and Recommended Dose for 20-ft Contour

Appendices

Appendix A	Sediment Phosphorus Fractionation Lab Tables
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1. Introduction

Lake Massapoag is an approximately 389-acre lake located entirely in the Town of Sharon. The lake consists of three coves; Horton's Cove, Fletcher's Cover, and the South Cove. The lake receives inflows from the Lagoon and several small tributaries, including a Canoe River tributary into the southern portion of the lake, and Sucker Brook into the southeast portion of the lake. The lake outflow is through Massapoag Brook to the north, which eventually flows into the Neponset River.

Under the *Final Massachusetts Integrated List of Waters for the Clean Water Act 2022 Reporting Cycle* (MassDEP 2023), Lake Massapoag is listed as a Category 4a water body (i.e., TMDL is completed) and is impacted by the following impairments:

1. Mercury in fish tissue
2. Non-native aquatic plants

Other management issues identified at Lake Massapoag include the following:

3. Harmful algal blooms
4. Nutrient/eutrophication biological indicators
5. Total phosphorus
6. Chlorophyll A/ Phycocyanin
7. *E. coli*
8. Beach closures due to *E. coli* or cyanobacteria

With the possible exception of the first impairment, these impairments and management issues are highly interrelated. For example, excessive total phosphorus is likely to result in eutrophication and harmful algal blooms, which likewise results in increased concentrations in chlorophyll A and phycocyanin in the water, shutting down the public beach and the summer day camps present along the shoreline. Excessive total phosphorus and eutrophic systems can also lead to excessive plant growth, fueling the growth of non-native plants (particularly fanwort, *Cabomba caroliniana*) observed in the lake. This suggests that the reduction of phosphorus concentrations in Lake Massapoag could have cascading benefits to multiple impairments and identified issues.

Several in-lake management options are currently being evaluated as means to improve water quality over the short term while watershed controls (septic and stormwater) are investigated and implemented to provide longer term reductions in nutrient loading. One potential option being investigated is the potential benefits from nutrient inactivation (e.g., alum treatment) that targets the internal release of phosphorus from the sediments.

Past sediment grab sampling conducted by TRC in 2022 and 2023 identified the extent of iron-bound and loosely sorbed (mobile) phosphorus in deep lake sediments that experience prolonged seasonal depletion of dissolved oxygen (TRC 2022; TRC 2023a). These observations indicated the potential for deep lake sediments to serve as a significant source for internal phosphorus loading within the lake.

While helpful, these results were from sediment grabs, which are a composite of sediments from an approximate 6-inch depth. To better delineate baseline conditions and provide detailed information needed for development of nutrient inactivation management recommendations, TRC recommended the collection and analysis of sediment cores from the lake.

The study approach, results, and recommendations are provided in the following sections.

2. Approach

TRC, accompanied by Dr. Keith Pilgrim of BEC Engineering & Geology, PC (BEC), visited Lake Massapoag on November 20, 2023 to collect sediment cores. Each element of the field program is described in more detail in the following sections.

Five sediment cores (LM1 through LM5) were collected using a gravity coring device (Willner-type coring device) modified to allow for the extrusion of sections from each core (Figure A). LM3 location was selected to target a resampling of the deep hole while the rest of the coring locations were expanded to provide a more representative distribution of samples from previously unsampled areas of the lake below the 25-foot contour (Figure 1).

Once retrieved, each core was sliced on-site in 2 cm increments for the top 10 cm of sediment. Additional sections were taken from each core at 13 to 15 cm and 18 to 20 cm deep. The exception was LM3 where samples were collected at 10 to 12 cm and 12 to 15 cm because the core could not push further into the more consolidated sediment at this location. The top layer of sediment is typically the most active layer, where phosphorus releases to the water column (internal phosphorus loading) while the deeper sediment provides an indication of historical conditions.



Figure A. Willner-type Coring Device in Use

Clockwise from upper right: the coring device upon retrieval at the surface, the core slicing head used to section the core, and the full core showing the sediment-water interface.

In total, 35 sections (i.e., 7 sections per core) were obtained. Sections were shipped on ice to the BEC phosphorus fractionation laboratory, where they were analyzed for different phosphorus forms or “fractions” according to the sequential fractionation method published by Psenner and Pucsko (1988). Phosphorus in bottom sediments is typically either bound to inorganic chemicals (e.g., calcium, manganese, iron, magnesium, and aluminum) or incorporated into organic matter (e.g., DNA, lipids, and phosphonates). Sequential fractionation makes use of acids, bases, reducing compounds, and an oxidizer to release these different types of phosphorus sequentially, and quantify the amount of phosphorus bound to iron and manganese (Fe-P), calcium and magnesium (Ca-P), and aluminum (Al-P), as well as the amount incorporated into organic matter (Org-P). The process is summarized in Figure B.

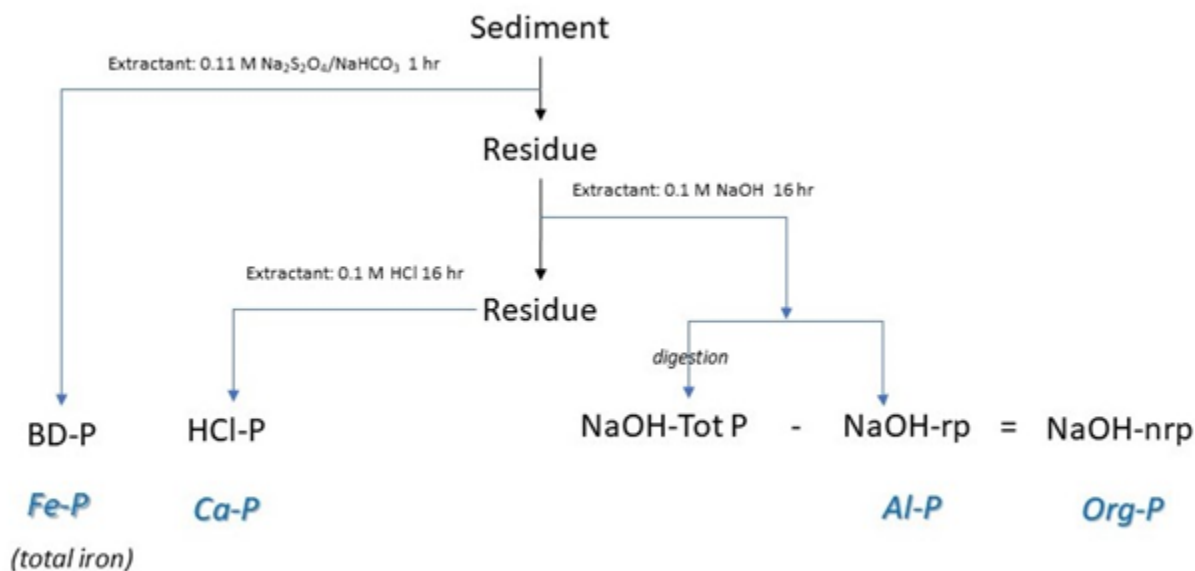


Figure B. Simplified Phosphorus Fractionation Scheme for Lake Bottom Sediments

In the natural environment, the dissolution of Fe-P in bottom sediments is responsible for most of the internal phosphorus release and loading to the water column when dissolved oxygen is low. However, the Org-P fraction decomposes as a function of temperature and can also contribute to internal loading where iron and dissolved oxygen levels are too low to recapture and bind it in the sediments as Fe-P. In contrast, Al-P and Ca-P fractions are stable under the environmental conditions present in most lake sediments, even when dissolved oxygen is not readily available.

In addition to the phosphorus fractionation analysis, each sample was also analyzed for moisture content, loss on ignition (percent carbon), and density. Total iron was analyzed from the Fe-P extraction for a subset of samples.

For quality assurance purposes, duplicate samples were analyzed at a 10% rate.

3. Results

Results of the water quality baseline monitoring and sediment phosphorus fractionation analysis are presented in the following sections.

A summary of the sediment properties and phosphorus fractionation results for the top four centimeters of sediment is provided in Table 1. Full sediment phosphorus fractionation laboratory results tables and charts are provided in Appendix A.

The sediment in general was highly inorganic in nature (approximately 74% of sediment solids by weight were inorganic). Sediment density was higher compared to lakes with a great proportion of organic solids. Water content of sediment was lower compared to the other lakes in the region (e.g., Santuit Pond) but similar to other deep lakes (e.g., Silver Lake).

Based on the laboratory results received from BEC (Table 1), iron-bound and loosely sorbed phosphorus (Fe-P) was the primary extractable phosphorus fraction, comprising approximately 50% of the total sediment phosphorus in surficial sediments (defined here as the top four centimeters) of each core on a dry-weight basis. The highest concentration of Fe-P observed was at LM4, the most southerly site, however values across all samples were observed to be near or above 1.0 mg/g (dry weight) in the top four cm of sediment (Figure C).

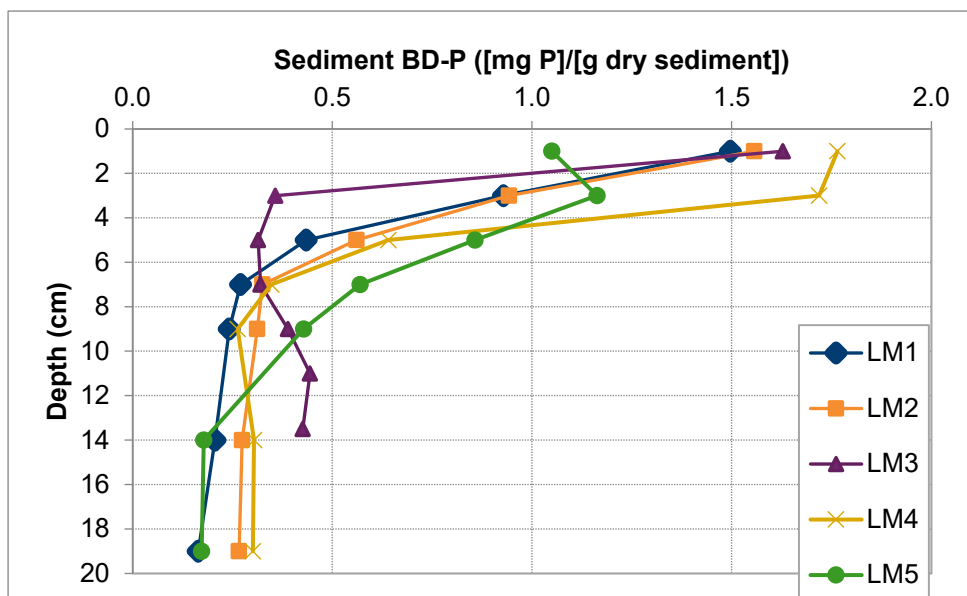


Figure C. Concentrations of Fe-P at Core Depth

Organically bound phosphorus (Org-P) constituted the second most abundant phosphorus fraction (with the exception of LM3, collected at the deep hole).

Extractable iron concentrations were on average 143 mg Fe/g (dry weight) in the top four cm of sediment. This equates to approximately 50 times more iron than total phosphorus in Lake Massapoag sediments and indicates that iron is plentiful enough to readily capture phosphorus in the presence of oxygen. This likely helps to intercept and attenuate the amount of phosphorus released into the water column from Org-P as the organic matter decays. The high concentrations of Fe-P lend support to this. However, when sediments become anoxic, as happens in the deeper portions of Lake Massapoag over much of the summer and early autumn, the Fe-P itself will eventually release from the sediments. Therefore, Fe-P is likely to be the primary source of internal phosphorus release into Lake Massapoag from deep sediments.

Table 1. Summary of Sediment Characteristics and Composition

Sed. Core ID	Approx Water Depth (ft)	Composition: Avg of Top 4 cm				Composition: Avg of Top 4 cm (mg/g dry sediment)					
		Sediment Density (g/cm ³)	% Moisture	% Organic Solids	% Inorganic Solids	Reducible Extractable Iron (Fe)	Iron and Loosely Sorbed P (Fe-P)	Organically Bound P (Org-P)	Calcium Bound P (Ca-P)	Aluminum Bound P (Al-P)	Total P
LM1	38	1.04	93%	26%	74%	154	1.21	0.65	0.14	0.42	2.42
LM2	33	1.05	89%	25%	75%	137	1.25	0.74	0.15	0.55	2.69
LM3	45	1.06	85%	31%	69%	139	0.99	0.51	0.59	0.65	2.75
LM4	28	1.05	90%	26%	74%	105	1.74	0.79	0.17	0.61	3.31
LM5	38	1.04	91%	24%	76%	179	1.11	0.40	0.16	0.40	2.06
Average	36	1.05	90%	26%	74%	143	1.26	0.62	0.24	0.53	2.65

Estimates of maximum potential internal loading (as mg phosphorus per meter squared (m²) of lake bottom sediment per day) are provided in Table 2. The estimates are based on relationships derived from published research (Pilgrim et al. 2007). The highest Fe-P concentration (and highest potential release rate of 28.21 mg/ m² per day) occurred in core LM4. However, sediments in each core exhibited a maximum internal phosphorus release rate exceeding 12 mg/ m² per day. For illustration purposes, the average rate of 19.93 mg/ m² per day would be the equivalent of more than 4.60 kg of phosphorus per day if only the deepest (i.e., deeper than the 25-ft contour) areas of the lake are included, and a total of 414 kg of phosphorus per year (assuming a 90-day period of anoxia). The 1984 *Diagnostic/Feasibility Study for Lake Massapoag* identified total phosphorus loading to be between 312 to 617 kg of phosphorus per year (IEP, Inc., 1984). Although the 1984 study did not identify internal loading as a significant component of the total phosphorus load, comparing our results suggest that internal loading is likely a significant component. Completion of an updated nutrient budget will provide a more accurate ratio of the proportion of internal loading related to the total phosphorus load. If areas as shallow as 20 ft are included, this would equate to a release rate of more than 10.16 kg of phosphorus per day. TRC notes that this value is assuming the average phosphorus release rate is uniform between the 20 and 25-ft contour; however, anoxia is less persistent in this shallower area.

Table 2. Estimated Internal Phosphorus Loading Rates from Fe-P

Sediment Core ID	Maximum Internal P Release Rate (mg/ m ² per day) Iron and Loosely Sorbed P (Fe-P)
LM1	12.80
LM2	20.72
LM3	23.62
LM4	28.21
LM5	14.31
Average	19.93

4. Recommendations

One way to address the observed issue of sediment phosphorus release at Lake Massapoag would be to increase the amount of an alternative, phosphorus-binding substrate in the sediments. The alternative substrate would need to be capable of maintaining a stable bond under the environmental conditions observed at the bottom of the lake, which include prolonged periods of seasonal anoxia. This approach would inactivate the phosphorus currently present in the lake regardless of the dissolved oxygen concentration, although external sources of phosphorus would still need to be controlled to prevent problems from redeveloping. Of the options available, aluminum is widely used to treat potable water sources, has the longest track record of safe and effective use as a phosphorus inactivation agent, and has been used for this purpose in a number of water bodies in Massachusetts, including drinking water reservoirs and sensitive kettle ponds on Cape Cod (Wagner et al. 2017). Additionally, aluminum is one of

the most widely distributed and common metals on Earth and is already present in Lake Massapoag sediments. The most frequently used method of increasing the available aluminum as a phosphorus-binding agent is through the careful application of aluminum sulfate (alum), often in conjunction with sodium aluminate to serve as a buffering agent.

Table 3 identifies the estimated amount of aluminum that would need to be added to Lake Massapoag sediments to convert readily released Fe-P to strongly bound Al-P.

Although the bulk of sediment phosphorus could be targeted with a single massive alum dose, this approach is not currently recommended at Lake Massapoag. In any alum treatment, some portion of the alum will sink below the active sediment layer (~top four centimeters in Lake Massapoag) or crystallize (age) before it can achieve its full potential for phosphorus inactivation. Another portion will end up moving downslope and concentrating in the deepest part of the lake before it is able to fully capture targeted phosphorus in the area where it was originally applied. Together, these factors impact the efficiency of an alum treatment. The very high concentrations of sediment iron and the steep slopes to the east and west of the Lake Massapoag deep hole mean that more alum will be “lost” to these inefficiency factors. Therefore, applying the full dose at once would be relatively inefficient and less cost-effective than an incremental alum treatment approach.

The incremental alum treatment approach would involve a smaller but still substantial initial application (equal to approximately one-third of the full dose), which is expected to inactivate over half of the currently present Fe-P in the active sediment layer. This incremental approach will allow the aluminum flocculent more time to become incorporated into the sediments before applying the full dose. On its own, the one-third alum dose would be anticipated to permanently inactivate more than 500 kg of phosphorus in the active sediment layer of Lake Massapoag and immediately reduce the internal phosphorus load by more than 200 kg/yr. However, newly deposited sediments and Org-P in the existing sediments will continue to serve as sources of phosphorus release in the future as organic matter decomposes over time. Therefore, if other management interventions are not implemented to substantially reduce external phosphorus loading and improve dissolved oxygen in deep waters of Lake Massapoag, the Town should plan to apply the second third of the full dose after approximately five to ten years to counter this input of new phosphorus-rich sediments and extend the benefits of the original treatment. Similarly, another third of the full dose may be warranted after an additional five to ten years. This timeline is approximate and intended as general guidance for planning purposes. If other interventions are successfully implemented concurrent with or soon after the initial alum treatment dose, it is possible that additional alum treatments would not be needed. Regardless of the approach taken, monitoring is recommended to more precisely determine if and when additional alum treatments or other management interventions are warranted in the future.

It is recommended that sediments in the deepest part of Lake Massapoag be the focus of sediment dose alum treatments. These deep areas are where anoxic conditions are likely to occur over the course of the growing season. Sediments in areas shallower than this are not likely to be as impacted by seasonal anoxia and therefore have less potential to release phosphorus at high rates. Additionally, sediments in shallow areas would be more likely to be of concern to NHESP for their ability to support known rare species in the lake.

Based on vertical dissolved oxygen profiles recently collected from Lake Massapoag, two possible scenarios are presented for consideration. In the first scenario, the area within the 25-foot contour (as mapped by the Massachusetts Division of Fisheries and Wildlife in 2019) would be targeted because it contains the sediments most severely impacted by extended duration of seasonal anoxia and represents the highest potential for release of phosphorus. An initial (i.e., one-third full dose) alum treatment focusing on this area would target approximately 57 acres and consist of the application of nearly 51,000 gallons of alum and sodium aluminate (Table 3). In the second scenario, the area within the 20-foot contour would be targeted. This area represents a more conservative estimate of sediments impacted by some level of anoxia over the course of the growing season. An initial (i.e., one-third full dose) alum treatment focusing on this area would target approximately 126 acres and consist of the application of nearly 112,000 gallons of alum and sodium aluminate (Table 4). These treatment areas are provided for illustration of recommended upper and lower bounds for sediment nutrient inactivation. However, the final treatment area should be selected to reflect the Town’s goals for phosphorus removal as refined by potential budgetary and environmental permitting limitations.

Table 3. Calculated Full Dose and Recommended Dose for 25-ft Contour

Element	Value		Unit
	Full Dose (Not Recommended)	1/3 Dose (Recommended)	
Aluminum Dosing			
Targeted Binding Ratio Al:Al-P formed	50	50	
Estimated Active Layer	4	4	cm
Initial Aluminum Dose	223.3	74	g Al/m ²
Alum and Sodium Aluminate Treatment Volumes			
Treatment Area	57	57	acre
Total Mass Aluminum Applied	51,425	17,142	kg
Liquid Alum Composition	0.22	0.22	kg Al/gallon
Liquid Sodium Aluminate Composition	0.57	0.57	kg Al/gallon
Total Treatment Volume as Alum	231,959	77,320	gallon
Targeted Ratio of Alum to Sodium Aluminate	2:1	2:1	
Recommended Alum Dose	101,478	33,826	gallon
Recommended Sodium Aluminate Dose	50,739	16,913	gallon
Recommended Alum Dose	1,783	594	gallons/acre
Recommended Sodium Aluminate Dose	892	297	gallons/acre

Table 4. Calculated Full Dose and Recommended Dose for 20-ft Contour

Element	Value		Unit
	Full Dose (Not Recommended)	1/3 Dose (Recommended)	
Aluminum Dosing			
Targeted Binding Ratio Al:Al-P formed	50	50	
Estimated Active Layer	4	4	cm
Initial Aluminum Dose	223.3	74	g Al/m ²
Alum and Sodium Aluminate Treatment Volumes			
Treatment Area	126	126	acre
Total Mass Aluminum Applied	113,507	37,836	kg
Liquid Alum Composition	0.22	0.22	kg Al/gallon
Liquid Sodium Aluminate Composition	0.57	0.57	kg Al/gallon
Total Treatment Volume as Alum	511,991	192,664	gallon
Targeted Ratio of Alum to Sodium Aluminate	2:1	2:1	
Recommended Alum Dose	223,984	74,661	gallon
Recommended Sodium Aluminate Dose	111,993	37,331	gallon
Recommended Alum Dose	1,783	594	gallons/acre
Recommended Sodium Aluminate Dose	892	297	gallons/acre

If using a buffered alum approach, we recommend that aluminum be applied at a 2:1 ratio of alum (aluminum sulfate) and sodium aluminate (sodium, aluminum, and hydroxide) injected simultaneously into the water column. This will buffer the treatment with a goal of maintaining pH within the desired band of 6 to 8 SU. Depending on the pH at initiation of treatment, this ratio may need to be altered slightly. However, the 2:1 ratio has performed admirably in other sediment dose applications to softwater ponds on the Cape, eastern Massachusetts, and Rhode Island when applied in spring, after water temperatures have warmed to approximately 6°C (43°F). This allows for good flocculent formation while also avoiding periods when ambient water quality puts more stress on aquatic life.

Although polyaluminum chloride (PAC) could also be used for the nutrient inactivation treatment, it is harder to obtain in large volumes and may prove cost-prohibitive when compared to buffered alum. Another alum alternative is Aqual-P, a proprietary, zeolite-based product that has not been widely used in the US but shows some potential for use in phosphorus inactivation and other water quality improvement applications. Other non-aluminum based nutrient inactivation agents, such as the proprietary product EutroSORB, could also be considered. Some EutroSORB products offered by the manufacturer disclose lanthanum modified bentonite (LMB) as the active phosphorus-binding agent. Lanthanum is a rare earth metal that has been successfully used to inactivate phosphorus.

Given the high sediment availability of iron, Lake Massapoag also has potential to benefit substantially from oxygenation of deep waters for phosphorus control. Oxygen saturation technology (OST) is just one method of oxygenation and it should be evaluated against other available technologies for feasibility at Lake Massapoag. Although it is beyond the scope of this study to assess the feasibility of accomplishing deep lake oxygenation, TRC recommends that the Town consider this in-lake management approach as a potential part of a comprehensive lake management program.

Finally, it is recommended that any nutrient inactivation project be accompanied by pre-, during, and post-treatment monitoring. This will allow changes in water quality to be documented and quantified while also ensuring that the treatment is implemented in way that avoids or minimizes impacts to protected resources.

5. References

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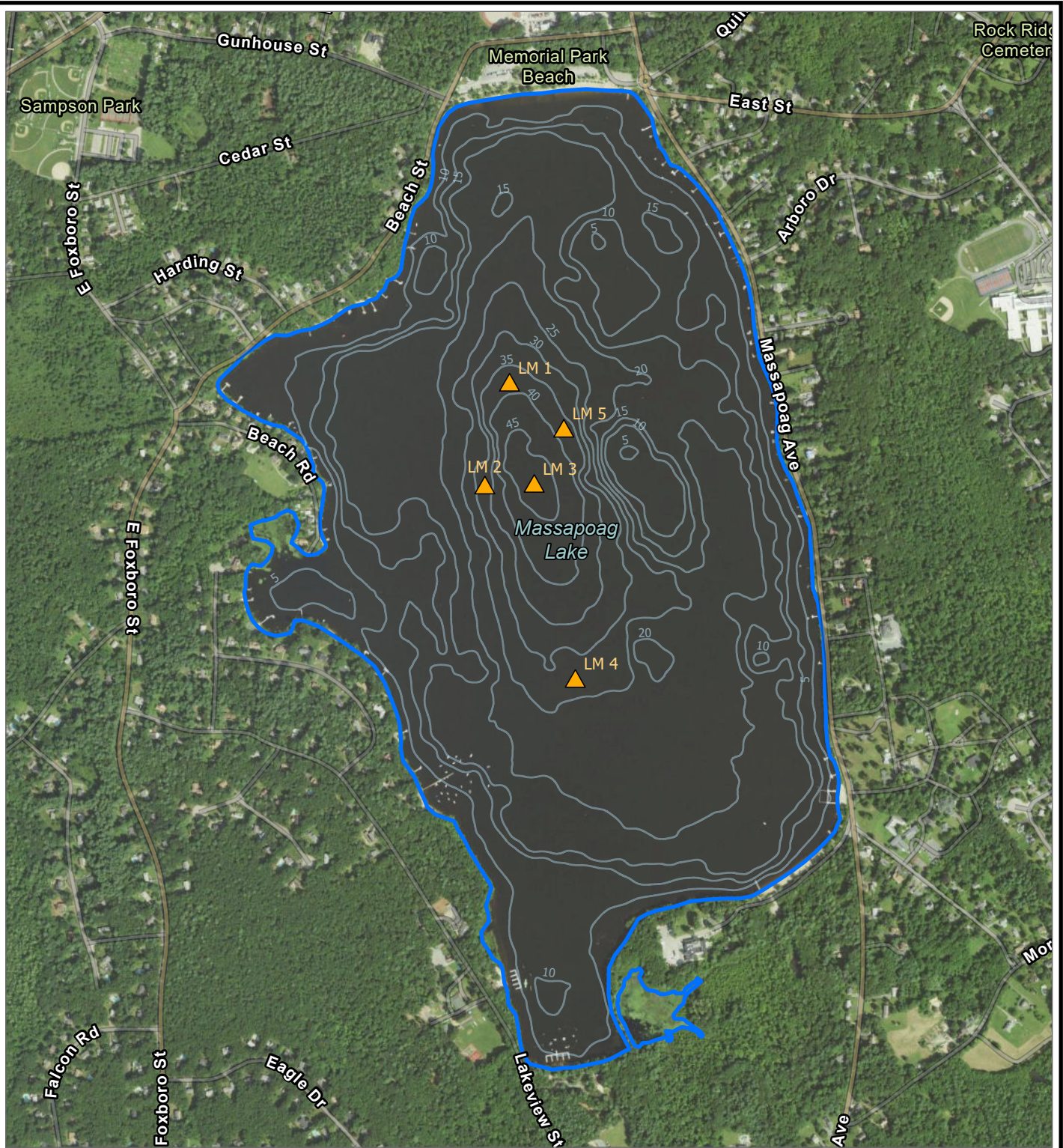
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Figures

COORDINATE SYSTEM: NAD 1983 2011 STATEPLANE MASSACHUSETTS MIND FIPS 2001 FTUS; MAP ROTATION: 0
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	BATHYMETRY CONTOURS (5 FOOT INTERVAL)
	SEDIMENT SAMPLE LOCATION
	SHORELINE

BASE MAP: ESRI, NAIP IMAGERY, 2018
 DATA SOURCES: TRC, GPS LOCATIONS, 2023
 MASSGIS, INLAND WATER BATHYMETRY, 2019

1:12,000 1" = 1,000'

PROJECT: ALUM DOSING PLAN LAKE MASSAPOAG TOWN OF SHARON, MA	
TITLE: SEDIMENT SAMPLING LOCATIONS NOVEMBER 20, 2023	
DRAWN BY: S. DEHAINAUT	PROJ. NO.: 570766.0000.0000
CHECKED BY: K. BACHAND	FIGURE 1
APPROVED BY: M. O'BRIEN	
DATE: JANUARY 2024	
10 HEMINGWAY DRIVE 2ND FLOOR EAST PROVIDENCE, RI 02915 PHONE: 401.330.1236	
FILE:	570766_LAKEMASSAPOAG_SEDCORINGOTHERFIGURES

Appendix A

Sediment Phosphorus Fractionation Lab Tables

RESULTS OF SEDIMENT CHEMICAL ANALYSIS

Core	Interval (cm)		Mid (cm)	General Properties			Phosphorus Fraction (mg P/ gram dry sediment)					Extractible Iron (mg Fe/g dry)
				% Moisture	% LOI	Density (g/cm ³)	Fe-P	Al-P	Org-P	Ca-P	Total P	
LM1	0	2	1	94%	27%	1.03	1.497	0.378	0.660	0.128	2.663	232
LM1	2	4	3	91%	25%	1.04	0.929	0.454	0.641	0.161	2.185	141
LM1	4	6	5	87%	23%	1.07	0.435	0.370	0.495	0.154	1.454	-
LM1	6	8	7	82%	21%	1.09	0.270	0.221	0.393	0.175	1.059	-
LM1	8	10	9	83%	21%	1.09	0.242	0.195	0.379	0.155	0.972	-
LM1	13	15	14	83%	21%	1.09	0.206	0.161	0.357	0.144	0.869	-
LM1	18	20	19	83%	21%	1.09	0.164	0.085	0.338	0.133	0.720	-
LM2	0	2	1	88%	27%	1.05	1.557	0.539	0.809	0.150	3.054	211
LM2	2	4	3	90%	24%	1.05	0.943	0.554	0.667	0.156	2.320	132
LM2	4	6	5	86%	22%	1.07	0.561	0.554	0.612	0.154	1.881	-
LM2	6	8	7	87%	21%	1.07	0.325	0.399	0.573	0.158	1.454	-
LM2	8	10	9	85%	21%	1.08	0.312	0.363	0.340	0.176	1.192	-
LM2	13	15	14	83%	20%	1.09	0.274	0.209	0.369	0.156	1.008	-
LM2	18	20	19	82%	21%	1.10	0.267	0.255	0.368	0.173	1.062	-
LM3	0	2	1	84%	41%	1.06	1.628	0.988	0.553	1.021	4.190	138
LM3	2	4	3	87%	21%	1.07	0.357	0.318	0.465	0.168	1.308	69
LM3	4	6	5	84%	21%	1.08	0.314	0.221	0.421	0.168	1.123	-
LM3	6	8	7	84%	24%	1.08	0.320	0.150	0.385	0.127	0.982	-
LM3	8	10	9	85%	22%	1.08	0.389	0.161	0.375	0.133	1.058	-
LM3	10	12	11	85%	21%	1.08	0.444	0.109	0.376	0.133	1.062	-
LM3	12	15	13.5	84%	22%	1.09	0.426	0.096	0.361	0.120	1.003	-
LM4	0	2	1	88%	26%	1.06	1.765	0.469	0.821	0.149	3.204	212
LM4	2	4	3	91%	26%	1.04	1.719	0.755	0.749	0.188	3.412	154
LM4	4	6	5	89%	23%	1.05	0.640	0.546	0.643	0.156	1.986	-
LM4	6	8	7	87%	22%	1.07	0.347	0.350	0.565	0.159	1.422	-
LM4	8	10	9	86%	23%	1.07	0.263	0.338	0.334	0.173	1.108	-
LM4	13	15	14	84%	20%	1.09	0.304	0.237	0.234	0.140	0.914	-
LM4	18	20	19	83%	20%	1.09	0.301	0.230	0.227	0.137	0.895	-
LM5	0	2	1	91%	25%	1.04	1.050	0.435	0.428	0.154	2.067	218
LM5	2	4	3	92%	24%	1.04	1.163	0.371	0.364	0.159	2.057	175
LM5	4	6	5	90%	24%	1.05	0.857	0.404	0.397	0.166	1.824	-
LM5	6	8	7	86%	22%	1.07	0.569	0.370	0.365	0.162	1.466	-
LM5	8	10	9	84%	21%	1.09	0.428	0.315	0.311	0.171	1.224	-
LM5	13	15	14	83%	20%	1.09	0.178	0.123	0.120	0.159	0.580	-
LM5	18	20	19	83%	20%	1.09	0.173	0.090	0.087	0.159	0.508	-

1. Phosphorus Fractionation Definitions:

Fe-P = Iron-bound and loosely sorbed phosphorus

Al-P = Aluminum-bound phosphorus

Org-P = Organically bound phosphorus

Ca-P = Calcium-bound phosphorus

2. Reducible-extractable iron is an extract of the iron-bound phosphorus extraction (BD step).

RESULTS OF SEDIMENT CHEMICAL ANALYSIS

Core	Interval (cm)		Mid (cm)	General Properties			Phosphorus Fraction (mg P/ gram wet sediment)				Extractible Iron (mg Fe/g wet)
				% Moisture	% LOI	Density (g/cm ³)	Fe-P	Al-P	Org-P	Ca-P	
LM1	0	2	1	94%	27%	1.03	0.0885	0.0223	0.0390	0.0076	13.7
LM1	2	4	3	91%	25%	1.04	0.0842	0.0411	0.0581	0.0146	12.8
LM1	4	6	5	87%	23%	1.07	0.0586	0.0498	0.0667	0.0207	-
LM1	6	8	7	82%	21%	1.09	0.0475	0.0389	0.0689	0.0307	-
LM1	8	10	9	83%	21%	1.09	0.0416	0.0335	0.0652	0.0266	-
LM1	13	15	14	83%	21%	1.09	0.0356	0.0277	0.0617	0.0249	-
LM1	18	20	19	83%	21%	1.09	0.0274	0.0142	0.0562	0.0221	-
LM2	0	2	1	88%	27%	1.05	0.1795	0.0621	0.0932	0.0173	24.3
LM2	2	4	3	90%	24%	1.05	0.0902	0.0530	0.0638	0.0149	12.6
LM2	4	6	5	86%	22%	1.07	0.0774	0.0765	0.0845	0.0213	-
LM2	6	8	7	87%	21%	1.07	0.0439	0.0538	0.0773	0.0212	-
LM2	8	10	9	85%	21%	1.08	0.0455	0.0529	0.0495	0.0257	-
LM2	13	15	14	83%	20%	1.09	0.0457	0.0348	0.0614	0.0259	-
LM2	18	20	19	82%	21%	1.10	0.0491	0.0468	0.0676	0.0318	-
LM3	0	2	1	84%	41%	1.06	0.2555	0.1550	0.0867	0.1602	21.7
LM3	2	4	3	87%	21%	1.07	0.0477	0.0425	0.0622	0.0225	9.3
LM3	4	6	5	84%	21%	1.08	0.0506	0.0355	0.0677	0.0270	-
LM3	6	8	7	84%	24%	1.08	0.0504	0.0235	0.0605	0.0200	-
LM3	8	10	9	85%	22%	1.08	0.0599	0.0248	0.0578	0.0205	-
LM3	10	12	11	85%	21%	1.08	0.0680	0.0167	0.0575	0.0204	-
LM3	12	15	13.5	84%	22%	1.09	0.0703	0.0159	0.0595	0.0197	-
LM4	0	2	1	88%	26%	1.06	0.2057	0.0547	0.0957	0.0173	24.8
LM4	2	4	3	91%	26%	1.04	0.1588	0.0698	0.0692	0.0174	14.2
LM4	4	6	5	89%	23%	1.05	0.0692	0.0590	0.0695	0.0169	-
LM4	6	8	7	87%	22%	1.07	0.0445	0.0449	0.0725	0.0204	-
LM4	8	10	9	86%	23%	1.07	0.0361	0.0463	0.0458	0.0237	-
LM4	13	15	14	84%	20%	1.09	0.0493	0.0384	0.0378	0.0227	-
LM4	18	20	19	83%	20%	1.09	0.0511	0.0391	0.0385	0.0233	-
LM5	0	2	1	91%	25%	1.04	0.0959	0.0397	0.0391	0.0141	19.9
LM5	2	4	3	92%	24%	1.04	0.0948	0.0302	0.0297	0.0130	14.2
LM5	4	6	5	90%	24%	1.05	0.0864	0.0407	0.0400	0.0167	-
LM5	6	8	7	86%	22%	1.07	0.0817	0.0530	0.0525	0.0232	-
LM5	8	10	9	84%	21%	1.09	0.0693	0.0510	0.0503	0.0277	-
LM5	13	15	14	83%	20%	1.09	0.0311	0.0215	0.0209	0.0278	-
LM5	18	20	19	83%	20%	1.09	0.0301	0.0157	0.0151	0.0277	-
LM4 DUP	2	4	3	-	-	-	0.1566	0.0743	0.0737	0.0166	-
LM5 DUP	2	4	3	-	-	-	0.0971	0.0367	0.0362	0.0135	-

1. Phosphorus Fractionation Definitions:

Fe-P = Iron-bound and loosely sorbed phosphorus

Al-P = Aluminum-bound phosphorus

Org-P = Organically bound phosphorus

Ca-P = Calcium-bound phosphorus

2. Reducible-extractable iron is an extract of the iron-bound phosphorus extraction (BD step).