Date: July 29, 2023
To: Jen Jespersen, Ecological Instincts
From: Ken Wagner, Water Resource Services
Subject: Update to internal loading to Unity Pond

Background

An analysis of potential internal loading of phosphorus (P) to Unity Pond (Lake Winnecook) was conducted in June 2022. Unity Pond covers about 1027 ha (2569) acres to a maximum depth of about 11.8 m (39 ft) with an average depth of about 5.3 m (17.5 ft) (Figure 1) There is adequate oxygen in water <6 m deep all the time, limited oxygen depletion at 6-8 m, and anoxia is often detected at >9-10 m, but there is a strong likelihood that oxygen right at the sediment-water interface is depleted at depths as shallow as 6 m.

There was a detectable increase in P mass in the lake over the summer of 2021, peaking at the end of September. If we consider the total change in P mass to represent internal loading, that represents 712-792 kg over the July-September or June-September periods, respectively. Some of this input could be from runoff, as summer of 2021 was a relatively wet summer. Yet the Phosphorus Control Action Plan (PCAP) prepared in 2004 included estimates of internal loading from 8 years that averaged 630 kg/yr and had multiple values near 800 kg/yr, with the most recent years among the highest values and suggesting increasing internal loading even 20 years ago.

It is likely that in Unity Pond cyanobacteria are initiating growth at the sediment-water interface, taking up P as it is released but before it enters the oxygenated water column. In June and early July, clarity is sufficient for enough light to penetrate to at least 9 m of water depth if not throughout the pond to the bottom. During July the cyanobacteria blooms commence, lowering clarity and stimulating further rises by cyanobacteria that have been growing on the bottom. The dominant genera found in Unity Pond (Dolichospermum, formerly known as Anabaena, Aphanizomenon, and Microcystis) are known to initiate growth at the sediment-water interface then rise in the water column to form blooms. The increase in P over the summer may therefore represent an accumulation of algae, especially cyanobacteria, and not simple release and mixing of inorganic P from the sediment. This is a common but understudied mechanism of eutrophication.

Very limited sediment data were available for the 2022 analysis. Using what data were available and making several assumptions, the potentially available P mass in the upper 10 cm over the area deeper than 6 m would be about 10,660 kg. Typically, only the P in the upper 1-2 cm is released in any given summer, with a value of 10% of the total for the 10 cm usually providing a good match for actual measurements where available. For Unity Pond that suggests a release of 1066 kg each summer, higher than the 630 kg average from the 2004 PCAP but within the realm of expected variation in sediment P release. More sediment testing was recommended to allow a more definitive estimate of internal loading.

Application of the LLRM, a linked watershed-lake water quality model, generates an estimated annual internal P load of 812 kg, close to the values calculated in the PCAP for 2000 and 2001 but higher than the P mass increase in Unity Pond over the summer of 2021 and lower than the sediment-based estimate. If we assume 10% less duration of anoxia and 10% lower release rates, a

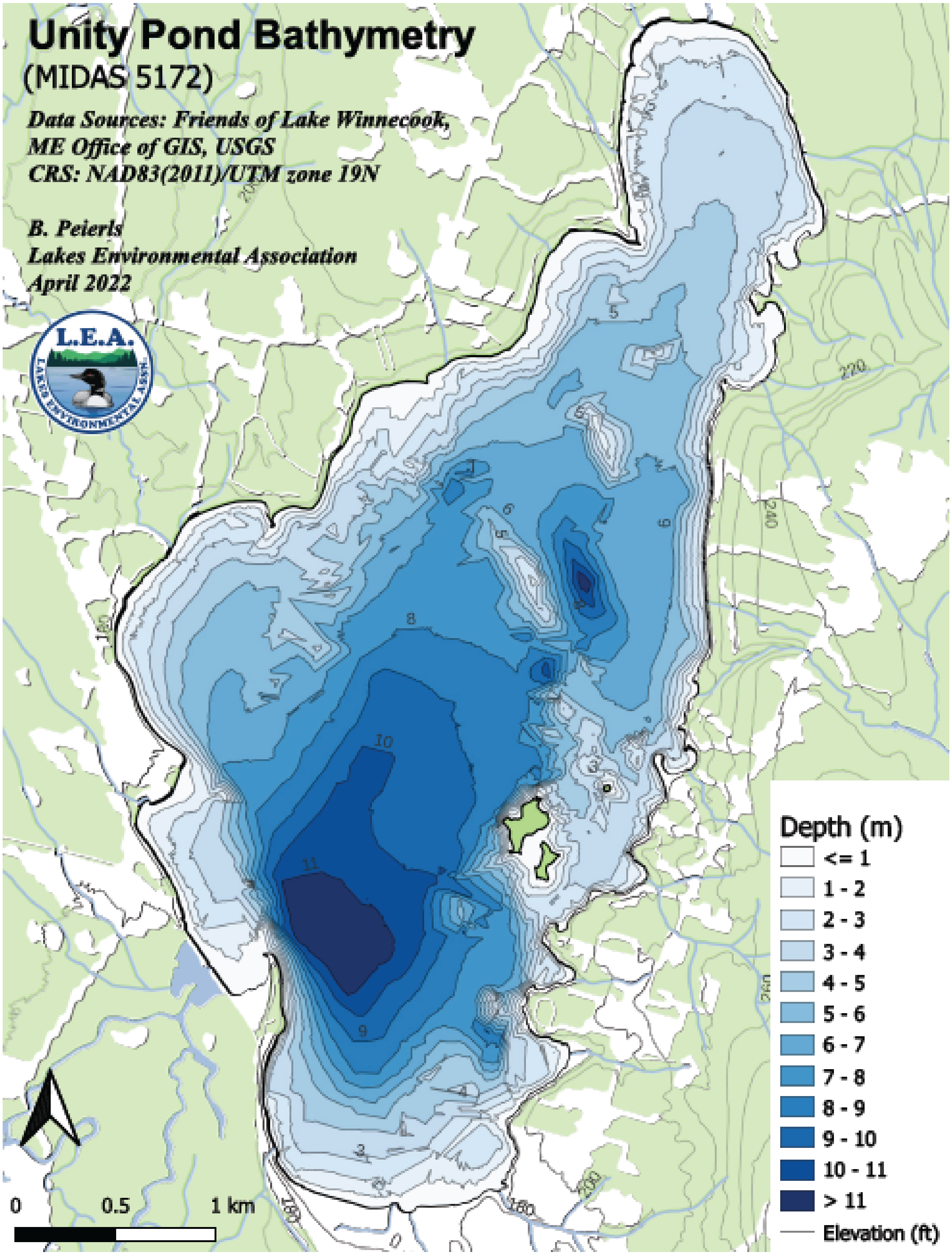

Figure 1. Bathymetry of Unity Pond, Maine

value of 657 kg/yr is obtained and is just slightly above the historic average of 630 kg/yr from the 2004 PCAP. Any value between about 500 and 1000 kg/yr seems possible for internal P loading in Unity Pond.

Based on the limited sediment data available, the dose of aluminum that would be needed to inactivate the redox-sensitive P in the upper 10 cm was estimated at between 54 and 78 g/m^2 in 2022. The upper 2.5 cm of sediment would require a dose of only 15 to 20 g/m^2 and would equate to volumetric doses of 1.5 to 3 mg/L in the targeted treatment zone, enough to strip most P from the water column. Such a treatment was estimated to cost about $700,000 and could provide benefits for up to 4 years, providing better conditions in the pond until watershed work to reduce P loading from drainage areas can be conducted. Further sediment work would be needed to refine this estimate.

2023 Data and Interpretation

Thirteen sediment samples were collected by ME DEP on May 15, 2023 and analyzed at St. Joseph's College. Most of the P was associated with organic or aluminum complexes (Figure 2); iron bound P was significant but not large. A check on the extractions would be advisable, as the amount of iron in the sediment is much higher than the Fe-P concentrations would suggest. Assuming the values are correct, however, the mass of P can be calculated for the upper 10 cm over any target area. Organizing station data by water depth, the mass of P under each depth area of the pond is derived (Table 1). The total mass over the area of Unity Pond that is subject to low oxygen during stratification is about 5700 kg. If a summer release of 10% of this total was assumed, the internal load would be 570 kg, lower than by the estimation methods applied in the 2022 analysis. If the P in the upper 10 cm is concentrated in the upper 2 cm, the internal load could be twice that much and slightly higher than the past estimates.

Based on these data, the average dose of aluminum that would be applied should be 10 to 25 times the mass of P per square meter, a range of 13 to 33 g/m^2 and in the low end of the range for doses to other New England lakes. Dosage often varies over the area of the lake, given different P mass in different areas, and most often the P mass per unit area rises linearly with water depth. However, the Unity Pond data indicate more variation among samples within a defined depth range than among averages from different depth ranges. This further suggests that a check on the extractions might be worthwhile. Based on the data, however, application of the same dose everywhere would be recommended based on these data, and probably near the high end of the suggested range.

An alternative dose estimation approach involves a lab assay in which aluminum is added to sediment samples and the decrease in available P is measured. A curve is generated, showing how the available P declines with increasing aluminum dose. For Unity Pond, two composite samples, one for the shallower (<8 m) samples and one for the deeper (>8 m) samples, were tested (Figure 3). The results suggest that available P continues to decline at doses in excess of 80 g/m^2, but that there are diminishing returns on added dose and the normal target of 50 mg/kg of available P is reached at around 40 g/m^2. While more aluminum will tend to increase the longevity of treatment benefits, the cost also rises and the efficiency of each added aluminum dose added over a short time decreases (i.e., less P is bound per unit of aluminum added). Most groups choose the lowest dose that will lead to a post-treatment available P concentration near 50 mg/kg. That suggests a dose of 40 g/m2 for all areas of Unity Pond >6 m deep.

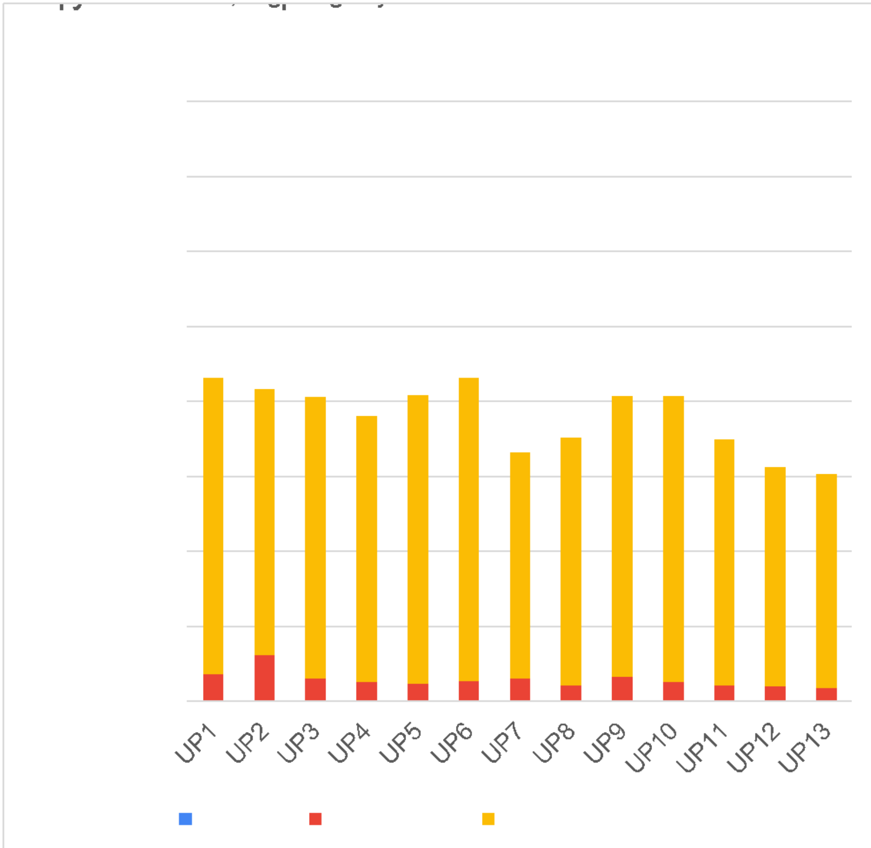

Figure 2. Unity Pond phosphorus speciation

Table 1. Phosphorus mass in defined areas of Unity Pond

Sample	Depth Range (m)	Area (m2)	Area for depth range (m2)	P (g/m2)	Avg mass/m2 for sample range (g/m2)	P mass (kg)
UP1	>11m	206135	206135	1.26	1.47	304
UP2	>11m	206135		1.69		
UP10	10-11m	398973	398973	0.96	0.96	382
UP6	9-10m	662177	662177	1.04	1.44	951
UP11	9-10m	662177		1.39		
UP9	8-10m			1.87		
UP5	8-9m	781422	781422	1.07	1.39	1083
UP12	8-9m	781422		1.70		
UP4	7-8m	984307	984307	1.08	1.35	1333
UP8	7-8m	984307		1.23		
UP13	7-8m	984307		1.75		
UP3	6-7m	1302424	1302424	1.31	1.26	1644
UP7	6-7m	1302424		1.22		
		Tot/Avg	4335438		1.31	5687

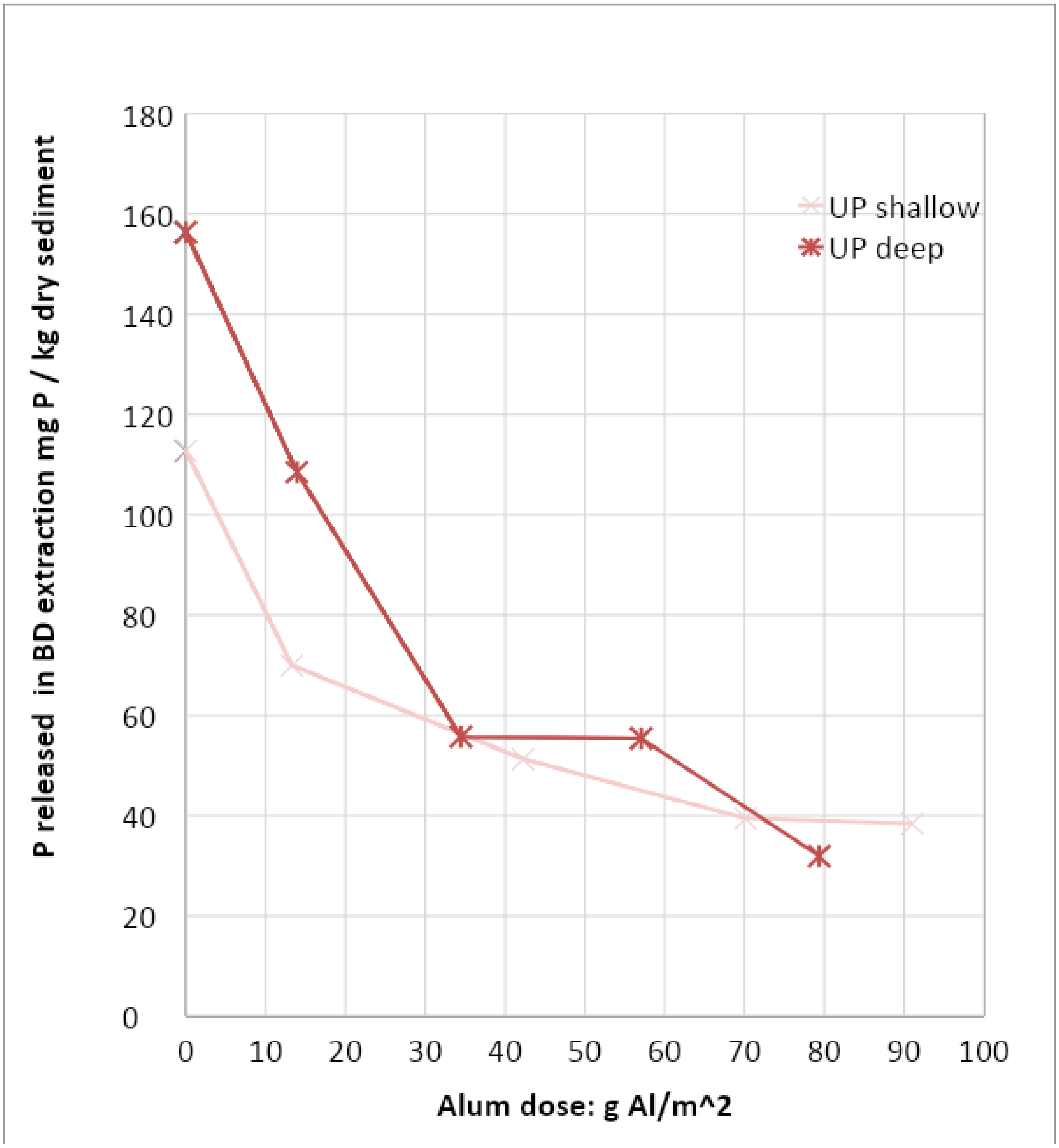

Figure 3. Decline in available P with aluminum addition to Unity Pond sediment

Yet another dose estimation approach involves consideration of the aluminum to iron (Al:Fe) ratio. At Al:Fe values >3:1, relatively little internal loading is observed. Calculation of how much aluminum must be added to achieve that 3:1 ratio is based on the sediment tests for Al and Fe, and suggests that there is much more Fe than Al and that the dose of Al necessary to achieve an Al:Fe ratio of 3:1 is very high (Table 2), mostly >100 g/m^2. The disconnect between the dose estimates from stoichiometry or aluminum assay and Al:Fe ratio is of concern and suggests some retesting of sediment is warranted. There are many different possible Al and Fe compounds in the sediment, so it is not clear that there is any problem with the analysis, but the discrepancy among dose calculation methods does warrant scrutiny.

Table 2. Calculation of dose based on achieving an Al:Fe ratio of 3:1.

Station	Tot Fe (mg/kg)	mmol Fe	Tot Al (mg/kg)	mmol Al	Al:Fe ratio	mmol Al needed for 3:1	mg/kg Al needed for 3:1	kg sed/m2 for upper 10 cm	Al needed for 3:1 (g/m2)
UP1	4579	82	1100	41	0.50	205	5536	18	101
UP2	4882	87	440	16	0.19	246	6635	14	92
UP3	5646	101	1538	57	0.56	246	6645	21	142
UP4	5013	90	1460	54	0.60	215	5805	21	124
UP5	5082	91	1857	69	0.76	204	5508	23	127
UP6	4908	88	1682	62	0.71	201	5431	20	107
UP7	4403	79	1712	63	0.80	173	4669	21	97
UP8	5028	90	1962	73	0.81	197	5324	29	154
UP9	5400	97	1962	73	0.75	217	5864	28	167
UP10	4765	85	1555	58	0.68	198	5350	19	102
UP11	4848	87	1791	66	0.76	194	5235	33	174
UP12	5326	95	2095	78	0.81	208	5623	42	234
UP13	3958	71	1535	57	0.80	156	4202	50	210

Doses in excess of about 60 g/m^2 are often split into two different applications at least a year apart. This avoids the decreasing efficiency of one-time application at higher doses, spreads the cost over a longer period of time, and allows further evaluation before the second dose is added. As long as the first applied dose is 20 g/m^2 or more, the full benefits tend to be achieved immediately, as the internal loading occurs at the sediment-water interface, and it takes time for additional P that has not been inactivated to migrate upward through the sediment along a concentration gradient. The value of additional aluminum dose relates to longevity of benefits, not the initial effect. Based on all data in hand, a dose of 35 to 40 g/m^2 would be recommended over the entire area of Unity Pond deeper than 6 m.

The cost of aluminum products has risen substantially over the last few years and created uncertainty in the costing of treatments. Based on the most recent projects and adjusting for some efficiency of scale for the large area to be treated, the cost of a 40 g/m^2 treatment over 433.5 hectares (1084 acres) would be on the order of $2.1 million. Although doses <50 g/m^2 are not typically split for reasons of efficiency, they can be split for reasons of cost and uncertainty of the need for a higher dose. A 20 g/m^2 application would be expected to cost about $1.1 million as of 2023. A 20 g/m^2 dose should provide full and immediate benefits, curtailing cyanobacteria blooms, but might last only a few years, likely at least 4 years but not likely for more than 10 years.