Watershed management and **rehabilitation of Lily Pond**

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Lily Pond is a small (surface area = 12 ha; volume = 0.48 hm^3), shallow (mean and maximum depths are 4 m and 7 m, respectively) lake located in the towns of Rockport and Camden in the Mid-coast region of Maine (Figure 1). Abundant growths of submerged and floating macrophytes have long been notable characteristics of the pond, especially along the southern and eastern shore, covering approximately 40 percent of the pond's surface area during the summer months. Land uses in the 86-ha watershed (Figure 2) include pasture, mixed forest, and limited development. In the absence of permanent streams, groundwater flow and surface runoff are primary sources of inflow. Periodic outflows from the pond are conveyed south toward Rockport Harbor. The annual flushing rate is 1.2 times per year

In the late 1800s and early 1900s, Lily Pond was widely known for the clarity of its water and the quality of ice cut in winter and stored for shipment south in the summer. At that time, a local newspaper article boasted that a person could read the New York Times through a block of Lily Pond ice. However, marked deterioration in water quality was apparent by the 1970s, raising concerns locally and at the Maine Department of Environmental Protection (MDEP). This eventually resulted in the development of the *Phosphorus Control Action Plan and Total Maximum Daily (Annual Phosphorus) Load Report* (Action Plan) in 2005 (final USEPA approval in 2008). The report (1) identified elevated phosphorus concentrations as the cause of observed declines in water quality, which resulted in excessive chlorophyll-a concentrations and reduced water clarity; (2) set a target lake total phosphorus concentration of 15 µg/L; and (3) recommended a number of watershed management actions for reaching that target. The latter included reducing the inputs of phosphorus from two principal sources – riparian landuse activities at Aldermere Farm and runoff of nutrient-rich landfill leachate from the former Jacob's Quarry.

Figure 1. Lily Pond, Rockport and Camden, Maine with Aldermere Farm in the foreground. (Photo courtesy of Ken Woisard Photography.

Best management practices at Aldermere Farm

Aldermere Farm, a working farm now owned and operated by the Maine Coast Heritage Trust (MCHT), is located on 55 ha in northeast Rockport. The property includes limited development (including offices, barns and related farm buildings), wood lots, hay grounds, and grazing pastures for the farm's Belted Galloway herd, which ranges from 75 to 100 head depending on season. Only 7.8 ha of the land dedicated to grazing are within the Lily Pond watershed. Remaining areas drain either to Rockport Harbor or directly to Penobscot Bay.

Recognizing the potential for impacts to Lily Pond from farm operations, MCHT staff consulted state agencies in 2000 concerning Best Management Practices (BMPs) designed to reduce impacts to Lily Pond. Based on MDEP and Maine Department of Agriculture, Conservation and Forestry recommendations, fencing around a pasture abutting Lily Pond was repositioned to eliminate a 0.3-ha area popular with the cattle and having high potential for runoff. Setbacks for manure spreading in pastures were established and selected areas not located in the Lily Pond

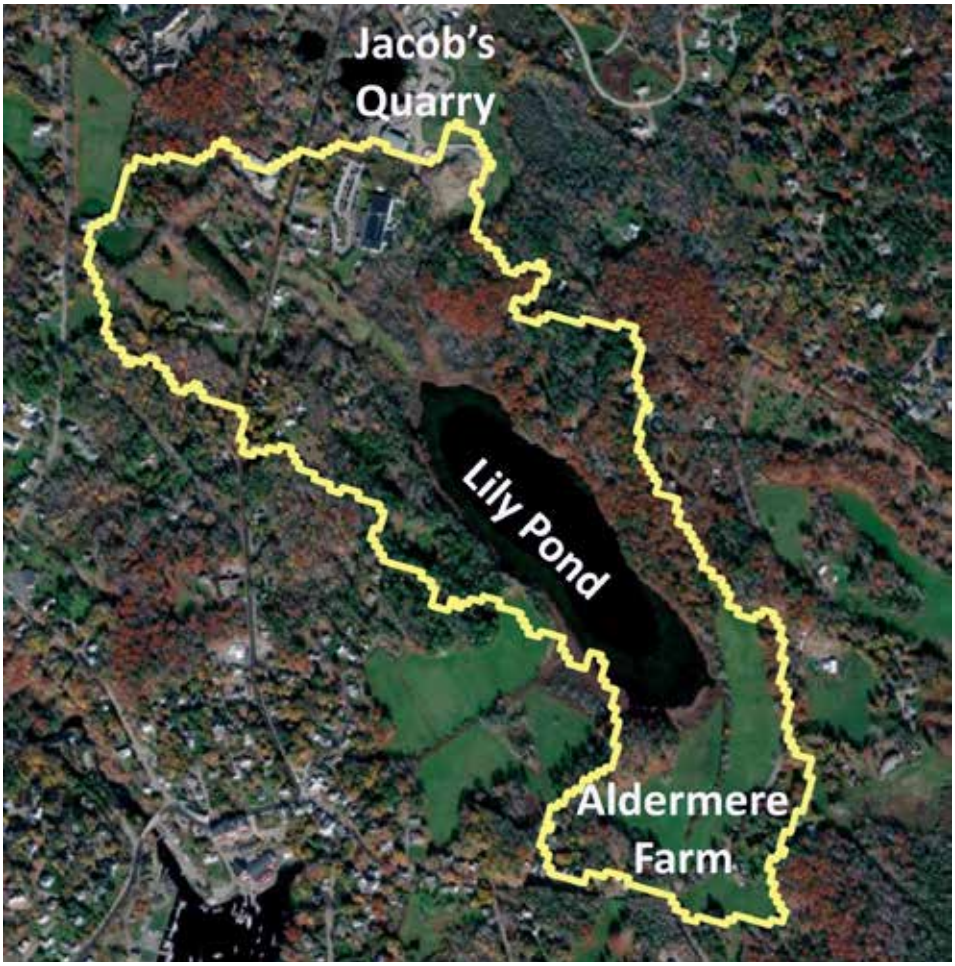

Figure 2. Lily Pond watershed boundary (yellow) and locations of Aldermere Farm and Jacob's Quarry.

watershed previously used for harvesting hay, were converted to grazing pasture to reduce grazing impacts and associated runoff from more vulnerable areas in the pond's watershed.

Farm staff developed a Nutrient Management Plan in 2007 that prescribed BMPs for managing soils, soil amendments and grazing, and recognized the protection of Lily Pond's water quality as a key management goal. Following state guidelines, the plan outlines practices that include comprehensive sampling and analyses of field soils and identifying amendments necessary for proper management of forages while minimizing impacts to Lily Pond. The Nutrient Management Plan was updated in 2023 to include increasing the pasture fence line setbacks to at least 7.6 m from drainages and 22.9 m from the shores of Lily Pond. Farm staff plan to establish native plant species in the riparian zone to enhance biodiversity and nutrient uptake.

Structural and operational changes at Jacob's Quarry

Jacob's Quarry, one of several limestone mining locations in Rockport, began operations in 1885. Early operations resulted in excavation of two primary pits. Much of the mined limestone was transported to nearby kilns, including those at Rockport Harbor. The resulting lime was shipped south by schooner for use in producing building plaster and mortar.

During the period of limited quarrying activity that followed in the early 1900s, pumps were required to remove accumulated drainage and seepage water from the two deep sections of the quarry. After cessation of operations in 1930, the quarry eventually filled with water and began overflowing toward Lily Pond. Starting in the 1940s, the Town of Rockport began using the quarry as a dump for municipal and industrial solid waste. In 1979, the quarry facility began serving three additional towns, eventually becoming managed and operated by the Mid-Coast Solid Waste Corporation. Cessation of municipal waste dumping was ordered by MDEP in 1983. Only the disposal of construction and demolition waste is currently allowed; household waste is either recycled or transferred offsite.

Leachate exported from the quarry site, either by groundwater flow or surface runoff, was identified in the Action Plan as a principal source of nutrient enrichment and the resultant deterioration of the pond's water quality. While historical data are limited, total phosphorus concentrations of surface water being discharged from the quarry toward Lily Pond were excessive when measured in April 1987 (1.8 mg/L) and August 1991 (0.145 mg/L).

In 1993, an *Administrative Consent Agreement and Enforcement Order* issued by MDEP dictated elimination of leachate export from the quarry site. To meet this requirement, pumping of groundwater from the quarry was initiated in 1994 to draw down the local water table thereby preventing or reducing groundwater movement off the quarry site. Connection to the local sewer system allowed extracted water and associated leachate to be treated at the Camden Wastewater Plant. The average pumping rate since initiation is 236.6 m^3/day. Measurements of groundwater levels indicate that the quarry currently acts as a groundwater sink preventing transport of leachate, associated nutrients and contaminants toward Lily Pond.

Additional efforts starting in 2009 addressed surface water runoff. The entire waste mass was reshaped, covered by 0.6 m of soil and seeded to reduce erosion. Slopes and added ditch work now allow diversion of most of the surface water from the facility to existing storm drains or to a detention pond, discharges from which are further detained in an adjacent wetland before draining toward Camden Harbor.

Water quality response

MDEP conducted water quality monitoring efforts from 1979 to 2008 to better describe water quality conditions, identify trends and formulate management options. These efforts included field measurements of Secchi disk transparency, water temperature and dissolved oxygen profiles, as well as collection of water samples for laboratory analyses for total phosphorus and chlorophyll-a. Water

samples were variously collected either directly from the surface, at selected depths throughout the water column using a grab device, or by using a weighted tube to collect an epilimnetic core sample from the upper mixed layer. Values for the mixed layer were also calculated as the unweighted averages of values for depth-wise samples.

The Rockport Conservation Commission (RCC) conducted monitoring efforts starting in 2013, collecting much of the same type of information that was collected earlier by the MDEP. Most recently (2018 to present), a Lake Stewards of Maine (LSM) volunteer has been measuring water clarity weekly or biweekly during June through September, and periodically collecting 3-4 water samples from the surface for determining total phosphorus concentration.

MDEP applies the narrative standard that lakes shall have (1) a stable or decreasing trophic state based on such measures as total phosphorus, chlorophyll-a and Secchi disk transparency subject only to natural fluctuations, and (2) be free of culturally induced algae blooms which impair their potential use and enjoyment. Recommended numeric targets in the Action Plan to attain these water quality goals are total phosphorus $\leq$ 15 µg/L , chlorophyll-a < 8 µg/L and Secchi disk transparency > 2 m.

Marked improvements in these water quality measures were observed during the period 1979-2021. Notably, there has been a clear trend of decrease in epilimnetic and surface total phosphorus concentrations to levels near or below the 15 µg/L target (Figure 3). This trend spans the period when ground water pumping in Jacob's Quarry was initiated to depress the local water table and prevent leachate movement toward Lily Pond (1994 to present), and when BMPs designed to reduce nutrient loading to Lily Pond were implemented at Aldermere Farm (2000 to present). These two watershed management efforts appear to have resulted in a substantial reduction in the load of total phosphorus entering Lily Pond.

Lily Pond exhibited other positive changes in water quality linked to the observed reductions in total phosphorus. Secchi disk depths (Figure 4), while frequently shallow prior to about 1995, have increased steadily since then and now meet MDEP's recommended level of > 2 m. Similarly, positive changes were observed in chlorophyll-a concentrations (Figure 5). Concentrations prior to 2005 were excessive, with values as high as 30 µg/L observed, far in excess of the MDEP's recommended < 8 µg/L. Concentrations since 2005 have been consistently below this level.

Despite these dramatic changes in key water quality characteristics, dissolved oxygen concentrations in Lily Pond's bottom waters continue to be reduced during summer when the lake is thermally stratified. Under stratified conditions, there is limited upward mixing of cooler, denser bottom waters and therefore limited opportunity for replacing oxygen consumed due to decomposition of organic matter. This is especially problematic in lakes that are moderately to highly productive and/or receive excessive loads of organic matter from the watershed. A comparison of four temperature and dissolved oxygen profiles recorded during the month of July suggests slight improvement over the period 1979 to 2018 (Figure 6). The oxygen depletion does not extend into the water column quite as far, and the degree of depletion is not quite as severe.

Despite reductions in phytoplankton biomass based on observed changes in chlorophyll-a concentrations, there is very likely a legacy load of organic matter in the sediments that continues to consume oxygen during decomposition, which is anticipated to slowly decrease over the next few decades

Given the substantial improvements in water quality following implementation of BMPs by Aldermere Farm, structural and operational changes at Jacob's Quarry, and the small watershed area relative to the area of the lake, it seems unlikely that the watershed continues to be the major source of excessive organic matter loads to the pond.

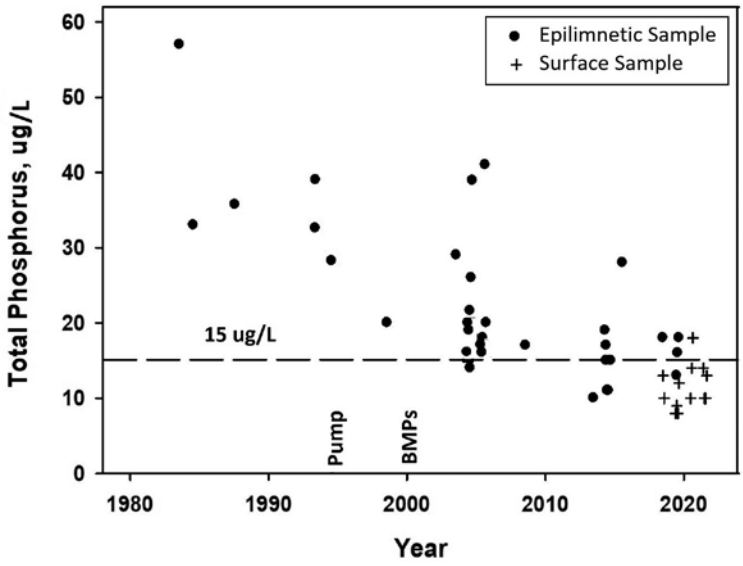

Figure 3. Changes in epilimnetic and surface total phosphorus concentrations relative to the Action Plan target of 15 µg/L (dashed line), and initiation of groundwater pumping and BMP implementation.

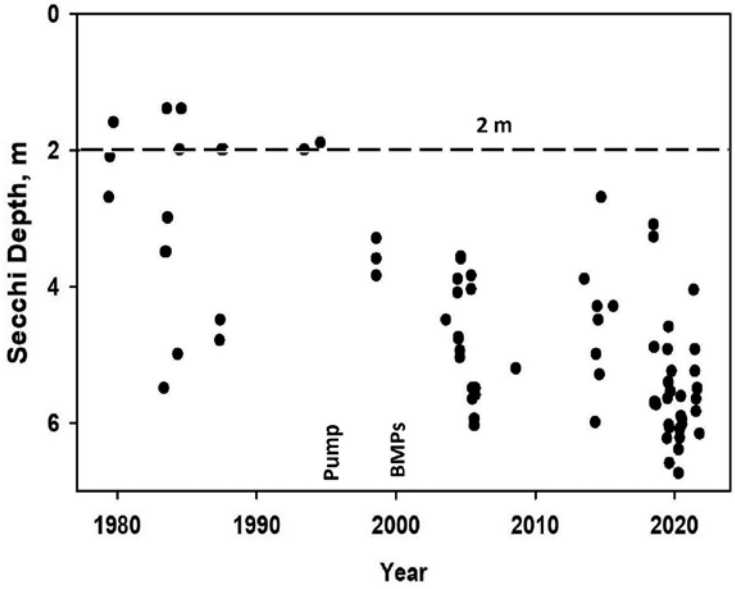

Figure 4. Changes in Secchi depth relative to the recommended value of > 2m (dashed line), and initiation of groundwater pumping and BMP implementation.

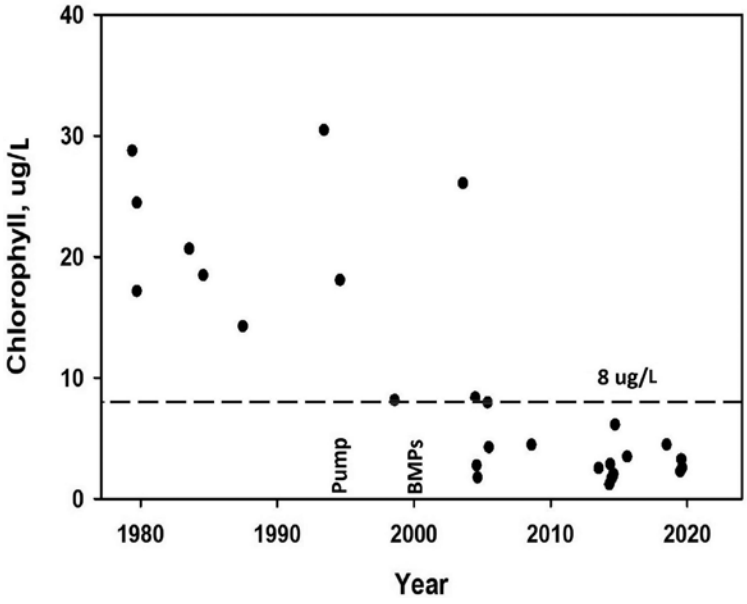

Figure 5. Changes in chlorophyll-a concentration relative to the recommended value of < 8 µg/L (dashed line), and initiation of groundwater pumping and BMP implementation.

In addition to legacy loads, there is more likely contributions from the pond's extensive and densely vegetated littoral area. High rates of plant productivity in these shallow waters likely add to the internal load of organic matter. The growth and subsequent senescence of littoral plants results in organic matter deposition, a portion of which is likely transported to deeper water sediments and contributing to the observed oxygen declines in bottom waters during stratified periods. Currently, available data are insufficient to quantify this source. However, littoral plants are an integral part of Lily Pond's ecosystem, providing nursery areas for fish, zooplankton, aquatic macroinvertebrates and amphibians. And the organic matter generated by aquatic plants is generally considered of higher quality than that from algae or external sources.

Implementation of management recommendations in the Action Plan by watershed partners has resulted in marked improvement in Lily Pond water quality. Based on monitoring data collected by MDEP and, most recently, by RCC and LSM, total phosphorus, chlorophyll-a and Secchi disk transparency now meet or exceed recommended values in the Action Plan. MDEP is currently considering a request to USEPA that Lily Pond be removed from the State's Section 303d list of impaired lakes. These concerted efforts demonstrate the importance of committed watershed partners to conserve and rehabilitate the region's legacy natural resources.

Selected references

Maine Department of Environmental Protection. 2008. Phosphorus Control Action Plan and Total Maximum Daily (Annual Phosphorus) Load Report. Lilly Pond – Rockport and Camden, Knox County, Maine. Available at https://www.maine.gov/dep/water/monitoring/tmdl/2008/lillypond_rep.pdf, Accessed Feb 6, 2024.

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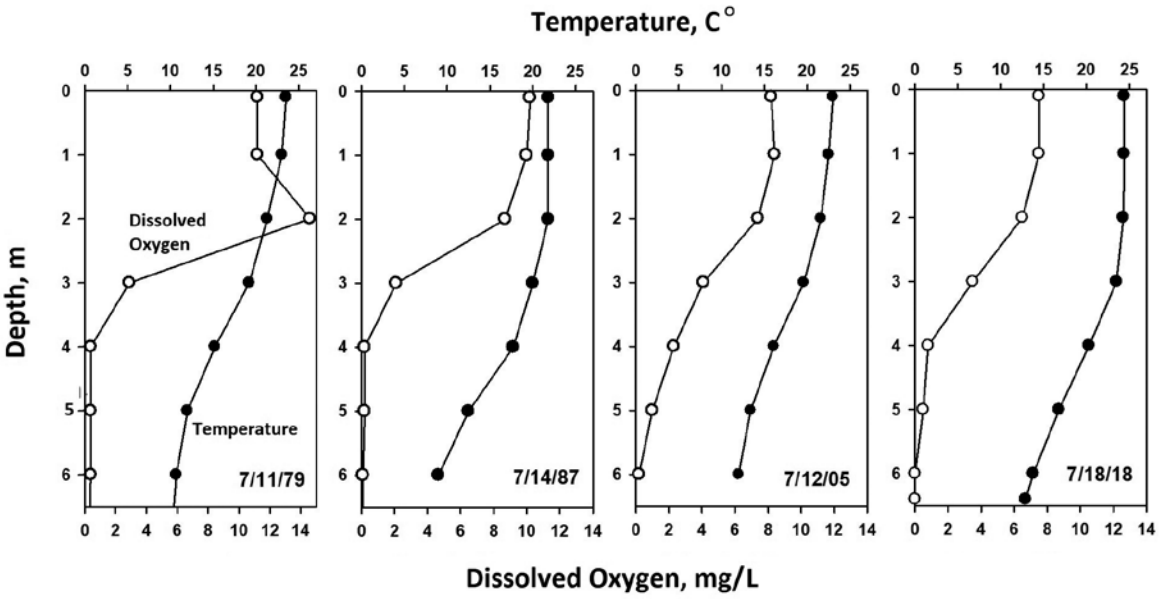

Figure 6. Vertical changes in temperature and dissolved oxygen observed in Lily Pond during July of selected years.