Chickawaukie Lake Water Quality (1973-2021)

Report of the Rockport Conservation Commission
Prepared by Robert Kennedy, PhD
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Introduction

Chickawaukie Lake, located in Rockland and Rockport, Maine, is a relatively shallow (mean and maximum depths are 21 and 33 feet, respectively) natural lake of moderate size (surface area is 362 acres).[1] Much of the 2,262-acre watershed, which includes Maces Pond (surface area is 40 acres), extends north with undeveloped areas accounting for just over 50% of the drainage area. While used primarily for recreation (swimming, boating and fishing), the lake has also served as an auxiliary water supply for Maine Water Company. A gated structure located at the southern end of the lake provides limited water depth/volume control.

Figure 1. Chickawaukie Lake, Rockland/Rockport

Concerns over deteriorating water quality in Chickawaukie Lake were raised as early as the mid-1970's. Reduced water clarity and late-summer algal "blooms," some severe, observed in the early 1980's led to initiation of intensive monitoring by the Maine Department of Environmental Protection (MDEP) and prompted local residents to establish the Chickawaukie Lake Association[2]. Efforts to ameliorate the lake's poor water quality were subsequently implemented in the mid-1990s.

Reported here is a summary of management initiatives and associated water quality changes for the period 1973-2021.

Management Initiatives

Healthy lake ecosystems depend on material inputs, including nutrients, from the terrestrial portion of the watershed. This process, referred to as "external loading," is influenced by local hydrology, geology and land use activities in the drainage area. However, when the external loading of nutrients, particularly phosphorus, is excessive, water quality impairments can occur. These

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[1] *Walker, W. W. 1988. Chickawaukie Lake Study prepared for Chickawaukie Lake Association, Rockland/Rockport, Maine.*

[2] *The Chickawaukie Lake Association was formed in November 1983 and became inactive in 2001.*

may include reduced water clarity, nuisance algal blooms and, for lakes that stratify thermally, bottom waters that are devoid or nearly devoid of dissolved oxygen.

In the absence of dissolved oxygen, a portion of the external phosphorus load incorporated in bottom sediments can be released back into the water column and be potentially available for algal growth. This is referred to as "internal loading." These releases, and redeposition of phosphorus in the sediments when oxygen is restored, are mediated primarily by iron. Under oxidized conditions, iron is insoluble and can bind with phosphorus thus retaining it in bottom sediments. In the absence of oxygen, iron becomes soluble releasing the bound phosphorus. This seasonal recycling of phosphorus can continue to promote excessive algal growth even if the external loads are reduced to levels that would otherwise reduce algal growth.

Management efforts for Chickawaukie Lake addressed both external and internal phosphorus loading[3]. Areas prone to high rates of runoff which could generate elevated loads of nutrients and sediment to the lake were remediated by the addition of rip-rap in areas of high erosion potential, re-ditching and re-culverting selected roadways, diverting some drainage to areas outside the watershed, discontinuing and grassing over selected sections of neighborhood roads and constructing phosphorus control detention ponds. These efforts were performed collaboratively by the City of Rockland, the Town of Rockport, the Maine Department of Transportation and the Camden-Rockland Water Company (now Maine Water Company).

Aluminum sulfate or alum was proposed in the 1970's as an in-lake method to reduce internal phosphorus loading.[4] Aluminum, like iron, can bind with inorganic phosphorus, but unlike iron, aluminum-phosphorus complexes can persist even in environments devoid of oxygen. Because of this property, increasing sediment aluminum content can limit phosphorus releases to the overlying water column. Toward that end, Chickawaukie Lake was treated with a mixture of aluminum sulfate and sodium aluminate in June 1992.[5] The injection of aluminum at a depth of 12-15 ft targeted 248 acres or 69% of sediment surface at an average dosage of 29.8 gm Al/m^2.

Data Sources

Water quality data were collected by the MDEP from 1973 to 2013 and are available online through the Lakes of Maine website[6]. Parameters included water temperature, dissolved oxygen (DO), Secchi disk depth (SD), total phosphorus (TP) and chlorophyll (CHL). The Rockport

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[3] *Maine Department of Environmental Protection. 1994. Chickawaukie Lake Restoration Project Final Report, EPA Section 314 Grant #S001225-01-0.*

[4] *e.g., Kennedy, R. H. and Cooke, G. D. 1982. Control of lake phosphorus with aluminum sulfate: dose determination and application techniques. JAWRA 18(3): 389-395.*

[5] This combination minimizes the potential for lowered pH levels and toxic concentrations of dissolved aluminum that can occur when aluminum sulphate alone is applied.

[6] *http://www.lakesofmaine.org*

Conservation Commission (RCC) sampled the lake for the same parameters in 2015 and on three occasions during summer 2021. Local Lake Stewards of Maine (LSM) volunteer, Sarah Andrus, recorded SD values at weekly or biweekly intervals during summer 2018-2021, and collected monthly surface water samples for TP analyses.

Water samples were collected either from just below the surface (surface grab or SG), approximately 1 m above bottom sediments (bottom grab or BG), at discrete depths throughout the water column (profile grab or PG) or using a tube to collect an integrated water sample between the surface and the top of the thermocline[7] (epilimnetic[8] core or EC). For purposes here, an unweighted average of PG values down to the depth of the top of the thermocline was used to estimate an EC value. In addition, PG values for samples collected at depths within 1 to 2 m of the bottom were defined as BG. Samples for chlorophyll analysis were always collected as an EC sample.

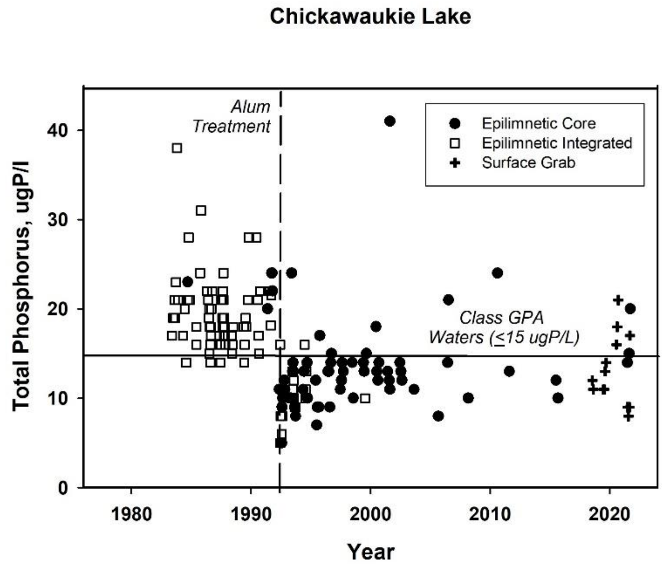

Figure 2. Epilimnetic and surface total phosphorus concentrations.

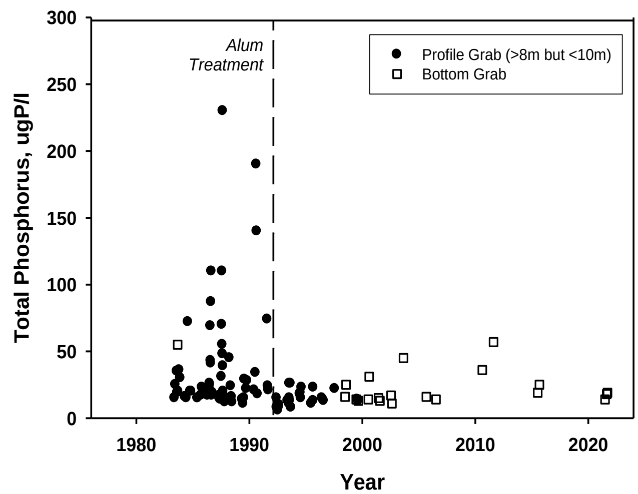

Figure 3. Near-bottom total phosphorus concentrations.

Water Quality

Phosphorus

Marked changes in TP concentrations were observed following implementation of watershed and in-lake phosphorus management efforts. TP concentrations in the epilimnion prior to 1992 (year of alum treatment) ranged from 14 to 38 ugP/l and averaged[9] 19.5 ugP/l with a majority of the observations exceeding the MDEP recommended level for lakes and ponds in Maine (15 ugP/l;

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[7] *The thermocline is generally defined as that portion of the water column where temperature changes 1 C°/m. Accompanying changes in water density can restrict mixing between surface and bottom waters.*

[8] *The epilimnion is the well-mixed portion of the water column extending from the surface to the thermocline.*

[9] *Geometric mean, which is more appropriate than the arithmetic mean for determining central tendency in a highly skewed dataset*

Figure 2). Total phosphorus concentrations after 1992 ranged from 7 to 41 ugP/l and averaged 12.9 ugP/l with a majority of the observations meeting or surpassing the MDEP recommended level.

Noteable for near-bottom samples collected following 1992 was the absence of extremely high TP concentrations as were observed prior to 1992 (Figure 3). Near-bottom TP concentrations prior to 1992 ranged from 11 to 230 ugP/l with a median value of 21 ugP/l, while those those observed following 1992 ranged from 8 to 57 ugP/l with a median value of 15 ugP/l. Twenty five percent of values observed prior to 1992 were greater than 40 ugP/l, while only 8% of values oberserved after 1992 exceeded that same level.

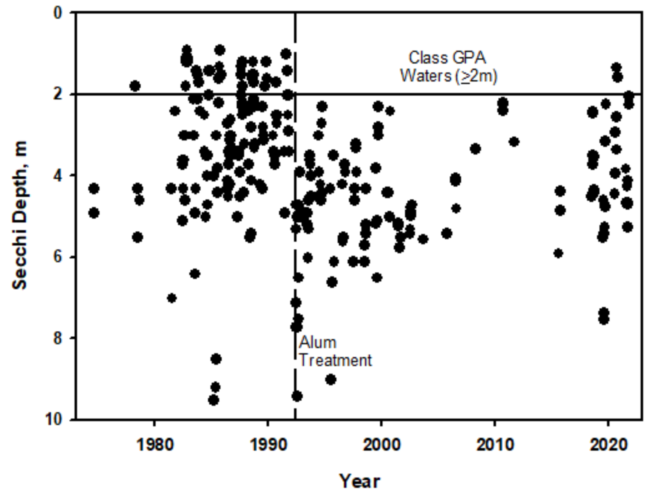

Figure 4. Secchi disk depth before and after alum treatment (vertical dashed line) relative to the MDEP recommended depth of 2m (horizontal solid line).

Water Clarity

Water clarity, as measured by Secchi disk depth, while highly variable throughout the period 1973-2021, exhibited notable changes following management efforts (Figure 4). Prior to 1992, Secchi depths were shallower than the MDEP recommendation of 2 m on numerous dates with a majority of observations measuring less than 4m. Secchi depths since then have exceeded 2m on all but two dates in 2021.

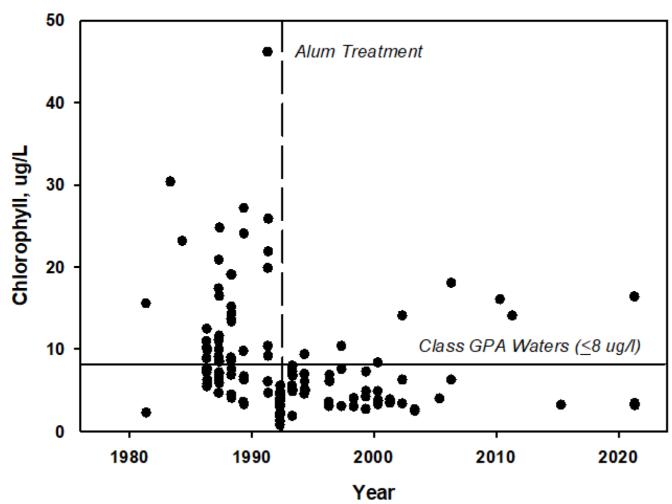

Figure 5. Epilimnetic chlorophyll concentration before and after alum treatment (vertical dashed line) relative to the MDEP recommended concentration of ≤ 8 ug/l (horizontal solid line).

Chlorophyll

Epilimnetic chlorophyll concentrations were highly variable and frequently exceeded the MDEP recommended level of ≤ 8 ug/l prior to 1992 but decreased precipitously in 1992 coincident with the alum treatment (Figure 5). Concentrations since 1992, while still highly variable were, with notable exceptions, near or below 8 ug/l.

Noted exceptions included elevated concentrations in 1997, 2002, 2010, 2011 and 2021 (10.3, 14, 16, 14 and 16.3 ug/l, respectively[10]; Figure 5) and may have been promoted by external loading events. Monthly precipitation[11] during the months when these elevated concentrations were observed ranged from 4.34 to 10. 05 inches and were 2.9 to 6.0 inches higher that the monthly norms for this same period.

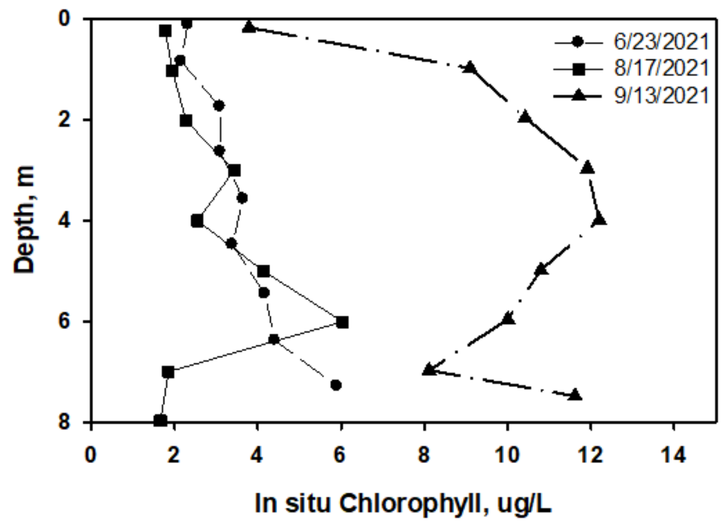

Figure 6. Vertical profiles of chlorophyll concentration estimated using an in-situ fluorometer. Values for 9/13/2021 suggest the occurrence of an algal bloom.

Elevated chlorophyll levels in late summer are not unexpected for moderately productive (mesotrophic) lakes and would be attributable to increased algal abundance. Such a late summer algal 'bloom' was observed by local residents in 2020 but was unsupported by field data.

Bloom conditions were documented with field data in mid-September 2021 when the measured epilimnetic concentration was 16.3 ug/l (Figure 5). Vertical profiles of chlorophyll concentration estimated in-situ using a fluorometer[12] on 23 June and 17 August, 2021 were similar and nearly uniform with depth; values ranged from 2 to 6 ug/l (Figure 6). The profile for 13 September was decidedly different. Estimated concentrations, while low near the surface, increased markedly with increasing depth. Maximum estimated values ranging from10 to 12 ug/l were recorded at mid depth in the profile; concentrations declined with further increases in depth likely due, in part, to reduced light availability.

Discussion

Control of External Phosphorus Loading

The absence of data describing changes in the quantity and quality of inflows to the lake precludes an assessment of the effectiveness of watershed management efforts intended to reduce

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[10] A concentration of 18 ug/l recorded in June 2006 is questionable since a duplicate sample had a concentration of only 6.2 ug/l.

[11] Data recorded at the West Rockport NOAA weather station and available online at https://www.weather.gov/

[12] The fluorometer used does not quantify chlorophyll per se but measures light emitted (fluoresced) from a parcel of water exposed to light of a particular wavelength; it is assumed that chlorophyll is the primary source of the fluorescence. The resultant data, while not quantitative, may provide information about chlorophyll distributions and relative concentrations.

external loading of nutrients, particularly phosphorus, to Chickawaukie Lake from diffuse, nonpoint sources (NPS). These sources generally occur in watershed areas prone to runoff from precipitation events and with land cover or land use characteristics conducive to the mobilization of pollutants during such runoff events.

A risk assessment conducted in 2015-2016[13] using land use and land cover data from 2011[14] identified several areas exhibiting characteristics which suggest the potential for moderate to high rates of NPS pollutant export (Figure 7). These include areas immediately west and north of the lake and along Route 17; areas southeast of the lake in the vicinity of Rockport Meadows subdivision; and areas that drain to Maces Pond. (The latter areas are of lesser concern since a portion of the nutrient load would be retained by Maces Pond.) The degree to which these areas actually generate NPS pollution has yet to be evaluated.

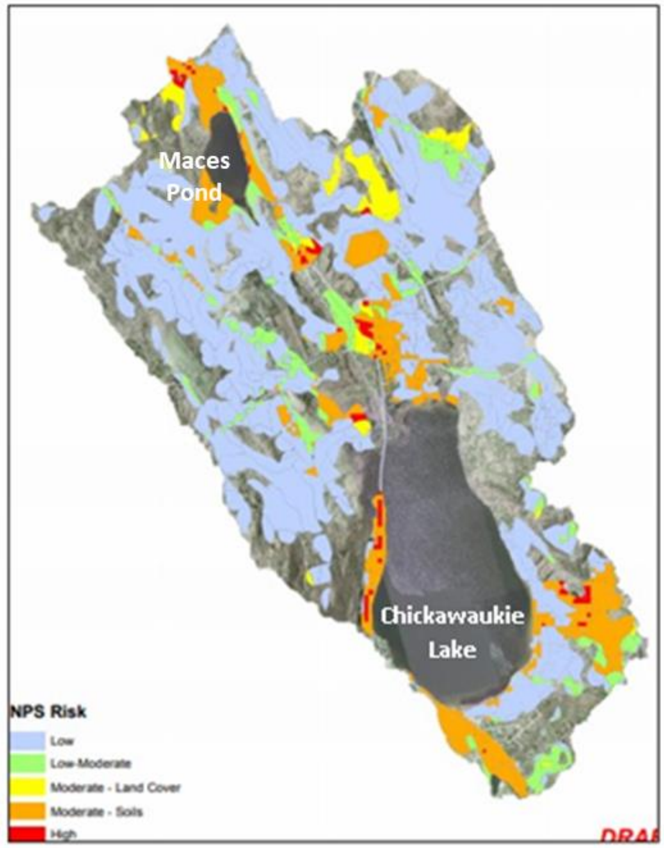

Figure 7. Nonpoint source (NPS) risk assessment for the Chickawaukie Lake watershed based on land cover, land use and soil data,

Effectiveness and Longevity of the Alum Treatment

The impacts of aluminum treatment were immediate and dramatic. Total phosphorus concentrations declined to low levels throughout the water column (Figures 2 and 3). Aluminum hydroxide precipitate or "floc" created during treatment would have adsorbed much of the inorganic dissolved phosphorus and entrapped particulate phosphorus as it settled through the water column.

The long-term effectiveness of aluminum treatments is difficult to predict and depends on a number of interacting factors including the quantity and fate of aluminum added to sediments, degree of success in managing of external loading and physical characteristics of the lake[15].

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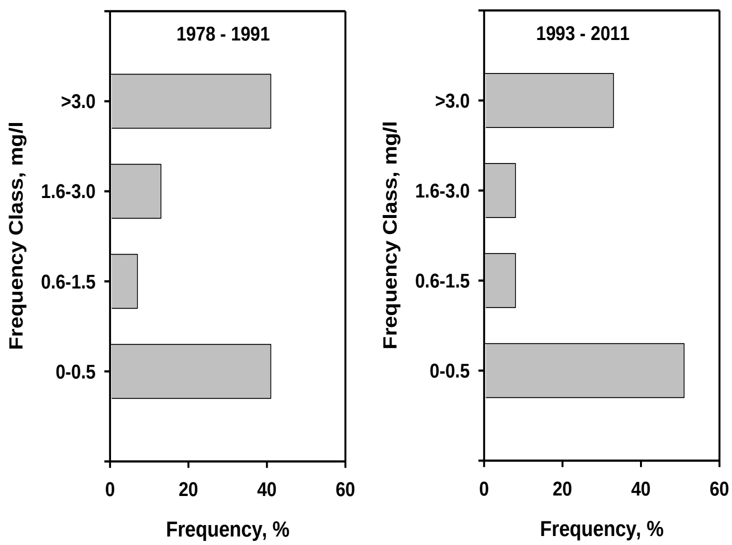
[13] *Kennedy, R. H. 2016. A watershed approach to managing land use impacts to coastal waters. Final Report, Coastal Community Coastal Grant Program, Maine Department of Agriculture, Conservation and Forestry.*

[14] *U.S. Geological Survey, 2014, National Land Cover Database (NLCD) 2011 Land Cover Conterminous United States: U.S. Geological Survey data release, https://doi.org/10.5066/P97S2IID.*

[15] *Welch, E. B. and G. D. Cooke. 1999. Effectiveness and longevity of phosphorus inactivation with alum. Journal of Lake and Reservoir Management 15:5-27.*

Figure 8. *Frequency distribution of dissolved oxygen concentrations above bottom sediments in May through September 1978-1991 (left) and 1993-2011 (right).*



Determining effectiveness of aluminum treatments is made more difficult by the fact that controls on external loading and in-lake treatments are often implemented coincidentally.

Chickawaukie Lake was included among 114 aluminum-treated lakes in a recent review of the longevity and effectiveness of such additions in ameliorating sediment phosphorus impacts on water quality.[16] Estimates of longevity were based on the time between treatment and the last year of improved water quality (defined as 50% or greater reduction in epilimnetic TP or CHL, or a commensurate increase in SD). A trend analysis was employed for lakes with an insufficient post-treatment data record. Based on this approach, the longevity of TP control for Chickawaukie Lake was estimated to be 39 years (i.e., until 2031).

Water quality data collected since implementation of management efforts offer a subjective assessment of effectiveness to date. Epilimnetic TP concentrations (Figure 2), while variable, remain on average, markedly lower than those observed prior to alum treatment and implementation of NPS management efforts. Extremely elevated near-bottom TP concentrations (greater than 50 ugP/l), as occurred prior to 1992, have not been observed since 1992 (Figure 3) despite that observation that the frequency of near-bottom dissolved oxygen concentrations below 0.5 mg/l was relatively unchanged (Figure 8). While sediment chemistry data are lacking, this may suggest that the added aluminum continues to diminish the release of sediment-bound TP during the summer stratified period.

Concluding Remarks

Positive changes in key water quality parameters (TP, CHL and SD) occurred in Chickawaukie Lake following (1) implementation of Best Management Practices to reduce external TP loading from the watershed and (2) application of aluminum sulfate/sodium aluminate to reduce internal TP loading from bottom sediments during periods of depleted dissolved oxygen concentrations during summer months. While there are no clear post-1992 trends in TP concentrations or response parameters CHL and SD to suggest

[16] *Huser, B. J. et al. 2016. Longevity and effectiveness of aluminum addition to reduce sediment phosphorus release and restore lake water quality. Water Research 97:122-132.*

that water quality conditions are again deteriorating, recent observations of algal blooms are concerning. These late summer blooms may be promoted by increased rates of external nutrient loading associated with episodic precipitation/runoff events.

The Rockport Conservation Commission and Lake Stewards of Maine continue to collect water quality data for Chickawaukie Lake on a seasonal basis. These data provide the critical means to assess ambient water quality conditions, identify potential trends, and provide timely management recommendations.