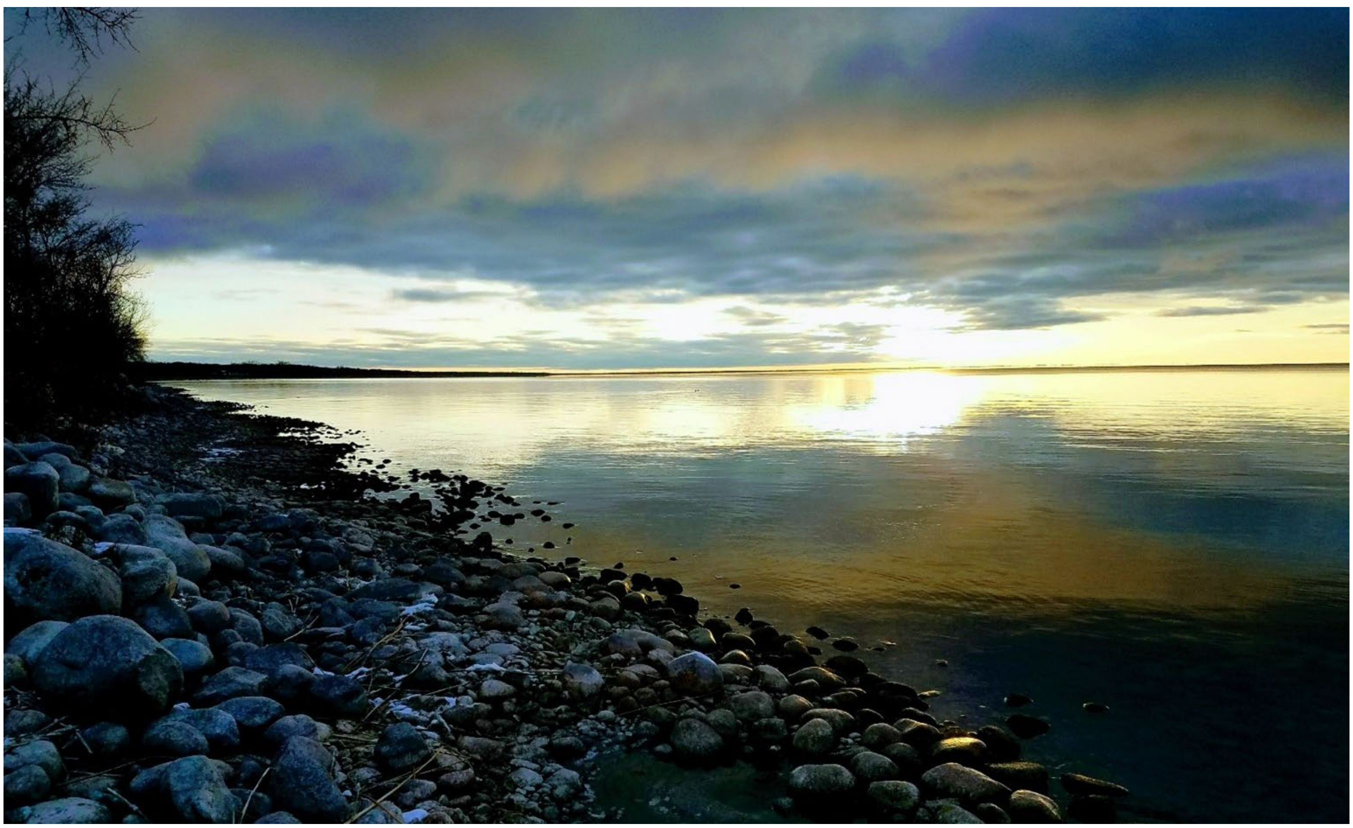
Site-specific standard

March 2024

Technical Justification for Site-Specific Lake Eutrophication Standards for Upper and Lower Red Lakes (04-0035-01 and 04-0035-02)



MINNESOTA POLLUTION CONTROL AGENCY

Authors

R. William Bouchard, Jr. (Minnesota Pollution Control Agency)

Kayla Bowe (Red Lake Department of Natural Resources)

Shane Bowe (Red Lake Department of Natural Resources)

David R.L. Burge (St. Croix Watershed Research Station)

Jesse P. Anderson (Minnesota Pollution Control Agency)

Mark B. Edlund (St. Croix Watershed Research Station)

Adam J. Heathcoat (St. Croix Watershed Research Station)

Minnesota Pollution Control Agency

520 Lafayette Road North | Saint Paul, MN 55155-4194 |

651-296-6300 | 800-657-3864 | Or use your preferred relay service | Info.pca@state.mn.us

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Executive summary

As Clean Water Act delegated entities, the Red Lake Nation, and Minnesota Pollution Control Agency (MPCA)[1] have the authority to develop site-specific standards (SSS) when available information demonstrates that a site-specific modification to statewide or ecoregion standards is appropriate. This document is a collaborative effort between the Red Lake Nation and MPCA which describes the process for establishing SSS and proposes site-specific modifications to the lake eutrophication standards (LES) for Upper (04-0035-01) and Lower (04-0035-02) Red lakes. The proposed SSS are not part of a Use Attainability Analysis (UAA) to demonstrate that the current beneficial use designation (Class 2) cannot be attained. Rather, these SSS are based on a demonstration that modifications to the LES, which apply to these waterbodies, will still result in attainment of Class 2 designated beneficial uses (aquatic life and recreation).

Description of Red Lake

Upper and Lower Red lakes[2] are large, important lake basins in northern Minnesota. Together these two lakes cover 288,800 acres by surface area. Lower Red Lake is nearly 25 miles from its western to eastern shores and 13 miles from north to south. Upper Red Lake is also close to 25 miles across but only 10 miles at its greatest distance from the northern to southern shores. Although both lakes have large surface areas, the morphometry of the two basins differs. Upper Red Lake is shallow with a maximum depth of only 16 feet and Lower Red Lake is deeper with a maximum depth of 33 feet. The estimated water residence time for Upper Red Lake is 10.8 years and for Lower Red Lake is 12.7 years. The geometry ratios[3] for the lakes also differ with a ratio of 30.4 $m^{-0.5}$ for Upper Red Lake and 16.2 $m^{-0.5}$ for Lower Red Lake. However, both geometry ratios predict that these lake basins are polymictic (> 4 $m^{-0.5}$). This is supported by measurements of temperature profiles in these lakes. There were over 600 temperature profiles measured during the summer index period (June through September) in each lake between 1990 and 2023. These profiles were considered mixed[4] for 89-91% of the profiles indicating that although the lakes may stratify for periods during the summer, these lakes are largely mixed. Based on these criteria, it may be more appropriate to apply a shallow lake standard to Upper and Lower Red lakes.

The major tributaries flowing into Upper Red Lake include the Tamarac River, Shotley Brook, and Manomin Creek. Major tributaries flowing into Lower Red Lake include the Battle River, Blackduck River,

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[1] *The MPCA's SSS rule language can be found here: [Minn. R. 7050.0220, subp. 7](#).*

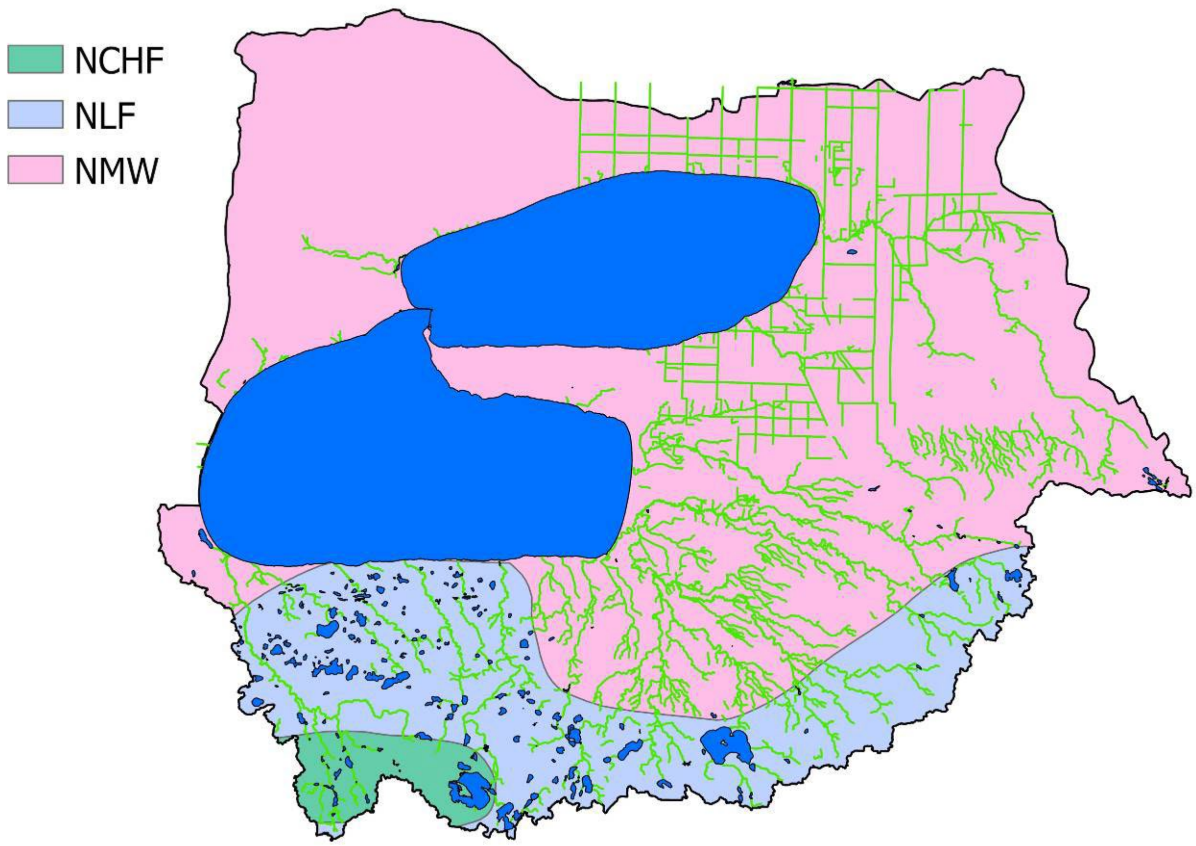
[2] *The nomenclature for Upper and Lower Red lakes varies depending on the source and it is necessary to clarify how we refer to these lake basins in this report. In some cases, we refer to both basins together as "Red Lake". This is consistent with Minnesota's lake system for cataloging lakes which uses the code 04-0035-00 to refer to both lakes. The codes 04-0035-01 (Upper) and 04-0035-02 (Lower) are used to refer to the two Red Lake basins. In most cases, we refer to these basins together as "Upper and Lower Red lakes" or individually as "Upper Red Lake" and "Lower Red Lake". This acknowledges that although these basins are connected, they are unique and most analyses in this report treat each basin as a separate water body.*

[3] *Geometry ratio can be calculated as: $A_0^{0.25}/z_{max}$, where A_0 is lake surface area (m^2) and z_{max} is maximum depth (m) (Stefan et al. 1996).*

[4] *A thermocline was considered to be present if a portion of the temperature profile changed >1°C per meter. Using this metric, a lake profile with a thermocline meeting this criterion was determined to be stratified.*

Hay Creek, Mud River, Pike Creek, and Sandy River. The Red Lake River is the only outlet to both Upper and Lower Red lakes and it is located at the western end of Lower Red Lake. Lake levels are largely determined by precipitation and evaporation with the outlet having a relatively minimal impact. There is a dam located at the outlet that is operated by the Army Corps of Engineers with the general goal of maintaining the water level of the lakes between 1174-1175 feet. This is only achievable over the long term and only in relatively stable conditions.

Figure 1. Level 3 ecoregions (Omernik 1987) in the Upper/Lower Red Lake watershed (HUC8: 09020302). Abbreviations: NCHF = North Central Hardwood Forests ecoregion, NLF = Northern Lakes and Forest ecoregion, and NMW = Northern Minnesota Wetlands ecoregion.



Upper and Lower Red lakes lie within the Upper/Lower Red Lake watershed (8-digit Hydrologic Unit Code 09020302) which encompasses 1,241,690 acres. This watershed is part of the Red River of the North Basin which drains to Hudson Bay. Most of the watershed is in the Northern Minnesota Wetlands (NMW) ecoregion with smaller portions in the North Central Hardwood Forests (NCHF) and the Northern Lakes and Forests (NLF) ecoregions (Figure 1). It is important to note that these lakes are on the border of these three Level 3 ecoregions (Omernik 1987). Ecoregions do not immediately transition at their defined borders and areas near ecoregion borders are ecotones that share characteristics of multiple ecoregions (Table 1). As a result, the Upper/Lower Red Lake watershed has characteristics of multiple ecoregions. The watershed is very rural with little development (Table 2; Figure 2). Most notable is that the watershed is dominated by wetland land cover (48%) with lower proportions of open water (24%), and forest/shrub (18%). Little of the watershed has been altered by humans with less than 2% developed, 6% pasture/hay, and <1% cultivated crops. Although there are some hydrologic alterations (i.e., ditching and dams) and some altered land cover types in the watershed, the Upper/Lower Red Lake watershed is largely natural. The high proportion of wetlands is of particular importance because this cover type can increase nutrient loading to downstream waters. For example, wetlands were found to increase total phosphorus (TP) concentrations in northern Michigan headwater lakes (Zhang et. al. 2012). In 20 relatively undisturbed forested watersheds in Ontario, wetland extent was correlated with the export of TP and DOC indicating that wetlands are TP sources to lakes (Dillon and Molot 1997). The location of these lakes in an ecotone and the high proportion of wetlands in the contributing watershed are indications that regional LES may not be appropriate.

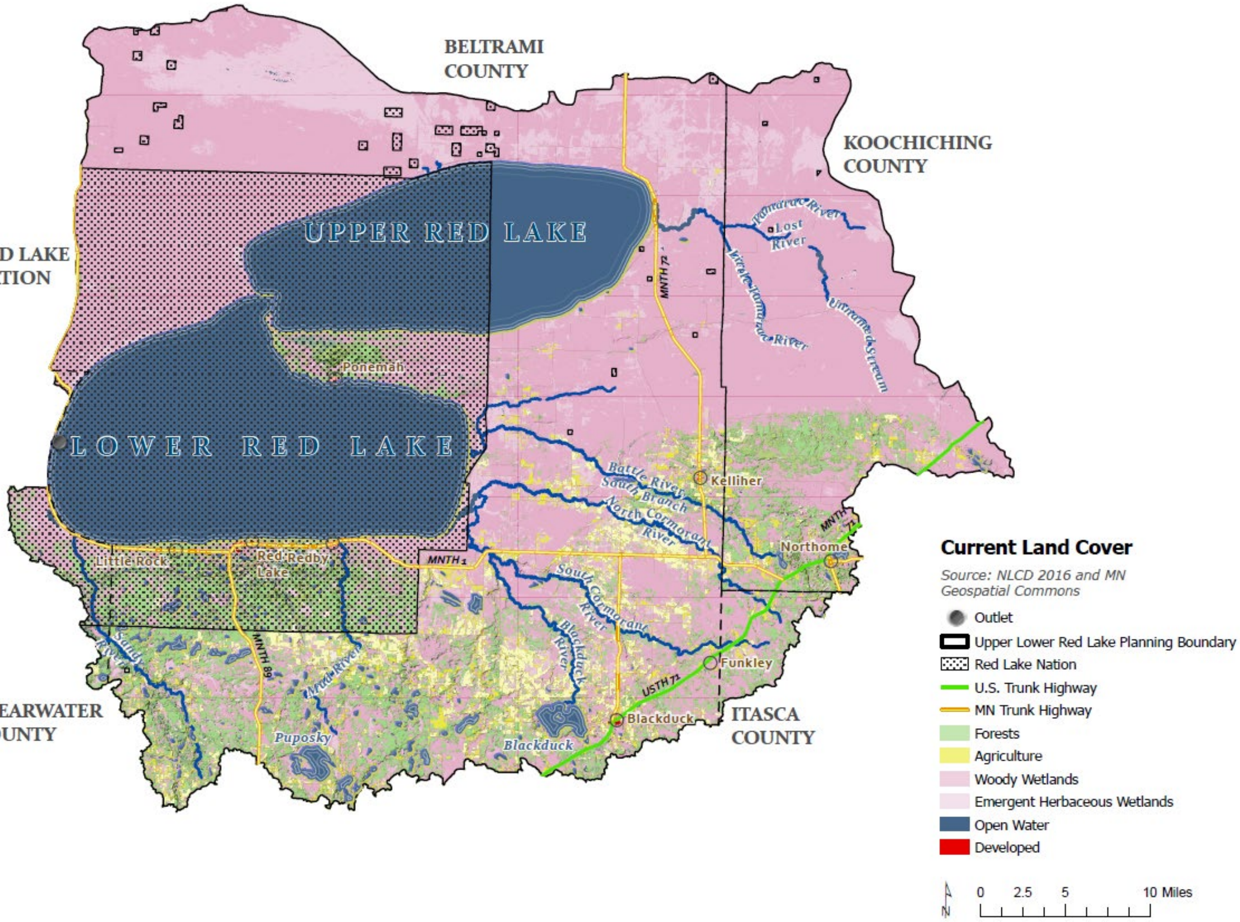
Table 1. Descriptions of ecoregions within the Upper/Lower Red Lake Watershed (from White 2020).

Northern Minnesota Wetlands (49)
“Much of the Northern Minnesota Wetlands Level III ecoregion is a vast and nearly level wetland that is sparsely inhabited by humans and covered by conifer bog, mixed forest, and boreal forest vegetation. Formerly occupied by broad glacial lakes, much of the flat terrain in this ecoregion is still covered by standing water. Some low-gradient streams and eroded river channels occur in the east.”
Northern Lakes and Forests (50)
“This Level III ecoregion has relatively nutrient-poor glacial soils, coniferous and northern hardwoods forests, undulating till plains, morainal hills, broad lacustrine basins, and areas of extensive sandy outwash plains. Soils are formed primarily from sandy and loamy glacial drift material and generally lack the arability of those in adjacent ecoregions to the south and west. Ecoregion 50, along with the [Northern Minnesota Wetlands] (49), have lower annual temperatures and a frost-free period that is considerably shorter than other ecoregions in Minnesota; this ecoregion also has the largest annual snowfall and the most days with snow cover. These conditions generally hinder agriculture; therefore, woodland and forest are the predominant land use/land cover. Numerous lakes dot the landscape.”
North Central Hardwood Forests (51)
“This Level III ecoregion is transitional between the predominantly forested Northern Lakes and Forests (50) to the north and the Western Corn Belt Plains (47) to the south and the Lake Agassiz Plain (48) to the west. Nearly level to rolling till plains, lacustrine basins, outwash plains, and rolling to hilly moraines comprise the physiography of this ecoregion. The land use and land cover in this ecoregion consists of a mosaic of deciduous forests, wetlands and lakes, cropland agriculture, pasture, and dairy operations. This ecoregion also contains the large urban metropolis of Minneapolis and St. Paul. The growing season is generally longer and warmer than that of Ecoregion 50 to the north, and the soils are more arable and fertile, contributing to the greater agricultural component of the land use. Lake densities are generally lower here than in the Northern Lakes and Forests but greater than in agricultural ecoregions south and west.”

Table 2: Land cover in the Upper/Lower Red Lake Watershed. Land cover is derived from the 2016 National Land Cover Database (NLCD).

Land Cover	**Area (acres)**	**%**
Wetlands	678,105	55
Water	300,120	24
Trees/shrubs	176,856	14
Cultivated Crops	42,243	4
Pasture/Hay	28,054	2
Development	16,312	1
Total	1,241,690	100%

Figure 2: Land use in the Upper/Lower Red Lake watershed (HUC8: 09020302) based on the 2016 National Land Cover Database (NLCD).



Upper and Lower Red lakes provide several important beneficial recreational uses including fishing, boating, and swimming. Both basins are also important to the tribe as the only source of commercial walleye fishery in Minnesota. Tribal members rely on the walleye as a source of subsistence as well as income. Lower Red Lake has 12 main public lake accesses used by tribal members which are primarily used to access the lake for fishing. A sandy area on the east shore of Lower Red Lake is referred to as the "cut off" and is extremely popular with tribal members as a beach and recreation area. This beach has on occasion had over 1,000 people using it for beach activities concurrently. Usage has increased in recent years. Upper Red Lake has a tribal access at Ponemah Point and on the south shore at the reservation line as well as public accesses (non-reservation) available on the Tamarac River. These accesses are used extensively during the open water fishing season. Private accesses are found at several resorts along the eastern and southern shore. Many of these resorts provide winter access as well. During the winter season, thousands of anglers access the lake for ice fishing. There is a public beach on Upper Red Lake in Waskish that is used occasionally by campers, and resort beaches are used regularly by visitors. In addition, some private residences on the south shore of Upper Red Lake have beach accesses.

Water quality standards

Minnesota's regional lake eutrophication standards

The LES were developed to protect Class 2 designated uses (aquatic life and recreation). They are largely based on an analysis of water quality relationships in Minnesota lakes and user perceptions relative to Secchi depth and the frequency and severity of nuisance algae blooms (Heiskary and Wilson 2005). This framework assigns different criteria to lakes of different depths and in different regions of the state (Table 3). In addition, more stringent criteria are assigned to lakes supporting or managed for trout species. The lake[5] standards place an emphasis on the ecological health of lakes but are also designed to be supportive of aquatic recreational use (e.g., swimming, wading, boating, etc.), where these beneficial uses are attainable (State of Minnesota 2007, p. 74). Minnesota's shallow lake standards similarly protect aquatic life (although expectations may be different) and should support recreational uses such as boating and waterfowl hunting. Although the specific aquatic life or recreational uses protected in lakes and shallow lakes may differ, there is overlap in these specific beneficial uses. For example, when suitable, a shallow lake may be protected for swimming uses. As a result, it is important, especially for a SSS, to consider the specific current and potential beneficial uses provided by a waterbody rather than relying on regional frameworks to assign beneficial uses.

Table 3. Lake eutrophication criteria (NLF = Northern Lakes and Forests, CHF = North Central Hardwoods, WCBP = Western Corn Belt Plains, NGP = Northern Glaciated Plains). * The likely most applicable standards for Red Lake.

Ecoregion	Total phosphorus (µg/L)	Chlorophyll-*a* (µg/L)	Secchi depth (m)
North			
NLF – Lake trout (Class 2A)	< 12	< 3	≥ 4.8
NLF – Stream trout (Class 2A)	< 20	< 6	≥ 2.5
NLF – Aquatic Rec. Use (Class 2B)*	< 30	< 9	≥ 2.0
Central			
CHF – Stream trout (Class 2A)	< 20	< 6	≥ 2.5
CHF – Aquatic Rec. Use (Class 2B)	< 40	< 14	≥ 1.4
CHF – Aquatic Rec. Use (Class 2B) Shallow lakes	< 60	< 20	≥ 1.0
South			
WCBP & NGP – Aquatic Rec. Use (Class 2B)	< 65	< 22	≥ 0.9
WCBP & NGP – Aquatic Rec. Use (Class 2B) Shallow lakes	< 90	< 30	≥ 0.7

The Statement of Need and Reasonableness (State of Minnesota 2007) and the promulgated LES, which were reviewed by an administrative law judge and approved by the EPA, state that these standards will not prevent algal blooms; however, they will serve to minimize the intensity and duration of severe

[5] *In Minnesota's lake eutrophication standards, the term "lake" is applied to lakes with a maximum depth >15' and with <80% of the lake area considered to be littoral. These lakes are typically dimictic. This contrasts with "shallow lakes" which do not meet these criteria (see definition in Minn. R. 7050.0150, subp. 4).*

nuisance blooms, which often make waters unusable (State of Minnesota 2007, p. 66). Such protections are especially necessary for waters which support primary contact uses such as swimming. Both Upper and Lower Red lakes are regularly used for swimming and as a result, any proposed SSS for Red Lake will need to set goals that will support and protect aquatic recreation in and on the water including boating, wading, and swimming.

Most of Upper and Lower Red lakes are within the NMW ecoregion (a small portion of Lower Red Lake is within the NLF ecoregion). The State of Minnesota's LES do not specifically provide criteria for lakes within the NMW ecoregion due to the small number of lakes in this region. As a result, the current LES are applied on a lake-specific basis for lakes in this ecoregion. Since Red Lake is geographically close to the NLF and even part of Lower Red Lake is within the NLF ecoregion, the most applicable standard would be the NLF LES standard. In addition, draft revisions to the standard for northern lakes combines lakes in the NLF and NMW ecoregions because in general, lakes within these ecoregions are similar. Based on the promulgated standards, the applicable LES standard for Red Lake would likely be the NLF lake standard (TP < 30 µg/L, chlorophyll-*a* [chl-*a*] < 9 µg/L, and Secchi depth > 2.0 m; Table 3). Because Red Lake is largely in the NMW ecoregion, any LES standard would need to be applied as a SSS (see Minn. R. 7050.0222, subp. 4a, Item A).

The State of Minnesota is currently in the process of revising LES for northern lakes which could have implications for the standards applicable to Red Lake. The promulgated LES do not make a distinction between dimictic lakes and polymictic (shallow) lakes in the NLF ecoregion. Draft revisions of the LES would create different standards for dimictic and polymictic lakes in the NLF and NMW ecoregions (Table 4). The draft LES for northern lakes would alter the applicable standards for Red Lakes since it would result in promulgated standards for lakes in the NMW ecoregion. The applicable LES for Upper and Lower Red lakes could be more or less stringent depending on which lake type is appropriate for Red Lake. However, an additional consideration would be which northern lake type is appropriate for Upper and Lower Red Lakes. Although both basins may be classified as a polymictic (shallow) lake because it is vertically mixed for most of the summer, it historically and currently supports swimming uses. Swimming uses are explicitly protected in the draft northern, dimictic lake standard. As a result, the dimictic lake standard may be more appropriate for Red Lake. However, the uniqueness of Upper and Lower Red lakes probably makes either the promulgated or draft LES inappropriate. However, the regional LES can be compared to a draft SSS for context with standards applicable to other lakes in the region.

Table 4. Current and draft lake eutrophication criteria for northern lakes. The current criteria are applicable to lakes in the Northern Lakes and Forests ecoregion, and the draft criteria would be applicable to lakes in both the Northern Lakes and Forests and Northern Minnesota Wetlands ecoregions.

Lake Type	**Total phosphorus (µg/L)**	**Chlorophyll-*a* (µg/L)**	**Secchi depth (m)***
Current criteria			
Northern lakes	30	9	2.0
Recommended criteria			
Northern polymictic lakes	30	16	1.1
Northern dimictic lakes	20	9	1.8

*lakes with color >73 platinum-cobalt units (PCU) or a_{440} >4 m^{-1} should not be assessed using Secchi depth and lakes with color >25 PCU or a_{440} >1.4 m^{-1} should be reviewed to determine the effect of CDOM on water transparency.

Minnesota's site-specific standards

The following two rules govern MPCA's adoption of site-specific standards:

Minn. R. 7050.0220, subp. 7, Items A, B and C:

Subp. 7. ***Site-specific modifications of standards.***

A. The standards in this part and in parts 7050.0221 to 7050.0227 are subject to review and modification as applied to a specific surface water body, reach, or segment. If site-specific information is available that shows that a site-specific modification is more appropriate than the statewide or ecoregion standard for a particular water body, reach, or segment, the site-specific information shall be applied.

B. The information supporting a site-specific modification can be provided by the commissioner or by any person outside the agency. The commissioner shall evaluate all relevant data in support of a modified standard and determine whether a change in the standard for a specific water body or reach is justified.

C. Any effluent limit determined to be necessary based on a modified standard shall only be required after the discharger has been given notice of the specific proposed effluent limits and an opportunity to request a hearing as provided in part 7000.1800.

Minn. R. 7050.0222, subp. 4a, Items A and E (emphasis added)**:**

Subp. 4a. ***Narrative eutrophication standards for class 2B lakes, shallow lakes, and reservoirs.***

A. Eutrophication standards applicable to lakes, shallow lakes, and reservoirs that lie on the border between two ecoregions or that are in the Red River Valley (also referred to as Lake Agassiz Plains), ***Northern Minnesota Wetlands****, or Driftless Area Ecoregion must be applied on a case-by-case basis. The commissioner shall use the standards applicable to adjacent ecoregions as a guide.*

In 2008, the state of Minnesota promulgated eutrophication water quality standards for Class 2 lakes (Minn. R. 7050.0222). The standards provide, among other things, the following:

a. In-lake eutrophication criteria (numeric values for TP, chl-*a*, Secchi depth) differ according to ecoregion and in some ecoregions the standards assign different numeric values for shallow and deep lakes (Minn. R. 7050.0222).
b. A provision that the application of standards for lakes in the Northern Minnesota Wetlands ecoregion be applied on a case-by-case basis (see Minn. R. 7050.0222, subp. 2a, Item E, subp. 3a, Item A, and subp. 4a, Item A).

As a result of the following factors, it is reasonable to consider the establishment of a SSS for Red Lake:

1) Red Lake is located in the NMW ecoregion, and as stated in rule (Minn. R. 7050.0222, subp. 4a, Item A), eutrophication standards are applied on a case-by-case basis to lakes in this ecoregion.
2) Red Lake is unique because of its unusual lake morphology, 2) a high proportion of wetlands in the watershed, and 3) its location within an ecotone.

Red Lake Band's Water Quality Standards

The Red Lake Band received eligibility for Treatment as a State (TAS) on November 23, 2021 upon demonstrating that the Band meets the requirements of CWA Section 518 and 40 C.F. R Section 131.8 to be treated in the same manner as a state for purposes of administering the water quality standards and certification programs under CWA Section 303(c) and Section 401. Draft standards for all Red Lake

Nation waters are nearly developed and are to be approved by the Tribal Council and submitted to the US EPA in conjunction with the submittal of this document. This will allow the SSS to be incorporated into the overall standards package from the beginning.

Water quality characteristics

The following section describes the data (i.e., sampling locations and data collection methods) used in the analyses in this report and characterizes temporal and spatial patterns of TP, chl-*a*, Secchi depth, color, and recreational suitability in Red Lake.

Water chemistry sampling sites and initial data filters

Water quality data (TP, chl-*a*[6], Secchi depth, color, and lake recreational suitability) collected from Upper (04-0035-01) and Lower (04-0035-02) Red lakes between the years 1990 and 2023 were used in analyses to support SSS (Table 5). For most analyses, the two basins were analyzed separately. Data from 10 water chemistry sites, including five stations in each basin (Figure 3), were used in the analyses for the Red Lake SSS. In cases where duplicate samples were collected at the same station or where multiple stations were sampled on the same day from the basin, water chemistry values were averaged. Only data from the summer season (June-September) were used for TP, chl-*a*, and Secchi depth analyses. All available data were used for color and lake recreational suitability analyses. Only water quality grab samples collected within 2 meters of the surface were used in the analyses. Non-detect values were a small fraction of the samples (Table 5), but the few in the database were processed by calculating the midpoint between 0 and the minimum detection limit for the method.

Table 5. Table of parameters and laboratory methods for Red Lake data.

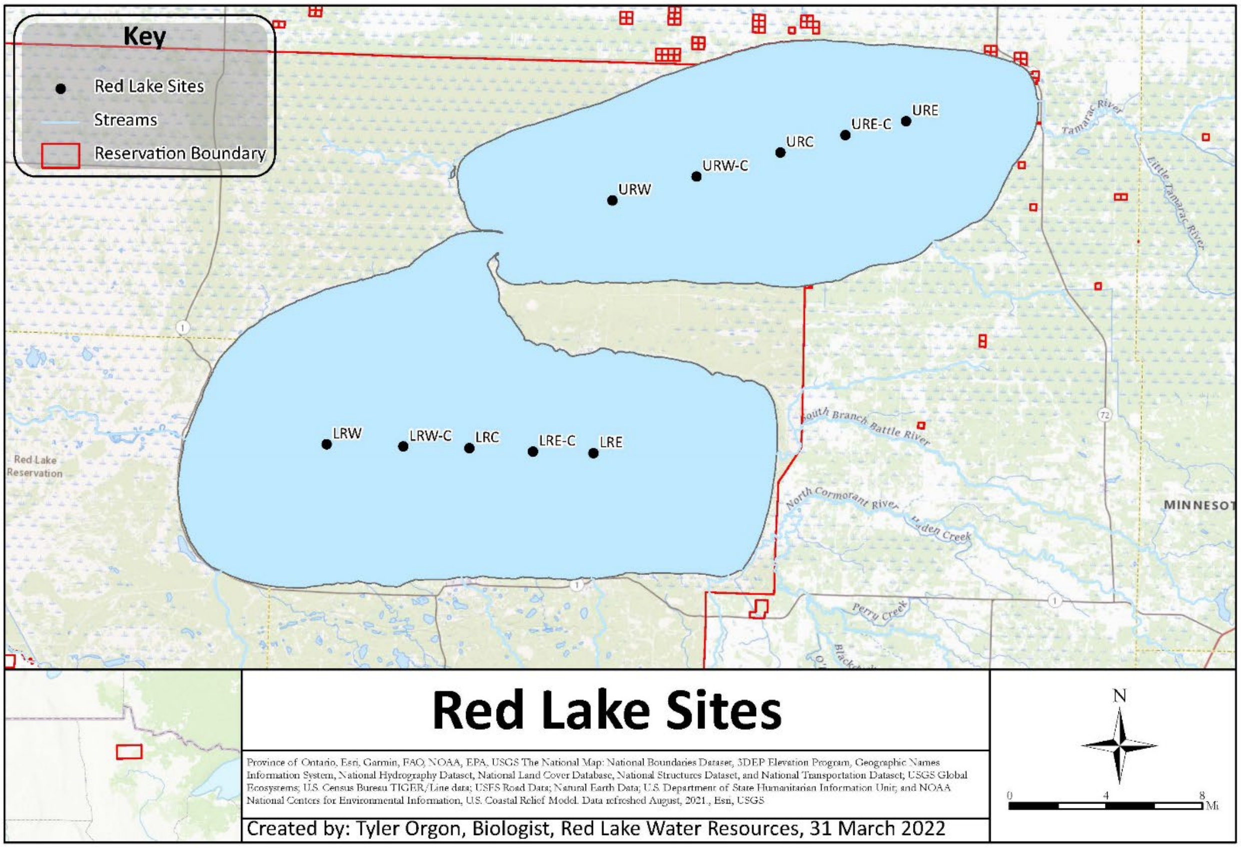
Parameter	Method code	Detection limit	Year range	Number of non detects
Total phosphorus	365.2, 365.3	0.003 mg/L	1996-2023	5
Chlorophyll-*a*	10200-H	1-3 µg/L	1996-2007	17
Chlorophyll-*a*, corrected for pheophytin	10200-H	1 µg/L	2008-2023	11
Secchi	Field Method	-	1990-2023	-
Color	2120-B	3-6 PCU	1996-2005	10
Lake recreational suitability	Field Method	-	1990-1992, 2022-2023	-

[6] *Chlorophyll-a data from 1996 through 2007 was not corrected for pheophytin. These data were included in analyses because they provided a long-term record of conditions in Red Lake. In addition, pheophytin was low in most samples (below detection limits in 98% of the samples collected in this period) and was assumed to have a minimal impact on chlorophyll-a measurements.*

Table 6. Water chemistry sampling sites on Upper and Lower Red lakes.

Upper Red Lake	Lower Red Lake
URW	LRW
URW-C	LRW-C
URC	LRC
URE-C	LRE-C
URE	LRE

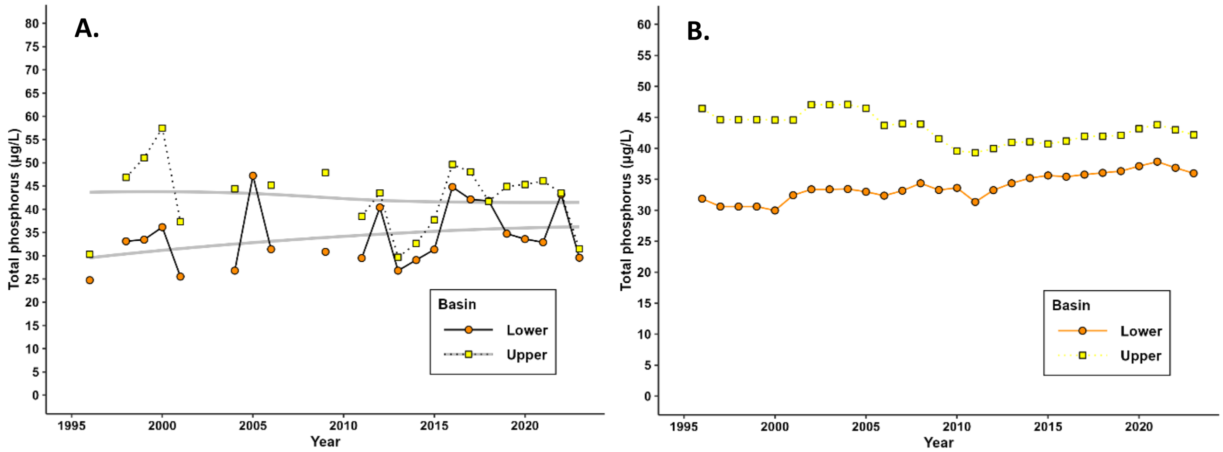
Figure 3. Location of water quality sampling stations in Upper and Lower Red Lakes.



Total phosphorus

Total phosphorus summer season data (June through September) from 1996-2023 consisted of one to nine sample dates per year. Fewer than four dates were sampled in 1997, 2002, 2003, 2005 (Upper only), 2007, 2008, and 2010 and these years were excluded from the following analyses. Across all years, average TP was 35 and 42 µg/L for Upper and Lower Red lakes, respectively. Annual averages ranged from 25-47 µg/L for Lower Red Lake and 30-57 µg/L for Upper Red Lake. Total phosphorus was largely stable through the sampling period for both basins (Figure 4A). A Mann-Kendall trend test was performed on annual average TP for both basins using the Kendall package (McLeod 2022) in R (R Core Team 2023). The Mann-Kendall tests did not detect a significant trend during the sampling period for either basin (Upper: p-value = 0.6506; Lower: p-value = 0.1669). Time-weighted, 10-year averages were calculated from 1996 through 2023 (Figure 4B) and also did not indicate a strong change in TP concentrations over the sampling period.

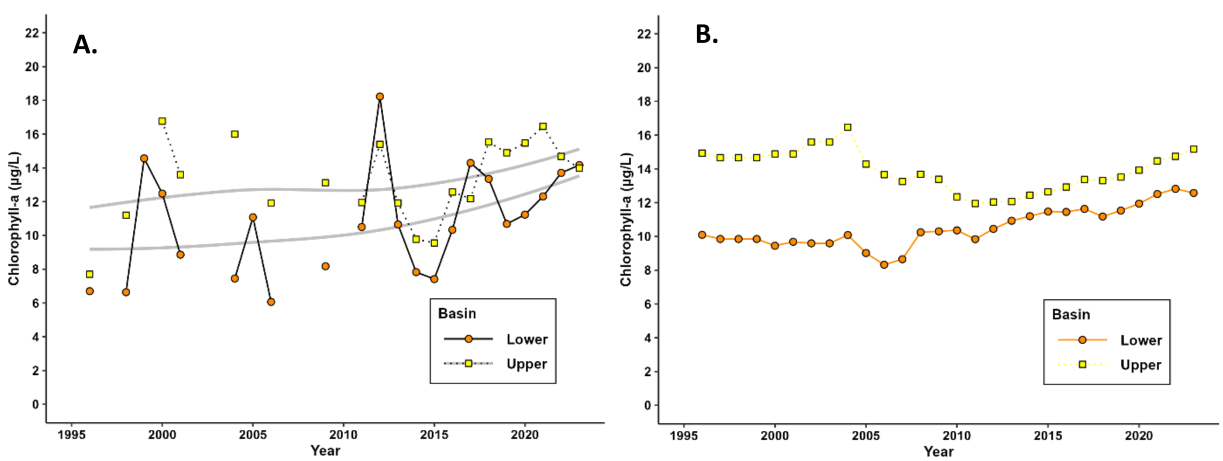
Figure 4: Annual total phosphorus patterns based on A) annual average concentrations and B) 10-year, time-weighted averages for Upper and Lower Red lakes (04-0035). Data sets are based on summer average data from all stations in each Red Lake basin. Grey lines are loess fits.



Chlorophyll-*a*

Chlorophyll-*a* summer season data (June through September) from 1996-2023 consisted of one to nine sample dates per year. Fewer than four dates were sampled in 1997, 2002, 2003, 2005 (Upper only), 2007, 2008, and 2010 and these years were excluded from the following analyses. Across all years, average chl-*a* was 11 µg/L and 13 µg/L for Lower and Upper Red lakes, respectively. Annual averages ranged from 6-18 µg/L for Lower Red Lake and 8-24 µg/L for Upper Red Lake. Annual maximum chl-*a* was on average 17 µg/L (9-32 µg/L) for Lower Red Lake and 20 µg/L (11-29 µg/L) for Upper Red Lake. Chlorophyll-*a* was largely stable through the sampling period for both basins (Figure 5A). A Mann-Kendall trend test was performed on annual average chl-*a* for both basins using the Kendall package (McLeod 2022) in R (R Core Team 2023). The Mann-Kendall tests did not detect a significant trend during the sampling period for Upper Red Lake (p-value = 0.4874); however, a significant ($\alpha < 0.05$) increasing trend was identified for Lower Red Lake (p-value = 0.0369). Time-weighted, 10-year averages were calculated from 1996 through 2023 (Figure 5B). Time-weighted averages chl-*a* patterns did not indicate a strong change in chl-*a* concentrations over the sampling period.

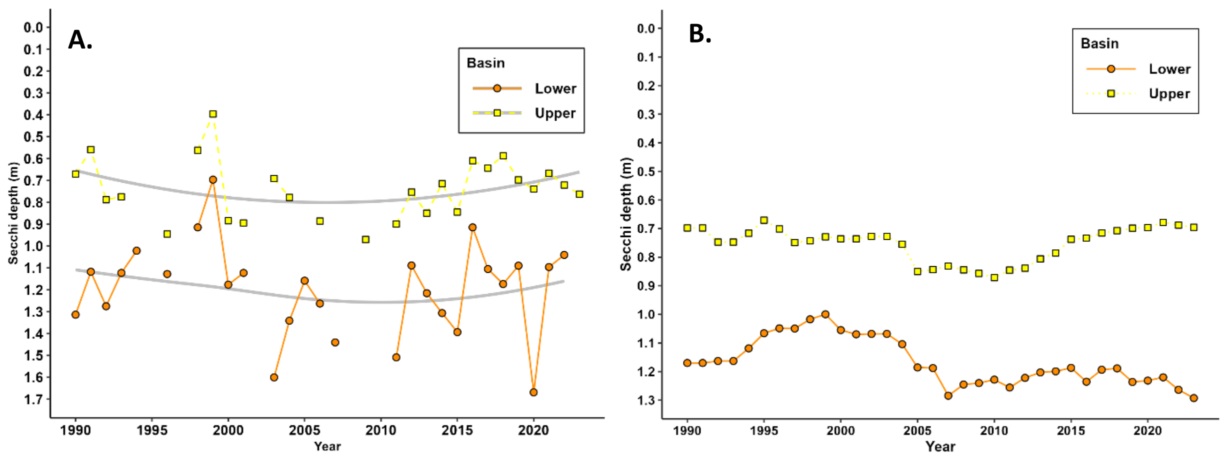
Figure 5: Annual chlorophyll-*a* patterns based on A) annual average concentrations and B) 10-year, time-weighted averages for Upper and Lower Red lakes (04-0035). Data sets are based on summer average data from all stations in each Red Lake basin. Grey lines are loess fits.



Secchi depth

Secchi depth summer season data (June through September) from 1990-2023 consisted of 1 to 9 sample dates per year. Fewer than four dates were sampled in 1995, 1997, 2002, 2003, 2007, 2008, 2009, and 2010 and these years were excluded from the following analyses. Average Secchi depths over the sampling period for Upper and Lower Red lakes were 0.9 m (range: 0.4-1.0 m) and 1.3 m (range: 0.7-1.6 m), respectively (Figure 6A). Secchi depth was largely stable through the sampling period for both basins (Figure 6A). A Mann-Kendall trend test was performed on annual average Secchi depth for both basins using the Kendall package (McLeod 2022) in R (R Core Team 2023). The Mann-Kendall tests did not detect a significant trend during the sampling period for either basin (Upper: p-value = 0.7703; Lower: p-value = 0.1046). Time-weighted, 10-year averages were calculated from 1990 through 2023 (Figure 6A) which also did not indicate a strong increasing or decreasing trend in Secchi depth (Figure 6B).

Figure 6: Annual Secchi depth patterns based on A) annual average concentrations and B) 10-year, time-weighted averages for Upper and Lower Red lakes (04-0035). Data sets are based on summer average data from all stations in each Red Lake basin. Grey lines are loess fits.



Colored dissolved organic matter

Characterizing the amount of colored dissolved organic matter (CDOM) in a lake can be important for determining if this is a factor that is affecting algal growth or clarity. This is especially important for determining if Secchi depth is a useful indicator of chl-*a* concentrations for a lake. Color was measured periodically from 1996-2005 in Red Lake, and this is likely sufficient to characterize the amount of CDOM in these basins. Overall color was higher in Upper Red Lake (14 PCU) compared to Lower Red Lake (9 PCU; Table 7). An examination of the effect of CDOM on lake clarity identified a threshold of 25 PCU where CDOM begins to affect clarity in a manner that could result in false positive errors when using Secchi depth to assess trophic condition (MPCA 2022). There was a single day on Upper Red Lake with an average color of 25 PCU, but all other days measured for color were below 25 PCU. This indicates that CDOM is not high in Red Lake and would not be expected to impact Secchi depth or other trophic measures. However, further evaluation of the effect of CDOM on clarity in Red Lake may be important due to a broadscale trend of increasing CDOM levels (Roulet and Moore 2006).

Estimates of CDOM from remote sensing was also available for Upper and Lower Red lakes from the Minnesota Lake Browser (https://lakes.rs.umn.edu/; accessed on 2/6/2024). These results are presented as the light absorption coefficient at 440 nm (a_{440}). Seasonal means (July 20 through September 20) of a_{440} were available from 2017-2021 and ranged from 1.0-1.5 m^{-1} for Upper Red Lake and 1.0-1.6 m^{-1} for Lower Red Lake. A review of the impact of CDOM on Secchi depth indicated that when a_{440} is above 4 m^{-1}, Secchi depth is not a reliable measure of productivity (MPCA 2022). When a_{440} is between 1.4 and

4 m^{-1}, Secchi data should be reviewed to determine if it is useful for LES assessment. For example, if Secchi depth is lower than expected based on chl-*a* concentrations, CDOM may be impacting Secchi depth and causing Secchi depth to be an unreliable indicator of trophic state. The data available for Upper and Lower Red lakes indicate that in some years, CDOM is high enough to potentially impact Secchi depth, but most years it is below 1.4 m^{-1}.

Table 7. Annual average color (PCU) for Upper and Lower Red lakes.

Year	Lower	Upper
1996	14	16
1997	7	15
1998	9	16
1999	11	13
2000	7	20
2001	10	13
2002	6	14
2003	4	6
2004		8
2005	7	10
Average	9	14

Recreational suitability

The protection of recreational uses is an important aspect of LES. Recreational uses include swimming, boating, fishing, and waterfowl hunting, but the specific uses protected in a lake may depend on which recreational uses are or can be reasonably supported in a lake. For Red Lake, these uses include swimming, boating, and fishing with swimming often being the most sensitive use. Measuring recreational suitability can be difficult, but user surveys are a valuable tool for measuring attainment of these beneficial uses (Smeltzer and Heiskary 1990, EPA 2021). A recreation suitability survey consists of a narrative survey which users of the resource or water quality managers can use to quantify how well a water fits categorical levels of recreational suitability (Table 8). This information can be used to determine if recreational uses are protected in a waterbody or how user interpretations of recreational suitability relate to water quality data. In the case of Red Lake, these data can be used to determine if current conditions are protective of recreational uses and what conditions (i.e., water quality measures) may contribute to nonattainment of these uses.

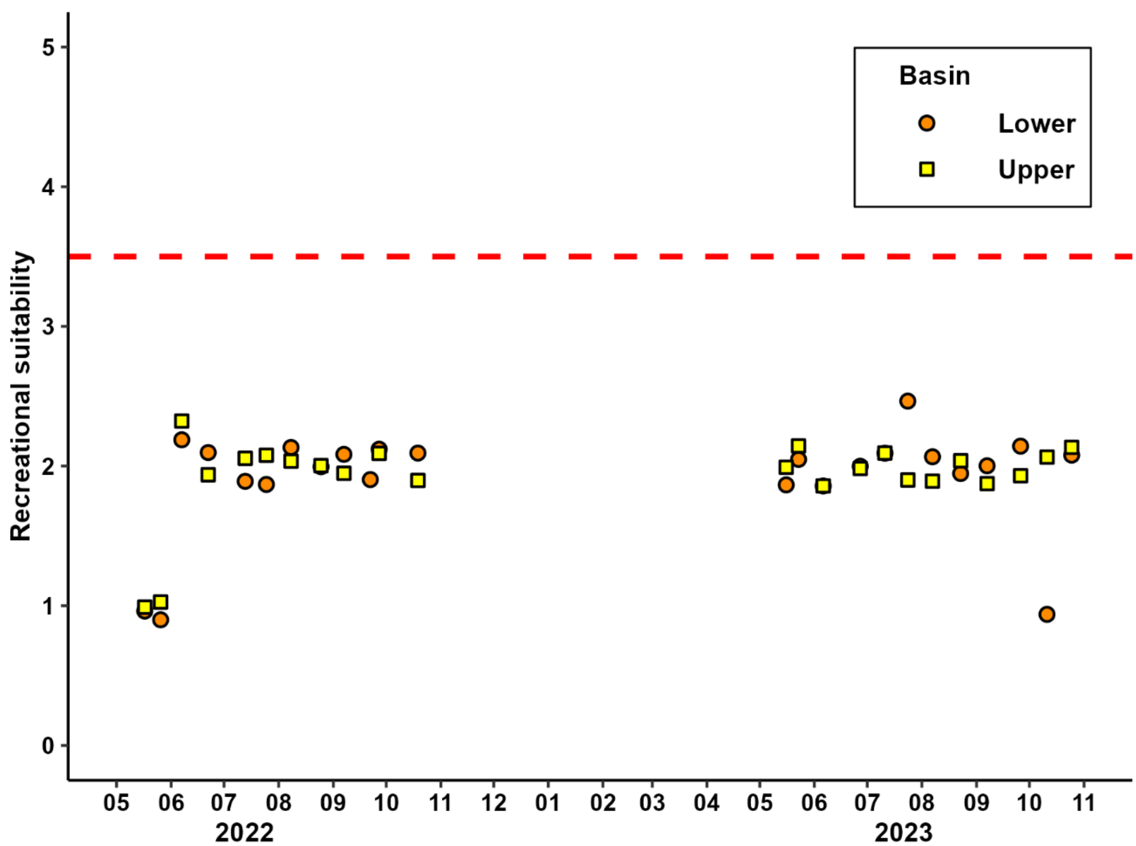
Table 8. Description of recreational suitability ratings used in lake surveys.

#	Description
1	Beautiful, could not be any nicer
2	Very minor aesthetic problems; excellent for swimming, boating, enjoyment
3	Swimming and aesthetic enjoyment slightly impaired because of algae levels
4	Desire to swim and level of enjoyment of the lake substantially reduced because of algae levels (would not swim, but boating is okay)
5	Swimming and aesthetic enjoyment of the lake nearly impossible because of algae levels

User perception data was collected periodically from 1990 through 2023; however, data collected before 2022 was determined to not be reliable due to a transcription error. As a result, the following analyses are based only on 2022 and 2023 data. User perception surveys consistently indicated that Red

Lake meets conditions that are defined as: "Very minor aesthetic problems; excellent for swimming, boating, enjoyment" and less commonly "Beautiful, could not be any nicer." These results indicate that Upper and Lower Red lakes are supportive of the recreation beneficial use (Figure 7). No surveys during this period indicated any days where conditions were not suitable for swimming. Although the available record of user surveys is limited for Red Lake, these surveys do provide insight into the relationship between chl-*a* and recreational suitability. During the available user surveys in 2022 and 2023, summer average chl-*a* (14-15 µg/L) and summer maximum chl-*a* (20-32 µg/L) was typical for the lake. This indicates that the current algal levels in Red Lake do not contribute to poor recreational suitability. In addition, thousands of Red Lake members have used Lower Red Lake recreationally for swimming, boating, and fishing in the past decade and we have had zero comments indicating that the lake was not suitable for recreation. The fact that both basins are regularly used for swimming, and we are not aware of any complaints related to nuisance algal blooms or pet or human illness caused by recreating in or on Red Lake, indicates that current conditions are protective of recreational uses.

Figure 7: Recreational suitability scores for Upper and Lower Red lakes in 2022 and 2023. The dashed red line indicates the approximate threshold for swimming suitability with scores below that line indicating attainment of swimming uses. The points are jittered to show overlapping samples.



Aquatic life

In general, the aquatic life in Red Lake have been extensively studied, especially fish. However, most of these studies are focused on gamefish and do not measure endpoints specifically linked to attainment of beneficial uses (e.g., Indices of Biotic Integrity). Even when such data are available, the uniqueness of Red Lake makes assessments of such endpoints difficult because there are no comparable lakes to use as reference. Therefore, the biological assessment tools for fish and macrophytes in lakes that have been developed in Minnesota tools are not appropriate for Red Lake (or at least they haven't been tested). As a result, assessment of aquatic life attainment in Red Lake is largely limited to a review of narrative conditions.

Fish

Red Lake is one of a handful of lakes in the State of Minnesota that is sampled annually as part of the large-lake sampling program. The State of Minnesota has sampled fish annually in Red Lake since 1984, and the Red Lake Nation has sampled fish annually since 1987. Currently, this lake is managed under a Memorandum of understanding through 2029 among the State of Minnesota, the Red Lake Band, and Bureau of Indian Affairs. Each jurisdiction uses standardized sampling methods, and these data are compiled together annually and reported to the Red Lake Fisheries Technical Committee (RLFTC). Important commercial and game species include walleye, yellow perch, northern pike, freshwater drum, lake whitefish, and goldeye. Of lesser importance are black crappie, bluegill, rock bass, largemouth bass, and burbot. Since 2007, the Red Lake Band has worked to restore a self-sustaining lake sturgeon population, and it is the only species which is currently being stocked on an annual basis in cooperation with the U.S. Fish and Wildlife Service. Cooperatively with the State of Minnesota, the Red Lake Band also annually samples for invasive species, and to date starry stonewort and zebra mussel veligers have been found. This system is intensively managed and protected because of its cultural and economic value to the local communities.

The overall health of the fish populations of Red Lake is better today than it has been since commercial fishing was brought to the Red Lakes in 1912 by the State of Minnesota. The Red Lake Band manages these populations to be dynamic, adaptable, and resilient because of the uncertainty associated with the future effects of climate change and aquatic invasive species on these populations. The Red Lake Band conducts comprehensive surveys of non-game species each year, and these data are archived. The lake whitefish population is currently the only population of fish species in trouble. This is a direct result of past summer kills which have prevented recovery of the population. The shallow bathymetry of Upper and Lower Red lakes makes these basins atypical lake whitefish habitat. The Red Lake Band is currently not actively working to recover this species due to these conditions.

The 227,000 acres of Upper and Lower Red lakes under the jurisdiction of the Red Lake Nation is home to the oldest and largest commercial walleye fishery in the United States. Commercial fishing began in the Red Lakes in 1912 by the State of Minnesota. Subsequently, the Red Lake Nation started the Tribal cooperative in 1929, and the fishery then was regulated by the Secretary of the Interior under a code of Federal regulations. The fishery thrived for 40 years before the population showed signs of over harvest. By the mid 1990's, the walleye population collapsed, and the tribal commercial fisherman suspended their 1997 fishing season. This was without Federal or State assistance, but the tribal commercial fishermen were committed to recovering their livelihood. In 1999, a memorandum of understanding was signed between the Red Lake Nation, State of Minnesota, and Bureau of Indian Affairs to recover the walleye population. By 2006, just 7 years after beginning this process, the Red Lake Fisheries Technical committee, a group of biologists and citizens at large, agreed that harvest could resume. Since this date, the Tribe has harvested over 10 million pounds of walleye, which has provided over 20 million dollars to tribal fisherman. This fishery is not only important to the Red Lake Nation, but it is an economic engine for many surrounding communities and for sports fishing off the Reservation. The walleye fishery on Upper and Lower Red lakes is managed cooperatively by the Red Lake Nation and the State of Minnesota and is currently healthy and sustainable.

Macrophytes

Macrophytes were surveyed in Upper Red Lake as part of the Minnesota Department of Natural Resources' (MNDNR) Minnesota County Biological Survey in 2011. This survey identified 30 species of aquatic macrophyte with a Floristic Quality Index (FQI) of 32.7. Radomski and Perleberg (2012) developed taxa richness and FQI thresholds for healthy macrophyte communities. While the size and morphology of Upper Red Lake make it unique compared to other lakes in Minnesota, the species richness and FQI was compared to the thresholds for Minnesota County Biological Survey samples from lakes the Northern Minnesota Wetlands ecoregion. The macrophyte sample scored well above both thresholds (Table 9). Although these thresholds may not be entirely applicable to Upper Red Lake, the high taxa richness and FQI score does generally demonstrate that this lake is currently supporting a healthy macrophyte community.

Table 9. Comparison of Red Lake macrophyte scores with possible thresholds developed by Radomski and Perleberg (2012) for Minnesota County Biological Survey samples in western Northern Lakes and Forest ecoregion lakes (3B).

	Deep lakes (zmax ≥ 15’) threshold	Shallow lakes (zmax < 15’) threshold	Upper Red Lake
Taxa richness	11	6	30
Floristic Quality Index	19.6	14.0	32.7

Water quality relationships

The following section examines the relationships between TP, chl-*a*, and Secchi depth. The primary goal of this section is to put these relationships into the context of the regional LES and to provide evidence for establishing TP, chl-*a*, and Secchi depth thresholds that are protective of the designated beneficial uses in Red Lake.

Comparison to Minnesota lake datasets

The development and adoption of Minnesota lake eutrophication standards in 2008 included models to describe the relationships between TP and chl-*a* and between chl-*a* and Secchi depth (Heiskary and Wilson 2005). These models where used to understand trophic relationships and to provide context for recommended standards. Draft revisions to the northern lake standards include updated models for these relationships (MPCA 2022). These updated models are based on statewide data from both dimictic and polymictic lakes. For the dataset used to model the chl-*a* and Secchi depth relationship, a filter was used for lakes with high colored dissolved organic matter (CDOM; >73 PCU or a_{440} >4 m^{-1}). Comparison between the LES development datasets and Red Lake data were made for TP-chl-*a* and chl-*a*-Secchi depth relationships. All values presented are summer means.

A comparison of Red Lake summer mean relationships for TP-chl-*a* demonstrated a similar relationship to other Minnesota lakes (Figure 8). On average, both Upper and Lower Red lakes grow less algae per unit of TP than other Minnesota lakes although Red Lake is near the 50^{th} percentile quantile regression indicating that this relationship is typical. In contrast, the chl-*a* and Secchi depth relationship for Red Lake is outside the 10^{th} percentile for the statewide dataset (Figure 9). This indicates that Red Lake has lower clarity than predicted based on chl-*a* concentrations. Possible causes of the lower than predicted Secchi depths could be CDOM or suspended sediment. CDOM is not especially high (average color = 9-14 PCU) and based on a statewide analysis of the effects of CDOM on Secchi depth (see MPCA 2022), these levels do not explain the low Secchi depths in Red Lake. Suspended sediment from wave action, especially in Upper Red Lake, may be an important factor. Regardless of the cause, the low Secchi depth does not appear to be primarily caused by high algal concentrations and indicate that it may not be an effective measure of trophic condition in Red Lake. As a result, a Secchi depth SSS is not recommended in this report for Upper or Lower Red lakes.

Figure 8. Comparison of summer mean total phosphorus and chlorophyll-*a* for Upper Red (yellow diamonds) and Lower Red (orange squares) lakes and the Minnesota lakes (blue and open circles) used to develop eutrophication standards. Red Lake points (yellow and orange) are summer (June-September) averages for individual years with at least four measurements/year. The large orange and yellow points are an average of all years. Statewide lakes are summer averages for lakes with at least two years of data and four measurements per year. Blue circles are northern, polymictic lakes and open circles are all other Minnesota lakes. The solid gray line is the 50th percentile the dashed grey lines are the 10th and 90th percentiles.

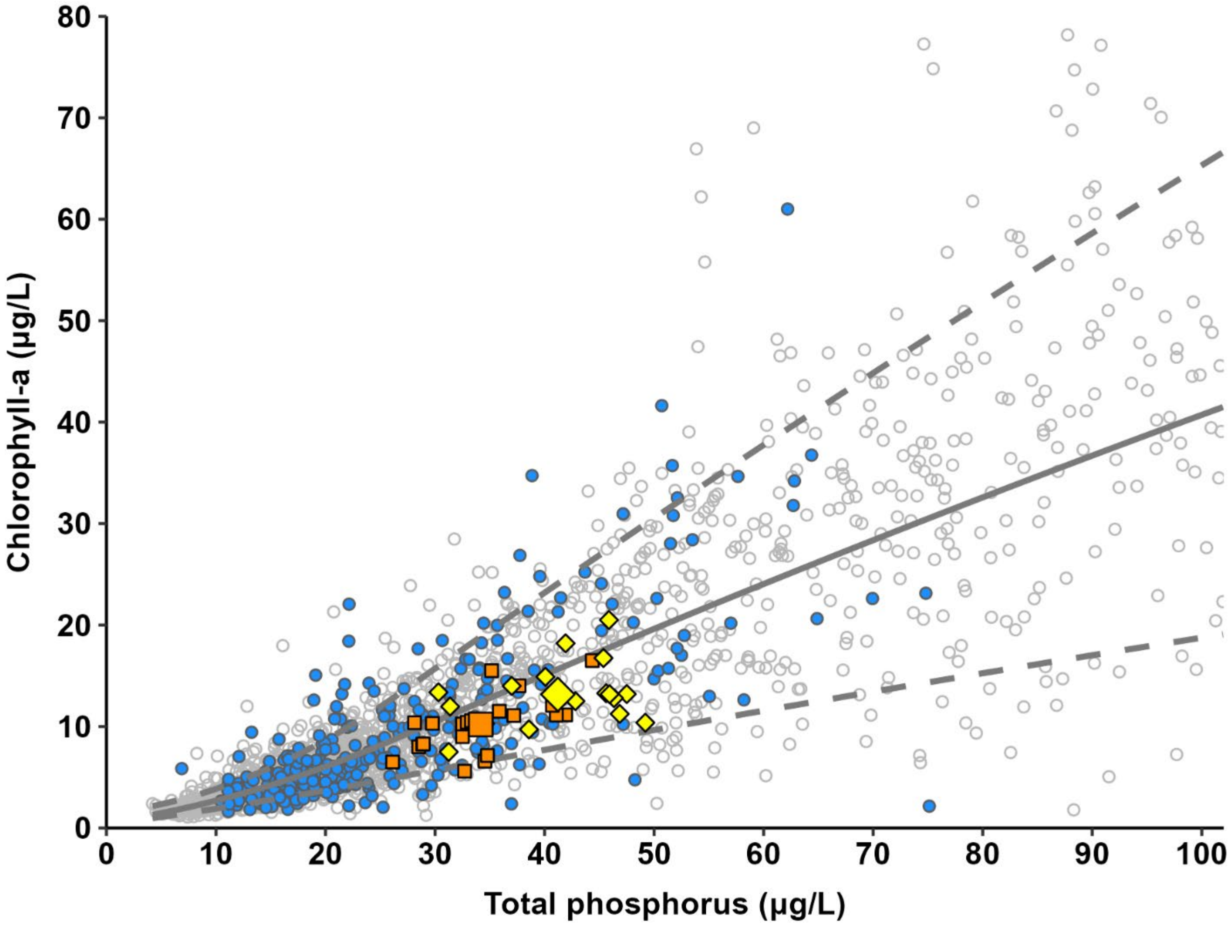
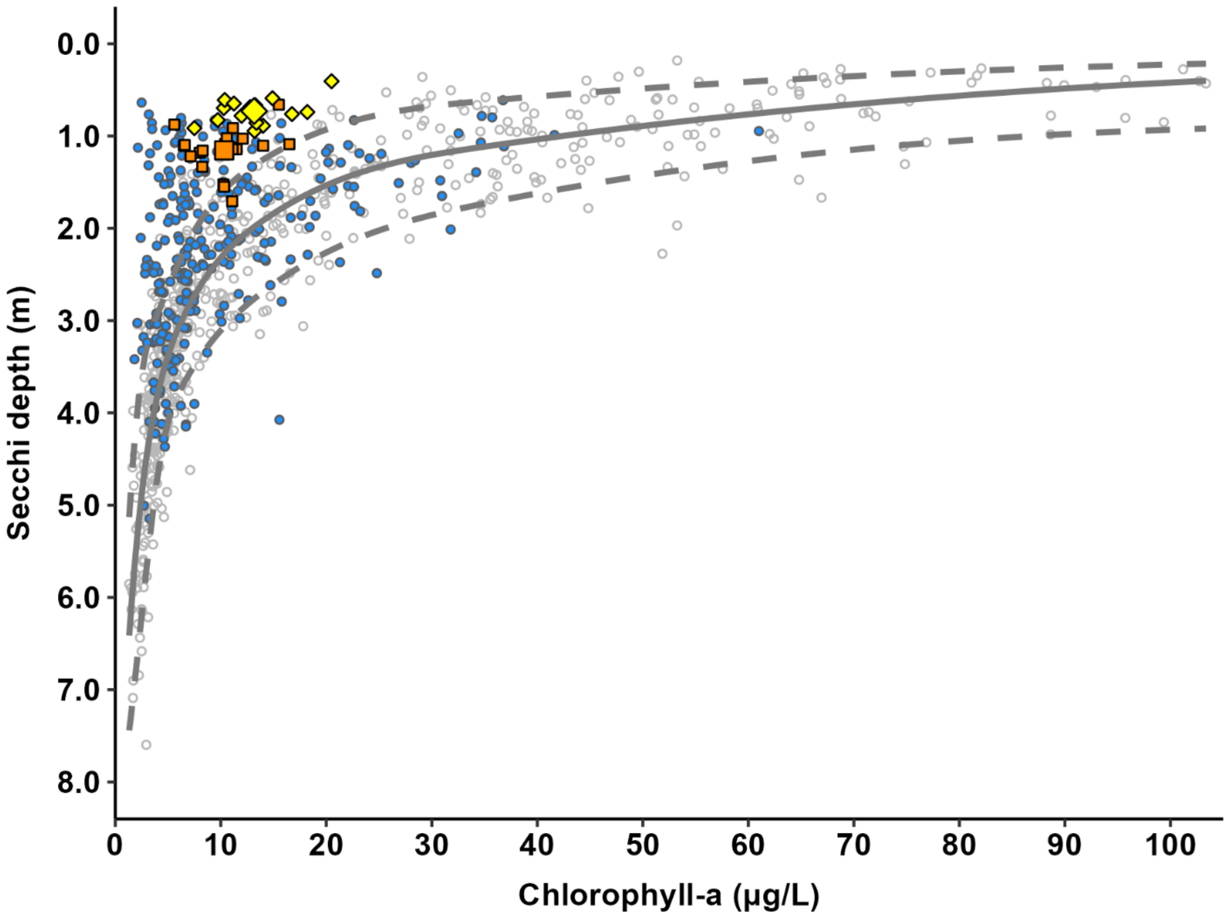


Figure 9. Comparison of summer mean chlorophyll-*a* and Secchi depth for Upper Red (yellow diamonds) and Lower Red (orange squares) lakes and the Minnesota lakes (blue and open circles) used to develop eutrophication standards (see MPCA 2022). Red Lake points (yellow and orange) are summer (June-September) averages for years with at least four measurements/year. The large orange and yellow points are an average of all years. Statewide lakes are summer averages for lakes with at least 2 years of data and four measurements per year. Blue circles are northern, polymictic lakes and open circles are all other Minnesota lakes. Lakes with color > 73 PCU or a_{440} > 4 m^{-1} were filtered from this dataset. The solid gray line is the 50th percentile the dashed grey lines are the 10th and 90th percentiles.



The original work supporting the 2008 lake eutrophication rule (Heiskary and Wilson 2005) analyzed the relationship between summer average and maximum chl-*a*. Reviewing maximum chl-*a* and determining how this metric relates to the average chl-*a* concentration used for assessments is important to determine if there are risks to the attainment of beneficial uses. Specifically, a LES should limit the time during the summer that a lake has nuisance algal blooms which impair swimming and other uses. Although Minnesota does not have a standard for maximum chl-*a*, there are some studies which suggest chl-*a* levels than can be considered nuisance levels. For example, Florida uses a chl-*a* threshold of >40 µg/L to indicate an algal bloom (Havens 2003). Heiskary and Walker (1988) also reviewed these conditions in a number of studies and identified that undesirable algal conditions generally occur in the range of >30-40 µg/L of chl-*a*. These values can be used as guidance to determine if Red Lake experiences nuisance algal conditions. On average, maximum chl-*a* is below 30 µg/L, and there is only a single year that exceeds that level (Lower Red Lake, 2023; Table 10). However, it should be noted that chl-*a* values considered nuisance do not necessarily indicate non-attainment of beneficial uses. The LES standard has been developed to minimize nuisance conditions (State of Minnesota 2007, p. 66), but it does not prohibit such conditions. Therefore, based on the available data, the present conditions in Red

Lake appear to be protecting beneficial uses by preventing or at least maintaining a low frequency of nuisance conditions.

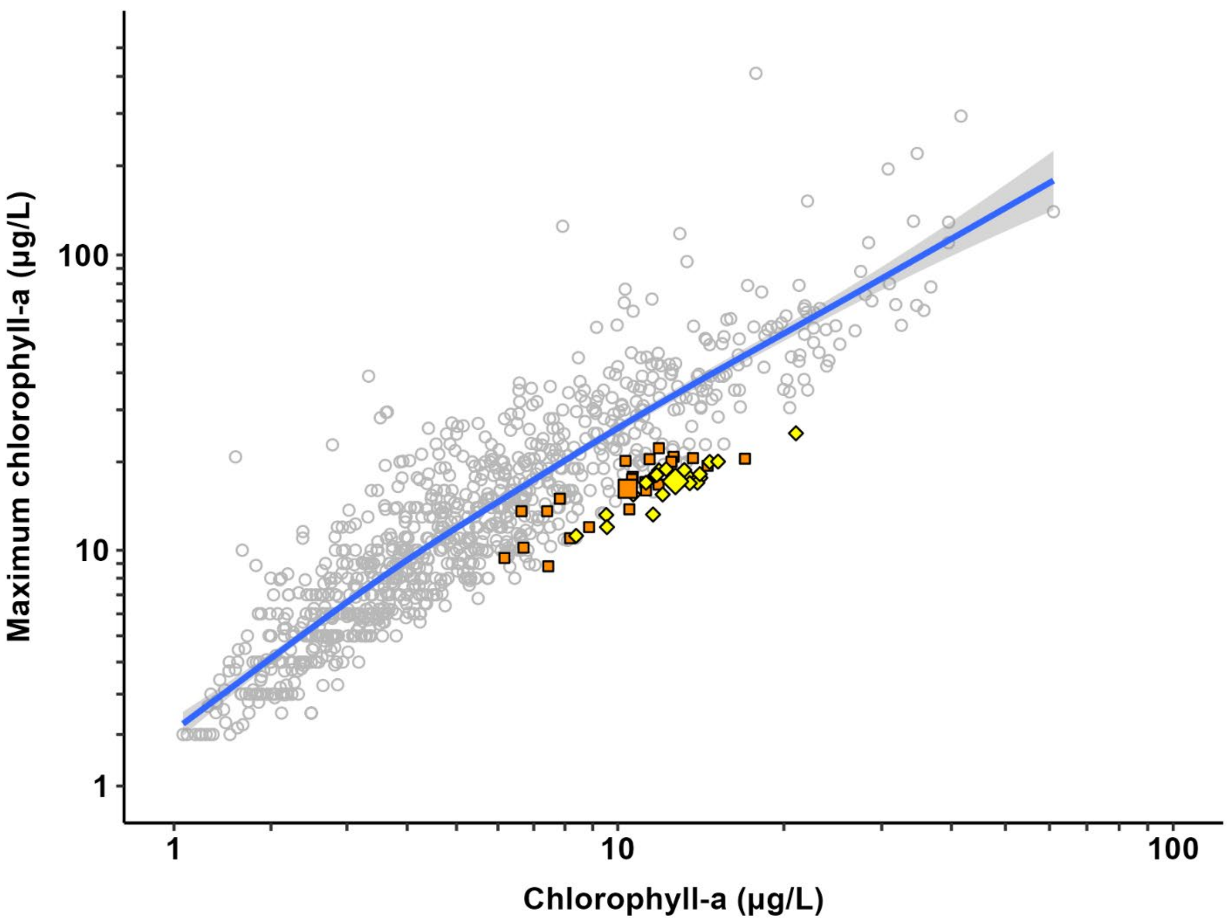
Table 10. Annual maximum chlorophyll-*a* (µg/L) for Upper and Lower Red lakes.

Year	Lower	Upper
1996	10	11
1998	14	16
1999	19	29
2000	17	21
2001	12	18
2004	9	24
2005	16	-
2006	9	16
2009	11	18
2011	14	17
2012	25	20
2013	18	20
2014	15	13
2015	14	12
2016	20	21
2017	23	19
2018	23	26
2019	18	20
2020	17	26
2021	26	25
2022	21	20
2023	32	20
Average	17	20

Both basins of Red Lake largely behaved similarly to other Minnesota lakes in regard to the relationship between summer mean and maximum chl-*a* (Figure 10). However, maximum levels of chl-*a* in Red Lake are lower than predicted by the statewide model. This is a positive attribute for the attainment of beneficial uses in Red Lake and indicates that a higher mean chl-*a* concentration will result in a low frequency of nuisance conditions that could impact beneficial uses such as swimming.

Overall, it is apparent that Red Lake behaves differently from other Minnesota Lakes in some regards including the chl-*a*-Secchi relationship and maximum chl-*a* concentrations. Although the TP-chl-*a* relationship is similar to other Minnesota lakes, the protective nature of the standard development process indicates that higher TP standards would be protective for Upper and Lower Red lakes. These attributes of Red Lake are evidence that a SSS is warranted and that current conditions will be protective of beneficial uses.

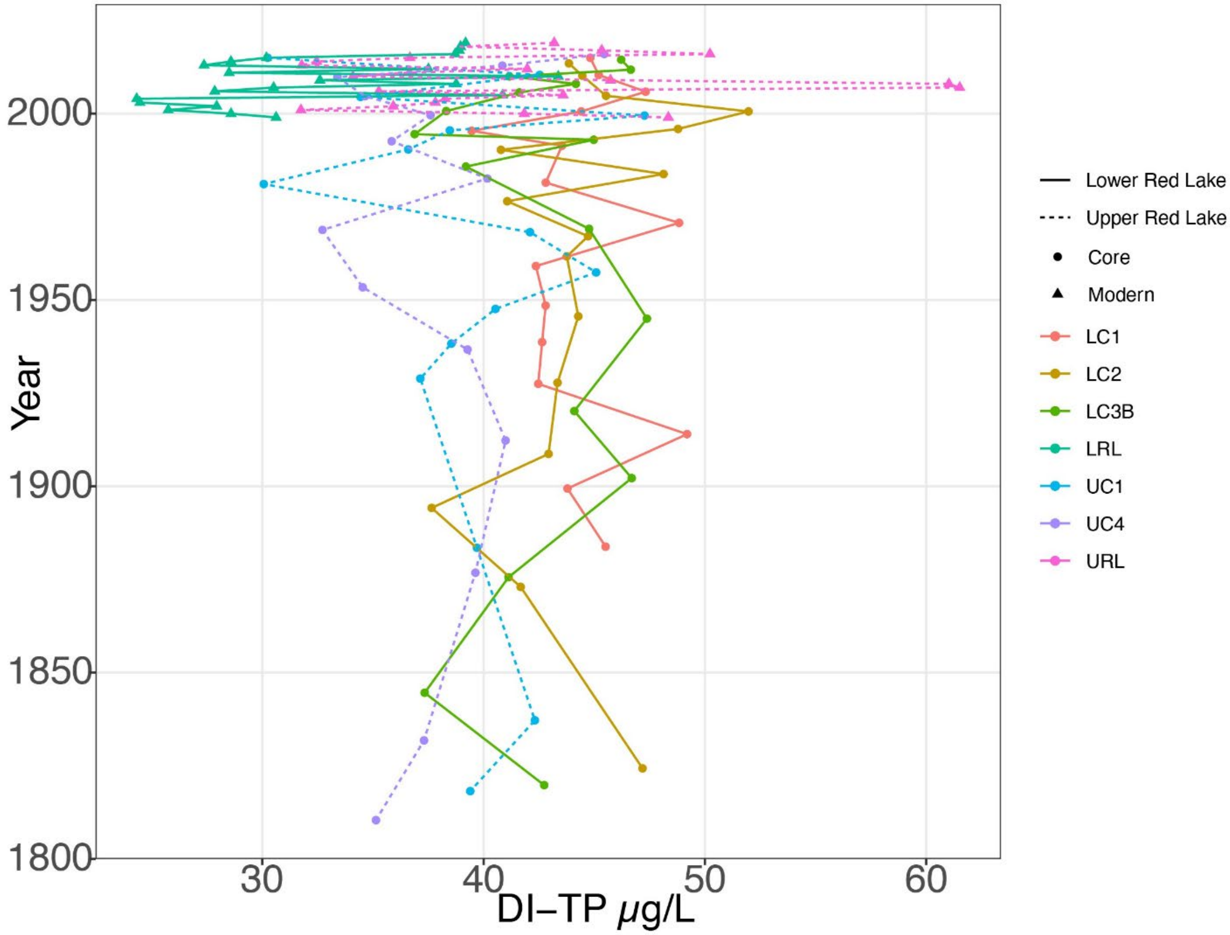
Figure 10. Comparison of mean chlorophyll-*a* and maximum chlorophyll-*a* data for Upper Red (yellow diamonds) and Lower Red (orange squares) lakes and northern Minnesota lakes (open circles; see MPCA 2022). Red Lake points (yellow and orange) are summer (June-September) averages for years with at least four measurements/year. The large orange and yellow points are an average of all years. Northern lakes are summer averages for lakes (both dimictic and polymictic) with at least 2 years of data and four measurements per year. The fit is a generalized additive model (GAM) logistic regression (bs = “tp”, k = 10) and shaded areas are 90% confidence intervals.



Paleolimnological reconstruction

Paleolimnology examines microfossils and geochemistry of lake sediments to interpret lake condition prior to the implementation of a water quality monitoring program. When paired with radioisotope age estimates, the interpretations of lake sediments can be used to detect ecological change and model historical nutrient concentrations. A paleolimnology study was conducted on 3 sediment cores from Upper Red Lake and 4 sediment cores from Lower Red Lake collected between 2016 and 2018 (Burge et al. 2019). Based on examination of lake sediment phosphorus concentrations, diatom microfossil community reconstruction, diatom inferred total phosphorus (DITP), and algae pigments, no significant change occurred to the primary productivity or nutrient dynamics of the Red Lakes since the late 19th century (Burge et al. 2024). The DITP modeled TP concentrations in both lakes at 40 µg/L on average, ranging from 24 µg/L to 61 µg/L throughout the 20th century. The modeled DITP values were within the range of modern measured values and showed no trends of increasing or decreasing through time (Figure 11). Based on the absence of change within the paleo-proxies and DITP values falling within modern monitored values, evidence suggests the modern monitored nutrients and algal communities for Upper and Lower Red lakes are consistent with trophic conditions in the last 200 years.

Figure 11. Diatom inferred total phosphorus (µg/L, circles) and the modern average monitored total phosphorus values (µg/L, triangles) for Upper and Lower Red lakes plotted by year. Dashed lines chronologically connect samples from Upper Red Lake and solid lines chronologically connect samples from Lower Red Lake.



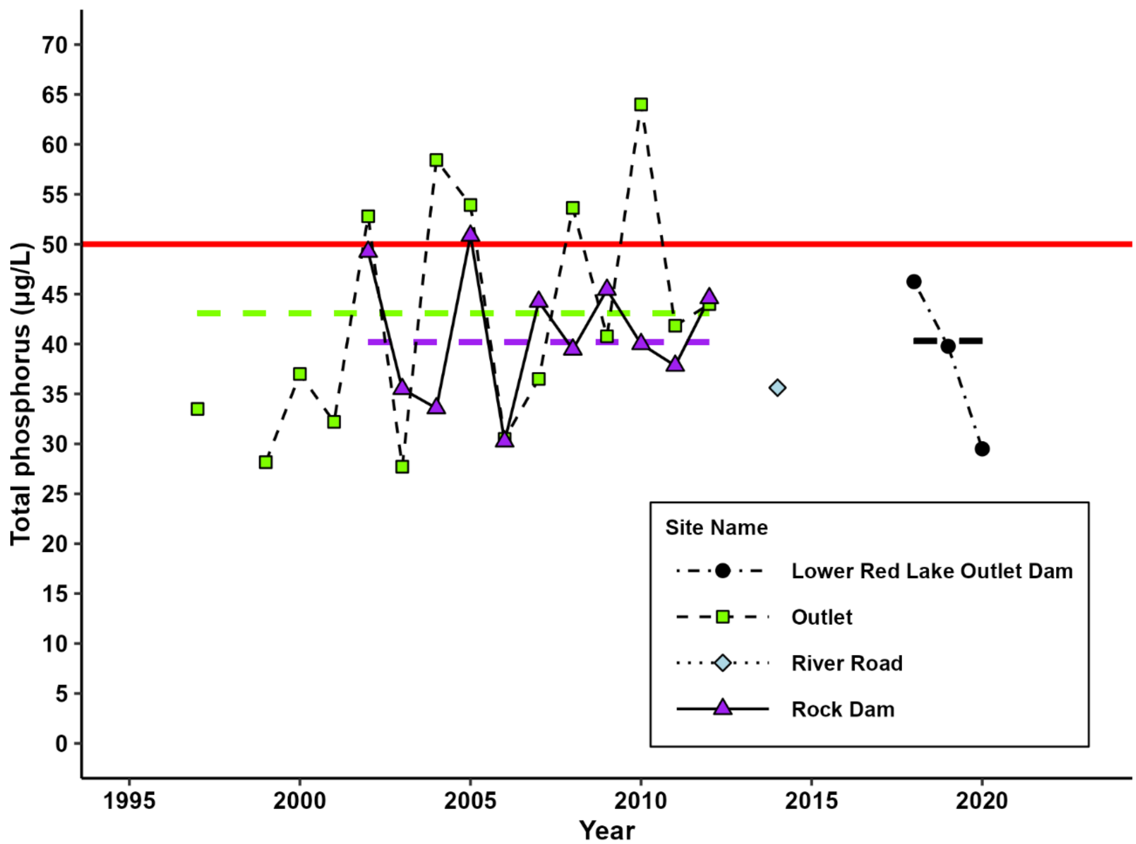
Protection of downstream beneficial uses

As part of a SSS, it is relevant to assess if the proposed standard will contribute to nonattainment of standards in downstream waters. For Red Lake, the waterbody of greatest concern is Red Lake River to which the lake discharges. Currently, there are no lake or river eutrophication impairments downstream of Red Lake on the Red Lake River. In addition, there are no eutrophication impairments on the Red River of the North between the Red Lake River confluence and the Minnesota/Canada border. This indicates that the current conditions in the reservoir are not causing downstream impairments related to eutrophication.

A further examination was carried out by comparing the available TP data for the Red Lake River to the river eutrophication standard. This analysis was limited to the reach immediately downstream of the lake (waterbody identification number: 09020303-560). No chl-*a* data were available from this reach. On average and during most years, the average TP concentration in this reach of the Red Lake River is below the applicable river eutrophication standard of 50 µg/L (Figure 12). Some samples and some summer average values exceed this threshold, but assessments are based on long-term averages and for all sites, the long-term average is below the criterion. In addition, the recommended SSS LES for Lower Red Lake

(42 µg/L) is below the standard applied to the Red Lake River. Based on these data, maintaining the current trophic conditions in Red Lake should protect downstream waters.

Figure 12. Summer average total phosphorus for Red Lake River sites below Lower Red Lake. Horizontal dashed lines are long-term site averages, and the solid red line indicates the total phosphorus standard for the Red Lake River.



Development of site-specific lake eutrophication standard for Red Lake

Derivation of SSS eutrophication standards for Red Lake was based on selecting concentrations that maintained current, protective conditions while minimizing the likelihood of assessment errors. To accomplish this, bootstrapped average concentrations for both TP and chl-*a* were generated and the distribution of these values was used to identify protective concentrations. The sampling methodology used for this analysis was designed to replicate data processing used in the assessment process (i.e., average of all summer data collected from at least 2 years). Data processing for this analysis was similar to previous analyses. Samples collected outside the summer index period were removed and duplicate samples (i.e., samples collected at the same site on the same day) were averaged. Next, daily averages for each basin were calculated by averaging all samples collected on a given day within each basin. Years with fewer than 4 measurements were excluded. Bootstrapping was performed by sampling a fixed number of years (1-10 years) 1000 times with replacement. For each sample size (i.e., number of years), the 95th percentile was calculated from the 1000 samples. These values were used to establish SSS for Red Lake. Although candidate criteria were calculated for different sample sizes, the recommended SSS is based on a 2-year sample size since this represents the minimum sample size required for assessment.

Larger sample sizes provide greater power to detect differences or changes in conditions, but it is more difficult to meet minimum requirements. As a result, the recommended SSS for Red Lake is based on a 2-year summer average (Figure 12). However, larger sample sizes may be useful for trend analysis or detecting smaller and possibly important changes in trophic conditions.

The current criteria most likely to be applicable to Red Lake are 30 µg/L TP and 9 µg/L chl-*a*. The MPCA is currently working on a revision to the LES for lakes in the northern region (i.e., NLF and NMW ecoregions) which would change the applicable regional standards for Red Lake to 30 µg/L TP and 16 µg/L chl-*a* (polymictic/shallow lakes) or 20 µg/L TP and chl-*a* µg/L 9 (dimictic lakes). However, both the promulgated and draft revised standards make it clear that consideration needs to be given to SSS standards because there are lakes in the northern ecoregions which do not conform to the regional standards. Based on the bootstrap analysis, the appropriate and protective standards for Upper Red Lake should be 50 µg/L TP and 17 µg/L chl-*a* and for Lower Red Lake these criteria should be 44 µg/L TP and 14 µg/L chl-*a* (Table 11). The chl-*a* values are similar to the draft revised standards for northern polymictic lakes although TP criteria are higher. The higher TP value is due to the how the draft standard was developed to ensure that a broadly applied standard is protective (MPCA 2022).

Table 11. The 95th percentiles of 1000 bootstrapped summer average concentrations of total phosphorus and chlorophyll-*a* for Upper and Lower Red lakes based on different sample sizes (i.e., 1-10 years). The orange highlight indicates the 2-year sample size which is the minimum size required for assessment of Minnesota lakes.

	Upper			Lower		
Sample size (years)	**Total phosphorus (µg/L)**	**Chlorophyll-*a* (µg/L)**	**Secchi Depth (m)**	**Total phosphorus (µg/L)**	**Chlorophyll-*a* (µg/L)**	**Secchi Depth (m)**
1	56	15	0.6	44	15	0.9
2	50	17	0.6	42	14	0.9
3	48	16	0.6	41	13	1.0
4	47	15	0.6	40	13	1.0
5	47	15	0.6	39	13	1.0
6	47	14	0.6	39	12	1.0
7	46	14	0.7	39	12	1.1
8	46	14	0.7	38	12	1.1
9	45	14	0.7	38	12	1.1
10	46	14	0.7	38	12	1.1

Table 12. Draft site-specific standards for Upper and Lower Red lakes with relevant regional lake eutrophication standards (*applicable to lakes in the Northern Lakes and Forests ecoregion; #applicable to the Northern Lakes and Forest and Northern Minnesota Wetlands ecoregions).

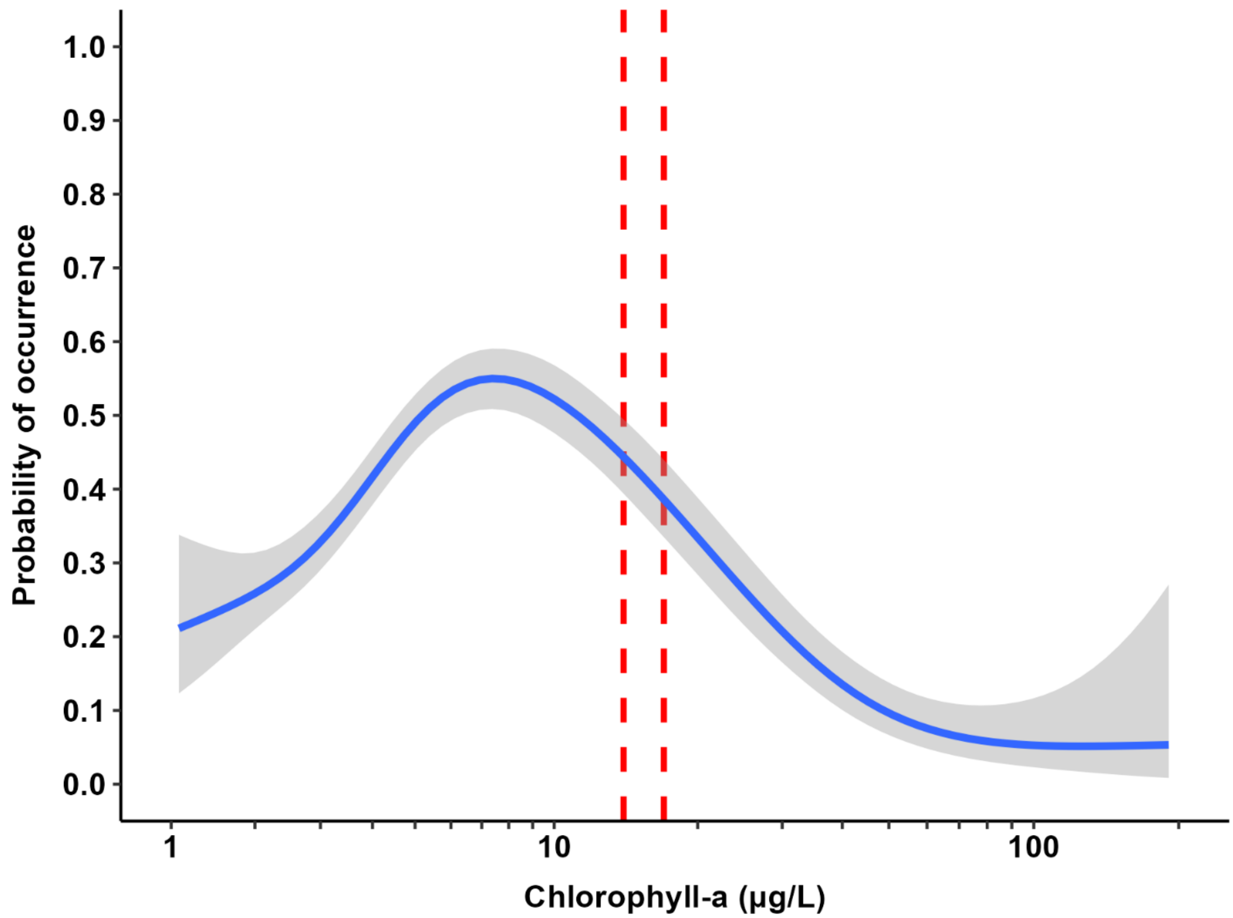
Ecoregion	Total Phosphorus (ppb)	Chlorophyll-a (ppb)	Secchi Depth (m)
Proposed Red Lake site-specific standards*			
Lower Red Lake	42	14	-
Upper Red Lake	50	17	-
North (current standards)			
North (Class 2B)*	30	9	2.0
North (draft standards)			
North, polymictic (Class 2B)#	30	16	1.1
North, dimictic (Class 2B) #	20	9	1.8

Wild rice

Wild rice (*Zizania palustris*) is a biologically and culturally important species that is a component of many macrophyte communities in northern and central Minnesota lakes (Hansen 2008). The distribution of wild rice in Minnesota and Wisconsin has declined (Pillsbury and McGuire 2009), and this species faces threats from climate change and water quality degradation. Some specific factors that contribute to declines in wild rice stands include watershed hydrologic changes, pore-water sulfide, and declines in water transparency (Myrbo et al. 2017). Since increased productivity in lakes often results in greater levels of suspended algae and decreased water transparency, it is relevant to consider eutrophication thresholds for northern mixed lakes and if they are sufficient to protect wild rice.

To assess the potential impact of a SSS LES for Red Lake, the probability of a lake supporting wild rice along a gradient of chl-*a* (log transformed) was modeled with GAMs using a logistic link function in R version 4.0.3 (R Core Team 2023) with the "mgcv" package (Wood 2017). The presence of wild rice was determined from the MNDNR's aquatic plant survey database where lakes with *Z. palustris* identified in any survey was coded as a lake with wild rice. Logistic regression indicated that the probability of occurrence of wild rice as a function of chl-*a* had a unimodal distribution (Figure 13). It should be noted that this analysis relied on presence/absence data and did not account for the quality or size of wild rice populations in these lakes. However, the amount of buffer between the thresholds derived to protect macrophyte communities (i.e., chl-*a* = 14-17 µg/L) indicated that the Red Lake SSS will be sufficient to protect wild rice if it is present from low transparency caused by elevated suspended algae.

Figure 13. Probability of occurrence of wild rice in a lake as function of chlorophyll-*a* (log transformed) for northern and central region Minnesota lakes. Fit is a generalized additive model (GAM) logistic regression (bs = "tp", method = "REML", k = 10) and the shaded area is the 90% confidence interval. Red, dashed lines indicate draft chlorophyll-*a* thresholds for Upper and Lower Red lakes.



Proposed site-specific standard for Red Lake

The following summarizes the findings of this study:

1. **Upper and Lower Red lakes are unique:** The drainage catchment, ecoregion, and morphology of Upper and Lower Red lakes make these waterbodies unique in several aspects compared to other lakes in Minnesota. The size and morphology of Upper and Lower Red lakes alone make these waters unique. Despite their large surface area, they are relatively shallow and have high geometry ratios (16-30 $m^{-0.5}$). This lake morphology results in wind mixing and infrequent and irregular stratification during the summer months. There is also a high proportion of wetlands in the contributing watershed which likely results in higher phosphorus loading compared to other natural lakes dominated by other land cover types such as forest. As a result, Red Lake has naturally higher total phosphorus concentrations compared to many of the lakes used to develop the regional LES. Red Lake is also located on the border of three ecoregions (NLF, NMW, and NCHF) which means the watershed shares characteristics of multiple ecoregions and classification into a single nutrient region is problematic. As a result of the 1) unique lake morphology, 2) high proportion of wetlands in the watershed, and 3) location within an ecotone, regional LES should not be assigned to Upper and Lower Red lakes.

2. **Recreation:** User surveys indicate that the lake at least meets a condition that is defined as: "Very minor aesthetic problems; excellent for swimming, boating, enjoyment." This can be considered to be in attainment of the recreational beneficial use.
3. **Aquatic life:** Based on available biological data gamefish populations are doing well and indicate that the aquatic life beneficial use is currently supported. Similarly, a macrophyte survey collected by the MNDNR indicates that Upper Red Lake supports a healthy macrophyte community.
4. **Current conditions:** Upper and Lower Red lakes maintain chl-*a* concentrations near the draft northern shallow lake standard. Maximum chl-*a* levels are comparatively low and rarely reach levels that could be considered nuisance.
5. **Paleolimnology:** Reconstruction of historical TP concentrations demonstrated that TP concentrations in Upper and Lower Red lakes are largely unchanged over the last 200 years.
6. **Protection of downstream uses:** Review of downstream standards and impairments indicate that the recommended SSS for Red Lake will not result in an impairment to downstream waters (i.e., Red Lake River and Red River of the North). There are currently no impairments downstream of Lower Red Lake, and TP concentrations in Red Lake River meet applicable river eutrophication standards. In addition, the recommended SSS LES for Lower Red Lake is below the standard applicable to Red Lake River.

The following is a summary of the recommended site-specific criteria and a description of the methodology for implementing these criteria. The criteria provided below are maximum concentrations allowable. As with Minnesota's LES, a determination of non-attainment requires that both the TP and chl-*a* criteria are exceeded.

- **Total phosphorus:** A TP summer-mean concentration of 50 µg/L should not be exceeded in Upper Red Lake, and a concentration of 42 µg/L should not be exceeded in Lower Red Lake. These concentrations are between the current TP criteria for northern[7] and Central Hardwood Forest shallow lakes.
- **Chlorophyll-*a*:** A chl-*a* summer-mean concentration of 17 µg/L should not be exceeded in Upper Red Lake, and a concentration of 14 µg/L should not be exceeded in Lower Red Lake. These values straddle the draft standard for shallow northern lakes (MPCA 2022).
- **Secchi depth:** No Secchi depth criteria are proposed because this parameter is apparently naturally low and does not provide a useful measure of trophic status in Upper and Lower Red lakes. As a result, there will be no Secchi depth standard assigned to these lakes.
- **Assessment requirements:** To assess compliance with these criteria, a minimum of two years of data are required. Each year must have at least 4 measurements collected during the summer index period (June through September). Samples should be collected throughout the summer with ideally at least one sample event per month. Samples should be collected well away from shore (ideally toward the middle of the lake). Samples should be collected within the upper 2 m of the water column. If multiple samples are collected from the same site on the same day (i.e., duplicates), these should be averaged or only one sample should be used for calculating average concentration. If samples are collected from multiple sites within the same basin on the same day, these should be averaged provided none are near-shore measurements. Once the data are processed to a single concentration value per basin per day, all values from within the last 10 years are averaged.

[7] *Note: The TP standard referenced here is the draft standard for northern shallow lakes (MPCA 2022)*

- **Review of the recommended SSS:** Available evidence suggests that the current conditions in Upper and Lower Red lakes are attaining aquatic life and recreational uses. However, since this standard is unique and some parameters are higher compared to the standards applied to lakes in northern Minnesota, this SSS may continue to be evaluated to ensure that aquatic life and recreational uses are protected. This should include long-term monitoring of eutrophication parameters and an awareness of complaints by users related to nuisance or harmful algal blooms.

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