Le Sueur River

September 2024

Bass Lake Water Quality Improvement Study

Identifying management strategies to improve and protect water quality of Bass Lake, a priority lake in the Le Sueur River Watershed

MINNESOTA POLLUTION CONTROL AGENCY

CLEAN WATER LAND & LEGACY AMENDMENT

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Cover Photo

Source: Google Earth imagery (2021)

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Abbreviations

1W1P	One Watershed, One Plan
AIS	aquatic invasive species
ATI	alternative tile intake
BMP	best management practice
Chl-*a*	chlorophyll-*a*
CLP	curly-leaf pondweed
CREP	Conservation Reserve Enhancement Program
DNR	Minnesota Department of Natural Resources
DO	dissolved oxygen
EDA	Environmental Data Access
EQuIS	Environmental Quality Information System
EWM	Eurasian watermilfoil
FIBI	fish-based lake index of biological integrity
HSPF	Hydrologic Simulation Program–Fortran
lb	pound
lb/ac	pound per acre
lb/yr	pounds per year
LAP	Lake Assessment Program
mg/L	milligrams per liter
MPCA	Minnesota Pollution Control Agency
MSU	Minnesota State University
PTMApp	Prioritize, Target, and Measure Application
SAM	Scenario Application Manager
SE	Simple Estimator model
STS	Score the Shore survey
SWCD	soil and water conservation district
TMDL	total maximum daily load
TP	total phosphorus
TKN	total Kjeldahl nitrogen

TN	total nitrogen
TSS	total suspended solids
WCBP	western corn belt plains
WRAPS	Watershed Restoration and Protection Strategy
µg/L	micrograms per liter

Executive summary

Bass Lake (22-0074-00) is located in northwest Faribault County in the Rice Creek Subwatershed of the greater Le Sueur River Watershed. Recent water quality monitoring efforts for Bass Lake suggest the lake currently meets water quality standards for aquatic recreation; and therefore, the lake has not been placed on the State of Minnesota's 303(d) list of impaired waters. While the lake is not currently considered impaired, average summer growing season chlorophyll-*a* (chl-*a*) concentrations often exceed state standards.

The Le Sueur River Watershed local partner team has identified Bass Lake as a high priority lake for water quality improvement and protection in their One Watershed, One Plan ([1W1P] ISG 2023) and other planning documents. The local partner team requested that a water quality study be completed for Bass Lake as part of the Watershed Restoration and Protection Strategy (WRAPS) update for Minnesota Pollution Control Agency's (MPCAs) Cycle 2 work for the Le Sueur River Watershed. This report presents the results of this work which includes the following components: review of background information and data (Section 1), development of a lake phosphorus budget and water quality model (Section 2), establishment of in-lake phosphorus targets and load reductions to improve water quality (Section 3), and potential strategies to achieve phosphorus targets and load reductions (Section 4). This report concludes with a final summary and considerations for future monitoring and tracking of best management practices (BMP) efforts (Section 5).

This study identifies three water quality improvement goal options for Bass Lake that local partners can use to help guide implementation efforts. Example strategies and BMPs to achieve these goals are presented in Section 4 and were selected using a variety of existing resources, input from local stakeholders, and best professional judgement from the MPCA staff. Stakeholders should consider these strategies and BMPs as a path to improve and protect Bass Lake, but it is anticipated that implementation may change as new information is learned. Example strategies include watershed practices (agriculture and residential) such as conservation till and no till, cover crops, alternative tile intakes (ATI), and rain gardens. Other example strategies and activities include native shoreline buffers, septic system improvements, managing internal phosphorus recycling, and monitoring. The strategies presented in this study are not required and implementation is considered voluntary.

1. Background information and data

1.1 Data sources and previous studies

Below is a summary of the data, studies, and models that were compiled and reviewed for this study. All items listed below are available online or were supplied by local partners. These studies and data sources are referred to throughout different sections of this memo.

- *Bass Lake Lake Assessment Program (LAP) Report* (MPCA 1993)
- *Assessment Report of Selected Lakes within the Le Sueur River Watershed Minnesota River Basin* (MPCA 2010)
- *Bass Lake Management Plan* (MSU Mankato 2021)
- *Seasonal Assessment of the Aquatic Plant Community in Bass Lake* (MSU Mankato 2022)
- *Le Sueur River Watershed Stressor Identification (SID) Report – Lakes* (DNR 2021)

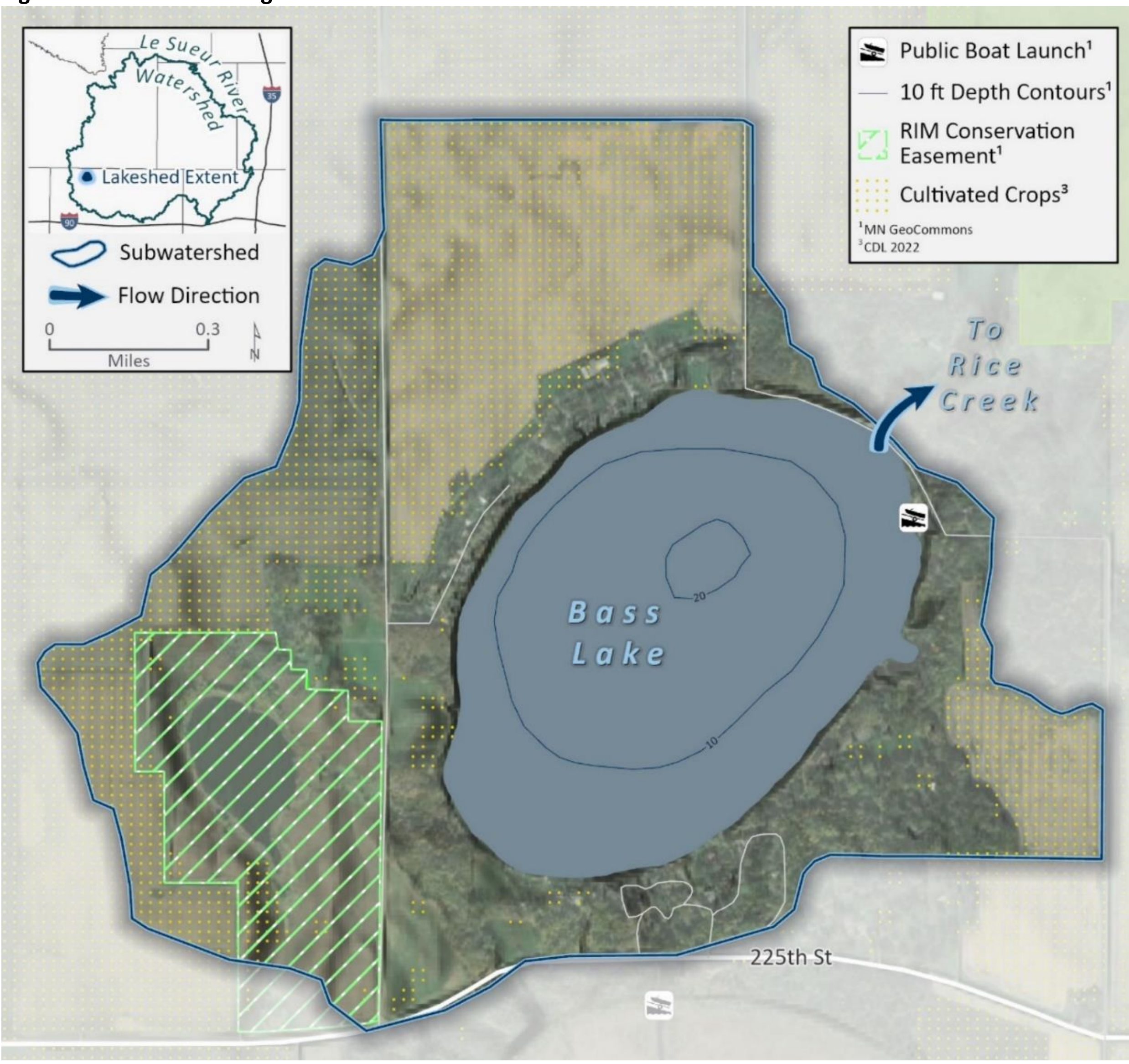
1.2 Lake and watershed characteristics

Bass Lake is located approximately three miles northeast of Winnebago, Minnesota in the Le Sueur River Watershed (Figure 1). Bass Lake was formed by the irregular deposition of glacial till from the Des Moines lobe (MPCA 1993). Lakes of this type are typically shallow with very gently sloping shoreland areas. Bass Lake is a moderately sized lake (~199 acres) that is relatively deep for the region (20 feet max depth and 51% of lake is 10 feet or greater). The lake has a natural outlet on the northeast corner of the lake that flows through a 24-inch metal culvert underneath 400th Avenue and then to a small wetland before flowing into Rice Creek.

The Minnesota Department of Natural Resources (DNR) Level 8 drainage area boundary layer shows the Bass Lake Watershed is approximately 300 acres in size (499 acres including lake surface areas). However, analyses done during the development of the Bass Lake Management Plan (MSU Mankato 2021) and this study (Faribault County SWCD personal communication) suggests that additional cropland fields to the north and east drain to the lake via subsurface drain tile. Therefore, the Bass Lake drainage area is approximately 227 acres larger than the DNR boundary (527 acres; 726 acres including lake areas; Figure 1). Bass Lake is considered a headwater lake meaning there are no major ditches, streams, or upstream lakes flowing to it. The lake receives flow and runoff from areas immediately surrounding the lake and has a small watershed to lake area ratio (3.6 to 1). Bass Lake has an estimated hydraulic residence time of approximately five years, and therefore retains a significant amount of sediment, phosphorus, and other pollutants that enter the lake.

There are approximately 50 seasonal and permanent homes located directly around Bass Lake, all of which have septic systems (MPCA 1993). There are no active registered feedlots located in the Bass Lake drainage area. Land cover throughout Bass Lake's 527-acre drainage area is primarily cropland (corn/soybean, 52%), followed by developed/residential (17%), wetland (15%), forest (10%), and hay/pasture (6%). An 87-acre Conservation Reserve Enhancement Program (CREP) wetland restoration easement was secured on a cropped area west of Bass Lake in 2001. The restoration project represents a fairly large portion of the Bass Lake drainage area (~17%). See Section 2 for additional information on Bass Lake land cover and model assumptions.

Figure 1. Bass Lake drainage area



1.3 Water quality

Lake water quality is often evaluated using three associated parameters: total phosphorus (TP), chl-*a*, and Secchi depth. Phosphorus is typically considered the limiting nutrient in Minnesota lakes, meaning that algal growth will increase with increases in TP. Chl-*a* is the primary pigment in aquatic algae and has been shown to have a direct correlation with algal biomass. Secchi depth is a physical measurement of water transparency. Increasing Secchi depths indicate less turbidity in the water column and increasing water quality. Conversely, rising TP and chl-*a* concentrations point to decreasing water quality and thus decreased water transparency. Measurements of these three parameters are interrelated and can be combined into an index that describes water quality.

Historic and existing water quality conditions for Bass Lake are described using data downloaded from the MPCA's Environmental Quality Information System (EQuIS) database and the University of Minnesota's Lake Browser. EQuIS stores data collected by the MPCA, partner agencies, grantees, and volunteers. All water quality sampling data utilized for assessments, modeling, and data analysis for this study and referenced reports are stored in this database and are accessible through the MPCA's Environmental Data Access (EDA) website. The University of Minnesota's Lake Browser provides satellite derived water quality data for over 10,000 Minnesota lakes. Data are created using an automated image processing system developed with resources from the University of Minnesota and the Environment and Natural Resources Trust Fund — Legislative and Citizens Commission on Minnesota Resources. The automated image processing system processes satellite data from Landsat 8 and Sentinel 2 and provides daily and monthly (May through October) lake clarity (i.e., Secchi depth), chl-*a*, and colored dissolved organic matter (CDOM) data for 2017 through 2021 (Page et al. 2019).

Water quality for Bass Lake has been evaluated against Minnesota's lake eutrophication standards for class 2B lakes in the Western Corn Belt Plains (WCBP) ecoregion. Minnesota State statute defines various categories of lakes for assessment purposes, including lake, reservoir, shallow lake, and wetland (Minn. R. ch. 7050.0150). The determination between the four categories requires an analysis of basin depth, littoral area, and other characteristics in Appendix D of the *Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment* (MPCA 2022a). Although Bass Lake is on the boarder of being considered a lake/reservoir and shallow lake, it has historically been assessed by MPCA as a shallow lake during the water quality assessment process. Table 1 shows the current lake eutrophication water quality standards for both shallow lakes and lakes/reservoirs in the WCBP ecoregion.

Table 1. Lake eutrophication standards for class 2B shallow lakes and lakes and reservoirs in the WCBP ecoregion.

Parameter	WCBP shallow lake	WCBP lakes and reservoirs
Total phosphorus (µg/L)	≤ 90	≤ 65
Chlorophyll-a (µg/L)	≤ 30	≤ 22
Secchi transparency (m)	≥ 0.7	≥ 0.9

The earliest water quality data available for Bass Lake in EQuIS are from the 1980s. Since 1986, Bass Lake has only seven years with three or more TP and chl-*a* measurements during the summer growing season (i.e., June through September) and therefore lacks a consistent record for these parameters. Secchi measurements were routinely monitored during the summer growing season between 1992 and 2001 but have only been collected occasionally since 2001. University of Minnesota Lake Browser chl-*a* and Secchi depth data are available for Bass Lake from 2017 through 2021 and were combined with the field samples available in EQuIS for the analyses presented in this report.

Results of the historic TP, chl-*a*, and Secchi depth data for Bass Lake are summarized in Table 2 and illustrated in Figure 2 through Figure 4. TP data indicate mean summer growing season concentrations have generally remained below the 90 µg/L WCBP shallow lake standard since sampling began in the 1980s. Figure 2 and Table 2 show mean summer TP concentrations may have improved in the 2000s compared to the 1980s and 1990s, likely due to the wetland restoration project and upgrades to septic systems around the lake (MSU Mankato 2021). Bass Lake summer chl-*a* concentrations have also improved during the recent time period; however, concentrations still consistently exceeded the 30 µg/L WCBP shallow lake standard. Mean summer Secchi depths, on the other hand, have remained fairly consistent over the entire monitoring period and have generally met the 0.7-meter WCBP shallow lake standard since monitoring began in the 1980s.

Table 2. Comparison of Bass Lake mean summer water quality during different time periods.

	TP (µg/L)			**Chl-*a* (µg/L)**			**Secchi (m)**		
Time period	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**
1985 through 1999	75	97	65	71	79	56	0.96	1.37	0.59
2000 through 2022	56	57	55	40	56	20	1.01	1.32	0.74
Entire record	67	97	55	53	79	20	0.98	1.37	0.59
WCBP shallow lake standards	≤90			≤30			≥ 0.7		

Figure 2. Bass Lake summer growing season mean TP concentrations (solid bars) from 1985 through 2022 for years in which at least three samples were collected. Error bars represent maximum and minimum summer growing season TP concentrations.

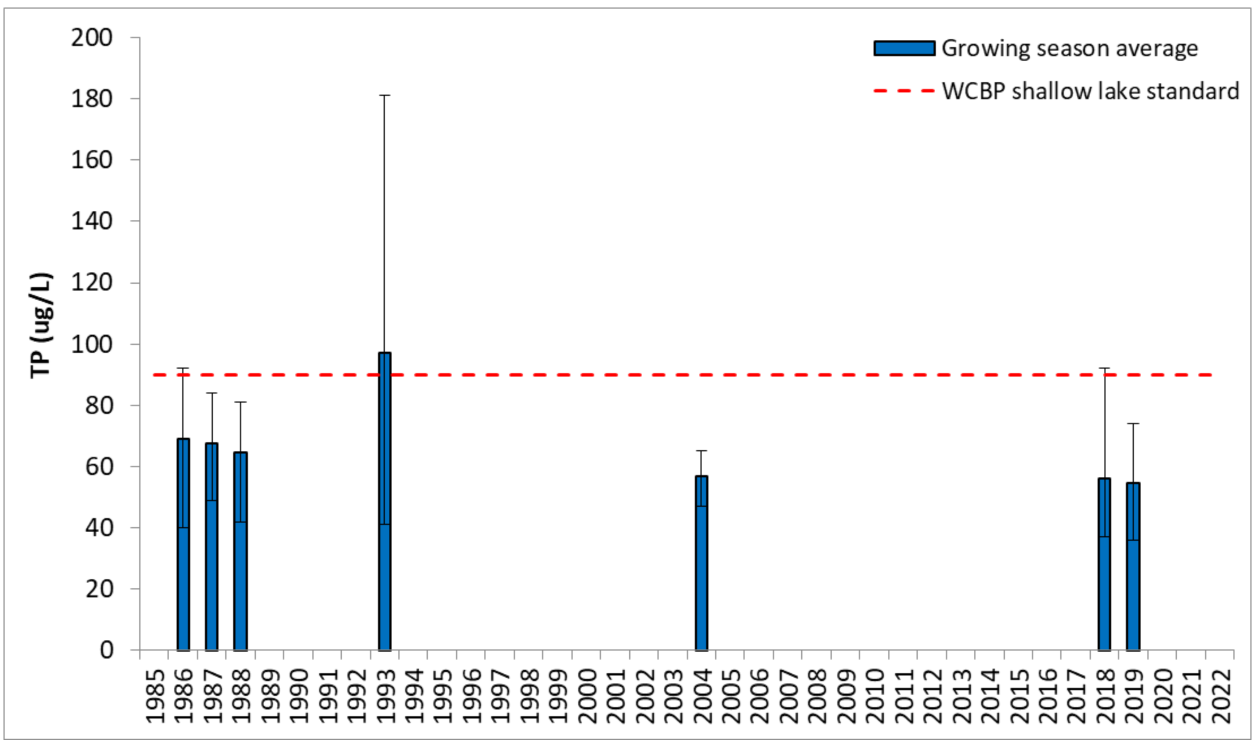


Figure 3. Bass Lake summer growing season mean chl-*a* concentrations (solid bars) from 1985 through 2022 for years in which at least three samples were collected. Error bars represent maximum and minimum summer growing season chl-*a* concentrations. Data includes discrete measurements from EQuIS (entire period) and satellite derived measurements from University of Minnesota Lake Browser (2017 through 2021).

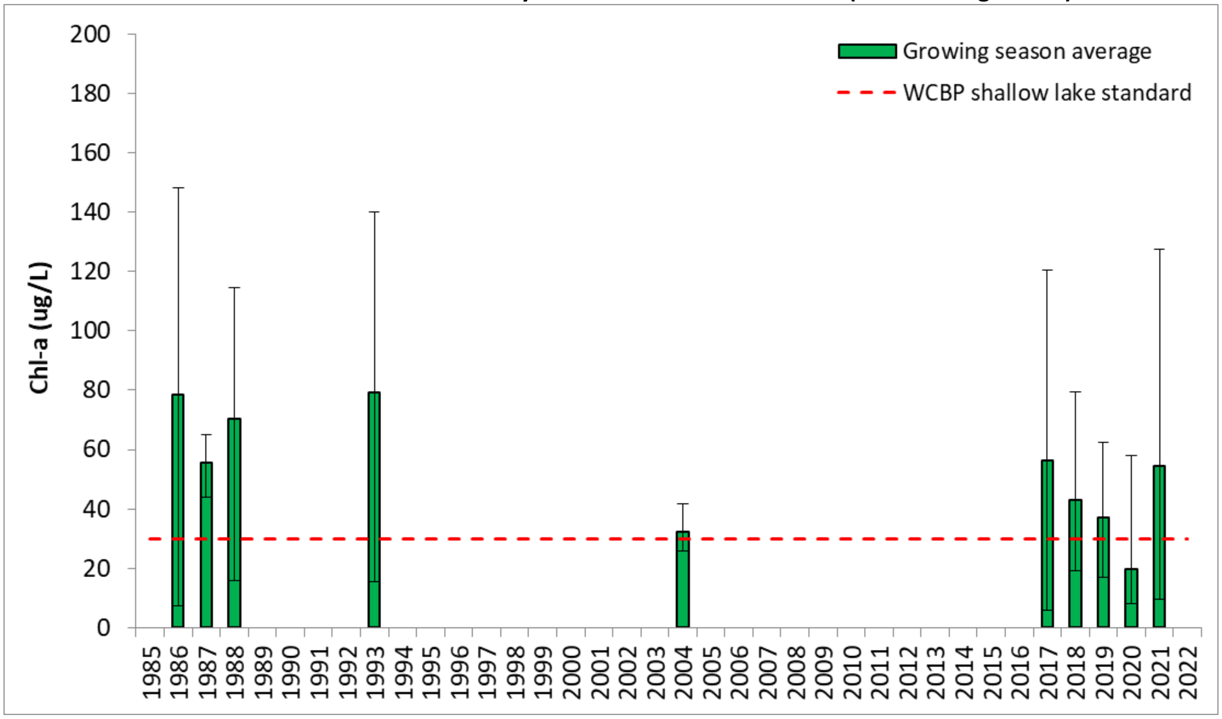
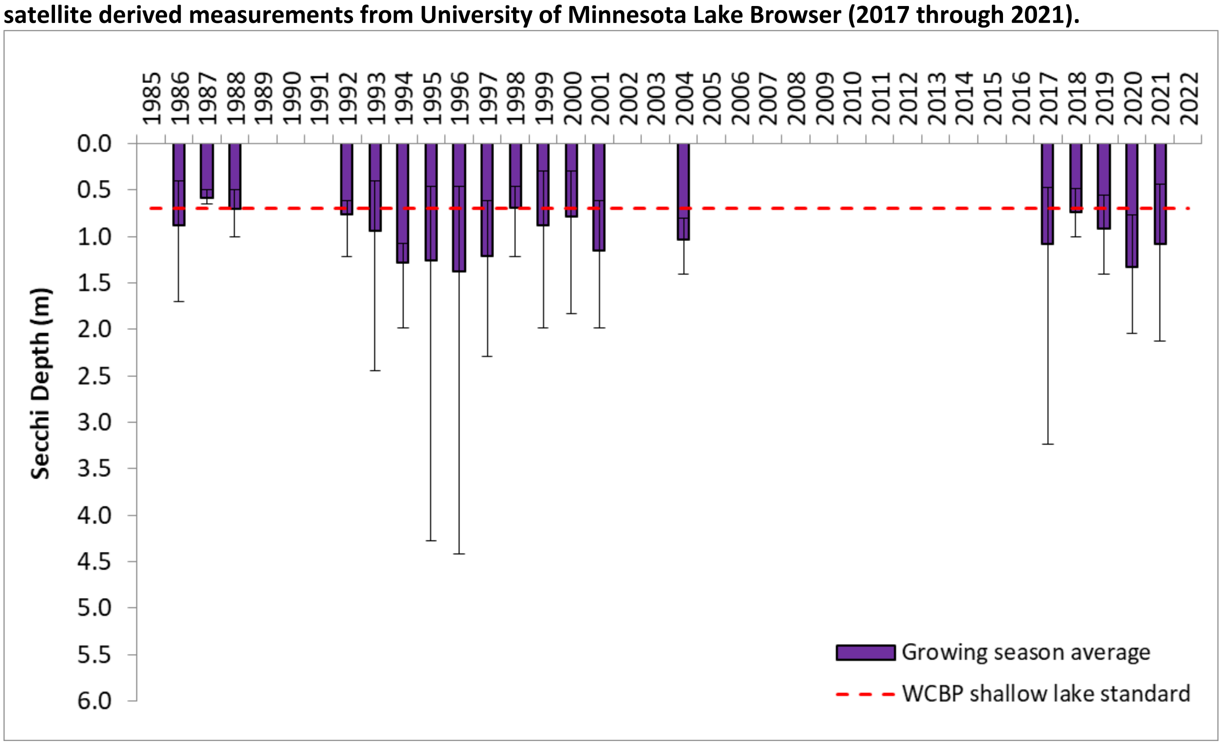
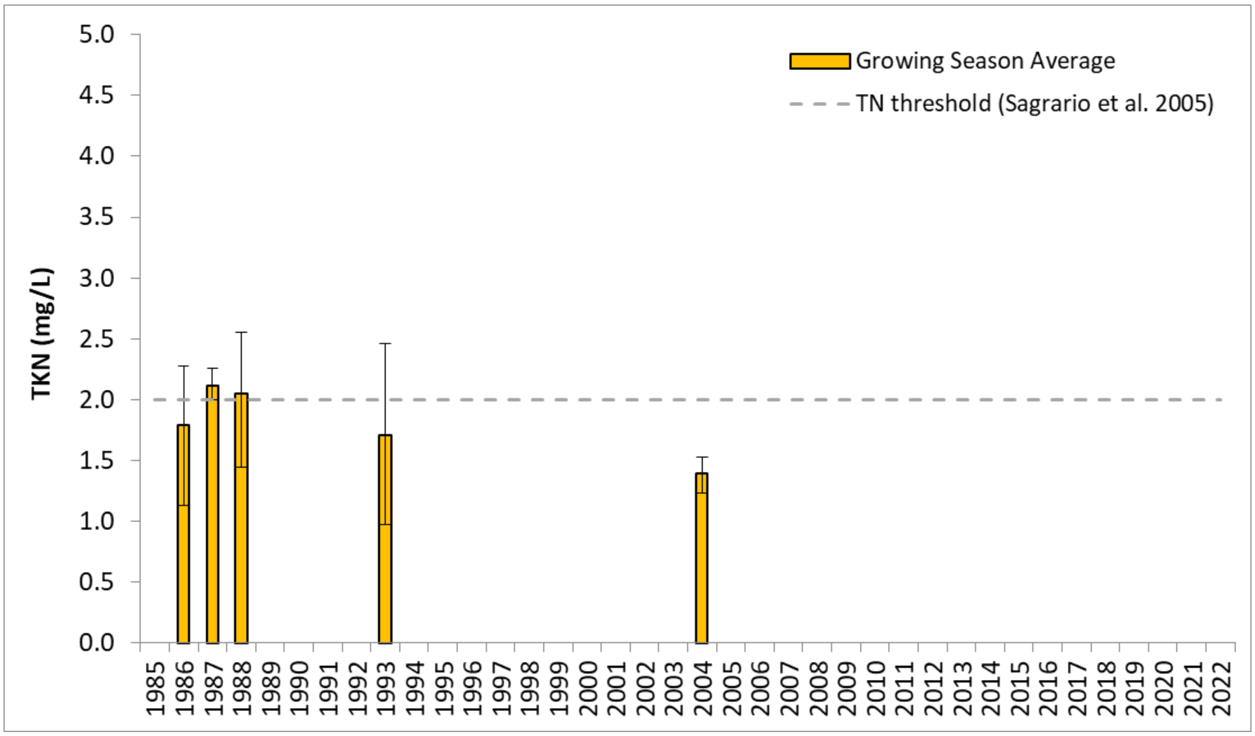


Figure 4. Bass Lake summer growing season mean Secchi depth (solid bars) from 1985 through 2022 for years in which at least three samples were collected. Error bars represent maximum and minimum summer growing season Secchi depth measurements. Data includes discrete measurements from EQuIS (entire period) and satellite derived measurements from University of Minnesota Lake Browser (2017 through 2021).



Although phosphorus is typically considered the limiting nutrient in most Minnesota lakes, nitrogen is an essential nutrient for algal and aquatic plant growth. Total nitrogen (TN; which is calculated as nitrate/nitrite + total Kjeldahl nitrogen [TKN]) has not been monitored in Bass Lake; however, TKN (i.e., organic nitrogen + ammonia) samples have been monitored periodically and were last collected in 2004 (Figure 5). Results show individual samples have ranged from 0.97 to 2.55 mg/L and summer mean concentrations have ranged from 1.39 to 2.12 mg/L. Studies have found that aquatic plant coverage and the number of plant species in lakes tend to decline when TN levels exceed ~2.0 mg/L (Sagrario et al. 2005; MPCA 2005a). More spring and summer in-lake TN measurements are needed in Bass Lake to better understand if/how nitrogen levels are impacting eutrophication (i.e., algae growth), aquatic plants, and other biota.

Figure 5. Bass Lake summer growing season mean TKN concentrations (solid bars) from 1985 through 2022 for years in which at least three samples were collected. Error bars represent maximum and minimum summer growing season TKN concentrations.



Water quality (nitrogen and phosphorus) was also monitored at six inlet points to Bass Lake on four occasions (May, July, and August) in 2019 (data available through Bass Lake Clean Water Coalition). Results of these efforts suggest inlet TP concentrations were moderate during these events (range = 50 to 200 µg/L) and nitrate concentrations were elevated at certain locations (range = below detection limit [<0.05 mg/L] to 14.2 mg/L). More inlet monitoring data is needed to better understand phosphorus and nitrogen loading to Bass Lake and to calibrate/validate the watershed model results presented in Section 2.

1.4 Fisheries

A reclamation of the Bass Lake fish community took place in 1988 with the goal of reducing the biomass of black bullheads which increased following a series of winterkills in the late 1970s (MPCA 1993).

Following the reclamation, Bass Lake was stocked with northern pike, largemouth bass, black crappie, bluegill, yellow perch, channel catfish, and flathead catfish. The 1988 reclamation event successfully reduced black bullhead biomass, and improved sportfish populations for several years (DNR 2021). However, by 1996, black bullhead catch rates had increased to pre-reclamation levels, driving a reduction in bluegill, black crappie and yellow perch catches by 2013.

Bass Lake is currently managed by the DNR for northern pike and walleye and these populations have been maintained successfully through regular stocking regimes since 2014. During the most recent DNR fisheries surveys in 2018, northern pike catch rates were sampled near normal ranges of similar lakes while average size was slightly above normal ranges. The walleye catch rates and sizes were both above expected ranges in 2018. Two fish species that are often associated with poor water quality conditions, common carp and black bullhead, were both sampled below normal ranges during the 2018 survey. Other species sampled in Bass Lake in 2018 included black crappie, bluegill, channel catfish, largemouth bass, yellow bullhead, and yellow perch. The regular stocking of northern pike and walleye has helped curb the black bullhead population but may also be partially driving the low panfish catch rates observed in recent years (DNR 2021).

A common misconception is that if a lake supports a quality gamefish population (e.g., high abundance or desirable size structure of a popular gamefish species), it should be considered a healthy lake. This is not necessarily true because both game and nongame fish species must be considered when holistically evaluating fish community health. Oftentimes, the smaller nongame fishes serve ecologically important roles in aquatic ecosystems and are generally the most sensitive to human-induced stress. In order to better evaluate the entire fish community, the DNR uses a fish-based lake index of biological integrity (FIBI) scoring system to assess lakes throughout the State of Minnesota. The FIBI assessments utilize fish community data collected from a combination of trap nets, gill nets, beach seines, and backpack electrofishing. From these data, an FIBI score can be calculated for a lake that provides a measure of overall fish community health based on species diversity and composition. If biological impairments are found, stressors to the fish community must be identified. More information about the sampling and assessment process can be found at the DNR lake index of biological integrity website.

Bass Lake was recently sampled and assessed in 2018 using the DNR's FIBI scoring system. Results of the FIBI assessment indicate Bass Lake (FIBI score = 21) scored below the FIBI impairment threshold established for similar lakes (FIBI threshold = 36) and therefore does not support aquatic life use and is considered impaired for aquatic life. A SID Report was developed for Bass Lake, along with two other impaired lakes in the Le Sueur River Watershed (DNR 2021), to identify primary stressors to the fish communities and to provide general strategies to help address the stressors. The SID report identified eutrophication and physical habitat alteration (nonnative species introduction, connectivity loss, moderate dock density, and Score the Shore (STS) scores as the probable cause of stress to aquatic life in Bass Lake.

1.5 Vegetation

Submergent and emergent aquatic vegetation are critical to lakes, providing spawning and cover for fish, habitat for macroinvertebrates, refuge for prey, sediment and water column nutrient uptake, and stabilization of sediments. Declines in the abundance and diversity of aquatic vegetation can be an indication of a shifting biological community and water quality state. As disturbances increase, sensitive vegetation species are lost from the system and often replaced with less desirable species (e.g., aquatic invasive species) or no vegetation at all.

The abundance of submerged vegetation in Bass Lake has varied over time. In the 1940s, submerged vegetation was described as being almost nonexistent throughout the lake (MPCA 1993). By the mid-1950s, sago pondweed was reported to be moderately abundant and local groups were planting various pondweeds and other native species throughout the lake. Curly-leaf pondweed (CLP) was formally documented in Bass Lake during a 1986 survey and comprised 100% of the surveyed community (MPCA 1993). However, permits to apply Diquat were being issued at least as early as 1978 suggesting that CLP colonization likely occurred prior to 1986. A transect survey conducted by DNR in 2008 found Bass Lake has moderate to high aquatic plant diversity relative to similar lakes in the region (DNR 2021). CLP was noted during the 2008 survey but has appeared to be less dominant since the 1988 fish reclamation event (DNR 2021). Additionally, Eurasian watermilfoil (EWM) was first identified in Bass Lake in 2019.

The most recent aquatic plant surveys for Bass Lake were performed by Minnesota State Mankato in 2022. These surveys consisted of point intercept surveys of 82 sample points in April, May, and August. A total of five native submersed plant species were sampled during these surveys: muskgrass, northern watermilfoil, leafy pondweed, and sago pondweed (MSU Mankato 2022). Two nonnative invasive plant species were also sampled during the surveys: CLP and EWM. Coverage of submersed aquatic plants ranged from 7% during the August survey to 27% during the May survey. Northern watermilfoil was the most dominant plant species (1.2% to 19.5% occurrence) observed followed by coontail (1.2% to 8.5% occurrence) and leafy pondweed (0% to 4.9% occurrence). CLP was observed at only 1.2% of the sample points during the May 2022 survey and was primarily limited to a relatively small area of the lake (~8 acres). CLP turion densities were also measured and ranged from 35 to 165 turions per meter squared. These densities are relatively low compared to established CLP populations (typically 1,000 to 3,000 turions per meter squared) and are indicative of an early colonizing infestation (MSU Mankato 2022). Similarly, EWM occurrence was low (0% to 2.4%) but is beginning to spread to new areas throughout the lake.

1.6 Lakeshore conditions

Lakeshore habitat assessments were conducted during the FIBI and SID process for Bass Lake. The primary tool used in the assessments was the DNR STS Rapid Assessment (DNR 2019a) which were performed by DNR staff. STS is a protocol developed to rapidly assess the quantity and integrity of lakeshore habitat. The survey is designed to assess differences in habitat between lakes and to detect changes over time. STS surveys require visual observation of lands accessible by boat. The intent of the survey is to assess habitat, not to inspect for violations. The STS assessments consist of surveying 100-foot sections of shoreline at predefined, equally spaced survey locations along the entire shoreline of the lake. Since only 100 feet of shoreline is surveyed per location, the full assessment covers a relatively small portion of the total shoreline and results are not tied to individual properties. During the surveys, three lakeshore zones (upland/shoreland, shoreline, and aquatic) are assessed independently at each survey location. Within each zone, surveyors score specific features related to habitat, which are then summed for an overall Zone Habitat Score. Higher scores indicate a greater amount of habitat. Lower scores indicate a low percent of the site remains natural and a higher amount has been physically disturbed or altered by humans. The feature scores within each zone are summed for an overall site habitat score. This scoring process provides a simple method of ranking sites based on the percent of each site that is in a natural condition versus the percent of the site that has been altered. A lakewide score is calculated using the mean site habitat score. Scores range from 0 to 100 and lakes with a high percentage of unaltered habitat score higher than lakes that have been highly altered. More information about the methods used for the STS surveys can be found in the *Minnesota Lake Plant Survey Manual* (DNR 2019a).

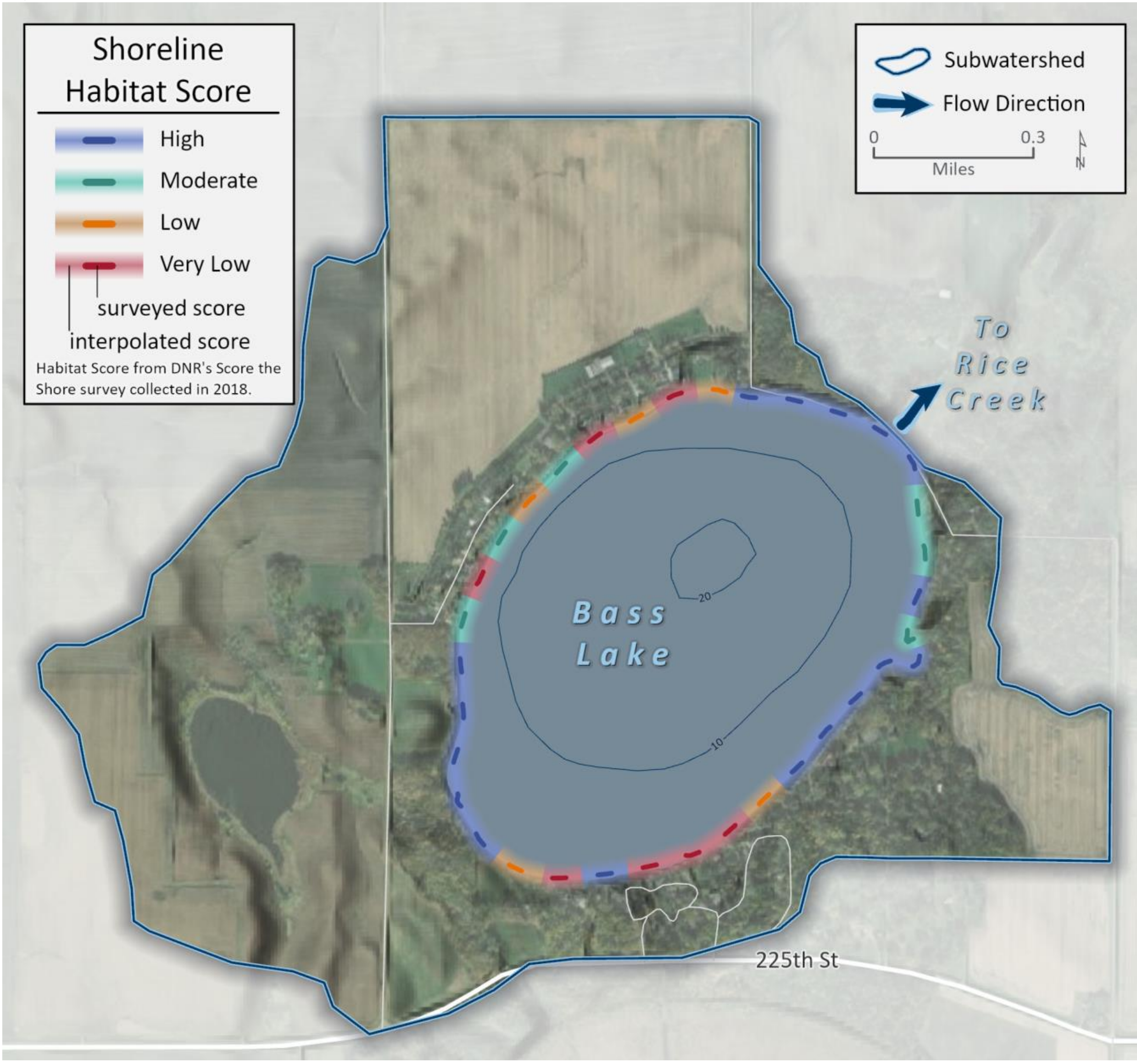
The DNR STS assessment results for Bass Lake are summarized in Table 3. Figure 6 illustrates the results of the overall habitat scores for the 35 STS survey locations. In this figure, the dark colored lines show the results of the individual surveyed locations (i.e., 100-foot survey sections). The lighter, thicker lines along the shoreline represent interpolated scores between the 100-foot surveyed sections. The overall score for Bass Lake is considered moderate and is close to the mean score of other lakes in the Le Sueur River Watershed (mean score = 73; N = 5) and lakes throughout the state of Minnesota (mean score = 74; N = 764). A moderate score indicates that, on average, surveyed sites have a high percentage of unaltered habitat but that at least one zone (i.e., shoreland, shoreline, or aquatic) has lower habitat quality than a high scoring site. Developed sites that generally retain a high percentage of natural habitat areas may score in this range. Development has had the largest effect on the shoreland and shoreline habitat components for Bass Lake, indicating that replacement of trees, shrubs, and natural ground cover with open yards has most likely occurred.

The DNR estimates that Bass Lake has approximately 47 docks (21.9 docks per mile of shoreline) based on review of 2015 Google imagery (DNR 2021). Dock densities exceeding 16 docks per mile can significantly affect fish communities and habitat (Jacobson et al. 2016, Dustin 2017). Based on the dock density estimate, aquatic plant removal has likely contributed to some physical habitat loss within the lake, which could result in changes to the fish community as evaluated by the FIBI (DNR 2021).

Table 3. DNR STS survey results for Bass Lake.

Category	**Result**
Dock density (#/mile)	21.9
Survey locations	35
Percent developed	83%
Shoreland zone score	26.2 moderate
Shoreline zone score	21.9 moderate
Aquatic zone score	24.2 moderate
TOTAL SCORE	72.3 moderate

Figure 6. Overall site habitat STS scores for individual sample locations.



1.7 Climate

The *Climate summary for watersheds: Le Sueur River* (DNR 2019b) report shows that annual average temperatures in the Le Sueur River Watershed have increased over the last century and that most years during the past two decades have been warmer than average. Monthly average temperatures in the Le Sueur River Watershed peak in July, and winter temperatures on average have increased over time. Annual precipitation has also shown an upward trend across the watershed. Monthly precipitation is typically highest in May and June, and increases in precipitation in recent years were most pronounced in April through July. The frequency of 1-inch and 3-inch rain events has increased in general in Minnesota, along with the size of the heaviest rainfall of the year. Minnesota has also experienced an increase in devastating, large-area extreme rainstorms (DNR 2022). Climate projections indicate these big rains will continue increasing into the future (DNR 2022).

Statewide lake data collected by the DNR, MPCA, and local partners shows that the climate trends described above have already impacted lakes throughout the state and region. According to MPCA's Climate Change and Minnesota's Surface Waters Viewer, lake surface temperatures have warmed during all seasons throughout southern Minnesota. During the summer growing season (June through September), lakes in southern Minnesota are, on average, approximately 2.7 to 4.4 degrees F warmer now than they were 50 years ago. Additionally, warmer winters have resulted in about 9 less days of ice coverage on average for lakes throughout the region since the mid-1970s.

Reduced ice coverage, higher year-around water temperatures, and more intense and frequent precipitation events can result in significant impacts to lakes and lake users, including but not limited to (MPCA 2021):

- Overall increase in flow, sediment, and nutrient loading from the lake drainage area
- Longer periods of stratification and anoxia resulting in increased internal phosphorus recycling
- Longer open water and growing season for algae and cyanobacteria blooms
- Larger fluctuations in lake level from year to year
- Potential for increased densities of aquatic invasive plants, such as CLP and EWM
- Decreases in walleye (who prefer summer water temps at 65 to 70 degrees F) in smaller, warmer lakes
- Potential for more fish kills as fish are squeezed into smaller zones to access oxygen
- Shortened season for safely recreating on ice-covered lakes

Although long-term supporting data is limited, it is likely that Bass Lake has or is currently experiencing many of the climate impacts described above. These impacts create additional challenges to effectively manage Bass Lake water quality and support healthy plant and fish communities. Adaptation strategies such as improving water management practices, enhancing soil health, planting conservation perennials, and natural shoreline buffers should be considered for Bass Lake to build resilience to these impacts and threats.

2. Lake phosphorus budget and model

A lake phosphorus budget and eutrophication model (BATHTUB) were setup for Bass Lake using methods similar to the lake total maximum daily load (TMDLs) in the *Le Sueur River Watershed TMDL Study* (MPCA 2015) and other lake TMDLs throughout the State. The four primary phosphorus sources considered for the Bass Lake model were loading from the Bass Lake drainage area, septic systems, atmosphere, and internal recycling. Each of these sources, and how they were estimated, are discussed below in more detail.

2.1 Drainage area

Precipitation that falls within the drainage area of a lake flows across the land surface and/or through sub-surface drain tiles, and a portion of it eventually reaches the lake. Phosphorus is carried with the runoff water and delivered to the lake. The primary phosphorus sources in runoff in the Bass Lake drainage area include soils, fertilizer, vegetation, wetlands, and impervious surfaces and lawns in residential areas surrounding the lake.

For the nonresidential portions (i.e., cropland, hay/pasture, forest, and wetlands) of the Bass Lake drainage area, flow and phosphorus loads were estimated using the Le Sueur River Watershed Hydrologic Simulation Program-Fortran (HSPF) model (2023 version). HSPF is a comprehensive, mechanistic model of watershed hydrology and water quality that allows the integrated simulation of point sources, land and soil contaminant runoff processes, and in-stream hydraulic and sediment-chemical interactions. Model documentation contains additional details about the Le Sueur River HSPF model development and calibration (TetraTech 2002, RESPEC 2014, TetraTech 2015, Tetra Tech 2016).

Watershed runoff volumes and TP loads from the developed areas within the Bass Lake drainage area (i.e., homes and residential areas immediately surrounding the lake) were estimated using the MPCA Simple Estimator (SE) model. The SE model is an Excel-based tool that is commonly used by municipalities in Minnesota to estimate flow, phosphorus loads, and BMP load reductions in urban and residential areas (link to Minnesota Stormwater Manual SE page).

The MPCA reviewed the assumptions used for the Bass Lake Subwatershed in the Le Sueur River HSPF model and noted that the drainage area delineation in the model is based on the DNR Level 8 drainage area boundary and therefore does not include the tiled cropland fields to the north and east of Bass Lake discussed in Section 1. To adjust for this, the MPCA re-digitized the drainage area boundary for Bass Lake (Figure 1) and re-defined landcover within the Bass Lake drainage area based on input from local partners (Faribault SWCD personal communication) and interpretation of air photos. Additionally, Faribault SWCD provided general information on likely management actions on cropland fields (e.g., drain tiling, tillage, fertilizer, and manure application) throughout the Bass Lake drainage area. Using this information, the MPCA extracted the average annual flow and TP loading rates (model years 2002 through 2017) for each landcover category from the SE (developed areas) and HSPF models (nonresidential areas) and multiplied them by the corresponding acreage in the Bass Lake drainage area to estimate average annual flow volumes and phosphorus loads delivered to Bass Lake from these sources (Table 4).

Table 4. Model estimated flow volume and TP loading rates and annual totals for the Bass Lake drainage area (modeled years = 2002 through 2017).

Landcover category	Area (acres)	Model used	Modeled flow rate (in/yr)	Modeled flow volume (acre-ft/yr)	Modeled TP load rate (lbs/acre/yr)	Modeled TP load (lbs/yr)
Cropland	274	HSPF	10.9	248	0.873	239
Developed/residential	90	SE	8.6	65	0.730	66
Wetland	77	HSPF	7.1	45	0.142	11
Forest	54	HSPF	6.5	29	0.098	5
Hay/pasture	32	HSPF	7.5	20	0.411	13
TOTAL	527			407		334

2.2 Septic systems

Flow and TP loads from septic systems were estimated using methods similar to the *Lower Minnesota River Watershed TMDL* (MPCA 2020a). An estimate of the total number of homes and part time residences with septic systems in the Bass Lake drainage area was made by reviewing recent air photos in Google Earth (~80 systems). Assumptions were made regarding the number of people per household (~2.1), the percent of homes that are occupied year around (50%) versus seasonally (50%), and current estimated septic compliance (~95% compliant and ~5% failing; Faribault SWCD personal communication). Septic system TP removal rates for compliant systems was assumed to be approximately 80%, while removal rates of 57% were assumed for failing systems (Barr Engineering 2004). Through this analysis it was estimated that compliant septic systems currently contribute approximately 49 lbs of TP per year to Bass Lake while noncompliant systems contribute approximately 5 lbs per year.

2.3 Atmosphere

Phosphorus is bound to atmospheric particles that settle out of the atmosphere and are deposited directly onto surface water. Phosphorus loading from atmospheric deposition to Bass Lake is estimated to be approximately 74 lbs/year based on the average deposition rate across the Minnesota River Basin (0.37 lb/acre/year; Barr Engineering 2007).

2.4 Internal phosphorus recycling

Internal phosphorus recycling, often referred to as “internal loading,” is a common occurrence in eutrophic and hypereutrophic shallow lakes throughout central and southern Minnesota. Phosphorus contained in the sediment of lakes originates as an external phosphorus load that settles out of the water column to the lake bottom. Typically, a significant amount of the external load to Bass Lake is delivered during snow melt and spring and early summer runoff. During this time, low water temperatures and flushing limit the amount of algae growth and biological activity within the lake. As water temperatures increase in mid-summer (e.g., late June and July), shallow lakes can become thermally stratified during quiescent periods and biological activity increases, which leads to higher rates of algae growth and bacterial decomposition. As this happens, dissolved oxygen (DO) is consumed by bacteria, and anoxic conditions (i.e., low DO) can develop at the sediment-water interface, which leads to the release of phosphorus from the lake sediments. The phosphorus that is released from the sediments is in a soluble form that is readily available to algae for uptake. In shallow lakes like Bass Lake, phosphorus that has accumulated near the sediment-water interface can be readily mixed into the surface waters during strong winds, storm events, and as stratification begins to weaken in the late summer. Internal phosphorus recycling is especially problematic in shallow lakes during dry and hot summers, when lower flows provide less dilution for P loads recycled from lake bottom sediments. Further, algae growth rates and sediment decomposition rates are elevated during dry and hot summers due to higher water temperatures and longer hydraulic residence times (Walker 2011).

There is evidence from the available data for Bass Lake that suggest internal phosphorus recycling occurs within the lake:

- Mean surface TP and chl-*a* concentrations increase from June through September in most years despite generally decreasing precipitation, watershed runoff, and external TP inputs during this time period.
- Although temperature and DO profile data for Bass Lake is limited, surface TP and chl-*a* concentration spikes have been observed when thermal stratification weakens or breaks down late in the summer and following water column mixing events (e.g., 2004, 2018, and 2019).

At this time, there is not enough data available to explicitly quantify the amount of phosphorus that is typically recycled within Bass Lake each year. In order to better characterize internal recycling, additional data would need to be collected such as continuous or high-frequency temperature and DO profiles, hypolimnetic phosphorus samples, and/or sediment cores. Since internal phosphorus recycling reflects recycling of loads that originally entered the lake from the lake drainage area and atmosphere, the amount of P recycling is expected to vary with external load over time.

Common carp are another potential source of internal phosphorus recycling. When present in high densities, carp can exacerbate poor water quality in lakes by destroying/uprooting aquatic vegetation and resuspending/recycling TP from lake sediments. Studies have demonstrated how adult carp can increase turbidity, total suspended solids (TSS), TP, and negatively affect macrophyte abundance through various direct and indirect processes (Parkos et al. 2003). Research suggests that negative impacts of common carp on turbidity and vegetation begin to occur at densities of around 89 lb/acre (Bajer et al. 2009). To our knowledge, common carp density has not been assessed in Bass Lake. Although the gear used in the DNR trap and gill net surveys tends to underrepresent common carp abundance due to high net avoidance, these surveys can provide a relative means to track carp trends and changes over time within a lake and compare catch rates to other lakes. Based on our review of the DNR trap and gill net surveys, common catch rates for Bass Lake have decreased from peak values in 1984 and 2002 that were above the median for similar lakes in the region. During the most recent DNR survey (2018), common carp were sampled but catch rates were below normal ranges (i.e., below 25th percentile of similar lakes), suggesting carp are likely not a major source of phosphorus recycling in Bass Lake at this time.

2.5 Lake eutrophication model and final phosphorus budget

A spreadsheet version of the lake model BATHTUB (Walker 1987) was established for Bass Lake to model current lake water quality conditions. BATHTUB is a steady state model that predicts eutrophication response in lakes based on empirical formulas developed for nutrient balance calculations and algal response (Walker 1987). The model was developed by the U.S. Army Corps of Engineers and has been used extensively in Minnesota and across the Midwest for lake nutrient TMDLs. Several models (subroutines) are available for use within the BATHTUB model, and the Canfield-Bachmann model was used to predict phosphorus settling/retention and the lake response to TP loads in Bass Lake. The BATHTUB model requires flow and phosphorus loading inputs from the lake's drainage area, upstream lakes, and atmospheric deposition. Lake morphometric data are also required by the model.

Drainage area runoff volumes and phosphorus loading inputs to the Bass Lake BATHTUB model were derived from the HSPF model (Table 4). Flow and phosphorus loading from atmospheric deposition and septic systems using the methods described above were also added to the model. With the primary external sources defined, the model predicted in-lake phosphorus concentration was compared to the 2000 through 2022 observed mean concentration (Figure 2 and Table 2). Phosphorus monitoring data prior to 2000 were not used due to the septic improvements and wetland restoration project completed in the 1990s and early 2000s. The model predicted in-lake TP concentration (55 µg/L) was within 2% of the observed concentration (56 µg/L) and therefore no model adjustments were required to calibrate the model.

The Canfield-Bachmann settling/retention model used in the Bass Lake BATHTUB model inherently includes an average amount of phosphorus recycling. In some cases, the amount of phosphorus recycled within a lake is greater than the amount inherent in the model and the modeler may choose to add additional load to improve model calibration. Alternatively, the Canfield-Bachman phosphorus sedimentation calibration factor can be adjusted to account for internal phosphorus recycling as recommended in the BATHTUB Version 6.1 Online Documentation (Walker 2006). Although there is evidence that phosphorus recycling occurs in Bass Lake, the BATHTUB model did not require an additional phosphorus load or adjustments to the phosphorus sedimentation calibration factor (Walker 2006). This suggests that internal recycling of phosphorus and external inputs are in equilibrium and management of external sources is the most appropriate starting point to achieve sustained, long-term improvements to in-lake water quality.

As shown in Table 5, loading from the Bass Lake drainage area (72%) represents the largest source of phosphorus to the lake followed by atmospheric inputs (16%) and septic systems (12%). Sedimentation/retention represents the largest sink of phosphorus (86%) suggesting a significant amount of the annual load delivered to the lake is retained in the lake and its sediments.

Table 5. Bass Lake current condition phosphorus budget (HSPF modeled years = 2002 through 2017).

Category	Annual Load (lbs/yr)	Percent of Total
Sources (+)		
Drainage area	334	72%
Atmosphere	74	16%
Septic Systems	54	12%
TOTAL	462	
Losses (-)		
Sedimentation/retention	398	86%
Outflow	64	14%
TOTAL	462	

3. Phosphorus targets and reductions

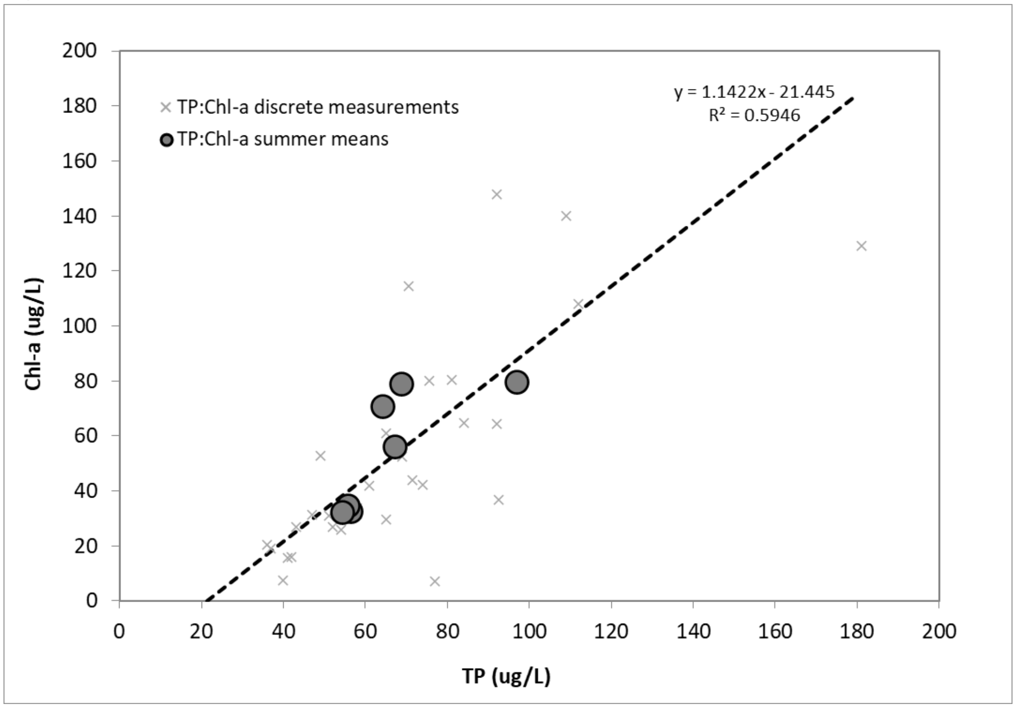
3.1 Establishing phosphorus targets to improve water quality

The primary objective of this study is to improve water quality conditions in Bass Lake. Bass Lake currently meets the 90 µg/L WCBP shallow lake TP standard but exceeds the 30 µg/L chl-*a* standard based on data collected since 2000 (Table 2). Therefore, an in-lake TP concentration target below the 90 µg/L standard and the current mean TP concentration (56 µg/L) will be needed to reduce summer chl-*a* concentrations and nuisance algae blooms. Here, we present three water quality targets local partners could consider for Bass Lake:

- Moderate target – decrease mean summer chl-*a* concentrations from 40 µg/L to 30 µg/L to meet WCBP shallow lake standards.
- Aggressive target – decrease mean summer chl-*a* concentrations to 22 µg/L to meet the WCBP lake and reservoir standard (Table 1).
- Very aggressive target – decrease mean summer chl-*a* concentrations to 14 µg/L.

Figure 7 shows the relationship between TP and chl-*a* concentrations for Bass Lake. Although this relationship has limited data points in the upper (i.e., TP > 90 µg/L) and lower (i.e., TP < 50 µg/L) TP ranges, it can be used as a starting point to establish TP targets to achieve the chl-*a* targets described above. Based on the TP: chl-*a* best-fit trendline displayed in Figure 7, TP targets of 45 µg/L, 38 µg/L, and 31 µg/L would achieve the moderate, aggressive, and very aggressive chl-*a* targets, respectively. It is recommended that the local partners collect more TP and chl-*a* data during the summer growing season to refine the TP: chl-*a* relationship presented in Figure 7 and better understand nutrient and algae dynamics in Bass Lake.

Figure 7. Bass Lake TP and chl-*a* relationship.



3.2 Load reduction goals

With the proposed chl-*a* and TP targets defined, the Bass Lake BATHTUB model was used to estimate the annual TP loads and reductions that will be needed to meet the in-lake chl-*a* concentration targets. Table 6 presents the current TP load to Bass Lake, the model-predicted TP load needed to meet each target condition, and the load reduction required to meet the target. Section 4 presents example strategies and BMP options to achieve the load reductions presented in Table 6.

Table 6. TP loads and reductions to meet in-lake water quality targets.

Water quality target	Chl-*a* target (µg/L)	TP target (µg/L)	Current TP (µg/L)	Current TP load (lbs/yr)	TP target load (lbs/yr)	TP load reduction (lbs/yr)	TP load reduction (percent)
Moderate	30	45	56	462	323	139	30%
Aggressive	22	38			246	216	47%
Very Aggressive	14	31			178	284	61%

4. Strategies to improve Bass Lake water quality and aquatic life

Example strategies were selected using a variety of sources, input from local stakeholders, and best professional judgement from the MPCA staff. Example strategies presented in this section are intended to provide potential options to achieve the water quality targets and loading goals for Bass Lake. The strategies are not required and implementation is considered voluntary. Stakeholders should use these example practices as a path to improve water quality, but it is anticipated that implementation may change as new information is learned and data is collected. It is recommended that stakeholders incorporate other known local issues or causes when implementing practices and strive to incorporate multiple benefits into projects.

4.1 Cropland best management practices

Phosphorus reductions from cropland BMPs that have been adopted throughout the Bass Lake drainage area were estimated using phosphorus reduction rates derived from the defaults in Hydrological Simulation Program Fortran- Scenario Application Manager (HSPF–SAM; version 2.0) and the Watershed Pollutant Load Reduction Calculator (MPCA 2022b). Below is a summary of the BMPs that have been adopted to date and their estimated load reductions and other benefits:

- The 87-acre CREP wetland restoration easement secured in 2001 has reduced annual TP loads by approximately 94 lbs annually (1.1 lbs/ac) and by over 2,000 lbs over the lifespan of the easement. Other benefits from this project include reduced sediment and nitrogen loads, water storage, flood retention, improved habitat, and other ecosystem services.
- It is estimated that about half of the cropland (129 acres) in the Bass Lake drainage area currently practices conservation tillage (i.e., 30%+ residue cover) every other year. Implementation of this BMP has decreased long-term annual TP loading by about 15 lbs per year. Other benefits from conservation tillage include reduced sediment and nitrogen loads and improved soil health.
- Currently, manure is not spread on any of the cropland fields in the Bass Lake drainage area. It is estimated that TP loads to Bass Lake could increase by as much as 60 lbs per year (0.22 lbs/ac) if manure spreading was a common practice throughout the watershed.

Collectively, the wetland restoration and increased conservation till BMPs described above have reduced TP loading to Bass Lake by approximately 109 lbs per year and played a major role in the improved water quality conditions observed in Bass Lake over the last 20 years (Table 2). The MPCA also consulted with local partner staff (Faribault SWCD personal communication) to develop a list of future cropland BMP and land use change example scenarios that could be considered for the Bass Lake to further improve water quality. These scenarios include:

- Implement conservation till every year on all fields currently practicing conventional till and periodic conservation till

- Implement no-till on all fields currently practicing conventional till and periodic conservation till
- Implement cover crops on all cropland fields
- Convert 25% of cropland fields to grassland
- Convert 75% of cropland fields to grassland
- Install alternative tile intakes (ATIs) on approximately 26 acres of poorly drained cropland fields

Table 7 presents the potential TP load reductions for each scenario using the models and tools described above. Phosphorus reductions from the example scenarios range from 12 to 117 lbs/yr and therefore, depending on the scenario selected and level of adoption, could help achieve a significant amount of the annual reduction goals identified in Table 6.

4.2 Developed/residential BMPs

It is estimated that there are approximately 80 homes/residences throughout the Bass Lake drainage area and residential areas account for 17% of the land use and 14% of the annual phosphorus load to Bass Lake. Most of the homes are on shoreline lots or other lots in close proximity to the lake. Based on investigation of air photos, most of the residential lots surrounding the lake are around one acre in size and impervious surfaces (i.e., rooftops, driveways, walkways, roads) generally cover approximately 1/3 of the lot (~0.33 acres per lot). Due to their proximity to Bass Lake, these impervious surfaces have high potential for stormwater to be delivered to the lake via surface runoff, drain tile, and/or shallow groundwater pathways.

A rain garden is one of the most efficient residential stormwater BMPs used to intercept runoff from impervious surfaces and remove pollutants before they enter surface waters. Below are three rain garden BMP example scenarios to reduce phosphorus loading from residential areas throughout the Bass Lake drainage area.

- Low adoption scenario – 10% of residences throughout the drainage area install and maintain rain gardens to treat impervious areas (assumes 8 rain gardens treating approximately 3 acres of impervious area)
- Moderate adoption scenario – 25% of residences install and maintain rain gardens (20 rain gardens and 7 acres treated)
- High adoption scenario – 50% of residences install and maintain rain gardens (40 rain gardens and 13 acres treated)

Phosphorus reductions from rain gardens were estimated using default rates provided in the MPCA SE model. Table 7 presents the potential TP load reductions for each scenario. Reductions range from 2 lbs/yr for the low adoption scenario to 8 lbs/year for the high adoption scenario. Although the total load reductions for the raingarden scenarios are less than the cropland BMP scenarios, raingarden TP reduction efficiency is higher than the cropland BMPs listed in Table 7. Thus, raingardens are an effective practice in reducing phosphorus loads from developed areas in the Bass Lake drainage area.

4.3 Lakeshore BMPs

The DNR Lake SID Report (DNR 2021) indicates that physical habitat alteration is likely occurring at a level that would contribute to an impaired fish community in Bass Lake based on review of information reflecting riparian lakeshore development. Shoreline development for Bass Lake is relatively high and has resulted in the loss of both riparian vegetation and native floating-leaf and emergent plant stands that serve as important habitat for fish and other organisms. Further, replacement of riparian vegetation with riprap and open lawns has resulted in increased nutrient inputs from fertilizer and lawn clippings, reduced buffering capacity, destabilized shoreline, and elimination of future contributions of coarse woody habitat into the lake (DNR 2021).

Shoreland owners can significantly improve shoreline habitat by choosing to reestablish or maintain native plants along their property. Natural shorelines provide overhead cover to fish and wildlife species, contribute important coarse woody habitat into the lake, and provide a buffer for nutrient runoff from lawns and impervious surfaces. While shoreline restoration projects vary in scope and size, all can be completed in ways that are visually appealing and that maintain a view of the lake. Once completed, these projects have potential to provide many ecosystem benefits that a more traditional developed shoreline (e.g., riprap, mowed lawn, and sand beach) could not offer. The DNR maintains an interactive Restore Your Shore webpage that provides guidance for shoreland owners and professionals to use in implementing shoreland restoration projects. Protection and restoration of floating-leaf and emergent aquatic vegetation should also be prioritized, especially where aquatic habitat is limited. Shoreland owners should be aware of and adhere to current laws that regulate shoreline and aquatic plant control, riprap, sand blanket, and retaining wall installation, and other shoreline alterations.

The DNR estimates that a developed shoreline with turf grass to the water's edge allows seven to nine times more phosphorus to enter the lake than a naturally vegetated shoreline (Radomski and Van Assche 2014). While the amount of phosphorus entering the lake from shoreline lots varies due to soil, slope, and other site-specific conditions, the average pollution from 100 feet of nonbuffered shoreline has been estimated at 0.2 lbs of TP per summer compared to 0.03 lbs per summer for a lot with a native vegetated shoreline buffer. Based on air photo interpretation and results of the Bass Lake DNR STS survey (Table 3 and Figure 6), there is at least 3,000 feet of shoreline that could benefit from native shoreline buffers. Implementation of native buffers in these areas would result in TP reductions of approximately five lbs/yr and provide several ecosystem benefits as described above and in Figure 7.

4.4 Septic system improvements

Faribault County has actively enforced the 1994 DNR shore land septic ordinance for all property owners in the Bass Lake drainage area. Sixty septic systems were upgraded between 1994 and 2000 (DNR 2021), All of which were failing and contributing directly to the lake. These upgrades resulted in an estimated TP load reduction of 44 lbs/yr according to the methods described in Section 2. It is estimated that about 5% of the septic systems (~4 systems) in the Bass Lake drainage area are noncompliant currently (Faribault SWCD personal communication). If these systems were brought into compliance, TP loading to the lake would be reduced by approximately 3 lbs/yr (Table 7).

4.5 Internal phosphorus recycling

As discussed in Section 2, net effects of internal phosphorus recycling were not explicitly estimated for this study. Although there is evidence that internal phosphorus recycling occurs within Bass Lake, it is assumed that the rate of recycling will decrease as the lake and sediments equilibrate to lower external phosphorus loads. Implementation strategies to decrease internal phosphorus recycling could be considered if in-lake TP and eutrophication response variables do not improve, or are slow to improve, as watershed reductions are achieved. Strategies to reduce internal recycling could also be pursued if BMP efforts to reduce external loads fall short of the targets and goals set by the local partners. Internal recycling strategies could include, but are not limited to, water level drawdown, sediment dredging, sediment phosphorus immobilization or chemical treatment (e.g., alum and Phoslock®). The MPCA recommends feasibility studies for any lake in which major in-lake management strategies are proposed. The *Minnesota State and Regional Government Review of Internal Phosphorus Load Control* paper (MPCA 2020b) provides more information on internal load BMPs and considerations.

At this time, CLP and common carp do not appear to be significant contributors to phosphorus recycling in Bass Lake (see Sections 1 and 2). However, efforts to limit CLP turion production and prevent the migration and movement of common carp from upstream/downstream water bodies could be considered as a protection strategy to prevent these threats from becoming problems in the future (MSU Mankato 2021). It is recommended that local partners work closely with DNR if they are interested in pursuing these strategies.

4.6 Nitrogen management

While the primary focus of this study is reducing phosphorus since it is typically the limiting nutrient in lakes, studies have demonstrated that nitrogen loading to lakes can affect eutrophication and should not be overlooked. As discussed in Section 1, nitrate inputs to Bass Lake can be high and in-lake TKN concentrations have, at times, exceeded levels that may affect aquatic plants. More nitrogen monitoring data is needed to better understand nitrogen dynamics in Bass Lake and its impact on eutrophication, aquatic plants, and other biota. Specific nitrogen targets and watershed load reduction goals for Bass Lake could be considered in the future as more data are collected. Nitrogen reductions alone may not be successful in reducing nuisance algae blooms because certain algae (e.g., blue-green algae) are able to fix atmospheric nitrogen (Wetzel 2001). However, reduction in nitrogen loading in conjunction with the phosphorus load reductions is likely the best approach for reducing algal growth and nuisance algal blooms (MPCA 2005). Table 7 presents TN reductions rates/efficiencies for most of the cropland BMPs discussed in this report.

Table 7. Bass Lake recommended strategies and BMP example scenarios with associated TP load reductions and other benefits.

Strategy type	BMP	BMP example scenario	Current level of adoption	BMP TP reduction rate/efficiency	TP load reduction (lbs/yr)	Other water quality and habitat benefits
Cropland BMPs	Conservation till	Conservation till on all cropland fields currently practicing conventional till (145 ac) and conservation till every other year (129 ac)	129 acres every other year	0.23 lbs/ac/yr[a]	48	sediment (reduction = 60 lbs/ac/yr[a]), nitrogen (reduction = 1.45 lbs/ac/yr[a]), improved soil health
	No till	No-till on all cropland fields practicing conventional till (145 ac) and conservation till every other year (129 ac)	none	0.48 lbs/ac/yr[a]	117	sediment (reduction = 80 lbs/ac/yr[a]), nitrogen (reduction = 3.47 lbs/ac/yr[a]), improved soil health
	Cover crops	Cover crops on all cropland fields (274 ac)	none	0.20 lbs/ac/yr[a]	55	sediment (reduction = 80 lbs/ac/yr[a]), nitrogen (reduction = 6.69 lbs/ac/yr[a]), improved soil health
	Cropland to grassland	Convert 25% of cropland fields to grassland (69 ac)	none	0.51 lbs/ac/yr[b]	35	sediment (reduction = 120 lbs/ac/yr[b]), nitrogen (reduction = 20 lbs/ac/yr[b])
		Convert 75% of cropland fields to grassland (206 ac)	none	0.51 lbs/ac/yr[b]	105	
	ATIs	Install ATIs on 26 ac of cropland	none	0.47 lbs/ac/yr[a]	12	sediment (reduction = 100 lbs/ac/yr[a]), nitrogen (reduction = 1.88 lbs/ac/yr[a])
Developed/ Residential BMPs	Rain gardens	Low adoption: 8 residences install raingardens to treat 3 acres	unknown	0.61 lbs/ac/yr[c]	1.8	sediment (reduction = 138 lbs/ac/yr[c]), water retention, groundwater recharge
		Moderate adoption: 20 residences install raingardens to treat 7 acres	unknown	0.61 lbs/ac/yr[c]	4.3	

Strategy type	BMP	BMP example scenario	Current level of adoption	BMP TP reduction rate/efficiency	TP load reduction (lbs/yr)	Other water quality and habitat benefits
		High adoption: 40 residences install raingardens to treat 13 acres	unknown	0.61 lbs/ac/yr[c]	7.9	
Shoreline BMPs	Native shoreline buffers	Implement native shoreline buffers on 3,000 feet of developed, nonbuffered shoreline	unknown	0.17 lbs/100-ft of shoreline[d]	5.1	filtering of sediment and other pollutants, reduced erosion, shoreline stabilization, habitat for insects, fish, birds, amphibians, decreased maintenance cost
Septic system improvements	Septic system upgrade	Upgrade all failing septic systems in watershed (~4 systems)	95% (~76 systems)	0.75 lbs/system/yr[e]	3.0	nitrogen and fecal coliform reductions (not quantified)

[a] Source: Watershed Pollutant Load Reduction Calculator (MPCA 2022b)

[b] Source: Le Sueur River HSPF–SAM (version 2.0)

[c] Source: MPCA Simple Estimator model

[d] Source: Radomski and Van Assche 2014

[e] Source: MPCA 2020a and Barr Engineering 2004

5. Summary and future monitoring and analysis

This study identifies three water quality improvement goal options for Bass Lake that local partners can use to help guide implementation efforts. The moderate goal is intended to reduce mean summer chl-*a* levels from 40 µg/L to 30 µg/L and requires TP load reductions of approximately 139 lbs/yr (~30% reduction; Table 6). The moderate goal could be achieved through a high level of adoption of the BMP scenarios identified in Section 4 and Table 7. The aggressive and very aggressive goals, which call for TP load reductions of 216 and 284 lbs/yr respectively, will be difficult to meet based on the BMP scenario reduction estimates presented in Section 4. To achieve these goals, drastic changes in land use/cover (e.g., conversion of cropland and residential to grass land or wetland) and/or engineered solutions such as in-lake treatments to decrease internal phosphorus recycling may be needed. The MPCA recommends feasibility studies be performed prior to pursuing in-lake management and these strategies be paired with watershed BMPs to improve project longevity.

Implementation of cropland BMPs such as conservation till, no-till, and cover crops will be critical to meet and maintain any of the three water quality goals presented in this study. Septic system upgrades and rain gardens on residential properties surrounding Bass Lake should also be targeted as these are pollutant sources with direct pathways to the lake. Although phosphorus reduction benefits are lower than some of the other BMPs presented in Section 4, native shoreline buffers will be an important strategy to restore and protect fish habitat. Bass Lake was recently listed as impaired for aquatic life (fish community) and a lack of native shoreline vegetation was identified as one of the primary stressors.

Finally, the following list of monitoring activities and analyses would be beneficial over the course of the implementation period. These items will help refine and update the watershed and lake models, assist in prioritizing and targeting BMPs, and track response to BMPs as they are implemented using an adaptive management approach.

- Collect surface water quality samples (i.e., TP, chl-*a*, Secchi depth) at least one time per month from April/May through October. Although the lake standards require June through September sampling, spring and fall data would be beneficial to better understand nutrient dynamics and eutrophication response over the entire open water season.
- Consider adding TN (i.e., TKN and nitrate/nitrite) to the list of surface water monitoring parameters to investigate if/how nitrogen may be affecting eutrophication and biological communities.
- Continue collecting water quality samples (phosphorus, nitrogen, sediment) at primary inlet points to Bass Lake to help validate and/or refine the models developed for this report and to track reductions as BMPs are implemented.
- Consider collecting sediment cores (i.e., laboratory incubations for sediment P release) and additional water column profiles (i.e., temperature and DO) to evaluate how stratification, water column mixing, and internal phosphorus recycling are affecting water quality and seasonal trends.

- Continue monitoring nonnative species (e.g., common carp, CLP, EWM) where they are present to ensure they do not reach densities that could substantially alter water quality and physical habitat in the future.
- Continue mapping and surveying native submerged and emergent vegetation communities to document baseline conditions and track changes as management occurs.
- Encourage individual lakeshore residents and lake association members to participate in the Minnesota Lake Steward Program and the Score Your Shore Survey to educate about sustainable land management, self-assess habitat conditions along their shorelines, and identify potential improvements.
- Utilize lidar-based terrain analysis products (e.g., Prioritize, Target, and Measure Application [PTMApp]) to identify and target locations (both cropland and residential) with higher rates of soil loss and sediment delivery throughout the Bass Lake drainage area.
- Periodically update the watershed model, lake model, TP: chl-*a* relationships, and other models and tools as new data is collected and BMPs are implemented.

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