Bear Lake 2025 Watershed Assessment

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Introduction

Bear Lake (Muskegon County, MI) is a small eutrophic lake located within the former Muskegon Lake Area of Concern (AOC). Because of elevated total phosphorus (TP) concentrations and excess algal growth, a Total Maximum Daily Load (TMDL) for phosphorus was issued for Bear Lake in 2008 with the goal of reducing both internal and external phosphorus loading (DEQ 2008). Subsequent research (Steinman and Ogdahl 2015) recommended that more emphasis be placed on reducing external loading, and as a result efforts were undertaken to restore the former celery fields to the north of Bear Lake (Steinman and Ogdahl 2016). Following restoration, TP concentrations declined significantly within these wetlands (Hassett and Steinman 2022); however, TP levels within Bear Lake remain above the desired threshold.

In October 2025, Muskegon Lake and its accompanying waterways (including Bear Lake) were officially delisted as an AOC, marking a major milestone in the recovery of the local watershed. Delisting indicates that restoration targets of past abuses of the AOC have been met but it does not address the current and potential new ones that have emerged since the 1990s. Hence, it remains important to monitor and maintain restoration efforts in order to continue to improve the health of the lake.

The Bear Lake - Lake Board has contracted with GVSU's Annis Water Resources Institute to monitor water quality conditions in Bear Lake since 2022. Our 2022 report noted that Bear Lake was still experiencing excess nutrients and chlorophyll *a* (an indicator of algal abundance). We recommended monitoring tributary nutrient concentrations in order to identify the major sources of nutrients entering Bear Lake, as well as more frequent monitoring of chlorophyll *a* and a survey of lake users to determine their priorities; in addition, the report included our support of the use of Phoslock® to help control phosphorus concentrations in the lake. Our 2023 report built upon lake monitoring efforts by additionally monitoring lake inflows from Bear Creek and Fenner's Ditch in addition to outflowing lake water at the Bear Lake channel. Bear Creek was found to have a diluting effect on phosphorus concentrations in Bear Lake; however, it was found that Fenner's Ditch may be a significant source that resupplies phosphorus to the lake, which is amplified during storm events. Our 2024 report (Steinman et al. 2025) analyzed the sediment contents in Fenner's Ditch; we observed considerable spatial variability in the sediment content but overall, concluded that the ditch is a likely source of phosphorus to Bear Lake.

This report contains the findings from our fourth year of monitoring Bear Lake and also includes results from sampling storm sewer drain outfalls after storm events. It is often not realized that inputs to our storm drains do not flow to the wastewater treatment plant; rather the ones we sampled flow directly into Bear Lake and may be a source of pollutants. We conclude with recommendations for future monitoring activities.

Methods

2025 Lake Water Quality

Bear Lake water quality monitoring sites were the same as in previous years to facilitate comparisons of 2025 data with prior results. Due to continued budgetary limits and the desire to sample earlier in the spring season, sampling in 2025 occurred in April, June through August, and in October (skipping May and September 2025); this is an identical sampling regime as in 2023-2024, while in 2022 we sampled monthly from May through October. The four monitoring sites included two sites monitored by Restorative Lake Sciences (RLS) in 2017-2021 (Sites 1 and 3) and two sites previously monitored by AWRI in 2011-2012 and 2022-2024 (Sites 2 and 4). Site locations are specified in Table 1 and Figure 1.

Lake samples were collected once monthly from a Jon boat throughout the monitoring period, with sampling occurring usually between 9:00-11:30 AM. Water transparency was measured as Secchi disk depth. General water quality parameters were measured using a YSI EXO2 sonde (YSI, Inc., Yellow Springs, OH), which included sensors for water temperature, dissolved oxygen (DO), pH, specific conductivity (SpCond), and turbidity. Water was collected at surface depth via grab sampling and at middle and near-bottom depths via a Van Dorn water sampler. Samples for water chemistry analysis were collected in 250-mL bottles, stored on ice, and returned to the lab for nutrient analysis, usually within 4 hours.

Separately, an additional 1-L sample was collected in amber bottles at surface and near-bottom depths at each site for chlorophyll a (chl *a*) extraction. One 250-mL sample was collected for phytoplankton identification from the middle depth of each site, which was later composited with subsamples from surface and near-bottom chl *a* sample bottles from each site into a single integrated depth phytoplankton sample per site.

Additionally, we subsampled from surface and near-bottom chl *a* bottles for microcystin analysis. Microcystin is the most common toxin produced by cyanobacteria (blue-green algae). We used the ELISA QuantiPlate kit for Microcystin – High Sensitivity (Envirologix, Portland, ME), which serves as a useful screening tool if microcystin is present in the lake. The US EPA (2016) has suggested a threshold for primary contact in recreational waterbodies for microcystin of 4 µg/L (= 4 parts per billion [ppb]).

We also collected water samples, using near-surface grabs only, to measure *E. coli* concentrations. One sample was collected from each site in addition to a field duplicate sample each month. These 100-mL aliquots were analyzed via the IDEXX Colilert-18® method. Briefly, substrate powder was added to aliquots and incubated in Colilert Quanti-Tray®/2000 at 35°C for 18 hours, then trays were exposed to long-wave ultraviolet light and blue tray wells were counted as positive. The number of positive wells was the most probable number (MPN) per 100 mL. The Michigan water quality standard for total body contact limit for *E. coli* is 300 cfu/100 mL (Rippke 2019).

After returning to the lab, water from each lake site was gently inverted and subsampled for analysis of 1) phosphorus (P) as both soluble reactive phosphorus (SRP) and total phosphorus (TP); and 2) nitrogen (N) as nitrate (NO_3^-), ammonia (NH_3), and total Kjeldahl nitrogen (TKN) species. Duplicate water quality samples were collected once a month for quality control. Water for SRP and NO_3^- analyses was syringe-filtered through acid-washed 0.45-µm membrane nylon filters into scintillation vials; SRP was refrigerated at 4°C, and NO_3^- was frozen until analysis. TKN was acidified with sulfuric acid; TP and TKN were kept at 4°C until analysis. SRP, TP, NO_3^-, NH_3, and TKN were analyzed on a SEAL AQ2 discrete automated analyzer (USEPA 1993). Any values below detection were reported as ½ of their respective method detection limits.

Chl *a* was subsampled for phytoplankton analysis by gently inverting and removing 250 mL from surface and near-bottom samples and combining them with the 250 mL middle depth sample. These integrated depth phytoplankton samples were preserved with 7.5 mL of Lugol's iodine to create a 1% final solution. Phytoplankton taxa were later identified down to either genus or species level, and abundance was estimated via light microscopy as the respective sum of each species' biovolume present at each site on each sampling date.

For a historic comparison of water quality conditions between the current sampling year and recent years of monitoring by Restorative Lake Sciences, AWRI's 2022-2025 data were reformatted to match RLS's data summary methods based on their 2021 Bear Lake water quality report, using only lake sites 1 and 3. AWRI water quality depth profiles (measured at one meter intervals from surface to bottom) and nutrient data (near-surface and near-bottom) were averaged into single point values per site, and April 2025 and July 2025 data were compared to historic Spring and Summer data, respectively.

Water quality dashboards for TP, chl *a*, and Secchi depth were created using historic (Steinman and Ogdahl 2013) and current AWRI Bear Lake monitoring data in conjunction with historic RLS data (RLS 2022); they can be found as Appendix A. AWRI 2025 data are presented seasonally by separately averaging surface data into Spring (April and June), Summer (July and August), and Fall (October) seasons. Water quality goals for chl *a* and Secchi depth were established based on thresholds used in AWRI's annual Muskegon Lake water quality dashboard (www.gvsu.edu/wri/dashboard); the TP category's "Meeting Goal" threshold was created from the Bear Lake's TMDL goal of 30 µg/L and the "Desirable" threshold of 24 µg/L from the Muskegon Lake water quality dashboard.

Table 1. Bear Lake and storm drain outfall site coordinates and mean max depth across 2025 sampling events. NA = not applicable.

Site	Latitude (°N)	Longitude (°W)	Max Depth (m)	Avg Secchi (m)
Lake 1	43.24892	86.29028	7.7	0.9
Lake 2	43.25357	86.28699	3.6	0.9
Lake 3	43.25495	86.28429	3.7	0.9
Lake 4	43.26054	86.27348	2.7	0.9
Drain NMBL001	43.249344	86.295194	NA	NA
Drain NMBL004	43.245819	86.294140	NA	NA
Drain NMBL005A	43.249456	86.287879	NA	NA
Drain NMBL006	43.253949	86.276950	NA	NA
Drain LT1413D	43.260773	86.291435	NA	NA

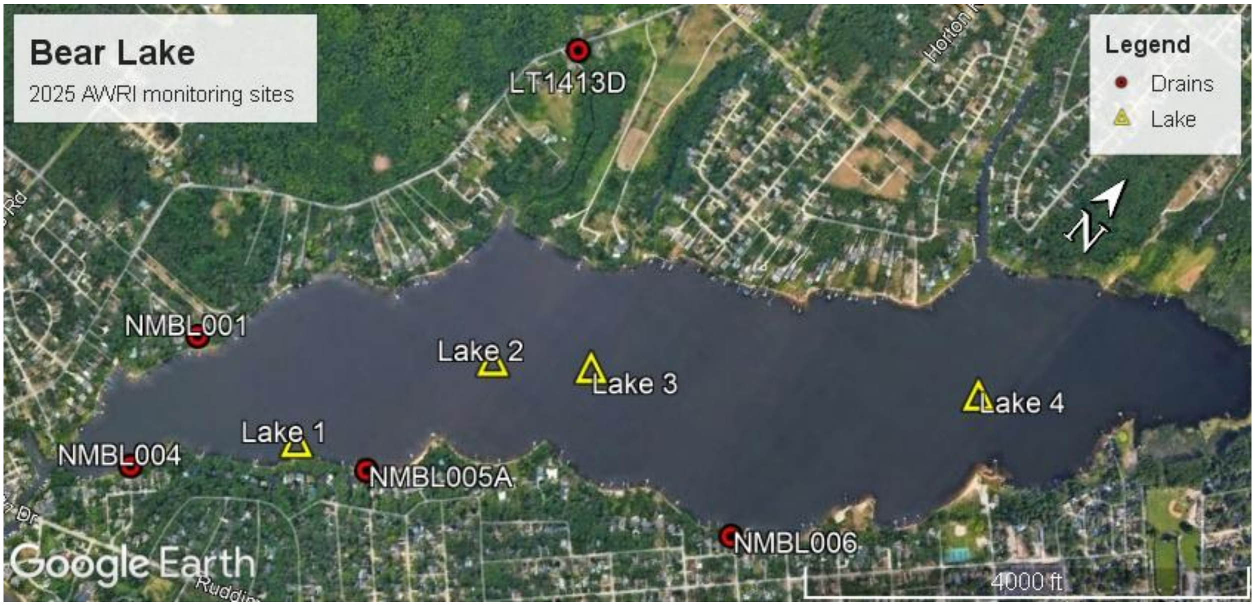


Figure 1. Map of Bear Lake water quality monitoring sites and storm drain outfall monitoring sites.

Storm Event Sampling

Stormwater outfall drains were identified using the Muskegon County GIS system website (https://maps.muskegoncountygis.com/) and five drains were selected based on geographic spread, site accessibility, and the sufficient elevation of outfall pipes such that there was no risk of outflowing drain water mixing with Bear Lake water. The selected drains are described in Table 1 and Figure 1. Drains were sampled during storm events on two dates: May 1 and September 3. Storms were defined as precipitation events accumulating ≥0.25 inches, preceded by 72 hours of dry weather. Water samples for general water quality parameters, nutrient chemistry, and *E. coli* were collected as close to outfall pipes as permitted by drain flow rates and drain animal exclusion bars; samples were analyzed as described above.

Results

2025 Lake Water Quality

Temperatures in Bear Lake varied seasonally, with lows of 9 – 10°C in April and highs of 25 – 27°C in July and August (Table 2, Figure 2). Through the entire sampling season, temperatures remained relatively homogenous throughout the lake, with no apparent differences between sites and minimal evidence of thermal stratification.

Table 2. Means (and standard deviations) of Bear Lake general water quality parameters averaged across sites (n=5). Temp = water temperature, DO = dissolved oxygen; SpCond = specific conductivity.

Month	Depth	Temp (°C)	DO (mg/L)	DO (%)	pH	SpCond (µS/cm)	Turbidity (FNU)	Secchi Depth (m)
Apr	Surface	9.7 (0.2)	11.5 (0.2)	101.7 (2.0)	8.4 (0.2)	358 (1)	4.0 (0.8)	0.9 (0.1)
	Middle	9.7 (0.3)	11.8 (0.2)	103.8 (1.3)	8.4 (0.1)	358 (1)	4.1 (0.3)	
	Bottom	9.4 (0.4)	11.6 (0.1)	101.5 (0.8)	8.3 (0.0)	359 (4)	5.1 (0.6)	
	Total	**9.6 (0.3)**	**11.6 (0.2)**	**102.3 (1.7)**	**8.4 (0.1)**	**359 (2)**	**4.4 (0.8)**	
Jun	Surface	20.4 (0.1)	7.9 (0.4)	88.1 (4.5)	8.4 (0.1)	383 (0)	5.6 (0.3)	1.1 (0.1)
	Middle	20.3 (0.1)	7.8 (0.6)	86.2 (6.3)	8.4 (0.1)	384 (0)	5.5 (0.3)	
	Bottom	19.8 (1.2)	6.1 (3.8)	67.1 (41.7)	8.2 (0.5)	385 (3)	5.6 (1.1)	
	Total	**20.2 (0.7)**	**7.3 (2.2)**	**80.4 (24.3)**	**8.3 (0.3)**	**384 (2)**	**5.6 (0.6)**	
Jul	Surface	26.8 (0.1)	7.2 (0.5)	89.9 (6.0)	8.3 (0.1)	388 (1)	6.3 (0.2)	1.0 (0.1)
	Middle	26.8 (0.2)	6.9 (0.8)	86.1 (9.6)	8.3 (0.1)	388 (0)	6.3 (0.4)	
	Bottom	26.0 (1.2)	5.3 (3.3)	65.7 (41.2)	8.0 (0.5)	398 (14)	10.4 (8.2)	
	Total	**26.5 (0.7)**	**6.4 (2.0)**	**80.6 (24.9)**	**8.2 (0.3)**	**391 (9)**	**7.7 (4.8)**	
Aug	Surface	26.8 (0.2)	9.1 (0.4)	114.1 (4.8)	8.9 (0.1)	387 (2)	5.6 (0.2)	1.0 (0.1)
	Middle	26.6 (0.2)	7.5 (2.6)	93.4 (32.6)	8.6 (0.4)	390 (2)	6.5 (1.1)	
	Bottom	26.2 (0.2)	4.7 (3.2)	58.7 (40.1)	8.2 (0.5)	394 (5)	8.2 (2.2)	
	Total	**26.5 (0.3)**	**7.1 (2.9)**	**88.7 (36.1)**	**8.6 (0.4)**	**390 (4)**	**6.7 (1.7)**	
Oct	Surface	21.2 (0.1)	8.4 (0.1)	94.8 (1.3)	8.4 (0.0)	434 (1)	5.2 (0.3)	0.8 (0.0)
	Middle	21.2 (0.1)	8.2 (0.2)	92.3 (2.1)	8.4 (0.0)	434 (1)	5.4 (0.5)	
	Bottom	21.2 (0.2)	8.1 (0.2)	91.5 (2.1)	8.4 (0.0)	434 (1)	5.5 (0.9)	
	Total	**21.2 (0.1)**	**8.2 (0.2)**	**92.9 (2.2)**	**8.4 (0.0)**	**434 (1)**	**5.4 (0.6)**	

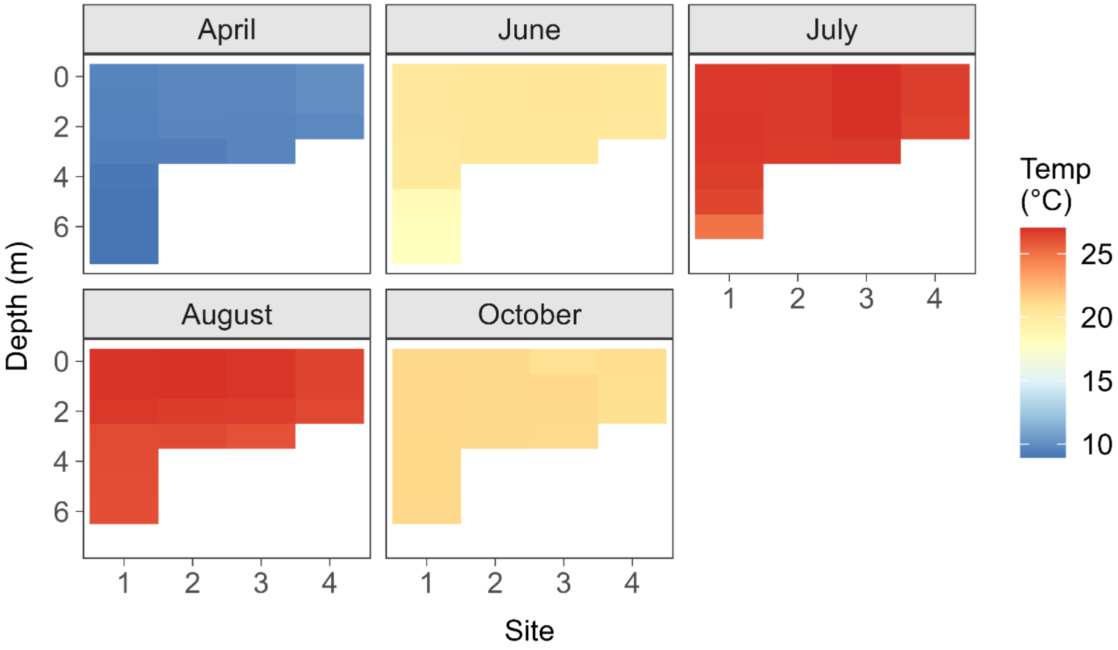


Figure 2. Bear Lake temperature profiles (°C) sampled April – October 2025.

Dissolved oxygen (DO) in Bear Lake was highest in April, with a concentration of approximately 11.6 mg/L across all sites and depths (Table 2,

Figure 3). In the summer months, DO concentrations dropped dramatically in the deepest part of the lake (Site 1), producing hypoxic conditions (<2 mg/L) in June and July. In these months, DO concentrations in near-surface waters displayed a slight gradient along the length of the lake, with marginally higher DO near the mouth of Bear Creek (Site 4) and lower DO nearer to the deep site and the channel to Muskegon Lake (Site 1). DO increased slightly in August, and by October the lake was once again well mixed, with a relatively healthy average concentration of 8.2 mg/L throughout.

Changes in pH tracked closely with changes in dissolved oxygen, with lower pH values co-occurring with lower concentrations of DO (Figure 4). Overall, pH values in Bear Lake were alkaline, ranging from 7.3 – 8.9. pH was highest in near-surface waters in August, with an average value of 8.9 (Table 2), likely due to high photosynthetic activity as the algae absorb carbon dioxide resulting in higher pH values.

Specific conductivity increased over the course of the sampling period, with a mean value of 359 µS/cm in April, means of 384 – 391 µS/cm in July through August, and a mean of 434 µS/cm in October (Table 2, Figure 5). For all months, conductivity was fairly uniform across sites and depths.

Turbidity was lowest in April (i.e., clearer water) and highest in July and August; in particular, turbidity was elevated in the deepest part of the lake (Site 1) in the month of August (Figure 6). Water clarity measured as Secchi depth was greatest in June, then decreased over the remainder of the sampling season (Figure 7).

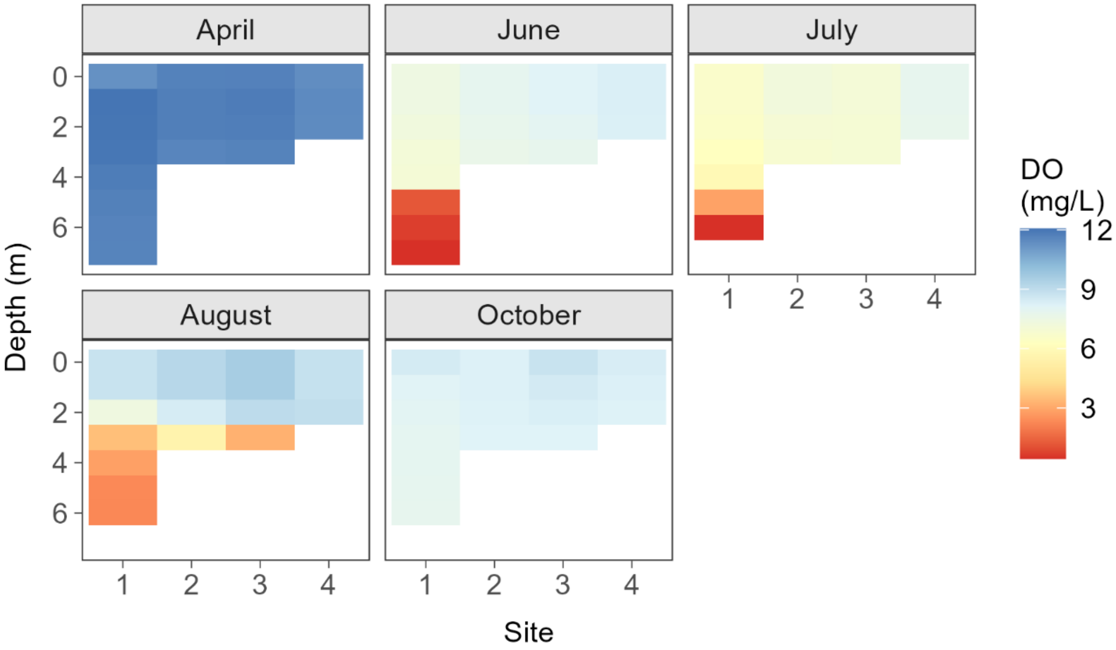


Figure 3. Bear Lake DO concentrations sampled April – October 2025.

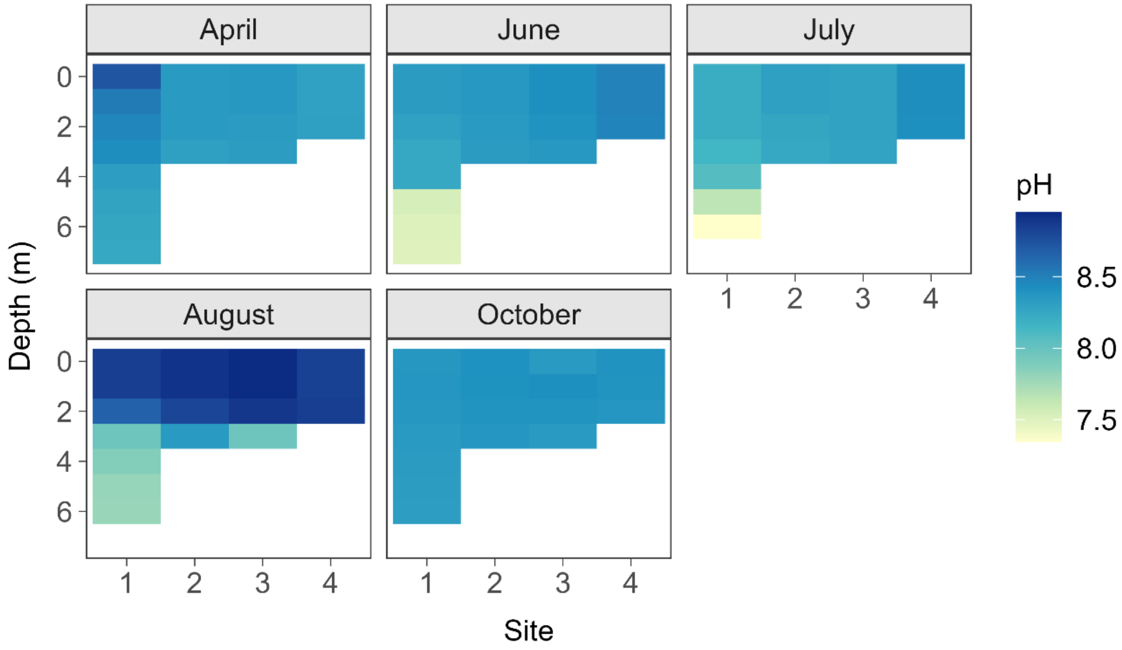


Figure 4. Bear Lake pH sampled April – October 2025.

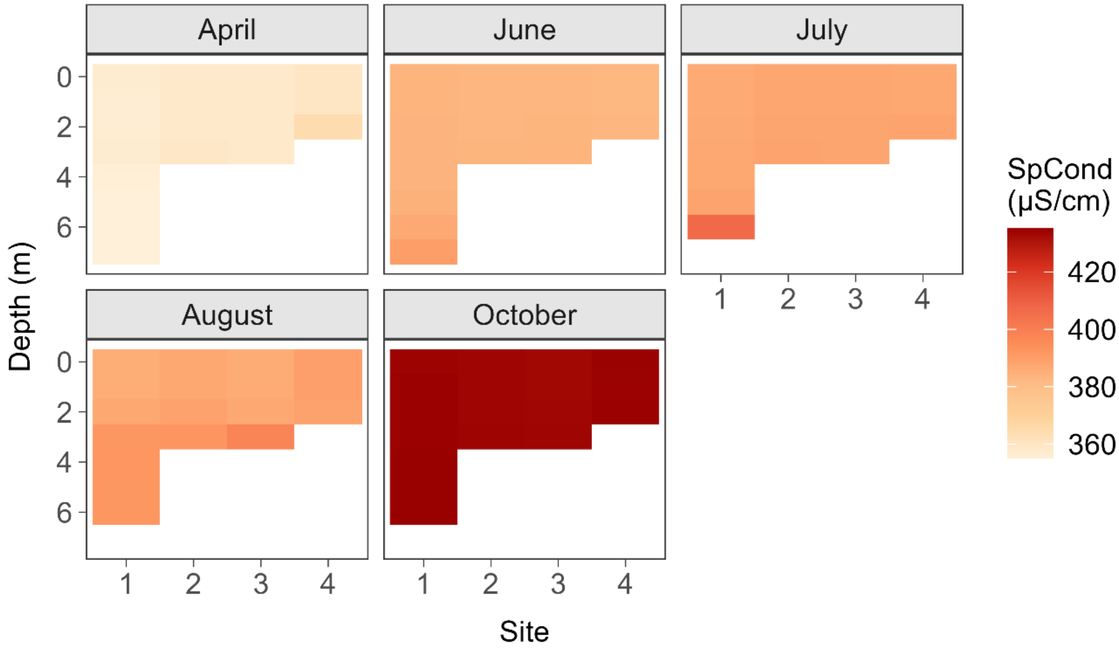


Figure 5. Bear Lake specific conductivity sampled April – October 2025.

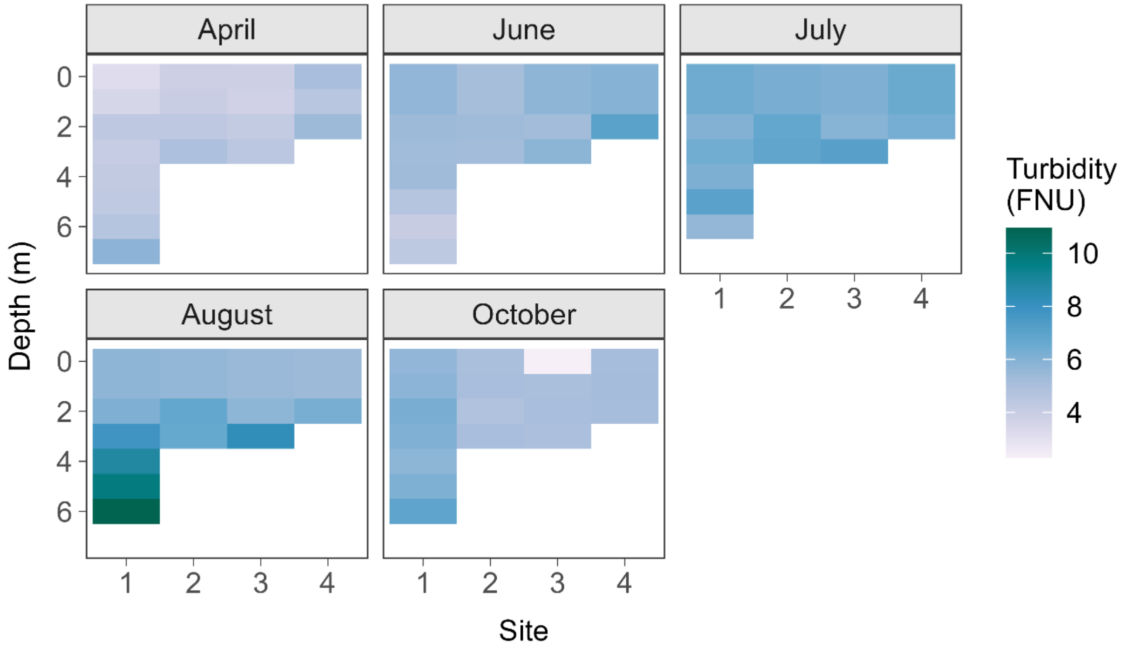


Figure 6. Bear Lake turbidity sampled April – October 2025. Higher values indicate cloudier water.

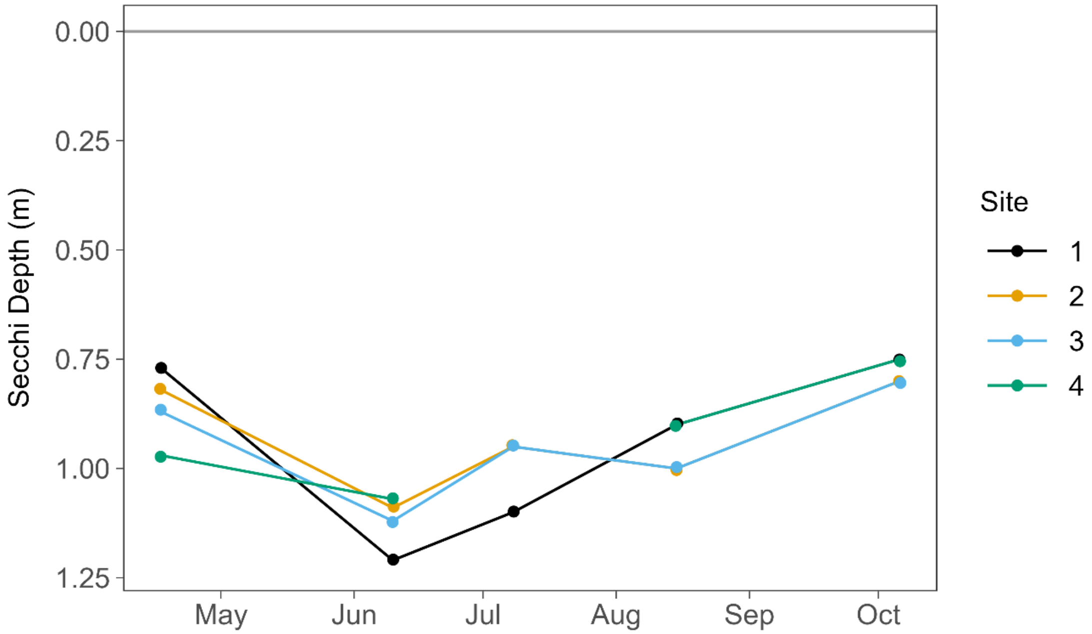


Figure 7. Bear Lake Secchi depth sampled April – October 2025. Note the reversed y-axis; the greater (deeper) the Secchi depth, the greater the water clarity. Values at some sites overlap.

2025 Lake Nutrients

Total phosphorus (TP) concentrations were generally comparable across sites and depths and tended to increase from April (lake-wide mean: 21 µg/L) to October (58 µg/L) (Table 3; Figure 8). TP concentrations reached their highest in the deepest portion of the lake in July at 114 µg/L. The mean surface TP concentration across the entire sampling season was 39 µg/L, with an annual mean of 48 µg/L in bottom waters; these values are in excess of the 30 µg/L target threshold set forth by the TMDL (DEQ 2008). The slightly higher bottom TP concentrations compared to the surface are suggestive of internal phosphorus loading, especially at the deeper sites, where low DO concentrations are more prevalent. However, if internal loading is occurring in Bear Lake, it is in very modest amounts compared to other local lakes, where bottom TP concentrations often reach 400 to 1,000 µg/L (Steinman and Ogdahl 2008, 2011; Steinman et al. 2009).

Soluble reactive phosphorus (SRP) was near or below the lower limit of detection for nearly all samples, with the exception of the deep hole in July, where SRP spiked concomitantly with TP to a maximum concentration of 30 µg/L (Figure 9). The low SRP concentrations can be deceptive as the reason they are below detection may be due to very rapid uptake by the algae, not because of low ambient concentrations in the water column.

Table 3. Means (SD) of Bear Lake total phosphorus (TP), soluble reactive phosphorus (SRP), nitrate (NO_3^-), ammonia (NH_3), and total Kjeldahl nitrogen (TKN). BD = below detection.

Date	Depth	TP µg/L	SRP µg/L	NO_3^- mg/L	NH_3 mg/L	TKN mg/L
April	Surface	19 (3)	BD	0.193 (0.005)	0.018 (0.001)	0.81 (0.13)
	Bottom	22 (3)	BD	0.216 (0.032)	0.018 (0.004)	0.68 (0.09)
June	Surface	39 (5)	BD	0.036 (0.009)	0.049 (0.012)	0.83 (0.07)
	Bottom	40 (5)	BD	0.037 (0.002)	0.130 (0.155)	1.03 (0.10)
July	Surface	48 (4)	BD	0.076 (0.007)	BD	0.60 (0.02)
	Bottom	66 (32)	11 (13)	0.098 (0.032)	0.244 (0.463)	0.76 (0.39)
August	Surface	37 (11)	BD	0.052 (0.009)	BD	0.90 (0.14)
	Bottom	47 (15)	BD	0.055 (0.004)	BD	1.05 (0.19)
October	Surface	53 (12)	BD	0.056 (0.015)	BD	1.00 (0.06)
	Bottom	64 (6)	BD	0.053 (0.016)	BD	1.08 (0.08)

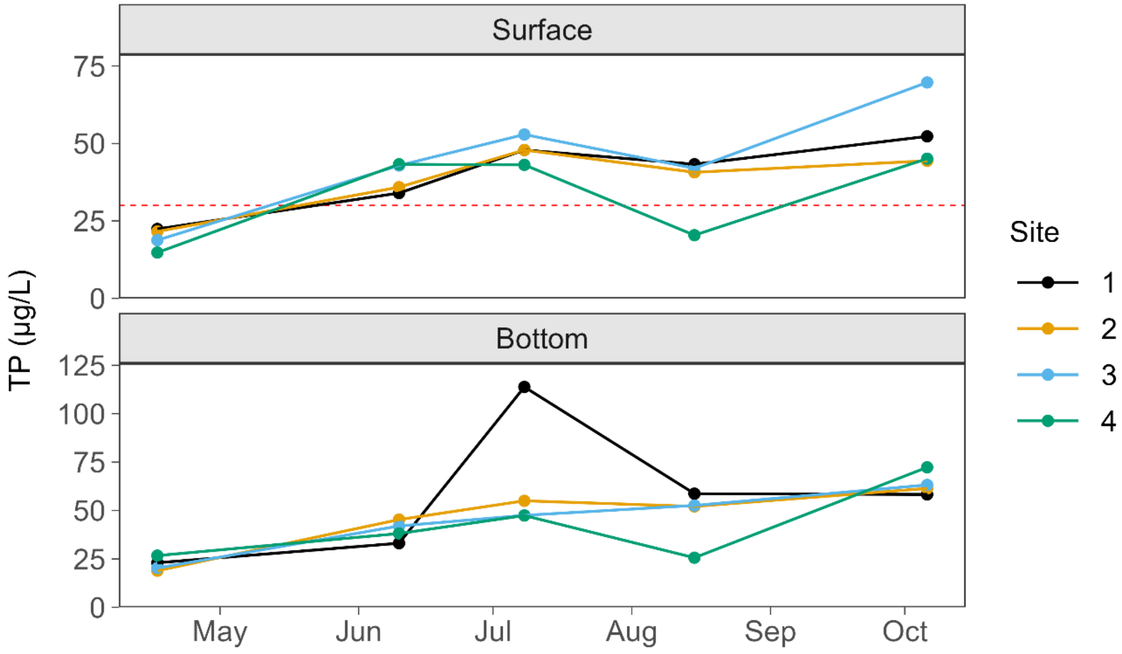


Figure 8. Bear Lake total phosphorus (TP) concentrations sampled April – October 2025 at near-surface and near-bottom depths. Red line on surface panel depicts 30 µg/L TMDL for Bear Lake. Note difference in y-axis scales.

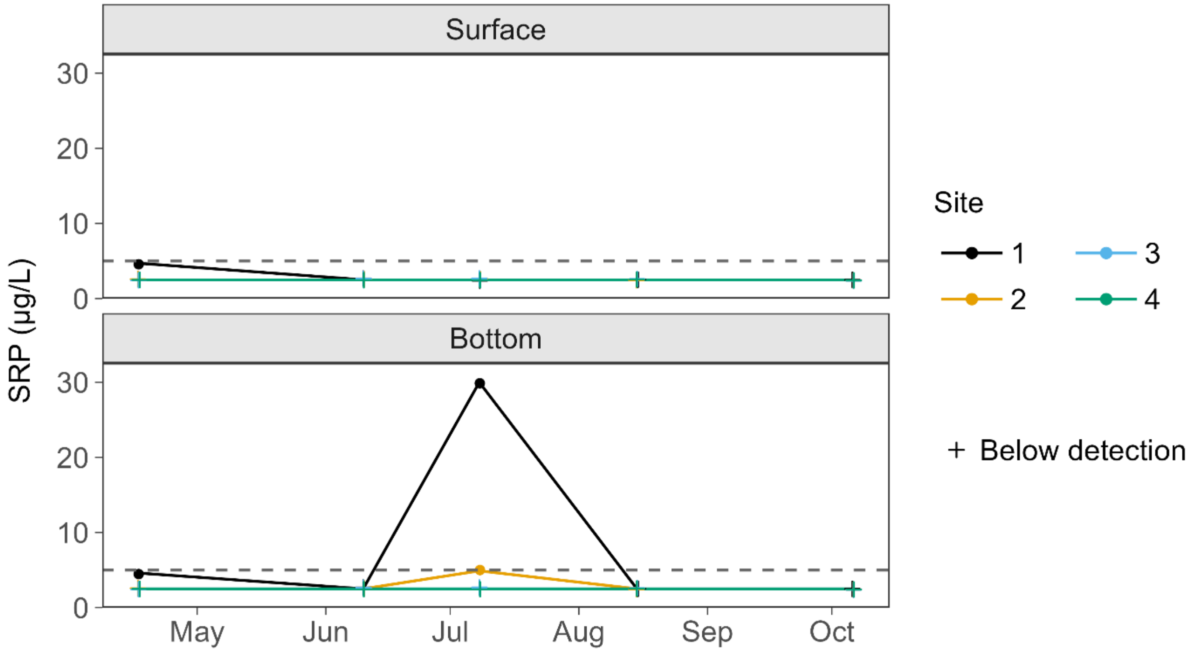


Figure 9. Bear Lake soluble reactive phosphorus (SRP) concentrations sampled April – October 2025 at near-surface and near-bottom depths. The horizontal dashed line shows the analytical lower limit of detection; points below this line (marked with a +) did not contain measurable concentrations of SRP.

Nitrate concentrations were very similar at all sites (Figure 10). Levels were highest in April, with a lake-wide mean concentration of 0.204 mg/L, before dropping and remaining below an average of 0.1 mg/L for the remainder of the sampling season (Table 3, Figure 10). Bottom nitrate concentrations in the deep hole were slightly elevated in July, though still lower than the lake-wide level from April.

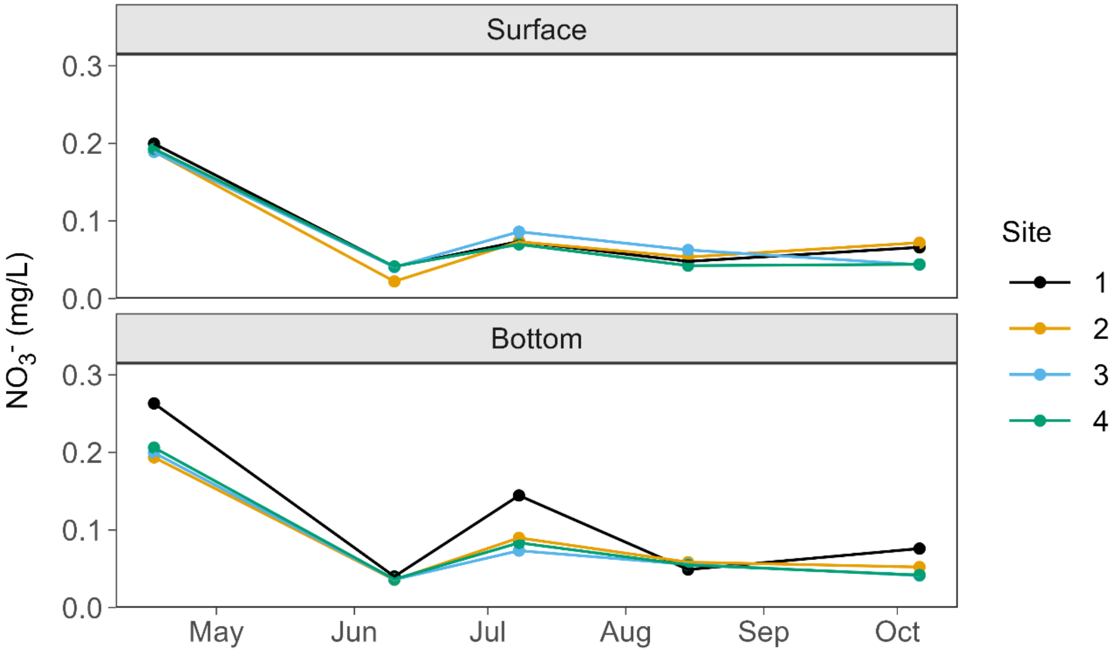


Figure 10. Bear Lake nitrate (NO_3^-) concentrations sampled April – October 2025 at near-surface and near-bottom depths.

Ammonia (NH_3) concentrations were higher in the earlier half of the sampling season; for all sites and depths except for the deep hole, levels peaked in June at no greater than 0.070 mg/L before dropping below detection for the remainder of the season (Table 3, Figure 11). In contrast, NH_3 levels in the deep hole (Site 1) continued to rise through June into July, reaching a maximum concentration of 0.938 mg/L - over an order of magnitude higher than any other measured concentration in the lake. However, by August NH_3 concentrations in the deep hole had also dropped below detection. Spikes of this order may be related to animal excretion or an episodic release of ammonia from the sediment; regardless, it does not appear to be a constant problem.

Total Kjeldahl nitrogen (TKN) concentrations, reflecting the combination of ammonia and organic nitrogen, were comparable across sites and depths with mean values ranging from 0.60 – 1.08 mg/L (Table 3, Figure 12). Concentrations dipped in July across all sites except the deep hole, where TKN instead increased somewhat (reflecting the ammonia spike); by October, levels were once again homogenous across the entire lake.

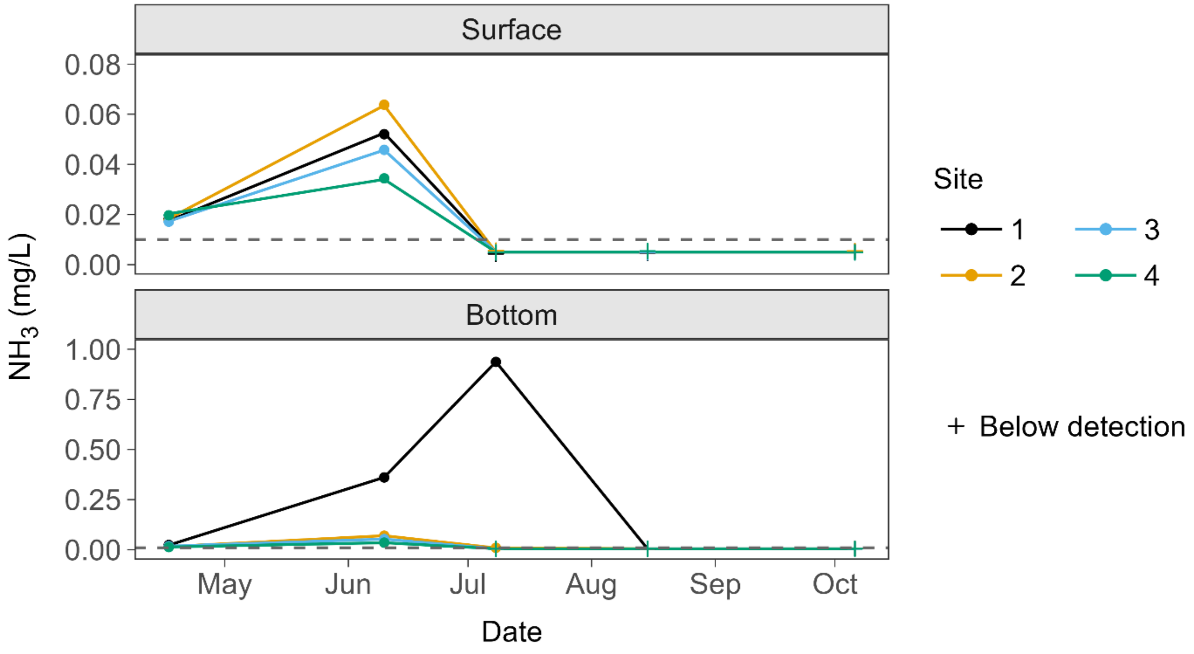


Figure 11. Bear Lake ammonia (NH_3) concentrations sampled April – October 2025 at near- and near-bottom depths. The horizontal dashed line shows the analytical lower limit of detection; points below this line are denoted with a +.

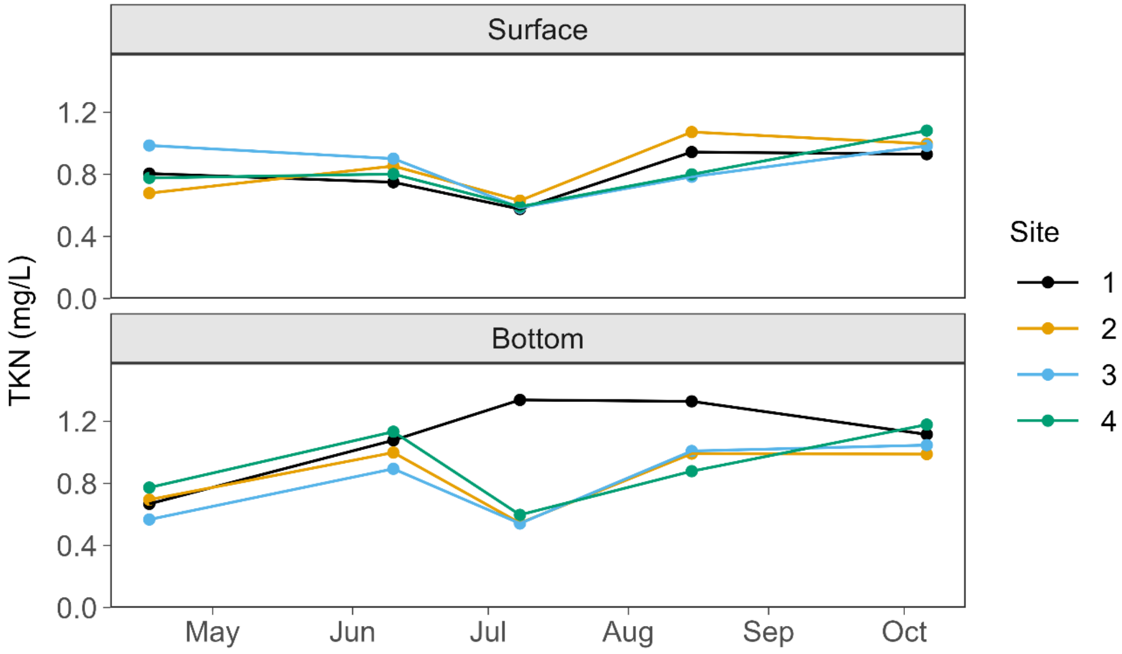


Figure 12. Bear Lake total Kjeldahl nitrogen (TKN) concentrations sampled April – October 2025 at near-surface and near-bottom depths.

2025 Lake Biological Parameters

Chlorophyll *a* (chl *a*) concentrations in Bear Lake tended to increase over the course of the sampling season from a lake-wide mean of 16.5 µg/L in April to 44.2 µg/L in October (Table 4; Figure 13). Nearly all samples had chl *a* concentrations higher than the 10 µg/L restoration target for Muskegon Lake (EGLE 2024).

Table 4. Means (SD) of Bear Lake biological parameters of water quality. Chl = chlorophyll. BD = below detection. BQ = Below quantification. NA = not applicable, as *E. coli* samples were not collected at bottom depth.

Month	Depth	Chl *a* (µg/L)	Microcystin (µg/L)	*E. coli* (cfu/100 mL)
April	Surface	16.2 (1.68)	BD	BD
	Bottom	16.9 (2.76)	BD	NA
June	Surface	15.3 (1.03)	BD	BD
	Bottom	11.4 (3.91)	BD	NA
July	Surface	27.2 (4.28)	0.46 (0.18)	3.6 (1.9)
	Bottom	23 (4.43)	0.19 (0.04)	NA
August	Surface	32.5 (4.86)	BQ	2.5 (1.3)
	Bottom	40.5 (12.7)	BQ	NA
October	Surface	43.2 (2.75)	0.23 (0.06)	2.2 (1.3)
	Bottom	45.2 (1.19)	0.40 (0.35)	NA

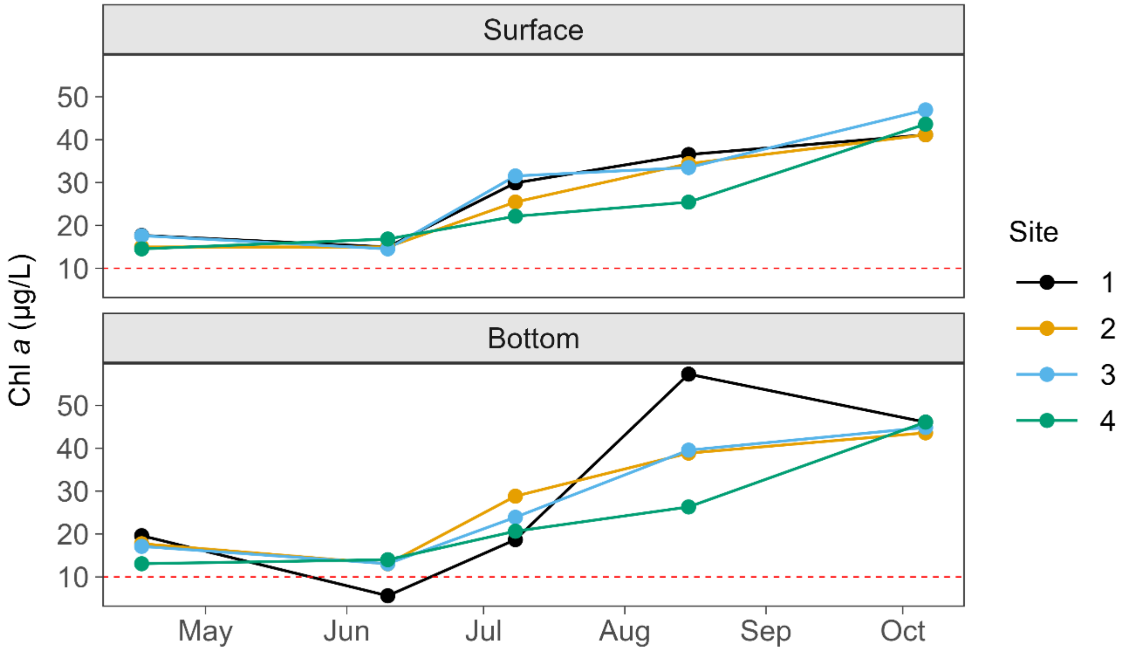


Figure 13. Bear Lake chlorophyll *a* concentrations sampled April – October 2025 at near-surface and near-bottom depths. Red line refers to restoration target of 10 µg/L for Muskegon Lake.

Microcystin levels spiked twice over the course of the sampling season, in July and October (Figure 14). However, even at their highest concentrations, they remained well below the US EPA's recreational advisory threshold of 4 µg/L (USEPA 2016) (Table 4; Figure 14). In July, surface concentrations reached a maximum value of 0.69 µg/L, while bottom water concentrations rose to near or slightly above the quantification limit of 0.15 µg/L. In October, surface water concentrations rose an average of 0.23 µg/L, while bottom concentrations averaged 0.40 µg/L and reached 0.85 µg/L at the deep site.

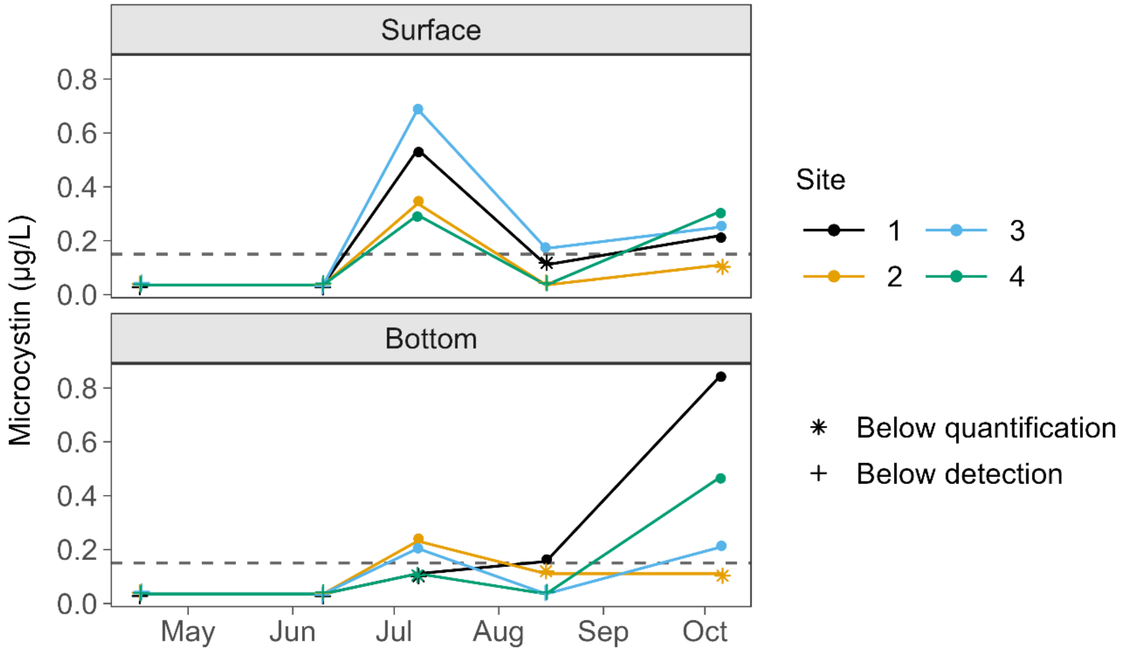


Figure 14. Bear Lake microcystin concentrations sampled April – October 2025 at near-surface and near-bottom depths. The horizontal dashed line shows the analytical lower limit of quantification. Samples with detectable levels of microcystin below this threshold are marked with a *; samples below the limit of detection are marked with a +.

E. coli in surface waters was detected more frequently in the latter part of the sampling season, though levels across all months remained far below the statewide total maximum daily limit (TMDL) for total body contact recreation of 300 cfu/100 mL (Rippke 2019; Table 4, Figure 15). In April and June, *E. coli* was detectable at only one of four sites; in July and August it was detected at three of four sites; and in October it was detected at all four sites.

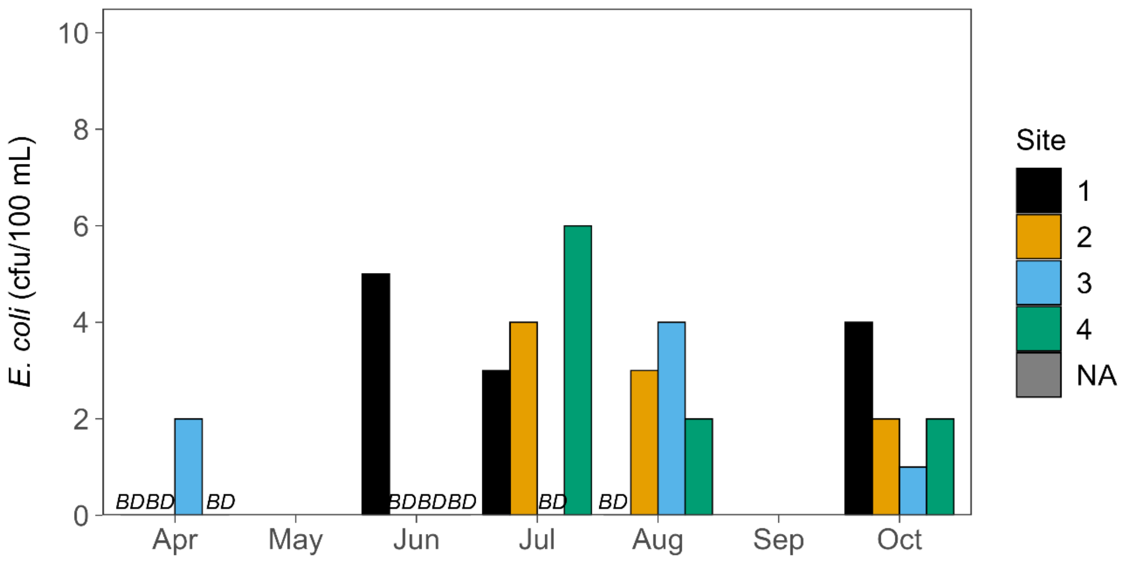


Figure 15. Bear Lake *E. coli* concentrations sampled April – October 2025 at the lake surface. BD = below detection.

Historical Bear Lake Water Quality

Baseline monitoring is critical to determine trends, but sampling on just one date per month can lead to unrepresentative results, so it is important to look at overall trends, not individual years. In addition, given the different analytical methodologies used by RLS and AWRI, comparisons between those two groupings of years should be done with caution. Ideally, an intercalibration study having both labs test the same water sample for multiple analytes would be conducted to assess inter-lab differences but that was not done in this case. Consequently, examining changes over time **within** each grouping (i.e., within 2017-2021 and within 2022-2025) provides the more accurate assessment. Comparisons over the entire period of record (i.e. 2017-2025) are made with caveats given the above limitation. Water quality parameters from spring and summer are summarized in Table 5 and 6 and Figure 16 – 22.

DO concentrations and specific conductivity measurements have remained stable over the past four years (Figure 16, Figure 17). Summer DO concentrations continue to be affected by hypoxic or near-hypoxic conditions in the deepest part of the lake. As in previous years, the lower mean DO concentrations observed in summer are driven largely by Site 1, which continues to experience hypoxic or near-hypoxic conditions.

Spring TP concentrations appear to trend downwards, with 2023 – 2025 measuring below the 30 µg/L TMDL (Figure 18). However, this may only reflect an earlier start to the sampling season, as measurements in 2024 and 2025 began in April rather than May. The TP concentration in 2025 reflects a continuation of the decline observed in 2024, following the anomalous spike in 2023; nonetheless the TP concentrations are still well above the desired threshold. Spring SRP concentrations have remained near or below detection for several years, and summer 2025 SRP concentrations mimic the pattern observed for summer TP levels: declines from the spike in 2023 but higher than desired (Figure 19).

For TKN, there were no noticeable trends over time in the spring while summer TKN levels have shown a steady decline over the past three years (Figure 20). Chlorophyll *a* concentrations in the spring appear to have decreased since 2023, though as with TP, this may reflect an earlier start to the sampling season (Figure 21). Regardless, they are higher than what was measured between 2017 and 2021. Mean summer chlorophyll concentrations were higher in 2025 than in the previous three years, all of which saw levels higher than the restoration target of 10 µg/L in neighboring Muskegon Lake (EGLE 2024). Secchi depths in both spring and summer of 2025 were shallower than in the previous three years, consistent with the higher chlorophyll levels (Figure 22).

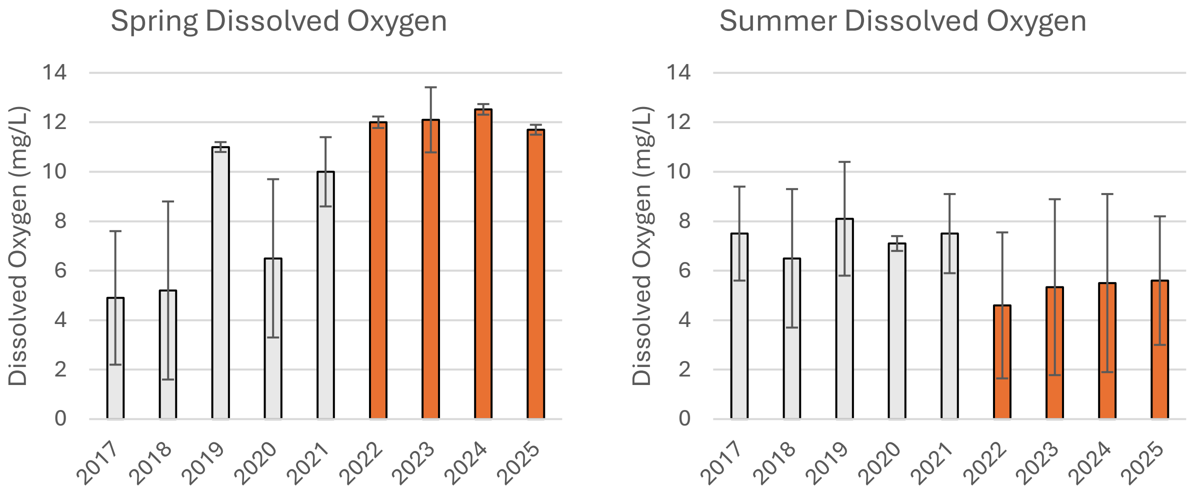
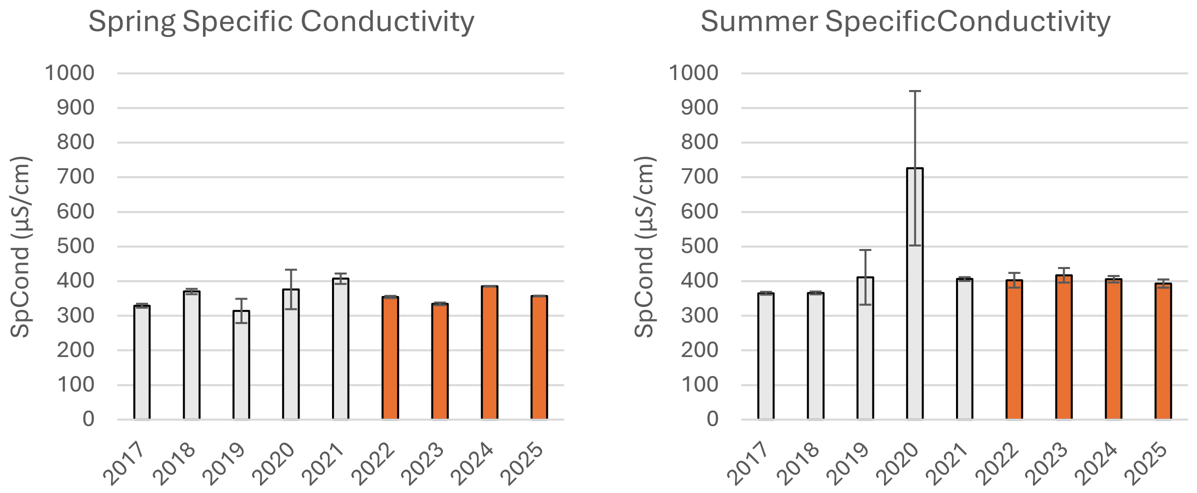


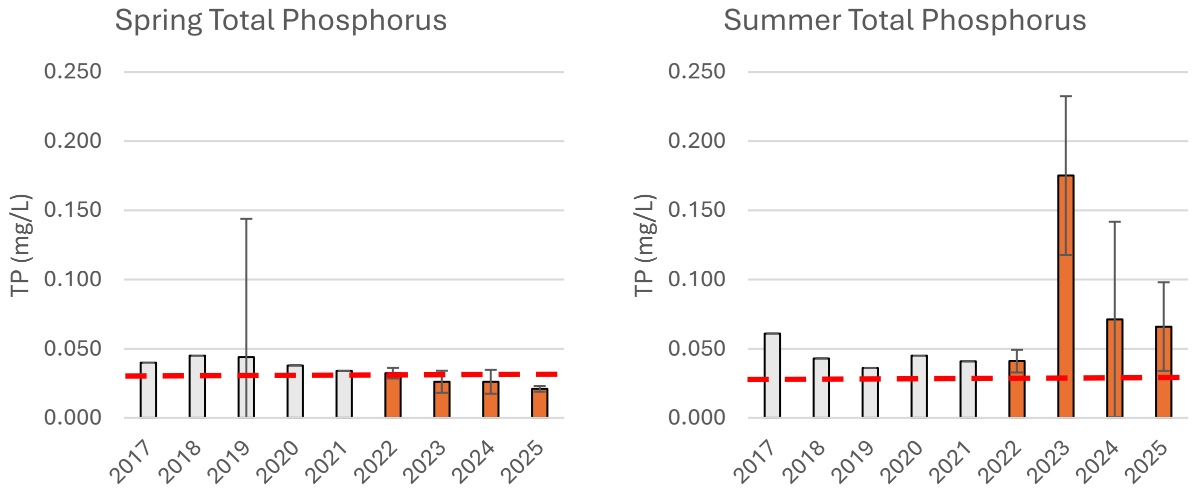
Figure 16. Lake grand mean (±SD) DO across water column depths at the sites 1 and 3 during April/May (left panel) and July (right panel) of each sampling year. Data: 2017-2021 (RLS); 2022-2025 (AWRI).



Spring Specific Conductivity

Summer SpecificConductivity

Figure 17. Lake grand mean (±SD) specific conductivity across water column depths at sites 1 and 3 during April/May (left panel) and July (right panel) of each sampling year. Data: 2017-2021 (RLS); 2022-2025 (AWRI, in orange).



Spring Total Phosphorus

Summer Total Phosphorus

Figure 18. Lake grand mean (±SD) total phosphorus (TP) concentrations across water column depths at sites 1 and 3 during April/May (left panel) and July (right panel) of each sampling year. Red dashed lines indicate Bear Lake's TMDL for TP: 0.030 mg/L. Data: 2017-2021 (RLS); 2022-2025 (AWRI, in orange).

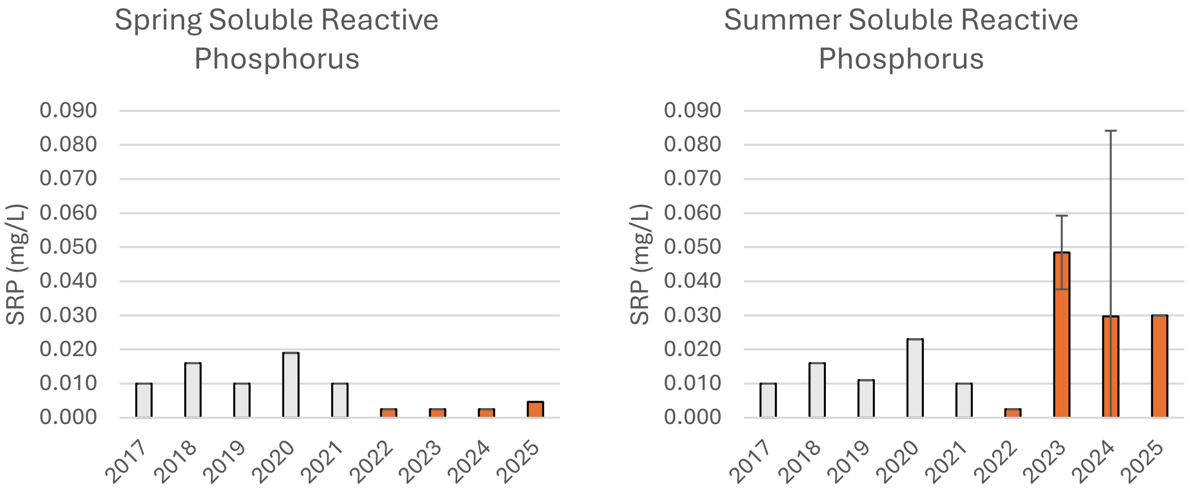


Figure 19. Lake grand mean (±SD) soluble reactive phosphorus (SRP) concentrations across water column depths at sites 1 and 3 during April/May (left panel) and July (right panel) of each sampling year. Data: 2017-2021 (RLS); 2022-2025 (AWRI, in orange).

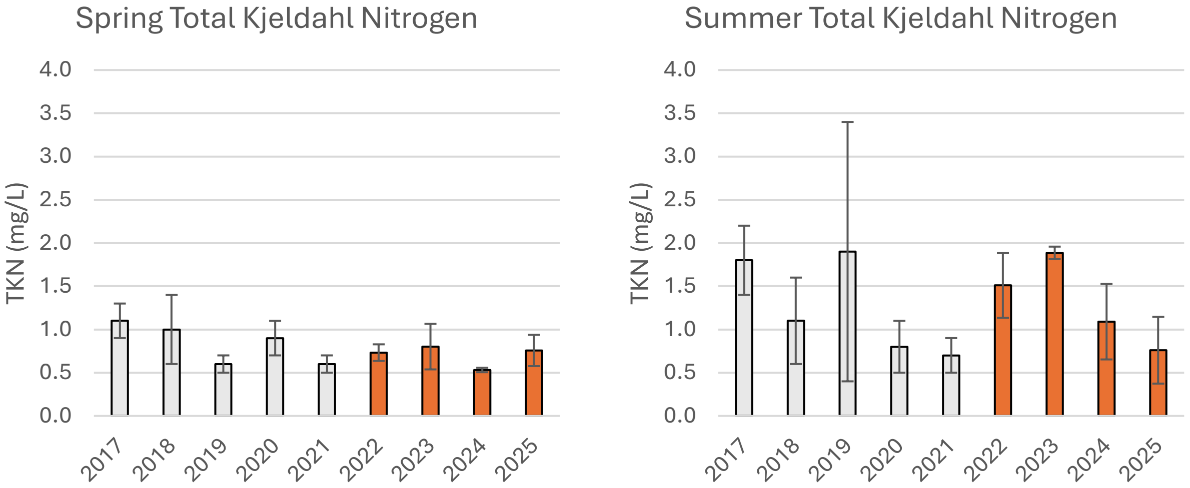
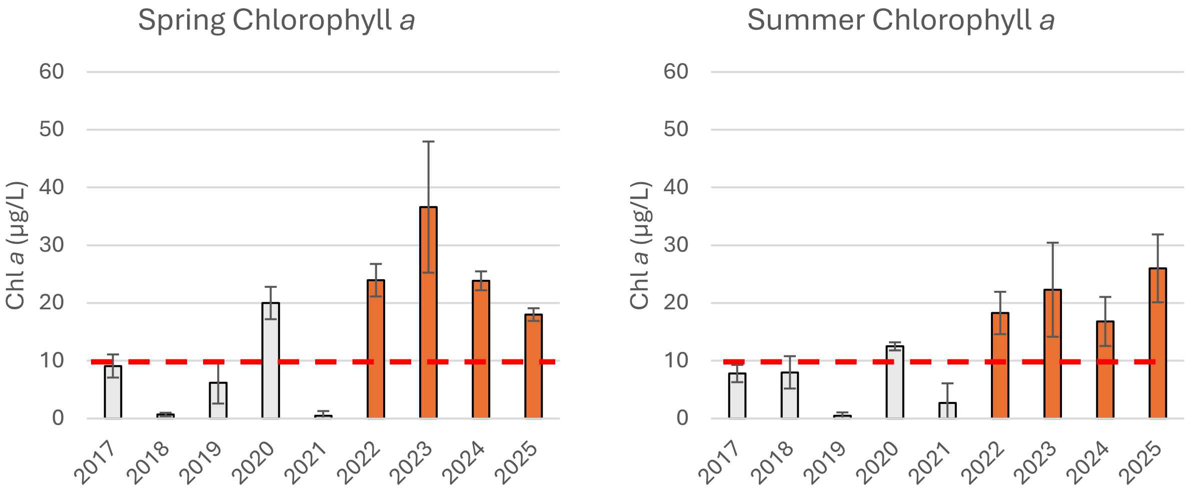
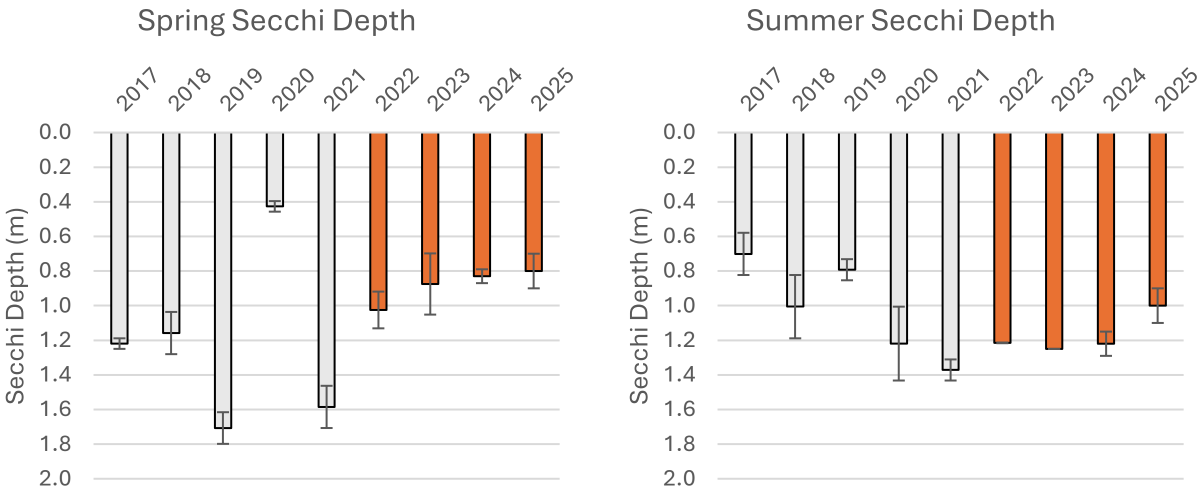


Figure 20. Lake grand mean (±SD) total Kjeldahl nitrogen concentrations across water column depths at sites 1 and 3 during April/May (left panel) and July (right panel) of each sampling year. Data: 2017-2021 (RLS); 2022-2025 (AWRI, in orange).


Spring Chlorophyll *a*

Summer Chlorophyll *a*

Figure 21. Lake grand mean (±SD) chlorophyll *a* concentrations across water column depths at sites 1 and 3 during April/May (left panel) and July (right panel) of each sampling year. Red dashed lines indicate Muskegon Lake's restoration goal for chl *a*: 10 µg/L. Data: 2017-2021 (RLS); 2022-2025 (AWRI, in orange).


Spring Secchi Depth

Summer Secchi Depth

Figure 22. Lake grand mean (±SD) Secchi depth across water column depths at sites 1 and 3 during April/May (left panel) and July (right panel) of each sampling year. Note that the y-axes are inverted so that data indicate the depth from the lake's surface. Red dashed lines indicate Muskegon Lake's restoration goal for Secchi depth: 2 m (~6.5 ft). Data: 2017-2021 (RLS); 2022-2025 (AWRI, in orange).

Table 5. Long-term trends of Bear Lake deep basin mean (±SD) spring water quality parameters. Shaded data analyzed by RLS; unshaded data analyzed by AWRI.

Year	DO (mg/L)	pH	SpCond (µS/cm)	TP (mg/L)	SRP (mg/L)	TKN (mg/L)	Chl *a* (µg/L)	Secchi Depth (m)
2017	4.9 (2.7)	8.2 (0.1)	329 (6)	0.04 (0)	0.010 (0)	1.1 (0.2)	9.1 (2)	1.2 (0)
2018	5.2 (3.6)	7.9 (0.4)	370 (8)	0.045 (0)	0.016 (0)	1.0 (0.4)	0.7 (0.3)	1.2 (0.1)
2019	11 (0.2)	8.2 (0.1)	314 (35)	0.044 (0.1)	0.010 (0)	0.6 (0.1)	6.2 (3.6)	1.7 (0.1)
2020	6.5 (3.2)	8.4 (0)	376 (57)	0.038 (0)	0.019 (0)	0.9 (0.2)	20.0 (2.8)	0.4 (0)
2021	10 (1.4)	8.4 (0.2)	407 (15)	0.034 (0)	0.010 (0)	0.6 (0.1)	0.5 (0.8)	1.6 (0.1)
2022	12.0 (0.2)	8.7 (0.1)	354 (3)	0.032 (0)	BD	0.7 (0.1)	24.0 (2.8)	1.0 (0.1)
2023	12.1 (1.3)	8.5 (0.4)	334 (4)	0.026 (0)	BD	0.8 (0.3)	36.6 (11.4)	0.9 (0.2)
2024	12.5 (0.2)	8.7 (0.1)	385 (1)	0.026 (0)	BD	0.5 (0)	23.8 (1.6)	0.8 (0)
2025	11.7 (0.2)	8.4 (0.2)	357 (1)	0.021 (0)	BD	0.8 (0.2)	18.0 (1.1)	0.8 (0.1)

Table 6. Long-term trends of Bear Lake deep basin mean (±SD) summer water quality parameters. Shaded data analyzed by RLS; unshaded data analyzed by AWRI.

Year	DO (mg/L)	pH	SpCond (µS/cm)	TP (mg/L)	SRP (mg/L)	TKN (mg/L)	Chl *a* (µg/L)	Secchi Depth (m)
2017	7.5 (1.9)	8.4 (0.4)	365 (4)	0.061 (0)	0.01 (0)	1.8 (0.4)	7.8 (1.5)	0.7 (0.1)
2018	6.5 (2.8)	8.2 (0.3)	366 (4)	0.043 (0)	0.016 (0)	1.1 (0.5)	8 (2.8)	1 (0.2)
2019	8.1 (2.3)	8.1 (0.1)	411 (79)	0.036 (0)	0.011 (0)	1.9 (1.5)	0.5 (0.6)	0.8 (0.1)
2020	7.1 (0.3)	8.2 (0.1)	726 (223)	0.045 (0)	0.023 (0)	0.8 (0.3)	12.5 (0.7)	1.2 (0.2)
2021	7.5 (1.6)	8.2 (0.3)	406 (6)	0.041 (0)	0.010 (0)	0.7 (0.2)	2.7 (3.4)	1.4 (0.1)
2022	4.6 (3.0)	7.9 (0.3)	403 (21)	0.041 (0)	0.003 (0)	1.5 (0.4)	18.3 (3.7)	1.2 (0)
2023	5.3 (3.6)	8 (0.4)	417 (21)	0.175 (0.1)	0.048 (0.01)	1.9 (0.1)	22.3 (8.1)	1.3 (0)
2024	5.5 (3.6)	7.9 (0.4)	406 (9)	0.071 (0.1)	0.030 (0.05)	1.1 (0.4)	16.8 (4.2)	1.2 (0.1)
2025	5.6 (2.6)	8.1 (0.4)	393 (12)	0.066 (0)	0.030 (0)	0.8 (0.4)	26.0 (5.9)	1.0 (0.1)

Storm Event Sampling

After significant rain events, water quality parameters were measured at the outflow of five different storm drains before they flowed into Bear Lake. pH measurements from the storm drains ranged from 7.0 – 7.8 and were all less alkaline than the lake-wide mean surface pH of 8.5 (Figure 23). Specific conductivity values in storm drain effluent were in most cases lower than in the lake surface mean, except for the LT1413D drain in September, where conductivity was 457 µS/cm (Figure 24). For both May and September, the drains on the northwest side of the lake (LT1413D and NMBL001; Figure 1) had higher specific conductivity values than those on the southeast side of the lake.

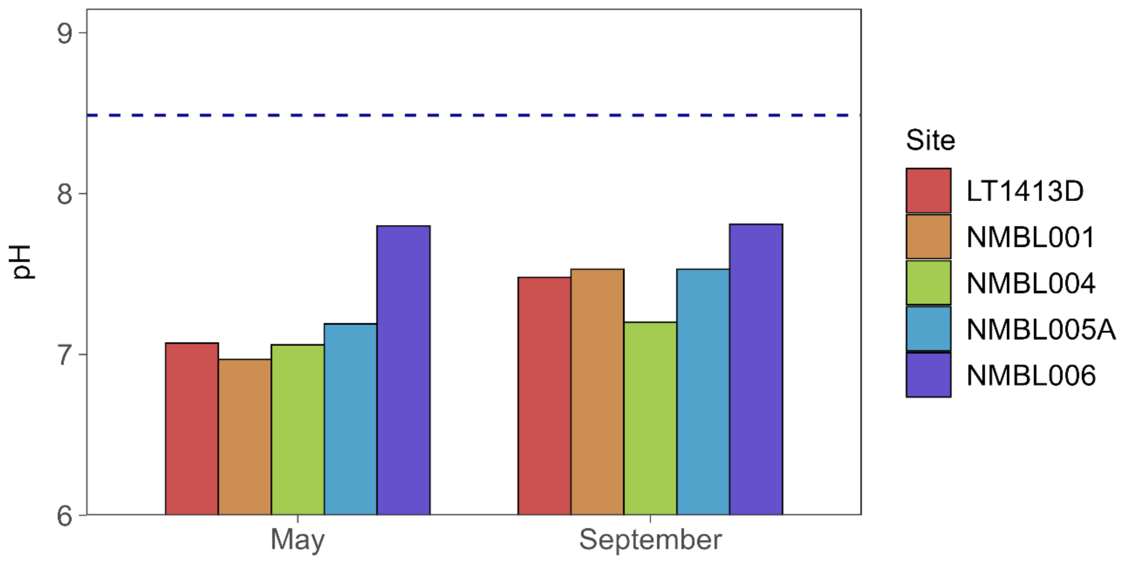


Figure 23. pH measured in storm drain effluent flowing into Bear Lake during two separate rain events. Dashed line represents the surface mean pH in Bear Lake across all sites and sampling events.

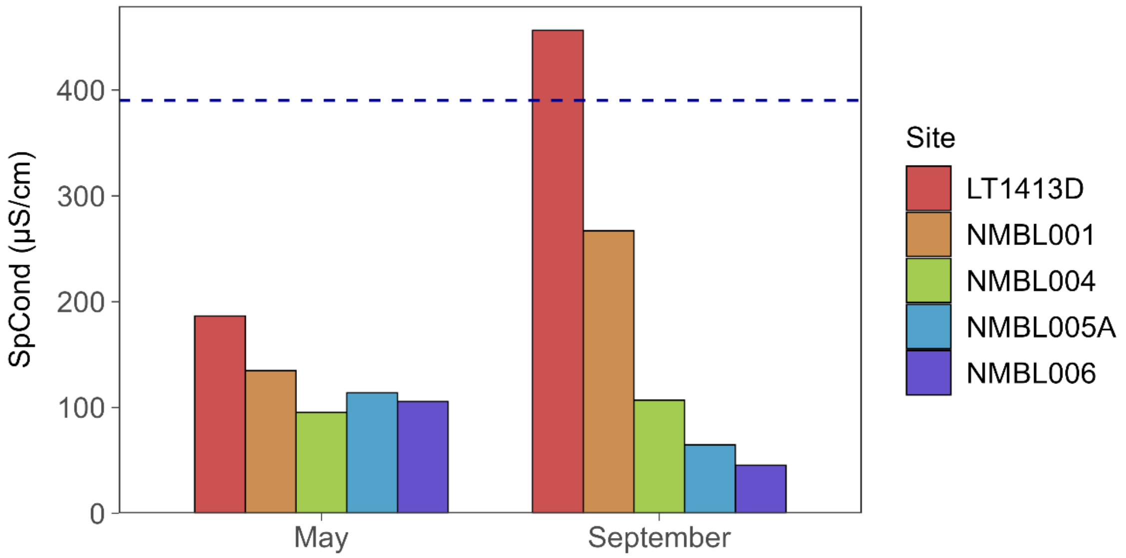


Figure 24. Specific conductivity measured in storm drain effluent flowing into Bear Lake during two separate rain events. Dashed line represents the surface mean specific conductivity in the lake.

All nutrient concentrations were higher in the storm drain effluent than in the lake proper. TP concentrations ranged from 101 – 342 µg/L, compared to a lake surface mean of 39 µg/L (Figure 25). The highest TP concentration was measured at NMBL004 in May. SRP concentrations ranged from 27 – 115 µg/L, whereas SRP levels in the surface waters of the lake were on average below detection (Figure 26). SRP concentrations were comparable between May and September, and levels at LT1413D tended to be lower than at other sites.

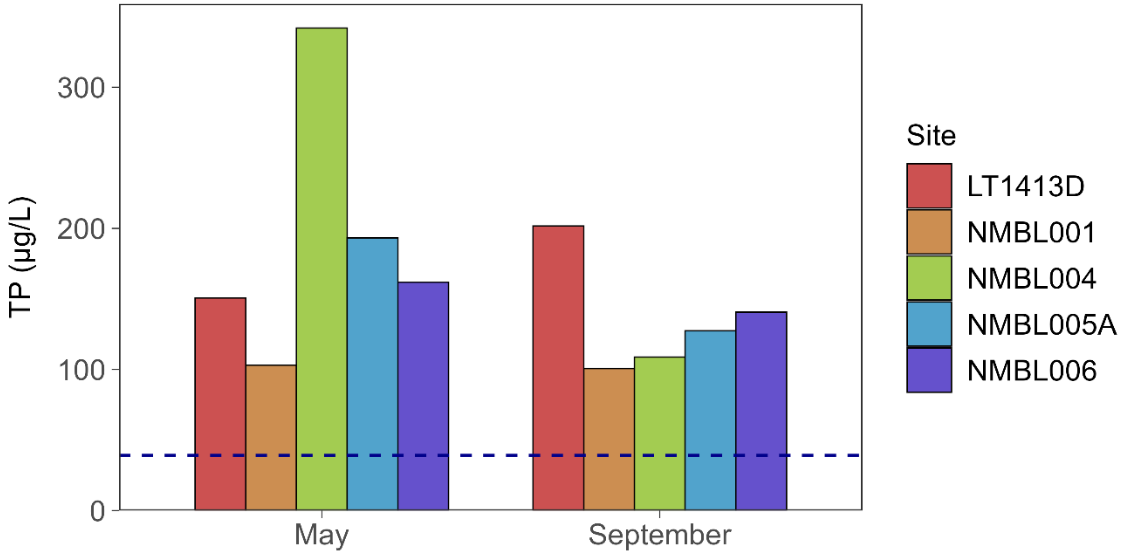


Figure 25. Total phosphorus (TP) measured in storm drain effluent flowing into Bear Lake during two separate rain events. Dashed line represents the surface mean TP concentration in the lake.

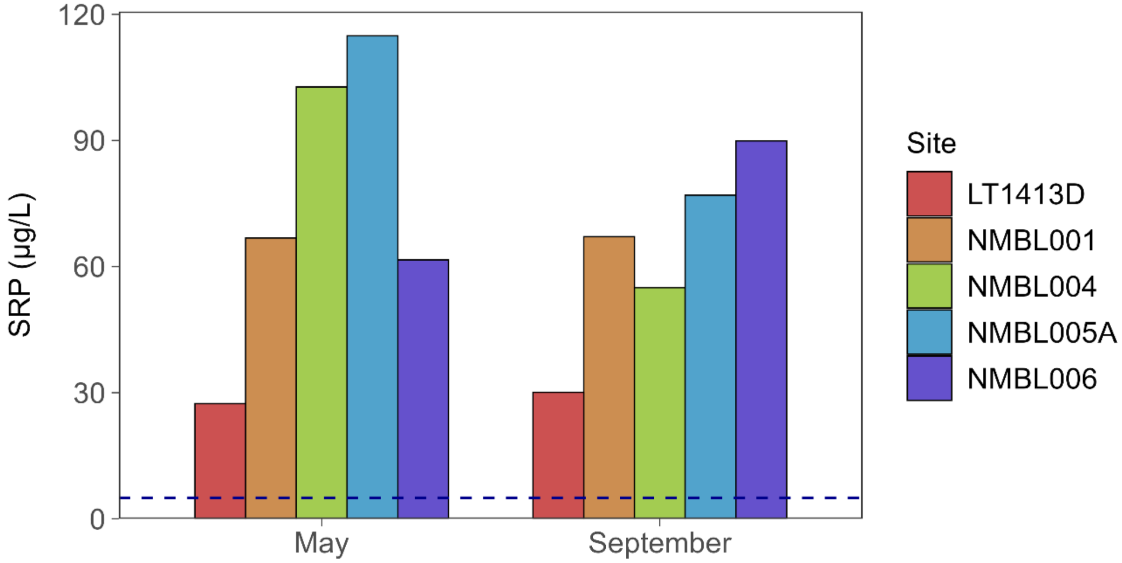


Figure 26. Soluble reactive phosphorus (SRP) measured in storm drain effluent flowing into Bear Lake during two separate rain events. Dashed line represents mean surface SRP concentration in the lake.

Similarly to SRP, nitrate concentrations were lowest at LT1413D (Figure 27). Nitrate concentrations ranged from 0.273 – 1.954 mg/L, compared to a lake surface mean of 0.091 mg/L. Levels were 2 to 7 times higher at NMBL001 than at all other sites. Ammonia levels were on average higher in May than in September, which is consistent with ammonia levels measured in the lake proper (Figure 28). Concentrations ranged from 0.101 – 0.891 mg/L, compared to a lake surface mean of 0.017 mg/L. In May, ammonia concentrations were noticeably lower at LT1413D than at all other sites, whereas in

September, the lowest ammonia concentrations were observed at NMBL001. TKN concentrations ranged from 0.57 – 4.66 mg/L, compared to a lake surface mean of 0.82 mg/L, and levels were generally higher in May than in September (Figure 29). A spike in TKN was observed at NMBL004 in May, which coincided with a spike in TP at the same site.

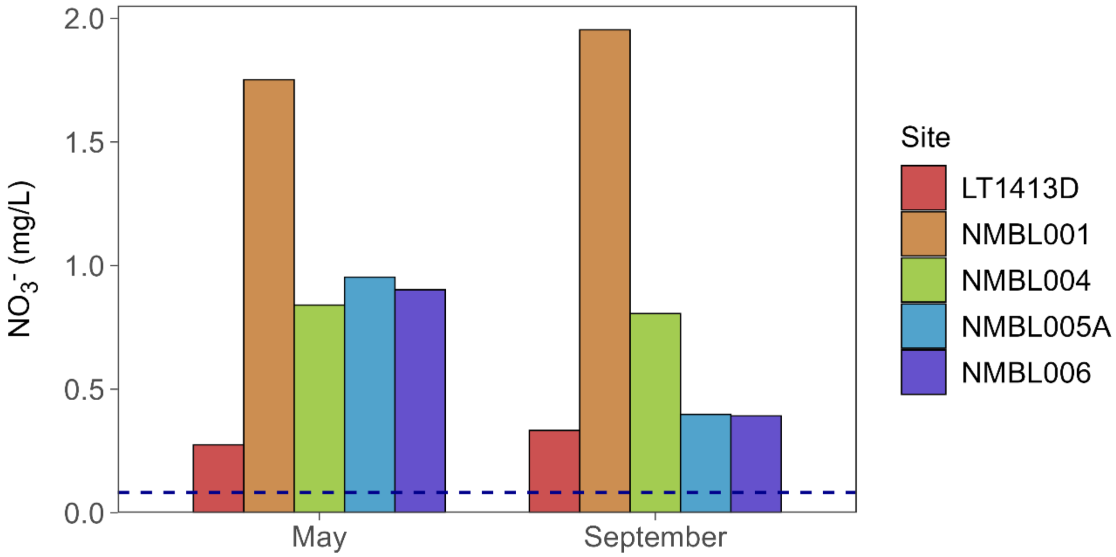


Figure 27. Nitrate (NO_3^-) measured in storm drain effluent flowing into Bear Lake during two separate rain events. Dashed line represents the surface mean nitrate concentration in the lake.

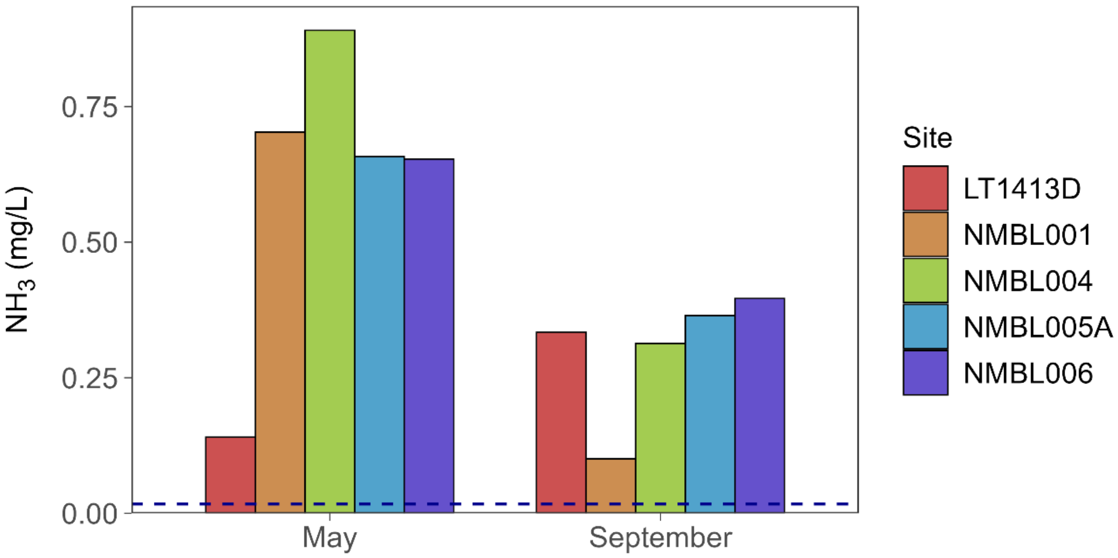


Figure 28. Ammonia (NH_3) measured in storm drain effluent flowing into Bear Lake during two separate rain events. Dashed line represents the surface mean ammonia concentration in the lake.

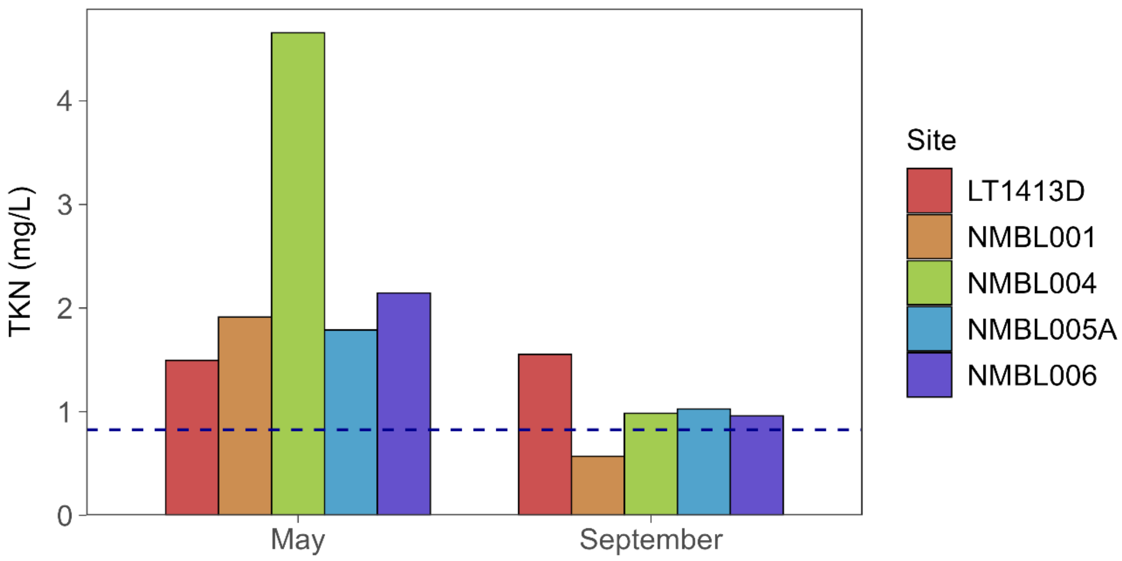


Figure 29. Total Kjeldahl nitrogen (TKN) measured in storm drain effluent flowing into Bear Lake during two separate rain events. Dashed line represents the surface mean TKN concentration in the lake.

E. coli concentrations were near or above the upper limit of quantification for nearly every storm drain sample. It is likely that these high concentrations are due to fecal matter from wildlife, which is a common phenomenon. However, given the very low *E. coli* concentrations in the lake (Figure 15), these storm drain populations are not a major concern in the lake's open water. Nonetheless, it may be worthwhile for the Lake Board to consider funding a microbial source tracking study in this upcoming year to see if the source of the *E. coli* could be determined. Using DNA markers and comparing them against a known library of potential DNA sources (e.g., human, bovine, canine, etc.), it is possible to identify the source of the pathogen, although not the exact location.

Table 7. *E. coli* concentrations measured in storm drain effluent during two separate rain events.

Date	Site	*E. coli* (cfu/100 mL)
5/1/2025	NMBL001	>2420
	NMBL004	2420
	NMBL005A	>2420
	NMBL006	>2420
	LT1413D	1986
9/3/2025	NMBL001	>2420
	NMBL004	>2420
	NMBL005A	>2420
	NMBL006	>2420
	LT1413D	>2420

Lake Phytoplankton

Of the ten most abundant taxa of phytoplankton collected from Bear Lake in 2025, only two are known to produce cyanotoxins: the cyanobacteria *Aphanizomenon* and *Limnothrix* (Table 8). In spring into early summer, phytoplankton communities were dominated by diatoms (Bacillariophyta). Green and blue-green algae (Chlorophyta and Cyanobacteria, respectively) began to emerge in July and increased in biovolume through October (Figure 30). In particular, the green alga *Mougeotia*, which has been known to form blooms under P-limited conditions (Tapolczai et al. 2015), grew to represent over half of the total phytoplankton biovolume in the month of October. The emergence of cyanobacteria in the latter half of the sampling season corresponds with measurable levels of microcystin (Figure 14), though none of the most abundant genera are known to be microcystin-producing. Planktonic community compositions were generally similar between sites, though green algal biovolumes were higher in the two mid-lake sites (Figure 31). Interestingly, the cyanobacterium *Microcystis*, which is common in Muskegon Lake (Gillett and Steinman 2011), was not especially abundant in Bear Lake in 2025. The greatest *Microcystis* biovolumes were observed in July (lakewide mean biovolume 6000/mL) and October (3800/mL), which tracks with the two microcystin spikes.

Table 8. Most abundant plankton genera by biovolume, averaged across sites and months. Bold text indicates genera capable of producing cyanotoxins.

Division	Genus	Mean Biovolume (mL^{-1})	%Total Biovolume
Bacillariophyta	*Aulacoseira*	1,363,000	33%
Chlorophyta	*Mougeotia*	1,074,000	26%
Bacillariophyta	*Synedra*	340,000	8%
Bacillariophyta	*Fragilaria*	270,000	7%
Cyanobacteria	***Aphanizomenon***	208,000	5%
Chlorophyta	*Staurastrum*	161,000	4%
Pyrrhophyta	*Ceratium*	112,000	3%
Bacillariophyta	*Diatoma*	89,000	2%
Cyanobacteria	***Limnothrix***	87,000	2%
Cyanobacteria	*Cryptomonas*	82,000	2%

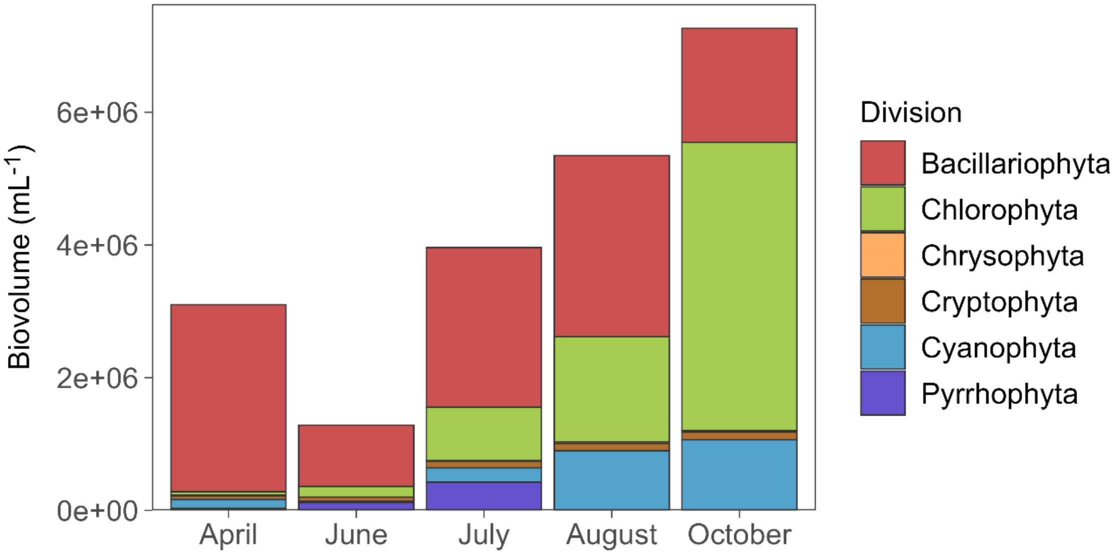


Figure 30. Distribution of plankton divisions by biovolume across months, averaged over all sites.

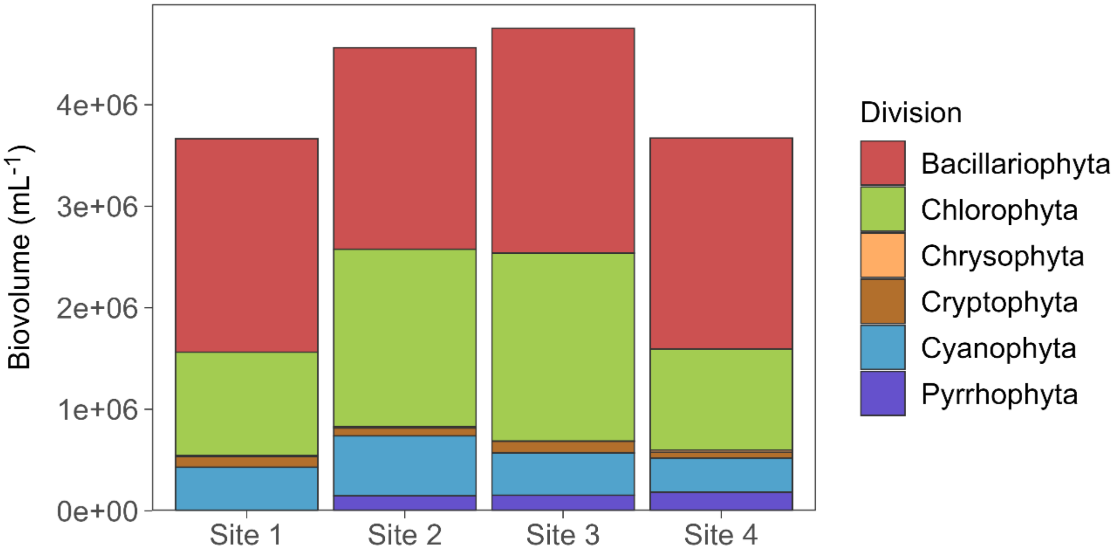


Figure 31. Distribution of plankton divisions by biovolume across sites, averaged across all months.

Dashboards

The TP dashboard (Figure A1) shows mixed results. The spring data are encouraging with some of the lowest TP concentrations measured in Bear Lake this time of year. However, conditions deteriorated throughout the summer, and by fall, mean TP concentrations were at levels comparable to those that motivated the establishment of the TMDL. It is unclear why TP concentrations jumped in fall; 2025 was a dry summer, which results in less runoff, and usually lower TP loads and concentrations. The storm drain samples clearly show elevated concentrations in the runoff but precipitation was very limited this summer so the overall load (concentration x flow) of phosphorus could not account for this increase.

The algae responded to the increased phosphorus concentrations as chlorophyll *a* levels tracked the TP trends very closely (Figure A2): limited (albeit above the desired level) growth in spring followed by increasing concentrations through the summer. As noted previously, discrete samples on just a few days of the summer can generate misleading results. However, when the trends become consistent over years, it is an indication that additional measures may be needed.

Water clarity also declined, although to a much smaller degree compared to the increases in TP and chl *a* over the past few years. As chlorophyll increases, water clarity decreases due to light absorption by the algae.

Summary

Similar to prior years, Bear Lake water quality indicates both positive and negative trends in 2025. Positive results include low *E. coli* and cyanotoxin concentrations. These two analytes present the most immediate danger to human health, and their low concentrations indicate that while users should always exercise proper judgment, there is little concern about health impacts from water quality impairments while recreating in Bear Lake.

However, phosphorus and nitrogen concentrations are higher, sometimes much higher, than recommended and ultimately may eventually lead to the emergence of pathogens and harmful algal blooms. As noted in prior reports, Bear Lakes has an established TMDL of 30 µg/L. While spring TP levels continue to be below this threshold, the summer TP concentrations remain well above the TMDL, although have come down from the 2023 spike. Mean TP concentrations of near surface and near bottom depths across all sampling months were 60 µg/L in 2023, 42 µg/L in 2024, and 43.5 µg/L in 2025. Because there is inherent year-to-year variability in nutrient concentrations (due to differing weather conditions), it is unclear if the TP concentrations have now stabilized at around 40 µg/L or if further reductions will be forthcoming.

Phytoplankton biomass, as reflected in terms of chlorophyll *a*, continues to exceed the target concentration of 10 µg/L both in spring and summer. Despite the high biomass, microcystin concentrations are still below federal guidelines but should continue to be monitored given their potential harm.

Phytoplankton abundance and species composition continue to indicate some degree of water quality impairment. Despite decreases in spring chlorophyll *a* concentration from the past few years, the levels in both spring and summer continue to exceed the target concentration of 10 µg/L, and at times are more than double that threshold. One positive development is that cyanobacteria (blue-green algae) no longer dominate the summer phytoplankton community; rather, diatoms and green algae dominated in 2025. However, the filamentous green alga *Mougeotia*, while not toxic, can form "clouds" of algae in the water column and on the sediment, creating aesthetic issues and causing concern among riparian homeowners and people recreating in the lake. In last year's report, we noted that increasing microcystin concentrations in the autumn surface waters, while still below federal guidelines, should continue to be monitored. The relatively small spikes observed in July and October in 2025 are still well below federal guidelines for recreation. Continued monitoring is recommended, especially given the high levels of *E. coli* found in the storm drains after rain events.

As we have done in past reports, we also looked at the trends in water quality going back to 2017 but with an important caveat. The data from 2017 to 2021 were generated by RLS, whereas the data from 2022 to the present were generated by AWRI, using different methods. Hence, any comparison over the entire period of record should be done with caution. It is more appropriate to examine trends from 2017 to 2021 separately from those using 2022 to 2025. The 2017-2021 trends are affected by an anomalous 2020, where the concentrations of most parameters exhibited unusually poor environmental conditions. Things improved in 2021, the final year of RLS' contract. Between 2022 and 2025, there were no dramatic changes in spring or summer, suggesting that Bear Lake is in a relatively stable, slightly eutrophic state that would benefit from some targeted management actions and continued monitoring.

Our analysis of water during storm events revealed two significant findings: 1) there was high variability in concentrations among the storm drains; and 2) nutrient concentrations in water leaving the storm drains can be considerably elevated compared to ambient lake concentrations. While elevated nutrient levels in stormwater is a common phenomenon, especially immediately after the storm flow begins ("first flush"), it suggests that management actions should be considered for this discharge (see recommendations).

The Bear Lake Dashboard (Appendix A) provides a quick and intuitive way to review the total phosphorus (TP), chlorophyll a, and water clarity data. TP concentrations remain higher than desired in 2025, especially during our fall sampling event. As noted last year, the substantial increase in chlorophyll concentration since 2022 is most likely attributable to a change in how chlorophyll was measured in the RLS years vs AWRI years (Figure A2); however, the increase in fall 2025 compared to the prior two years is related to increased algal production. This may be related to the increased phosphorus concentrations; west Michigan had a dry fall, suggesting the TP may be coming from the sediment.

The water clarity data, which are based on Secchi disk depth, and hence rely simply on the human eye, are comparable across time; the data show slight improvements in spring and summer 2025 but a continued decline in clarity in fall (Figure A3). Overall, the dashboard metrics in most seasons fall into the undesirable category, indicating that Bear Lake (in association with Muskegon Lake) is no longer listed as an Area of Concern, Bear Lake remains in an impaired state, and therefore, a need for continued monitoring and management remains.

Recommendations:

1) Bear Lake monitoring: As noted in previous reports, our monthly (or semi-monthly) snapshot monitoring is useful for assessing long-term trends but can miss critical events between sampling dates or potentially give unrepresentative information in the short-term (for example, sampling during a short-lived algal bloom can lead to an overstatement of bloom conditions). Over time, with a sufficient sample size, those anomalous events will have less effect. As a consequence, we recommend continuing the 4 in-lake sites, but again recommend that the Lake Board consider the purchase of a sonde that would provide continuous water quality data throughout the ice-free seasons. The White Lake Association (WLA) recently purchased and deployed a sonde in 2025. These sondes require that an individual(s) be dedicated to their maintenance and operation, but the benefits can be significant over time. The contact person at the WLA is Jim DeBoer (jdeboer007@hotmail.com) if there is interest; more information is available at this website: https://www.nexsens.com/.

2) The elevated nutrient concentrations in stormwater runoff is a common phenomenon. Addressing this issue can involve two, non-mutually exclusive approaches. First involves citizen awareness, so fewer pollutants, such as from lawn and garden fertilizers, enter the storm drains. Second, structural approaches can be installed to trap the nutrients before reaching the lake. In the case of

Bear Lake, there is insufficient land to install any kind of constructed wetland or detention area to treat the runoff before it enters the Lake. Instead, the Lake Board, in consultation with their lake management firm (PLM), may want to consider installing nutrient traps at the outfall to capture nutrients before they enter the lake proper. Biochar filter socks have been heavily promoted (see https://www.youtube.com/watch?reload=9&v=FxKxXFtKdg0). A study conducted as part of a bachelors degree thesis examined the nutrient removal performance of biochar, sphagnum moss and woodchips in an 11-day experiment (Nick 2018). He measured total phosphorus, phosphates, total nitrogen, total organic carbon, conductivity and pH, and concluded that the performance of the filter columns was satisfactory, with the exception of poor removal efficiency of phosphates and total phosphorus (Nick 2018). The Lake Board may want to consider installing a few filter socks in 2026 and assess their performance.

3) The phytoplankton composition revealed a shift from summer dominance by cyanobacteria to green algae and diatoms. Potentially toxic cyanobacteria are still present in Bear Lake, but their microcystin production remains relatively low. As noted in last year's report, the presence of cyanobacteria has been reported previously in Bear Lake (Xie et al. 2011). Microcystin concentrations in Bear Lake continue to remain below the threshold established for recreational water use by US EPA. If their presence is a function of a changing climate (longer, warmer summers), this obviously is beyond any lake management action but it does warrant additional vigilance in the future.

Acknowledgements

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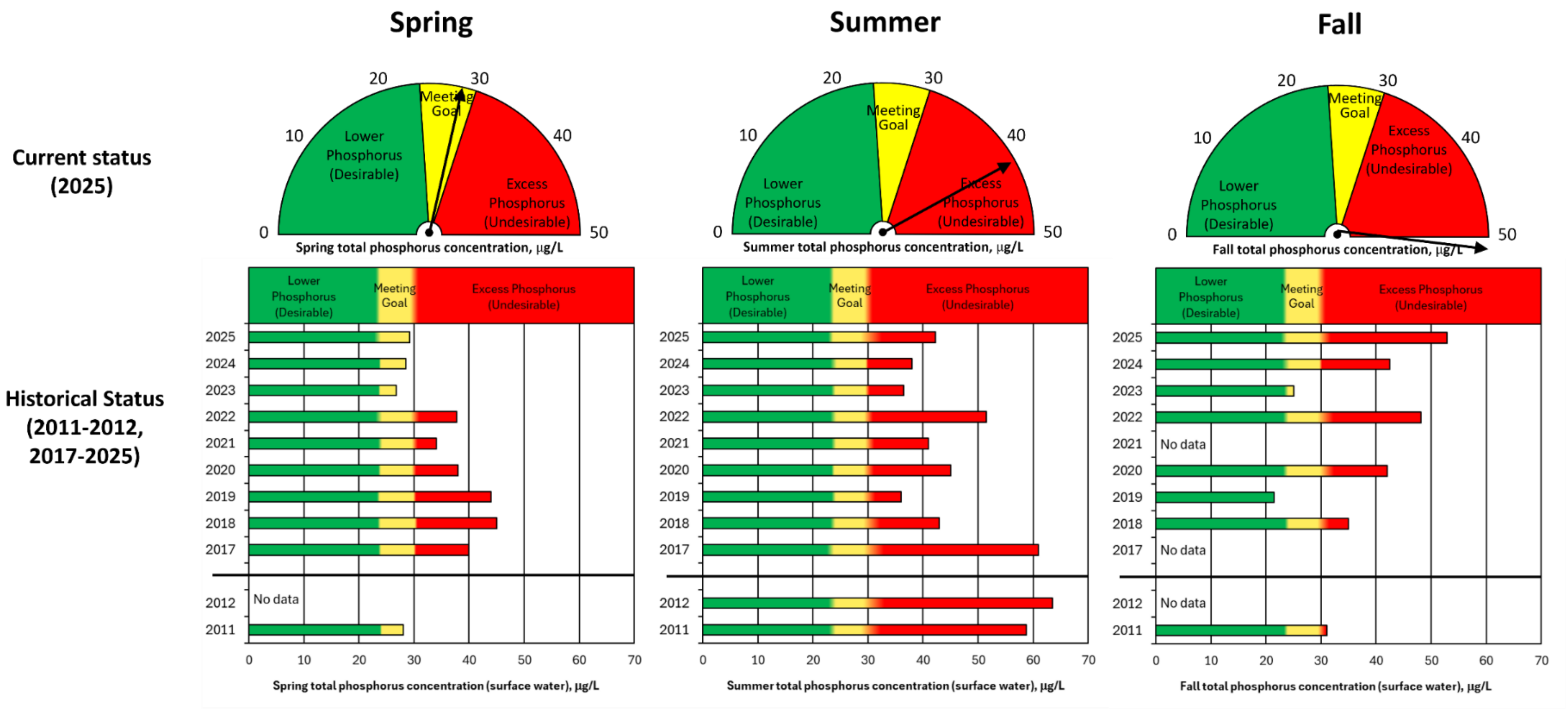
Appendix A: Bear Lake 2025 Dashboards

Fig. 1A. Total Phosphorus

Fig. 1B. Chlorophyll *a*

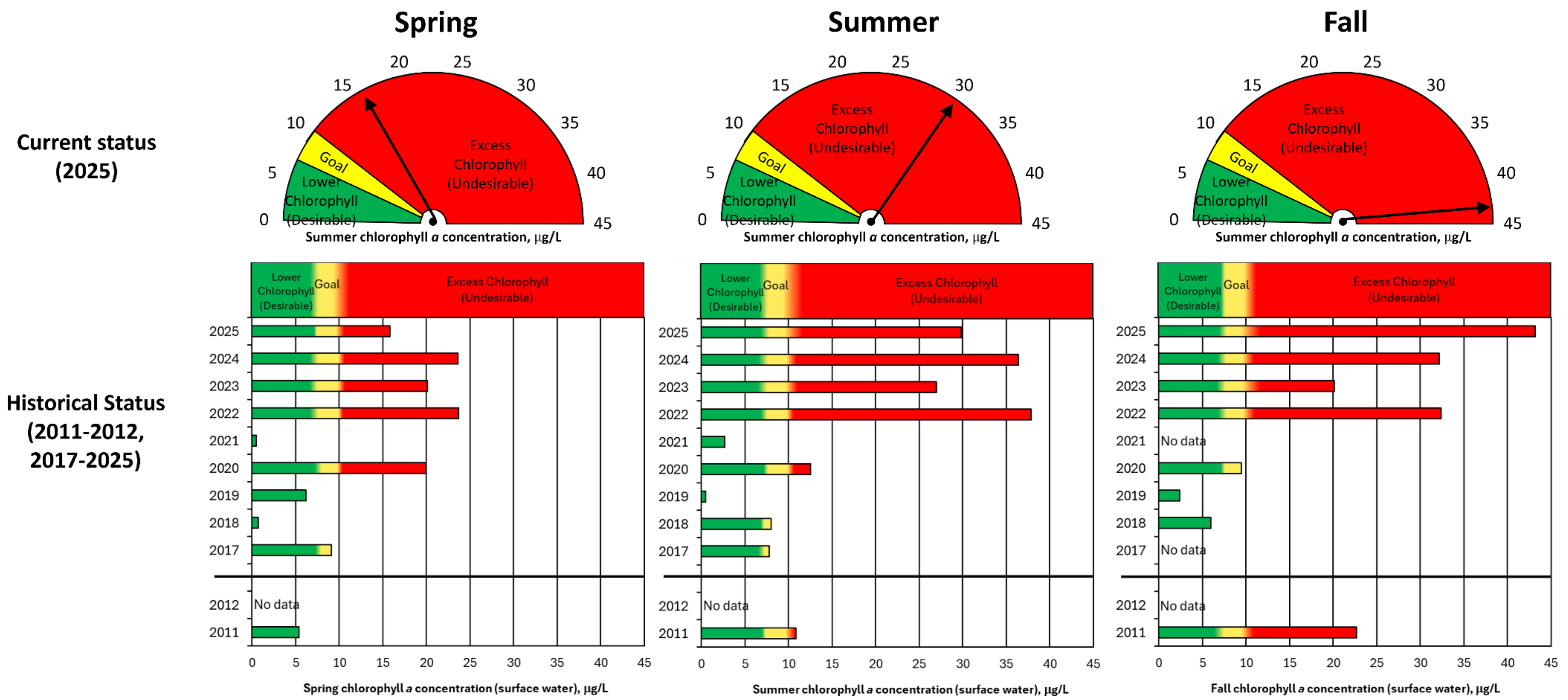
Fig. 1C. Water clarity

Figure A1. Bear Lake 2025 total phosphorus seasonal dashboard. Classifications are based on >30 µg/L "undesirable" threshold of Bear Lake TMDL, and the <30 µg/L "meeting goal" threshold and <24 µg/L "desirable" threshold of the Muskegon Lake long-term monitoring dashboard.



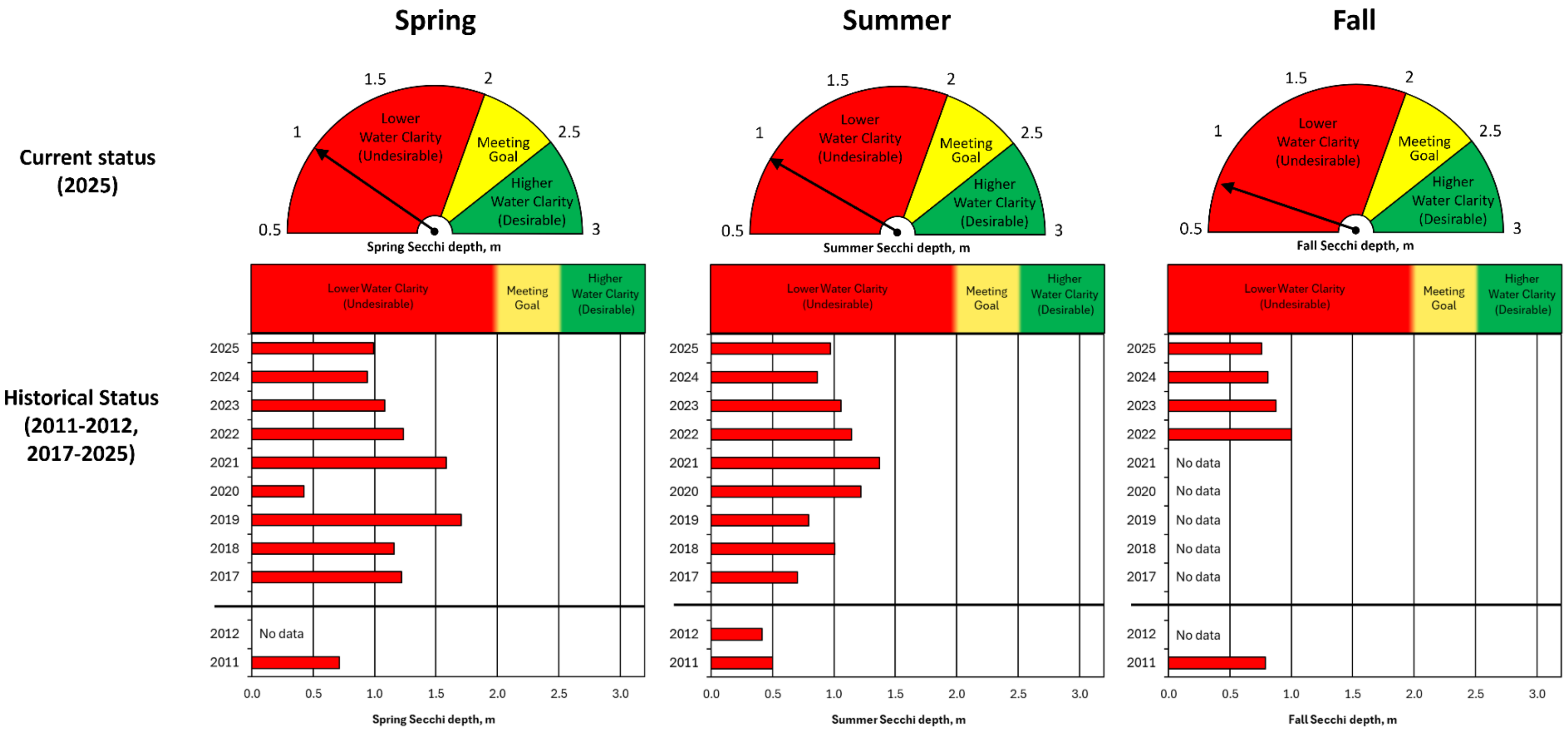
Data sources: RLS (2017-2021) and AWRI (2011-2012; 2022-2025 unpublished data)

Figure A2. Bear Lake 2025 chlorophyll *a* seasonal dashboard. Classifications are based on >10 µg/L “undesirable” threshold, <10 µg/L “meeting goal” threshold, and <7.3 µg/L “desirable” threshold of the Muskegon Lake long-term monitoring dashboard.



Data sources: RLS (2017-2021) and AWRI (2011-2012; 2022-2025; unpublished data)

Figure A3. Bear Lake 2025 Secchi disk depth seasonal dashboard. Classifications are based on >2 m “undesirable” threshold, <2 m “meeting goal” threshold, and <2.5 m “desirable” threshold of the Muskegon Lake long-term monitoring dashboard.



Data sources: RLS (2017-2021) and AWRI (2011-2012; 2022-2025; unpublishe