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Staff Memorandum

WAVE PROPAGATION AND WATER QUALITY STUDY OF NORTH LAKE, WAUKESHA COUNTY, WISCONSIN

December 6, 2024

BACKGROUND INFORMATION

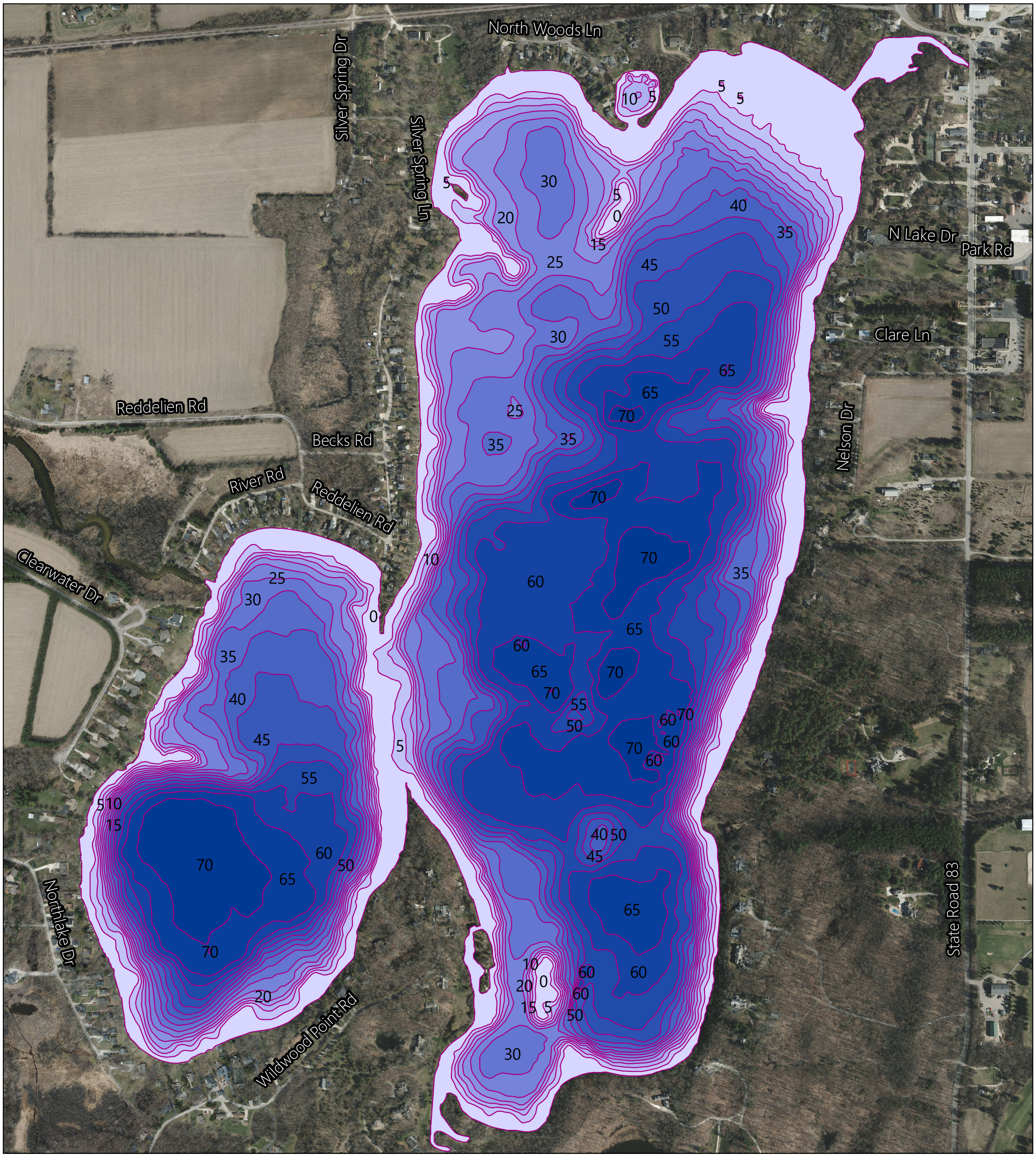
Southeastern Wisconsin's lakes are prized natural resource assets and are intensively used for a wide variety of recreational pursuits. Given the Region's high human population density and the great popularity of these lakes, user conflict is likely to occur in certain instances. For example, waves produced by power boating can interfere with the ability of others to enjoy more passive lake-based recreational pursuits. Additionally, in some cases, boat wakes may destabilize shorelines, disrupt lakebeds, and damage aspects of lake ecology. This concern has long been widely recognized and led to boating ordinances that help reduce user conflict and lake damage at critical time periods (e.g., slow-no-wake restrictions during high water). Over the years, water-based recreation has become even more popular in the Region and customary boating practices and equipment have changed. In many lakes, boats have become more numerous, larger, and more powerful. In some instances, boats are now used to support more active/aggressive forms of water-based recreation, while some boats are purposely engineered to produce large wakes at modest speed to support certain water-based sports. This situation has generated heightened concern amongst residents and users of many of Southeastern Wisconsin's lakes, which has raised questions regarding the impact of boating on area lakes.

North Lake is a 440-acre lake located in the Town of Merton in north-central Waukesha County along the Oconomowoc River chain of lakes. The lake consists of two basins that are largely separated by a north-south trending shoal (see Figure 1). Each lake basin is quite deep, with maximum depths over 70 feet, and each is ringed by shallow-water shelves that extend up to 120 feet from shore. The large east basin is 335 acres in size and the smaller west basin is 105 acres in size. Although they are connected, each basin does operate somewhat independently of one another. For example, comparison of the deep hole station in each basin on August 16, 2021, amongst 9 profiles taken roughly every 2 hours from morning to evening shows that the smaller west basin had significantly higher dissolved oxygen concentrations that extended down to depths of nearly 25 feet deep compared to less than 20 feet in depth in the east basin.[1] From June through September in 2022 the larger east basin was found to consistently have elevated total phosphorus, chlorophyll-*a*, nitrate and nitrite, and ammonia concentrations as well as higher dissolved inorganic nitrogen to soluble reactive phosphorus ratios compared to the smaller west basin as summarized in a recent study.[2] The Lake's water level is unaltered and is not artificially controlled, with the Lake receiving flow from the Oconomowoc River, Mason Creek, and via outflow from Cornell Lake while discharging water to the Oconomowoc River at its outlet. The North Lake Management District's (District) endeavors to manage the Lake in a manner that sustainably support human needs and desires while considering its long-

[1] *Personal communication: profile data provided by Mark Thiesen, North Lake resident and water quality volunteer monitor.*

[2] *Russell Cuhel and Carmen Aguilar,* Water Characteristics of North Lake, Waukesha County, Wisconsin: *Nitrogen* Enrichment Focus, *Final Written Report, UW-Milwaukee School of Freshwater Sciences, January 2023.*

Figure 1
Revised Bathymetric Contours for North Lake: 2020



LAKE DEPTH (FEET)

0-5	15-20	30-35	45-50	60-65
5-10	20-25	35-40	50-55	65-70
10-15	25-30	40-45	55-60	>70

Source: SEWRPC

term overall health. The District remains vigilant of issues that could influence recreational quality and lake health. The District reports that the Lake water clarity has been decreasing over the years while nearshore areas have been more prone to accumulate fine and/or organic sediment during portions of the summer.

The District's Lake Usage Committee completed a study in 2019 evaluating recreational use of North Lake.[3] As a result of this study, the District has become increasingly concerned that boat-wake generated waves could compromise Lake shoreline integrity, its ecology, and/or the Lake's ability to sustain a variety of high-quality recreational pursuits. As a follow up to the May 2019 Lake Usage Committee study, the District requested that the Commission collaborate with the District and others to develop methods to evaluate various in-lake factors influencing North Lake's water quality, shoreline stability, bottom sediment, and ecology. A pilot study was conducted between 2019 and 2020 to evaluate data collection methods and generate preliminary information. This work collected basic information on wave propagation, water levels, and water quality in the Lake's nearshore areas. The Commission completed a staff memorandum summarizing the efforts and results of this pilot study in March 2021.[4]

The District desired for these studies to be continued and expanded into second and third phases. With pledged support from the Commission, the District applied for and received a Wisconsin Department of Natural Resources (WDNR) Surface Water Grant to complete additional studies on how boat wake propagation affects lake water quality, bottom sediment, and aquatic plant communities. These studies consist of three phases that were funded through separate but interrelated grants:

- "Grant A" (LPL177921)[5]
    - Measurements of waves caused by boat wakes
    - Drone photography twice a week for eighteen weeks
    - Compilation of boat traffic conditions during drone photography
    - Compilation of weather during drone photography

- "Grant B" (LPL179521)[6]
    - Measurement of sediment plumes caused by boat wakes
    - Collection of water clarity and dissolved oxygen at six sites twice a week in summer of 2021
    - Collection of total suspended solid (TSS) and total phosphorus twice a week from May through September
    - Aquatic plant sampling

- "Grant C" (LPL179621)[7]
    - Analysis of the difference in wave impacts based on type of boat
    - Develop methodology for analyzing wave impacts on lake shorelines, lake sediment, water quality, and vegetative communities
    - Outline of proposed protective ordinances to address human induced wave impacts
    - Present results at minimum of two public meetings.

All data, digital images, maps, and other project deliverables for all three grants are to be provided to the WDNR via input into the Surface Water Integrated Monitoring System (SWIMS) database or in a format specified by the WDNR regional lake biologist.[8] Funding provided through Grant A was dedicated toward retaining the services of Terra Vigilis Environmental Services Group (Terra Vigilis) to conduct commercial drone operations and to differentiate between the effects of powered vessels on wave characteristics (i.e., amplitude, frequency,

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[3] *North Lake Management District, Lake Usage Committee Report, May 2019*.

[4] *Staff Memorandum,* Preliminary Morphology, Water Level, Water Quality, and Wave Propagation Update for North Lake, Town of Merton, Waukesha County, *March 2021*.

[5] *See apps.dnr.wi.gov/swims/Projects/ProjectDetail?id=269094781*.

[6] *See apps.dnr.wi.gov/swims/Projects/ProjectDetail?id=271828746*.

[7] *See apps.dnr.wi.gov/swims/Projects/ProjectDetail?id=269094778*.

[8] *See "Monitoring" tab on the following webpage for water quality data uploaded to SWIMS for this project: apps.dnr.wi.gov/swims/Projects/ProjectDetail?id=271828746*.

and length), subsurface sediments, development of plumes sufficient to re-deposit sediments, down wash wave characteristics, and impacts to subsurface plants and habitat. Grant B funding was dedicated toward paying the State Laboratory of Hygiene for water quality sample analyses and toward retaining Terra Vigilis to document sediment plume events through aerial and subsurface imagery, evaluate the impact of sediment redistribution on aquatic plant communities, and collect water quality and sediment samples throughout the summer 2021 primary boating season. Reports completed by Terra Vigilis in July 2022 and December 2022, subtitled "Phase 2 Report" and "Phase 3 Report" respectively, provide information regarding project activities funded through Grants A and B.[9,10] The Phase 2 Report describes monitoring activities conducted during summer 2021 while the Phase 3 Report describes findings from summer 2022 with comparisons to summer 2021 measurements. Commission staff provided input on aspects of the study design and water quality monitoring as well as feedback on draft versions of the Phase 2 and 3 Reports; however, the Commission was not directly involved in collecting water quality data nor writing the initial report drafts.

A portion of the Grant C funding was dedicated toward retaining the Commission to help the District use the information collected via Grants A and B to analyze the effects of wave propagation on water quality, sediment redistribution, the lake shoreline, lake bottom, and subsurface plants and habitat and to prepare a report outlining the key findings and recommendations to develop protective ordinances. This staff memorandum report is intended to help meet this project deliverable and fulfill the Commission's involvement in the overall study.

DATA COLLECTION

As discussed above, physical, chemical, and biological measurements were conducted on a variety of factors and by several entities in the summers of 2021 and 2022 in fulfillment of project deliverables for Grants A and B. Map 1 indicates all monitoring sites referenced in this report. Boating activity and shoreline turbidity was monitored along the western shores of both lake basins. Water quality measurements were taken at eight nearshore sites in waters approximately 20 feet deep ranging between 200 and 500 feet from shore as well as two "deep hole" sites at the deepest points in each basin. Water elevations were monitored at the northern shore of the western basin while water level loggers were placed in shallow water at eight locations across both basins. The following section will describe data collection efforts, provide a concise summary of data trends and analysis, and put this information in context regarding impacts from general powerboating activity as well as wake-enhanced boating.

2021 Study Period

The District and Terra Vigilis started data collection in the summer of 2021 by establishing a weather station, monitoring Lake water elevations and boat activity, taking water quality measurements including water clarity, temperature, dissolved oxygen, total phosphorus, and total suspended solids. The summer 2021 data collection is included in Appendix B of the Phase 2 report, so a brief data description will only be included as relevant to analyses in this report.

Water quality monitoring occurred at seven sites spread across both basins of the Lake (see "WQ Sites" 1 through 7 on Map 1). Aside from one Saturday sampling event on July 10th, the total phosphorus and total suspended solids sampling occurred on either Sunday or Tuesday from June 27th through August 24th with the intent that Sundays would represent high boating activity days and Tuesdays would represent low boating activity days. Water clarity measurements were conducted on various dates between June 3rd and August 24th, some of which matched other sampling efforts. Temperature and dissolved oxygen concentration monitoring occurred on four dates: Friday, July 2nd; Tuesday, July 6th; Tuesday, July 13th; and Tuesday, August 10th. As mentioned in the Phase 2 report, dredging occurred in the channel between the eastern and western basins of the Lake between July 26th and August 3rd that may affect some water quality measurements.

Boat activity monitoring was conducted on several days nearly every week between May 29th and September 6th, 2021 on both basins by volunteers from the District. These volunteers detailed the types and activities of all boats observed during the monitoring periods each day, which substantially varied in length. Despite the extensive monitoring, only four boat monitoring periods occurred simultaneously with water clarity

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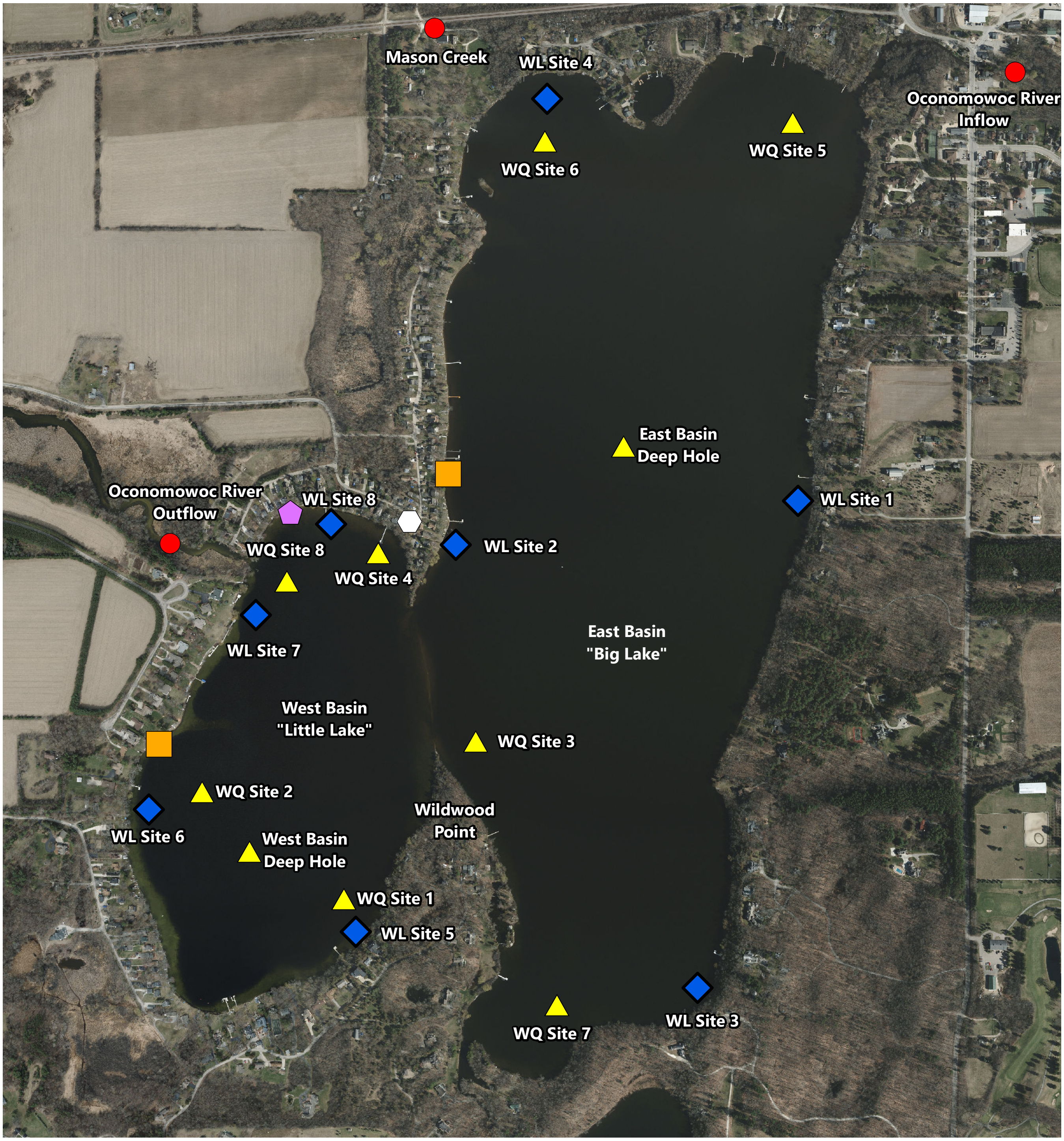
[9] *Terra Vigilis Environmental Services Group,* Water Quality and Wave Impacts Study: Phase 2 Report*, July 20th, 2022.*

[10] *Terra Vigilis Environmental Services Group,* Water Quality and Wave Impacts Study: Phase 3 Report*, December 30th, 2022.*

Map 1
North Lake Monitoring Stations and Place Names: 2022



MONITORING SITES

WATER LEVEL MONITORS

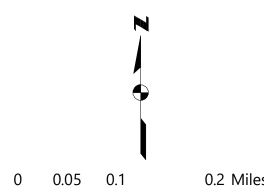
BOAT ACTIVITY AND TURBIDITY

OCONOMOWOC RIVER AND MASON CREEK WATER QUALITY MONITORING

LAKE WATER QUALITY SAMPLING

WATER ELEVATION MONITORING

WEATHER STATION



Source: SEWPRC

measurements and only six occurred simultaneously with total phosphorus and total suspended solids measurements. All four temperature and dissolved oxygen monitoring efforts occurred on the same days with boat monitoring, but even on these days these activities were not conducted at the same time, with boat monitoring sometimes occurring after the water quality sampling. The lack of alignment between the water quality and boat activity monitoring limits the analyses possible with this data.

Following this monitoring effort, the District and Terra Vigilis adjusted their monitoring based on feedback from Commission staff. These adjustments included moving the weather station (described in more detail below), adding an eighth water quality monitoring site near the outlet to the Oconomowoc River in the western basin, measuring turbidity using the Commission's turbidity sensors, standardizing the boat monitoring period lengths, and ensuring that the boat activity monitoring and water quality sampling were occurring simultaneously so these data could be more readily used for analysis. The remainder of this section will describe the 2022 monitoring efforts as these were more relevant for analyses on how boating activity affects water quality on the Lake.

Weather

The District installed a Tempest weather station by WeatherFlow-Tempest, Inc. on the northwest shore of the eastern basin in spring 2021 (see Map 1). This weather station recorded air temperature, barometric pressure, precipitation, wind speed, wind direction, and wind gust speed among other parameters of less relevance to this study. On the advice of Commission staff, the District moved this station to the northeast shore of the western basin in spring 2022 to reflect prevailing wind speeds and direction more accurately without protection from the steep and forested western nearshore area. These measurements were made every minute throughout the 2022 study period of May 1st, 2022 to September 15th, 2022.

Commission staff compared mean, maximum, and minimum air temperatures as well as total precipitation to NOAA 2006 – 2020 Climate Normals recorded at the Oconomowoc Wastewater Treatment Plant weather station.[11] These climate normals are calculated by averaging the monthly mean, maximum, and minimum air temperatures for the indicated period. Mean air temperatures recorded at the Lake station were similar to monthly normals. Monthly maximum air temperatures for May, June, July, and August 2022 all exceeded the climate normals by 2.1°F to 18.7°F while minimum air temperatures ranged from 14.8 to 4.6°F below the climate normals each month. The total amount of precipitation over the course of the 2022 study period was similar to the climate normals; however, May had two inches less precipitation than its climate normal while September had two inches more precipitation than normal.

Wind speed, wind gust speed, and wind direction were also recorded by the weather station. Average sustained wind speeds ranged from 4.9 to 6.1 miles per hour (mph) in summer 2022, with lowest average winds in August and the highest in June. Winds were predominantly from the northwest during all months except for June, which had predominantly southwestern winds. Mean wind gusts ranged from 6.52 to 7.97 mph, with the highest mean gusts again in June. The maximum instantaneous wind gusts recorded each month ranged from 32.7 mph in May to 55.1 mph in July. The maximum minute-average wind speeds recorded each month ranged from 20.1 mph in May to 43.0 mph in September.

Water Levels

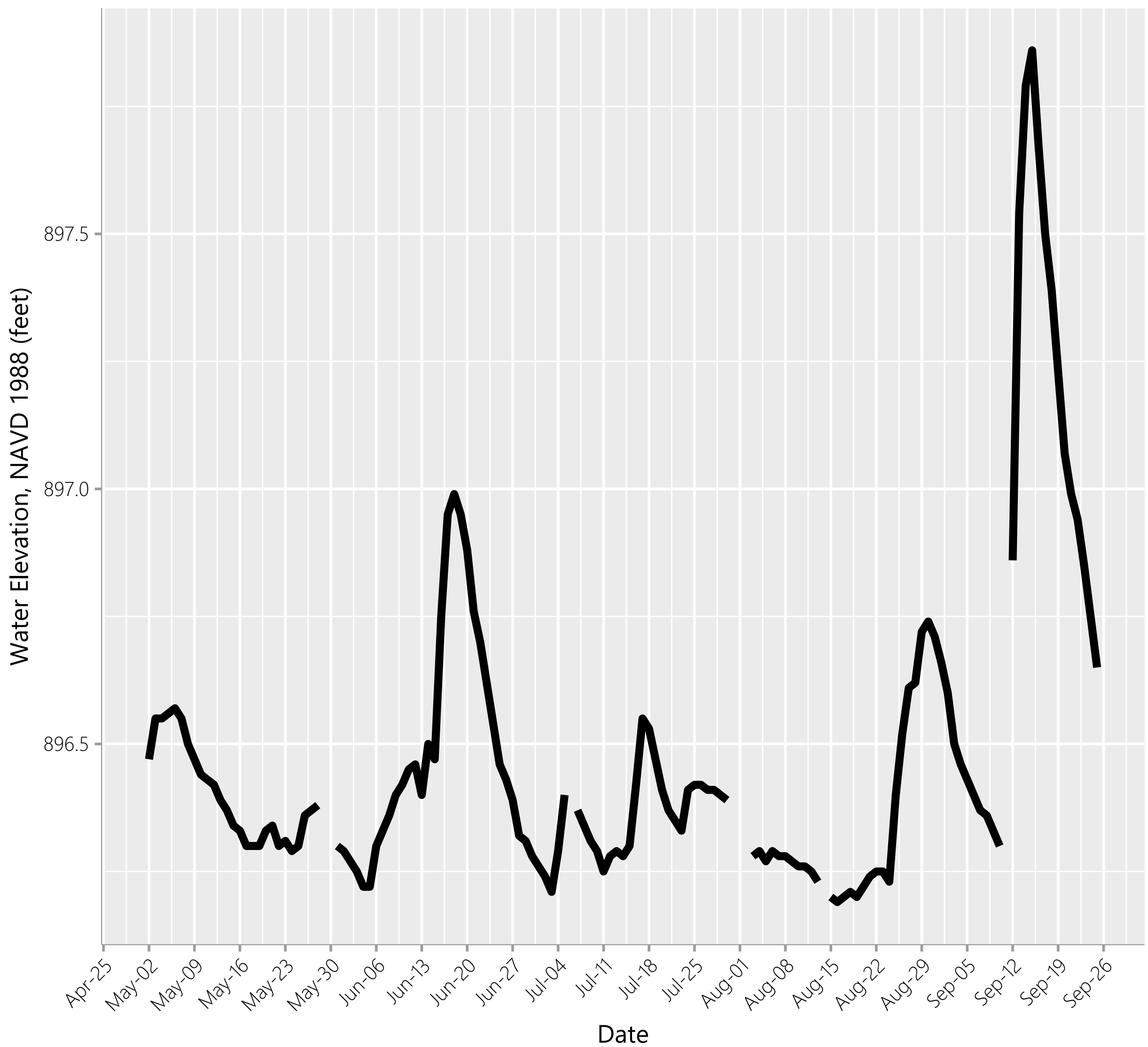
Water depth in the nearshore environment affects nearshore wave behavior and characteristics. Wave speed is a function of wavelength when water depth is more than half the wavelength. However, wave speed becomes a function of water depth when the water depth is less than 1/20th the wavelength. Furthermore, waves increase in height and power in shallower water. Therefore, measuring Lake surface water elevations can help inform nearshore wave behavior. Additionally, waves may have a greater impact on shoreline infrastructure (e.g., docks, seawalls, riprap) and boats at higher water levels than at lower levels.

[11] *Monthly NOAA Climate Normals for the Oconomowoc weather station can be found at the following link: www.ncei.noaa.gov/access/us-climate-normals/#dataset=normals-monthly&timeframe=15&location=WI&station=USC00476200.*

Water Elevations

Surface water elevations in NGVD 88 were recorded daily from May 2nd, 2022 to September 25th, 2022 by the District on the northern shore of the western basin (see Figure 2 and "Water Elevation Monitoring" on Map 1). Water elevations ranged 1.67 total feet over the study period from a low of 896.19 feet, recorded on August 16th, to a high of 897.86 feet, recorded on September 15th following days of heavy rainfall. It is common for water levels to fluctuate so much on North Lake. The September rainfall event caused water levels to exceed the 897.2 feet high water mark, which triggered a slow-no-wake speed limit that lasted for about 7 days.[12] Nonetheless, with the exceptions of short post-rainfall rises in mid-June, late August, and mid-September, the water elevations on the Lake remained relatively steady throughout the 2022 study period.

Figure 2
Surface Water Elevations on North Lake: 2022



Source: North Lake Management District and SEWRPC

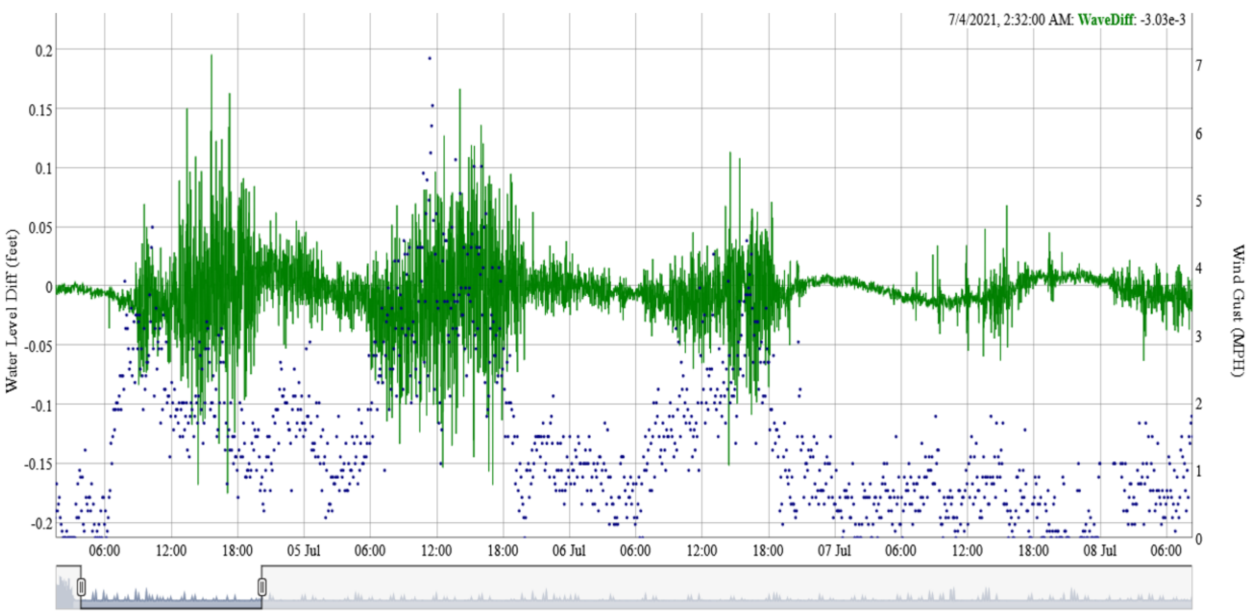
[12] *See Section (6) SPEED RESTRICTIONS, subsection (d) Speed Limit – Slow-No-Wake – High Water of the Town of Merton Ordinance 20.04 – NORTH LAKE AND OCONOMOWOC RIVER. (Am. 4/24/90; Am. 6/22/16; Rep. & recr. 3/26/18(2)) for detailed information.*

Water Level Loggers

In 2021, with the assistance from the District, Commission staff deployed water level loggers to determine their utility in understanding the relationship between water levels and wind speed. Figure 3 shows an overlay of wind speed (blue) pulled from the weather station data superimposed by water levels (green) from Sunday July 4th to Wednesday July 7th on North Lake. Several features illustrated in Figure 3 are summarized below:

- Day versus night-wind speeds and water levels are much lower at night than during the day.
- Wednesday July 7th had both the lowest wind speeds and lowest wave heights compared to all previous days July 4th through 6th.
- Tuesday July 6th had intermediate water level fluctuations compared to the other days and shows very consistent patterns between wind speed and water level fluctuations increasing from the morning to the afternoon and then decreasing again at night.
- Both Sunday July 4th and Monday July 5th had the greatest wave heights and fluctuations compared to the other days. These were also the busiest boating days of the year on North Lake. However, note that Monday July 5th was much windier than July 4th, so this likely contributed to the greater wave heights and fluctuations recorded during this week.

Figure 3
Water Levels and Wind Speed: Example from 2021 Study Period



Source: SEWRPC

These results indicated that these water level recorders were effective in capturing water level changes on North Lake, so they were re-deployed in the 2022 study period.

With the assistance of the District, Commission staff deployed eight water level loggers spread throughout the Lake to evaluate changes in water levels as well as approximate wave activity during the 2022 study period (see "Water Level Monitoring" on Map 1) These loggers were deployed on March 16th, 2022 through September 16th, 2022 and measured water levels above the sensor every minute during this period. Over the course of the season, these loggers mirror the water elevations observed by the District, including similar post-rainfall rises in mid-June, late August, and mid-September. These loggers were removed from the water every month to download the data and were then returned as closely as possible to their former positions. However, there are some slight shifts in the water levels between these monitoring periods due to slight differences in the placement of these loggers (see Figure 3 for an example of the water depth data from one of the loggers).

Commission staff attempted to approximate wave activity using the one-minute interval water level logger data. A one-hour rolling mean was computed for each site and for each monitoring period individually to estimate the “flat” water level at each timestamp while accounting for changes in water level elevation during the 2022 study period. For each observation, Commission staff calculated the absolute value of the difference between the observation and the rolling mean at that timestamp to attain the difference between the water level for that observation and the “flat” water level (see Figure 4). This difference would presumably be the capture of the rising crest or falling trough of a wave. As wave heights are measured from crest to trough, these water level differences were multiplied by two to better approximate this measurement. For any given observation, it is unlikely that the actual wave crest or trough was observed, thus these approximated wave heights are likely a conservative underestimate of the actual wave heights during that period.

The estimated wave heights from the water level loggers during daytime hours was significantly higher on weekend sampling dates than on weekday sampling dates (*test significance*, $p<0.001$).[13] The sampling dates with the five highest mean wave heights were all weekends: July 3rd, July 10th, July 17th, May 29th, and July 31st. May 31st had the highest mean wave height of any weekday sampling date and the highest mean wind speeds of any sampling date during the 2022 study period.

Boating Activity

The District monitored boating activity on the Lake throughout the 2022 study period, with observations timed to occur on the same Sundays and Tuesdays and at roughly the same time as the water quality monitoring. One observer recorded boating activity observations on the western basin while another recorded observations for the eastern basin (see “Boating Activity and Turbidity” on Map 1). Each observer recorded their observations using monitoring forms provided by the Commission, which requires the observer to identify the number, type, and traveling speed of all watercraft including motorboats (e.g., wake boats, pontoons, fishing boats), personal watercraft, sailboats, and paddling boats (e.g., canoes, kayaks). These observers also noted if specific events or activities, such as a sailboat race, were occurring during their monitoring. For the purposes of this study, the following discussion will focus on motorboat counts and activity as the waves produced by non-motored vehicles are negligible in comparison to wind- and motorboat-produced waves.

In general, motorboat counts were higher in the eastern basin than in the western basin, in the afternoon than in the morning, and on Sundays than on Tuesdays (see Figure 5). The higher numbers of motorboats during afternoons and weekends were as expected by Commission staff based on other studies as well as anecdotal observations. In addition to the larger surface area for recreation, the difference in motorboat counts between the basins may be in part due to the guidance posted by the District limiting wakeboat operation in the western basin.[14] The highest motorboat count during the 2022 study period occurred on the afternoon of July 3rd on the eastern basin with 30 motorboats observed. The second, third, and fourth highest counts all occurred during Sunday afternoons (May 29th, June 19th, and July 10th) in the eastern basin. The highest motorboat count in the western basin was 15 boats, which also occurred on the afternoon of July 3rd. Among the motorboats, pontoon boats cruising at low speed were the most observed type at 210 observations, followed by personal watercraft at 114 observations, and then powerboats “skiing/wakeboarding/tubing” (68 observations) and cruising at low speed (58 observations).[15] Motorboats constituted approximately 86 percent of all boat observations, although observer notes did not always indicate a specific number of non-motored boats at certain times, so this percentage is likely an overestimate.[16] As North Lake’s public access launch is carry-in only, most if not all boat traffic was from Lake residents.

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[13] *Due to the non-normality of the data, all calculations of statistical significance for this study utilized the non-parametric Kruskal Wallis test via the function “kruskal.test” from the “stats” package in R version 4.1.1.*

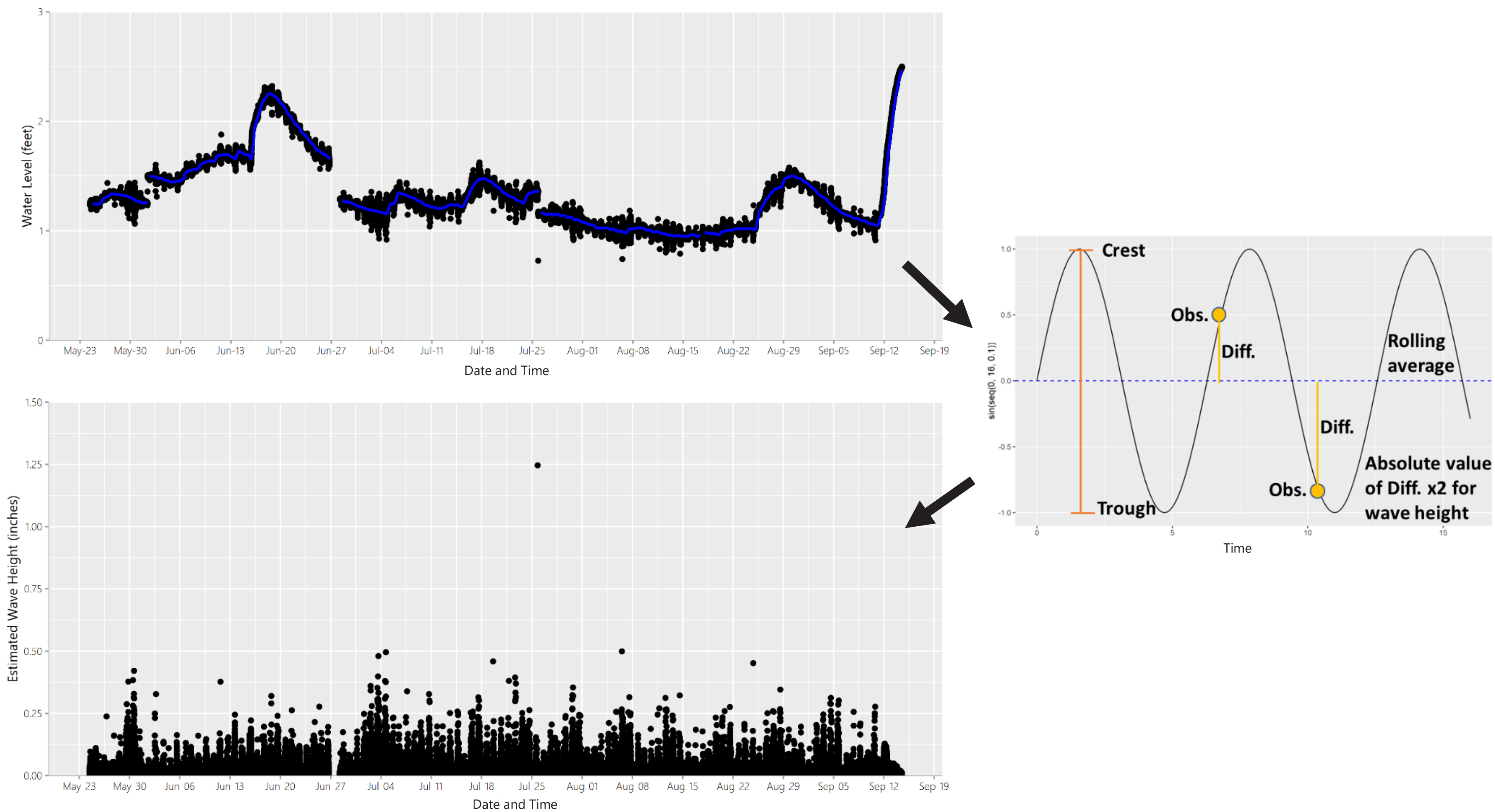
[14] *As per a North Lake Management District April 26, 2022 newsletter, the District established guidelines requesting boaters to not operate in “wake surf” mode on the western basin and that wake boats should operate as close to the middle of the Lake as possible. For more information, see the following link: nlmddotorg.files.wordpress.com/2022/07/north-lake-water-and-boater-safety-laws-and-guidelines-220426.pdf.*

[15] *Wake boats were distinctly counted by the observer on the western basin but were included in the “skiing/wakeboard/tubing” tally for the observer on the eastern basin.*

[16] *As an example, observer notes would occasionally state “sail school” with a checkmark rather than providing a tally of the number of sailboats.*

Figure 4

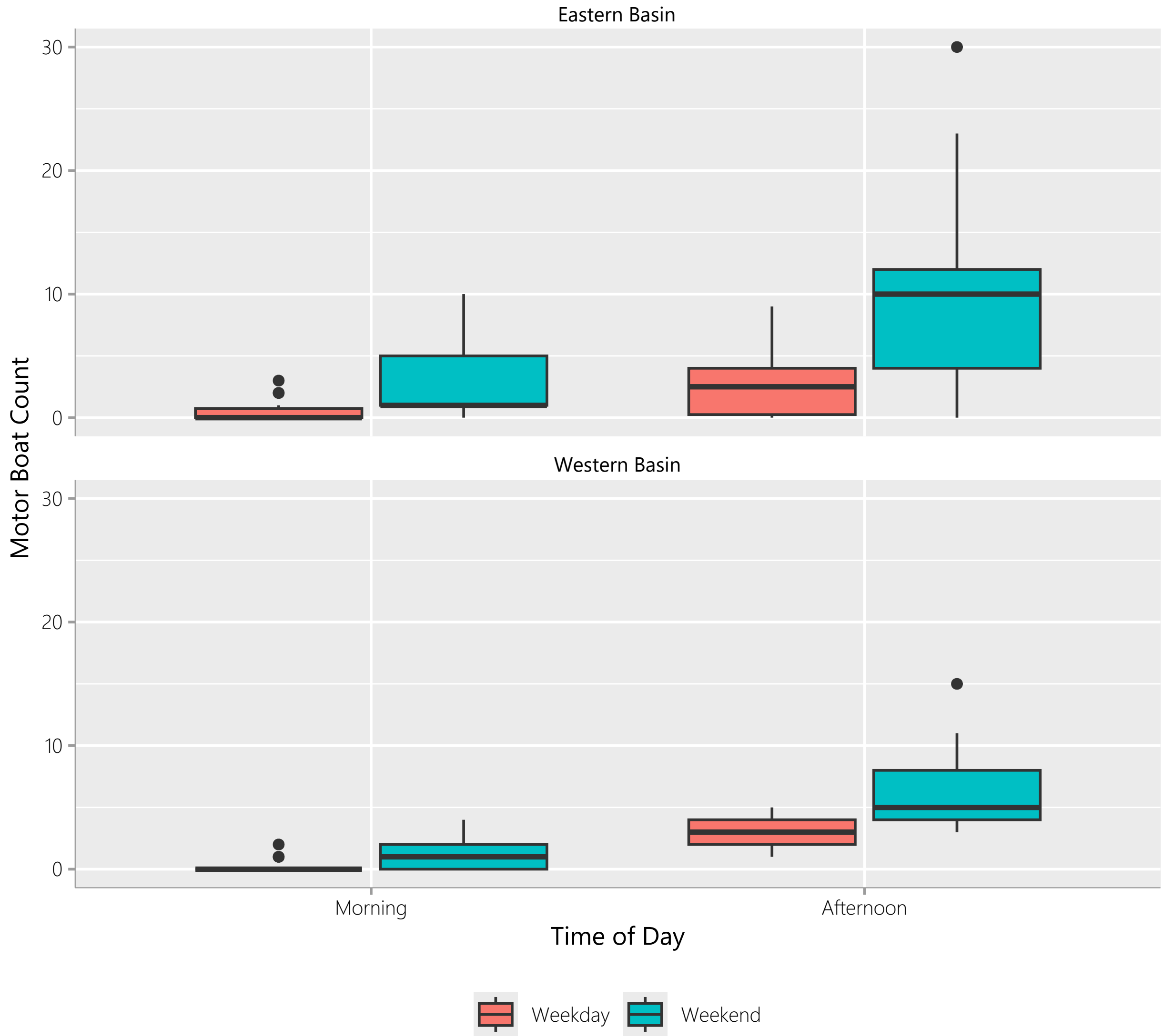
Recorded Water Levels, Wave Height Calculation, and Estimated Wave Heights at Site 7: Summer 2022



Note: The blue line in the top image represents the 10-hour rolling average of the recorded water levels. In the diagram on the right, an example wave is illustrated in black with the crest, trough, and wave height measurement (red line with bars) indicated. The rolling average is represented as a blue dashed line. Each water level observation (Obs.) is represented as an orange dot on the wave while the difference (Diff.) between the observation and the rolling average is shown as an orange line. The estimated wave height is the absolute value of the difference for each water level observation multiplied by two as each observation only represents half of the wave height measurement (i.e., either the crest or trough).

Source: North Lake Management District and SEWRPC

Figure 5
Motor Boat Count by Time of Day on North Lake: 2022



Source: North Lake Management District and SEWRPC

Commission staff conducted an analysis intended to quantify desirable levels of Lake boat traffic following methods outlined by a study on Michigan lakes. This study concluded that 10 to 15 acres of usable lake area per boat provides a reasonable and conservative average maximum desirable boating density, and covers a wide variety of boat types, recreational uses, and lake characteristics.[17,18] Use rates above this threshold are considered to negatively influence public safety, environmental conditions, and the ability of a lake to host a variety of recreational pursuits. High-speed and other higher impact watercraft require more space, necessitating boat densities less than the low end of the range. The suggested density for a particular lake is:

Minimum desirable acreage per boat = 10 acres + (5 acres x (high-speed boat count/total boat count))

In both the eastern and western basins, the highest boat use during the 2022 observational periods occurred during Sunday afternoons and holidays. Most boats in use during peak periods were capable of high-speed

[17] *Useable lake area was defined in the study as the size of the open water area that is at least 100 feet from the shoreline.*

[18] *A.E. Progressive*, Four Township Recreational Carrying Capacity Study, Pine Lake, Upper Crooked Lake, Gull Lake, Sherman Lake, *Study prepared for Four Township Water Resources Council, Inc. and the Townships of Prairieville, Barry, Richland, and Ross, May 2001.*

operation; however, only an average of 34 percent were operated at high speed across the observation periods. Given that only 74 acres are usable for high-impact boating in the western basin, only five to seven boats should be present in the western basin at any one time to avoid use problems, depending on the number of boats in high-speed operation.[19] Recorded boat use in the western basin exceeded this optimal density during 11 of 47 observation periods (23 percent). Nearly all these exceedances occurred during Sunday afternoons, except one exceedance on the morning of Sunday, July 10th and two others during the afternoons of Tuesday, July 19th and Tuesday, August 9th. The eastern basin has 274 acres which are usable for high-impact boating, meaning that between 18 to 27 boats should be present at any one time to avoid or limit potential user conflict problems. Eastern basin recorded boat use exceeded this optimal density during 4 of 48 observations periods (8 percent). All four exceedances occurred during Sunday afternoons. In both basins, the busiest boating days had a recorded number of boats that was over double the optimal number of boats to avoid use conflicts on the Lake.

Lake Water Quality

North Lake was a hub of water quality monitoring during the summer of 2022, with several groups conducting studies concurrently. The following section summarizes the water quality collection efforts and highlights results that are particularly important for evaluating changes in water quality due to wind or boating activity.

The District, in collaboration with Terra Vigilis Environmental Services, monitored several water quality parameters on North Lake throughout the study, including water temperature, dissolved oxygen, turbidity, total phosphorus, and total suspended solids. These measurements were taken at eight nearshore sites spread throughout the Lake (see "Water Quality Monitoring" on Map 1). Samples were generally collected on either Sundays or Tuesdays to evaluate the effects of boating activity on water quality, with Sundays representing a high boating activity period and Tuesdays a low activity period.

Separately, researchers from the University of Wisconsin – Milwaukee conducted a nitrogen-focused nutrient study on North Lake. These researchers measured several forms of nitrogen and phosphorus as well as water temperature, dissolved oxygen, and chlorophyll-*a*. Algal communities within the Lake were also characterized as part of this project. While this monitoring was spatially extensive, these measurements were limited to three sampling events during late spring, early summer, and late summer. For the purposes of this report, these measurements are more useful for establishing a seasonal context for changes in the Lake's water quality and less helpful for evaluating changes due specifically to wind or boating activity.

Temperature

During summer, many Wisconsin lakes with water depths greater than 20 feet experience a layering of their waters known as stratification. As summer progresses and surface waters warm, a difference in water temperature and density forms a barrier between the shallow and deep waters. This barrier is comprised of a temperature gradient known as the thermocline characterized by approximately 0.5°F of change per foot of water depth. The thermocline separates the warmer, less dense, upper layer of water (the epilimnion) from the cooler, more dense, lower layer (the hypolimnion). Across southeastern Wisconsin, the thermocline is generally found somewhere between 10 and 30 feet below the surface, with the depth varying by lake, month, and year. This thermocline range in depth is also representative for North Lake as can be observed amongst the historical lake profile data from years 1991 through 2024 in the WDNR Water Explorer tool.[20]

Terra Vigilis staff measured temperature profiles at eight sites spread throughout nearshore areas of the Lake in 2022 (see Figures A.1 and A.2 in Appendix A). These measurements were conducted on Sunday and Tuesday afternoons, aside from one Saturday measurement on May 7th in lieu of a measurement that Sunday. Surface temperatures ranged from 48.8°F on May 7th to 86.0°F on July 5th while temperatures at 20 feet water depth ranged from 47.1°F on May 7th to 69.5°F on August 30th. All sites exhibited seasonal progressions in temperature, with cooler temperatures in May and the warmest temperatures in July and August. This seasonal change was also evident through the development of the thermocline, as all sites had fairly uniform temperatures with depth on May 7th but each exhibited stratification with depth starting in mid-May and continuing through the remainder of the 2022 study period. There were no significant differences in water temperature by monitoring site.

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[19] *Useable lake area for each basin was calculated as the size of the open water area at least 200 feet from shore.*

[20] *See the WDNR Water Explorer tool at the following link: dnr-wisconsin.shinyapps.io/WaterExplorer.*

Water temperatures were significantly cooler during weekends than weekdays (*test significance*, $p<0.002$) (see Figure 6), even after excluding May 7th for which there was no corresponding weekday date. However, sampling date weekend air temperatures recorded at the Tempest weather station were also significantly cooler than sampling date weekday air temperatures (*test significance*, $p<0.001$), suggesting that this difference is most likely driven by weather rather than boating activity. At the 20 foot depth temperatures in the eastern basin were significantly warmer than the western basin (*test significance*, $p<0.001$), weekdays are significantly warmer than weekends, and significance differences by month (see Figure 7). September and August were warmer than July and June, which was warmer than May. None of this can be attributed to boating differences, but just like the five foot depth changes, these changes are driven by weather and show how this deeper water continues to increase in temperature from May to September.

Dissolved Oxygen

Dissolved oxygen (DO) levels are one of the most critical factors affecting the living organisms of a lake ecosystem. DO is generally higher at the surface of a lake where there is an interchange between the water and atmosphere, stirring by wind action (which aids in atmospheric oxygen diffusion into the surface waters at the air-water interface), and oxygen production by plant and algae photosynthesis. Metabolic processes, such as bacterial decomposition and respiration by aquatic organisms, consume oxygen and decrease DO concentrations. A minimum DO concentration of 5 mg/l is considered necessary for survival of most species of fish.

Dissolved oxygen was measured by Terra Vigilis staff at the same times and locations as water temperatures (see Figures A.3 and A.4 in Appendix A). As with water temperature, dissolved oxygen showed patterns of stratification with depth as well as seasonal trends. Surface waters ranged in dissolved oxygen concentrations from 7 mg/l on August 14th to 14 mg/l on May 15th while concentrations at 20 feet water depth ranged from 0.35 mg/l on August 9th to 16 mg/l on May 17th and June 12th (see Figures 8 and 9, respectively) There were significant differences in dissolved oxygen between monitoring sites (*test significance*, $p<0.001$), with the highest median concentrations at Sites 1 and 4 in the western basin and the lowest median concentrations at Site 7 in the eastern basin.

Water Clarity

Water clarity is a major component of water quality and is often what comes to mind when people think of "clean water." Clarity may decrease because of turbidity caused by:

- High concentrations of small, aquatic organisms, such as algae and zooplankton
- Suspended sediment and/or inorganic particles
- Color caused by high concentrations of dissolved organic substances (e.g., tannins that stain water of bog lakes in northern Wisconsin)

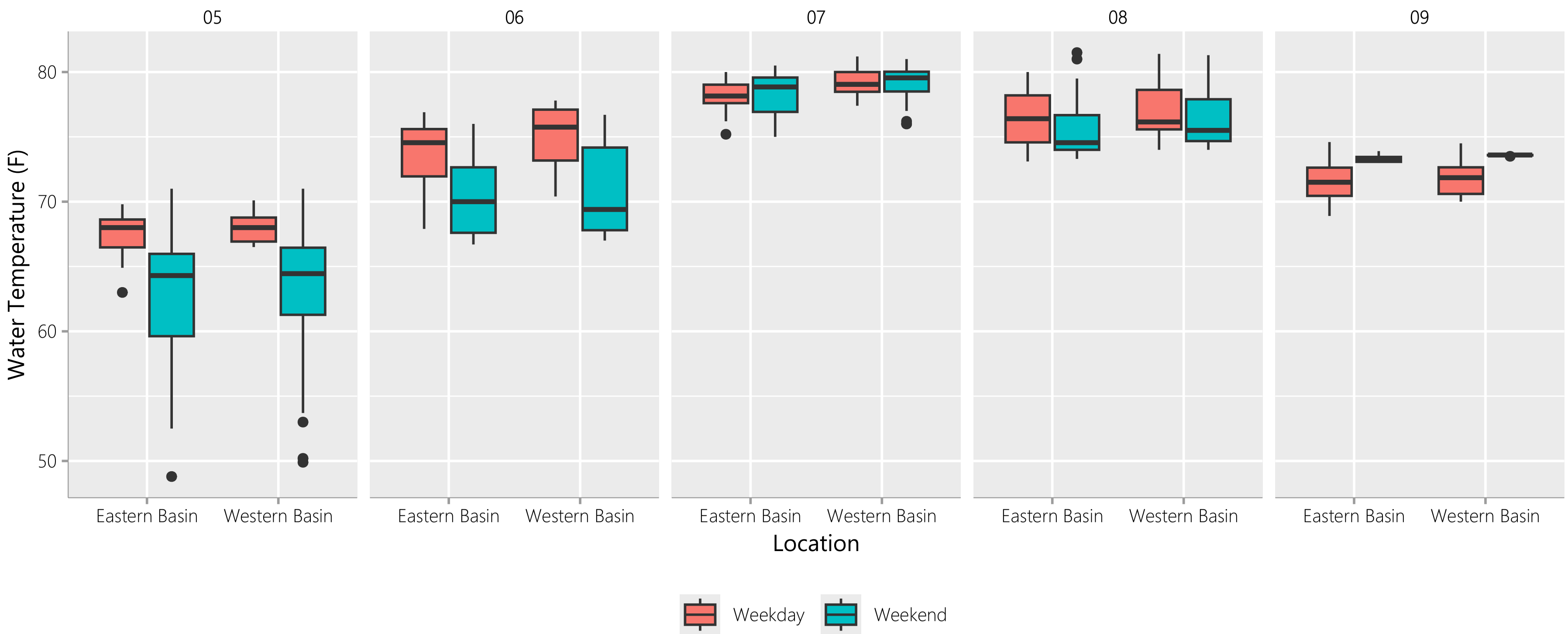
In most Southeastern Wisconsin lakes, water clarity is influenced by the abundance of algae and suspended sediment. Water clarity generally varies throughout the year as algal populations increase and decrease in response to changes in lake temperature, sunlight, and nutrient availability.

Secchi Depth

Secchi depth refers to a metric of water clarity, which is measured using a standard black-and-white "Secchi disc." This disc is lowered to a water depth at which point the observer can no longer see it, at which point the disc is then raised to a depth until it becomes visible to the observer again. The average of these two depths is the Secchi depth.

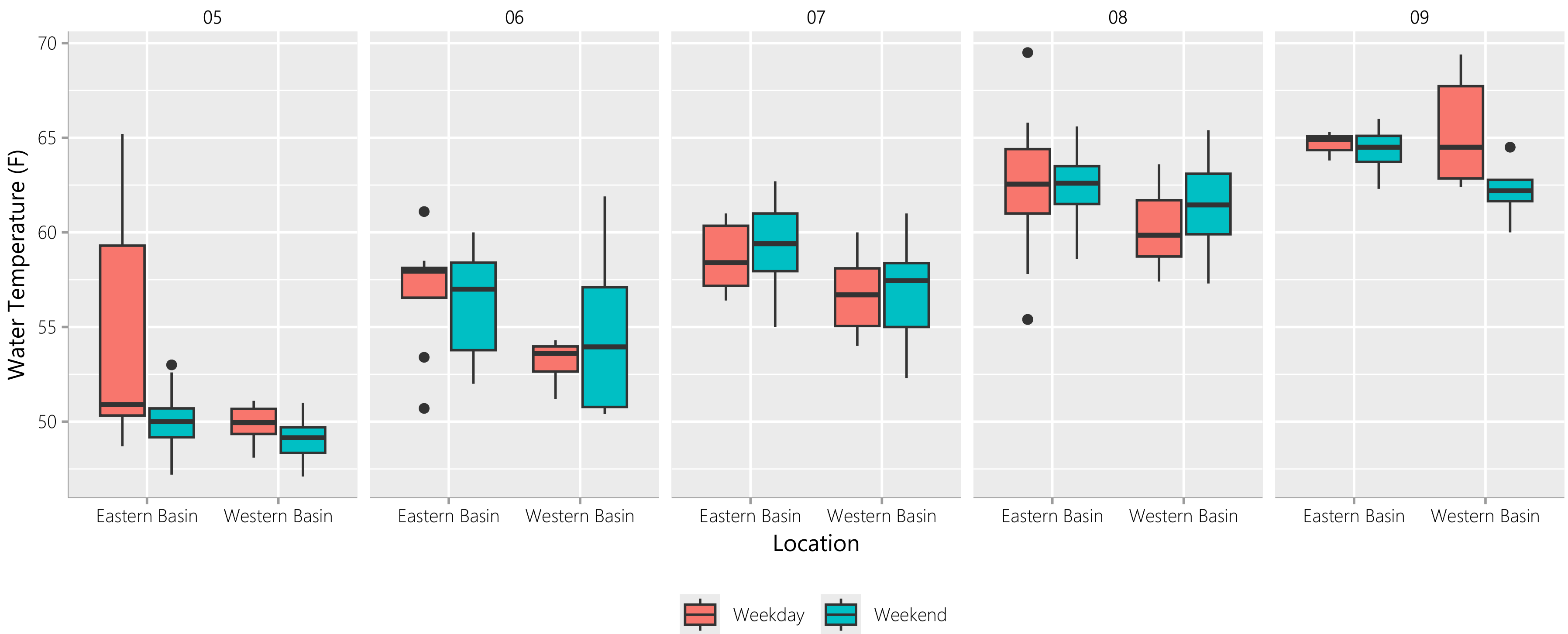
As with water temperatures and dissolved oxygen concentrations, secchi depths were measured by Terra Vigilis staff at eight sites spread across the Lake on Sunday and Tuesday afternoons throughout the 2022 study period. Secchi depths were generally higher at all sites in early summer, with Secchi depths of up to 17 feet observed in early June. Clarity declined rapidly through mid- to late June and Secchi depths remained around six to seven feet throughout July and early August. In mid- to late August, clarity improved with Secchi depths of nine to eleven feet before declining by a foot or so in early September. Commission

Figure 6
Water Temperature at Five-Foot Depth on North Lake: 2022



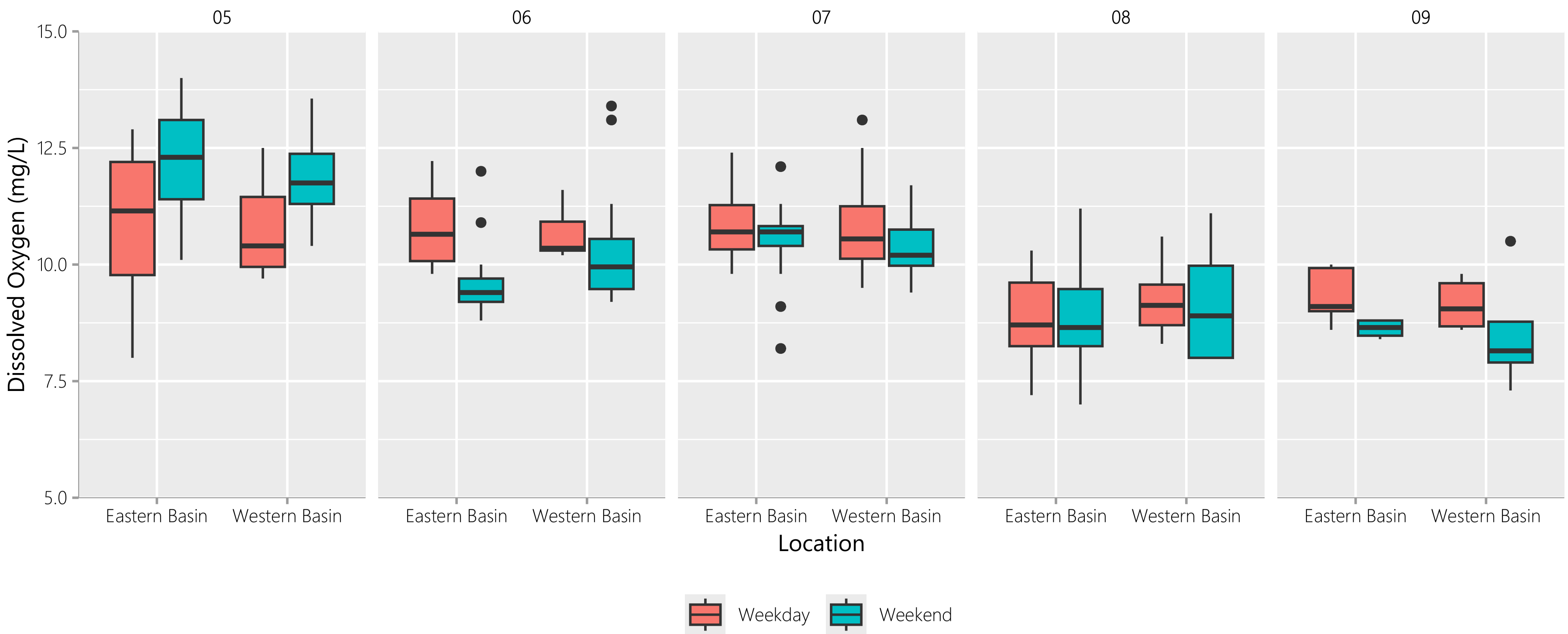
Source: North Lake Management District and SEWRPC

Figure 7
Water Temperature at Twenty-Foot Depth on North Lake: 2022



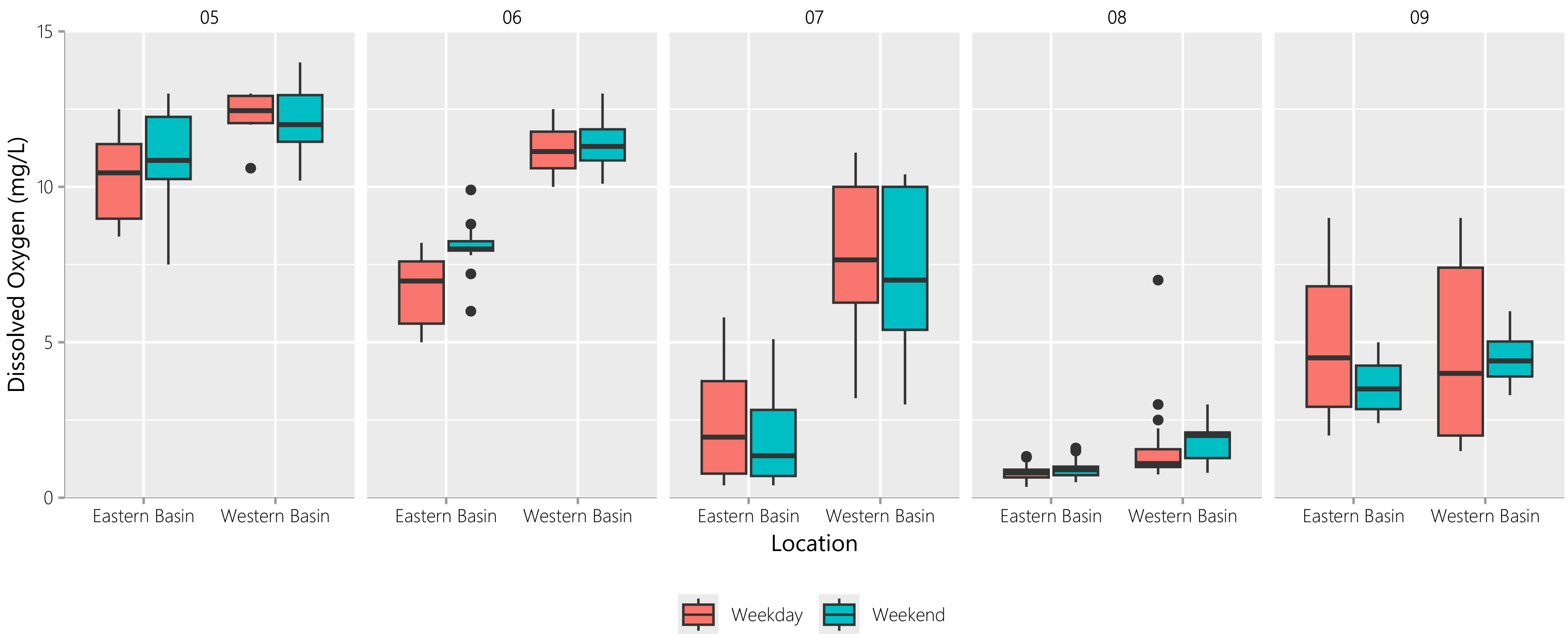
Source: North Lake Management District and SEWRPC

Figure 8
Dissolved Oxygen Concentrations at Five-Foot Depth on North Lake: 2022



Source: North Lake Management District and SEWRPC

Figure 9
Dissolved Oxygen Concentrations at Twenty-Foot Depth on North Lake: 2022



Source: North Lake Management District and SEWRPC

staff did not determine a statistically significant difference in Secchi depth between weekday and weekend observations, but the western basin had significantly higher clarity than the eastern basin ($p=0.007$) and there were significant differences in clarity by month: May and June were significantly clearer than August and September, which were significantly more clear than July ($p<0.001$) (see Figure 10).

Turbidity

Turbidity refers to the concentration of suspended particles that cause water to have a cloudy appearance. As mentioned above, turbidity can be caused by suspended algae, silt and/or clay particles, or dissolved organic substances. The District monitored turbidity on Sunday and Tuesday mornings and afternoons at two sites, one on the eastern basin and one on the western basin. These measurements were taken concurrently and from the same location as the boating activity observations described in the "Boating Activity" section earlier in this report. Due to difficulties with calibrating the turbidity monitoring equipment, only turbidity values from the eastern basin were analyzed for this report.

Through May and into early June, turbidity remained low during nearly all monitoring sessions. Starting in mid-June, afternoon turbidity measurements nearly always exceeded morning measurements and Sunday measurements were generally higher than Tuesday measurements. The highest turbidities observed during the 2022 study period were on the afternoons of July 3rd at 106 NTU, July 24th at 101 NTU, July 5th at 37 NTU, and September 4th at 35 NTU.[21] As described during the "Boat Activity" subsection earlier in this report, the afternoons of July 3rd and July 24th had some of the highest boat observations during the study while July 5th followed a busy boating weekend as well as some of the highest wind gusts observed during the study.

Total Phosphorus

Phosphorus is a key nutrient for aquatic plants and algae, with the availability of phosphorus often limiting their growth and abundance. Two forms of phosphorus are commonly sampled in surface waters: total phosphorus and dissolved phosphorus. Total phosphorus consists of all the phosphorus contained in material dissolved or suspended in water while dissolved phosphorus consists of the phosphorus contained in material dissolved in water. Terra Vigilis staff measured TSS at the same eight sites and on the same Sunday and Tuesday afternoons as the Secchi depth, water temperature, and dissolved oxygen measurements. Phosphorus concentrations generally ranged from 0.01 to 0.03 mg/l, but Terra Vigilis staff observed a period with concentrations were elevated up to 0.132 mg/l on Sunday, July 10th and 0.143 mg/l on Tuesday, 12th.[22] Nearly all total phosphorus measurements exceeded the WDNR regulatory limit for two-story lakes of 0.015 mg/l. Commission staff did not find a statistically significant difference in total phosphorus concentrations between weekdays and weekends, but August had significantly lower total phosphorus than all other months and total phosphorus was significantly lower in the western basin vs. the eastern basin (see Figure 11). Lower total phosphorus concentrations in August may reflect increased uptake by aquatic plants and algae, which generally reach their highest biomass in August.

Total Suspended Solids

Total suspended solids (TSS) consist of particles at least two microns in size that are suspended in the water column. These solids vary in type and origin, including lake sediment (e.g., silt, sand, clay), plant materials, animal tissue, and plankton. Terra Vigilis staff measured TSS at the same sites and times as the total phosphorus and other water quality measurements. Across all locations and sampling periods, TSS concentrations ranged from 2 to 8 mg/l with the highest TSS observations on July 3rd and July 21st at Site 1 in the western basin of the Lake. Commission staff did not determine a statistically significant difference in TSS between the eastern and western basins, but TSS was significantly higher on weekends than weekdays ($p<0.03$) and was significantly higher in July than in other months ($p<0.001$) (see Figure 12).

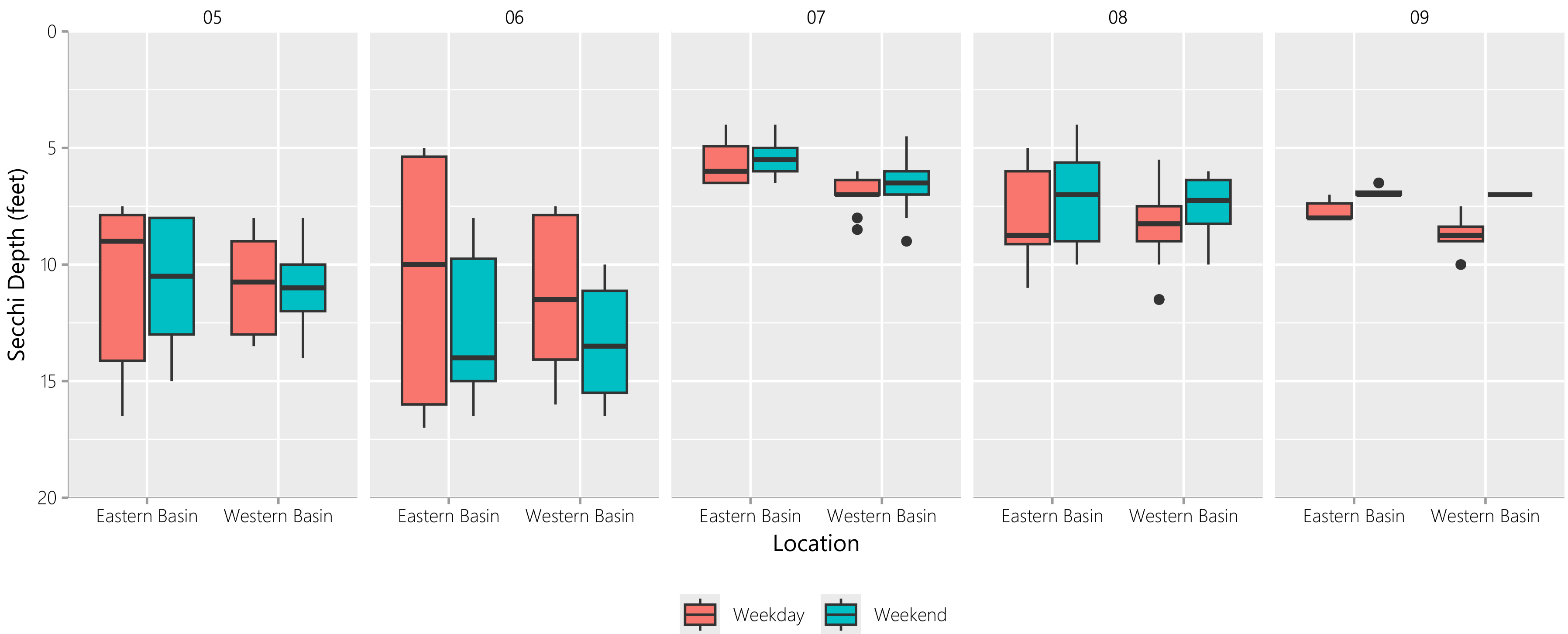
Stream Monitoring

This subsection will briefly describe ongoing streamflow and total phosphorus monitoring conducted by the Oconomowoc Watershed Protection Program (OWPP) on Mason Creek and the Oconomowoc River, which are the major inflows and outflows from the Lake. These measurements are important for providing context to analyses of Lake water quality changes.

[21] *Despite recording the second highest turbidity during the 2022 study period, the observer noted a water appearance of "clear." The observer also added a note questioning the high value and stating that the sample was tested twice.*

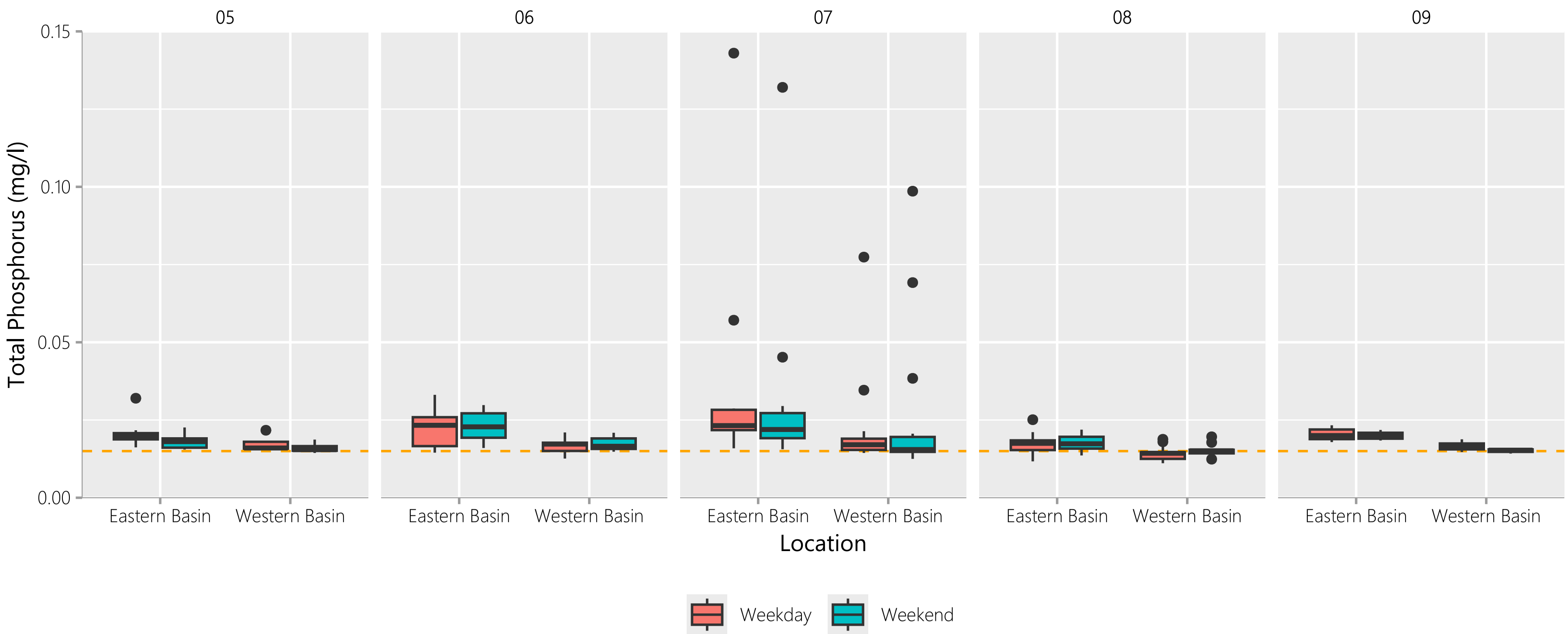
[22] *A fireworks show was held on North Lake on July 10th, 2022.*

Figure 10
North Lake 2022 Secchi Depth by Month, Basin, and Day of Week



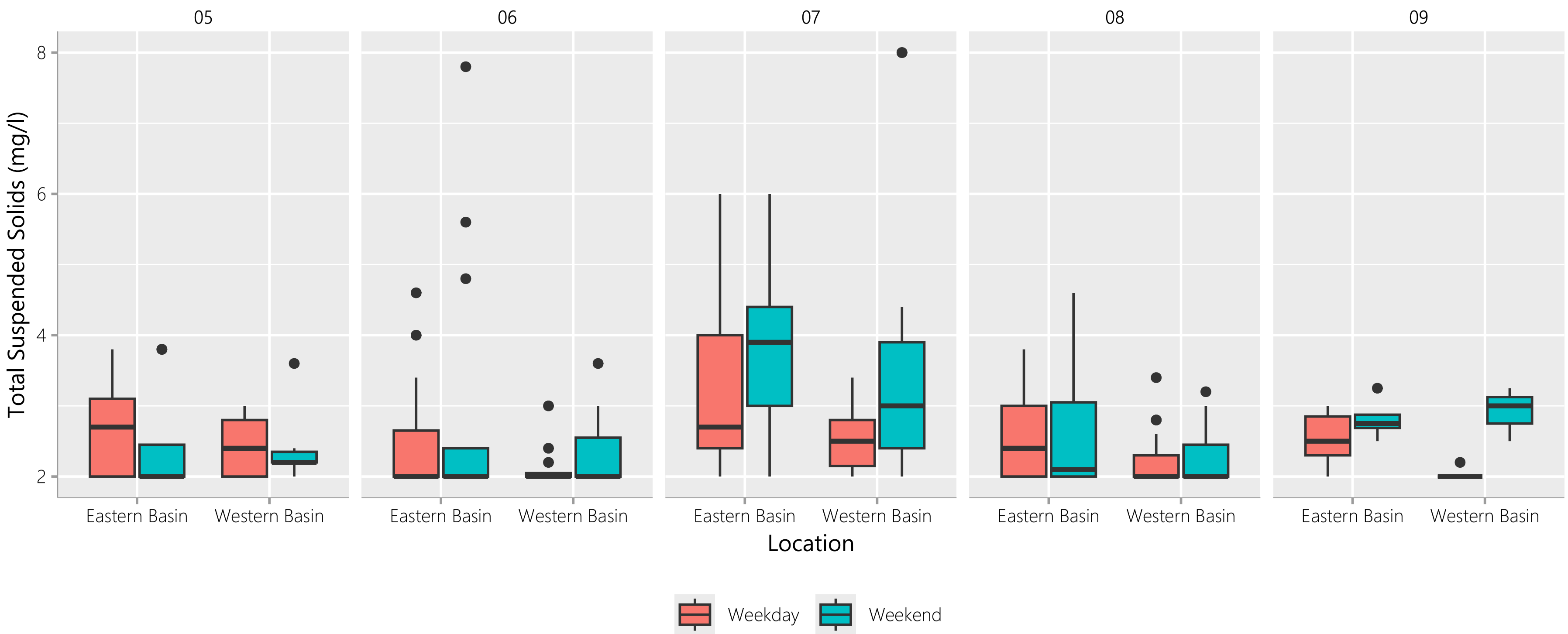
Source: North Lake Management District and SEWRPC

Figure 11
North Lake Total Phosphorus by Month, Basin, and Day of Week: 2022



Source: North Lake Management District and SEWRPC

Figure 12
North Lake Total Suspended Solids by Month, Basin, and Day of Week: 2022



Source: North Lake Management District and SEWRPC

The OWPP monitored total phosphorus and streamflow on Mason Creek as well as the Oconomowoc River at the Highway 83 crossing northeast of the Lake and downstream of the Lake on Sunday and Tuesday from July 10th, 2022 to September 13th, 2022. Streamflow was calculated from water velocity, stream width, and water level measurements; the stream width and difference in water level from a reference level was used to calculate an appropriate trapezoidal area to determine a total cross-section of water for each site. The stream velocity was then used to calculate the streamflow at the site in million of gallons per day. The total phosphorus concentration was multiplied by the streamflow for each day at each site to determine the total phosphorus load (in pounds per day) for each site.

Total phosphorus loads on the Oconomowoc River at Hwy 83 and on Mason Creek ranged between 3.0 to 15.8 pound per day and 0.4 to 5.9 pounds per day, respectively, during the relatively dry weather between July 10th and September 10th. Following heavy rainfall during mid-September, total phosphorus loads at both sites increased to their maximums observed during the study of 63.9 and 66.2 pounds per day for the Oconomowoc and Mason Creek, respectively. While total phosphorus loads were not calculated for the first half of the study, the precipitation and Lake water elevation data suggest that higher total phosphorus loads may have occurred following heavy rainfall in mid- to late June. Incoming phosphorus loads were relatively stable throughout July and August, so notable changes in Lake total phosphorus concentrations during these months (e.g., on July 10th) were unlikely to be caused by a change in these incoming loads.

The total phosphorus loads measured on the Oconomowoc River downstream of the Lake largely reflect changes in total phosphorus concentrations within the Lake, with the highest loads observed on July 10th at 14.2 pounds per day and on September 13th at 15.2 pounds per day. The September 13th total phosphorus load was driven by higher streamflow following heavy precipitation. Hence, although the actual total phosphorus concentration is slightly lower than average for the measurements conducted during the 2022 study period, the total load was higher because of the increased flow volumes.

Wave Propagation

This section will attempt to distinguish wind- and boat-produced waves on North Lake to the extent feasible using data from Phases 1, 2, and 3 of the study as well as monitoring equipment installed by the Commission. Wave characteristics and behavior will be described as well as the potential largest waves that could be produced via wind or watercraft.

Wind-Produced Waves

Weather, particularly precipitation and wind speed, influences lake circulation, water quality, wave action, and recreational use. Elevated precipitation can increase surface water elevations, amplifying the effect of increased wave heights on shorelines. Additionally, increased runoff following heavy precipitation events can potentially affect water clarity as well as the concentrations of chlorophyll*a*, total phosphorus, and total suspended solids. Wind speed greatly influences wave height and power. Documenting local wind speed and direction is essential to understand natural wave dynamics on the Lake, whether boatproduced waves can exceed the height and power of windproduced waves, and the additive effects of wind on boatproduced waves.

As described in a 2021 staff memorandum report, Commission staff utilized the WDNR's shoreline erosion calculator tool to estimate the wave heights and energies that could be expected on North Lake during a storm event (defined as wind speed of 35 mph).[23] Storm wave height and energy were calculated for each basin for both approximately north-south and east-west winds using the longest fetches possible. Under these assumptions, the maximum windproduced wave height that can be expected on North Lake is approximately 1.13 feet, garnering a moderate storm wave energy rating. However, as North Lake has predominantly westerly winds, storm wave heights of 0.6 to 0.8 feet and of low energy are likely much more common for both Lake basins.

As described in the "Water Levels" section earlier in this report, Commission staff estimated wave activity by calculating a one-hour rolling mean of one-minute interval water level data and then calculating the absolute value of the difference between each observation and the rolling mean. These differences were

[23] *Staff Memorandum,* Preliminary Morphology, Water Level, Water Quality, and Wave Propagation Update for North Lake, Town of Merton, Waukesha County*, March 2021.*

multiplied by two as wave heights are measured from crest to trough. This estimate is likely conservative as the water level logger is unlikely to record the crest or trough of any given wave. Commission staff analyzed the water level differences observed during periods of varying wind speeds: 0 to 5 mph, 5 to 10 mph, 10 to 15 mph, and over 15 mph. Higher wind speeds were associated with higher median water level differences at each monitoring station, with the highest median water level difference of 1.1 inches on the eastern side of the eastern basin with winds of over 15 mph (see "WL Site 1" on Map 1). Consequently, higher wind speeds cause heightened wave activity on North Lake.

Boat-Produced Waves

Commission staff utilized several different methods to evaluate the size and activity of boat-produced waves, including review of Phases 2 and 3 of the Terra Vigilis study on North Lake, review of other relevant studies, and analyses using the Commission's water level loggers. The Commission also compared these boat-produced waves against the maximum likely wind-produced waves observed during the 2022 study period as well as the potential highest wind-produced waves possible for North Lake.

Wave Measurements

As described in the Phase 2 and 3 reports, Terra Vigilis measured maximum wave heights produced by four different boats: a 2004 jet ski, a 1991 pontoon boat, a 2014 wake board boat, and a 2020 wake board boat (see Table 1).[24] The jet ski, pontoon boat, and 2020 wake board boat were all operated at 250 feet from shore during Phase 1 while only the 2020 wake boat was operated at 200 and 300 feet from shore in Phase 2 and only the 2014 wake boat was operated at 200, 300, and 400 feet from shore in Phase 3. The highest waves measured were ten inches and were produced by the 2020 wake board boat operating 250 feet from shore. The 2020 wake board boat operating 200 feet from shore produced waves of equivalent height (eight inches) to the 1991 pontoon boat operating 250 feet from shore while the jet ski at 250 feet from shore produced waves larger than the 2014 wake board boat operating 200 feet from shore.[25] At 300 feet from shore, both the 2014 and 2020 wake boat produced wave heights lower than the jet ski or pontoon boat operating at 250 feet from shore. The reports for Phase 2 and 3 do not provide a clear explanation on why the wake boat would produce wave heights lower than a jet ski or pontoon boat. Nonetheless, this could be due to potential design flaws in the wave study, such as moving the wake sensors to different monitoring depths and sites between phases as that would greatly affect measured wave heights.

Table 1
Maximum Wave Heights of Boats at Various Distances from Shoreline

Phase	Boat Model	Operating Weight During Test (lbs.)	Maximum Wave Height (inches) for Each Distance to Shoreline			
			200 feet	250 feet	300 feet	400 feet
1	2020 Super Air Nautique GS20, "Surf Mode"	6,784		10″		
1	1991 Sun Cruiser Pontoon Boat	Not provided		8″		
1	2004 SeaDoo PWC Model GTX 4TE	Not provided		5″		
2	2020 Super Air Nautique GS20, "Surf Mode"	6,784	8″		4.5″	
3	2014 Ski Nautique V-Drive with Hydrogate, "Ski Mode"	3,600	3″		2″	1″
3	2014 Ski Nautique V-Drive with Hydrogate, "Surf Mode"	4,304	3″		1.5″	1″

Source: North Lake Management District, Terra Vigilis Environmental Group, and SEWRPC

[24] *See Table 1 of Terra Vigilis, December 2022,* op cit. *for more information.*

[25] Ibid.

These wave height measurements were collected in different water depths in each Phase, which limits the ability to make meaningful comparisons between test runs in different Phases as water depth strongly affects wave characteristics and behavior.[26] Thus, the only direct comparisons that can be made using this wave data are those from test runs within each Phase as the monitoring location was presumably not moved. Within Phase 1, the 2020 wake board boat produced larger waves than the pontoon boat or the jet ski. The wave period of the wake board boat remained relatively constant at approximately two seconds throughout the wave packet while the wave period of the pontoon boat and jet ski began at two seconds but decreased to approximately one second by the end of the wave packet.[27] Within Phase 3, there was little difference in maximum wave height at 200 or 400 feet from shore between the 2014 wake board boat operating in "ski mode" and in "surf mode."[28] This result is not consistent with other wave studies to date which have found that using wake-enhancing equipment and modes should create a larger wave than not utilizing this equipment and traveling on plane. Therefore, even within the limited capacity of this study to make direct comparisons in wave heights between boats due to experimental design flaws, there are still inconsistencies with other studies that are difficult to explain.[29] These inconsistences are compounded with a lack of run replication and notes on critical aspects of the study, which makes interpreting the results even more challenging. Consequently, the wave height measurements from this study are of limited use and Commission staff largely utilized other published studies for the preparation of the "Boating Activity Impacts to Lakes" section below.

Water Level Loggers

Commission staff analyzed the water level logger data to evaluate whether boat-produced waves could be distinguished from wind-produced waves. This analysis was conducted in two ways: by evaluating water level differences during the boat activity observation periods and by examining high water level differences during periods with low wind speeds.

Commission staff evaluated water level differences during the boating activity observation periods to determine if there was a correlation between more boating activity and higher wave activity. As illustrated in Figure 13, there are weak but positive correlations between the number of motorboats active during the observation periods and the median water level differences. These correlations are higher in the eastern basin, which had a higher number of active motorboats, than they were in the western basin.

As illustrated in Figure 14, the water level loggers recorded dozens of water level differences between two and four inches during daylight hours while wind speeds were 10 mph or less. These observations are likely indicative of wave activity produced by boating activity, as many of these observations occurred during weekends and holidays. Consequently, these records indicate that waves likely produced by boating activity match or exceed those produced by wind speeds over 15 mph on North Lake.

Wind-Produced vs. Boat-Produced Waves

Using "waver" package in R 4.1.1, Commission staff calculated the wave energy of the 2020 wake board boat wave measured in Phase 2 of this study as well as the 2020 Super Air Nautique in "Surf Mode" wave measured in Phase 1.[30] With a significant wave height of 8 inches and a period of 2 seconds, the Phase 2 wave had an energy of 0.039 kW/m. This energy is roughly equivalent to a significant wave height from a 42.9 mph wind on an east-west fetch of the western basin or a 38.5 mph wind on an east-west fetch of the western basin (see Figure 15). The Phase 1 wave had a significant wave height of 10 inches and a period of 2 seconds, with a wave energy equivalent energy to a 57 mph wind on an east-west fetch of the western basin.

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[26] Ibid.

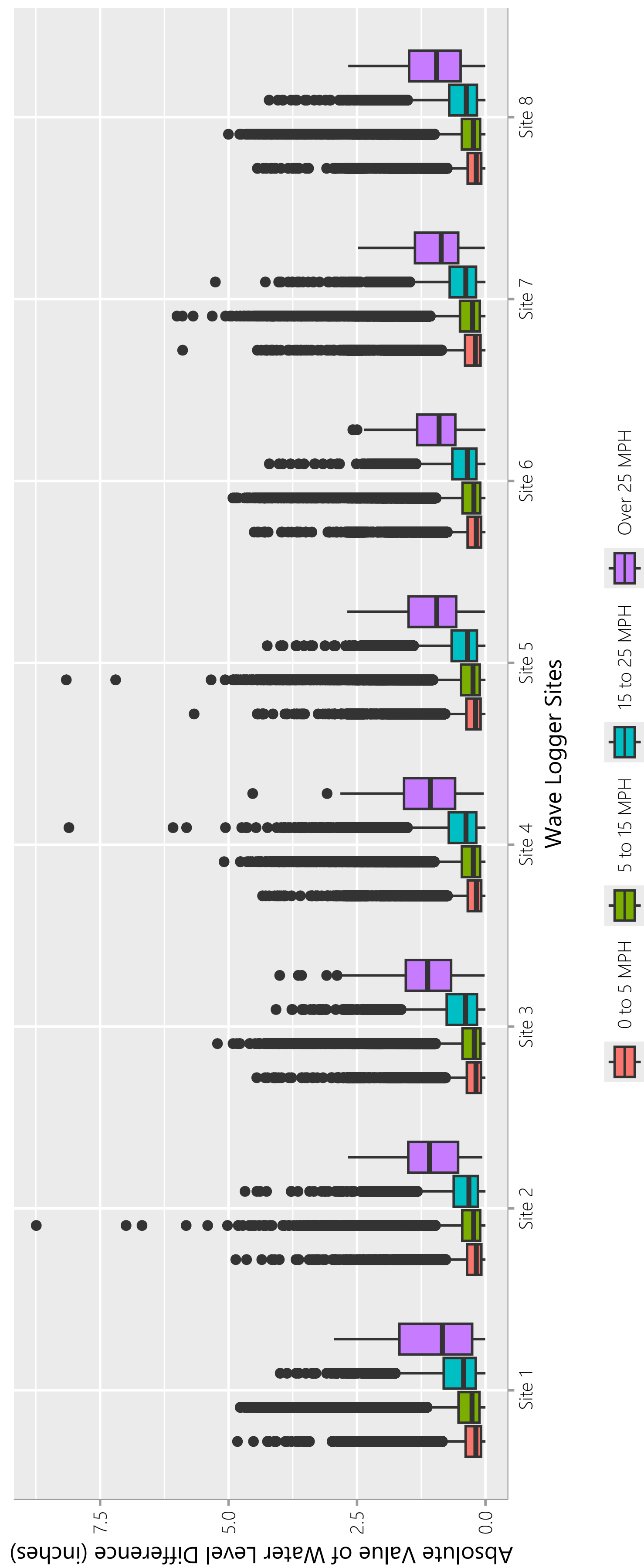
[27] *Terra Vigilis, July 2022,* op cit.

[28] *In "ski mode," the boat weighs 3,600 pounds and is operated on plane at 30 mph with the Hydrogate lowered. In "surf mode," the boat weights 4,300 pounds and is operated at 12 mph with the Hydrogate lifted so the boat transom sits lower in the water.*

[29] *Commission staff did not receive a clear explanation for this report's inconsistencies with other published studies in either Phase 2 or 3 reports nor from the report authors.*

[30] *Philippe Marchand and David Gill (2018).* waver: Calculate Fetch and Wave Energy. *R package version 0.2.1. CRAN.R-project.org/package=waver.*

Figure 13
Water Level Differences on North Lake During Daytime at Various Wind Speeds: 2022



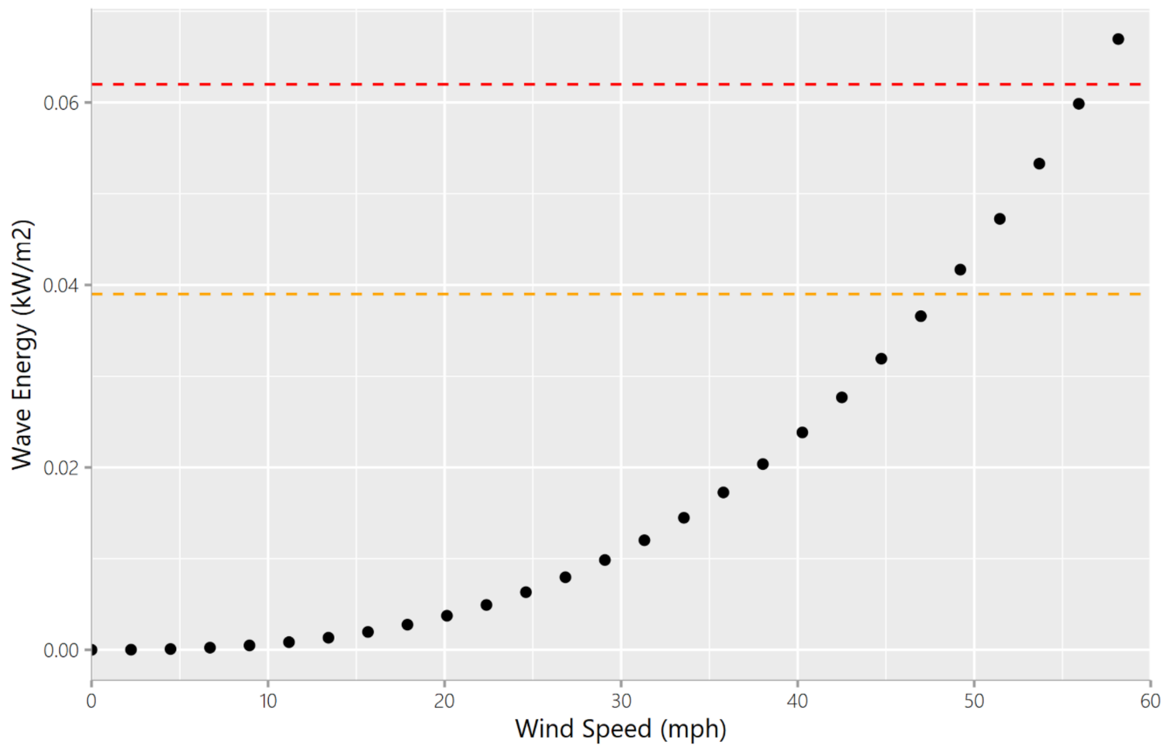
Source: North Lake Management District and SEWRPC

Figure 14
Presumed Boat-Generated Water Level Differences: 2022

Note: This figure shows the absolute value of water level differences over two inches during the daytime when wind gusts were less than five mph.
These water level differences are presumed to be generated by boating activity.

Source: North Lake Management District and SEWRPC

Figure 15
Wave Energy by Wind Speed for East-West Fetch on Western Basin of North Lake



Note: The orange dashed line represents the corresponding wave energy for the wake boat wave reported in Phase 2 while the red line represents the largest wake boat wave in Phase 1.

Source: North Lake Management District and SEWRPC

BOATING ACTIVITY IMPACTS TO LAKES

Boat wakes have been shown to erode shorelines,[31] scour and disrupt the bottom sediments of a lake,[32] damage aquatic vegetation and disrupt aquatic animal communities,[33] and temporarily decrease water clarity.[34] However, boat wake energy is event-dependent and is influenced by the vessel length and weight, water depth, waterbody bathymetry, and boat speed.[35] Wakes are most destructive in shallow and narrow waterways because wake energy does not have the opportunity to dissipate over distance.[36] Although boat wakes are periodic disturbances in comparison to wind waves, they can be a significant source of erosive wave force due to their longer wave period and greater wave amplitude.[37] Even small recreational vessels

[31] *Bilkovic, D., M. Mitchell, J. Davis, E. Andrews, A. King, P. Mason, J. Herman, N. Tahvildari, J. Davis,* Review of Boat Wake Wave Impacts on Shoreline Erosion and Potential Solutions for the Chesapeake Bay, *STAC Publication Number 17-002, Edgewater, MD, 2017*

[32] *Asplund, T.R. (Wisconsin Department of Natural Resources),* The Effects of Motorized Watercraft on Aquatic Ecosystems, PUBL-SS-948-00, *University of Wisconsin– Madison, Water Chemistry Program, 2000.*

[33] *Asplund, T.R., and C. M. Cook, "Effects of Motor Boats on Submerged Aquatic Macrophytes,"* Lake and Reservoir Management*, 13(1): 1-12, 1997.*

[34] *U. S. Army Corps of Engineers (USACE),* Cumulative Impacts of Recreational Boating on the Fox River - Chain O' Lakes Area in Lake and McHenry Counties, Illinois: Final Environmental Impact Statement*, Environmental and Social Analysis Branch, U.S. Army Corps of Engineers, Chicago, IL. 194 p., 1994; Asplund, T. R.,* Impacts of Motorized Watercraft on Water Quality in Wisconsin Lakes*, Wis. Dep. Nat. Res. Bur. Research, Madison, WI. PUBL-RS-920-96., 1996.*

[35] *STAC Publication Number 17-002, 2017, op. cit.*

[36] Ibid.

[37] *Houser, C., "Relative Importance of Vessel-generated and Wind Waves to Salt Marsh Erosion in a Restricted Fetch Environment,"* Journal of Coastal Research *262: 230-240, 2010.*

operating within 500 feet of the shoreline are capable of producing wakes that can erode shoreline and increase nearshore turbidity.[38]

Wake boats are specifically designed to artificially enhance the height and size of the generated wakes to enable specific watersports, such as wake-boarding and wake-surfing. These boats can create waves that have several times the energy and height of other powerboats, which they can achieve by using specialized equipment such as ballast tanks to increase the boat's weight as well as shaped boat hulls and hydrofoils to "shape" and heighten the boat wake.[39,40] Both perceptions from lakeshore residents as well as scientific studies have indicated the wake board boats, whether wake surfing or wake boarding, can produce larger and more powerful waves along shorelines than other boats. The results of this study on North Lake are consistent with other studies in this regard. For example, results from Phase 1 illustrate that wake-enhanced boating produced larger maximum wave heights than pontoon boats and jet skis on North Lake. The wake heights recorded from wake board boats in Phases 1 and 2 are comparable to height measurements from the St. Anthony Falls study. Additionally, results from Phase 1 and 2 indicate that wake board boats can affect water movement down to 20 feet below the Lake surface while jet skis, ski boats, and pontoon boats only affect water down to five feet below the surface. These results demonstrate that enhanced-wake recreational boating can generate larger waves than other powerboats. Enhanced wake operations can also generate larger waves than most small inland lakes experience, except during rare high wind events.[41,42]

The larger and more powerful wakes produced from wake-enhanced boating have the potential to affect lake water quality and aquatic habitat more strongly than other boats when operated at similar distances from shore and in similar water depths. Several recent studies have focused on the impacts of wake-enhancement on the shorelines, water quality, and aquatic biota within inland lakes.[43] As mentioned earlier in this section, powerboat wakes can have erosive effects on shorelines and these effects are likely to be heightened with the increased wave size and energy from wake-enhanced boating, because the energy of the wave is directly proportional to the height or size of the wave.[44,45] The following subsections will describe the impacts to water quality, aquatic habitat, and bottom sediment as measured in this study and put these findings in context with other scientific studies on these topics.

Water Quality

The field monitoring efforts conducted throughout the summers of 2021 and 2022, as described in the Phase 2 and Phase 3 reports, did not enable Commission staff to directly measure the effects of individual boat wakes, whether from powerboats, personal watercraft, or wake boats, on water quality or aquatic habitat. Commission staff evaluated how water quality differed between high and low boating activity periods as well as examined potential correlations between some water quality parameters (water clarity, total phosphorus, total suspended solids, turbidity, temperature, and dissolved oxygen) and the number of active motorboats.

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[38] *STAC Publication Number 17-002, 2017, op. cit.*

[39] *Marr, J., Riesgraf, A., Herb, W., Lueker, M., Kozarek, J., and K. Hill, A Field Study of the Maximum Wave Height, Total Wave Energy, and Maximum Wave Power Produced by Four Recreational Boats on a Freshwater Lake, University of Minnesota St. Anthony Falls Laboratory, February 2022.*

[40] *Mercier-Blais, S. and Y. Prairie, Project evaluation of the impacts of waves created by wake boats on the shores of the lakes Memphremagog and Lovering, University of Quebec, 2014*

[41] *Marr et al., 2022,* op. cit.

[42] *Water Environmental Consultants,* Boat Wake Impacts Analysis: Lake Rabun and Lake Burton*, Georgia, 2021.*

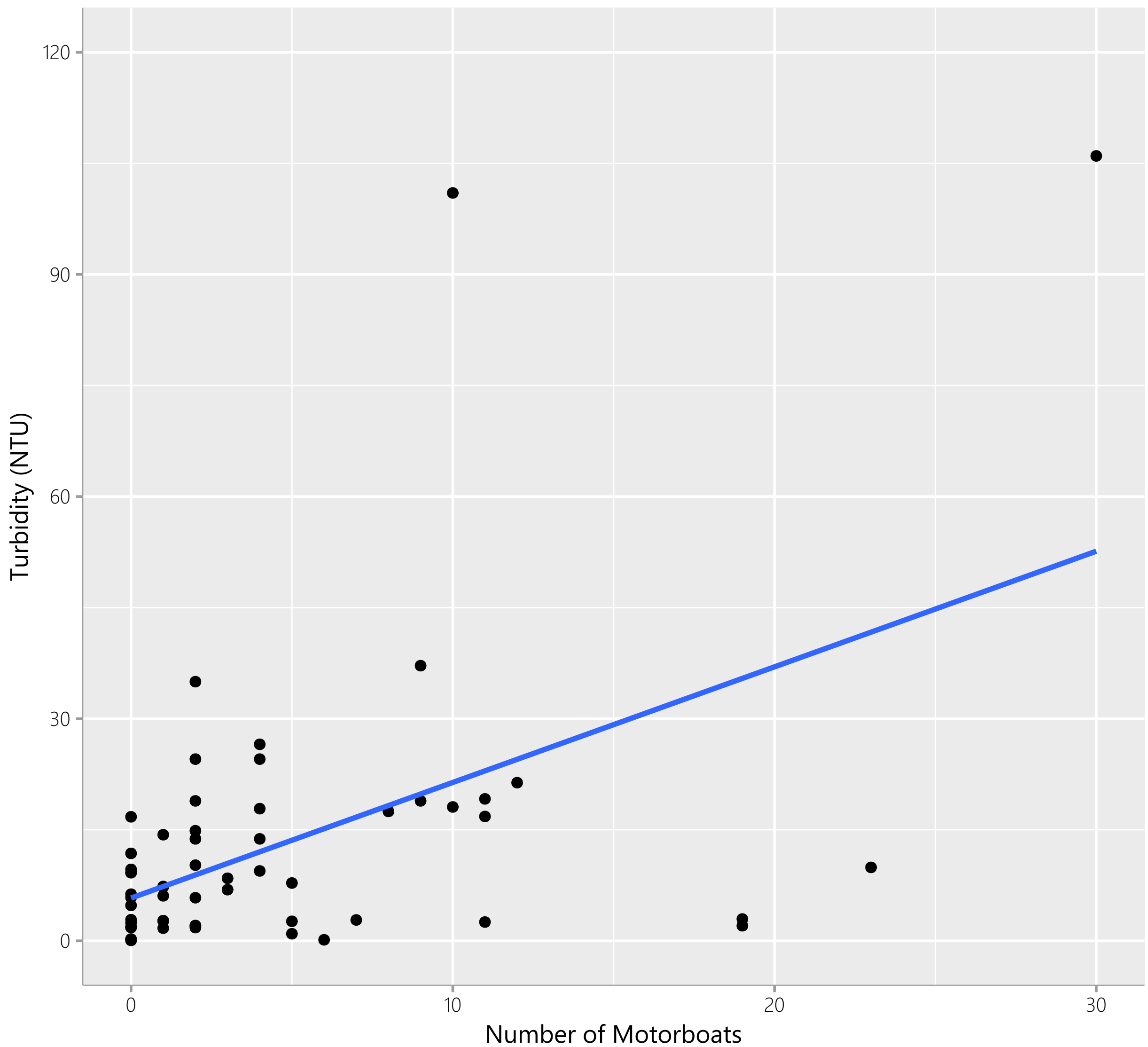
[43] *See Francis, J., Nohner, J., Bauman, J., and B. Gunderman,* Wake boats: concerns and recommendations related to natural resource management in Michigan waters*, State of Michigan Department of Natural Resources, September 2022, (mymlsa.org/wp-content/uploads/2022/09/DNR-Wake-Boat-Report.pdf) and Ortiz, D.A., Meyer, M., Daulton, T., and B. Kovar,* The Effects of Wake Boats on Lake Ecosystem Health: A Literature Review, Wisconsin Greenfire*, May 2024 (wigreenfire.org/2019/wp-content/uploads/2024/05/WakeBoatsLakeEcosystemHealth_WGF-May2024_Final.pdf) for recent literature reviews on these topics.*

[44] *Bilkovic et al., 2017,* op. cit.

[45] *Francis et al., 2022,* op. cit.

Using the turbidity measurements collected on the eastern basin, Commission staff evaluated whether there was a correlation between turbidity and boating activity within this basin. As illustrated in Figure 16, there was a noisy but statistically significant correlation between the number of motorboats observed and the nearshore turbidity (test significance, $p<0.001$, *adjusted* $R^2=0.24$). Significant but even noisier correlations were observed between the number of active motorboats and total suspended solids concentrations ($p<0.005$, *adjusted* $R^2=0.09$) as well as total phosphorus concentrations ($p<0.01$, *adjusted* $R^2=0.07$). There was not a significant correlation between Secchi depth and the number of active motorboats, but the water clarity was six feet or lower when more than twenty motorboats were active at one time. These results corroborate those observed in other studies that boating activity can stir up sediment in shallow water, causing decreases in water clarity and increases in water column phosphorus concentrations.[46,47]

Figure 16
Shoreline Turbidity by Motorboat Count



Source: North Lake Management District and SEWRPC

[46] *Asplund, 1997,* op. cit.

[47] *USACE, 1996,* op. cit.

As discussed in Domain 6 in the Phase 2 report, total phosphorus measurements were collected at three sites established 100 feet from shore and in three to five feet of water directly before and after a wake board boat run.[48] This test was the only direct measurement of how an individual wake board boat wave affects Lake water quality. The Phase 2 report notes a 17 to 33 percent increase in total phosphorus concentrations after the run compared to the baseline measurements taken before the run. While the post-run measurements were higher than nearly all the baseline measurements, these differences were equivalent to or just greater than the differences between baseline measurements within each site. Additionally, no similar tests were conducted for pontoon boats or jet skis to evaluate whether wake board boats caused greater increases in total phosphorus concentrations than other boat types. These results are inconclusive and would require further testing to verify.

Commission staff evaluated temperature and dissolved oxygen data between high and low boating activity periods and determined that there were no statistically significant differences in either parameter between these periods. The Commission could not determine whether boating activity caused an immediate disruption to the thermocline as the experimental design did not lend itself to such analyses. A follow-up study with temperature and dissolved oxygen profiles immediately before and after a boat passes or a research buoy with continuous temperature and dissolved monitoring at several depth intervals before, during, and after the boat passes may better be able to detect such changes. Nonetheless, if the thermocline had been disrupted by boating activity during the 2022 study period, it would have likely led to increased total phosphorus spikes in either basin. This was not observed, except for one spike in concentration that seemed to be related to the delayed 4th of July fireworks event. Hence, boating activity is not likely related to any disruption of the thermocline on North Lake, which is expected given that North Lake is a deep water lake.[49, 50]

Aquatic Habitat

This study did not directly measure the impacts of wake board boats or any other individual boat type on aquatic plants or habitat. As discussed in Domain 3 of the Phase 2 report, Terra Vigilis staff conducted videography surveys during fall 2020 and on May 26th and September 25th, 2021 of the aquatic plant community near Wildwood Point. Of the information presented in the Phase 2 report, the May 26th survey appears to have largely occurred in shallow water with depths between two to three feet reported on the linked video while the depths reported on the linked video for the September 25th report are between 12.8 to 14 feet. Abundant and largely native plant growth is visible on the May 26th video while little to no vegetation is visible in the September 25th video; however, there is no clear link provided between the absence of vegetation in the second survey area and impacts from wake board boats. The lack of vegetation at lower depths, as shown in the September 25th video, is consistent with previous aquatic plants as discussed in the Phase 2 report.

While the Phase 2 report suggests that sediment redeposition from wake board boats may be causing detrimental impacts to aquatic plants, it also states that this suggestion was not tested or verified in this study. The suggested sediment covering the aquatic vegetation in the fall 2020 survey was not confirmed and no video evidence was provided of sediment suspended by boating activity causing deposition of sediments onto vegetation in this or any other area. No other information is provided from this study regarding the impact of wake board boats or any other types of boats on aquatic plant communities.

All powerboating activities impact native aquatic flora and fauna, but these impacts are again likely to be greater with wake-enhanced boating because of the larger waves and deeper propellor compared to other powerboats.[51,52] These impacts can be direct, such as propellor scarring of the lake bottom that destroys aquatic habitat or fragmenting and propagating invasive aquatic plants, or indirect, such as water quality impacts that can affect fish feeding or spawning behavior as well as can alter nutrient and light availability for aquatic plants and algae.

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[48] *Terra Vigilis, July 2022,* op. cit.

[49] *Yousef, Y. A., McLellon, W. M., and H. H. Zebuth, "Changes in phosphorus concentrations due to mixing by motorboats in shallow lakes,"* Water Research *14: 841-852, 1980.*

[50] *Asplund, 1996,* op. cit.

[51] *Asplund, 1997,* op. cit.

[52] *Francis et al., 2022,* op. cit.

Bottom Sediment Disturbance

Domain 6 of the Phase 2 report suggests that wake board boats can cause water movement up to 20 feet below the Lake surface while pontoon boats and jet skis can only cause movement up to five feet below the surface. Similar videography of fiber optic cable movement from pontoon boats and jet skis are not presented in the report. Commission staff could not determine from this video whether the fiber optics are responding to propeller downwash or to movement from the pole (to which the fiber optics are attached) from surface waves.[53] Since this is presumably the same technique used by Terra Vigilis staff in the Phase 3 report on Okauchee Lake to document propeller downwash to a depth of 20 feet, then these results are preliminary and should be re-verified with documentation that the study equipment is not subject to movement due to waves at the surface.[54] This study did not address whether the energy produced by this propwash would be large enough to cause disturbance of lake bottom sediment nor did it document sediment resuspension occurring at depths of 20 feet or greater within North Lake. Instances of nearshore sediment disturbance along Wildwood Point were documented through aerial imagery in Phase 1 at depths less than five feet.

Several other studies on water quality impacts from wake-enhanced boating have focused on sediment resuspension.[55] Powerboat-induced sediment resuspension has been shown to decrease water clarity and increase turbidity and total phosphorus concentrations in inland lakes and rivers.[56,57] All powerboats can cause lake bottom sediment disturbance and resuspension, but these effects have been shown to be increased with greater wave energy as well as a deeper and more downward-angled propellor in wake-enhanced operations than other powerboating operations.[58,59] Sediment resuspension with an associated and statistically significance increase in total nitrogen was observed at a depth of five feet in one such study;[60] no statistically significant changes were observed in water depths of ten or fifteen feet following a single pass of a wake boat.[61] Results from this study also suggest that the lake sediment composition and coverage by vegetation are important factors for resuspension by boating activity; flocculent mucky sediment and sediment without aquatic vegetation covered were more susceptible to resuspension by boating activity than sandy sediment or sediment with abundant aquatic plant coverage.[62]

SUMMARY OF OBSERVATIONS

The following observations can be gained from this study.

Recreational Boat Counts

- More motorboats on:
  - Weekends than weekdays
  - Afternoons than mornings
  - Eastern basin than on western basin

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[53] *See fiber optic cable video from Phase 2 report at following link: www.youtube.com/watch?v=9ujTrHpEl1U.*

[54] *Commission staff have not provided with any video of the propwash study on Okauchee Lake.*

[55] *Francis et al., 2022,* op. cit. *and Ortiz et al., 2024,* op. cit.

[56] *Asplund, 1997,* op. cit.

[57] *USACE, 1996,* op. cit.

[58] *Mercier-Blais and Prairie, 2014,* op. cit.

[59] *Daeger, A., Bosch, N.S., and R, Johnson, "Impacts on Nutrient and Sediment Resuspension by Various Watercraft Across Multiple Substrates, Depths, and Operating Speeds in Indiana's Largest Natural Lake,"* Proceedings of the Indiana Academy of Sciences *130(2): 112-122, 2022.*

[60] *Increases in total phosphorus and suspended solid concentrations were also observed at a depth of five feet but these increases were not statistically significant.*

[61] *Daeger et al., 2022,* op. cit.

[62] Ibid.

- Boat "carrying capacity" exceedances
  - 10 times (16 percent of observation periods) on western basin
    - Holidays, weekend afternoon, and morning of fireworks show
  - 4 times (7 percent of observation periods) on eastern basin
    - Holidays and weekend afternoons

What effect did boating have on water quality in North Lake?

- Nearshore lake water quality sampling Sites 1 through 7 in both basins
  - No relationship between motorboat counts and nearshore water clarity (as measured by secchi depth)[63], total phosphorus, temperature, or dissolved oxygen
  - Significant difference in TSS on weekends vs. weekdays

- Boat activity and turbidity site on the eastern basin only
  - Significant increase in shoreline turbidity and total motorboat counts
  - Significant difference in turbidity among months and weekdays vs weekends

Motorboat versus wind-generated wave measurements

- Higher wind speeds were associated with higher median water level differences at each monitoring station, with the highest median water level difference of 1.1 inches on the eastern side of the eastern basin with winds of over 15 mph. Consequently, higher wind speeds cause heightened wave activity on North Lake.

- Large water level differences at low wind speeds (less than ten mph) were presumed to be waves generated by boating activity. Some of these boat-generated waves exceeded the largest waves generated by high winds during the 2022 study period.

- All boats tested had both surface and subsurface impacts, however, the wake boats in surf mode had significantly greater wave impacts (total wave height and energy) compared to other vessels (i.e., ski boat, pontoon boat, and personal watercraft (PWC)). This was also consistent with greater intensity of darker turbidity within the nearshore areas (less than five feet in depth) of the Lake shoreline areas compared to all other boats tested.

- Greater distance from shore (200 vs. 300 vs. 400 feet) reduced wave heights for each vessel type.

- The larger and heavier wake boats in wake surf mode generate a larger wave with more wave energy than a vessel in wake surf mode that has a lower total operating weight.

- Results from different phases of the study indicate that pontoon boats and PWC may have similar or greater maximum wave heights than the older and lighter wake boats in either ski or surf mode. However, the measurement location (i.e., sampling depth and potential slope differences) was moved between different phases of the study so results between different phases cannot be directly compared. Additionally, this finding is not consistent with other similar studies showing that wake boats in wake surf mode create significantly larger waves than other types of boats.[64]

- Wake boats in surf mode created wakes with energy equivalent to very high wind events (i.e., 48 to 57 mph wind speeds).

- Subsurface propwash depths for wake boats in surf mode were stated to go down to a depth of 20 feet from the water surface, which was attributed to differences in propeller angles, ballasting, and larger engine output. Propwash depths for other vessels (pontoon boat, ski boat, and PWC) while planing were stated to be no more than three to five feet.

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[63] *This lack of a relationship for water clarity is most likely a result of a combination of low boating activity, the substantial distance of the monitoring locations from the shoreline, and timing of boat activity compared to monitoring.*

[64] *See Mercier-Blais and Prairie, 2014 and Marr et al., 2022.*

RECOMMENDATIONS FOR ORDINANCE DEVELOPMENT

All boating activity can negatively affect water quality and aquatic habitat in various ways, but many forms of recreational boating are still allowed on most Wisconsin waterbodies. Thus, the relevant questions for ordinance development regarding wake-enhanced boating should not focus on whether these boats negatively affect lakes, but how to mitigate their impacts to be more comparable to other types of boating. This section will describe the current ordinances and guidelines in effect on North Lake as well as potential options for ordinance development regarding the regulation of wake-enhanced boating.

Current Ordinance and Guidelines on North Lake

The Town of Merton has established ordinances for boating operations on North Lake which the Village of Chenequa has adopted.[65] These ordinances list a maximum speed limit, set slow-no-wake hours, prohibit certain operations, describe placement of navigational markers, and adopt Wisconsin state boating and water safety laws, among other provisions. There are currently no ordinances regulating wake-enhanced boat operations nor establishing a separate slow-no-wake zone near shore from the zone established by *Wisconsin State Statute* 30.66(3)(a). This statute states that motorboats shall not be operated in excess of slow-no-wake speeds within 100 feet of any dock, raft, pier, or buoyed restricted area of the Lake nor within 100 feet of the shoreline.[66]

Following a report by the Lake Stewardship Committee, the District established guidelines for safe boating on North Lake in 2019 that were intended to act as a test for 2019 and 2020. The guidelines most relevant for this study were that all boats with wakes stay at least 250 feet from shore, that wake board boats should operate in the middle of the Lake, and that boats should not drive over sandbars. Since 2020, the District has continued these guidelines and modified them to ask boaters that wake surfing mode should not be conducted in the western basin of the Lake and that all wake board traffic should operate at least 500 feet from shore.[67] While entirely voluntary, the District has shared that most boaters readily comply with these guidelines and there has been little wake boat activity within the western basin, aside from the tests conducted for this study.

Potential Ordinance Examples

Several governments, including lake districts, municipalities, Counties, and States, have proposed and in some cases established regulations regarding wake-enhanced boating. This subsection will present regulations that have either been adopted or proposed by other governments as potential ordinance examples for North Lake. These examples have either prohibited wake-enhancing equipment and operations entirely or they have limited the areal extent to which these operations are permitted. Note that a legal expert should review any proposed ordinance to ensure compliance with Wisconsin state regulations. Additionally, the WDNR would need to review any proposed ordinance at least 60 days before action by the governing entity.[68]

Maintain Current Guidelines

As boaters seem to largely follow the safe boating guidelines established by the District, one option is to maintain these guidelines without drafting any additional ordinances. If Lake boaters regularly violate these guidelines, then establishing ordinances based on these guidelines or examples from other jurisdictions may become warranted.

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[65] *Town of Merton Ordinance 20.04 North Lake and Oconomowoc River, March 26th, 2018. library.municode.com/wi/merton,_waukesha_co/codes/code_of_ordinances?nodeId=CH20LABE_20.04NOLAOCRIAM42490AM62216RERE326182*

[66] Wisconsin State Statute *30.66(3)(a), docs.legis.wisconsin.gov/statutes/statutes/30/v/66/3/a.*

[67] *North Lake Management District Newsletter, May 2023. See nlmddotorg.files.wordpress.com/2023/05/230530-revised-lake-stewardship-boating-guidelines.pdf.*

[68] *Wisconsin Department of Natural Resources Bureau of Law Enforcement,* A Guideline for Creating Local Boating Ordinances and Placing Waterway Markers in Wisconsin Waters, PUB-LE-317-2019*, August 2018. dnr.wi.gov/files/PDF/pubs/le/LE0317.pdf.*

The North Lake Lake Management District guidelines currently do not a specify a minimum water depth for wake-enhanced operations.[69] However, based on the conclusion from this and other studies, the District could also consider adopting a minimum depth for wake-enhanced operations of 15 feet or an even more protective guidance of 20 feet deep.

Limit Areal Extent of Wake-Enhanced Operations

Governments have drafted or enacted rules regulating the areal extent of where wake-enhanced boat operations can occur. For example, the State of Vermont has received proposed draft rules to regulate wake boats while engaging in wakesports on public waters and is currently amid the rulemaking process for these draft rules.[70] These draft rules are as follows:

- Wake boats shall only be operated in wake sports mode on lakes, ponds, and reservoirs with a minimum of 50 contiguous acres that are 500 feet from shore on all sides and 20 feet deep

- Wake boats must be 500 feet from shore at all times while engaging in wakesports

- A wake boat must stay in one lake per calendar year unless the boat is decontaminated by a Department of Environmental Conservation-approved entity

The proposed rules regarding operating 500 feet from shore and requiring a minimum of 50 contiguous acres are similar to the current guidelines on North Lake. Adopting ordinances similar to these rules would prohibit wake sports in the western basin of the Lake due to lack of the required 50 contiguous acres. Use of wake enhancement would still be permitted in the eastern basin in the same manner as the current guidelines recommend.

Many studies about the impacts of enhanced wakes on inland lakes have addressed the effect of distance from shore and/or depth of water on mitigating wave impacts. These studies generally either recommend wake-enhanced operations at specific distances from shore and greater than specific depths of water or these studies have found equivalent distances for wake-enhanced operations to commonly accepted operations of non-ballasted powerboats at 200 feet from shore. Examples include:

- Recommend operation at least 500 feet from shore and in at least 15 feet of water[71]

- Operation at 600 feet equivalent to non-ballasted powerboat at 200 feet[72]

- Recommend operation at least 600 from shore and in at least 20 feet of water[73]

- Operation at 984 feet from shore required for wake-boat waves to dissipate completely[74]

Several municipalities in Sawyer County, Wisconsin have enacted ordinances within the past few years regulating wake-enhanced operations, including the Towns of Bass Lake, Hayward, Hunter, and Round Lake. These ordinances all use similar language that prohibits operating a motorboat in a manner that enhances an elevated wake for over fifty feet in length closer than 700 feet from shore or any dock, pier, raft, or other restricted area. An elevated wake is defined as a trail of disturbed water in excess of 24 inches following the watercraft.

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[69] *North Lake Management District, 2023,* op. cit.

[70] *Vermont Department of Environmental Conservation, Maps of Wake Sports Areas based on Proposed Draft Rule Conditions, accessed August 2023, dec.vermont.gov/watershed/lakes-ponds/maps-wake-sports-areas-based-proposed-draft-rule-conditions.*

[71] *Francis et al., 2022,* op. cit.

[72] *Marr et al., 2022*, op cit.

[73] *Ortiz et al., 2024,* op. cit.

[74] *Mercier-Blais and Prairie, 2014,* op. cit.

Restrict Hours for Wake-Enhanced Operations

Commission staff are not aware of any proposed or enacted ordinances that would set restricted hours for when wake-enhanced operations could occur on specific waterbodies. Setting these limits may be permitted under current State regulations via the same authority granted to set slow-no-wake operation hours. Setting periods for permitted wake-enhanced operations could be used instead of or in addition to areal extent limits to allow wake sports on the Lake while limiting impacts to the Lake and its other users.

Prohibit Wake-Enhanced Operations

Wisconsin state laws do not allow lake district, municipal, or County government to prohibit the use of any type of boat as this would violate the Public Trust Doctrine ensuring the public's access to its navigable waterways. However, these governments can regulate the operation of these boats, including prohibiting the use of wake-enhancing equipment and wake-enhanced operations on navigable waterbodies within their jurisdiction. The Town of Merton and Village of Chenequa could consider the following examples from other Wisconsin municipalities if they wish to adopt a similar ordinance for the Lake.

The City of Mequon and Village of Thiensville adopted ordinances in 2009 and 2010, respectively, that prohibited the use of any device, including water sacks, ballasts, or submersible wings, that can cause a boat to operate in a bow-high manner or increase a boat's wake on the Milwaukee River.[75,76] The Town of Rhine in Sheboygan County adopted an ordinance on April 13th, 2021, that restricted artificial wake enhancement on Crystal Lake utilizing language similar to the Mequon and Thiensville ordinances.[77] This ordinance was adopted by the Town Board as the Board had determined that artificially enhanced wakes cause environmental damage to the lake and its shorelines; that these wakes cause physical damage to private property; that these wakes cause dangerous conditions for swimmers, anglers, and other watercraft; and that boats with a ballast system increase the probability of aquatic invasive species transmission. The ordinance prohibits the use of equipment that increases a boat's wake, including water sacks, ballast tanks, and submersible wings, and prohibits operating a boat in an artificially bow-high manner to increase a boat's wake. Several other municipalities, including the Town of Oakland in Jefferson County; the Towns of Dayton, Farmington, and Lind in Waupaca County; and the Towns of Bass Lake, Round Lake, and Hayward in Sawyer County, have also recently passed ordinances that prohibit artificially enhanced wakes on lakes within their jurisdiction.[78,79,80,81,82,83,84]

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[75] *City of Mequon Ordinance 90-5(b), Prohibited Equipment. library.municode.com/wi/mequon/codes/code_of_ordinances?nodeId=PTIICOOR_CH90WA.*

[76] *Village of Thiensville Ordinance 50-205(c)(2), Prohibited Equipment. library.municode.com/wi/thiensville/codes/code_of_ordinances?nodeId=PTIIMUCO_CH50PARE_ARTIIIBO_S50-205GERE.*

[77] *Town of Rhine Ordinance 5.12, Restricting Artificial Wake-Enhancement on Crystal Lake, April 2021. townrhine.com/wp-content/uploads/2022/01/O.-Creating-5.12-Limiting-Wake-Enhancement-on-Crystal-00151708-7xB94F0.pdf.*

[78] *Town of Oakland 2023-02, Ordinance Repealing and Recreating Ordinance No. 2 of the Municipal Code of the Town of Oakland, April 2024. lakeripley.org/wp-content/uploads/2024/04/Boating-Ordinance-2024.pdf.*

[79] *Town of Dayton Ordinance 07/23/2024 (2024), An Ordinance to Restrict Artificial Wake Enhancement on Certain Lakes Within the Town of Dayton. cdn.townweb.com/town-dayton.com/wp-content/uploads/2024/08/Wake_Enhancement_Ord._07-23-242024_Signed.pdf.*

[80] *Town of Farmington Ordinance No. 00/0/24 (2024), An Ordinance to Restrict Artificial Wake Enhancement on Certain Lakes Within the Town of Farmington. wcwlc.org/wp-content/uploads/sites/14/2024/05/Ordinance-to-Restrict-Artificial-Wake-Enhancement-Town-of-Farmington.pdf.*

[81] *Town of Farmington Ordinance No. 00/0/24 (2024), An Ordinance to Restrict Artificial Wake Enhancement on Spencer Lake Within the Town of Farmington. wcwlc.org/wp-content/uploads/sites/14/2024/05/Ordinance-to-Restrict-Artificial-Wake-Enhancement-Town-of-Farmington.pdf.*

[82] *Town of Bass Lake Ordinance 2018-10-08, Town of Bass Lake Sawyer County Motorboat Wake Protection Area Ordinance, November 2018. static1.squarespace.com/static/589d2006ebbd1a9c437fd84a/t/5c991eee7817f76762bc84be/1553538798461/Boat+wake-Bass+Lake+Twp+Protection-Area-Ordinance+final.pdf.*

[83] *Town of Round Lake Ordinance 01-2020, Town of Round Lake Sawyer County Motorboat Wake Protection Area Ordinance, August 2020. www.townofroundlakewi.org/wp-content/uploads/2020/08/town015@centurytel.net_20200814_204352.pdf.*

[84] *Town of Hayward Ordinance 07-2021, Town of Hayward Sawyer County Motorboat Wake Protection Area Ordinance, July 2021. townofhayward.com/wp-content/uploads/2021/07/07-2021-Motorboat-Wake-Ord.pdf.*

SUPPLEMENTAL RECOMMENDATIONS

As previously mentioned, the current public access launch on North Lake is carry-in only. Reported compliance with existing ordinances and the proposed boating guidelines has been fairly good as all the motorboats operating on the Lake are owned by residents that currently live on the Lake.[85] This situation also reduces the likelihood of invasive species transmission, because the boats are staying on the Lake. However, if this public access launch were upgraded to allow boat trailered access in the future, then perhaps pursuing an ordinance may be more appropriate.

Maintaining a healthy and abundant rooted aquatic plant community is essential to protecting the Lake from boat wakes by physically slowing waves down and reducing sediment resuspension. Protecting rooted aquatic plants has the added benefits of providing habitat for fish and wildlife and improving water quality. Although not addressed in this study, shoreline slope can greatly affect wave intensity. Steep shorelines can reflect waves back out into the Lake, which can cause accelerated lakebed or shoreline erosion. Hence, steep slopes along the shoreline are subject to more erosion and less stability. This erodibility is amplified by soil type and removal or lack of vegetation. More gentle shoreline slopes and/or natural vegetated slopes can allow waves to dissipate their energy, which helps to reduce erosion rates. Therefore, promoting better shoreline slopes designed with vegetation (i.e., living shorelines)[86] as well as log and root wad revetment (i.e., fish sticks and tree drops) structures to reduce wave energy in front of shorelines are additional options for residents on North Lake to reduce erosion and promote fisheries habitat.[87]

Water quality monitoring should be continued in both basins of North Lake. Continued participation in the WDNR Citizen Lake Monitoring program is essential because any change in water quality could be an indicator of a serious problem.

Since wake boats and other heavy boats can generate larger and higher energy waves, it might be important to consider either reducing the existing slow-no-wake ordinance elevation of 897.2 feet high water mark or consider establishing additional guidance for wake boats and other heavy boats not to operate when water levels on North Lake get within a 0.5 feet or some equivalent of the 897.2 feet elevation. Since wake boats in surf mode were capable of producing wave heights of 8 to 10 inches in height, such wakes would exceed the 897.2 feet elevation even if water levels were 6 inches (896.7 feet) below the 897.2 feet surface water elevation. The District should consider installing a yellow warning buoy that could be anchored on the island between the small and large lake similarly to how a green buoy is deployed for slow-no-wake exceedance times.

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[85] *Personal communication between Commission and District staff.*

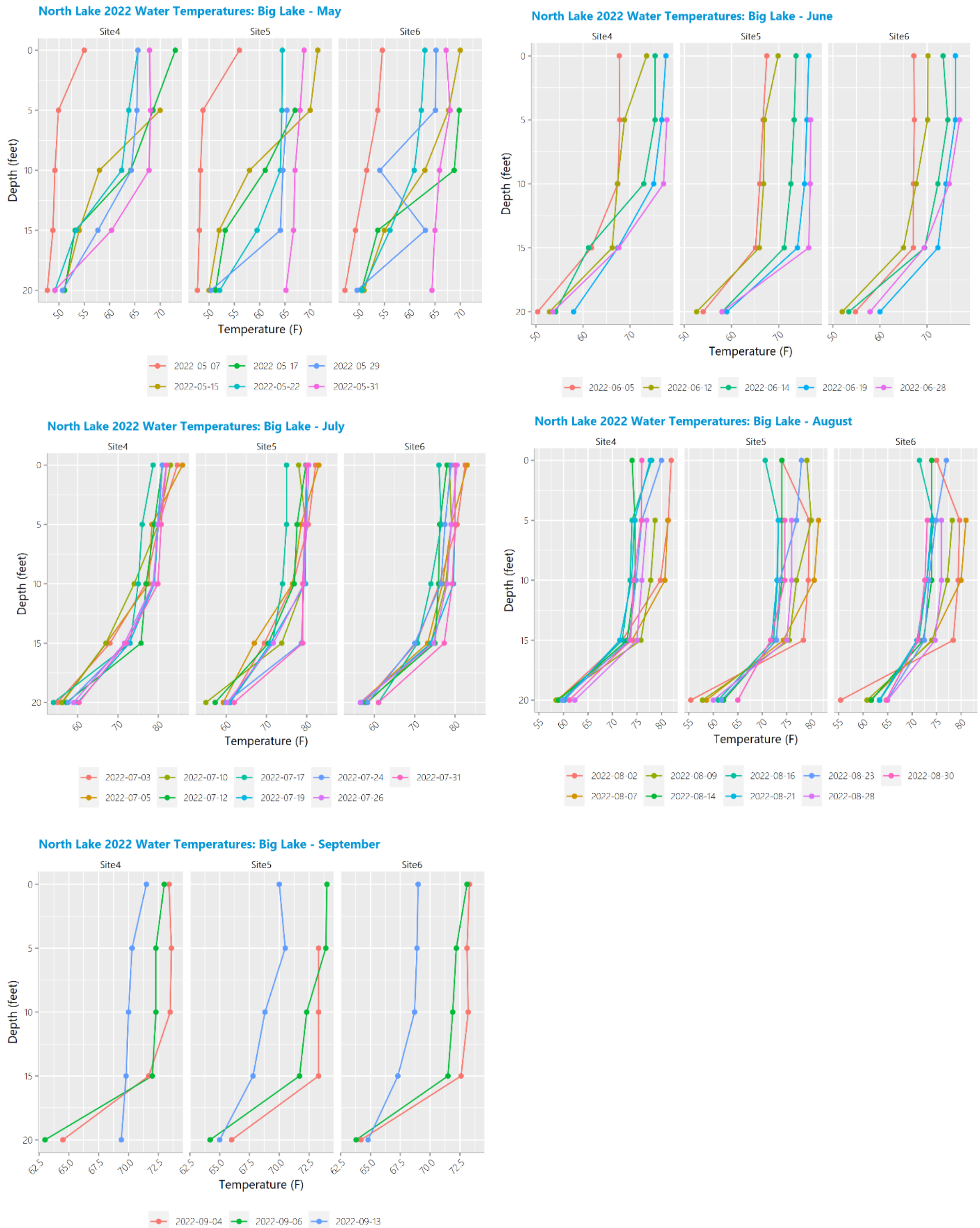
[86] *National Oceanic and Atmospheric Administration,* NOAA Guidance for Considering the Use of Living Shorelines*, 2015, www.habitatblueprint.noaa.gov/wp-content/uploads/2018/01/NOAA-Guidance-for-Considering-the-Use-of-Living-Shorelines_2015.pdf*

[87] *WDNR,* Shoreline Stabilization: A Guide For Homeowners and Conservationists On Inland Lakes and Flowages*, The Wisconsin Shoreline Stabilization Outreach Project, With Assistance From the Wisconsin Land and Water Conservation Association, 2021, wisconsinlandwater.org/assets/documents/Shoreline-Stabilization-Guide-for-Homeowners_Email-Version.pdf*

APPENDIX A

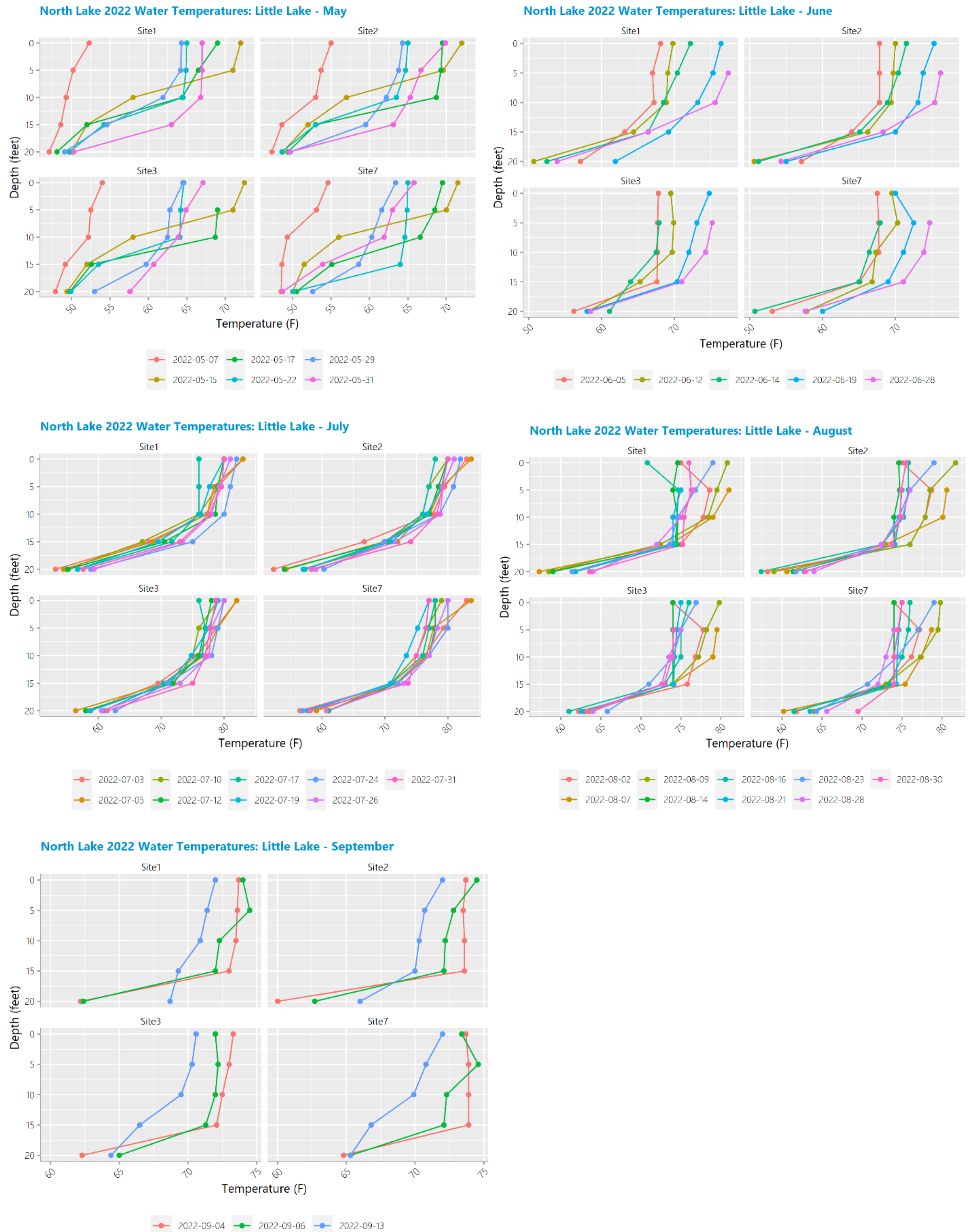
WATER TEMPERATURE AND DISSOLVED OXYGEN PROFILES

Figure A.1
Eastern Basin Water Temperature Profiles: May – September 2022



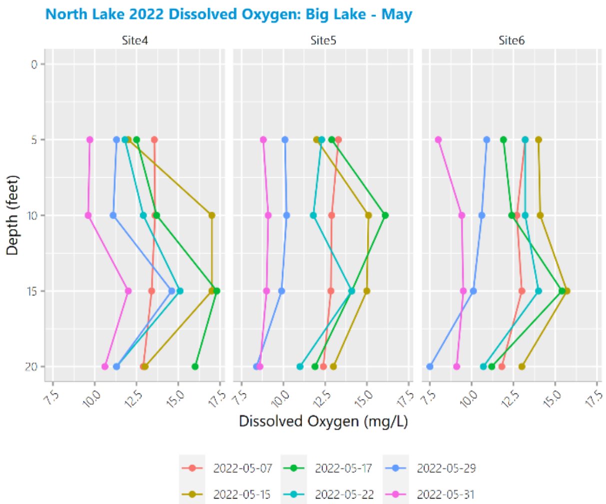
Source: North Lake Management District and SEWRPC

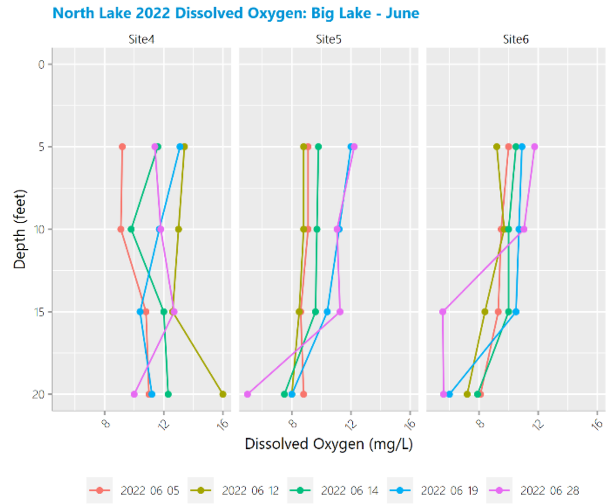
Figure A.2
Western Basin Water Temperature Profiles: May – September 2022

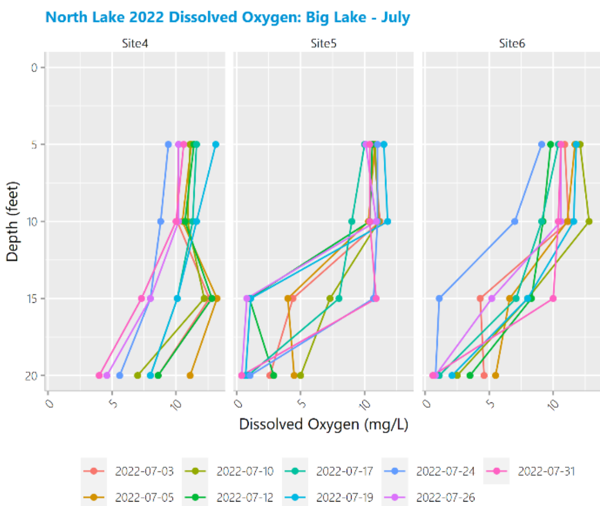


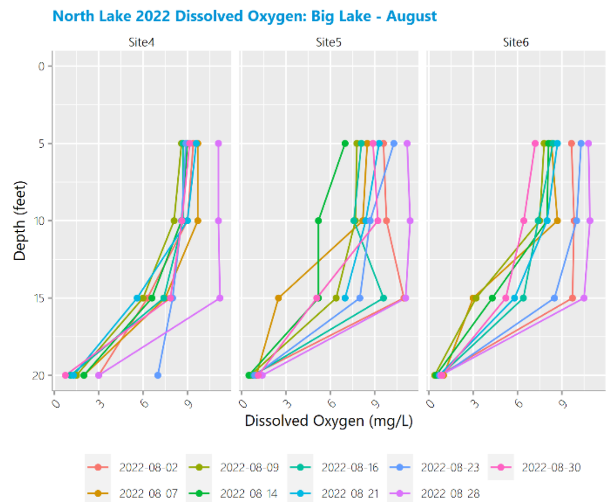
Source: North Lake Management District and SEWRPC

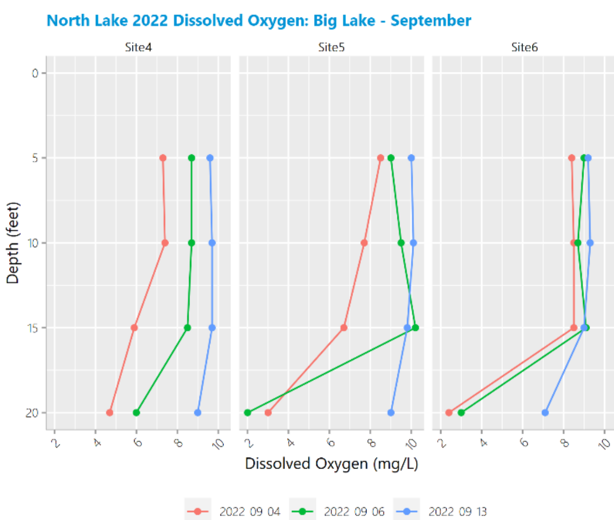
Figure A.3
Eastern Basin Dissolved Oxygen Profiles: May – September 2022





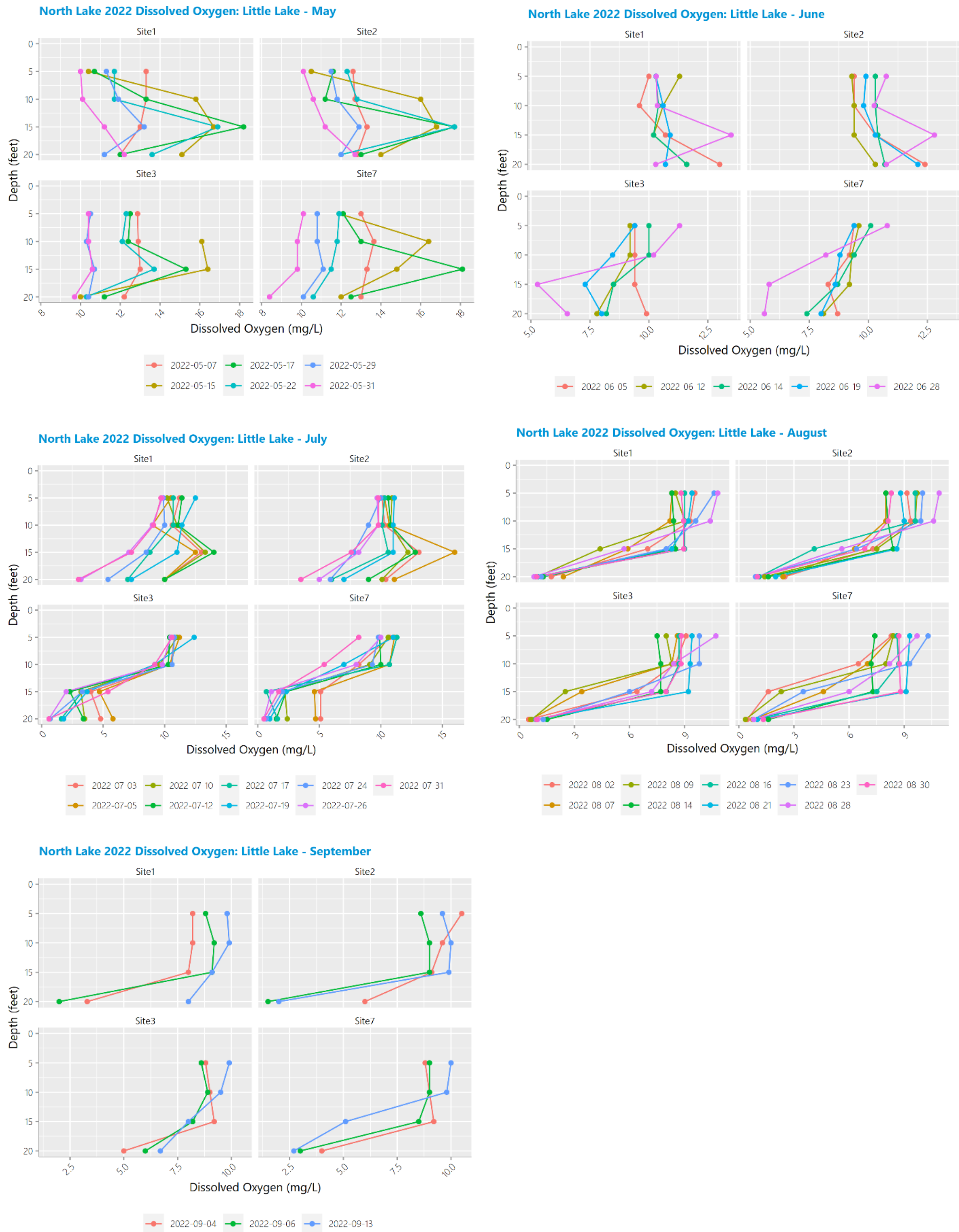






Source: North Lake Management District and SEWRPC

Figure A.4
Western Basin Dissolved Oxygen Profiles: May – September 2022



Source: North Lake Management District and SEWRPC