SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

W239 N1812 ROCKWOOD DRIVE • PO BOX 1607 • WAUKESHA, WI 53187-1607 • **TELEPHONE (262) 547-6721**
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SEWRPC Staff Memorandum

PRELIMINARY MORPHOLOGY, WATER LEVEL, WATER QUALITY, AND WAVE PROPAGATION UPDATE FOR NORTH LAKE, TOWN OF MERTON, WAUKESHA COUNTY

March 10, 2021

BACKGROUND

Southeastern Wisconsin's lakes are highly valued natural resource assets and are intensively used for a wide variety of recreational pursuits. Given the Region's high human population density and the popularity of the 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, dislodge moored boats, damage docks, and harm aspects of a lake's ecology. This concern has led to boating ordinances that aim to reduce user conflict and lake damage at critical time periods (e.g., slow-no-wake ordinances 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 forms of waterbased 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, in turn, has raised questions regarding the impact of boating on area lakes.

North Lake is a medium-size lake, covering approximately 440 acres, but is essentially two lakes connected over a north-south trending shoal (see Map 1). Each lake basin is quite deep, with maximum depths over 70 feet. A rarity for drainage lakes in Southeastern Wisconsin, the Lake's water level is unaltered and is not artificially controlled, a condition that in turn may contribute to the existence of a shallow water shelf ringing most of the Lake's nearshore area.

The North Lake Management District (the District) is actively involved with a variety of issues that influence the ability of the Lake to sustain high quality recreational use and aims to promote its overall health. For example, the District recently worked with the Commission to complete a sediment/nutrient loading study focusing on Mason Creek,[1] and the Commission is currently working with the District to complete a sediment study in the Oconomowoc River upstream of the Lake. The District remains vigilant of issues that could influence recreational quality and lake health. In alignment with this interest, the District's Lake Usage Committee completed a study evaluating recreational use of North Lake.[2] As a result of this study,

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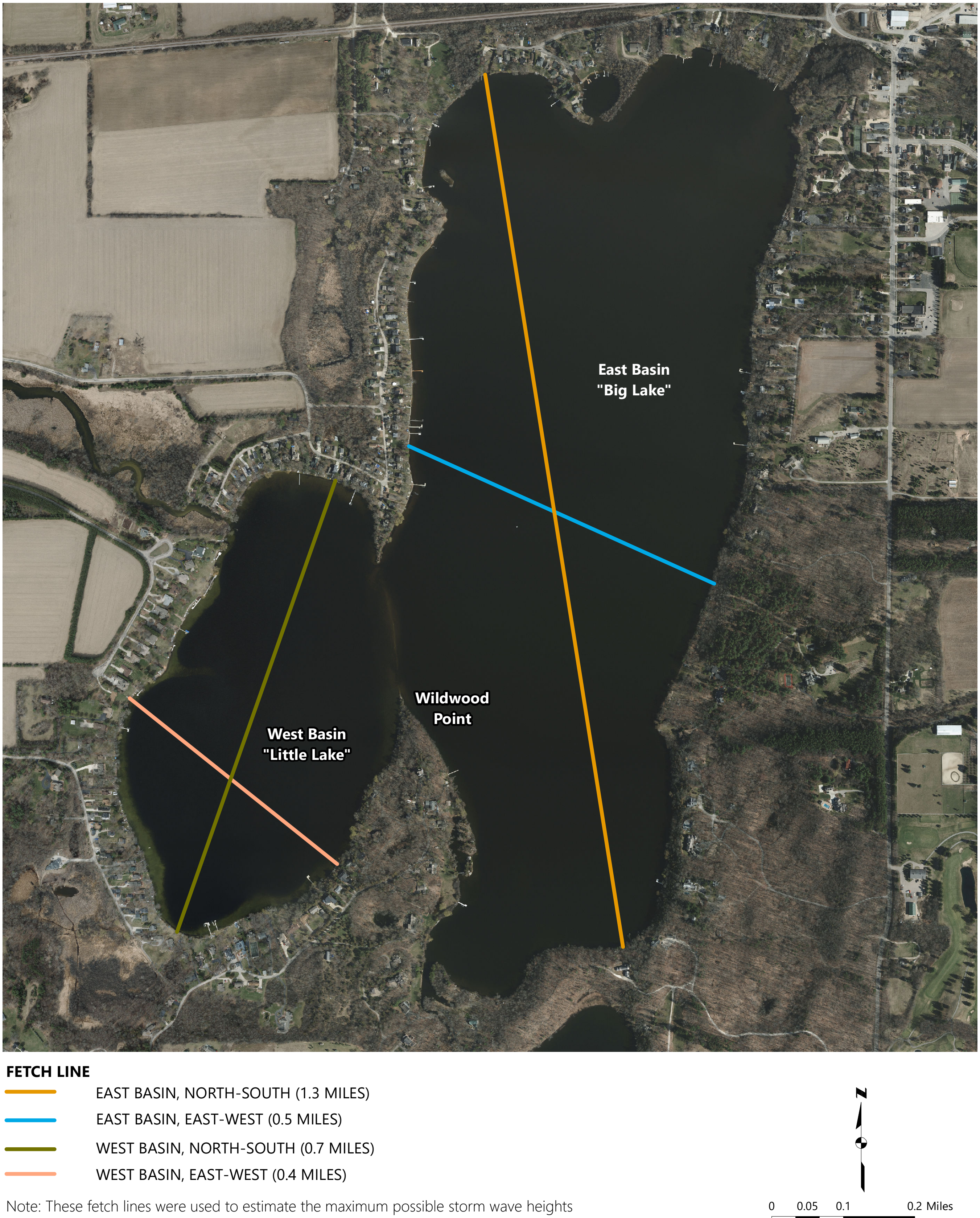
[1] *Southeastern Wisconsin Regional Planning Commission Community Assistance Planning Report Number 321,* Mason Creek Watershed Protection Plan*, June 2018. Copies may be downloaded at the following website address: www.sewrpc.org/SEWRPCFiles/Publications/CAPR/capr-321-mason-creek-protection-plan.pdf.*

[2] *North Lake Management District,* Lake Usage Committee Report*, May 2019. nlmddotorg.files.wordpress.com/2019/07/190528-lake-usage-comittee-report.pdf*

Map 1
North Lake Place Names and Fetch Lines



Note: These fetch lines were used to estimate the maximum possible storm wave heights on North Lake using the Wisconsin Department of Naural Resources shoreline erosion tool.
Date of Orthophotography: 2015

Source: SEWPRC

the District has become increasingly concerned that more frequent and intense boat-wake generated waves could compromise Lake and shoreline integrity 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 to study wave action on North Lake. The prime intent of the study is to help the District understand how the Lake's water quality and sediment dynamics are influenced by wave action. This includes differentiating wave activity propagated by boats versus wind, as well as distinguishing the potential effects that large waves have on water quality, lakebed/shoreline sediment dynamics, and nearshore Lake ecology/infrastructure. The District's concerns and questions regarding lake waves are shared by many others throughout Southeastern Wisconsin. The Commission has received similar questions from several other lake groups. By actively participating in the North Lake study, the Commission hopes to produce information that will not only help the North Lake Management District, but also may help lake managers throughout the Region better understand and manage lake waves and boat-wake-related concerns.

The District initiated a pilot study that gathered data during the summers of 2019 and 2020 and examined the value of monitoring approaches and datasets for addressing the overall project goals. The Commission, District, Carroll University, and Terra Vigilis Security Group (a private commercial firm specializing in unmanned aerial vehicle (UAV) technology), contributed to a range of data collection and analysis activities selected to evaluate the influence of lake morphology, surface water elevations, weather, and boat activity on wave propagation in North Lake, as well as potential impacts from these waves on Lake shorelines, water quality, and aquatic plants. This report inventories preliminary data collection efforts and examines the effectiveness and potential applications of these approaches. Several additional data collection efforts outlined in the pilot study scope of work either remain uncompleted or could be modified to better address the study questions. This report identifies these data gaps, highlights the importance of these datasets for the overall study, and recommends modifications to the monitoring scheme to rectify these information gaps. It is important to note that the District is pursuing a Wisconsin Department of Natural Resources (WDNR) Lake Management Planning Grant to fund a more comprehensive and detailed study (phase 2) and the information and findings in this pilot study were intended to help to guide and refine cost-effective techniques, data, and other aspects to improve success of the phase 2 study.

INVENTORY AND EVALUATION OF PRELIMINARY DATA COLLECTION EFFORTS

Monitoring Boat Activity and Wave Propagation

Gathering information on boat use on North Lake is essential for understanding wave dynamics on the Lake and the potential impacts of wave propagation on water quality. The pilot study scope of work proposed several approaches to monitor boat activity on North Lake, including video recording from UAV flights, static ground-based video recorders facing the Lake, and active monitoring by volunteers along the shoreline.

Unmanned Aerial Vehicles

In July 2019, the District, Carroll University, and Terra Vigilis tested the capacity of UAV imagery to monitor boat traffic and wave propagation. UAVs were flown over the southeastern portion of the western basin (locally known as the "Little Lake") on Sunday, July 21st, 2019,[3] and Sunday, November 3rd, 2019. Four thirty-minute flights were conducted on July 21st using a Phantom 3 UAV equipped with a high-resolution camera at altitudes between 100 to 250 feet. Three thirty-minute flights were conducted on November 3rd using a Yuneek H520 UAV equipped with a thermal camera at an altitude of 100 feet. Flight length was limited by UAV battery life. However, the thermal camera's resolution was insufficient to produce usable data;[4] thus, Commission staff did not evaluate imagery from these flights while evaluating the effectiveness of UAV flights for monitoring boat and wave activity.

[3] *Water surface elevation for North Lake on July 22, 2019, was 897.00 (plus or minus 0.08 feet) reported by Donald Reinbold, North Lake resident.*

[4] *Mike Mortensen (Carroll University), personal communication with Commission staff (Justin Poinsatte), November 21st, 2019.*

Different types of boats (e.g., a pontoon boat versus a fishing boat), as well as the waves that these boats propagate, can clearly be distinguished using the high-resolution UAV imagery (see Figure 1). The UAV was able to follow and capture an entire wave lifespan, including creation, travel, and termination along the shoreline. For example, the UAV followed boat-produced waves to their terminus along the shoreline of "Wildwood Point," the narrow peninsula that nearly divides the east and west basins of the Lake. At this termination point, the UAV captured imagery of apparent sediment disturbance and suspension along the shoreline, potentially caused by the boat-produced waves (see Figure 2). Thus, the UAV flights appear effective for short-term monitoring of boat traffic and operation, wave propagation, and potentially sediment disturbance from boat activity in limited areas and during calm conditions that are conducive to flying.

The UAV was also able to capture boat activity and wave propagation from a fixed altitude, enabling georeferencing of UAV imagery from the 2019 flights. Using this approach, a grid of known distances was overlain upon UAV imagery (see Figure 3). Using the grid, Commission staff were able to approximate the speed, wavelength, period, and shoreline run-up length of individual boat-produced waves. For example, boat-produced waves were noted to approach the shoreline at a velocity of nine feet per second, create up to three feet of wave run-up along shoreline riprap, and vary in their wavelength from approximately 9 to 20 feet. Furthermore, UAV surface water imagery can be rendered as a three-dimensional model using surface displacement modeling. Wave shapes and height may be determined from UAV recording by applying surface displacement modeling with Autodesk® Maya® software. However, shoreline measurements of wave parameters would be necessary to verify the accuracy of these modeling efforts (e.g., to verify wave heights hitting shoreline, wave run-up distances, and/or erosional impacts). Such analyses were beyond the scope of this pilot study; however, this three-dimensional modelling would be possible if detailed shoreline measurements of wave parameters were collected.

During summer 2020, a Phantom 4 RTK UAV was deployed to record wave propagation and nearshore wave effects from different boat types, including jet-skis, pontoon boats, and wakeboard boats. These UAV recordings were paired with simultaneous video recording from a QYSEA FIFISH underwater remotely operated vehicle, a 360° video camera posted in the nearshore area, and a Nest video camera pointed towards the Lake from a nearby residence. The paired recordings show the wave propagation from each type of boat, the distance of the boats from the shore, and wave effects on the nearshore lake bottom as well as on the shoreline (see Figure 4).[5] This technique appears to be very effective for demonstrating the different types of waves produced by each boat type, how much each wave type dissipates at a range of distances from shore, and documenting sediment disturbance in the nearshore area.

Carroll University faculty and students also conducted aerial mapping of a site on the southeastern shoreline of the "Little Lake" during summer 2020. This aerial mapping was used to develop accurate wireframe and textured three-dimensional models of the site based on two ground control points located near the shoreline. These models can be used to estimate shoreline erosion over time by comparing summer 2020 baseline models with future models that will be developed using the same ground control points after another boating season. This comparison can help estimate the rate of erosion as well as shoreline characteristics (e.g., slope, soil texture, vegetation presence) that are more susceptible to erosion.

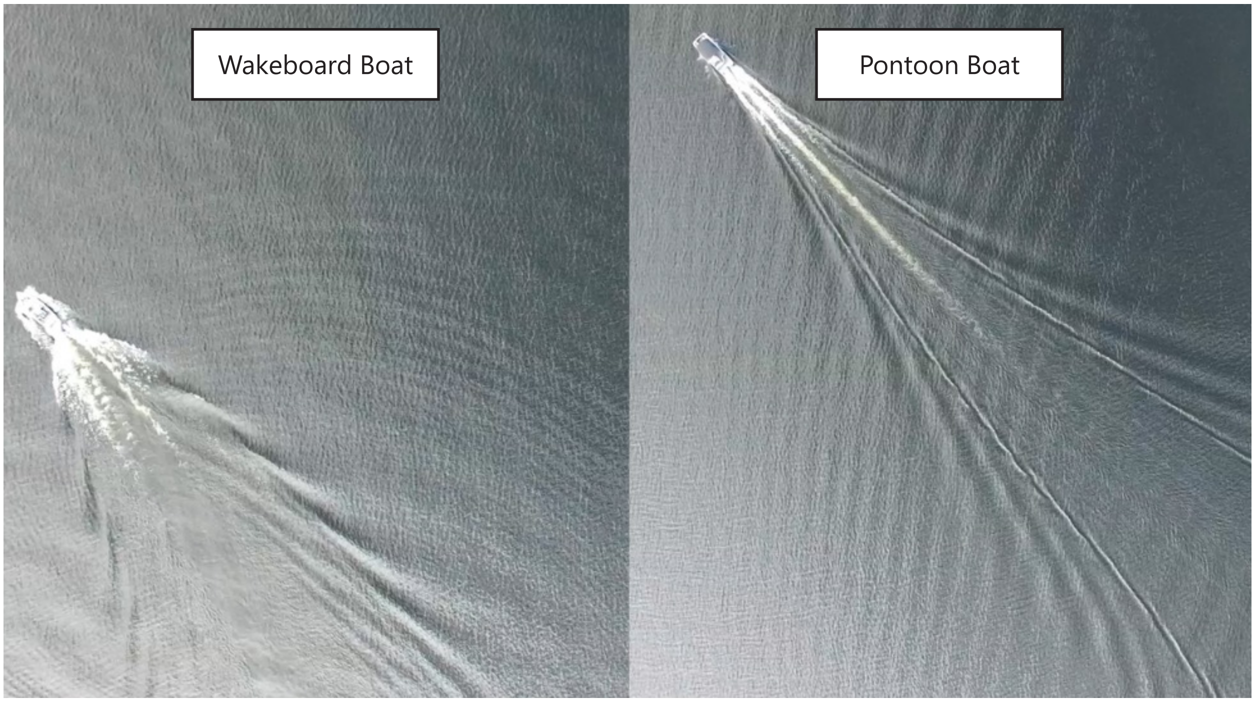
In summary, the UAV flights were able to accurately document boat type, activity, and differences in wave propagation by boat type, distance from shore, and travel speed. Measurement of boat speeds as well as wave amplitude and wavelength may be individually calculated using distancescaled UAV imagery. Additional analyses derived from UAV-based imagery, such as surface displacement modeling or wireframe modeling, can supplement ground-based measurements by estimating wave properties across a larger spatial scale and shoreline erosion rates. Thus, UAV flights are not only useful to document boat and wave activity but also provide useful information to evaluate wave impacts on North Lake.

Static, Ground-based Video Recorders

The pilot study also utilized a 360° camera placed in the nearshore area to record the waves propagated by boating activity. A staff gage was deployed near the 360° camera to measure wave height; however, the gage readings are not close enough to the camera to be legible in the video recordings. This camera

[5] *Results from the 2020 summer portion of the pilot study can be viewed at the following website: storymaps.arcgis.com/stories/3bb6845a097e42b8aad5f0fc0537567f*

Figure 1
Unmanned Aerial Vehicle (UAV) Imagery of Boat Activity and Wave Propagation on North Lake: July 2019



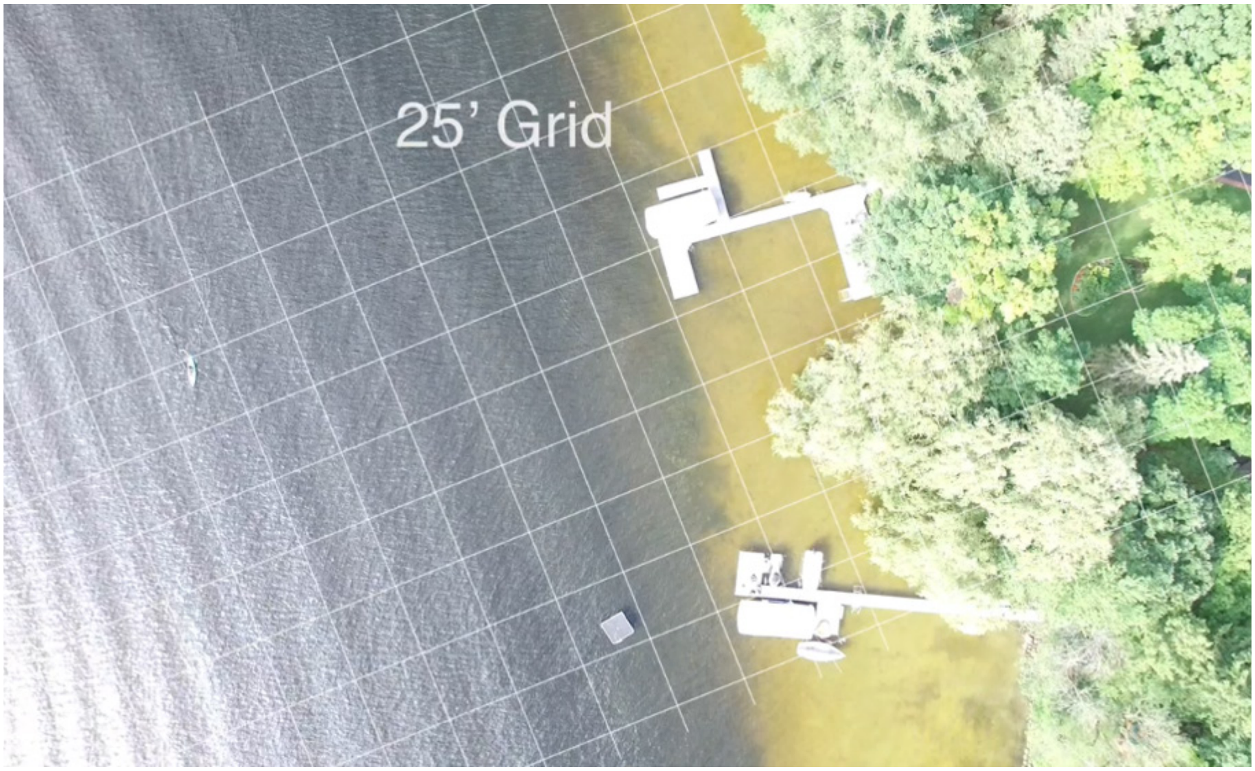
Source: Carroll University, North Lake Management District, and SEWRPC

Figure 2
Unmanned Aerial Vehicle (UAV) Imagery of Sediment Disturbance on North Lake: July 2019

Note: The blue arrow indicates the sediment plume coursing around Wildwood Point.

Source: Carroll University, North Lake Management District, and SEWRPC

Figure 3
Scaled Unmanned Aerial Vehicle (UAV) Imagery on North Lake: July 2019



Source: Carroll University, North Lake Management District, and SEWRPC

Figure 4
Paired Recordings of Wave Propagation, Travel, and Impact Along North Lake Shorelines: 2020

Source: Carroll University, Terra Vigilis, North Lake Management District, and SEWRPC and staff gage setup effectively documented relative wave heights, the amount of shoreline run-up, and nearshore sediment disturbance at 15 meters from the shoreline. Wave properties, including amplitudes, wavelengths, crests, and troughs, were measured for waves propagated from wakeboard boats, pontoon boats, and personal watercraft (PWC). Maximum wave heights of 0.25, 0.42, and 0.67 feet were recorded for PWCs, pontoon boats, and wakeboard boats, respectively.[6] Commission staff subsequently recommend that video cameras be placed so that the staff gage readings are legible in the video for phase 2 of the study.

In addition to the nearshore video camera, another video camera was affixed to a house on the southeastern shore of the "Little Lake" and positioned to face the Lake. While boats and the waves propagated by boats are visible from this camera's recordings, it is not possible to easily distinguish the types of boats from the video or the relative heights of the waves that are produced. Furthermore, the video recordings were not scheduled to monitor the number of boats or the boating activity on the Lake, but instead were used in conjunction with the UAV, underwater ROV, and the nearshore cameras to record video during a set of tests. Since it is not possible to distinguish boat types from these videos, it does not seem that using such cameras at locations relatively distant from the Lake provides an effective method to monitor boat activity on the Lake.

Active Monitoring by Volunteers

To supplement UAV and ground-based recorder observations, volunteers actively observed the degree of recreational boat use on North Lake. This involved direct counts of boats actually in use at a given time. During 2020, North Lake volunteers counted the numbers and types of watercraft in use on North Lake during typical summer weekends. The surveys were limited to the smaller, western basin of North Lake (the "Little Lake") and generally occurred in the morning, between 9am and 10:30am, in the afternoon between 1pm and 4pm, and in the evening between 6pm and 7:30pm. It is important to note that slow-no-wake hours begin at 6pm on weekends and holidays. Survey results are summarized in Tables 1, 2, and 3.

Morning surveys (see Table 1) revealed that high-speed recreation is popular on the "Little Lake." This is unusual compared to other lakes in the region, where fishing and kayaking are often the most popular morning activities. Approximately 2 to 4 boats were observed on an average morning, predominantly engaged in activities such as tubing, high-speed cruising, and wakeboarding. Kayaking, fishing, and sailing were observed but were found to be less frequent activities. It is possible that those activities occur prior to 9am in order to avoid other boats that engage in high-speed recreation.

Afternoon surveys (see Table 2) revealed that high-speed recreation doubles on the "Little Lake" compared to morning activity. Upwards of 7 to 9 boats were observed during an average afternoon, predominantly engaged in activities such as tubing, water skiing, and wakeboarding. PWCs were also popular during the afternoon. Kayaking and sailing were observed in small amounts.

Evening surveys (see Table 3) showed that, although slow-no-wake ordinances apply starting at 6pm on weekends, high-speed cruising and wakeboarding do occasionally occur on the "Little Lake" after 6pm. The other popular activity was low-speed cruising in pontoon boats. Overall, evening activity is very low.

Morning recreation remained steady throughout the summer, with 6 to 9 watercrafts of all kinds present on the Lake. Afternoon recreation was highest in July and usage dropped throughout August into September. Evening recreation was sporadic throughout the summer.

In addition to on-lake observations, North Lake volunteers also documented incoming visitors at the boat launch. As can be seen in Table 4, anywhere from 1 to 22 non-lakeshore residents arrived at North Lake each day. On average, approximately 6 watercrafts were brought to North Lake on a typical weekend. Only a few observations were made on weekdays, with weekday visitor numbers ranging from 3 to 9 watercraft. It is unknown if those visitors primarily utilized the "Little Lake" or larger, eastern basin of North Lake (the "Big Lake").

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[6] *Ibid.*

Table 1
North Lake Recreational Survey: Weekend Mornings on Little Lake Summer 2020

Category	Observation	Date						
		July 26	August 2	August 9	August 11	August 15[a]	August 16	September 5
Watercrafts Observed on "Little Lake," North Lake								
Type of Watercraft (number in use)	Powerboats	2	1	2	1	--	2	3
	Pontoon Boat	2	--	--	1	--	1	--
	Fishing Boat	--	1	1	1	--	--	--
	Kayak/Canoe	--	7	3	1	--	4	--
	Personal Watercraft	2	--	--	2	--	--	--
	Sailboat/Wind Board	--	--	--	--	--	--	Boat Race (unknown number)[b]
	Row Boat/Paddle Boat	--	--	--	--	--	--	--
Activity of Watercraft (number engaged)	Motorized Cruise/Pleasure Low Speed	1	--	--	1	--	1	--
	High Speed Cruising	--	--	--	--	--	--	--
	Skiing/Tubing	2	--	1	1	--	2	1
	Wake Boarding	1	1	1	--	--	--	2
	Fishing	--	1	1	1	--	--	--
	Rowing/Paddling/Pedaling	--	7	3	1	--	4	--
	Sailing/Windsurfing	--	--	--	--	--	--	Boat Race (unknown number)[b]
	Jet Skiing	2	--	--	2	--	--	--

Note: Morning observations were typically made between 9:00 a.m. and 10:30 a.m.

[a] *No activity observed.*

[b] *Sailboat race occurred on larger portion of North Lake.*

Source: North Lake Management District

Table 2
North Lake Recreational Survey: Weekend Afternoons on Little Lake Summer 2020

Category	Observation	Date						
		July 26	August 2	August 9	August 11[a]	August 15	August 16	September 5
Watercrafts Observed on "Little Lake," North Lake								
Type of Watercraft (number in use)	Powerboats	6	1	6	--	3	2	7
	Pontoon Boat	2	2	3	--	--	5	--
	Fishing Boat	--	--	--	--	--	--	--
	Kayak/Canoe	4	--	--	--	--	2	--
	Personal Watercraft	3	1	3	--	--	1	--
	Sailboat/Wind Board	1	--	--	--	--	--	--
	Row Boat/Paddle Boat	--	--	--	--	--	--	--
Activity of Watercraft (number engaged)	Motorized Cruise/Pleasure Low Speed	--	2	3	--	--	5	--
	High Speed Cruising	--	--	--	--	--	--	--
	Skiing/Tubing	5	--	1	--	1	1	4
	Wake Boarding	3	1	5	--	2	1	3
	Fishing	--	--	--	--	--	--	--
	Rowing/Paddling/Pedaling	4	--	--	--	--	2	--
	Sailing/Windsurfing	1	--	--	--	--	--	--
	Jet Skiing	3	1	3	--	--	1	--

Note: Afternoon observations were typically made between 1:00 p.m. and 4:00 p.m.

[a] *No observations made at this time on this date.*

Source: North Lake Management District

Table 3
North Lake Recreational Survey: Weekend Evenings on Little Lake Summer 2020

Category	Observation	Date						
		July 26[a]	August 2	August 9[a]	August 11	August 15[b]	August 16	September 5
Watercrafts Observed on "Little Lake," North Lake								
Type of Watercraft (number in use)	Powerboats	--	1	--	3	--	--	1
	Pontoon Boat	--	--	--	3	--	7	--
	Fishing Boat	--	--	--	--	--	--	--
	Kayak/Canoe	--	--	--	5	--	--	--
	Personal Watercraft	--	--	--	--	--	--	--
	Sailboat/Wind Board	--	--	--	--	--	--	--
	Row Boat/Paddle Boat	--	--	--	--	--	--	--
Activity of Watercraft (number engaged)	Motorized Cruise/Pleasure Low Speed	--	--	--	4	--	7	--
	High Speed Cruising	--	1	--	--	--	--	--
	Skiing/Tubing	--	--	--	--	--	--	--
	Wake Boarding	--	--	--	2	--	--	1
	Fishing	--	--	--	--	--	--	--
	Rowing/Paddling/Pedaling	--	--	--	5	--		--
	Sailing/Windsurfing	--	--	--	--	--	--	--
	Jet Skiing	--	--	--	--	--	--	--

Note: Evening observations were typically made between 6 p.m. and 7:30 p.m. "Slow-No-Wake" hours begin at 6 p.m. on Saturday, Sunday, and Holidays.

[a] *No observations made at this time on this date.*

[b] *No activity observed.*

Source: North Lake Management District

There is no clear guidance or regulatory standard on applicable boat traffic density and useable lake surface area to sustain safe boating conditions in Wisconsin. However, a study completed in Michigan attempted to quantify desirable boat traffic intensity on an array of lakes used for a variety of purposes. That study, which covered a wide variety of boat types, recreational uses, and lake characteristics, concluded that 10 to 15 acres of useable lake open water area provides a reasonable and conservative average maximum desirable boating density.[7,8] 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 watercrafts 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))

The 2020 recreational survey suggests that on weekends most boats in use on the "Little Lake" during peak periods were capable of high-speed operation and were being operated at high speed. If one assumes that ten percent of the boats could potentially be operating at high speed during the day, the formula set forth above suggests that 12 to 13 or more acres of useable open water should be available per boat. Given that roughly 95 useable acres are available for boating in the "Little Lake," no more than 7 to 8 boats should be present on the "Little Lake" at any one time to avoid use problems. The number of boats actually observed on the "Little Lake" indicates that the "Little Lake" is occasionally at, but not over, safe capacity during heavy use periods.

Table 4
Saturday Boat Count at North Lake Launch

Year	Date	Count
2015	5/23	1
	5/30	8
	6/6	22
	6/13	9
	6/20	10
	6/26	6
	7/11	8
	7/18	3
	7/26	5
	8/1	1
	8/8	3
	8/15	2
	8/22	4
	9/19	5
	9/25	4
	10/10	2
2016	5/8	6
	7/4	7
2020	5/30	6
	6/6	5
	6/13	7
	6/20	5
	6/27	9
	7/5	10
	7/11	13
	7/18	6
	7/25	7
	8/1	4
	8/15	4

Note: Four additional counts were collected. Two on Thursdays: 6/11/2015 yielded 8 boats; 6/25/202 yielded 5 boats. Two counts were on Fridays: 7/3/2015 yielded 9 boats; 7/10/2020 yielded 3 boats.

Source: North Lake Management District

Lake Water Surface Elevation Monitoring

Quantifying North Lake's surface water elevation is essential to understanding the effect waves may have on the Lake's shoreline. Intense boating activity at higher surface water elevations enables higher wave run-up, potentially overtopping features protecting shoreline.

Based upon a combination of WDNR, Waukesha County, and District information collected since 1975, North Lake's water surface elevation generally ranges between 895.7 and 897.6 National Geodetic Vertical Datum 1929 adjustment (NGVD 29).[9] The average WDNR determined Ordinary High Water Mark elevation survey on North Lake was 897.18 (NGVD 29).[10] The Lake's specified slow-no-wake elevation is 897.2 mean sea level.[11]

[7] *"Useable lake area" is the size of the open water area that is at least 100 feet from the shoreline.*

[8] *Progressive AE*, 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.*

[9] *Amy Barrows, Senior Planner, Waukesha County Department of Parks and Land Use-Planning and Zoning Division, personal communication.*

[10] *Marc Budsberg, WDNR.*

[11] *Merton, Waukesha County, Wisconsin Code of Ordinances 20.04(6)(d)1.a. library.municode.com/wi/merton,_waukesha_co/codes/code_of_ordinances?nodeId=CH20LABE_20.04NOLAOCRIAM42490AM62216RERE326182.*

Several known flooding events and associated water elevations are summarized below (all elevations in NGVD 29):[12]

- Year 1975: Lake water surface elevation of 899.6 feet
- Year 2008: Lake water surface elevation of 899.5 feet
- Year 2010: Lake water surface elevation of 899.1 feet

More precise readings will help to establish "normal" water level ranges and baseline conditions that will be essential to understanding how Lake levels fluctuate and how they influence waves and associated nearshore and shoreline wave impacts.

A volunteer Lake resident recorded daily surface water elevations on the north shore of the west basin of North Lake from October 8th, 2019, to December 16th, 2019, and then again from May 17th, 2020, to October 21st, 2020.[13] During the 2019 monitoring period, surface-water elevation ranged from 896.65 to 897.64 feet (NAVD 88) with an average of 896.99 feet.[14] The Lake's slownowake elevation of 897.2 feet was exceeded during the first five days of this data collection period. The volunteer noted that the highest Lake surface water elevation recorded in fall 2019 was 898.5 feet, which was observed prior to daily record-keeping commenced. Fall 2019 observations ended with the onset of lake ice formation. The surface water elevation during the 2020 observations ranged from 896.36 to 897.43 feet (NAVD 88) with an average of 896.54 feet. The Lake's slow-no-wake elevation was matched or exceeded from May 19th to May 23rd and then was not exceeded during the remainder of the monitoring period. Surface waters dropped to a low point by July 7th before rapidly rising 0.33 feet by July 10th following 2.09 inches of rain.[15] Aside from this short spike, water elevations remained relatively level throughout the remainder of the 2020 summer study period. These elevations are firmly within historical ranges for the Lake, indicating that the wave run-ups observed during the pilot study are likely a good representation of normal conditions.

The Commission maintains a continuous water level monitoring station on the Oconomowoc River just upstream of the Lake where water levels have been recorded on a five-minute interval since October 1st, 2018. These data may be useful to estimate the Oconomowoc River's contribution to the Lake water budget, as well as help explain changes to Lake surface water elevation since the River's water level tracks well with Lake surface water elevations (see Figure 5). As the Oconomowoc River is known to deliver substantial amounts of sediment to the Lake, tracking the River's water level may also help distinguish turbidity contributed by the River versus wave-induced sediment suspension.

Water Quality Analysis

Actual and perceived water quality are generally high priority concerns to lake and stream resource managers, residents, and Lake users. North Lake residents have expressed concern that sediment disturbance and shoreline erosion caused by boating activity could compromise Lake water quality. The water quality information presented here provides historical condition baselines and trends as well as forming a foundation to evaluate potential future changes to water quality.

Long-term Water Temperature, Dissolved Oxygen, and Trophic Status Trends

When a lake is stratified, near-surface water (the epilimnion) is considerably warmer, supports abundant algae, and contains abundant oxygen. The thermocline is found below the epilimnion and in Southeastern

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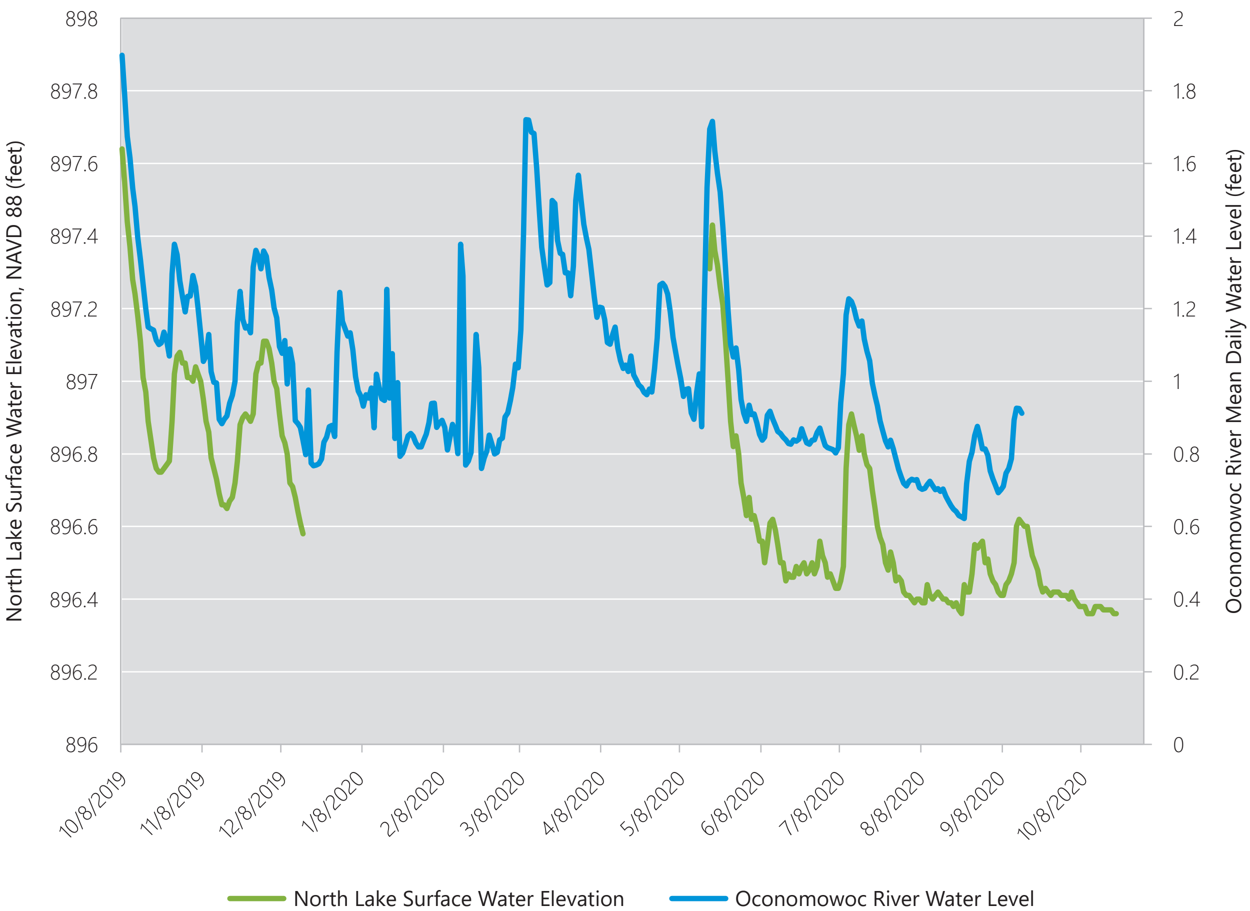
[12] *USACOE,* Reconnaissance Report for Section 205 Flood Control Project, North Lake, Waukesha County, Wisconsin*, June 1982 report; and, Waukesha County's Forward of Appeal-Preliminary FIRM and FIS Relative to the Rock River Basin Riskmap Update to WDNR, January 21, 2014.*

[13] *Donald Reinbold, Registered Professional Engineer and former Commissioner of the North Lake Management District, established a water level gauge at his house on the north shore of the "Little Lake" with an established benchmark to the North American Vertical Datum of 1988 and been monitoring lake levels for 14 years.*

[14] *According to published benchmarks produced by the Commission, within this area the NAVD 88 datum is 0.05 feet higher than compared to the NGVD 29 datum, which means these projections are effectively the same.*

[15] *Weather observations are from a nearby station: www.wunderground.com/dashboard/pws/KWIHARTL18.*

Figure 5
North Lake Surface Water Elevations and Oconomowoc River Water Levels: Oct. 2019 – Oct. 2020



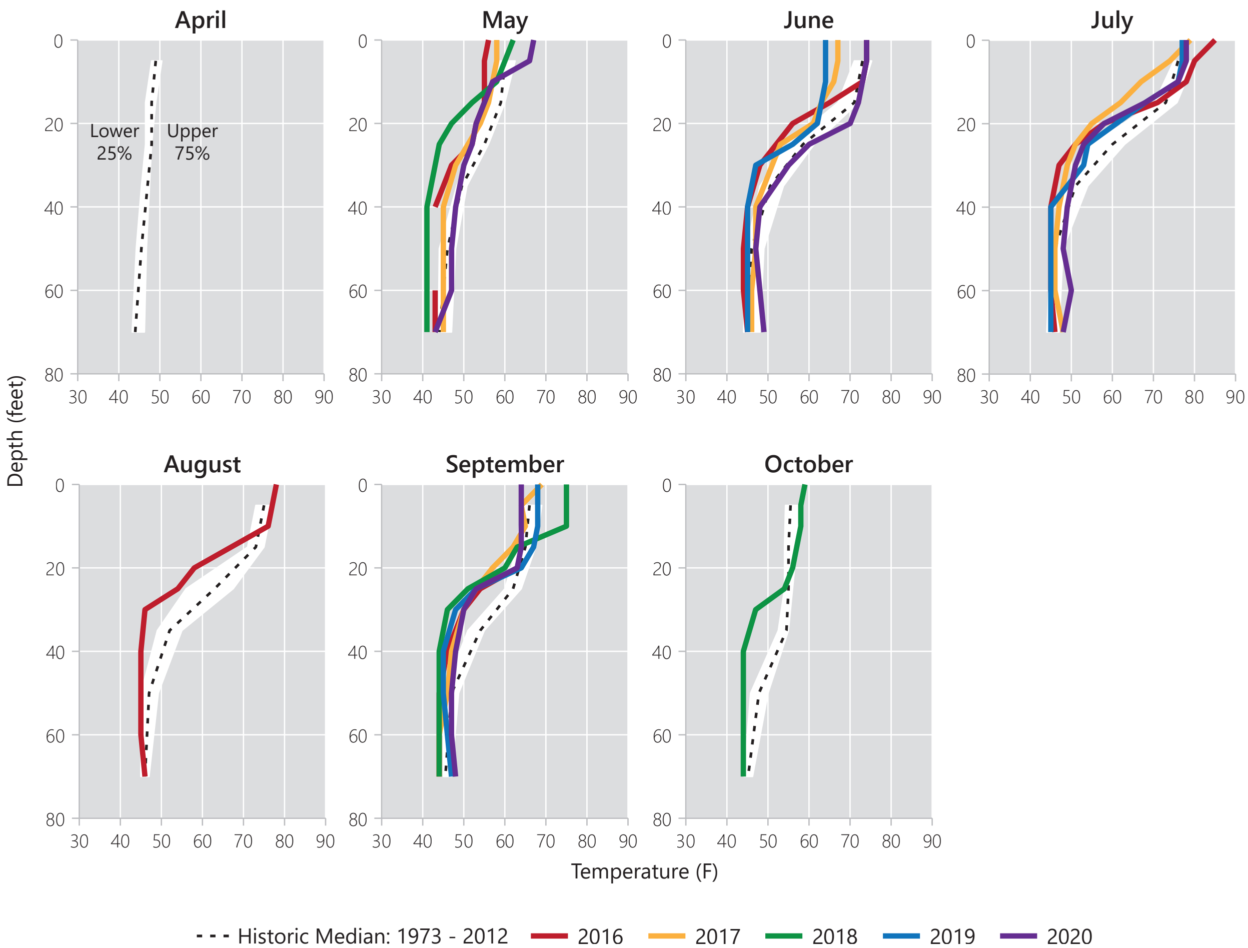
Source: North Lake Management District and SEWRPC

Wisconsin lakes is generally found somewhere between 10 and 30 feet below the surface, with the depth varying lake-to-lake, month-to-month, and year-to-year. Water within the thermocline rapidly cools with depth and often contains less oxygen than the epilimnion. Below the thermocline, water in the deep portions of a lake (the hypolimnion) is much colder than water at the lake's surface and may not mix with the epilimnion until fall. Little sunlight penetrates past the thermocline; therefore, the deeper portions of lakes do not host significant photosynthetic activity and hence do not receive oxygen from plants. However, oxygen continues to be consumed by decomposition and other processes in the deeper portions of the lake. As a result, oxygen concentrations in the hypolimnion decline after the lake and may not be replenished until the lake fully mixes during its fall turnover.

Temperature and oxygen concentration profiles were assembled from data spanning more than 40 years. These profiles suggest that North Lake stratifies every year and remains stratified throughout the summer (see Figures 6 and 7). The summer thermocline is generally around 10 feet thick and is found somewhere between 10 and 40 feet below the Lake's surface. As summer progresses, the epilimnion thickens and the thermocline is generally found deeper in the Lake. Denser, warmer water occasionally accumulates in the deepest areas of the Lake during winter, producing weak stratification.[16] Recent water temperature profiles (2016 to 2020) indicate that Lake water was within the historical range (1973 to 2015) throughout most of the profile, with surface temperatures occasionally exceeding the historical range. Recent dissolved oxygen profiles are generally within the historical range and indicate that hypoxic (oxygen concentrations below

[16] *Water achieves its maximum density in its liquid form at approximately four degrees Celsius, or 39 degrees Fahrenheit. Therefore, water near its freezing point temperature is more buoyant.*

Figure 6
North Lake Water Temperature Profiles: 1973-2020



Note: The white ribbon indicates the lower 25 percent and upper 75 percent quantiles of the historic range.

Source: Wisconsin Department of Natural Resources and SEWRPC

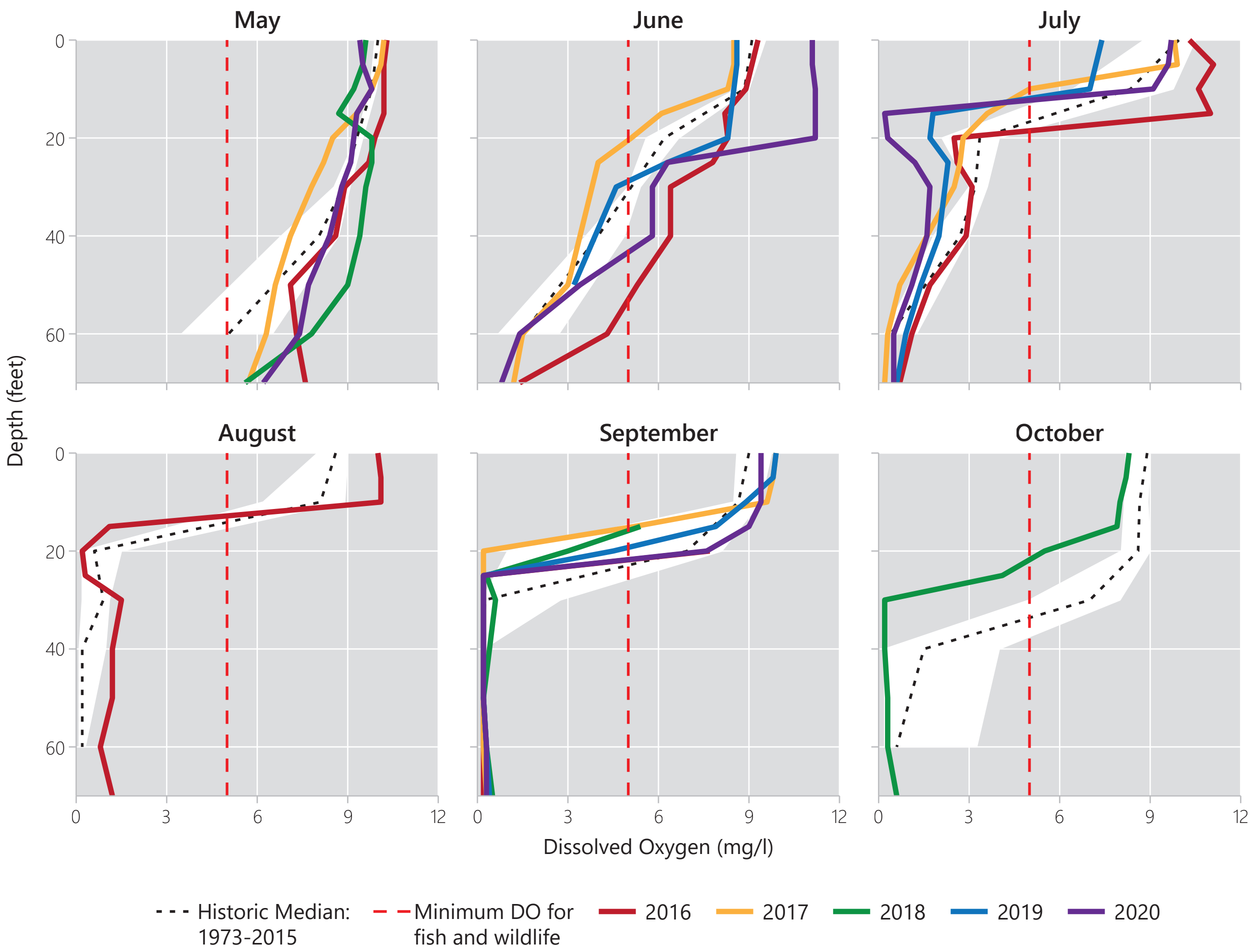
5 mg/l) conditions persist throughout most of the summer from depths of 20 feet to the lake bottom. These hypoxic conditions are perilous to the health of aquatic organisms, particularly fish, and are generally driven by elevated nutrient concentrations, particularly nitrogen and phosphorus, within the waterbody. However, these conditions have been observed in the Lake since the earliest water quality analyses in 1906, so these may be more reflective of long-term watershed influences than any recent changes in boating activity.[17]

North Lake and other large, deep lakes in the immediate vicinity are biologically unique. Many of these deep lakes naturally host or formerly hosted cisco (*Coregonus artedi*), a fish sometimes also known as lake herring. Cisco require cold water during summer months, retreating to well-oxygenated deep-water areas. Unfortunately, this fish persists in only a handful of Waukesha County lakes (Fowler, North, Oconomowoc, Okauchee, and Pine Lakes).[18] However, it was once widespread in Waukesha County, and was also formerly found in Lac La Belle, Nagawicka, Upper and Lower Nashotah, Upper Nemahbin, Golden, and Dutchman

[17] *Birge, E.A. and C. Juday, "The Inland Lakes of Wisconsin: the Dissolved Gases of the Water and their Biological Significance,"* The State, *No. 64, 1922.*

[18] *Lyons, J., J. Kampa, T. Parks, and G. Sass,* The Whitefishes of Wisconsin's Inland Lakes: The 2011-2014 Wisconsin Department of Natural Resources Cisco and Lake Whitefish Survey, *Fisheries and Aquatic Research Section, Wisconsin Department of Natural Resources, 2015.*

Figure 7
North Lake Dissolved Oxygen Profiles: 1973-2020



Note: The white ribbon indicates the lower 25 percent and upper 75 percent quantiles of the historic range.

Source: Wisconsin Department of Natural Resources and SEWRPC

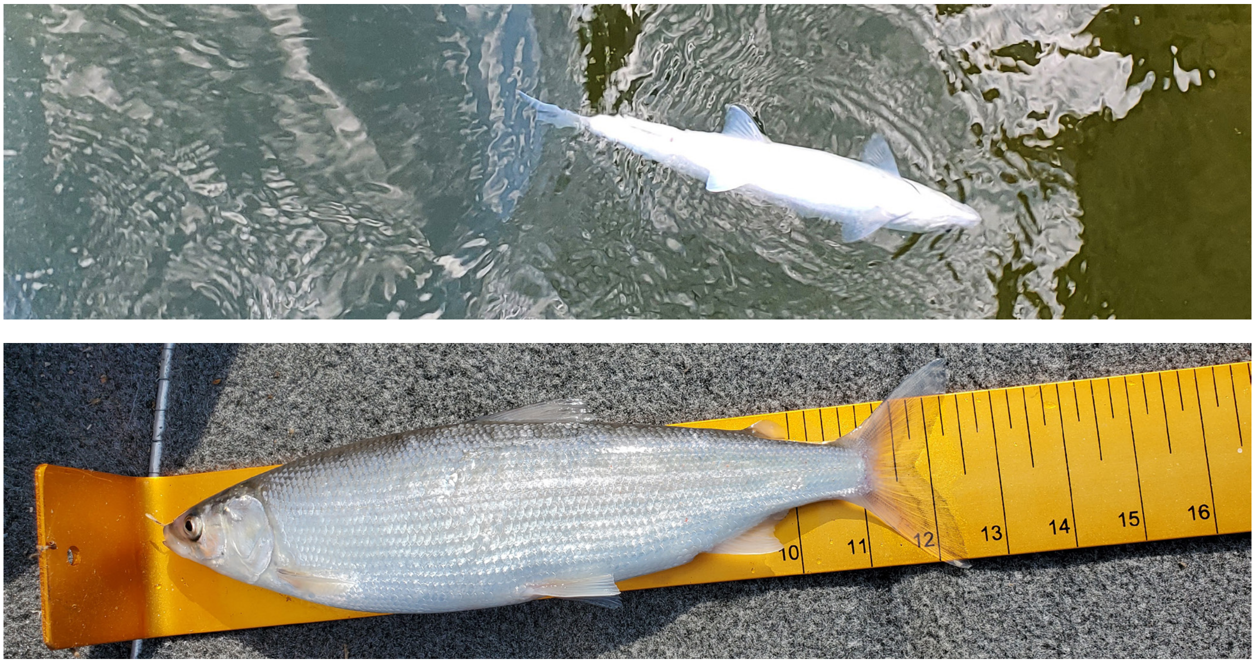
Lakes.[19,20] In August 2020, North Lake residents noted dead cisco on a beach near Reddelien Road as well as over 150 dead cisco floating on the surface of the "Little Lake" (see Figure 8). This fish kill and another reported in the summer of 2017 illustrate ongoing water quality challenges that are particularly concerning to the District.[21] Both of these fish kill events were likely due to low dissolved oxygen conditions in the cold, deeper water preferred by cisco combined high water temperatures in the well-oxygenated surface waters. North Lake residents conducted a series of water temperature and dissolved oxygen profiles in several deep-water locations in the Lake in August 2020 looking for cisco refuge areas (see Figure 9). These profiles reveal that deep-water areas throughout the Lake do not contain sufficient oxygen to support cisco. However, a narrow band of cool, oxygenated water does persist near the bottom of the thermocline in some areas. These areas are extremely limited in extent and may act as a refuge for cisco when the Lake stratifies. From the available photographs, cisco seem to grow well in the Lake. Cisco are an important forage fish for several sport species, particularly walleye, so loss of cisco in North Lake could be very detrimental to the Lake's fishery as well as an indicator of decreasing water quality conditions in the Lake.

[19] *Cahn, A. R., "An Ecological Study of Southern Wisconsin Fishes,"* Illinois Biological Monographs*, XI(1), 1927.*

[20] *Mark Theisen (North Lake Management District), personal communication with Commission staff (Dale Buser), August 22nd, 2020.*

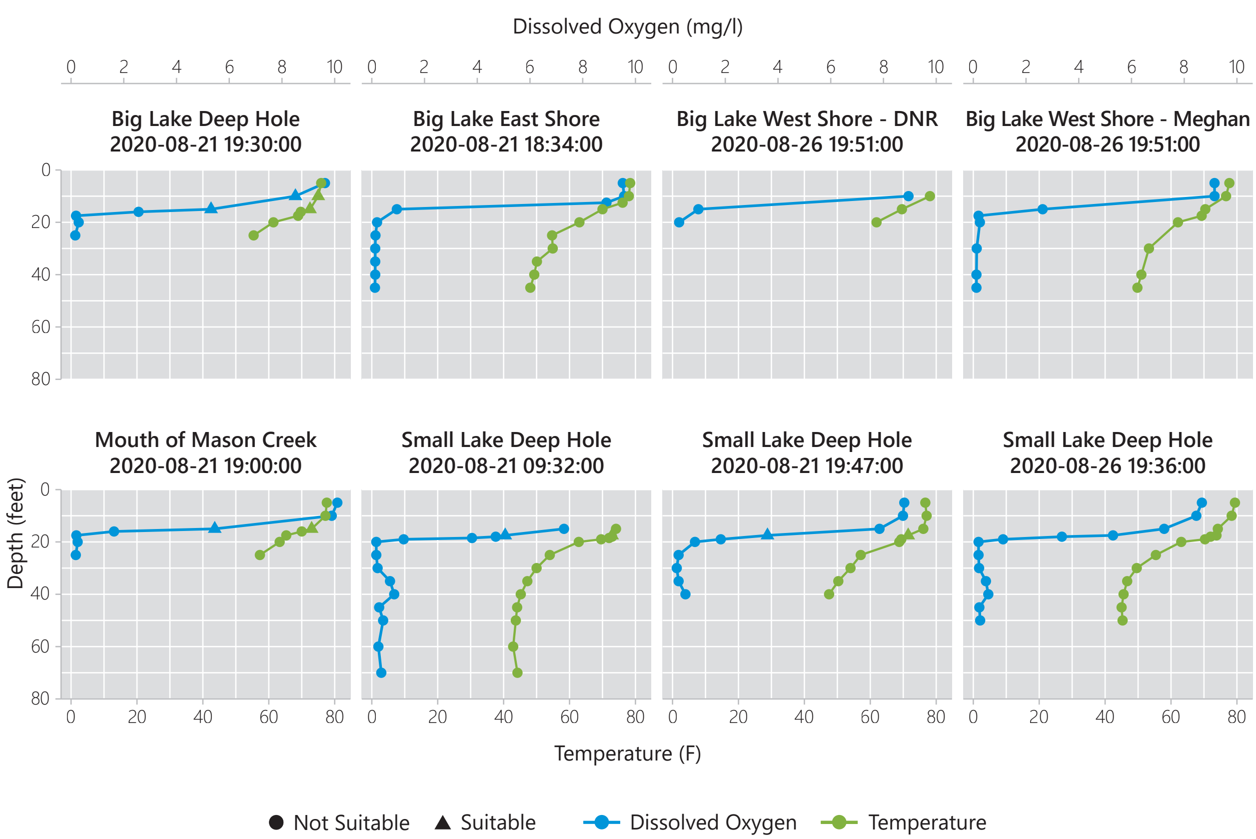
[21] *Benjamin Heussner, Fisheries Biologist (WDNR) personal communication with Commission staff (Thomas Slawski), November 19th, 2020.*

Figure 8
Photographs of Dead Cisco (*Coregonus artedi*) in North Lake: August 2020



Source: North Lake Management District and SEWRPC

Figure 9
North Lake Temperature and Dissolved Oxygen Profiles: August 2020



Source: North Lake Management District and SEWRPC

Trophic state index (TSI) equations are used to convert measurements of summer water clarity, measured using a Secchi disk; chlorophyll-*a*, a measure of algae abundance; and total phosphorus concentrations to a common unit used to assess the overall productivity of a lake. This common unit allows lake-specific information to be compared to other lakes.[22] TSI values based upon chlorophyll-*a* are considered the most reliable estimators of lake trophic status. Commission staff calculated the trophic status of North Lake using summer (defined as June 1st to September 15th) surface measurements of these three parameters collected at the deepest point in the Lake (see Figure 10). North Lake borders between mesotrophic and eutrophic conditions, with mean TSI for chlorophyll-*a,* water clarity, and total phosphorus of 52, 44, and 52, respectively, and a total mean TSI of 49 over the past five years. Since 1974, there has been a slight trend toward more eutrophic conditions in chlorophyll-*a* and water clarity while the trend in total phosphorus has remained stable. These trends indicate that the water clarity is decreasing due to increasing prevalence of lake algae, which are utilizing available phosphorus entering the Lake. Reducing phosphorus loads to the Lake is a major focus of the Commission's Mason Creek plan and the forthcoming Oconomowoc River sediment and nutrient study.[23]

Potential Effects of Boating on Water Quality

Boat wakes have been shown to erode shorelines,[24] scour and disrupt the bottom sediments of a lake,[25] damage aquatic vegetation and disrupt faunal communities,[26] and temporarily decrease water clarity.[27] However, boat wake energy is event-dependent and is influenced by the vessel length, water depth, channel shape, and boat speed.[28] Wakes are most destructive in shallow and narrow waterways because wake energy does not have the opportunity to dissipate over distance.[29] 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.[30] Even small recreational vessels operating within 500 feet of the shoreline are capable of producing wakes that can erode shoreline and increase nearshore turbidity.[31]

Understanding the timing of boating activity is important to interpret changes in water quality. According to a Statewide survey that subdivided results by region,[32] boaters in Southeastern Wisconsin took to the water in the greatest numbers during July, with slightly lower numbers of boaters found on the water during June and August (see Table 5). These months account for approximately two-thirds of the total number of boater-days logged in the Region for the entire year. About three times as many boaters use their boats on weekends than weekdays (see Table 6). Powerboating activities are popular on many lakes in Southeastern

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[22] *Lillie, R. A., S. Graham, and P. Rasmussen,* Trophic State Index Equations and Regional Predictive Equations for Wisconsin Lakes, Research Management Findings, Number 35*, Bureau of Research – Wisconsin Department of Natural Resources, May 1993.*

[23] *SEWRPC CAPR 321,* Mason Creek Watershed Protection Plan, *2018,* op. cit.

[24] *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*

[25] *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.*

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

[27] *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.*

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

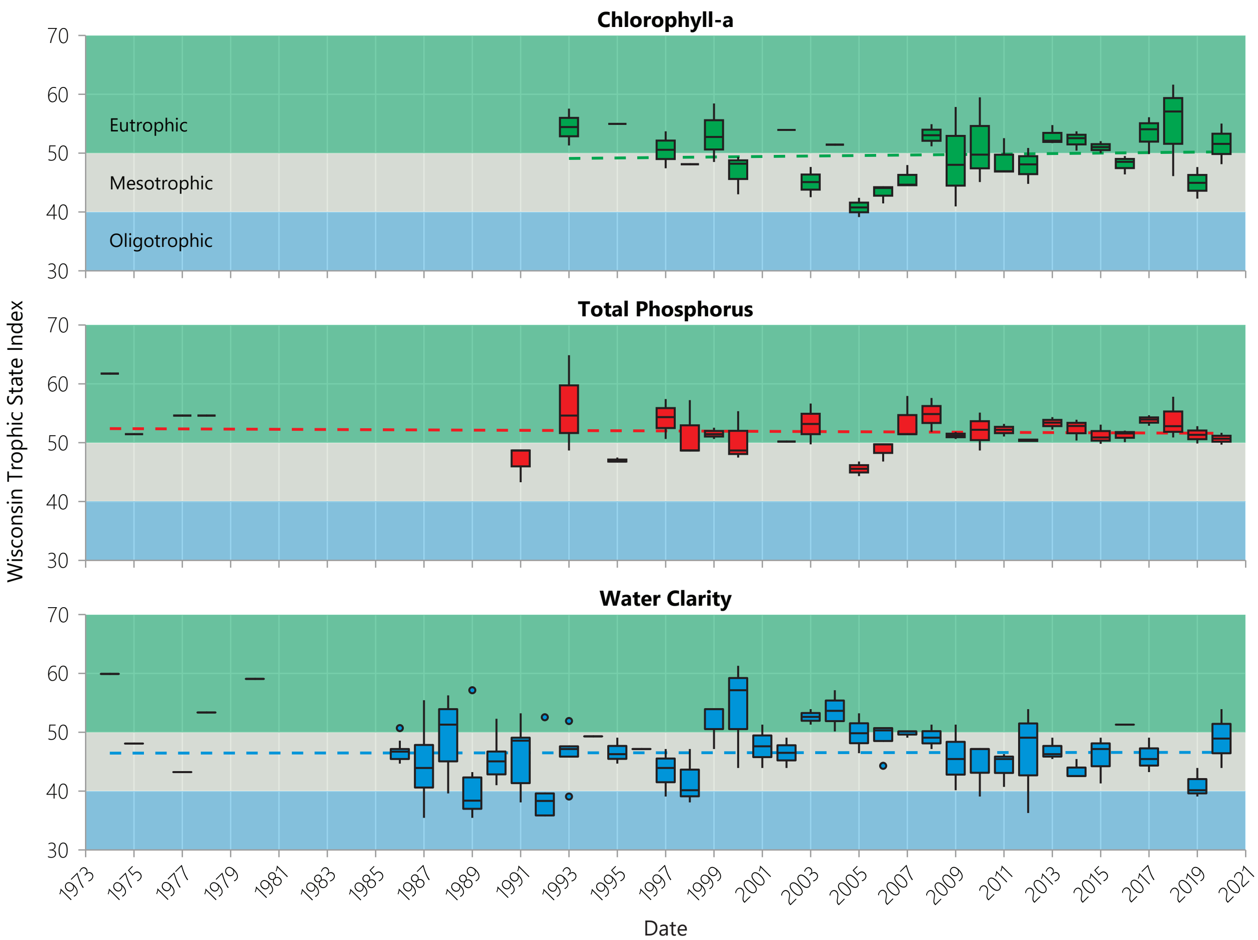
[29] *Ibid.*

[30] *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.*

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

[32] *Wisconsin Department of Natural Resources Technical Bulletin 174*, Boating Pressure on Wisconsin's Lakes and Rivers, Results of the 1989-1990 Wisconsin Recreational Boating Study, Phase 1, *1991.*

Figure 10
North Lake Summer (June 1st to September 15th) Trophic State Index Trends: 1973-2020



Source: Wisconsin Department of Natural Resources and SEWRPC

Table 5
Southeastern Wisconsin Boat User Activity by Month: 1989-1990

	Percent Respondents Participating[a]						
Activity	April	May	June	July	August	September	October
Fishing	68	57	49	41	44	42	49
Cruising	29	39	42	46	46	47	43
Water Skiing	3	9	20	27	19	16	8
Swimming	2	4	18	31	25	19	5
Average boating party size: 3.4 people							

[a] *Respondents may have participated in more than one activity.*

Source: Wisconsin Department of Natural Resources

Wisconsin, including North Lake, where activities such as water-skiing, wake boarding, wake surfing, tubing, and jet skiing have been documented.[33] On North Lake, the most popular time for powerboating is midday, while pontoon boats are most common in the late afternoon to evening and canoeing/kayaking occurs throughout the day.[34]

Table 6
Southeastern Wisconsin Day-Of-The-Week Boat Use: 1989-1990

Day of the Week	Percent Respondents Participating[a]
Sunday	46
Monday	16
Tuesday	14
Wednesday	16
Thursday	13
Friday	17
Saturday	46

[a] *Respondents may have participated in more than one day.*

Source: Wisconsin Department of Natural Resources

Using the long-term monitoring data described in the section above, Commission staff evaluated whether the day of the week influenced North Lake's summer water clarity, temperature, and dissolved oxygen concentrations using data collected between 1998 and 2018. As shown on Figure 11, Lake water was most clear during the middle of the week, when boating activity is generally lower, and less clear on the weekends. However, it is important to note that limited weekend Secchi depth data are available for the Lake and boating activity was not recorded concurrently with the Secchi measurements, so these findings are preliminary. Lake profiles were rarely collected during weekends (i.e., only two August weekend sampling events since 1998), inhibiting more detailed interpretation of this information. More frequent monitoring is necessary to evaluate whether differences between weekday and weekend water quality truly exist and determine potential impacts that boating activity might have on water quality. Nonetheless, multiple residents have observed that water clarity during the weekend is much worse than during the weekdays and it generally takes at least two days for water clarity to improve within North Lake after the weekend. This has important potential implications for North Lake water quality conditions, and it also has potential important implications for the interpretation of trophic index conditions using secchi depth observations, if it is being skewed or influenced by boating activity.

2020 Near-Shore Water Quality Monitoring

Volunteers have collected monthly water quality data on North Lake as part of the Citizen Lakes Monitoring Network, but these data have predominantly been collected on weekdays and are most useful for analyzing long-term water quality trends. Additionally, this long-term water quality monitoring has only been conducted in the "Big Lake" and may not reflect conditions in the "Little Lake," particularly given the disparity in basin size and powerboating activity.[35] The pilot study scope of work proposed that water quality data be collected more frequently, particularly during low and high boating activity periods, and at more locations across the Lake, in order to evaluate the impacts of boating-induced wave action on water quality. A wider range of water quality measurements, including clarity, temperature, dissolved oxygen, total phosphorus, chlorophyll-*a*, and turbidity, was also proposed in the pilot study scope of work.

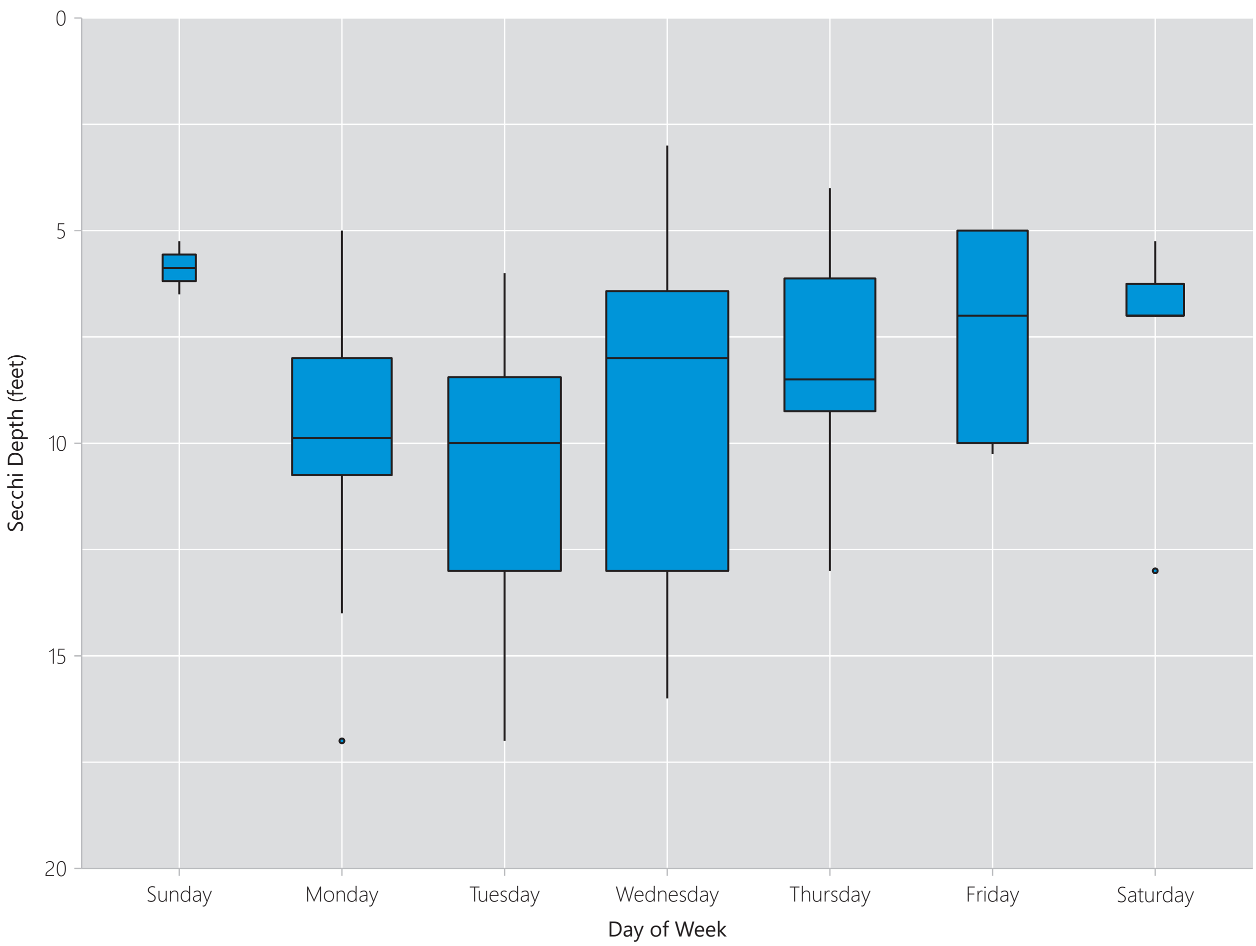
While volunteers continued to monitor monthly water quality at the "deep hole" site on the "Big Lake," no additional water quality measurements were collected in 2019. However, water quality monitoring efforts were enhanced in 2020, with measurements of water temperature, pH, and dissolved oxygen concentrations at surface depths (0 to 3 feet) of six locations on six sampling dates (6/28, 7/05, 7/12, 7/14, 8/02, 8/09). Surface water temperatures ranged between 77.0 and 84.6^{o}F, water pH ranged between 8.1 and 8.9 SU, and dissolved oxygen concentrations ranged between 8.6 and 12.7 mg/l. These conditions are consistent with historical surface measurements at the Lake's "deep hole," which indicate that the Lake is an alkaline waterbody with surface temperatures and dissolved oxygen concentrations that can support aquatic life. However, surface conditions are typically not reflective of temperatures and dissolved oxygen concentrations in deeper waters, particularly for lakes that stratify in the summer such as North Lake.

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

[34] *Jerry Heine (North Lake Management District), personal communication with Commission staff (Justin Poinsatte), November 21st, 2019.*

[35] *Jerry Heine and Tim Tyre (North Lake Management District), personal communication with Commission staff (Tom Slawski, Dale Buser, Zofia Noe, and Justin Poinsatte), July 15th, 2019.*

Figure 11
North Lake Secchi Depth by Day of Week: 1998-2018



Note: Boxplot widths increase with the number of samples (n); fewer samples results in narrower boxplots.

Source: Wisconsin Department of Natural Resources and SEWRPC

Water clarity was also measured via Secchi depth at five of the six locations on seven sampling dates in 2020 (5/30, 6/01, 6/12, 6/15, 6/27, 7/11, 8/08). Secchi depth is often used as an easy-to-measure and understand water quality indicator. Water clarity can be affected by physical factors like water color and suspended particles, such as sediment, as well as biological factors like planktonic algae. Water clarity declined throughout the summer, from Secchi depths ranging from 12.5 to 17 feet across all sites in May to depths of 5 to 6.5 feet across all sites in August. This decline limits light availability for algae and aquatic plants in addition to affecting the Lake's aesthetics. Many stratified lakes within the midwestern United States generally exhibit seasonal patterns of water clarity, with higher clarity in late spring and lower clarity in mid-summer.[36,37] Further analyses of water clarity during low and high boating activity periods, such as comparisons of weekdays versus weekends as well as weekend mornings versus weekend afternoons, may help distinguish whether boating activity is contributing to observed water clarity declines.

Surface water samples (0 to 3 feet depth) were collected from each of the six sampling locations on two dates (6/22/20 and 08/21/20). Samples were analyzed for concentrations of chloride, nitrate, sulfate, and phosphate using ion chromatography at Carroll University. Generally, concentrations of these ions were

[36] *Sommer, U., Z. M. Gliwicz, W. Lampert, and A. Duncan, "The PEG-model of Seasonal Succession of Planktonic Events in Fresh Waters,"* Arch. Hydrobiol.*, 106(4): 433–471, 1986.*

[37] *Read, E. K., L. Carr, L. De Cicco, H. A. Dugan, P. C. Hanson, J. A. Hart, J. Kreft, J. S. Read, and L. A. Winslow, "Water Quality Data for National-Scale Aquatic Research: The Water Quality Portal,"* Water Resour. Res.*, 53: 1735–1745, 2017.*

similar across all six locations on each sampling date. Slight increases in chloride and sulfate concentrations were observed between the two sampling events, but there was no such increase in nitrate concentrations. The chloride concentrations observed in this study, while elevated from the 10 mg/l observed in 1907 and the 12 to 17 mg/l observed in the Lake from 1973 to 1975, were lower than those recently observed in some nearby lakes.[38] Observed sulfate concentrations in the nearshore (14 to 16 mg/l) were much lower than concentrations measured from 1973 to 1975 at the "deep hole" site (33 to 74 mg/l with mean of 44.3 mg/l).

Documenting Ambient Local Weather Conditions

Weather, particularly precipitation and wind speed, has a significant influence on lake circulation, 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 boat-produced waves can exceed the height and power of wind-produced waves, and the additive effects of wind on boat-produced waves.

Commission staff gathered meteorological data from a nearby weather station that records air temperature, average and maximum wind speed, wind direction, precipitation, and barometric pressure every ten minutes.[39] As this weather station is only two miles east of North Lake, these data may be useful for approximating conditions on the Lake. However, no weather data have been collected on the Lake so local differences in weather could not be evaluated.

Using the WDNR shoreline erosion calculator,[40] Commission staff calculated the wave heights and energy that could be expected during storm conditions (defined as wind speed of 51.33 feet per second) on North Lake. As both of North Lake's basins have their largest fetch along a north-south orientation, storm wave height and energy were calculated for each basin for both north-south and east-west winds (see Map 1 and Table 7). Under these assumptions, the maximum wind-produced 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. It is important to note that preliminary boat generated waves have been shown to produce wave heights ranging from about 0.3 to 0.7 feet in height (see "*Static, Ground-based Video Recorders*" section above). Therefore, collecting weather data at North Lake will verify whether these model assumptions are accurate and help identify areas that may be more susceptible to large, wind-induced waves as well as to help distinguish magnitude and frequency of wind- versus boat-generated wave impacts.

Lake Bathymetry

Understanding lake bathymetry is essential for determining its influence on wave parameters, particularly wave height, speed, and power. As shown in Figure 12, 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, as a wave's power is influenced by its height through the following relationship:

$$P = \frac{pg^2TH^2}{32\pi}$$

where P is wave power, *p* is the density of water, *g* is gravitational acceleration, *T* is the wave period, and *H* is the wave height. Increased wave height and power can cause waves to overtop shoreline riprap, particularly when Lake elevations are already high and suspend fine-grained sediment, such as silt and clay, into the water column.

[38] *Birge, E.A. and C. Juday, 1922,* op. cit.

[39] *Weather observations are from a nearby station: www.wunderground.com/dashboard/pws/KWIHARTL18.*

[40] *The erosion calculation tool is at the following link: dnr.wi.gov/topic/Waterways/shoreline/erosioncalculator.html.*

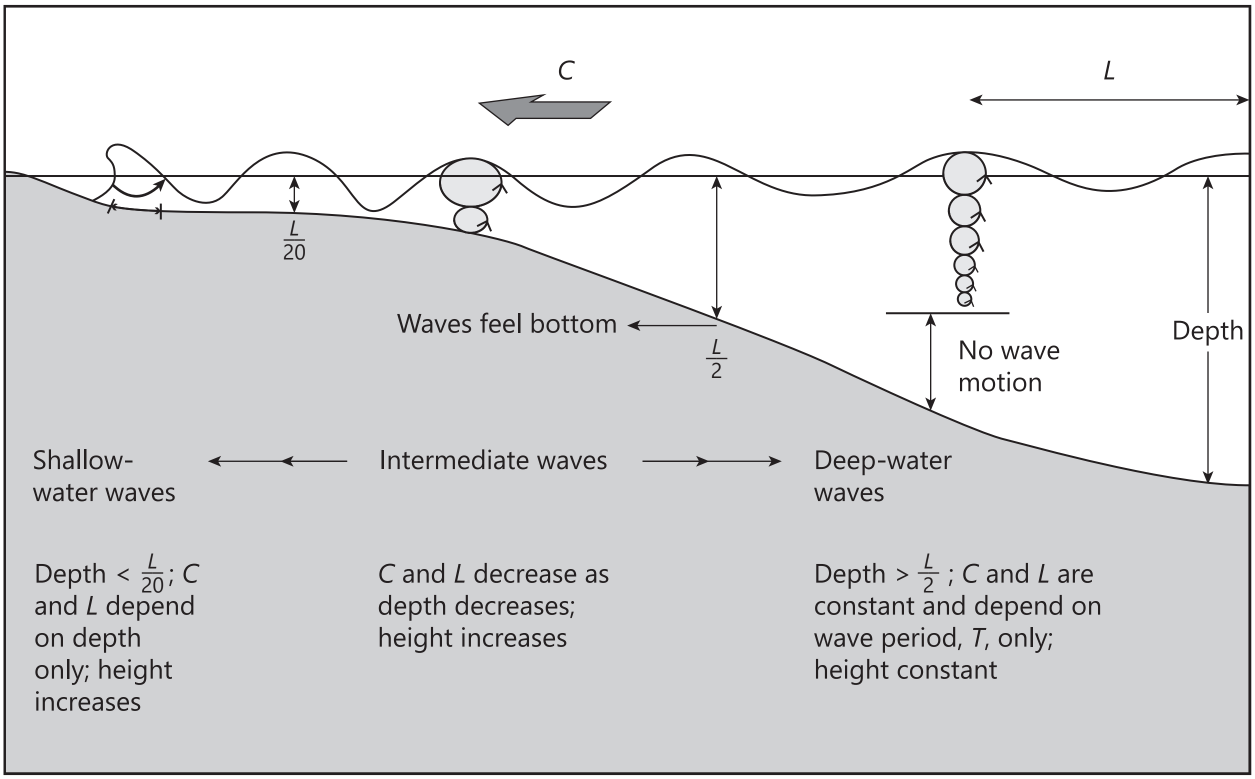
Table 7
Predicted Storm Wave Heights and Energy on North Lake

Lake Basin	Wind Direction	Storm Wave Height (feet)	Storm Wave Energy Category
East ("Big Lake")	North-South	1.13	Moderate
	East-West	0.72	Low
West ("Little Lake")	North-South	0.83	Low
	East-West	0.61	Low

Note: Predicted storm wave heights and energy were calculated using the Wisconsin Department of Natural Resources shoreline erosion tool.

Source: Wisconsin Department of Natural Resources and SEWRPC

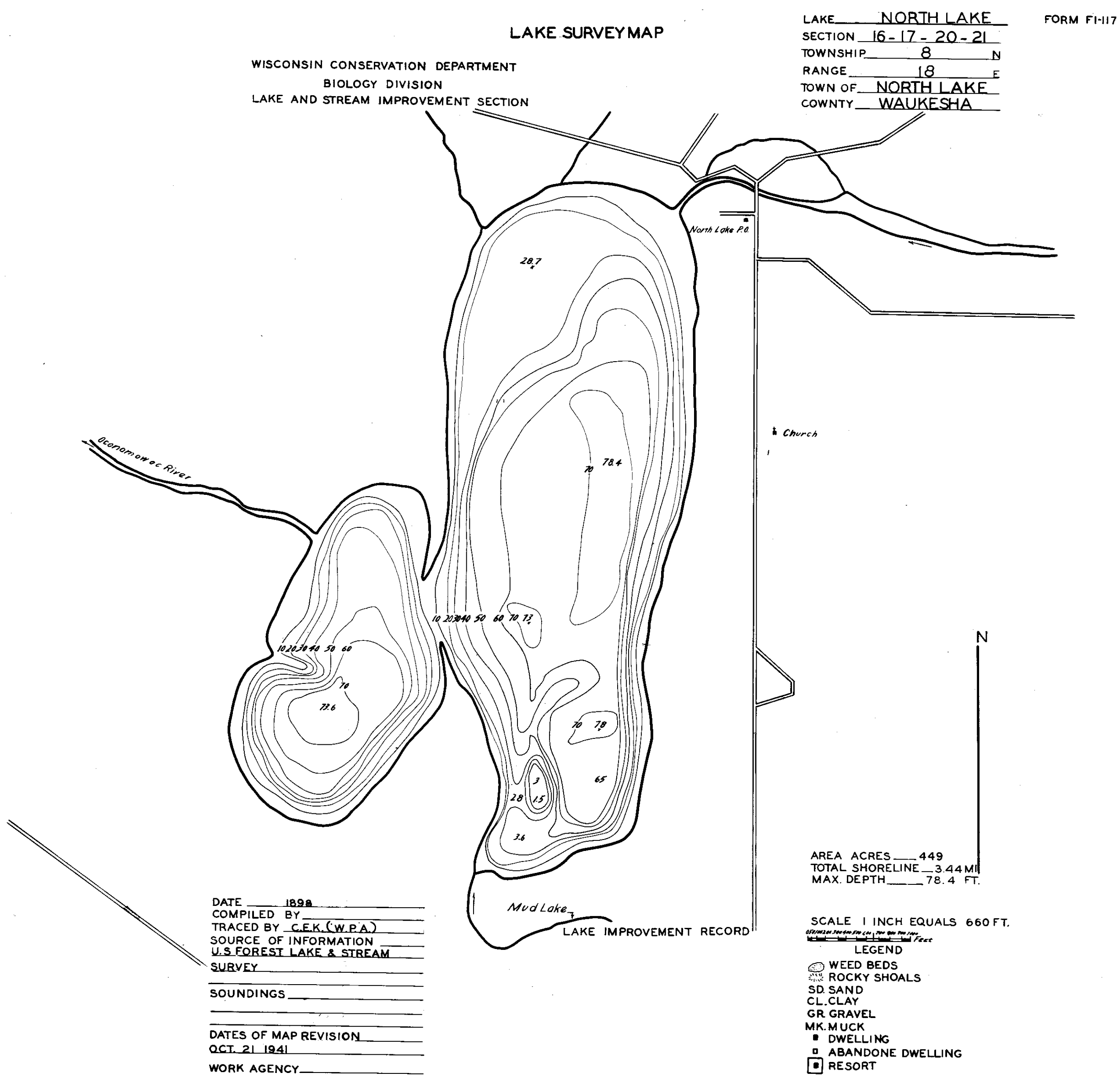
Figure 12
Relationship Between Water Depth and Wave Behavior



Source: John A. Knauss, Introduction to Physical Oceanography, and SEWRPC

The Wisconsin Conservation Department (now the WDNR) first prepared a bathymetric map of North Lake in 1898 and most recently revised this map in 1941 (see Figure 13). While suitable for general lake bathymetry, a greater level of detail would enhance modeling of the interactions between surface waves and the lake bottom as well as nearshore areas susceptible to sediment disturbance and/or shoreline erosion. The Commission has worked with the District and a local Lake resident to update Lake bathymetric information using sonar depth soundings. As shown in Figure 14, the updated bathymetry has greater detail than the 1941 revised bathymetric map, allowing for more accurate calculations of Lake surface area and volume under a range of surface water elevations. In addition, greater detail in shallow nearshore areas will enable more detailed calculations of wave power and potential erosive force. In combination with wind and boat activity information, this updated bathymetric information can be used to evaluate Lake areas most conducive to forming high waves as well as determine vulnerabilities for low-water and high-water conditions around the perimeter shallow shelf and shoreline of the Lake.

Figure 13
1941 North Lake Bathymetry



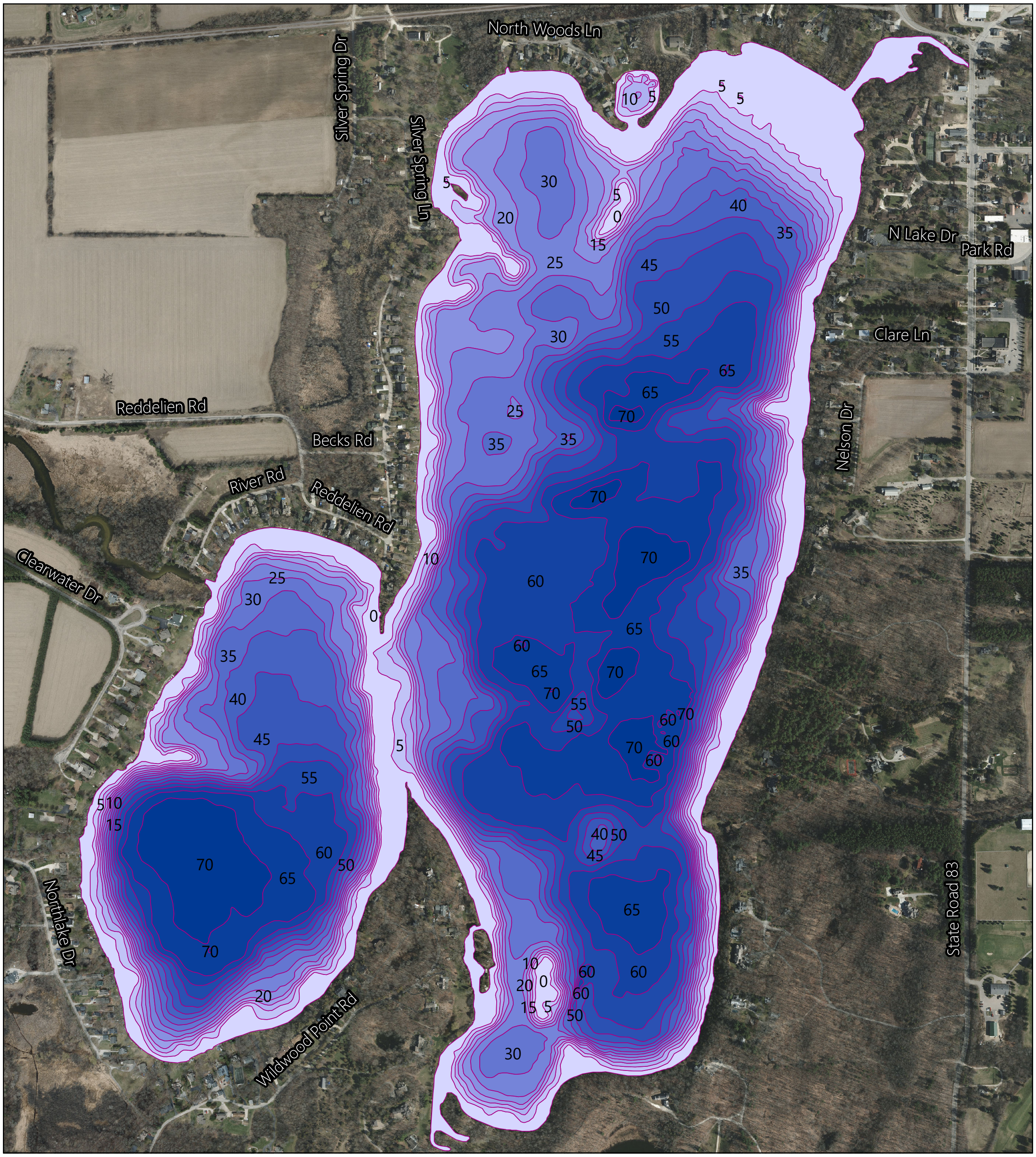
Source: Wisconsin Department of Natural Resources and SEWRPC

ENHANCING DATA COLLECTION EFFORTS

While nearly every task outlined in the scope of work was conducted during the pilot study, the effectiveness of several data collection efforts could be enhanced by monitoring additional parameters or by adapting the monitoring techniques. In addition, some tasks identified in the scope of work were not conducted and thus remain as study data gaps. Data collection efforts could be enhanced, and data gaps rectified in these following tasks:

- Monitoring boat numbers and activity with UAVs
- Monitoring recreational use throughout the boating season
- Enhanced water quality monitoring
- Documenting local weather conditions

Figure 14
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

The importance of collecting these supplemental data is described and brief recommendations for monitoring strategies are provided below.

Monitoring Boat Activity with UAV and Static Video Recordings

The monitoring conducted by Carroll University and Terra Vigilis demonstrated that it is possible to document boating activity on the Lake by UAV, as the numbers and types of boats could be distinguished from UAV recordings at a flight altitude of 300 to 400 feet. However, no systematic effort was made to survey boat numbers and types across the entire Lake using a UAV-based survey. A systematic monitoring approach, such as monitoring the entire Lake on a set flight path or for a set period, would provide a quantitative dataset that would be more useful in understanding boat activity patterns on the Lake over time (e.g., weekday vs. weekends) and space (e.g., "Little Lake" vs. the "Big Lake"). Additionally, collecting and using quantitative datasets would enhance estimates of boating pressure and recreational use conflict on the Lake, such as determining the boat "carrying capacity" of the Lake. Commission staff are available to consult with members of the District, Carroll University, and Terra Vigilis on how best to design a UAV-based boating activity survey of the Lake. An example of a boat survey conducted using UAV-based video recordings was shared with the District by Commission staff in 2020.

Use of UAVs as well as static video recorders to monitor the total number, types, and activities of boats at different times and dates on the Lake was discussed prior to and during the study. However, these approaches were not completed during the study period. While boat numbers and types can be incidentally counted during some of the UAV recordings, it is not possible to calculate a quantitative amount, such as number of boats per hour, as there was no systematic use of the UAVs for monitoring. Thus, the effectiveness of these approaches and potential changes in monitoring strategy, such as the timing of active monitoring or the placement of video recorders on the Lake, could not be evaluated. We recommend that the District pursue these approaches in future monitoring efforts. These approaches can complement information captured during the UAV flights by collecting data on boat types and activity over greater lengths of time and by providing greater flexibility in evaluating boat activity across ranges of weather conditions, times of day, and day of the week (e.g., weekday versus weekend).

Monitoring Recreational Use Throughout the Boating Season

Initial active volunteer-based observations created a recreational use baseline for North Lake. However, observations were limited to only the smaller, western basin of North Lake and were limited to certain times mostly on weekends. Phase 2 of this study should include observations from both the "Little Lake" and the "Big Lake" basins of North Lake to get a better understanding of usage type, preference, and intensity across the entire Lake as well as how boating use and pressure may differ between the two basins of the Lake. These observations should be randomized to include times throughout the day that are outside of the current survey information and should include days throughout the week to better characterize lake usage. Furthermore, coordinating collection of boat usage with a same-day boat launch that includes both boat type and trailer type would create a better understanding of resident versus visitor usage of the Lake. This information will further support potential ordinance changes for Lake use.

Additionally, since public access is limited on North Lake, it would be beneficial to characterize recreational use intensity by completing a watercraft census (i.e., a boat count along the Lake's shoreline). This would provide information on types of boats used on the Lake and popularity of different crafts. This would further support potential changes to ordinances for Lake use. Such ordinances and regulations should be conscientiously enforced to help reduce the potential for problems related to boat overcrowding during periods of peak boat traffic.

Enhancing Water Quality Monitoring

While the District and Carroll University have increased the frequency and locations of water quality monitoring, there are still enhancements that could be made to better assess potential boating activity effects. The following approaches would enhance direct measurements of boating-induced water quality changes (e.g., measuring suspended sediment before and after boat-induced waves) as well as enhance the study's capacity to rule out other mitigating factors (e.g., is the seasonal decline in water clarity caused by boating activity or by other factors, such as more turbid water entering the Lake from its tributaries).

Water temperature, pH, dissolved oxygen, and chemical analytes were only measured or collected from the top three feet of Lake water. Surface waters do not reflect water quality conditions at depth in stratified lakes, such as North Lake. Future measurements should measure conditions along a depth profile extending at least through the Lake's thermocline (15 to 25 feet deep). Otherwise, changes to water quality conditions occurring below the surface may be missed by the measurement and sampling regime. A more targeted effort to coordinate monitoring at the six nearshore locations with monitoring at the Lake's "deep hole" would help better contrast recent monitoring with the longer monitoring record of the Lake. While monitoring at the six locations around the Lake does present a thorough summary of potential wave effects on nearshore conditions, concurrent monitoring at the "deep hole" would provide a better indicator of whether these effect are only limited to the nearshore or whether they are affecting the main body of the Lake.

The chemical analysis should be expanded to include total phosphorus with some consideration given to measuring total suspended solids as well. Other parameters could be discontinued if budgets so dictate (e.g., chloride). Total phosphorus is the nutrient that generally limits algae and aquatic plants growth in Southeastern Wisconsin lakes. Waves propagated by boating activity appear to agitate bottom sediment along the nearshore areas, potentially resuspending phosphorus from the lake bed and thus making it more available for algae. Measuring total phosphorus and total suspended solids would help answer how much sediment suspension is caused by boat activity and whether the total phosphorus is being mobilized by sediment suspension. If observed, mobilizing phosphorus from the Lake bottom may be an important boating-induced process influencing the Lake's water clarity, dissolved oxygen concentrations, trophic status, and overall water quality. The second phase of the study should frequently measure total phosphorus concentrations in the Lake at different locations and at different depths in the water column.

Monitoring tributary water turbidity using a secchi disk or turbidity tube was proposed in the scope of work but was not addressed in the preliminary study. The Oconomowoc Watershed Protection Program monitored turbidity in Mason Creek just upstream of North Lake from May 1st to June 30th during 2020. Their turbidity data indicate that water clarity was fairly high in early May, but clarity declined somewhat in early June and leveled off for the rest of the monitoring period. Clarity did decline sharply to its lowest point between May 16th and 17th, which may be attributed to precipitation events on May 11th, 14th, 15th, and the 17th. Clarity quickly rose again following this brief decline. The Oconomowoc Watershed Protection Program's monitoring effort should be continued through the study period and extended to tracking the turbidity of the Cornell Lake inlet and the Oconomowoc River to help explain changes in the Lake's water clarity and quality as well as provide a baseline to evaluate effects from boating activity against. If this monitoring is not conducted, it will be difficult to differentiate whether a decrease in Lake water clarity is due to boating activity or whether it is instead related to turbid water entering the Lake from its tributaries.

Similarly, monitoring water clarity using a turbidity tube in the near-shore area before and after waves propagated by different types of boats may provide a quantitative indication of short-term changes in water clarity caused by these waves. Near-shore turbidity measurements could also be conducted before and after intense boating periods, such as in the early morning and the early evening, to quantitatively evaluate daily effects of boating on water clarity.

Documenting Local Weather Conditions

Weather greatly influences lake water quality, wave activity, and recreational use. While high-frequency weather data can be gathered from nearby weather stations, the Lake and its surrounding topography can strongly influence local weather conditions, particularly wind speed and direction. Therefore, the scope of work proposed that weather data be collected at the Lake to supplement and compare against data from nearby weather stations. However, additionally weather monitoring at the Lake was not conducted during the study period, thus it is not possible to determine if data from nearby weather stations are adequate to accurately capture Lake conditions. We recommend that weather data be collected at several well-exposed locations around the Lake in order to accurately determine if local weather conditions differ from nearby stations and what influence these conditions have on Lake water quality and wave activity.