Terra Vigilis Environmental Services Group

Lake Waramaug Wave Impact Study

Final Report

Prepared for the Lake Waramaug Inter-Local Commission

November 15, 2024

Table of Contents

<u>List of Figures</u>

<u>List of Tables</u>

Executive Summary

Introduction

In 2023, the Lake Waramaug Interlocal Commission (LWILC) with the jurisdictions of Kent, Warren and Washington, CT retained the Terra Vigilis Environmental Services Group (TVES) to conduct studies focused upon wave enhancing system impacts to Lake Waramaug. This project began in the Fall of 2023 and has included three phases. Phase 1 involved a survey of both on and off lake resident attitudes and opinions regarding recreational lake usage patterns, awareness of wave enhancing systems and their impacts, and a variety of regulatory options to preserve and protect the waters of Lake Waramaug. Phases 2 and 3 conducted during the summer of 2024 involved in-lake study of wave propagation features and propeller downwash impacts to both the surface and subsurface of Lake Waramaug. Commercial aerial and submersible drone technologies were deployed during these phases of the project.

This executive summary highlights the final report and findings contained therein.

Major Findings from the Lake Waramaug Resident Survey

The principle findings of the Phase 1 survey project showed a broad community interest and concern for preservation of the Lake Waramaug water quality and protection of this unique resource from environmental and recreational usage threats. Phase 1 survey data highlighted a focused concern for the impacts of large displacement waves to the lake. Survey data also revealed that approximately half of the residents that surround and live on the shores of the lake are unaware of specific large wave impacts to the surface and subsurface features of Lake Waramaug. The survey data revealed a large percentage of community members who are unaware of the local, state and federal regulations that govern safe boating practices. Importantly, a majority of community members support enhanced regulatory and or voluntary guidelines to be developed and used to protect and preserve Lake Waramaug. Safety concerns regarding the introduction of Wake Board Boats to the lake and the continued unregulated use of personal watercraft (PWC) were specifically noted as a safety factor to be addressed. Finally, the Phase 1 study supported a science-based study of in-lake wave impacts to better understand and manage this resource.

Major Findings of the In-Lake Study at Lake Waramaug

Phase 2 of the in-lake project involved a comparative study of wave characteristics and impacts to the near shore, lake bottom as well as sediment re-deposition events. Aerial imagery and surface measures of wave heights and wave energy were completed. Comparisons between the wave characteristics of water ski boats, cruising boats and wake board boats in “surf mode” were accomplished. Wave propagation from boats operating at staggered distances from shoreline including 100, 300, and 500 foot distances were measured to establish both impacts and provide data on reasonable buffering distances so wave attenuation distances can be established on Lake Waramaug.

Wave Heights on average were at least 200% (i.e. twice, 2X) as high for Wake Board Boats in Surf Mode compared to Ski Boats at the same distances from shore. This results in Wave Energy from a Wake Board Boat in Surf Mode that is 400% (i.e. 4X) the amount of Wave Energy from a ski boat at the same distance. To dissipate the Wake Board Boat in Surf Mode wave to the same height and energy as a Ski Boat at 100 ft requires increasing the distance from shore to over 500 feet. This corresponds with results from other studies including: Marr (U of Minnesota), WEC, TVES-NLMD.

Phase 3 of the in-lake project involved measurements of, and imagery capturing evidence of deep-water propeller downwash. The study revealed impacts at depths of at least 26 feet for Wake Board Boats in surf mode. Comparative data did not reveal deep water propeller downwash effects from water ski or cruising boats. Deep water videography established fluid kinetic energy effects to the bottom sediments to include sediment re-deposition and nutrient (Phosphorous) release events for Wake Board Boats in Surf Mode during start-up and course pass operations. Again, these impacts were not seen with traditional water ski boats.

The final report also contained a detailed literature review of studies which have addressed similar large wave impacts in freshwater lakes in the Midwest, far West and Southeastern portions of the United States. Implications for lake ecosystems are described based upon these findings.

Appropriate references to studies informing portions of the current Lake Waramaug research are cited. Appendix A provides a summary of the resident survey executive summary and appropriate links are also made available.

1. Introduction

Terra Vigilis Environmental Services Group (TVES) was retained to provide a water quality and wave impact study for the LWILC. The scope of work included a three-phase study. The first phase was designed to determine community attitudes regarding water quality and large wave displacement impacts on surface and subsurface portions of Lake Waramaug. The second phase involved an in-lake study of large displacement wave impacts to the surface, subsurface, near shore and bottom sediments of the lake. Measures of wave energy, wave characteristics, wave attenuation distances were gathered. The third phase involved an in-lake study of propeller downwash depths to include videos of lake bottom sediment redistribution.

Lake Waramaug is a freshwater lake located in west central Connecticut. The lake is approximately 656 acres with an average depth of 22 feet and several deep sections at approximately 40 feet. The lake is 2.5 miles long and has a maximum width of 1.75 miles. The surface elevation of the lake is 692 feet. Flat portions of the bottom consist of sand, mud and organic muck. The surrounding topography is hilly, and the lakeside slopes are steep with slope bottom consisting of gravel, cobbles and boulders. TVES utilized a recent (2023) Bathymetric map obtained from LWILC to facilitate this study (See Figure 3).

Lake Waramaug is a drainage lake, fed by Sucker Brook, several small streams and ground water springs. The watershed of the lake is approximately 14 square miles with 74% of the watershed being forested. The remaining 26% is residential and commercial agricultural land (both livestock and crops). Lake Waramaug is surrounded by three communities including Kent, Warren and Washington. There are 284 Riparian owners of record on the lake and the surrounding number of community residents is approximately 3400. Shoreline development includes residential homes, seasonal cottages and several commercial entities (private clubs). Public access is available at the Lake Waramaug State Park located at the Northwestern end of the lake.

The introduction of Wake Board Boats to Lake Waramaug in 2015, prompted concern for large wave impacts, and possible water quality effects. The LWILC (combined jurisdictions of Kent, Warren and Washington), elected to conduct scientific studies on these impacts in order to inform policy-making regarding management of these impacts. The present study was designed to capture the extent of both surface and subsurface large wave impacts to better understand how it may be affecting Lake Waramaug. Commercial drone technologies have been employed in this project to capture imagery allowing ease in understanding these various impacts. Imagery is combined with traditional water quality measurements to further clarify and guide public policy management decisions for protection of sensitive lake ecology.

2. Literature Review (Large Wave Impacts)

The introduction of Wake Board Boats to the freshwater lakes throughout the United States began around 2010. The marine industry currently (2024) produces vessels with wave enhancing design characteristics allowing for the creation of large displacement waves of approximately 3-4 foot surface heights. The typical Wake Board Boat utilized for "surf mode" operations has three primary characteristics enabling large displacement wave production:

1) A powerful engine (350-500 hp)
2) Wave Enhancing (Shaping) Devices and ballasting systems
3) High bow angle, and low stern configuration (10-15 degree trim angle).

Figure 1 Wake Board Boat in Surf Mode

These vessels typically operate at 9-10 mph per hour to maximize large wave production. The spread of these recreational boats has been controversial, with increasing public concerns for wave impacts to other surface vessels, near shoreline, fish and waterfowl habitat and shoreline structures. These concerns have prompted scientific study which has produced a growing body of data supporting surface and subsurface wave and propeller downwash impacts. In particular, the studies reveal bottom re-deposition impacts from propeller downwash of wake board boats in surf mode. Nutrient release, bottom "scrubbing" damage, and related unseen impacts from powerful wave energy is reflected in this work. The bathymetric characteristic of a particular lake is a variable, with shallower lakes (less than 20 feet) showing more evidence of large wave impact.

The current project benefits from reference to additional studies being conducted in the Midwest, far West and Southern portions of the United States. These comparative studies have occurred on freshwater lakes with a similar focus upon large wave impacts to the near shore, lake bottom and wave energy comparisons between wake board boats in surf mode and traditional ski boats.

Water Environment Consultants, SC (WEC) completed a recent (2021) wave impact analyses on Lakes Burton and Rayun in the northeast corner of Georgia. In addition, the WEC group studied three of six lakes in a series of reservoirs created by the Tallulah River system (owned and operated by the Georgia Power Company). This work was completed in 2020-21.

The principal findings of the WEC project established that wake board boats in surf mode (Maximum ballasting, slow speed, high bow angle) produce a more powerful wave, with higher speed, height and energy resulting in a need for longer attenuation distances than waves produced from wake board boats in non-surf mode and/or traditional water ski boats. Longer buffering distances from shore and other vessels were recommended to manage these impacts.

Note to the reader: Wave energy is proportional to the square of wave height. A wave that is 2X in height has 4X the amount of energy. This formula was used in TVES calculations relative to wave energy. A similar method is used in the Marr data allowing comparisons.

An interesting comparison from the WEC work involving wind waves versus wakesurfing vessel wakes is also noted:

"Wakesurfing vessel wakes exceed wind waves at every site at distances within 500 feet of the vessel sailing line. In contrast, typical cruising vessel wakes do not exceed wind waves at every site, except within a very close proximity to the vessel, i.e., 75 feet"

Consideration for shoreline erosion was included in the WEC (2021) project. Although shoreline erosion is a complex predictive problem, influenced by localized conditions such as sediment properties, topographic slope, presence of hard structures and vegetation, the WEC study did conclude that wakesurfing and wakeboard boating vessels are much more likely to contribute to shoreline erosion than typical boat waves or wind waves.

Finally, the WEC study addressed shallow near shore areas for bottom scrubbing impacts by wake surf mode vessels. Risks for "slip failure" of the soils behind sea walls leading to bulkhead failures was reported. "Overtopping" effects based on excessive wave heights from the surf mode wakeboard vessels can also produce structural damage per the WEC (2021) data.

Previous studies by Terra Vigilis Environmental Services (TVES) on midwestern lakes (North Lake Management District, DNR Grant Funded, 2019-2021) have established similar impacts based on large wave energy by wake board boats in surf mode. TVES completed comparative studies of wave attenuation distances, bottom scrubbing, sediment redistribution and nutrient release events following wake surf mode activity. High energy wave features with bottom scrubbing impact and plume development are documented in the TVES 2020-21 data. Appendix B of this report contains excerpts of the relationship between water depth and wave behavior. Nutrient release (Phosphorous) into the water column has also been reported in the TVES work.

The University of Minnesota, St. Anthony Lab project (2020) headed by Jeff Marr and his research team, has also studied the impact of wake board surf mode impacts relative to wave attenuation distances, wave energy measures and propeller downwash depths. The Marr team has called for extended buffering distances of 500-700 feet from active surf mode vessels, and the research team is currently completing additional work measuring propeller downwash depths using sonar acoustic returns.

Alex Ray from Western Colorado University has completed a series of studies (2020-21) at Payette Lake, Idaho. This work has focused on the impact of propeller slipstreams (downwash) on lakebed sediments in Payette Lake. Based upon growing concern for nutrient load impacts to the waters of this large lake system, and specifically the risk of toxic blue green algae and other cyanobacterial blooms, the author studied non-buoyant jet streams produced by current model, powerful wake board boats in surf mode (ex: 2019 Axis T-23). Significant impacts from surf mode operations and their consequent slipstream bottom impacts on sediment redistribution were delineated in this work. See Figures 2 and 3.

"According to modeling results, wake boat slipstreams have the potential to affect bed sediments at 33' of depth" Ray, 2021

Ray goes further by noting,

"Adding passengers and ballast also creates higher slipstream velocities, as it increases drag on the boat. Additionally, while most boats pass through the RPM band correlating to the highest slipstream velocities (during acceleration to planing mode), surf-boats are often continuously operated at the speed where displacement, slipstream velocities, and trim angle are highest."

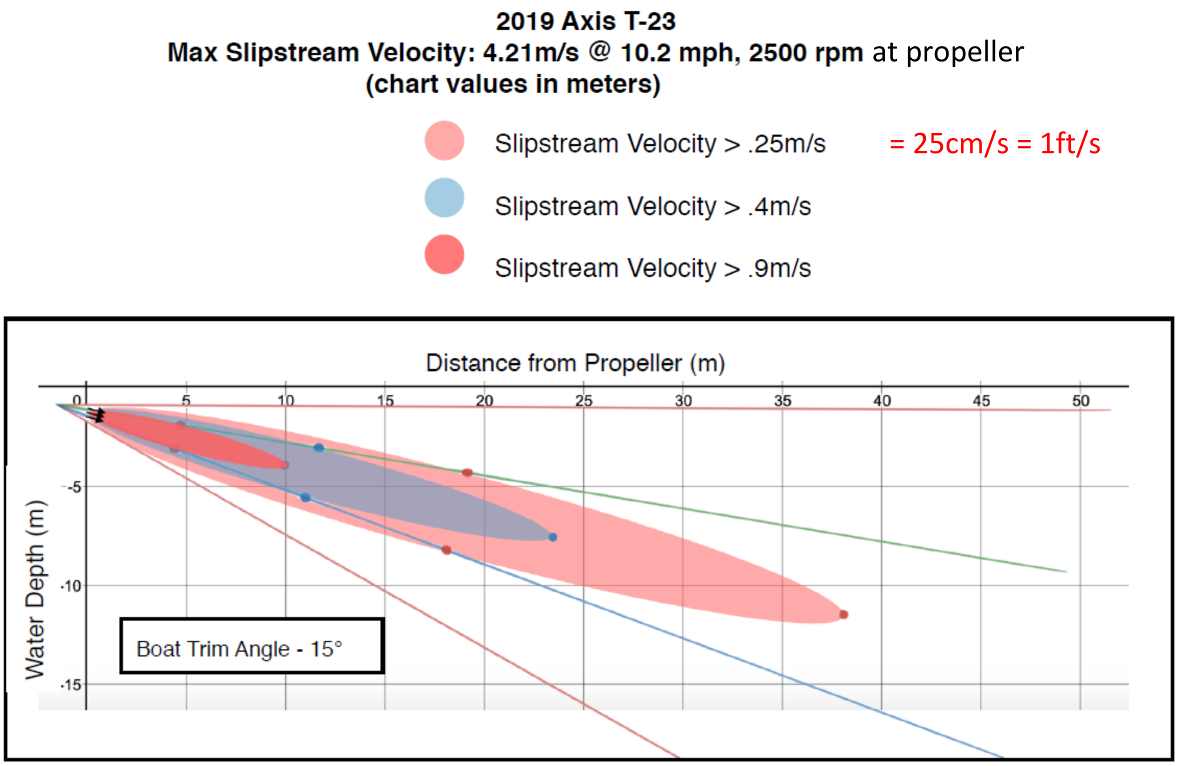

Figure 2 Slipstream Impacts Payette Lake. Ray (2021) Final Report, Payette Lake

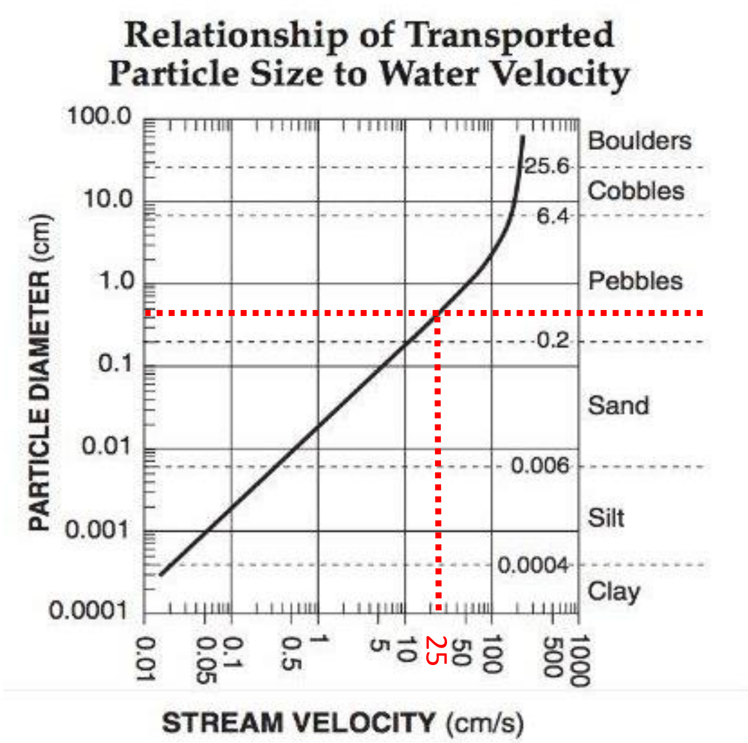

Figure 3 Sediment Redistribution: Slipstream velocity needed to move particles based on size

In summary, there is an impressive consistency in the studies being conducted which demonstrates larger, faster, high energy, large displacement wave risks across multiple areas including:

1) Surface threats to other vessels
2) Near shoreline disruptions
3) Bottom scrubbing effects
4) Shoreline structure impacts
5) Nutrient release events to the water column
6) Deep penetration propeller downwash effects
7) Wave attenuation distances prompting changes to traditional buffer distances

This final report of the Lake Waramaug project by TVES, also identifies examples from comparative studies of large wave energy surface and subsurface characteristics to underscore the consistency of these data.

3. Wave Impact Study Lake Waramaug, CT : Methodology

The Lake Waramaug study was conducted in three phases including:

1) A residential survey of attitudes and awareness of large wave impacts by the constituency surrounding and living on Lake Waramaug. (See Appendix)

2) In-lake measures of surface wave impacts (near shore) taken at both shallow and steep shorelines with waves generated at staggered distances from shore by vessels in common use on the lake.

3) In-lake subsurface measures of propeller downwash impact by Wake Board Boats in "Surf Mode" and typical water ski boats. Both start-up and buoy pass testing conditions were arranged as part of the study design at selected testing sites.

A combination of aerial and submersible drone imagery was used to measure wave dynamics as well as reflecting fluid kinetic energy.

Detailed description of the UAS devices (drones) used in the present study follow. In addition, the subsurface measurement equipment, camera specifications, certified laboratory analyses specifications and imagery preparation techniques are explained.

Together, these measures provide a clearer picture of large displacement wave impacts to Lake Waramaug and a basis for comparable recreational lakes where wakeboard boats in surf mode operations are occurring.

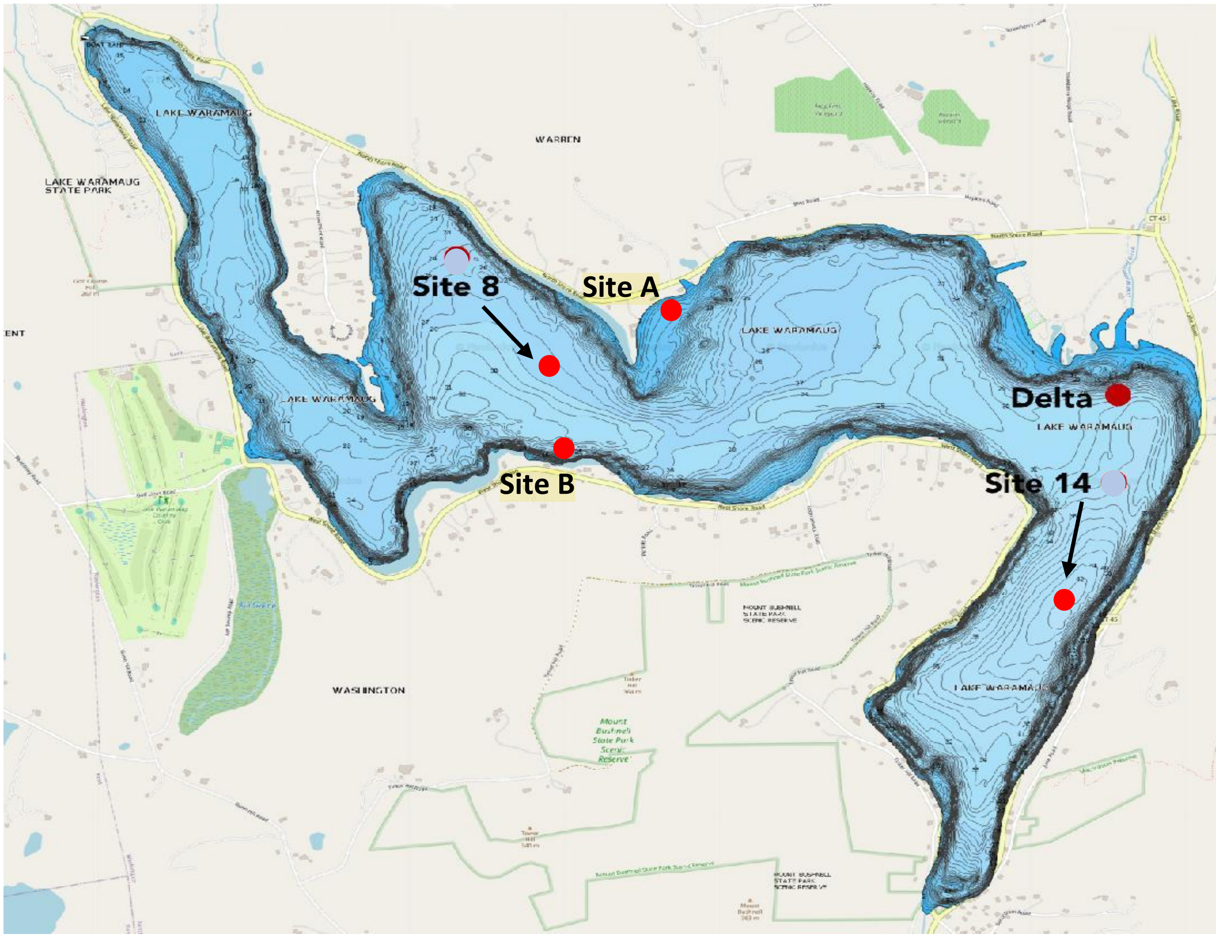

Figure 4 Bathymetric survey and study test site locations, Lake Waramaug, CT 2024.

Test sites A and B were chosen for wave propagation/attenuation distance comparisons with various vessels used on Lake Waramaug. Site A was chosen to measure near shore wave impacts due to shallow water depths near the shoreline. Site B was chosen to measure near shore wave impacts due to deep water depths (steep shoreline).

Site 8 was chosen as a location for propeller downwash measurements based upon a uniform depth of water at 26 feet where Wake Board Boats in surf mode typically operate. Site 14 was chosen for propeller downwash measurements based upon a deeper bottom area of approximately 36 feet.

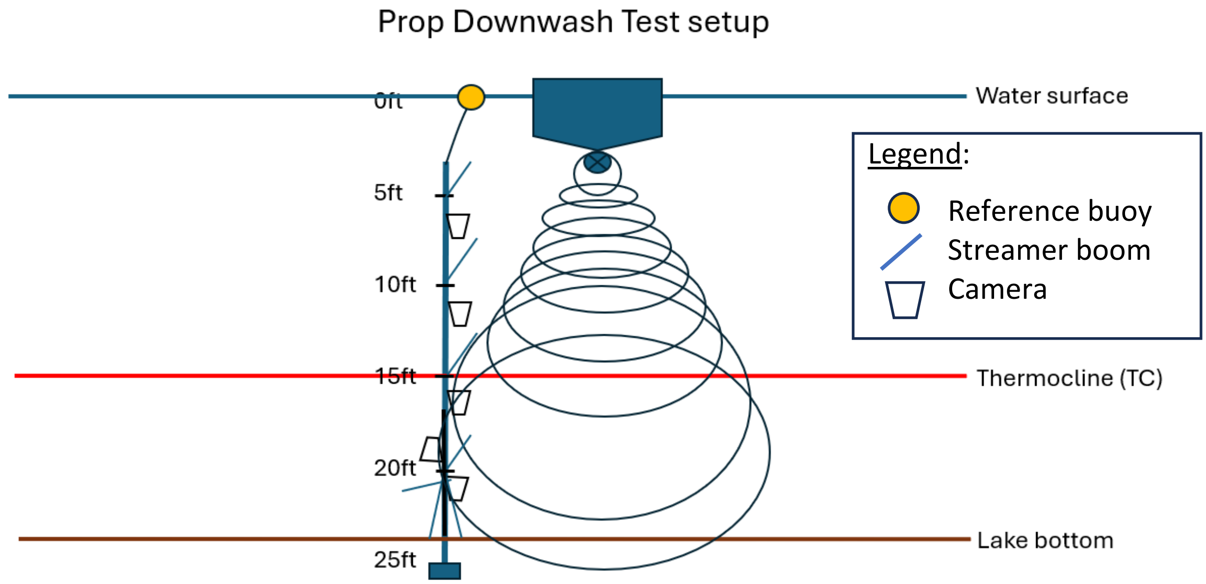

Figure 5 Subsurface Equipment and Hardware

The TVES engineered subsurface hardware is depicted in figure 5. A twenty-five-foot telescoping aluminum pole with anchor system was deployed at test site 8 and 14. The vertical pole had five, 36-inch extended fixtures attached at a 90-degree angle to the vertical pole. Each boom extension was affixed with a camera and color sensitive streamers to reflect dynamic water flow from propeller downwash energy. The boom extensions were affixed at 5, 10, 15, 20, 25 feet on the vertical pole. A camera with illumination was placed near the bottom of the vertical pole to record bottom sediment disruptions and re-distribution. All video captured was date and time stamped.

The submersible measurement system utilized was a remote underwater rover (ROV) with surface maneuvered commands from remote pilot using a virtual goggle system. The ROV was capable of a 250-foot range. The ROV was equipped with a propeller system, powerful lighting (4,000 lumens), cameras and a mechanical arm to grasp and hold objects. See Figure 6 ROV "Fifish".

Figure 6 QY Sea V6 Fifish

Aerial drone imagery was captured with several UAS platforms, including a DJI Mavic Pro Quadcopter, with Hasselbad 4K camera system.

Figure 7 Mavic Pro UAS (Drone)

All TVES submersible equipment and hardware was pre-tested for stability, signal reliability, and battery supply prior to testing conditions. All TVES use of commercial drones were conducted by FAA commercial UAS pilots with visual observers.

Wave Propagation/Attenuation Distances

Buoy markers were placed at staggered distances from the shoreline at Sites A and B allowing for a professional driver, operating a Wake Board Boat in Surf Mode, and a typical water ski boat to make multiple individual passes at 100 feet, 300 feet and 500 feet from the shoreline. Multiple aerial, surface, and subsurface cameras recorded each pass with pause intervals allowing wave activity to dissipate fully between passes. See Figure 8 of a four-quadrant image from the various time synchronized cameras. Post-processing of the videos provided measurements of wave crest and wave trough amplitudes, wave heights, and wave lengths in a repeated measures design as depicted by the insert on Figure 8. These measurements provide graphical representation of wave height versus time as shown in Figure 9. Wave energy was also derived from these measurements. See the results section for a data summary and graphical display of these comparative data sets. Video clips of wave propagation will be presented at scheduled town meetings and made available thorough Hyperlinks.

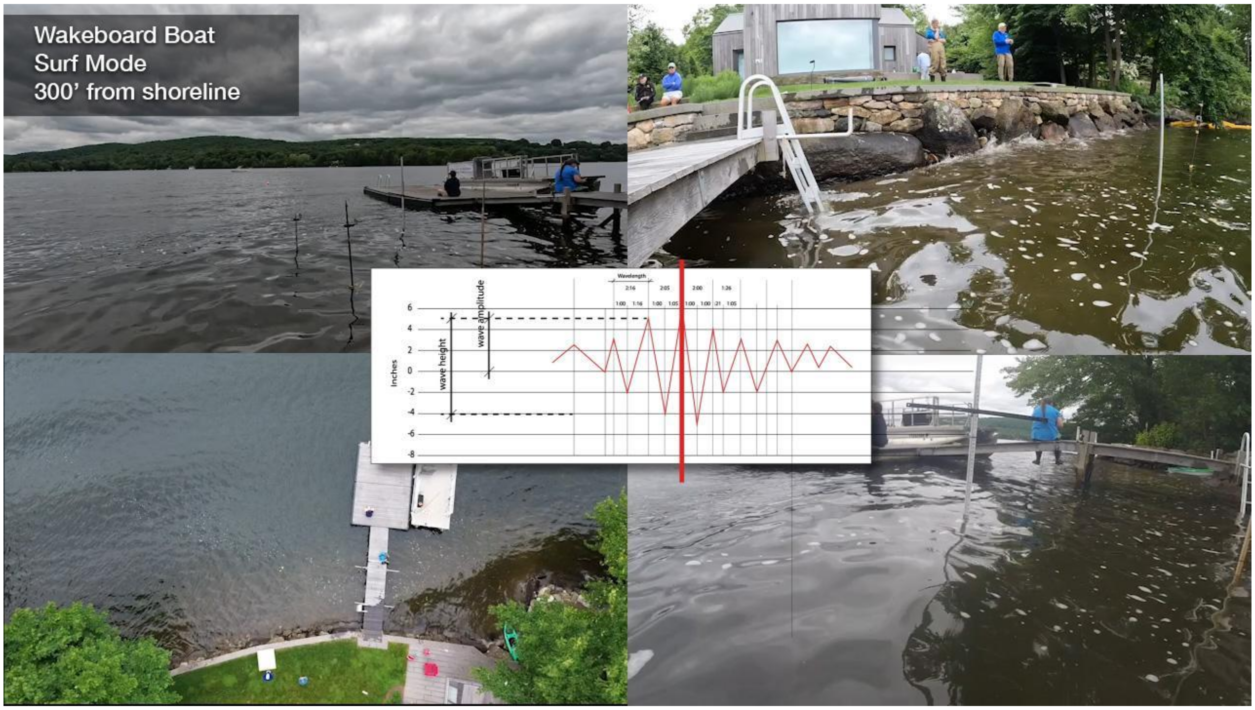

Figure 8: Four Quadrant view of Wakeboard Boat in Surf Mode at 300 feet from shoreline

Propeller Downwash Depths under Start Up Conditions and Surface Passes at Controlled Vessel Type Speeds.

Reference buoy markers were secured, with surface passes and startup propeller downwash depth measurements obtained for a Wake Board Boat in surf mode and then compared to a water ski boat in ski mode operating on the same course. During the testing phases, three separate startup conditions were measured for each vessel type. See the results section for a data summary and imagery reflecting fluid kinetic energy impacts. Video imagery reflecting propeller downwash and bottom sediment impacts were obtained for each vessel type.

Surface Vessel Specifications Used in the Lake Waramaug Study

Comparative Wave Propagation (Sites A,B)

<u>Water Ski Boat</u>
Cobalt 190 (model year 1998)
Stern Drive
Length Overall 19 ft
Weight 2,825 lbs
Power plant 245 hp (Modified)
Test Speed…22-25 mph

<u>Wake Board Boat (Medium Size)</u>
Maristar (Model Year 1999)
Stern Drive
Length Overall 21 ft
Weight 3,350 lbs (before ballasting)
450 lb bow ballast bag
1,500 lb stern ballast bags
Wave Shaper
Power Plant 330 hp
Test Speed…9 mph

<u>Cruising Boat</u> (Photo Unavailable)
Custom Cruiser Provided by Lake Resident
Stern Drive (Modified Outboard)
Length Overall 18 ft
Weight 1,500 lbs (estimate)
Power Plant 25 hp Outboard
Test Speed…5 mph

Comparative Propeller Downwash Startup and Buoy Passes (Site 8)

<u>Water Ski Boat</u>
Cobalt 190 (model year 1998)
Stern Drive
Length Overall 19 ft
Weight 2,825 lbs
Power plant 245 hp (Modified)
Test Speed…22-25 mph

<u>Wake Board Boat (Large Size)</u>
Malibu Wakesetter 23 LSV
Stern Drive
Length Overall 23'7
Weight 5,700 lbs (without ballasting)
Power Plant 400 hp
Stern Ballasting 4,400 lbs
Test Speed…9 mph

** Professional Drivers were used to operate vessels in specified modes (deck angle, speed, and ballasting)

4. Lake Waramaug Wave Impacts Results Summary

4.1 Wave Propagation Impacts

Near shore wave characteristics including wave heights, wave trough depth, and wave amplitude are depicted in Figure 9 with waves generated at 100 feet, 300 feet and 500 foot distances from the shoreline. These wave characteristics are shown at both shallow and deep water testing sites A and B respectively. Wake board boats in surf mode produce significantly higher waves, significantly deeper trough depths, and a significantly higher wave energy than a water ski boat at all staggered distances tested. A separate calculation of wave energy is also shown in Table 1. The wave features of the Wake Board Boat operating in surf mode are demonstrably different from the ski boat comparative data. These data are consistent with other studies referenced in the literature review. Wake Board Boats operating in surf mode create a very different wave phenomenon, with a larger, faster, and more penetrating energy dimension under these test conditions.

The wave height data captured at Site B with the steep shoreline has limited distance for wave interaction with the lake bottom. The wave height data captured at Site A with a shallow lake bottom approaching the shoreline reveals that the waves propagating towards shore were scrubbing the lake bottom, thereby reducing the wave height and dissipating wave energy, but also causing sediment redistribution and nutrient release into the water column. See Appendix B Relationship Between Water Depth and Wave Behavior.

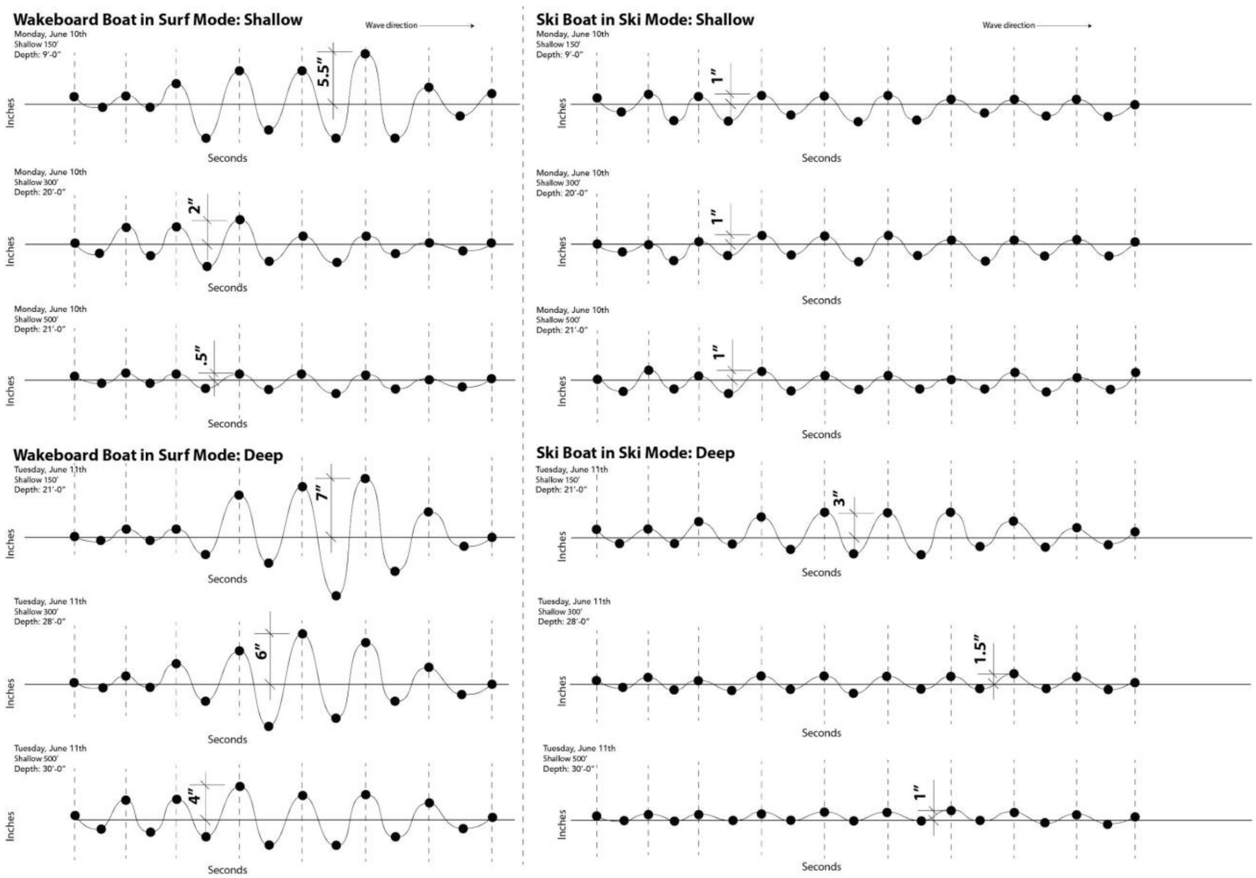

Figure 9 Wave Propagation Impacts at 100', 300', 500' from Shore in Shallow and Deep Test Sites A and B at Lake Waramaug, 2024.

Note: Test site A has a shallow lake bottom near shore, so the 100' buoy was actually located 150' from shore to have a water depth of 9 feet to safely operate the wake board boat in surf mode without hitting the lake bottom.

Distance from Shoreline (ft)	Wave Height (in)	Percent Increase in Height over Ski boat at same distance	Percent Increase in Energy over ski boat at 100ft		Distance from Shoreline (ft)	Wave Height (in)	
100	14	233%	544%		100	6	
300	12	400%	400%		300	3	
500	8	400%	178%		500	2	
>500	6		100%				

Table 1: Wave Height and Wave Energy comparison based on Operating Mode

Wave Heights on average were at least 200% (i.e. 2X) as high for Wake Board Boats in Surf Mode compared to Ski Boats at the same distances from shore. This results in Wave Energy from a Wake Board Boat in Surf Mode that is 400% (i.e. 4X) the amount of Wave Energy from a ski boat at the same distance. To dissipate the Wake Board Boat in Surf Mode wave to the same height and energy as a Ski Boat at 100 ft requires increasing the distance from shore to over 500 feet. This is depicted by the green highlighted bars in Table 1. This corresponds with results from other studies including: Marr et al, WEC, TVES-NLMD.

For the reader of this document: Wave energy is proportional to the square of wave height. A wave that is 2X in height has 4X the amount of energy. This formula was used in TVES calculations relative to wave energy. A similar method is used in the Marr et al, data allowing comparative reference.

4.2 Propeller Downwash Impacts

Propeller downwash depths were measured under repeated startup and buoy pass testing conditions and reveal deep fluid kinetic energy activity for wake board boats in surf mode compared to minimal impacts by a water ski boat under identical testing conditions. Subsurface imagery as depicted in Figure 10 reveals propeller downwash impacts occurring at depths of at least 26 feet for a wake board boat in surf mode.

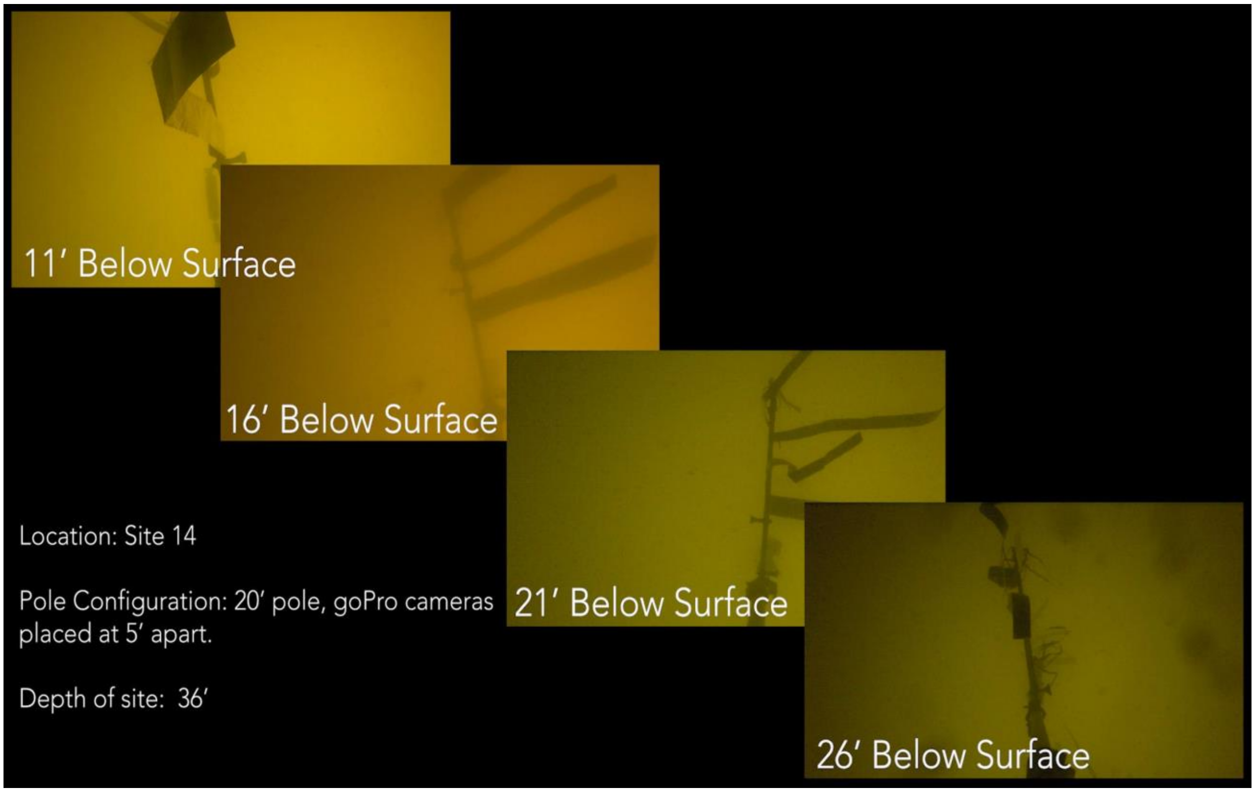

Figure 10 Propeller Downwash Impacts of at least 26 feet Depth by Wake Board Boat in Surf Mode. (Test Site 14) Lake Waramaug, 2024

Bottom Sediment Re-Deposition & Disturbance at Deep Water Test Site (Site 8)

Imagery was gathered at deep water test site 8. Cameras placed at the base of vertical poles in 26 feet of water depth revealed propeller downwash impacts including sediment re-distribution due to wake board boat propeller downwash in wake surf mode. See Figure 11.

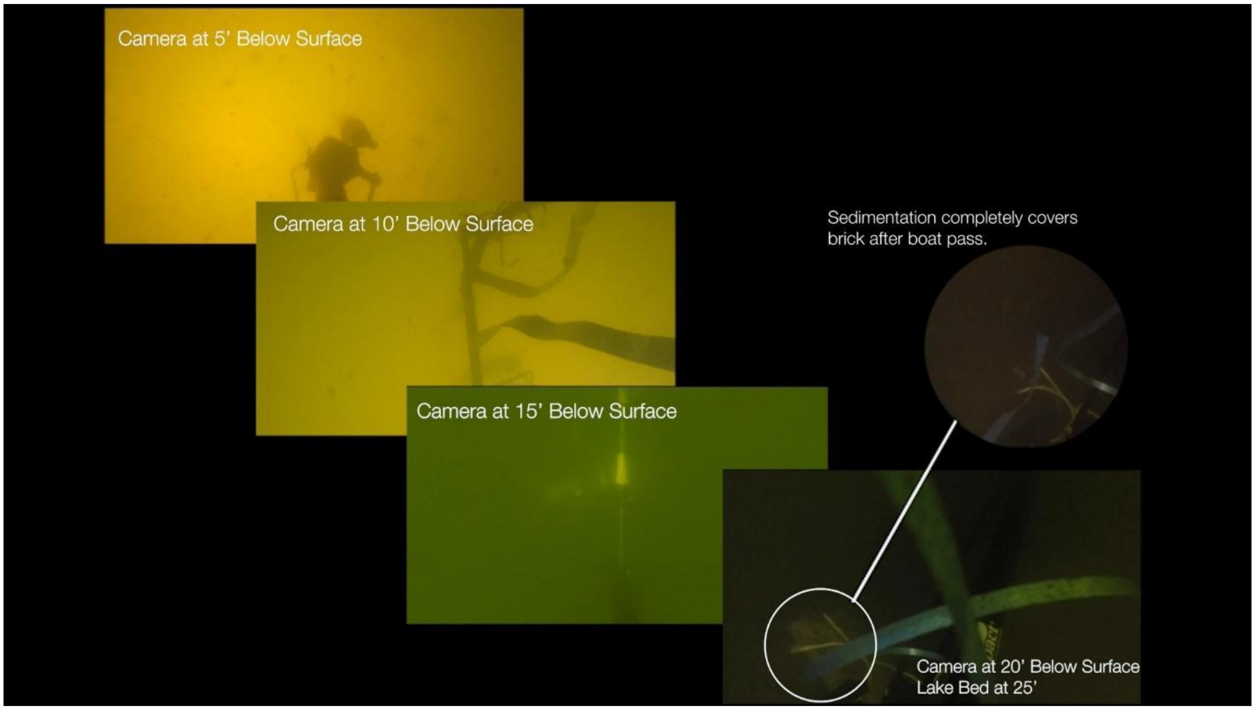

Figure 11 Images at Site 8 of Propeller Downwash and Sediment Re-distribution

Of additional interest, total Phosphorus sampling at these deep sites (sampled at 20 feet), also reveal a 110% increase in Total phosphorus levels released immediately following startup impact **measures for wake board boats in surf mode. By comparison, *no significant increase in measured Total phosphorous levels was found for water ski boats in startup conditions.*** *(The reader is cautioned that this finding is preliminary in nature, was not the primary focus of the project, and warrants additional study.)*

Propeller downwash effects are occurring at depths at and below the measured thermocline for Lake Waramaug (approximately 17 feet, mid-late summer 2024). The potential disruption of "mixing cycles" associated with this finding warrants additional study.

This nutrient release data is similar to previous study by the TVES group in North Lake, Wisconsin. In 2021, TVES designed a pre-post sampling procedure of phosphorous release events on a controlled, 800-meter course in 15' to 25' of depth with a wake board boat in surf mode. After two boat passes, measurements of 25% to 30% percent increases in Total phosphorus levels (dip sampling) were demonstrated in the near shore in that study. See Figure 12.

Nutrient release events into the water column as described above, are noted for specific additional study. Professional opinions from Limnology experts should be sought relative to the impacts of persistent Total phosphorus release events and thermocline penetration by wake surf mode operations in Lake Waramaug.

Figure 12 Increased Phosphorous Release Events Following Wake Board Boat in Surf Mode Operations, North Lake, Wisconsin Study (2021).

5. Lake Waramaug Impact Management Issues for Consideration

TVES group has completed a three-phase study of Lake Waramaug. Phase 1 surveyed resident attitudes regarding lake usage, and Phases 2 and 3 involved in-lake studies measuring large displacement wave impacts to the lake.

In 2023, a survey of community and lake resident opinions was released and briefed to local residents in the Kent, Warren and Washington, CT municipalities. Both an executive summary and final report were made available to interested citizens on local municipal websites. Principle findings included*:

- A large percentage of survey respondents are aware of large wave displacement vessels and devices.
- Only 50% of survey respondents are aware of the surface and subsurface lake impacts from wake board boats in surf mode.
- Both wake board boats and personal watercraft were identified by a majority of survey respondents to be a safety risk.
- 50% of survey respondents are aware of local, state and federal safe boating regulations.
- A majority of survey respondents are in favor of mandatory regulations to manage large wave impact vessels on Lake Waramaug.

*(See Appendix to this report for the full survey report and executive summary).

During Phases 2 & 3 in-lake scientific studies were performed in the summer of 2024 on Lake Waramaug. These studies addressed comparative wave features produced by vessels in common use on Lake Waramaug, including water ski boats, cruising watercraft and wake board boats in surf mode.

Wave impacts were studied at staggered distances from shoreline (100 ft, 300 ft, and 500 feet) to address wave attenuation dynamics. In addition, deep water, subsurface impacts, were studied allowing comparative measure of propeller downwash depths and bottom sediment impacts (disturbance and re-distribution).

The in-lake study on Lake Waramaug has demonstrated that large displacement wave action from wake board boats in surf mode are larger, faster and of higher energy at all distances from the near shore than any other vessels in common use on the lake. These findings are consistent with similar studies, from multiple research groups, in the Midwest, West and Southeast portions of the United States.

The in-lake study on Lake Waramaug has also demonstrated deep fluid kinetic energy impacts at depths of at least 26 feet from Wake Board boats in surf mode on both start up and passing over a controlled course. These impacts are not demonstrated from vessels not operating in surf mode configurations. These findings are also consistent with similar studies, from multiple research groups, in the Midwest, West and Southeast portions of the United States.

Action Items for Consideration at Lake Waramaug, CT

- Develop and establish management procedures for large displacement wave action impacts on Lake Waramaug, CT
- Develop and establish management procedures to assure a 500-foot minimum distance from the near shore, other vessels and shore structures relative to Wake Board boats in surf mode on Lake Waramaug, CT
- Develop and establish management procedures to assure minimum depth areas to be designated and protected from sediment redistribution events from Wake Board boats in surf mode on Lake Waramaug, CT
- Develop and establish educational programs to address measured limits of public knowledge regarding safe boating practices for all vessel types and lake usage on Lake Waramaug, CT
- Develop and establish educational programs to address public awareness of large wave impacts to the surface and subsurface of Lake Waramaug, CT
- Additional study of sediment re-distribution and nutrient release

6. References

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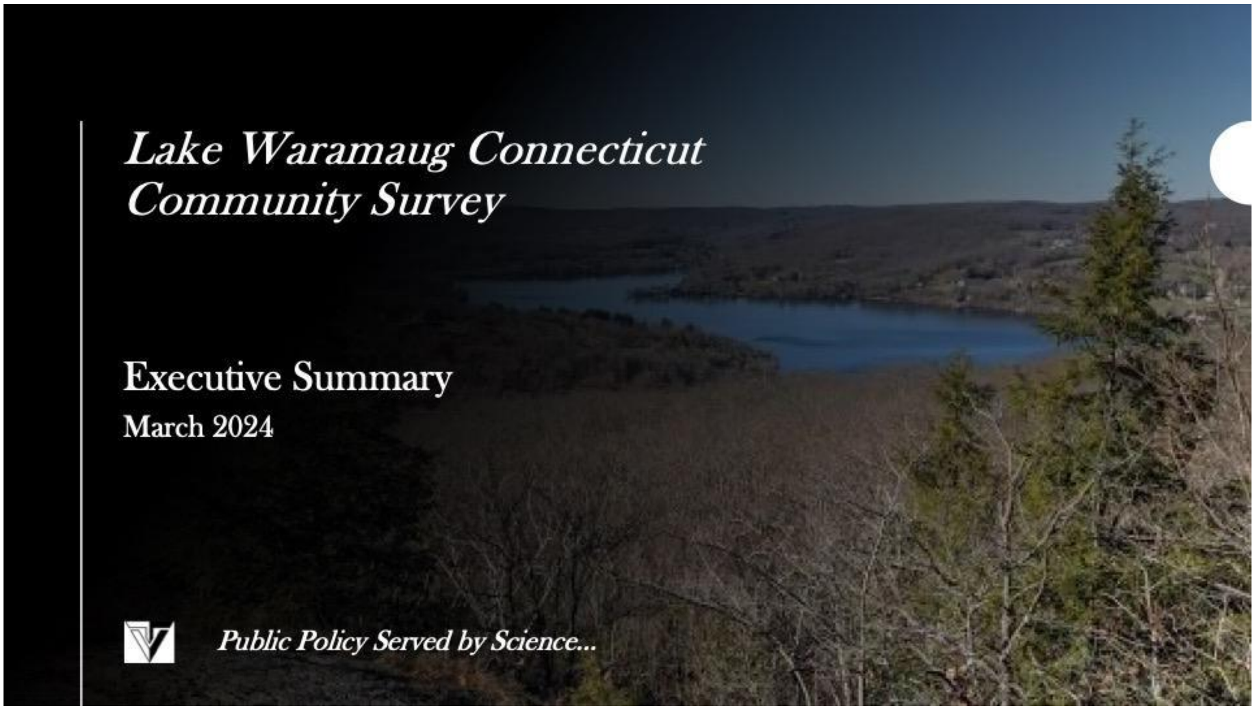
Appendix A

Lake Waramaug Resident Lake User Survey, Executive Summary, 2024



Excerpt of Principle Findings
– Survey Analysis and Conclusions
Full survey analysis results are provided in the "Community Survey" final report (47 pages). The detailed survey analysis includes an organized index of open-ended commentary from respondents in the appendix.

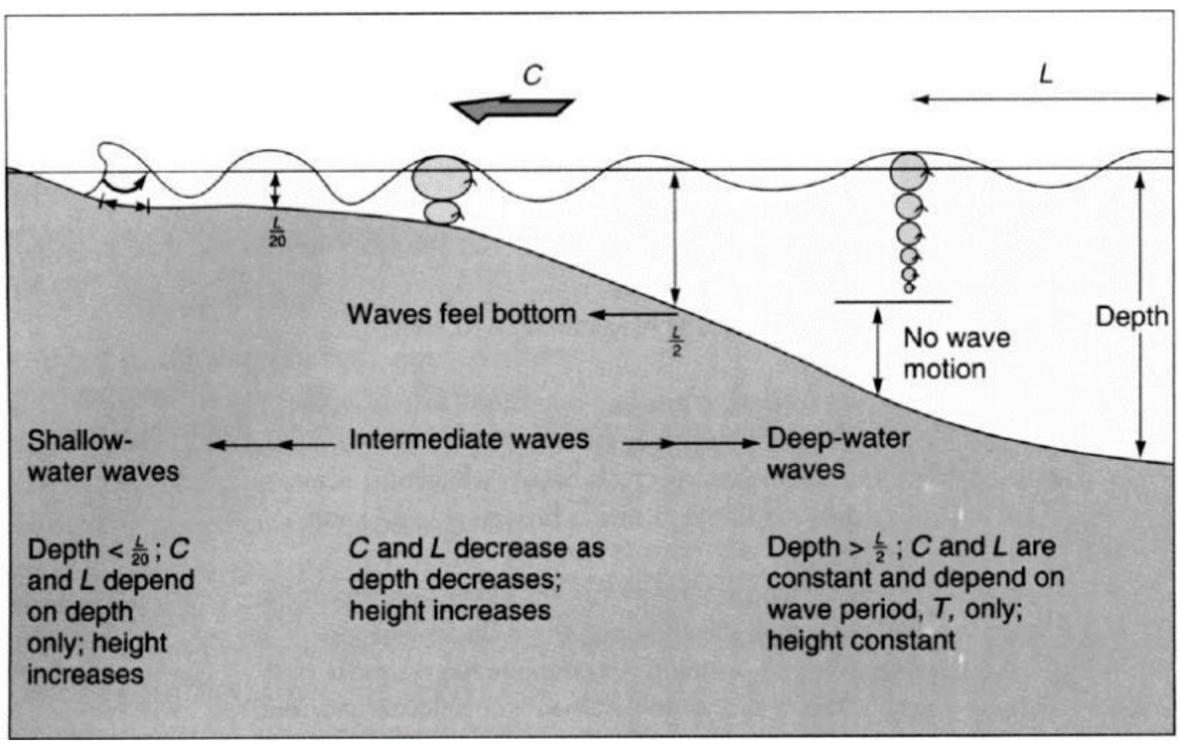
- PWC and Wake Surf mode operations are major concerns
- PWC and Wake Surf mode are proportionately a small percentage of lake usage with high identified impact
- High percentage of lake users are unaware/uneducated about safe boating regulations
- On-lake boat operator conduct should continue to be managed
- Widespread awareness that water quality impacts property values and quality of lake life
- Multi-user recreational lake with significant number of non- lake property owners taking an active interest and use in the lake
- Majority of survey respondents prefer enforceable regulations. This is in comparison to the majority of Lake Property Owners who favor voluntary compliance.

Appendix B

Relationship Between Water Depth and Wave Behavior (Excerpt from: TV-ES North Lake Water Quality and Wave Propagation Study Phase 2 Report)

Background

It is important to provide some background on general characteristics of waves, how they move through the water, and what affects them. The figure below shows the relationship between water depth and wave behavior. In deep water conditions (i.e., water depths greater than ½ wavelength of a wave) the speed (C) and wavelength (L) of a wave produced by a particular vessel type and operating mode are constant and are not influenced by the lake bottom and the water particles move in a circular motion. For example, a wave with a wavelength of 20 feet is considered a deep wave in depths of 10 feet or greater. Wavelength is defined as the distance between the top or crest of a wave to the next or adjacent crest. Although not illustrated on the diagram, wave amplitude is the difference in height between a wave crest and adjacent wave trough. Wave period (T) is defined as the time for one wavelength to pass a fixed location.



Relationship Between Water Depth and Wave Behavior
Source: John A. Knauss, Introduction to Physical Oceanography, and SEWRPC

When water depth is less than half the wavelength of a wave, the lakebed begins to slow the wave by friction (bottom scrubbing) and the water particles start to move elliptically as shown. As the wave slows, wavelength shortens, and wave height increases until the ratio reaches or exceeds 7:1 (wavelength/wave height), when the wave breaks. As shown the wave is considered an intermediate wave, meaning some interactions with the lake bottom, when water depths are between ½ and 1⁄20 of the wavelength. Below 1⁄20 wavelength, the wave is considered a shallow water wave. For the example given, a wave with a wavelength of 20 ft would be an intermediate wave between 10 ft and 1 ft of water depth and a shallow wave below 1 ft of water depth. These definitions become important for understanding the results of this study and its relationship to other wave studies or research.