



Terra Vigilis Environmental Services Group

Lake Waramaug Shallow Water Environment
Wave Impact Study
Final Report



Prepared for the Lake Waramaug Task Force
December 15, 2024

Lake Waramaug Shallow Water Study 2024

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Executive Summary

Introduction

The Lake Waramaug Task Force (LWTF) retained the Terra Vigilis Environmental Services Group (TVES) to conduct studies focusing on wave enhancing system impacts to the shallow water environments at Lake Waramaug. In-lake studies were conducted during the summer of 2024 involving wave propagation impacts to the subsurface of Lake Waramaug, particularly shallow water environments and specifically at Sucker Brook Delta. Commercial aerial and submersible drone technologies were deployed during this project.



This executive summary highlights the final report and findings contained therein. Excerpts from the “Phased Study of Wake Boat Impacts to Lake Waramaug, Connecticut, 2024” are included, and the Reader should also refer to that report for additional details and background.

Major Findings of the Shallow Water Environment Wave Impact Study at Lake Waramaug

- Wake Boat (surf mode) operations in proximity to the Delta Site produce significant surface and subsurface disruptions to this region sufficient to produce sediment re-distribution, compromise water clarity and produce nutrient release.
- The bottom topography of Lake Waramaug in the Delta Site region, enhances bottom scrubbing by large displacement waves sufficient to cause wave re-emergence effects
- Specific Lake management steps are required to protect this sensitive area of Lake Waramaug (Delta Site)

1. Introduction

Terra Vigilis Environmental Services Group (TVES) was retained to provide water quality and wave impact study for the LWTF. The scope of work included the use of aerial, surface, and sub surface videography at the Sucker Brook Delta to identify wave propagation impacts to the shallow water environment including disturbance of lake bottom sediments.

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 2).

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 3,400. 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 Boats to Lake Waramaug in 2015, prompted concern for large wave impacts, and possible water quality effects. This study was designed to capture the extent of both surface and subsurface large wave impacts, specifically wave propagation impacts on shallow water areas (i.e. Sucker Brook Delta) in an effort 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 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 Boat utilized for “surf mode” operations have 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 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 impacts. In particular, the studies reveal bottom re-deposition impacts from lake bottom scrubbing by wake 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.

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A related 2024 in-lake project at Lake Waramaug 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 boats in “surf mode” were accomplished. Wave propagation from boats operating at staggered distances from the 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 Boats in Surf Mode compared to Ski Boats at the same distances from shore. This results in Wave Energy from a Wake 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 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.

Under water videography of propeller downwash also established fluid kinetic energy effects to the bottom sediments to include sediment re-deposition and nutrient (Phosphorous) release events for Wake Boats in Surf Mode during course pass operations.

Additional studies have been 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 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 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 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.

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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 of 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 concluded that wake surfing 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 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 surf mode impacts relative to wave attenuation distances and wave energy measures. The Marr team has called for extended buffering distances of 500-700 feet from active surf mode vessels.

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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 to provide In-lake measures of surface and subsurface wave impacts (near shore) taken at shallow shorelines with waves generated at the current state statute:

No person shall operate a motorboat, excluding a personal watercraft, at a speed in excess of Slow-No-Wake within 100 feet of shore, a dock, pier, float, or anchored or moored vessel. Unless taking off or landing a waterskier.

No person shall operate a personal watercraft at a speed in excess of Slow-No-Wake within 200 feet of shore, a dock, pier, float, or anchored or moored vessel. Unless taking off or landing a waterskier.

A combination of aerial and submersible drone imagery was used to visually capture wave dynamics and effects.

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 wake boats in surf mode operations are occurring.

Lake Waramaug Shallow Water Study 2024

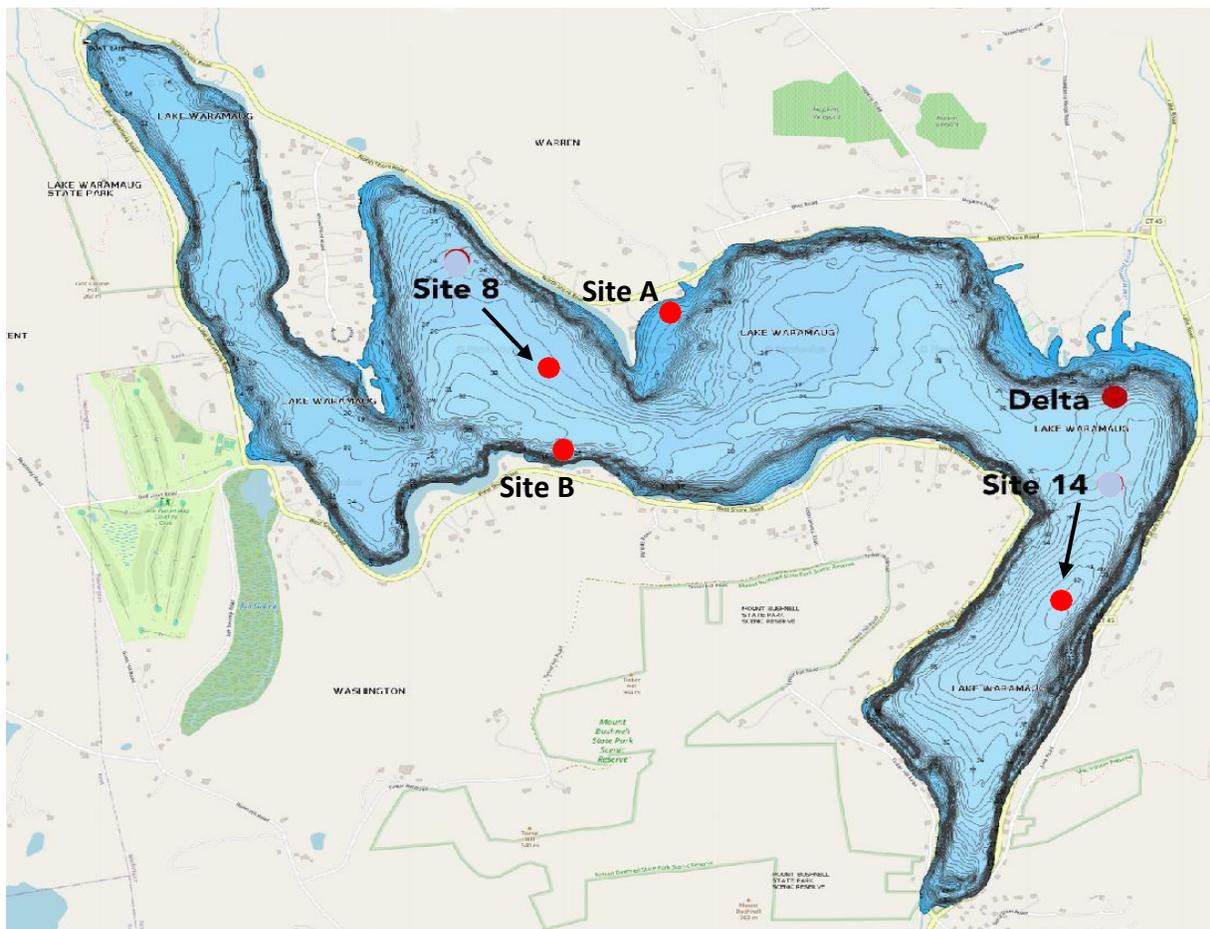


Figure 2 Bathymetric survey and study test site locations, Lake Waramaug, CT 2024.

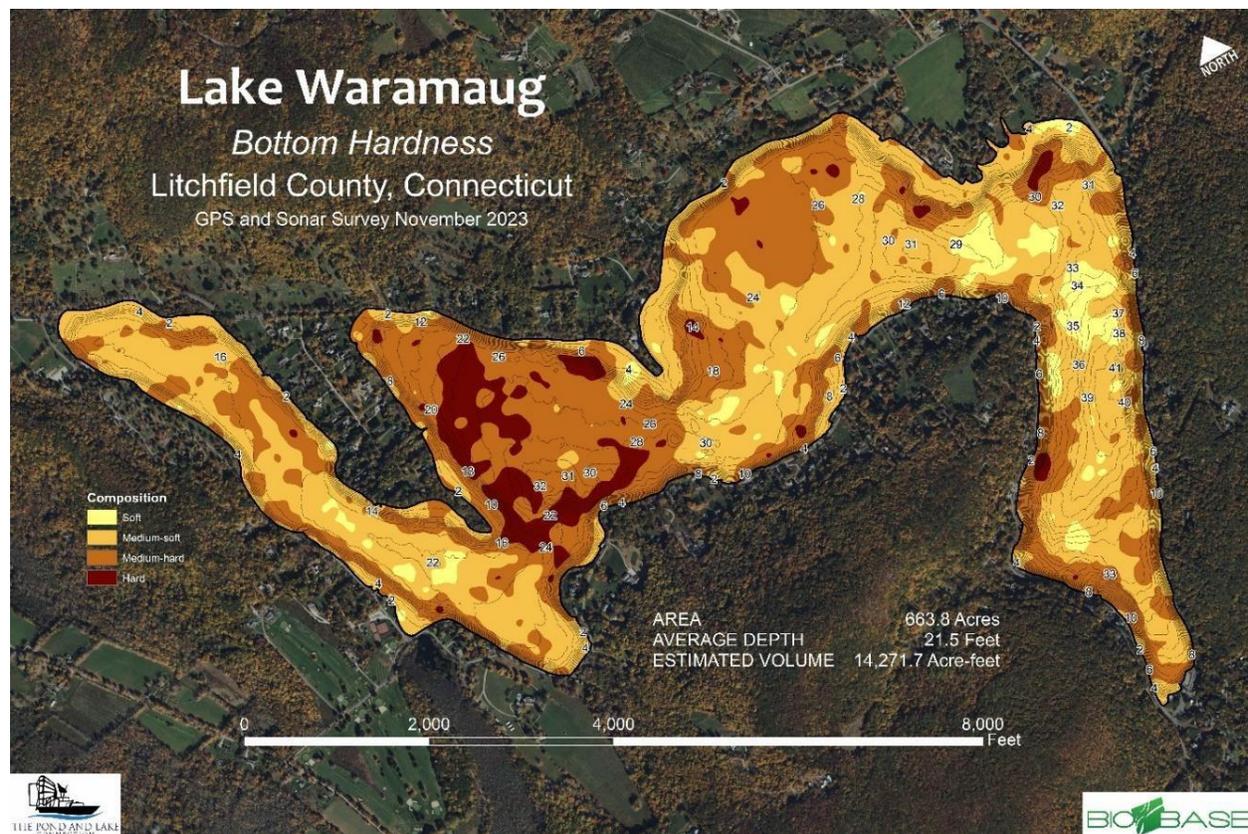


Figure 3 Bathymetric map of lake bottom composition, Lake Waramaug, CT 20204

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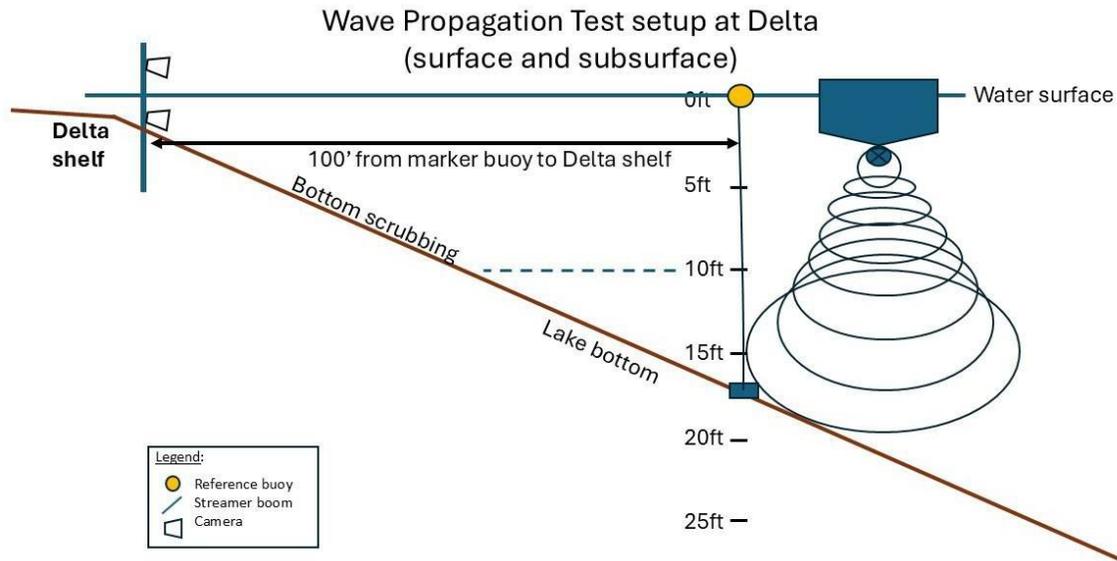


Figure 4 Surface and subsurface Equipment setup at Delta shelf

The TVES engineered surface and subsurface equipment is depicted in figure 4. A ten-foot rod was pushed into the bottom sediment at two locations at the edge of the Delta shelf approximately 250' from shore in a water depth of 3' (see figure 5). A vertical pole with two cameras was attached to the stationary rod. One camera was attached above the water surface to record wave action, one camera was attached below the water surface to record bottom sediment disruptions and re-distribution. All video captured was date and time stamped.

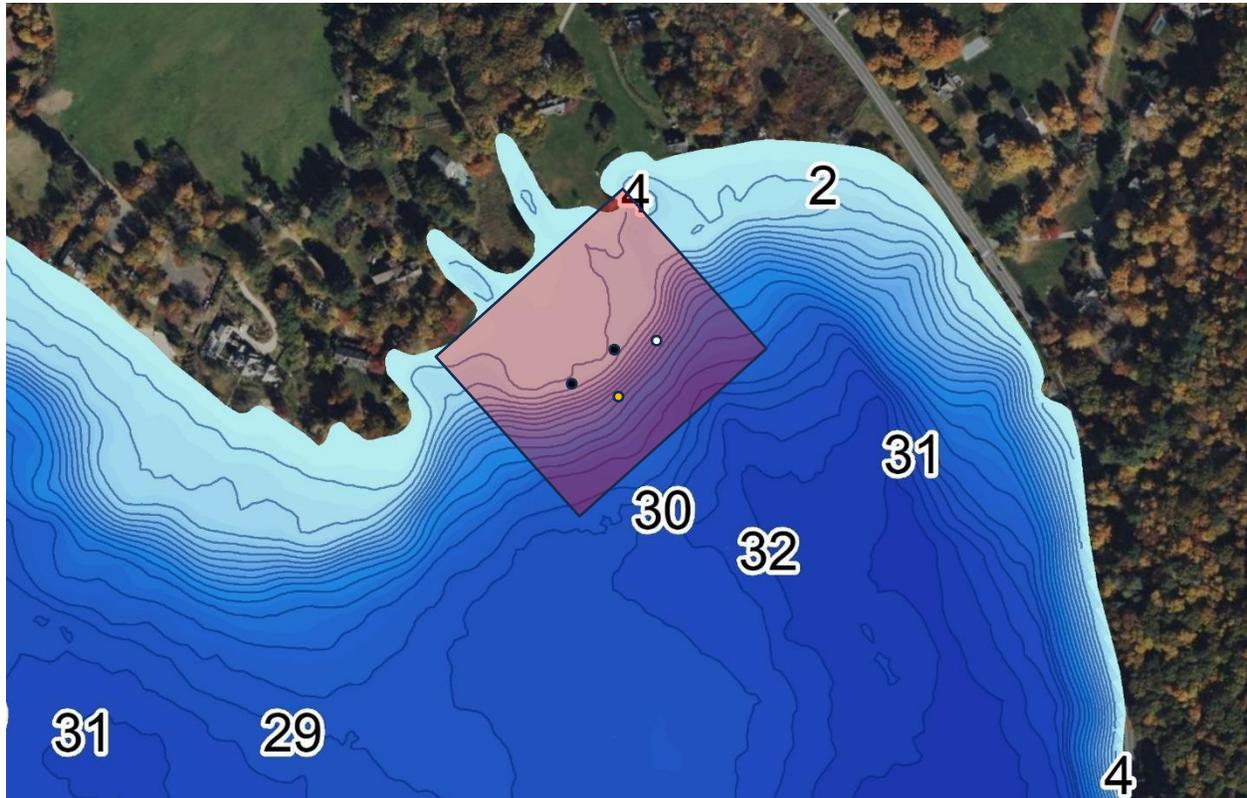


Figure 5 Sucker Brook Delta bathymetric (2023) with test setup and 500' reference from shoreline

Two camera poles (shown as black circles) were located at the edge of the Delta shelf in 3' of water approximately 250' from the shoreline. The orange marker buoy was located 100' from the delta edge and camera poles. A white channel navigation buoy was also present. The Wake boat in Surf Mode made three separate passes in a direction perpendicular to the shoreline with the pass adjacent to the outside of the orange marker buoy located 100' from the Delta Edge and Camera poles.

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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 Hasselblad 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.

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Surface Vessel Specifications Used in the Lake Waramaug Shallow Water StudyJune (aerial video)Wake Boat (Medium Size)**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

Aug (surface and subsurface videos)Wake Boat (Large Size)**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)

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4. Lake Waramaug Wave Impacts Results Summary

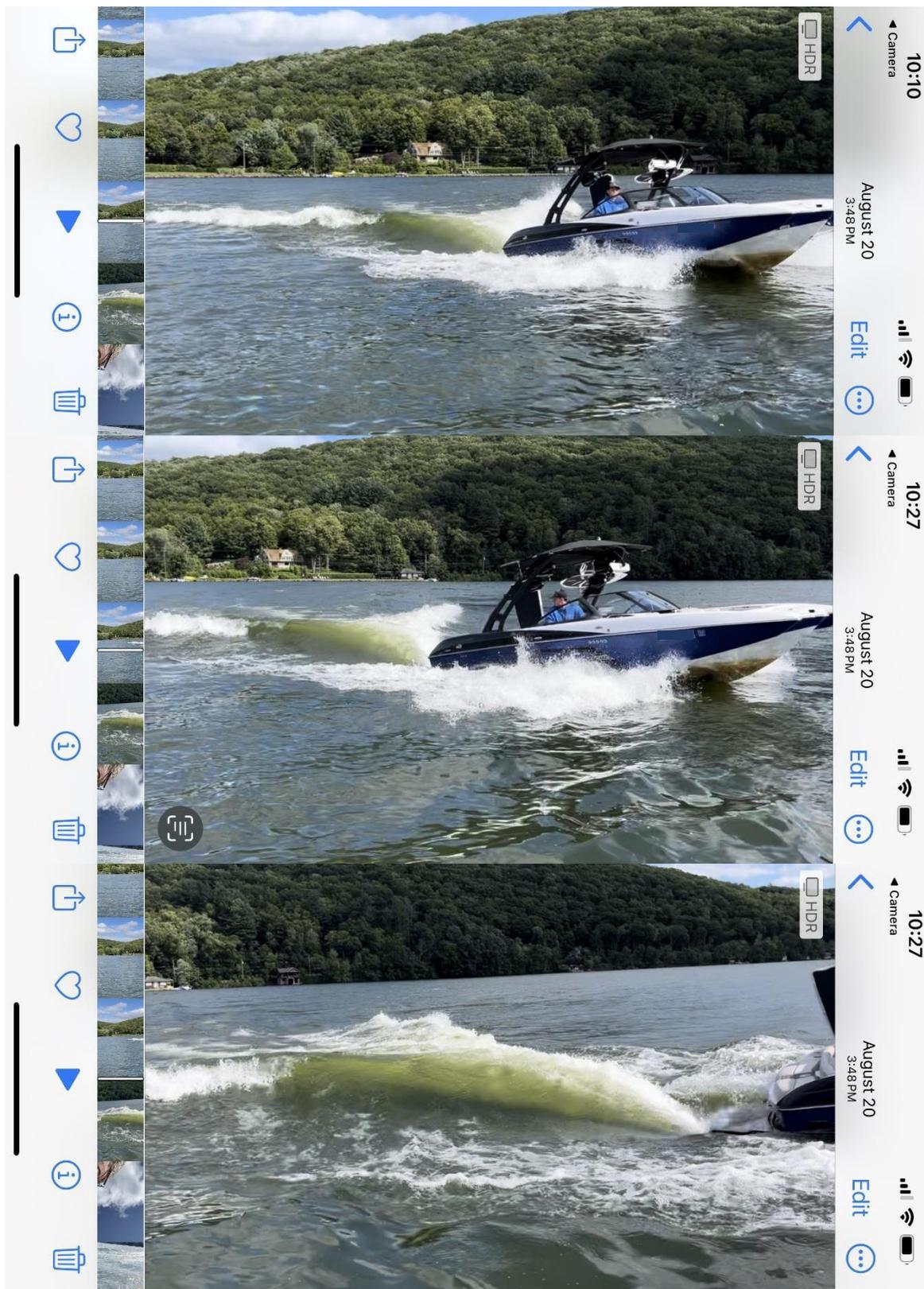


Figure 8 Wake Surf Wave produced by wake boat in Surf Mode boat during a pass

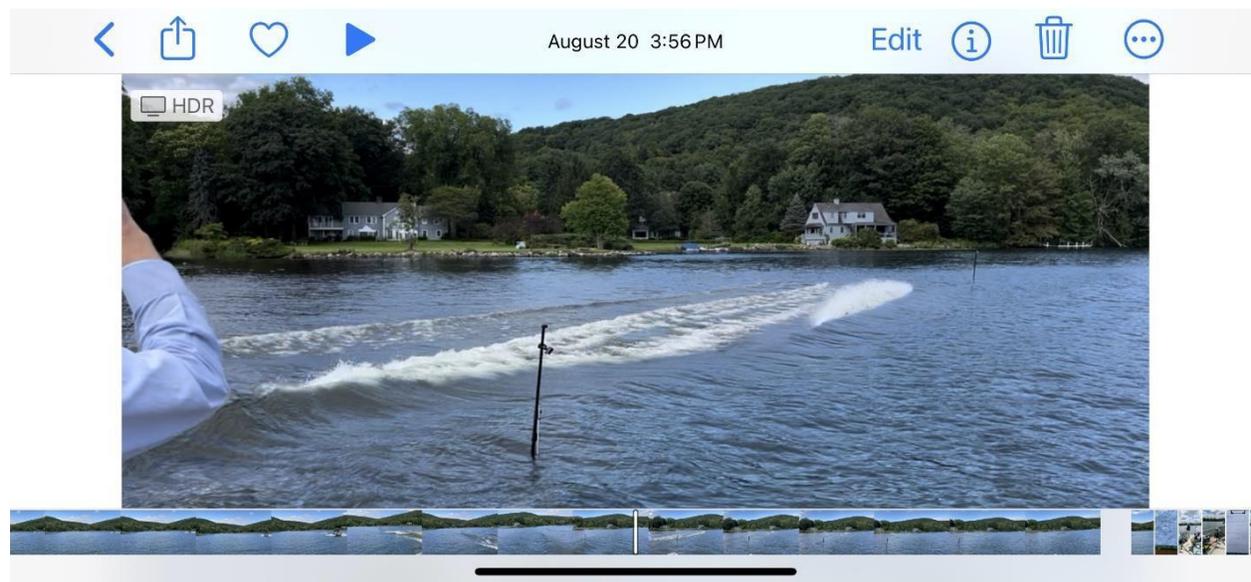


Figure 9 Wake Surf Wave at 15 sec Reappearing and Emerging out of the water at the edge of the Delta and breaking onto the shallow Delta

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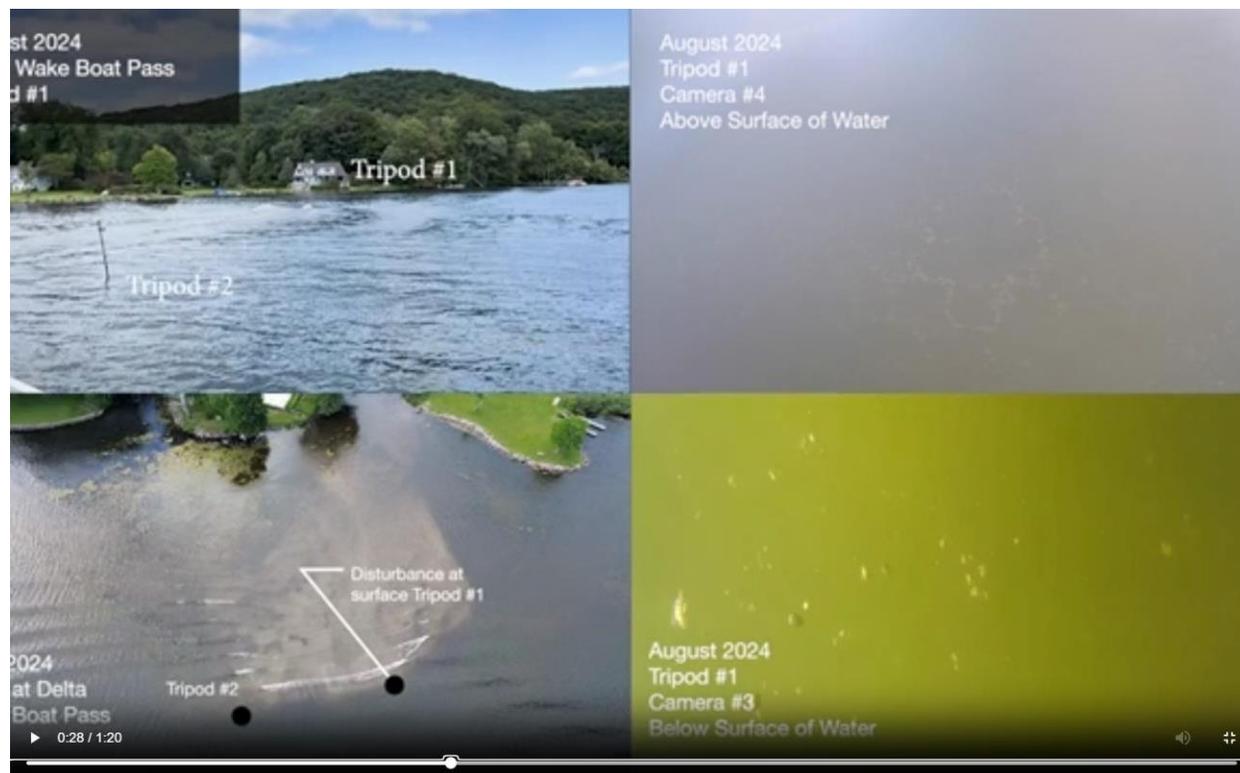


Figure 10 Images from 4 Quadrant Delta Video at 28sec showing the effects from wave impacts to the shallow lake bottom at the Delta (includes bottom scrubbing, plume development, gas release from disturbed sediments, and sediment redistribution)

Air bubbles noted in surface, aerial, and subsurface views. This is triggered by the subsurface waves scrubbing the lake bottom sediment and releasing trapped gases (CO₂, Methane, NO₂) [Lakes & Climate Change - Lake Scientist](#)

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Figure 11 Images from 4 Quadrant Delta Video at 51sec showing the effects from wave impacts to the shallow lake bottom at the Delta (includes bottom scrubbing, plume development, gas release from disturbed sediments, and sediment redistribution)

Significant amount of crud noted flying around the subsurface camera for an extended time period. This can also be seen in the aerial view as a dark plume outside the Delta edge near Tripod #1. Plume trails over the shallow delta also noted in the aerial view.

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Two Sucker Brook Delta sediment grabs were collected and analyzed for Total Phosphorus prior to wave testing. Delta sediment Total Phosphorus results were 216mg/kg and 710 mg/kg dried. Total Phosphorus concentrations in the water before, during and after wave testing is detailed below. Note the several orders of magnitude difference when comparing sediment concentrations of Total Phosphorus to the results for the water quality grabs.

Sample	Date&Time	P (mg/l)	% increase
Delta On Pre	08/20/2024 15:42:00	0.021	Baseline
Delta On Run 1	08/20/2024 15:51:00	0.032	50%
Delta On Run 2	08/20/2024 15:59:00	0.088	320%
Delta On Run 3	08/20/2024 16:05:00	0.043	105%
Delta On Post 1 Hour	08/20/2024 17:10:00	0.031	48%

Table 1: Phosphorus levels on Delta before and after Wake Surf Passes:

Phosphorus measurements were obtained from water samples taken on the Delta by LWTF personnel before and after each Wake Surf pass. Of particular interest, total Phosphorus sampling at this shallow water site (sampled on the Delta after each pass), revealed that significant increases in Total phosphorus were released immediately following a pass by a wake boat in surf mode. Increases in Total Phosphorus ranged from 50-320% based on the specific sample location on the delta relative to the plumes generated by the waves. *(These effects warrant additional study regarding short- and long-term impacts to water clarity and chemistry in this region and beyond.)*

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 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.

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

5. Lake Waramaug Impact Management Issues for Consideration

TVES group has performed and completed in the summer of 2024 on Lake Waramaug an in-lake study of large displacement wave impacts to shallow water environments in the lake.

Wave impacts were studied at the edge of the Delta shelf (250' from the shoreline) including the resulting bottom sediment impacts (disturbance and re-distribution into the water column).

The in-lake study on Lake Waramaug has demonstrated that large displacement wave action from wake boats in surf mode propagating towards shallow water areas require increased buffer distances to reduce surface and subsurface wave impacts. Wake Surf waves 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.

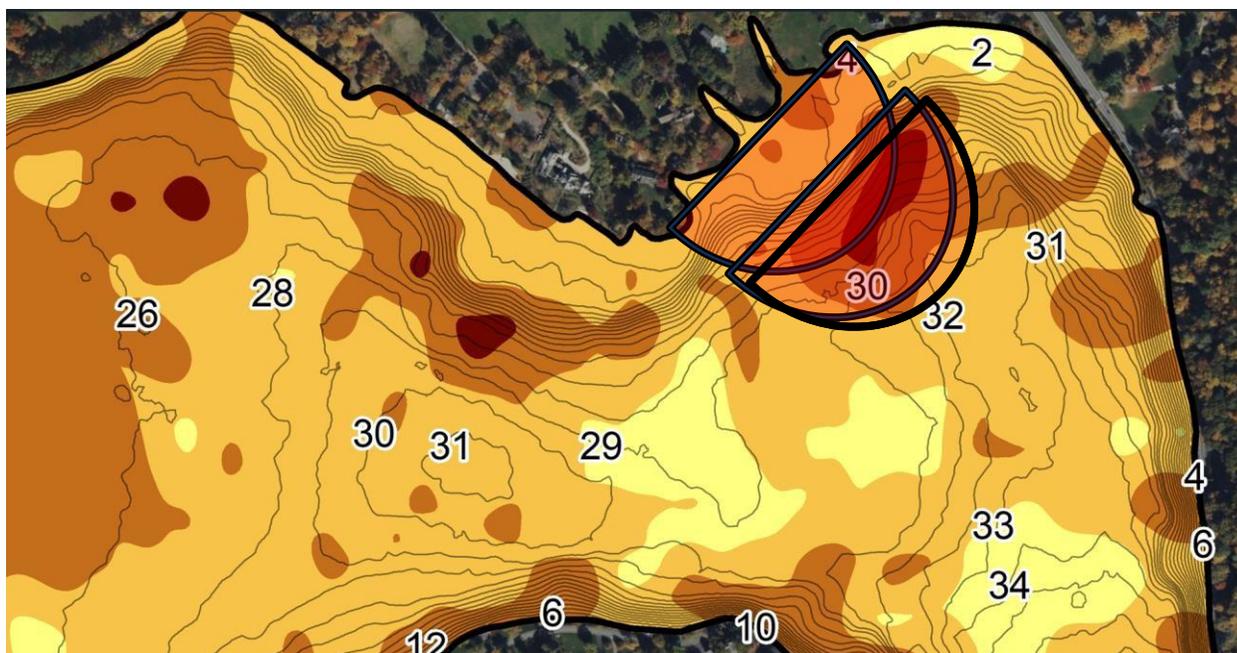


Fig 13 Lake Waramaug - Sucker Brook Delta area and lake bottom sediments and profile with 500' buffer zones shown from shoreline, Delta edge, and 10' Water Depth

Recommendations: Slow No Wake distance markers

- Minimum: 500' from shoreline (250' from edge of Delta shelf)
- Improved: 500' from edge of Delta shelf (750' from shore)
- Preferred: 500' from 10' water depth (1/2 wavelength)

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The steep lake bottom causes bottom scrubbing and upward wave displacement starting at $\frac{1}{2}$ wavelength (10ft water depth) and results in the wave height rising rapidly as it scours the steep shelf, and then creates a large surface wave that breaks over the delta edge and impacts the shallow sediment on the delta resulting in significant sediment redistribution and nutrient release. See Appendix for additional information on the **Relationship Between Water Depth and Wave Behavior**.

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 shoreline, steep shelves and shallows of sediment deltas, shore structures, and other near shore shallow areas relative to Wake 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 boats in surf mode 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

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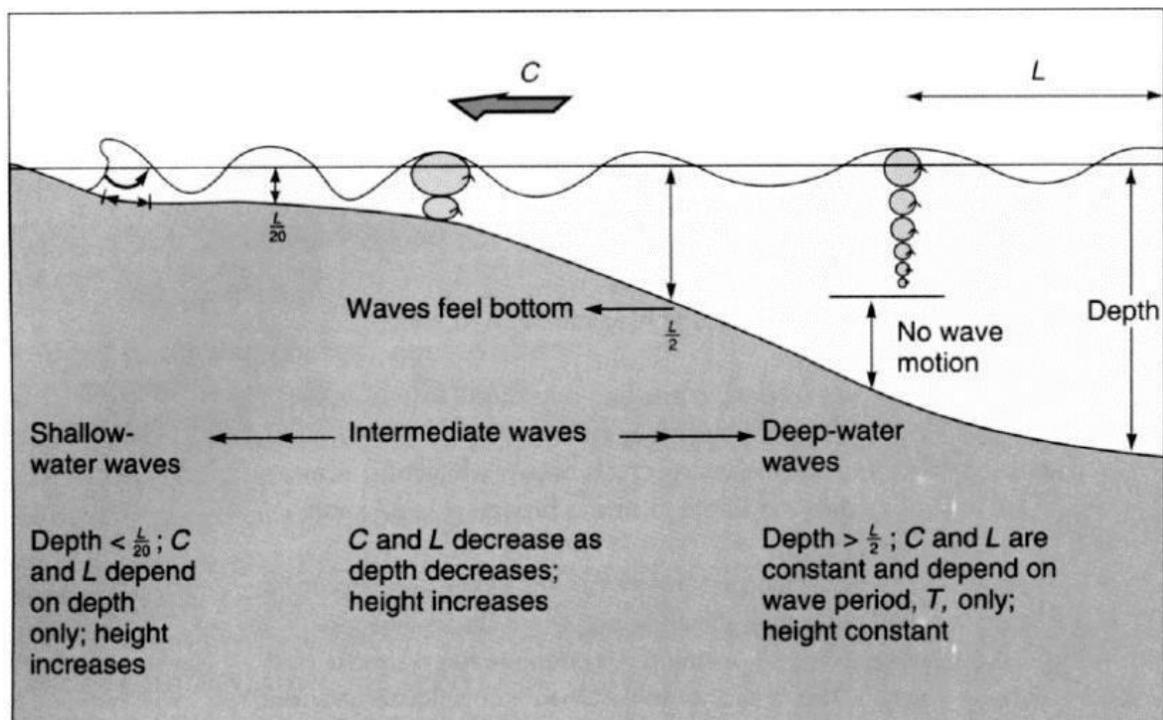
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Appendix

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 $\frac{1}{2}$ 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

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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 $\frac{1}{2}$ and $\frac{1}{20}$ of the wavelength. Below $\frac{1}{20}$ 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.