Wake Enhancing Boats and Activities

Terra Vigilis Environmental Services

A Presentation Prepared for the Lake Beulah Management District and the Protect Lake Beulah Organization

Science Informs Public Policy

Large Displacement Wave Impacts

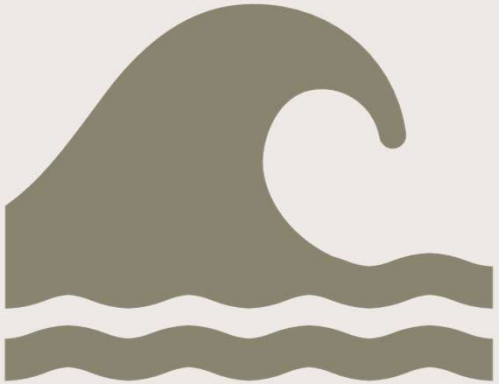
A Summary of Current Science and Lake Beulah In-Lake Studies

August 2025

Introduction

This presentation summarizes both current scientific and engineering studies which have established large displacement wave impacts (by Wake Enhancing Boats) to surface and subsurface areas in freshwater lakes in the United States and specifically on Lake Beulah, WI. There are 8 primary areas which will be described in this presentation including:

- Recreational Boat Design Technologies
- Displacement Wave Dynamics
- Surface Impacts
- Wave Attenuation Buffering Distances
- Subsurface Impacts
- Propeller Downwash (Slipstream) Impacts
- Near Shore Impacts
- Sediment Redistribution and Nutrient Release Impacts



Wake Enhancing Boats and Activities: Terms

"**Wake boat**" means a motorboat that has one or more ballast tanks, ballast bags or other devices or design features used to increase the size of the motorboat's wake.

"**Wake sports**" means:

1. to operate a wake boat with ballast tanks, bags, or other devices or design features engaged to increase the size of the boat's wake; or
2. to use a surfboard, wakeboard, hydrofoil, or similar device to ride on or in the wake:
    1. directly behind a wake boat without a rope; or
    2. directly behind a wake boat with or without a rope, when the wake boat has ballast tanks, bags, or other devices or design features engaged as described in Section 1 above.

"**Wake sports zone**" means an area of a lake, pond, or reservoir that has a minimum of 50 contiguous acres that are at least 500 feet from shore on all sides, at least 20 feet deep, and at least 200 feet wide.

NOTE: Wake sports zones are open to all uses permitted on the subject waterbody and are not exclusive to wake sports.

Wake Boat Technology and Design

The engineering associated with manufacture of a contemporary wake boat is designed to increase (enhance) wave height and wave shaping for wake surf operations. The boating industry has focused upon high engine power, pilot controllable ballasting, hull design, speed control, and wave shaping technologies to accomplish this outcome.

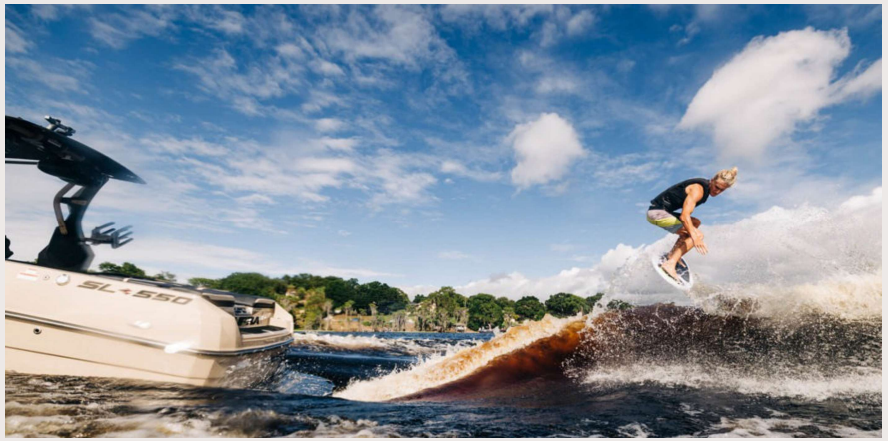


Photo from manufacturer advertising, open source

Wake boat engine 630hp

Mastercraft XT24-25

Waterski engine 250hp

Volvo Penta I/O Engine

Specifications for Wake Boat Engines

Power Plant

Typically, the engine system on current day Wake Boats is an inboard "V-drive" configuration. This engine is designed to accommodate a deeper "V" hull allowing a larger displacement wave. Most often, the engine is near the stern, and drives a propeller located underneath the hull. **The wake boat horsepower range is 250 hp to 630 hp, trending upwards.**

*** In-Lake study at Lake Beulah used 2021 Axis with 430 hp**

MasterCraft...Ilmor supercharged 6.2L engine available on XT24 and XT25 models. This power plant can produce 630 hp and 665 ft-lbs of torque for a powerful displacement wave.

Volvo Penta... I/O 4.3 Litre V6 250 hp. **Considered an ideal water-skiing engine system**.

Wake Boat Hull Design Features

The deep “V” hull design accommodates the production of larger displacement wave features by sitting deeper in the water. The hull designs are engineered to integrate with power plant systems to coordinate the production of large wave size and shape.

Photo from manufacturer advertising, open source

Wave Enhancing Devices & Shaping Technology

Auto Wave

A patented hull management system which can automatically manipulate hull position to produce precision featured wakes or waves. Typically includes control surfaces (plates, wedges, foils, gates), speed control (9-10mph non-planing), and ballasting.

Wake Boat Ballasting Control Systems

Surf System (Subfloor Ballasting)

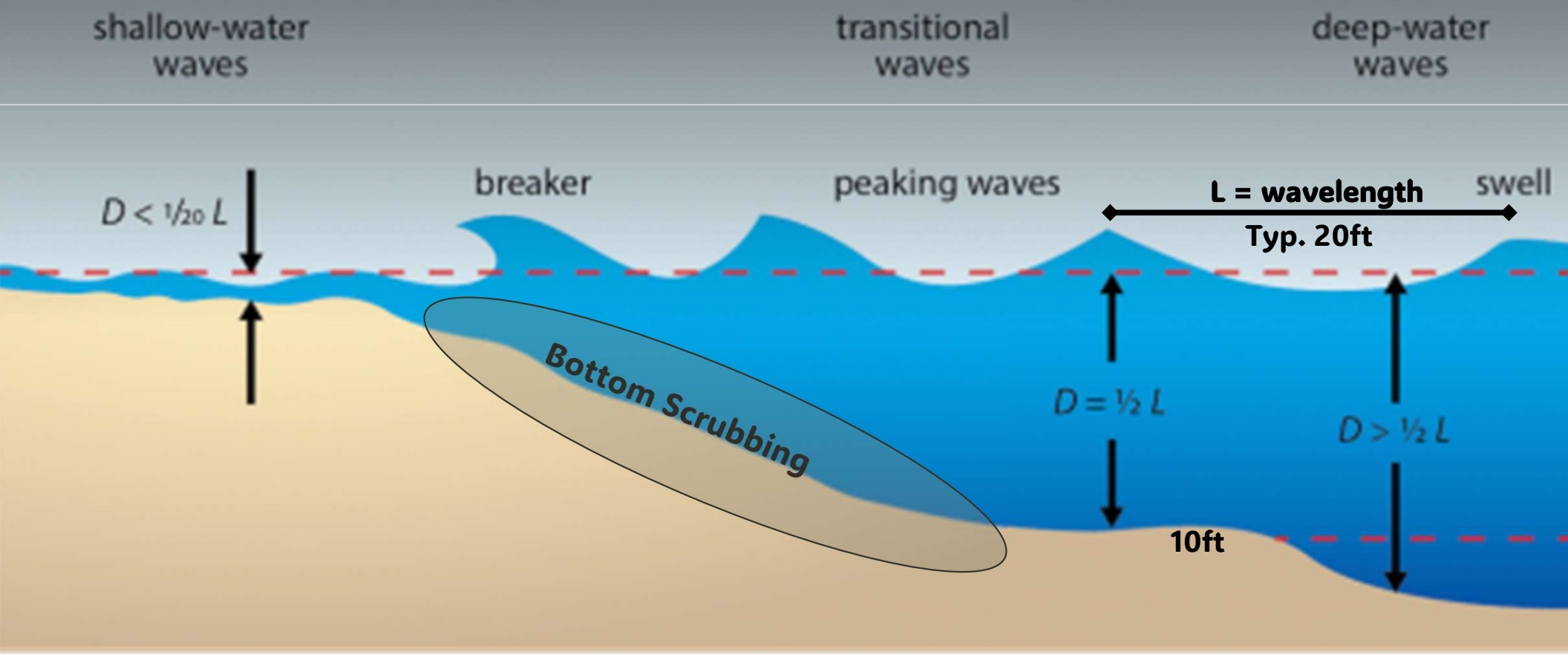
Pilot controlled ballasting pumps can automatically add water weight to bladder bags or tanks positioned throughout the vessel to increase the hull displacement resulting in produce a bigger “shaped” wave.

The subfloor models are designed to keep the pumped in water weight below the vessel’s decking to allow additional passenger space (and more displacement weight).

Wake Boat Surf Mode Operational Configuration

The actual operation of a wake boat in surf mode is easy to identify. The features of high bow angle, slow speed and very large wave development are unmistakable and accordingly, lake boat patrols and other regulatory agencies can efficiently identify this type of activity.

LARGE DISPLACEMENT WAVE PHYSICS



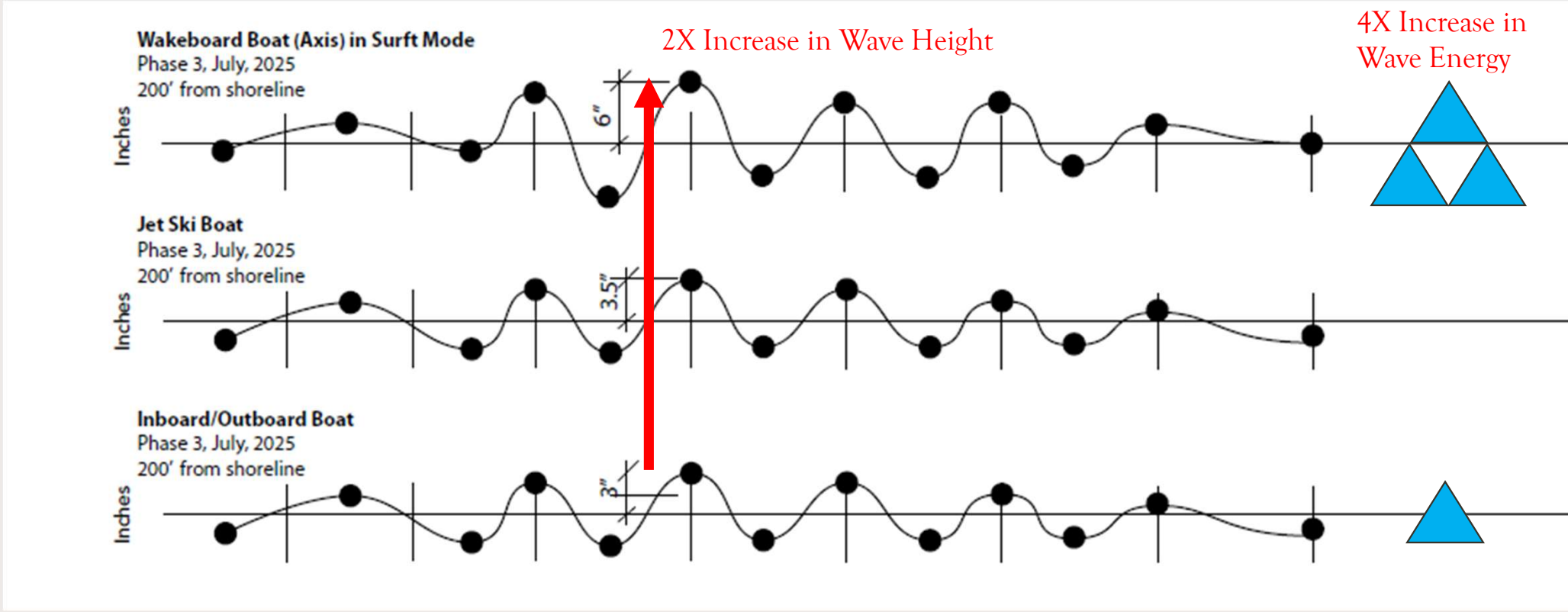
Large Displacement Wave Surface Impacts

Note: *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 is common in calculations of wave energy in well designed studies.*

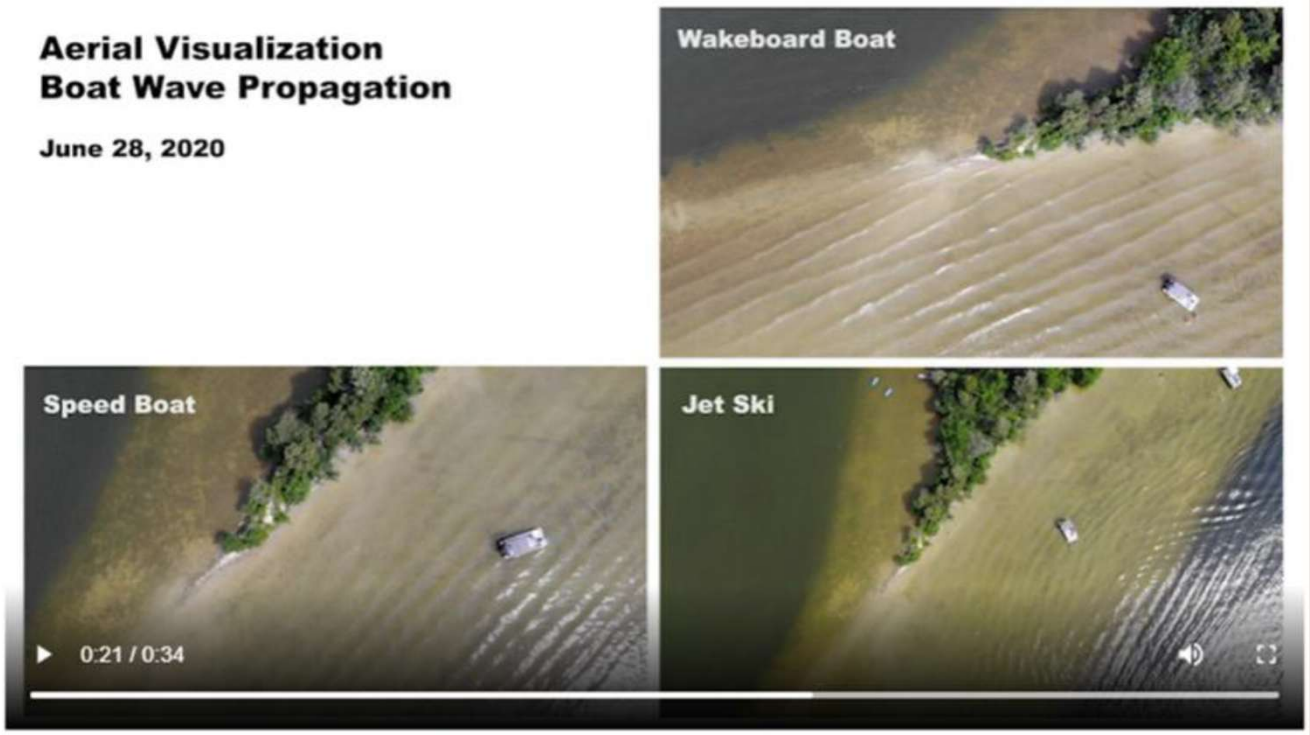
A series of studies have been conducted in the Midwest, far West and Eastern U.S. focused upon Wake Boat surf mode operations and the impacts resulting from the large surface waves produced by these vessels. The specific features of large displacement waves have been uniformly described to have characteristics including, higher than usual wave heights (3 to 4 feet), higher than usual wave energy, and longer than usual attenuation distances.

- UoM SAFL Marr, et al, Minnetonka Lake, MN
- Terra Vigilis Environmental Services, (TVES), North Lake Management District (WDNR)
- TVES, Lake Waramaug, CT
- TVES, Lake Beulah, WI
- Water Environment Consultants, WEC
- Western Colorado University, Lake Payette, Idaho

Large Displacement Wave Comparative Data (Lake Beulah, WI, Terra Vigilis Environmental Services, 2025)



Large Displacement Wave Surface Impacts Drone Imagery (NLMD, TVES, 2020)

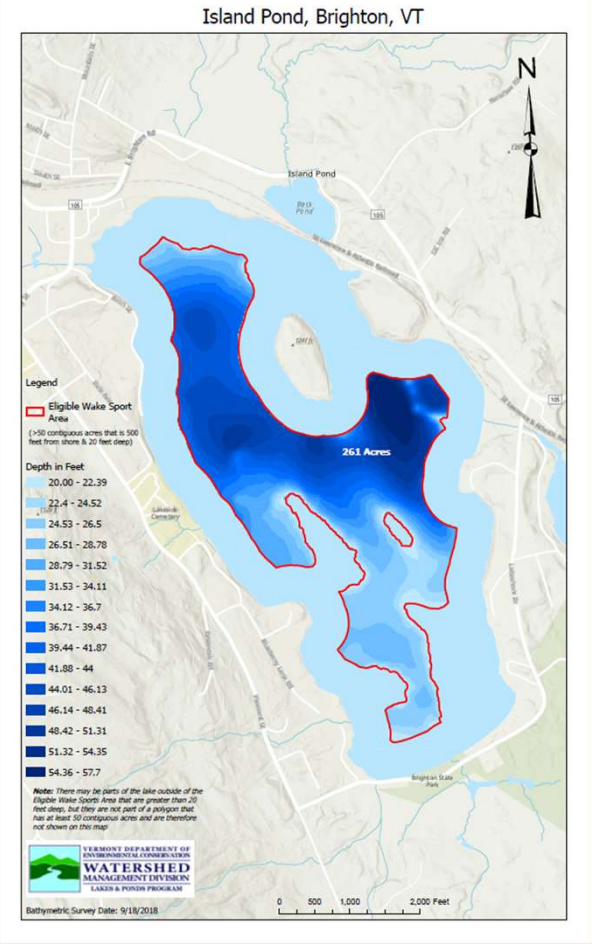


Aerial Visualization of Different Types of Waves

LAKE BEULAH NEAR SHORE SURFACE IMPACTS:

Note wake boat waves significantly impacting shore and the boat tied to dock.

LAKE BEULAH NEAR SHORE SURFACE IMPACTS:

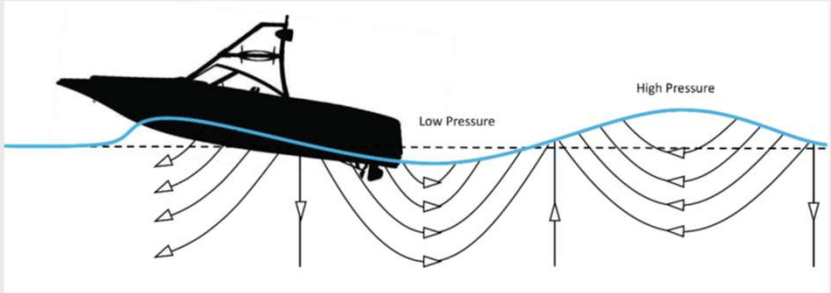


Wave Attenuation Buffering Distances

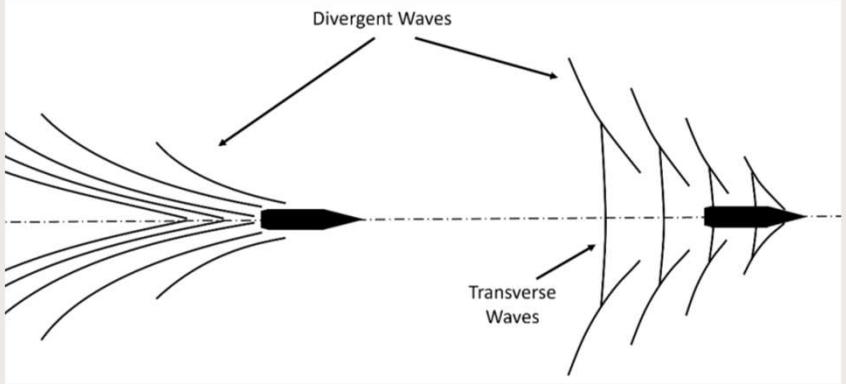
Traditional (non-wake surf mode operation) surface vessel wave buffering distances have been previously established for freshwater lakes though-out the United States. Historically, states have adopted a 100' or 200' standoff distance from shorelines and other vessels to minimize risk and damage. The introduction of Wake Boats, particularly in "surf mode" however, has produced wave features *incompatible with existing standoff distance statutes established for the traditional water ski and cruising boats* that produce waves that are smaller, with less surface energy and have shorter attenuation distances.

Studies have identified this concern with recommendations for buffering distances ranging from 500' to 1,000' depending upon lake size and shoreline features. The basis for these recommended increased distances are the wave energy impacts based directly upon wave heights.

- Marr et al
- TVES, Lakes Beulah & Waramaug
- Lake Payette
- WEC



SUBSURFACE WAVE PHYSICS



- **Propeller Wash** – The turbulent thrust of water created by the boat's propulsion system.
- **Bow Wave** – The pressure wave (down and forward) that forms at the bow of a boat hull as it displaces water during motion.
- **Stern Wave** – The pressure wave that forms at the stern of a boat generated by the restorative upward motion of the water as it fills the volume previously displaced by the hull.
- **Transverse Waves** – A set of wake waves that extend astern and move in the same direction and speed as the powerboat itself, with crests oriented perpendicular to the direction of boat travel.
- **Penetration Depth** – The depth from the water surface that is reached by a hydrodynamic (water movement) phenomenon (i.e., bow/stern waves, transverse waves, propeller wash).

Large Wave Subsurface Impacts

Recent studies have also focused upon **subsurface** impacts of large displacement waves and propeller downwash. The studies have established that "unseen" energy related to these large waves, have significant impacts to subsurface structures, lake bottom integrity, sediment release and water chemistry. In addition, the subsurface energy impacts to shoreline structures, the bottom composition securing sea walls and related structures has also been noted as a concern. In shallower areas, impacts to fish habitat, waterfowl nesting and aquatic plant life have been noted. Deep water disturbances have been measured to 25'.

Hull design, engine power, ballasting and propeller downwash impacts combined to produce these effects. These effects are **not reflected when compared with other recreational vessels**.

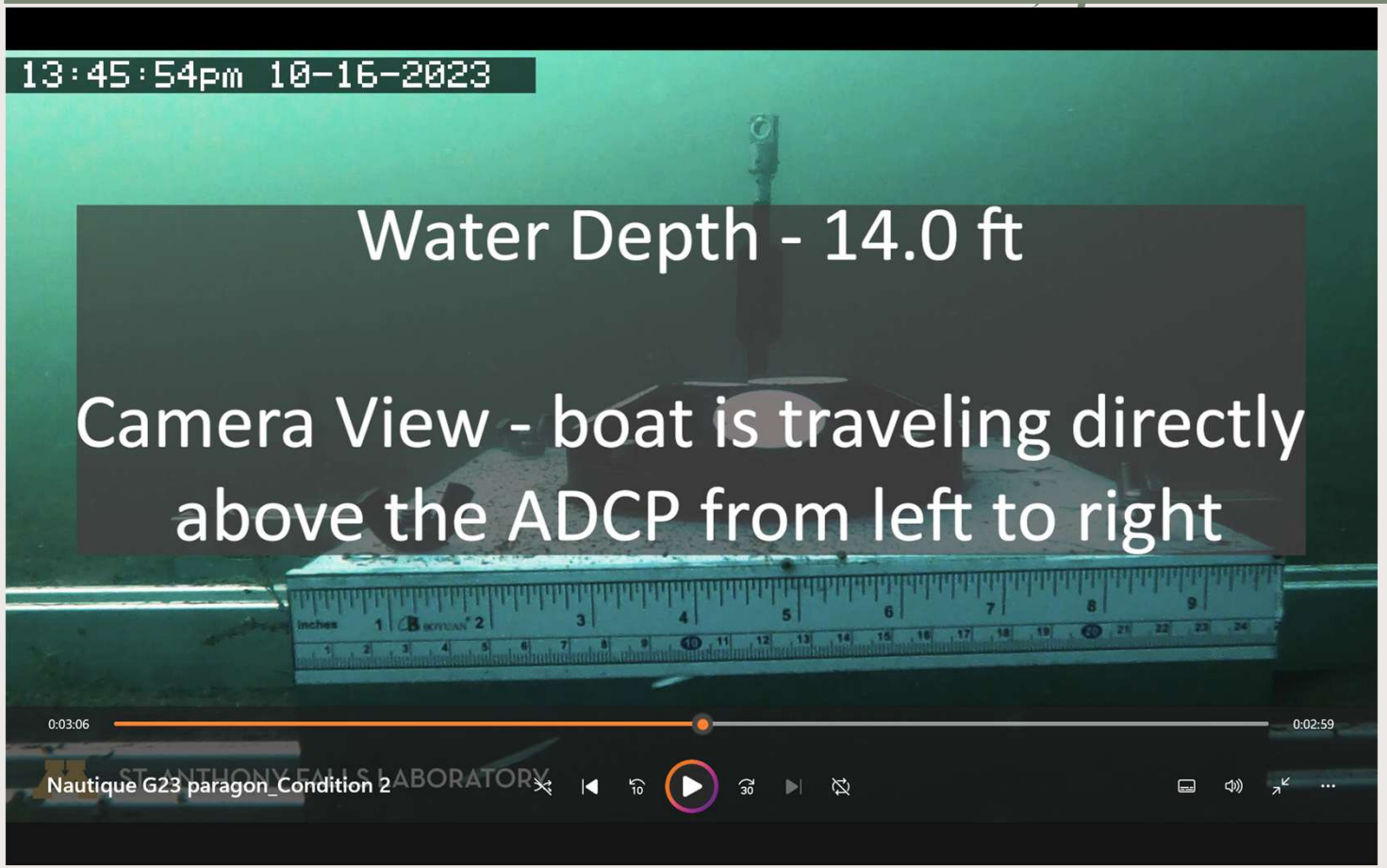
- Vermont
- WEC
- Lake Waramaug, CT
- TVES North Lake, WI
- Lake Beulah, WI
- U of M SAFL

LAKE BEULAH SUBSURFACE IMPACTS, 2025

Note plant fragments moving past cameras

Significant sediment and plant disruption at 15’ site May 6

UNIVERSITY OF MINNESOTA PHASE 2 STUDY VIDEOS, JULY 2025



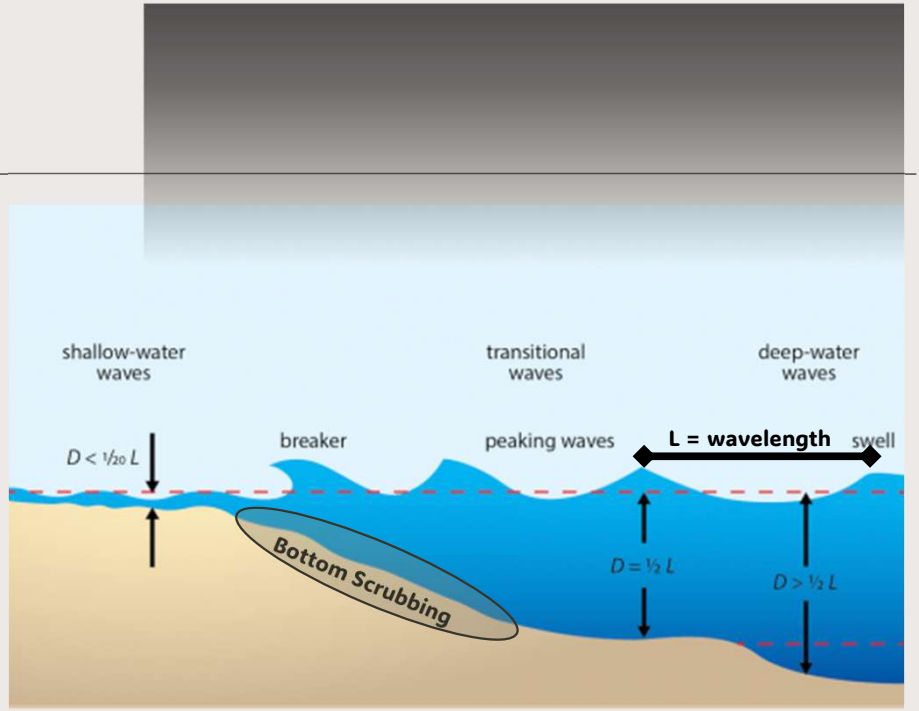
LAKE BEULAH SUBSURFACE IMPACTS, 2025

Note sediment movement on brick (Camera 3) at 25’ from bow, stern, and transverse waves

Wake Boat
Near Shore Impacts

The wave physics associated with large displacement wave action has been demonstrated to produce near shore lake bottom* “scrubbing effects”. The water depth and shoreline slope of lakes has been demonstrated as a critical variable in protection of the lake shoreline environment.

- TVES
- Lake Waramaug
- WEC

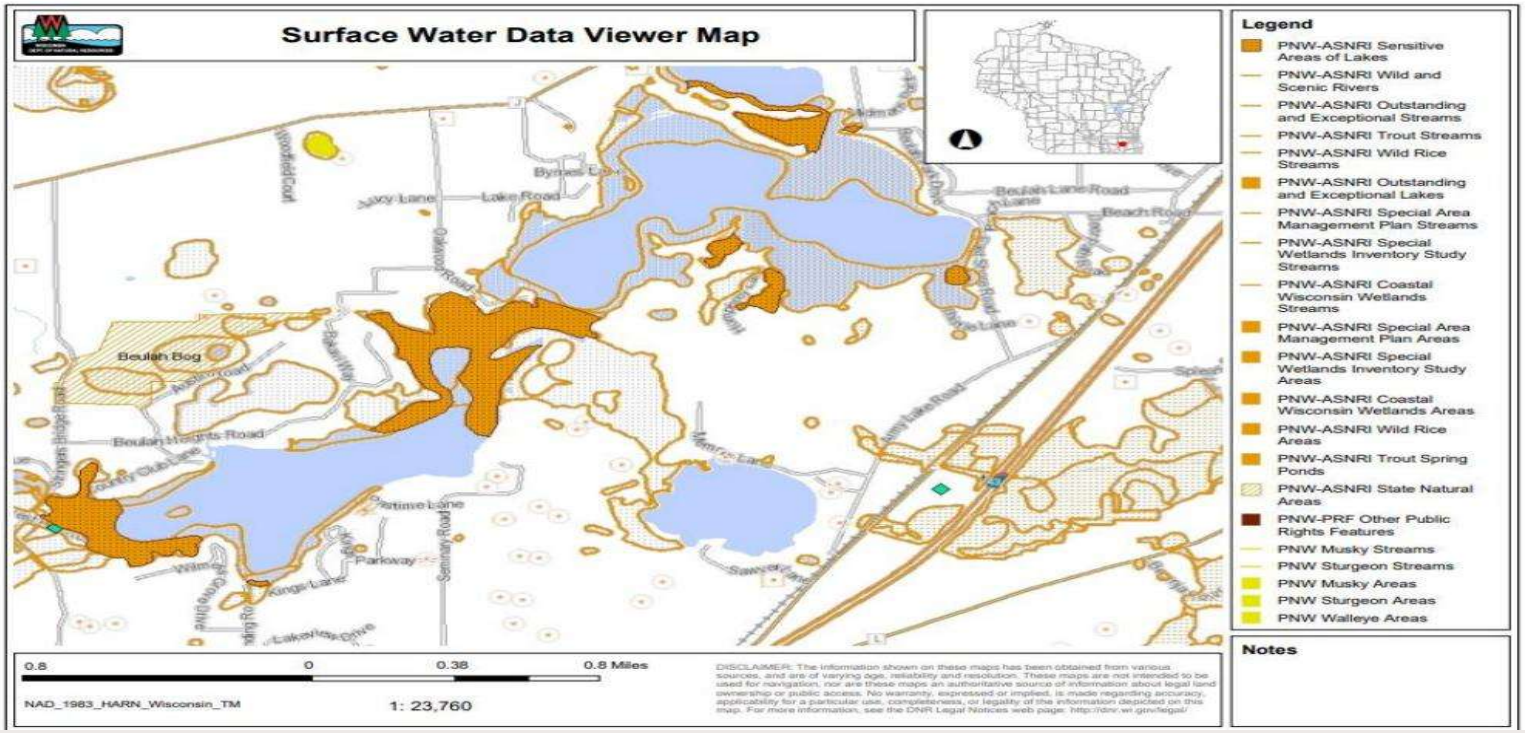


* Also includes sandbars, humps, and “sunken” islands

LAKE BEULAH WDNR DESIGNATED SENSITIVE AREAS

CRITICAL HABITAT AREAS

Lake Beulah has eight sensitive areas designated by the DNR in 1994.
These were further designated as critical habitats by the DNR.



LAKE WARAMAUG IN-LAKE DELTA STUDY

(TVES, 2024)

Note subsurface wave reemerging at shallow delta

Sediment Re-Distribution and Nutrient Release

Studies have established that powerful kinetic energy from propeller downwash is capable of lake bottom sediment redistribution which reduces water clarity. It also causes release of nutrient concentrations. The re-introduction of phosphorus and other bottom sediments into the water column is a concern for development of toxic algal blooms in freshwater recreational lakes.

- Lake Payette, Idaho
- North Lake, WI
- Lake Waramaug, CT

*** Many Wisconsin lakes used arsenic dispersals extensively for aquatic plant control in the years 1920-1970. This chemical risk is contained in lake bottom sediments throughout the state. Human exposure to this carcinogen would occur via the food chain from contaminated game fish. Both Big Cedar lake and Pewaukee Lake are noted for concentrations of this chemical by the Wisconsin DNR comprehensive report published in 2019. (See reference section)*

Wake Enhancing Impacts Summary

There is an impressive consistency to the studies being conducted which demonstrates larger, faster, high energy, displacement wave risks across multiple areas including:

- Surface safety threats to other vessels and lake users
- Near shore disruptions
- Bottom scrubbing effects
- Shoreline structure impacts
- Nutrient release events to the water column
- Deep penetration propeller downwash subsurface effects
- Wave attenuation distances prompting changes to traditional buffer distances

Wave Enhancing Studies References

Ray, Alex., Western Colorado University, “Analyzing Environmental Threats from Motorized Recreational Vessels on Payette Lake, Idaho”, Big Payette Lake Water Quality Council, City of McCall Idaho, January 2020

Houser, C., “Relative Importance of Vessel-Generated and Wind Waves to Salt Marsh Erosion in a Restricted Fetch Environment”, Journal of Coastal Research. Pp. 230-240., 2010

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USACE, “Vessel Wake prediction Tool”. Technical report No. ERDC/CHL CHETN-IV-121, U.S. Army Corps of Engineers, Washington, D.C. 2020

Water Environment Consultants (WEC), “Boat Wake Impact Analysis”, Lakes Rabun & Burton, Georgia, January 2021

Wisconsin Department of Natural Resources (WDNR), “Strategic Analysis of Aquatic Plant Management in Wisconsin”, 2019

HIGHLIGHTS OF THE 2025 LAKE BEULAH STUDY SURFACE IMPACTS

Phase 1…High impact damage areas are noted adjacent to DNR “Critical Habitat” designations. Study site selections are made accordingly.

Phase 2…Near shore dockage and moored vessel impacts are revealed from 200’ distance from Wake Boat surf mode surface wave impact. Minimal impact demonstrated from comparative ski boat.

Phase 3…In-Lake testing reveals Wake Boat surf mode near shore impacts to dockage and moored vessels from 500’ distance. Minimal impact demonstrated from comparable ski boat.

HIGHLIGHTS OF THE 2025 LAKE BEULAH STUDY SUBSURFACE IMPACTS

Phase 1....Visual evidence of large aquatic plant loss areas. Specific plants include Coontail, Cabbage (Broad-leaf Pondweed), Chara. These plants are favorable for fish habitat.

Phase 2...In-Lake testing of lakebed impacts at 15' depths (start ups, controlled passes). Wake Boat surf mode reveals bottom plant damage and sediment re-deposition impacts. Ski boats and other planing vessels do not show evidence of impacts at these depths.

Phase 2...In-Lake testing of lakebed impacts at 21 ' depths (start-ups, controlled passes). Wake Boat surf mode reveals bottom plant movement and sediment disturbance. Ski boats do not show evidence of impacts at these depths.

Phase 3...In-Lake testing of lakebed impacts at both 15' and 21' depths were replicated (plant and sediment disturbance) with a more representative Wake Boat (power plant, ballasting). Comparable ski boat no impacts noted.

LAKE BEULAH IN-LAKE STUDY CONCLUSIONS

Wake boat surf mode operations are producing lake bottom impacts in Lake Beulah which are notable for disturbance to aquatic plant habitat areas. These impacts do not appear to be produced by water ski and other planing vessel operations under similar test conditions.

Recent DNR plant survey data supports sensitive area impacts to aquatic plants considered favorable to game fish and lake water quality in Lake Beulah. Opinion should be obtained from a subject matter expert (SME) with specific expertise in aquatic plant root structures and fish habitat.

A DNR “Critical Habitat Area” study has established that areas being impacted by Wake boat surf mode operations are occurring in and adjacent to several of the designated critical habitat areas in Lake Beulah.

LAKE BEULAH IN-LAKE STUDY CONCLUSIONS (CONTINUED)

Wake boat surf mode operations (propeller downwash) are producing sediment disruption and re-distribution impacts to the water column. The composition of these sediments was not within the scope of the current study. Similar impacts were not seen with vessels in planing mode.

There is a sizable population of “home lake” wake boats capable of surf mode operations on Lake Beulah. This number is aggravated by off-lake Wake boats which also utilize Lake Beulah.

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