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Saint Anthony Falls Laboratory

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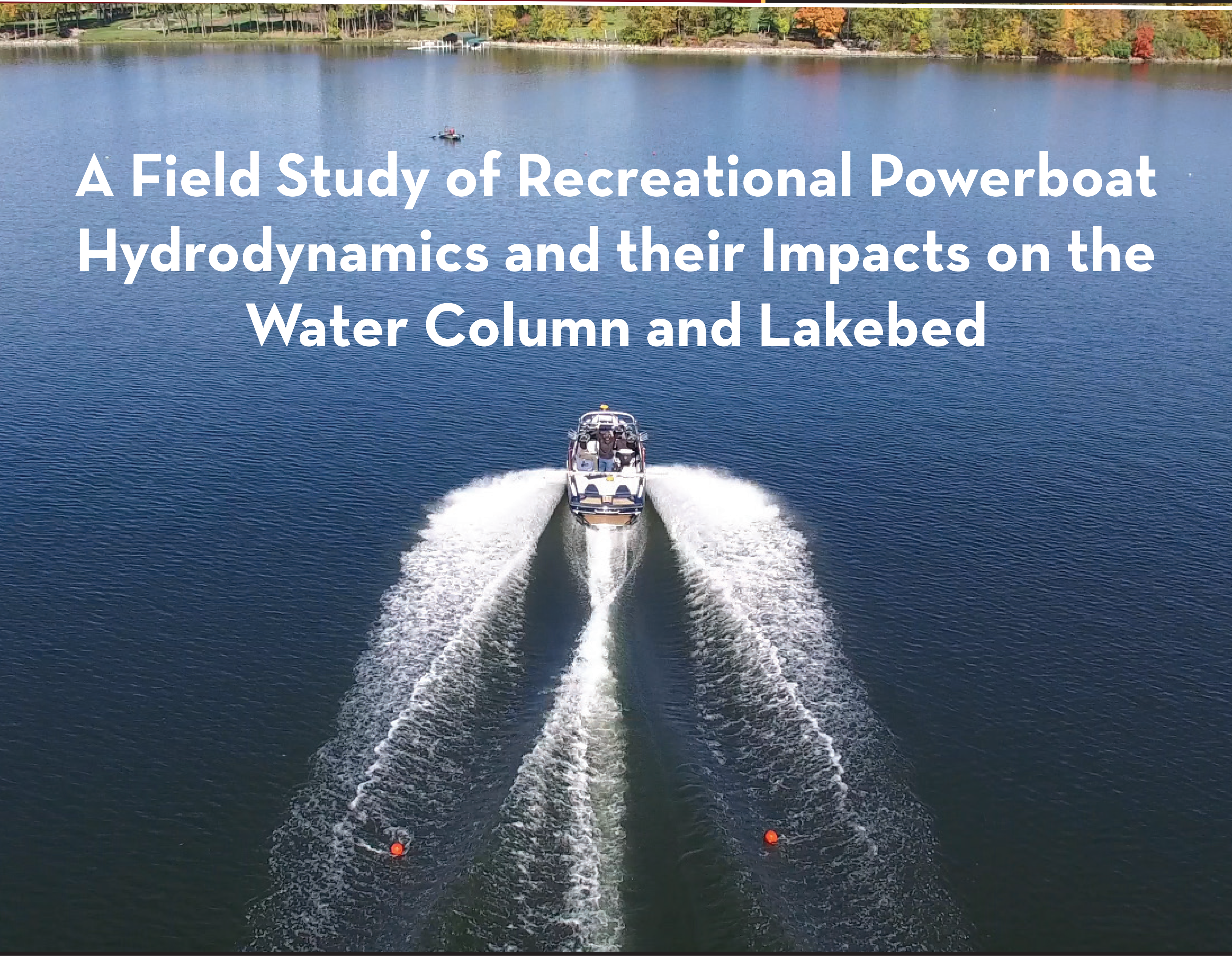
A Field Study of Recreational Powerboat Hydrodynamics and their Impacts on the Water Column and Lakebed



College of Science & Engineering

Authors:
Andrew Riesgraf, Jeffrey Marr, William Herb, Matthew Lueker, Jessica Kozarek

REPORT

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Motivation and Objectives

The recreational use of powerboats continues to increase along with increased boat size, horsepower, and new wake-enhancing technologies. This has led to concerns about the impacts of boating on the aquatic environment. In particular, the impacts of wakeboats operating in wakesurfing mode is a topic of intense public interest. This field-based study was motivated by a need to better understand the environmental impacts within the water column and at the lakebed of different types of recreational powerboats traversing under their typical modes of operation.

The objectives were to: 1) clarify and define the various hydrodynamic phenomena that are created by a recreational powerboat in motion, and how these phenomena vary with water depth and mode of operation, 2) investigate the depth of penetration and duration of emission gases (e.g., engine exhaust bubbles), 3) investigate the water column velocities and depth of penetration of the bow, stern, and transverse waves and their potential to resuspend lakebed sediment, 4) Investigate the propeller wash velocity and depth of penetration, and the potential to resuspend lakebed sediment, 5) investigate the effects of repeated boat passage on thermal stratification and mixing in the water column, 6) capture underwater and aerial video of the hydrodynamic phenomena and any subsequent impacts (e.g., sediment resuspension). This study generated a wealth of data that we used to develop recommendations for the minimum operational depth that recreational powerboats, under their typical modes of operation, should maintain to minimize impacts to the lakebed.

Design

A total of seven recreational powerboats were tested including two deck boats with outboard engines (Hurricane SS203, StarCraft Limited 2000), three bowriders with inboard/outboard engines (Sea Ray SPX190, Cobalt R5, Cruisers Yachts 34GLS), and two wakeboats with inboard engines (Nautique Super Air G23 Paragon, Malibu Wakesetter VLX). These boats are representative of those commonly operated on lakes and rivers.

Testing was performed during two fieldwork campaigns that took place in 2022 and 2023. For each campaign, acoustic-based sensors that measured pressure and velocities through the water column and at the lake bottom were deployed on the lakebed in two different locations and at two different depths. In total, data were collected at four locations of different water depths (9, 14, 16, 27 ft). Additional data were collected including various water quality parameters and lakebed sediment samples. In 2023, we also deployed underwater cameras and an aerial drone.

The boats were tested under two operational conditions that are representative of their typical usage (Figure 1). For the non-wakeboats (deck and bowrider) this was displacement mode (leisure cruise) and planing mode (cruising), and for the wakeboats this was semi-displacement mode (surfing) and planing mode (cruising). The boats were driven directly over the measurement sensors (Figure 2) a total of five times for each operational condition to gather replicate data for statistical analysis.

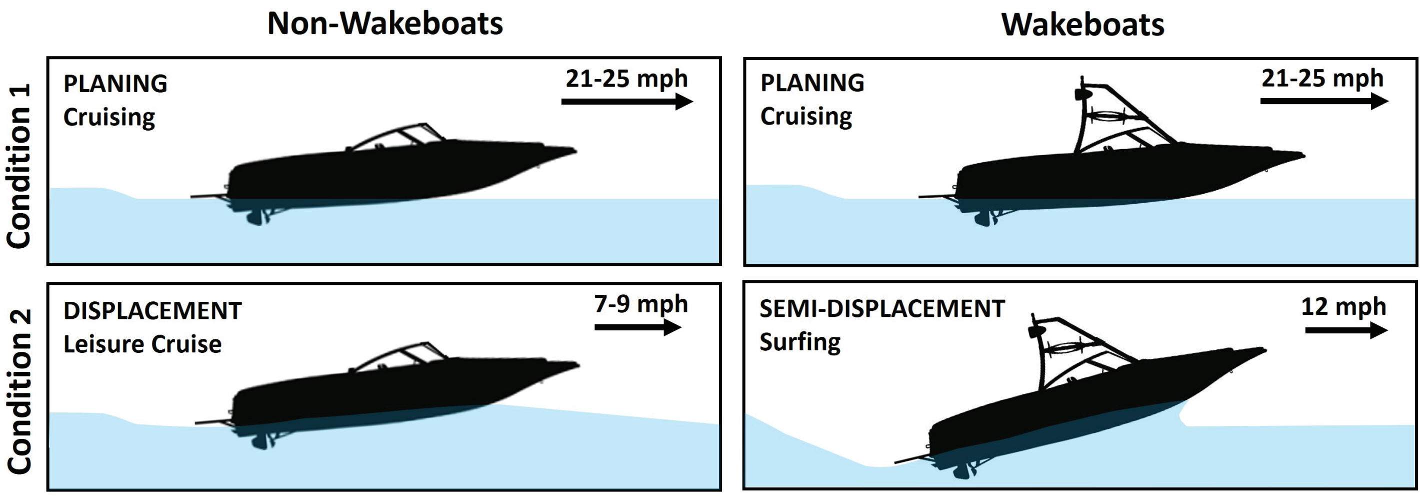


Figure 1. Illustration of the operational conditions testing in this study.

Figure 2. Wakeboat in semi-displacement mode (surfing) being driven over an acoustic-based sensor that measured water pressures and velocities through the water column and at the lake bottom.

This report identifies three distinct hydrodynamic phenomena produced by common recreational powerboats that have the potential to impact the water column and lakebed.

Findings

This report identifies three distinct hydrodynamic phenomena produced by common recreational powerboats that have the potential to impact the water column and lakebed: 1) bow and stern pressure waves, 2) transverse gravity waves, and 3) propeller wash (Figure 3).

1) Bow and Stern Pressure Waves – As the hull moves through the water, it creates elevated pressure at the bow. At the stern, water that was pushed out of the way by the hull rebounds upward creating reduced pressure. The bow and stern pressure waves merge to form a single wave motion that can extend deep below the boat and, depending on depth, can interact with the lakebed and/or submerged aquatic vegetation. The short-duration bow and stern waves were found to be the primary hydrodynamic phenomena that initiates the movement of lakebed sediments but were not sufficient to cause sustained sediment resuspension.

2) Transverse Gravity Waves – Boats that operate below planing speeds form transverse gravity waves. While most boaters are familiar with the divergent waves that make a V-shape wake behind the boat; transverse waves are less obvious, and thus less familiar. These waves have crests that are perpendicular to the travel direction of the boat and move at approximately the same speed as the boat, so they appear, from a passenger's perspective, to be a stationary feature of the wake. Transverse waves can penetrate deep into the water column, persist for several minutes after the boat has passed, and generate velocities large enough to resuspend and entrain lakebed sediment.

3) Propeller Wash – Most recreational boats in use today are powered by an internal combustion engine that generates power to rotate a propeller. The spinning propeller creates a highly complex 3-dimensional jet of water, defined as propeller wash, that pushes the boat through the water. The engine exhaust is injected into the propeller wash as entrained bubbles. The bubbles interact with the propeller wash by dampening energy and proving buoyancy. Because the boat is moving, the direction of the propeller wash is altered by a crossflow effect - the propeller wash plume bends in a direction opposite the boat travel. The cumulative effect of the exhaust bubbles and crossflow limit the penetration depth of the propeller wash. However, propeller wash was shown to impact the water column for several minutes after the boat pass and, under certain modes of operation, contributed to the resuspension and entrainment of bottom sediment. It was further observed that propeller wash can directly cause shearing and complete uprooting of submerged aquatic vegetation under certain operating conditions.

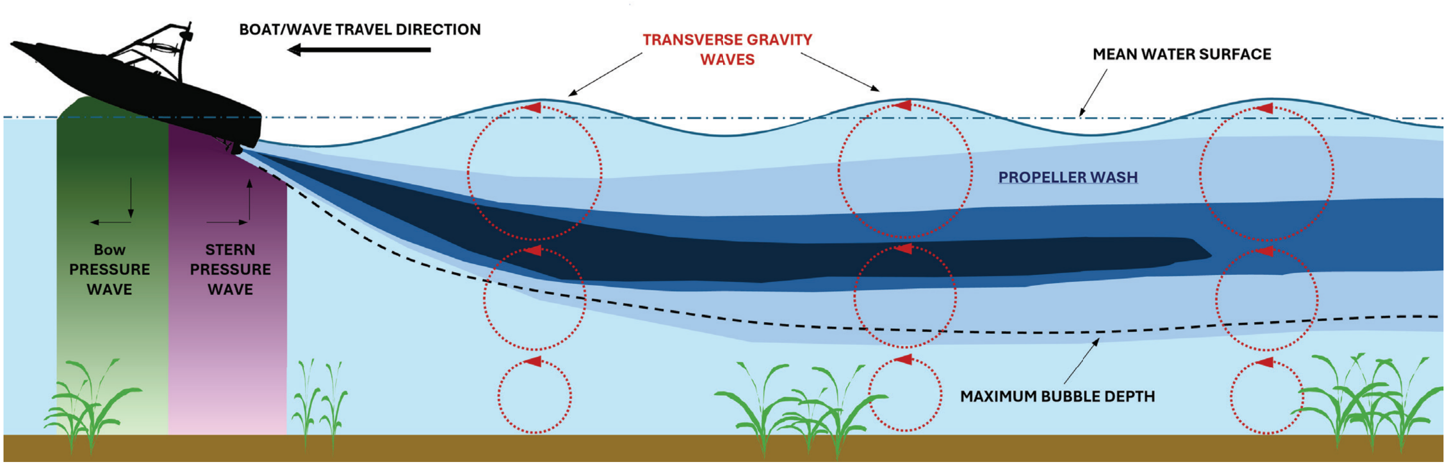


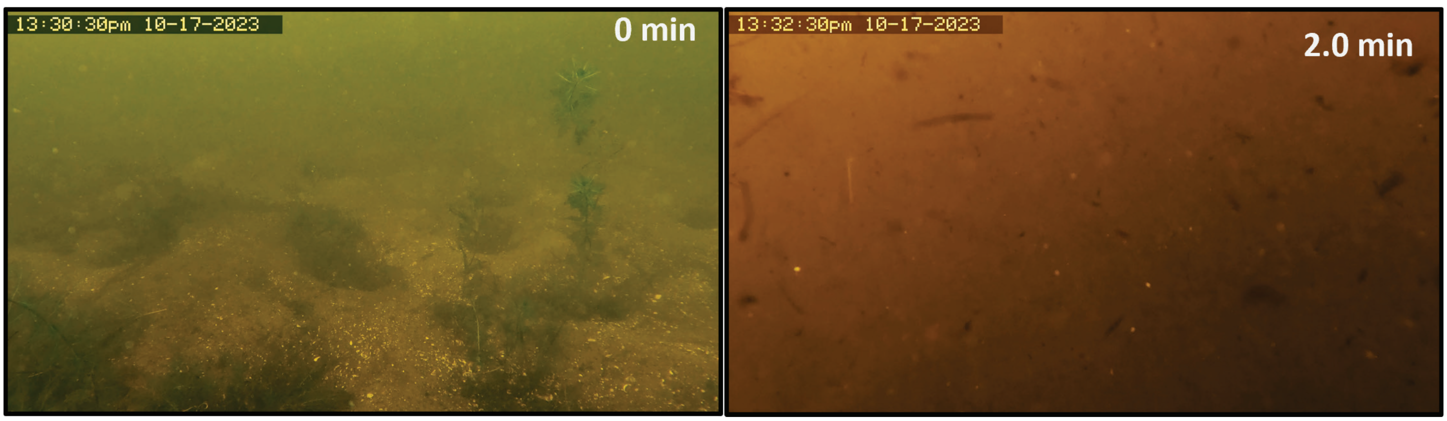
Figure 3. Illustration of the three hydrodynamic phenomena produced by a powerboat and how they interact with the water column beneath the boat.

We found that the velocities of the hydrodynamic phenomena and their depths of penetration are tightly linked to how the boat is being used.

- In planing mode (Condition 1 - cruising), the bow and stern pressure wave velocities were large enough to disturb lower density sediments (e.g., detritus, silt) at depths >10 ft; however, the absence of transverse waves and minimal propeller wash velocities at depths ≥10 ft prevented the sediments from resuspending and entraining in the water column.

- In displacement mode (Condition 2 – leisure cruising), the bow and stern pressure wave velocities were large enough to disturb sediments at depths >10 ft; however, the transverse wave and propeller wash velocities were minimal at depths ≥10 ft, which prevented these sediments from being resuspended and entrained in the water column.

- Wakeboats in semi-displacement mode (Condition 2 - surfing) produce all three phenomena at greater magnitudes compared to the other test conditions. The bow and stern pressure wave velocities were large enough to disturb lakebed sediments to depths of approximately 20 ft. The transverse wave velocities were capable of disturbing fine sediments down to a depth of 15-16 ft. By 20 ft deep the transverse wave velocities had decreased to near zero. The propeller wash velocities were significant down to depths of ~10 ft. After the initial prop wash jet, propeller wash currents were predominately moving towards the water surface (upwelling), which likely played a significant role in the sustained sediment suspension and entrainment into the water column. Below a depth of ~15 ft, propeller wash velocities decreased to near zero. Underwater video and aerial drone video confirmed that lakebed sediment (detritus) had resuspended at a depth of 14 ft.



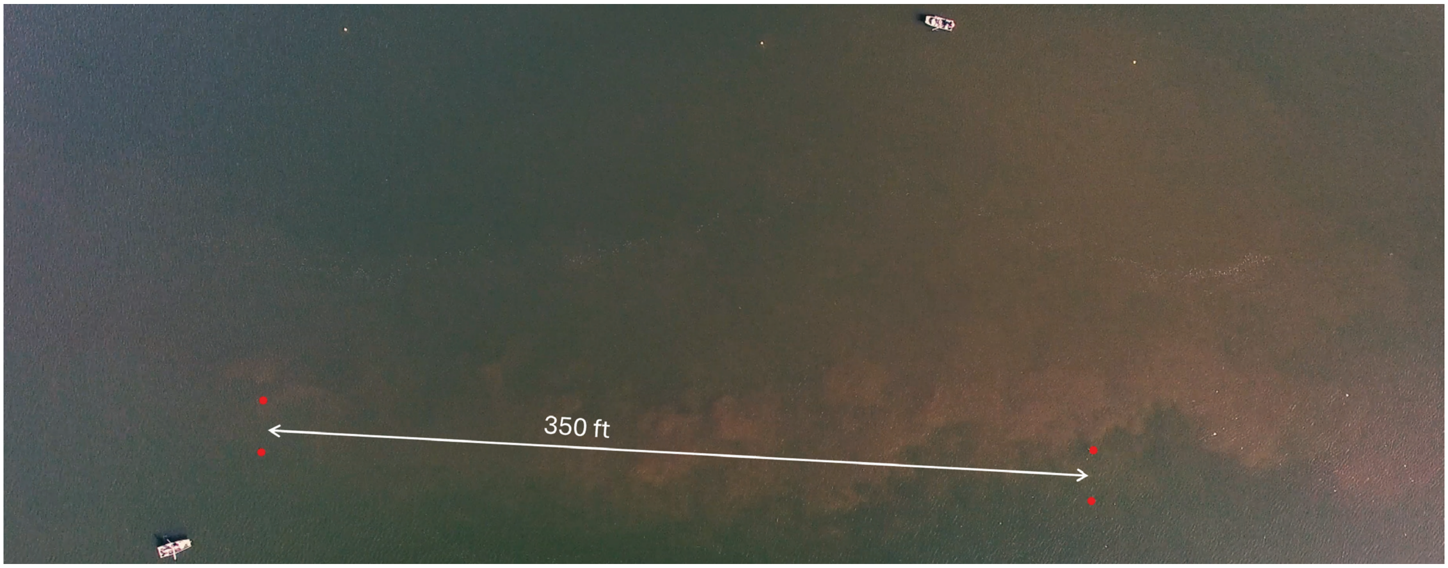


Figure 4. (Upper) Underwater video screenshots taken in 9 ft of water during the first pass of the Malibu VLX Wakesetter in surfing mode. The left image was taken immediately before the boat arrived and the right image was taken two minutes after the boat had passed. (Lower) Aerial video screenshot captured one hour after the first pass of the Malibu VLX Wakesetter under surfing conditions. The distance between the red buoys (data collection locations) is 350 ft.

Recommendations

Depth of Operation to Limit Impacts on the Lake Environment

Although these hydrodynamic phenomena are not fully visible from the water surface, powerboats can create large waves and currents that can extend deep into the water column and, depending on the water depth, can disturb the thermal regime, submerged aquatic vegetation, and lakebed. To minimize impacts to the lakebed, we provide the following depth recommendations for recreational powerboats operating in their typical modes:

- ✔ ***Recommended depth of operation for planing mode (cruising).*** Recreational boats, like the ones studied in this project, should operate in 10 ft of water or greater when planing to minimize impacts on the lakebed.

- ✔ ***Recommended depth of operation for non-wakeboats and wakeboats in displacement mode (leisure cruising).*** Recreational boats, like the ones studied in this project, should operate in 10 ft of water or greater when in sustained displacement mode to minimize impacts on the lakebed.

- ✔ ***Recommended depth of operation for wakeboats in semi-displacement mode (surfing).*** Wakeboats should operate in 20 ft of water or greater when in semi-displacement mode to minimize impacts to the lake bottom.

University of Minnesota
Saint Anthony Falls Laboratory

2 SE 3rd Avenue
Minneapolis, MN 55414

Research questions: marrx003@umn.edu
Media inquiries: erdma158@umn.edu

cse.umn.edu/safl
cse.umn.edu/saf l/Healthy_Waters

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