Healthy Waters Initiative

Phase II Scope of Work

Project Title

Characterizing the propeller wash hydrodynamics of recreational boats under various modes of operation and their implications on water quality

Research Team

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Version

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BACKGROUND

Phase I of this work was funded by crowdfunding through the Healthy Waters Initiative and focused on characterizing the surface wave characteristics from a variety of recreational boats, including wakesurf boats. **For Phase II, the primary research topic is on the hydrodynamic characterization of the propeller wash generated by motorized recreational boats, including wakesurf boats.** Propeller wash is an understudied characteristic of recreational boats that may have great impacts on water quality and aquatic habitat.

The project duration for Phase II is estimated at 14 months. The same team that carried out and published the Phase I study will also perform this Phase II study.

PHASE II SCOPE OF WORK

Motivation

Propeller wash is a general term to describe the **turbulent jet produced by the propeller (prop) of a boat motor**. Motors and propellers of all sizes produce prop wash and we know that when generated can interact (e.g., erode, stir-up) the lake/river bottom. As the size (e.g., length, width, and weight) of recreational boats and their powertrains (i.e., motor, driveshaft, and prop) increase, and the mode of operation (e.g., speed, boat pitch, engine thrust, etc.) change, there is great need to understand how prop wash interacts with lake and river systems.

Propeller trim angles are set in relation to the boat's hull and the pitch of the boat in the direction of travel varies whether the boat is on plane (cruising) or sub-planning(surfing). The sum of this propeller trim angle and the boat's pitch during operation is approximately the angle of the prop wash to the lake/river bottom, which is critically important to characterize for various recreational boats and their modes of operation, as it likely relates to the depth of prop wash penetration through the water column. In addition, the thrust of the propeller during various operational conditions is an important variable to characterize. We expect that heavier boats and operational conditions that displace large amounts of water (e.g., slow sub-planning speeds)

will have greater pitch that require higher propeller thrust, resulting in greater prop wash penetration. We also expect that boats traveling at high on-plane speeds will also produce high propeller thrust that also results in powerful prop wash, however, the pitch of the boat at these speeds in less, likely resulting in less prop wash penetration.

Overview of Scope of Work

We will carry out a field-based study that will measure the propeller wash produced by several types of recreational boats under various mode of operation, with a specific focus on inboard boats (e.g., skiing and wakesurf boats). This study will seek to "characterize" the hydrodynamics of the propeller wash by measuring the geometry of the jet (streamwise and lateral spread angles and depth of penetration) and the velocities and turbulent fluctuations (Turbulence Kinetic Energy).

The following variables will be explored:

- **Boat size and weight, engine size, and power during operation** - smaller/lighter and larger/heavier boats, ballasted and non-ballasted, various horsepower, and differing propeller characteristics.
- **Boat speed** - planning (cruising) and sub-planning (surfing) speeds
- **Boat pitch** - lower angle associated with cruising conditions and higher angles associated with surfing conditions
- **Water depth** - measurements taken at various depths to understand interaction with bottom
- **Water quality** - vertical water sampling before and after operation for suspended solids

Research Hypotheses

This project seeks to test three hypotheses:

1. Propeller wash is a turbulent jet formed by the spinning propeller and the geometry of the jet (i.e., rate of spread with depth and maximum depth) follows published models for stationary turbulent jets with adjustments made for the boat's motion atop the water surface.

2. The jet velocity immediately downstream of the spinning propeller, the diameter of the propeller, the angle of the propeller shaft to the water surface, and the velocity of the boat are the primary parameters that influence the depth of propeller wash penetration.

3. The magnitude of velocities and turbulent fluctuations associated with propeller wash decreases with distance from the propeller and, for boats tested in this study, contain sufficient energy to re-suspend inorganic sediment (silts and sands) and lightweight organic detritus. The extent of re-suspension is a function of prop wash incident angle, net propeller thrust, and water depth.

Overview of Research Methods:

The detailed research plan is still being developed, however, below is a summary of the current research design.

Data Collection:

- **Acoustic Doppler Current Profilers (ADCP)** will be deployed on a lake bottom at two water depths (~15 ft and 30 ft). Using the two-way travel time of sound and physics of Doppler shift, the ADCPs will measure velocity field changes through the entire water column as a boat passes by.
- **On-board boat position and attitude sensors** will be mounted on each of the test boats that will precisely measure the boat's location and direction, speed, pitch, tilt, and yaw.
- **Hull position sensors** will be mounted on the fore and aft gunwales of the boat that will measure the vertical submergence of the hull. This information is vital to determining the water displacement volume of the boat during operation.

- **Underwater Autonomous Vehicle (UAV) videography** will be used to document any visual change in water clarity or sediment movement during testing. The UAV will be positioned on the lake bottom with the shallower ADCP being the field of view.
- **Boat power-train characterization** will be performed on each test boat. This will include documenting the geometry of the hull, engine, driveshaft, and propeller. A revolutions per minute (RPM) sensor will be mounted to the driveshaft. The dry weight and ballasted weight of the vessels will also be documented.
- **Water Sampling** will be performed before and during boat evaluation. The current plan involves capturing physical water samples from multiple positions in the water column using Van Dorn water samplers. Two samplers will be used simultaneously to rapidly collect samples at each ADCP location. Water samples will be post-processed to determine Total Suspended Solids (TSS) and their composition (inorganic, organic, particle densities, nutrient content).

Test Boats:

We will evaluate multiple boats, with the focus being on inboard powertrains (i.e., direct drive and v-drive). The boats will vary in motor size (horsepower), length, and weight. Moreover, we will evaluate boats that are equipped or can be equipped with wave enhancing technologies (e.g., ballast capacity, hydrofoil, wake shaper).

Field Site:

The field site has not yet been finalized but will be located at a local Twin Cities lake. The test site will have a mildly sloping bottom with sandy substrate and minimal aquatic vegetation. We will seek a site that is wind sheltered and has low boater traffic. It is possible that several lakes will be used in this study.

Test Site Layout and Testing Scheme:

The figures below summarizes the current testing plan for this project. This plan may change depending on the test site/sites. The two ADCPs and guide buoys will be deployed in the water to establish a boat track. Each test boat will make a pass along the u-shaped track under a specific

operational condition (e.g., sub-planning speed with wake enhancing technologies activated). After a pass, water samples will be collected at both ADCP locations. Another pass will then be repeated under the same operational conditions. This cycle will be repeated a minimum of four times with sufficient time between each pass to let the water column return to a quiescent state. The set of passes will be repeated for different boat conditions (see next section).

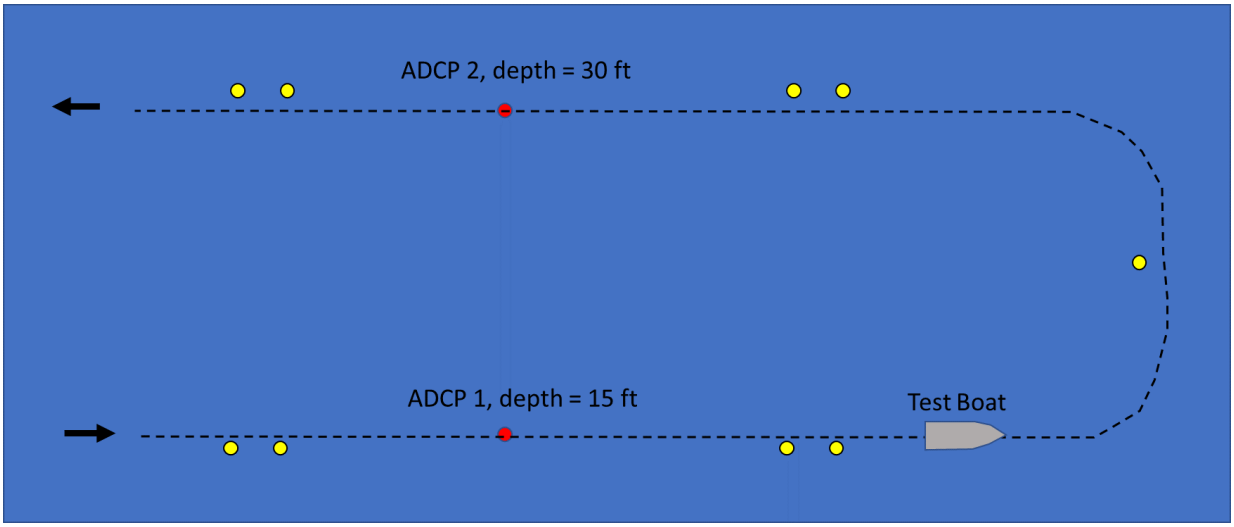

Figure 1. Schematic of the testing scheme. The test boat will travel a u-shaped track denoted by yellow buoys (circles) that passes over two bottom-mounted ADCPs deployed in approximately 15 ft and 30 ft of water.

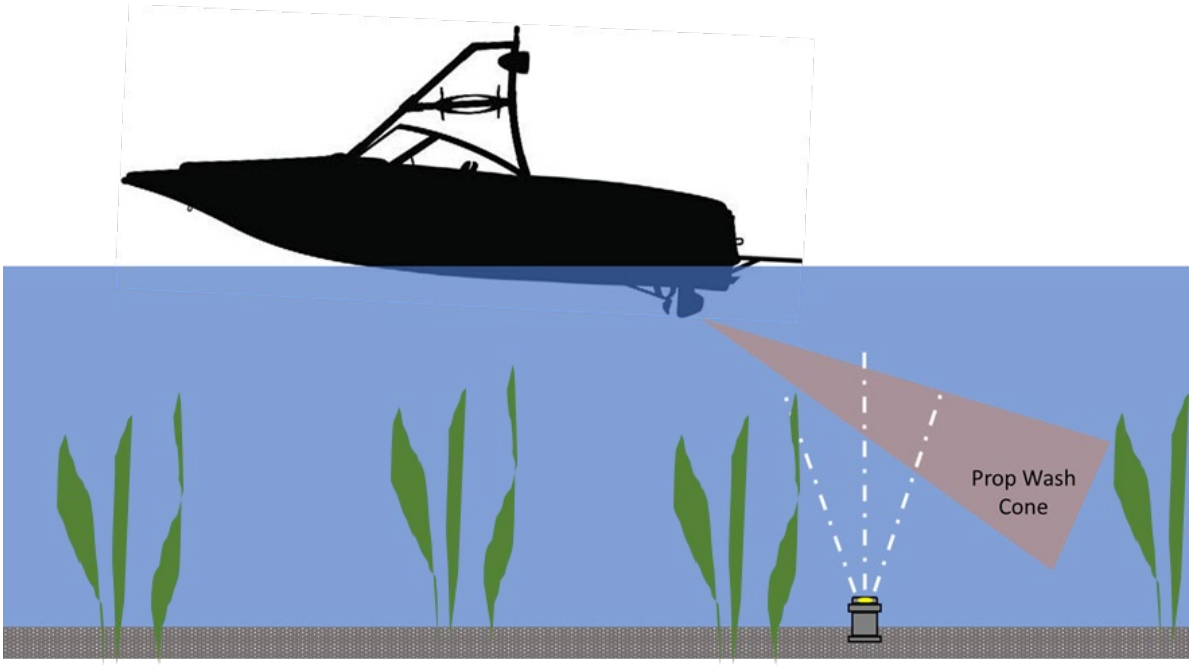

Figure 2. Conceptual drawing of propeller wash test with ADCP placed upward-looking.

Test Conditions:

Each boat will be evaluated under various operational conditions that include the following variables.

- Boat weight (e.g., length, width, motor horsepower,) and distribution (e.g., fore, amidships, aft)
- Boat speeds ranging from sub-planning to planning
- Presence and absence of wake enhancing technology (e.g., ballast water, hydrofoil, wake wedge, etc.)

Project Schedule

The project will largely be a field-based study conducted on a local Twin Cities lake during the 2022 open-water season. Data will be analyzed over the fall and early winter of 2022-23. A draft project report will be developed winter 2023 and submitted for an independent technical review by subject matter experts. A final draft of the report will be produced that incorporates reviewer comment and the final report will be published on the University of Minnesota Digital Conservancy with the target publication date of August 2023.

Funding

Because of the urgent need for research on this topic, we are launching a crowdfunding campaign to support this research. Our Phase I research project was also funded in this way and successfully completed its objectives. **The baseline fundraising goal is $175,000.** We are confident that this research will have an important impact on stakeholders and decision-makers that are developing solutions toward shared-use and protection of our lakes and rivers.

Below, we outline additional research items that could be included in the Phase II project if the fundraising goal is exceeded (see **Additional Scope Items** section below for details).

We want to emphasize that the project described here (to be funded through crowdfunding) is the next step in what we envision as a larger research effort addressing several topics of study.

The urgency of the research necessitates utilizing crowdfunding so that a 2022-23 research program can begin. Concurrent to this research program, we will continue to pursue other sources of funding. We are currently in the process of developing a proposal to be submitted to the 2022 LCCMR RFP process (funds available in summer 2023). We also have plans to submit several proposals to the National Science Foundation.

Additional Scope Items

This section includes additional research scope items that can be added to the primary scope if we are able to raise money beyond the $175,000 goal. There are three areas that are listed in order of priority.

Addition 1 - Paper study and report on wind generated and boat generated waves ($23,000)

This subproject will involve conducting a literature and data review, including research completed by the Healthy Waters Initiative team. The goal is to develop a publicly available report that summarizes the primary differences and similarities between wind-generated and boat-generated wake waves, which is of keen interest to various stakeholders at this time.

Addition 2 - Incorporating additional environmental sensors into the propeller wash field study ($32,400)

The environmental impact of propeller wash is a critically important area of research. To keep the cost as low as possible on the primary scope of work, we have included only a minimal investigation of environmental impacts (i.e., water sampling and analysis). With additional funding, we will be able to add more robust environmental monitoring such as including real-time turbidity sensors and additional water sampling (e.g., nutrient composition).

Addition 3 - Further development of cost-effective lake wave monitoring technology and prototyping designed for deployed by citizen scientists **($20,500)**

At the launch of the Healthy Water Initiative, one of the goals was to help establish a citizen-science based program to deploy and monitor a network of affordable wave monitoring stations. A small part of the Phase I crowdfunding dollars went towards this goal. The purpose of the

citizen-science wave monitoring program is to: 1) help establish connections of SAFL researchers to citizens and lake associations that may be experiencing boat wake impacts on their lakes, and 2) begin collecting data on boat-generated and wind-generated waves over a variety of lake and shoreline types, to determine which locations are most vulnerable to boat wake waves.

We have developed a relatively cheap (< $1,200) wave monitoring station prototype that can be deployed by citizens (e.g., riparian owners, lake associations, etc.). We have partnered with the Mississippi Headwater Audubon Society (MHAS), an environmental conservation organization that focuses on ecological research and outreach, to hopefully deploy the prototype this spring 2022. The prototype will be deployed at Spearhead Lake, which is within the Neilson Spearhead Center, a 466-acre preserve southwest of Bemidji, Minnesota that is owned and operated by MHAS. With additional funding, we will refine this wave monitoring station prototype and get additional wave monitoring masts deployed by citizen scientists.

Project Budget Estimate

Below is a table that summarizes the draft budget including the primary scope of work and the additional scope items should more than $175,000 be raised.

Summary - Healthy Waters Initiative - Phase II

Primary Scope	Category		Costs	Description of Research
	Salary and Fringe	$	150,682	Primary research focused on characterizing the propeller wash (turbulence, velocities, and depth of penedtration) of various types of recreational boats under varying operational conditions. Includes communication, donor stewardship, report development, external report review, and final publication of a SAFL project report.
	Supplies and rental	$	15,400	
	Travel	$	5,000	
	Direct Costs	$	171,082	
	Overhead/UMF Assessment	$	4,705	
	Total Costs	**$**	**175,787**	
Addition 1 - Wind and Boat Wave Report		$	23,083.47	Small paper study and report summarizing differnces between wind and boat waves. Publish as a SAFL Report.
Subtotal		**$**	**198,870.26**	
Addition 2 - Addition of environmental monitoring		$	32,481.70	Add environmental sensors to the Primary Scope (i.e., propeller wash) field study, which will provide initial insight into water quality impacts
Subtotal		**$**	**231,351.96**	
Addition 3 - Citizen Science, wave monitoring		$	20,486.17	Add pilot-scale program to further develop cost effective wave monitoring technology and prototyping on several inland lakes.
Subtotal		**$**	**251,838.14**	

DONOR/RESEARCHER EXPECTATIONS

The research team and University of Minnesota are grateful for the individuals and organizations that choose to provide financial support to this research. Crowdfunding is a unique and new way of funding research at the University of Minnesota. The donations made by individuals and organization to this research program are made through the University of Minnesota Foundation and are considered a philanthropic gift to UMN, designated specifically to the Healthy Water Initiative. With the exception of a 2.5% administrative fee charged by the UMF, all donations are directly allocated to this research project. Donor name and gift ranges are considered public information under Minnesota law.

Typical UMN research is performed under a legal contract established between the project sponsor and the UMN. This is not the case for this crowdfunded research. The donor should understand that UMN intends to conduct the research as outlined in this scope of work document. We have done our best to be transparent on the scope of work, schedule, and deliverables. In the absence of a contract, we provide this summary of what donors can expect from the UMN research and project management personnel and what we expect from donor and stakeholders while carrying out this research:

<u>Expectation for what donors can expect from UMN</u>

- UMN will carry out a robust research effort with high standards for data methods, quality control, analysis and publication.
- UMN will remain unbiased throughout this research project. We will analyze data without bias and will provide interpretation of the data that is based on that data, not on pre-conceived conclusions.
- UMN will provide communication on the project through our project website. The following communication will be provided:
    - Pre-project webinar summarizing the project plan. The webinar will be pre-recorded and posted on our project website.

- The final version of this Phase II Scope of Work document including budget summary and donor/researcher expectations memo will be available on our project website.
- University of Minnesota Foundation will provide a gift receipt for all donations.
- Gift letters will be developed and emailed by SAFL to the donors that contribute over $5,000.
- Once the research project has begun, the research team will limit communication with donors and project stakeholder to quarterly updates posted to the project website. An email will be sent to those who have signed up to receive our newsletter notifying them of the new web post. Updates will include any changes to scope of work or schedule.
- Upon completion of the final report, the report will be posted on the University Digital Conservancy. An email and website update will direct donors to the report, press release, public video and photography, and other media support information.
- Upon completion of the final report, the research team will present a public webinar on the outcomes of the research. The webinar will be recorded and posted.

<u>Expectation for what UMN can expect from donors</u>

- UMN appreciates input and observations from donors on sustained research pertaining to the shared use and environmental impacts of inland lakes and rivers.
- UMN requests that once the research project has begun that donors will provide us the space to work independently and without influence. We will communicate updates as described above.
- UMN will appreciate support in sharing the final project report with other stakeholder and constituents.