Do horsepower and wake boating matter to your lake?

Jeff Marr, Andy Riesgraf

William Herb, Matthew Lueker, Jessica Kozarek, Kimberly Hill

May 4, 2022

Presented to:

Itasca Waters:

Practical Water Wisdom 2023

Motivation for Research Program

- In 2019 and 2020 – emails and phone calls from concerned citizens and organizations. **Research needed on impacts of large recreation boats on lakes and rivers – specifically, wakesurf boats and wakesurfing**
  - **Adverse env. impacts** – decrease in water clarity, signs of erosion, floating vegetation
  - **Property damage** – impact of waves on shorelines, docks, etc.
  - **Safety** – concerns for smaller vessels, paddlers, swimmers, wildlife, etc.
  - **Shared use of lakes** – lake use is limited when wakesurf boats are active

- UMN-SAFL has an important role to play in these types of issues
  - Source of reliable information – unbiased, high-quality, accessible.
  - Remain neutral – we are a data generator. We don't write policy/law.

Overview of Research Program

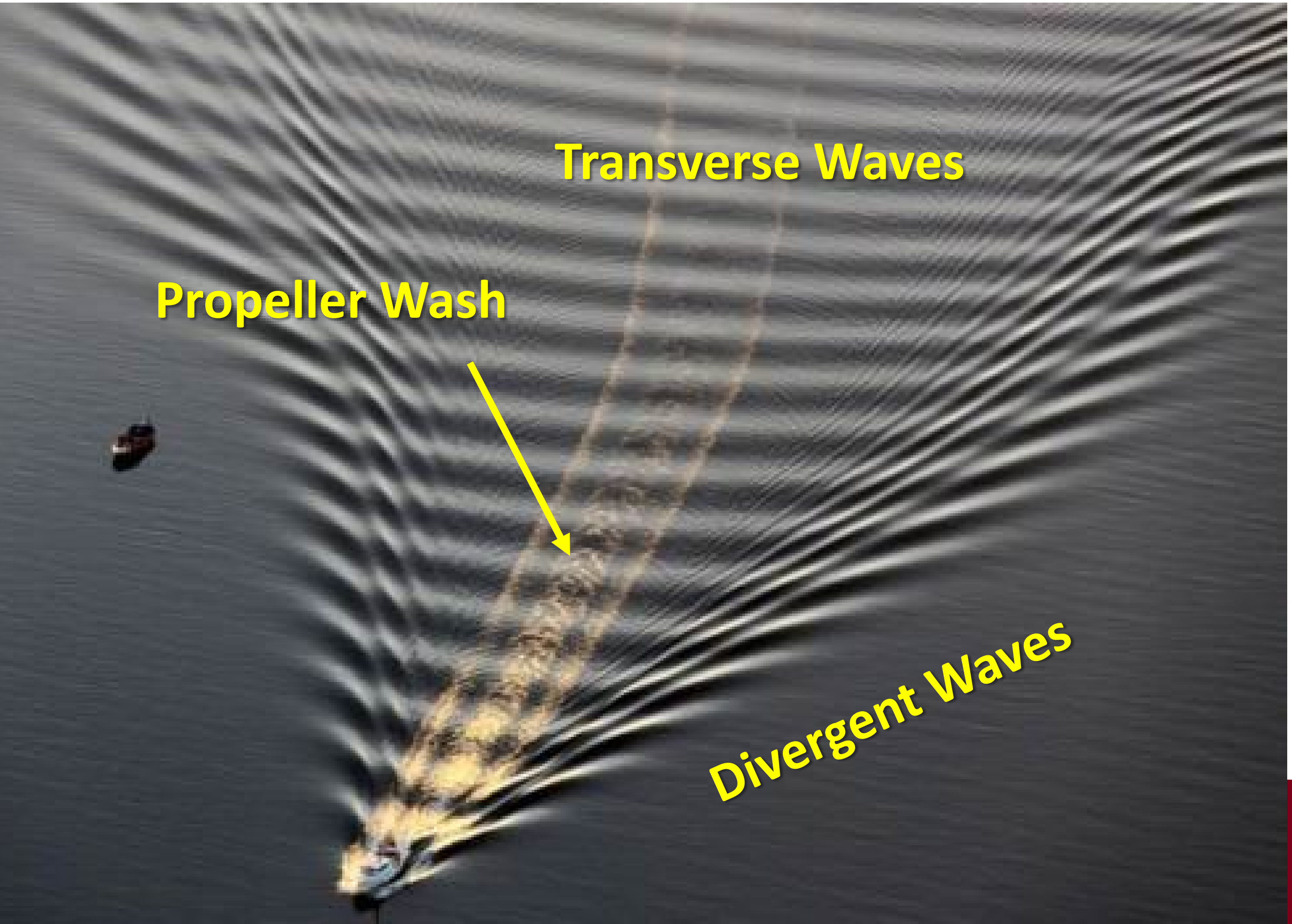
Phase 1: Measure/quantify wake waves produced by recreational boats, including both wakesurf and non-wakesurf boats.

Phase 2: Measure/quantify the propeller wash produced by recreational boats, including both wakesurf and non-wakesurf boats.

Phase 3: Quantify impacts that wake waves and propeller wash have on lake environments and water quality

Introduction to Boat Waves

The physics of surface water waves and vessel wakes is a rich topic and complex!



What is important to know for recreational boat operation?

- ***A recreational boat is displacing water***
- ***Three primary phenomena result from this displacement:***

1. **Divergent waves**
2. **Transverse wave (only at speeds below hydroplaning)**
3. **Propeller wash**

Much more to this story involving water depth, boat planing condition, boat speed.

Displacement versus hydroplaning

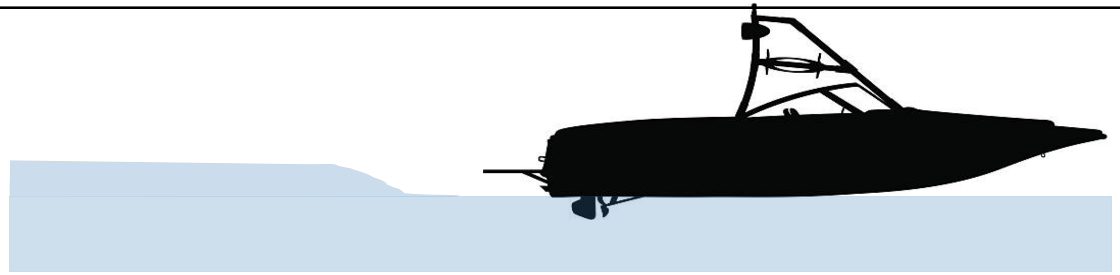
Hydrodynamic hull conditions of recreational vessels

Displacement mode – Slow speed (<5mph)

- Hull is at maximum draft
- ***Site seeing, maneuvering, trolling (fishing)***

Sub planing mode – moderate speed (10-13 mph)

- Transition region between displacement and planing. "plowing mode"
- Drag on the hull is at a maximum
- ***Surfing condition***



On-plane or hydroplaning – high speed (>15 mph)

- Boat lifts up to top of water surface
- Lowest drag on hull
- ***Waterskiing, tubing, wake boarding, cruising***

Phase I – Objectives

1. Conduct a field study to measure/quantify characteristics of the diverging wake waves produced by recreational boats, including both wakesurf and non-wakesurf boats.

    - How big are the wake waves produced by these boats?
    - ***Move the discussion from anecdotal observations to actual numbers.***

2. Produce a report that is robust, externally reviewed, and accessible to all.
    - Phase I report released on February 1, 2022.
        - https://hdl.handle.net/11299/226190
        - The report has been downloaded ~ 11,300 times

Phase I – Study Site

(Andy)

- Maple Plain, Minnesota
- Lake Independence – 832 acres
- Typical Minnesota recreational lake
- Eastern shoreline (red box)
- Substrates primarily sand with a riprap shoreline
- Minimal aquatic vegetation
- Gradual increase in water depth with distance from shore (5% slope)

Phase I – Test Boats

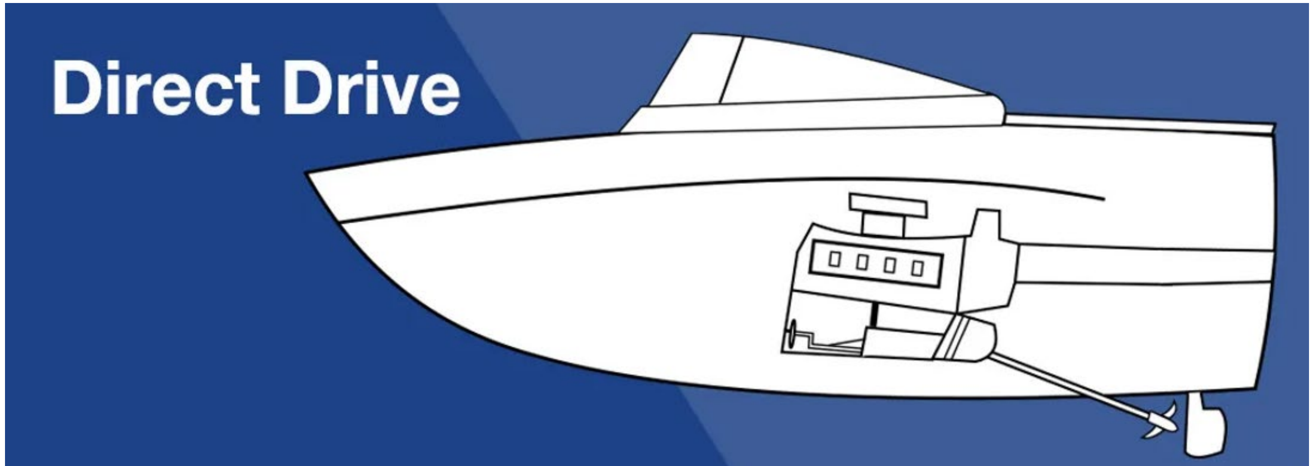
	Manufacturer	Model	Year	Drive	Horsepower	Beam (ft)	Length (ft)	Dry Weight (lbs)	Ballast (lbs)	Hydrofoil	Wake Shaper
Non-Wakesurf	Larson	LXI 210	2004	Sterndrive (I/O)	260	8.3	21	2925	No	No	No
	Malibu	Response LX	2004	Direct Drive (I)	310	7.5	20	2450	No	Yes	Yes -aftermarket

https://www.smartmarineguide.com/L52397675

https://matsonauto.com/whats-the-difference-between-inboard-outboard-and-sterndrive

Phase I – Test Boats

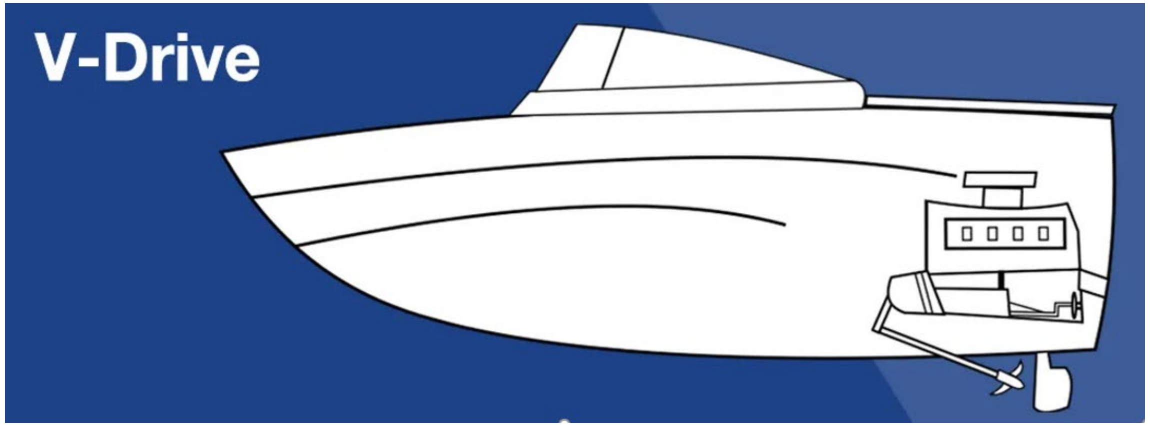
	Manufacturer	Model	Year	Drive	Horsepower	Beam (ft)	Length (ft)	Dry Weight (lbs)	Ballast (lbs)	Hydrofoil	Wake Shaper
Non-Wakesurf	Larson	LXI 210	2004	Sterndrive (I/O)	260	8.3	21	2925	No	No	No
	Malibu	Response LX	2004	Direct Drive (I)	310	7.5	20	2450	No	Yes	Yes -aftermarket



https://matsonauto.com/whats-the-difference-between-inboard-outboard-and-sterndrive

Phase I – Test Boats

	Manufacturer	Model	Year	Drive	Horsepower	Beam (ft)	Length (ft)	Dry Weight (lbs)	Ballast (lbs)	Hydrofoil	Wake Shaper
Wakesurf	Malibu	Wakesetter VLX	2019	V-Drive (I)	450	8.2	21	4200	3690	Yes	Yes
	Malibu	Wakesetter MXZ	2019	V-Drive (I)	450	8.5	24.5	5500	4885	Yes	Yes



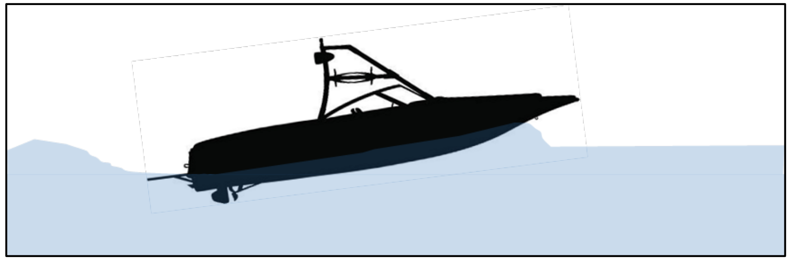
Phase I – Test Boats

	Manufacturer	Model	Year	Drive	Horsepower	Beam (ft)	Length (ft)	Dry Weight (lbs)	Ballast (lbs)	Hydrofoil	Wake Shaper
Non-Wakesurf	Larson	LXI 210	2004	Sterndrive (I/O)	260	8.3	21	2925	No	No	No
	Malibu	Response LX	2004	Direct Drive (I)	310	7.5	20	2450	No	Yes	Yes -aftermarket
Wakesurf	Malibu	Wakesetter VLX	2019	V-Drive (I)	450	8.2	21	4200	3690	Yes	Yes
	Malibu	Wakesetter MXZ	2019	V-Drive (I)	450	8.5	24.5	5500	4885	Yes	Yes



Phase 1 – Operational Conditions Tested

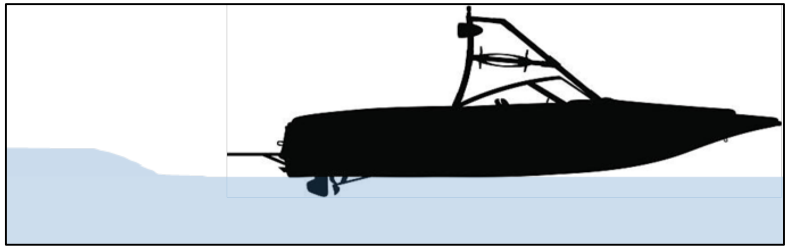
Condition 1a



- Non-wakesurf boats - **Largest wave/plowing (10 mph)**
- Wakesurf boats - **Surfing (11 mph)**

Boat	Speed (mph)	Trim Setting (%)	Ballast (% filled)	Hydrofoil	Wake Shaper	People Aboard (qty)	People Weight (lbs)
Larson LXI 210	10	50 (middle)	N/A	N/A	N/A	2	330
Malibu Response LX	10	N/A	N/A	Down	On – Port Side	2	330
Malibu VLX Wakesetter	11	N/A	100	Down – Setting #3	On – Port Side	4	740
Malibu MXZ Wakesetter	11	N/A	100	Down – Setting #3	On – Port Side	4	740

Phase 1 – Operational Conditions Tested



Condition 2

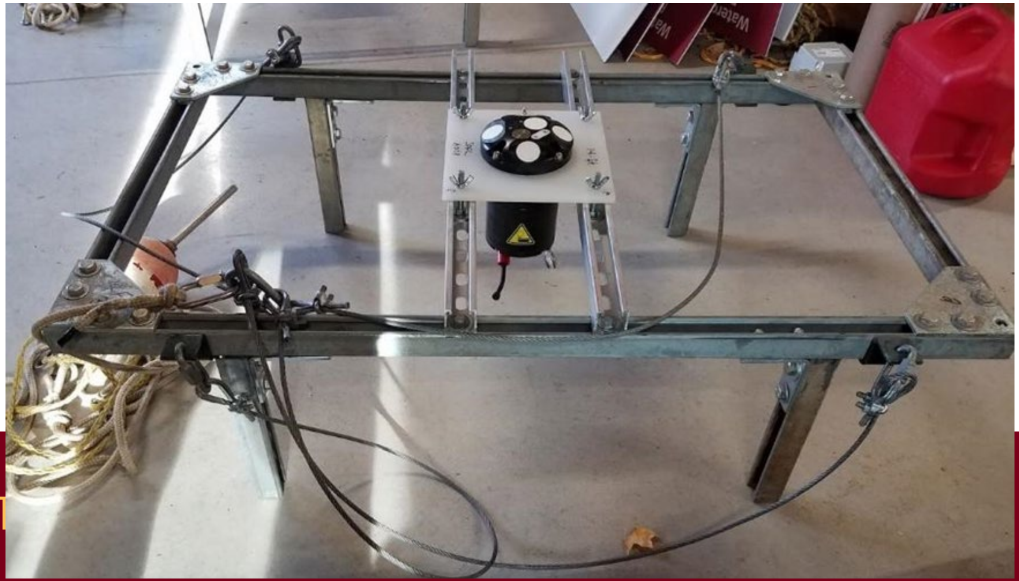
- **All boats on plane (20 mph)** – represents water skiing, tubing, wakeboarding, cruising
- Ballast empty, wake wedge stowed/removed

Boat	Speed (mph)	Trim Setting (%)	Ballast (% filled)	Hydrofoil	Wake Shaper	People Aboard (qty)	People Weight (lbs.)
Larson LXI 210	20	100 (down)	N/A	N/A	N/A	2	330
Malibu Response LX	20	N/A	N/A	Down	Off	2	330
Malibu VLX Wakesetter	20	N/A	0	Down – Setting #3	Off	4	740
Malibu MXZ Wakesetter	20	N/A	0	Down – Setting #3	Off	4	740

Phase 1 – Data Collection

<u>3 Masts + 2 Pads</u>

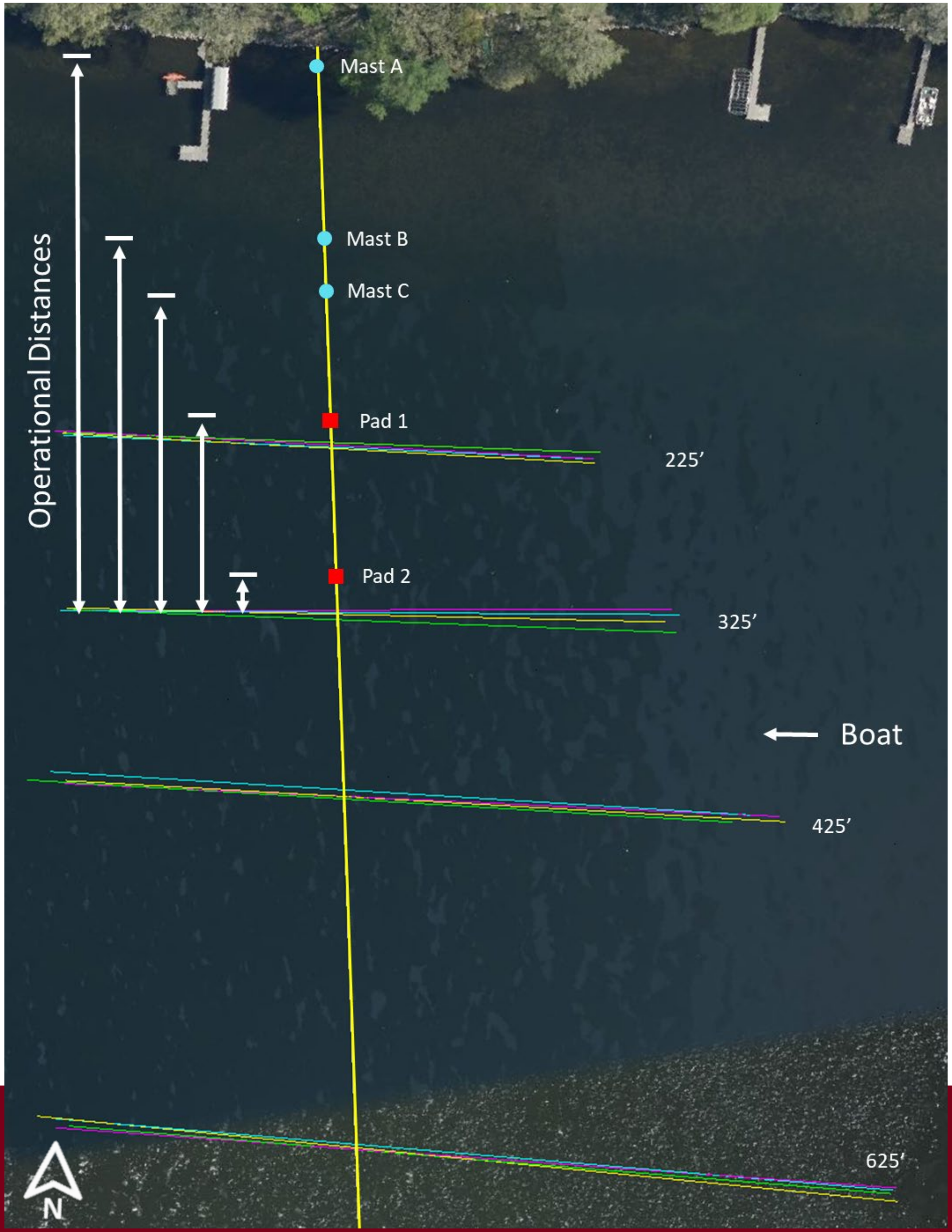
- Masts: Deployed in water depths < 10 ft
- Masts: Pressure sensor
- Pads: Deployed on the lake bottom in 14 and 22 ft of water
- Pads: Acoustic Doppler Current Profiler



Phase 1 – Operational Distances

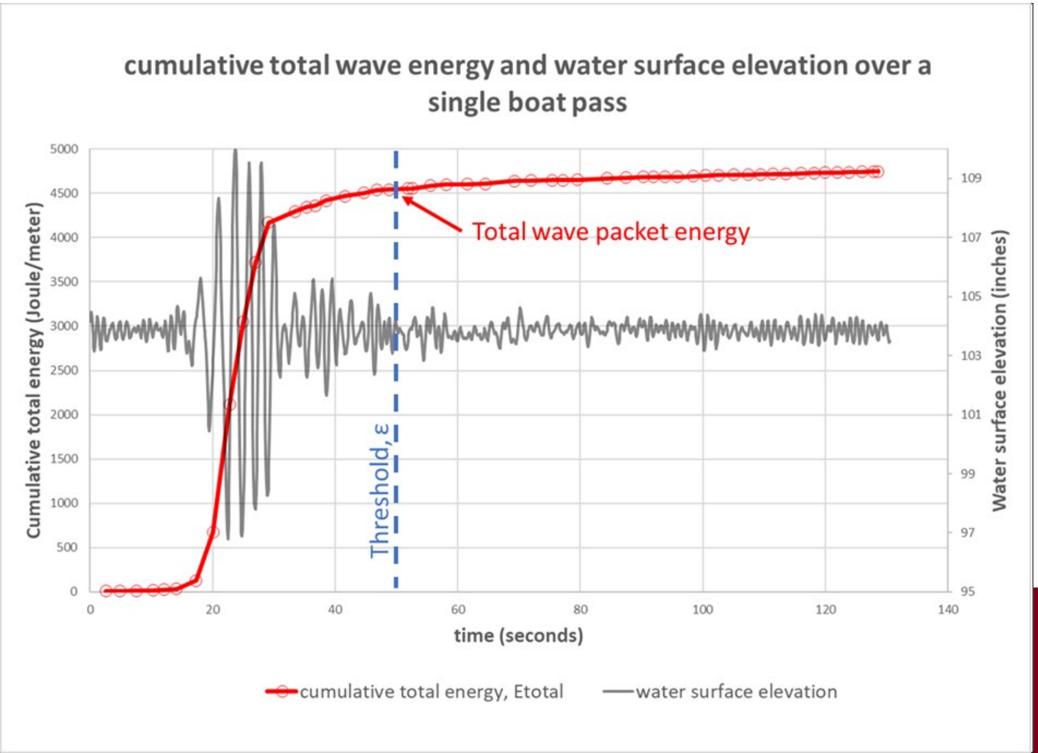
For each condition tested (1a, 2, 1b)

- Track lines ran parallel to the shoreline and perpendicular to the masts/pads
- Passes were made along the track lines from east to west
- Colored lines are an example of the real-time boat positional data for each pass plotted in AutoCAD



Phase 1 – Wake Wave Characteristics

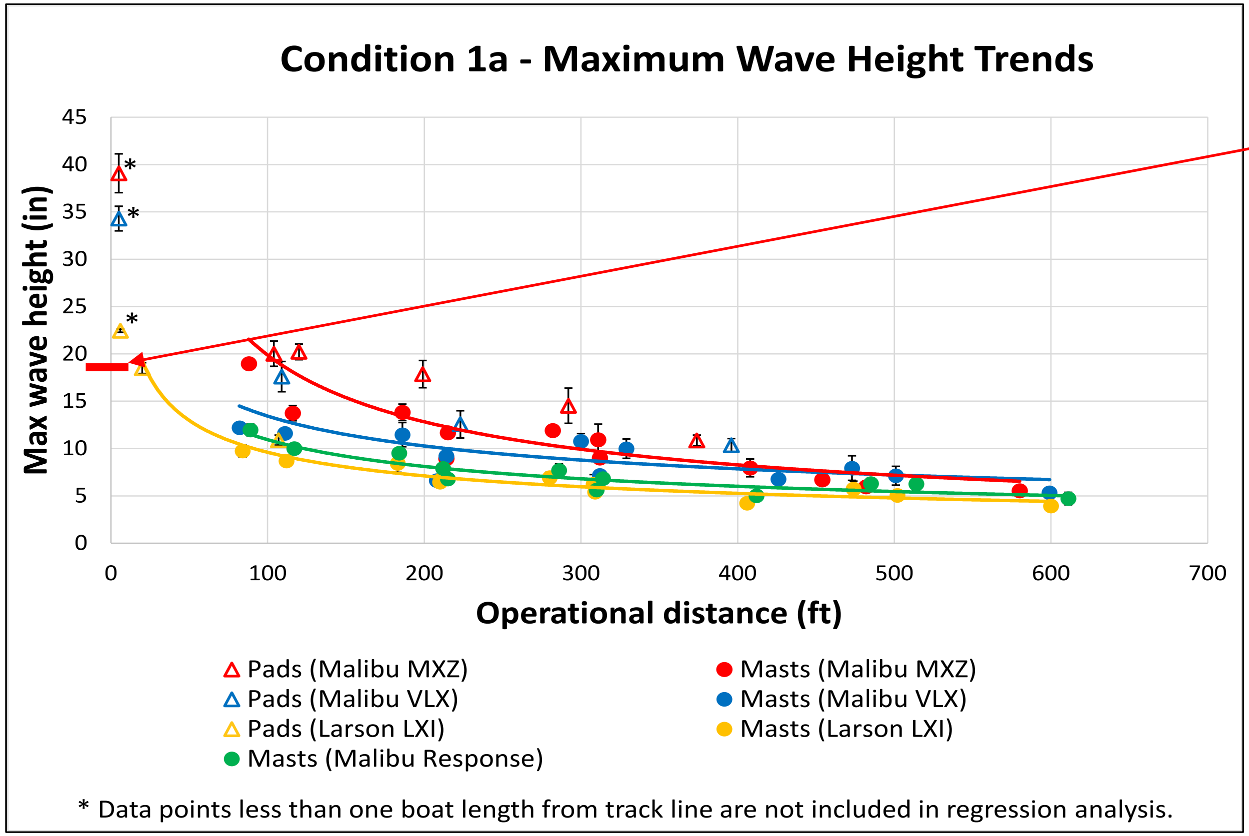
- **Wave Height** – vertical distance measured from trough to crest of a wave.
- **Wave Power** – the rate at which energy is transferred or used. For wake waves, it is the rate at which energy is transferred away from the track line.
- **Wave Energy** – the ability of the wave(s) to do work or make change. In physics, work is often quantified as force applied over a distance.

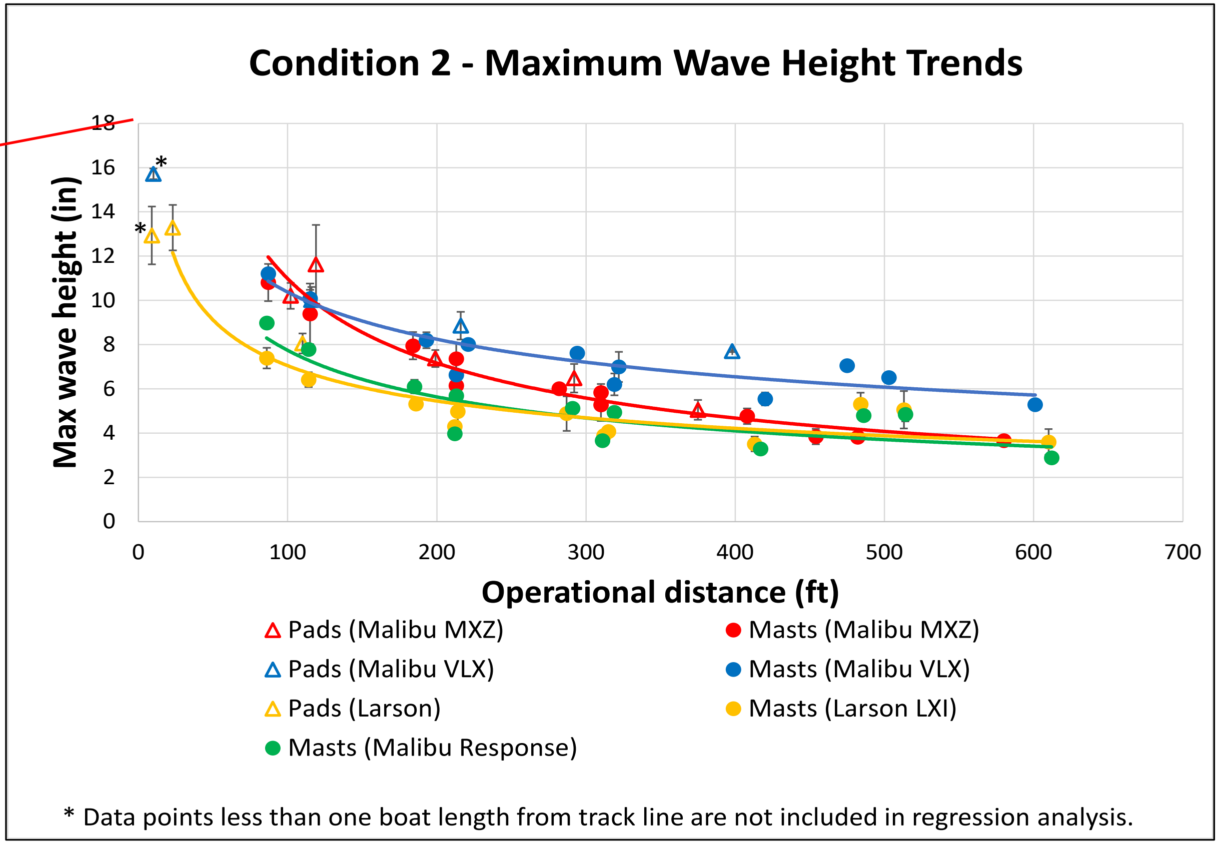


$$P_{max} = \left(\frac{\rho g (H_{max})^2}{8} \frac{g T_{max}}{4\pi}\right)$$ Max wave power

$$E_{total} = \sum_{i=1}^{n} \frac{\rho g H_i{}^2 \lambda_i}{8}$$ Total wave packet energy

Phase 1 Results – Cond 1a & Cond 2: Max Wave Height



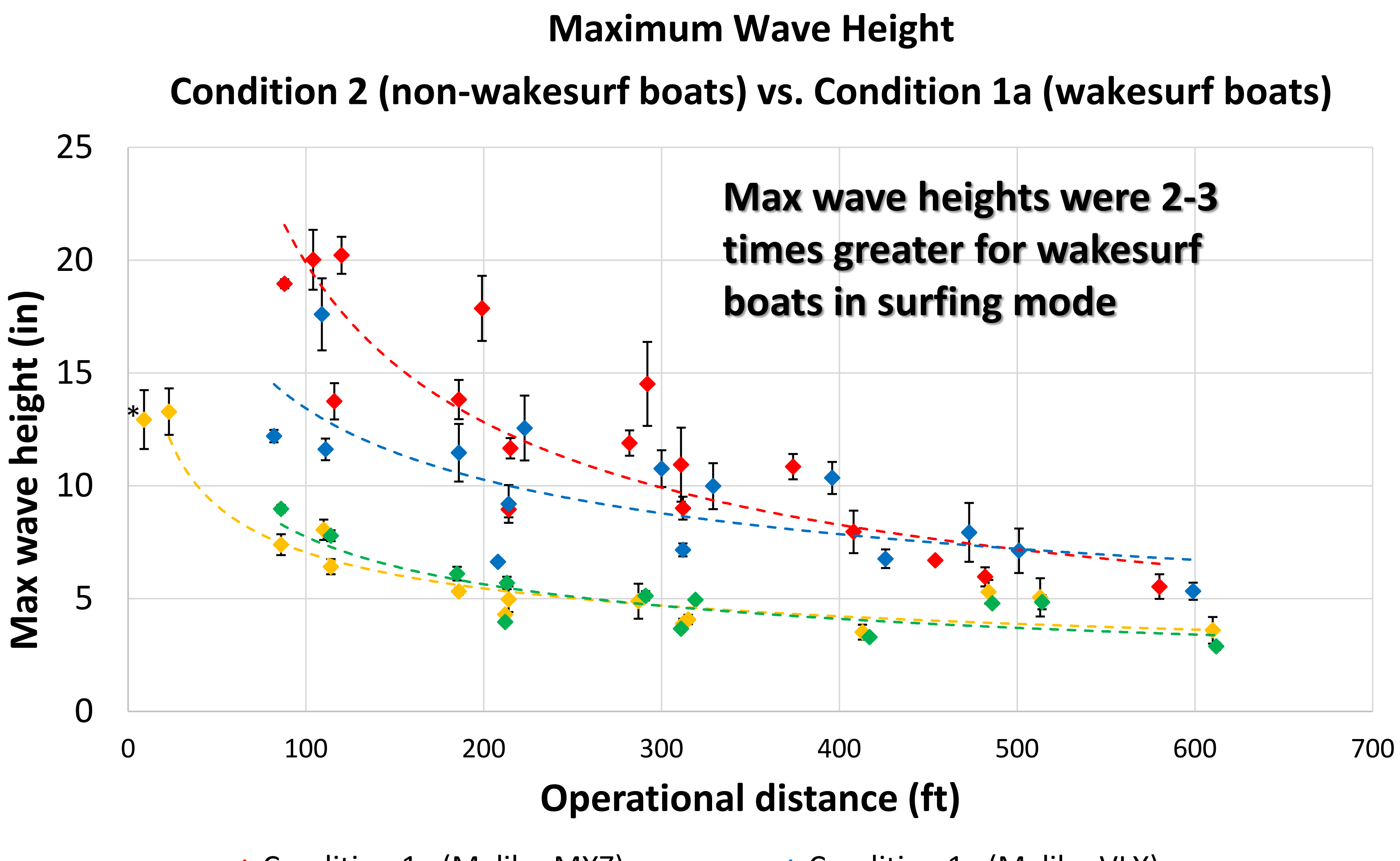


Phase 1 – Summarizing Findings for Cond 1a vs Cond 2

- *Remember our different hull conditions* (displacement, sub planing, planing)
- Wakesurfing is at **sub-planing** condition; different from other tow-sports

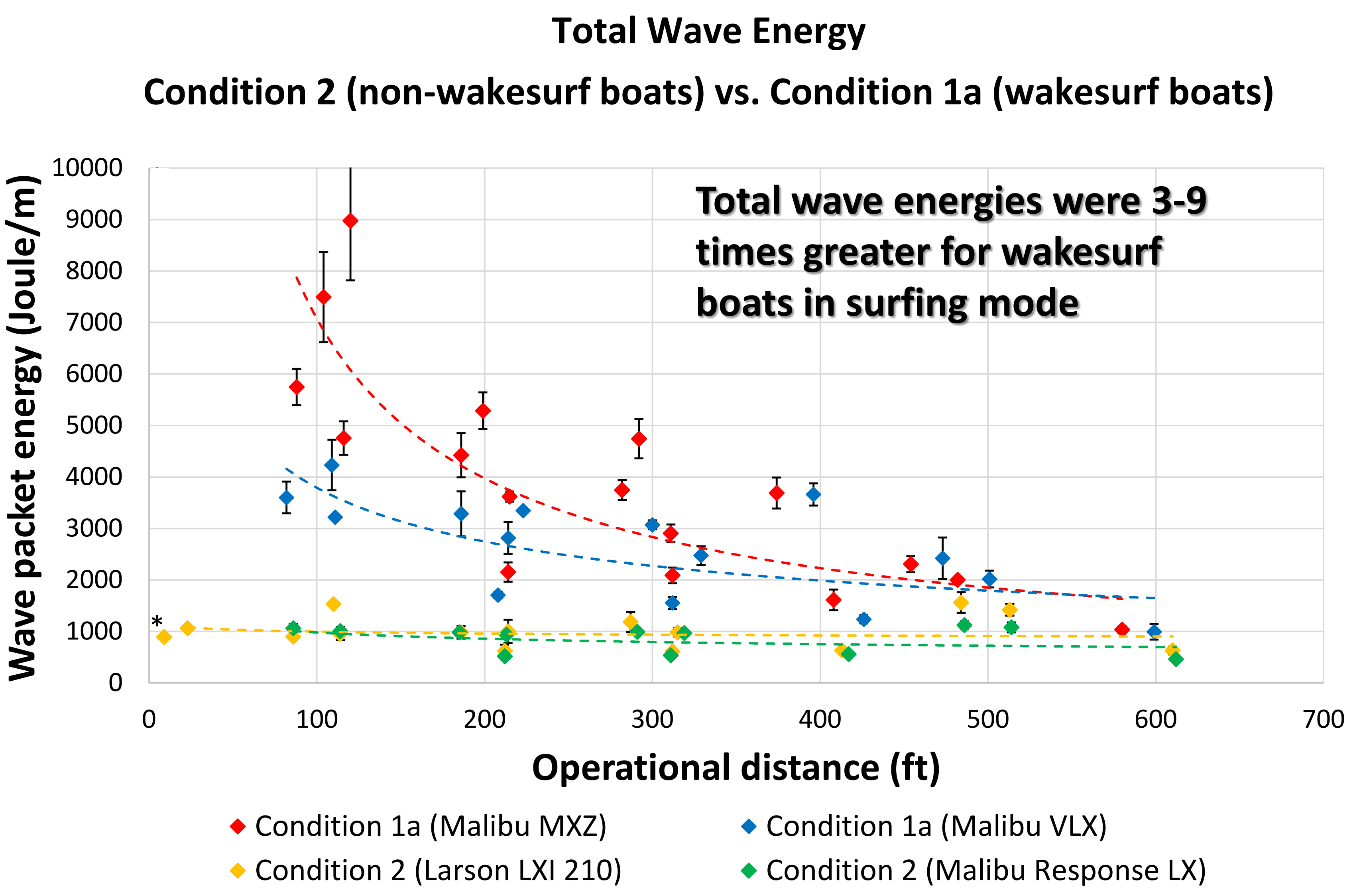
- Compare boats under their "Typical Usage".
  - **Comparison:** Wakesurf boats in surfing mode (Cond 1a) versus non-wakesurf boats in planing mode (Cond 2)

Phase 1 – Summarizing Findings for Cond 1a vs Cond 2



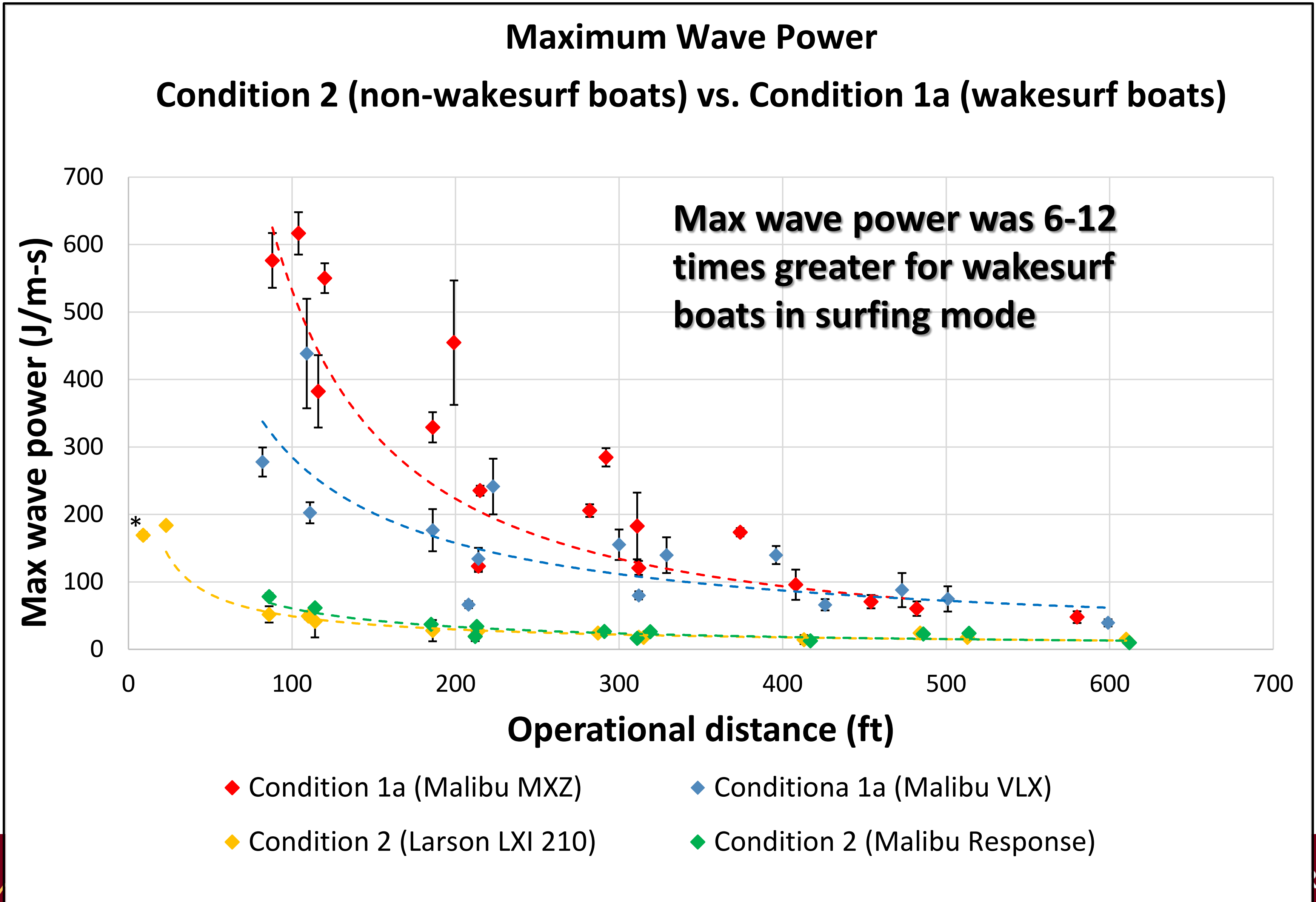
* Data points less than one boat length from track line are not included in regression analysis.

Phase 1 – Summarizing Findings for Cond 1a vs Cond 2



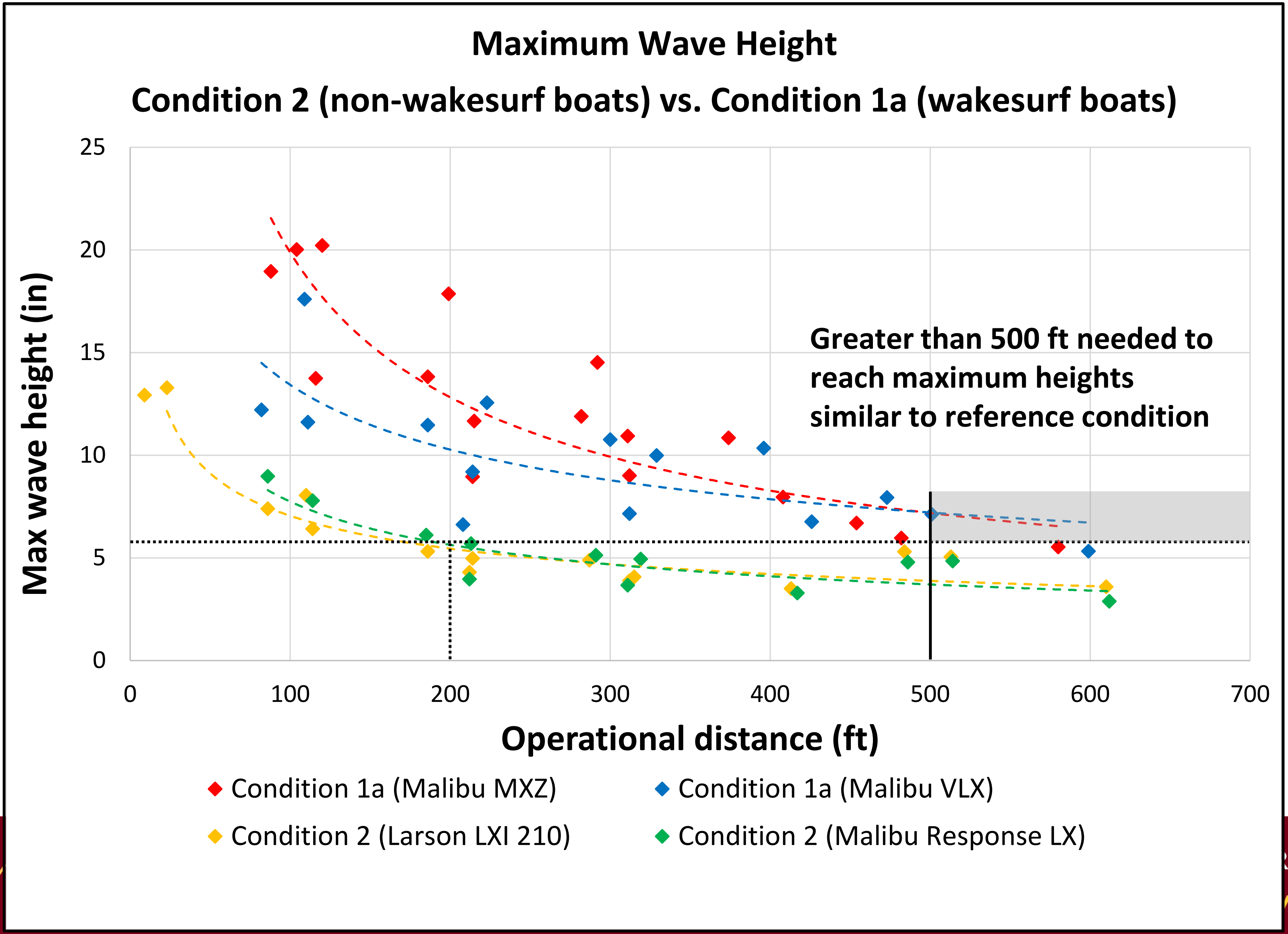
* Data points less than one boat length from track line are not included in regression analysis.

Phase 1 – Summarizing Findings for Cond 1a vs Cond 2

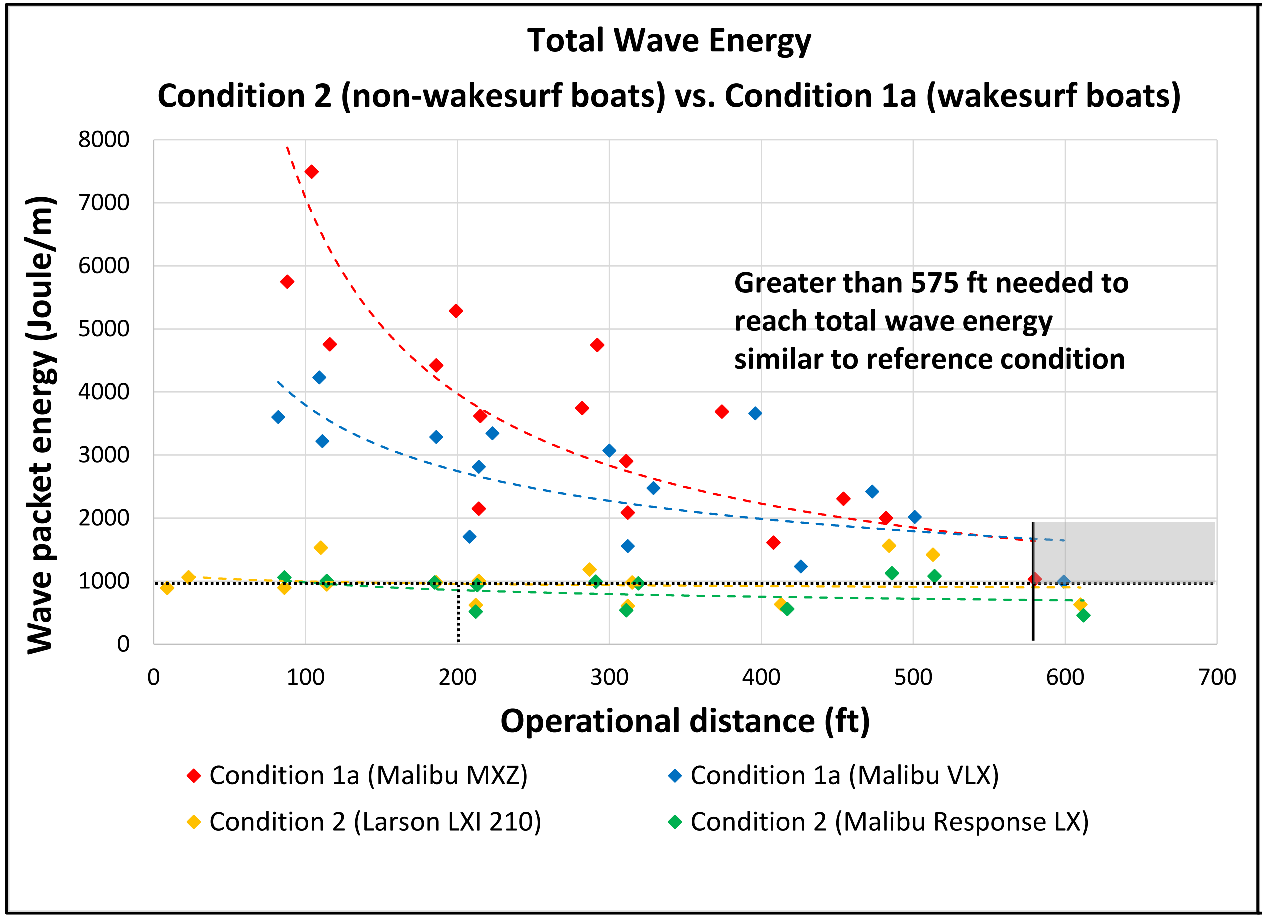


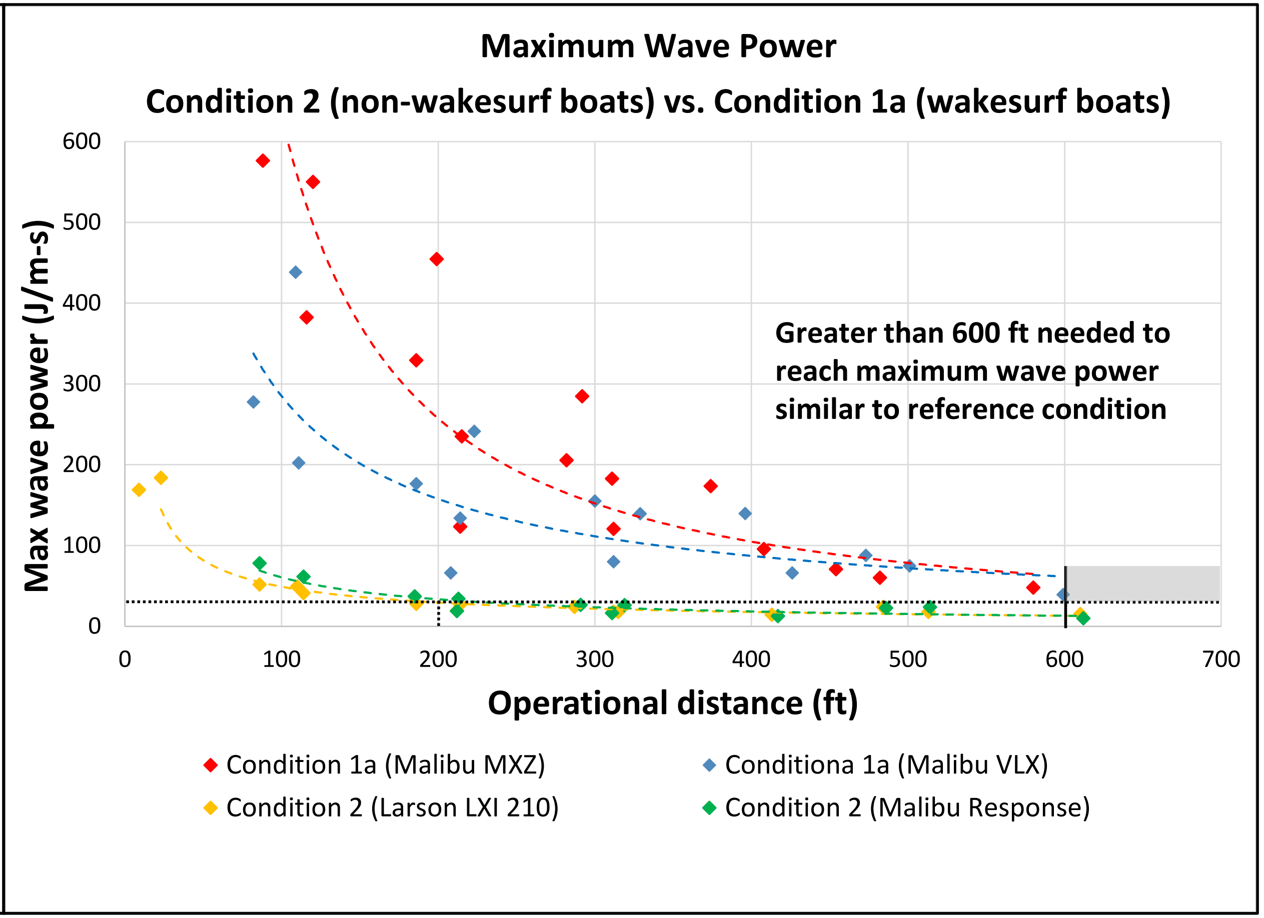
* Data points less than one boat length from track line are not included in regression analysis.

Phase 1 – Example 1 of using data for guidance



Phase 1 – Example 1 of using data for guidance cont.





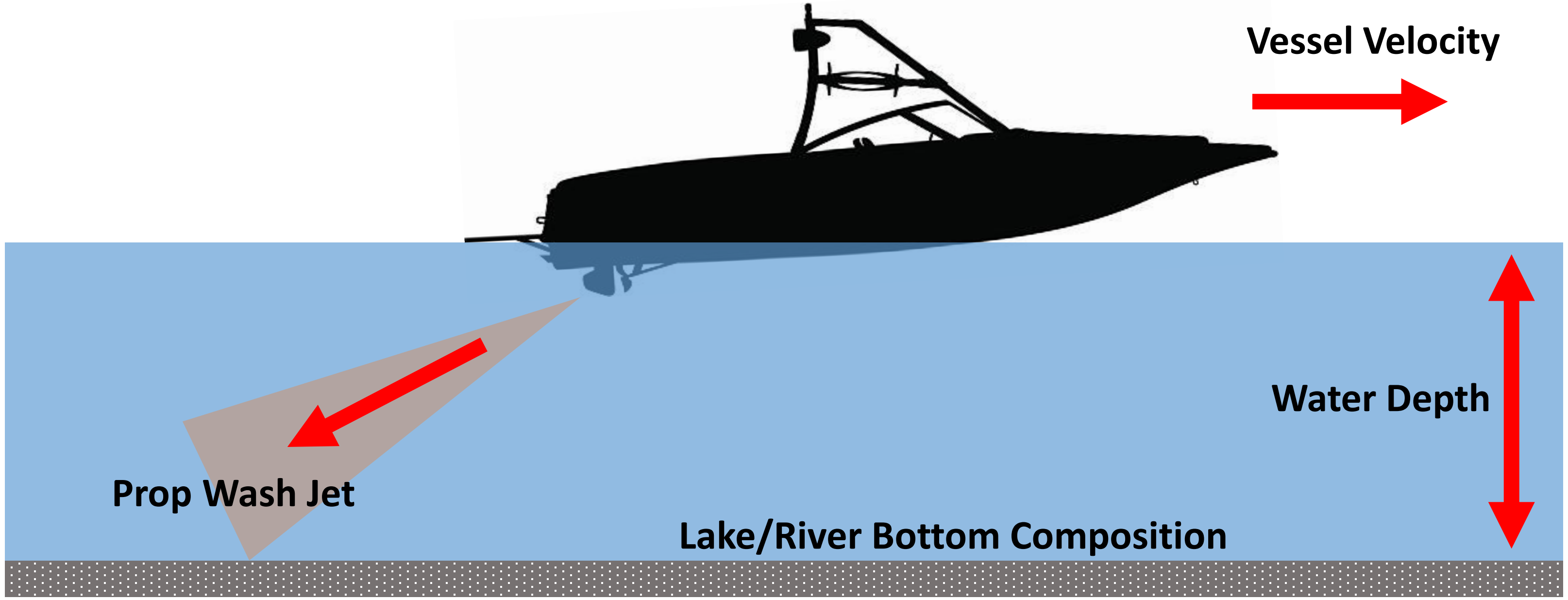
Phase 1 – Summary of findings

- Comparing individual boats, we quantify the difference in wave characteristics between a planing condition (Condition 2) and transition to planing (Condition 1a).
- The wakesurf boats produced the largest waves under all conditions and substantially larger under Condition 1a (surfing).
- **How a boat is used is important to consider as the wave characteristics are vastly different between usage modes.**
- Data suggests **distances greater than 500 feet are required to achieve wave characteristics similar to non-wakesurf boats**.

Introduction to Phase II: Propeller Wash (In Progress)

Propeller wash: high velocity jet of water produced by the boat engine, driveshaft and propeller.

Newton's 3rd Law of Motion – for every action there is an equal and opposite reaction.



Phase 2 – Objectives

1. Conduct a field study to measure/quantify characteristics of the propeller wash produced by recreational boats, including both wakesurf and non-wakesurf boats (field portion completed fall 2022)

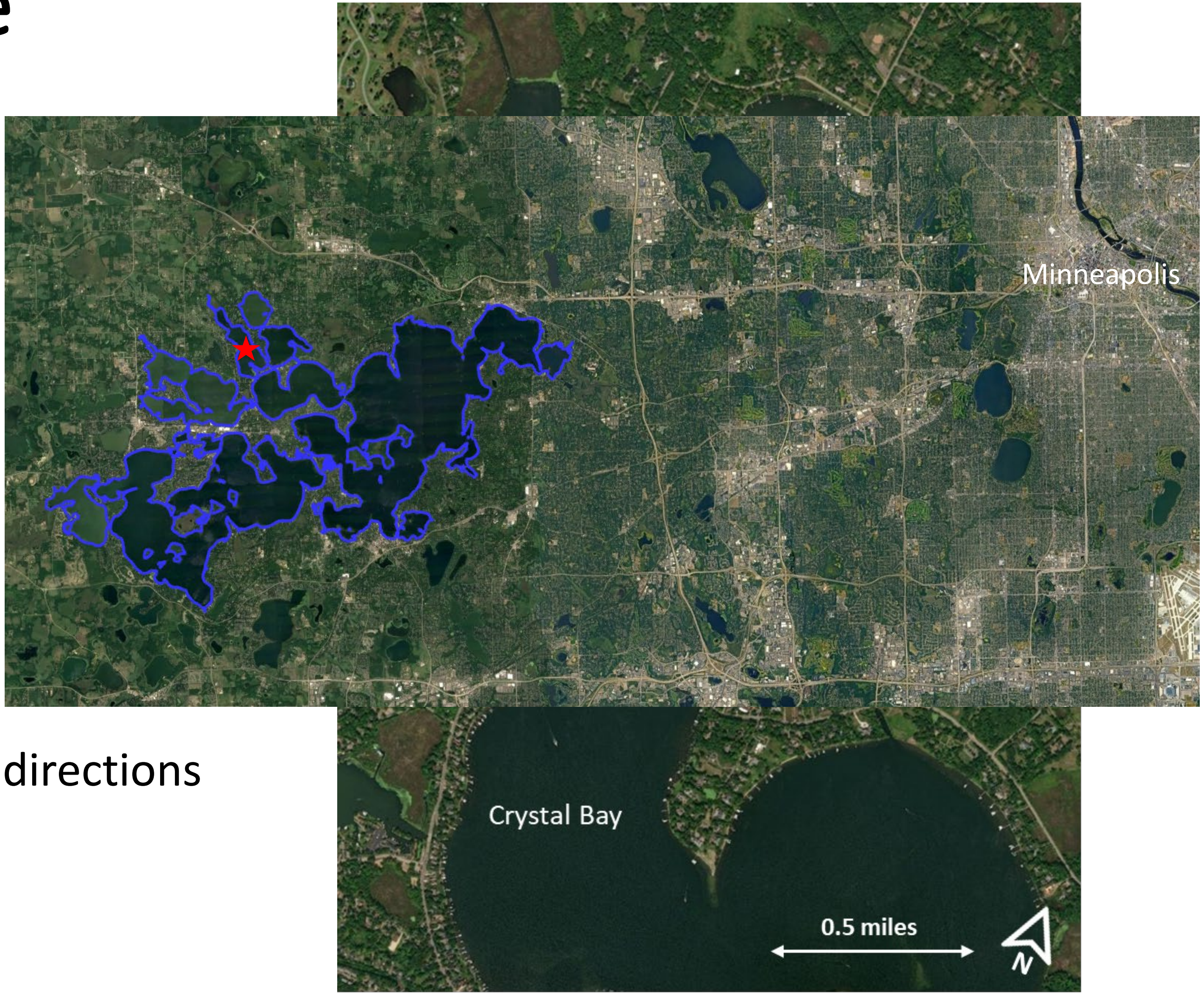
    - How deep does the propeller wash penetrate into the water column?
    - At what depth does propeller wash begin to interact with the lake bottom, and what happens when it does (e.g., changes in water quality)?
    - How long does it take for the turbulent wash to subside?
    - What are the magnitudes of velocities and turbulent fluctuations of the wash?
    - ***Again, move the discussion from anecdotal observations to actual numbers.***

2. Produce a report from the field study that is robust, externally reviewed, and accessible to all (underway)

Phase 2 – Field Study Site

(Andy)

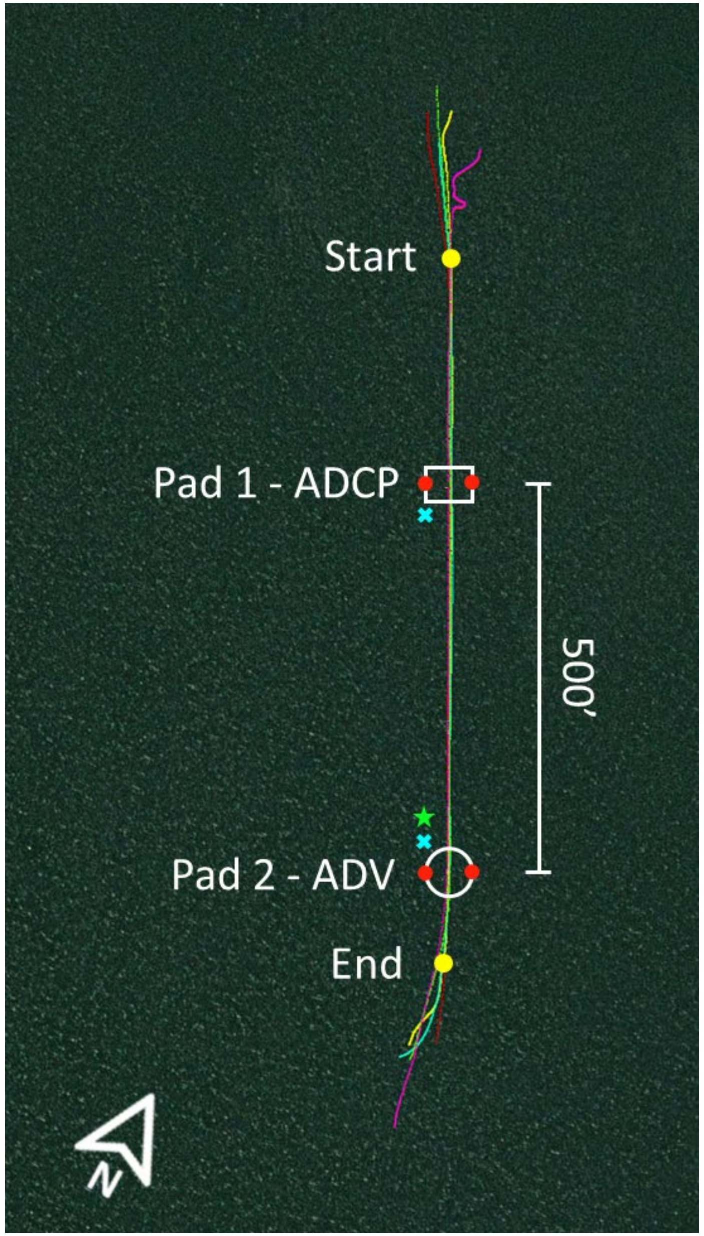
- Lake Minnetonka, Minnesota
- Popular Minnesota recreational lake
- Many connected bays totaling 14,200 acres and 130 miles of shoreline
- Test site (red box)
    - North Arm Bay – 307 acres
    - >500 ft from the shoreline in all directions
    - No aquatic vegetation



Phase 2 – Site Layout/ Data Collection

Multiple Sensor Deployments

- light/temperature chains (blue x)
- water quality Sonde – continuous turbidity (green star)
- Acoustic Doppler Current Profiler (white rectangle)
- Acoustic Doppler Velocimeter (white circle)

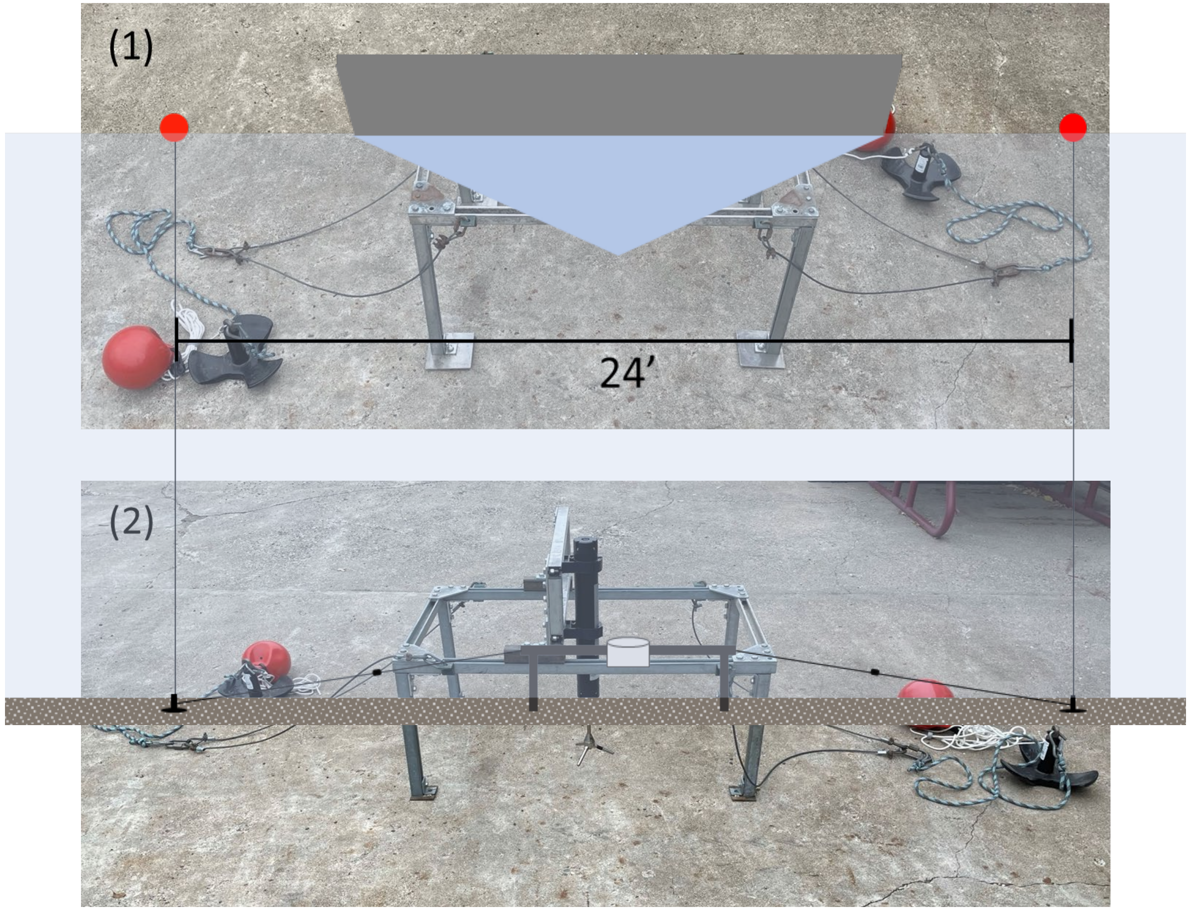


Phase 2 – Data Collection

Pad - rectangular structures made of steel channel strut

- Pad 1 - Acoustic Doppler Current Profiler (ADCP)
  - Deployed in 27 ft of water – up looking
  - Collected high-resolution data on **current velocities and turbulence** through the water column at 4 Hz

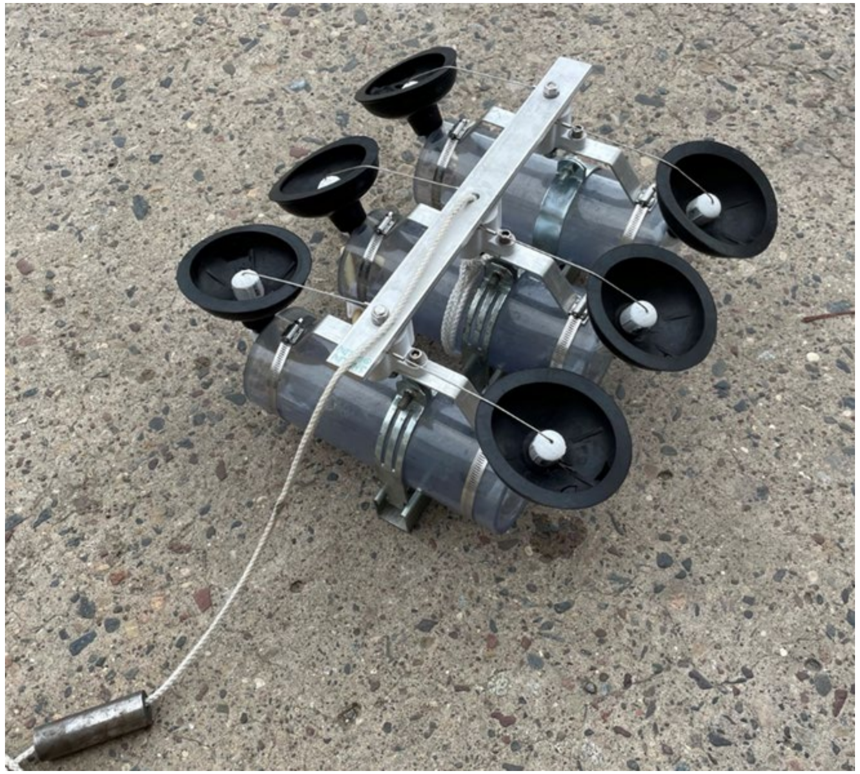
- Pad 2 - Acoustic Doppler Velocimeter (ADV)
  - Deployed in 16 ft of water – down looking
  - Collected a small volume of **3D velocity measurements** at the lake bed at 32 Hz



Phase 2 – Data Collection

Physical Water Sampling

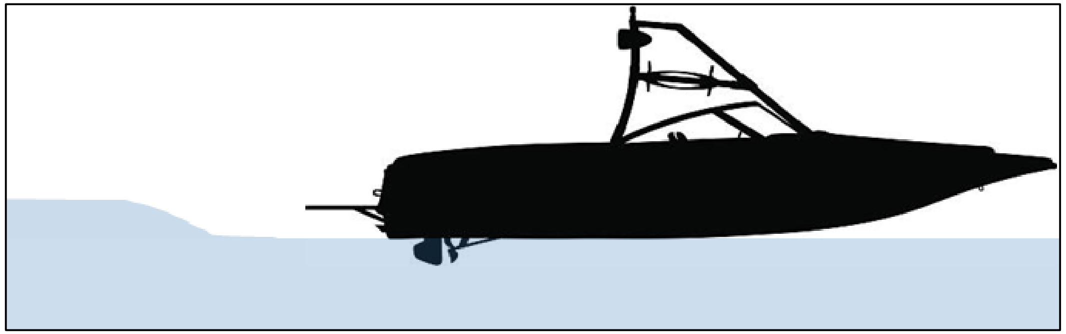
- Collected via SAFL built Van Dorn samplers
  - Instantaneously captures triplicate samples
  - At each pad, samples were collected from 2 depths (middle and near bottom)
  - For each condition, samples were captured just prior to the 1st pass, immediately after the 1st pass, and immediately after the 5th/last pass
  - Samples sent to UMN Research Analytic Lab for analysis of **total phosphorous (TP)** concentration, **total suspended solids (TSS)**, and **volatile suspended solids (VSS)**



Phase 2 – Test Boats

	Manufacturer	Model	Year	Drive	Max Horsepower	Length (ft)	Beam (ft)	Dry Weight (lbs)	Ballast (lbs)	Trim Plate/ Hydrofoil	Wake Shaper
Non-Wakesurf	Hurricane	SS 203	2016	Outboard (O)	175	20.3	8.5	3080	No	No	No
	Cobalt	R5	2021	Sterndrive (I/O)	300	25.7	8.5	4880	No	No	No
	Cruiser Yachts	34 GLS	2022	Twin Sterndrive (I/O)	760	35.8	11.7	14530	No	No	No
Wakesurf	Nautique	Super Air G23 Paragon	2022	V-Drive (I)	600	23.0	8.5	7200	2200	Yes	Yes
	Malibu	Wakesetter VLX	2019	V-Drive (I)	450	21.0	8.2	4200	3690	Yes	Yes

Phase 2 – Operational Conditions Tested



Condition 1 – on plane speeds

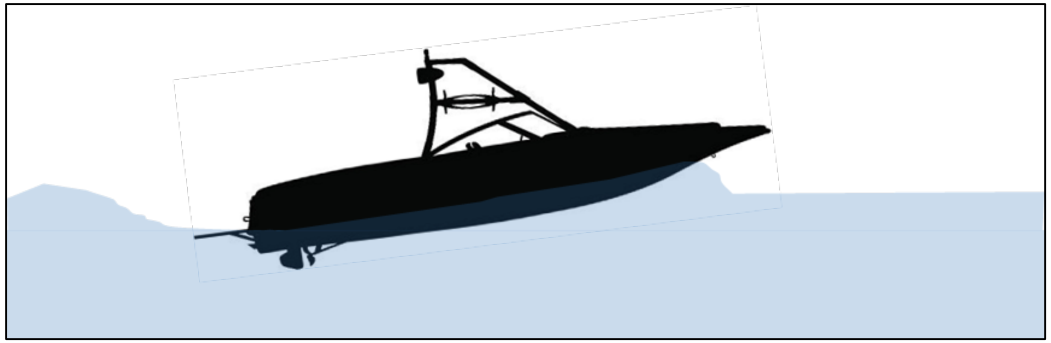
- represents tow sports like wakeboarding, tubing, and waterskiing, or fast cruising

Boat	Boat Speed (mph)	Engine Speed (RPM)	Trim Position (%)	Ballast (lbs)	Trim Plate/ Hydrofoil	Wake Shaper
Hurricane SS203	21.0	3250	100 (down)	N/A	N/A	N/A
Cobalt R5	21.0	3000	100 (down)	N/A	N/A	N/A
Cruiser Yachts GLS34	25.0	3650	100 (down)	N/A	N/A	N/A
Nautique G23 Paragon	21.0	2900	N/A	0	Stowed	Off
Malibu VLX Wakesetter	21.0	3800	N/A	0	Stowed	Off

Phase 2 – Operational Conditions Tested

Condition 2 – sub-plane speeds

- leisurely cruise for non-wakesurf boats
- surfing for wakesuf boats

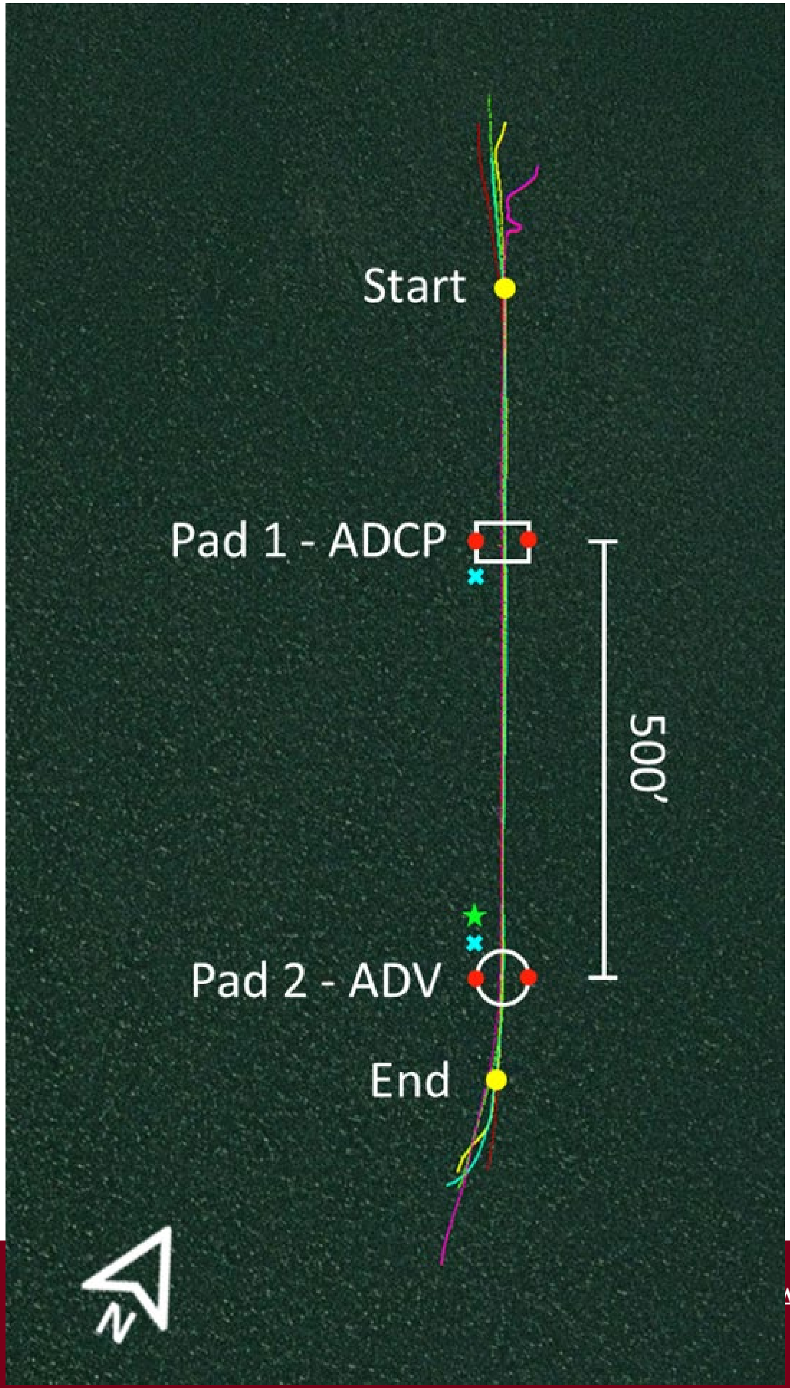


Boat	Boat Speed (mph)	Engine Speed (RPM)	Trim Position (%)	Ballast (lbs)	Trim Plate/ Hydrofoil	Wake Shaper
Hurricane SS203	9.0	2400	100 (down)	N/A	N/A	N/A
Cobalt R5	9.0	2000	100 (down)	N/A	N/A	N/A
Cruiser Yachts GLS34	9.0	1650	100 (down)	N/A	N/A	N/A
Nautique G23 Paragon	11.6	2800	N/A	2200	Stowed	Port - Postion #5
Malibu VLX Wakesetter	11.6	4400	N/A	3690	Down – Setting #2	Port - Deployed

Phase 2 – Generating Prop Wash

For the 2 conditions tested

- Each boat was tested in a single day when winds <10 mph
- Boats made 5 passes in a straight line over the pads (colored lines are the real-time positional data plotted)
- 15-minute waiting period transpired between each pass
- 1-hour waiting period between the 2 conditions tested



(Jeff)

Phase 2 – Propeller Wash Data

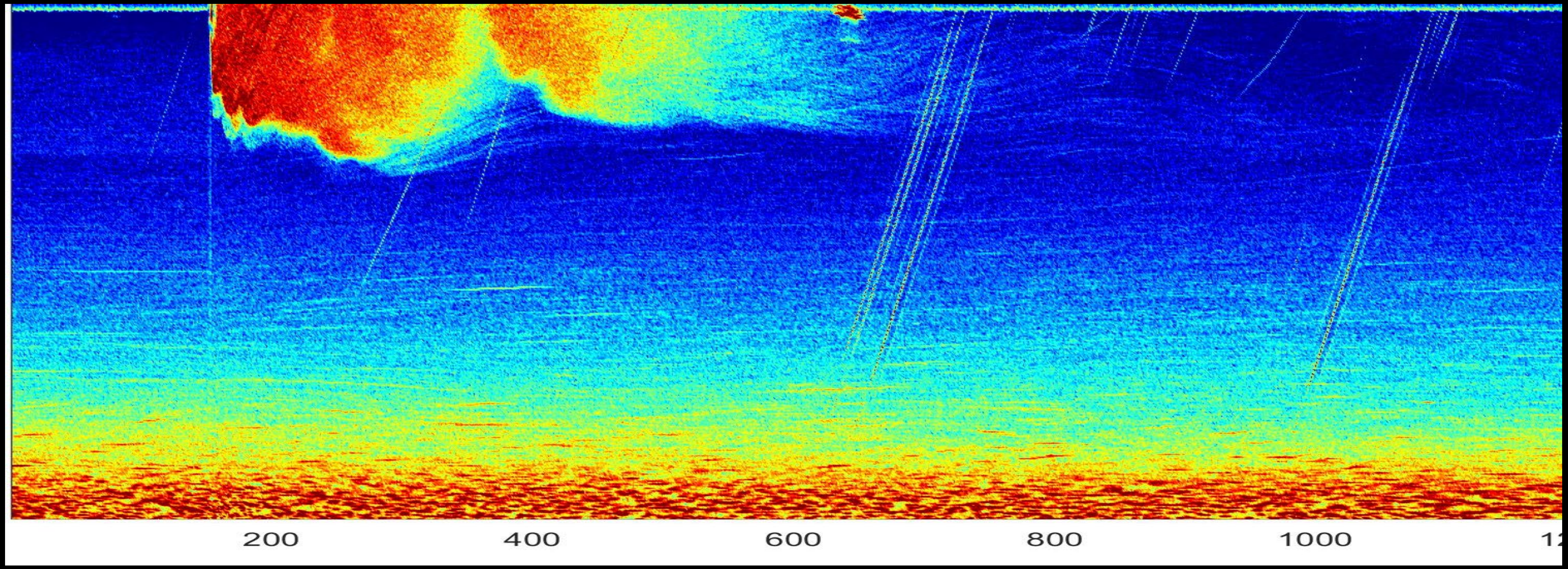
Echodata – sound reflection from the prop wash zone

- Detect strong signal from entrained air/exhaust. Depth of bubble penetration.
- Bubbles are sustained for minutes within the water column

Water Surface

Depth

Lake Bottom



TIME

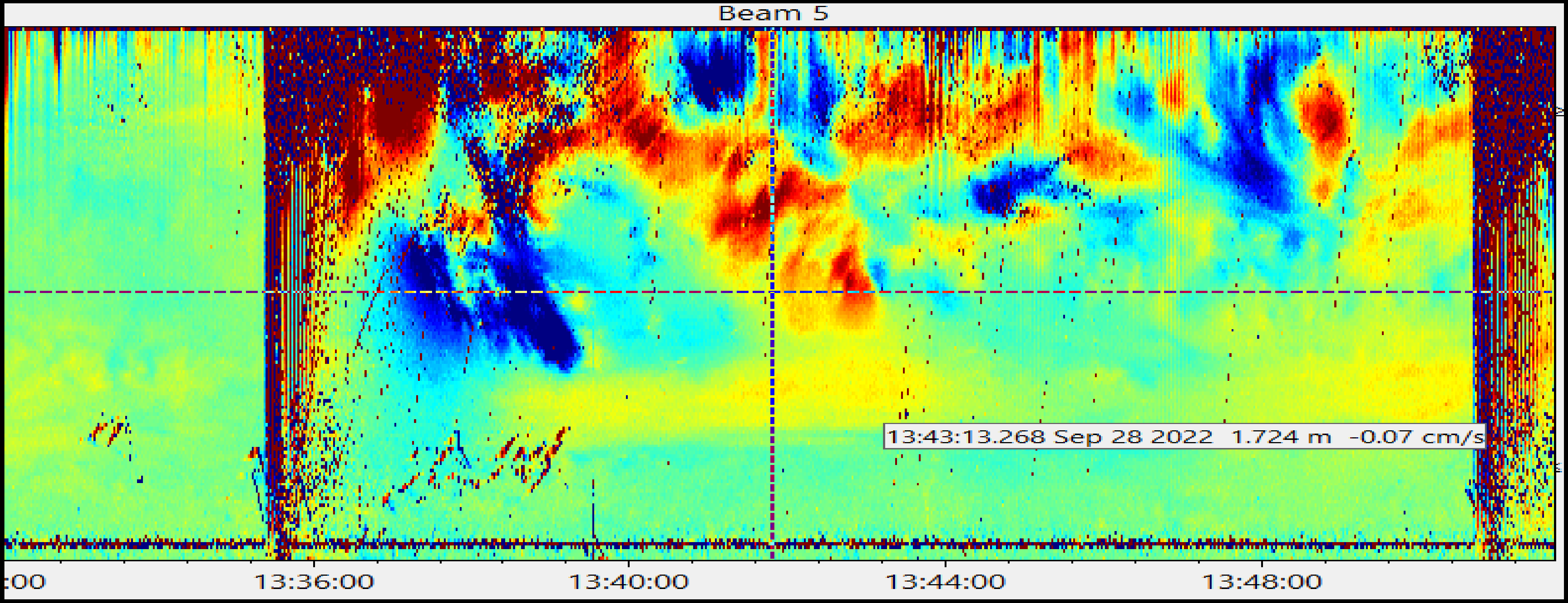
Phase 2 – Propeller Wash Data

Vertical Velocity Fluctuations - evidence of large scale fluctuations (minutes)

Water Surface

Depth

Lake Bottom

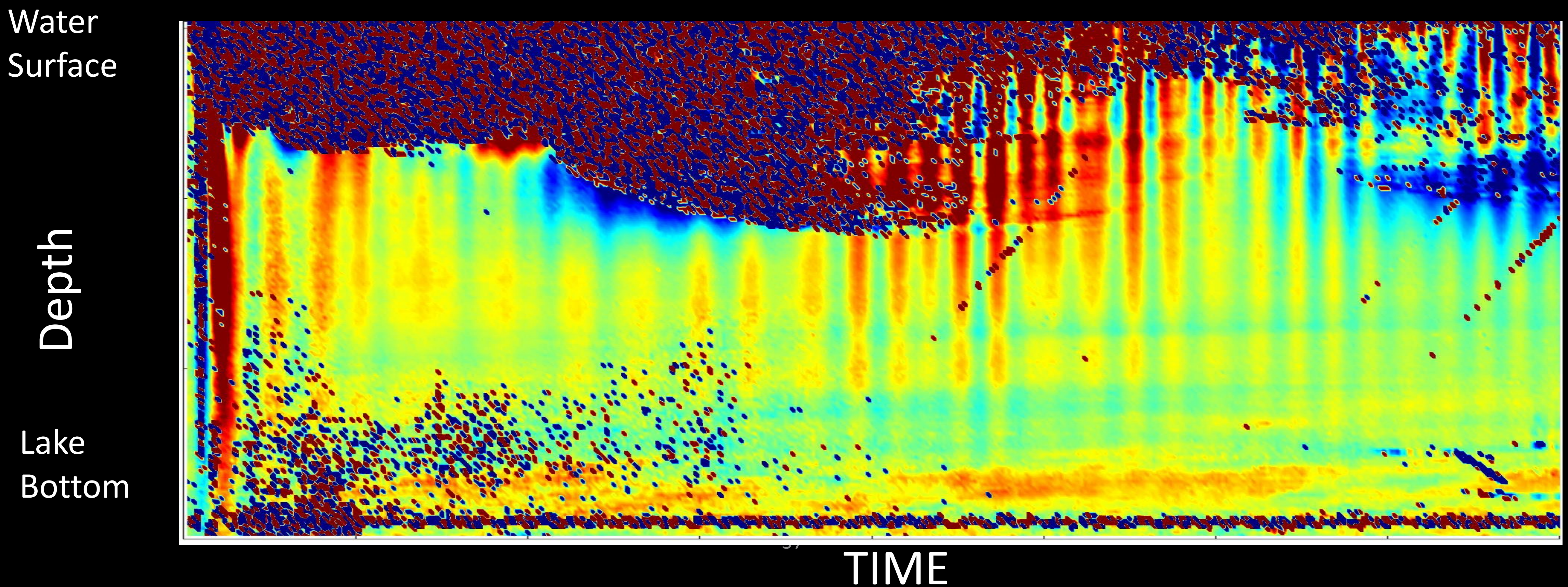


TIME

Phase 2 – Propeller Wash Data

Vertical Velocity Fluctuations - Evidence of Transverse Waves

- Propeller wash measured within lake. Duration and depth of penetration analysis underway.
- Oscillations in the water column were measured. Period of 3-4 seconds. Same as observed from surface and other velocity sensor. (TRANSVERSE WAVES).



Phase 2 – Propeller Wash - Next Steps and Outcomes

Next Steps:

- Finish data processing of all data
- Finish drafting report and submit for peer review
- Finalize document and publish

Anticipated Outcomes:

- Characterization of propeller wash – depth of penetration, duration, structure.
- Document any changes in water quality from prop wash at the test site (16-ft and 27-ft)
- Insight into safe operational depth for recreational boat including boats used for wakesurfing.

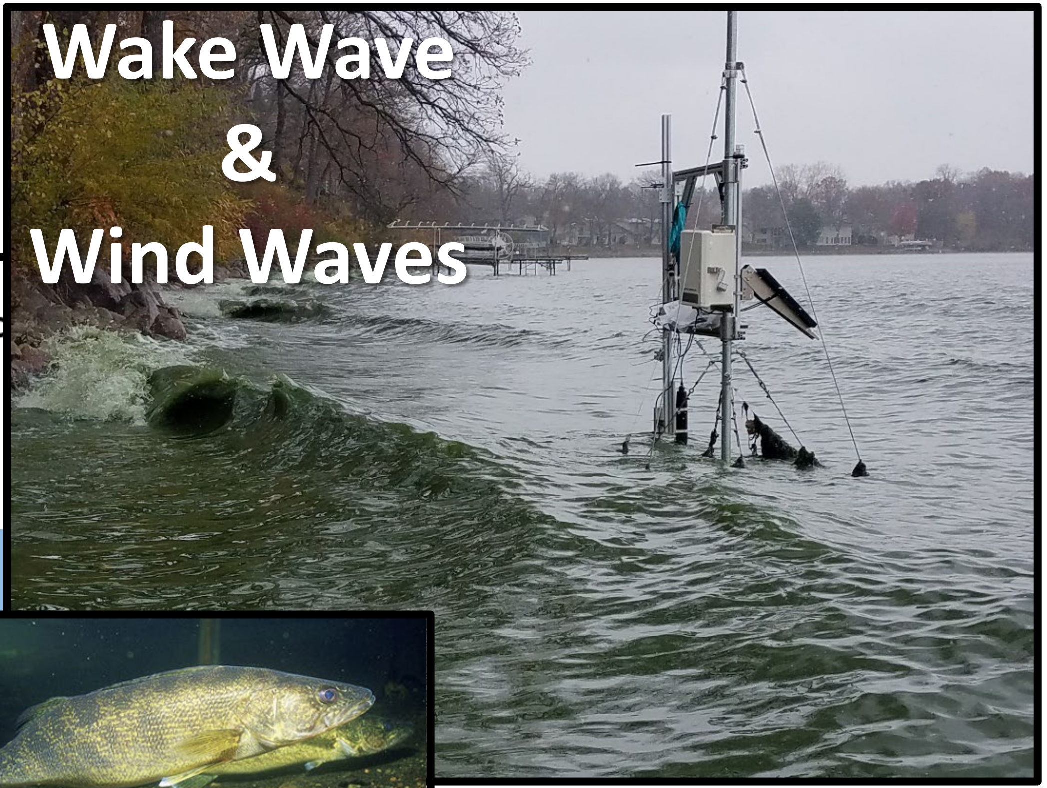
Phase 2 – Funding

- Project Funding is through a crowdfunding campaign.
- We are grateful for the support of hundreds of donors to the project
- Funding raised to date: $135,000

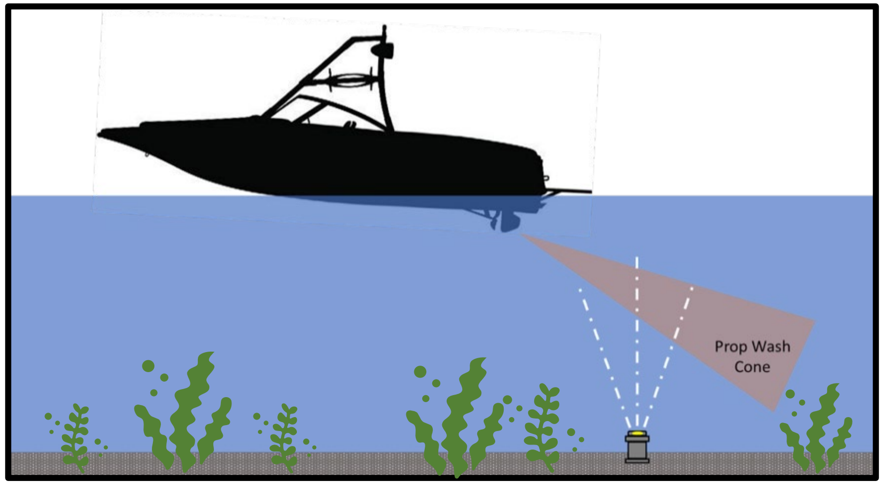
- **More information and to contribute to the project:**

z.umn.edu/SAFLHealthyWaters

Phase 3 – Coming Soon!



Phase 3 – Overview



- Three Year Project – July 2023 – June 2026
- $415,000 - State of Minnesota (LCCMR)
- Year 1 – Expanding on Phase 2 propeller wash
  - Looking at different water depths
  - Sediment compositions
  - Aquatic vegetation
- Years 2 & 3 – Examine environmental impacts of both wind waves and boat wake waves
  - bottoms sediments, aquatic vegetation, water quality, and shorelines.
  - Metro and northern MN lakes (targeting variable environmental attributes of lakes)

Thank You!

Jeff Marr
marrx003@umn.edu
612.624.4427

Andy Riesgraf
riesg029@umn.edu

z.umn.edu/SAFLHealthyWaters