Wave Damage – Part 2
Natural Wind vs Wake-Sport Boats

15 Mar 2025

Prepared by Grant Miller, President, Sacheen Lake Association

How to Participate in the Zoom Meeting

- I will be sharing my screen with you to display the presentation
- Be sure that the presentation is large on your screen
- Please put your mic on mute for the meeting
  - Your choice to use your camera or not
- During the presentation I will be focusing on the slides and cannot see raised hands nor will I be able to concentrate on chat notes
- If you want to talk, unmute your mic and interrupt at an appropriate time (“excuse me, Grant, I have a comment/question”)
  - Be sure I have your attention before you speak so we don’t talk over each other
- After our joint discussion, mute your mic again
- For ease of execution, please do not interject into an ongoing discussion

Thank you!

Why is the SLA Involved?

This is an exact copy of slide 5 from the Oct 2024 presentation, except the highlight box

- SLA By-laws:
  - SLA is a benevolent, non-profit business registered with the WA Secretary of State
  - We are required to follow our By-laws
- Our By-laws Mission Statement:
  - ***The purpose of the Sacheen Lake Association is to advocate for the conservation as well as safe and environmentally sustainable use of Sacheen Lake and surrounding ecosystems, while promoting a strong sense of rural community.***
- Conservation, environmentally sustainable use:
  - Shorelines are being damaged by large wakes
  - Studies show that bottom sediment is disturbed by downward pointed props causing harmful release of phosphorus which causes algae growth which cuts off oxygen and sun
- Safe use of Sacheen:
  - Large wakes create an unsafe environment to property and people as is demonstrated by community responses to our survey and damage photos received this year
- Strong sense of rural community:
  - Our rural community is suffering the financial, time, and effort impacts of repairing damage caused by artificially created large wake rather than enjoying Sacheen Lake

This slide is similar to slide 3 of the Oct 2024 presentation. It was created after careful consideration of some community members' comments

Contrary to Some People's Thoughts …

- The SLA has received emails from community members that believe that I and/or the SLA Board have an agenda. I think they believe that agenda is to get wake boat sports banned on the lake
- The SLA Board has no intention of making any decisions for the community
- The SLA Board is trying to help the community get informed, and as needed organized, so they can make a decision on what to do, if anything
  - The SLA Board created a laundry list of what-to-do options that are contained in the Oct 2024 presentation
  - That laundry list was briefly reviewed and the audience at the time recommended doing only education
- ***Today's presentation is more educational information created as a direct result of comments from the Oct 2024 meeting***

The Plan

This slide was not in your version of the presentation. It was created after careful consideration of some community members' comments

- One of the SLA By-laws Goals is:
  - "Promote education, involvement, and SLA membership of and by the local rural community for enduring SLA Mission Statement advocacy and a strong sense of community."
- The following is what the SLA Board has agreed to do:
  - Educate the community on the technical research findings regarding wake-sport boat waves. Part 1 is completed; Part 2, the last part, is today
  - Execute an anonymous survey to allow the community to provide input on what has happened to their property, what they believe is the cause of the damage, and what they want to do about it.
    - A website link to the survey will be released soon via email and postcards sent via USPS
  - Inform the community as to the results of the survey at the SLA Annual Meeting on 14 June 2025
  - Should the community want to do something after the survey*, the SLA Board has agreed to help facilitate the community

* The SLA Board will continue to fulfill our By-laws documented goal to educate the community on lake issues regardless of the outcome of this process

Purpose and How Accomplished

- To address comments made by the audience at the October 2024 SLA Board Wake Damage presentation regarding wind damage as compared to wake-sport boat wave damage
- Specifically, to compare the energy imparted by wake-sport boats as compared to wind in a real-world scenario on Sacheen Lake
- A 2015 study on wake-sport boat wave energy that analyzes wind wave energy will be explained and then used as the basis for analysis relating to Sacheen Lake

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During the Oct 2024 Wave Damage presentation by the SLA Board, an audience member commented that wind damage could be causing as much damage as wake-sport boats.

One of the audience members provided, upon request, a copy of a study performed in 2015 that not only measured and compared cruising ("travel" in one reference), wakeboarding, and wake surfing wave energy, but also provided an analysis of the energy imparted by the wind to a shoreline.

This presentation summarizes the study and performs an assessment of the wake-sport boat and wind wave analyses as they apply to Sacheen Lake.

Warning?

- This presentation contains a lot of technical data
- There is no expectation that the audience understands the math behind the data!!!
- Bottom line is presented up front for those that don't care about the "how to reach the conclusions" portion of the presentation
  - But I encourage you to stay anyway to hear any discussions that may occur
- Purpose of the technical details and presentation approach:
  - Illustrate the validity of the study by comparison to the two other studies the SLA presented in October 2024
  - To accept that the analysis approach is equally applied to measured boat-wave data and analytical wind data
  - To illustrate that the data and curves presented on wave and wind energy can be used for real-world conditions on Sacheen Lake
- Feel free to ask questions!

A lot of technical data is presented. Nobody has to understand the math behind the analysis. But what I hope to get across is that the study:

- Uses an analysis approach to have measured wave height data translated into a single energy value
- Uses mathematical equations/tables and wave modeling to perform the same calculation of wind wave energy from wind wave height modeling
- Compares the energies of a wake-sport boat's waves to the wind's created waves.

I am going to use the same process to determine the boat and wind energies for real-world conditions on Sacheen Lake.

To reiterate, what is important in the illustration of the process is the understanding that I use the same processes as the study to illustrate the comparative nature of wake-sport boat wave and wind wave energies on Sacheen Lake.

Topics

- Bottom Line Up Front
- Summary of Oct 2024 Wave Damage Presentation
- Wake-sport Boat and Wind Study
  - Study Setup and Measured Data
  - Study Analysis Approach and Findings
  - Study Analysis on Wind Waves
  - Assessment of the Conclusions of the Study
- Application of the Analysis and Conclusions for Sacheen Lake
- Wrap Up
- Addendum / Backup Slides

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This presentation has three main parts:

- A summary of some of the information presented in October 2024 for those that were not present and as a refresher to others

- A summary of the boat and wind wave study referenced herein as well as an attempt to illustrate the process of going from wave height to an energy value

- An application of the study's process to turn wave height to energy for Sacheen Lake using a real-world scenario.

It also has a summary explaining how the study does or does not apply to Sacheen Lake based on the third item above.

Bottom Line Up Front

- New study's measured wake-sport boat wave data is similar to the two studies presented in October 2024
  - Wake-sport boats in wakeboard and surf mode create much more energy than recreational boats or wake-sport boats in cruise mode (no ballast)
  - Per the study, an additional 220 ft (shallow water) to 320 ft (deep water) of distance from shore is needed for surf mode waves to dissipate to that of cruise mode at 110 ft from shore. These numbers are from curves of smoothed data points; the data points themselves for deep water, specifically, show that further distances are needed
- Conclusions regarding wind vs wake-sport boats in the study are misleading; real-world conditions, especially for smaller lakes, are **not** taken into account
  - Wind strength and fetch of the study are **not** comparable to Sacheen Lake
  - The study uses a smoothing technique in comparing imparted boat and wind wave energies that reduces the real-world higher, short-term power impact of boat waves
  - Breaking / tensile strength of docks, etc., is **not** taken into account in how they compare waves from wind vs waves from boats
- An analysis of Sacheen Lake's real-world conditions illustrates that wind waves are much less likely to cause damage to physical property
  - Shoreline impacts fall into a different category of how wind vs boat waves affect the shoreline; gradual wear and tear of shoreline may / may not fall into a breaking / tensile strength category
  - It is common sense (and my experience) that larger waves can pick up debris on the lake's bottom and use this material as an additional wear and tear force that small wind waves cannot

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This slide provides the bottom-line conclusions of understanding and using the measured data and analysis approach of the study to understand how wind and wake-sport boats on Sacheen Lake compare relative to the damage experienced on the lake. The bullets on this slide are self explanatory. Details of how these conclusions are reached are provided through the information and analysis presented in the slides.

In difference words than this slide, the conclusions are: (1) the measured wind data and wind analysis of the new study illustrate that wake-sport boats create and impart higher instantaneous energy than wind; (2) the new study uses a smoothing concept of the boat wave energy that in the real-world ignores breaking strengths of physical objects. Breaking strength is NOT addressed in this study; that is, the study does not account for what is happening to docks, retaining walls, etc., as witnessed on Sacheen Lake. The study compares total long-term energy imparted at a shoreline and ignores the real-world nature of a large force over a short time vs a smaller force over an extended duration of time. For example, a person standing on their dock can be knocked off their feet by one large wave and yet the same person could be on their dock and never experience stability problems during small wave conditions.

Summary of Oct 2024 Wave Damage Presentation

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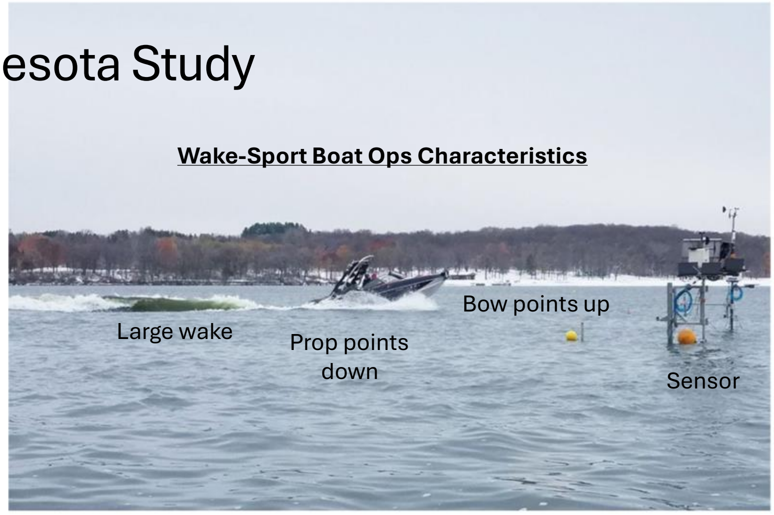
Data from two studies was presented in October 2024. The data will be summarized herein without an explanation of how they translated wave heights to energy values.

References for the studies are included herein.

I have included a new diagram from one of the studies that was not presented in October 2024. This diagram is similar to one in the new study that I will be summarizing. Seeing a plot of wave energy vs distance from a sensor is a theme in the new study and this new chart from the prior references will help familiarize the audience with the concept of wave energy and illustrate that the studies have fundamentally the same results. Similar results implies the data is more believable.

U. of Minnesota Study

- Photo illustrates measurement equipment of the study
- Caption discusses what they did
  - Recreation boats
  - Wake-sport boats
- https://cse.umn.edu/college/news/umn-researchers-study-waves-created-recreational-boats
- Study results: Need an additional ~500 ft for the wake-sport boat wake to dissipate to the level of the waves of the recreational boat in the test



Researchers from the University of Minnesota St. Anthony Falls Laboratory carefully measured the maximum height, total energy, and maximum power of the waves from wakes produced by four recreational boats—two wakesurf boats and two more typical recreational boats. They also measured how the wake waves changed as they moved away from the boats and toward shore. Photo credit: Healthy Waters Initiative, University of Minnesota

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This slide is from the October 2024 presentation and illustrates the physical scenario of the wake-sport boats' and recreational boats' measurements.

Recall that they measured 4 different boats – details are provided on the following slide.

Recall that WA State has a law that boats should not make wake within 100' of docks, people, shorelines, etc.

The study's conclusion is that another ~ 500' is required for the wake-sport boat in surf mode waves to dissipate to that of a similarly sized recreational boat.

U of M: Wave Packet Energy

(Chart Not Included in Oct 2024 Presentation)

- The mast and pad data points are the sensors
- Distances are distance from the sensors
- Boats were:
  - 2004 Larson LXI 210 (recreation only)
  - 2004 Malibu Response LX (recreation with hydrofoil and aftermarket wave shaper)
  - Malibu VLX and MXZ (ballast, hydrofoil and wave shaper)
- At 100’, the wake-sport boat energy is 3.5 times more than the recreational boats
- At 100m (328ft), the wakesurf boat energy (~2670 J/m) is ~ 2x energy of the recreational boats (1330 J/m)
- At ~ 425 ft, the wakesurf boat energy is equal to the energy of the recreational boat at 100 ft (additional 325 ft for energy dissipation)
  - Note: The prior 500 ft was from text of the report; which appears different from this generalized plot of the field data. But the prior statement <u>does</u> match the data points displayed!

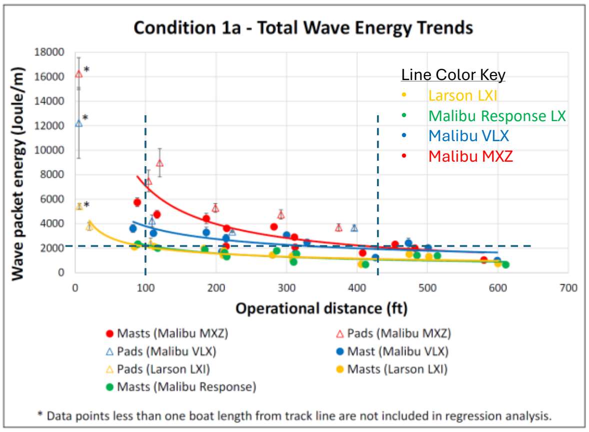

Figure 18. Condition 1a trendlines for the four test boats showing total wave energy over operational distance.

The dashed lines above illustrate where the Malibu MXZ energy equals the Larson LXI energy at 100 ft

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This chart helps illustrate how they reached their conclusions.

Note the 4 boats used and their wave generating capabilities; there are two recreation boats (one with an after-market wave shaper) and two factory-built wake-sport boats (but one with an after-market wave shaper).

They turned the measured data into a measure of the energy from the waves and plotted the boats’ energies as distances from the sensors.

The recreational boats impart approximately 2000 Joule/m at 100’.

The wake-sport boat’s energy in surf mode is not reduced to the same ~ 2000 J/m until ~ 425’.

The 325’ described here is less that the 500’ previously briefed because I used their model of the wave energy illustrated in Figure 18 and not the actual data or number reported in the Executive Summary of the report.

Canadian Study: Turbulent Kinetic Energy (TKE) Data

- “The turbulent kinetic energy (TKE "turbulent kinetic energy") contained in a wave (created by a boat or otherwise) can be calculated by knowing the speed dimension as it passes, according to the equation: $TKE = \frac{1}{2}\left(\overline{x^2} + \overline{y^2} + \overline{z^2}\right)$,

  where z, y and z are the speeds of the micro-turbulence measured in three dimensions (Wist 2004).”

- **At 100m (328 ft), the TKE of wake-sport boat in wakesurf mode ~= 2 x TKE of the same wake-sport boat in travel mode (empty ballast)**

- **The U of M study at 100m illustrates the same 2X as this study, therefore, it is quite likely extrapolating this data to 100ft produces the same 3.5 factor as the U of M study**

- **Reference:** Project Evaluation of the Impact of Waves Created by Wake Boats on the Shores of the Lakes Memphremagog and Lovering, by Sara Mercier-Blais and Yves Prairie June 2014

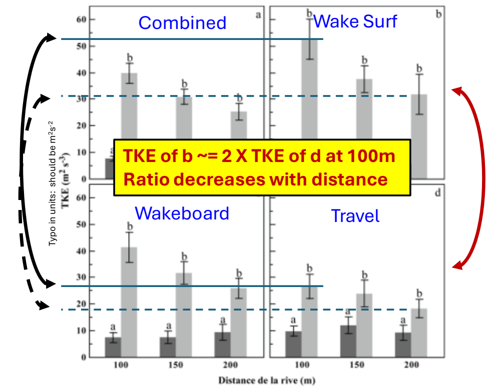

Figure 5. Energy (TKE) present in normal waves (dark gray) and that present in the waves following the passage of a wake boat 100, 150 and 200m from the shore, and the type of transition from boat (a: for all types of passage; b: 10 miles/h; c: 20 miles/h; d: 30miles/h).

a. Normal Conditions: No passing boat (dark bars)
b. Wake Surf: Ballast on one side only filled
c. Wakeboard: Both ballast tanks filled
d. Travel: Empty ballast tanks

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The 2nd study the SLA Board presented was from a Canadian team. This study used one wave-sport boat in 3 modes: travel (no ballast), wakeboard (full ballast), surf mode (one-sided ballast). They also converted measured wave height data to energy in the form of Turbulent Kinetic Energy (TKE). This study’s closest distance to the sensor was 100 m (328 ft).

At 100 m, the wake-sport boat in surf mode creates about 2 times as much wave energy as the same boat in travel mode at 100 m. (53 m^2/s^2 surf mode vs 27 m^2/s^2 travel mode)

If we go back to the U of M study on the prior slide and compare the travel mode and surf modes at ~ 328 ft, we find the same 2 times comparison.

It can also be seen that surf mode waves require more than 328’ to reduce to the travel mode wave energy at 328’ from shore. That is, doubling the distance from the shore for the surf mode is still not enough additional distance to dissipate to the same energy in travel mode.

Conclusion: U of M and Canadian studies illustrate the same data implying that the data and analysis is quite likely valid AND that wake-sport boat wave energy takes a fair distance more to dissipate to the same energy of waves made by the same boat not using ballast or waves made by a standard recreational boat.

Canadian Study: Shoreline Slope Impact of Wave Energy

- Two shoreline slope values tested
- Slope did not have a significant impact on TKE of wake-sport boat wake (TKE delta = 7 m^2/s^2 or 26%)
  - Steeper slope wave had larger TKE
- **TKE wake boat =**
  - **4.4 x TKE wind for steep shore**
  - **3.9 X TKE wind for not steep shore (“coastal slope”)**
- Ref: same as prior slide
  - Report did not distinguish the operational mode of the wake boat (travel, wakeboard, surfing) for this chart

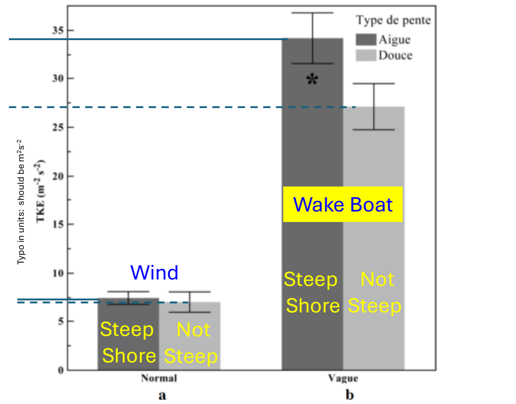
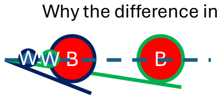


Figure 11. Energy (TKE) that reached the shore between sites with sloping coastline of acute (dark gray), coastal slope (pale gray), for normal waves (a) and that from a wake boat (b).

Note: The asterisk (*) represents a significant increase ($p < 0.05$).

Why the difference in gaps for the boat vs the wind?



Boat (B) and Wind (W) waves encountering the bottom as depicted in the bar chart of Figure 11.; for the boat, more energy dissipation occurs before hitting the shore in shallow vs deep as compared to shallow vs deep for the smaller wind waves.

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This study also presented an energy comparison of the wake-sport boats to **measured** wind data.

Furthermore, they analyzed the impact of the steepness of the two measurement sites' shorelines to the boat wave energy dissipation. The steep shore allowed 26% more energy to arrive at the shoreline over the coastal slope (not steep).

The wind comparison illustrates that the wind at this lake during their measurements was significantly less impactful than the wake-sport boat by a factor of nearly 4 to greater than 4 based on the two shoreline slopes.

They conclude that the shoreline's steepness was not a large factor on dissipation of wave energy, especially for smaller waves (the wind in this case). Logically, this make sense for the wind waves because the bottom doesn't begin to impact the waves until their depth is about ½ their height, the wind waves were much smaller than the boat waves, and the bottom's influence will be much closer to the shoreline than the boat's waves. The large boat waves would be affected further out from the shoreline than the wind waves since the much larger boat wave height becomes large sooner for shallow shorelines vs steep shorelines. See the bottom left diagram.

Canadian Study: Summary of Data Analysis

- Wake-sport boats in wakeboard and surf mode create significantly more turbulent kinetic energy (TKE) in their wake than the same boat without any ballast loading ("travel" mode)
  - At 100m (328 ft): TKEsurf = 2 x TKEtravel (same results as U of M)
  - At 200m (656 ft): TKEsurf = 1.7 x TKEtravel
- Waves from the wake-sport boat had significantly more energy that that of normal (wind*) waves
  - TKEwake-boat = 4.4 x TKEwind for steep (acute) shoreline
  - TKEwake-boat = 3.9 x TKEwind for not steep (coastal) shoreline

- **Reference:** Project Evaluation of the Impact of Waves Created by Wake Boats on the Shores of the Lakes Memphremagog and Lovering, by Sara Mercier-Blais and Yves Prairie June 2014

* The study did not provide details on the wind speed. Longest fetch is ~ 650 ft on Lake Memphremagog and < 2 mi on Lake Lovering; it is unclear how the sensors and prevailing winds align with these fetches. This wind data may not be comparable to the wind analysis of the boat and wind comparison study discussed later herein (i.e., not persistent enough and not a long enough fetch)

This slide just summarizes the results of the prior slides on one slide.

1. Wake-sport boats in an artificial large wave making mode have significantly more energy that those of the same boat not making artificial waves.
2. The wind wave energy is small in comparison to the wake-sport boat.

The conditions that made the wind during this study are not defined well enough to compare them to well known mathematical equations used for steady-state winds.

2023 Annual Meeting - Shoreline Erosion Survey Response

- As of 5/29/23, 19 community members responded to the survey, one member responded to the presence of the survey
- Of the 19 responses
  - 10 responded with damage to their property (one or more of): dock, pilings, anchor chains, broken ropes, landings, dock sections came apart, tie downs ripped from the dock, retaining /sea walls, broken items on the dock, reduced/eliminated ability to moor boat to dock, lost trees on shoreline
    - One person replied a cost of $26,000 for dock and anchor replacement and a rock breakwater
    - Many did repairs on their own
    - Some have repairs to do still with costs expected to be $20,000 or more
  - 11 responded with shoreline erosion. One noted trees lost due to erosion
    - One person reported 6' of loss and a cost of $18,000 to stabilize the shoreline (a neighbor paid the same for repairs)
  - 2 responded with people being knocked off their feet on their dock (multiple times), being thrown into the water. No injuries reported!
    - Almost falling (1)
  - 4 responded with no damage or injury
    - 1 of these indicated they do not tie their boats to the dock anymore when wake boats are running for fear of damage
  - Multiple people commented that water activities are curtailed by wake boat activity due to safety concerns (e.g., kids swimming/floating next to a dock)
    - Fear of injury to their kids/grandkids, or kids afraid to be on the dock when wake boats are present

In 2022 and 2023, the SLA Board received community complaints about large waves on the lake causing damage and being dangerous.

The SLA Board sent a survey to the community via email and summarized and presented the results at the 2023 June SLA Annual Meeting.

These pages summarize the results for property damage and personal injury survey.

(The sub-bullets under "Of the 19 responses" are self explanatory. – No speaker note are provided.)

2023 Annual Meeting - Shoreline Erosion Survey Results

- Survey results:
  - 1. Property damage or personal injury: See prior slide
  - 2. Property direction: Damage occurred in all shoreline facing directions and throughout most of the lake. Implies that damage is not caused by natural prevailing winds
  - 3. Area: Damage is greatest on the 35 mph sections of the lake. One reported damage in the Narrows (no wake zone)
  - 4. Cause: wake/surf boat wake is sited as the primary cause (14 of 19 inputs)
  - 5. Repairs: Dock repairs/replaced, replaced anchor chain/rope, breakwater built, beefed up dock landing, replaced dock to landing attachment, repositioned dock anchor, replaced anchor chain. Still need to repair: 3
  - 6. Cost ranges from hundreds to multiple 10's of thousands of dollars. One cited $450 for POC permit. Total costs of all repairs reported & projected repairs is about $83K and does not include 2 locations that have not yet done repair work
  - 7. Preemptive steps: don't use their dock or don't use it or the shoreline when large waves present, placed or already have rocks or logs as shoreline breaks. About 1/2 took no action; at least 2 investigating installing retaining walls

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Seven questions were asked in the survey and this slide summarizes the responses.

Ultimately, 14 out of 19 respondents indicated they thought the wave problems were a result of wake-sport boats.

Damages have been experienced (review bullet 5).

The actual repair costs to date (in 2023) have been over $83K.

People change their activities on the lake when wake-sport boats are present and have taken preemptive steps to reduce the impact of the large waves to their property.

2024 Damage Reports

- Residents have independently been sending emails of damage
  - Broken docks
  - Moved docks
  - Washed out shorelines
  - Damaged retaining walls
- Photos available in Addendum

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The SLA Board continued to receive complaints in 2024.

This chart summarizes the types of complaints.

As you can see, the types of damage vary and may be extensive.

Photos are illustrated in the back of the presentation. I don't plan to illustrate them, but they include crumpled dock ramps, torn apart docks, retaining wall damage, landing damage, and shoreline erosion.

At the October 2024 meeting, audience members argued that the wind waves and/or property age or materials could be the culprit of the damages. No analysis of breaking or tensile strength has been performed on any of the reported items. However, it is logical that small winds likely cannot create energy equal to that needed to cause breakage of materials. Persistent smaller waves could cause wear and tear on ropes, cause bolts to rub and possibly break over a long period of time, but are not likely to crumple a dock ramp, move docks by 10 ft in a weekend, or other cause some of the other resident-reported issues. Shoreline erosion is a different, long-term exposure issue.

Wake-sport Boat and Wind Study

Ref:

Characterization of Wake-Sport Wakes and their Potential Impact on Shorelines,
WATER SPORTS INDUSTRY ASSOCIATION (WSIA), November 2015 (Draft Rev 2 (or 11???))

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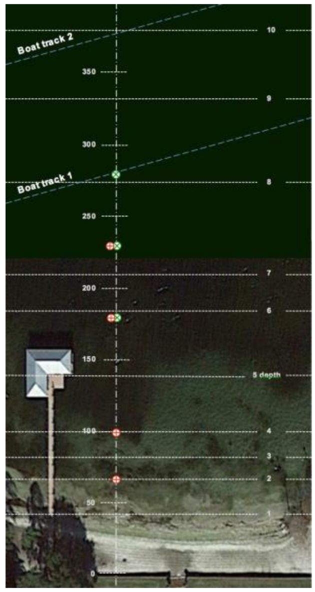
The remainder of the presentation deals with assessing a study that was similar to the prior two just illustrated and extends their findings to an analysis of possible impacts by wind waves.

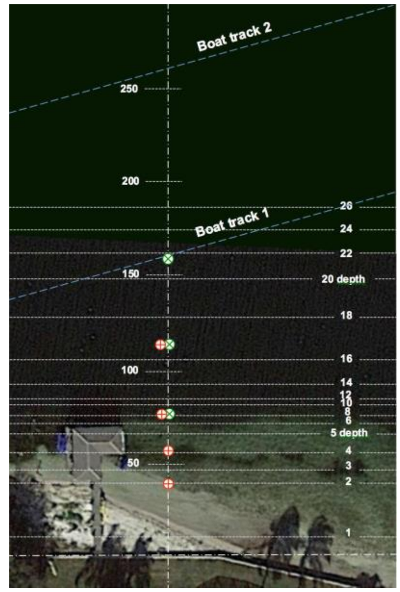
The study report was prepared for the Water Sports Industry Association (WSIA).

WSIA Study Setup

- Two test setups: shallow water, deep water
- One boat in 3 modes of ops:
  - Cruising: No ballast added
  - Wakeboard: Max ballast
  - Wakesurf: Additional ballast
- Five sensor locations each
- Two sensor types
  - Correlation / calibration of least sensitive (pressure sensor) to most sensitive (capacitance wave probe) due to overlap at two locations



Shallow Test Range



Deep Test Range

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This study had two sites, one boat in 3 modes, five sensor locations at each site, and two sensor types.

The less sensitive sensor types had overlaps with the more sensitive type and the analysis included calibration of the less sensitive sensors to make their data look like what the more sensitive sensors would have illustrated.

The photos to the right include distances from the shore and depth as well as 2 of the 3 boat tracks.

Test Runs

Ballast Weight Added	
Cruise -	0 lbs
Wakeboard -	2,850 lbs
Wakesurf -	4,250 lbs

- 42 test conditions, 94 runs covering all 42 test conditions (mode, speed, track from sensor #1)
- Resultant test data is expressed as a function of distance from the closest sensor
  - Sensor #1 to: Track 1 = 10’, Track 2 =110’, Track 3 = 210’
  - See tracks relative to depth below
  - Top scale is distance from shoreline
  - Sensor distances from shore are shown

Length overall:	23’ / 7.01 m
Max beam:	102” / 2.59 m
Light displacement:	5,900 lbs / 2,676 kg

Figure 9. The Nautique G23 test boat in wakesurf condition.

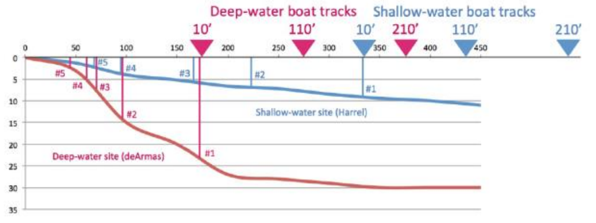

Figure 2. Depths, sensor locations, and boat tracks for the two test venues.

Mode	Speed (mph)	Distance from Station #1 (ft)		
Cruising	20	10	110	210
	25	10	110	210
	30	10	110	210
Wakeboard	21.2	10	110	210
	22.2	10	110	210
	23.2	10	110	210
Wakesurf port	10	10	110	210
	11	10	110	210
	11.5	10	110	210
	12	10	110	210
Wakesurf starboard	10	10	110	210
	11	10	110	210
	11.5	10	110	210
	12	10	110	210

Table 3. The test matrix for both the shallow and deep-water test sites.

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A wide variety of test runs were executed with boat mode, speed, and distance from the #1 sensor as the key parameters – see the table on the bottom right.

One boat was used, and its specifications are given for the three different modes of operations: cruise (no ballast), wakeboard (full ballast), surf (additional ballast) as illustrated in the upper right.

The speed of the boat depended on the mode in use at the time, which is illustrated in the bottom right chart.

As with one of the other studies, there was only one boat used and its weight without added ballast is on the order of 1300 lbs more than a comparable recreational boat.

The test distances and shoreline profile for the two test sites are illustrated in the bottom left chart. Three different boat-track distances from the closest sensor are illustrated: 10’, 110’ and 210’ at both test sites.

The test conditions led to a large amount of sample runs (42) just to cover the variables, but they also took multiple samples with the same set of conditions.

Test Results – Cruise Vs Wakeboard, Shallow for Track 1 (10' from sensor #1)

- Graphs illustrated with same vertical scale
- Height illustrated is trough to crest height
- Note that the further the boat is from the sensor, the more elongated in time the wave structure becomes and the smaller the maximum wave height
- Almost all wave height plots illustrate that the waves fully pass each of the sensors within 60 seconds

Each wave height plot recenters at the 0 value; the scale across wave plots is the same

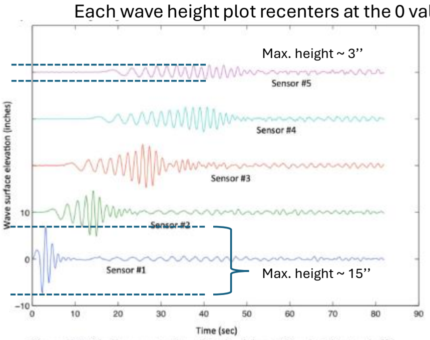


Figure 10. Shallow-water Run #6 - Cruising, 25 mph, 10' standoff.

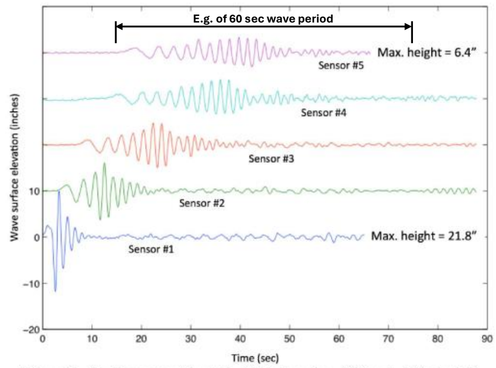


Figure 11. Shallow-water Run #15 - Wakeboarding, 22.2 mph, 10' standoff.

- Max wave height of wakesurfing is 21.8" compared to 15" for cruising

22

This slide illustrates what the waves, generated by one boat passing by, looked like as the waves passed each of the five sensors. The closest sensor is illustrated at the bottom of each chart and the subsequent curves represent the wave amplitudes measured at the other 4 sensors.

The two plots illustrated here are for two modes at the same test site: cruising and wakeboard operations at the shallow-water test site.

The scale of each wave starts at "0" at the line where the data intersects at 0 seconds.

What is common regardless of the boat's mode is that:

1) the further the boat is from the sensor, the smaller and more elongated the waves are as they pass;
2) the total duration of wave energy is on the order of 60 seconds;
3) for each wave, it is a set of waves whose duration of the main set of larger waves is on the order of 5 to 20 seconds.

Test Results – Cruise Vs Wakesurf (port), Shallow for Track 1 (10' from sensor #1)

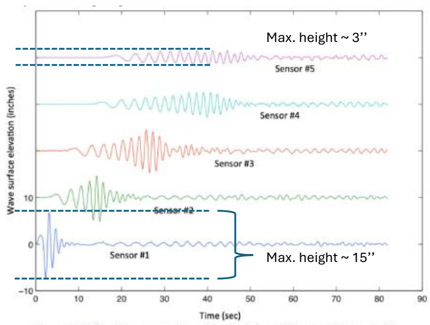


Figure 10. Shallow-water Run #6 - Cruising, 25 mph, 10' standoff.

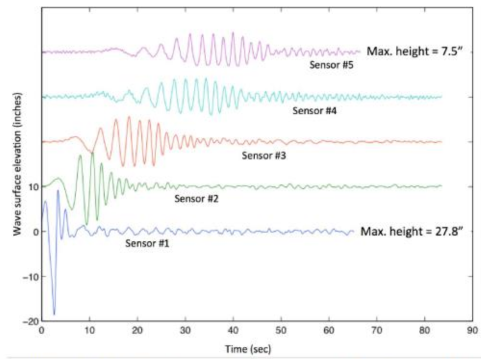
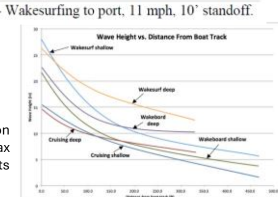


Figure 12. Shallow-water Run #24 - Wakesurfing to port, 11 mph, 10' standoff.

- Max wave height of wakesurfing is 27.8" compared to 15" for cruising
- Chart at right is a smoothing of the data

Extrapolation Plot Of Max Wave Heights



23

This chart is like the prior chart but compares the cruising test run to the wakesurfing test run.

What can immediately be seen is that the amplitude of the surf-mode waves is much higher than that of the cruise mode.

Looking at sensor 1, the wave height is almost a factor of 2 (15' vs 27.8"), which implies that the power and energy difference of the two modes is a factor of 3.4 ($3.4 = 27.8^2/15^2$) since the power and energy are proportional to the square of the wave height.

The bottom right chart is a graphical and curve-smoothed summary of all the test data in terms of wave height based on the boat mode and the test location (deep or shallow water) and depicts <u>maximum</u> wave height as a function of distance from the sensor.

Wave Height vs Distance from Shore

For example: The weight of this boat is 5,900 lbs (65 gal gas, one driver) vs 3,797 lbs (dry) for a Bayliner 22'7" VA6 of nearly the same beam (102" wake-sport beam vs 96" beam on the Bayliner). Sun Tracker PARTY BARGE® 20 DLX weight = 2,080 lbs (dry) or 3,745 lbs (loaded)

- The plot to the right illustrates the following:
  - Wave height of the wakesurf mode compared to cruising mode is nearly 2 times at 100 feet (deep water)
    - Cruise = 7.5"; wakesurf = 14.7"
  - Chart does not show how far away the wakesurf boat has to be to have the same wave height as the cruise mode at 100 ft (deep water tests), but linear extrapolation appears to indicate another 320' would be required (Addendum slide 47)
  - U of M study graph indicated ~325' additional distance
  - For the shallow water test, an additional ~220' is required (Addendum slide 48)
- **But remember, these tests do NOT compare wake-sport boat to a recreational boat!!!**

Wave height conclusions of this study: wakesurf mode requires a lot more distance to dissipate compared to that of a recreational boat (remember, this study uses only one boat in different modes). *See text box in upper right.*

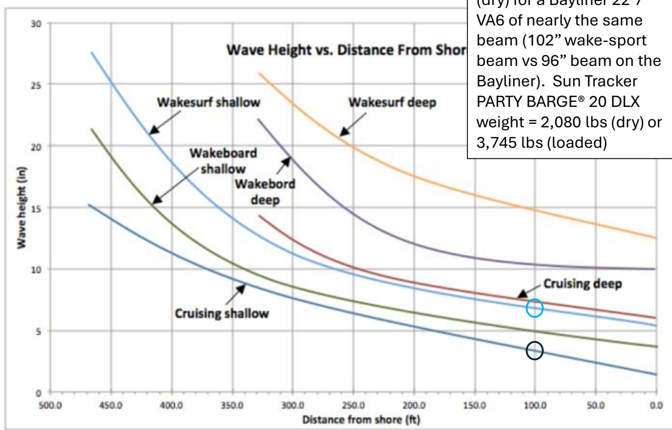


Figure 26. Wave height vs. distance from shore, trend lines only.

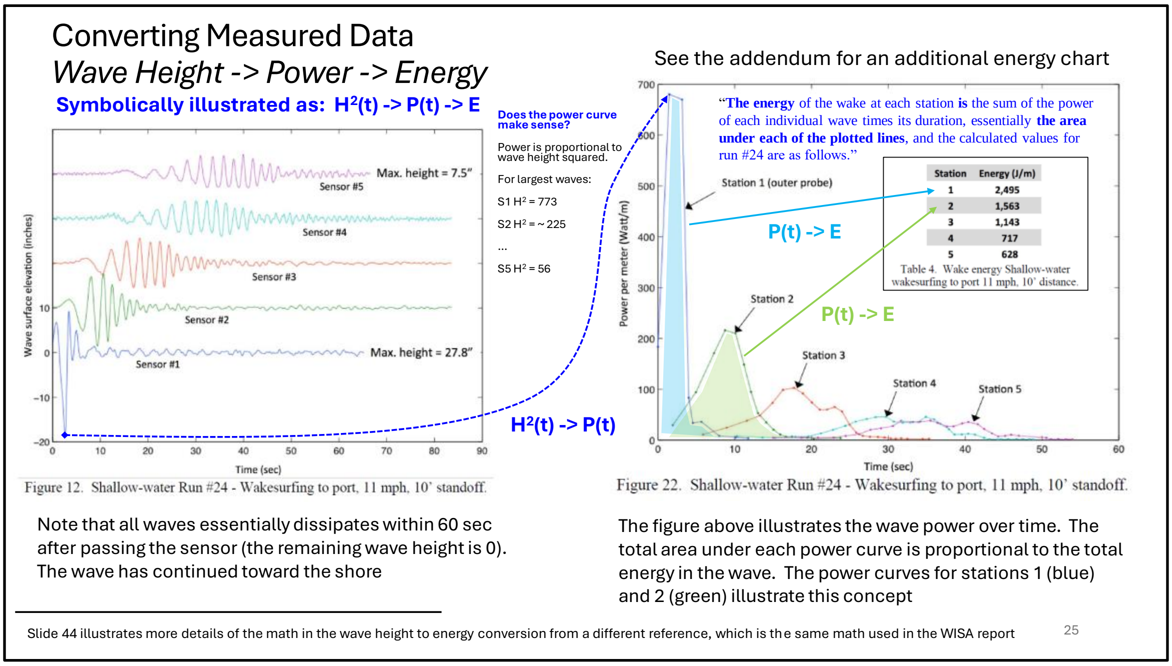
24

This chart is similar to the bottom right chart of the previous page, but the data has been converted from distance from the sensor to distance from shore using the distance of the track to the sensor(s) plus the distance of the sensor(s) to the shore.

When examining this relative to WA State law (e.g., staying 100 ft away from the shoreline), one can see looking at the small circles on the chart that the waves heights of cruising vs the surf modes at 100 ft is a factor of ~2 or more for shallow water (3" vs 7") or deep water (7.5" vs ~ 15").

If the surf mode data is extrapolated, we can again see that an additional 220' to 320' (depending on the bottom profile) of distance is needed to dissipate the surf mode wave height to the same level at 100' of the cruise mode (see the addendum slides 47 and 48).

And again, this study is not comparing recreational boats to wake-sport boats; wake-sport boats are heavier than similarly-sized recreational boats. More weight "generally" means more water displacement (yes, displacement is also a function of hull shape). Therefore, one would expect to see smaller waves from a recreational boat as compared to an empty wake-sport boat of similar length and beam width.



The study converts the wave height data to energy so that ultimately wave energy can be compared to mathematical wind energy models.

The wave height over time is converted to power over time, which is then summed over time (or integrated) to provide the single value of total energy in the wave. The concept is represented by the symbol: **$H^2(t)$ -> P(t) -> E** (read as wave height squared at time "t" can be converted to power at time "t", which can be converted to a single energy value)

Remember that all the waves as they pass the sensors last about 60 seconds, so that also becomes the common summing (integration period) to find the total energy.

Looking at the height data and squaring it, i.e., the numbers between the two charts (plus using other constants), produces the power curve at the right from the wave height curve on the left.

The total area under the power curve defines the total wave energy created. Two samples, the blue and green areas, are illustrated.

Total Wake Energy

(Shallow, wakesurf mode)

- Do the energy plots make sense?
- Compare the power curve to the energy:
  - Energy is the area under the power curve
  - Area under Station 1 (shallow) ~ = 675 W/m x 3.5 sec = 2363 J/m
  - Energy shallow at sensor 1 = ~ 2480 J/m
- The total wake energy is reduced the further away the track is from the sensor (same as the wave height)
  - Station 2 (shallow) power integration = ~ (225 W/m) x (7 sec) = 1575 J/m, which matches Fig 23

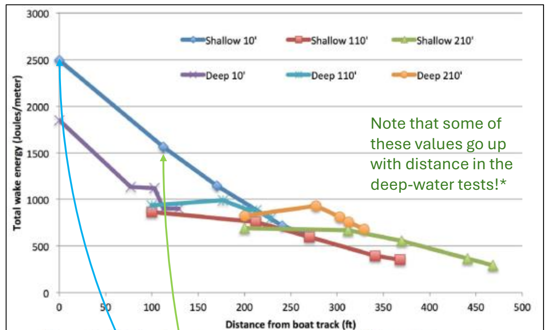


Figure 23. Total wake energy wakesurfing to port in shallow and deep waters.

P(t) -> E

Integrate (sum) power over time = energy. Blue box is an approximation of the area for Station 1. Green box is for Station 2

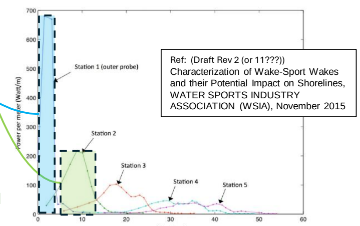


Figure 22. Shallow-water Run #24 - Wakesurfing to port, 11 mph, 10' standoff.

* The report does not illustrate any wave height plots over time in deep water. But Figures 18 and 19 of max wave heights show higher max wave heights at further distances (cruising at 25 mph and wakeboarding at 25 mph). See addendum

26

This slide illustrates how the power curve over time is converted to a single value of energy for the various shallow and deep water tests while in the wakesurfing mode.

An approximation of the area under the power curves for stations 1 and 2 are illustrated by the blue area and green area, respectively. The approximations match the data on the chart within estimation reason.

The document provides some explanation of why the shallow water 10' distance track creates more energy than the same 10' distance track in deep water. "Shallow water has other effects in that it adds to the resistance of the boat requiring additional propulsive power to achieve a specified speed compared to deep water. As a result, for the same speeds, the shallow-water runs generated higher initial wakes but they dissipated more rapidly. At the shoreline, the energy remaining was significantly less in shallow water compared to those from the same operating conditions in deep water where waves progress with fewer losses."

Cruising Mode Wave Energy Curves – *Selecting an Example for Later Use*

- The height to power to energy conversions were done to create plots of energy vs distance from the boat track for all measurements
- Plot to the right shows total energy for the deep-water sensor test area with the 3 boat tracks (10’, 110’, and 210’ from sensor #1)
- Track 2 (Deep 110’) at sensor 1 produces 349 J/m of energy. This example is used later to compare to the wind-wave energies (Table 7)

Note: This plot seems to illustrate energy increasing as the wave travels further. See addendum slide 45 for a different story. It is noted in the addendum that the deep water wave height data has more variance from the wave height trend lines than shallow water data.

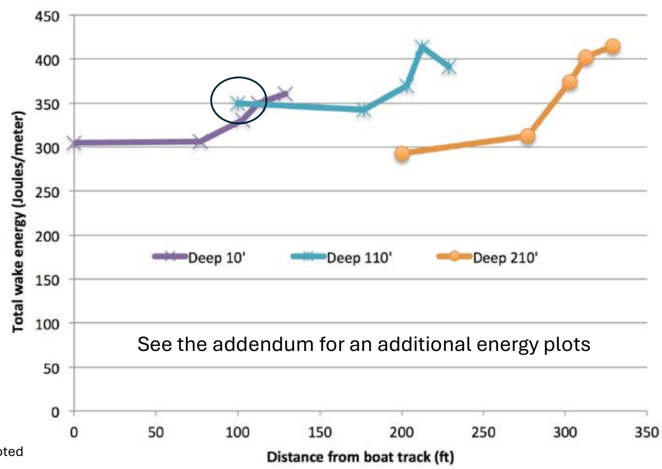


Figure 24. Total wake energy cruising at 25 mph in deep waters. 27

The graph to the right illustrates energy as a function of distance from the sensors for each of the three boat tracks taken. Each track produces a different set of these values; all three tracks’ data are plotted. Note that there are 5 data points, i.e., 5 sensors for each boat track.

One specific sample of the conversion for wave height to energy for the boat operating in the cruise mode is circled on the graph. It is used later in the report and herein for comparison to wind wave energy. Looking at the chart, the boat in cruising mode on track 2 (110’ from sensor 1) going 25 mph creates 349 J/m of energy at sensor 1.

Also note that the energy SHOULD be decreasing as a function of distance from the boat track. We saw this in the wave height plots: the wave height reduces from sensor 1, to 2, to 3, etc. The energy, being related to the square of the wave height, should also reduce as the distance to the sensor increases. But this plot shows energy increasing as the energy from a boat pass reaches sensors further and further away. For example, the energy at sensor 1 on track 1 is less than the same wave’s energy nearly 135’ away at sensor 5. Logically, that does not make a lot of sense, nor is this the same behavior as generally depicted in the graph on slide 45. It is not clear if or what other real-world impacts may have created this non-increasing nature for some data points or whether this is an error in the draft version of the report. What is mathematically clear that since the energy is proportional to the square of the wave height, if the measured wave data has some real-world variations, those variations will be highly exaggerated by squaring the height to power, then integrating to get energy; a small difference can look like a large difference after it has been squared (e.g., consider 8 vs 8 x 8 = 64).

Wind Wave Height

- The study uses well recognized steady state mathematical models for wind-created waves to determine the energy received at shore by wind-generated waves
  - Fetch is the "… area of ocean or lake surface over which the wind blows in an essentially constant direction, thus generating waves"
  - Waves grow in height with more wind and longer distances (up to 1,000 miles)
  - https://www.britannica.com/science/fetch
- Wave height for a 20 mph wind with a 4-mile fetch: (see ● on the graph)
  - Requires ~ 1.5 hours of wind to reach steady state (mathematically predictable)
  - Produces waves of 1.19 ft in height (Table 5*)
- Wave height for 10 mph wind over 1 mile fetch is 0.3 ft (Table 6*) : (see ● on the graph)

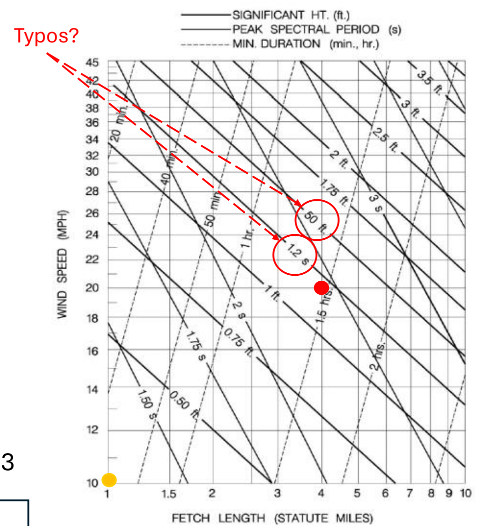


Figure 28. A nomograph for wind-driven waves (*VDOT Drainage Manual*).

* Tables 5 and 6 are on the next slide

Peak Spectral Period is the duration of the most energetic of the waves

28

Mathematical models are well established for determining wave heights under certain conditions. The chart to the right illustrates multiple curves of wave height, duration of wind, and period of a wave (peak spectral period) as a function of fetch length (horizontal axis) and wind speed (vertical axis). For any point on the chart, the wind speed, fetch length, wind duration, wave period, and wave height can be determined. The peak spectral period is illustrated at the bottom center of the slide.

Two examples are illustrated on the chart.

- The red dot illustrates the wave height of a 20 mph wind over a 4 mile fetch. The location of the dot for the wind/fetch values (vertical and horizontal axis, respectively) implies that the wind must be steady for at least ~1.5 hours, that the peak spectral period is ~2.5 seconds and the wave height is ~1.25 ft (trough to crest).
- The yellow dot illustrates the wave height of a 10 mph wind over a 1 mile fetch. The location of the dot implies the wind must be steady for at least ~47 minutes, that the peak spectral period is ~1.3 seconds and the wave height is ~0.30 ft (trough to crest).

Note: "A nomograph is defined as a graph, usually containing three parallel scales graduated for different variables so that when a straight line connects values of any two, the related value may be read directly from the third vertical line at the point intersected by the line." https://www.sciencedirect.com/topics/engineering/nomograph.

Note: "The peak wave period … is defined as the wave period associated with the most energetic waves in the total wave spectrum at a specific point." https://search.yahoo.com/search?fr=mcafee&type=E211US1079G0&p=what+does+peak+spectral+period+mean

Energy from Wind Waves

- Using the prior table and mathematical wave modeling, they determine the energy produced from 3 wind speeds and 2 fetches (distances)
  - Calculations assume the wind blows long enough to create steady state waves
  - The wind energy calculations follows the same process as for the wake-sport boat

Fig 28 data -> Table 5 -> modeling SW -> wind wave height over time → $H^2(t)$ -> P(t) -> E

Waves as a Function of Wind and Fetch

- Hmo = significant wave height
- Te = dominant wave period

Wind (mph)	Fetch 1 mile		Fetch 4 miles	
	Hmo (ft)	Te (s)	Hmo (ft)	Te (s)
10	0.30	1.30	0.60	1.98
20	0.62	1.58	1.19	2.42
30	0.90	1.76	1.82	2.77

Table 5. Wave conditions vs. wind and fetch.

Wind Wave Shape Model

- Uses parameters of table to the left

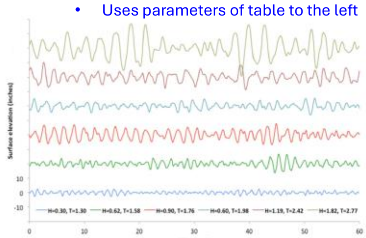


Figure 29. WAFO sea spectra time series for six wave specifications.

Calculated Wind Wave Energy

- Height -> Power -> Energy

Wind speed (mph)	Fetch (mi)	H_{mo} (ft)	T_e (s)	Energy (Joules/min)
10	1	0.3	1.3	208
20	1	0.62	1.6	790
30	1	0.9	1.8	3,148
10	4	0.6	2	1,046
20	4	1.19	2.4	2,418
30	4	1.82	2.8	17,572

Table 6. Energy of the Table 5 sea states in Joules/minute/meter.

Example highlighted on next slide

29

The study presented values of wave height and period based on 3 wind speeds and 2 fetch distances. See Table 5 at the lower left.

A standard software model used those parameters to create a plot of the what the waves would look like. See the graph at the bottom center of the slide.

The study then determined the energy produced by the waves from those wave height models using the same process as was used to determine the energy from the wake-sport boat waves. That is: **$H^2(t)$ -> P(t) -> E**. See Table 6 at the bottom right.

The highlighted row in Table 6 is used for an example to illustrate how the wind energy and wake-sport boat wave energy can be compared.

The example chosen was as close as possible to real-world conditions that might be possible on Sacheen Lake. More will be presented on the comparisons for our lake.

Calculated Wind Wave vs Boat Wave Energy

- Table illustrates the periodicity required of boats passing by the shore to equal the same energy of persistent wind waves
- Wind wave energy is calculated over 60 seconds with a one-meter width
- The periodicity of the boat is determined by finding the amount of time the boat waves will produce the same energy as the wind
- For a boat cruising by the shore at 110’
  - Wind: 208 J/m is to 60 seconds as
  - Boat: 349 J/m is to X seconds
  - X = (349*60)/208 = 101 seconds

$$\frac{208}{60\ s} = \frac{349}{X\ s}$$

Wind vs Boat

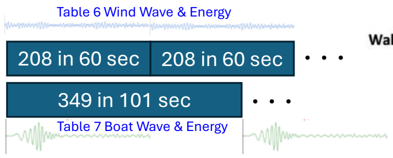


Table 6 Wind Sample vs Table 7 Boat Sample

Wind speed (mph)	Fetch (mi)	H_{mo} (ft)	T_e (s)	Energy (Joules/min)
10	1	0.3	1.3	208

Operating mode	Water depth	Stand off (ft)	Total wake energy (J/m)	Recurrence equivalent (sec) 10 mph/1mi	20 mph/4 mi
Cruising	deep	10	305	88	8
		110	349	101	9
		210	293	85	7
	shallow	10	280	81	7
		110	274	79	7
		210	230	66	6
Wakeboarding	deep	10	850	245	21
		110	616	178	15
		210	602	174	15
	shallow	10	666	192	17
		110	519	150	13
		210	478	138	12
Wakesurfing	deep	10	1846	533	46
		110	937	270	23
		210	821	237	20
	shallow	10	2495	720	62
		110	868	250	22
		210	692	200	17

Table 7. Total wake energy and wind-wave recurrence equivalent.

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Table 7 to the right illustrates the test conditions for the three operating modes, two water depths (shallow, deep), and three standoff distance from sensor 1 (i.e., 3 tracks). The portion of Table 6 from the prior slide is copied to illustrate which wind scenario is being compared to which boat scenario. The wind and fetch of Tables 6 & 7 must match for a valid comparison. The 110 ft track was chosen since it is close to the WA State safe boating distance. The least wave generating boat mode (cruising) and shoreline (deep) best approximating Sacheen Lake were chosen for this comparison. Note that in general, more boat wave energy implies it cannot pass by as often as illustrated in Table 7. The smallest boat energy has the shortest recurrence equivalent (cruising in shallow at 210’ track); the largest boat energy has the largest recurrence equivalent (wakesurfing in shallow at 10’ track).

For each row, the “Total wake energy (J/m)” produced by the boat is provided. This is the calculation of the energy in the wave based on the test scenario represented by that specific row. For the highlighted case, the wave produced 349 J/m for one pass by the sensor of the boat in cruise mode in deep water on the 110 ft track from the sensor.

The next column to the right, “Recurrence equivalent (sec)” illustrates how often the wave energy produced by that test case has to repeat in order to equal the continual energy of the same wind speed and fetch distance in that row. For the highlighted case, the wake-boat would have to go by every 101 seconds to equal the same energy of the waves from persistent 10 mph winds over a 1 mile fetch.

The math and figure at the bottom illustrate the concept of determining the recurrence equivalent of the boat’s wave energy as compared to the wind wave energy. The assumption is that the wind blows constantly and that the wake-sport boat goes by the shoreline often enough that the two impart the same cumulative energy to the shoreline over an extended duration of time. What is not addressed is the impact of the higher energy, such as breaking strength, being imparted by the boat over a shorter duration of time.

Assessment of Study's Conclusions (Boat vs Wind)

- "By comparing boat-wave energy with the energy of wind waves associated with various combinations of wind speed and fetch distance, equivalent recurrence intervals can be determined, 1-mile the frequency of wake events that would equal a specified wind condition. **Because wind waves are persistent, in many settings they represent a more significant source of shoreline impact than boat wakes**."
- The phrase "in many settings" is somewhat misleading. **The likelihood that the real-world characteristics are the same as the wind model assumptions is overstated**, i.e., this is a general statement that leaves the reader pondering the applicability of the statement
  - The nature of the wind wave models they use requires persistent wind and long fetches. The plot shown on slide 25 (Fig 28 nomograph) does not have wind speeds below 10 mph. The shortest wind persistence shown is approx. 47 minutes at 10 mph with a 1-mile fetch
  - Real world characteristics of the lake shape, tree line, prevailing wind direction(s), strength, and duration, etc., are not addressed. For example, how strong are prevailing (persistent) winds, how do they align with the shoreline, are they in the same location on the lake as boating, etc.
- The authors discuss the **reduction of a wave's height in terms of percentage drop over distance** as they leave the boat; they do not point out the fact that **percentage drop is not as important as the remaining height (e.g., wake-sport vs recreational boating) at the destination (dock or shoreline)**
  - The data (graphs, etc.) presented surely indicate that wakeboard or wakesurf modes of wake-sport boats produce larger waves, even after wave dissipation as compared to recreational boats at a given distance (shoreline, dock, another watercraft, etc.)
  - Remember, this study used the same wake-sport boat, but without additional ballast, as representative of recreational boats. A normal recreational boat of similar beam width and length likely has less displacement than wake-sport boats (dry weight comparison)
  - Yes, there is a trade between weight and beam width as it applies to displacement, but I don't have any data on it
- Another **element of the study not addressed is breaking or tensile strength of objects receiving the wave energy**. **The unstated assumption that receiving lower energy over time is the same as receiving strong energy repeatedly does not apply to breakage**
  - Consider for example stretching a rubber band 1000 times, but never to the point of breaking vs one stretch that breaks the rubber band –the total energy imparted by each experiment could be equal

31

The purpose of this chart is to introduce the fact that the wind analysis performed has some fairly strict assumptions that don't necessarily apply to real-world conditions. There are three main parameters that define the wave heights in this model: (1) continuous wind, (2) wind coming from the same direction and (3) wind over a specific distance (i.e., the fetch).

The lowest wind rate, distance and time they have assumes 10 mph winds, a 1 mile fetch, and sustained wind for a minimum of about 47 minutes. Small lakes, like Sacheen Lake, do not have long fetches. Lakes like Sacheen Lake may not experience winds of at least 10 mph very often. Their statement "in many settings" is not as applicable as they imply.

The authors attempt to obfuscate the real issue of energy imparted by addressing a percent reduction of wave height over distance. The percentage drop is irrelevant if the energy remaining at the shoreline or dock, for example, is still high. This SLA Board presentation focuses on what matters: the energy imparted at the object receiving the wave energy.

The authors also don't address breaking strength. Their focus was on energy at the shoreline when comparing wind vs the wake-sport boat waves. In their comparison, they assume that receiving small amounts of energy continually is the same thing as receiving large amounts of energy periodically. This only applies if something doesn't break under the larger amount of received energy. This slide illustrates this concept by using the example of stretching a rubber band 1000 times (just an example number) but never to the breaking strength vs stretching it to its breaking limit once where the total energy imparted in the two stretching techniques is the same.

Application of the Analysis and Conclusions for Sacheen Lake

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In this next section, the study's data will be extrapolated for comparison to Sacheen Lake. We'll look at real-world scenarios of wind and wake-sport operations on Sacheen Lake. I'll use the same techniques of the study to compare the lake's wind and wake-sport boat surf mode operations impacts to Sacheen Lake's shoreline. The study determined "recurrence equivalent (sec)" of a wake-sport boat wave energy as compared to persistent wind wave energy and I'll do the same thing for the real-world scenario defined for Sacheen Lake.

Data needed for Sacheen Lake must describe the wind speed and fetch of persistent winds in order to use the study's wind model plots. Persistence is key here as that is part of the assumption when determining the wind wave energy. Prevailing wind direction and average wind speed is the approach used herein to establish a persistent state for the analysis.

We'll examine the real-world scenario of wave energy imparted to the lake's shoreline by looking at an actual boat path on the lake and Sacheen Lake's prevailing winds (need persistence). We'll analyze how the boat imparts energy on the shoreline all around it's path vs how a prevailing wind over a long fetch would impart energy on the same path's shoreline.

Sacheen Lake Wind

Ref: https://www.weatherworld.com/climate-averages/wa/sacheen+lake.html

Sacheen Lake Monthly Climate Averages

12 Month Climate Scroll °F °C

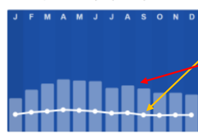
Month	January	February	March	April	May	June	July	August	September	October	November	December
Avg. Temperatures	Hi 31°F Lo 20°F	Hi 34°F Lo 21°F	Hi 43°F Lo 27°F	Hi 52°F Lo 33°F	Hi 64°F Lo 42°F	Hi 71°F Lo 48°F	Hi 83°F Lo 56°F	Hi 83°F Lo 56°F	Hi 72°F Lo 48°F	Hi 54°F Lo 37°F	Hi 39°F Lo 28°F	Hi 31°F Lo 21°F
Avg. Wind Speed	3 mph	4 mph	4 mph	5 mph	4 mph	4 mph	4 mph	4 mph	4 mph	4 mph	4 mph	3 mph
Avg. Precipitation	3.3 in	2.4 in	3.4 in	2.6 in	2.5 in	2.2 in	0.5 in	0.7 in	1.3 in	2.8 in	4.3 in	4.4 in
Average Humidity	94%	91%	86%	74%	67%	64%						
Avg. Cloud Cover	71%	67%	59%	49%	39%	33%						
Pressure Average	30.2 in	30.1 in	30.0 in	30.0 in	29.9 in	29.9						
Average Dry Days	10	11	13	19	24	24						
Avg. Precip. Days	12	10	11	9	7	6						
Avg. Snow Days	10	7	7	2	0	0						
Average Fog Days	1	1	1	0	0	0						
Average UV Index	1	1	2	2	4	5						
Avg. Hours of Sun	78	73	104	135	195	220						

Averages are based on historical weather data from the past 10 years. Click and drag this table...

Deer Lake is likely to have more tunneling of the wind due to its terrain than Sacheen Lake, i.e., higher wind speeds. The same scale is used on both maps.

- Sacheen Lake's wind averages are 5 mph or less
- Yes, Sacheen Lake receives much higher winds
- A wind speed occurrence curve (probability distribution) was not available for direct use. A specific reference's general modeling of the statistics is used.
- Closest available data aiding in statistical understanding of wind was for Deer Park airport; the average and average maximum winds are used

Climate (2010–Present)
Deer Park, Deer Park Airport (13 miles)



Deer Lake Winds (> Sacheen)

- Ave Range: 5.5 to 6.7 mph
- Ave Max Range: 11.3 to 17.4 mph
- Ave Max is 2 to 2.5 x Ave

Ref: https://wind.willyweather.com/wa/pend-oreille-county/sacheen-lake.html

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This table illustrates the AVERAGE wind speed during a month at Sacheen Lake.

Yes, the average is not the full answer, but average implies the most likely wind, which is the best place to start for also experiencing persistent winds of a long duration sufficient to use the mathematical model for wave height.

As you can see on the figure, Sacheen Lake's average wind speed is 3 mph (2 of 12 months), 4 mph (9 of 12 months) or 5 mph (1 of 12 months). I used the most pessimistic, or highest, wind speed to analyze Sacheen Lake's wind waves.

Another attribute of statistics, or the data that determined the average wind speed for this table, is how spread out is the wind speed statistically speaking? I found some relevant data that described this: (1) the maximum average and specifically at Deer Lake and (2) what the statistical distribution of wave speeds looks like (a study done for wind energy production – see addendum slide 49).

For Deer Lake, we see in the bar chart on the bottom right that their average wind speeds are slightly higher than Sacheen Lake. Its average maximum speed is 2 to 2.5 times higher than its average wind speed. But how and why does that compare to Sacheen Lake?

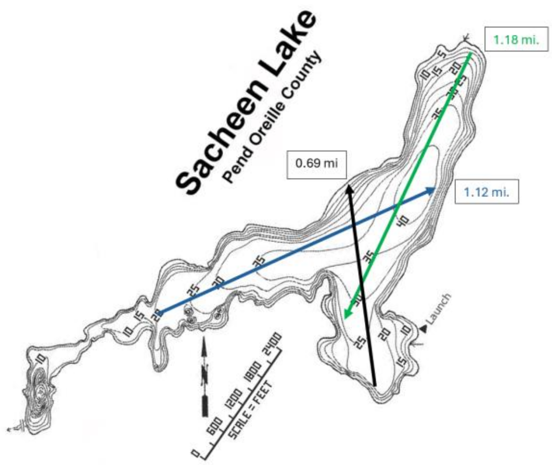
The Google Maps terrain capture illustrates the hills around both lakes, and it is likely from the terrain that there is more wind tunneling at Deer Lake, especially for SW and NE prevailing winds. For clarify, the scale of the two maps is the same; Google Maps screen captures of the two locations were used without reshaping the map to produce the same scale.

Sacheen Lake Prevailing Wind and Fetch

- Prevailing Winds (based on experience) and Fetch Distance (Google Maps measure function)

Direction	Fetch
SW to NE	1.12 miles
NNE to SSW	1.18 mi.
SSE to NNW	0.69 mi.

- The study did not have data on steady state winds below 10 mph
  - However, those waves were only 0.3' (3.6") high with 10 mph winds on a 1-mile fetch
- Sacheen's wave heights on average wind days will be less than 3.6" (more on this later)
- Note: The prevailing winds impart their full fetch distance energy on only a limited range of the shoreline! A majority of shoreline around Sacheen Lake has a fetch much shorter than 1 mile



Note that the assumed prevailing wind directions match the longest fetch where the lake speed is 35 mph. This is the "best" combination to obtain the largest wind waves.

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The study parameters used wind speed and fetch to determine wave height. So what does Sacheen Lake's prevailing wind fetches look like?

From my experience on Sacheen Lake, we appear to have 3 directions of prevailing winds on Sacheen Lake. And these 3 directions coincide with the longest fetches in the skiable area of Sacheen Lake.

The longest fetch on Sacheen in the direction of our prevailing winds is 1.18 miles.

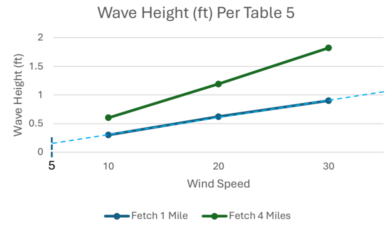
The study illustrated that for 10 mph, as compared to Sacheen Lake's worst case ave wind speed of 5 mph, that the wave height over a 1 mile fetch is 3.6 inches.

Sacheen Lake's waves from persistent average wind speeds will be less than 3.6 inches. We'll extrapolate the study data to determine this in an upcoming slide.

While looking at the map, also consider how the wake-sport boat wave directions will be relative to the 3 indicated longest fetches and prevailing wind direction. Most of the prevailing winds over a 1 mile fetch will affect only a few of the shorelines. According to the 2023 survey results, wave damage around the lake is ubiquitous, i.e., occurs on almost all shorelines. Many of those shorelines have fetches on the order of 1750 ft or less (1/3 mile).

Wave Height for 5 Mph Winds (Extrapolation) & Resultant Wind Energy

- Linear extrapolation of Table 5 data implies a wave height of ~ 1/3 * 0.5' = 0.15' (=1.8"). See graph to the right
  - The lines to the left are already linear in nature, so linear extrapolation should be "accurate"
- This height for 5 mph is ½ of the height of the 10 mph wind waves which produces an energy of 208 J/m
- Therefore, the energy (proportional to H squared) should be ¼ of the energy or 52 J/m for 5 mph over a 1-mile fetch
- Wakesurfing in the study at 110' from sensor 1 in deep water produced 937 J/m
  - In order to produce the same energy as the 5 mph, the wakesurf mode boat 110' from shore needs to meet the following: 937/X = 52/60. X = 937*60/52 = 1,081.2 seconds
  - Repetition rate of wakesurfing every 1,081 seconds (18 minutes) produces the same total energy as Sacheen's prevailing average wind at 5 mph for a 1-mile fetch of prolonged wind (from Figure 28, at least 50 min of prevailing wind is required for steady state waves)
- The probability of average max winds of 10 mph is low as illustrated in the addendum slide 49
  - Recall that Deer Valley data showed 2 X ave wind = ave max wind
  - High winds should, conceptionally, have a small probability of occurrence



Wind (mph)	Fetch 1 mile Hmo (ft)	Fetch 1 mile Te (s)	Fetch 4 miles Hmo (ft)	Fetch 4 miles Te (s)
10	0.30	1.30	0.60	1.98
20	0.62	1.58	1.19	2.42
30	0.90	1.76	1.82	2.77

Table 5. Wave conditions vs. wind and fetch.

Source data for above graph

		...ff	Total wake energy (J/m)	Recurrence equivalent (sec) 10 mph/1mi	Recurrence equivalent (sec) 20 mph/4 mi
			305	88	8
			349	101	9
			293	85	7
			280	81	7
			274	79	7
			230	66	6
			850	245	21
		110	616	178	15
		210	602	174	15
		10	666	192	17
	shallow	110	519	150	13
		210	478	138	12
Wakesurfing	deep	10	1846	533	46
		110	937	270	23
		210	821	237	20
	shallow	10	2495	720	62
		110	868	250	22
		210	692	200	17

Table 7. Total wake energy and wind-wave recurrence equivalent.

$H^2(t)$ -> P(t) -> E Source data for energy calculation

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The upper right graph shows an extrapolation of the wind's wave heights based on data in Table 5. The Table 5 values were plotted (10, 20, 20 mph winds) and extended to a 5 mph wind for the 1 mile fetch, i.e., the largest ave wind over the longest possible distance on Sacheen Lake . The plot for the 3 wind speeds in the study is linear, so a linear extrapolation is likely quite accurate. And the extrapolation looks like it will be 0" waves for 0 mph wind; i.e., the logic of the extrapolation holds.

That extrapolation yields a wave height of 1.8 inches for 5 mph winds. Note that this wave height is ½ the wave height of the 10 mph winds. Since energy is proportional to the square of the wave height, cutting the wave height in half cuts the energy in ¼. The 10 mph wind over 1 mile of fetch which yields 208 J/m should yield only 52 J/m at 5 mph over a 1 mile fetch.

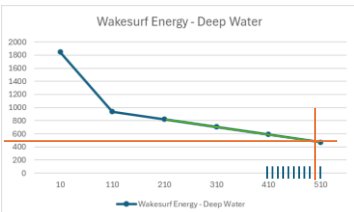
Using the same logic (and math) as before to determine the "recurrence equivalent (sec)", a wake-sport boat in surf mode and 110 ft from shore (yellow highlighted row in Table 7) would have a repetition rate of once every 1,081 seconds or 18 minutes in order to impart the same persistent energy as wind waves blowing 5 mph for at least 50 minutes over a 1 mile fetch on Sacheen Lake. But hopefully, most wake-sport boats stay further than 110 ft from shore. We'll analyze that case shortly.

What about stronger winds on Sacheen Lake? Slide 49 in the addendum shows a probability curve of winds reaching 10 mph on Sacheen Lake based on a study of wind probability for wind generators. It is not highly likely that persistent, 10 mph winds will be blowing on Sacheen Lake. Yes, we have gusts of > 10 mph and storms of >10 mph, but we're trying to compare wake boating to persistent winds as did the study.

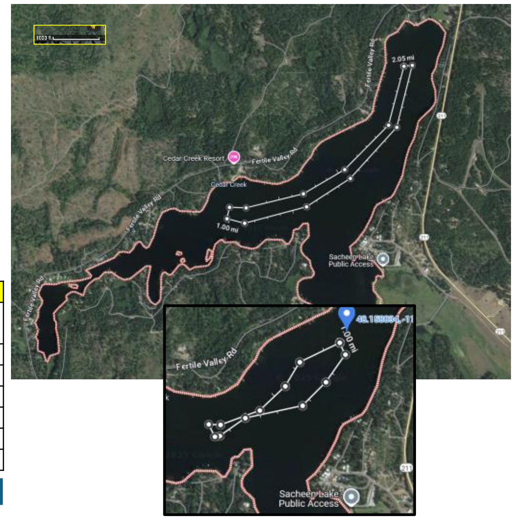
One Surf Loop Around Sacheen – Energy Produced

- Long loop distance* on larger map to the right is 2.05 mi. Loop path is always > 100' from shore
- Time for the loop = Distance of the loop/Rate of travel
  - Tsurf = 2.05mi/10 mph = 12.3 min
  - Twakeboard = 2.05/20 = 6.15 min
  - Tcruise = 2.05/30 = 4.1 min

  Assuming no other lake traffic or falls
- If the loop is made smaller and kept ~ 500ft from shore:
  - Tsurf = 1mi/10 mph = 6 min
  - See "Smaller surfing loop" map to the lower right
- Energy of wakesurf at shore on a loop 500 ft from shore = 485 J/m
  - See below chart. Green line is the linear extrapolation, orange lines show energy at 500 ft



Wakesurf Energy - Deep Water		
Distance from Sensor	Energy (J/m)	Source
10	1846	Table 7
110	937	Table 7
210	821	Table 7
310	705	Extrap
410	589	Extrap
510	473	Extrap
500	484.6	Calc



Smaller surfing loop

* Distances determined by Google Maps

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So now we have a picture of what the wind wave energy might produce in terms of wave height on Sacheen Lake's shoreline. But what about what the wake-sport boats produce? What energy do they impart? Where is that energy imparted and how does that location compare to 1 mile wind fetches on Sacheen? We already noted that damage was reported around almost the entire lake, so that somewhat rules out 1 mile fetches of prevailing winds at 10 mph as suggested by the study. And we saw on the previous map that damage locations based on prevailing winds at Sacheen Lake have limited locations of 1 mile fetches in the same direction as prevailing winds.

For this analysis, I had to extrapolate the Table 7 wakesurf mode data of the study so it compares to the distances wake-sport boat waves on Sacheen Lake would dissipate if a conservative distance from shore is maintained. Table 7 data was linearly extrapolated (see the green line in the graph).

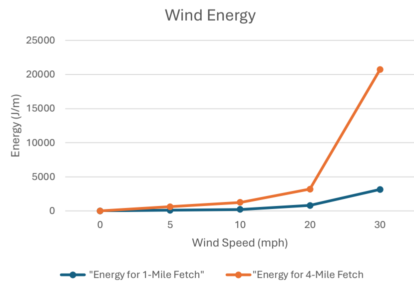
Using the study's distance from shore vs wakesurf energy plot, I linearly extrapolated the data and determined the resulting energy at distances of about 500 feet from shore, which is a more reasonable distance from the shore for wakesurfing. The bottom-center table illustrates the calculated value of 473 J/m at 510 feet. At 500 ft, the extrapolation equation shows 485 J/m of wakesurf mode energy.

But how realistic is 500 ft distance on Sacheen Lake for a wake-sport boat? The maps at the right illustrate a 2 mile loop that places boats closer to the shoreline and a 1 mile loop that allows a larger distance from the shoreline. The smaller loop was constructed to estimate 500' from the shoreline.

Wind Comparison to One Short Loop Around Sacheen

- Energy at shore with 5 mph winds and 1-mile fetch = 104 J/m (below chart/graph). How often can the boat in wakesurf mode go by and produce the equivalent shoreline energy?
  - Solve: 104/60 = 485/X -> X = 4.7 min
  - The wakesurf boat would have to go by every 4.7 minutes to produce the same total energy the wind at 5 mph. This is more frequent than going around a 1-mile loop at 10 mph (once every 6 min.)
- The fetch length of the winds perpendicular to the wakesurf loop and hitting against the shoreline is about 1750 ft (e.g., width of the lake from NW to SE)
- Energy from the wind imparted on the shorelines opposite the boat path would be a lot less than the 104 J/m of a 5 mph prevailing wind over a majority of the ski path because there is insufficient distance to build up the waves to the equivalent height obtained in a 1-mile fetch
- The boat's energy (485 J/m or 5X of the prevailing wind) will reach most of the shoreline around the entire boat path. The periodic, much higher energy from the boat (vs the wind) will have a greater impact when considering breaking forces

Wind Direction Key
- Perpendicular to Path
- Prevailing (1.12 mi)



$H^2(t)$ -> P(t) -> E

Wind Speed	Fetch	Energy (J/m)	Source
0	1	0	Extrap
5	1	104	Extrap
10	1	208	Table 6
20	1	790	Table 6
30	1	3148	Table 6

Note that on slide 32, the wind energy was calculated at 52 J/m. The number on the linear extrapolation is 2X what was previously calculated*. That is, the analysis on this slide assumes more wind energy than there might be.

* Depending on the parameters, a linear curve will be higher than an exponential curve in the beginning

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We need to determine the wind energy imparted at the shoreline on Sacheen Lake from the wave height we just calculated. I again used the study's data and created a linear extrapolation of the wind energy based on wind speed and fetch. The bottom left plot is that extrapolation and the data is in the bottom-center table.

The average winds of 5 mph of prevailing wind on 1 mile fetches on Sacheen Lake produce an energy of 104 J/m. Note that this is 2 times what we predicted using wave height comparisons for waves at 10 mph vs 5 mph over a 1 mile fetch; that value was 52 J/m. Using the 104 J/m is a more conservative (higher) energy impact from Sacheen Lake's winds.

Now we have to determine the "recurrence equivalent (sec)" for the wake-sport boat. I used the smaller of the two previously illustrated boat paths and a speed of 10 mph in surf mode. So we need to see how often a boat would go by to equal 104 J/m of wind energy. Recall that the wakesurf mode energy 500 ft from shore was 485 J/m (4.7 x more energy than the wind). Using the previous concept to determine "recurrence equivalent" the recurrence equivalent is 4.7 minutes.

The wake-sport boat in surf mode at 10 mph requires 6 minutes to make the shorter 1 mile loop once around lake. A wake-sport boat probably cannot produce quite the equivalent persistent energy as the wind because it takes longer to go around the lake than the recurrence equivalent (sec), but the wind waves are only 1.8" high compared to the large waves we receive at the shoreline from wakesurfing. Again, what is the breaking force required and does the much smaller persistent energy of the wind support breaking docks, etc.? Furthermore, most of the shoreline around Sacheen Lake is NOT going to receive the energy from persistent 5 mph 1 mile fetch wind because the fetch is closer to 1750 ft (~1/3 mile) for much of the shoreline along the boat's path. But the wake-sport boat will produce the energy at the shoreline around most of the 35 mph section of the lake's shoreline.

Conclusions for Applicability to Sacheen

- Sacheen residents complain about broken items, waves too large to be in/around due to boating, reaction of docks to wake-sport boats (and 100' distance violators), and their inability to be on their docks or in small watercraft during wake-sport boating
- Sacheen's *prevailing average wind* waves do not produce significantly large waves (around 2" in height – trough to crest) nor do *prevailing winds* impart energy on all of the lake's shoreline
- An average wave height of prevailing winds over a 1+ mile of fetch on Sacheen lake will not have a significant amount of energy in it (~ 104 J/m)
- The average wave height from winds along the shoreline perpendicular to the path of the small-loop wakesurf path is produced with a fetch of about 1750 ft. Therefore, the energy produced will be a lot less ($E \ll 104$ J/m) than that of the nearly 1-mile fetches on Sacheen Lake previously illustrated herein
- Items on Sacheen Lake that break (docks, retaining walls, etc.) are likely to have a much higher breaking point in terms of energy required to break them as compared to the energy produced by prevailing average winds on Sacheen*
  - The analysis illustrated that wake-sport boats on Sacheen impart ~ 5 times the energy as prevailing winds
- Shoreline erosion can occur with smaller, persistent waves (prevailing winds or not), but larger waves are also more likely to pick up bottom sediment and use it as a breaking element against the shoreline*

* These comments are those of the author using logic.

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We have had complaints about broken, damaged, or moved objects based on wake-sport boats on Sacheen Lake, as well as dangerous situations for people.

In here we determined that the prevailing winds of the longest fetches probably produce waves on the order of 2 inches in height. We also note that most of the shoreline would experience winds from perpendicular directions to the shoreline of only around 1750 ft, so persistent wind waves of less than 2 inches for our average winds, for most of the lake's shoreline.

In the real-world, we have to consider things like tensile or breaking strength of the items being broken. Persistent (average) wind with 1 mile fetches don't produce waves likely to have breaking strength energy or cause someone to be hurt.

Shoreline erosion is a different scenario of concern relative to comparing wind waves and wake-sport boat waves. Waves can wash out dirt with relatively small waves; larger waves can pick up bottom material and use those as smashing agents against the shoreline. And persistent boat waves can cause even more erosion since they are bursts of higher energy, not energy distributed over time.

Conclusions for Applicability to Sacheen (cont.)

- The executive summary of the study states: “In all but the most protected of shorelines, it would be difficult for boating to match the role of wind waves and natural currents on shaping shorelines.”
- Sacheen Lake’s real-world conditions are significantly different from the wind assumption in the study
  - Sacheen Lake’s average (statistically persistent) wind speeds are ½ of the smallest speed considered in the study
  - Sacheen has treelined protected boundaries around almost the entire lake
  - Sacheen fetches are short, especially along the shorelines perpendicular to boat traffic, and the winds perpendicular to those shorelines cannot build up waves over a sufficiently long distance
  - Sacheen Lake does not have significant shoreline natural currents due to waves*
    - There are however directional currents based on the flow of water from Moon Creek, for example
  - Shorelines may also be shaped by the waves picking up already broken off parts of granite rock and using the wave force to beat the rock pieces against the shoreline (I see it at my place with large waves, but not typically with wind waves)*
  - Sacheen Lake residents have visually experienced breaking forces which have NOT been attributed to wind
- Conclusion: Real-world considerations strongly suggest that Sacheen Lake’s shorelines, docks, etc., are not as affected by the winds as suggested in the study. In fact, the data shows that Sacheen’s wind effects are significantly less than those presented in the study as well as significantly less (5 time less) than wake-sport boats on Sacheen Lake at 500 ft from shore
- Breaking strength analysis was not done in the study, but evidence on our lake illustrates that it is a concern, and eyewitnesses indicate that wind has not been the cause of crumpled ramps, etc.

* These comments are those of the author using logic.

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The study’s statement quoted here does not appear to be applicable to Sacheen Lake for multiple reasons: (1) we don’t have average winds of the strength analyzed in the paper, and (2) we don’t have long fetches around the entire shoreline that allow wave height to build.

Sacheen Lake’s real-world conditions introduce other reasons why the wind analysis of the study is not as applicable as they imply: (1) we have tree line around most of the lake and we don’t have a lot of wind tunneling terrain around the lake, (2) most of our shoreline has very short fetches for winds perpendicular to the shoreline, (3) our waves don’t appear to create shoreline natural currents, but our stream or underground water does create some shoreline waterflow. Furthermore, the waves that I see that are strong enough to pick up bottom debris don’t come from the wind, but rather boating activity.

The Sacheen Lake analysis shows that wave burst energies from wake-sport boats are significantly larger than persistent wind energy and that prevailing wind energy, direction and strength don’t coincide with the ubiquitous nature of locations where damage has been experienced by property owners.

The study does not address breaking strength issues of bursts of energy vs smaller amplitude energy persistently applied.

Questions / Comments?

Wrap Up

- Thank you for attending and taking an interest in what goes on at Sacheen Lake!
- The presentation is posted on the SLA website
- The wave damage survey will soon be released via email and post cards (trying to reach all lake property owners)
  - The survey is digital and access requires the link we'll provide
- Please take the survey so we all have a better understanding of how our community feels about wave damage
- The wave damage survey results will be presented at the SLA's June 2025 Annual Meeting and posted on our website
  - We will likely host a Zoom call for this year's Annual Meeting as well as meeting at the Hwy 211 fire station

Addendum / Backup Slides

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Additional slides are provided as reference material used herein. They include:

- 4 slides from the October 2024 presentation
- 1 slide containing more detailed mathematical presentation of the conversion of wave height to power and power to energy
- 2 slides illustrating data vs trending for wave height
- 2 slides providing how some study data was extrapolated for results provided herein
- 1 slide on wind probability distribution and what it means for average wind and maximum average wind
- 1 slide illustrating general wave characteristic and parameters

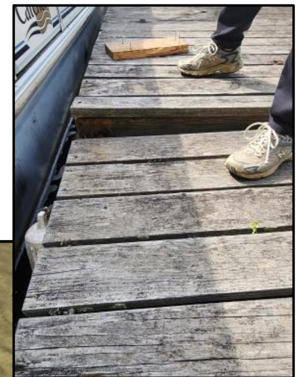
From SLA Oct 2024 Wave Damage Meeting Presentation

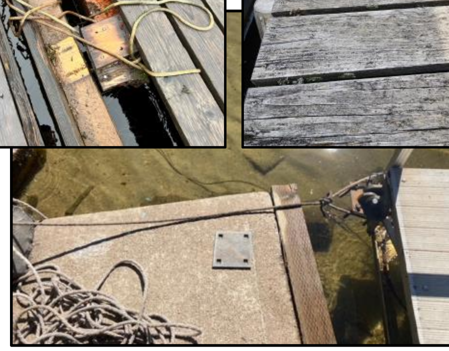
Shoreline Damage – Retaining wall, Dock landing, actual shoreline

This and the next two slides are photos presented in Oct 2024 of damage people have experienced around the lake dues to waves.

Dock Damage

- Wave action has been pushing on docks and breaking anchor chains, moving docks, and breaking dock pieces apart.
- Damage: "We had to disconnect our floating dock sections and upgrade the hardware pinning them together. Cost was $1,012. We did this work ourselves, otherwise it would have been more."
- Dock movement e.g.: I tied a corner of my dock to a tree so the ramp would not fall off the landing and get bent.





From SLA Oct 2024 Wave Damage Meeting Presentation

Dock Damage

July 2024 damage

From SLA Oct 2024 Wave Damage Meeting Presentation

Non-attributed Recent Email Quotes on Large Wakes

- 8/8/24: “What is done about the large waves that are created by the wake boats, and people not allowed to enjoy their own dock and the concern of children swimming when the waves come in. It is powerful enough to throw you against the dock or knock children down or off their floating devices, even when they are in the bigger part of the lake …”
- 8/12/24: Based on a photo of a crumpled ramp - “… their approach really took a beating. My approach broke a month ago and yesterday a ski boat was washed off its boat lift and ended up on a rocky beach”
- 8/26/24: “We live on Eastshore, directly across from what people say is the biggest part of the lake. The wake boats go back and forth, and back and forth, sometimes with a jet ski jumping the waves it's making. Pretty soon the waves breaking on our shoreline are huge. As a result, we can't let our toddler grandson play on our beach when the wake boats are out because the waves will knock him down. Besides it being dangerous, it's sadly made him afraid to play there. We completely disagree with those who have said that as long as they stay in the middle of the biggest part of the lake they won't affect the shoreline. Our lake is too small for wake boats. Period.”
- 9/3/24: “What a frustrating weekend at the lake due to HUGE waves created by the "Wake Setter" black surf boat and other surf boats. Our shoreline and dock were beat to hell with no reprieve all weekend. We had ropes snap and had to move our dock 10' over to the east to get it to the original position.”

From SLA Oct 2024 Wave Damage Meeting Presentation

How to Convert Wave Height to Power to Energy

- Reference:
  https://www.azocleantech.com/article.aspx?ArticleID=227

$H^2(t)$ -> P(t) -> E

Wave Power Formula

In general, larger waves are more powerful but wave power is also determined by wave speed, wavelength, and water density. The power of a wave is determined by the 'Wave Power Formula'. In this case, the 'power 'does not refer to the power that would be produced by a wave power machine, rather it means the 'wave energy flux', or the transport rate of wave energy. In deep water where the water depth is larger than half the wavelength, the wave power is found using the following equation:

$$P = \frac{\rho g^2}{64\pi} H_{m0}^2 T \approx \left(0.5 \frac{\mathrm{kW}}{\mathrm{m^3 \cdot s}}\right) H_{m0}^2\, T,$$

Where P is the wave energy flux per unit of wave-crest length, Hm0 the significant wave height, T the wave period, ρ the water density and g the acceleration by gravity. The above formula also says that wave power is proportional to the wave period and to the square of the wave height. If the significant wave height is given in meters, and the wave period in seconds wave power has units of kilowatts (kW) per meter of wavefront length.

Wave Energy

In average ocean conditions, the average energy density per unit area of sea surface waves is proportional to the wave height squared, shown in the following equation:

$$E = \frac{1}{16} \rho g H_{m0}^2,$$

where E is the mean wave energy density per unit horizontal area (J/m2), the sum of kinetic and potential energy density per unit horizontal area. The potential energy density is equal to the kinetic energy, both contributing half to the wave energy density E.

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This quote illustrates the math used to convert wave height to Power.

As discussed in the main portion of the presentation, the power (P) in a wave is proportional to the square of the wind height (H), as is illustrated in the top equation.

The energy that power can produce can then be determined by adding up all the power over time (in math terms, it is the integral of the power of the wave over the time period of the wave).

The presentation illustrates the math concept of this conversion from wave height to power to energy as: **$H^2(t)$ -> P(t) -> E**

$H^2(t)$ -> P -> E

Max Wave Height Figures 18 and 19 from Wave & Wind Study

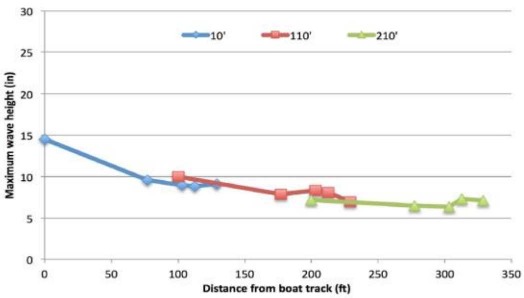

Figure 18. Maximum wave heights cruising at 25 mph in deep water at various standoffs.

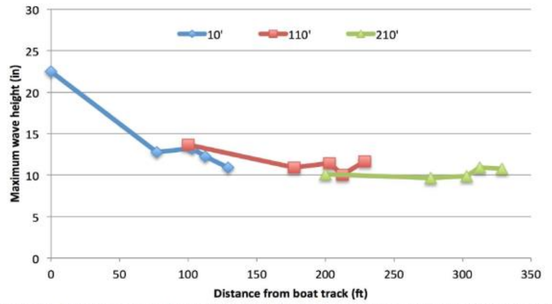

Figure 19. Maximum wave heights wakeboarding at 25 mph in deep water at various standoffs.

Note the increase in max wave height for further distances; the nature of test data is not precise since all variables cannot be controlled in the real world

Ref: (Draft Rev 2 (or 11???))
Characterization of Wake-Sport Wakes and their Potential Impact on Shorelines,
WATER SPORTS INDUSTRY ASSOCIATION (WSIA), November 2015

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These two plots illustrate the maximum wave height (the strongest one as the boat passes a sensor) for the boat in two modes: cruising (plot to the left) and wakeboarding (plot to the right). The surf mode produces even larger maximum wave heights as illustrate on slide 20.

Data vs Trending

- This plot illustrates that the deep-water measurements less closely follow the trend line than the shallow water data and trend line. It is not clear from the report why this occurs. Some speculations are provided.

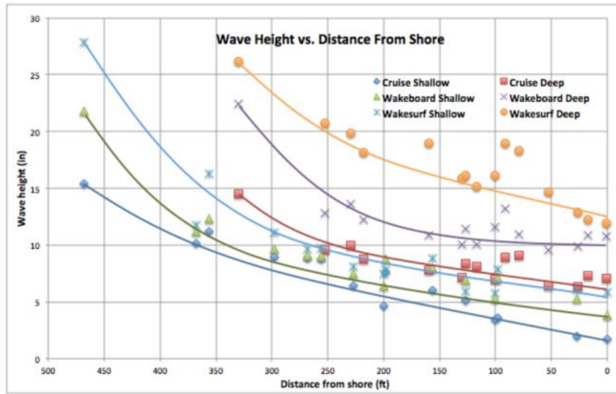
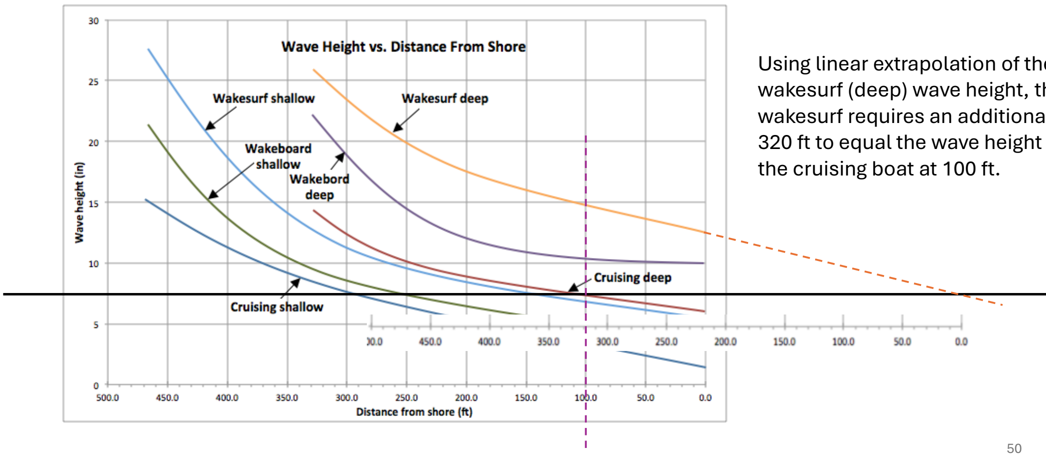


Figure 25. Wave height vs. distance from shore in shallow and deep water.

49

This plot show that the data smoothing curves created in the study have a fair amount of variance for the deep water tracks.

Wakesurf Distance to Equal Cruise Wave Height at 100’ (Deep)



Using linear extrapolation of the wakesurf (deep) wave height, the wakesurf requires an additional 320 ft to equal the wave height of the cruising boat at 100 ft.

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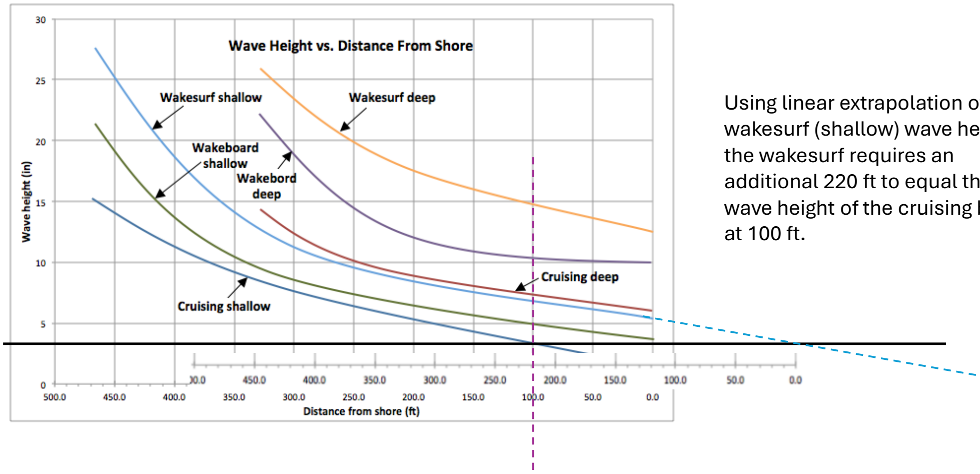
This slide illustrates the extrapolation of the wakesurf deep water plot to determine the extra distance needed to have the same wave height as the same boat in cruise mode at 100 ft. An additional 320 ft is required.

Wakesurf Distance to Equal Cruise Wave Height at 100’ (Shallow)



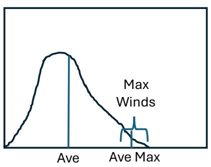
Using linear extrapolation of the wakesurf (shallow) wave height, the wakesurf requires an additional 220 ft to equal the wave height of the cruising boat at 100 ft.

51

This slide illustrates the extrapolation of the wakesurf shallow water plot to determine the extra distance needed to have the same wave height as the same boat in cruise mode. An additional 220 ft is required. Most of Sacheen Lake’s shoreline in the 35-mph section of the lake are more closely aligned with the deep water tracks of the study. Compare slides 18 (study’s deep water profile) and 31 (Sacheen Lake depth contours).

Probability of Winds > 5 Mph On Sacheen Lake

- Generic wind (mph) probability illustrating the mean value. Graph matches Deer Valley airport mean and average max wind in nature (Ave Max = ~ 2x Ave)
- Probability of max ave winds is small (area of the curve in the "Max Winds" area)
- Wake surfing on Sacheen is not 24/7occurrence, neither are winds of 5 mph, even less probable are winds at 10 mph



Wind probability distribution chart (license protected) created during a study of wind for energy generation purposes is generically depicted as shown to the left

Ref: Distributed Active Power Optimal Dispatching of Wind Farm Cluster Considering Wind Power Uncertainty, April 2022

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This slide illustrates a generalized wind speed distribution curve based on a reference. The plot in the reference is license protected, so only the characteristics of the plot are replicated.

The average wind is determined over the entire scope of possible winds. The plot illustrates how likely each wind speed is; the closer the speed is to the average, the more likely it is to happen. Since there are extreme winds, you can also see that the average is not at the peak of the curve. The average has to shift to the right to compensate for the much larger winds.

The Average Maximum speed is determined by looking at the subset of wind speeds that are the highest. How far away from the average wind speed the area for the maximum average wind speed is was not clear from the Deer Park data. However, the chart illustrates an average maximum wind speed that is 2X the average wind speed which IS consistent with the real world measured data at Deer Lake. The area labeled "Max Winds" is the area where the average maximum wind is calculated.

Additional Reading on Wind and Waves

- https://opentextbc.ca/geology/chapter/17-1-waves/#:~:text=As%20this%20happens%2C%20a%20point%20on%20the,equal%20to%20the%20wave%20amplitude%20(Figure%2017.3).&text=The%20wave%20%E2%80%9Corbits%E2%80%9D%20are%20both%20flattened%20and,wavelength%20decreases%20(the%20waves%20become%20much%20steeper)

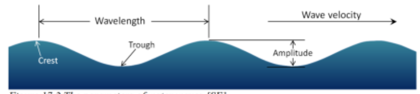

Figure 17.2 The parameters of water waves [SE]

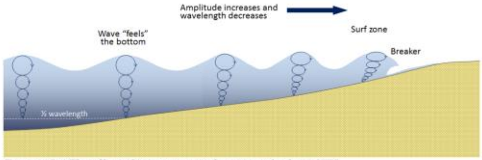

Figure 17.4 The effect of waves approaching a sandy shore [SE]

Even though they bend and become nearly parallel to shore, most waves still reach the shore at a small angle, and as each one arrives, it pushes water along the shore, creating what is known as a **longshore current** within the **surf zone** (the areas where waves are breaking) (Figure 17.7).

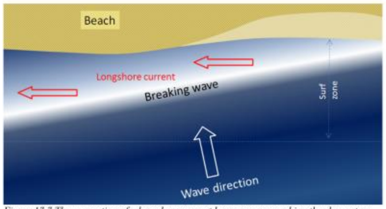

Figure 17.7 The generation of a longshore current by waves approaching the shore at an angle. [SE]

Wind Speed	Fetch	Duration	Amplitude	Wavelength	Wave Period	Wave Velocity	
km/h	km	h	m	m	s	m/s	km/h
19	19	2	0.27	8.5	3.0	2.8	10.2
37	139	10	1.5	33.8	5.7	5.9	19.5
56	518	23	4.1	76.5	8.6	8.9	32.0
74	1,313	42	8.5	136	11.4	11.9	42.9
92	2,627	69	14.8	212	14.3	14.8	53.4

Table 17.1 The parameters of wind waves in situations where the wind blows in roughly the same direction for long enough for the waves to develop fully. The duration times listed are the minimum required for the waves to develop fully. [SE from data at: http://en.wikipedia.org/wiki/Wind_wave]

Looking at the first row

- 19 km/h wind = 11.8 mph
- 19 km fetch = 11.8 miles
- At least 2 hours of steady wind is required
- 0.27 m height = 10.6 inches
- 8.5 m wavelength = 27.9 ft
- 10.2 km/h wave velocity = 6.3 mph

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These illustrations provide more background on waves.

Top left: Illustrates wave parameters.
Top right: Illustrates how the wave's circular motion is impacted by shallow water.
Bottom left: Illustrates how longshore currents can be created by wind that is not perpendicular to the shore
Bottom right: Illustrates specific wind speed and fetch examples. To the right of the table an example is illustrated in feet or miles and mph.