Current Science Behind Hazardous Wakes

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Overview

- Generally accepted technical standards
    - US Army Corps of Engineers Coastal Engineering Manual Part 2: "Water Wave Mechanics"
- Peer-reviewed published research
    - 2022 St. Anthony Falls Laboratory study: "A Field Study of Maximum Wave Height, Total Wave Energy, and Maximum Wave Power Produced by Four Recreational Boats on a Freshwater Lake"
    - 2016 Volume and contents of residual water in recreational watercraft ballast systems
- Academic technical reports
    - 2020 Western Colorado University, as part of work towards a Master's degree: "Analyzing Threats to Water Quality from Motorized Recreation on Payette Lake, Idaho"
    - 2015 University of Laval (Quebec): Impact of the Navigation - sediment suspension study: Lake Masson and Sand Lake cases
- Industry sponsored/authored studies
    - 2015 Water Sports International Association: "Characterization of Wake-Sport Wakes and Their Potential Impact on Shorelines"
    - 2022 Journal of Water Resource and Protection: "Numerical Study of the Impact of Wake Surfing on Inland Bodies of Water"
- Lake Organization sponsored studies
    - Boat Wake Impact Analysis – Lake Rabun and Lake Burton, Georgia
- Governmental report summaries and recommendations
    - 2022 State of Michigan Dept. of Natural Resources, Fisheries Division: Wake boats: concern and recommendations related to natural resource management in Michigan waters"
- Vilas County Total Phosphorus Trends

USACE Water Wave Mechanics

<u>Background</u>

- Manual for coastal engineering
- Describes wave theory
- Document link: https://www.publications.usace.army.mil/usace-publications/engineer-manuals/

USACE Water Wave Mechanics

<u>Take Home Message</u>

- Airy wave theory: Total wave **energy** (the capacity to do work) is related to the square of the wave's height and the wavelength of the wave.

$$\frac{\rho g H^2 L}{8}$$

  - Ie. An 8 inch tall wave contains 4 times the energy of a 4 inch tall wave, and 16 times the energy of a 2 inch tall wave.
- This wave theory (Airy wave theory) is simplified. Many other aspects can impact how waves function, such as deep/shallow water. However, Airy wave theory is often used for simple modeling.

St. Anthony Falls Study

Background

- University of Minnesota College of Science & Engineering at St. Anthony Falls Laboratory
- Funding was crowd-sourced
- Donors had no input in project design, data collection, or analysis
- Used sensors to collect data, analyzed results
- Document link: https://conservancy.umn.edu/handle/11299/226190

St. Anthony Falls Study

Take Home Messages

- Wakesurf boat wake wave heights are 2-3 time larger than typical recreational boats
- Wakesurf boats wake wave energy is 3-9 times larger than typical recreational boats
- Propellor wash from wakesurf boats is likely stirring up bottom sediments and impacting aquatic vegetation/habitats more so than typical recreational boats (quantitative results likely to be released in fall 2023)

St. Anthony Falls Study

<u>Take Home Messages (continued)</u>

- wakesurf boats require distances greater than 500 ft to attenuate wake wave characteristics to levels equivalent to non-wakesurf boats operating in typical planing conditions

Results for required operational distance illustrating how data from this study may be used

Reference condition	Operational distance required by wakesurf boat to attenuate to reference condition levels
Example 1 non-wakesurf boat planing at an operational distance of 200 ft (Condition 2 - planing)	Maximum Wave Height: >500 ft. Total Wave Energy: >575 ft. Maximum Wave Power: >600 ft.
Example 2 non-wakesurf boat transition to planing at an operational distance of 200 ft (Condition 1a - largest wave)	Maximum Wave Height: >425 ft. Total Wave Energy: >425 ft. Maximum Wave Power: >425 ft.

Campbell et. al.

<u>Background</u>

- University of Wisconsin study on amount of water and plankton found in ballast tanks that were “emptied”
- Examined ballast of 23 wakeboats
- Document link: https://www.researchgate.net/publication/306920452_Volume_and_contents_of_residual_water_in_recreational_watercraft_ballast_systems

Campbell et. al

Take Home Messages

- Found residual water in ballast tanks was highly variable. Range was from 1 liter to 86.8 liters (1 quart to 23 gallons). Average residual water was 8 gallons.
- Found live native plankton in ballast water.
- On 2 occasions, found live invasive zebra/quagga mussel veligers (early life stage of zebra mussels).

Payette Lake Idaho Study

- Background
  - One individual’s work towards a Master’s Degree from Western Colorado University
  - Work was coordinated with Big Payette Lake Water Quality Council
  - Work considered only impacts towards environmental resources
  - Study focused on the potential for motorized boats to disturb bottom sediments and shorelines in Payette Lake
  - Study used sensors to collect data
  - Document link: https://lakeaumanwatch.files.wordpress.com/2021/06/payettelake.pdf

Payette Lake Idaho Study

Take Home Messages

- Maximum slipstream velocities of 2 different wakeboats “decayed” such that bottom sediments (sand) could still be **moved** at 33 ft deep.
  - Assumes a 15 degree boat trim angle
  - Particle **suspension** could occur at roughly 20 ft deep
  - Particles were sand in this study – silt could be moved/suspended with lower slipstream velocities, but this was not investigated
  - Wind waves were likely to disturb sediments at depths up to 5 ft.
- Used data and bathymetry map to recommend revising the current 300 ft from shore slow no wake zone to at least a 500 ft slow no wake.

Laval Study

<u>Background</u>

- Study through University of Laval with University of Montreal's proposed trials
- Commissioned by the "Coalition of Sustainable and Responsible Navigation"
- Investigated how deep the water column is impacted by wakesurf activities
- Used sensors to collect data
- Document link: https://www.documentcloud.org/documents/6801170-S%C3%A9Bastien-2015-English-U-of-Laval-1.html

Laval Study

Take Home Messages

- Water column disturbances from a pontoon with a 100 hp motor at 3 mph, 6mph, and max speed were seen at 3-6 ft deep
- Water column disturbances from wakesurf boat was up to 16 ft deep
- Water column stays disturbed for over 1 minute

Goudey Study

Background

- Consultant group study (C.A. Goudey & Associates) from Massachusetts, study occurred in Florida inland lakes
- Funded by Water Sports Industry Association (WSIA)
- Study looked at wave height generated from cruising, wakeboarding, and wakesurfing in a wakeboat
  - Considered wake dissipation
- Compared wake energy from wake boats to wind generated wave energy
- Used sensors to collect data
- Document link: https://www.familiesforboating.com/wp-content/uploads/2021/09/WSIA_draft_report_Rev_II.pdf

Goudey Study

<u>Take Home Messages</u>

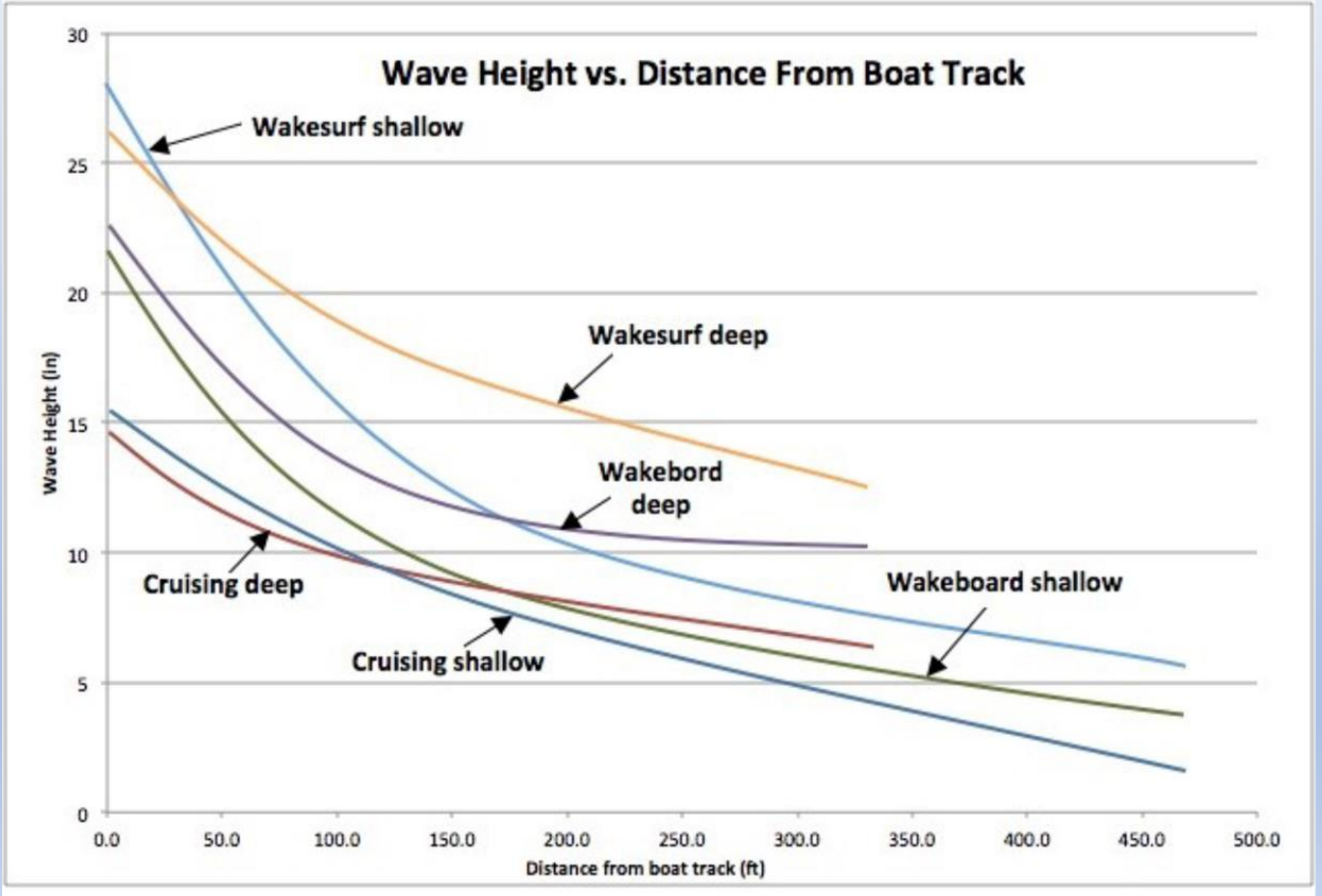
- Waves dissipate from 1) a few large waves to many smaller waves; 2) friction against the lake bottom; and 3) through breaking on the surface
- Larger waves created from wakeboarding and wakesurfing decrease in height rapidly over roughly 200 ft from their source due primarily to breaking. An exception to this is wakesurfing in deep water: it takes 300 ft for the wake to decrease to half its original height. (Does not consider wave energy)
- A wake boat in surf mode passing 100 ft from shore has the same total energy as 4.5 minutes of a 10 mph breeze over 1 mile of open water. (Does not consider wave height. His data show wave height is nearly 20” for that boat wake, and less 4” for the wind waves.)

Goudey Study

<u>Take Home Messages (continued)</u>

See graph

- Shallow = 8-10 ft deep
- Deep = 22-30 ft deep



Goudey Study

<u>Take Home Messages (continued)</u>

See graph

- Shallow = 8-10 ft deep
- Deep = 22-30 ft deep

		Maximum wave height (in)			
Distance from track (FT)		0	100	200	300
Cruising	Shallow	15.42	10.16	8.83	5.09
Cruising	Deep	14.54	9.95	7.19	6.32
Wakeboard	Shallow	21.82	11.18	9.13	6.93
Wakeboard	Deep	22.46	13.63	10.10	9.87
Wakesurf	Shallow	27.83	11.75	9.63	5.91
Wakesurf	Deep	26.14	19.88	15.89	12.92

Fay et. al. Study

Background

- Study investigated wind waves and wakesurfing waves; and modelled their potential to impact lake bottom and shorelines
- Study was funded by the National Marine Manufacturers Association (NMMA)
- Two of the 3 authors work for marine manufacturing companies
- Report uses physics theories and modelling to create conclusions (no field data collection)
- Published in Journal of Water Resource & Protection (SCRIP open access journal publisher)

Fay et. al. Study

Take Home Messages (consider in context)

- Finds bottom and shoreline impacts from wakeboats are “minimal” if operated 200 ft from shore and in water at least 10 ft deep.
- Indicates propwash is within 7.5 ft of the water surface, assuming propeller sits at 3 ft below the water surface
- Makes mention that anecdotally wakesurfers prefer water that is at least 16 ft deep to create the best waves
- This study finds conclusions that are quite different from the other studies available
- ***Journal and article have received significant criticism***

Lake Rabun and Lake Burton Study

Background

- Lake organization funded study of safety concerns and shoreline erosion potential on 2 reservoirs in Georgia
- Both lakes a long and narrow, with some areas 500 ft or less wide
- 66% of lake association member survey respondents reported frequent or occasional swamping caused by wake boat waves (57% response rate in survey, total of 486 responses)
- Used sensors to collect data
- Document Link: https://img1.wsimg.com/blobby/go/cf65b112-4ce9-4da9-a066-f09ac53fad63/Boat%20Wake%20Impact%20Analysis%20-%20Final%20Report%20-%20202.pdf

Lake Rabun and Lake Burton Study

<u>Take Home Messages</u>

- Wake height attenuation was similar to the Goudey study for wakeboats: cruising/water skiing causing the smallest wake, wakeboarding causing an intermediary wake, and wakesurfing causing the largest wake.
- Wakesurfing caused a wake twice as high as cruising/water skiing.
- Wakesurfing waves contained about 500% more energy than cruising/waterskiing, even 500 ft from shore.
- Horizontal forces on vertical walls created by wakesurfing waves was over 100% more than a cruising/waterskiing, even when 500 ft from shore.
- Recommended 100 yd (300 ft) for wakeboarding and 150 yd (450 ft) for wakesurfing distance from shore, admitting that it is not quite long enough for wakesurf waves to attenuate to the levels of cruising/water skiing 100 ft from shore.

MI DNR Paper

Background

- Summarized findings from other research projects, many are previously mentioned
- Offered recommendations for wakeboat operation
- Document link: https://mymlsa.org/wp-content/uploads/2022/09/DNR-Wake-Boat-Report.pdf

MI DNR Paper

Take Home Messages

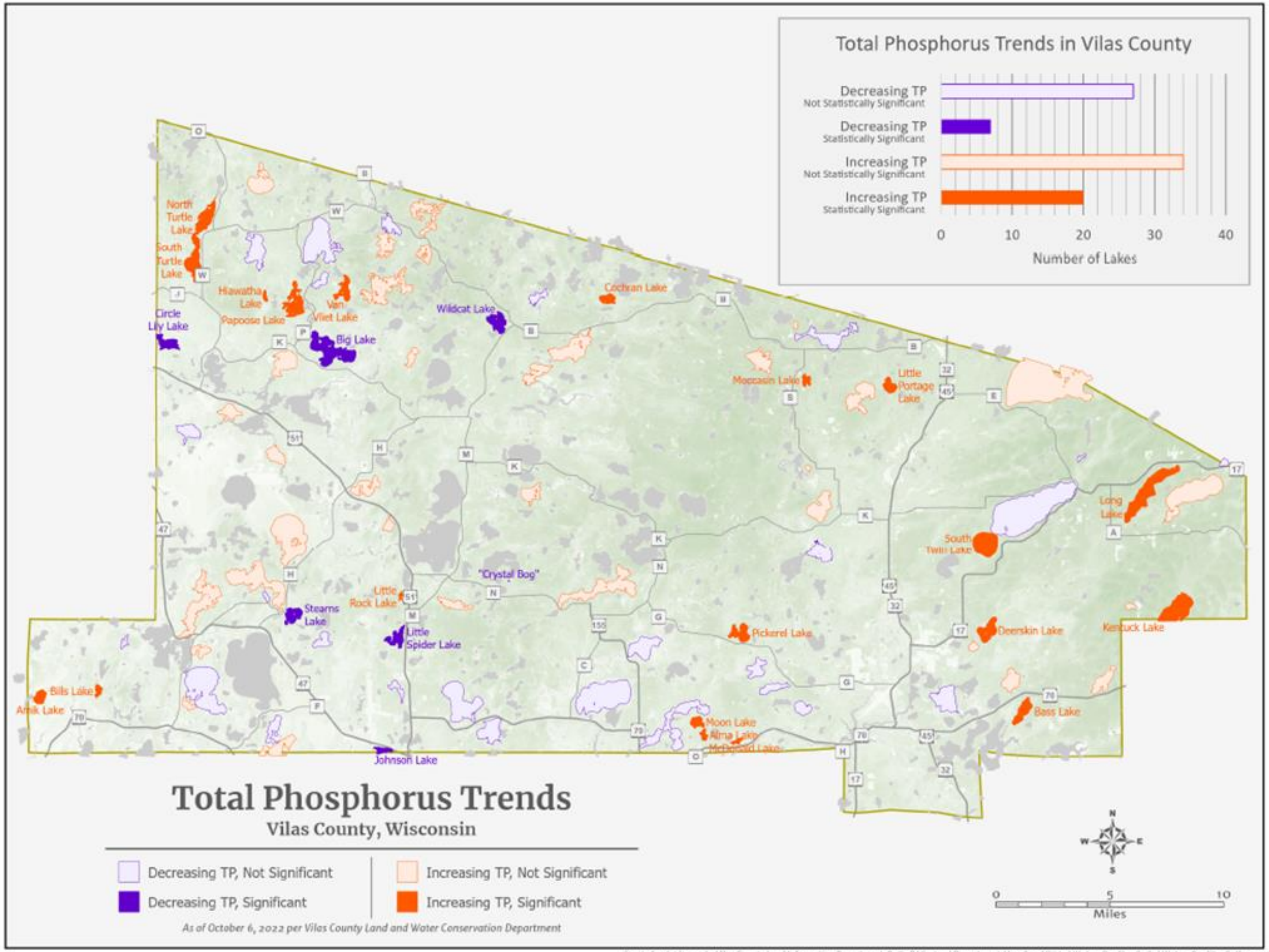
- Boats operating in wakesurfing or wake boarding mode should:
  - operate at least 500 ft from shore and docks
  - Be in water at least 15 ft deep
  - Drain ballast tanks completely before transporting over land
- Regulatory authorities should implement an increased educational and outreach campaign to improve awareness of wake boat operators

Vilas County Total Phosphorus Trends

From 1990-2019, total phosphorus trends are more so trending to higher total phosphorus concentrations.

- Of 88 lakes that had enough data between 1990-2019 to analyze for total phosphorus trends in Vilas County, 27 show statistically significant trends: 74% were increasing in total phosphorus over time, and 25% were decreasing in total phosphorus over time, indicating overall degrading water quality.

Document link: https://www.vilascountywi.gov/departments/services/land_water_conservation/lakes.php


Total Phosphorus Trends in Vilas County
Decreasing TP
Not Statistically Significant
Decreasing TP
Statistically Significant
Increasing TP
Not Statistically Significant
Increasing TP
Statistically Significant
0
10
20
30
40
Number of Lakes
North Turtle Lake
South Turtle Lake
Hiawatha Lake
Papoose Lake
Van Vliet Lake
Circle Lily Lake
Big Lake
Wildcat Lake
Cochran Lake
Moccasin Lake
Little Portage Lake
Long Lake
South Twin Lake
"Crystal Bog"
Little Rock Lake
Stearns Lake
Little Spider Lake
Pickerel Lake
Deerskin Lake
Kentuck Lake
Bills Lake
Amik Lake
Moon Lake
Alma Lake
McDonald Lake
Bass Lake
Johnson Lake
Total Phosphorus Trends
Vilas County, Wisconsin
Decreasing TP, Not Significant
Decreasing TP, Significant
Increasing TP, Not Significant
Increasing TP, Significant
As of October 6, 2022 per Vilas County Land and Water Conservation Department
Miles

Summary

- Wave impacts are based on wave height and wavelength. Of these, wave height is most impactful.
- Wakesurfing makes waves which are 2-3 times higher and contain 3-9 times more energy than when cruising.
- Residual ballast water can be plentiful and contain live plankton, including invasive mussels capable of reproducing.
- Wakesurfing can disturb bottom sediments between 16 to 33 ft deep.
- Waves from wakesurfing attenuate most over the first 200 ft; wakesurfing waves are still more than twice as large as they would be from cruising in the same boat.
- Wakesurfing waves contain 6 times as much energy than cruising waves, even 500 ft from shore.
- Horizontal forces on vertical walls from wakesurfing are about 2 times more than cruising/waterskiing, even 500 ft from shore.
- Many Vilas County lakes have total phosphorus levels that are increasing. Disturbing bottom sediments and eroding shorelines is one way of many that increases total phosphorus in water. Impacts from high total phosphorus in lakes can include excessive plant and algae growth and depleted oxygen for fish.

Sources

Campbell, Tim; Verboomen, Todd; Montz, Gary; and Seilheimer, Titus. 2016. Volume and contents of residual water in recreational watercraft ballast systems. *Management of Biological Invasions.* Vol 7.

Fay, Endicott; Gunderson, Andrew; and Anderson, Arden. 2022. Numerical study of the impact of wake surfing on inland bodies of water. *Journal of Water Resource and Protection*.

Francis, James; Nohner, Joel; Bauman, John; and Gunderman, Brain. Sep 2022. Wake boats: concerns and recommendations related to natural resource management in Michigan waters. State of Michigan Dept. of Natural Resources. Fisheries Report 37 (FR 37).

Higley, Cathy. May 2022. Vilas County lakes assessment: a look at water quality trends in Vilas County lakes from 1990-2019. Vilas County Land & Water Conservation Department.

Goudey, C.A. and Girod, L.G. 2015. Characterization of wake-sport wakes and their potential impact on shorelines. Watersport Industry Association, Orlando, Florida.

Marr, Jeffrey; Riesgraf, Andrew; Herb, William; Lueker, Matthew; Kozarek, Jessica; Hill, Kimberly. 2022. A Field Study of Maximum Wave Height, Total Wave Energy, and Maximum Wave Power Produced by Four Recreational Boats on a Freshwater Lake. Retrieved from the University of Minnesota Digital Conservancy, https://hdl.handle.net/11299/226190.

Ray, Alex. August 2020. Analyzing threats toe water quality from motorized recreation on Payette Lake, Idaho. Master's thesis. Western Colorado University.

Raymond, Sebastien and Rosa Galvez-Cloutier. 2015. Impact of lake navigation – sediment suspension study: Lake Masson and Sand Lake cases. Laval University, Quebec.

USACE 2012 Coastal Engineering Manual - Part II - Coastal Hydrodynamics, Manual of the United States Army Corps of Engineers. EM 1110-2-1100 Ch. 1.

Water Environmental Consultants. 2021. Boat wake impact analysis, Lake Rabun and Lake Burton, Georgia. Water Environmental Consultants, Final Report, Mount Pleasant, South Carolina.