COTTY FAY MARINE DESIGN INC

TECHNICAL REPORT

TR-25-0020

CRITICAL REVIEW OF SAFL PROJECT REPORT NO. 611: "A Field Study of the Recreational Powerboat Hydrodynamics and their Impacts on the Water Column and Lakebed"

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DATE	**10/8/25**						

Contents

ABSTRACT

This review of SAFL Project Report No. 611 evaluates the hydrodynamic and environmental impacts of recreational powerboats, with emphasis on wakeboats. Field data from Lake Minnetonka show that all boats generate waves and propeller wash that can increase turbidity, resuspend nutrients, and disturb vegetation in shallow water; however, these effects are not unique to wakeboats and depend mainly on depth, speed, and operator behavior. The study's methodology—testing non-wakeboats at unrealistic low speeds under light loading while maximizing wakeboat ballast—introduces significant bias and excludes popular vessel types such as pontoons. Comparative analysis was further limited by the lack of baseline turbidity data accounting for wind, rain, and seasonal watershed variability.

For manufacturers and operators, the review underscores that ecological impacts are not exclusive to wakeboats but are broadly shared across recreational vessels, depending on depth, speed, and operator behavior. Lakes deeper than 8–10 feet generally exhibit no measurable long-term environmental impact from responsible boating activity. The report ultimately emphasizes that watershed development and runoff, rather than boating, are the dominant drivers of nutrient loading and eutrophication.

This analysis supports manufacturers in contextualizing wake-related debates, highlighting the need for balanced policy based on realistic vessel operating conditions, and encouraging operators to follow depth and distance guidelines to minimize shoreline and habitat disturbance.

EXECUTIVE SUMMARY

The Saint Anthony Falls Laboratory's Phase II study examines the hydrodynamic effects of recreational powerboats, with a particular emphasis on wakeboats, on the water column and lakebed of Lake Minnetonka in Minnesota. Conducted in 2022 and 2023, the study tested seven boats- two deck boats, three bowriders, and two wakeboats—focusing on hydrodynamic forces such as bow and stern pressure waves, transverse gravity waves, and propeller wash.

While the study aims to provide science-based guidelines for minimizing ecological damage from recreational boating, significant methodological flaws and biases undermine its conclusions and applicability to real-world recreational boating scenarios. This study and its report should not be used as the basis for public policy.

Key Flaws and Biases in the Study

The study's operational testing was heavily biased toward exaggerating wakeboat impacts. Wakeboats were tested at full load and maximum trim to maximize wake and wave energy, conditions not representative of typical wake-surfing operations.

But what the study didn't examine was telling. Other boats, such as the Sea Ray 190 (tested at 7 mph in 2023) and the Cobalt R5 (tested at 9 mph in 2022), were operated lightly loaded at slow, near-idle speeds, akin to no-wake zone conditions. Notably, the Cobalt R5, advertised as a wake-surfing boat **(Figure 1)**, was not tested in a manner reflecting its typical recreational use, rendering comparisons to wakeboats invalid.

The exclusion of other popular boat types, such as pontoon boats, which are often heavily loaded and used for water sports **(Figure 2)**, further limits the study's scope and relevance.

The study's use of the length Froude number for comparing boats is misleading, as it does not account for the operational range of planing and semi-displacement craft. A volumetric Froude number would have provided a more realistic comparison, but the chosen metric obscures typical recreational boating impacts.

Testing was conducted in September and October, outside peak recreational season, and lacked a control dataset to account for natural variations due to wind or rain. The data revealed spikes in suspended solids unrelated to testing, highlighting environmental variability not addressed in the study's conclusions.

Figure (1): Cobalt R5 Wake Surfing

Findings and Environmental Impacts

The study identifies hydrodynamic phenomena, including bow and stern waves, transverse gravity waves, and propeller wash, which can resuspend sediment, increase turbidity, and release nutrients like phosphorus, potentially contributing to algae growth. Propeller wash was also noted to disrupt thermal stratification, dissolved oxygen levels, and aquatic vegetation in shallow water. However, the study fails to differentiate between inboard, outboard, or sterndrive exhaust arrangements, which could influence these impacts. The data suggests that all boats contribute to these phenomena, but the biased testing exaggerates wakeboat effects compared to other recreational boats.

Recommendations and Their Limitations

The report recommends restricting all motorized boats in water depths under 10 feet, wakeboats in depths under 20 feet, and enforcing no-wake zones (speeds under 5 mph) in shallow areas. It also advises avoiding areas with aquatic vegetation. While these recommendations appear to support lake management policies, they are based on flawed testing protocols that do not reflect typical recreational boating practices. The study's focus on wakeboats, driven by their funding and scope, overlooks the broader context of recreational boating, including the comparable impacts of other boat types when operated responsibly.

The study discusses the similitude used to compare the boats as the length Froude number which is defined using the waterline length of the boat. In the case of planing and semi-displacement craft, the scaling is done with the volumetric Froude number. The impact is the boats should be tested at the same volumetric Froude number to provide a realistic comparison. The length Froude number in the study provides cover and legitimacy for the data but doesn't represent the operational range of these boats at full capacity or the likely wake produced by the boat being operated in a recreational setting. The testing was all staged and the operation of the boats was done by the authors during the off season in September and October. In addition, the data does not have a datum point outside of the testing area that would show the natural occurring variation in the suspended solids over the testing period caused by wind and rain events. The data clearly shows numerous spikes in the reported suspended solids that were outside of the operational testing runs caused by other environmental phenomena.

All the boats tested were tested lightly loaded with one or two people on board. It is not unrealistic to see a pontoon boat or other boat crowded with the extended family and all their weekend gear. Although the wake boat was tested at full load and maximum trim, the other boats are simply a footnote. A lot of very popular boats were left out of the testing including the ever-popular pontoon boat. The pontoon boats are generally rated for twelve or more passengers and their gear.   They have the power to cruise at speed and provide performance for all sorts of water sports.   **Figure (2)** shows a pontoon boat used for wake surfing.

Figure (2): Pontoon Boat Wake surfing on a small lake.

Contextual Data

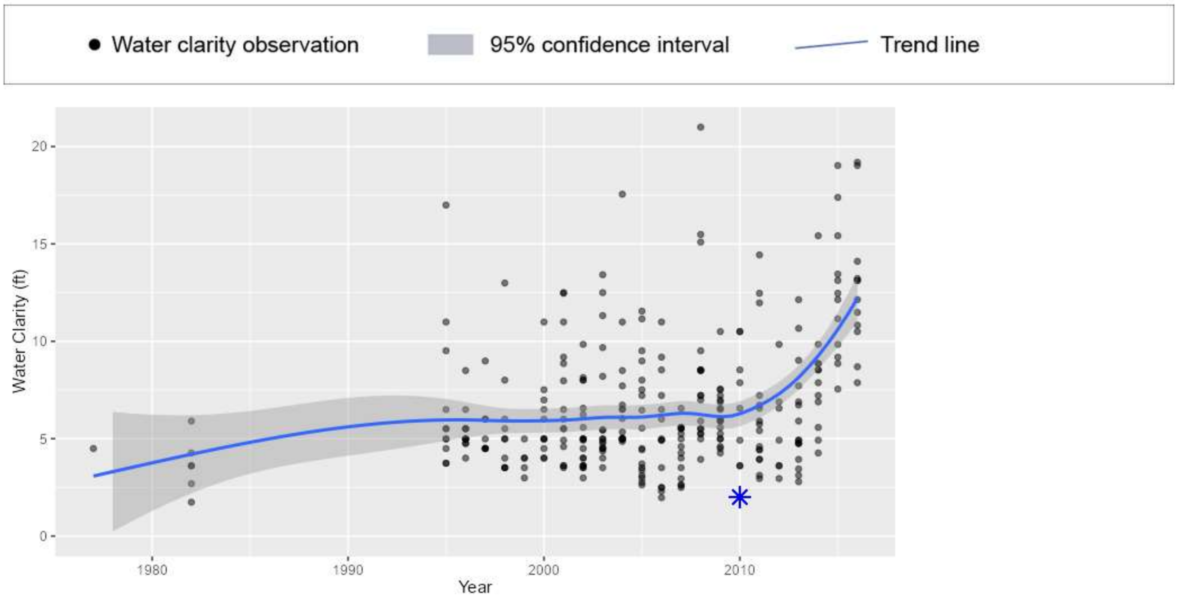
Long-term data from Maxwell Bay **(Figure 3)** shows improving water clarity over the past 30 years, likely due to reduced nutrient runoff from land repurposed from farmland to residential use. This trend undermines claims that wake-surfing boats uniquely contribute to eutrophication. When operated responsibly, recreational boats, including wakeboats, have no measurable environmental impact on lakes deeper than 10 feet and over 50 acres, a finding not adequately reflected in the study's conclusions due to its biased methodology.

Lake Transparency Trend

This figure show water clarity over time on this lake. The trend analysis was performed with a Seasonal Mann Kendall test. This statistical test detects changes in water clarity over time by comparing months across years (example - Mays are compared to Mays, Junes to Junes, etc…). For lakes with enough data, the figures include a trend line, which shows the direction of detected changes in water clarity. The gray area around the trend line represents the range where the actual clarity measure will fall with 95% certainty.

Trend analysis result:

For years 1977 to 2016 there is evidence of improving water clarity at this lake, of approximately 0.8 feet per decade. For the most recent year of the analysis, median water clarity was 6.13 feet deeper than the watershed median. Zebra mussels were discovered in this lake in 2010.



Water transparency is an excellent indicator of water quality, and the majority of these data are collected by volunteers. Many years of data are needed to detect trends in water quality, and we are always looking for new volunteers. Join the MPCA's Citizen Lake Monitoring Program and help collect this important information for your lake.

Figure (3): Water Clarity Observation over the thirty years

Conclusion

While the Saint Anthony Falls Laboratory's Phase II study provides some insights into hydrodynamic impacts, its methodological flaws, biased testing, and narrow focus on wakeboats limit its utility for informing equitable lake management policies. Policymakers and lake managers should approach the study's recommendations with caution, recognizing that all recreational boats, when operated responsibly, have comparable and minimal impacts in appropriately sized and deepened lakes.

ENVIRONMENTAL IMPACT

The report is purported to be a detailed review of the impact of a range of recreational motorboats traversing a lake and their effect on the turbidity in the water column through to the lakebed. The report answers the question if the wake from a wakeboat can be measured through the water column to the lakebed in 9 feet and 27 feet of water. But the report does not determine if this impact is environmentally harmful to the lake. The area of disturbance for the wakeboat is about a third of the beam of the boat or approximately 2.75 feet. The amount of phosphorus suspended into the water will depend on the lake, depth and type of sediment. The bottom of the lake is disturbed by all types of actions including.

Anthropogenic Impacts

Swimmers

Municipal beaches

Municipal boat ramps

Docks on shoreline homes

Beaches on shoreline homes

Shoreline construction

Recreation motor craft

Natural Impacts

Wind Event – the wave action generated by the wind causes a steady mixing of the water column as noted in report during the day when the level of suspended solids increased during the day.

Rain Event – runoff over the watershed, roads and developed areas.

The report focuses on the total suspended solids (TSS) in the water as the benchmark for the environmental impact. The report does not tie the impact of the operation of the wake boat to the level of suspended solids of the lake. The anthropogenic and natural impacts on the level of suspended solids are difficult to separate and quantify. The report attempts to quantify the impact of recreational boating on the level of suspended solids, but as noted below from the report in bold, the author discusses the impact of wind and rain events.

Excerpt taken from the report, page 109, In 2022, all samples collected in North Arm Bay had relatively low TSS concentrations regardless of date, location, depth, or morning or afternoon (<10 mg/L; Figure 61). Across boats and conditions, sampling location and sampling depth were most frequently significant in 2022 (Table 11). **Although boat pass had a significant effect on suspended solids for some boat operating conditions, there was not a consistent pattern with TSS (total), VSS (organic) or FSS (inorganic fraction) (Figure 61).**

Suspended solids concentrations overall were slightly higher in Maxwell Bay in 2023 than in North Arm Bay in 2022, especially on the day the Sea Ray SPX190 was tested (Figure 62). **On this day the average wind speeds increased from approximately 7 mph in the morning to approximately 15 mph in the afternoon which may account for some of the increase.**

Figure (4) shows Figure (61) from the report SAFL 611 and shows no correlation with any impact from wake surfing. The level of suspended solids decreases from before to after the boat passes the sensors during the testing in 2022.

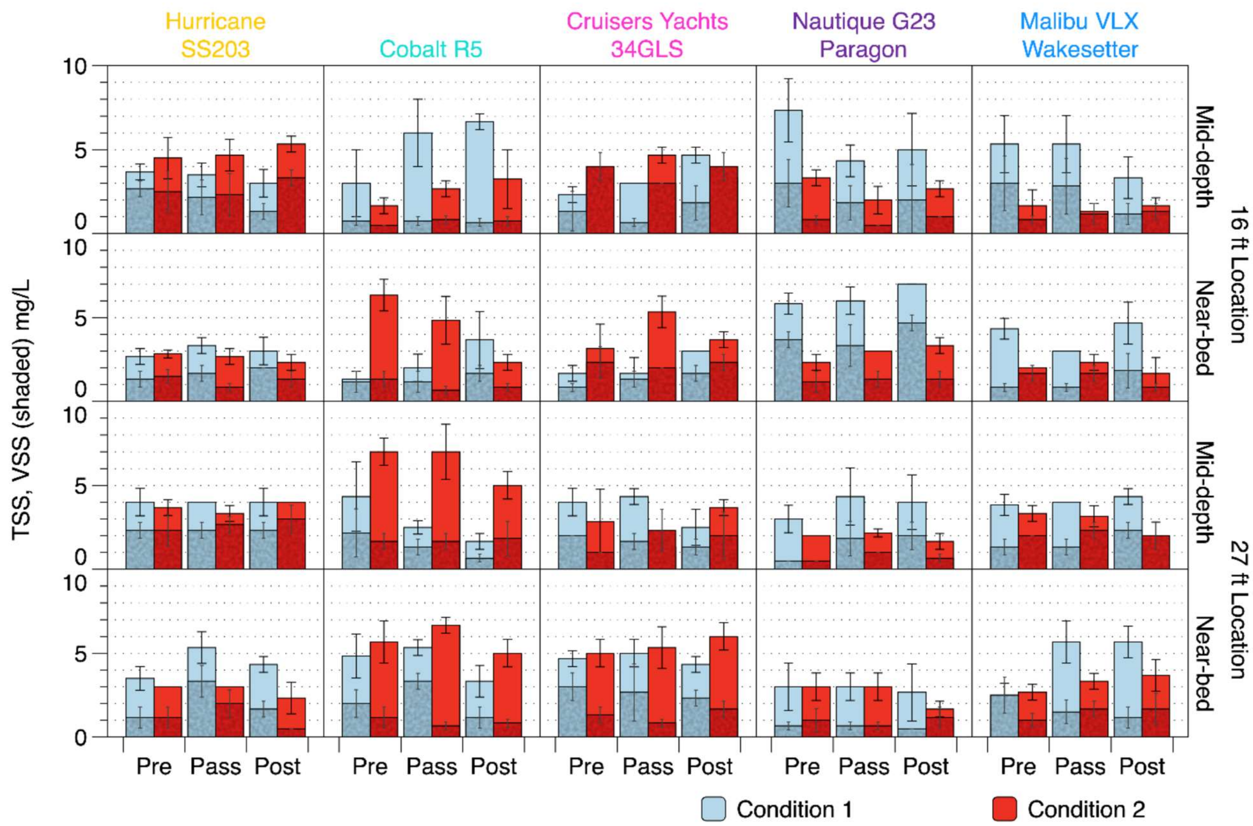


Figure 61. Total suspended solids (TSS) and volatile suspended solids (VSS; shaded) for 2022 water samples in North Arm Bay. The blue and red bars are planing mode (Condition 1), and displacement mode for the non-wakeboats and semi-displacement for the wakeboats (Condition 2), respectively. The difference between TSS and VSS is the fixed suspended solids (FSS).

Figure (4): Figure (61) from Report SAFL 611

The testing of the wake boats and the Sea Ray 190 were conducted on October 9th 2023 after a wind event spanning a few days. **Figure (5)** shows the level of suspended solids in Figure (62) of the report. The figure shows a reduction in the level of suspended solids during the test. The level of turbidity was taken on the day of the test at the locations of the sensors but not taken at any control point to get a sense of the normal variability of the turbidity during the day as stated in the report. The turbidity changes could have been happening all day where the boat would have a minimal impact on the variability in turbidity or level of total suspended solids. The two heavier boats, the Cobalt R5 and the Cruiser 34 GLS were not tested in 2023 which would have been a more appropriate comparison to the wake boats.

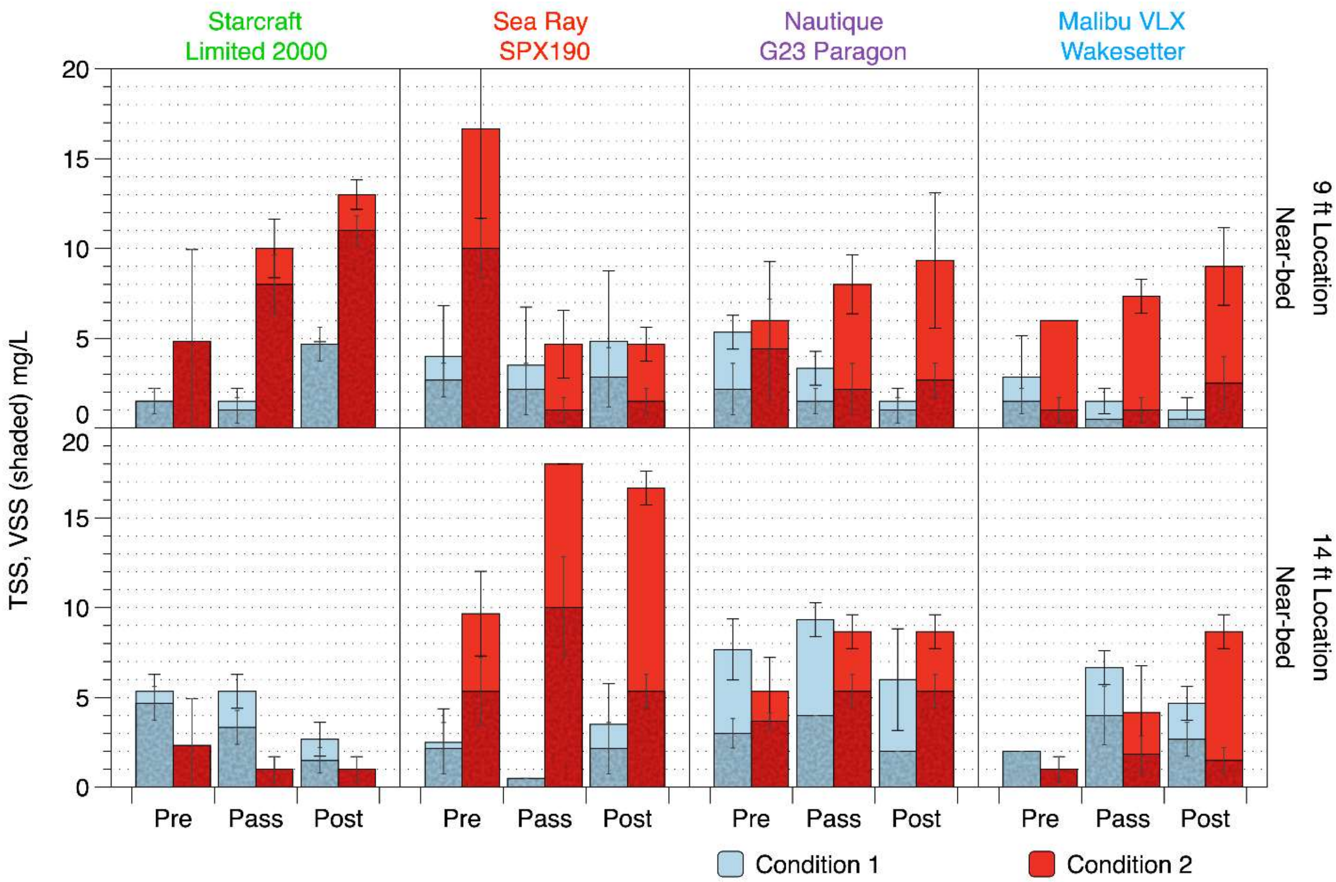


Figure 62. Total suspended solids (TSS) and volatile suspended solids (VSS; shaded) for 2023 water samples in Maxwell Bay. The blue and red bars are planing mode (Condition 1), and displacement mode for the non-wakeboats and semi-displacement for the wakeboats (Condition 2), respectively. The difference between TSS and VSS is the fixed suspended solids (FSS).

Figure (5): Figure (62) from report SAFL 611

The testing of the wake boats was also done after a wind and heavy rain event where the variability of the turbidity would be in question. The three days prior to the wake boat test on the 16th of October there was steady rain with 1.94 inches of rain and a steady wind of 15 mph with gusts to 24 mph. The residual runoff and mixing generated by the wind would affect the turbidity throughout the lake during the testing of the two wake boats making the data inconclusive and unreliable.

In order to visualize the water flow in the water column a CFD analysis was conducted. The movement of the boat through the water generates a three-dimensional disturbance of flow over the surface of the water. The relative flow is highest and deepest on the centerline of the boat path, which intuitively makes sense. **Figure (6)** shows the relative velocity of the boat over a nine-foot depth at 12 mph (5.37 m/s). In the analysis the boat is stationary, and the water is moving at 5.37 meters per second (12 mph). The higher speed around the transom shows the flow acceleration at the stern which projects to the bottom. **Figure (7)** shows the velocity profile at 4.9 feet (1.5m) off centerline. The velocity profile in **Figure (7)** shows a marked decrease in the effect of the hull on the water column. The distance off centerline is the outer beam of the boat. After the boat passes the water column mixes and disperses outward from the path of the boat.

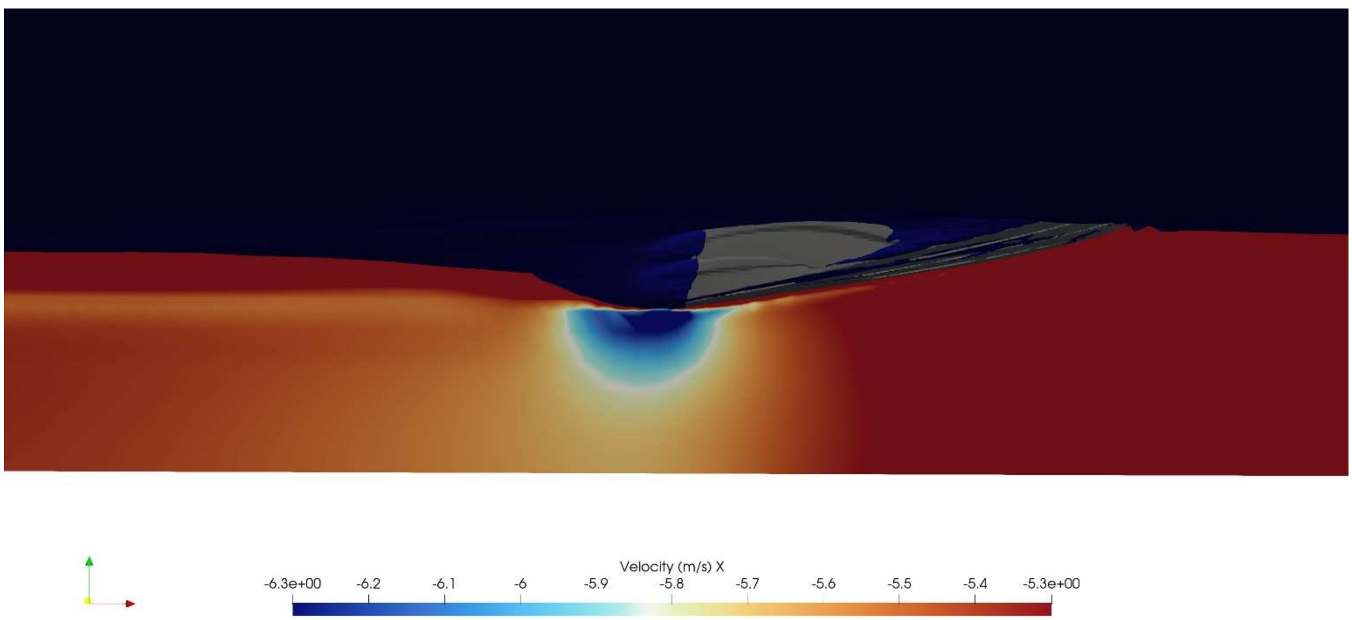


Figure (6): Velocity Profile through Centerline in 9 feet of water.

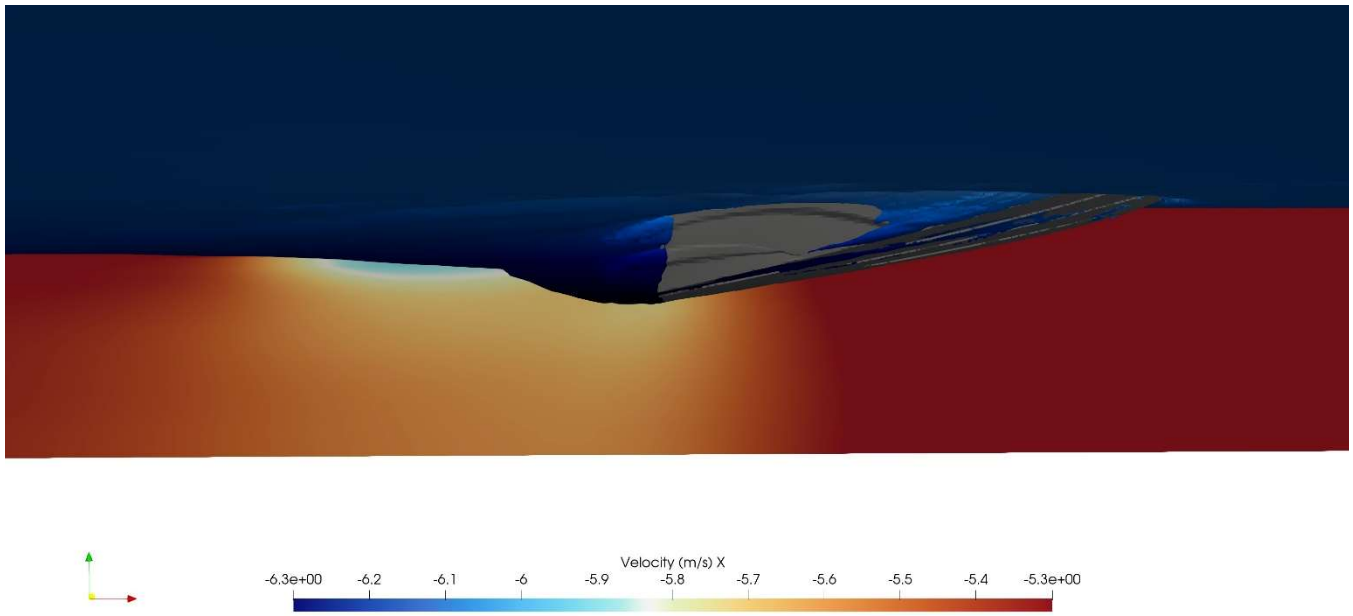


Figure (7): Velocity Profile at 1.5 m off Centerline in 9 feet of water.

Figure (8) shows Figure 31 from report SAFL 611. The data spikes at the nine-foot ADV sensor for turbidity show the random nature of the turbidity level during the day of testing. The orange spikes during the testing of the Malibu VLX Wakesetter show spikes at 13:17 and 13:58 that occur before the boat test and were not related to the run.

The spikes are random occurrences because of natural cycles in the lake caused by other phenomena. There are also spikes at the fourteen-foot level during the Starcraft, Searay and Nautique tests. Each boat was run five times each at planning and displacement speeds. The data set is small with more anomalies than data which infers that the results are inconclusive to show much of anything.

Maxwell Bay has five test points registered with the state. The test points are designated as 27-0133-11-(100, 101, 201, 301). The study could have located a long term test point at any of these locations to get a range of the turbidity data over the summer months when the recreational boats are active on the lake. At a minimum, they could have positioned the sensors for a week during the summer to get the daily range of turbidity during peak use and its variability.

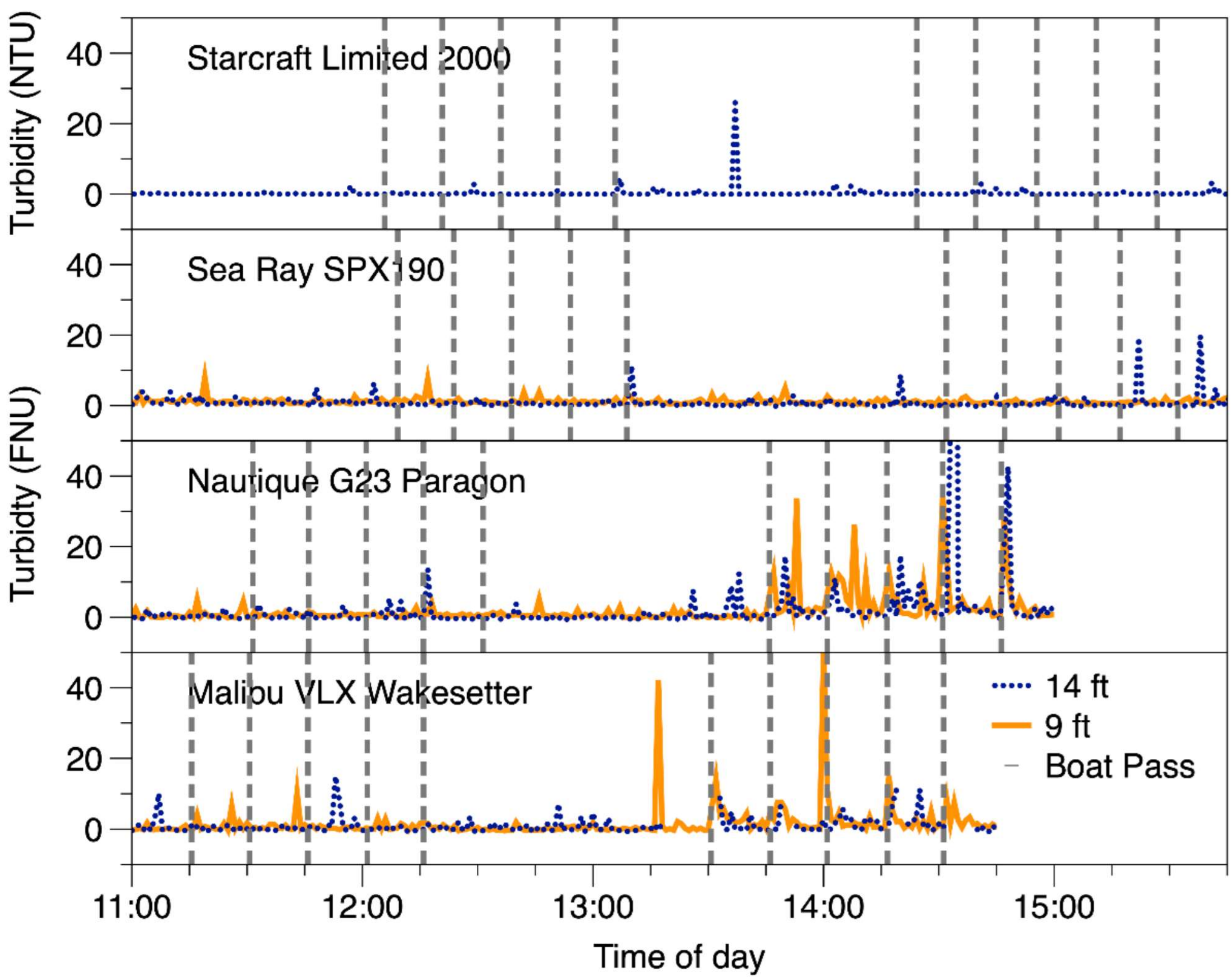


Figure 31. Measured turbidity (unfiltered) in 2023 in Maxwell Bay. Dashed vertical lines note the timing of the individual boat passes, where the first five were in planing mode (Condition 1) and the second five were in displacement mode for the non-wakeboats and semi-displacement mode for the wakeboats (Condition 2). The orange solid lines are the measured turbidity at the 9 ft ADV site, and the blue dotted lines are the measured turbidity at the 14 ft ADCP site. A single measurement for the Nautique G23 Paragon at the 14 ft sampling location was abnormally high (~400 FNU) and is not included in this graph.

Figure (8): Figure (31) from report SAFL 611

The eutrophication of the body of water is a natural phenomena which generally occurs over the course of a millennia. The acceleration of the process of the buildup of sedimentation is a result of anthropogenic pressures. The principal culprit of this acceleration is a result of development and agriculture use within the watershed of the body of water. Lake Minnetonka is surrounded by beautiful homes with lawns, driveways, man-made beaches and driveways connected to access roads around the lake. The added sediment includes runoff with lawn care products, tire debris, road salt and erosion around roadside swales and parking areas as shown in **Figure (9)**, an aerial view of the test area in Maxwell Bay.

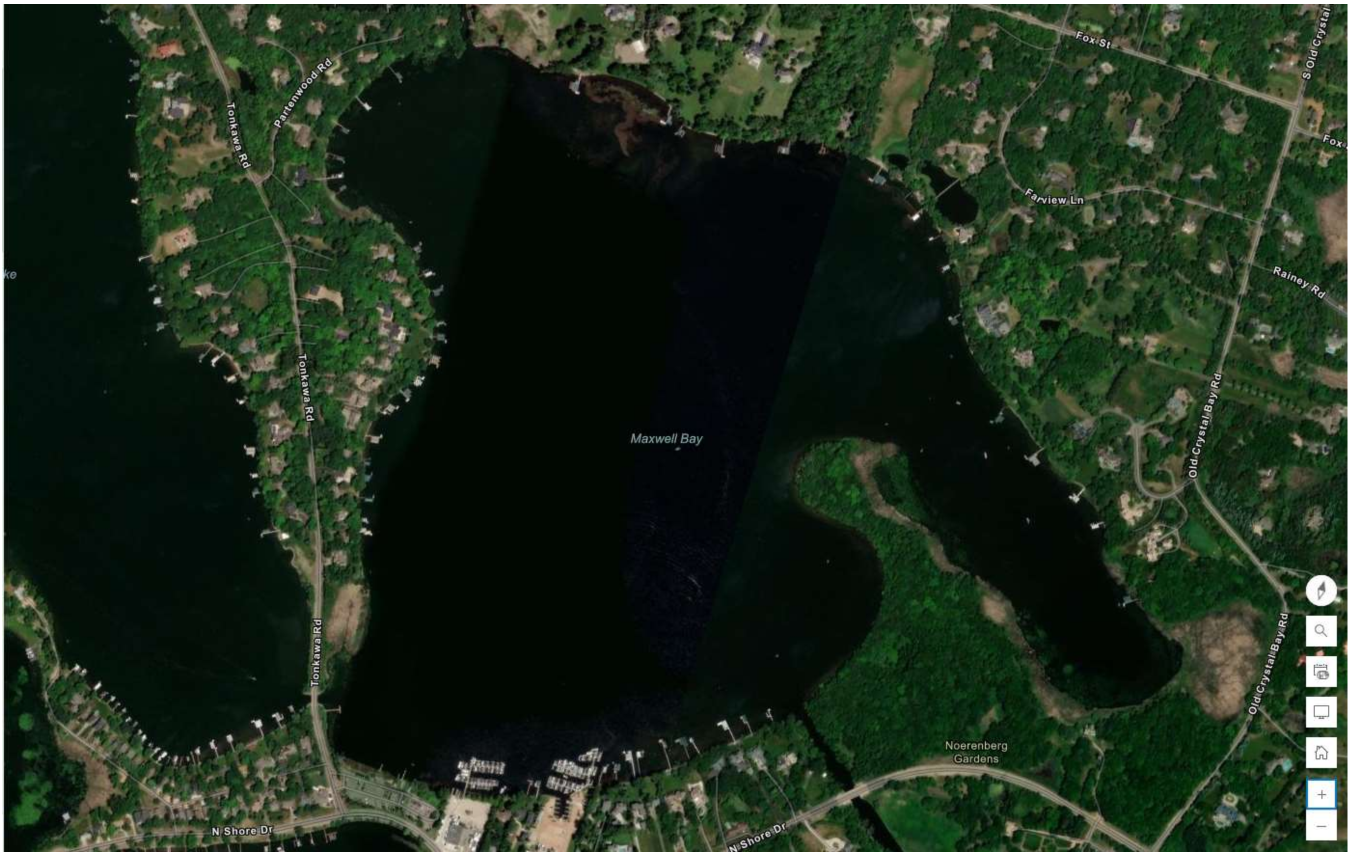


Figure (9): Test Area in 2023

The sediment is raised from the bottom during wind and rain events that occur regularly and can last for days. The sediment around the perimeter of lake is raised with lakeside use, with swimming and boating even human powered canoes and kayaks. The operation of a wake boat for a few hours does not have a measurable environmental impact on the water quality of the lake when compared to all the other impacts.

On a technical note, the study uses the Froude number based on the waterline length of the boat. The waterline line length varies drammatically with boat speed. As a result the Froude number for planing craft is generally taken using the displaced volume of the boat defined as the follows.

$$F_{\nabla} = V \Big/ \sqrt{g \nabla^{\frac{1}{3}}}$$

Where:

V	:	Speed in feet per second
g	:	acceleration due to gravity = 32.17 feet/sec^2
∇	:	Volumetric Displacement = cubic feet

The transition to planing speeds is estimated at a volumetric Froude number of 2. For the wake boats in the study at a displacement of up to 10150 pounds the fully planning speed is 26.5 feet per second or 18 mph. At speeds below 18 mph, the boat is semiplaning and is partially supported by buoyancy. The normal wake surfing speed is approximately 12 mph which is midway between the displacement speed and planing speed with a Froude number of 1.33. The total power applied to the water is the engine power absorbed by the propeller. The wake of the propeller generates the thrust needed to propell the boat and overcome the resistance generated by the frictional and wave making components. The propeller efficiency is proportional to the thrust times speed divided by the torque times engine RPM. The thrust from the propeller is equal to the resistance of the boat plus a thrust deduction to overcome the added resistance caused by the high velocity water off the propeller that strikes the rudder and reduces the pressure under the hull increasing the trim of the boat. The thrust deduction is generally estimated at ten percent so the required propeller thrust can be estmated at approximately 110% of the estimated resistance of the boat. The boats tested in the study are shown in the table below.

Test Boats: 2023 Boat Tests are highlighted

TEST	BOAT	LOA	LWL	BEAM	DISP	EFFECTS	BALLAST	TOTAL	SPEED	FV
1	HURRICAN SS 203	20.8		8.5	2600	750		3350	21	2.798586
3	COBALT R5	25.7		8.5	4880	1000		5880	21	2.548124
5	CRUISERS 34 GLS	35.8		11.7	14530	1750		16280	25	2.559976
7	NAUTIQUE SUPER AIR	23		8.5	7200	750	0	7950	22	2.538602
9	MALIBU WAKESETTER VLX	21		8.2	4200	750	0	4950	21	2.622294
11	STARCRAFT LIMITED 2000	20.3		8.5	2715	750	0	3465	21	2.782888
13	SEA RAY SPX 190	19.6		8.3	2675	750	0	3425	21	2.788278

TEST	BOAT	LOA	LWL	BEAM	DISP	EFFECTS	BALLAST	TOTAL	SPEED	FV
2	HURRICAN SS 203	20.8		8.5	2600	750		3350	9	1.199394
4	COBALT R5	25.7		8.5	4880	1000		5880	9	1.092053
6	CRUISERS 34 GLS	35.8		11.7	14530	1750		16280	9	0.921591
8	NAUTIQUE SUPER AIR	23		8.5	7200	750	2200	10150	12	1.329449
10	MALIBU WAKESETTER VLX	21		8.2	4200	750	3690	8640	11.6	1.320098
12	STARCRAFT LIMITED 2000	20.3		8.5	2715	750	0	3465	7	0.927629
14	SEA RAY SPX 190	19.6		8.3	2675	750	0	3425	7	0.929426

The study is biased in the range and the manner of the boats tested. The test compares the Sea Ray SPX 190 and Starcraft Limited 2000 at 7 mph to the wakeboats running at 11.6 mph.

The Froude number of the Starcraft and Sea Ray tests at 7 mph is 0.93. At this speed the Starcraft and Sea Ray boats are running at idle leaving little or no wake. In order to compare the boats, the speed of the Starcraft and Sea Ray tests should have been run at 10 mph. In addition, the four boats tested in 2023 do not come close to the range of boats operating on the lake and provide an incredibly biased viewpoint by using the two small boats lightly loaded.

The correct speed for the Sea Ray and Starcraft boats is 10 mph but still doesn't represent the range of boats commonly used on the lake. The best comparison would have been the Cruisers 34 and the Cobalt R5 seen in the 2022 testing to provide the study with a more realistic range of the boats running on the lake. In 2022, the Cruiser and Cobalt boats were run at 9 mph lightly loaded. For a fair comparison, the Cruiser and Cobalt should have been run at 13 and 11 mph respectively. The other boats in the test were not run in their normal weekend load with people and gear at the same Froude number as the wakeboats for a more realistic comparison. Pontoon boats were not considered in the study and very popular on the lakes. Most pontoon boats are certified for up to fourteen passengers and can leave a significant wake with two or three pontoons. The range and duration of data is inconclusive on its own without any baseline data and then with the thinly veiled FNS data the author leaps to the conclusion that if we get rid of wake boats all the lakes in Minnesota will be saved.

Figure (10): Cruisers 34 GLS

Figure (11): Typical Inboard Wake Boats

WATER QUALITY

The water quality of the lake is a function of the health of the watershed feeding the streams and runoff that flow into the lake over the course of the year. The watershed is a natural part of the water cycle. The impact of development has disrupted or skewed the natural environment. The amount of water entering a lake is a function of the watershed area and the amount of rain. A portion of the water arrives as runoff down slopes into streams and finally into the lake. Another portion enters the lake through seepage and springs around the perimeter of the lake and slower moving streams. A third portion runs directly over impervious surfaces into the lake from roads, parking lots and driveways.

The watershed generally covers an area up to ten times the area of the lake. The use of the land and the level of development will greatly affect the quality of the water flowing over the hills and down the streams into the lake. The common sources of pollution include the following.

Agricultural Products. The big three components of fertilizers include nitrogen, phosphorus and potassium. The nitrogen component is in the form of nitrates, urea or anhydrous ammonia, the phosphorus is in the form of phosphate rock and the potassium is generally potassium chloride. Depending on timing, precipitation and plant development, some of the nutrients get transported into the lake. The level of these nutrients in the lake can cause different levels of eutrophication where dangerous algae blooms can cause dead zones. When these applied nutrients are not fully utilized by growing crops, they can be lost from the fields and impact air and downstream water quality.

The excess nitrogen and phosphorous can be washed from fields from snow melt and rain events as well as leach through the ground water and soil over time.

Commercial and Residential Development. The main impact of all types of development with the watershed is the pollutants generated by human activity and commerce become part of the water cycle. In that cycle runoff from residential streets, lawns, driveways, roofs, etc. all tend to supply toxins to the water as it runs over the myriad of surfaces on its way to the lake. The residential development generates added nutrients from fertilizer use, herbicides and pesticides from lawn care and home maintenance and erosion from landscaping with the loss of the natural native buffer around the lake. The residential septic systems also tend to add soluble chemicals and pharmaceuticals into the ground water that do not breakdown in the soil before leaching into the lake. Commercial development impact the environment by adding large areas of impervious surfaces including roadways, parking areas, commercial buildings and manufacturing zones. The large impervious surfaces add to the amount of runoff from contaminated surfaces that will run directly into the lake from the watershed.

Micro-Plastics. The amount of plastic in the environment has been in the news lately showing vast areas of plastic debris floating in the ocean and around coastal areas in the Philippines and Brazil and in the open ocean in the Pacific Ocean. Micro plastics are small bits of plastic that occurs when plastic is dragged along abrasive surfaces. The range and impact of micro plastics on the environment is unknown at this time, but researchers have found that these small particles are being eaten by zooplankton and small fry fish. In most cases the plastic is not toxic, but does cause harm by blocking the digestion or being digested and entering the food chain. The most disturbing micro plastic source effecting lakes in the United States is from vehicle tires.

It is estimated that two million tons of tire dust enters the environment each year. The small bits of tire is found on every road in every town where vehicles travel. The issue with tire plastic is it contains oil-based chemicals and heavy metals such as zinc that are toxic to small animals. These chemicals used in the manufacture of tires are proprietary. In the state of Washington research has shown that a chemical used in the manufacture of tires to protect the tire from ozone, a reactive atmospheric gas is the primary culprit in the death of spawning Coho salmon. The chemical is known as 6PPD-quinone and leaches out of the tire particles that wash into waterways. At this time, the extent of the toxicology on other species is unknown, but it is assumed that these chemicals will affect other species as well.

Internal Combustion Engines. The use of internal combustion engines on the lake are one source of pollutants in addition to the sources from the land-based vehicles within the watershed. The primary impact of burning fossil fuels in the production of Polycyclic Aromatic Hydrocarbons, (PAH). They make up about 30% of gasoline and end up in lake water where they do not readily breakdown. The sources of PAHs come from boating, runoff and wildfires. The impact of PAHs have extended to remote areas as a result of precipitation after wildfires. In general, the compounds have a Threshold Effect Concentration (TEC) and a Probable Effect Concentration (PEC).

Water Cycle. All lakes have a watershed where the natural cycle of water is precipitation in the form of rain or snow over the watershed area that supplies the lake with a renewable source of water to replace flow out of the lake, evaporation and seepage. The water quality of the lake is cyclic generated by seasons for the particular lake. The lake has a nutrient budget based of the plant life water cycle time in the lake and other factors. The primary culprits for a nutrient over-budget are phosphorus and nitrogen. Additional phosphorus found dissolved in the water column is relative steady with temperature from day to day. If phosphorus enters the lake as a particulate it will quickly settle to the bottom and become part of the sediment. If the sediment is disturbed regularly it can encourage algae blooms that can be toxic to fish and humans. Nitrogen can come from agriculture and residential fertilizer as well as airborne sources from air pollution and ammonia gas released from fertilized agricultural areas.

The measure of sediment disturbance has been associated with turbidity. The unit of measure are nephelometric turbidity unit (NTU) or the past (UTU) unit. The NTU uses a sample of water with a white light at 90 degrees. The UTU method known as the Jackson Candle Method uses a measure of the length of a column of sample water needed to obscure a candle flame viewed through it. It has been found in research on lakes in Florida, **reference (4)** that all motorboat activity on the lake raises the turbidity level and increases the dissolved oxygen level in the body of water. The sediments in most lakes are colloidal where the particles are well dispersed through the water column. The methodology of turbidity is outlined by the EPA in Method 180.1 with a NTU range from 0 to 700. The results in suspended solids is taken at 3.422 milligrams per liter (mgl) times the NTU figure.

Studies have shown that deeper lakes with sandy bottoms see little impact on nutrients from turbidity. The heavier particles tend to drop out of the water column quickly reducing the impact of additional nutrients in the water column. Wind and wave action also contributes to turbidity depending on fetch, wind direction and shoreline. Heavy rains and snow melt contribute to turbidity generated from fast moving water in streams and runoff. The danger of an algae bloom is its effect on wildlife. If the algae are toxic it is an obvious concern. In the case of a benign algae bloom, the algae can block the gills of small fish and can cause pockets of hypoxia in warm shallow water when the algae die and begins to decompose consuming the dissolved oxygen in the water. **Figure (12)** shows an image of a fish surrounded by dense green algae.

Figure (12): Algae Bloom causing Hypoxia

A study contracted by the EPA in 1974 and conducted by Yousef, **reference (4)**, studied the impact on boating on four lakes in Florida. The lakes were Mizell, Osceola, Maitland and Claire. The lakes are of varying sizes and depths. The study used an array of sensors over each lake at key locations to monitor oxygen content, turbidity, conductivity and dissolved phosphorus. The data were taken over a range of depths below the surface. The turbidity of the lake was a function of the operating time, depth and rated power of the motorboat engines operating on the lake. In all cases the effect was noted for all ranges of engines. The turbidity was a function of traffic and was noted that higher levels of turbidity were measured in the shallow areas. In all cases the level of dissolve oxygen increased through the water column with boating activity.

Figure (13) shows ice flows on lakes where the level changes and the ice re-freezes pushing ice that has grounded on the lake bed up onto shore. The ice along the shore freezes to the bottom and pulls up the sediment when it is pushed onto the shore with a change in lake level.

Figure (13): Ice Push on a large Midwestern lake

The sediment is deposited onto the shore when the ice melts. The spring rains and lake waves will erode some of the sediment back into the lake, but the cycle of freezing and thawing are a natural cycle of the lakes in the higher latitudes. The amount of lake sediment moved in the winter actually changes the shape of the shoreline returning a natural berm at the edge of the lake where home owners have created small beach areas for easy access. The ice damage areas along the shore are re-graded by the home owners further disturbing the shoreline and sediment load on the lake.

WIND AND WAVES

The lake chemistry is affected by the health of the watershed as well as the air to water interface. The wind level around the lake depends on the fetch and buffer zones around the lake. Most lakes experience a significant number of days per year with a steady wave train breaking on the shores generated by seasonal prevailing winds and weather systems. The wind generated waves help mix the water column to distribute nutrients and oxygen rich water. The wind generated waves disturb the shoreline causing wide spread turbidity in combination with well oxygenated water. The wind generated waves can cause minor erosion early in the season where the shoreline has been impacted by ice pushing or loading.

Wind generated waves on lakes and small bodies of water are unique that they are generally small, but develop very quickly. For a wind speed of 25 miles per hour, the wave train is fully developed in approximately twelve minutes over a fetch of 800 yards. The significant wave height is ten inches with a wave period of 1.6 seconds and a wavelength of 8.4 feet.

The wind and wave data was developed from **reference (3)**. The equations were extrapolated to accept shorter fetches and were checked based on observation and computational fluid dynamics. The equations are split into a wave height equation and a wave period equation and include a function for water depth.

The wave height equation:

$$\frac{gH}{U^2} = 0.283 \tanh\left[0.578\left(\frac{gd}{U^2}\right)^{0.75}\right] \times \tanh\left[\frac{0.0125\left({}^{gF}/_{U^2}\right)^{0.42}}{\tanh\left[0.578\left({}^{gd}/_{U^2}\right)^{0.75}\right]}\right]$$

The wave period equation:

$$\frac{gT}{2\pi U} = 1.20 \tanh\left[0.520\left(\frac{gd}{U^2}\right)^{0.375}\right] \times \tanh\left[\frac{0.077\left({}^{gF}/_{U^2}\right)^{0.25}}{\tanh\left[0.520\left({}^{gd}/_{U^2}\right)^{0.375}\right]}\right]$$

Where H : wave height – feet

U	:	wind speed – feet per second
g	:	acceleration due to gravity 32.2 ft/sec^2
F	:	fetch distance in feet
d	:	water depth in feet
T	:	wave period in seconds

The significant wave length, L_w:

$$L_w = \frac{gT^2}{2\pi}\left[\tanh\left(\frac{4\pi^2 d}{T^2 g}\right)\right]^{\frac{1}{2}}$$

The equation has been analyzed to include smaller fetches and checked using computational fluid dynamics (CFD). The Table shows the results of the equation at a wind speed of 25 mph (11.2 m/s) at a depth of 16 feet (5 m) and a fetch of 800 yards (750 m). The line in the table is highlighted that shows the details of the CFD model.

Table : Wave Height Estimate

FETCH YARDS	FETCH FEET	WIND FT/SEC	DEPTH FEET	WAVE HEIGHT	WAVE PERIOD	WAVELENGTH FEET	TIME MINUTES	WAVESPEED FT/SEC
100	300	36.7	16	0.337	1.038	5.32	2.45	2.35
200	600	36.7	16	0.450	1.213	6.22	4.13	2.75
300	900	36.7	16	0.532	1.326	6.80	5.62	3.00
400	1200	36.7	16	0.599	1.410	7.23	6.99	3.19
500	1500	36.7	16	0.656	1.477	7.57	8.27	3.34
600	1800	36.7	16	0.707	1.534	7.86	9.50	3.47
700	2100	36.7	16	0.752	1.582	8.11	10.68	3.58
800	2400	36.7	16	0.794	1.625	8.33	11.82	3.68
900	2700	36.7	16	0.833	1.663	8.52	12.92	3.76
1000	3000	36.7	16	0.869	1.697	8.70	14.00	3.84
1200	3600	36.7	16	0.934	1.757	9.00	16.07	3.98
1400	4200	36.7	16	0.993	1.808	9.26	18.07	4.09
1600	4800	36.7	16	1.046	1.852	9.49	20.00	4.19
1800	5400	36.7	16	1.095	1.891	9.69	21.87	4.28
2000	6000	36.7	16	1.140	1.926	9.87	23.69	4.36

The table takes the fetch, wind speed and water depth and provides the wave height, wave period and time in minutes for the wave state to become fully developed. In the case of a fetch of 800 yards, the waves will become fully developed after a period of ten minutes. The wave height is 0.794 feet (0.242 m), the wavelength is 8.33 feet (2.54 m) and the wave period is 1.63 seconds. The impact of the wind event would have a 0.794 foot high wave impacted the shoreline every 1.63 seconds or approximately 2208 times per hour. The other interesting factor is the sea state is fully developed in just ten minutes.

CONCLUSION

The report has shown that the operation of motorboats on a lake has a minor impact on the environmental health of the body of water. The impact of erosion and turbidity from motorized craft is universal and not related to one boating activity or another and will depend on the operator of the boat. The general operation of motorcraft raises the turbidity level on a particular day, but the diurnal nature of the use of recreational craft tends to allow the raised sediment to resettle on the bottom. The level of phosphorus in solution is generally unchanged allowing the particulate phosphorus to resettle on the bottom. The impact of rain events and modest wind events also tend to raise the level of turbidity and are the primary cause of erosion on shorelines and the introduction of sediment into the lake.

The annual or seasonal water cycle of a lake includes runoff from the watershed into streams, brooks and sometimes rivers. The sediment in these moving water sources comes from runoff and are the source of added nutrients to the lake. The budget of nutrients for the lake, if exceeded tend to raise the eutrophication of the lake where if unchecked can cause algae blooms that can be at best annoying and at worst toxic to fish, animals and people. The operation of motorboats are not part of the annual water cycle and the short season of recreational boating in the higher latitudes pretty much eliminate any measurable impact on the lake from boating.

The real impact on the health of the lake is human activity in the form of residential and commercial development. The impact of development increases the nutrients and pollutants available in the runoff over impervious surfaces. The addition of lawns, parking areas, and swimming beaches all impact the health of the lake. The large watershed may include agricultural areas that produce large amounts of nutrients in the runoff and in the groundwater that flows into streams as seepage from stream banks.

In the course of operating any motorboat on a small body of water, the depth of water and the proximity to shore should be considered for the people on shore as well as the health of the lake. Motorcraft operate unrestricted in water over eight feet in depth. At this depth, the turbidity levels near shore would be out of the high traffic areas and the wash from the propeller(s) would not endanger any native water plants or disturb small fry. The distance from shore should be 100 feet to minimize the wave impact on shore to allow the wave to dissipate before arriving on the beach. All towing activities and wake surfing should be done at a distance of 200 feet from shorelines that are congested with docks, beaches and people swimming otherwise 100 feet is adequate.

The depth of water may require some further study to consider reducing the level below eight feet, but the nutrient load on lakes and pollutants from runoff are getting worse with added pressure for development so at this time the depth should stand at eight feet to eliminate the impact on the lake's health from power boats.

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