Boat Wake Impact Analysis

Lake Rabun and Lake Burton, Georgia

Prepared for:

Lake Rabun Association, Inc.
&
Lake Burton Civic Association

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Executive Summary

Water Environment Consultants (WEC) was contracted by the Lake Rabun Association, Inc. (LRA) and the Lake Burton Civic Association (referred to hereafter as the Associations) to evaluate and quantify the incremental recreational and environmental impacts of wakeboarding and wakesurfing boats (wake boats) on the respective lakes, located in Northeast Georgia. The Associations are concerned about larger wakes causing unsafe conditions on the lakes, as well as other adverse effects such as increases in shoreline erosion, and collateral damage to docks or vessels or other structures. The goal of this study is to provide the lake associations with a technical reference to facilitate discussions with Georgia Power Co., Georgia Department of Natural Resources (GADNR) and other appropriate regulatory and legislative agencies to pursue the development and implementation of management measures to improve safety and minimize the adverse effects of wake boats.

As mentioned above, the primary concern of the Associations is the *safety* of boaters and swimmers. Safety is also of primary importance for Georgia Power, as illustrated by their published Core Safety Beliefs:

(1) Safety takes precedence over all other requirements;

(2) Safety is a personal value;

(3) All hazards can be controlled; and

(4) The "Spirit of Safety" is a constant.

The Associations are concerned about increased risk of injury or death of boaters and swimmers that is caused by increasingly large wake waves on the lakes. Large wakes can create unsafe conditions by swamping recreational craft, impacting other boats, or causing falls overboard. Small craft, including canoes, kayaks, and sailboats are particularly at risk of being swamped, broached, or capsized by steep waves from wake boats. In their statistical report of recreational boating accidents, the U.S. Coast Guard cited that "flooding/swamping" was the 4th most common type of accident reported in 2019, resulting in 45 deaths and 124 injuries (U.S Coast Guard 2020). Between 2015 and 2018, it was the 3rd most common boating accident. Additionally, "forces of wave/wake" was one of the top ten contributing factors in accidents in 2019, resulting in 12 deaths and 117 injuries. "Falls overboard" was the fifth most common accident in 2019, resulting in 189 deaths and 122 injuries (U.S Coast Guard 2020).

As detailed by this report, wake boats produce much higher waves than typical cruising or waterskiing craft, and they also produce longer, more energetic waves. The increases in wave heights and wave lengths caused by wake boats increase the risk of injury or fatal accidents on these lakes through several possible mechanisms. These larger waves can:

- Increase risk of swamping of small crafts that have a low freeboard, which in turn increases risk of drowning or injury;
- Increase risk of falls overboard, which also increases risk of drowning or injury;

- Increase incidence of cruising boats slamming into waves, resulting in passenger injury; and
- Increase incidence of vessels being pushed or slammed into docks or shoreline bulkheads, which increases risk of injury or death for people near the vessel.

These increased risks are substantiated by anecdotal reports on Lake Rabun and a survey of its members conducted in 2020. The survey received 486 responses, which is a very high response rate (57%) for member surveys (see Appendix A of this report). Seventy-five percent of survey responses indicated that wake boats create a boating safety issue. Member comments included multiple safety incidences or safety concerns:

> *"We were visiting friends on the lake who were in lockdown due to covid. We were in our boat, approximately 10 feet away from their dock and seawall, chatting with them on their dock. A wakeboat came by and the wake was so large that it crashed our boat into the seawall, even as we were making every effort to move away from it. Ultimately this led to our boat sinking and being declared a total loss. I just don't believe Lake Rabun is large enough to accommodate this size boat."*

> *"Difficult to enjoy the lake safely with small children. Can no longer do normal water skiing. Difficult to swim near our dock. Difficult and unpleasant to drive a pontoon boat."*

> *"Two times ballast boat waves have come over the bow of my 22' open bow boat. I felt there was a danger of sinking. Generally it is not pleasant to navigate rough water and big waves. This is ruining our boating experience."*

> *"We have small children who are often knocked over by such huge waves."*

> *"With the wake boats so numerous and dominant out on the water now, I can't remember the last time being on the lake where I didn't fear for my family's safety at least once. This is true of time we spend on our boat, as well as time we spend swimming near our dock."*

> *"Dropping the boat in the water and taking the boat out of the water, getting in and out of the boat during that time is really dangerous when giant waves come in."*

> *"The larger waves directly affect the ability to steer a boat. On many occasions I have been unable to steer one of my boats and worried that I would be pushed into another boat."*

> *"While untying boat (with 3 people in it) at dock, the wave was so strong that one of the people on boat was thrown in water!"*

Swamping typically means that a boat fills with water but remains floating. According to the LRA, there have been numerous anecdotal reports of wakes causing swamping or water coming over the bow and gunwales of a boat such that it raises the risk of total swamping. The LRA member survey results show that 66 percent of respondents (227 members) reported occasional or frequent swamping caused by wake boat waves.

Cruising boats hitting large wakes can cause injury or death. One incident on Lake Rabun involved a boat passenger thrown in the air after their boat hit a large wave from a wake boat. Injury to the passenger required treatment at the emergency room. Another example includes a tragic accident on Lake Burton on July 18, 2014 that claimed the life of a boy who was ejected from a boat when it hit a large wake. This incident did not necessarily involve a wake boat generated wave, but it illustrates the fact that large wakes increase the risk of fatal accidents. The LRA member survey results indicate that 95 percent of respondents (329 members) reported occasional or frequent jostling of boat passengers caused by wake boat waves, and 14 percent of respondents (47 members) reported occasional or frequent injury of boat passengers caused by wake boat waves.

In addition to impacts to other vessels, the wake impacts to docks and bulkheads can cause unsafe conditions. Anecdotal reports also include vessel wakes overtopping docks and sweeping deck chairs into the water, even though the wake boats were outside the 100-ft buffer. As witnessed in the wake measurement study on Lake Rabun, a wakesurfing wake can easily overtop a bulkhead even 300 ft from the sailing line (see Figure 3-3). The LRA survey responses summarized above include an incident where a wake boat wave caused a boat to crash into a bulkhead, resulting in sinking of the boat. The LRA member survey results indicate that 83 percent of respondents (291 members) reported occasional or frequent endangerment or inconvenience of swimmers or people on docks caused by wake boat waves.

Many parts of these lakes are quite narrow, including most of Lake Rabun and much of Lake Burton. It is in these narrow channels where safety is of particular concern. These channels are generally 500 ft wide or less, with a typical width around 300 feet. Within these channels, large wakes may cause passing vessels to yaw and alter course, increasing the risk of collision. The curving nature of the channels causes wake heights to amplify on the insides of the channel bends, increasing wake hazards in these areas. Additionally, two passing wake boats in the channel can create much larger waves where their wakes intersect. Therefore, large waves from wake boats increase the risk of accidents in the narrow areas of the lakes.

To quantify the incremental increase of wake boat impacts requires an understanding of wake conditions generated from both a wake boat as well as a typical vessel operating on the lakes. One previous study focused on wake boats was commissioned by the Water Sports Industry Association (WSIA) in 2015 to scientifically measure the wake heights and wake energy produced by a wake boat. WEC used data from the WSIA study to produce wake height plots for a wakesurfing, wakeboarding, and typical cruising (e.g., waterskiing) operating conditions in deep water, as shown by the dashed curves in Figure ES-1. The figure shows the wake height on the vertical axis and the distance away from the vessel sailing line on the horizontal axis. The figure illustrates how the wake height attenuates with increasing distance away from the vessel.

Figure ES-1 also includes curves based on wake measurements made by WEC. On September 30, 2020 WEC conducted a field study on Lake Rabun to: 1) validate and verify data from the WSIA wake analyses; and 2) quantify wake heights and wake attenuation at a site-specific location in one of these north Georgia lakes. The methodology incorporates a wake sport vessel making consistent passes near two stationary wave gage instruments. The vessel operated in cruising/skiing, wakeboarding, and wakesurfing conditions to simulate wakes generated from operational conditions. WEC analyzed the wave gage data, created wave attenuation curves based on the data, and compared the results from the WSIA study, as shown in Figure ES-1 (the WEC data are indicated by the solid line curves). A comparison of the wave height curve for cruising/skiing operation in Figure ES-1 to the wave height curves for wakeboarding and wakesurfing operation shows that wakeboarding and wakesurfing operation produces much higher wave heights than those generated by cruising or typical water skiing.

The Georgia "Rules of the road for boat traffic" (O.C.G.A § 52-7-18) require boats to maintain idle speeds within 100 ft of "of any vessel which is moored, anchored, or adrift outside normal traffic channels, or any wharf, dock, pier, piling, bridge structure or abutment, person in the water, or shoreline adjacent to a full-time or part-time residence, public park, public beach, public swimming area, marina, restaurant, or other public use area." Given the existing Georgia rules, the increases in wake heights 100 ft from the vessel represent the increases in impacts to docks or shorelines caused by wake boats under the current wake management regime. As shown by Table ES-1, at this distance, a wakeboarding wake at the shore is 22% larger than a typical cruising vessel wake, and a wakesurfing wake is 111% larger than a typical cruising vessel wake. Based on these data, the proliferation of wakesurfing and wakeboarding boats on the lakes resulted in large increases in wake heights reaching docks and shorelines, as allowed under the current rule requiring non-idling boats to maintain a 100 ft buffer.

The effects of boat wakes on these lakes are much greater than those caused by typical wind waves. WEC calculated typical monthly maximum wind wave conditions at two locations within Lake Rabun and three locations within Lake Burton. Using the wake height curves developed from the field study, WEC compared wake heights with estimated maximum monthly wind wave heights at the five sites.

In narrow areas of the lakes, wind waves are very small. Therefore, vessel wake heights are much higher than typical monthly maximum wind wave heights. Even at sites with the largest fetches that generate the largest wind waves, wake boats moving 100-feet off the shoreline create waves exceeding the monthly maximum wind waves. Therefore, vessel wake effects should not be dismissed as insignificant as compared wind wave effects, which may be the case in much wider lakes.

Table ES-2 presents the percent increase in wake impacts on shoreline erosion potential as compared to a typical cruising vessel. WEC evaluated change in wave energy, which is generally considered related to shoreline erosion. Given the present management rules requiring only a 100-ft buffer distance between non-idle speed boats and the shoreline, these results indicate that wave energy from wakesurfing and wakeboarding vessels are much more likely to contribute to shoreline erosion than typical boat wakes or wind waves. Shoreline erosion from waves depends on localized conditions. Erosion may not be an issue where the shoreline is hardened (e.g., many homes on each lake have vertical bulkheads or rock shoreline stabilization), but sensitive shoreline areas may require wake management measures to minimize the potential for wake-induced erosion.

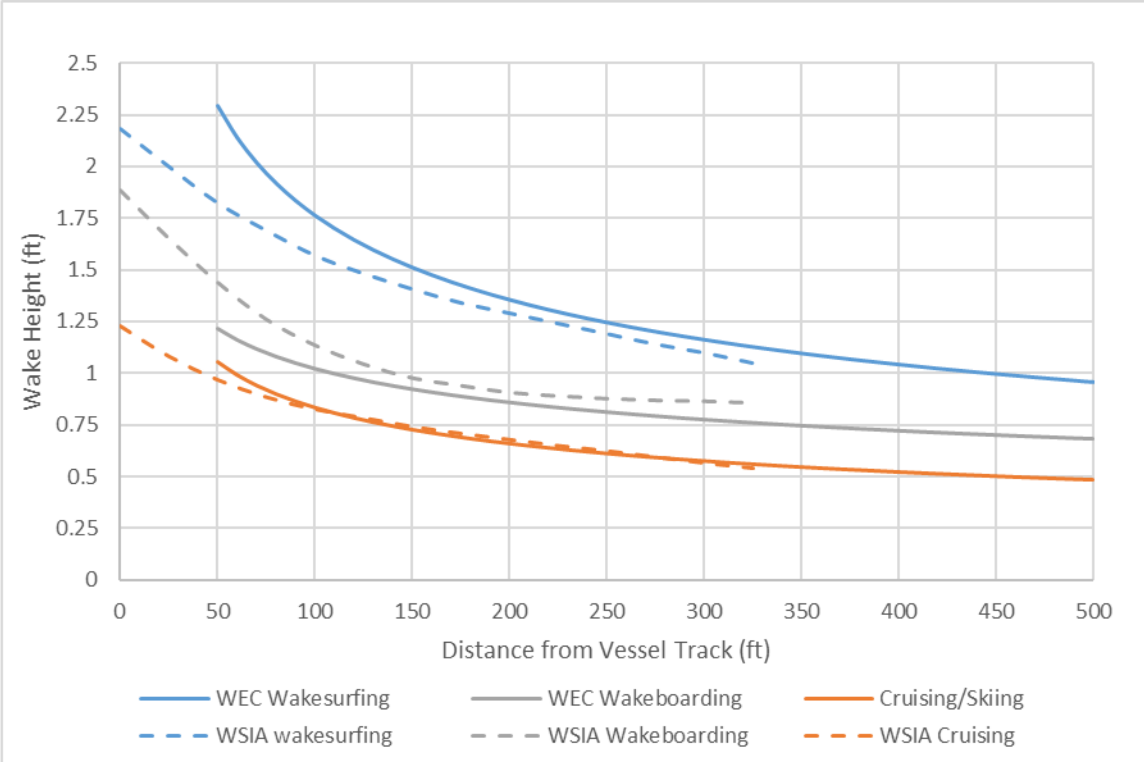

Figure ES-1. WEC measured wake heights and wake attenuation compared to WSIA study (digitized deep water curves from Goudey and Girod 2015)

Table ES-1. Increase in measured wake heights as compared to cruising vessel

Distance from sailing line (ft)	Increase in height (ft)		Percent increase	
	Wakeboarding	Wakesurfing	Wakeboarding	Wakesurfing
100	0.2	0.9	22%	111%
150	0.2	0.8	27%	108%
200	0.2	0.7	30%	105%
250	0.2	0.6	33%	104%
300	0.2	0.6	35%	102%
400	0.2	0.5	39%	100%
500	0.2	0.5	41%	98%

Table ES-3 presents the percent increase in wake forces on vertical wall structures. At the 100-ft distance, the minimum buffer required under the present management rules, the lateral wave forces from wakeboarding wakes are 25 percent greater (an increase of 359 pounds per linear foot) than those from cruising vessels, and lateral wave forces from wakesurfing wakes are 131 percent (1,900 pounds per linear foot) greater. These results indicate that these larger waves are more likely to cause damage to dock and shoreline structures that are not built to withstand repeated exposure to these larger waves.

Table ES-2. Wave energy at the shoreline and percent increase compared to cruising vessels

Vessel Distance from Shore (ft)	Energy (ft·lb) Cruising	Energy (ft·lb) Wakeboard	Energy (ft·lb) Wakesurf	Percent Increase Wakeboard	Percent Increase Wakesurf
100	2587	4346	17621	68%	581%
150	1964	3549	12948	81%	559%
200	1615	3073	10405	90%	544%
250	1387	2749	8782	98%	533%
300	1226	2509	7646	105%	524%
400	1008	2173	6144	116%	510%
500	866	1944	5186	124%	499%

Table ES-3. Horizontal wave forces on vertical walls and percent increase compared to cruising vessel

Vessel Distance from Shore (ft)	Force per linear foot (lbf/ft) Cruising	Force per linear foot (lbf/ft) Wakeboard	Force per linear foot (lbf/ft) Wakesurf	Percent Increase over Cruising Wakes Wakeboard	Percent Increase over Cruising Wakes Wakesurf
100	1454	1813	3354	25%	131%
150	1253	1623	2810	29%	124%
200	1129	1501	2482	33%	120%
250	1041	1413	2257	36%	117%
300	975	1345	2089	38%	114%
400	880	1245	1851	42%	110%
500	812	1173	1687	44%	108%

WEC evaluated the incremental impact of wake boats on berthing conditions at docks on the lake. Wakes can adversely impact vessels moored to docks either by causing damage to boats or docks, or by creating unsafe conditions for boarding or disembarking. The industry standard for “moderate” tranquility in a marina (which permits 25% greater wave action than “good” tranquility conditions), allows for 0.6-ft high waves when boats are oriented in the same direction as the wave (head seas). The calculated have height for a cruising vessel traveling passing 250 ft from the shoreline (0.6 ft) satisfies the moderate criterion. However, wakesurfing and wakeboarding wave heights do not meet the moderate criterion even if the vessels pass 500 feet from shore. At the 100-ft distance, the minimum buffer required under the present management rules, the wake heights from wakesurfing and wakeboarding are 0.4 and 1.2 feet above the moderate berthing criterion, respectively. This supports the conclusion that the current management measures are insufficient to avoid vessel wakes from creating poor vessel berthing conditions at docks, and there is a potential for wakes to cause physical damage to boats or docks, or create unsafe conditions for boarding or disembarking from moored boats.

The above summarizes the significant increase in wake heights caused by wake boat vessels, the increased force and energy of these wakes, and the potential for destructive damage to shoreline and property; however, as discussed above, the Associations are most concerned with the safety of boaters and swimmers. Under the current management measures, the larger wave heights and wave lengths generated by wake boats increase the risk of injury or death on these lakes, as compared to conditions prior to the proliferation of wake boats. Anecdotal reports of unsafe conditions from boat wakes supports the conclusion that the present management rules are insufficient and/or insufficiently complied with to provide reasonably safe recreation on the lake for small crafts. In the absence of new management measures, the increasing trend in the number of wake boats on the lakes will continue to increase the risk for injury or fatality from boating accidents related to swamping or interaction with boat wakes.

Altogether, our review and analysis of the available data on wake boats and their effects on Lake Rabun and Lake Burton supports the conclusion that the present rules should be complemented by additional management measures suitable for narrow, deep lakes such as these. It is likely that the best management regime adopted for any given site will need to involve a combination of operational and non-operational measures. Below are management measures for consideration.

Operational measures may include:

1. Restrict the factory installed ballasts from being filled to maximum capacity and prohibit the use of additional ballast items (i.e. “fat sacs”). Doing so would reduce vessel displacements and lower wake heights.

2. Limit wakesurfing and wakeboarding to the middle sections of the widest parts of the lake.

3. Restrict wake boats to operate in normal unballasted cruising conditions or no-wake conditions within the narrow sections of the lake.

4. Require wakeboarding operations try to stay at least 100 yards away from any shoreline, dock, fixed objects or small craft. A 100-yard distance (a football field length) is likely more easily visualized by a boat operator than one described as a 300-ft distance. At a 100-yard buffer distance, wakeboarding wake heights will be slightly less than waterskiing or cruising wake heights at a 100-ft buffer distance. For wakesurfing operations, require the vessel maintain a 150-yard buffer distance. At 150 yards from the sailing line, the wake height is approximately 1 ft, still slightly larger than a cruising/skiing vessel at the 100-ft buffer distance, but it will be more manageable than the under the existing rules. These additions would result in only a few permissible wake boat zones in the middle of the widest parts of the Lake Rabun and Lake Burton.

5. Prohibit wakesurfing and wakeboarding operation under low light conditions (dusk, dawn or night) when wakes are less visible to others.

6. Prohibit on-board ballast when cruising or waterskiing. Often, wakeboat operators simply fail to empty ballast while cruising or waterskiing.

Non-operational measures that may include:

1. Post signage where wake boats should minimize their wake,
2. Engage in outreach activities to educate the public regarding vessel wake impacts and provide wake management guidelines similar to those provided by the WSIA (except with a revised minimum buffer distance of 100-yards/150-yards from the shoreline and inclusion of a buffer distance around small craft),
3. Coordinate with neighboring lake associations to pool resources and identify other successful means of wake management.

To provide data to assess the effectiveness of wake management measures or the need for adjustment of wake management measures, WEC recommends that the Associations track occurrences of boat wake incidences. This may include requesting members to report any safety incidences or personal property damages as a result of wake boat operation. This should be documented with available specific information regarding the time and date of the incident(s), a detailed description of the damage, along with videos or photographs, and the registration number of the watercraft rendering the damage, if possible.

1 Introduction

The Lake Rabun Association, Inc. (LRA) and the Lake Burton Civic Association (referred to hereafter as the Associations) retained Water Environment Consultants (WEC) to complete this evaluation of boat wakes and related effects caused by wakesurfing activities on the lakes. The lakes are located in the northeast corner of Georgia and are three of six lakes in a series of reservoirs that follow the original path of the Tallulah River (Figure 1-1). The lakes are owned and operated by the Georgia Power Company and used to generated hydroelectric energy. With the growing popularity in the sport of wakeboarding and wakesurfing, an increasing number of wake-enhancing vessels (wake boats) operate on each reservoir.

The Associations are concerned about larger wakes causing adverse effects in several ways, including safety, increases in shoreline erosion, and collateral damage to docks or vessels or other structures. The goal of this study is to provide the Associations with a technical reference to facilitate discussions with Georgia Power Co., Georgia Department of Natural Resources (GADNR) and other appropriate regulatory and legislative agencies to pursue the development and implementation of management measures to minimize adverse impacts of wake boats.

As directed by the Associations, this study aims to evaluate and quantify the incremental increase in wake boat impacts as compared to typical vessels and naturally occurring wind-waves on the lake. This gives an indication of the changes in boat wake effects following the advent of wakesurfing and wakeboarding activities on the lake. The report is subdivided into the following sections:

- Section 2, Background on vessel wakes: presents background information on vessel wakes and their impacts;
- Section 3, Wake Impacts: presents estimates of the incremental increase of wake boat impacts on shoreline erosion, dock structures, moored vessels, and safety; and
- Section 4, Management Measures: Suggests possible management strategies to minimize adverse impacts from wake boats.

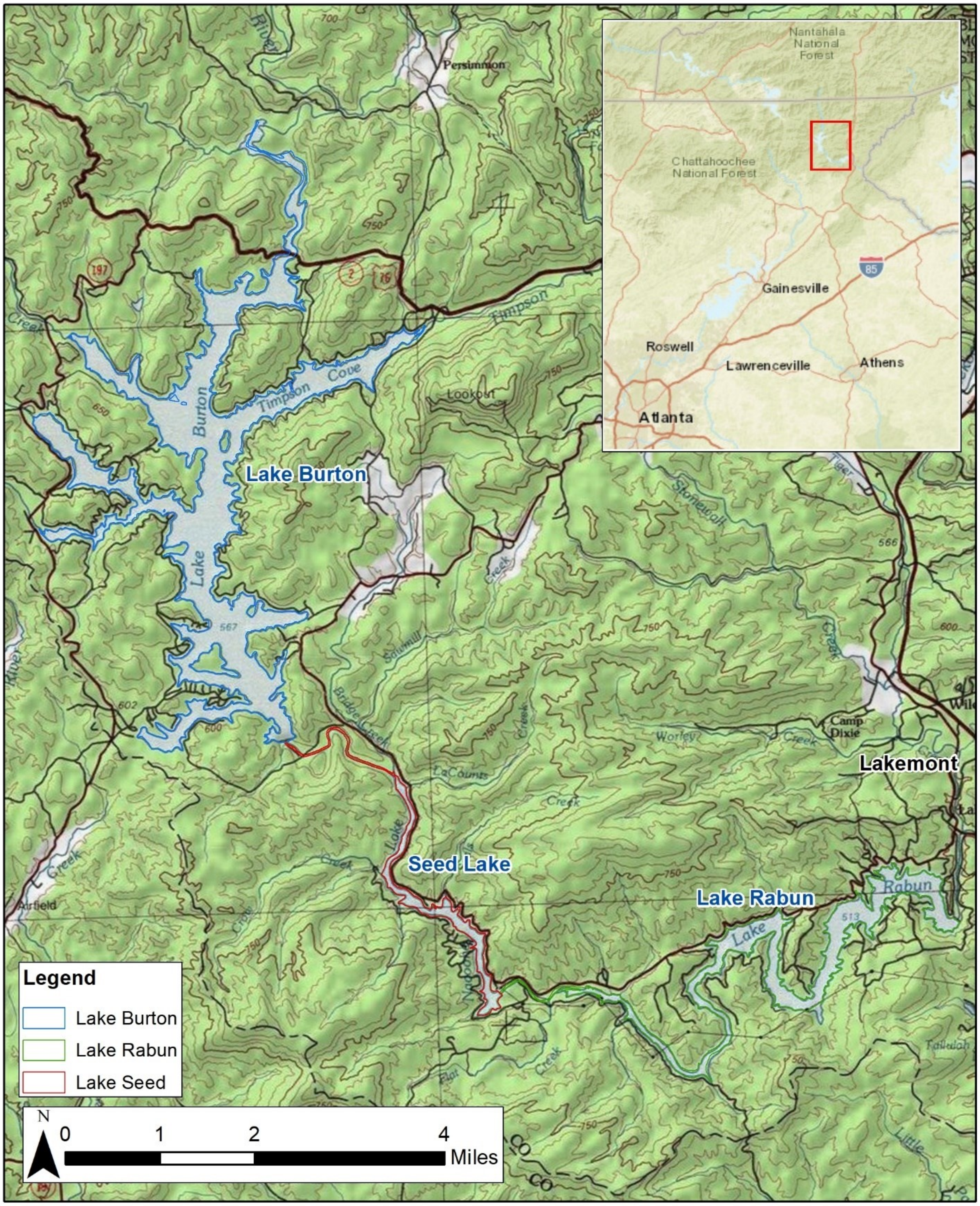

Figure 1-1. Project location map

2 Background on Vessel Wakes

2.1 Vessel Wave Patterns

The general wave pattern generated by recreational vessels is affected by water depth and vessel speed. At sub-critical speeds, all vessels produce a wave pattern termed the Kelvin wave pattern (Figure 2-1), which includes two wave types: transverse and divergent waves. Transverse waves propagate parallel to the vessel's sailing line. The height of these waves is largely a function of vessel displacement-length ratio, with a heavy, short vessel producing higher waves (Macfarlane 2009). Divergent waves propagate obliquely to the vessel's sailing line, as shown in Figure 2-1, and they are generally steep and close together near the vessel.

As vessel speed increases or water depth decreases, the vessel will approach the critical speed, which is the point at which the vessel waves reach their maximum speed. The vessel will experience a peak in resistance at the critical speed. At critical speed, the wave pattern may consist of only one long-period wave, termed a wave of translation, propagating parallel to the sailing line.

At super-critical speeds (i.e., higher than the critical speed), a vessel's wake pattern changes again. At these speeds, transverse waves disappear, and divergent waves propagate at a greater angle away from the sailing line.

Whereas significant transverse waves can be generated by large commercial vessels, they are generally not a significant problem caused by recreational vessels. Therefore, divergent waves are the focus of our analysis.

2.2 Vessel Speeds

In addition to the three vessel wave patterns described above, there are also three vessel speed regimes. Displacement speed is the slowest regime. The upper limit of the displacement speed regime is the hull speed, which is the point at which the longest wave generated equals the waterline length of the vessel. To travel faster than hull speed, the vessel must begin to “climb its own bow wave.” In general, operating at speeds up to 75% of the maximum displacement speed will produce modest wash height and period (Macfarlane 2009).

Above the hull speed, the vessel moves into the semi-displacement speed regime. The transverse waves move aft of the transom, and the running trim increases. In this regime, wave making resistance is at its highest, and wake height increases to its maximum. Semi-displacement speeds occur when the vessel appears to be “climbing the hump” before planing, which is often referred to as hump speeds. This is a speed regime to avoid when there is a need to minimize vessel wake heights.

The third speed regime is high speed. For vessels with a power-to-weight ratio sufficient to travel faster than hull speed, they can power through the hump just above hull speed before entering the high-speed regime. For vessels with a planing hull, this will be point at which the boat begins to plane.

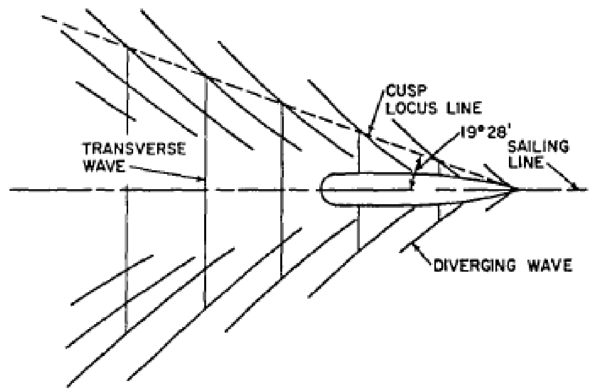

Figure 2-1. Sub-critical vessel wake pattern (Sorenson 1973)

2.3 Vessel Wave Propagation

Vessel wakes spread out and are reduced in amplitude as they move away from the vessel sailing line. As a packet of waves propagates, the waves are affected by both dispersion and attenuation. Wave dispersion is caused by varying wave lengths within a wave packet moving at different speeds. This results in the wave packet widening as it moves away from the sailing line. What appears as a few wake waves near the vessel will appear to become a larger number of waves at increasing distances from the sailing line.

In deep water, before the wave interacts with the bottom, wave attenuation is primarily caused by diffraction, which spreads wave energy along the wave crest. As water becomes shallower, the wave interacts with the bottom, and wave transformation is affected by refraction, shoaling, and bottom friction. Waves may also be reflected by the shoreline, structures or the bottom.

Wave transformation processes generally cause an attenuation in wave height as the wave propagates away from the sailing line, until it reaches very shallow water, at which point wave shoaling causes an increase in wave height before wave breaking. The wave period, however, does not change during wave propagation.

Estimates of wave transformation can be provided by numerical models, but more commonly wave attenuation is estimated by empirical evidence from either laboratory scale models or field measurements of the vessel wakes of interest. This analysis relies upon field measurements of wake boat waves from three sources. Two of these sources are prior studies, Goudey and Girod (2015) and Ruprect et al. (2015), and the third is field measurements completed by WEC on Lake Rabun. The following subsections summarizes this data.

2.4 Wake Boats Waves

There has been an increasing number of recreational boats on Lake Rabun and Lake Burton that are designed and manufactured for the sport of wakeboarding and more recently, wakesurfing. These wake boats are designed, through the use and control of ballast and customized trim, to maintain a breaking wave at the optimal operational speed (typically 10 knots for wakesurfing and 19 knots for wakeboarding) (Ruprect et al. 2015). Wake heights generated by some boats can exceed four feet immediately behind the vessel, according to manufacturer marketing (e.g., Figure 2-2 shows a screen shot from a promotional video for the Malibu 22 LSV wave with factory ballast setup).

Wakesurfing vessels use wake enhancement devices (WED) to increase the speed at which the vessel can maintain its critical speed condition, ensuring that they can generate large displacement waves at speeds between 12 and 19 knots (Ruprect et al. 2015). WED may include: increasing the ballast in the vessel (either through inflatable water bags or internal ballasting); modifying the hull design; installing wedge platforms on the stern of the vessel which impacts vessel trim; and installing elevated towing platforms (Ruprect et al. 2015). Ballast can also be distributed unevenly to enhance wake height: placing the majority of the ballast near the aft corner on the side to be surfed (biased ballasting) will produce a larger wave on one side of the boat than the other.

Vessel wakes have been studied extensively for commercial vessels and recreational vessels, but there are few studies focused specifically on wake boats with WED. WEC reviewed the data from two relevant studies in addition to conducting field measurements of vessel wakes on Lake Rabun. The first is a study by Goudey and Girod (2015) commissioned by the Water Sports Industry Association (WSIA) in 2015 to measure the wake heights and wake energy produced by a wake boat in Orlando, FL. The second is a study completed by Ruprect et al. (2015) to measure wake heights and wake energy from three different late-model wake boats. Lastly, WEC conducted field measurements in September 2020 on Lake Rabun with the goal of measuring site-specific wave heights created by a wake boat and attenuation of the wave heights as they travel away from the vessel.

2.4.1 WSIA Wake Analysis (Goudey and Girod 2015)

In the Spring of 2015, the WSIA commissioned C.A. Goudey & Associates to measure the wakes produced by professional quality wake-sport boats at two lakes in Orlando, FL. The study venues included a reach of shallow-water and deep-water conditions. This is an important distinction, as wave mechanics behave distinctly different whether in deep or shallow water, and shallow water attenuates wake heights more quickly. Lake Rabun is a flooded river valley with relatively deep water in close proximity to the shoreline. Therefore, WEC analyzed only the deep-water results presented by Goudey and Girod (2015), since this is the relevant data for evaluating vessel wake impacts on Lake Rabun.

The vessel used in the study was a Nautique G-23 wake-sport boat, typical of the growing fleet of wake-sport boats available from various manufacturers at the time. The vessel was tested for three different conditions: cruising, wakeboarding, and wakesurfing. "For the cruising condition the boat was operated 'light,' meaning only one person aboard but with a full fuel tank (65 gal.). For the wakeboarding condition the standard factory-installed ballast tanks were filled to capacity, adding 2,850 pounds. For the wakesurfing runs, the weight was supplemented with four 'fat sacks' positioned aft and in the bow, adding another 1,400 pounds for a total displacement of 10,150 pounds" (Goudey and Girod 2015). Figure 2-3 illustrates the vessel operating under wakesurf conditions. The scenarios tested by Goudey

Figure 2-2. Malibu 22 LSV wave with factory ballast setup (Source: Guinn Partners 2019).

Figure 2-3. Nautique G-23 used during WSIA study operating under wakesurfing condition (Goudey and Girod 2015)

and Girod did not include biased ballasting to increase wake heights on one side of the boat, and therefore, these test results do not represent the largest wakes that can be generated by these types of vessels. Wave height sensors, which measured the wake height produced from a vessel passing the testing venue, were spaced at incremental distances from the shoreline. For each of the three conditions (cruising, wakeboarding, and wakesurfing) the vessel passed the wave sensors at varying speeds to simulate the respective operating procedure. Cruising speeds included 20, 25, and 30 mph. Wakeboarding speeds included 21.2, 22.2, and 23.2 mph. Wakesurfing speeds included 10, 11, 11.5, and 12 mph. For this analysis, it is reasonable to assume that the wakes generated by unballasted cruising conditions are representative of the maximum wakes typically generated by other recreational vessels cruising on the northern Georgia lakes, such as waterski vessels.

Goudey and Girod (2015) plotted measured wave heights versus distance from sailing line for each vessel operating condition, and they fit a trendline to the measured data. The WSIA study did not provide tables of the measured data, and therefore, WEC digitized the plotted trendline results for the deep water measurements in the WSIA study, as shown in Figure 2-4. The data points used to generate these curves are provided in Table 2-1.

Figure 2-4 shows the observed attenuation of wave height as the wake travels away from the vessel sailing line. In general, wave heights decrease quickly within the first 50 to 100 feet from the sailing line. After that point, the curves flatten out, as the wave attenuates more slowly at greater distances from the sailing line. This figure highlights the difference in wake height between the three operating conditions. Of the three operating conditions, wakesurfing generated the largest wake heights, wakeboarding generated smaller wake heights, and cruising produced the smallest wake heights.

Of interest to our analysis are the incremental increases in wake heights created by wakeboarding and wakesurfing beyond that of typical cruising boat wakes. As mentioned previously, it is reasonable to assume that the wakes measured for cruising conditions are representative of the wakes typically generated by other recreational vessels cruising on Lake Rabun and Lake Burton. Therefore, the incremental increase is calculated as the wakeboarding and wakesurfing wave heights minus the cruising wave heights. Table 2-2 presents the incremental increase in wave heights at the shoreline due a wakesurfing and wakeboarding vessel as compared to a cruising vessel.

In Georgia, the “Rules of the road for boat traffic” (O.C.G.A § 52-7-18) state that “No person shall operate any vessel or tow a person or persons on water skis, an aquaplane, a surfboard, or any similar device on the waters of this state at a speed greater than idle speed within 100 feet of any vessel which is moored, anchored, or adrift outside normal traffic channels, or any wharf, dock, pier, piling, bridge structure or abutment, person in the water, or shoreline adjacent to a full-time or part-time residence, public park, public beach, public swimming area, marina, restaurant, or other public use area.” Given the Georgia rules, the differences in wake heights 100 ft from the vessel represent the increases in impacts under the current wake management regime. Based on the data in Table 2-1, a cruising vessel produces wakes of about 0.8 feet in height at a distance 100 feet from the vessel. In comparison, a wakesurfing or wakeboarding boat produces wakes about 1.6 or 1.1 feet in height, respectively, at the same distance (100 feet) from the vessel. As shown by Table 2-2, at this distance, a wakeboarding wake is 37% larger than a typical cruising vessel wake, and a wakesurfing wake is 90% larger than a typical cruising vessel wake. Based on these data, the proliferation of wakesurfing and wakeboarding boats on

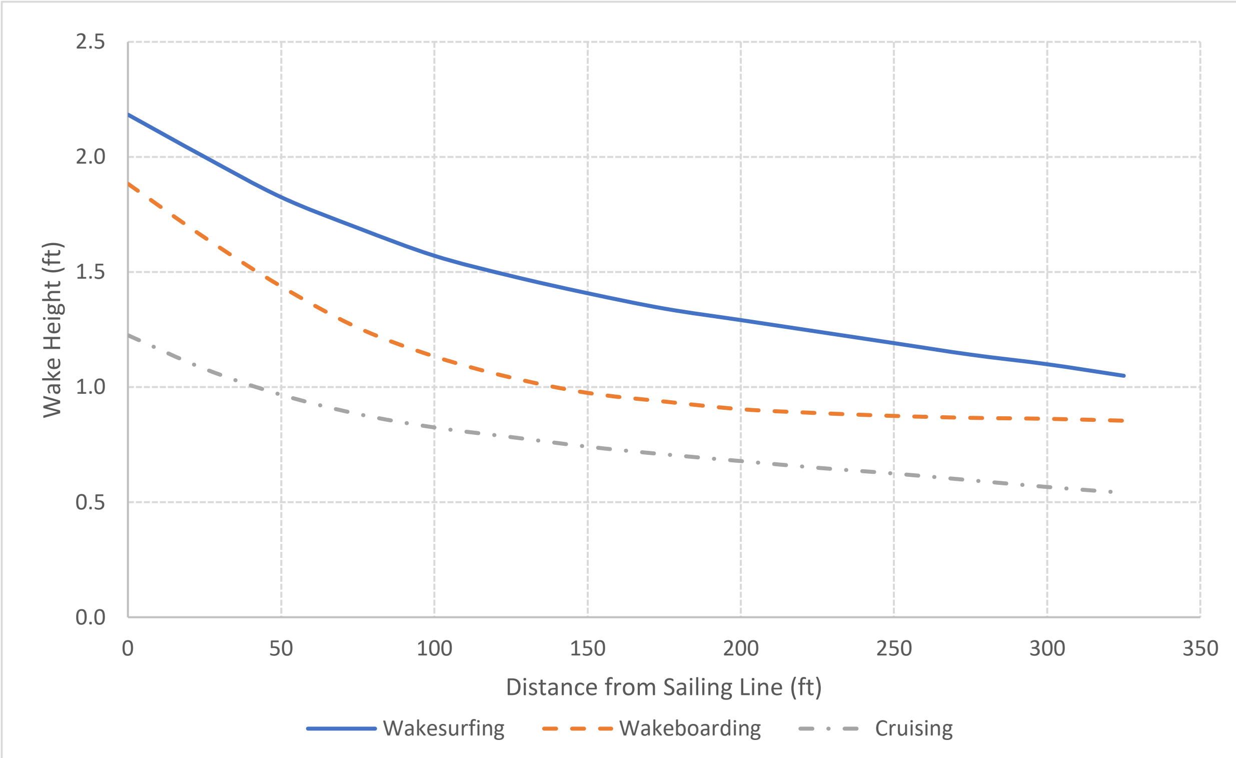

Figure 2-4. Wake height vs. distance from sailing line at deep water site (digitized curves from Goudey and Girod 2015)

Table 2-1. Wake heights vs. distance from sailing line

Distance from Sailing Line (ft)	Wave Height (ft)		
	Wakesurfing	**Wakeboarding**	**Cruising**
0	2.2	1.9	1.2
25	2.0	1.7	1.1
50	1.8	1.4	1.0
75	1.7	1.3	0.9
100	1.6	1.1	0.8
125	1.5	1.0	0.8
150	1.4	1.0	0.7
175	1.3	0.9	0.7
200	1.3	0.9	0.7
225	1.2	0.9	0.7
250	1.2	0.9	0.6
275	1.1	0.9	0.6
300	1.1	0.9	0.6
325	1.1	0.9	0.5

Table 2-2. Increase in wake height as compared to cruising vessel

	Increase in height (ft)		Percent increase	
Distance from sailing line (ft)	**Wakesurfing**	**Wakeboarding**	**Wakesurfing**	**Wakeboarding**
100	0.7	0.3	90%	37%
150	0.7	0.2	90%	31%
200	0.6	0.2	90%	33%
250	0.6	0.3	91%	40%
300	0.5	0.3	94%	52%

Lake Rabun and Lake Burton has resulted in large increases in wake heights, as allowed under the current rule requiring non-idling boats to maintain a 100 ft buffer.

WEC estimated average wave periods generated by each operating condition by measuring the water surface elevation time series plots given by Goudey and Girod (2015). The resulting estimates of average wave period of the largest waves (approximately five) in each wake are listed in Table 2-3. The results show increasing wave period from cruising to wakeboarding to wakesurfing conditions. This is important, because an increase in wave period results in increases in wave energy and wave power, which in turn may affect other vessels, docks, or shoreline erosion. Typically, when a vessel increases its speed, the wave period of the generated wake also increases. However, this is not the case when comparing the three vessel operating conditions in Table 2-3, because the increased ballasts for wakeboarding and wakesurfing conditions increase the vessel displacements, which increases the wave periods of the vessel wakes.

Goudey and Girod (2015) evaluated the relative importance of the vessel wakes on shoreline erosion by comparing to wind waves. Wave height alone is a poor indicator of potential shoreline erosion, and derived parameters such as wave energy, power and energy per unit wave height are much better indicators of potential erosion (Macfarlane et al. 2008). Goudey and Girod (2015) cite Macfarlane et al. (2008) in asserting that "cumulative energy of all the waves associated with a wake is the best measure," but our review did not find this claim anywhere in Macfarlane et al. (2008). Goudey and Girod (2015) then sum the cumulative wave power from vessel wakes and compare to cumulative power from various wind wave scenarios. The approach is flawed, however, because it neglects consideration of the fact that there is a threshold below which waves will not cause erosion. Erosion only occurs when the wave-generated shear stress at the bottom is sufficient to mobilize bed sediments. The error in the approach used by Goudey and Girod (2015) is illustrated by the fact that simply summing the energy from many small wind waves that are insufficient to individually mobilize bottom sediments may exceed the energy of a single boat wake that is sufficiently powerful to mobilize bottom sediments. In this scenario, the method used by Goudey and Girod (2015) would incorrectly conclude that the cumulative energy from the small wind waves is more impactful to shorelines than that from the single boat wake.

Table 2-3. Estimated average wave periods based on time series plots from Goudey and Girod (2015)

Operating Condition	Average wave period (s)
Cruising	1.8
Wakeboarding	2.0
Wakesurfing	2.2

Goudey and Girod (2015) conclude that shorelines that routinely experience wind-driven waves are more tolerant of wakes from all types of boating activity, and given the persistence of wind waves, in many settings they represent a more significant source of shoreline impact than boat wakes. WEC agrees with this conclusion for shorelines exposed to large fetches and subjected to energetic wind wave action. However, for shorelines along narrow water bodies with short fetches, such as the reservoir lakes in northern Georgia, wind waves are not the most dominant factor impacting shoreline, as discussed further in Section 3.2 of this report.

2.4.2 Ruprecht et al. (2015) Wake Analysis

Ruprect et al. (2015) tested the hypothesis that wakesurfing waves are equivalent to wakeboarding waves by conducting a series of field measurements on three different wakeboarding vessels. The boats tested included: a Malibu Wakesetter VLX (2014); a Tigé RZ2 Platinum Edition (2011) and a Super Air Nautique G23 (2014). The methodology included measurement of vessel wakes using multiple wave gauges in a deep water environment unaffected by strong currents or wind. The experimenters set up an 820 ft long sailing line using four floating buoys, and wave gauges were deployed at distances of 72, 115 and 246 ft from the sailing line.

The testing program included a range of vessel speeds and ballast conditions. Each vessel was tested at speeds of 9, 12, 16, 22, 28, and 35 mph. Ruprect et al. (2015) tested the vessels with full ballasts (except 12 and 35 mph), without towing a rider and with 1 to 4 people onboard. Biased ballasting was used at 12 mph to undertake an examination of waves generated in association with wakesurfing. Empty ballasting was used at 35 mph for comparison with waves generated by waterski vessels at their operational speed. Replicate runs were completed for each vessel, resulting in a total of 36 runs per vessel.

Ruprect et al. (2015) found that, regardless of design differences, all three vessels generated a similar wake for a given speed. At 72 ft from the sailing line the wave typically had a large maximum wave height, with waves bunched in a tight wave train. Table 2-4 summarizes the average maximum wave height (H_{max}) measured at 72 ft from the sailing line for all three boats tested. The highest average H_{max} values were recorded at 9 mph for wakeboarding activities and 12 mph for wakesurfing activities.

Table 2-5 summarizes the average peak wave period (T_{peak}) at 72 ft from the sailing line for all three boats tested. Peak wave period was defined as the wave period of the highest wave in the wave train. Similar to the measurements by Goudey and Girod (2015), the lower speeds at which the largest wave periods were recorded are also the speeds at which the highest waves were generated.

Table 2-4. Average maximum wave heights measured by Ruprecht et al. (2015) at 72 ft from the vessel sailing line

Speed (mph)	Average Maximum Wave Height, H_{max} (ft)
9	0.89
12	1.25
16	0.79
22	0.72
28	0.62
35	0.43

Table 2-5. Average peak wave period measured by Ruprecht et al. (2015)

Speed (mph)	Average Peak Wave Period, T_{peak} (s)
9	2.02
12	2.02
16	1.85
22	1.75
28	1.61
35	1.57

Table 2-6 summarizes the average energy of the maximum wave height (Energy H_{max}) at 72 ft from the sailing line for all three boats tested. The highest average Energy H_{max} values were recorded at 9 mph for wakeboarding activities and 12 mph for wakesurfing activities.

Ruprecht et al. (2015) found that the wave energy associated with the single maximum wave height for wakesurf operating conditions is approximately four times that of wakeboard operating conditions. Because wakesurfing, wakeboarding and waterskiing each produce significantly different waves, Ruprecht et al. (2015) recommended that these three activities be assessed and managed separately. Ruprecht et al. (2015) give only two examples of management options, including:

- Restrict those activities to wide parts of the river to allow for natural wave height attenuation.
- In certain situations, where maximum wave height is a concern, and insufficient distance is available to allow for natural attenuation, management of the sport may result in restricting activities or the implementation of artificial shoreline enhancements (i.e. bank armoring, rip-rap, rock fillets etc.).

Table 2-6. Energy of maximum wave measured by Ruprecht et al. (2015)

Speed (kt)	Speed (mph)	Average Energy of Maximum Wave, Energy H_{max} (kg.m/s2)
8	9	595
10	12	1219
14	16	379
19	22	286
24	28	175
30	35	90

2.4.3 WEC Field Measurements and Wake Analysis

On September 30, 2020 WEC conducted a field study on Lake Rabun to: validate and verify data from the aforementioned wake analyses; and quantify wake heights and wake attenuation at a site-specific location. WEC placed two wake monitoring instruments at two distances from the sailing line (162 and 267 ft) to measure the attenuation of the wake height propagating away from the sailing line. A SonicXB gauge, manufactured by Ocean Sensor Systems, Inc., was mounted an aluminum tripod at each monitoring location. Figure 2-5 shows the sensor mounted above the water surface. The sailing course and instruments were set up in an area of Lake Rabun where the bottom is less than 35 feet deep. Figure 2-6 shows the test venue, sailing line, and instrument locations.

The field study included a total of 49 test cases using a 2017 Super Air Nautique G22 (Figure 2-7) wake boat driven by an experienced captain. The test cases included three operational modes: cruising/waterskiing, wakeboarding, and wakesurfing. Three vessel speeds were tested for each operational mode, and five replicate tests were completed for each vessel speed.

The cruising/waterskiing tests included two passengers with no additional ballast (i.e., ballast tanks were empty). The combined gross weight of the boat, passengers and gas was roughly 6,000 lb. Test speeds included 20, 25 and 30 mph. Figure 2-7 shows the boat running on a plane during the cruising/waterskiing tests.

For the wakeboarding tests, the factory-installed internal ballast tanks were filled, resulting in a combined gross weight of roughly 8,000 lb. Test speeds included 21, 22 and 23 mph. Figure 2-8 shows the boat with a full ballast tank during the wakeboarding tests.

For the wakesurfing tests, an additional ballast bladder was added on board for an extra 2,000 lb., roughly, bringing the gross combined weight to approximately 10,000 lb. Test speeds included 10, 11 and 12 mph, with a couple additional runs at 9 mph. Figure 2-9 shows the boat operating under wakesurfing conditions.

Figure 2-5. SonicXB gauge mounted to tripod in Lake Rabun

For each test case, WEC measured the maximum wake height at each gauge. The maximum wave heights for each vessel speed and operational condition were then averaged. WEC developed a wave attenuation equation for each operational condition. Macfarlane and Renilson (1999) give the following equation to describe the attenuation of divergent wakes according to deep-water vessel wave theory:

$$H = \gamma y^n$$

where H is the wake height, y is the distance from the sailing line, and γ is a vessel-dependent function of speed. The exponent n has a theoretical value of -⅓ for divergent wakes. Macfarlane (2002) analyzed a wave wake database and found that the deep water, divergent wave decay exponent generally varies between a range from -0.22 to -0.4, and -0.33 is considered a reasonable engineering approximation. WEC used the Lake Rabun test data to solve for the variables γ and n for each operational condition, using the average wave height from the vessel speed producing the maximum

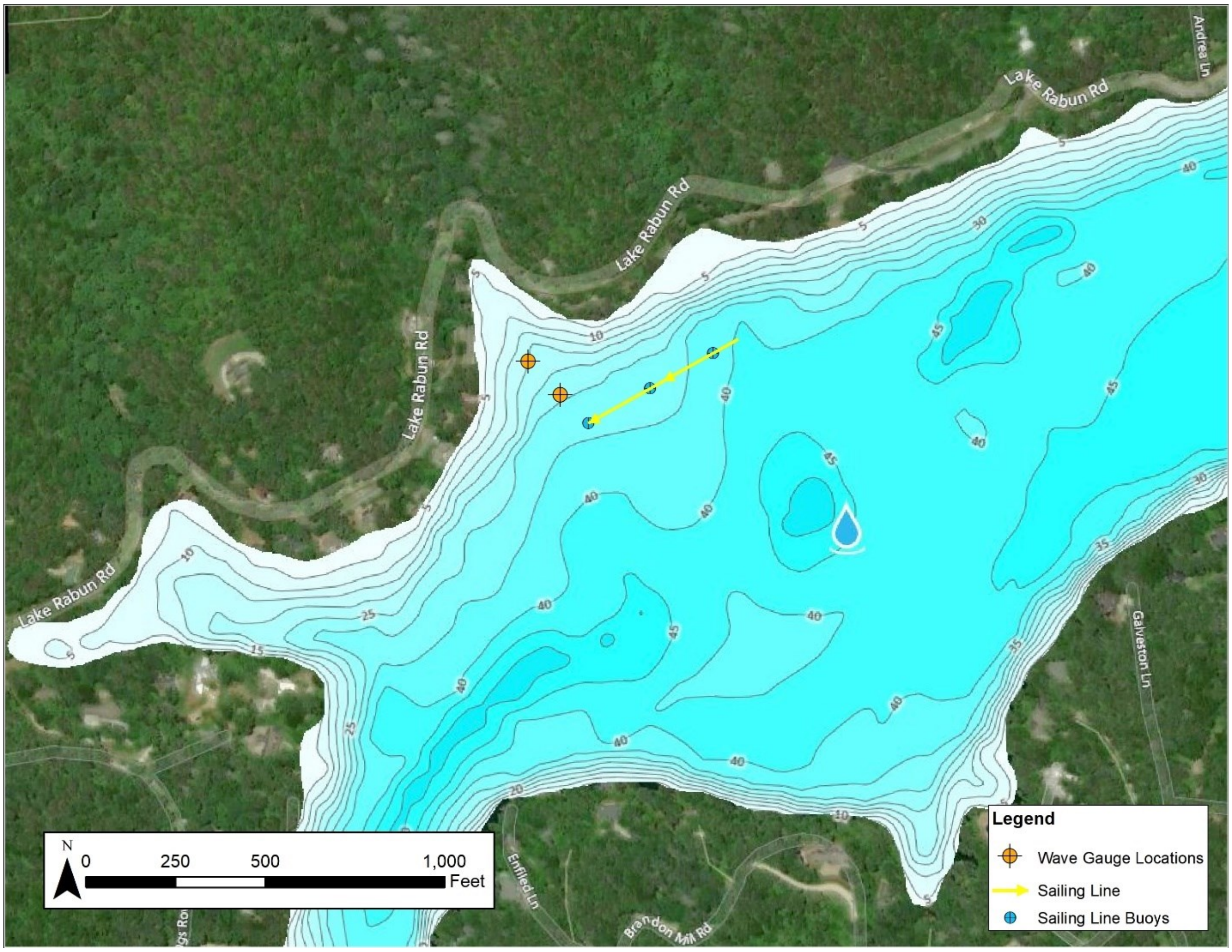

Figure 2-6. Wake measurement instrument locations and sailing course

Figure 2-7. Super Air Nautique G22 during cruising/waterskiing test run

Figure 2-8. Super Air Nautique G22 with full ballast during wakeboarding test run

Figure 2-9. Super Air Nautique G22 with additional ballast during wakesurfing test run

wake heights. The result is an equation to describe the wake heights and attenuation at various distances other than those where they were directly measured.

Figures 2-10 through 2-12 illustrate the wave curve results for each operating conditions. Figure 2-13 compares the Lake Rabun wake attenuation results to the WSIA wake boat study results from Goudey and Girod (2015). As noted earlier, only the deep water results from the WSIA study are shown in Figure 2-13, because the Lake Rabun test site was in deep water. Overall, the Lake Rabun observations are generally consistent with those from the WSIA study. Wake attenuation measurements from the cruising/waterskiing scenario on Lake Rabun are very similar to those measured by Goudey and Girod (2015). The Lake Rabun measurements for wakeboarding conditions are slightly lower than those observed by Goudey and Girod (2015). The Lake Rabun measurements for wakesurfing conditions are slightly higher than those observed by Goudey and Girod (2015).

The results can be used to determine the appropriate minimum buffer distance for wake boats (i.e., the minimum distance that wake boats should maintain from shoreline and other vessels). As discussed earlier, the Georgia "Rules of the road for boat traffic" (O.C.G.A § 52-7-18) states that non-idle vessels should maintain a 100-ft buffer distance from other vessels, people, structures and shorelines.

An appropriate buffer distance for wakeboard/wakesurfing boats might be one that produces wake heights that are similar to those from cruising/waterskiing boats at the buffer distance. As recommended by Ruprecht et al. (2015), these three activities can be assessed and managed separately.

As shown by the Lake Rabun results (Figure 2-14), the typical maximum wake height for cruising/waterskiing boats is about 0.8 ft at the currently effective 100-ft buffer distance. During wakeboarding conditions, the wake height is reduced to 0.8 ft at a distance of about 225 feet from the sailing line. A possible management measure based on this data would be to require a minimum buffer distance of 225 feet during wakeboarding operation. For wakesurfing, the wave height equation indicates the height does not attenuate to 0.8 ft until approximately 950 feet from the sailing line. At 500 feet of the sailing line, the wake height is approximately 1 ft. Appropriate buffer distances for wakesurfing operation may include 500 feet (allowing for higher and more powerful waves), or 950 feet (requiring wave heights no greater than typical cruising/waterskiing conditions).

Table 2-8 summarizes the average wave period from the Lake Rabun field data. Since waves generated by wakeboarding and wakesurfing have longer periods than those from cruising/waterskiing, they have more energy and power. Therefore, even a 225-ft buffer for wakeboarding and a 950-foot buffer for wakesurfing conditions will still allow waves to impact other vessels, structures, or the shoreline with more power than those from cruising/waterskiing at a 100-ft buffer distance.

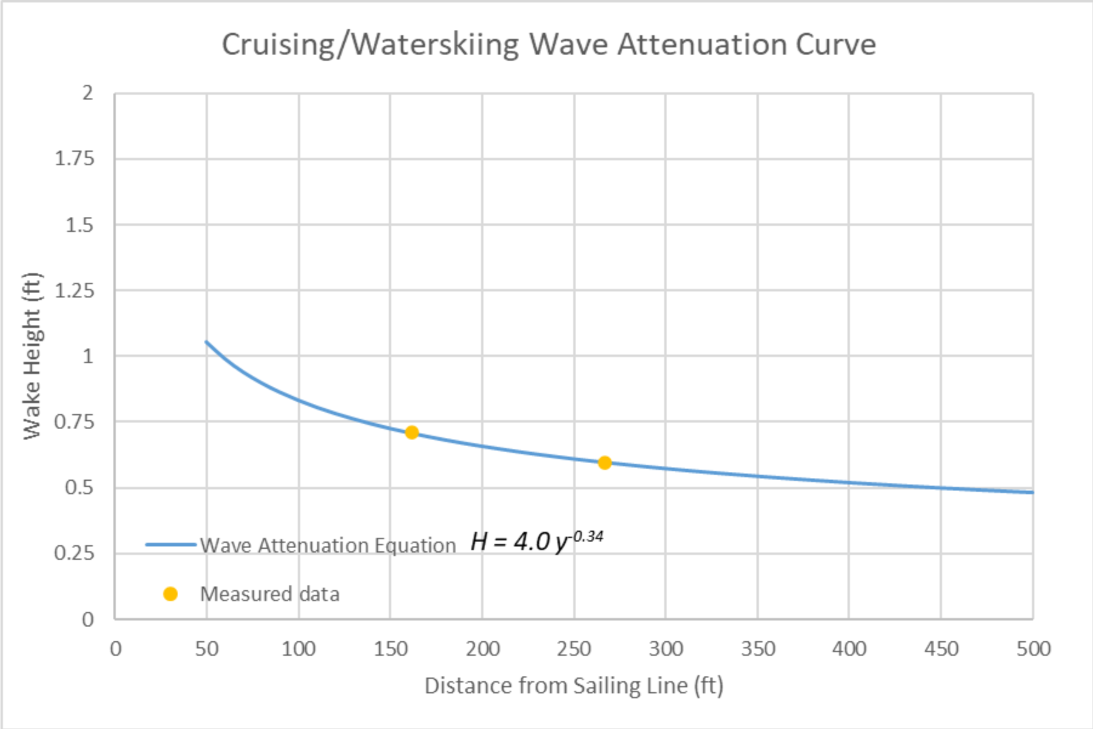

Figure 2-10. Maximum wake height versus distance from sailing line for cruising/waterskiing conditions at Lake Rabun

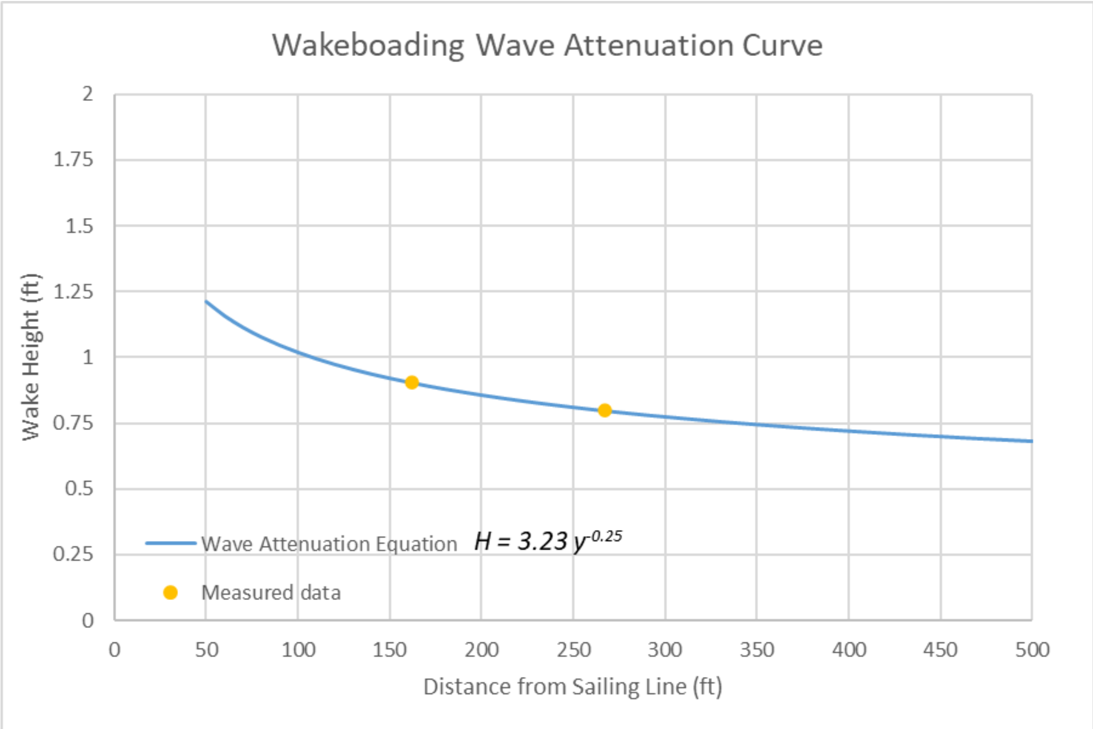

Figure 2-11. Maximum wake height versus distance from sailing line for wakeboarding conditions at Lake Rabun

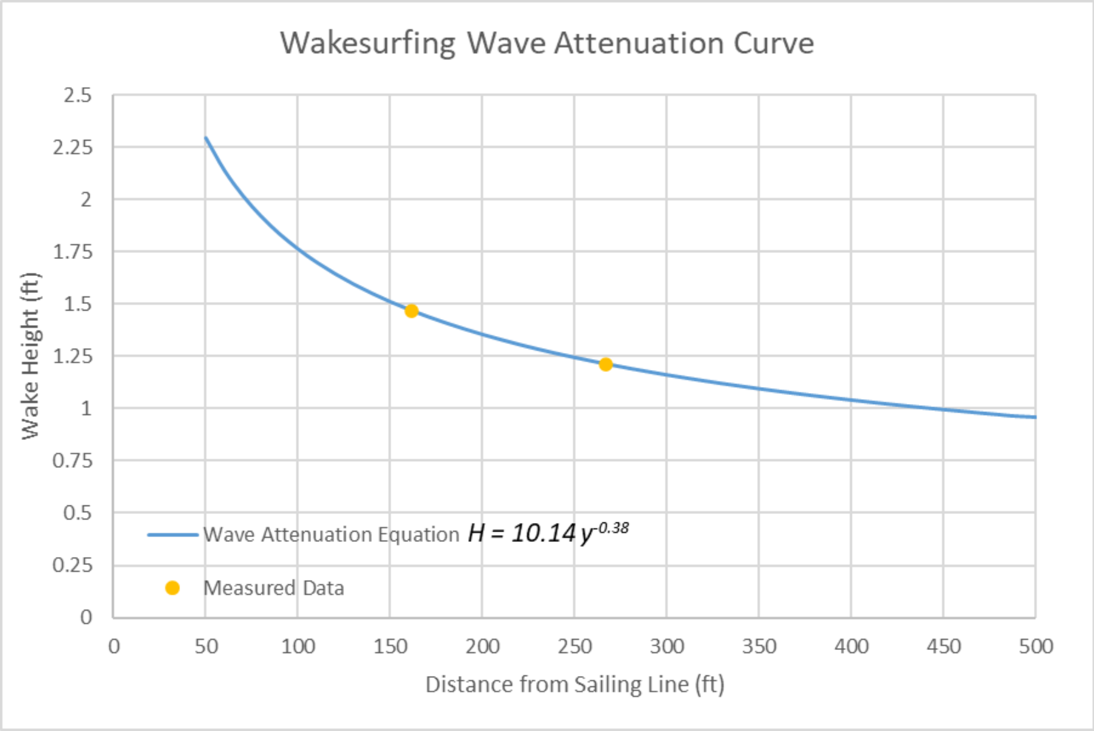

Figure 2-12. Maximum wake height versus distance from sailing line for wakesurfing conditions at Lake Rabun

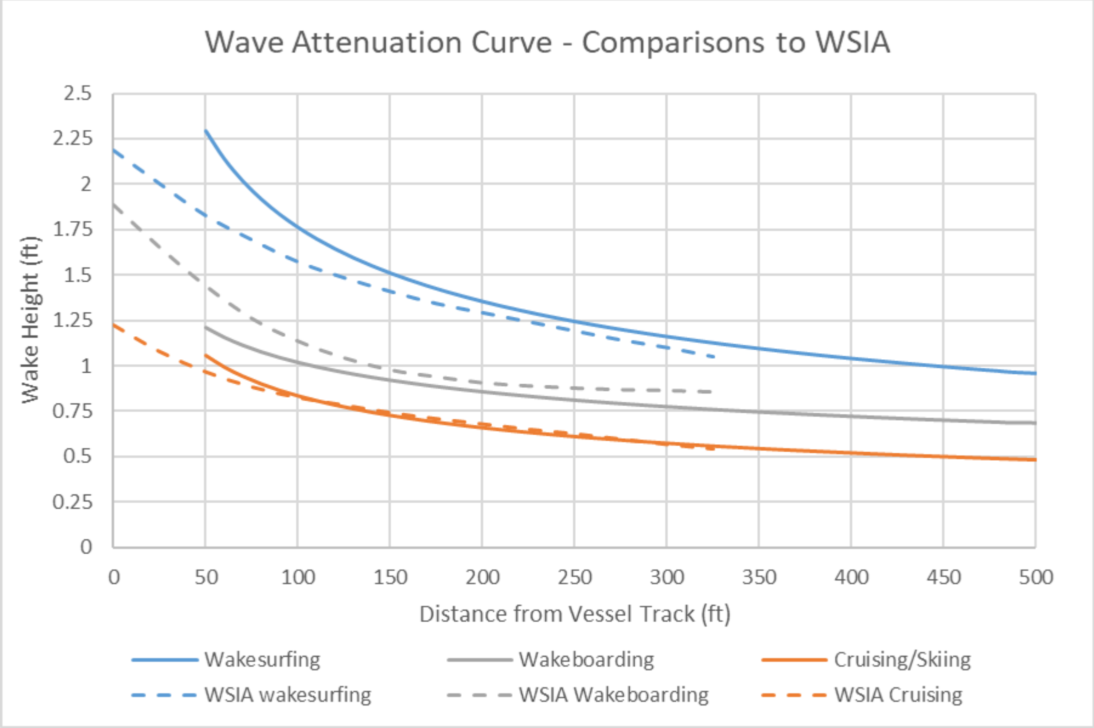

Figure 2-13. Comparison of Lake Rabun field study results to 2015 WSIA study results for deep water measurements

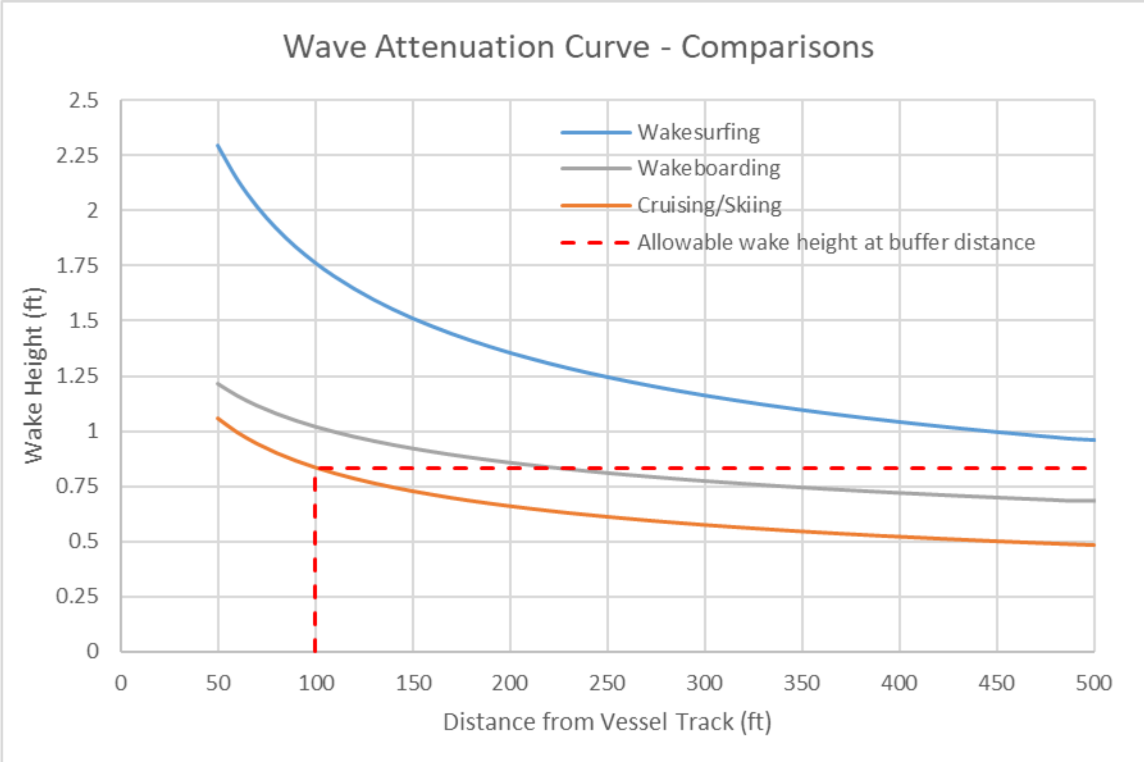

Figure 2-14. Wake attenuation curves from Lake Rabun field study and example of allowable wave height at buffer distance

Table 2-7. Incremental increase in wake height, by feet and percentage, for wakeboarding and wakesurfing as compared to cruising conditions

Distance from sailing line (ft)	Wakeboarding [ft and (%)]	Wakesurfing [ft and (%)]
100	0.2 (22%)	0.9 (111%)
150	0.2 (27%)	0.8 (108%)
200	0.2 (30%)	0.7 (105%)
250	0.2 (33%)	0.6 (104%)
300	0.2 (35%)	0.6 (102%)
400	0.2 (39%)	0.5 (100%)
500	0.2 (41%)	0.5 (98%)

Table 2-8. Average wave period of vessel wakes by operating condition from Lake Rabun field data

Operating Condition	Average wave period (s)
Cruising	1.7
Wakeboarding	1.8
Wakesurfing	2.1

3 Wake Impact Assessment

This report section evaluates wake boat impacts on Lake Rabun and Lake Burton, with a focus on the incremental increase in impacts from wakesurfing and wakeboarding vessels above and beyond those from typical cruising vessels. The evaluation includes an analysis of wind waves, followed by an assessment of impacts to shoreline erosion, dock and shoreline structures, moored vessels and safety.

3.1 Wind Wave Analysis

WEC calculated wind wave conditions at five locations within Lake Rabun and Lake Burton using the straight-line fetch methodology and equations described in the U.S. Army Corps of Engineers' (USACE) Coastal Engineering Manual (CEM) (USACE 2011). The method estimates wind wave growth along a fetch for a given wind speed. WEC did not assess all shoreline locations, but instead chose locations representative of typical fetch distances, as depicted in Figure 3-1. These locations include sites in narrow areas of each lake that are relatively sheltered from wind wave action, as well as sites exposed to longer fetches and larger wind waves. Wind waves were not analyzed here as conditions are expected to be similar to the other narrow sites, particularly the one on Lake Rabun. For each location, wind waves were estimated for the shore-perpendicular fetch line, as well as fetches rotated 45° in either direction.

Wind wave growth is a function of fetch length and wind speed. Areas with longer fetches (i.e., wider parts of the lake) allow for larger wind waves. To determine and representative wind speed, WEC analyzed hourly wind records from the Toccoa Airport located roughly 14 miles southeast of Lake Rabun. Winds records dated from 2012 through 2020. WEC chose a monthly return period to evaluate monthly maximum wind waves. In other words, this wind speed should be expected to occur once every month. This will result in a wind wave estimate that is conservatively high for comparison to vessel wakes that occur on a more frequent weekly basis.

Table 3-1 summarizes the results of the wind wave analysis. Per the CEM methodology, WEC adjusted the wind time-averaging duration iteratively to identify the maximum fetch-limited wind wave growth conditions for each fetch. The reported wind-wave condition in Table 3-1 is the average of the shore-normal and the ±45° fetch results at each location. The CEM method estimates the significant wave height, H_s, which is the average of the highest one-third of waves in the irregular wave field. The maximum wave height is estimated as $1.6H_s$, which is a value approaching the average height of the highest one percent of waves during storms (Federal Emergency Management Agency [FEMA] 2007).

A comparison of wake heights from WEC's field study with estimated maximum monthly wind wave heights at the five sites is shown in Figure 3-2. Because the lakes are generally narrow, wind waves are relatively small at each site. Portions of Lake Burton, however, can be wider than the other lakes and susceptible to larger wind driven waves. Wakesurfing vessel wakes exceed wind waves at every site at distances within 500 feet of the vessel sailing line. In contrast, typical cruising vessel wakes do not exceed wind waves at every site, except within very close proximity to the vessel (i.e., less that 75 feet

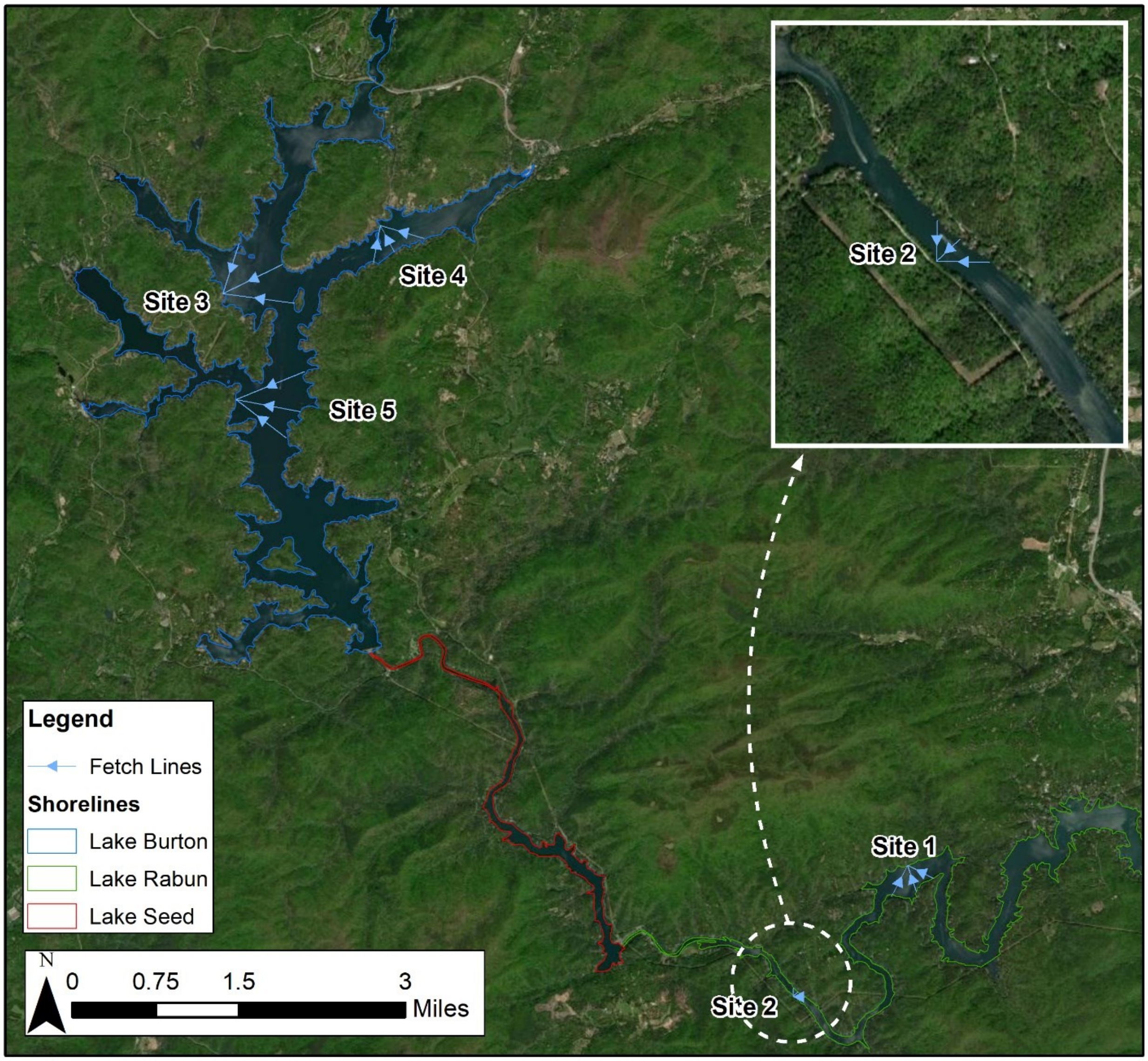

Figure 3-1. Straight-line fetch analysis locations within Lake Burton and Lake Rabun

Table 3-1. Summary of average wind wave estimates for monthly event at each location

Variable	Site 1	Site 2	Site 3	Site 4	Site 5
Fetch length (mi)	0.28	0.08	0.58	0.34	0.61
Observed wind speed (mph)	28.8	28.8	28.8	28.8	28.8
Observed wind duration (min)	2	2	2	2	2
Duration for fetch-limited conditions (min)	15	7	25	18	26
Adjusted wind speed, U_t (mph)	25	26	25	25	25
Calculated sig. wave height, H_s (ft)	0.40	0.23	0.57	0.44	0.59
Calculated maximum height, H_{max} (ft)	0.64	0.36	0.91	0.71	0.94

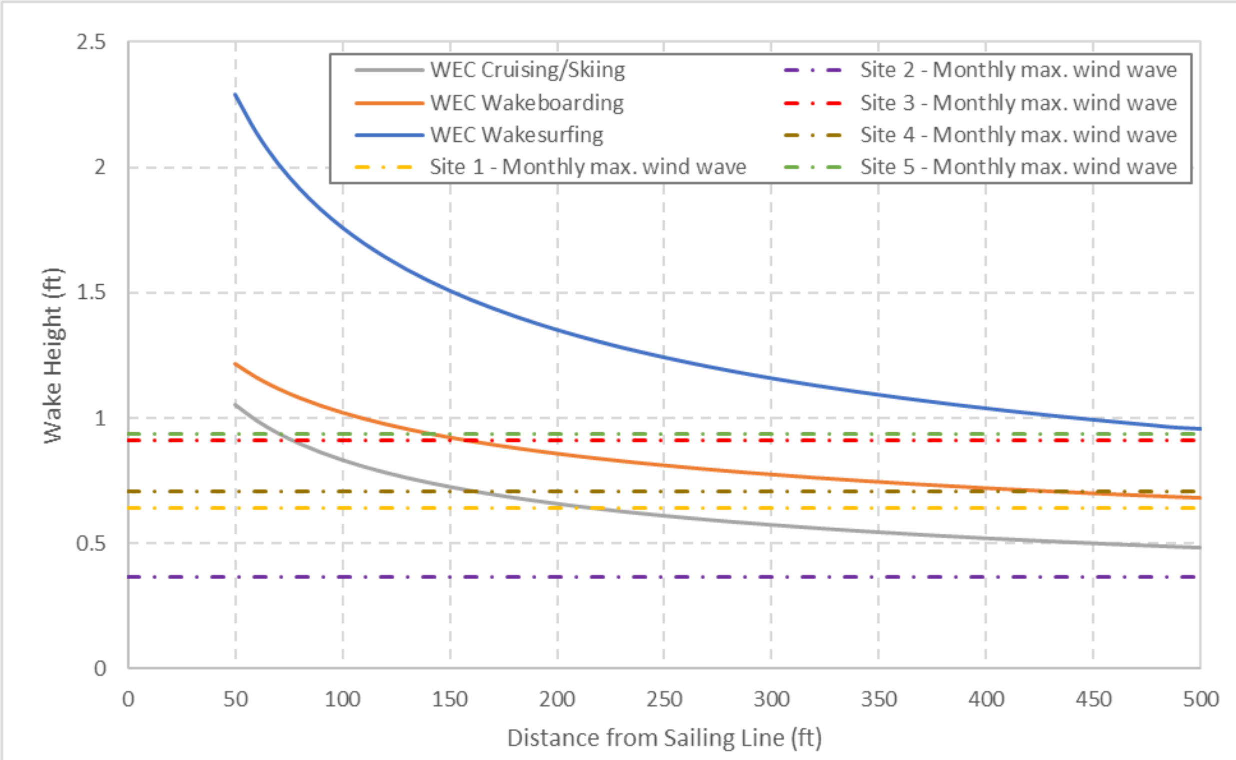

Figure 3-2. Comparison of WEC measured wake heights to maximum monthly wind wave heights

from the vessel). Therefore, vessel wake effects should not be dismissed as insignificant as compared wind wave effects, which may be the case in much wider lakes.

3.2 Shoreline Erosion

Vessel wakes have been shown to have the potential for adverse impacts to shorelines, including shoreline erosion (Castillo et al. 2000, Bauer et al. 2002), scour of the bottom of the shoreface, and temporary reduction in water clarity (USACE 1994, Asplund 1996). Shoreline erosion in a reservoir such as Lake Rabun and Lake Burton are a complex process dependent on site-specific, localized conditions, such as the sediment properties, topographic slope, presence of hard structures or vegetation, surface runoff, groundwater seepage, slumping, lake water levels and incident wave climate. Quantifying estimates of actual site-specific erosion rates is beyond the scope of this study. Instead, WEC evaluated the incremental changes in wave energy, which is generally considered related to shoreline erosion. Wave energy is a better measure for evaluating shoreline erosion than wave power (Macfarlane et al. 2008, USACE 2017). Ideally, cumulative wave energy above a critical minimum threshold to start causing erosion is likely the best way to compare vessel wakes and wind wave impact on shoreline erosion, but that level of analysis is beyond the scope of this study.

Wave energy can be expressed by the following formula:

$$E = \frac{\rho g^2 H^2 T^2}{16\pi}$$

Where E = Energy,
ρ = water density,
g = gravity
H = wave height, and
T = wave period.

Using the above equation, WEC computed the wave energy at the shoreline using the wave attenuation curves from the Lake Rabun measurements (Section 2.4.3 of this report) and the wind-generated wave estimates from the previous section. Based on the resulting wave energy, WEC calculated the incremental increase of energy from wakesurfing and wakeboarding vessels compared to a cruising vessel (Tables 3-2 and 3-3). The results are based on vessels passing at varying distances from the shoreline. The incremental increase as compared to cruising vessels is provided as a calculated value and percentage. From these tables, a wakesurfing wake 100 ft from the vessel's sailing line has 581% (15,034 foot·pounds) more energy than a cruising vessel's wake that traveled the same distance.

The percent increase is even larger when compared to the wind-waves at the two study locations within Lake Rabun (Table 3-3). Table 3-3 compares vessel wake wave energy to the wind wave energy at the longest fetch evaluated in the previous section (Site 5). The monthly maximum wind wave energy at this site is far lower than the vessel wake energy largely because the wind waves are a shorter wave period of 1.2 seconds as compared to the wakeboarding and wakesurfing periods of 1.8 and 2.1 seconds, respectively. The wave energy is proportional to the *square* of the wave period, and therefore the longer waves from the vessels produce much greater wave energy than individual wind waves.

Given the present management rules requiring only a 100-ft buffer distance between non-idle speed boats and the shoreline, these results indicate that wave energy from wakesurfing and wakeboarding vessels are much more likely to contribute to shoreline erosion than typical boat wakes or wind waves. As mentioned above, shoreline erosion from waves depends on localized conditions. Erosion may not be an issue where the shoreline is hardened (e.g., many homes on Lake Rabun have vertical bulkheads or rock shoreline stabilization), but sensitive shoreline areas may require wake management measures to minimize the risk of wake-induced erosion.

3.3 Structures

Estimating wave forces on structures is a complex task that is dependent on the specific structure type and geometry (e.g., pile diameters, deck height, horizontal members, vertical wall height, etc.). Dock and boathouse structures along each lake are also subjected to wave uplift forces on the underside of decks, wave drag forces on piles, horizontal loads on vertical faces of structures, and mooring line loads from moored vessels. Evaluating each of these types of loads is unnecessary to give a general illustration of the relative impact of various waves on structures. As a simplified measure to

Table 3-2. Wave energy at the shoreline and percent increase compared to cruising vessels

Vessel Distance from Shore (ft)	Energy (ft·lb)			Percent Increase	
	Cruising	Wakeboard	Wakesurf	Wakeboard	Wakesurf
100	2587	4346	17621	68%	581%
150	1964	3549	12948	81%	559%
200	1615	3073	10405	90%	544%
250	1387	2749	8782	98%	533%
300	1226	2509	7646	105%	524%
400	1008	2173	6144	116%	510%
500	866	1944	5186	124%	499%

Table 3-3. Wave energy at varying distances from sailing line and percent increase as compared to wind-waves

Vessel Distance from shore (ft)	Energy (ft·lb)			Percent Increase over Wind Waves	
	Long Fetch Wind Waves	Wakeboard	Wakesurf	Wakeboard	Wakesurf
100	666	4346	17621	553%	2546%
150	666	3549	12948	433%	1845%
200	666	3073	10405	362%	1463%
250	666	2749	8782	313%	1219%
300	666	2509	7646	277%	1048%
400	666	2173	6144	226%	823%
500	666	1944	5186	192%	679%

demonstrate the incremental effect of varying wake heights on structures, WEC estimated horizontal wave forces on a vertical wall structure.

The wave load method prescribed by FEMA is given by Walton et al. (1989), who recommend the methodology of Ham-ma and Horikawa (1964 & 1965 *in* Walton et al. 1989). This same methodology is recommended in the American Society of Civil Engineers (ASCE) standard ASCE 07-10, *Minimum Design Loads for Buildings and Other Structures* (ASCE 2010), and FEMA's *Coastal Construction Manual* (CCM) (FEMA 2011).

Table 3-4 summarizes the lateral wave force on a vertical wall, in units of pounds-force (lbf) per linear foot of shoreline, and percent increase as compared to a cruising vessel. At the 100-ft distance, the minimum buffer required under the present management rules, the lateral wave forces from wakeboarding wakes are 25 percent greater than those from cruising vessels, and the lateral wave forces from wakesurfing wakes are 131 percent greater than those from cruising vessels (i.e., the forces on the wall are more than double those from cruising vessels). Even with a 500-ft buffer distance, the

Table 3-4. Horizontal wave forces on vertical walls and percent increase compared to cruising vessel

Vessel Distance from Shore (ft)	Force per linear foot (lbf/ft)			Percent Increase over Cruising Wakes	
	Cruising	Wakeboard	Wakesurf	Wakeboard	Wakesurf
100	1454	1813	3354	25%	131%
150	1253	1623	2810	29%	124%
200	1129	1501	2482	33%	120%
250	1041	1413	2257	36%	117%
300	975	1345	2089	38%	114%
400	880	1245	1851	42%	110%
500	812	1173	1687	44%	108%

lateral force from a wakesurfing wake is more than twice that of a cruising vessel at the same distance. These results indicate that these larger waves are more likely to cause damage to dock and shoreline structures that are not built to withstand repeated exposure to these larger waves.

The results in Table 3-4 should not be directly compared to those for wave energy discussed in the previous section on shoreline erosion, because the wave force on a vertical wall is different than wave energy. Wave energy increases with the square of the wave height and the square of the wave period (or wave length). In contrast, wave force acting on a vertical wall increases with wave height, and it is not affected by changes in wave length. Therefore, increases in wave height and wave length caused by wake boats are expected to cause much greater increases in wave energy than wave force on a vertical wall. The results of our analysis are consistent with this expectation.

Wave reflection can further amplify the impacts on dock and boathouse structures. Many properties along the shoreline of Lake Rabun and Lake Burton are protected by vertical bulkheads. In general, vertical walls reflect 70 to 100 percent of incoming wave energy (Thompson and Hadley 1995). The reflected waves can interact with other incoming waves to cause even greater increase in forces on dock and boathouse structures than the increases described above.

In shallow areas, waves can also cause scour of the lake bottom along the toe of bulkheads or around pilings. Scour depth below the surrounding grade is typically estimated as equal to the incident wave height. Therefore, at the effective 100-ft minimum buffer distance, the incremental increase in potential lake bottom scour near shallow water structures caused by wakeboarding is minor (up to 0.2 ft). On the other hand, wakesurfing wakes can potentially cause up to 0.9 ft more bottom scour at the toe of shallow water structures. Toe scour can lead to slip failure of the soils behind the wall, resulting rotation of the wall or “kick out” at the toe. Increased scour from boat wakes increases the risk of bulkhead failure, because failure of the toe will generally lead to failure throughout the entire structure.

Increased wave overtopping from boat wakes also increases the risk of bulkhead failure. Figure 3-3 shows a wake impacting a bulkhead during the Lake Rabun field measurements. The wake was

Figure 3-3. Example wave run-up from wakesurfing wave impact during field testing

generated from the test vessel operating in wakesurfing conditions, and the wall is approximately 300 ft from the sailing line. Maximum height of wave spray at the wall was in the range of 5 to 6 feet above the lake water surface, and a fraction of this water falls behind the wall (wave overtopping). Repetitive overtopping of structures can slowly erode material on the backside of walls and, if not reinforced, the structure could eventually fail as a result of this erosion. Figure 3-4 shows an example of erosion from wave overtopping behind a bulkhead on Lake Burton. Also, overtopping can cause excess water pressure behind the bulkhead, which can cause anchor failure or toe “kick-out” failure.

3.4 Damages

As discussed above, increased boat wake heights can result in damage or failure of shoreline bulkheads by way of increased wave scour at the toe of the structure or increased wave overtopping of the structure. The costs of these damages are unknown for Lake Burton; however, a recent survey provides an indication of the cost of damages on Lake Rabun. The LRA conducted a member survey during November 30 – December 6, 2020 and received 486 responses, which is a very high response rate (57%) for member surveys. A summary of the member survey is provided in Appendix A

Figure 3-4. Erosion of soils from behind bulkhead on Lake Burton

of this report. Table 3-5 summarizes the results for the responses to the question "Have you experienced shoreline erosion or structural damage as a result of large waves?" The table also includes the responses to the same question from a 2018 survey. The table shows an increasing rate of shoreline and structural damage caused by large waves.

Comments from survey respondents include:

> *"The constant pounding of wake boat waves against our dock has caused significant damage. I'm repairing it at least twice as much as before the surge in wake boats on the lake. And the small beach area by our dock has eroded so much it's a fraction of what it once was. My children can barely swim/play on that beach area anymore without being jostled and thrown by huge wake boat waves."*
>
> *"Rock Seawall and patio had no damage for 20 years. Has extensive damage in past 3 years due to gigantic waves reaching shoreline."*
>
> *"We've had our house for two generations and have never seen such erosion to our shoreline."*

Table 3-5. LRA survey response to the question "Have you experienced shoreline erosion or structural damage as a result of large waves?"

Response	2020 Survey	2018 Survey	Change
No erosion or structural damage	24.5%	33.8%	-9.3%
Minor shoreline damage	38.9%	29.4%	9.5%
Major shoreline damage	28.5%	22.3%	6.2%
Structural damage	32.1%	14.5%	17.6%

The wave-induced damages have resulted in substantial costs to homeowners. Table 3-6 summarizes costs to repair shoreline/structure damage, for those respondents who were able to estimate these costs.

3.5 Moored Vessels

On Lake Rabun and Lake Burton, wakes can adversely impact vessels moored to docks, either by causing damage to boats or docks, or by creating unsafe conditions for boarding or disembarking (for example, see the wave runup in Figure 3-3). The most applicable standards for moored vessels are related to small-craft harbors. PIANC (1994) published criteria for small craft harbor quiescence based on Canadian standards, which limits waves within a marina basin according to the values in Table 3-7. These criteria are for "good" marina basin tranquility conditions. The "moderate" marina basin tranquility conditions are given in Table 3-8. The values presented in Table 3-7 assume some level of vessel occupancy during storm events and are sensitive to vessel/dock orientation to incident wave direction. These criteria are typically used for evaluating conditions in a small craft harbor that would lead to significant physical damage to boats or docks, or that represented a life safety concern. These criteria consider the interaction of the vessel and the dock, and therefore they are far more stringent than those commonly accepted for boats left anchored freely in open water away from structures.

The appropriate criterion to consider for impacts to dock mooring conditions depends on the vessel orientation and the frequency of occurrence. It is reasonable to assume that docked boats on the lakes are typically not oriented parallel to the shoreline. Also, the issue under consideration in the study is the typical operational conditions (i.e., weekly conditions), not extreme storm conditions. Therefore, the appropriate tranquility criterion to consider in Tables 3-7 and 3-8 are the weekly head seas condition.

Figure 3-5 illustrates the wake heights measured on Lake Rabun and the moderate head seas berthing criterion. The calculated wave height for a cruising vessel passing 260 ft from the shoreline (0.6 ft) satisfies the moderate criterion. However, wakesurfing and wakeboarding wave heights do not meet the moderate criterion even if the vessels pass 500 feet from shore. At the 100-ft distance, the minimum buffer required under the present management rules, the wake heights from wakesurfing and wakeboarding are far above the moderate berthing criterion. This supports the conclusion that the current management measures are insufficient to avoid vessel wakes from creating poor vessel berthing

Table 3-6. LRA survey responses estimating cost to repair shoreline/structure damage, if known

	Spent to date	Estimated to complete
Sum	$609,600	$1,057,450
Average	$8,467	$12,441
Median	$2,800	$3,500
# of respondents	72	85

Table 3-7. Marina basin wave tranquility criteria for good conditions

Wave Direction Relative to Vessel	Significant Wave Height (ft) Not exceeded more than once per: Week	Year	50 Years
Head	0.5	1.0	2.0
Beam	0.3	0.5	0.8

Notes: 1. Multiply wave heights by 0.75 for "excellent" and 1.25 for "moderate" conditions.
2. For wave periods > 2 seconds.

Table 3-8. Marina basin wave tranquility criteria for moderate conditions

Wave Direction Relative to Vessel	Significant Wave Height (ft) Not exceeded more than once per: Week	Year	50 Years
Head	0.6	1.2	2.5
Beam	0.3	0.6	0.9

Notes: 1. For wave periods > 2 seconds.

conditions at docks, and there is a potential for incoming wakes to cause physical damage to boats or docks, or create unsafe conditions for boarding or disembarking from moored boats.

In addition, wake wave reflection from vertical bulkheads along the shoreline can further increase wave heights in berthing areas. As mentioned previously, many properties along each lake's shoreline are protected by vertical bulkheads, and waves reflected from these walls can interact with other incoming waves to cause even greater wave heights than those described above.

3.6 Safety

The previous sections highlight the significant increase in wake heights from wake boat vessels, the force and energy of these wakes, and the potential for destructive damage to shoreline and property; however, of utmost importance to the Associations is the *safety* of boaters and swimmers. Safety is also of primary importance for Georgia Power, as illustrated by their published Core Safety Beliefs:

(1) Safety takes precedence over all other requirements;

(2) Safety is a personal value;

(3) All hazards can be controlled; and

(4) The "Spirit of Safety" is a constant.

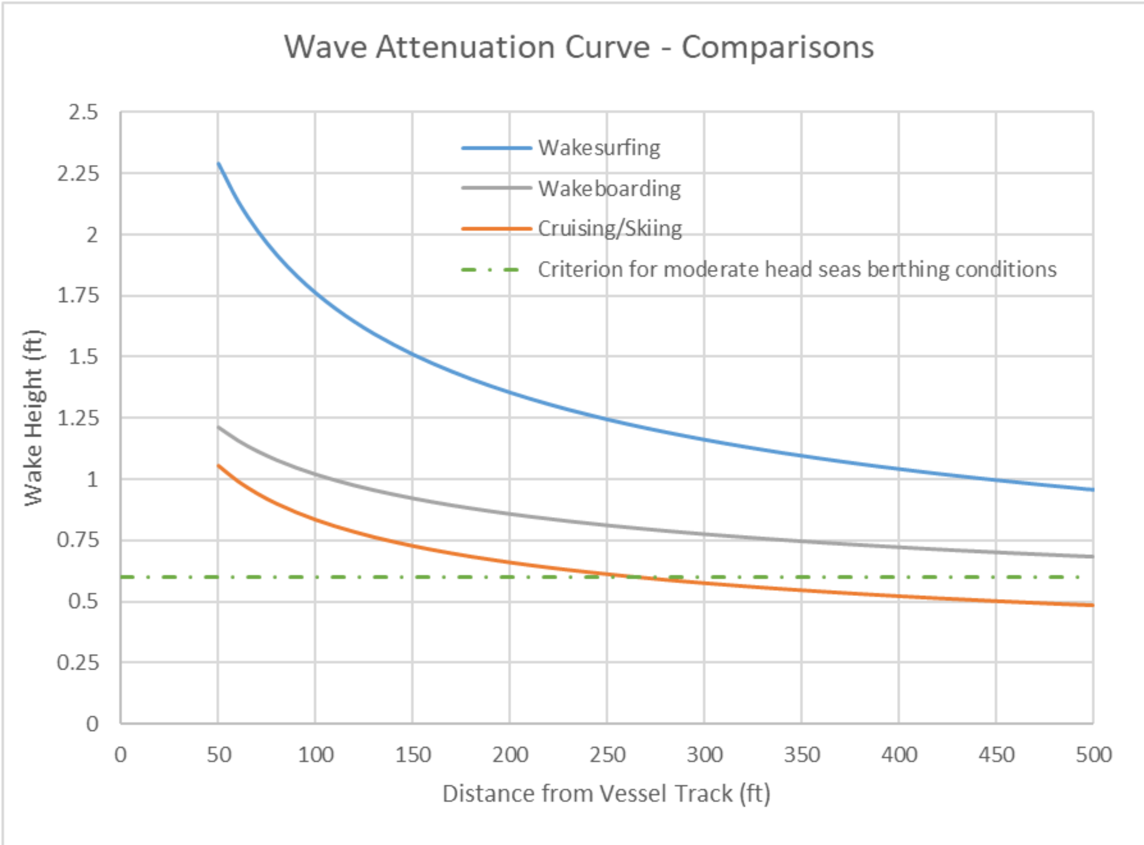

Figure 3-5. Comparison of measured wake heights at Lake Rabun to criterion for moderate head seas berthing conditions

Large wakes can create unsafe conditions by swamping recreational craft, impacting other boats, or causing falls overboard. Small craft, including canoes, kayaks, and sailboats are particularly at risk of being swamped, broached, or capsized by steep waves from wake boats. In their statistical report of recreational boating accidents, the U.S. Coast Guard cited that "flooding/swamping" was the 4th most common type of accident reported in 2019, resulting in 45 deaths and 124 injuries (U.S Coast Guard 2020). Between 2015 and 2018, it was the 3rd most common boating accident. Additionally, "forces of wave/wake" was one of the top ten contributing factors in accidents in 2019, resulting in 12 deaths and 117 injuries. "Falls overboard" was the fifth most common accident in 2019, resulting in 189 deaths and 122 injuries (U.S Coast Guard 2020).

As discussed previously, a wake boat can produce 1.8 ft high waves at a distance 100 feet from its sailing line. Furthermore, when a wake boat turns it can create much larger waves on the inside of the turn, and when there is more than one wake boat operating in the same area of the lake, the intersection of their wakes can cause localized wave heights to double. As mentioned previously, many properties along the lakes' shoreline are protected by vertical bulkheads, and 70 to 100 percent of incoming wave energy may be reflected by these vertical walls. Reflected wake waves can interact with other waves to further increase wave heights in the lake. Not only do wake boats produce higher waves, but they also produce longer waves. Wake boat waves have about a two second period, which corresponds to a 20 ft long wave in deep water.

The increases in wave heights and wave lengths caused by wake boats increase the risk of injury or fatal accidents on these lakes through several possible mechanisms. These larger waves can:

- Increase risk of swamping of small crafts that have a low freeboard, which in turn increases risk of drowning or injury;
- Increase risk of falls overboard, which also increases risk of drowning or injury;
- Increase incidence of cruising boats slamming into waves, resulting in passenger injury; and
- Increase incidence of vessels being pushed or slammed into docks or shoreline bulkheads, which increases risk of injury or death for people near the vessel.

These increased risks are substantiated by anecdotal reports on Lake Rabun. As mentioned previously, the LRA conducted a member survey during November 30 – December 6, 2020 and received 486 responses, which is a very high response rate (57%) for member surveys (see Appendix A of this report). Seventy-five percent of survey responses indicated that wake boats create a boating safety issue. Member comments included multiple safety incidences or safety concerns:

> *"We were visiting friends on the lake who were in lockdown due to covid. We were in our boat, approximately 10 feet away from their dock and seawall, chatting with them on their dock. A wakeboat came by and the wake was so large that it crashed our boat into the seawall, even as we were making every effort to move away from it. Ultimately this led to our boat sinking and being declared a total loss. I just don't believe Lake Rabun is large enough to accommodate this size boat."*

> *"Difficult to enjoy the lake safely with small children. Can no longer do normal water skiing. Difficult to swim near our dock. Difficult and unpleasant to drive a pontoon boat."*

> *"Two times ballast boat waves have come over the bow of my 22' open bow boat. I felt there was a danger of sinking. Generally it is not pleasant to navigate rough water and big waves. This is ruining our boating experience."*

> *"We have small children who are often knocked over by such huge waves."*

> *"With the wake boats so numerous and dominant out on the water now, I can't remember the last time being on the lake where I didn't fear for my family's safety at least once. This is true of time we spend on our boat, as well as time we spend swimming near our dock."*

> *"Dropping the boat in the water and taking the boat out of the water, getting in and out of the boat during that time is really dangerous when giant waves come in."*

> *"The larger waves directly affect the ability to steer a boat. On many occasions I have been unable to steer one of my boats and worried that I would be pushed into another boat."*

> *"While untying boat (with 3 people in it) at dock, the wave was so strong that one of the people on boat was thrown in water!"*

Swamping typically means that a boat fills with water but remains floating. According to the LRA, there have been numerous anecdotal reports of wakes causing swamping or water coming over the bow and gunwales of a boat such that it raises the risk of total swamping. For example, on July 4, 2016, a vessel on Lake Rabun was swamped and sank from the combined effects of multiple wakes flooding over the sides. Although this particular accident was not necessarily the result of wake boats, it illustrates that high wake action can contribute to serious accidents from vessel swamping. The LRA member survey results show that 66 percent of respondents (227 members) reported occasional or frequent swamping caused by wake boat waves. The survey results indicate that wake boat waves significantly increase the risk of boat swamping.

Cruising boats hitting large wakes can cause injury or death. One incident on Lake Rabun involved Mr. Ed Sims, who was cruising in a MasterCraft at dusk. A passenger on his boat was thrown in the air after his boat hit a large wake from a wake boat that suddenly stopped. The airborne passenger landed on the gunwale, bruising multiple ribs requiring treatment at the emergency room. This incident illustrates that low light conditions when wakes are less visible enhance the risk of a serious accident from wake boat waves. Another example includes a tragic accident on Lake Burton on July 18, 2014 that claimed the life of a boy who was ejected from a boat when it hit a large wake. This incident did not necessarily involve a wake boat generated wave, but it illustrates the fact that large wakes increase the risk of fatal accidents. The LRA member survey results indicate that 95 percent of respondents (329 members) reported occasional or frequent jostling of boat passengers caused by wake boat waves, and 14 percent of respondents (47 members) reported occasional or frequent injury of boat passengers caused by wake boat waves.

In addition to impacts to other vessels, the wake impacts to docks and bulkheads can cause unsafe conditions. Anecdotal reports also include vessel wakes overtopping docks and sweeping deck chairs into the water, even though the wake boats were outside the 100-ft buffer. As witnessed in the wake measurement study on Lake Rabun, a wakesurfing wake can easily overtop a bulkhead even 300 ft from the sailing line (see Figure 3-3). The LRA survey responses summarized above include an incident where a wake boat wave caused a boat to crash into a bulkhead, resulting in sinking of the boat. The LRA member survey results indicate that 83 percent of respondents (291 members) reported occasional or frequent endangerment or inconvenience of swimmers or people on docks caused by wake boat waves.

Many parts of these lakes are quite narrow, including most of Lake Rabun and much of Lake Burton. It is in these narrow channels where safety is of particular concern. These channels are generally 500 ft wide or less, with a typical width around 300 feet. Within these channels, large wakes may cause passing vessels to yaw and alter course, increasing the risk of collision. The curving nature of the channels causes wake heights to amplify on the insides of the channel bends, increasing wake hazards in these areas. Additionally, two passing wake boats in the channel can create much larger waves where their wakes intersect. Therefore, large waves from wake boats increase the risk of accidents in the narrow areas of the lakes.

Determining what constitutes safe operating conditions on the lake is necessarily a somewhat subjective assessment. We are not aware of any specific standards to define what wake heights and periods cause unacceptably unsafe conditions on these lakes. Therefore, the evaluation of safety on these lakes should be viewed in the context of managing risk injury or death on the lakes. Recreation on any lake is never without risk, and the goal of management measures should be to reduce risk while still achieving the goal of providing enjoyment of the lake for recreational activities.

Under the current management measures, the larger wave heights and wave lengths generated by wake boats increase the risk of injury or death on these lakes, as compared to conditions prior to the proliferation of wake boats. Anecdotal reports of unsafe conditions from boat wakes supports the conclusion that the present management rules are insufficient and/or insufficiently complied with to provide reasonably safe recreation on the lake for small crafts. In the absence of new management measures, the increasing trend in the number of wake boats on the lakes will continue to increase the risk for injury or fatality from boating accidents related to swamping or interaction with boat wakes.

4 Management Measures

The Associations and Georgia Power should consider revisions to existing management measures to increase safety and reduce risk of injury or death on the lakes while still achieving the goal of providing enjoyment of the lakes for recreational activities. This section of the report reviews existing management measures and wake boat-specific management measures proposed by the WSIA. This is followed by a discussion of potential additional management measure approaches for consideration.

There are existing management measures that apply to boating activities on Lake Rabun and Lake Burton. The Georgia "Rules of the road for boat traffic" (O.C.G.A § 52-7-18) are as follows:

> *(a) All vessels operating on the coastal waters of this state shall conform to the "Steering and Sailing Rules" established by Section II, Rules 11 through 18, of the International Navigation Rules Act of 1977, as amended.*
>
> *(b) All vessels operating on the inland waters of this state shall conform to the "Steering and Sailing Rules" established by Subpart II, Rules 11 through 18, of the Inland Navigation Rules Act of 1980, as amended.*
>
> *(c) It shall be the duty of each operator to keep his vessel to the starboard or right side of the center of any channel, stream, or other narrow body of water; provided, however, this provision shall not give to the operator of a sailing vessel the right to hamper, in a narrow channel, the safe passage of another vessel which can navigate only inside that channel.*
>
> *(d) Powered vessels approaching nonpowered vessels shall reduce their speed so that their wake shall not endanger the life or property of those occupying the nonpowered vessel.*
>
> *(e) Whenever a vessel approaches a bend, point, or other blind area, it shall be the duty of the operator to:*
>
> > *(1) Move as far to the right or starboard as possible;*
> >
> > *(2) Reduce speed to allow for an unexpected stop if necessary; and*
> >
> > *(3) Sound a blast of eight to ten seconds' duration on a sounding device if such a device is carried.*
>
> *(f) No person shall operate any vessel or tow a person or persons on water skis, an aquaplane, a surfboard, or any similar device on the waters of this state at a speed greater than idle speed within 100 feet of any vessel which is moored, anchored, or adrift outside normal traffic channels, or any wharf, dock, pier, piling, bridge structure or abutment, person in the water, or shoreline adjacent to a full-time or part-time residence, public park, public beach, public swimming area, marina, restaurant, or other public use area. This subsection shall not be interpreted to prohibit any person from initiating or terminating water skiing from any wharf,*

dock, or pier owned by such person or used by such person with the permission of the owner of said wharf, dock, or pier nor shall it be interpreted to prohibit the immediate return of a tow vessel to a downed water skier.

(g) No vessel shall run around or within 100 feet of another vessel at a speed greater than idle speed unless such vessel is overtaking or meeting such other vessel in compliance with the rules of the road for vessel traffic.

(h) No vessel shall be operated in such a manner as to ride or jump the wake of another vessel within 100 feet of such other vessel unless the vessel is overtaking or meeting such other vessel in compliance with the rules of the road for vessel traffic and, having passed or overtaken such other vessel, the operator of the passing or overtaking vessel shall not change or reverse course for the purpose of riding or jumping the wake of such other vessel within 100 feet of such other vessel.

(i) Subsections (f), (g), and (h) of this Code section shall not apply to ocean-going ships or to tugboats or other powered vessels which are assisting ocean-going ships during transit or during docking or undocking maneuvers.

Our review and analysis of the available data on wake boats and their effects on the lakes supports the conclusion that the present management rules are insufficient to avoid adverse impacts from the growth in wake boat activity. These adverse impacts include increased risk of shoreline erosion in unprotected areas, increased risk of damage to moored vessels or shoreline structures, and increased risk of unsafe conditions on the lake for small crafts. The present rules should be complemented by additional management measures suitable for narrow, deep lakes such as these.

Based on the results of Goudey and Girod (2015), the WSIA published a Wave Energy Study Summary and Recommendations (2019). The management measures strongly recommended by the WSIA include following:

1. *Always try to wakeboard or wakesurf in the center of any given body of water, and avoid narrow channels or thoroughfares, if possible.*

2. Always try to stay at least 200 feet away from any shoreline, dock, or fixed objects.

3. Maintain a reasonable sound level on your stereo.

4. Always respect the shoreline you are using and if the property owner asks that you leave, do so immediately, and always be gracious with the property owner.

5. Repetitive passes result in an accumulation of energy reaching the shoreline. Repetition is never a good idea and can lead to risk of waterway conflicts.

6. The non-surfing side of a wakesurfing boat creates waves that are 10% to 23% smaller with 23% to 33% percent less energy than the surfing side. When possible, present the non-surfing side of the boat to the closest shoreline.

7. Waves tend to increase in height on the inside of a gradual turn. Avoid such maneuvers close to shore.

8. Glass calm water is not a requirement for wake surfing, be respectful and operate as far from shore as you can.

The 200-ft offset recommended by the WSIA, however, is based on the conclusion that "wakeboard and wakesurf wakes/waves, when operated at least 200 feet or more from shore, do not carry enough energy to have a significant impact on most shorelines or on properly maintained docks and other man-made structures." This conclusion is based on an overly simplistic analysis by Goudey and Girod (2015), as discussed previously. Nonetheless, this conclusion is partially true for some shorelines, but it is not true for shorelines exposed to limited fetches and limited wind wave action. At a 200-foot offset, wakesurfing wake heights can still exceed 1.3 feet, which exceeds acceptable mooring conditions.

PIANC (2003) explains that mitigation measures can be divided into three categories: vessel design, operational measures, and non-operational measures. It is likely that the best management regime adopted for any given site will need to involve a combination of operational and non-operational measures. Below are management measures considered in each category:

1. Vessel Design: Hull form is the primary means for managing vessel wakes with hull design. This approach was adopted by some Alaska state agencies by using flat bottom boats to reduce wake impacts on shoreline erosion (Maynord 2008). In addition to hull design, wakesurfing and wakeboarding boats are specifically designed with WED to generate enhanced wakes. Managing wakes by prohibiting certain vessel designs may be a drastic measure, given that there are alternative measures to manage wakes, as discussed below. A prohibition of certain vessel designs would certainly raise many objections from lake users, and therefore the Associations may want to consider advocating for less drastic management measures.

2. Operational measures that may be applicable to Lake Rabun and Lake Burton include:

    a. Restrict the factory installed ballasts from being filled to maximum capacity and prohibit the use of additional ballast items (i.e. "fat sacs"). Doing so would reduce vessel displacements and lower wake heights.

    b. Limit wakesurfing and wakeboarding to the middle sections of the widest parts of the lake,

    c. Restrict wake boats to operate in normal unballasted cruising conditions or no-wake conditions within the narrow sections of the lake.

d. Require wakeboarding operations try to stay at least 100 yards away from any shoreline, dock, fixed objects or small craft. A 100-yard distance (a football field length) is likely more easily visualized by a boat operator than one described as a 300-ft distance. At a 100-yard buffer distance, wakeboarding wake heights will be slightly less than waterskiing or cruising wake heights at a 100-ft buffer distance. For wakesurfing operations, require the vessel maintain a 150-yard buffer distance. At 150 yards from the sailing line, the wake height is approximately 1 ft, still slightly larger than a cruising/skiing vessel at the 100-ft buffer distance, but it will be more manageable than the under the existing rules. These additions would result in only a few permissible wake boat zones in the middle of the widest parts of the Lake Rabun and Lake Burton.

e. Prohibit wakesurfing and wakeboarding operation under low light conditions (dusk, dawn or night) when wakes are less visible to others.

f. Prohibit on-board ballast when cruising or waterskiing. Often, wakeboat operators simply fail to empty ballast while cruising or waterskiing.

3. Non-operational measures that may be applicable to Lake Rabun and Lake Burton include:

   a. Post signage where wake boats should minimize their wake,

   b. Engage in outreach activities to educate the public regarding vessel wake impacts and provide wake management guidelines similar to those provided by the WSIA (except with a revised minimum buffer distance of 100-yards/150-yards from the shoreline and inclusion of a buffer distance around small craft),

   c. Coordinate with neighboring lake associations to pool resources and identify other successful means of wake management.

To provide data to assess the effectiveness of wake management measures or the need for adjustment of wake management measures, WEC recommends that the Associations track occurrences of boat wake incidences. This may include requesting members to report any safety incidences or personal property damages as a result of wake boat operation. This should be documented with available specific information regarding the time and date of the incident(s), a detailed description of the damage, along with videos or photographs, and the registration number of the watercraft rendering the damage, if possible.

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Appendix A. Lake Rabun 2020 Homeowner Survey Summary

Lake Rabun Association Wake Boat Survey
December 2020
Summary of Results

Survey open: November 30 – December 6, 2020

Total responses: 486

Response rate: 57%

Key results:

Q1 Have large waves from wake boats had a negative effect on you while boating on the lake? Select one.

Answered: 485 Skipped: 1

ANSWER CHOICES	RESPONSES	
No	12.99%	63
Occasionally	26.80%	130
Frequently	60.21%	292
TOTAL		485

Q2 How have you been negatively affected by wake boat waves while boating? Select all that apply.

Answered: 401 Skipped: 85

ANSWER CHOICES	RESPONSES	
I limit the amount and times of boating	62.09%	249
Difficulty loading and unloading passengers	51.62%	207
Difficulty navigating boat	70.07%	281
Other (please describe below)	33.92%	136
Total Respondents: 401		

Some comments:

We were visiting friends on the lake who were in lockdown due to covid. We were in our boat, approximately 10 feet away from their dock and seawall, chatting with them on their dock. A wakeboat came by and the wake was so large that it crashed our boat into the seawall, even as we were making every effort to move away from it. Ultimately this led to our boat sinking and being declared a total loss. I just don't believe Lake Rabun is large enough to accommodate this size boat.

Difficult to enjoy the lake safely with small children. Can no longer do normal water skiing. Difficult to swim near our dock. Difficult and unpleasant to drive a pontoon boat.

Two times ballast boat waves have come over the bow of my 22' open bow boat. I felt there was a danger of sinking. Generally it is not pleasant to navigate rough water and big waves. This is ruining our boating experience.

Q3 Do you believe that waves from wake boats create a boating safety issue?

Answered: 476 Skipped: 10

ANSWER CHOICES	RESPONSES	
No	18.49%	88
Yes	75.00%	357
No opinion	6.51%	31
TOTAL		476

Q4 If you believe waves from wake boats create a boating safety issue, please indicate how by answering the following. Select all that apply.

Answered: 357 Skipped: 129

	NEVER	RARELY	OCCASIONALLY	FREQUENTLY	TOTAL RESPONDENTS
Waves swamp my boat	13.16% 45	21.05% 72	46.78% 160	19.59% 67	342
Passengers jostled	1.44% 5	4.02% 14	36.49% 127	58.05% 202	348
Passengers hurt	56.44% 184	29.75% 97	13.19% 43	1.23% 4	326
Skiers or rafters inconvenienced or endangered	2.33% 8	7.00% 24	36.73% 126	53.94% 185	343
Kayakers and paddle boarders inconvenienced or endangered	1.78% 6	5.03% 17	29.59% 100	63.91% 216	338
People on docks or swimming inconvenienced or endangered	4.27% 15	12.82% 45	44.44% 156	38.46% 135	351
Other (please explain below)	2.44% 2	1.22% 1	17.07% 14	79.27% 65	82

Some comments:

We have small children who are often knocked over by such huge waves

With the wake boats so numerous and dominant out on the water now, I can't remember the last time being on the lake where I didn't fear for my family's safety at least once. This is true of time we spend on our boat, as well as time we spend swimming near our dock.

Dropping the boat in the water and taking the boat out of the water, getting in and out of the boat during that time is really dangerous when giant waves come in.

The larger waves directly affect the ability to steer a boat. On many occasions I have been unable to steer one of my boats and worried that I would be pushed into another boat.

While untying boat (with 3 people in it) at dock, the wave was so strong that one of the people on boat was thrown in water!

Q5 Have you experienced shoreline erosion or structural damage as a result of large waves? You may select minor or major shoreline erosion and structural damage as applicable.

Answered: 445 Skipped: 41

ANSWER CHOICES	RESPONSES	
No erosion or structural damage	24.49%	109
Minor shoreline damage	38.88%	173
Major shoreline damage	28.54%	127
Structural damage	32.13%	143
Total Respondents: 445		

Question 5 is a repeat of the same question asked in the 2018 LRA Member Survey. As the table below shows, the percent of respondents reporting shoreline or structural damage has increased over the past two years.

Response	2020	2018	Change
No erosion or structural damage	24.49%	33.78%	-9.29%
Minor shoreline damage	38.88%	29.39%	9.49%
Major shoreline damage	28.54%	22.30%	6.24%
Structural damage	32.13%	14.53%	17.60%

Lake Rabun Association Wake Boat Survey
December 2020
Summary of Results

Some comments:

The constant pounding of wake boat waves against our dock has caused significant damage. I'm repairing it at least twice as much as before the surge in wake boats on the lake. And the small beach area by our dock has eroded so much it's a fraction of what it once was. My children can barely swim/play on that beach area anymore without being jostled and thrown by huge wake boat waves.

Rock Seawall and patio had no damage for 20 years. Has extensive damage in past 3 years due to gigantic waves reaching shoreline.

We've had our house for two generations and have never seen such erosion to our shoreline.

Q6 Cost to repair damage (materials and labor) if known

Answered: 198 Skipped: 288

ANSWER CHOICES	RESPONSES	
Actual amount spent to date on repairs	67.68%	134
Estimated amount to complete repairs	72.73%	144

The following statistics apply to respondents who reported dollar amounts for Question 6.

	Spent To Date	Estimated to Complete
Sum	$609,600	$1,057,450
Average	$8,467	$12,441
Median	$2,800	$3,500
Count	72	85

Q7 Do you believe policies should be put in place to address wake boat activity on Lake Rabun?

Answered: 462 Skipped: 24

ANSWER CHOICES	RESPONSES	
No need for any policies	12.34%	57
Yes, policies are needed	81.82%	378
No opinion	5.84%	27
TOTAL		462

Lake Rabun Association Wake Boat Survey
December 2020
Summary of Results

Q8 How effective do you believe the following policies would be in mitigating any negative effects of wake boat activity?

Answered: 373 Skipped: 113

	NOT EFFECTIVE	SOMEWHAT EFFECTIVE	VERY EFFECTIVE	DON'T KNOW	TOTAL
Restrict times for ballast operations that create larger waves	23.97% 87	36.64% 133	29.75% 108	9.64% 35	363
Limit boat weight	6.94% 25	21.67% 78	54.44% 196	16.94% 61	360
Limit ballast operations to wake boarding and surfing; empty ballast tanks when cruising or waterskiing	14.44% 53	26.43% 97	49.32% 181	9.81% 36	367
Restrict areas of the lake for ballast operations	13.55% 50	24.39% 90	54.20% 200	7.86% 29	369
Require a wider buffer for wake boats (distance to other watercraft or shoreline)	14.52% 53	28.22% 103	52.05% 190	5.21% 19	365
Minimize repetitive wake boat runs in same area	15.30% 56	28.96% 106	46.72% 171	9.02% 33	366
Training and education for wake boat owners and surfers	16.62% 61	31.34% 115	45.23% 166	6.81% 25	367
Other (Please explain below)	6.41% 5	3.85% 3	64.10% 50	25.64% 20	78

Q9 Do you believe policies regarding loud volumes of music from boats on the lake should be adopted?

Answered: 455 Skipped: 31

ANSWER CHOICES	RESPONSES	
Yes	59.34%	270
No	20.66%	94
No opinion	20.00%	91
TOTAL		455

Some comments:

Not all people like the same music. Respect is lost with increased volume.

Loud radios are extremely disruptive and disturbing.

Blasting music load enough for everyone on the shore to hear is noise pollution

Q10 What is your primary concern about wake boats on Lake Rabun? Select one.

Answered: 451 Skipped: 35

ANSWER CHOICES	RESPONSES	
I have no concerns	11.09%	50
Shoreline or structural erosion and damage	39.69%	179
Negative effects on boating (e.g. difficulty navigating or limiting boating activity)	23.50%	106
Boating safety	20.84%	94
Other (please describe below)	4.88%	22
TOTAL		451

Q11 Any other comments you wish to make?

Answered: 221 Skipped: 265

Some comments:

The few who have wake boats significantly interfere with enjoyment of the lake by the many

If families are going to continue to enjoy Rabun together we have to accept wake boats. Kids do not water ski much anymore. I am sure that when ski boats began to replace wood boats on Rabun there were similar responses. We have to be able to allow future generations the ability to enjoy watersports and our beautiful lake together.

Please address this issue. It is affecting our enjoyment of the lake and damaging our property values

I enjoy surfing a lot but unfortunately Lake Rabun is not well suited for modern day surf boats. Or at least not that many and I have no idea how to police them.

As an owner of a wake board boat with ballast I don't believe the problem is with the boat but rather how and where its operated. Owners need to be educated to empty their ballast when not in use and to turn down their speaker volume!!!!!