Proceedings of the ASME 2021
International Mechanical Engineering Congress and Exposition
IMECE2021
November 1-5, 2021, Virtual Conference

IMECE2021-71796

EVALUATION OF WAVE ENERGY ON THE WILLAMETTE RIVER

Dr. C.J. Poor
Associate Professor Civil Engineering
University of Portland
Portland, OR. United States

Rachel Anderson
Undergraduate Research Assistant
University of Portland
Portland, OR. United States

Dr. H.E. Dillon
Professor Mechanical Engineering
University of Washington
Tacoma WA. United States

ABSTRACT

The trend of using larger boats for wake surfing in river systems has caused concern for dock stability, bank erosion, safety of other boaters, and natural resource conservation. This study evaluates the wave energy due to boat traffic in the Newberg Pool of the Willamette River using budget conscious equipment and involving community stakeholders. Low-cost motion activated game cameras were used to record videos of waves when boats passed.

The video processing was completed using image analysis in the computational tool Matlab. For each image a high-contrast point of reference was used for the tracking, often tape on a dock piling. As the wave or dock moved, the reference point in the image was tracked in Matlab using the maximum or minimum grayscale pixel in a specific part of the image. This calculation allowed the research team to approximate the change in vertical direction in pixels.

A computational analysis tool was used at 4 sites, 2 in wake surfing zones, 1 in a wake zone, and 1 in a no wake zone, to quantify wave height and period. A total of 8567 videos were collected from the four sites, and 1227 were analyzed. For the wake surfing zone, the average and maximum wave heights were 0.026 m and 0.149 m, respectively, and average and maximum wave energies were 0.905 W/m and 19.2 W/m, respectively. In the wake zone, the average and maximum wave heights were 0.031 m and 0.137 m, respectively, and average and maximum wave energies were 1.405 W/m and 5.74 W/m, respectively. The average wave energy was higher in the wake zone, however, the maximum wave height and the number of boat-caused waves recorded were higher (2984 in the wake surfing zone compared to 1117 in the wake zone) in the wake surfing zone. Cameras were attached to dock pilings which may have resulted in lower values due to the dampening of the dock. Wake surfing was also observed in wake zones, where it is not allowed. This study indicates that the large boats used for wake surfing create larger waves that can potentially cause damage to property along the river and natural resources.

The processes and procedures used within this research would not have been possible without citizen involvement. The citizens partaking in the research allowed for their property to be used as a heavily monitored site or a self-monitored site. The self-monitored sites were a useful tool in collecting more data.

INTRODUCTION

Wake surfing, which is a water sport where a person surfs on a boat's wave without a tow rope, has become a popular sport in recent years [1]. In order for the boat to create large enough waves for surfing, boats larger than typical water skiing boats are used and typically use wake enhancing devices (WEDs). WEDs include increasing the ballast in the vessel, modifying the hull design, installing wedge platforms on the stern, operating at slower speeds, and installing elevated tow platforms to optimize wake waves [1]. Waterfront property owners and conservationists have become concerned that these waves cause significant damage to river banks and increase turbidity to levels that can cause damage to nearshore habitat and aquatic ecosystems on the Willamette River, as has been demonstrated in other aquatic systems [2]. An overview of the recreational boat wake interaction with a dock is shown in Figure 1.

In 2019, the Oregon State Marina Board (OSMB) implemented new rules to allow wake surfing in the Newberg Pool of the Willamette River [3]. These rules allowed wake surfing only in specific reaches, with other recreational boating activities (water skiing, fishing, etc.) allowed in other reaches of the Newberg Pool. These new rules concerned community

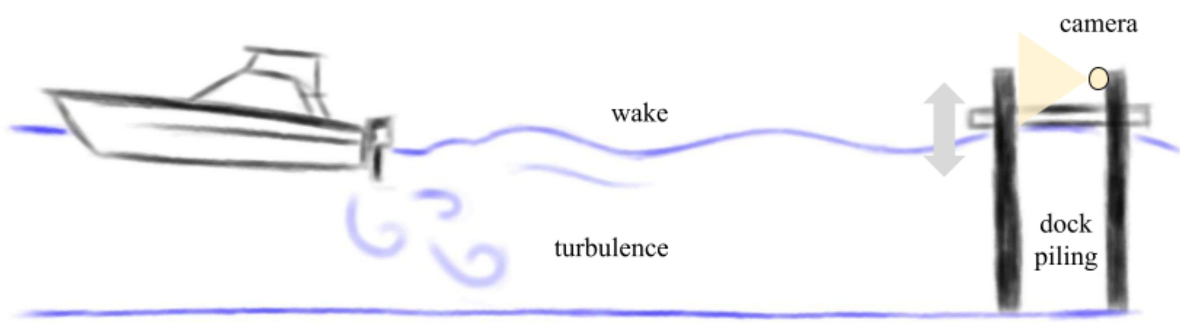

Figure 1. Recreational boat wake and dock interaction, with the generalized experimental setup.

stakeholders, including a homeowner group, Oregon River Safety and Preservation Alliance (ORSPA), and river protection groups (Willamette Riverkeepers, Calm Water Coalition). Members of ORSPA expressed concern after observed damage to docks and erosion of their river banks as a result of wake surfing that had occurred prior to the implementation of the new rules. Although wake surfing was not permitted, wake surfing still occurred in the Newberg Pool due to low enforcement. ORSPA members noted that it was not safe to be on their docks, particularly young children, when a wake surfing boat passed due to the vertical movement of the dock and large wave that would often wash over the top of the dock.

In addition, the National Oceanic and Atmospheric Administration (NOAA) has notified OSMB that their new rules may violate the Endangered Species Act (ESA) due to the population of salmon and steelhead in this section of the river [4]. According to the letter to OSMB from NOAA, the danger of the wakes is high with juvenile salmon. Regular boat waves can beach juveniles on the river bank as noted from work done by the National Marine Fisheries Service (NMFS). The risk of beaching juvenile salmon increases with the larger waves caused by wake surfing boats.

Due to lack of data specific to Newberg Pool, OSMB was not able to address these concerns. As a result, community stakeholders agreed to help with a study to evaluate wave energy in the Newberg Pool of the Willamette River. The research team organized data collection using low-cost equipment installed at homeowner's docks to evaluate the impacts of the new wake surfing zones. The goals of this study were to:

1. Quantify the volume of recreational boating along the three river zones.
2. Determine the viability for low-cost video analysis using computer software to estimate wave energy.
3. Compare wave energy in zones allowing wake surfing to wave energy in non-wake surfing zones.

BACKGROUND

Several studies have evaluated the impacts of boat wakes on water quality [5]–[7] and erosion of riverbanks [2], [7]–[10]. These studies found a significant increase in turbidity and erosion as a result of boating activity. Johnson observed that peak turbidity corresponded to peak boating activity, and found a direct correlation between the number of boat passes and suspended solids [7].

The size of boats has increased significantly in the past 50 years, which exacerbates erosion and degradation of water quality. Asplund found that more than 40% of registered boats were 16-39 ft long in 1997-1998 compared to only 18% in 1968-1969 in Wisconsin [11]. The horsepower of these boats has also doubled. Boat waves have been estimated to contribute 80% of total energy dissipation against the banks [10]. Bhowmik et al. found that longer boats that create a deep draft create larger waves, and increased speed diminished the size of the waves. The slow speed and deep draft necessary for wake surfing likely causes higher waves and increased wave energy. The wave energy associated with wake surfing, which requires a large boat to create a big enough wave to surf, has been found to be four times larger than the energy created from wakeboarding or water skiing [1]. Many studies have found that waves from boats cause significant erosion [2], [7]–[9]. Johnson measured total erosion of 14 feet in a channel with intense boating activity compared to less than 3 feet in a similar channel with light boating activity on the Mississippi River [7], and Dorava and Moore found that bank loss was 75% higher in a high boat use area compared to a non-motorized area [10].

Measurement of wave height and energy from boats in freshwater systems has been previously studied using wave probes or electronic wave gauges. A summary of prior studies in freshwater is shown in Table 1. Wave probes or gauges require significant instrumentation at the site. In most river systems, the Army Corps of Engineers has a significant permitting process before a river can be instrumented. Video analysis is one way to evaluate wave height and energy without instrumentation in the river. A few studies in ocean environments have conducted qualitative video analysis [12], [13], but we are not aware of any studies using video analysis in freshwater. This study is one of the first to use videos to observe waves and quantify wave energy in a river system.

Table 1. Summary of previous studies evaluating wave height and energy from boat wakes in freshwater systems.

Author	Year	Analysis Type	Results
Nanson et al [9]	1994	Wave Probes	Wave heights above 30 cm cause erosion
Bhowmik et al [8]	1992	Electronic Wave Gauge	Maximum wave height = 0.52 m, 0.065 m on average
Johnson [7]	1994	Electronic Wave Gauge	Wave height from boat waves 10-25” compared to 4-8” for natural waves.
Ruprecht et al. [14]	2015	Wave Probes	Wave energy associated with wake surfing compared with wave heights.
This Study	2021	Wave height estimates from video	Low cost video and citizen science useful for quantifying wave height and wave energy.

METHODS

Study Sites

The recreational zones established by OSMB in the Newberg Pool (RM 30-50) are summarized in Table 2 by River Mile (RM) [3]. Zone 1 is a slow no wake zone, and includes the river reach with Boones Ferry Marina (RM 38.5-38.6) and within 100 feet of a dock. Zone 3 allows all recreational boating activities including wake surfing. The five river reaches that allow wake surfing include: RM 30-34.5, RM 35.5-37, RM 41.5-42.5, RM 46-48.5, and RM 49.5-50. Zone 2 allows all recreational boating activities except for wake surfing, which includes the remaining reaches of the Newberg Pool.

Table 2. Recreational boating zones at the time of the study [3].

Project Terms	Description	Bounding River Miles
Newberg Pool	Refers to all portions of the river regardless of the zone designation	30-50
Zone 1	Slow, no wake zone: no activity that creates a wake	Boones Ferry Marina (38.5-38.6), within 100 feet of a dock
Zone 2	Wake activity zone: allows for all water and boating activities except for wake surfing	34.5-35.5, 37-38.5, 38.6-41.5, 42.5-46, 48.5-49.5
Zone 3	Wake surfing zone: allows for all water and boating activities including wake surfing	30-34.5, 35.5-37, 41.5-42.5, 46-48.5, 49.5-50

Figure 2 shows the wake surfing zones and study sites in the Newberg Pool. Two sites were selected in Zone 3. For comparison, one site in Zone 1 and one site in Zone 2 were also selected. RM 38-5 is located in a no wake zone near a major interstate bridge. The no wake zone was used as the control reference for the other sites. RM 42-1 and RM 47-17 are both located in Zone 3, where wake surfing is allowed. RM 42-1 is near a major interstate and Boones Ferry Marina, resulting in much higher boating traffic compared to RM 47-17 which is in an agricultural area near Newberg, Oregon. RM 40-12 is located

Figure 2. Study sites in Newberg Pool on the Willamette River.

in a wake activity zone but some wake surfing traffic was observed during the study period. This could be due to its proximity to Boones Ferry Marina and a river reach designated as Zone 3 (wake surfing zone); RM 41.5-42.5. The variety of locations allowed for observations of waves in the different zones with many types of boating traffic. A summary of the data collection sites is shown in Table 3.

Three of the 4 sites (RM 42-1, 40-12, and 47-17) were located on private property that citizens allowed us to access and monitor. The Zone 1 site (RM 38-5) was located in a park owned by the City of Wilsonville.

Table 3. Study sites by river mile and river zone.

Site Name	River Mile	Number of Videos Collected /Analyzed	Analysis
Zone 3 **RM42-1**	42	2984 /810	Quantitative Matlab processing of 230 videos, qualitative review of 580 videos
Zone 2 **RM40-12**	40	1117 /210	Quantitative Matlab processing of 33 videos, qualitative review of 177 videos
Zone 1 **RM38-5**	38	2139 /41	Qualitative review of videos
Zone 3 **RM 47-17**	47	2327 /166	Qualitative review of videos

Experimental Setup

A Campark T45 Trail Hunting Game Camera 14MP 1080P was used to record videos at each site. The cameras were selected for price and useability after testing with other low-cost trail cameras.

The cameras were attached to stationary objects including dock pilings and trees (Figure 1). The cameras were then pointed to look at another stationary object, such as a dock piling. Yellow tape was put on the stationary object to help with visibility and video analysis. The motion sensor on the camera detected when boats went by, and recorded the wave created by the boat. Known dimensions of the stationary objects were used to estimate the size of the waves. The sites were monitored by the research team on a weekly basis. Data was collected from May to September 2019. To verify this method, staff gages were installed in August 2019 and an additional camera was installed to record changes in water height with the staff gage. Comparison of data from the docks and staff gages indicated that waves were dampened by the dock by ~25%.

Videos were qualitatively reviewed to evaluate whether wave height could be measured quantitatively through video processing in Matlab. Some videos did not have sufficient resolution or waves were not large enough to quantify and could not be processed in Matlab. No waves of notable size were observed at RM 38-5, and thus none of the videos were processed in Matlab. However, this indicates that wave energy in the no wake zone is negligible. No videos were processed from RM47-17 due to the lack of a dock/stationary object in the river and permit delays for installation of staff gauges. The number of videos collected at RM 42-1 was much higher than the other sites, which may be due to the higher boat traffic (including wake surfers) observed in that zone.

Video Processing Method

The video processing was completed using image analysis in the computational tool Matlab. First, each video was loaded into the software as a sequence of image files. The embedded video information for frame rate capture by the camera was extracted from the video metadata. The image files were converted to matrices on a grayscale from 0 to 100. Each pixel in the original image was coded based on the grayscale.

For each image a high-contrast point of reference was used for the tracking, often tape on a dock piling. As the wave or dock moved, the reference point in the image was tracked in Matlab using the maximum or minimum (lightest or darkest) grayscale pixel in a specific column of the matrix (green vertical line in the lower left image of Figure 3). This calculation allowed the research team to approximate the change in vertical direction in pixels. An example video screen in Matlab is shown in Figure 3.

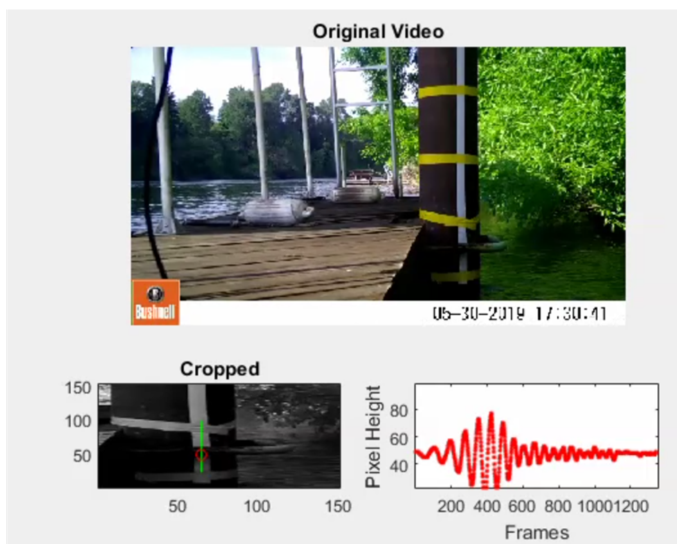

Figure 3. The Matlab screen used by the research team for monitoring the calculations. The upper image is the original video, the lower left shows the green vertical line of pixels where the tracking is occurring. The lower right shows the pixel height measurement over each frame of the video.

Once the image was loaded in Matlab, a reference was used for the pixel to length conversion. The reference was to a known dimension in the camera field of view, often the diameter of a dock piling or the width of the marking tape used on the dock. This conversion introduces the most error in the calculations, so the measurements in pixels were done carefully by the research team. The pixel to length conversion was used to convert the vertical change in position in pixels to meters, as shown for one example video in Figure 4.

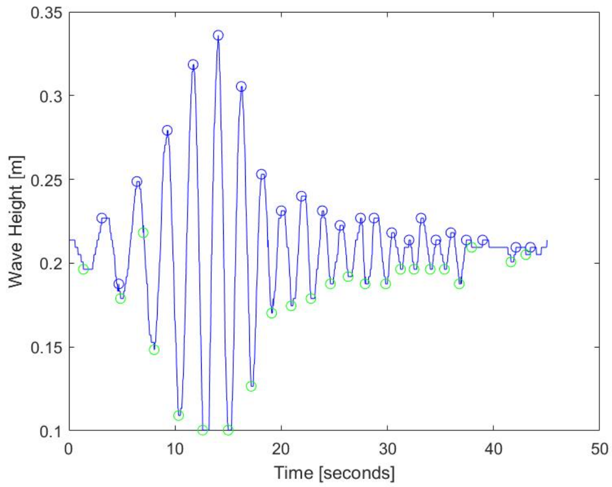

Figure 4. Example of a wave height calculation from a video on site RM 42-1 recorded in late May 2019. Circles indicate the maximum and minimum height of the wave calculated by the algorithm.

Once the wave height (H) was determined using the software algorithm, the wave trace was used to calculate other parameters. The wave height was calculated as the difference between the peak and valley determined by the algorithm in meters. The period (T) was calculated as the difference of wave peaks in seconds. The frequency (f) is determined as the inverse of the period, where f=1/T.

The wave power was determined from the density of water (ρ), gravity (g), the wave height (H), and the period of the wave (T). The wave power is determined in kW/m [15].

$$Power = \rho g^2 H^2 T / 64\pi$$

The density of the water (ρ) was assumed to be 997 kg/m^3 for all sites.

Visual Gauge Validation

A visual analysis was conducted to verify the numbers from the MATLAB code. The maximum height from the code was compared to the maximum height observed against the staff gauge. The MATLAB code provides a value 25% or less than the value observed by the staff gauge. This confirms the MATLAB code is providing a conservative estimate due to the dampening of the dock. The dock removes a portion of energy from the wave, decreasing the amplitude. When observing the movement of the dock it can be seen it does not move in a traditional wave pattern. Waves create more movement horizontally than vertically, for the dock. This is another reason why there is such a large difference between the heights of the two different methods. Another potential source for error is the difference of location between the dock pilings and the gauges. The distance was under 10 meters, but still may have impacted the results due to the inconsistencies of the river.

RESULTS

A summary of the wave energy statistics by site is provided in Table 4. The average statistics in this table were calculated as the mean value from the total collection of videos. Average values in the two zones were about the same, but maximum values were higher in the wake surfing zone (site RM 42-1). The similar average values may be due to the data collection method. All types of waves were recorded, making the data a mix of waves coming from all types and sizes of boats. In addition, wake surfing was observed in the non-wake surfing zone (site 40-12). Due to many different types of boats in each zone, the maximum values may be a better indicator of how wake surfing is impacting the river.

Table 4. Wave energy statistics from sites RM 42-1 and RM 40-12.

Site	RM 42-1	RM 40-12
Number of Videos Analyzed	230	33
Wave Energy [W/m]		
Average	0.905	1.405
Maximum	19.2	5.74
Wave Height [m]		
Average	0.026	0.031
Median	0.022	0.029
Maximum	0.149	0.137
Standard Deviation	0.019	0.015
Period [s]		
Average	1.92	1.98
Maximum	7.18	3.22
Average Maximum Amplitude [m]	0.057	0.069
Average Frequency [1/s]	0.520	0.509

For site RM 42-1 the most videos were analyzed, which provided a more detailed view of the type of wave events as shown in Figures 5-7. The average values in these figures was calculated for each video, since the wave height varied over the time duration of each video clip.

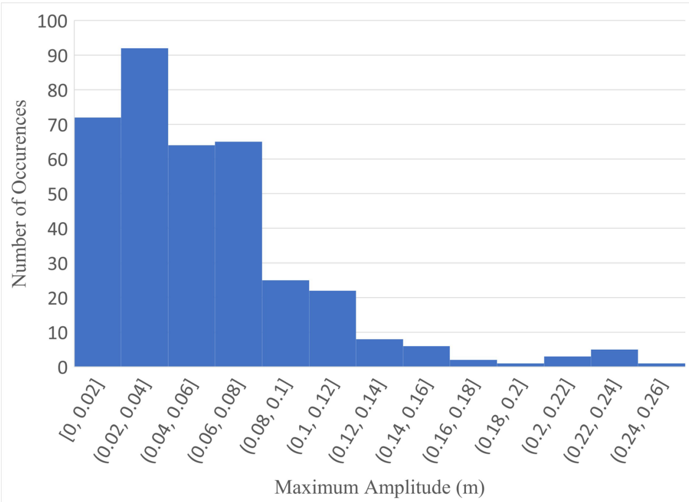

Figure 5. Histogram of the maximum wave amplitude at site RM 42-1.

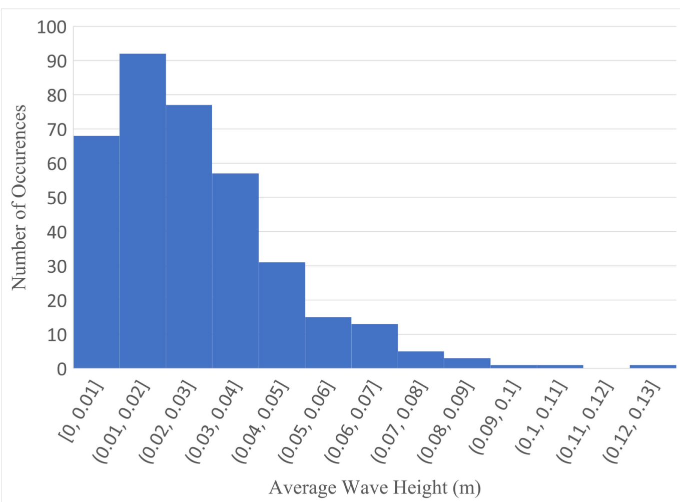

Figure 6. Histogram of the average wave height at site RM 42-1.

The results have some uncertainty due to variability of boat distance from the bank/cameras. The distance of boats from the point of data collection varied based on the width of the river at the site and the direction the boat was moving. The river depth also changed depending on the site location. Because waves slowly dissipate with distance and depth of water, some measurements may be lower than others. Dampening of the waves due to the dock also decreased the wave height and resulting wave energy. Therefore, wave height and energy are likely higher than the data in this study.

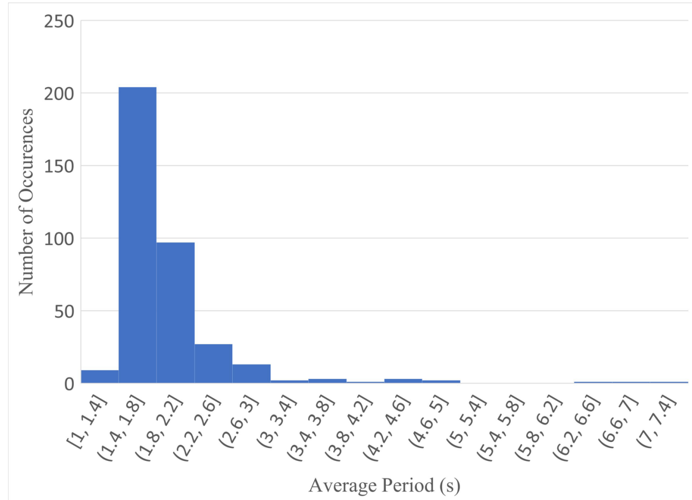

Figure 7. Average wave period at site RM 42-1.

CONCLUSIONS

This study indicates that the large boats used for wake surfing create larger waves that can potentially cause damage to property along the river and natural resources. Maximum wave energy and wave height was higher in the wake surfing zone compared to the non-wake surfing zone.

Inexpensive video capture was used to quantify, with low precision, the wave energy due to boat activity. The processes and procedures used within this research would not have been possible without citizen involvement. The citizens participating in the research allowed for their property to be used as a heavily monitored site or a self-monitored site. The self-monitored sites were a useful tool in collecting more data points with the collection being performed by the homeowners.

The citizens acted as the driving force for the research. Many of them are parts of organizations which helped voice concerns which impacted new boating regulations. New boating regulations were passed requiring those who plan on boating within the Newberg Pool to take an educational safety course. This will help inform boaters on where certain activities are allowed and how far they must stay away from structures like docks or the bank of the river. The zones have also been altered. The Zone 3 areas were pushed to the outer edges of the Newberg Pool. This minimizes the impact on homeowners as the new areas have fewer residents along the river.

ACKNOWLEDGMENTS

The authors would like to thank Katie Ferrell and the Oregon River Safety and Preservation Alliance (ORSPA) for providing dock access and supporting this study. Thanks to Davey Robeck, who helped with data collection and processing. Additional thanks to Kerry Rappold, Dr. Desiree Tullos, and Derek Godwin for their support and advice.

REFERENCES

[1] J. E. Ruprecht, W. C. Glamore, I. R. Coghlan, and F. Flocard, "Wakesurfing: Some wakes are more equal than others," *Aust. Coasts Ports 2015 Conf.*, no. September, pp. 779–784, 2015.

[2] D. M. Bilkovic and J. Davis, "Review of boat wake wave impacts on shoreline erosion and potential solutions for the Chesapeake Bay Distribution of Diamondback Terrapins in the Chesapeake Bay View project," pp. 1–68, 2018, [Online]. Available: www.chesapeake.org/stac.

[3] OSMB, *Permanent Administrative Order: Boat Operations on the Willamette River in the Newberg Pool*, no. OSMB4-2019. 2019, pp. 1–6.

[4] K. Kratz, "Effects of Wake Boat Activity on ESA-Protected Fish and Designated Critical Habitat."

[5] Y. A. Yousef, W. M. McLellon, and H. H. Zebuth, "Changes in phosphorus concentrations due to mixing by motorboats in shallow lakes," *Water Res.*, vol. 14, no. 7, pp. 841–852, Jan. 1980, doi: 10.1016/0043-1354(80)90265-1.

[6] J. Hilton and G. L. Phillips, "The Effect of Boat Activity on Turbidity in a Shallow Broadland River," *J. Appl. Ecol.*, vol. 19, no. 1, Apr. 1982, doi: 10.2307/2402998.

[7] S. Johnson, *Recreational Boating Impact Investigations: Upper Mississippi River System, Pool 4, Red Wing, Minnesota.*, no. February. 1994.

[8] N. G. Bhowmik, T. W. Soong, W. Reichelt, and W. C. Bogner, "Waves generated by recreational traffic on the upper mississippi river system," *Hydraul. Eng. - Proc. 1990 Natl. Conf.*, pp. 855–860, 1990.

[9] G. C. Nanson, A. Von Krusenstierna, E. A. Bryant, and M. R. Renilson, "Experimental measurements of river-bank erosion caused by boat-generated waves on the gordon river, Tasmania," *Regul. Rivers Res. Manag.*, vol. 9, no. 1, Mar. 1994, doi: 10.1002/rrr.3450090102.

[10] J. M. Dorava and G. W. Moore, "Effects of boatwakes on streambank erosion Kenai River, Alaska. Report, US Geological Survey and Alaska Department of Fish and Game," pp. 1–89, 1997, [Online]. Available: https://pubs.usgs.gov/wri/1997/4105/report.pdf.

[11] T. R. Asplund, "The Effects of Motorized Watercraft on Aquatic Ecosystems," 2000.

[12] Y. Gal, M. Browne, and C. Lane, "Long-Term Automated Monitoring of Nearshore Wave Height From Digital Video," *IEEE Trans. Geosci. Remote Sens.*, vol. 52, no. 6, Jun. 2014, doi: 10.1109/TGRS.2013.2272790.

[13] C. Lane *et al.*, "A new system for breakzone location and the measurement of breaking wave heights and periods," in *International Geoscience and Remote Sensing Symposium (IGARSS)*, Jul. 2010, pp. 2234–2236, doi: 10.1109/IGARSS.2010.5652740.

[14] J. E. Ruprecht, W. C. Glamore, I. R. Coghlan, and F. Flocard, "Wakesurfing: Some Wakes are More Equal than Others," 2015.

[15] V. C. Nelson and K. L. Starcher, *Introduction to Renewable Energy*, 2nd ed. Routledge, 2015.