# Analyzing Threats to Water Quality Caused by Motorized Recreation on Payette Lake, Idaho

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Table of Contents

List of In-Text Maps, Graphs, and Figures

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### *Abstract*

*While the negative effects of motorized recreation on aquatic ecosystems have been thoroughly studied over the years, case specific research is necessary to inform comprehensive resource and recreation management plans. In this paper I explore threats to water quality posed by motorized recreation on Payette Lake in Central Idaho, and recommend policy actions to mitigate for potential negative impacts.*


## Introduction

Of all the tools humankind has learned to craft over the ages, boats are perhaps one of the most important. Not only have they helped nourish entire communities and cultures, they have assisted humans in rapidly expanding their presence on Earth. Boats have existed since the beginning of time, and some evidence suggests *Homo Erectus* made seaworthy, raft-like vessels as long as 900,000 years ago. The earliest known true boat made by *Homo Sapiens*, a 3-meter dugout canoe found in present day Crete, dates to nearly 10,000 years ago (Vaucher, 2014). By the dawn of the age of Christ, over 2,000 years ago, massive vessels made of wood, bronze, and iron already plied the seas in pursuit of commerce, exploration, war, and grandeur.

Over the ages boats have become inexorably woven into the fabric of human culture. But with all the benefits they can provide humankind, and not unlike most of our technology, we have become loathe to analyze their negative impacts. Today, however, a new design of watercraft demands special attention be paid to the potential detrimental effects of these boats, as well as their management in a crowded and space-limited resource. These boats are called wake boats, and they are designed to create a wake so slow and large it can be surfed without a tow rope, as is used in traditional water skiing and wake boarding (see photo below).

This new boat design has allowed for the rapid expansion of wake sports across a far wider audience, because it is safer and easier than wake boarding or water skiing. However, the new design has drawbacks; large wakes have been attributed to accelerated shoreline erosion in some areas, the use of wake boats can displace other users, the ballast tanks of wake boats can harbor and transport invasive species, and the boats have a greater potential to disturb bottom sediments than traditional motorized watercraft. While substantial research has been conducted on the effects of wake boats and the waves they produce, the sport is still in its infancy, and there is still much to be learned.

## Literature Review

Modern wave theory was first presented to the world in 1678 by the Dutch physicist Christiaan Huygens, who posited that light traveled in waves, rather than straight lines as suggested by particle theory (FSU, 2020). Huygens' theories were quickly applied to water wave theory, and after early work by Newton around the turn of the 18th century, French and German mathematicians rapidly advanced theories of linear and non-linear water waves (Craik, 2004). In 1887, the famed British physicist Lord Kelvin introduced the world to his own wave research which showed that the bow wake from an object traveling through the water propagated at a consistent 19.47° angle away from the centerline of travel, regardless of the size, shape, or speed of the object (Perkinson, 2010). Although we now know this is not always true, his discovery set the stage for rapid advancements in wave theory.

In the mid 1800's, University of Cambridge physicist Sir George Stokes and the English engineer and hydrodynamicist William Froude produced important work on water waves. Stokes created a concept termed the Reynolds Number which helped explain the relationship in fluid flow between inertial and viscous forces, otherwise known as turbulence (GWU, 2020). Froude introduced the world to the Froude number which "represents a ratio of the speed with which two processes, namely advection and wave propagation, carry information of a disturbance throughout a system" (Mayer & Fringer, 2017). Functionally, the Froude number can be used to describe whether a boat is operating in displacement or planing mode.

By the 1900's, general water wave theory was well established, and since that time, the science has been refined by countless researchers and academic organizations around the world. Highly accurate models can now predict the size and propagation angles of conflicting and complimentary waves under many different scenarios and parameters, and field research has provided an immense body of knowledge. This information is used to design massive vessels, forecast storm surges, and predict potential environmental impacts from motorized boats, among other uses.

Today, due to the rise in popularity of wake boats and the oversize waves they produce, state and local governments, communities, academic institutions, and concerned citizens are beginning to attempt to define the parameters under which these boats should operate in order to best protect other resources. The boating industry has also weighed in, attempting to prove that wake boats are no more impactful than other motorized vessels. With all this information at hand, some of which is contradictory, the establishment of rules and regulations for wake boats has proven difficult for many land and recreation managers. In many situations, case specific and data driven research has become necessary to determine the potential for negative impacts..

## **Specific Threats to Water Quality Caused By Motorized Boats**

The predominant threats to water quality caused by motorized boats are shoreline erosion and resuspension of bottom sediments. These threats are magnified by wake boats due to the size and energy of the waves and prop-wash (slip-stream) they create. Other types of large boats are also responsible for inflicting this type of environmental damage, and in the last several decades, many researchers have begun studying the phenomenon. A seminal study on boat induced erosion was performed during the summer of 1979 on the Chesapeake Bay in Maryland, where researchers found that there was a high likelihood that increased boat traffic, and boat traffic passing too close to shore, was responsible for accelerated rates of shoreline erosion (Zabawa & Ostrom et al., 1980).

Throughout the 1990's, substantial research on shoreline erosion (attributed to boats) was performed in the U.S., as well as in Australia, New Zealand, and Tasmania. In a study conducted in Tasmania in 1993, researchers showed that lowering ferry traffic speeds along the Lower Gordon river could substantially reduce shoreline erosion (Nanson, et al., 1994). In a study on the Kenai River in Alaska in the mid-1990's, researchers found that small fishing boats were responsible for accelerated erosion along the river banks (Dorava & Moore, 1997). Other work includes a study of the Upper Mississippi River System by the Minnesota Department of Natural Resources which found that commercial and recreational boat traffic accelerated shoreline erosion (Johnson, 1994).

More recent studies on shoreline erosion include work from Canada, Tasmania, and the Chesapeake Bay. In Tasmania, additional research showed wave height by itself was a poor indicator of erosion potential, and power and energy should also be considered (Bradbury, 2005). In 2013, researchers with University of British Columbia - Okanagon in Canada analyzed the relationship between boat wakes and river bank erosion along the lower Shushwap River in British Columbia. They found that motorized boats were likely responsible for stream bank erosion (Laderoute & Bauer, 2013). Finally, long-term research on the Chesapeake Bay showed that boat traffic was definitively responsible for accelerated shoreline erosion, and the authors of the study suggested protective policy measures be adopted to mitigate wake energy in highly vulnerable systems (Bilkovic, et al., 2017).

Although not caused by the same mechanisms, bed sediment disturbance due to motorized watercraft has been studied simultaneously with shoreline erosion. Some of the most frequently cited work was performed in 1980 by researchers with the University of Central Florida. Their research showed changes in phosphorus concentrations in the water column after the passage of motorized boats in several shallow lakes in Central Florida after the passage of motorized boats (Yousef, et al. 1980). Other seminal work occurred in 1987 on the Norfolk Broads in the English countryside, where researchers with the School of Environmental Sciences at the University of East Anglia found that bed sediment resuspension contributed to turbidity and algae blooms (due to the release of nutrients). They also showed that resuspension of bed sediments could be caused by the passage of a single boat, and they noted the management implications of their work (Garrad & Hey, 1987).

More recent work on bed sediment resuspension has been performed in Illinois, Wisconsin, and Canada. On the Fox River Chain O' Lakes in northeastern Illinois, researchers with the US Army Corps of Engineers determined that there was a direct correlation between boat traffic and the amount of suspended solids in the water column. Their research also showed that while wind could produce waves capable of generating turbidity, the frequency of boat passes was much higher than the frequency of high winds (USACE, 1994). In Wisconsin, Timothy Asplund of the University of Wisconsin investigated several area lakes and found that motorized boat traffic increased turbidity, which then contributed to nutrient regeneration and algal stimulation (Asplund, 1996). Research on lakes in the Whiteshell Provincial Park in Manitoba, Canada, also found that bed sediment disturbance by motorized watercraft released stored phosphorous into the overlying water column (Nedohin & Elefsiniotis, 1996).

Some of the most important work occurred in the early 2000's. Drawing on their own studies, as well as those of their predecessors, researchers with the Department of Civil and Environmental Engineering at The Pennsylvania State University published a paper analyzing the potential for recreational watercraft to disturb bed sediments. Published in 2003 in the *Journal of Lake and Reservoir Management*, authors M.M. Beachler and D.F. Hill presented and validated a simplified method to model turbulent prop-wash and jet-wash from motorized watercraft. They suggested their method could be used to determine appropriate operating depths for motorized boats, and could have important implications for management and policy decisions (Beachler & Hill, 2003).

While many of the previously referenced studies concerned wakes and slip-streams created by motorized boats of all different types and sizes, more recent studies have examined (V-Drive) wake boats specifically. In 2014, researchers at the University of Quebec at Montreal studied wake boats on Memphremagog and Lovering Lakes and found that waves from wake boats imparted significantly more energy on shorelines than waves from other boats. They also found this effect could be mitigated by operating wake boats at least 300 meters from shore (Mercier-Blais & Prairie, 2014). In 2015, the Wave Sports Industry Association (WSIA) released the results of privately funded (and non-peer reviewed) research conducted by Clifford Goudey of C.A. Goudey & Associates, a private consulting firm in Newburyport, Massachusetts. This research showed that while waves created by wake boats start out relatively high, they dissipate rapidly upon breaking. Goudey also presented information that showed the maximum measured height of waves at 285 feet from the sensor was 7.5 inches, with a maximum measured starting height of 27.8 inches (Goudey, 2015).

Perhaps the most important contribution to the conversation, however, has been a paper published in 2014 by researchers at the School of Civil and Environmental Engineering at the University of New South Wales, Australia. They specifically analyzed wave energy from waves produced by wake boats, and they found that "[T]he wave energy associated with the single maximum wave height (Energy $H_{max}$) for the wake surf 'operating condition', is approximately four times that of the wakeboard 'operating condition', and twice that of the wakeboard 'maximum wave' condition". They also suggested operation of wake boats should be limited to areas far enough from shore to allow sufficient distance for natural wave attenuation (Ruprecht, et al., 2014).

**A Brief History of Wake Boat Regulation**

With an abundance of research showing the potential and actual negative effects of wake boats, communities and management agencies around the world face the hard task of regulating their use. In the process they have encountered fierce opposition from boat owners and the boating industry, and many communities are struggling to balance recreation and natural resource protection. Where waterways are the source of municipal drinking water, such as in McCall, Idaho, the tension has been further heightened. Here, I offer a review of previous legislative efforts to regulate wake boats in the U.S. in order to provide insight into the processes in which many communities are engaging.

In Bonner County, Idaho, the location of Lake Pend Orielle, Priest Lake, and numerous small rivers and waterways, recreational boating has been a significant economic driver for many years (Black, et al., 2016). To help regulate rapidly growing use, in 2016, the Bonner County Board of Commissioners passed Ordinance 552. The ordinance set a 200 foot no-wake zone on major lakes and rivers in the county. By 2018, however, and partially due to the rise in popularity of wake boats, it was clear the no-wake zone was not sufficient to protect lakeshore resources. Anecdotal evidence suggested that docks and retaining walls were being destroyed, and county officials noticed evidence of shoreline erosion (Viydo, 2018).

Resource managers promptly began collecting public input on the matter, but due to the contentions nature of the subject, no decision modifying the no-wake zone has been made to date. Just to the south, on Lake Coeur d'Alene in Kootnai County, residents are also urging the county to expand the 200 foot no-wake zone to protect shorelines and shoreline infrastructure from damage caused by large wakes. Although Kootnai County passed an ordinance in 2020 restricting the use of wake boats on rivers, the county has yet to address their use on lakes. This has left many residents in the county concerned and frustrated (Bartholdt, 2020).

In Portland, Oregon, conservation groups, residents, boaters, and the state Marine Board have collaborated over the last two years to adopt and approve rules regulating the use of wake boats in the Newberg Pool, a 20 mile stretch of the Willamette River. Residents had complained for some time about riverbank erosion and damage to shoreline infrastructure in the narrow waterway, and the Willamette Riverkeepers, a local non-profit environmental group, exposed risks to wildlife and riverine habitat from excessive wakes. Officials with the National Oceanographic and Atmospheric Administration (NOAA) also warned that wake surfing in the river could harm salmon and steelhead, potentially placing the state in violation of the Endangered Species Act (Profita, 2020).

In early 2020, after much debate and public input, the Oregon Marine Board agreed to change the rules regarding wake surfing in the Newberg Pool. Instead of banning boats over 3,500 pounds, effectively prohibiting the use of wake surf boats, the Board decided to reduce the number of zones available for wake surfing from 5 to 3. Additionally, the Marine Board altered the no-wake zone designations in the Newberg Pool to include the following rules:

> (5) A person must not operate a motorboat between river mile 30 and river mile 50:
>
> (a) In excess of “slow-no wake” speed within 100 feet of a private dock, boathouse or moorage legally permitted by the Oregon Department of State Lands.
>
> (b) For the purposes of wakeboarding within 200 feet of a dock, boathouse, moorage or floating home legally permitted by the Oregon Department of State Lands, except as specified in (5)(e).
>
> (c) For the purposes of wake surfing within 300 feet of a dock, boathouse, moorage or floating home legally permitted by the Oregon Department of State Lands, except in an area listed in (6) or as specified in (5)(e).
>
> (d) In excess of “slow-no wake” speed for the purposes of towing an inflatable device within 200 feet of a dock, boathouse, moorage or floating home legally permitted by the Oregon Department of State Lands, except as specified in (5)(e). (OAR 250-010-0010)

Finally, Oregon House Bill 2352 was passed in early 2020. The bill created an education program administered by the Marine Board, and required an endorsement by the Board for boaters who wakeboard and wake surf on the Willamette River in the Newberg Pool. To receive the endorsement (evidenced by a decal affixed to the sides of their boats), boat operators are now required to pass an approved towed watersports education course (HB 2352). The new rules represent a compromise between multiple stakeholders. They became effective on July 1, 2020, so there has not yet been adequate time to evaluate their effectiveness.

Generally, officials in the central and eastern U.S. have taken a far more conservative approach to restricting the use of wake boats on public waterways. After a similar mandate by New York Governor Andrew Cuomo in 2017, an act was passed in New York in 2018 that amended state navigation law to prohibit boats using ballast from creating a wake within six hundred feet from the shore (State of NY, 2017). In Winnebago County, Wisconsin, Ordinance 9.41 imposed a no-wake zone within 500 feet of any permanent structure on navigable waters (Winnebago County, 2020). in New Hampshire, House Bill 137, passed in 2019, established a commission to examine the effects of wake boats in the state. The bill ordered the commission to gather "the appropriate data  and information on the positive and negative uses of wake boats, specifically regarding:

(a) The spread of aquatic invasive species.

(b) The relationship to shoreline erosion and impacts to private property.

(c) The economic impact of recreational boating and the popularity of water sports among families in New Hampshire.

(d) The safety of swimmers and other boaters. (New Hampshire, 2019)

In McCall, Idaho, where the present research was conducted, the regulation of motorized boats has been just as contentious as in many other communities. Until 2008, long standing Idaho state law set a no-wake zone of just 100 feet on Payette Lake. At that time, however, in an effort to regulate growing use on the lake, Valley County enacted ordinance #08-01, which mandated a 300 foot no-wake zone on county waterways (Valley County, 2008). In 2018, during the process of renewing the ordinance, it was discovered the original ordinance was improperly worded and implemented, and it would have to be re-written and voted on again.

At that time numerous private boat owners, local business owners, and boating industry representatives intervened. They asked the county to revert to the previous 100 foot no-wake zone as defined by the state. After significant, and at times heated debate, in June of 2020, the Valley County Board of Commissioners passed Ordinance #20-11, which re-enacted many parts of the previous ordinance, including the 300 foot no-wake zone restriction (Valley County, 2020).

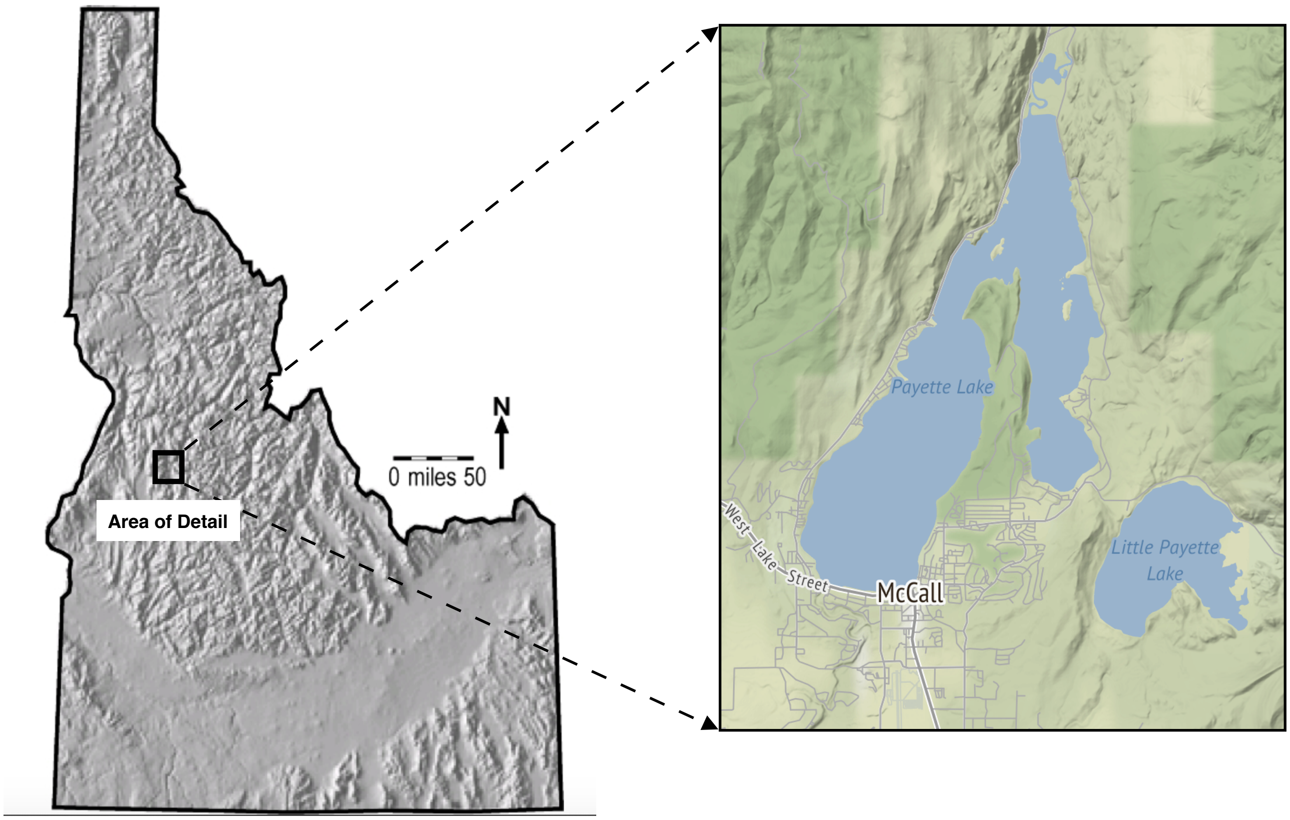
Unfortunately, not all members of the community in Valley County have been satisfied by the re-implementation of the old rules. Many believe that a 300 foot no-wake zone does not provide sufficient protection for environmental resources and shoreline infrastructure and could lead to displacement of other lake users. Furthermore, some are worried the heightened risk of turbidity and blue-green algae blooms from increased shoreline erosion and lakebed sediment disturbance could threaten the town of McCall's drinking water supply. Given these concerns, and lack of relevant data on the subject, case specific research has now become necessary to determine the severity of the risks and threats posed by motorized recreation, as well as strategies and techniques to mitigate them.

**McCall, Idaho, and Payette Lake**

Payette Lake is a 5,000 acre, 300 foot deep glacial lake lying in the heart of Central Idaho (see map next page). The lake the source of the towns drinking water, and it is one of the predominant tourist attractions in the area; all summer long its cool, clear waters are plied by sail boaters, kayakers, paddle boarders, fisherman, swimmers, and hordes of enthusiastic motor boaters. In winter months the lake freezes, attracting ice-fishers, cross country skiers, and snowmobilers, and when conditions are just right, ice skaters. Local legend also says the icy depths are inhabited by a monster, colloquially known as Sharlie.

McCall, Idaho, contains just over 3,000 full time residents. The population increases dramatically in the summer with an influx of seasonal workers and second home owners. In the McCall impact area there are over ten thousand houses. McCall's economy is almost entirely dependent on tourism and it retains a small town feel that draws visitors from far and wide. Codes and ordinances are intended to maintain this character, and a main tenet of the McCall Comprehensive Plan is to "protect and preserve McCall's crown jewel, Payette Lake, water and air resources, natural areas, and the scenic beauty of the region" (City of McCall, 2018).

Map 1 - McCall, Idaho and Payette Lake Overview




While the varieties of outdoor recreation opportunity are innumerable around McCall, motorized boating is responsible for a large share of the tourism. There are nearly 500 individual docks on the lake with slip space accommodating well over 1,000 boats. Numerous boat and jet ski rental business also exist comfortably alongside each other. Evidence indicates use of the lake has been growing, and while nearly all sectors of the recreation industry saw increases in use in recent decades, nationwide, motorized boating (and more specifically wake sports) was a notable example; between 1999 and 2009 there was a 33.1% increase in total wake sport participants and a 20% increase in total user days (the study did not differentiate between water-skiing, wakeboarding, and wake-surfing). Since 2009, the upward trend in motorboat use has continued, and in 2016, gross sales of motorized boats and accessories reached nearly $39 billion (NMMA, 2018). The US Department of Agriculture anticipates motorized water use will increase another 29.9% by the year 2030 (USDA, 2016).

**Needs Assessment**

In general, the increased use of motorized boats in a static number of waterways, including Payette Lake, has heightened the potential for user conflict, aquatic invasive species dispersal, and water quality degradation. As previously noted, particular risks from motorized boating include shoreline erosion and lakebed sediment disturbance, both of which can result in increased turbidity and resuspension of contaminants and nutrients such as phosphorous in the water column (Beachler & Hill, 2003; Yousef et al., 1980). Once in suspension, phosphorous can foster toxic blue green algae and other cyanobacteria blooms, severely affecting water quality and the recreation potential of waterways.

In Cascade Reservoir, the other major body of water in Valley County, Idaho, toxic blue-green algae blooms have forced summer recreation closures for many years running. In 2014 the city of Toledo, Ohio, had to shut down their entire drinking water system due to a toxic cyanobacteria bloom in Lake Erie. The shutdown cost the city and state millions of dollars and caused severe disruption to residents (Henry, 2014). In both cases, excess available phosphorous and other nutrients in the water were found to be a contributing factor for the blooms.

In the 1997 report, “The Eutrophication Potential of Payette Lake,” Paul Woods of the USGS described in detail the hydrologic and nutrient regimes in the lake. His research found a water residence time of nearly 2.5 years, high volumes of natural and anthropogenic nutrient inputs, and elevated phosphorous levels in many areas of lakebed sediment; especially in the lake's heavily populated and trafficked southwest basin (Woods, 1997). Along with rising boat use, all of these factors contribute to an increased threat of water quality degradation and cyanobacteria blooms in Payette Lake, demanding that the issue be studied in further detail.

## Study Design and Methodology

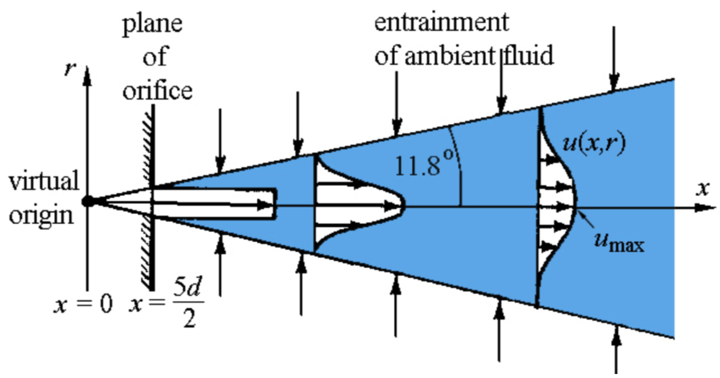
To evaluate the threats to water quality posed by motorized recreation on Payette Lake, I modeled and directly measured: (a) motorized boat slip-streams, (b) motorized boat wakes, and (c) wind and wind waves. Wind and wind waves were measured to provide baseline conditions on wind wave regimes on lake, not only to assess their potential to induce shoreline erosion, but to provide a standard of comparison when analyzing motorized boat wakes.

### Slip-Stream Analysis

The theoretical bases for the slip-stream studies are computational models developed by researchers with the Department of Civil and Environmental Engineering at Pennsylvania State University and the Department of Civil Engineering at Clemson University. Their research focuses on the simulations of turbulent, non-buoyant jets and was later validated in field studies (Beachler & Hill, 2003; Aziz et al., 2008). Both teams of researchers independently developed equations for growth rates and mean velocity decay rates along the stream-wise (x) axis of the jet.  The present models were produced from these equations.

Substantial research has shown that turbulent, non-buoyant jet streams (such as the slip-streams found behind boats) develop in predictable ways. After an initial zone of establishment, the slip-stream expands radially along the x-axis at a consistent 11.8°, and velocity profiles across the slip-stream exhibit consistent distributions (Fig. 1).

Fig. 1 - Establishment of slip-streams for turbulent, non-buoyant jets (Cushman-Roisin, 2008)




Using the established models predicting rates of velocity decay within the slip-stream (Appendix A, p. 36), I calculated initial slip-stream velocities for several boats. Information used in the modeling was sourced from boat manufacturers, publicly available data from propeller manufacturers, and data crowdsourced from wake-surf boating forums. The latter proved to be the most valuable, as that data represented real speed to RPM curves and initial slip-stream velocity measurements observed under actual operating conditions. Velocity profiles were then developed and correlated with shear forces necessary to disturb and suspend bottom sediments (Appendix. B, p.37).

Information on boat trim angle under normal operating conditions (Appendix C, p. 37) was recorded on Oct. 30, 2019, on Anderson Ranch Reservoir near Mountain

Home, Idaho. The trail angle data was collected with a Hobo Pendant G Accelerometer oriented along the x-axis, onboard a 2019 MB Sports F22 Tomcat surf boat.

On Payette Lake, bathymetric information was sourced from existing USGS data, and distance from shore was estimated for the 6 meter (20 foot) and 10 meter (33 foot) depth contours. These contours were then correlated with the existing 300 foot no-wake zone boundary to determine where vulnerable areas of lake bed may occur, given the depth influence of the modeled slip-stream profiles. Sediment type and grain size was estimated using USGS soil data. Sediment samples were taken for measurement from Legacy Beach and near the Ponderosa State Park Visitor Center on Payette Lake.

**Slip-stream Modeling Results and Discussion**

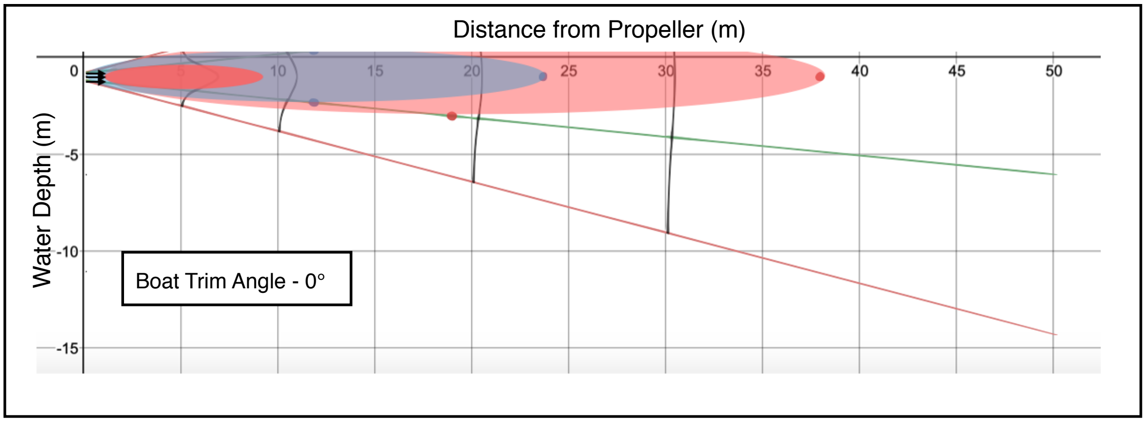
The charts on the following pages show slip-stream velocity profiles for three V-Drive wake boats; a 2019 Malibu LSV22, a 2016 Malibu 22LSV, and a 2019 Axis T23. The shaded regions within the profiles are defined by the minimum water velocity found in that region, and they have been correlated to crucial thresholds for sediment motion and suspension. Distance behind the source (propeller) is shown on the x-axis, and water depth is measured on the y-axis. As can be seen on the charts, slip-streams from wake boats are likely capable of disturbing sediments at depths over ten meters (33 feet).

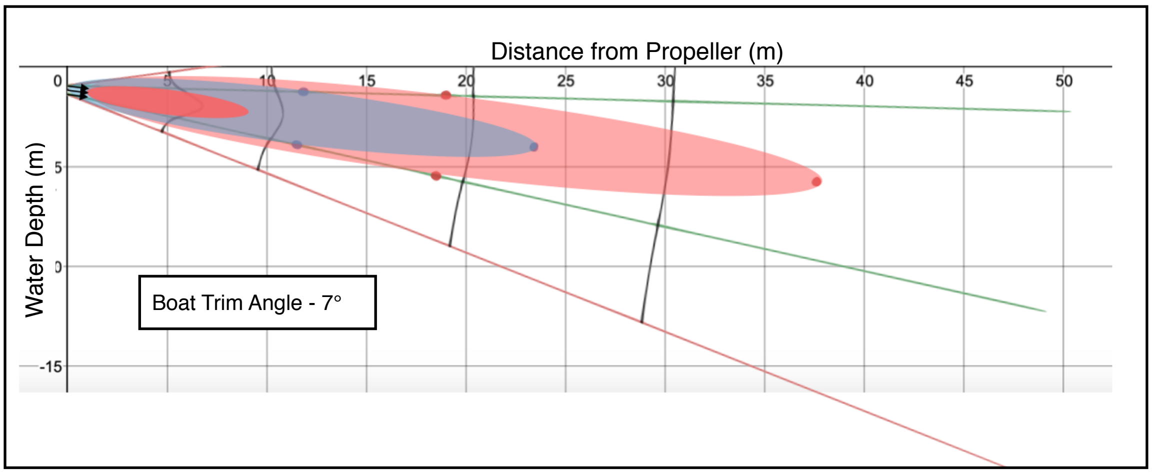
**Charts 1-3: 2019 Malibu 22LSV**
**Max Slip-stream Velocity: 4.1m/s @ 11 mph, 2300 rpm**
**(chart values in meters)**

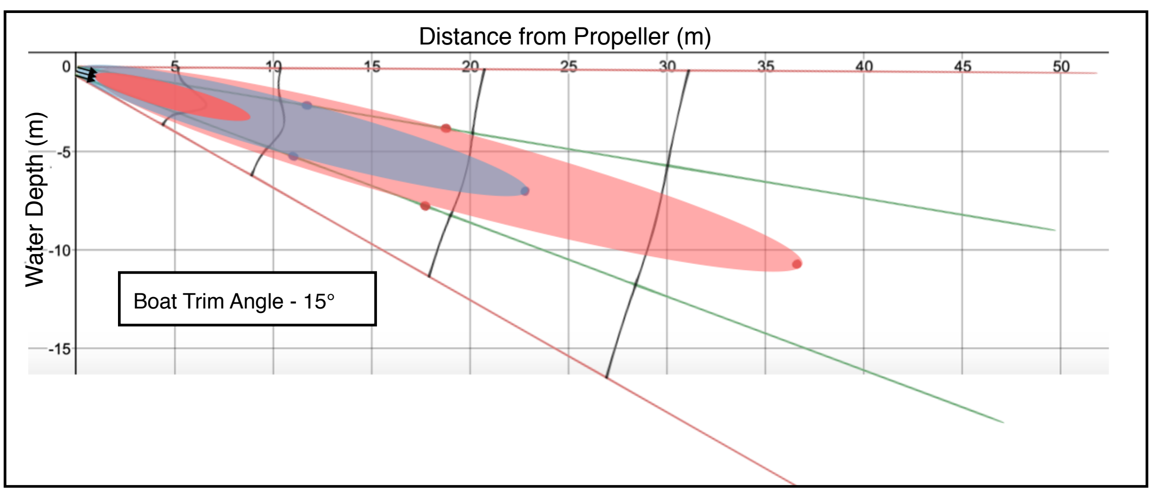
Slip-stream Velocity > .25m/s

Slip-stream Velocity > .4m/s

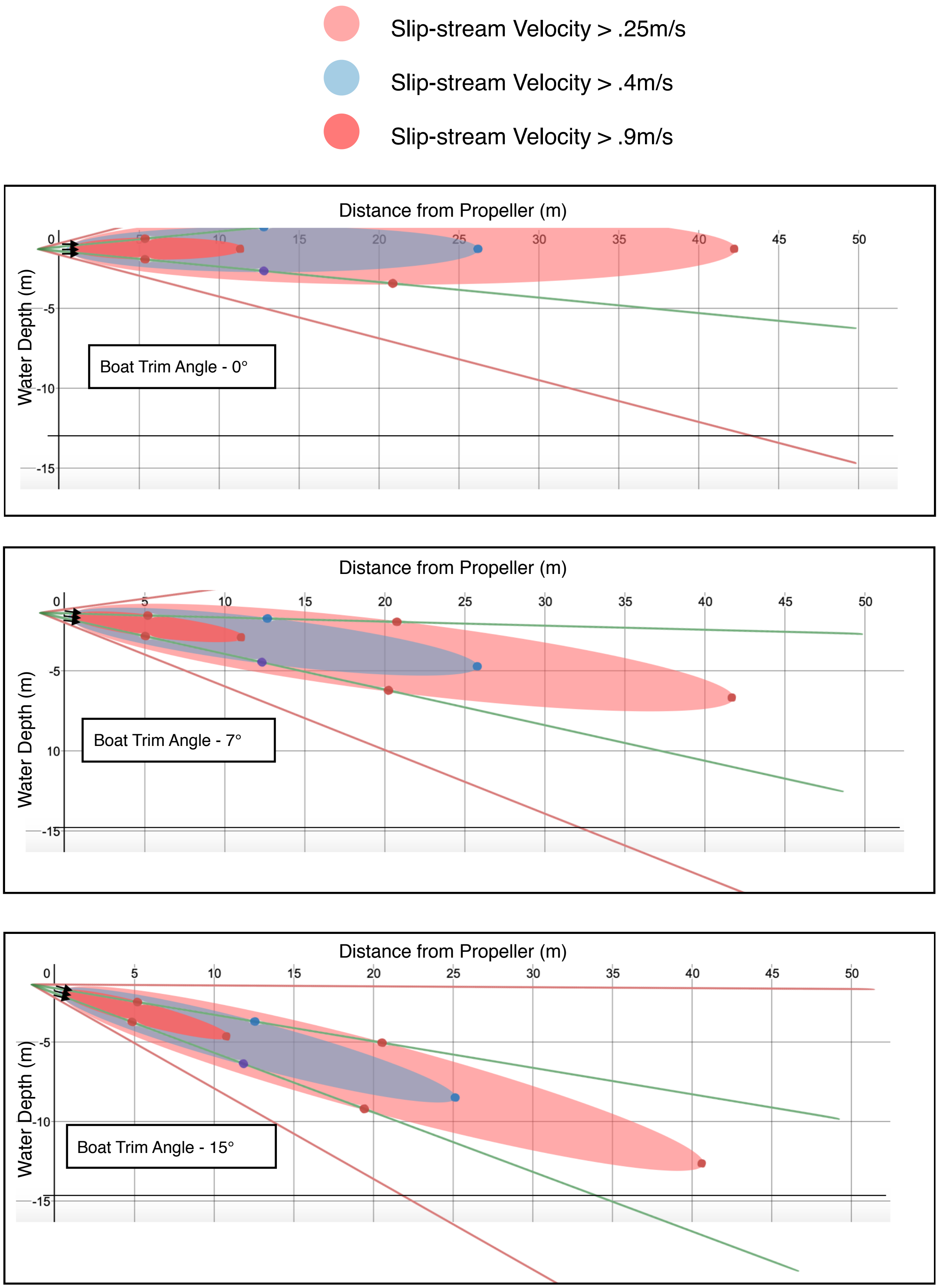
Slip-stream Velocity > .9m/s



**Charts 4-6: 2016 Malibu LSV22**
**Max Slip-stream Velocity: 4.49m/s @ 11 mph, 2400 rpm**
**(chart values in meters)**

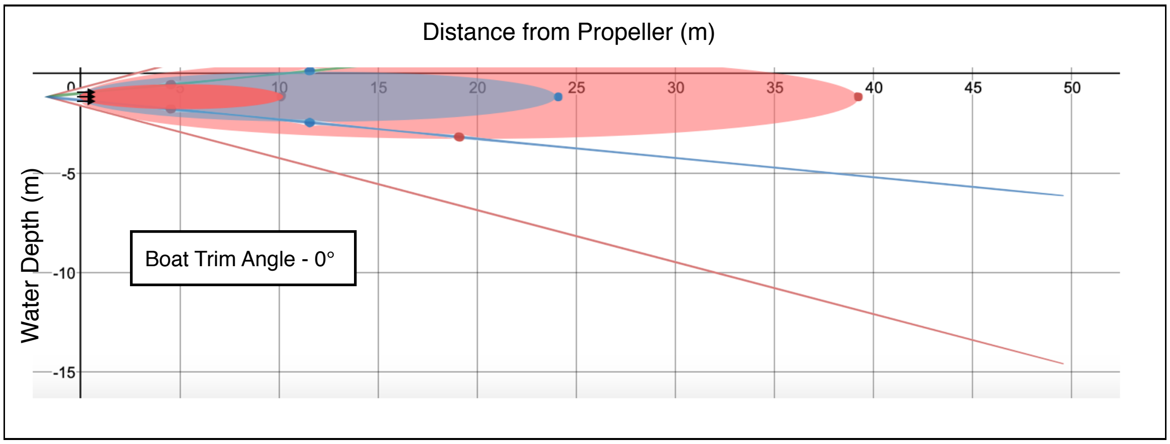


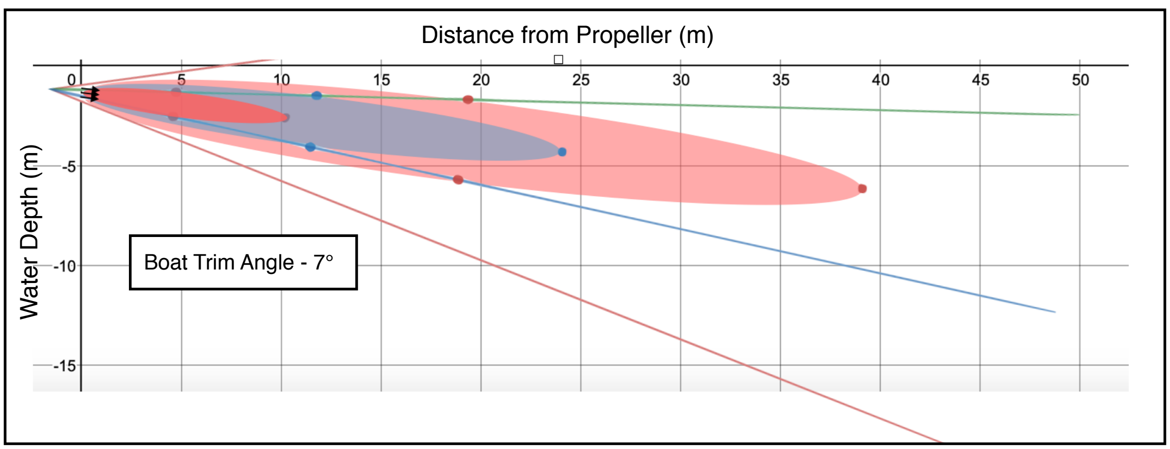
**Charts 7-9: 2019 Axis T-23**
**Max Slip-stream Velocity: 4.21m/s @ 10.2 mph, 2500 rpm**
**(chart values in meters)**

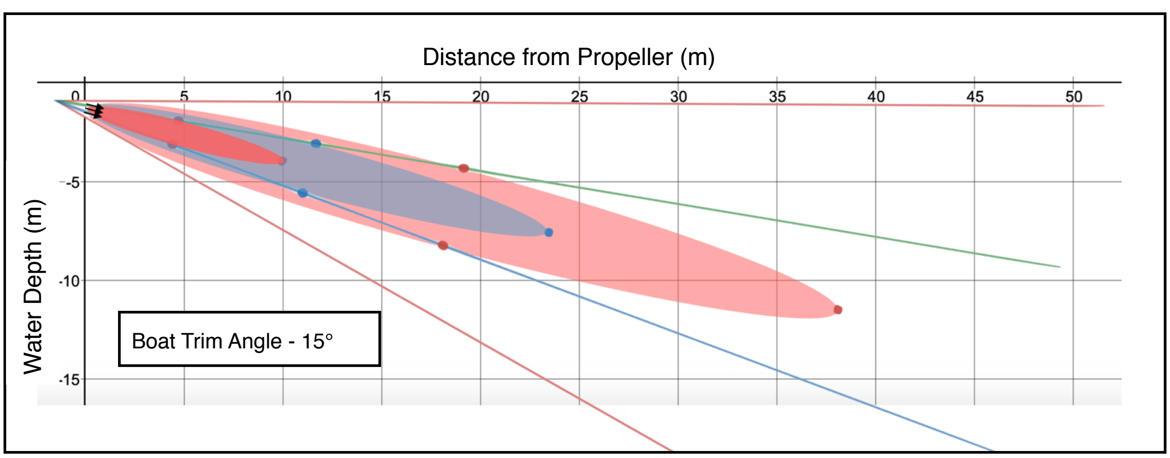
Slip-stream Velocity > .25m/s

Slip-stream Velocity > .4m/s

Slip-stream Velocity > .9m/s



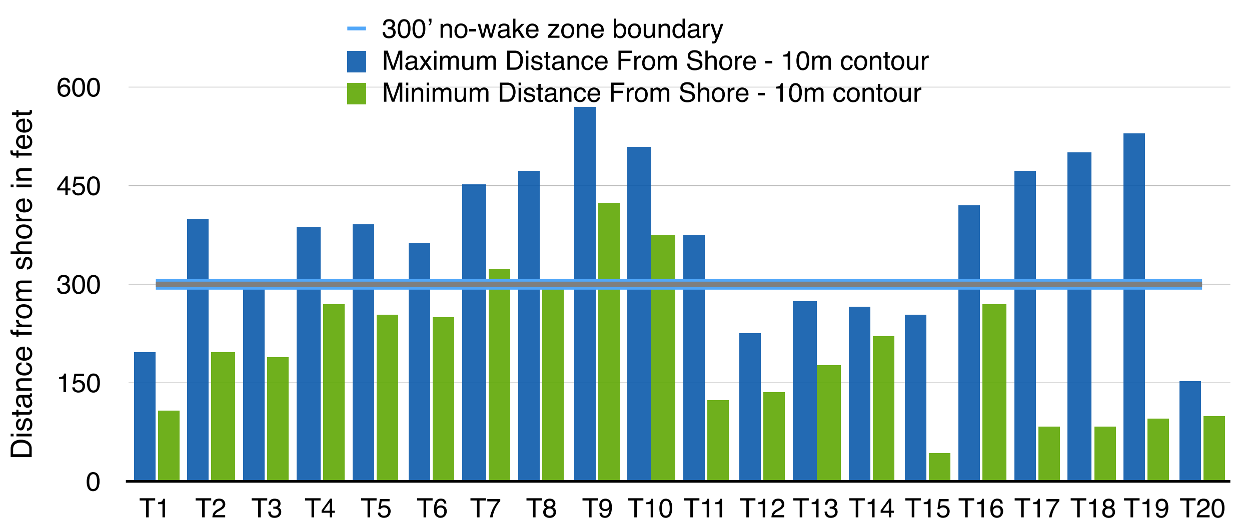



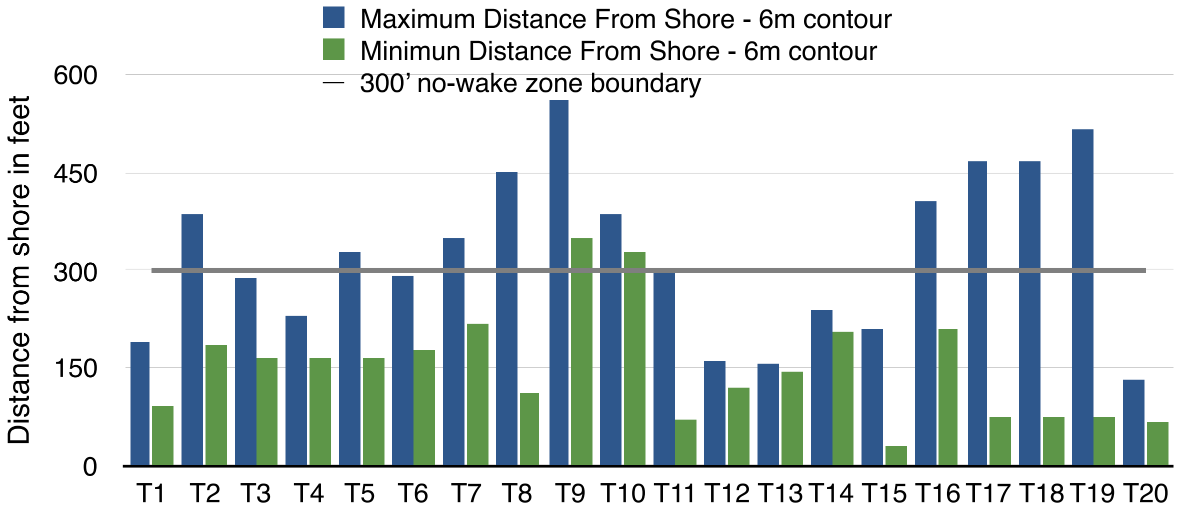
To correlate the findings from slip-stream modeling with water depths at the 300 foot no-wake zone boundary in Payette Lake, a survey was performed using publicly available bathymetric information from the United States Geological Survey (USGS). This data assumed a full-pool lake elevation of 1519.7m (4986 ft). Five miles of lakeshore in the Southwest basin was then divided in to approximately quarter mile transects (see map, appendix D, p.38), and minimum and maximum distances from shore were estimated for the 6 meter (20 foot) and 10 meter (33 foot) contours in each transect.

As displayed in graph 1 below, at least some portion of the lake was less than 10 meters (33 feet) in depth at the 300 foot no-wake zone boundary in thirteen out of twenty transects. At the no-wake zone boundary in four of these thirteen transects, the lake was shallower than 10 meters deep across the entire quarter mile segment. Graph 2 shows that in ten out of twenty transects portions of the lake were less than 6 meters (20 feet) in depth at the 300 foot no-wake zone boundary. In two of these transects, the lake was less than 6 meters deep at the no-wake zone boundary across the entire quarter mile segment.

Graph 1 - 10m depth contour max. and min. distance from shore.



Graph 2 - 6m depth contour max. and min. distance from shore.




Next, to determine the the types of bed sediments in Payette Lake and whether they were susceptible to disturbance by motorized boat slip-streams, materials were collected from select locations in the Southwest basin and grain size was measured with a digital caliper. Sediment analysis from Legacy Beach revealed an average sand particle size of approximately 0.25mm, with a high distribution of particles near the 0.15mm size. This sediment is characteristic of a majority of the transects sampled. Sediment analysis at Ponderosa Park revealed a slightly larger average particle size of approximately 0.4mm. However, the general lakebed substrate at both sites was characterized by gravel, cobble, and woody debris distributed within a matrix of fine sand, silt, and organic material. Sediment samples were not taken from a third location, Rotary Beach, as the general substrate was observed to be cobble, gravel, and woody debris distributed within a fine silt matrix.

Sand is characterized by a particle size of .0625 to 2mm. Silt is characterized by a particle size of .0039mm to .0625mm. The chart in Appendix B (p.37) denotes general shear forces necessary to initiate motion and suspend sand particles of various sizes, although other studies have found that particles as large as 0.3mm can be suspended by currents as low as .25 m/s (Beachler & Hill, 2003). The chart does not show shear forces necessary to initiate motion and suspend silt particles, which are lower than the shear forces necessary to initiate motion and suspend sand particles. As displayed, this research shows that the turbulence imparted by the modeled slip-streams is sufficient to disturb silt and sand size sediments commonly found in Payette Lake, at depths regularly encountered at or beyond the 300 foot no-wake zone boundary.

It is worth noting that although the boats used to develop models were typical of boats available for rent in McCall, the information used to develop speed to RPM curves and slip-stream velocity profiles was recorded from boats with no passengers, and at elevations between 500 feet and 700 feet. At higher elevations, such as in McCall (5,020 feet), the same motors will run at higher RPM for the given speed. At the higher RPM they will create higher slip-stream velocities (and increased depth influence) than are displayed here. Adding passengers and ballast also creates higher slip-stream velocities, as it increases the boats drag through the water. Additionally, while most boats pass through the RPM band correlating to the highest slip-stream velocities (during acceleration to planing mode), surf-boats are often continuously operated in a displacement mode where slip-stream velocities and trim angle are highest.

**Boat Wake and Wind Wave Analysis**

Boat wake analyses were conducted on Anderson Ranch Reservoir, near Mountain Home, Idaho, on Oct. 30, 2019, and on Payette Lake during several days in July, 2020. Due to logistical challenges and weather constraints, deep and open water measurements of wake surf boat waves proved difficult. The small amount of data recorded lacks the integrity necessary to yield definitive conclusions. However, shallow water measurements of boat and wind waves on Payette Lake proved to be highly successful. The data collected may also provide more realistic insight on near and on-shore wave conditions, as well as the potential for waves to induce shoreline erosion.

Boat and wind waves were measured using a Global Water WL-16 Water Logger, factory calibrated to measure water depths up to 50 feet. The design of the unit allowed for automatic compensation for barometric pressure, and the logger was programmed to collect water depth readings 10x/second during sampling periods.

Wind data was collected during two months in the fall of 2019, using two RainWise Inc. WindLog Wind Data Loggers, programmed to collect wind speed, gust speed, and wind direction 6x/hour. The units were deployed on Payette Lake at the west end of Rotary Park and near the Ponderosa State Park visitor center, and were placed at approximately 12 feet above lake level on the trunks of large trees prominently facing the lake. Other relevant wind data was collected from the National Oceanographic and Atmospheric Administration (NOAA) website.

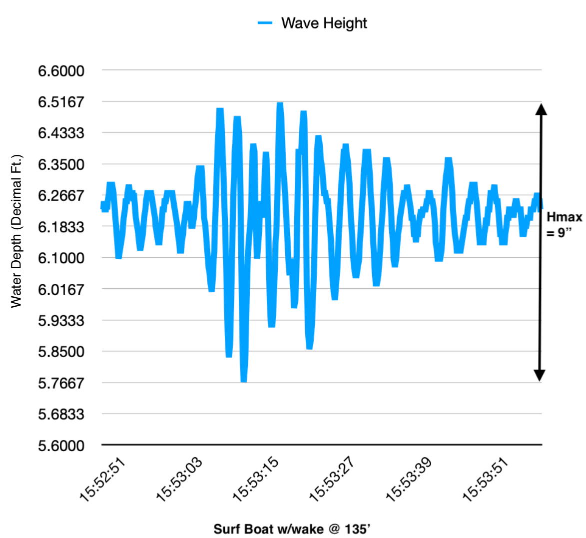
**Boat Wake Study Results and Discussion**

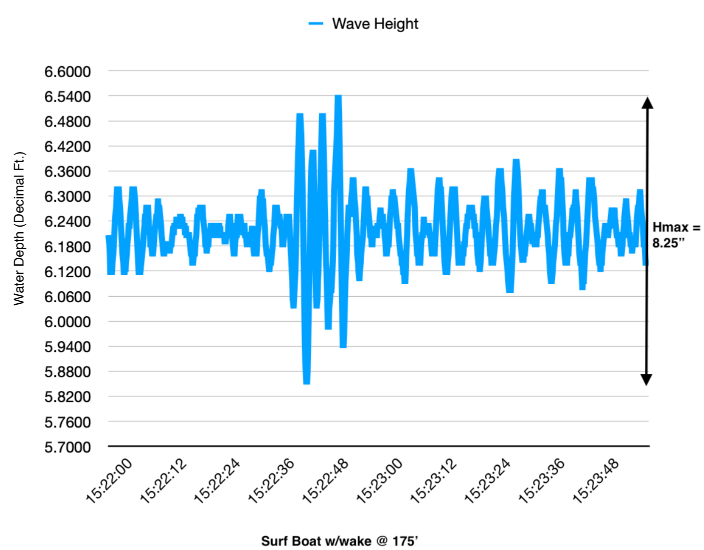
On July 3, 2020, boat wakes were measured for five hours on a small, rocky point immediately north of the cliffs swimming area on Payette Lake. Boat traffic was moderate to heavy during the entire sampling period, and the full results of 44 minutes of sampling are displayed in Appendix E (p.39-41). As wave-height data was collected at 10x/second during the entire sampling period, and nearly 180,000 data points were collected during the 5 hour sampling period on July 3rd alone, only some data sets are included in this paper.

Graphs 3-8 show wave height data for wake boats operating in displacement mode that passed the sampling station on July 3rd. The wave height recorder was placed in 6 feet of water and approximately 12 feet off-shore. Boat distance from shore was measured using a Nikon Aculon 6x20 digital range finder.

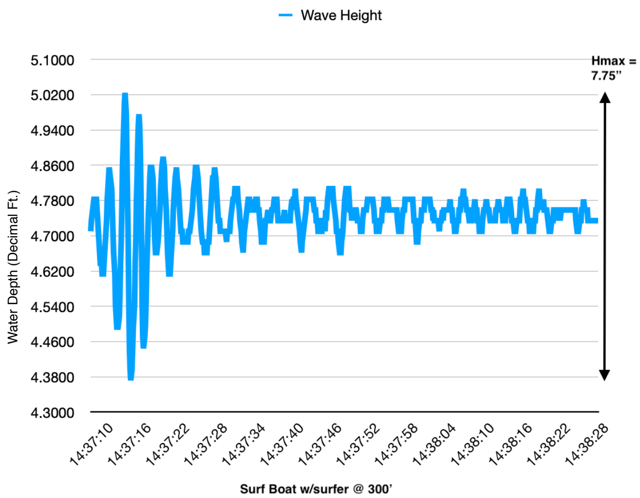
As displayed in the graphs, a wake boat operating at the 300 foot no-wake zone boundary can produce a wave that is still 7.75 inches high when it reaches shore. A wake boat operating at 135 feet from shore can produce a wave that is still 9 inches high when it reaches shore. Measurements also showed wake boats operating nearly 1000 feet from shore could produce a wave that was still 4 inches high when it reached shore.

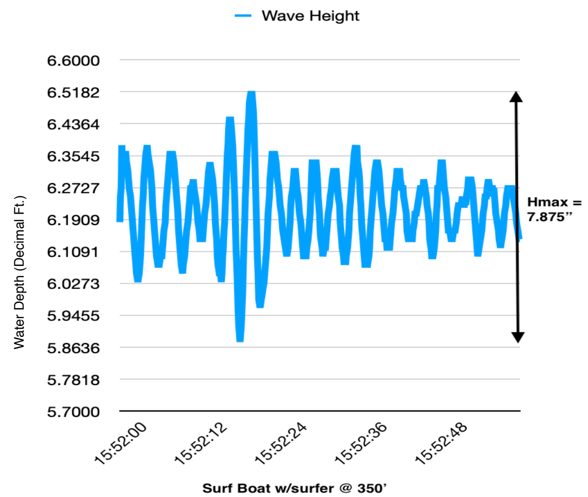
Graphs 3-8 - Surface wave measurements for wake boats at varying distances from shore.

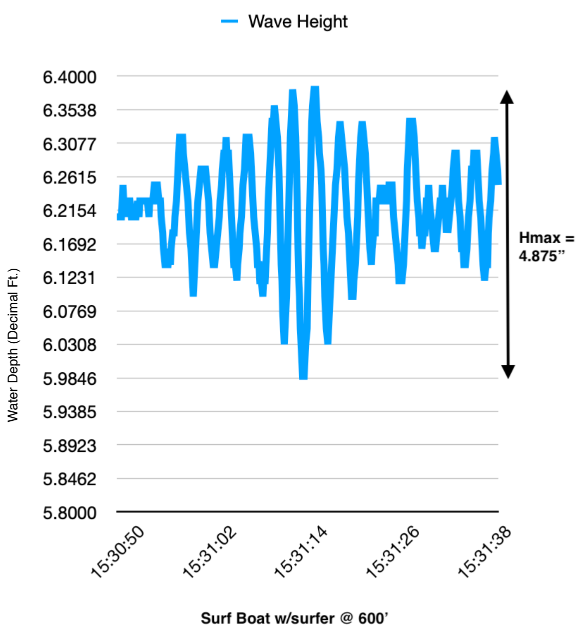


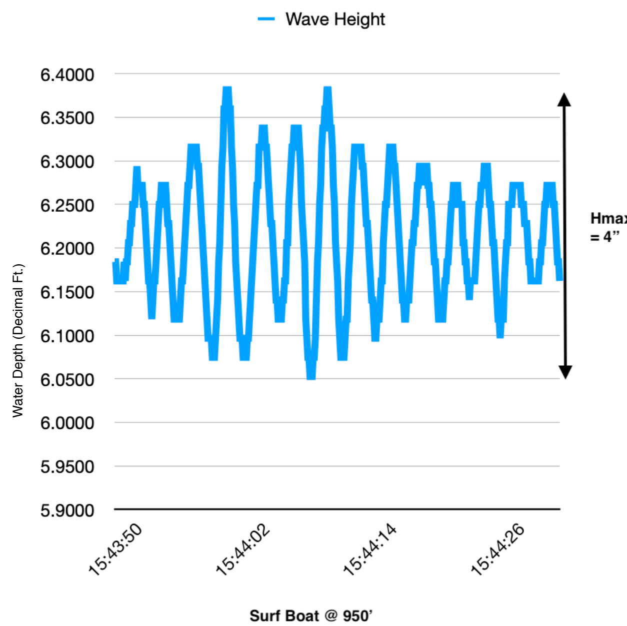



Graphs 3-8 Cont.



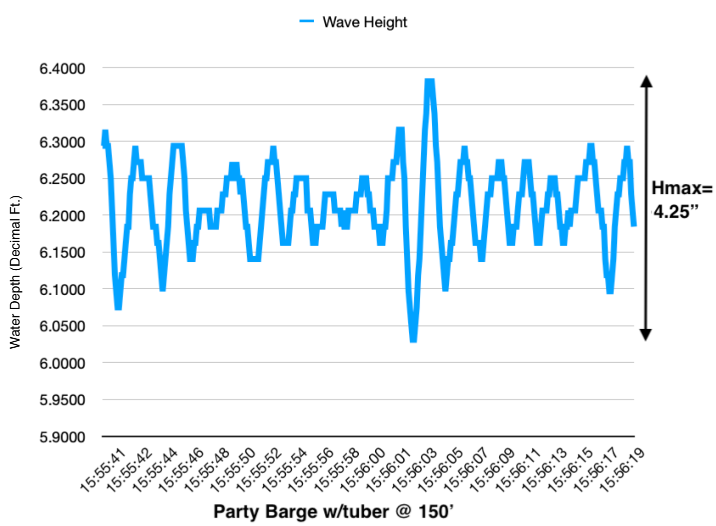



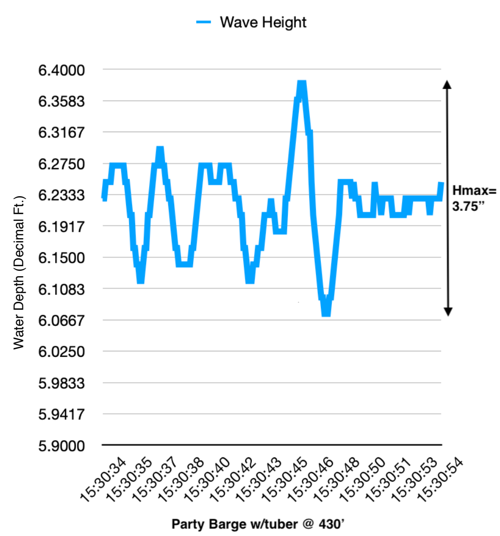




The results of this field sampling are consistent with data collected by C.A. Goudey & Associates in 2015 (Goudey, 2015), which measured waves from wake boats at heights of 7.5 inches 300 feet from the source of propagation. The results are also consistent with results from University of Quebec studies which showed waves created by wake boats could propagate 1000 feet or further (Mercier-Blais & Prairie, 2014). Wave height data was also collected during the sampling period on July 3rd for other boat types, which in comparison shows wake boats create the longest and largest wave trains of any boats observed.

Graphs 9 and 10 below show the wave profiles from two party barges (pontoon boats with outboard motors) that passed during the July 3rd sampling period. Both boats were running at sufficient speed to tow a tuber and they were operating 150 feet from shore and 430 feet from shore respectively. As shown in the graphs, the peak wave period for waves produced by party barges (a) is shorter than the peak wave period produced by wake boats (b) is defined by one large wave, rather than two to six large waves as typically produced by wake boats; and (c) rapidly decreases in height and in duration when compared to waves produced by wake boats.

Graphs 9-10 - Party barge wave profiles



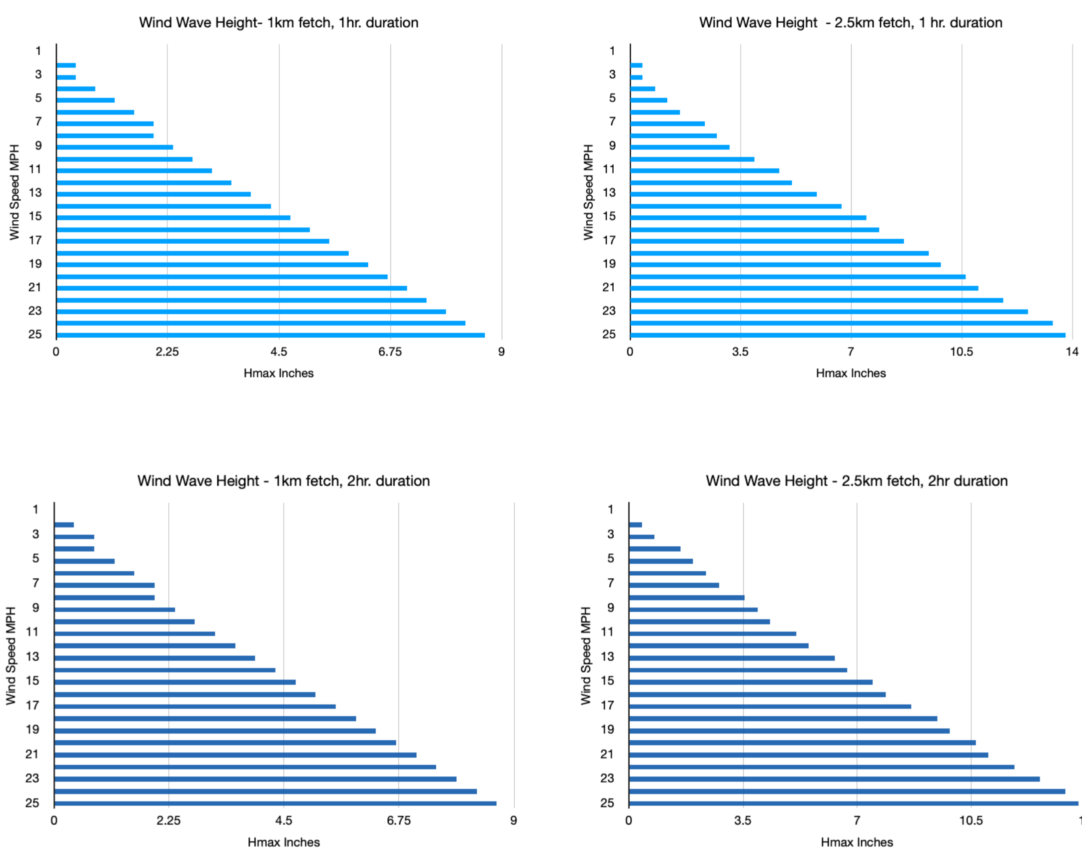




## Wind Wave Study Results and Discussion

The size of wind waves is determined by three factors; wind speed, wind duration, and fetch. The last factor, fetch, is the length of open water the wind is blowing across. Payette Lake contains only relatively small areas of open water, so the lake is considered fetch limited. In other words, the relatively short spans of open water limit the size of wind waves that can be formed for a given wind speed, regardless of the duration of the wind.

Wind wave analysis during ice free months on Payette Lake revealed long periods of relatively calm wind across the lake punctuated by (storm) events with average wind speed in the 10-15 mph range, and gusts in the 15-25 mph range.The graph in Appendix F (p. 42) shows a small selection of wind and gust speeds recorded during Fall, 2019, and the graphs below display the maximum wave heights for winds based on various fetch, wind speed, and wind duration parameters. The specific parameters to produce these graphs were selected based on wind and fetch conditions observed on Payette Lake.

Graphs 11-14— Wind Wave Maximum Height ($H_{max}$) Reference



According to (a) wind data collected on Payette Lake, (b) direct measurements of wind waves, and (c) the laws governing wind wave formation, typical wind regimes on Payette Lake produce waves with average heights of 2-4 inches. Storm events can produce waves up to 8 inches high, and wind conditions may occur at times that can produce waves up to 12 inches high. However, while the height of these waves may be similar to those produced by wake boats, the wave length of even the largest wind waves is far less than that of the waves produced by motorized boats.

Modeling shows 4 inch high wind waves on Payette Lake have a maximum wavelength of approximately 6 feet. Eight inch high waves have a maximum wavelength of approximately 10 feet. Conversely, the wavelength of waves produced by wake boats can be 15 feet to 25 feet. These factors become significant when the relative energy and depth influence of waves is considered.

## General Discussion

While wave theory is well established, and much can be learned from the size, shape, and speed of a wave, I did not attempt to calculate wave energies produced by wind waves or boat wakes for this study. Because of the physical properties of boat induced waves such as their considerably longer wave length, boat induced waves carry far more energy than the typical wind waves on Payette Lake, thus, boat indued waves are more likely to mobilize bed sediments. Furthermore, while some of the differences in wave heights recorded during the study may seem inconsequential, wave energy grows exponentially with a linear increase in wave height; A wave of 8 inches contains four times the energy of a 4 inch wave, and sixteen times the energy of a 2 inch wave (U of H, 2020). Energy also increases as wavelength increases, indicating boat induced waves carry far more energy than wind waves on Payette Lake.

To illustrate these dynamics of waves, the first diagram below (fig. 2) shows general properties of waves, while the following diagram (fig. 3) shows the general motion and potential bed effects from waves.

Figure 2 - Wave Properties (retrieved from https://www.open.edu/openlearn/ocw/mod/oucontent/view.php?id=73764&section=2)

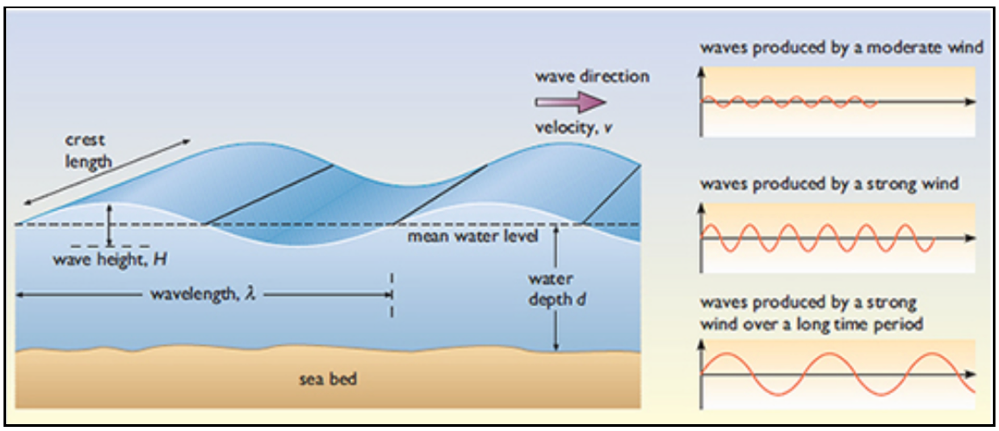
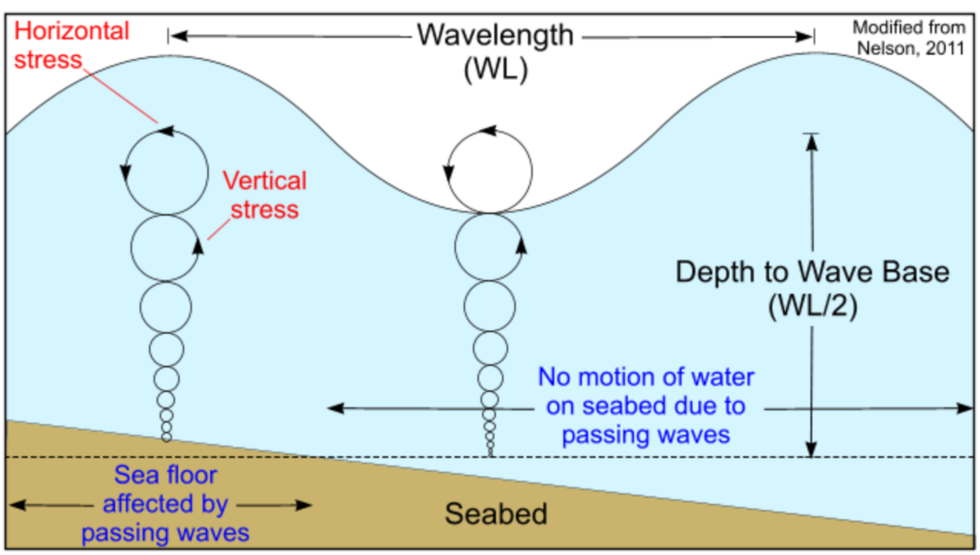



Figure 3 - Wave Dynamics (retrieved from http://www.seafriends.org.nz/oceano/waves.htm)



A far more in depth study would be necessary to determine the exact amount of wave energy reaching the shores of Payette Lake from wind waves and waves propagated by motorized watercraft. However, given what is known about the lake, the shoreline bathymetry, and nutrient loading in lakebed sediments, the results of this study indicate the threats posed by motorized recreation on Payette Lake are not negligible. Furthermore, because McCall's drinking water is sourced from the lake, special attention should be paid to the threats.

Given the results of my research and the physical dynamics of the waves seen on Payette Lake, three important and case specific details are evident regarding motorized recreation and the use of wake boats on the lake:

1. The 300 foot no-wake zone boundary likely does not provide sufficient protection against accelerated shoreline erosion due to the large waves propagated by motorized watercraft, and specifically wake boats.
2. Lakebed sediments at water depths up to 12 feet are likely to be disturbed by boat propagated waves, while wind waves are likely only to regularly disturb sediments at water depths up to 5 feet.
3. Slip-streams from wake boats may disturb lakebed sediments at water depths of up to 33 feet.

As previously discussed, the disturbance of lakebed sediments is of special concern in Payette Lake as it could potentially cause cyanobacteria or other algal blooms. While the concentrations of nutrients in shoreline and near-shore lakebed sediments are unknown, and may be negligible due to continual disturbance, updated information should be gathered regarding potential changes in nutrient loading in lakebed sediments since the last sampling 25 years ago.

**<u>Management Implications and Recommendations</u>**

Given the findings presented in the preceding text, two especially important and case specific conclusions regarding motorized recreation on Payette Lake are evident:

- **The turbulence imparted by a wake boat slip-stream is sufficient to disturb sediments commonly found in Payette Lake, at water depths regularly encountered at or beyond the 300 foot no-wake zone boundary.**
- **Due to the large waves propagated by motorized watercraft, and specifically wake boats, the 300 foot no-wake zone boundary likely does not provide sufficient protection against accelerated shoreline erosion and near-shore lakebed sediment disturbance.**

Based on these conclusions, and to protect water quality from the threats posed by motorized recreation on Payette Lake, **<u>I recommend extending the no-wake zone on Payette Lake to 500 feet.</u>**

Although opponents of extending the no-wake zone contend that substantial portions of of the lake would become off-limits to boats, GIS data revealed that moving the no-wake zone to 500 feet would only decrease usable area in the Southwest basin of the lake by less than 200 acres, or approximately 7%. There is little evidence suggesting use is approaching the carrying capacity of Payette Lake, therefore this decrease in usable area is likely to have negligible effect on motorized recreation. Furthermore, expanding the no-wake zone would open up a larger corridor for higher density, non-motorized use, thus increasing the overall recreation potential of the lake.

It is also worth noting that during the sampling period on July 3, 25% of boats observed creating a wake were operating within the 300 foot no-wake zone boundary. Sampling on July 15 revealed 20% of boats creating a wake were operating within the no-wake zone. This further exemplifies the need to expand the no-wake zone, as it could help provide a larger buffer to deter users from operating too close to shore.

**Additional Research Needs**

This research was conducted to determine specific threats to water quality on Payette Lake posed by motorized recreation. Other potential threats from motorized recreation on the lake include user displacement, user conflict, over-crowding, noise pollution, invasive species dispersal, and shoreline infrastructure damage. While over-crowding may not be especially relevant at this time, user displacement has occurred on the lake, and anecdotal evidence suggests shoreline erosion and infrastructure damage is occurring. The water ballast used in wake boats also raises concerns about invasive species dispersal. Given these additional threats, I recommend the following areas of further research to fully inform a comprehensive lake management plan:

- **Updated information on nutrient concentrations in lakebed sediments.**
- **High resolution recreational boating information, such as user day surveys, visitor use surveys, and carrying capacity research.**
- **Information concerning the economic effects of shoreline erosion and shoreline infrastructure damage.**
- **Strategies to reduce the risk of invasive species dispersal.**

**Conclusion**

As resource utilization changes over time, and our toys become more and more powerful, management schemes must also adapt. This data-driven approach to analyzing the effects of motorized boat use was designed to bring an objective look at recreation management on Payette Lake and to inform decision makers with the most relevant and up-to-date data. Although this research informs perhaps the most important aspect of resource management on Payette Lake, protecting water quality, I urge the City of McCall and Valley County to address the other gaps in information concerning recreation and resource protection on the lake. With use of the lake destined to grow in the future, I also urge decision makers to act before the threats are realized. This includes promptly extending the no-wake zone to 500 feet.

**Acknowledgements**

I would like to thank my community sponsor, the Big Payette Lake Water Quality Council for supporting my research, the Haley Fund at Western Colorado, the Staff at Western Colorado, the Fereday Family, Brady Akinson and Taylor Donner, Dr. Scott Harris, my parents and my partner Evonne, and last but not least, Dr. John and my advisor Sally Thode for welcoming me with open arms in to the Master in Environmental Management program at Western Colorado University. Thank you all for all your support!

## Appendix A - Model Formulas (Beachler & Hill, 2003; Aziz et al., 2008)

**1. Slip-stream Velocity**

$$V_s = \omega P - V_b$$

$V_s$ = Slip-stream Velocity
w = Propeller Angular Velocity (rps)
P = Pitch of Propeller (m)
$V_b$ = Boat Speed (m/sec)

**2. Slip-stream Velocity Decay**

$$u(x, r) = 7 \frac{M_0^{1/2}}{x} \exp\left[-\left(\frac{r}{0.107x}\right)^2\right]$$

x = streamwise coordinate
r= radial distance from jet axis
$M_o = \pi(V_s{}^2)(D^2)/4$
$V_s$ = Slip-stream Velocity (m/s)
D = Prop Diameter (m)

**3. Slip-stream Velocity Decay**

$$\frac{u_m}{u_o} = \frac{A_4}{x/d + \alpha_2}$$

$u_m$ = Slip-stream Velocity at point *x* (m/s)
$u_o$ = Initial Slip-stream Velocity (m/s)
$A_4$ = 6.3 (constant)
x = streamwise coordinate
d = diameter of jet (m)
$a_2$ = correction for virtual origin

**4. $U_{max}{}^{1/2}$ Velocity Decay**

$$b/d = A_2\left(x + \bar{x}\right)/d$$

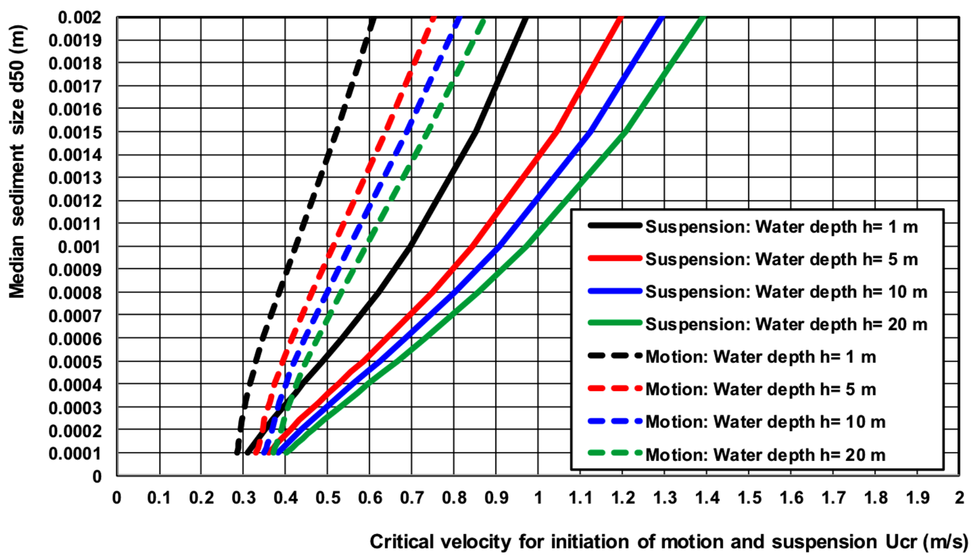
b = distance to $.5U_{max}$ from centerline
d = diameter of jet (m)
$A_2$ = .097 (constant)
x = streamwise coordinate
$\bar{x}$ = distance to virtual origin (m)

**5. Radial Velocity Decay Profile**

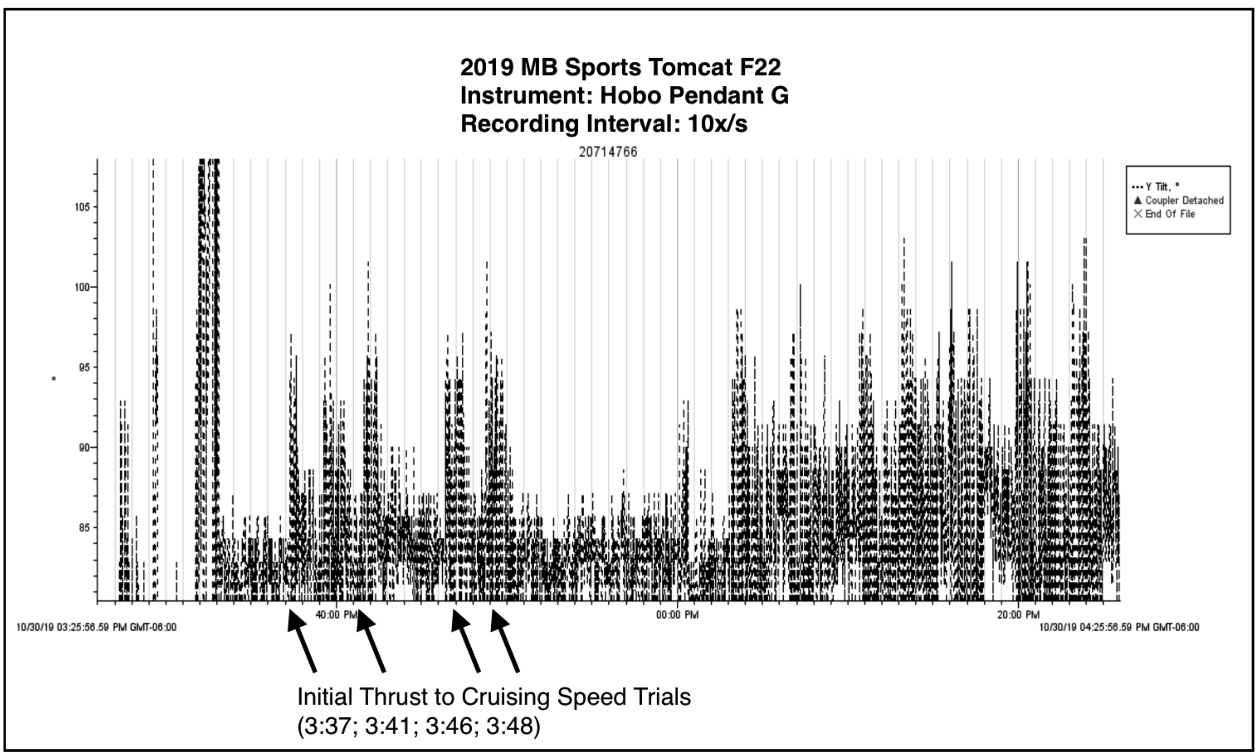
$$\frac{u}{u_m} = \exp\left(-0.693\lambda^2\right)$$

$u_m$ = Slip-stream Velocity at point *x* (m/s)
u = Initial Slip-stream Velocity (m/s)
λ = r/b
r = radial coordinate
b = distance to $U_{max}{}^{1/2}$ from x-axis (m)

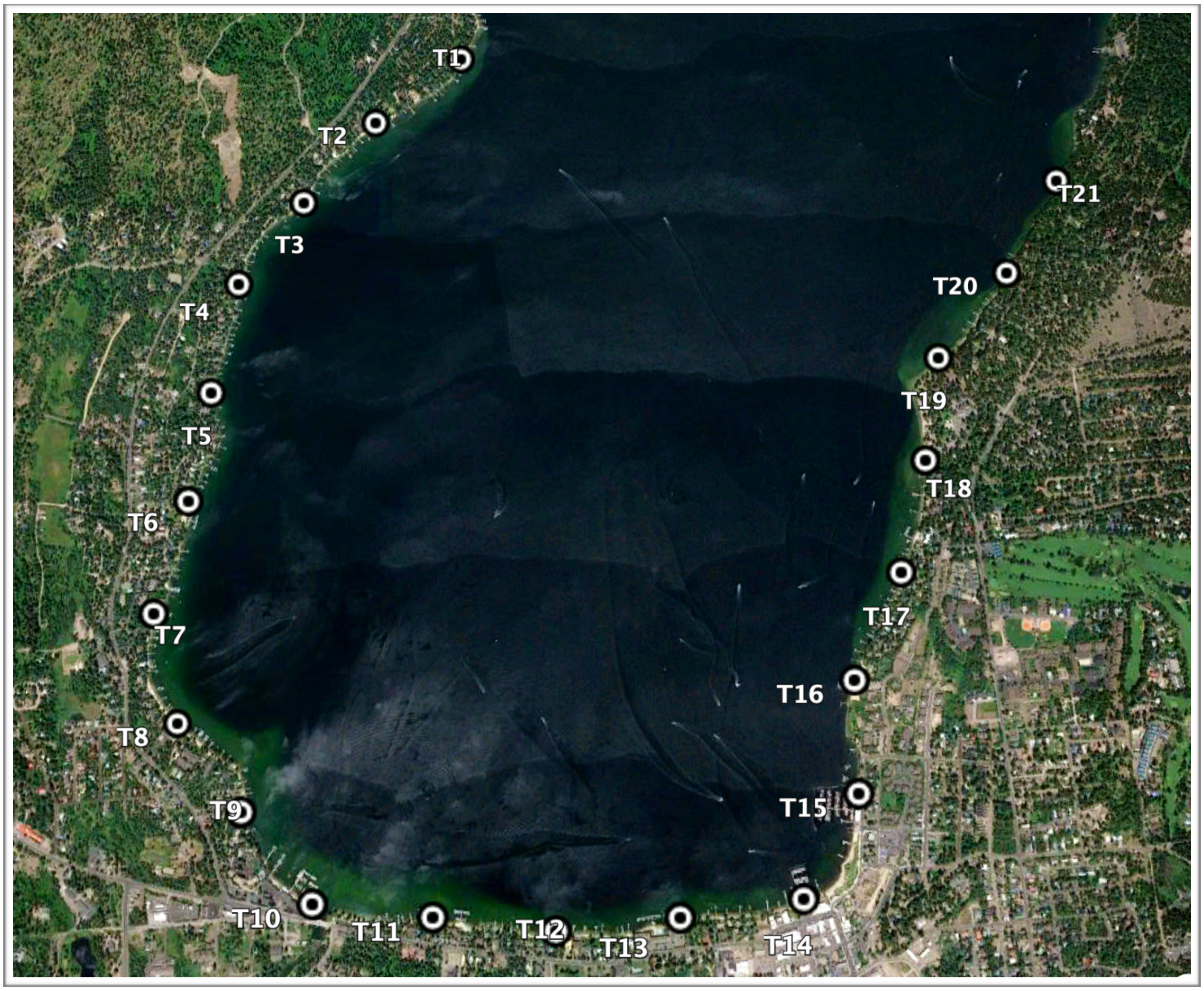
## Appendix B - Sediment Shear Forces (Van Rijn, 2020)




## Appendix C - Boat Trim Angle During Standard Operation

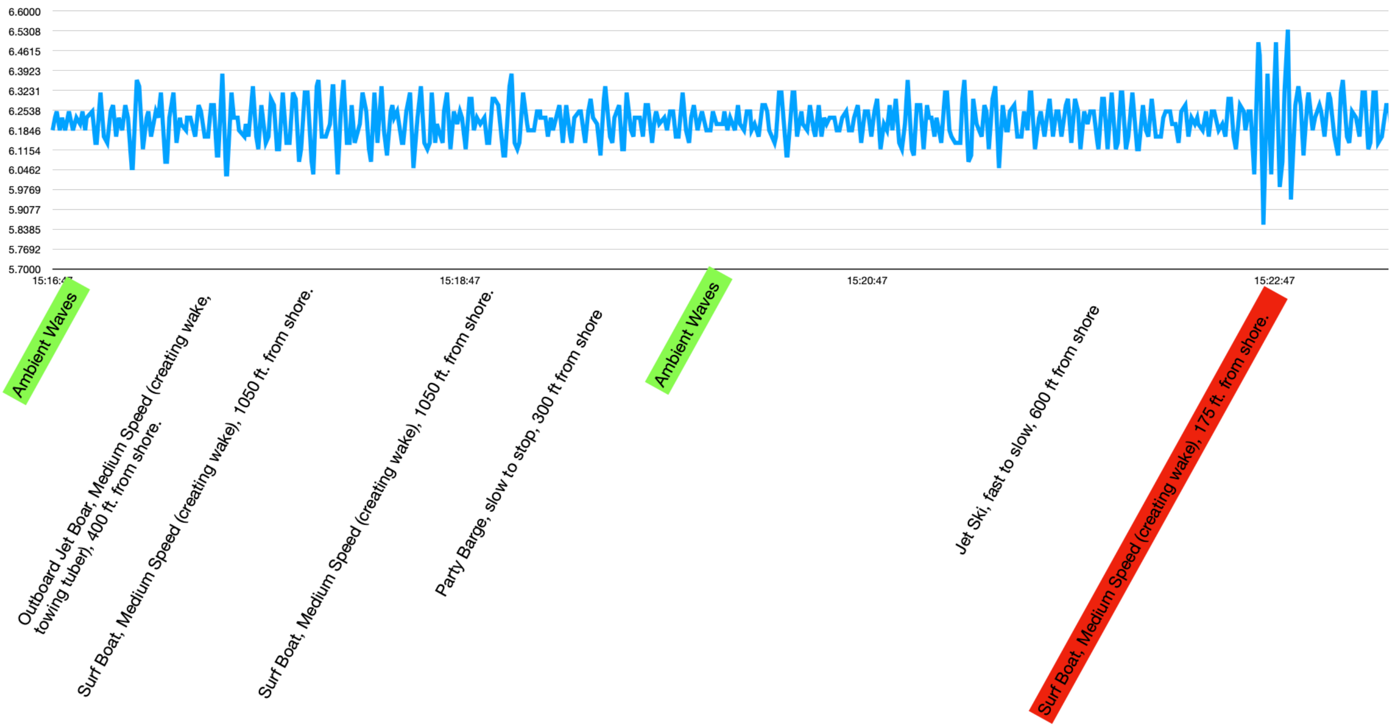


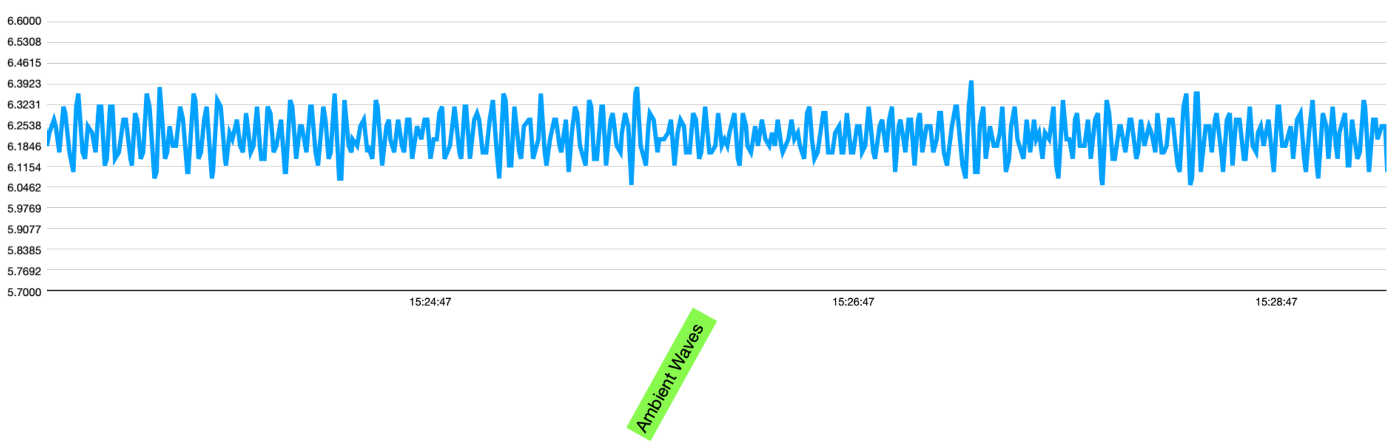
Appendix D - Transect Map

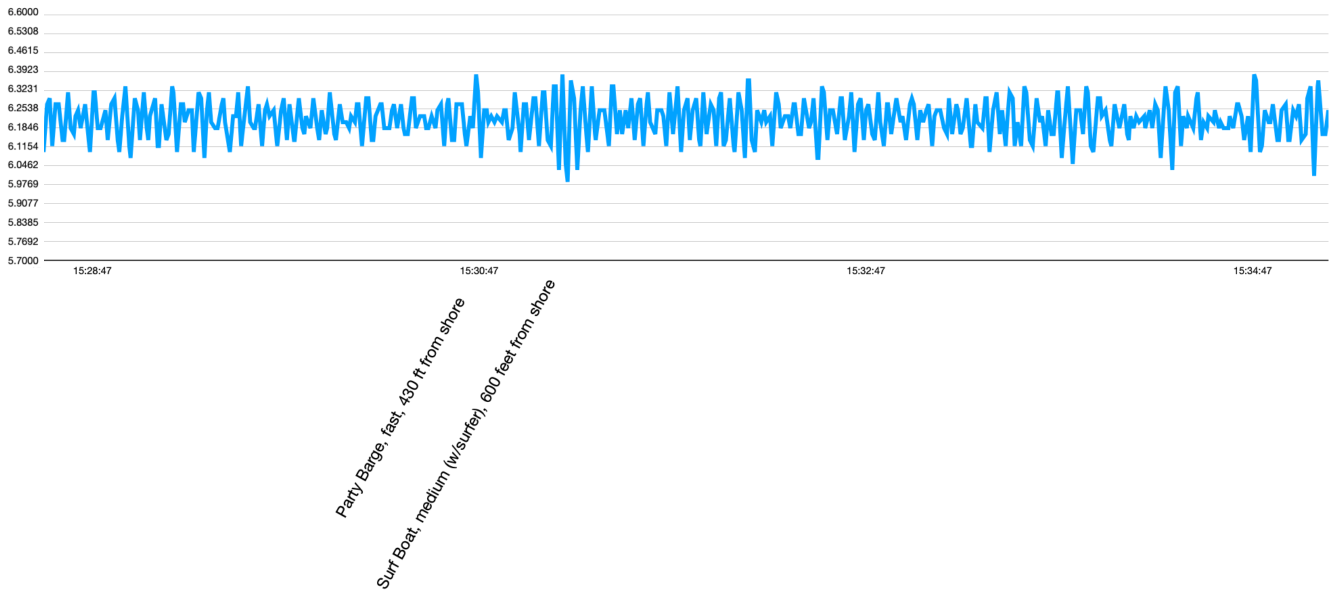


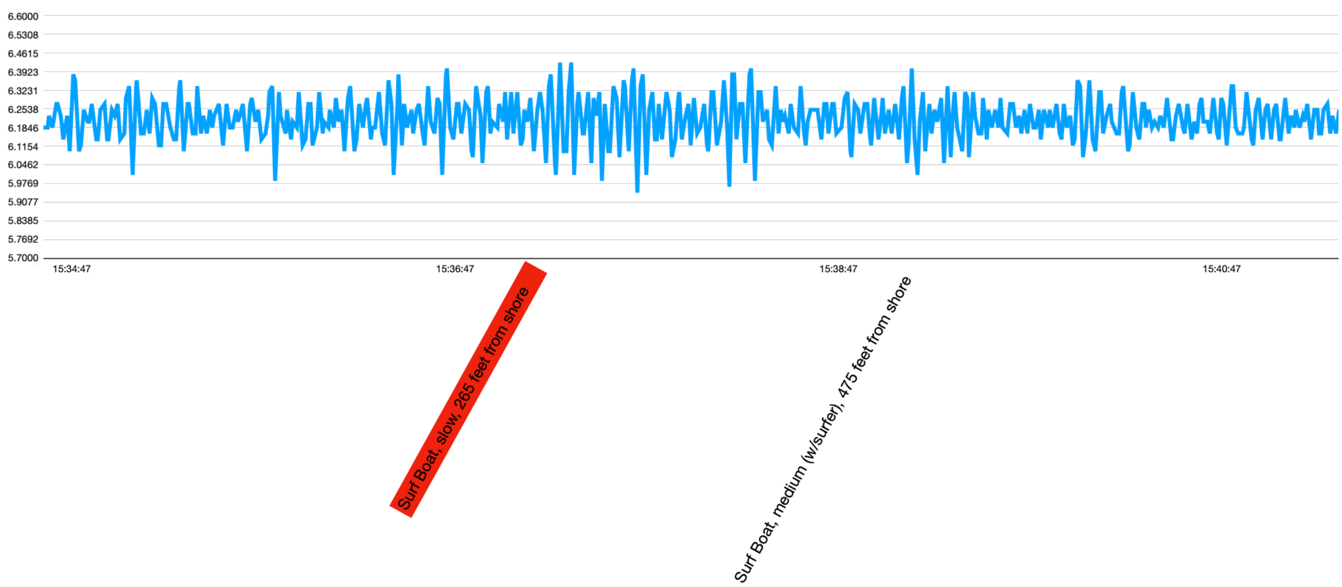
<u>Appendix E - Surface Wave Monitoring Results</u>

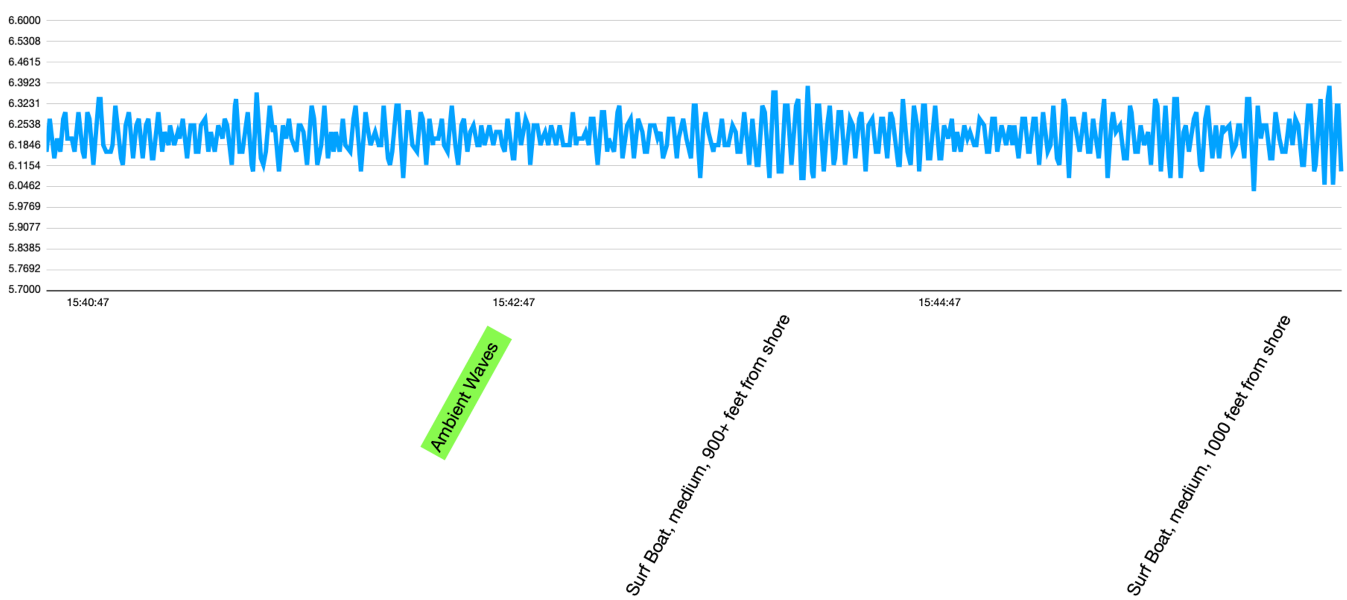
**July 3 Wave Monitoring**
**N 44.9806° W -116.0600° (Cliffs Area)**
**3:16:47 pm to 4:01:00 pm**

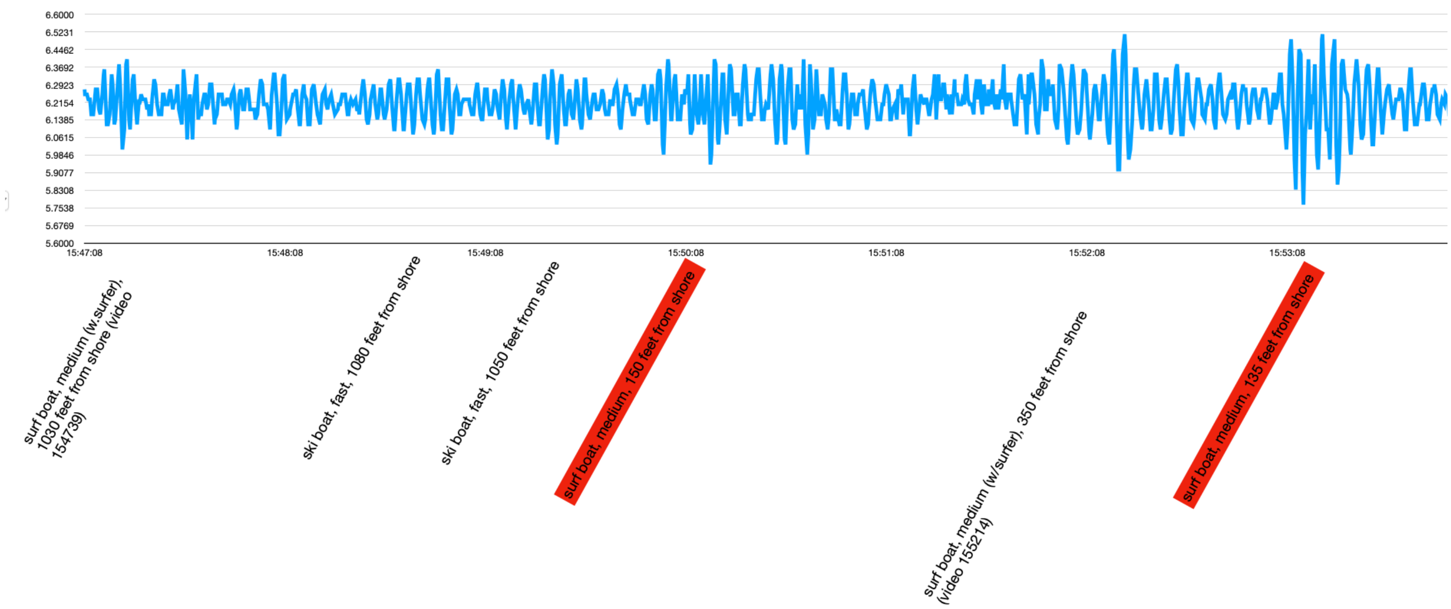



6.6000
6.5308
6.4615
6.3923
6.3231
6.2538
6.1846
6.1154
6.0462
5.9769
5.9077
5.8385
5.7692
5.7000
15:28:47
15:30:47
15:32:47
15:34:47
Party Barge, fast, 430 ft from shore
Surf Boat, medium (w/surfer), 600 feet from shore


6.6000
6.5308
6.4615
6.3923
6.3231
6.2538
6.1846
6.1154
6.0462
5.9769
5.9077
5.8385
5.7692
5.7000
15:34:47
15:36:47
15:38:47
15:40:47
Surf Boat, slow, 265 feet from shore
Surf Boat, medium (w/surfer), 475 feet from shore


6.6000
6.5308
6.4615
6.3923
6.3231
6.2538
6.1846
6.1154
6.0462
5.9769
5.9077
5.8385
5.7692
5.7000
15:40:47
15:42:47
15:44:47
Ambient Waves
Surf Boat, medium, 900+ feet from shore
Surf Boat, medium, 1000 feet from shore


6.6000
6.5231
6.4462
6.3692
6.2923
6.2154
6.1385
6.0615
5.9846
5.9077
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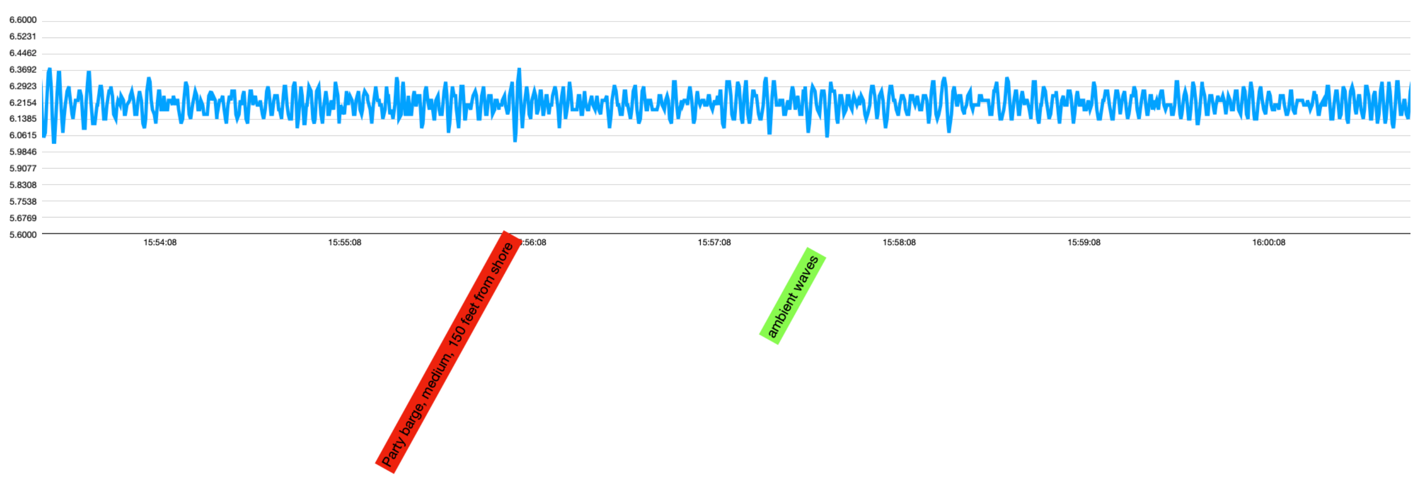
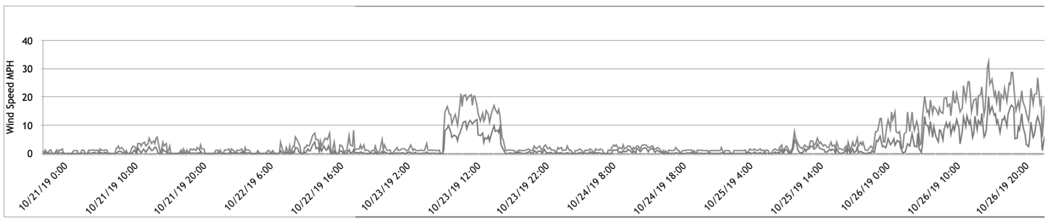
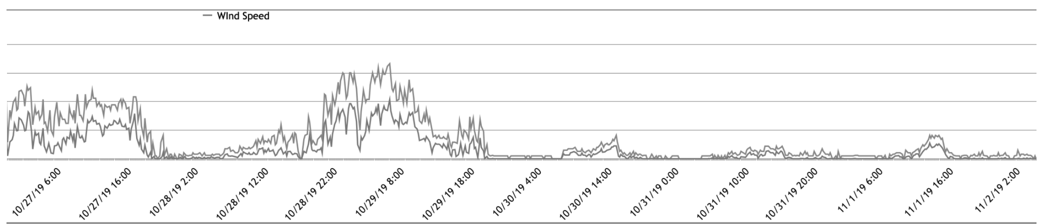
5.7538
5.6769
5.6000
15:47:08
15:48:08
15:49:08
15:50:08
15:51:08
15:52:08
15:53:08
surf boat, medium (w.surfer), 1030 feet from shore (video 154739)
ski boat, fast, 1080 feet from shore
ski boat, fast, 1050 feet from shore
surf boat, medium, 150 feet from shore
surf boat, medium (w/surfer), 350 feet from shore (video 155214)
surf boat, medium, 135 feet from shore

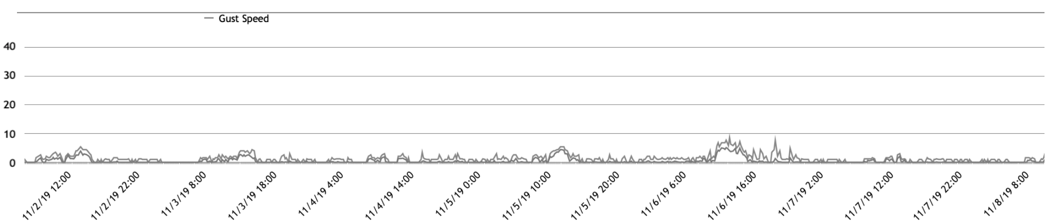

6.6000
6.5231
6.4462
6.3692
6.2923
6.2154
6.1385
6.0615
5.9846
5.9077
5.8308
5.7538
5.6769
5.6000
15:54:08
15:55:08
15:57:08
15:58:08
15:59:08
16:00:08
Party barge, medium, 150 feet from shore
ambient waves

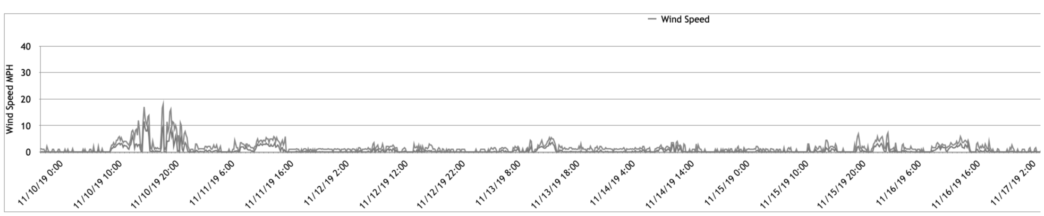
<u>Appendix F - Wind Records 10-21-19 to 11-23-19</u>

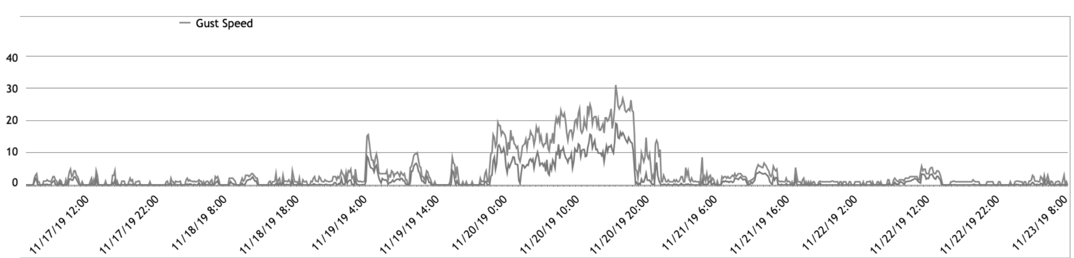
**Rainwise WindLog 6x/hr int.**
**N 44.925741°, W -116.092265° (Ponderosa State Park Visitor Center)**
**W Fetch: 2.25km, SW Fetch: 2.5km, NW Fetch: 2km**



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*"Water is the most critical resource issue of our lifetime and our children's lifetime. The health of our waters is the principal measure of how we live on the land." – Luna Leopold*