Considerations in assessing shoreline and near shore impacts of wind-driven waves vs motorboat waves in Vermont

Responsible Wakes for Vermont Lakes – David Johnson - July 9, 2022. (Note: Most of the information in this document was assembled after the Petition was submitted.)

Introduction

The latest Water Sports Industry Association (WSIA) sponsored study[1] concludes that wake surfing wakes at 200 feet distance are no worse than those from sustained 20 mph winds with a half mile fetch:

> "Based on both the field data and CFD data, the key to reducing the impact of wake surfing is to operate the boat far enough offshore to allow the wake near the boat to dissipate into its component parts where the individual wave heights of the group are reduced to a height less than 28 cm (11 inches). The field test data[2] found 200 feet to be adequate to reduce the wave heights to under 28 cm (11 inches). **In comparison to wind generated waves, the wave height of 28 cm is common in a modest wind event on lakes with a fetch of a half mile (0.8 km) at a wind speed of 20 mph** (9.0 m/s). The full wave spectrum would be fully developed in less than 20 minutes and the average wave period would be 1.5 seconds." (3rd ¶ of Conclusions Section of ref. 1)

In this document, we evaluate the relevance of this conclusion to concerns regarding wave-induced shoreline erosion and near-shore bottom disturbance for inland Vermont Lakes. This evaluation relies exclusively on publicly available, archived wind speed and wind directional data from Automated Surface Observing System (ASOS) participating Vermont airports to illustrate that sustained 20 mph wind events are neither "common" nor "modest" in Vermont inland lakes. This document also argues for a more relevant basis for the comparison of the shoreline and near-shore impacts wind and ballasted wake boat generated waves.

Accessing wind data from Vermont Airports

Vermont Airport wind direction and wind speed data from ASOS participating airports may be accessed through the following steps:

1. Click on https://mesonet.agron.iastate.edu/sites/locate.php?network=VT_ASOS
2. Click on the airport location on the map and then on "Select Station".
3. Select "Custom Wind Roses".
4. Fill in Start/End Time fields. The data shown below and in the Appendix excluded December – April when lakes are likely ice covered.

5. Click on “Submit” and wait for wind rose to appear.
6. The data used to generate the wind rose is available by clicking “View Raw Data for Chart”

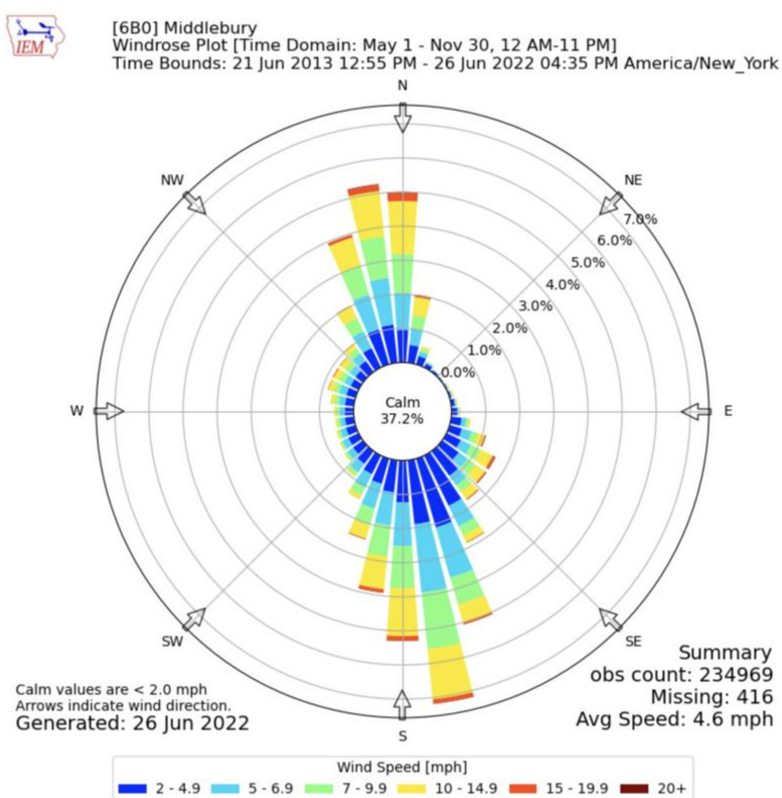
The full archived dataset for an airport can be accessed through the following steps:

1. Click on https://mesonet.agron.iastate.edu/sites/locate.php?network=VT_ASOS
2. Click on the airport location on the map and then on “Select Station”.
3. Select “Download”
4. Select station again and click “Add Selected”
5. Select “All available data” in field 2 and the other fields in 1-6
6. Select “Get Data” in field 7
7. This data can be loaded into Excel to sort, filter and display
8. Note that the wind speed in this download is in knots, and 1 knot = 1.15 mph

This procedure was used to download data for the example in the next section to determine the frequency of sustained winds over 20 mph.

Example – Data from Middlebury Airport 4 miles from Lake Dunmore.

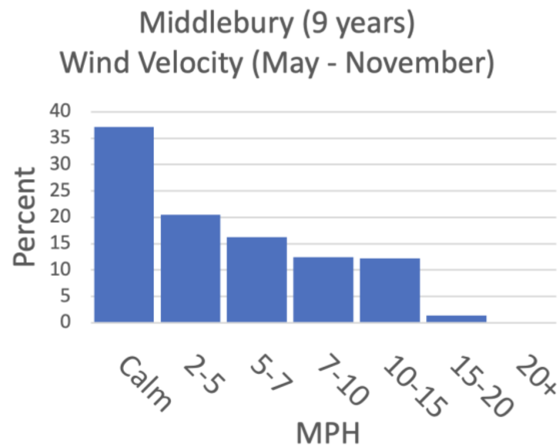
Using the procedures outlined above, the May 1 to Nov 30, i.e., Spring/Summer/Fall when lakes are ice-free, windrose for the Middlebury airport is displayed below.



Data used to generate the Middlebury Airport windrose is shown here in tabular form:

Direction	Calm	2.0-4.9	5.0-6.9	7.0-9.9	10.0-14.9	15.0-19.9	20.0+
355-004	37.170	0.953	1.143	1.088	1.552	0.237	0.037
005-014		0.524	0.474	0.399	0.542	0.065	0.008
015-024		0.257	0.128	0.090	0.064	0.003	0.001
025-034		0.122	0.047	0.012	0.008	0.000	0.000
035-044		0.065	0.012	0.003	0.002	0.000	0.000
045-054		0.038	0.012	0.005	0.002	0.000	0.000
055-064		0.038	0.016	0.011	0.019	0.005	0.001
065-074		0.055	0.024	0.013	0.027	0.003	0.000
075-084		0.107	0.032	0.024	0.021	0.003	0.000
085-094		0.162	0.049	0.015	0.023	0.003	0.001
095-104		0.307	0.135	0.066	0.049	0.004	0.000
105-114		0.376	0.289	0.194	0.204	0.037	0.011
115-124		0.468	0.326	0.327	0.388	0.071	0.018
125-134		0.599	0.319	0.301	0.338	0.042	0.009
135-144		0.900	0.346	0.233	0.258	0.032	0.005
145-154		1.646	0.664	0.302	0.216	0.021	0.003
155-164		2.102	1.531	0.821	0.553	0.053	0.006
165-174		1.889	2.015	1.663	1.486	0.122	0.014
175-184		1.233	1.279	1.234	1.408	0.130	0.012
185-194		0.947	0.975	0.921	0.962	0.098	0.009
195-204		0.774	0.752	0.507	0.408	0.026	0.003
205-214		0.609	0.442	0.255	0.116	0.005	0.000
215-224		0.466	0.300	0.132	0.038	0.001	0.000
225-234		0.361	0.209	0.078	0.029	0.000	0.000
235-244		0.334	0.194	0.070	0.028	0.000	0.000
245-254		0.291	0.171	0.081	0.041	0.001	0.000
255-264		0.264	0.145	0.084	0.054	0.000	0.000
265-274		0.257	0.152	0.101	0.057	0.001	0.000
275-284		0.259	0.183	0.136	0.090	0.006	0.000
285-294		0.279	0.219	0.167	0.162	0.017	0.000
295-304		0.263	0.202	0.168	0.185	0.029	0.001
305-314		0.276	0.211	0.159	0.179	0.020	0.000
315-324		0.394	0.270	0.179	0.162	0.013	0.000
325-334		0.634	0.550	0.435	0.379	0.025	0.001
335-344		1.067	1.059	0.886	0.859	0.078	0.009
345-354		1.123	1.372	1.233	1.336	0.188	0.018
	Calm	2-5	5-7	7-10	10-15	15-20	20+
Total %	37.170	20.439	16.247	12.393	12.245	1.339	0.167

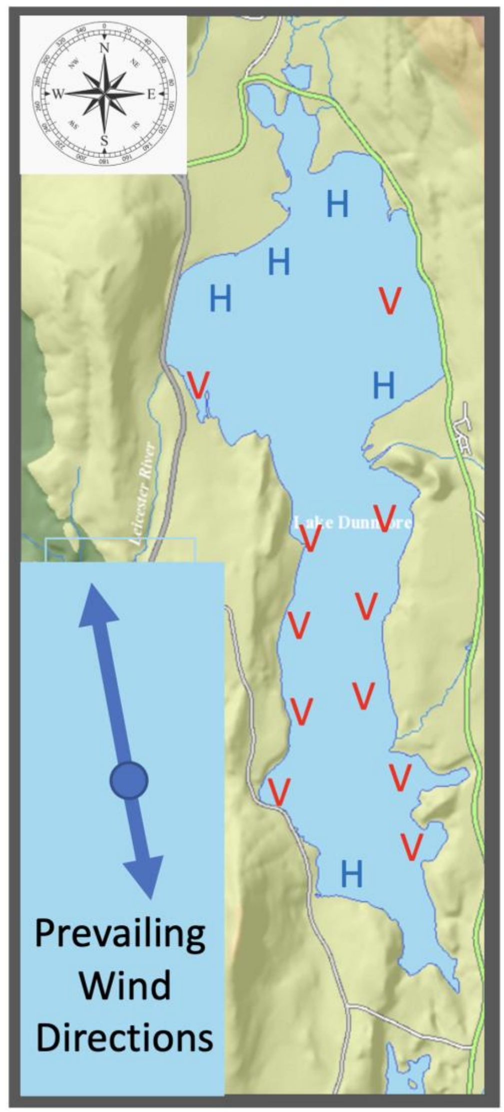
There are two important features to note about these data. First, the windrose indicates that the wind direction during these ice-free months is very directional, with south winds most common, and north winds slightly less common. Second, the probability of winds 20 mph and greater is very low, i.e., only 0.167% of the total time. As explained below, even this small percentage consists mainly of short-term wind gusts.



The bar graph at right shows the data taken from the last two lines of the table on the previous page.

By looking at the archived dataset, the frequency of sustained winds of 20 mph or greater can be determined. Two-minute averages are archived every 20 minutes. In this Middlebury Airport example, over the nine-year period of archived data and during the May – November months, consecutive readings of 20 mph or more occurred only 6 times, 5 times for 2 consecutive samples and once for 3 samples. This indicates that sustained winds of 20 mph and more occur only rarely and are short-lived at this airport. This is also likely to be the case at Lake Dunmore, 4 miles away.

The directionality of the prevailing winds in this example needs to be considered when assessing the shoreline impacts of wind-driven waves. The map of Lake Dunmore indicates shorelines hardened (H) by strong head-on winds from the south and the north, and a large fraction of the shorelines that do not experience direct strong wind exposure, and hence are vulnerable (V) to waves from motorboats. These vulnerable shorelines have been exposed to decades of waves from traditional watersports like waterskiing and tubing.



Appendix A shows ASOS data from all 11 participating Vermont airports. Winds 20 mph and greater are rare and that in many locations, winds are highly directional.

A Better Basis for Comparison and the Implications

Vermont airport wind data in the Appendix strongly indicates that shorelines are very rarely exposed to sustained winds of 20 mph and more. Thus, wake surfing wakes produced by a wake boat traveling parallel to the shoreline at 200 ft distance will be much larger than the typical wind waves hitting that shoreline. This is especially true for the vulnerable shorelines that almost never have significant wind wave exposure.

There have been many studies linking shoreline erosion to motorboat waves (see, for example references 3 and 4). Additional research showed wave height by itself was a poor indicator of erosion potential, and power and energy should also be considered[5]. The recent 2021 study[6] on an inland lake shoreline in Ontario found that the energy deposited by motorboat waves far exceeded that from wind waves.

To assert that wake surfing wakes are bigger than typical waves and therefore represent a significant risk for increased shoreline erosion, one needs to compare such waves to "typical" waves. A better basis for comparison is waves not from wind events that rarely occur in Vermont inland lakes, but rather from motorboats at the currently regulated distance of 200' engaged with traditional watersports, like waterskiing and tube towing.

A recent St. Anthony Falls Laboratory (SAFL) study[7] compares wave heights, total wave energy and peak wave power vs distance for two wake boats in wake surfing mode with two ski/tow boats in water skiing mode. As explained in the ANR petition, the data needed to compare wake surfing wakes to conventional ski wakes is available in the SAFL study along with "best-fit" formulations to facilitate this comparison. Table 4 below from page 17 our RWVL ANR petition summarizes the results by listing the equivalent distances that the wake surfing boats require for the listed parameters to be the same as for ski boats at 200 ft distance. The distance of 1000 ft was chosen for the new rule based on these data.

Table 4. For each of the two wake boats in SAFL Wave Study, the equivalent distance (in feet) for the parameters listed in the left-most column to reach the average value of the same parameter for the two boats at 200 ft. These values were computed using the formulas derived in the SAFL Wave Study.

Parameter	Malibu VLX Condition 1a (feet)	Malibu MXZ Condition 1a (feet)
Maximum Wave Height	981	756
Total Wave Train Energy	2137	1179
Peak Wave Train Power	1316	1013

Summary

The boating industry argues that wake surfing wakes are not a problem because at 200 ft from shore, the waves arrive at the shore with a wave height comparable to waves driven by sustained 20 mph winds. They assert these wind events are "modest" with the implication that they are common.

On the contrary, the Vermont airport data indicate that such wind events are extremely rare. Even when strong winds do occur, because of the high directionality of such winds in Vermont, there will be significant fractions of the shoreline that do not face head-on strong winds and are thus vulnerable to boat waves. Thus, for most Vermont inland lake shorelines, wave-driven shoreline erosion and near-shore bottom disturbance will be dominated by motorboat waves.

It is therefore of high relevance to compare wake surfing wakes to those from traditional water skiing or tubing. Data from the recent SAFL study indicate that 1000 ft or greater distance from shore is needed for wake surfing wakes arriving at the shore to be equivalent to traditional water sports like waterskiing and tubing taking place at 200 ft distance.

It is worth noting that the authors of the 2015 WSIA sponsored study, in a recent presentation of their findings, conclude the following:

> "If a shoreline does not experience wind or if it is narrow in the prevailing wind direction, then it may not experience much energy from wind waves and might benefit from being designated a no-wake zone."

See Appendix B for the first and last slides of this presentation. This conclusion supports our concerns about vulnerable shorelines and that action is appropriate to protect these shorelines.

References

(Note: References 1, 4, 5, and 6 do not appear in the petition.)

[1] Fay, E., Gunderson, A. and Anderson, A. (2022) Numerical study of the impact of wakesurfing on inland bodies of water. Journal of Water Resource and Protection, 14, 238-272. DOI: 10.4236/jwarp.2022.143012.

[2]Goudey, C.A. & Associates. (2015). Characterization of wake-sport wakes and their potential impact on shorelines. Report commissioned for the Wave Sports Industry Association. Retrieved from: https://www.wsia.net/wpcontent/uploads/2020/03/WSIA_draft_report_Rev_II.pdf

[3]Bilkovic, D., M. Mitchell, J. Davis, E. Andrews, A. King, P. Mason, J. Herman, N. Tahvildari, J. Davis. 2017. Review of boat wake wave impacts on shoreline erosion and potential solutions for

the Chesapeake Bay. STAC Publication Number 17-002, Edgewater, MD. 68 pp. Retrieved from: http://ccrm.vims.edu/2017_BoatWakeReviewReport.pdf

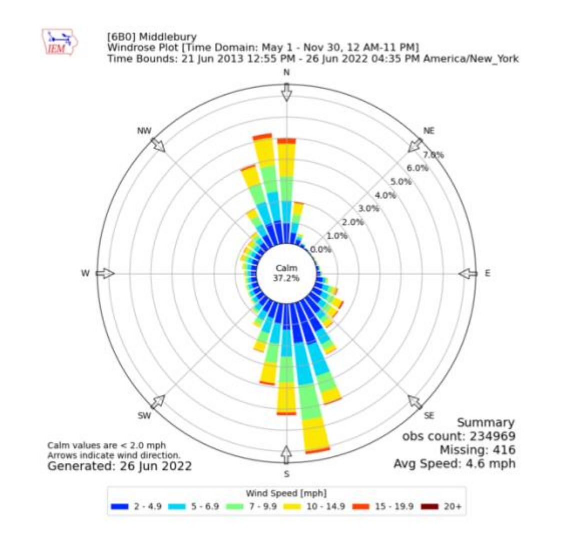
[4]Johnson, S. (1994). *Recreational boating impact investigations - Upper Mississippi River System, Pool 4, Red Wing, Minnesota.* Report by the Minnesota Department of Natural Resources, Lake City, Minnesota, for the National Biological Survey, Environmental Management Technical Center, Onalaska, Wisconsin, February 1994. EMTC 94-S004. Retrieved from https://www.umesc.usgs.gov/documents/reports/ 1994/94s004.pdf

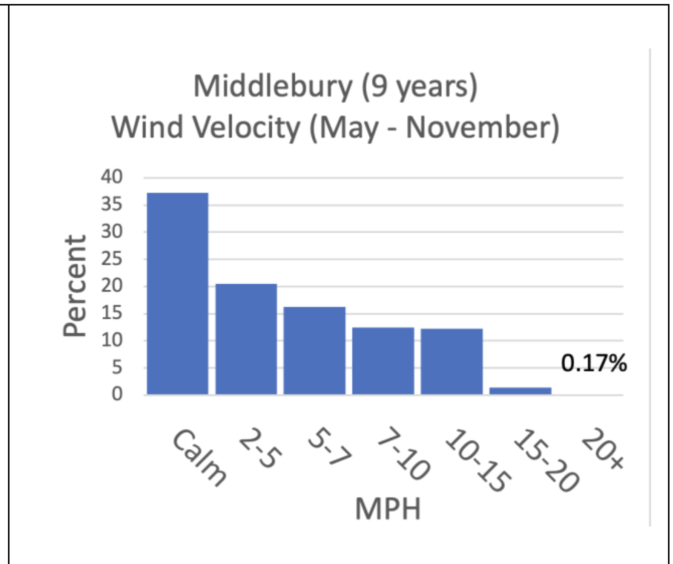
[5]Bradbury, J. (2005) Revised wave wake criteria for vessel operation on the Lower Gordon River. Report for the Tasmania Resource Mgmt. and Conservation Division, Dept. of Primary Industries, Water and Environment. Retrieved from https://dpipwe.tas.gov.au/Documents/Revised-Wave-Wake-Criteria-2005.pdf

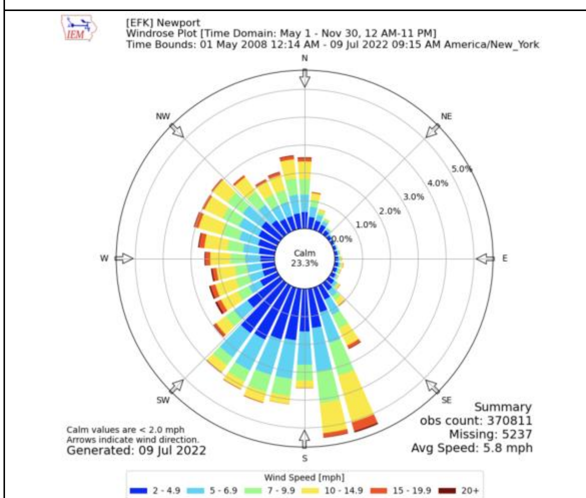
[6]Houser C, Smith A, Lilly J, Relative importance of recreational boat wakes on an inland lake, Lake and Reservoir Management, (2021). DOI: 10.1080/10402381.2021.1879325

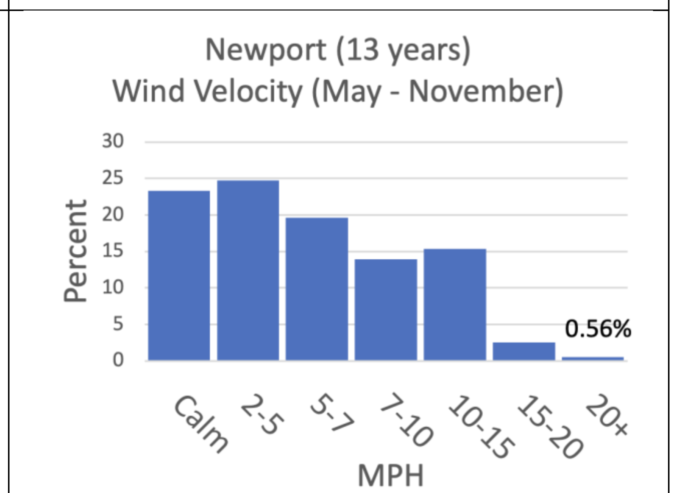
[7]Marr, J, A. Riesgraf, W. Herb, M. Lueker, J. Kozarek, K. Hill, A field study of maximum wave height, total wave energy, and maximum wave power produced by four recreational boats on a freshwater lake, St. Anthony Falls Laboratory, Univ. of Minnesota, (2022). https://hdl.handle.net/11299/226190

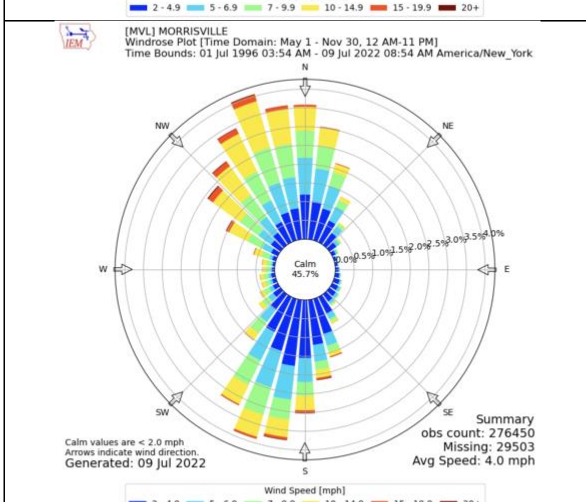
Appendix A – Wind rose and wind velocity data from Vermont ASOS **participating airports**

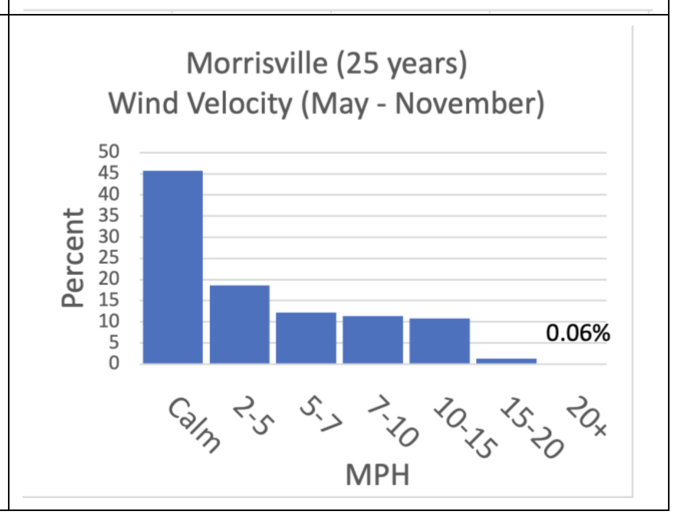


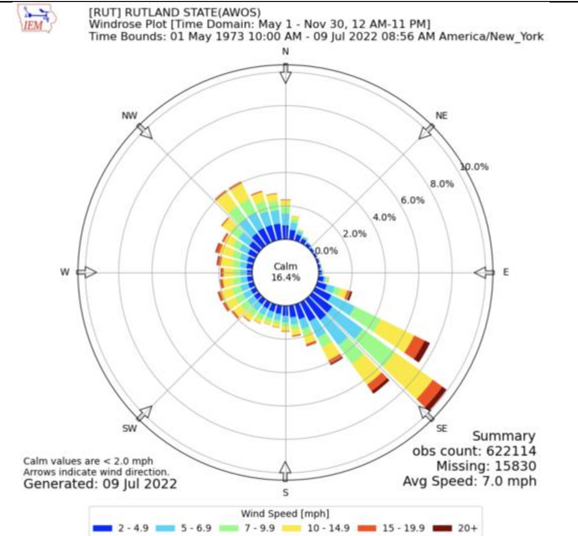


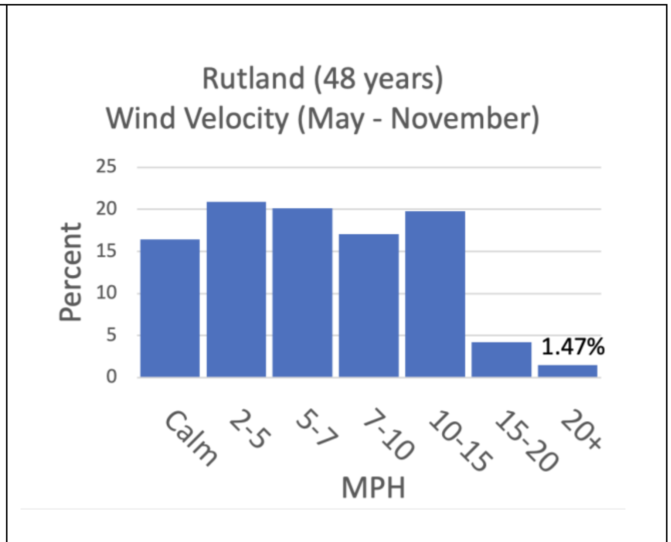


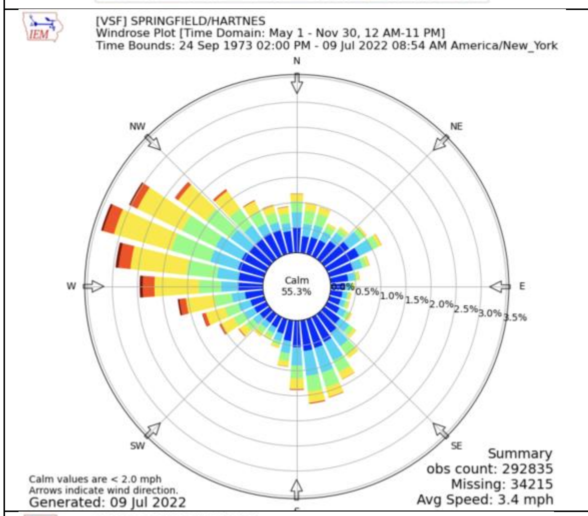


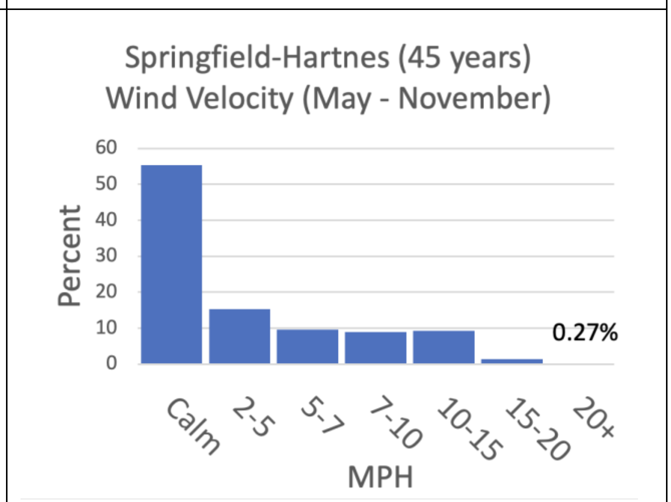


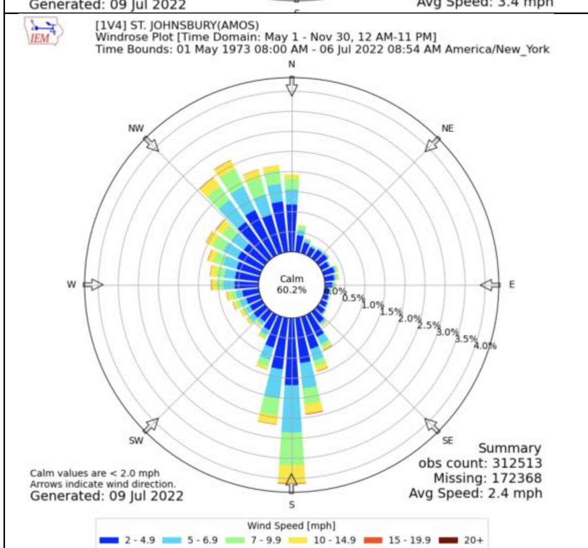


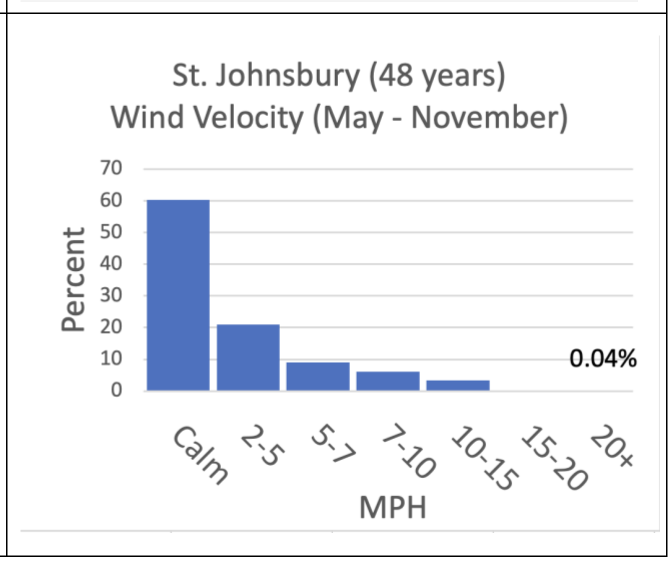

[RUT] RUTLAND STATE(AWOS)
Windrose Plot [Time Domain: May 1 - Nov 30, 12 AM-11 PM]
Time Bounds: 01 May 1973 10:00 AM - 09 Jul 2022 08:56 AM America/New_York
Calm
16.4%
Summary
obs count: 622114
Missing: 15830
Avg Speed: 7.0 mph
Calm values are < 2.0 mph
Arrows indicate wind direction.
Generated: 09 Jul 2022
Wind Speed [mph]
2 - 4.9
5 - 6.9
7 - 9.9
10 - 14.9
15 - 19.9
20+

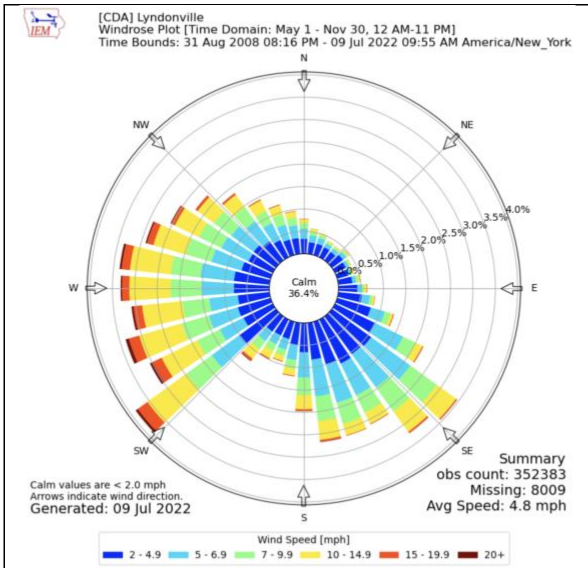

Rutland (48 years)
Wind Velocity (May - November)
Percent
1.47%
Calm
2-5
5-7
7-10
10-15
15-20
20+
MPH

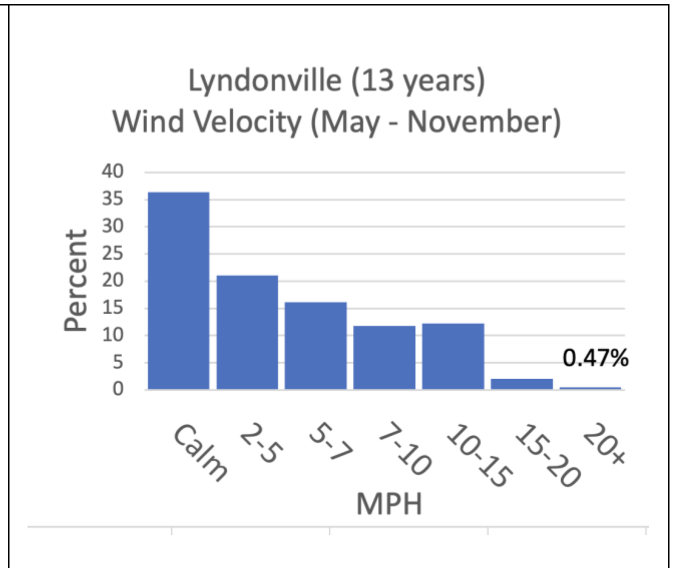

[VSF] SPRINGFIELD/HARTNES
Windrose Plot [Time Domain: May 1 - Nov 30, 12 AM-11 PM]
Time Bounds: 24 Sep 1973 02:00 PM - 09 Jul 2022 08:54 AM America/New_York
Calm
55.3%
Summary
obs count: 292835
Missing: 34215
Avg Speed: 3.4 mph
Calm values are < 2.0 mph
Arrows indicate wind direction.
Generated: 09 Jul 2022

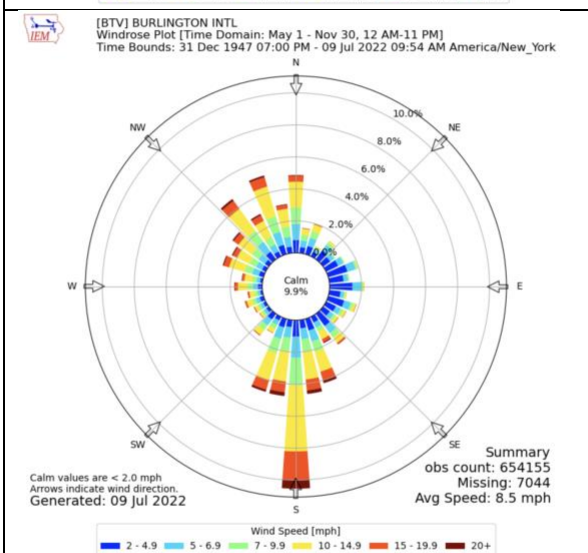

Springfield-Hartnes (45 years)
Wind Velocity (May - November)
Percent
0.27%
Calm
2-5
5-7
7-10
10-15
15-20
20+
MPH

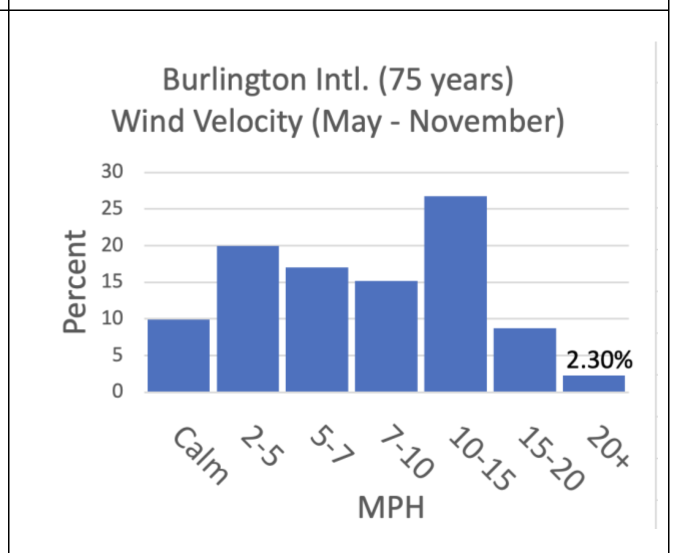

[1V4] ST. JOHNSBURY(AMOS)
Windrose Plot [Time Domain: May 1 - Nov 30, 12 AM-11 PM]
Time Bounds: 01 May 1973 08:00 AM - 06 Jul 2022 08:54 AM America/New_York
Calm
60.2%
Summary
obs count: 312513
Missing: 172368
Avg Speed: 2.4 mph
Calm values are < 2.0 mph
Arrows indicate wind direction.
Generated: 09 Jul 2022
Wind Speed [mph]
2 - 4.9
5 - 6.9
7 - 9.9
10 - 14.9
15 - 19.9
20+

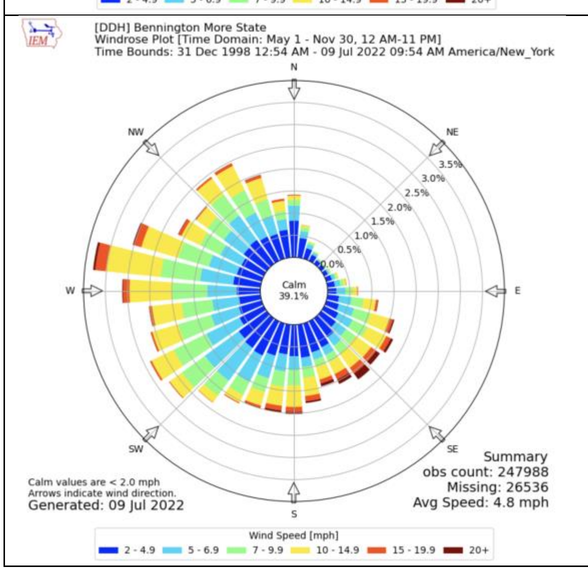

St. Johnsbury (48 years)
Wind Velocity (May - November)
Percent
0.04%
Calm
2-5
5-7
7-10
10-15
15-20
20+
MPH

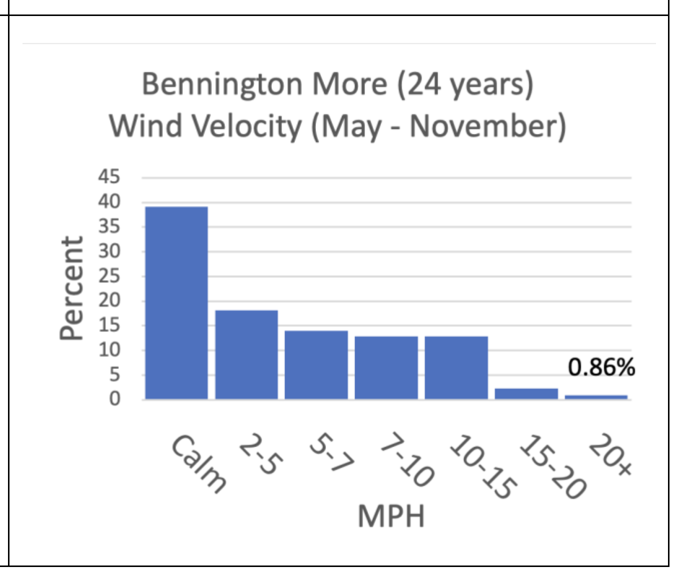

[CDA] Lyndonville
Windrose Plot [Time Domain: May 1 - Nov 30, 12 AM-11 PM]
Time Bounds: 31 Aug 2008 08:16 PM - 09 Jul 2022 09:55 AM America/New_York
Calm 36.4%
Summary
obs count: 352383
Missing: 8009
Avg Speed: 4.8 mph
Calm values are < 2.0 mph
Arrows indicate wind direction.
Generated: 09 Jul 2022
Wind Speed [mph]
2 - 4.9
5 - 6.9
7 - 9.9
10 - 14.9
15 - 19.9
20+

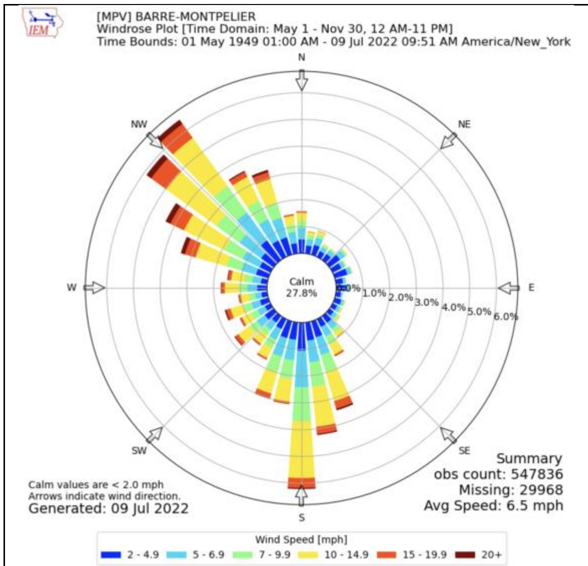

Lyndonville (13 years)
Wind Velocity (May - November)
Percent
0.47%
Calm
2-5
5-7
7-10
10-15
15-20
20+
MPH

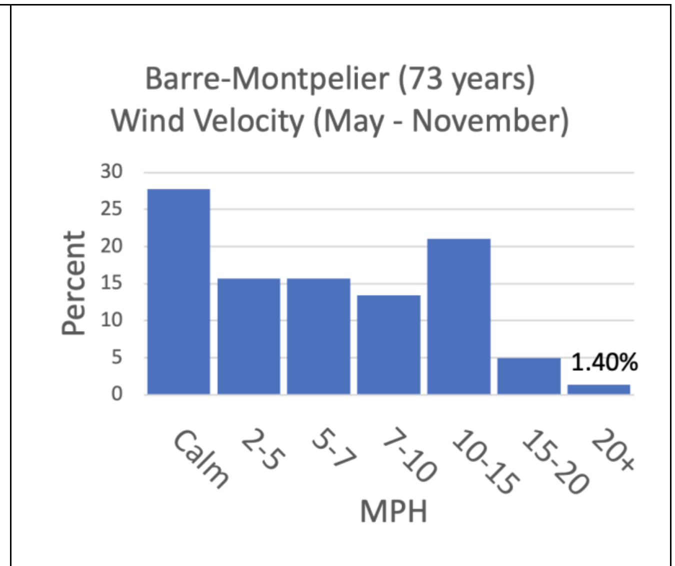

[BTV] BURLINGTON INTL
Windrose Plot [Time Domain: May 1 - Nov 30, 12 AM-11 PM]
Time Bounds: 31 Dec 1947 07:00 PM - 09 Jul 2022 09:54 AM America/New_York
Calm 9.9%
Summary
obs count: 654155
Missing: 7044
Avg Speed: 8.5 mph
Calm values are < 2.0 mph
Arrows indicate wind direction.
Generated: 09 Jul 2022
Wind Speed [mph]
2 - 4.9
5 - 6.9
7 - 9.9
10 - 14.9
15 - 19.9
20+

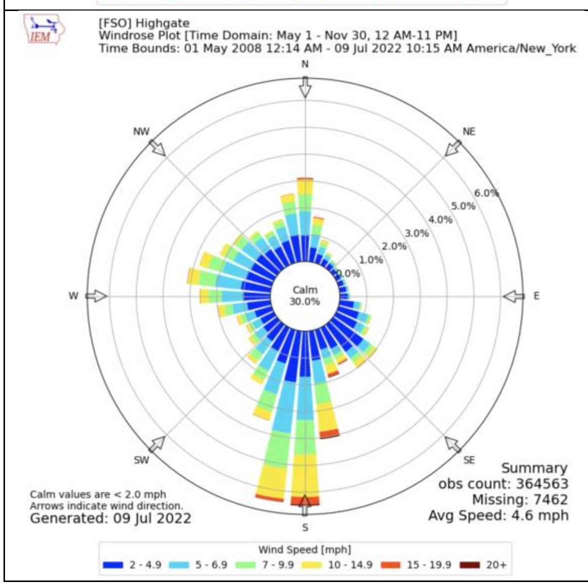

Burlington Intl. (75 years)
Wind Velocity (May - November)
Percent
2.30%
Calm
2-5
5-7
7-10
10-15
15-20
20+
MPH

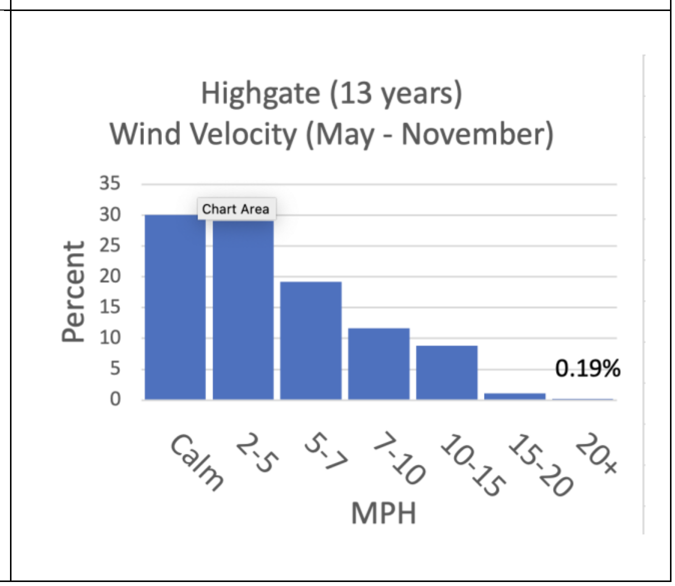

[DDH] Bennington More State
Windrose Plot [Time Domain: May 1 - Nov 30, 12 AM-11 PM]
Time Bounds: 31 Dec 1998 12:54 AM - 09 Jul 2022 09:54 AM America/New_York
Calm 39.1%
Summary
obs count: 247988
Missing: 26536
Avg Speed: 4.8 mph
Calm values are < 2.0 mph
Arrows indicate wind direction.
Generated: 09 Jul 2022
Wind Speed [mph]
2 - 4.9
5 - 6.9
7 - 9.9
10 - 14.9
15 - 19.9
20+


Bennington More (24 years)
Wind Velocity (May - November)
Percent
0.86%
Calm
2-5
5-7
7-10
10-15
15-20
20+
MPH

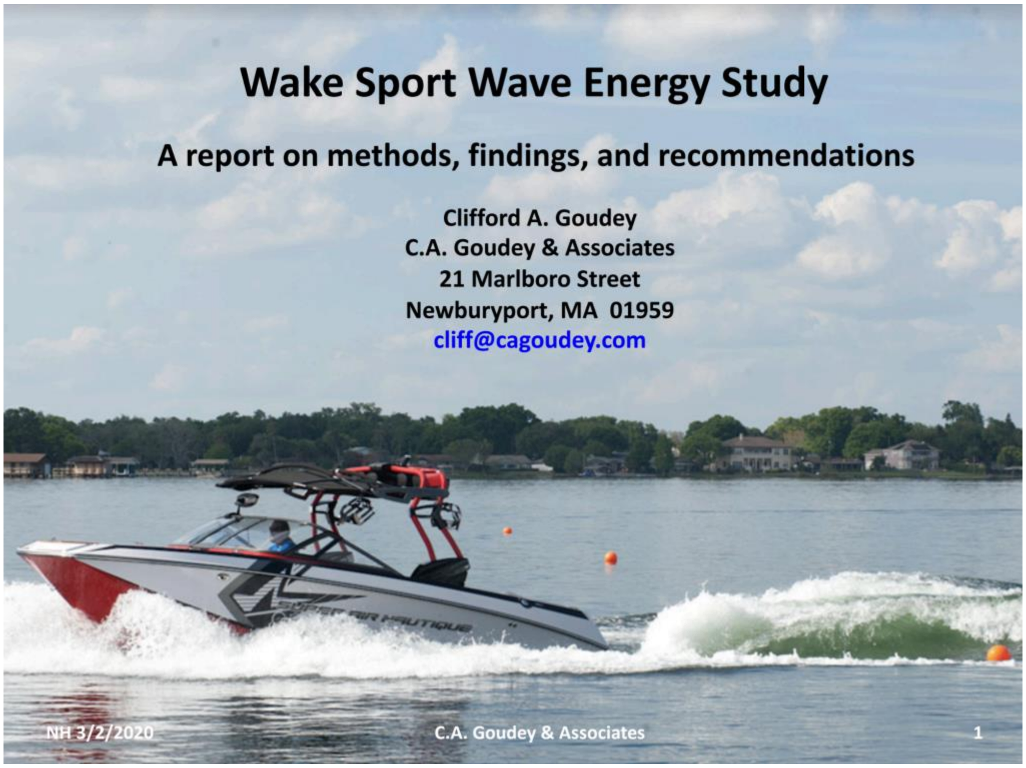

[MPV] BARRE-MONTPELIER
Windrose Plot [Time Domain: May 1 - Nov 30, 12 AM-11 PM]
Time Bounds: 01 May 1949 01:00 AM - 09 Jul 2022 09:51 AM America/New_York
N
NE
E
SE
S
SW
W
NW
Calm
27.8%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
Summary
obs count: 547836
Missing: 29968
Avg Speed: 6.5 mph
Calm values are < 2.0 mph
Arrows indicate wind direction.
Generated: 09 Jul 2022
Wind Speed [mph]
2 - 4.9
5 - 6.9
7 - 9.9
10 - 14.9
15 - 19.9
20+


Barre-Montpelier (73 years)
Wind Velocity (May - November)
Percent
30
25
20
15
10
5
0
1.40%
Calm
2-5
5-7
7-10
10-15
15-20
20+
MPH


[FSO] Highgate
Windrose Plot [Time Domain: May 1 - Nov 30, 12 AM-11 PM]
Time Bounds: 01 May 2008 12:14 AM - 09 Jul 2022 10:15 AM America/New_York
N
NE
E
SE
S
SW
W
NW
Calm
30.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
Summary
obs count: 364563
Missing: 7462
Avg Speed: 4.6 mph
Calm values are < 2.0 mph
Arrows indicate wind direction.
Generated: 09 Jul 2022
Wind Speed [mph]
2 - 4.9
5 - 6.9
7 - 9.9
10 - 14.9
15 - 19.9
20+


Highgate (13 years)
Wind Velocity (May - November)
Chart Area
Percent
35
30
25
20
15
10
5
0
0.19%
Calm
2-5
5-7
7-10
10-15
15-20
20+
MPH

Appendix B – Extracted slides from 3/20 presentation by authors of reference 2



Similar relationships can be made for any offset distance vs. any wind and fetch condition

The take-home message is that compared to modest waves over modest distances, boat wakes are a minor source of energy.

General findings:

- **Wake-surfing waves start out very high but dissipate rapidly compared to other wakes.**
- **The wake on the surfing side is 10% higher and conveys 23% more energy. It's best to set up and to surf on the offshore side.**
- **Wave energy dissipates rapidly upon breaking, such as just behind the boat and as water becomes shallow causing friction and more breaking.**
- **If a shoreline does not experience wind or if it is narrow in the prevailing wind direction, then it may not experience much energy from wind waves and might benefit from being designated a no-wake zone.**
- **Our methodology has established a high standard for the conduct of such field studies.**

NH 3/2/2020 C.A. Goudey & Associates 29

New, Relevant Data Post-ANR Petition Submission

Provided by the Terra Vigilis Security Group (www.TerraVigilis.com)

Summary. Two sets of new research data performed in 2021 on wake boats in North Lake Wisconsin were presented at a conference in June 2022 that have direct bearing on our ANR petition. One set focuses on the measurement of wake boat propeller down wash disturbances when operating in wake surf mode, and the other on acute changes in water phosphorus following overhead wake boat wakesurfing operation. In the first, direct measurements of wake boats propeller wash were made while wake boats were operated in wake surf mode were obtained demonstrating downwash energy effects to a depth 20 ft of water. Other typical motorized lake vessels (pontoon boats, inboard jet drive [PWC], and fishing boats) tested under identical conditions demonstrated downwash energy effects to only 3 to 5 ft of water. In the second set of experiments, phosphorus levels were measured after only two passes of a wake boat operated in surf mode that demonstrated increases of ~25%. The details of these two sets of experiments are included below. This is followed after this by the PowerPoint that accompanied this presentation.

Citation/source

2022 Northwest Wisconsin Lakes Conference

Friday, June 17, 2022 from 9:00 AM to 3:45 PM (CDT)

Spooner High School, 801 County Highway A, Spooner, WI 54801
"Wave Propagation & Water Quality Impacts on Fresh Water Lakes, Phase 2"
Presentation Link: https://www.youtube.com/watch?v=t3KpNPlGyw0

Investigators/Presenters

Terra Vigilis Security Group (www.TerraVigilis.com).

- Tim Tyre, Ph.D. (tim@terravigilis.com)
- Charles Luebke (Charles@Terravigilis.com)

Funding

Wisconsin Department of Natural Resources (3-yr), "North Lake Study: A Phased Study of Water Quality and Wave Propagation Dynamics Currently Impacting a Small Southeast Wisconsin Freshwater Lake"
(https://storymaps.arcgis.com/stories/3bb6845a097e42b8aad5f0fc0537567f)

Publication

These data are unpublished. Terra Vigilis group has indicated that they plan to subject their data to peer review and subsequently to publication. They are also planning to do additional "Phase 3" studies of wake boat impacts that will examine additional water quality issues, effects on lake biota, and economic impacts.

Principle Findings Relevant to Two Relevant Responsible Wakes for Vermont Lakes' ANR Petition Topics (The slide numbers below reference the presentation slide deck following this section).

1. ***Propeller downwash characteristics have been measured showing significant bottom effects*** from Wake boats in "surf mode" at depths greater than 20 feet. This depth effect is

not observed from the other three categories of vessels owing to reduced engine power, propeller angles, hull design, lack of ballasting, and the mode of operation ("planing").

Experimental synopsis provided Tim Tyre, Ph.D. This collaborative research effort between Terra Vigilis Inc., Carroll University (Depts Aviation Science and Chemistry/Environmental Science), and the Southeast Wisconsin Regional Planning Commission was focused on measures of propeller downwash depths by wake boats in surf mode. The wake boats used were 2020 Super Aire Nautique (450 hp, 6000 lb ballast capacity). and the 2014 Sport Nautique (400 hp, 4100 lb ballast capacity). The research team engineered a 30-foot aluminum pole secured vertically in the lake (Slides 12). The device had horizontal fixtures placed at 5-ft intervals to 25 ft which had fiber optic strands at each fixture's end. These strands were "movement sensitive" to downwash energy (Slides 19). Each of the wand fixtures had a camera and light extending on the horizontal axis to capture (with video filming) the downwash impacts. The research team documented wake boat surf mode disturbances to a depth of 20 feet (Slide 13's link to silent video: https://www.youtube.com/watch?v=9ujTrHpEl1U). Comparative data with typical lake vessels (Pontoon boats, PWC, fishing boats) did not show these effects as their propwash dynamics are generally horizontal to the surface and remain within 3 to 5 feet. Similar data to our 20-foot depth measures is seen from studies by Ray in 2020 at Payette Lake in Idaho (https://payetteenvironmental.com/document-3) and preliminary work at the University of Minnesota St. Anthony Lab. All testing occurred on calm water days with study vessels operated at standard methods for their use.

2. ***Bottom impacts from wake boats in surf mode have a significant impact on sediment redistribution and phosphorous nutrient release into the water column*** when measured after periods of less than 30 minutes (i.e., a 25% increase in phosphorous). This effect was measured in depths of 5-8 ft. The wake boat survey course was in 15 ft to 25 ft of water at 200 ft from shore.

   Experimental synopsis provided Charles Luebke. Testing was performed to measure phosphorous release by roil effect, i.e., creating water turbidity by disturbing the sediment. Wave propagation was produced by a wake boat in surf mode operation along a buoy demarcated course 200 ft from the shoreline with a course length of approximately 800 yds (0.45 miles) (Slide 15). Samples for phosphorous determination were obtained at three sites along the course both before and after the disturbance of sediments produced by two passes of a wake boat in surf mode operation. water samples were collected 6 inches below the water surface at a distance of 100 ft from the shoreline where the water depth was 3 to 5 ft. A total of two course runs (one northward followed by one southward) under calm water conditions in the morning were made by the wake boat in full ballasted surf mode with a raised bow angle of ~15% at 10 mph. There was no boat traffic that occurred prior to the morning sampling. Water depths along the buoyed course ranged from 25 feet at the southern end of the course to 15 ft at the northern end, with an average depth of 20 ft. The phosphorous data obtained from state certified laboratory analyses showed an increase levels in the water column that ranged from 17% to 33% within 30 minutes of the initial disturbance (Slide 15). This is an average increase in phosphorus levels of 25% across the three sample sites from the disturbance of sediment by waves propagating from a wake boat in surf mode.

………….

Ancillary Principle Findings of the Above Terra Vigilis study

1. There were significant differences noted between the wave characteristics and impacts of wave action from various powered vessels (Slides 9 to 11). Less impactful wave effects were noted from Pontoon boats, fishing vessels, and PWC compared to wake boats in surf mode. Wake boats in surf mode had both surface and subsurface impacts.
2. Near shore impacts from wave propagation showed significant differences between vessel type and distance from shoreline. At measured distances from shoreline (300 ft) Wake boats in surf mode produced wave oscillations larger than all other categories with bottom impacts including scrubbing and re-deposition of sediments (Slide 11). This effect was particularly notable on the Little Lake owing to its shallow water “shelf” between it and Big Lake (see Slide 6).
3. Water quality measures were responsive to boating activity levels ,with evidence of increased Total Suspended Solids (TSS) noted during periods of high boating activity on weekends which became reduced by midweek.
4. Re-deposition sediment effects were notable from persistent Wake boat activity in surf mode on the Little Lake basin with evidence of plume deposits along the majority of the Wildwood Point Reef (Slide 15). Depositional materials appeared to have an impact on aquatic plant life.

A Phased Study of the Water Quality and Wave Propagation Dynamics Currently Impacting a Small Southeast Wisconsin Freshwater Lake: Waukesha

June 2022

Terra Vigilis
Environmental Services

Introduction

Terra Vigilis Environmental Services was retained by the North Lake Management District (NLMD) in 2019 to conduct a 3-phase water quality and wave propagation impact study on North Lake. The scope of work included gathering of metrics on selected water quality markers and the use of commercial aerial and submersible drones for measurement of wave impacts on surface and subsurface environments. The 3-phase study is a collaborative effort between Carroll University (Chemistry, Environmental & Aviation Sciences), SEWRPC and Terra Vigilis Technical and Research Staff. The study is funded by NLMD and a WDNR grant.

The following research domains were addressed in this study:

- Water Clarity and Chemistry
- Lake Sediment Redistribution
- Plume Development via Wave Enhancing Boats
- Measurement of Wave Enhancing Propwash Impacts
- Shoreline Erosion Baselines (aerial photometric data)
- Aquatic Plant Species

Primary Research Study Team – Carroll University

- Mike Mortensen, MSArch, Distinguished Lecturer GRC, Director of Aviation Science
- Joseph Piatt, Ph.D., M.S.C.E - Professor of Chemistry and Environmental Science
- Julio Rivera, Ph.D. - William B. Yersin Professor of Applied Business Analytics
- Katie McCarthy, Ph.D. - Assistant Professor of Applied Business Analytics, Business
- Timothy Tyre, Ph.D. - Aviation Science
- Alex Navin, Student of Chemistry
- Jenna Bales, Student of Environmental Science Southeastern Regional Planning Commission

Primary Research Study Team

SEWRPC, TVES

Southeastern Regional Planning Commission

- Tom Slawski, Ph.D. - Chief Biologist
- Dale Buser, PE, Ph.D. - Chief of Hydrology

Terra Vigilis Environmental Services

- Chuck Howard - Chief Technology Office
- Charles Luebke – Field Operations

Methodology

- Seven sampling sites (large and small basins)
- Water quality measurements: Phosphorous, Total Suspended Solids, Dissolved Oxygen, Temperature
- Water quality measurements taken at surface and selected depths of 5’, 10’ 15, 20’ as lake depth allowed
- Standard Secchi disk procedures were used for measuring water clarity
- Samplings gathered weekly at all sites across a 13 week sequence (June-Sept 2021)
- State Certified Labs for Phosphorous/TSS sample testing
- Commercial Aerial Drone Imagery depicting plume development and wave features
- Commercial Submersible Drone Imagery for Wave Enhancing Vessel Propwash Depths and Aquatic Plants
- Establishment of Thermocline Levels
- Specific Testing of Phosphorous Release Events Following Wave Enhancing Vessel Traffic

North Lake Phase 2 Sampling Sites

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Wave Propagation Measurement Systems

Wave Heights and Downwash Physics

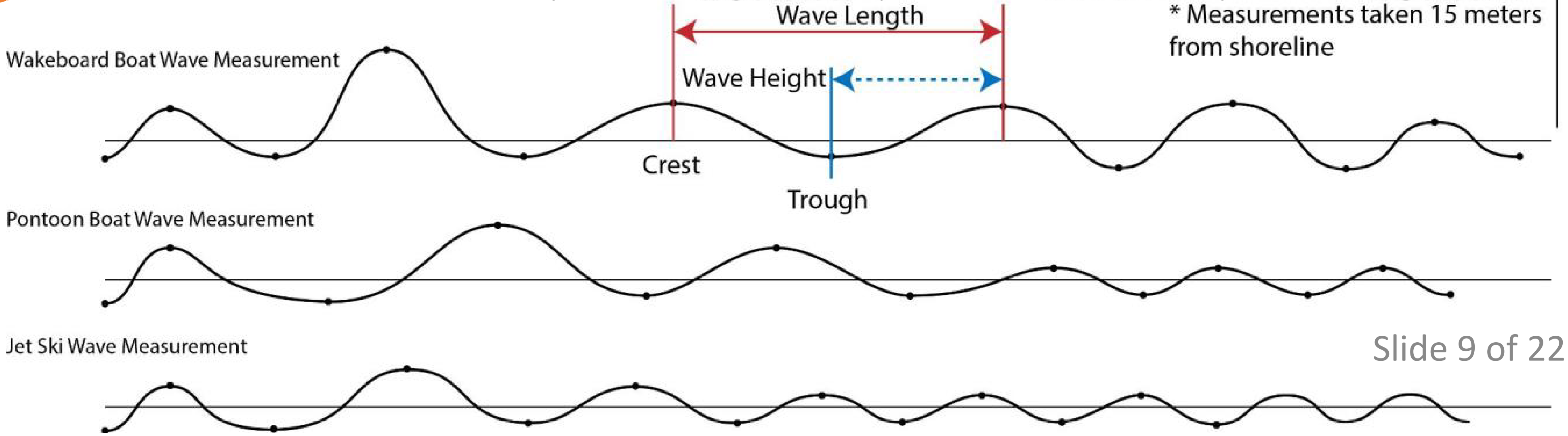
- Procedure 1. The Terra Vigilis Team (TVT) used a sonic sensor attached to a Mavic Pro aerial drone platform. The drone was calibrated from the dock surface prior to flight (constituting a baseline). The drone was flown approximately 3 meters above the surface. As wave actions passed below the sonic sensor a digital measurement was taken.
- Procedure 2. The TVT recorded aerial drone video using a high-resolution camera in its nadir position. Images from the videos were extracted and converted to displacement maps. A wire frame computer model was created. The 3D wireframe models were scaled to match known measurements from the images. This photogrammetry procedure was used for the wave heights measurements during sampling. Both wave heights and frequencies were digitally captured.
- Procedure 3. The TVT placed an engineered tripod into the water at approximately 30 ft from the shoreline and 6 ft from the dockside. The tripod placement was weighted to alleviate response to wave movement during measurement intervals. A 360-degree camera was attached to the tripod. The camera was placed at 2 ft above the water's surface. The camera video was continuously recorded. All data was time coded and archived. Camera angles included capture of the 12 ft measuring ruler and rod (perpendicular to one another). Post-production analyses included stamped time codes and heights to provide wave frequency.
- Procedure 4. The TVT placed an engineered 30' aluminum propwash measuring device with cameras and fibre optic wands at staggered depths of 5', 10', 15', 20' and 25'. Downwash impacts were captured with digital video camera footage at vessel startups and wake surf mode passes within 5' of the anchored device.

Wave Length & Height Measures

Wave Measurements at 15 meters from shoreline

Wakeboard Boat Wave: Wavelength	Height	Time	Pontoon Boat Wave: Wavelength	Height	Time	Jet Ski Wave: Wavelength	Height	Time
	-2	@ 0;00;03;17		-1	@ 0;00;31;19		-1	@ 0;00;11;19
	+2”	@ 0;00;04;11		+3”	@ 0;00;32;12		+2”	@ 0;00;12;12
15’ - 4”	-2”	@ 0;00;05;21	20’-5”	-3”	@ 0;00;34;10	12’-5”	-2”	@ 0;00;14;16
	+8”	@ 0;00;06;10		+5”	@ 0;00;35;12		+3”	@ 0;00;15;12
17’ - 11”	-2”	@ 0;00;07;21	17’ - 11”	-2”	@ 0;00;36;23	15’ - 4”	-2”	@ 0;00;16;21
	+4”	@ 0;00;08;13		+3”	@ 0;00;37;23		+3”	@ 0;00;17;21
20’-5”	-2”	@ 0;00;10;05	17’ - 11”	-1”	@ 0;00;39;01	17’ - 2”	-1”	@ 0;00;19;01
	+3.5”	@ 0;00;10;28		+1.5”	@ 0;00;39;22		+1.5”	@ 0;00;19;18
15’-4”	-2”	@ 0;00;12;18	10’ - 3”	-2”	@ 0;00;40;29	11’ - 6”	-1”	@ 0;00;20;27
	+4”	@ 0;00;13;10		+1”	@ 0;00;41;25		+1”	@ 0;00;21;22
12’-10”	-3”	@ 0;00;14;15	10’ - 3”	-1”	@ 0;00;42;19	11’ - 3”	-1”	@ 0;00;22;12
	+2”	@ 0;00;15;06		+1”	@ 0;00;43;10		+1”	@ 0;00;23;02

* Measurements taken 15 meters from shoreline



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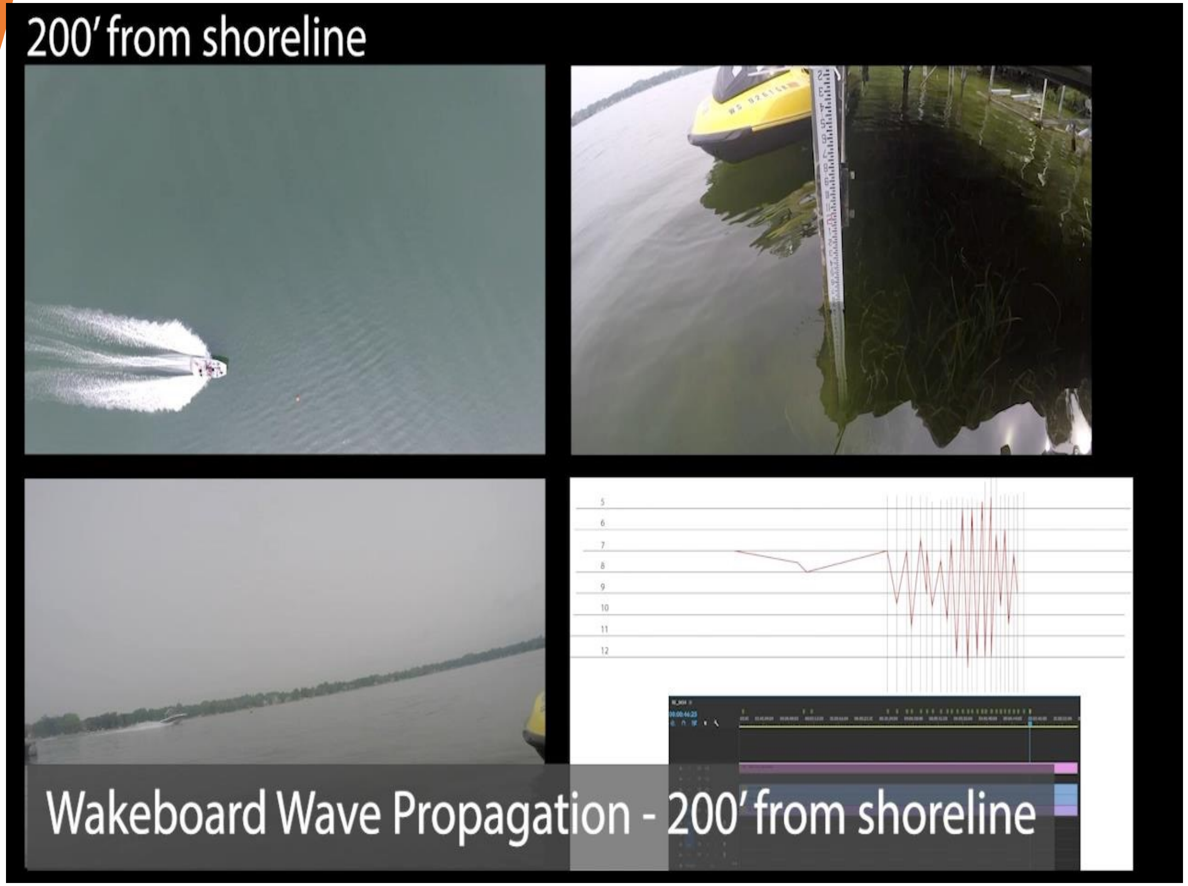
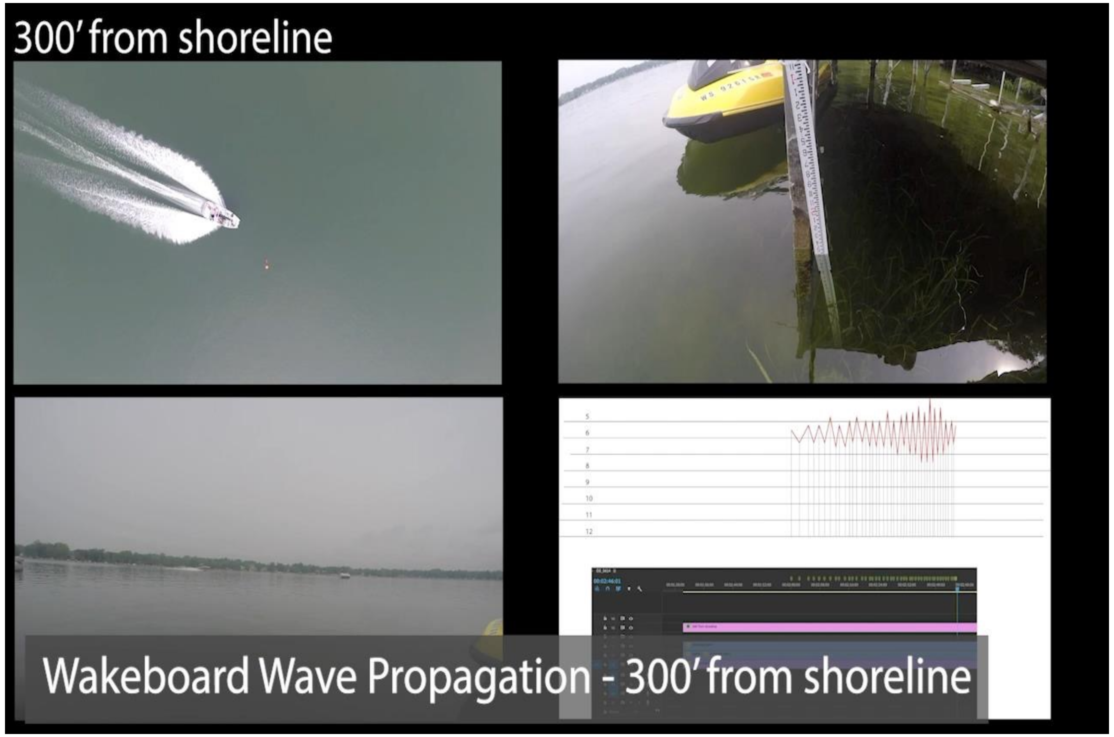
Wave Oscillations at 200’ From Shoreline



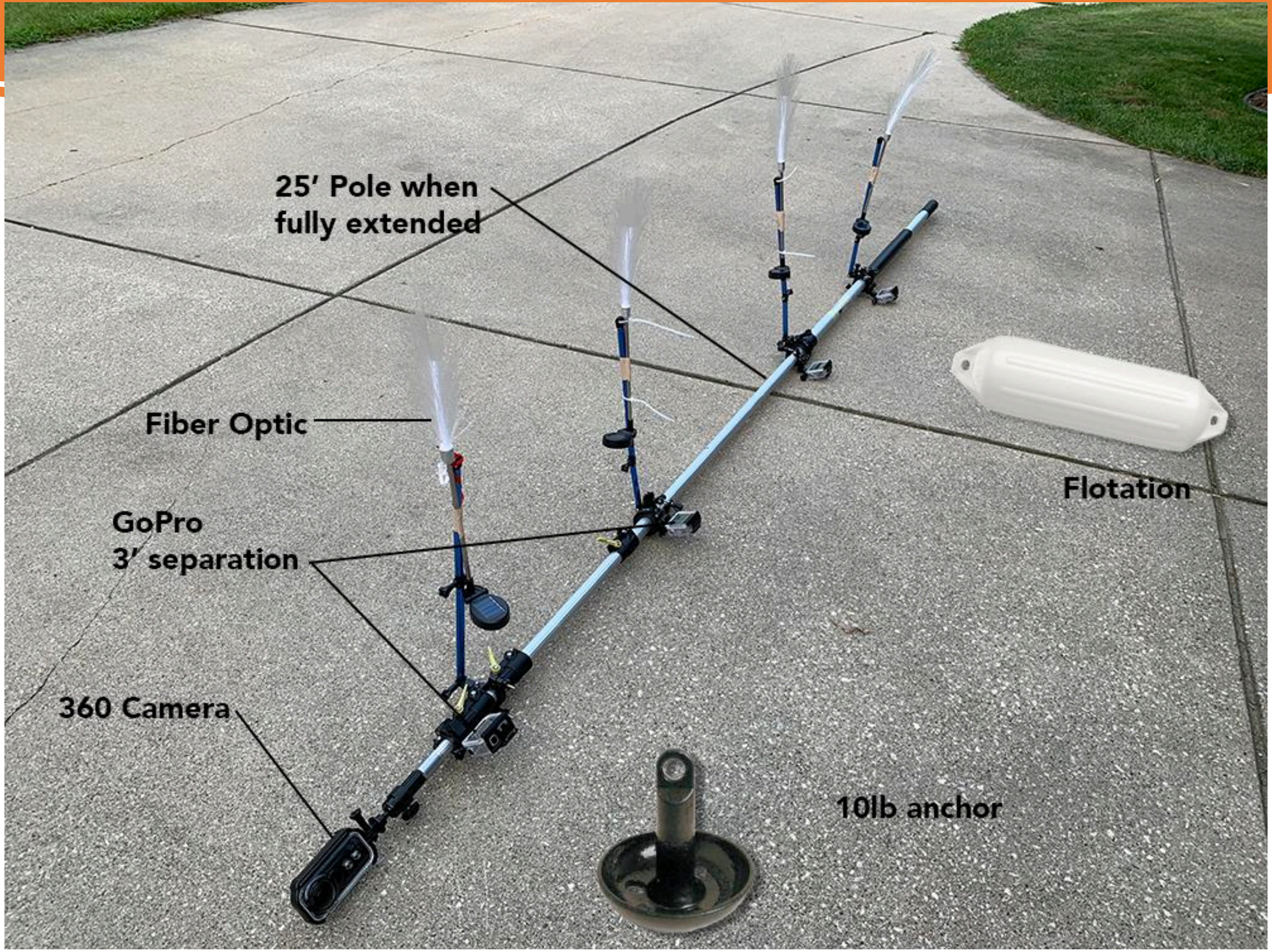
[Video: Wave Oscillation Data 200’ from Shoreline]

Wave Oscillations at 300 ft From Shore



[Video: Wave Oscillation Data 300' from Shoreline]

Prop Downwash Measurement



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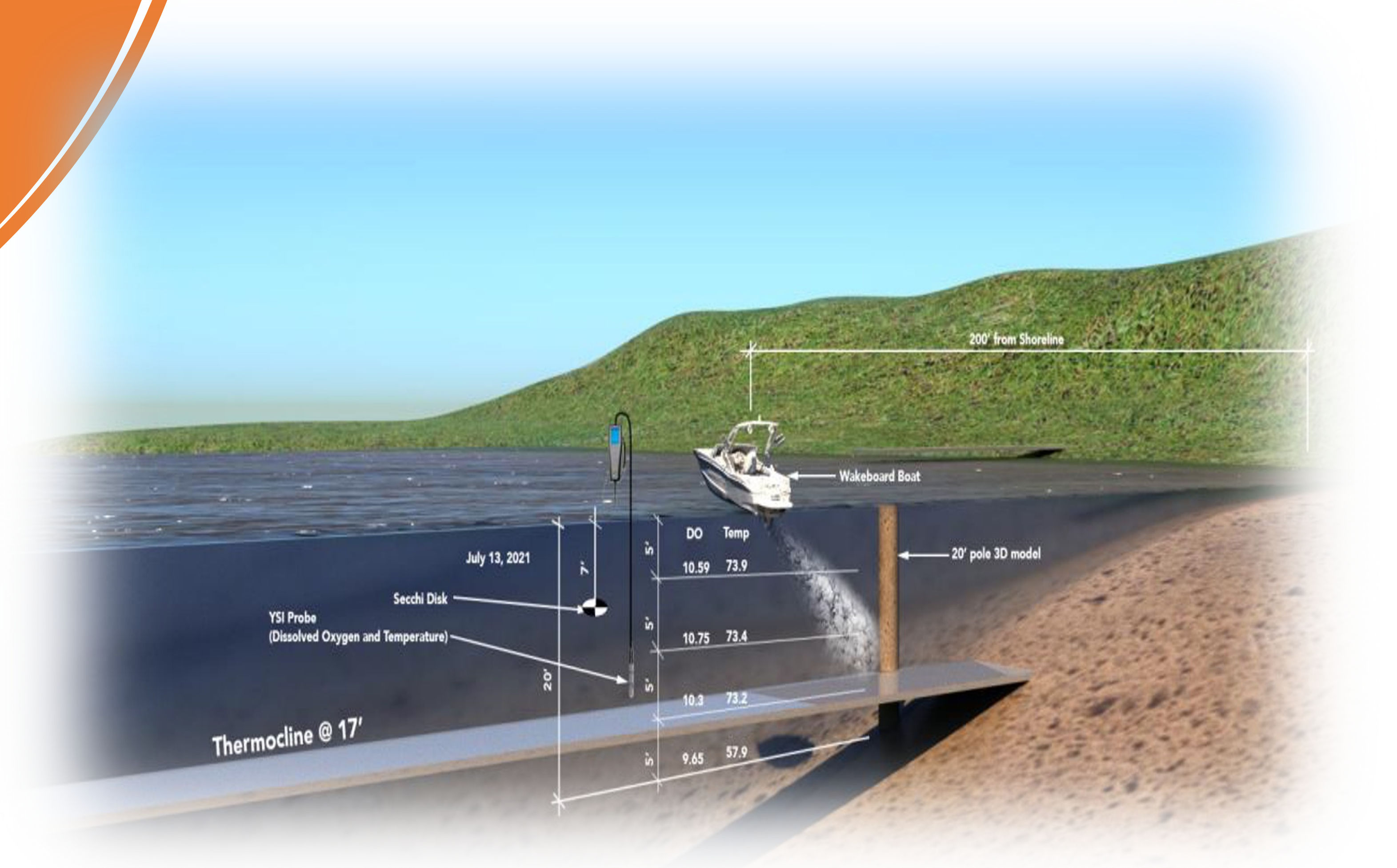
Propwash Wake1 - YouTube

"Wave Propagation & Water Quality Impacts on Fresh Water Lakes, Phase 2" June 17, 2022 Northwest Wisconsin Lakes Confr

Propwash Depth from Wake Surf Mode (Computer Imagery)



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Wake Surf Mode Water Chemistry Impacts: 25% Phosphorus Increase

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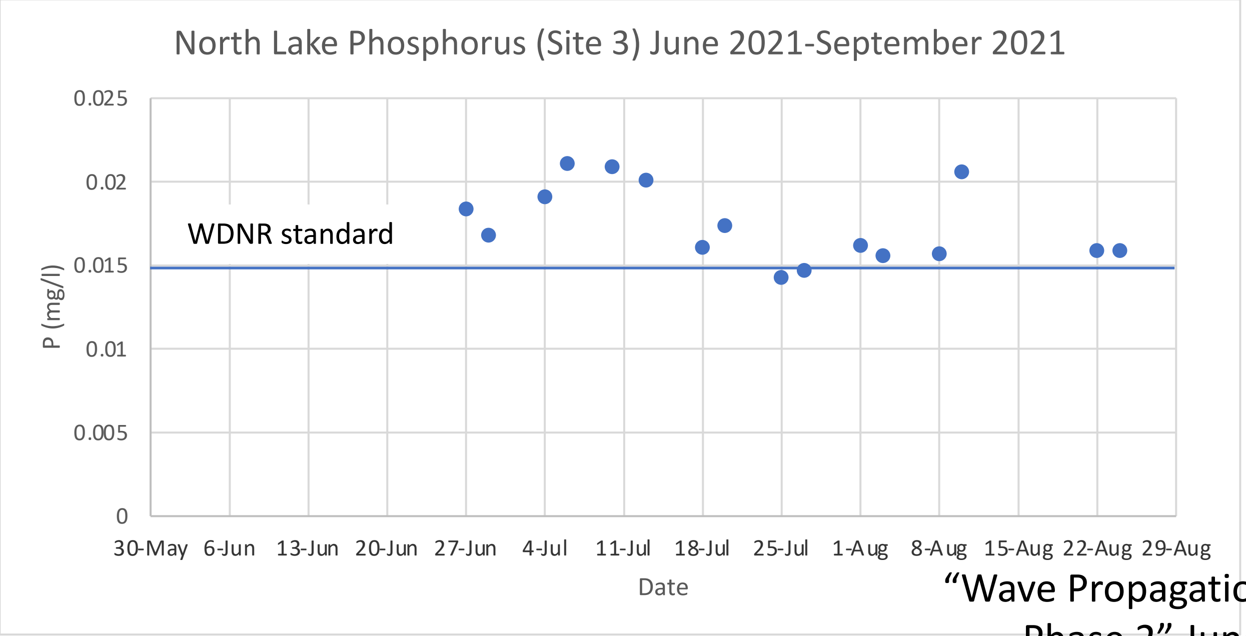
Water Chemistry Findings



- Phosphorous sample values exceeded WDNR Standard of 0.015 mg/L across all sampling dates except for 25 July 2021. Spiked values are shown at mid-July and early August which exceeds Wisconsin standards. These dates correlate with high ambient temperatures and rainfall days increasing nutrient inflows from the river inlets to North Lake. These samples were gathered at site 3 on the large lake basin which was identified from Phase 1 study as a critical transfer location from the large to small lake basin and an area where plume deposits were identified to be settling after persistent disturbance from boating activity.

Wake Surf Mode Plume Events

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[Wave Propagation and Water Quality Impacts on Fresh Water Lakes - 2021 NW WI Lakes Conference - YouTube]() (31:19)

North Lake Subsurface Impacts

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Equipment Used – Phase 2

The Wave Enhancing Watercraft Used in the Phase 2 Study

- 2020 Super Aire Nautique Wake Board Boat with 450 HP Inboard Engine, 6,000 lb ballast capacity and adjustable electronic bow /stern angle options
- 2014 Wake Board Boat (Sport Nautique) with 400 HP Inboard Engine, 4100 lb ballast capacity and adjustable bow/stern angle options

Measurement Equipment Used in the Phase 2 Study

- Terra Vigilis ©Extendable Propwash Measuring System with extender arms and cameras at staggered depths
- YSI Pro20 DO and Temp Probe (with digital memory core)
- Standard Secchi Disks
- 12’ measurement stick model (surveyors)
- Laser distance gun “Laserlink” RH2 (vessel distances)
- Lowrance X100C/D Depth Sonar, Temp and Speed Unit
- Terra Vigilis ©AQUA subsurface measurement system UAV
- FiFish QY6 ROV with Omnidirectional Camera and Video Goggles
- Laboratory Procedures (refrigerated protocols per laboratory specs)
- TSS samples (surface dips)
- DO samples (staggered measurements at: surface, 5 ft, 10 ft, 15 ft, 20 ft)
- Phosphorus samples (surface dips)

Qysea FiFish V6S

YSI Dissolved Oxygen Probe

DJI Phantom 3 Professional

Secchi Disk

Principle Findings Phase 2

- There are significant differences noted between the wave characteristics and impacts of wave action from various powered vessels. Less impactful wave effects are noted from Pontoon boats, fishing vessels, and PWC compared to Wakeboard Boats in “Surf Mode”. Wakeboard Boats in surf mode have both surface and subsurface impacts.
- Propeller downwash characteristics have been measured showing significant bottom effects from Wakeboard boats in “surf mode” at depths greater than 20 feet. This depth effect is not observed from the other three categories of vessels owing to reduced engine power, propeller angles, hull design, lack of ballasting, and the mode of operation (“planing”).
- Near shore impacts from wave propagation show significant differences between vessel type and distance from shoreline. At measured distances from shoreline (300’) Wakeboard boats in surf mode produce wave oscillations larger than all other categories with bottom impacts including scrubbing and re-deposition of sediments. This effect is particularly notable on the little lake owing to the shallow water “shelf”.

Principle Findings Phase 2 continued

- Bottom impacts from Wakeboard boats in surf mode have a significant impact on sediment redistribution and nutrient release into the water column after periods of less than 30 minutes (25% increase in phosphorous). This effect was measured in depths of 5-8'. The wakeboard survey course was in 15' to 25' of water at 200' from shore.
- Water quality measures are responsive to boating activity levels with evidence of increased Total Suspended Solids (TSS) during periods of high boating activity on weekends and reduced TSS by midweek.
- Re-deposition effects are notable from persistent Wakeboard boat activity in surf mode on the little lake basin with evidence of plume deposits along the majority of the Wildwood Point reef. Depositional materials appear to have an impact on aquatic plant life.

Questions are Welcome

Follow up details available if you contact by email:

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- Charles@Terravigilis.com

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www.TerraVigilis.com