UNIVERSITÉ LAVAL

IMPACT OF THE NAVIGATION IN MILIEU LACUSTRE -

CAS OF AC MASSON AND THE AC OF SABLES

through

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Ing. Quebec City, November

252015

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Table of materials

List of figures.....3
List of Tables.....3

1. Introduction.....5

2. Problem.....8

3. Study site.....9

3.1.....Masson Lake Features.....9

3.2.....Sand Lake Features.....9

4. Methodology.....10

5. Results.....14

5.1 Lake Masson: from the laboratory to the field 14

5.2.....Sand Lake: Taking Action.....14

5.2.1.....Physical-chemical parameters 14

5.2.2.....Wake Boat Pass Impacts and Generated Speeds.....15

5.2.3.....Changes in parameters at the bottom of Sand Lake.....19

6. Discussion.....22

6.1Previous Impact Studies.....22

6.2Speeds generated at the bottom of Lake.....23

6.3.....Oxygenation and phosphorus transfer?.....24

7. Conclusion and Outlook.....26

8. Thanks.....28

9. References.....29

Table of Figures

Figure 1: Photograph of the "WakeBoat" used for testing on Lake Masson.....6

Figure 2: Locations of test areas on Lake Masson based on bathymetric maps. .10

Figure 3: Test Area Locations on Sand Lake based on bathymetric maps.....11

Figure 4: Photograph of equipment at the bottom of Lake 12

Figure 5: 3D power measurements.....13

Figure 6: Profile of the physical-chemical parameters on the entire water column prior to the completion of the tests
.....
15

Figure 7: Average intensity (a) and speed generated (b) when the Wake Boat passes at different speeds for the 1st day of testing
.....
16

Figure 8: Average intensity (a) and speed generated (b) when the Wake Boat passes at different speeds for the 2nd day of testing
.....
18

Figure 9: Zoom of Figure 8a on the passages of boats in "Wake surf" mode for the 2nd day on Lake.....
of The Sands
.....
19

Figure 10: Time evolution of conductivity, dissolved oxygen and turbidity parameters at the bottom of Sand Lake for the 2nd day of measurements
.....
20

Figure 11: View of the experimental device before (a) and 2 minutes after (b) the passage of a "Wake Boat"

.... 21

Figure 12: Speeds near sediments depending on boat speed 22

Figure 13: Abacus connecting the power of a boat and the maximum disturbance deepeur of particles of different sizes
24

THEISTE OF TABLEAUX

Table 1: Masson Lake Morphometric and Hydrological Data 9

Table 2: Sand Lake Morphometric and Hydrological Data.....9

Table 3: Speed Measurement Scheme for a Test.....11

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Reference to quote:

Raymond, S., and Galvez, R., Impact of Lake Navigation - Sediment Suspension Study: Lake Masson and Sand Lake Cases - 2015. Laval University. 30p.

1. INTRODUCTION

Quebec's lakes are resorts where people need to balance recreational activities, environmental protection and regulations. In particular, navigation on lakes is a federal jurisdiction (Coalition Navigation, 2014). In Canada, it is the Canada Shipping Act, and its related regulations, that regulate pleasure craft. By agreement between the federal government and the Quebec government, the Quebec Security service is responsible for enforcing this law. However, it is possible for municipalities to dictate regulations on the use of boats on the federal government's permission. It is possible to define an ethical code for protecting the environment of lakes. However, these "voluntary codes of conduct" require 100% user support. They often lead to difficult-to-resolve debates between the various stakeholders involved in communities across Canada (Coalition Navigation, 2014).

Studies have shown the impact of motorboats on lake ecosystems. Several factors affect the impact of a boat's passage such as the speed of navigation, the strength and type of engine, the geometry of the propeller, the geometry of the hull, the cohesion of the sediments, the size and mass of the particles forming sediments, water depth, lake stratification.

The popularity of wakeboats (Figure 1) among boaters is steadily increasing. The configuration of these boats can create substantial waves that allow enthusiasts to "surf" at the back of their boat.

Figure 1: Photograph of the "WakeBoat" used for testing on Lake Masson

In 2014, Mercier-Blais and Prairie show that the waves produced by wakeboats must travel a distance of 300m or more on either side of the wake to dissipate the energy generated by it. completely resulting in sediment suspension and accelerated shoreline erosion. Wave action and turbulence as a result of shallow water navigation in lakes produce obvious sediment suspension and release of nutrients and pollutants into the water column (Alexander and Wigart, 2013 ; Bastien et al., 2009; Gélinas et al., 2005; Wang et al., 2009; Zoumis et al., 2001), as well as bacteria that are indicative of non-recent fecal contamination*(Escherichia coli* and total coliforms) (An et al., 2002) that have an impact on water quality. These processes are reinforced by the harvesting of macroalgae by helicopter and boat hulls (Lenzi et al., 2005, 2013).

Anthony and Downing (2003) tracked the effect of wind, boat traffic and turbidity on sediment resuspension and showed that higher wind speeds of 20 $m.s^{-1}$ (45 mph) can mobilize up to 98% surface sediments and increase phosphorus concentrations (up 100%) ammonia (toxic levels) in the water column. The authors also observed that the correlation between boat traffic and sediment suspension was low, but that heavy boat traffic appears to exacerbate wind resuspension, which may slow the deposition of the suspended sediments. Lenzi et al. (2013) examined the amount and distances travelled by sediments and nutrients from boat disturbance. They showed that the mass of suspended material was relatively large, and that total phosphorus increased. Also, motorized recreational activities (motorboating, water skiing, jet skiing) can significantly increase pollution levels in lakes (metals, polycyclic aromatic hydrocarbons, etc.), which represents a high level of risk for aquatic organisms, particularly benthic invertebrates (Mosisch and Arthington, 2001). However, the influence of different types of boats, speeds and accelerations on sediment resuspension is poorly understood.

In this context, the Department of Civil and Water Engineering at Laval University was asked by Isabelle and Mr. Dubitsky of the "Coalition for Sustainable and Responsible Navigation" (known as the "Navigation Coalition") to carry out proposed trials by Professor Y Prairie of the University of Montreal. Specifically, the tests involve the assessment of sediment resuspension and thus describe the impact of the passage of a "Wake boat" on the water column.

2. PROBLÉMATIQUE

In Quebec, the increase in water sports activities on lakes is a concern for citizens, associations, municipalities and residents concerned about the ecological impact that these recreational activities produce. The challenge lies in the inability to find sustainable environmental solutions that are satisfactory in terms of regulation. On the other hand, many question whether there is a causal link between the passage of motorized boats and the degradation of lake environments.

This project is therefore defined in order to provide preliminary scientific data with the ultimate goal for the Navigation Coalition to propose recommendations that will be proposed to the federal government in order to better regulate the use of boats on lakes.

The project seeks to assess the impact of wakeboat motorized boats. In order to broaden knowledge about the impact of navigation on lakes, including sediment resuspension, the study we propose aims to:

i) define the impact of the depth of the jets of the motorboat propulsion systems,
ii) measure the generated speed that can resuspend sediments in the water column.

3. SITE STUDY

The study took place on two lakes in the Laurentian region (Quebec): Lake Masson (74-02'05"O - 46-02'30"N) and Lac des Sables (74-18'08"O - 46-02'35"N).

3.1 Masson Lake Features

Lake Masson is located in the MRC of The Countries of High at the level of the municipalities of Sainte-Marguerite-du-Lac Masson and Estérel. Masson Lake's morphometric and hydrological data are presented in Table 1. The Lake has a significant average depth of 11.3 m which will allow us to calibrate our protocol without environmental risk.

Table 1: Masson Lake Morphometric and Hydrological Data

Lake area	2,5 km² (618 acres)
Volume of the lake	28 202 000 m³ (995944230.88 ft³)
Maximum depth	47,3 m (155 ft)
Average depth	11,3 m (37 ft)
Altitude	335,3 m
Watershed area including lakes	34,9 km² (13.5 mi²)
Renewal time	1.41 years

3.2 Sand Lake Features

The Sand lake is located in the MRC Les Laurentides at the level of the municipality of Saint-Agathe-des-monts. The morphometric and hydrological data from Sand lake are presented in Table 2. It has a slightly lower average depth of 7.1 m but has similar characteristics to Lake Masson.

Table 2: Sand Lake Morphometric and Hydrological Data

Lake area	2,96 km² (731 ac.)
Volume of the lake	21 105 000 m³ (745316041 ft³
Maximum depth	23.6 m (77.4 ft)
Average depth	7.1 m (23.3 ft)
Altitude	376.6 m
Watershed area including lakes	38.8 km² (15 mi²)
Renewal time	0.95 year

4. MÉTHODOLOGIE

To measure the impact of lake navigation, the speed and depth impacted by wake boat passage were measured: Five speeds were tested:

- 5 km/h (~3mph);
- 10 km/h (~6mph);
- Maximum speed: 50 to 70 km/h(from 33 to 44 mph).
- Wave Surf's speed: 19 km/h (up 12 mph)
- Wake Boat's speed: 29 km/h (up 18 mph)

At least two depths have been tested by lake, approximately 15 meters (50 ft) and meters 9 (30 ft) on Lake Masson and about 6 (20 ft) and 5 meters (16 ft) for Sand Lake. The data acquisition points are visible on the bathymetric maps of Masson Lake and Sand Lake shown in Figure 2 and Figure 3, respectively.

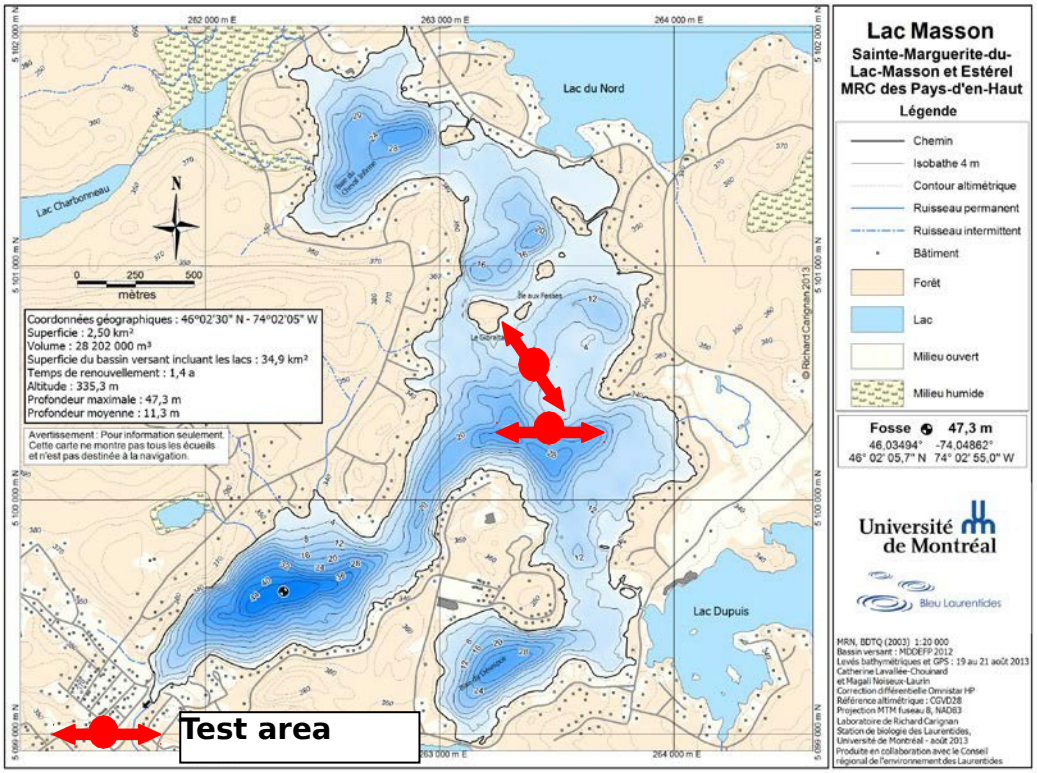


Figure 2: Locations of test areas on Lake Masson based on bathymetric maps(http://www.crelaurentides.org/dossiers/eau-lacs/atlasdeslacs?lac=12214)

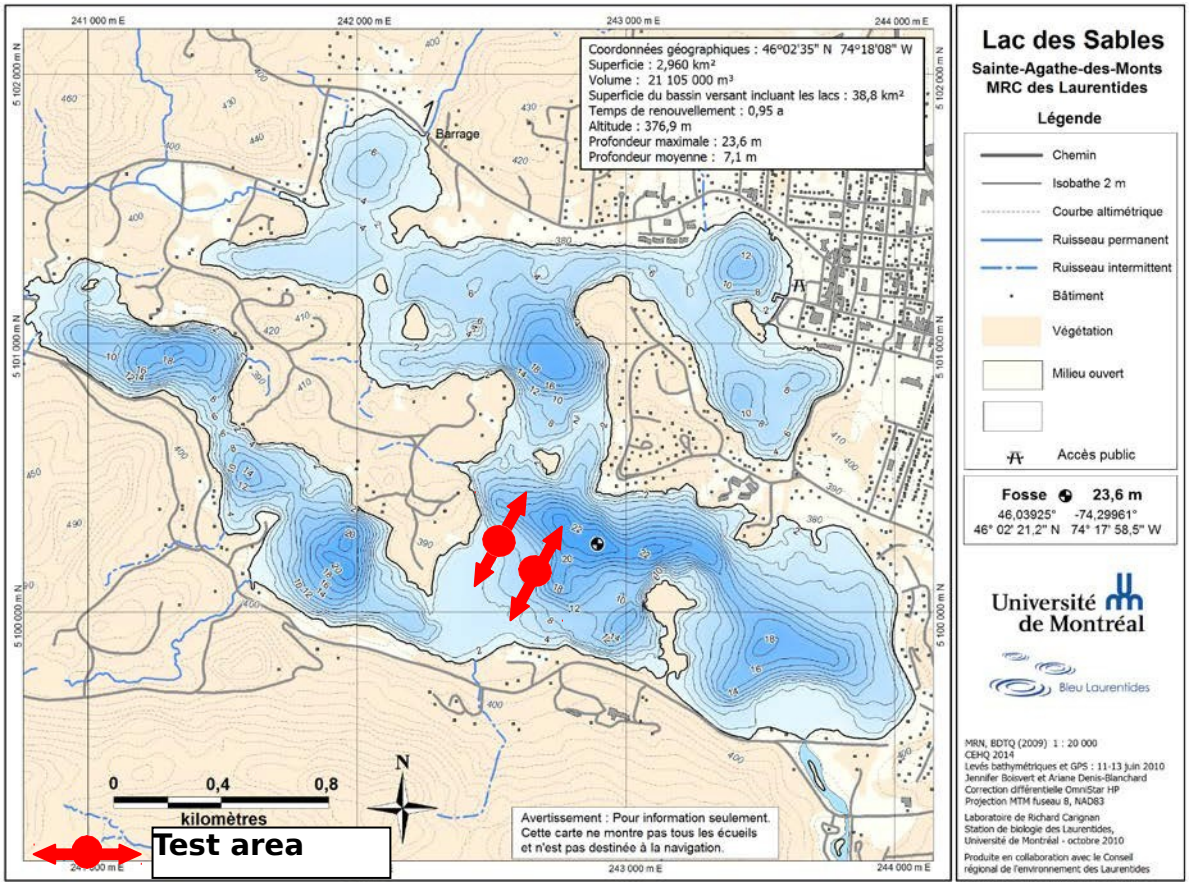


Figure 3: Locations of Test Areas on Sand Lake based on bathymetric maps(http://www.crelaurentides.org/dossiers/eau-lacs/atlasdeslacs?lac=12138)

This data will assess a critical depth of impact of the Wake Boat. Depending on the velocity generated in the water column, it is at this critical depth that the bottom sediments will potentially be suspended. All trials will be conducted in triplicate to obtain representative data as summarized in Table 3.

Table 3: Speed Measurement Scheme for a Test

Speeds (km/h)	Depth (m)	Type of boat	Number of passes per experience
▪ 5 (3.1 mph) ▪ 10 (6.2 mph) ▪ max. (33-44 mph) ▪ Wave surf speed (up to 12 mph) ▪ Wake boat speed (up 18 mph)	▪ 10 (32.8 ft) ▪ 20 (65.9 ft)	▪ Wake boat	3 times

The tests were carried out during the months of August to September, a temperature profile was carried out to find out if there is stratification of the lakes.

The fieldwork included the installation of an ADCP (Acoustic Doppler Current Profiler) which defines itself as (Figure 4):

- Acoustic - Using a sound wave;
- Doppler - Doppler effect applied to speed measurement. The Doppler effect allows you to make very high-frequency sounds and by listening to echoes returned by reflectors in the water.
- Current - Measuring water speed;
- Profiler - Measuring a speed profile, not a point speed.

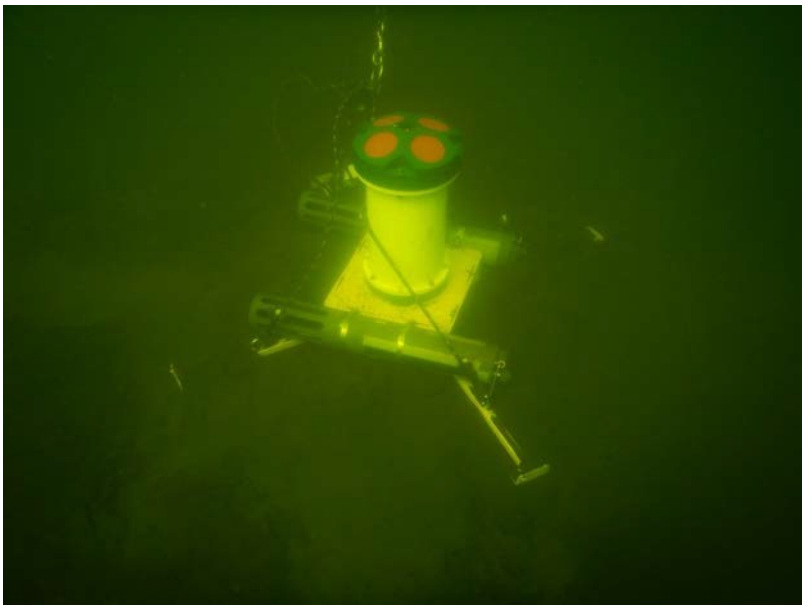
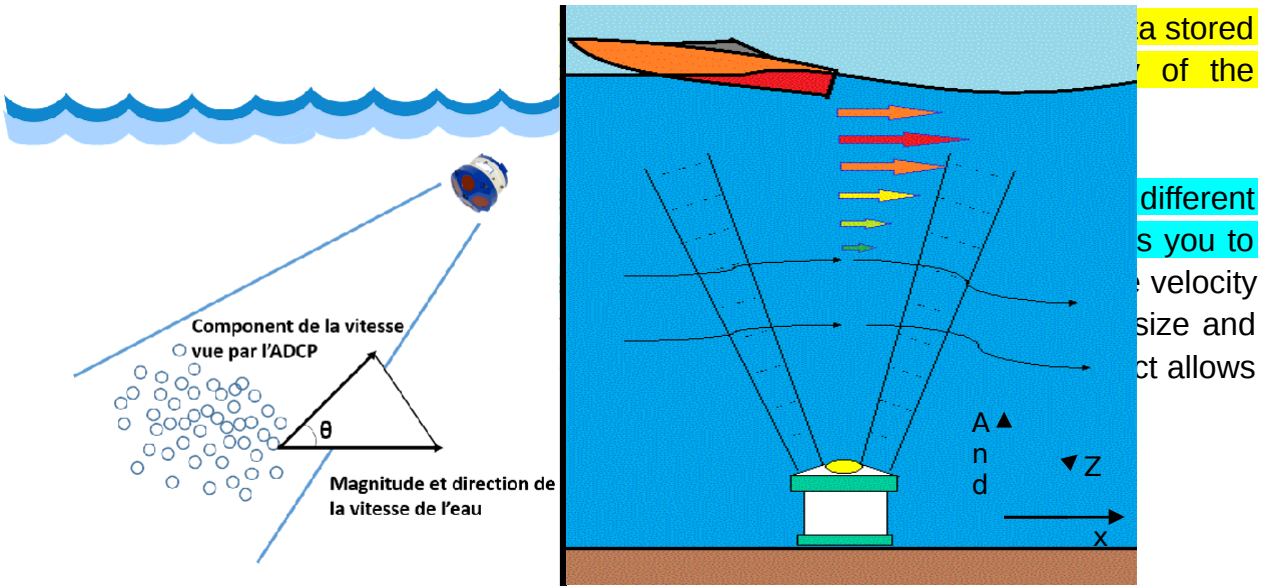


Figure 4:Photograph of equipment at the bottom of the lake



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sounds to be transmitted at fixed frequencies and listening to the echoes returned by the reflectors in the water. These reflectors are small microscopic particles of sediment or plankton naturally present in the water, which move at a speed equal to the water and reflect the sound towards ADCP (Figure 5). The ADCPs selected for the tests have 4 transducers that emit acoustic pulses at frequencies in the order of 1.2 MHz. These pulses are returned and more or less distorted by particles (reflectors) in suspension in the water according to their speeds. The distance between the particle (reflector) and the ADCP is calculated based on the time between the emission and the receipt of the pulse (Lane et al., 1999; RD Instruments, 1989). Although the speed of the sound with the density of the medium along acoustic paths, the preservation of the horizontal component of the number of waves allows to determine horizontal velocity from the knowledge of the speed of sound at the transducer level only. Using the Doppler effect, the system calculates the water speed in three dimensions (2 horizontal and 1 vertical) to the right of each beam (3 or 4 beams) by using trigonometric rules.

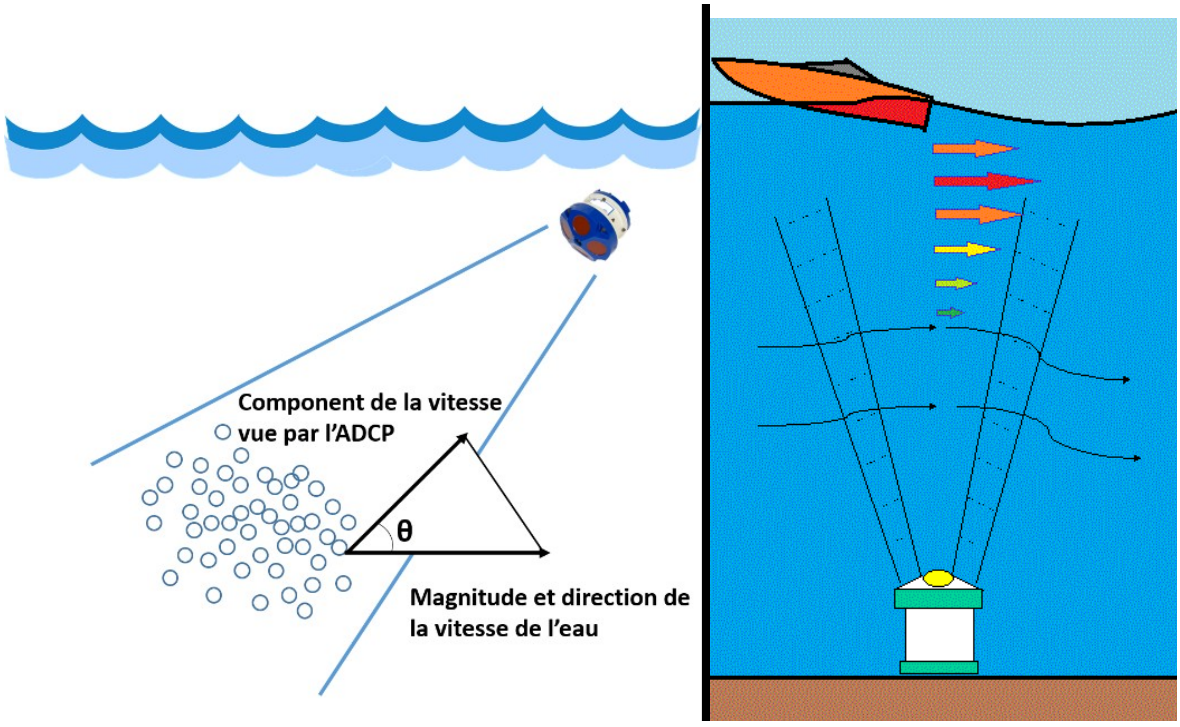


Figure 5: 3D Yard Measures (RD Instrument, 1989)

Acoustic technologies are non-intrusive and have the advantage of providing information simultaneously and in the same place on the topography of the bottom, the speed field (Thorne et al., 2002).

5. RÉSULTS

The results will be presented by lake to differentiate the two field campaigns and focus on the interests of each.

5.1 Lake Masson: from the laboratory to the field

Lake Masson was the first lake to participate in this type of research. It was a major element in the development of the instrumentation implementation protocol. Indeed, the only tests carried out took place in the laboratory with controlled conditions both in the calibration of the device and in the implementation of the instrumentation. However, natural trials are often different and much more difficult than those in the laboratory, and these tests have only confirmed the adage.

Nevertheless, the trials on Lake Masson were essential to understand the dysfunctional elements of the protocol. Difficulties in calibrating the device appeared on the boat as well as difficulties in setting up the instrumentation related to the winds and the complexity of the device.

Following the two tests carried out, we were able to optimize the device and we also improved the implementation of the instrumentation by simplifying the device. In the end, it was faster and safer.

5.2 Sand Lake: Taking action

Once the protocol was optimized, the first measurements were taken on Sand Lake.

5.2.1 Physical-chemical parameters

Figure 6 shows the temperature, turbidity and dissolved oxygen profiles in the water column for the 2nd day of water measurements on Sand Lake. The results of the two days of measurements are similar.

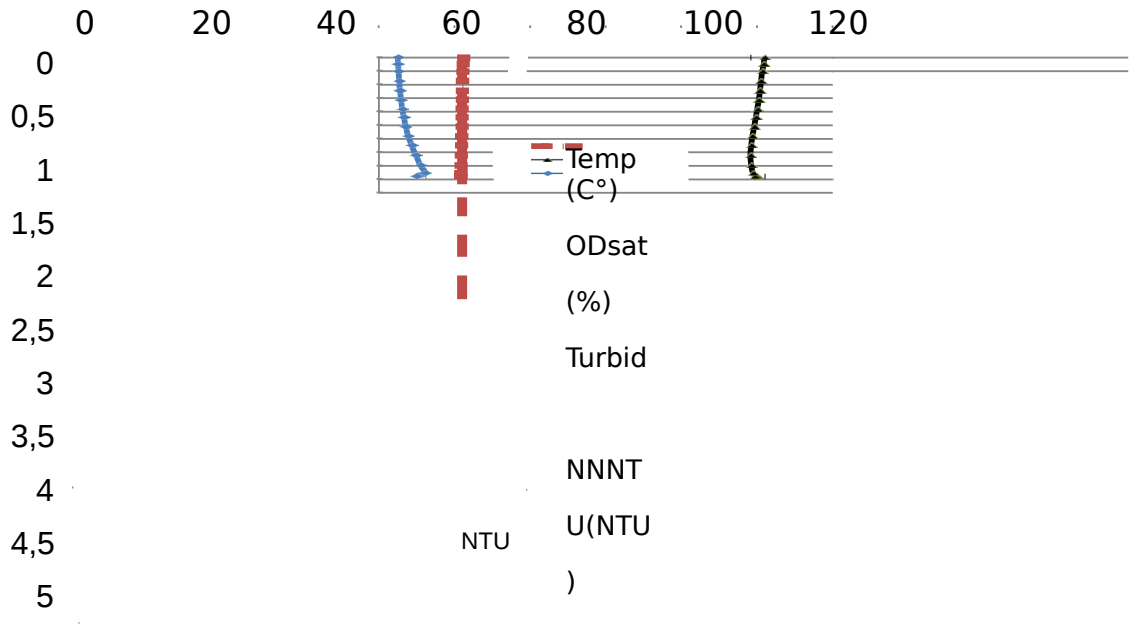


Figure 6: Profile of the physical-chemical parameters on the entire water column before the tests are carried out

NTU = nephelometric turbidity units

The values are also similar to those measured in 2006 by the Laurentian Regional Environment Council (CRE Laurentides). In their work, it appears that the lake is laminated during the summer for depth values ranging between 7m and 9m. Our tests were conducted in shallow waters, so there is no apparent stratification at this depth. It should be noted that in the case of this study, it is not so much the value of these parameters that is interesting but their variations if necessary, during a passage from "Wake Boat".

The tests were therefore conducted in good conditions because there was no impact of the stratification.

5.2.2 Wake Boat Impacts and Generated Speeds

Figures 7 and 8 present the results of the test days on Sand Lake for the 1st and 2nd day respectively. This distinguishes the results of the average intensity in the number of strokes (Figure 7a and 8a) that characterizes the intensity of the disturbance and goes so to respond to the depth of impact.

Figures 7b and 8b will indicate the speeds generated by the Wake Boat passage.

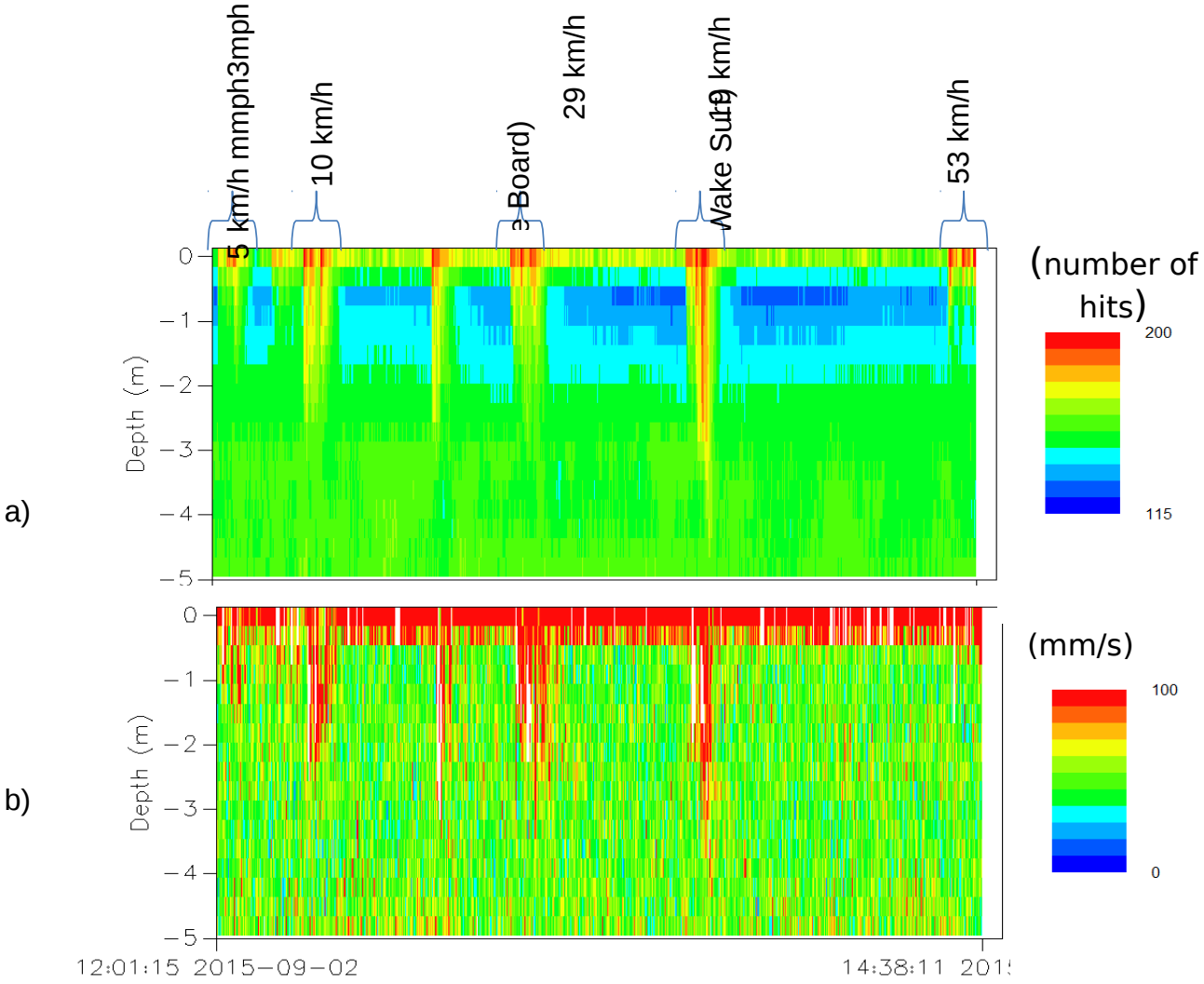


Figure 7: Average intensity (a) and speed generated (b) when the Wake Boat passes at different speeds for the 1st day of testing ***5km/hr = 3mph; 10km/hr = 6mph; 19km/hr = 12mph; 29km/hr = 18mph ; 53km/hr = 33mph.***

The number of moves allows us to define the intensity of the disturbance, it corresponds to the number of pulses received for the device. The larger the number of strokes, the more reflectors there are in the water, so the greater the number of pulses received by the ADCP. Figure 5a shows that each passage from "Wakeboat" to an impact on the water column. At 5 km/h **(3 mph)** and at 53 km/h **(33 mph)** the impacts on the water column do not exceed the meter deep. For speeds of 10 km/h **(6 mph)** and/or in Wake Board mode (29 km/h**) (18 mph)** the impacted depth is about 2.5m **(8 ft).**The impact The more important is The fashion Wake Surf (19 km/h) **(12 mph)** which is measured up to 4.5m **(15 ft.).**

Figure 7b shows the depths at which speeds of at least 0.1 m/s (0.33 ft/sec) are generated in the water column by passing boats. The correlation with figure 7a is obvious. Boat crossings at low (5 km/h) or high speeds (50 km/h) generate speeds of at least 0.1 m/s (0.33 ft/sec) up to about 1 m **(3 ft)** deep. For boat crossings at 10 km/h **(6mph)** and in "Wake Boat" and Wake Surf use, speeds of 0.1 m/s **(0.33 ft/sec)** are generated in the water column up to about 4.5m **(15 ft):**

- 2m (6.5 ft.) for 10km/h
- 2.5m (8.2 ft.) for the Wake Board
- 3m (10 ft.)for Wake Surfing

Figures 8a and 8b represent the same indicators as Figures 7a and 7b for the 2nd day respectively. The impacts are similar, but they appear clearer and more pronounced. Indeed, the adjustments made on the 2nd day in terms of navigational conditions were optimal: the rear ballasts were filled and there were 3 people in the Wake Boat to add weight. This made it more like reality because these boats are remembered as a party place where it is not uncommon to have more than six or seven people on board. The most impactful passages on the water column are clearly during the wake surf and Wake Board mode. The depth of impact can exceed 4.5 meters (15 ft) in this case.

The first peaks that appear are due to the passage over our instrumentation of a pontoon (100HP) at a speed of 15 km/h **(9 mph).** Even if this is not the purpose of the study, one can notice for this type of motorized boat, an impact depth of up to 2.20m. **(7 ft)**

The passages of boats in use "Wake surf" and "Wake Board" generates speeds in the water column of 0.1 m/s up to 4.5m and 4m respectively. It is therefore potentially possible for these vessels to resuspend sediments of 50 µm up to 4.2 **(14 ft)** to 5m **(16 ft.)** deep. Indeed, the peaks go down to a depth of 4.5m **(15 ft)** but there is a 'blind' zone due to the resonance of the transmitter (RDI, 1996) of about 20cm (0.7 ft) to 30cm **(1ft)** above the ADCP as well as the size of the device which is about 40cm. It is therefore reasonable to assume that speeds of 0.1m/**s (.33 ft/sec)** can be generated up to 5m **(16 ft).**
Unlike day one, the ballasts were filled for wake board passages. We can see the difference and the importance of this factor in the depth impacted. Indeed, with full ballasts the impact is much greater: 4m **(13ft)** instead of 2 **(7 ft)** to 3m **(10 ft).**

The maximum speed generated in the water column reaches values of 0.6 m/s to 0.7 m/s (2 – 2.3 ft/sec) when the boat goes into Wake surf mode. There is therefore a low impact (about 1m) (0.6 ft) for low or high boat speeds and a strong impact (up to 4.5m (16 ft.) to 5m (16 ft)) for intermediate boat speeds.

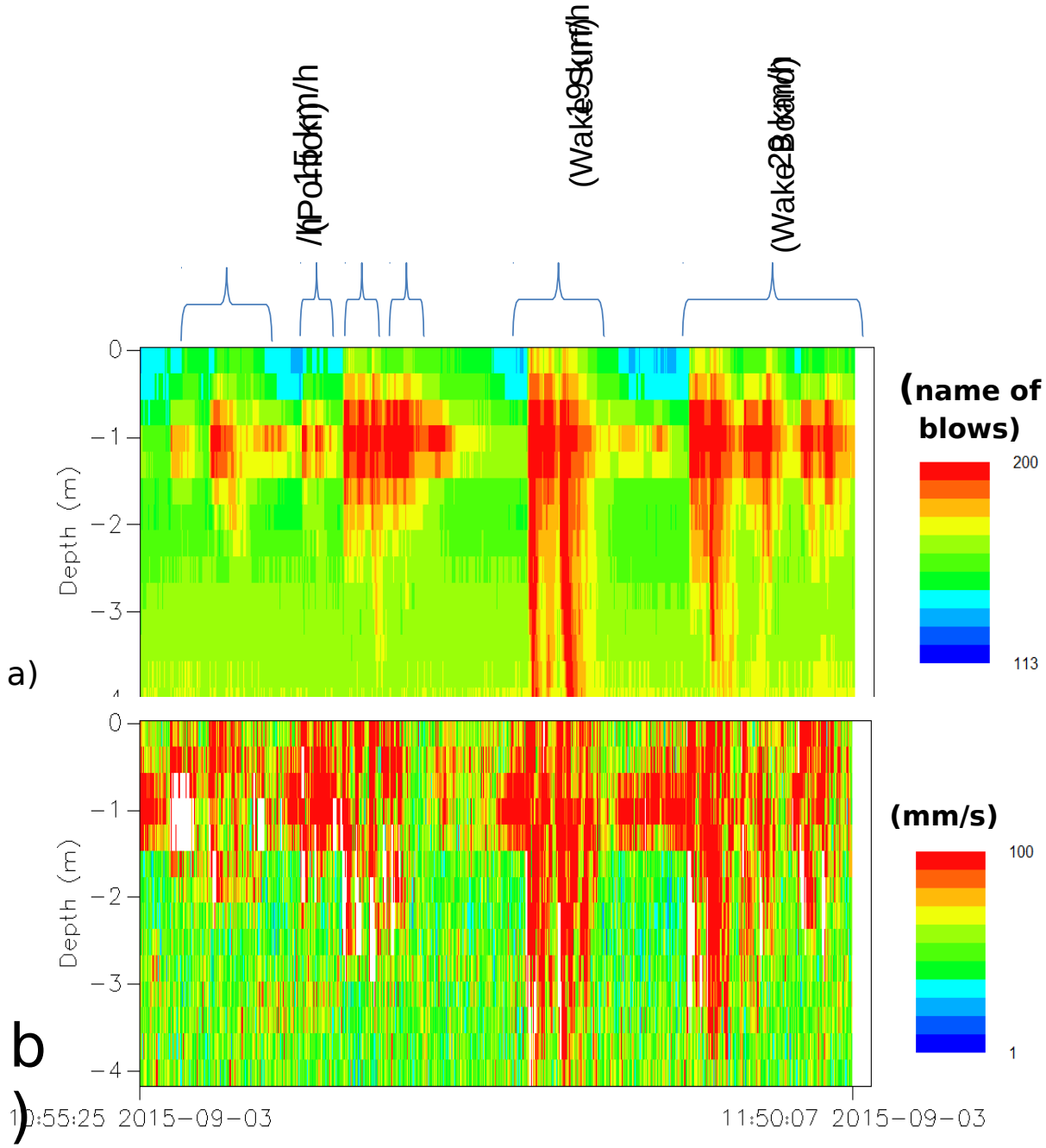


Figure 8: Average intensity (a) and speed generated (b) when the Wake Boat passes at different speeds for the 2nd day of testing

It is also important to know the duration of this impact in the water column. Figure 9 measures the duration for the wake surf for the 2nd day.

Each is framed in black and measures between 72 and 80 seconds. We can clearly see in the3rd passage the movement of the disturbance in the water column and in the time.

The individual impact of each pass is therefore well marked and lasts a few minutes.

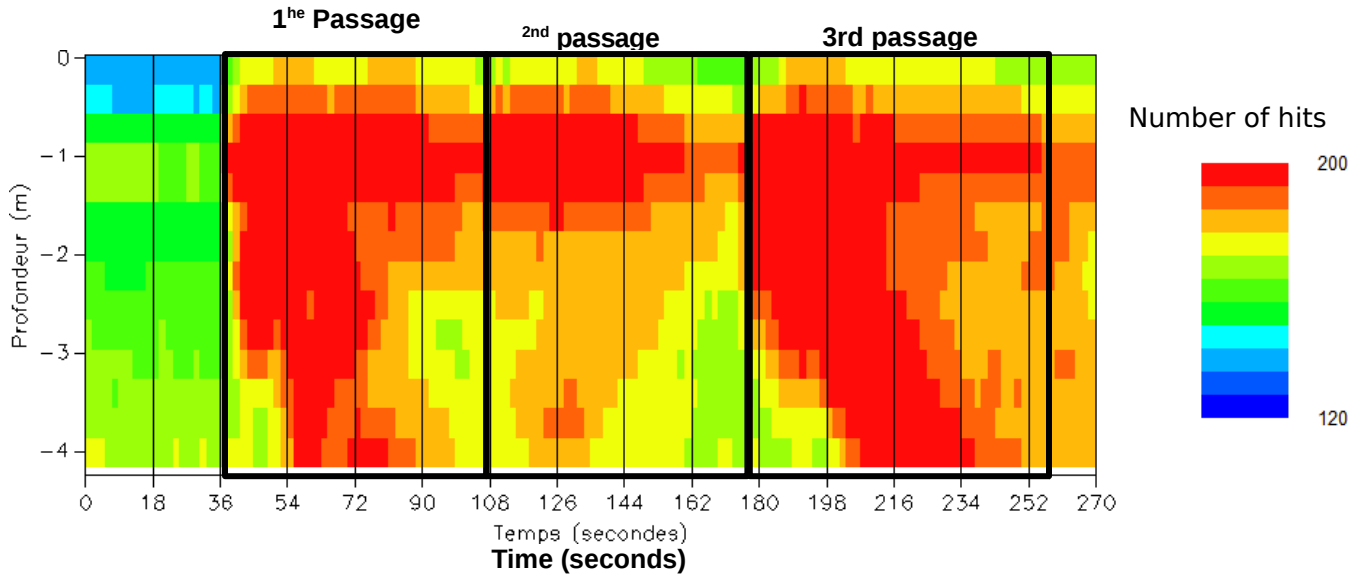


Figure 9: Zoom of Figure 8a on the passages of boats in Wake surf mode for the 2nd day on The Sand Lake

5.2.3 Changes in parameters at the bottom of Sand Lake

Using multiparametric probes, turbidity (Figure 10a), conductivity (Figure 10b) and dissolved oxygen (Figure 10c) parameters were measured at the bottom of Sand Lake during boat crossings. Figure 10 thus shows the complement of these three parameters in time for the 2nd day of measurements on Sand Lake. This day is selected because it is the one whose impact on the water column is most marked. The absolute values of the parameters are less important to us here than their variations. However, there is no significant variation in these parameters, despite the fact that speeds of 0.1 m/s are generated at these depths.

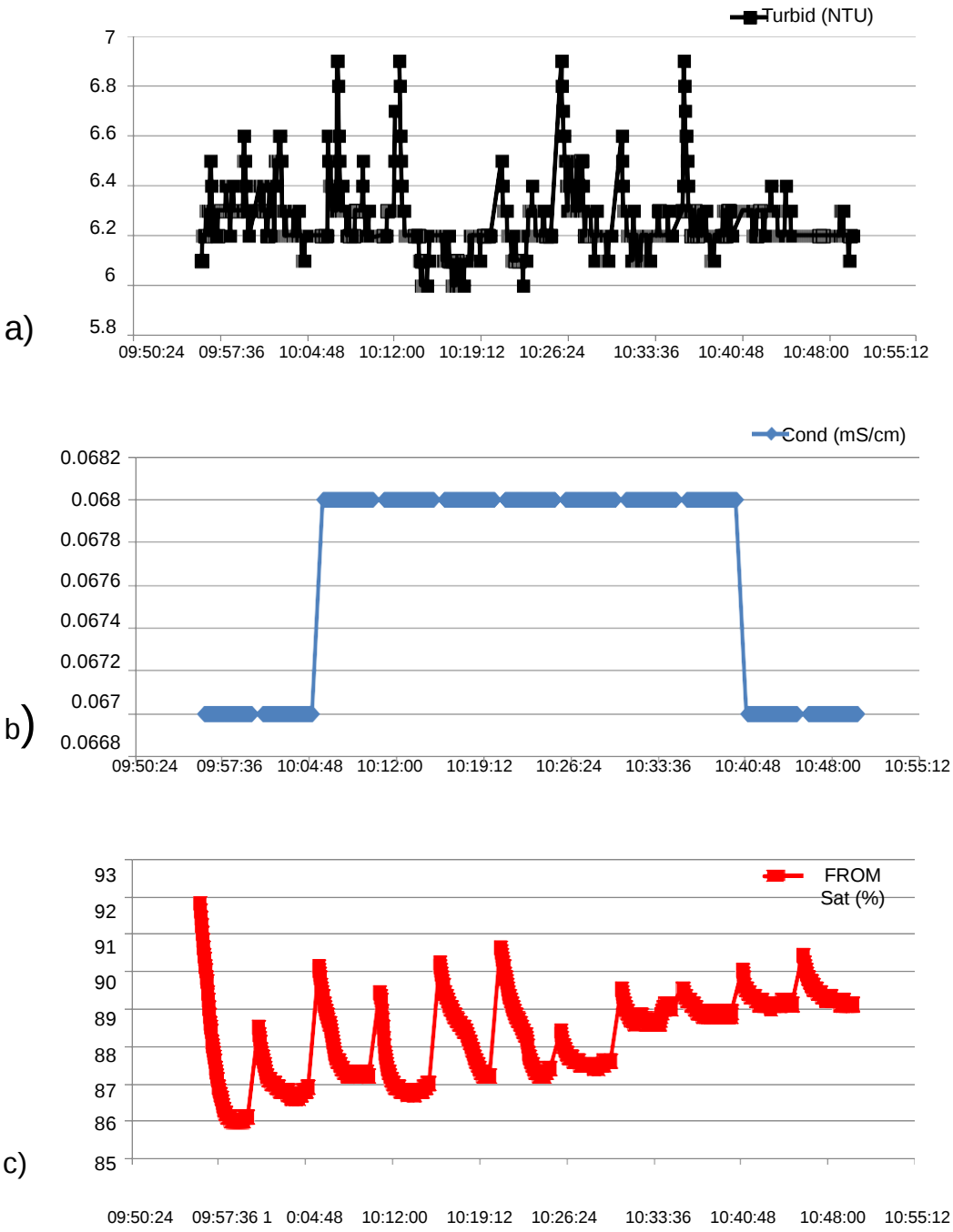


Figure 10: Time evolution of conductivity, dissolved oxygen and turbidity parameters at the bottom of Sand Lake for the 2nd day of measurements

This was confirmed by the observations of the diver visible in Figure 11. He did not notice any material suspended as a result of the passage of the boats. The most plausible hypothesis is that the granulometry of the bottom sediments is mostly greater than 50µm in this part of the lake and therefore requires speeds greater than 0.1 m/s to resuspend sediments in the water.

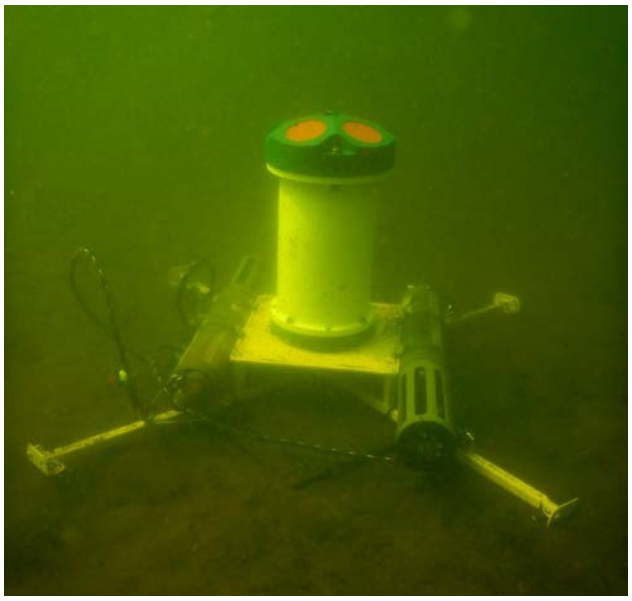
a)  b)

Figure 11: View of the experimental device before (a) and 2 minutes after (b) the passage of a "Wake Boat"

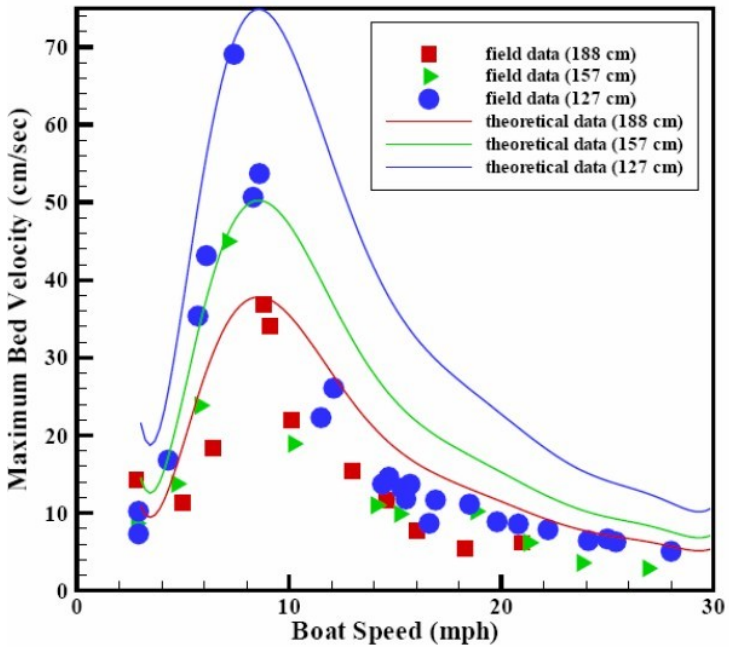
6. DISCUSSION

It is important to compare the results obtained with those obtained by other researchers in previous studies.

6.1 Previous impact studies

Using other methodologies and/or technologies, several authors have measured the impact of motorboats. These boats have strengths of up to 150 HP. They measure a release of phosphorus for depths of 1.5 to 3.4 m **(5–11 ft.)** (Youssef, 1980) and estimates that boats are responsible for at least 17% of total phosphorus intakes during the summer season (James et al, 2002). Anthony and Downing (2003) observe an increase in turbidity for lake depths ranging from 127 to 188 cm **(4 – 6 ft)**. They estimate that low-speed vessels and high-speed vessels do not induce deep water movement compared to intermediate speeds as shown in Figure 12. The results even indicated that a speed of 30 mph (48 km/h) had less impact than a speed of 3 mph (5km/h).

Figure 12: Speeds near sediments based on boat speed after Anthony and Downing (2003)



These studies are in line with our results with respect to impacts at low and high pass speeds. The depths measured are lower than those of this study, but the vessels used at the time did not have150HP. They also did not have the technologies to measure disturbances in real time.

Some studies have found that outboard engines have more impacts than intermediate-lived internal engines, and vice versa at high speeds. But in general, the three types of engines (outboard, in-house and marine motorbike) caused water to move near the similar bottom (Anthony and Downing, 2003). These conclusions are to be qualified because the depths of the tests are very small (less than 2 meters). In view of our results and in view of the evolution of the boats over the last 15 years, it is reasonable to think that the different types of engines will impact the lake differently in terms of depth and speed.
There was no stratification of the lake at the depths tested, but it could limit the impact of boats on sediments by its resistance to mixing (James et al., 2002).

6.2 Speeds generated at the bottom of the lake

Sediment suspension is correlated with depth speed, low at low or high boat traffic speeds, and maximum at intermediate speeds. Beachler (2002) theoretically indicates, and observations confirm, that the rate of movement of a 0.3 mm **(0.01 in)** sand particle is about 25 cm/s **(.8 ft/sec)** while a clay particle of 50 µm requires a water velocity of 12 cm/s **(0.4 ft/sec).** A particle of 2 µm requires a speed of 2.5 cm/s **(0.08 ft/sec).**

The results show that this can be achieved when the Wake Boat is in Wake Surf, about 12 mph (19 km/h).

Several models have been developed linking depth, engine strength and particle size (Figure 13). However, this work stops at a power of 200HP which prevents the results from being correlated but offers interesting prospects for future research. However, they confirm that the higher the power of the boat, the greater the speed of this study using much more powerful boats, so it makes sense that the impacts obtained reach depths not yet observed, namely 5 m.

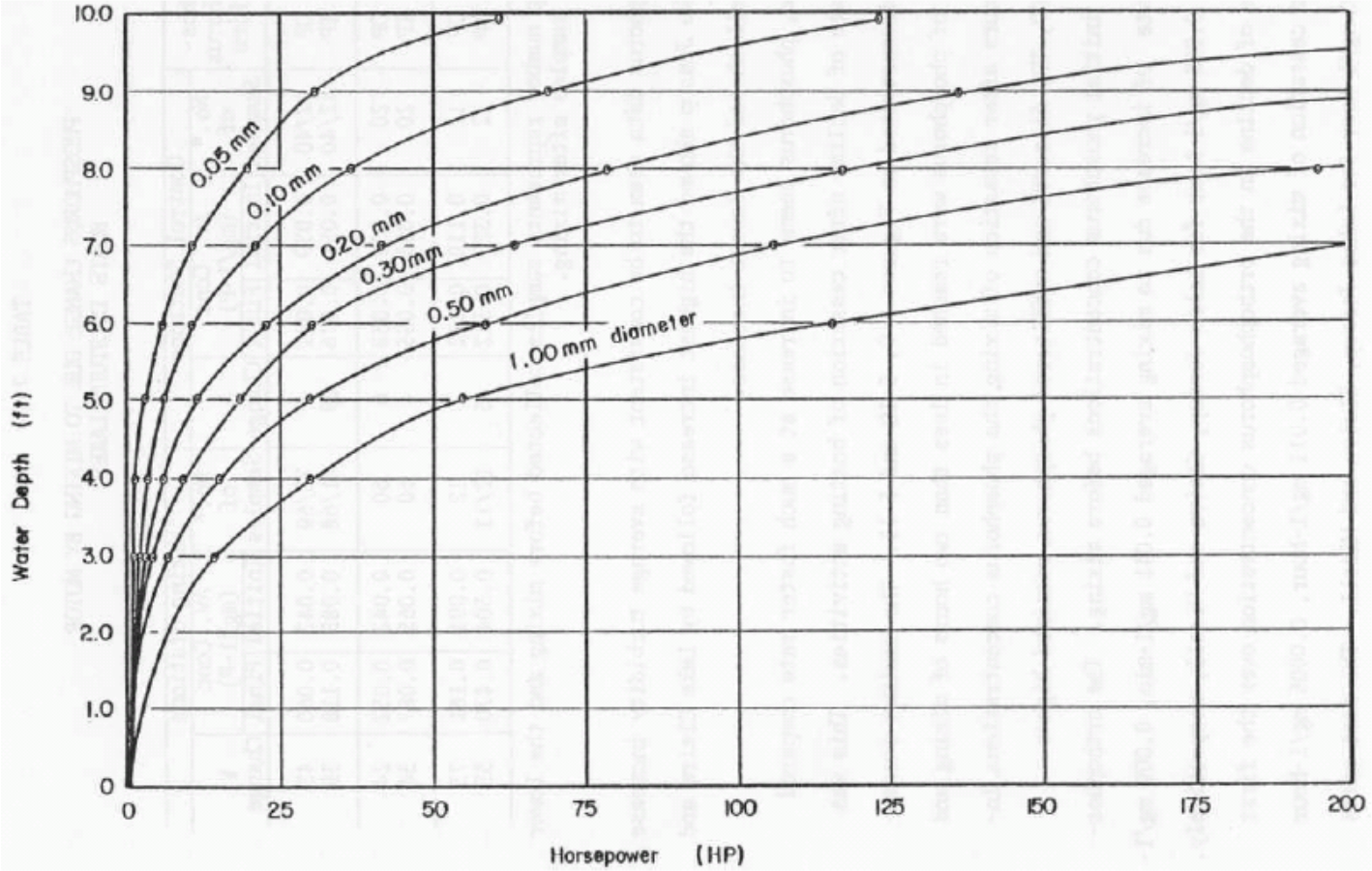


Figure 13: Calculations (graph?) produced by Youssef (1978) linking the power of a boat (HP) and the maximum disturbance depth of particles of different sizes according to Beachler (2002).

It is important to mention that if the speed of movement is reached near the bottom, this does not involve the suspension of the particle. The speed of movement must indeed be higher than the rate of sedimentation described by Stokes Law.

6.3 Oxygenation and phosphorus transfer?

One comment that comes up regularly by wake boat users concerns the oxygenation of the bottom of the lake. Repeated "Wake Boat" passages would thus be useful and beneficial to the health of the lake by introducing oxygen into the water column. This theory is obviously wrong. Bottom sediments are often phosphorus reservoirs in lakes, when boating, if suspended then the boats could even contribute significantly to the transfer of phosphorus into the water column. In oxic condition, a parameter that seems important in the release of PO_4^{3-} is pH. The higher (basic) it is, the higher the release of PO_4^{3-} (James et al 2002). Similarly, the temperature appears to be aborting the release

of phosphorus, suggesting the dominance of biological processes under oxygen-rich conditions. In oxic condition, brewing would therefore be favorable to the lay-off of the PO^{3-} contained in the sediments. This allows us to consider scenarios that could be harmful to the health of the lakes. It could be said that several Quebec lakes meet the following adverse conditions:

- Passage of many Wake Boat boats
- Phosphorus-rich sediments
- Low depth so no stratification and rich in oxygen on the whole water column or introduced by the "Wake Boat"
- pH due to the presence of microphyll with ears (Raymond and Galvez, 2014)
- High temperature

All of these conditions promote the release of phosphorus under oxic conditions and thus promote the phenomenon of eutrophication or accelerated aging of the lake.

7. CONCLUSION AND PERSPECTIVES

Boating on Quebec's lakes is constantly increasing. Wake Surfing practices and the power of boat engines continue to grow. These practices have a significant impact on the water column and would increase water turbidity, total phosphorus and orthophosphate concentration, dissolved oxygen near the bottom and thus the potential for oxydo-reduction and would reduce the sediment consolidation. Total phosphorus release and especially orthophosphate may be a factor in premature aging of lakes called eutrophication. This increase in phosphorus in the water column can also promote the development of cyanobacteria **(Blue-Green Algae)**, which is becoming a major problem in many Quebec lakes.

The objective of this study was to assess the impacts in the water column by Wake Boat, which are motorized boats with a power of more than 350 hp. These impacts were measured here for the first time using ADCP technology. This tool can determine the depth and speeds generated by the passage of boats in real time. The innovative nature of the study therefore depends as much on the nature of the boats and practices tested as on the technology used to quantify impacts. The questions that can be answered relate to the depth of the impact and the velocity generated in the water column.

In terms of depth, the results show that at low and high boat speeds (5 km/h **(3 mph)**, 10 km/h **(6 mph)** and maximum speed), there is a limited impact on the water column not exceeding 1 to 2m **(3-6 ft)** deep. Wake surfing and wake board practices impact the water column up to 5 m **(16 ft).** No study has yet quantified an impact of this magnitude on the lakes. This disturbance has also been quantified over time, allowing to determine a duration going to vary between 70 and 80 seconds.

For speeds, speeds are greater than 0.1 m/s **(.3 ft/sec)** up to 5m **(16 ft)** for wake surfing and 4m **(13 ft)** for wake board. These velocities are theoretically capable of carrying particles 50 µm in diameter.

Under the conditions studied, the wake surf/Wake board has the potential to impact the water column and remobilize bottom sediments up to 5m for more than a minute.

These results are to be compared with those held by Mercier-Blais and Prairie in 2014 who evaluated that during the "Wake surf" and "Wake board" practices, the surface wave created needed at least 300m to lose its energy and no longer erode the banks.

Thus, for a responsible and sustainable navigation it is necessary to prevent the impact of boats on shoreline erosion, on the suspension of sediments, and thus the availability of phosphorus in the water column. It is therefore necessary to advocate a practice of Wake Surf and Wake Board (with 350HP boats) in areas 600m wide and at least 5m deep. If one of these conditions is not met, then these navigation practices must be limited/framed as they impact the environment. Other recreational boating practices should also be monitored with speeds of no more than 5km/h in areas below 2m deep and 10km/h in 2 to 5m zones.

The study here is limited to the Wake Boat, which is required to have a full range of impacts, other types of motorized craft will need to be considered and studied. The same tests can be done with all types of boats (motorized or not) and this on the water column as well as on the lateral impact of surface and banks. This would allow for a clear and complete view of the impacts and would recommend lake navigation conditions that would have little or no impact.

In order to complete this, it would also be interesting to take into account the traffic on the lake. It has been determined here that a "Wake Boat" passage alone has an impact over a period of more than one minute, but what happens if another passage takes place in the same area and in the same minute? Is there a cumulative effect of the passages and therefore an even greater depth of impact? This would involve different sailing conditions, should we increase the depth even further, train the drivers not to pass in the same places, limit the maximum number of boats on the lake?

This study is an important first step in understanding the impacts of motorized boats enabling responsible and sustainable navigation. However, there are still many elements and conditions to be explored in order to have a complete picture of the types of practices, ridership on lakes in Quebec and Canada, and impacts on water quality and shoreline erosion.

8. REMERCIEMENTS

This pioneering project has benefited from the financial support of more and more sponsors whom we would like to thank:

- **Lac-Masson in Estérel and Ste-Marguerite-du-Lac-Masson**
    - MRC of the High Countries
    - Municipality of Estérel and its mayor Jean Pierre Neveu
    - Municipality of Ste-Marguerite-du-Lac-Masson and its mayor Gilles Boucher

- **Lac-des-Sables in Ste-Agathe-des-Monts**
    - City of Ste-Agathe-des-Monts
    - The Landing Committee, of the Association for the Protection of the Environment of Sand lake

- A special mention to all the volunteers who kindly donated their time, their materials and who allowed the realization of this study:
    - Roger Martel (membersof the Estérel CityCouncil)
    - Christine Corriveau (members of estérel City Council)
    - Luc Lafontaine (Ceo of the City of Estérel)
    - Daniel Piché
    - Maxime Piché
    - Marc Legault
    - Gilles Morin

- We also thank Mr Jean-Pierre Dumoulin of Xplorations Without Limits who dived to allow the proper installation of the instrumentation as well as for the sharing of this knowledge and his sympathy.

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