Flow Dynamics In An In-Water Algal Growth System

A thesis submitted in partial fulfillment of the requirements for the degree of Bachelor of Science degree in Physics from the College of William and Mary

by

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Abstract

This paper aims to characterize the flow dynamics in an in water algal growth system. Algal harvesting has the two-fold purpose of removing pollutants from the environment while generating an alternative fuel source. This paper looks at two sets of data taken in two different bodies of water. The first set of data comes from when the Research Platform was in the York River while the second set of data comes from when the Research Platform was moved into Lake Matoka. A Nortek Vectrino Velocimeter was used to measure the velocities of the water flow in three different directions. From this measurements, a power spectrum was created to compare the two sets of measurements. Kolmogorov's 3/5ths law was applied to both sets of spectra to determine the extent of turbulent flow.

Introduction

Although nitrogen and phosphorous discharges into the Chesapeake Bay have been declining in recent years, there were 264 million pounds of nitrogen and 35 million pounds of phosphorous added to the Bay in 2011(1). This excess of pollutants is troublesome as it fuels algae growth. When the algae die, they inevitably sink to the bottom of the Bay where bacteria decomposes it. In the decomposition process, oxygen is consumed and nitrogen and phosphorus are released into the Bay. The fuels even more algae growth, which then dies, and is decomposed once more. Again, more oxygen is consumed and nitrogen and phosphorous are re-released into the bay perpetuating the cycle. This problem in this cycle is that oxygen is never replaced and dead zones emerge. These dead zones are incapable of supporting life due to a lack of oxygen (2). The dead zones are not isolated in the Chesapeake Bay; "dead zones have now been reported from more than 400 systems, affecting a total area of more than 245,000 square kilometers, and are probably a key stressor on marine ecosystems" (3).

The ultimate goal of algae harvesting is twofold: remove excess nitrogen and phosphorous from the environment and simultaneously provide an alternative source of fuel to oil. Since algae have a high natural growth rate, it consumes excess nutrients quickly. Harvesting algae from the Chesapeake Bay breaks the cycle by preventing bacteria from decomposing it and thus prevents oxygen depletion in the Bay. Harvested algae lipids can be turned into biodiesel and it carbohydrates fermented into ethanol (4).

The objective of my work will be to determine and characterize the flow inside the York River Research Platform (YRRP). Algae growth depends on a water flow to provide the necessary nutrients for growth. Thus algae growth could be deterred by the removal of nutrients (removal or pollutants) or by insufficient water flow to bring in nutrients. The transverse and velocity and the flow velocity are of importance. It has been determined that sloshed, pulsed flow enhances the growth of the algae (5). The flow through the platform will determine how much water will be treated by the algae and how nutrients will be distributed to the algae. This project will measure the turbulent flow through the platform.

Kolmogorov's 3/5ths law provides a relationship between the energy spectrum, *E*, the energy flow ϵ, and the wave number *k*

$$E(k) \approx C\varepsilon^{2/3}k^{-3/5}$$

Assume the energy flow is constant

$$E(k) \approx Ak^{-3/5}$$

with *A* as a scaling constant

Procedure

I analyzed measurements from May 17, 2012 taken at the York River. 15 different measurements were taken along the width of the platform between two screens using a Nortek Vectrino Velocimeter (description in Appendix). The first measurement was up against one of the screens and subsequent measurements were in 5mm increments from the screen. Each measurement was taken at a frequency of 50hz and last about 90 seconds long with a few exceptions. Measurement 1 was cut short on accident, Measurement 11 was longer than 90 seconds due to a wake that came by, and Measurement 15 was cut short due to the death of the computer battery. All measurements were taken at the same (unknown) depth. Assuming that the Vectrino was inserted into the water as in Figure 1, the Z direction is the flow direction, the X direction is the vertical direction and the Y direction is the transverse direction: I show sample data for Measurement 8 since it is at the halfway point of the measurements taken.

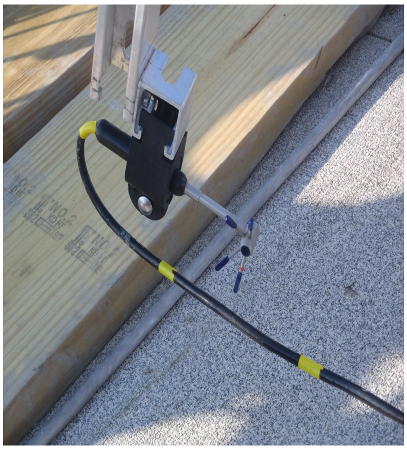


Figure 1: Vectrino Mount for the York River Measurements

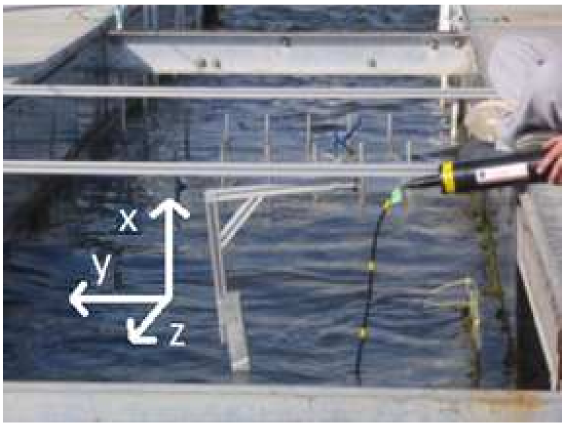


Figure 2: Vectrino in the water and axis for York River Measurements. (7)

The platform was moved into Lake Matoka and I took more measurements there. First I verified the direction of the X, Y, and Z-axis relative to the Vectrino. I hooked up the Vectirno to the computer and inserted into the water. I moved the Vectrino in each of the three directions, one direction at a time. Each movement corresponded with a velocity increase in a distinct direction. Figure 3 shows in which are the X, Y and Z directions relative to the Vectrino.

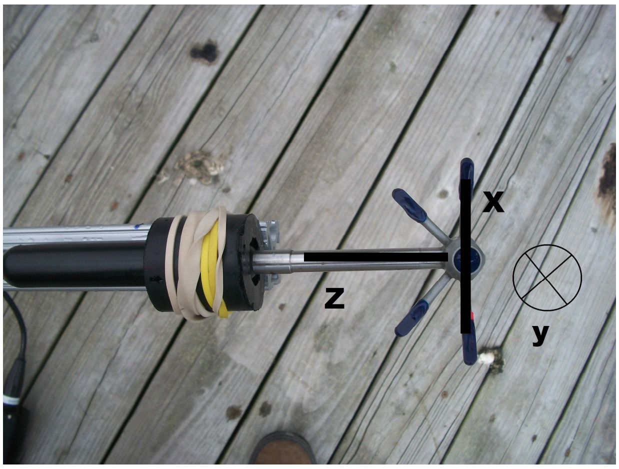


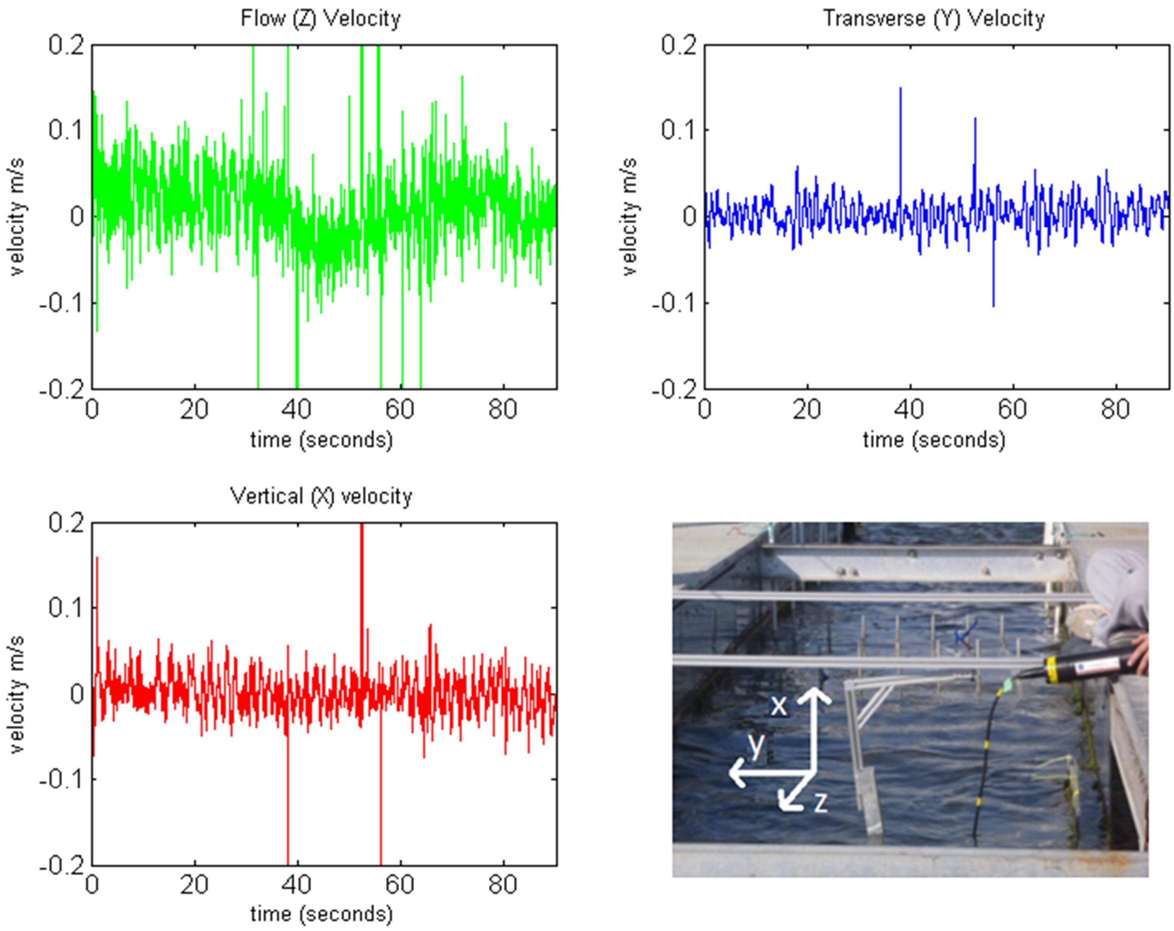
Figure 3: Axis for the Matoka measurements relative to the Vectrino. The x-direction is along the red beam, the y direction is into the page and the z direction is in the direction of the beam the Vectrino is attached to.

I inserted the Vectrino into the water so that the Z-axis was perpendicular to the surface of the water due to the mount displayed above being unavailable. This makes the Z direction the vertical direction, the Y direction the flow direction, and the X direction the transverse direction.

I took measurements both inside and outside the platform at depths of 5 inches and 15 inches from edge of the Vectrino. There were no screens at in the platform at the time of the measurements were taken and the pump was not on due to a lack of power. The inside measurements were taken in the cage closest to the platform, approximately at the center. Each measurement was 70 seconds long and taken at a sampling rate of 50 Hertz. I held the Vectrino in place by attaching it to a beam and holding the beam with my hand.

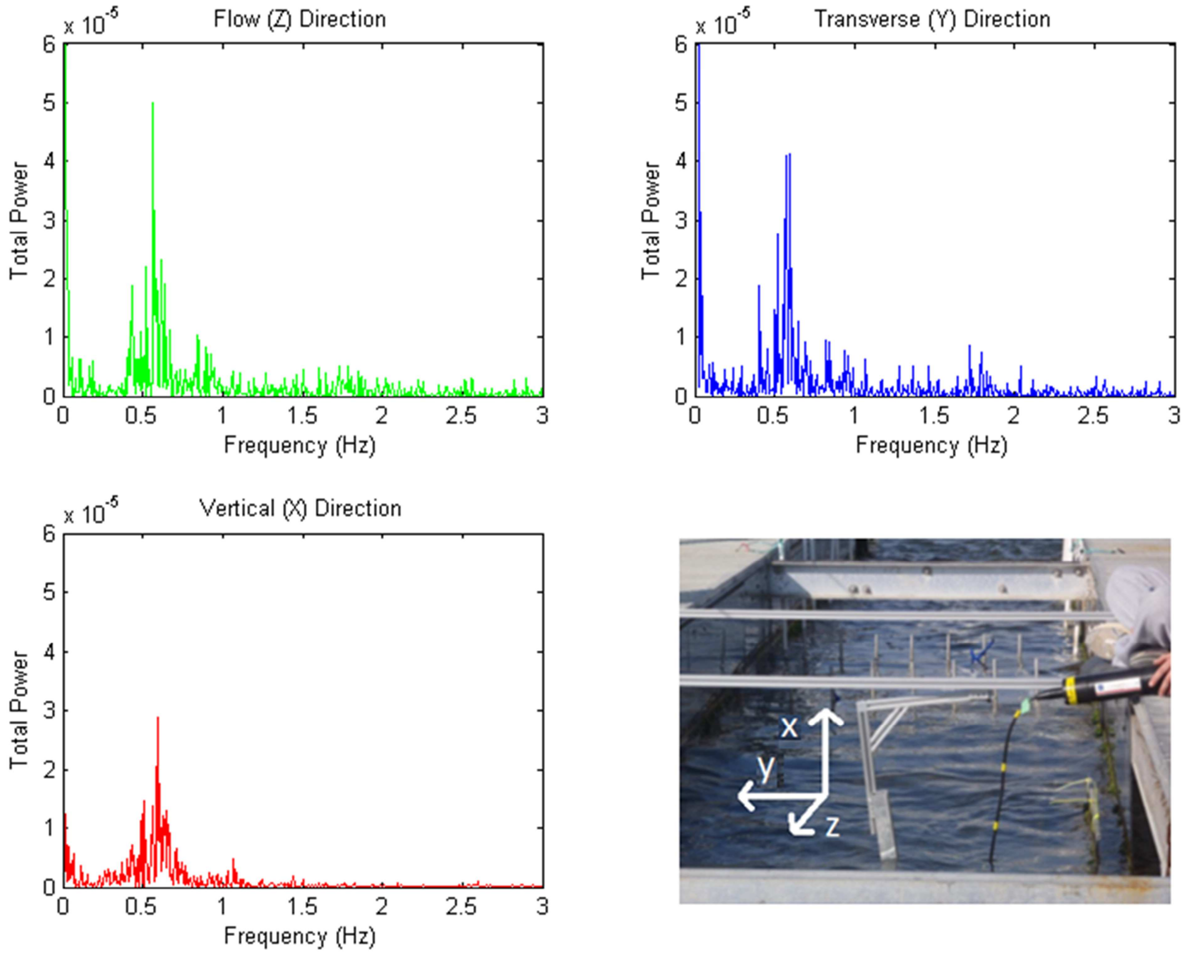
Data and Analysis for York River Measurements

Velocity vs. Time Plots for Measurement 8, 0.35mm From Screen



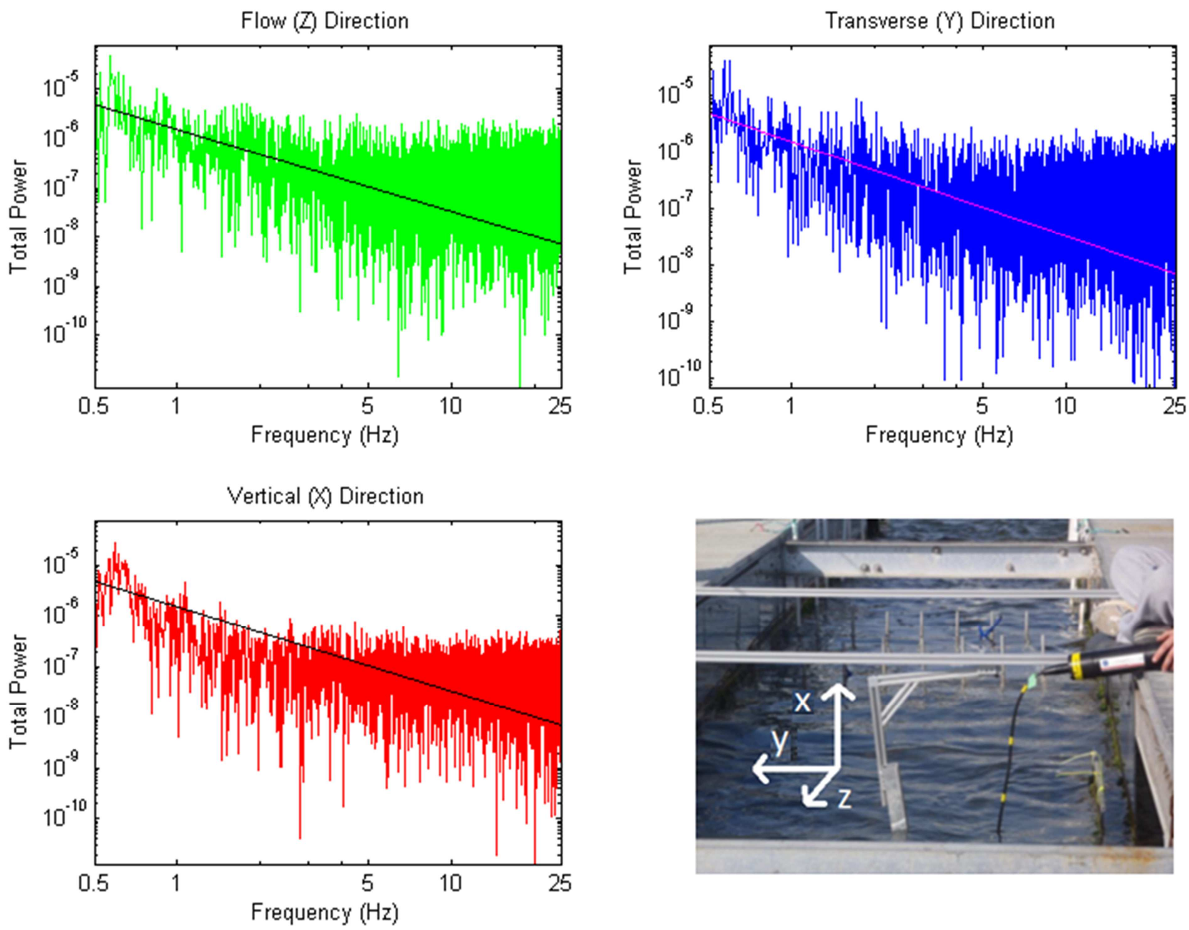
The graphs contain 4500 data points. The velocity of water in the platform is periodic with time for all three directions. This holds for all other measurements in all directions and suggests that sloshed, pulse flow occurs. The flow (Z) velocity seems to have the highest magnitudes. The periodic nature allows us to take the Fast Fourier Transform to obtain the power spectrum.

Power Spectrum for Measurement 8, 0.35mm From Screen



All the Fourier Transforms for each of the direction and each of the measurements are similar the same in the sense the low frequency behavior is exhibits the highest velocities. As the frequency increases, the velocities decrease. In the low frequency region, the graphs peak between 0.5 Hertz and 1 Hertz.

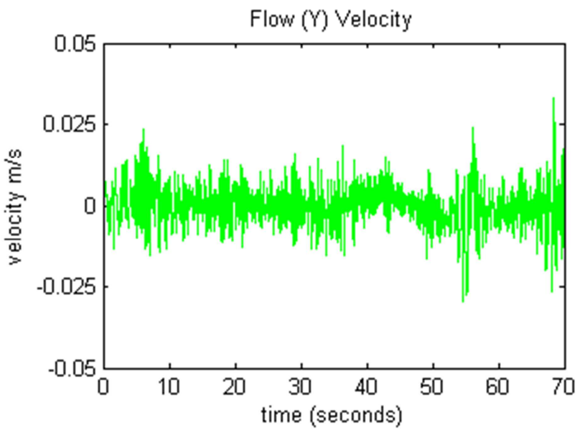
Power Spectrum for Measurement 8, 0.35mm From Screen (log scale)

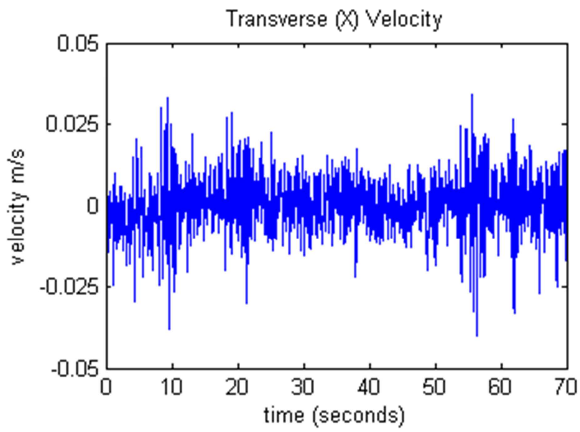


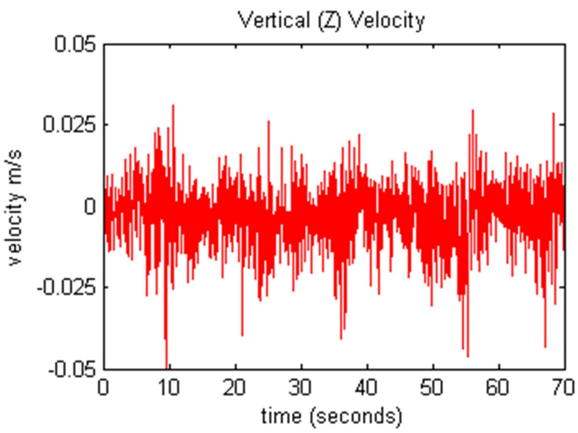
For A = 10^{-9} the plots fit Kolmogorov's equation for low frequencies. This supports the notion of turbulent flow in between the screens.

Data and Analysis of Lake Matoka Measurements

Inside the Platform, 5 inches deep

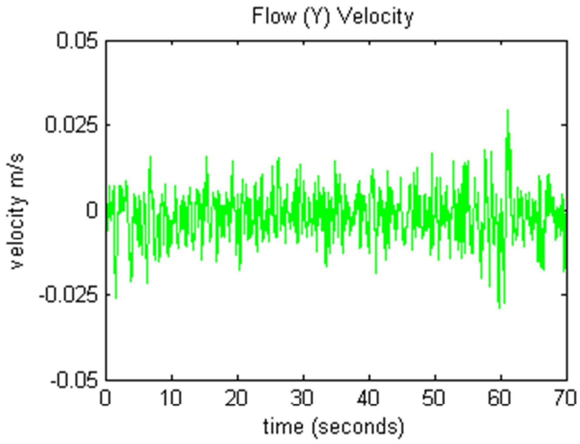


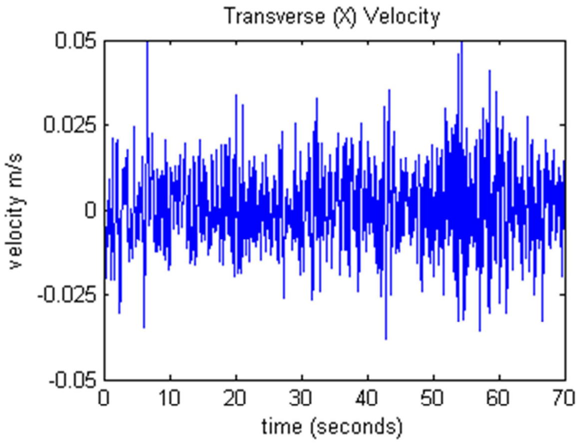


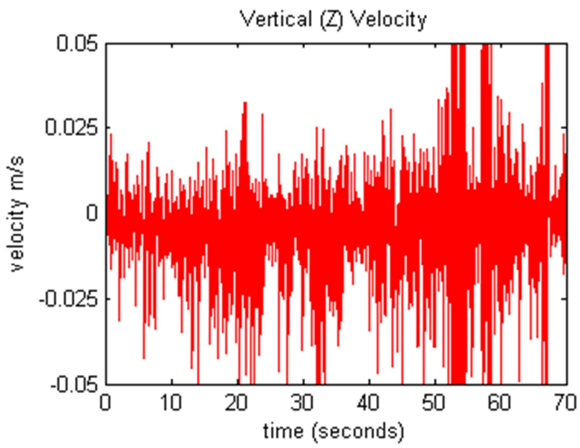


z is perpendicular to the water

Inside the Platform, 15 inches deep

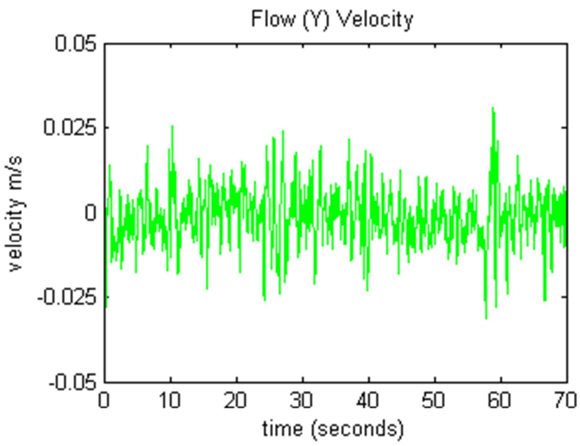


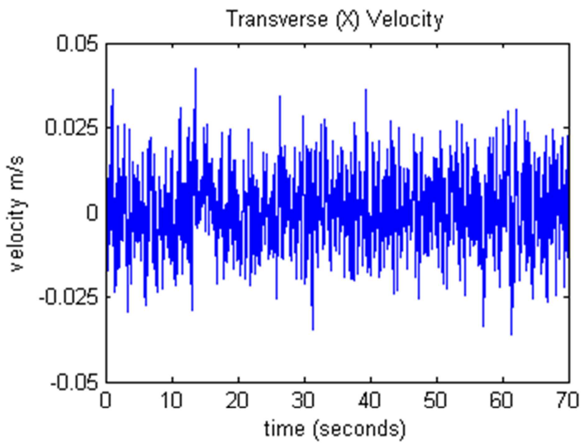


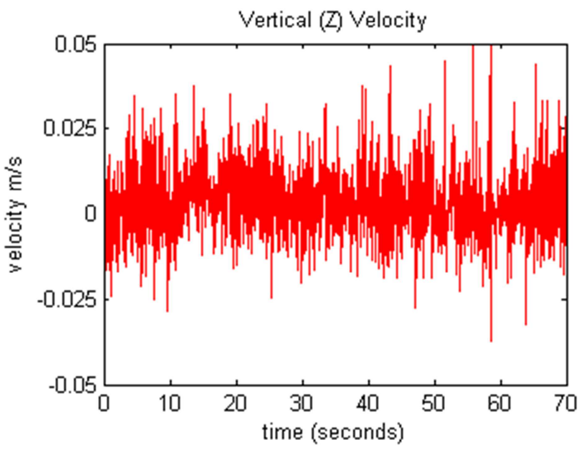


z is perpendicular to the water

Outside the Platform, 5 inches deep

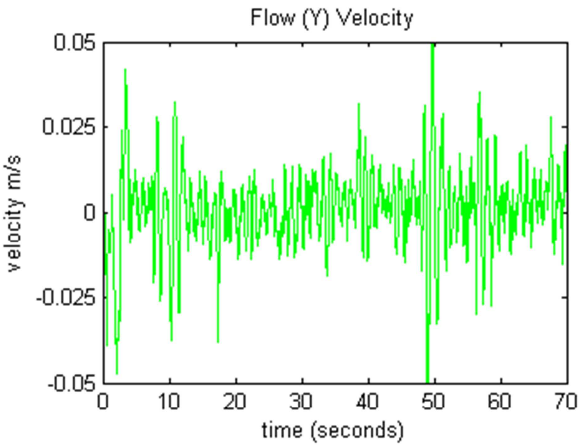


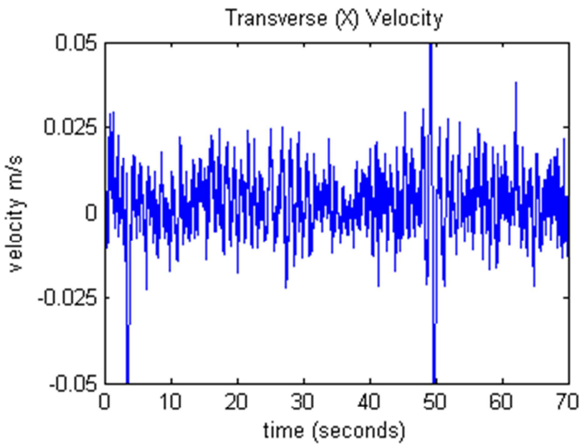


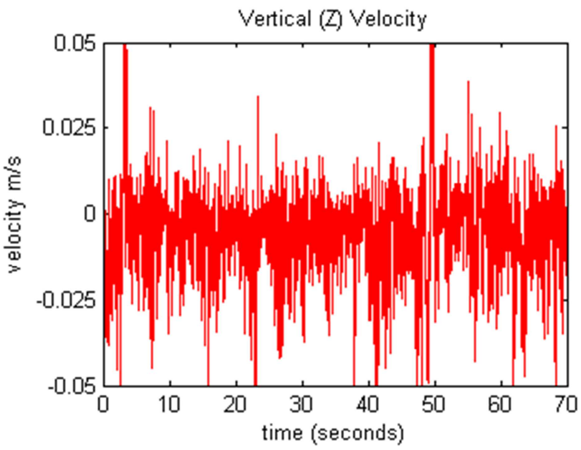


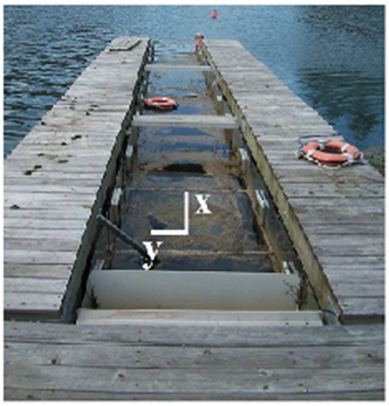
z is perpendicular to the water

Outside the Platform, 15 inches deep





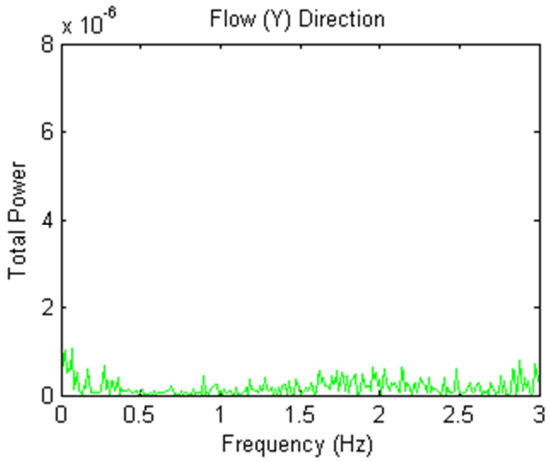


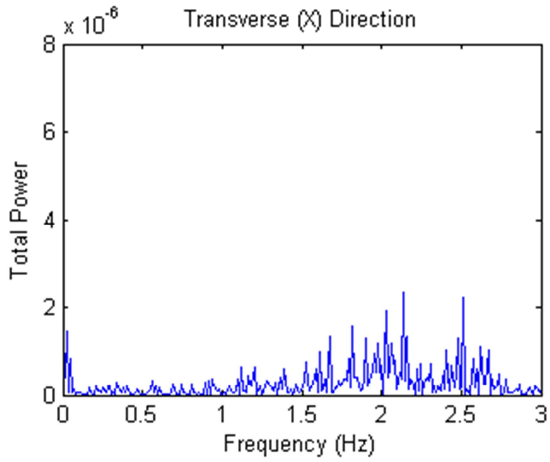


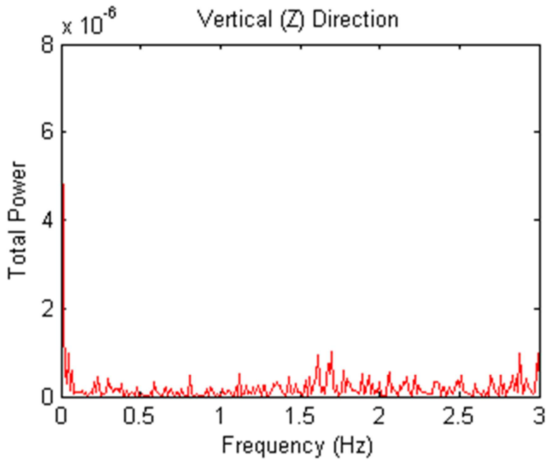
z is perpendicular to the water

The graphs contain 3500 data points. Again the velocities are periodic in time for all measurements in all directions. This suggest pulsed flow occurs and once again allows us to perform a Fourier Transform and obtain the power spectrum. The magnitude of the flow direction appears to be much smaller for the measurements in Lake Matoka than the measurements in the York River.

Power Spectrum, 5 inch depth inside

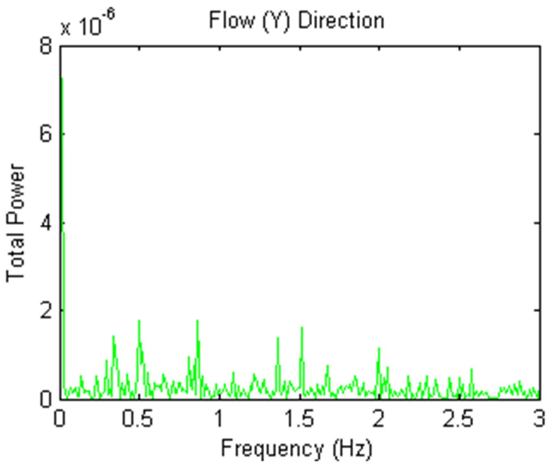


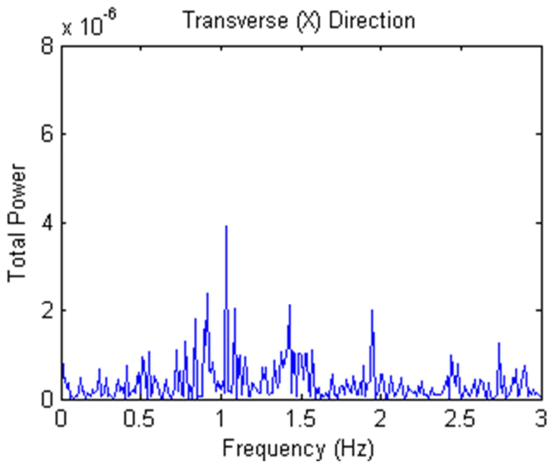


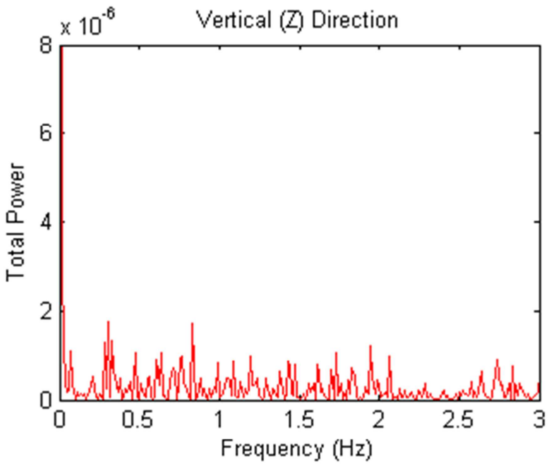


z is perpendicular to the water

Power Spectrum, 15 inch depth inside

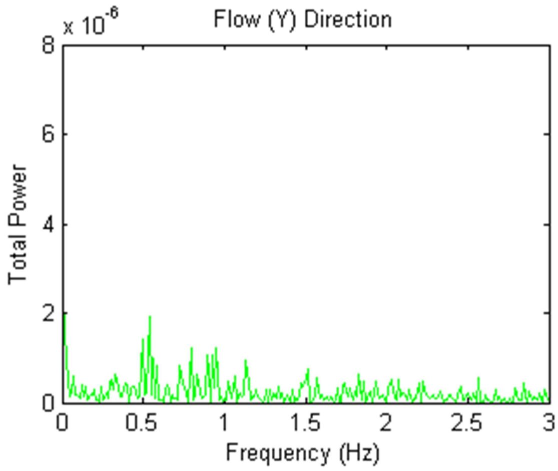


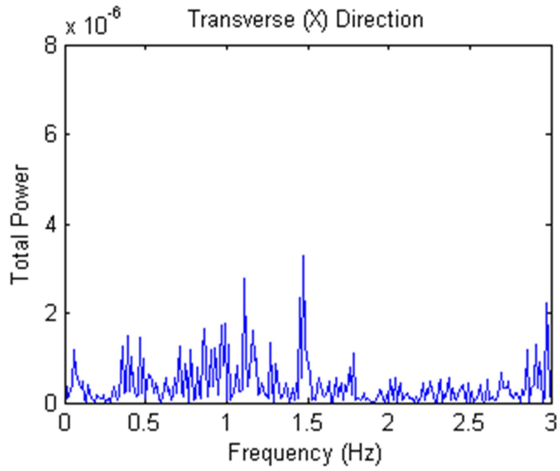


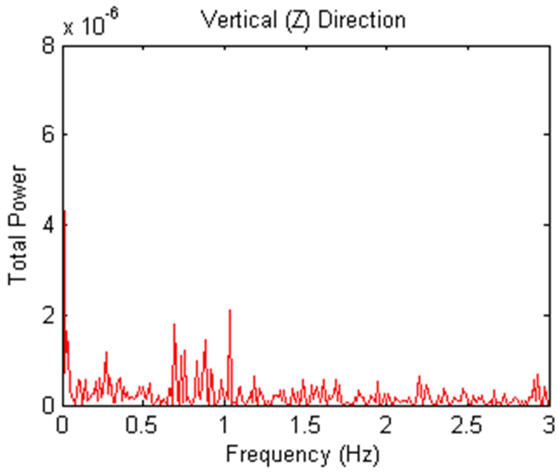


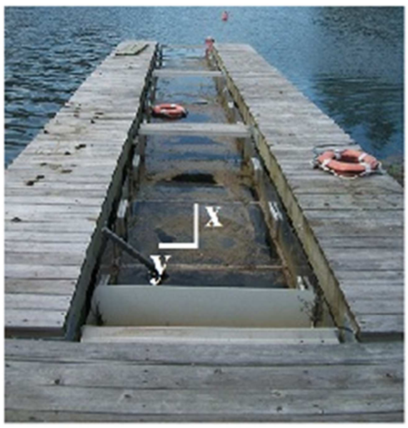
z is perpendicular to the water

Power Spectrum, 5 inch depth outside



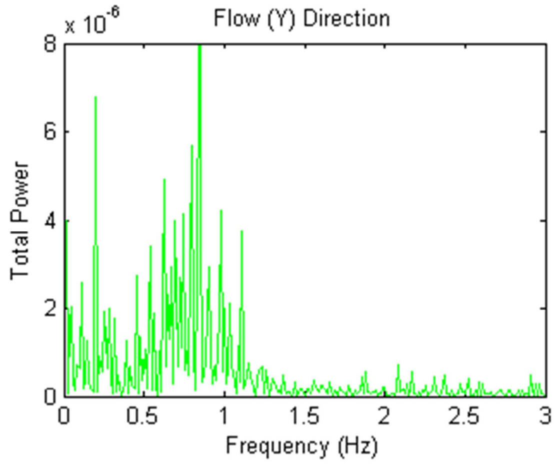


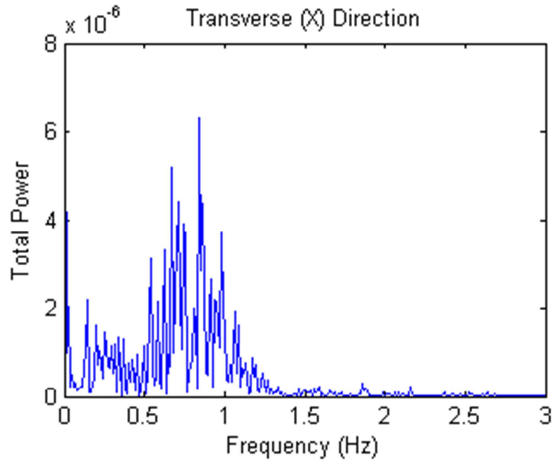


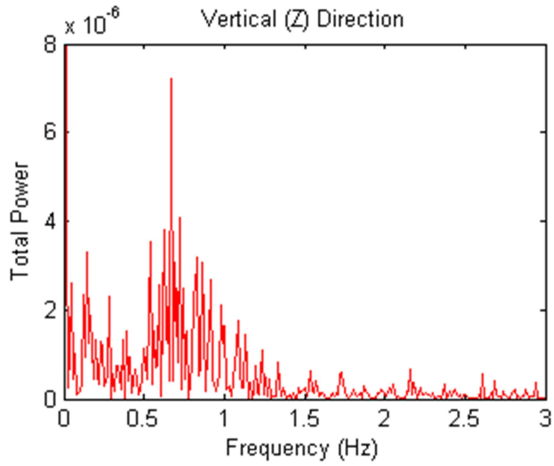


z is perpendicular to the water

Power Spectrum, 15 inch depth outside



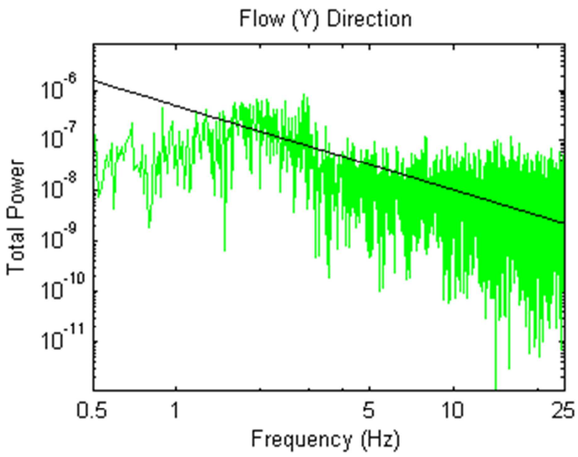


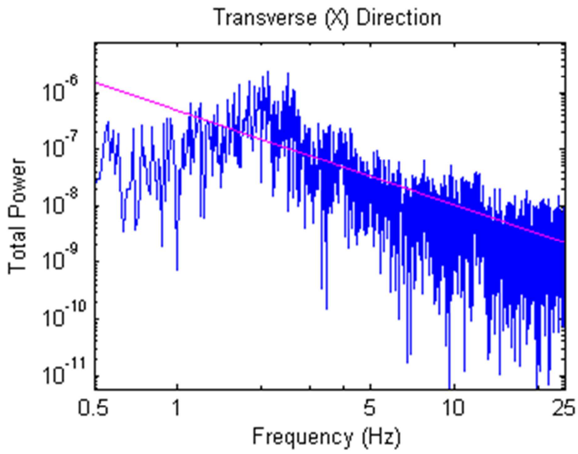


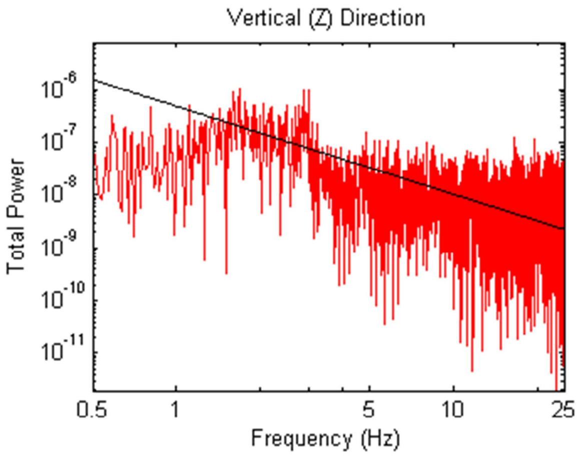
z is perpendicular to the water

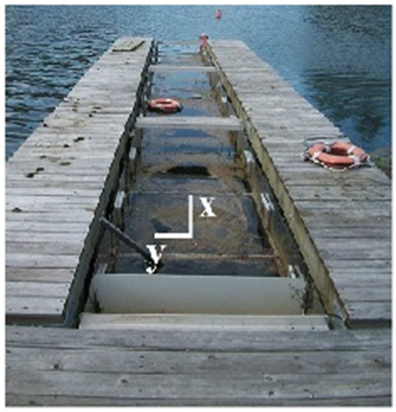
The power spectrum for the Matoka measurements differs from the power spectrum of the York River. First, of the spectrum is about 10 times smaller. This makes sense because the Lake is relatively still and the pump wasn't on. Peaks are smaller occur at frequencies other than 0.6 Hertz but still below 3 Hertz. Some of these peaks could be due to the shaking of my hand from holding the Vectrino in place. The outside measurement for 15 inches of depth has most of its peaks at the same place as the York River measurements and some other peaks at lower frequencies. These low frequencies peaks (below 0.6 Hertz) can be attributed to the shakiness of my hand.

Power Spectrum, 5 inch depth inside (log scale)



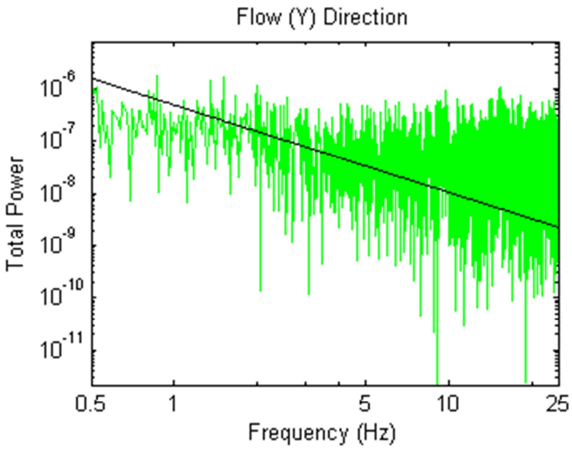


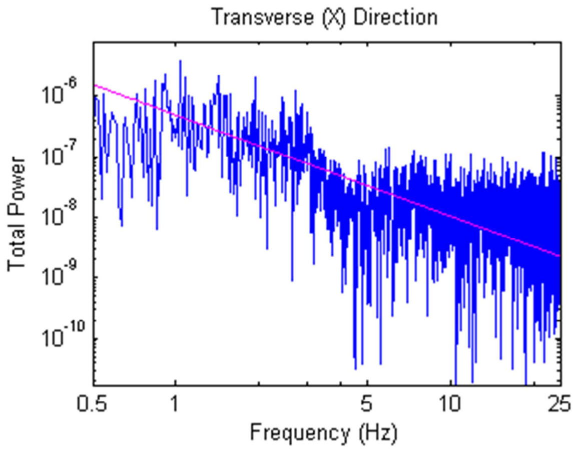


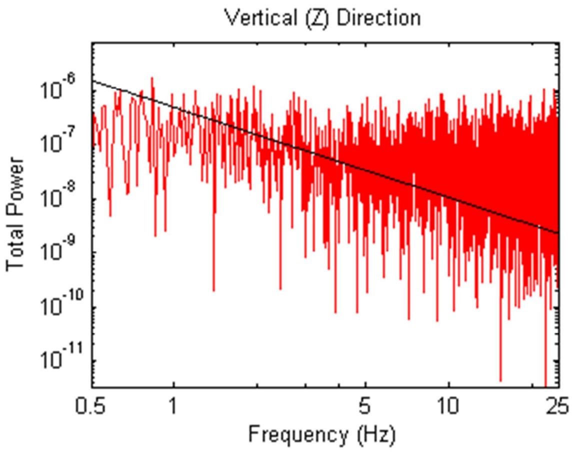


z is perpendicular to the water

Power Spectrum, 15 inch depth inside (log scale)

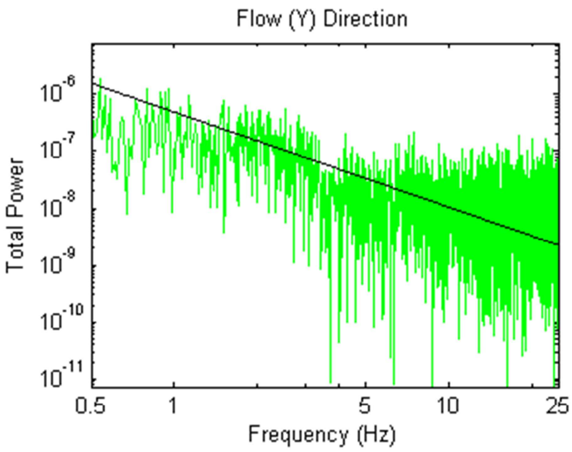


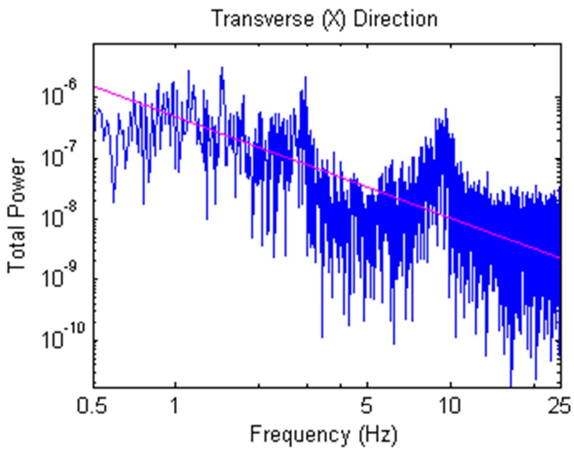


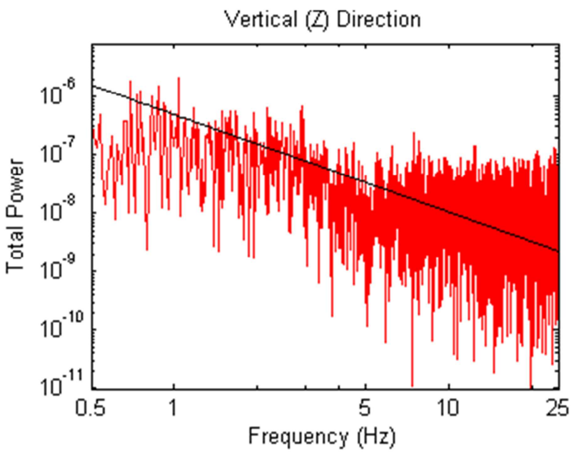


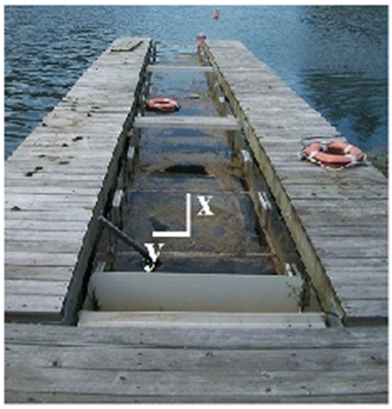
z is perpendicular to the water

Power Spectrum, 5 inch depth outside (log scale)



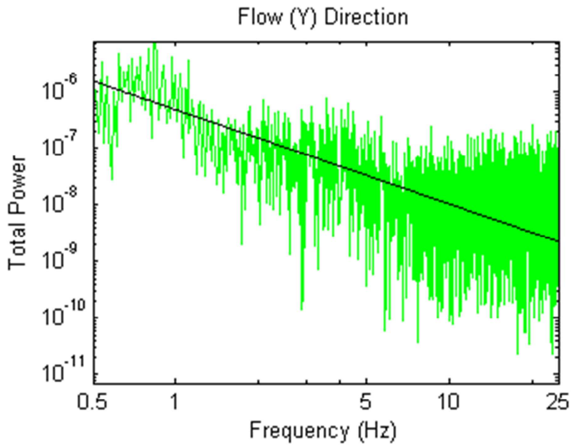


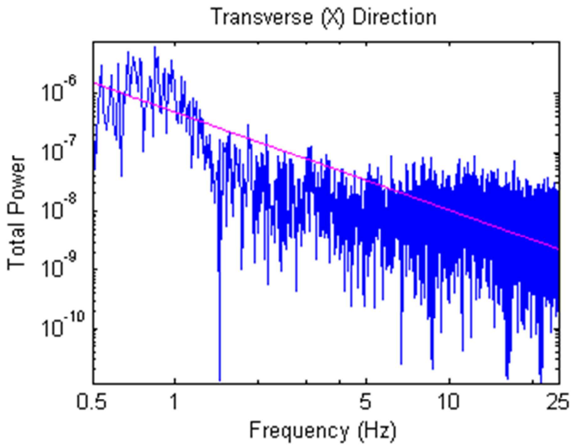


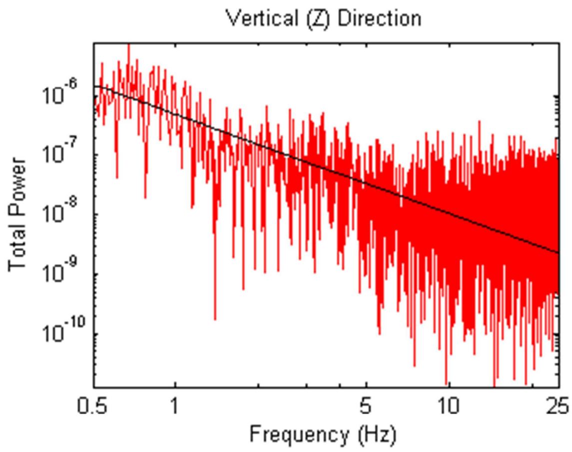


z is perpendicular to the water

Power Spectrum, 15 inch depth outside (log scale)







z is perpendicular to the water

For A = 10^{-9} the plots fit Kolmogorov's equation but for a narrower range of frequencies than for the measurements in the York River. This suggests that there is some turbulent flow even without the screens. The outside measurements at 15 inch depth suggest that turbulent flow even occurs outside the platform.

Conclusions

The power spectrum for the flow through the Research Platform when it was in the York River versus the flow when it was in Lake Matoka were comparable since peaks occurred at similar frequencies (less than 3 Hertz). However, the peaks for the power spectrum at the York River were larger and occurred more consistently at around 0.6 Hertz whereas the Lake Matoka power spectrum peaks were more dispersed. It is important to recall that the measurements in the York River created a profile of the water velocity in between the space of two screens and that a sturdy mount was used. In contrast, the measurements in Lake Matoka captured the water velocity at two distinct depths with no screens within the platform and with no mount.

References

(1) http://stat.chesapeakebay.net/?q=node/130&quicktabs_10=2

(2) Diaz, Robert. Spreading Dead Zones: How Low Dissolved Oxygen Became a Global Problem. http://portal.ncdenr.org/c/document_library/get_file?uuid=96144f55-fcd1-49d6-8116-d986938aae76&groupId=61563

(3) Diaz, Robert. Spreading Dead Zones and consequences for Marine Ecosystems. August 2008. http://www.sciencemag.org/content/321/5891/926.full.pdf

(4) Biofuels from industrial/domestic wastewater. Merinews http://www.merinews.com/article/biofuels-from-industrialdomestic-wastewater/135399.shtml

(5) The Chesapeake Algae Project. William and Mary Economic Development. http://www.wm.edu/research/ideation/science-and-technology/to-harness-the-wild-algae5832.php

(6) Vectrino Velocimeter User Guide, October 2004.

(7) Rhodes, Kristin. Characterization of Flow Rates in an In-Water Algal Harvesting Flume.

Appendix

Description of Vecrtrino

To measure the different components of velocity, a Nortek Vectrino Velocimeter was used. The Vectrino utilizes the Doppler effect to measure velocities of water in the X, Y and Z directions. The Vectrino reflects sound from particles suspended in the water (think sediment or zooplankton) and these particles move with the same average speed as the water. This effectively measures the speed of water. The Vectrino transmits through the center beam and receives through the four beams on its side. The Vectrino obtains 3 velocity components from the volume pictured n Figure 1. The beams intersect at 50mm from the transmitter. The pulse fired from the transmitter fires a pulse 3 – 15 mm long (user adjustable) with a diameter of 6 mm. (6)

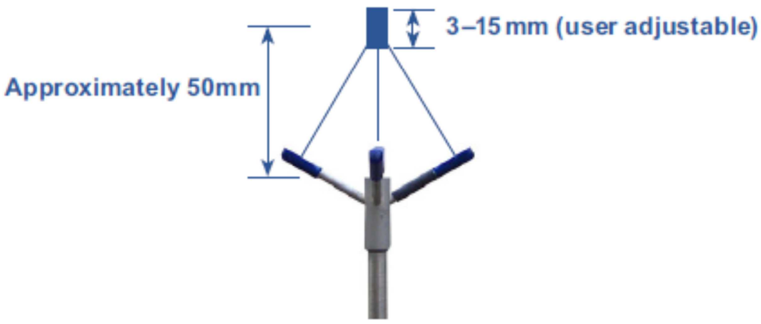


Figure 1: Velocity components obtains from the volume

Figure 2 marks out the X, Y, and Z components reported by the Vectrino. Arrows indicate positive directions. The marked arm defines the positive X-direction.

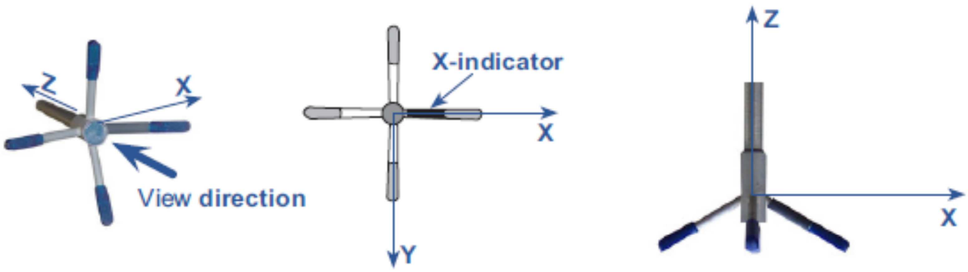
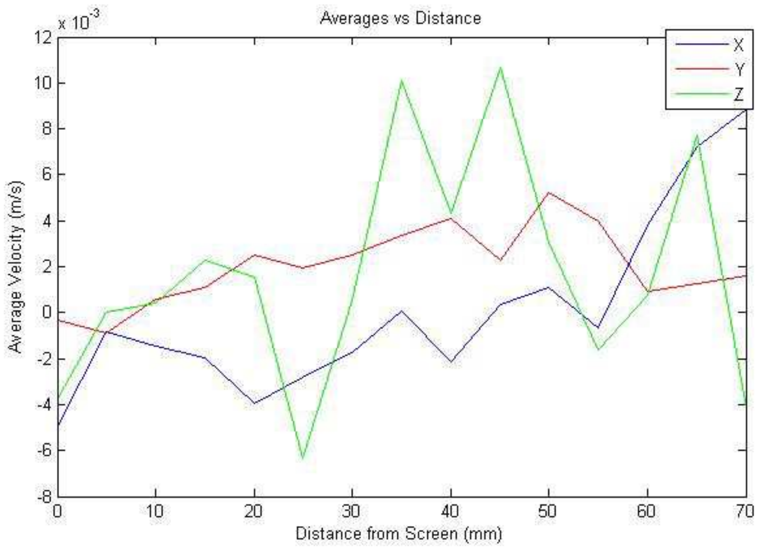


Figure 2: The X, Y and Z directions of the Vectrino

Additional Data and Charts

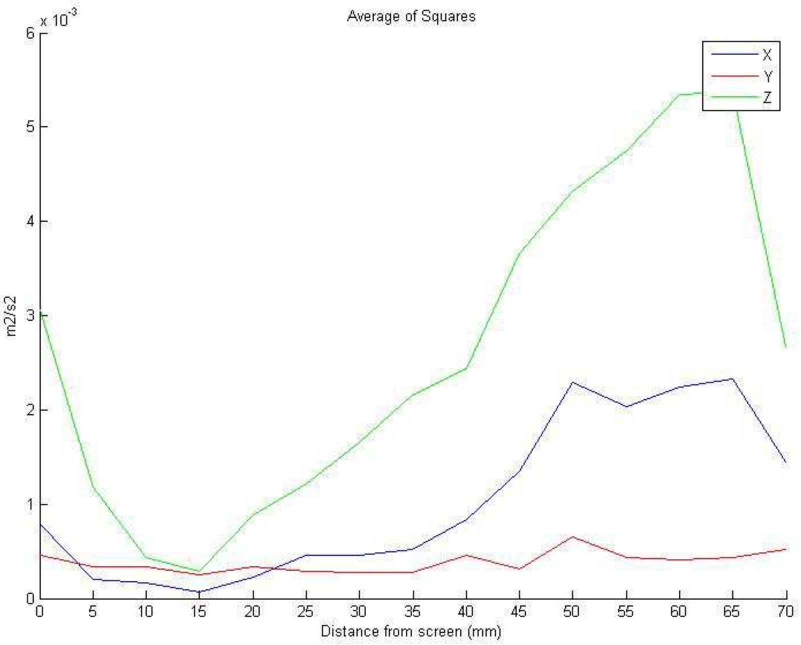
Average velocities for each measurement

Measurement	Distance from Screen (mm)	X direction (mm/s)	Y direction (mm/s)	Z direction (mm/s)
1	0	-4.9870	-0.3066	-3.7946
2	5	-0.8513	-0.9153	0.0330
3	10	-1.4777	0.5625	0.4210
4	15	-1.9900	1.0990	2.2631
5	20	-3.9676	2.4853	1.5198
6	25	-2.8108	1.9427	-6.3528
7	30	-1.7643	2.5166	0.5006
8	35	0.0578	3.3812	10.1127
9	40	-2.1315	4.0716	4.3021
10	45	0.3744	2.2572	10.6906
11	50	1.1189	5.2113	3.0887
12	55	-0.6638	3.9768	-1.6351
13	60	3.8262	0.9095	0.7731
14	65	7.2107	1.2389	7.7394
15	70	8.8673	1.6120	-4.1770



Averages of the squares of the velocities

Measurement	Distance from Screen (mm)	X direction ($m^2/s^2 \bullet 10^{-3}$)	Y direction ($m^2/s^2 \bullet 10^{-3}$)	Z direction ($m^2/s^2 \bullet 10^{-3}$)
1	0	0.8001	0.4643	3.0830
2	5	0.2072	0.3368	1.1827
3	10	0.1638	0.3331	0.4348
4	15	0.0701	0.2499	0.2931
5	20	0.2250	0.3398	0.8909
6	25	0.4628	0.2916	1.2197
7	30	0.4555	0.2734	1.6500
8	35	0.5225	0.2779	2.1519
9	40	0.8329	0.4610	2.4331
10	45	1.3535	0.3174	3.6617
11	50	2.2852	0.6539	4.3144
12	55	2.0395	0.4378	4.7487
13	60	2.2373	0.4092	5.3494
14	65	2.3224	0.4293	5.3711
15	70	1.4483	0.5223	2.6749



The averages and averages of squares for the Z direction tend to be the largest. This indicates that the Z direction is most likely the flow direction (if most of the velocity is in the flow direction). The magnitude seems to increases as we move away from the screen. This suggests that there might be turbulent flow at the edges.

Average velocities for Lake Matoka Measurements

Measurement	X direction (mm/s)	Y direction (mm/s)	Z direction (mm/s)
Inside, 5 inch depth	0.1451	-0.0536	2.8656
Inside, 15 inch depth	0.9093	-1.6843	-4.9745
Outside, 5 inch depth	0.7559	-1.2243	3.6274
Outside, 15 inch depth	2.4925	1.1123	-6.1775

Averages of squares for Lake Matoka Measurements

Measurement	X direction ($m^2/s^2 \bullet 10^{-3}$)	Y direction ($m^2/s^2 \bullet 10^{-3}$)	Z direction ($m^2/s^2 \bullet 10^{-3}$)
Inside, 5 inch depth	0.0748	0.0431	0.0811
Inside, 15 inch depth	0.1083	0.0480	0.3861
Outside, 5 inch depth	0.1161	0.0665	0.0982
Outside, 15 inch depth	0.1249	0.1578	0.2067

The averages squares suggests that measurements taken at deeper levels have higher amplitudes. The averages of squares also suggests that measurements taken outside have higher amplitudes.