Technical Report

University of Manitoba

Resource characterization of tidal flow in Blind Channel for the placement of a hydrokinetic turbine

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Abstract

Resource characterization is performed for a hydrokinetic demonstration project in Blind Channel, British Columbia, Canada. The regional bathymetry is assessed using a sonar and GPS system and the flow velocities are measured with an Acoustic Doppler Current Profiler. Bathymetry is assessed to create the boundaries for the demonstration region and to identify a route for the power cable. A grid of bathymetry data is collected during measurements, which is then interpolated using Tecplot and a contour plot is created. A 3D geometry is created using Matlab. Flow velocity results show highly energetic flow in the deployment region, with acute differences between the flood and ebb tidal cycles. These differences are attributed to the asymmetric bathymetry in the region.

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1 Introduction

Blind Channel is a tidal channel located off of the coast of British Columbia, between the mainland and Vancouver Island. It is a boat up resort that serves as a vacation spot, rest stop and fueling station for customers in the area. The owners of the resort run the facility and their homes off of diesel generators. Due to the expense of purchasing and transporting diesel fuel to and from the resort, as well as the environmental issues associated with burning fossil fuels, the owners of the resort have expressed interest in an alternative energy solution. To meet this interest, Mavi Innovations is performing a demonstration project for them by supplying them with a hydrokinetic turbine. This turbine operates using the tidal flow that passes through the channel according to the tidal cycle.

The Canadian Hydrokinetic Turbine Test Centre (CHTTC) has assisted Mavi in the testing of their turbine model in the past. In addition, researchers at the CHTTC have gained expertise in performing hydrokinetic resource characterization. A representative of the CHTTC is sent to Blind Channel with Mavi to assist in the characterization of the resource in Blind Channel.

2 Measurement procedures

To characterize the resource in Blind Channel, information on the bathymetry and velocity in the region is required. To meet this requirement, the selected measurement instruments include: the Sontek M9 Acoustic Doppler Current Profiler (ADCP), Humminbird 898c sonar system and the Teledyne horizonal ADCP (HADCP). The ADCP gathers velocity profile information, which shows the shape of the velocity profile and the location of maximum power potential in the water column. The Humminbird system has a depth sounder and GPS recorder which allows for the collection of bathymetric data. Finally, the HADCP gathers velocity data across a horizontal plane of the river. This can characterize a large area very quickly. Additionally, Mavi has developed a flow measurement device designed to sample flow at a point over a long period of time. This device gathers the velocity of the flow and us useful for measuring the angle of the ebb and flood cycles of flow.

A measurement arm is constructed to hold the instruments in the flow. The measurement arm is attached to a boat such that the device is held over the side. The boat is driven to the measurement point. Once at the measurement point, the driver holds the boat steady in the current by matching the speed of the flow while facing the opposite direction as the flow. The measurement arm is constructed partially from materials available on-site, including lumber and clamps. The horizontal and vertical portions of the arm are joined by a metal plate which was fabricated by Mavi, prior to arriving at Blind Channel. The plate is bolted to horizontal portion of the arm, which is then clamped to the boat, as depicted in Figure **??**. Adapters for the devices, a support plate to support the vertical portion of the arm and a metal pole designed to be mate to the adapters are designed and fabricated prior to arriving at Blind Channel. Figure **??** shows the measurement arm holding the ADCP in the water, off of the side of the boat.

Figure 1: Horizontal portion of measurement arm clamped to boat stern. This portion of the arm is fabricated on-site, with available materials to reduce the amount of equipment during travel.

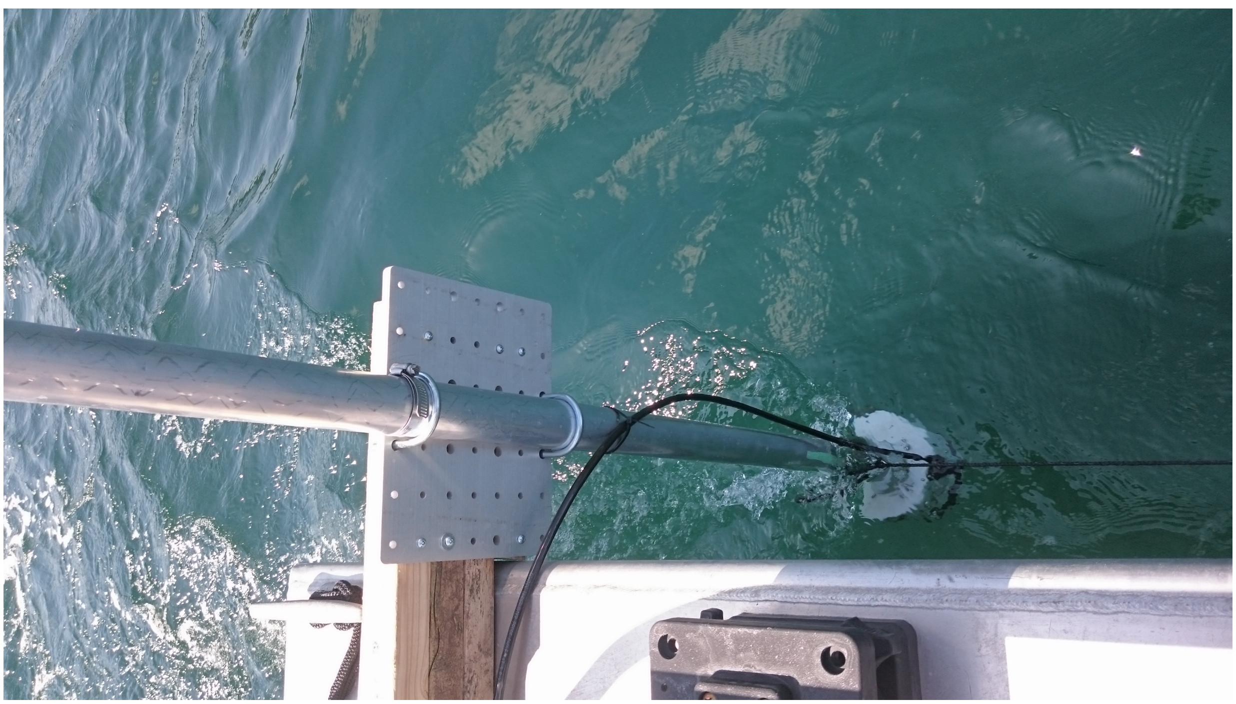

Figure 2: Measurement arm fabricated from on-site and pre-fabricated materials. The metal pole is purchased and machined to mate to the device adapters. Device adapters are designed by the CHTTC.

Finally, a safety line is attached to the vertical portion of the pole. This prevents the tilting of the instruments during measurement and ensures that the instruments are retrievable if

Figure 3: Google Earth view of Blind Channel. The area inside of the read circle is the proposed turbine deployment location.

anything should happen to the arm.

It should be noted that a different arm is used to hold the Humminbird system. In this case, a wooden pole is used, instead of a metal one. This allows the adapter for the Humminbird sonar to be screwed directly into the arm using the materials supplied by the manufacturer of the Humminbird, which is more practical than performing further machining on the metal pole.

2.1 Location and measurement points

Blind Channel Resort is situated in an area where the the ebb and flood of the tide result in high velocities near the resort. These high velocities are also caused by the geography and bathymetry of the region. The flow accelerates around a peninsula and results in high velocities downstream of the peninsula. It is in this location that the turbine is to be placed. Figure 3 shows an overview of the area.

Measurements are performed in the accelerated flow region. Bathymetric data is collected over the deployment area and also over the proposed power cable route, which traces back to the resort. For velocity measurements, a measurement grid is set up, with measurement points labeled with letters from A to Q. The measurement grid is shown in Figure 4.

Figure 4: Google Earth view of measurement points. A measurement grid is set up in the area known to have high flow velocities.

3 Results

Data is collected during the days of May 25^{th} to May 27^{th}. Bathymetry is collected on May 25^{th}, while ADCP data is collected every day in that period and HADCP data is only collected on May 27^{th}. For the ADCP, data is collected once during the ebb and once during the flood in each day.

3.1 Bathymetry

The bathymetry data is collected from the Humminbird unit and loaded into excel. Using the Navionics app, Height Of Tide (HOT) data is obtained from the Canadian Hydrographic Service (CHS). Fine time resolution is difficult to obtain via the app, so data is collected from the app and a sinusoidal model is fit to the data. The model is only applied to data within the time period that the bathymetry data was being taken. Multiple sinusoidal models were fit and it was found that the best fit is a combination of two sinusoids. The model is shown fit over the data in Figure 5.

Once the HOT can be found for any time within the measurement period using the model, the bathymetry data for the humminbird is normalized by subtracting the height of tide at data point. In this way, the bathymetry is relevant regardless of the time of day and tidal cycle. Finally, the HOT compensated data is loaded into Tecplot and plotted as a contour map. The results are shown in Figure 6.

Additionally, the GPS data is converted to Universal Trans Mercator (UTM) coordinates. This is done so that simply by looking at the points, it is clear how far they are apart without

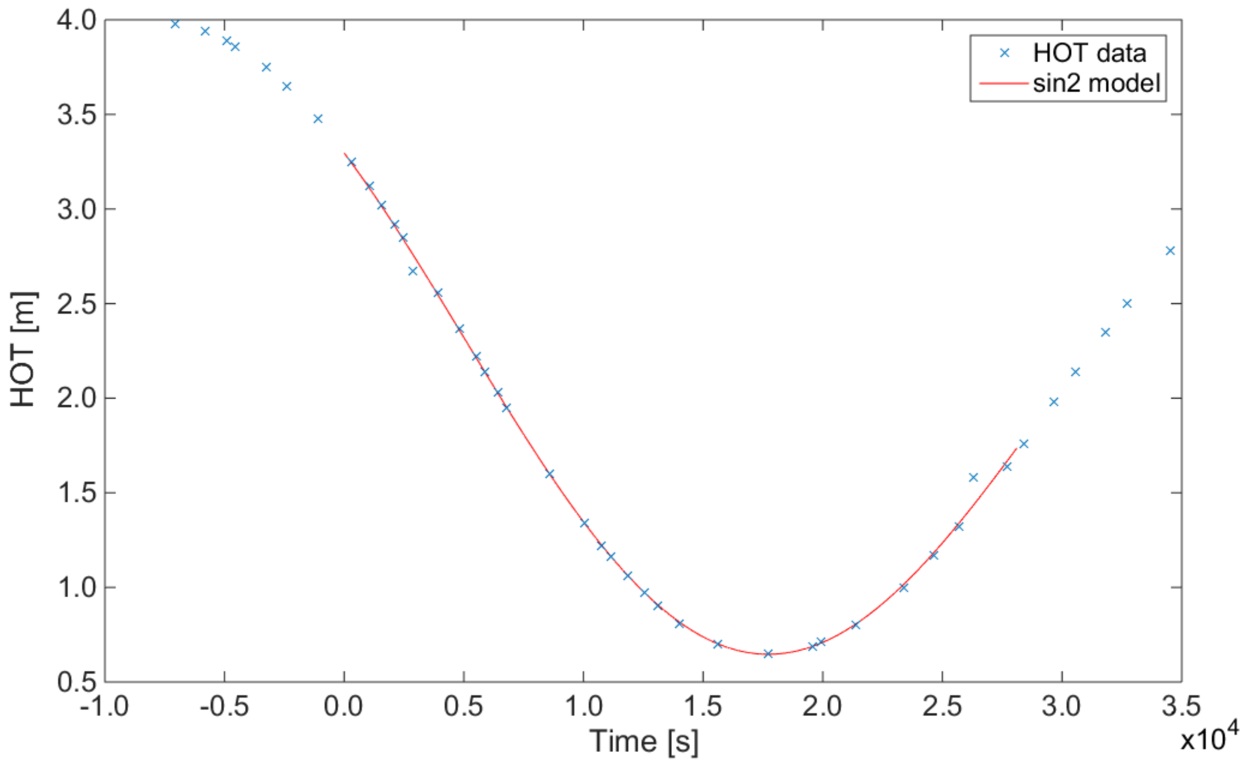

Figure 5: Height of tide data collected from the Canadian Hydrographic Survey via the Navionics app. Time is relative to the beginning of the collected bathymetry data and the model is fit within this time period. Height of tide data is collected before and after the bathymetry recordings so as to provide a better model.

having to measure latitudinal and longitudinal distance. The resulting bathymetry contour is shown in Figure 7.

Within Matlab, it is possible to mesh together a grid and plot surfaces of the bathymetry to give an idea of the shape of the bed forms. Figure 8 shows the underwater surface. Additionally, the three-dimensional surface can be smoothed and filled. This allows for a better view of detailed features. An smoothed view of the model is shown in Figure 9. With knowledge of the bathymetry, placement and anchoring of the turbine is possible and can be decided such that the turbine does not run the risk of hitting shore upon tide change.

3.2 ADCP

The ADCP results are collected and post processed using software developed by the CHTTC research group, which is publicly available at `www.chttc.ca`. Since the boat cannot be held perfectly stationary, as well as the bathymetry being relatively complex with high gradients, the ADCP changes the number of cells recorded during each recording, as the boat moves slightly and the depth changes. This is addressed using the software developed by the CHTTC. The number sets of cells are identified and for each different set of cells, time-

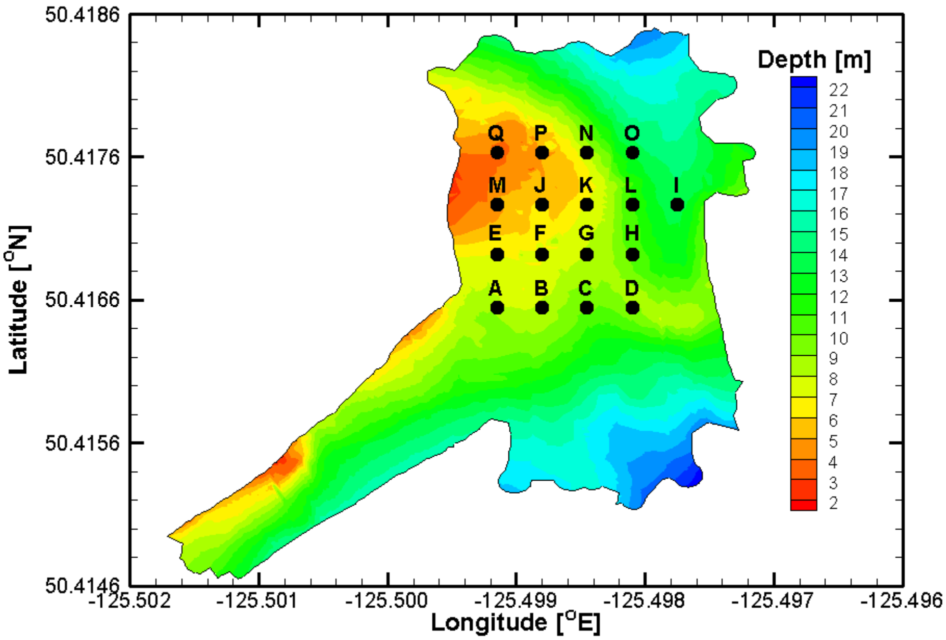

Figure 6: Contour plot of bathymetry in the turbine deployment area compensated by height of tide. Measurement points are shown.

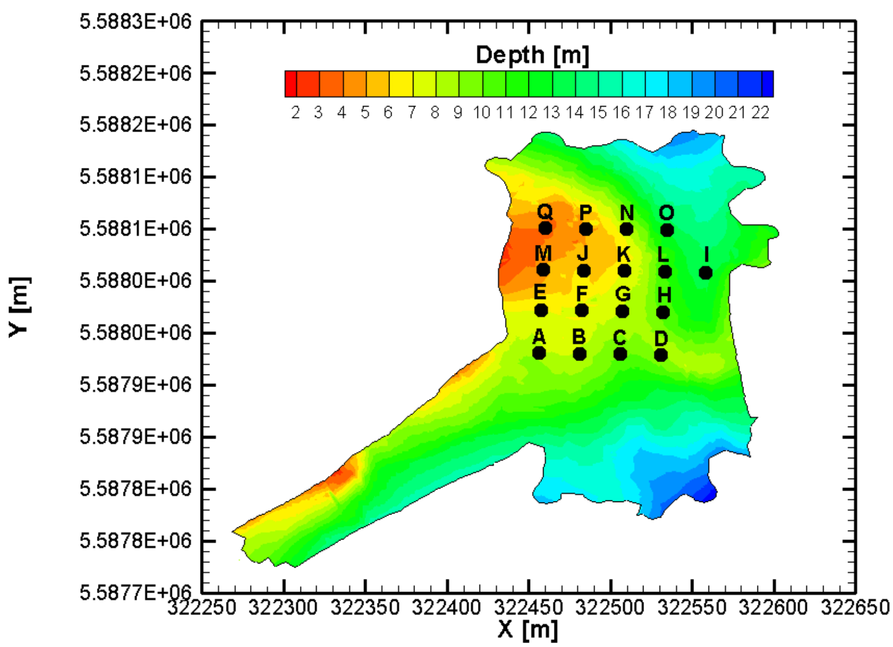

Figure 7: Bathymetry compensated by height of tide in UTM coordinates. Measurement points are shown.

averaged velocities are obtained from the ADCP data. The two profiles are then merged together but the appropriate cell depths are maintained. If one of the sets of cells makes up less than 25% of the data, this set of cells is removed. This is to ensure that if a set of cells only appears once or twice in the data, it is not influencing the mean, since numerous

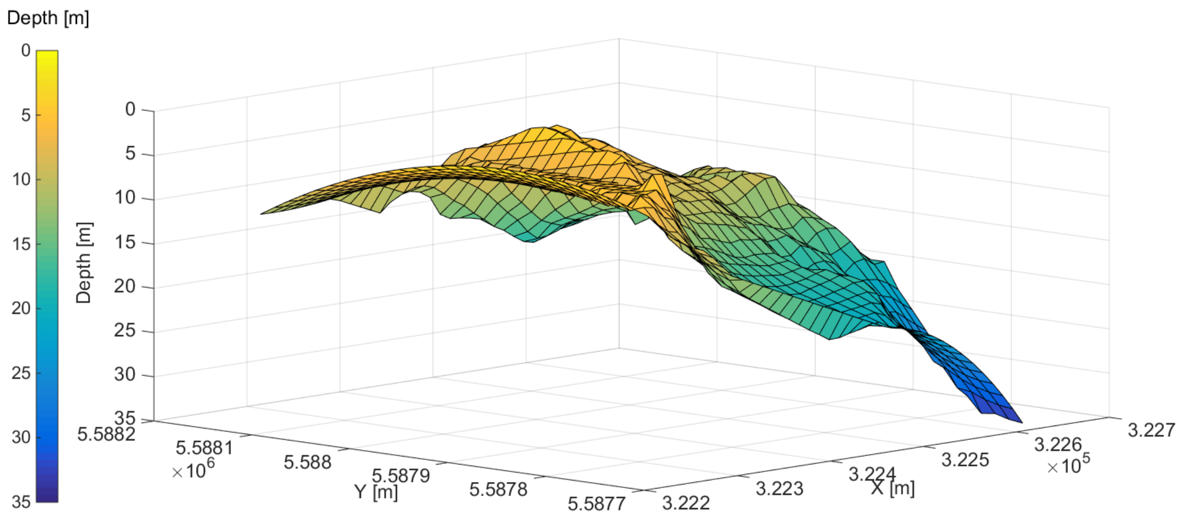

Figure 8: Meshed three-dimensional surface of the bathymetry at Blind Channel.

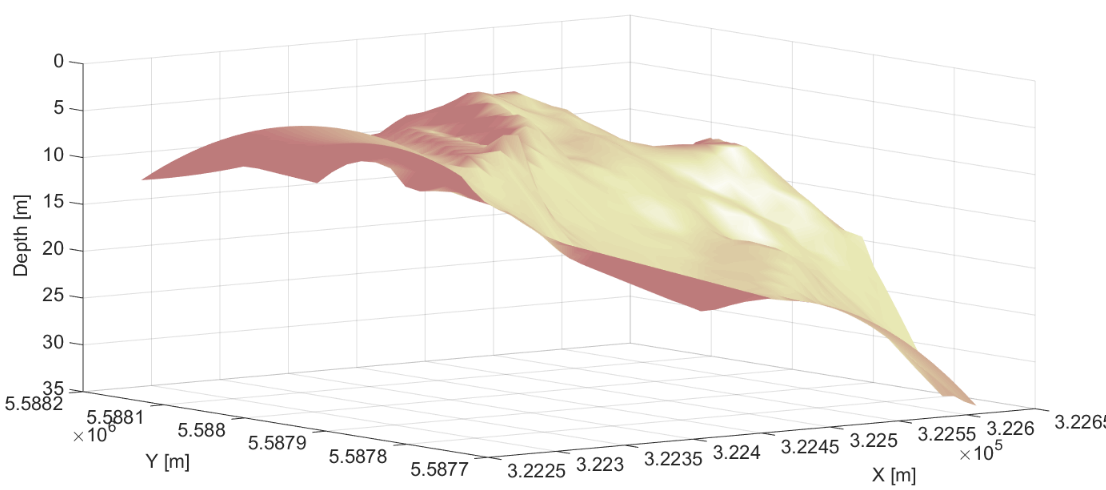

Figure 9: Filled surface plot of the bathymetry at Blind Channel.

samples are needed to be statistically valid.

To have a better idea of how the measurement times line up with the tidal cycle, HOT data is obtained for the three measurement days. The data is obtained for the Chatham station, which is near Blind Channel, as HOT data exactly at Blind Channel was unavailable. The data is still relevant for observing the timing of the tidal cycle in the area. The data from the CHS is plotted and shown in Figure 10 [1].

When the HOT is at local minimum or maximum, this indicates a period of no or low flow. This is because, once the tidal height has reached a maximum, the flow reverses direction and the tide begins to recede or ebb. When the tidal height has reached a minimum, the flow again reverses direction and begins to flood. Theoretically, the point of maximum flow

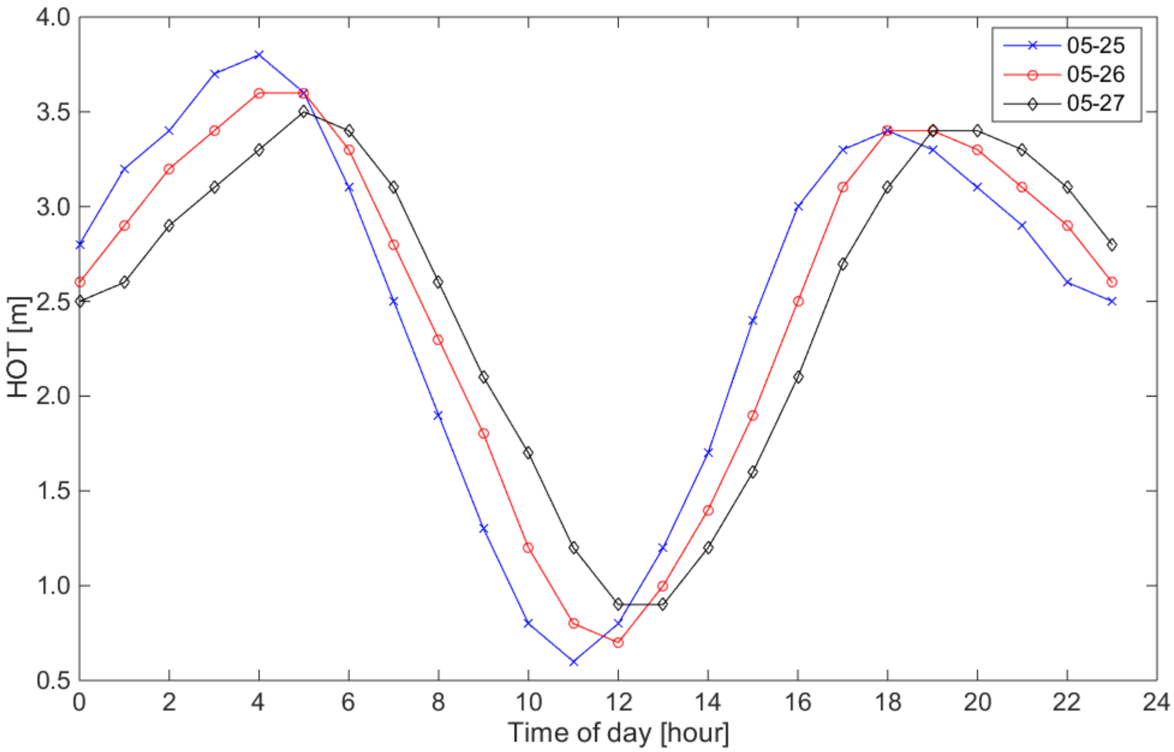

Figure 10: Tidal cycles during measurements. Data obtained from the Canadian Hydrographic Survey [1].

is halfway between the local minimum and maximum in the height of tide data. As an example, the velocity profiles at measurement point G are extracted and plotted for the first measurement day. Multiple measurements were taken during the ebb and flood of the tidal cycle. The velocity profiles for the ebb period of May 25^{th} are shown in Figure 11.

As is evident in Figure 11, the maximum velocity decreases with time, agreeing with the HOT data acquired from the CHS. Observing the flow profiles for the ebb, all profiles exhibit similar behaviour, with boundary layer thicknesses of approximately 6 m. However, these profiles are all during the ebb portion of the tidal cycle. The flood profiles are shown in Figure 12.

It is evident that the bi-directional nature of tidal flow has an effect on the velocity profiles. In the flood profiles, a clear boundary layer is not exhibited in any of the profiles. However, the maximum velocity does decrease with time, as expected, since the data collected is after the peak velocity in the tidal cycle. The change in flow profiles could be due to a number of things. Due to a non-uniform bathymetry and geography, the flow experiences completely different boundary conditions in ebb flow than in flood. This affects the velocity profiles at point G. To ensure that this is not a function of time or date, the velocity profiles for the ebb and flood are plotted at point G for measurements taken on May 27^{th}. The results are shown in Figure 13.

As shown in Figure 13, the lack of boundary layer is consistent across measurement days in the flood portion of the tidal cycle. To determine if the velocity profiles in separate locations

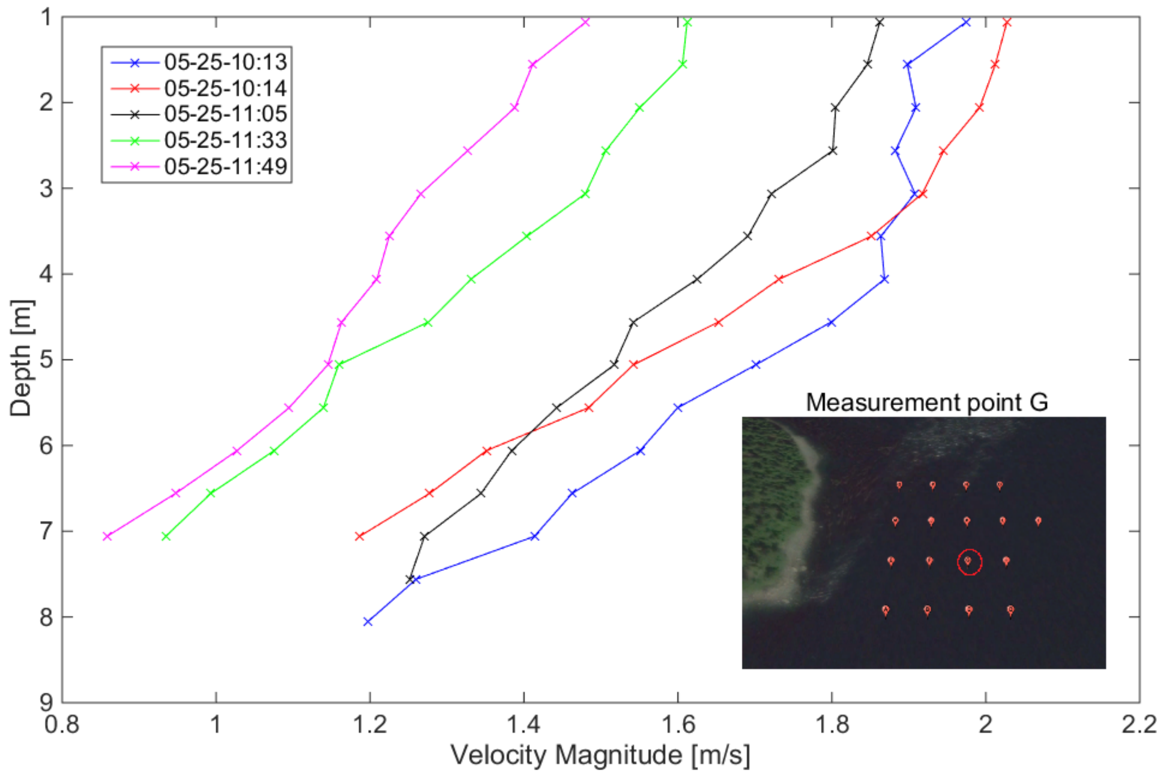

Figure 11: Velocity profiles collected by the ADCP at measurement location G. Multiple measurements were taken at different times during the same tidal cycle. It is evident that as time goes on, the velocity slows down, consistent with the fact that the start of the data collection occurs after the point of highest velocity in the tidal cycle.

are likewise affected, the velocity profiles are plotted for location P for the same day, May 27^{th}. The results are shown in Figure 14.

As observed in Figure 14, the flow profiles at location P exhibit a more pronounced boundary layer than is seen at measurement location G. This is likely due to the geometry unique in both locations.

Using the flow measurement instrument developed by Mavi, long term flow measurements are obtained over the second measurement day, May 26^{th}. From this data, periodic flow speed and directional data are obtained. This allows for the calculation of the directions of the ebb and flood tidal flows. Interestingly, the flows are not exactly opposite, or 180° apart. This is likely due to the bathymetry of the region. A 3D surface plot with the flow directions and locations of measurement points P and G are shown in Figure 15.

From viewing Figure 15, it is evident that the bathymetric geometries are completely different between ebb and flood, from the flow's perspective. This could be causing the difference in flow profiles seen at point G between the ebb and flood. Interestingly, this difference is not observed at point P. This is likely due to the bathymetry as well. It can be seen that there is a channel structure in the bathymetry when the flow is coming from the ebb direction.

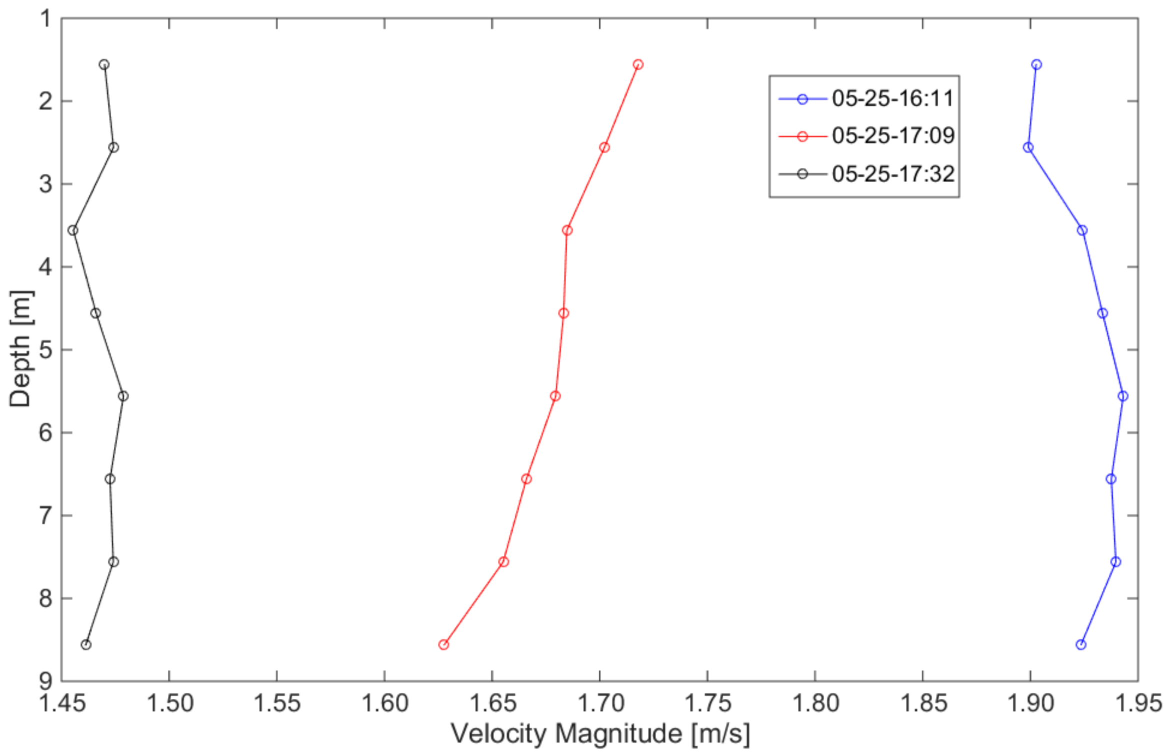

Figure 12: Velocity profiles collected by the ADCP at measurement location G during the flood portion of the tidal cycle on the first measurement day, May 25th.

Table 1: Highest velocity magnitudes found and corresponding location and depth

Date	Flow period	Maximum velocity magnitude [m/s]	Measurement location	Depth [m]
05-25-2017	Ebb	2.082	I	1.56
05-25-2017	Flood	1.948	J	1.56
05-26-2017	Ebb	2.010	P	1.06
05-26-2017	Flood	2.006	J	3.56
05-27-2017	Ebb	2.270	Q	1.11
05-27-2017	Flood	1.793	N	2.06

To determine the measurement locations with the highest hydrokinetic energy, each velocity profile is searched for the maximum available hydrokinetic energy at any depth. The highest velocities during each flow period are summarized in Table 1.

From Table 1, it is observed that the measurement locations with the highest velocity magnitudes are I, J, N, P, and Q. The highest velocities were found in the Ebb portions of the tidal cycle. This could be due to either the bathymetry differences between ebb and flood, as well as the strength of the tidal cycle during the measurement periods. Additionally, the typical depth at which the highest velocity was found is between 1 and 2 metres deep. In some cases, this is the first measurement cell taken by the ADCP, which due to the instrumentâĂŹs blanking distance from the measurement head. It is possible that higher velocities

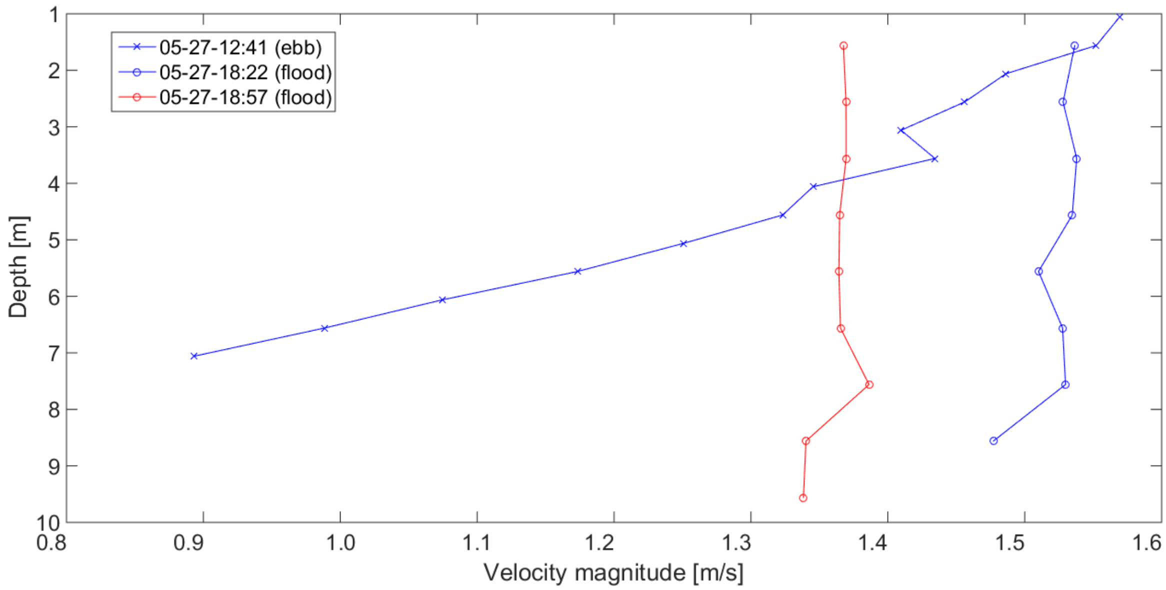

Figure 13: Velocity profiles collected by the ADCP at measurement location G during both ebb and flood portions of the tidal cycle on the third measurement day, May 27^{th}. Data marked with X is data collected during the ebb portion of the tidal cycle and data marked with O is collected during the flood portion of the tidal cycle. Color indicates the chronological order in which collected. For example, the blue data marked with X is the first data collected during the ebb and the blue data marked with O is the first data collected during the flood.

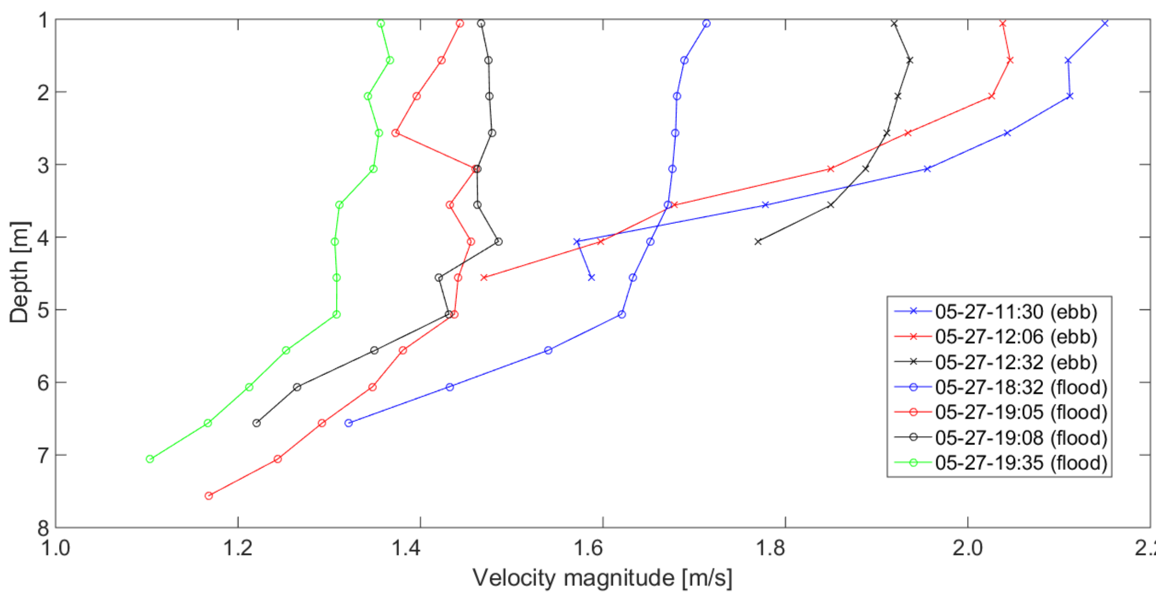

Figure 14: Velocity profiles collected by the ADCP at measurement location P during both the ebb and flood portion of the tidal cycle on the third measurement day, May 27^{th}.

are observed closer to the surface. However, in some cases, the highest velocity is not found

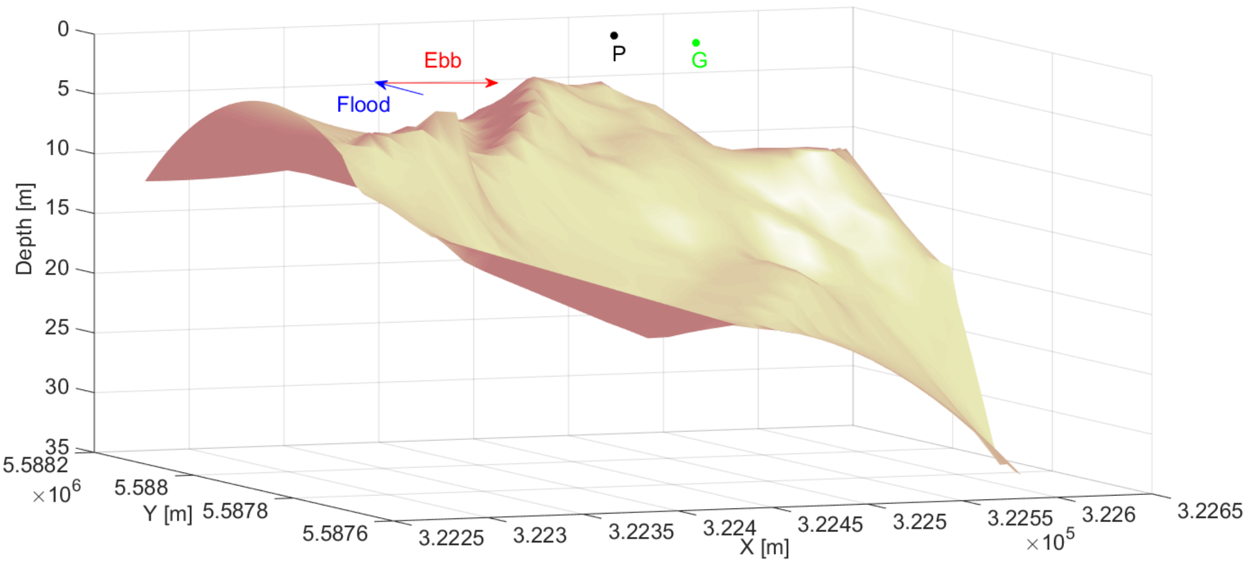

Figure 15: 3D surface plot of bathymetry with ebb and flood directions shown. Ebb and flood directional data obtained from long-term flow measurement device developed by Mavi.

in the first measurement cell, which indicates a dip phenomenon in the velocity profile, where the velocity actually slows down approaching the water surface, and the maximum velocity is reached closer to the middle of the flow. This phenomenon is consistent with open channel flows [2]. This could be due to the shear of the moving water surface with the air.

4 Considerations for flow measurements in tidal environments

Since CHTTC expertise has thus far been obtained in riverine deployments and measurements, the work performed at Blind Channel has unearthed challenges in oceanic flow measurements that do not appear in river measurements. For example, height of tide must be compensated for in bathymetry. Normally, river flows stay at approximately the same height, with gradual hourly variations. In tidal environments, the water level changes drastically over the course of a day. However, due to the cyclic nature of tidal cycles, the water level changes are fairly easy to predict using publicly available data and sinusoidal models.

Another consideration not present in river measurements is the salt in the water. This corrodes some of the measurement equipment, especially the metal members submerged in the salt water. Many of the metallic components used in measurement rusted upon return to Winnipeg, which does not normally occur in river measurements. Fasteners were especially susceptible to corrosion. Most of the components were rinsed off with desalinated water. This seemed to mitigate the rusting effects of the salt water.

Finally, the changing direction of flow poses challenges for both flow measurement and for turbine design. The flow is bi-directional, meaning that there are two primary flow directions.

The turbine must be designed in such a way as to be able to move itself in the flow as the direction changes, so as to maximize energy extraction. Additionally, new mooring solutions must be developed that allow for the movement of the turbine in the changing flow directions, as well as mitigating the risks of cable entanglement due to rotation of the turbine device. Finally, it means that two separate flow regimes must be fully characterized, adding time and complexity to flow measurements. The angle of the flow can be captured using long term measurement devices, which record over multiple tidal cycles and output the magnetic orientation of the device. The magnetic orientation must then be converted from magnetic north to true north coordinates, which can easily be done given time of day, as well as latitude and longitude. For the measurements in this report, the difference is about 19°.

5 Conclusion

In conclusion, bathymetric data and flow characterization measurements were successfully performed at Blind Channel. Measurement equipment was secured partially with pre-fabricated attachments, as well as arms and securing equipment built on-site, with available materials. This shows the versatility of the measurement devices and the ease with which they can be adapted to different types of flow environments.

Bathymetric data collected resulted in smooth contours which clearly show the underwater surface. Both 2D contour and 3D surface plots can be plotted with ease using Tecplot and Matlab. Bathymetric data can also be quickly converted to UTM coordinates, which allow for easy viewing of the contour plots, and an intuitive coordinate system where the distances on the plot are in metres.

Finally, velocity data collected with the ADCP showed that flow velocities and profiles vary with tidal period. Ebb velocity profiles were found to have higher velocities than flood profiles. The maximum velocities were most commonly found 1 to 2 m below the water surface, with a few exceptions where the maximum velocity is located closer to 3 m deep. Flow profiles varied with measurement location due to the complex bathymetry found in the region. Some flow profiles exhibited typical flow profiles and boundary layers in both ebb and flood flow regimes, while others, such as measurement point G, were found to lack a clear boundary layer in the flood regime, but not in the ebb regime.

6 Acknowledgements

We would like to acknowledge Zeev Kapitanker for his work in designing and manufacturing the adapters for the acoustic devices used to measure the flow velocity. Additionally, we would like to thank the staff at Blind Channel for facilitating this work and working with us through all phases of this demonstration project. Finally, we would like to thank MITACS for the funding of the project.

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