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Riverine hydrokinetic resource assessment and site selection using low cost satellite and aerial winter imagery

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INTRODUCTION

Hydrokinetic energy is a type of renewable energy that is currently being thoroughly researched in many areas around the world. It is a competitor with other types of energy production, such as wind, diesel and solar energies. In terms of energy per unit area, it offers much more potential than wind or solar energy [1]. It offers an environmentally friendly alternative to diesel power, commonly used by isolated communities, and has the potential to be more cost-effective [2].

In terms of identifying potential sites for hydrokinetic turbine placement, there are few techniques to identify potential sites, other than visually identifying high flow rates, or by word of mouth from locals, which is unreliable. There have been some studies into mathematical approaches to determining locations, however, this too can be unreliable. Today no standardized method of locating riverine hydrokinetic sites exists. As such, a reliable method of riverine hydrokinetic site assessment is in high demand.

With the technology of the present day, it is easy for the average person to view satellite images. Viewing rivers with this technology reveals that, in regions that experience ice formation on rivers, there are occasionally openings in the sheets of ice that cover rivers. A possible theory (the one utilized in this study) is that ice formation is hindered at high flow velocities. With this, openings in surface ice should be visible and clearly provide locations of high flow velocity in a river.

Little literature exists on the behaviour of ice formation at high flow velocities; however some experiments indicate that a surface flow velocity greater than approximately 0.6 m/s will impede surface ice formation [3] [4].

The goal of this study is to locate ice openings and develop a procedure to measure the velocities at the site, which determine the validity of the theory that ice formation is impeded at high velocities.

EXPERIMENTAL PROCEDURE

This study was conducted along Canada's Winnipeg River, which flows from Lake of the Woods, Ontario to Lake Winnipeg, Manitoba. The Winnipeg River system was chosen for two reasons; close proximity to the researchers involved and known areas of fast river flow.

A small plane was chartered in February 2013 and flew the Winnipeg River System starting from the river's mouth at Lake Winnipeg to approximately the Manitoba/Ontario border. Handheld digital cameras were used to photograph any visible surface ice openings along the river. The images of the ice openings were compared to Google Maps in order to find the exact position of the ice openings. Once located, the positions of the ice openings were then marked for later comparison to satellite imagery. An example of the aerial imagery is shown in Figure 1.

FIGURE 1. AERIAL IMAGERY OF THE LAMPREY RAPIDS ON THE WINNIPEG RIVER

Easily accessible high resolution satellite imagery of the Winnipeg River System taken during the cold winter months needed to be collected. Taking advantage of DigitalGlobe's online satellite imagery search tool, ImageFinder, high resolution satellite imagery needed for this study was collected. The earth observation satellites imagery was collected from are WorldView-1, WorldView-2, GeoEye-1 and QuickBird-2. Locations of surface ice openings were clearly visible on the collected satellite images and their locations were marked. These areas are denoted by dark sections on an otherwise white landscape. Figure 2 depicts the lamprey rapids (as seen in Figure 1) from the satellite imagery for comparison.

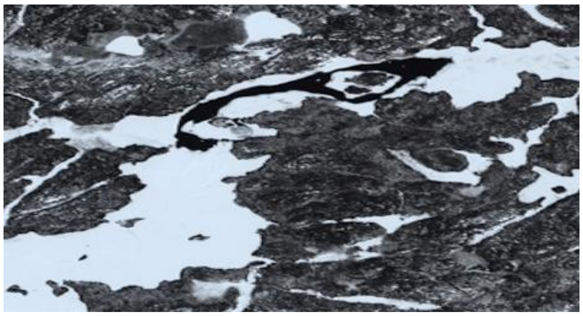

FIGURE 2. SATELLITE IMAGERY OF THE LAMPREY RAPIDS ON THE WINNIPEG RIVER

An important observation is that the satellite imagery in Figure 2 and the aerial imagery in Figure 1 were taken during different times of year, in different years. Figure 1 was taken in February of 2013 and Figure 2 was taken in March of 2011. It is evident from these two photographs that the approximate size and shape of the ice opening is similar, leading to the conclusion that the ice openings are not greatly affected by time of year (so long as there is ice cover) or by year-to-year variations in weather (such as temperature and water level). This similarity was found among all ice openings located for this study.

After comparing the aerial and satellite imagery and the locations of the openings, waypoints at each open location were marked on Google Earth where the highest flow velocities were thought to be. Normally the waypoint was placed at approximately the center, or centerline of the opening along the river's direction of flow. The waypoints were then uploaded to a Humminbird 898c HD GPS Fishing System for accurate navigation to each test location once on the river. Figure 3 lists all of the measurement locations and the corresponding label and GPS coordinates.

Once the measurement points were selected and marked, a procedure needed to be created to measure each region and compare the velocities. Since the water velocity cannot be accurately measured from land, equipment that could be used by a vessel on the water was required.

Location ID	Location Name	GPS Coordinates	Location ID	Location Name	GPS Coordinates
L1	Manitou Rapids	50.57415, -96.21637	L17		50.19266, -95.61320
L2	Manitou Rapids	50.57268, -96.20111	L18		50.20052, -95.60250
L3	Pine Falls Generating Station	50.56845, -96.18080	L19		50.21473, -95.5872
L4		50.51351, -96.0935	L20	Slave Falls Generating Station	50.22244, -95.57023
L5		50.50049, -96.08566	L21		50.2348, -95.5574
L6		50.47160, -96.0656	L22	Eight Foot Falls	50.28638, -95.5366
L7	Great Falls Generating Station		L23	1 Pointe Du Bois Generating Station	50.29751, -95.54659
L8		50.43951, -95.99296	L24	Lamprey Rapids & Halliday Rapids	50.37176, -95.4135
L9		50.41721, -95.98972	L25A		50.3696, -95.3426
L10	McArthur Generating Station	50.40197, -95.99517	L25B		
L11		50.38299, -95.97530	L25C	Indian Island	50.3538, -95.2817
L12	Seven Sisters Generating Station		L25D		50.35687, -95.2556
LA	Furey Island, Pinawa, MB	50.13722, -95.89248	L25E		50.35701, -95.24022
LB	Sylvia Lake/Eleanor Lake	50.12506, -95.8596	L26	Pine Island	50.3538, -95.2160
LC	Otter Falls	50.15144, -95.8161	L27X L4.8?		
LD	Pinawa Golf Club	50.14259, -95.86831	L28	Ontario/Manitoba Border	50.2471, -95.1586
L13		50.15161, -95.77765	L29	Boundary Island	50.22085, -95.10296
L14	Barrier Bay	50.17214, -95.6925	L30		50.21314, -95.0920
L15	Sturgeon Rapids	50.15687, -95.65995	L31	South Boundary Falls	50.18499, -95.11292
L16	Scots Rapids	50.1881, -95.6176			

FIGURE 3. MEASUREMENT LOCATIONS AND IDENTIFICATION LABELS

The measurement device employed was an acoustic Doppler velocimeter (ADV). The model used was the Nortek Vector ADV. The device was attached to a boat via a two-pole system that allowed fast and simple deployment and retrieval of the device. The poles were designed to withstand the high velocities expected in the Winnipeg River. The ADV was connected to a laptop computer which runs the software that controls and records data from the ADV. Figure 4 depicts the experimental set up used in the experiment.

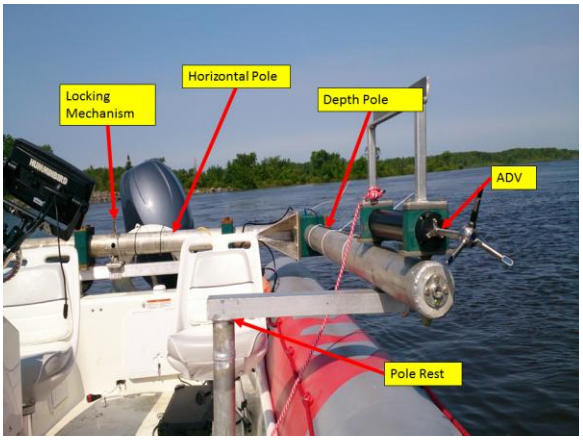

FIGURE 4. MEASUREMENT EQUIPMENT USED FOR DETERMINING VELOCITIES AT OPEN-ICE LOCATIONS.

Once a measurement location was reached, the ADV was deployed and the boat driver held the boat's position and orientation as steady as possible. A recording was then performed using the ADV and the data was stored in the computer for later analysis. Once the recording was complete, the ADV was retrieved and a depth reading was taken of the location for later use.

RESULTS AND DISCUSSION

A total of 34 locations were measured along the Winnipeg River. At each location, one measurement was recorded at a constant depth (approximately 1.5 m, not accounting for vertical motion of the boat). This was to ensure that the free-stream velocity was captured at each location. In this measurement, a time series of velocity was collected and analyzed upon return to shore. The raw data was de-spiked and was set to a relative time scale (0 being the start of the data recording). Figure 5 shows an example of the de-spiked data to be analyzed.

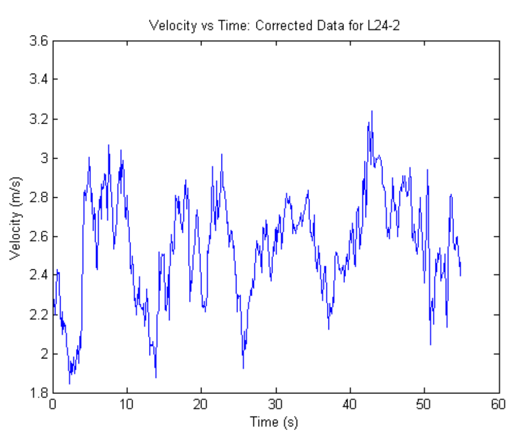

FIGURE 5. CORRECTED DATA RECORDING FROM ONE MEASUREMENT LOCATION

the mean streamwise velocity, standard deviation of velocity, signal-to-noise ratio (SNR) and the ADV correlation were maintained. No post-processing corrections were applied to adjust for the motion of the boat and measurement device. However, since the boat driver held the boat as steady as possible while the measurements were being taken, the assumption was made that the boat motions were relatively small, and since only average velocities are considered, these small motions would cancel upon taking an average. The results show that locations that were not covered with ice during winter months had an minimum mean streamwise velocity of 1.16 m/s and a maximum mean streamwise velocity of 3.42 m/s. The average mean streamwise velocity for all locations was found to be 2.05 m/s, with a standard deviation of 0.67 m/s. The average SNR was 26.77 and the average correlation was 93.08%, indicating that the results are highly accurate. Finally, a comparison was made between the velocity and the depth of each location. Figure 6 shows a plot of the mean streamwise velocity at each location versus the water depth at that location.

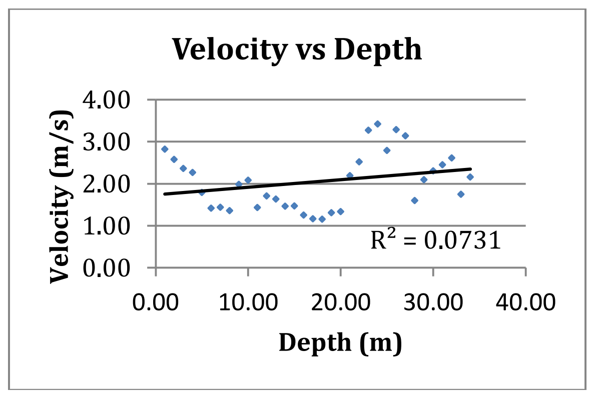

FIGURE 6. PLOT OF VELOCITY VS TOTAL WATER DEPTH AT THAT LOCATION

An R^2 value of 0.07 was found, indicating little to no correlation between the total water depth of the location and the mean streamwise velocity found at that location.

The results show that at these ice openings, high velocities that are suitable for hydrokinetic turbines were found. How these results compare to the other areas of the river remains unclear and data collection at the areas of the river that are covered with ice during the winter season is necessary for a full comparison. Upon a visual comparison at the time of measurement, the ice covered areas were slow in comparison (occasionally they were almost stagnant), however this would need to be tested with further measurements.

Additionally, data collection during different times of year would be ideal, as this would give insight into what the flow velocities area like year round, which would lead to better knowledge of monthly fluctuations in power production of hydrokinetic turbines. This, however, would require an entirely different measurement technique, as deploying a vessel and retrieving in a mostly ice-covered environment would be difficult.

CONCLUSIONS AND FUTURE WORK

In this study, it was demonstrated that using satellite imagery to locate openings in frozen rivers is a valid procedure to identify areas of high velocity river flow. These high flow areas are potential locations to place hydrokinetic turbines that could replace other forms of energy generation, such as the diesel generators primarily used in these remote locations. This technique is especially useful for isolated communities that do not have many access roads or are difficult to navigate. Even for areas with access roads, this dramatically cuts down the time and cost to identify potential hydrokinetic turbine sites by removing the need to hire personnel and send them up and down the river and measure until they find an area with high flow.

In terms of seasonal variation, it is currently unknown as to how these velocities change during different times of year. With the current measurement procedure, it is difficult to measure flow velocities during the winter when the surface is frozen. To determine how the water velocity varies with time of year, a new measurement procedure would have to be devised to allow for velocity measurements in a frozen environment. However, it is known that the shape and size of the ice openings remains the same from month to month (so long as the river is covered with ice) and from year to year, so it can be expected that a relatively high velocity will be found in these locations, regardless of time of year or year of interest.

Finally, the results of this study lead to the belief that the method of satellite and aerial winter imagery is a good starting point for site assessment for hydrokinetic turbines in cold climates. The areas can be easily, quickly and cheaply located and can then be further examined using flow measurement techniques. This works especially well for remote areas that are difficult to access by typical site assessment methods, lending aid to those who live in remote communities.

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The next step in this study is to return to the measurement sites and determine how these velocities vary year to year. Additionally, data will be taken in ice covered locations to compare the mean streamwise velocity between the open and covered locations.

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