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COB-2021-2278 Appling the Large-Scale Particle Image Velocimetry with drone images for determining the hydrokinetic potential in rivers

Felipe Ribeiro de Toledo Camargo
Reginaldo Nunes da Silva
Rafael Castilho Faria Mendes
Tayogara Oliveira
Antonio Brasil Junior
UnB - Brasilia, Federal District, 70910-900
felipertc@gmail.com, profreginaldo.n@gmail.com, rafael.cfmendes@gmail.com, taygoara@unb.br, Brasiljr@unb.br

Abstract. *The hydrokinetic potential in rivers is proportional to the flow rate, where it is crucial to find high velocities to make it viable to install hydrokinetic turbines. In some cases, due to the large scales, the velocity measuring is a problematic process and demands expensive equipment, like acoustic Doppler current profiles (ADCP). In this view, this work intends to demonstrate a low-priced methodology of Large-Scale Particle Image Velocimetry (LSPIV) with drone images for measuring the velocities on the river's surface. The tests were carried on the Rodeador river in Federal District, Brazil. The presence of trace marks also was analyzed, where some sawdust was deployed on the river to improve the LSPIV results. The measurements were compared to traditional ADCP results.*

Keywords: *Large-Scale Particle Image Velocimetry, acoustic Doppler current profiles, Hydrokinetic potential.*

1. INTRODUCTION

Increasing the supply of renewable and clean energy is global demand. Energy use and GDP (Gross Domestic Product) are positively correlated so is extremely important that a country like Brazil can expand its energy matrix to increase the GDP and improve the quality of life of Brazilians.

Aware of this global need to increase energy supply in a clean and renewable way and aware of the situation of the Brazilian energy matrix, which is mostly composed of hydroelectric plants, this work proposes to analyze a methodology to determine the hydrokinetic potential in rivers using the LSPIV technique.

Hydrokinetic energy is defined as the energy associated with the movement of water in rivers, coastal areas, and oceans, whose primary energy sources are of origin gravity, associated with surface drainage in relief of hydrographic, tidal effects, or ocean currents on a planetary/regional scale. This water mass movement in water currents provides potential relevant energy, which can be used for conversion into electricity employing suitable electromechanical devices. In this sense, this bias of energy restraint has been the object of an important development axis of technologies over the last decade (e.g. (Yuce and Muratoglu, 2015), (Sood and Singal, 2019)).

New methods that can help in the hydrological characterization are totally necessary, mostly in a country like Brazil. The benefits of this method if compared to usual ones, like bathymetry, sonar, and ADCP (Acoustic Doppler Current Profiler) is that LSPIV is a non-intrusive instrument, so it does not need to be in contact with the fluids. Ensuring more safety for the operator of the system and the possibility to records measurements in extreme events, without the risk of losing or breaking the equipment during (Camargo *et al.*, 2020).

The LSPIV method derives from the PIV (Particle Image Velocimetry) method, which was typically adopted to solve mechanics fluids problems in the early eighties. PIV found great acceptability of the scientific community for being a cheap and efficient method and at that time was expected that with technologies advances this method becomes even more efficient, cheaper, and reliable (Fincham and Spedding, 1997).

PIV is an experimental technique that allows the acquisition of velocity field data of a flow in fractions of seconds. The working principle of PIV is based on measurements of the displacement of particles present in the fluid, carried out by capturing multiple images. Small diameter particles are generated and dispersed in the flow by a seeder. A plane of light, formed by a set of optical lenses and a laser, as shown in Figure 1, is generated to illuminate the area of interest, managing to highlight the particles and allowing them to be visualized by the camera. The image capture process is done multiple times and very quickly, wherein the interval between photos, it is possible to visualize the path taken between the particles. The entire PIV process is synchronized such that the system fires the first laser pulse, takes the first photo, then fires the second pulse and takes the second image capture. The time between photos will depend on speed and data transmission. After acquiring the images, a pair of subsequent photos is compared to compute the displacement of the particles. The PIV methodology results in the measurement of the velocity field in the captured image area, being able to even distinguish the two velocity coordinates in the plane.

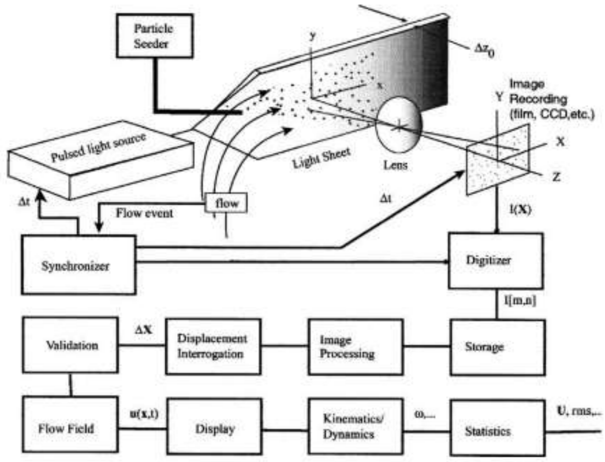

Figure 1: PIV Setup (Adrian 2005)

Fujita (Fujita *et al.*, 1998) is the first author to use the name LSPIV (Large Scale Particle Image Velocimetry) for large-scale PIV experiments. The first time this technique was applied to measure the velocity of a river was in Japan and as the studied area was larger than the traditional ones used for PIV experiments, the name LSPIV become more adequate (AYA *et al.*, 1995). It could be experiments in hydraulic laboratories, rivers, channels, or floods events. Measuring the surface velocity of a watercourse is a very important factor in hydrological characterization.

The LSPIV technique employs the same principle as the classic PIV but is applied to larger length scales, normally found in situations external to laboratory situations, such as river surface velocity calculation applications. From this point onwards, the main distinction between PIV and LSPIV cases are the orders of magnitudes found in the problems, in which, generally, the large length scales are accompanied by smaller scales of times and characteristic speeds found in the cases of LSPIV. Thus, the application of the LSPIV methodology is less costly than the classic case of PIV, not depending on sophisticated equipment to capture images quickly.

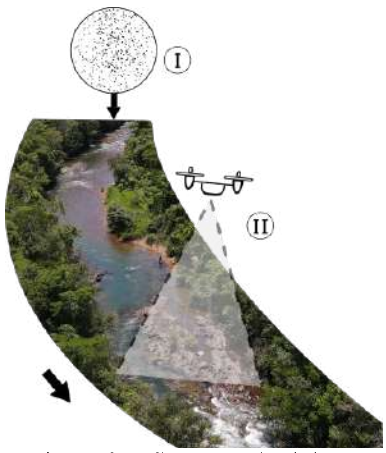

Figure 2: LSPIV Methodology

Generally, the LSPV technique is applied in cases of water runoff, with great emphasis on surface runoff. The standard LSPIV technique is illustrated in Figure 2 and is based on standard PIV elements, except for laser and synchronizer elements. These reservations are based on low speeds and the natural presence of a flat surface. Returning to the illustration in Fig 2, the methodology can be described as two steps: I) dissemination of particles on the river surface and II) image acquisition, which in the case of this work was performed by a drone, but there are acquisition options through fixed cameras.

The experiment was conducted at the Rodeador River, which is located in the Federal District the capital of Brazil. The River is in the administrative region of Brazlândia, a predominantly rural region. The Rodeador River is the main tributary of the Descoberto reservoir, the primary water reservoir in the Federal District. Using a DJI Mavic Air 2 Drone the images of the river flow were capture and processed at PIVLAB, an open-source PIV tool. Also, an ADCP measure was performed at the River so it could be possible to compare both techniques.

2. Methodology

This work methodology is divided into two steps. The first step is the field data collection, where the site location, the ADCP equipment operation, and the image acquisition with the drone are gone be presented. The second step is the processing phase, with the support of the software RIVeR (Patalano *et al.*, 2017) to correct the displacement from the drone that captures the images and the PIVLab (Thielicke and Stamhuis, 2014) to process the frames from the videos.

2.1 Field Data Collection

As mention before, the images were collected at Rodeador River. The river is barred to form the Rodeador Channel, the region's major irrigation channel (ADASA, 2018), see Fig 3. The flow from both river and channel is monitored by the ADASA, the water agency from Brasília.

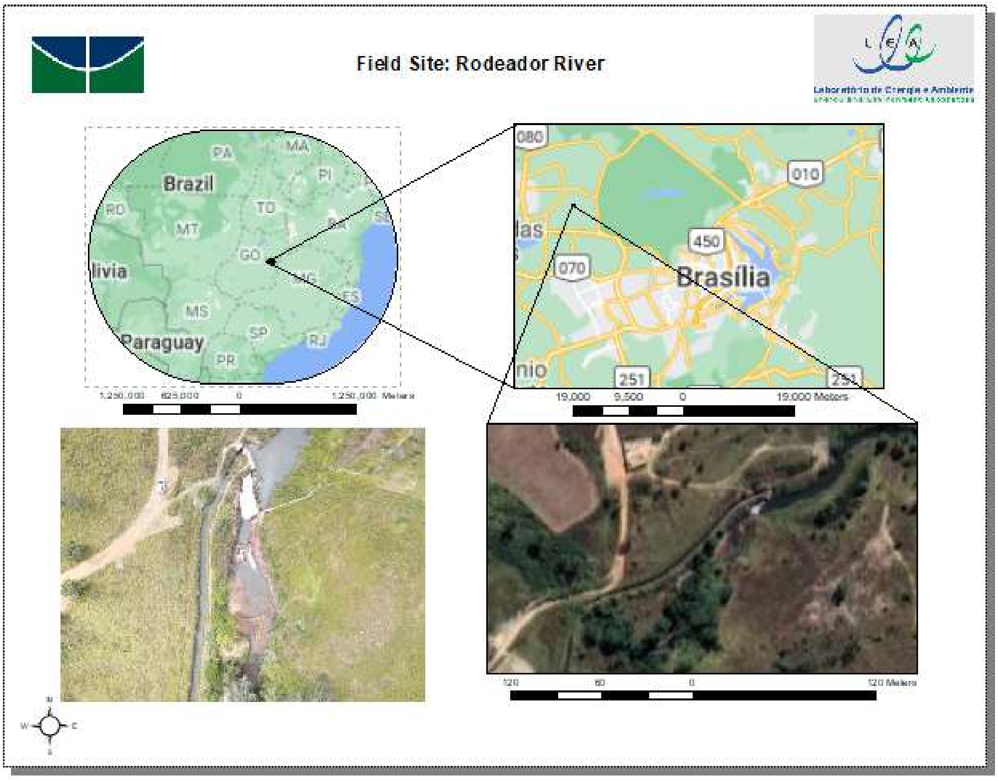

Figure 3: Location map

The ADCP equipment is the M9 ADP from Sontek that is a nine-beam system with two sets of four profiling beams and one vertical beam, see Fig 4a 4. The M9 has a velocity profiling range of up to 30 m and a discharge measurement of 80 meters. It measures water currents with sound, using a principle of sound waves called the Doppler effect. The ADCP works by transmitting "pings" of sound at a constant frequency into the water. As the sound waves travel, they ricochet off particles suspended in the moving water and reflect into the instrument.

(a) M9 ADP by Sontek (b) Board design and built to operate the M9 (c) Rope and board set at the river

Figure 4: Detail from the M9 sensor and the Board

A board was constructed to operate the M9 sensor through the river, see Fig. 4b. This board with the auxiliary of a rope enabled the measurement, see Fig. 4c. The boat traveled through a region of interest to collect information on both the river's bathymetry and velocity profiles. With this information gathered the flow of the river was calculate and compared with the flow measured by the hydroelectric.

The drone took off in a flat region away from any type of vegetation and was manually driven to the area of interest, previously measured by defining the M9 sensor. Positioned 6 meters above the water level and with its camera positioned orthogonally to the direction of the river's flow. Sawdust was added to the flow to work as a natural tracer.

Sawdust was added to the river to works as a natural tracer. It is a biodegradable material and won't cause any harm to the river ecosystem. So two analyses were made from the LSPIV to compare with the M9 equipment. One with the addition of sawdust and the other without.

2.2 Processing Phase

As the field data collection is completed. The processing phase starts. The M9 sensor has software to extract and visualize the results. The Sontek offers an interface called River Survey live that is possible to analyze the path the sensor has taken and extract information from both bathymetry and velocity profiles into a format compatible with MatLab files. The LSPIV method was processed with the support of two software. First, the PIVLAB (Thielicke and Stamhuis, 2014) is used to extract the frames from the videos, then with the RIVeR program (Patalano *et al.*, 2017) the displacement from the drone is corrected to each frame previously extract.

The video was recorded at a rate of 60 frames per second, with a Δt of 10 seconds the RiVER program extracted 600 frames and we used a tool from the same program to calibrate and correct the instability of the Drone's flight. The Δt of 10 seconds was defined after an analysis of the convergence of both mean and standard deviation from the velocity results obtained from the processing phase. With the 600 frames extracted and corrected, the image correlation analysis procedure begins.

The technique consists of an image matching pattern. Each pair of frames will be analyzed together. The program works by defining a region of interest (ROI) in the first frame of the pair. This ROI defines a searching area (SA), grid box that decreases in size proportionally. The idea is to characterize the pixel inside these boxes, calling this characterize pixel of interrogation point and search for this same pattern in the next frame of the image pair (Camargo *et al.*, 2020). This characterization and search for a pattern is the most sensitive part of the LSPIV. This analysis is made by a cross-correlation algorithm. In essence, cross-correlation is a statistical pattern matching technique that tries to find the particle pattern from interrogation area A back in interrogation area B (Thielicke and Stamhuis, 2014). This statistical technique is implemented with the discrete cross-correlation function, see equation 1:

$$C_{m,n} = \sum_{k=i}^{n} \sum_{k=j}^{n} A(i,j)B(i-m, j-n) \quad (1)$$

Where A and B are corresponding interrogation areas from frame A and frame B. There are two common approaches to solve equation 3. The most straightforward approach is to compute the correlation matrix in the spatial domain, this approach is called direct cross-correlation. The other approach is to compute the correlation matrix in the frequency domain and is called Discrete Fourier Transformation (DFT). Both approaches are available at PIVLab, and both have their advantages and disadvantages. For this work, the discrete Fourier transformation was used because it demands a lower computational cost to solve the cross-correlation. After defining the ROI and the SA in the first pair of frames, we expand the selection to all the frames extracted from the videos, and through DFT the surface velocity vectors of the channel are obtained (Camargo *et al.*, 2020).

3. Results

The M9 Sensor collected data from the region of interest determined, see Fig. 5. From this area, three cross-sections were extracted from the LSPIV method and from the ADP equipment to compare the velocity and flow results that were obtained, which are represented by the dashed lines in the Fig 5. Some parts of the area analysis were too shallow for the M9 sensor to be able to collect information, therefore some pieces of the section went unmeasured. The bathymetry and the velocity profile from the section are shown in Fig 6 and 7 respectively.

The PIVLAB results are 600 text files that contain the velocity measured from each one of the frames evaluate. To inspect these results and that could perform a good comparison with the ADCP method, the mean velocity value was extracted from all the 600 frames inspect and plot through the cross-section.

The LSPIV results are one from the recorded with sawdust and one without, see Figures 8 and 9. The behavior and magnitude from the velocity through the cross-section were similar from both this analysis. The Rodeador River has a natural tracer from itself, the turbulence caused by rocks and unevenness generate a foam that serves as a particle tracer that improves the analysis from the LSPIV. So the addition of sawdust didn't improve the method in this experiment but maintain the results.

Figure 5: Drone view from the Rodeador River, with the region of interest define

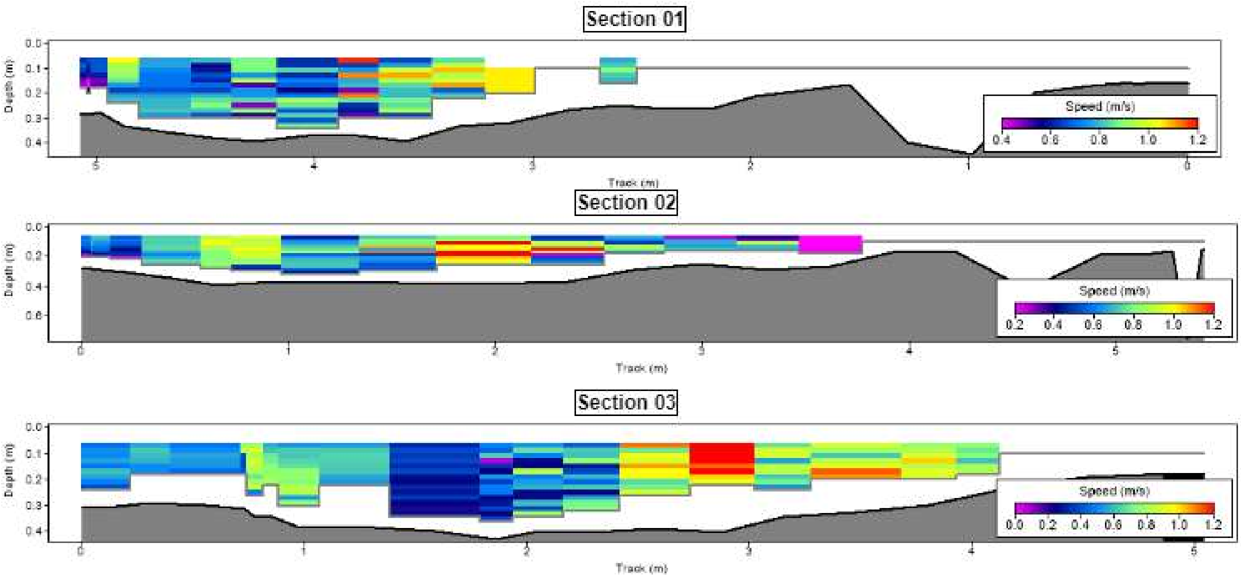

Figure 6: Bathymetry and Velocity from each section measured by the ADP equipment

The velocity that is presented in Fig 8 and Fig 9 are corresponding to the superficial velocity from the river. To compare the profile velocity measure by the M9 sensor with the superficial velocity measure by the LSPIV an index-velocity value will be assigned to estimate the discharge measurements. A value of $k = 0.85$ is generally accepted for river flows and used in conjunction with other measurement techniques (Costa et al., 2000). The value of the index-velocity coefficient is based on the assumption that the vertical velocity distribution is logarithmic (Muste *et al.*, 2008).

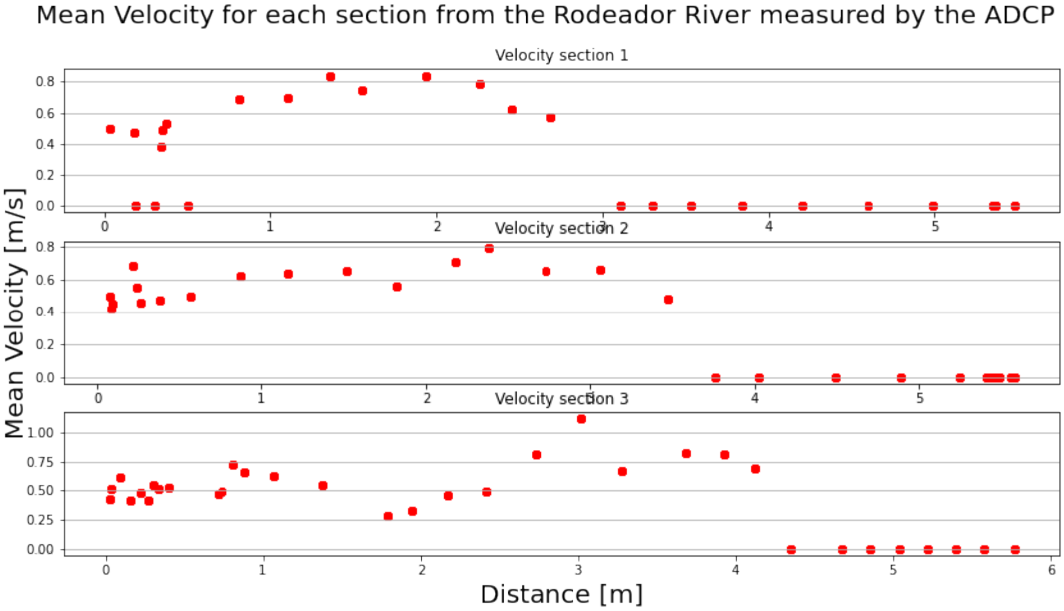

Figure 7: Mean velocity through the cross-section measured by the M9

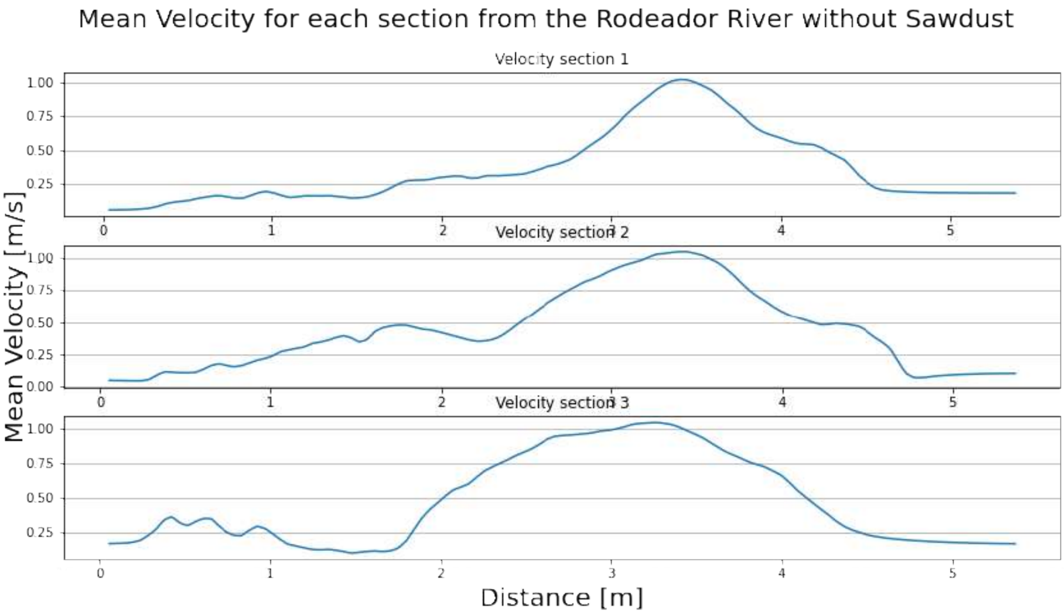

Figure 8: Superficial Velocity from the LSPIV method without sawdust added

Now with the velocity's values corrected by the index value, the method can relate, see Fig 10. Some results can be pointed out from this graph. The behavior of increasing speed through sessions remained present in both methods. The difference in the final speed value remained below 10%.

The discharge was calculate using the mean area measured by the M9 sensor. The value from the areas are show below and they units are in m^2:

Area 01	Area 02	Area 03
1.568	1.542	1.369

The value from the calculate discharge can be seen at Fig 11. The units of the discharge are m^3/s and the kept the difference between each methods preserved below 10%.

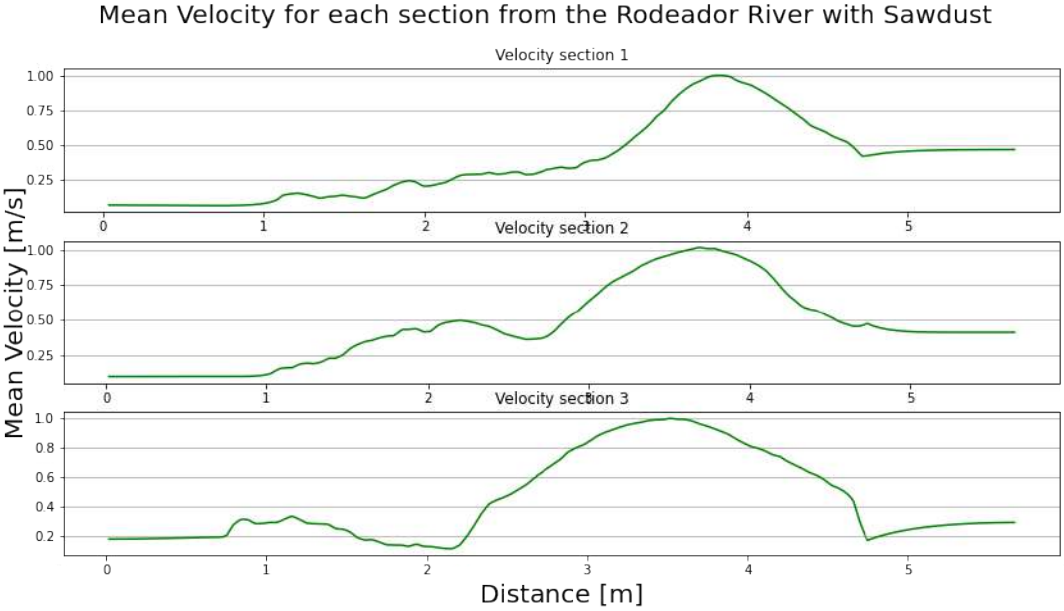

Figure 9: Superficial Velocity from the LSPIV method with sawdust added

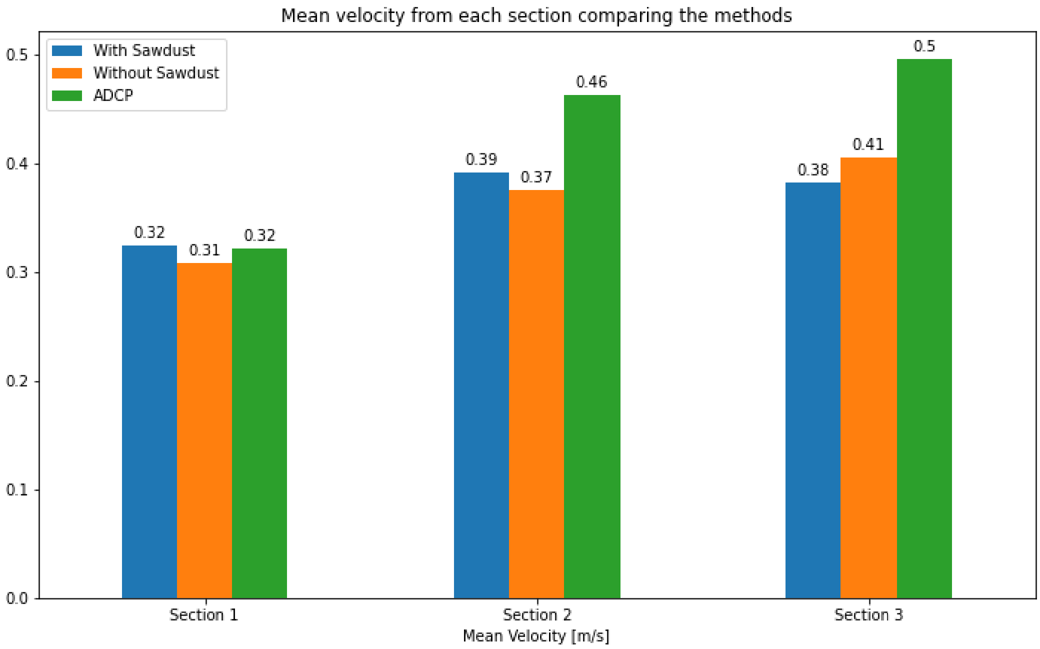

Figure 10: Mean velocity's value from each method and section

4. Conclusion

New measures techniques are extremely important for river characterization. The LSPIV is a safe, fast, and reliable technique to perform superficial velocity measures. The difference between the values from each method was more than expected but that can be a result of the location that the video recorded. There were a lot of shadows from trees that affect the image analyses. Adding a particle tracer, like sawdust, is important to improves the analysis from LSPIV technique when the river flow does not present a visible identification pattern.

Focusing on new methodology to enhance the renewable matrix from the world is a global demand. The challenge to achieve net zero until 2050 requires the investment in research and development. New methods and analysis that can encourage the research on renewable energy sources are necessary. Even though the location could not physically receive

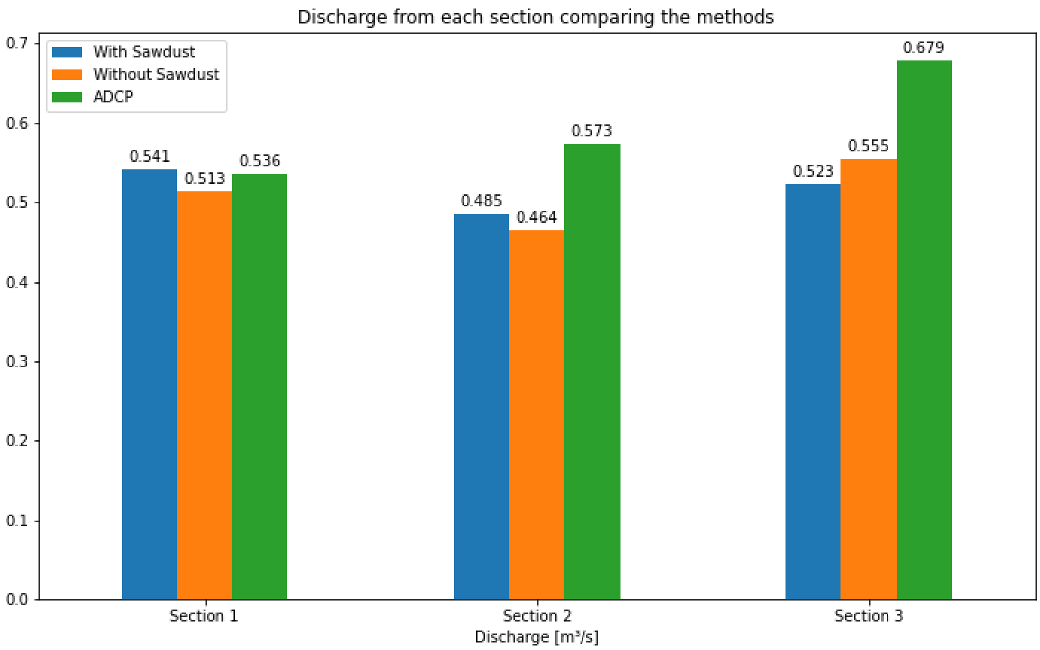

Figure 11: Discharge value from each method and section

the installation of a hydrokinetic turbine, the experiment was able to determine the hydrokinetic potential in the Rodeador river that was the prime objective of this work.

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