RECREATING RIVER FLUID DYNAMICS IN THE UNIVERSITY OF VIRGINIA WATER CHANNEL

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Abstract: Rivers are multifaceted systems that play a vital role in helping model the Earth's surface and maintain the ecological system. Studying river fluid dynamics in controlled environments aids in modeling and testing riverine fields and replicating the complexity of natural rivers which pose challenges. Having controlled testing parameters can be ideal or impractical to help push thresholds for change in riverine field testing. The river fluid dynamics field does not have a research approach that recreates a river environment in a water channel with turbulence and mean velocity profiles as well as free surface fluctuations. One of the key challenges in studying river fluid dynamics is the complex nature that needs to be replicated in the testing facility. Turbulence is a subtopic of extreme importance when considering river fluid dynamics, and how turbulence affects the transport of sediment and other materials. The recreation of the river in the Water channel will need to be achieved, and the mean velocity profile and turbulence intensity profile need to be replicated to mirror an actual river at 0.2m/s.

1 Introduction

Research Questions:

1. How can this present study replicate a riverine environment in the UVA Water Channel?
2. What impact do turbulence intensity profile and mean velocity profiles have on recreating a riverine environment?

The water channel at the University of Virginia will serve as the testing facility for this research. This closed-loop Water Channel has a testing section with dimensions of 1.52m by 0.51m. In Figure 1 there is a side view schematic of the water channel which shows the velocity profile before the turbulence grid and after, the location of the turbulence grid, the free surface in the water channel, and the dimensions of the testing section of the water channel. This testing facility comes with a laminar flow. A passive turbulence grid will be used to create varying levels of turbulence to mimic an actual river. The turbulence grid is set at alternating angles (see Table 1). In Figure 2 there is a 3-D schematic of turbulence grid. The winglets are attached to the rods in both vertical and horizontal directions. The rods can be adjusted to include the angle that is needed to achieve the turbulence intensity levels.

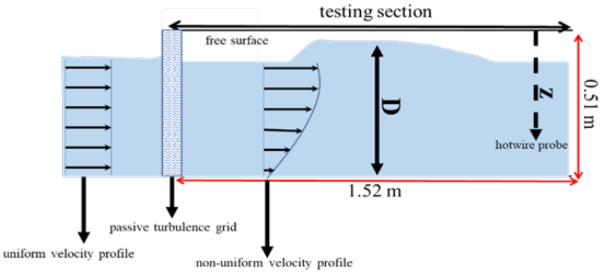

Figure 1: Two-dimensional side view Water Channel schematic.

Table 1: Turbulence grid vane settings. Vertical Rods are all set to 0°. The first vein is not submerged in the water

Horizontal Rod	Angle (°)
1	25°
2	−25°
3	25°
4	−25°
5	25°
6	−45°
7	45°
8	−90°

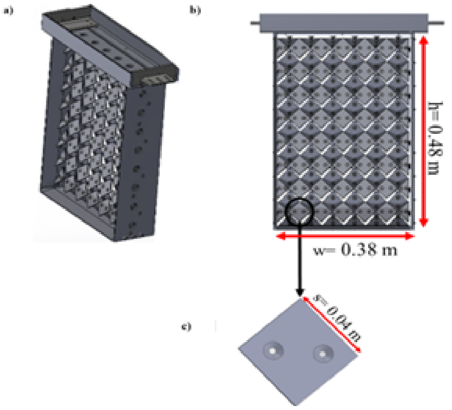

Figure 2: Three-dimensional schematic of the turbulence grid. a) Isometric view b) Front facing view with dimensions c) Winglet (square plate) with dimensions.

The objective of the proposed Phase I work is to generate turbulence using the passive turbulence grid in Figure 2. The Experimental setup can be observed in Figure 3. to replicate the riverine conditions (reproducing the riverine velocity and turbulence profiles) measured in the Kvichak River (Alaska) in the water channel. The Kvichak River is an ideal system to function as a baseline for testing because of the variety of conditions and the potential impact of hydro-energy on the local communities [1]. The residents in the remote towns and villages will significantly benefit from the micro-scale green power technology we aim to develop and test in future studies. Especially, under the most extreme conditions including when the river is frozen and during the high-flow spring runoff procedures [1]. One of the main goals of this study is to contribute to the riverine fluid dynamic field in a way to help contribute to renewable energy, especially for more compromised communities.

The first milestone is to replicate the environment of the average river. The testing parameters that I will be implementing in the water channel will come from a range of rivers, those rivers include Kvichak River, the R.G. Canal, and the Mississippi, Missouri, Hurunui, and Severn Rivers [2]. The water channel is being refined and validated with a passive turbulence grid. The best course of action to establish testing parameters in recreating the river environment, was to use mean velocity and turbulence intensity profiles.The preliminary results are within the average river velocity and turbulence profiles across a range of observed conditions and previous studies. To contribute to current practices of references determined by the United States Geological Survey (USGS) there are a variety of rivers assessed along with a variety of time ranges [3]. By refining and validating the water channel, this study will enable the riverine field to evaluate new riverine-energy technology in a controlled environment with no impact on the riverine ecosystems.

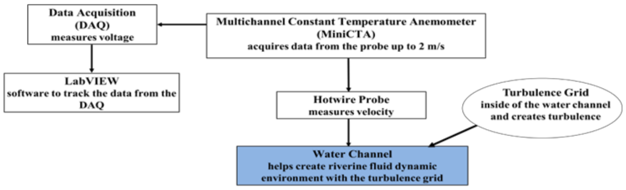

Figure 3: Flowchart of the experimental setup for velocity collection.The arrows indicate what equipment is joined, to achieve experimental project results.

2 Methods

A series of experiments were conducted to measure key parameters such as velocity profiles, and turbulence intensity in the water channel. The turbulence grid's configuration, including the vertical and horizontal rods (Table 1), was varied to achieve the desired turbulence intensity levels. Additionally, sensors placed along the testing section of the water channel provided real-time data on velocity and turbulence intensity, enabling the researchers to fine-tune the system to match river conditions.

The following experiments were performed:

- ***Experiment 1:*** Measurement of velocity profiles at varying distances from the turbulence grid
- ***Experiment 2:*** Analysis of turbulence intensity profiles

The experiments detailed in this study were performed at the University of Virginia Water Channel, in Charlottesville, Virginia. The experimental setup for this study is detailed in Figure 3 with a flowchart to give a visual representation of the laboratory setup.

2.1 Turbulence Generation and Characterization of the Flow

A passive turbulence grid was used to generate the turbulence required for this experiment and inserted into the water channel (see Figure 1). The winglets on the grid were set at alternating angles that varied (see Table 1). The grid disturbed the flow non-uniformly, creating a controlled level of turbulence in the test section.

3 Results

To initiate the replication of a riverine environment, the mean velocity and turbulence intensity profiles must be produced. Figure 4 represents a comparison of velocity distribution in a vertical profile of a flow. In the graph the ($\frac{U}{U_{\max}}$) as a function of the relative depth ($\frac{z}{D}$). For Figure 4, four sets of data were compared. Kvichak Data 2019 (blue circles) [1], Neary Data 2011 (purple diamonds) [2], the Present Study (red squares), and an Empirical Shear Profile with β = 0.2 (green curve with dotted markers). This plot helps to evaluate how well the present study data compares to real rivers. The shear profile (green curve with dotted markers) was used to model the data to get the best line fit to visually display the data and the extent to which it agrees.

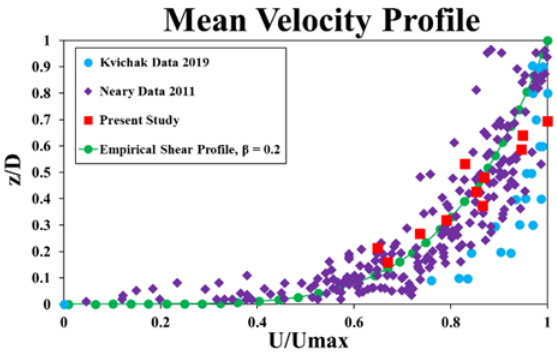

Figure 4: Mean Velocity Profile are plotted against z/D. z/D is depth of the hotwire probe in the UVA water channel/depth of the water. In the graph you can observe the Neary 2011, Guerra and Thomas 2019, UVA data. The Neary data is R.G. Canal, and Mississippi, Missouri, Hurunui, and Severn Rivers. The Guerra and Thomas data is the Kvichak River. The fit line is the riverine shear value of 0.2. Typical β values for wind turbines could range between 0.1 & 0.2.

In Figure 5 the turbulence intensity is displayed for three different sets of data. Kvichak Data 2019 (blue circles), Neary Data 2011 (purple diamonds), and the Present Study (red squares). Turbulence intensity (TI%) is a critical parameter for characterizing the unsteadiness and mixing behavior in open channel and shear flows.

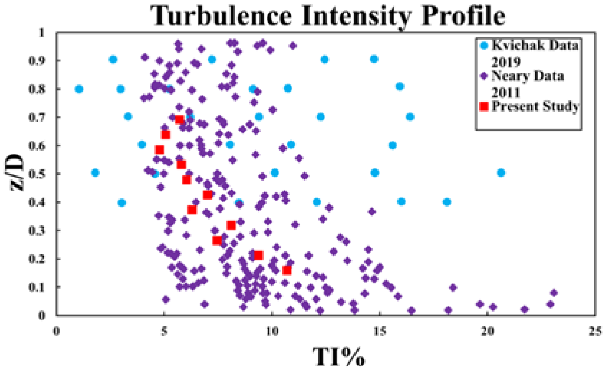

Figure 5: Turbulence Intensity Profiles. The riverine velocity profiles and turbulence intensity profiles are plotted against z/D, where z/D is the depth of the hotwire probe in the UVA water channel divided by the total depth of the water. The graph shows both Neary (2011) and UVA data. The Neary data includes R.G. Canal, and the Mississippi, Missouri, Hurunui, and Severn Rivers. TI is turbulence intensity normalized by local velocity, and TI^* is TI normalized by maximum velocity. The range of TI^* is $10\% \leq TI^* \leq 25\%$.

4 Conclusion

In this research study the experimental study has aimed at recreating riverine fluid dynamics within a controlled environment, this study specifically utilized a water channel for the controlled environment. In the water channel a passive turbulence grid was inserted to create turbulence. In the water channel there was varying flow speeds and turbulence parameters, which simulated naturally occurring behaviors found in riverine systems. A key aspect of this project lies in its emphasis on pushing the limits of the testing facility to uncover both its capabilities and constraints. The ability to mimic real-world river conditions within a laboratory setting will provide valuable insights that are both transferable to field applications and fundamental to advancing hydrodynamic understanding.

The novelty of this research stems from the ability to replicate realistic turbulence observed in natural rivers, and the ability of this research to be a scalable, low-cost, and modular testing system. This approach allows us to investigate flow characteristics under controlled conditions, facilitating detailed studies that are often impractical in natural environments. By systematically exploring the effects of varying turbulence intensities and flow regimes, we aim to develop a comprehensive understanding of how riverine conditions evolve, which can be directly applied to environmental modeling, and energy generation.

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6 References

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