The River Runs Over It

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Flow Visualization: Get Wet

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I. INTRODUCTION

The purpose of this image is to capture the delicate beauty of a flowing waterway and the robust physics that describe water moving together in a river. The fluid dynamics of rivers is what made me excited about taking a fluids class in my engineering curriculum, and I was sorely disappointed when the complexities of this phenomenon were too in-depth for the surface-level class. This continued desire to know more brought me to a river for my "Get Wet" project. I began by taking photos of the October Hole rapid as kayakers went through the river, but could not get a detailed enough image, so I began to experiment in the shallow flow nearby. This is where I found the inspiration for my photograph and found that it elegantly encapsulated many river phenomena in one frame.

II. PHENOMENON

The October Hole in Lyons, Colorado is a man made rapid for kayakers to use recreationally. Surrounding the hole are large rocks with small open channels for water to flow through. While peering into the channels, I saw quite a few common whitewater phenomenon such as open channel flow, hydraulic jumps, ligaments, and satellite droplets.

a. Setup

Creating an exact, repeatable experiment using a river is challenging due to the variable nature of water flow. Streamflow is measured in the United States on a per-state basis, and since Colorado is known as 'The Headwater State', there are many streamflow gauges here. The gauge that I used to measure the flow rate of the St. Vrain on September 3, 2022 was the St. Vrain Creek below Bouder Creek at HWY 119 which was 68 cubic-feet-per-second (CFS) at 12:00.

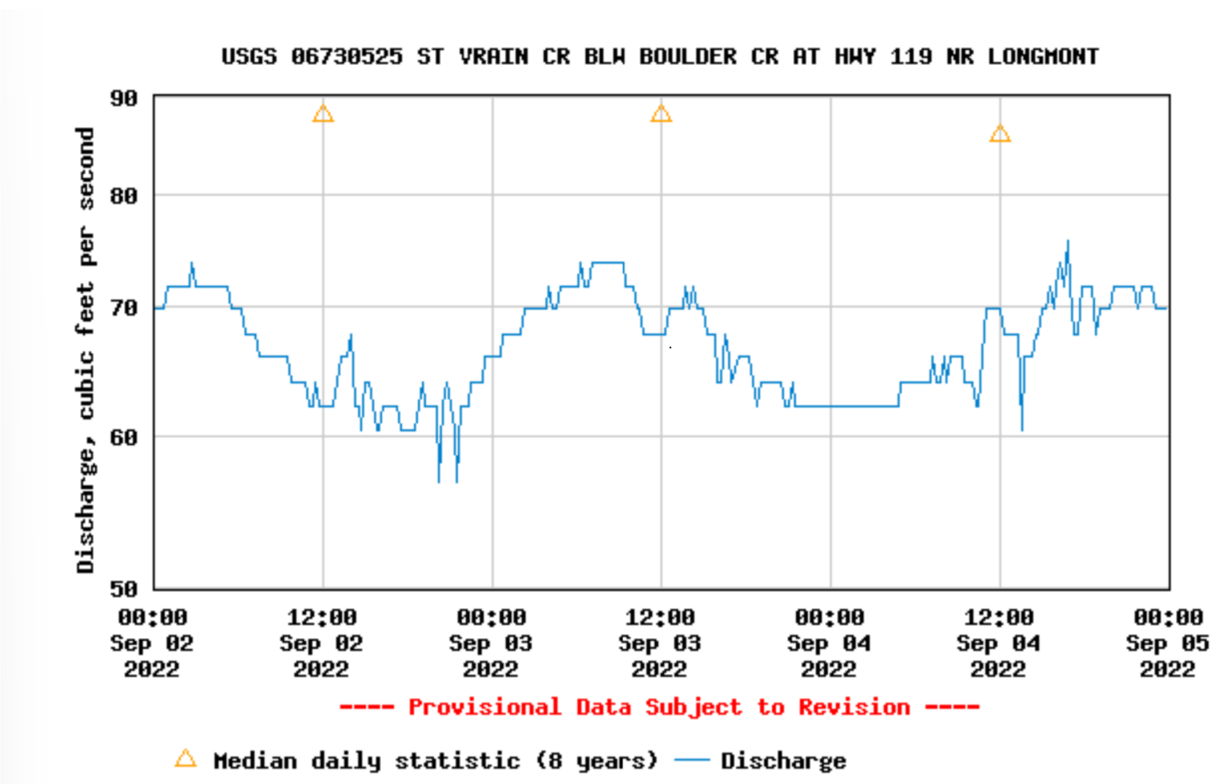

Figure 1. The flow rate of the St. Vrain creek between midnight on September 2 and midnight on September 5 (waterdata.usgs.gov 2022).

The image was photographed in full sunlight, with no clouds in the sky. The sun's color temperature, 6000 K, is very appealing to humans due to our evolutionary nature. This made the natural lighting a good fit for the image because humans need sun and water to survive.

Next, I got close to the image target. I was positioned three feet away from the rock in view, angled 40˚ from the ground plane, as shown in Figure 1.

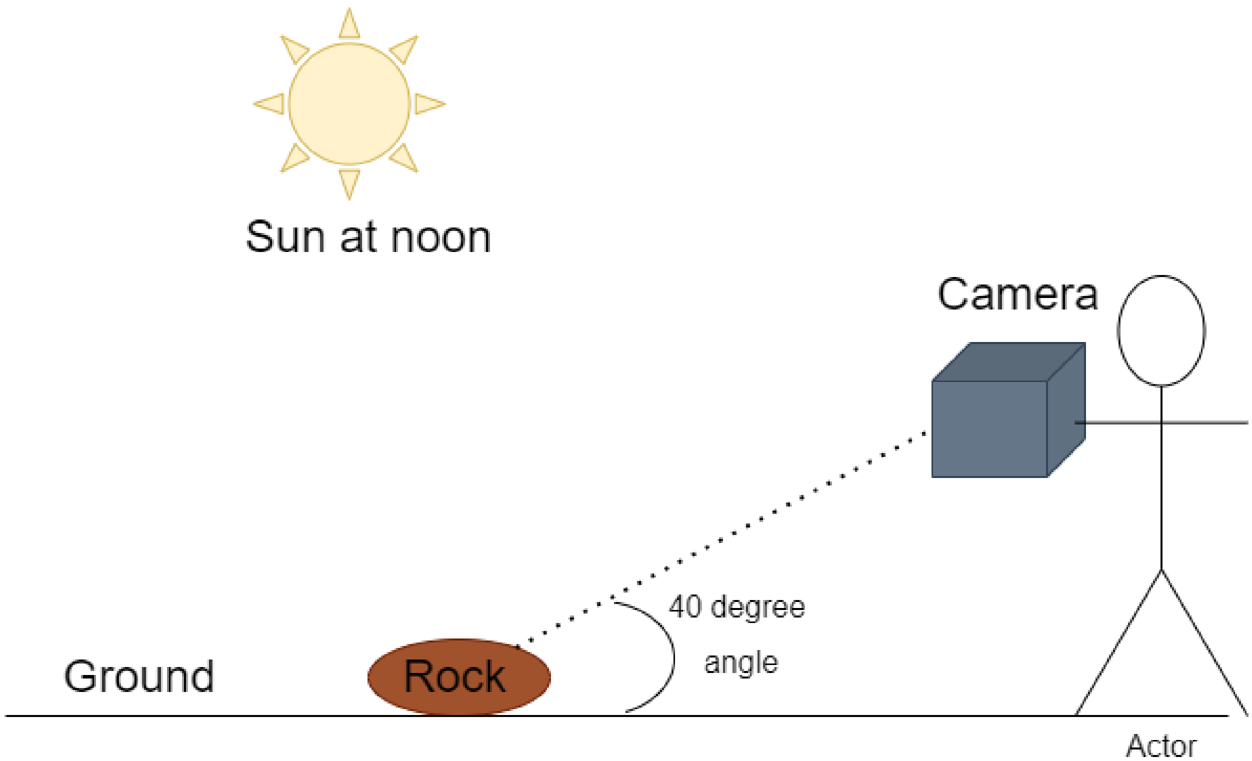

Figure 2. An image depicting the setup of the image, including the camera angle and sun location.

Using the setup shown above, I was able to capture a beautiful image that describes open channel flow well.

b. **Flow**

The basic flow shows water flowing over a 4" tall rock, at a point right before a wave is formed on the front side. The rock has a thin layer of water covering it, but it is not fully submerged in the flow. Channels of water flow to either side of the rock. Upon inspecting the image, the flow above the rock appears relatively smooth and undisturbed suggesting that the flow is laminar. About an inch in front of the rock, the fluid rises up and begins to form a wave. The changes in shape and characteristics of the water suggest the flow is now turbulent.

i. **Open Channel Flow**

Open channel flow defines many natural and manmade flows where the fluid is open to the atmosphere. In this case, the entire river is an open channel. Since it is common knowledge that rivers flow downstream, two forces drive the motion: pressure and gravity. Further, parameters of free flow are density, viscosity, cross-sectional geometry, slope, depth, and velocity. Since the channel is open, the pressure impacting the flow is hydrostatic, so the head becomes

$$H = dcos\theta + z_0 + \frac{V^2}{2g} \quad \text{(Equation 2.1)}$$

Equation 2.1. H is total head, d is water depth (normal to bed), θ is the bed slope, z_0 is the bed elevation, V is the flow velocity, g is gravity (Chanson).

Applying Equation 2.1 to approximate the total head of the smooth flow above the rock in my image, I find that $H = 4[in] * \cos(5°) + 0 + \frac{68 * \frac{1}{\frac{4}{12} * \frac{7}{12}}}{2 * 32.2} \frac{\left[\frac{ft^3}{s} * \frac{1}{ft^2}\right]}{[\frac{ft}{s^2}]}$ and calculate it out such that $H = 213\ [J]$. This value shows that even though the rock is relatively small, there is still a large amount of energy above the rock from the speed of the water and the difference in height.

ii. **Hydraulic jump**

A hydraulic jump dissipates energy due to the sudden change of water level and gradient, particularly over a weir or a rock. In engineering design, hydraulic jumps can be used to take fluid from higher energy to lower energy such as in stepped weirs when energy is dissipated more with each step. Since the rock is not very large, not much energy is dissipated in relation to the overall velocity of the stream. Using the Froude number (Equation 2.2)

$$Fr = \frac{v}{\sqrt{g \cdot d}} \qquad \text{(Equation 2.2)}$$

Equation 2.2. v represents the velocity of the flow, g represents gravity, d represents the depth of the flow.

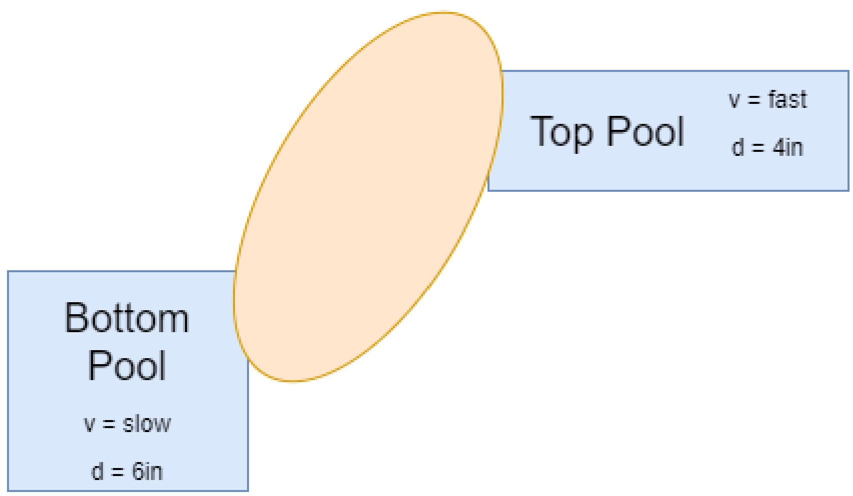

Figure 3. A depiction showing the relative speeds and depths of the top and bottom pools to calculate the Froude numbers.

I calculated the Froude number both above and below the hydraulic jump so that $Fr_{above} = 105$ and $Fr_{below} = 25$ (Appendix). The Froude number above the rock is much higher than the Froude number below, showing that the inertial forces are higher before the hydraulic jump, and after the water slides off the back of the rock, the inertial forces are much lower, which shows that energy has been dissipated (AlTalib 2019, Froude Number 2006).

iii. **Ligaments & Satellite Droplets**

Ligaments and satellite droplets occur as the water flow collides with the front side of the rock and a wave begins to form. Differences in driving forces, such as location and velocity of collision with the rock, lead to different styles of satellite droplets, some with ligaments and some without. As the water mixes with the surrounding air, droplets fly off and will bubble and froth on top of the pool just beneath the rock. Any air or bubble forces below the surface during the hydraulic drop will rise to the top of the bottom pool and may pop. Smaller satellite droplets are influenced more heavily by surface forces and larger droplets are influenced by body forces (Wang 2021).

III. VISUALIZATION TECHNIQUES

I did not choose to use any visualization techniques in the making of this image. I wanted the flow of the river to replicate the natural flow as well as possible. This was also accomplished by using natural sunlight as my lighting for the image. I used the bright sunshine at noon to light my image, and there were no clouds in the sky.

IV. PHOTOGRAPHIC TECHNIQUE

For my field of view, I wanted to encapsulate a few different flow phenomenon in a single image, while not making the image too busy; To do this, I choose a field of view that was about 8 inches across. The rock was about three feet away from my camera. I used a Canon EF-M 15-45mm f/3.5-6.3 IS STM lens with a focal length of 45 mm, focus distance of 1.19m, aperture of f/6.3, ISO of 800 and exposure of 1/4000. I choose a very small exposure because the bright sunny day provided ample light for my image and the time needed to capture the correct lighting was very short. I used a Canon EOS M50 digital camera. The final width and height were 6288px and 4056px respectively. To process the image, I cropped out the extra details, and played around with the RGB-levels to accomplish a visually appealing image. I slightly turned up the whites, but didn't turn them up too much because I like the detail of the greens under the water.

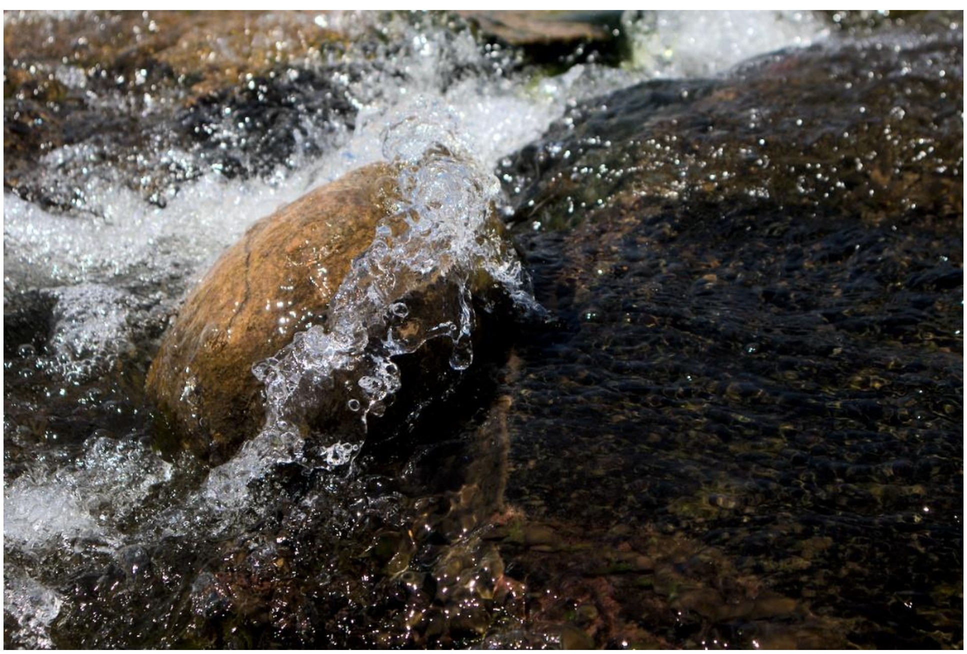

Figure 4. Pre-processed image.

V. IMAGE

Overall, I am very happy with the way the image reveals a wave about to form in front of the rock. I find that it accurately encapsulates the feeling and flow I was hoping to capture. I like the small amounts of color that appear on the bottom of the small pond above the rock and crisp details of the in-focus water droplets. I don't like that I wasn't able to achieve the whitest whites in the foam during post processing.

The fluid physics described above are shown very well in the image. To further improve and develop this idea, I would scale the image up to a much larger boulder in the main stream of a river. The small side channel was easier to photograph, but showed a scaled down version of the phenomena that excite me.

VI. **APPENDIX**

Froude number calculations

$$Fr_{above} = \frac{350}{\sqrt{32.2 \cdot \frac{4}{12}}} \frac{\left[\frac{ft}{s}\right]}{\left[\left(\frac{ft}{s^2} \cdot ft\right)^{\frac{1}{2}}\right]}$$

$$Fr_{below} = \frac{100}{\sqrt{32.2 \cdot \frac{6}{12}}} \frac{\left[\frac{ft}{s}\right]}{\left[\left(\frac{ft}{s^2} \cdot ft\right)^{\frac{1}{2}}\right]}$$

VII. BIBLIOGRAPHY

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