

A Small Creek On A Rainy Day

MCEN 4151-001 Flow Visualization

Get Wet Report

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Background & Introduction

"A Small Creek On A Rainy Day," depicted in Fig. 1 below, is my attempt to delve into the world of flow visualization, a medium that bridges the realms of art and physics. For this assignment, I embarked on a weekend trip to my family cabin nestled between Estes Park and Allenspark, deep within the Rocky Mountains. At an elevation of approximately 9,100 feet above sea level, our cabin occupies a five-acre plot of land adjacent to Rocky Mountain National Park. Hidden behind a stack of boulders on the hillside, there is a small creek that flows nearly year-round. This small creek is no wider than a few feet at its widest point and sometimes narrows down to mere inches. While deciding what to attempt for my Get Wet assignment I thought I might be the first person to capture this exact location at this time of year. This is why I chose it for my foray into flow visualization. For this project, I concluded that a long exposure shot taken close to the ground would provide the best means to visualize the transition between turbulent and laminar flow, the primary physics phenomenon I aimed to capture. This weekend trip into the mountains was a personal getaway for me before classes got too busy. Because of this, I captured this image without any assistance.

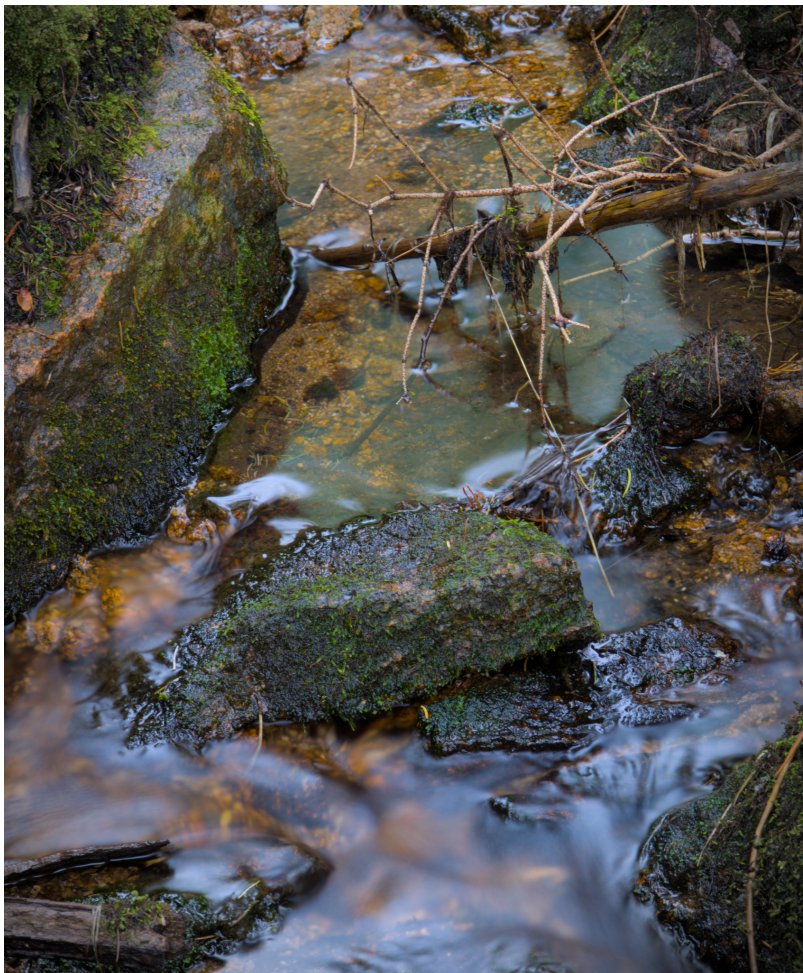


Figure 1. "A Small Creek On A Rainy Day"

Methods & Physics

I decided to take this image located on the creek wall about 1 meter away from my target composition from the top pointing down towards the water. See Fig. 2 for a sketch depiction of my setup.

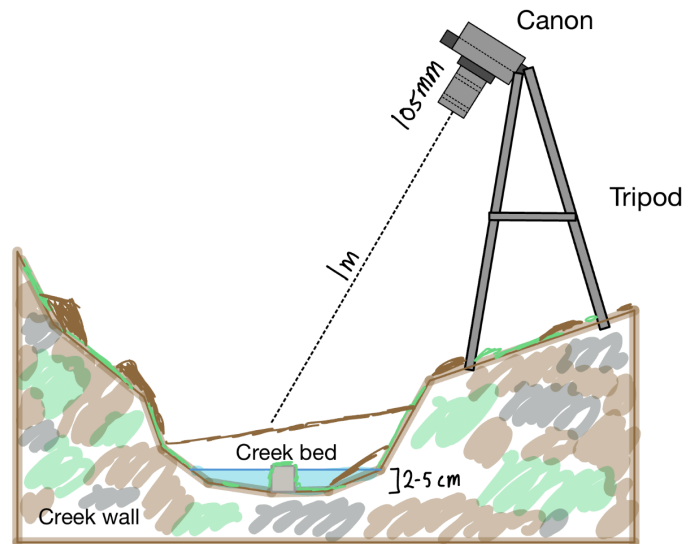


Figure 2: Sketch depiction of my setup

The main fluid phenomenon on display in “A Small Creek On A Rainy Day” is that of laminar and turbulent flow. In fluid mechanics, the defining characteristic of a stream's flow pattern is its Reynolds number. The Reynolds number is a dimensionless parameter that takes into account a fluid stream's density, velocity, characteristic length, and dynamic viscosity. This equation takes the formula of:

$$Re = \frac{\rho u L}{\mu} \quad (1)$$

Where “Re” is the resultant Reynolds number, “ ρ ” is the fluid density at a given temperature, “ u ” is the fluid's free stream velocity, “ L ” is the characteristic length, and “ μ ” is the dynamic viscosity of the fluid. If calculated property, the resulting Reynolds number should be dimensionless.

For my system, that of a small mountain creek-bed, I would expect a Reynolds number varying between 1,000 to 10,000+. On the low end, closer to 1,000, the stream would behave laminar with collinear flow lines. Towards the higher end, closer to 10,000, the stream would behave as turbulent with flow lines that act random, yet still confined to the creek bed.

The second, and arguably driving fluid phenomena on display in this image is the law of conservation of mass. For a closed system, the law of conservation of mass states that any matter that enters the system must leave the system. This means that as the cross sectional area of the stream narrows, the relative velocity of the fluid must increase such that the mass flow rate into and out of the system remains constant. The equation for conservation of mass flow rate in a closed system is as follow:

$$Q_1 = \rho A_1 u_1 = \rho A_2 u_2 = Q_2 \quad (2)$$

Where Q_1 and Q_2 are the mass flow rates, ρ is the density of the fluid, A_1 and A_2 are the relative cross sectional areas, and u_1 and u_2 are the relative velocities. For this equation point '1' is located at the start of a system and point '2' is located at the end of a system.

If we follow Eq. (2) we can see that as the stream narrows in cross sectional area, the velocity of the fluid must increase linearly and proportionally to account for the area change. This resulting increase in velocity will have a linear increase in the Reynolds number of the fluid at that specific point.

To gain an approximation of the Reynolds number at different regions of my system I first had to solve Eq. (2) at two different points along the water flow path. The first point was located in the predicted laminar basin toward the top of the image. I estimated a fluid velocity of 0.05 meters per second with a characteristic linear depth of 2cm and a stream width of about 35cm. The second point I chose to calculate was in the predicted turbulent confined section in the middle of the image. I estimated a characteristic linear depth of around 2.5cm and a stream width of about 2.5cm. From these values I was able to calculate the velocity of the predicted turbulent section as follows:

$$0.05 \frac{m}{s} (0.02m \cdot 0.35m) = u_2 (0.025m \cdot 0.025m) \quad (3)$$

$$\rightarrow u_2 = \frac{0.05 \frac{m}{s} (0.02m \cdot 0.35m)}{(0.025m \cdot 0.025m)} = 0.56 \frac{m}{s} \quad (3.1)$$

Using the results of Eq. 3.1, I was able to calculate an approximate Reynolds number of the laminar and turbulent flow regions of my system. The first point was located in the predicted laminar basin toward the top of the image. Given my estimated fluid velocity of 0.05 meters per second with a characteristic linear depth of 2cm, and the ambient water temperature of around 50 degrees C, the resulting Reynolds number would be around 1,800. See Eq. (4) for my calculation.

$$Re = \frac{\rho u L}{\mu} = \frac{(988 \frac{kg}{m^3})(.05 \frac{m}{s})(.02m)}{0.0005471 \frac{kg}{m \cdot s}} = 1,806 \quad (4)$$

The second point was again located in the confined predicted turbulent region towards the center of the image. Given my calculated fluid velocity of 0.56 meters per second with a characteristic linear depth of 2.5 cm, and the ambient water temperature of around 50 degrees C, the resulting Reynolds number would be around 25,300. See Eq. (4.1) for my calculation.

$$Re = \frac{\rho u L}{\mu} = \frac{(988 \frac{kg}{m^3})(.56 \frac{m}{s})(.025m)}{0.0005471 \frac{kg}{m \cdot s}} = 25282 \quad (4.1)$$

From these calculations we can see that the top half of the image behaves as a laminar flow ($Re < 2,000$), and the bottom half of the image behaves as a turbulent flow ($Re > 2,000$).

In reality, these values are general approximations. The creek bed is a complex and dynamic system with changing surface characteristics, water depths, and sediment enriched segments. All of these variables would have an effect on Reynolds number and thus the flow

patterns of the creek. Chances are we would see transition regions between laminar and turbulent in the fluid as fluid velocity increases. This is because discontinuous and sudden changes in fluid velocity are unrealistic in nature. Realistically, my calculated Reynolds number values are ballpark estimates for the true nature of the stream and should be taken with a grain of salt.

All physical values were imputed and taken directly from the Reynolds Number Calculator on omnicalculator[1].

Photographic & Visualization Technique

This image was shot on a Canon EOS R6 Mark II mirrorless camera with a kit 24-105mm zoom lens. No discrete visualization techniques, such as adding dye or smoke to the system, were used. Instead, to capture the relative water motion within the laminar and turbulent regions, I decided to take longer exposure shots. The exposure of an image is primarily tied to the shutter speed. In a sense, the longer the shutter remains open on the camera body, the longer light has to hit the sensor. To capture instant movement and in a sense ‘freeze’ the target in frame, shorter shutter speed speeds are often used. Examples of fast shutter speed action shots include photographing a Formula1 race car flying around the circuit, or the motion of a bird soaring through the air. These can often be shot at shutter speeds ranging from 1/125 to 1/500 of a second. Longer exposure shots, sometimes 20 to 30 seconds, are often used to take night shots of the moon or stars. I decided to aim for a middle ground at around 4 to 8 seconds to capture the motion of water over time as it flows through the creek.

Some initial shots were taken with a 4” shutter speed. To truly capture the waterfall type turbulent crash between the laminar flow upper basin and the turbulent flow lower basin, I settled on a final shutter speed of 6”. To hold the camera steady for 6 seconds I used a tripod and the camera’s built-in 2 second timer setting to limit the amount of camera shake after I pressed the shutter button. Since I decided to use a shutter speed of 6” I had to use a small aperture stop at f/16.0 to not blow out the image with too much light. This small aperture stop constricted the amount of light able to enter the camera by closing the iris diaphragm. See figure 3 below for a pictorial representation of different aperture settings [2].

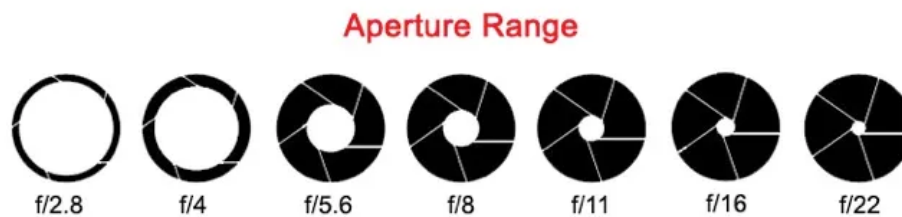


Figure 3: Pictorial representation of different aperture settings

The last setting that affects the amount of light the sensor can pick up is the ISO setting. This setting is directly tied to the camera sensor’s sensitivity to light. Low ISO numbers means the camera is at its least sensitive setting. While high ISO settings can allow the camera to pick up more light by being more sensitive, it can often lead to image graining where the resulting

image looks fuzzy. Sometimes this can be an artistic preference. For this project I decided to keep my ISO at my camera's lowest setting of 100 and adjust the amount of light in the shot via the shutter speed and aperture settings.

The resulting image I decided to use for my project was shot at a focal length of 105mm at about 1 meter from the target. This image was shot in the Canon native RAW format.

During post processing I decided to crop down the original image from 5999 pixels wide by 4000 pixels tall to 3327 pixels wide by 3998 tall. The main source of light in this image was from diffuse sun rays piercing through busy mountain rain clouds. Because of this, the resulting image was relatively flat in color. For this reason, I decided to increase the image's vibrance and color contrast to bring out some of the greens and blues. I also decided to edit out an out of focus branch in the top center third of the image using the retouch tool. See Fig. 4 below for the RAW image taken directly from the camera and Fig. 1 for final image after post processing.



Figure 4: RAW image taken of creek imported directly from camera.

Artistic Revelation

In this captivating image, nature's contrasting forces are vividly depicted as the scene is bisected horizontally by an intricate interplay of rocks and twigs. The upper half of the frame showcases a serene display of laminar flow, where the water's surface appears smooth and tranquil, resembling a glassy sheet. This juxtaposition against the lower half of the image is striking, where the water takes on a turbulent character, as if in an impassioned dance, as it surges and swirls around the rocky obstacles. This captivating composition not only captures the beauty of nature's duality but also evokes a sense of balance and harmony amidst the dynamic forces at play.

I believe the image I took is of appropriate class quality and accurately represents the principles of fluid physics I aimed to capture. The balanced portrayal of laminar and turbulent flow, combined with the inclusion of rocks and twigs, makes it a compelling and informative snapshot. Moving forward I would like to venture further into proper image framing and composition. While I believe the image I settled on is able to convey the intended fluid

mechanics I attempted to achieve, I also believe that there is plenty of room to improve. For instance, while I think the rock situated in the center of the image is an important piece that impedes water movement and fundamentally causes the transition from laminar to turbulent, I also think that it takes up too much real estate in the image and overpowers the intended focus of the image, the water itself.

Moving forward I would like to scale the concept of waterfall/flowing water photography up. There are countless places in Rocky Mountain National Park that provide unlimited flow visualization photography opportunities. I am excited to continue this new hobby of mine and I am eager to get out there and capture my next image!

References

[1] Czernia, Dominik. "Reynolds Number Calculator." *Omnicalculator*, omnicalculator, 5 June 2023, www.omnicalculator.com/physics/reynolds-number.

[2] Werner, Danielle. "Seeing in Depth of Field: A Simple Understanding of Aperture." *Digital Photography School*, Digital Photography School, 2015, digital-photography-school.com/seeing-in-depth-of-field-a-simple-understanding-of-aperture/.