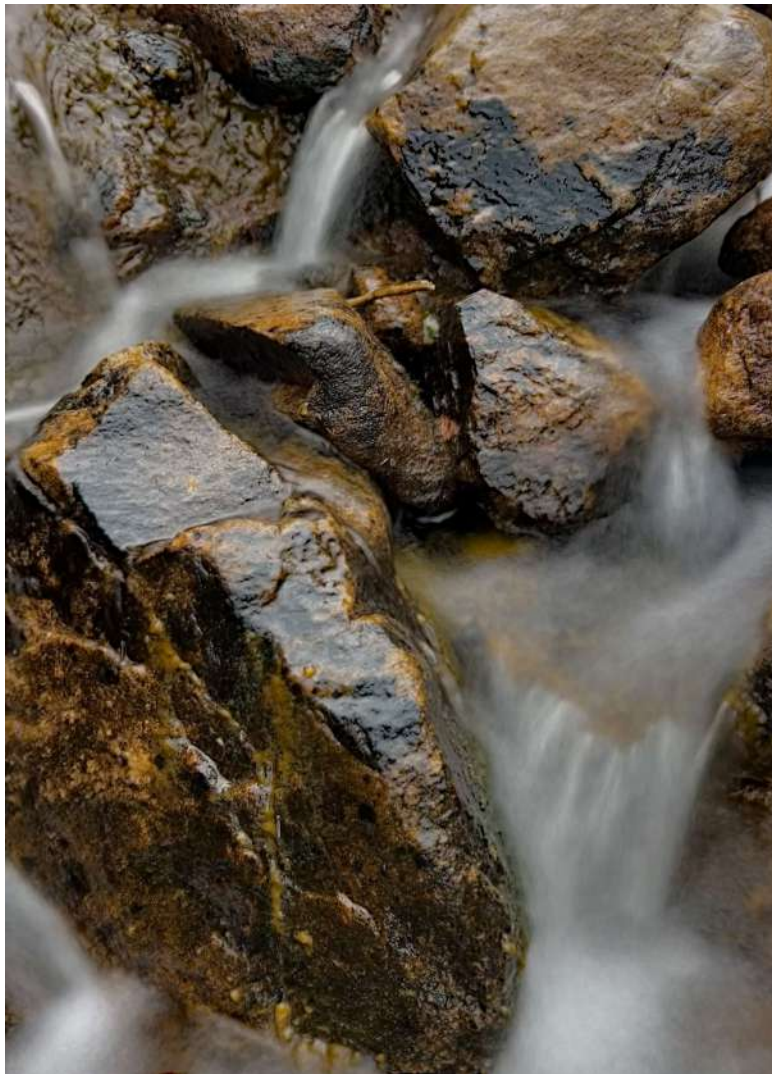




High Alpine Lake Outflow

MCEN 5151: Flow Visualization

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Get Wet Assignment

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1 Introduction

The image of outflow water from Yankee Doodle Lake captured in this document visualizes natural fluid dynamic phenomena, specifically free-surface streamflow over obstacles, boundary layer interaction with submerged rocks, and distinct flow geometries. This photograph was taken in accordance with the Get Wet assignment, utilizing the visualization principles outlined in MCEN 5151: Flow Visualization. The primary objective was to capture the streamlines and geometry of a mountain stream to evaluate its boundary layers and flow regimes. Initially conceived as a short-exposure capture of instantaneous turbulent flow, a long-exposure approach was ultimately selected, as it significantly enhanced the definition and traceability of the flow paths. Artistically, the photograph bridges natural aesthetics and fluid mechanics into a visually engaging composition. The natural illumination across the water-covered granite presents a compelling visual depiction of the underlying technical flow structure.

2 Flow Phenomena

To analyze the fluid dynamics within the image, one must first examine the two primary geometrical flow configurations dominating the stream. In both instances, the motion and visual structure of the fluid are governed by a continuous dynamic balance between gravitational acceleration, inertial momentum, viscous shear, dynamic pressure gradients, and surface tension forces.

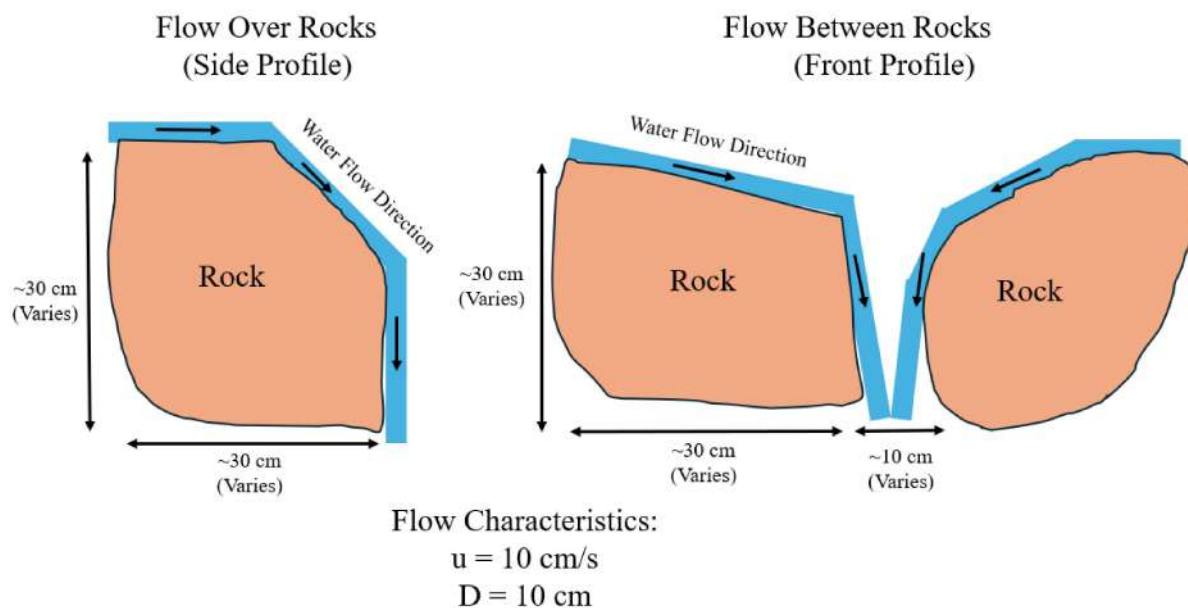


Figure 1: Flow Geometries Around and Over Rocks

The first geometry is identified upon closer inspection of the specular reflections along the rock surfaces. Due to high surface tension, a continuous thin film of water flows down the rock faces, producing the observed surface sheen. This process is illustrated schematically on the left side of Figure 1, which shows a cross-sectional view of the rock profile and depicts thin-film flow over the apex and down the vertical boundary.

The second geometry corresponds to inter-rock channel flow, which is more prominently defined. Gravitational potential drives the fluid along the path of least resistance, which, in an alpine stream bed, corresponds to the channels formed between adjacent obstacles. By traversing these gaps, the fluid bypasses the direct normal forces imposed by structural barriers, descending freely to a lower potential energy state. This configuration is illustrated on the right side of Figure 1 in a frontal elevation view, demonstrating flow confinement through the inter-rock gaps.

To quantitatively evaluate the inter-rock channel flow, the local Reynolds number was estimated. For analytical tractability, the channels are modeled as open-channel conduits. The Reynolds number is a dimensionless ratio of inertial forces to viscous forces used to characterize the flow regime. The formulation is given by Equation 1, where V represents the mean flow velocity, D denotes the characteristic hydraulic length, and ν represents the kinematic viscosity of the fluid. The local velocity was estimated at approximately 10 cm/s, the characteristic channel width at approximately 10 cm, and the kinematic viscosity of water at alpine ambient temperatures ($\sim 10^\circ\text{C}$) is $1.376 \times 10^{-6} \text{ m}^2/\text{s}$. These parameters were evaluated via direct physical measurement and particle-tracking techniques using surface bubbles over a fixed duration. Substituting these values into Equation 1 yields:

$$Re = \frac{VD}{\nu} = \frac{(0.15 \text{ m/s})(0.10 \text{ m})}{1.376 \times 10^{-6} \text{ m}^2/\text{s}} \approx 1.09 \times 10^4 \quad (1)$$

Because the calculated Reynolds number significantly exceeds the critical threshold ($Re > 2000$), the flow is confirmed to be fully turbulent. Visual evidence in the photograph supports this conclusion; the long-exposure capture renders the temporal velocity fluctuations as diffused, attenuated streaks, reflecting the stochastic nature of the turbulent field within the channel constraints.

The free-surface behavior across different regions of the channel is governed by the Froude number (Fr), which quantifies the ratio of inertial forces to gravitational forces. On the inclined rock face where the water forms a shooting thin film ($h_{\text{sheet}} \approx 0.01 \text{ m}$, $U_{\text{sheet}} \approx 0.45 \text{ m/s}$), the Froude number is calculated as:

$$Fr_{\text{sheet}} = \frac{U_{\text{sheet}}}{\sqrt{g \cdot h_{\text{sheet}}}} = \frac{0.15 \text{ m/s}}{\sqrt{(9.81 \text{ m/s}^2)(0.01 \text{ m})}} = \frac{0.15}{0.313} \approx 0.479 \quad (2)$$

This value of $Fr_{\text{sheet}} < 1$ confirms the flow over the rock face remains subcritical, allowing surface gravity waves to propagate upstream and preventing severe wave breaking. This is consistent in the image, as the flow over the rocks presents a "glossy" finish with no wave breaking over them. Similarly, in the downstream pool (middle right side of image) where depth increases ($h_{\text{pool}} \approx 0.10$ m) and velocity slows ($U_{\text{pool}} \approx 0.15$ m/s), the Froude number transitions to

$$Fr_{\text{pool}} = \frac{0.15}{\sqrt{9.81 \times 0.10}} \approx 0.151. \quad (3)$$

Because $Fr_{\text{pool}} < 1$, the receiving pool is subcritical (tranquil), permitting surface gravity waves to propagate in all directions and smoothing the water surface. This is also backed in the image, as the pool is the least cloudy portion of the flow, indicating minimal wave propagation and a relatively smooth surface.

Surface tension plays a dominant role in maintaining the cohesion of the water sheet as it glides over the rock faces. The relative magnitude of inertia to surface capillary forces across the liquid film thickness ($L = h_{\text{sheet}} \approx 0.01$ m) is quantified by the Weber number (We):

$$We = \frac{\rho \cdot U_{\text{sheet}}^2 \cdot L}{\sigma} = \frac{(999.7 \text{ kg/m}^3) (0.15 \text{ m/s})^2 (0.01 \text{ m})}{0.0742 \text{ N/m}} \approx 3.03$$

A Weber number of $We \approx 3.03$ demonstrates that surface tension forces of water at high alpine temperatures ($\sigma = 0.0742$ N/m) significantly outweigh inertial forces. Because We is far below critical breakup thresholds ($We_{\text{crit}} \sim 100$), surface tension suppresses droplet atomization, forcing the water to cling tightly to the granite surface as a continuous, glassy sheet rather than spraying outward into isolated droplets.

These observed physical mechanics studied above align directly with archived technical literature on open-channel hydraulics and free-surface turbulence [2]. Savage and Johnson (2001) [2] demonstrated that surface tension exerts a stabilizing influence on thin-film free-surface flows over crested rock obstacles, suppressing surface wave breakdown at low Weber numbers. Furthermore, Brocchini and Peregrine (2001) [1] analyzed free-surface turbulence dynamics, establishing that low Froude number regimes ($Fr < 1$) allow capillary and gravitational forces to smooth surface strain and maintain cohesive streaklines along the flow front. Finally, investigation of boulder hydraulics by Shamloo et al. (2002) [3] confirms that boundary layer detachment and adverse pressure gradients downstream of bed obstacles generate stationary recirculation zones, explaining the white-water foam boundary surrounding the submerged rocks in this image.

3 Visualization Technique

The execution of the flow visualization technique relied on minimal setup and natural flow tracers. Access to the field site required traveling to Rollins Pass to access the alpine stream section. A suitable location was selected based on visual clarity and the presence of distinct flow interactions around structural rock boundaries. The camera was positioned directly above a small pool near the stream surface, maintaining stability over a 3-second long-exposure duration to eliminate camera movement blur. Entrained air bubbles resulting from localized turbulent mixing served as natural tracer particles, yielding a streak-line representation of the velocity field. Ambient diffuse lighting provided by an overcast sky yielded uniform illumination across the surface without requiring artificial flash units.

4 Photographic Technique

This image was captured using an iPhone 14 main camera, resulting in an uncropped resolution of 2511×3351 pixels. The camera optics feature a 26 mm equivalent focal length with a maximum aperture of $f/1.5$. Operational exposure settings were set to ISO 40, an aperture of $f/1.5$, and an exposure duration of 3 seconds.

The object-to-lens distance was approximately 0.457 m, yielding a physical field of view measuring roughly 0.61 m horizontally by 0.91 m vertically. The spatial framing was subsequently adjusted during post-processing in darktable. As shown in Figure 2, outer regions of the stream bed along the left and upper margins were cropped to isolate the primary flow structures. Additionally, tone curves were modified to attenuate high-luminance specular highlights on the wet rock surfaces and deepen shadow values, emphasizing the natural texture and tones of the granite substrate.



Figure 2: Original, Unedited Get Wet Photo

5 Artists Statement

This image illustrates the underlying scientific complexity inherent in natural fluid systems. While natural open-channel flows are frequently viewed purely through an aesthetic lens, rigorous physical analysis demonstrates the intricate interplay of governing fluid forces. The image transforms a standard mountain stream scene into a subject for quantitative dynamic evaluation, highlighting the relevance of fluid mechanics within naturally occurring systems.

Future work will incorporate digital single-lens reflex (DSLR) camera systems to achieve higher spatial resolution, improved optics, and sharper edge definition along physical boundaries.

Further development of this study could explore broader environmental flow conditions, including open lake surfaces or precipitation runoff. Additionally, high-speed, short-exposure imaging could be employed to resolve instantaneous turbulent structures and localized boundary interactions across the rock surfaces.

References

- [1] Brocchini, M., & Peregrine, D. H. (2001). The effects of strain on free-surface turbulence. *Journal of Fluid Mechanics*, 449, 225–254.
- [2] Savage, M. G., & Johnson, M. C. (2001). Flow over ogee spillways: the effect of surface tension and viscosity. *Journal of Hydraulic Engineering*, 127(11), 911–917.
- [3] Shamloo, H., Rajaratnam, N., & Katopodis, C. (2002). Hydraulics of submerged boulders in shallow open channels. *Journal of Hydraulic Engineering*, 128(6), 521–532.