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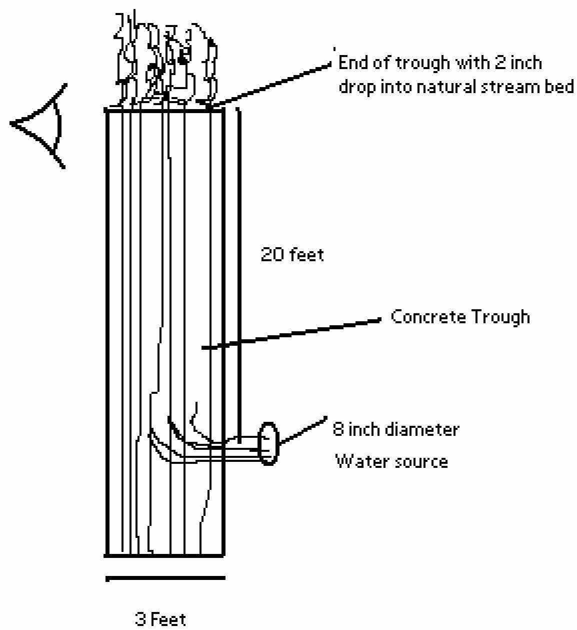
This is the first project in Flow Visualization for spring 2006. The intent is to photograph a standing wave in a stream of water.

In order to produce a standing wave, water was run down a long, wide concrete trough and allowed to fall a short distance from the end of the trough. This set up can be seen in the rough schematic below.



This setup produces a very smooth, laminar flow along the trough, as long as the amount of water coming from the source is kept reasonably low. For example, in this experiment, the flow rate from the source was about 7-10 gallons per minute. Depth of the water is one inch. The estimated Reynolds Number for this flow, considering volumetric flow rate and cross section of flow along the trough, is 60,000. Once the stream reaches the end of the trough, it drops a distance of 2 inches into a natural stream bed. This cascading flow accelerates the water into the turbulent motion shown in the photograph. The Reynolds Number for this turbulent flow is estimated to be about 7,000,000 due to increased velocity. Since the wave is somewhat stationary and the velocities involved are relatively low, high temporal resolution is not necessary. Faster shutter speeds would allow a more frozen appearance and enable more insight into the momentary positions and motions of the fluid. On the other hand, a long exposure would smooth out much of the motion and allow visualization of the wave's behavior over time. With the shutter speed set to be $1/60^{th}$ of a second, and approximating a velocity of $1/10^{th}$ of a meter per second, the fluid moved approximately $1/600^{th}$ of a meter, or about 1.7 millimeters. This is a fairly large amount of motion for the type of imaging that is being done. An improved temporal resolution could be achieved through faster shutter speeds, and would be a necessity for faster flows.

Flow over the concrete lip does not require complicated visualization techniques. The photograph shown was taken with a handheld camera without any preparation of fluid or boundary marking. Lighting was provided from sunshine, though it was diffuse so as to reduce glare off of the surface of the water.

The photograph was created with a Nikon D50 digital camera with 6 mega pixel resolution. Lens focal length was set to 55 millimeters. Shutter speed was $1/60^{th}$ of a second, and aperture was at F number 5.6. Field of view for this particular photograph is approximately 6 inches wide by 4 inches high, taken from a distance of 2 feet. Once the image had been collected, the data was modified through the use of Adobe Photoshop, which was used to alter the coloration and contrast of the image, as well as to crop unwanted borders.

The image shows the turbulent flow that can occur within a standing wave. The fast moving water cascading over the trough's edge plummets through to the bottom of the stream bed and loses energy as it collides with the channel floor. This water is continuously being pushed from behind as more water plunges in. The result is that the slower fluid is pushed forward and up. Once at the surface, the slower fluid is riding upon a layer of faster moving water. A shear stress is induced at the interface of these opposed flows. The slower surface flow begins to curl upon itself as the momentum of the fast sub-layer takes effect and pulls the water along downstream. Surface flow becomes unstable and chaotic as fluid skips and churns, driven in a cyclic, flowing wave. During this process, some air is pulled under the wave, carried along by the falling water and enveloped by the rising flows. This creates the bubbles that can be seen in the photograph.

What I like most about the image is that it really shows the transition from a very smooth laminar flow to that of a very turbulent wave with many interesting features. The bubbles create interesting shapes and contours of color, and the leaping water to the right of the wave gives the impression of great instability and motion. However, I wish that I understood the physics a little more. Little can be found online about standing waves in this sense. I am unsure what exactly is causing this motion, though I have some intuition that I can not confirm. In order to improve upon my project I would like to learn more about the physics involved and put my curiosity to rest. To further explore the subject, I may be able to construct a devise that would create these standing waves, but in a transparent vessel so that I may take photographs from the side, or even from the bottom. I could then introduce particles to the fluid and track their motion throughout the wave.