A New Era of Debris Flow Experiments in the Oregon Woods

What do a backhoe, expanding foam, half-ton concrete blocks, and a 100-meter-long hillslope slide have in common? All were part of reviving the U.S. Geological Survey's experimental debris flow flume.

The U.S. Geological Survey's (USGS) 95-meter-long debris flow flume facility is located near Blue River, Ore., in the H.J. Andrews Experimental Forest. As seen here in June 2018, the flume is heavily instrumented during experiments, including with 4K video cameras (under the umbrellas and in the mobile, remotely controlled white box) and multiple digital still cameras with synchronized shutter releases to enable photogrammetry. Credit: USGS

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Studying the physics of landslide initiation and the dynamics of debris flows is challenging, as these phenomena occur spontaneously, commonly in remote locations, and usually during inclement weather. Those who do this work trudge into the muck not only because the unpredictable natures of natural slope failures and landslide runouts are scientifically interesting in their own right, but also because illuminating these phenomena can help (https://eos.org/science-updates/an-early-warning-system-for-landslide-danger) in hazard mitigation efforts (https://eos.org/research-spotlights/simple-actions-can-help-people-survive-landslides).

Field monitoring (https://eos.org/editors-vox/downhill-all-the-way-monitoring-landslides-using-geophysics) of landslide sites plays a big role in helping us understand these hazards, and so do reliable data obtained from repeatable experiments. These crucial data are used in validating landslide models and in understanding the underlying physics of landslide phenomena, and they can be collected only in controlled settings.

Our inaugural experimental plan was perhaps foolishly ambitious and led to harrowing near misses with enormous concrete blocks and frequent battles with a crotchety backhoe.

Rarely do scientists studying landslide hazards have opportunities to do experiments. Luckily, as the new keepers of the U.S. Geological Survey (USGS) debris flow flume, we have just such an experimental facility with which to play. After taking over a couple of years ago, we set out to continue the facility's legacy of revealing new details about landslide processes. Our inaugural experimental plan, however, was perhaps foolishly ambitious and led to harrowing near misses with enormous concrete blocks and frequent battles with a crotchety backhoe.

But our persistence paid off and rewarded us with a wealth of data to help in model validation and in improving our knowledge of debris flow and water interactions and dam breach processes.

This past year, between the ongoing pandemic and the wildfires that raged across Oregon (coming within half a kilometer of the flume), the survival of the flume and its surrounding facilities was in question. Thanks to courageous work by firefighters in fending off the Holiday Farm Fire (https://www.eugene-or.gov/4543/McKenzie-Holiday-Farm-Fire) in September and October, it lives on. Our work there is on hold for the time being, but when conditions improve, the flume will be ready for its next set of experiments—and to continue producing valuable data and insights.

A New Day for the Flume

Three decades ago, Richard Iverson of the USGS proposed turning an Oregon mountainside near

Blue River in the Western Cascades into a large-scale experimental facility. Through collaboration between the USGS and the U.S. Forest Service, this dream was realized, and the debris flow flume was constructed in 1991 and used beginning in 1992 [*Iverson et al.* (https://doi.org/10.3133/ofr92483), 1992; *Iverson* (https://doi.org/10.1029/2019CN000117), 2020].

Located in the 6,500-hectare H.J. Andrews Experimental Forest, the USGS flume is a 95-meter-long, 2-meter-wide concrete channel perched on a 31° hillslope: Picture the last steep descent on an amusement park log flume ride. With a hopper at the top and extensive instrumentation all along its course, this steep channel flattens into a 26-meter-long, 2° depositional runout pad at the bottom of the hill—like the splash zone at the bottom of the log flume.

For many decades, the flume was instrumental in revealing elusive physical principles underlying debris flow mobilization and runout [e.g., *Iverson* (https://doi.org/10.1029/97RG00426), 1997; *Iverson et al.*, 1997 (https://doi.org/10.1146/annurev.earth.25.1.85), 2000 (https://doi.org/10.1126/science.290.5491.513), 2010 (https://doi.org/10.1029/2009JF001514), 2011 (https://doi.org/10.1038/ngeo1040); *Johnson et al.* (https://doi.org/10.1029/2011JF002185), 2012]. Video recordings of the 163 experiments conducted there from 1992 to 2017 are viewable online [see *Logan et al.* (https://doi.org/10.3133/ofr20071315), 2018].

We designed a project involving debris flows hitting a pool of water at the base of the flume and generating waves that overtop an earthen dam—like how a landslide might produce a tsunami. Despite the recent retirements of Iverson, the flume's scientific captain, as well as of instrumentation wizard Richard LaHusen and operational guru Matthew Logan, the flume perseveres. And exciting research continues, such as work exploring alternative methods for debris flow detection like using seismic data to measure basal stresses or off-the-shelf 4K video cameras to determine 3D surface deformation [*Allstadt et al.* (https://doi.org/10.1029/2020JF005590), 2020; *Rapstine et al.* (https://doi.org/10.1029/2019JF005348), 2020]. We officially took over in November 2018, but the transition of leadership was gradual, allowing us to soak up as much of the initial crew's expertise as we could.

New at the helm, we designed an initial project involving debris flows hitting a pool of water at the base of the flume and generating waves that overtop an earthen dam—like how a landslide might produce a tsunami. That overtopping might also instigate erosion and breaching of the dam—and all of this would be observable in a single, albeit complicated, set of experiments. Fast moving debris flows are among the most deadly varieties of landslides on their own, and adding interactions with surface water bodies that can generate tsunamis or dam breaches can potentially create even more catastrophic consequences. These experiments were designed to validate and improve models of landslide-generated waves and of the overtopping and erosion of sediment dams.

Typically, debris flow and dam breach experiments at the flume have been conducted separately, as each requires different logistics and 8–10 people with varied skill sets and understanding of the inner workings of the flume's infrastructure to carry them out. Only one person (Obryk) is dedicated full time to the flume, so teams are stitched together with an ad hoc assemblage of regular moonlighters from USGS as well as rookies—scientists and their students lured from around the world. Regardless of their expertise, all quickly become expert dirt shovelers.

Challenges, Expected and Unexpected

For this first project, we assembled a team of eight. First, we had to construct a pond at the foot of the flume. The flume's 2-meter-wide channel is flanked by 1.2-meter-high walls that end at the runout pad. With custom-fabricated concrete blocks that have been used for decades at the flume, we extended the flume's sidewalls to create the sidewalls of the pond. At the far end of the pond, we constructed an earthen dam out of compacted beach sand.

Although real earthen dams and moraines consist of far more heterogeneous materials, using beach sand offered practical and scientific advantages. Not only was construction of a viable dam easier with fine beach sand, but also the sand's relatively uniform and small particle size meant we could accommodate scaling effects, allowing for broader interpretation of results from repeated experiments. A major related consideration was how to ensure that the setup could be assembled and disassembled quickly to facilitate these repeated experiments.

Lifting roughly half-ton concrete blocks to assemble a makeshift “pond” at the base of the flume required heavy-duty chains, a temperamental tractor, and a skilled operator. Credit: USGS

Moving the roughly half-ton concrete blocks into place for the pond walls required a skilled operator at the wheel of our temperamental 40-year-old backhoe loader. After the blocks were placed as precisely as possible, we performed fine-tuning with suitable instruments: pry bars, sledgehammers, and considerable elbow grease.

The second hurdle was waterproofing the pond. Far from being smooth, flush against one another, and waterproof, the aging concrete blocks and runout pad left gaps of up to several centimeters wide. Similar ponds have been constructed at the flume previously to study dam breaching using a draped rubber liner as a waterproof barrier [*Walder et al.* (https://doi.org/10.1002/2014WR016620), 2015]. However, the impact of a debris flow would destroy a fragile rubber liner, so this was not a feasible option for our experiments; in addition, cleanup between experiments would be intractable and costly.

We considered a variety of alternatives for waterproofing concrete structures and in fall 2017 journeyed to the flume to test the most promising ones. Beyond providing an affordable, durable, and completely waterproof seal, we needed the application to be easy, again to facilitate rapid assembly and disassembly of the pond for cleaning between experiments. Equipped with a collection of commercial samples, we assembled a scaled-down version of the pond and began side-by-side waterproofing tests. Four products we tested failed, but commercial expandable foam showed promise, despite leaking a little.

This view looks up the flume from inside the unfilled pond, the walls of which were constructed of concrete divider blocks and sealed with commercial-grade, expandable orange foam. Credit: USGS

The following spring (2018), we arrived at the flume full of optimism, ready to test a full-scale pond with this commercial-grade foam. We sealed and filled the pond and could hardly believe our eyes. There was not a single leak—it was as tight as a drum.

Disassembling the pond sidewalls proved to be more exciting than we had hoped. We planned to lift each concrete block with our backhoe, figuring that the grip of the foam would succumb to gravity and to the backhoe's hydraulic power. For the most part, this worked; on a few occasions it did not. While lifting a block at one point, an adjacent half-ton block came along for the ride, attached solely by the foam! The foam's strength was impressive and unexpected, and it boosted confidence in our waterproofing efforts. Yet the swinging block was a dangerous surprise, especially for team members standing nearby. Putting safety first, we modified the disassembly protocol by precutting the foam.

Going with the Flow

With a sense of accomplishment and pride, we began planning further proof-of-concept experiments for that summer. We still had to figure out appropriate scaling that would allow us to observe the phenomena as we intended. The inclination of the runout pad and the length of the pond dictate the water height at the flume's mouth: the longer the pond, the lower the water level. Predicting how debris flows and water interact is complex, and the dynamics depend on the water height and the flow entry angle. So we ran three simplified experiments, the first without a dam and the next two with an earthen dam at the far end, and adjusted the pond size and water levels based on our observations. With lessons learned, we scheduled our next experiments for spring 2019 to focus on how we would acquire and reproduce data.

The filled pond setup with an earthen dam at the far end is seen in late May 2019 shortly before an experimental debris flow was released. Credit: USGS

After nearly 2 years of planning and trials, we were ready for one of the most novel and complex investigations at the flume yet. We acquired and tested sonic sensors for wave height detection, deployed a depth camera and worked out a photogrammetry setup to capture the sequence of events in 3D, and ordered nearly 40 cubic meters of sediment for debris flows and dams. Our team of scientific and technical recruits from Washington, Oregon, and Colorado assembled at the flume, ready to begin.

There was only one problem.

A week before the experiments, with several of us at the flume to get a head start on the setup, the trusty, rusty backhoe—our most essential tool—died. No lights, no beeping, no diesel fumes. Without a tractor mechanic available on short order nearby, we found a rental. However, we soon discovered that whereas our ancient backhoe had made light work of hauling big concrete blocks and vast amounts of dirt, these tasks proved far too much for the younger, less rusty rental unit.

Dread came over us because we feared the flume season was doomed. Rescheduling experiments is not trivial, and lodging and personnel availability are limited. But the flume environment inspires a borderline pathological can-do spirit. Our group of highly trained scientists and technicians, now a ragtag team of novice tractor mechanics, pressed on. After hours of frustration and thwarted efforts, the tractor begrudgingly succumbed to our pleas and came back to life.

Continuing a Legacy

During an experiment in early June 2019, the earthen dam blocking the pond failed as a result of a debris flow displacing the water in the pond and generating a tsunami. Instrumentation used to document the experiment included sonic sensors (mounted on wooden crossbeams) for wave height detection, a depth camera (mounted on an aluminum crossbeam) to capture dam erosion, pressure plates (not visible at the base of the pond), and pore pressure sensors throughout the dam (not visible). Credit: USGS

With the backhoe back in action and the new flume setup planned and assembled, our experiments over the next 2 weeks proved successful. (The tractor died again on the last day of experiments after the final cleanup was finished. What a trooper! It has since been serviced by a professional mechanic and is running great again.) In the end, we generated an exceptional data set that will now allow us to study debris flow and water interactions, tsunami wave generation and propagation, dam overtopping and stability, and dam breach initiation.

Ultimately, the legacy of nearly 3 decades of debris flow research at the flume are the novel insights into the physics of damaging and deadly debris flows that have come from it. As the flume's new leaders, we aim to preserve its capabilities and continue studies of debris flow initiation and runout dynamics. We also see the potential for expanded investigations into related phenomena in the years ahead. Such studies could include testing new geophysical tools for in situ and seismic debris flow detection, looking at water runoff and bed sediment entrainment, and studying interactions between debris flows and bodies of water as well as ice-laden flows and the effects of wildfire—the latter of which has new urgency following 2020.

Through our first project, we came to realize that extending the flume's legacy requires experience passed down from our predecessors and creativity to push flume experiments in new directions, as well as the dedication and persistence of all team members. It also didn't hurt to have luck on our side to cajole rusty old equipment to keep working and to spare the flume from wildfire.

References

Allstadt, K. E., et al. (2020), Measuring basal force fluctuations of debris flows using seismic recordings and empirical Green's functions, *J. Geophys. Res. Earth Surf.*, *125*(9), e2020JF005590, https://doi.org/10.1029/2020JF005590 (https://doi.org/10.1029/2020JF005590).

Iverson, R. M. (1997), The physics of debris flows, *Rev. Geophys.*, *35*(3), 245–296, https://doi.org/10.1029/97RG00426 (https://doi.org/10.1029/97RG00426).

Iverson, R. M. (2020), Landslide disparities, flume discoveries, and Oso despair, *Perspect. Earth Space Sci.*, *1*(1), e2019CN000117, https://doi.org/10.1029/2019CN000117 (https://doi.org/10.1029/2019CN000117).

Iverson, R. M., J. E. Costa, and R. G. LaHusen (1992), Debris-flow flume at H.J. Andrews Experimental Forest, Oregon, *U.S. Geol. Surv. Open-File Rep. 92–483*, 2 pp., https://doi.org/10.3133/ofr92483 (https://doi.org/10.3133/ofr9248).

Iverson, R. M., M. E. Reid, and R. G. LaHusen (1997), Debris-flow mobilization from landslides, *Annu. Rev. Earth Planet. Sci.*, *25*, 85–138, https://doi.org/10.1146/annurev.earth.25.1.85 (https://doi.org/10.1146/annurev.earth.25.1.85).

Iverson, R. M., et al. (2000), Acute sensitivity of landslide rates to initial soil porosity, *Science*, *290*(5491), 513–516, https://doi.org/10.1126/science.290.5491.513 (https://doi.org/10.1126/science.290.5491.513).

Iverson, R. M., et al. (2010), The perfect debris flow? Aggregated results from 28 large-scale experiments, *J. Geophys. Res. Earth Surf.*, *115*(F3), F03005, https://doi.org/10.1029/2009JF001514 (https://doi.org/10.1029/2009JF001514).

Iverson, R. M., et al. (2011), Positive feedback and momentum growth during debris-flow entrainment of wet bed sediment, *Nat. Geosci.*, *4*(2), 116–121, https://doi.org/10.1038/ngeo1040 (https://doi.org/10.1038/ngeo1040).

Johnson, C. G., et al. (2012), Grain-size segregation and levee formation in geophysical mass flows, *J. Geophys. Res. Earth Surf.*, *117*(F1), F01032, https://doi.org/10.1029/2011JF002185 (https://doi.org/10.1029/2011JF002185).

Logan, M., R. M. Iverson, and M. K. Obryk (2018), Video documentation of experiments at the USGS debris-flow flume 1992–2017 (version 1.4, January 2018), *U.S. Geol. Surv. Open-File Rep. 2007–1315*, https://doi.org/10.3133/ofr20071315 (https://doi.org/10.3133/ofr20071315).

Rapstine, T. D., et al. (2020), Reconstructing the velocity and deformation of a rapid landslide using multiview video, *J. Geophys. Res. Earth Surf.*, *125*(8), e2019JF005348, https://doi.org/10.1029/2019JF005348 (https://doi.org/10.1029/2019JF005348).

Walder, J. S., et al. (2015), Controls on the breach geometry and flood hydrograph during overtopping of noncohesive earthen dams, *Water Resour. Res.*, *51*(8), 6,701–6,724, https://doi.org/10.1002/2014WR016620 (https://doi.org/10.1002/2014WR016620).

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