
**Intense rain triggered mudslides in Glenwood Canyon, Colorado, during June and July last year — one year after a fire scorched the area.**

# THE ONE-TWO PUNCH OF FIRES AND MUDSLIDES

Regions that never used to burn are now suffering from forest fires — and that raises the risks of devastating mudslides that are hard to forecast. **By Jane Palmer**

The summer of 2021 brought ideal fire weather to southern British Columbia in Canada. A dome of hot, high-pressure air settled over the area, sending temperatures soaring into record territory after months of drought.

In early July, an average of 40 fires sprang up each day in the province — in what would become one of the region's worst wildfire seasons ever recorded. Flames scorched the steep, tree-covered slopes above the valleys that are home to the Trans-Canada Highway and national railway lines, as well as oil and gas pipelines. The blaze raised concern about another imminent threat: landslides from the destabilized hills.

In mid-November, a massive storm known as an atmospheric river dumped a month's worth of rain on the region in just two days. When the downpour hit the burnt, scarred slopes, it set off giant surges of mud and debris that swept across the highway and railway lines. "They severed several key transportation corridors in western Canada, which then meant critical supply-chain interruptions," says Matthias Jakob, a geoscientist at BGC Engineering in Vancouver, Canada, who worked on assessing the potential for landslides in the region.

Although they might not be as deadly as hurricanes or heatwaves, landslides such as this can cost hundreds of millions of dollars in economic damage, Jakob says. And more are expected this winter as atmospheric rivers pummel the northwest of the United States and British Columbia, following a year of intense and widespread fires.

This one-two punch of fire and flood, is just a taste of what's to come there, and in many other regions. Climate change is increasing the frequency and intensity of fires around the world, and it is also leading to more extreme bouts of precipitation[1]. When rain hits recently burnt hillsides it can trigger a particularly deadly type of landslide called a debris flow — a water-laden mass of soil, rocks and other matter that can surge downslope with devastating force.

In regions prone to these types of hazard, scientists have developed models that can feed into warning systems and save lives. But wildfires are now claiming hill slopes that have rarely been burnt before. This is happening around the world, from the boreal forests of Alaska and Canada to the mountains of Austria, where fires are burning more frequently and more intensely than ever before.

"There will be an increased likelihood of both fire and post-fire debris flows in areas where they are currently only a theoretical possibility," says Bruce Malamud, a geophysicist at King's College London.

The central region of British Columbia has always had wildfires but now the province is even seeing blazes in coastal areas. The models used to forecast inland debris flows simply wouldn't work for these regions, where the soils and vegetation differ, Jakob says. It's a similar scenario in the United States, where fires in the past few years have scorched areas of northern California, Oregon and Washington that rarely burn.

Evidence suggests that the debris-flow behaviour is going to be different in these wetter, more vegetated regions than in arid southwestern states, where fires and landslides are more common, says Jason Kean, a hydrologist at the United States Geological Survey (USGS) National Landslide Hazards Program in Golden, Colorado.

"While it's kind of clear what's happening in the drier areas, the picture gets murkier as we move north," Kean says. "So right now, we are scrambling to collect data to figure out how well our current model works and how to make a better one."

## Surging slopes

When rainfall hits an unburnt slope, it gets caught on trees or shrubs and then slowly trickles to the ground, where it can filter into the soil. But fires make it harder for hillsides to soak up water. When flames burn away vegetation, that allows rain to hit the surface with its full force. And fires burn off the waxy compounds that coat leaves and needles, some of which then evaporate and condense on cooler soil particles just below the surface. That can form a water-repellent layer that stops the soil from absorbing water[2].

"That takes the soil from acting like a sponge that just soaks up the rain, to acting like a giant plastic sheet that water runs off," says Gary Sheridan, a soil scientist at the University of Melbourne, Australia.

Rain runs off this water-repellent surface until it reaches a crack and then can soak into the soil. But if the rain is falling at an intense rate, only some of it seeps into crevices and the rest forms rivulets that flow downhill. These streams pick up soil and rocks, which gain speed, and surge downhill creating a debris flow.

> **"We are scrambling to collect data to figure out how well our current model works."**

"It can be a small amount of rainfall, but it needs to be intense," says Stefan Doerr, a wildfire scientist at Swansea University, UK. "Particularly soon after a fire, because the stuff is just sitting there, ready to be moved."

When an extreme storm, known as a bomb cyclone, blasted California and the Pacific Northwest in October 2021, it broke single-day rainfall records for several regions that didn't burn and caused flash flooding, but didn't set off any significant mudslides in the burnt areas. "It is not about the storm total rainfall, but the intensity of the rain," says Nina Oakley, a research meteorologist at the Scripps Institute of Oceanography in San Diego,California, who studies the connection between extreme rainfall events and landslides. "That's why you really need 15-minute rainfall information to forecast post-fire debris flows."

Mudslides and similar types of slope failure can cause tremendous damage. In the United States, rough estimates put the direct economic costs of landslides in the range of several billion dollars each year, says Jonathan Godt, the coordinator of the Landslide Hazards Program at the USGS. But the indirect costs, which include losses in commerce and related factors, are probably several times that estimate, Godt says.

In January 2021, Congress passed the National Landslide Preparedness Act, which authorized US$37 million annually from 2021 to 2024 for federal agencies to broaden their efforts to reduce the hazards from landslides. One goal of the bill is to expand existing early-warning systems for post-wildfire burnt landscapes in the United States.

After a fire, teams of US federal and academic soil scientists, hydrologists, biologists and landslide experts typically flock to the area immediately, even before the flames are completely out, to assess the damage. US Forest Service researchers evaluate the severity of the burn on vegetation from the ground and from the skies, by comparing satellite imagery from before and after a fire. They pass on the information to USGS landslide researchers, who feed the data into their models and create hazard maps, designed to indicate the potential for debris flows across the burnt region.

The models take into account the size and steepness of the affected area, how severely the fire scorched it and the nature of the soil, as well as a multitude of other variables. With all of that information, the models indicate how probable debris flows will be depending on the intensity of rainfall. It's a statistical association based on data from previous post-fire mudslides in the southwest of the United States.

Although relatively simple, the models have proved effective at informing early-warning systems in that part of the United States, where the slopes share similar vegetation and soils. After a fire tore through Glenwood Canyon, Colorado, in August 2020, scientists were quick to assess the damage and feed the data into a model, which helped emergency-response managers to assess the risks of debris flows when rainstorms approached. In mid-2021, that warning system prompted authorities to close Interstate 70 — a highway that runs through the canyon — a number of times. Several debris flows surged across the major road. No lives were lost, but it will cost more than $100 million to repair the damage to the highway.

When the local authorities in Oregon ask the USGS scientists to make hazard maps after fires in the state, however, the model output has limited value because the environment is so different from conditions in the arid southwest. "You can't take the probability numbers at face value because the model doesn't apply to that area," Kean says.

## Delayed disasters

That became clear after a fire tore across hillsides in Oregon's Columbia River Gorge in September 2017. In the steep, forested slopes, fir trees typically tower over a dense, lush undergrowth of ferns and bushes. The fire that year incinerated the vegetation in a 20,000 hectare area. But despite some intense storms in the following three years, there were no catastrophes. Then, in January 2021, heavy rains triggered a deadly mudslide. The torrent of mud swept away a car driving through the gorge, killing its driver.

The delayed catastrophe didn't surprise geologist Joshua Roering, at the University

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**A fire scorches hillsides in Glenwood Canyon in August 2020.**

of Oregon in Eugene, who has been studying landslides in the Pacific Northwest for nearly two decades. Roering's group has been investigating how the Pacific Northwest soils can behave differently from those in drier locations, after a fire.

So far, his group has found that after flames scorch vegetation, a water-repellent layer coats the soil, but it is fragmented and not as continuous as the coatings formed farther south. So water can soak into the ground during extreme rainfall in the Pacific Northwest, even after a fire. The fact that several significant storms haven't triggered debris flows in the region, suggests that the hydrologic system behaves differently from those observed in southern California, Roering says.

That doesn't mean the post-fire danger disappears, Roering cautions. Instead, the risks of debris flows are delayed, a pattern researchers have seen after timber harvesting on slopes. When a tree is cut, its roots decay over several years. And as their hold on the soil loosens, the chances grow for a slope to slide when rain hits[3]. "You cut down a tree, or you burn a tree," Roering says. "It doesn't matter how you kill a tree, those root systems in the upper metre of the soil are losing about 90% of their strength after three, four or five years."

If this theory bears out, scientists and emergency managers will need to prepare for storms several years after wildfires in the heavily wooded Pacific Northwest, Roering says. "If that's the case, then we're sort of sitting on this ticking time bomb in terms of badly burned areas, with steep slopes, perched above major travel corridors and freeways," he says.

Researchers don't expect the same kind of delay for the central region of British Columbia, which is more arid and has different soils from coastal parts of the Pacific Northwest. "We really need to create our own model for British Columbia, ideally one for the coast and one for the drier interior," Jakob says. "But for that we need much more data."

In Australia, researchers are also grappling with changing patterns of fires and debris flows. Wildfires are common in southeastern Australia, where Sheridan works, but now they're starting to spring up in the wet, alpine areas of Tasmania, which have rarely seen flames before. Rather than create a whole new landslide model, Sheridan's group is attempting to refine it, one fire at a time, and to test its effectiveness with each debris flow. But it's a tricky and drawn-out process, Sheridan says.

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After a fire, there's such a diverse range of outcomes, from almost no change to the landscape to catastrophic debris flows and landslides, and everything in between, Sheridan says. Landslide researchers around the world are discussing a common set of factors that can be fed into a universal forecasting model, but such a model is still a long way off, because the landscape, climate and soil behaviour varies in each location, he says. "There's such a high variability in risk from place to place, and we still don't know why," Sheridan says.

Debris-flow models can only go so far. They help to save lives, but it's more difficult to keep buildings or transport networks safe. In British Columbia, there simply isn't the money to protect roads, railway lines or pipelines from every single slope that could yield a debris flow, Jakob says. "Early-warning systems can prevent harm to people, but infrastructures will still be damaged or obliterated."

Moving forwards, it will be even more important to use models to identify roads or pipelines at risk, so that authorities can then prioritize where to shore up defences, Jakob says. Homeowners, too, need to know the risks to their property, and lives.

"With the dramatic and rapid change in climate, many people may not know that they are at risk from post-fire landslides," Jakob says. Still, such efforts are not without controversy. Politicians and developers have been known to oppose efforts to create landslide hazard maps because they see them as hindering growth and income.

Only time, more storms and more data will help researchers learn how to better forecast when or where landslides might strike after fires. In anticipation of the winter storm season in the western United States, researchers have installed instruments on some of the slopes that burnt last year in California blazes, including the giant Caldor fire and the Dixie fire – the largest individual blaze in state history.

The combined network of instruments will tell scientists the intensity of rainfall that does, or doesn't, trigger debris flows; how much water seeps into the ground; how much runs off; and other crucial variables that will help to improve current models or build region-specific ones, Kean says.

The biggest challenge to building a clearer picture is the lack of resources in relation to the scale of the wildfire devastation, Kean says. The Dixie fire alone burnt nearly 400,000 hectares and the scientists have a restricted number of instruments, which limits their ability to build up knowledge regarding debris flow behaviour in new regions. "We don't have a big-data problem. We have a little-data problem," Kean says.

The lack of resources and information about landslides is universal for researchers across the world and it hinders the community's ability to advance its understanding. "You've got a tiny little bit of data," says Sheridan, "and it's like you're trying to read the tea leaves and work out what's going on."

**Jane Palmer** is a freelance journalist in Colorado.

1. Tabari, H. *Sci. Rep.* **10**, 13768 (2020).
2. Mataix-Solera, J. *et al. Catena* **108**, 6–13 (2013).
3. Montgomery, D. R. *et al. Geology* **28**, 311–314 (2000).