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That Liquefaction of Her Clothes: Mitigating Debris Flows in the Post-wildfi re Landscape

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Joint Fire Science Program

Fire Science Brief

RESEARCH SUPPORTING SOUND DECISIONS

A perfect storm of earth phenomena: fire that has removed anchoring plants and rendered soils hydrophobic by waxy compounds released from those plants; rain that loosens and transports soil, grit, rocks and branches; and gravity that sends the flow downward.

That Liquefaction of Her Clothes: Mitigating Debris Flows in the Post-wildfire Landscape

Summary

Fire, burned landscapes, rain, debris flows—the sequence is familiar to most who live in or observe the western United States. Because even relatively small rainstorms can trigger debris flows on lands altered by fire, a variety of treatments such as mulching, seeding, and emplacing barriers and fences are used to reduce hazards. Based on measurements of debris flow volumes for 46 events, as well as field observations, surveys, and literature reviews, the scientists found hillslope treatments are most effective in reducing runoff and improving infiltration. Conversely, channel treatments effectively capture debris, inhibiting these materials from joining and increasing the size of the debris flow. All treatments depend on proper design, installation, density on the landscape, and maintenance.

Key Findings

- The great majority of material in post-fire debris flows eroded from channels rather than from the hillslope.
- Locating hillslope or channel erosion control measures in areas of lowest channel gradients may be an effective way to decrease the volume of debris flows.
- Most failures of debris flow mitigation efforts resulted from inadequate concentrations of the methods used, improper design or installation of the treatment, or insufficient maintenance and refurbishing of the treatment tool.
- Debris flow hazards can be mitigated, but may require undertakings—of tools designed and emplaced in high concentrations over a small area, and their associated costs—beyond the reach of most current post-fire rehabilitation programs.

Introduction

"Sea, earth, air, sound, silence, Plant, quadruped, bird, By one music enchanted, One deity stirred, Each the other adorning, Accompany still; Night veileth the morning, The vapor the hill." The nineteenth century American poet Ralph Waldo Emerson saw every single thing on earth, tangible and intangible, as adorning every other thing. The conceit of an earth clothed is found over and over in the tales, creation stories, poems and lyrics that poets and peoples use to describe the almost ineffable sweetness of a planet wrapped in great phenomena. Those phenomena—of earth processes and biological processes—are ever-changing. The poet Tennyson described "all the spaces, Of blank earth-baldness clothes itself afresh." In seasonal cycles, and natural hazard cycles, earth wraps herself anew, on timescales determined by the conditions created from an altering event.

With ever-increasing desire to steward our lands, scientists and managers have explored and adopted myriad measures to reduce the effects of one great phenomenon that has the power to dramatically alter landscapes. Using treatment tools designed to reduce plant material, fuels specialists can lessen the potential for serious wildfire. On a landscape after fire, often reduced to a blank earth-baldness, scientists and managers also have a wide array of tools from which to choose to reduce erosion and debris flows. Muddy, gritty, rock-bearing and log-carrying, slurries can plunge: after soil-anchoring plants have been burned; after soils have become hydrophobic or "water-fearing" by the waxy layer of organic substances that once were plants; when rain, enhanced by gravity, sends the loosened covering on earth's surface surging down conduit channels. What are the best accoutrements to use to clothe the landscape in protective gear that will veil the earth from such rain-sponsored flows? Paul M. Santi, Professor of geology and geological engineering at the Colorado School of Mines, and his team looked with the gaze known to poets and scientists.

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Forty-six basins in nine burn areas across three states provided the study areas where the team collected debris flow measurements in 2004 and 2005.

Project runaway

From a safe distance, a debris flow is a fantastic thing to watch. Thick slurries of mud, wood, rocks, sediments can be quickly entrained in a flow of water, often with no warning. Even mild slopes can host debris flows that, like the proverbial snowball, gather momentum and mass as the flow travels downward. While fantastic to watch from the safety of a far ridge, or a comfortable seat in front of the television, debris flows in the wildland-urban interface can pose a serious threat to people and communities in the hazard's path. While a number of studies have examined erosion control treatments in burned areas, Santi and the team sought to look at a larger picture than the plot or hillslope. They examined debris flow mitigation options for burned areas on the scale of entire basins.

The scientists measured the volume of material that contributed to debris flows after fire in 46 basins in California, Colorado and Utah, and compared it to the:

- distance the flows traveled,
- characteristics of the basins' shapes,
- number of streams and how much branching in the stream network of each basin,
- amount of rainfall that triggered the debris flow, and
- burn severity.

With this information, they proposed different treatment approaches that could lessen such flows and the impacts of these events. These measurements, coupled with field observations, surveys, and literature reviews, enabled the team to develop models that can compare predicted debris-flow volumes from treated basins with untreated basins. By modeling where a debris flow might occur, scientists can test whether post-fire debris flow mitigation treatments can greatly reduce debris flow hazards, and the appropriate size and siting of such treatments in the basin. But before treatments can be planned for a burned landscape, managers must choose from a variety of options. What are the advantages or shortcomings of each treatment?

Recommendations for seeding call for an application of roughly 40 pounds per acre. For the erosion control program at Lemon Dam, one of the study sites, managers applied 60–75 pounds per acre over the entire basin. Researchers noted that a rainstorm on September 9, 2003 triggered a debris flow from an adjacent basin, but not from the treated basin. The amount of sediment produced from the untreated basin was 200 times higher than the treated basin.

Sheaths in the armoire

Seeding is a short term (1–3) year treatment option that introduces the seeds of fast-growing plants to burned areas where much, if not all, of the ground covering protection of plants has been lost. Slopes with inclines greater than 75 percent pitch, the scientists offer, are too steep for revegetation. The downside of seeding is that timing is extremely important—winds can blow seeds; rains can wash them away. Also a problem is that most debris flows begin on slopes at pitches greater than that suggested for successful seeding.

Mulching can help prevent erosion of soils and rock after a fire. Hand-placed application that is crimped in the soil is far more effective than aerial drops of straw where the material lands in clumps, with bare ground in between.

Also used for areas that have experienced a severe burn where most or all of the ground cover is consumed is mulching. Mulch made of straw, or less common, wood chip, is applied for a short-term benefit, and like seeding, helps to lessen the impact of raindrops and hold topsoil in place. Mulching, like seeding, is often applied by aircraft, but the downside of this aerial approach for mulching is that the straw material sometimes lands in clumps over the burned area. The clumps leave areas where bare ground can still be eroded during rainfall, and they inhibit plants from regenerating from underneath them. A better approach is hand mulching because the straw can be spread evenly, and crimped into the soil. This can be accomplished in smaller areas, but is prohibitive across large areas.

Log erosion barriers keyed into a burned slope at Lemon Dam. To work effectively, logs must be placed on contour with the topography and with good ground contact to inhibit undercutting by flowing water.

Log erosion barriers (LEBs) are familiar to many who've traveled in the back country. Placed perpendicular to the path flowing water would take, LEBs inhibit runoff and the cutting of gullies that down flowing water can create, while increasing infiltration and catching eroded soil. But of course as with most things concerning real estate, location is key. “The first requirement of LEB implementation is the presence of suitable tall and straight trees on the slope,” Santi offers. “Pine trees are suitable, while chaparral is not.” LEBs have their limitations, too—they work on slopes angled at less than 40 percent, with fine soils. Slopes with thin soil, high rock content, and pitch greater than 75 percent should be particularly avoided, the scientists explain. LEBs do not consistently reduce erosion, the scientists explain, and they are ineffective during heavy downpours.

Most often silt fences are destroyed during a debris flow that rips through the center of a channel.

Silt fences, made of woven synthetic fabric braced by steel or wooden stakes, are placed to catch fine sediments while allowing water to flow by. In reality, silt fences are often overwhelmed by flows that rip through, and are only capable of handling sediments and water flowing from very small rainfall amounts. Debris racks perform a similar function—they promote large, coarser debris to deposit while allowing fine sediment and water to pass.

Debris racks installed as part of the Lemon Dam sediment control program in southwest Colorado performed as they were intended. The treatment site in this photo captured debris and prevented it from entering a road and spillway of Lemon Dam. For such treatments to be successful, they require proper design and maintenance—engineered for the site and the anticipated volume of debris flows; emptied of debris to allow for the collection of new materials; refurbished to maintain integrity of the structure.

Check dams are built in a series in channels to decrease steep channel gradients by encouraging debris material to settle and deposit. Arresting the movement of debris down channel also minimizes the scouring these materials would have wrought along the channel bed and on the sides of the channel. Debris collected in check dams is usually not removed. Check dams must be properly designed if they are to limit debris flows. If spillways are not constructed in the dams, as the researchers determined, the dams can fail by water cutting underneath and on the sides of the channel banks. The dam must be designed, the team explains, for the volume of material and constructed of materials that are strong enough to withstand debris flow forces.

Debris basins, not studied for this project, retain coarse material that may occur from a single debris flow. In order for the basin to function as a mitigation treatment for the next flow, it must be emptied.

In order for check dams to function in collecting debris, they must be properly keyed into the banks of a channel. Weirs in the center of each dam allow excess water or debris to pass. When positioning check dams in the upper reaches—areas where debris flows begin in the burned landscape—the focus is on preventing materials from the channel bed from entraining.

Though the scientists faced certain challenges in many instances when trying to measure volumes after debris flows—debris that harmed bridges, roads and buildings were often removed quickly after an event by crews, and masses of materials also were removed by travel through the stream system that flushed evidence into larger arteries and carried it away—they had their data sets in one hand, and treatment options in the other. Where were the majority of debris materials coming from? What could they recommend as practical and viable solutions for managers? How could land planners assess the effectiveness of the different erosion control treatments?

Origins of materials stripped, teased out

The scientists determined that the volume of material eroded from the hill sides, coming from gullies, or rills, that were gouged by rain, represented only a small percentage of the total debris flow volume. “Rill erosion was identified for 30 percent of the flows, with rills contributing only between 0.1 and 10.5 percent of the total volume, with an average of just 3 percent,” Santi offers. “This finding suggests that material eroded from hillslopes may not significantly affect debris-flow volume in burned areas, but perhaps influences the likelihood of debris-flow generation.” On the other hand, the scientists found that an average of almost a quarter of the debris comes from side channels. Fifty-two percent of the debris flows studied had debris transported from side channels to main channels. In studying the flows, the team noted significant increases in the growth of debris flows part way down the channels, sometimes a three-fold increase in the amount of material it was adding as it moved downstream. A confounding factor in understanding debris entrainment is that though these increases in flow size are common, predicting their occurrence could not be pinpointed by locating them a certain distance down a channel, or at a certain pitch of the slope where the debris would originate, or other factors, the team found.

By examining the data, the team was able to suggest an approach for managers to identify the spots where their efforts to lessen debris flows with treatments would yield the best results: “We suggest that by locating mitigation measures within the area of the basin that would be contributing to the lowest channel yield rates, it may be possible to shift the location of the transition farther down channel, decreasing the volume of material contributed to the flow, and thus decreasing the potential hazard. This shift could be accomplished either by increasing infiltration on hillslopes (and decreasing the amount of runoff that can erode channels), or by decreasing the potential within the channel through installation of a series of check dams.” The scientists explain that mangers can plan the best sites for placing erosion control measures in burned basins that have not yet experienced debris flows by measuring channel gradients—the lowest levels of debris flow growth occurred most often in the areas with the lowest channel gradients, hence the best sites for mitigation.

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Among the choices to sheath the earth from stripping flows, the team found that seeding and LEBs, working alone, were not effective in reducing debris flows. The best attire was an ensemble—a combined treatment of seeding, mulching and LEBs applied almost throughout the entire basin. This ensemble has the potential, the researchers explain, to reduce debris flow volume by as much as 99 percent.

Management Implications

- For drainage basins smaller than roughly one square mile, some effective erosion and sediment control measures that managers can use should target both the hillslope and channel.
- On the hillslope, managers should use treatments that increase water infiltration, best accomplished by using a combination of seeding, mulching and LEBs.
- In the channel, managers should use treatments that decrease erosion potential and intercept coarser debris flow material such as rocks, large grit, and branches, best accomplished by using properly designed check dams or debris racks.

The right cut

By understanding where placements of treatments should occur, and the potential for greater success by using combinations best suited to a site, managers can protect basins from the catastrophic surface stripping that debris flows often wreak on a landscape. With the computer model tools developed by the team, managers can also compare known measures with modeled measures to judge treatment success. In fashioning the garb that grabs debris, land managers and planners can help the earth clothe herself afresh.

Further Information: Publications and Web Resources

Gartner, J.E., S.H. Cannon, P.M. Santi, and V.G. deWolfe, 2008. Empirical Models to Predict the Volumes of Debris Flows Generated by Recently Burned Basins in the Western U.S. *Geomorphology*, vol. 96, pp. 339-354.

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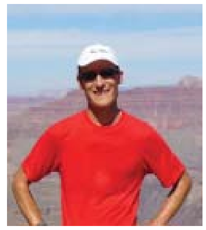
Scientist Profile

Paul M. Santi is a Professor of Geology and Geological Engineering at the Colorado School of Mines. He has research interests in debris flows, landslides, rockfall, earthquakes, and the impacts of geology on constructed works.



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