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Prediction of Post-Wildfire Debris-Flow Activity and Hazard Delineation

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Abstract

Debris flows can be some of the most destructive hazards to impact an area after a wildfire. Recent fires throughout the western U.S. have burned hundreds of thousands of acres of mountainous terrain (much of which is public land) and made it susceptible to increased debris-flow activity. The millions of dollars spent yearly to mitigate the effects of wildfire points to the need to develop tools to identify and quantify the potential hazards posed by debris flows produced from burned watersheds.

The focus of this project is to develop tools and methodologies for the prediction of post-wildfire debris-flow activity and hazard delineation. Land-management agencies dealing with post-wildfire rehabilitation and emergency planning need tools to determine both the probability and the magnitude of such potentially destructive events from individual drainage basins. We are developing GIS-based approaches for assessing debris-flow hazards from recently burned watersheds based on combinations of data and information readily available immediately following wildfires. In addition, we have established a monitoring network for the collection of post-wildfire peak runoff and rainfall data from basins burned during the summers of 2000 and 2001. This data is being used to develop multi-variate statistical models that relate peak runoff to rainfall rates, basin morphology, soil physical properties, and burned extent. These models can be combined with digital elevation models (DEMs) to delineate the probability of fire-related debris flow susceptibility and the magnitude of the response.

We are also working to develop models for fire-related debris flow initiation processes. The great majority of fire-related debris flows initiate by a process of progressive bulking of storm runoff with sediment eroded from hillslopes and channels, rather than by failure of discrete landslides. The focus of this task is to conduct field and theoretical studies of the mechanics of this process of debris-flow initiation. These studies will lead to the development and calibration of physically-based models for debris-flow movement that can be used to predict the volume of material that can be eroded from hillslopes and channels for given rainfall conditions. The contribution of material eroded from hillslopes and channels to runoff events is a critical issue in post-wildfire hazard assessments, as well as non-fire related events.

Effects of Wildfire and Rainfall on Watersheds

Debris flows generated from Coal Seam fire near Glenwood Springs, Colorado in response to 8.5 mm of rainfall in 15 minutes.

Wildfire can result in profound changes of the runoff response of burned watersheds. Removal of the rainfall-intercepting canopy and of the soil mantling organic liter and duff, the presence of wood ash on burned soils, and the generation of water-repellent soils can result in significant changes in infiltration and runoff characteristics from pre-fire conditions. One of the most hazardous consequences of the changes wrought by wildfire can be the generation of debris flows.

Levees lining debris flow generated from Coal Seam fire.

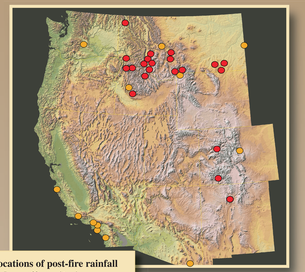
Research Activity

Methodologies for assessing debris-flow hazards

Monitoring:

In studies of debris-flow processes throughout the western U.S., we have demonstrated the relative importance of runoff-dominated, rather than infiltration-dominated, processes of debris-flow initiation in recently burned basins. This finding indicates that methodologies developed for unburned basins to map landslide potential are generally not be appropriate for recently burned areas. As an alternative, we are exploring the idea that the relations traditionally defined between peak discharges of floods and basin characteristics may be useful in predicting the magnitude of potential debris-flow response from burned basins.

In order to examine such relations we need data to quantify the magnitude of the debris-flow response, the rainfall trigger, and basin and fire characteristics. We scoured the literature for case studies of burned areas that might include such information (orange dots), and in cooperation with the WRD District offices, established monitoring programs in basins burned by the fires in 2000, 2001, and 2002 (red dots). We installed tipping bucket rain gages to measure rainfall intensities, characterized the response of each basin to storms throughout the summer thunderstorm season (debris flow or sediment-laden flood), and obtained measures of peak discharge in the event of a debris-flow response. This data provides the basis for the development of models to predict the response of basins that burn in the future.

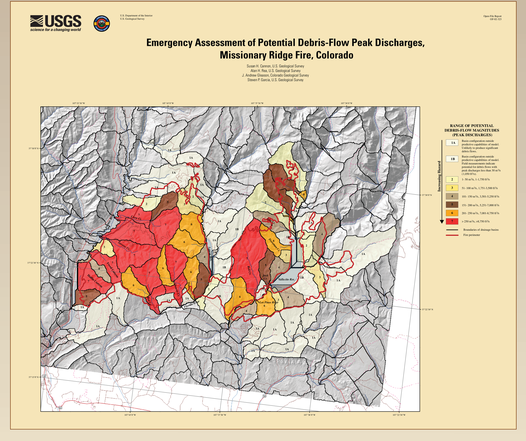


Locations of post-fire rainfall and runoff monitoring
- **Data from literature**
- **Data from USGS monitoring**

Tools:

Using the data compilation that characterizes the debris-flow response of recently burned basins, we have developed a model for debris-flow peak discharge as a function of storm intensity, basin area, basin gradient, and burned extent. This model was used to perform emergency assessments of the potential hazard posed by debris flow from the basins burned by the Coal Seam and Missionary Ridge fires of the summer of 2002 in Colorado. The assessments provide a range of possible peak discharges that can be generated from each of the burned basins in the event of the 25-year, 1-hour storm. Maps showing the results of these assessments were distributed to emergency-response and water resources-management personnel to aid in the design of mitigation measures and the planning of evacuation timing and routes. Under a USGS/Colorado Geological Survey (CGS) cooperative agreement, CGS personnel worked closely with the La Plata County emergency Manager, engineers from the National Resource Conservation Service, and affected citizens to assist with map interpretation and debris-flow hazard mitigation decision-making.

The database compiled through our monitoring program will also be used to define those unique conditions that indicate a propensity specifically to post-wildfire debris flow, provide the basis for the development of probabilistic models for debris-flow susceptibility, and to define rainfall threshold conditions for fire-related debris-flow activity throughout the western U.S.



Research Activity

Mechanics of debris-flow initiation

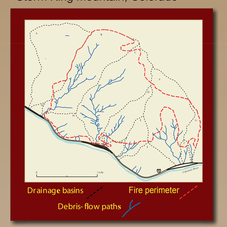
In studies of recently burned basins throughout the western U.S., workers have described debris flows that are generated through a process of progressive bulking of storm runoff with material eroded from hillslopes and channels, rather than from the mobilization of discrete landslides on hillslopes. Debris flows are much more frequently generated from recently burned basins by the runoff-dominated process of progressive sediment bulking than by the infiltration-dominated process of landslide failure.

To examine this process of debris-flow generation, we use detailed field and aerial photographic mapping of debris-flow events throughout the western U.S. to

- characterize the process,
- investigate the conditions which result in variations in the process,
- assess the relative hazards posed by debris flows under these variable conditions.

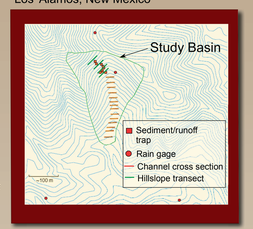
Each of the studies reveals variations in the process that allow us to gain a better understanding of debris-flow generation from recently burned basins.

South Canyon fire,
Storm King Mountain, Colorado



Detailed maps of the debris-flow paths, geology, and topography allowed for definition of the conditions that resulted in debris flows.

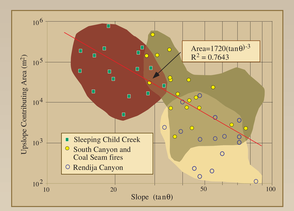
Cerro Grande fire,
Los Alamos, New Mexico



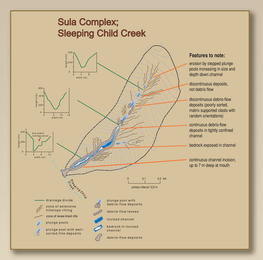
Monitoring of the response of a small basin to rainfall events provides data for the development of a physically-based model for debris-flow initiation.

Motivation

Understanding of post-wildfire initiation processes and their impacts is necessary to make appropriate hazard assessments and for the design of effective mitigation approaches.



Graph of contributing area as a function of gradient of contributing areas underlain by metamorphic rocks and mantled with consolidated and well-developed soils (Sleeping Child Creek), fine-grained sedimentary rocks and abundant loose, unconsolidated material (South Canyon and Coal Seam fires), and volcanic materials and abundant loose gravel lag (Rendija Canyon).



Detailed mapping of runoff and erosional response of burned basins provides understanding of conditions that control post-fire debris flow production.

Collaborators:

Colorado Geological Survey
Montana Bureau of Mines and Geology
USDA Forest Service

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