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Post-Wildfire Debris Flows: Literature Review

Wildfires are a common disaster that has a devastating effect on local environments through their persistent and quickly moving uncontrollable flames. Debris flows are an erosional event that will also produce a destructive effect on the nearby and downslope surroundings. In this literature review, I will explore how wildfires make slopes more susceptible to debris flows. I will review the geomorphic processes that relate the two hazards, as well as explore some local case studies, discuss the spatial impact that these events can affect, and will discuss the methods that are being created to predict susceptible areas which will lead to how this can be a step towards risk prevention.

Wildfires can have many effects on a drainage basin that will alter the landscape significantly and through this, have proven to increase the risk of a debris flows in an otherwise stable environment (Susan H. Cannon et al., 2010). In general, wildfires have been studied and shown to decrease soil infiltration and increase runoff generation. One of the more visually obvious results from a wildfire is the lack of vegetation left behind. Similarly to an area clear-cut for logging, if vegetation is burnt up then the absence of protective vegetation will introduce factors that will reduce stability of the slope (Addison et al., 2019). Vegetation on slopes are important in intercepting rainfall through evapotranspiration and general increased water storage capacity in comparison to bare earth (Jordan, 2016; Megahan, 1983). If there is no vegetation to intercept the rainfall, the impact of water drops can result in rain splash erosion and rilling and can increase the soil moisture content. These processes can result in surface erosion and overland flow, respectively (Jordan, 2016; Megahan, 1983). Vegetation can also act as dams, preventing some material from being carried in a smaller debris flow (DiBiase & Lamb, 2020). The greatest hazard for debris flows in post-wildfire environments is generally up to 2-3 years after the fire, after which the risk decreases with each year as vegetation re-establishes. Deforestation of an area can also increase snow accumulation and therefore snowmelt, which will be hazard for longer than 2-3 years as vegetation is still small and has little effect with preventing snow collection (Jordan, 2016). Another hazard due to the absence of vegetation on a slope that will have a longer effect is root decay. Since there is increased soil moisture and dead trees present, around 5-10 years after a fire the tree roots will begin to decay, decreasing the shear strength of the soil (Wondzell & King, 2003). A less obvious result from wildfires that will contribute to debris flow susceptibility is the physical and hydrological characteristics of soil. The ash produced from the fire as well as the small particulate matter that is upturned has been found to seal the soil surface pores of a slope which reduces infiltration capacity (Larsen et al., 2009). Interestingly, there has been a lot of research regarding the tendency for soil to become water repellent after a severe fire. Hydrophobic organic compounds condense due to the heat of the fire underground and leave ~~the~~ a water repellent layer of soil behind (DeBano, 2000). There is a high degree of spatial heterogeneity in post-wildfire soil relative to unburned environments and so sealed soil surface pores and hydrophobic compounds may not be found everywhere on a burnt slope (McGuire et al., 2018). Soil spatial patterns depends on both the spatial patterns of individual storms and the burn severity (DiBiase & Lamb, 2020).

There are two main processes in which debris flows can be initiated in post-wildfire landscapes – runoff or infiltration dominated. Runoff generated debris flows are more common and extensive with increasing burn severity as shown in figure 1 (Nyman et al., 2019). Runoff-triggered processes are caused by small soil slips that only involve the top few millimeters of soil which form rills and then travel as shallow and narrow debris flows towards a channel and eventually grow in volume as larger material becomes entrained in the flow. Infiltration-triggered processes are the type also associated with debris flows in unburned environments. These occur when a landslide block breaks apart and mobilizes into a fluid debris flow as it travels downslope (S. H. Cannon et al., 2001). Debris flows in post-wildfire environments will often require lower intensity and shorter duration rain events relative to debris flows in unburned areas, due to the factors listed above (Susan H. Cannon et al., 2008).

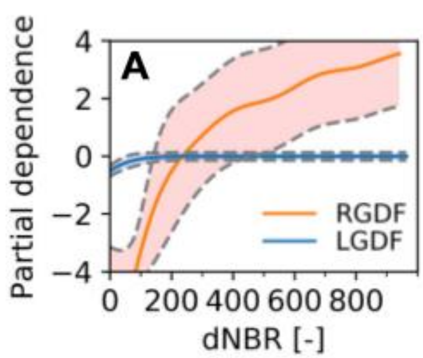

Figure 1: Partial dependencies represent the magnitude of impact on density. RGDF is runoff generated debris flows. LGDF is landslide generated debris flows (or infiltration-triggered). dNBR is fire severity (difference normalized burn ratio). (Nyman et al., 2019).

Debris flows in post-wildfire environments are relatively common in the lower latitudes of Canada but are often not reported and weren't studied until the past two decades or so (Jordan, 2016). Debris flows require high peak flows in channels and generally steep terrain. Areas with moderate to high severity burning and a thicker layer of colluvium upon a restricted layer have been shown to have higher chances of post-wildfire debris flows (Addison et al., 2019). In British Columbia, there is a lot of rain, snow, steep mountainous terrain, and as of recent, wildfires. Post-wildfire debris flows in British Columbia are often triggered by spring snowmelt, high-intensity summer rainstorms, and low-intensity fall rainstorms (Jordan, 2016). In Peter Jordan's paper, "Post-wildfire debris flows in southern British Columbia, Canada", he describes several debris flow events that have occurred in the past 20 years. I will be exploring two events that I thought were particularly interesting that were a result from the big wildfire season in the summer of 2003.

Kuskonook and Jansen Creek catchment debris flows

This was the most destructive event that occurred due to the 2003 fires. They happened during the night of August 6-7 in 2004, one year after the Kuskonook wildfire just southeast of these catchments. A high-intensity summer rainstorm triggered two large debris flows in which two houses were destroyed, a highway was closed for several days and a large portion of the Kuskonook Creek fan was left debris-covered (figure 2). These catchments showed high burn severity, extensive water repellent soils and overland flow draining into steep channels from plateaus above. The debris flow would most likely be classified as runoff triggered as it was reported that the surface erosion was shallow, and the debris was relatively a small volume but was very widespread.

Figure 2: Two houses were destroyed and debris covered the highway for days following the debris flows in the Kuskonook Creek catchment (Jordan, 2016).

Ingersoll Fire

This series of debris flows occurred 2 years after the Ingersoll fire, on October 17, 2005. A two-day rainstorm triggered at least 15 debris flows/slides over the steep bedrock dominated slopes that were burnt by the fire. These were runoff generated debris flows caused by the low intensity but long duration storms that are common in BC in the autumn. Jordan claims that snowmelt would've also likely contributed to the overland flow as well as lingering hydrological and physical effects from the high soil burn severity reducing infiltration capacity. There were also cut blocks in some areas lower on the slopes that would've made the area even more susceptible to debris flows.

Debris flows can vary in size and hazard drastically. Often, multiple debris flows will occur from the result of one large fire, as with the Ingersoll fire. An estimated average of 350 million hectares of land are affected by wildfires worldwide each year (Van Der Werf et al., 2006) and there are predictions of increasing occurrence as the trends of temperature increase and intense drought-like conditions are more common in the forests of western North America (Westerling et al., 2006). Sediment yields from post-wildfire debris flows are 2-3 orders of magnitude greater than annual background rates of erosion in unburned forests (Nyman et al., 2015). The Lamb Creek fire near Cranbrook in BC had an estimated 30,000-50,000 m^3 of debris be deposited during one debris flow event in 2004 (Jordan, 2016). Not only is the spatial and volumetric extent of wildfires broad, the time scale in which a slope remains hazardous must be considered as the threat of debris flow occurrence should be required for several years after a wildfire (Addison et al., 2019).

There is extensive research occurring in predicting the susceptibility to debris flows of a slope following a wildfire. Compiling information such as the severity of a wildfire, the shape of the basin where the wildfire has burned through, rainfall characteristics and soil properties can help to develop predictive models to isolate susceptible areas as well as identify where flows may initiate and produce peak flow timing to within a few minutes for storms that can last several hours (Rengers et al., 2019). Logistic models have been developed using characteristics of past debris flows and a probabilistic approach. This is effective because decent results can be obtained with little data input, and it is fast and easy to interpret (Susan H. Cannon et al., 2010). Although with more research and experimentation, it's been determined that predicting sediment yield increases and debris flows is difficult due to the uncertainty in sediment transportation methods that are most prominent for each landscape (DiBiase & Lamb, 2020). Models are often tested by simulating runoff on synthetic topography as well as comparing results to other methods and past events (McGuire et al., 2018). Lidar can be used to investigate elevation change and therefore sediment yield from debris flows that occurred in post-wildfire environments as shown in figure 3 (Pelletier & Orem, 2014).

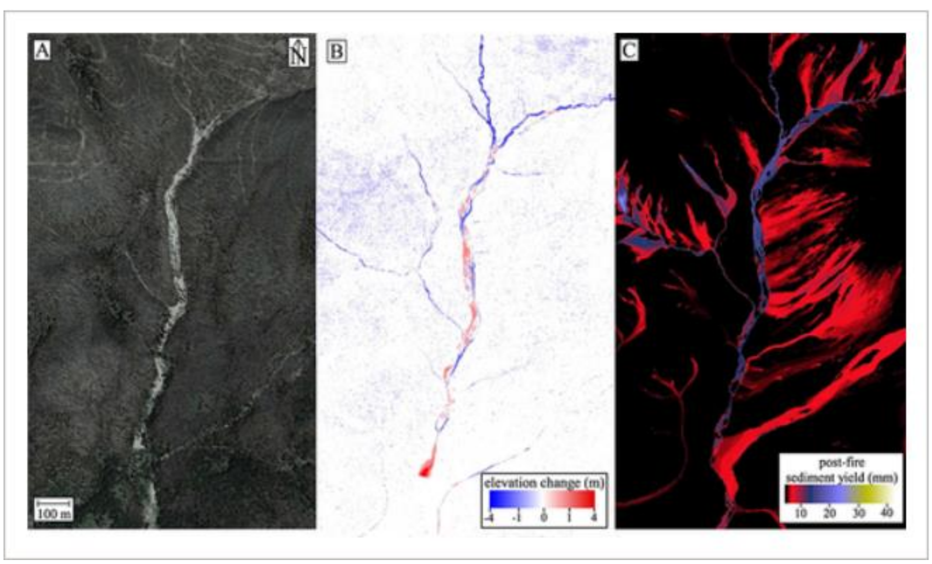

Figure 3: DEM-of-Difference (DoD) images of the Valle los Posos study subarea which was affected by the 2011 Las Cochas fire and subsequent rainstorms that occurs one year after the fire in New Mexico (Pelletier & Orem, 2014).

By creating models that can predict potential debris-flow hazards before wildfires happen, areas that require risk reduction projects and emergency management plans can be prioritized and mitigation projects to reduce the impact of incoming debris flows can be created. Without these predictions land managers, emergency managers and local officials will have little time to plan emergency evacuations and there poses a much higher risk for residents, infrastructure, and natural and cultural resources that are downslope (Staley et al., 2018).

Wildfires may not be the cause of all debris flows but can create crucial hazards that shouldn’t be forgotten when initial wildfire remediation is complete. Wildfires change the landscape in many obvious as well as less visible ways and debris flows in post-wildfire environments can be triggered by much less precipitation than is required to initiate a debris flow in unburned landscapes. Models and experiments should be run in any areas with communities or resources downslope to enable the implementation of mitigation and management plans.

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