Geomorphology 206 (2014) 362–373

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

Functional and structural connectivity within a recently burned drainage basin

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ARTICLE INFO

Article history:
Received 9 March 2012
Received in revised form 8 October 2013
Accepted 11 October 2013
Available online 21 October 2013

Keywords:
Terrestrial laser scanning
GIS
Hillslope
Wildfire
Sediment transport

ABSTRACT

Studies examining post-wildfire sediment transport have often focused on changes to individual landscape compartments (planar slopes, rills, gullies, channels, or alluvial fans) or have captured coarse-scale hydrologic and sediment transport events at the drainage basin scale. We advance the understanding of functional and structural connectivity by quantifying changes of the morphodynamics of and sediment transport along seven rill-gully threads (RGTs) after two low intensity rainstorms in a burned basin from the 2008 Gap fire near Goleta, CA, USA. TLS surveys conducted within two months of the initial fire and three days after the rainfall events provide point clouds for high-resolution digital terrain models (DTMs). DTM differencing techniques and morphological sediment budgets from the RGTs showed discontinuous sediment transport along the extent of these two landscape compartments immediately after the rainfall. Surface runoff was unable to remove dry ravel deposits within the RGTs and implied a high degree of structural disconnectivity there. Dry ravel and runoff erosion from the contributing areas to the RGTs indicated functional and structural connectivity at this scale of analysis. The results provide clear evidence that small amounts of rainfall and gravity-induced erosion are interacting at different scales within the recently burned watershed to produce structural and functional disconnectivity along the RGTs. While the current system was transport-limited during the analyzed event, higher magnitude rainstorms may produce enhanced connectivity, resulting in the ability of surface runoff to remove the stored sediments and perhaps produce debris flows.

1. Introduction

Wildfire, an omnipresent hazard throughout Southern California, has been exacerbated as urban sprawl expands the wildland-urban interface into the surrounding mountainous terrain. Expansion of the interface, coupled with increases in the frequency and size of wildfires (Westerling et al., 2006), places more people, homes, and infrastructure at greater risk. Wildfire also drastically modifies the structures and functions of steep watersheds adjacent to or within the wildland-urban interface. Partial or total loss of vegetation in a recently burned watershed represents: (1) a reduction in surface roughness and therefore, the ability to dissipate surface runoff and sediment transport capacity along certain pathways (Scott et al., 2009); (2) a loss of a level of structure that intercepts rainfall, thereby increasing sediment detachment by rain splash (Shakesby and Doerr, 2006; Moody and Martin, 2009; Zavala et al., 2009); and (3) a reduction in colluvium and soil strength as roots may no longer be present to prevent erosion (Moody and Martin, 2009). Runoff and sediment transport are further enhanced when the previously mentioned modifications are combined with physical and chemical changes to the soil. Ultimately, these combined environmental changes promote greater water and sediment discharge than a similar watershed in an unburned state (Zelt and Wohl, 2004; Moody and Kinner, 2006). A critical first step to unraveling these complex changes and potential hazards involves an analysis of the sediment pathways and the timing of sediment transport within and between the different landscape compartments of recently burned watersheds; hillslope, hollow, and channel compartments are commonly identified in many recently burned basins (Fig. 1). Here, we present field-based experimental research examining sediment transport between the hillslope and hollow landscape compartments of a recently burned watershed using the concept of connectivity.

Brierley et al. (2006), Fryirs et al. (2007), Bracken and Croke (2007), and Fryirs (2013) have synthesized various aspects of the connectivity literature. These authors have built succinct definitions, common terminology, and conceptual frameworks encompassing a wide range of geomorphic processes and settings. The definitions of connectivity and disconnectivity by Fryirs (2013) are adopted to assist in our analysis of the degree to which landscape compartments exhibit connectivity. Connectivity is defined as the transfer of matter between two different landscape compartments (Jain and Tandon, 2010; Wainwright et al., 2011). Connectivity between landscape compartments may be defined in two ways. Connectivity occurs when there is physical contact between two compartments, such as when material eroded from a hillslope is transported directly to a stream channel when no floodplain is present. Connectivity may also occur when there is a transfer of matter or energy between two physically disconnected compartments, such as aeolian transport of material from dry lake beds and deposition

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http://dx.doi.org/10.1016/j.geomorph.2013.10.011

Compartments	Structures	Processes
a. Hillslopes	Flat planar or convex surfaces, rills and interrill areas, shallow landslides	Rainsplash, infiltration, runoff generation, detachment, sediment transport, dry raveling, sediment deposition, grain flows
b. Hollow	Gully network, colluvial wedge, dry ravel deposits, shallow landslides	Gully erosion, sediment transport, sediment deposition
c. Channel	Morphological features such as knickpoints, step-pool features, bedrock-confined reaches, and pre-existing channel deposits	Channel erosion and deposition, sediment transport

Fig. 1. Landscape compartment diagram and their structures (structural) and processes (functional) in a recently burned basin in California.

on an alluvial fan. Disconnectivity is defined as any process or structure limiting physical contact or transfer of sediment, organic material, chemicals, nutrients, or water.

Recent advances within the connectivity discourse have synthesized the types of approaches and vocabulary within and between the disciplines of ecology, hydrology, and geomorphology (Turnbull, 2008; Ali and Roy, 2009; Wainwright et al., 2011; Fryirs, 2013). Wainwright et al. (2011) provide a broader interdisciplinary contextual framework for connectivity research whereby structural and functional connectivity are proposed as universal terms. Structural connectivity describes the extent to which landscape units are contiguous or physically linked, at multiple spatial and temporal scales. Functional connectivity accounts for the way in which the multiple structural characteristics of the system in question affect geomorphic, ecologic, and hydrologic processes. Herein, the terms structural and functional connectivity are adopted to examine sediment transport (erosion and deposition) within and between landscape compartments of recently burned watersheds (Figs. 1 and 2).

Specifically, we examine how erosion from two small rainstorms and precipitation-independent sediment transport immediately after a wildfire translate to the connectedness along flow pathways within the hillslope and hollow landscape compartments. We expand upon the work of Wainwright and Parsons (2002) that examined functional connectivity along an unburned hillslope by examining structural connectivity through inferences of our morphological sediment budgets and detailed mapping of drainage basin features. We investigate event-based sediment transport from the hillslope through the hollow to its connection with the trunk stream. Most studies to date have only considered sediment transport at points, within a single landscape compartment, or at the drainage basin scale.

Our connectivity research is focused on two spatial scales. The coarsest scale of analysis consists of sediment transfer from the contributing area throughout the drainage network in the hillslope and hollow compartments. The second scale of analysis occurs along the extent of the rill-gully thread (RGT). An RGT refers to the combination of a single rill (longest linear extent of the master rill) and a connecting gully that ends at a confluence with the trunk stream. The nested sampling approach permits us to draw greater inferences about the degree of connectivity between the hillslope and hollow compartments of the recently burned basin (Wainwright et al., 2011). Furthermore, the

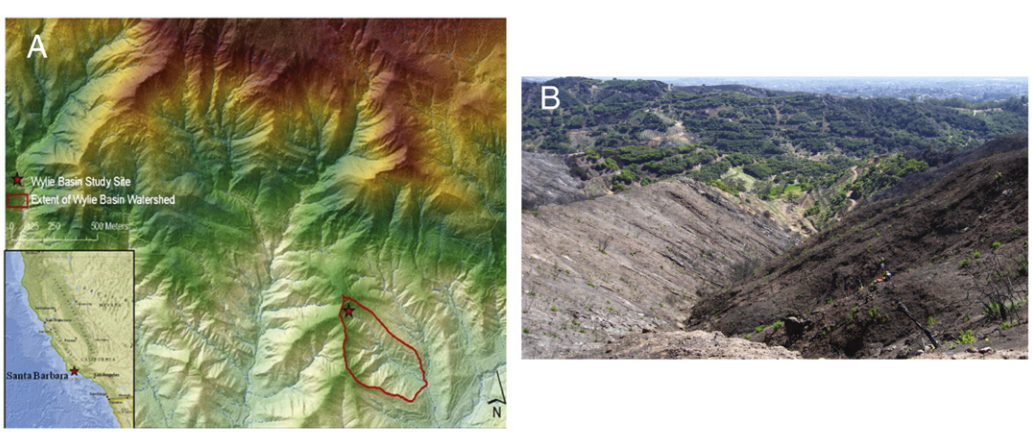

Fig. 2. Study site location and post-fire structure. A) Map depicting the location of the Wylie Canyon catchment. The star demarcates the location of the small sub-basin use in the current study. B) Image showing a major portion of the recently burned sub-basin at Wylie Canyon.