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Wildfire as a hydrological and geomorphological agent

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Abstract

Wildfire can lead to considerable hydrological and geomorphological change, both directly by weathering bedrock surfaces and changing soil structure and properties, and indirectly through the effects of changes to the soil and vegetation on hydrological and geomorphological processes. This review summarizes current knowledge and identifies research gaps focusing particularly on the contribution of research from the Mediterranean Basin, Australia and South Africa over the last two decades or so to the state of knowledge mostly built on research carried out in the USA.

Wildfire-induced weathering rates have been reported to be high relative to other weathering processes in fire-prone terrain, possibly as much as one or two magnitudes higher than frost action, with important implications for cosmogenic-isotope dating of the length of rock exposure. Wildfire impacts on soil properties have been a major focus of interest over the last two decades. Fire usually reduces soil aggregate stability and can induce, enhance or destroy soil water repellency depending on the temperature reached and its duration. These changes have implications for infiltration, overland flow and rainsplash detachment. A large proportion of publications concerned with fire impacts have focused on post-fire soil erosion by water, particularly at small scales. These have shown elevated, sometimes extremely large post-fire losses before geomorphological stability is re-established. Soil losses per unit area are generally negatively related to measurement scale reflecting increased opportunities for sediment storage at larger scales. Over the last 20 years, there has been much improvement in the understanding of the forms, causes and timing of debris flow and landslide activity on burnt terrain. Advances in previously largely unreported processes (e.g. bio-transfer of sediment and wind erosion) have also been made.

Post-fire hydrological effects have generally also been studied at small rather than large scales, with soil water repellency effects on infiltration and overland flow being a particular focus. At catchment scales, post-fire accentuated peakflow has received more attention than changes in total flow, reflecting easier measurement and the greater hazard posed by the former. Post-fire changes to stream channels occur over both short and long terms with complex feedback mechanisms, though research to date has been limited.

Research gaps identified include the need to: (1) develop a fire severity index relevant to soil changes rather than to degree of biomass destruction; (2) isolate the hydrological and geomorphological impacts of fire-induced soil water repellency changes from other important post-fire changes (e.g. litter and vegetation destruction); (3) improve knowledge of the hydrological and geomorphological impacts of wildfire in a wider range of fire-prone terrain types; (4) solve important problems in the determination and analysis of hillslope and catchment sediment yields including poor knowledge about soil losses other than at small spatial and short temporal scales, the lack of a clear measure of the degradational significance of post-fire soil losses, and confusion arising

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from errors in and lack of scale context for many quoted post-fire soil erosion rates; and (5) increase the research effort into past and potential future hydrological and geomorphological changes resulting from wildfire.

Keywords: wildfire; forest fire; rock weathering; soil erosion; mass movement processes; sediment yield; soil hydrophobicity; infiltration; peakflow; total flow; palaeofire; global warming

1. Introduction

Over short and long timescales, wildfire (i.e. uncontrolled or naturally occurring fire) can be an important, if not the major, cause of hydrological and geomorphological change in fire-prone landscapes. Rock surfaces may be subject to widespread weathering, though damage to or loss of vegetation and litter cover represent the obvious changes in the landscape and they can affect the interception, evapotranspiration and storage of rainfall and can also influence snow accumulation and melting behaviour in affected landscapes. The heating of soils tends to alter their physical and chemical characteristics, including water repellency behaviour and stability of aggregates. These changes often result in enhanced hydrological and geomorphological activity, with considerably more overland flow on slopes and increased discharge and peakflow, channel changes and substantially increased hillslope soil redistribution and catchment sediment yields. Where conditions are suitable, the fire-induced changes can cause increased wind erosion, increases in snow–avalanche activity, gravity flow of dry sediments, landslides and debris flows. The magnitude and duration of post-fire increased hydrological and geomorphological activity can vary enormously and depend on an often complex interplay of factors including site and fire characteristics, and also post-fire rainfall patterns. Many researchers have attempted to determine accurately and predict its hydrological and geomorphological effects, but this has been made difficult by the unpredictable nature of wildfire. Building a coherent knowledge base, however, has proved difficult as results of this work vary widely, associated with regional differences in climate, terrain and fire characteristics, but also due to differences in research approaches and scales of investigation. Furthermore, research has been inter-disciplinary in nature and also has hazard and conservation implications so that much of the literature is disseminated amongst a number of government agency reports and conference proceedings as well as peer-reviewed academic journals across a range of disciplines. There have been a number of reviews dealing with aspects of fire impacts on hydrology and geomorphology (e.g. Anderson et al., 1976; Tiedemann et al., 1979; Swanson, 1981; McNabb and Swanson, 1990; Robichaud et al., 2000; Neary et al., 2003), but some are now outdated, most appear in non-peer reviewed literature, feature mainly post-fire conservation issues or deal more with prescribed fire rather than the impacts of wildfire. In addition, there is an emphasis on North American examples with much less attention paid to the literature from other parts of the world (notably Europe, and the Mediterranean Basin, southern Africa and Australia) where fire impacts have differed due to different types of natural environmental conditions and land use history.

This paper attempts to provide a critical review of the available literature concerning the hydrological and geomorphological impacts of wildfire. It considers impacts on hydrology, fluvial geomorphology, rock weathering, mass movement processes and soil erosion from the range of fire-affected regions that have been studied world-wide. Over the last 20 years or so, a growing body of literature has been concerned with wildfire impacts in the Mediterranean Basin in particular, but also other parts of the world, notably Australia and South Africa, which has given different perspectives on hydrological and geomorphological impacts. Examples in this review are drawn mainly from studies in forest and woodland and to a lesser extent from scrub and grassland areas, with an emphasis on the results of field monitoring and observations of processes under natural rather than simulated rainfall. The hydrological and geomorphological effects of prescribed fires, the modelling of wildfire impacts and remedial measures to alleviate these impacts are not considered.

2. Wildfire: global significance, causes, frequency and severity

2.1. Global significance and causes

Wildfire is an important disturbance factor in most vegetation zones throughout the world and is believed to have been more or less common since late Devonian times (Schmidt and Noack, 2000). In many ecosystems it is a natural, essential, and ecologically significant force, shaping the physical, chemical and biological attributes of the land surface. The main causes are lightning, volcanoes and human action, the latter