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Determining wildfire ash saturated hydraulic conductivity and sorptivity with laboratory and field methods

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ABSTRACT

Post-fire landscapes are often blanketed with a layer of ash that is capable of altering post-fire infiltration response. Documentation of ash layer characteristics, specifically ash sorptivity and hydraulic conductivity, is instrumental to understanding and modeling post-fire environments and infiltration response. The aim of this study was to evaluate laboratory methodologies for determining ash hydraulic conductivity and sorptivity based on established methodologies from soil measurements. A series of field and laboratory tests were conducted on ash from 13 high severity wildfires within western North America to evaluate; *i*) a non-destructive method for the rapid assessment of saturated hydraulic conductivity in the laboratory, *ii*) a method for directly measuring ash sorptivity in the laboratory and *iii*) compare these laboratory methods, conducted on disturbed samples, to field measurements taken in-situ.

The air permeametry method and the use of a sorptivity probe are viable methodologies for obtaining ash saturated hydraulic conductivity and sorptivity values respectively in the laboratory. Air permeametry was non-destructive, allowing ash samples to be further processed, while the sorptivity probe provided a direct measurement of sorptivity as values were collected with no gravitational component. Results were consistent between laboratory- and field-based methodologies, indicating that disturbed laboratory readings are a viable substitute for in-situ field measurements when pertaining to ash sorptivity and hydraulic conductivity. Both methodologies provide fundamental information regarding ash characteristics, which can be incorporated into modeling systems to aid in predicting post-fire infiltration response.

1. Introduction

Following wildfires the hydrological response of the landscape is often altered leading to increased runoff and erosion response (Shakesby, 2011). Ash layers, deposited from the combustion of vegetation and duff layers during a wildfire, are known to contribute to changing post-fire infiltration response (Bodí et al., 2012; Ebel et al., 2012; Stoof et al., 2010; Woods and Balfour, 2008, 2010) by producing a two-layered soil system (Kinner and Moody, 2008, 2010; Onda et al., 2008). Moody et al. (2009) suggest that infiltration-excess overland flow regimes in these burned two-layered systems are controlled by the hydraulic properties and changes in soil moisture conditions. Moody et al. (2009) further explain these burned two-layered systems by separating infiltration into short- and long-term components, with the former dependent upon sorptivity, reflecting the capillary potential of initial infiltration, and the latter dependent upon saturated hydraulic conductivity in which gravitational potential is the main driver (Smith, 2002). Therefore the documentation of ash layer characteristics, specifically sorptivity and saturated hydraulic conductivity, is instrumental to understanding variations in post-fire infiltration response.

In a post-fire study conducted primarily on soil samples taken from three wildfires within the western U.S., Moody et al. (2009) highlighted the importance of wildfires altering soil physics, as well as the necessity of incorporating such changes into physically based models to accurately predict runoff response in burned watersheds (Moody et al., 2009). The importance of including ash layer hydrologic properties in post-wildfire runoff generation models was further highlighted at the catchment scale by Ebel et al. (2012) following the Fourmile Canyon wildfire in the Colorado foothills. While both studies address the importance of including post-wildfire ash layer characteristics to fully understand the post-fire hydrological responses, limited data is often collected regarding ash. One reason for the lack of documentation of ash characteristics may be due to the delicate nature of ash and the often rapid alterations it undergoes. For example, ash can increase in particle size when wetted and exposed to air due to agglomeration (Steenari et al., 1999) or swelling (Etiegni and Campbell, 1991) as shown for ash produced via industrial burning of biofuel and sawdust. Similar alterations have been observed with the hydration of wildfire ash in laboratory settings (Stoof et al., 2010), while other studies have indicated that the chemical stability and behavior of wildfire ash may vary with exposure to water (Balfour and Woods, 2013; Gabet and Sternberg, 2008; Onda et al., 2008). The instability of ash makes the collection of ash characteristics time sensitive in the field, as collection should occur rapidly prior to

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hydration for accurate measurements. Emphasis on laboratory processing of ash characteristics would allow field time to be more effectively spent acquiring samples and focusing on necessary in-situ measurements.

Another reason for the lack of detailed documentation regarding ash characteristics maybe due to site availability and access issues, as access onto active wildfires is often not feasible until after control or containment of the wildfire, which occasionally coincides with considerable rainfall and therefore alteration of ash characteristics. Finally there is the issue of adequate ash sampling for laboratory measurements and contamination of the ash layer sampled with underlying soil. According to conventional soil methodology for conducting one-dimensional infiltration measurements in the laboratory, the diameter of the sample column should be approximately equal to that of the mini-disk base (4.4 cm), whereas for three-dimensional measurements the column diameter must be large enough that the wetted part of the ash does not touch the walls of the column (Dane and Hopmans, 2002). In both cases the column should be long enough so that the wetting front does not reach the bottom during the test, which for most ash samples requires a 20 cm high column. The relatively low bulk density of ash, 0.12–0.45 g cm^{-3} (Cerdà and Doerr, 2008; Ebel et al., 2012; Gabet and Bookter, 2011; Moody et al., 2009; Woods and Balfour, 2008) suggests that large quantities (35–135 g) would be needed for each laboratory infiltration measurement making replication difficult or in some cases impractical. Furthermore the chemical instability of ash precludes samples from being reused as the original characteristics may have been altered by hydration (Balfour and Woods, 2013). Therefore it is desirable to seek out non-destructive alternatives to traditional soil infiltration methodologies in order to conserve ash samples, by using smaller volumes and avoiding chemical alterations.

The intention of this study was to assess if established laboratory methodologies from other fields of research could be applied to wildfire ash as alternatives to determining saturated hydraulic conductivity and sorptivity. Specifically a series of field and laboratory tests were conducted to address three main goals: *i*) develop a non-destructive method for the rapid assessment of saturated hydraulic conductivity in the laboratory, *ii*) develop a method for directly measuring ash sorptivity in the laboratory and *iii*) determine how accurately the laboratory methods, conducted on disturbed samples, reflect field measurements taken in-situ. These methodologies presented allow for collecting adequate data, pertaining to ash hydraulic characteristics, which can be incorporated into modeling systems.

2. Methods

2.1. Field sites and ash collection

Prior to post-fire rainfall, vegetative ash was sampled from 13 high severity wildfires, which occurred over a seven-year period (2005–2011) within western North America (Fig. 1). Ash samples were collected by first creating a small trench (~1 m long), to assess the ash-soil profile, then removing ash with a sharp trowel to avoid soil contamination (Fig. 2). Numerous ash samples, at least five transects for each site, were collected and combined to produce a composite ash sample for laboratory testing. High fire severity was verified in the field based on visual indicators (the surface organic layer, know as

Fig. 1. Location map of the 13 wildfire sites within North America, denoted by asterisks.