Water Quality Risk Due to Fire Disturbance

Tools for Quantifying

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ABSTRACT:

Damaging debris flows and other large erosion events are hazards that often emerge in mountainous landscapes due to the combination of fire disturbance and intense rainfall. Quantifying the water quality risk associated with these hazards is a complex task requiring deterministic catchment response models in combination with models that represent the stochastic conditioning by fire disturbance and storms in space and time. This presentation summarizes three years of Bushfire CRC research where modeling and intensive data collection were combined in order to develop operational and strategic management tools for evaluating water quality risk. Operational land managers are typically concerned with spatial variation in risk as a function of fire severity, recovery and catchment properties. In this context our research has aimed to identify the key landscape variables that can be used to quantify spatial variation in risk across large catchment where severity, soil properties and topography are often highly variable.

At a strategic level, the land managers want to evaluate risk as a function of fire and rainfall regimes that change over time due to climate change and prescribed burning (i.e. risk is non-stationary). In this context our research has aimed to isolate the first-order effects of fire and rainfall regimes on the frequency of significant water quality impacts. This was achieved by modeling fire disturbance and storms as random processes (or patches) that overlap in space and time. In this type of model the risk responds directly to changes in fire and rainfall regimes, thus eliminating some of the uncertainties associated with the exact response of any particular hillslope or catchment. The presentation concludes with examples of management scenarios where operational and strategic modeling tools can be applied to evaluate the water quality risk due to fire disturbance.

Introduction

Debris flows and other erosion processes in mountainous landscapes can intensify due to the combination of fire disturbance and intense rainfall. The impacts of burned catchments on water quality in rivers and reservoir can be large. After the Canberra wildfires in 2003, for instance, there were large increases in turbidity and nutrient concentrations in the Cotter Catchment, which resulted in disruptions to water supply (White et al. 2006). Another example is the Ovens River after the Eastern Victorian alpine wildfires in 2003 where there were large water quality impacts due to a pulse of sediment and nutrients from debris flows in burned headwaters (Lyon and O'Connor 2008). Debris flows were also a source of contamination in Lake Glenmaggie after the 2007 wildfires in Victoria (Smith et al. 2011). Impacts of burned catchment on water quality have been documented elsewhere in southeast Australia including the Nattai Catchments near Sydney (e.g. Wilkinson et al. 2007) and the Lofty ranges near Adelaide (e.g. Morris et al. 2012). These impacts may be of concern to water supply agencies and there is a demand for models that support decisions and risk assessments regarding prescribed burning, erosion control works and investments in treatment capacity.

An important feature of risk is that the forcing variables, processes and management interventions contributing to risk (and opportunities) are dependent on time and space. For instance, the opportunities and risks are very different when faced with a current fire disturbance (i.e. timeframe of 1 - 10 years) as opposed to a fire regime (i.e. timeframe of 10 -100's of years) (Figure 1). Similarly for space, the opportunities and risks are different when faced with a single catchment (1 - 10 km2) as opposed to multiple catchments in a landscape (10 - 100's km2) (Figure 1). Models that operate at short temporal scales are usually concerned with the processes and properties that drive variability in response from different catchments after a fire event. This scale of modelling has a long history in the hydrological sciences and is concerned with transforming rainfall to a catchment response (Merritt et al. 2003). At larger and longer spatial-temporal scales, the there is an increased emphasis on the fire regime itself, the rainfall regimes and their interaction with local catchment properties such as vegetation, soil and landform (Gill and Allan 2008; Luce et al. 2012). The paucity of literature around the effect of regimes (fire and rainfall) on catchment processes is surprising given the emerging concerns regarding landscape scale effects of climate change and prescribed burning (Bradstock et al. 2008; Gill and Allan 2008; Goode et al. 2012; Luce et al. 2012; Stephens et al. 2012).

Quantifying risk – the issue of scale

The spatial-temporal perspectives on risk influence models in terms of the resolution and scale required to provide relevant information to managers. Resolution is the level of detail in process representation. Scale is the temporal and spatial extent of the modelling space. Variations in resolution and scale are driven by i) purpose of modelling (or focus question), ii) the data availability and iii) the tradeoffs between predictive power and explanatory depth (Dawdy 2007). Resolution and scale determine how fire impacts, rain storms and hydrologic processes are represented in models. Within hillslopes at a plot scale it is the soil physical properties and the instantaneous rainfall intensity that determine the response (Figure 1). A very high spatial-temporal resolution is therefore required to represent internal parameters and processes (Moody and Ebel 2013). Models at this scale serve as tools for understanding processes, thus providing a stronger physical basis on which to develop larger-scale response models.

High spatial-temporal resolution is sometimes carried through from plot scale to larger scales because of the need to explicitly capture and represent the hydrologic effects of management interventions such as log barriers and mulching (e.g. models such as FERGI and ERMiT; Istanbulluoglu et al. 2003; Robichaud et al. 2007). High resolution in process representation at larger scales is made possible through distributed models that represent the transfer of water and sediment across model elements. With increasing scale, however, there is extra complexity due to spatial burn patterns (area burned at different severities), storm properties (size, durations and intensity) and the catchment configuration (slope, relief, channel configuration and variation in soil properties). This means increased data demands and increased uncertainty around the internal processes leading to a response.

In cases were data and process understanding is limited, or where high resolution is unnecessary, the alternative approach is to lump models and calibrate the catchment response directly with parameters describing the contributing area and storm properties as a whole (Cannon et al. 2010; Moody 2012). Lumped models reflect a priority towards prediction of catchment scale response, as opposed to understanding and representing the internal processes contributing to the catchment response (Dawdy 2007). The level of detail in the parameterisation is sufficient for predicting the fire impact and catchment scale responses which emerge implicitly as a result of internal (or intra-catchment) processes. The management questions in these types of models are typically concerned with engineering design, warning systems and evacuation procedures.

Sometimes the management question demand models which predict catchment processes over time scales that extend beyond the hydro-geomorphic processes underlying each individual event. This introduces uncertainty around how often and how strongly a catchment is affected by fire and rain storms. The modelling task therefore shifts from magnitude ('how much') to magnitude and frequency ('how much and how often') (Istanbulluoglu et al. 2004; Jones et al. 2011). At his temporal scale, the catchment processes are determined by rainfall regimes in combination with the fire regime and landscape characteristics such as tectonics, geology and vegetation (Swanson 1981). Factors such as climate change, fire management, and changing patterns of land-use will influence the disturbance regime, and hence the expected hydro-geomorphic processes operating in a catchment (Bradstock et al. 2009). For instance, the reduced rainfall and increased frequency of high temperatures due to climate change can lead to more days with extreme fire conditions, thus resulting in increased fire frequency in places such as southeast Australia (Hennessy et al. 2005), the Mediterranean (Mouillot et al. 2002) and parts of the western US (Westerling et al. 2006). At the same time, the widespread application of prescribed fire can increase in the area that is burned at any one time but reduce the average annual area burned by wildfire as a result, due to a trade-off between frequent, low-intensity fire and infrequent, high-intensity fire (Bradstock and Williams 2009). The process representation for these types of questions must be aligned to correspond with:

1. size and frequency of storm cells,
2. size and frequency of fires,
3. variation in earth surface properties and landforms.

These are characterised at scales that are much larger than the internal factors which drive catchment or hillslope processes within events (Figure 1).

Figure 1. Runoff and erosion from burned areas can be modelled at different spatial and temporal scales. The factors contributing to risk change depending on scale.

Bushfire CRC research supporting operational and strategic land management decisions

This presentation summarizes three years of Bushfire CRC research where intensive data collection was combined with modeling in order to develop operational and strategic management tools for evaluating water quality risk. Operational land managers are typically concerned with spatial variation in risk as a function of fire severity, recovery and catchment properties. In this context our research has aimed to identify the key landscape variables that can be used to quantify spatial variation in risk across large catchment where severity, soil properties and topography are often highly variable. At a strategic level, the land managers want to evaluate risk as a function of fire and rainfall regimes that change over time due to climate change and prescribed burning (i.e. risk is non-stationary). In this context our research has aimed to isolate the first-order effects of fire and rainfall regimes on the frequency of significant water quality impacts. This was achieved by modeling fire disturbance and storms as random processes (or patches) that overlap in space and time. In this type of model the risk responds directly to changes in fire and rainfall regimes, thus eliminating some of the uncertainties associated with the exact response of any particular hillslope or catchment.

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