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Welcome from Editors

It is our pleasure to bring to you the compiled papers from the Research Forum of the AFAC and Bushfire CRC Annual Conference, held in the Perth Exhibition and Convention Centre on the 28th of August 2012.

These papers were anonymously referred. We would like to express our gratitude to all the referees who agreed to take on this task diligently. We would also like to extend our gratitude to all those involved in the organising, and conducting of the Research Forum.

The range of papers spans many different disciplines, and really reflects the breadth of the work being undertaken, The Research Forum focuses on the delivery of research findings for emergency management personnel who need to use this knowledge for their daily work.

Not all papers presented are included in these proceedings as some authors opted to not supply full papers. However these proceedings cover the broad spectrum of work shared during this important event.

The full presentations from the Research Forum and the posters from the Bushfire CRC are available on the Bushfire CRC website www.bushfirecrc.com.

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The hydrogeomorphic sensitivity of forested water catchments to wildfire

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Abstract

Wildfires are a strong driver of change in many landscapes (e.g. south-eastern Australia, western USA, Canada, and the Mediterranean). Vegetation removal and changes to soil properties by wildfire result in altered surface hydrology and erosion rates. When wildfire occurs in a water catchment these changes can cause negative impacts on water quality, supply, and treatment. Therefore, being able to predict the potential response of a landscape to wildfire is important in informing resource management decisions.

This research project investigates erosional response of catchments following the 2009 fires in Victoria. This paper details methods and results of preliminary work undertaken on this project. Field surveys were used to quantify error associated with remote identification of channel initiation points (CIP) from aerial photographs. Movement in the CIP is one way of measuring erosional response and post-fire sensitivity. Error in estimating the CIP was found to depend on vegetation cover. The average distance errors for increasingly denser vegetated classes (0-24%, 25-49% and 50-100%) were 23.0m ± 5.5m, 11.1m ± 1.9m and 23.2m ± 4.8m.

A difference in the morphology (area and slope) between catchments exposed to high and low annual average radiation was found. Catchments exposed to higher radiation were found to have, on average, steeper slopes and smaller catchments (16.2° and 16150m^2) compared with lower radiation sites (9.6° and 39015m^2).

The wider research project will explore the link between dryness (radiation), morphology and post-fire response in future work. These future project outcomes and benefits to resource managers are discussed.

Introduction

Wildfire within a catchment can result in severe downstream impacts on soil and water resources, infrastructure, and lives (Nyman et al., 2011; Emelko et al., 2011). Altered hydrological flow and erosion rates occurring after wildfire (Shakesby and Doerr, 2006) pose a risk through large sediment inputs into water courses and flooding (Emelko et al., 2011). These hydrogeomorphic changes can vary depending on the landscape properties, burn severity and rainfall following the fire (Shakesby and Doerr, 2006).

A number of large wildfires over the last decade have prompted increased focus on wildfire and forest management, emerging from this, one area of concern is the effects of wildfire on water quality (Ellis et al., 2004; Parliment of Victoria, 2008; Victorian Bushfires Royal Commission, 2009).This issue is particularly pertinent in south-eastern Australia, where a large proportion of the water supply comes from forested catchments or surface water sources (Marsden and Pickering, 2006). Post-fire erosion events increase the amount of suspended sediment in streams and may hinder or prohibit water treatment (Smith et al., 2011a).

Potential hydrological and erosional response to wildfire is difficult to predict as not all landscapes react in the same way or to the same degree. A review of the literature reveals the hydrogeomorphic changes after wildfire in south-eastern Australian landscapes can be highly variable (Prosser and Williams, 1998; Lane et al., 2006; Sheridan et al., 2007; Smith and Dragovich, 2008; Smith et al., 2011a; Nyman et al., 2011). Thus, some landscapes appear more sensitive to wildfire.

There is a need to quantify the potential response of landscapes in order to provide information to resource managers. The risk of post-fire impacts is an important consideration for management in planning risk mitigation activities. It is also an important consideration for incident controllers. For example, resource coordinators need to weigh risks and benefits of protecting particular assets (like water supply catchments) when determining where to place resources during an operation. Thus, knowing the consequences of a particular catchment being burnt is very important.

Differences among landscape responses are dependent on the properties of the landscape that enable it to resist, adapt to, or bounce back from change (Phillips, 2009). Through investigating the cause of an observed wildfire response we can gain greater understanding of the relationship between landscape properties and hydrogeomorphic sensitivity. With this information the research can also be used to begin to predict the potential response of other landscapes.

This project aims to increase understanding of the relationship between landscape properties and post-fire hydrogeomorphic processes. The project will quantify post-fire erosional response (indicative of hydrogeomorphic processes) of two burnt areas and connect these data to catchment properties. Results will identify properties which cause the sensitivity of a given landscape to wildfire.

Measuring Sensitivity

Hydrogeomorphic sensitivity can be measured by investigating the degree of change in water flow and erosion processes following wildfire. These processes require a certain threshold of energy input to be reached before initiation. Due to changes in vegetation and soil after wildfire, erosion processes can be initiated with less rainfall energy input, thus, the thresholds are lowered by wildfire (Prosser and Williams, 1998). The observed magnitude of hydrogeomorphic response will therefore provide information on the lowering of process thresholds and sensitivity. Some visible signs of erosion include movement in the position of channels, scouring of channels and sediment deposits.

The initiation point of a channel at the head of a catchment shifts after wildfire as the threshold for sediment movement changes (Montgomery and Dietrich, 1992). Channel initiation points (CIP) occur where there is sufficient overland flow to cause erosion and channelization (Montgomery and Dietrich, 1992). CIP are dependent on the relationship between the catchment area above that point and the hill slope (Montgomery and Dietrich, 1994). The topographic threshold between channelled and unchannelled parts of the landscape marks a change in erosional processes from diffuse to more active sediment transport (Montgomery and Dietrich, 1994). Therefore, CIP may provide information about energy and process change after wildfire. After wildfire, the threshold for channelization is lowered causing channels to form higher in the catchment. The greater the change in the location of the initial point of a channel, the greater the shift in thresholds, and hence the greater the sensitivity.

In addition to fluvial erosion along channels, runoff generated post-fire debris flows may develop along drainage lines and scour a channel. The occurrence of debris flows in some Australian forests appears to be controlled by wildfire (Nyman et al., 2011). Debris flows can deliver a large amount of sediment to waterways and pose a serious threat to water quality (Smith et al., 2011b). The most commonly observed debris flows following wildfire are generated by runoff (Nyman et al., 2011) and develop due to a feedback process called ‘progressive sediment bulking’ (Cannon et al., 2003).

Research into the initiation and occurrence of post-fire debris flows in Australia is limited. By investigating the initiation point of channels which produce debris flows and channels which do not, features which make a particular area susceptible or sensitive to this process after wildfire can be determined. Channels in non-debris flow areas tend to begin lower down in the system due to lower energy (i.e. less overland flow) following wildfire. In systems that experience debris flows, it is hypothesised there should be some clear differences in terms of slope-area threshold for initiation.

Study site and methods

The sensitivity of post-fire hydrogeomorphic processes was investigated in the Kilmore-Murrindindi and Beechworth fire complexes (Figure 1). These areas in central and northeast Victoria were burnt in February 2009. The wildfire and subsequent rainstorms resulted in widespread erosion and debris flow activity in forested water catchments.

These wildfires burnt over 300 000 ha, providing study catchments with a wide variety of forest types, geologic background and soil types. The study area is part of the central uplands formation, located between 200 and 800 meters above sea level. Geology largely consists of sedimentary rocks (mudstone, sandstone and conglomerates) overlying a metamorphic gneisses and schist bedrock. (Jenkins, 1991).Vegetation is mixed eucalypt forest, mainly consisting of peppermint species (*E. dives*); and gums (*E. globulus, E. cypellocarpa, E. viminales*) with an understory of Acacia, shrubs, and bracken.

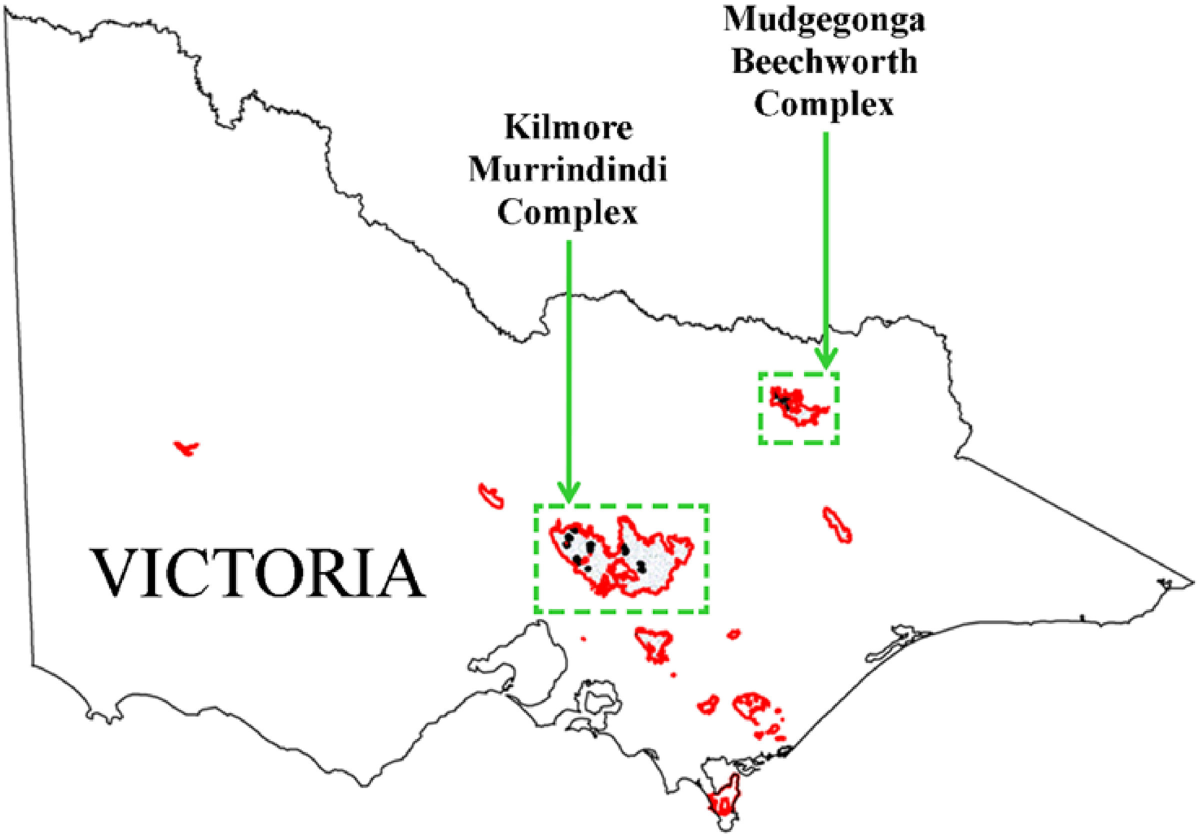

Figure 1: Approximate location and extent of Kilmore-Murrindindi and Beechworth fires in Victoria in February 2009.

Two aerial photos datasets will be used to investigate the magnitude of erosion following these wildfires. The first set, taken approximately 2 weeks after the fire, will be compared with photos taken approximately 10 months after the fire. As no rainfall occurred immediately post-fire, the first set shows a 'before' picture of the landscape (i.e. after fire, but before surface erosion processes). An 'after' picture is provided by the second set.

The photos will be used to identify movement in channel initiation points (CIP) and location of debris flow producing channels. This method of using aerial images for quantifying shifts in CIP after wildfire has not been previously reported in the literature.

Identifying channel initiation points

A set of rules were developed for identifying channel initiation points (CIP) in the aerial photographs (AP) and then tested for accuracy through a field investigation. A summary of the AP and field identification rules are given in Table 1. A selection of forested catchments within the burnt area, previously identified as having post-fire erosion by the Forest and Water Group of The University of Melbourne, were chosen for a preliminary study. All CIP within these areas were identified on AP, using the identification rules.

A field investigation was then carried out to quantify error associated with the AP identification method. CIP were identified in the field using the rules in Table 1. These rules were again based on channel literature, experience in the field and with the aerial photos. It was important that CIP could be identified on AP and in the field. Points in the field were recorded using a hand-held Sokkia GPS unit and transferred to ArcGIS 10 for further processing.

Aerial photo identification	**Field identification**
1:800 scale is used	The channel generally occurs at the lowest point between two hillslopes
The channel is a single, linear feature that extends more or less uninterrupted until its confluence with a creek or river	CIP is the starting point of an incision that has a minimum depth of 20 cm
Channels show lighter than their environment, except for shadows projected by the banks	The incision will clearly be an area where concentrated water flow occurs, with evidence of erosion
From the drainage divide, follow the channel until the first position it meets these criteria for at least 5 m	From the drainage divide, follow the channel until the first position it meets these criteria for at least 5 m
A debris deposition is not a CIP	
Upstream of a fork, each branch is treated as a separate feature that has to qualify the above criteria to identify as a channel	

Table 1: Summary of AP and field rules for identification of CIP.

ArcGIS analysis

CIP identified in the field and using AP were compared in ArcGIS 10. Sokkia Spectrum Survey software imported GPS data directly from the GPS unit. The AP consisted of three-band true colour 7 cm resolution TIFF-files.

ArcGIS tool Near (Spatial Analyst) was used to calculate the distance between the CIP identified in the AP and the CIP identified in the field. Contributing catchment areas above the CIP were delineated by hand, using the DEM (20m) contour lines and AP as a guide. The error between the AP and the field identified catchments was then calculated for each channel. Within the catchment areas mean slope, aspect, and average annual radiation was also calculated using the ArcGIS 10 tools (Slope (Spatial Analyst), Aspect (Spatial Analyst), Area Solar Radiation (Spatial Analyst) and Zonal Statistics (Spatial Analyst)).

The fractional vegetation cover around the CIP was estimated by placing a 40x15 m rectangle above and below the CIP identified on AP. Vegetation cover within the rectangle was estimated into three categories of cover; 0-24%, 25-49%, and 50-100%. An independent t-test was performed to test whether vegetation cover had a significant difference on the mean distance error.

For analysis of catchment morphology, catchments were grouped into North (315° to 45°) and South (135° to 225°) aspect groups. An independent t-test was used to determine if there was a significant difference in mean catchment slope and area between these groups.

Future methods

This preliminary study aimed to quantify the error associated with identifying the CIP from AP. The intent is to use this method to analyse a large number of catchments across the 2009 fire area as part of the wider research project. A second method for the identification of debris flow producing channels will also be developed and tested.

An automated GIS script will then be written to automatically identify catchment areas and associated properties. GIS layers containing information on vegetation, soil, geology, rainfall, and burn severity will provide variables which are important in post-fire erosion response. Collection of data through remote sensing is considerably less resource intensive and time consuming than other methods and presents a way to collect data efficiently.

This data will be used to create a logistic or multiple regression model (depending on the variables used) to predict erosion response following wildfire. Post-fire studies to date suggest that some components of a landscape are more sensitive to wildfire than others and may therefore contribute more to overall landscape response (Shakesby et al., 2007). This model will be used to test the contribution of various components of the landscape to the post-fire erosion response. This knowledge will contribute to our understanding of what causes different responses.

Results and discussion

Channel initiation point identification

The comparison of 56 CIPs identified on AP and in the field showed an average error of 20.1m in distance along the channel, a median error of 10.0m, and a standard deviation of 23.0m.

This error was found to differ according to the percentage of vegetation cover immediately surrounding the CIP. As shown in Figure 2, the average distance errors in meters for increasingly denser vegetated classes (0-24%, 25-49%, and 50-100%) are 23.0 ± 5.5 (n = 5), 11.1 ± 1.9 (n = 20), and 23.2 ± 4.8 (n = 31). Independent t-test results show that the differences between these classes are statistically significant (class 1 and 2 p = 0.0471, class 2 and 3 p = 0.0248).

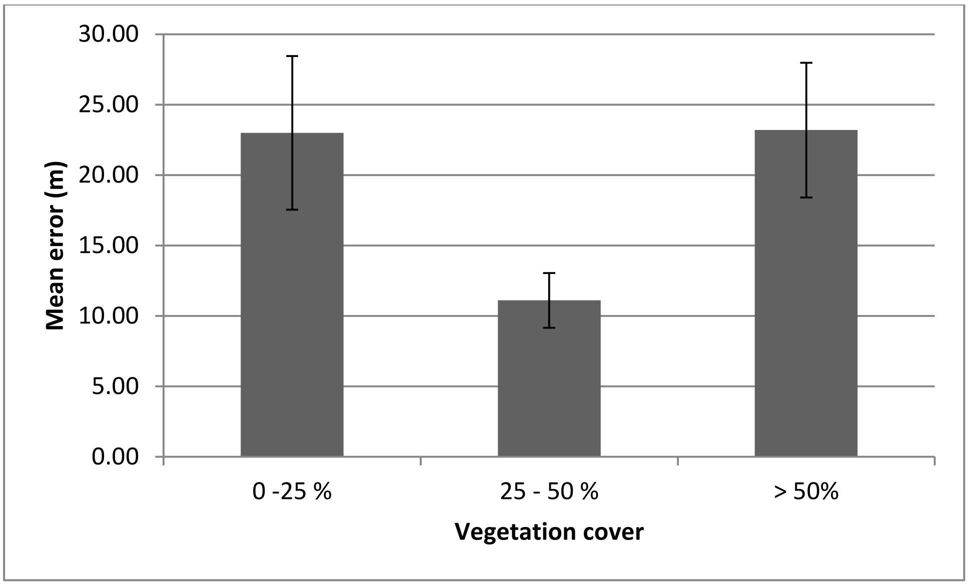

Figure 2: Average error associated with vegetation cover.

A difference in error between vegetation classes was expected as the method used was based on visual identification. Results indicate the lowest error in CIP identification occurs in the moderately vegetated channels. This suggests that some vegetation is helpful in identifying the channel incision. It appears a high amount of vegetation obscures the view of the channel, both with physical plants and shadows. A low amount of vegetation seems to allow observation of too greater detail and results in rills being mistaken for channels. A moderate amount of vegetation seems to cover the rills and the flatter area above the channel, making the CIP more obvious.

Part of the error could also be due to CIP movement in the time between the AP being taken (2009) and the field work (2012). However, any movement would likely be negligible. The AP were taken 10 months after the wildfire and as major winter storms occurred during this period it is likely all post-fire CIP movement occurred during this time. Prosser and Soufi (1998) found that channel movement stabilised after 1 year following clearing of eucalypt forest for conversion to pine plantation, and that channels were generally stable under forested conditions.

Morphology and dryness

Preliminary field investigations suggest that dryness, a measure of radiation and precipitation balance (Budyko, 1958), may be an important variable in predicting the sensitivity of landscapes to post –fire hydrogeomorphic changes. When contributing catchment size and slope are considered for north facing (higher radiation) and south facing (lower radiation) catchments a clear difference can be seen. Figure 3 illustrates this considerable difference in the morphology of headwaters with different radiation inputs or dryness. Drier channels with high radiation are characterised by smaller, steeper contributing catchments than wetter ones with low radiation. Table 2 gives a summary of average slope and catchment size by aspect, along with t-test results.

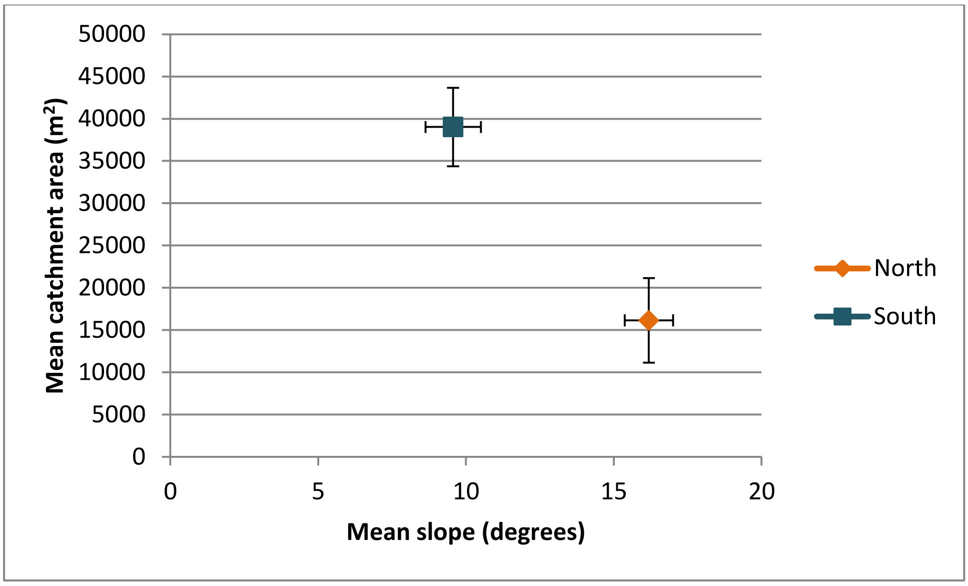

Figure 3: Catchment area and slope contributing to channels in high and low radiation catchments.

	Solar radiation (kWh/m^2)	Slope (degrees)	Area (m^2)
North	1608.49	16.18	16149.77
South	1441.20	9.56	39015.53
Significance (2 tailed)	*0.000*	*0.000*	*0.002*

Table 2: Average annual solar radiation (kWh/m^2), slope (degrees), catchment area (m^2) and t-test results (p values) for north and south aspect catchments. n=45.

Drier headwater catchments generally have poorly developed soils that are more likely to generate runoff and erosion, resulting in steeper slopes and channel heads that extend further upslope than sites with more structured and permeable soils (Wittenberg et al., 2007). If this research project can link a measure of dryness to post-fire hydrogeomorphic sensitivity, land and fire managers can use this to better predict potential post-fire risks associated with erosion.

Conclusion

The identification of potentially sensitive or high risk catchment areas is essential for decision making about resources and land management. This research project will investigate the relationship between landscape properties and post-fire response, to increase our knowledge of the causes of sensitivity. The project has progressed through the development stage and is now entering a phase of intensive data collection. Data collection, analysis, and modelling are expected to continue for the next 12-18 months.

Preliminary results suggest channel initiation points can be identified from aerial photography, with some margin of error. This error is lowest when vegetation cover is moderate (25-50%). An examination of catchment morphology (slope and size) reveals differences between catchments exposed to lower and higher long term radiation. These results suggest a measure of radiation-precipitation balance (dryness) could be important in determining catchment morphology and consequently post-fire sensitivity.

Findings of the project will be adapted into a format suitable for use by resource managers and other end users. Sensitivity prediction will provide important information to aid in three levels of decision making; 1) before a wildfire: Where will mitigation practices be best placed? Should we put resources into fire breaks or fuel reduction? 2) during a wildfire: What is the value of protecting a particular asset (e.g. water supply)? What is the real risk to an asset if the area associated with it is burnt? 3) after a wildfire: Is remediation (e.g. building log dams) needed? Where will it be most effective?

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