Wildfire, Catchment Health and Water Quality: a review of knowledge derived from research undertaken in Sydney’s Water Supply Catchments 2002-2007

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Abstract

This paper summarises knowledge gained from an extensive research program undertaken by the Sydney Catchment Authority and collaborators in relation to wildfire, catchment management and water quality. The research program was initiated in 2002 after extensive wildfires burnt through 225,000 hectares of forested water supply catchment managed by the Sydney Catchment Authority and NSW Department of Environment and Conservation. Key results from this research have resulted in a better understanding of short and long-term effects of wildfire on vegetation management, catchment health, erosion and water quality.

Introduction

On 25 December 2001 a series of lightning strikes initiated several wildfires in Sydney’s drinking water supply catchments managed by the Sydney Catchment Authority. A combination of drought, high vegetative fuel load, strong north-westerly winds, low humidity and remote location of those ignitions resulted in a rapid expansion of several wildfires, eventually burning over 225,000 hectares of forested catchment (Chafer et al. 2004).

The extent and severity of the vegetation destruction resulted in the SCA commencing a comprehensive scientific investigation into the impacts of wildfire on vegetation management, catchment health, erosion and water quality. This paper synthesises the results of that research that have been published to date in the scientific literature.

Review

All material that has been published, in press or nearing completion for submission as of the completion date of this report was collated, read and synthesised hereunder.

To date 4 book chapters, 15 scientific papers, 7 technical reports and 2 unpublished works have been written dealing with aspects of the 2001/02 wildfire event. Additional to that, but not included in this summary, results have been presented at 12 international conferences between 2003 and 2007. Major research findings are summarised below.

1. Vegetation

- Fuel loads can be adequately measured at the landscape level and assessed in terms of risk using remote sensing technologies, field work and modelling within a GIS (Chafer et al. 2004). Annual development of a fuel load map could assist in planning fuel/hazard reduction burns.
- Fire severity and intensity can be quantified across the landscape using a combination of remote sensing technologies, field work and modelling with a GIS (Chafer et al. 2004, Hammill & Bradstock 2006).
- The health of vegetation communities can be monitored through time using remote sensing technologies to assess recovery from disturbance events such as wildfire (Cassar & Chafer 2007). Preliminary analysis of this data shows that recovery of vegetation after fire is spatially variable and undoubtedly linked to the severity of the wildfire.
- Wildfire is spatially heterogenous, in both patchiness and severity (Chafer et al. 2004). This is important from an ecological perspective as unburnt forested areas provide temporary refugia[1] for fauna to survive the fire and then repopulate areas burnt by lower severity as they recover (DEC 2004).
- Long-term impacts of wildfire on upland swamps have been reviewed by Keith et al. (2006) and Tomkins & Humphreys (2006). They found that swamps across the plateau have developed at different times through the Holocene, with the oldest being dated to 12,800 years BP, the youngest 300 years BP. Sediment cores extracted from a numbers of swamps show that cut and fill erosion patterns have occurred through the Holocene, as have extensive wildfires. The near synchronous development of peat layers around 2,500 years BP suggests a major climate shift to a moister weather pattern at that time. They show that significant post-fire erosion has occurred in at least three study swamps after the 2001 wildfires event. In these study swamps some pre-fire erosion was evident, though whether this is linked to the impacts of underground mining or an extension of pre-mining erosion is not clear. No post-fire erosion occurred at those three study swamps after the similarly extreme 1968 wildfire, so a definitive explanation of what triggers major erosion events in upland peat swamps is still unclear.

2. Fauna

- NSW Department of Environment and Conservation are undertaking a long-term study on the impact of wildfire on the fauna within the SCA catchments on the Woronora plateaux. Comparisons are being made with fauna in long unburnt areas Preliminary finding demonstrate that the severely burnt areas were affected an order of magnitude greater than low to moderately burnt areas. Arboreal mammals, litter-dwelling reptiles and nectar-feeding birds were most affected, with little or no recovery in these species groups after three years of vegetation recovery (DEC 2004).
- It has been suggested that frequent fire in some habitats has led to the local extinction of some species. For example, Long-nosed Potoroo, Ground Parrot and Eastern Bristlebird have become locally extinct since 1900 and inappropriate fire regimes have been identified as the likely cause of those species' demise (DEC 2005).

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[1] Refugia – an area of bushland not affected by the wildfire that may provide temporary accommodation for displaced fauna

3. Soils

- The potential impact of wildfire on soils can be coarsely assessed using inference from remote sensing analyses and limited field work. Depth of heating penetration is related to fire severity and intensity (Shakesby et al. 2003).
- Removal of vegetation and surface litter coupled with higher fire severity reduces soil wettability and increase runoff (Wallbrink et al. 2005, Shakesby & Doerr 2006).
- In areas of extreme severity it was demonstrated that energy levels reached at least 70,000 kWm^{-1}, soil temperatures exceeded 350^{o}C at depths of 1.5–2 cm and large volumes of burnt topsoil were redistributed locally and to the valley footslopes (Shakesby et al. 2003, Chafer et al. 2004, Doerr et al. 2006). Further transport downstream was limited by extensive bioturbation[2] in the footslopes (Shakesby et al. 2003, 2006, 2007).
- Environmental radionuclides[3] and mineral magnetics were used to quantifiably measure and describe sediment and nutrient budgets and their redistribution in the Little and Nattai catchments (Humphreys et al. 2003, Wallbrink et al. 2005, Blake et al. 2004, 2005, 2006a,b, English et al. 2005, Tomkins et al. 2007a). These budgets show significant sediment redistribution from plateau top to footslope and downstream movement through the drainage network, culminating with deposition in the sediment fan at the month of the Nattai River where it enters Lake Burragorang (Wilkinson et al. 2007). Importantly, sediment mobilisation occurred in conjunction with burnt organic material and ash. Although redistribution of sediments was locally extensive (Tomkins et al. 2007a), post-fire bioturbation and litter dams reduced the potential distance transported by erosion and overland flow events, especially in areas affected by low to moderate fire severity (Shakesby et al. 2007).
- The high severity of wildfire through the Little River catchment resulted in large amounts of surface material being delivered to the drainage network and pulses of sediment distributed distally from the source during several moderate rainfall events. As vegetation cover re-established, the delivery of coarse and fine sediment and nutrients declined (Wilkinson et al. 2006).
- As expected, the delivery of sediment and nutrient loads through the drainage network is event driven. The larger the rainfall event, the greater the erosion and delivery of loads to the drainage network and transport downstream. The highest loads originated in areas that experienced the highest fire severities (Wilkinson et al. 2006).
- Following severe wildfire events, the post-fire recovery period of soil stability is 1-4 years (Doerr et al. 2006). During this phase of recovery, above average rainfall events will lead to erosion and subsequent downstream deposition of sediments and nutrients (Wilkinson et al. 2006).
- The complexity of soil hydrophobicity[4] in eucalypt forests in the SCA water supply catchments has been extensively reviewed by Doerr et al. (2006). They found that there is a naturally high repellence in most forest types. In unburnt areas, relatively deep litter layers absorb rainfall and this maintains soil stability during higher rainfall events reducing erosion. Low to moderate wildfire severity reduces the litter layer, providing conditions favouring higher overland flows once soil saturation is achieved, though erosion is still minimal. In areas of higher fire severity the surface repellence is

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[2] Bioturbation - The stirring or mixing of sediment or soil by organisms, especially by burrowing or boring; in this case mostly ants

[3] Radionuclides - A nuclide tracer in soil particles that exhibits radioactivity

[4] Hydrophobicity - the property of being water-repellent; tending to repel and not absorb water

broken down and becomes wettable, but a ubiquitous subsurface layer remains repellent at around 2 cm depth. Thus, once the wettable layer becomes over saturated, overland flow may occur and entrain soil material leading to enhanced erosion events. Such events appear to occur when local rainfall exceeds 40-60 mm day^{-1} (Tomkins et al. 2007b).

- Shakesby et al. (2007) provide a comprehensive review of post-fire effects on soil erosion in south-eastern Australia, with a focus on the Sydney basin.

4. Water Quality

- Long-term annual rainfall pattern through the catchments shows a constant declining trend over the past 15 years (Chafer 2007).
- Long-term annual water yield pattern through the catchments also shows a constant declining trend over the past 15 years (Chafer 2007). Post-fire annual discharge in Nattai catchment has not exceeded 50% of the pre-fire mean annual discharge (3-20 GL/yr vs mean 1965–2001 of 41 GL/yr) (Wilkinson et al. 2006).
- There is some suggestion that post-fire water yields increase then decline in the more extensively burnt subcatchments; however data analysis is insufficient at this time to statistically confirm that assessment. However it appears that water yield with SCA catchments is not impacted in the same significant way as in Victorian catchments, where water yield is depressed for several decades after major wildfire (Chafer 2007).
- Post-fire phosphorus concentrations (TP) were 7 times those of pre-fire loads in the Little River catchment, while post-fire nitrogen concentrations (TN) were only 1.6 times pre-fire concentration maxima. These elevated nutrient levels have returned to near pre-fire levels after five years (Wilkinson et al. 2006).
- Post-fire total suspended solids (TSS) were up to 43 times those of pre-fire concentrations during major discharge events, but negligible at low flows (Wilkinson et al. 2006).
- Post-fire sedimentation rates were one to two orders of magnitude above pre-fire levels and are now returning towards equilibrium as vegetation cover is re-established (Wilkinson et al. 2006). It is also noted that the extreme severity of the wildfire in Little River catchment increased the proportion of surface erosion source from 10% pre-fire to 84% post-fire sediments. This surface erosion material also contained higher proportions of nutrients as expected (Wilkinson et al. 2006).
- The significance of post-fire water quality degradation was reduced owing to below-average rainfall in the years following the 2001 wildfire event (Wilkinson et al. 2006, 2007).

5. Catchment Management

- Recommendations from research to date call for an increase in annual fuel reduction through the water supply catchments. It is noted that a major limiting factor is available suitable days for fire suppression activity (DEC 2005, Wilkinson et al. 2006).
- It is demonstrated that areas where fire severity was high to extreme subsequently exhibit the greatest susceptibility to erosion, take the longest time to recover and have the greatest impact on fauna (DEC 2005, Wilkinson et al. 2006. Cassar & Chafer 2007). The implication here is that suppressing wildfire before it can become a major event is a preferred option.
- There appears to be some potential long-term risk of water quality degradation caused by fire-induced landslides adjacent to the reservoirs (Tomkins et al. 2004).

- A map of the spatial distribution of fire severity is a vital tool for monitoring the impact of fire on biodiversity (DEC 2004) and erosion risk (Shakesby et al. 2003, 2007).
- It is well known that major wildfire events over the past 60 years correlate with El Niño Southern Oscillation episodes (Kiem et al. 2006, Tomkins et al. 2007b). However developing a better understanding of climate cycles is also important in terms of better managing hazard reduction burns and wildfire patterns (DEC 2005).
- Kiem et al. (2006) suggest that the most likely period for both wildfire and flood events is the September to April window. They also suggest that a more precise risk assessment can be made several months prior to an event occurring based on El Niño (dry) and La Niña (wet) phase development modelling.

Summary

- Fire severity can be quantified using pre- and post-fire satellite image interpretation. This can be used to infer impact on vegetation communities and soils and identify potential areas of increased erosion / sedimentation.
- Post-fire recovery of vegetation can be quantified using satellite image interpretation. This could be useful for post-fire monitoring of vegetation health and a proxy for reducing erosion risk.
- Vegetation in areas impacted by low to moderate fire severity can recover to pre-fire condition within 3–4 years. In areas impacted by high to extreme severity, vegetation recovery may take 5–10 years.
- Widespread severe wildfires have a long-term negative impact on fauna populations.
- It is unambiguously clear that the most important areas of concern after wildfire are those affected by a fire severity greater than high. In these areas, surface temperatures reach or exceed 350°C, destroying surface repellency, changing soil chemistry and creating a wettable layer that can absorb “normal” rainfall events but becomes mobilised when rainfall exceeds 40–60 mm day^{-1}. Thus erosion potential is increased and post-fire redistribution of sediments can be locally extensive in rainfall events >60 mm/day.
- As most large (severe) wildfires appear to occur during El Niño periods (below average rainfall), the occurrence of extreme post-fire rainfall events is reduced. Nevertheless, localised thunderstorms can initiate short-term high intensity rainstorms that do initiate erosion events. During such events large post-fire deposits of ash, debris and burnt soil can be mobilised. It may take several high rainfall events over several years to push ash/sediment plumes from source to sink at the stream's entrance to a given water storage reservoir.
- During high post-fire rain events, downslope erosion is increased; however, riparian vegetation, litter dams and bioturbation of the soil surface can significantly reduce sediment/nutrient delivery to the drainage network channels.
- There is some evidence that post-fire water yield is initially increased in the years immediately post-wildfire, then becomes depressed for a couple of years, before returning to prefire yields. This result is similar to results in water-supply catchments in the ACT following the 2003 wildfire in that Territory, but significantly different from Victorian research. Further research is required to assess this preliminary finding.

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