Fire in the Landscape

Annual Report July 2011-June 2012

bushfire CRC

THE UNIVERSITY OF SYDNEY

THE UNIVERSITY OF MELBOURNE

Executive summary

The four research projects in the Fire in the Landscape program sit within the research stream called 'Managing the Threat'. Researchers from the University of Melbourne and the University of Sydney are investigating the nature of above- and belowground carbon pools and how they change after fire and the effect of fire on water quality and quantity, through a variety of field- and laboratory-based studies. Work is well underway for all projects with the 2011-2012 period including the establishment of field sites, collection of data during field campaigns and development of working models for water and carbon balances. Our results have been described in oral and poster presentations at national and international conferences and publication in peer-reviewed journals. More importantly, interaction with End User agencies has been through production of FireNotes and organisation of laboratory and field visits to explain how sites and experiments have been set up and what data has been produced and the capacity of analytical equipment being used.

Project 1 (*Environmental impacts of prescribed and wildfire – emissions management*) is quantifying the effects of fuel reduction burning on carbon balances in forests and modelling emissions to the atmosphere. Eleven field sites have been established in dry sclerophyll forests in Victoria, Tasmania and Queensland and most have been sampled before and after prescribed burning. Additional sites are planned for New South Wales and South Australia. Sampling protocols have been established and documented and the sampling design has been shown to be sufficient to detect differences in carbon pools pre- and post fire. At all sites, the greatest proportion of carbon is held aboveground in tree biomass but the total amount is dependent on site location.

Project 2 (*Greenhouse gas emission from fire and their environmental effects*) is developing our knowledge of greenhouse gas emissions from fires and is investigating their impacts on the environment. Over the past 12 months, three laboratory-based experiments have been completed. For these experiments, data relating to gaseous emissions and heat release during combustion of fuel (eucalypt leaves) at different moisture content and fuels of different types has been assembled. Two of these experiments have been developed into manuscripts for publication. Data from the third experiment is being analysed and material for a fourth experiment has been collected. From the research completed to date, emissions of CO_2 and CO are dependant of the condition of the fuel but not necessarily the type of fuel.

Project 3 (*Quantifying risk of water quality impacts from burned areas*) is quantifying the frequency and magnitude of post-fire debris flows to help understand the risk to water quality. Slope and ecological vegetation class (EVC) have been found to be important predictors of debris flow occurrence but there are many interactive processes occurring. A systematic investigation of the relationship between fire severity, post-fire runoff and erosion response in dry forests for different soil types is also being undertaken. From this, a water quality risk model is being developed and tested to extrapolate process-based (site-specific) responses to landscape-scale catchments.

Project 4 (*Fires and hydrology of south-eastern Australian mixed-species forests*) had a starting point of refining an existing model (the soil-plant-air model) to quantify overstorey

tree water-use in regenerating mixed-species forests. Instead, a new process-based model for tree water-use based on resistance to water loss imposed by leaves has been developed as part of this project. The data collected from field sites is now being used in this model to predict the amount of water used by resprouting mixed-species forests after fire. Once the model has been calibrated, it can be used in whole-of-catchment models. Immediately after crown-removing fires in 2009, the water-use of burnt trees changed dramatically. Since then, as the canopy structure slowly changes tree water-use also changes. This project has documented that the regenerating canopy has developed from many small branches distributed evenly along the stem to fewer and larger branches which will eventually form a full canopy.

All projects have made excellent progress during Year 2 with collection of considerable amounts of data from the field and the laboratory. Outputs detailing the research have been developed and End Users have been engaged in a variety of ways. Continuing postgraduate students have made substantial progress and two new students have begun their research projects. There has been exceptional Lead End User involvement and collaboration amongst the researchers is ongoing. The next 12 months of research will see the completion or near completion of most of the projects and continued outputs and End User engagement.

Impact Statement from Lead End User

There have been a number of highlights from the four projects in the Fire in the Landscape research theme during the last 12 months. Not only has good progress been made in research, the new knowledge and understanding that was developed has been transferred to agencies in a variety of ways. Field and laboratory site visits conducted this year were particularly useful in delivering information to End Users and recognises that people take up information in different ways.

A demonstration of the analytical capabilities of the University of Sydney facilities in Cobbitty, NSW in February 2012 introduced a number of people who didn't fully understand the project to what is being done and what could potentially be done. This exercise led to a new collaboration within my organisation and a paper describing the work done was presented at the annual AFAC and Bushfire CRC conference in August this year. The site visit was teamed up with a whole of group meeting and included presentations from PhD students. This component was particularly useful for Tim McGuffog and myself as we are both named End Users for student projects and we were provided with an update on their progress.

I was unable to attend the joint University of Melbourne and University of Sydney excursion to field sites related to both of the Water projects. I did however get good feedback from those who did attend. The field demonstration was described as being hands on and provided an important bridge for the gap between research and operational delivery. Researchers had a chance to demonstrate the scope of the research they have been doing and End Users could gain an appreciation of the hard work required to collect data.

I presented an overview of the research being done in the Fire in the Landscape project at the SCION Rural Fire Research Workshop in June 2012. This workshop marked the 20-year anniversary of fire research in New Zealand and had an audience of about 100 people including land managers and researchers. The audience was very keen to learn about the research being done in the Bushfire CRC and the various paths that have been taken. My presentation identified some of the critical points of the relevance of carbon and water research to the fire industry. All of the feedback that I received was very positive and End Users are looking forward to practical application into the future.

I also presented a research update to the Forest Fire Management Group (FFMG) and Rural Land Managers (RLM) in June 2012. I believe that this is the very best way to get research information to practitioners. The audience is comprised exclusively of land managers so the information presented is pitched at a practical level. Group members include lead operational people such as Andrew Stark for the AIIMS community and Liam Fogarty from the Victorian Department of sustainability and Environment, both of whom are Lead End Users for other Bushfire CRC projects. I have provided updates for Fire in the Landscape projects to these two groups on several occasions and the members can now see that real progress is being made. With each presentation I aim to reinforce project ideas and their effectiveness for land managers.

Another opportunity for research updates is the Research Advisory Forum (RAF). Here the audience is comprised of a wider range of End Users, research providers and researchers than FFMG and RLM. During the last 12 months, RAFs were held in Canberra in October 2011 and Hobart in May 2012. The two projects based at the University of Sydney (Projects 2 and 4) were presented in Canberra and the two based at the University of Melbourne (Projects 1 and 3) were presented in Hobart. I gave introductions to all four projects and fielded questions where appropriate. The feedback from End Users in the audience at the RAF in Canberra, and comments provided later via the Bushfire CRC, was very useful, particularly for the Carbon project (Project 2). This interaction resulted in an amendment being made to the testing regime for fuel moisture content and a request for measurement of emissions from grasses. The audience of the RAF in Hobart was skewed towards social sciences and the presentations made were not as well received as they have been elsewhere. This leads to the question of how to effectively present the knowledge gained in these projects to variable audiences and to management.

To maintain the success of the Fire in the Landscape project over next 12 months it is critical that our contact with End Users continues. A communication plan has been discussed and will include the production of Fire Notes and peer-reviewed journal articles – possibly even use of short videos posted on U-tube. It will also continue to make use of oral presentations tailored for a range of audiences. It is important that we get the message out to End Users in as many ways as we can. In addition, we need to produce some outputs from the research being done that can be used by End Users. The research does not need to be complete; it can be presented as an interim guide or model. The most important feature will be that it will demonstrate that water- and carbon-related research is being taken up and used by land management agencies.

Impact Statement from End User Agencies

One of the greatest issues for the Department is integrating multiple values into analysis of fire management. The Fire in the Landscape program is delivering real knowledge in determining the influence fire has on carbon storage and flux. Knowledge that is able to be integrated, at the landscape scale, into better understanding a range of ecosystem services and informing the Department of risks and opportunities of the emerging carbon market. The knowledge generated in collaboration with the Fire in the Landscape team is positioning the Department well for changes in the way the National Greenhouse Gas Accounts are calculated. The research is invaluable and directly informs policy and strategic thinking.

Jaymie Norris, Manager, Carbon Science (Environmental Policy and Climate Change)
Department of Sustainability and Environment

Water quality and yield are paramount considerations for water authorities. Projects 3 and 4 are essential research projects that are yielding valuable insights into the effects of fire on these paramount considerations. An understanding of the risk to water quality from post fire debris flows, the vulnerability of catchments and the frequency and magnitude of such events is a precursor to being able to undertake any mitigation action. This kind of knowledge will guide risk mitigation actions so that they can be targeted and prioritised to both reduce risk levels and maximise the cost benefits of carrying out any works.

Understanding the effects of fire on water yield is critical to strategic water management. Modelling of water yield in mixed species forest has probably been overlooked to date in favour of work in wet forests. A better understanding of the fire and water yield interrelationship in these mixed forests will give strategic water planners a greater certainty in their modelling of water networks and better outcomes in balancing water supplies to customers.

Craige Brown, Team Leader, Water Supply Catchments and Bushfire, Civil and Strategic Asset Management, Melbourne Water

<u>Project 1</u>: Environmental impacts of prescribed and wildfire – emissions management

Research institute: *Department of Forest and Ecosystem Science, University of Melbourne*

Researchers: *Chris Weston and Luba Volkova*

Collaborators and affiliations: *Department of Sustainability and Environment, Victoria; Tasmanian Parks and Wildlife Service; Queensland Parks and Wildlife Service*

Postgraduate student: *Hari Shrestha*

Project outline

This project aims to measure the impact of fuel reduction burning on forest carbon stocks and release of greenhouse gases to the atmosphere. Study sites have been established in southern temperate Australian forests. The main carbon pools, including aboveground biomass, dead wood, litter and organic carbon in soil, have been measured before and after prescribed burning. Based on biomass differences, loss of carbon and greenhouse gases emission can be calculated. Estimated emissions have been correlated with fireline intensity to establish relationship between these two parameters. Results of this project will help forest managers and policy makers to understand which of the carbon pools are most affected by fire and how fire intensity affects emissions. This can provide opportunities for emission abatement through altering existing forest management techniques.

State of knowledge

Regular fuel reduction burning (hereafter referred to as planned fires) over large areas is essential to reduce the risk of large-scale bushfires in forests near population centres and important assets such as forested water catchments and commercial forests. Fire both oxidises organically-bound carbon to release CO_2 (and an array of other products) and modifies forest organic matter to produce a wide range of charred and partially oxidised materials that are generally more long-lived than non-fire modified fuels and organic matter (Andreae and Merlet, 2001). The accession of burnt organic matter to the soil surface and the modification of soil organic matter by fire are likely to have profound impacts on both total litter and soil carbon and its turnover rate – and thus on CO_2 release to the atmosphere. Fire also temporarily reduces carbon inputs to forests by killing the photosynthetic tissues of understorey trees, shrubs and grasses and, in some cases, the canopy of the overstorey trees (Adams and Attiwill, 2011).

Currently there is scant information in the literature to calculate impacts of planned fires on net CO_2 release from forests to the atmosphere during burning or in the years and decades afterwards, nor is there a good basis for comparing CO_2 emissions from repeated planned fires with long-interval mega-fires (Attiwill and Adams, 2008).

Progress made in 12 months

Site establishment and data collection
During Year 2 of the project we have (1) documented the methodology used for measuring post-fire carbon losses from forests, (2) produced drafts of a discussion paper on carbon losses from forests, and (3) organised a field inspection and briefing session for End Users from Tasmania. In addition, we have (4) established a number of new sites in Tasmania, Victoria and Queensland, and (5) agreed with Forests NSW on the establishment of study sites and a timeframe for measurements in forests near Eden, NSW.

To date, 11 study sites have been established in long unburnt dry sclerophyll forest in south-eastern Australia from Tasmania to Queensland (Fig. 1.1). Each study site consists of three circular plots, 0.16 ha in area. For measurements of carbon pools, the forest has been 'divided' into components:

- Aboveground alive (live overstorey trees, understorey vegetation, elevated fuels)
- Aboveground dead (stumps, dead standing trees, coarse woody debris)
- Litter (dead leaves, bark, twigs and branches on the forest floor with diameter <2.5 cm)
- Soil (soil organic matter, soil 0-30 cm)

Standard inventory techniques were used to estimate biomass in each of the carbon pools before and immediately after a planned fire. Diameter and height were measured for overstorey trees. Litter and elevated fuels were collected from four locations within each plot and analysed for total carbon and nitrogen. Fire characteristics (i.e. flame height, rate of spread) and burning efficiency of fuels were measured *in situ* during planned burns. Based on biomass changes after prescribed fire, emission of CO_2 and non-CO_2 gases (e.g. methane, nitrous oxide) were estimated follow National Guidelines (NGGIC, 2008).

Figure 1.1. Yellow pins represents the location of study sites. Each study site is composed of three plots, 0.16 ha in area.

Results to date

Our preliminary results indicate that overstorey trees represent the major carbon pool in the forests studied (Fig. 1.2). Location of the study site significantly affected overstorey biomass; trees in sites in the Otways and Gippsland, Victoria were bigger in diameter at breast height than trees in sites located in Queensland and Tasmania. Tree density (number of trees per ha) was also higher in Victorian forests (Table 1.1) than in forests in Tasmania and Queensland. Biomass of understorey trees did not differ among locations (Fig. 1.2). Analysis of the data collected revealed that nine plots per location provide strong sample power (i.e. >90% probability) for detect 25 to 50% change in overstorey and understorey biomass and litter loads after planned fire. However, great variability in the amount of coarse woody debris (CWD) within plots and among sites requires greater number of plots (up to 28) to detect at least 50% change in CWD after planned fire.

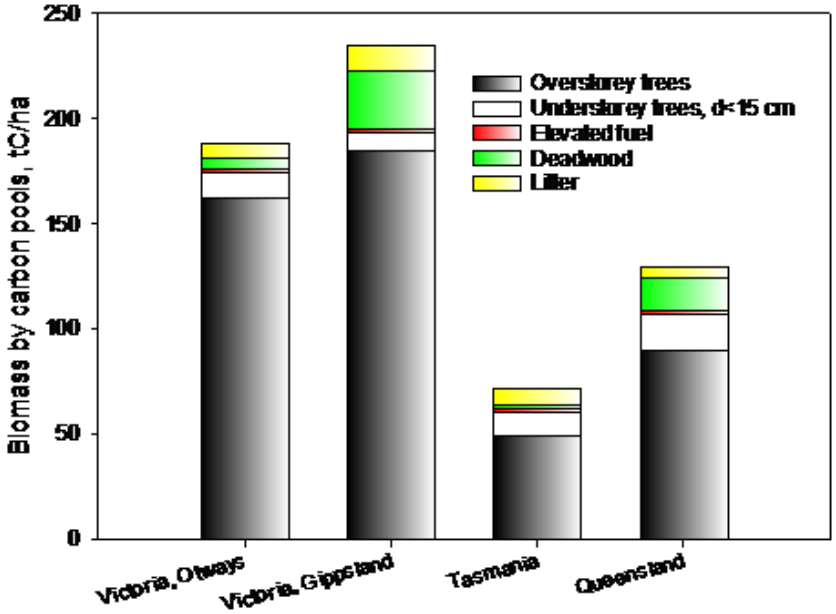

Figure 1.2. Forest biomass by carbon pool at four study locations. The largest pool of aboveground carbon is the overstorey trees.

An exceptionally wet summer and autumn in 2012 prevented land management agencies to burn all of the plots that were established, and only 13 plots were burnt. Despite this, initial results show that planned fire affects litter loads the most with losses greater than 60%. Strong correlations were found between estimated emissions, both for CO_2 and non-CO_2 gases and fireline intensity. Small sample sizes prevent us from drawing conclusions at present and we hope to collect more data during spring burns in 2013.

Proposed activities for the next 12 months

During the next 12 months we plan to finalise data collection in unburnt plots established in study sites in Gippsland, Tasmania and Queensland and to establish more sites in NSW and SA. The data collected will be used to develop relationships among measured parameters (i.e. tree height and diameter *versus* biomass, overstorey biomass *versus* understorey biomass, emission *versus* fire intensity). This information will help land management agencies to estimate the amount of carbon in their managed forests and predict carbon

losses and emissions for different burn scenarios. In addition, in collaboration with Dr Mick Meyer from CSIRO Marine Division, we plan to collect smoke samples *in situ* from different fuels during planned burns (i.e. litter, CWD) to better estimate CO_2, methane and nitrous oxide concentration in smoke at different fire intensities and fuel moistures. This knowledge will help us to improve emission estimates for forests in southern Australia.

Figure 1.3. We acknowledge in-kind support from land management agencies.

Postgraduate student project

Hari Shrestha – Effects of fire on soil carbon fractions in forest soils
Prescribed fire or planned burning has been practiced on Victorian public land to reduce the risk of wildfires and for biodiversity and silvicultural purposes for last 50 years. The area of prescribed fire has increased in recent years. However, present knowledge about the ecological impacts of repeated prescribed fire, especially on soil carbon and cycling of other nutrients is relatively poor and needs to be better understood for the sustainable management of Victorian native forests. This study aims to investigate the effects of repeated low intensity prescribed fire on the formation and distribution of various fractions of soil organic matter (SOM) such as particulates, humic and charcoal. The availability of soil nitrogen and phosphorus can be affected by changes in the composition SOM fractions and will also be investigated. The study will improve our knowledge about fire effects on soil carbon dynamics in Australian forest ecosystems. The results will contribute to the scientific basis underpinning planned burning in sustainably managing Victorian native forests.

Hari Shrestha commenced working on this project in February 2011. He successfully completed his 12-month probationary period in February 2012 (a condition of continued enrolment at the University of Melbourne) by giving a seminar and producing a report

including a literature summary. Hari has had training for Mid-Infra Red Spectroscopy, Pyrolysis-Gas Chromatography-Mass Spectroscopy and statistics and he has completed his autumn sampling in the Fire Effects Research Area in the Wombat Forest, Victoria. Soil samples have been processed and analysed for a range of variables including total C, N and extractable P and will be used for more complex analyses. Hari's research proposal was supported by Neil Cooper from ACT Parks and Conservation Service. He is partially funded by a University of Melbourne scholarship and a top-up Bushfire CRC scholarship.

Publications, conferences and presentations

Conferences and presentations

Volkova L, Weston C, poster presentation. Impact of fuel reduction burning on carbon balance in *Eucalyptus* forests of south-eastern Australia, Mega Fire Reality Conference, Tallahassee, USA, November 2011.

Volkova L, Weston C, project presentation. Environmental impacts of prescribed and wildfire – emissions management. Bushfire CRC Research Advisory Forum, Hobart, May 2012.

References

Adams MA, Attiwill PM (2011) *Burning Issues: Sustainability and Management of Australia's Southern Forests*. CSIRO Publishing, Collingwood, Victoria, Australia, 144 p.

Andreae MO, Merlet P (2001) Emission of trace gases and aerosols from biomass burning. *Global Biogeochemical Cycles* 15, 955-966.

Attiwill PM, Adams MA (2008) Harnessing forest ecological sciences in the service of stewardship and sustainability: a perspective from 'down-under'. *Forest Ecology and Management* 256, 1636-1645.

National Greenhouse Gas Inventory Committee (2008) *Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2006*. Department of Climate Change, Commonwealth of Australia, Canberra.

Table 1.1. General information for study sites and forest characteristics.

Site location	Agency	Number of plots	Dominant species	Overstorey trees (diameter ≥20 cm)			Time since fire (years)	Average annual rainfall (mm)
				Diameter at breast height (cm)	Height (m)	Density (trees ha^{-1})		
Coles Bay, St Helens, TAS	Tas Parks and Wildlife Service	8 (4 burnt)	*Eucalyptus amygdalina* *E. obliqua*	34	10	175	>22	>600
Gippsland, VIC	Vic Department of Sustainability and Environment	9 (burns postponed)	*E. sieberi* *E. obliqua*	47	26	227	13-19	>900
Otways, VIC	Vic Department of Sustainability and Environment	9 (all burnt)	*E. obliqua* *E. radiata*	44	24	234	26-28	>1000
Gympie, QLD	Qld Parks and Wildlife Service	6 (planned for burning in July 12)	*E. acmenoides* *Corymbia maculata*	36	25	154	15-20	>1100

<u>Project 2</u>: Greenhouse gas emission from fire and their environmental effects

Research institute: *Faculty of Agriculture and Environment, University of Sydney*

Researchers: *Tina Bell and Malcolm Possell*

Postgraduate students: *Vicky Aerts, Val Densmore and Felipe Aires*

Project outline

Fire directly impacts the carbon balance of forests through emissions of CO_2, volatile organic compounds and other greenhouse gases formed during combustion of vegetation and litter. We currently lack all but the most rudimentary knowledge of the direct effects of fuel reduction fires or their secondary effects on ecosystem carbon balances. Consequently, we have very little empirical data to model carbon losses during fire.

Our research aims to further develop our knowledge of greenhouse gas emissions from fuel reduction fires and their potential impacts on the carbon balance of forested ecosystems. We will use this knowledge to provide guidelines and advice as to how best to manage these fires to minimise their ecological and economic impacts. This is an important area to investigate as the 'carbon' costs of fuel reduction fires are yet to be determined and will likely have considerable economic value in future.

State of knowledge

Vegetation fires inevitably lead to the production of smoke. There are many well documented effects of fires on ecosystems (e.g. Harden *et al*., 2000) including atmospheric chemistry – through the production of trace gases (a gas that makes up less than 1% by volume of the atmosphere of the Earth) and aerosols (a suspension of fine solid particles or liquid droplets in a gas; Radke *et al*., 1978; Crutzen *et al*., 1979). These trace gases and aerosols have enormous consequences for regional air quality, pollution and climate (Crutzen and Andreae, 1990; Langmann *et al*., 2009). Trace gases produced during fire include a range of chemicals that are both non-toxic and harmful to humans including carbon dioxide, carbon monoxide, methane, ozone and volatile organic compounds (VOCs). Typical aerosols include particulate matter and water vapour and this group of emissions are responsible for the physical appearance or plume of smoke. The majority of the components of smoke are harmful to humans either during the fire (e.g. inhalation by firefighters) or in the smoke plume that has an effect away from the immediate fire area (e.g. reduced visibility, triggers for asthma).

A number of peer-reviewed studies have published emission factors (amounts of compound released per unit mass of fuel) for different fuel types and ecosystems. The majority of these studies have been undertaken in the United States or have been done in vegetation types not found in Australia, such as those found in the Mediterranean Basin. There is only a limited number of studies investigating fire emissions from vegetation in Australia, specifically, grasslands found in savannas (Hurst *et al*., 1994a; b; Paton-Walsh *et al*., 2010)

and combustion of peat (Blake *et al*., 2009). Comparisons among these studies are difficult as the emission measurements are not all for the same range of gases (e.g. Shirai *et al*., 2003). Such limited data restricts our ability to model smoke composition during fire events and does not allow assessment of ecological and health consequences that may follow.

Improvements in the certainty of emission estimates can come from either field studies of different ecosystems or from laboratory studies where burning conditions can be strictly controlled. The ability to control conditions in a laboratory environment will allow for a rapid increase in data of emission factors from different fuel types and assessment of how different factors, such as moisture content, affect flammability and smoke composition. This project aims to improve our understanding of the relationships among fuel type and condition and burning conditions on emissions of greenhouse gases.

Progress made in 12 months

Strong progress has been made during the second year of this project. Three experiments were planned during the life of this project and all three are progressing. Experiment 1 was modified (see below) and a fourth experiment was developed according to feedback from End Users. A very rewarding event was the demonstration of the analytical equipment associated with the project to a number of researchers and End Users (Fig. 2.1). The capacity of the Mass-Loss Calorimeter (MLC), the Proton Transfer Ratio-Mass Spectrometer (PTR-MS), the Gas Chromatography-Mass Spectrometer (GC-MS) and Pyrolysis unit were described by Malcolm Possell and Tony Winters.

Figure 2.1. The capacity of the analytical equipment used in the project is demonstrated to End Users and researchers.

Experiment 1 – Effect of fuel moisture content on greenhouse gas emissions
This experiment has been completed and a manuscript detailing the research has been accepted for publication in the *International Journal of Wildland Fire* (Possell and Bell, 2012). Leaves from three species of *Eucalyptus* were combusted in the MLC to characterise the effect of fuel moisture on energy release and combustion products (see Fig. 2.2 for examples). Increasing moisture content reduced peak heat release and the effective heat of

combustion (used in fireline intensity calculations) in a negative exponential pattern while simultaneously increasing time-to-ignition. Estimates of the probability of ignition, based upon time-to-ignition data, indicated that the critical fuel moisture content for a 50% probability of ignition ranged from 81 to 89% on a dry-weight basis. CO_2 concentrations during combustion declined exponentially with increasing fuel moisture while CO concentrations increased exponentially. However, CO_2 mixing ratios were always greater by at least one order of magnitude. Additional data for leaves combusted at alternative fuel moisture content was generated after feedback from End Users at the Research Advisory Forum in Canberra.

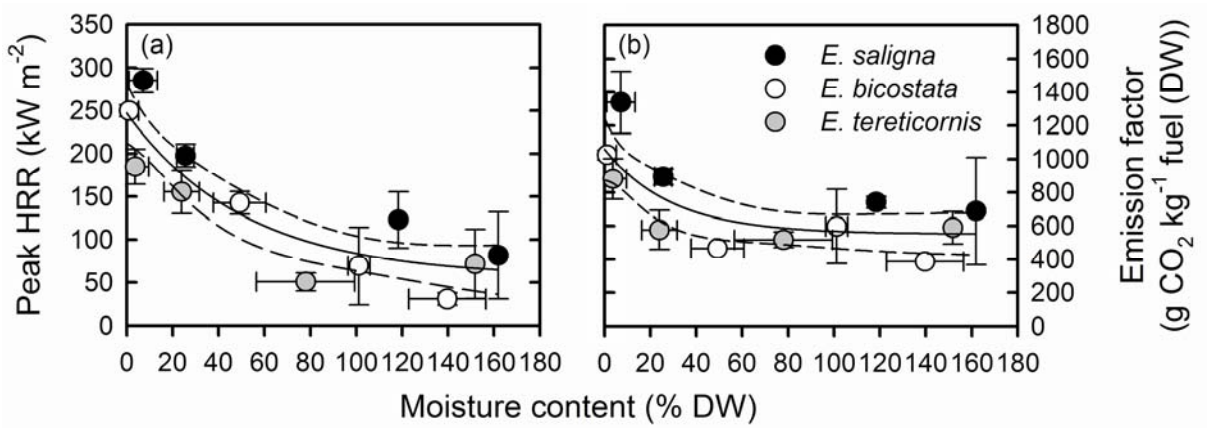

Figure 2.2. The effect of fuel moisture content on (a) peak heat release rate and (b) the emission factors for CO_2 for three *Eucalyptus* species. In all panels values represent means ± 1 SD (n = 3). The solid line in each panel is a non-linear regression and the dashed lines represent the 95% confidence limits.

Experiment 2 – Effect of moisture availability on flammability and emissions
In this experiment we tested if plant water availability affected leaf water content and the resulting fuel moisture of live leaves and therefore greenhouse gas emissions in smoke. This experiment 'scaled-up' from leaves as single fuel components (tested in Experiment 1) to whole-plant water availability using plants grown under glasshouse conditions with different watering regimes. The same species used in Experiment 1 were grown under three different watering regimes for 12 weeks to assess how different levels of water availability affects flammability and emissions. At the time of harvest, all species had different soil moisture content but this difference was not reflected in the moisture content of the leaves. The samples have been combusted for this experiment and analysis of the for data energy release and combustion products is underway. A manuscript or an internal Bushfire CRC report will be produced to describe the experiment depending on the strength of the results.

Experiment 3 – Field validation of moisture availability on flammability
The sample material for the third planned experiment has been collected and is awaiting analysis. Four biomass fractions (organic matter <2 mm diameter, leaf litter >2 mm, dead mixed leaves and live mixed leaves) will be combusted in the MLC and the energy release and combustion products measured. In addition, green leaves from two species representing the understorey vegetation, *Eucalyptus muelleriana* and *Acacia dealbata*, will

be combusted. The sample material will be combusted dry and at approximately 20% fuel moisture content to represent conditions most likely found under bushfire and prescribed burn conditions. It is envisioned that by using these biomass fractions, the results will be useful in estimating carbon loss under high intensity (bushfire) and low intensity (prescribed burning) fire situations as each situation will burn different amounts and types of biomass. This experiment will also provide data from naturally grown material that can be used to assess the validity of the empirical relationships found between fuel moisture content, energy release and combustion products in Experiments 1 and 2 from laboratory grown trees.

Experiment 4 – A comparative study of smoke composition and flammability between sub-tropical and temperate grasses

Grassland occupies an area of approximately 440 million hectares in Australia (DCCEE, 2012) and can be divided into two main regions: tropical/subtropical and temperate. Tropical and subtropical grassland cover large areas in northern Australia extending from the Kimberley region in Western Australia, through much of the Northern Territory and eastward into Queensland. Temperate grassland occupies a smaller north-south band across southern Queensland, New South Wales and Victoria between the arid interior and temperate forests to the east. Both the northern and southern Australian seasonal bushfire outlook for 2011-2012 predicts above normal activity due to an increase in grass biomass as a result of heavy rains experienced in 2011. As a consequence, End Users expressed an interest in knowing the composition of smoke that might be expected if fires in grassland occur as predicted.

Six grass species, three characteristic of sub-tropical grassland and three species representing temperate grassland were combusted in the MLC to determine their energy release and combustion products. The experimental data shows that there are a number of differences in the components of flammability and gas-phase emission factors between grass species but, except for CO_2, there were no obvious patterns between grasses species from the sub-tropical grassland compared to the temperate. Emission factors for CO_2 were greater for grasses collected in the sub-tropical grasslands compared to those from the temperate. Examples of the results can be seen in Figure 2.3. This project has been completed and will be presented at the AFAC/Bushfire CRC Annual Conference in 2012.

Additional sampling

Three grass species (one native, one introduced, and one weed) and two sets of pine (brown and green needles of the same species) collected from ACT have been combusted in the MLC to determine their energy release and combustion products. Fuels from PhD projects associated with this project have also been combusted and data will be incorporated into the relevant theses.

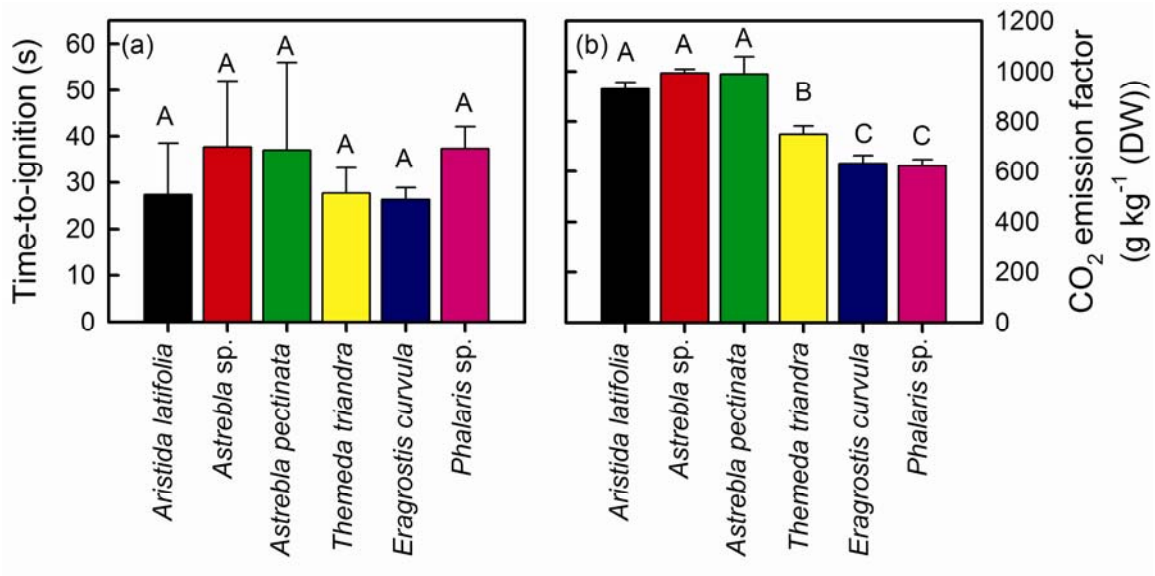

Figure 2.3. (a) Time-to-ignition and (b) emission factors for CO_2 measured during the combustion of six grass species. Bars represent means ± 1 standard deviation. Within each panel, bars with the same letter are not significantly different ($P \geq 0.05$).

Effect of smoke on grapevine leaves

In recent years, bushfires and planned burning have caused substantial economic loss due to smoke taint in wine. Considerable research is being done to ameliorate smoke taint in wine but the information available about the effect of smoke on wine grapevine plants is limited. In this study the physiological effects of short-term exposure to smoke on leaves of several varieties of wine grapevines were examined. Photosynthesis, stomatal conductance and transpiration were measured prior to and after short-term exposure of leaves to smoke. Smoke was produced by combustion of two different fuels. For most wine grapevine varieties, short-term exposure to smoke had little effect on leaf physiology. For varieties which were affected by smoke, patterns of reduction and recovery of leaf physiology depended on fuel type. Short-term exposure to smoke had, at best, no significant effect and, at worst, only temporary effects on leaf physiology of wine grapevines and all varieties had recovered within 48 hours. This research has been submitted to the *International Journal of Wildland Fire* (Bell, Stephens and Moritz) and the results have been adapted for a FireNote.

Proposed activities for the next 12 months

Over the next 12 months, Experiments 2 and 3 will be completed and prepared for publication. The emissions and combustion data has been collected for Experiment 2 and awaits analysis. The samples for Experiment 3 have been collected and require processing. Any additional sampling, either related to End User requirements or postgraduate student needs, will be completed as they become a priority. We would like to develop a database of emissions from a range of fuel types so will put out a call to End Users (as we did this year) to nominate and collect fuels that they deal with.

Postgraduate student projects

Vicky Aerts – The effect of smoke on plant physiology
Vicky's study is examining the effect of smoke from bushfires and prescribed burning on agricultural and native Australian plant physiology. She has completed her first two studies and is in the process of analysing and preparing her data for her thesis. In the first experiment she used a single fuel type (air-dried leaves of *Eucalyptus saligna*) to determine the effect of smoke on a range of agricultural and native species. Her field sites for this experiment were at the Hawkesbury campus of the University of Western Sydney and Australian Botanic Garden, Mount Annan. The experiment involved measurement of photosynthesis, transpiration and stomatal conductance of small branches of each species before and after exposure to smoke. Vicky is in the process of examining the anatomy of the leaves of each species tested to see if there are features that may confer protection against the effects of smoke (e.g. thick cuticle, hairs). Her second experiment used four of the species tested in Experiment 1 and exposed them to smoke from a range of different fuel types. From preliminary analysis, the smoke from grass seems to have the greatest effect on leaves of native and agricultural species.

Vicky presented her work as a poster and a '3-minute thesis' challenge at the Faculty of Agriculture and Environment Science Forum in May and as posters at the 2011 and 2012 AFAC/Bushfire CRC Annual conferences in Sydney and Perth.

Valerie Densmore – Fire-woody legume associations in south-eastern forests
Valerie is trying to determine the underlying causes of patterns of distribution of legumes after bushfires in Victoria in 2009. While there are general observations to the effect that seeds of many of leguminous species require fire for germination, this does not account for either their distribution or persistence. Soil factors may well be implicated in both but this hypothesis has not been tested in Australia. From a management point of view, Valerie will gain insight into how legumes may contribute to overall fuel loads. Valerie is currently investigating how the phosphorus status of soil influences the distribution of woody legumes and fuel loads. For this she has identified high and low densities of six species of *Acacia* that have germinated from seed post-fire in Victoria. She has sampled and analysed soil for a range of physical and chemical properties and, together with climatic and landscape features such as aspect, slope and rainfall periods, is testing which features best correlate with plant density. Valerie is also investigating the germination requirements for a wider range of species of Acacia to determine if there are patterns that are related to distribution.

Valerie has presented her work as a poster at the Faculty of Agriculture and Environment Science Forum in May and as posters at the 2011 and 2012 AFAC/Bushfire CRC Annual conferences in Sydney and Perth.

Felipe Aires – Fire ecology of woody weeds in Australian forests and woodlands
A change in fire behaviour in weed-infested areas can be expected due to differences in architecture, biomass and combustibility characteristics of the invasive species compared to the native species in the invaded area. Research relating to woody weeds and fire is relatively new and few studies have quantified fire behaviour in weed-invaded areas. Of

these limited studies, none contain information for developing predictions of fire behaviour that would be applicable to prescribed fire conditions. Felipe is investigating if woody weed invasion can alter the structure of fuels loads, particularly fine fuels in forests and woodlands. He has selected two weed-infested areas, one in NSW and one in Canberra. The site in NSW (Australian Botanic Garden, Mount Annan) has a long history of invasion by African Olive (*Olea europea* ssp. *cuspidata*), and Felipe had characterised the fuel structure and load in uninvaded Cumberland forest, grassland that has been partially invaded by African Olive and an areas that have been completely invaded. Prescribed burns are planned for some of these sites but wet weather has prevented this to date. The second weed-infested area has been invaded by Cootamundra Wattle (*Acacia baileyana*). Frequent or poorly timed burning of woodland in urban areas has promoted proliferation of this species and is thought to be adding to the fuel load of the mid-storey of the vegetation. Felipe will characterise fuel and structure and load of invaded and invade areas.

Felipe has presented her work as a poster at the Faculty of Agriculture and Environment Science Forum in May and as posters at the 2011 and 2012 AFAC/Bushfire CRC Annual conferences in Sydney and Perth.

Publications, conferences and presentations

Publications

Possell M, Bell TL (2012) The influence of fuel moisture content on the combustion of *Eucalyptus* foliage. *International Journal of Wildland Fire* (accepted).

Bell TL, Stephens SL, Moritz MA (20XX) Short-term physiological effects of smoke on wine grapevine leaves. *International Journal of Wildland Fire* (submitted for review).

Presentations

Possell M, Bell TL, project presentation. Greenhouse gas emissions from fire and their environmental effects. Bushfire CRC Research Advisory Forum, Canberra, October 2011.

Bell TL, Possell M, project presentation. Greenhouse gas emissions and their environmental effects, NSW Fire and Rescue, July 2011

Bell TL, oral presentation. Fire and resilience of Australian ecosystems. Faculty of Agriculture and Environment Annual Research Forum, University of Sydney.

References

Blake D, Hinwood AL, Horwitz P (2009) Peat fires and air quality: volatile organic compounds and particulates. *Chemosphere* 76, 419-423.

Crutzen PJ, Andreae MO (1990) Biomass burning in the tropics – impact on atmospheric chemistry and biogeochemical cycles. *Science* 250, 1669-1678.

Crutzen PJ, Heidt LE, Krasnec JP, Pollock WH, Seiler W (1979) Biomass burning as a source of atmospheric gases CO, H_2, N_2O, NO, CH_3Cl and COS. *Nature* 282, 253-256.

DCCEE (2012) Australian National Greenhouse Accounts, National Inventory Report 2010, Volume 2, Department of Climate Change and Energy Efficiency, Canberra, Australia.

Harden JW, Trumbore SE, Stocks BJ, Hirsch A, Gower ST, O'Neill KP, Kasischke ES (2000) The role of fire in the boreal carbon budget. *Global Change Biology* 6, 174-184.

Hurst DF, Griffith DWT, Carras JN, Williams DJ, Fraser PJ (1994a) Measurements of trace gases emitted by Australian savanna fires during the 1990 dry season. *Journal of Atmospheric Chemistry* 18, 33-56.

Hurst DF, Griffith DWT, Cook GD (1994b) Trace gas emissions from biomass burning in tropical Australian savannas. *Journal of Geophysical Research-Atmospheres* 99, 16441-16456.

Langmann B, Duncan B, Textor C, Trentmann J, van der Werf GR (2009) Vegetation fire emissions and their impact on air pollution and climate. *Atmospheric Environment*, 43, 107-116.

Paton-Walsh C, Deutscher NM, Griffith DWT, Forgan BW, Wilson SR, Jones NB, Edwards DP (2010) Trace gas emissions from savanna fires in northern Australia. *Journal of Geophysical Research-Atmospheres* 115, doi:D1631410.1029/2009jd013309.

Radke LF, Stith JL, Hegg DA, Hobbs PV (1978) Airborne studies of particles and gases from forest fires. *Journal of the Air Pollution Control Association* 28, 30-34.

Shirai T, Blake DR, Meinardi S, Rowland FS, Russell-Smith J, Edwards A, Kondo Y, Koike M, Kita K, Machida T, Takegawa N, Nishi N, Kawakami S, Ogawa T (2003) Emission estimates of selected volatile organic compounds from tropical savanna burning in northern Australia. *Journal of Geophysical Research-Atmospheres* 108.

<u>Project 3</u>: Quantifying risk of water quality impacts from burned areas

Research institute: *Department of Forest and Ecosystem Science, University of Melbourne*

Researchers: *Gary Sheridan, Petter Nyman, Patrick Lane, Philip Noske and Chris Sherwin*

Collaborators and affiliations: *Owen Jones, Department of Mathematics and Statistics, University of Melbourne; Peter Robichaud, US Forest Service, Idaho; Sue Cannon, US Geological Surveys, Colorado*

Postgraduate student: *Rene Van Der Sant*

Project outline

Fire poses an immediate threat to the water supplies of towns and cities because the key water treatment facilities in south-eastern Australia (and often in other parts of Australia) are designed to treat relatively clean water from unburnt forested catchments. For example, following the 2003 fires, Bendora Reservoir (Canberra's water supply) experienced turbidity values 30 times the previously recorded maximum, forcing water restrictions on the Canberra and the Australian Capital Territory (White *et al*., 2006). Melbourne's water supply is also at risk, with approximately 80% of the city's water sourced from the (forested) Upper Yarra and Thompson catchments, with minimal treatment capacity. In the last decade, post-fire debris flows have been identified as a key erosion process following fire and in south-eastern Australia, the significance of debris flows generated from convective storm events has only recently been recognised as a risk to water quality (Nyman *et al*., 2011; Sheridan *et al*., 2009; Smith *et al*., 2011). However the magnitude of the risk to water quality (i.e. the probability of interruption to water supplies) and the degree to which this risk is modified by management actions (e.g. prescribed burning) is unknown.

The *scientific* aim of this research area is to quantify the relationship between burn severity and the probability of water quality impacts in excess of water treatment thresholds in Australian catchments. The methods include survey of extreme erosion events and field experiments to quantify the relationships between fire severity and hillslope hydrologic and erosion properties. The *management* aim of this project is to help fire managers answer the question "What are the real risks to uninterrupted water supply if this catchment is burnt by wildfire, and can I reduce this risk with prescribed fire?"

State of knowledge

Past research on fire effects on hydrology have focused on *post-fire* processes within specific catchments and been concerned primarily with how fire of various severities may impact a particular catchment. Modelling tools and a conceptual framework is lacking when it comes to quantifying risk at larger scales where both fire regimes (*cause*) and rainfall regimes (*driver*) influence the frequency and magnitude of erosion events. These regimes represent important components of risk, especially given the strong influence of management activities and climate change on fire. A landscape-scale perspective on fire and

its effect on erosion results in a major shift in how fire-effects on water quality should be quantified. Our Bushfire CRC outputs over the last year are unique in that the research adopts a hazard based framework for quantifying disturbance effects at a scale which corresponds with the key processes of fire and rainfall which drive changes in risk (Jones *et al*., 2011; Nyman, 2011). The ideas that have been presented as part of this research in the last year appear to resonate with other research groups (locally and internationally) where similar and generic issues of scale and dominant processes are highly topical.

Progress made in 12 months

Overview

The research project can be split into three broad categories which are closely linked but have different research aims:

1. *Experimental field site and monitoring of runoff and erosion.* The site specific and intensive measurements of hydrological processes and post-fire erosion responses provide critical information on fire-effects, recovery and their interaction with landscape properties.
2. *Landscape scale mapping of erosion events.* This extensive survey of post-fire erosion response delivers information on rainfall and landscape properties as drivers of variability in erosion response after fire.
3. *Landscape scale modelling of burned areas as a source of water contamination.* In this component we attempt to link detailed process understanding with landscape-scale response patterns using models which take into account variable rainfall and fire-effects.

These components were addressed in separate presentation during an End User field excursion to our research sites in north-eastern Victoria.

Site establishment and data collection

1. *Experimental field site: post fire monitoring of runoff and erosion*

Milestones relating to the experimental field sites for 2011-12 included “Ongoing field and laboratory measurements” and “Developing quantitative relationship between burn severity and hillslope hydrology”. The Mudgegonga experimental areas in north-eastern Victoria (small catchments ca 0.3 ha in size) were burnt by the 2009 wildfires. Experimental apparatus was established (Fig. 3.1) within two small catchments, Stony Creek North and Stony Creek South to monitor erosion, runoff, soil water status, and soil physical properties during the years following vegetation recovery. These two experimental catchments have different aspects and are particularly useful for quantifying the sensitivity of different forest types to post-fire erosion. Measurements of surface runoff and erosion continued during this reporting period for a third year since the 2009 fire, and the data is currently being analysed and prepared for a journal publication.

Figure 3.1. Field instrumentation for measuring runoff and erosion from small burnt and unburnt catchments.

In 2012, three additional catchments were instrumented to compliment the sites at Stony Creek North and South. The location of these three new catchments relative to the two existing catchments is shown in Fig. 3.2. The three newly instrumented catchments will help us understand and predict how different levels of fire severity, in different forest types, will affect the risks of post-fire erosion and water quality impacts. The instrumented catchments cover a range of fire severity (unburnt, prescribed burnt, wildfire burnt) and "dryness" levels (Fig. 3.3). A small differential in dryness is achieved in this experiment through the selection of small catchments with different aspects. Dryness represents the balance of rainfall and radiation at a location, and is one of the important predictors of soil characteristics and vegetation type in south-eastern Australia. It is hypothesised that dryness may be a useful predictor of post-fire risk to water quality. If this is found to be true, this will enable better prediction of the areas at risk of generating water quality impacts following fire.

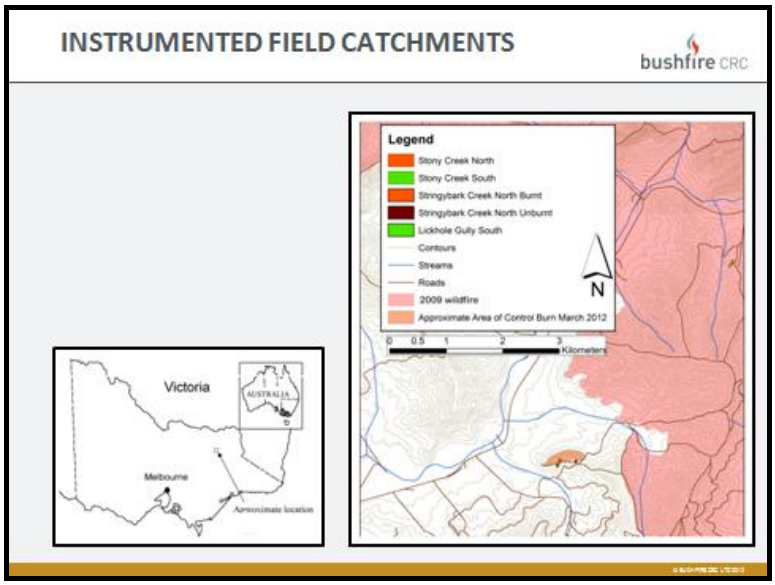

Figure 3.2. The location of the three newly-installed monitoring catchments at Stringybark Creek and Lickhole Gully. Sites are shown relative to the existing two instrumented catchments at Stony Creek North and South.

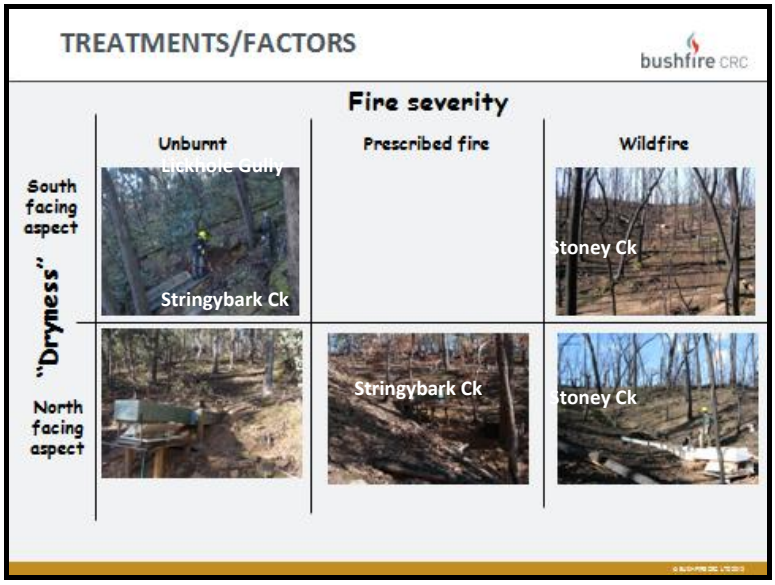

Figure 3.3. A matrix showing how the experimental catchments represent different levels of forest "dryness" and "fire severity". The two unburnt catchments and the prescribed burnt catchment were instrumented in 2012.

2. *Mapping of post-fire debris flows resulting from the 2009 Black Saturday fires*

Milestones relating to the debris flow mapping for 2011-2012 included “Documentation of methodology and preliminary field and laboratory measurements of debris flow sites” and “Ongoing field and laboratory measurements”.

The research focuses on the Kilmore-Murrindindi and Beechworth fires (Black Saturday, Victoria, 2009; Fig. 3.4) where aerial imagery was obtained immediately after the fire and then again one year after the fire. The main activities over the period include collecting field data to validate observations of debris flow occurrence in burnt areas made from interpretation of aerial photography. A methodology was developed for linking field-based measurements with observations from aerial imagery and an analysis was performed in order to quantify the error induced from aerial photography interpretation.

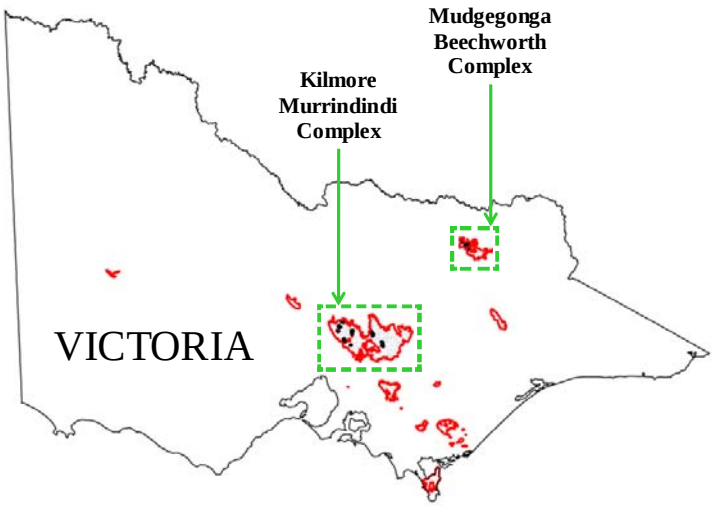

Figure 3.4. The location of the Beechworth and Kilmore-Murrindindi fires used in the analysis of debris flow occurrence.

The error for detecting the presence and absence of debris flows in the landscape using aerial photography was found to be small (and satisfactory) but larger in terms of the exact location of deposits (Fig. 3.5). A survey of debris flow occurrence in the Kilmore-Murrindindi and Beechworth fire has been completed. All forested areas were mapped as debris flow or non-debris flow generating areas. More than 100 catchments were found to have produced debris flows in the areas surveyed. Debris flow producing catchments were defined as the entire area above the terminal deposit of the debris flow.

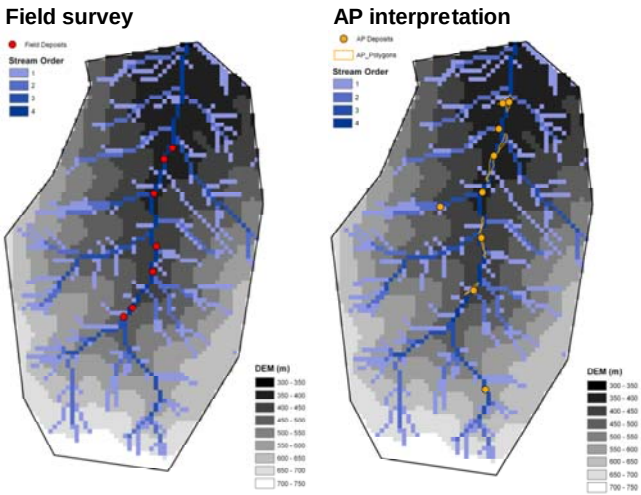

Figure 3.5. The locations of deposits within a debris flow affected catchments as detected in the field and from aerial photography.

Preliminary analysis indicates that slope and ecological vegetation class (EVC) are important predictors of debris flow occurrence. However, there are many interactive processes occurring and the analysis requires a multivariate approach. The data is binary (presence *versus* absence) so a logistic regression will be used to develop model where the outputs is given in terms of the probability of debris flow occurrence as a function of predictor

variables such as rainfall intensity, slope, and forest type (e.g. Figure 3.6). The next steps in this project include the preparation of data sets for input into the regression model. Rainfall data is the driver of debris flow events and a large part of the preparation is the processing of radar data to indentify peak rainfall intensities across the burnt areas. Another important step in the analysis is the development of a "dryness index" for the study areas. The dryness index is a metric which drives differences in vegetation and soil properties and provides a direct and a physically meaningful parameter which is better than EVC categories currently used to distinguish between different landscape units.

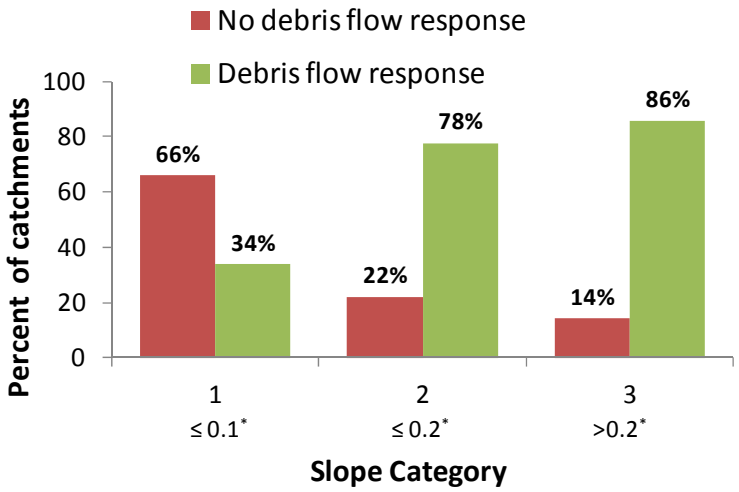

Figure 3.6. Slope as an example of a predictive variable. The slope categories 1-3 represent catchments with different proportions of slopes greater than 25%. 86% of catchments in small pilot study area produced debris flows when more than 20% of catchment consisted of slopes greater than 25%.

3. Model development and parameterisation

The main modelling focus of this project is the link between process-based (site-specific) response models and landscape-scale responses. This shift in focus calls for a new modelling framework which considers rainfall and fires a landscape-scale process. A new model was presented and published at the MODSIM conference in Perth in late 2011 (Jones *et al.*, 2011). The links between existing knowledge and this new modelling framework is addressed in a journal article which was submitted to the Bushfire CRC for approval (July 2012) (Nyman *et al.*, in prep). Obtaining data to drive and test the new model is difficult since most post-fire erosion research has been conducted at hillslope- to catchment-scales. Some data from the aerial photography analysis (above) will be used to test and drive the model. However, longer and more extensive records have been kept by United States Geological Survey (USGS) for California and other western states in the US. A successful meeting was held in December 2011 with Sue Cannon and her colleagues at USGS Colorado to discuss the potential for collaborating and using some of their databases to test the model that has been developed as part of the BF CRC project. Discussions were also held with Ross Bradstock in order to provide a better linkage between prescribed fire and wildfire in the coverage model. It appears that the model can be tweaked so that both prescribed fire and wildfire can be represented as dependent processes through the

concept of leverage (internal tradeoffs between size and frequency for fires) (Bradstock and Williams, 2009).

Proposed activities for the next 12 months
The complex interactions between local landscape properties, rainfall and fire mean that landscape-scale responses can only be predicted using a multi-scale approach. The overall project approach is to combine measurements and modelling at various scales in order to tease out how wildfire and prescribed fire will interact with each other and the landscape to produce erosion from forested areas. The simultaneous focus on multiple elements ensures that the research is detached from site and context specific conditions that are typical of single catchment or hillslope studies which dominate the literature on post-fire erosion. The issue however is that the project attempts to deal with complex issues of space, time and shifting dominant processes, something which may seem abstract and irrelevant to agencies where questions are often concerned with specific locations, burn conditions and management objectives. An important task will therefore be to explain the importance of addressing these quite complex conceptual ideas within the research, and to illustrate the value of these conceptual and modelling developments to the End User community.

The main focus over the next 12 months will be to analyse data and begin to write journal articles as per project milestones. These research papers will be broad in scope and topic in order to appeal to and maintain relevance to an international audience. Concurrently we will be taking project components and tailor these so that they provide specific outputs which are directly relevant to the End User community and their ability to prioritise and make informed decisions relating to burned areas as a source of risk to water resources and infrastructure.

Postgraduate student project

Rene Van Der Sant – Quantifying water quality risks following wildfire: the relationship between fire severity and extreme erosion events
The last 12 months has seen Rene progress through the project development phase and into initial data collection. Field work in areas associated with the 2009 Victorian fires was undertaken, with the help of an exchange student (Pim Rijkee, an intern from Wageningen University, Netherlands), to develop and refine a method to identify channels in aerial photos. The project outline and initial findings were well received at the IAHS-ICCE International Conference on Wildfire and Water Quality: Process, Impacts and Challenges, held in Banff, Canada in June 2012. This conference provided an opportunity to make contacts and discuss the work with distinguished researchers in the field. Opportunities to discuss the work with End Users were also provided during the Bushfire CRC field trip and Research Advisory Forum in Hobart. Rene also presented her work as posters at the 2011 and 2011 AFAC/Bushfire CRC Annual conferences in Sydney and Perth. Rene is now well placed to begin main data collection and analysis.

Publications, conferences and presentations

Publications

Jones OD, Nyman P, Sheridan GJ (2011) A stochastic coverage model for erosion events caused by the intersection of burnt forest and convective thunderstorms. Proceedings of the 19th International Congress on Modelling and Simulation, Perth, Australia, 12-16 December 2011. http://www.mssanz.org.au/modsim2011/E12/jones.pdf

Nyman P, Sheridan, GJ, Jones, OD, Lane PNJ (2011) Erosion and risk to water resources in the context of fire and rainfall regimes. Proceedings of the AFAC and Bushfire CRC 2011 Conference Science Day, RP Thornton, ed. Bushfire CRC, Victoria.

Nyman P, Sheridan GJ, Lane PNJ (20XX) Post-fire response models and their applications in hazard prediction and land management. *Progress in Physical Geography* (submitted for review).

Conferences and presentations

Nyman P, Sheridan GJ, Jones O, oral presentation. A model for predicting erosion under variable fire and rainfall. Seminar Series Fall 2012. Colorado University.

Nyman P, Sheridan GJ, Moody JA, Smith HG, Lane PNJ, oral presentation. Depth-dependent erodibility: representing burnt soils as a two-layered cohesive/non-cohesive system. American Geophysics Union, Fall Meeting, the Moscone Convention Center, San Francisco, California , 5-9 December 2011.

Sheridan GJ, Nyman P, Lane P, Jones O, Cannon S, project presentation. Quantifying water quality risks following fire. Bushfire CRC Research Advisory Forum, Hobart, May 2012.

Sheridan GJ, plenary speaker. Fires, storms, and water supplies: modelling the post-fire window of hydrologic risk. IAHS ICCE Conference on Wildfire and Water Quality, Banff, Canada, 11-15 June 2012.

Sheridan GJ, Nyman P, Jones O, oral presentation. A stochastic germ-grain model to estimate wildfire induced debris flow risks in a changing climate. American Geophysics Union, Fall Meeting, the Moscone Convention Center, San Francisco, California , 5-9 December 2011.

References

Bradstock RA, Williams RJ (2009) Can Australian fire regimes be managed for carbon benefits? *New Phytologist* 183, 931-934.

Nyman P, Sheridan GJ, Lane PNJ (in prep.) Post-fire response models and their applications in hazard prediction and land management.

Nyman P, Sheridan GJ, Smith HG, Lane PNJ (2011) Evidence of debris flow occurrence after wildfire in upland catchments of south-east Australia. *Geomorphology,* 125, 383-401.

Sheridan G, Lane P, Smith H, Nyman P (2009) A rapid risk assessment procedure for post-fire hydrologic hazards: 2009/10 fire season. *Technical Report.* Melbourne: Victorian Department of Sustainability and Environment.

Smith HG, Sheridan GJ, Lane PNJ, Nyman P, Haydon S (2011) Wildfire effects on water quality in forest catchments: a review with implications for water supply. *Journal of Hydrology* 396, 170-192.

White I, Wade A, Worthy M, Mueller N, Daniell, T, Wasson R (2006) The vulnerability of water supply catchments to bushfires: impacts of the January 2003 wildfires on the Australian Capital Territory. *Australian Journal of Water Resources* 10, 1-16.

<u>Project 4</u>: Fires and hydrology of south-eastern Australian mixed-species forests

Research institute: *Faculty of Agriculture and Environment, University of Sydney*

Researchers and technical support: *Tarryn Turnbull, Michael Kemp, Neil Murdoch, Audrey Deheinzelin and Jeremy Platt*

Collaborator: *Tom Buckley, Department of Biology, Sonoma State University*

Postgraduate student: *Jessica Heath*

Project outline

In all southern eucalypt forests, water use by vegetation (understorey plus overstorey) is directly dependent on water availability that varies strongly both seasonally and annually. Availability of water to the understorey is clearly dependent on the balance between rainfall and the water demands of overstorey eucalypts. Rainfall can be assessed at a reasonable spatial scale using Bureau of Meteorology resources but we currently lack models to predict the availability of water to understorey vegetation. In addition, we do not know how tree and understorey water use varies across the landscape but it may be as much as 20% of total water use in some forests. When considered together, the water use by overstorey and understorey vegetation dictates water yield or run-off from forested sub-catchments. Water yield is strongly leveraged to water use by vegetation such that a 5% change in water use may result in a 20% reduction in streamflow.

We have been developing approaches that allow us to quantify overstorey water use in relation to soils and climate, and models that allow extrapolation to annual time scales and sub-catchment geographic scales. We now need to develop this ability further such that it can be used with forests regrowing after fire – both bushfire and prescribed fire. In the areas affected by the 2009 bushfires, key questions are those related to how resprouting eucalypts differ from eucalypts that regenerate from seed (e.g. Ash-type eucalypts). In particular, we know almost nothing about the water use of resprouting eucalypts and how this is affected by leaf anatomy and phenology. This project will fill an important gap in knowledge for modelling of tree water use in catchments in fire-prone forest.

State of knowledge

Mixed-species forests constitute a considerable percentage of the catchment estate in south-eastern Australia. Most research into water use by eucalypts in these catchments has concentrated on the tall open forests dominated by *Eucalyptus regnans.* These forests regenerate by seed after fire, whereas mixed-species forests predominately regenerate vegetatively. As all of the eucalypts that dominate mixed-species forests differ in life history to *E. regnans* we cannot assume that the severity or longevity of reductions in catchment yield following fire will be the same. Recent work in mixed-species eucalypt forests (Mitchell

et al., 2012) show that transpiration by the overstorey accounts for the majority of the catchments water-budget, and that it is closely coupled to edaphy and climate.

We have been developing approaches that allow quantification of overstorey water use in relation to soil and climate for use with models that allow extrapolation to annual time scales and geographic scales of sub-catchments. Previously, our models were based on the empirical soil-plant-atmosphere (SPA) model described and used by Williams *et al.* (1996; 2001) and Zeppel *et al.* (2008). Instead of refining this model for resprouting mixed-species forests in north-eastern Victoria we have published a new process-based model for tree water use, based on resistance to water loss imposed by leaves (Buckley *et al*., 2012). As such, we will use the data from this project to predict water used by resprouting mixed-species forests in north-eastern Victoria. Once the model has been calibrated for these forests, it can be 'handed over' to catchment mangers for incorporation into whole-of-catchment models.

Progress made in last 12 months

Overview

The project has continued to progress well in its second year. Collection, analysis and presentation of data is on-track (in accordance with milestones related to: ongoing collection and analysis of base-line data, publication of data in peer-reviewed journal, third annual field campaign, draft FireNote, posters for AFAC/Bushfire CRC Annual conferences in 2011 and 2012). Milestones have been completed to the satisfaction of our Lead End User and other interested agencies. This success is largely the result of temporary employment of three additional technical staff (Murdoch, Dehienzelin and Pratt) who have periodically assisted the Lead Researcher and Technical Officer with the field work and subsequent laboratory work. The highlight of the year was a 1-day visit to sites from this project for representatives from End User agencies and the Bushfire CRC. The field visit was held in conjunction with researchers from the equivalent Fire in the Landscape project run by the University of Melbourne. This field visit enabled us to demonstrate first-hand the complexities of field work whilst also demonstrating the success of the project.

Tree water use and micrometeorology has been continuously recorded for over twelve months now and interrogation of data indicates that the equipment installed remains fully functional. Successful campaigns in February and April 2012 ensured that we now have three successive years of data for canopy allometry and key leaf physiological variables. We have successfully captured the data necessary to parameterise stand-level models of vegetation water use for epicormic trees as they progress through the first three years of growth after a major fire.

Site characterisation

The 'Stanley' sites are located 5 km from Stanley, north-eastern Victoria. Vegetation in the broad research area ranges from Heathy Dry Forest (EVC 20) to Shrubby Dry Forest (EVC 21) depending on altitude, rainfall, soil type and exposure. The overstorey layer is dominated by *Eucalyptus* spp. at a height of 20-25 m. A mid-storey tree layer rarely develops. Understorey vegetation is generally medium to low forming a sparse to dense layer of small-leaved shrubs including heaths and peas and grasses depending on fire frequency. At higher

elevations, the Stanley sites are vegetated with a number of eucalypt species dominated by peppermints *E. radiata, E. dives* and gums *E. mannifera* and *E. globulus* ssp. *bicostata*. Down slope at mid-elevations, the species composition change to stringybarks (*E. macrorhyncha*) and boxes (*E. polyanthemos* and *E. goniocalyx*). Crown fires passed through the region in February 2009, and shortly thereafter trees sprouted from epicormic shoots with juvenile foliage (Fig. 4.1).

We are using the Stanley sites to quantify and model tree water use at two elevations (800 and 500 m asl). At each elevation we have paired burnt and unburnt plots. Unburnt areas may have been subjected to a mild fire but of with an intensity too low to stimulate epicormic sprouting. The high elevation sites are located on steeper slopes with stony soils and friable brownish gradational soils whereas the low-elevation sites have either weakly bleached yellowish gradational soils (Clutterbuck and McLennan, 1978).

Both sites are now completely instrumented and tree water use is continuously measured using the heat ratio method (HRM). Meteorological data used to parameterise models is gathered continuously (e.g. soil moisture, air temperature, relative humidity and radiation) using sophisticated instrumentation including weather stations and soil probes and periodically via targeted campaigns during late spring and summer (e.g. edaphic data, canopy allometry and key leaf physiological variables that relate to tree water use; Fig. 4.1).

Figure 4.1. Study sites burnt in February 2009. Accessing the high elevation site to measure aspects of leaf physiology of epicormic shoots (left), and the equipment used to record tree water use at the low elevation site (right).

Fifteen trees, three each of the dominant species, have been selected for measurement of sap flow in each of the burnt and unburnt plots at both elevations. These trees encompass the range of diameters for each species, which will enable us to model stand-level water use. The stocking rate, leaf area index and edaphy of these sites have all been assessed and

soil moisture and micro-meteorology is continuously measured. An additional three trees per species at the high elevation site were selected for annual characterisation of canopy allometric relationships and measurement of key leaf physiological variables. These trees are, on average, 20 m tall and 24-55 cm in diameter. Leaf area is distributed evenly up the main stem so sample points are located at three heights on each tree: low (<2 m), middle (7-11 m) and top (14-17 m).

The closest weather station to Stanley is at Beechworth (approximately 5 km distant). Long-term climatic data from the Bureau of Meteorology for this weather station indicate that annual average rainfall is 950 mm with most falling during winter months of June to August. The average minimum temperature is 7.8 °C and the maximum is 18.4 °C with temperatures rarely rising above 30 °C or falling below 0° C. Localised weather stations will be used to take into account variations due to aspect and altitude and this more precise climatic data will be used in modelling.

Data collection

Collation and interrogation of three successive years of data related to tree structure, leaf structure and leaf physiology has begun. We have found that 3 years after the crown-removing fires, all trees are still bearing epicormic branches and juvenile foliage. The canopy structure is slowly changing over time, moving from many small branches that are distributed evenly up the stem in 2010 (Fig. 4.2) to fewer and larger branches in 2012. The canopy has yet to regain full dominance but larger branches in the upper reaches of the trees represent the beginning of this process. Whilst the structure is different, the maximum carrying capacity of leaf area during regeneration has been conserved as total tree leaf areas in 2010 and 2012 are similar for *E. radiata* and *E. dives* (Fig. 4.3).

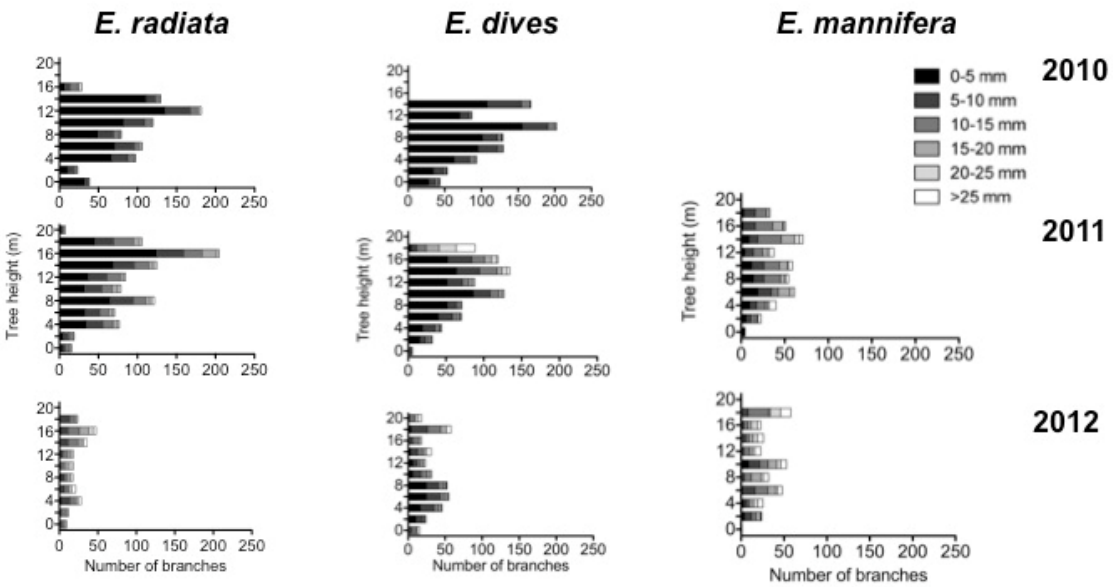

Figure 4.2: Within-tree structure of epicormic branching for dominant eucalypt species (*Eucalyptus radiata, E. dives* and *E. mannifera*) at the high elevation site near Stanley. The total number of branches is fewer and branches with greater diameter are becoming dominant in the upper parts of the tree.

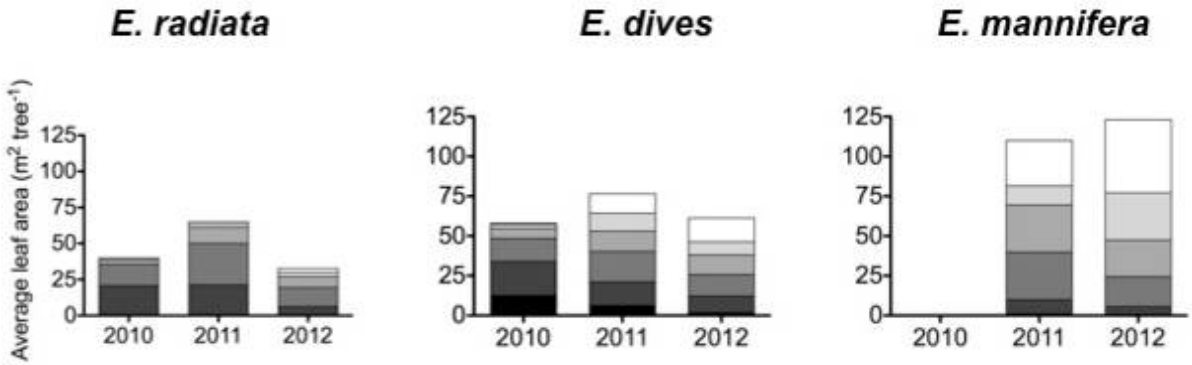

Figure 4.3: Average leaf area per tree for dominant eucalypt species (*Eucalyptus radiata, E. dives* and *E. mannifera*) at the Stanley high elevation site. Overall, leaf area has increased and larger diameter branches (white bars) are associated with greater leaf area.

A simple physiological model to predict sap flow in eucalypts based on knowledge of stomatal conductance has recently been published (Buckley *et al*., 2012). By combining a sub-set of our tree water use data with leaf physiological data from our periodical campaigns, we found the model could predict patterns and volume of water use by mixed-species eucalypt forests as they regenerate after a fire.

Proposed activities for the next 12 months

Considering all of the fieldwork, the End User engagement and presentation of preliminary results at an international conference, this has been a very productive year for the project. We are now in the sound position of having one full year of sap flow data for all sites combined with a very comprehensive data set detailing how tree structure, leaf structure and leaf physiology has changed during the first three years after a fire for eucalypts that regenerate by epicormic growth. To build on our knowledge of temporal and spatial variation in tree water use, we will begin installing sap flow probes in other trees at sites adjacent to those currently instrumented. Once this final deployment ceases we will remove equipment in line with the agreement on long-term maintenance and management of these sites.

The Lead Researcher in conjunction collaborators will continue to analyse the data already collected and will collate the last of the sap flow data. In the coming months we will use these data and data from the three targeted field campaigns to model tree water use. The models will be incorporated into manuscripts for peer review and FireNote for distribution by the Bushfire CRC. The first FireNote related to this project detailed the methods that were used to measure key features of physiology of resprouting eucalypt trees (in production).

Postgraduate student project

Jessica Heath – What are the impacts of bushfire on the hydrology of Sydney's water supply catchments?
Jessica's research is focused on examining the impact of bushfire on hydrological processes in the outer Sydney Basin after summer fires in 2001-2002. She has progressed well through the year and is moving towards the final stages of data analysis and preparation of manuscripts and a thesis. The study area she is working in is in Sydney's water supply catchments located in the Hawkesbury-Nepean catchment. The area includes 18 monitoring sites on unregulated streams where flow and water quality has been monitored since the 1970s. The drainage area of eight of the sites was impacted by the 2001-2002 bushfires, the other 10 sites were unburnt and have been used as controls. The four burnt sub-catchments include Burke River, Glenbrook Creek, Erskine Creek and Nattai River and the unburnt sub-catchments include Grose River, Kedumba River and Kowmung River. Jessica's research uses Landsat imagery for determining the Normalized Difference Vegetation Index (NDVI) and the Normalised Burn Ratio (NBR) along with fire severity mapping and random point sampling to develop models of how the sub-catchments have been affected by fire.

Jessica has produced a manuscript determine the impacts of severe wildfires on the post-wildfire hydrology of a catchment in the Sydney Basin. She has prepared a poster and will deliver an oral presentation at the 2012 AFAC/Bushfire CRC conference in Perth titled "The affects of wildfire on water yield and its relationship to vegetation response: A case study of the summer 2001/2002 Sydney Basin wildfire".

Publications, conferences and presentations

Publications
Buckley TN, Turnbull TL, Adams MA (2012) Simple models for stomatal conductance derived from a process model: cross-validation against sap flux data. *Plant Cell and Environment* doi: 10.1111/j.1365-3040.2012.02515.x

Conferences and presentations
Turnbull TL, project presentation. Fires and hydrology of south-eastern Australian mixed-species forests. Bushfire CRC Research Advisory Forum, Canberra, October 2011.
Turnbull TL, Barlow AM, Buckley TN, Gharun M, Adams MA, oral presentation. Canopy re-establishment and leaf physiology of resprouting eucalypts explain increases in vegetation water use after wildfire. IAHS ICCE Conference on Wildfire and Water Quality, Banff, Canada, 11-15 June 2012.

References

Clutterbuck R, McLennan R (1978) *A proposal for proclamation prepared by the Soil Conservation Authority for the consideration by the Land Conservation Council*. Soil Conservation Authority, Kew, Victoria.
Mitchell PJ, Benyon RG, Lane PNJ (2012) Responses of evapotranspiration at different topographic positions and catchment water balance following a pronounced drought in a mixed species eucalypt forest, Australia. *Journal of Hydrology* 440-441, 62-74.

Pfautsch S, Bleby TM, Rennenberg H, Adams M (2010) Sap flow measurements reveal influence of temperature and stand structure on water use of *Eucalyptus regnans* forests. *Forest Ecology and Management* 259, 1190-1199.

Vivian LM, Cary GJ, Bradstock RA, Gill AM (2008) Influence of fire severity on the regeneration, recruitment and distribution of eucalypts in the Cotter River Catchment, Australian Capital Territory. *Austral Ecology* 33, 55-67.

Waters DA, Burrows GE, Harper JDI (2010) *Eucalyptus regnans* (Myrtaceae): a fire-sensitive eucalypt with a resprouter epicormic structure. *American Journal of Botany* 97, 545-556.

Williams M, Bond BJ, Ryan MG (2001) Evaluating different soil and plant hydraulic constraints on tree function using a model and sap flow data from ponderosa pine. *Plant, Cell and Environment* 24, 679-690.

Williams M, Rastetter EB, Fernandes DN, Goulden ML, Wofsy SC, Shaver GS, Melillo JM, Munger JW, Fan S-M, Nadelhoffer KJ (1996) Modelling the soil-plant-atmosphere continuum in a *Quercus-Acer* stand at Harvard Forest: the regulation of stomatal conductance by light, nitrogen and soil/plant hydraulic properties. *Plant, Cell and Environment* 19, 911-927.

Zeppel M, Macinnis-Ng C, Palmer A, Taylor D, Whitley R, Fuentes S, Yunusa I, Williams M, Eamus D (2008) An analysis of the sensitivity of sap flux to soil and plant variables assessed for an Australian woodland using a soil-plant-atmosphere model. *Functional Plant Biology* 35, 509-520.