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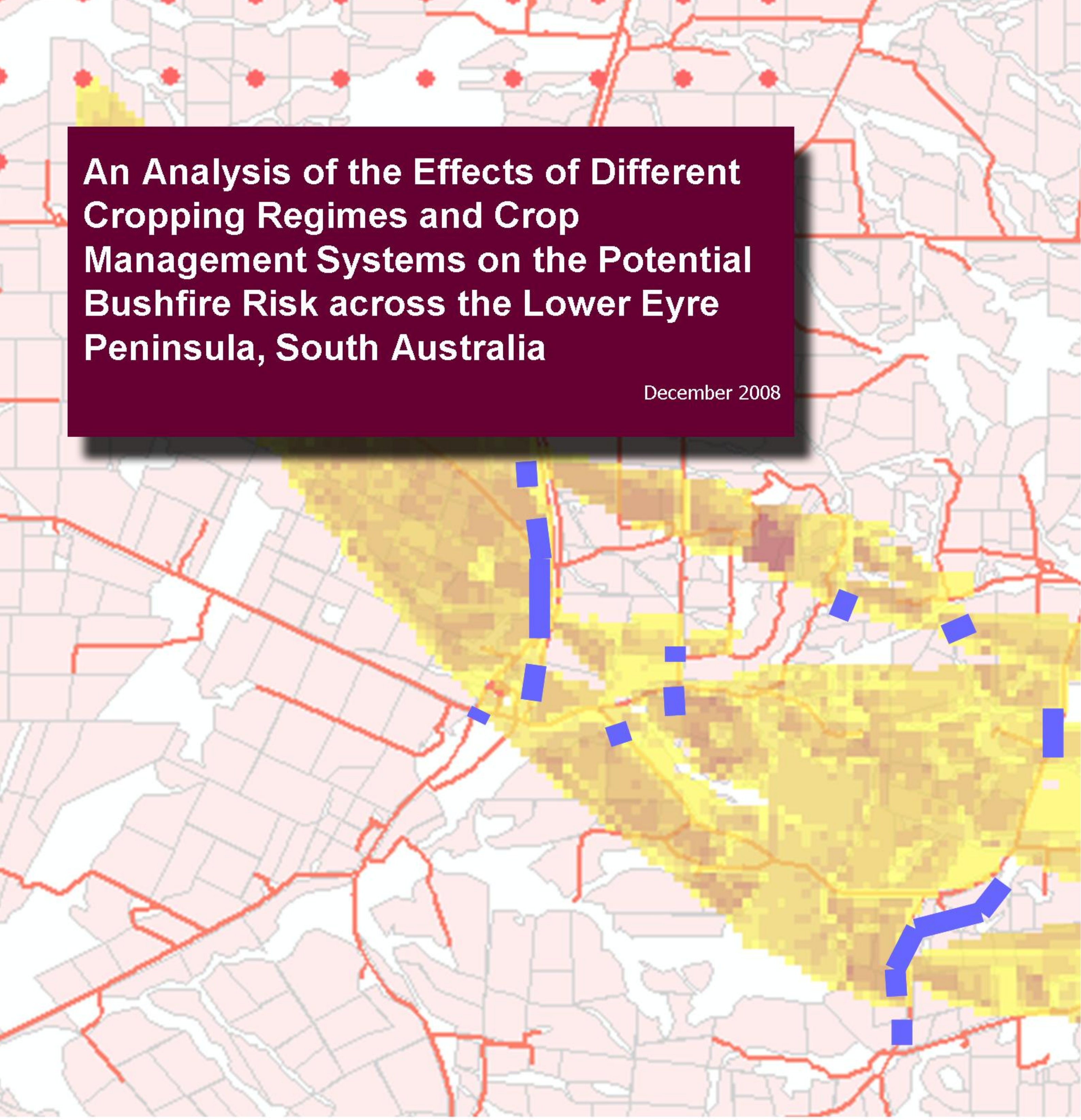
December 2008



THE UNIVERSITY OF MELBOURNE

bushfire CRC

Government of South Australia
Primary Industries and Resources SA

SARDI
SOUTH AUSTRALIAN RESEARCH AND DEVELOPMENT INSTITUTE

An Analysis of the Effects of Different Cropping Regimes and Crop Management Systems on the Potential Bushfire Risk across the Lower Eyre Peninsula, South Australia

A report prepared for the Minister for Emergency Services (acting through the South Australian Research and Development Institute) under contract with the University of Melbourne (in association with the Bushfire Cooperative Research Centre)

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Executive Summary

This report is the second and final report commissioned by the SA Minister of Emergency Services in relation to two recommendations from the Coronial Inquiry (29.9.2 & 29.9.3) into the Wangary Fire of 2005 (Schapel 2007, p.579). In broad terms, the first recommendation was concerned with the effects of continuous cropping and minimum tillage practices on bushfire risk and prevention and the second recommendation was concerned with identifying opportunities for minimizing the level of bushfire risk in cropping districts such as the Lower Eyre Peninsula.

The first report, "*A review of the effect of farming practices, including continuous cropping, minimum tillage and direct drilling, on bushfire risk and prevention*" by Tolhurst, Egan and Duff (2008) was delivered in June 2008. This review identified, amongst other things, that fire behaviour in cropland has been poorly studied and that the practice of conservation tillage is probably less of an issue to the level of bushfire risk than the reduction in the level of livestock grazing.

This second report summarizes the findings of fire risk management modelling applied to an annual cropping system, using a risk management tool being developed by the Bushfire Cooperative Research Centre.

The main findings of this study are:

1. Fire weather severity, as measured by the McArthur's Grassland Fire Danger Index, is the main driver of fire extent and impact.
2. Quick and effective fire suppression significantly reduces the extent and impact of fires, even under "Worst-case" weather conditions.
3. Seasonal growing conditions affect fuel amount and continuity, with firebreaks and fire suppression being less effective in "Good" seasons.
4. Strategic harvesting of hay or straw (~15% of total cereal crop area), used in conjunction with 20 m roadside firebreaks, in "Good" seasons has a similar effect in reducing the extent of fires as having a "Poor" or "Median" growing season.
5. Firebreaks need to be at least 20 m wide to significantly impact on headfire spread under "Extreme" and "Worst-case" weather conditions.
6. Strategically locating firebreaks adjacent to public roads and areas of remnant native vegetation significantly reduces the area needing treatment without significantly reducing the effectiveness of the strategy.

It must be noted that not all possible bushfire mitigation options have been explored in this work and other options or combinations of options should also be considered based on social, economic and other practical realities. The work reported here has demonstrated the value of strategic fuel modification and the importance of making sure any fuel modification measures, such as ploughed firebreaks, are sufficiently extensive to be effective under "Worst-case" weather conditions. The benefits of increasing fire suppression resources and response times have not been considered. Similarly, the benefit of reducing the probability of ignition during "Extreme" and "Worst-case" weather conditions has not been explored either.

It is the authors' expectation that the results of this work will be considered in a wider context and that further research will be undertaken to remove some of the uncertainties involved in modelling fire behaviour in the annual cropping situation.

1.0 Background

On January 11, 2005, an extreme bushfire event swept across the Lower Eyre Peninsula region in South Australia. The fire burnt through approximately 78,000 hectares, about 80% of which was highly productive agricultural land used for cereal, oilseed and pulse grain production and extensive livestock grazing on improved pastures. Nine lives were lost in the fire, leading to a Coronial Inquest. Two recommendations in the Coroner's report called for a review of land management practices on Lower Eyre Peninsula, in terms of the impact of changed practices in recent years on bushfire risk and prevention. In particular, the Coroner recommended that the practices of continuous cropping, minimum tillage, stubble retention and direct seeding should be investigated, in conjunction with techniques (such as ploughing paddocks and firebreaks after harvest) to minimise the fire risk (Schapel 2007).

The University of Melbourne in collaboration with the South Australian Research and Development Institute (SARDI) was contracted by the Minister of Emergency Services SA to undertake a review of the literature and undertake preliminary research to address the issues raised by the Coroner.

The review of existing knowledge particularly focussed on the following issues:

1. Impact of crop type, i.e. winter cereals (wheat and barley), canola, pulses (lupins, faba beans or field peas) or grazed annual pasture, on flammability and other fire characteristics of mature paddock residues over summer.
2. Effect of tillage and stubble retention practices on accumulation of above ground, readily combustible fuel over time – e.g. how much more combustible is a paddock after continuous cropping and stubble retention for 2, 3 or more years, compared with a single year of cropping preceded and followed by grazing?

This review was completed in June 2008 (Tolhurst, Egan and Duff 2008). One of the major conclusions was that stubble retention was not likely to be adding significantly to paddock fuel loads and fire risk during the peak summer fire risk period. Post-harvest tillage of paddocks to incorporate or bury crop residues would only be effective in reducing fire risk if practised early in summer, but most paddock working was generally not done until later in summer or early autumn. The review also concluded that the greater intensity and continuity of cropping, increased crop yields and the reduction in grazing of pasture and crop stubble paddocks were the likely main contributors to increased fire risk in recent times.

The review concluded that farming practices with potential to reduce fire risk include:

- Strategically located firebreaks, as cultivated, sprayed or mown strips, and heavily grazed areas;
- Windrowing crops prior to harvest;
- Cutting and baling paddocks for hay;
- Grazing crop stubbles;
- Baling cereal straw;
- Harvest management to reduce stubble height and hasten decomposition of crop residues, e.g. using straw choppers or spreaders on headers;
- Post-harvest stubble management, such as rolling, chaining, harrowing or slashing.

The second component of this study was to use the fire characterization model PHOENIX (Tolhurst *et al.* 2007, Tolhurst *et al.* 2008) to explore the effects of different cropping regimes and crop management practices on wildfire spread.

2.0 Method

2.1 Questions addressed in this study

This report presents the results of investigating the potential impacts and benefits of various cropping regimes and practices to fire spread and control. However, these effects will also be influenced by other factors that were not specifically investigated as part of this study. These include the sources of ignition, weather patterns as they affect fire danger, fire suppression response time, level of effort and effectiveness, extent and type of native remnant vegetation, and roads and tracks providing access and acting as fuel breaks.

The study attempted to address the following specific questions:

1. Is there a particular “pattern” of cropping that would limit the spread of wildfire under extreme fire weather conditions?
    a. Pattern defined in terms of the intensity of cropping across the district (e.g. from 50% up to almost all arable paddocks in the district cropped in any year), the mix and arrangement of crop types (cereals, canola and pulses) and pasture paddocks across the landscape.
    b. Stubble retention versus stubble reduction practices, e.g. cultivation, rolling, slashing, baling and removal. (assumed paddock sizes remain unchanged).

2. The influence of seasonal growing conditions, resulting in a range of fuel loads over summer.

3. As for 1. and 2. above, but under more moderate (and more frequently experienced) fire weather conditions.

4. What effect would bare (ploughed) firebreaks of varying widths (3, 6, 9 and 20 m) between fences and crops have on fire spread?
    a. Around all crop boundaries?
    b. Only along roadside fences and vegetation boundaries?

5. What effect do roads have, through:
    a. Passive impact on fire spread and intensity?
    b. Assistance given to fire suppression efforts?

    (Note that these are implicit in the model, but not explicitly quantified).

6. The effect of different types of roadside vegetation (i.e. mallee, sugar gum, shrubs/sedges, grasses):
    a. On fire spread?
    b. On the ability to suppress fires?

    (Again these are implicit in the model, but not explicitly quantified).

2.2 Summary of model assumptions

The modelling of fire risk was done for the post-harvest situation, e.g. from early January onwards on Lower Eyre Peninsula. This period was chosen rather than pre-harvest due to the following considerations:

- Fire risk across the district as a whole was considered to be lower prior to harvest, due to the wide range of maturity, and hence moisture content and fuel flammability, in different crop paddocks.

- There is a higher level of fire awareness and preparedness during harvest, with farmers, contractors, etc, out and about and able to detect and respond to any fire outbreaks early and rapidly.
- The dynamic situation of crops maturing and being progressively harvested as grain moisture content falls below acceptable storage and delivery standards (about 12% to 13%) makes it difficult to model, in terms of specifying model parameters such as typical paddock fuel loads and distribution across the district.

The modelling study with PHOENIX was based on the following assumptions and data sets:

- A 16 km x 16 km area of Lower Eyre Peninsula was used for the simulation study, using the actual topography, road network, paddock sizes and placement.
- Main roads were assumed to be 8m wide, minor roads 5m wide and tracks 4m wide.
- The extreme fire danger conditions are similar to those experienced in the January 11, 2005 fire on Lower Eyre Peninsula. Weather conditions on this day were taken to be “Worst-case” and a modified version of these used for “Extreme” fire conditions.
- Assumed that fires start at 1000 hrs.
- The average time from ignition to first fire suppression work is 20 minutes.
- There is a wind change 2 hours after ignition from a NW’ly wind to a SW’ly wind.
- Three large fire tankers will be at the fire within 20 minutes of the fire starting, 8 large tankers within 30 minutes, and 20 large tankers within 60 minutes.
- Two road graders (with support vehicles) could be at the fire within 2 hours of it starting.

2.3 Site characteristics

In order to make the modelling exercise as realistic as possible, a section of the Lower Eyre Peninsula was used as the simulation area. The road network, pattern of remnant vegetation, drainage lines, paddock size and location and topography are therefore based on real data.

All fire simulations were conducted in an area approximately 16 km x 16 km, or 26,250 ha (Figure 1). There were 855 paddocks in this area ranging in size from 4 to 94 hectares, with an average area of 24 ha.

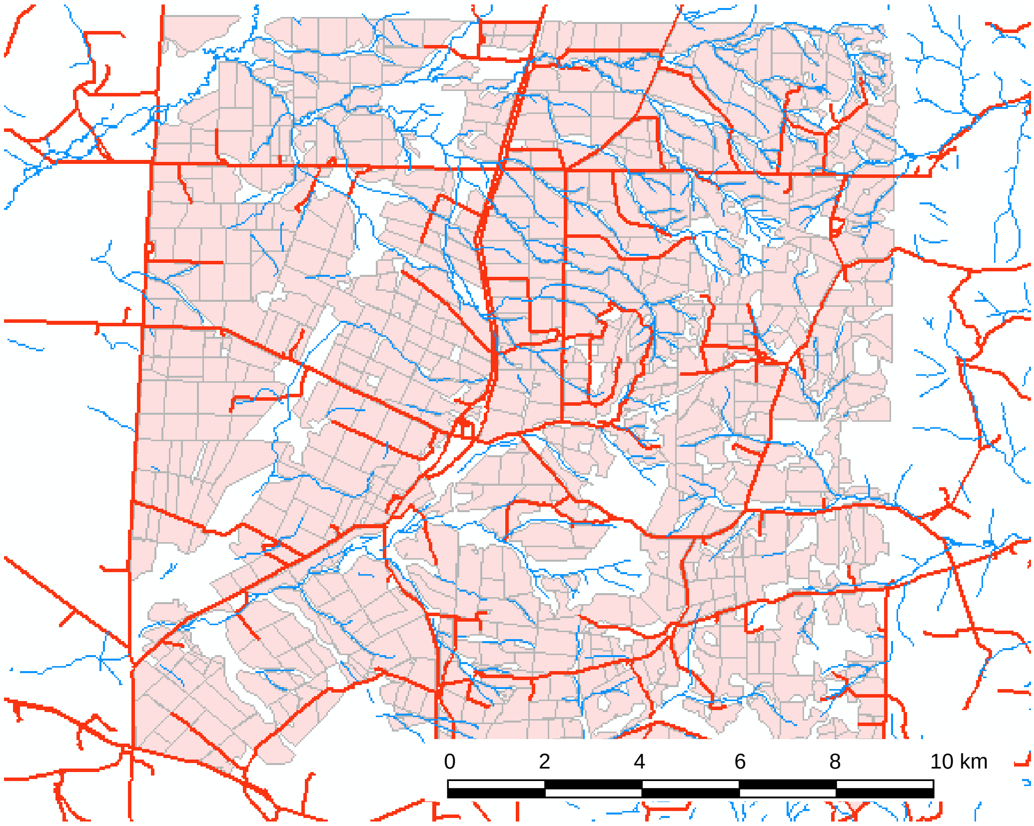

Figure 1. Simulation area from the Lower Eyre Peninsula showing the road (red), gully (blue) and paddock (pink) layout in an area approximately 16 km by 16 km.

2.4 Fuel characteristics

Crop types were allocated to each paddock to produce a range of cropping intensities and crop rotational mixes. The seven cropping scenarios thus generated are described in Table 1. Crop dry matter production, grain yields and post-harvest residue yields were assigned to each of the crop types in "Poor", "Median" and "Good" seasons (Table 2), on the basis of estimated Lower Eyre Peninsula district yields over the ten-year period 1998 to 2007. These were the fuel loads used in the various scenarios of the simulations. It was assumed that crops had been harvested before the fire season, so crops were present as stubble (e.g. Figure 2).

Table 1. Cropping scenarios applied to the simulation area to give a range of cropping intensities and rotational mixes.

Scenario	Scenario Name	Details
S1	Cropping 48%	Pasture/cereal crop rotation in arable paddocks (1 year pasture / 1 year cereal).
S2	Cropping 64%	1 year pasture / 2 year cereal crop rotation in arable paddocks.
S3	Cropping 72%	1 year pasture / 3 year crop (2 cereal and 1 canola) rotation in arable paddocks.
S4	Cropping 77%	1 year pasture / 4 year crop (2 cereal, 1 canola and 1 lupin) rotation in arable paddocks.
S5	Cropping 81%	1 year pasture / 5 year crop (3 cereal, 1 canola and 1 lupin) rotation in arable paddocks. This is about the current average district practice.
S6	Cropping 95%	Continuous cropping on arable paddocks: pastures only on non-arable land, crop rotation of 3 cereals, 1 canola and 1 lupin in arable paddocks.

Table 2. Crop dry matter, grain yield and post harvest residues for Lower Eyre Peninsula. "Poor" is equivalent to the lowest yielding year in the 10-year period 1998 to 2007, and "Good" is equivalent to the highest yielding year in this period.

CROP	Minimum yield "Poor" (t/ha)	Median yield "Median" (t/ha)	Maximum yield "Good" (t/ha)
Total dry matter yield (pre-harvest) [1]			
Wheat	4.0	5.8	7.5
Barley	3.3	5.4	7.5
Canola	1.5	3.3	5.0
Lupins	2.0	3.9	6.0
Grain yield [1]			
Wheat	1.6	2.5	3.4
Barley	1.3	2.3	3.4
Canola	0.6	1.3	2.0
Lupins	0.8	1.6	2.4
Stubble residue [2]			
Wheat	2.4	3.3	4.1
Barley	2.0	3.1	4.1
Canola	0.9	2.0	3.0
Lupins	1.2	2.3	3.6
Grazed pasture (January) [3]	***1.0***	***1.5***	***3.0***

Source:

[1] Grain yield estimates from Primary Industries and Resources SA Field Crop Production Estimates, in Monthly Crop and Pasture Reports, for 1998 to 2007 inclusive.

[2] Stubble residue estimates post-harvest calculated from grain yields, on the basis of:
Cereal stubble dry matter (t/ha) = 1.5 x grain yield at low yields and 1.2 x grain yield at high yields. Median stubble yield calculated as 1.35 x median grain yield.
Canola and lupin stubble dry matter (t/ha) = 1.5 x grain yield.

[3] Grazed pasture residues estimated for early January based on discussions with Rural Solutions SA consultants.

Figure 2. Post-harvest crop stubbles in a “Median” season, showing differences in density, continuity and total bulk, which affect their fire fuel characteristics. Clockwise from top left: barley, canola, lupins (note residual cereal stubble from previous season), and faba beans.

2.5 Remnant vegetation fuels

Vegetation in non-arable paddocks was classified into various types ranging from sedgelands, to shrubland to woodlands (Figure 3). These data were supplied by the Department of Environment and Heritage, S.A. The characteristics of each vegetation type were used to classify them into fuel types. Each fuel type was allocated an appropriate surface, elevated and bark fine fuel hazard rating. These specific fuel characteristics were used in the simulations.

Of particular interest is the remnant vegetation incorporating eucalypts. The bark on the eucalypts has the potential to produce burning firebrands which may breach firebreaks and roads, starting new spotfires.

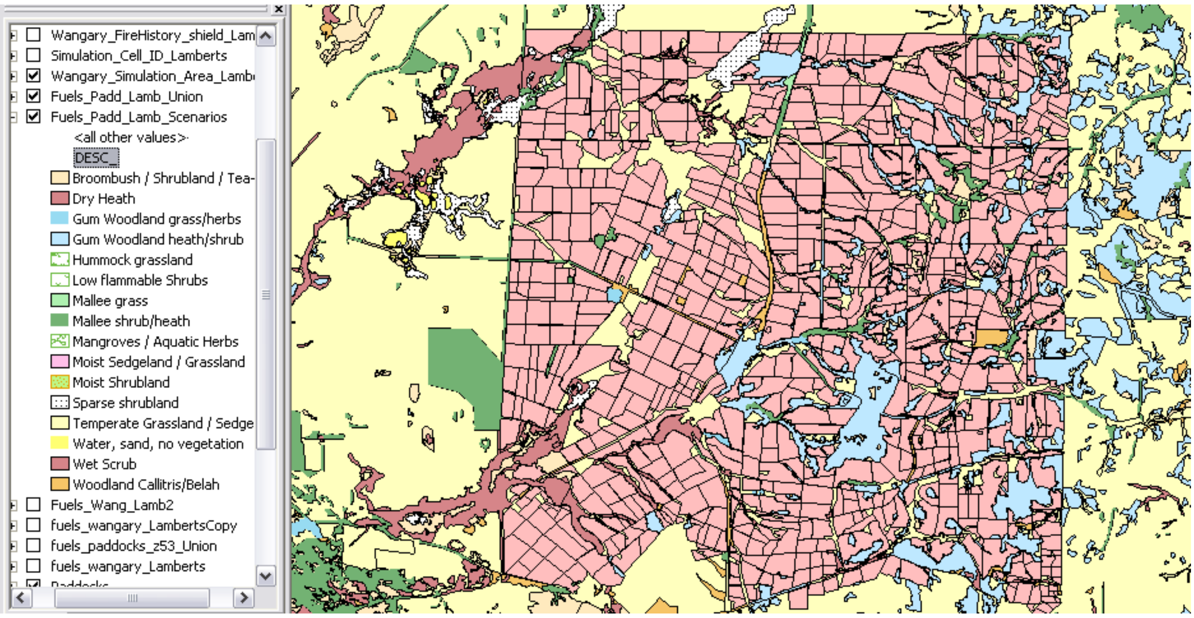

Figure 3. Remnant vegetation and pastures on non-arable land, in the simulation area of Lower Eyre Peninsula.

2.6 Fire protection works

Firebreaks were included in the modelling in three different configurations. Firstly, only existing roads and drainage lines were included as firebreaks and their effective width was assigned based on their importance, i.e. 8 m for "secondary roads", 5 m for "other roads sealed" and 4 m for "vehicular tracks", and 8 m for "watercourses" and 5 m for "channels" and "drains". Secondly, it was assumed that firebreaks would be ploughed around all arable paddocks to various widths (3, 6, 9 and 20 m). The extent of such a network is shown in Figure 4. Thirdly, it was assumed that firebreaks would be ploughed in arable paddocks only along fencelines adjoining areas of remnant vegetation and public roads. The extent of this network is shown in Figure 5.

The extent of each type of firebreak is given in Table 3. Watercourses have a total mapped length of 301 km and an area of 240 ha or 0.9% of the simulation area, and road pavements have a combined length of 238 km, covering an area of 141 ha or 0.5% of the simulation area. The total extent of the firebreaks represent up to 13.4% of the total area, which is considerably greater than the existing roads and watercourse network. Concentrating the firebreaks only to fencelines adjacent to public roads and areas of remnant vegetation halves the extent of the firebreaks.

In addition to the use of firebreaks, cereal crops adjacent to main roads were also assumed to be harvested for straw or hay thus reducing the residual fuel loads to 1 t/ha (e.g. Figure 6). An example of the layout of these paddocks is shown in Figure 7. Note that the paddocks are not continuous, so gaps exist for fire to penetrate these areas. In this modelling exercise, the area harvested for straw varies from about 1,000 ha to about 2,500 ha between cropping scenarios (see Table 9).

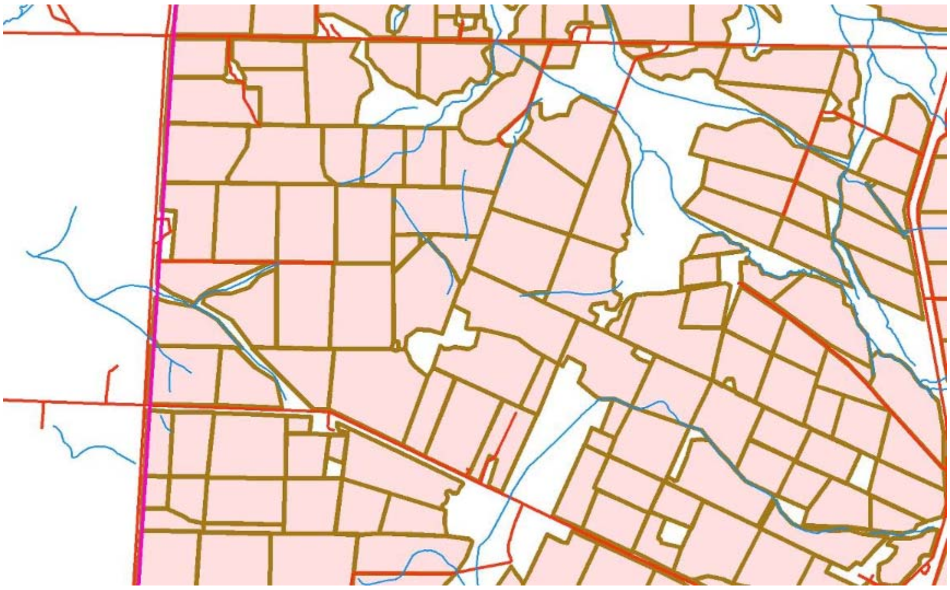

Figure 4. An example of the extent and location of firebreaks placed around each arable paddock (brown lines).

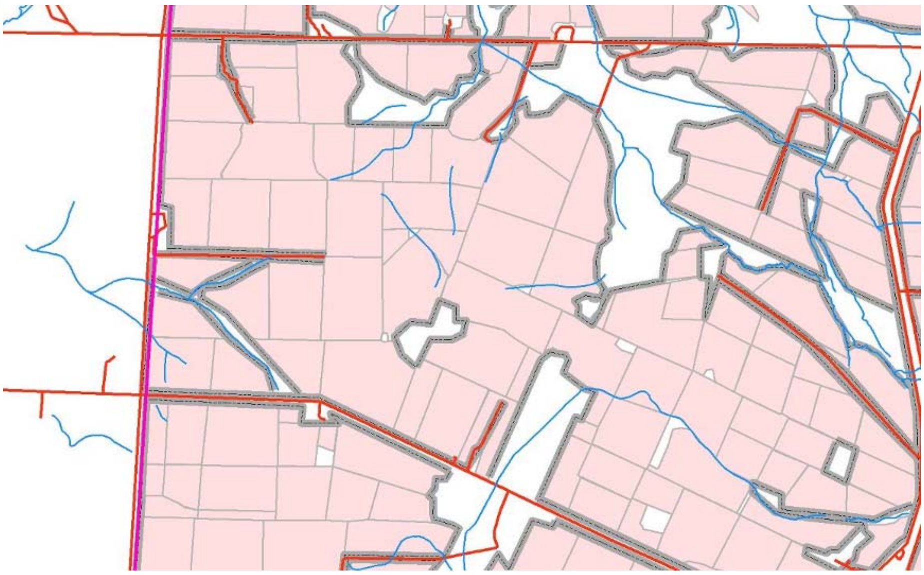

Figure 5. An example of the extent and location of firebreaks placed in arable paddocks adjacent to public roads and areas of remnant vegetation (broad grey lines).

Table 3. Total length (km), areal extent (ha) and relative proportion (%) of the simulation area occupied by complete perimeter firebreaks and strategic firebreaks adjacent to roadsides depending on their width.

Firebreak Type	Length (km)	3 m wide Area (ha)	6 m wide Area (ha)	9 m wide Area (ha)	20 m wide Area (ha)
Paddock Perimeter	1753	526 (2.0%)	1,052 (4.0%)	1,578 (6.0%)	3,506 (13.4%)
Paddock Roadside	753	226 (0.9%)	452 (1.7%)	678 (2.6%)	1,506 (5.7%)

Figure 6. Strategically located cereal paddocks cut for hay or baled as straw post-harvest can significantly reduce fire risk and improve effectiveness of fire suppression measures.

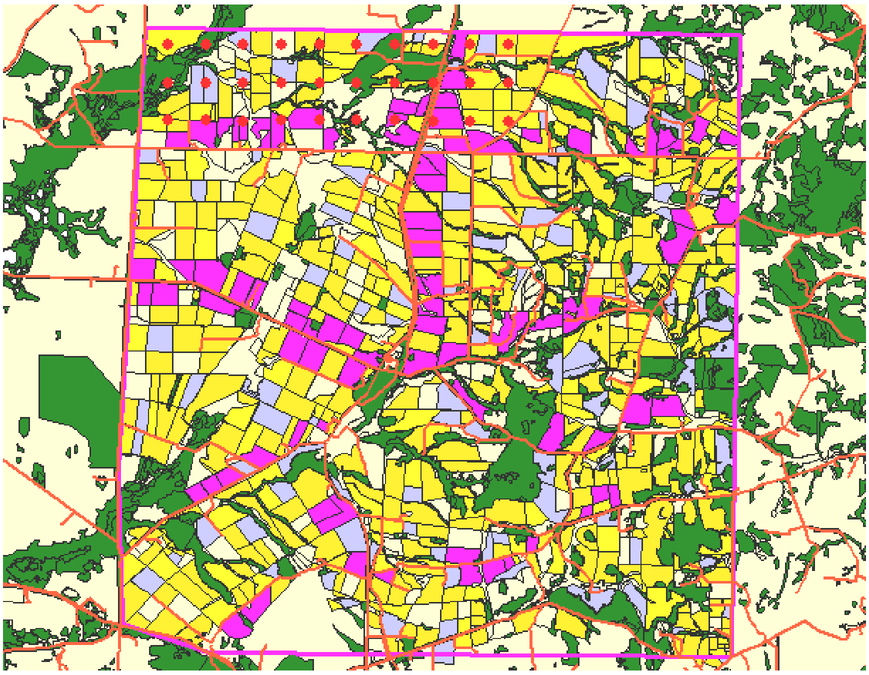

Figure 7. Paddocks coloured pink indicate cereal crops adjacent to main roads selected to be harvested for straw in cropping Scenario 5.

2.7 Ignition pattern

A fixed grid, 1 km x 1 km, of 30 ignition points was used for each simulation (Figure 8). The results reported here are for the average of these 30 fires within the specified simulation area. Each fire was run separately on the assumption that there would be only one fire in the area at any one time.

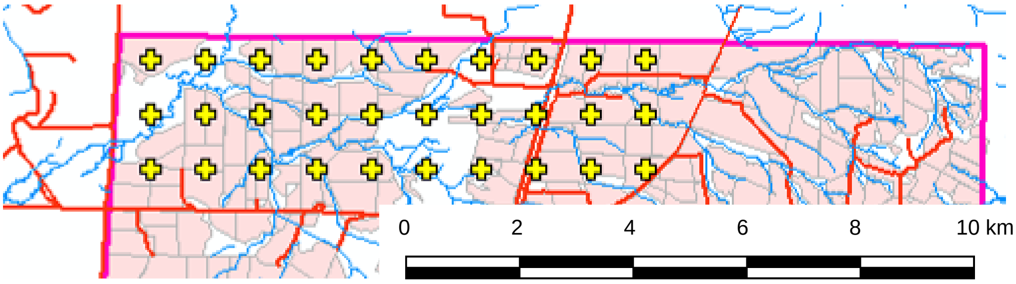

Figure 8. Grid of 30 ignition points, at one kilometre spacing, used in each simulation.

2.8 Weather pattern

Two sets of weather conditions were used in the simulations. The first set was the observed weather on January 11, 2005 on Lower Eyre Peninsula, which represents the highest recorded Grassland Fire Danger Index (GFDI) in Australia. The GFDI was developed by McArthur (1966) and has a scale from zero to 100, with 100 representing the worst known fire weather at the time of the index's development. The maximum GFDI calculated by extrapolation on January 11, 2005 was 340 at around noon. This set of weather conditions was therefore taken to be the "Worst-case" weather scenario (Table 4) and is based on a combination of the weather records from the Port Lincoln airport automatic weather station, selected observations taken in the field during the fire and inferences of wind direction derived from fire spread reconstructions as presented in the Coronial Inquiry by the author (KT).

The second set of weather conditions were based on the first. In order to keep as many variables as possible constant, a less severe but still "Extreme" weather scenario was developed, based on the observations from January 11, 2005. To do this, temperatures were reduced to 90% of observed, observed relative humidities were uniformly increased by 8% and wind speeds were reduced to 60% of the observed. This still resulted in Extreme fire weather for about one hour and Very High fire weather for about 4 hours (Table 5).

Table 4. Weather characteristics used to represent the "Worst-case" fire weather conditions. These are based on the observed weather on January 11, 2005 on Lower Eyre Peninsula.

Date / Time	Temp. (^oC)	RH (%)	Wind Speed (km/h)	Wind Dir (deg)	Grass FDI
11/01/2005 10:04	38.2	6	7	350	9
11/01/2005 10:34	39.9	5	43	323	124
11/01/2005 11:04	40.4	4	46	321	159
11/01/2005 11:34	41.4	3	54	312	242
11/01/2005 12:04	42.3	3	61	291	340
11/01/2005 12:16	37.2	9	56	288	177
11/01/2005 12:34	35.3	10	54	283	149
11/01/2005 13:04	35.5	9	54	282	156
11/01/2005 13:26	34.9	14	48	277	101
11/01/2005 14:04	33.8	16	57	278	140
11/01/2005 14:34	32.1	21	52	251	92
11/01/2005 14:44	31.6	25	46	229	64
11/01/2005 15:04	31.2	24	44	228	59
11/01/2005 15:34	31.3	9	48	226	108
11/01/2005 16:04	30.5	11	44	223	83
11/01/2005 16:24	29.6	15	41	221	59
11/01/2005 16:34	28.9	18	39	217	49
11/01/2005 17:04	26.7	31	39	215	34
11/01/2005 17:34	25.5	40	35	210	23
11/01/2005 18:04	24.6	44	35	211	21
11/01/2005 18:34	24.1	44	31	213	17
11/01/2005 19:04	22.7	50	33	230	16
11/01/2005 19:34	22.1	52	30	220	13
11/01/2005 20:04	20.8	58	28	230	10
11/01/2005 20:36	19.8	59	20	230	6
11/01/2005 21:04	19.1	65	20	230	5
11/01/2005 21:34	18.6	71	19	240	4
11/01/2005 22:04	18.3	75	17	240	3
11/01/2005 22:34	18	77	15	250	3
11/01/2005 23:04	17.6	79	15	250	3
11/01/2005 23:34	17	81	11	240	2

Table 5. Weather characteristics used to represent the "Extreme" fire weather conditions in the simulations. These follow the same patterns as those observed on January 11, 2005 on Lower Eyre Peninsula, but have been modified to represent more typical weather conditions.

Date / Time	Temp. (^{o}C)	RH (%)	Wind Speed (km/h)	Wind Dir (deg)	Grass FDI
11/01/2005 10:04	34.4	14	4	350	4
11/01/2005 10:34	35.9	13	26	323	32
11/01/2005 11:04	36.4	12	28	321	38
11/01/2005 11:34	37.3	11	32	312	53
11/01/2005 12:04	38.1	11	37	291	69
11/01/2005 12:16	33.5	17	33	288	42
11/01/2005 12:34	31.8	18	32	283	37
11/01/2005 13:04	32	17	32	282	38
11/01/2005 13:26	31.4	22	29	277	27
11/01/2005 14:04	30.4	24	34	278	35
11/01/2005 14:34	28.9	29	31	251	25
11/01/2005 14:44	28.4	33	28	229	19
11/01/2005 15:04	28.1	32	27	228	18
11/01/2005 15:34	28.2	17	29	226	28
11/01/2005 16:04	27.5	19	27	223	23
11/01/2005 16:24	26.6	23	24	221	18
11/01/2005 16:34	26	26	23	217	15
11/01/2005 17:04	24	39	23	215	11
11/01/2005 17:34	23	48	21	210	8
11/01/2005 18:04	22.1	52	21	211	7
11/01/2005 18:34	21.7	52	19	213	6
11/01/2005 19:04	20.4	58	20	230	6
11/01/2005 19:34	19.9	60	18	220	5
11/01/2005 20:04	18.7	66	17	230	4
11/01/2005 20:36	17.8	67	12	230	3
11/01/2005 21:04	17.2	73	12	230	2
11/01/2005 21:34	16.7	79	11	240	2
11/01/2005 22:04	16.5	83	10	240	2
11/01/2005 22:34	16.2	85	9	250	1
11/01/2005 23:04	15.8	87	9	250	1

2.9 Simulation setups

The simulation program, PHOENIX, was used to run each of the 30 fires independently. These were run with the two weather scenarios ("Worst-case" and "Extreme"), two firebreak layouts with four firebreak widths (3, 6, 9 and 20 m), for each of the three seasonal growing conditions ("Poor", "Median" and "Good"), with just one fire suppression resourcing option, six cropping scenarios and a limited application of cereal straw harvesting options. This represented 30 x 2 x 2 x 4 x 3 x 6, or 8,640 simulations using a one hectare resolution across the 26,250 ha study area. Eighteen simulations were run to estimate the potential impact of the suppression effort on reducing the extent of the fires.

Comparisons between scenarios were only made in terms of the relative area burnt, number of fires exceeding 200 ha, average fire intensity for all fires in a scenario, average flame height for all fires in a scenario and the relative area burnt in each scenario expressed as a percentage of the area burnt in the untreated reference scenario (e.g. Table 6). The relative area burnt is only relevant for the area burnt within the simulation area. Some fires are likely to continue burning outside the simulation area and become much larger. A fire of 200 ha was taken to be one that was controlled early in its development by firefighters. Once fires exceeded 200 ha, there was a strongly likelihood that the fires would be much larger before they were controlled. The average fire intensity and flame height gives an indication of how readily the fire might be suppressed if firefighting resources were present in sufficient numbers. Generally, fires exceeding an average intensity of 3,000 kW/m or with average flame heights exceeding 3 m would be difficult to suppress regardless of the number of resources. Finally, the percentage area burnt is simply a relative measure to make comparisons between different types of treatments easier.

No attempt was made to look at the relative impact of the fires on particular assets such as houses, fences, sheds or critical infrastructure. The potential social, economic and environmental impacts have been assumed to be related to the extent of the fires.

3.0 Results

The fire statistics presented in this analysis only represent that portion of the fires occurring within the simulation area (about 26,250 ha). Most of the larger fires burn an area much larger than the areas reported here, therefore the average fire size should only be taken as a relative measure, not an absolute one. If a much larger simulation area was to be considered, then the conclusions drawn here would be supported by greater absolute differences.

As discussed later under “Cropping intensity and rotational mix impact”, the six cropping scenarios ranging from 48% of arable area cropped (to cereals only) to 95% cropped (with a mix of cereals, canola and pulses such as lupins) all showed similar responses to fire weather severity, seasonal growing conditions and firebreak strategies. For simplicity therefore, simulation results for the two extreme cropping intensity scenarios only are shown in the following discussion of these major effects (Tables 6 and 7).

3.1 Daily fire weather impact

The simulation results demonstrate the significant difference in the extent of the area burnt and the larger number of fires greater than 200 ha that could result from fires starting during the “Worst-case” weather scenario as occurred on January 11, compared with an “Extreme” fire danger day as might be expected several times each year. In the case of cropping scenario 1 (Table 6) where there is about 48% of the arable area in cereal crop and the remainder in grazed pasture, there is about a 6-fold greater number and extent of fires with the “Worst-case” weather. In the case of cropping scenario 6 (Table 7) where about 95% of the arable area is under a combination of cereal, lupin and canola crops, the effect of the weather conditions is even greater - about 9-fold difference in the extent of fires. This is because the lupin and canola residues are less in quantity and therefore do not carry fire as well as cereal stubble or grazed pasture.

3.2 Seasonal growing conditions impact

Seasonal conditions also have a large impact on the extent and number of fires. In the two extremes of cropping intensity shown in Tables 6 and 7, generally fewer than half the fires reach 200 ha or more in the “Median” and “Poor” seasons than in “Good” seasons, regardless of the daily fire weather severity. This is due to the significantly lower levels of fuel in both crop and pasture paddocks in these seasons.

3.3 Firebreak width and location impact

In both cropping scenario 1 and 6, the 3, 6 and 9 m firebreaks have only minimal value in “Good” growth seasons and under “Worst-case” fire weather conditions (Figure 9). It was not until 20 m firebreaks were used that they became effective under these conditions. Nine metre wide firebreaks were relatively effective following “Poor” to “Median” growing seasons or in less severe fire weather conditions.

Table 6. Simulated fire characteristics for cropping scenario 1 (48% cropped - see Table 1) with two weather scenarios and three sets of seasonal conditions and nine firebreak arrangements. Firebreak "p" means perimeter of all paddocks and "r" means only adjacent to roadsides and remnant vegetation.

Weather	Season	Break_type (perimeter / roadside)	Break_width (m)	Area (ha)	>200ha (#/30)	Intensity (kW/m)	FlameHt (m)	% Area
Worst-case	Good	nil	0	3,762	21	12,643	2.6	100
		p	3	3,547	21	12,393	2.6	94
		p	6	2,922	20	11,177	2.5	78
		p	9	2,352	17	9,257	2.0	63
		p	20	265	4	1,672	0.3	7
		r	3	3,592	21	12,457	2.6	95
		r	6	3,323	21	11,960	2.6	88
		r	9	2,981	19	10,743	2.3	79
		r	20	1,007	11	5,146	1.1	27
	Median	nil	0	1,414	15	4,489	1.6	38
		p	3	1,047	12	3,398	1.3	28
		p	6	472	8	2,033	0.7	13
		p	9	173	3	1,087	0.3	5
		p	20	2	0	235	0.0	0
		r	3	1,248	14	4,011	1.4	33
		r	6	789	9	2,775	0.9	21
		r	9	379	6	1,869	0.5	10
		r	20	47	1	898	0.1	1
	Poor	nil	0	124	3	569	0.2	3
		p	3	19	1	196	0.0	0
		p	6	5	0	127	0.0	0
		p	9	0	0	35	0.0	0
		p	20	0	0	47	0.0	0
		r	3	101	2	101	0.2	3
		r	6	22	1	221	0.0	1
		r	9	3	0	158	0.0	0
		r	20	2	0	158	0.0	0
Extreme	Good	nil	0	656	5	1,505	0.3	17
		p	3	319	3	877	0.2	8
		p	6	218	3	789	0.1	6
		p	9	152	3	692	0.1	4
		p	20	0	0	133	0.0	0
		r	3	560	5	1,426	0.3	15
		r	6	437	5	1,344	0.3	12
		r	9	292	4	1,034	0.2	8
		r	20	20	1	295	0.1	1
	Median	nil	0	26	1	173	0.0	1
		p	3	11	1	105	0.0	0
		p	6	2	0	112	0.0	0
		p	9	0	0	50	0.0	0
		p	20	0	0	49	0.0	0
		r	3	18	1	132	0.0	0
		r	6	5	0	87	0.0	0
		r	9	2	0	88	0.0	0
		r	20	1	0	117	0.0	0
	Poor	nil	0	0	0	0	0.0	0
		p	3	0	0	0	0.0	0
		p	6	0	0	0	0.0	0
		p	9	0	0	0	0.0	0
		p	20	0	0	0	0.0	0
		r	3	0	0	0	0.0	0
		r	6	0	0	0	0.0	0
		r	9	0	0	0	0.0	0
		r	20	0	0	0	0.0	0

Table 7. Simulated fire characteristics for cropping scenario 6 (95% cropped - see Table 1) with two weather scenarios and three sets of seasonal conditions and nine firebreak arrangements. Firebreak "p" means perimeter of all paddocks and "r" means only adjacent to roadsides and remnant vegetation.

Weather	Season	Break_type (perimeter / roadside)	Break_width (m)	Area (ha)	>200ha (#/30)	Intensity (kW/m)	FlameHt (m)	% Area
Worst-case	Good	nil	0	3,894	21	13,688	2.7	100
		p	3	3,662	21	13,304	2.7	94
		p	6	2,994	20	12,095	2.6	77
		p	9	2,485	17	9,888	2.1	64
		p	20	413	**5**	2,880	**0.6**	11
		r	3	3,743	21	13,436	2.7	96
		r	6	3,539	21	13,068	2.6	91
		r	9	3,189	20	11,983	2.4	82
		r	20	1,292	**13**	6,335	**1.3**	33
	Median	nil	0	2,031	16	6,067	**1.8**	52
		p	3	1,678	**15**	5,399	**1.7**	43
		p	6	1,232	**14**	4,730	**1.4**	32
		p	9	656	**10**	2,972	**1.0**	17
		p	20	5	**0**	440	**0.0**	0
		r	3	1,822	**15**	5,502	**1.7**	47
		r	6	1,426	**14**	4,845	**1.6**	37
		r	9	1,091	**13**	4,174	**1.3**	28
		r	20	102	**2**	1,144	**0.2**	3
	Poor	nil	0	246	**5**	934	**0.3**	6
		p	3	145	**3**	588	**0.2**	4
		p	6	6	**0**	311	**0.1**	0
		p	9	4	**0**	262	**0.0**	0
		p	20	1	**0**	110	**0.0**	0
		r	3	159	**3**	667	**0.2**	4
		r	6	52	**3**	592	**0.1**	1
		r	9	27	**1**	495	**0.0**	1
		r	20	3	**0**	250	**0.0**	0
Extreme	Good	nil	0	410	**3**	1,276	**0.2**	11
		p	3	569	**5**	1,705	**0.3**	15
		p	6	388	**5**	1,448	**0.3**	10
		p	9	146	**3**	1,109	**0.2**	4
		p	20	0	**0**	106	**0.0**	0
		r	3	354	**3**	1,225	**0.2**	9
		r	6	344	**4**	1,434	**0.2**	9
		r	9	191	**3**	1,134	**0.2**	5
		r	20	50	**1**	680	**0.1**	1
	Median	nil	0	43	**2**	428	**0.1**	1
		p	3	5	**0**	199	**0.0**	0
		p	6	3	**0**	117	**0.0**	0
		p	9	1	**0**	100	**0.0**	0
		p	20	0	**0**	116	**0.0**	0
		r	3	36	**2**	397	**0.1**	1
		r	6	13	**1**	185	**0.0**	0
		r	9	3	**0**	162	**0.0**	0
		r	20	2	**0**	196	**0.0**	0
	Poor	nil	0	0	**0**	0	**0.0**	0
		p	3	0	**0**	0	**0.0**	0
		p	6	0	**0**	0	**0.0**	0
		p	9	0	**0**	0	**0.0**	0
		p	20	0	**0**	0	**0.0**	0
		r	3	0	**0**	0	**0.0**	0
		r	6	0	**0**	0	**0.0**	0
		r	9	0	**0**	0	**0.0**	0
		r	20	0	**0**	0	**0.0**	0

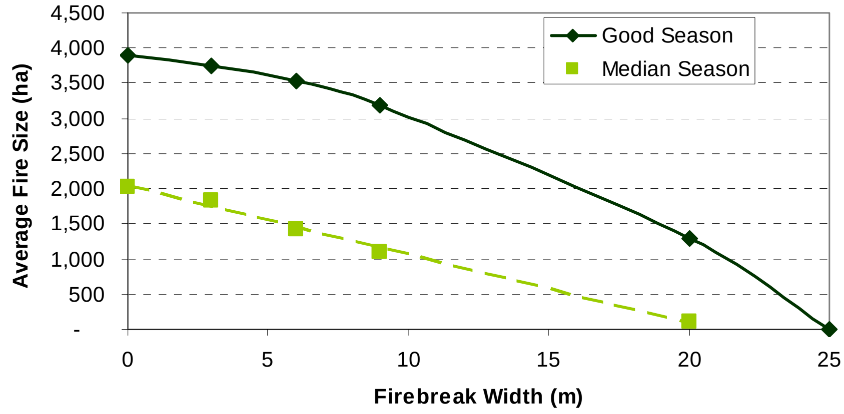

Figure 9. Effectiveness of different firebreak widths under "Worst-case" weather conditions in terms of average fire size under continuous cropping (scenario 6), following "Good" and "Median" growing seasons, assuming the firebreaks were adjacent to public roads and remnant vegetation.

3.4 Cropping intensity and rotational mix impact

If we just consider using 20 m firebreaks, then there is no significant difference between the six cropping scenarios investigated (Table 8). Weather and seasonal conditions are far more important in determining the average extent of areas burnt.

Table 8. Simulated average fire extents (ha) for all six cropping scenarios (see Table 1) with two weather scenarios and three sets of seasonal conditions and three firebreak arrangements. Firebreak "p" means perimeter of all paddocks and "r" means only adjacent to roadsides and remnant vegetation.

Weather	Season	Break_type (perimeter / roadside)	Break_width (m)	Cropping Scenarios S1	S2	S3	S4	S5	S6
Worst-case	Good	nil	0	3762	3918	3796	3852	3907	3894
		p	20	265	468	290	305	324	413
		r	20	1007	1152	984	1166	1018	1292
	Median	nil	0	1414	1916	1586	1740	1891	2031
		p	20	2.0	3.7	2.1	2.1	2.1	5.1
		r	20	47	15	47	40	13	102
	Poor	nil	0	124	254	109	83	32	246
		p	20	0.2	0.2	0.2	0.6	0.3	0.7
		r	20	2.1	3.3	2.1	1.1	1.1	3.2
Extreme	Good	nil	0	656	397	704	228	626	410
		p	20	0.4	0.5	0.8	0.6	0.5	0.3
		r	20	20	25	23	24	69	50
	Median	nil	0	26	56	27	12	49	43
		p	20	0.2	0.2	0.3	0.3	0.2	0.4
		r	20	1.2	0.9	1.3	0.4	0.7	2.0
	Poor	nil	0	0.0	0.0	0.0	0.0	0.0	0.0
		p	20	0.0	0.0	0.0	0.0	0.0	0.0
		r	20	0.0	0.0	0.0	0.0	0.0	0.0

3.5 Impact of harvesting cereal straw on fire extent

It was seen that when fuel levels were reduced by poorer seasonal growth conditions, the extent of burning was significantly reduced. This was a result of less intense fires and more effective suppression under these conditions. It is reasonable to expect that by harvesting some of the cereal stubble, there might be a similar reduction in fire intensity and increased ability to suppress fires even in good growing seasons.

Cereal paddocks adjacent to major roads were selected with the expectation that these would give the best fire control value by combining with the effects of roads and firebreaks. Only the effect of harvesting cereal straw in “Good” seasons in combination with 20 m firebreaks adjacent to roads and remnant vegetation was investigated to give an indication of the potential value of straw harvesting. It was assumed that the harvesting of cereal straw would still leave 1 t/ha of residue, the equivalent of a grazed pasture in a poor year (Table 2). This is would assumed that 3 of the 4 t/ha of cereal stubble would be harvested for straw in a good growing season.

Depending on the cropping scenario used, the extent of straw harvesting ranged from 8 to 21% of the arable land, which represented about 15% of all cereal crops and about 7% of the landscape (Table 9).

Straw harvesting approximately halved the average extent of fires in the landscape (Table 10). In the case of the “Worst-case” weather conditions, straw harvesting reduced the extent of fires to somewhere between a “Poor” and “Median” growing season, even though less than 10% of the landscape had been treated.

Table 9. Extent of different crop types in each of the cropping scenarios including the extent of cereal stubble harvested for straw.

	Extent (Ha)					
CropType	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**
Wheat/Barley	7,708	9,396	7,902	5,810	7,802	9,105
Lupins	0	0	0	3,727	2,833	3,408
Canola	0	0	4,324	3,637	3,177	3,637
Cereal Straw	1,245	2,492	1,205	1,086	1,280	1,540
Pasture/other	9,653	6,718	5,175	4,346	3,514	916
Cropping Intensity (%)	48	64	72	77	81	95

Although not specifically modelled in this study, cutting and baling a cereal crop for hay in late spring could be expected to produce a similar result in terms of reduction in fire risk, provided the residual stubble was reduced to around 1 t/ha and there was no subsequent regrowth of the cereal following cutting. Baling cereal hay can be a profitable option for farmers, and has the advantage of being done prior to harvest, thereby reducing fire danger earlier in the season. An alternative strategy, but one which was also not specifically considered in this study, is to cut and bale hay from a 20 m wide strip around the perimeter of cereal paddocks, creating a firebreak and leaving the remainder to be harvested later as grain.

Table 10. Simulated average fire extents (ha) for all six cropping scenarios (see Table 1) with two weather scenarios and three sets of seasonal conditions and three firebreak arrangements. Data in grey shaded row indicate average fire size in "Good" seasons where straw has been harvested from selected paddocks. Firebreak "p" means perimeter of all paddocks and "r" means only adjacent to roadsides and remnant vegetation.

Weather	Season	Break_type (perimeter / roadside)	Break_width (m)	Cropping Scenarios						
				S1	S2	S3	S4	S5	S6	
Worst-case	Good	nil	0	3,762	3,918	3,796	3,852	3,907	3,894	
Worst-case	Good	p	20	265	468	290	305	324	413	
Worst-case	Good	r	20	1,007	1,152	984	1,166	1,018	1,292	
Worst-case		r	20	554	424	527	592	533	718	Straw
Worst-case	Median	nil	0	1,414	1,916	1,586	1,740	1,891	2,031	
Worst-case	Median	p	20	2	4	2	2	2	5	
Worst-case	Median	r	20	47	15	47	40	13	102	
Worst-case	Poor	nil	0	124	254	109	83	32	246	
Worst-case	Poor	p	20	0	0	0	1	0	1	
Worst-case	Poor	r	20	2	3	2	1	1	3	
Extreme	Good	nil	0	656	397	704	228	626	410	
Extreme	Good	p	20	0	0	1	1	1	0	
Extreme	Good	r	20	20	25	23	24	69	50	
Extreme		r	20	11	3	12	5	28	19	Straw
Extreme	Median	nil	0	26	56	27	12	49	43	
Extreme	Median	p	20	0	0	0	0	0	0	
Extreme	Median	r	20	1	1	1	0	1	2	
Extreme	Poor	nil	0	0	0	0	0	0	0	
Extreme	Poor	p	20	0	0	0	0	0	0	
Extreme	Poor	r	20	0	0	0	0	0	0	

3.6 Impact of fire suppression

Active fire suppression, using the level of resources currently available, approximately halves the average extent of fires within the simulated area following "Good" growing seasons and under "Worst-case" weather conditions (Table 11). When the effects of suppression and firebreaks are combined, then fire suppression decreases the average fire extent by a third. In more normal "Extreme" weather conditions, the average fire extent is reduced by a factor or 10 or more. There is a very significant reduction in the number of fires exceeding 200 ha.

Suppression effectiveness is significantly improved by strategic reduction of fire intensity as can be achieved by firebreaks and straw harvesting.

Table 11. Comparison of average extent of fires and number of fires exceeding 200 ha following “Good” growing seasons for continuous cropping (S6), with and without fire suppression efforts.

Weather	Season	Break_type (perimeter / roadside)	Break_width (m)	No Suppression: Area (ha)	No Suppression: >200ha (#/30)	With Suppression: Area (ha)	With Suppression: >200ha (#/30)
Worst-case	Good	nil	0	6,567	29	3,894	21
		p	3	6,337	29	3,662	21
		p	6	5,936	28	2,994	20
		p	9	5,335	27	2,485	17
		p	20	2,067	18	413	**5**
		r	3	6,419	29	3,743	21
		r	6	6,197	29	3,539	21
		r	9	5,674	28	3,189	20
		r	20	3,422	24	1,292	**13**
Extreme	Good	nil	0	4,420	29	410	**3**
		p	3	3,723	27	569	**5**
		p	6	2,841	24	388	**5**
		p	9	1,782	20	146	**3**
		p	20	468	**11**	0	**0**
		r	3	4,014	28	354	**3**
		r	6	3,254	26	344	**4**
		r	9	2,542	25	191	**3**
		r	20	1,215	22	50	**1**

3.7 Combined impacts

The impacts of various fire protection measures interact to produce an effect greater than the sum of the individual factors. Figure 10 shows an example of a fire burning under the “Worst-case” weather conditions, following a “Good” growing season, where 20 m wide firebreaks have been ploughed in paddocks adjacent to roads and areas of remnant vegetation (“r20”) (e.g. Figures 12 and 13), stubble in paddocks also adjacent to these roads has been harvested as straw (“straw”) and fire suppression has been applied with the standard available resources. As a result, the intensity of the fire varies in a patchy fashion (Figure 10), which results in some areas being easily suppressed or being stopped by firebreaks and straw harvesting (blue lines). The effectiveness of the firebreaks is enhanced by the straw harvesting. The strategic location of firebreaks on either side of roads enhances the disruption to the spread of the fire to a point where it effectively stops it at many places.

In contrast, Figure 11 shows the resultant fire in the absence of fire suppression, ploughed firebreaks, and strategic straw harvesting. Roads and bare drainage lines result in locally reduced fire intensity, but the fire still breaches these barriers. The extent of the area burnt within the study area is more than three times as great in this simulation as under the conditions used to produce the result shown in Figure 10.

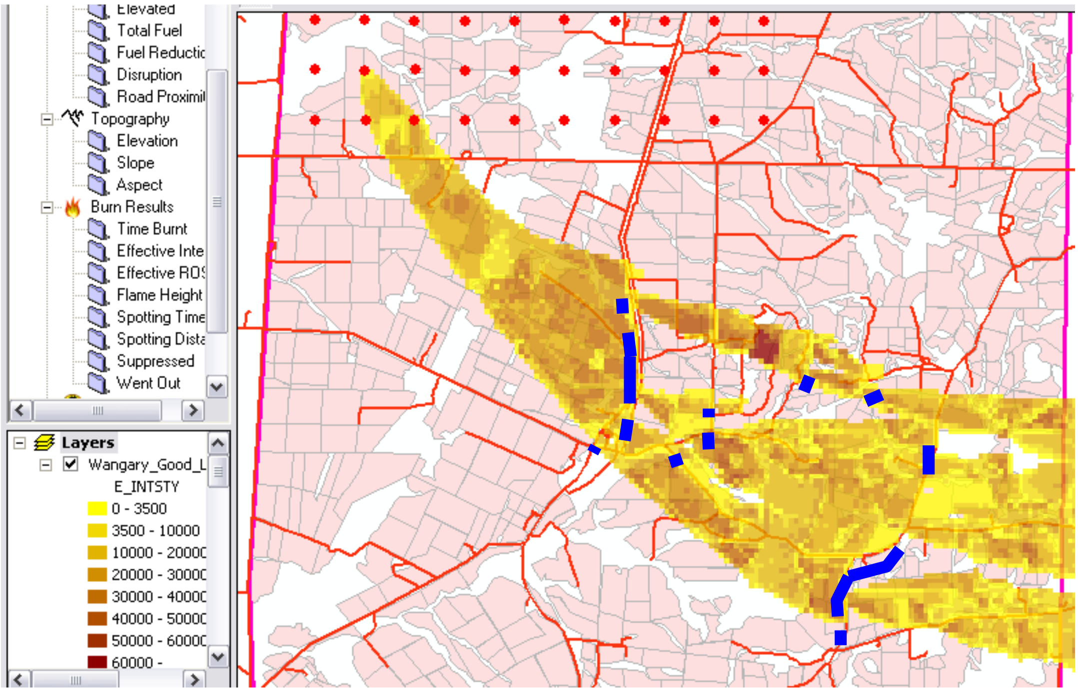

Figure 10. An example of the combined effect of 20 m “roadside” firebreaks, strategic straw harvesting and fire suppression under “Worst-case” weather conditions, following a “Good” growing season, for the continuous cropping scenario (scenario 6). The shades of yellow to brown show increasing levels of fire intensity within the burnt area.

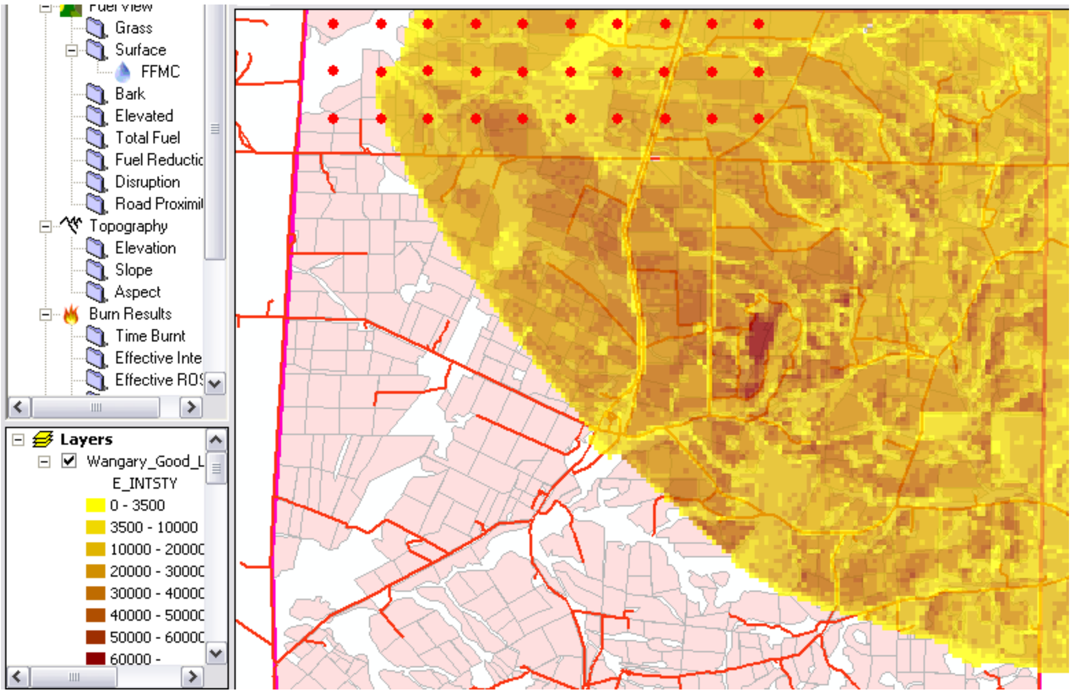

Figure 11. Intensity and extent of fire shown in Figure 10 without suppression, firebreaks (other than roads and streams), or straw harvesting, following a “Good” growing season with the “Worst-case” weather conditions and continuous cropping (scenario 6). The shades of yellow to brown show increasing levels of fire intensity within the burnt area.

Figure 12. An example of a 20 m wide firebreak ploughed around a field pea crop after harvesting. This is the size of firebreak needed to be effective under “worst-case” fire weather conditions.

Figure 13. An example of a 3 m wide firebreak ploughed around a cereal crop after harvesting. Modelling here only found this type of break to be effective under mild fire weather conditions.

4.0 Conclusions

The main findings of this study are:

1. Fire weather severity, as measured by the McArthur's Grassland Fire Danger Index, is the main driver of fire extent and impact.
2. Quick and effective fire suppression significantly reduces the extent and impact of fires, even under "Worst-case" weather conditions.
3. Seasonal growing conditions affect fuel amount and continuity, with firebreaks and fire suppression being less effective in "Good" seasons.
4. Strategic harvesting of hay or straw (~15% of total cereal crop area), used in conjunction with 20 m roadside firebreaks, in "Good" seasons has a similar effect in reducing the extent of fires as having a "Poor" or "Median" growing season.
5. Firebreaks need to be at least 20 m wide to significantly impact on headfire spread under "Extreme" and "Worst-case" weather conditions.
6. Strategically locating firebreaks adjacent to public roads and areas of remnant native vegetation significantly reduces the area needing treatment without significantly reducing the effectiveness of the strategy.

In response to the question:
Is there a particular "pattern" of cropping that would limit the spread of wildfire under extreme fire weather conditions?
The six levels of cropping intensity, ranging from 48 to 95% of arable land cropped in any year, all resulted in similar fire impacts. It is concluded that variation in cropping intensity on its own does not significantly affect the extent of fire in the landscape. Seasonal growth conditions were more important in providing fuel continuity across the landscape than cropping intensity. But note that this result is based on the assumption that pasture paddocks are grazed effectively throughout the year, providing efficient pasture utilisation while maintaining adequate soil cover to protect soil from erosion through summer and autumn.

In response to the question:
What effect would bare (ploughed) firebreaks of varying widths (3, 6, 9 and 20 m) between fences and crops have on fire spread?
It was found that narrow firebreak widths (<10 m) did not have a very significant effect on the extent of fires because of their inability to stop the headfire. The effectiveness of firebreaks was significantly reduced as the level of fuels in the landscape increased (i.e. in good growing seasons) and under "Worst-case" weather conditions. For firebreaks to have their greatest benefit under "Worst-case" weather conditions in a "Good" growing season, they need to be about 20 m wide.

Much of the benefit from firebreaks can be achieved if they are only located in arable paddocks adjacent to public roads and along boundaries with remnant vegetation. For 20 m wide firebreaks, this reduces the proportion of the landscape in firebreaks from 13.4% to 5.7%, with only limited loss of the value of the firebreaks.

In response to the question:
What effect do roads have on fire spread?
Roads did not have a significant effect on restricting the extent of fires in the landscape under the "Worst-case" weather scenario. They were generally too narrow to stop the head of the fire. Fire intensity did reduce at roads, but the fire still crossed them.

Roads assisted in the suppression of the fire, but under "Worst-case" weather, the fires were spreading too fast for suppression forces to keep up with the rate of spread. Under "Extreme" conditions, fire suppression efforts were able to restrict the extent of the fires, keeping most of them to less than 200 ha. A significant amount of suppression still needed to be undertaken in paddocks as the road network was not dense enough to keep all fires small.

In response to the question:
What effect do different types of roadside vegetation have on fire spread?
Roadside vegetation was sufficiently dense that fires in them under "Worst-case" weather conditions were able to breach the roads. This vegetation slowed the wind speed locally to some extent, but only for a short period of time. Medium to long-range spotting from roadside vegetation did not appear to be common, but this is based on the vegetation mapping indicating very few eucalypts in the vegetation in the study area.

One of the objectives of having firebreaks in paddocks adjacent to public roads and remnant vegetation is to reduce the run of fire into these areas. This achieves the benefit of wind reduction without the disadvantage of locally more intense fires being as great a problem.

Overall, it is concluded that a combination of fire prevention and suppression measures are needed. The main threat from fire occurs when "Worst-case" weather conditions coincide with a season where there has been good growth. A combination of strategic hay baling or straw harvesting and ploughed or graded firebreaks adjacent to public roads and remnant vegetation will provide the greatest level of protection for the minimum cost and level of soil disturbance.

It should be noted that the results of this modelling study are heavily dependent on the crop and pasture residue yield assumptions shown in Table 2, for a range of seasonal growing conditions on Lower Eyre Peninsula. Livestock numbers and the level of grazing pressure can have a major effect on pasture residues into summer and the ability to reduce the bulk of crop stubble residues post-harvest. Different grazing pressures were not incorporated into the simulation study.

5.0 References

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