Controlling Bushfires – A Feasibility Study

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Abstract

Rural Australian communities face a significant risk of losing lives or property to bushfires. As the climate trends warmer, there is an expected increase in the incidence of weather in which extreme fires occur. Simultaneously, multiple oil/gas extraction operations on state, national and global scales must either dispose of or reuse decommissioned flexible flowlines. These flowlines consist of high-quality materials and can transport fluids at high pressures even after decommissioning. Thus, there is an opportunity to investigate whether these flowlines can be used in combatting the increasing threat of bushfires. This project examines the technical feasibility of using these flowlines to produce a fixed bushfire containment grid. On ignition of a fire within the grid, each grid cell disperses water to ensure containment of the fire within a single grid cell. To determine this feasibility of this grid, modelling was conducted starting from a set of environmental conditions, then working out the expected severity of the bushfire under these conditions, the volumetric flowrate required to contain the fire at the grid boundary, to arrive at at a required peak and total flowrate of water for containment. It was found that the proposed grids could feasibly protect against highly severe bushfires.

1. Introduction

Bushfires pose severe economic, social, and environmental risk to Australian society (DSE, 2010), and many societies around the world (Gill et al., 2013). The 2009 Black Saturday bushfires in Victoria were projected to have caused around AUD$1.8 billion of direct economic losses, most of this figure deriving from the loss of residential and agricultural structures and properties (DSE, 2010). These fires claimed 174 lives and destroyed 2298 residences (DSE, 2010). This fire event was estimated to have emitted around 165Mt of CO2, around a third of Australia's annual emissions (DSE, 2010). Fires are estimated to cost around AUD$8.5 billion annually, ~1.15% of Australia's GDP (Sharples, et al., 2016).

Current research indicates that the incidence of "fire weather" (hot, dry and windy weather correlated with high fire severity) as quantified by the McArthur Forest Fire Danger Index (FFDI) have progressively increased over south-eastern Australia for the last 35 years (Booth and Riordan, 2009), consistent with a projected increase in annual total FFDI linked to climate change (Dowdy, 2018; Clarke et al., 2012). Given that FFDI is a projection of the likelihood and severity of bushfires occurring under the given conditions (Booth and Riordan, 2009), this indicates that the frequency of extreme bushfires will likely rise as the climate changes.

This thesis considers a new fire containment method based on a tessellated bushfire containment grid with the use of decommissioned flexible subsea petroleum flowlines. A diagram of the proposed cell arrangement may be noted in Figure 1. A model was developed to assess the potential for these pipes to be used. In forming this grid, the pipes shall be retrofitted with water dispersal attachments to prevent the spread of a bushfire of a specified magnitude between cells of the grid. These dispersal attachments will be designed such that they can be rapidly automatically activated by a detection system upon ignition of a flame within the cell (the exact method of detection will be a subject of future research).

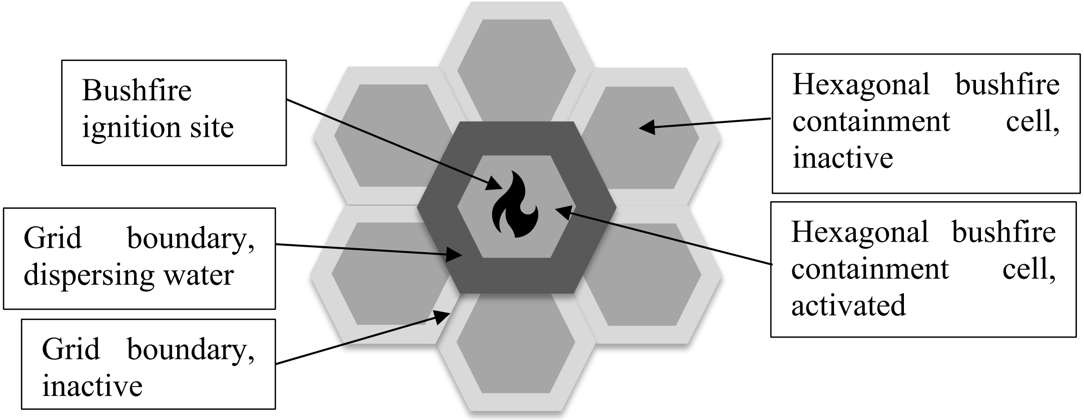


Figure 1 Example grid arrangement, showing the central cell activating to contain a bushfire ignition site.

Water can combat a fire via absorbing heat from either the flames, the burning fuel or from objects that are located near to the fire. By cooling surrounding objects, it is possible to limit the spread of the fire by ensuring that potential fuel items do not reach the temperature required for ignition (Mawhinney et al., 1994). By cooling the flames or fuel, the heat flux incident onto the fuel is reduced and thus the pyrolysis rate (essentially the rate of fuel consumption) is similarly reduced (Mawhinney et al., 1994). Considering that larger droplet sizes of water penetrate further through flames before vaporisation (Yu & Liu, 2018), larger droplet sizes are more effective at absorbing heat and extinguishing the fire (Mawhinney et al., 1994).

Water vapour can also combat fire by displacing oxygen from the atmosphere surrounding the fire (Mawhinney et al., 1994). Water increases in volume by an order of 1900 times as it evaporates, and particularly in the case of fires in enclosed compartments can effectively exclude oxygen from the atmosphere (Mawhinney et al., 1994). Bushfires, however, occur in an open environment, making the degree to which oxygen is displaced from the nearby atmosphere small in comparison to a compartment fire, and can be neglected (Hansen, 2012).

Water can also attenuate thermal radiation, preventing surrounding unignited fuel from reaching the ignition temperature (Mawhinney et al., 1994). The degree of attenuation is significantly affected by the size of the mist droplets, with the percentage of light attenuated being maximised when the size of the droplets is on the same order as the light's wavelength (Balner & Barcova, 2017). If the light spectrum of a bushfire is idealised as emitted by a 1300K black body, 95% of the wavelengths are in the 1-10μm range (Balner & Barcova, 2017). Thus, the ideal size of droplet for attenuation occurs when the average size of the droplets approaches this range. The degree of attenuation also varies upon the mass concentration of the mist which the radiation is passing though, increasing with a greater quantity of mist within the attenuation region with diminishing returns (Balner & Barcova, 2017).

As water causes extinguishment via cooling of the flames/fuel, the amount of water required can be found via balancing energy such that the enthalpy requirement for ignition of new fuel is not met (Hansen, 2012). This involves balancing the heat input to the system from combustion against the heat being extracted from the system via absorption by the water or otherwise exiting the system via heat flux (Hansen, 2012). The moisture content of the fuel material significantly impacts both the probability and time of ignition under a given intensity of incident radiation (Ramadhan et al., 2021; Possell & Bell, 2013). Fuel sources of different species exhibit comparable ignition behaviour, Possell & Bell (2013).

2. Feasibility Assessment Methodology

The feasibility of the grid was assessed via multiple successive steps of modelling:

1. Modelling bushfire propagation and severity under set environmental conditions.
2. Predicting the optimal required quantity of water to contain a fire of known severity per metre of barrier.
3. Calculating peak and total water consumption required to contain the bushfire to a single cell of the grid.

The bushfires were modelled via the software Spark1. Spark1 is a purpose-built modelling program that takes environmental, fuel and topography inputs and estimates the geometry and severity of bushfire expected to result under these conditions based on empirical studies (CSIRO Data 61, n.d.). Two flora conditions were modelled as representative archetypes of the vast number of Australian ecosystems, “grassland” and “dry eucalypt forest” conditions. Typically, forests tend to accumulate a larger mass of fuel per area than grasslands (Booth and Riordan, 2009). 6t/ha and 30t/ha were adopted as the worst-case fuel accumulation value for grassland and forest conditions respectively (NSW Rural Bushfire Service, 2019).

Weather inputs were also introduced into the model, their severity summarised in the results as a single index value of FFDI. FFDI’s of 40-100 were considered at increments of 5, corresponding to weather conditions of “very high” and “catastrophic” fire danger respectively. Weather conditions of FFDI 25-49 are classed as having “very high” fire danger, conditions of FFDI between 50-74 are classed as having “severe” fire danger, conditions between 75-99 are classes as having “extreme” fire danger and finally all conditions of 100+ FFDI are classed as having “catastrophic” fire danger. Each model produces results for the expected flame lengths and fireline intensities at the front of the bushfire, as well as the directional propagation rates of the bushfire.

The optimal water usage for bushfire containment per unit length of barrier was determined via use of a generalised reduced gradient method optimisation solver, determining the optimal amount of water to be attributed to each of three containment mechanisms:

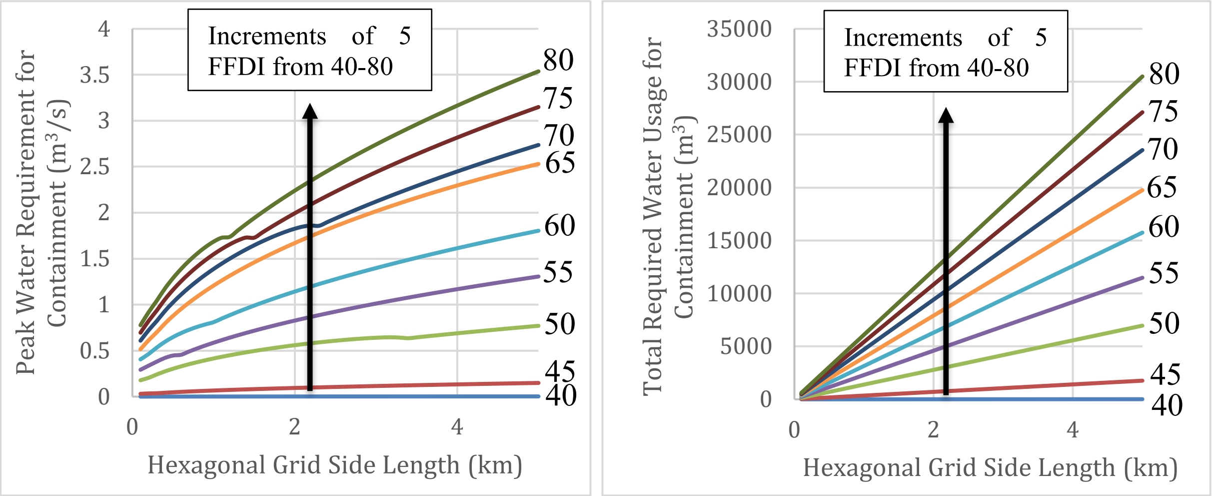
1. Application of water to the incoming bushfire front to extinguish flames.
2. Creation of a mist “barrier” to attenuate incident thermal radiation and reduce the heat flux upon unignited fuels.
3. Spraying of cooling water upon unignited fuel to prevent ignition.

The effect of each of these mechanisms upon the flames and unignited fuel was quantified using standard literature calculation procedures. Additionally, the spray range of each of these mechanisms was constrained via the expected allowable pressure within the flowlines. This allowable pressure was determined via consultation with industry professionals. Barriers composed of either a single row or multiple rows of dispersal flowlines were analysed in this step. The flames considered in this portion of the modelling were generated from the outputs of the previous step, the flame heights and fireline intensities generated at the front of bushfires occurring under set environmental conditions. This phase of modelling determined whether the barrier could contain the bushfire under a set pressure limit, and the total and per-mechanism volumetric flowrates of water required per length of barrier if containment is possible.

Finally, hydraulic modelling was completed to determine the total volume and peak flowrate of water consumption required to contain a bushfire under set environmental conditions and given barrier dimensions. These variables were calculated via utilisation of the per-length volumetric flowrates calculated in the previous modelling phase in combination with the worst-case lengths of barrier exposed to flames as calculated from the directional propagation rates found from the bushfire models. Thus, peak, and total water consumption was determined for each permutation of weather and grid size for both flora archetypes.

3. Results and Discussion

Containment modelling indicated that the dispersal boundaries were likely to be capable of protecting against bushfires occurring under FFDIs of 80 and 65 for grassland and forest conditions respectively under the set allowable pressure. These FFDI values respectively correspond to weather conditions of “extreme” and “severe” fire danger. It is expected that forest conditions produce fires that are more difficult to contain under the same weather conditions, this is likely driven by the greater mass of fuel that typically accumulates in forests in comparison to grasslands. This greater mass of fuel leads to a greater release of energy per surface area of fuel consumed, resulting in the bushfire modelling program predicting both larger flames and a greater outgoing intensity of heat flux upon unignited fuel. Figures 2 & 3 show the peak flowrate and total consumption of water for containment of the bushfire to a single grid cell under varied grid size and FFDI in both flora conditions.



Figures 2 & 3 Peak (Figure 2, Left) & Total (Figure 3, Right) water requirements for containment of water to a single grid cell under varied FFDI and grid size for a pressure limit of 20bar in grassland conditions allowing multiple flowline rows.

Both peak and total water usage increase as FFDI or grid size increase in both flora cases. This is expected, a more severe fire (one which occurs under higher FFDI) should require a greater volume of water for containment. It is also expected that a greater grid size should lead to increased total water usage if the entire length of the barrier is exposed to flames. The peak flowrate of water for containment also increased with grid size, this is likely due to a larger grid offering more time for the fire front to gain width before hitting the grid boundary. Finally, it should be noted that forest flora conditions require significantly higher peak and total water usages in comparison to grassland conditions, this is likely caused by higher fuel loads and thus more severe fires under forest conditions.

4. Conclusions and Future Work

This thesis considered a variety of different conditions under which a bushfire can occur, out of a near unlimited set of permutations. It was found that under optimal conditions, the arrangement of grid boundary dispersal mechanisms could protect against fires occurring in conditions up to FFDIs of 80 ("extreme" fire weather) and 65 ("severe" fire weather) in grassland and forest conditions respectively. In considering these values, the predicted effectiveness of the system varied with allowable pressure and whether multiple pipe rows were allowed. These results seem to indicate the possibility of technical feasibility of the proposed grid arrangement and begin to quantify the relationships between key input and output parameters to create a pool of knowledge from which future research may draw upon and add to. Technical feasibility of the proposed containment system should be underscored by noting that the feasibility of providing water, pump stations and power supplies was not addressed in the scope of this project. This topic could be included in future works.

Future works could examine and improve upon multiple points in the numerical modelling process, including examination of a greater number of spread models, consideration of a greater number of ignition locations and orientations in the spread modelling and an in-depth convergence analysis of the numerical integrations used. Furthermore, a greater number of weather combinations, varied wind speed/directions and the effect of terrain gradient could be added to the modelling process These improvements would verify the consistency of the modelling results, ensure the bushfire behaviour remains as expected in a broader set of environments and potentially improve the accuracy of the results.

Additionally, future works could complete experimental verifications of the extinguishment mechanisms outlined in the report, particularly the spray attenuation process. This should focus on ensuring both the spray kinematics and cross-sectional attenuation properties predicted in this thesis conform with experimental results. These experiments could use infrared radiation sources as a stand-in for live flames to verify the light attenuation factors at varied cross-sections of the mist cone for varied, spray angles, pressures, and droplet size distributions. Further research into the mist behaviour may alter the modelling process for mist attenuation, potentially allowing the efficiency of the process to begin to compete with the other two mechanisms.

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