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Research Article

Comparison of Techniques for Visualising Fire Behaviour

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Abstract

During every Australian summer fires are common in the south-eastern region of the continent. The combined forces of climate, topography and vegetation make Victoria in particular, one of the most fire prone regions on earth (DSE 2003). Throughout its history, Victoria has seen a number of devastating bushfires, including Black Friday 1939, Ash Wednesday 1983, and more recently in the northeast of the State in 2003. The loss of life combined with the damage caused to land and property results in a heavy cost to the community. In Victoria, two of the organizations involved in fire management are the Victorian Department of Sustainability and Environment (DSE) and the Country Fire Authority (CFA). Both use fire 'meters' to determine potential fire behaviour given certain conditions. Values for temperature, wind speed, fuel load and vegetation type are input and a numerical estimate of fire danger given. There are a number of different meters used for different locations and environmental types. The most common meter used in Victoria is the McArthur Meter (CSIR0 2001b). The output data from this meter is numerical, and provides no spatial representation of fire danger. This paper looks at a variety of techniques used to visualise the numerical output from the McArthur Forest Fire Danger Meter. The article outlines the different models used by fire managers to simulate a fire situation, to assess future scenarios and for decision making involving fire management. Particular emphasis is placed on the McArthur Forest Fire Danger Meter as this is commonly used by fire departments in Australia. The article then focuses on geographical visualisation and a number of techniques employed to convey spatial information are discussed. The article then goes on to describe the fire simulation prototypes created for a study, a visualisation proof-of-concept product for organizations involved in managing bushfires in Australia. Finally, results from the evaluation of the prototype are presented.

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1 Introduction

During every Australian summer, bushfire danger is constantly present – affecting the lives of people who live in rural and urban fringe areas. This danger is particularly present in the south east of the continent where a combination of hot and dry weather in the summer and autumn months leaves the region most susceptible to fire. Along with weather conditions, the combined forces of vegetation and terrain make this region one of the most fire prone on earth (DSE 2003). The loss of lives and property destruction caused by bushfires in Victoria alone has been demonstrated on many occasions, with major bushfires occurring in 1939, 1983 and more recently, 2003.

The main goal of wildland fire management is to reduce the negative impacts of fire to society (Bachmann and Allgower 2002). Currently, fire managers can use a number of fire behaviour tools ranging from McArthur's circular slide meter to more complex spatial information systems, which depict fire behaviour. These fire behaviour tools are used for the purpose of assessing the characteristics of a current fire, projecting the future development of a fire, and evaluating alternative control strategies (Gould 2003). Current models depict different characteristics of fire behaviour including the extent of a fire front, rate of spread, intensity, flame height and spotting distance. The majority of research into fire behaviour models focuses on the accuracy of the input data given certain conditions, vegetation types and fuel loads. This is necessary so that models can become more reliable and give fire managers a far more accurate tool for predicting fire behaviour.

In addition to the accuracy of the outputs from fire behaviour models, the way in which the outputs are presented is also important. There are a number of different options available to view spatial information and selecting the right one or combination is essential for effective communication. This article looks at a number of techniques for visualizing spatial data, specifically fire behaviour.

The article begins by looking at the factors that affect fire behaviour. Factors describing fuel, terrain and weather are necessary in predicting fire behaviour. The article then outlines the different meters and models used by fire managers to simulate a current fire situation, to assess future scenarios and for decision making involving fire management. The limitations of the models in terms of accuracy are discussed as well as their development into the future. Particular emphasis is placed on the McArthur Forest Fire Danger Meter, as this is commonly used by the relevant fire departments in Australia. An outline of the meter operation, the input data required, the meter output describing fire characteristics and its use by the relevant fire authorities is provided. Its limitations in terms of accuracy also are documented with examples from studies into fire behaviour. The article then focuses on geographical visualisation of spatial information related to bushfires. An analysis of a visualisation study by Verbree et al. (1999) focuses on the techniques employed to convey spatial information to the user/viewer. The article then goes on to describe the fire simulation prototypes created for the study and the results from evaluation by the people and organizations involved in bushfire management in Victoria, Australia.

2 Fire Behaviour

There are a number of factors that contribute to bushfire characteristics: a fire's intensity; flame height and rate of spread. These are of interest to fire departments who are in charge of fire prevention and suppression. The rate at which fire spreads is determined by three factors: fuel; weather; and topography (NSW Fire Brigades 2004). If data on all these factors are available the characteristics of the fire can be predicted, allowing plans and procedures to be put in place for fire fighting. While topography can be determined from contour maps or Digital Terrain Models (DTMs), obtaining data for fuel and weather is more difficult and time consuming. Weather can vary over time and area, and fuel can change in type, continuity and density across a landscape. Both weather and fuel are the cause of the greatest uncertainty in predicting bushfire behaviour (Gould 2003).

2.1 *Fire Behaviour Models*

Fire behaviour models are used by fire departments to assess a current fire situation, to assess future scenarios and for decision making involving fire management (Gould 2003). The output from these models generally provides information about fire intensity, rate of spread, extent and flame height. This information is important for decision making in a fire fighting situation for potential fire threat, minimising fire damage to parks, buildings and towns, and public or fire fighter health and safety (Gould 2003). A broad range of fire models have been developed, and the appropriateness of a model for a fire situation is determined by the model's complexity, available input data, environmental conditions, computational resources and time availability (Gould 2003). Cary (1999) identified a number of fire models ranging from simple models that predict a fire's forward rate of spread, to computer simulation models and fire threat analysis.

The simplest of the fire behaviour models are the slide rules like the McArthur Forest Fire Danger Meter (Gould 2003). Input data for these models include weather conditions, fuel and topography. The models then predict certain aspects of fire behaviour including the rate of spread, intensity and flame height. Models like the McArthur Forest Meter have been created after experimentation with fire and observing unplanned wild fires (Cary 1999). A similar fire behaviour model for fire conditions in the United States is the Rothermel Model (Bachmann and Allgower 2002). It was developed by the United States Department of Agriculture (USDA) in 1972 for calculating the behaviour of a surface fire. Rothermel's model produces a number of outputs which describe fire behaviour including rate of fire spread, the direction of maximum spread, fire line intensity, heat release per unit area and flame length (Bachmann and Allgower 2002). Seventeen input variables are necessary, including eight that describe fuel type, five for fuel moisture and two for both wind and terrain. This model is still widely used, however in Australia the preferred fire behaviour tool is the McArthur meter.

2.2 *McArthur Forest Fire Danger Meter*

The principal factors contributing to forest fire behaviour were first formalised by Australian forest researcher A.G. McArthur in the form of a circular slide rule known as the McArthur Meter (Chapman 1994). McArthur's fire danger rating system was devised after observing 800 experimental fires, burning for between 15 and 60 minutes (McArthur 1967). Separate fire meters for grasslands and forests, predict fire behaviour given certain conditions. The McArthur Forest Fire Danger Meter (FFDM) (see Figure 1) requires a number of inputs including fuel load, wind speed, temperature, humidity, slope and recent rainfall. From the inputted data the meter makes predictions for a fire's

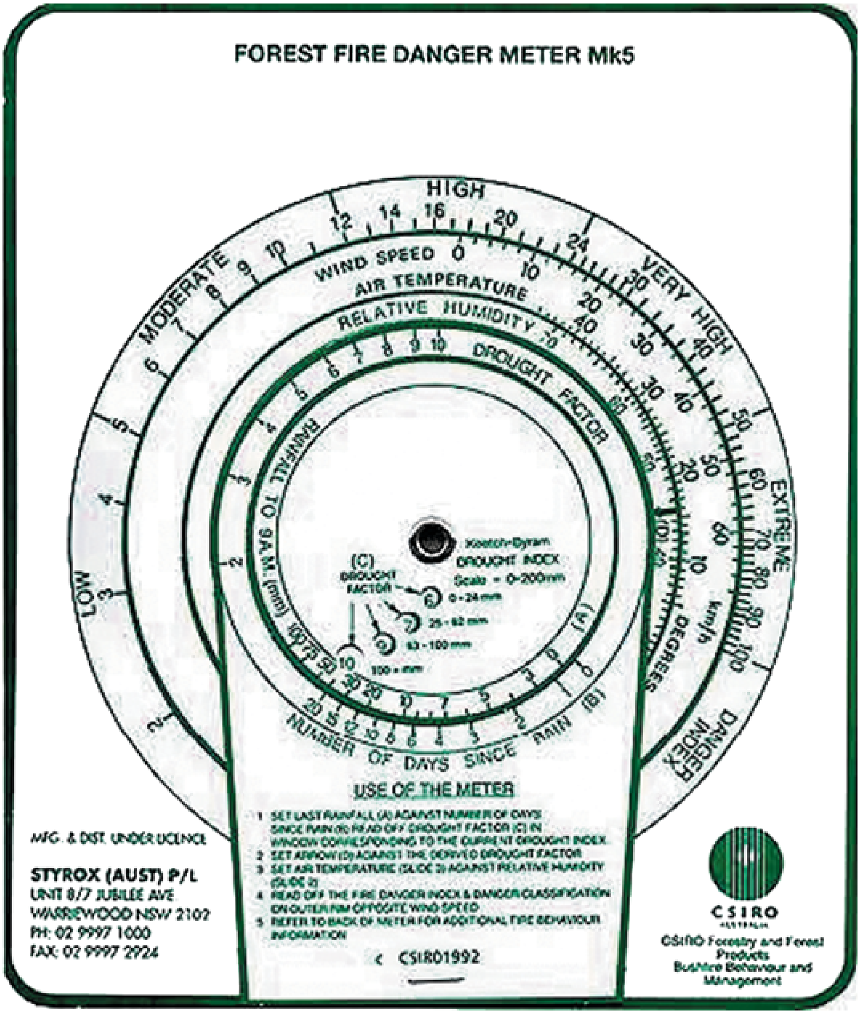

Figure 1 McArthur Forest Fire Danger Meter (CSIRO 2001c)

rate of spread, flame height, spotting distance (the distance flames are carried forward of the fire front, starting new fires) and a value for the Fire Danger Index (FDI).

The FDI ranges from 1 to 100 and is related to a fire's characteristics and the likelihood of suppression. An index of 1 indicates that a fire will burn slowly or not at all, resulting in easy control of the fire. An index of 100 indicates that a fire will burn at a hot temperature and spread to an extent where control is virtually impossible (McArthur 1967). FDI values are used to classify fire danger into; low, moderate, high, very high and extreme. These classes have been widely used by fire managers in Australia for fire danger forecasting, to set preparedness levels and for issuing public warnings on fire danger (Cary 1999).

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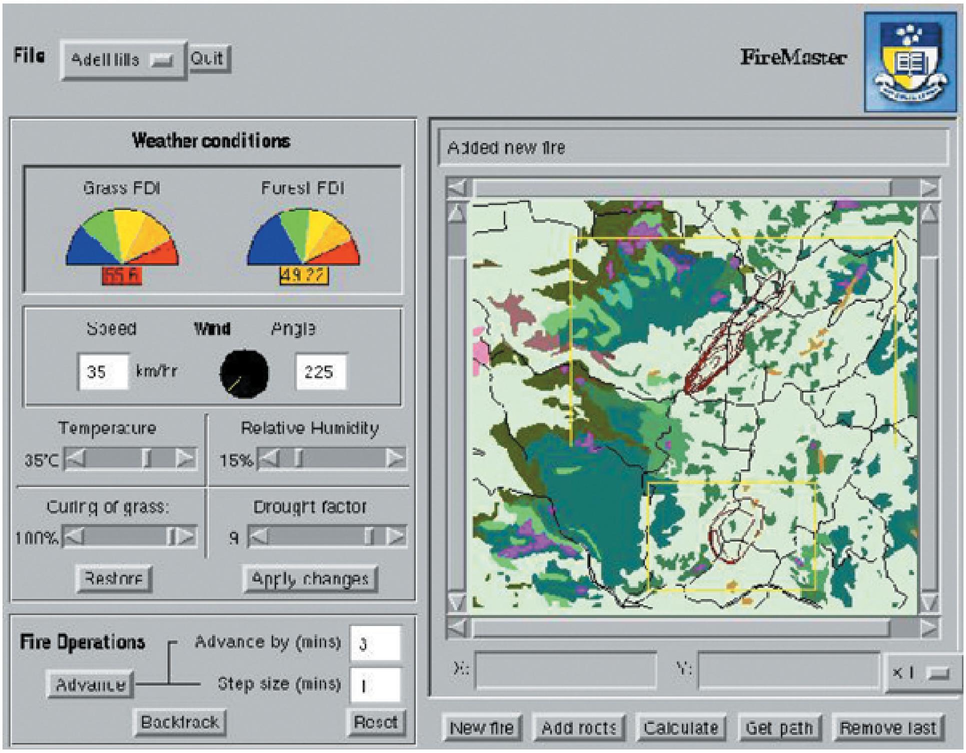
Cary (1999) says McArthur's Forest Fire Danger Meter is limited in making fire behaviour predictions to a specific area and time. Accurate prediction of fire behaviour for a broader area, over different time intervals, requires regular adjustments to the input data. This is in recognition of the changes in terrain, fuel and climatic conditions that result in varied fire behaviour (Cary 1999). For this reason, the McArthur meter is used sparingly during large-scale bushfire situations due to the regular adjustments needed for accurate fire predictions. In 2001, the CSIRO surveyed fire managers on their usage of the McArthur Meter. The survey found that fire managers widely used the meter, in particular calculating the FDI on a regular basis. However, it was used infrequently in calculating a fire's forward rate of spread in a wildfire situation, which was its original purpose (CSIRO 2001a, c). Fire managers felt that their own experience was sufficient and they indicated that they would prefer to use actual fire spread information rather than an estimate. The survey also revealed that fire managers found it difficult to include the effect of topography with the McArthur Meter (CSIRO 2001a, c). The CSIRO survey found that "The complexity of calculations and the sheer number of calculations required to incorporate the effects of topography, the changing fuel types and the changing meteorological conditions mean that a fire controller must expend a lot of vital time to utilise the McArthur meters effectively" (CSIRO 2001a, c).

3 Computer-Based Fire Simulation Modelling

A computer simulation model of fire behaviour was created by CSIRO's Bushfire Behaviour and Management group. Sirofire, which is a PC-based bushfire simulator, operates in a similar manner to the bushfire meters described above, however fire spread is shown graphically. Input data for temperature, wind speed and direction, relative humidity, fuel load and conditions, grass curing and slope are required for the fire simulation to be performed (CSIRO 2001a, c). The simulation predicts the likely spread of fire in all directions and depicts its perimeter at certain time intervals (Coleman and Sullivan 1996). The extent of the fire is displayed on a map and changes over time, giving the fire manager a predictive visual tool for fire behaviour (CSIRO 2001a, c). The fire spread is influenced by terrain, which is derived from a digital elevation model, and fuel type, which is stored in the geographic database (Cary 1999). Once the fire manager inputs fuel load and weather conditions, the simulation can then be performed. From the simulation fire managers are able to view the movement and extent of the fire, identify natural or constructed features under threat and coordinate fire suppression strategies. Sirofire is only one example of a fire simulator. Other models created in Australia include FireMaster and Firescape. Figure 2 shows the user interface for the fire simulator FireMaster. Users input data on the left of the screen for wind, temperature, humidity, drought factor and fire ignition (co-ordinates). The movement of the fire across the landscape is then shown on the right.

4 Threat Analysis

Wildfire Threat Analysis (WTA) not only concerns fire behaviour (described as 'hazard' in WTA), but also the risk of ignition and recognises that there are natural and man-made features in the environment (Cary 1999). WTA requires three components (Government



Added new fire

Grass FDI 55.6

Forest FDI 49.77

Speed 35 km/hr

Angle 225

Temperature 35°C

Relative Humidity 15%

Curing of grass: 100%

Drought factor 9

Advance by (mins) 3

Step size (mins) 1

Figure 2 Graphic User Interface for the *FireMaster* simulation model (Eklund 2001, p. 367)

of South Australia 2004); one for fire hazard, in which an investigation into fire behaviour over the landscape, given certain fuel, weather conditions and changes in slope is performed. The second component is a risk assessment, where analyses of the possibility of fire ignition are conducted. This is influenced by what the environment is used for, the proximity to roads, residential areas (Cary 1999), and other factors which affect the probability of a fire starting in the first place. The third component is a value assessment of all natural and constructed assets in the environment. In this component different land uses and features, such as residential properties, sheds, reservoirs, farmland and forests are identified, and values are assigned according to their material worth (Cary 1999). Areas where higher natural and constructed values are present, are the primary concern for fire prevention and suppression. For fire threat to be evaluated for a particular area all three components; hazard, risk and value are combined. An overall fire threat map identifies and classifies areas into low, moderate, high, very high and extreme fire threat. These categories are assigned to an area depending on fire behaviour, risk of ignition and the values placed on natural and constructed values (Government of South Australia 2004). The method described above was used by the South Australian Government in identifying the threat of wildfires in national parks and is just one example of conducting a WTA. As there are no set criteria for constructing a WTA, different results may be found depending on which department or organisation conducts the analysis (Cary 1999).

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4.1 *Accuracy of Fire Behaviour Models*

As with all models representing real life events, bushfire behaviour models cannot be relied on to give an accurate representation of the real life situation. The Wildland Fire Operations Group (2004) states that the results from the models do not always agree with the observed fire behaviour for the following reasons:

- The model may not be applicable to the situation;
- The model's inherent accuracy may be at fault; and
- The data used in the model may be inaccurate.

Most research into fire behaviour modelling has focussed on the accuracy of the input data used for the various models. Heywood et al. (2002) points out that the accuracy of the input data is important, as models representing real world events are only as accurate as the data used to construct them. When investigating errors present in fire behaviour modelling Bachmann and Allgower (2002, p. 122) state that in "fire behaviour modelling much more emphasis should be put on the assessment of input data."

Unlike topographic data, it is difficult to gather accurate data on weather and fuel, which are the main cause of error in fire behaviour models (Gould 2003). Many models require input data for fuel load. However, fuel load is only one of the many characteristics that describe fuel. Fuel has many other characteristics that could be input into a model, including continuity, type, density, moisture content and percentage of dead material (Gould 2003). The Wildland Fire Operations Research Group (2004) state that the problem with describing fuel in a fire behaviour model is the assumption that the fuel bed is continuous and uniform across an area and there is no distinction made between surface, elevated or crown fuel. On this, the Wildland Fire Operations Research Group (2004) claim that "the more the real fuel situation departs from this ideal (uniform and continuous), the more erratic the prediction will be when compared to real fire behavior." Due to time and cost constraints, gathering accurate data on all elements for fuel is difficult. Therefore, most fire models only require input data for fuel load over an area, which results in only one of the fuel characteristics entered into the model.

Another source of error in fire behaviour models is caused by weather. As wind direction and speed is constantly changing along with relative humidity, models need to be updated regularly. At present research is being conducted to improve the accuracy of wind data by creating terrain models, combined with satellite weather data and ground stations so that more accurate data can be used in fire behaviour models (Gould 2003).

4.2 *Future Development*

While fire behaviour models, such as the McArthur Forest Fire Danger Meter are still in use and provide fire managers with a guide to fire behaviour, new possibilities exist by visualising fire characteristics through fire simulation models. These models, developed for computer screen output, display fire behaviour graphically. Some examples of these include FireMaster, Firescape and Sirofire. Like the fire models created in the past, future fire behaviour models will depend on accurate input data as explained by Gould (2003, p. 63) "the next generation of fire behaviour models needs to have the ability to predict extreme fire behaviour from readily available weather, fuel and topographic data." Constantly updating data is necessary for models to show current fire behaviour conditions. For this reason, Gould (2003) sees that it is necessary for future fire models

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to be capable of receiving and including current weather conditions from a variety of sources, like weather stations and global positioning systems.

5 Fire Visualisations

As the accuracy of models and input data is important, so too is the way information is presented to an end user. It is evident that a number of possibilities exist when visualising data. Certain visualisations may suit the needs of different people or open up alternative areas for data exploration. With multiple presentations of the same data, users are able view information through a number of 'windows' allowing for greater analysis of the data. Taking this into account the following research question was developed:

> Fire behaviour can be depicted graphically in a variety of different ways. What is the most effective way of displaying fire behaviour, so that the appropriate organizations and the people affected gain accurate and easy to understand information?

To answer this question three visualisations were created based on a study by Verbree et al. (1999) which outlined a number of visualisation techniques to depict construction work in the Netherlands. They discussed the development of a 3D GIS and Virtual Reality system. The purpose of the system was to give the user a number of visualisations to gain a greater understanding of large-scale infrastructure projects in the Netherlands. The system gave the user three views to proposed buildings that assisted decision makers in the design, development and presentation of the building project. The three different visualisations created for the system were a plan view, model view and world view. The plan view was created in a GIS and was similar in appearance to a traditional map. However, a greater amount of geographical information was available beyond what was visible on the screen. A user could view an object's attributes, select and query information, and perform a number of analytical operations. The model view was a symbolic, 3D representation of buildings and the environment and gave the user a bird's eye view of the scene. This visualisation lacked detail and only provided a general representation of the 3D objects within the scene. It was used for depicting size, dimension, the relation between objects and their general arrangement. Analysis preformed at this level included the calculation of volume, distances, shadowing and line-of-sight. The world view was 3D and photo realistic, giving the user a virtual reality view of the scene. It allowed the user to see the building project from within any position in the environment. The scene was continually updated so the user was able to 'walk through' and view buildings from different perspectives.

The three views, plan, model and world, offered the user a choice of their preferred method of visualisation. Each view, while depicting the same environment, had a different purpose in the analysis and visualisation of the scene. By having more than one method of viewing data the user is able to gain a better understanding of what is being visualised. This can be attributed to the different visualisations offering a number of 'windows' to view data, allowing the user to choose what is most suitable for them. A similar situation exists where an architect creates a plan view of a proposed building, then sketches the building from a certain angle, then finally constructs a 3D model of the building in its environment. The system outlined by Verbree et al. (1999) allowed for all these views to be seen and analysed with greater efficiency.

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For this study, a number of visualisations were created, all depicting fire spread over the study area. To visualise fire spread, data were gathered and input into the McArthur Forest Fire Danger Meter. The meter requires input data for fuel load, temperature, relative humidity, wind speed, drought factor and ground slope. Data were collected for fuel load using the method outlined by McCarthy et al. (1998) in the Victoria Department of Natural Resources and Environment, Fuel Hazard Guide. Values for temperature, relative humidity and wind speed were gathered and reflect conditions expected in the summer months where fire danger is at its peak. Ground slope was determined through GIS analysis. These data were then used in the McArthur Forest Fire Danger Meter that gave the expected rate of spread of the fire. While care was taken in gathering data, the meter output was only used as a guide to how quickly the fire might travel across the area. The purpose of this was to assist in the animation process, so the visualisations would approximate the fire propagation that might occur in the study area. The data used to calculate fire spread was the same for each of the visualisations as was the point of fire ignition. The data used to construct the visualisations was the 1:25,000-scale Land Victoria Topographic Dataset. A satellite image of the area was also used in creating visualisation 3.

All visualisations were tested using participants who were most likely to use fire simulations. The test participants were from the Victoria Department of Sustainability and Environment (DSE), who would find visualisations of fire spread useful to assess a current fire situation, to assess future scenarios and for decision making involving fire management (Gould 2003). The testing procedure required the participant to view a number of visualisations of fire behaviour. They were asked to find certain information that each view was able to show. Through the participant viewing these visualisations and seeking information they became familiar with what each view had to offer. An evaluation of each view was then completed by the participants outlining the respective strengths and weaknesses of each visual representation. Feedback from the participants indicated user preferences, and helped in making recommendations for effectively visualising fire spread.

The software used to create the three fire visualisations included ArcGIS, CorelDraw and Macromedia Flash. ArcGIS was used for analysing spatial data and preparing it for export to Macromedia Flash where the animations were created. In CorelDRAW graphics were created for the timeline and input data column. The data column was the same for the three visualizations as they are not fully working fire simulation models (users could not enter their own data).

- **Visualisation 1 – Digital Topographic Map (Figure 3).** A computer screen display of the area, similar to what is viewed in a traditional topographic map. The 2D computer screen displays the geographical features and roads of the area. Fire is viewed spreading across the study area using the user controls.

  A digital topographic map was imported into Macromedia Flash. Fire spread data from the McArthur Forest Fire Danger Meter was used in creating the animation. The animation showed fire spread over the study area for a five hour time span. The fire spread graphic was manipulated in Macromedia Flash with the use of shape hints and guides to represent how a fire might propagate within the study area. A timeline was included into the graphic user interface to indicate the progress of the fire. Users were able to control the simulation with 'stop', 'start' and 'reset' buttons located below the simulation window. In CorelDraw, a data input panel was created and imported to

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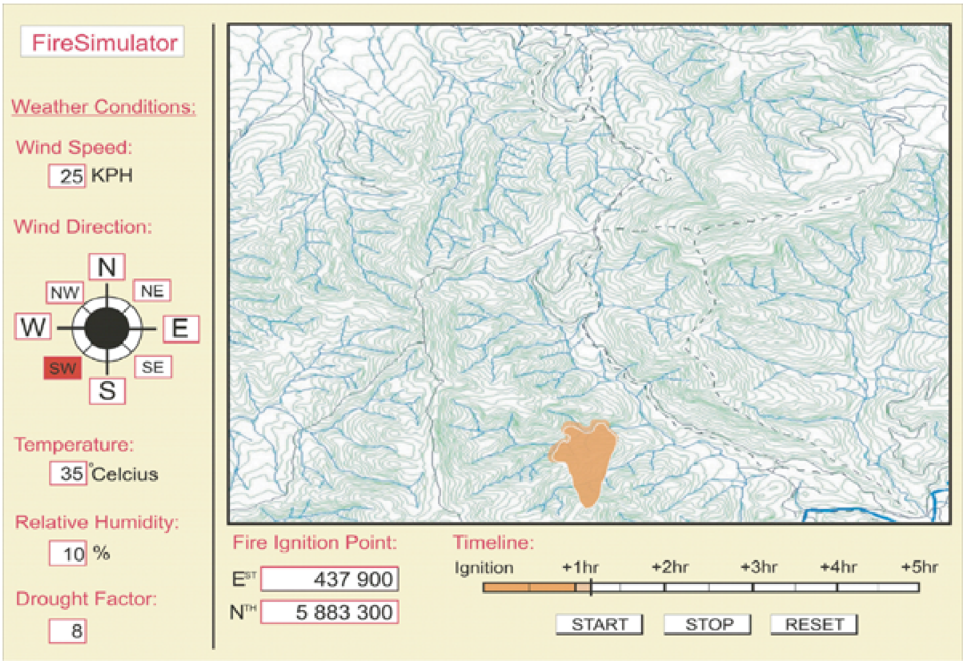

Wind Speed: 25 KPH

Temperature: 35°Celcius

Relative Humidity: 10 %

Drought Factor: 8

Fire Ignition Point:

EST 437 900

NTH 5 883 300

Figure 3 Visualisation 1 – Digital Topographic Map

Flash to give the impression that it was a fully working fire simulation model. This was to show the user the circumstances under which the visualisations would be used. As it was not a fully working model users were not able to enter their own input data.

- **Visualisation 2 – Digital Elevation Model (Figure 4).** A simple, abstract, 3D model of the scene showing the topography of the area with the same natural and human-made features shown in visualisation 1. This view gives the user a view to the terrain of the area with fire spreading across the landscape.

  In ArcMap a height elevation raster was created from the Land Victoria digital topographic data. The raster was then viewed in ArcScene where the data's 3D attributes could be viewed. A colour scheme was given to the elevation model according to height, with roads and hydro features overlaid. The scene was then exported into Macromedia Flash where the fire spread was created over the study area. The same fire spread data from the McArthur Fire Danger Meter used in view 1 was implemented. The fire spread graphic was manipulated with the use of shape hints and guides to represent how a fire would react within the study area. A timeline was included into the graphic user interface to indicate the progress of the fire. As with visualisation 1 users were able to control the simulation with 'stop', 'start' and 'reset' buttons located below the simulation window. The same graphic user interface described in visualisation 1 was used in visualisation 2.
- **Visualisation 3 – Digital Elevation Model with Satellite Image Overlay (Figure 5).** A 3D view of the area with greater realism than visualisation 3. A satellite image is draped over a Digital Elevation Model of the study area.

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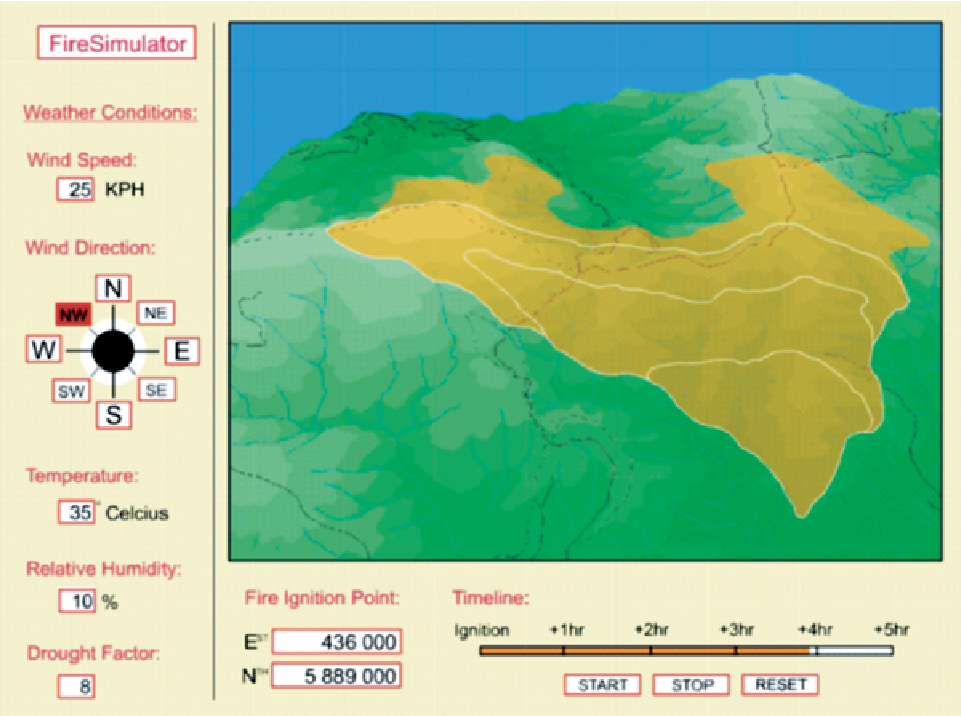

Wind Speed: 25 KPH

Wind Direction: NW

Temperature: 35° Celcius

Relative Humidity: 10 %

Drought Factor: 8

Fire Ignition Point:

E 436 000

N 5 889 000

Figure 4 Visualisation 2 – Digital Elevation Model

Visualisation 3 uses the same elevation model used in visualisation 2. In ArcScene a satellite image of the study area was imported and overlaid on the elevation model. The scene was then imported into Flash where the fire spread graphic, timeline, user controls and graphic user interface where the same as in visualisation 2.

6 Results

The study found that each visualisation contributed to the level of information that participants acquired. There was not one visualisation that could be determined as the ideal visualisation, but through a combination of views, a greater understanding was achieved. The Digital Topographic Map allowed for the calculation of distance the fire had travelled, the rate of spread and for an uninterrupted view of the fire's perimeter. While it was preferred by two participants for viewing topographic features, its main advantage was being able to view fire spread across the fire area.

The Digital Elevation Model presented a 3D view of the area to the participant. From the results of the task scenario's and questionnaires, it was clear that this view was beneficial for identifying topographic features of the area. Using the same data as the Digital Topographic Map, the Digital Elevation Model enabled a more detailed description of the area in a time efficient manner. It was also found that the Digital Elevation Model provided participants with a better view to the effect of topography on fire spread.

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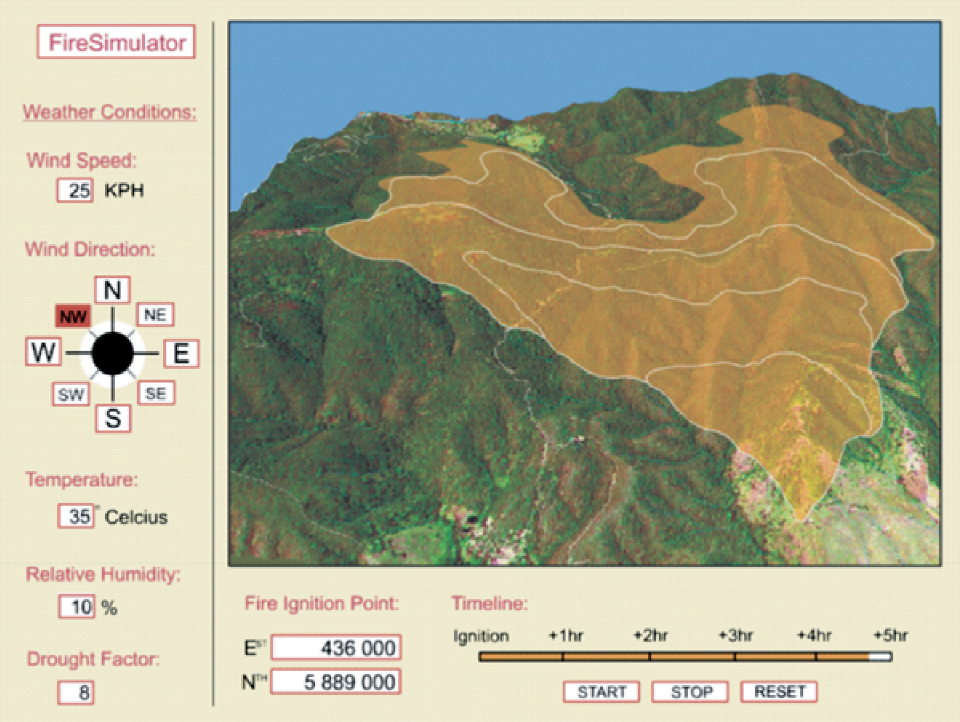

Wind Speed: 25 KPH

Wind Direction: NW

Temperature: 35° Celcius

Relative Humidity: 10 %

Drought Factor: 8

Fire Ignition Point:
EST 436 000
NTH 5 889 000

Figure 5 Visualisation 3 – Digital Elevation Model with Satellite Image Overlay

The Digital Elevation Model with the satellite image overlay provided the participant with the most realistic view of the area. From the study, it was found that this view provided important information that the other two views did not. While the Digital Topographic Map and the Digital Elevation Model provided elevation, road and hydro information, the Digital Elevation Model with the satellite image overlay allowed for vegetation cover to be viewed. This enabled the identification of plantation areas, state forest and farmland.

The results of the study found that both of the 3D scenes would be beneficial to fire officers who have a limited knowledge of the area. When using paper topographic maps, fire officers are able to match features on the map with their own experience, resulting in a sufficient knowledge of the region. However, fire officers and crews often are called to adjoining fire regions or even interstate where their knowledge of the area is limited. Participants indicated that the realistic nature of the 3D visualisations and satellite image, would be beneficial to fire officers or crews in the successful identification of features in the area.

The study also found that for understanding a fire's characteristics numerical data should accompany the fire visualisation. The McArthur Forest Fire Danger Meter which describes a fire's characteristics (rate of spread, flame height, spotting distance) only uses numerical output to describe a fire. The visualisations that were created for the purpose of this study only showed the output for fire spread visually. It was found in the study that both the numerical data and visualisation graphics should be available.

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Participants noted that they could see the fire spreading but the accompanying data for rate of spread, flame height and spotting distance should be used to complement the visual output and gain a better understanding of the fire situation.

Each visualisation offered essentially the same information; fire spread, topography and features in the area. However, the visualisation technique used to display this information affected the type and ease of information found. The study found that there was not one visualisation alone that was ideal for viewing all the information that fire managers require. Each view had strengths and weaknesses in conveying certain information and therefore all visualisations contributed to a greater understanding of the fire scenario.

7 Discussion

7.1 Multiple Views of Fire Spread Allow for a Better Understanding of the Fire Scenario

The results indicate that each of the visualisations contributed to a greater understanding of the fire event. Each visualisation showed fire spread over the Timbertop area, however the technique used to view fire spread, determined what information could be obtained and the difficulty in obtaining that information. For example, both the Digital Topographic Map and the Digital Elevation Model provided elevation data but it was presented differently. Both views could be used to find the same information with some participants preferring to use the Digital Topographic Map based on their own map reading experiences. However, the results indicated that when it came to identifying topographic features, participants were able to give a more detailed description of the topography of the area using the Digital Elevation Model rather than the Digital Topographic Map.

While each view showed fire spread over time, the Digital Topographic Map was found to be the ideal visualisation technique to view a fire's spread and perimeter. This was due to the easier calculation of the distance fire had travelled and being able to view the fire perimeter.

The Digital Elevation Model with the satellite image overlay extended the number of features that could be identified in the area. Both the Digital Topographic Map and the Digital Elevation Model presented the same information; elevation, roads and hydro features. Assets shown in these views such as roads and hydro features are necessary for fire officers to identify, however the satellite image offered an even greater amount of information. Forests, plantations and farmlands could be identified which could influence decisions made by fire managers especially in the deployment of resources.

Having multiple options to view information allows users to choose which visualisation or combination of visualisations suits their own requirements, experience and preferences. Therefore, future fire simulation models should allow the fire officer to view a fire's characteristics using a visualisation technique that is both suitable to gather the required information and fits comfortably with a user's preferences.

7.2 Both Numerical Data and Visual Representations of Fire Spread are Required

The McArthur Forest Fire Danger Meter uses only numerical output to describe a fire's characteristics (rate of spread, flame height, spotting distance). The visualisations created for this study only showed the spreading and the extent of the fire. The study found that the numerical output from the McArthur Forest Fire Danger Meter should be available with the visualisations. As the visualisation shows fire spread across the area, data, in numerical form describing rate of spread, flame height and spotting distance should be used to complement the visual output and gain a better understanding of the fire situation.

The visualisations are only a few of the many techniques used to view spatial information. A number of other visualisation techniques are possible and can be viewed in a variety of output devices. These techniques include Virtual Reality Systems that have the ability to offer realistic and fully immersive environments. These virtual environments may have applications in showing events associated with geography such as bushfires. With the user able to move around the near-reality landscape, a better understanding of the location and attributes of features such as trees, grasslands, mountain ranges, ridgelines, valleys, creeks, rivers, buildings, etc. may be beneficial to fire departments in bushfire management. These new techniques need to be tested for what they can offer in viewing scenarios like bushfire.

7.3 Greater Realism for Users who are Less Familiar with the Area

The three visualisations used in this study provided three different levels of realism. The Digital Topographic Map could be considered to be the most abstract of the three. The visualisation gives clues to the user about the topography of the area through the spacing, shape and labelling of contours. It gives sufficient information to users who have knowledge of the area, as they are able to identify features on the topographic map and associate them with their own experience of the area to gain sufficient understanding of the topography, land cover and proximity to other features. This, in some circumstances is all that a fire officer would require, as they have worked and are familiar with their own fire management zone.

However, fire crews are often called into other fire management zones, or even interstate where their knowledge of the area is poor. The 3D scenes presented in this study offered the participants greater realism of the area. The Digital Elevation Model gave participants a more realistic representation of the area, with contours replaced by a 3D model. Participants were able to see at a glance all the features in the area, without having to interpret the contours. The Digital Elevation Model with the satellite image overlay, offered participants the same 3D view as the Digital Elevation Model, but also included land cover information. This enabled users who had never seen the area before, a near-realistic representation of the area. One participant stated that the visualisation gave them the feeling they were actually viewing a fire event. This view would be ideal for fire officers/crews with little knowledge of the area as they are given a realistic representation of the area they are working in.

8 Conclusions

This paper has addressed the application of a number of visualisation techniques for depicting bushfire scenarios. It was found that most research into bushfire management has focused on the accuracy of the models and better methods of obtaining input data. This is important to ensure that the data used in the models are accurate and current,

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giving fire managers confidence when making forecasts. As the accuracy of input data used in the models is important, it is argued, so too is the way the data are presented to the user. Through a comparison of visualisation techniques, which this paper has only explored a few, an understanding of what is needed to better communicate spatial information for certain applications and user groups can be established. For bushfire management appropriate visualisations will hopefully lead to a greater understanding of bushfire behaviour, and in turn lead to more informed decisions being made by professional fire fighting managers and the public alike.

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