A decision support system for evaluating fuel management strategies for wildland urban interface areas[1]

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Abstract

Wildfire poses threats to public safety and property in many Wildland-Urban Interface (WUI) areas. We describe a spatial Decision Support System (DSS) that can be used to help evaluate fuel treatment measures for WUI areas in terms of their impact on burn probabilities across the landscape. Our DSS is embedded in a computer-based geographic information system (GIS) platform that describes the structure of the landscape, its fuel mosaic, where structures and other values at risk are located and where fires might ignite and how they might spread across the landscape. It has a graphic interface that includes a digital map of the landscape on which fire managers and planners can delineate areas where proposed fuel treatment activities might take place. Mathematical models of fire ignition, suppression and spread processes are used to predict the potential impact of such measures on the landscape and display those impacts on a burn probability map which shows the predicted probability that any point on the landscape will burn given the current landscape and the proposed fuel treatment measures that are to be evaluated.

Keywords: forest fire management, fuel management, decision support systems, geographic information systems, wildland fire

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Introduction

The term Wildland Urban Interface (WUI) is used to refer to areas where homes or other structures are located in or adjacent to flammable forest or wildland fuels. Fires that burn across WUI areas can ignite the homes and other structure by direct flame contact, by radiation, or from firebrands that land on their surfaces. Flame contact and radiation may rupture windows and ignite building contents. Firebrands can ignite roofs, siding and decks or flammable fuels such as dry grass and twigs located close to the structure. They can also enter structures through open eaves and windows. The probability that a wildfire will ignite a structure depends on the level of exposure of the structure and the flammability of the material exposed to the fire.

FireSmart measures (Partners in Protection 1999) such as fuel treatments that “cool” the landscape can reduce the risk to homes and other structures. Fire managers and planners must carefully assess many possible alternatives when they decide when and where to treat fuels and their decisions are complicated by the daunting task of assessing the cost and potential impact of many complex, spatially explicit alternatives. This paper describes the structure and illustrates the use of a spatial decision support system (DSS) that can be used to help evaluate such strategies. We begin with a brief literature review which describes some of the pertinent WUI research that has been carried out in the past. We then describe the types of measures that might be used to mitigate fire losses in WUI areas and the structure of our DSS and illustrate its use by applying it to a study area in the province of Ontario in Canada. We conclude with a brief discussion of the need for further research in this area.

Literature Review

Some authors have used historical fire and structure loss data to develop aspatial statistical models of the probability that a structure will be damaged by fire in a WUI area. Wilson and Ferguson (1986) for example, used data from the 1983 Ash Wednesday Fire in Australia to develop a logistic regression model that relates the probability that a house will survive a WUI fire to several variables including those that indicate whether or not someone was in or near the structure attempting to prevent its destruction at the time the fire passed, the presence of nearby burning objects, the roofing material, and the fire intensity. They found that fire intensity had the most significant impact on house survival. Chen and McAneney (2004) also used data from major historical fires in Australia and modelled the probability of home destruction as a linear function of distance from the adjacent wildland fuels boundary and found fire intensity and human intervention strongly influenced the probability of ignition. Fried and others (1999) modelled the subjective probability of a structure being destroyed in a WUI fire elicited from a panel of local fire professionals. They found that the clearance of trees near a structure and fall mowing of grass to deprive spring fires of fuel had a significant influence on the probability a structure was ignited. Haight and others (2004) looked beyond individual structures and approached the problem from a landscape scale and used historical fire regimes and current fuels to identify the areas with high wildfire risk.

Cohen’s (1995) Structure Ignition Assessment Model (SIAM) can be used to assess the risk of structure ignition as a function of its structure, the surrounding fuel and topography, and fire weather severity. Cohen and Butler (1996) found that extensive vegetation management is not required to prevent the ignition of structures in WUI areas and they also found that neighbouring structures can pose greater ignition threat to a structure than the surrounding vegetation since they have longer flame residence times than the surrounding vegetation. Gettle and Rice (2002) studied the separation of structures from wildland fuels in WUI areas and developed a model that can be used to determine the safe separation between wildland fuel and structures. They found that setbacks of 9 m in width are adequate for fuels that do not produce flame lengths exceeding 6 m.

The WARM (Wildland-Urban Area Fire Risk Management) project (Caballero, 2004) focused on the identification of WUI areas and the assessment of wildland fire vulnerability in Mediterranean Europe. The WARM project was developed for three levels of analysis - regional, landscape and site, and those involved in the project have developed wildfire risk characterization methodologies at all three scales. Their approach to WUI problems is primarily descriptive and they focus on the identification of where and why wildfire threatens WUI structures.

There have been few DSS's developed to support fire management in WUI areas. Radke (1995) described a spatial DSS for dealing with wildland/urban interface fire hazards in the East Bay Hills of California. His system produces GIS risk maps generated by two models, one which produces assessments of the wildland fire hazard and the other which produces an assessment of the urban and residential fire hazard. A knowledge-based model developed with information elicited from a local expert panel survey was used to model and rate the fire hazard in the residential area. The BEHAVE fire behaviour prediction system was used to model fire behaviour under extreme weather conditions. Fire hazard assessment maps indicate spatially cumulative wildland fire risk. The system produces separate risk maps for each model (wildland fire hazard and residential fire hazard) to provide planners and policy makers with information concerning fire risks in a designated area.

Fire managers can implement a broad range of strategies to reduce the wildfire hazard in WUI areas including thinning, timber harvesting or prescribed burning, fuel isolation strategies such as the construction of fuel breaks, greenbelts and defensible zones around WUI sites, fuel conversion, and the creation of a defensible space around WUI areas and between structures within WUIs.

The research that has been carried out on fire in WUI areas to date has provided fire managers and planners with valuable insight into the potential impact of fire on structures and other values at risk in WUI areas and the growth of such knowledge will no doubt accelerate as more researchers study wildland fire in WUI areas. We will now describe our DSS and how it can be used to facilitate the use of such knowledge by fire managers and planners who are responsible for developing fuel management strategies for mitigating fire losses in WUI areas.

A Spatial Wildland Urban Interface Decision Support System (WUI DSS)

"FireSmart Forest Management" is a term that is used to describe forest management practices that are designed to mitigate wildfire losses while fulfilling traditional forest management objectives such as the production of timber (Hirsch and others 2001). FireSmart practices can include the design and construction of roads in strategic locations where they can serve as fuel breaks as well as satisfy transportation needs and the use of harvesting and silvicultural practices that vary both in intensity and timing to both enhance timber production and alter forest fuel complex to "cool" the landscape. FireSmart strategies can be used to mitigate fire losses in WUI areas as well but the evaluation of such strategies calls for the compilation and processing of vast amounts of spatial and aspatial data that describe potential fire occurrence and spread including, for example, fuel type maps, weather, historical fire occurrence patterns, the location and productivity of fire suppression resources, and values at risk. The challenge is not simply to compile and process such information but given the enormous number of fuel management strategies that can be implemented on most landscapes, the real challenge is to facilitate the use of such information by fire managers and planners that must decide when and where to implement fuel management measures on the landscape. We have therefore designed a DSS (which we henceforth refer to as the WUI DSS) that couples such information with fire ignition and fire growth models as illustrated in *figure 1*, so fire managers can use them to help resolve such decision-making problems.

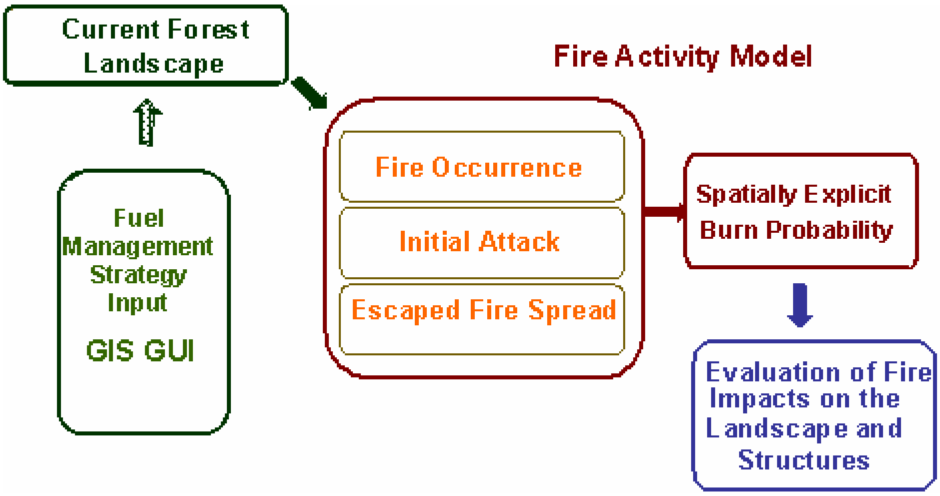

Figure 1— Schematic diagram of the WUI DSS.

Our WUI DSS uses the spatial Burn Probability (BP) mapping model developed by Cui and others (2003). The BP model produces estimates of the probability that any point on the landscape will burn during the next fire season and displays that information in the form of a map like the one shown in *figure 2*.

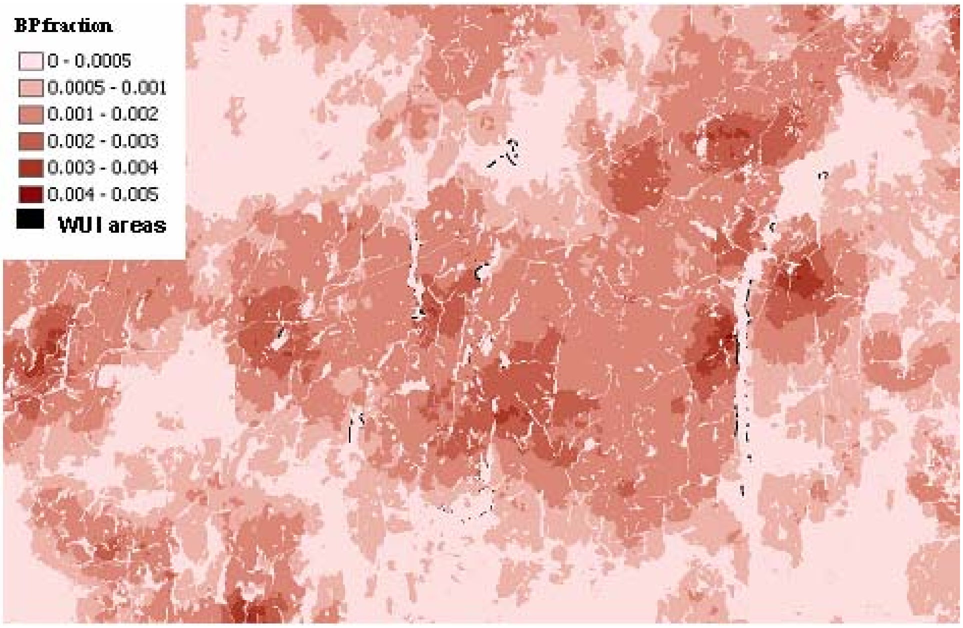

Figure 2— Predicted burn probability given the current landscape.

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Once the base case fire regime has been assessed, fuel management strategies can be designed to mitigate the detrimental impacts of wildfire on the landscape. The WUI DSS has a graphic interface (*fig. 3*) that is designed to make it relatively easy for fire managers to describe where such activities might take place. Once a fuel management strategy has been delineated on a computer-based map of the landscape, the predicted fire activity is analyzed and a revised burn probability map like the one depicted in *figure 4* is produced. Comparisons of the performance of alternative strategies will, we contend, provide fire and forest managers with useful insight that can be used to help identify strategies that will best address their objectives.

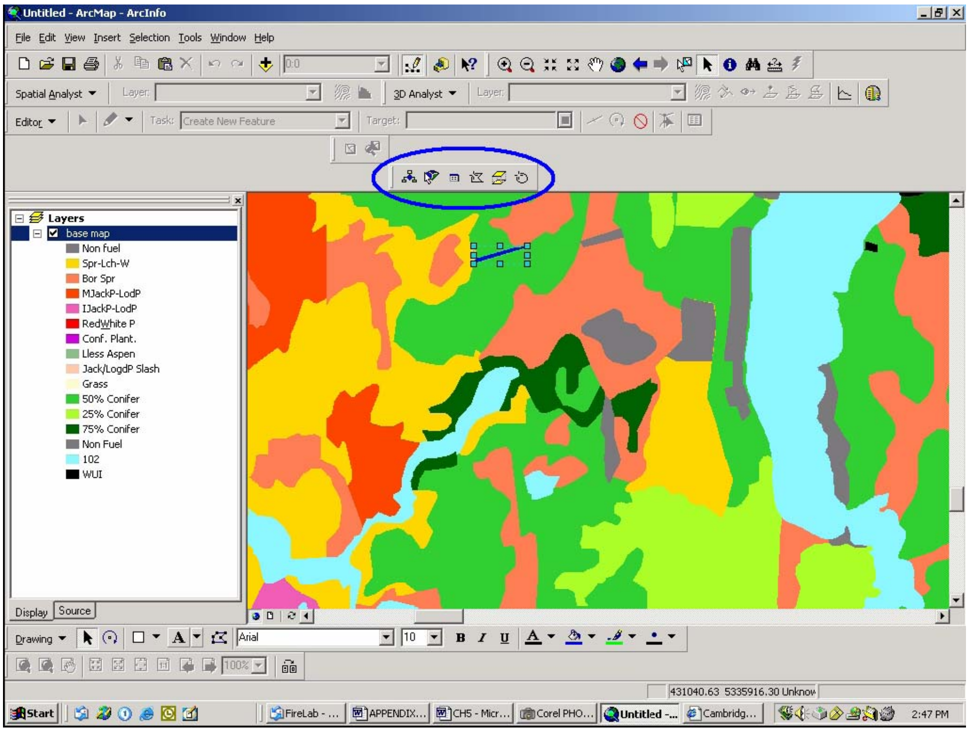

Figure 3—The WUI DSS graphic user interface.

Figure 4—Predicted burn probability if the proposed fuel treatment strategy is implemented.

Our WUI DSS uses the ArcGIS™ GIS to store and process landscape data. One of the required inputs is a digital description of the current forest landscape.

The current forest landscape for which fuel management strategies are to be developed and evaluated is described in a file which contains data that describes both the forested and WUI areas. The data needed to describe the forested area includes historical fire ignition densities and the fuel type and topography data that are used to model the behaviour of any fires that occur there.

The BP model has a fire occurrence module, an initial attack simulation module and a fire spread module. The fire occurrence module simulates the occurrence of fires during the next fire season. Predicted fire ignition is based on the number of fires that have occurred on the landscape in the past assuming recent spatial fire occurrence patterns can be used to model future ignition spatial patterns. The fire season is divided into 3 sub-seasons: spring, summer and fall based on the fact that fuel characteristics and fire occurrence patterns vary by sub-season. Fires are partitioned into 2 fire cause groups (lightning-caused fires and people-caused fires) to account for the fact that number of fires and the spatial locations pattern of fires also differ by sub-season and cause. We assume the probability distribution of the number of fires (by sub-season and cause) is Poisson with an average based on historical fire patterns for the area. We developed and used fire ignition density maps to describe the historical spatial fire patterns. The input data consists of two ASCII files that contain the fire density (fires/km^2) for each cell; one for people-caused fire occurrence density and a second for the lightning-caused fire occurrence density.

The BP initial attack module models the effectiveness of fire suppression activities on the landscape by predicting the fraction of fires that escape the initial attack. Fires that escape initial attack can grow to become major fires. The BP model assumes that the probability that a fire will escape initial attack is determined by its head fire intensity at the start of initial attack action and the initial attack response time, the time interval between the time the fire is reported and the initiation of suppression action by the initial attack crew.

It is reasonable to assume that the probability that a particular fire will escape initial attack will increase as its head fire intensity increases and decrease as its response time decreases. The Escape Index (EI: the product of the response time and the square root of the head fire intensity) is calibrated to model the performance of the initial attack system. All historical fires are ranked in increasing order of their EI and the critical threshold value is the one which corresponds with the historically observed percentile of escaped fires. For example, if the historical fire data indicates that 5 percent of the fires escaped initial attack in the study area, the 95th percentile of the EI is the threshold beyond which all fires are assumed to escape initial attack.

The growth of the fires that escape initial attack is modelled using Todd's (1999) WILDFIRE spread model. WILDFIRE is an eight-point contagion cellular fire growth model first developed by Kourtz and others (1977), that uses fuel data and the Canadian Forest Fire Behaviour Prediction System (FBP) calculations (FCFDG 1992) to project the growth of a fire's perimeter. WILDFIRE grows fires that have escaped initial attack and records the total area burned as well as the area burned by fuel type in each cell of the landscape.

The simulated fire activity is used to predict the burn probability of each cell on the landscape. All the cells burned by each simulated fire that occurs over a sample size of N iterations or simulated years are identified. Suppose n_i is the number of times cell i burns during those N simulated years. Then B_i, the estimated probability that cell i will burn during the next fire season is n_i / N.

The predicted burn probabilities are then displayed on a map which indicates areas where fires are most likely to occur and spread, information which fire managers can use when they develop and assess fuel management strategies.

The WUI DSS interface has a toolbar, buttons and commands that can be used to "implement" proposed fuel management treatments on the displayed map of the landscape. Pressing and clicking these buttons and commands directs the GIS to perform the designated programmed operations on the data and produce a revised landscape file with modified attributes that reflect the fuel changes that result from the proposed fuel management strategy. Examples of fuel management strategies that can be inserted on the map of the landscape using the GUI include 1) fuel reduction strategies such as thinning, timber harvesting, prescribed burning, 2) fuel isolation measures such as the creation of fuelbreaks, 3) fuel conversion measures such as the establishment of greenbelts and 4) the creation of defensible spaces around structures.

An Illustrative Example

We used our WUI DSS to assess the potential impact of fuel management in a 140,999 ha portion of the 628,907 hectare Romeo Mallette Forest (RMF) southwest of the city of Timmins in the Boreal Forest Region of Northeastern Ontario in Canada. The dominant forest type is black spruce (Picea mariana Mill.); however, other distinct forest types and associations can be found on a site-to-site basis. Fuel type data for the study area was obtained from the Ontario Ministry of Natural Resources (OMNR) fuel database.

The digital descriptions of the WUI areas in our study area were provided by the OMNR which has developed and maintains the Natural Resource & Value Information System (NRVIS), a GIS based system for managing the OMNR's digital land related information in a standardized manner. There were a total of 196 hectares of WUI in our study area. The fire weather data for the fire season (April to October) was extracted from the OMNR’s fire weather archive. Fire information extracted from the OMNR’s digital historical fire report archive.

Figure 2 is a map of the burn probabilities for the original landscape (without fuel treatment), and *figure 4* shows the predicted burn probability for the landscape given the implementation of a hypothetical fuel management strategy (decrease the percentage of spruce in mixedwood stands) that is to be evaluated. The percentage of spruce in mixedwood stands (higher than 25 percent for all stands) is decreased until 25 percent for all mixedwood stands treated. As part of the same fuel strategy some others stands are converted to trembling aspen (Populus tremuloides). As a result of this fuel treatment the percentage of less flammable species on the landscape is increased. *Table 1* shows the area of the stands treated, a total of 0.85 percent of the total study area (140, 999 ha).

Table 1— *Proposed FireSmart strategy: fuel conversion area treated.*

Vegetation composition	Area (ha)
70 pct to 25 pct spruce	529
50 pct to 25 pct spruce	540
Spruce/lichen woodland to aspen	121
Total area changed	1,191
Pct changed	0.85 pct

Evaluation of Fuel Management Strategies

Alternative fuel management strategies can be evaluated by comparing the predicted burn probability outcomes. The high burn probability intervals denote areas for which the probability of burning during the next fire season is high. These are hazardous areas in which wildfires can occur and spread out to neighbouring WUI areas. We therefore also augmented the basic burn probability mapping capabilities of our DSS with a distance model that can be used to quantify the distance between structures and high burn probability areas.

Distance is calculated using the analytical functions for modeling distance contained in the Spatial Analyst functions added to ArcMap™. The mapping distance function used here is the Straight Line Function (Environmental System Research Institute, Inc. 2001) which measures the straight line distance from a specified point called the source of interest to each cell in a coverage that has specified attributes. We used the WUI areas as the source of interest and calculated the distance from the WUI to areas with high burn probabilities. The distance is zoned into different intervals that allow for the classification of the WUI areas proximity to the high burn probability areas and we identified the WUI areas that are close to the regions more likely to burn are identified.

Figure 5 shows the location of the WUI areas within the study area with respect to the areas of high burn probability without any fuel management. The distance from any WUI area to any high burn probability cell in the coverage is less than 5 km in all cases.

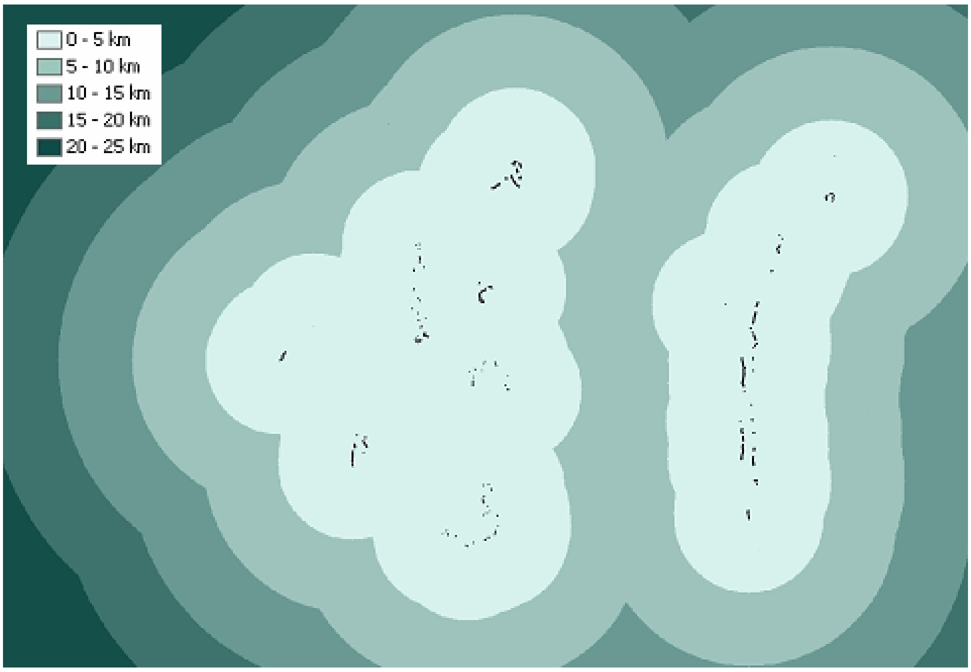

Figure 5— Distance analysis map for the original landscape.

If the fuel strategy described above was implemented, the distance from the WUI areas to the high burn probability areas would change as shown in *figure. 6*.

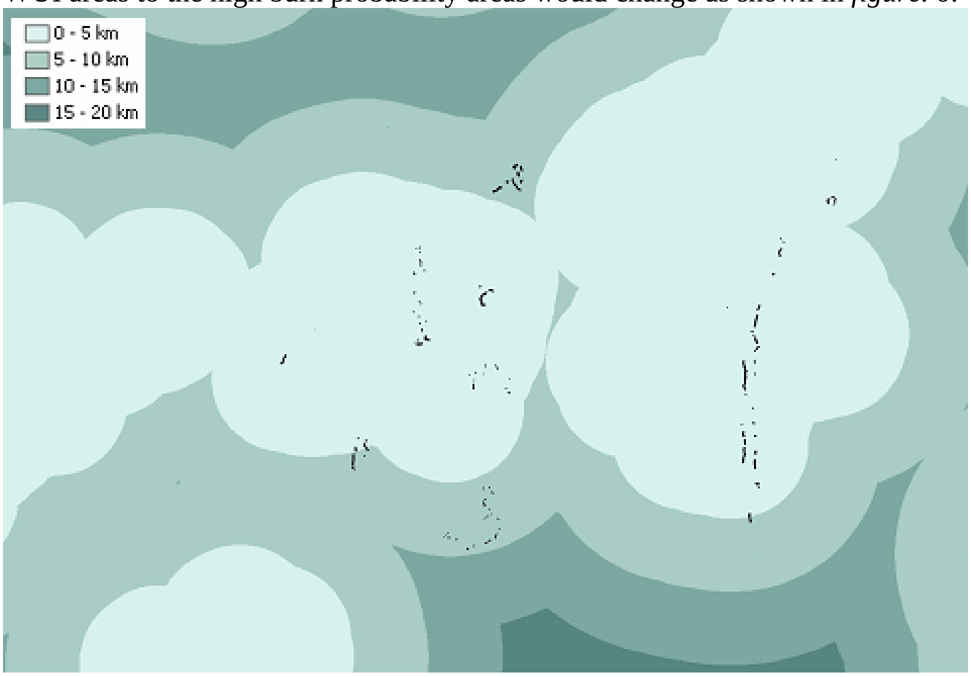

Figure 6— Distance analysis map for the proposed fuel treatment strategy.

The distance from some WUI areas to the hazardous high burn probability areas has increased to the 5-10 km range. Some of the WUI areas still remain within the 5 km radius but some would now be within the ring of 10 km from highest burn probability area. The proposed strategy would therefore reduce the hazardous zones located close to the WUI areas.

Potential Applications and Further Research

Our WUI DSS was developed to enhance fuel management in WUI areas by predicting how burn probabilities will vary across the landscape given the current structure of a landscape and the modified landscape structure that would result from proposed fuel management treatments and it includes a user friendly interface that fire managers and planners can use to delineate fuel treatment alternatives on an interactive map of the landscape being managed. It can be used to evaluate fuel management strategies in terms of changes in the magnitude and spatial distribution of the landscape burn probability and to gain insight into the performance of other strategies such as, for example, increasing the level of protection by means of the deployment of additional fire suppression resources and/or decreasing the number of people-caused fires through prevention efforts.

Local planning agencies responsible for reviewing and approving development proposals and the granting of building permits should provide adequate safety for communities from existing risk of fire. Our WUI DSS can be used to help evaluate the suitability of a location for a proposed housing development with respect to wildfire risk. Planners could use our WUI DSS to identify the areas in which the wildfire hazard is high and prohibit development in such zones.

Insurance companies could also use our WUI DSS to evaluate the wildfire hazard on WUI areas. They could analyze the location of certain WUI areas and, based on the burn probability of the surrounding area, decide either if coverage should be provided for that area or if mitigation strategies must be undertaken by owners in that particular area in order to be able to insure their property. The WUI DSS could be used to establish incentive programs to promote the adoption of fuel reduction measures by property owners. If building specific estimates of loss that would result from building burning were available, those loss estimates could be multiplied by the pixel level burn probabilities to estimate expected annual losses.

Burn probability maps could also be used to help raise public awareness in public education campaigns. Residents would develop a better understanding of the hazard that wildfire may pose to their property when they see where their property lies on a risk map. Awareness of the existing wildfire hazard might stimulate them to implement site level strategies to reduce the flammability of structures and the vegetation on their property.

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