Wildfire Threat Analysis and the Development of a Fuel Management Strategy for British Columbia

Judi Beck and Brian Simpson [1]

Abstract

The 2003 fire season in British Columbia, Canada was one of the worst in recent history. Fire in the wildland-urban interface destroyed over 334 homes and many businesses, and forced the evacuation of over 45,000 people. Drought cycles and forest health decline have contributed to the recent events of extreme fire behaviour across the province. To address key recommendations from post-season reviews, a balanced approach to fire management is being implemented with some emphasis on strategic fuel management, community wildfire protection plans, and fuel treatment projects.

In Canada, the most significant structural losses due to wildland fire have occured as a result of ember transport rather than by way of direct flame contact, hence an analytical approach has been developed to identify those forest stands that are capable of spotting and would threaten homes within the wildland-urban interface. For the potential spotting analysis, the CFFDRS has been applied along with spotting models, which have been calibrated for each of the fuel types within the Canadian Fire Behaviour Prediction (FBP) System, and a spotting potential for each area was assigned.

A structure density map was developed for the province based on structure density. Developments with approximately 10 to 1000 structures/km^2 are the focus for provincial fuel treatment priorities, because fuels become sparse as concrete dominates more urban areas and the cost of treating isolated structures becomes impracticable.

Spotting potential was then combined with structure density to prioritize areas for fuel treatment. The results of the analytical approach developed are well correlated spatially with the general structural losses that were incurred during the Okanagan Mountain Park fire in 2003, and suggest that 1.7 million hectares potentially require fuel treatment in British Columbia.

This paper describes the provincial wildfire threat analysis, and discusses future potential model refinements. It also details the British Columbia's fuel management strategy, which includes community protection planning and fuel treament programs to help local governments, partners, industry and stakeholders mitigate the impacts of wildland fire and implement fuel treatments.

Key Words: fuel management, wildfire threat, interface, fuel treatment, spot fires

[1] British Columbia Ministry of Forests and Range, Protection Program, PO Box 9502 Stn Prov Govt, Victoria, BC, V8W 9C1, CANADA.

Introduction

The 2003 fire season was one of the most catastrophic in British Columbia's recent history. Due to an extended drought in the southern half of the province, forest firefighters faced conditions never seen before in Canada. Nearly 2,500 fires burnt more than 265,000 ha, destroyed over 334 homes, and resulted in the single largest evacuation due to wildfire in Canadian history, which involved more than 30,000 people. More than 10,000 firefighters and support personnel responded to wildland fire incidents, at a total cost estimated at $700 million CND (Filmon 2003).

British Columbians have weathered significant losses including homes, businesses, historical sites, and valuable timber from numerous fire seasons (Office of the Auditor General of British Columbia 2001, 2003; Ombudsman of British Columbia 1999; Price Waterhouse 1995). As people build their homes near forested areas, there is potential that forest fires will threaten them and their property. In recognizing this risk, British Columbia has been working since the 1980s to develop a number of programs, culminating in what is currently FireSmart (Partners in Protection 2003). Since the 2003 fire season, the British Columbia Ministry of Forests and Range, the Union of British Columbia Municipalities (UBCM) and the First Nation Emergency Services Society (FNESS) have worked together to heighten provincial awareness through the promotion of FireSmart programs, and the implementation of a provincial fuel management strategy.

After the 2003 fire season, a review was conducted by Filmon (2003) to examine the interface fires that caused unprecedented damage in British Columbia. The review noted that all levels of government as well as individual homeowners share the responsibility to manage development and mitigate the impacts of wildland fire on communities, businesses and residences. Filmon (2003) recommended that the provincial government lead the development of a strategic plan to improve fire prevention in the interface through fuel management that:

- identifies areas of the province where communities, infrastructure and watersheds have the greatest potential to be impacted by large-scale fire;
- identifies fuel management priorities based on threats to human life, property and resource values;
- requires a community protection plan where fires of consequence in the wildland-urban interface are probable; and
- is cost shared with local governments.

It was also recommended that a program of pilot fuel treatment projects be implemented in cooperation with provincial, municipal and regional governments to demonstrate the costs and benefits of fuel treatments.

A Fuel Management Strategy for British Columbia

The provincial fuel management strategy includes three key initiatives to mitigate the potential impacts of wildfire on the communities of British Columbia:

- a provincial strategic wildfire threat analysis to identify hazardous forest fuels that have the potential to exacerbate fire behaviour near wildland-urban interface areas;
- a program to help local governments develop Community Wildfire Protection Plans; and

- pilot and operational fuel treatment programs to help local governments, partners, industry and stakeholders implement fuel treatments.

Strategic Threat Analysis

A prototype Wildfire Threat Rating System (WTRS) was first produced for the McGreggor Model Forest in British Columbia (Hawkes and Beck 1997; Hawkes and others 1997a, 1997b, 1997c) based on a similar system initially developed for Western Australia (Beck and Muller 1989, Beck 2000). The WTRS was developed to integrate, explore, and analyze, through the use of applied GIS (Geographic Information System), key factors that contribute to wildfire threat, for example: the effects of management actions on the threat of wildfires; the potential impacts of wildfires on forest resources; and, options to reduce the probability of large, intense wildfires. The prototype WTRS, which has been adopted and advanced by others (Ohlson and others 2003), defined threat as a function of four main components: risk of ignition; values to be protected; potential fire behaviour; and, suppression capability.

The majority of structural losses in the wildland-urban interface are ignited by way of fire brands and embers (Chisholm Fire Review Committee 2001), rather than by way of direct flame contact. The analysis reported herein has been developed to define the potential scope of the provincial fuel treatment program, and to help communities identify priority treatment areas. Hence the current threat analysis has been developed to identify forest stands that have potential for crown fire activity and the release of fire brands (spotting) that could threaten nearby communities within the wildland-urban interface.

Fire History and Risk

Fire occurrence or risk of ignition is the probability or chance of a fire starting. Historical records of lightning and person caused fires have been used to define fire risk based on records from 1950-1991 (Blackwell 2004a). Ignition locations have been applied over a radius of 500 m due to due to the lower accuracy of fire locations in older records. Fire risk has been defined as nil, low, moderate or high given 0, 1-2, 2-4 and greater than 4 fires per 4 km^2 over 41 years (*figure 1*). Throughout the paper, sample maps at a scale of 1:20,000 are presented for the coverages produced (e.g. *figure 1*), although all map sheets (approximately 7000) for the province have been processed.

Interface

The distribution of buildings from the provincial TRIM (Terrain Resource Information Mapping) dataset was applied to define a structural density map and interface areas for the province (Blackwell 2004b). The ARC/INFO POINTDENSITY function was applied to calculate the number of structures (homes or residential buildings) per 0.78 km^2 using a search radius of 500 m. The output raster grid was then converted to polygons and intersected with water features. Structure density (*figure 2*) was then classified as urban (> 1000), developed (100-1000), mixed (10-100), undeveloped (1-10) and isolated (< 1). In this analysis, the wildland-urban interface has been defined as areas with structure densities in the developed and mixed developed classes (10 – 1000). The wildland-urban interface is the highest priority for fuel treatment and community protection, since concrete dominates urban areas and the area and costs associated with treatments to protect isolated structures would be prohibitive.

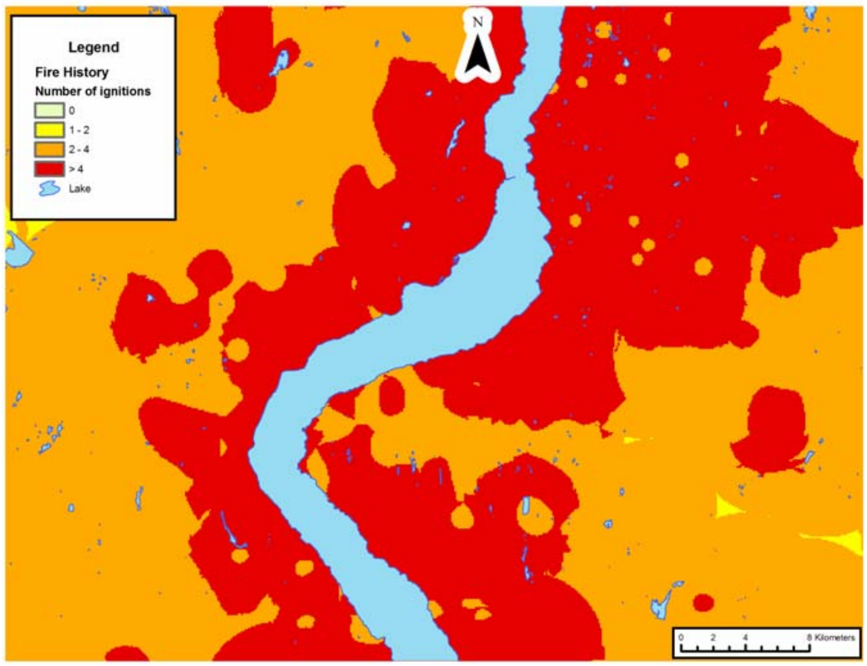

Figure 1-Fire risk has been defined as nil, low, moderate or high given 0, 1-2, 2-4 and greater than 4 fires per 4 km^2 over 41 years.

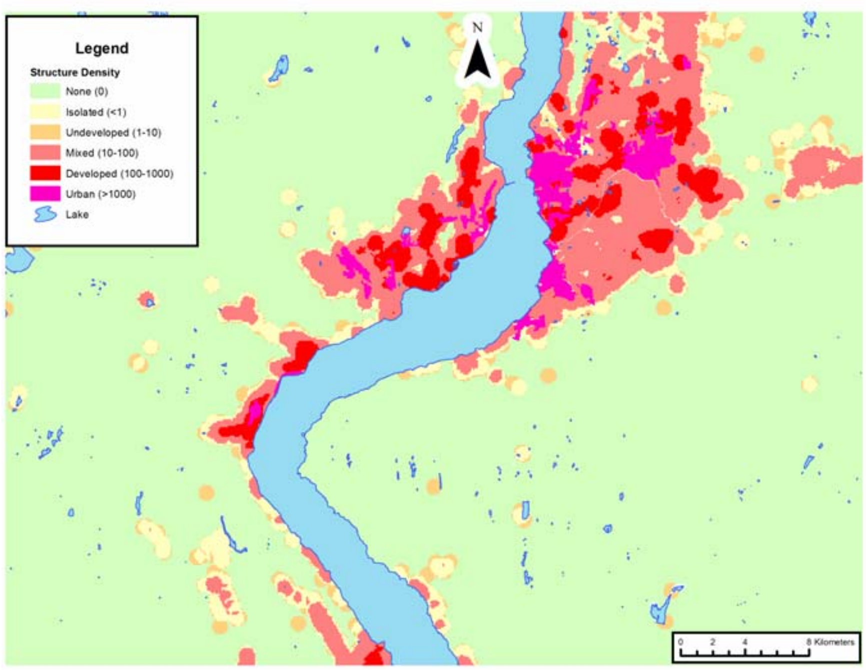

Figure 2-Structure density has been classified as urban (> 1000), developed (100-1000), mixed (10-100), undeveloped (1-10) and isolated (< 1). The wildland-urban interface is defined by areas with structure densities in the developed and mixed classes (10–1000).

Spotting and Interface Breach Potential

The Canadian Forest Fire Danger Rating System (CFFDRS) is used across Canada for evaluating forest fire danger and for predicting fire behaviour characteristics (Taylor and Alexander 2006). The Canadian Forest Fire Behaviour Prediction (FBP) System (Forestry Canada Fire Danger Group 1992) organizes fuel types into five major groups (coniferous, deciduous, mixedwood, slash and grass), with a total of 16 discrete fuel types. Fuel types in the FBP System are described qualitatively using terms describing stand structure and composition, surface and ladder fuels, and the forest floor cover and organic (duff) layer. A simple classification system was developed and implemented to classify FBP System fuel types in British Columbia (*figure 3*) based on forest cover and inventory information available at a 1:20,000 scale (Hawkes and others 1995).

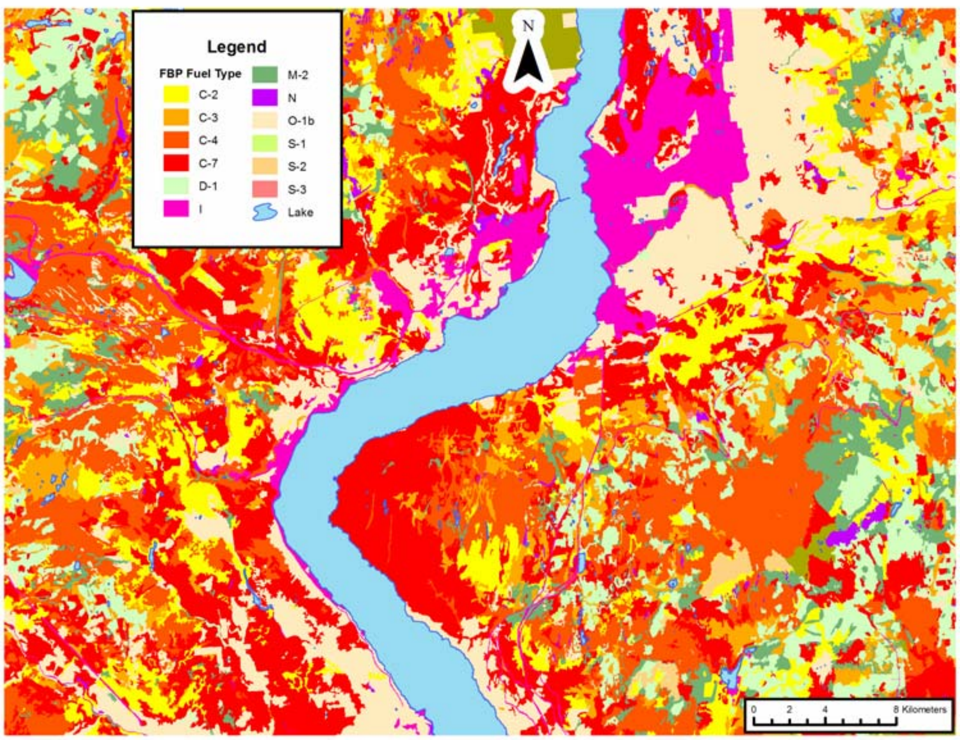

Figure 3-FBP System fuel types have been classified based on forest cover and inventory information available at 1:20,000 scale.

The FBP System defines the rate of spread of as the forward movement of the fire front per unit time after having reached equilibrium, and hence the impacts of crowing and spotting are automatically accounted for in terms of their influence on the overall spread rate (Forestry Canada Fire Danger Group 1992). While the FBP System predicts the critical surface fire intensity (CSI) and fire type (surface, intermittent crowning and crown fire) using methods developed by Van Wagner (1977), it does not include separate models to predict spotting distances.

Within the FBP System, the CSI varies with conifer foliar moisture content (FMC) and by fuel type as a function of crown base height (CBH), which is the height (m) above the ground that the live crown base begins:

$$CSI = 0.001 * CBH^{1.5} * (460 + 25.9 * FMC)^{1.5}$$

For all but the deciduous, slash (S) and grass (O) fuel types, it is possible to compare FBP System fuel types according to the conditions that are required for the onset of crowning, assuming the mid-summer maximum conifer foliar moisture content of 120 percent (*table 1*). Crowning potential based on fuel type alone can be interpreted by way of the CSI, where the lower the CSI value the easier it is for a given fuel type to crown. Given CSI values for each FBP System fuel type, the relative ease with which a given fuel type will experience crowning and hence has the potential to spot can be classified (CSI class) using the CSI for that fuel type as a proportion of the minimum CSI (603 kW/m) required for the onset of crowning.

Table 1-*Crtical surface fire intensity (CSI) and CSI class for each coniferous and wixedwood FBP System fuel type as a function of crown base height (CBH) assuming the mid-summer, maximum foliar moisture content of 120 percent.*

Fuel type	Fuel description	CBH (m)	CSI (kW/m)	CSI class (CSI/CSImin)
C-1	Spruce-lichen Woodland	2	603	1
C-2	Boreal Spruce	3	1107	2
C-3	Mature Jack or Lodgepole Pine	8	4823	8
C-4	Immature Jack or Lodgepole Pine	4	1705	3
C-5	Red and White Pine	18	16276	27
C-6	Conifer Plantation	7	3947	7
C-7	Ponderosa Pine/Douglas-Fir	10	6740	11
M-1	Boreal Mixedwood - leafless	6	3132	5
M-2	Boreal Mixedwood - green	6	3132	5
M-3	Dead Balsam Fir Mixedwood - leafless	6	3132	5
M-4	Dead Balsam Fir Mixedwood - green	6	3132	5

Albini's (1979) model for predicting maximum spotting distances for single or group tree torching firebrand sources has been applied using equations documented by Chase (1984), assuming flat terrain and given general assumptions on representative species, DBH (diameter at breast height) and tree height values for each of the coniferous (C) and mixed-wood (M) fuel types within the FBP System (Alexander 2004; Alexander and others 2004). Maximum spotting distances (*table 2*) were calculated for intensities set at CSI for each fuel type (*table 1*) given a 50 km/h wind speed measured in the open, 10 m above the ground (assumed to be 1.15 times that at a height of 6 m).

Applying the CSI for intensity, calculated maximum spotting distances varied from a minimum of 775 m to a maximum of 1028 m. At higher intensity values, which were common during the 2003 fire season in British Columbia, observed spotting distances associated with significant wind events often reached 1 to 2 km. Only one fire was documented to have spotted beyond 2 km, but this occurred in steep terrain under the influence of significant valley winds. Others have reported spotting distances in Canada up to about 1.9 km (Kiil and others 1977), with rare events in boreal-like conifer forests to a distance of 4 km (Haines and Smith 1987).

Spotting potential has also been evaluated for slash and grass fuel types using Albini's model for wind driven surface fires (Albini 1983, Chase 1984). In comparison to conifer and mixed-wood fuel type, nominal spotting distances can be expected for slash and grass fuel types. Rapid rates of spread in fully cured grassland fuels are apt to be more problematic from a potential interface breach perspective rather than by way of spotting. Hence grass and slash fuels have been classified somewhat subjectively based on their spread rate potential rather than on spotting potential *per se*.

Table 2-*Maximum spotting distances given 50 km/h winds and general assumptions on representative species, DBH (diameter at breast height), tree height, maximum number of trees burning (MNTB) at the critical surface fire intensity (CSI) for a given fuel type.*

Fuel type	DBH (cm)	Tree height (m)	MNTB	CSI (kW/m)	Spotting distance (m)
C-1	7	10	15	603	775
C-2	4	7	30	1107	877
C-3	18	18	15	4823	1019
C-4	5	10	30	1705	734
C-5	33	25	5	16276	812
C-6	15	14	10	3947	883
C-7	25	20	5	6740	813
M-1	11	13	10	3132	1026
M-2	10	8	20	3132	1028
M-3	7	10	15	3132	775
M-4	4	7	30	3132	877

Based on this analysis, FBP System fuel types have been classified for their spotting and interface breach potential (*figure 4*) as high (C-1, C-2, and C-4), moderate (M-1, M-2, M-3, and M-4), low (C-3, C-7, C-6 and O-1) and nominal (C-5, S-1, S-2, S-3, D1).

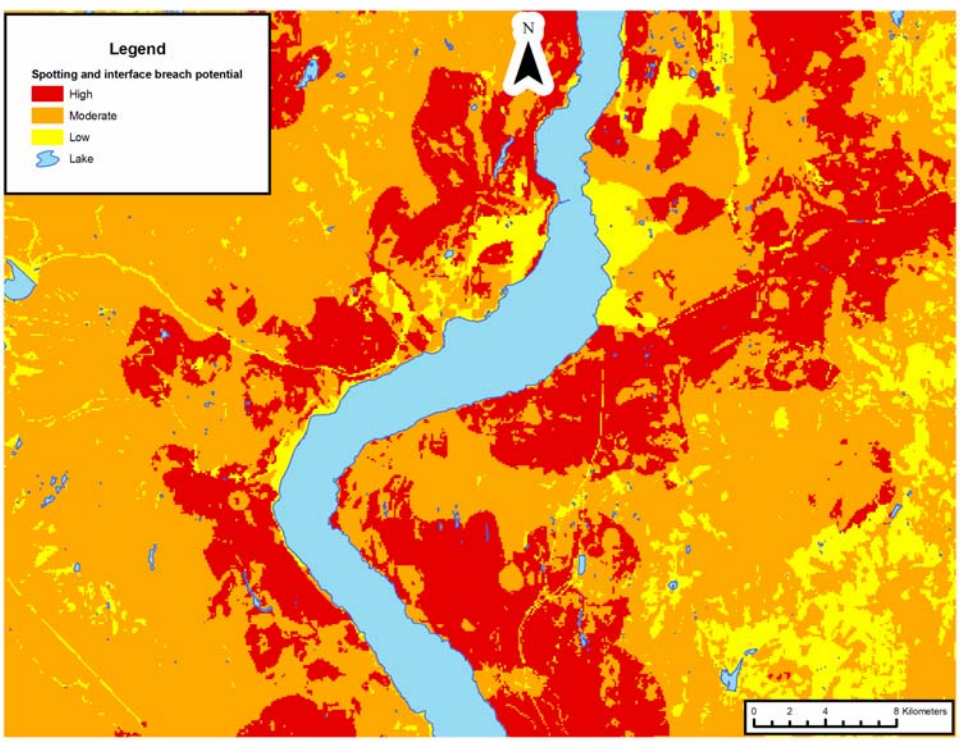

Figure 4-Spotting and interface breach potential has been classified as high (C-1, C-2, and C-4), moderate (M-1, M-2, M-3, and M-4), and low (C-3, C-7, C-6 and O-1) and nominal (C-5, S-1, S-2, S-3, D-1).

Interface areas (10 to 1000 structures per 0.78 km^2) have been buffered by 2 km (based on observed maximum spotting distances), and intersected with the spotting and interface breach potential coverage to develop a final coverage that depicts those stands that are able to threaten communities.

Of the 95 million ha of British Columbia analyzed, data were missing for about 9.5 million ha, and 3.1 million ha of the missing data were within the 2 km buffer area around interface. Forest cover and inventory data have been maintained largely to support commercial forestry interests, and the largest contiguous block of missing data is on Vancouver Island, which is dominated by private land.

Okanagan Mountain Park Fire Case Study Validation

It is difficult to validate most WFTR systems, but a simple case study has been carried out to evaluate the usefulness of the approach described above to identify areas where communities have the greatest potential to be impacted by fire.

The Okanagan Mountain Park fire burnt 25,000 ha and was the most significant interface wildfire of the 2003 season. The fire threatened the communities of Naramata and Kelowna, and caused the evacuation of 33,050 people; 4,050 of these people were evacuated twice. A total of 238 homes were lost or damaged with the passage of a cold front that brought strong, south west and then westerly winds.

Analysis of the maps that have been produced based on data at the time of the fire (*figure 5*) illustrates that forest stands that have a high spotting potential are well correlated spatially with structural losses incurred. The currency of the TRIM data means that new homes and developments may not always be depicted in the structural density coverage, and this is reflected in discrepancies between interface areas and the structures digitized from more recent aerial photographs. Nonetheless, these results suggest that interface areas identified with a high potential for spotting are indeed an appropriate focus for fuel treatment.

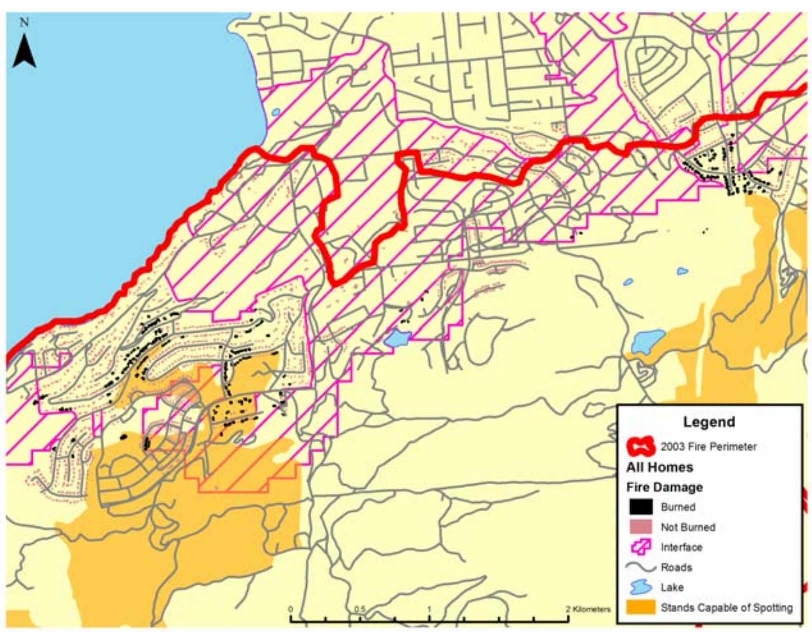

Figure 5-Forest stands that have a high spotting potential are well correlated spatially with the structural losses incurred in Kelowna during the Okanagan Mountain Park fire. The fire burnt the entire area south of the red line.

Provincial Fuel Treatment Implications

Given the analysis described above, approximately 1.72 million ha potentially pose a threat to interface areas in of British Columbia and may require fuel treatment (*table 3*). Moreover, as a result of the current mountain pine beetle epidemic, it is projected that 80 percent of the merchantable pine in British Columbia could be killed by 2013, and well over half that pine could be dead by the summer of 2007. Further analysis, based on the presence of greater than 20 percent pine for stands 60 years and older, also suggests that mountain pine beetle (*Dendroctonus ponderosae*) is likely to accelerate the need to treat 460,000 of the 1.72 million ha identified.

Table 3-*Summary of forest stands (ha) that pose spotting and interface breach potential within 2 km of interface (10 – 1000 structures per 0.78 km^2) areas.*

Land Ownership	Spotting and Interface Breach Potential			
	Low	Moderate	High	Total
Federal	3,863	15,599	25,433	44,895
Private	22,966	168,094	154,350	345,409
Provincial	38,460	786,447	505,945	1,329,852
Total	65,290	970,140	684,728	1,720,158

Fuel Management Strategy Implementation Progress

The strategic threat analysis described herein is a high level analysis that identifies forest stands that may pose a risk of fire to wildland-urban interface areas of British Columbia. This analysis broadly prioritizes areas for treatment, and has been shared with local governments, First Nations, Indian and Northern Affairs Canada, Natural Resources Canada and Public Safety and Emergency Preparedness Canada. Improvements to the existing analysis could incorporate stronger linkages between fire weather climatology and the probability of crown fire and spotting. An alternative analytical approach could incorporate models, such as those under development elsewhere[*], to quantify the probability of a crown fire impacting an interface area.

Through partnerships with the Union of British Columbia Municipalities and the First Nations Emergency Services Society, a program is also underway to support the development of Community Wildfire Protection Plans (CWPPs). These action plans are developed by communities and outline a strategy for protection from catastrophic wildfires. Local governments may use the provincial strategic threat analysis, but because of weaknesses in the currency or availability of provincial information, they may refine the provincial strategic threat analysis based on more detailed local information on values at risk, fire occurrence, forest fuels and interface areas.

A CWPP includes a general description of the community and the fire risk it faces, identifies priority areas and maintenance requirements for fuel mitigation work, and outlines a wildfire prevention program. FireSmart (Partners in Protection 2003) principles are often a key component of these plans, which may also address the need for development restrictions or bylaw requirements for buildings, developments or fire prevention.

[*] Taylor, S.W., J.V. Parminter, and G. Thandi. 2005. Logistic regression models of wildand fire probability in British Columba. Unpublished final report to the B.C. Forest Science Program. Natural Resources Canada, Victoria, B.C. 12 p.

Once a CWPP has been developed, a community is encouraged to implement their plan and to undertake pilot or operational fuel treatment projects. Pilot projects are small scale projects intended to explore a range of fuel treatments to gain a clear understanding of treatment effectiveness, impacts on other values, maintenance implications and costs. These projects are cost shared between local and provincial governments, and may involve communities, forest consultant professionals, the forest Industry, utility industries, the bio-energy sector, and research groups like the Canadian Forest Service, the Forest Engineering Research Institute of Canada and Universities. A cost shared funding program has also been established through the Union of British Columbia Municipalities and the First Nations Emergency Services Society for those communities that choose to implement large scale operational treatments.

As treatment projects are completed and evaluated, information and lessons learned will be shared publicly, and information from these projects will also be used in the development of best practices for fuel management. Since the inception of the program in 2004, the total area treated has been growing (approximately 4300 ha in 2005 and 6830 ha in 2006), and treatments are expected to accelerate as more communities finalize their CWPPs' (82 plans initiated and 39 plans completed to date).

Conclusions

In the implementation of British Columbia's fuel management strategy, the province provides funding and technical support to local governments and First Nations' communities through fuel management specialists, and the Union of British Columbia Municipalities and the First Nations Emergency Services Society provide administrative support. This delivery partnership provides guidance and tools to support communities to plan and implement fuel treatments, but all projects must be initiated and lead by a local government. The province recognizes that local governments have a vested interest in these plans, but they also have real limitations with regards to funding, technical knowledge, staff and other resources. Although some communities do no believe it is their responsibility to lead initiatives on lands beyond their local jurisdiction, they may be more inclined to lead fuel planning and treatment initiatives when treatments simultaneously enhance safety, visual quality, ecological values, wildlife habitat or other community values.

Fuel management has been successful where communities have initiated planning and treatment work, and the public has been supportive and actively engaged. The fuel management strategy that has been developed in British Columbia attempts to foster cooperation between multiple partners and stakeholders in the planning, management, and maintenance of forest fuels near the wildland-urban interface. This is consistent with recommendations made by others (Filmon 2003, Taylor 2004), who have expressed the need for all levels of government, as well as individual homeowners, to share responsibilities for mitigating the impacts of wildland fire in the wildland-urban interface.

Acknowledgments

B.A. Blackwell and Associates Ltd. first implemented the strategic threat analysis described in this work while on contract for the Union of British Columbia Municipalities with technical input from the British Columbia Ministry of Forests and the Canadian Forest Service. Discussions with Steve Taylor, Marty Alexander, and Brad Hawkes of the Canadian Forest Service, as well as Peter Fuglem and Chris

Duffy of the Ministry of Forests and Range, were instrumental in the development of this work. Steve Taylor and Gurp Thandi digitized the structural losses that were incurred in the Okanagan Mountain Park fire, and Dana Hicks and Rick Lanoville were part of a team of specialists that documented these losses in the field. Sunjit Mark and George Eade provided GIS data for the project, and Matthew Barker produced all of the figures in this report. Marty Alexander and Nathalie Lavoie reviewed an earlier draft of this work.

References

Albini, F.A. 1979. **Spot fire distance from burning trees – a predictive model**. USDA For. Serv. General Technical Report INT 56; 73p.

Albini, F.A. 1983. **Potential spotting distance from wind-driven surface fires**. USDA For. Serv. Research Paper INT 309; 27p.

Alexander, M.E. 2004. **Nominal diameter-at-breast height and tree height values for Canadian Forest Fire Behavior Prediction (FBP) System fuel types for use in Albini's maximum spoting distance model.** Forest Engineering Research Institute of Canada, Wildland Fire Operations Research Group, Hinton, Alberta. 3 p.

Alexander, M.E.; Tymstra, C.; Frederick, K.W. 2004. **Incorporating breaching and spotting considerations into PROMETHEUS – the Canadian wildland fire growth model.** Chisholm/Dogrib Fire Research Initiative, Quicknote 6, Foothill Model Forest, Hinton, Alberta. 2p.

Beck, J. A. 2000. **Towards an operational geographical information and modeling system for fire management in Western Australia**. School of Spatial Analysis, Curtin University of Technology, Perth. Ph.D. dissertation.

Beck, J.A.; Muller, C. 1989. **The inception and development of decision support systems for forest fire management in Western Australia.** In: Daniel, T.C.; Ferguson, I.S., ed. Proceedings of the US-Australia Workshop Integrating Research on Hazards in Fire-Prone Environments: Reconciling Biological and Human Values in the Wildland/Urban Interface. June 12-16, 1989, Melbourne, Victoria. The United States Man and the Biosphere Program, Washington, D.C; 94-100.

Blackwell, B.A. 2004a. **Development and implementation of a regional scale assessment of forest fire risk, values at risk and hazard.** Unpublished proposal prepared for the Protection Program, Ministry of Forests, British Columbia.

Blackwell, B.A. 2004b. **Interface analysis options: urban interface samples – Kelowna.** Unpublished presentation prepared for the Protection Program, Ministry of Forests, British Columbia.

Chisholm Fire Review Committee. 2001. **Final Report.** Produced for the Alberta Ministry of Sustainable Resource Development, Edmonton, Alberta.

Chase, C.H. 1984. **Spotting distance from wind-driven surface fires – extensions of equations for pocket calculat**ors. USDA Forest Service, Intermountain Forest and Range Experiment Station, Research Note INT-346, Ogden, Utah.

Filmon, G. 2004. **Firestorm 2003 Provincial review.** Province of British Columbia, Victoria, British Columbia.

Forestry Canada Fire Danger Group. 1992. **Development and structure of the Canadian Forest Fire Behavior Prediction System.** Information Report ST-X-3, For. Can., Science and Sustainable Development Directorate, Ottawa. 63 p.

Haines, D.A.; Smith, M.C. 1987. **Three types of horizontal vortices observed in wildland mass and crown fires.** Journal of Climate and Applied Meteorology 26: 1624-1637.

Hawkes, B.; Beck, J. 1997. **A wildfire threat rating system.** Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre. Technology Transfer Notes 1 (July 1997). 6 p.

Hawkes, B.; Beck, J.; Sahle, W. 1997a. **Wildfire threat rating system for the McGregor Model Forest.** In: Proceedings of the 13th Fire and Meteorology conference, Oct. 28-31, 1996, Lorne, Australia, Proceedings being printed by International Association of Wildland Fire.

Hawkes, B.; Beck,J; Sahle,W. 1997b. **A wildfire threat rating system for the McGregor Model Forest: Final report for the McGregor Model Forest.** Available from McGregor Model Forest Association, Prince George, B.C. (contains 5 sections, Conference Paper, Feedback Workshop, GIS Documentation, Fuel Type Photo Series, and Wildfire Threat Maps).

Hawkes, B.; Sahle, W.; Beck, J. 1997c. **Wildfire threat rating system for McGregor Model Forest – technical GIS documentation.** Canadian Forest Service. Pacific Forestry Centre. 25 p.

Hawkes, B.C.; Goodenough, D.; Lawson, B.; Thomson, A.; Sahle, W.; Niemann, O.; Fuglem, P; Beck, J.; Bell, B; Symington, P. 1995. **Forest fire fuel type mapping using GIS and remote sensing in British Columbia.** In: Proceedings of the Ninth Annual Symposium on Geographic Information Systems, GIS95, Vancouver, B.C.: 647-656.

Kiil, A.D.; Miyagawa, R.S.; Quintillio, D. 1977. **Calibration and performance of the Canadian Fire Weather Index in Alberta.** Environment Canada, Canadian Forestry Service, Information Report NOR-X-173, Northern Forest Research Centre, Edmonton, Alberta.

Office of the Auditor General of British Columbia. 2001. **Report 1: Managing Interface Fire Risks.** Victoria, BC.

Office of the Auditor General of British Columbia. 2003. **Report 8: Follow-up Performance Reports.** Victoria, BC.

Ohlson, D.W.; Blackwell, B.A.; Hawkes, B.; Bonin, D. 2003. **A wildfire risk management system – an evolution of the wildfire threat rating system.** In: Proceedings 3rd International Wildland Fire Conference and Exhibition. Sydney Australia. October 3-6, 2003.

Ombudsman of British Columbia. 1999. **The Silver Creek fire review.** Public Report No. 39.

Partners in Protection. 2003. **FIRESMART: protecting your community from wildfire.** Second Edition, Partners in Protection, Edmonton, Alberta.

Price Waterhouse. 1995. **Garnet fire review.** British Columbia Ministry of Forests, Protection Program, Vancouver, British Columbia. 94 pp.

Taylor, S.J. 2004. **Managing interface fire risk is a shared responsibility.** FORUM Magazine. A publication of the Association of Forest Professional, Vancouver, British Columbia.

Taylor, S.W. and M.E. Alexander. 2006. **Science, technology, and human factors in fire danger rating: the Canadian experience.** International Journal of Wildland Fire 15(1):121-135.

Van Wagner, C. E. 1977. **Conditions for the start and spread of crown fire.** Can. J. For. Res. 7: 23-34.