VILLAGE OF LIONS BAY
COMMUNITY WILDFIRE PROTECTION PLAN

B.A. Blackwell & Associates Ltd.
April, 2007

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Considerations for Wildland Urban Interface Management in the Village of Lions Bay, British Columbia

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I certify that I have reviewed this document and I have determined that this work has been done to standards acceptable of a Registered Professional Forester.		

Executive Summary

B.A. Blackwell and Associates Ltd. were retained to develop Community Wildfire Protection Plans for nine municipalities, including the Village of Lion's Bay, in consultation with the GVRD and representatives of participating member municipalities. The project was funded by the GVRD, participating municipalities and a supplementary grant from the Union of B.C. Municipalities.

The key priorities for wildfire management planning in the Village were identified as:

- Hazard and risk mapping of the Village to establish areas of the community that are at greatest risk from fire;
- Communication and education to local residents, all levels of government, and the general public;
- Review of the policy and planning tools available to improve structure protection within the Village;
- Review of emergency response capability in terms of access in and out of the Village and available resources;
- Training for Fire Department departments and volunteers;
- Fuel management within and around the municipal boundary; and,
- Post-fire rehabilitation.

A Wildfire Risk Management System (WRMS) was developed to identify key areas of risk within the community and to support the development of the Plan. A synopsis of key findings and plan recommendations follows. In total, 21 recommendations were developed for consideration by the Village.

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1.0 Introduction

1.1 Background

In 2006 B.A. Blackwell and Associates Ltd. were retained to assist the Village of Lions Bay, the GVRD and eight other member municipalities in developing Community Wildfire Protection Plans, hereinafter referred to as “the Plan”. ‘FireSmart – Protecting Your Community from Wildfire’ (Partners in Protection 2004) was used to guide the protection planning process. Within the Village, the assessment considered important elements of community wildfire protection that included communication and education, structure protection, training, emergency response, and vegetation management.

The social, economic and environmental losses associated with the 2003 fire season emphasized the need for greater consideration and due diligence in regard to fire risk in the wildland urban interface (WUI). In considering wildfire risk in the WUI, it is important to understand the specific risk profile of a given community, which can be defined by the probability and the associated consequence of fire within that community. While the probability of fire in coastal communities is substantially lower when compared to the interior of British Columbia, the consequences of a large fire are likely to be very significant in lower mainland interface communities given population size, values at risk, and environmental considerations.

The results of this study will provide the Village with a framework that can be used to review and assess areas of identified high fire risk. Additionally, the information contained in this report should help to guide the development of emergency plans, emergency response, communication and education programs, bylaw development in areas of fire risk, and the management of forest lands adjacent to the community.

1.2 Purpose and Scope

B.A. Blackwell and Associates Ltd. were retained to develop Community Wildfire Protection Plans for nine municipalities, including the Village of Lions Bay, in consultation with the GVRD and representatives of participating member municipalities. The project was funded by the GVRD, participating municipalities and a supplementary grant from the Union of B.C. Municipalities. The purpose of the Plan is to quantify and identify fire risk within the Village, recommend management actions that can be undertaken to minimize the risk, and provide a tool to communicate and educate Lions Bay residents and visitors about fire risk and management issues.

The scope of this project included three distinct phases of work:

- **Phase I** –Assessment of fire risk and development of a Wildfire Risk Management System to spatially quantify the probability and consequence of fire.
- **Phase II –** Identification of hazardous fuel types and estimation of spotting risk.

- **Phase III –** Development of the Plan, which outlines measures to mitigate the identified risk through structure protection, emergency response, training, post-fire rehabilitation, communication, and education.

2.0 Village of Lions Bay

2.1 Study Area

Lions Bay is located approximately 11 km north of Horseshoe Bay, on the eastern shore of Howe Sound on Highway 99, (the Sea to Sky Highway). The small seaside village situated at the base of the Coast Mountain Range has a land area of 255ha[1] which is characterized by steep forested terrain and creeks. Surrounded by mountains, with spectacular views of the ocean and the Gulf Islands, Lions Bay is primarily a residential community of single detached housing, with homes perched high on the mountainside and scattered along the waterfront.[2]

The total study area that makes up this plan includes the municipal boundary and a 5 km buffer that consists of map sheet numbers: 092G.025, 092G.026, 092G.035, 092G.036 092G.045, and 092G.046. The total study area is 11,676 hectares. Of this area, 5,207 ha did not have fuels data either because it was water (5,091 ha) or because it was unclassified adjacent island area (116 ha). The areas without fuels data were excluded from area summaries describing fuels and biogeoclimatic data, therefore, the total area that contributed to the summary data was 6,469 ha.

1 http://www.gvrd.bc.ca/growth/keyfacts/municipalities.htm
2 http://www.lionsbay.citymax.com/f/Lions_Bay_OCP_REPORT.pdf

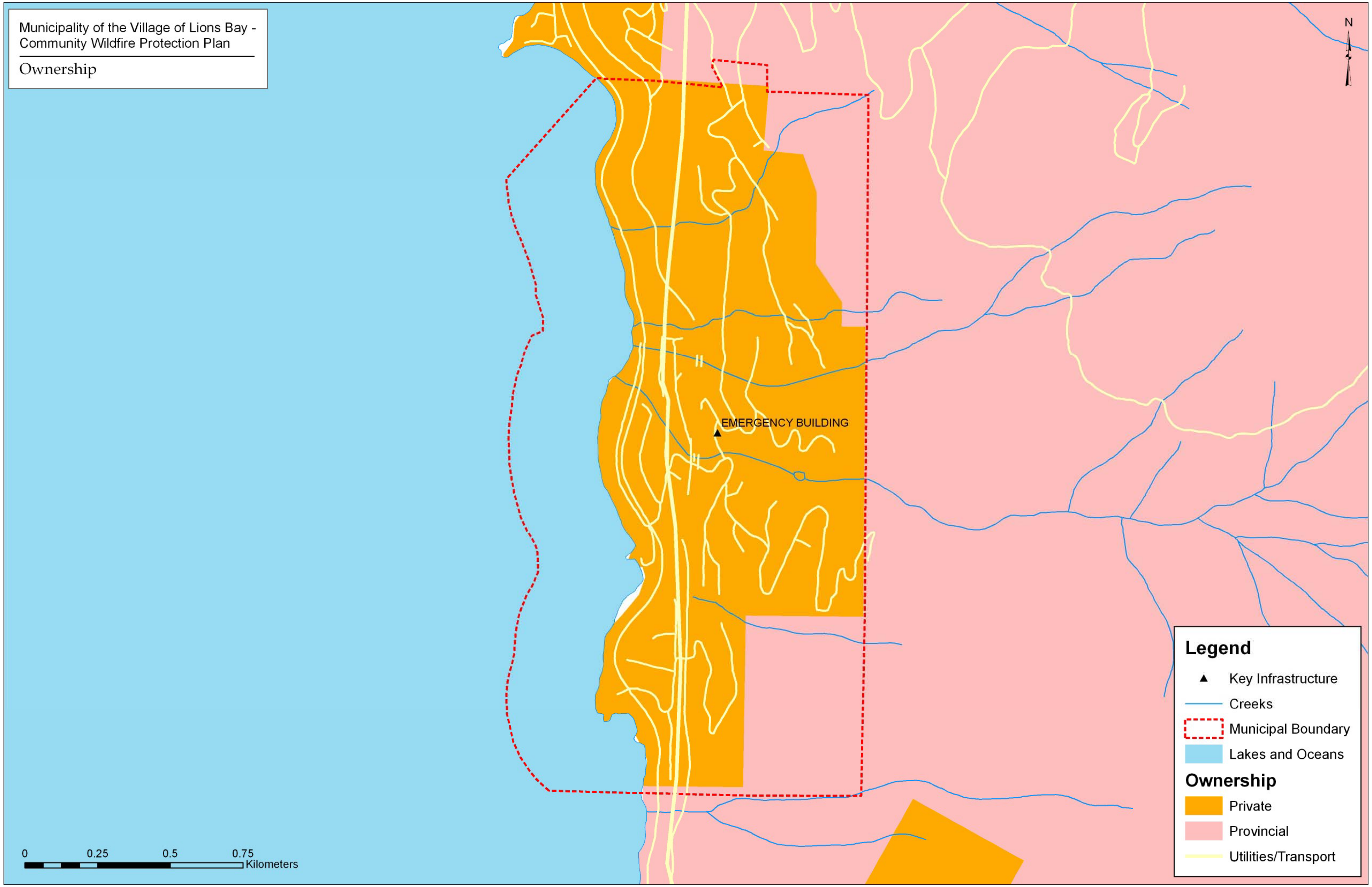


Figure 1. Map showing the land ownership categories within the Village of Lions Bay.

2.2 Topography

The Village of Lions Bay is located along the Sea-to-Sky highway amid dramatic topography and on steep terrain.

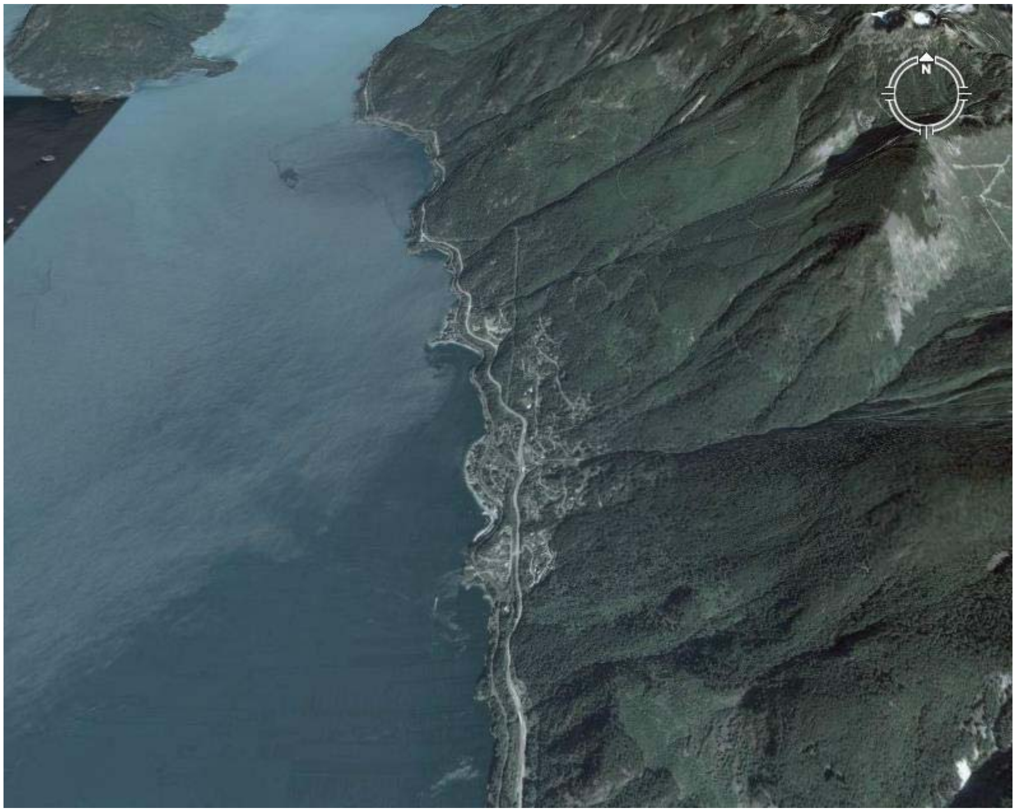


Figure 2. View of topographic relief of the Village looking north (sourced from Google Earth™, 2007).

2.3 Population

One of the smallest municipalities in the GVRD, the Village of Lions Bay had a population of 1,439 in 2001. The population has remained relatively unchanged since then, with 1,421 residents in 2005[3]. The Village has limited growth potential due to its small land base and topographical constraints. However, through redevelopment and permission of secondary suites, the Village is hoping to reach a population of 2100 in the next 20 years[4].

3 http://www.bcstats.gov.bc.ca/data/dd/facsheet/cf179.pdf
4 http://www.lionsbay.citymax.com/f/Lions_Bay_OCP_REPORT.pdf

2.4 Economy

Being primarily a residential community of some 530 homes[5], Lions Bay does not have major employment opportunities and is somewhat remote from many services. In 2001, Lions Bay had about 180 jobs, of which 160 were in home businesses. The number of jobs is expected to increase to about 250[6]. The location and natural surroundings of the Village provide many outdoor recreational opportunities, including dozens of mountain hiking trails, as well as a shoreline well suited to boating and diving. The Village's commercial area is a mixed-use area containing a small store and café, the post office, and an artist's studio which all rely heavily on outside traffic for financial viability. The Marina, located at the south end of Lions Bay Avenue, provides a variety of recreation and commercial activities[7].

2.5 Infrastructure

The local Fire and Rescue Service (volunteer) is critical to emergency response service in the community. However, in the event of a localized emergency within the Village of Lions Bay, adjacent municipalities with health care and emergency response facilities may also be able to provide relatively rapid emergency response. The Fire Hall is the foundation for incident command and response during a fire event and therefore must be prepared to deal with large and complex situations.

Emergency response is dependent on electrical and water service within the community in the event of a large-scale emergency. The community is dependent on surface water from Harvey and Magnesia Creeks. Any disturbances (human and/or natural) within or around these waterways has the potential to impact the supply of drinking water to the community.

Electrical service to the community comes from a network of transmission infrastructure that runs in through the Village. A large fire has the potential to impact this service by causing a disruption in network distribution through direct or indirect means. For example, heat from the flames or fallen trees associated with a fire event may cause power outages. Consideration must be given to protecting this critical service and providing power back up at key facilities to ensure that the emergency response functions are reliable.

The key infrastructure discussed above was considered as part of the Wildfire Risk Management System. The results of this analysis indicate that consideration must be given to protection of the critical infrastructure identified above.

5 http://www.lionsbay.citymax.com/page/page/526499.htm
6 http://www.lionsbay.citymax.com/f/Lions_Bay_OCP_REPORT.pdf
7 http://www.lionsbay.citymax.com/f/Lions_Bay_OCP_REPORT.pdf

3.0 Fire Environment

3.1 Fire Weather

The Canadian Forest Fire Danger Rating System (CFFDRS), developed by the Canadian Forestry Service, is used to assess fire danger and potential fire behaviour. The Ministry of Forests and Range (MOFR) maintains a network of fire weather stations during the fire season that is used to determine fire danger on forestlands within the community. Similarly, other lower mainland communities monitor fire weather information provided by the MOFR Protection Branch to determine hazard ratings and associated fire bans and closures within their respective municipalities.

It is important to understand the likelihood of exposure to periods of high fire danger, defined as Danger Class IV (high) and V (extreme), in order to determine appropriate prevention programs, levels of response, and management strategies. Fire danger within the Village can vary from season to season. The Village is defined by the regional climate of the Coastal Western Hemlock dry maritime (CWHdm). The study area used to assess fire risk also contains Coastal Western Hemlock very dry mild (CWHxm1), submontane very wet maritime (CWHvm1), montane very wet maritime (CWHvm2), Mountain Hemlock windward moist maritime (MHmm1), and Alpine Tundra (AT) biogeoclimatic units.

Table 1. BEC Area Summary not including unclassified area of water or urban development

BEC Unit	% of Total Study Area	Area within Total Study Area (ha)	% of Lions Bay	Area within Lions Bay (ha)
ATunp	8	503	0	0
CWHdm	27	1,750	100	211
CWHvm1	3	163	0	0
CWHvm2	24	1,522	0	0
MHmm1	39	2,533	0	0
Total	100	6,469	100	211

Fire danger within the study area can vary significantly from season to season. Figure 3 is a compilation of available weather station data within the CWHdm biogeoclimatic unit (representative of the study area) that dates back to 1875 and provides a summary of the total number of Danger Class IV and V-days from April through to October for each year. This compilation shows that, within any given year, the fire danger can fluctuate substantially from fewer than 20 days to over 70 days. On average, the number of Danger Class IV and V-days within the CWHdm is 46 per year. Typically, the most extreme fire weather occurs between the middle of July and the third week of August. When compared to other regional climates of the coast, such as the Coastal Western Hemlock very dry maritime biogeoclimatic unit (CWH xm1 - east coast of Vancouver Island) and Coastal Douglas Fir biogeoclimatic unit (CDF - Southern Vancouver Island and Gulf Islands), the Lower Mainland is not as dry.

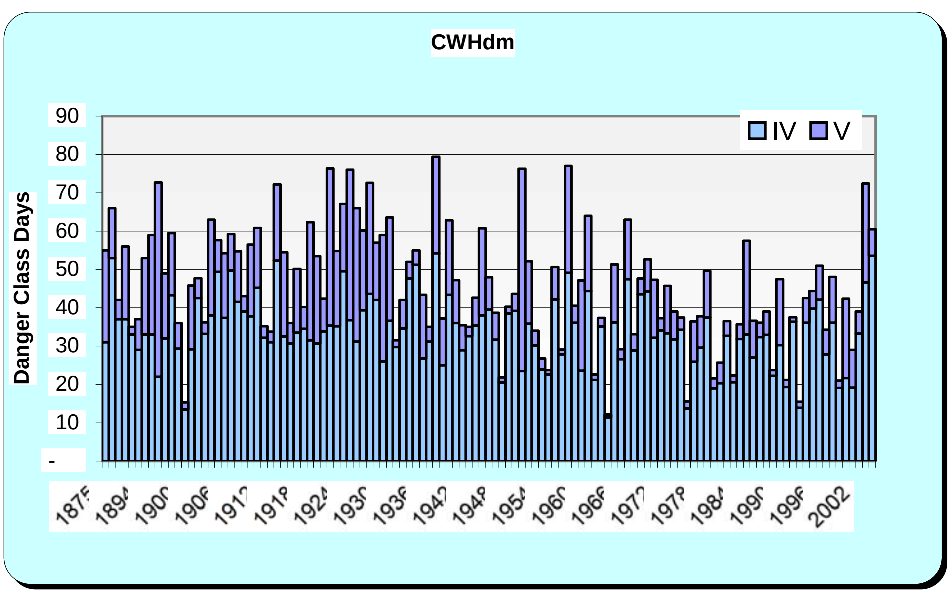


Figure 3. Seasonal variability (April-October) in the number of Danger Class IV and V-days within the study area as described by the regional climate of the CWHdm.

A summary of historic drought codes provides a similar comparison to danger class days and reinforces the point that the Village experiences extended periods of summer drought (Figure

4). A drought code that exceeds 500 is considered high and is associated with extreme fire behaviour.

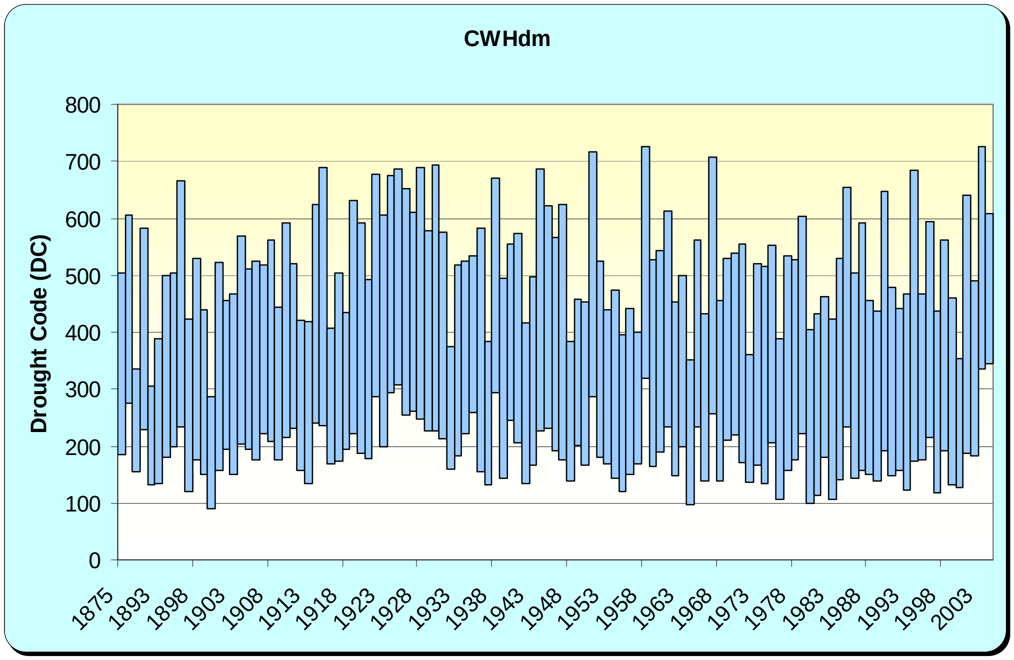


Figure 4. Summary of seasonal (April-October) high and low drought codes by year in the CWHdm within the Village.

The results of the weather data analysis show that, historically, there have been a number of years when fire danger in the study area has been high or extreme for an extended period during the summer months. Complacency is an inappropriate response to fire risk. Management responses, in terms of fire prevention, mitigation and response, should be adjusted in accordance with the level of risk.

3.2 Fuels

Fuel classification was based on the CFFDRS and a summary of fuel type attributes collected in the field. Typically, the CFFDRS fuel types only adequately describe the variation in fuels present in the Village. In a number of areas, the classification was not correct. This was primarily a function of large areas of forest being classified as D1 when, in fact, they were better represented by other CFFDRS fuel types (Figure 5). An algorithm that uses input from Vegetation Resource Inventory (VRI) data was used to gain a better approximation of CFFDRS fuel types for the study area. This was incorporated with existing fuel typing and ground truthing that had been completed for GVRD parks in the study area. For each type identified, we have attempted a best approximation of the CFFDRS classification and have supported this classification with a summary of detailed attributes. The updated Ministry of Forests and Range fuel typing was improved upon and adjusted to incorporate local variation.

3.2.1 Fuel Type Summary

Table 2 and Table 3 summarize the fuel types by BEC Unit and area. A description of each fuel type is provided in Appendix 2.

Table 2. Percentages of each fuel type within each BEC unit based on the total study area not including unclassified area of water or urban development

BEC Unit	C2	C3	C4	C5	C7	D1	M2	M2c	Non	Total
ATunp	0	0	0	26	1	2	4	0	67	100
CWHdm	1	14	3	45	1	12	1	6	17	100
CWHvm1	0	37	5	50	0	6	0	0	2	100
CWHvm2	3	5	8	62	3	4	8	1	5	100
MHmm1	<1	2	2	56	1	5	8	<1	25	100

Table 3. Summary of fuel types based on the total study area not including unclassified area of water or urban development

	C2	C3	C4	C5	C7	D1	M2	M2c	Non	Total
Area (ha)	68	431	231	3,382	101	412	372	125	1,348	6,469
% Total	1	7	4	52	2	6	6	2	21	100

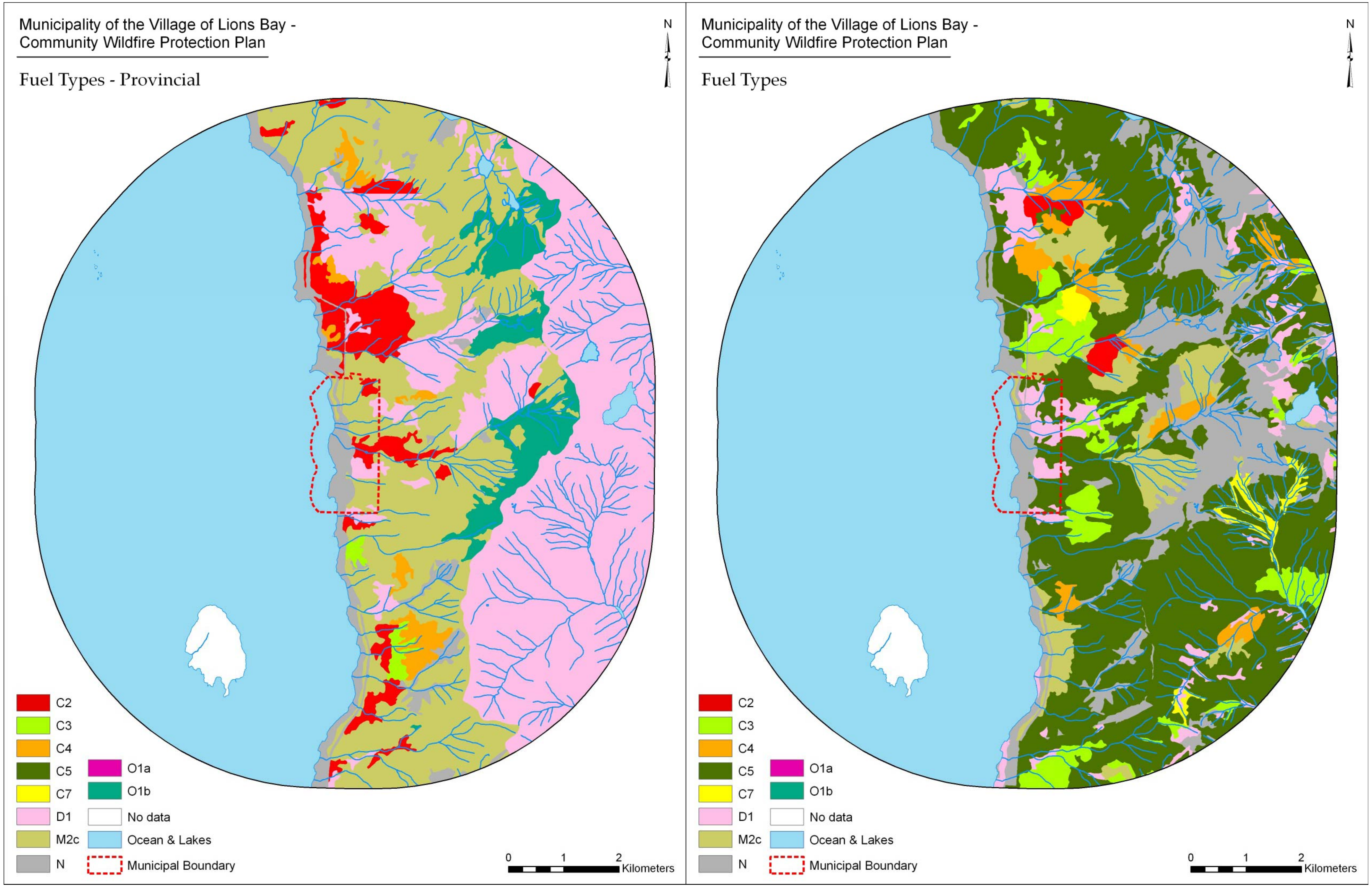


Figure 5. Comparison of original MOF fuel typing (left) and updated fuel typing (right) for the Village.

3.3 Historic Ignitions

The MOFR fire reporting system was used to compile a database of fires back to 1950 in the WRMS study area. Figure 6 shows the ignition locations within the Municipality. The average number of fires per year by decade is as follows: 1950-59 – 1.82; 1960-69 – 1.1; 1970-79 – 2.3; 1980-89 – 1.2; 1990-1999 – 0.8. The most significant fire year in recent history was 1956 when six fires were reported in the study area.

Table 4 summarizes the fires that have occurred between 1950 and 2005 in the study area by size class and cause (lightning and human caused). The total number of fires during this period was 74, of which 88% were the result of human causes. The remaining 12% of fire ignitions were lightning caused. Ninety-three percent of all fires that burned between 1950 and 2005 were smaller than four hectares, while only five fires were greater than four hectares. The largest fire within the Municipality since 1950 occurred in 1956 by an undetermined cause and burned an area of 46.5 hectares.

Table 5 summarizes fire cause by decade. Through the time of record, human caused fires have far out-numbered those caused by lightning. On average, there are 14.4 fires each decade (minimum 8 in the '90s and maximum 23 in the '70s). The majority of fires have been inconsequential in size.

Table 4. Fire history summary within the study area from 1950 - 2005.

Size Class (ha)	Total Number of Fires	% of Total	Human Caused	Lightning Caused
< 4.0	69	93%	61	8
4.0 - 10.0	3	4%	2	1
> 10.0	2	3%	2	
Total	74	100%	65	9

Table 5. Summary of fire cause within the study area.

Decade	Lightning	%	Direct Human1	%	Industrial2	%	Miscellaneous3	%	Total
1950-1959		0	11	61	5	28	2	11	18
1960-1969		0	8	73	1	9	2	18	11
1970-1979	3	13	14	61	1	4	5	22	23
1980-1989		0	11	92		0	1	8	12
1990-1999	6	75	2	25		0		0	8
2000-2005		0	1	50		0	1	50	2
Total	9		47		7		11		74

[1] Campfire, smoker, incendiary, juvenile set, fire use
[2] Equipment, railway
[3] Undetermined, burning building

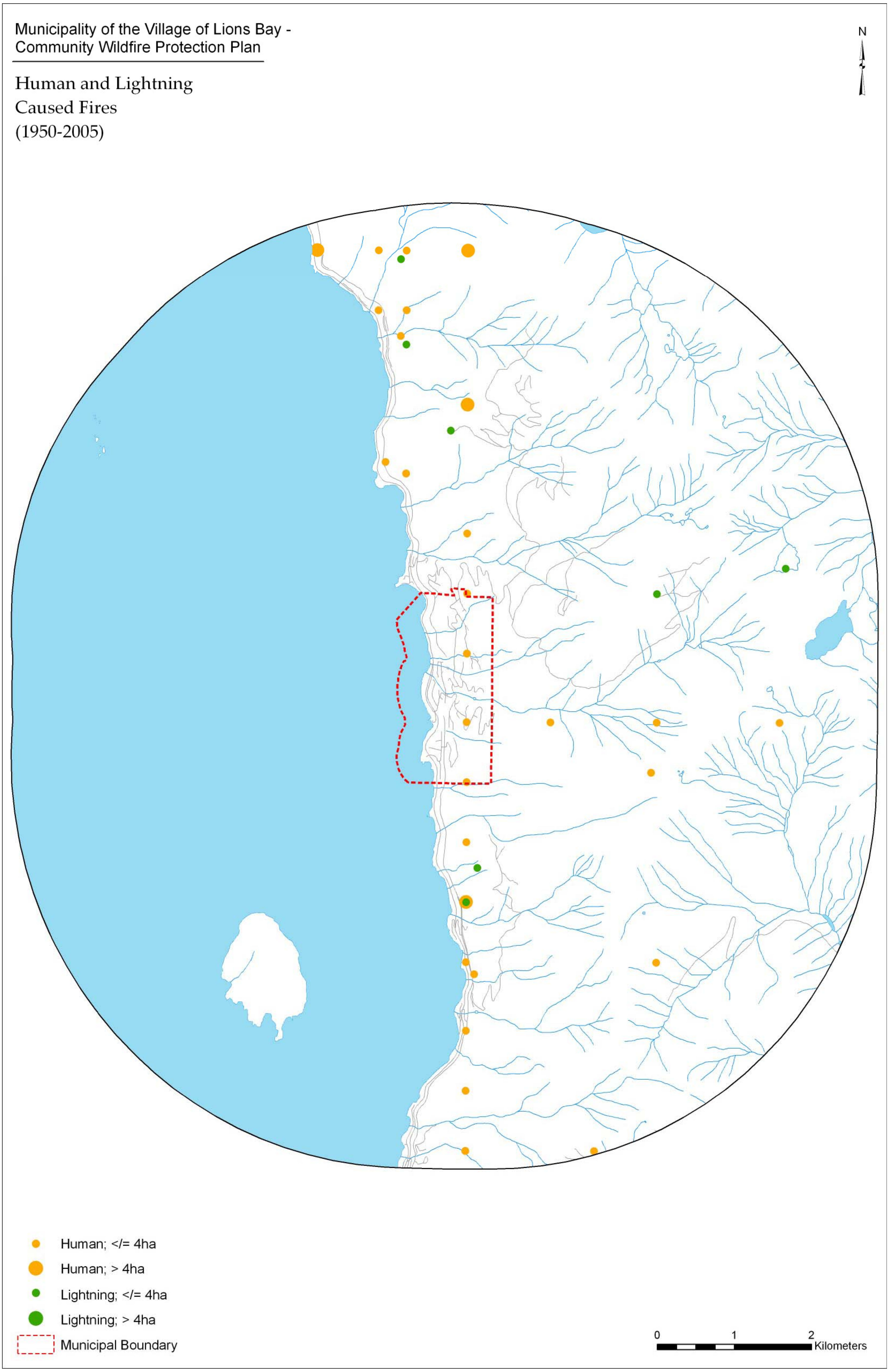


Figure 6. A spatial summary of human and lightning caused fire ignitions within the Village (1950 to 2005).

4.0 The Wildland Urban Interface

The classical definition of wildland urban interface (WUI) is the place where the "*forest meets the community*" and is graphically depicted in Figure 7. Other configurations of the WUI can be described as intermixed. Intermixed areas include smaller, more isolated developments that are embedded within the forest. An example of an intermixed interface is shown in Figure 8.

In each of these cases, fire has the ability to spread from the forest into the community or from the community out into the forest. Although these two scenarios are quite different, they are of equal importance when considering interface fire risk. Within the Village, the probability of a fire moving out of the community and into the forest is equal or greater to the probability of fire moving from the forest into the community. Regardless of which scenario occurs, there will be consequences for the Village and this will have an impact on the way in which the community plans and prepares for interface fires.

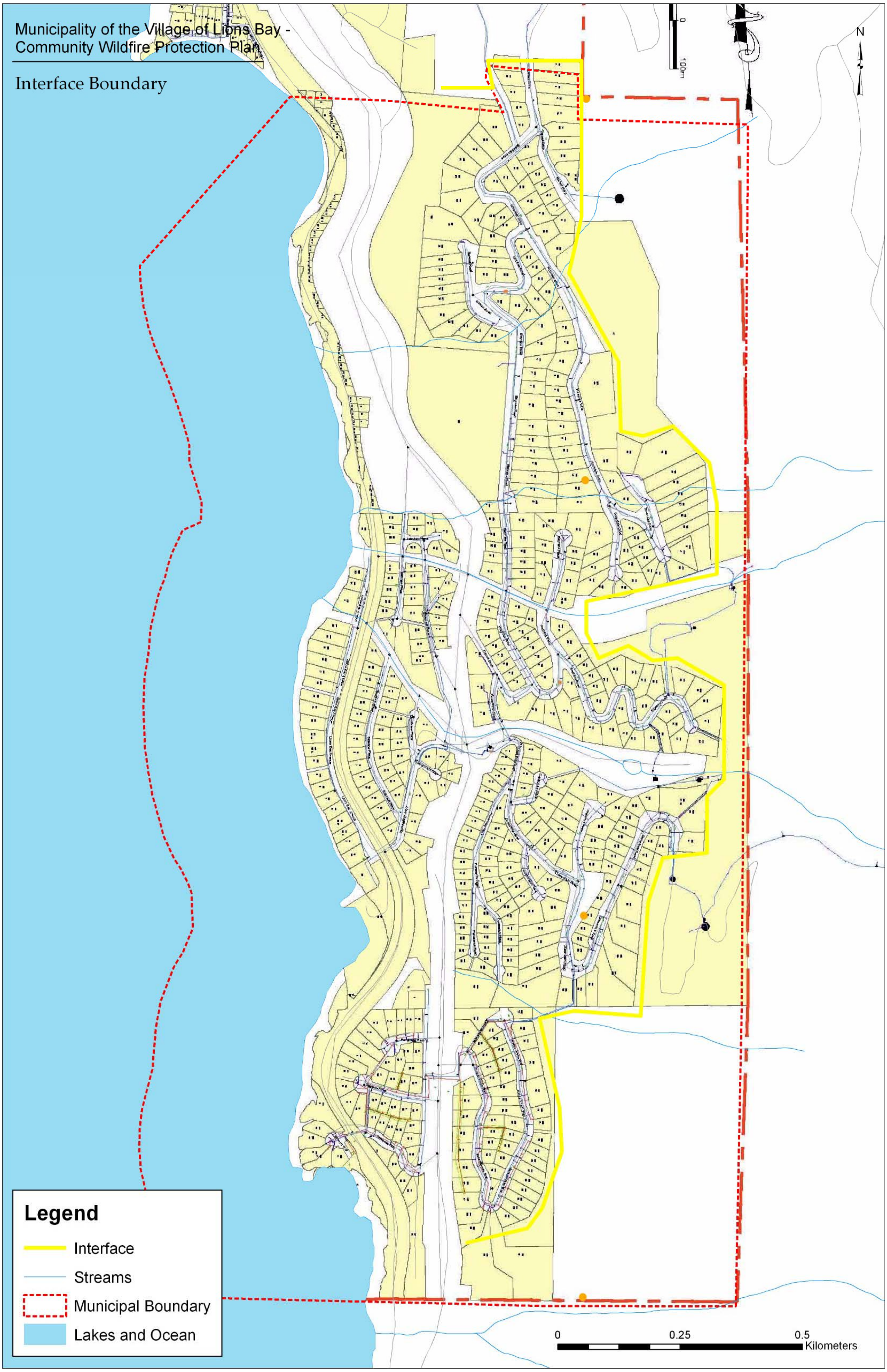


Figure 7. Wildland urban interface defined by yellow border where the forest meets the community.

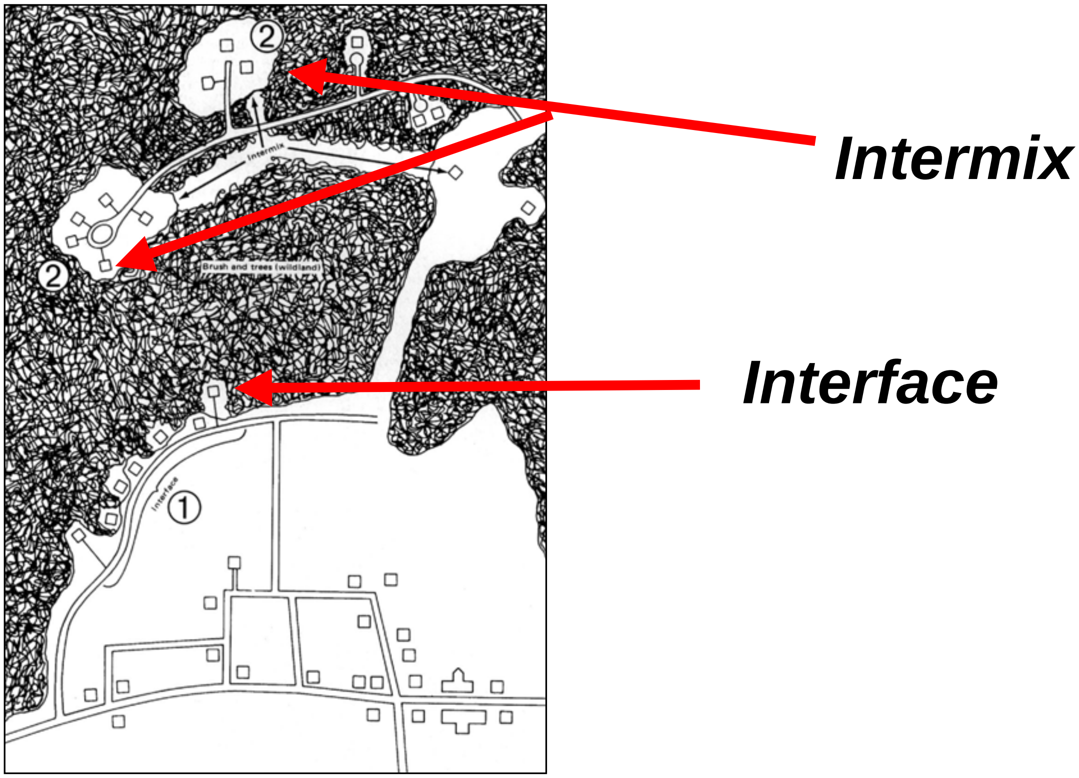


Figure 8. Graphical example showing variation in the definition of interface.

4.1.1 Vulnerability of the Wildland Urban Interface to Fire

Fires spreading into the WUI from the forest can impact homes in two distinct ways: 1) by sparks or burning embers carried by the wind or convection that start new fires beyond the zone of direct ignition (main advancing fire front) and alight on vulnerable construction materials (*i.e.* roofing, siding, decks etc.) (Figure 9); 2) through direct flame contact, convective heating, conductive heating or radiant heating along the edge of a burning fire front (burning forest) or through structure-to-structure contact. Fire can ignite a vulnerable structure when the structure is in close proximity (within 10 meters of the flame) of either the forest edge or a burning house (Figure 10).

Figure 9. Firebrand caused ignitions: burning embers are carried ahead of the fire front and alight on vulnerable building surfaces.

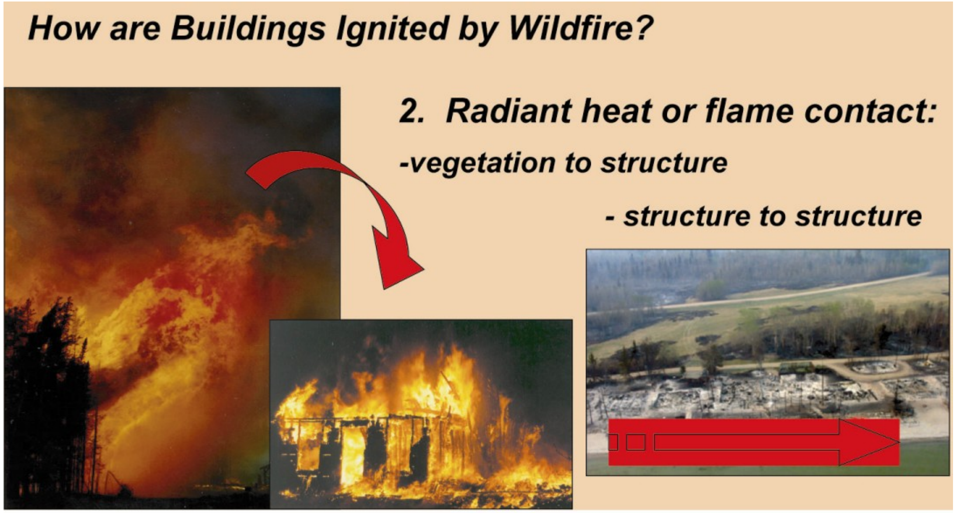


Figure 10. Radiant heat and flame contact allows fire to spread from vegetation to structure or from structure to structure.

The wildland urban interface continuum (Figure 11) summarizes the main options available for addressing WUI fire risk in the Community Wildfire Protection Planning process. In addition to standard fire management actions, the issue of post fire rehabilitation is identified as a management concern that should be addressed in areas (such as the Village) where slope stability and protection of water quality are of primary concern following wildfire.

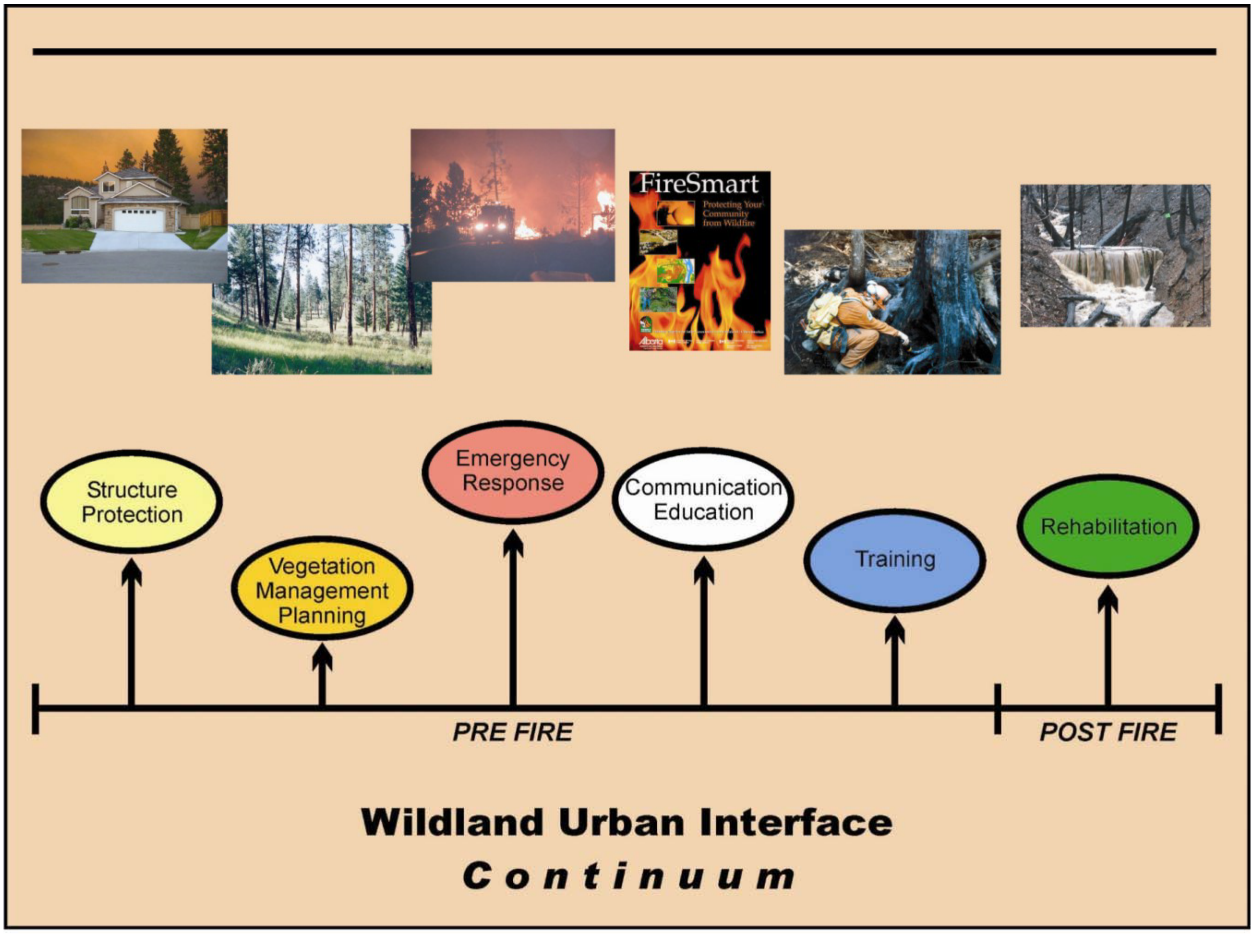


Figure 11. Wildland urban interface continuum.

The appropriate management response to a given wildfire risk profile is based on the combination and level of emphasis of several key elements:

- Communication and education.
- Emergency response.
- Training.
- Structure protection.
- Vegetation management.
- Post-fire Rehabilitation.

For example, in an interface area with a high-risk profile, equal weight may be given to all elements. Alternatively, in this same high-risk example, active intervention through vegetation management may be given a higher emphasis. This change in emphasis is based on the values at risk (consequence) and level of desired protection required. In a low risk situation the emphasis may be on communication and education combined with emergency response and training. In other words, a variety of management responses are appropriate within a given community and these can be determined based on the Community Risk Profile.

5.0 Community Risk Profile

The WRMS developed in support of this plan identified that the core area of the Village is at moderate to high risk from wildfire (Figure 12). Public safety, and many of the important values, facilities and structures, may be severely impacted by a major fire in the Village.

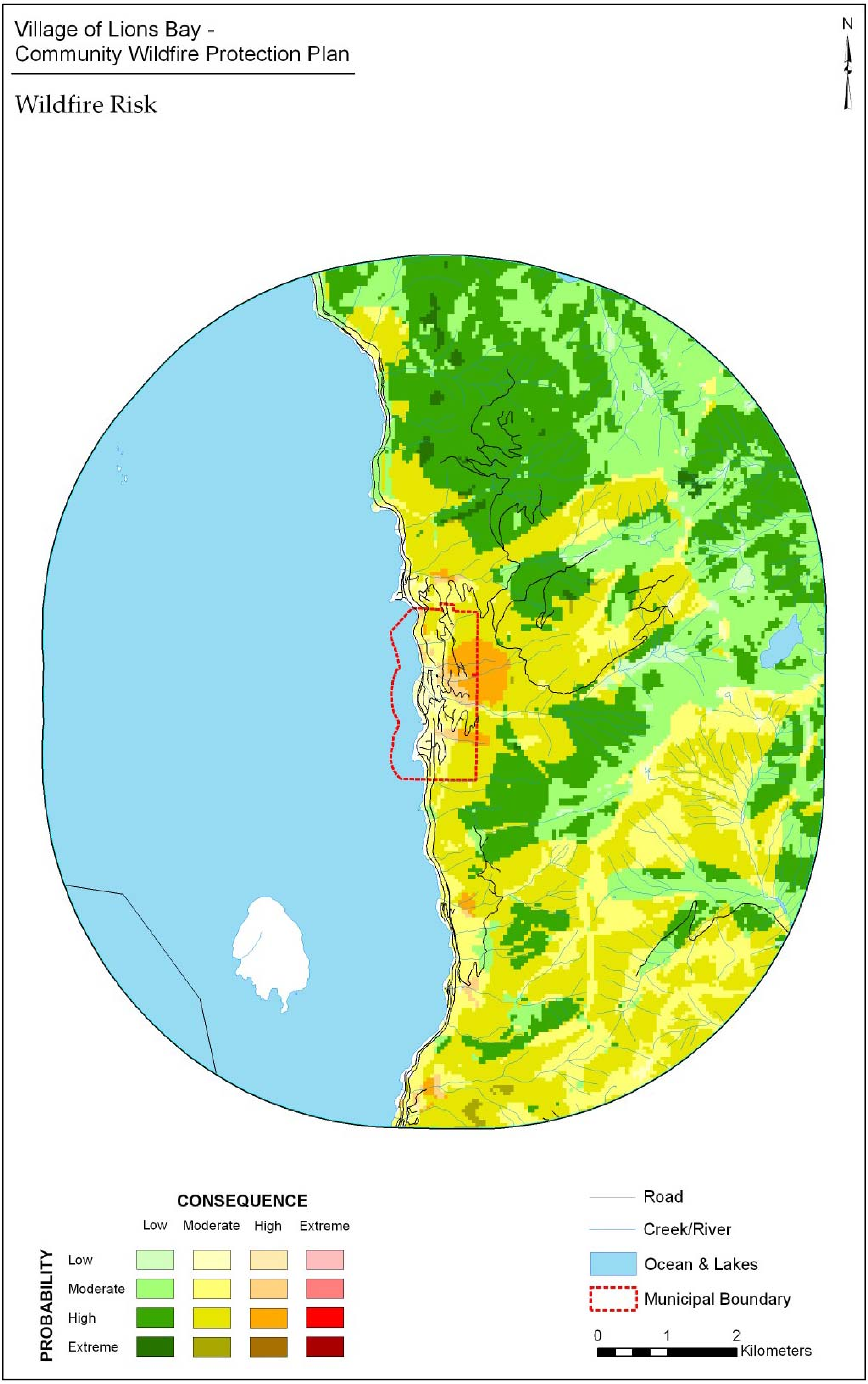
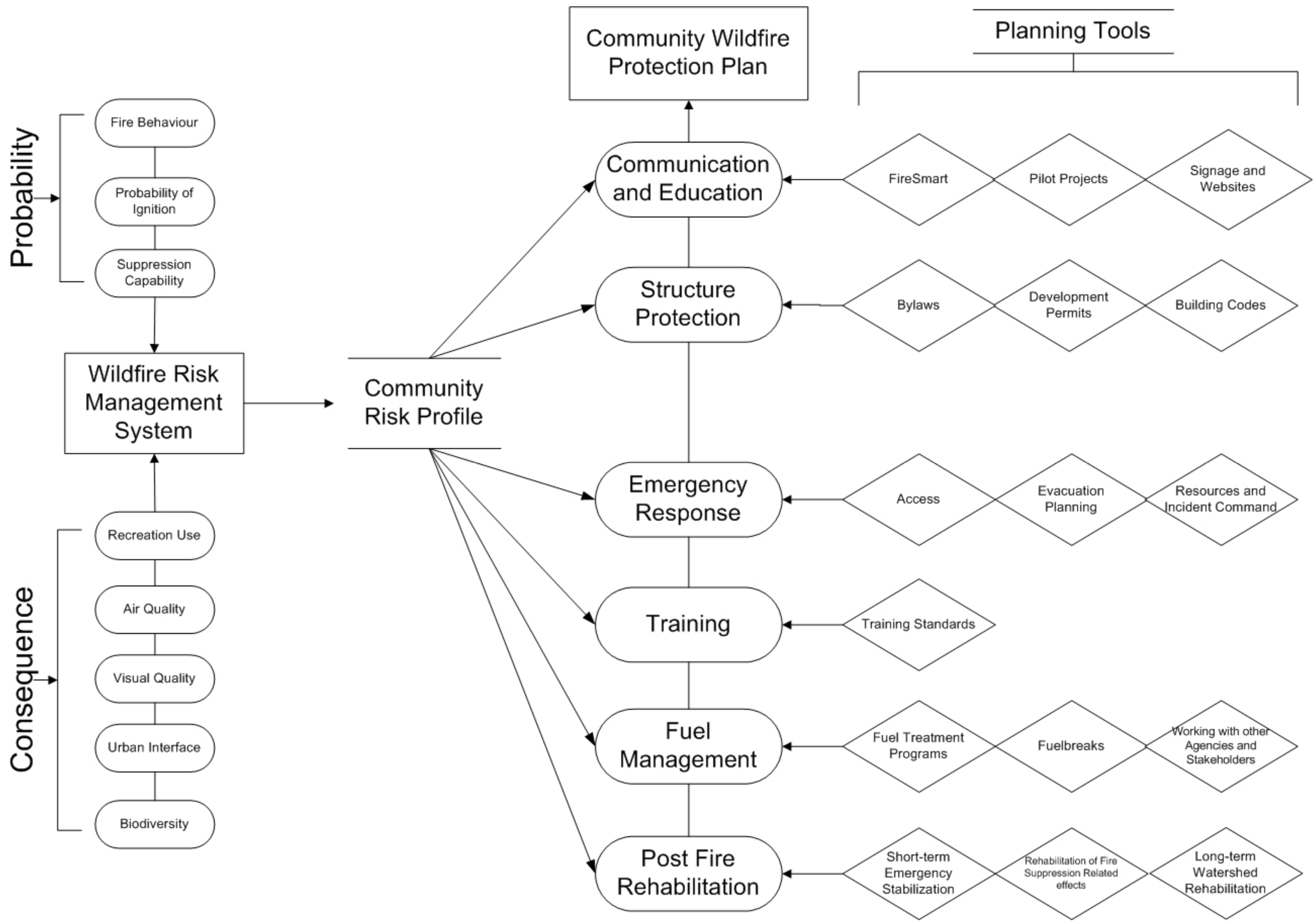


Figure 12. Final overlay of probability and consequence from the Wildfire Risk Management System.

6.0 Community Wildfire Protection Planning Process



7.0 Action Plan

The Action Plan consists of the key elements of the Community Wildfire Protection Plan and provides recommendations addressing each element. Each of these elements is further explained in Section 8.0 Community Wildfire Protection Planning Background, which provides background information to support the Action Plan.

7.1 Communication and Education

7.1.1 Goals

- Educating residents and businesses on actions they can take to reduce fire risk on private property.
- Establishing a sense of homeowner responsibility for reducing fire hazards.
- Raising the awareness of elected officials as to the resources required and the risk that wildfire poses to communities.
- Making residents and businesses aware that their communities are interface communities and educating them about the associated risks.
- Increasing awareness of the limitation of municipal and provincial firefighting resources to encourage proactive and self-reliant attitudes.
- Working diligently to reduce ignitions during periods of high fire danger.

7.1.2 Objectives

- Develop a community education program in the next two years.
- Establish a FireSmart home pilot project in the next five years.
- Enhance the community's website to better communicate wildfire protection planning to the community in the next two years.
- Improve fire danger and evacuation signage in the next two years.

7.1.3 Issues

- Currently some there is little information available on the Fire and Rescue Services site. It would be beneficial to add information on what individual homeowners can do to protect their homes as well as information on up-to-date fire danger and fire restrictions.
- There are a number of high hazard fuel types on Crown Land adjacent to the municipality that would be appropriate for the focus a fuel treatment pilot project. The areas in Figure 13 have been identified as appropriate locations to consider fuel reduction strategies and/or

conversion to deciduous fuel types. Treatments are eligible for funding if they are within 5 km of the municipal boundary.

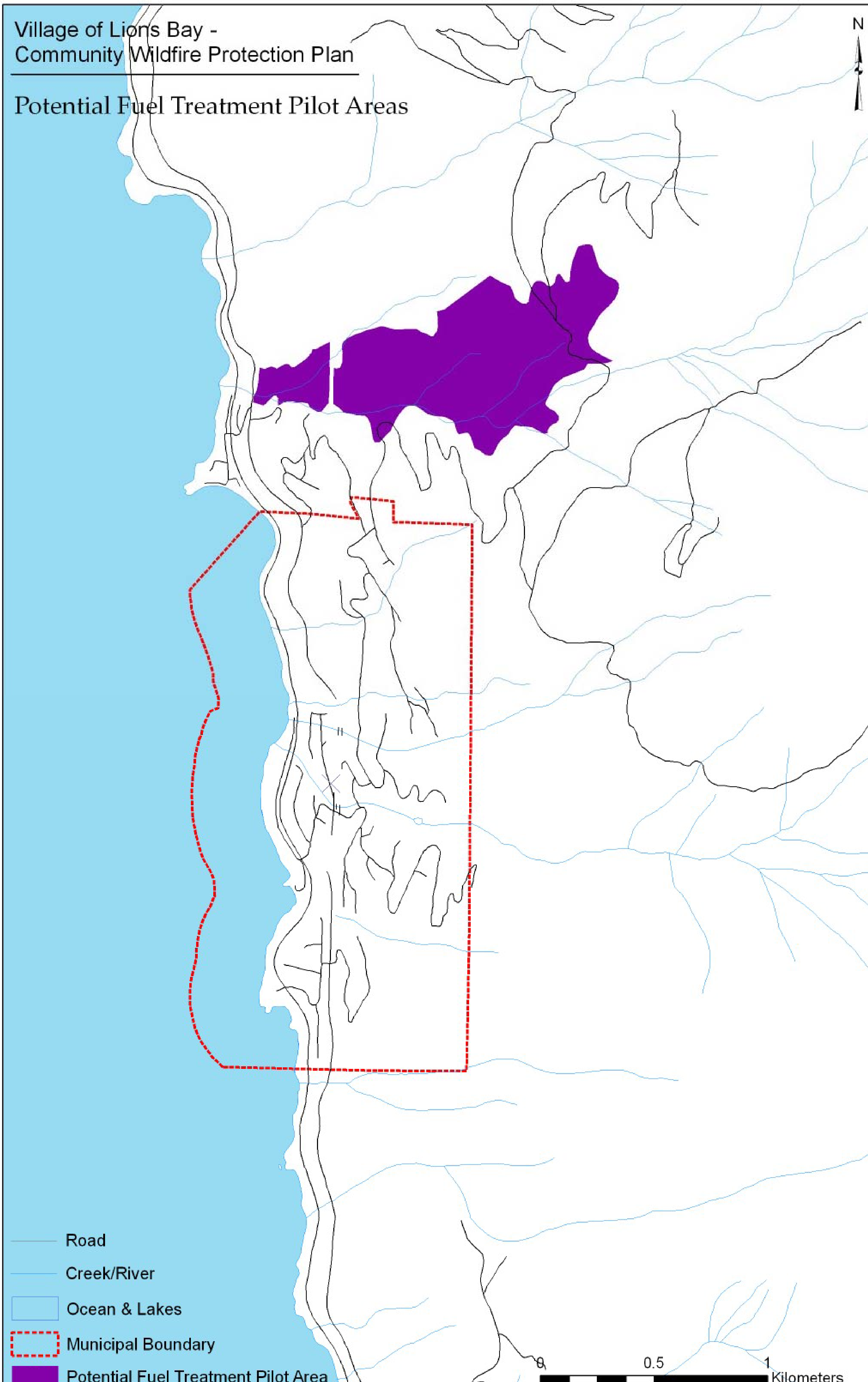


Figure 13. Areas for potential fuel treatment pilots.

7.1.4 Recommendations

Recommendation 1: The Village should develop a communication plan to outline the purpose, methods and desired results of communication and education in the community. The plan should cover the principles of fire risk to the community, fire behaviour, spotting, structure protection and vegetation management. Educational information and communication tools need to be stakeholder specific. To establish effective communication within target groups, the plan should identify spokespersons who can best establish communication ties with target audiences and provide the educational information required.

Recommendation 2: The Village should investigate the potential for working with local developers to construct a FireSmart show home to be used as a tool to educate and communicate the principles of FireSmart to the public. The demonstration home would be built to FireSmart standards using recommended materials for interface communities. Additionally, vegetation adjacent to the home would be managed to guidelines outlined in the FireSmart program.

Recommendation 3: The Village should enhance their existing website to outline community fire risks and current fire danger. Information, such as fire danger and FireSmart demonstration/pilot projects should be added to the local site.

Recommendation 4: Signage consisting of current fire danger and warnings to be careful with fire should be posted at each end of the community on the Sea-to-Sky Highway. Signs should be updated with current fire danger information as required.

Recommendation 5: The Village should work with other lower mainland municipalities and the MOFR to develop a regional approach to enhancing education and communication related to this issue.

Recommendation 6: The Village should investigate applying for UBCM funding to carry out a fuel treatment pilot project that will strategically mitigate fuel hazard within the treatment area. This pilot project will provide a tool to demonstrate the principles of fuel hazard reduction treatments to the public and contribute to fire risk reduction for the Village. The recommended location of this fuel treatment pilot is in the polygon shown in Figure 13. A detailed prescription signed by a Qualified Professional is required for each of the areas.

7.2 Structure Protection

7.2.1 Goals

- Adopt a FireSmart approach to site and structure hazard assessment and structure protection.

7.2.2 Objectives

- Use policy tools to adopt FireSmart standards over the next five years.

7.2.3 Issues

- Many homes do not meet the FireSmart structure hazard standards for interface fire safety.
- Currently, there is no fire vulnerability standard for roofing material used in the Village. Many homes are constructed with unrated materials that are considered a major hazard during a large fire event. In addition to the vulnerability of roofing materials within the community, adjacent vegetation is often in contact with roofs, or roof surfaces are covered with litter fall and leaves from adjacent trees. See examples in Figure 14, Figure 15 and Figure 16.
- Unrated roofing materials contribute significantly to fire risk. In the short term, a resolution to this issue is difficult given the significant cost to homeowners. However, over the long-term, altering the building code or bylaws to encourage a change in roofing materials when roof replacement of individual residences is required may be a solution.
- Combustible materials stored within 10 m of residences are also considered a significant issue. Woodpiles or other flammable materials adjacent to the home provide fuel and ignitable surfaces for embers.

Figure 14. Photograph showing unrated roofing material present on many homes within the wildland urban interface.

Figure 15. Example of home with wood siding.

Figure 16. Example of Lions Bay home with open decks and no setback to forest vegetation.

7.2.4 Recommendations

Recommendation 7: It is recommended that the Village conduct detailed FireSmart assessments in identified high risk areas of the community to further communicate and promote fire risk reduction on private property. The WRMS developed for the Village provides a sound scientific framework on which to complete more detailed local neighbourhood risk assessments.

Recommendation 8: The Village should begin a process to review and revise existing bylaws to be consistent with the development of a FireSmart Community. In areas of identified high wildfire risk, consideration should be given to the creation of a Wildfire Bylaw that mandates fire resistant building materials, providing for good access for emergency response, and specifies fuel management on both public and private property. The Village should consider requiring roofing materials that are fire retardant with a Class A and Class B rating within new subdivisions. While it is recognized that wholesale changes to existing roofing materials within the Village are not practical, a long-term replacement standard that is phased in over the roof rotation period would significantly reduce the vulnerability of the community. The Village should obtain legal advice regarding the implementation of building requirements that are more restrictive than the BC Building Code.

Recommendation 9: The Village should consider working with the Building Policy Branch to create a structure that would enable the Village to better address wildland urban interface protection considerations for buildings.

Recommendation 10: Many homes and businesses are built immediately adjacent to the forest edge. In these neighbourhoods, trees and vegetation are often in direct contact with homes. The Village should incorporate building set backs into bylaw with a minimum distance of 10 m when buildings border the forest interface.

Recommendation 11: The Village Tree Cutting policy for private land should be reviewed to ensure that it does not limit the ability of homeowners to address wildfire hazards associated with trees on private property immediately adjacent to homes.

7.3 Emergency Response

7.3.1 Goals

- Develop an emergency response plan that enables effective evacuation, improves firefighter suppression capability and maintains firefighter safety.

7.3.2 Objectives

- Improve access within isolated portions of the community over the next 10 years.
- Review the community's evacuation plan in the next 12 months.
- Over the next 12 months, develop a contingency plan in the event that smoke requires evacuation of critical emergency service facilities.

7.3.3 Issues

- Evacuation of residents and access for emergency personnel is an important consideration given the amount of forest fuels in close proximity to many homes. Within the neighbourhoods identified in Figure 17 there is only one access and evacuation route available to motor vehicles and emergency responders. Given the potential for heavy traffic in some of these locations, prompt evacuation could be difficult. The situation could be further complicated by smoke and poor visibility, creating the necessity for traffic control in specific neighbourhoods. The Village should consider establishing secondary or alternate evacuation routes for these neighbourhoods.
- In addition to the evacuation of residents, safety of firefighting personnel is a major consideration. Figure 17 emphasizes that under extreme fire conditions it may be difficult for the Lions Bay Fire Rescue Service to access specific areas of the Village due to the potential for resources to be isolated or cut off. Defence of these neighbourhoods would be secondary to safety considerations.

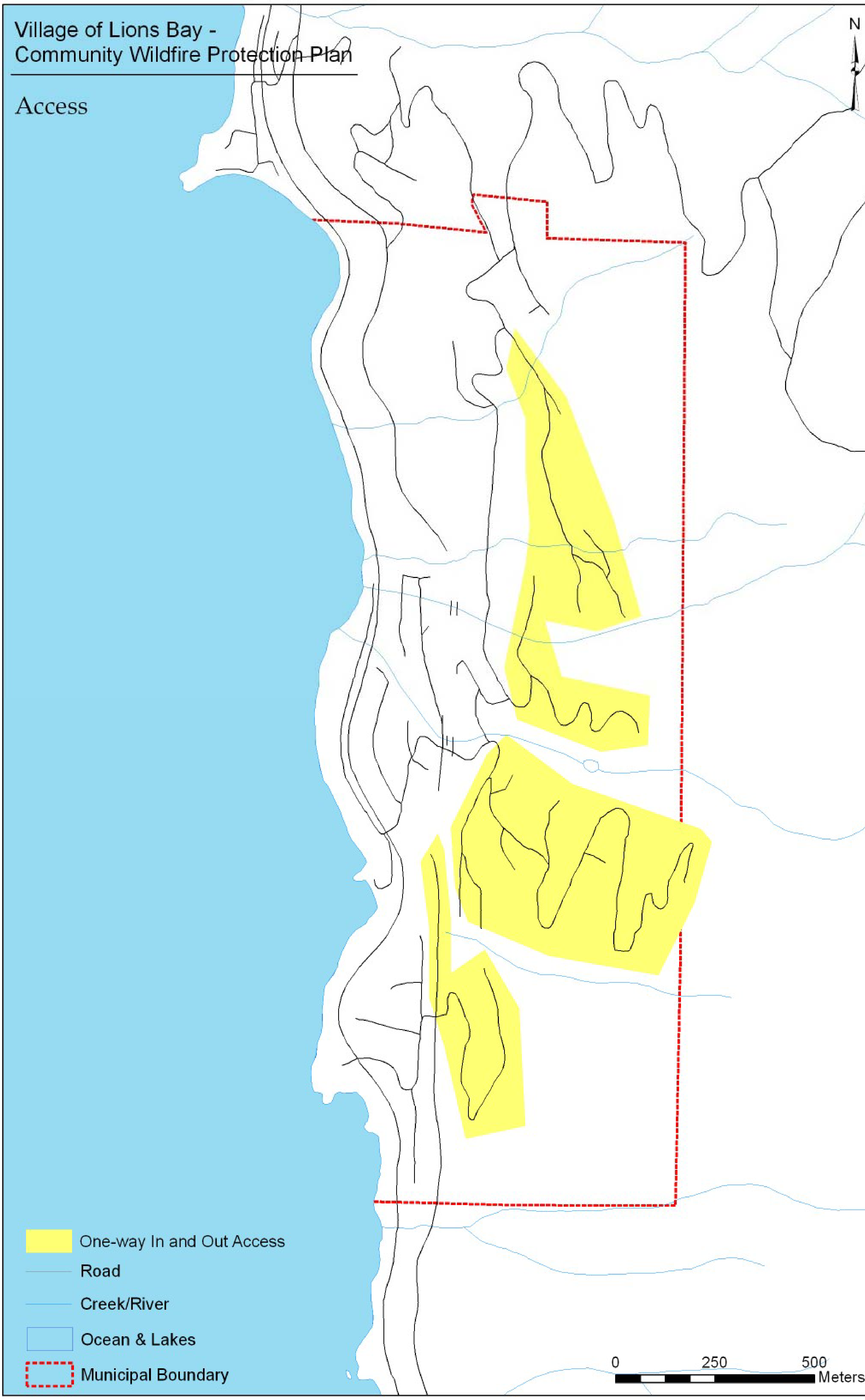


Figure 17. Overview of access routes in the Village – Note: yellow highlights indicate neighbourhoods or portions of the Village with poor access and evacuation routes.

7.3.4 Recommendations

Recommendation 12: The Village must work towards improving access in identified areas of the community that are considered isolated and that have inadequately developed access for evacuation and fire control.

Recommendation 13: A Village evacuation plan should be developed and appropriate evacuation routes should be mapped and signed.

Recommendation 14: Given the values at risk identified in this plan, it is recommended that, during periods of high and extreme fire danger (danger class IV and V), the Village work with adjacent municipalities and the Ministry of Forests and Range to maintain a local helicopter with a bucket on standby within 15 minutes of the community. Depending on specific circumstances, coordination with the GVRD may be necessary.

7.4 Training

7.4.1 Goals

- To ensure adequate and consistent training for firefighter personnel and to build firefighter experience.

7.4.2 Objectives

- Train all Fire Department personnel to the Provincial standard (S100 and S215) on an annual basis.

7.4.3 Issues

- Not all members of the Lions Bay Volunteer Fire Department have current training to provincial standards.

7.4.4 Recommendations

Recommendation 15: The current level of training is considered adequate, but given the risk of fire to the community, the Village of Lions Bay Fire and Rescue Services should adopt an advanced program that fosters continuous improvement and skill renewal.

7.5 Vegetation (Fuel) Management

7.5.1 Goals

- To proactively lessen potential fire behaviour, thereby increasing the probability of successful containment and minimizing adverse impact.

7.5.2 Objectives

- There are no hazardous fuel types (C2, C3, C4) within the municipal boundary. However, there are some of these fuel types immediately adjacent to the municipal boundary. Ideally, over the next five years the majority of these fuel types within 2 km of the municipal boundary would be converted to deciduous fuel types.

7.5.3 Issues

- The WRMS developed in support of this plan identified that the core area of the Village is at moderate risk from wildfire (Figure 12). However, there are areas of extreme wildfire probability immediately adjacent at the interface. Public safety, and many of the important values, facilities and structures, may be severely impacted by a major fire.

- There are a number of hazardous stands of C2, C3 and C4 fuel types in the study area (Figure 18). However, these fuel types fall outside the municipality on Crown Land. Within 2 km of the municipal boundary, thinning on Crown Land should be focused on the highest priority areas: C2 and C4 fuel types. The goals of thinning are to remove hazardous fuels and to reduce the overall fire behaviour potential adjacent to the community.

- High hazard fuels are capable of spotting into or out of the interface. Figure 19 shows that all Lions Bay interface area is vulnerable to spotting from these fuel types based on 9 km windspeed in any wind direction.

- Within 2 km of the municipal boundary, there are 323 ha of priority 1 and 2 fuel types. While it is not feasible to treat all of these areas, it is possible to develop an annual program that targets progressive fuel reduction prioritized in these areas over the next decade. Figure 18 shows high priority fuel types that may be suitable for fuel treatments. An area suggested for assessment for a fuel treatment pilot project is shown in Figure 13.

- There are number of existing natural and human constructed fuelbreaks within the Village that could provide a foundation on which to build a more comprehensive fuelbreak. Natural fuelbreaks include wetlands, BC Hydro right-of-ways and deciduous forest stands (Figure 20). Where tree cover is removed along the rights-of-way, these areas have the potential to limit fire behaviour and spread.

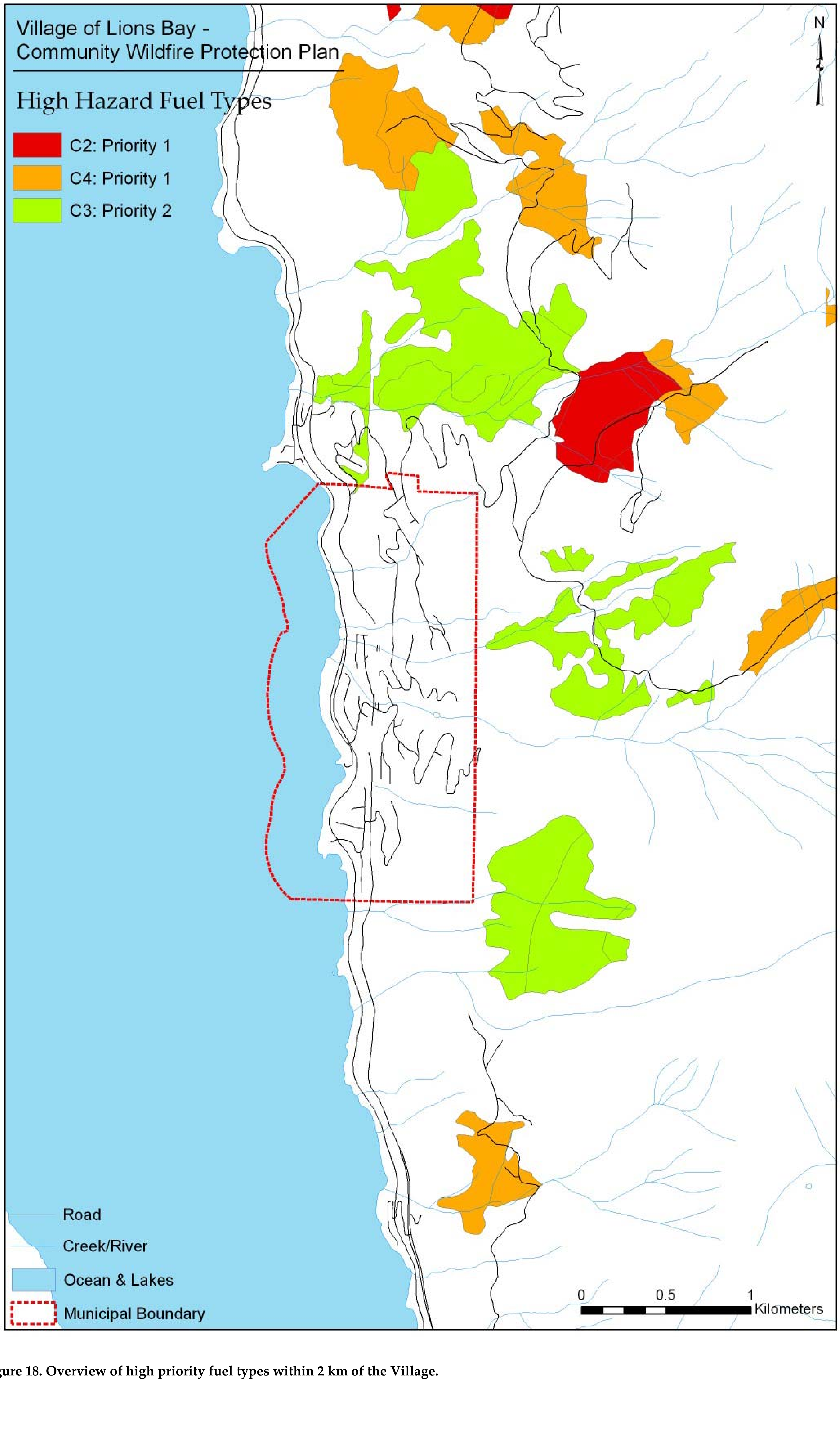


Figure 18. Overview of high priority fuel types within 2 km of the Village.

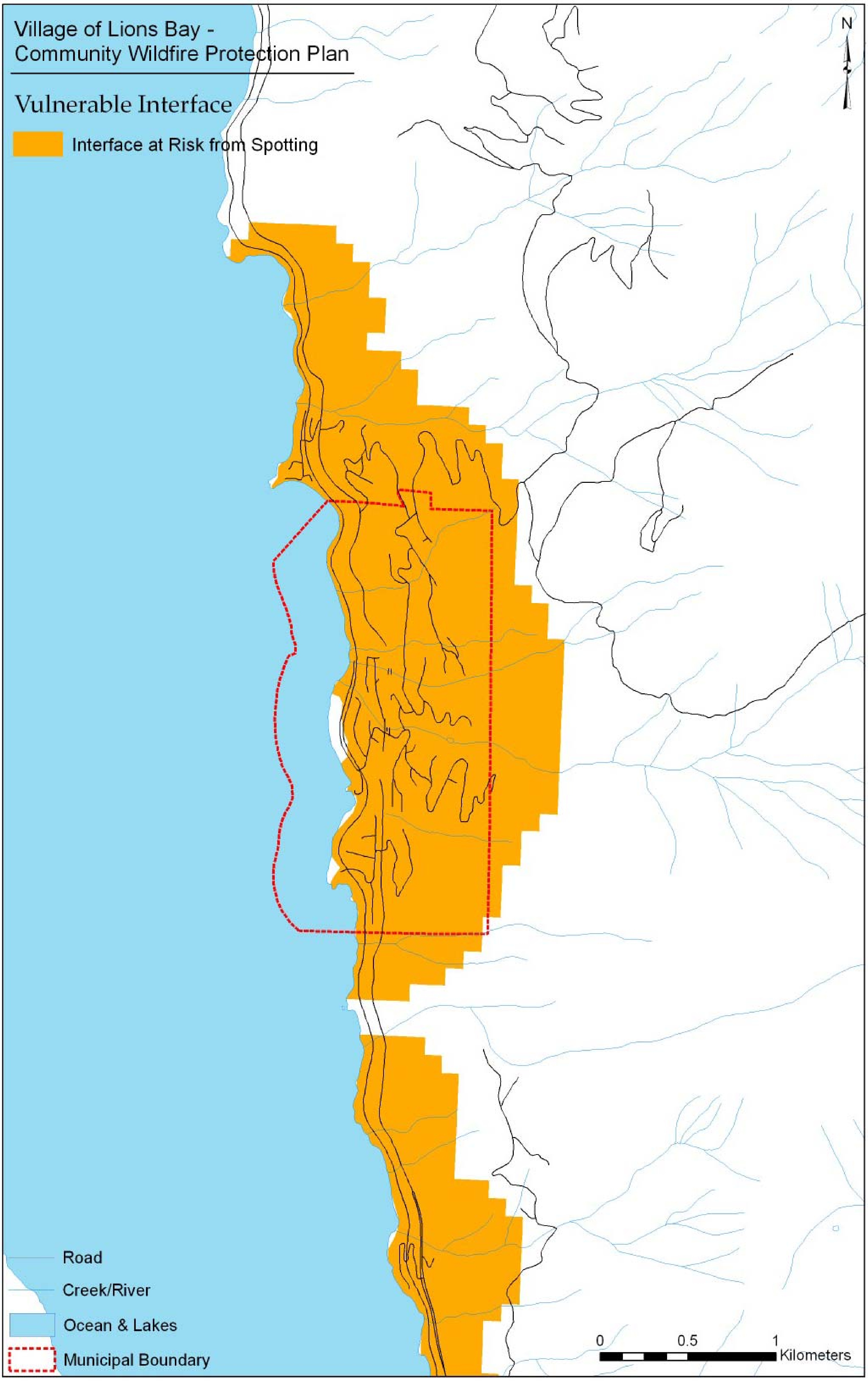


Figure 19. High vulnerability interface areas

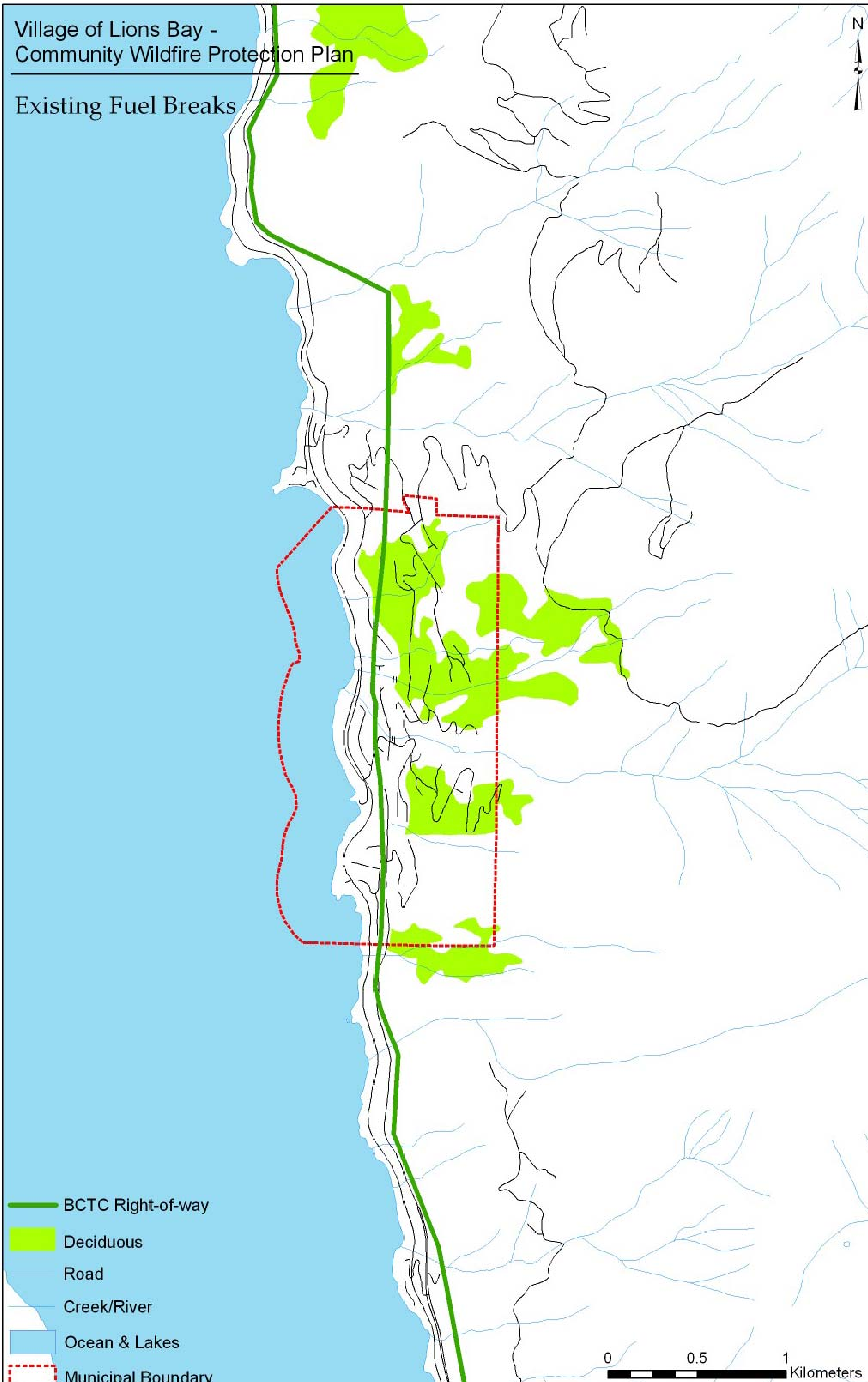


Figure 20. Overview of the deciduous fuel types, hydro right-of-way and roadways that may serve as fuelbreaks within the Village.

7.5.4 Recommendations

Recommendation 16: A number of high hazard areas immediately adjacent to the community have been identified as part of the wildfire risk assessment. The hazardous fuel types that are within 2 km of the Village boundary should be the focus of a progressive thinning program implemented over the next 5 to 10 years.

Recommendation 17: The Village should lobby the Province to identify, document and address hazardous fuel types on crown land adjacent to residential neighbourhoods that could be impacted by a wildland urban interface fire. Effort must be directed at encouraging the Province to initiate a fuel treatment program for these lands and this may include coordinating lobbying initiatives with other local governments from within the Lower Mainland.

Recommendation 18: A qualified professional, with a sound understanding of fire behaviour and fire suppression, should develop fuelbreak plans and fuel treatment prescriptions.

Recommendation 19: Prioritize the development of a fuel break network that builds on existing breaks such as the BC Transmission Corridors running through the Village.

Recommendation 20: The Village should work with British Columbia Transmission Corporation (BCTC) to ensure that transmission infrastructure can be maintained and managed during a wildfire event. Maintaining the transmission corridor to a fuel break standard will provide the community with a more reliable power supply that is less likely to fail during a fire event and will reduce the probability of fire spreading into the community. In addition, the Village should work with BCTC to schedule slashing and clean-up of debris resulting from vegetation management on transmission rights-of-way and identified high risk areas.

7.6 Wildfire Rehabilitation Planning

7.6.1 Goals

- To reduce the impact of negative post-wildfire effects on the community by preparing a strategic, effective and rapid post-wildfire response.

7.6.2 Objectives

- Develop advanced planning for post-fire stabilization and rehabilitation in the next five years.

7.6.3 Issues

- Lions Bay contains steep slopes and soils with high erosion potential and terrain stability issues.

7.6.4 Recommendations

Recommendation 21: The Village should develop a plan for post fire rehabilitation that considers the procurement of seed, seedlings and materials required to regenerate an extensive burn area (1,000-5,000 ha). The opportunity to conduct meaningful rehabilitation post fire will be limited to a short fall season (September to November). The focus of initial rehabilitation efforts should be on slope stabilization and infrastructure protection. These issues should form the foundation of an action plan that lays out the necessary steps to stabilize and rehabilitate the burn area.

8.0 Community Wildfire Protection Planning Background

8.1 Communication and Education

One of the key elements to developing FireSmart communities and neighbourhoods is cultivating an understanding of fire risk in the wildland urban interface. An effective communication strategy should target elected officials (regional and local governments), structural and wildland fire personnel, appropriate municipal departments (planning, bylaw, and environment), the public and the private sector. The principles of effective communication include:

- Developing clear and explicit objectives, or working toward clear understanding;
- Involving all parties that have an interest in a transparent process;
- Identifying and addressing specific interests of different groups;
- Coordinating with a broad range of organizations and groups;
- Not minimizing or exaggerating the level of risk;
- Only making commitments that you can keep;
- Planning carefully and evaluating your effort; and
- Listening to the concerns of your target audience.

To effectively minimize fire risk in the interface zone requires the coordination and cooperation of many levels of government including the B.C. Ministry of Forests and Range, the Greater Vancouver Regional District, local Municipal government departments, and other government agencies. However, if prevention programs are to be effective, fire risk reduction within interface areas of the Village must engage the local residents. This requires a commitment to well-planned education and communication programs that are dedicated to interface fire risk reduction. There is generally a lack of understanding about interface fire and the simple steps that can be taken to minimize risk in communities. Typically, there is either apathy and/or an aversion to dealing with many of the issues highlighted in this report. Public perception of fire risk is often underdeveloped due to public confidence and reliance on local and provincial fire rescue services. Two useful websites that provide links to wildfire education resources and basic fire information include www.efire.org and http://www.pssg.gov.bc.ca/firecom/. Figure 21 shows a screen capture from the City of Chilliwack's public wildfire education website as an example of a clear, navigable and informative public communication method.

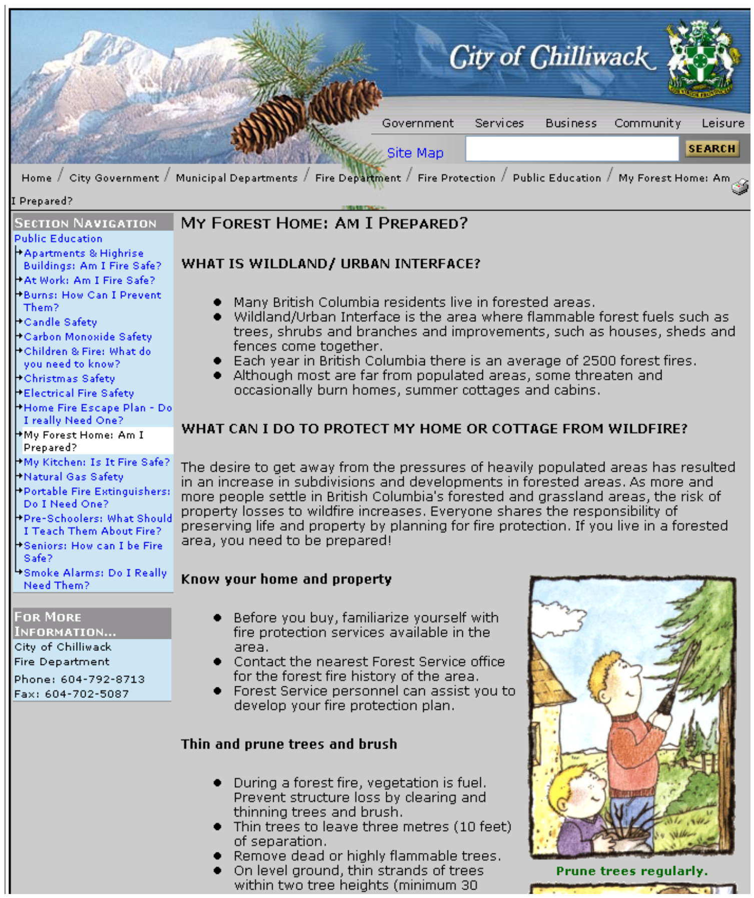


Figure 21. Example of municipal website providing fire education information (http://www.chilliwack.com/main/page.cfm?id=627).

8.1.1 Target Audiences

Historically, there has been limited understanding of wildland urban interface fire risks within many communities of British Columbia. However, the lessons learned from the 2003 fire season have significantly increased local fire rescue service awareness and local, regional, and provincial organizations have upgraded fire suppression understanding and capability. Despite this, there is limited understanding among key community stakeholders and decision makers. Education and communication programs must target the broad spectrum of stakeholder groups within communities. The target audience should include, but not be limited to, the following groups:

- Homeowners within areas that could be impacted by interface fire;
- Local businesses;
- Municipal councils and staff;
- Greater Vancouver Regional District directors;
- Local utilities; and
- Media.

8.1.2 Pilot Projects

Pilot projects that demonstrate and communicate the principles of FireSmart and its application to Community Wildfire Protection should be considered. The focus of these pilot projects should be to demonstrate appropriate building materials and construction techniques in combination with the FireSmart principles of vegetation management, and to showcase effective fuel management techniques. Several homes and businesses could be identified by the Village to serve a communication and education function that would allow residents to see the proper implementation of FireSmart principles. The fuel treatment pilot should focus on hazardous fuel types identified in the CWPP.

These pilot projects are considered a high priority for the urban interface to provide information on different fire hazard reduction techniques and demonstrate appropriate fire risk reduction methods to the community including municipal staff, community leaders and the public. These demonstration areas will also provide sites for improved public understanding of the methods to mitigate fire risk that can be applied on individual properties.

8.1.3 Website

Websites are considered one of the best and most cost effective methods of communication available. Fire related information such as fire danger and fire restrictions, as well as fire risk assessment information should be included on any fire protection website. Pictures and text that outline demonstration/pilot projects can also be effective in demonstrating progress and success of fire risk reduction activities. During fire season it is particularly important that wildfire safety related information be posted so that it is easily accessible to the general public.

8.1.4 Media Contacts, Use and Coordination

Media contact plays an essential role in improving public awareness about fire risk in the community. Interest in wildfire protection can be cultivated and encouraged to improve the transfer of information to the public by more frequent media contact.

Key issues in dealing with the media include:

- Assignment of a media spokesperson for the Village;
- Providing regular information updates during the fire season regarding conditions and hazards; and
- Providing news releases regarding the interface issues and risks facing the community.

8.1.5 Other Methods

Educational information and communication tools need to be stakeholder specific. To establish effective communication within target groups, spokespersons who can best establish communication ties and provide the educational information required should be selected. The following subsections outline potential communication methods for specific stakeholder groups.

8.1.5.1 Homeowners

- Conduct surveys and consult the public to ascertain current attitudes.
- Designate spokespersons to communicate to this group and establish a rapport.
- Establish community information meetings conducted by spokespersons.
- Mail out informational material.
- Provide FireSmart hazard assessment forms and information.
- Provide signage at trailheads and other prominent locations.

8.1.5.2 Government Ministries, Village and Municipal Officials, Disaster Planning Services, Utilities

- Develop material specific to the educational needs of the officials.
- Present councils with information and encourage cooperative projects between municipalities.

- Establish memoranda of understanding between agencies.
- Appoint a spokesperson to communicate to the groups and help foster inter-agency communication.
- Raise awareness of officials as to the views of the public regarding interface risks in their community.

8.1.6 General Messages

Education and communication messages should be simple yet comprehensive. The level of complexity and detail of the message should be specific to the target audience. A complex, wordy message with overly technical jargon will be less effective than a simple, straightforward message. A basic level of background information is required to enable a solid understanding of fire risk issues. Generally, messages should have at least the following three components:

1. Background Information
    - Outline general issues facing interface communities.
    - Communicate specific conditions in the community that cause concern.
    - Provide examples of potential wildfire behaviour in the community.
    - Provide examples of how wildfire has affected other communities.
    - Explain the effects that a wildfire could have upon the community.
    - Convey FireSmart principles.
2. Current Implementation and Future Interface Planning
    - Provide information on the current planning situation.
    - Explain who is involved in interface planning.
    - Explain the objectives of interface wildfire planning.
    - Explain the limitation of firefighting crews and equipment in case of a wildfire.
    - Outline the emergency procedure during a wildfire.
3. Responsibilities and Actions
    - Outline the responsibilities of each group in reducing wildfire hazards.
    - Explain the actions that each group may take to meet these responsibilities.

8.2 Structure Protection

8.2.1 FireSmart

Another important consideration in protecting the wildland urban interface zone from fire is ensuring that homes can withstand an interface fire event. Often, it is a burning ember traveling some distance (spotting) and landing on vulnerable housing materials, rather than direct fire/flame (vegetation to house) contact, that ignites a structure. Alternatively, the convective or radiant heating produced by one structure may ignite an adjacent structure if it is within close proximity. Structure protection is focused on ensuring that building materials and construction standards are appropriate to protect individual homes from interface fire. Materials and construction standards used in roofing, exterior siding, window and door glazing, eaves, vents, openings, balconies, decks and porches are primary considerations in developing FireSmart neighbourhoods. Housing built using appropriate construction techniques and materials is less likely to be impacted by interface fires.

While many communities established to date in BC were built without significant consideration with regard to interface fire, there are still ways to reduce home vulnerability. Changes to roofing materials, siding, and decking can ultimately be achieved through long-term changes in bylaws and building codes.

The FireSmart approach has been adopted by a wide range of governments and is a recognized template for reducing and managing fire risk in the wildland urban interface. The most important components of the FireSmart approach are the adoption of the hazard assessment systems for wildfire, site and structure hazard assessment, and the proposed solutions and mitigation outlined for vegetation management, structure protection, and infrastructure. Where fire risk is unacceptable, the FireSmart standard should, at a minimum, be applied to new subdivision developments and, wherever possible, the standard should be integrated into changes to, and new construction within, existing subdivisions and built up areas.

8.2.1.1 Roofing Material

Roofing material is one of the most important characteristics influencing a home's vulnerability to fire. Roofing materials that can be ignited by burning embers increase the probability of fire related damage to a home during an interface fire event.

In many communities there is no fire vulnerability standard for roofing material. Homes are often constructed with unrated materials that are considered a major hazard during a large fire event. In addition to the vulnerability of roofing materials, adjacent vegetation may be in contact with roofs, or roof surfaces are covered with litter fall and leaves from adjacent trees. This increases the hazard by increasing the ignitable surfaces and potentially enabling direct flame contact between vegetation and structures.

8.2.1.2 Building Exterior - Siding Material

Building exteriors constructed of wood are considered the second highest contributor to structural hazard after roofing material. Wood siding within the interface zone is vulnerable to direct flame or may ignite when sufficiently heated by nearby burning fuels. Winds caused by convection will transport burning embers, which may lodge against siding materials. Siding materials, such as wood shingles, boards, or vinyl are susceptible to fire. Brick, stucco, or heavy timber materials offer much better resistance to fire.

8.2.1.3 Balconies and Decking

Open balconies and decks increase fire vulnerability through their ability to trap rising heat, by permitting the entry of sparks and embers, and enabling fire access to these areas. Closing these structures off limits ember access to these areas and reduces fire vulnerability.

8.2.1.4 Combustible Materials

Combustible materials stored within 10 m of residences are also considered a significant issue. Woodpiles or other flammable materials adjacent to the home provide fuel and ignitable surfaces for embers. Locating these fuels away from structures helps to reduce structural fire hazards.

8.2.2 Planning and Bylaws

There are two types of wildfire safety regulations most commonly used by local governments: Type 1) regulations that restrict the use of fire; and, Type 2) regulations that restrict building materials, require setbacks or restrict zoning. While most municipalities have bylaws for Type 1 regulations, Type 2 regulations are not as common. However, these regulations are an important contributor to wildfire risk reduction. Several Type 2 policy options are generally available to local governments. These primarily include:

- Voluntary fire risk reduction for landowners (building materials and landscaping)
- Bylaws for building materials and subdivision design
- Covenants requiring set-backs and vegetation spacing
- Site assessments that determine the imposition of fire protection taxes
- Education
- Zoning in fire prone areas
- Treatments on private and public land (commercial thinning, non-commercial mechanical thinning, clear-cut commercial harvesting or prescribed burning)

There are two prominent issues that may be corrected through the bylaw process. Unrated roofing materials contribute significantly to fire risk. In the short term, a resolution to this issue is difficult given the significant cost to homeowners. However, over the long-term, altering building codes or bylaws to encourage a change in roofing materials when roof replacement of individual residences is required is generally a viable option.

The second prominent issue relates to the creation of large setbacks between buildings and the forest. Where forest trees encroach onto balconies and building faces, the potential for structure ignition is greater and may result if more houses being engaged by fire, thereby reducing firefighter capability to successfully extinguish both wildland and structural fires throughout a community. These two suggestions represent only a fraction of the changes that can be considered and more can be identified on a community specific basis by completing a thorough review of current bylaws as they relate to fire risk.

Local governments have an important role in managing community fire hazard and risk. Through the Local Government Act, Development Permit Areas authorize local governments to regulate development in sensitive or hazardous areas where special conditions exist.

For example, Development Permit Areas can be designated for such purposes as:

- Protection of the natural environment;
- Protection from hazardous conditions;
- Protection of provincial or municipal heritage sites;
- Revitalization of designated commercial areas; or
- Regulation of form and character of commercial, industrial and multi-family residential development.

As a land use planning tool, the establishment of Development Permit Areas for interface fire hazards could protect new developments from wildfire in the urban interface. For the purpose of fire hazard and risk reduction a development permit may:

- Include specific requirements related to building character, landscaping, setbacks, form and finish; and
- Establish restrictions on type and placement of trees and other vegetation in proximity to the development.

8.2.3 Sprinklers

As part of the Firestorm 2003 Provincial Review, the provincial government responded to the interface fire issue by purchasing mobile sprinkler kits that can be deployed during interface fires. Given the value of the interface in many communities, it is appropriate to consider employing a sprinkler system in these areas. Training may be required to ensure appropriate deployment and use during an interface fire emergency.

8.2.4 Joint Municipality Cooperation

Interagency cooperation on issues related to resource capacity, training, mutual aid, and equipment sharing is common practice in BC. An expanded role for this relationship could include developing community based communication and education tools for use at a regional scale. Currently, many municipalities are developing in house standards and materials to improve public awareness. A more unified approach could improve efficiency, create consistent messages, and more broadly inform the public of interface fire issues and risk.

8.2.5 Structured FireSmart Assessments of High Risk Areas

The WRMS provides a tool to identify specific areas of high risk within municipalities The WRMS provides a sound scientific framework on which to complete more detailed local neighbourhood risk assessments.

8.3 Emergency Response

The availability and timing of emergency response personnel often dictates whether interface fire protection is successful. Well-planned strategies to deal with different and difficult interface fire scenarios are part of a comprehensive approach to addressing interface fire risk. In communities where the risk is considered low, emergency response alone may be considered an adequate management response to protect the community. As risk increases so too should the level of emergency response. Emergency response alone may not be an adequate management strategy to develop depending on the level of risk.

Unlike static emergencies (*e.g.* landslides), fires are dynamic and situations can change dramatically over short periods of time, potentially overwhelming resources. Therefore, it is important to consider a wide range of issues including, but not limited to, evacuation strategies, access for emergency vehicles and equipment, management of utility hazards associated with hydroelectric and gas infrastructure, and the reliability and availability of key fire fighting infrastructure during a fire event.

8.3.1 Access and Evacuation

The 2005 Berkley landslide emergency in the District of North Vancouver highlighted some of the difficulties associated with access and evacuation. Parked cars blocked the way for fire and emergency response personnel, dead end roadways made turning equipment around difficult, and evacuation of residents was complicated by the size and requirements of the emergency response.

In any emergency, evacuation is a critical function of emergency services. Given that a forest fire is a dynamic event, evacuation planning is considered of critical importance. Fire Departments must be prepared for evacuation of the sick, disabled, and the elderly when dealing with a wildland fire emergency. This issue adds complexity to any emergency situation.

Evacuation of residents and access for emergency personnel is an important consideration in any community. It is particularly important in neighbourhoods with limited access and with forest fuels in close proximity to homes. Evacuation can be further complicated by smoke and poor visibility, creating the necessity for traffic control. Where this is likely to be the case, establishing secondary or alternate evacuation routes is essential.

In addition to the evacuation of residents, safety of firefighting personnel is a major consideration. Where access in one-way in and out, there is the potential for resources to be isolated or cut off. Defence of neighbourhoods with poor access is secondary to safety considerations.

8.3.2 Fire Response

Fire suppression efforts in municipalities are constrained by the ability of firefighters to successfully defend residences with:

- Contiguous fuels between the forest and adjacent homes;
- Steep slopes of greater than 35%; and
- Human caused fuel accumulations and fuel tanks adjacent to homes.

Close proximity of fuels to homes and vulnerable roofing material are the two most significant factors that reduce the ability of firefighters to defend residences. During ember showers, multiple fires can ignite on vulnerable roofs within the wildland urban interface. Fuel continuity can provide a pathway for fire between the forest and homes. A lack of fuel breaks between houses and forest is likely to increase suppression resource requirements. While there will always be a limited ability to protect homes from extreme fire behaviour, or to modify fuels and topography, communities do have control over issues such as defensible space and home construction materials, and can make changes to reduce community vulnerability to fire.

Residences and businesses on steep slopes are vulnerable to increased fire behaviour potential and should be the immediate focus of initial attack if there is a fire start within these areas. Flame length and rate of spread will increase on these slopes, resulting in suppression difficulty and increased safety issues for both wildland and structural fire fighters.

Another significant issue that could affect emergency response is the impact of smoke on critical infrastructure such as fire departments and hospitals. Heavy smoke from a large fire could force evacuation of these facilities depending on their location.

In the event of forest fire, municipalities rely heavily on the MOFR to action fires in the forests within the community. During periods of high fire load throughout the Province, resources of the MOFR can be stretched thin. Often high fire activity is concentrated in the interior of the Province and availability of aircraft and equipment can be limited on the coast. In steep heavily forested terrain, the most effective method of fire control is generally air tanker action or bucketing with water from a helicopter. Therefore, under extreme fire conditions it may be appropriate for some municipalities to retain a contract helicopter on standby. This may substantially improve the community's probability of containing a fire during the most severe part of the fire season, and may provide the MOFR with the time necessary to mobilize equipment and resources from other parts of the Province.

8.4 Training Needs

The events of the 2003 fire season increased municipal awareness with regard to necessary training and equipment improvements. The division between local fire departments/rescue services and the MOFR Protection Branch has narrowed through improved training and communication. Training is fundamental to managing interface fire risk. Crossover abilities between provincial wildland fire and municipal structural fire personnel will enhance and improve the collective agency response to wildland urban interface fire. Therefore, all management strategies designed to protect the wildland urban interface should be supported by an adequate level of training to ensure emergency response addresses both wildland and structural fire.

All municipal firefighters should be trained in the S-100 Basic Wildland Fire Fighting course on a yearly basis. This is carried out by instructors endorsed by the B.C. Forest Service.

In general, it is recommended that:

- The S-100 course instruction be continued on an annual basis;
- Municipal Parks outside staff be given the S-100 course on an annual basis;
- A review of the S-215 course instruction be given on a yearly basis;
- The S-215 course instruction be given to new career staff and Paid On-Call officers on an ongoing basis; and
- Incident Command System training be given to all career and Paid On-Call officers.

Although not a true course, it is also recommended that municipal fire departments meet with the B.C. Forest Service meet prior to the fire season to review the Incident Command System structure in the event of a major wildland fire. This is based on the suggested training from above.

8.5 Vegetation (Fuel) Management

Vegetation management is considered a key element of the FireSmart approach. Given public concerns, vegetation management is often difficult to implement and must be carefully rationalized in an open and transparent process. Vegetation management should be strategically focused on minimizing impact while maximizing value to the community. For example, understory thinning or surface fuel removal may suffice to lower fire risk. In situations where the risk is high, a more aggressive vegetation management strategy may be necessary. Vegetation management must be evaluated against the other elements outlined above to determine its necessity. Its effectiveness depends on the longevity of treatment (vegetation grows back), cost, and the resultant effect on fire behaviour.

8.5.1 Principles of Fuel Management

8.5.1.1 Definition

Fuel management is the planned manipulation and/or reduction of living and dead forest fuels for land management objectives (*e.g.,* hazard reduction). It can be achieved by a number of methods including:

- Prescribed fire;
- Mechanical means; and
- Biological means.

8.5.1.2 Purpose

The goal is to proactively lessen the potential fire behaviour, thereby increasing the probability of successful containment and minimizing adverse impacts. More specifically, the goal is to decrease the rate of fire spread, and in turn fire size and intensity, as well as crowning and spotting potential (Alexander 2003).

Fire triangle

Fire is a chemical reaction that requires three main ingredients:

- Fuel (carbon);
- Oxygen; and
- Heat.

These three ingredients make up the fire triangle. If any one is not present, a fire will not burn.

Fuel is generally available in ample quantities in the forest. Fuel must contain carbon. It comes from living or dead plant materials (organic matter). Trees and branches lying on the ground are a major source of fuel in a forest. Such fuel can accumulate gradually as trees in the stand die. Fuel can also build up in large amounts after catastrophic events, such as insect infestations or disease.

Oxygen is present in the air. As oxygen is used up by fire, it is replenished quickly by wind.

Heat is needed to start and maintain a fire. Heat can be supplied by nature through lightning. People also supply a heat source through misuse of matches, campfires, trash fires, and cigarettes. Once a fire has started, it provides its own heat source as it spreads.

8.5.1.3 Forest Fuels

The amount of fuel available to burn on any site is a function of biomass production and decomposition. Many of the forest ecosystems within British Columbia have the potential to produce large amounts of vegetation biomass. Variation in the amount of biomass produced is typically a function of site productivity and climate. The disposition or removal of vegetation biomass is a function of decomposition. Decomposition is regulated by temperature and moisture. In wet maritime coastal climates the rates of decomposition are relatively high when compared with drier cooler continental climates of the interior. Rates of decomposition can be accelerated naturally by fire and/or anthropogenically by humans.

A hazardous fuel type can be defined by high surface fuel loadings; high proportions of fine fuels (<1 cm) relative to larger size classes, high fuel continuity between the ground surface and overstory tree canopies, and high stand densities. A fuel complex is defined by any combination of these attributes at the stand level and may include groupings of stands.

8.5.1.4 Surface Fuels

Surface fuels consist of forest floor, understory vegetation (grasses, herbs and shrubs, and small trees), and coarse woody debris that are in contact with the forest floor (Figure 22). Forest fuel loading is a function of natural disturbance, tree mortality and/or human related disturbance.

Surface fuels typically include all combustible material lying on or immediately above the ground. Often roots and organic soils have the potential to be consumed by fire and are included in the surface fuel category.

Surface fuels that are less than 12 cm in diameter contribute to surface fire spread; these fuels often dry quickly and are ignited more easily than larger diameter fuels. Therefore, this category of fuel is the most important when considering a fuel reduction treatment. Larger surface fuels greater than 12 cm are important in the contribution to sustained burning conditions, but are often not as contiguous and are less flammable because of delayed drying and high moisture content, when compared with smaller size classes. In some cases where these lager size classes form a contiguous surface layer, such as following a windthrow event or wildfire, they can contribute an enormous amount of fuel, which will increase fire severity and potential for fire damage.

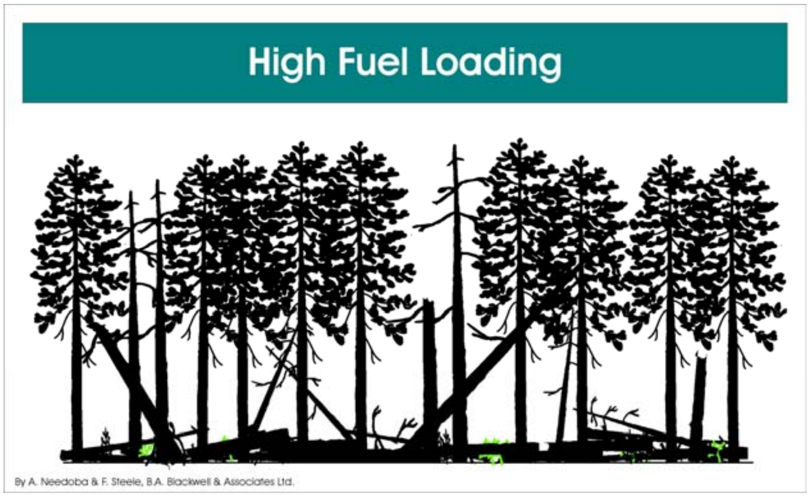


Figure 22. High surface fuel loading under a forest canopy

8.5.1.5 Aerial Fuels

Aerial fuels include all dead and living material that is not in direct contact with the forest floor surface. The fire potential of these fuels is dependent on type, size, moisture content, and overall vertical continuity. Dead branches and bark on trees and snags (dead standing trees) are important aerial fuel. Concentrations of dead branches and foliage increase the aerial fuel bulk density and enable fire to move from tree to tree. The exception is for deciduous trees where the live leaves will not normally carry fire. Numerous species of moss, lichens, and plants hanging on trees are light and flashy aerial fuels. All of the fuels above the ground surface and below the upper forest canopy are described as ladder fuels.

Two measures that describe crown fire potential of aerial fuels are the height to live crown and crown closure (Figure 23 and Figure 24). The height to live crown describes fuel continuity between the ground surface and lower limit of the upper tree canopy. Crown closure describes the inter-tree crown continuity and reflects how easily fire can be propagated from tree to tree. In addition to crown closure, tree density is an important measure of the distribution of aerial fuels and has significant influence on the overall crown and surface fire conditions (Figure 25). Higher stand density is associated with lower inter tree spacing, which increases overall crown continuity. While high density stands may increase the potential for fire spread in the upper canopy, a combination of high crown closure and high stand density usually results in a reduction in light levels associated with these stand types. Reduced light levels accelerate self-tree pruning, inhibit the growth of lower branches, and decrease the cover and biomass of understory vegetation.

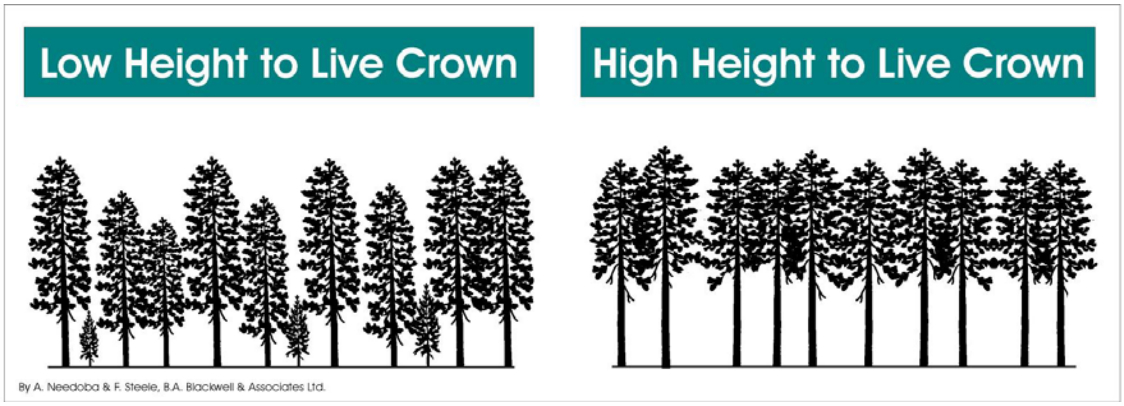


Figure 23. Comparisons showing stand level differences in the height to live crown.

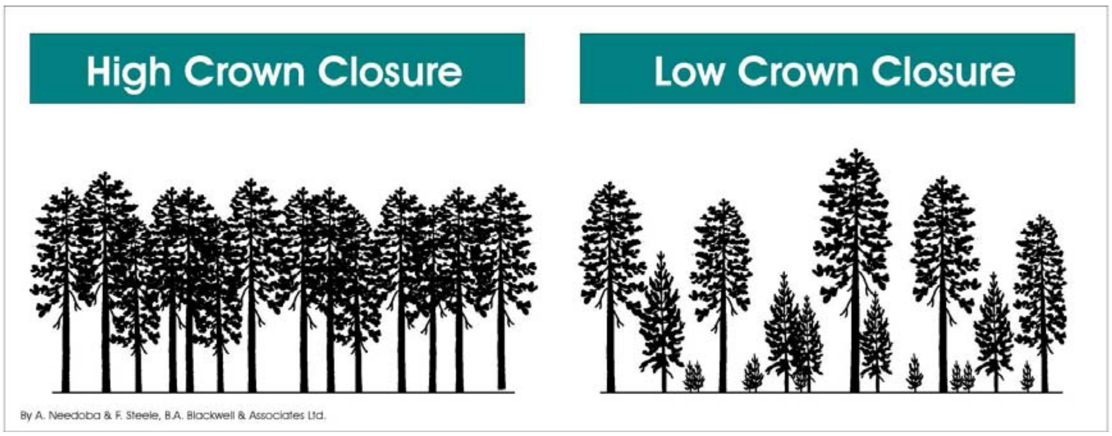


Figure 24. Comparisons showing stand level differences in crown closure.

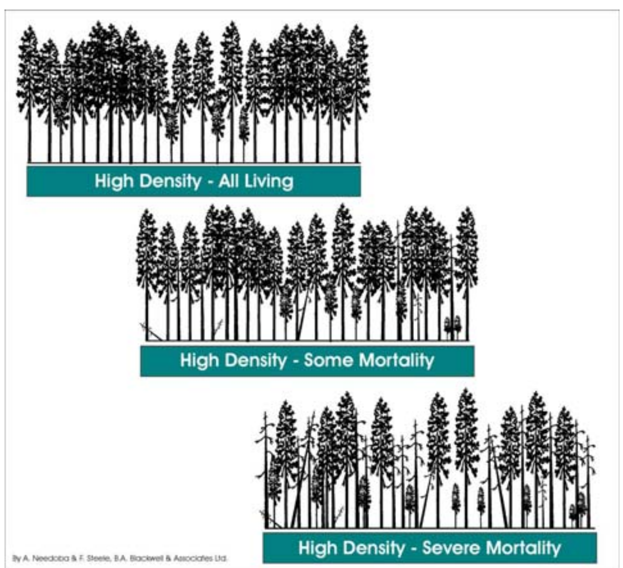


Figure 25. Comparisons showing stand level differences in density and mortality.

Thinning is a preferred approach to fuels treatment (Figure 26) and offers several advantages compared to other methods:

- Thinning provides the most control over stand level attributes such as species composition, vertical structure, tree density, and spatial pattern, as well as the retention of snags and coarse woody debris for maintenance of wildlife habitat and biodiversity.
- Unlike prescribed fire treatments, thinning is comparatively low risk, is not constrained to short weather windows, and can be implemented at any time.
- Thinning may provide marketable materials that can be utilized by the local economy.
- Thinning can be carried out using sensitive methods that limit soil disturbance, minimize damage to leave trees, and provide benefits to other values such as wildlife.

The following summarizes the guiding principles that should be applied in developing thinning prescriptions:

- Protect public safety and property both within and adjacent to the urban interface.
- Reduce the risk of human caused fires in the immediate vicinity of the urban interface.
- Improve fire suppression capability in the immediate vicinity of the urban interface.
- Reduce the continuity of overstory fuel loads and related high crown fire risk.
- Maintain the diversity of wildlife habitat through the removal of dense understory western hemlock, western red cedar, amabilis fir, Douglas fir and other minor tree species.
- Minimize negative impacts on aesthetic values, soil, non-targeted vegetation, water and air quality, and wildlife.

The main wildfire objective of thinning is to shift stands from having a high crown fire potential to having a low surface fire potential. In general, the goals of thinning are to:

- Reduce stem density below a critical threshold to minimize the potential for crown fire spread. Target crown closure is less than 35%;

- Prune to increase the height to live crown to a minimum of 2.5 meters or 30% of the live crown (the lesser of the two) to reduce the potential of surface fire spreading into tree crowns; and
- Remove slash created by spacing and pruning to maintain surface fuel loadings below 5 kg/m^2.

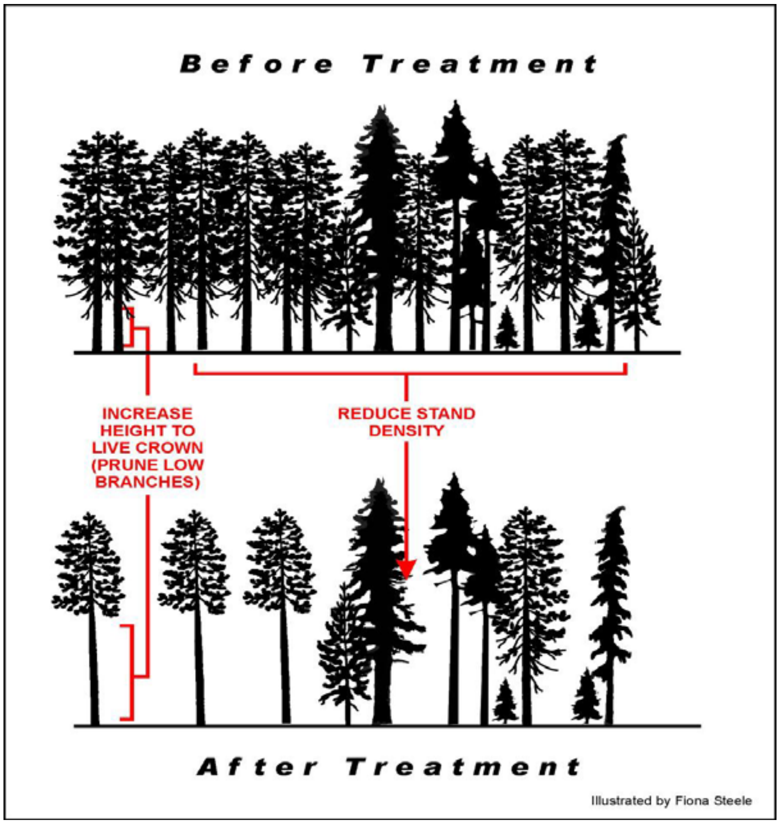


Figure 26. Schematic showing the principles of thinning to reduce stand level hazard.

8.5.1.6 The Principles of Landscape Fuelbreak Design

Fuelbreaks can be defined as strategically placed strips of low volume fuel where firefighters can make a stand against fire and provide safe access for fire crews in the vicinity of wildfires, often for the purpose of lighting backfires. Fuelbreaks act as staging areas where fire suppression crews could anchor their fire suppression efforts, thus increasing the likelihood that fires could be stopped, or fire behaviour minimized, so that the potential for a fire to move fluidly through a municipality and into the interface is substantially reduced. The principles of fuelbreak design are described in detail in Appendix 1.

The Village must be sensitive to visual concerns and public perception. Therefore, specific area treatments or other manual/mechanical methods are most desirable. A fuel treatment is created by reducing surface fuels, increasing height to live crown and lowering stand density through tree removal (Figure 27). Fuelbreaks can be developed using a variety of prescriptive methods that may include understory and overstory fuel removal, timing of treatment, synergistic effects with other treatments, and placement on the landscape.

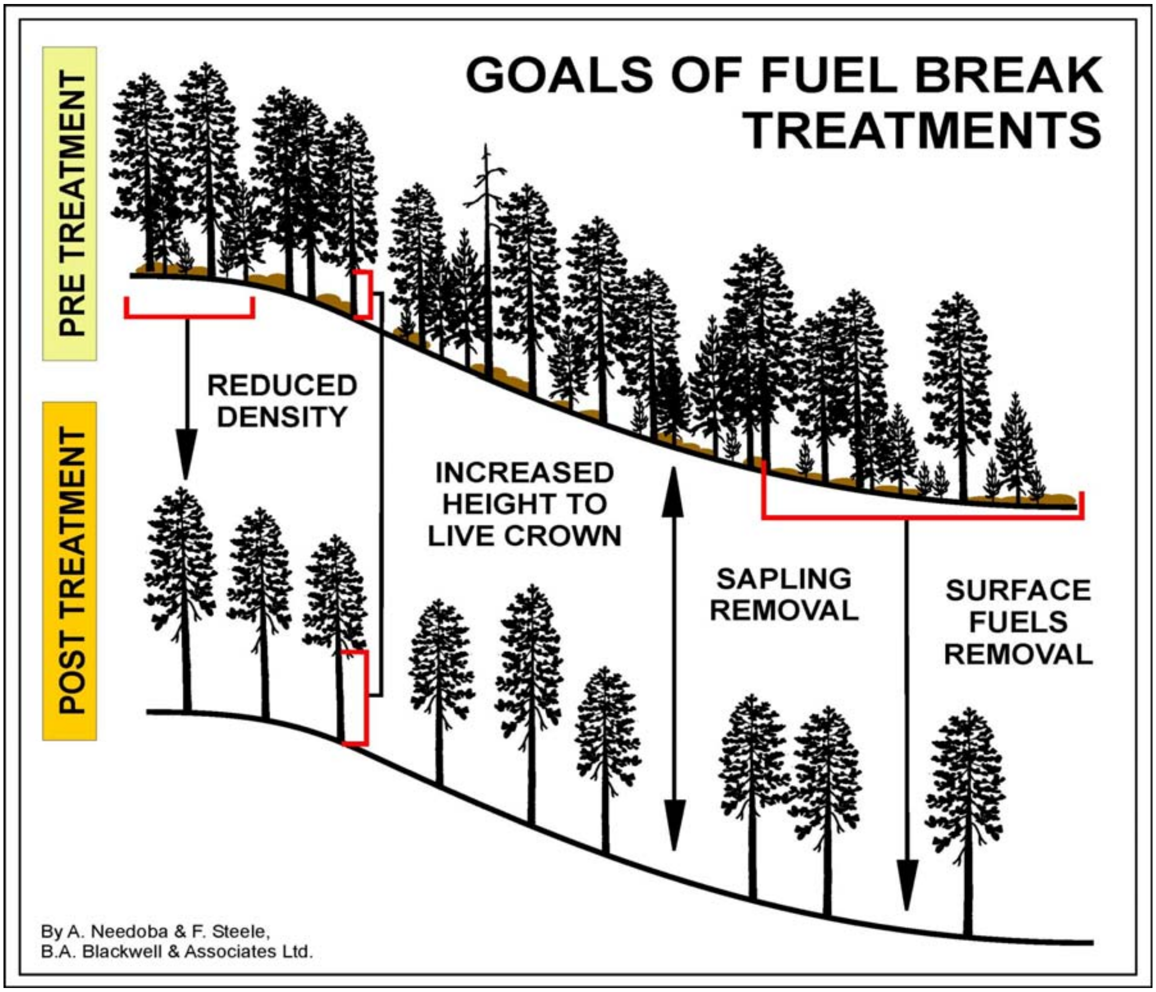


Figure 27. Conceptual diagram of a shaded fuelbreak pre treatment and post treatment.

When developing fuelbreak prescriptions, the CFFDRS fuel type classification for the area and the potential fire behaviour must be considered in order to predict the change in fire behaviour that will result from altering fuel conditions. The identification of potential candidate areas for fuelbreaks should be focused on areas that will isolate and limit fire spread, and provide solid anchors for fire control actions. The search for candidate areas should be conducted using a combination of aerial photographs, Terrestrial Resources Information Mapping (TRIM), topographic maps, and personal field experience.

Prior to finalizing the location of fuelbreaks, fire behaviour modeling using the Canadian Fire Behaviour Prediction system (FBP) should be applied to test the effectiveness of the size and scale of proposed treatments. These model runs should include basic information from fieldwork pertaining to the fuel types, height to live crown base, crown fuel load, surface loads, and topography. The model runs should be used to demonstrate the effectiveness of treatments in altering fire behaviour potential.

Treatment prescription development must also consider the method of fuel treatment. Methods include manual (chainsaw), mechanical, and pile burning or any combination of these treatments. To be successful, manual treatments should be considered in combination with prescribed burning of broadcast fuels or pile and burn. Mechanical treatments involve machinery and must be sensitive to ground disturbance and impacts on hydrology and watercourses. Typically, these types of treatments reduce the overstory fuel loads but increase the surface fuel load. The surface fuel load must be removed in order to significantly reduce the fire behaviour potential. Increased surface fuel load is often the reason that prescribed burning or pile and burn are combined in the treatment prescription.

Final selection of the most appropriate fuelbreak location will depend on a number of factors including:

- Protection of recreation and aesthetics;
- Protection of public safety;
- Reduction of potential liabilities;
- Minimizing future suppression costs;
- Improved knowledge;
- Impacts on visual quality;
- The economics of the treatments and the potential benefits;
- Treatment cost recovery;
- The impact of treatments on the alteration of fire behaviour; and
- Public review and comment.

Fuelbreaks should not be considered stand-alone treatments to the exclusion of other important strategies already discussed in this plan. To be successful, municipalities need to integrate a fuelbreak plan with strategic initiatives such as structure protection, emergency response, training, communication and education. An integrated strategy will help to mitigate landscape level fire risk, reduce unwanted wildland fire effects and the potential negative social, economic and environmental effects that large catastrophic fires can cause.

8.5.2 Maintenance

Once a municipality commits to the development of a fuelbreak strategy, decision makers and municipal staff must recognize that they are embarking on a long-term commitment to these types of treatments and that future maintenance will be required. Additionally, the financial commitment required to develop these treatments in the absence of any revenue will be high. A component of the material to be removed to create fuelbreaks has an economic value and could potentially be used to offset the cost of treatment, thereby providing benefits to municipalities and the local economy.

Fuelbreaks require ongoing treatment to maintain low fuel loadings. Following treatment, tree growth and understory development start the process of fuel accumulation and, if left unchecked, over time the fuelbreak will degrade to conditions that existed prior to treatment. Some form of follow-up treatment is required. Follow-up is dependent on the productivity of the site, and may be required as frequently as every 10 to 15 years in order to maintain the site in a condition of low fire behaviour potential.

8.6 Post Wildfire Rehabilitation Planning

Wildfires have immediate short and long-term impacts on the social, economic and environmental values of an interface community. In steep environments, post fire impacts (*i.e.* removal of ground cover) can result in an elevated risk of landslides and debris flows. Within watersheds, post fire impacts can include increased nutrient and sediment flow into reservoirs. These impacts can be reduced or avoided through the development of post fire mitigation plans and effective response following fire. In communities that have identified risk of landslide and debris flow, it is appropriate to consider the development of a post fire rehabilitation plan that will guide actions following a fire event.

Emergency rehabilitation and restoration activities are intended to mitigate some of the damage caused by suppression actions, as well as some of the potential soil erosion and landscape level impacts caused by precipitation events on burned slopes following a fire. Post fire impacts are dependent on a complex relationship between fire severity, ecosystem type, slope and soils. A stable watershed is defined by intact vegetation, forest floor and soil where sedimentation is limited. Consequently, watershed stability could be severely impacted after a major fire disturbance.

Advanced planning (pre-planning) for post-fire stabilization and rehabilitation is a relatively new concept in BC. However, the purpose of pre-planning is to facilitate a rapid post-fire assessment and response to ensure rehabilitation is completed before any storm events occur that might trigger undesirable post-wildfire effects. Assembling information in advance will subsequently allow for the rapid refinement of planned strategies for emergency stabilization, and short and long-term rehabilitation.

Pike and Ussery (2005) outline the key considerations when pre-planning for post-wildfire rehabilitation. They are listed as follows:

- Keep planning simple, clearly define terms and match goals to planned activities.
- Consider landform characteristics.
- Identify key community values.

- Determine priority areas for action.
- Clarify jurisdictional issues.
- Predict areas most susceptible to post-fire erosion.
- Understand the triggers for undesirable post-fire conditions.
- Learn from existing experience.
- Develop risk-based strategies.
- Match techniques with needs.
- Think long-term.
- Consider proactive approaches to reducing risk.
- Identify training and communication needs.

The primary goal of post wildfire rehabilitation planning is to prepare for a strategic, effective and rapid post-wildfire response (Pike and Ussery 2005). Although some post-burn scenarios can be forecast, the focus of the plan should be on information gathering rather than outcome prediction and preparation for all possible events. There are three categories of stabilization/rehabilitation: i) short term emergency stabilization; ii) rehabilitation of fire suppression related effects; and iii) long-term watershed rehabilitation.

Given the need for quick action and the substantial resources that are often required for post-fire stabilization and rehabilitation, it is important to match the intensity of these activities with the level of risk to key watershed values. The most comprehensive stabilization and rehabilitation activities should be directed at the areas with the highest values at risk. It is also important to consider the potential risk to watershed values from access, machinery, and materials in post-fire interventions.

Pre-planning should identify priority areas in watersheds for fire suppression and post-fire stabilization/rehabilitation based on the results of a risk/consequence assessment. Similar to wildfire planning, post fire response should consider a risk-based approach to assessing potential hazards from fire and post-fire conditions, and the potential consequences of such hazards on key community values.

Rehabilitation plans for communities must consider the potential for negative effects on areas downstream of the fire site and address accompanying inter-jurisdictional issues (such as damage to highways, railways, community infrastructure and/or private property). Slope stability, erosion potential and sediment transport all influence post wildfire susceptibility and impacts. High intensity rainfall events, even of relatively short duration, on areas with water repellent soils have been shown to increase flooding and accelerate erosion.

A list of qualified professionals with expertise in post-fire assessments, risk analyses and emergency stabilization and rehabilitation should be developed. It is important to have a list of professionals at hand to facilitate a rapid response to emergencies. This list should be updated annually. The administrative and financial policies and procedures for retaining contract services in emergency situations should also be in place and well understood.

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Appendix 1 – Fuel Type Descriptions

Fuel Type Descriptions

The following is a general description of the dominant fuel types within the study area

C3 fuel type

Area of Fuel Type (ha)	3,274
Structure Classification	Late pole sapling to late young forest
Dominant Tree Species	*Pseudotsuga menziesii* (Douglas-fir), *Tsuga heterophylla* (western hemlock), *Thuja plicata* (western redcedar) and *Abies amabilis* (amabilis fir)
Tree Species Type	> 80% Coniferous
Understory Vegetation	Low (< 50% cover)
Age	40 – 80 yrs
Height	20 – 33 m
Stand Density	700 – 1,200 stems/ha
Crown Closure	40 – 100 %
Height to Live Crown	Average 8 m
Surface Fuel Loading	< 5 kg/m^2
Burn Difficulty	Moderate; however, if fire is wind driven then there is a high potential for extreme fire behaviour and active crown fire.

Table 6. Estimated fire behaviour in C3 fuel types by BEC assuming 90th percentile weather conditions, 9 km windspeeds and flat terrain.

Fuel Type	BEC	Rate of Spread (km/h)	Head Fire Intensity (kW/m)	Crown Fraction Burned	Ignition Potential	Flame Height (m)	Crown Base Height (m)	Area (ha)
C3	CWHdm	6	6,810	27%	91%	4	8	1,347
C3	CWHvm1	5	3,820	0%	85%			1,304
C3	CWHvm2	3	1,525	0%	82%	2	8	433
C3	CHWxm1	8	11,800	63%	96%		8	159
C3	MMmm1	2	1,126	0%	71%			31

Figure 28. Example of evenly stocked, moderate density second growth stand – classified as a C3 fuel type.

C4 fuel type

Area of Fuel Type (ha)	182
Structure Classification	Pole sapling
Dominant Tree Species	*Pseudotsuga menziesii* (Douglas-fir), *Tsuga heterophylla* (western hemlock), *Thuja plicata* (western redcedar) and *Abies amabilis* (amabilis fir)
Tree Species Type	> 80% Coniferous
Understory Vegetation	Low (< 25% cover)
Age	20 – 40 yrs
Height	10 – 20 m
Stand Density	700 – 2000 stems/ha
Crown Closure	40 – 80 %
Height to Live Crown	Average 4 m
Surface Fuel Loading	< 5 kg/m^2
Burn Difficulty	Moderate to high; however, if fire is wind driven then there is a high potential for extreme fire behaviour and active crown fire.

Table 7. Estimated fire behaviour in C4 fuel types by BEC assuming 90th percentile weather conditions, 9 km windspeeds and flat terrain.

Fuel Type	BEC	Rate of Spread (km/h)	Head Fire Intensity (kW/m)	Crown Fraction Burned	Ignition Potential	Flame Height (m)	Crown Base Height (m)	Area (ha)
C4	CWHdm	17	23,978	97%	100%	7	4	26
C4	CWHvm1	15	17,405	95%	98%			18
C4	CWHvm2	11	9,640	84%	90%	5	4	115
C4	CHWxm1	21	31,987	99%	100%			2
C4	MMmm1	10	7,823	77%	79%			21

Figure 29. Example of a moderate to high-density second growth stand of hemlock and Douglas-fir classified as a C4 fuel type.

C5 fuel type

Area of Fuel Type (ha)	7,934
Structure Classification	Mature and old forest
Dominant Tree Species	*Pseudotsuga menziesii* (Douglas-fir), *Tsuga heterophylla* (western hemlock), *Thuja plicata* (western redcedar) and *Abies amabilis* (amabilis fir)
Tree Species Type	> 80% Coniferous
Understory Vegetation	Moderate (> 40% cover)
Average Age	> 80 yrs
Average Height	30 – 40 m
Stand Density	700 – 900 stems/ha
Crown Closure	40 – 100 %
Height to Live Crown	Average 18 m
Surface Fuel Loading	< 5 kg/m^2
Burn Difficulty	Low; however, if fire is wind driven then there is a moderate potential for active crown fire.

Table 8. Estimated fire behaviour in C5 fuel types by BEC assuming 90th percentile weather conditions, 9 km windspeeds and flat terrain.

Fuel Type	BEC	Rate of Spread (km/h)	Head Fire Intensity (kW/m)	Crown Fraction Burned	Ignition Potential	Flame Height (m)	Crown Base Height (m)	Area (ha)
C5	CWHdm	2	1,992	0%	94%	2	18	1,064
C5	CWHvm1	2	1,124	0%	92%			1,471
C5	CWHvm2	1	1,650	0%	92%	1	18	3,634
C5	CHWxm1	3	3,423	0%	98%		18	128
C5	MMmm1	1	270	0%	84%			1,637

Figure 30. Example of mature forest of Douglas fir, western hemlock and western red cedar – classified as a C5 fuel type

C7 fuel type

Area of Fuel Type (ha)	361
Structure Classification	Young forest to mature forest
Dominant Tree Species	*Pseudotsuga menziesii* (Douglas-fir), *Tsuga heterophylla* (western hemlock), *Thuja plicata* (western redcedar) and *Abies amabilis* (amabilis fir)
Tree Species Type	> 80% Coniferous
Understory Vegetation	Variable depending on site quality and moisture availability
Average Age	20 – 80 yrs
Average Height	10 – 30 m
Stand Density	Variable, typically less than 600 stems/ha
Crown Closure	20 – 40 %
Height to Live Crown	Average 4 m
Surface Fuel Loading	< 5 kg/m^2
Burn Difficulty	Low; however, if fire is wind driven then there is a moderate potential for active crown fire.

Table 9. Estimated fire behaviour in C7 fuel types by BEC assuming 90th percentile weather conditions, 9 km windspeeds and flat terrain.

Fuel Type	BEC	Rate of Spread (km/h)	Head Fire Intensity (kW/m)	Crown Fraction Burned	Ignition Potential	Flame Height (m)	Crown Base Height (m)	Area (ha)
C7	CWHdm	4	3,318	0%	97%	3	10	37
C7	CWHvm1	3	2,643	0%	96%			12
C7	CWHvm2	2	1,650	0%	97%			153
C7	CWHxm1	4	4,318	0%	99%		10	42
C7	MMmm1	2	1,435	0%	93%			117

D1 fuel type

Area of Fuel Type (ha)	1,580
Structure Classification	Pole sapling to mature forest
Dominant Tree Species	*Populus trichocarpa* (cottonwood), *Acer macrophyllum* (bigleaf maple), *Alnus rubra* (red alder)
Tree Species Type	> 80% Deciduous
Understory Vegetation	High (> 90% cover)
Average Age	> 20 yrs
Average Height	>10 m
Stand Density	600 – 2,000 stems/ha
Crown Closure	20 – 100 %
Height to Live Crown	< 10 m
Surface Fuel Loading	< 3 kg/m^2
Burn Difficulty	Low

Table 10. Estimated fire behaviour in D1 fuel types by BEC assuming 90th percentile weather conditions, 9 km windspeeds and flat terrain.

Fuel Type	BEC	Rate of Spread (km/h)	Head Fire Intensity (kW/m)	Crown Fraction Burned	Ignition Potential	Flame Height (m)	Crown Base Height (m)	Area (ha)
D1	CWHdm	3	1,225	0%	81%	2	-	710
D1	CWHvm1	3	964	0%	65%			274
D1	CWHvm2	2	605	0%	44%	1	-	394
D1	CWHxm1	4	1,566	0%	90%		-	66
D1	MHmm1	2	522	0%	38%			136

Figure 31. Moist rich site dominated by red alder – classified as a D1 fuel type.

M2c fuel type

Area of Fuel Type (ha)	870
Structure Classification	Pole sapling, young forest, mature and old forest
Dominant Tree Species	*Tsuga heterophylla* (western hemlock), *Pseudotsuga menziesii* (Douglas-fir), *Thuja Plicata* (western redcedar) and *Abies amabilis* (amabilis fir), *Populus trichocarpa* (cottonwood), *Acer macrophyllum* (bigleaf maple), *Alnus rubra* (red alder)
Tree Species Types	Coniferous 10-80% / Deciduous
Understory Vegetation	variable
Average Age	> 20 yrs
Average Height	> 10 m
Stand Density	600-1500 stems/ha
Crown Closure	40 – 100 %
Height to Live Crown	6 m
Surface Fuel Loading	< 5 kg/m^2
Burn Difficulty	Moderate; however, if fire is wind driven then there is a high potential for extreme fire behaviour and active crown fire.

Table 11. Estimated fire behaviour in M2 fuel types by BEC assuming 90th percentile weather conditions, 9 km windspeeds and flat terrain.

Fuel Type	BEC	Rate of Spread (km/h)	Head Fire Intensity (kW/m)	Crown Fraction Burned	Ignition Potential	Flame Height (m)	Crown Base Height (m)	Area (ha)
M2	CWHdm	1	834	0%	100%	5	6	423
M2	CHWvm1	1	604	0%	100%			367
M2	CWHvm2	1	525	0%	100%	3	6	36
M2	CHWxm1	2	1,426	0%	100%		6	44

Figure 32. Mixed fir/cedar/sword fern site with a deciduous component of red alder and big leaf maple – classified as an M2 fuel type.

Appendix 2 – Principles of Fuel Break Design

The information contained within this section has been inserted from "The Use of Fuelbreaks in Landscape Fire Management" by James K. Agee, Benii Bahro, Mark A. Finney, Philip N. Omi, David B. Sapsis, Carl N. Skinner, Jan W. van Wagtendonk, and C. Philli Weatherspoon. This article succinctly describes the principles and use of fuelbreaks in landscape fire management.

> The principal objective behind the use of fuelbreaks, as well as any other fuel treatment, is to alter fire behaviour over the area of treatment. As discussed above, fuelbreaks provide points of anchor for suppression activities.
>
> - Surface Fire Behaviour
>
> Surface fuel management can limit fireline intensity (Byram 1959) and lower potential fire severity (Ryan and Noste 1985). The management of surface fuels so that potential fireline intensity remains below some critical level can be accomplished through several strategies and techniques. Among the common strategies are fuel removal by prescribed fire, adjusting fuel arrangement to produce a less flammable fuelbed (e.g., crushing), or "introducing" live understory vegetation to raise average moisture content of surface fuels (Agee 1996). Wildland fire behaviour has been observed to decrease with fuel treatment (Buckley 1992), and simulations conducted by van Wagtendonk (1996) found both pile burning and prescribed fire, which reduced fuel loads, to decrease subsequent fire behaviour. These treatments usually result in efficient fire line construction rates, so that control potential (reducing "resistance to control") can increase dramatically after fuel treatment.
>
> The various surface fuel categories interact with one another to influence fireline intensity. Although more litter and fine branch fuel on the forest floor usually results in higher intensities, that is not always the case. If additional fuels are packed tightly (low fuelbed porosity), they may result in lower intensities. Although larger fuels (>3 inches) - are not included in fire spread models, as they do not usually affect the spread of the fire (unless decomposed [Rothennel 1991]), they may result in higher energy releases over longer periods of time when a fire occurs, having significant effects on fire severity, and they reduce rates of fireline construction.
>
> The effect of herb and shrub fuels on fireline intensity is not simply predicted. First of all, more herb and shrub fuels usually imply more open conditions. These should be associated with lower relative humidity and higher surface windspeeds. Dead fuels may be drier - and the rate of spread may be higher - because of the altered microclimate compared to more closed canopy forest with less understory. Live fuels, with higher foliar moisture while green, will have a dampening effect on fire behaviour. However, if the grasses and forbs cure, the fine dead fuel can increase fireline intensity and localized spotting.

- Conditions That Initiate Crown Fire

A fire moving through a stand of trees may move as a surface fire, an independent crown fire, or as a combination of intermediate types of fire (Van Wagner 1977). The initiation of crown fire behaviour is a function of surface fireline intensity and of the forest canopy: its height above ground and moisture content (Van Wagner 1977). The critical surface fire intensity needed to initiate crown fire behaviour can be calculated for a range of crown base heights and foliar moisture contents, and represents the minimum level of fireline intensity necessary to initiate crown fire (Table 1); Alexander 1988, Agee 1996). Fireline intensity or flame length below this critical level may result in fires that do not crown but may still be of stand replacement severity. For the limited range of crown base heights and foliar moistures shown in Table 3, the critical levels of flame length appear more sensitive to height to crown base than to foliar moisture (Alexander 1988).

Table 1. Flame lengths associated with critical levels of fireline intensity that are associated with initiating crown fire, using Byram's (1959) equation.

Foliar Moisture Content (%)	Height of Crown Base in meters and feet			
	2 meters	6 meters	12 meters	20 meters
	6 feet	20 feet	40 feet	66 feet
	M ft	M ft	M ft	M ft
70	1.1 4	2.3 8	3.7 12	5.3 17
80	1.2 4	2.5 8	4.0 13	5.7 19
90	1.3 4	2.7 9	4.3 14	6.1 20
100	1.3 4	2.8 9	4.6 15	6.5 21
120	1.5 5	3.2 10	5.1 17	7.3 24

If the structural dimensions of a stand and information about foliar moisture are known, then critical levels of fireline intensity that will be associated with crown fire for that stand can be calculated. Fireline intensity can be predicted for a range of stand fuel conditions, topographic situations such as slope and aspect, and anticipated weather conditions, making it possible to link on-the-ground conditions with the initiating potential for crown fires. In order to avoid crown fire initiation, fireline intensity must be kept below the critical level. Managing surface fuels can accomplish this such that fireline intensity is kept well below the critical level or by raising crown base heights such that the critical fireline intensity is difficult to reach. In the field, the variability in fuels, topography and microclimate will result in varying levels of potential fireline intensity, critical fireline intensity, and therefore varying crown fire potential.

- Conditions That Allow Crown Fire To Spread

The crown of a forest is similar to any other porous fuel medium in its ability to burn and the conditions under which crown fire will or will not spread. The heat from a spreading crown fire into unburned crown ahead is a function of the crown rate of spread, the crown bulk density, and the crown foliage ignition energy. The crown fire rate of spread is not the same as the surface fire rate of spread, and often includes effects of short-range spotting. The crown bulk density is the mass of crown fuel, including needles, fine twigs, lichens, etc., per unit of crown volume (analogous to soil bulk density). Crown foliage ignition energy is the net energy content of the fuel and varies primarily by foliar moisture content, although species differences in energy content are apparent (van Wagtendonk et al. 1998). Crown fires will stop spreading, but not necessarily stop torching, if either the crown fire rate of spread or crown bulk density falls below some minimum value.

If surface fireline intensity rises above the critical surface intensity needed to initiate crown fire behaviour, the crown will likely become involved in combustion. Three phases of crown fire behaviour can be described by critical levels of surface fireline intensity and crown fire rates of spread (Van Wagner 1977, 1993): (1) a passive crown fire, where the crown fire rate of spread is equal to the surface fire rate of spread, and crown fire activity is limited to individual tree torching; (2) an active crown fire, where the crown fire rate of spread is above some minimum spread rate; and (3) an independent crown fire, where crown fire rate of spread is largely independent of heat from the surface fire intensity. Scott and Reinhardt (in prep.) have defined an additional class, (4) conditional surface fire, where the active crowning spread rate exceeds a critical level, but the critical level for surface fire intensity is not met. A crown fire will not initiate from a surface fire in this stand, but an active crown fire may spread through the stand if it initiates in an adjacent stand.

Critical conditions can be defined below which active or independent crown fire spread is unlikely. To derive these conditions, visualize a crown fire as a mass of fuel being carried on a "conveyor belt" through a stationary flaming front. The amount of fine fuel passing through the front per unit time (the mass flow rate) depends on the speed of the conveyor belt (crown fire rate of spread) and the density of the forest crown fuel (crown bulk density). If the mass flow rate falls below some minimum level (Van Wagner 1977) crown fires will not spread. Individual crown torching, and/or crown scorch of varying degrees, may still occur.

Defining a set of critical conditions that may be influenced by management activities is difficult. At least two alternative methods can define conditions such that crown fire spread would be unlikely (that is, mass flow rate is too low). One is to calculate critical windspeeds for given levels of crown bulk density (Scott and Reinhardt, in prep.), and the other is to define empirically derived thresholds of crown fire rate of spread so that critical levels of crown bulk density can be defined (Agee 1996). Crown bulk densities of 0.2 kg m^{-3} are common in boreal forests that burn with crown fire (Johnson 1992), and in mixed conifer forests, Agee (1996) estimated that at levels below 0.10 kg m^{-3} crown fire spread was unlikely, but no definitive single "threshold" is likely to exist.

Therefore, reducing surface fuels, increasing the height to the live crown base, and opening canopies should result in (a) lower fire intensity, (b) less probability of torching, and (c) lower probability of independent crown fire. There are two caveats to these conclusions. The first is that a grassy cover is often preferred as the fuelbreak ground cover, and while fireline intensity may decrease in the fuelbreak, rate of spread may increase. Van Wagtendonk (1996) simulated fire behaviour in untreated mixed conifer forests and fuelbreaks with a grassy understory, and found fireline intensity decreased in the fuelbreak (flame length decline from 0.83 to 0.63 m [2.7 to 2.1 ft]) but rate of spread in the grassy cover increased by a factor of 4 (0.81 to 3.35 m/min [2.7-11.05 ft/min]). This flashy fuel is an advantage for backfiring large areas in the fuelbreak as a wildland fire is approaching (Green 1977), as well as for other purposes described later, but if a fireline is not established in the fuelbreak, the fine fuels will allow the fire to pass through the fuelbreak quickly. The second caveat is that more open canopies will result in an altered microclimate near the ground surface, with somewhat lower fuel moisture and higher windspeeds in the open understory (van Wagtendonk 1996).

- Fuelbreak Effectiveness

The effectiveness of fuelbreaks continues to be questioned because they have been constructed to varying standards, "tested" under a wide variety of wildland fire conditions, and measured by different standards of effectiveness. Green (1977) describes a number of situations where traditional fuelbreaks were successful in stopping wildland fires, and some where fuelbreaks were not effective due to excessive spotting of wildland fires approaching the fuelbreaks.

Fuelbreak construction standards, the behaviour of the approaching wildland fire, and the level of suppression each contribute to the effectiveness of a fuelbreak. Wider fuelbreaks appear more effective than narrow ones. Fuel treatment outside the fuelbreak may also contribute to their effectiveness (van Wagtendonk 1996). Area treatment such as prescribed fire beyond the fuelbreak may be used to lower fireline intensity and reduce spotting as a wildland fire approaches a fuelbreak, thereby increasing its effectiveness. Suppression forces must be willing and able to apply appropriate suppression tactics in the fuelbreak. They must also know that the fuelbreaks exist, a common problem in the past. The effectiveness of suppression forces depends on the level of funding for people, equipment, and aerial application of retardant, which can more easily reach surface fuels in a fuelbreak. Effectiveness is also dependent on the psychology of firefighters regarding their safety. Narrow or unmaintained fuelbreaks are less likely to be entered than wider, well-maintained ones.

No absolute standards for width or fuel manipulation are available. Fuelbreak widths have always been quite variable, in both recommendations and construction. A minimum of 90 m (300 ft) was typically specified for primary fuelbreaks (Green 1977). As early as the 1960's, fuelbreaks as wide as 300 m (1000 ft) were included in gaming simulations of fuelbreak effectiveness (Davis 1965), and the recent proposal for northern California national forests by the Quincy Library Group (see web site http://www.qlg.org for details) includes fuelbreaks 390 m (0.25 mi) wide. Fuelbreak simulations for the Sierra Nevada Ecosystem Project (SNEP) adopted similar wide fuelbreaks (van Wagtendonk 1996, Sessions et al. 1996).

Fuel manipulations can be achieved using a variety of techniques (Green 1977) with the intent of removing surface fuels, increasing the height to the live crown of residual trees, and spacing the crowns to prevent independent crown fire activity. In the Sierra Nevada simulations, pruning of residual trees to 3 m (10 ft) height was assumed, with canopy cover at 1-20% (van Wagtendonk 1996). Canopy cover less than 40% has been proposed for the Lassen National Forest in northern California. Clearly, prescriptions for creation of fuelbreaks must not only specify what is to be removed, but must describe the residual structure in terms of standard or custom fuel models so that potential fire behaviour can be analyzed.