An Evaluation of the Pre-Industrial Forest Conditions

Spray Lake Sawmills FMA, Alberta

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Source: mountainlegacy.ca

January 2013

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GLOSSARY

Fire Regime Terms

Definitions were extracted from the Glossary of Forest Fire Management Terms published by the Canadian Interagency Forest Fire Centre (2003). Some definitions have been expanded on for clarification.

Fire Regime - the kind of fire activity or pattern of fires that generally characterize a given area. A number of elements define a fire regime and they are individually described below.

Fire Frequency - the average number of fires that occur per unit time (usually per year or decade) for a given region. The information often needs to be normalized for a set number of hectares so that different regions can be evenly compared.

Fire Occurrence - The number of fires started in a given area over a given period of time.

Fire Size - average fire size and size class distribution encountered during a given period of time.

Fire Cause - the assignment of a wildfire to a category according to the causative agent responsible for starting the fire. Fire cause classes are: lightning, recreation, resident, forest industry, other industry, railroads, incendiary, unknown and miscellaneous. For the purpose of measuring departure of the fire regime conditions, the cause of fire has been considered irrelevant and will not be evaluated.

Fire Season - the period of the year during which fires are likely to start. The fire season can be evaluated based on the distribution of number of fires, fire cause and area burned for each month of the year. The fire season is also documented based on the seasonal flammability of fuel types: spring, summer and fall.

Mean Fire Return Interval - the average number of years between the occurrence of fires in a given region (point location, watershed, topographic elements).

Fire Cycle - the number of years required to burn over an area equal to the entire area of interest. During one cycle, some areas may burn more than once, while others may not burn at all. This parameter is one of the most useful in terms of fire and forest management. The inverse of the fire cycle is equal to the yearly rate of forest disturbance (average number of ha burned each year). This value varies on both a temporal and spatial scale.

Weighted Mean Stand Age - the average age of the forest based on the proportion of each age-class on the landscape. This parameter helps us to understand if a forest is predominantly young, mature or old.

Fire Type - categories of wildfires which include: ground fire, surface fire, intermittent and active crown fires. Note that fire history studies based on tree ring data and aerial photo interpretation, cannot detect or map ground fires. Many times historical surface fires cannot be mapped from aerial photography due to the short period of evidence from these fires.

Fire Intensity - the intensity is the rate of heat energy released per unit time per unit length of fire front. This parameter is estimated from flame size and is used to describe fire behaviour during an active fire. For a fire regime study, where historical fires are assessed, severity of fire is the surrogate parameter to quantify fire intensity.

Fire / Burn Severity - the post-fire effects on overstory and understory species, woody debris, the forest floor and mineral soil. The importance of these effects are primarily dependent on fire intensity and duration of the burn. For a fire regime study, where historical fires are scrutinized, it is the proportion of forest crown removal and post-fire regeneration lapse time that indicate if a fire was predominantly burning under low, moderate or high fire intensities. It then translates directly by saying that a fire was a low, mixed or high severity fire. Most stand replacing fires that burn for an extended period of time under variable fire intensities end-up as mixed severity fires. This definition of fire severity and how to measure severity should not be mistaken with measures used following a recent fire, which are different and more extensive.

Fire Behaviour Terms

Canadian Forest Fire Behaviour Prediction (FBP) System - A subsystem of the Canadian Forest Fire Danger Rating System. The FBP System provides quantitative outputs of selected fire behaviour characteristics for certain major Canadian fuel types and topographic situations. The system depends partly on the Canadian Forest Fire Weather Index System components as inputs.

Canadian Forest Fire Danger Rating System (CFFDRS) - The national system of rating fire danger in Canada. The CFFDRS includes all guides to the evaluation of fire danger and the prediction of fire behaviour such as the Canadian Forest Fire weather Index System and Canadian Forest Fire Behaviour Prediction System.

Canadian Forest Fire Weather Index (FWI) System - A subsystem of the Canadian Forest Fire Danger Rating System. The components of the FWI System provide numerical ratings of relative fire potential in a standard fuel type (i.e. a mature pine stand) on level terrain, based solely on consecutive observations of four fire weather elements measured daily at noon (1200 hours local standard time or 1300 hours daylight saving time) at a suitable fire weather station; the elements are drybulb temperature, relative humidity, wind speed, and precipitation. The system provides a uniform method of rating fire danger across Canada. The FWI System consists of six components. The first three are fuel moisture codes that follow daily changes in the moisture contents of three classes of forest fuel; higher values represent lower moisture contents and hence greater flammability. The final three components are fire behaviour indexes representing rate of spread, amount of available fuel, and fire intensity; their values increase as fire weather severity worsens. The six standard codes and indexes of the FWI System are:

> **Fine Fuel Moisture Code (FFMC)** - A numerical rating of the moisture content of litter and other cured fine fuels . This code indicates the relative ease of ignition and flammability of fine fuel.
>
> **Duff Moisture Code (DMC)** - A numerical rating of the average moisture content of loosely compacted organic layers of moderate depth. This code indicates fuel consumption in moderate duff layers and medium-sized woody material.
>
> **Drought Code (DC)** - A numerical rating of the average moisture content of deep, comp act, organic layers. This code indicates seasonal drought effects on forest fuels, and the amount of smouldering in deep **duff** layers and large logs.
>
> **Initial Spread Index (ISI)** - A numerical rating of the expected rate of fire spread. It combines the effects of wind and FFMC on rate of spread but excludes the influence of variable quantities of fuel.
>
> **Buildup Index (BUI)** - A numerical rating of the total amount of fuel available for combustion that combines DMC and DC.
>
> **Fire weather Index (FWI)** - A numerical rating of fire intensity that combines ISI and BUI. It is suitable as a general index of fire danger throughout the forested areas of Canada.

Duff - The layer of partially and fully decomposed organic materials lying below the litter and immediately above the mineral soil. It corresponds to the fermentation (F) and humus (H) layers of the forest floor . When moss is present, the top of the duff is just below the green portion of the moss.

Fine Fuels - Fuels that ignite readily and are consumed rapidly by fire (e.g. cured grass, fallen leaves, needles, small twigs). Dead fine fuels also dry very quickly

Fire Behaviour - The manner in which fuel ignites,flame develops, and fire spreads and exhibits other related phenomena as determined by the interaction of fuels, weather, and topography. Some common terms used to describe fire behaviour include the following:

> **Smouldering** - A fire burning without flame and barely spreading.
>
> **Creeping** - A fire spreading slowly over the ground, generally with a low flame.
>
> **Running** - A fire rapidly spreading and with a well-defined head.
>
> **Torch** or **Torching** - A single tree or a small clump of trees is said to "torch" when its foliage ignites and flares up, usually from bottom to top. Synonym - Candle or Candling.
>
> **Spotting** - A fire producing firebrands carried by the surface wind, a fire whirl, and/or convection column that fall beyond the main fire perimeter and result in spot fires.

Fire Danger - A general term used to express an assessment of both fixed and variable factors of the fire environment that determine the ease of ignition, rate of spread, difficulty of control, and fire impact.

Fire Risk Occurrence - The probability or chance of fire starting determined by the presence and activities of causative agents (i.e. potential number of ignition sources).

Fire Scar - An injury or wound on a tree caused or accentuated by fire.

Fire Weather - Collectively, those weather parameters that influence fire occurrence and subsequent fire behaviour (e.g. dry-bulb temperature, relative humidity, wind speed and direction, precipitation, atmospheric stability, winds aloft).

Fuelbreak - An existing barrier or change in fuel type (to one that is less flammable than that surrounding it), or a wide strip of land on which the native vegetation has been modified or cleared, that act as a buffer to fire spread so that fires burning into them can be more readily controlled. Often selected or constructed to protect a high value area from fire. In the event of fire, may serve as a control line from which to carry out suppression operations.

Fuel Type - An identifiable association of fuel elements of distinctive species, form, size, arrangement, and continuity that will exhibit characteristic fire behaviour under defined burning conditions.

Litter - The uppermost part of the forest floor consisting of freshly cast or slightly decomposed organic materials (i.e. the L layer).

1.0 INTRODUCTION

This document has been prepared with the aim of furthering our understanding of past natural disturbances and pre-industrial forest conditions. The beginning of the industrial era for the largely unpopulated landscape of the Spray Lake Sawmills FMA corresponds with changes in fire suppression policies by the Government of Alberta. Following devastating fire years in the early 1900's, 1930 was a turning point with regards to fire suppression (Murphy *et al.* 2006). Notably, with technological advances no large-scale fires have been recorded on the FMA since 1942 and this turn of events has brought a marked change in the forests condition. While climate has been targeted by some as the cause of the reduced burn area (Johnson and Larsen 1991), fire weather studies in nearby Banff National Park have concluded that many days since 1940 actually had conditions conducive to producing large size fires (Feunekes and Van Vagner 1995, Luckman and Seed 1995). Thus, fire suppression has been flagged as the main cause of the change in the fire regime and 1930 is the benchmark year from which the pre-industrial forest conditions are defined.

With the objectives of protecting human life, communities, sensitive watersheds and soils, natural resources and, infrastructure, the government's fire exclusion policy has been detrimental in the long run to the ecological integrity of fire-driven ecosystems. Ecosystems that historically experienced multiple back-to-back fires of lesser intensity and severity, such as those found on the FMA, are now faced with the risk of fire conflagrations due to increased fuel build-up and denser forest stands. These high intensity, full stand replacing fires contribute to the homogeneity of the stand age mosaic and thus reduce the diversity of habitats. Further, the scorching temperatures increase fire severity by exposing the mineral soil and can delay tree regeneration. Forest removal using a harvest process, while not a surrogate to fire, will help bring back a certain age/vegetation mosaic complexity which, in turn, may help retain the wildlife or avifauna associated with younger aged forests, and those dependant upon a diversified stand-age mosaic. The removal of timber also helps with the reduction of conditions ripe for insect or disease related infestations that fire naturally controlled.

In recent years, a better understanding of the ecological effects of natural disturbances has prompted Government and the forest industry to initiate a form of forest management that will attempt to emulate the effect of natural disturbances to some degree. An understanding of past fire regimes and pre-industrial forest conditions are necessary to facilitate attempts at this replication and to assist managers with the implementation of innovative and adaptive harvesting strategies.

This document highlights in Section 2 the natural disturbances found on the FMA, while Sections 3 and 4 summarize findings from the fire regime analysis and fire history study that were undertaken on the Spray Lake Sawmills FMA (Rogeau 2004, 2005a, 2006). Section 5 provides specific information with regards to the Pre-Industrial Conditions (PIC) of the forests in terms of the historical Mean-Fire-Return-Intervals, trends in the spatial distribution of stand ages, age-class distributions by fuel type, patch size distribution and, island remnant distribution. To close, Section 6 describes benchmarks that will be evaluated for the forest management planning process. In Appendix A you will find information on the fire growth simulation model and how PIC fire regimes and stand origin maps were created.

2.0 NATURAL DISTURBANCES

2.1 PRIMARY DISTURBANCE AGENTS

It is well documented that forest fires have been part of the Rocky Mountains and Foothills Regions for thousands of years, and many endemic plant and tree species are morphologically adapted to fire, which is a testimony to both the relevance and prevalence of forest fires on this landscape. Table 2-1 lists documented fire cycles of regional landscapes. It was observed that fire cycles and mean-fire-return-intervals used to be relatively short in the region, especially on the Spray Lake Sawmills FMA. The occurrence of wildfire and the wildfire regime of the FMA are fully described in the following chapters.

Table 2-1 Fire cycles (FC) or Mean-Fire-Return-Intervals (MFRI) documented in and around the region of the Spray Lake Sawmills FMA.

Location / Reference	Subalpine	Montane	U. Foothills	L. Foothills
Banff National Park (Rogeau et al. 2004)	FC: 65 to 220 (spatial variation)	FC: 44 to 145 (spatial variation)	x	x
Banff National Park (White et al. 2003)	FC: 100 to 200 MFRI: 70 to 173	FC: 10 to 100 MFRI: 20 to 90	x	x
N. Saskatchewan, Whitegoat & Siffleur Wilderness Areas (Rogeau 1999)	FC: 103 to 244	FC: 71 to 82	x	x
FMU C5 Rogeau (2005b)	FC: 93 to 139	FC: 76 - 108	x	x
FMU R11 Rogeau (2010a)	FC: 81 to 211	N. Sask.: FC: 36 to 65 Clearwater-Red Deer: FC: 64 to 98	FC: 59 to 97	x
Kananaskis Valley (Johnson and Larsen 1991)	FC: 90	x	x	x
Peter Lougheed P.P. (Hawkes 1980)	FC: 101 to 304	x	x	x
Bow Valley - Canmore area (Rogeau 2005a)	x	MFRI: 6	x	x
Kananaskis District / SLS FMA (Rogeau 2004,2005a, 2006)	FC: 124 to 172 (simulations)	FC: 30 to 52 (sim.) MFRI: 31 (field data)	MFRI: 50 (field data)	MFRI: 55 (field data)
SLS FMA - Pre-Industrial Conditions fire regime simulations (this document)	MFRI: 52 - 96	MFRI: 45 - 60	MFRI: 42 - 53	MFRI: 52 - 78
Elbow Fire Management Compartment Rogeau (2011) - field data	MFRI: 58 - 133	MFRI: 32 - 70	x	x

2.2 SECONDARY DISTURBANCE AGENTS

Aside from fire, there are a number of natural disturbance agents that have been documented and observed on the Spray Lake Sawmills FMA. All of these agents play a very small role in the rotation and age mosaic patterns of the forested areas on the FMA. The reality is that these disturbances only contribute to increasing the fuel load on the ground and affecting the behaviour of the next occurring fire (Keane *et al.* 2002). Thus, in the absence of fire suppression, fire was the lead forest disturbance agent and while fire intervals are now greater, fire will still have the upper hand. A good example was the current fire situation in British-Columbia during the 2010 fire season. In combination with drought conditions, the fuel load of cured organic material created over several years of mountain pine beetle infestations provided the perfect conditions for extreme fire behaviour and broadscale disturbances.

2.2.1 Windthrow

Small patches of windthrow have been observed in the field, but 1950 aerial photography or photos from surveyors (Arthur Wheeler photography 1898-99) did not show any noticeable areas of wind thrown trees.

2.2.2 Infestations and Diseases

The Alberta Mountain Pine Beetle information web site (http://www.mpb.alberta.ca) states that southwestern Alberta is at the eastern limit of most infestations due to cold winter temperatures which prevent a strong establishment of the beetle in Alberta. There have been localized infestations in the past with the largest one starting in 1975 and lasting a decade in the south-west corner of Alberta. It was not until 2002 that the beetle came back. The web site presents a series of maps showing the spatial distribution of the beetle in that region, but the information presented is well to the south of the Highwood River, and does not address the beetle infestation history on the Spray Lake Sawmills FMA.

Overall, the information is scarce on this matter as it would appear that before the industrial era, large-scale insect infestations and tree diseases were not common. Following a full screening of the 1949-52 aerial photography for the region, forest health issues of significance (i.e. at least 1 km^2 in size for them to contrast against the complex fire patterning) were not observed. Personal communications with Brad Jones from Alberta Sustainable Resource Development, Calgary Office, indicated that to his knowledge there was no documentation on forest pathogens or infestations of significance from that period in the FMA region. And according to annual reports on forest health, current forest health issues have been closely associated with the long-term absence of fire as a mitigating agent.

2.2.3 Avalanche

The last forest disturbance agent is snow loading on steep slopes of the Subalpine landscape, which maintain avalanche paths and prevent forest stands from forming. This form of disturbance is not extensive within the FMA and is confined mainly to the region south of the Highwood River and near the Continental Divide.

3.0 CURRENT FIRE REGIME CONDITIONS

The current conditions of the fire regime makes reference to the fire suppression period, which started around 1930 in southern Alberta. Provincial fire occurrence statistics from 1961 to 2003 were used by Rogeau (2004) to establish a fire regime profile for each of the Natural Subregions[1] found within the Spray Lake Sawmills FMA. Table 3-1 is a summary of these findings.

Table 3-1 Summary of fire regime characteristics by natural subregion. Percent occurrence is estimated for a normalized area (N)of 100,000 ha. Data source: 1961 to 2003.

	Natural Subregions					
Fire Regime Parameters	**Alpine**	**Subalpine**	**Montane**	**U. Foothills**	**L. Foothills**	**Parkland**
% occurrence (N)	1	12	44	27	14	2
% lightning	45	25	9	58	15	13
% anthropogenic	55	75	91	42	85	88
burning season*	July-Aug.	July-Sept.	May-Sept.	May-Oct.	May-Oct.	April-Oct.
fire size	<1 ha: 91.5% of fires, <10ha: 98%					
fire cycle (1961-2002) disturbance rate	1457yrs, 395ha/yr or 0.07% of forested area					

* large size fire records are too scarce to calculate a temporal distribution of burn area. These are estimates from general knowledge on the occurrence of large size fires in this region.

The leading cause of fire for the FMA is people, which accounts for 70% of the total fire occurrences. Of these, the dominant cause is attributed to recreational users and accounts for a sizable 77% of all anthropogenic fire occurrences.

The reason for the low occurrence of lightning-caused fires is due to the fact that the western portion of the FMA sits in a lightning strike shadow (Wierzchowski et. al. 2002). In Alberta, the

[1] The partitioning of the Natural Subregions has changed since 2003, when this analysis was performed. The Lower Foothills south of Hwy 1 has now been re-labelled "Montane". The original Montane only included the Bow Valley and lower portions of the Ghost and Waiparous watersheds.

shadow extends from the Continental Divide to the Front Ranges where very little lightning strike activity is recorded in comparison with the Prairies or the boreal forest. Lightning activity increases as one travels east of the Divide and congregates over the Upper Foothills. This explains why this subregion sees significantly more lightning fires over other subregions of the FMA. The average density of strikes, recorded on 5km x 5km grid cells, ranges from 3 to 130 strikes per year (Figure 3-1). The highest density of lightning strikes occurs along Waiparous Creek and north of the Ghost River.

However, the highest concentrations of lightning-caused fires occur around the junction of Fallen Timber and Pinto Creeks in the northern portion of the FMA. It is worth noting that there is an even greater risk of lightning fires adjacent to the FMA, in the south end of FMU R10, with a peak risk approximately 7 km to the north of the Red Deer River. The FMA, being positioned downwind from the area with the highest lightning fire risks, would be directly impacted if such fires were to escape.

The distribution of lightning fires is closely associated with natural subregions, but also with elevation as these two variables are auto-correlated to some extent. On a normalized land base, 61% of lightning fires fall within the Upper Foothills between the elevations of 1500m and 1800m. Aspect does not affect the distribution of lightning fires in any significant way. N and SW facing slopes have slightly more lightning fire ignitions than any other aspects, and W facing slopes have the least. The probability of lightning ignition model developed for Kananaskis District and the FMA is posted in Figure 3-2.

The monthly distribution of lightning-caused fires prevails in July and August, while anthropogenic fires tend to occur between the months of April and September with a peak occurrence in May. Burn area distribution could not easily be evaluated due to the lack of large size fires. However, typical fire weather conditions allow for large burns to occur in July, August and September. With early season drought conditions, prior to green-up of aspen trees and grass, large-scale May fires are a potential threat as well.

The very long fire cycle of 1,457 years calculated for the period between 1961 and 2002, reported in Table 3-1, is attributed largely to an aggressive fire suppression program. At time of writing, the fire cycle has increased to 1,701 years since 2002 as a result of the increasing fire deficit. Climate change has been considered as a potential cause of the lengthening of the fire cycle, but no evidence in this region was found to support this assumption. A dendroclimatic reconstruction of precipitation for sites in the Southern Canadian Rockies was done by Watson and Luckman (2001). They documented a wetter period in the latter half of the twentieth century, but unfortunately no clear correlation can be established from these findings as documented historical wetter periods have seen a fair number of large fire events. Daily and seasonal fire severity ratings have also been reconstructed by Feunekes and Van Wagner (1995) and it appears that the post 1950 period saw just as many severe fire weather days conducive to large fire events as the early part of the century.

In comparison to the period between 1930 and 1950, today's fire cycle is 16 times longer than what was calculated for the Subalpine Subregion. And, when compared to the pre-industrial fire regime conditions (pre-1930) of the Foothills Region and Montane Subregion, today's fire cycle has become 43 times longer. The lengthening of the fire cycle can have adverse effects on the ecological integrity of ecosystems, as well as serious impacts on fire fighting effectiveness. Little fire on the land results in an accumulation of fuels on the ground and denser forests. Combined with severe fire weather conditions, these fires become extremely difficult to manage under intense fire behaviour and post-fire effects are also more severe. The 2003 fire season in Alberta's Crowsnest Pass and in Central British Columbia is a good example of such conditions. A lack of fire can also promote insect infestations and diseases, which are both detrimental to the forest heath and have negative impacts on the forest industry.

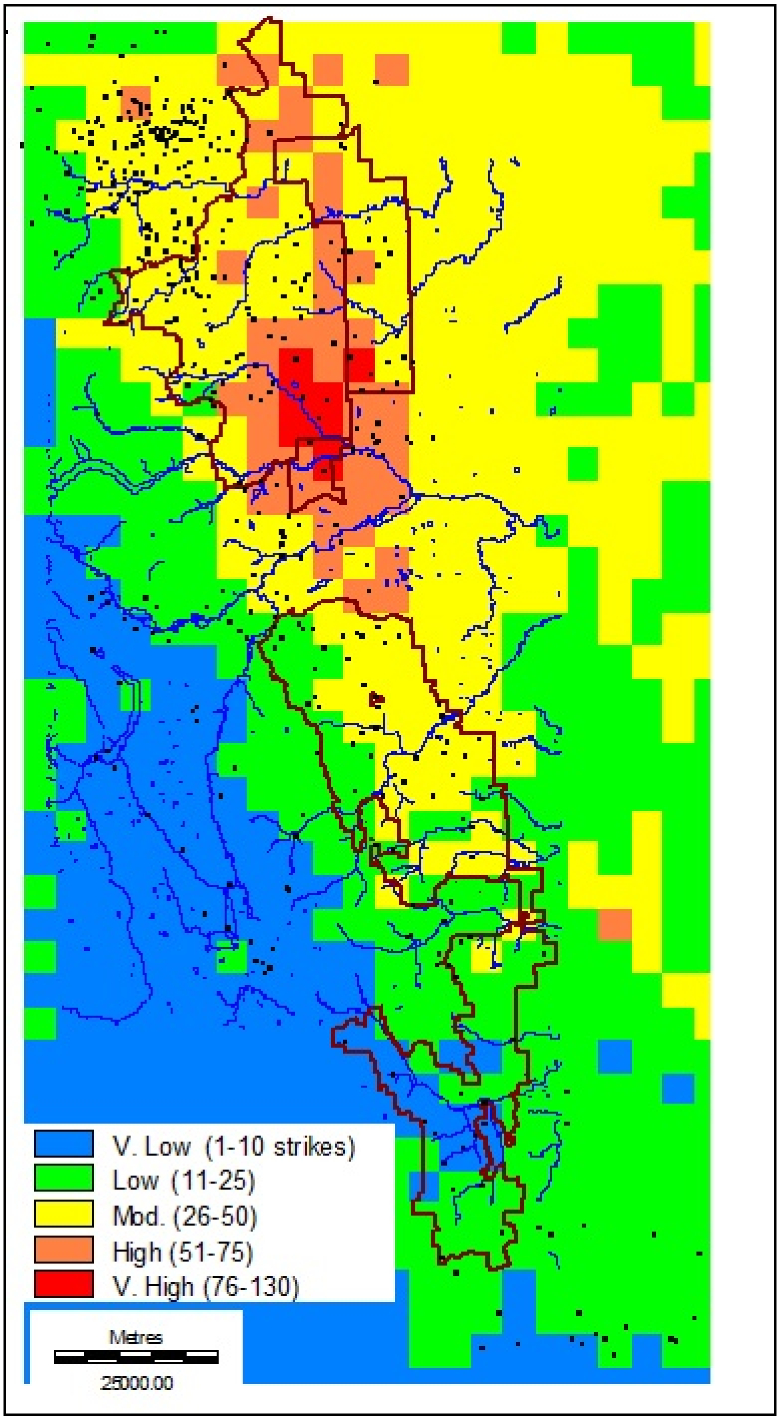

Figure 3-1 Average density of lightning strikes recorded on 5 km x 5 km grid cells for the period between 1990 and 2003. Lightning-caused fires between 1961 and 2003 are overlaid onto the map.

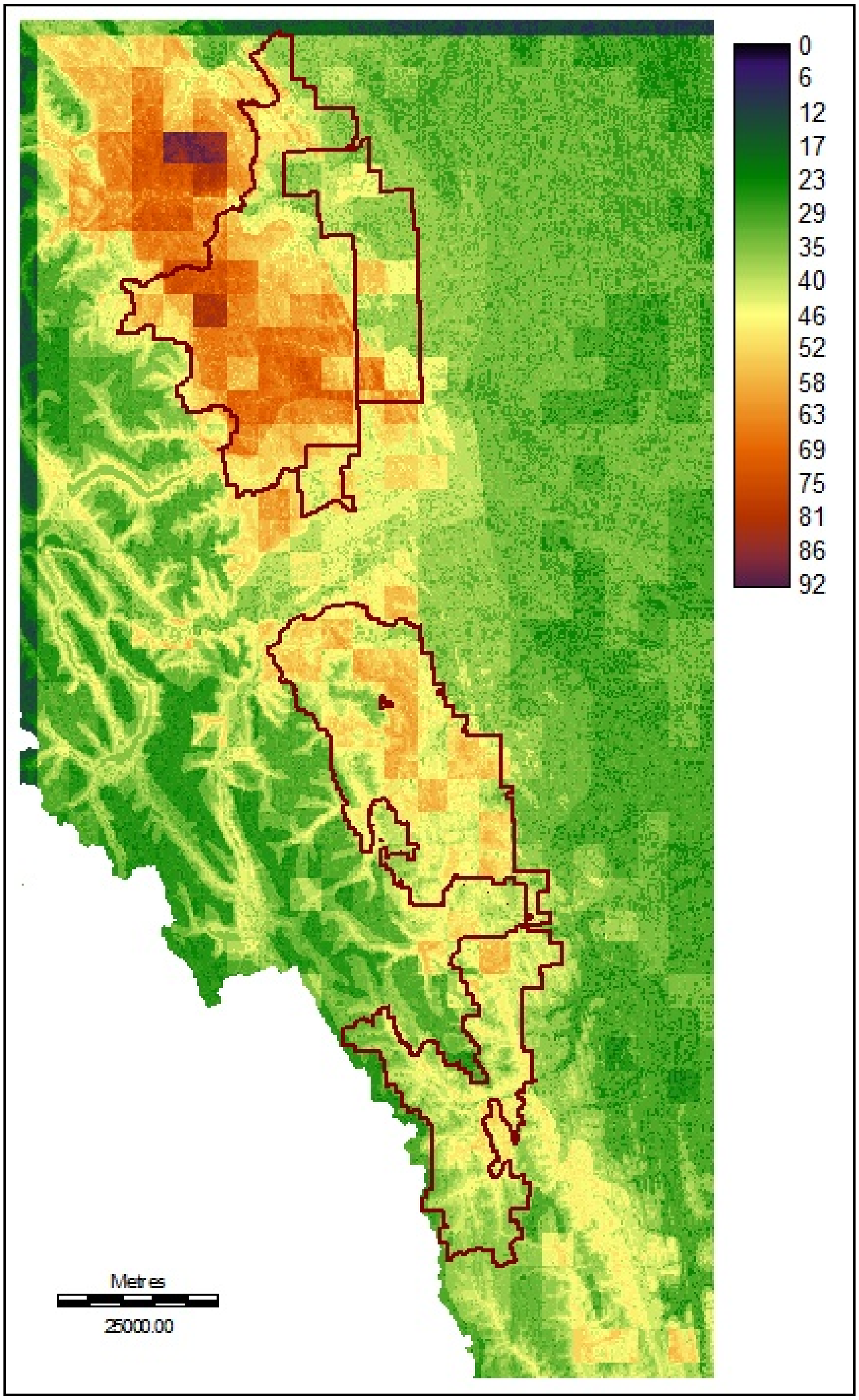

Figure 3-2 Percent probability of lightning fire ignition model for the District of Kananaskis.

4.0 HISTORICAL FIRE REGIME CONDITIONS

Historical conditions of the fire regime were defined by Rogeau (2004) using 1950 aerial photography to establish the number of visible fires by watershed, as well as the complexity of the vegetation/age mosaic. Rogeau reported that the accuracy of the information was best from circa 1900 to 1950, but deteriorated for forests originating prior to the 1900's. Fire boundaries from the mid 1800's were for the most part still visible, but the homogeneity of lodgepole pine forest cover originating prior to ~1850 prevented the air photo interpreter from making confident assessments for disturbances dating prior to that time.

The vegetation complexity is defined as the level of patchiness of the age mosaic as a result of burning patterns. The complexity is most often driven by the frequency of fires and their intervals. Landscapes with greater fire frequencies and short fire return intervals between overlapping fires, most often result in intricate patterns of stand ages. In comparison, long fire intervals and fewer fires produce a forest age mosaic that is more homogeneous with few fire boundaries and with stand replacing fire characteristics involving few island remnants. Figure 4-1 provides examples of opposite vegetation mosaic complexities.

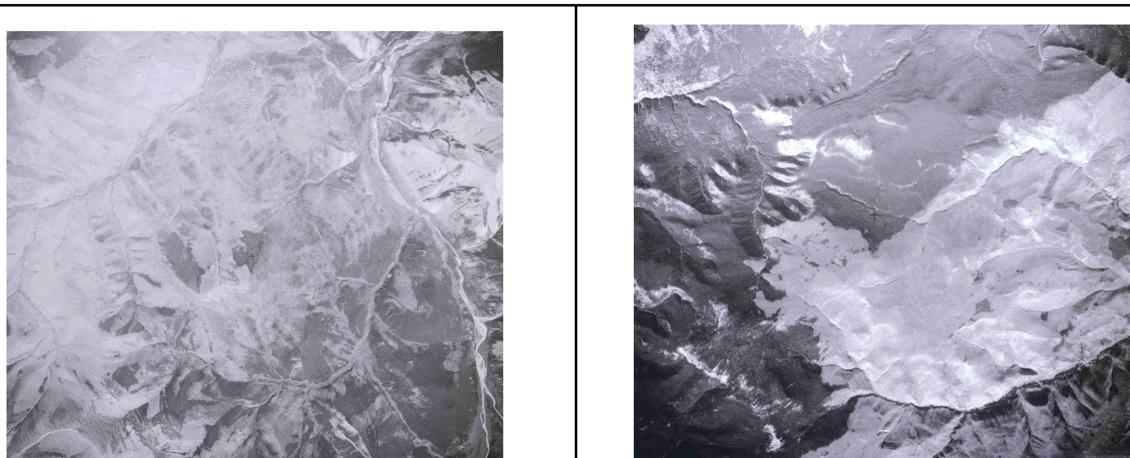

Figure 4-1 On the left is an example of a very complex vegetation mosaic as a result of at least five overlapping fires at short intervals. On the right is an example of one high intensity stand replacing fire which left few island remnants within its perimeter.

Vegetation complexity is also related to fire severity effects. More complex age mosaics, which result from multiple fires at close intervals imply that fire intensities and severities were less. This is due to the fact that ground fuel and tight stand density do not have time to form in between burning events. The increasing period of time since the last fires on the FMA has now created a dense, homogeneous canopy cover. Any fires burning under extreme fire weather conditions (elevated drought codes and windy conditions) will result in conflagrations producing stand replacing fires of high fire severity, which may have adverse affects such as soil scorching and delayed post-fire regeneration of tree species.

Figure 4-2 shows the distribution of vegetation complexity rating across the landscape. There appears to be a complexity gradient flowing from west to east, with the lowest complexities found exclusively along the west boundary of the study area, which corresponds to the main ranges of the Canadian Rockies. The front ranges of the Rockies have a mix of low and moderate complexities, and the highest complexities are found at the east end of the study area. This corresponds to the Foothills Natural Region watersheds that fringe on the Parkland Natural Region, and most of the Montane Natural Subregion with the exception of the Bow Valley watershed between Banff National Park and Lac des Arcs, which displays a moderate vegetation complexity.

The total number of fires per watershed, estimated from the different tones and textures of the forest cover, ranged from 3 to 27 in a period estimated to be approximately 350 years (Figure 4-3). Watersheds with most historical fires are Jumpingpound, Upper Highwood and Little Red Deer. As per the 1950 aerial photography, the remainder of the FMA saw an average of 10 to 20 fires, which approximates a Mean-Fire-Return-Interval of 18 to 35 years. These values were subsequently validated as part of an extensive fire history field data collection program in 2004 and 2005 (see Chapter 5). When the total number of fires are normalized and classified (Figure 4-4), it can be observed that the watersheds located to the east and at the southern tip of Kananaskis District, are more fire prone. Watersheds with more fires are also those that tend to show greater vegetation complexities.

The total number of fires and vegetation complexity were individually found to be spatially correlated at 40% with the Natural Subregions. However, a stronger relationship of 80% was established with fuel continuity. Subalpine watersheds, which are bound by rocky ridges on two to three sides (headwall and one or two side walls) generally have less fires and an age mosaic that is less complex.

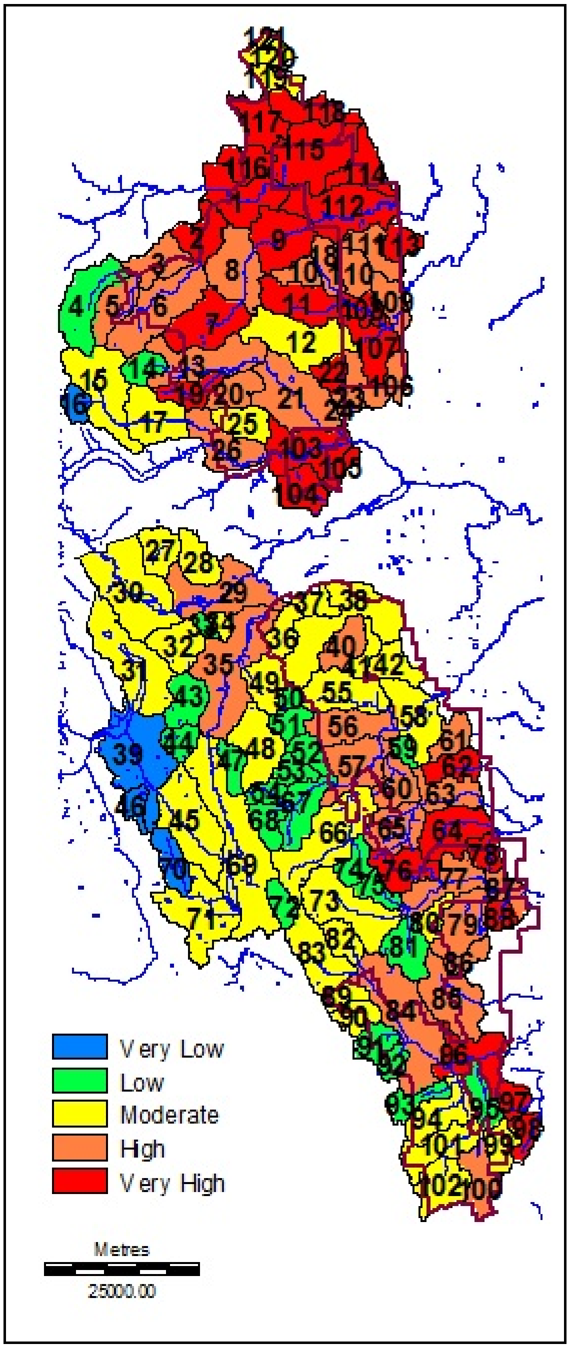

Figure 4-2 Vegetation complexity rating established from the air photo screening process.

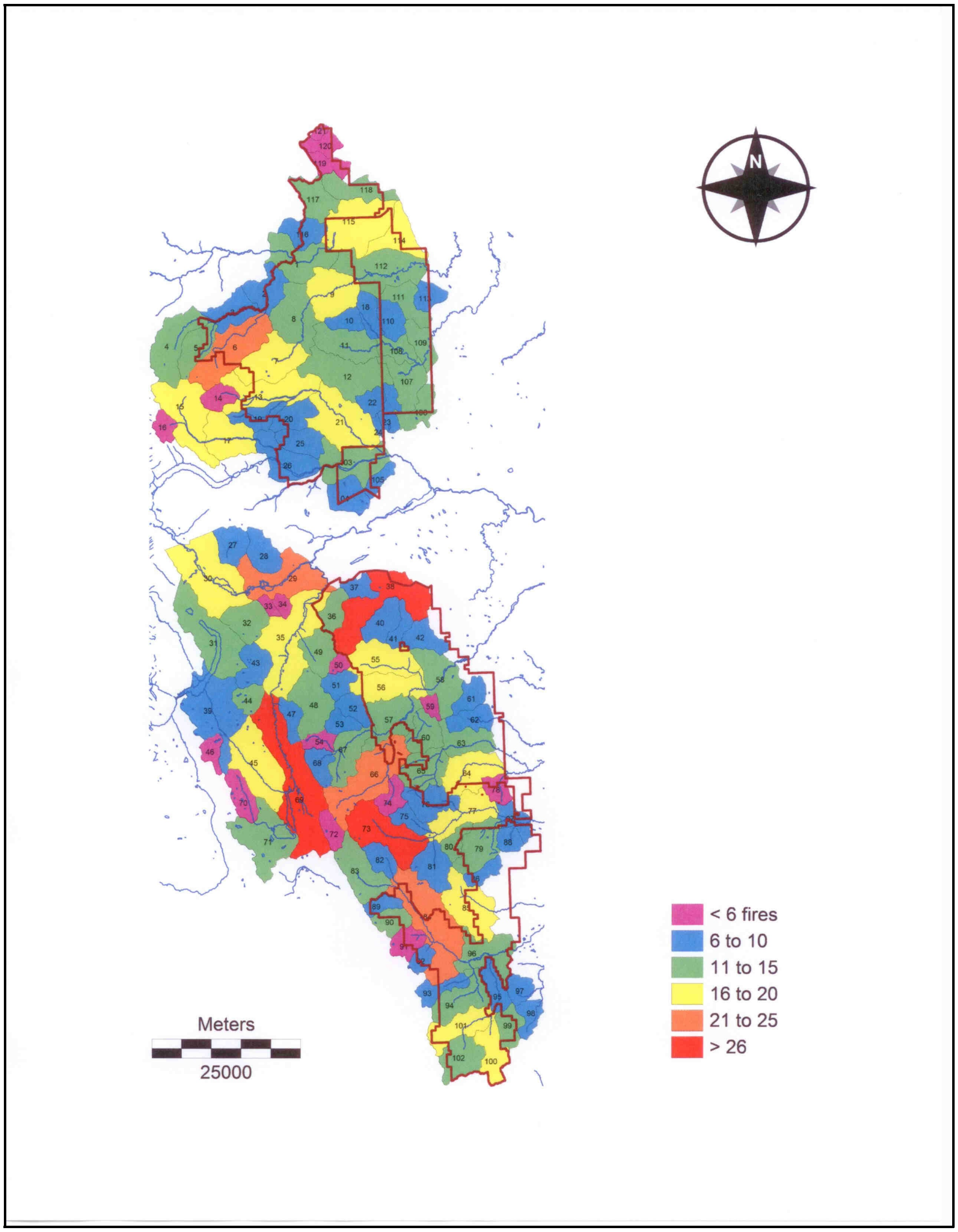

Figure 4-3 Total number of fires per watershed identified from a visual screening of the air photos for an estimated period of 350 years (1600 to 1950).

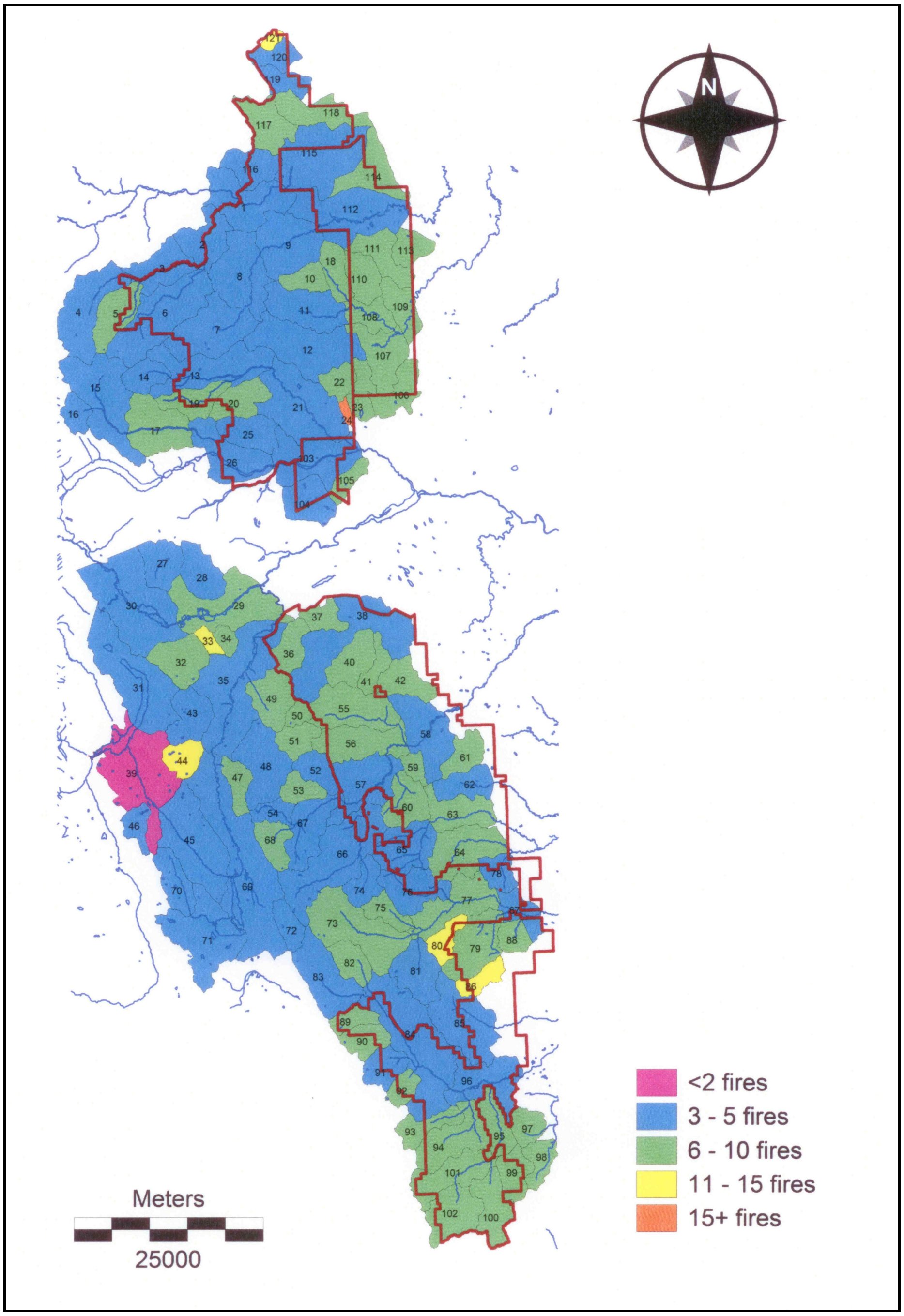

Figure 4-4 Normalized (25 km^2) values of the total number of fires per watershed from Figure 3-3.

5.0 PRE-INDUSTRIAL FOREST CONDITIONS (PIC)

In the case of the Spray Lake Sawmills FMA, the "pre-industrial" period refers to the period prior to 1930 or before fire suppression became very effective (Murphy *et al.* 2006). The first settlers arrived to the Foothills in the 1880's and 1890's, but there is little evidence of settlements on the FMA. Still, in 1950 the aerial photography only shows slight human disturbance. Some road access and dispersed settlements in the south portion of B9 (south of the Ghost) were present, and minimum logging activity was visible in B10, some of which tied to salvage logging around the Elbow and the Sheep Rivers following broadscale fires from 1934 and 1936.

Evidence of traditional land use in the Montane portion of the Bow Valley and along the Red Deer River, near the Ya Ha Tinda Ranch, dates back several thousand years (Kay and White 2001, Francis and Langemann 1993). The fur trading years were also active in the region for a couple of hundred years (1700s - 1800s). While the extent and intensity of the land use by First Nations on the FMA itself will always remain obscure, personal communication with Scott Stephen, historian with the Parks Canada Agency - Western and Northern Service Centre out of Winnipeg, shared some interesting facts on the matter. It would appear that in 1822/23, the Hudson's Bay Company's Bow River Expedition, which included 143 men plus a number of women and children, was posted on the Bow River. Hunting and exploratory parties were sent out in all directions, including to the edge of the Rockies as they were hoping to open up trade with the Shoshone of the upper Columbia Valley. In addition, this expedition attracted a lot of attention from the Niitsitapi. On one occasion, an exploratory party encountered 800 tents of Gros Ventre, and on another occasion as many as 1000 Niitsitapi warriors came to the fort. As a result, there was a lot of people roaming about in the region at that time and it is well established that fire was a common tool used by First Nations (Barrett and Arno 1982, Kay 2007, Lewis 1977).

All significant fire events in the Foothills in the 1900s were of anthropogenic origin. Below are excerpts from the Forestry reports and timber conditions survey reports from the Department of the Interior from the turn of the 19th century.

1906: Early part of April fires were set out by unknown persons in township 32, ranges 6 and 7, west of the 5th meridian (upper tip of B9). This fire spread and burnt up the area lying between the Red Deer and James Rivers. It burnt considerable valuable timber on timber berth 253. At about the same time, fires set out by Indians in township 31, range 7, west of the 5th meridian, burnt over the area lying between the Red Deer river and Fallen Timber creek. This fire, after desperate fighting by all the available men we could get, got beyond control on a very windy day, and burnt about 50 million feet on timber berth 252.

1910 (timber survey): From the Elbow River to the North Saskatchewan River. The timber is largely of the same type as that farther south, and has suffered from fire in the same way. The mature virgin stand does not exceed twenty-five per cent in the area examined.

1910: In the southern part of Alberta the dry conditions continued well on through the summer, and as a result fires started in every direction, and at one time there was a line of fire more or less continuous of over seventy-five miles. The total area burned over was approximately 494 square miles, and, although this included a considerable area of prairie and scrub land, still the damage to the forest was serious. Fires began about the middle of April and were not all extinguished before August 5. One of the most disastrous fires was one that swept the valley of the High river for a distance of thirty miles, with a width of five or six miles. The fire event was caused by a fire lighted as a smudge for horses by a survey party. The fire got away, and with a gale behind it, swept the valley. No fire ranger or staff of fire rangers could stop its progress.

Fire occurred also in the vicinity of Elbow and Ghost rivers, causing the destruction of ten to twenty million feet board measure of merchantable timber.

In townships 17, 18 and 19 a fire followed the Highwood river for a distance of forty miles, with an average width of about three miles. About 50,000,000 feet of saw timber was destroyed in this fire and a large area of young spruce, pine and poplar from thirty to forty years old.

Township 21, range 6, west of the 5th meridian, killing young pine which covered about half the township. (McLean Cr. area).

Townships 28 and 29, ranges 6, 7 and 8, west of the 5th meridian, a large fire occurred which burned during the months of July and August and covered an approximate area of 110 square miles. (Waiparous area).

Along Fallen Timber creek in township 30, ranges 6 and 7, a fire destroyed about a quarter township of young pine about four or five feet high.

1914: Two fires on the Bow River division of the Rocky Mountains reserve which were in a district difficult to reach, and which got out of control owing to the high winds prevailing at the time. These two fires were responsible for damaging 343.500,000 feet board measure, of timber. Fires known as the Tunnel, Ghost, and Yellowhead fires, slash was undoubtedly a factor in the rapid spread of the fires.

1919: The largest fires in Alberta, however, occurred a little later (in June) on the Bow River forest, both caused by camp-fires. Over $20,000 was expended in fighting these two fires which burned over 1,450,000 acres.

With the exception of 1906, all large fire events have been recorded on the FMA as part of the extensive fire history study that took place in the Upper Foothills and Montane-South (formerly Lower Foothills) in 2004 and 2005 (Rogeau 2005a, 2006). These findings are summarized in Sub-section 5.1 and set the tone for the expected PIC Mean-Fire-Return Intervals. PIC age-class distributions were determined through stand origin modelling using a fire growth model and are presented in Sub-Section 5.2.

5.1 PIC MEAN-FIRE-RETURN-INTERVALS

An extensive fire history study was undertaken in 2004 and 2005 in the Montane North (MT-N) (Ghost and Lower Waiparous watersheds), Upper Foothills (UF) and Montane South[2] (MT-S) of the FMA. Tables 5-1, 5-2 and 5-3 list all fire years that were recorded along with the frequency of occurrence (number of forest stands sampled that were affected by that fire). An important number of forest fires were detected in all natural subregions since the 1650s. However, due to the extent of some of the burns from the early 1900s, it is normal to find less and less evidence of old forest stands (i.e. old burns). It should be understood that their extent could have been just as great as those from the 1860s and that many fires have likely not been depicted as a result of the lack of evidence.

Table 5-1 List of all fire dates recorded in the Montane - North Natural Subregion around the Ghost and Lower Waiparous watersheds. The frequency represents the number of forested stands sampled. It is possible that some dates with only a one year interval could be the same fire year due to dating inaccuracies.

MONTANE NORTH					
Fire dates	**Freq**	**Fire dates**	**Freq**	**Fire dates**	**Freq**
1959	2	1897	1	1837	2
1956	3	1896	7	1825	1
1947	5	1893	1	1823	1
1942	6	1889	4	1811	1
1940	1	1885	5	1804	1
1937	1	1880	1	1798	1
1936	4	1877	3	1790	2
1934	5	1873	3	1760	2
1931	1	1870	2	1755	1
1928	8	1864	26	1750	1
1925	1	1851	2	1730	2
1919	35	1850	7	1720	1
1910	17	1845	1	1670	1
1898	1	1840	3		

[2] This natural subregion was formerly referred to as the Lower Foothills when the field data collection took place.

Table 5-2 List of all fire dates recorded in the Upper Foothills Natural Subregion between the Upper Waiparous and the Little Red Deer Rivers. The frequency represents the number of forested stands sampled. It is possible that some dates with only a one year interval could be the same fire year due to dating inaccuracies.

UPPER FOOTHILLS					
Fire dates	**Freq**	**Fire dates**	**Freq**	**Fire dates**	**Freq**
1965	1	1863	8	1774	1
1942	3	1850	4	1770	2
1936	5	1849	2	1765	3
1934	5	1845	4	1760	2
1933	2	1840	4	1755	4
1929	1	1838	3	1750	1
1927	3	1837	4	1749	1
1926	2	1835	1	1745	2
1925	2	1830	1	1740	1
1919	30	1825	2	1735	7
1915	34	1820	2	1730	3
1910	24	1816	1	1727	1
1903	1	1815	1	1725	6
1901	1	1813	2	1720	1
1900	2	1807	1	1715	2
1899	10	1805	1	1710	2
1895	7	1803	2	1700	7
1889	58	1801	2	1695	3
1878	4	1800	1	1690	1
1877	8	1798	1	1675	2
1876	3	1796	3	1670	1
1874	1	1795	1	1665	2
1873	1	1790	1	1660	1
1869	2	1788	2	1615	1
1867	7	1786	2	1565	1
1865	2	1777	1	1535	1
1864	7	1775	1		

Table 5-3 List of all fire dates recorded in the Montane-South Natural Subregion between the Sheep and Jumpingpound Rivers. The frequency represents the number of forested stands sampled. It is possible that some dates with only a one year interval could be the same fire year due to dating inaccuracies.

MONTANE SOUTH					
Fire Date	**Freq**	**Fire Date**	**Freq**	**Fire Date**	**Freq**
1965	1	1880	1	1788	1
1945	2	1878	1	1785	1
1936	6	1877	3	1775	2
1935	1	1876	2	1770	1
1930	1	1875	4	1766	1
1929	2	1874	3	1765	2
1928	1	1873	1	1750	1
1926	1	1869	2	1747	1
1925	2	1863	33	1740	6
1924	9	1850	1	1730	10
1921	1	1846	3	1725	1
1919	1	1841	2	1720	1
1916	2	1840	2	1715	2
1915	1	1837	2	1710	2
1910	57	1827	1	1705	2
1902	1	1825	1	1700	2
1900	1	1820	7	1695	2
1898	2	1810	4	1690	3
1896	1	1805	1	1680	1
1893	21	1800	1	1675	1
1890	1	1795	1	1650	1
1885	7				

In a regional context, the Mean-Fire-Return-Interval (MFRI) between significant fire events used to be short. A "significant" fire event is one that was recorded at more than five sites. For this exercise, fire years with only a one year interval were lumped together as fire scars are not always extremely accurate due to rot or missing rings. Also, only post-1850 fires were considered for this calculation because reasonable amounts of evidence of older fires become too scarce due to the continued overlapping of fires over time. The outcome, shown in Table 5-4, was that in the Montane-North, a significant fire event was expected every 11 years, while in the UF and MT-S, a large fire was anticipated every 8 and 15 years, respectively.

Table 5-4 also provides MFRI from individual point locations (i.e. forest stands) across the entire sampling area. The FRI used to range from 4 to 219 years in the UF with a MFRI of 50 years. This calculation was based on 186 individual fire intervals from 160 sampling sites. In the Montane-North, the FRI used to range from 6 to 144 years with a MFRI of 31 years (97 intervals from 77 sampling sites). Using the 129 sampling sites from the MT-S, from which 113 fire intervals were obtained, the FRI ranged from 6 to 226 years with a MFRI of 55 years. Both the UF and MT-S (formerly Lower Foothills) had a relatively similar fire frequency. It is unclear why the Government of Alberta re-labelled the Lower Foothills of this region as Montane because it does not exhibit fire regime characteristics typical of Montane landscapes, but rather of the Foothills type.

Table 5-4 List of significant fire events and associated fire return intervals (FRI). Statistics on regional and point location fire intervals in years are posted. MFRI = Mean-Fire-Return-Interval.

Montane-North		Upper Foothills		Montane-South	
Fire event	**FRI**	**Fire event**	**FRI**	**Fire event**	**FRI**
1947	5	1936	2	1936	12
1942	8	1934	15	1924	14
1934	6	1919	4	1910	17
1928	9	1915	5	1893	8
1919	9	1910	11	1885	22
1910	14	1899	4	1863	
1896	11	1895	6		
1885	21	1889	12		
1864	14	1877	10		
1850		1867	3		
		1864	14		
		1850			
Regional Mean-Fire-Return-Intervals					
MFRI post 1850	10.8		7.8		14.6
Point location Fire Return Interval Statistics					
MFRI	30.6		50.3		54.5
Range	6 to 144		4 to 219		6 to 226
Count	97		186		113

The number of fires recorded are testimony to the influence of traditional land use and burning on this landscape, especially for regions that are within the lightning strike shadow. Another indication of the strong association of anthropogenic activities with the fire regime was that

88% of burning activity used to take place before or after the green or leaf-out period (i.e. April to early June or Sept. - Oct.), which coincides with a time when lightning storm activity is unlikely. This was determined by an assessment of the position[3] of fire scars within the growth rings for the sample plots of the Montane-South subregion (Table 5-5). Similar findings were recorded in the R11 FMU (Rogeau 2010a) located further north of the FMA. Overall, the short fire intervals documented explain why many plant species are morphologically adapted to thrive after burning (shade intolerant species such as the lodgepole pine and aspen trees), or are dependent on the recurrence of fires to maintain an open forest canopy.

Table 5-5 Seasonal distribution of fire scars within trees' annual growth rings.

Relative Position Within Tree Ring	Seasonal Descriptor	Count	% Occ.
ME: Middle-Early Wood	Middle-spring: late-May, early June	22	23.91
LE: Late-Early Wood	Late spring: June	4	4.35
LW: Late Wood	Summer: August	7	7.61
D: Dormant	Spring/Fall: April-May, Sept-Oct	59	64.13
		92	100

5.2 PIC Simulated Mean-Fire-Return-Intervals

Mean-Fire-Return-Intervals for the different natural subregions of the FMA were predicted using STANDOR, a fire growth simulation model (Rogeau 2004). The model replicates historical fire regime conditions using a Digital Elevation Model (DEM), current Fire Behaviour Prediction fuel types, and spatial probabilities of ignition as base layers, and also makes use of real fire weather statistics for the region (Rogeau *et al.* 1996). Fires are grown using fire spread equations from the Canadian Forest Fire Behaviour Prediction System (Forestry Canada Fire Danger Group 1992). A description of STANDOR, map layers, fire regime data input and model calibrations, are fully described in Appendix A.

[3] Scar tissue coinciding with the dark ring (winter wood) means that the fire burned during the dormant period of the tree, that is early in the spring or during the fall after the growing season ended. Scar tissue located immediately after the dark ring also indicate an early spring fire before the leaf-out period.

STANDOR produces three kinds of outputs:

1) fire frequency per pixel map, from which a MFRI interval can be obtained;
2) a stand origin map, from which age-class distributions can be derived; and
3) a list of all fire sizes (Section 5-4).

The model's historical fire regime data input rely on results from the historical fire regime analyses and fire history data. The advantage of using a fire growth simulation model is that the model is able to keep track of burn area perimeters over time and will produce accurate stand origin maps. Because a stand origin map offers a "snapshot in time" of the fire regime, another benefit of a simulation model is that multiple iterations can be performed to produce multiple stand origin maps and age-class distributions. This process allows for the evaluation of the natural range of variation in age-class distributions, as well as the trends and patterns in the spatial distribution of fire (i.e. stand ages) over long periods of time, while maintaining a homogeneous fire regime.

For each FMU modelling region, ten iterations of 1000 years of fire regime simulations were produced, for a total of 10,000 years of fire records. Figures 5-1a, 5-2a and 5-3a present the mean fire frequency distribution for the three fire regime modelling regions. These frequencies (1000 years divided by the number of fires that occurred at each land pixel) were converted into classes of MFRIs and are shown in Figures 5-1b, 5-2b and 5-3b. Table 5-6 lists the weighted MFRIs by Natural Subregion and fuel type cover. The expected weighted mean-age calculated from the age-class distributions (Section 5.3) is also presented. In areas of relatively homogeneous fire distribution, the MFRI and weighted mean ages are very similar, if not equal. In areas where the MFRI varies spatially in a significant way, such as in the Upper Subalpine, the weighted mean age can be off by several decades. Within the FMA, the discrepancy amounted to a maximum of 27 years for the Subalpine's aspen fuel type located in Upper B10. Long-term burning trends indicate that the longest fire intervals coincide for the most part with headwaters of watersheds, and longer intervals tend to be associated with spruce forests. It would appear that deciduous forest types tend not to burn as frequently as pine. Unless severe droughts subsist, aspen stands will not burn during the summer time when the leaves are out and the tall grass is lush. At the other end of the spectrum, shorter fire intervals have a tendency to be found at valley bottom in areas of greater fire ignition probabilities. It is in these areas that younger forest stands will prevail (Section 5.3).

Table 5-6 Weighted Mean-Fire-Return-Interval and weighted mean age by Natural Subregion and fuel cover type.

	B9 FMU						**Upper B10 FMU**				**Lower B10 FMU**	
	UF		LF		MT-N		MT-S		SA		SA	
	MFRI	Mean Age	MFRI	Mean Age	MFRI	Mean Age	MFRI	Mean Age	MFRI	Mean Age	MFRI	Mean Age
C1	52	75	59	76	57	66	47	54	75	88	96	116
C3	43	53	52	61	52	64	45	49	64	69	65	64
D1	53	60	78	105	57	67	60	72	69	96	63	70
M1	42	46	55	72	50	61	51	56	52	51	54	58

C1 = spruce, C3 = pine, D1 = aspen, M1 = mixedwood

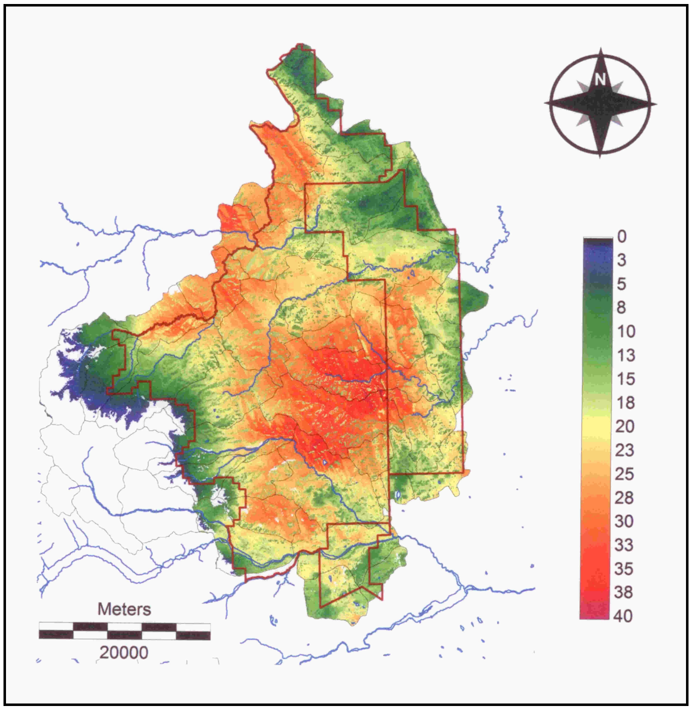

Figure 5-1a Mean fire frequency distribution, B9 FMU modelling region.

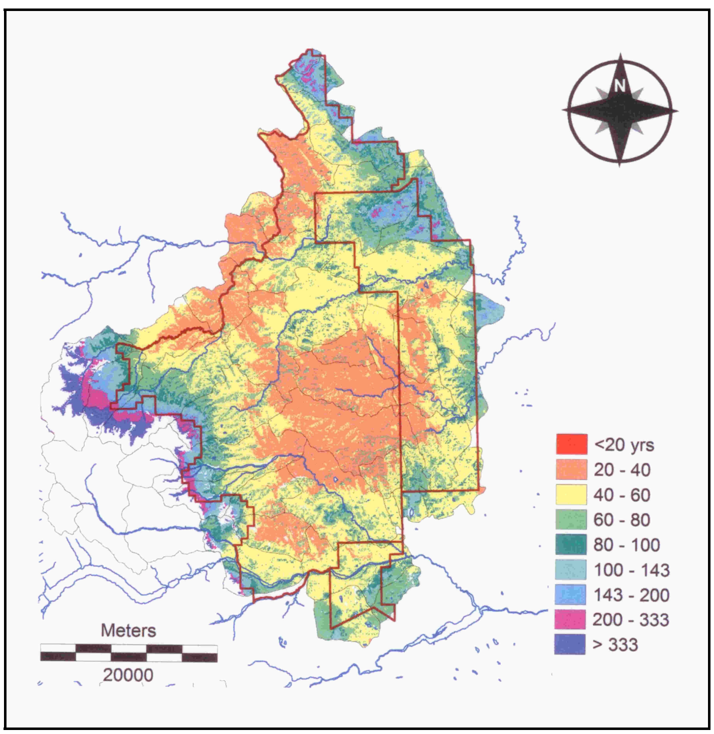

Figure 5-1b Mean-Fire-Return-Intervals, B9 FMU modelling region.

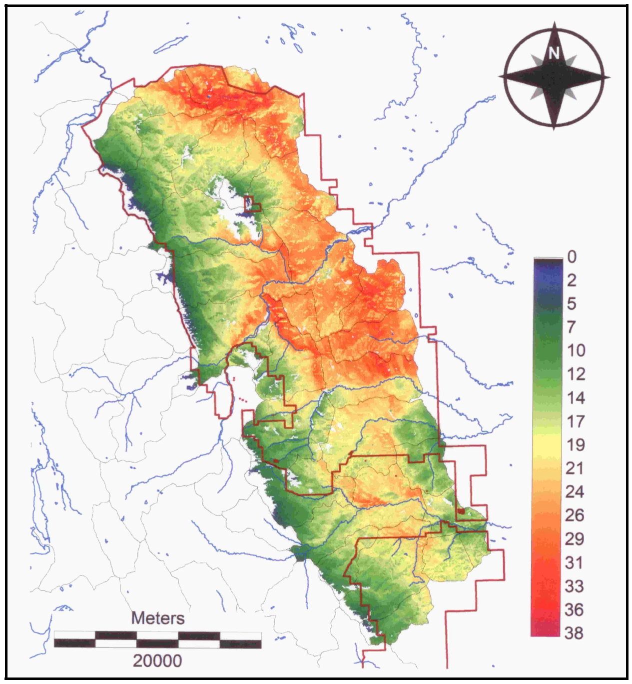

Figure 5-2a Mean fire frequency distribution, Upper B10 FMU modelling region.

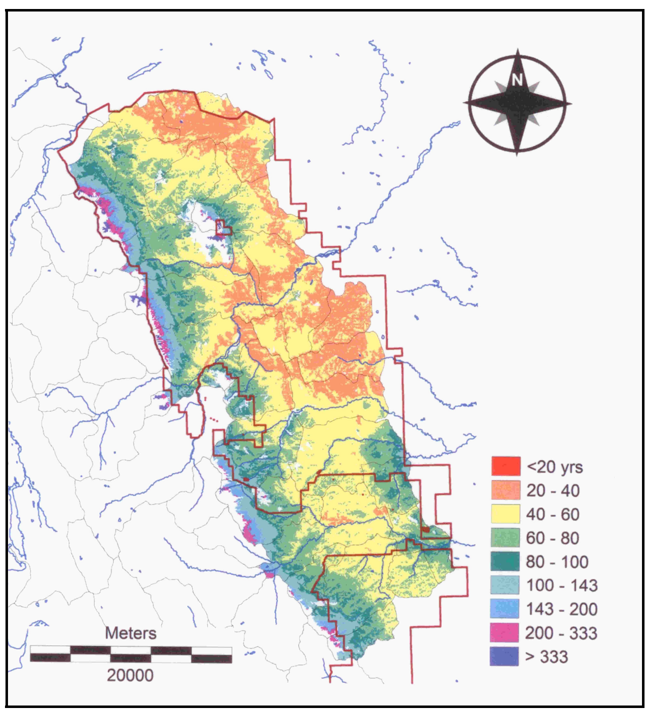

Figure 5-2b Mean-Fire-Return-Intervals, Upper B10 FMU modelling region.

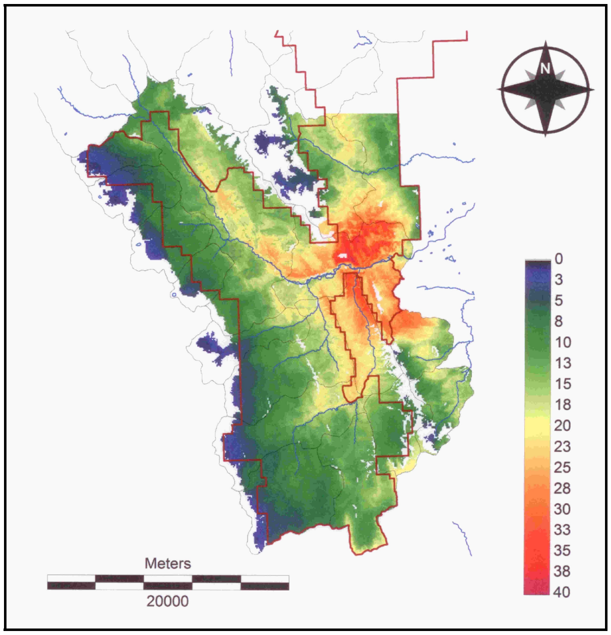

Figure 5-3a Mean fire frequency distribution, Lower B10 FMU modelling region.

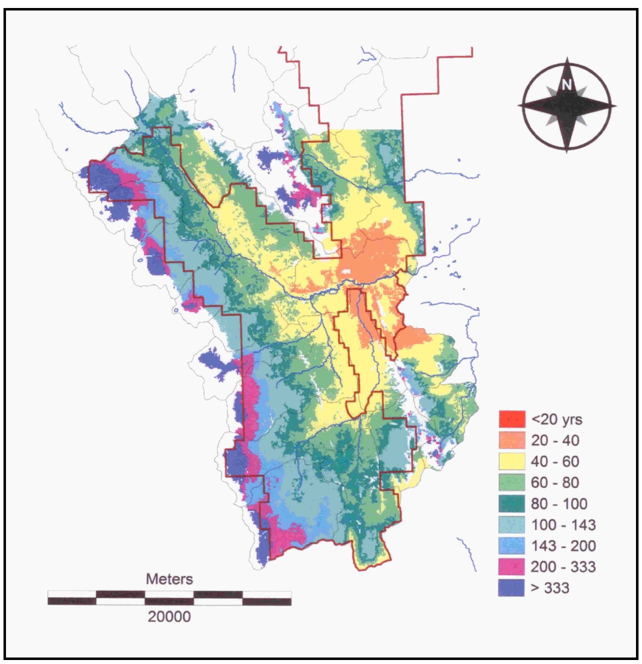

Figure 5-3b Mean-Fire-Return-Intervals, Lower B10 FMU modelling region.

5.3 PIC SIMULATED STAND ORIGIN MAPS

5.3.1 Spatial distribution of forest stand ages

After each fire regime simulation of 1000 years, a stand origin map was produced, for a total of 10 maps per modelling region. These maps were averaged to produce a mean stand origin map (Figures 5-4, 5-5, 5-6). The mean stand origin map captures spatial patterns of young, mature and old-growth forests. These patterns closely match those of the average MFRI classes presented in the above section. It is interesting to observe that under a homogenous fire regime, a "snap shot" in time of the age mosaic can be highly variable depending on the amount of dry periods in the previous couple of decades leading to the snap shot (or the end of a simulation run). While every stand origin map can look quite different, as shown in Figures 5-7 and 5-8, their long-term patterns indicate definite trends in terms of where younger aged forests tend to prevail and where old-growth forests have the ability to persist.

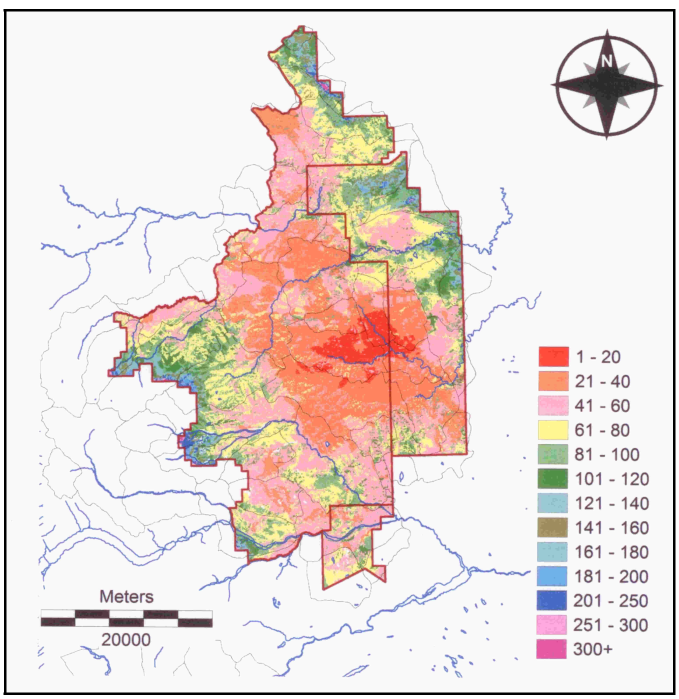

Figure 5-4 Mean stand origin map (age-classes), B9 FMU modelling region.

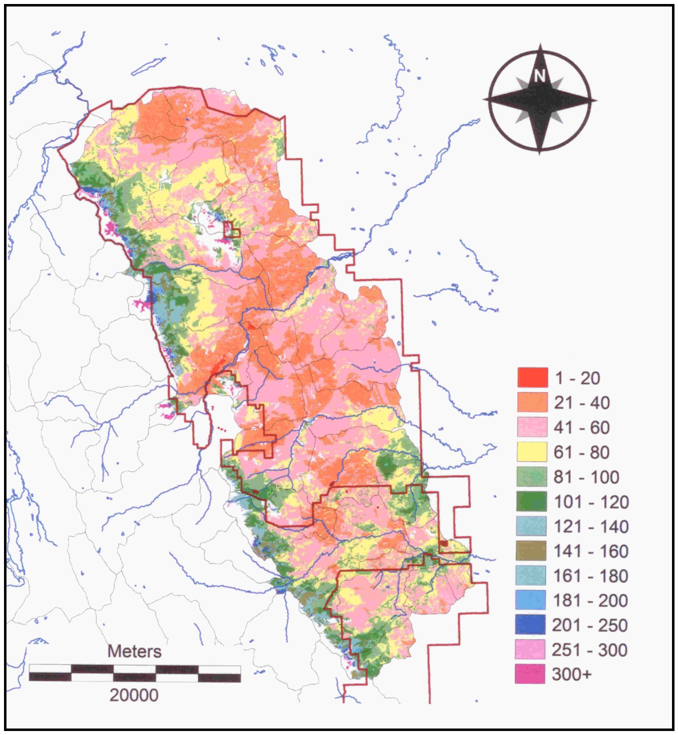

Figure 5-5 Mean stand origin map (age-classes), Upper B10 FMU modelling region.

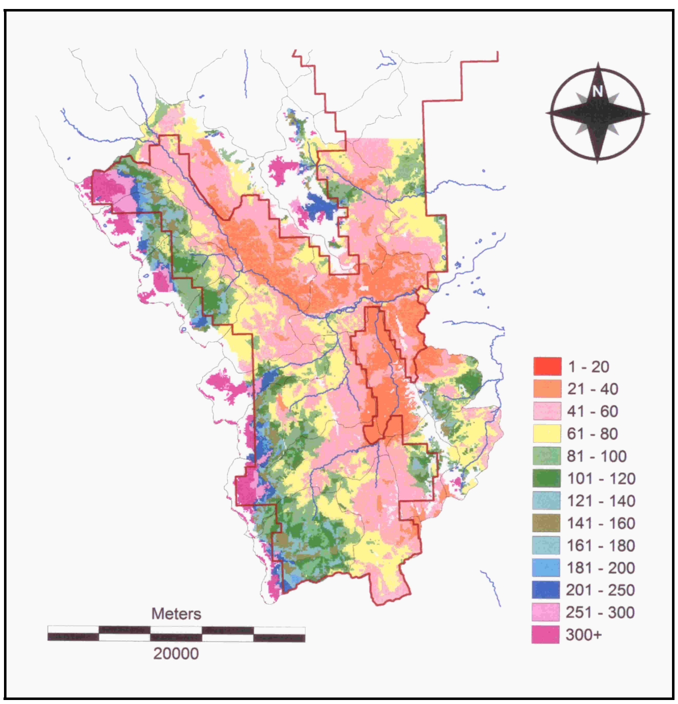

Figure 5-6 Mean stand origin map (age-classes), Lower B10 FMU modelling region.

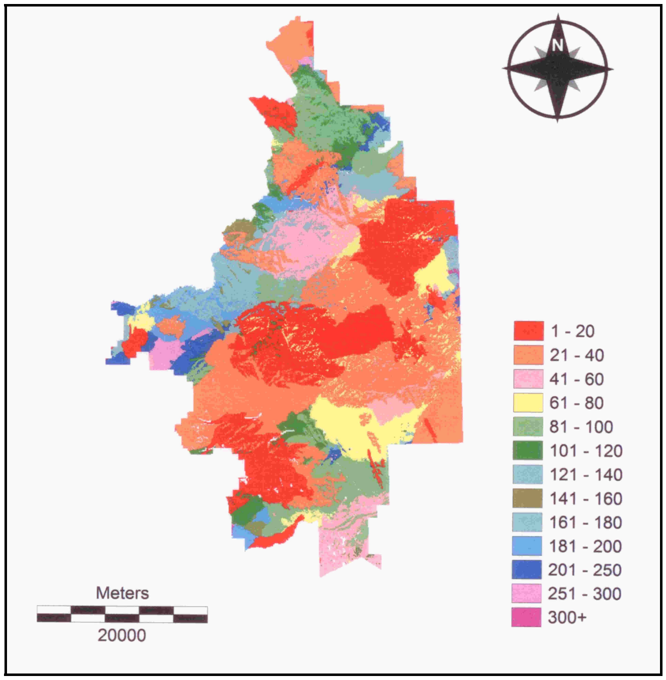

Figure 5-7 Example of a stand origin map produced from simulation No.1, B9 FMU modelling region.

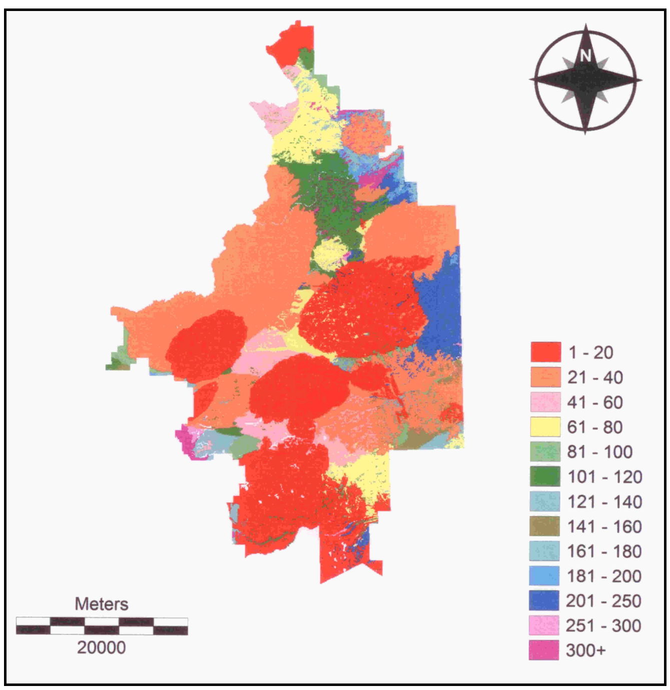

Figure 5-8 Example of a stand origin map produced from simulation No.2, B9 FMU modelling region.

5.3.2 Age-class distributions by fuel cover type

Tables 5-7 through 5-12 provide the mean age-class distributions by fuel cover type for each Natural Subregion that was modelled. The standard deviation around the mean, as a way to measure the natural range of variation, is also included. The same information was also lumped into seral age-classes and is presented in Tables 5-13 through 5-18 in the following sub-section. Spreadsheets of individual simulation outputs will be provided to SLS, along with the digital map outputs, so that managers can experiment with the age-class partitioning.

Note: the average and standard deviation around the mean values are not as reliable when land areas are only a few hundred hectares. This is especially true for aspen and mixedwood fuel types in the subalpine natural subregion.

Table 5-7 Percent age-class distribution by fuel cover type, Upper Foothills, B9 FMU.

	Spruce		Pine		Aspen		Mixedwood	
Age-class	**AVG**	**STD**	**AVG**	**STD**	**AVG**	**STD**	**AVG**	**STD**
1 to 20	27.48	13.14	34.14	17.10	31.39	23.54	38.66	19.21
20 to 40	23.70	12.88	28.04	15.18	23.44	19.76	30.89	18.12
40 to 60	10.14	8.95	8.97	6.70	11.63	14.18	8.37	8.38
60 to 80	8.72	5.01	9.63	5.60	9.88	10.36	9.18	7.85
80 to 100	9.16	7.60	7.41	5.62	7.17	4.99	3.27	3.44
100 to 120	4.76	2.91	2.95	1.87	6.93	10.64	2.94	3.83
120 to 140	2.95	2.65	3.19	3.43	1.68	1.86	2.29	2.05
140 to 160	1.72	2.76	1.18	1.11	3.20	4.68	1.77	2.26
160 to 180	1.25	1.00	0.89	0.76	1.99	3.18	0.83	1.41
180 to 200	3.03	2.85	1.30	1.27	0.37	0.51	0.16	0.22
200 to 250	2.40	2.63	1.05	0.77	1.23	2.49	0.91	1.56
250 to 300	2.19	1.90	0.72	0.63	0.74	1.13	0.54	0.85
300+	2.50	1.99	0.54	0.66	0.35	0.66	0.17	0.35
Wgt Mean age	75		53		60		46	

Table 5-8 Percent age-class distribution by fuel cover type, Lower Foothills, B9 FMU.

	Spruce		Pine		Aspen		Mixedwood	
Age-class	AVG	STD	AVG	STD	AVG	STD	AVG	STD
1 to 20	27.15	11.46	31.62	14.98	17.78	8.40	31.54	15.58
20 to 40	27.08	18.29	31.53	19.13	23.56	19.04	29.13	21.89
40 to 60	3.86	3.78	4.59	5.20	2.58	2.39	3.16	4.69
60 to 80	12.58	10.63	11.01	10.27	11.48	12.98	10.46	10.82
80 to 100	6.72	5.90	4.47	4.71	9.02	5.73	3.03	2.60
100 to 120	4.55	4.36	3.48	4.17	6.03	5.52	2.61	2.52
120 to 140	2.32	2.63	1.81	1.83	4.19	5.52	2.49	3.26
140 to 160	2.23	2.32	2.14	3.01	3.28	4.20	2.55	3.23
160 to 180	2.33	1.77	1.33	1.35	2.78	2.01	2.63	2.44
180 to 200	3.00	2.22	2.03	1.93	3.45	2.35	2.08	1.75
200 to 250	4.42	3.22	4.07	3.79	7.63	4.78	7.40	7.99
250 to 300	1.74	2.65	1.29	2.36	3.19	3.65	1.65	3.19
300+	2.02	1.77	0.63	0.73	5.02	4.30	1.26	0.82
Wgt Mean age	76		61		105		72	

Table 5-9 Percent age-class distribution by fuel cover type, Montane-North, B9 FMU.

	Spruce		Pine		Aspen		Mixedwood	
Age-class	AVG	STD	AVG	STD	AVG	STD	AVG	STD
1 to 20	24.47	28.43	25.11	25.62	23.99	29.28	25.07	30.81
20 to 40	23.90	21.30	24.85	23.45	22.87	25.65	26.17	21.80
40 to 60	15.73	16.51	11.39	11.74	15.97	21.13	18.66	21.65
60 to 80	12.92	11.43	14.75	10.64	14.02	12.91	10.38	10.83
80 to 100	7.74	9.54	6.83	8.41	8.72	15.49	3.99	6.40
100 to 120	2.82	7.62	5.84	13.27	4.75	12.94	5.00	14.07
120 to 140	2.02	3.79	3.64	6.90	1.40	2.43	2.26	5.72
140 to 160	1.31	1.84	0.56	0.61	0.32	0.55	0.86	1.10
160 to 180	3.57	8.94	1.96	3.20	1.83	4.78	3.54	9.86
180 to 200	0.46	0.63	1.30	2.26	0.61	1.00	0.48	0.74
200 to 250	2.60	3.26	2.14	2.02	2.19	3.55	2.06	3.57
250 to 300	1.02	1.85	0.63	1.04	0.71	1.97	0.48	0.70
300+	1.44	2.25	1.00	1.13	2.62	6.74	1.04	2.41
Wgt Mean age	66		64		67		61	

Table 5-10 Percent age-class distribution by fuel cover type, Montane-South, Upper B10 FMU.

	Spruce		Pine		Aspen		Mixedwood	
Age-class	AVG	STD	AVG	STD	AVG	STD	AVG	STD
1 to 20	31.90	17.09	34.63	17.76	26.25	15.99	26.25	15.99
20 to 40	24.37	11.75	26.13	10.54	21.36	15.56	21.36	15.56
40 to 60	13.45	9.17	11.63	7.48	9.78	5.47	9.78	5.47
60 to 80	12.32	13.09	13.70	14.91	9.92	8.62	9.92	8.62
80 to 100	4.23	2.60	3.39	1.84	4.20	2.76	4.20	2.76
100 to 120	5.82	6.86	4.75	5.60	13.35	13.02	13.35	13.02
120 to 140	2.83	2.08	2.58	1.79	3.35	3.64	3.35	3.64
140 to 160	1.57	1.92	0.75	0.90	2.43	3.69	2.43	3.69
160 to 180	1.07	2.07	0.75	1.43	3.59	5.63	3.59	5.63
180 to 200	0.90	1.28	0.52	0.56	1.25	1.38	1.25	1.38
200 to 250	0.70	0.62	0.47	0.35	2.26	2.38	2.26	2.38
250 to 300	0.66	0.81	0.61	0.75	0.97	1.46	0.97	1.46
300+	0.18	0.26	0.06	0.08	1.28	2.90	1.28	2.90
Wgt Mean age	54		49		72		56	

Table 5-11 Percent age-class distribution by fuel cover type, Subalpine, Upper B10 FMU.

	Spruce		Pine		Aspen		Mixedwood	
Age-class	AVG	STD	AVG	STD	AVG	STD	AVG	STD
1 to 20	22.75	12.72	30.67	13.79	38.09	19.05	45.28	20.87
20 to 40	14.99	7.43	19.87	8.32	10.07	10.05	15.38	11.93
40 to 60	12.19	7.14	13.23	6.73	11.58	9.57	14.91	14.17
60 to 80	8.36	11.67	11.20	11.88	9.12	15.85	9.06	9.48
80 to 100	5.38	3.71	4.98	3.34	1.29	1.36	5.28	6.43
100 to 120	4.76	4.58	5.25	5.02	6.54	8.67	3.68	4.25
120 to 140	2.99	4.58	3.75	4.96	3.20	4.31	1.42	3.02
140 to 160	1.23	2.73	1.91	2.30	1.18	1.52	0.38	0.86
160 to 180	1.59	0.50	0.81	0.75	0.74	1.40	0.09	0.28
180 to 200	2.76	3.15	2.26	3.02	6.43	10.99	1.89	3.94
200 to 250	2.44	2.59	2.37	2.33	3.60	6.85	1.04	1.95
250 to 300	3.65	1.81	1.57	1.50	2.76	5.39	1.60	2.92
300+	5.33	3.23	2.15	1.88	5.40	7.83	0.00	0.00
Wgt Mean age	88		69		96		51	

Table 5-12 Percent age-class distribution by fuel cover type, Subalpine, Lower B10 FMU.

	Spruce		Pine		Aspen		Mixedwood	
Age-class	**AVG**	**STD**	**AVG**	**STD**	**AVG**	**STD**	**AVG**	**STD**
1 to 20	16.96	11.52	25.21	16.41	23.78	20.80	34.90	23.69
20 to 40	18.79	9.65	26.07	11.93	20.26	14.10	24.74	14.34
40 to 60	14.00	7.17	14.62	8.09	19.28	19.82	16.28	13.60
60 to 80	11.77	5.66	10.73	6.40	7.14	8.56	5.76	5.26
80 to 100	6.47	2.16	6.16	3.47	5.47	7.13	4.96	5.13
100 to 120	5.34	4.59	5.28	3.85	5.58	7.69	3.01	2.39
120 to 140	5.04	3.51	4.31	4.09	9.37	13.69	4.10	4.75
140 to 160	3.36	3.90	1.95	2.46	1.17	2.23	0.89	1.14
160 to 180	2.19	2.01	1.21	1.31	0.89	1.75	1.08	1.86
180 to 200	1.22	1.20	0.62	0.60	2.20	5.17	0.11	0.33
200 to 250	2.96	2.29	1.14	1.16	3.44	4.86	1.85	3.49
250 to 300	2.33	2.20	0.77	1.05	0.56	0.84	0.32	0.80
300+	9.56	4.10	1.92	1.04	0.86	1.37	1.99	2.25
Wgt Mean age	116		64		70		58	

5.3.3 Seral age-class distributions

PIC age-class distributions were re-assessed by broad seral stages (regenerating, young, mature, and old growth) in order to ease comparisons with current forest conditions for benchmark purposes. These seral age groupings were developed for west-central Alberta using forest condition and ecological process thresholds (Morgantini and Kansas 2003).

Table 5-13 Percent seral age-class distribution by fuel cover type, Upper Foothills, B9 FMU.

		Conifers				Deciduous				
		Spruce		Pine			Aspen		Mixedwood	
Seral age		Avg	STD	Avg	STD	Seral age	Avg	STD	Avg	STD
Regen.	1 to 20	27.48	13.14	34.14	17.10	1 to 20	31.39	23.54	38.66	19.21
Young	21 to 70	38.73	11.14	42.43	15.97	21 to 50	27.42	21.03	33.67	19.33
Mature	71 to 170	23.18	6.79	19.45	6.26	51 to 110	29.28	17.88	19.67	14.10
O.G.	> 170	10.60	6.09	3.98	2.28	> 110	11.91	9.76	8.00	7.07

Table 5-14 Percent seral age-class distribution by fuel cover type, Lower Foothills, B9 FMU.

		Conifers				Deciduous				
		Spruce		Pine			Aspen		Mixedwood	
Seral age		Avg	STD	Avg	STD	Seral age	Avg	STD	Avg	STD
Regen.	1 to 20	27.15	11.46	31.62	14.98	1 to 20	17.78	8.40	31.54	15.58
Young	21 to 70	38.94	15.08	43.02	16.10	21 to 50	24.85	19.30	31.40	21.28
Mature	71 to 170	21.24	12.02	16.66	10.99	51 to 110	25.32	13.01	15.75	12.56
O.G.	> 170	12.67	7.50	8.70	6.32	> 110	32.05	9.38	21.31	11.53

Table 5-15 Percent seral age-class distribution by fuel cover type, Montane-North, B9 FMU.

		Conifers				Deciduous				
		Spruce		Pine			Aspen		Mixedwood	
Seral age		Avg	STD	Avg	STD	Seral age	Avg	STD	Avg	STD
Regen.	1 to 20	24.47	28.43	25.11	25.62	1 to 20	23.99	29.28	25.07	30.81
Young	21 to 70	33.45	24.42	31.12	24.57	21 to 50	31.20	29.89	36.50	28.10
Mature	71 to 170	33.40	16.14	37.84	13.00	51 to 110	30.79	23.79	23.04	15.33
O.G.	> 170	8.68	12.34	5.94	6.36	> 110	14.03	21.01	15.39	25.79

Table 5-16 Percent seral age-class distribution by fuel cover type, Montane-South, Upper B10 FMU.

		Conifers				Deciduous				
		Spruce		Pine			Aspen		Mixedwood	
Seral age		Avg	STD	Avg	STD	Seral age	Avg	STD	Avg	STD
Regen.	1 to 20	31.90	17.09	34.63	17.76	1 to 20	26.25	15.99	34.40	18.41
Young	21 to 70	46.51	17.26	47.57	16.76	21 to 50	27.40	16.91	27.44	13.67
Mature	71 to 170	18.67	9.55	15.74	7.63	51 to 110	29.27	16.42	26.78	19.76
O.G.	> 170	2.91	2.85	2.06	1.43	> 110	17.08	15.02	11.38	10.09

Table 5-17 Percent seral age-class distribution by fuel cover type, Subalpine, Upper B10 FMU.

		Conifers				Deciduous				
		Spruce		Pine			Aspen		Mixedwood	
Seral age		Avg	STD	Avg	STD	Seral age	Avg	STD	Avg	STD
Regen.	1 to 20	28.50	12.72	30.67	13.79	1 to 20	38.09	19.05	45.28	20.87
Young	21 to 70	37.13	12.57	40.36	10.95	21 to 50	15.77	8.12	24.25	13.73
Mature	71 to 170	21.29	6.29	20.28	7.42	51 to 110	19.63	21.33	22.83	15.56
O.G.	> 170	13.08	4.47	8.69	3.22	> 110	26.51	10.01	7.64	5.51

Table 5-18 Percent seral age-class distribution by fuel cover type, Subalpine, Lower B10 FMU.

		Conifers				Deciduous				
		Spruce		Pine			Aspen		Mixedwood	
Seral age		Avg	STD	Avg	STD	Seral age	Avg	STD	Avg	STD
Regen.	1 to 20	16.99	13.89	23.25	15.81	1 to 20	25.58	19.44	38.06	27.56
Young	21 to 70	42.64	12.49	46.73	11.76	21 to 50	35.81	25.71	36.38	21.74
Mature	71 to 170	26.20	14.19	25.06	9.99	51 to 110	22.98	16.76	18.28	15.12
O.G.	> 170	14.16	5.26	4.96	3.12	> 110	15.63	17.82	7.28	8.36

5.4 Fire Size Distribution

5.4.1 From stand origin simulations

Fire sizes for the Pre-Industrial era were obtained from the three fire regime simulation regions: B9, Upper B10 and Lower B10 FMUs. However, it was not possible to parse this information by natural subregion because modelling parameters were not established to track that specific information by natural subregion. The fire growth model retained fire size information of those fires that ignited within the FMU boundaries, but only kept track of burn areas falling within the FMU. For those fires that ignited outside, but spread to within FMU boundaries, the burn areas were retained and were entered as fire size entries.

While the fire growth model can be set to track fire sizes specifically by natural subregion through the use of a mask to specifically target one subregion at a time, it is not considered necessary in the case of the SLS FMA. The natural subregions of the FMA are not extensive, they tend to be narrow, and as a result most large fires burn across more than one natural subregion.

From Table 5-19, it can be observed that the B9 FMU has the fewest small size fires (<11ha), as well as most large size fires in comparison to the remainder of the FMA. In contrast, Lower B10 has the least amount of fires that are greater than 5000 ha in size. In terms of maximum fire size recorded by region, the range was 34,400ha recorded in the Lower B10, while Upper B10 and B9 FMUs saw fires as large as 51,000 and 97,000 ha, respectively. The prevailing reason for these differences in fire size are the fuel continuity and fire weather. Lower B10 lies at higher elevations (cooler) in the rugged subalpine that is parted by rocky ridges, which in turn limit fire spread. Upper B10 has some rocky fuel breaks notably in its centre, whereas B9, largely composed of Upper Foothills, does not have any.

Table 5-19 Fire size class distribution by FMU.

Size class (ha)	B9 % Freq.	B10_Upper % Freq.	B10_Lower % Freq.
<1	0.62	1.61	1.57
2 to 10	4.32	8.44	7.41
11 to 100	16.05	25.00	22.84
101 to 250	10.78	13.20	13.02
251 to 500	9.46	9.71	11.12
501 to 1000	10.74	9.71	10.82
1001 to 2000	11.95	9.10	11.25
2001 to 5000	14.83	10.95	13.74
5001 to 10000	9.40	6.68	5.54
10001 to 15000	4.92	2.78	1.84
15001 to 20000	2.41	1.29	0.59
> 20000	4.52	1.52	0.26

5.4.2 From recent fire mapping

Extracted integrally from Rogeau 2004 - Section 10.2 p.88-89.

This method makes use of stand replacing fires that occurred between circa 1930 to 1950. This is a period when fires can still be easily identified on the 1950 aerial photography. Fires from this period are also less likely to have been overlapped by subsequent burns. This period should provide more realistic fire sizes that have not been affected as severely by fire suppression tactics. Unfortunately not enough fires have been identified to be able to address the fire size distribution by natural region. This time period includes one of the most severe fire season (1936) where many large size fires occurred throughout the Province. Fire weather and burning conditions in 1936 were equivalent to what has been seen during the 2003 fire season, and as such, it provides a very good spectrum of fire size distribution.

Table 5-20 presents the recent fire mapping results as well as fire information recorded by Delisle and Hall (1987). Table 5-21 shows the percent of fires recorded in each size class, as well as the percent forested area it corresponds to.

Table 5-20 Burn area (ha) results from the recent fire mapping method. Some fires were not mapped as they were covered by Delisle & Hall (1987) and stand origin mapping work from Johnson and Fryer (1987) (Kan. Valley).

Fire Id #	Area Mapped	Delisle&Hall	Subregion
1	195.43		Subalpine
2	2,624.92	2,137	L. Foothills
3	185.53	405	Subalpine
4	2,594.04		L. Foothills
5	2,712.29		L. Foothills & Sub.
6	1,635.21		Subalpine
7	4,247.79		Subalpine
8	1,044.53	821	L. Foothills
9	914.59		Subalpine
10	113.54		Subalpine
11	5.81		Subalpine
12	115.38		Subalpine
13	5,572.23		Subalpine
70	4,178.48	4,897	U. Foothills
73	2,760.97		Subalpine & U. Foot.
	28,900.73		
19		583	Subalpine
25		24,500	Subalpine
27		2,948	L. Foothills
29		3,950	Subalpine
Kan valley		7,955	Subalpine
		39,936	

Table 5-21 Percent of fire recorded in each size class and percent of forested area burned by size class. Forested area estimated at 357,586 ha.

Fire size class (ha)	Count	% occ	Total area	% of forested area
<100	1	5	5.81	0.00
100 to 500	4	20	609.88	0.17
500 to 1000	2	10	1,498.00	0.42
1000 to 2000	2	10	2,679.74	0.75
2000 to 5000	8	40	26,016.48	7.28
5000 to 10000	2	10	13,527.23	3.78
>10000	1	5	24,500.00	6.85
	20	100	68,837.14	

5.5 ISLAND REMNANT DISTRIBUTION

This aspect of the fire regime is difficult to address for a number of reasons. First, there is no historical data that exists for the SLS FMA. The only known database on wildland fire island remnants was produced by the Foothills Research Institute (McLean *et. al* 2003, Andison 2004). Some of these results could potentially be borrowed to apply to the Foothills region of the FMA, but with caution. The PIC Mean-Fire-Return-Interval on the SLS FMA's Montane and Foothills natural regions can be half of those found further north in the Athabasca basin. On the FMA, the complexity of the vegetation mosaic during the PIC era was such that the whole landscape was made up of an intricate pattern of stands as a result of many repeat fires that burned at lesser intensities and left scattered individual trees or pockets of trees.

The greatest issue with the evaluation of wildfire island remnants when used to predict overall fire patterning, numbers, and size of islands, is that each fire has a very unique behaviour. Fire weather, fuel type, seasonality and topography all interact in intricate manners and in ways that will constantly modify fire behaviour and the dynamics of island remnants. The most volatile component is the weather. A shift in wind speed or direction, the passage of a cold front that dramatically increases wind speed, or the occurrence of light scattered showers that will cool the fire down temporally, all affect the formation and patterning of island remnants. A change in fuel type from conifers to mixedwood or deciduous, can also reduce fire intensities and create conditions that form island remnants; this phenomenon can be even more pronounced during the leaf-out period. Any occurrence of natural fuel breaks such as rocky outcrops, or water bodies will increase the chance for island remnants to form. For mountain landscape fires, the discontinuity in the fuel cover which is broken up by rocky ridges, and the effect of topography on the spatial fire distribution (aspect, elevation, proximity to headwaters) are all factors that will drive the retention of island remnants over long periods and form fire refugias (Rogeau *et al.* 2004, Rogeau 2010b.)

6.0 MANAGEMENT BENCHMARKS FROM PIC

The information contained in this report provides guidelines for the planning and management of forests in the context of ecosystem departure from the historical forest disturbance regime. The historical regime was defined as the Pre-Industrial Era, which ended in 1930. It was also determined that the lead disturbance agent was wildfire.

When used specifically for the planning of harvest blocks, not all elements of a fire regime can be replicated, but a number of parameters can be addressed. Notably, the spatial distribution of disturbances, yearly rate of disturbance, size of disturbances, patterning and, seral age-distributions of fuel cover types. The following sub-sections summarize findings from this PIC assessment report, identify key parameters and, indicate which benchmark or threshold values to use.

6.1 SPATIAL DISTRIBUTION OF OLD GROWTH RETENTION

It was found that probabilities of ignition are not a random process and that some areas tend to burn more often than others. Conversely, some areas burn much less frequently and are able to sustain large patches of old growth forests. From thousands of years of fire simulations, corroborated by field data, the natural range of fire distribution was captured from which spatial

Mean-Fire-Return-Interval maps could be produced (Section 5.2). In summary, it was found that the B9 FMU had an overall MFRI of 44, 52 and 55 years for its Upper Foothills, Montane and Lower Foothills, respectively. The Montane portion of Upper B10 had a MFRI of 46 years, while the Subalpine portion used to see a MFRI of 66 years. In the Subalpine region of Lower B10 (Highwood Region), the MFRI was 73 years.

As a general rule there is a strong resemblance between a mean stand origin map and a mean-fire-return-interval map. The SLS FMA is no exception and it was observed that younger aged cohorts do prevail in regions of short MFRIs, while old growth forests persist in areas that were shown to have repeatedly long MFRIs. To alleviate ecosystem departure, areas having the shortest fire return intervals (i.e. where younger aged forests were historically maintained) should be the primary focus when planning harvest blocks. While this approach may seem contrary to the typical forest management practice of scheduling older age cohorts for harvest, it is important to remember that in this case, targeting "young" forest from the PIC fire simulations refers to forest stands that today are at least 100 years of age as a result of 80 years of successful fire suppression and fire removal.

To maintain the ecological integrity of each natural subregion's ecosystem, it would be advisable to exclude from harvesting 2% to 5% of the land that falls within the longest fire intervals of the MFRI distributions. These tail-end distributions correspond with fire refugias that are naturally able to preserve old growth forests. With the purpose of preserving a certain amount of old age and old growth forests, arbitrary percent land base values of 2%, 3%, 4% and 5% were set for this exercise. Table 6-1 presents the corresponding threshold MFRI values for pine and spruce that must be used in order to meet the permanent retention benchmarks. The MFRI distributions for pine and spruce forests that were used to calculate the values in Table 6-1 can be found in Appendix B.

Table 6-1 can be interpreted in the following manner. If it is determined that 3% of old growth spruce will be retained in the Upper Foothills of B9, the parcels of land to exclude can be located in two ways. Firstly, the stands should preferably be located within the MFRI classes that are longer than 200 years. Secondly, as MFRIs are similar to weighted mean ages, actual forest ages should also be used in conjunction, regardless of the MFRI classes. One important point to remember is that the MFRIs provided below are from the PIC era. To be able to compare these values to today's forest stand ages, MFRIs need to be increased by the time-since-1930 (PIC benchmark), which is ~80 years for ease of calculation. To return to the example above, actual stand ages that would be targeted for exclusion from harvesting would need to be 280 years or older (200 + 80). Any patches older than 280 years of age found outside of their respective MFRI zone would be defined as unique in any environments that can sustain MFRIs that are less than 150 years. Thus, such island remnants should be prioritised for permanent retention to safeguard their ecological significance.

Table 6-1 Threshold PIC Mean-Fire-Return-Interval values (in years) that are able to naturally maintain old growth forest under certain percent of landbase retention. P = pine, S = spruce.

Percent land base retention	B9						Upper B10				Lower B10	
	UF		LF		MT		SUB		MT		SUB	
	S	P	S	P	S	P	S	P	S	P	S	P
2%	200	111	167	125	100	100	250	167	100	83	350	167
3%	200	100	143	111	100	100	250	167	91	77	350	167
4%	167	91	143	100	100	91	250	143	83	77	350	143
5%	167	91	143	100	91	91	200	143	83	71	350	143

However, prior to implementing this approach, it is important to recognize that much of the longer MFRI classes, where old growth forests occur, largely coincide with the headwaters of watersheds. For the most part, these headwaters actually fall on the outskirt of the western edge of the FMA. Historically, old growth forests were not a common occurrence within the FMA boundaries, notably in B9 and Upper B10. From a watershed management and ecological perspective, it would be advisable to include the valley headwaters in the planning process and use these areas, already set aside as wildland parks, to evaluate the need for old growth forest retention.

The above statement is not an endorsement nor a recommendation that no old growth retention is required on the FMA. Old growth stands do occur throughout the FMA, but they tend to be scattered small patches. These patches, which have been able to escape at least two fires, tend to prevail in an environment that is conducive to escaping fires, such as moist areas found in depressions or gullies, or against a natural fuel break. Such stands are most often composed of spruce community types and offer a different biodiversity over the pine ecosystem that dominates this landscape. Old growth conservation on the FMA should thus focus on these island remnants, which are quickly disappearing as they are often targeted for harvesting. It is important to note that the level of simulation detail from the STANDOR program and the 100m resolution used, does not allow to produce small patches of remnants. Also the MFRI outputs came from averaging 10,000 years of fire data, so any island remnants that could have formed for a few centuries would eventually disappear from averaging fire frequencies.

In terms of forest retention, at this time over 30% of the FMA land falls in the passive category where forests may never be cut due to a variety of reasons. However, in the future, some passive areas may change status and become part of the active landbase (e.g. currently unproductive sites). Table 6-2 shows the number of hectares necessary to exclude from logging in order to meet the percent retention of old forest based on the PIC MFRI thresholds established in Table 6-1. The lower and higher old age forest retention percentages of 2% and 5% were used as examples. It can be observed that under the 2% retention scenario, much of the old forest to be retained can be achieved from the passive landbase. That said, the spatial distribution and size of these older forest patches located in the passive landbase would need to be evaluated in order to determine how disjointed these are. A heavily broken up distribution of old patches may not be self-sustainable due to natural disturbances such as epidemics, windthrow or fire, and the ecological needs for species survival (e.g. vegetation and wildlife) could be challenged.

Table 6-2 Number of ha of land required to maintain a 2% and 5% old forest retention using PIC Mean-Fire-Return-Interval thresholds. P = pine, S = spruce.

	B9						Upper B10				Lower B10	
	UF		LF		MT		Sub.		Montane		Sub.	
Old age retention %	S	P	S	P	S	P	S	P	S	P	S	P
Threshold at 2%	200	111	167	125	100	100	250	167	100	83	350	167
Nb. of ha in FMA	328.22	1208.22	296.64	418.32	50.24	210.02	159.64	622.26	171.38	704.28	383.44	457.3
Nb. of ha in passive	810	1104	171	251	10	39	285	443	22	291	358	237
Deficit	481.78	-104.22	-125.64	-167.32	-40.24	-171.02	125.36	-179.26	-149.38	-413.28	-25.44	-220.3
Threshold at 5%	167	91	143	100	91	91	200	143	83	71	350	143
Nb. of ha in FMA	820.55	3020.55	741.6	1045.8	125.6	525.05	399.1	1555.65	428.45	1760.7	958.6	1143.25
Nb. of ha in passive	810	2159	171	251	129	164	285	443	64	1190	358	237
Deficit	-10.55	-861.55	-570.6	-794.8	3.39	-361.05	-114.1	-1112.65	-364.45	-570.7	-600.6	-906.25

6.2 Annual Disturbance Rate

Mean-fire-return-intervals indicate how frequently a parcel of land is expected to be disturbed. In order to determine the annual rate of disturbance, the land that falls within each MFRI class must be recorded. For example, if 10,000 ha are under a 50-year mean-fire-return interval, 200 ha of land would need to be disturbed annually within the spatial boundaries of that class to achieve this rotation.

Due to fire suppression, there is currently an imbalance towards older aged forests and there is a significant natural disturbance deficit that can be addressed to some degree with harvesting. Calculation tables to estimate the annual number of hectares disturbed during the PIC era and the total disturbance deficit (as of today) were not computed for this exercise. Since PIC era disturbance rates would have been much greater than current rates of disturbance from harvest, emulating the PIC era disturbance rate would be socially unacceptable and unsustainable over the long-term from a harvesting perspective. For example, in the B9 FMU alone, 1,905 ha of forest would need to be cut annually to match the disturbance rate for the land under the 50 year MFRI. Another 663ha would also need to be cut to maintain the forest that is under the 100 year MFRI, and so forth. Focussing harvesting activity repetitively in young stands (less than 40-60 years) to emulate short intervals would also be economically unsustainable on this dry site of the Rocky Mountains where tree growth rate is slow.

6.3 DISTURBANCE SIZE

It was found that the vast majority of natural wildfires were much greater in size than the typical socially acceptable harvest block (i.e. 100 ha) (Section 5.4). Overall, the bulk of fires ranged in size from 11 to 5000 ha across the entire FMA. 79%, 65% and 68% of wildfires were greater than 100 ha, within B9, Upper B10 and Lower B10 FMUs, respectively. In order to bridge the gap between the size of harvest blocks and those created by wildfire, a harvesting strategy that builds on the same harvested area year over year, (e.g. over a period of 10 years) would be a potential strategy. In this regard, the perimeter of the cutblock would simply increase every year while leaving a patchwork of island remnants within the perimeter. This patchwork would create and address requirements for connectivity between wildlife corridors and riparian areas, as well as old growth retention. The effect of topographic features and fuel cover type on fire behaviour would also play an important role in determining the size and distribution of these island remnants. For example, gullies are often protected from burning as are stands that are on the wind protected side of natural fuel breaks, such as rocky ridges. Tree line and the first couple kilometers of valley headwaters are most often conducive to forming large patches of fire refugia. The rate of fire spread also drops significantly on flat landscape and any features such as hydric meadows, water bodies or strongly meandering water courses can produce island remnants. Lastly, a strong component of deciduous trees near coniferous stands can work as natural fire guards shortly after the leaf-out period and when the grass is lush and thick. These stand conditions can reduce the rate of fire spread, thus producing potential for island remnant formation or scattered remnant trees.

The approach of focussing harvesting on one watershed over a sustained period of time limits logging road access and human interference on wildlife, while alleviating pressure on other areas. Further, the total disturbance edge and total kilometre of road construction get reduced, and road reclamation could be done more efficiently.

6.4 PATTERNING

Patterning can be described as the level of intricacy of a boundary (number and smoothness of angles) and the abundance and size of remnant patches left within a disturbance. The goal is to reproduce patterns that are reminiscent of those created by wildfires during the PIC era. This is an important point to stress because other studies that have looked at island remnant distributions have used recent fires, which burned under more severe conditions due to fuel build-up (Andison 2004). Andison's results could be assessed for potential application in the Subalpine subregion of Lower B10 because there are similarities between the fire regimes. However, burning severities under short fire intervals, as documented in the Upper B10 and B9, do not fit the profile of Andison's landscape and thus should not be applied to these portions of the SLS FMA.

As explained in Section 5.5, island remnants produced from natural wildfires are unique due to a range of uncontrollable factors (fire weather) and controlling ones (topography, fuel type), which can equally affect fire behaviour. In the context of forest planning and creating anthropogenic age mosaics, the distribution of island remnants must be tailored to the terrain and the environment, and incorporate PIC era patterning schemes. For the Foothills natural subregion of the FMA, and for the PIC era, no statistics exist on number of island remnants produced by wildfire size category and what percent of tree removal within stands should be executed. Therefore there are no real adequate guidelines which Spray Lake Sawmills can draw from. The desired outcome will need to result from a skilled forester that is able to create designs that have a natural visual appeal while contributing to the ecological functioning of the watershed (water quality, habitat, corridors) and forest stands (coarse woody debris, recruitment, target species habitat).

Much of the patterning in the rugged subalpine landscape (south of the Highwood River) will be dictated by topographic features that will determine where retention patches should fall. For instance, wildfires that burn on steeper slope gradients have an increased fire spread and greater fire intensities, which in turn are not conducive to forming island remnants at mid-slope. From personal observations and twenty years of work in the mountains, island remnants are most likely to form along treeline, in steep gullies, in meandering bends of creeks and rivers, and at the headwaters of drainages. These zones happen to coincide with factors that often exclude harvesting due to terrain constraints / or riparian buffers.

Implementing patterning in the Foothills and Montane natural subregions requires great skill and artwork. The pre-industrial forest conditions showed that the entire forest matrix was comprised of an intricate pattern of stands as a result of short fire intervals, lower fire intensities and overlapping fires. At this time, there is no quantitative data that capture the level of intricacy of the age mosaic. Designing patterns can be inspired from the 1950 aerial photography, as well as the Legacy photos from the turn of the 19th century. Quantitative data on the percent landbase that sees full or partial stand replacement could be evaluated by running a spectral image analysis on key 1950 aerial photos as an option for further research. This methodology was applied to the Chinchaga region of the boreal forest with some success (Rogeau 2008). The process would consist of choosing 5 sampling areas of 5 km x 5 km along the Foothills within the FMA boundary. The spectral image analysis can depict the variety of image tones in clusters of pixels and provide the relative quantity of age-classes present. The more tones that are depicted means more scattered clusters of remnant trees. A four-class classification system can be used: 1) < 25% of trees remain, 2) 26 to 50% of trees remain, 3) 51 to 75% of trees remain and 4) >75% remain. The proportion of trees that remained after burning would be translated into the proportion of trees that need to be retained in a harvest patch. While historically forests were frequently thinned out by fire, selective logging to thin out mature lodgepole pine stands is not necessarily advocated. This process could be incorporated on an as needed basis when immature pine stands require thinning management.

Patterning can also include the removal of any island remnants within younger aged-stands, a common practice in the forest industry. In light of findings from this research, and years of field observation, spruce island remnants found in the Montane and Foothills will tend to fall within the end tail of the age-class distribution. Some of these island remnants, while not always extremely old, can be characterised as old growth when found in a PIC fire regime that was driven by recurring fires every 15 to 50 years. Because of the ecological significance of some of these island remnants, it would be recommended to filter out smaller size patches. In that regard, a threshold size of island remnants would need to be established based on wildlife requirements and resilience ability for an old forest to self-maintain. It is recommended to seek the advice of an expert and do a literature search on the matter. An interesting point is that probabilities of burning decrease when travelling from the edge of the island remnant to its centre. Field observations have shown that trees are increasingly older as one samples from the edge to the centre of an island remnant. These longer fire return intervals create unique ecosystem processes associated with old-growth forests. Thus, preserving the centre of island remnants with a decent buffer is an essential point to safe guarding old growth forests. From field observations, such processes are most visible for island remnants that are at a minimum 200m x 200m (4ha). Under this assumption, if such an approach was to be implemented, only those island remnants that are much larger in size could be considered for harvesting as a 4 ha core would need to be preserved. The relevance of this practice is further explained in Section 6.5.1, which deals with age-class departure.

6.5 Seral-Age Distribution

PIC age-class distributions are incorporated in the long-term forest planning process to help balance the distribution of young, mature and old-growth forest within each broad fuel cover type. As part of the stand origin simulation exercise, mean age-class distributions produced by fuel cover type for each natural subregion, were lumped into seral classes. The percent landbase thresholds per seral stages can be found in Section 5.3.3. Theoretically, if the PIC annual rates of disturbance associated with PIC MFRIs were to be implemented, they would yield the identified seral age-class distributions.

Fuel cover types have different probabilities of burning due to their growing locations, and environmental and physiological features that can make them less vulnerable to fire. The seral age distributions by fuel cover type have captured these differences to some degree and they can help determine the proportion of pine, spruce, mixedwood or aspen forests to be targeted for harvest in each seral class.

In that regard, the spatial Mean-Fire-Return-Interval map and mean stand origin map can be useful in managing and distributing harvest blocks as they indicate the differences in disturbance frequencies observed among fuel types. For example, spruce forests tend to burn less frequently and should be found pre-dominantly in older stand origin classes and longer MFRI groups.

Today, as a general rule, 40 to 70% of the landscape is departed from its Pre-Industrial-Condition. The removal of fire contributed to a flat line aging of 80 years across the entire FMA. There is now an important imbalance in the age-class distribution that is skewed towards the mature seral stage (not to be confused with old growth). This shift has occurred to the greatest extent in the Foothills and Montane. Thus, harvesting should be prioritized in forests that are less than 150 years old for conifers and less than 130 years old for deciduous and mixedwood fuel types. Old growth forest ecosystems are not departed, but were likely never abundant to begin with in this type of fire regime. Forest management should aim to respect the percent landbase thresholds (keep within the standard deviation around the mean) established in the seral age distributions.

6.5.1 AGE-CLASS DEPARTURE

The purpose of this sub-section was to identify differences between the current and PIC seral age-class distributions. The "current" distribution used was the Time Zero benchmark year of 2012 from which SLS has been doing it's forest management planning and forecasting. The series of tables below portray the percent seral age distributions. For the PIC era, it is the average from 10 sets of stand origin simulations, including the standard deviation around the mean (STD). The deficit data entry represents the difference between Time 0 and PIC, and the departure represents the proportion of the deficit in comparison to the PIC value..

The deficit/departure from the pre-industrial conditions was colour coded based on the level of deficit in relation to the PIC average (AVG) and PIC standard deviation (STD). It must be taken into consideration that because a small number of simulations was carried out (i.e. 10), some STDs are quite broad and can be larger than the average itself. This indicates the wide level of variance in stand age distribution despite keeping a homogenous fire regime. The STD suggests that some large wildfires could eradicate an entire seral age-class. This is not however a desirable outcome and one must keep in mind that a computer model cannot address with certainty all the complexities that a fire environment entails. Values coded in red are highly departed, beyond the natural range of variation from PIC conditions. Values coded in orange are within the STD, but are still considered moderately departed and should be tracked closely. Values coded in green are within their natural range of variation, and for the old seral age classes, indicate a surplus from PIC conditions.

As a result of fire removal over the last 80 years and a PIC fire regime that favoured short fire return intervals, the greatest departures are found in the young aged forests: 21 to 70 for the conifers, and 21 to 50 for the deciduous types. The regeneration seral age class (< 20 years) also tends to be significantly departed with a lack of regeneration forest across most of the landscape. However, there is one exception for the pine forest cover in the Lower Foothills of FMU B9. In this case, there is a significant departure beyond the natural range of variation with too much regeneration forest, likely as a result of over-harvesting in that region. At the other end of the spectrum, the old seral age class is moderately to highly departed. The most departure tends to be observed in the Montane conifer forests, and most pronounced in the pine cover type for the Lower and Upper Foothills. In general there is too much old forests of the deciduous and mixedwood fuel types.

Some of the departure in the old seral age class can be attributed to two factors. First, the Alberta Vegetation Inventory does not survey and date every single stand. Old aged stands do blend in over time within younger aged forest cover (e.g. 140 year vs 170 year old pine stands will not be noticeable on an air photo) and it is possible that not all old stands have been accounted for. Second, SLS may have been too aggressive in removing the old island remnants.

There can also be departure in the sense that too much forest is found in one seral age-class. This is true across the entire FMA for all of the mature seral age-classes (71-170 and 51-110). There is one instance on the FMA where too much old forest exists, and its extent goes well beyond the

STD. The Upper Foothills of the B9 FMU sees too much old spruce. This can be explained by the fact that the small Subalpine area was lumped with the Upper Foothills. The Subalpine hosts the longest MFRIs, thus the oldest forests, and due to its topographic location and fire regime, spruce do better in that zone. This pool of old forests, mainly located at the headwaters, has not been harvested to date due to its difficulty of access.

Table 6-3 Comparison of PIC and Time Zero (2012) seral age distributions. Conifers, B9 FMU.

	Spruce					Pine				
					Upper Foothills					
Seral age	**PIC Avg%**	**PIC STD**	**Time 0 %**	**Deficit**	**Departure**	**PIC Avg%**	**PIC STD**	**Time 0 %**	**Deficit**	**Departure**
1 to 20	27.48	13.14	6.30	-21.19	-77.08	34.14	17.10	17.43	-16.70	-48.94
21 to 70	38.73	11.14	1.53	-37.21	-96.06	42.43	15.97	4.14	-38.29	-90.24
71 to 170	23.18	6.79	57.76	34.58	149.17	19.45	6.26	77.60	58.15	299.05
> 170	10.60	6.09	34.42	23.82	224.62	3.98	2.28	0.82	-3.16	-79.30
					Lower Foothills					
1 to 20	27.15	11.46	13.58	-13.57	-49.98	31.62	14.98	67.67	**36.05**	113.99
21 to 70	38.94	15.08	5.17	-33.77	-86.72	43.02	16.10	16.74	-26.28	-61.09
71 to 170	21.24	12.02	74.73	53.49	251.86	16.66	10.99	14.02	-2.64	-15.83
> 170	12.67	7.50	6.52	-6.15	-48.55	8.70	6.32	1.57	-7.13	-81.91
					Montane					
1 to 20	24.47	28.43	0.59	-23.89	-97.61	25.11	25.62	5.87	-19.24	-76.62
21 to 70	33.45	24.42	1.77	-31.68	-94.72	31.12	24.57	0.55	-30.56	-98.22
71 to 170	33.40	16.14	97.65	64.25	192.34	37.84	13.00	93.58	55.74	147.32
> 170	8.68	12.34	0.00	-8.68	-100.00	5.94	6.36	0.00	-5.94	-100.00

Table 6-4 Comparison of PIC and Time Zero (2012) seral age distributions. Deciduous, B9 FMU.

	Aspen					Mixedwood				
					Upper Foothills					
Seral age	PIC Avg%	PIC STD	Time 0 %	Deficit	Departure	PIC Avg%	PIC STD	Time 0 %	Deficit	Departure
1 to 20	31.39	23.54	24.14	-7.25	-23.09	38.66	19.21	24.07	-14.59	-37.74
21 to 50	27.42	21.03	8.01	-19.41	-70.80	33.67	19.33	6.22	-27.45	-81.54
51 to 110	29.28	17.88	45.49	16.21	55.38	19.67	14.10	36.11	16.44	83.60
> 110	11.91	9.76	22.36	10.45	87.68	8.00	7.07	33.60	25.60	320.00
					Lower Foothills					
1 to 20	17.78	8.40	3.43	-14.35	-80.73	31.54	15.58	10.58	-20.96	-66.46
21 to 50	24.85	19.30	3.56	-21.29	-85.67	31.40	21.28	3.28	-28.11	-89.54
51 to 110	25.32	13.01	52.65	27.33	107.90	15.75	12.56	62.18	46.43	294.69
> 110	32.05	9.38	40.36	8.31	25.94	21.31	11.53	23.96	2.65	12.43
					Montane					
1 to 20	23.99	29.28	0.48	-23.50	-97.98	25.07	30.81	0.47	-24.60	-98.11
21 to 50	31.20	29.89	0.62	-30.58	-98.00	36.50	28.10	0.00	-36.50	-100.00
51 to 110	30.79	23.79	91.27	60.48	196.46	23.04	15.33	82.01	58.97	255.96
> 110	14.03	21.01	7.63	-6.40	-45.63	15.39	25.79	17.52	2.13	13.81

Table 6-5 Comparison of PIC and Time Zero (2012) seral age distributions.

Conifers, Upper B10 FMU.

	Spruce					Pine				
					Montane					
Seral age	PIC Avg%	PIC STD	Time 0 %	Deficit	Departure	PIC Avg%	PIC STD	Time 0 %	Deficit	Departure
1 to 20	31.90	17.09	9.24	-22.66	-71.03	34.63	17.76	17.91	-16.73	-48.29
21 to 70	46.51	17.26	1.56	-44.95	-96.65	47.57	16.76	5.64	-41.92	-88.14
71 to 170	18.67	9.55	85.16	66.49	356.14	15.74	7.63	76.34	60.60	385.02
> 170	2.91	2.85	4.03	1.12	38.46	2.06	1.43	0.11	-1.95	-94.86
					Subalpine					
1 to 20	28.50	12.72	3.80	-24.70	-86.68	30.67	13.79	1.96	-28.71	-93.62
21 to 70	37.13	12.57	0.47	-36.66	-98.75	40.36	10.95	3.63	-36.73	-91.01
71 to 170	21.29	6.29	82.40	61.11	286.97	20.28	7.42	94.07	73.79	363.82
> 170	13.08	4.47	13.34	0.26	1.99	8.69	3.22	0.35	-8.35	-96.01

Table 6-6 Comparison of PIC and Time Zero (2012) seral age distributions.

Deciduous, Upper B10 FMU.

	Aspen					Mixedwood				
	Montane									
Seral age	PIC Avg%	PIC STD	Time 0 %	Deficit	Departure	PIC Avg%	PIC STD	Time 0 %	Deficit	Departure
1 to 20	26.25	15.99	2.07	-24.18	-92.12	34.40	18.41	5.81	-28.59	-83.11
21 to 50	27.40	16.91	1.47	-25.93	-94.65	27.44	13.67	0.98	-26.46	-96.43
51 to 110	29.27	16.42	70.03	40.76	139.24	26.78	19.76	54.61	27.82	103.89
> 110	17.08	15.02	26.43	9.36	54.80	11.38	10.09	38.60	27.22	239.10
	Subalpine									
1 to 20	38.09	19.05	0.00	-38.09	-100.00	45.28	20.87	0.08	-45.20	-99.82
21 to 50	15.77	8.12	0.00	-15.77	-100.00	24.25	13.73	0.00	-24.25	-100.00
51 to 110	19.63	21.33	59.63	39.99	203.72	22.83	15.56	63.79	40.96	179.40
> 110	26.51	10.01	40.37	13.87	52.31	7.64	5.51	36.13	28.49	372.82

Table 6-7 Comparison of PIC and Time Zero (2012) seral age distributions.

Conifers, Lower B10 FMU.

	Spruce					Pine				
	Subalpine									
Seral age	PIC Avg%	PIC STD	Time 0 %	Deficit	Departure	PIC Avg%	PIC STD	Time 0 %	Deficit	Departure
1 to 20	16.99	13.89	11.45	-5.54	-32.60	23.25	15.81	3.30	-19.95	-85.82
21 to 70	42.64	12.49	1.03	-41.61	-97.58	46.73	11.76	5.15	-41.58	-88.98
71 to 170	26.20	14.19	65.71	39.51	150.78	25.06	9.99	87.93	62.87	250.87
> 170	14.16	5.26	21.80	7.64	53.95	4.96	3.12	3.63	-1.33	-26.89

Table 6-8 Comparison of PIC and Time Zero (2012) seral age distributions.

Deciduous, Lower B10 FMU.

	Aspen					Mixedwood				
	Subalpine									
Seral age	PIC Avg%	PIC STD	Time 0 %	Deficit	Departure	PIC Avg%	PIC STD	Time 0 %	Deficit	Departure
1 to 20	25.58	19.44	0.00	-25.58	-100.00	38.06	27.56	0.00	-38.06	-99.99
21 to 50	35.81	25.71	0.00	-35.81	-100.00	36.38	21.74	0.00	-36.38	-100.00
51 to 110	22.98	16.76	96.69	73.70	320.69	18.28	15.12	86.84	68.56	375.01
> 110	15.63	17.82	3.31	-12.32	-78.80	7.28	8.36	13.16	5.88	80.85

It is recommended that SLS creates an inventory of its old-aged patches of island remnants in order to determine their spatial dispersion and what percentage of islands is left to date. Retention of old aged and old growth forests within the Montane and Foothills should preferably be focussed on island remnants. Due to their scarcity, a number of these islands could be permanently retained, while others could be part of a rotational harvesting scheme. Particularly in the Montane and Foothills, island remnants survive for a reason. An attempt at "growing" old forest for future retention, in a random approach over the course of a few hundred years, may prove to be a futile exercise on a landscape that is fire prone. The best approach would be to facilitate the regeneration of old age stands on the same locations that they were cut. However, there is never any guaranteed results. As stands get older they can become more fire "proof" due to moister conditions from fuel buid-up, and they tend to have the ability to escape fires of moderate intensities. Young stands (i.e. the regeneration of an old patch that was cut) surrounded by dense forests of mature pine trees may not fair so well under today's fire regime that fosters higher fire intensities and severities. This stresses the need for allocating old-aged island remnants and listing them on the list to be permanently retained and be moved on to the passive landbase.

6.6 FUEL COVER TYPE

As a final note, the fire regime simulation model used cannot account for forest species change over time. It was today's forest cover types that were used for the PIC fire regime modelling under the assumption that species distribution was very similar historically. Pine forests were maintained from short fire intervals, and current pine forests have still not succeeded to spruce types. Spruce types dominate in more humid areas, in headwaters of watersheds, and along north facing slopes where fire intervals are greater. Aspen stands remain prevalent at lower elevations near grasslands areas. While aspen trees are shade intolerant and thrive well after fire, photos from early explorers and aerial photography from circa 1950 did not indicate that the range of aspen forests is different now than it was historically. Aspen forests should have been able to expand further to the west as a result of the very short fire intervals, but this was not observed. This is an indication that soil and/or climate conditions are not conducive to their dispersion, or that there were other agents, such as heavy grazing, that may have impeded their expansion.

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APPENDIX A: FIRE REGIME MODELLING

The model and data layer descriptions are largely adapted from the Fire Regime Analysis report that was produced for Kananaskis District and Spray Lake Sawmills by Rogeau in 2004. For this PIC project, the model was re-calibrated specifically to resolve old issues with the fuel type map and allow for the evaluation of Mean-Fire-Return-Intervals and age-class distributions by fuel cover type. Calibrations also took into consideration new fire history field data that was collected in 2004 and 2005, after the original simulations were performed.

A.1 General

The stand origin modelling technique used to study fire distribution patterns over the landscape is thought to be a reasonable approach for areas with limited, or lack, of stand age polygon information. As a general rule, fire history data has its own set of limitations which include: an insufficient amount of fire evidence due to the overlap of fires over time, life expectancy of trees sometimes being shorter than the fire return interval, poor quality of tree samples for accurate dating (rotten cores), restricted access and, the inability to sample every single stand due to the time and cost of such research. However, the greatest drawback of the stand origin mapping technique is that we are limited to a single snapshot in time, which amounts to a sample of one, of a landscape that has been shaped for thousands of years by fire. The modelling approach becomes a good complementary technique as it provides a series of stand origin maps and stand age distributions from which basic statistics (average, standard deviation, minimum and maximum) can be drawn. The strongest asset of the STANDOR[4] model, used in this study, is its ability to keep track of the sizes of burned areas before being over-burned or partially re-burned. This feature allows managers to obtain the range of variation in fire size and to calculate the true fire cycle. Another useful feature of the model is that it allows the user to keep stand age information only for areas of interest, such as natural subregions.

A.2 STANDOR Model: How it Works

STANDOR is a landscape disturbance model that uses real fire size and frequency statistics typical of an area in order to emulate its long term fire distribution patterns. It distributes fires over the landscape in a randomly "adjusted" fashion that accounts for differential spatial probabilities of ignition. To do so, a "likelihood of getting an ignition" map must be developed. This map is based on the knowledge of historical human use, spatial density distribution of lightning strikes and lightning fire occurrences specific to the study area.

Fire growth is achieved in two ways depending on the burning season: summer or spring/fall. The first one is based on a fuel map that has no factor limiting fire growth, aside from pixels designated as non fuel which will not support fire spread. In this case, every pixel representing fuel has an equal chance of burning. This burning strategy can be used on flat landscapes, or when fire weather indices are high enough that fire will spread without regard to aspect and elevation. For the

[4] STANDOR is a fire growth model that was developed by New-Brunswick based RemSoft Inc (Ugo Feunekes) in 1994 (Rogeau et al. 1996) and is the proprietary design of Wildland Disturbance Consulting (i.e. Marie-Pierre Rogeau).

spring/fall burns, the other way of growing fires on the landscape is based on topography driven probability values of fire spread. In the mountains, the spread of spring and fall fires are frequently influenced by topographic components such as elevation and aspect. In early June for example, fuels located on low and southwest facing slopes in mountainous terrain are often available for burning, while there can still be a meter of snow above 1800 meters on north and east facing slopes. This differential drying process of fuels largely controls fire spread in the mountains during the spring and fall months.

STANDOR allows the user to modify the fire regime up to five times per simulation by varying the probability of ignition map and range of fire frequencies by time period. This system can allow for the modelling of fire regimes under different climate change scenarios, which can produce more or less fires, or by modifying the probability of ignition map according to levels of human use on the landscape, which may change through time. In the case of the Pre-Industrial Forest Conditions modelling, only one variant of the fire regime was considered.

The length of the simulation was set to 1000 years, and the time-step period was set to 10 years, to produce 10-year age-class distribution outputs. A range in fire frequency by decade (to match the time-step period), derived from fire history data and observations from historical aerial photography, was one of the key inputs to replicate PIC forest landscapes. Fire size was governed by the fire growth module, which uses equations from the Canadian Forest Fire Behaviour Prediction System, fuel type, fuel availability, slope, number of daily burning hours and maximum number of days fires are permitted to grow. The intervals between fires on a per pixel basis, was set to 10 years. This means that within the same decade, or during the same time-step period, a forest pixel could not re-burn, but it could in the following decade.

For each simulation the model produces a fire frequency map, a stand origin map, and an age-class distribution. The model also keeps track of the number of fires per time period and the burn area associated with each fire. This feature is critical to calculating the simulated fire cycle.

Model algorithms for fire ignition, spread and extinction

1. Randomly select the number of fires for the time period. This is defined by the minimum and maximum fire frequency range.

2. Verify the likelihood of a randomly selected pixel being affected by fire (using the probability of ignition map). If the random number is smaller or equal to the probability of ignition value, then a fire starts. Repeat step 2 until a pixel can support a fire.

3. Verify the fuel type. If the pixel is categorized as non-fuel, repeat step 2 and 3 until the pixel is coded as fuel.

4. Verify the lapse time since the last fire. If fuel is not yet available for burning, repeat step 2 to 4.

5. Verify in which weather zone the fire will start. Then randomly pick a start date within the appropriate weather zone from the fire weather database.

5.1 If the date of ignition is not during the summer fire season, then the probability of burning (p_burn) map will be chosen to determine fuel availability.

a) determine the valley orientation for initial fire spread during Day1. The fire has a 50/50 chance of spreading in either valley direction.[5]

b) determine the probability of burning of adjacent cells by looking at their fuel type, time-since-last fire and p_burn value. If it is not available for burning, repeat step 2 to 5. The p_burn of adjacent cells is determined by comparing their p_burn value to that of the ignition pixel. If their p_burn value is less than that of the ignition pixel, then the fire doesn't spread in that direction.

c) repeat step 5.1b) until fire weather values are too low to support a fire[6], or until the allowable burning time has expired, or until there is no fuel available to burn.

5.2 If the date of ignition chosen falls during the summer months, then no p_burn map is used, which means that there are no burning restrictions.

a) determine the valley orientation for initial fire spread during Day1. The fire has a 50/50 chance of spreading in either valley direction.

b) fire burns until fire weather values are too low to support a fire, or until the allowable burning time has expired, or until there is no fuel available to burn.

6. Repeat step 2 to 5 until the number of fires chosen for the time period (step 1) is reached.

7. Before starting a new period, verify if the fire regime has changed in order to select the appropriate database for the fire frequency and probability of ignition map.

8. Repeat step 1 to 7 for the length of the simulation divided by the length of the time period. For example, the whole process will be repeated 100 times in a 1000-year simulation using a 10-year time step.

[5] The direction of fire spread is difficult to manage due to the fact that weather stations, where the fire weather data is extracted from, can be many kilometres away from the location of burning fires. Further, in mountainous terrain there is the possibility that the wind direction may be different than that of the valley where the weather station is located. By using a valley orientation map for the first day of burning, it over-rules the wind direction input from the fire weather database and makes the spread of fire a bit more realistic.

[6] The rate of spread is determined by the FFMC (fine fuel moisture code) and wind speed. The minimum rate of spread is set to be of 1 m/min. Stand replacing fires are set to occur on days with BUI (build-up index) values greater than 60 or 70 depending on the region modelled.

A.3 Fire Modelling Regions

When different fire regimes are pooled, as would be the case for modelling a large landscape, it is difficult to address the average fire size which can be greater in one region than the other. It also becomes more difficult to apply the proper fire frequency. When probabilities of ignitions vary widely across a landscape, a portion of fires meant to burn in regions of lower fire frequencies undoubtably end up in regions of high probabilities of ignition. This skews the fire regime by increasing the fire frequency in some regions, while reducing it in others to levels that are atypical of the natural historical fire regime. It was thus found that dividing the landscape into smaller regions that share similar fire regime characteristics yield map outputs that are more realistic to conditions observed.

The fire regime regions represent groupings of contiguous watersheds that share similar topographic and fire characteristics. These groups were identified by using information from the 1950 aerial photo screening process (Rogeau 2004) and fire frequency information from the fire history study (Rogeau 2005a, 2006). Three clusters of watersheds were identified as described in Table A-1. As focus was put on one portion of the FMA at a time, the fire modelling window was reduced to an area that included roughly a 5 to 15 km buffer around the fire regime regions. Figure A-1 shows the outline of the modelling windows, while Figures A-2a), b), c) show the outline of targeted watersheds or "mask" region for which fire simulation data was recorded.

Table A-1 List of watersheds assigned to each fire modelling region.

Fire Modelling Region	Watershed name and id numbers
B9 FMU: Upper Foothills, Lower Foothills and Montane-North NSR	1- Red Deer , 2- no name, 3 & 4- N. Burnt Timber, 5- Pinto, 6- Pretty Place, 7,8 & 9-Fallen Timber, 10- Grease, 11- Harold, 12-Little Red Deer, 13-U.Waiparous, 18- Grease, 19- Johnson, 20 -Meadow, 21- L. Waiparous, 22-Owl & Loblaw, 23-Rabbit, 24- no name, 103 -Lesueur, L. Ghost, 104- Joshua, 105- Baymar, 106- Dogpound, 107 & 109- L. Little Red Deer, 108- L. Grease, 110- Turnbull, 111- Silver, 112- L. Fallen Timber, 113- Big Prairie, 114-Nitchi, 115- L. Red Deer, 116- Brown, 117- no name, 118- Smith, 119- Walton, 120- Bearberry, 121- Barry
Upper B10 FMU: Montane-South, Subalpine NSR	36- Lusk & Stony, 37- Sibbald, 38- Jumpingpound, 40-Coxhill, 41- Moose, 42- Bragg, 55- Canyon, 56- Prairie, 57- M. Elbow, 58- L. Elbow, 59- Silvester, 60- Quirk, 61- Fish, 62- Fisher, 63- Three Point, 64- Ware, 65- Three Point & Volcano, 76- Gorge, 77- M. Sheep, 78- Death Valley, 79- Coal, 80- Dyson, 86- Sullivan, 87- L. Sheep, 88- Wolf
Lower B10 FMU: Subalpine NSR	84- U. Highwood, 85- Trap, 89- Odium, 90- Loomis, 91- McPhail, 92- Carnarvon, 93- Baril, 94- Etherington, 95- L. Cataract, 96- L. Highwood, 97- Greenfield, 98- Perisko, 99- Salter, 100- Wilkinson, 101- Cataract, 102-Lost & Cummings

A.3.1 B9 FMU Region

This region is bound to the north by the Red Deer River watershed and to the south by the Ghost River watershed. The western portion of the FMU represents Upper Foothills landscape and is largely dominated by conifers, while the east portion falls within the Lower Foothills Natural Subregion and sees an increased amount of aspen and mixedwood patches among conifers. The southern portion of the FMU, including the Lower Wapairous and Lower Ghost watersheds, exemplifies a Montane setting that is largely dominated by conifers with some aspen and mixedwood forests on the south fringe. The headwaters of the western watersheds are bound by rocks in a subalpine environment, but they fall outside of the FMU. The contiguous valleys within the FMU have an uninterrupted forest cover and are more likely to see larger size fires.

A.3.2 Upper B10 FMU Region

This modelling region encompasses the land between the Jumpingpound and Sheep watersheds. The western edge falls within the Subalpine natural subregion, while the east is made up of Montane type landscapes (formerly Lower Foothills). The subalpine environment is only bound by rocky ridges at the headwaters of watersheds. The contiguous valleys within the FMU have an uninterrupted forest cover and are more likely to see larger size fires. This region is largely composed of pine/spruce forests with a concentration of aspen stands along the Sheep River, the east end of the Ware Valley, most of the Death Valley and, the Lower portion of the Sheep watershed.

A.3.3 Lower B10 FMU Region

All watersheds draining into the Highwood River were grouped to form this modelling region that is entirely in a subalpine setting. It is dominated almost equally by pine and spruce forests, the latter of which being concentrated towards the headwaters of each watershed.

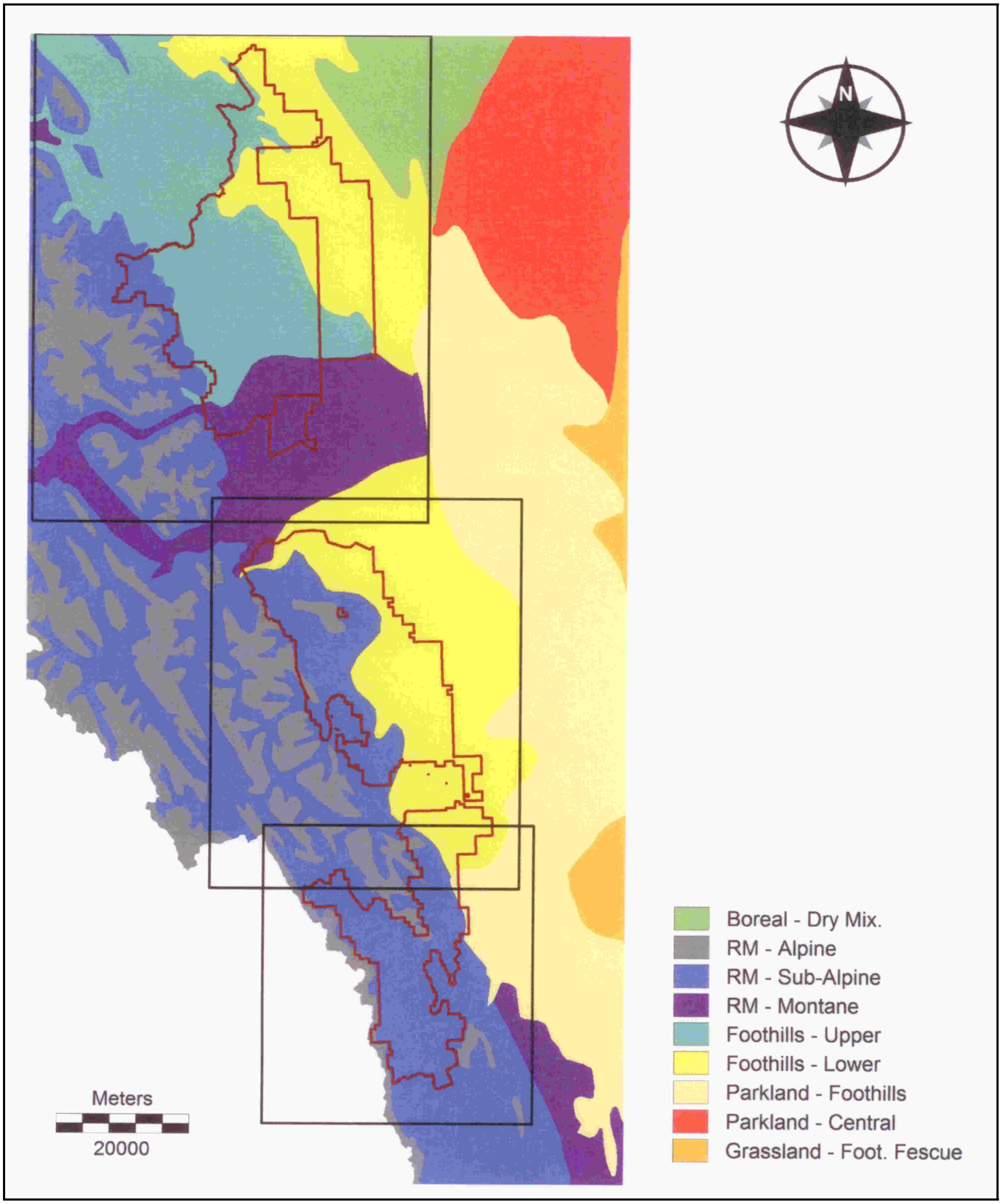

Figure A-1 Fire growth simulations were carried out by windowing in on three separate regions of the Spray Lake Sawmills FMA as shown by the frames.

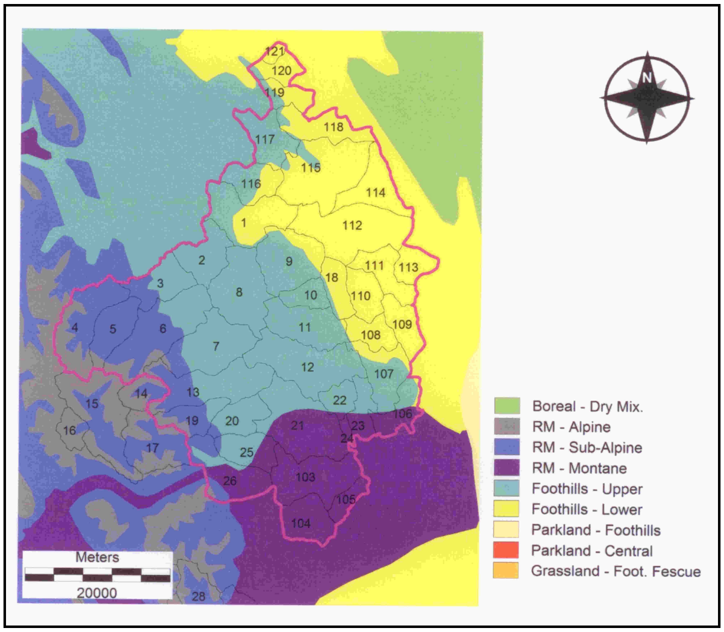

Figure A-2a Outline of the B9 FMU Region (pink). Thinner black lines represent watershed boundaries with their ID number.

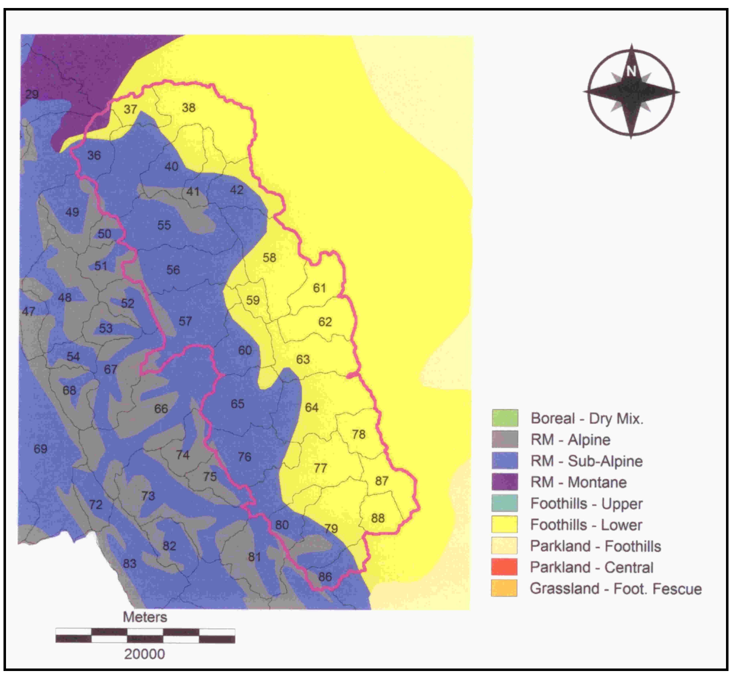

Figure A-2b Outline of the Upper B10 FMU Region (pink). Thinner black lines represent watershed boundaries with their ID number.

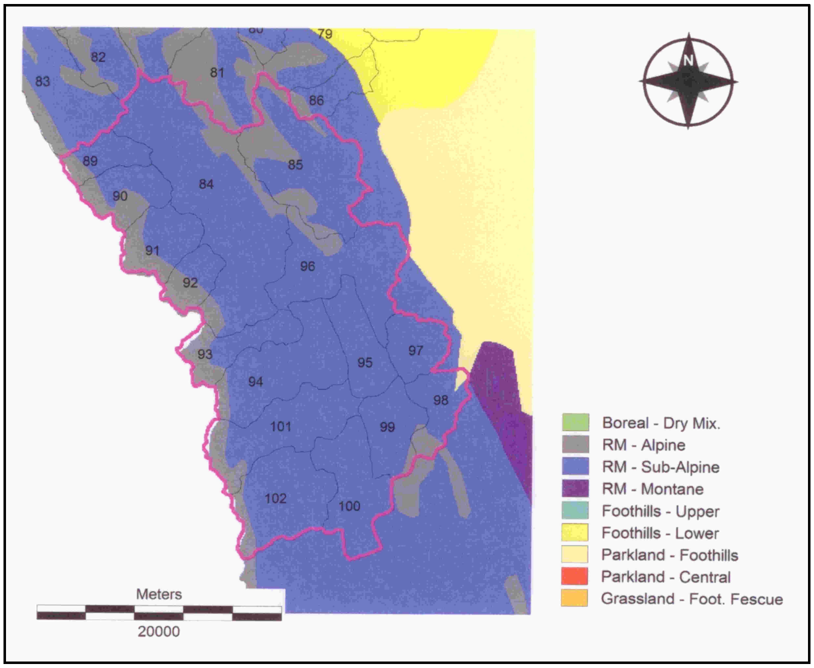

Figure A-2c Outline of the Lower B10 FMU Region (pink). Thinner black lines represent watershed boundaries with their ID number.

A.4 DATA LAYERS

A set of map layers is needed to run the model, as well as information on fire frequencies and distributions that are specific to each fire modelling region. Note that all GIS raster layers that were originally created at a 20m resolution for the fire regime analysis (Rogeau 2004), were converted to 100m resolution to use with STANDOR. This is a necessary procedure to allow for the fact that the program was written under the old MS-DOS technology and that the size of the landscape at 20m resolution contains too many rows and columns for the program to process. Despite the coarser resolution (1ha or 100m^2), it is largely sufficient for forest management planning considering that computer modelling is not a precise science, but a supplemental tool to understanding the fire regime.

A.4.1 Fuel type map

This map represents the type of forest fuels as described by the Canadian Forest Fire Behaviour Prediction System (CFFBS) (Forestry Canada 1992). The model uses formulas from the CFFBS to calculate the rate of fire spread based on a combination of these elements: fuel type, slope, wind speed, FFMC (Fine Fuel Moisture Code) and BUI (Build-Up Index). A total of 10 fuel type categories can be found on the Spray Lake Sawmills FMA (Table A-2 and Figure A-3).

Modifiers had to be applied to the fuel type map to allow for realistic burn patterns and fire intervals. Cut blocks often typed as grass, or slash, or immature pine were given their original fuel type when known[7]. If unknown, it was arbitrarily given the Fire Behaviour Prediction C3 fuel code (mature pine) as this is the prevailing fuel on the FMA. Cut blocks located at the northern tip of the FMA in significant areas of prevailing spruce, were manually reclassed as such. Roads and oil and gas sites were reclassed either as pine or grass, and the 2001 large size Dog Rib fire was reclassified as mature pine.

It was observed from long-term fire regime simulations that the C2 fuel type (boreal spruce) produced shorter fire return intervals and younger aged forests than the C3 mature pine fuel type. This is contrary to field observations where spruce forests can become significantly older than pine, especially in rugged terrain. It was found that most patches of remnants dating from the 1700's in the Upper Foothills were largely associated with spruce types in micro-depressions that tend to remain moist. It is important to stress that Fire Behaviour Prediction fuels, and their associated rate of fire spread equations, were developed in boreal forest types located in the Northwest Territories. Modifiers such as switching fuel types, or calibrating FFMC and BUI fire weather values, are often necessary to achieve the desired outcome. Thus, the C2 fuel type was replaced with C1, which has a lower rate of combustion and is more difficult to ignite. While not perfect, it did achieve the desired outcome of producing longer fire intervals in spruce forests.

Table A-2 Area (ha) per fuel type category distributed by fire regime modelling region on the SLS FMA.

			Fuel cover type			
NSR	**Spruce**	**Pine**	**Aspen**	**Mixedwood**	**Grass**	**Non-fuel**
			B9 FMU			
Subalpine	3,270	4,753	1	0	495	159
Montane	2,576	11,110	2,968	1,346	4,336	241
U. Foothills	13,145	55,733	2,565	750	9,734	308
L. Foothills	15,262	21,195	9,867	3,008	10,654	126
Sub-total	34,253	92,791	15,401	5,104	25,219	834
			Upper B10			
Subalpine	8,796	31,808	278	109	5,340	1,715
L. Foothills*	8,655	35,365	8,467	1,655	6,802	599
Sub-total	17,451	67,173	8,745	1,764	12,142	2,314
			Lower B10			
Subalpine	19,065	24,855	1,509	466	7,785	792
L. Foothills*	279	3,269	960	176	761	37
Sub-total	19,344	28,124	2,469	642	8,546	829
TOTAL	71,048	188,088	26,615	7,510	45,907	3977

* used the old partitioning of the natural subregions map. The Lower Foothills in the B10 unit are now referred to as Montane.

[7] The cutblock attribute table was re-coded as such. For [Block_Stat] attribute: REFO = C1, HARV = C3. For [Species_Co] attribute: SW = C1, FD = C1, PL = C3.

A.4.2 Elevation map

An unclassified 1:20,000 digital elevation model (DEM) was used as part of a base layer to grow fires on (Figure A-4). Elevation values are used by the model to determine terrain slope and calculate the appropriate rate of fire spread. Rate of spread of fires moving down hill move at the same rate as fires burning on flat terrain. The minimum rate of fire spread in the modelling exercise was set at 1m/min.

A.4.3 Valley orientation map

This map is used to determine the initial direction of burning of the fire during day 1. This feature was implemented because the fire weather data comes from weather stations that can be located in a valley that is under the influence of different valley wind directions from where fires are actually burning. To account for valley wind, the fire has a 50/50 chance of spreading in either direction of the valley. For example, in a valley running west to east, there is a 50% probability that the fire will spread to the east and a 50% probability that it could spread to the west. This map was created by outlining watersheds and assessing each individual valley for their direction of flow. A watershed that had a significant change of direction was parted accordingly. Four directions were considered: NW-SE, NE-SW, N-S and E-W.

A.4.4 Weather zone map and fire weather data

This map is used to outline zones of similar fire weather data. Each zone is linked to either a single or a set of weather stations. This is an important feature for mountain landscapes, as higher elevations portray higher levels of humidity and cooler temperatures, hence reduced FFMC and BUI values. As a result, ignitions at higher elevations may initially not spread as fast as those from lower elevations. The exception to the rule is during the occurrence of temperature inversions, but this phenomenon is not common during the summer time on the east slopes of the Canadian Rockies.

Fire weather zones are set by partitioning the DEM into elevation strata and by outlining zones, or perimeter of influence, for the weather stations considered. The weather zone map created in 2003 for the fire regime simulations (Rogeau 2004), represented five weather zones that took into account data from six weather stations and a land partition using two elevation strata (either below or above 1600m). The partition and allocation of fire weather data by zone were somewhat changed for this exercise and are presented in Figures A-5a,b,c.

During model calibration, it became apparent that the period of data coverage of most stations was too short to capture a wide array of drier weather and droughts to be representative of historical weather conditions where a number of large size spring or fall fires used to occur. Under the available data set, it was most difficult to produce any spring fires of significance because the 1990s were particularly wet in the mountains. It was decided to ignore protocol and simply use the Banff fire weather data, which goes back to 1953, for the entire Upper B10 modelling region. In Lower B10 (Highwood Region), the Banff data was used for elevations less than 1700m, while the Barrier fire weather data was used for elevations greater than 1700m. For the Upper Foothills of the B9 FMU, the Ram Falls weather station, located further north of the FMA, was used in place of

Mockingbird Hill data as it is more representative of this type of landscape. Table A-3 lists the weather stations that were available for use, while Table A-4 summarizes the weather zone and weather data modifiers that were applied in order to achieve burning patterns that produced Mean-Fire-Return-Intervals that were in-line with field observations. Modifiers included the length of the leaf-off period (in Table A-3), and calibration of FFMC and BUI values. Note that all records falling within the spring or fall season were increased so that there would be a ratio of 75% spring/fall days to 25% summer burning days. This calibration was required to induce more frequent burning in aspen stands during the leaf-off period, and to also mimic the timing of real fire occurrences, which tend to prevail during the cured months of the fire season.

Table A-3 Fire weather stations considered for the fire growth simulations.

Station (code)	Lat. - Long.	Elevation (m)	Data coverage	Summer Period
Banff (BF)	51.1667 - -115.5667	1384	1953 - 2003	June 15 - Sept. 1
Kan. Boundary (B4)	50.9278 - -115.1233	1464	1995 - 2003	June 15 - Sept. 1
Bow Valley (XA)	51.0833 - -115.0667	1326	1993 - 2003	June 15 - Sept. 1
Mockingbird Hill (MH)	51.4248 - -115.0707	1907	1974 - 2003	June 21 - Sept. 1
Highwood (B1)	50.3972 - -114.3706	1580	1989 - 2003	June 15 - Sept. 1
Barrier Lake (BP)	51.0481 - -115.0789	2021	1983 - 2003	June 21 - Sept. 1
Ram Falls (R2)	52.0877, -115.8442	1641	1987 - 2009	June 21 - August 21

Table A-4 Description of weather zones and their associated weather stations.

<table>
<tr><th>Modelling Region</th><th>Wx zone</th><th>Description</th><th>Partition zone</th><th>Weather stations</th><th>Modifiers</th></tr>
<tr><td rowspan="3">B9 FMU</td><td>1</td><td>Montane, Lower Foothills</td><td rowspan="3">based on NSR map</td><td>BF</td><td rowspan="3">spring/fall: FFMC+2, BUI + 5 for May & June</td></tr>
<tr><td>2</td><td>Upper Foothills</td><td>R2</td></tr>
<tr><td>3</td><td>Subalpine</td><td>MH</td></tr>
<tr><td>Upper B10 FMU</td><td>1</td><td>Montane, Lower Subalpine</td><td>none</td><td>BF</td><td>none</td></tr>
<tr><td rowspan="2">Lower B10 FMU</td><td>1</td><td>Lower Subalpine</td><td><1700m</td><td>BF</td><td></td></tr>
<tr><td>2</td><td>Upper Subalpine</td><td>>1700m</td><td>BP</td><td>spring/fall: FFMC+2</td></tr>
</table>

A.4.5 Initial stand age map

This is the initial stand age layer used to grow fires on. The entire study area was simply given an arbitrary age of 100 years. At the end of the 1000 year period of simulations, anything that had not burned during that time could easily be tracked down by looking for stands 1100 years of age.

A.4.6 Probability of ignition map

The probability of ignition map represents the chance a pixel has of getting an ignition. The model generates a random number from 0 to 100. If the random number is less than or equal to the p_ignition value of the pixel, then the fire starts. The probability of ignition map that was created attempted to capture probabilities of ignitions from the 1800's and early 1900's, before the land was highly influenced by settlers. That said, a certain amount of influence from anthropogenic activity had to be included in the fire regime simulations because we know that lightning ignitions contribute to only 25% to 60% of all ignitions. As the landscape appears to have been burned repeatedly according to the air photo screening process, we must assume that there were always a certain number of fires ignited by land users. First Nation People have been part of this region and the ecosystem since the retreat of the ice cap, and as such they must be part of the equation when modelling the historical fire regime.

Although this project did not involve an in-depth archival research on land use for the last 300 to 500 years, it is common knowledge that First Nations used the land extensively during that time period, as reported in Chapter 4. To incorporate the risk of ignitions from historical anthropogenic sources, roads that are commonly and highly travelled today (2 lane roads), as well as towns and campgrounds, were taken into consideration. In many cases these roads are located in the same travel corridors that were used by natives, first explorers and fur traders. A modifier was implemented during the model calibration to increase the amount of fire burning between the Elbow and the Sheep Rivers to capture similar fire return intervals as those from the fire history study. Three paths linking the Elbow and the Sheep, the Threepoint and the Sheep, and along the Threepoint River were digitized to increase the likelihood of burning. All paths and roads were attributed a buffer zone of 500m on each side (= 1 km wide) with a probability of ignition of 50%, which was added to the existing probabilities of ignition derived from lightning fire activity. Figure A-6 shows the spatial variation in probabilities of ignition over the FMA from pre-industrial times. With the combination of lightning and anthropogenic sources, probabilities of ignition ranged across the landscape from 8 to 129%. This means that a fire will always take place for cells with probability values greater than 100%. As such, all values above 100% were grouped in the 100% class.

A.4.7 Probability of burning map

Probabilities of burning vary with topographic locations. An extensive study covering the east slopes of the Canadian Rockies (immediately to the west of the Greater Kananaskis District) found that valley orientation, elevation, aspect and distance from the Continental Divide play a significant role in fire distribution and spread in the mountains (Rogeau et al. 2004). Results from this study were borrowed and modified when needed to build a GIS weighing and ranking model that should reflect probabilities of burning further east of the mountains. Partitioning of elevation and aspect data was slightly modified and, the valley orientation variable was discarded because many valleys in the Greater Kananaskis District did not have an orientation assigned to them, and some valley orientations found in this study area were not present in the topography study, and vice-versa. Distance from the Continental Divide was also excluded due to the remoteness of the study area from the Divide. Excluding valley orientation from the probability of burning model is assumed not to have a significant effect on probabilities of burning. As valley orientation is spatially auto-correlated with both aspect (there can only be two prevailing aspects by valley orientation) and elevation, some of the effects of valley orientation on burning patterns are accounted for. During the spring and fall seasons, the fuel drying process and its availability for burning are largely driven by temperature and sun exposure, which are both captured by aspect and elevations.

The spring/fall season is determined in the fire weather database. The length of the summer season in the SLS FMA region varies among natural subregions and elevation (Table A-3). During the summer, all pixels are assumed to have the same probability of burning and no p_burn map is used. For all other dates, the fire spread is determined in part by the p_burn map. For example, if a spring fire starts at low elevation and on a south facing slope, that fire will not be allowed to spread higher than a certain elevation or on to north or east facing slopes. But, if that fire starts at a high elevation or on a north facing slope, it would be able to spread anywhere as other p_burn values would be greater than the p_burn value from the ignition pixel.

Topographic classes were ranked on a scale of 1 to 5, 5 being the highest likelihood of burning. Each variable was also weighed by multiplying the ranked map with a percentage value in terms of its relative influence on fire distribution. Results from the grouping, ranking and weighing process are shown in Table A-5. Each ranked and weighed map was then overlaid and subsequently divided by 5 (the number of ranks) to obtain the p_burn map. These map manipulations can be represented by the following equation:

$$\text{p\_burn} = (0.40*[\text{elevation\_r}] + 0.60*[\text{aspect\_r}]) / 5$$

(r = ranked)

With this model, probabilities of burning range spatially from 20 to 100% (Figure A-7). Warm aspects and elevations less than 1700m scored the highest and had no impact on probabilities of fire spread.

Table A-5 Ranks and weights of topographic groups used to create the probability of burning map.

Aspect (60%)	Elevation (40%)
5: SE, S, SW, W	5: < 1700m
3: NE, E, Flat	4: 1700 - 1800m
1: NW, N	3: 1800 - 1900m
	2: 1900 - 2000m
	1: 2000m+

A.4.8 Mask map

The mask has a value of one for the area of interest and a value of zero for the remainder of the landscape. This map layer is utilised to keep track of the fire frequency by decade. While fires are dropped all over the modelling window, only fires started within the mask, or fires that encroached from the outside, are considered. This feature allows the user to calculate the exact fire cycle for the target zone and to keep track of the range in fire size. For this project, masks were used to focus on watersheds sharing similar fire regime conditions.

A.4.9 Fire size

Fire size is regulated by a number of factors. The greater the BUI, FFMC values and wind speed, the faster the rate of fire spread. To ensure a successful ignition, only BUI values greater than 60 were considered. Crown fire activity is only supported past a break-point value of about 60 for the mountain region. Simulated fires will stop burning when they run out of fuel, but most likely when the number of consecutive days with BUI values greater than 60 stops. During the spring, there are few occurrences of multiple days with sustained BUI values above 60. However, it is not uncommon during the summer period to see dry conditions that last several days to several weeks. In order to keep burn perimeters within realistic dimensions, a maximum number of burning days is required because under a pixel size set to 100m, fires can expand rapidly. The fire growth model was calibrated using a maximum number of burning days set to 5 for all modelling regions. Under these settings the average fire size and maximum fire size produced were in-line with field observations. The fire size could also be calibrated by changing the number of daily burning hours. The standard is to use 1/3 of the day light hours (Table A-6) and this is what was used for these simulations.

Table A-6 Number of day light hours* associated with time of year.

Dates	Day light hours	Dates	Day light hours
April 1 - 13	13	Aug. 12 - 31	14
April 14 - 30	14	Sept. 1 - 11	13
May 1 - 19	15	Sept. 12 - 25	12
May 20 - July 22	16	Sept 26 - Oct. 31	11
July 23 - Aug. 11	15	Nov. - March	10

*Based on day light hour data for the City of Calgary, obtained from www.theweathernetwork.com

A.4.10 Fire frequency

The number of fires that will burn per period (10 years for these simulations) are chosen randomly between a given minimum and maximum fire frequency. Either the actual number of fires sampled by watershed, or the mid-range class of the total number of fires per watershed recorded from the 1950 aerial photo screening process (Rogeau 2004), can be used as a benchmark value to determine an average decadal fire frequency. Following fire history data collection, it was found that the total number of fires identified from data collection for the period between 1700 to 1950, was fairly close to the number of fires identified from the screening process. Hence, it is with relative confidence that the photo screening values can be used to estimate the historical fire frequency during this 250-year period. Because fires cross watershed boundaries, it was also found that about 25% of the fires needed to be discarded to avoid double-counting when tabulating the number of fires for all watersheds in a fire regime modelling region. Table A-7 demonstrates how fire frequency values were achieved. Using this average number of fires per decade, an arbitrary range is assigned in order to capture a realistic range of variations from wet to very dry fire seasons within a decade.

As a side note, it was attempted to use the empirical regional fire frequency value for areas with actual fire history data and documented fire events. However, because many of the fires sampled were very large and expanded across several watersheds, it was found nearly impossible to reproduce such large fires in the Upper B10 FMU with the fire weather data from Banff, which covers the longest period from 1953 to 2003. A large event would occur only about once every 250 years during the summer period. I came to the conclusion that these historical large fire events could burn for several weeks at a time and could easily have 2 to 5, or more, separate fire events where a fire "takes a run" within the same burning season. It was thus decided that Mean-Fire-Return-Intervals would be better captured by using the total number of fires per watershed, and discarding 25% of them to account for simulated burns that do straddle a couple of watersheds. Using this approach, results showed that simulated MFRI were very similar, if not equal, to those recorded from field data.

Table A-7 Evaluation process of fire frequency values for each fire regime modelling region.

B9 FMU
104 fires (from mid-range class) x 75% = 78 fires / 250 years for an area of 59,347 ha (area sampled) = 286 fires / 250 years for a total modelled area of 217,342 ha = 11 fires /10 years, range: 5 - 17
Upper B10 FMU
179 fires (field data) x 75% = 134 fires / 250 years for an area = 66,241 ha (area sampled) = 243 fires / 250 years for a total modelled area of 120,168 ha = 10 fires /10 years, range: 5 - 15
Lower B10 FMU
184 fires (from mid-range class) x 75% = 138 fires / 250 years for an area = 80,472 ha = 138 fires / 250 years for a total modelled area of 80,472 ha = 6 fires /10 years, range: 3 - 9

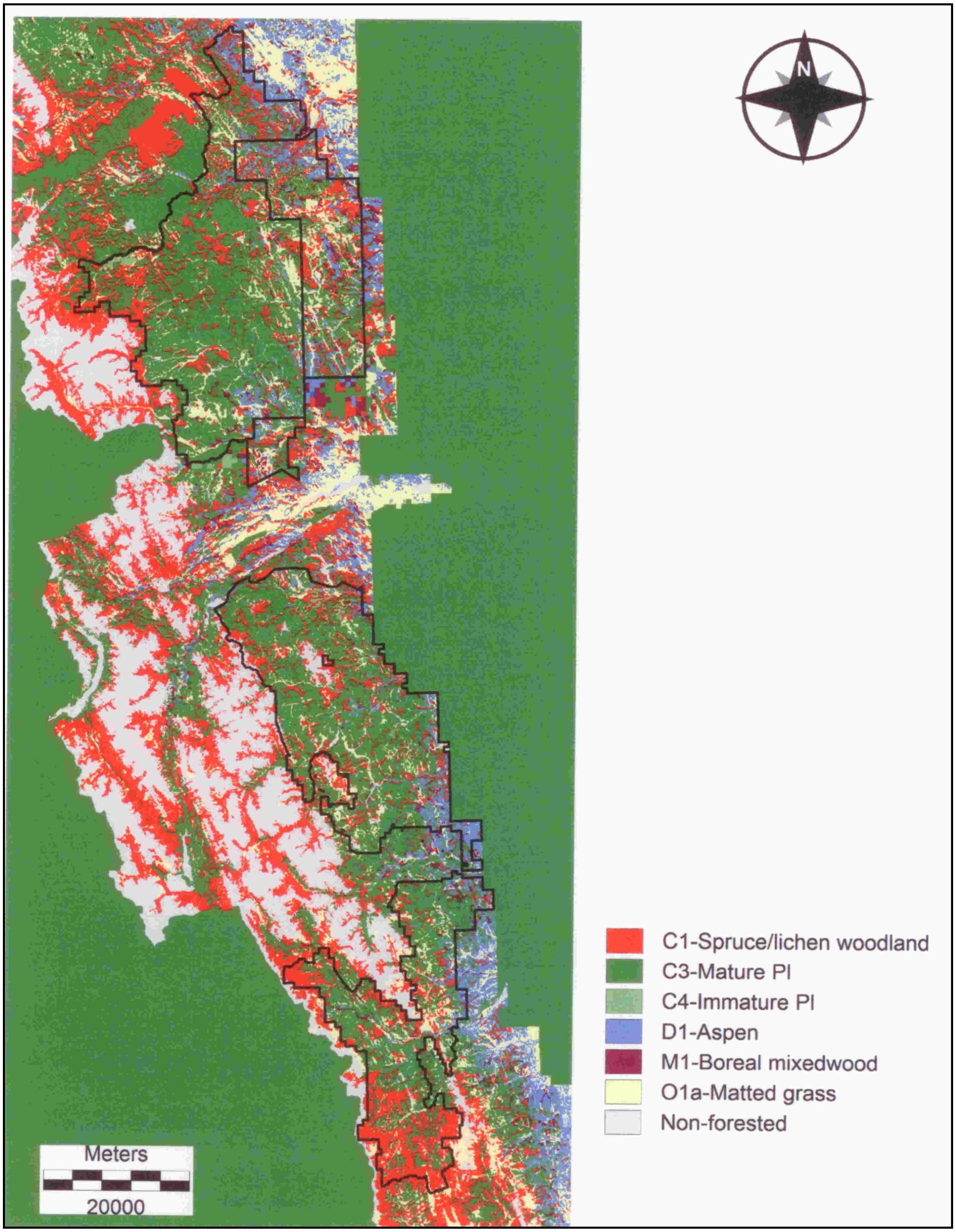

Figure A-3 Modified fuel type map for the Greater Kananaskis District.

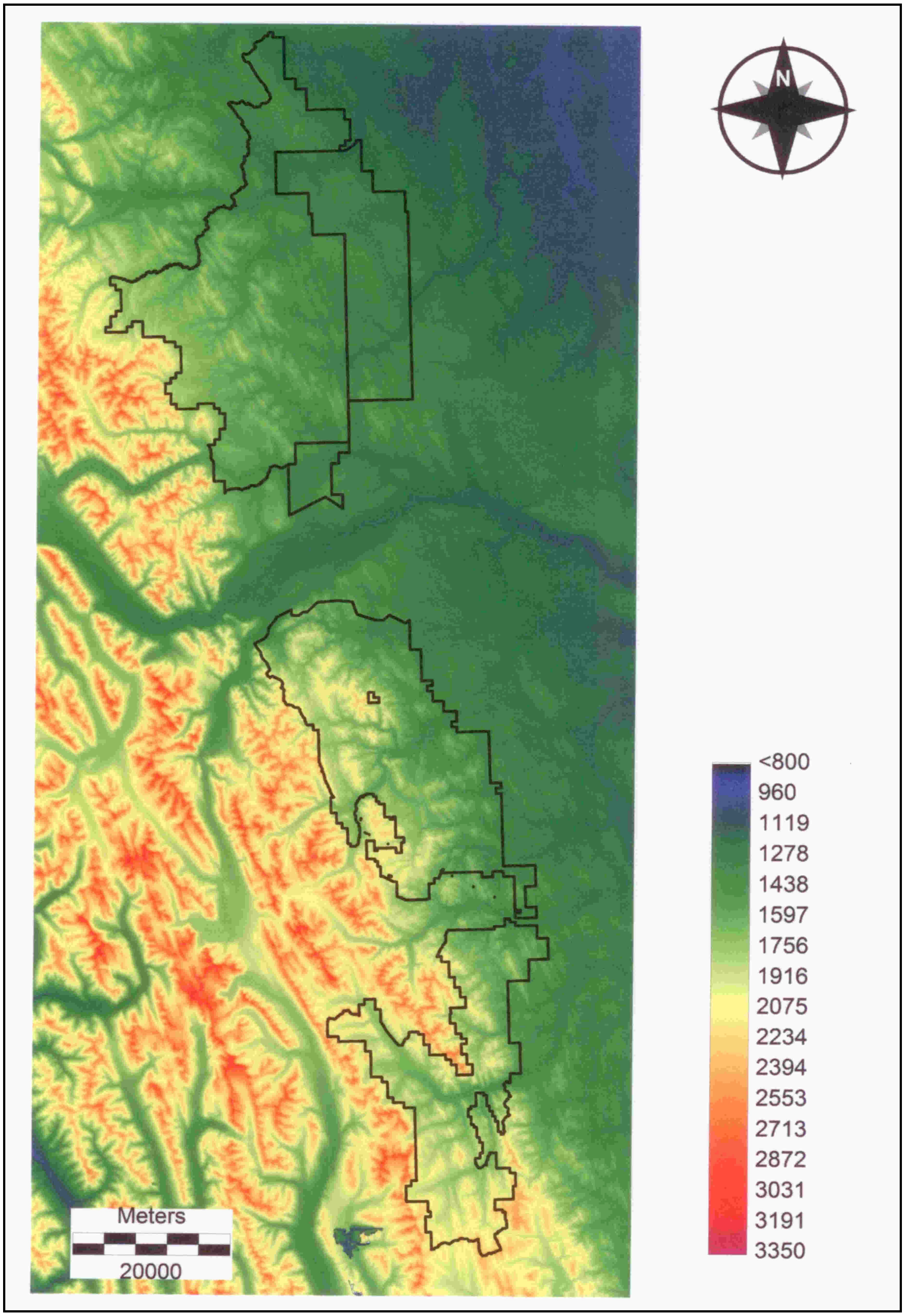

Figure A-4 Elevation model for the Greater Kananaskis District.

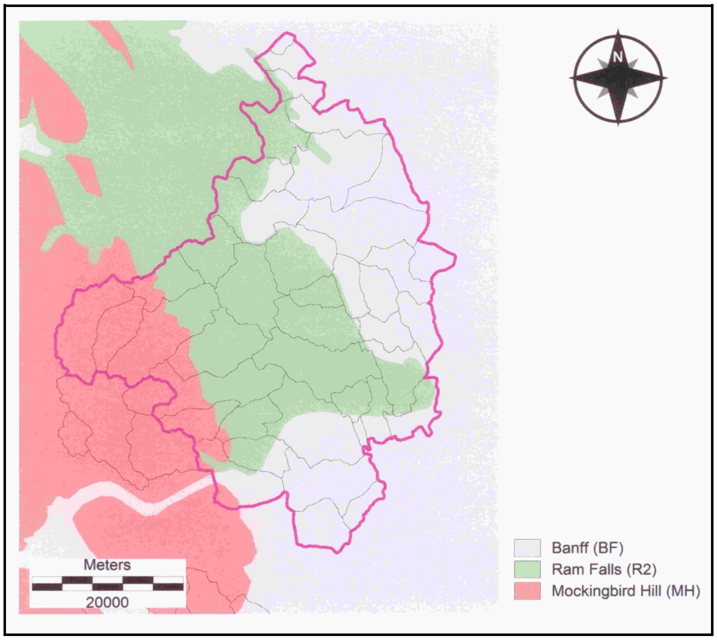

Figure A-5a Zones of similar fire weather and weather stations used. B9 FMU.

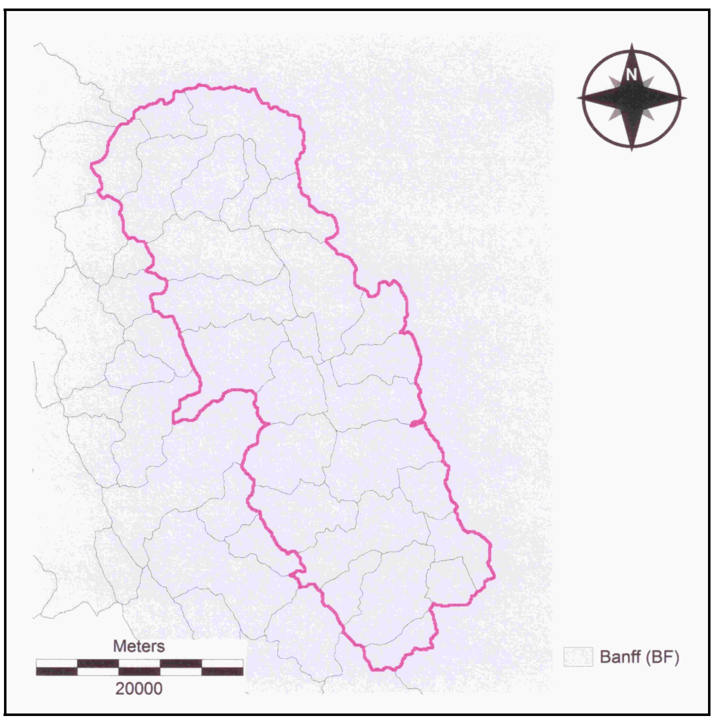

Figure A-5b Zones of similar fire weather and weather stations used. Upper B10 FMU.

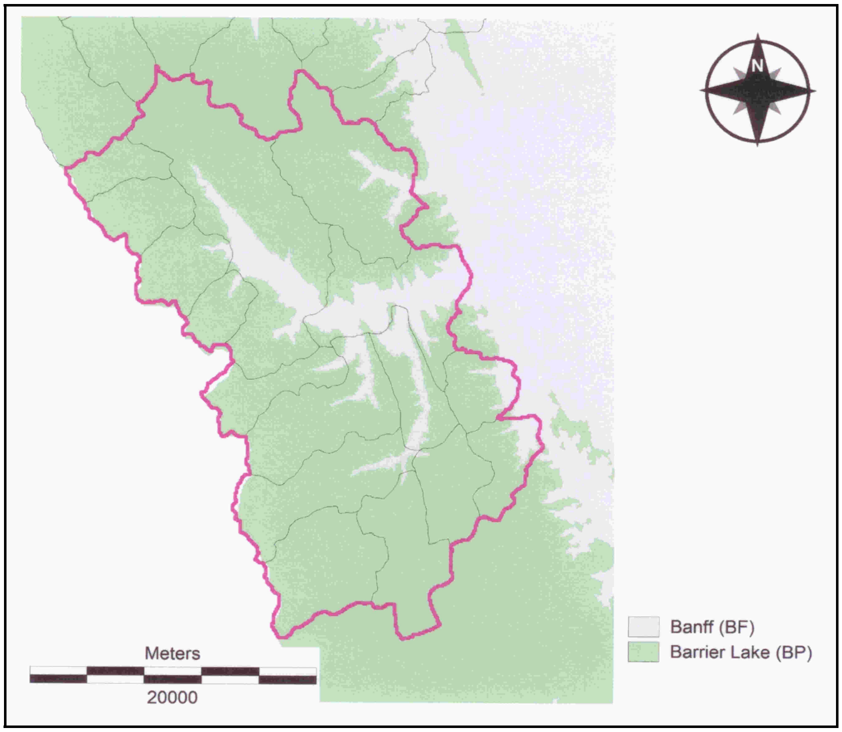

Figure A-5c Zones of similar fire weather and weather stations used. Lower B10 FMU.

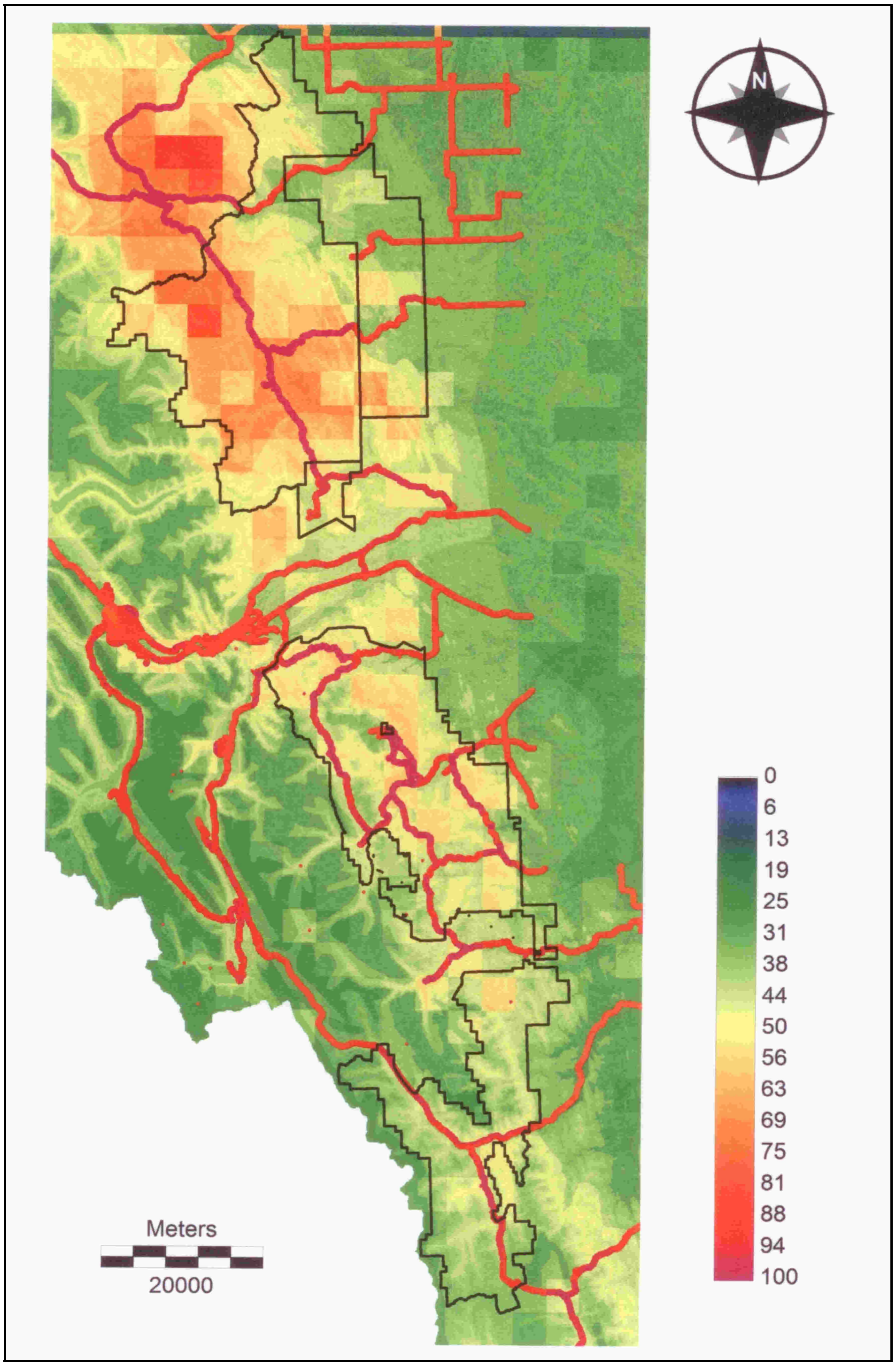

Figure A-6 Probability of ignition model from both lightning and anthropogenic ignitions. Presented in percent probability values.

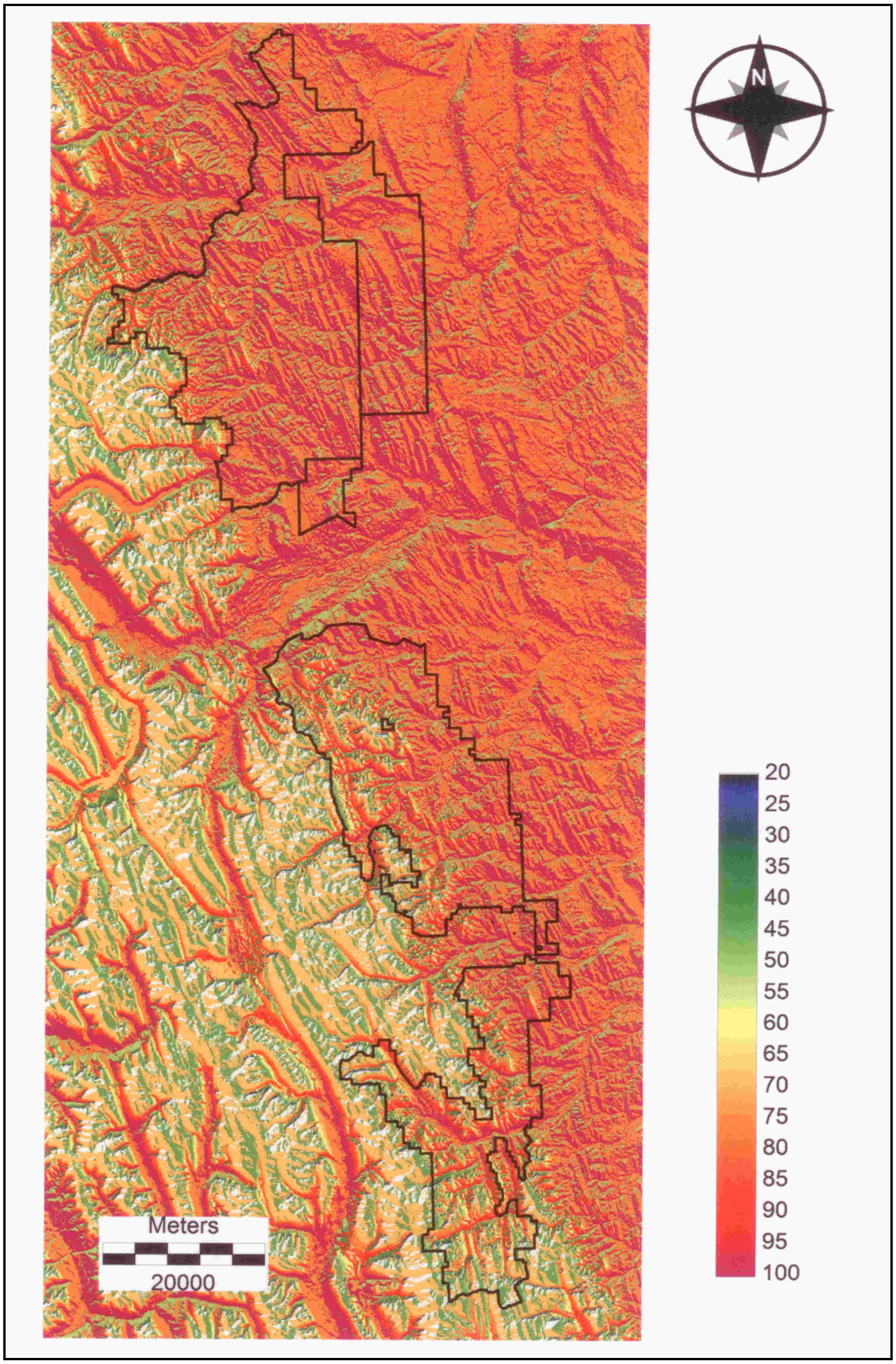

Figure A-7 Probability of burning model based on elevation and aspect. Presented in percent probability values.

APPENDIX B: MFRI DISTRIBUTIONS

B9 FMU - Upper Foothills							
		Spruce			Pine		
Fire Freq. (1000 yrs)	MFRI	Area (ha)	% area	wgt freq	Area (ha)	% area	wgt freq
2	500	5	0.03	0.00	0	0.00	0.00
3	333	33	0.20	0.01	0	0.00	0.00
4	250	181	1.10	0.04	2	0.00	0.00
5	200	304	1.85	0.09	23	0.04	0.00
6	167	298	1.82	0.11	70	0.12	0.01
7	143	417	2.54	0.18	174	0.29	0.02
8	125	335	2.04	0.16	275	0.46	0.04
9	111	358	2.18	0.20	534	0.88	0.08
10	100	385	2.35	0.23	830	1.37	0.14
11	91	478	2.91	0.32	1207	2.00	0.22
12	83	378	2.30	0.28	1108	1.83	0.22
13	77	515	3.14	0.41	1349	2.23	0.29
14	71	747	4.55	0.64	1661	2.75	0.38
15	67	703	4.28	0.64	1944	3.22	0.48
16	63	617	3.76	0.60	2146	3.55	0.57
17	59	695	4.23	0.72	2323	3.85	0.65
18	56	710	4.33	0.78	2097	3.47	0.62
19	53	809	4.93	0.94	1906	3.16	0.60
20	50	880	5.36	1.07	2120	3.51	0.70
21	48	867	5.28	1.11	2575	4.26	0.90
22	45	797	4.86	1.07	2711	4.49	0.99
23	43	615	3.75	0.86	3111	5.15	1.18
24	42	618	3.77	0.90	2892	4.79	1.15
25	40	771	4.70	1.17	3300	5.46	1.37
26	38	782	4.77	1.24	3656	6.05	1.57
27	37	753	4.59	1.24	3521	5.83	1.57
28	36	629	3.83	1.07	3752	6.21	1.74
29	34	505	3.08	0.89	3202	5.30	1.54
30	33	319	1.94	0.58	2565	4.25	1.27
31	32	290	1.77	0.55	2492	4.13	1.28
32	31	214	1.30	0.42	2327	3.85	1.23
33	30	138	0.84	0.28	1380	2.28	0.75
34	29	91	0.55	0.19	1146	1.90	0.64
35	29	77	0.47	0.16	903	1.49	0.52
36	28	54	0.33	0.12	594	0.98	0.35
37	27	18	0.11	0.04	357	0.59	0.22
38	26	23	0.14	0.05	133	0.22	0.08
39	26	2	0.01	0.00	24	0.04	0.02
40	25	0	0.00	0.00	1	0.00	0.00
	Total:	16411	100.00	19.38	60411	100.00	23.41
	Wgt MFRI:			51.61			42.71

B9 FMU - Lower Foothills							
		Spruce			Pine		
Fire Freq. (1000 yrs)	MFRI	Area (ha)	% area	wgt freq	Area (ha)	% area	wgt freq
4	250	12	0.08	0.00	0	0.00	0.00
5	200	116	0.78	0.04	27	0.13	0.01
6	167	253	1.71	0.10	75	0.36	0.02
7	143	372	2.51	0.18	112	0.54	0.04
8	125	511	3.45	0.28	242	1.16	0.09
9	111	467	3.15	0.28	288	1.38	0.12
10	100	500	3.37	0.34	438	2.09	0.21
11	91	580	3.91	0.43	525	2.51	0.28
12	83	620	4.18	0.50	651	3.11	0.37
13	77	701	4.73	0.61	757	3.62	0.47
14	71	847	5.71	0.80	1037	4.96	0.69
15	67	785	5.29	0.79	1015	4.85	0.73
16	63	815	5.49	0.88	1077	5.15	0.82
17	59	1138	7.67	1.30	1709	8.17	1.39
18	56	1055	7.11	1.28	1932	9.24	1.66
19	53	841	5.67	1.08	1281	6.12	1.16
20	50	710	4.79	0.96	1234	5.90	1.18
21	48	762	5.14	1.08	1124	5.37	1.13
22	45	738	4.98	1.09	1284	6.14	1.35
23	43	866	5.84	1.34	1303	6.23	1.43
24	42	723	4.87	1.17	1104	5.28	1.27
25	40	429	2.89	0.72	941	4.50	1.12
26	38	358	2.41	0.63	802	3.83	1.00
27	37	312	2.10	0.57	589	2.82	0.76
28	36	178	1.20	0.34	474	2.27	0.63
29	34	68	0.46	0.13	310	1.48	0.43
30	33	47	0.32	0.10	193	0.92	0.28
31	32	14	0.09	0.03	136	0.65	0.20
32	31	5	0.03	0.01	109	0.52	0.17
33	30	8	0.05	0.02	67	0.32	0.11
34	29	1	0.01	0.00	37	0.18	0.06
35	29	0	0.00	0.00	32	0.15	0.05
36	28	0	0.00	0.00	11	0.05	0.02
37	27	0	0.00	0.00	0	0.00	0.00
	Total:	14832	100	17.08	20916	100	19.26
	Wgt MFRI:			58.54			51.92

B9 FMU - Montane							
		Spruce			Pine		
Fire Freq. (1000 yrs)	MFRI	Area (ha)	% area	wgt freq	Area (ha)	% area	wgt freq
5	200	0	0.00	0.00	1	0.01	0.00
6	167	0	0.00	0.00	7	0.07	0.00
7	143	2	0.08	0.01	3	0.03	0.00
8	125	5	0.20	0.02	24	0.23	0.02
9	111	25	1.00	0.09	71	0.68	0.06
10	100	71	2.83	0.28	191	1.82	0.18
11	91	120	4.78	0.53	331	3.15	0.35
12	83	110	4.38	0.53	305	2.90	0.35
13	77	147	5.85	0.76	353	3.36	0.44
14	71	158	6.29	0.88	409	3.89	0.55
15	67	104	4.14	0.62	495	4.71	0.71
16	63	140	5.57	0.89	549	5.23	0.84
17	59	266	10.59	1.80	700	6.67	1.13
18	56	307	12.22	2.20	848	8.08	1.45
19	53	248	9.87	1.88	978	9.31	1.77
20	50	239	9.51	1.90	965	9.19	1.84
21	48	153	6.09	1.28	934	8.89	1.87
22	45	105	4.18	0.92	718	6.84	1.50
23	43	108	4.30	0.99	719	6.85	1.57
24	42	75	2.99	0.72	636	6.06	1.45
25	40	70	2.79	0.70	438	4.17	1.04
26	38	31	1.23	0.32	353	3.36	0.87
27	37	12	0.48	0.13	257	2.45	0.66
28	36	9	0.36	0.10	138	1.31	0.37
29	34	3	0.12	0.03	54	0.51	0.15
30	33	4	0.16	0.05	20	0.19	0.06
31	32	0	0.00	0.00	4	0.04	0.01
	Total:	2512	100.00	17.61	10501	100.00	19.25
	Wgt MFRI:			56.78			51.96

Upper B10 FMU - Subalpine							
		Spruce			**Pine**		
Fire Freq. (1000 yrs)	**MFRI**	**Area (ha)**	**% area**	**wgt freq**	**Area (ha)**	**% area**	**wgt freq**
2	350	29	0.36	0.01	0	0.00	0.00
3	350	66	0.83	0.02	14	0.04	0.00
4	250	259	3.24	0.13	111	0.36	0.01
5	200	339	4.25	0.21	212	0.68	0.03
6	167	428	5.36	0.32	533	1.71	0.10
7	143	342	4.28	0.30	657	2.11	0.15
8	125	440	5.51	0.44	1146	3.68	0.29
9	111	377	4.72	0.43	1201	3.86	0.35
10	100	508	6.36	0.64	1632	5.25	0.52
11	91	374	4.69	0.52	1512	4.86	0.53
12	83	588	7.37	0.88	1985	6.38	0.77
13	77	504	6.31	0.82	1918	6.16	0.80
14	71	574	7.19	1.01	2829	9.09	1.27
15	67	400	5.01	0.75	2248	7.23	1.08
16	63	466	5.84	0.93	2613	8.40	1.34
17	59	326	4.08	0.69	2007	6.45	1.10
18	56	370	4.64	0.83	2413	7.76	1.40
19	53	254	3.18	0.60	1428	4.59	0.87
20	50	280	3.51	0.70	1484	4.77	0.95
21	48	187	2.34	0.49	954	3.07	0.64
22	45	148	1.85	0.41	843	2.71	0.60
23	43	163	2.04	0.47	580	1.86	0.43
24	42	167	2.09	0.50	622	2.00	0.48
25	40	147	1.84	0.46	548	1.76	0.44
26	38	134	1.68	0.44	711	2.29	0.59
27	37	69	0.86	0.23	413	1.33	0.36
28	36	21	0.26	0.07	290	0.93	0.26
29	34	12	0.15	0.04	119	0.38	0.11
30	33	7	0.09	0.03	70	0.22	0.07
31	32	3	0.04	0.01	17	0.05	0.02
32	31	0	0.00	0.00	3	0.01	0.00
	Total:	7982	100	13.40	31113	100	15.59
	Wgt MFRI:			74.61			64.15

Upper B10 FMU - Montane							
		Spruce			Pine		
Fire Freq. (1000 yrs)	MFRI	Area (ha)	% area	wgt freq	Area (ha)	% area	wgt freq
4	250	1	0.01	0.00	0	0.00	0.00
5	200	3	0.04	0.00	4	0.01	0.00
6	167	6	0.07	0.00	8	0.02	0.00
7	143	9	0.11	0.01	4	0.01	0.00
8	125	73	0.85	0.07	39	0.11	0.01
9	111	37	0.43	0.04	104	0.30	0.03
10	100	39	0.46	0.05	153	0.43	0.04
11	91	83	0.97	0.11	209	0.59	0.07
12	83	170	1.98	0.24	382	1.08	0.13
13	77	194	2.26	0.29	434	1.23	0.16
14	71	299	3.49	0.49	931	2.64	0.37
15	67	306	3.57	0.54	987	2.80	0.42
16	63	414	4.83	0.77	1517	4.31	0.69
17	59	399	4.66	0.79	1610	4.57	0.78
18	56	482	5.62	1.01	2105	5.98	1.08
19	53	440	5.13	0.98	1809	5.14	0.98
20	50	554	6.47	1.29	2451	6.96	1.39
21	48	524	6.12	1.28	2136	6.07	1.27
22	45	576	6.72	1.48	2217	6.30	1.39
23	43	497	5.80	1.33	1884	5.35	1.23
24	42	776	9.06	2.17	2583	7.34	1.76
25	40	706	8.24	2.06	2488	7.07	1.77
26	38	645	7.53	1.96	2980	8.46	2.20
27	37	439	5.12	1.38	2149	6.10	1.65
28	36	318	3.71	1.04	2386	6.78	1.90
29	34	185	2.16	0.63	1468	4.17	1.21
30	33	177	2.07	0.62	993	2.82	0.85
31	32	85	0.99	0.31	547	1.55	0.48
32	31	34	0.40	0.13	342	0.97	0.31
33	30	36	0.42	0.14	148	0.42	0.14
34	29	34	0.40	0.13	77	0.22	0.07
35	29	18	0.21	0.07	30	0.09	0.03
36	28	7	0.08	0.03	27	0.08	0.03
37	27	3	0.04	0.01	12	0.03	0.01
38	26	0	0.00	0.00	0	0.00	0.00
	Total:	8569	100	21.45	35214	100	22.43
	Wgt MFRI:			46.61			44.58

Lower B10 FMU - Subalpine							
		Spruce			Pine		
Fire Freq. (1000 yrs)	MFRI	Area (ha)	% area	wgt Freq	Area (ha)	% area	wgt Freq
1	350	571	2.14	0.02	0	0.00	0.00
2	350	1356	5.09	0.10	12	0.04	0.00
3	350	1160	4.35	0.13	37	0.13	0.00
4	250	1621	6.08	0.24	136	0.48	0.02
5	200	1299	4.87	0.24	243	0.85	0.04
6	167	1863	6.99	0.42	411	1.44	0.09
7	143	1232	4.62	0.32	594	2.08	0.15
8	125	1528	5.73	0.46	1177	4.12	0.33
9	111	1748	6.56	0.59	1258	4.41	0.40
10	100	2231	8.37	0.84	1740	6.10	0.61
11	91	1730	6.49	0.71	1736	6.08	0.67
12	83	2115	7.94	0.95	2124	7.44	0.89
13	77	1547	5.80	0.75	1747	6.12	0.80
14	71	1496	5.61	0.79	1927	6.75	0.95
15	67	1023	3.84	0.58	1842	6.45	0.97
16	63	795	2.98	0.48	2460	8.62	1.38
17	59	517	1.94	0.33	1691	5.92	1.01
18	56	441	1.65	0.30	1744	6.11	1.10
19	53	292	1.10	0.21	1207	4.23	0.80
20	50	312	1.17	0.23	1264	4.43	0.89
21	48	221	0.83	0.17	969	3.39	0.71
22	45	289	1.08	0.24	1177	4.12	0.91
23	43	198	0.74	0.17	739	2.59	0.60
24	42	238	0.89	0.21	614	2.15	0.52
25	40	118	0.44	0.11	368	1.29	0.32
26	38	143	0.54	0.14	343	1.20	0.31
27	37	85	0.32	0.09	284	0.99	0.27
28	36	124	0.47	0.13	250	0.88	0.25
29	34	75	0.28	0.08	132	0.46	0.13
30	33	77	0.29	0.09	137	0.48	0.14
31	32	34	0.13	0.04	72	0.25	0.08
32	31	55	0.21	0.07	61	0.21	0.07
33	30	41	0.15	0.05	23	0.08	0.03
34	29	27	0.10	0.03	14	0.05	0.02
35	29	27	0.10	0.04	8	0.03	0.01
36	28	9	0.03	0.01	2	0.01	0.00
37	27	11	0.04	0.02	2	0.01	0.00
38	26	2	0.01	0.00	0	0.00	0.00
39	26	0	0.00	0.00	0	0.00	0.00
40	25	0	0.00	0.00	0	0.00	0.00
	Total:	26651	100.00	10.39	28545	100.00	15.44
	Wgt MFRI:			96.26			64.75