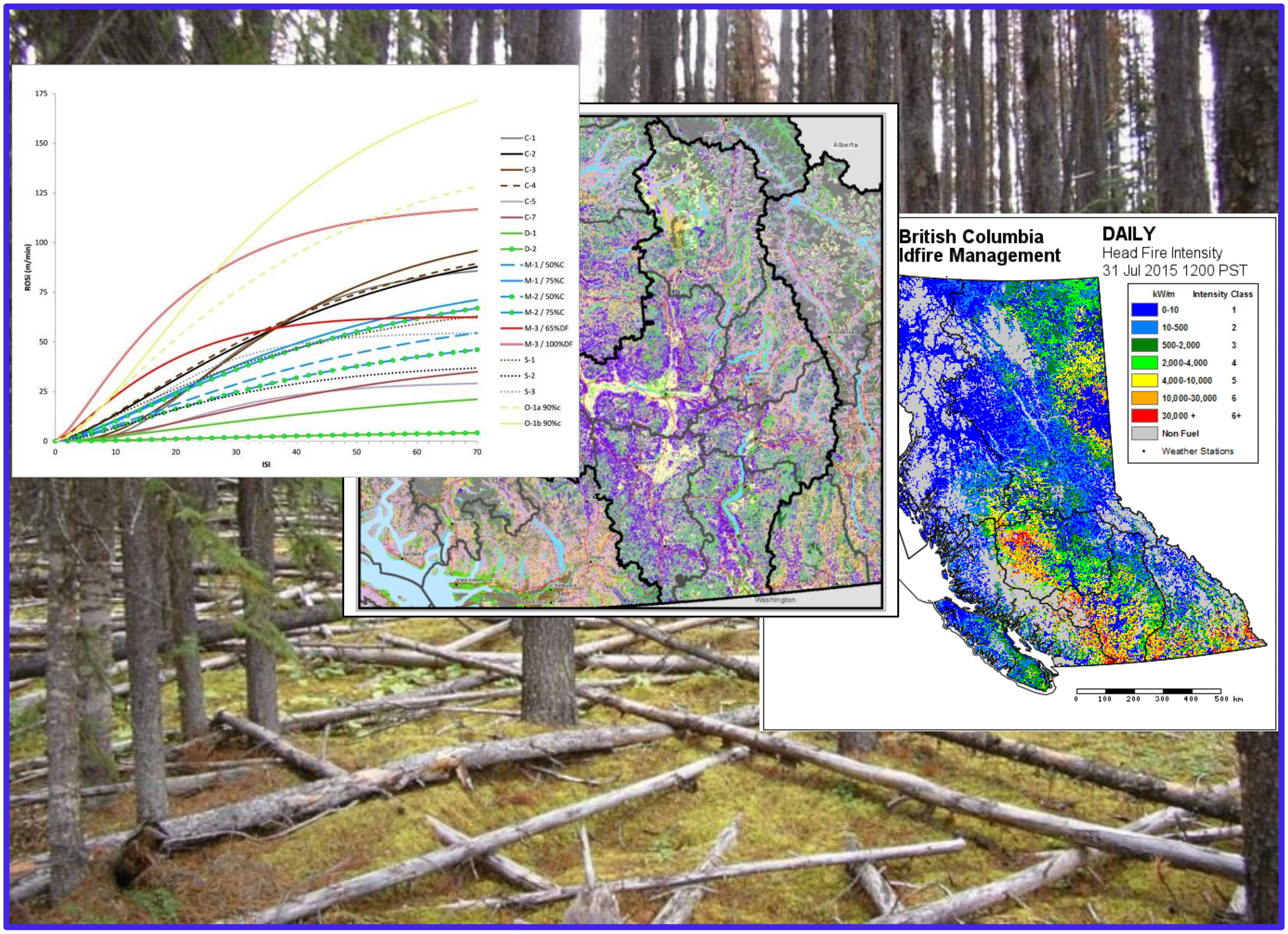
British Columbia Wildfire Fuel Typing and Fuel Type Layer Description

2015 Version

FINAL



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“Fire managers must rely upon the fuel type descriptions to equate FBP System fuel types to existing forest inventory/site classification schemes […], including the production of FBP System fuel type maps.”[1]

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[1] From B.J. Stocks, B. D. Lawson, M. E. Alexander, C. E. Van Wagner, R. McAlpine, T. J. Lynham, and D. E. Dube. 1989. The Canadian Forest Fire Danger Rating System: an overview. The Forestry Chronicle **65**:450-457 (p. 454).

BC Wildfire Fuel Typing and Fuel Type Layer Description, 2015 Version

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Introduction

1. Background: fire behaviour prediction and the CFFDRS in British Columbia

This document provides the technical description for the BC Wildfire Service Provincial Fuel Type Layer (FTL). The FTL is a spatial data layer used to inform fire behaviour prediction at multiple scales and in different contexts.

Fire behaviour prediction is the science and application of predicting characteristics of wildland fire such as ignition, spread rate and intensity (Pyne et al. 1996, Canadian Interagency Forest Fire Centre (CIFFC) 2003). The main variables affecting wildland fire behaviour are fuels, weather and topography – characteristics that comprise the fire environment (Countryman 1966). The term 'fuels' encompasses vegetation and biomass structure, biomass loading, dominant species (especially for treed landscapes), and other characteristics such as forest floor characteristics and forest health issues (e.g. outbreaks of bark beetles or other insects) that affect the flammability and availability of biomass for combustion.

Because of the diversity of forest and non-forest ecosystems across BC, describing fuels for fire behaviour prediction purposes is a complex task, and one that can be approached in different ways. Fuels can be described qualitatively (using discrete fuel types) or using various quantitative variables related to fuel structure or the amount of available fuel (fuel loading, tree height, crown base height, etc.). In BC, the primary modeling system used by the BC Wildfire Service (BCWS) for fire behaviour prediction is the Canadian Forest Fire Danger Rating System (CFFDRS; Stocks et al. 1989), which uses the fuel types described in the Fire Behaviour Prediction (FBP) System, a component of the CFFDRS. The FBP System represents a primarily qualitative approach to fuel classification, one which matches the assumptions of its overall empirical (as per Sullivan 2009b) modeling system approach (i.e., the CFFDRS).

A full review of fuel measurement and characterization, including the benefits and limitations of different modeling systems, is beyond the scope of this document. The BCWS relies on the CFFDRS for many aspects of wildland fire management, including operational fire behaviour prediction (decision support related to safety, suppression efficiency, tactics, aircraft and equipment use, etc.); fire season preparedness and resource pre-location; regulation of industrial and recreational activities; participation with national and interagency resource exchanges and working groups; training for suppression staff; and modeling of fire hazard and risk for planning and risk mitigation purposes outside the fire season. The depth of experience among BC fire management personnel with the current and past versions of the CFFDRS extends for several decades among our most senior staff. One fuel and fire behaviour prediction system is used provincially for the vast majority of fire management tasks in the province. In step with other fire management agencies across Canada, that system is the CFFDRS/FBP System, and is likely to remain such for the foreseeable future. A brief discussion of alternatives to the CFFDRS can be found in Section 9, although these are not the focus of the majority of this report.

This document therefore describes the process by which the entire geographic extent of the province that is covered by flammable biomass is categorized into one of the FBP fuel types. The non-flammable areas (primarily water bodies; alpine rock and ice; and developed agricultural (irrigated), urban, or fully cleared surfaces) are typed as non-fuel or water.

1.1 Previous fuel-typing efforts

The present process builds upon a number of similar initiatives aimed at categorizing the provincial landscape for fire behaviour purposes previously conducted in BC and elsewhere. Stocks et al. (1989) first suggested that fire managers should use the FBP fuel type descriptions to develop agency fuel type maps based on forest inventory data. Hawkes et al. (1995) developed the first such scheme for classifying portions of BC into FBP fuel types, using spatial data at a 4 km^2 resolution as part of an early fire threat analysis. Taylor et al. (1998) followed with an effort that included succession modeling of stand and fuel changes through time in southern interior BC. Between approximately 1999 and 2001, a new provincial fuel type was produced by J. Beck and G. Eade (unpublished files, BC Ministry of Forests, Lands and Natural Resource Operations, Victoria, BC), based on the newer Vegetation Resource Inventory polygons (see Section 2, below) and the increasing availability of GIS platforms and spatial data, gridded resolution of 0.25 ha.

It is worth noting that most other agencies in Canada have developed similar schemes, several of which are available as published reports: for example, Quebec (Pelletier et al. 2009), Yukon Territory (Ember Research Services Ltd. 2002), several areas managed by Parks Canada (e.g. Wilson et al. 1994, Achuff et al. 2001) and a number of national schemes (e.g. Nadeau et al. 2005) have been documented and are publicly available. The principal problem throughout these various efforts has been how (or even *if* it is appropriate) to assign the most representative FBP fuel type to a the wide variety of vegetation types and structures that comprise a particular administrative area; the challenge exists given that vegetation communities defined and described by forest inventory variables are usually aimed at informing timber management objectives rather than fire behaviour prediction. This results in a certain degree of subjectivity associated with fuel type assignments, since the forest inventory data is often lacking the details needed to assign FBP fuel types using purely objective or scientific criteria. This is discussed in greater detail in Section 5.3.

Similar to these previous efforts, the present fuel typing project was based partly on objective criteria, including scientific studies, experimental burn data, wildfire documentation, and informed assumptions from fire behaviour theory; however, much of it was ultimately based on the opinions of the authors and our colleagues[2], and our ability to express in logical coding various informal heuristic practices (generally recognized by practitioners as 'rules of thumb'). Although we have striven for clarity and transparency as much as possible in this document, the FBP fuel typing process is inherently subjective, and the vegetation communities of BC frequently fall through the cracks between the FBP fuel types. Empirical fire behaviour prediction systems require a very large dataset of studied fires, and in a large and diverse province such as ours, many additional fuel types would need to be studied and defined to encompass the variety of terrestrial ecosystems. The broad goals for all of these efforts are to improve fireline safety and fire management efficiency; secondary objectives include overall institutional

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[2] Additional contributors and reviewers are listed in the Acknowledgements section.

accountability and transparency, and facilitating continuous improvement in fire behaviour prediction and wildfire management in general.

2. Objective – BC Provincial Fuel Type Spatial Data Layer (FTL)

The objective of the fuel characterization process was to produce a spatial data layer that classified the provincial area into FBP fuel types. The resultant product is termed the Provincial FBP Fuel Type Layer (FTL), and is a raster dataset that provides forest fuel type information for all of BC for fire behaviour prediction and related purposes. The FTL was assembled primarily from FLNRO forest inventory data from the provincial Vegetation Resource Inventory (VRI) dataset[3]. The VRI dataset, in turn, consists of a set of polygons and their respective land cover attributes[4] covering all of British Columbia; for the FTL, polygons smaller than 1 ha were merged with their larger neighbours. The resulting dataset consists of over 4 million VRI polygons (and therefore fuel type polygons in the FTL) representing over 90 million hectares of land, which were finally converted to an ArcGIS raster grid (0.25 ha pixels) for further processing in fire behaviour software modeling systems (see Section 3, below).

The basis for converting VRI polygons to FBP fuel types was an extensive set of decision rules (called the 'fuel layer algorithm'), fully documented in the Appendix (Section A4). These decision rules describe the conversion details between vegetative, ecological, and stand history variables (including forest harvesting and other disturbances and management activities) and best fit FBP fuel types, and represent the technical heart of the fuel typing process.

The algorithm has been assembled based on the authors' experience in implementing the FBP System in British Columbia, with considerable input from other members of the BCWS Fire Behaviour Specialist Working Group (FBS WG). A Fuel Typing task group (see Acknowledgements, below) initiated the present process of renewing the FTL in 2009, but was dissolved in 2011 when it was determined that the 'committee conference call' approach would not be effective for defining the steps in a complex decision matrix, much of it based on uncertain information. The FBS WG is continually involved in the process of updating and refreshing the algorithm, as new evidence is incorporated; these include observations from wildfires and prescribed burns, published case studies, and new research findings.

The FTL is refreshed annually following the VRI update cycle; typically this occurs during the winter or early spring. Since the process is labour-intensive, a semi-annual (every two years) update schedule is being considered for future updates.

3. Uses and limitations of Fuel Type Layer

The FTL is used as basis for FBP System-based fire behaviour modeling and forecasting across the province at multiple scales and in different contexts:

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[3] For a full description of the VRI program, including recent updates, see http://www.for.gov.bc.ca/hts/vridata/ .

[4] VRI attributes are described and defined in a published data dictionary; see https://www.for.gov.bc.ca/hts/vridata/standards/datadictionary.html

- At the level of wildfire operations, the FTL can be used as a starting point for fire behaviour forecasting and tactical planning; field assessment of fuels is usually conducted by Fire Behaviour Analysts assigned to large fires, but a fuels map based on the FTL is a useful starting point prior to on-site arrival and field assessment;
- At the regional (Fire Centre) level, the FTL can help with the decision to issue Fire Behaviour Advisories (based on forecast headfire intensity), and for other purposes related to resource preparedness for operational fire management;
- At various spatial and temporal scales, the FTL serves as a base layer for running fire behaviour modeling software applications based on the FBP System:
    - SFMS (Spatial Fire Management System; see Figure 1) – provincial-scale daily and hourly approximations of fire behaviour and danger rating (Englefield et al. 2000)
    - Prometheus (fire behaviour simulation program, scenario-based) – for fine scale, incident-based fire behaviour prediction for operational and planning scenario use (Tymstra et al. 2010) [5]
    - PFAS (Probabilistic Fire Analysis System) – long-term fire behaviour simulation program for fire incidents, for estimating probability and direction of large fire growth using climatology (Anderson 2010)
    - Burn P3 (Burn Probability, Prediction, and Planning) – regional scale fire probability and risk modeling system, using simulations of thousands of fires based on local fire history (Parisien et al. 2005, Parisien et al. 2013)
    - CanFire (Canadian Fire Effects model; formerly BORFIRE, or Boreal Fire Effects Model) – model of fire impacts, emissions, and tree mortality (De Groot 2006, 2010)
    - Enterprise modeling of wildfire response and resource deployments (e.g. BC Wildfire One project, currently in the planning stages)

Earlier versions of the FTL have also been integral to developing fire risk and threat analyses, which usually incorporate fire behaviour calculations based on defined benchmark conditions (Hawkes and Beck 1997, Beck and Simpson 2007). A more recent Provincial Fire Threat Analysis (using the present fuel type layer) is currently being finalized for this purpose as well (Osbourne and Perrakis In prep.).

A decision was made early on that the fuel type layer needed to be seamless, representing the entire land area of the province (including inland water bodies) with no ‘gaps’ or ‘white areas’; this was a software requirement for running some of the modeling programs. Additionally, a seamless layer was deemed important to at least provide some minimum information on fire behaviour potential for all areas of the province. It is of little benefit to leave an blanks on the map, which suggests that nothing whatsoever is known about fuel structure in a particular area, and therefore nothing can be predicted about fire behaviour.

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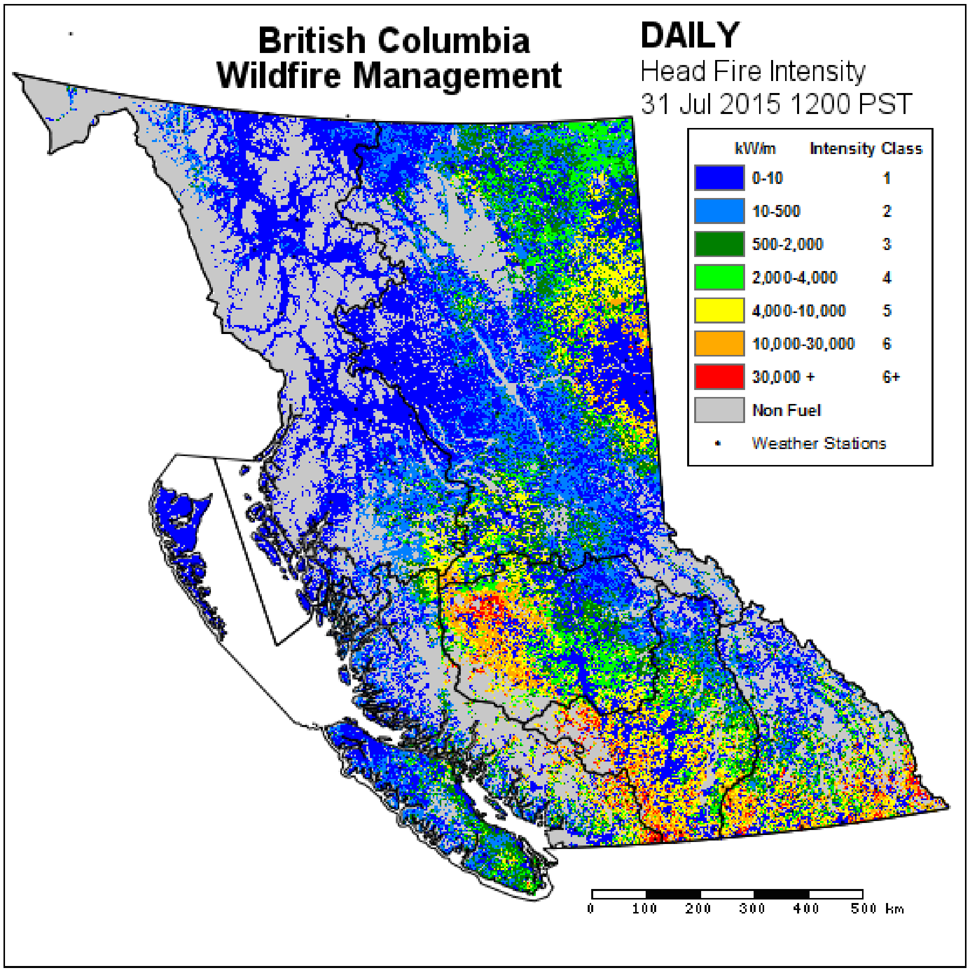
[5] See also http:\\firegrowthmodel.com\Prometheus

Figure 1. Example of Headfire Intensity screen from BC's implementation of the recently updated Spatial Fire Management System (Englefield et al. 2000)



While every effort was made to produce a comprehensive fuel type product to be used for detailed fire behaviour prediction, the FTL is not intended to replace local ground-truthing of the vegetation in the selection of best-choice fuel type. The FTL process and algorithm are updated annually and when new information becomes available; this is done at the province-wide scale, and often misses detailed local information that can have a significant effect on fire behaviour characteristics. Operational fire behaviour prediction, in particular, demands proper ground-truthing of fuel type and fuel structure. A broader discussion of field verification of vegetation and fuel type attributes can be found in Section 9.2.

Methods

4. Fuel Type Layer development process

4.1 Spatial data and pre-processing

Although most of this document describes a process for selecting FBP fuel types, implementing these choices operationally involved many steps of spatial data processing and manipulation. Several procedures needed to be completed to prepare the VRI dataset for fuel typing using the FTL algorithm, while other processes were developed to fill gaps in the VRI where data was nonexistent or suspect. Additional details around VRI data gaps can be found in Section 7.

This pre-processing consisted of four steps, primarily implemented by running Python scripts in an ArcGIS environment[6]:

- Defining a layer of recently harvested cutblocks
    - This layer is a product ('Consolidated_Cutblocks') produced by the Forest Analysis and Inventory Branch; our process used the harvest openings from the past 10 years to reflect disturbances newer than the latest VRI updates
- Importing additional data to fill gaps in the VRI layer from Tree Farm License areas (separately acquired data; see Section 7)
- Importing additional data from national fuel type raster to fill additional VRI gaps (private timberlands and missing TFL areas); see Section 7
- Clean-up of problem polygons that caused (or were known to cause) errors when processed using the fuel typing algorithm
    - This applied to certain ocean areas, polygons with missing geometry, missing biogeoclimatic zone[7] information, very old Harvest_Date attributes (pre-1900), etc.

These pre-processing steps were much more technically involved than the cursory description provided here. Additional details are documented and held by the authors and can be provided upon request.

After these steps were completed, the resultant polygon layer was ready for the main processing steps described in the fuel typing algorithm (shown in full detail in the Appendix, section A4). The final step in assembling the fuel type layer was to append the fuel type maps from neighbouring administrative areas (Yukon Territory, Northwest Territories, Alberta, and northern sections of the USA states Washington, Idaho and Montana) to the BC border. This process is described in section 5.5.

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[6] Additional details are documented in the working document 'WMB Fuel Type Update', by George Eade, Geo-Tech Systems; latest version written in August 2015 and held by BC Wildfire Service, Fire Prevention Section, Victoria, BC.

[7] See the BC BECWEB site for more information: https://www.for.gov.bc.ca/hre/becweb/

4.2 FBP System fuel type parameters and descriptions

The FTL fuel types consist of the standard fuel types from the Canadian Forest Fire Danger Rating System, Fire Behaviour Prediction System (see Forestry Canada Fire Danger Group 1992, Wotton et al. 2009); see the Appendix (Sections A1, A2) for more detailed descriptions.

A brief overview of the FBP System fuel types follows, including their application for fire behaviour prediction in BC vegetation types.

- There are 16 official FBP System fuel types, although some of these are seasonal variants (e.g. M-1 and M-2); one unofficial type is also frequently used (D-2; see Alexander 2010); additional new fuel types (official or unofficial) may be used in near future (e.g. C-3R for red-attack mountain pine beetle-killed stands; Perrakis et al. 2014)[8].
- In general, fuel types are defined in the FBP System by overall vegetation structure (e.g. mature conifer forest); dominant species (e.g. fully stocked lodgepole pine)[9]; and understory, ladder fuel, and forest floor characteristics (e.g. continuous feathermoss (*Pleurozium sp.*) with a sparse understory conifer layer)
- Each fuel type model consists of a set of parameters for use in rate of spread equations and fuel consumption equations, as well as other constants (crown base height (CBH), crown fuel load (CFL), buildup effect parameters); these parameters are meant to be constants used in calculations, applied categorically to the discrete fuel types; they are not considered 'user inputs' and are not meant to be modified, except in certain well-understood cases, as follows:
    - The M-1 and M-2 fuels have a ‘percent conifer’ value (0 to 100%) that must be specified;
    - In many software applications, a green-up date switches between the ‘leafless’ and the ‘green’ or ‘leafed-out’ fuel type on the estimated date of deciduous bud-flush, in late spring or early summer
    - The M-3 and M-4 fuel types have a ‘percent dead fir’ value (0 to 100%) that must be specified, and a green-up date can be used to switch between these two types;
        - However, M-3 and M-4 are not typically used in BC, except in one specific case (red-phase mountain pine beetle-attacked pine stands; see Section 5.4 below)
    - The ‘Open’ O-1 fuel type, typically used for grass fuels, has several parameters than can be user-selected:
        - O-1 has two variants, each with separate parameters, that define the matted or cut (winter/spring; O-1a) and standing (summer/autumn; O-1b) phases, respectively;
        - Some software applications use a grass green-up date for switching between O-1a to O-1b

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[8] At the time of writing, some Fire Centres use fuel type assignments developed internally that have not been formally documented and are not official FBP fuel types. Thus, the ‘modified C-3’ and ‘C-7b’ fuel types are used in some Fire Centres for certain operational processes, such as preparedness planning; these are not considered here. Contact the authors for further details.

[9] Common names are used for all vegetation species in this document (as per forestry conventions in British Columbia and the BC Vegetation Resource Inventory standards); see Appendix 3 for species codes and Latin names.

        - A ‘percent curing’ value (0 to 100%) must be specified, describing to what extent the new growth has cured, or become desiccated; this is highly influential on fire behaviour
        - a grass fuel load value (0 to about 20 t/ha) can be specified which affects fire intensity (but not spread rate); alternatively, the national default value (3.5 t/ha; Wotton et al. 2009) can be used
    - The C-6 value has a ‘crown base height’ value that must be specified; however, this fuel type is not used at this time in BC (see section 5.4.1 below).
- Other than the quantitative constants and variables mentioned above, other fuel type parameters are described only qualitatively. Thus, users must rely on their own experience and training to identify and characterise forest stand structure terms such as ‘well-stocked’, ‘moderate density’, ‘continuous [or discontinuous] litter’, ‘shallow’, ‘moderately deep’ and so on.
- The FBP System outputs include a variety of primary and secondary fire behaviour characteristics; however, the outputs of greatest interest are usually rate of spread (ROS) and frontal intensity (as per Alexander 1982), referred to here as headfire intensity (HFI), as per FBP System convention.

Figures below show examples of predicted ROS (Figures 2-3) and headfire intensity (Figure 4) for most fuel types used in BC. For fuel types with variable user-controlled parameters, commonly used examples are provided (e.g. M-2 50% conifer). While the HFI values go off the chart for certain fuel types, the relationship between fuel types is apparent from the graph (Figure 4).

Although the graphs are dependent on certain assumptions regarding weather and fuel moisture, particularly for calculating HFI (Figure 4), the relative ranking of fuel types in terms of ROS and HFI is generally consistent. For example, the C-3 fuel type exhibits a faster spread rate and higher HFI than C-7, C-5, D-1 or D-2 for any given combination of fire weather index conditions. The C-2 fuel type has higher ROS and higher HFI than C-3 in most conditions, though the reverse is true at very high or extreme ISI levels (ISI > 36 or so), due mostly to the higher CFL value of C-3. Similarly, the C-2 fuel type by definition has faster spread and higher HFI than any percent conifer value of boreal mixedwood (M-1 or M-2) fuel type, as these are an arithmetic blend of C-2 and the much less volatile D-1 type (Forestry Canada Fire Danger Group 1992). The only ambiguous rankings (where rankings vary depending on FWI values) between commonly used fuel types in BC are between C-5 and C-7. These fuel types have approximately similar spread rate relationships (small but possibly important differences; Figures 2, 3); the HFI ranking depends on BUI and ISI levels (C-7: 10 m CBH, 0.5 kg/m^3 CFL; C-5: 18 m CBH, 1.5 kg/m^3 CFL; Forestry Canada Fire Danger Group 1992).

The other highly variable fuel type is O-1 (*a* and *b* variants), which varies from the fastest-spreading fuel type at high curing rates (Figure 2) to barely able to sustain fire spread at lower curing rates (below 50%; not shown).

These figures, showing relative spread rates and HFI values predicted by the different FBP fuel type models, were used considerably in the fuel typing process as a means of comparing the various fuel type models.[10]

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[10] The FBP Graphing Tool is a MS Excel- (Microsoft Corp., Redmond, Washington, USA) based tool that is available for public download. See https://www.researchgate.net/publication/275894359_FBP_Fuel_Type_Graphing_Tool_%28FBP_Graph%29_V._2.1

Figure 2. Rate of spread curves for most FBP fuel types on flat ground; ISI represents the Initial Spread Index; excludes Buildup Index effects on spread rate.

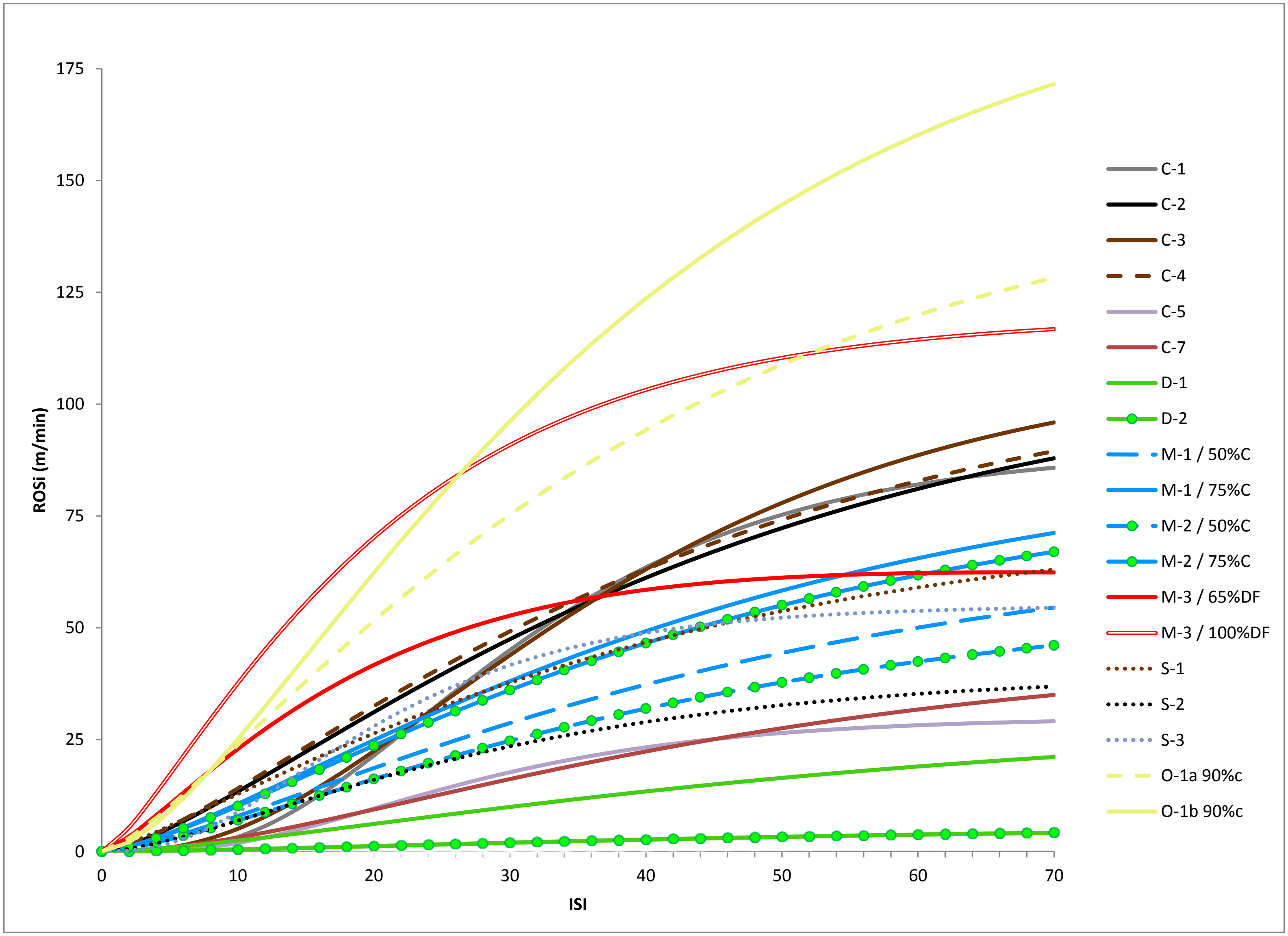


Figure 3. Rate of spread curves for most common forest fuel types; lower ISI values only for greater detail.

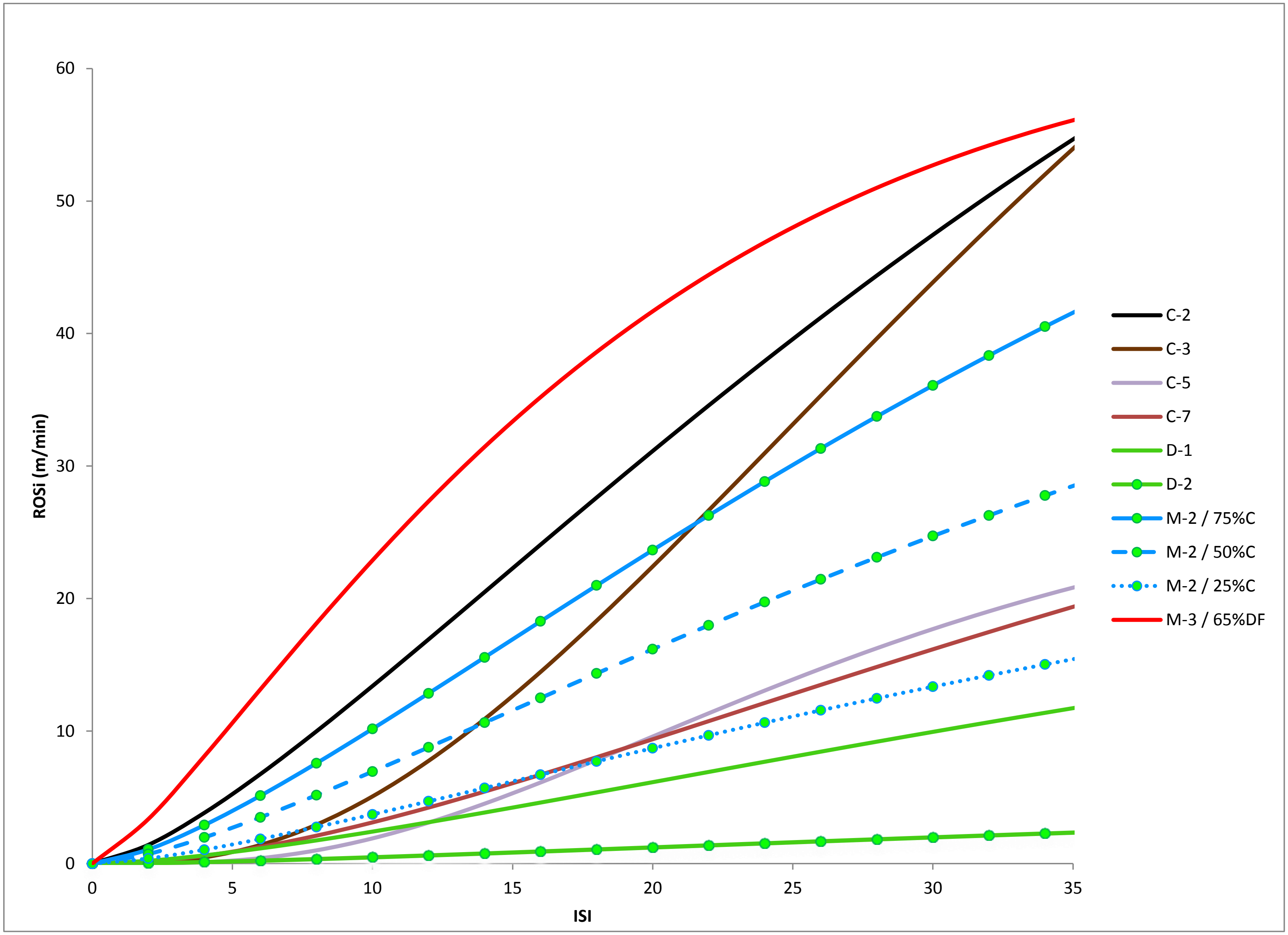
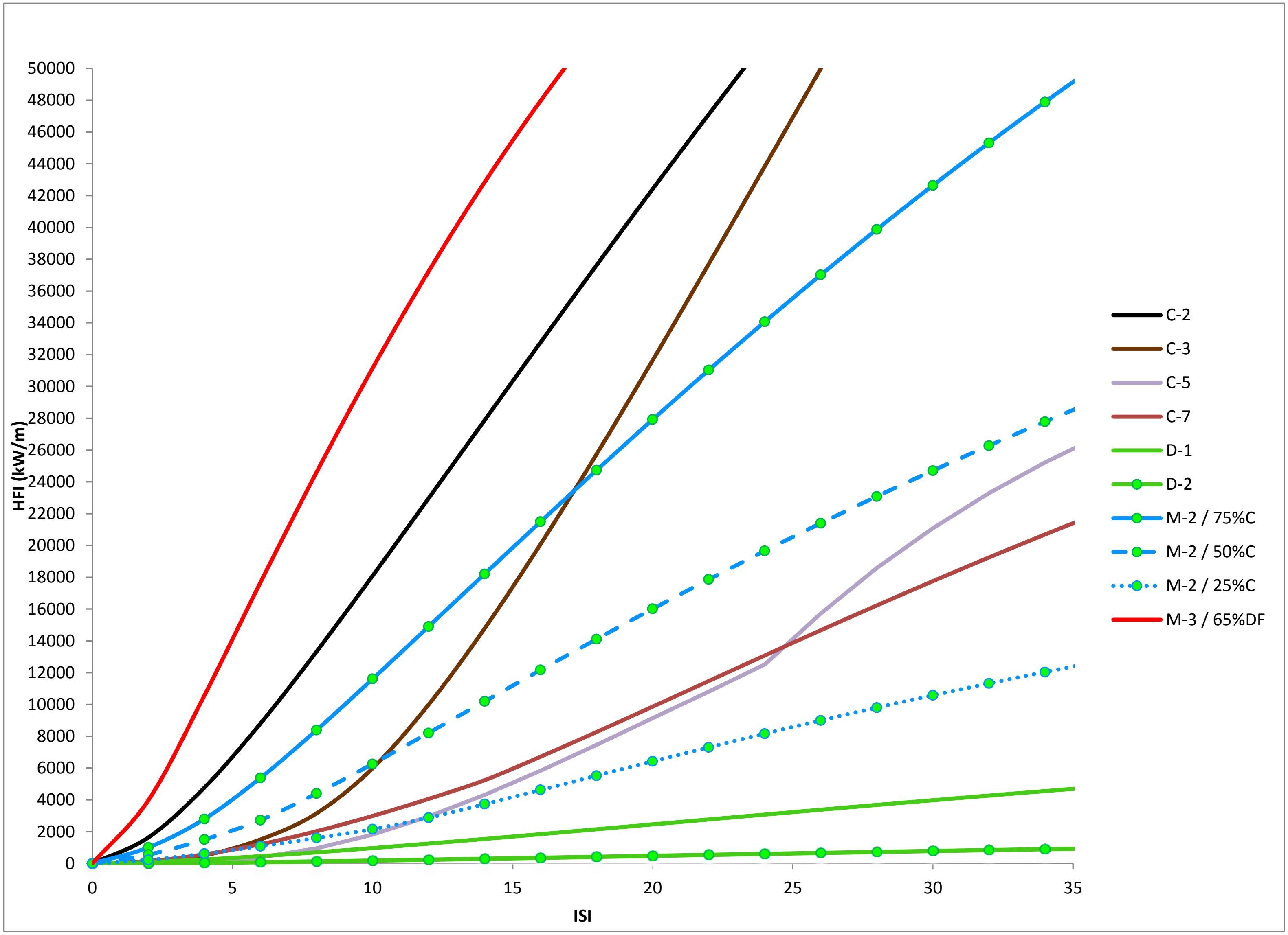


Figure 4. Headfire intensity (HFI) of common fuel types at lower ISI values; excludes BUI effects on spread rate. Assumptions: FFMC 91, BUI 70, FMC 97, flat ground; curve shapes are approximate.



5. Fuel typing specifics – process, decisions, and assumptions

5.1 Fuel Typing Algorithm

The fuel typing algorithm defines the detailed decision rules that were used to classify a polygon into one of the FBP fuel types (or identify it as non-fuel), based on VRI attribute data. The most recent version of the full algorithm is shown in the Appendix (Section A4).

In order to assign the most appropriate fuel type for predicting fire behaviour, vegetation inventory attributes were interpreted using a logical hierarchy. Attribute values for a polygon include very basic vegetation information (e.g. describing if a spatial polygon is vegetated or non-vegetated – BCLCCS Level 1; see below) as well as more detailed characteristics of a forest stand, for example. Additional attributes provide detailed quantitative values from measured, projected (modeled), or interpreted sources (e.g. tree height, crown closure, percent of trees that are dead). Although the VRI data model contains over 100 attribute fields, it is important to note that many attributes are frequently not populated (i.e. contain null values). This is sometimes because the attribute does not apply to a particular stand or location; for example, there are attributes for up to 6 different species of trees; stands with 1 or 2 species will have null values for Species_3 through Species_6. In other cases, the attribute could apply, but has not been populated due to decisions made or data available at the time of data entry during the inventory interpretation process. For example, many treed stands do not have 'Site_index' attribute populated, as this attribute has not been studied or estimated for that area and/or species. Other attributes such as those describing understory characteristics (e.g. 'Herb_cover_pct', 'Shrub_height', 'Bryoid_cover_pct') are frequently null. Therefore, the decision rules in the FTL algorithm must, in many cases, be capable of accommodating both detailed information as well as complete uncertainty (null values) for many vegetation characteristics.

Decision rules for classification were established based on both broad (e.g. treed vs non-treed) and specific (e.g. tree height > 4 m) attributes, based on vegetation species, stand structure, and other characteristics believed to be structural drivers of fire behaviour (see Section 5.2, below, for the list of attributes used in the FTL algorithm). In addition to vegetative or ecological characteristics, VRI attributes also include administrative and geographic information (e.g. parcel number, name of interpreter, polygon area, etc.) that are not used in this process.

Coarse classification: BCLCCS

The initial, coarsest attributes for determining overall fuel characteristics for most stands were the BC Land Cover Classification (LCCS) values. The BC LCCS comprises 5 levels of derived attributes that define broad cover types for the VRI polygons[11]:

- Level 1: **vegetated** (V: forest, grassland, shrubland, etc.) vs. **non-vegetated** (N: for rock, water, recently disturbed bare land, etc.);
- Level 2: **treed** (T: forest stands) vs. **non-treed** (N: < 10% crown closure);

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[11] See the VRI data dictionary for further details; available online: https://www.for.gov.bc.ca/hts/vridata/standards/datadictionary.html

- Level 3: **alpine** (A) vs. upland (U) or wetland (W) sites; only used to identify alpine areas in FTL
- (Level 4 describes overall vegetation lifeform (e.g. Treed Mixedwood, Shrub Tall); these are not used in the fuel typing process)
- Level 5: vegetation density class
    - for treed polygons, classified as **Sparse** (SP: 10-25% crown closure), **Open** (OP: 26- 60% closure), or **Dense** (DE: > 60% closure);
    - definitions differ for non-treed cover types (not used in FTL)

Additional attributes: forest stand characteristics

Following the first stages of the BCLCCS (Levels 1 and 2), the harvest history (Harvest_date = 'Null' versus a specified year) helped determine whether harvesting activities (slash, site preparation, newly planted seedlings/saplings) would be the dominant influence on fuel structure. Very recently harvested areas (< ≈10 years, depending on biogeoclimatic zone) were assumed to be behave as slash fuels in most cases, depending on the time since harvest. Most post-harvest stands in BC are replanted with seedlings (usually conifer trees), and after the first few years, the effects of the young plantation began to dominate stand fuel structure. Stands were assumed to behave as forests once trees reached a height of 4 m height for fully stocked stands. The young plantation stage (≈4-12 m in height) is poorly represented by FBP fuel types, and the expected fire behaviour in these stands is heavily influenced by surface fuels left from the previous cohort; this is further discussed below (Sections 5.4 and 6).

Forested (treed) polygons were then divided into single-species (or nearly so) stands, where the dominant tree species cover (SPECIES_PCT_1) represented 80% or more of the tree layer, vs. mixed-species stands (Species_pct_1 < 80%). Decision rules needed to encompass all tree species found in BC, including all conifer and deciduous species (as well as appropriate classification for non-forested areas). Further differentiation beyond tree species depended on other stand characteristics deemed important to fire behaviour, including harvesting history (recently logged or not), tree heights (dominant cohort), secondary species, crown closure (sometimes used in addition to the BCLCCS Level 5 category), tree age (dominant cohort), mountain pine beetle attack (for lodgepole pine stands), and other attributes (see Section 5.2 for the list of VRI attributes used in fuel typing; Section 5.5 for specific fuel typing assignment details).

The FTL algorithm was implemented by coding a Python script with over 2000 lines of code as of summer 2015. The script classified an existing ArcGIS 10.1 feature (polygon) data layer consisting of the pre-processed (Section 4.1) VRI data. The classified fuel type polygons were then converted to 0.25 ha (50 x 50 m) pixels for export use by fire modeling software, as previously described (Section 3).

5.2 Vegetation attributes used in fuel typing algorithm (from VRI):

The following attributes, as well as brief descriptions, from the veg_comp_poly_rank1 VRI layer are currently used in the FTL algorithm (detailed attribute descriptions and definitions can be found in the

VRI data dictionary[12]). In most stands, only a few of these attributes are used for fuel typing. Categorical variable levels are noted in **bold**.

- BC Land Cover Classification Level 1 (BCLCS_level_1): **Vegetated** (V) or **Non-Vegetated** (N)
- BCLCS_Level_2: **Treed** (T) or **Non-treed** (N; non-treed is assigned when Crown Closure < 10%)
- BCLCS_Level_3: Designate various categories of broad land cover; used in FTL to designate **Alpine** (A) areas, consisting of rock and ice and very little vegetation cover
- BCLCCS_Level_5: Crown Closure category (**Dense** (DE: 61-100%), **Open** (OP: 26-60%), **Sparse** (SP: 10-25%))
- Species Code 1 (Species_cd_1): species of dominant tree (based on basal area for older stands; stems/ha for very young stands)[13]
- Species_cd_2: species of 2nd (co-)dominant tree
- Species_pct_1: percent cover of dominant tree species
- Species_Pct_2: percent cover of 2nd dominant tree species
- Sp1 Height: (Proj_Height_1): projected height, in m, of dominant tree species
- Sp1 Age: (Proj_Age_1): projected age of dominant tree species
- Crown_closure: percentage of ground covered by tree canopy, used to infer stand density
- BEC_zone_code: Biogeoclimatic Ecosystem Classification zone[14]
- BEC_subzone: Biogeoclimatic Ecosystem Classification subzone
- Harvest_date: year of most recent harvest activity (null if never harvested)
- Earliest Non-Logging Disturbance Type (Earliest_nonlogging_dist_type): category code used to identify disturbances such as insect attack, fire, etc.
- Earliest_non-logging_dist_date: estimated year of disturbance (e.g. year of mountain pine beetle attack)
- Stand_percentage_dead: derived percentage of overstory trees estimated to be dead (new or older snags)
- VRI_live_stems_per_hectare: stand density of live overstory trees/ha
- VRI_dead_stems_per_hectare: stand density of dead overstory trees/ha
- Non_productive_code: used in older inventory data for non-forested areas to identify and differentiate brush, swamps, old burns, gravel pits, etc.
- Land_cover_class_code: used in newer inventory data for non-forested areas to identify and differentiate brush, swamps, old burns, gravel pits, etc.

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[12] Descriptions provided here are interpreted in the context of fire behaviour modelling, and may be slightly different from those in the VRI data dictionary. For formal attribute definitions, see https://www.for.gov.bc.ca/hts/vridata/standards/datadictionary.html

[13] Species codes in the VRI system consist of 2-letter abbreviations; these are described fully in the VRI data dictionary (see above link, p. 214-217).

[14] See the BC BECWEB site for more information: https://www.for.gov.bc.ca/hre/becweb/

5.3 Working assumptions and applied decision rules for FBP fuel typing

The art and science of FBP System fuel typing

It is worth mentioning at this point that the process of selecting an appropriate FBP fuel type, for operational fire management purposes, is taught in advanced fire behaviour training courses provided by the Canadian Interagency Forest Fire Centre (currently coded as S-490, Advanced Fire Behaviour and S-590, Wildfire Behaviour Specialist courses). A significant step in fuel typing, from the perspective of field and operational users, involves making a qualitative visual comparison between a given forest stand (or non-forest area) and a very small number of benchmark photographs of the various fuel types (De Groot 1993). Clearly, this is not a process that can be automated or quantified, which is why fuel typing using the FBP System remains subjective. This type of fire behaviour prediction (and wildfire management, more generally) is often described as a blend of art and science (e.g. Murphy 1990), requiring the application of knowledge from both formal research as well as 'real world' experience in order to be proficiently applied in operational situations. This is particularly true in BC because of the limitations of the existing fuel types; with some exceptions, FBP System fuel types were developed for boreal and sub-boreal forest types that are common across most of Canada (Stocks et al. 1989, Forestry Canada Fire Danger Group 1992).

Nonetheless, BC has used the FBP System with increasing success to guide fire behaviour prediction and fire response for approximately two decades now (e.g. Beck et al. 2005). This has been accomplished by learning and applying various 'rules of thumb' to the somewhat idiosyncratic FBP fuel types for use in BC ecosystems. This section attempts to document these working rules, as interpreted by the authors, and create a framework for continuous future improvement in use of the CFFDRS in British Columbia.

Intended vs. interpreted FBP fuel type assignments, and use of informal wildfire observations

For at least some areas in the province, fuel types C-2, C-3, C-4, C-7, M-1, M-2, S-1, S-2, S-3, D-1, D-2, and O-1 were assigned more or less 'as intended' according to the descriptions and guidelines in the FBP System (Forestry Canada Fire Danger Group 1992). In these cases, tree species, stand structure, understory characteristics, and ladder fuels were assigned when they matched (based on the attribute data available) the characteristics of the fuel type in question (see Appendix, Section A2, for detailed FBP fuel type descriptions). These fuel type assignments, where the stand attributes matched those in the original research or wildfire observations, were made with relatively high confidence.

In addition to these more straightforward assignments, some fuel types were interpreted and assigned with lower confidence based on a less formal heuristic process based on comparisons between fuel types (e.g. Figures 2-4). For these more challenging assignments, we attempted to harness the collective knowledge and experience of BC's fire behaviour specialists and fire management staff (and other jurisdictions, when available) using information summarized from wildfire observations. These fuel type assignments are therefore somewhat outside of the scope of the original FBP fuel types and are applied with lower levels of documentation and lower confidence overall. As wildfires tend to occur outside the realm of formal research and controlled conditions, there can be many variables that confound the simple fire environment conditions most sought for assembling data for empirical fuel typing. Wildfire behaviour observations are written records documenting the actual stand conditions, fire weather and topography, and relevant fire suppression or management activities that determined observed fire behaviour. These can be formal (published case studies, as per Alexander and Thomas 2003), or, more commonly, informal records, including photograph series, video clips, emailed visual reports, and (sometimes sparse or questionable) verbal descriptions from eyewitnesses. The varying quality of fire behaviour observations has been previously identified as an issue of concern by several researchers (e.g. Gould et al. 2011), but is not easily resolved. Because the density and frequency of these reports far surpasses formal research records, these records are relied upon in the absence of other information for certain stand types and cannot be ignored. Nonetheless, this remains an imperfect dataset and we hope to continue assembling our fire behaviour documentation data to validate or refute (and improve) these much less confident fuel type assignments.

The assumption with these more speculative fuel type assignments is that a stand could have a relatively good match coincidentally with the fire behaviour characteristics (e.g. spread rate or fire type) of existing FBP fuel types, despite very different fuel structure characteristics from the benchmark fuel type. These assignments were made when at least a theoretical understanding suggested a certain pattern of fire behaviour, even if there may have been very few (if any) records of measured or observed fire behaviour in a particular fuel complex. This process becomes increasingly complex when varying ages and successional stages of developing forest stands are considered. Although the confidence associated with some of these assignments can be rather low, we have attempted to make these assignments with careful consideration of stand characteristics and presumed successional pathways. Topics related to forest ecology, including tree silvics and stand succession (e.g. Klinka et al. 2000) and direct studies of fuel succession (e.g. Van Wagner 1983, Agee and Huff 1987, Feller and Pollock 2006) were used when possible, although the links with the mostly fixed FBP fuel types were not always obvious. Theoretical and semi-mechanistic approaches to fire behaviour(e.g. Van Wagner 1977, Alexander et al. 2006; see also Section 9.3) were also used in simulation games to compare predictions with standard FBP System outputs in several of these cases.

5.4 Specific fuel typing assignments:

5.4.1 Conifer fuel types:

- The **C-1** fuel type (spruce-lichen woodland) is defined by its very open structure of black spruce interspersed with *Cladonia* reindeer lichen species (Alexander et al. 1991); these stands can be found in northern boreal forests of BC. Since the lichen component is a defining component of the fuel type structure and is not easily indicated in VRI data, the C-1 type is assigned for any pure black spruce (or unspecified spruce) stands in the Boreal White and Black Spruce or Spruce Willow Birch biogeoclimatic zones where the BCLCCS Level 5 is **Sparse**. This is likely a slight overprediction of the extent of C-1, as other types of understory vegetation (e.g. grass, herb/forb, or shrub understory) are probably more common than reindeer lichen in this area.

The C-1 fuel type produces spread rate prediction that are very similar to the C-3 fuel type (Figure 2).

- The **C-2** fuel type (boreal black and white spruce) is defined by dense lowland and upland sites of the eponymous species; this structure exists across the boreal plains and shield across Canada. Although these vegetation communities exist to some degree across BC, particularly in the Peace River basin in northeastern BC, this fuel type is also used, based on observed fire behaviour, for mid-elevation interior white spruce and hybrid spruce stands elsewhere in the province (R. Lanoville, unpublished reports held by BC Wildfire Service, Victoria, BC).
- The **C-2** fuel type is also used in the present algorithm for representing certain MPB-affected stands in the gray phase of attack (≈ 5 – 15 years post-attack); this is an active area of research and monitoring, but experimental burning and data from the 2010-2014 wildfire seasons have shown reasonable correlation between stands dominated by grey-stage MPB-killed pine and the C-2 model predictions for rate of spread (D. Perrakis, unpublished data). However, we also suspect that some of the rapid spread rates observed in these stands have been due to the presence of significant cover of regenerating spruce, subalpine (balsam) fir, or other conifer species in the understory. Since the VRI data almost never includes the presence of these cohorts, this is a topic of considerable uncertainty and active research. See Table 1, below.
- The **C-3** fuel type was used to represent classic stands of fully stocked, pure mature lodgepole pine (interpreted as > 12 m height and **Open** or **Dense** stand structure, low levels of (or no) MPB attack). In addition, the C-3 fuel type was also used to represent several other species and stand structure combinations; the following is a non-exhaustive list:
    - Mixed stands (100% conifer) dominated by mature lodgepole pine, with spruce (any species) or subalpine fir as secondary species; also, similar stands dominated by interior spruce with lodgepole pine or fir as secondary species
    - Shorter (4 – 12 m tall) stands of pure lodgepole pine, density < 8000 stems/ha (see C-4 fuel type description, below)
    - Certain classes of pure and mixed lodgepole pine stands (100% conifer) affected by MPB attack at low to moderately high attack densities (see Table 1, below)
    - Pure and mixed, **Dense** stands (100% conifer) dominated by Douglas-fir, 4-12 m height
    - **Open** (not **Sparse** or **Dense**) stands of pure Engelmann or interior spruce
    - **Open** or **Dense**, pure or mixed stands (100% conifer) dominated by subalpine fir
    - **Dense** pure or mixed stands (100% conifer) dominated by western redcedar, western hemlock or yellow-cedar and
        - 4-15 m height or
        - > 15 m height and < 60 years old
    - Areas noted as non-treed that were logged > 25 years ago in SBS, MS, ESSF, ICH (dry subzones) or IDF (wet subzones), where stand succession has likely occurred (i.e. inventory data is stale)
- Fuel type **C-4** (immature jack or lodgepole pine) is defined in the FBP system by immature stands of jack or lodgepole pine with horizontal and vertical fuel continuity and heavy accumulations of dead fuels (Stocks 1987, Forestry Canada Fire Danger Group 1992). Spread rate and fire intensity

values predicted in C-4 fuels are nearly identical to those of the very volatile boreal spruce (C-2) fuel type (Figure 2). In the present algorithm, C-4 is assigned to forested conifer stands from 4 to 12 m in height with > 8000 stems/ha (live plus dead), or 'dense' stands (> 60% crown closure) 4-12 m in height with a significant (> 34%) percentage of dead stems. These rules were assigned as an estimate of reasonable threshold values compared to the main experimental burn study defining the C-4 fuel type (Stocks 1987). That series of burns took place in an approximately 30-year old central Ontario stand of overstocked jack pine saplings (≈10,000 live stems/ha plus a nearly equal density of dead standing trees). A cutoff density value to discriminate between C-3 and C-4 fuel types needed to be set, and since dead trees are not often extensively surveyed in the VRI process, the value of 8000 stems/ha was set for the present fuel typing iteration; this value may change in the future if observed or measured fire behaviour in these stands suggest otherwise. In general, it is very uncommon to see stands of pine (or most other conifers) exhibit the very fast rates of spread and extreme intensity values suggested by the C-4 fuel type.

- The **C-5** fuel type (red and white pine) describes a forest type from eastern Canada that does not exist in BC (Forestry Canada Fire Danger Group 1992). However, due to the high crown base height (18 m) and high deciduous shrub component of this fuel type, it has been used to approximate fire behaviour in mature stands of low- to mid-elevation coastal vegetation communities of mature Douglas-fir, western hemlock and/or western redcedar. This working rule was first suggested over 20 years ago by operational fire behaviour specialists in BC, and has held up fairly well over time. It is important to note that the surface fuel loading in older west coast stands can be much greater than in the benchmark red and white pine stands from Ontario, particularly if coarse woody debris are included (Agee and Huff 1987, Forestry Canada Fire Danger Group 1992). As a result, fuel consumption and fire intensity can be higher than predicted by the C-5 fuel type under drought conditions. Monitoring efforts to formally confirm or refine this fuel type assignment are slow but ongoing.
- **Mountain pine beetle-killed lodgepole pine** stands in the first few years post-attack are represented by the M-3 fuel type (with 65% dead balsam fir); no other variant of the M-3 fuel type is used at the present time (the M-4 fuel type is not used). The research basis for this is described in Perrakis et al. (2014). The M-3 fuel type is used only in cases when the stands consist of pure lodgepole pine or are lodgepole pine-dominated (interior spruce (Sx) or subalpine fir (Bl) are secondary species), with more than 50% of standing trees killed by MPB, and the disturbance date (Earliest_non-logging_dist_date) was within the past 5 years (difference of 5 years or less between the present year and the inventory year). Other fuel types (C-3 and C-2) are used when these variables differ, as discussed previously, and as shown in Table 1, below.

Table 1. Fuel typing for mountain pine beetle-affected pine stands

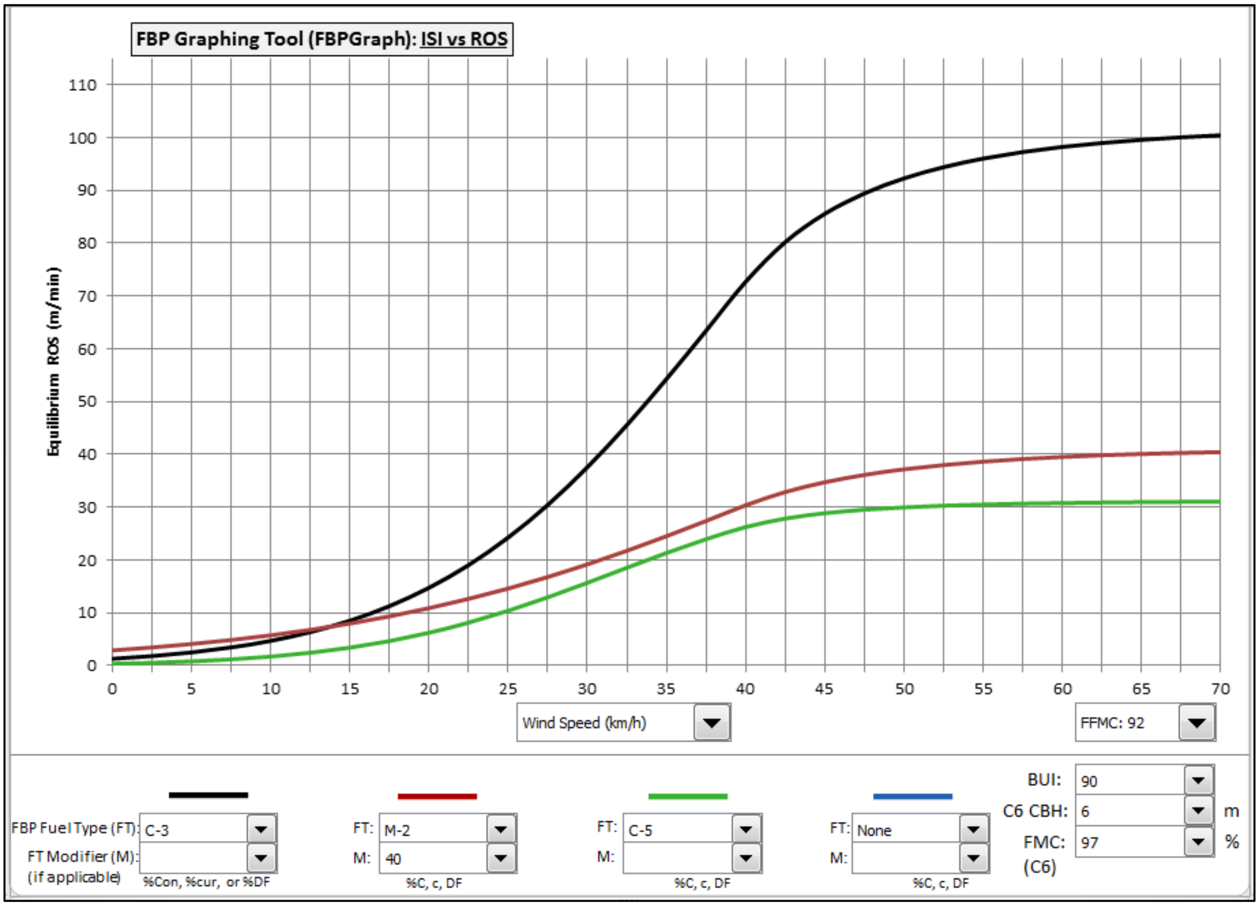
MPB-killed pine:	**Open** stands Years since attack	Pure Pl	2 sp Pl/Sx or Bl
0-24% dead	0-5 yrs	C-3	C-3
25-50% dead	0-5 yrs	C-2	C-2
51-100% dead	0-5 yrs	M-3/65	M-3/65
0-24% dead	6+ yrs	C-3	C-3
25-50% dead	6+ yrs	C-3	C-3
51-100% dead	6+ yrs	C-2	C-2

	Dense stands Years since attack	Pure Pl	Pl/Sx or Bl
0-24% dead	0-5 yr	C-3	C-2
25-50% dead	0-5 yrs	C-2	C-2
51-100% dead	0-5 yrs	M-3/65	M-3/65
0-24% dead	6+ yrs	C-3	C-3
25-50% dead	6+ yrs	C-3	C-2
51-100% dead	6+ yrs	C-2	C-2

- **Conifer stands with Sparse tree cover** (BCLCCS Level 5 ‘SP’, with 10-25% crown closure) represent challenging cases. These stands are usually transitional between forested and non-forested areas, and would probably only rarely support crown fire behaviour due to the wide gaps between tree crowns (i.e., low canopy bulk density). In these stands, the understory (herbaceous and shrub) vegetation is very important for preserving fuel continuity and determining fire spread potential. Since VRI data is often weak with respect to understory structure, biogeoclimatic zone information is often used to infer the flammability of understory fuels. Fuel types are mostly assigned to be less volatile (lower ROS and fire intensity) than would be associated with a fully-stocked similar stand; for example, in an **Open** or **Dense** mature lodgepole pine typed as C-3, the similar stand with **Sparse** density would be typed as C-7 or C-5 depending on the biogeoclimatic zone.
- **Coastal forests** dominated by coastal Douglas-fir, redcedar and western hemlock at low elevations; and Amabilis fir and mountain hemlock at higher elevations, represent a unique challenge. These stands are very different in structure and vegetation composition than the boreal or sub-boreal vegetation that is addressed by most FBP fuel types. Older low elevation stands, with high canopies and low light and wind penetration, are typed as C-5, as described above. For varying ages of younger stands, research studies have suggested a U-shaped model for surface fuel hazard, where fine surface fuel loading is highest in younger (<20 years) and old-growth stages, and lower in pole-sized and mature stands (100-200 years) (Agee and Huff 1987); however, crown fire hazard was not considered. A similar pattern was also found by Feller and

Pollock (2006), who examined different stand ages following harvesting in southwestern BC; however, that study also included a model of crown fire hazard, which showed a very different pattern, with crown fire hazard highest in dense pole-sized regenerating stands (20-90 years). These findings have been incorporated into the present fuel typing scheme by classifying dense pole-sized stands as C-3 (see above). Amabilis fir stands have been typed as M-2 40%conifer, representing predicted ROS and HFI values somewhere between C-5 and C-3 outputs (Figure 5). In most fire weather conditions, M-2 40%C produces ROS near the C-3 prediction, although at high and extreme fire danger conditions (ISI > 25 or so), the predicted spread rate is lower, representing more canopy openings and discontinuities which are believed to occur in these stands.

Figure 5. Example of comparison of predicted spread rate between Amabilis fir-dominated stands (typed as M-2 40%C) and C-3 and C-5 FBP fuel types, using FBP Graphing Tool. Note selected fire weather indices.



Wind Speed (km/h)

FFMC: 92

FBP Fuel Type (FT): C-3
FT Modifier (M):
(if applicable)
%Con, %cur, or %DF

FT: M-2
M: 40
%C, c, DF

FT: C-5
M:
%C, c, DF

FT: None
M:
%C, c, DF

BUI: 90
C6 CBH: 6 m
FMC: 97 %
(C6)

- Fuel type **C-6** (conifer plantation) is still being investigated for use in BC; use of this fuel type requires modeled or estimated crown base height, which is a variable not currently in the inventory attributes. Preliminary observations of the structure of conifer plantation in BC (Douglas-fir, lodgepole pine, white/hybrid spruce, and other species) do not seem to match the defined C-6 structure (continuous needle litter and complete crown closure); fire behaviour observations and additional research are ongoing.

5.4.2 Mixedwood and deciduous fuel types:

While the fuel type algorithm must encompass all tree species found in BC, much more fire behaviour information is available for conifer stands; consequently, broadleaf-species stands are mostly typed as D-1/2 (deciduous, leafless/ deciduous, green), indicating low fire danger in these forest types under most fuel moisture and weather conditions

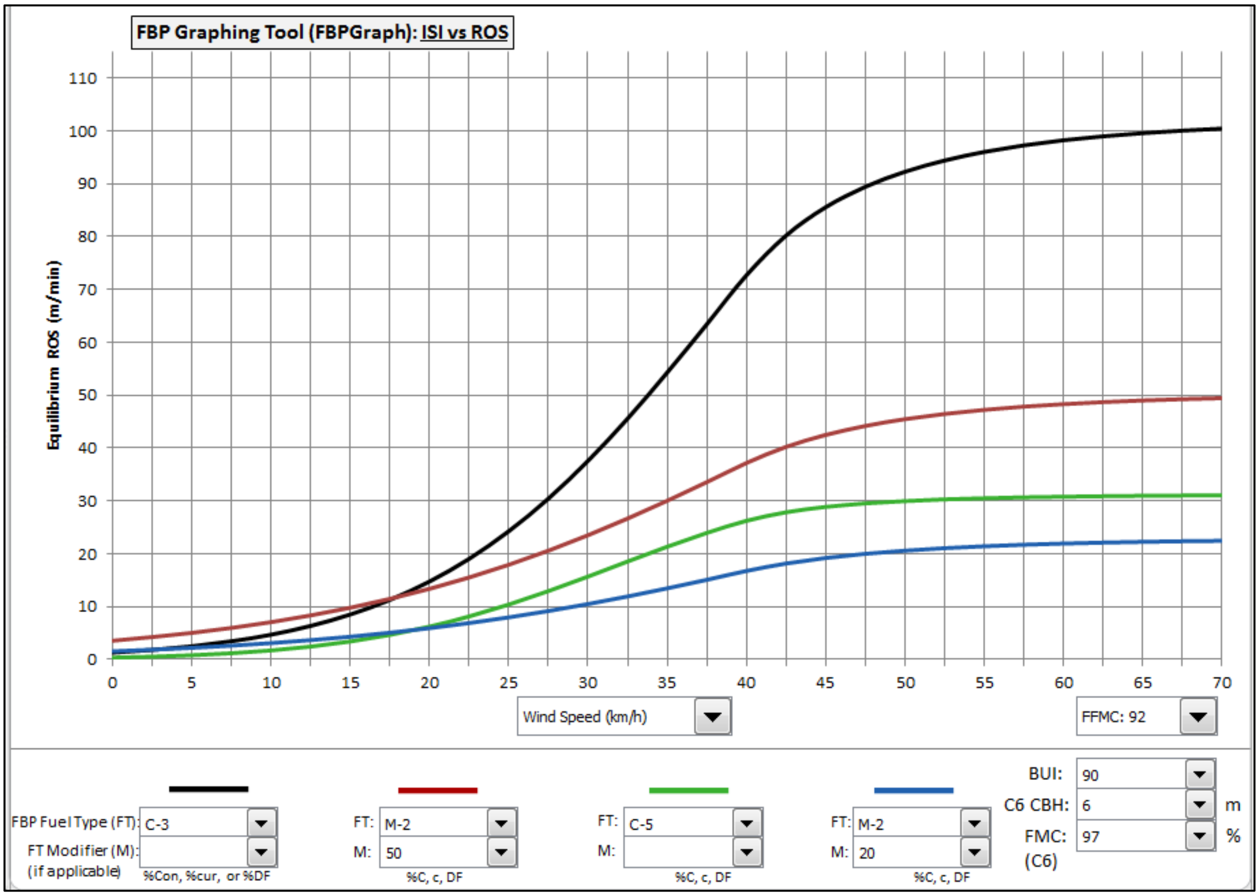
- **Larch** (*Larix* spp.), a genus of conifer trees with deciduous needles (annually shed and regrown, similar to many broadleaf species), was also classified as a deciduous group for fire behaviour purposes; larch species in BC include western larch, subalpine larch and tamarack
    - No reports have ever suggested that these species can support crown fire; because all foliage is new, foliar moisture is much higher than other conifers (>250% usually), and therefore they act similar to broadleaf species
    - Pure stands typed as D-1/2, similar to pure aspen stands
        - Larch produces very little persistent litter, so the D-1 fuel type likely overestimates fire spread potential of these stands
    - In mixed-species stands with other conifers, larch is considered to contribute to the deciduous portion of the stand; this is implemented using the M-1/M-2 fuel types

Mixedwood stands of species other than boreal spruce and trembling aspen present a particularly complex case.

- The **M-1** and **M-2** fuel types were originally artificially created by blending the C-2 and D-1 fuel types based on the 'percent conifer' (%C) fraction of a stand (Forestry Canada Fire Danger Group 1992, Wotton et al. 2009, Alexander 2010). As suggested previously, this procedure is used 'as is' for stands of white or black spruce mixed with any deciduous tree species
- For species other than white/black spruce, the %C is multiplied by a decimal proportion (between 0 and 1) to reduce the effective percent conifer; this has the effect of reducing the predicted fire behaviour (spread rate and intensity). These calculations and the specific proportions in the FTL were chosen based on the following assumptions:
    - Conifer trees in stands contribute to most fire activity; both conifer litter and conifer trees (bark and especially crowns) are much more flammable than deciduous litter and trees
    - Conifer stands (trees, overall structure) other than black and white spruce are largely less flammable and volatile than the C-2 standard that underlies the M-1/M-2 fuel types, to varying degrees that depend on surface fuel characteristics, crown base height, and various edaphic conditions
    - Therefore, adding deciduous trees to a conifer stand is assumed to reduce the rate of spread, fuel consumption, crown fraction burned, and headfire intensity compared to pure conifer stands

- The appropriate %C for these stands was assigned iteratively, aiming for a resultant M-1/2 fuel type with lower or equal ROS or HFI than the FBP fuel type representing the original pure conifer stand (as much as is possible within the confines of the fairly rigid equations)
- For example, an open stand with a blend of 65% mature lodgepole pine and 35% paper birch would be typed as M-1/2, with the %C multiplied by 0.7 and rounded up (resultant fuel type would be M-1/2 50% C); a stand of 50% red alder, 40% western hemlock and 10% Douglas-fir would be typed as M-1/2 20%C (original %C multiplied by 0.4). Figure 6 shows ISI/ROS representing these two examples, as well as the equivalent pure conifer stands.

Figure 6. Comparison of headfire intensity for mixedwood fuel type examples.



Wind Speed (km/h)

FFMC: 92

BUI: 90

C6 CBH: 6 m

FMC: 97 %

(C6)

FBP Fuel Type (FT): C-3

FT Modifier (M):

(if applicable)

%Con, %cur, or %DF

FT: M-2

M: 50

%C, c, DF

FT: C-5

M:

%C, c, DF

FT: M-2

M: 20

%C, c, DF

5.4.3 Slash and post-harvest fuels:

Fuel types for harvested areas, including slash fuel types (**S-1, S-2, S-3**), were assigned based on the estimated timing of harvesting and the species replanted. Post-harvest (or other disturbance) polygons represent some of the greatest levels of uncertainty, due to site-specific factors and rapid change in the first few years.

Factors associated with forest harvesting can profoundly influence the loading and characteristics of the subsequent surface fuel. These factors include site preparation (e.g. broadcast burning prior to replanting), characteristics of the pre-harvest forest stand (forest floor depth, dominant species, etc.), and details of the harvest operation (e.g. processing at the stump vs. at the landing), among others that define the fuels available in the post-harvest environment. These variables will be most influential for a few years (5-20 in most stands), until the characteristics of the new plantation begin to dominate overall fuel structure, through processes such as litterfall, the gradual development of a canopy fuel layer, and the buildup of a duff layer (the ‘F’ layer of organic material on the forest floor).

Harvested blocks are assumed to consist of slash (S-1, S-2, or S-3 fuel type, depending on species planted) for a few years, depending on assumed decomposition rate (based on BEC zone); this stage is followed by the dominance of non-forested vegetation for a few more years. Where the disturbance (and update to inventory data) is more than 25 years old, stand succession is assumed to have occurred, indicating a return to a young forest (conifer in most cases) in most biogeoclimatic zones. This pattern is also the closest we can approximate the ‘U’-shaped fuel succession pattern that has been detected over time in many forest stands.

Slash fuel types in the FBP System may not properly represent modern forest management practices; see discussion in Section 6.

The following assumptions were made for these stands:

- Following harvest (clearcutting is assumed), fuel structure is best represented by slash fuel types for the first 5 years post-harvest
    - Although this overpredicts in the case of post-harvest broadcast burning or other intensive hazard reduction (or site preparation) efforts, we believe this is the most likely situation where true slash fuel types will be encountered
    - Detailed site management activities (e.g. discing, mounding, fertilization, etc.) are not well represented in the VRI attributes; we are exploring links to additional data sources to incorporate this information in future analyses.

5.4.4 Grass and non-forested fuels:

Non-forested (vegetated) polygons were an important component of the FTL algorithm. In practice, fuel typing options were limited for these areas (few FBP fuel types available). As a result, these areas were classified as one of the following:

- O-1a/b (open grassland, matted or standing); grass fuel types were assigned in the following cases:

    - Non-vegetated lands post-harvest, 7-24 years since harvesting, dry BEC zones (≥ 7 years post-harvest in the case of PP and BG zones) – assumes slash fuels have decomposed or been removed as part of site preparation
    - Non-vegetated, unlogged sites, with trees present, dry BEC zones – these are non-productive very dry bunchgrass ecosystems with very sparse trees
    - Vegetated, non-treed, unlogged sites with or without trees present, in dry BEC zones, defined as very short or sparse treed stands, or other non-forest areas (brush, old burns, meadows, hayfields, open range, shrub or herb ecosystems, etc.)
    - Juniper stands
    - Very open Fd stands ≥ 4 m height (crown closure < 26%)
- D-1/2 (deciduous forest, leafless or green (surface fire only))
    - Used for moist areas where vegetation is believed to consist mostly of deciduous herbs and shrubs
- Non-fuel (used for alpine areas with patchy vegetation that would not normally support fire; also for exposed rock or ice, roads or other paved or built surfaces, irrigated croplands, etc.)
- Water (all water bodies, saturated marshes and bogs that would not normally support fire spread); identical to non-fuel, for modeling purposes
- Decision rules also needed to address recently disturbed areas (burned, harvested, or recently cleared lands only at this time)
    - For most disturbed areas, assumptions based on biogeoclimatology were used to identify likely successional pathways for these areas
        - For example, post-fire areas in dry stands of the interior are best described as 'open' (grasslands or shrublands) for several years (O-1a/b fuel type), prior to their evolution to young forest stands
    - Although there is considerable uncertainty associated with these assumptions, VRI updates will eventually correct errors as stands evolve and are re-surveyed
    - We are currently in discussion with staff from the Forest Inventory & Analysis Branch on how to best include newly burned areas in the VRI process based on burn severity assessments

5.5 Neighbouring lands

Through partnerships and collaboration, portions of the fuel layers of our neighbouring agencies have been acquired and attached seamlessly to avoid problems when modeling fuels or fires near the BC border. At the present time, the FTL includes some FBP fuel type grid data from the **Yukon Territory**, **Northwest Territories**, **and Alberta;** there is also some interpreted US vegetation classification data (very coarse quality) for Washington, Idaho, and Montana along our southern border.

- Some of these are required to run modeling software (e.g. Burn P3, PFAS) or are useful for fire behaviour prediction near provincial borders
- At this time we have acquired fuels data of approximately ≈100 km in width to the north (Yukon), NE (NWT), and E (Alberta)

- The border of the Alaska panhandle is entirely considered ‘non-fuel’ due to the alpine nature of the landscape (high mountains, glaciers and exposed rock); although this is inaccurate, it is believed to be of little consequence due to the westward nature of winds in the area and to the very high moisture (and low flammability) of the vegetation in the mountain passes along the border
- For the NW USA (Washington, Idaho, Montana), FBP fuel types have been crudely estimated based on publicly available landscape ecosystem maps; these are only presented for completeness and are a poor substitute for local data.
- These data are updated much less frequently than our BC polygons, and in most cases have not been verified by BCWS; they are presented with no guarantees whatsoever.

6. Uncertainty and Knowledge Gaps

Some vegetation communities in BC are, at best, a poor match with any of the FBP types. The greatest uncertainty in fire behaviour is probably associated with these vegetation communities:

- Shrublands and shrub-dominated communities – known to be very flammable in some cases (sagebrush, bog birch, juniper, Labrador tea, Scotch broom, others) and completely impervious to fire in other cases (e.g. willows, huckleberry, salal, slide alder, false azalea, and others)
- Subalpine parklands, with subalpine fir and Engelmann spruce (interior) or mountain hemlock and amabilis fir (coast) occurring in clumps separated by wet meadows and shrublands; the open herb- and shrublands tend to be dominated by forbs and graminoids (rushes, sedges, heather, etc.) and are less flammable than classic O-1 grasslands; the conifers have crowns extending to the ground; these trees will burn readily and support crown fire, but it is very hard to link crowning with a surface fire intensity threshold in these stands.
- Young plantations – managed stands, logged and replanted with (mostly) conifer species; at very young ages (0-2m height), post-harvest slash and surface fuel characteristics tend to dominate fuel structure; by 3-4 m in height, depending on the species, site characteristics and stocking, planted trees begin to form a continuous canopy and crown fire once again becomes a concern. None of these stages are well represented by FBP fuel types, with the exception of C-4 (representing heavily overstocked 9-10 m stands). The C-6 (conifer plantation) fuel type sounds promising, but assumes a pure understory fuelbed of pine needle litter and completely closed canopy; although there have been no focussed studies on the subject, anecdotally the C-6 has not been found to be realistic for predicting fire behaviour in most plantations in BC.
- Coastal conifer plantations represent a specific case of uncertainty – species such as Douglas-fir and western redcedar growing on productive sites, with abundant herbaceous and shrub species in the understory; sometimes these blocks are planted directly through untreated slash; other times, slash is burned before planting; currently, these stands sometimes type out as C-5, sometimes as D-1/2, sometimes as slash (S-3); in the authors’ opinion none of these is a particularly good fit, and more research is needed to represent managed stands in coastal areas

- Mixed-conifer stands of the interior wet belt – species such as western white pine and western larch growing in multi-story canopies, usually associated with Douglas-fir, redcedar, lodgepole pine, or other species; with these stands we face similar challenges as coastal conifer plantations
- Recent clearcuts with piled slash, before or after burning (Figure 8); current forestry practices often are quite different from those of the 1970s and 1980s, when the slash fuel types were developed from experimental burns; consequently S-1 through S-3 types probably do not represent modern slash blocks adequately (but are used due to a lack of other options).

Figure 7. Piling of coastal slash represents altered forestry practices in recent decades, where most (not all) woody fuels from harvest activities are piled at landings; slash fuel types (e.g. S-3) probably do not match this type of slash management.

- Agricultural croplands – these represent everything from dense hayfields (with graminoids and other herbaceous species) to post-harvest stubble; flammability often depends on characteristics and timing related to agricultural practices (crop species, timing of irrigation, timing of harvest, stubble characteristics, etc.); these areas could burn under certain conditions (e.g. fallow fields during drought conditions) but are non-fuel during most conditions; predicting the fire behaviour characteristics of these areas accurately using a provincial-scale inventory-based process is a tall order; for the time being, they are mostly treated as non-fuel.

7. Exceptions to VRI and data pre-processing

Although the VRI polygons cover the entire province seamlessly, there were certain cases where data was missing and an alternate approach was required (briefly described in Section 4.1). In these areas, all vegetation cover attribute data were absent from the VRI polygons (due to ownership or administrative reasons), resulting in great uncertainty with respect to fuel typing.

7.1 Tree Farm Licenses – data provided

In areas managed as Tree Farm Licenses (TFLs), forest industry licensees are responsible for maintaining vegetation inventory data and providing this information to the Ministry of FLNRO. Compliance with that requirement has varied considerably. In some TFLs, licensees have provided full inventory to FAIB and these data were already included in the VRI. In other cases, licensees provided some polygon data specifically for the purposes of this project (outside the VRI process) with simplified forest stand information, with many key attributes missing. For example, in many TFLs, BCLCS attributes were not assigned (these are assigned by FA&I Branch as part of the VRI process); other attribute data that is part of the VRI standard was often missing (tree heights, crown closure, harvest information, disturbance types and dates, etc.).

- The vast majority of these areas consisted of productive conifer forest land, simplifying the logic processing somewhat
- We estimated some of these attributes during the course of this project (e.g. by making simple age-height relationships) as well as possible from the basic overstory tree species, cover percentages, and timber volume information that was provided by licensees
    - The VRI process typically uses sophisticated tree and stand modeling to produce this information, but it was not possible to have this done as part of this project
    - Accuracy of stand attributes produced by simple regression modeling (during this project) is likely less accurate than the VRI-produced estimates
    - Consequently, we assume greater uncertainty in vegetation attributes and in fuel type modelling in these stands
- At this time, the total area covered by TFL data that did not meet the VRI standard was 2,037,629 ha, or 2.15% of the provincial area
- The TFLs covered by these data include the following: 6, 14, 19, 23, 25, 37, 38, 39, 41, 44, 61

7.2 TFLs and Private timberlands with no data provided

In some TFL areas, despite provincial requirements, no inventory information was obtained. This was also the case on most private forest lands, where inventory, if it existed, was not obtainable.

- Attribute values in these polygons (other than administrative and geographic identification attributes, polygon size, and derived attributes such as biogeoclimatic zone) are all null (no data)
- Over time, we may have better data for these areas as Ministry staff seek compliance from licensees in obtaining inventory data

- With few options, we used portions of a national satellite imagery-based fuels layer provided by Natural Resources Canada (Nadeau et al. 2005, and recent unpublished updates (B. Simpson, Canadian Forest Service Northern Forestry Centre, Personal Communication)) to fill in the gaps in spatial data
- The fuel typing in these areas is based on mixed classification (classified and unclassified) image processing using benchmark sites; this is a less transparent process than the VRI-based procedure used in most of the province and has not been validated; very limited metadata is available
- Cursory testing suggests that this method does adequately distinguish, for example, alpine areas classified as non-fuel from subalpine forests and valley bottom vegetation
- However, the fuel typing process, decisions, and transparency in these areas are not consistent with the majority of the provincial scheme
- At this time, the total area covered by National fuels grid coverage is 2,919,143 ha, or approximately 3.09% of the province. This area is disproportionately high in certain regions, particularly southeastern Vancouver Island, due to the historically high areas of private timberlands there.

7.3 Recently harvested and intensely managed areas

According to provincial regulations, all managed stands must be surveyed, with the stand attributes updated in provincial inventory using the RESULTS system. However, in many recently harvested areas (particularly the areas heavily affected by mountain pine beetle and recently salvage-logged), there appears to be a lag of several years (≈3-7) between harvest activities and updates in RESULTS; consequently, the VRI is sometimes out of date.

- The Forest Analysis and Inventory Branch creates an annual ‘Consolidated_Cutblocks’ layer, based on newly created forest openings (‘depletions’) detected by satellite imagery
- To capture some information regarding these depletions that are not reflected in the VRI, the following steps were taken:
    - The depletions were used in the present fuel typing process when the year of disturbance for a depletion polygon was greater (more recent) than the VRI polygon it covers – this shows that the VRI polygon is stale with respect to the most recent disturbance
    - Depletion polygons were then overlaid into the VRI layer and treated as harvested areas consistent with the fuel typing algorithm
    - The harvest date was then set to the depletion date, indicating the newly detected year of harvest
- At this time, the area covered by these depletions is 1,099,527 ha, or approximately 1.16% of the provincial area; these areas are scattered across the province in the productive forestry land base.

Results and Discussion

8. Fuel type maps and frequency tables

8.1 Fuel type maps

Overview maps show the geographic distribution of fuel types across various portions of the province. The provincial overview map (Figure 9) also shows the portions of fuel type layers provided by our neighbouring land management agencies, to the north, east, and south of BC (see section 5.5). Figures 10 - 15 show fuel type maps for each of BC's 6 Fire Centres (FC): Cariboo FC, Coastal FC, Northwest FC, Prince George FC, Kamloops FC, and Southeast FC[15].

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[15] For further administrative information of the six Fire Centres in BC, see http://bcwildfire.ca/hprScripts/WildfireNews/FireCentrePage.asp

Figure 8. Provincial Overview map.

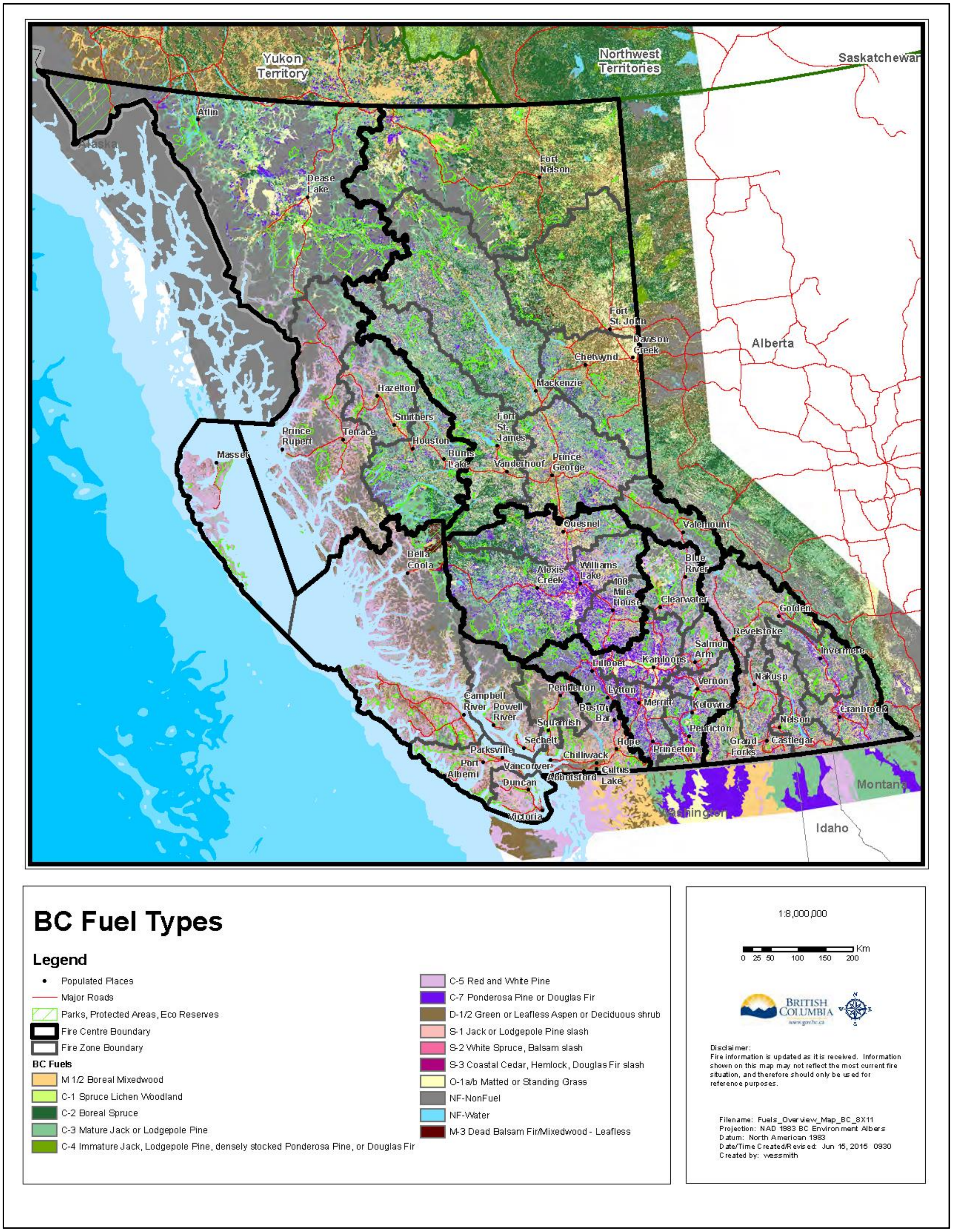


Figure 9. Cariboo Fire Centre overview.

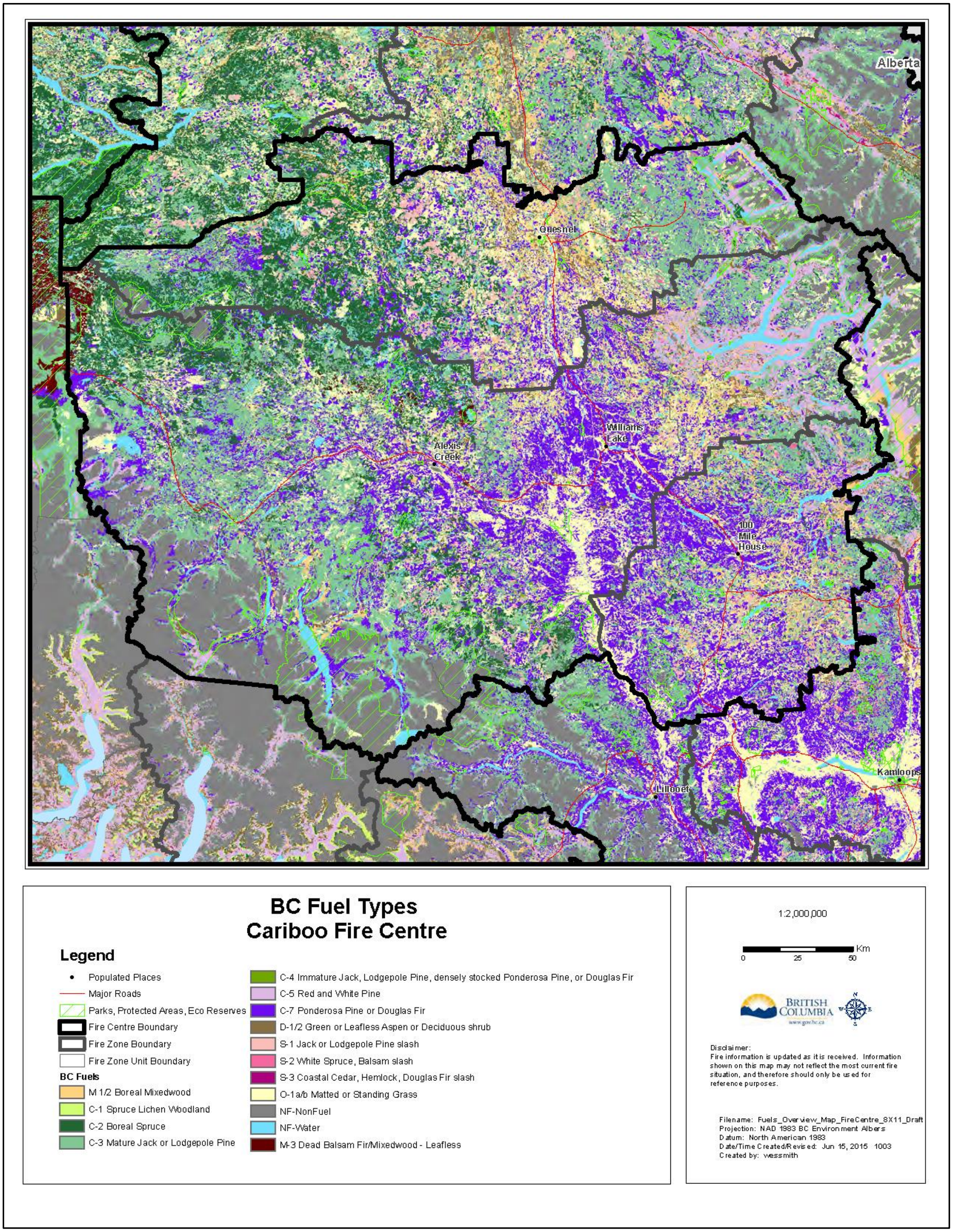


Figure 10. Coastal Fire Centre overview.

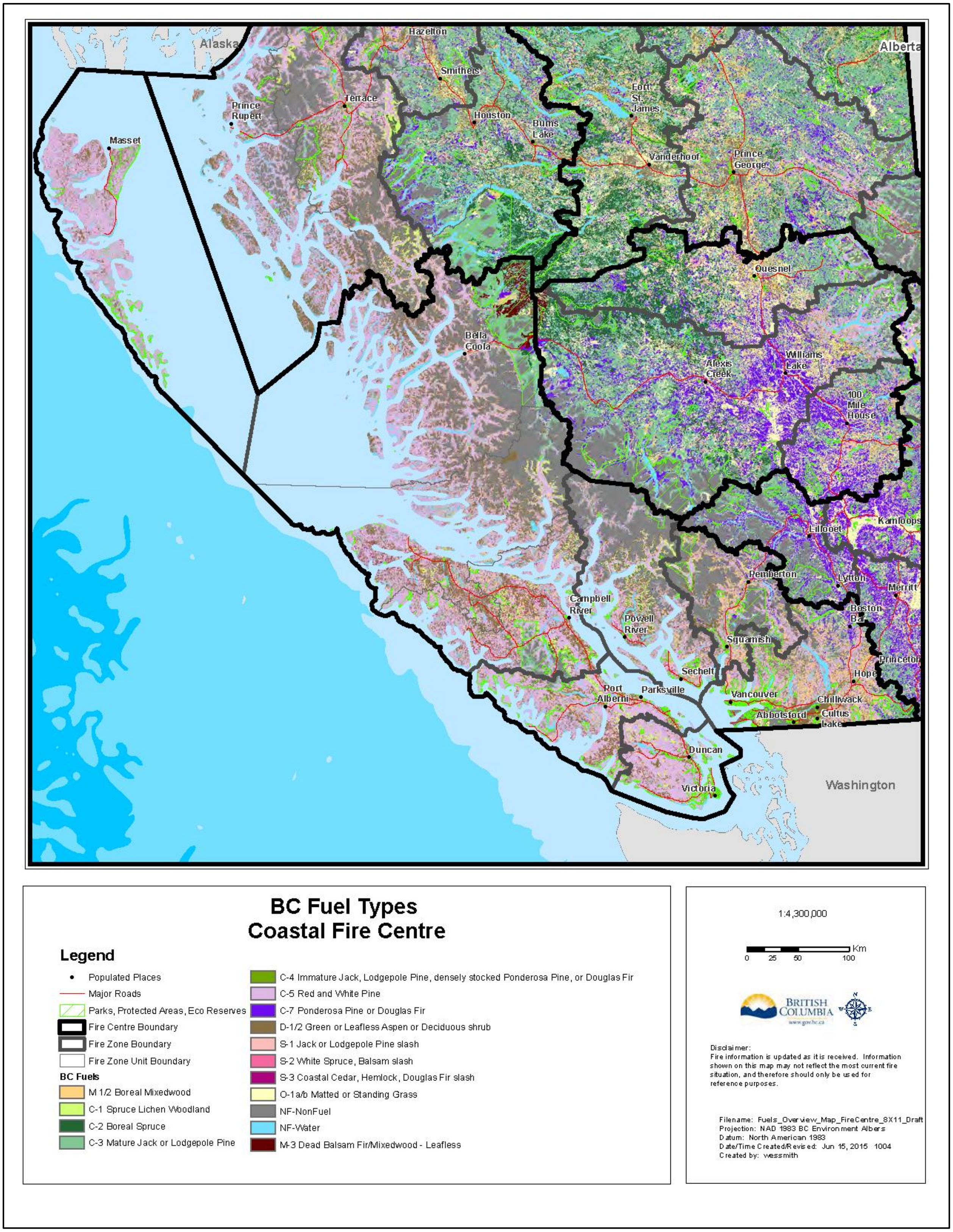
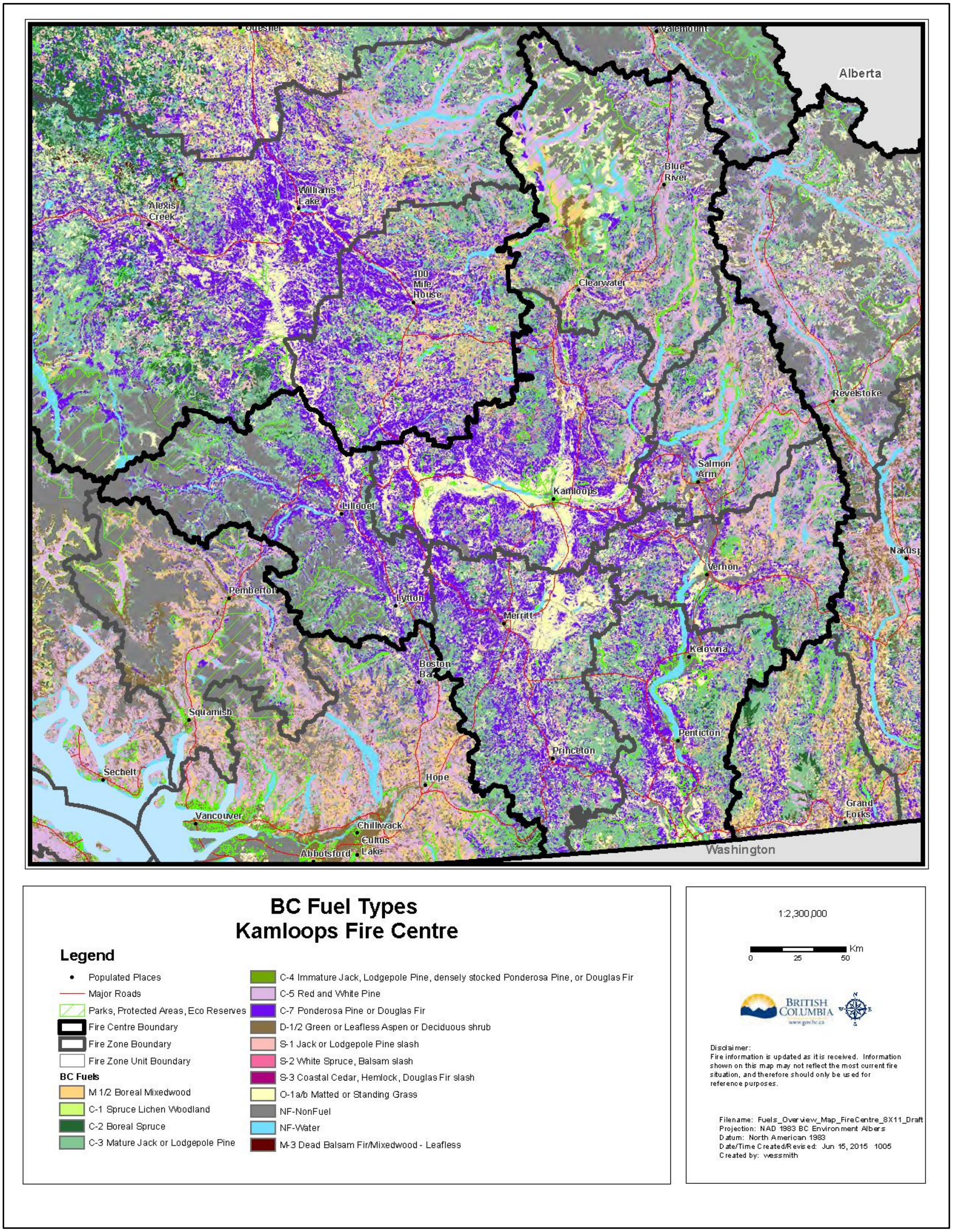


Figure 11. Kamloops Fire Centre overview.



Disclaimer:
Fire information is updated as it is received. Information shown on this map may not reflect the most current fire situation, and therefore should only be used for reference purposes.

Filename: Fuels_Overview_Map_FireCentre_8X11_Draft
Projection: NAD 1983 BC Environment Albers
Datum: North American 1983
Date/Time Created/Revised: Jun 15, 2015 1005
Created by: wessmith

Figure 12. Northwest Fire Centre overview.

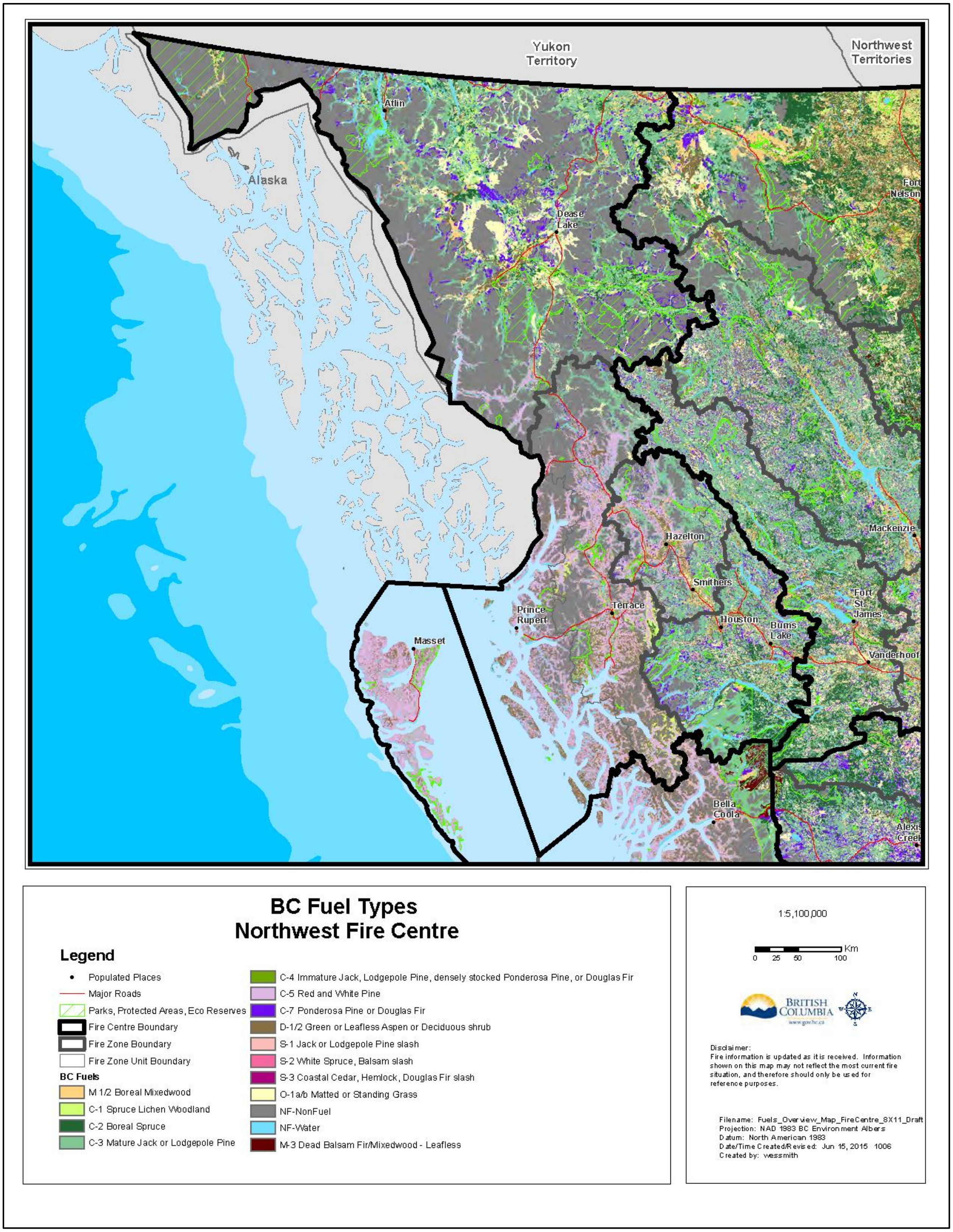
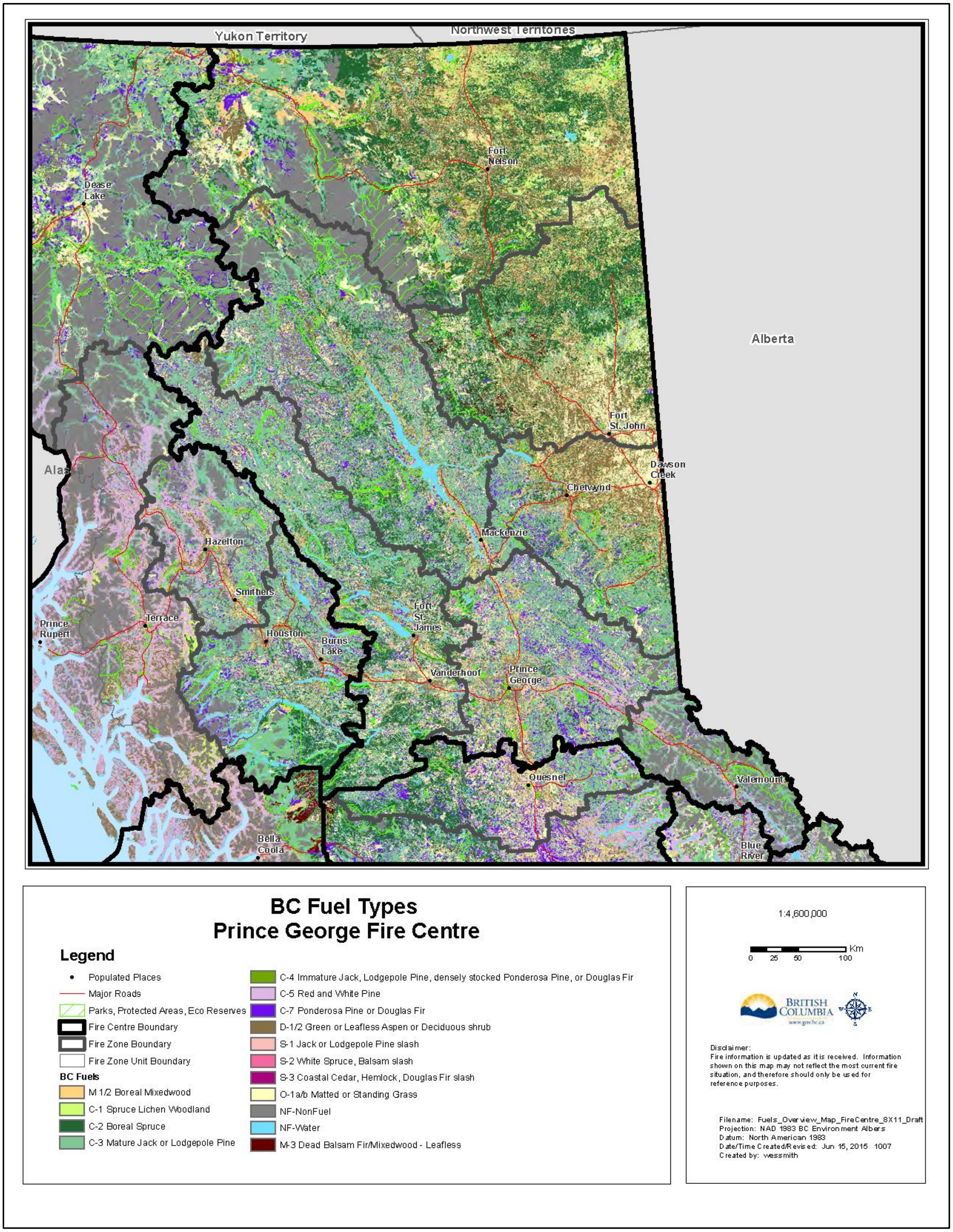


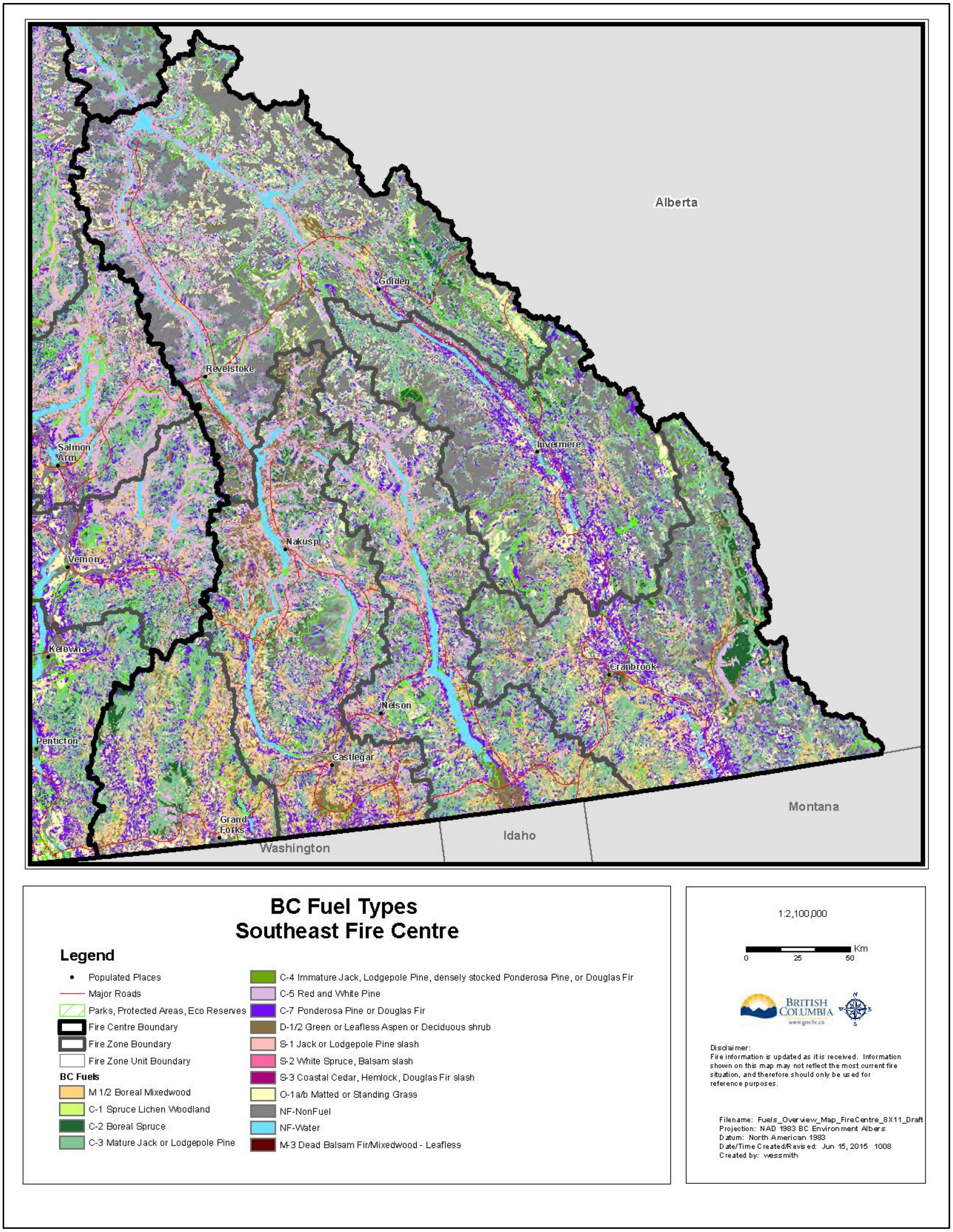
Figure 13. Prince George Fire Centre overview.



Disclaimer:
Fire information is updated as it is received. Information shown on this map may not reflect the most current fire situation, and therefore should only be used for reference purposes.

Filename: Fuels_Overview_Map_FireCentre_8X11_Draft
Projection: NAD 1983 BC Environment Albers
Datum: North American 1983
Date/Time Created/Revised: Jun 15, 2015 1007
Created by: wessmith

Figure 14. Southeast Fire Centre overview.



8.2. FBP Fuel Type Frequencies

The relative importance of various fuel and cover types across the province is shown in Table 2, below. Provincially, the most common cover type is N (non-fuel), reflecting primarily the vast alpine areas across our mountainous regions. The most abundant actual (flammable) fuel type is C-3, typed from mature lodgepole pine stands, as well as mature, fully-stocked stands of several other conifer species across the province. The next most common fuel type is C-5, used to represent the extensive areas of coastal forests that have relatively lower potential fire behaviour (Figures 11, 13). Other dominant fuel types (covering more than 5% of the provincial area) include O-1, C-2, D-1/2, C-7, and M-1/2. The total area of the FTL, including neighbouring lands and portions of the ocean adjacent to our coastal areas and islands, is 176,7681,713 ha (see Figure 7).

Table 2. Fuel type frequency table - all fuel and cover types

Fuel Type	# of polygons	Hectares	%
C-1	61,737	1,568,821.9	1.65
C-2	505,118	8,553,599.3	9.02
C-3	1,163,377	19,544,979.9	20.61
C-4	1,303	42,350.7	0.04
C-5	660,043	10,140,179.0	10.70
C-7	451,551	7,320,661.6	7.72
D-1/2	505,461	7,686,735.3	8.11
M-1/2	464,603	6,732,679.9	7.10
M-3 65% DF	16,055	220,254.6	0.23
O-1a/b	493,302	9,075,549.1	9.57
S-1	56,741	841,581.7	0.89
S-2	16,242	146,449.4	0.15
S-3	15,870	97,856.0	0.10
N	160,157	19,782,205.7	20.87
W	110,200	3,055,624.1	3.22
Total	4,681,760	94,809,528.1	100.0

The fuel type breakdown by Fire Centre is shown in Table 3[16]. The variability in fuel types around the province is readily apparent. For example, C-7 is a dominant fuel type (> 20% of total) in the Cariboo and Kamloops Fire Centres (FC's), still very important in the Southeast FC (> 10%) but of smaller importance (< 6%) in other areas. It is important to note that C-7 is also used to represent **Sparse** tree density of various conifer species in northern areas (Prince George and Northwest FC's) despite the lack of Ponderosa pine or Douglas-fir trees in these areas (see Section 5.4.1). Similarly, C-5 is a dominant component of Coastal FC (> 40% of total), still important in Kamloops, Southeast, and Northwest FC's

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[16] For an overview and map of the 6 Fire Centres across BC, see http://bcwildfire.ca/hprScripts/WildfireNews/FireCentrePage.asp

(≈10%), but relatively rare in Cariboo FC (<4 %) and a very small player in Prince George FC (< 1%). These variations generally reflect well-understood ecological differences between regions, summarized in documents such as the BC Biogeoclimatic Ecosystem Classification System[17].

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[17] See the BC BECWEB site for more information: https://www.for.gov.bc.ca/hre/becweb/

Table 3. Fuel type frequency by Fire Centre – all cover types

	Cariboo Fire Centre			Coastal Fire Centre			Kamloops Fire Centre		
Fuel Type	# of polygons	Ha	%	# of polygons	Ha	%	# of polygons	Ha	%
C-1	60	221.2	0.00	2,669	155,507.5	1.18	30	152.4	0.00
C-2	44,344	836,165.3	10.14	4,768	71,317.5	0.54	10,235	124,028.7	1.66
C-3	124,009	2,014,378.0	24.42	48,668	835,142.5	6.36	131,071	1,871,491.6	25.08
C-4	185	5,065.6	0.06	18	256.9	0.00	543	6,588.1	0.09
C-5	13,154	282,460.3	3.42	389,102	5,542,945.9	42.19	38,627	673,166.2	9.02
C-7	94,079	1,697,767.2	20.58	10,899	148,907.7	1.13	113,940	1,716,304.3	23.00
D-1/2	15,359	171,869.5	2.08	162,652	2,226,043.2	16.94	17,718	233,667.9	3.13
M-1/2	36,584	493,778.3	5.99	73,145	836,330.9	6.37	23,337	328,787.0	4.41
M-3 65% DF	3,206	37,435.1	0.45	4,088	82,251.9	0.63	88	609.4	0.01
N	6,550	776,073.0	9.41	36,851	2,624,445.6	19.98	13,177	844,761.8	11.32
O-1a/b	73,280	1,335,568.5	16.19	11,823	136,351.7	1.04	60,429	1,250,199.6	16.75
S-1	14,346	229,292.9	2.78	5,560	34,827.6	0.27	9,924	148,332.9	1.99
S-2	3,696	25,556.9	0.31	817	4,456.3	0.03	3,327	25,131.5	0.34
S-3	100	1,217.2	0.01	12,206	68,655.6	0.52	1,074	8,669.5	0.12
W	17,597	341,179.3	4.14	13,423	370,734.5	2.82	7,137	229,993.1	3.08
Total	446,549	8,248,028.2	100.0	776,689	13,138,175.4	100.0	430,657	7,461,884.0	100.0

	Northwest Fire Centre			Prince George Fire Centre			Southeast Fire Centre		
Fuel Type	# of polygons	Ha	%	# of polygons	Ha	%	# of polygons	Ha	%
C-1	6,885	426,359.5	1.75	51,351	981,614.2	2.94	742	4,967.1	0.06
C-2	37,036	966,792.0	3.97	399,054	6,345,615.8	19.02	9,681	209,680.0	2.55
C-3	156,697	4,679,061.6	19.21	567,977	8,177,474.4	24.51	134,955	1,967,431.8	23.90
C-4	47	3,716.6	0.02	432	25,456.8	0.08	78	1,266.6	0.02
C-5	144,828	2,533,151.6	10.40	16,019	237,422.2	0.71	58,313	871,032.9	10.58
C-7	37,130	1,071,694.7	4.40	130,332	1,704,134.7	5.11	65,171	981,853.0	11.92
D-1/2	72,527	1,427,797.4	5.86	198,888	3,027,763.3	9.07	38,317	599,593.9	7.28
M-1/2	38,543	763,968.8	3.14	246,738	3,604,728.4	10.80	46,256	705,086.5	8.56
M-3 65% DF	170	1,350.6	0.01	8,475	98,258.5	0.29	28	349.0	0.00
N	22,599	10,015,000.0	41.11	55,698	3,905,081.9	11.70	25,282	1,616,843.3	19.64
O-1a/b	48,111	1,353,338.8	5.55	248,426	4,060,542.7	12.17	51,233	939,547.8	11.41
S-1	5,804	68,649.5	0.28	15,981	283,777.9	0.85	5,126	76,700.9	0.93
S-2	2,598	29,921.5	0.12	4,764	51,674.2	0.15	1,040	9,709.0	0.12
S-3	980	6,567.3	0.03	158	2,357.8	0.01	1,352	10,388.6	0.13
W	36,975	1,015,830.1	4.17	29,568	858,700.7	2.57	5,500	239,186.3	2.90
Total	610,930	24,363,200.2	100.0	1,973,861	33,364,603.6	100.0	443,074	8,233,636.7	100.0

Table 4 shows the provincial frequency distribution of the mixedwood stands (M-1/2), by proportion of conifer species. Note that this scheme treats larch species as deciduous (see Section 5.4.2). Stands with 10 - 25% conifer cover comprise about 26% of M-1/2 stands; those with 30 - 55% conifer comprise 46% of mixedwood stands, and those with 60 - 80% conifer form the remaining 27%.

Table 4. Mixedwood (M-1/2) percent conifer frequency table

% Conifer	# of grid cells	Ha	%
10	456	114	0.00
15	202,253	50,563	0.75
20	689,493	172,373	2.57
25	2,208,167	552,042	8.23
30	3,974,459	993,615	14.82
35	1,476,730	369,183	5.51
40	5,562,653	1,390,663	20.74
45	1,622,798	405,700	6.05
50	3,077,055	769,264	11.47
55	694,536	173,634	2.59
60	3,153,734	788,434	11.76
65	1,157,618	289,405	4.32
70	1,301,215	325,304	4.85
75	653,637	163,409	2.44
80	1,046,287	261,572	3.90
Total	26,821,091	6,705,273	100.00

Conclusions and next steps

9. Conclusions

9.1 Decision frequencies within the FTL

This project is considered successful, in that a province-wide fuel type layer has been created, implemented, used effectively with a suite of fire behaviour models and finally documented. Due to the constant gathering of new knowledge and information, the fuel type layer is not considered complete at this time, but is rather in a state of continuous improvement. The current FTL algorithm has a few notable inefficiencies – where the resulting number of polygons is either too low or too high. Most of these will be targeted during the next revision.

As the FTL algorithm table shows, the polygon frequencies are highly uneven. There are several instances where logical queries resulted in zero polygons; these lines are clearly superfluous in the algorithm and could be removed in the next iteration (although there is always a chance that such vegetation attributes could exist in the future). For example, there are currently zero polygons that result from a query of stands of pure (single species or nearly so) ponderosa pine (Py) between 4 and 12 m in height with more than 8000 stems/ha. Other decisions currently result in too many results, and highlight the need for further discrimination, particularly when it is obvious that the resulting fuel structure could vary considerably. An example of the latter is stands of pure (single species) true fir ('Balsam') that are neither grand nor Amabilis fir and are not **Sparse** (i.e., Open or Dense); these are mostly subalpine fir, *Abies lasiocarpa* ('Bl'), and there are more than 260,000 such polygons in the VRI (all typed as C-3). Subsequent revisions will aim to further differentiate these stands using additional attributes.

9.2 Ground-truthing and fuel types

While designing this project, we have attempted to produce a comprehensive fuel type layer for fire behaviour prediction using the best available and most current data available. However, there are significant limitations to the provincial scale approach when it comes to examining fine-scale variations in fuel structure on the landscape and modeling the behaviour of individual fires. It is apparent that this process could be significantly improved by ground-truthing, or field validation, of vegetation and fuel structure. As with any modeling, both the VRI inventory process and the separate fuel typing process described in this document involve human interpretations that are often uneven or prone to error. Both processes could clearly benefit from some quality control. There are several important considerations to note related to field verification of fuel types:

- Ground-truthing of forest inventory data (general vegetation and forest stand attributes) is important, and should be done as part of continuous improvement and building confidence with the base inventory data
    - The BC Forest Analysis and Inventory Branch is tasked with this, and undertakes a certain amount of provincial-level validation annually
    - It would also be advisable for the BCWS staff to ground-truth the VRI data, as much to breed familiarity with the variety of forest types as to verify that the data meets desired accuracy standards – a polygon mapped as a 140-year old stand of Douglas-fir and lodgepole pine with 1200 stems per hectare should indeed match that description, more or less
    - Ground truthing of specific VRI attributes used in the fuel typing (section 5.2, above) could be accomplished using straightforward forestry techniques, and is highly recommended
        - Examples of VRI attributes that could be readily verified in the field (by properly trained technicians) include tree species composition, tree height, tree density, tree age, and canopy cover; stand attributes can be deduced from individual tree attributes with proper sampling.
- Ground-truthing of fuel structure characteristics specific to fire behaviour prediction can also be undertaken – this involves assessing attributes that have been found to be particularly significant in affecting fire behaviour, and may or may not be part of general forest stand

characteristics: fuel loading (fine and coarse woody debris, litter and duff depth, crown fuel load), crown base height, canopy bulk density (difficult to measure directly), tree height, etc.

  - Crown attributes (especially crown base height and canopy bulk density) can also be assessed by combining measured stand attributes with modeled crown fuel characteristics;
  - Various tables and calculators can be used for such purposes (e.g., Cruz et al. 2003a, Reinhardt et al. 2006, Alexander and Cruz 2014); predictions based on these studies would also benefit from field validation, although these efforts often consist of significant research projects (e.g. destructive sampling and measurement of entire tree crowns) rather than simple field measurements
  - These characteristics can be used to inform the selection of the best fit FBP fuel type; however, it is not always obvious how to do so. For example, surface fuel loading or canopy bulk density are not described quantitatively for FBP fuel types in the technical system description (Forestry Canada Fire Danger Group 1992).

Ground-truthing of FBP fuel types, however, is more problematic. As previously discussed, assigning an FBP fuel type to a particular stand or vegetation polygon is a complex, somewhat subjective process, often described as a blend of 'art' and science, and often implemented with regional idiosyncrasies (see Section 5.3). Evaluating FBP fuel types in the field requires specialized training and experience in a particular vegetation type, and is not readily done by most field technicians or contractors[18]. Through the present effort, we are seeking to make the fuel typing process more objective by typing stands with similar attributes identically. Improving the fuel typing process, then, becomes a matter of improving forest inventory data as well as the collection of fire behaviour case studies in documented vegetation types. This would, in theory, negate the need for actual FBP fuel type field validation – if the attributes of the vegetation community are correctly represented in a vegetation inventory polygon, and a reasonably robust fuel type model exists for that vegetation type, there would be no separate fuel type validation required.

Despite this intention, however, there are certain characteristics that are important to fire behaviour that are not (and are unlikely to ever be) captured by the VRI process. Attributes such as litter and duff depth and loading, the presence or abundance of dead conifer branches on standing trees, density of arboreal lichens, the presence of particular understory species known to be particularly flammable (due to volatile oils or resins), etc., are all potentially important for fire behaviour at the site level but are beyond the scope of VRI stand attribute mapping. These are also stand characteristics that are unlikely to be within the detection capabilities of remote sensing technologies, at least in the next few years (we would be glad to be proven wrong on that point). Some of these attributes are easily measured in the field and could potentially be used to aid in fire behaviour prediction. Due to the large number of potentially important attributes, such field-based evaluations of fuel type are likely to remain subjective in nature; at the least, measurement effort is expected to remain very uneven. Therefore, we do recommend that some fuel type validation would be valuable, if performed by personnel who have

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[18] The issue is not that these individuals cannot provide useful fuel type assessments (they sometimes can), but rather that the reasoning behind these subjective fuel type assessments is of greater interest.

locally relevant fire behaviour skills and experience. Ultimately, fire behaviour observations and case studies are the best evidence – the fire is never wrong – but in the absence of such observations, careful field assessment of fuel type can also provide value.

9.3 Alternatives to the CFFDRS and FBP fuel types

Since the publication of the FBP System in its 'final' form (Forestry Canada Fire Danger Group 1992), there has been growing interest in modeling fire behaviour using models based on physical attributes; that is, dispensing with the somewhat artificial fuel type categories in favour of quantifiable fuel parameters. While the majority of this document has focused on fuel typing using the standard FBP System fuel types, some of these alternative modeling systems are worth discussing as viable alternatives in certain cases.

Crown Fire Initiation and Spread (CFIS) software model

One of the significant weaknesses of the FBP System approach is the lack of flexibility of the fuel types. For instance, the system offers almost no ability to represent the various chronological or successional stages that a vegetation community undergoes; fuel treatments or partial harvesting that reduce overstory fuel loading are also not captured. For example, a Douglas-fir/Ponderosa pine stand (typed as C-7) might undergo a mechanical fuel treatment that removes 30-50% of basal area and most tree stems, focused on the smaller diameter ladder fuels. This treatment would certainly reduce canopy bulk density and likely increase canopy base height; however, this stand has no obvious post-treatment FBPS fuel type match (under the present algorithm, it would likely still be typed as C-7).

A software-based modeling system that was addressed specifically to address this gap is the Crown Fire Initiation and Spread (CFIS) system, developed by Cruz, Alexander and others (Cruz et al. 2003b, Cruz et al. 2005, Alexander et al. 2006). The CFIS software package[19] allows users to simply calculate the probability of crown fire initiation, and, if crown fire is predicted, the spread rate and type of crown fire behaviour (Figure 16). Notably, CFIS is sensitive to varying crown fuel parameters and somewhat sensitive to surface fuel loading as well, allowing for gaming with respect to fuel treatment parameters.

Limitations to more extensive use of CFIS include the lack of capacity for sloped terrain, the overly simplistic surface fuel consumption categories, and the lack of integration with other software tools. It is a useful tool for limited scope applications but lacks an interface to be modular with other applications, such as spatial (GIS) data platforms or script-based analysis platforms. There are additional challenges using CFIS in the operational decision-support environment because of its lack of common terminology and commonality of inputs compared with CFFDRS standards (FBP System fuel types, HFI and out outputs, etc.). Although CFIS is designed to stand alone (i.e. lack of integration can be considered a

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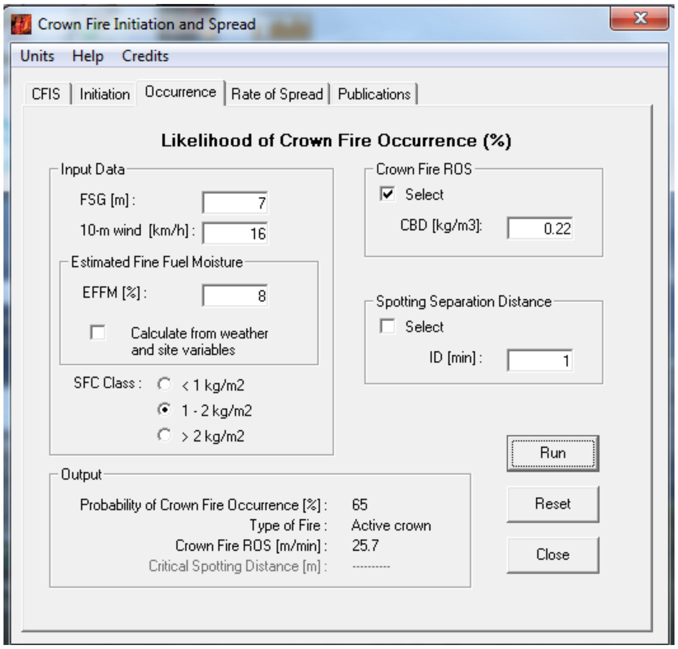
[19] For the CFIS software package and additional information, see www.frames.gov/cfis

feature rather than a limitation), it is challenging for users to compare CFIS outputs with standard FBP System outputs.

Despite various limitations, CFIS (and the models developed by its authors) represents a valuable tool that is currently being explored by the BCWS Fuel Management program for developing and evaluating mechanical forest fuel treatments and fuel treatment objectives. At the present time, these analyses will be done in parallel with the standard FBP System approach for fire behaviour prediction; there is no way to integrate outputs from CFIS (or similar alternative fire behaviour models) into the fuel type layer, for instance.

Figure 15. Screen shot of CFIS (Crown Fire Initiation and Spread) software model.



Likelihood of Crown Fire Occurrence (%)

Input Data
FSG [m] : 7
10-m wind [km/h] : 16
Estimated Fine Fuel Moisture
EFFM [%] : 8
☐ Calculate from weather and site variables
SFC Class : ○ < 1 kg/m2
● 1 - 2 kg/m2
○ > 2 kg/m2

Crown Fire ROS
☑ Select
CBD [kg/m3]: 0.22

Spotting Separation Distance
☐ Select
ID [min] : 1

Output
Probability of Crown Fire Occurrence [%] : 65
Type of Fire : Active crown
Crown Fire ROS [m/min] : 25.7
Critical Spotting Distance [m] : ---------

Pure physical models

There is another class of models that dispenses entirely (or almost) with the empirical approach in favour of seeking mechanistic processes underlying fire behaviour. These models (physical and quasi-physical models, as per Sullivan 2009a) use complex 3- and 4-dimensional physics and chemistry processes, including heat transfer and fluid mechanics equations to seek a more fundamental and scalable understanding of fire dynamics (e.g. Linn et al. 2002, Mell et al. 2009, Hoffman et al. 2012). These examples show varying degrees of promise, but remain research (non-operational) tools for the time being. This is mostly due to the complexity of building datasets to use them, and the computing power and time required to run their software versions.

This may change in the future, but at the present time, these models are not being considered for operational purposes by the BCWS, and no effort is being made to prepare datasets for their use in BC. As discussed in the Introduction, the CFFDRS is the primary tool for operational fire behaviour, both on wildfires and in planning processes.

9.4 Final Conclusions

The present document has described the background, motivation, history, methodology, and results associated with a new provincial fuel type layer for fire behaviour prediction and calculations using the Canadian Fire Behaviour Prediction (FBP) System. The fuel type layer is currently being used by BC Wildfire Service for fire behaviour prediction and planning at multiple scales. The resultant data layer, and this document, are considered 'living' processes that are continuously being refined; at the time of writing the layer is re-processed annually when the new provincial Vegetation Resource Inventory data are published. The logic in the fuel typing algorithm is updated gradually as new information from wildfire observations and new studies emerge.

Although fire behaviour prediction using the FBP System remains a partly subjective endeavour, through this document we have attempted to make the process more transparent and accountable, and thereby encourage continued progress and innovation.

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Appendix:[20]

A1. FBP Fuel Types:

- Fuel type is defined as “an identifiable association of fuel elements of distinctive species, form, size, arrangement, and continuity that will exhibit characteristic fire behaviour under defined burning conditions” (CIFFC 2003)
- The main list of FBP fuel types is copied from Forestry Canada Fire Danger Group (1992); the D-2 fuel type is described in Alexander (2010); detailed descriptions are provided below
- Reports describing additional new fuel types have been published but have not been finalized or formally adopted for use in the FBP System (e.g. Stocks et al. 2004, Pepin 2014, Perrakis et al. 2014)

Table A1. FBP System fuel types (from Forestry Canada Fire Danger Group 1992, p. 11, and Alexander 2010).

Group / Identifier	**Descriptive name**
Coniferous	
C-1	Spruce-lichen woodland
C-2	Boreal spruce
C-3	Mature jack or lodgepole pine
C-4	Immature jack or lodgepole pine
C-5	Red and white pine
C-6	Conifer plantation
C-7	Ponderosa pine-Douglas-fir
Deciduous	
D-1	Leafless aspen
D-2	Green aspen
Mixed wood	
M-1	Boreal mixed wood-leafless
M-2	Boreal mixed wood-green
M-3	Dead balsam fir mixedwood-leafless
M-4	Dead balsam fir mixedwood-green
Slash	
S-1	Jack or lodgepole pine slash
S-2	White spruce-balsam slash
S-3	Coastal cedar-hemlock-Douglas-fir slash
Open	
0-1	Grass

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[20] Full references for citations in the Appendix have been added to the References section in the main document.

A2. FBP Fuel Type Descriptions (Forestry Canada Fire Danger Group 1992):

Table 3. Summary of Canadian Forest Fire Behavior Prediction (FBP) System fuel type characteristics.

Forest floor and organic layer	Surface and ladder fuels	Stand structure and composition
Fuel Type C-1 (Spruce–Lichen Woodland)		
Continuous reindeer lichen; organic layer absent or shallow, uncompacted.	Very sparse herb/shrub cover and down woody fuels; tree crowns extend to ground.	Open black spruce with dense clumps; assoc. sp. jack pine, white birch; well-drained upland sites.
Fuel Type C-2 (Boreal Spruce)		
Continuous feather moss and/or *Cladonia*; deep, compacted organic layer.	Continuous shrub (e.g., Labrador tea); low to moderate down woody fuels; tree crowns extend nearly to ground; arboreal lichens, flaky bark.	Moderately well-stocked black spruce stands on both upland and lowland sites; *Sphagnum* bogs excluded.
Fuel Type C-3 (Mature Jack or Lodgepole Pine)		
Continuous feather moss; moderately deep, compacted organic layer.	Sparse conifer understory may be present; sparse down woody fuels; tree crowns separated from ground.	Fully stocked jack or lodgepole pine stands; mature.
Fuel Type C-4 (Immature Jack or Lodgepole Pine)		
Continuous needle litter; moderately compacted organic layer.	Moderate shrub/herb cover; continuous vertical crown fuel continuity; heavy standing dead and down, dead woody fuel.	Dense jack or lodgepole pine stands; immature.
Fuel Type C-5 (Red and White Pine)		
Continuous needle litter; moderately shallow organic layer.	Moderate herb and shrub (e.g. hazel); moderate dense understory (e.g. red maple, balsam fir); tree crowns separated from ground.	Moderately well-stocked red and white pine stands; mature; assoc. sp. white spruce, white birch, and aspen.
Fuel Type C-6 (Conifer Plantation)		
Continuous needle litter; moderately shallow organic layer.	Absent herb/shrub cover; absent understory; tree crowns separated from ground.	Fully stocked conifer plantations; complete crown closure regardless of mean stand height; mean stand crown base height controls ROS and crowning.
Fuel Type C-7 (Ponderosa Pine–Douglas-fir)		
Continuous needle litter; absent to shallow organic layer.	Discontinuous grasses, herbs, except in conifer thickets, where absent; light woody fuels; tree crowns separated from ground except in thickets.	Open ponderosa pine and Douglas-fir stands; mature uneven-aged; assoc. sp. western larch, lodgepole pine; understory conifer thickets.
Fuel Type D-1 (Leafless Aspen)		
Continuous leaf litter; shallow, uncompacted organic layer.	Moderate medium to tall shrubs and herb layers; absent conifer understory; sparse, dead, down woody fuels.	Moderately well-stocked trembling aspen stands; semimature; leafless (i.e., spring, fall or diseased).

Table 3. Continued.

Forest floor and organic layer	Surface and ladder fuels	Stand structure and composition
Fuel Types M-1 and M-2 (Boreal Mixedwood)		
Continuous leaf litter in deciduous portions of stands; discontinuous feather moss and needle litter in conifer portions of stands; organic layers shallow, uncompacted to moderately compacted.	Moderate shrub and continuous herb layers; low to moderate dead, down woody fuels; conifer crowns extend nearly to ground; scattered to moderate conifer understory.	Moderately well-stocked mixed stand of boreal conifers (e.g., black/white spruce, balsam/subalpine fir) and deciduous species (e.g., trembling aspen, white birch). Fuel types are differentiated by season and percent conifer/ deciduous sp. composition.
Fuel Types M-3 and M-4 (Dead Balsam Fir Mixedwood)		
Continuous leaf litter in deciduous portions of stands; discontinuous feather moss, needle litter and hardwood leaves in mixed portions of stands; organic layers moderately compacted, 8–10 cm.	Dense continuous herbaceous cover after greenup; down woody fuels low initially, but becoming heavy several years after balsam mortality; ladder fuels dominated by dead balsam understory.	Moderately well-stocked mixed stand of spruce, pine and birch with dead balsam fir, often as an understory. Fuel types differentiated by season and age since balsam mortality.
Fuel Type S-1 (Jack or Lodgepole Pine Slash)		
Continuous feather moss; discontinuous needle litter; moderately deep, compacted organic layer.	Continuous slash, moderate loading and depth; high foliage retention; absent to sparse shrub and herb cover.	Slash from clearcut logging; mature jack or lodgepole pine stands.
Fuel Type S-2 (White Spruce–Balsam Slash)		
Continuous feather moss and needle litter; moderately deep, compacted organic layer.	Continuous to discontinuous slash (due to skidder trails); moderate foliage retention; moderate loading and depth; moderate shrub and herb cover.	Slash from clearcut logging; mature or overmature white spruce, subalpine fir or balsam fir stands.
Fuel Type S-3 (Coastal Cedar–Hemlock–Douglas-fir Slash)		
Continuous feather moss or compacted old needle litter below fresh needle litter from slash; moderately deep to deep, compacted organic layer.	Continuous slash, high foliage retention (cedar), moderate for other species; heavy loading, deep slash; sparse to moderate shrub and herb cover.	Slash from clearcut logging; mature to overmature cedar, hemlock, or Douglas-fir stands.
Fuel Type O-1 (Grass)		
Continuous dead grass litter; organic layer absent to shallow and moderately compacted.	Continuous standing grass (current year crop). Standard loading is 0.3 kg/m^2, but other loading can be accommodated; percent cured or dead must be estimated. Sparse or scattered shrubs and down woody fuel. Subtypes for both early spring matted grass and late summer standing cured grass are included.	Scattered tress, if present, do not appreciably affect fire behavior.

A3. BC conifer species codes

The following list has been excerpted from the VRI Data Dictionary.[21] The second code letter is sometimes shown in lowercase (e.g. Fd for Douglas-fir). Deciduous species, being much less important for fire behaviour, are not shown.

Code	Common name	Latin name (excl. authority)
B	True fir	*Abies spp.*
BL	Alpine fir	*Abies lasiocarpa*
BA	Amabalis fir	*Abies amabalis*
BG	Grand fir	*Abies grandis*
CW	Western redcedar	*Thuja plicata*
FD	Douglas-fir	*Pseudotsuga menziesii*
H	Hemlocks	*Tsuga spp.*
HW	Western hemlock	*Tsuga heterophylla*
HM	Mountain hemlock	*Tsuga mertensiana*
L	Larch	*Larix spp.*
LA	Alpine larch	*Larix lyalli*
LT	Tamarack	*Larix laricina*
LW	Western larch	*Larix occidentalis*
PF	Limber pine	*Pinus flexilis*
PL	Lodgepole pine	*Pinus contorta*
PW	Western white pine	*Pinus monticola*
PA	Whitebark pine	*Pinus albicalis*
PY	Yellow pine	*Pinus ponderosa*
PJ	Jack pine	*Pinus banksiana*
S	Spruce	*Picea spp.*
SB	Black spruce	*Picea mariana*
SE	Engelmann spruce	*Picea engelmannii*
SS	Sitka spruce	*Picea sitchensis*
SW	White spruce	*Picea glauca*
SX	Hybrid spruce	*Picea spp.*
YC	Yellow-cedar	*Chamaecyparis nootkatensis*

A4. Fuel Typing Algorithm:

The full fuel typing algorithm is including in the following pages; note that some references to VRI attributes are informal (e.g. ‘Pure pine’ signifies overstory composition of 81% pine species, or greater). Technical rationale for fuel typing assignments are found in Section 5.

Right-hand column headings are as follows:

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[21] See https://www.for.gov.bc.ca/hts/vridata/standards/datadictionary.html

- FBP FT: FBP fuel type; also includes N (non-fuel) and W (water; treated as non-fuel in modeling programs)
- Modifier: FBP FT modifier; at this time mostly associated with mixedwood (M-1/2) stands
    - Percent conifer (%C), percentage of overstory composed of conifer species
    - For some stands, this is fixed (e.g. 50%), simulating an M-1/2 stand of 50% spruce and 50% deciduous trees
    - For other stands, this varies, depending on the percent conifer and dominant tree species in the stand (see section #5)
    - As noted above (Section 5.4), newly attacked (red-attack) MPB-killed stands are typed as M-3 (65% dead fir); in this case, the modifier is the % dead fir (fixed at 65)
- Process #: nominal (categorical) unique value designated to each fuel type assignment to keep track of logic and decisions
    - Process numbers are not available for polygons typed using the National fuel type grid (#9000); see section 7.2).
- Freq. : frequency (number of polygons) associated with each fuel type assignment, colour-coded as follows:

Gray	0 – 100
Bronze	101 – 10,000
Pink	10,001 – 75,000
Red	75,001 +

- Some logical combinations exist in the algorithm but have zero (or very few) polygons with those attributes (gray colour, as noted in table above); others are overly abundant (red in table above), and may be further subdivided in the next update of the algorithm. See discussion in text (section 9.1).

Fuel Type Algorithm 2015						FBP FT	Modifier	Process	Freq.
Non-vegetated (BCLCCS Lv1 = N)									
	Logged (Harvest date NOT null)								
		Harvest date 0-6 years ago							
			Coast			S-3		500	697
			Interior			S-1		502	2477
		Harvest date 7-24 years ago							
			BEC = CWH, MH, ICH			D-1/2		508	760
			Else (dry)			O-1a/b		510	2099
		Harvest date 25+ years ago							
			BEC = CMA, IMA			N		512	0
			BAFA			D-1/2		514	0
			CWH - dry			M-1/2	40	516	35
			CWH - wet			C-5		518	82
			BWBS			C-2		520	17
			SWB			M-1/2	50	522	0
			SBS			C-3		524	40
			SBPS			C-7		526	15
			MS			C-7		528	27
			IDF - dry			C-7		530	32
			IDF - wet			C-3		532	2
			PP			O-1a/b		534	0
			BG			O-1a/b		536	0
			MH			D-1/2		538	1
			ESSF			C-7		540	428
			CDF - dry			C-7		542	0
			CDF - wet			C-5		544	1
			ICH - dry			C-3		546	46
			ICH - wet			C-5		548	538
	Else (not logged)								
		BCLCCSC Lv 2 = L (bare land), or Null							
			If Alpine (BCLCS_Lv3 = A)			N		504	41780
			Else						
				If trees present (Sp.1 not Null)					
					BEC = CWH, MH, ICH	D-1/2		1537	1141
					Else (dry)	O-1a/b		1539	2814
				Else (Sp1 Null)		N		1541	56203

		BCLCCSC Lv 2 = W (water)									W		506	72912
		Else									N		1543	0
Vegetated (BCLCCS Lv1)														
	Treed (T, BCLCCS Lv2; 10% or more tree cover)													
		Sp.1 >= 80%												
			Sp. 1 Conifer (except Larch (L*))											
				Pure Pine										
				Pl, Pli, Plc, Pj, P										
					Logged (Harvest_date) <= 7 years ago						S-1		15	1565
					Else (older Harvest date or Harvest date null)									
					Sparse (BCLCCSC Lv5 = SP)									
						BEC = CWH, CDF, MH or ICH (wet)					D-1/2		12	1436
						Else (other BEC zone)					C-7		13	47205
					Else (dense or open)									
						< 4 m height (Sp. 1 height < 4 m)					O-1a/b		14	1891
						4 - 12 m height (Sp. 1 height 4-12m)								
							Overstocked (Live stems/ha + Dead stems/ha > 8000)				C-4		18	1048
							Else (fully stocked, not overstocked, or LiveS/Ha and Dead S/Ha both null)				C-3		16	39493
						Else (> 12 m height)								
							Crown closure < 40 (very open stand type)							
								BEC = BG, PP, IDF, or MS			C-7		20	8758
								BEC = CWH, MH, ICH			C-5		21	673
								Else (other BEC zone)			C-3		19	22490
							Else (closed forest or crown closure null)							
								If MPB (Earliest nonlogging dist_type = IBM)						
									If Year of attack <=5 years ago					
										Stand_percent_dead >50%	M-3	65	1510	10722
										Stand_percent_dead 25-50%	C-2		1512	5894
										Else (percent dead < 25%)	C-3		1514	6323
									Else (Year of attack > 5 years ago)					
										Stand_percent_dead >50%	C-2		1516	103593
										Stand_percent_dead 25-50%	C-3		1518	45161
										Else (percent dead < 25%)	C-3		1520	46003
								Else (non-MPB closed mature pine stand)			C-3		1522	69190
				Py (ponderosa pine)										
					Dense or Open (BCLCCSC Lv5 = DE or OP)									
						Logged (Harvest_date) <= 10 years ago					S-1		1526	0

Veg	Treed	Sp. 1 >=80				Else (older logging or Harvest date null)								
							< 4 m height				O-1a/b		1528	1
							4 - 12 m height (Sp. 1 height 5-12m)							
								Overstocked (Live stems/ha + Dead stems/ha > 8000)			C-4		1530	0
								Fully stocked (Live stems/ha + Dead stems/ha 3000 - 8000)			C-3		1532	0
								Else (Moderately stocked (<3000 /ha) or null)			C-7		1534	31
							12-17 m height							
								Dense			C-3		1536	15
								Else (Open)			C-7		1538	188
							Else (> 17 m height)				C-7		1540	1824
					Else (Sparse)									
						Stand_percent_dead >= 40%					O-1a/b		1542	96
						Else (percent dead < 40%)								
							Logged (Harvest_date) <= 10 years ago				S-1		1544	5
							Else (older logging or Harvest date null)				C-7		1546	1782
				Pa, Pf, Pw							C-5		10	2064
				Pure Douglas-fir										
				Fd (any F)										
					Logged (Harvest_date) <= 6 years ago									
						BEC=CWH, MH, ICH (wet), CDF					S-3		1548	175
						Else (dry BEC zone or ICH (dry))					S-1		1550	128
					Else (older logging or Harvest date null)									
						< 4 m height								
							BEC=CWH, MH, ICH (wet), CDF				D-1/2		22	634
							Else				O-1/ab		23	459
						>= 4 m height								
							Crown closure > 55 (quite dense)							
								4-12 m height						
									BEC=CWH, MH, ICH (wet), CDF		C-3		24	580
									Else (dry BEC zone or ICH (dry))					
										Stand Percent dead > 34	C-4		25	1
										Else	C-3		29	418
								Else (> 12 m height)						
									BEC=CWH, MH, ICH (wet), CDF		C-5		26	17011
									Else (dry BEC zone or ICH (dry))		C-7		27	21355
							Crown closure 26-55 (or Null)							
								BEC=CWH, CDF, MH or ICH (wet)			C-5		28	13509

Veg	Treed	Sp. 1 >=80					Else (interior, drier BEC zones)			C-7		31	71413
						Crown closure < 26							
							BEC = CWH, CDF, MH or ICH (wet)			D-1/2		95	6929
							Else (other BEC zone)			O-1a/b		96	32067
			Pure spruce										
			Se										
				Logged (Harvest_date) <= 10 years ago						S-2		1552	43
				Else (older logging or Harvest date null)									
					Sparse					D-1/2		32	5255
					Dense					C-2		33	1353
					Else (open)					C-3		34	16975
			Ss										
				Logged (Harvest_date) <= 6 years ago						S-3		1554	1
				Else (older logging or Harvest date null)									
					Sparse					D-1/2		1556	316
					Dense or Open					C-5		36	2276
			Sb or Sw										
				Logged (Harvest_date) <= 10 years ago						S-2		1558	4
				Else (older logging or Harvest date null)									
					Dense or Open					C-2		38	193338
					Else (Sparse)								
						BEC = BWBS or SWB				C-1		42	39967
						Else				M-1/2	30	44	12113
			S(other - Sx or S)										
				Logged (Harvest_date) <= 7 years ago						S-2		1560	395
				Else (older logging or Harvest date null)									
					BEC = BWBS or SWB								
						Dense or Open				C-2		46	34143
						Else (Sparse)				C-1		50	8805
					Else (not BWBS or SWB)								
						Sparse				C-7		51	24491
						Else (open or dense)							
							BEC = CWH or CDF			C-5		52	404
							Else (interior spruce, not sitka)						
								< 4 m height		O-1a/b		53	446
								Else (> 4 m height)					
									Open	C-3		54	50507

Veg	Treed	Sp. 1 >=80	Else (Dense)	C-2		55	3482
			Pure Hemlock, Redcedar or Yellow-cedar				
			H(any), C(any), Y(any)				
			Logged (Harvest_date) <= 6 years ago	S-3		1562	180
			Else (older logging or Harvest date null)				
			Dense				
			< 4 m height	D-1/2		58	23
			4-15 m height	C-3		60	1300
			Else (taller, dense stands)				
			Age <60	C-3		62	2161
			Age 60-99	M-1/2	40	64	3714
			Else (old, dense or unknown stands)	C-5		66	13643
			Open	C-5		1564	60057
			Else (Sparse)	D-1/2		68	21216
			Pure Fir (Balsam) or others				
			Bg	C-7		82	26
			Ba	M-1/2	40	84	10415
			B(other - mainly Bl)				
			Sparse	C-7		86	94732
			Else	C-3		88	269271
			T(any)	C-5		90	4
			J(any)	O-1a/b		93	1
			Sp. 1 Deciduous/broadleaf or Larch - Deciduous stands	D-1/2		94	177156
		Sp. 1 < 80% (at least 2 tree species)					
			% C (except Larch) <=20% (Mixed-species deciduous stand)	D-1/2		100	63973
			% C > 20 (multi-species conifer or mixedwood stand)				
			%C 21-40 (decid.-dominated mixedwood stands)				
			Logged (Harvest_date) <= 6 years ago	S-1		1529	174
			Else (older logging or Harvest date null)				
			Dominant conifer species (DCSp): Sb, Sw, Sx, Se	M-1/2	= %C	102	56868
			DCSp S				
			Coast	M-1/2	= %C * 0.5	1545	264
			Else (interior)	M-1/2	= %C	1547	6184
			Else				
			Sparse	M-1/2	= %C * 0.5	104	6714
			Else	M-1/2	= %C * 0.7	106	47765

				%C 41-65 (mixedwood stands, close to 50/50 conifer-decid.)									
					Logged (Harvest_date) <= 6 years ago					S-1		1531	419
					Else (older logging or Harvest date null)								
						DCSp: Pl, Pli, Plc, Pj, P							
							Sparse			M-1/2	= %C *0.6	112	5241
							Open			M-1/2	= %C *0.7	114	20447
							Dense			M-1/2	= %C *0.8	116	6980
						Py				M-1/2	= %C *0.6	1533	0
						Pa, Pf, Pw				M-1/2	= %C *0.5	118	413
						Fd (any F)							
							BEC = CWH, CDF or ICH			M-1/2	= %C *0.5	120	10255
							Else			M-1/2	= %C *0.6	122	9016
						Se							
							Sparse			M-1/2	= %C *0.6	124	256
							Else (dense or open)			M-1/2	= %C *0.9	126	1674
						Ss				M-1/2	= %C *0.4	128	642
						Sb or Sw				M-1/2	= %C	130	39380
						S(other - Sx, S)							
							BEC = BWBS or SWB						
								Dense or Open		M-1/2	= %C	132	6781
								Else (Sparse)		M-1/2	= %C *0.6	136	1120
							Else (not BWBS or SWB)						
								Sparse		M-1/2	= %C *0.6	138	3019
								Else (open or dense)					
									Interior	M-1/2	= %C *0.8	140	10647
									Else (Coast)	M-1/2	= %C *0.5	142	194
						H(any), C(any) or Y(any)				M-1/2	= %C *0.4	144	6408
						B(any)				M-1/2	= %C *0.6	146	3558
						T(any)				C-5		148	8
						J(any)				O-1a/b		149	0
				%C 65-80 (conifer-dominated mixedwood stands)									
					Logged (Harvest_date) <= 6 years ago					S-1		1535	668
					Else (older logging or Harvest date null)								
						DCSp: Pl, Pli, Plc, Pj, P							
							Sparse			M-1/2	= %C *0.5	154	8211
							Open			M-1/2	= %C *0.7	156	34184
Veg	Treed	Sp >=2	%C>20				Dense			M-1/2	= %C *0.8	158	11380

Veg	Treed	Sp >=2	%C>20			Py					C-7		160	229
						Pa, Pf, Pw					C-5		162	422
						Fd (any F)								
							BEC = CWH, CDF or ICH (wet)				C-5		164	12895
							Else							
								Dense			M-1/2	= %C *0.7	166	2624
								Else			C-7		168	19321
						Se								
							Sparse				M-1/2	= %C *0.6	170	529
							Else (dense or open)				M-1/2	= %C *0.7	172	3199
						Ss					C-5		174	735
						Sb or Sw					M-1/2	= %C	176	47493
						S(other - Sx, S)								
							BEC = BWBS or SWB							
								Dense or Open			M-1/2	= %C	178	5771
								Else (Sparse)			M-1/2	= %C *0.6	182	880
							Else (not BWBS or SWB)							
								Sparse			M-1/2	= %C *0.6	184	4577
								Else (open or dense)						
									Interior		M-1/2	= %C *0.8	186	17657
									Else (Coast)		C-5		188	203
						H(any), C(any) or Y(any)					C-5		190	11246
						B(any)					C-7		192	6748
						T(any)					C-5		194	0
						J(any)					C-7		195	0
				%C 81-100 (conifer-dominated, mixed-species stands)										
					Sp.1 Pl, Pli, Plc, Pj, P									
						Logged (Harvest_date) <= 7 years ago					S-1		1570	2276
						Else (older Harvest date or Harvest date null)								
							Sparse (BCLCCSC Lv5 = SP)							
								BEC = CWH, CDF, MH or ICH (wet)			D-1/2		290	5026
								Else (other BEC zone)			C-7		292	28799
							Else (dense or open)							
								< 4 m height (Sp. 1 height < 4 m)			O-1a/b		208	1051
								Else (>= 4 m height)						
									Sp.2 S(any) or B(any)					
										4 - 12 m height (Sp. 1 height 4-12m)				

				Overstocked (Live stems/ha + Dead stems/ha > 6000)	C-4		210	232
				Else not overstocked, or LiveS/Ha and Dead S/Ha both null)	C-3		211	14342
				Else (> 12 m height)				
				Crown closure < 40 (very open stand type)				
				BEC = BG, PP, IDF, or MS	C-7		209	1445
				BEC = CWH, MH, ICH	C-5		1572	304
				Else (other BEC zone)	C-3		1574	14324
				Else (closed forest)				
				If MPB (Earliest nonlogging dist_type = IBM)				
				If Year of attack <=5 years ago				
				If Dense				
				Stand_percent_dead >50%	M-3	65	1576	2459
				Stand_percent_dead 25-50%	C-2		212	2951
				Else (percent dead < 25%)	C-2		1578	2528
				Else (Open)				
				Stand_percent_dead >50%	M-3	65	1580	2821
				Stand_percent_dead 25-50%	C-2		1582	3299
				Else (percent dead < 25%)	C-3		214	3509
				Else (Year of attack > 5 years ago)				
				If Dense				
				Stand_percent_dead >50%	C-2		1584	7219
				Stand_percent_dead 25-50%	C-2		1586	5674
				Else (percent dead < 25%)	C-3		1588	4102
				Else (Open)				
				Stand_percent_dead >50%	C-2		215	30809
				Stand_percent_dead 25-50%	C-3		1590	25852
				Else (percent dead < 25%)	C-3		293	18078
				Else (non-MPB closed mature pine stand)	C-3		294	35856
				Else (Sp2 other)				
Veg	Treed	Sp >=2	%C>20	Crown closure < 40				
				BEC=IDF, PP, BG, SBPS, MS	C-7		296	2305
				BEC=CWH, CDF, ICH	C-5		297	2149
				Else	C-3		298	1288
				Else (Crown closure >=40 or unknown)	C-3		299	26279
				Sp. 1 Py				
				Logged (Harvest_date) <= 7 years ago	S-1		1566	4
				Else (older Harvest date or Harvest date null)				

Veg	Treed	Sp >=2	%C>=20			< 4 m height (Sp. 1 height < 4)						O-1a/b		1568	128
						Else (taller)									
							Dense (BCLCCSC Lv5 = DE)					C-3		200	55
							Else (open or sparse)					C-7		202	3414
				Sp. 1 Pa, Pf, or Pw								C-5		204	6041
				Sp. 1 Fd (any F)											
					Logged (Harvest_date) <= 6 years ago										
						BEC=CWH, MH, ICH (wet), CDF						S-3		1592	402
						Else (dry BEC zone or ICH (dry))						S-1		1594	175
					Else (older Harvest date or Harvest date null)										
						< 4 m height									
							BEC=CWH, MH, ICH (wet), CDF					D-1/2		1596	1546
							Else					O-1/ab		1598	991
						>= 4 m height									
							Crown closure > 55 (quite dense)								
								4-12 m height							
									BEC=CWH, MH, ICH (wet), CDF			C-3		216	1505
									Else (dry BEC zone or ICH (dry))						
										Stand Percent dead > 34		C-4		217	9
										Else					
											Sp.2 = PY	C-7		218	11
											Else (other Sp. 2)	C-3		1549	313
								Else (> 12 m height)							
									BEC=CWH, MH, ICH (wet), CDF			C-5		220	30353
									Else (dry BEC zone or ICH (dry))			C-7		221	13987
							Crown closure 26-55 (or Null)								
								BEC=CWH, CDF, MH or ICH (wet)				C-5		222	23562
								Else (interior, drier BEC zones)				C-7		223	35035
							Crown closure < 26								
								BEC = CWH, CDF, MH or ICH (wet)				D-1/2		225	9037
								Else (other BEC zone)				O-1a/b		219	9755
				Sp. 1 S(any)											
					Logged (Harvest_date) <= 6 years ago							S-2		1511	1121
					Else (older logging or Harvest date null)										
						Sp. 1 Se									
							Sparse					C-7		224	9846
							Dense or Open								

				Sp. 2 = Bl, B, Pl, P, Pli				
				Dense	C-2		1513	4333
				Else	C-3		1515	53505
				Sp. 2 = Hw, Hm, Cw, Yc				
				Dense	C-3		1517	421
				Else	C-5		1519	3341
				Else (other Sp. 2)	C-3		1521	6259
				Sp. 1 Ss	C-5		228	8665
				Sp. 1 Sb				
				Dense or Open	C-2		230	41936
				Else (Sparse)				
				BEC = BWBS	C-1		234	2992
				Else	C-3		236	2566
				S(other - Sx, Sw, S)				
				BEC = BWBS				
				Dense	C-2		238	7558
				Open	C-3		240	27123
				Else (Sparse)	C-1		244	3395
				Else (not BWBS)				
				Sparse	C-7		246	33994
				Else (open or dense)				
				BEC = CWH or ICH	C-5		248	18376
				Else (dry, nonboreal forest type)				
				Dense	C-2		1523	19536
				Else (Open)				
				Stand percent_dead > 34	C-2		1525	10933
				Else (percent_dead <= 34 or Null)	C-3		250	147838
				H(any), C(any), Y(any)				
				Logged (Harvest_date) <= 6 years ago	S-3		1527	427
				Else (older logging or Harvest date null)				
				Dense				
				< 4 m height	D-1/2		252	52
				4-15 m height	C-3		253	6815
				Else (taller, dense stands)				
Veg	Treed	Sp >=2	%C>20	Age <60	C-3		254	8185
				Age 60-99	M-1/2	40	256	10368
				Else (old, dense or unknown stands)	C-5		255	79483

Veg	Treed	Sp >=2	%C>20				Open	C-5		257	331836
							Else (Sparse)	D-1/2		258	63903
					Bg			C-7		274	134
					Ba						
						Sp. 2 = Se, Sw, S		C-3		276	1686
						Else		M-1/2	40	277	38074
					B(other - mainly Bl)						
						Sparse		C-7		278	31032
						Dense					
							Sp. 2 = Se, Sw, S	C-2		279	14092
							Else	C-3		280	4779
						Else (Open)		C-3		281	152486
					T(any)			C-5		282	2
					J(any)			C-7		286	0
	Non-treed (BCLCCS Lv2 = N)										
		Logged (harvest date NOT null)									
			Sp. 1 NOT <null> (trees present)								
				Harvest date 0-7 years ago							
					Sp. 1 P(any)			S-1		300	27026
					Sp. 1 S(any), B(any)			S-2		302	14653
					Sp. 1 Cw, Yc, H(any)			S-3		304	9856
					Sp. 1 Fd						
						BEC = CWH, ICH		S-3		306	4133
						Else		S-1		308	2320
					Else			S-1		310	3480
				Harv. date 8-24 years ago							
					BEC = CWH, MH, ICH (wet)			D-1/2		600	23685
					Else (dry)			O-1a/b		602	57414
				Harv. date >=25 years ago - BEC							
					BEC = CMA, IMA			N		604	6
					BAFA			D-1/2		606	0
					CWH - dry			M-1/2	40	608	629
					CWH - wet			C-5		610	2299
					BWBS			C-2		612	1275
					SWB			M-1/2	50	614	0
					SBS			C-3		616	6393

Veg	Non-treed	SBPS	C-7		618	1365
		MS	C-3		620	3290
		IDF - dry	C-7		622	1626
		IDF - wet	C-3		624	239
		PP	O-1a/b		626	75
		BG	O-1a/b		628	1
		MH	D-1/2		630	258
		ESSF	C-3		632	3465
		CDF - dry	C-7		634	0
		CDF - wet	C-5		636	21
		ICH - dry	C-3		638	287
		ICH - wet	C-5		640	3743
		Sp. 1 null (no trees)				
		Harvest date 0-5 years ago	S-1		312	15944
		Harv. date 6-24 years ago				
		BEC = CWH, MH, ICH	D-1/2		642	6600
		Else (dry)	O-1a/b		644	17516
		Harv. date >=25 years ago - BEC				
		BEC = CMA, IMA	N		646	1
		BAFA	D-1/2		648	0
		CWH - dry	M-1/2	40	650	162
		CWH - wet	C-5		652	483
		BWBS	C-2		654	208
		SWB	M-1/2	25	656	0
		SBS	C-3		658	2201
		SBPS	C-7		660	236
		MS	C-7		662	358
		IDF - dry	C-7		664	555
		IDF - wet	M-1/2	50	666	95
		PP	O-1a/b		668	50
		BG	O-1a/b		670	6
		MH	D-1/2		672	41
		ESSF	C-7		674	358
		CDF - dry	C-7		676	0
		CDF - wet	C-5		678	4
		ICH - dry	M-1/2	40	680	35
		ICH - wet	C-5		682	582

Veg	Non-treed	Unlogged (harvest date null)				
		Sp1 = Not Null (trees present)				
		BEC=CMA, IMA	N		400	6353
		BEC=CWH, MH, ICH, BAFA	D-1/2		402	51654
		Else (dry)	O-1a/b		404	196259
		Sp1 = Null (no trees)				
		If FIP (Inventory_Standard_CD = F)				
		If Non-productive Code = 11, 12, 13 (brush, old burn, etc.)				
		BEC = CWH, MH, ICH	D-1/2		406	12477
		Else (dry)	O-1a/b		408	27706
		If Non-productive Code = 35 (swamp)	W		410	33701
		If Non-productive Code=42 (clearing - usually agricultural field)	N		412	6171
		If Non-productive Code = 60, 62, 63 (meadow, hayfield, open range)	O-1a/b		414	12712
		If Non-productive Code = Null				
		BEC=CMA, IMA	N		416	145
		BEC=CWH, MH, ICH, BAFA	D-1/2		418	10583
		Else (dry)	O-1a/b		420	11021
		Else (other non productive)	N		422	8
		Else (I_S_CD =VRI or I)				
		If Land_cover_class_CD = LA, RE, RI, OC	W		424	1903
		If Land_cover_class_CD = HG	O-1a/b		426	12962
		If Land_cover_class_CD = BY, BM, BL	D-1/2		428	9082
		If Land_cover_class_CD = SL, ST, HE, HF or Null				
		BEC = CMA, IMA	N		430	4788
		BEC = CWH, MH, ICH	D-1/2		432	15204
		Else (dry)	O-1a/b		434	89965
		Else (L_c_c_CD = rock, ice or other bare or unburnable land)	N		436	39317
Else (BCLCS Level 1 Unknown or null and BCLCS Level 4 contains National Fuel Type Code)						
		National FT = 101	C-1	100	9000	
		102	C-2	100	9000	
		103	C-3	100	9000	
		104	C-4	100	9000	
		105	C-5	100	9000	
		106	C-6	100	9000	
		107	C-7	100	9000	
		108	D-1/2		9000	
		109	M-1/2	50	9000	

110	M-1/2	50	9000	
111	C-2	100	9000	
112	C-2	100	9000	
113	S-1		9000	
114	S-2		9000	
115	S-3		9000	
116	O-1a/b		9000	
117	O-1a/b		9000	
118	W		9000	
119	N		9000	
120	D-1/2		9000	
121	N		9000	
122	O-1a/b		9000	

[End]