4654

Ninth Annual Symposium on Geographic Information Systems

GIS 95

Vancouver British Columbia Canada

Forest Fire Fuel Type Mapping Using GIS and Remote Sensing in British Columbia

Brad Hawkes

Canadian Forest Service
Pacific Forestry Centre
506 West Burnside Road
Victoria
British Columbia V8Z 1M5
Canada
Phone: 604 363-0665
Fax: 604 363-0775
E-mail: bhawkes@a1.pfc.forestry.ca

Olaf Niemann

Deptartment of Geography
University of Victoria
PO Box 3050
Cornett Building, Rm 206
Victoria
British Columbia V8W 3P2
Phone: 604 721-7329
Fax: 604 721-6216
E-mail: olaf@geography.geog.uvic.ca

David Goodenough
Bruce Lawson
Alan Thomson
Wendmagegn Sahle

Canadian Forest Service
Pacific Forestry Centre
506 West Burnside Road
Victoria
British Columbia V8Z 1M5
Canada
Phone: 604 363-0600
Fax: 604 363-0775
E-mail: dgoodenough blawson
athomson@a1.pfc.forestry.ca
wsahle@alder.pfc.forestry.ca

Peter Fuglem
Judi Beck
Bryan Bell

Ministry of Forests
Protection Branch
31 Bastion Square
Victoria
British Columbia V8W 3E7
Phone: 604 387-8732
Fax: 604 387-5685
E-mail: pfuglem@galaxy.gov.bc.ca
jabeck@galaxy.gov.bc.ca

Phil Symington

Ministry of Forests
Corporate Policy and Planning Branch
610 Johnson St. 3rd Floor
Victoria
British Columbia V8W 3E7
Phone: 604 356-0610
Fax: 604 356-6076
E-mail: psymington@mfor01.for.gov.bc.ca

Preliminary results of two multiagency projects to map fuel types using Geographic Information Systems (GIS) and forest inventory data in British Columbia (B.C.) are reported. A multiphase project in the Victoria watershed is associated with a larger project at Pacific Forestry Centre called SEIDAM (System of Experts for Intelligent Data Management) led by Dr. David Goodenough. Phase one of this project to characterize forest and non-forest fuels from multiplatform, multitemporal remote sensing, involved analysis of attributes contained in the Victoria watershed forest inventory data base using a rule-based algorithm applied at the polygon level. Fuel types are also being classified on a 2 by 2 km grid basis for 7000 (1:20 000) map sheets covering most of B.C. by the B.C. Ministry of Forests Protection Branch using the fuel type algorithm. The resulting fuel type maps will be used in the advanced fire management decision support system (Windows based) as one data layer required to predict fire behavior and displayed directly to illustrate fuel types spatially for use by fire managers in B.C.

GIS World, Inc.

Using the algorithm developed, a total of 34 forest and non-forest fuel types were possible using criteria based on general forest canopy characteristics available in the B.C. Ministry of Forests forest inventory (*e.g.* tree height, crown closure, and crown type and density), and surface fuel characteristics (derived from tree species groups). These initial fuel types were further translated into one of 12 applicable Canadian Fire Behavior Prediction System fuel types based on expert knowledge. The more general fuel type analysis was shown to have potential for use in a new fire environment model being developed currently by the Canadian Forest Service, which will allow more flexible input of forest fuel characteristics that influence fire behavior. The potential uses of the fuel mapping products and data bases are discussed.
Keywords: Fuels, Remote Sensing, Fire, Forest Inventory, Expert, Rules, Fire Behavior Prediction, Decision Support Systems

Introduction

Resource management requires increasingly more effective fire management. Fire managers require ways of evaluating the various elements affecting ignition potential and probable fire behavior for proper fire control and use (Stocks *et al.* 1989). Fuel, weather and topography are the main factors that affect fire behavior. The Canadian Fire Behavior (FBP) Prediction System (Forestry Canada Fire Danger Group 1992) is a series of quantitative fire behavior models for 16 major Canadian fuel types. Fuel type has been defined as "an identifiable association of fuel elements of distinctive species, form, size, arrangement, and continuity that will exhibit characteristic fire behavior under defined burning conditions" (Merrill and Alexander 1987).

The list of 16 fuel types in the FBP system was not intended to be comprehensive or fixed, since additions and refinements to the system are foreseen in the future (Forestry Canada Fire Danger Group 1992). Many fuel types present in British Columbia (B.C.) are not represented in the 16 FBP fuel types. Work is also under way in the Canadian Forest Service fire research community on the development and testing of physically-based fire behavior models within a comprehensive fire environment modeling approach (CFS Fire Danger Working Group 1994) which will require an expansion of FBP fuel types based upon available and new vegetation information. This fuel typing will still be based on qualitative information such as stand structure and composition, surface and ladder fuels, forest floor cover and the type of organic layer with emphasis on properties of importance to fire behavior. One difference will be the requirement for more quantitative fuels information (*e.g.* bulk density and loading) and the need for high resolution spatial information (*e.g.* area and location) of fuel types on the landscape. In addition to the need for a more general fuel type classification scheme, there is a requirement to improve the translation of forest inventory information into FBP fuel types in order to fully utilize the FBP system within fire management decision support systems.

Some initial work has been done in using remote sensing information such as Landsat data (Kourtz 1977), forest ecosystem classification (De Groot 1988), vegetation inventory (Tymstra and Ellehoj 1994), national forest inventory (Kourtz personal communication 1994), and detailed forest cover information (Fuglem 1984; Mazek *et al.* 1995) to classify fuel types in Canada. Until recently, fuel type classification was generally done on a coarse scale (*e.g.* 15 by 15 km grid in British Columbia (B.C.) used in the Advanced Fire Management System (AFMS)) without detailed information on forest stand species composition (*e.g.* conifer, deciduous, and mixedwood) and structure (no information on crown closure and height).

A more detailed (2 by 2 km) grid for fuel types was completed in association with the B.C. Ministry of Forests Protection Branch's (BCMOF Prot. Br.) values system which displayed information on timber and property values, fuel types, and water bodies (Fuglem 1994). This initial work (written in FORTRAN) was completed just as the FBP system was being introduced and required updating because of the simple fuel type algorithm (based on translation of inventory type groups and condition (maturity, residual, or logged) to species specific fuel types) and the change in forest cover in the last 10 years. With the recent incorporation of Geographic Information Systems (GIS) into fire management information systems and the need for high resolution fuels information, there is a need for a methodology to automate the analysis of forest inventory information and translate the general fuel types into the current FBP system fuel types at the polygon or stand level.

Currently in B.C. the BCMOF Prot. Br. AFMS includes a grid-based system for fuels that is 15 by 15 km. This coarse resolution was adequate for fire danger rating on a provincial and regional scale but is not adequate for more detailed and precise decision making in fire management. The BCMOF Prot. Br. AFMS required increased resolution of fuel information at a 2 by 2 km grid for their new (Windows-based) AFMS. This required a method of analyzing the provincial forest inventory at the polygon level to determine FBP fuel types and then, producing grided information.

A second approach to fuel typing, utilizing GIS and remote sensing information, has been undertaken concurrently with this provincial level fuel typing. This second multiagency project involved using a number of test sites (initially concentrated in the Greater Victoria watershed area), which had multiplatform, multitemporal remote sensing information, forest inventory data, terrain data, and ground truth plot results to develop new methods and approaches to classify fuel types. This second project has many partners in university, the private sector, and federal and government departments. The results of the project will be integrated with those of the SEIDAM (System of Experts for Intelligent Data Management) project at Pacific Forestry Centre (Goodenough *et al.* 1993), and will make available a much wider array of remote sensing images of the Greater Victoria watershed than are normally available. Phase one of the project in the Victoria watershed involves the development of an algorithm for analyzing forest inventory data within a GIS (ARCINFO) framework to determine both general fuel types and translation to actual FBP fuel types.

The objectives of this paper are:

1. To describe the approach and algorithm to classify fuel types from forest inventory information at the provincial and watershed levels. To illustrate a first approximation of a method to translate the more general fuel types into FBP fuel types.

2. To illustrate and discuss preliminary output of provincial and watershed level mapping efforts and describe their possible uses.

3. To describe possible future work in these fuel typing projects.

Algorithm Development and Description

The fuel types in the FBP system are described in mostly qualitative rather than quantitative terms (Stocks *et al.* 1989). For example, the description for C7 - Ponderosa Pine is (Forestry Canada Fire Danger Group 1992):

Forest Floor and organic layer: Continuous needle litter; absent to shallow organic layer (<3 cm).

Surface and ladder fuels: Discontinuous grasses, herbs, except in conifer thickets, where absent; light woody fuels; tree crowns separated from ground except in thickets.

Stand structure and composition: Open ponderosa pine and Douglas-fir stands (canopy closure <50%); crown base height (average 10 m) and crown fuel load (average 0.5 kg/m2); mature uneven-aged; associated species are western larch, lodgepole pine; understory conifer thickets.

There was a need to summarize the important stand structure features and surface fuel conditions that affect fire behavior, taken from the description of the 16 FBP fuel types, in order to develop an algorithm to classify forest inventory information according to these features and conditions. Figure 1 illustrates the characteristics thought, by fire personnel in the B.C. Ministry of Forests and Canadian Forest Service (Pacific Forestry Centre, Victoria), to affect fire behavior that would be required to classify using existing forest inventory information. The most basic classification is whether an area is forested, logged, windthrown or non-forested. Within the forested polygons the canopy characteristics and surface fuels conditions need to be described further.

Canopy characteristics such as tree height, crown closure and type (*e.g.*, conifer, mixedwood, and deciduous) were considered most important, with crown base height also important but not available currently within the B.C. forest inventory data base. Within a conifer crown type, the density of the individual crown (*e.g.* a dense spruce crown vs an open lodgepole pine crown) provided an indicator of crown bulk density which was felt to influence fire behavior (*i.e.* dense crowns burn more quickly and are more efficient in heat transfer than more open crowns thus increasing crown fire rate of spread (ROS)). Surface fuels can consist of various combinations and sizes of woody material, tree needles, herbs, grasses and shrubs. The bulk density (weight per unit volume) of this material was felt to be most important in terms of being flashy (quick to dry and efficient support of flaming combustion and heat transfer to adjacent fuels) or compact (slow to dry and less efficient

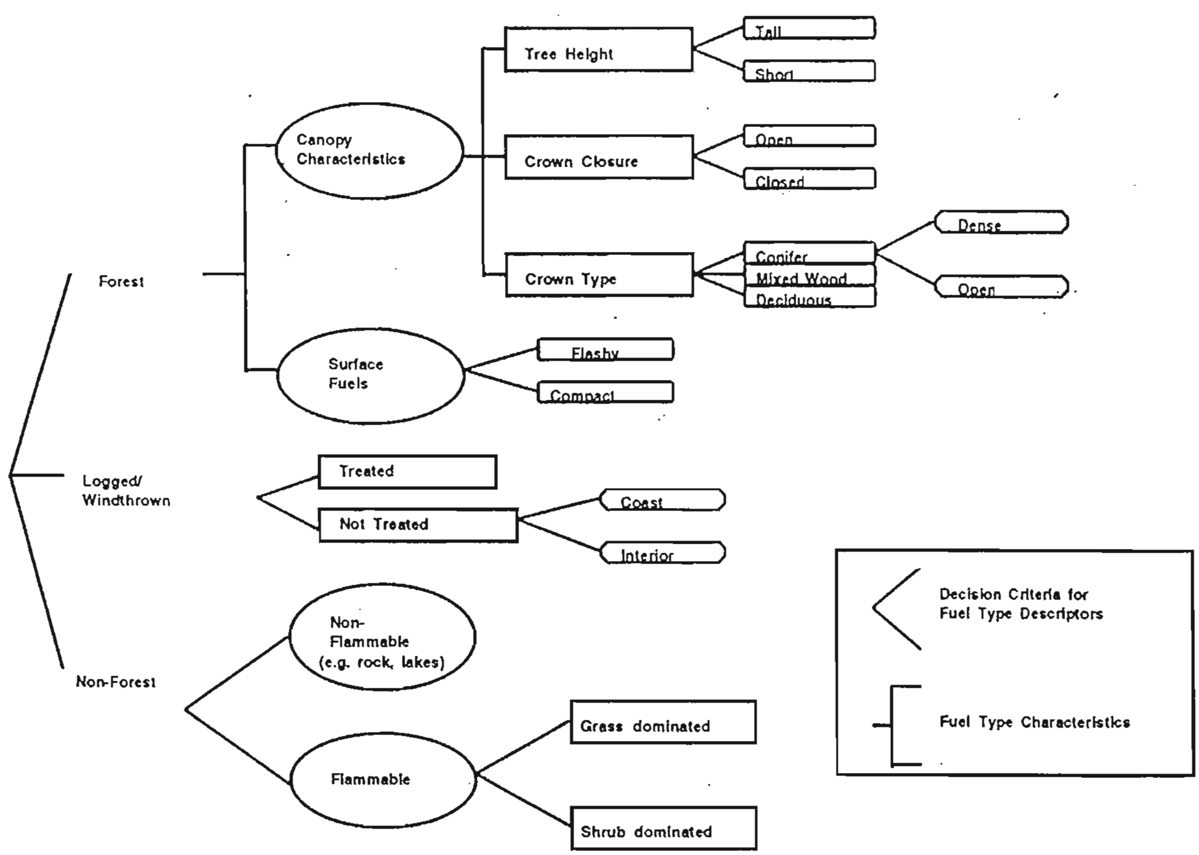

Figure 1: *Key to classify fuel types from British Columbia forest inventory data.*

support of flaming combustion and heat transfer).

Although there was not a specific attribute in the forest inventory data base to use to classify surface fuels, inventory type groups (42 typical combinations of tree species) were available, along with a general description of their location (coast or interior). Each group was assigned a surface fuel condition based on expert opinion (B. Hawkes and B. Lawson). Also assigned, based on expert opinion, was the crown type of each inventory type group and the crown density for the conifer crown types. The use of these inventory groups simplified the classification of possible combinations of the 38 tree species (as leading and secondary species within forested stands) present in the forest inventory data base.

An area is considered logged or windthrown if this activity has occurred within the last 5 years on the coast and the last 10 years in the interior of B.C. This time limit is used to distinguish the period that is required for slash to break down and for a site to regenerate and grow to a young stand condition, so that one would consider it to be forested. Logged or windthrown areas are further described by whether or not they have been treated or not-treated to reduce the fire hazard of residue. The logged or windthrown areas that were not treated were further broken down according to their location. Species of logging slash was not used to further refine FBP fuel type selection because species is not present in the forest inventory data base until the area has been regenerated (in addition, the regenerated species are not necessarily the same ones present in the slash fuels). In addition, historic inventory information was not available readily to determine what species were present before logging.

At a provincial scale, the type of logging (selective or seed tree logging systems which leave a significant tree cover) and the degree of windthrow was not used to assign fuel types. The type of logging and degree of windthrow is not available directly in the inventory data base, although these characteristics can be assumed given forest attributes such as crown closure are available. Additional criteria were added to the algorithm for Victoria watershed to ensure that logged or windthrown areas were not actually forested with significant forest cover (crown closure exceeded 10%). Other disturbances such as wildfire, insects, diseases, land slide, avalanche, fume kill or flooding were not examined specifically, and are first examined to determine whether they meet the criteria for a forested area, and if the criteria is not met the area is classified as non-forest. Stand tending as a disturbance is also not examined because of the lack of information on a province-wide basis and in the Victoria watershed forest inventory data base.

Non-forested areas were classified as non-flammable or flammable (able to support a spreading fire) based on expert opinion using the list of non-forest descriptors in the B.C. forest inventory data base. Some non-forest and non-productive forest types have significant forest cover and were classified as forested if crown closure exceeded 10%. Flammable non-forested areas were further classified according to whether they were dominated by grasses or shrubs. This was again based on expert opinion using the non-forested descriptors.

An initial algorithm or key was developed with three classes of tree height, crown closure, conifer crown density and surface fuel condition. There were 138 possible combinations of parameters, which resulted in too many general fuel types. The algorithm was simplified to only two classes of each variable, which resulted in a possible 34 general fuel types which could then be translated, based on expert opinion, to the existing 16 FBP fuel types. Because the final translation to FBP fuel types is a separate process, changes or additions to fire behavior models or in the existing FBP system could be accommodated easily.

The algorithm incorporated in the computer code for the classification of forest inventory information for the Victoria watershed is listed below. At this point, the provincial algorithm does not include additional criteria required to further refine the classification of logged or windthrown areas to ensure that only significant forest cover removal is considered. Descriptions of inventory type groups, non-forest and non-productive descriptors, and species codes can be found in the B.C. Ministry of Forests, standards and procedure manual (Ministry of Forests 1991). For areas of the province that do not have crown closure information in the attribute list, a preliminary system based on stocking, age, site class and tree species was developed to determine whether the stand is closed or open.

Forest Criteria

Any standing timber: commercial, non commercial, non productive (Basic Class = 0 - Basic class is a basic identifier distinguishing forested and non-forested areas). 1st species present in layer 1 and history record present but no history of logging or windthrow within <=5 years on coast and <=10 years in interior; If history of logging or windthrow within <=5 years on coast and <=10 years in interior then crown closure must be >10% to be forested (*i.e.* partial overstory removal through logging or windthrow situations).

If Basic Class 10 (alpine forest) or 12 (non-productive) and species present and crown closure >10% then classify as forested. If <=10% crown closure then Basic Class 10 is classified as grass-dominated non-forested and Basic Class 12 is classified as shrub dominated non-forested.

Specific Criteria for Forested Fuel Type Descriptor Classes

Height class

- Tall >28.4 m, Projected Height Class >=3
- Short <=28.4 m, Projected Height Class 1 or 2

Crown closure

If Crown Closure Known (CC class >0)

- Open <=49% crown closure, class 1-4
- Closed >49% crown closure, class 5-10

If Crown Closure Not Known (CC class = 0)

- Projected Stocking Class Code = 0 (Immature Stands)

- Species 1 in first layer = Pl or Pa or growth type group = O,P,or Q
- Open projected site class = L or P or projected site class = M or G and projected age class=1-2.
- Closed projected site class = M or G and projected age class=3-4
- Species 1 in first layer = All other species than Pl or Pa
- Open projected site class L or P and projected age class=1-5 or projected site class M or G and projected age class=1-2.
- Closed projected site class L or P and projected age class=6 or projected site class M or G and projected age class=3-6
- Projected Stocking Class Code = 1- 4 (Mature Stands)
- Leading species in first layer = Pl or Pa
- Open projected site class = L or P
- Closed projected site class = M or G
- Leading species in first layer not = Pl or Pa
- Open projected site class = L or P
- Closed projected site class = M or G
- Projected stocking class = R (residual stand - 25 to 75% disturbance)
- Open - all that fall into this stocking class.

Crown type/crown density

Conifer
- Dense
  - inventory type group = 1,2,3,4,9,10,11,12,13,14,15,16,18,19,20,21,22,23,24,25
- Open
  - inventory type group = 5,6,7,27,28,29,30,32,33,34
- Mixedwood
  - inventory type group = 8,17,26,31,35,37,41
- Deciduous
  - inventory type group = 36,38,39,40,42

Surface fuels

Flashy
- inventory type group = 1(interior),5,6,7,8(interior), 27,28,29,32,33,34,35,36,37,38,39,40,41,42.

Compact
- inventory type group = 1(coast),2,3,4,8 (coast), 9,10,11,18,19,20,21,22,23,24,25,26,30,31.

Logged or Windthrown Criteria

Flammable timber lying on the ground (not decomposed). History record is present and activity code is L or W and both are <=5 years since activity on coast and <=10 years in interior and crown closure is <=10%.

Treated
- attribute = SI and activity code = M,B,S, or MS but must meet the age criteria of logged or windthrown

Not Treated
- attribute = SI and activity code = M,B,S, or MS but is >5 years since site preparation on coast and > 10 years in interior.
- attribute not = SI
  Coast (location code)
  Interior (location code)

Non-Forest and Non-Productive Criteria

No significant forest standing or fallen. Basic Class >0. Includes lakes, meadows, non productive brush, etc.

Flammable
- Grass Dominated basic class = 10,2,60,62,63
- Shrub Dominated basic class = 11,12,13,42

Non Flammable
- Other (Low or No Fuel to Burn) basic class = 1,3,6,7,9,16,18,26,54,64.

Non Flammable
- Lakes basic class = 15
- Rivers basic class = 25
- Swamp basic class = 35
- Roads basic class = 50

The algorithm developed to translate the general fuel types into FBP fuel types was done by expert opinion (B. Hawkes and B. Lawson) using the fuel descriptions provided by the Forestry Canada Fire Danger Group (1992); grouping of similar ROS and Initial Spread Index (ISI) curve shapes and magnitudes in Forestry Canada Fire Danger Group (1992) to determine appropriate FBP fuel types to assign to the more general fuel types; and knowledge of differences in expected fire behavior between coast and interior forests in B.C. within the same general fuel type.

Although the preliminary algorithm has been reviewed by the BCMOF Prot. Br., changes will result from additional input from B.C. Ministry of Forests region and district staff and Canadian Forest Service fire researchers, and ground truth information collected throughout B.C. The expert rule approach also allowed the application of surrogates for general fuel types that do not have a specific FBP fuel type match (*e.g.* mixedwood with 75% conifer for some of the conifer types). Table 1 shows the first approximation of the general fuel type translation to FBP fuel types. Only 12 of the possible 16 FBP fuel types have been used in the translation process, because not all FBP fuel types exist in B.C. Furthermore, the list of FBP fuel types does indicate variations in the flammability of various fuel types seasonally, although this may be considered when fuel type information in implemented for fire danger rating or fire behavior prediction.

Implementation and Application of the Fuel Type Algorithm

The provincial level fuel typing was done without GIS software but used the provincial Forest Inventory Program Files (FIP) which were analyzed utilizing the fuel type algorithm programmed in Visual Basic. The B.C. FIP files contain polygon level forest attributes as well as the area of that polygon that is contained within its UTM grid (2 by 2 km or 400 ha). Individual polygons were classified for the general fuel type and then translated into a FBP fuel type.

Table 1: *Algorithm to translate general fuel types into Fire Behavior Prediction fuel types. See Forestry Canada Fire Danger Group (1992) for full descriptions of fuel type labels (e.g. C-2 is Boreal Spruce fuel type).*

1. Forested Polygons

Canopy Height	Crown Closure	Crown Type	Crown Density	Surface Type	FBP Fuel Type
Tall	open	conifer	dense	flashy	C-2
				compact	M-2 (75% conifer) interior
					C-7 coast
			open	flashy	C-7
				compact	C-5
		mixed wood	not applicable	flashy	M-2 (75% conifer)
				compact	M-2 (30% conifer)
		Deciduous	not applicable	flashy	D-1/D-2
	closed	conifer	dense	flashy	C-2
				compact	M-2 (75% conifer) interior
					C-7 coast
			open	flashy	C-7
				compact	C-3
		mixed wood	not applicable	flashy	M-2 (75% conifer)
				compact	M-2 (30% conifer)
		Deciduous	not applicable	flashy	D-1/D-2
Short	open	conifer	dense	flashy	C-1
				compact	C-2 interior
					C-5 coast
			open	flashy	C-4
				compact	C-7
		mixed wood	not applicable	flashy	M-2 (75% conifer)
				compact	M-2 (30% conifer)
		Deciduous	not applicable	flashy	D-1/D-2
	closed	conifer	dense	flashy	C-2
				compact	C-6 coast
					C-4 interior
			open	flashy	C-4
				compact	C-7
		mixed wood	not applicable	flashy	M-2 (75% conifer)
				compact	M-2 (30% conifer)
		Deciduous	not applicable	flashy	D-1/D-2

2. Logged / Windthrown Polygons

Treated	Coast/Interior	FBP Fuel Type
Yes	not applicable	D-1
No	Coast	S-3
	Interior	S-2

3. Non Forested Polygons

Flammable	Type	FBP Fuel Type
Yes	Grass dominated	O-1b
	Shrub dominated	O-1a
No	Lakes	Water
	Other Non Fuel	Non Fuel

The areas for each of the possible 12 FBP fuel types were totaled for each 2 by 2 km grid. There is a total of 7000 map sheets at a scale of 1:20000 (with approximately 17, 2 by 2 km cells, on each map sheet) that cover most of B.C. In some areas of the province, forest inventory information is not available (*e.g.* some provincial parks and private land), and remote sensing data could be used to complete fuel type mapping. For these missing areas, the previous 15 by 15 km grid fuel map was completed by headquarters personnel manually filling in fuel types for each grid based on adjacent grids with information. The computing time required to analyze the 7000 map sheets for B.C. was a few days using a pentium PC. This processing speed would allow annual updating of the 2 by 2 km fuel type map.

The Victoria watershed analysis was done taking forest inventory information originally available in Terrasoft/ DBASE III+ software and translating it first to PAMAP/ DBASE III+. This information in PAMAP was then transferred to ARCINFO/INGRES software which was used for further analyses. The transfer from PAMAP to ARCINFO had some difficulties because PAMAP and ARCINFO have different methods of polygon numbering which prevented a straight transfer of vectors and polygon labels. The fuel type algorithm was programmed in Standard Query Language (SQL) and then run with the INGRES data base. The complexity of the algorithm, when programmed, caused the SQL program to crash so the algorithm was broken up into different parts and run separately. This SQL program will form a part of the SEIDAM system to allow users to create fuel type maps with minimum skills in using GIS or data base software.

Only two maps sheets (Sooke and Goldstream) at a scale of 1:10000 are needed to cover the area of the Victoria watershed. The processing time for this size of area is minimal (only 3000 polygons to process) but would increase dramatically if thousands of map sheets required processing. Both the general fuel type and specific FBP fuel type were determined for each polygon with that information retained in the INGRES data base for mapping.

The BCMOF Prot. Br. has developed their own mapping software (Protection Information Mapping) for the AFMIS, which allows a bit map to be produced of the FBP fuel types at a provincial, regional and district level. The district level can be further zoomed to the individual 2 by 2 km grid or cell with the ability to display a legend. The legend allows the user to view specific information on the FBP fuel types, their individual and total area, UTM location, latitude and longitude, volume of timber at the highest utilization level. The first fuel type listed in the legend has the largest area in the highlighted 2 by 2 km cell. Figure 2 illustrates this product for a small area of the province. As one goes to the regional and provincial level then the individual grid shapes disappear because the edges are not as obvious to the eye. Rough shapes of lakes and icefields will be visible at this size of grid. Each grid is coloured to correspond to the most predominant fuel type, which might consist of mostly rock or water.

The Victoria watershed fuel type mapping was done within ARCINFO with all the features available in that software including access to INGRES data base information for each polygon. The map product for the watershed will include the FBP fuel type as well as retaining informa-

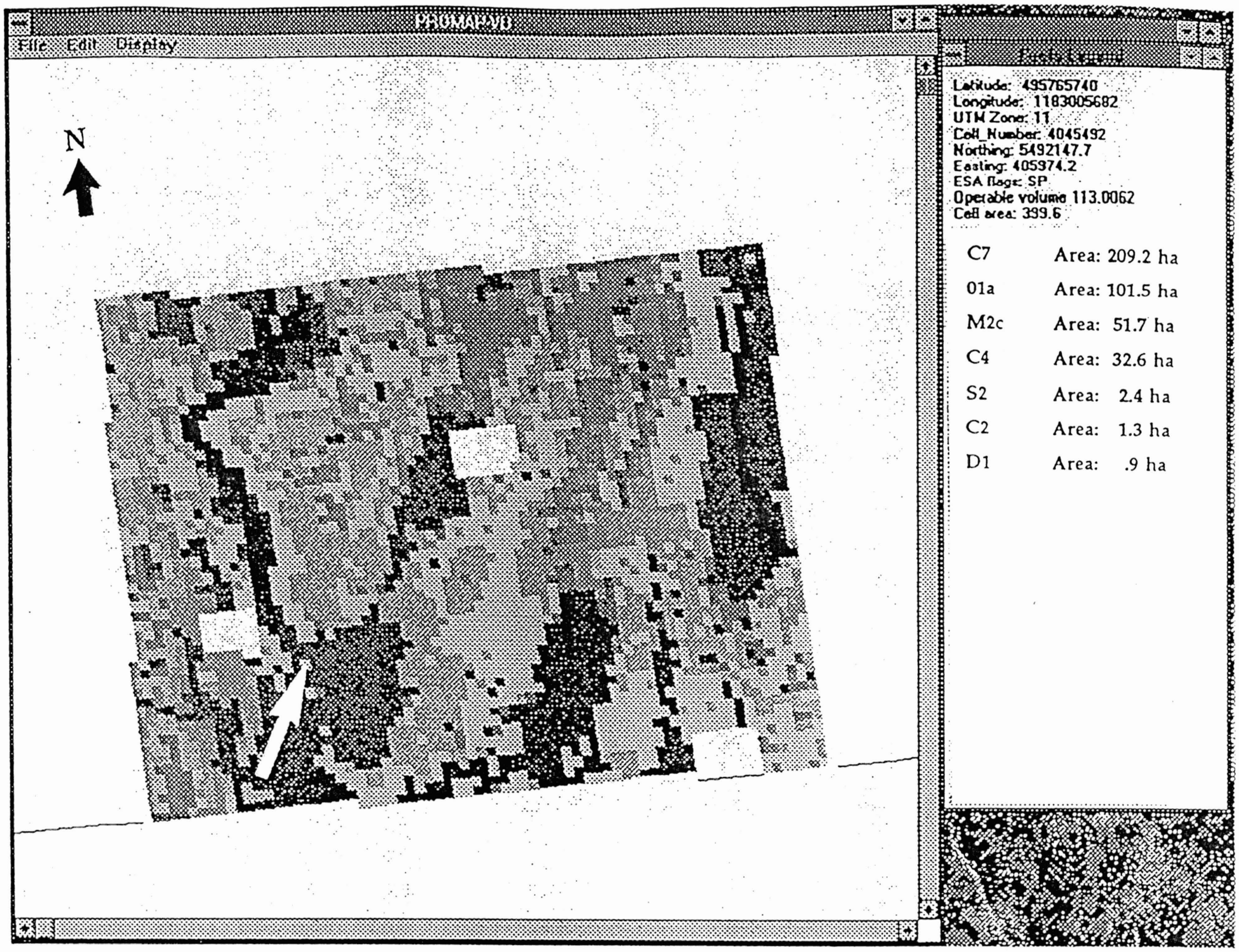

Figure 2: *Example of British Columbia Ministry of Forests Protection Branch fuel type map for one area around Penticton, B.C. White blocks are missing map sheets. The Fire Behavior Prediction fuel type listed first in the legend covers the greatest area within the 2 by 2 km cell highlighted by the mouse cursor location (arrow). The colour of each 2 by 2 km cell matches that of the fuel type with the highest coverage (in the colour version of map).*

tion on the more general fuel type and specific attributes of forest cover that are available in the INGRES data base. Figure 3 illustrates the Goldstream watershed showing the FBP fuel types at the polygon level. Versions of the Sooke and Goldstream map will be produced as colour hard copy products to allow input from field fire personnel on the translation and accuracy of the mapping. Future data layers available for the Victoria watershed will allow fuel types to be overlaid, for example, with terrain (TRIM) and soil moisture information.

Fuel type mapping is useful at both provincial and watershed levels, not only for determining the spatial coverage of fuel types but, when connected to other data layers and fire behavior models (perhaps in spatial spreadsheets) can be used for fire management planning purposes. An example would be fire preparedness (*e.g.* movement of fire suppression resources based on levels of potential fire behavior). Both strategic (preparedness) and tactical (*e.g.* suppression, natural prescribed fire) aspects of fire management can use site specific fuels information which, when combined with information on topography and weather, allow prediction of potential and real time fire behavior. The BCMOF Prot. Br. AFMS is essentially a GIS based system because a grid or raster based system is used to access information such as fuels, weather, property and land values. The transition to an actual GIS based approach is possible and under way in other parts of Canada as provincial and federal departments and ministries move to storing and accessing resource management information through commercial GIS systems.

The prediction of potential fire behavior in fuel types that are within and adjacent to new urban developments to determine fire hazard is required because of recent fire problems in wildland-urban interface areas. This kind of information coupled with knowledge of fire risk, values to be protected, and suppression capability (all on a spatial basis) allows a wildfire threat analysis to be completed. Wildfire threat analyses are now possible because of the capability GIS gives of combining this information on a spatial basis. Wildfire threat analysis is a new concept which allows the resource manager to explore alternative fuel and fire management options to reduce the probability of large, intense, wildfire occurrences in the future. The wildfire threat analysis methods, in conjunction with landscape fire modeling efforts, can assist in determining the effects of forest management practices and past and future fire suppression on the role of fire in shaping future landscape biodiversity. This threat analysis can be espe-

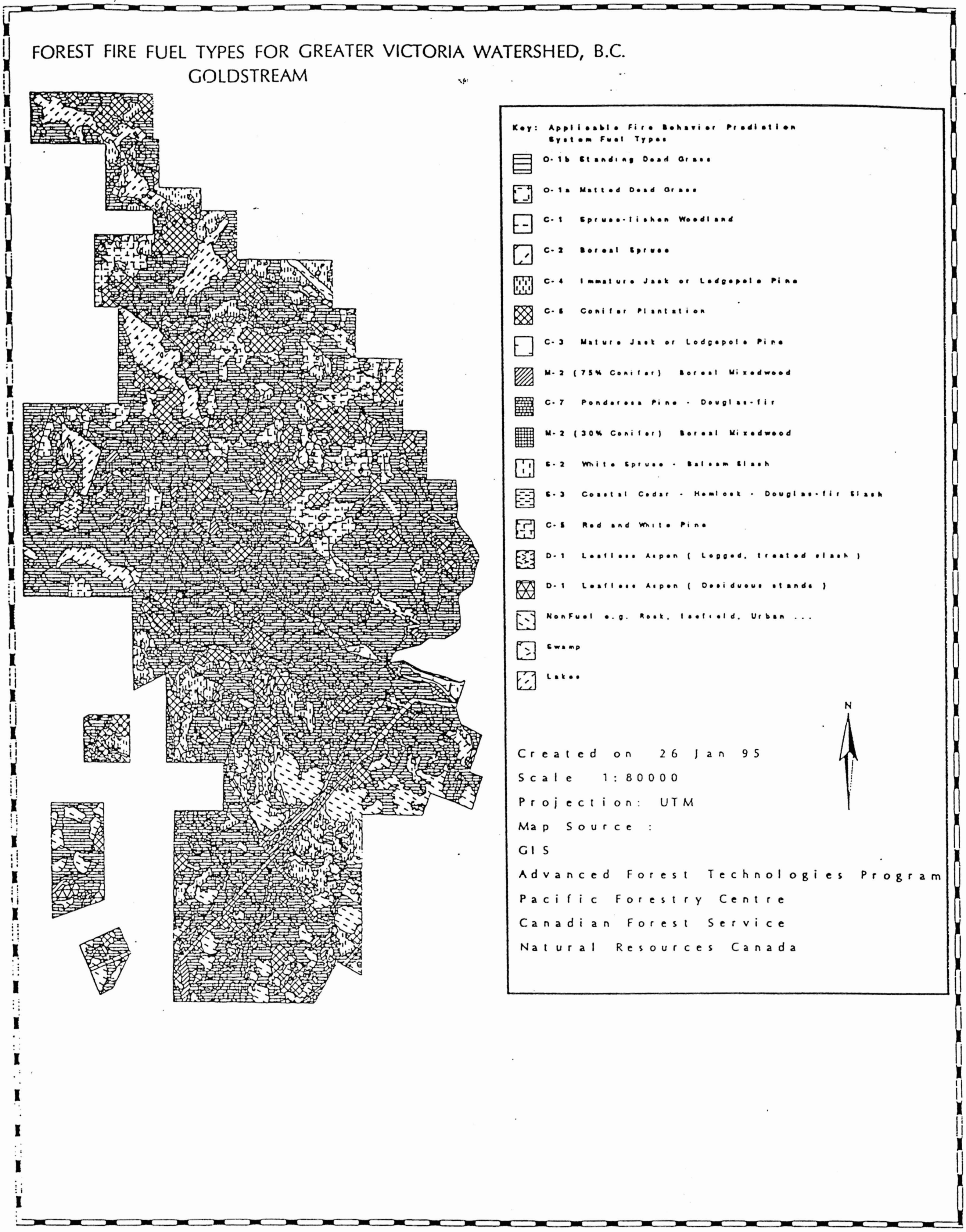

Figure 3: *Example of the Greater Victoria Watershed (Goldstream area) Fire Behavior Prediction fuel type map illustrating individual polygons. Map was produced using ARCINFO GIS software.*

cially useful at the watershed level and will be tried in the Victoria watershed.

New technologies such as aircraft-, vehicle-, and backpack-mounted Global Positioning Systems and portable computers will allow access to fuels and fire behavior information at the location and time it is most needed. Fuels and fire behavior information may soon be available to large fire overhead teams to assist in various aspects of fire suppression planning and action.

Future Research and Implementation of Fuel Typing

Provincial level mapping will be extended to areas that are not covered by the present 7000 map sheets using other data sources such as existing forest inventory available within Tree Farm Licenses, old inventory which is updated using remote sensing information, and remote sensing information for other areas. Once all the province has fuel type information on a 2 by 2 km grid, this information, through the BCMOF Prot. Br. AFMS mapping system, might be made available at the field level through the use of portable computers and the new provincial resource tracking system. Fuel type information will eventually be made available at the stand or polygon level in order to make maximum use of fire growth models and other decision support systems.

Ground truthing of the provincial level data will be done in the future through the use of existing photograph fuel type series available for some of the B.C. Ministry of Forests regions. These photo series consist of within-stand photographs which illustrate an area where quantitative fuel and stand characteristics have been sampled. Additional sample information will also become available through new standard operating procedures for fuels being developed by the B.C. Ministry of Forests to be used throughout the province as part of the Forest Practices Code implementation.

Phase two of the Victoria watershed study will examine the use of remote sensing information to determine other forest fuel characteristics not available from inventory data such as crown closure (more accuracy and with greater spatial detail than in present inventories or in areas where it is not available), surface vegetation type and condition, and surface woody fuel loading and arrangement (in more open stands and possible use of temporal change). Radar information may be used to determine two story stands and the presence of ladder fuels (those providing a linkage between surface fuels and major overstory crowns). The remote sensing information and expert systems to display and analyze the data are being collected and developed as part of the SEIDAM project.

In 1993, the following imagery was obtained for the Victoria watershed (as well as Tofino Creek and Parson) in the SEIDAM project (some of which will be used to improve the fuel type mapping):

Satellite: LANDSAT 5,6; SPOT 3; ERS-1; JERS-1; NOAA/AVHRR; MOS-1A,B

Aircraft: NASA airborne SAR (X,L,P - polarimetric); NASA AVIRIS + MODIS Airborne Simulator; CCRS SAR (X,C - polarmetric); CCRS MEIS (push broom scanner); CCRS AMSS; CASI; Oregon State Ultra-lite (Spectrometer + Video)

A similar data set was obtained in 1994, for the Victoria watershed with emphasis on NASA radar spectrometer imagery, and extending the coverage to the whole of Clayoquot sound (covering most of the Long Beach Model Forest) rather than just Tofino creek. Space shuttle imaging radar data were also acquired on these test sites through the larger SEIDAM project.

Preliminary examination of some of these remote sensing images will be done for the Victoria watershed to determine which images will provide possible relationships with fuel characteristics. Priorities will be set for the location of ground truth plots from these images and fuel type maps produced from forest inventory information. Existing information on fuel loading will be collected from other sources and summarized with their specific location documented.

FBP fuel types will be overlaid on the TRIM data in preparation for a wildfire threat analysis which will be attempted in the Victoria watershed. Other possible data layers that would be suitable for a wildfire threat analysis will be obtained and examined, such as soil types, soil moisture distribution, spatial fire risk based on fire suppression effectiveness, lightning and person-caused fire patterns, and roads and water source locations. Forest inventory information outside the Victoria watershed will be obtained to provide coverage that corresponds to the SEIDAM test site area for the Victoria watershed.

Links were also established with McGregor Model Forest (near Prince George, B.C.) and Foothills Model Forest (near Hinton, Alberta) on parallel efforts of determining fuel types from provincial forest inventory information. A project has been started by B. Hawkes and B. Lawson on a wildfire threat analysis in McGregor Model Forest. Exchange of methodology and computer code will enable progress to be made on different fronts at the same time, especially in the area of wildfire threat analysis.

Conclusions

An algorithm was successfully developed to classify forest inventory information into general fuel types having some of the descriptive characteristics needed for a new fire environment model. These more general fuel types were then translated into 12 possible FBP fuel types (in B.C.) using expert opinion utilizing FBP fuel type ROS/ISI curve shapes and magnitudes to construct surrogate fire behavior models where no direct linkage to existing FBP types was possible. The algorithm and FBP translation is a first approximation and still requires further review, field testing and ground truthing. The algorithm was developed to use existing forest inventory information and was simplified in order to reduce the total possible general fuel types from 138 to 34 fuel types.

The fuel typing algorithm was programmed in Visual Basic to analyze 7000 FIP files on a provincial level to determine fuel types on a 2 by 2 km grid (400 ha). The algorithm was also programmed in SQL language to analyze forest inventory information in an INGRES data base for the Victoria watershed. Both approaches proved successful for the scale of mapping desired. Output on a provincial, regional, and district level was done using mapping software developed by the BCMOF Prot. Br. which allowed zooming to more detailed levels and the display of specific FBP fuel type, location, and forest volume in a legend, by placement of a mouse cursor on the point. Output of the Victoria watershed was as maps at 1:10000 scale displayed in ARCINFO with capability to display polygon attributes.

The new fuel type maps at the provincial and watershed levels will provide critical spatial information for fire behavior prediction and growth modeling. Their use will be at the fire management strategic planning level as well as at the fire suppression tactical level. The new spatial fuels information, in combination with GIS layers of weather, topography, fire risk, suppression capability, and fire potential, will provide the means to conduct wildfire threat analyses to further improve fire management in B.C.

Future work will consist of utilizing multiplatform, multitemporal remote sensing information to determine where improvements or additions can be made to fuel typing using current forest inventory information. Fuel sampling plots will provide ground truthing of fuel typing efforts. Provincial fuel photo series and fuel assessment standard procedures will provide additional ground truth information.

Acknowledgments

Funding for the research in the Victoria watershed has been provided by CFS Green Plan Fire Program with data being made available through the Greater Victoria watershed and their GIS contractor—Hugh Hamilton, Vancouver B.C. Funding for the provincial level fuel typing efforts has been provided by BCMOF Protection Branch. Much in-kind funding has been provided by the various cooperators in these studies. Special mention is made of the Advanced Forest Technologies program at Pacific Forestry Centre for GIS software and hardware as well as remote sensing information.

References Cited

CFS Fire Danger Working Group 1994. Strategic plan 1994-1999 (Draft): October 1993, In: Reports tabled at the forty second annual meeting, Canadian Committee on Forest Fire Management, Charlottetown, Prince Edward Island, Jan. 20-22, 1994.

De Groot, W.J. 1988. Forest ecosystems in the mixedwood section of Saskatchewan and standard fuels for predicting fire behavior. For. Can., Can. For. Serv. Dist. Off., Prince Albert, Sask. Technol. Transfer Note S-003. 4 p.

Forestry Canada Fire Danger Group 1992. Development and structure of the Canadian forest fire behavior prediction system. Forestry Canada, Information Rep. ST-X-3. 63 p.

Fuglem, P. 1984. Value systems for forest protection: Progress report and Development proposal; Forest protection values system subfile creation from inventory grid database. In: Reports tabled at the 1984 Canadian Committee on Forest Fire Control, Saskatoon, Saskatchewan, Jan. 24-25, 1984.

Goodenough, D.G., Balser, R., Wakelin, J., Lee, J., and D. Manak 1993. Intelligent information extraction and data management. Pages 839 to 848, In: Proceedings of GIS'93 Symposium, Vancouver, B.C.

Kourtz, P.H. 1977. An application of Landsat digital technology to forest fire fuel type mapping. Pages 1111 to 1115, In: Proceedings of the Eleventh International Symposium on Remote Sensing of Environment, April 25-29, 1977, Ann Arbor, Michigan.

Kourtz, P.H. 1994. Personal communication. Project Leader, Fire Management Systems, Canadian Forest Service, Petawawa National Forestry Institute, Chalk River, Ontario.

Mazek, P., Yurach, K., and B.S. Lee. 1995. A new fuel type map for the Province of Saskatchewan. In: Proceedings of GIS'95 Symposium, Vancouver, B.C. (In Press).

Merrill, D.F. and M.E. Alexander (eds). 1987. Glossary of forest fire management terms. Fourth edition, Natl. Res. Counc. Can., Can. Comm. For. Fire Manage., Ottawa, Ontario, Publ. NRCC No. 26516. 91 p.

Ministry of Forests 1991. Standards and procedures for the acquisition of forest inventory data. Ministry of Forests, Inventory Branch, Resource Inventory Section, Victoria, B.C. Manual, Jan. 1991.

Stocks, B.J., Lawson, B.D., Alexander, M.E., Van Wagner, C.E., McAlpine, R.S., Lynham, T.J., and D.E. Dube 1989. The Canadian forest fire danger rating system: An overview. For. Chron. December Issue. Vol. 65, No. 6: 450-457.

Tymstra, C. and E. Ellehoj 1994. Fire behaviour prediction fuel type mapping using the Alberta vegetation inventory. Pages 887 to 893, In: Proceedings of GIS'94 Symposium, Vancouver, B.C.