Spatial Fire Management System

The Spatial Fire Management System (sFMS) is an advanced fire management information system that integrates fire science models and decision support planning modules into a geographic information system. It is designed to be used by fire management agencies for daily operational planning purposes at the strategic, tactical, and landscape levels.

The system incorporates a full implementation of the Canadian Forest Fire Danger Rating System, providing assessments of fire ignition and growth potential and predicted fire behavior. It also includes tools for resource allocation planning and wildfire threat rating.

The system is delivered as a set of interdependent ArcView GIS extensions.

Introduction

Fire information analysis and reporting are ideally suited for a GIS platform. Fire danger rating, fire occurrence prediction, and preparedness planning all include spatial data inputs and outputs. GIS tools provide the technology to integrate weather, drought, fuels, and terrain data to produce information necessary for many aspects of fire management operations, including:

- fire danger monitoring and fire behavior prediction
- initial and sustained attack decision-making
- logistic and tactical planning
- policy setting and review
- establishment and maintenance of attack bases, weather stations, and fire detection systems

Computer-based fire management systems have been used in Canada for over 25 years. With ever-increasing computing capabilities being brought to bear, these systems have become more and more powerful. The Fire Management System developed by Kourtz (1984) and the Intelligent Fire Management Information System developed by Lee and Anderson (1989) were stand-alone applications that included GIS tools for analyzing and displaying spatial data. However, these functions can now be provided more effectively by third-party GIS software.

The Spatial Fire Management System was developed first on ArcInfo for Unix and written in AML. This version of sFMS is used for the Canadian Wildland Fire Information System (Lee 1995), in the state of Florida (Brenner et al 1998), and as a demonstration system for the Association of Southeast Asian Nations. Beginning in 1996 the system was developed for ArcView GIS for Windows, written mainly in Avenue. The ArcView version has since been implemented by several Canadian provinces, as well as being used as a demonstration for Mexico (Sistema de Información de los Incendios Forestales). To see information and output products from some of these systems on the web, see the links on the sFMS web site.

Models

SFMS provides a framework for easily and powerfully incorporating fire science models that is user friendly and displays outputs in an intuitive and meaningful way. The models that provide the core of sFMS are those making up the Canadian Forest Fire Danger Rating System (Stocks et al 1989, Alexander et al 1996). These are the Fire Weather Index (FWI) System (Van Wagner 1987) and the Fire Behavior Prediction (FBP) System (Forestry Canada 1992).

Other models that have been incorporated into sFMS include Wildfire Ignition Probability Prediction (Lawson et al

1994, Ember Research Services Ltd. 1997) and Probability of Containment (Hirsch et al 1998). A version of the pre-suppression planning tools first developed by Anderson and Lee (1991) has also been incorporated.

Requirements

The ArcView extensions that make up sFMS were developed for ArcView GIS 3.1, ArcView Spatial Analyst 1.1 and Dialog Designer 3.2. Input weather data must be supplied by the user in an ODBC-compliant database. The FWI and FBP systems require temperature, relative humidity, wind speed, wind direction and 24-hour precipitation measurements taken at local noon daily. The system retrieves the data via ODBC.

The features of the major sFMS extensions are described below in more detail, including further data requirements.

FWI (Fire Weather Index) Extension

The FWI extension forms the basis of sFMS, on which the rest of the extensions depend. It incorporates the calculations of the Canadian Forest Fire Weather Index System. These calculations are based on over 50 years of fire research by the Canadian Forest Service.
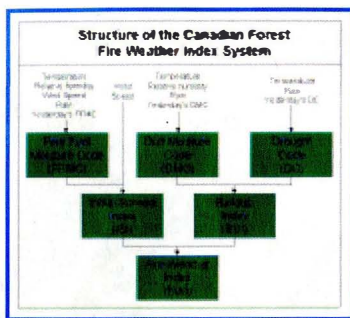
The FWI extension's main function is to produce raster maps (grids) of weather and fire weather components. The grids produced by the FWI extension can be used by fire managers to monitor weather conditions and make qualitative predictions of fuel moisture and fire hazard.

The seven outputs from the system are:

- **Fine Fuel Moisture Code** - represents the moisture content of litter and other fine fuels in a forest stand
- **Duff Moisture Code** - represents moisture content of loosely compacted, decomposing organic matter
- **Drought Code** - represents moisture content of a deep layer of compact organic matter
- **Initial Spread Index** - a measure of the rate of spread without the influence of variable quantities of fuel
- **Buildup Index** - a measure of the amount of fuel available to the spreading fire
- **Fire Weather Index** - a measure of the intensity of the spreading fire as energy output rate per unit length of fire front
- **Daily Severity Rating** - a measure of fire control difficulty

The first three components are fuel moisture codes. Consecutive daily weather observations are used for the purpose of tracking fuel moisture. The fuel moisture calculations require today's weather and yesterday's fuel moisture.

All of these components are relative (unitless) measures of the values they represent. Quantitative predictions of spread rate, fire intensity, and fuel consumption require fuel type information, and can be made using the FBP extension (see below).
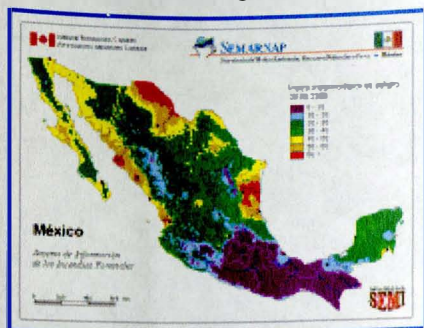
The FWI output grids can be built either by interpolation or cell-by-cell calculation, according to user preference. If the grids are built by interpolation, the FWI calculations must be made daily at each station and the values included in the database to be retrieved by sFMS. If the grids are built by calculation, then yesterday's fuel moisture grids must be present to be used as inputs. An FWI calculator that can be used to update the database is currently being developed. A comparison of the results of the two methods (interpolation and calculation) was done by Flannigan et al (1998).

The interpolation technique used by sFMS is inverse distance weighting (IDW). The sampling method, radius and count are user-specified. The use of interpolation for estimating weather conditions between weather stations has various drawbacks (Flannigan and Wotton 1989). In the case of temperature and relative humidity, these drawbacks have been addressed to a small extent by adjusting for elevation. This option requires an elevation grid. The lapse rate is user-specified and can be a constant (typically -6.5°C/km), a grid, or in a field in the weather table.
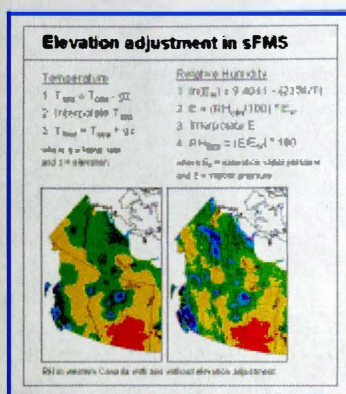
No modeling is done for the wind speed and precipitation, which are probably represented the least well by interpolation; however, models for these elements are complex and would increase processing (and programming) time too much to be practical. Precipitation radar data, if supplied to the system in ARC GRID format, can be used instead of an interpolated grid.

Several utilities are included to support and enhance the FWI extension's grid-building functionality. These include utilities to

- set analysis and display parameters and options
- define multiple configurations within the same project
- display and delete grids
- display weather stations and query them for today's weather
- save changes to grid legends
- build grids in batch processes
- retrieve theme information

All sFMS extensions come with on-line context-sensitive help.

Database Access

The following database features are supported:

- Any ODBC-compliant database can be used
- Field names are user-specified
- Any field can be used to build interpolated grids
- Data values can be numeric or text
- The date elements (year, month, day, hour) can be in one field, separate fields, or any combination thereof
- The date field or fields can be in any format - numeric, text, or date
- A numeric or text value can be specified as representing missing data
- SQL query is user-specified

The database must contain weather station locations in degrees latitude and longitude; noon weather observations by date and station; and FWI system components. For FWI calculations, the three fuel moisture codes (FFMC, DMC, and DC) are required. The other components are recommended, but can be calculated from these three. All of the components can be calculated, but the moisture code calculations use the values from the day before as an input. If the grid from the previous day is not present, it must be interpolated.

The link between weather data and weather station locations is typically made by joining the station identifier fields in the weather table and the weather station table.

FBP (Fire Behavior Prediction) Extension

The FBP extension calculates components of the Canadian Forest Fire Behavior Prediction System (Forestry Canada 1992, Hirsch 1996) in a raster (grid) environment. The FBP system uses, among other things, fuel type and weather data as inputs to estimate fire behavior parameters such as spread rate and fire intensity. It also uses some components of the FWI system as inputs.

Like the FWI system, the FBP system is a forest fire management tool. It builds grids that can be used by fire managers in making quantitative predictions of spread rates, fuel consumption, and fire intensity. The FBP extension outputs include:

- **Foliar Moisture Content** in % - the moisture content of live conifer needles expressed as the ratio of the weight of water to the dry weight times 100%. It is calculated from the location and elevation and varies between 85% and 120%.
- **Surface Fuel Consumption** in kg/m² - predicted consumption of dead and down woody fuel, litter, and duff.
- **Adjusted Initial Spread Index** - a measure of the rate of spread like the ISI from the FWI system, but adjusted for wind-slope interaction.
- **Rate of Spread** in m/min - the frontal (forward) fire spread rate, optionally adjusted for wind-slope interaction
- **Crown Fraction Burned** - the fraction of the crown (treetops) consumed by the fire. This is used to determine the fire type: surface, intermittent crowning, or continuous crowning.
- **Total Fuel Consumption** in kg/m² - the fuel consumption including both surface fuels and crown fuels
- **Head Fire Intensity** in kW/m - the frontal fire intensity expressed as energy release per unit length of fire front
- **Fire Size** in hectares - predicted fire area at a user-specified time after ignition or detection, based on a simple elliptical fire growth model
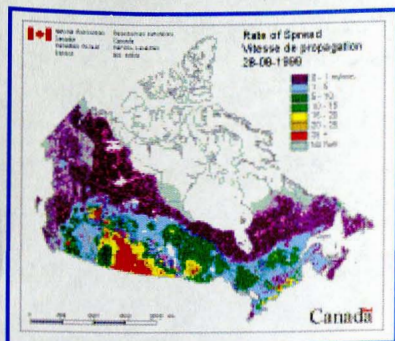
The FBP extension requires two static input grids: elevation and fuel type. Slope and aspect grids are recommended, but can be derived from the elevation grid if necessary. The fuel types recognized by the system are those specified by the Canadian Forest Fire Behavior Prediction System. These basic fuel types can be modified by various parameters, which are set by the user in the FBP extension prior to building the grids. These parameters include greenup date, crown base height, and percent conifer.

FBP System Fuel Types		
Category		**Fuel Type**
Coniferous	C1	Spruce-Lichen Woodland
	C2	Boreal Spruce
	C3	Mature Jack or Lodgepole Pine
	C4	Immature Jack or Lodgepole Pine
	C5	Red and White Pine
	C6	Conifer Plantation
	C7	Ponderosa Pine-Douglas Fir
Deciduous	D1	Leafless Aspen
Slash	S1	Jack or Lodgepole Pine Slash
	S2	White Spruce-Balsam Slash
	S3	Coastal Cedar-Hemlock-Douglas Fir Slash
Open	O1	Grass
Mixedwood	M1	Boreal Mixedwood - Leafless
	M2	Boreal Mixedwood - Green
	M3	Dead Balsam Fir Mixedwood - Leafless
	M4	Dead Balsam Fir Mixedwood - Green

As with the FWI extension, a view legend title, classification and color scheme can be specified and automatically applied for each component. New components can be added by users by providing an Avenue script to calculate that component.

Some components are required to build other components. For example, ROS is required for the HFI grid. If an HFI grid is requested and the ROS grid for this date already exists, it will be used. If an HFI grid is requested and the ROS grid does not exist, it will be built and saved (but not displayed). If the ROS grid is requested later, the existing grid will be displayed.

ORAP (Optimal Resource Allocation and Positioning) Extension

ORAP is the Spatial Fire Management System's resource allocation planner. The extension includes the same functionality as its predecessor, the Intelligent Fire Management Information System (Anderson and Lee 1991). Its purpose is to assist fire managers in deciding where to place their fire-fighting resources (i.e. initial attack aircraft and air tankers). Tools are provided for making and editing resource deployment plans. The ORAP optimizer can make deployment suggestions based on the number of resources required and the amount of time a fire would take to reach a critical size, which in turn is based on the fire spread rate predicted by the FBP system.

Deployments can be edited by adding and removing aircraft from base locations. Coverage assessment and probability of containment grids assist in evaluating deployments.

The main ORAP extension products are the attack time, resources required, coverage, coverage assessment, and probability of containment grids.

- **Attack time (AT)** is the amount of time it would take a fire to reach a user-specified critical size. In ORAP, this size is user-specified.
- **Resources required (RR)** is based on the head fire intensity (HFI). The user specifies how many resources (if any) must be covering an area in a particular HFI range for that area to be considered adequately covered.
- **Coverage (COV)** indicates the number of resources covering each cell, based on the current resource deployment.
- **Coverage assessment (CA)** indicates whether or not the coverage achieved meets the requirements in the resources required grid.
- **Probability of containment (POC)** indicates the percentage probability that a fire in a given grid cell will be contained (Hirsch et al 1998). There are 2 options for calculating probability of containment: using aircraft travel times based on the current deployment, or using a constant travel time.

Two optimization routines are included with the ORAP extension for the purpose of suggesting deployments. Both use the attack time and resources required grids as inputs. The first (Maximize Coverage) places a limited number of resources to achieve maximum coverage. The second (Minimize Resources) places the minimum number of resources required to achieve a minimum percent coverage. Deployments returned by the optimizer can be edited like any other deployment.

The ORAP extension also includes a detection assessment utility, which provides a quick projection of fire behavior based on the weather and fuels at the time and location of ignition. Calculation is done by an external executable. The results are displayed in an ArcView table, and the ignition location is displayed on the view. Values for the input parameters are determined either by sampling the appropriate grids or using values from the nearest weather station. The output provides estimates of ROS, HFI, CFB, spread distance, area burned, and perimeter length every 15 minutes for the first hour, and every hour thereafter until midnight.

Managing Deployments

A deployment is a point shape file containing information about bases and the aircraft on them (if any). Deployments are used in ORAP to calculate travel time for COV, CA and POC maps. ORAP includes several utilities to manage deployment themes, including:

- Making a new (empty) deployment theme
- Making an optimal deployment theme
- Editing a deployment (adding and removing aircraft and editing aircraft properties)
- Combining two or more deployments
- Labeling a deployment theme
- Theme information button: This is part of the FWI extension, but when used with deployment themes it displays the number of aircraft deployed and the number of active bases. It can also be used with Coverage Assessment themes to determine the percentage of the area that is covered, has no coverage, or is partially covered.

To make deployments, a base locations theme is required. An aircraft table containing aircraft specifications like speed and range is supplied with ORAP, but users must supply information for aircraft not found in the table. An aircraft table editor utility is provided to add aircraft to the table and edit aircraft information.

SFC (Spatial Fire Climatology) Extension

The SFC extension builds mean and percentile grids for Fire Weather Index and Fire Behavior Prediction components. These can be used to compare and summarize historical fire weather and behavior in a spatial environment.

A percentile grid contains values interpolated from or based on the Nth percentile of the input data, where N is a percentage value between 0 and 100. Grids can be built for any FWI (Fire Weather Index) or FBP (Fire Behavior Prediction) component, for any period of time. Any percentile can be specified. The only limitation is the data in the weather/FWI database table. FWI and FBP grids are built and displayed according to the parameters set in those two extensions.
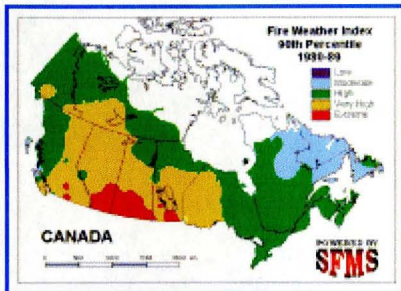
The SFC extension requires a historical weather and FWI database accessible by ODBC. It is recommended that there be at least 10 years of data in the database. The fields required for FBP calculations are wind speed (km/h), wind direction (degrees), FFMC (Fine Fuel Moisture Code), and BUI (Buildup Index). The static grids required for FBP calculations are fuel type and elevation.

Interpolated (weather and possibly FWI) percentile grids are based on the Nth percentile of the data for each individual station. For example, a 90th percentile Initial Spread Index (ISI) grid is made by retrieving all the ISI values for the selected time period for each station, then assigning to each station its 90th percentile value as the value to be used in the interpolation.

Calculated (FBP and possibly FWI) percentile grids are calculated from Nth percentile weather grids. For example, a 90th percentile Rate of Spread (ROS) grid is calculated from grids of 90th percentile temperature, wind speed, etc. As a result, it is not a true 90th percentile ROS grid, but the ROS based on a fictitious day on which the weather is the historical 90th percentile at every station.

A brief report of query results is written to the sFMS log file if the log file option is enabled. This report contains the average number of stations reporting (number of data points divided by the number of fields, divided by the number of stations) and the total number of stations reporting.

For each field returned by the query, the values are sorted and the requested percentile value is selected. For example, if 100 values are returned and the 90th percentile was requested, the 90th value is selected. If 80 values are returned, the 72nd is selected. If 2 values are returned, the 2nd is selected. The completeness of the weather database is an issue, because a station returning just one record receives as much weight in the interpolation as a station returning 1000 records.

The sorting of values is ascending for all fields except wind direction, relative humidity, and precipitation. For RH and precipitation the values are sorted in descending order. For wind direction, the values are not sorted. The prevailing wind direction (vector mean) is determined regardless of the percentile.

The SFC extension can be used for historical weather and fire danger climatologies, wildfire threat rating schemes, fire occurrence prediction, landscape models, and probabilistic fire growth models.

SFMS Distribution

SFMS is currently distributed to fire management agencies on an individual basis. Anyone interested in obtaining a license should contact the authors.

Existing Implementations

SFMS is typically used by forest management agencies on a daily basis during the fire season. The system is set up to run on a scheduler, and the batch process includes:

- Weather data retrieval
- Building grids
- Displaying and making images of the grids
- Posting the images on the web

The grids can also be posted on the web with the Internet Map Server, which allows web clients to zoom, pan, and query the maps. For examples of sFMS products on the web, see the links on the sFMS web site.

Future Development

SFMS development is ongoing. Improvements and new features are typically made in response to requests from users. International projects have generated interest in foreign language versions of sFMS, as well as regional adjustments to the Canadian Forest Fire Danger Rating System. Other planned developments (with varying probabilities of completion) include:

- Fire Occurrence Prediction - for both man-caused and lightning-caused fires
- Regional reporting and statistics
- Fire Weather Index calculator
- Keetch-Byram Drought Index calculator (Keetch and Byram 1968)
- Fire Growth Modeling - including both a long-term, probabilistic model (Anderson 1999) and a short-term, deterministic model. The latter will be the Canadian Wildland Fire Growth Model, currently being developed by a group of government agencies and forestry companies.

Acknowledgments

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Peter Englefield, Bryan Lee and Rod Suddaby
Natural Resources Canada
Canadian Forest Service
5320-122 Street
Edmonton, Alberta
T6H 3S5 Canada

Correspondence should be sent to the primary author.
E-mail: penglefi@nrcan.gc.ca
Phone: (780) 435-7254
Fax: (780) 435-7359