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INFORMATION SYSTEMS FOR WILDLAND FIRE MANAGEMENT

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GUIDELINES FOR CONTRIBUTORS

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Fire Management *notes*

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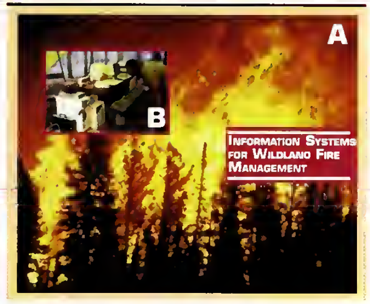

(A) The Hell Roaring Fire, a crown fire in lodgepole pine, Yellowstone National Park, WY, 1988. (B) Computer equipment in a fire camp, Yellowstone National Park, WY, August 1988. Information systems play a vital role in all aspects of wildland fire management today. Photos: Tiana Glenn, USDI Bureau of Land Management, National Interagency Fire Center, Boise, ID, 1988.

The FIRE 21 symbol (shown below and on the cover) stands for the safe and effective use of wildland fire, now and in the 21st century. Its shape represents the fire triangle (oxygen, heat, and fuel). The three outer red triangles represent the basic functions of wildland fire organizations (planning, operations, and aviation management), and the three critical aspects of wildland fire management (prevention, suppression, and prescription). The black interior represents land affected by fire; the emerging green points symbolize the growth, restoration, and sustainability associated with fire-adapted ecosystems. The flame represents fire itself as an ever-present force in nature. For more information on FIRE 21 and the science, research, and innovative thinking behind it, contact Mike Apicello, National Interagency Fire Center, 208-387-5460.

FIRE 21

Firefighter and public safety is our first priority

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Y2K—WHY ME?

Mike Funston, Mike Barrowcliff, and Bill Rush

As the new millennium approaches, many wildland fire managers want to know what (if any) problems they might encounter with the computer applications they use after January 1, 2000. Almost everyone has heard that many computer applications were originally written to process dates with years that have only two digits. This works fine in processing information from a single century, but it won't work for information that spans the millennia.

Origins of the Problem

Some might wonder why computer programmers were so shortsighted as to create a ticking time bomb. The main reason is that way back in the "Dark Ages," computer programmers had to devise clever ways to conserve precious memory and disk space, a concern that advancing computer technology has virtually eliminated. Whatever the reason, the problem is real and requires prompt attention.

In October 1997, the USDA Forest Service's National Fire and Aviation Information Systems Team (NIST) began a concerted effort to assess the applications in question, initiate repairs, and verify the results. This sounds easy, but we found that many of the date-code issues were very subtle and sometimes required much more effort to detect and repair than originally anticipated. Moreover, this is one project for which the deadline (January 1, 2000) is absolutely fixed and cannot be changed.

> We are working to ensure that,
> by the end of February 1999,
> all critical applications are Y2K compliant
> and migrated off the Data General.

Finding a Solution

In the Forest Service, efforts were already under way to migrate our existing computer applications from the Data General to the new IBM platform. Migration coincided with our Year 2000 (Y2K) renovation efforts, providing us with an opportunity to address both issues simultaneously. Accordingly, we implemented a strategy to ensure that, by the end of February 1999, all critical applications were:

- Certified for Y2K compliance, and
- Migrated off the Data General.

Meeting these two objectives is NIST's main focus.

We are heavily engaged in migration efforts and Y2K fixes, and will be very busy during winter 1999 meeting our objectives. The functionalities of some applications are being consolidated into a single replacement application. Other applications will undergo significant "facelifts." Still others will change in stages as they gradually evolve on the new platform(s).

All this is necessary to ensure that there is no disruption to the operation of critical applications after January 1, 2000. We ask the indulgence of the wildland fire community during this potentially difficult period of transition, and we thank everyone for their continued patience.

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CLASSIFICATION OF FIRE SIMULATION SYSTEMS*

Dorothy Albright and Bernard N. Meisner

With the advent of powerful computer workstations, a growing number of fire simulation systems are emerging for use by wildland fire planners and managers. These systems, with their graphical user interfaces, linkages to digital maps produced by geographic information systems (GIS's), and colorful outputs of spatial fire patterns, have taken wildland fire prediction beyond tables and graphs to three-dimensional displays of fire behavior across entire landscapes. Capable of consistently representing fire behavior and spatially validating fire prediction models, today's fire simulation systems can be valuable tools for wildland fire management.

Capable of accurately predicting fire behavior, fire simulation systems can be valuable tools for today's wildland fire managers.

A fire simulation system combines an underlying fire prediction model with a fire simulation technique. By categorizing the various types of fire prediction models and simulation techniques, we can identify the similarities and differences among the systems. The resulting classification scheme for fire simulation systems can enable fire managers and planners to compare the various systems and decide which ones best meet their needs.

Fire Prediction Models

As components of fire simulation systems, fire prediction models simulate fire behavior (such as rate of spread, fire intensity, and flame height) using site-specific data such as weather, terrain, and fuel type and condition. A spreading fire releases energy from combustion and transports some of it to adjacent unburned fuels, heating them to the point of ignition (Albini 1985). Different fire prediction models use different predictive methods to quantify these fire spread processes. There are four different types of fire prediction models: physical, physical–statistical, statistical, and probabilistic.

Physical. Physical fire prediction models predict fire spread based on the physics of combustion. They distinguish among three modes of heat transfer: conduction, convection, and radiation. For example, Albini (1986) models fire spread by balancing two-dimensional radiative heating against the cooling countereffect of reradiation and convection on unignited fuels. Although several physical models have been developed, none are currently used in fire management because they require such large amounts of detailed data.

Physical–Statistical. Physical–statistical fire prediction models combine physical theory with statistical correlation to generate formulas for fire behavior. Examples include:

- ***Rothermel's (1972) model*** as incorporated into the BEHAVE Fire Behavior Prediction and Fuel Modeling System (Andrews 1986). Based on the principle of conservation of energy, Rothermel (1972) represents the rate of fire spread as a function of fuel density, particle size, bulk density, and rate of fuel consumption. Because an analytical solution to the problem of fire behavior is not possible on this basis, Rothermel approximates a solution from laboratory experiments.
- ***The Canadian Forest Fire Behavior Prediction (FBP) System*** (Forestry Canada Fire Danger Group 1992). Based on moisture physics research and heat transfer theory, the FBP System uses observations from 495 experimental fires and wildfires to relate fuel characteristics to features of fire behavior such as rate of spread and fuel consumption.

Statistical. Statistical fire prediction models fit a set of equations to data derived from test fires. The

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**This article summarizes a more detailed treatment of this subject by the authors. For a copy of the full paper, contact Dorothy Albright, USDA Forest Service, Fire and Aviation Management, 3735 Neely Way, Mather, CA 95655, tel. 916-364-2823, fax 916-364-2820.*

equations predict fire parameters such as rate of spread, fuel consumption, and fireline intensity. Because these models are not based on physical processes, their success in predicting fire behavior is limited to conditions similar to those of the test fires. For example, McArthur's fire danger meters (McArthur 1966; Noble et al. 1980) describe forest and grassland fire behavior based on more than 800 fires, but do not consider the physical relationship between parameters.

Probabilistic. Probabilistic fire prediction models are based on contingency tables rather than physical or statistical equations. In probabilistic models, each environmental variable (such as fuel type, fuel moisture, and windspeed) is assigned to one of several discrete categories. The probabilities in the contingency tables are then used to simulate the likely fire spread from one location to the next. Because the numerical values for the probabilities are not based on physical processes, probabilistic models are applicable only under conditions similar to those for which they were developed. They are usually used to simulate the ignition and probability of spread for a sequence of hypothetical fires over a landscape, not for predicting the rate of spread for a specific fire.

Fire Simulation Techniques

Every fire simulation system uses, in addition to an underlying fire prediction model, a fire simulation technique to represent the spread of fire through the landscape. Fire simulation techniques differ from each other in how they represent the landscape and the spreading process. If the landscape is shown as a lattice of discrete boxes or elements, then the spread of fire from one box to the next is governed by a specific set of rules or a probability of occurrence. If the landscape is shown as a continuous medium, the shape of the fireline is represented by mathematical functions.

Given sufficient resolution, fire simulation systems can describe fire behavior in heterogeneous fuels over varied terrain.

Bond Percolation. The bond percolation fire simulation technique represents the landscape as a lattice of square, triangular, or hexagonal boxes. A fire in one box spreads to neighboring boxes that contain ignitable fuel. Users can adjust spread probability for direction of spread due to factors such as wind velocity, topography, and differences in fuel types (MacKay and Jan 1984; Ohtsuki and Keyes 1986). If most of the boxes contain unburned fuel and the probability of propagation is high, then the fire spreads (percolates) throughout the lattice.

A bond percolation technique must be "tuned" by adjusting the probabilities such that the modeled fire spreads in a manner comparable to that of actual fires over similar terrain under similar weather and fuel conditions. Because the technique is not based on a physical process, success in simulating fire spread is limited to conditions similar to those for which the technique has been tuned.

Cellular Automaton. Like the bond percolation technique, the cellular automaton fire simulation technique represents the landscape as a lattice of boxes or cells, each with a set of possible values (such as slope, aspect, fuel type, or fuel condition). Each cell begins in an initial state at the time of ignition. The likelihood of fire spreading to each cell in the lattice is determined by a set of rules that are the same for all cells. These rules relate the future state of the cell to its initial state and the states of the neighboring cells. Users can use parameters such as fuel type and moisture, topography, and weather to determine the spread of fire through the lattice. Because the rules relating fire spread among the lattice of cells can be based on physical processes, the cellular automaton technique can apply to a wide variety of conditions.

The attractiveness of using the bond percolation and cellular automaton techniques to simulate fire spread lies in the fundamental simplicity of their components for producing an overall fire behavior that can be extremely complex (Wolfram 1984). Both techniques yield reasonable estimates of fire spread when its physical determinants are unknown.

Elliptical Wave Propagation. The elliptical wave propagation fire simulation technique projects the landscape as a continuous medium rather than as a lattice of boxes or cells. Fires burning in continuous uniform fuels under constant conditions of slope, wind velocity, and fuel moisture assume an

Fire simulation systems should be capable of meeting different requirements, including wildfire suppression, prescribed burning, fire management training, and public education.

elliptical shape (Richards 1990). Based on Huygen's principle of wave propagation, Anderson et al. (1982) identify regularly spaced points on the fire perimeter where small fires spread elliptically outward, with the size and shape of each ellipse determined by local conditions. The fire perimeter at each succeeding time step is the envelope that encompasses all of the small ellipses burned.

For this group of ellipses, Richards (1990) develops a set of differential equations that describe fire spread for variable fuel, weather, and topographic conditions. The size and shape of each ellipse depends on a small set of parameters based on the FBP System (Forestry Canada Fire Danger Group 1992). Although the technique does require some numerical adjustments to ensure that the small fires do not overlap or burn previously burnt areas and that the simulated ignition points on the perimeter remain evenly spaced, a user can implement a finite difference solution to the equations on a PC.

The elliptical wave technique requires no local tuning, assuming that the fuels, weather, and topography in the area of interest are sufficiently similar to those for which the underlying parameters were recorded. However, this technique should not be used under conditions for which representative parameters are not available.

Additional Considerations

In choosing a fire simulation system, fire planners and managers should consider other factors in addition to modeling and simulation techniques, such as intended use, required inputs, associated outputs, and required platform and software.

Intended Use. The developer of a fire simulation system usually describes its intended use. However, prospective users can also deduce the intended use from the underlying fire prediction model. For example:

- BEHAVE is designed to describe an advancing flame front in surface fuels less than 6 feet (1.8 m) from the ground (Rothermel 1983);
- The FBP System is intended to describe fire behavior for specific fuel types; and
- The probabilistic models are designed to describe potential burn patterns on a landscape scale.

Inputs. Fire simulation systems require two general types of input:

1. Digital maps (such as GIS's) showing the spatial distribution of topography, fuel type and condition, and weather; and
2. Descriptive numerical parameters.

Most fire prediction models depend on a quantitative description of forest fuels in terms of a set of standard or custom fuel models, or on empirical data from a particular landscape. For example:

- Models based on Rothermel (1972) such as BEHAVE require inputs based on the standard fire behavior fuel models (Anderson 1982) developed to characterize typical surface fuels. Parameters include fuel loading, surface-area-to-volume ratio, fuel depth, fuel particle density, heat content of fuel, and moisture of extinction (the minimum fuel moisture content that begins to affect fire spread).
- The FBP System (Forestry Canada Fire Danger Group 1992) requires inputs based on 16 discrete fuel types in 5 major fuel groups (coniferous, deciduous, mixed wood, slash, and open). Parameter values derived from empirical data for rate of spread are given for each fuel type.

Additional required inputs depend on the system's fire prediction model. For example:

- Systems using the empirical Rothermel model require data on dead fuel moisture content, live fuel moisture content, slope, and wind direction and speed.
- Models based on the FBP System require additional inputs such as weather, topography, and foliar moisture content.

Outputs. The outputs generated by the different fire simulation systems vary in complexity. All systems generate maps of predicted fire perimeters over the study area. Some offer additional output options, such as graphs and charts showing fire area, intensity, spread rates, and other data. Output resolution generally depends on input resolution.

Platform and Software. Most fire simulation systems run on PC's or UNIX workstations. None require a Macintosh platform and software, but some require additional software such as a GIS package (e.g., pMAP or ARC/INFO), and others might require programming language compilers such as C or FORTRAN.

Sample Fire Simulation Systems

Table 1 compares recently developed fire simulation systems. Each system is described below.

Clarke Cellular Automation System. The fire simulation system developed by Clarke et al. (1993) uses simulations of potential wildfire propagation and extinction behavior to assess fire risk. One version of the system uses a probabilistic approach to estimate fire risk based on a Monte Carlo implementation of the cellular automaton. The system can also simulate fire behavior for a single fire under varying or constant conditions (Clarke 1994).

Input data are obtained from remote sensing, U.S. Geological Survey digital elevation models (DEM's), and local environmental conditions. The input includes GIS maps of fuel types and terrain. Additional input includes temperature, relative humidity, fuel moisture, and a table of wind direction and speed. Other factors are calibrated using site data such

Table 1—*Comparison of numerical fire simulation systems*

	Components			*Input*			
Fire simulation system	***Prediction model***	***Simulation technique***	***Intended use***	***GIS***	***Additional***	***Output***	***Platform and software***
Clarke Cellular Automation System (Clarke et al. 1993)	Probabilistic	Cellular automaton	To simulate landscape-scale fire risk and assessment as well as burn patterns.	• Vegetation • Elevation • Fuel moisture	• Temperature • Relative humidity • Windspeed • Wind direction	Map of fire risk (98-foot (30-m) resolution)	UNIX workstation with C compiler and Xwindows interface
DYNAFIRE (Kalabokidis et al. 1991; Hay 1991)	Physical-statistical (BEHAVE)	Cellular automaton	To simulate the spread of low- to moderate-intensity surface fires.	• Standard fuel types • Elevation • Slope • Aspect • Stream network	• Temperature • Relative humidity • Fuel moisture • Windspeed • Wind direction	Maps of: • Fire perimeter • Fireline intensity • Average spread rate	PC with MS-DOS and pMAP
EMBYR (Hargrove et al. 1995)	Probabilistic	Bond percolation	To simulate landscape-scale burn patterns.	• Vegetation classified by species and age	• Fuel moisture • Windspeed • Wind direction	Map of final burn pattern (164-foot (50-m) resolution)	UNIX workstation with FORTRAN compiler
FARSITE (Finney 1993)	Physical-statistical (BEHAVE)	Elliptical wave propagation	To simulate the spread and behavior of wildland fire.	• Standard/custom fuel types • Elevation • Slope • Aspect • Canopy cover	• Temperature • Relative humidity • Windspeed • Wind direction • Canopy characteristics	Maps of: • Fire behavior • Fire perimeters (adjustable resolution)	PC with Windows 3.1 and WIN32s, Windows NT, or Windows 95
FIREMAP (Ball and Guertin 1992)	Physical-statistical (BEHAVE)	Cellular automaton	To simulate the spread of low- to moderate-intensity surface fires.	• Standard fuel types • Elevation • Slope • Aspect	• Temperature • Relative humidity • Fuel moisture (optional) • Windspeed • Wind direction	Maps of: • Spread rate • Fireline intensity • Flame length • Heat/unit area • Reaction intensity • Fire perimeter	UNIX workstation with PROMAP
WILDFIRE (Wallace 1993)	Physical-statistical (FBP System)	Elliptical wave propagation	To simulate the spread of low- to moderate-intensity surface fires.	• Standard fuel types • Elevation	• Windspeed • Wind direction	Maps of: • Fire perimeters • Fire intensity (3.3-foot (1-m) resolution)	PC with MS-DOS

as rate of spread, maximum number of ignitions, weighting factors for slope, and necessary conditions for extinction. Output maps and assessments, at the same resolution as the input data, permit identification of areas with high fire risk.

DYNAFIRE. DYNAFIRE (Kalabokidis et al. 1991; Hay 1991) estimates potential fire behavior by spatially resolving the BEHAVE (Andrews 1986) fire prediction model. DYNAFIRE is a macro that runs within pMAP (Spatial Information Systems, Inc. 1986) using a cellular automaton technique. Calculations are made for a lattice of evenly spaced cells; parameters remain constant within cells but can vary among cells. A separate DOS program called FIRERATE (Kalabokidis et al. 1991) relates weather, fuel, and terrain data to determine the fire spread rates that are used to generate a fire spread rate friction layer and fireline intensity layer. The friction layer incorporates both heading and backing rates in controlling how the fire burns through each cell. It also identifies any barriers such as roads or water.

Inputs required by DYNAFIRE include GIS data layers (digital maps) of fuel types, elevation, slope, aspect, and stream channels. Fuel types correspond to the standard fire behavior fuel models used in BEHAVE (Burgan and Rothermel 1984). The elevation layer can be input from DEM's. Slope and aspect are computed from the elevation data. Stream channel information can be digitized from topographic maps. The elevation layer is regraded using the stream channel layer to provide allowable directions for fire growth (Hay 1994). Additional required inputs are diurnal weather and fuel moisture information, including temperature; relative humidity; wind direction and speed; and 10-hour, 100-hour, and live fuel moistures.

Resolution of output maps is a function of the data base. However, resolution should not, according to the developer, exceed 164 feet (50 m) (Hay 1994). The output maps contain hourly time contours for fire perimeter, fireline intensity, average fire spread rates, and fire spread direction.

EMBYR. Unlike other simulation systems, EMBYR (Hargrove et al. 1993) is not designed to predict the hourly or daily behavior of a particular fire. Instead, it is a probabilistic model that attempts to predict potential burn patterns of large fires, given the landscape-scale variations in fuel types and weather patterns of an area. Using gridded data layers, fire spreads from cell to cell using a bond percolation technique (Stauffer 1985). The probabilities of ignition in neighboring cells are based on empirical data. Users can start ignitions at random points or specific locations. Additional ignitions from firebrands are simulated, with firebrand production depending on fuel type. The SPOT subroutine in BEHAVE (Andrews 1986; Andrews and Chase 1989) estimates spotting distances.

The system requires a GIS data layer of fuel types deduced from age classes and species composition. Based on empirical data, the user specifies a table of fire spread probabilities for the various fuel types under one of three fuel moisture conditions: wet, intermediate, or dry. Fire spread probabilities are then adjusted by introducing a bias factor that includes one of three windspeed categories and one of eight wind directions.

Output from EMBYR consists of the final burn pattern of one or more potential landscape-scale fires. Such maps can be used to evaluate the possible impact of future fires on an area. However, the tremendous diversity in forest species composition and age classes under varying fuel moisture conditions at a landscape scale makes generating empirical probability maps and tables difficult. Therefore, EMBYR could be hard to implement.

FARSITE Fire Area Simulator. FARSITE (Finney 1994a; see also related article in this issue by Finney and Andrews) simulates fire spread and behavior based on BEHAVE (Andrews 1986) and Richards' (1990) wave propagation technique. Fuel moistures are computed using weather data from available observation stations. Users can start ignitions at a single point or at a multitude of points grouped as lines or areas. FARSITE transitions from ground fire to crown fire and simulates spotting from firebrands.

Required input includes GIS data bases describing fuels, weather, and topography, in either raster or vector form. The fuel layer uses the standard fire behavior fuel models (Anderson 1982). The user can define custom fuels. The crown fire model (Van Wagner 1993) requires maps of forest cover percentage. Input weather data include temperature, relative humidity, and wind direction and speed for up to five locations. The topography layer requires slope classification that can be derived from DEM's. The user can specify spatial and

The output from a fire simulation system can supplement the knowledge and experience of wildland fire managers.

temporal resolution of the computations. To ensure that the simulated fire does not leap across barriers or fuel boundaries, the system decreases the time step when the fire approaches a barrier or boundary between fuel types.

The output includes GIS vector files of predicted fire perimeter locations at user-specified time steps and GIS raster files of fire arrival time, rate of spread, and fireline intensity. This system was tested during the summer of 1994 at Yosemite National Park, primarily to gather user feedback on its input and output features. Indepth testing of system accuracy is planned using a large data base of actual fires (Finney 1994b).

FIREMAP. FIREMAP (Ball and Guertin 1991; 1992) uses the cellular automaton technique to simulate surface fire spread through heterogeneous fuels over nonuniform terrain. By incorporating the BEHAVE (Andrews 1986) program as the underlying fire behavior model, FIREMAP predicts the direction, speed, and intensity of surface fire.

A raster-based GIS provides the necessary data layers, including standard fire behavior fuel models (Anderson 1982) and the elevation, slope, and aspect of the terrain. FIREMAP offers the option of specifying the fuel moistures or calculating them using the BEHAVE equations (Burgan and Rothermel 1984). Other surface data include wind direction and speed, time of day, temperature, and relative humidity. Diurnal variations in temperature and humidity are computed using typical curves. Work is currently underway to include spatial and temporal variations in wind velocity.

Output map options include rate of spread, fireline intensity, flame length, heat per unit area, and reaction intensity. Output maps are at the same resolution as the input data. A cell size of 2.5 to 5 acres (1 to 2 ha) is considered ideal.

WILDFIRE. WILDFIRE (Wallace 1993) offers a simple system for simulating fire behavior under various physical conditions. Its elliptical wave propagation technique requires specification of the head fire rate of spread and the elliptical shape parameters, such as those characterized by the FBP System (Forestry Canada Fire Danger Group 1992), to predict the position of the fireline over time. This system's accuracy remains to be evaluated for actual fires.

Fuel cover and terrain data, entered through a graphical user interface, appear in the system as a grid of points. Spatial resolution can be as small as 3.3 feet (1 m). Users can also specify barriers such as roads and bodies of water. Up to three fuel classes can be represented at any one time. The system permits variations in slope over the area. Weather conditions are assumed to be spatially uniform, but the wind velocity may be changed over time. Output consists of maps of fire perimeters at user-defined steps and a final fireline intensity.

Discussion

Table 2 classifies existing fire simulation systems by prediction model and simulation technique. The combinations shown are few for several reasons:

- Because of their complexity, physical fire prediction models have not been implemented operationally, and no fire simulation system is based on one.
- The bond percolation fire simulation technique, based as it is on the probability of a fire spreading through a lattice, is naturally aligned with the probabilistic fire prediction model.
- High-performance graphic computer systems and GIS technology are relatively new (perhaps the biggest limiting factor).

Potential areas for improvement include integrating high-resolution spatial variations in weather parameters available from numerical weather analysis and prediction systems (Fujioka et al. 1995). None of the systems have been tested on more than a few fires, and there is no standard procedure for validating a fire simulation system. Systems also require local tuning (or calibration) to include site-specific environmental conditions.

Andrews (1989) notes that fire simulation systems must address specific applications with different requirements. For wildfire suppression, for example, users might require information on fireline

Table 2—*Classification of numerical fire simulation systems*

Simulation technique	Prediction model			
	Physical	**Physical–statistical**	**Statistical**	**Probabilistic**
Bond percolation	—	—	—	EMBYR (Hargrove et al. 1995)
Cellular automaton	—	DYNAFIRE (Kalabokidis et al. 1991; Hay 1991); FIREMAP (Ball and Guertin 1992)	—	Clarke Cellular Automaton System (Clarke et al. 1993)
Elliptical wave propagation	—	FARSITE (Finney 1993); WILDFIRE (Wallace 1993)	—	—

location, flame length (fire intensity), and potential for crowning. They might also need a system that can accommodate a fireline construction model and predict the probability of containment (Mees and Strauss 1995). For prescribed burning, users might require information on area burned, percent of fuels burned, and subsurface temperatures (fire intensity). They might also need a system that can incorporate fire effects for long-term ecosystem management planning. Besides supporting fire management decisions, fire simulation systems could be used as training tools to enhance fire management skills. Fire simulation systems might also be useful in displaying and explaining fire behavior and management strategies to those unfamiliar with wildland fire, particularly to the public.

As more natural resource agencies acquire GIS technology, the amount of available information will increase and the sophistication of computer applications will grow. Developers of fire simulation systems will need to constantly exchange information with potential users so that:

- Developers include the information that fire managers need,
- Developers incorporate user feedback on system applicability,
- Users know what data are required to run a fire simulation system,
- The GIS data that users collect can interface with fire simulation systems, and
- Users know the appropriate uses and limitations of fire simulation systems.

Users should remember that fire simulation systems can only approximate reality. The output from a fire simulation system cannot replace the knowledge and experience of wildland fire managers. Nevertheless, today's fire simulation systems are important tools that can help fire managers make better decisions while saving time, money, and perhaps even lives.

For more information on fire simulation systems, contact Dorothy Albright, USDA Forest Service, Fire and Aviation Management, 3735 Neely Way, Mather, CA 95655, tel. 916-364-2823, fax 916-364-2820.

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FARSITE—A PROGRAM FOR FIRE GROWTH SIMULATION

Mark A. Finney and Patricia L. Andrews

Fire growth simulation is the modeling of fire spread and behavior across landscapes with heterogeneous fuels, weather, and topography. There are numerous uses for fire growth simulation, including planning for potential wildland fires, prioritizing and locating fuel treatments, tactical support on active fires, and fire incident reconstruction.

The FARSITE Fire Area Simulator is a computer program designed to simulate fire growth using existing models of fire behavior found in the BEHAVE Fire Behavior Prediction and Fuel Modeling System (Andrews 1986) and in the Canadian Forest Fire Behavior Prediction System (Forestry Canada Fire Danger Group 1992). Because FARSITE can generate spatial maps of fire behavior, it is useful for producing detailed analyses of fire behavior and fire effects on geographic information systems (GIS's) (fig. 1). However, this modeling capability requires digital maps of terrain and fuels in GIS formats, which is the main limitation for users who want to do simulations.

Nevertheless, FARSITE is widely used by State and Federal agencies as well as private parties in the United States, who recognize the value of having GIS-based data on fuels and vegetation for a variety of applications. A national, interagency training course has been developed for FARSITE application and operation. Other special-purpose workshops are also taught. This article summarizes the uses, capabilities, data requirements, and training needed for FARSITE and identifies new features planned for a future release.

Figure 1*—A FARSITE display using ArcView 3.0 to show fire intensity and perimeter output. FARSITE's spatial maps of fire behavior can help produce detailed analyses of fire behavior and fire effects.*

Uses

FARSITE has three main uses:

- Simulation of past fires,
- Simulation of active fires, and
- Simulation of potential fires.

Analysis of past fires reveals how well the simulation reproduces known fire growth patterns, given available input data. Simulating past fires is critical in developing confidence for using FARSITE to project the growth of active fires.

FARSITE was originally developed for long-range projection of active prescribed fires, generally on national parks or wilderness areas (Finney 1994). Simulations of active fires are run for general long-range weather scenarios to suggest possible outcomes of fire growth over many weeks. Potential fire growth is examined under various weather patterns, such as

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Currently, the most common use of FARSITE is to support fire planning by simulating potential fires at various locations under a variety of fuel and weather conditions.

persistence of current conditions or periodic frontal passage. A similar procedure using manual methods was reported by Mutch (1998) and Rothermel (1998). Recently, FARSITE has also been used for short-range (1- to 2-day) projections on large wildfires, where simulation results are used to support strategic firefighting decisions. If only part of the fire perimeter is of immediate interest, FARSITE can be used to simulate partial sections of the fire front. This application of FARSITE is similar to manual methods described by Rothermel (1983).

Fire planning is an appropriate use of FARSITE and currently its most common application. A potential fire can be simulated at various locations under a variety of fuel and weather conditions. Fire planning activities include, for example, analyzing spatial fuel management alternatives and examining suppression opportunities for fires that start in different locations or under various weather scenarios. Finney et al. (in press) used FARSITE to examine the economic consequences of potential wildfires occurring with and without fuel management activities.

Capabilities

The fire behavior models currently included in FARSITE calculate surface fire behavior, crown fire behavior, fire acceleration, spotting from torching trees, and fuel moisture (Finney 1998). The surface fire model (Rothermel 1972) is linked to the Van Wagner (1977; 1993) crown fire criteria to simulate transition to crowning and to the Rothermel (1991) crown fire spread correlation model. Spotting distance is simulated using the torching tree model by Albini (1979). Buildup of fire spread rate over time and with changes in environmental conditions is simulated using the point-source fire acceleration model of the Canadian Forest Fire Behavior Prediction System (Forestry Canada Fire Danger Group 1992; McAlpine and Wakimoto 1991).

FARSITE produces maps of fire growth (perimeter positions) and fire behavior in data formats that are suitable for ARC/INFO, ArcView, and GRASS GIS's. Most fire perimeter data are in vector format showing time contours of fire position. Vectors can be produced in ASCII as well as ArcView Shapefile formats. Raster maps can also be produced to show frontal fire behavior at each cell within the fire area. Fire behavior maps can be used for analyses of fire effects or for estimating suppression options.

Fire suppression can be simulated in FARSITE using several ground attack tactics as well as aerial attack. Ground tactics include direct, indirect, and parallel attack. Direct attack follows the immediate edge of the fire front using data on fireline production rate according to fuel and crew type. Indirect attack builds impermeable fireline along a predetermined route. Parallel attack, like direct attack, builds fireline at a specified constant distance from the moving fire front. The air attack features currently allow the user to place retardant drops by coverage level (retardant density) for a given aircraft (George 1992).

Data Requirements

Data required for FARSITE simulations make up the three legs of the fire environment triangle: fuel, weather, and topography. Fuel and topography are required as spatial themes, whereas weather data are generally provided as a "stream" or table of values over time. The spatial data must come from a GIS. GRASS and ARC/INFO ASCII raster data formats are accepted. Currently, spatial data for eight variables are used in FARSITE: elevation, slope, aspect, surface fuel model (Anderson 1982), canopy cover, canopy height, crown base height, and crown bulk density.

Weather data are divided into two files: one contains temperature, humidity, and precipitation data used for calculating changes in dead fuel moisture; the other contains wind and cloud cover data. The source for these data depends on the FARSITE application. Analysis of past fires is based on observed weather records. Short-range simulation of active fires requires the user to translate specific fire weather forecast information into the proper data format. Long-range simulation of active fires requires weather that goes beyond the period for which weather can be forecasted. Weather scenarios can be developed from summaries of nearby Remote Automatic Weather Stations over several years and percentile weather variables. Fire simulation for planning applications can use local weather and wind data to define typical or extreme weather patterns.

The fire suppression module of FARSITE requires the user to have estimates of fireline production rates in local fuel types for actual crews and crew types, as well as knowledge of the capabilities of available aerial firefighting resources.

Training and Implementation

Learning how to run the FARSITE program is different from learning how to define inputs and properly interpret the results. A fire behavior analyst uses FARSITE to simulate the growth of an active fire to support decisionmaking on wildfires and prescribed fires where lives and property might be at stake. The analyst is required to successfully complete the newly developed FARSITE Fire Growth Simulation (S–493) course and its prerequisites, and also to have a firm foundation of on-the-ground fire experience. The S–493 course provides a thorough understanding of the technical workings of FARSITE, including its limitations, so that the user can make the required judgment calls that must be made in simulating an active fire.

Other, less formal training sessions and workshops have been offered to meet specific needs. Less training is needed if a person is using FARSITE for educational purposes or exploring the interactions among components of fire and environment. Overview presentations have been offered to those who are interested in learning the range of possible uses of FARSITE.

Future Developments

Improvements to FARSITE are likely in the next several years. Better models for fire behavior will probably be substituted when they become available. Specifically, the current fuel moisture model will be replaced. Also, FARSITE will be modified to simulate general postfrontal combustion. This will allow smoke and heat from a fire to be calculated behind the flaming front. The results will be useful as input into separate atmospheric models used for estimating smoke dispersion.

The status of FARSITE and the most recent version of the program can be found on the Internet at <**http://fire.org**>.

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BEHAVE Fire Modeling System: Redesign and Expansion

Patricia L. Andrews and Collin D. Bevins

Effective wildland fire management requires the ability to model fires in both the planning and the operational setting. The BEHAVE Fire Behavior Prediction and Fuel Modeling System, which has been in use since 1984, helps decisionmakers in both settings. The original BEHAVE consists of five programs:

- FIRE1 and FIRE2 provide fire behavior predictions from simple input supplied directly by the user (Andrews 1986; Andrews and Chase 1989).
- RXWINDOW reverses the calculations, providing tables that can be used for prescribed fire planning (Andrews and Bradshaw 1990).
- NEWMDL and TSTMDL are used to develop custom fuel models (Burgan and Rothermel 1984; Burgan 1987) when the standard 13 fire behavior fuel models (Anderson 1982) are inadequate. Custom fuel models are saved in files for use by the three fire behavior prediction programs.

The revised BEHAVE will be a single program that offers additional fire and fuel modeling capabilities (fig. 1) with an improved user interface and links to other fire management systems. To reflect its expanded scope, it will be called the BEHAVE Fire Modeling System.

Reasons for Updating BEHAVE

As useful as the original BEHAVE system has been, it urgently needs an overhaul. Separation into five programs was largely due to the limited computer resources available at the time BEHAVE originated. In fact, BEHAVE was designed for use on Silent 700 computer terminals, which were limited to paper output. The old BEHAVE programs ask users, "Are you using a terminal with a screen?" They also offer a "Terse" option to limit the number of words "printed." Commercial versions of portions of the BEHAVE system feature an updated Windows interface. The BEHAVE redesign and expansion that we describe here, however, goes far beyond an improved interface for the old programs.

The fire modeling capabilities of BEHAVE have not been updated since 1989. There is a pressing need to include available crown fire models (Rothermel 1991; Van Wagner 1977, 1993). In addition, we will incorporate a model for large fuel burnout behind the fire front (Albini and Reinhardt 1995, 1997; Albini et al. 1995). This model shows promise for modeling fuel consumption, fire intensity, and emission production. Fuel characterization needs to be expanded beyond the fine fuels that carry surface fire spread. There is a need to redesign BEHAVE so that new research can be more easily incorporated.

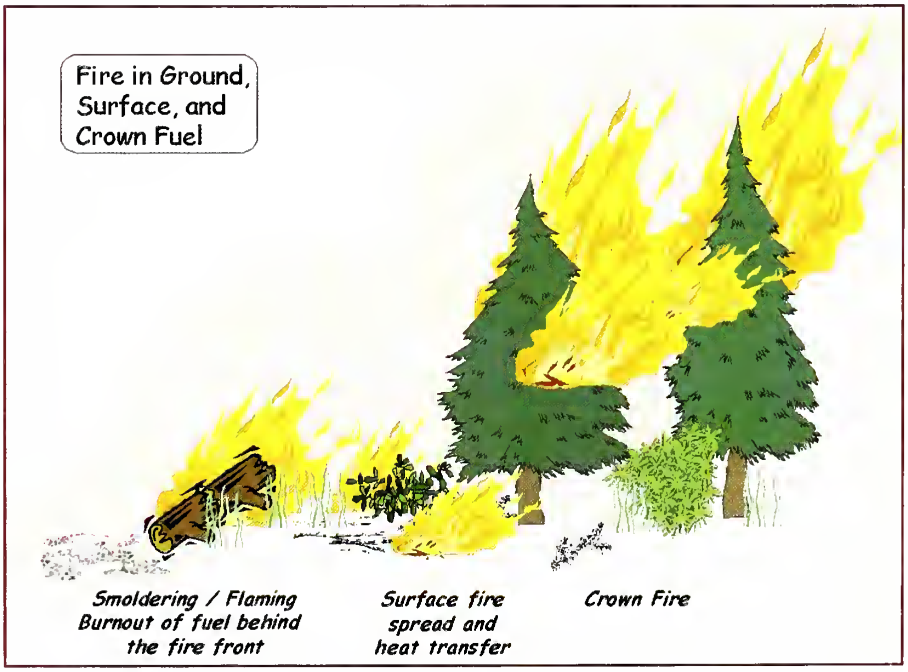

Figure 1—The BEHAVE Fire Modeling System will model fire in ground, surface, and crown fuel, including fuel burnout behind the fire front.

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An informal survey of participants in several regional and national fire workshops and courses in 1997 validated the need for a BEHAVE update and indicated how people use the system and what features they would like it to include. Of the 74 people surveyed, only 2 said that there is no need for a BEHAVE update, whereas 33 indicated that it should be high priority. According to several respondents, BEHAVE is used for "all wildland fire applications." Applications specifically listed include wildfire projection, fire planning, ecosystem management, training, prescribed fire burn plans, National Environmental Protection Act documentation, fuel treatment assessment, and contingency planning. Several people reminded us that BEHAVE has achieved its success through its simplicity, and that we should keep that in mind in developing a replacement. One respondent suggested that "the program should know intuitively what I want, all the inputs, and provide precise and accurate outputs as soon as the machine boots up."

Design Features

The challenge in redesigning the BEHAVE user interface is to offer more options and flexibility without overburdening the user with repeated choices and option selections. To meet this challenge, we've developed a "configuration" approach. Models, linkages, and input/output options are defined for a configuration so that the user isn't faced with additional options during similar repeated runs. In defining a configuration, for example, a user might specify that a 20-foot (6-m) windspeed be input (rather than midflame wind) and that rate of spread, flame length, and scorch height be output (but not fireline intensity or reaction intensity). Several configurations will be supplied with the program; the user can define others. A custom worksheet can be printed for each configuration.

BEHAVE will be a single program that runs under several operating systems—Windows 95, NT, Mac, or UNIX. Specific features include the following:

- Choice of metric or U.S. units, using either the default sets or a personalized set. For example, the default U.S. units for rate of spread will be chains per hour, but a user might prefer feet per minute.
- Bookmarks for saving run setups for continuation at another sitting.
- Graphical guidance for such inputs as wind/slope/fire direction and crown ratio.
- Ability to save input and output results in reports that can be edited, exported, and incorporated into other documents.
- Ability to use multiple values for table and graphic output for most input variables, not just for those with numeric values. For example, several fuel models can be used in producing a table or graph.
- Online help that essentially includes an entire user's manual.
- Simultaneous runs to allow comparison of alternatives.

Fire Models

The revised BEHAVE will include the fire modeling capabilities in the old BEHAVE, supplemented by improved and new fire models (see sidebar). The system design will allow additional fire models to be added as they are developed.

Fuel Characterization

The 13 standard fire behavior fuel models and the custom fuel modeling programs in the old BEHAVE system describe fuel for Rothermel's fire spread model (Rothermel 1972) and include only the fine fuels that burn in the fire front. The initial implementation of the revised BEHAVE will allow custom fuel modeling through a simple adjustment to the 13 standard fire behavior fuel models. Future releases of BEHAVE will expand fuel characterization. In order to model fire in ground, surface, and crown fuels, all components must be included in a description of the fuel complex. A variety of methods will be available for assigning a fuel description; BEHAVE will incorporate available research results.

FIRE MODELS TO BE IN THE BEHAVE FIRE MODELING SYSTEM

- Surface fire spread, intensity, and flame length
- Area and perimeter of a point source fire
- Spotting distance
- Probability of ignition
- Scorch height
- Tree mortality
- Fine-fuel moisture from hourly weather data
- Containment, with additional suppression options
- Transition to crown fire
- Crown fire spread
- Fuel burnout behind the fire front
- Emission production
- Soil heating

Relationship to Other Systems

We are working toward the goal of an integrated fire management decision support system. That doesn't mean one big computer program that does everything for everyone, but rather an integrated system that resolves conflicts among current systems (such as different sets of fuel models), shares data (such as between fire behavior and fire danger rating), and strengthens linkages among system components (such as between fire behavior and fire effects). The fire models in BEHAVE will form the foundation for the integrated system.

Fire behavior and fire danger rating will form a link as BEHAVE is expanded and as fire danger rating and fire planning programs are consolidated into the PC program FireFamily+. The 1,000-hour moisture values from FireFamily+ can be used in modeling burnout of large fuels in BEHAVE; and Remote Automatic Weather Station data and a new fine fuel moisture model will be used for both fire behavior prediction and fire danger rating.

The FARSITE Fire Area Simulator models fire growth across the landscape through variable fuel and terrain under changing weather conditions. Although FARSITE is based on the fire models in BEHAVE (Finney 1994; 1995; 1998), it is not the "next-generation BEHAVE." FARSITE is used when spatial and temporal information is required for a specific simulated fire and when the detailed data required to run it are available. Users still need the simple, straightforward tables and graphs produced by BEHAVE, which allow them to easily examine the effect that a change in an environmental parameter has on a fire. The fire models in the revised BEHAVE will be consistent with those in FARSITE.

The Rare Event Risk Assessment Process (RERAP) (Wiitala and Carlton 1994) is based on the fire models in the old BEHAVE and historical weather records from the National Fire Danger Rating System (NFDRS). An expanded BEHAVE and links to FireFamily+ will provide the opportunity for stronger links among the three systems.

A series of national, interagency courses is being developed to teach application and operation of computer systems, including NFDRS, RERAP (course number S–492), and FARSITE (S–493). The 400-series courses are intended to be offered at the regional/area level. Advanced Fire Behavior Calculation (S–490) is a prerequisite for these courses, which are in turn prerequisites for Fire Behavior Interpretation (S–590). S–490 is based in large part on the old BEHAVE. The BEHAVE revision and an S–490 rewrite will be coordinated, thereby increasing efficiency in training. Individual fire models can be taught through use of BEHAVE in S–490, eliminating the need to cover them in the other courses. For example, crown fire modeling will be included in BEHAVE and can be taught in S–490, allowing the S–493 FARSITE course and the S–492 RERAP course to concentrate on application of the crown fire model as implemented in those systems.

> The challenge in redesigning BEHAVE is to offer more options and flexibility without overburdening the user with repeated choices and option selections.

The Revision Process

The initial release of the revised BEHAVE will focus on the system's new look and feel—the user interface, output form, and run configuration concept. Subsequent releases will include currently available fire models, such as crown fire; additional new fire models, such as soil heating; and links to other systems, such as use of fuel moisture values produced by FireFamily+.

Successful development and implementation of the BEHAVE Fire Modeling System involves working with several groups, including:

- The National Wildfire Coordinating Group (NWCG) Training Working Team, NWCG Fire Use Working Team, and National Interagency Fire Center Fire Management Training Group to coordinate the BEHAVE revision and an S–490 rewrite.
- The NFDRS, S–492, S–493, and S–590 steering groups and faculty to ensure that the revised BEHAVE meets their needs.
- Individuals and groups from the user community.

The schedule and status of BEHAVE development, testing, and implementation can be found on the Internet at <**http://www.fire.org**>.

The revised BEHAVE will include the fire modeling capabilities in the old BEHAVE, supplemented by improved and new fire models.

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NEXUS: A SYSTEM FOR ASSESSING CROWN FIRE HAZARD

Joe H. Scott

Decades of fire suppression and succession to shade-tolerant species have changed the structure of many forest types across North America, making crown fires more common. A crown fire will burn many more acres than a surface fire in the same forest, causing more site damage and increasing risk to life and property. Therefore, wildland fire managers are increasingly interested in managing fuels to reduce the incidence of crowning by wildfires. Doing so requires assessing the relative crown fire potential of different stands across the landscape and comparing the effectiveness of mitigation treatments.

> NEXUS integrates models of surface and crown fire behavior to simulate the full range of fire behavior possible in a forest stand.

Assessing Crown Fire Hazard

Scott and Reinhardt (in preparation) developed two quantitative indices of crown fire hazard—the Torching Index and the Crowning Index—that managers can use to assess the potential for crowning by wildfires. The indices are derived from the links among separate fire behavior models. The Torching Index is the 20-foot (6-m) windspeed at which a crown fire could start. The Crowning Index is the 20-foot (6-m) windspeed at which an active crown fire is possible.

Scott and Reinhardt also showed how the crown fire modeling concepts used in the Canadian Forest Fire Behavior Prediction System (Forestry Canada Fire Danger Group 1992) can be applied to the fire behavior models used in the United States. To implement their coupled model of surface and crown fire behavior, Scott and Reinhardt developed an Excel-based spreadsheet application, called NEXUS, that couples Rothermel's (1972) surface fire and (1991) crown fire models to simulate the full range of fire behavior possible in a forest stand.

NEXUS was originally designed as a research tool to explore the implications of linking existing models and to develop a crown fire hazard assessment method. It included only the essential elements for modeling surface and crown fires from existing models. The developers later extended the capabilities and improved the utility of the spreadsheet so that NEXUS could be used for more general fire behavior modeling. This article describes the fire behavior models in NEXUS, its unique features, its advantages and disadvantages, and its relationship to other fire modeling systems.

Fire Behavior Models in NEXUS

NEXUS includes fire behavior models for surface, crown, and transitional fires. Like the BEHAVE Fire Behavior Prediction and Fuel Modeling System (Andrews 1986) and the FARSITE Fire Area Simulator (Finney 1998), NEXUS predicts surface fire behavior using Rothermel's (1972) mathematical model. In addition, NEXUS estimates potential behavior of an active crown fire using Rothermel's (1991) correlation of crown fire spread rate with predictions based on his surface fire model. Based on Van Wagner (1977), NEXUS links these surface and crown fire predictions by estimating the transition points between surface fire, passive crown fire (also called torching, candling, and intermittent crowning), and active crown fire (also called a running or continuous crown fire). NEXUS estimates final (overall) fire behavior by scaling between surface and crown fire behavior predictions using a transition function. NEXUS also includes several submodels to compute secondary fire behavior outputs, such as fire size and shape.

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NEXUS is the only tool that wildland fire managers can use to explore the links among existing surface and crown fire models.

Because NEXUS estimates both surface and crown fire behavior, the user must provide inputs for both surface and crown fuels. The basic inputs for surface fire behavior prediction are the same as for BEHAVE, with a few exceptions:

- In NEXUS, the user specifies the 20-foot (6-m) windspeed and wind reduction factor to compute the midflame windspeed, whereas in BEHAVE the midflame windspeed can be entered directly.
- NEXUS allows the user to build and use custom fuel models that have an additional class of live and dead fuel. Therefore, the moisture content inputs include space for these new classes.

When using the standard fuel models, these extra inputs have no effect on the output. Basic surface fuel inputs are:

- Fuel model (standard or custom),
- Live and dead surface fuel moistures,
- Slope,
- 20-foot (6-m) windspeed,
- Wind reduction factor, and
- Wind direction.

For crown fire behavior prediction, crown base height and crown bulk density are also required. If desired, information on stand height and canopy closure can be used to estimate the wind reduction factor.

An "options" dialog box allows the user to set options for obtaining the desired simulation. For example, the user can specify whether to enable crown fire behavior predictions and whether the wind reduction factor should be computed from canopy cover and stand height or directly entered in the input table. Illogical output from NEXUS often results from unintended settings in the options dialog box.

The basic output of NEXUS includes the standard fire behavior outputs from BEHAVE (spread rate, heat per unit area, fireline intensity, flame length, reaction intensity, effective midflame windspeed, direction of maximum spread, length-to-breadth ratio, perimeter growth rate, fire area, and map spread distance). These outputs are computed for the full range of wildfire behavior, from surface fire through active crown fire. NEXUS reports the type of fire predicted (surface, passive crown, or active crown) and degree of crowning, along with two indices of crown fire hazard and several threshold crown fire transition values.

In addition to its tabular output, NEXUS displays:

- A graph of a selected fire behavior output (such as spread rate and fireline intensity) over a range of 20-foot (6-m) windspeeds;
- A crown fire hazard assessment chart that details the links among surface and crown fire models; and
- A fire characteristics chart.

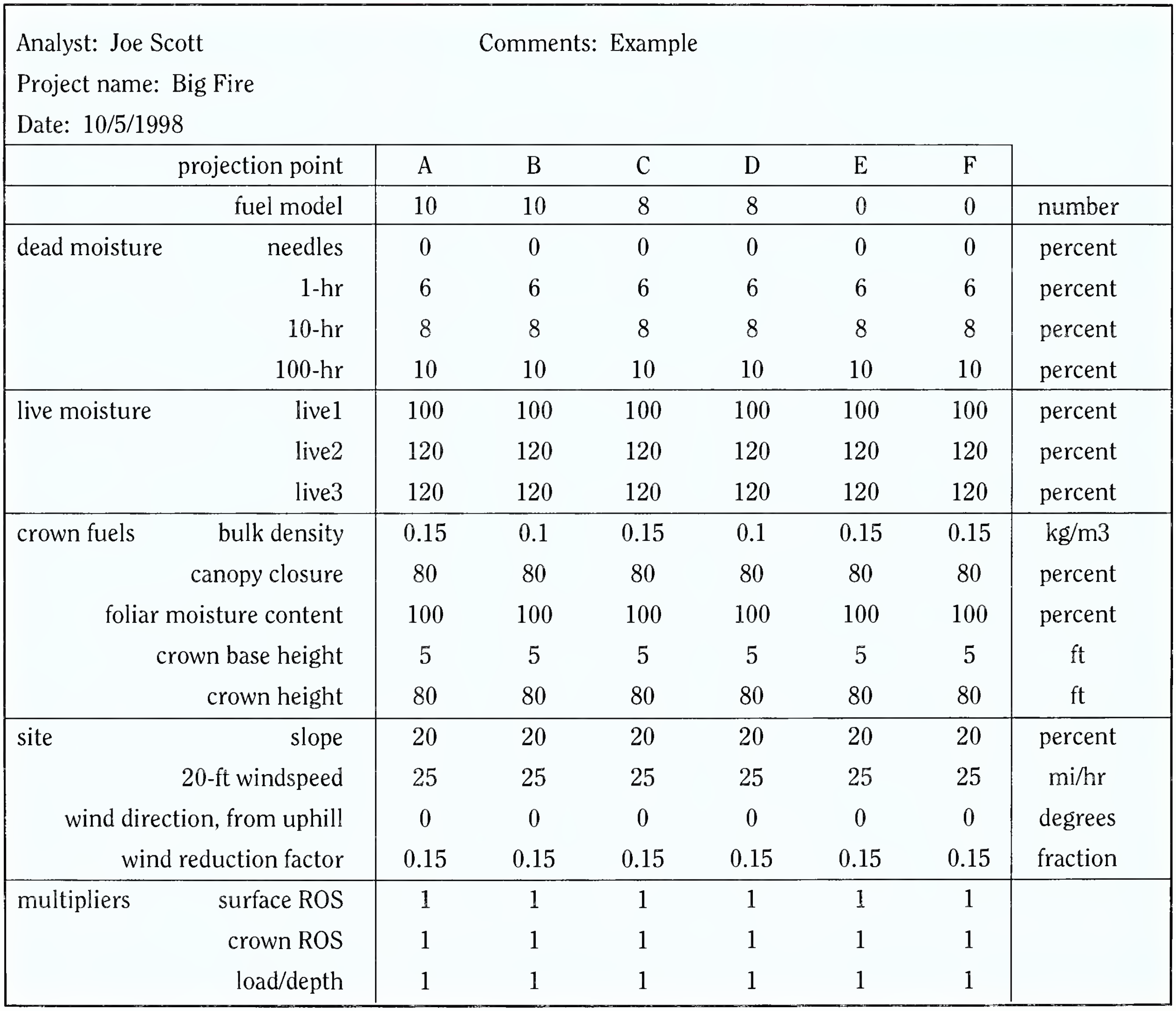
Unique Features of NEXUS

NEXUS offers users these unique features:

- *Simultaneous comparisons of crown fire hazard and predicted fire behavior for up to six surface/crown fuel complexes (projection points).* The user enters input data in a table (fig. 1), specifying fuel model, surface fuel moisture, and crown fuel and site characteristics. Constants such as mineral fractions and particle density can be entered in a separate table. The six projection points can be used to compare different stands or treatments or to perform a sensitivity analysis by varying one input while holding others constant.
- *Automatic tabular and graphical output over a range of windspeeds.* A table (fig. 2) automatically displays fire behavior characteristics for the projection points, including fireline intensity, rate of spread, flame length, fireline intensity, and crown fraction burned. These outputs are also shown graphically over a range of 20-foot (6-m) windspeeds.
- *Rate of spread and fuel model adjustment factors.* The user can perform sensitivity analyses and fine-tune a simulation by using one of three adjustment factors that are entered in the input table. The rate of spread adjustment factor linearly affects both

rate of spread and intensity. The load/depth adjustment factor adjusts the loading and depth of all classes within the fuel model itself. Spread rate varies linearly with this multiplier, but fireline intensity varies with its square. Finally, spread rate predicted with Rothermel's (1991) crown fire correlation is adjusted by the crown fire spread rate multiplier. This adjustment factor does not affect intensity.

- *Worksheet for designing and testing custom fuel models.* The user can easily create or adjust a fuel model using slider bars and direct entry of load and surface-area-to-volume ratios. Results can be displayed graphically for comparison with any other custom or standard fuel model. Calculations are similar to the NEWMDL program of the BEHAVE system.
- *Integration of surface and crown fire behavior predictions.* The transition between surface and crown fire is predicted from fuel complex characteristics. The transition is based on Van Wagner's (1977) criteria and his crown-fraction-burned transition function (Van Wagner 1993).
- *Crown fire hazard assessment.* NEXUS computes the critical windspeeds required to initiate and sustain a crown fire. A crown fire hazard assessment chart is displayed for any one of the six fuel complexes described in the input table. This chart shows predicted and critical rates of spread, overall rate of spread, and crown fraction burned.



Analyst: Joe Scott
Comments: Example
Project name: Big Fire
Date: 10/5/1998

	projection point	A	B	C	D	E	F	
	fuel model	10	10	8	8	0	0	number
dead moisture	needles	0	0	0	0	0	0	percent
	1-hr	6	6	6	6	6	6	percent
	10-hr	8	8	8	8	8	8	percent
	100-hr	10	10	10	10	10	10	percent
live moisture	live1	100	100	100	100	100	100	percent
	live2	120	120	120	120	120	120	percent
	live3	120	120	120	120	120	120	percent
crown fuels	bulk density	0.15	0.1	0.15	0.1	0.15	0.15	kg/m3
	canopy closure	80	80	80	80	80	80	percent
	foliar moisture content	100	100	100	100	100	100	percent
	crown base height	5	5	5	5	5	5	ft
	crown height	80	80	80	80	80	80	ft
site	slope	20	20	20	20	20	20	percent
	20-ft windspeed	25	25	25	25	25	25	mi/hr
	wind direction, from uphill	0	0	0	0	0	0	degrees
	wind reduction factor	0.15	0.15	0.15	0.15	0.15	0.15	fraction
multipliers	surface ROS	1	1	1	1	1	1	
	crown ROS	1	1	1	1	1	1	
	load/depth	1	1	1	1	1	1	

***Figure 1**—A completed NEXUS input table. The table allows direct entry of fuel model number, fuel moistures, crown fuel characteristics, site characteristics, and adjustment factors. Up to six fuel complex scenarios can be specified.*

- *Graphical display of fire size and shape with respect to wind/slope.* NEXUS automatically displays a graph showing the shape and orientation (with respect to upslope) of a fire for any one of the six fuel complexes. This graph can be used to examine the relationships among windspeed, wind direction, and slope for different fuel models. The use of slider bars for some inputs allows animation of this analysis.

Advantages and Disadvantages of NEXUS

The spreadsheet format is a simple, highly flexible programming environment. Most users of fire behavior modeling systems are familiar with computer spreadsheets. Many users will be able to use NEXUS to customize analysis by modifying the basic spreadsheet structure. New or task-specific models can be added by any proficient user. Spreadsheets have built-in analysis tools (such as sensitivity tables, input scenarios, and backwards solving) that can be used in fire behavior analysis and prescription development. Input entry is logical and easy. Links with graphing and word-processing programs are simple in the Windows 95 operating system.

However, there are many disadvantages to the spreadsheet format. The user must already have the spreadsheet program running on a computer. Moreover, a spreadsheet

OUTPUTS	fuel scenario						
	A	B	C	D	E	F	
crown fire type	active	passive	surface	surface	surface	surface	
crown fraction burned	100%	14%	0%	0%	0%	0%	percent
rate of spread	73.6	15.7	1.5	1.5	0.0	0.0	chains/hr
heat per unit area	6892	1789	188	188	0	0	BTU/ft2
fireline intensity	9299	515	5	5	0	0	BTU/ft/sec
flame length	90.1	16.2	1.0	1.0	0.0	0.0	feet
reaction intensity, surface	5840	5840	924	924	0	0	BTU/ft2/sec
wind reduction factor	0.15	0.15	0.15	0.15	0.15	0.15	fraction
effective mid-flame wind	10.2	4.9	4.0	4.0	3.9	3.9	mi/hr
direction of max spread	0	0	0	0	0	0	degrees
scorch height	441	62	1	1	0	0	feet
length-to-breadth ratio	3.5	2.2	2.0	2.0	2.0	2.0	ratio
perimeter growth rate	161.5	38.9	4.3	4.3	0.0	0.0	chains/hr
fire area	122	10	0	0	0	0	acres
map spread distance	2.43	0.52	0.05	0.05	0.00	0.00	inches
	Critical values for crown fire						
Torching Index	15.7	15.7	204.8	204.8	N/A	N/A	mi/hr
Crowning Index	21.3	28.9	21.3	28.9	N/A	N/A	mi/hr
Surface intensity	92	92	92	92	N/A	N/A	BTU/ft/sec
Surface ROS	4	4	27	27	N/A	N/A	ch/hr
Crown base ht	7	7	1	1	N/A	N/A	feet
Crown fire ROS	60	89	60	89	N/A	N/A	chains/hr

Figure 2*—A NEXUS output table. Based on inputs, the table automatically displays predictions of fire behavior; fire type (surface, passive crown, or active crown); fire size and spread direction; critical parameters for crown fire initiation and sustained spread; and indices of crown fire hazard.*

offers less control of user input and less opportunity for error trapping than does a conventional computer program. Therefore, the NEXUS user must accept more responsibility for ensuring that inputs are correct.

Comparison With Other Systems

NEXUS is a tool for comparing the relative crown fire hazard and potential fire behavior of different stands. It is the only system now available that integrates surface and crown fire models for one-dimensional projections. (Other computer tools are available for similar tasks.)

The BEHAVE family of computer programs is still the national standard for surface fire behavior prediction in the United States. The keyword interface of the BEHAVE programs is cumbersome to use, but error trapping helps keep novice users out of trouble. The BEHAVE system is currently being redeveloped (see related article in this issue by Andrews and Bevins). The first release of the new system will still be limited to predicting surface fires, but will have a much-improved user interface. Additional models of crown fire transition and fuel consumption will eventually be added.

The FARSITE Fire Area Simulator (Finney 1998) simulates the two-dimensional spread and behavior of fires in complex fuels and topography. Like NEXUS, FARSITE simulates crown fire behavior by integrating existing fire behavior models. NEXUS can be used to better understand the crown fire behavior patterns observed in FARSITE.

New features are added to NEXUS regularly. The current version can be obtained at the Systems for Environmental Management Internet site at <**ftp://ftp.wildfire.org/nexus/nexus3.exe**>. The download file is a self-extracting executable that contains two files: the spreadsheet itself and a brief user's guide. A more detailed user's guide is being written. For more information, contact Joe Scott at Systems for Environmental Management, P.O. Box 8868, Missoula, MT 59807, tel. 406-329-4837, e-mail joescott@montana.com.

Acknowledgment

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A WILDFIRE THREAT RATING SYSTEM*

Brad Hawkes and Judi Beck

Natural Resources Canada Ressources naturelles Canada
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The Wildfire Threat Rating System enhances Canada's existing Fire Danger Rating System by incorporating spatial information.

Reducing the risk of wildfire is a complex challenge facing most land managers in British Columbia, Canada, and elsewhere across North America. Although wildland fire is a natural process that has shaped many of British Columbia's ecosystems, wildfire threatens such forest values as timber supplies, recreation opportunities, and wildlife habitat. From 1986 to 1996, wildfires consumed an average of 74,000 acres (30,000 ha) annually.

To help meet this challenge, land managers in British Columbia use Canada's Fire Weather Index and Forest Fire Behavior Prediction Systems, excellent tools that have been adapted by many countries worldwide. Together, they comprise the main components of Canada's Forest Fire Danger Rating System. Recently, researchers have developed a prototype Wildfire Threat Rating System (WTRS) that enhances the existing Fire Danger Rating System by incorporating spatial information.

The WTRS provides a repeatable means of integrating and analyzing key factors that contribute to wildfire threat. When used with a geographic information system (GIS), wildfire threat analysis allows resource managers to explore:

- The effect of management actions on the threat of wildfires;
- The potential impact of wildfires on forest resources; and
- Options for reducing the probability of large, intense wildfires.

The WTRS can also assist in presuppression planning.

Origins of the WTRS

Based on a similar system initially developed for Australia, Canadian researchers produced a prototype WTRS for the McGregor Model Forest (MF), located 19 miles (30 km) northeast of Prince George, BC (fig. 1). The McGregor MF has an area of 447,269 acres (181,000 ha) primarily located in the subboreal spruce and Engelmann spruce–subalpine fir biogeoclimatic zones. One of 10 model forests across Canada, the McGregor MF provides a site for developing, testing, and applying state-of-the-art forest research and forest management practices that contribute to sustainable forestry. One of the greatest advantages of using the McGregor MF for developing a WTRS is the opportunity to integrate the system with landscape management planning and to witness the system's ability to test the fire-related impacts of various resource management strategies (fig. 2).

WTRS Components

Wildfire threat is a function of four main components:

- Risk of ignition,
- Values to be protected,
- Suppression capability, and
- Likely fire behavior.

The WTRS assesses and maps each component separately and then combines them to provide an overall rating of wildfire threat. Considerable data and information must be assembled to develop each component; table 1 details the data sources used. The computer modeling, spatial analysis, and mapping required for wildfire threat analysis are run on GIS using the GRID program in ARC/INFO.

Risk of Ignition. Risk of ignition is the probability or chance of a fire starting. For the prototype WTRS on the McGregor MF, researchers considered both natural and human sources of ignition. Fire risk, determined from historical fire frequency records from 1950 to 1991, was expressed as the number of fires per 1.5 square miles (4 km^2) over 41 years.

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Analysis of potential fire behavior through the Wildfire Threat Rating System can assist resource managers in determining suppression resource requirements, potential fire damage, and probability of initial-attack success.

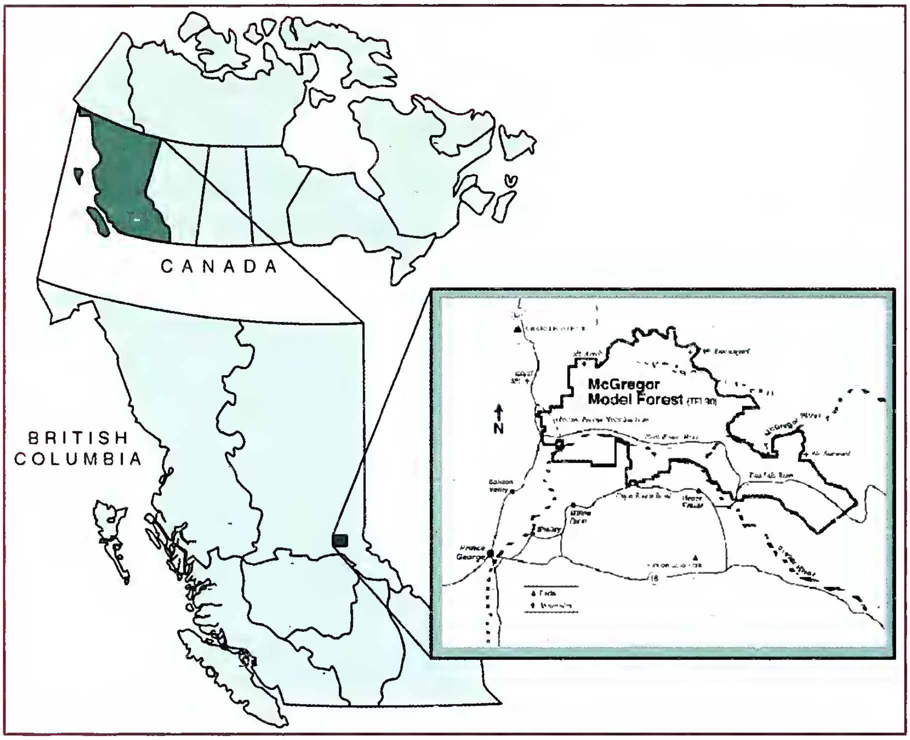

Figure 1—Location of the McGregor Model Forest in British Columbia, where Canadian researchers produced a prototype Wildfire Threat Rating System.

Figure 2—Site of a lightning-caused wildfire on the McGregor Model Forest, British Columbia, 1981. Photo: Glen Singleton, McGregor Model Forest, Prince George, BC.

On the McGregor MF, lightning-caused fires are far more frequent than human-caused fires and therefore were assigned a higher weighted value; table 2 shows the values assigned to each factor. The fire risk map (fig. 3) reflects the spatial distribution of both lightning- and human-caused fires. Knowing risk of ignition is very useful for planning presuppression and developing operational fire prevention programs.

Values at Risk. Values to be protected from wildfire include human life, community and commercial assets, and natural resources. Researchers assessed four factors to determine the overall rating for values at risk:

- Size and type of development* within or near the model forest,
- Proximity to a populated area,
- The most prominent timber values within 1.6 miles (2.5 km) of each grid cell center, and
- Visual quality for recreation.

In calculating the total values at risk, researchers assigned higher weighted values to the factors indicating a potential for loss of life (table 2), namely the size and type of development and the distance to a population center. Timber and visual quality factors were given equal emphasis but weighted less heavily than the first two factors.

Values at risk are a critical component of the WTRS because protecting human life and property has driven and justified fire suppression programs for the last 50 years.

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*Development included, in addition to unpopulated improvements such as microwave installations, populated areas such as farms and towns, which made up the second risk factor. The intent was to treat populated areas specifically as an additional risk factor over and above development.

Table 1—*Data sources for the four components of wildfire threat*

Data source	*Scale*	*Risk of ignition*	*Values at risk*	*Suppression capability*	*Fire behavior*
Forest inventory	1:10,000	–	√	–	√
Silviculture	1:10,000	–	–	–	√
Rivers and lakes	1:250,000	–	–	√	–
Road details	1:10,000	–	–	√	–
Digital elevation model	1:20,000	–	–	–	√
Fire history	Point of origin	√	–	–	–
Towns, recreational sites, and visual quality	1:65,000	–	√	–	–
Initial-attack bases	Point locations	–	–	√	–

Table 2—*Values and data ranges for wildfire threat components and contributing factors*

Threat component/ Contributing factor	*Maximum value*	*Number of value classes*[a]	*Data range*	
			U.S. units	*Metric units*
Risk of ignition	62	4	—	—
Lightning-caused fires[b]	41	4	0–7 per 1.5 mi^2	0–7 per 4 km^2
Person-caused fires[b]	21	4	0–3 per 1.5 mi^2	0–3 per 4 km^2
Values at risk	62	4	—	—
Development	25	5	—[c]	—[c]
Proximity to populated area	24	5	0.6–25 mi	1–40 km
Visual quality for recreation	7	4	—[d]	—[d]
Timber values	6	5	—[e]	—[e]
Suppression capability	62	4	—	—
Helitack time	25	4	15–40 min	15–40 min
Steepness of terrain	20	5	0–>47%	0–>47%
Proximity to water source	10	2	0–>328 ft	0–>100 m
Proximity to roads	7	5	0–>1.2 mi	0–>2 km
Fire behavior	62	4	—	—
Fire intensity	25	6	0–>8,700 Btu/s•ft	0–>30,000 kW/m
Crown fraction burned	25	4	0–100%	0–100%
Rate of spread	12	5	0–>131 ft/min	0–>40 m/min

a. For example, each threat component has four value classes: low, moderate, extreme, and high.
b. From 1950 to 1991.
c. Value range is 0–25.
d. Value range is 1–7.
e. Value range is 0–6.

Identification of all significant resource values, including critical wildlife habitat and significant silvicultural investments, and their incorporation into the values at risk component will strengthen the outcome of WTRS analysis for its users.

One of the strengths of the Wildfire Threat Rating System is that it can be adjusted and adapted to reflect the specific conditions of a given landscape.

On the McGregor MF, only 5 percent of the area was rated with extreme or high values at risk (fig. 3), because developments on the forest are relatively small (for example, there are no towns) and population centers on the forest (such as campgrounds) are concentrated in the south. WTRS analysis can be more beneficial in areas of British Columbia with significantly more development.

Suppression Capability. The ability to suppress fires depends on the speed of detection, the time that elapses between detection and initial attack, and the physical characteristics of the landscape (such as steepness of terrain and

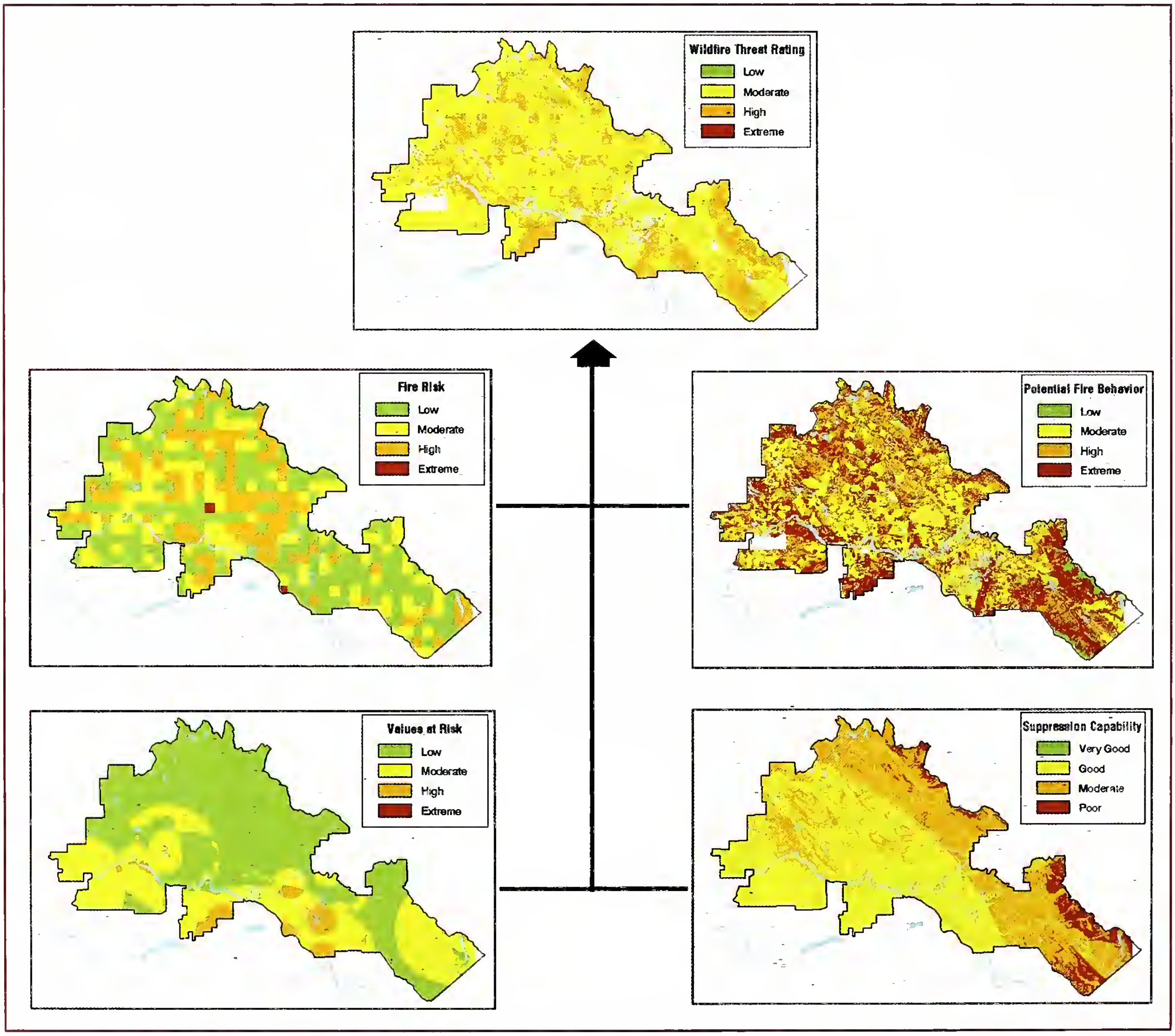

***Figure 3**—Maps for risk of ignition, values at risk, suppression capability, and fire behavior, the four components of the Wildfire Threat Rating System developed on the McGregor Model Forest in British Columbia. The component maps are compiled to produce an overall wildfire threat rating map.*

The Wildfire Threat Rating System can help determine how different land use decisions will affect the wildfire threat in a given area.

access to water and ground transportation). Researchers assessed four factors in determining the suppression capability:

- Initial-attack time from the permanent helitack base in Prince George, BC;
- Steepness of terrain based on slope classification;
- Proximity to a water source (rivers and lakes); and
- Proximity to roads.

Detection factors were not included because they are changeable and difficult to quantify. Initial-attack time received the highest weighted value in determining overall suppression capability (table 2) because aggressive initial attack is emphasized in British Columbia. Steepness of terrain received the second highest weighted value because of its potential to restrict fire crew access and fireline productivity. Ground and water access were not weighted as heavily as the first two factors.

The suppression capability component could be strengthened by incorporating more detailed information, such as distance and travel times for ground crews and whether and how soon roads are usable. Because a high suppression capability is needed to protect wildland values and minimize timber losses, analysis of suppression capability is useful in making decisions about road decommissioning and the location of fire suppression resources.

Fire Behavior. Fire behavior is an important part of the WTRS because it influences both the extent of resource damage and the success of any suppression action. To determine potential fire behavior, researchers compiled spatial information on:

- Fuel types,
- Topography (slope and aspect), and
- Fire weather (Fire Weather Index codes and indices based on extreme conditions).

This information was then fed into the Canadian Forest Fire Behavior Prediction System to calculate the following key factors of potential fire behavior:

- Fire intensity,
- Crown fraction burned, and
- Rate of spread.

In calculating the fire behavior component, researchers assigned a higher weighted value to fire intensity and crown fraction burned (table 2) because these factors contribute directly to suppression difficulty and resource damage. Rate of spread was weighted at half this value.

Fuel type, along with slope and aspect, constitutes the basis of fire behavior predictions. Because fuel types change over time as young stands mature and older stands are harvested, they must be modeled to be usable in making management decisions about future landscapes. Analysis of potential fire behavior through the WTRS can assist resource managers in determining suppression resource requirements, potential fire damage, and probability of initial-attack success.

Overall Wildfire Threat Assessment

After mapping its four components, the WTRS combines them into a wildfire threat map reflecting overall wildfire threat values (fig. 3). A wildfire threat map is best interpreted by examining the four components of wildfire threat and the factors that contribute to each. The individual component maps provide insight into why a particular area has a certain wildfire threat value and what action(s) would reduce the risk.

For the prototype WTRS, the four components were weighted equally (table 2). However, different weights can be placed on each component to reflect different land management objectives and scales, such as a single licensed tree farm versus the entire province of British Columbia.

Management Implications

Wildfire threat analysis primarily supports fire management planning at the strategic level. However, the WTRS can be used to support tactical suppression planning and fire prioritization if information on suppression resources, fire weather, and fire occurrence is available on a daily or hourly basis. Other possible applications of wildfire threat rating include:

- Examining the implications of a major shift in harvesting and silvicultural systems;

- Evaluating access management plans and identifying roads most needed for fire protection;
- Evaluating alternative locations for initial-attack bases; and
- Determining the best locations for prescribed burns on parks and wilderness areas.

The prototype WTRS will evolve based on feedback from potential users. One of the system's strengths is that it can be adjusted and adapted to reflect the specific conditions of any given landscape. For example, seasonal influences on wildfire threat could be incorporated to reflect the differences between northern and southern British Columbia.

Developing a WTRS on a provincial scale would be a challenge. Assembling the necessary data bases, range of values, and management objectives would be difficult due to differences in agency and jurisdictional interests and responsibilities. However, the benefits would be tremendous and far reaching.

Incorporating a WTRS into landscape management planning can assist resource managers in decisionmaking, helping to reduce wildfire risk. Ultimately, this can help to save lives, property, timber supplies, and other wildland values.

Further information on the Canadian Forest Service Fire Research Network is available on the World Wide Web at <**http://www.nofc.forestry.ca/fire/fmn**>. The final WTRS report and interactive Web-based WTRS model are available at <**http://www.mcgregor.bc.ca/**>.

Acknowledgments

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DON'T GET BITTEN BY THE MILLENNIUM BUG!

Delvin R. Bunton

January 1, 2000, is fast approaching and computer programmers are busily working to repair computer problems created decades ago. Why should you care? Three reasons:

- *The internal clock of most desktop computers assumes that all years are 19xx.* Some computers will not recognize the year 2000. Testing your computer is relatively easy, but the results may surprise you.
- *Some software will incorrectly assume that all data belong in the 20th century.* Weather analysis programs, for example, will give incorrect results with data input from before and after January 1, 2000. To fix this problem, the Forest Service and other Federal agencies are checking our software and will have it certified and ready well before January 1, 2000.
- *Some control systems (such as environmental controls) will fail.* Some analysts believe that widespread power outages could result, shutting down other computers, turning off lights, and otherwise disrupting technologies we depend on.

To avoid surprises, test your computers and software and fix what you can before a serious and unexpected problem affects your business operations. For more information on how to prepare for the computer millennium bug, contact the National Information Systems Help Desk, National Interagency Fire Center, Boise, ID, at 1-800-253-5559 or 208-387-5417. ■

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A Fire-Based Hazard/Risk Assessment

Timothy A. Burton, Deirdre M. Dether, John R. Erickson, Joseph P. Frost, Lynette Z. Morelan, Leon F. Neuenschwander, William R. Rush, John L. Thornton, and Cydney A. Weiland

The Boise National Forest (NF) in southern Idaho has an especially acute forest health crisis. Its ponderosa pine forests are among the most endangered and threatened ecosystems in the United States (Noss et al. 1995). Historically maintained by frequent, low-intensity fire, the 1.1 million acres (440,000 ha) of ponderosa pine forests on the Boise NF have been altered by decades of fire suppression, grazing, and logging that have removed fire-adapted species. In these and other areas throughout the interior West, many ponderosa pine forests are now dominated by dense stands of small-diameter Douglas-fir and other fire-sensitive species (Noss et al. 1995) (fig. 1).

***Figure 1**—Contrasting sites on the Boise National Forest, ID. Historically, open stands of ponderosa pine forest (left) were maintained by frequent, low-intensity fire on 1.1 million acres (440,000 ha) of what is now the Boise National Forest. However, decades of fire suppression, grazing, and logging have removed fire-adapted species. Many ponderosa pine forests are now dominated by dense stands of small-diameter Douglas-fir and other fire-sensitive species (right). Photos: Karen Wattenmaker, USDA Forest Service, Boise National Forest, Boise, ID, 1998.*

When wildland fires now occur in ponderosa pine forests with altered fire regimes, they are larger, more intense, and more severe. The historic nonlethal surface fires that provided nutrients and prevented dense understories of saplings or pole-sized trees from developing have given way to uncharacteristic, stand-replacing fires that can turn large areas of forestland into grass- and shrubland (Crane and Fischer 1986).

On the Boise NF, wildfires in ponderosa pine forest have been increasingly large and severe since 1986. Nearly 500,000 acres (201,860 ha) of national forest land (about 50 percent of the Boise NF's ponderosa pine forest and almost 20 percent of the land managed by the forest) have burned, often with uncharacteristic intensity (fig. 2). The cost of suppressing these fires and rehabilitating watersheds has exceeded $100 million. In many severely burned areas, soil productivity, aquatic resources, and wildlife and plant habitat have been critically damaged (USDA Forest Service 1992; 1995).

A Hazard/Risk Assessment

Preliminary analysis shows that within the next 20 years, remaining mature ponderosa pine forest could be further fragmented, with only isolated pockets remaining (Neuenschwander 1995). To respond to this threat to the forest's ponderosa pine ecosystem,

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a forest interdisciplinary team, working in partnership with the University of Idaho in Moscow, ID, developed a hazard/risk assessment using a geographic information system (GIS).

On a forestwide basis, the assessment indicated where forest ecosystems are most likely to experience uncharacteristically intense wildfires that place important resources at risk. The assessment established five GIS submodels:

1. Forested vegetation outside the historical range of variability (HRV),
2. Fire ignition,
3. Wildlife habitat persistence,
4. Watershed hazard (erosion and sedimentation potential), and
5. Fisheries condition.

When linked, these submodels showed where large, severe wildfires would alter the composition, structure, and function of an ecosystem by:

- Depleting late-successional habitat needed by old-growth-dependent and other wildlife species,
- Accelerating levels of erosion and sedimentation, and
- Reducing the viability of fish populations.

Methodology

In developing the hazard/risk assessment, the team employed a GIS, state-of-the-art computer software designed to process and analyze spatial information. Written using ARC/INFO version 7.03, the assessment utilized automated machine language to process data in the GRID, ArcPlot, ArcEdit, and TABLES modules.

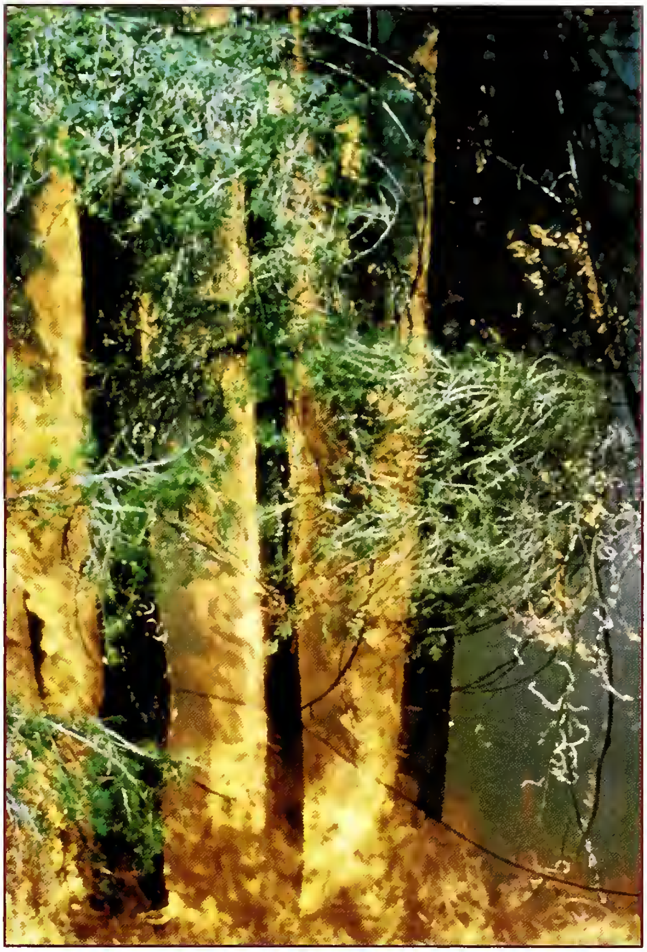

Figure 2*—Impact of a recent crown fire on the Boise National Forest, ID. About half of the Boise National Forest's ponderosa pine forest has burned since 1986, often with uncharacteristic intensity (right). In many severely burned areas (below), soil productivity, aquatic resources, and wildlife and plant habitat have been critically damaged. Photos: Karen Wattenmaker, USDA Forest Service, Boise National Forest, Boise, ID, 1998.*

Most of the analysis was performed using rasterized data in the GRID module, ArcPlot for graphic output, and TABLES for reports. Data were analyzed and displayed on a system that included an IBM RISC–6000 "390" server and AIX 3.2.5 operating system on a Thinwire Ethernet local area network.

Given the interior West's potential loss of ponderosa pine forests in the next 20 years, the hazard/risk assessment can be a primary tool for prioritizing areas most at risk.

The assessment was made on the basis of 82 watersheds on the Boise NF, each with a drainage of about 30,000 acres (12,111 ha). Each watershed contains several subwatersheds of about 6,000 acres (2,422 ha) each, for a total of 378 subwatersheds. The assessment proceeded by:

- Creating five GIS submodels to evaluate hazards for specific resources.
- Assigning a relative hazard rating of 1 (lowest) to 5 (highest) to each subwatershed for each of the five submodels.
- Assigning an overall hazard rating of "high" to subwatersheds that received hazard ratings of 3 to 5 for all five submodels.
- Assigning an overall hazard rating of "high" to watersheds that had at least one subwatershed with an overall hazard rating of "high." This scheme reflects the forest's observation that the recent uncharacteristic wildfires on the Boise NF are burning across vast landscapes and entire watersheds.

Forested Vegetation Outside HRV. The forested vegetation submodel, based on the June 1992 LANDSAT satellite imagery classification, located areas where ponderosa pine is or once was a climax or major seral species and evaluated the density of the forested vegetation in these areas. Hazard ratings were assigned to each subwatershed based on the number of acres in satellite imagery cover types that represent forest vegetation outside HRV, relative to the total number of acres in the subwatershed. In assigning hazard ratings, historical structure information from the Boise Basin (Sloan 1994), analysis from the Deadwood Landscape Assessment (USDA Forest Service 1994), and documentation of research on similar habitat types in Montana (Arno et al. 1995) were used. Based on professional judgment validated through proportional analysis, hazard ratings of 3 to 5 for forested vegetation outside HRV were assigned to subwatersheds where 25 percent or more of the area consisted of moderate to dense stands of mixed Douglas-fir, ponderosa pine, and grand fir; mixed Douglas-fir and ponderosa pine; homogeneous Douglas-fir; or homogeneous ponderosa pine.

Fire Ignition. The fire ignition submodel, based on Boise NF fire records from 1956 to 1994, determined where wildfires have historically started, regardless of cause. This submodel was based on the assumption that wildfires will continue to start where they have originated historically.

The Boise NF's fire ignition data base was first sorted by 640-acre (258-ha) sections to determine the number of total ignitions in each section, which ranged from 0 to 14. A grid map of the Boise NF showing sections and number of ignitions per section was then overlaid with a map of subwatersheds, and a fire ignition score was assigned to each subwatershed based on the highest number of ignitions in any one section of the subwatershed. Based on professional judgment validated through proportional analysis, hazard ratings were then assigned to fire ignition scores; subwatersheds with four or more fire starts in any one section from 1956 to 1994 received hazard ratings of 3 to 5.

Wildlife Habitat Persistence. Wildfire burning in an altered regime in dense, late-successional habitat can alter the successional pathway, changing the current vegetation structure into shrub- and brushfields and displacing or eliminating wildlife populations dependent on late-successional habitat for several hundred years. Large, severe wildfires can also result in ecosystem simplification, with greater landscape homogeneity and loss of biodiversity, including genetic diversity (Neuenschwander 1995). The wildlife habitat persistence submodel was therefore based in part on the assumption that extensive, contiguous, stand-replacing fires are the primary threat to wildlife habitat persistence (Erickson and Toweill 1994).

Satellite imagery of forest cover types was combined with digital elevation model information (such as elevation, slope, and aspect) to develop a map of habitat types, showing potential natural vegetation and indicating the successional pathway following a disturbance such as fire. Next, habitat types with similar successional pathways and disturbance regimes were combined into "habitat type groups." "Habitat at risk" and "habitat not at risk" were then delineated by identifying habitat groups of mid- and late-seral

The model's structure, which uses selected criteria to progressively narrow the area of consideration, is particularly well suited to situations where time and resources are limited.

habitat "outside" and "within" HRV, respectively. Finally, persistence hazard ratings were developed to reflect the likelihood that suitable habitat would not survive an uncharacteristically large, stand-replacing wildfire.

The rating system was based on the assumption that the more extensive the vegetation outside HRV, the higher the likelihood that extensive, stand-replacing wildfires might occur, destroying mid- and late-seral habitats. Hazard ratings of 3 to 5 for wildlife habitat persistence were assigned to subwatersheds where, following a wildfire, late-successional habitat would remain on less than 15 percent of the area and cover less than two patches 350 acres (141 ha) or more in size. (Low-elevation subwatersheds consisting primarily of grass-, brush-, and shrublands were not included in this analysis.)

Watershed Hazard. The watershed hazard submodel was based on inherent differences in natural (undisturbed) sedimentation rates between different land types (areas with similar soils and landforms and therefore similar hazards and capabilities) within a watershed. Because erosion and sedimentation rates are known to increase following a wildfire (Megahan and Molitor 1975; Helvey 1980; Schultz et al. 1986; Troendle and Bevenger 1994), the submodel evaluated potential natural sediment yield, as determined from land types. Subwatersheds with an average potential natural sediment yield of 35 tons per square mile per year (0.06 t/ha/yr) received ratings of 3 to 5 for watershed hazard.

Fisheries Condition. The fisheries condition submodel selected spring and summer chinook salmon and bull trout as indicator species, because in Idaho chinook have been listed as "endangered" and bull trout as "warranted but deferred" under the Endangered Species Act of 1973. The submodel used a scheme to prioritize watersheds for species protection, along with population strength and fragmentation factors identified by Rieman and McIntyre (1993). Ratings for each of three components (species, relative population strength, and isolation) were assigned to each subwatershed, based in part on sampling information located in the Boise NF's Aquatic Survey Database. These components were used to identify the strongest chinook salmon and bull trout populations, as well as nearby weakened populations with the greatest chance for recovery. The three components were then averaged to calculate an overall hazard rating for each subwatershed.

The fisheries condition submodel was based on the assumption that large wildfires burning in conditions outside HRV will produce environmental disturbances (such as floods) that decrease the likelihood of persistence for chinook salmon populations already low in abundance and for local bull trout populations important to the viability of regional populations. For chinook salmon, hazard ratings of 3 to 5 were generally assigned to subwatersheds that had spawning and rearing habitat. For bull trout, hazard ratings of 3 to 5 were assigned to subwatersheds that had strong regional populations but local populations at risk from large, stand-replacing wildfires due to their relatively low abundance, small areal extent, and isolation from other populations.

Results

The hazard/risk assessment was designed in part to answer two questions:

- ***Where are forest ecosystems most at risk from large, severe wildfires burning outside HRV?*** The forest ecosystems most at risk from uncharacteristic, stand-replacing wildfires include large areas of moderate and dense forest where ponderosa pine is or was a major seral species and where moderate to high numbers of fires (more than four in any single 640-acre (258-ha) section in a subwatershed) occurred from 1956 to 1994. By linking the fire ignition and forested vegetation submodels, the assessment showed that up to 152 subwatersheds covering 1,196,781 acres (484,526 ha) are most at risk from uncharacteristic wildfire (fig. 3). Many of these subwatersheds are located in steep canyons in the Boise and Payette River watersheds.
- ***What important resources are at risk from severe wildfires?*** To determine resources at risk, the hazard/risk assessment located areas where uncharacteristic wildfires would affect specific wildlife, watershed, and fisheries resources. By linking all five submodels, the assessment showed that in 20 watersheds

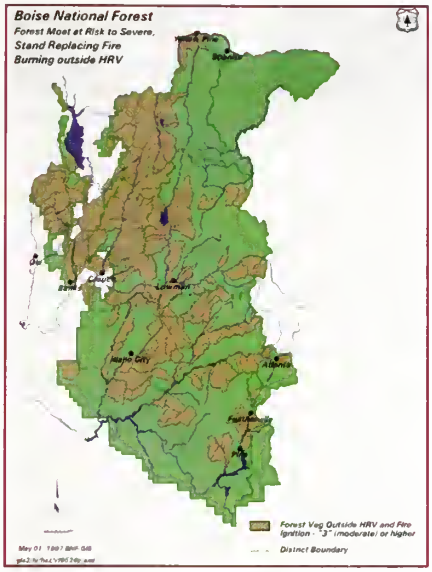

Figure 3—Forestland most at risk from severe, stand-replacing wildfire on the Boise National Forest, ID. Brown areas are subwatersheds with moderate to dense forest where ponderosa pine is or was a major seral species and where moderate to high numbers of wildfires historically occur. These 152 subwatersheds cover 1,196,781 acres (484,526 ha).

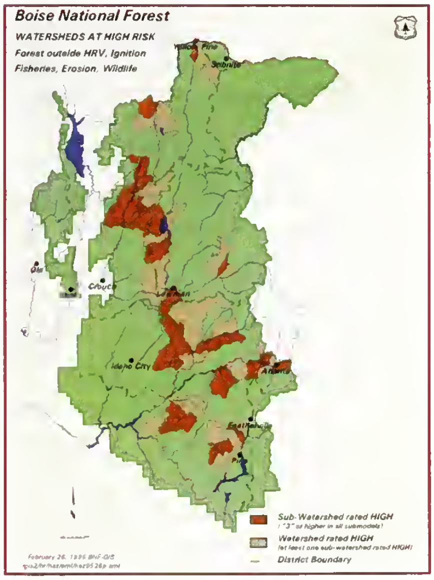

Figure 4—Watersheds at high risk from damage to all forest resources by severe, stand-replacing wildfire on the Boise National Forest, ID. Red areas are subwatersheds with ratings of moderate to high for each of five risk factors (forest vegetation, wildfire ignition, wildlife habitat, watershed hazard, and fisheries condition). Brown/red areas are watersheds containing at least one high-risk subwatershed. In the 20 high-risk watersheds, which cover 610,389 acres (247,121 ha), all important resources could be adversely affected by stand-replacing wildfire.

covering 610,389 acres (247,121 ha), all important resources could be adversely affected by uncharacteristic wildfire (fig. 4). Table 1 summarizes information on forestland most at risk from uncharacteristic, high-intensity wildfire.

Discussion

The hazard/risk assessment had two broad purposes:

1. To evaluate the relative size and extent of the Boise NF's challenge in managing sustainable ponderosa pine ecosystems.
2. To tell land managers where to focus attention, that is—
    - Where to begin evaluating site-specific conditions on a smaller scale,
    - Where to begin determining a desired future condition for a landscape at risk, and
    - Where specific projects might be needed to begin restoring sustainable ecosystem conditions across the landscape.

The assessment was designed to fall between the large-scale analysis of the Upper Columbia River Basin (UCRB) assessment and the more site-specific evaluation of watershed- and landscape- or project-level analyses. Habitat types developed for the wildlife persistence submodel were based on section information established by the UCRB assessment. The assessment is compatible with the Forest Service National Hierarchical Framework of Ecological Units; the forest lies in section M332A (Idaho Batholith) of province M332 (Middle Rocky Mountain Steppe–Coniferous Forest–Alpine Meadow) (McNab and Avers 1994). Information from the hazard/risk assessment can thus be aggregated to ecological sections at a larger scale.

The hazard/risk assessment is an important addition to the analysis toolbox available to land managers today. It recognizes the potential for damage to important resources from large, severe wildfires burning under altered fire regimes, and it acknowledges the large-scale interruption of successional pathways that have helped create uncharacteristic conditions that threaten to disturb the structure and function of an entire ecosystem. Given the potential loss of

Table 1—*Ponderosa pine forestland most at risk from uncharacteristic, high-intensity wildfire on the Boise National Forest (NF)*

Risk factor	***Location***	***Acres (ha)***[a]	***Proportion of the Boise NF***[b]
Forest ecosystems most at risk	152 subwatersheds	1,196,781 (484,526)	40%
All important resources at risk	20 watersheds	610,398 (247,121)	20%

a. All acres within the corresponding subwatersheds and watersheds, including some areas of grassland, shrubland, subalpine fir, etc.

b. In relation to the 3 million acres (1,214,100 ha) encompassed by the Boise NF, as captured by 1992 LANDSAT imagery. To facilitate midscale analysis, about 350,000 acres (141,645 ha) of State, other Federal, and private land were included in this area. The Boise NF has no jurisdiction over this land.

The assessment's use of GIS as the modeling medium is especially appropriate for examining landscape-level conditions.

ponderosa pine-dominated forests on the Boise NF in the next 20 years, the hazard/risk assessment can be a primary tool for prioritizing areas most at risk. The model's structure, which uses selected criteria to progressively narrow the area of consideration, is particularly well suited to situations where time and resources are limited.

The assessment's use of GIS as the modeling medium is especially appropriate for examining landscape conditions, because GIS can analyze large amounts of data and sophisticated relationships across extensive areas. Because GIS is a widely used, state-of-the-art analysis tool, it lends itself to sharing information among resource specialists from different agencies and organizations. GIS therefore allows the hazard/risk assessment to expand across multiple ownerships and boundaries to address resources, resource users, and cross-jurisdictional challenges to ecosystem health at many scales.

Forest scientists recognize that to restore the resistance and resilience of ecosystems with altered fire regimes, land managers must use several tools, including timber harvest and prescribed fire (Agee 1995; Mutch 1995). In today's altered landscapes, thinning is needed to remove trees from dense areas where using prescribed fire alone could result in intense, stand-replacing wildfires. The Boise NF will need to thin to remove less fire-resistant trees such as Douglas-fir and grand fir, leaving the fire-resistant ponderosa pine. The forest will also need to apply low-intensity fire under prescribed conditions to remove ground fuels, recycle nutrients, and begin restoring fire-dependent ecosystems. By identifying the areas most at risk, the hazard/risk assessment can help land managers focus on the areas where such restoration treatments might be most needed and effective.

For more information on the Boise NF hazard/risk assessment, contact Cydney Weiland, Boise National Forest, 1249 S. Vinnell Way, Boise, ID 83709, tel. 208-373-4135, fax 208-373-3111, e-mail cweiland/r4_boise@fs.fed.us.

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SHARING INFORMATION THROUGH FIRE REPORTING

Delvin R. Bunton

Fire reports on individual fires are crucial tools for collecting, compiling, sharing, and assessing information needed to better understand the Nation's wildland fires. Using information from fire reports, we can determine better ways to effectively manage wildland fires. Fire reports provide key information on where fires occur and what causes them, and can sometimes help identify problems that cross jurisdictional boundaries, such as arson.

Effective fire reporting requires a seamless system of information sharing among fire organizations nationwide. Winston Churchill once told Congress, "We are two peoples separated by a common language." Fire reporting faces a similar problem. Whereas rural and urban fire departments use one type of report, most land management agencies use another, and each report uses a different terminology. By exploring the similarities and differences in the two report methods, we can identify potential information-sharing opportunities. When local, regional, and national fire managers have an accurate picture of the fire problems across fire services, we can improve collaboration.

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> The Forest Service compiles and summarizes wildland fire statistics for the Nation and publishes them in various forms.

Wildland Fire Reports

From its inception in 1905, the USDA Forest Service has collected information on wildland fires (USDA Forest Service 1905). Although the form used and type of data gathered have been revised about every 10 years (Donoghue 1982), the current Forest Service fire report form (form FS–5100–29) includes many data items first adopted in 1905 (USDA Forest Service 1995). The most detailed forms were used from 1930 to 1950, with gradual reductions in detail thereafter. The Forest Service collects data on wildland fires on national forest lands. Official records are not kept on false alarms, medical and nonfire responses (such as washing down a fuel spill), structure fires that stay within structures, or fires that were discovered after they went out naturally.

The U.S. Department of the Interior (USDI) and many State land management agencies use fire report methodologies and a data classification similar to those used by the Forest Service. The USDI form (form DI–1202) also captures data on false alarms, fires that went out naturally, and assistance rendered to other agencies (USDI BLM 1996). Some State agencies have shifted to a modified urban-type report that includes some items from wildland fire reports. Such hybrid reports are most often used in States where little wildland fire suppression is needed (including many Eastern States) or where the fire protection agency has both urban and wildland fire protection responsibilities (such as California).

Urban Fire Reports

The first known urban fire report system began simultaneously in New York, NY, and Chicago, IL, in 1933. In the years that followed, other large cities began data collection. The National Fire Protection Association (NFPA) published a fire report system in 1938 and called a national conference on fire reporting in 1961. Subsequently, the NFPA developed a system of codes to record information on fires. The NFPA updates its fire code system, the Standard Classifications for Incident Reporting and Fire Protection Data (NFPA 901), about every 5 years.

The U.S. Fire Administration (USFA) began collecting fire report data from the States in about 1975. Its data collection evolved into the National Fire Incident Report System (NFIRS) in about 1981. The current version of NFIRS and most urban fire department reporting use the data classifications in the 1976 edition of NFPA 901 (NFPA 1976).

The USFA is developing a new version of NFIRS (FEMA USFA 1998) that combines new codes with codes from the 1995 edition of NFPA 901 (NFPA 1995). Currently being tested in several States, the new NFIRS will modernize and improve urban fire reporting. The basic fire form captures general data on fire cause, structure burned, and fire department actions. In addition, NFIRS requires specific forms to be filled out when applicable to capture more detailed information on structure fires and other incident types. Although most NFIRS forms collect little data on open fires (nonstructure fires in vegetation, such as wildland fires), a separate form for wildland fires captures basic data such as cause, size, fuel type, and some environmental factors.

The value of NFIRS data in assessing the effects of open fires (those of greatest interest to wildland fire management agencies) will depend on the widespread adoption by fire departments of the new NFIRS wildland fire form. The wildland fire form is the only urban fire report form that includes acres burned. However, the name "wildland" might discourage many urban and rural fire departments from using the form for open fires in the wildland–urban interface. A recent search of the NFIRS data base found records for less than a dozen wildland fires. Another recent NFIRS request for data on open fires revealed that many fire departments do not record such information, possibly under the mistaken impression that wildland fires do not exist in urban areas.

The Oakland Hills Fire that devastated parts of Berkeley and Oakland, CA, in October 1991 dramatically demonstrated the danger of wildland–urban interface fire within city limits (NFPA 1992). Los Angeles, CA, and nearby cities protect large areas with natural vegetation where wildfires sometimes burn structures (Wilson 1962). The new NFIRS wildland fire form can capture data on such fires.

Similarities and Differences

Table 1 compares wildland and urban fire report characteristics. There are many similarities, and most differences are not critical impediments to information sharing. However, some differences—especially cause coding differences and the presence or absence of certain data items—materially affect what can be analyzed.

Most land management agencies record information on almost all of the fires in their jurisdictions. When fires burn across jurisdictional boundaries (which often happens for large fires), each agency involved generally reports on the entire fire, with a breakout for the portion of the fire in its particular jurisdiction. Data summaries for individual jurisdictions are usually quite accurate. However, summaries that cross jurisdictions almost always duplicate the fire count and acres burned. It is generally possible to sort out duplication on the acres burned but difficult to get an exact fire count (accuracy is probably within 1–2 percent).

In their annual wildland fire summaries, the State Foresters report the number of fires and acres burned by fire size class (using size classes A through G) and by statistical cause (using nine broad cause classes). There are separate tables for size class and cause, making it nearly impossible to link data between the two tables. For example, the data reported by Nebraska in 1995 (fig. 1) do not indicate what caused the three large (class G) fires.

Another problem is data duplication. Some States combine data for all wildland fires within their borders, regardless of who managed each fire. Fires on Federal wildlands are often counted twice in those States—once in State annual fire summaries and once in Federal fire summaries. Moreover, wildland fire data from the State Foresters might or might not include data that urban and rural fire departments report to the State Fire Marshal; each State differs in this regard.

The Forest Service compiles the wildland fire summaries from the States and other Federal agencies and periodically publishes the compilation. The compiled wildland data summaries are often used to analyze fire cause trends and link the data with other information sources. Figure 2, for example, shows the acres burned by cause on State and private lands in Nebraska from 1984 to 1990. The acres burned by lightning and miscellaneous fires show a dramatic increase in 1989, whereas the acres from debris burning remain relatively constant. Planners can use such information to better understand fire patterns in the Nation's wildlands.

Most urban and some rural fire departments record information on fires and other incidents within

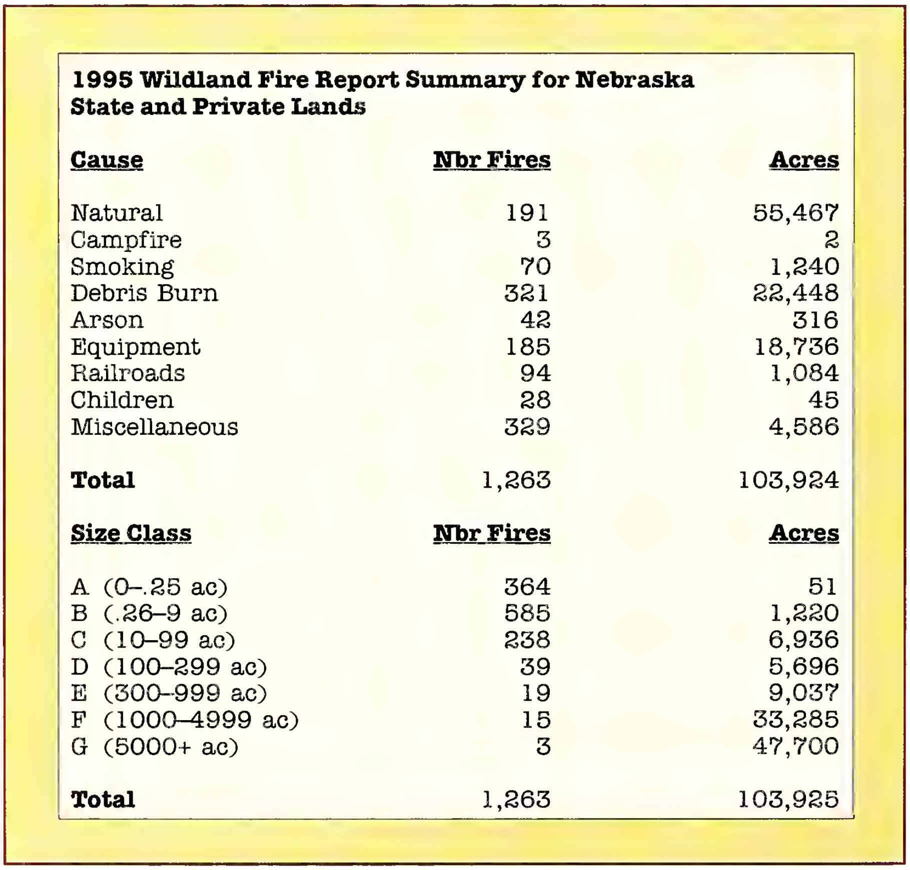
Table 1—*Comparison of wildland and urban fire reports*

Characteristic	*Wildland Fire Report* [a]	*Urban Fire Report (National Fire Incident Report System (NFIRS))*	
		Current [b]	*New* [c]
Incident type	Open (outdoor) fires in vegetation, regardless of duration. Does not include information on casualties, emergency medical responses, hazardous materials, personnel, or arson (other than fire cause).	All risks; includes information on structure fires, wildland fires (limited), casualties, emergency medical responses, hazardous materials, apparatus (resources), personnel, and arson.	Same as current report.
Data type	Area burned and environmental factors that influenced ignition and fire behavior.	Point of ignition, with great detail on structure and equipment involved.	Same as current report.
Area burned	Includes breakout in acres by broad land ownership within the fire perimeter.	Does not include area burned.	*Basic form:* Does not include area burned. *Wildland form:* Includes acres burned.
Dates/times	Records date and time of ignition, discovery, attack (first action), control, and fire out.	Records date and time of alarm (when fire department was notified), but only time (not date) for all other events (such as arrival and last unit cleared). Therefore, does not capture fire event times for periods longer than 24 hours.	*Basic form:* Same as current report, but records date and time for each event, and therefore captures fire event times for periods longer than 24 hours. *Wildland form:* Similar to wildland fire report.
Damages	Generally does not record damages.	Includes estimated dollar loss (however, most urban fire departments consider vegetation as zero dollar loss).	Same as current report.
Structure details	Does not report structure details, although sometimes deals with fires that spread from structure to wildland fuels.	Reports extensive details on structures burned.	Same as current report.
Detection	Records who reported the fire (wildland agencies actively seek to detect fires).	Records whether an automatic fire detector was used in structure.	*Basic form:* Same as current report. Unknown whether other detectors can be coded.
Fuel types	Includes several descriptors of fuel type.	Does not record fuel type.	*Wildland form:* Includes National Fire Danger Rating System fuel types.
Geographic reference	Usually records latitude and longitude, sometimes geographic reference based on the Public Land Survey System.	Records address of structure where fire occurred.	*Basic form:* Same as current report. *Wildland form:* Records both latitude/longitude and geographic reference based on the Public Land Survey System.
Injuries	Links poorly (if at all) to a separate system for reporting injuries.	Uses a very good system to tie firefighter and civilian injuries and deaths to a specific incident.	Same as current report.
Hazardous materials	Links weakly to a separate system for reporting hazardous materials responses where fires were involved.	Uses an excellent record system for hazardous materials responses, regardless of whether fires were involved.	Same as current report.
Data users	Federal wildland management agencies and many State wildland management agencies with fire protection responsibility.	Urban and rural fire departments and the U.S. armed forces. Some State fire protection agencies use an enhanced urban report.	Same as current report.
Data managers	Individual land management and protection agencies.	Individual fire departments, State Fire Marshals, the U.S. Fire Administration.	Same as current report.

Table 1—*Comparison of wildland and urban fire reports (continued)*

Characteristic	Wildland Fire Report[a]	Urban Fire Report (National Fire Incident Report System (NFIRS))	
		Current[b]	New[c]
Fire cause codes	Forest Service codes (for broad statistical cause, specific cause, human activity, and people involved). Good categorization of wildland causes, poor for structural causes.	Basic system codes (for heat source, form and type of material first ignited, and equipment and mobile property (such as autos) involved in the ignition). Excellent for the fire types that urban fire departments routinely experience, moderate to poor for wildland fire causes.	*Basic form:* Same as current report. *Wildland form:* Codes for 9 general wildland fire causes.
Probability of report	*Federal agencies:* Very high. *State agencies:* Very high.	*State agencies:* Very high *Urban and rural fire departments:* Varies with size (very high for large and professional fire departments, very low for many small and volunteer departments). Generally low without incentives.	Same as current report.

a. Based on the Forest Service (1995) and USDI Bureau of Land Management (1996) fire report systems
b. Based on the current (NFPA 1976) forms.
c. Based on the new (FEMA USFA 1998; NFPA 1995) NFIRS forms.



1995 Wildland Fire Report Summary for Nebraska State and Private Lands

Cause	Nbr Fires	Acres
Natural	191	55,467
Campfire	3	2
Smoking	70	1,240
Debris Burn	321	22,448
Arson	42	316
Equipment	185	18,736
Railroads	94	1,084
Children	28	45
Miscellaneous	329	4,586
Total	1,263	103,924

Size Class	Nbr Fires	Acres
A (0–.25 ac)	364	51
B (.26–9 ac)	585	1,220
C (10–99 ac)	238	6,936
D (100–299 ac)	39	5,696
E (300–999 ac)	19	9,037
F (1000–4999 ac)	15	33,285
G (5000+ ac)	3	47,700
Total	1,263	103,925

Figure 1—*Typical annual wildland fire summary reported by the State Foresters. The separate tables for size class and cause make it nearly impossible to link data between the two tables. For example, there is no indication what caused the three class G fires.*

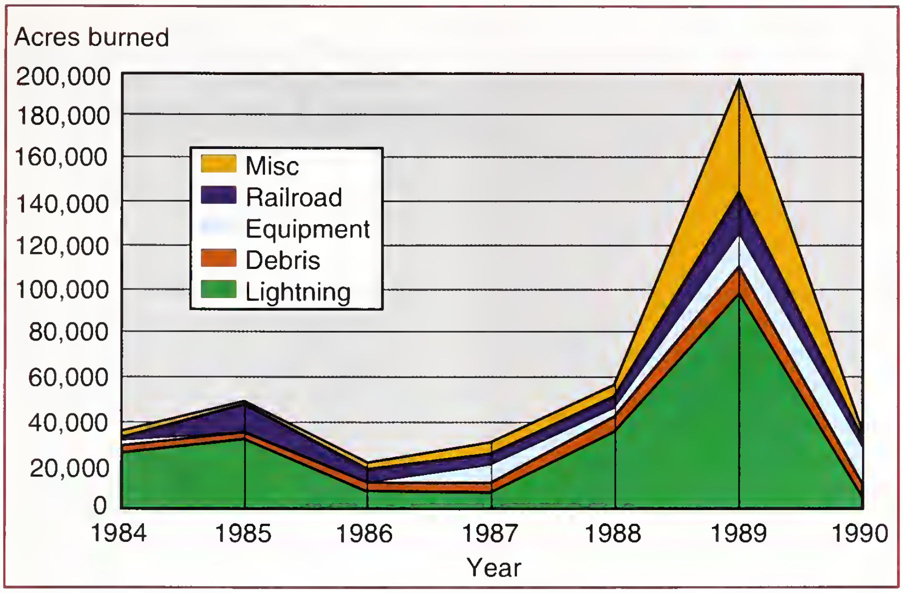


Figure 2*—Acres burned by cause on State and private land in Nebraska, 1984–90 (USDA Forest Service 1992). This graph shows a dramatic increase in acres burned by lightning and miscellaneous fires in 1989, whereas the acres from debris burning remain relatively constant over the period. Planners can use such information to better understand fire patterns and to focus prevention efforts.*

their jurisdictions. Each year, many (but not all) fire departments send fire data to their State Fire Marshals or equivalent State entities. Most States (45 submitted data in 1996) then forward the data to the USFA for inclusion in the NFIRS. In addition, 32 large metropolitan fire departments (in urban areas with populations of 500,000 or more) report data directly to the USFA.

The greatest unknown is the number of fires in the jurisdictions of urban and rural fire departments that are never recorded or reported to State Fire Marshals or the USFA. Rural fire protection districts in particular might be sources of valuable additional information. Many rural fire departments are volunteer organizations, and relatively few actually complete reports on individual fires and submit them to State Fire Marshals. Haphazard fire reporting, coupled with the major differences between urban and wildland fire report systems, makes it difficult to meet a growing need by State and Federal fire managers for fire occurrence summaries over large cross-jurisdictional areas.

Differences in cause codes between urban and wildland reports are another major obstacle to information sharing. The National Interagency Fire Statistics Information Project (NIFSIP), chartered by the Federal land management agencies, is working with the USFA, the National Association of State Foresters, and other fire groups to define a new set of wildland fire cause codes. Even after adoption, however, differences (particularly in the detailed cause codes) will persist in coding methods for fire causes, making data sharing difficult but not impossible.

Information-Sharing Opportunities

In the next 3 to 5 years, as fire departments shift to the new NFIRS, we can bridge many differences between urban and wildland fire reports in purpose, data use, and detail. Users will be able to generate most of the State-supplied data they currently need from the new NFIRS. Moreover, the new NFIRS wildland fire report can capture valuable additional information not currently reported to any State or national agency.

In addition, by taking a few simple steps, Federal agencies, States, and urban and rural fire departments can work together to improve data collection. For example:

- States that collect wildland fire data showing acres burned could submit a composite data summary that shows number of fires and acres burned by cause as well as by size class. States would continue to report two sets of data—number of fires and acres burned. However, each set of data would appear in tables for both cause and size class (fig. 3). This would allow analysis of fire cause by size class.
- In their annual summaries, States could exclude records for fires where the data do not include acres burned. Analysis of wildland fires of unknown size yields little useful information.
- Through State and Private Forestry, the Forest Service could work with the State Fire Marshals and State Foresters to increase rural fire reporting by encouraging fire departments to complete the basic and wildland fire forms in the new NFIRS. In particular, the Forest Service could encourage any State that does not already do so to award priority points for the assignment of new equipment to fire departments that use the new NFIRS and that submit data

Wildland Fire Report Summary—Number of Fires

Cause	***Size Class***							
	A	***B***	***C***	***D***	***E***	***F***	***G***	***Total***
Natural								
Campfire								
Smoking								
Debris burning								
Arson								
Equipment								
Railroads								
Children								
Miscellaneous								
Total								

Figure 3—*Proposed improved wildland fire summary format for reporting by State Foresters. A second, identical table would be used for reporting acres burned. By linking cause to size class, this format would permit better analysis of fire cause trends.*

collected to the State. This might give fire departments that benefit from the Federal Excess Property Program an added incentive to report wildland fires.

- Federal land management agencies could work with the USFA to encourage urban and rural fire departments to automatically use the NFIRS wildland fire form for:
  - Fires that burn more than a certain number of acres (possibly 10), regardless of the vegetative cover or fuel type. This might help urban and rural fire departments to better understand the purpose of the form and to capture useful information.
  - Fires that burn in open areas. This might help fire departments to realize the extent of the wildland–urban interface fire problem in their areas.
- Federal land management agencies could expedite review of the fire cause coding scheme developed by the NIFSIP and begin the adoption process.
- The NIFSIP or a similar project could develop a standard process for converting fire cause codes and other key identifiers between urban and wildland coding systems. This, together with the preceeding recommendation, would facilitate multijurisdictional analysis of landscape-level fire.

For more information on fire reporting, contact the National Information Systems Help Desk, National Interagency Fire Center, Boise, ID, at 1-800-253-5559 or 208-387-5417.

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NEW WEATHER OBSERVATION TRANSFER FORMAT

Delvin R. Bunton

In May 1998, the National Advisory Group for Fire Danger Rating reviewed and approved a new weather observation data transfer format (WxObs98) (see sidebar). This decision signals the impending retirement of the weather observation format developed for the 1972 version of the National Fire Danger Rating System (NFDRS) (Deeming et al. 1972). Furman and Helfman (1973) described the 1972 data format and created the first of many applications for its use. The format change will affect many applications.

The 1972 format was defined as input to weather analysis programs that calculated indices for the NFDRS. Over time, new applications used the same input format. Some of the most widely used programs that rely upon the 1972 format are:

- *FIREFAMILY,* a set of programs that calculate NFDRS indices and percentiles (Furman and Brink 1975; Main et al. 1982; Main et al. 1990);
- *Fires,* a recent program that analyzes and compares weather and NFDRS indices against fire occurrences (Andrews and Bradshaw 1997);
- *PC Historical Analysis,* a part of the National Fire Management Analysis System (for fire planning) that uses weather and fire occurrence data to characterize a planning unit's fire work-load (USDA Forest Service 1996); and
- *PCDANGER,* a program that calculates NFDRS indices from input weather files or from direct entry (Bradshaw and Law 1997).

Why Change Something That Works?

The 1972 format served the wildland fire community well, but it suffers from problems common to data formats from that era. The rise of new observation equipment (such as the Remote Automated Weather Stations (RAWS's)), the ability to measure weather hourly or upon command, and the desire to collect new data (such as solar radiation) indicate a need to change the format. New analysis software under development also necessitates change.

The most serious problems with the 1972 format include:

- *A 2-digit year,* common practice in 1972. Using the 1972 format after January 1, 2000, will cause problems with some analysis programs when observations before and after that date are included in the same data file.
- *No observation clock time.* Without it, only one observation per day is possible.
- *Obsolete data items.* Several items in the 1972 format are for data that are no longer collected or used by analysis programs. Examples include lightning activity level and human-caused risk.
- *Missing data items.* Several new data items that are now collected have no place in the 1972 format. Examples include shrub and herbaceous greenness factors and solar radiation.

Advantages of the New Transfer Format

The new format attempts to meet current and future needs, and to remedy the shortcomings of the 1972 format. The principal new features that the 1998 format provides include:

- Using four digits for the year, which makes the 1998 format year-2000 compliant;
- Allowing both U.S. and metric measurement for temperature, windspeed, and precipitation amount;
- Including observation clock time, thereby permitting multiple observations per day as long as the times are different;
- Including values required by NFDRS–88 calculations, including greenness factors (shrub and herbaceous) and season code;
- Allowing several observation data types, including NFDRS observation, RAWS observation, and forecast data; and
- Permitting possible inclusion of station header information as a separate record type in the data transfer.

As software developers modify or replace existing analysis software, the 1998 format will replace the long-used 1972 format. The 1972 format will be phased out in

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December 1999 for transfers to and from the National Interagency Fire Management Integrated Database, where the wildland weather observations are stored. The first production application to use the 1998 format will likely be FireFamily+, now under development, which will replace many of the weather analysis programs currently in wide use.

The data transfer format and related information on the 1998 format are available on the Internet at <**http://www.fs.fed.us/fire/planning/nist**> or by contacting the National Information Systems Help Desk, National Interagency Fire Center, Boise, ID, at 1-800-253-5559 or 208-387-5417.

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Weather Observation Data Transfer Format, 1998 (WxObs 98)

Item	Cols	Type	Description
1	01-03	3A	Record type (W98). All records begin with this record type identifier code.
2	04-09	6N	Station Number.
3	10-17	8N	Observation date (YYYYMMDD).
4	18-21	4N	Observation time (0000-2359).
5	22	1A	Observation type (O=NFDRS, R=RAWS other than at the standard NFDRS observation time, F=Forecast, X=Other).
6	23	1N	State of weather code.
7	24-26	3N	Dry bulb temperature (degrees Fahrenheit or degrees Celsius based on Measurement Type code [col. 63]).
8	27-29	3N	Atmospheric moisture (wet bulb temperature, relative humidity (percent), or dewpoint temperature based on Moisture Type code [col. 63]).
9	30-32	3N	Wind direction azimuth measured from true north. 0 (zero) means no wind direction, 360 is north.
10	33-35	3N	Average windspeed over a 10-minute period (miles or kilometers per hour based on Measurement Type code).
11	36-37	2N	Measured 10-hour time lag fuel moisture.
12	38-40	3N	Maximum Temperature (degrees Fahrenheit or degrees Celsius based on Measurement Type code [col. 63]).
13	41-43	3N	Minimum Temperature (degrees Fahrenheit or degrees Celsius based on Measurement Type code [col. 63]).
14	44-46	3N	Maximum relative humidity (percent).
15	47-49	3N	Minimum relative humidity (percent).
16	50-51	2N	Precipitation duration (hours).
17	52-56	5N	Precipitation amount based on Measurement Type code [col. 63]. Blanks=no precipitation. *U.S. measurement:* inches with implied decimal nn.nnn format; trace shown as 00005. *Metric measurement:* measured in millimeters, no implied decimal; trace shown as 00001.
18	57	1A	Wet flag (Y/N).
19	58-59	2N	Herbaceous greenness factor (0-20).
20	60-61	2N	Shrub greenness factor (0-20).
21	62	1N	Moisture Type code (1=Wet bulb, 2=Relative humidity, 3=Dewpoint).
22	63	1N	Measurement Type code: 1=U.S., 2=Metric. Affects temperature (Fahrenheit or Celsius), wind (miles or kilometers per hour), and precipitation (decimal inches or millimeters).
23	64	1N	Season code (1=Winter, 2=Spring, 3=Summer, 4=Fall).
24	65-68	4N	Solar radiation (watts per square meter).

SYSTEMS HELP DESK SERVES THE WILDLAND FIRE COMMUNITY

Suz Rittenhouse

"Fire application support, may I help you?" These words are familiar to those who have called the USDA Forest Service's National Information Systems Team's help desk. In 1995, the Forest Service's Fire and Aviation Management (F&AM) staff put together a team at the National Interagency Fire Center in Boise, ID, to support the needs of the wildland fire and aviation community for high-quality information products and services. The team's goal is to provide the best assistance possible.

Professional Systems Support

The Forest Service help desk is staffed by three members of the Forest Service Washington Office F&AM systems group (Sue Petersen, Sharon Shepard, and Suz Rittenhouse). Together, these professionals have many years of systems experience at all organizational levels, from ranger districts to the Washington Office. In addition, a systems expert from the USDI Bureau of Land Management (BLM) (Tina Vorbeck) works at the BLM help desk to assist BLM employees.

All four help desk staffers enjoy solving any problems people encounter using fire and aviation

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Forest Service systems help desk staff, including (from left) Suz Rittenhouse, Sharon Shepard, and Sue Peterson, standing on the site of the new Wildland Firefighters Monument at the National Interagency Fire Center in Boise, ID. Photo: Janelle Smith, USDI Bureau of Land Management, National Interagency Fire Center, Boise, ID, 1998.

Bureau of Land Management systems help desk staffer Tina Vorbeck at the National Interagency Fire Center in Boise, ID. Photo: Janelle Smith, USDI Bureau of Land Management, National Interagency Fire Center, Boise, ID, 1998.

The help desk staff enjoys solving all kinds of problems that people encounter using fire and aviation software applications.

software applications. Most callers are with the Forest Service or BLM; other Federal agencies provide their own systems support for their employees but use the help desk as an additional resource. The help desk also takes calls and e-mail from State and local fire units, universities, and anyone else using fire or aviation applications.

The help desk staff works closely with all agencies involved in wildland fire and aviation management to provide technical updates, new and updated applications, and notifications affecting fire application users. The help desk currently supports more than 40 applications or systems. Customers call with a wide range of requests, such as for:

- User guides,
- F&AM software and training packages for various applications,
- Guidance on weather station catalogs and indices,
- Observations and forecasts regarding the Weather Information Management System, and
- Help in solving data problems with the Interagency Cache Business System or Aviation Management Information System.

Help desk staffers track change requests for applications or user guides. If staffers don't have an answer at their fingertips, they research the problem and find the answer.

New Help Desk Tools

In January 1998, the help desk acquired the Help Desk Expert Automation Tool, a computerized system that tracks calls and creates a data base of solutions to customers' problems. Whenever a new problem is logged, the system searches for a solution in the data base. The data base also identifies problem areas where additional training or modifications to user guides might be required.

The help desk has created a customer data base that will automatically provide staff with such information as phone and fax numbers for future callers. Staff has developed a Website to show solutions to common problems and to distribute applications, updates, and technical notes. Customers can access the Website at <**http://www.fs.fed.us/fire/planning/nist**>.

The help desk is open year round from Monday through Friday, 7:30 a.m. to 5 p.m. mountain time. At all other times, callers can leave voice mail. During fire season (usually March through November), callers can reach staff 24 hours a day through emergency paging.

The Forest Service help desk staff can be reached at 1-800-253-5559 or by fax at 208-387-5292. The BLM help desk's phone number is 208-387-5417. The help desk's Forest Service e-mail address is fire?/wo, nifc; our Internet e-mail address is fire?/wo_nifc@fs.fed.us. ■

BUSINESS CONTINUITY PLANNING FOR JANUARY 1, 2000

Delvin R. Bunton

Many older computer systems are not equipped to recognize dates with years that do not begin with the digits "19" (see related article by Delvin Bunton in this issue). Some experts predict widespread disruptions and outages of telephone, data communication, and power service on January 1, 2000. If this happens, will you be prepared?

For example, what would you do if the power went out at your dispatch center for 3 hours? For 12 hours? Or for more than 3 days? If you have a ready answer, you already have the start of a business continuity plan (BCP). The main concerns that might affect wildland fire operations include:

- Disruptions in long-distance voice and data communications caused by power loss or telephone circuit loss.
- Systems outages for more than 3 hours at key dispatch locations or for more than 1 day at other sites.
- Extensive power outages that affect regular business operations.

Plan now for reasonable problems. A BCP is no guarantee, but it will give you a chance to successfully cope. The USDA Forest Service has a BCP to guide agency personnel in what to do if problems occur on or soon after January 1, 2000. Copies can be obtained by contacting the National Information Systems Help Desk, National Interagency Fire Center, Boise, ID, at 1-800-253-5559 or 208-387-5417. ■

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WEBSITES ON FIRE*

USDA Forest Service, Fire Applications Support

An important resource for fire managers and computer systems staff, this Website describes the status and availability of fire-related data bases and applications (such as the FARSITE Fire Area Simulator) and offers user guides and applications for downloading. The site also posts frequently asked questions, technical notes on various applications, and contact information for computer systems specialists in the Forest Service. *Found at* <**http://www.fs.fed.us/fire/planning/nist**>

Firewise Home Page

Sponsored by the Federal land management agencies, the National Association of State Foresters, and the National Fire Protection Association, this Website was "created for people who live or vacation in fire prone areas of North America." It focuses on the wildland–urban interface, providing information on such matters as firewise landscaping and homebuilding. *Found at* <**http://www.firewise.org**> ■

**Occasionally,* Fire Management Notes *briefly describes Websites brought to our attention by the wildland fire community. Readers should not construe the description of these sites as in any way exhaustive or as an official endorsement by the USDA Forest Service. To have a Website described, contact the editor, Hutch Brown, at 4814 North 3rd Street, Arlington, VA 22203, tel. 703-525-5951, fax 703-525-0162, e-mail: hutchbrown@erols.com.*

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