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Fire Management Notes

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An international quarterly periodical devoted to forest fire management

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Contents

Cover: The Texas Forest Service modified this "excess" military vehicle for use fighting fires. Excess *refers to property obtained and owned by the USDA Forest* Service that is placed on long-term loan to State and local firefighting agencies.

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Assisting Portugal—Fire Handtool Training

Pat Velasco

District Fire Management Officer, USDA Forest Service, Tonto National Forest, Payson, Ariz.

As a result of a request by Portugal's Secretary of State for Agricultural Production to the U.S. Agency for International Development (AID), a team of U.S. fire control experts went to Portugal to assess the fire control situation and to develop a strategy for improving Portugal's fire control system.

Background

Portugal has suffered enormous forest fire losses in recent years. During the decade beginning in 1972, Portuguese forests were burning at the average rate of 35.4 thousand hectares per year. More than 60,000 hectares burned in 1981. As the production of forest products becomes increasingly important to the country's economy and as the value of the products rise, this situation is becoming critical.

In the past, the responsibility for protecting forest lands has been somewhat vague in that the Portuguese Federal Forest Service (PFFS) has assumed the responsibility for fire suppression on public lands and has often assisted or assumed the temporary responsibility for private forest land fires. The Servicio Nacional DeBombeiros (SNB) (the municipal and volunteer fire departments) had assumed the responsibility for structural fire protection and emergency medical service for each municipality and had assisted and assumed temporary responsibility for private forest land fire protection.

Recently, the Government of Portugal adopted legislation that assigned the fire detection, fire prevention, and fuels management responsibility to the PFFS; all wildland fire suppression responsibilities to the SNB; and the fire investigation responsibility to the Public Safety Police.

Traditionally, the SNB has handled urban (mostly structural) fires. So, the bombeiros are embarking on their legally mandated job of fighting forest fires with equipment, training, experience, and staffing that are largely inappropriate.

The SNB is a force of approximately 35,000 firefighters divided into 457 fire brigades. Each brigade consists of 50 to 85 persons. Approximately 90 percent are part-time volunteers, and the remaining 10 percent are paid, full-time professionals.

Based on the concerns of the Government of Portugal, private forestry industries, and the SNB, the Secretary of State for Agricultural Production requested assistance from US AID in instituting more effective ways to deal with the critical fire control situation.

A team of U.S. fire control experts were summoned to develop a strategy for improving the existing forest fire control system. They were: Richard Montague, Assistant Director, USDA Forest Service, Aviation and Fire Management Staff; Rex N. Griggs, Chief, Region VI, California Department of Forestry; and Bentley Lyon, Forester, USDA Forest Service, Forest Fire and Atmospheric Sciences. Montague and Griggs went to Portugal to study forest fire control operations in April and July of 1982. Lyon visited during the peak of the 1982 forest fire season.

The Assistance Program

As a result of the team's recommendations, the Government of Portugal, the SNB, and AID agreed to the following assistance:

- Three Portuguese forest fire experts would train for 1 month at the California Department of Forestry Fire Academy.
- California Department of Forestry Captains William R. Clayton and Hector Reed would establish a course for fire captains and design the curriculum for future courses at the national emergency relief and fire school.
- A 4-week training course was planned for firefighters in Portugal, particularly in the use of American wildland fire handtools and some small water-handling equipment.

American firefighting tools were given to Portugal, including 40 pulaskis, McLeods, long-handled shovels, brush hooks, hard hats, and electric head lamps with batteries; 10 backpack pumps; and several cases of files. The Portuguese plan to manufacture their own tools using the American tools as prototypes. Handtool instructors were: Pat Velasco, District Fire Management Officer, USDA Forest Service, Tonto National Forest, Payson, Ariz.; Captain Theodoro Mendoza, California Division of Forestry, Alpine, Calif.; and David Quintana, District Fire Management Officer, USDA Forest Service, Santa Fe National Forest, Pecos, N. Mex.

- Courses in fire prevention training for Madiera Island and fire detection program planning would be given by Miguel Lopez, USDA Forest Service R-5, and Joe Cruz, USDA Forest Service R-6.

Portuguese firecrew standing by.

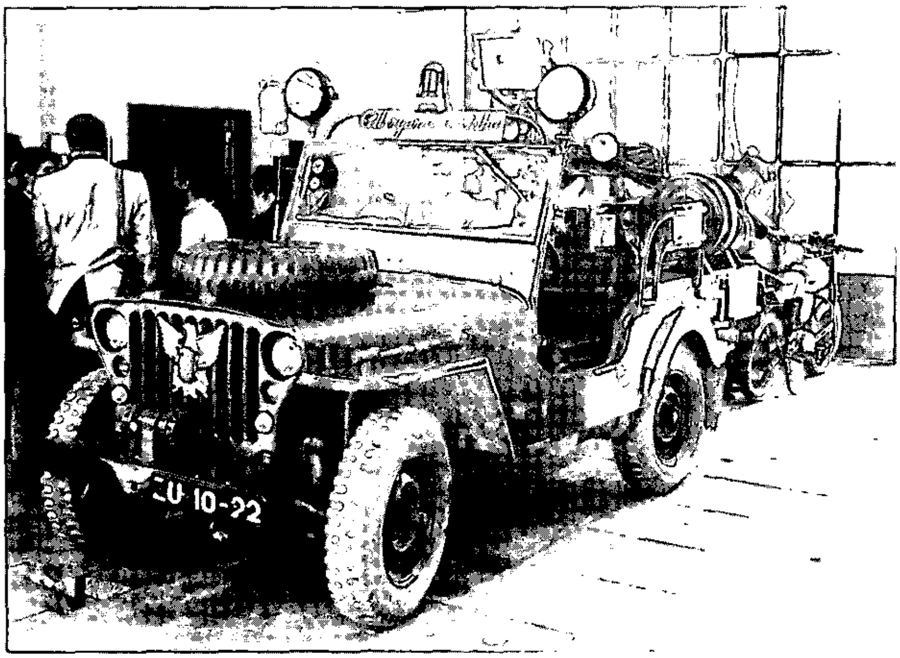
Handtool Training Program

Velasco, Mendoza, and Quintana met in Washington, D.C., reviewed lesson plans and training materials, and met with Portugal fire control expert Ben Lyon to discuss training objectives and training techniques.

The team arrived in Portugal on May 5, 1983, and met with the AID staff to discuss the handtool training program. Twelve briefings and six demonstrations were planned in 12 cities. The briefings were formal training meetings scheduled from between 2100 and 2400 hours. Demonstrations were hands-on training with handtools scheduled on weekends from 0900 to 1230 hours. The training dates and hours were set to accommodate the volunteer firefighters' off-duty and travel hours.

Basics about helicopter management and safety and the use of bulldozers for fireline construction were added to the agenda. The team agreed to include the basics in the agenda at briefings and demonstrations. It was also agreed that Spanish would be the common language.

The Briefings. The briefings were held in the cities of Lamego, Oporto, Viana Do Castello, Vidalgo, Aveiro, Leiria, Viseu, Serta, Guarda, Olivera Do Hospital, Villa Nova De Poiares, and Sintra. Attendance ranged from 30 to 250 people for a total of 1,237 trainees.



A fire suppression vehicle in Portugal.

Portuguese firecrew in action.

Briefings were evening sessions. Most of the sessions were held in the fire stations; however, one was held at a townhall and one was held in an old theater.

After brief introductions of the instructors, the handtool team showed two films: "Handtools for Wildfire," narrated in Spanish, and the Spanish version of "Helicopter Management." A slide presentation of the tactics and strategies of handline construction, mop up, abandonment of fires, the basics of tractor lines, and command and communication in fire control was also shown. The presentations stressed safety, and personal protective equipment was displayed. Our display included 8-inch, lace-up boots, Nomex pants and shirts, Firecraft gloves, Bullard hardhat with neck and face protection, goggles, day pack, first aid kits, fire shelter, canteens, compass, belt weather kit, and 8-inch file with file guard and sheath.

The Demonstrations. Demonstrations were held in Viana Do Castello, Vidalgo, Viseu, Serta, Villa Nova De Pioares, and Sintra on forest sites. Attendance ranged from 100 to 340 people for a total 1,140 trainees. At each meeting, three crews of 20 persons each were trained with the handtools in tool safety tactics and strategy in handline construction. The crews were also trained in the progressive line construction method. The crews then actually constructed up to 10 chains of fireline each, and resharpened their tools. A question and answer period followed.

While only up to 60 trainees would participate in the actual hands-on training, the spectators, principally fire department officers and local SNB administrators, also benefited.

At Serta, an army helicopter simulated water drops along the fireline (without a bucket). A 100-foot dozer line was also constructed.

At several sites, we also demonstrated hose-laying principles. At Viana Do Castello, Vidalgo, and Viseu the engine crew actually set up simple hose lays along the fireline.

***The Need for Training and* Equipment.** While the team did not have the opportunity to observe actual firefighting in Portugal, we were impressed that the firefighters were dedicated to doing a good job. Most said that they needed more training to suppress wildland fires. In Guarda, a firefighter told me that he was pleased to see American firefighting techniques because the Portuguese firefighters had been fighting fires by instinct and were relieved to know that they were on the right track.

Many fire stations we visited were undergoing remodeling. Most stations were large and had training rooms, museums, shops, auditoriums, offices, dormatories, showers, vehicle stalls for up to 20 vehicles, and recreation rooms with bars.

The fire equipment needed in Portugal is smaller than what we use in the United States. Most forest roads in Portugal require smaller, faster vehicles for rapid initial attack. While there are many small 4' x 4' fire vehicles, many fire engines are generally too large for effective firefighting. A problem with all the engines that we saw was that they were all equipped with very large hoses (approximately 1-1/2" to 2-1/2"). They also lacked fittings to set up hose lays or fittings for adjustable nozzles. ■

A Matrix Approach to Fire Prescription Writing

Steven Raybould and Tom Roberts

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Writing fire prescriptions is a formal procedure by which most prescribed fire managers set fire behavior determinants within certain limits. The limits are usually a combination of fire behavior modeling (*1*) and the fire manager's personal experience, and include both "fixed" and "variable" elements (fig. 1) (*2*). Prescriptions thus derived are intended to produce fires intense enough to achieve the objectives of the fire and manageable enough to control with a cost-effective effort.

A fire prescription is usually a simple list of estimated or premeasured values for the fixed elements and a list of acceptable ranges for the variable elements on the day of the burn (fig. 1).

A. Fixed Indicators
- Dead fuel (percent): 50+
- Live fuel moisture (percent): 80+
- Slope, average: 35 percent
- Aspect: NW
- Continuity of fuel (percent): 80 to 90
- Season: February 15 to June 30

B. Variable Indicators
- Fuel stick moisture (percent, 10 hours): 9 to 12
- Relative humidity (percent): 20 to 35
- Wind speed: 0 to 10 mi/h
- Air temperature: 60 to 80° F
- Time of day: 0830 to 1600 hours

Figure 1—*A fire prescription. Indicators are expressed as ranges.*

The Problem

During the development of a prescribed fire program on the San Bernardino National Forest in California, we found this approach to be unnecessarily restrictive. The separate elements in a prescription are not closely interrelated. Windspeed, for example, has little to do with relative humidity; 10-hour fuel sticks can read quite low on a dry day, but green fuel moisture might be high. Thus, while general and long-term trends will push all indicators in the same direction (toward "hotter" or "cooler" conditions), during any given burning period, indicators can act in ways that offset each other.

We commonly encountered situations where one element was out of prescription on the "hot" side and one was out on the "cool" side. Rather than seeing these as two reasons not to do the burn, experience and theory told us that the two elements would compensate for each other and that the burn could proceed safely. For legal reasons, however, this was not possible. Approved burn plans represent formal authorization to take certain acceptable risks on behalf of the USDA Forest Service. The project or prescribed fire manager is usually not free to make changes in the prescription without going through the time-consuming process of re-approval.

The Prescription Matrix

Our solution to the problem was to devise a system that would more closely reflect the subtle ways in which different prescription elements interact. At the core of this approach is the severity level, expressed as a numerical range of "severity points." The concept of a severity level or range is far more useful than ranges of prescription elements, since humidity levels or fuel-stick readings are not important by themselves, but rather as determinants of how vigorously a fire will burn.

The severity levels are defined in conventional fire behavior terms in figure 2. The point score, which determines if conditions are "in prescription," is determined by adding together individual scores read from a matrix (fig. 3). In the matrix each prescription element, fixed or variable, can be assigned a value. In this way, a wind of 15 mi/h (point score of 9) can be used to compensate for a high relative humidity of 50 percent (point score 1). Either of these values would be "out of prescription" according to the old system in figure 1. But windspeed compensates for high humidity (we have burned under these conditions) and the score given by these values (10) is the same as that given by the "in prescription" values of windspeed of 6 mi/h (point score 5) and relative humid-

Severity level		Fire behavior description
	Points	
Light burn	13 26	Up to 20 percent of the area will be burned. Most prescribed burns in 1-hour fuels occur in this range. There is very little ignition; some spotting may occur, but is associated with winds above 9 mi/h. Flame lengths will usually be a minimum of 2 to 3 feet; 0 to 55 Btu's.
Light burn		Charred leaf litter is produced when poorly aerated litter is not totally incinerated. Some grayish ash is present. Maximum temperature during this "black ash" condition is 350° F; soil surface temperature is 25° F to 3 inches down. A light burn has less than 2 percent of the area severely burned; the remaining area is lightly burned or not burned at all. Less than 40 percent of the brush canopy is consumed.
Light burn	29 39	Twenty to 40 percent of the area may be burned. This generally represents the limit of control for handcrews at the flaming front. Glowing brands could cause spotting below 50 percent humidity. Handlines should be able to hold the fire. Flame lengths will usually be a minimum of 3 to 4 feet; 56 to 110 Btu's.
Moderate burn	41 52	Forty to 50 percent of the area may be burned. The flaming front will be too intense for handcrews to work directly. Machines, engines, tractors, or indirect methods can be used successfully. Fuel burns easily. Flame lengths will usually be a minimum of 4 to 6 feet; 111 to 280 Btu's.
Moderate burn	65	The leaf litter and fine woody material is consumed leaving a "bare-soil" condition. Maximum temperatures produced are 750° F; soil surface temperature is 550° F to 3 inches down. A moderately burned area has less than 10 percent of the area severely burned and over 15 percent moderately burned. Between 40 and 80 percent of the area is consumed with the remaining charred twigs larger than one-quarter to one-half inch in diameter.
Moderate burn	70 78	Fifty to 60 percent of the area could be burned. Fuel has high ignitability, with occasional crowning and spotting caused by gusty winds; otherwise, moderate burning conditions. A standard handline might not hold the fire if there is considerable litter, rat nests, or grass across the line. Flame lengths should be the same height or greater than the fuel for a successful burn at this severity level. Flame lengths could be a minimum of 7 to 9 feet; 231 to 520 Btu's.
Severe burn	80 91	Sixty to 70 percent of the area will be burned. The fuel has quick ignition with rapid build-up. The heat load for anyone within 30 feet is dangerous. However, the flaming front should only last a few minutes near the line. Flame lengths will usually be a minimum of 10 to 13 feet; 521 to 670 Btu's.
Severe burn	98	Severe burns are typically characterized by a "white ash" condition. Maximum temperatures exceed 950° F; soil surface temperature exceeds 750° F to 3 inches down. A severely burned area has more than 10 percent severely burned with more than 80 percent moderately or severely burned. Eighty percent of the brush canopy is completely consumed leaving plant stems greater than one-half inch in diameter.
Severe burn	104 110 117	Up to 80 percent of the area will be burned. Extended spotting and fire whirls could occur with fire behavior being on the extreme side. Any spot fires will spread rapidly. Suppression efforts at the head of the fire, without existing control lines, will be ineffective. Flame lengths will generally exceed 14 feet; 671 to 1,050 Btu's.

Figure 2—*Description of fire severity levels and corresponding fire behavior.*

ity 29 percent (point score 5). The implication here is not that the fire will behave identically no matter how the score of 10 is derived, but that control will be possible with the same forces and that approximately the same percentage of the area will burn.

Limitations

The matrix uses eight fixed and five variable indicators. The point

Severity points	Indicators												
	Fixed								Variable				
	Average fuel depth (feet)	Continuity of fuel (percent of cover)	Dead fuel (percent of total)	Live fuel moisture (percent)	Slope (percent)	Aspect	Season	Model (SCAL)	Dead fuel moisture 10 hour stick (percent)	Relative humidity (percent)	Wind speed (mid-flame mi/h)	Temperature (° F)	Time of day (hours)
1	1	20	15	90	0	N	Spring		15	60	0	20	1900
	2						April 15-30.						
2		30	20	80	10		May	G	12	45	2	45	
					15		Late spring						
							Early summer						900
3	3	40	30	76	25	NE	June. July		10	35	4	59	1800
4	4	41	31	75	30	E	Winter		9	34	5	60	
							Jan., Feb.						1000
5	5	55	40	65	35	SE/NW		B	7	29	6	70	1700
					40		Early spring						
							March,						
6		70	45	60	50	W	April 1-14		6	25	8	80	1600
7	6	71	46	59	55	SW	Early winter		5	24	9	81	1500
							Dec.						1100
8		80	55	50	60		Summer	C	4	19	10	89	1400
							Aug. Sept.						
	7				65		Fall				11		1300
	8						Oct., Nov.						
	9	90	65	45	70	S			3	15	15	95	
9	10												1200

To find severity level, follow indicator column down to appropriate figure and then left to severity points. Total points for level of severity. Use one half points as needed.

Figure 3—*A fire prescription matrix.*

score assigned to an indicator is, of course, the aspect of the matrix that will prove or disprove the validity of this approach. Fire-behavior determinants produce effects that are notoriously nonlinear. For example, according to the Fireline Handbook (*3*) rate of spread doubles when dead fuel moisture drops from 15 to 10 percent, but it triples between 10 and 5 percent. Fuel depths appear to have an essentially arithmetic relation to intensities up to a certain point, after which effect is much less.[1] It is worth noting also that even the most sophisticated fire behavior models do not always agree with observed fire behavior (*3*).

The point values given in figure 3 represent a working compromise between fire behavior models available and experience of both researchers and fire managers. We anticipate many changes as the matrix approach is refined. Currently, we are doing chaparral burning with matrix prescriptions in the 41 to 78 range. Generally, prescribed fires have behaved in the manner predicted by the severity level score. However, the matrix underpredicts somewhat for windspeed and when chamise (*Adenostoma fasciculatum*) predominates on a site.

[1] Jack Cohen, Research Forester, U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. Personal communication.

Summary

This matrix has been adopted by the San Bernardino National Forest. It is an attempt to increase the flexibility of prescribed fire managers without sacrificing safety. Modifications of the point scoring system will occur as more information becomes available.

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BEHAVE and YOU Can Predict Fire Behavior

Richard C. Rothermel

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Can wildland fire behavior really be predicted? That depends on how accurate you expect the answer to be. The minute-by-minute movement of a fire will probably never be predictable—certainly not when predictions are based on weather conditions forecasted many hours before the fire. Nevertheless, practice and experienced judgment in assessing the fire environment, coupled with a systematic method of calculating fire behavior, yields surprisingly good results. This paper describes a fire behavior prediction and fuel modeling system called BEHAVE that provides the systematic method while YOU, the fire manager, provide the experience.

What BEHAVE Is

BEHAVE is a system of interactive computer programs designed to predict or estimate fire behavior characteristics needed for many fire management purposes (*4*). It has been designed to be user-friendly so that operation requires no previous knowledge of computer oprations. It is designed for use by fire managers who are familiar with fuels, weather, fire situations, and the associated terminology. People who have been using the Texas Instruments TI-59 with a fire behavior CROM (Custom Read Only Memory) have said that BEHAVE is much easier to use. BEHAVE does not require a data base; it is designed to utilize a minimum amount of site-specific input for describing the fuels, the environment, and the fire situation. Such data can readily be drawn from observations and experience.

What BEHAVE Will Do

BEHAVE will estimate fire spread rate and intensity, then interpret its estimate to predict probable flame length, containment time, and final fire size. It will also estimate maximum probable spotting distance and other details about the fire, such as the probable spread direction due to a wind blowing cross-slope.

To do this requires a great deal of internal interpretation by the program about fuels, weather, time, overstory, fuel moisture, and position of fire on a slope. BEHAVE features a method to aid in development of site-specific fuel models from a few field observations. It also incorporates the Canadian method for calculating fine fuel moisture, with additions to account for solar drying of fuels and changes in fuel moisture throughout the day/night cycle.

The site-specific or custom fuel models developed by BEHAVE can be either static or dynamic; the latter includes the effect of curing of herbaceous fuels similar to the NFDRS models (*7*). If a custom fuel model is not needed, the same set of 13 standard fuel models used with nomograms or TI-59 is available (*1*, *2*). The performance of the new fuel model can be examined in tabular or graphic form and compared with any of the 13 standard fuel models. If the new fuel model does not respond correctly, it may be changed and retested until the user is satisfied that it matches the behavior of fire in these fuels.

The originator may save the new custom fuel model for future use in BEHAVE or offer it to others. Instructions are also given for using your new fuel model with the TI-59 calculator equipped with a fire behavior CROM.

Two types of prediction are possible. The first type is designed to aid in operational planning. Combinations of input variables may be specified and used to examine their effects on fire behavior. For instance, input variables like "the fine fuel moisture varies between 5 and 10 percent" and "the wind varies between 2 and 12 mi/h," and BEHAVE prints tables of corresponding fire behavior predictions. The second type of prediction is site specific. It requires a larger number of input variables and provides several models within the program to aid the user in estimating fine fuel moisture, mid-flame windspeed, and slope. Outputs are specific for the site described.

Outputs available from BEHAVE are:

- Rate of fire spread (chains/h)
- Flame length (ft)
- Fireline intensity (Btu/ft/sec)
- Heat per unit area (Btu/ft^2)
- Reaction intensity (Btu/ft^2/min)
- Effective windspeed (mi/h)
- Direction of maximum spread (degrees)
- Area (acres)
- Perimeter (chains)
- Length-to-width ratio
- Forward fire spread distance (chains)
- Containment time (h)
- Length of line (final perimeter) (chains)
- Required line construction rate (chains/h)
- Final area (acres)
- Maximum spotting distance (mi)

Where BEHAVE Applies

BEHAVE is not designed to rate the fire danger over large areas on a day-to-day basis. That is the province of the National Fire Danger Rating System. The site-specific features of BEHAVE make it better suited to smaller areas. The size is set by how well the fuels, topography, and weather are known. It may be as large as a drainage or as small as an experimental plot.

The Basis of BEHAVE

BEHAVE incorporates state-of-the-art mathematical models developed for predicting fire behavior and organizing the necessary fuel and environmental factors. BEHAVE has evolved over several years in conjunction with the material developed for training fire behavior officers (course S-590) at the National Advanced Resources Technology Center in Marana, Ariz. The S-590 course progressed from using nomograms in 1976 to use of the TI-59 calculator in 1980. BEHAVE was designed to utilize those same predictive techniques and also those models that cannot be run without a high-speed computer. Complete instructions will be available when the BEHAVE users' manual by Andrews, Burgan, and Rothermel is completed.

Limitations

The fire model used in BEHAVE is primarily intended to describe steady-state fires advancing along a front. The model was designed for fires in uniform continuous surface fuels within 6 feet of the ground and contiguous with the ground. Typical of such fuels are grasses, litter, shrubs, dead and down limbwood, and logging slash. The prediction methods in BEHAVE do not apply to smoldering combustion such as occurs in tightly packed litter.

Severe fire behavior such as crowning, spotting, and fire whirls is not predicted by the fire model. Nevertheless, the onset of severe fire behavior can be inferred from the fireline intensity of the surface fire and the character of the overstory. BEHAVE does have the capability of calculating the maximum probable spotting distance from torching trees or burning piles of wood. A method for predicting the maximum probable spotting distance from running surface fires will be added later.

The outputs produced by BEHAVE describe the behavior at the head of the fire, where the fine fuels are assumed to carry the fire. Backing fire or flanking fire on slopes and in crosswinds can also be described with models not previously available. The burnout of fuels, usually large fuels and tightly packed litter, behind the fire front is being studied and will be included in the system later.

It is assumed that the fire has spread far enough so that it is no longer affected by the source of ignition. Therefore, the system is of limited use in predicting behavior of prescribed fires, where the pattern of ignition is often used to control fire behavior. Nevertheless, the predictions have been found to be useful in planning prescribed fires by assessing the free-spreading fire potential both inside and outside of the proposed burn area.

How BEHAVE Has Been Tested

Testing has been conducted on internal models and on the system as a whole. Andrews (*3*) compiled the results of several tests on the fire model. Norum (*9*) tested the spread prediction system as packaged for fire behavior officers. Simard and Main (*12*) have tested methods that support adoption of the Canadian method for predicting fuel moisture in fine fuels.

Rothermel and Rinehart (*11*) have prepared guidelines for use by field practitioners for testing and analyzing fire behavior data. These data may be used to test predictions made with nomograms, the TI-59, or BEHAVE.

To be accepted by the Forest Service Computer Systems Coordinating Council, a new system must undergo a prescribed order of tests. Accordingly, BEHAVE was tested by 29 users from various agencies, States, and universities during the summer of 1982. Feedback from the development test has resulted in changes to BEHAVE (*5*). A pilot test was conducted during the summer of 1983 by all Forest Service regions except region 10, by the National Park Service, Bureau of Indian Affairs, Bureau of Land Management, three agencies of the U.S. Department of the Interior, and six States. The pilot test examined the performance of BEHAVE in operational situations and the problems of installing it on other computers. Deficiencies found during the pilot test are being corrected before it is released for field use. Assuming acceptance with minor revisions, BEHAVE should be operational by the summer of 1984.

Applications

BEHAVE is a general purpose program that may be utilized whenever an assessment of fire potential is needed. During development tests, fire specialists and fuels specialists have found it easy to use and especially helpful for preparing operational guidelines for initial attack and prescribed fire plans tailored to their local fuel and weather conditions. This type of operational planning for both wildfire and prescribed fire is expected to be a major use of BEHAVE. Since 1976, the methods available in BEHAVE have been adapted for many purposes. A brief explanation of some of the applications may be helpful.

Large Fires. BEHAVE can be used to assess fire behavior for the immediate future or to plan the next day's activities on a fire that has escaped initial attack. The procedure is described in the section titled "The Fire Prediction Process" of Rothermel's (*10*) fire prediction manual.

Dispatch. BEHAVE offers a dispatching option for estimating fire size and containment time. We do not expect our program to meet the needs of all dispatching offices. The source and amount of information on fuels, topography, weather, and fire starts varies among dispatching organizations. We do believe, however, that the routines required for assessing initial fires and expected fire behavior are available in BEHAVE.

Prescribed Fire. BEHAVE can be used to define a range of acceptable burning conditions for prescribed fires and for assessing fuel and weather conditions as burn time approaches. It may be used to estimate the behavior of a potential escaped fire in contingency plans. Care must be used in estimating fire behavior within the burn area. The system was designed to describe the behavior of a line of fire free of influences from the drafts of other fires. Many prescribed fires are ignited in patterns intended to control the behavior. Ring firing, center firing, mass firing, or strip head fires with controlled spacing are examples. Fires conducted for vegetation manipulation or site treatment may require burning prescriptions based on factors that are not yet predictable, such as scorch height on steep slopes or expected mortality of shrubs and trees. Experience with and calibration of the predictions with observed effects in specific fuel types can overcome some obstacles.

Planning. BEHAVE is not designed for long-range fire planning, but was found during the development test to be useful for operational fire planning.

The capability of building and storing fuel models tailored for an area will allow a manager to assess what is likely to happen under various environmental conditions. The effect upon fire behavior due to planned fuel treatments can be assessed by adjusting the fuel model to simulate the proposed treatment. For this purpose it is not necessary to go through an elaborate determination of fuel moisture, wind, and slope. The manager can specify a range of these values that are typical for the area and BEHAVE will produce tables of expected fire conditions.

Monitoring Fires. BEHAVE, in conjunction with a fire behavior officer's (FBO) procedures, is especially well suited for monitoring and predicting the behavior of fires resulting from unplanned ignitions that meet an approved prescription and, therefore, do not require immediate suppression action. Experience on the Independence fire in Idaho in 1979 demonstrated the usefulness of anticipating the day-by-day movement of a large fire burning under prescription conditions for several weeks in rugged mountain country. The Forest Service categorizes these fires in planned areas as a prescribed fire from an unplanned ignition. Most agencies permit such fires to burn, providing all fire behavior variables remain within the prescription developed in an approved plan. Prescribed fires in this category come closest to matching a wildfire situation. Control activities, if any, are usually confined to protecting boundaries or improvements. Additional ignitions are usually not made. Because these fires may span several burning periods, they offer excellent opportunities for both predicting fire behavior and verifying the prediction methods.

Training. BEHAVE should be very helpful for teaching the interactions between fuels, weather, topography, and fire behavior at all levels of training. It should be especially helpful for studying the effect of fuel composition on fire behavior. One of the programs in BEHAVE produces graphs illustrating the effect of input variables upon the behavior of the fire.

How BEHAVE Is Accessed

During the pilot tests, BEHAVE has been installed on several computers, Fort Collins Computer Center, two minicomputers at the forest level, one minicomputer in Region 5 South Zone, and at one university. Access was limited during the pilot test. For operational use within the Forest Service, we expect to use FLIPS (Forest Level Information Processing System), a system of interconnected minicomputers. We are working with other Federal agencies and States to make it available on their computers. The BEHAVE programs are written in ANSI X3.9 FORTRAN and are quite large. (The largest program is 240K bytes.)

Conclusion

BEHAVE is no substitute for experience, but by coupling experience with a systematic prediction method, BEHAVE will benefit the effective implementation of new concepts in fire management. The Aviation and Fire Management staff in the USDA Forest Service Washington, D.C. office is responsible for implementing BEHAVE. Questions regarding access and training should be directed to that office.

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NIIMS Simplified: The Texas Perspective

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The Texas Forest Service (TFS) provides intensive fire protection to 22.4 million acres of land in east Texas. This job is accomplished by a relatively small organization with limited resources and flexibility. The TFS relies heavily and formally upon local cooperators when fire business is above normal.

To meet the operational challenge of protecting such a large area with limited people, equipment, and funding, the TFS has evolved a fire management system based on the following elements: personnel, including recruitment, training, and certification; a concept of operations; readiness and hazard rating; detection, alarm, and reporting; communications and dispatching; and equipment.

All of these elements are essential to successful rural fire management. Personnel and equipment are operationally inseparable and demand most of the fire budget. So, the efficient and economical management of operations, readiness, detection, and communications is crucial to rural fire agencies in these times of tight budgets.

The TFS system borrows heavily from and closely resembles the National Interagency Incident Management System (NIIMS). The NIIMS concept has been largely promoted as a disaster-response mechanism. However, it offers its principal benefits for day-to-day fire operations, particularly in States where major fire disasters are rare.

Like NIIMS, the TFS system provides for an orderly buildup in phases as the fire problem builds in complexity. However, local fire management terminology has been retained by the TFS. Adoption of NIIMS terminology is being studied.

The TFS system assumes that the initial attack will eventually fail. At that point, the suppression effort must be reorganized, and forces must be increased within a set of priorities. The TFS system bridges the gap between failure of the initial attack and the ponderous, historic reaction to a full-blown disaster.

The TFS system recognizes five operational phases from "normal" through "IV." Conditions for each phase are identified and operational requirements are prescribed in the chart.

The TFS training scheme is composed of three levels of training; each requires 30 hours of classroom instruction and successful completion of a fire simulator test problem. The basic fire training course concentrates on normal containment situations and phase I fires when initial attack has failed. The intermediate level emphasizes concepts and techniques needed on phase II fires. The subjects of the TFS's advanced fire training are extended attack situations in phase III fires and multi-agency command incidents in phase IV fires.

Much of the classroom work is devoted to case studies of specific Texas fires. Trainees are taught to recognize the conditions and requirements for making the transition from lower to more complex operational phases.

Once line and fire staff officers met and agreed upon the basic TFS concept, the fire control training committee developed training materials and curriculum and trained Texas field personnel. The TFS is now training forest industry cooperators and will eventually train key volunteer fire departments.

Most managers of rural fire protection programs must concern themselves with protecting large areas with limited resources in these times of tight budgets. We believe that the TFS version of NIIMS enhances TFS's ability to work with cooperators in a more professional way and provides better rural fire protection in Texas.

The Texas Forest Service Fire Management System

Fire phase	Strategic position	Conditions	Operational requirements
Normal	Offensive	• Aggressive, close-up attack • Fire is small, two-dimensional • One or two firecrews involved • Three firefighting objectives met at once: life and safety; containment; final suppression.	• Fire boss is first firefighter (technician) responding • Usual for containment: attack head; establish line, backfire • Quick mop-up, reposition
I	Offensive	• Initial attack fails and several other attempts fail • Fire is more intense • One to five crews involved • Span-of-control (management of firefighters) running smoothly • Emphasis on containment • Most of firecrews on head, some on flanks, but all working on fire • Fire boss assessment: rapid control seems possible	• Fire boss is first firefighter (technician) responding • Fire boss formally declares fire phase I to crews on fire and dispatcher in area office • Usual for containment: attack head; establish double line, backfire • Observers in plane overhead desirable but optional
II	Offensive/defensive	• Fire is uncontained, free-burning • Fuels/weather the same or worse • Five or more crews available or dispatched (including cooperators) • Fire behavior erratic: may be crowning • Change in span-of-control: fire boss does not know where the head of fire is, or where the firecrews are • Fire boss assessment: considering elapsed time between first attack and the failure to contain fire, strategy should change	• Fire boss is a first-line supervisor (district technician) or above • Fire boss formally declares fire phase II to crews on fire and dispatcher in area office • Modification to original plans • Designation of sectors: division of fire perimeter: assign sector boss(es) crews • Observer in plane overhead required
III	Defensive/offensive	• Fire is larger, complex • Fuels/weather the same or worse • Uncontained second day after ignition (second-period fire) • Fire is being managed by a single jurisdiction • Span-of-control is stabilized and holding, waiting for additional resources to arrive	• Fire boss is a middle manager (administrative officer, district forester) or above • Fire boss formally declares fire phase III to crews on fire and dispatcher in area office • Organization becomes more formal • Fire boss establishes headquarters/command post • Divisions are established • Larger support staff and more resources are required • Fire cache and communications van used • Large Fire Frequency used for radio communication
IV	Defensive	• Fire is large, complex, uncontained • Fuels/weather the same or worse • Fire is being managed by more than one jurisdiction—more than one agency involved • Fire poses grave threat to lives, property, resources, all-out disaster	• Fire is managed by multi-agency command team • Fire boss is an area forester or above • Fire boss formally declares fire phase IV to crews on fire, dispatcher in area office, agencies involved • Organization is highly complex • Specific headquarters are set up • TFS overhead fire team • Fire cache and communications van used • Large Fire Frequency used for radio communication ■

Update: USDA Forest Service Fire Reports

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Did you know that at one point up to 700 entries were possible on the USDA Forest Service fire report, and almost two-thirds of the items on the current form date back to the 1920's or earlier? If you've ever filled out a Forest Service Individual Fire Report, you've probably thought about the reporting process—the length of time it requires, how good the information is, who uses the data, and the like. You also probably came up with some good ideas for changing the reporting system to make it easier to use.

We conducted two studies to trace the history and describe the current status of Forest Service wildfire reporting. The results of these studies should aid those responsible for making changes in the Forest Service wildfire reporting system in the future.

What We Found in the First Study

From looking at Forest Service fire reports issued each decade since 1905, we learned that the content and design of the current Individual Fire Report, Form 5100-29, are based largely on historical precedent. More than half of the items have been reported continuously for 60 years or more, and nearly all of the remaining have been on Forest Service fire reports for 20 to 40 years. Only two items are unique to the current form—watershed number and value class at origin.

Because fire control and fire prevention planning in the Forest Service is based in part on fire report information, reliable data from the 5100-29's are essential. Managers often question the reliability of fire report information, however, indicating a lack of confidence in some of the report entries and resulting data summaries (*1*, *2*, *3*).

We surveyed people who fill out the 5100-29's on 62 ranger districts in region 9 and found that most of them had much confidence in the accuracy of their fire report entries. They considered data reported on equipment/personnel, fuel/site descriptions, and fire times the most reliable; but expressed less certainty in data entries for acreage/timber destroyed, fire danger/weather, value of resources damaged or destroyed, and fire causes.

In this survey, we also found that:

- reports were usually ready for an approving officer's signature within a day or two after the fire;
- the total time spent investigating a fire cause, collecting information, and filling out the form ranged from 30 minutes to 26 hours, with a median time of 3 hours; and
- nearly half of the reports had coding errors that escaped detection. These errors were concentrated mostly in the areas of fire times and cover and fuel types—areas in which the information was considered highly reliable.

In another part of this study, we learned that people with fire-reporting responsibilities generally have a variety of attitudes and opinions about the 5100-29 that may affect the quality of fire report information. For instance, more than half of those interviewed had a positive attitude toward the form because it supplied valuable data and was simpler to complete than the form it replaced. Most of the people felt the 5100-29 had a useful purpose—to supply information that would aid managers at various administrative levels and also to facilitate research, fire planning, fire prevention, and historical data analysis. Even though they felt that the 5100-29's were important, however, they didn't use much of the information at the ranger district level. A few of the items were used primarily to determine fire occurrence patterns and as an aid to fire planning and fire prevention. They were used less often as input into law enforcement analyses and court cases and in fire-danger assessment.

One-fourth of the people we interviewed were dissatisfied with the 5100-29 for the following reasons, listed in descending order of importance. First, it requires a great deal of time and effort to complete; second, it contains ambiguous and useless items; third, the format and coding are complicated and confusing; fourth, the form design impairs readability; and, finally, some fire report entries are inaccurate because it's difficult to reduce complex events into simple codes.

Those involved directly with fire reporting are in an excellent position to identify problems with the wildfire report and to recommend changes. Of the 87 percent who said the 5100–29 needed improvement, most suggested revisions in form content and design. Some of the specific changes they suggested include the following:

- Reducing the number of items reported for Class A and B fires.
- Consolidating fire causes and redesigning them to reflect actual field situations.
- Incorporating degrees of certainty with difficult-to-measure variables such as fire cause.
- Consolidating the most important information in one area on the form.
- Redesigning the form for easy typing—the report should be on one side only, with proper spacing, item sequencing, and directions that eliminate the use of a template.

Because many people were dissatisfied with the Forest Service fire-cause classification system, we conducted a second study to identify problems with the system due to its historical development and to suggest some alternatives.

What We Found in the Second Study

The current Forest Service fire report contains four cause-related items (statistical cause, general cause, specific cause, and class of people) that evolved, with very few changes, from the reporting system implemented in 1905. Although this lack of change has ensured consistent fire report data, it has also perpetuated a major problem of overlapping and repetitious fire-cause categories.

Because the categories are not mutually exclusive, people can classify a particular wildfire cause in a number of different ways, all of which could be correct. For instance, a dump fire set by an unidentified person is reported in region 9 using seven different cause and class-of-people combinations (table 1). Part of this problem is due to statistical and general causes that include categories of people (such as children, resident), activities involving intentional fire use (such as debris-burning, incendiarism), and recreation or work-related activities accidentally causing wildfires (such as timber harvest, hunting). Class-of-people categories, also not mutually exclusive, add to this problem.

The broad and repetitious nature of fire-cause categories compounds the problem of overlapping ones. A classic example of this problem is the use of "Miscellaneous-Other-Other-Other" to describe a known fire cause. With such a system, information about the fire cause that may be essential to a fire prevention program is either submerged in these broad, repetitious categories or not reported at all.

The lack of adequate methods for indicating the reliability of

Table 1—*Classifications of dump fires used in region 9*

Statistical cause	General cause	Specific cause	Class-of-people
1. Incendiary	Incendiary	Burning dump	Local permanent
2. Incendiary	Incendiary	Grudge	Local permanent
3. Debris burn	Other	Trash burning	Visitor
4. Debris burn	Resident	Burning dump	Local permanent
5. Debris burn	Incendiary	Trash burning	Local permanent
6. Debris burn	Other	Burning dump	Local permanent
7. Miscellaneous	Resident	Burning dump	Local permanent

fire-cause data is another major reporting problem (*2*). With no "unknown" category available, an unknown cause is typically classified as a smoking, incendiary, or miscellaneous wildfire. Because reporters cannot indicate the reliability of fire causes (both known and unknown causes are given equal weight), the accuracy of the data is often questionable. Such data may lead to erroneous assumptions about fire prevention problems.

Two possible remedies would be to modify the current system or adopt a completely new one. The first alternative would ensure historical data compatibility. With a few improvements (such as including "certainty of cause" categories, expanding categories, analyzing and standardizing reporting procedures for a given fire cause), some of the problems discussed earlier could be eliminated and data reliability could be increased. The second alternative, adopting a new reporting system, may also be beneficial. One method, called the "Building Block" system, was recently proposed by State and Federal land managers.

No fire-cause reporting system will ever be perfect. But when deciding which system to use, fire managers must consider the information they need, the level of resolution they desire, and the degree of error they are willing to accept. These factors must also be weighed with the current drive to adopt a standardized State and Federal fire-cause reporting system and with the desire to maintain historical data compatibility.

For complete analyses of the studies mentioned here, consult Linda R. Donoghue's "The History and Reliability of the USDA Forest Service Wildfire Report," Research Paper NC-226; and "Classifying Wildfire Causes in the USDA Forest Service: Problems and Alternatives," Research Note NC-280. Both are available from the North Central Forest Experiment Station—1992 Folwell Avenue, St. Paul, MN 55108.

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Radios and Data Transmission: Computers in the Field

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In the past 10 years, several computer data systems have been developed to support fire suppression efforts. In order to take full advantage of these computer-based systems, portable computers and portable terminals are needed in the field. Recognizing the need for portable equipment and the potential benefits to improved fire-base communications, the USDA Forest Service Electronics Center investigated the feasibility of using radio and radio-telephone circuits with portable computer equipment.

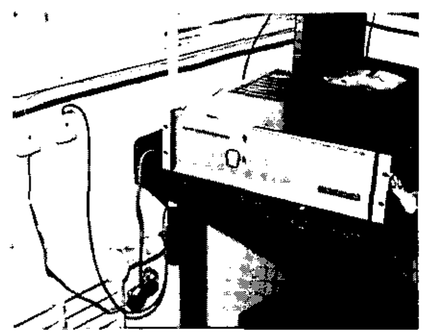
Several problems in using radio and radio-telephone circuits were addressed in the Electronics Center's investigation:

- Crowded radio frequencies often have little extra air time for increased traffic.
- The unavailability of additional very high frequency (VHF) and ultra-high (UHF) radio frequencies that can be reserved for fire cache type use.
- The limited or complete lack of telephone service in many areas where fire camps are established.
- The continuing need for a hard copy record of the information that has been transmitted and received.

Two test projects were undertaken at the Electronics Center. The first project was to study the problems associated with transmitting American Standard Code for Information Interchange (ASCII) coded data between standard computer terminals over standard Forest Service radio circuits. The second project was to study the problems associated with transmitting the same type of data through telephone facilities using full duplex UHF radio circuits. Both projects considered only portable type equipment.

The approach was first to establish general requirements, and then to review the marketplace for commercial equipment. Nothing was found commercially available for the first project, although several manufacturers were conducting similar tests and several wanted to design, test, and build to written specifications. The second project was easier. There were several manufacturers producing rural telephone systems. This allowed for the purchase of a UHF full duplex radio system with automatic telephone interface to support the tests.

UHF radio-telephone system: 12V remote unit with phone.



UHF radio-telephone system: telephone line interface unit.

Data Transmitted via VHF Radio

The first project, computer terminals and Forest Service radios, involved designing, building, and testing two interface/control boxes and modifying two old 300-bits-per-second (bps) commercial modems. Special adapter cables to interconnect the various pieces of equipment were also prepared. The heart of the system is a relatively simple interface/control box. It matches the radio receiver output and the transmitter input to the modem. It senses when the computer terminal operator presses a key and automatically switches everything to transmit condition. It switches the modem between originate and answer modes. It sets a timer to hold the system in transmit for 7 to 10 seconds following the last keystroke, and it automatically switches back to a receive condition.

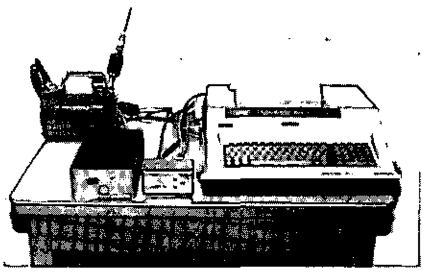
The equipment required at each end of the circuit includes a standard ASCII/teletype (TTY) computer terminal, a portable packset radio (A Motorola PT300 was used in this test), an interface/control box, a 300-bps modem with originate/answer, and interface cables. The terminal and modem used for the tests required 110 volts AC power; however, battery-powered equipment is available. The radio and interface/control box had self-contained battery power. Installation and setup requires that the radio be located at least 10 feet from the other equipment to minimize radiofrequency (RF) radiation on the modem.

Operation requires "keying" in at least two carriage returns and one line feed on the terminal to give the equipment time to switch to a transmit condition and set the receiving equipment at the start of a new line. The desired message may then be typed. When the transmission is complete or the operator stops keying data for 7 to 10 seconds, the equipment will automatically switch back to receive. Operation of the remote unit is conducted in the same manner. Tests using Execuport 300 terminals and both point-to-point and repeater radio circuits were conducted. The transmission speed was 300 bps. Signal-to-noise measurements of weak signal capabilities were surprising in that errors were not observed until a substantial noise level was introduced (0.3 microvolts (uv) signal into a receiver requiring 0.4 uv for 20 decibel (dB) quieting). While it is hard to estimate actual transmission range because of varying terrain, elevation, and other on-site factors, it is felt that low-speed (300 bps) data transmission can be effective over any VHF circuit capable of reasonably good voice quality. The only problem noted was that the receiver squelch burst at the end of each transmission caused the terminal to print a few unwanted characters. This can probably be corrected with new modems or tone-controlled squelch.

Data Transmission via UHF Radio-Telephone

The second project, the UHF full duplex radio-telephone circuit, involved testing various configurations of existing computer terminal and radio equipment through both good and poor telephone circuits. The tests used both the Texas Instruments Silent 700 and the Execuport 300 terminals with built-in modems and a standard telephone set connected to the radio. The transmission speed was 300 bps.

The radio equipment manufacturer designed and adjusted the receiver squelch and control circuits to react only to both a specific tone and a high quality signal (0.8 uv signal providing full intermediate frequency (IF) limiting).



VHF radio-data system. (Control box in center of photo.)

The system proved it was capable of providing error-free data transmission during poor signal conditions. It was found that as long as the system could hold the telephone line open, accurate data transmission was possible. It is recognized that data transmissions could be made with weaker signals but, in the interest of accuracy both in dialing and in transmission of data to a computer, it is felt that the built-in strong signal safeguard is warranted. These tests indicate that the system, as set by the factory, is designed to prevent dial tone to the user unless the signal is strong enough to guarantee error-free touch-tone dialing. This provides a reasonable guarantee that there will be error-free data transmission over the radio portion of the circuit. Additional tests indicate that matching the interconnection between radio equipment and telephone lines is not particularly critical. One of the local telephone circuits used in the tests is similar to the long-haul rural lines often encountered in operational systems. The other circuit used was a "tuned" data line. The system functioned well on both lines with no adjustments.

Conclusion

Both projects provided the center with enough positive results to warrant their being considered for actual operational tests. The UHF radio-telephone data system could be implemented in a fire cache-type operation; with a minimum of packaging design. The VHF radio data system would require replacement of modems with current market models and a new housing to hold both modem and interface/control board circuits. At this time, the UHF system is being prepared for operational tests controlled out of the Boise Interagency Fire Center (BIFC), and the VHF system is getting modem and housing changes. ■

Producing a Prescribed Crown Fire in a Subalpine Forest with an Aerial Drip Torch

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Although prescribed burning is recognized as an important tool in the management of forested stands (*5*), there are few documented prescribed burns on which to base management decisions or strategies (*10*). This paper describes a prescribed crown fire that was ignited using a Simplex helitorch. It describes the justification for burning, the fuel, the weather and site conditions before burning, the burning prescription, the ignition pattern, and the effects of burning using the Canadian Forest Fire Weather Index (*9, 11*).

The techniques and procedures used in developing a fire prescription are adequately discussed by Martin and Dell (*6*). Generally, given specific management objectives for an area, a fire boss considers how weather parameters affecting fire behavior can be combined with various fuel conditions and the existing topography to produce desired results. Also, it is generally accepted that ignition procedures may, at times, compensate for slight variations in fuel and weather conditions that are not "within prescription" (*6*). For example, a fire boss may reduce the distance between strips when igniting a strip head fire if the actual windspeed is a little higher than prescribed. Another general approach in developing a prescribed fire plan is to consider how a fire will behave as it progresses from a surface fire to a ground or crown fire (usually the litter fuels are ignited first). Considering fire behavior as it proceeds is done even if the unit is to be ignited from the air.

The Area and Objectives

The Ram Mountain study area, the site of the burn, is located on the east side of the Rocky Mountains approximately 60 kilometers (37 mi) west of Rocky Mountain House, Alberta (latitude 52°22'N, longitude 115°48'N). This area supports a resident population of about 100 Rocky Mountain bighorn sheep (*Ovis canadenis*). The Alberta Department of Energy and Natural Resources, Fish and Wildlife Division, Wildlife Research Branch, believes tree invasion on these high elevation slopes may be limiting the size of the sheep population on this mountain. A prescribed burn was planned to increase the carrying capacity of this range for sheep. A high intensity crown fire was prescribed because the major goals were to kill the overstory tree cover without significantly affecting the shallow soil profiles. Soils on this site are primarily Brunisols on the downslope edge of the burn unit and Regosols towards the top. The organic profiles of litter, partially decayed litter, and humus is very shallow throughout most the burn unit. The specific burn objectives were the following:

- Eliminate 90 percent of the overstory spruce and fir canopy cover.
- Top kill 90 percent of the shrubs.
- Remove less than 40 percent of the duff layer.
- Expose less than 40 percent of the mineral soil.
- Reduce down-and-dead fuel loading by 80 percent for 1-hour time-lag fuels (fuels less than 0.635 cm (0.25 in) in diameter); 60 percent for 10-hour time-lag fuels (fuels 0.635 to 2.54 cm (0.25 to 1 in) in diameter); and 20 percent for 100-hour time-lag fuels (fuels 2.54 to 7.62 cm (1 to 3 in) in diameter).

Site Conditions, Strategy, and Methods

An 18-hectare (44-acre) stand of mature white spruce (*Picea glauca* (Moench) Voss) was selected for burning because conditions in this stand were representative of subalpine forest associations at this elevation on southwest facing slopes (table 1). Also, the area burned is bordered on the west, north, and east by rock-covered slopes at least 400 meters (1,312 ft) wide, reducing the costs involved in establishing a fireguard around the unit. Only 150 meters (493 ft) of handline needed to be constructed to tie into an existing riverbed 3 to 5 meters (9.8 to 16.4 ft) wide to

Table 1—*Conditions (pre- and postburn) of subalpine forest stands on Ram Mountain burn site*[1]

Fuel diameter class	Average fuel loading (t/ha)				Reduction
	Blowdown area		Undisturbed plots		
Cm	*Preburn*	*Postburn*	*Preburn*	*Postburn*	*Percent*
<0.64	.88	.07	1.18	.03	95
0.65–2.54	6.34	.40	4.89	.16	95
2.55–7.60	5.06	4.11	2.97	.63	47
>7.6 rotten	58.11	12.33	27.20	.93	86
>7.6 sound	51.39	6.87	12.88	14.04	61
Total	121.78	23.78	49.12	15.79	76.8

[1] Average fuel loading (t/ha) measurements were taken at six permanent sites in the blowdown area and nine permanent sites on undisturbed plots to insure that all slope positions were represented.

complete the fuelbreak. The slope of the unit averages 42 percent but ranges from 25 percent at the lower elevation (1740 m (5,708 ft)) to 55 percent at the highest elevation (1950 m (6,397 ft)).

The fuel loading, continuity, and condition varied significantly from the bottom to the top of the unit (table 2). Generally, the highest surface fuel loadings were found on the lower 40 percent of the unit where high-speed winds had blown over a large proportion of the trees. Surface fuel loadings were not considered adequate to sustain a crown fire throughout the other 60 percent of the unit because of the poor fuel continuity along the horizontal plane and the light down-and-dead fuel loadings. Down-and-dead ladder fuels were absent, but live tree crowns did extend almost to the ground on most stems.

In our opinion, a high-intensity crown fire could be achieved only if live tree crowns could be ignited without the aid of surface fuels. We hypothesized that upslope winds in combination with the steep terrain features of this site would produce a fast-spreading crown fire (table 3) that would not consume ground fuels, particularly if these layers were still wet (duff moisture content and drought code values less than 30) (*4*). The droughty conditions commonly found in the spring produce the desired conditions. At the time of burning, snow remained on sheltered sites and where drifting had occurred over the winter, although the burn unit was snow free. Fuel moisture samples were collected from the upper and lower slope positions at 1400 hours and 1650 hours on the day of the burn (May 30, 1983). The fuel moisture content of dead aerial fuels (greater than 2.5 cm (1 in) in diameter), live aerial needles (mature), and down-and-dead litter and duff (greater than 2.5 cm (1 in) in

Table 2—*Average down-and-dead fuel loadings before and after burning for the Ram Mountain prescribed burn site*

Variables	Prescription	Actual weather data	
		Baldy Lookout [1]	Baseline Lookout [2]
Weather			
Temperature (°C)	≥18	17	17
Relative humidity (%)	25-45	33	33
Ignition time (h)	1300-1800	1729	1729
Windspeed (km/h) & direction	≤18 SW	11 S–SE	11 S–SE
Season of burn	spring	spring	spring
Fire			
Fine fuel moisture code	≥85	90	91
Duff moisture code	≤30	28	31
Drought code	≤30	54	66
Initial spread index	≥10	10	12
Buildup index	—	28	31
Fire weather index	15-25	16	20

[1] Elevation is 2,025 m.
[2] Elevation is 1,890 m.

Table 3—*Prescribed and actual weather data (at 1700 h on 30 May 1983) for the Ram Mountain prescribed burn, as well as Canadian Forest Fire Weather Indices pertinent to the fire*

Conditions	Blowdown		Undisturbed plots	
	Preburn	*Postburn*	*Preburn*	*Postburn*
Basal area live stems (m ²/ha)	11.8	5.7	31.9	0.5
Snag density (stems/ha)	127	743	156	1772
Live tree density (stems/ha)	658	308	1101	46
Mean litter depth (cm)	2.27	.20	1.16	0.0
Mean duff depth (cm)	7.33	4.93	3.64	2.25
Shrub cover (percent) [2]	4.02	T [3]	3.24	T [3]
Rocky or mineral soil exposed (percent)	10.63	16.09	10.59	14.39

[1] Measurements were taken at six permanent sites in the blowdown area and nine permanent sites on undisturbed plots to insure that all slope positions were represented.

[2] A field survey 2 months after burning found shrubs are now resprouting.

[3] T = trace or < 1 percent.

depth) at the top of the unit was 11.9 percent, 92.4 percent, and 88.9 percent, respectively. At the bottom of the unit these values were 6.1 percent, 85.5 percent, and 34.1 percent, respectively. Fuel moisture contents were determined using a COMPU-TRAC fuel moisture meter (*8*).

Weather data collected at Baldy Lookout (elevation: 2025 m (6,643 ft)) 27 kilometers (16.75 mi) northwest of the burn site and Baseline Lookout (elevation: 1890 m (6,200 ft) 35 kilometers (21.75 mi) to the southeast were used to calculate the Canadian forest fire weather indices (*3*) required to validate the burning prescription. Onsite weather data were collected on the day of the burn. A Campbell Scientific Micrologger located 40 meters (131 ft) from the top edge of the burn unit recorded, calculated, and stored hourly averages of windspeed and direction from readings taken at 1-minute intervals. Temperature and relative humidity measurements were taken once every hour on the hour.

Down-and-dead roundwood fuels were inventoried at 15 permanently marked sites, which were systematically located throughout the burn unit so that all slope positions were represented. Fuels less than 7.6 centimeters (3 in) in diameter were inventoried along a 6-meter-long (20 ft) line by use of planar intersect procedures described by Brown (*1*) for natural fuelbeds. The 6-meter-long plane was extended to 9 meters (29 ft) for inventorying fuels greater than 7.6 centimeters (3 in) in diameter. Duff and litter depth measurements were taken at five predetermined locations along, but at least one-third of a meter (1 ft) from, the plane.

The basal area of live stems, snag density, live tree density, and the percentage canopy cover of shrubs was estimated from data collected in a circular plot with a 10-meter (32 ft) radius (.03 ha (0.07 acres)). The center of this circular plot was located at the midpoint of the 6-meter-long (20 ft) fuel plane.

The percentage cover of exposed rock and mineral soil was estimated for each of 20 subplots (one-third of a meter x one-third of a meter (1 ft x 1 ft) nested along the 6-meter-long (20 ft) fuel plane.

Aerial ignition was selected for safety reasons after considering the size of the burn area and its steepness. The Simplex helitorch was chosen because we wanted the ignition fuel to be intercepted by the tree crowns where it would stay and provide relatively long burnout time. We did not know how much heat or residence time (burnout time) would be required to ignite the tree crowns or the large-diameter, down-and-dead fuels in the blowdown area.

A strip head fire ignition pattern, starting at the top of the unit, was used to ignite the stand. Over 90 percent of the unit was ignited with a Simplex helitorch with a 33-imperial-gallon (150 liter) capacity, using a standard mixture of Alumagel (M-4 fuel thickener) and gasoline (approximately 3 kg (7 lbs) of M-4 thickener per 33 gallons of gasoline). The gel/gas mixture was applied at a speed of approximately 56 kilometers per hour (35 mi/h). Drop heights varied from 23 to 30 meters (75 to 100 ft) above the trees which were 9.1 to 18.3 meters (30 to 60 ft) tall. Distance between strips varied from 75 meters (246 ft) at the top of the unit to 125 meters (410 ft) at the base. The lower 10 percent of the unit was ignited using drip torches and fuses. These ignited strips followed the margin of the fuelbreak.

Results and Discussions

Ignition of the fuels in the unit began at 1729 hours after a delay of over 2 hours because of high downslope winds (greater than 30 km/h (19 mi/h)). The first strip of fire was laid across the top of the unit as a test of how the fire would behave. Trees ignited by the gel/gas mixture began to torch-out in approximately 15 to 20 seconds. Residence time for flaming combustion in individual tree crowns rarely exceeded 10 minutes. Flame lengths were estimated to be 1- to 1-1/2-times the height of individual trees (15 to 27 m (45 to 88 ft)).

It was obvious from both the ground and the air that surface burning did not significantly contribute to the crown fire behavior we observed. Fire brands that landed on the ground rarely spread because of the lack of continuity in litter fuels or the moisture content of the surface fuels. In the blowdown portion of the stand, it was obvious that significant burning (long flame lengths and residence times) was only occurring on or along the overturned stems. Fire spread was poor to nonexistent in the lower portions of the unit where fuses and drip torches had been used to ignite surface fuels. The ignition phase of the burn was completed by 1815 hours. Containment of the fire was not a problem and no suppression actions were required.

An immediate postburn survey (4 July 1983) suggested that specific burn objectives were met or exceeded. Over 90 percent of all trees within the unit were killed as a result of burning (table 1). Those not killed were located along the edge of the unit, particularly at the base of the slope where hand ignition methods were used. More importantly, almost all aerial fuels less than 1.3 centimeters (0.5 in) in diameter were consumed where crowning had occurred.

All shrubs were top killed in all but two plots (table 1). Generally, charred stems less than 5 centimeters (2 in) in height were the only evidence that shrubs once existed in plots that had experienced crowning. Live shrubs were only found in two plots where crowning had not occurred.

Duff depths were reduced an average of 33 percent on the blowdown area and 38 percent in the undisturbed plots (table 1). However, the amount of duff that remained was considered adequate to sustain plant growth and to protect the mineral soil from erosion. There was a 34-percent increase in the amount of rock or mineral soil area exposed after burning in disturbed portions of the unit; in undisturbed portions of the unit, the amount of rock or mineral soil exposed only increased by 26 percent. Yet, organic material still covered over 84 percent of the ground surface area.

Surface burning did occur and most of the down-and-dead roundwood fuels were consumed (table 2). Surface fuel reduction was highest in the blowdown area (80 percent reduction) largely because this portion of the unit had the greatest amount of available fuel. But fuel loadings were significantly reduced even in the undisturbed portion of the stand (68 percent reduction). Although the actual magnitude of the reduction was masked by the deposition of large diameter materials (greater than 7.6 cm (3 in) in diameter soundwood) which were deposited subsequent to burning (table 2). Generally, the effects of burning exceeded the goals established for reductions in surface fuels.

Management Implications

Crown fires can be prescribed even when surface fuel loadings are low and ground fuels are wet if the crowns of standing live trees are relatively dry and an aerial drip torch is used as an ignition source. In general, the principles of fire behavior normally applied to surface fuels are, in our case, applied to the aerial fuelbed because this is where most burning will occur under the conditions described in this report. The technique described is probably most applicable to subalpine areas or to dense conifer stands that support very little surface fuel loadings because of natural productivity of the site or the age of the stand or the tree density of the stand. The aerial ignition device also allows managers or scientists to burn in the winter when snow cover would prohibit fire spread in this surface or ground fuel zone.

It would appear that burning embers carried aloft in the convection column are not capable of igniting live tree crowns, although we did not test for this effect. The propagating heat flux intensity (*7*) is probably not high enough to initiate a fire in a tree crown where the moisture content is higher than 85 percent. If this assumption is true, then the presence of high winds need not prevent managers from burning. In fact, high wind conditions (greater than 20 km/h (12 mi/h)) may be prescribed to compensate for limitation in the horizontal continuity in the fuelbed. This technique is commonly used when burning low density grasslands. High windspeeds can significantly increase the fireline intensity (*2*), which, in turn, increases flame length and reduces the distance for radiative and convective heat transfer.

A Final Caution

Implementing the burning prescription described here, even if the stand, fuel, weather, and site conditions are identical to those described in this report, could be hazardous. The decision to burn or not to burn must be made by qualified fire management officers who have a good first-hand knowledge of fire behavior and fire effects.

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NIIMS Update

Training That Bridges the Gap

Course material to train personnel qualified under existing fire management systems for National Interagency Incident System (NIIMS) Incident Command System (ICS) has been developed by the National Wildfire Coordinating Group in cooperation with the Boise Interagency Fire Center and Firefighting Technologies Implementation Project. The packages, which include prework, instructor's guide, and exercises, will be available in the fall of 1983.

Basic Incident Command System (I-220)

Material for the entry level course for all managerial positions in the NIIMS Incident Command System (ICS I-220) is ready for transmittal to the National Audiovisual Center. The course material contains new visuals and a student workbook. I-220 should be available for agency purchases within the next few months.

Incident Command System Developmental Packages

Developmental training courses for the managerial positions in the NIIMS, Incident Command System (ICS), in operations, planning, and logistics are undergoing final review. These training packages to develop new personnel and to move people into higher level positions are being developed through a grant by the California Department of Forestry Training Center.

New Source for NIIMS-ICS Publications

The International Fire Service Training Association (IFSTA), a nonprofit organization dedicated to the purpose of service to firefighters, will be publishing and distributing several NIIMS-ICS documents.

- Operational Systems Description and Field Operations Guide in a single publication including a pocket-size Field Operations Guide. Estimated cost—$12.00.
- A packet of five pocket-size Field Operations Guides. Estimated cost—$10.00.
- Position descriptions by function for all positions within the Incident Command System: command, operations, planning, and logistics. No cost estimate available at this time.

For additional information write to: Customer Services, Fire Protection Publications, IFSTA Headquarters, Oklahoma State University, Stillwater, Okla. 74078.

Fireline Handbook

An effort is underway to update the Fireline Handbook (National Wildfire Coordinating Group Handbook 3) to include the material contained in the Fire Operation Guide (ICS 420-1). This material is currently being processed at the Boise Interagency Fire Center. An interagency team will soon be editing and formatting the material. This project should be completed by the spring of 1984.

NWCG Qualifications (Q) and Certification (C) Working Team

The National Wildfire Coordinating Group's Q & C Working Team is designing a guide of the various components of the Wildland Fire Qualifications System. This guide will address issues such as physical requirements, prerequisite training, management and skill positions, a flow chart for moving through the system, and a description of complexity levels. The target date for completing the guide is January 1, 1985.

NWCG Training Working Team

The National Wildfire Coordinating Group's Training Working Team has an active role in the development of training packages in support of the NIIMS-ICS, such as Basic ICS (I-220) Transition Training, instructor qualifications, and the development of a system for managing documents and publications.

Research News

Satellite Imagery Used To Map Forest Fuels

Two problems confront fire managers assessing the risk of fire over large geographic areas: How to gather data economically and how to obtain data detailed enough to be useful. Researchers at the U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, may have the answer—combining satellite imagery and digital terrain data to map forest vegetation types.

Results of a pilot study show that forest vegetation types can be mapped over large areas and interpreted locally as "fuels" by combining the two types of information. The mapping systems may substantially reduce costs over manual inventory methods.

Researchers used satellite data stored at the U.S. Department of the Interior, Geological Survey, and Earth Resources Observation System Data Center in South Dakota, a cooperator in the work. The digital terrain data came from the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, U.S. Coast and Geodetic Survey. Ground truth data points were established to teach the computer how to discern fuels from the satellite imagery and the terrain data. The new technique is being used by two agencies of the U.S. Department of the Interior—the National Park Service, Yosemite National Park; and the Bureau of Land Management, eastern Oregon and Alaska. Both agencies have adapted the mapping system for their own purposes.

The Intermountain Forest and Range Experiment Station has also published a guide for selecting fuel models for use in predicting fire behavior on specific sites where better delineation of fuels is required. Descriptions and colored photographs illustrate typical or "model" fuels. These fuel models are being used in training sessions for forestry professionals sponsored by the Interagency National Wildfire Coordinating Group.

Research Explains Odd Fire Pattern

Narrow strips of unburned tree crowns a mile long are sometimes left in the wake of crown fires on level terrain. Often, the trees in the strips are unburned, but the ground is black. Scientists at the North Central Forest Experiment Station of the USDA Forest Service theorize that air movement in "horizontal roll vortices" cause this pattern of burned and unburned vegetation.

Researchers believe the vortices are caused when rising gases along the perimeter of a fire meet the normal horizontal wind. This creates a wind shear that acts much like a dust devil on its side. The wind rolls forward in a spiral motion along the flanks of the fire, creating the odd pattern of unburned crowns. The theory was developed from observations of forest fires in Michigan and New Jersey, and from knowledge of fire patterns in other parts of the country.

By combining laboratory findings with data from actual fires, researchers hope to learn how to predict when vortices are likely to occur because they pose serious threats to the safety of firefighters. The research has applications throughout the eastern United States, southeastern Canada, Australia, and other areas where crown fires occur in relatively flat terrain.

Recent Fire Publications

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Seaver, David A.; Roussopoulos, Peter J.; Freeling, Anthony N. S. The escaped fire situation: A decision analysis approach. Res. Pap. RM-244. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1983. 12 p. ■

10 Standard Firefighting Orders

1. Keep informed on *fire weather* conditions and forecasts.
2. Know what your *fire* is *doing* at all times—observe personally, use scouts.
3. Base all actions on current and expected *behavior* of *fire*.
4. Have *escape routes* for everyone and make them known.
5. Post a *lookout* when there is possible danger.
6. Be *alert*, keep *calm*, *think* clearly, *act* decisively.
7. Maintain prompt *communications* with your firefighters, your boss, and adjoining forces.
8. Give clear *instructions* and be sure they are understood.
9. Maintain *control* of your personnel at all times.
10. Fight fire aggressively, but provide for *safety* first.

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