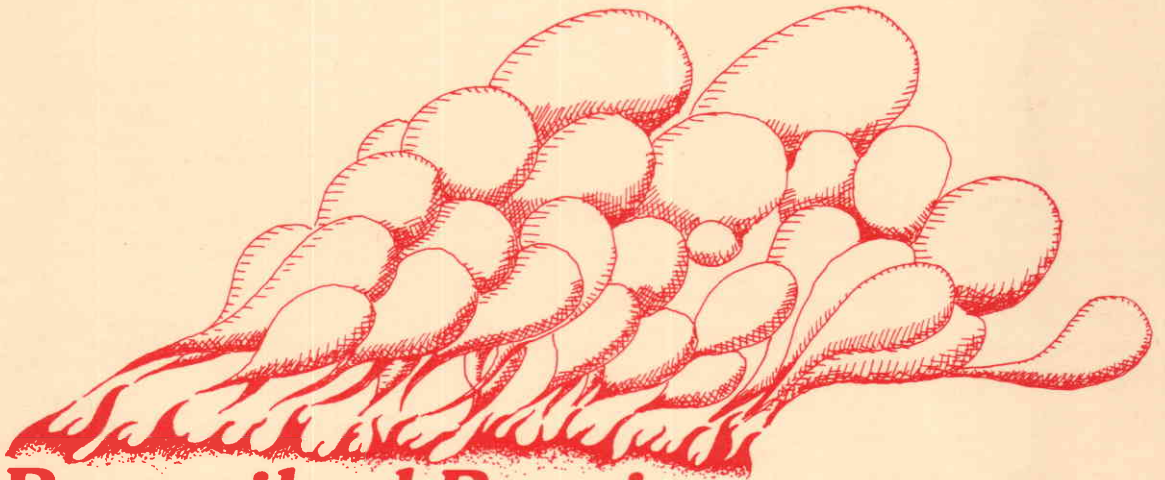


EDITOR'S
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Planning for **Prescribed Burning** in the Inland Northwest

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and
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PRESCRIBED BURNING. "Skillful application of fire to natural fuels under conditions of weather, fuel moisture, soil moisture, etc. that will allow confinement of the fire to a predetermined area and at the same time will produce the intensity of heat and rate of spread required to accomplish certain planned benefits to one or more objectives of silviculture, wildlife management, grazing, hazard reduction, etc. Its objective is to employ fire scientifically to realize maximum net benefits at minimum damage and acceptable cost" (Society of American Foresters 1958).

Successful prescribed burning depends on:

SKILLFUL APPLICATION of fire from a
CAREFUL PRESCRIPTION developed for a
DEFINITE AREA to accomplish
SPECIFIC OBJECTIVES.

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Foreword

We prepared this report to help managers and others understand the effects of fire and how to use fire in managing forests and rangelands. The literature cited in the fire effects section is limited for readability; however, we list many publications in the "Additional References" section for more information. Publications, such as "Environmental Effects of Forest Residues Management in the Pacific Northwest" (Cramer 1974) and "Fire and Ecosystems" (Kozlowski and Ahlgren 1974) have extensive literature citations.

The reader may wish to read about fire effects and potential uses of fire or to use it in planning a specific burn. The second and third sections deal with uses and effects. For planning purposes, the sections "Planning the Prescribed Burn" and "Sample Burning Situation" should be helpful.



Abstract

Fire has historically played a role in forests and ranges of the inland Northwest. This guide has been prepared to help managers understand the role of fire and the potential uses of fire and to plan for fire use in managing these lands. Sections deal with these topics, and steps in planning a prescribed burn are outlined. A sample burning situation illustrates the planning and execution of a prescribed burn. References are given to help the reader locate pertinent information.

KEYWORDS: Fire use, fire effects, fire planning, fire management, prescribed burning.



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Introduction

PURPOSE AND OBJECTIVES

The purpose of these guidelines is to aid forest and range managers in eastern Oregon and Washington to understand more completely the key elements of planning and using prescribed fire as a management tool. Specifically, these guidelines are designed to provide the land manager with:

1. Information on possible uses for prescribed fire.
2. Information on some basic effects and impacts of wildfire and prescribed fire on forest and range ecosystems.
3. A practical reference for planning and executing prescribed burning operations, including methods and techniques.
4. Guidelines for evaluating burns to determine effectiveness in meeting prescribed objectives and to gain information for future planning.

Information is presented on potential uses for prescribed burning in the inland Northwest, effects of fire, planning for prescribed burning, and prescription parameters. A sample burning situation and other aids to prescribed burning are at the end of the paper.

FIRE HISTORY AND ECOLOGY IN THE INLAND NORTHWEST

Fire is a natural force in the development of forest and range ecosystems. It has played an important role in eastern Oregon and Washington, and attempts to exclude it from this area have frequently altered the vegetation to a less favorable condition. Even with the efforts of organized fire control, we have not been completely successful in excluding fire and, on occasion, have allowed a buildup of fuel so that wildfires became large and destructive. Controlling catastrophic fires is hazardous and extremely expensive.

In attempting to exclude fire from east-side forest and range ecosystems, man has been running contrary to a natural succession which established and maintained those systems. In doing so, we have allowed a significant accumulation of dead organic matter that does not decay rapidly in the cool, dry climate of eastern Oregon and Washington.

Today, forest and range managers are beginning to realize that fire, if managed properly, can actually help maintain vegetation in a condition that is more ecologically stable, as well as more pleasing and useful to man. By using fire judiciously, we can work with the natural system more economically and rationally--rather than trying to force the system into unusual patterns.

The frequency and severity of natural fires in eastern Oregon and Washington vary considerably with location because of the marked differences in climate and vegetation, which can range from alpine to desert. Our best record of prehistoric fire comes from scarred tree trunks. Many other fires undoubtedly occurred but were too low in intensity to leave any trace. Early travelers in this area described the ponderosa pine^{1/} forests as parklike and open to travel, presumably as a result of frequent low-intensity fires.

^{1/} Scientific names not given in the text will be found in table 2, page 12.

The frequency of fire scars in ponderosa pine forests in this region varies from 6 years (Soeriaatmadja 1966) to 47 years (Weaver 1959, 1961); most often, somewhere between these extremes. Although we do not know how many of the prehistoric fires were started by Indians or lightning, we do know that lightning starts an average of 21 to 40 fires per million acres each year in this region (Schroeder and Buck 1970). Historically, fire periodicity in open rangeland may also have varied considerably. In the wetter sage-grass sites, Martin and Johnson^{2/} think fires occurred from 5 to 15 years apart. In the drier sage-grass types, fire may be much less frequent.

The role of fire in ecosystems is quite varied, depending on the successional stage of the system, condition of the vegetation and fuels, and nature and frequency of fires. If the classical concept of vegetative succession is used, plant communities move from the pioneer or early vegetation stage through the seral or intermediate vegetation stage to climax vegetation, which will remain on the site unless a disturbance occurs. If severe disturbances such as fire, insects, disease, or windthrow occur, succession is usually retarded or moved back toward earlier stages. Moderate disturbances, such as frequent light fires, may advance, back up, or merely hold succession at a given stage (Martin et al. 1976). For example, a moderate fire may thin a stagnated ponderosa pine stand and move it forward toward a climax condition such as a mature ponderosa pine-bitterbrush community. On the other hand, a potential grand fir (*Abies grandis* (Dougl.) Lindl.) site may, through repeated low-intensity fires, remain in ponderosa pine.

Frequent periodic fires maintain forest fuel hazards at a low level. Weaver (1967) describes how prescribed underburning has reestablished this condition in some managed east-side ponderosa pine stands where it has been applied repeatedly over a period of years. Hall (1976), in a study of fire ecology in the Blue Mountains of eastern Oregon, pointed out that fire exclusion is causing ponderosa pine to be replaced by white fir (*Abies concolor* (Gord. & Glend.) Lindl.) or Douglas-fir, gradually changing the plant community from fire resistant to fire susceptible. He emphasized the important role that prescribed fire can play in reducing fire hazard, improving soil conditions for pine growth, providing control of stocking level, and increasing forage and browse for livestock and wildlife.

Today, population pressures, particularly in the urban/wildland interface, greatly influence the practicality of natural fire. Protection of life, property, and resources are paramount issues with fire protection agencies. Yet, carefully prescribed fires can be useful tools in helping to reduce high intensity wildfires and potential losses.

Dell (1976) described several new directions foresters are exploring today in applied fire use on National Forests in the inland Northwest. He discussed recent studies of prescribed fire designed for timber stand improvement, treatment of understory vegetation and slash from logging and thinning, and range and wildlife habitat improvement.

^{2/} Martin, Robert E., and Arlen H. Johnson. 1978. Fire management of Lava Beds National Monument. In Proceedings 1st Conference on Research in the National Parks. NSF-NPS, New Orleans, Nov. 1976.



Potential Uses of Prescribed Burning in the Inland Northwest

The forest or range manager develops objectives for the units of land being managed. With these objectives in mind, the manager looks at the available ways in which they can be met. Decisions to use fire or other tools would logically proceed from land management objectives to the tools to be used and thence to the specific treatment objectives.

Any prescribed burn may have more than one objective. By coordinating efforts among various resource personnel, the manager may accomplish two or more objectives with one burn. As an example, burning of thinning slash will reduce fire hazard, increase accessibility for livestock and wildlife, and perhaps improve tree growth through nutrient release and reduction of plant competition. Esthetics and human access may be improved by the same fire.

HAZARD REDUCTION

One of the most obvious uses of prescribed burning is to reduce the vegetative material produced by forests and ranges. This material ignites readily when dry. Under adverse weather conditions, the dead material and much live vegetation can result in a very destructive wildfire that is difficult to control. Reduction of the fuels under moderate burning conditions reduces the possibility of conflagration in that area for a time.

We do not have substantial data for the rate of fuel accumulation in the inland Northwest. Consumption of slash from logging in this area, however, should require only one prescribed burn in most cases. Prescribed burning under most ponderosa pine stands every 5 to 15 years should keep natural fuels at an acceptable level. The frequency of burning, as well as the conditions and season of burning, will vary, depending on the objectives of the manager for a particular area (fig. 1). Reduction of hazard is often most crucial in thinning or logging slash. To date we have made little use of fire in reducing thinning slash, but there is great potential as there are many thousands of acres of untreated or partially treated thinning slash in the region. Fire can be used to reduce the hazard (fig. 2).

SILVICULTURE

There are several ways in which prescribed burning can be used to accomplish silvicultural objectives, such as site preparation, vegetation manipulation, and insect and disease control.

Site preparation.--Regeneration of timber stands requires preparation of the site for natural regeneration, seeding, or planting. The site may require treatment because of slash accumulations, shrubs or grasses, or heavy duff (fig. 3). Fire can be used in these cases. In the brush field, the treatment prescription may call for an herbicide or desiccating chemical in combination with fire.^{3/}

^{3/} All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended. Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife--if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

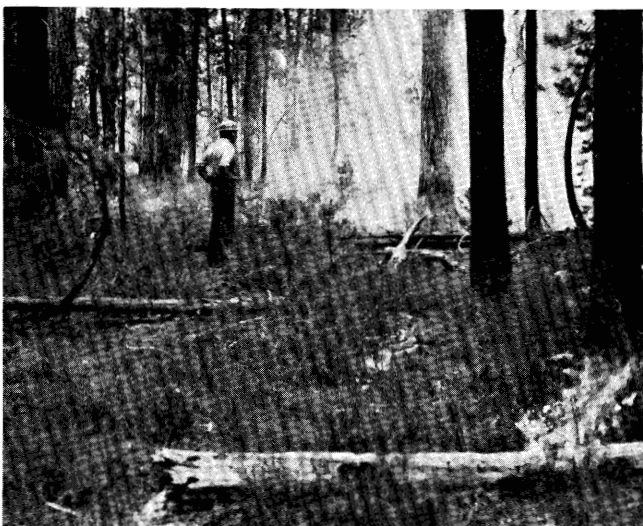


Figure 1.--Hazard reduction was a principal objective in this burn along a heavily used recreation highway. Esthetics of the area was also improved.

Figure 2.--Fire is being used here to reduce thinning slash. The prescription called for cool weather and light wind at a time when the larger fuels were too moist to burn.



Figure 3.--Site preparation was accomplished by this prescribed slash burn in clearcut slash, where both the slash and heavy duff would hinder planting. Fire hazard was also greatly reduced.

Species manipulation.--Different frequencies, intensities, and seasons of fires will favor different plant communities on any given site. Relatively frequent, low-intensity fires may favor ponderosa pine (fig. 4); less frequent, intense fires may favor the prolific lodgepole pine; whereas, without fire or other disturbance, succession on inland forests may lead to a stand of Douglas-fir, true fir, or incense-cedar. By prescribed fire we might also reduce stocking of any species to provide optimum growing space. After setting realistic goals for any piece of land, we can prescribe fire to help meet many of these goals.



Figure 4.--A low-intensity fire was used in this ponderosa pine stand to remove a dense understory of incense-cedar. Reduction of shrub competition and fire hazard was a secondary objective accomplished with the burn.

DISEASE AND INSECT CONTROL

Insects, disease, and fire are all interrelated. Fire has been instrumental in controlling some diseases, such as dwarf mistletoe (*Arceuthobium campylopodium* Engel.) (Alexander and Hawksworth 1975). Apparently the parasite spread rapidly after effective fire control was developed. Prescribed fire has been used to burn diseased slash and heavily infected regeneration so that a healthy new stand could develop. Research underway is designed to test use of fire in reducing mistletoe infestation in released ponderosa pine. Critical information is lacking on the relationship of fire to other important tree diseases in this area.

Fire and insects are closely related. Fire often creates insect problems. For example, fire-damaged trees are vulnerable to bark beetle attack, and insects may increase fire hazard by increasing the supply of dead fuel. Prescribed fire, properly applied, may control insects directly or reduce their damage through indirect means. At certain stages in an insect's life cycle that are sensitive to fire, we can achieve direct control. For insects dependent on a certain habitat condition which fire can remove, such as duff accumulation or the presence of fire-sensitive host species, we can achieve indirect control through prescribed burning. For example, the proportion of true fir in a mixed stand could be reduced by prescribed burning; this would reduce the risk of losses to the Douglas-fir tussock moth (*Orgyia pseudotsugata* McDunnough) (fig. 5).



Figure 5.--Prescribed burning was used in this case to impede development of fir in a ponderosa pine stand. The research burn was conducted because circumstantial evidence indicates that many warmer, dry fir habitats should be held in pine to reduce Douglas-fir tussock moth susceptibility.

WILDLIFE HABITAT MANAGEMENT

Fire is well known for its contributions to habitat improvement for many wildlife species, notably large mammals and birds. Generally, fire will favor some species of wildlife, whereas lack of fire might favor others. When the mixture of wildlife that is most desirable on an area is decided, the land manager can develop a prescribed burning program to meet the objectives. With low-intensity prescribed burning, old decadent stands of wildlife browse species may be regenerated or caused to resprout, providing palatable and nutritious food for game. Examples are bitterbrush, mountainmahogany, and several species of ceanothus. High elevation meadows, now being invaded by tree species, can be maintained by prescribed burning (fig. 6). Livestock and wildlife could have access to areas now inaccessible because



Fig. 6.--This high elevation meadow is slowly being invaded by subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.). Fire could be used to maintain the meadow for wildlife.

of thickets or dead and down trees. Forage and browse could simultaneously be improved by prescribed burning, at the same time leaving escape and thermal cover for wildlife. By developing a mosaic of prescribed burns, no burns, and burns of

different sizes, intensities, and periodicity, we provide for various needs of different wildlife. Wildfires did this in the past, as they burned intensely at one time and crept gently along at another, often leaving vegetative islands completely untouched.

RANGE MANAGEMENT

Fire has been important in producing more palatable and nutritious forage for domestic livestock, whether in timbered or open range. Much original bunchgrass range in this region is now dominated by juniper, sagebrush, and other woody species, probably as a result of overgrazing and fire suppression. Prescribed burning, possibly aided by chemical or mechanical treatment and seeding, can be used to rejuvenate desirable grasses. Once range is reconditioned and properly grazed, fire alone may be used to maintain a satisfactory condition (fig. 7).



Figure 7.--Fire rejuvenated native grasses in the foreground, juniper and sagebrush dominate the vegetative complex in the background.

ESTHETICS, RECREATION, AND ACCESS

A forest managed with fire is often much more pleasing to look at, provides more opportunities for recreation, and allows better access. Frequent, low-intensity wildfires generally kept the ponderosa pine forests of the region open and parklike, where early pioneers could "let their horses take their heads." In contrast, many of these same forests today are choked with shrubs or stagnated thickets of reproduction because of fire exclusion (fig. 8). Reintroduction of fire can reduce the shrubs and thickets, recreate parklike vistas, provide more space for recreation, and create access for man and animals. When a forest is reconditioned by prescribed burning, there may be a 1- to 3-year period when scorching or char can detract from esthetics.



Figure 8.--This ponderosa pine stand once provided open vistas and ready access. Fire exclusion has permitted dense white fir thickets to form. Wildfire, once started, would destroy the entire stand, including the once-fire-resistant ponderosa.



Fire Effects

When considering the use of fire as a tool in forest and range management, one must inevitably ask the question, "What are the effects of fire--on living and dead plant materials, on animals, on soil and nutrients, and on water and air?" We will present a brief account of these effects.

BASICS OF COMBUSTION

A forest and range fire rapidly oxidizes the organic materials produced by living plants. Much the same process occurs over long periods of time through various decomposing organisms. Completely combusted fuel yields about 8,600 British thermal units (Btu) per pound or 20 000 kilojoules (kJ) per kilogram (kg). It is this heat that is primarily responsible for damaging or killing plants. We will discuss the effects of heat later. In practical land management situations, we know that many fuels are not burned at all and others are incompletely burned; only about 6,000 Btu/lb (14 000 kJ/kg) are available from burning. The results of incomplete burning are residual fuel, smoke, and carbon monoxide; the effects on air are covered later.

FUEL CONSUMPTION

Fuel consumed by a fire is the source of energy output. The amount to be consumed on any prescribed burn can be modified by the prescription set by the fire manager (table 1). Slash burning in the Northwest generally consumes from 50 percent to over 90 percent of the fuels less than 3 inches (7.62 cm) in diameter (fig. 9);

Table 1--*Fuel consumption of prescribed burning under ponderosa pine and Douglas-fir stands*^{1/}

Fuel portion	Loading before fire	Moisture content	Fuel consumed	Source
	<u>Tons/acre</u> ^{2/}	- - - <u>Percent</u> - - -		
Ponderosa pine:				
Duff layers--				
L and F	--	8.0 to 8.6	--	
L, F, and H	10 to 17	--	70 to 73	Davis et al. 1968
H	--	17 to 26	--	
Douglas-fir:				
0-0.25 inch (0-0.64 cm)	1.6	12 to 17	82	
0.25-1 inch (0.64-2.54 cm)	2.3	13 to 16	67	
1-3 inches (2.54-7.63 cm)	5.0	12	41	Swanson 1974
>3 inches (>7.63 cm)	36.0	--	31	
Duff, needles	--	15 to 20	--	
Duff, total	39.6	--	71	
Duff, lower	--	49 to 59	--	

^{1/} Dashes indicate no data were given.

^{2/} To convert to tonnes per hectare, multiply tons per acre by 2.24.

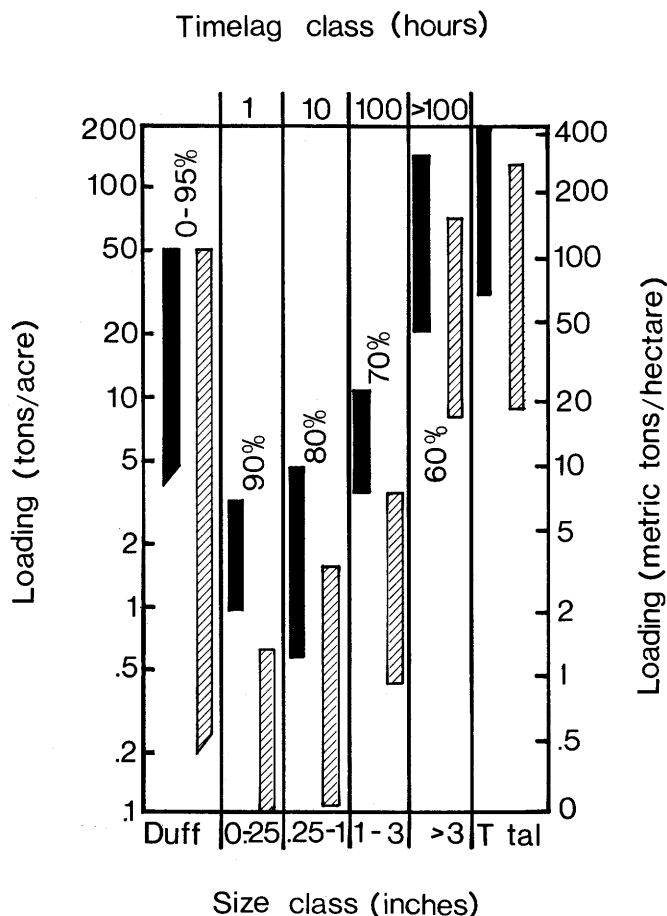


Figure 9.--Amount and consumption of various residue components before and after broadcast slash burning, as condensed from Bevins (1976) and Beaufait et al. (1975). Solid bars indicate fuel loading before burning; cross-hatched bars, after burning (figure from Martin 1977). Length of bars indicates the range of loading levels. The percent figures indicate a rough average of the amount of each size class of fuel consumed by the documented burns.

the average is about 80 percent (Beaufait et al. 1975, Bevins 1976). Generally, 60 percent or less of the larger fuels are consumed, but the percentage may vary widely. The amount of duff consumed is strongly related to the moisture content of the lower duff; consumption can vary from 0 to 95 percent. When prescribing a slash burn, the land manager will need relatively dry foliage and other fine fuels to carry the fire and generate large amounts of heat to disperse the smoke upward. It is possible to obtain the heat needed and yet leave substantial amounts of large fuels and duff for seedling shade, soil protection, and wildlife.

Prescribed burning under stands will also consume differing amounts of the fuel present. Unfortunately, we have limited data on fuel consumption by prescribed burning in this region. Burning in two diverse fuel types indicates about 70 percent of the duff (L, F, and H) layers was consumed (table 1).

NUTRIENTS AND SOIL

Nutrients vital to plants are contained in the fuels a fire consumes. The nutrients are released by the fire; their fate depends on the fire, vegetation, weather, and soil characteristics.

Most of the nutrients remain at the site after the fire (Grier 1972). Rains leach the nutrients into the soil where they may be held by cation exchange, soil micro-organisms, or plant roots. Some, however, may be leached through the subsurface water system and lost in runoff. We can expect more subsurface nutrient loss when more fuel is consumed and when soil organisms and plant roots are killed. Heavy precipitation may carry away nutrients by surface or subsurface flow.

Fire is often an important agent in recycling nutrients bound in living and dead plant materials; it improves growth potential for surviving or new vegetation. Without fire, the nutrients may remain bound for long periods and be inaccessible for growth of other plants. The released nutrients in light fires are almost all held at the site by plant roots, micro-organisms, and the soil.

Nitrogen is affected differently than other nutrients by burning. Two studies indicate 60 to 80 percent of the nitrogen contained in the fuels consumed is lost in the smoke from the fire (DeBell and Ralston 1970, Wallace 1976). Generally, this is a small part of the total nitrogen capital of the site. Even though the total nitrogen capital is reduced, available nitrogen is increased (Lewis 1974). Furthermore, nitrogen fixation may be enhanced by an increase in soil surface temperature and pH, both favoring nitrogen-fixing bacteria (Ahlgren and Ahlgren 1960, Martin et al. 1969, Bollen 1974). Fire may also stimulate nitrogen-fixing plants such as ceanothus or legumes.

Soil heating and direct damage to soil structure or biology will occur only under heavy fuel loadings, such as logs or stumps, or when burning consumes much of the duff.

The long burnout time for large fuels is the cause of soil heating. Generally, such fuels are well dispersed, so damage to the soil is not a problem. Large windrows or slash piles may temporarily sterilize areas of soil which could reduce forage or timber production.

Fire may also cause soil to become water repellent. Generally, this effect occurs after very intense, devastating fires and is probably due to condensation of certain nonwetttable organic compounds in upper layers of the soil. Water-repellent soil is common in intense chaparral fires in the Southwest (DeBano and Krammes 1966, DeBano 1969, DeBano et al. 1970), and some occurs after slash burning. The condition almost disappears in 5 years (DeByle 1973). Little or none should occur after light underburning or range burning. Light burning in chaparral may increase infiltration (Burgy and Scott 1952, Scott 1956, Scott and Burgy 1956).

PLANTS

The effect of fire on plants not only controls the vegetation itself but also affects animals, soil, and water. The resistance of plants to fire varies greatly between species and within species, depending on size, condition, and season of burning. Some species of plants which are individually very susceptible to fire benefit from fire because of their ability to sprout or regenerate following fire. A summary of the effects of fire on some plants is presented in table 2.

Of trees of the inland Northwest, probably ponderosa pine is most resistant to fire throughout its life. Even some seedlings 1 or 2 feet (0.3 to 0.6 m) high survive light fires, although most are killed. As ponderosa pine progresses to the mature stage, its resistance increases greatly. Thick twigs and buds are important in the tree's resistance to crown kill by fire, and the thick bark of older trees protects the main stem.

Next in fire resistance would be western larch because of the thick bark on older trees, the ability to refoliate after crown scorching, and the protected follicles. Small larch do not have the resistance of young ponderosa pine to fire.

Large Douglas-fir are quite resistant to moderate surface fires because of thick bark at the base. The crown is very sensitive to scorching, and the fine twigs and buds are readily killed by excessive heat.

Lodgepole pine is much less resistant to fire than are ponderosa pine, western larch, and Douglas-fir. But the species often does well after fire because of its ability to restock an area from seed. Although much of the lodgepole pine in this region does not have the serotinous cone habit, its reliable seed crops help compensate for the lack of seed storage.

Hemlock, true firs, and spruce succumb to fire much more readily than the other tree species do. Generally, fire reduces their numbers in an area.

The above ground portions of most perennial grasses, shrubs, and short tree species are generally killed by fire. The ability of these plants to maintain themselves in a fire regime is dependent on their sprouting and special seed characteristics. The number of these plants is so extensive that a discussion of most will not be attempted here. A great deal more information is needed on the relationship of grasses, shrubs, and herbs to fire.

Notable among species which do well in a fire regime are snowbrush *ceanothus* and redstem *ceanothus* (*C. sanguineus* Pursh.). They sprout readily following top-kill, and the seeds can be dormant for many years until activated by fire. Green rabbitbrush sprouts more frequently than does gray rabbitbrush after fire, as do bitter cherry and native perennial bunchgrasses. Bitterbrush will sprout if the burning conditions are not too severe, but the greenleaf manzanita in this area does not seem to sprout after most fires. Sagebrush is readily killed by fire.

Plant responses also vary by season and by level of physiological activity at the time of the fire. Dormant tissue will generally withstand a longer exposure to high temperature than will active tissue. Most studies have shown needles and seedling stems will withstand 120°F (49°C) for almost an hour but will succumb to temperatures of 140°F (60°C) in about 1 minute (Lorenz 1939, Nelson 1952, Silen 1963). Dormant seeds have withstood 185°F (85°C) for over 10 minutes and 167°F (75°C) for 50 minutes (Martin et al. 1969).

Growing tissue not only is more susceptible to high temperatures but is often more exposed. For instance, the dormant bud of ponderosa pine is protected by both its outer layers and old needles, but the growing shoot loses both protective mechanisms.

Trees injured by fire in the spring and summer may be subjected to insect attack before they have time to recover. On the other hand, trees injured in the autumn or

Table 2--Summary of the effects of fire on some plant species

Species	General response to fire	Comments
Trees:		
Ponderosa pine (<i>Pinus ponderosa</i> Laws.)	Probably most resistant to fire of any western tree	Often killed by crown damage from intense fires
Western larch (<i>Larix occidentalis</i> Nutt.)	Some consider it the most resistant Northwest tree; seedlings more susceptible than ponderosa pine seedlings	Able to refoliate after scorching of crown
Lodgepole pine (<i>Pinus contorta</i> Dougl.)	Killed or injured by all but light surface fires	Seeds prolifically after fire, even where not serotinous
Western white pine (<i>Pinus monticola</i> Dougl.)	Killed or injured by all but light fires	Species generally reduced by fire
Sugar pine (<i>Pinus lambertiana</i> Dougl.)	Old trees resistant to fire	Young trees susceptible to fire
True firs (<i>Abies</i> spp. Mill.)	Killed or injured by all but light fires	Species generally reduced by fire
Douglas-fir (<i>Pseudotsuga menziesii</i> (Mirb.) Franco)	Old trees fairly resistant to fire	Young trees susceptible to fire through scorching of crown or girdling of tree; fire can be used to control species
Engelmann spruce (<i>Picea engelmannii</i> Parry)	Susceptible to all but light fires	Fire can be used in controlling species
Incense-cedar (<i>Libocedrus decurrens</i> Torr.)	Old trees resistant to fire	Young trees readily killed and species controlled by fire
Western juniper (<i>Juniperus occidentalis</i> Hook.)	Old trees somewhat resistant to all but intense fire	Fire can be used to control increase in juniper
Quaking aspen (<i>Populus tremuloides</i> Michx.)	Top readily killed by all but light surface fire	The species root-suckers profusely after fire
Western hemlock (<i>Tsuga heterophylla</i> (Raf.) Sarg.)	Old trees somewhat resistant to fire where extensive root damage not caused by complete duff consumption	Species generally reduced by fire
Shrubs:		
Big sagebrush (<i>Artemisia tridentata</i> Nutt.)	Readily killed by fire; does not sprout	Fire useful in controlling species
Gray rabbitbrush (<i>Chrysothamnus nauseosus</i> (Pall.) Brit.)	Top killed by fire; sprouting depends on burning conditions	Fire will control species; burn must be moderately hot
Green rabbitbrush (<i>Chrysothamnus viscidiflorus</i> (Hook.) Nutt.)	Top killed by fire; sprouts more readily than gray rabbitbrush	Need more data on sprouting after fire
Horsebrush (<i>Tetradymia canescens</i> DC.)	Top killed by fire; some sprouting after fire	Need more data on sprouting
Bitter cherry (<i>Prunus emarginata</i> (Dougl.))	Top readily killed by fire	Sprouts readily even after intense fires
Bitterbrush (<i>Purshia tridentata</i> (Pursh.) DC.)	Top readily killed by fire	Up to 30-percent sprouting in cool moist soil after spring burning; may seed in a few years after fire
Greenleaf manzanita (<i>Arctostaphylos patula</i> Greene)	Top readily killed by fire; does not sprout in this area	Dormancy of seeds in duff and soil broken by fire
Snowbrush ceanothus (<i>Ceanothus velutinus</i> (Dougl. ex Hook.))	Top readily killed by fire; sprouts readily	Dormancy of seeds broken by fire; repeated burns under timber may reduce ceanothus
Curlleaf mountainmahogany (<i>Cercocarpus ledifolius</i> Nutt.)	Top killed by fire; very little sprouting	Species easily controlled by fire, but often requires very dry, windy conditions to burn
Grasses:		
Bluebunch wheatgrass (<i>Agropyron spicatum</i> (Pursh.) Scribn. and Smith)	Resistant to fire, generally rejuvenated	Burning shortly after rain will reduce crown damage
Idaho fescue (<i>Festuca idahoensis</i> Elmer)	Resistant to fire	Burning shortly after rain will reduce crown damage; may recover more slowly than bluebunch wheatgrass
Bottlebrush squirreltail (<i>Sitanion hystrix</i> (Nutt.) J. G. Sm.)	Resistant to fire	Species generally increases after fire
Cheatgrass (<i>Bromus tectorum</i> L.)	Response to fire depends on season	Fire immediately after cheatgrass cures will reduce numbers

winter will have a greater time to recover before insect activity begins.

Killing of foliage and aboveground portions by burning early in the active growing season should have a greater effect on reducing sprouting vigor. At this time, food reserves of the plant are generally low because they are used to initiate that year's growth and are not yet replaced by photosynthesis. How significant this would be in controlling shrub competition in this region is not known.

WATER

Fire may have deleterious effects on water by increasing its turbidity, changing its chemical content, and influencing flood and low water levels. Much of the data on the adverse effects of burning on water quality came from wildfires or large prescribed slash fires conducted before foresters became concerned about water quality (Tiedemann and Klock 1976, Rothacher and Lopushinsky 1974, Helvey et al. 1976).

Prescribed burning can be conducted in such a way that even small watercourses adjacent to the burn need not be modified severely. Smaller areas can be burned under moderate conditions and buffer strips left near streams to reduce negative effects. In some shrub-to-grass conversions in southwestern range burned by prescribed fire, turbidity of water was actually reduced (Ingebo and Hibbert 1974). Fire planning should involve watershed experts whenever water quality is a concern.

ATMOSPHERE

Smoke from prescribed burning is probably the greatest single factor causing public concern, and public concern in Oregon and Washington is as great as anywhere else in the Nation. The amount of smoke emitted and its dispersal are affected by how and when we burn. A slow-burning backfire spreading into the wind will emit less smoke per pound of fuel consumed than will a fast-spreading head fire (table 3).

Table 3--*Summary of best data on emissions from head fires and backfires*^{1/}

Emission	Emissions from		Problems caused by emission
	Backfire	Head fire	
<u>Pounds per ton of fuel consumed^{2/}</u>			
Carbon dioxide (CO ₂)	2,000-4,000	2,000-4,000	No major problem
Water (H ₂ O)	1,000-2,000	1,000-2,000	Visibility problems
Particulates	3-50	50-200	Visibility and possibly health problems
Carbon monoxide (CO)	20	150	Health problems, but only immediately adjacent to fire
Hydrocarbons (HC)	10	40	Photochemical problems
Nitrogen oxides (NO _x)	2	6	Photochemical and ozone problems
Sulfur oxides (SO _x)	0	0	

^{1/} High-intensity head fires emit more particulates, carbon monoxide, and hydrocarbons than backfires do; but the emissions may also be dispersed higher in the atmosphere (data from P. W. Ryan, Southern Forest Fire Laboratory, Macon, Georgia, and modified somewhat by Martin 1977).

^{2/} For kilograms per metric ton of fuels consumed, divide figure in table by 2.

Smoke from intense fires may disperse upward in the atmosphere, whereas smoke from low intensity fires will drift along the ground. When fire is prescribed, atmospheric stability and wind direction are important for avoiding excessive problems in smoke sensitive areas.

The major atmospheric problem caused by forest and range burning is reduction in visibility. Condensed vapor and particulates combine to form visible, generally white smoke which may obscure scenery and reduce visibility. If smoke reduces visibility on highways, dangerous traffic situations can be created.

Health problems can be caused by emissions of particulates, carbon monoxide, hydrocarbons, and nitrogen oxides. Since the amounts of these emissions that are tolerable vary with different situations, burning should be regulated as much as possible to "avoid overloading natural clearance mechanisms--both pulmonary and environmental" as suggested in the "Southern Forestry Smoke Management Guidebook" (Southern Forest Fire Laboratory 1977). The guidebook also has detailed procedures for calculating smoke impact; although these relate to situations in the South, the procedures may be helpful in the Northwest.

Carbon monoxide levels drop rapidly to nearly normal levels just outside the fire area. It is a matter of concern only for persons working close to the fire.

Over 25 hydrocarbons have been detected in slash fire smoke, and more will undoubtedly be detected by research now being conducted. The health implications of these have not been evaluated.

Nitrogen and sulfur oxides are present in minute or undetectable amounts. Temperatures of open fires are generally not hot enough to form the nitrogen oxides, and the amounts created are much less than would occur from normal biological activities. The low sulfur content of forest fuels probably accounts for sulfur not being detected in smoke.



Planning the Prescribed Burn

Planning a prescribed burn involves considerably more than just writing a burning plan, which should be considered the last step in the planning process. Most prescribed burns are part of a prescribed burning program. The burning program is part of the overall land management planning of the organization (Martin 1978).

The overall land management planning for a given large area of land is derived from the basic philosophy of management in a business organization or in the founding legislation of a government agency. From this, the management objectives for individual pieces of land having certain characteristics are developed. To achieve the objectives, the manager must consider the tools available (mechanical, manual, chemical, biological, fire) to see which might effectively and economically help obtain the objectives. Two or more types of tools together or at separate times might be used to meet the objectives. Having chosen the tool, the manager will decide on specific objectives of a treatment and on the conditions or prescription needed to accomplish it. If the treatment cannot be accomplished within constraints, the manager must reconsider which tools to use or even which objectives must be forgone for that piece of land. Finally, after treatment, the manager must evaluate

the effects of the treatment to improve future treatments or even to decide whether or not the land management objectives can be met.

Careful preparation for a prescribed burning operation should include:

1. Reconnaissance of the area, including inspection and classification of the plant community.
2. Determination of specific objectives and how these objectives fit into management goals for the land unit as a whole.
3. Analysis of budgeting, costs, manpower, equipment, and other logistical needs that must be considered in planning and accomplishing the burn.
4. Thorough review of the planned burning and discussion with other disciplines to identify potential current and future influences and impacts of the burn on all resources.
5. Scheduling of time required to accomplish planned burning for the optimum time of the year, including coordination needed with other units, agencies, etc.
6. Determination of specific prescription elements (fuel, weather, and ignition) needed to accomplish objectives.
7. Preparation of a written plan that provides a place for summary documentation of all the factors.

COORDINATION BETWEEN RESOURCES

Currently, fire is usually prescribed on east-side forests to reduce fire hazards, particularly as a method of fuel treatment on timber sale areas. This, however, does not mean that the fire manager can operate independently in planning and conducting burns. The planned prescribed burn, for whatever purpose, requires involvement of the entire management group. The burn may affect or benefit silviculture, esthetics, range, wildlife, or soil and water quality. Effects may be short term or long range, depending on method of burning, timing, season of application, prescription parameters, and many other factors. A thorough analysis must be made so that the best possible results can be obtained for all resources concerned.

Sometimes compromises and trade-offs are necessary to reach burn objectives. The dominating principle is the overall goal of land management for the unit concerned. Proper conclusions can be reached only after a thorough analysis by all principals who have a stake in the results.

Plant community analysis.--The impact of both conflagrations and low-intensity underburning on forest vegetation and soil is very evident on east-side National Forests. Hall (1976), in a comprehensive ecological evaluation of the Blue Mountains of eastern Oregon and southeastern Washington, determined that fire directly influences tree dominance and development of ground vegetation and of soil.

It is important that the land manager make a comprehensive analysis of the plant community on which prescribed burning is to be applied. This provides documentation of preburn vegetative conditions and provides a means to evaluate whether silviculture, soil, range, wildlife, fire, and other objectives are being met through fire applications.

In Region 6, area guides describe the naturally occurring plant communities within the Region (Hall 1973, Volland 1976). Each guide provides a dichotomous vegetation site key to assist field personnel in onsite identification of the plant communities; productivity data and management considerations are summarized in appendix tables.

Each site for which a prescribed burn is planned should be inspected and its vegetation described and documented; ecoclass type with accompanying descriptive data should be recorded. The description of the vegetation should be attached to and filed with each burning plan.

Environmental analysis report (EAR).--The use of fire as a forest and range management tool can affect nearly every aspect of the ecosystem--soil, air, wildlife, trees, and all other plant life. The fire manager must analyze any planned use of prescribed fire in relation to the ecosystem within and adjacent to the unit of planning.

A written environmental analysis report may be necessary for a prescribed burn, depending on the scope of effect on resources, other land uses, or the environment. The EAR might be for the major land management project (i.e., timber sale, timber stand improvement, etc.), of which prescribed burning is only a part. This report may be simple and brief if only minor impacts will occur over a small acreage; or it may be very detailed if major impacts on biotic and abiotic relationships and/or significant social and economic factors are expected. The interrelationship between these factors and the effects of the proposed project on each factor singly and together must be considered.

Forest Service Manual 8410^{4/} describes the responsibilities and details for preparation of an EAR within the Forest Service. The following outline is used. Other agencies have their own formats, but the same subjects are covered. All analyses use a multidiscipline approach.

- A. Summary sheet.
- B. Approval page.
- C. Description.
- D. Environmental impacts.
- E. Favorable environmental effects.
- F. Adverse environmental effects that cannot be avoided.
- G. Alternatives to the proposed action.
- H. Relationship between short-term uses of the environment and long-term productivity.

DETERMINING BURN OBJECTIVES

The term "prescribed burning" indicates that certain variables of weather, fuel, vegetation, and management objectives will be used to set limits on how, when, and under what conditions burning will be done. The key to successful prescribed burning lies in clearly defined objectives, carefully prepared plans to meet these objectives, and proper application of fire. Objectives should not be weakly or loosely stated but should imply how the success of the burn will be measured.

Some examples of poorly stated burn objectives are:

1. To see what fire will do in a mixed conifer stand. (It just might go over the hill.)
2. To try fire as a tool in managing timber stands.
3. To reduce fuel loading.

Better statements of objectives are:

1. To reduce 1- and 10-hour timelag^{5/} (TL) fuels 90 percent and 100-hour TL and larger fuels 50-60 percent.

^{4/} U.S. Department of Agriculture, Forest Service. 1977. Forest Service Manual, Title 8400 - Environmental statement process, Chapter 8410 - Environmental analysis and report, sections 8410.2 to 8413, Amend. 4.

^{5/} The interval in which a fuel particle loses about 63 percent of the moisture it can potentially lose under a particular set of environmental conditions.

2. To reduce 1- and 10-hour TL fuels to 3 tons per acre (7 metric tons per hectare) or less.
3. To make 90 percent of the stand area accessible to cattle and big game.
4. To kill 90 percent or more of junipers less than 10 feet (3 meters) tall and to kill 40-50 percent of all larger junipers.

In these last examples, the objectives indicate what will be measured and the levels to which the prescribed burn will probably effect a change. The manager should not, however, forget that one prescribed burn can often accomplish several objectives.

In developing a plan and objectives for a burn, the manager should remember that the burn may be only one in a comprehensive prescribed burning program with repeated burns on the same area and on adjacent areas. All the burns should fit the management goals or objectives.

DEVELOPING BURNING PRESCRIPTIONS

Burning prescriptions should meet the specific objectives on a definite piece of land. We give here some levels of prescription variables that have been successful, as well as a prescription that might be developed to meet objectives on a given piece of land where certain vegetation and fuel conditions exist.

Variables that can be used in developing prescriptions include fire, fuels, vegetation, soil, weather, time, National Fire-Danger Rating System (Deeming et al. 1978) variables, and firing technique.

Fire

The fire and its effects are the final integrators of all the prescription variables.

Flame length.--The slant length of flames is probably the most used fire variable, especially under tree canopies. Together with wind and temperature, flame length has a strong influence on scorch height. Flame length and scorch height can be estimated using Albini's (1976) publication.

Flame height.--The vertical distance from bottom to top of flames can be used but is not as helpful as flame length.

Fuels

Moisture content (MC) by size class.--Determines how each size class of fuel burns and how fast it will burn. Moisture content of fine fuels can be estimated from the National Fire-Danger Rating System (NFDRS) tables of Deeming et al. (1978), and MC of larger fuels measured. Low MC in fine fuels may be wanted to carry fire, but high MC in large fuels to reduce heat output.

Distribution.--Crushing or other pretreatment of fuels may be necessary to modify burning.

Duff moisture content.--Strongly influences how much of the duff will burn and the decision to expose or protect mineral soil; MC of lower duff is important in leaving a protective layer.

Vegetation

Condition.--The state of vegetation, whether active or dormant, can modify effects of fire on it; may need to use desiccant or defoliator before burning.

Moisture level.--Especially that of foliage may make a difference in whether or not it is consumed; this in turn modifies the fire characteristics.

Soil

Moisture content.--Especially important in sprouting of some plants and potential soil modification.

Weather

Relative humidity.--Strongly influences fine fuel MC and thus determines how a fire will burn, if at all; one of the most used prescription variables; also influences spotting potential.

Temperature.--Influences how fast fuels will dry and also their final MC; influences effect of fire on plants and soils.

Wind.--Very important in how fire behaves; influences scorch height; a much used variable.

Precipitation.--Especially important in affecting MC of fuels, plants, and soil; a good general index of when to get ready to burn.

Time

Season.--Very important as it relates strongly to plant conditions, sprouting, seed sources, and potential insect attack.

Diurnal.--Daily changes in temperature, humidity, and wind can help achieve prescription condition.

National Fire-Danger Rating System

The 1978 system (Deeming et al. 1978) should be more useful than older systems; may use fuel MC, temperature, wind, etc., as well as burning index, energy release component, ignition component, and spread component.

Firing Technique

Used to modify fire under any given conditions; important in allowing wide variation in other variables, yet meeting objectives.

Selecting the Variables

Whatever the prescription variables, *the final integrating factors are the fire and its effects*. If the fire is not accomplishing the objective, the manager should modify the burning procedure accordingly. Burning crews must know what kind of fire is wanted so they can report differences and adjust their lighting procedures. If adjusting the procedure does not meet the prescription, then the burning should be postponed until the objectives can be met.

With any prescribed burn, there will usually be both ideal and satisfactory levels of meeting objectives. As an example, if red thinning slash is being burned under a stand 60 feet (18 m) tall, an ideal plan would remove almost all the 1- and 10-hour TL fuel classes and 40 to 60 percent of the larger classes. If, however, it has recently rained and a hot, dry summer is almost here, it is more desirable to reduce the fines as much as possible to keep from carrying red slash through the summer, even though reduction of the larger fuels will be minimal.

Use of only one or two prescription parameters by themselves may not give a sensitive enough prescription to meet the manager's objectives. As an example, in prescribing a burn under ponderosa pine, the manager should not say simply that the prescription for a fall burn will be for a given temperature, wind, and relative humidity. Most likely, the manager will also want to prescribe 1 or more inches of rain in September within a week before the burn, this would insure some wetting of larger fuels, increased moisture in soil and duff, and less flammable foliage.

As a prescribed burning program is developed, prescriptions can often be broadened and simplified. A major reason for this is that the fuel loadings under a stand of trees would have been reduced and made more uniform by the second or third time the area is burned. Often the broadening will be toward the more severe fire weather conditions--lower humidities and fuel moistures, higher temperatures and winds. A second reason prescriptions may be broadened is the more sensitive application of fire by the burning crews as they develop skills in prescribed burning.

Before we discuss prescriptions for various situations, there are some general points to consider.

1. In burning under tree canopies, wind is desirable unless the crowns are so high and the flames so low that there is no problem with scorching the crowns. The wind not only increases the distance the heat must travel to the crown but also increases the smoke's mixing with cooler air, both of which reduce temperatures in the crowns.
2. Certain prescription parameters may override others. For instance, flame lengths may override fuel moisture and humidities, as the flames are the final factor in the outcome of the treatment.
3. Any prescriptions used must be adjusted to the site conditions in the burn area. The prescriptions used in an old-growth stand probably would not serve well in a small pole stand. The prescription for burning in pure pine surface litter will not work where heavy needle drape occurs in shrubs.
4. When one or more prescription parameters are adjusted toward a more severe fire condition, there should usually be an adjustment of others toward a less severe condition. Generally, all the parameters should not be in the most severe or least severe conditions.
5. Where conditions vary within the burn area, the prescription should be adjusted. Burning in stages to remove fuel concentrations or needle drape under very moderate conditions and later burning the rest of the stand may be suitable.
6. Prescription levels as summarized in table 4 are only guides to developing prescriptions.

Several sources for help in developing prescriptions are Albini (1976)--estimating scorch heights, flame lengths, rate of spread, and energy release; Brown (1974)--measuring down and dead woody fuels; Brown et al. (1977)--estimating how much slash will be produced; and Deeming et al. (1978)--following weather variables and predicting fire behavior (dummy stations should be established at burn site).

FIRING TECHNIQUES

Firing a prescribed burn unit may be accomplished in various ways, depending on intensity of fire needed to meet objectives.

Based on fire behavior and spread, a prescribed burn moves either in the same direction as the wind (head fire), in the opposite direction (backfire), or at a right angle to the wind (flank fire). Other variations that may be considered are spot fires, center fires, or ring fires.

Table 4--Some general prescription levels for Northwest forest and range types^{1/}

Vegetation	Wind in stand		Relative humidity	Moisture content of fine dead fuels	Temperature	Season	Precipitation	Fireline	Firing pattern	Comment
	Miles per hour	Kilometers per hour								
- - - Percent - - -										
Sagebrush, rabbitbrush, horsebrush, bunchgrasses, cheatgrass:										
Much dead, woody fuel	7-12; gusts to 15	11-19; gusts to 24	20-25	5-15	50 ⁰ -90 ⁰ F (10 ⁰ -32 ⁰ C)	Spring, early summer, fall	One or more days after significant rain if it is a fall burn	Burn out to at least 200 ft (60 meters) on downwind side; need less burnout for grass	Strip head fire, head fire, ring, or center fire	Rest land from grazing in summer before burning to increase fuel continuity for better spread
Little dead, woody fuel	7-12; gusts to 15	11-19; gusts to 24	15-25	5-12	50 ⁰ -90 ⁰ F (10 ⁰ -32 ⁰ C)	Spring, early summer, fall	One or more days after significant rain if it is a fall burn	Burn out to at least 200 ft (60 meters) on downwind side; need less burnout for grass	Strip head fire, head fire, ring, or center fire	Rest land from grazing in summer before burning to increase fuel continuity for better spread
Cheatgrass	3-12; gusts to 15	5-19; gusts to 24	20-30	8-13; duff should also be dry	50 ⁰ -80 ⁰ F (10 ⁰ -26 ⁰ C)	Early summer	Sufficient time for duff to dry	Burn out to 50 ft (15 meters) on downwind side	Strip head fire, head fire, ring, or center fire	Burn in early summer as soon as cheatgrass is cured to reduce cheatgrass density and seed load
Bitterbrush, mountainmahogany:										
Much dead, woody fuel	1-7; little gusting	2-11	25-35	6-12	60 ⁰ -90 ⁰ F (16 ⁰ -32 ⁰ C)	Spring, early summer, fall	No data	Burn out to 50 to 200 ft (15 to 60 meters) on downwind side; then proceed slowly, depending on wind and fuel moisture	Backfire, strip head fire, ring or center fire	Burning when soil is in cool, moist condition in spring or early summer may result in up to 25-percent sprouting of bitterbrush
Little dead, woody fuel	5-10; gusts to 12	8-16; gusts to 19	20-25	5-10	60 ⁰ -90 ⁰ F (16 ⁰ -32 ⁰ C)	Spring, early summer, fall	No data	Burn out to 50 to 200 ft (15 to 60 meters) on downwind side; then proceed slowly, depending on wind and fuel moisture	Strip head fire, ring, or center fire	Burning when soil is in cool, moist condition in spring or early summer may result in up to 25-percent sprouting of bitterbrush
Ponderosa pine, with understory of fir, cedar, bitterbrush, mountainmahogany, ceanothus, manzanita:										
Much dead, woody fuel and needle drape	3-7 in stand	5-11 in stand	30-85	8-12	20 ⁰ -80 ⁰ F (-7 ⁰ -26 ⁰ C)	Spring, early summer, fall, or winter; avoid midsummer	One or more days after significant fall rain	Slowly widen lines with backfires and strip head fires	Backfire, strip head fire, flank fire; may want to burn in stages	Winter burning when ground is frozen may result in excessive needle desiccation and stand reddening but little permanent damage to stand
Little dead, woody fuel and needle drape	1-10 in stand	2-16 in stand	20-50	5-12	20 ⁰ -80 ⁰ F (-7 ⁰ -26 ⁰ C)	Anytime, once stand is in condition	No data	No data	Once stand is in condition can also use head fire	Burning heavy needle drape, particularly in bitterbrush in low crowns, can be accomplished shortly after rain with humidities to 85 percent; may need to complete burn in second stage to consume other fuels
Larch-fir (Norum 1977)	Less than 8	Less than 13	25-60	No data	50 ⁰ -75 ⁰ F (10 ⁰ -24 ⁰ C)	No data	No data	No data	Strip head fire	Once stand has been conditioned with prescribed burning, prescriptions can be broadened

^{1/} Timber type prescriptions are prescribed underburning. Prescriptions will vary depending on objectives, and we can indicate here only the ranges of successful prescription variables.

Table 5 provides a quick guide to the various firing techniques used in prescribed burning. The following summary and figure 10 describe each technique in detail:

Head fire.--The head fire technique will generally produce the largest area burned per unit of time and with a minimum of ignition. The method can be used in shrub or grass areas, in clearcut areas where wide firelines have been established, and under timber stands where previous burning has reduced surface fuels to a sufficiently low level and ladder fuels are not present. It is not recommended for early stages of prescribed burning under tree canopies.

Downwind firelines should be wide enough to prevent the fire from jumping or spotting across the line. Wright (1974) recommends a 100-foot (30-m) fireline for grass fuels and a 400-foot (120-m) fireline for piled juniper and other fuels that produce embers, and relatively high wind conditions. The wide lines are constructed with plowlines on each side; the intervening distance is burned out under moderate burning conditions. Instead of plowed lines, it is possible to use wet lines, with or without retardants, where duff is not deep, and it is desirable to not leave permanent scars (Martin et al. 1977). The Bend Silviculture Laboratory has used this technique in prescribed burning research at Lava Beds National Monument. In light needle litter under timber stands, downwind firelines backfired to a width of 10 or 20 feet (3 to 6 m) would be adequate for the burning conditions normally selected. If conditions or fuels were worse than that, one should not be using head firing under those stands.

Backfire.--The backfire is the gentlest and slowest moving fire. It is lighted on the downwind side and allowed to creep upwind through the area. Internal lines may be constructed within the prescribed burn area, then backfires started at each. The slow rate of spread and considerable internal line construction generally make backfiring more expensive than other methods of burning. Once internal lines are built to a certain orientation, the burner is committed to a given wind direction with which he must burn.

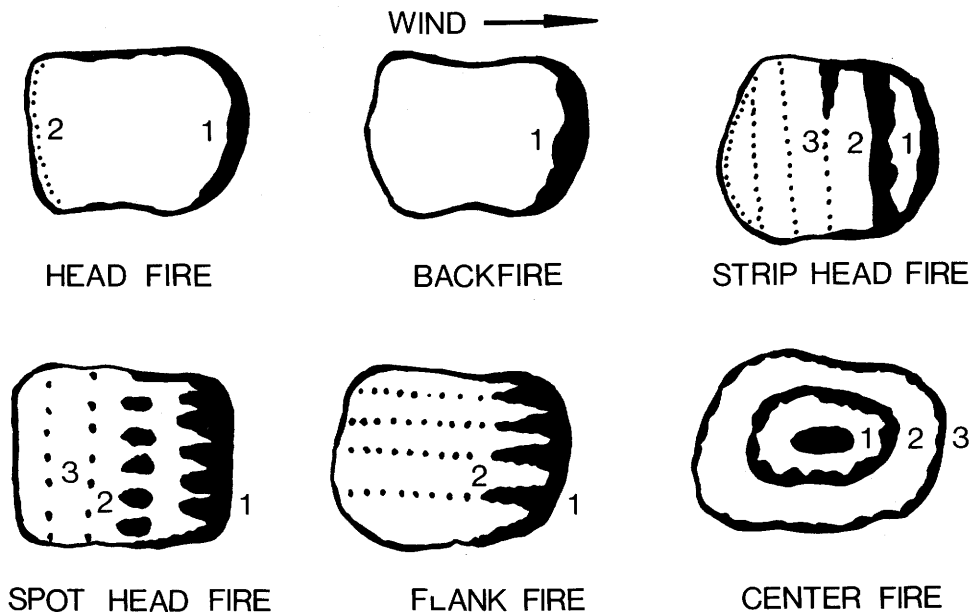


Figure 10.--Basic firing techniques used in prescribed burning. The numbers indicate the sequence of ignition.

Table 5--Firing techniques for prescribed burning^{1/}

Technique	Where used	How done	Advantages	Disadvantages
Head fire	Large areas, brush fields, clearcuts, under stands with light fuels	(1) Backfire downwind line until safe line created (2) Light head fire	Rapid, inexpensive, good smoke dispersal	High intensity, high spotting potential
Backfire	Under tree canopy, in heavy fuels near firelines	(1) Backfire from downwind line; may build additional lines and backfire from each line	Slow, low intensity, low scorch, low spotting potential	Expensive, smoke stays near ground, the long time required may allow wind shift
Strip head fire	Large areas, brush fields, clearcuts, partial cuts with light slash under tree canopies	(1) Backfire from downwind line until safe line created (2) Start head fire at given distance upwind (3) Continue with successive strips of width to give desired flames	Relatively rapid, intensity adjusted by strip widths, flexible, moderate cost	Need access within area; under stands having 3 or more strips burning at one time may cause high intensity fire interaction
Spot head fire	Large areas, brush fields, clearcuts, partial cuts with light slash, under tree canopies; fixed-wing aircraft or helicopter may be used	(1) Backfire from downwind line until safe line is created (2) Start spots at given distances upwind (3) Adjust spot to give desired flames	Relatively rapid, intensity adjusted by spot spacing, can get variable effects from head and flank fires, moderate cost	Need access within area if not done aerially
Flank fire	Clearcuts, brush fields, light fuels under canopy	(1) Backfire downwind line until safe line created (2) Several burners progress into wind and adjust their speed to give desired flame	Flame size between that of backfire and head fire, moderate cost, can modify from near backfire to flank fire	Susceptible to wind veering; need good coordination among crew
Center or ring fire	Clearcuts, brush fields	(1) For center firing, center is lighted first (2) Ring is then lighted to draw to center; often done electrically or aerially	Very rapid, best smoke dispersal, very high intensity, fire drawn to center away from surrounding vegetation and fuels	May develop dangerous convection currents; may develop long distance spotting; may require large crew

^{1/} Martin (1977).

Backfires generally require lower fuel moisture in fine litter fuels than do head fires or flank fires. They also require better fuel continuity for fire spread, as the short flames reach back over the burned out fuel rather than ahead into fresh fuel. The backfire may consume more fuel than a head fire does, especially if the duff contains some moisture.

When surface litter fuels are sufficient to carry a backfire and lower litter and duff layers are moist, the backfire may tend to burn deeper into these fuels than a head fire does. The head fire may rapidly skim over the surface layers, whereas the flames of the backfire radiate heat into the burned-over area, often drying them sufficiently to burn.

Slopes may be used effectively for backfiring when little or no wind is present. Often it is possible to start a fire on a ridgetop and have it back down both sides, or from a hilltop and have it back down in a circular fashion.

Strip head fire.--The strip head fire is probably the most versatile method of prescribed burning. The downwind line is backfired to provide a fireline sufficiently wide to prevent the first strip head fire from jumping it. After that, each strip head fire is lighted a distance upwind that will keep flame lengths (and fire intensity) below the maximum the burner feels are tolerable for the prescription. If conditions change or different fuel complexes are encountered, the strip width can be adjusted to give the desired fire. If, within the burn area, small areas of very heavy fuels are encountered, it may be desirable or necessary to back a fire through that area.

Strip head fires are generally of variable intensity. The lowest intensity is where the fire on the upwind side of each strip backs into the wind. It is a relatively narrow area as the head fire side spreads much more rapidly. As the head fire spreads from each strip, its intensity, flame length, and rate of spread may increase or decrease, the result depending on fuels and burning conditions. Generally, however, intensity will increase as the head fire spreads. The lighter must then adjust the strip width to hold fires within the desired intensity. The hottest portion of the burn will be where the head fire from one strip and the backfire from the previous strip meet. At this point, the two fires interact to produce the largest flames, highest intensity, and greatest vertical convection.

Strip head firelines should be kept relatively straight and normal to the wind. Deep curves in the line can cause the fire on each side to interact and produce a very intense local fire. A strong vertical convection column can then cause scorching or even torching of the tree crowns.

Another situation to avoid if vertical development of the fire is of any concern is three or more strip head fires burning at one time. The fire interaction among strips is most prevalent where fuels are heavy and flashy, winds light, and strips closely spaced. Scorching or torching of crowns can occur readily where the fires interact.

Spot head fire.--The spot head fire is similar to the strip head fire except that spot fires are started as a line of spots rather than continuous lines of fire. Each spot fire typically burns independently in an elliptical pattern of individual fires until it burns close to another spot fire, at which time interaction between the two may occur.

Spot head fires may give a great degree of variability in results as each spot will burn with varying intensity, ranging from the low-intensity backfire to intermediate-intensity flank fire to high-intensity head fire. The spot head fire is particularly appropriate when ignition can best be accomplished with a series of spot fires, such as from aircraft or other encapsulated means of ignition.

Flank fire.--The flank fire is intermediate in intensity between the head fire and backfire. As it spreads across the wind, it may develop small head fires and

backfires because of irregularities in fuel and wind. Several lighters start lines of fire as they walk simultaneously into the wind, and the fires spread out in a V behind them. Eventually the fires from each lighter merge and form a burned out area. Steepness of the V's depends on relative speed of the lighter and the flanking rate of spread of the fire. Where two adjacent fires merge, a line of higher intensity fire is produced because of fire interaction. If winds veer much, the flank fires may become a series of head fires and backfires, with varying intensity.

A type of flank fire known as the chevron burn is often used on the ends of ridges; the pattern is produced by each burner walking downhill beginning at the ridge line. Similarly, the slope of a hill could be used in place of a wind. A starburst pattern may be created if flank fires are started by lighters walking downhill from the crest of round hills, such as many of the buttes in eastern Oregon and Washington.

Center or ring fire.--This method is used to develop high intensity fires, rapid burnout, and vertically dispersed smoke. Its most common use is in slash burning, but it can be used in any situation where available fuels can produce fire intensities high enough to overcome winds and there is no concern for trees within the burn. The indraft draws fire away from surrounding fuels and tree crowns. Although the high intensity may produce more embers, these will be drawn upward with the smoke column and must travel a much greater distance before coming in contact with new fuel than they would in a fire leaning over new fuel.

Lighting begins with a center ring of fires of such a diameter that the fires will draw toward the center. As the intensity increases, the draft from outside the area will increase, so that the next ring of fire will be drawn toward the center and further increase total heat release rate and indraft. Finally, the outer perimeter of fire is lighted. On slopes or with some wind, the upslope or downwind line may have to be widened or the lighting modified so that the indraft will be sufficient at all times.

IGNITION METHODS

Once the firing techniques are decided on, the method of ignition can be chosen. The firing technique, as well as the fuel-vegetation complex and the size of the area to be burned, will put constraints on the ignition method. Common methods are given in table 6. Although many methods are available, the drip torch still appears to be the most common and most economical.^{6/}

LOGISTICS

Logistics is the art of bringing together all the required resources (equipment, supplies, and manpower) at the right place and time. It is important to develop this well head in planning; especially at the start of a prescribed burning program, there may be a need to purchase new equipment or arrange some manpower exchange to supplement crews.

For the short term, arrangements must be made to have crews and equipment at given locations at given times. Both crew and equipment needs will change--in preparing the unit for burning, in conducting the burn, and in postburn mopup and treatment.

^{6/} Muraro, S. J. 1975. New ignition systems. Paper presented to the West For. Fire Comm., Vancouver, B.C.

Table 6--Ignition methods for prescribed burning^{1/}

Method	Where used	How used	Advantages	Disadvantages
Flamethrower	Slash or brush; broadcast or jackpot burning	Burner walks firelines or skid trails and ignites fuel combinations	Fastest hand-carried igniter; burner can reach several feet with flame to avoid walking in slash brush	Somewhat more expensive and complicated than drip torch, heavier to carry and uses more fuel than drip torch does
Drip torch Drag torch	Almost any situation	Burner walks firelines, trails or through fuels, dropping burning fuel	Simple, light, inexpensive, reliable equipment	Slower than flame thrower; burner must often move through heavy fuel
Helitorch	Clearcut slash; could be used in brush or other low vegetation	Helicopter carries large drip torch in sling; drips burning fuel	Very fast ignition; not committed to predetermined firing plan	Helicopter expensive; safety not yet determined
Electrical ignition (primacord/jellied gasoline)	Clearcuts in west coast States; heavy slash and smoke dispersion considerations	(1) Primacord is wrapped around metal or plastic containers of jellied gasoline (2) Electrically detonated in desired pattern	Extremely rapid ignition and convective buildup; excellent for smoke dispersal	Expensive to wire; once wired must burn
Fusees	Anywhere; best used as an auxiliary to other methods when needed	Burner walks fireline or trails or through fuels; must hold flame to fuel for short period to insure ignition	Inexpensive, light; can be carried in vest or pocket to use as auxiliary method	Very slow; must pause to hold flame to fuel; expensive in labor time to start fire
6-inch igniter cord-safety fuse (DAID'S)	Large or remote areas, from aircraft; Australia, Everglades	(1) Ignited by cigarette lighter (2) Dropped from plane or helicopter to start spot fires (3) Flames 15-20 seconds after ignition	Can ignite remote areas; intermediate expense; can cover large area	Dangerous if mishandled or in crash
Potassium permanganate/ethylene glycol capsules	Large or remote areas, from aircraft; Australia	(1) Chemicals mixed by liquid injection (2) Dropped from plane or helicopter to start spot fires (3) Ignites 30-60 seconds after mixing	Capsule and contents inexpensive; can easily cover large areas	Best only for large remote areas

^{1/} Martin (1977).

THE WRITTEN BURNING PLAN

Prescribed burning requires a knowledge of fire behavior, control strategy, suppression technology, and the effect of fire on the environment. If an effective and safe prescribed burn that will meet management objectives is to be developed, a burning plan that considers all planning elements must be prepared. On extremely large or very complex burns, supplemental plans and instructions may be necessary. In most situations, however, a burning plan format similar to the example shown in figure 11 will adequately document detailed planning.

The plan should be prepared well in advance of the burning season to allow for selection of burn unit, preburn evaluation, planning strategy, interfunctional coordination, and any necessary arrangements for financing, manpower, equipment, and other needs.

Size of unit to be burned will vary, but each area for which a plan is being prepared should be fairly uniform in topography and type and amount of fuel. In an area where broad variations in these elements exist, developing an effective burning prescription is difficult, if not impossible. It is better to divide such areas into several burn units, as practical, and prepare a separate burning plan for each.

The following guidelines should be used to prepare a burning plan.

FOREST	DISTRICT	FY-
TRI COMPARTMENT (NAME & NUMBER)	GRID NUMBER	BURN UNIT
LOCATION: T _____, R _____, S _____	GROSS AREA	NET AREA
I&E CONTACTS	APPROPRIATION(S)	
	EAR PREPARED BY	DATE
BURN AREA DESCRIPTION: DESCRIBE TREES & SHRUBS OVER 12 FEET TALL, SHRUBS & TREES UNDER 12 FEET, AND GRASSES AND FORBS.		
ECOCODE(S) _____ TOPOGRAPHY _____ SLOPE _____ ASPECT _____		
SOIL TYPE(S) & DESCRIPTION _____		
FUELS (NATURAL &/OR ACTIVITY)		
0 - 1/4" SIZE CLASS _____ T/A	SHRUBS _____ T/A	TOTAL _____ T/A
1/4" - 1" SIZE CLASS _____ T/A	HERBACEOUS _____ T/A	
1" - 3" SIZE CLASS _____ T/A	DUFF DEPTH _____ IN	FUEL CLASSIFICATION _____
3" + SIZE CLASS _____ T/A	SURFACE FUEL DEPTH _____ FT	NFDR FUEL MODEL _____
MANAGEMENT GOALS OF THIS BURN		
OBJECTIVES OF BURN	(CHECK)	(SPECIFICS)
HAZARD REDUCTION	_____	_____
SILVICULTURE	_____	_____
SITE PREPARATION	_____	_____
WILDLIFE HABITAT	_____	_____
RANGE MANAGEMENT	_____	_____
INSECT/DISEASE CONTROL	_____	_____
SPECIES MANIPULATION	_____	_____
OTHER	_____	_____
BURNING PRESCRIPTION		
SEASON _____	TEMPERATURE (RANGE) _____ to _____ °F	WIND DIRECTION: _____
TIME OF DAY _____	RH (RANGE) _____ to _____ %	PREFERRED _____
DAYS SINCE RAIN _____	WIND SPEED (RANGE) _____ to _____ MPH	ACCEPTABLE _____
FUEL MOISTURES: 1 HR TL _____ %	10 HR TL _____ %	100 HR TL _____ %
1000 HR TL _____ %	DUFF _____ %	SHRUB _____ %
FLAME LENGTH: MAXIMUM _____	AVERAGE _____	FLAME HEIGHT _____
ALLOWABLE SCORCH HT (FT); CROWN _____	BOLE _____	NFDR DATA: BI _____, ERC _____, IC _____, SC _____
FIRING PATTERN _____	IGNITION METHOD _____	
LOGISTICAL INFORMATION		
CHAINS LINE TO CONSTRUCT: TRACTOR _____	HAND _____	OTHER (SPECIFY) _____
CHAINS LINE TO FIRE: EXTERIOR _____	INTERIOR _____	TOTAL _____
MANPOWER NEEDS: UNIT PREPARATION _____	BURNING _____	
HOLDING _____	MOPUP _____	
EQUIPMENT NEEDS: UNIT PREPARATION _____		
BURNING _____		
HOLDING _____		
MOPUP _____		
BURN SUMMARY		
DATE BURNED _____	TIME OF DAY _____	DAYS SINCE RAIN _____
ACTUAL WEATHER: TEMP _____	RH _____	WIND SPEED & DIRECTION _____
FUEL MOISTURES: 1 HR _____	10 HR _____	100 HR _____
FIRE BEHAVIOR: ROS _____	CH/HR, AVERAGE _____	FLAME LENGTH _____
SCORCH HEIGHT: BOLE _____	FT, CROWN _____	FT, HEIGHT _____
BURN EVALUATION (If additional space is needed, use additional sheet)		
PLAN PREPARED BY: _____	DATE _____	
PLAN REVIEWED BY: _____	DATE _____	
PLAN APPROVED BY: _____	DATE _____	

Figure 11.--Prescribed burning plan format.

Location and Unit Information

- Enter National Forest or administrative unit or code numbers.
- Enter fiscal year in which unit will be burned.
- If appropriate, enter any special descriptive codes for locating units in conjunction with an information storage and retrieval system, such as Pacific Northwest Region's Total Resource Information System.
- Enter burn unit name and/or number.
- Enter township (T), range (R), section (S).
- Enter gross area in acres. Include all acres within burn unit boundary (including "leave" islands, etc.).
- Enter net area in acres. Include only the acres that will actually be burned.
- Enter appropriation number to which burn project should be charged.
- Enter initials of person who prepared Environmental Analysis Report (EAR) and date of approval. Note: EAR may have been prepared for a timber sale in which the prescribed burning unit is located. In such a case, any burning would be considered part of the environmental analysis of the parent project.

Information and Education (I&E)

- Briefly describe public and/or in-Service I&E contacts to be made (local media, residents, landowners, recreationists, etc.).

Burn Area Description

- Describe vegetation in detail; stand examination information, if available.
Attach the form to the burning plan.
- Identify ecoclass code (Forest Service) or other ecological designation.
- Describe topography (flat, broken, steep, etc.).
- Enter slope percent and aspect (direction slope faces).
- Identify soil type and briefly describe characteristics.
- Enter fuel tonnages and duff and litter depth from preburn fuel inventory data.
- Designate fuel type classification (i.e., HM, HH, LM, etc.)^{7/}
- Designate the National Fire Danger Rating (NFDR) fuel model most appropriate for the area.

Management Goals

- Describe general management goals for this land unit and how this application of prescribed fire will help meet these goals.

Objectives of Burn

- Check one or more objectives of prescribed burn and briefly explain specifics (see "Determining Burn Objectives", page 16).

^{7/} The letters refer to Forest Service Pacific Northwest Region's system of fuel hazard rating. The first letter designates the rate of spread; the second, resistance to control. Ratings are only relative: E = extreme, H = high, M = medium, L = low.

Burning Prescription

- Identify season of year and time of day when burn will be accomplished.
- Designate preferred number of days between last precipitation and planned burn date.
- Designate specific ranges of temperature, relative humidity (RH), and wind conditions that will produce the best environment to achieve objectives.
- Designate desired fuel moisture percentages by size class to achieve needed fuel consumption.
- Describe desired flame length and height in feet that will achieve necessary fuel consumption and keep scorch heights to designated levels.
- Designate optimum NFDR BI (burning index), ERC (energy release component), IC (ignition component), and SC (spread component). Refer to "The National Fire-Danger Rating System" (Deeming et al. 1978). Specify firing pattern to be used (back, strip head, flank, center, etc.) and ignition method (drip torch, aerial, remote, etc.).

Logistical Information

- Specify chains of tractor, hand, or other exterior or interior line to be constructed.
- Specify chains of exterior or interior lines to be fired.
- Identify specific manpower and equipment needs for the various phases of the burning program.

Note: If more space is needed to describe special requirements, use additional sheets of paper.

Burn Summary and Evaluation

- Indicate date the burn was accomplished and time of ignition. Record number of days since last actual precipitation and amount of total precipitation for season to date of burn.
- Summarize actual weather, fuel moistures, and burning index on day of burn (from observations taken *onsite* during the burn).
- Record actual observed rate of spread (ROS) of fire, and average flame lengths, flame heights, and scorch heights for boles and crowns.

A good burn evaluation will require more space than allowed for on this form. Evaluation is an extremely important part of the documentation needed for a prescribed burn project. It will provide the history and background necessary for making future prescribed burning decisions.

Evaluation should be done in two phases, short term and long term. There are some obvious effects of a burn that are evident almost immediately and should be recorded. A thorough evaluation, however, may require several trips to the site at time periods after the burn. This evaluation should include, but is not limited to, some of the following specific items:

Fuel consumption.--How much was fuel amount reduced (i.e., by size class, duff depth, etc.)?

Fuel classification.--What is the fuel hazard classification for the area?

Soil exposure.--On what percent of area has soil been exposed?

Vegetative effects.--What happened to grasses, forbs, shrubs, and trees?

Visual impacts.--What problems, if any, affect management of the visual resources of the area? What can be done to correct them?

Plan Preparation and Approval

- Record names of individuals preparing, reviewing, and approving the burning plan.
- Date each entry.



Execution of the Prescribed Burn

If a thorough planning job is done, the prescribed burn can be accomplished in an efficient and safe manner.

The burning boss should assemble and organize the crew in sufficient time to allow a thorough orientation and briefing. Firing, holding, and mopup equipment must be ordered, assembled, and checked out well ahead of scheduled burning. Communications equipment, transportation, food, and water needs must be considered and allowed for.

A brief checklist for the burning boss follows:

1. Brief crews completely on burn objectives, procedures, safety, and contingency plan if problems develop.
2. Distribute copies of burning plan, maps, photos, or other instructional material needed.
3. Have current weather forecast in hand and be prepared to receive updated weather information throughout the day. Be aware of current smoke management conditions and necessary requirements.
4. Have a belt weather kit on hand for periodic observations, or have a crewmember assigned this task. Keep yourself and crew informed.
5. Check firelines and other preparations. Reinforce or modify firelines as needed.
6. Notify local residents, media, and fire organizations of intentions to burn.
7. Post road signs and/or assign traffic controllers if smoke will reduce visibility on travel access routes.
8. Check moisture of fuel and soil.
9. Notify headquarters of ignition time.
10. Set a small test fire in unit before start of regular firing.
11. From results of test fire, *MAKE DECISION TO PROCEED OR HOLD*. Inform all parties.
12. If decision is to proceed, be alert to changing conditions--keep crewmembers advised.
13. Have sufficient personnel lined out for mopup and patrol of perimeters throughout all phases of the operation.
14. If conditions change or fire is not behaving as desired, modify ignition to get proper burning or STOP. If the decision is to stop, put out fire and proceed with mopup.
15. Do not leave burn area until you have personally completed the "BURN SUMMARY" portion of the prescribed burning plan.



Other Prescribed Burning Guidelines

In preparing this guideline, we have drawn from Allen et al. (1968), USDA Forest Service (n.d., a and b) Beaufait (1966), Mobley et al. (1977), Wright (1974), and U.S. Department of the Interior, Bureau of Land Management.^{8/} We have tried to modify the best parts of each to fit eastern Oregon and Washington.



Sample Burning Situation

Your district has a variety of vegetation habitat types, from sagebrush-bunchgrass to mixed conifer-ceanothus. In one area, the transition from open range to the upper-slope mixed conifers occurs within a few miles (fig. 12); we will talk about burning in this area. A major highway travels from northwest to southeast, and most of the sagebrush types lie to the west of it. Elevation increases to the northeast; vegetation gradually changes to types requiring cooler, moister sites. The area has many small vehicle trails and one road used extensively by recreationists to get to Blue Lake, nestled among mixed conifers. Facilities at the lake include a guard station, lodge, cabins, and an improved campground.

The climate in the area is typical of what might be expected in eastern Oregon and Washington. Precipitation comes mostly between September and May. June, July, and August are generally quite low in precipitation; humidity is low during the warm, clear summer days. Dry lightning storms are common during the summer months. Your analysis of fire causes shows that two-thirds of the wildfires are caused by lightning. In an area around Blue Lake, risk from man-caused fires is high--specific causes vary but generally reflect the high recreation pressures in the area.

Your brief analysis of fire scars conducted for fire history information shows that fires have been frequent in the area--the average period between fires ranges from 5 to 10 years in the lower elevations and 35 to 40 years in the higher elevations. The acreage burned has decreased greatly in the past 60 years as fire control has improved. Fire control has made it possible for you to practice forest management, but some problems are now evolving. There are some biological problems pointed out by the resource staff, such as increases in insect susceptibility and mistletoe infestation and reduction in tree and forage growth; and the fuels assistant has indicated that fuel accumulation could lead to catastrophic fires.

^{8/} U.S. Department of the Interior, Bureau of Land Management. 1976. Prescribed fire handbook. Missoula, Mont.

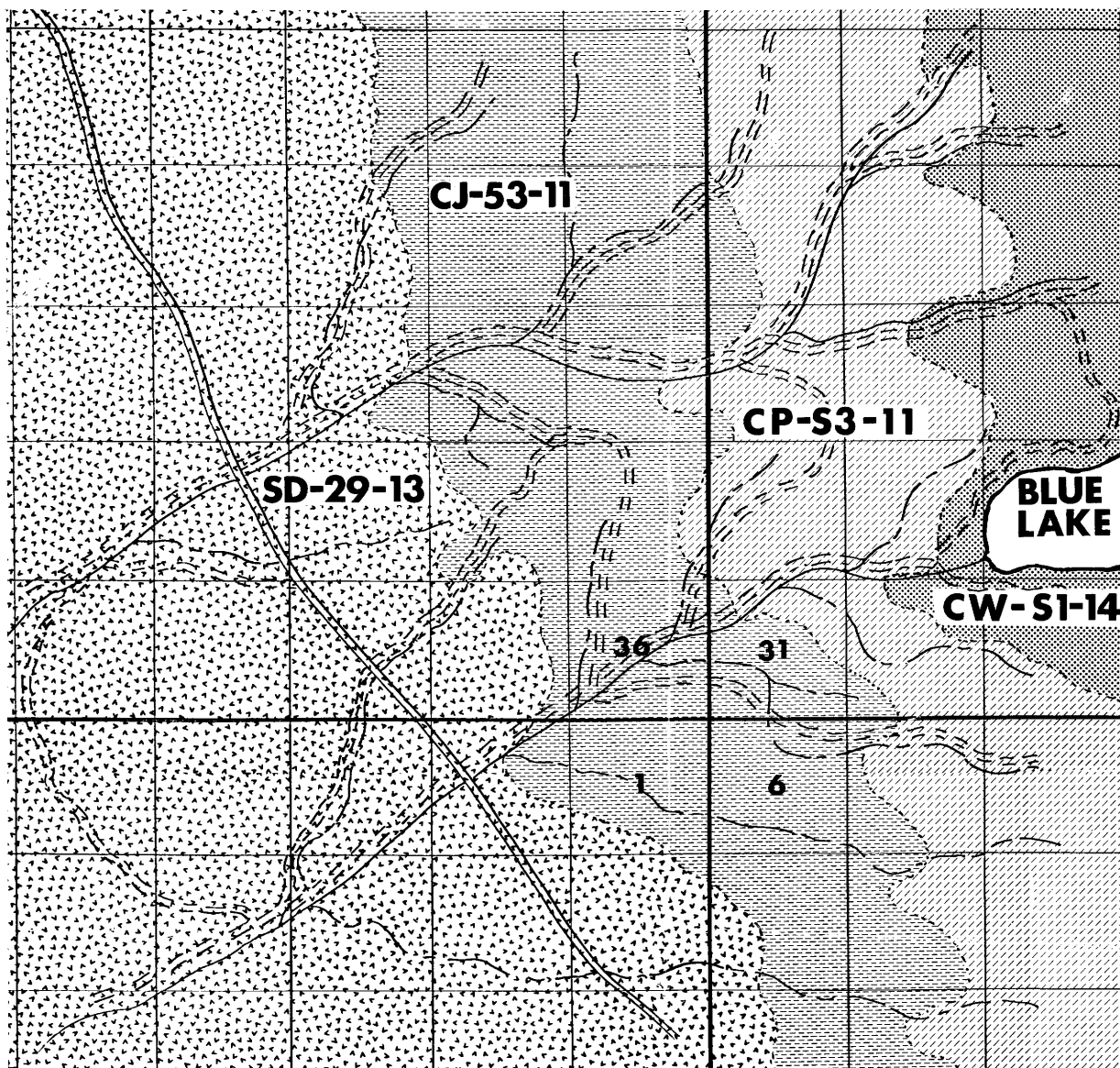


Figure 12.--The area in which you are considering use of prescribed fire. Vegetation varies from sage-grass (SD-29-13) in the warmest, driest area, through juniper-bitterbrush-bunchgrass (CJ-53-11) and ponderosa pine--bitterbrush-snowbrush (CP-S3-11) to mixed conifer-snowbrush (CW-S1-14) on the highest, coolest, wettest areas.

A quick look at the area suggests the first consideration for modifying fire potential should be done to protect the high values at risk around Blue Lake. Records indicate most of the wildfires have moved from the southwest, west, or northwest (fig. 13). You develop a plan calling for a fuel break system that would help protect the Blue Lake environs from wildfires on the north, west, and south.

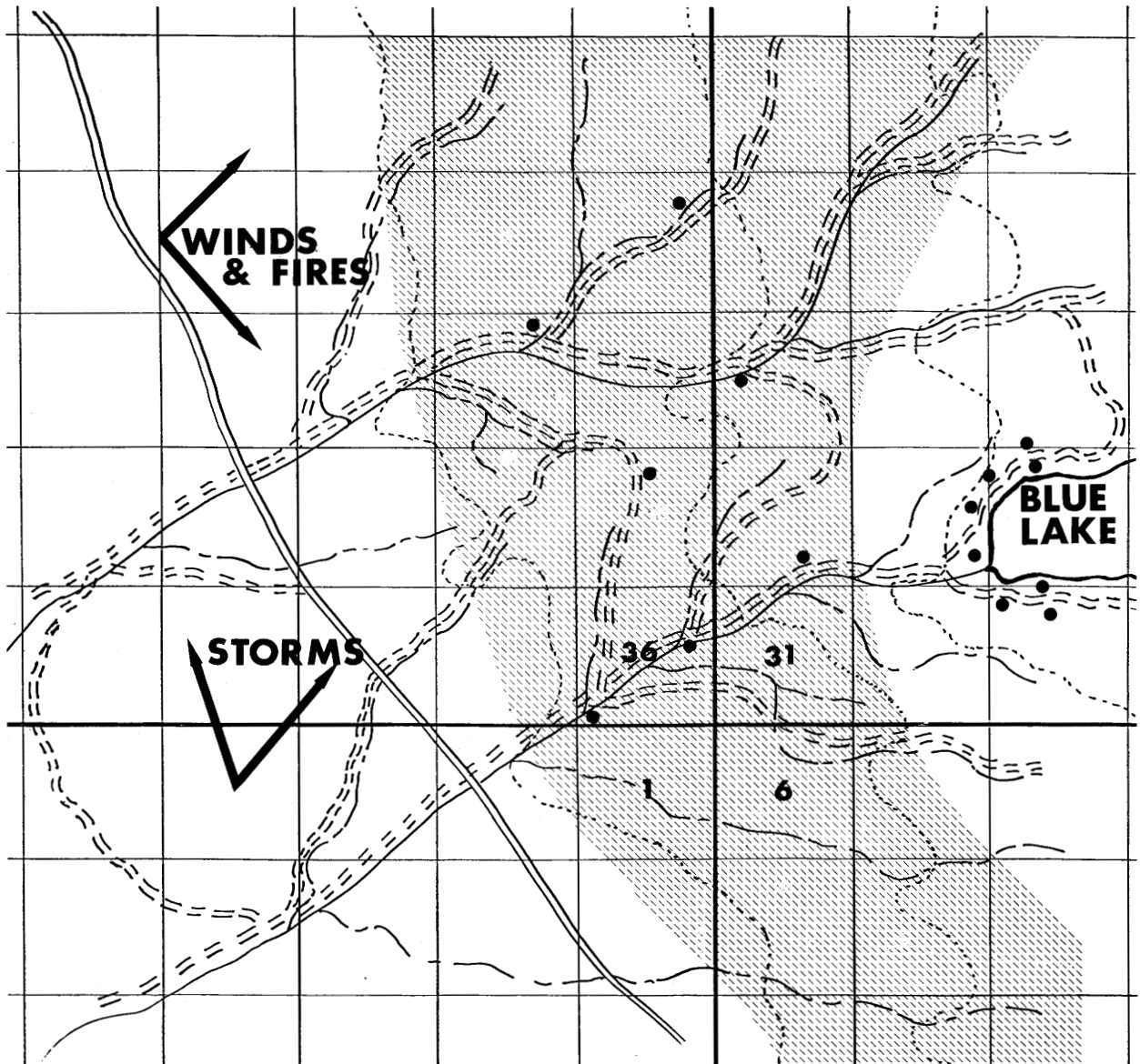


Figure 13.--The fire situation in Blue Lake area. Most wildfires have moved from the southwest to northwest quadrant. Man-caused fires (dots) have been centered around Blue Lake, and lightning-caused fires have been started in a broad belt west of the lake (cross-hatched area).

(The fuel break would also help control man-caused fires around the lake.) Since shaded fuel breaks (Dell 1976, Green 1977) give only a limited amount of protection from high-intensity, fast-moving head fires, development of wider, more effective fuel modification areas is desirable where feasible. The ponderosa pine area in section 29 appears to offer this opportunity.

You take a field trip with resource people representing timber, wildlife, range, soils, water, recreation, and fire. At the site, you tour most of the area involved. Discussion then covers each resource subject, and there is a consensus that no extensive permanent damage will be done to any resource if the fire is properly prescribed and executed. Your fire personnel have conducted small burns with excellent success, and the resource staff have had a chance to evaluate effects of the burns.

Effects of the proposed prescribed burn on different resources are assessed as follows in field and office discussions:

<u>Resource</u>	<u>Positive</u>	<u>Negative</u>	<u>Constraint</u>
Soils	May warm soil as duff is reduced, increase nutrient availability; may increase pH.	Possibly increased erosion where soil is exposed; possibly reduced organic matter and soil destruction if fire is too hot.	Burn to leave lower duff on most of the area.
Water	On this site, no expected benefits.	Possibly increase turbidity and nutrients in water	If necessary, put a fireline around it; since only rock-bottomed intermittent streams are present, burn so fuel is still moist along watercourses.
Air	None except improved view of sunset.	Smoke drift into recreation or highway area.	Burning should be done in low recreation period, spring or fall.
Timber	Potential growth stimulation from nutrient release and reduced competition.	Possible loss of some trees, scarring of others; possible growth loss.	Develop gentle prescription and carefully execute fire.
Wildlife	Provide more succulent browse and forage; cause increase in some species; provide better access for large mammals.	Cause decrease in some species and a temporary decrease in browse; may lose wildlife habitat in trees and snags; may lose hiding and thermal cover.	Perhaps vary burning to give different effects; could install fireline in some areas; leave trees and snags.
Range	Provide more forage and favor more succulents; make area more accessible to livestock.	May have to let area rest for good response.	Be sure area can be isolated without affecting livestock allotments.
Recreation	Provide open vistas and accessibility in parklike stands; generally improve esthetics.	May be adverse public reaction to burning, black bark, and red needles; fire may be considered unnatural.	Gentle prescription and careful execution are important; install interpretive signs and perhaps conduct campfire sessions.

You receive tentative approval to proceed with the prescribed burn if the EAR is favorable. There are still reservations about the outcome of the burn--can the fire management group conduct the burn as they say they will?

You begin planning of the prescribed burn with a reconnaissance of the area; you combine this information with that from aerial photos and develop a good map for the burning. At the bottom of the unit, ponderosa pine dominates the vegetation; bitterbrush is the major understory plant (figs. 14 and 15). There are many interspersed pine thickets. At the top of the unit, ponderosa pine still dominates the overstory; snowbrush ceanothus and greenleaf manzanita dominate the understory (fig. 16). Large numbers of Douglas-fir and true fir seedlings and saplings are becoming established. You make notes on firelines, crew location, and possible firing patterns (fig. 17). The area has a distinct westerly aspect with slopes from 0 to 30 percent. You decide that any wind between southwest and north will be satisfactory as you can vary your lighting orientation (fig. 18). You begin filling out the prescribed burning plan (fig. 19) which serves also as a checklist of items to be done.

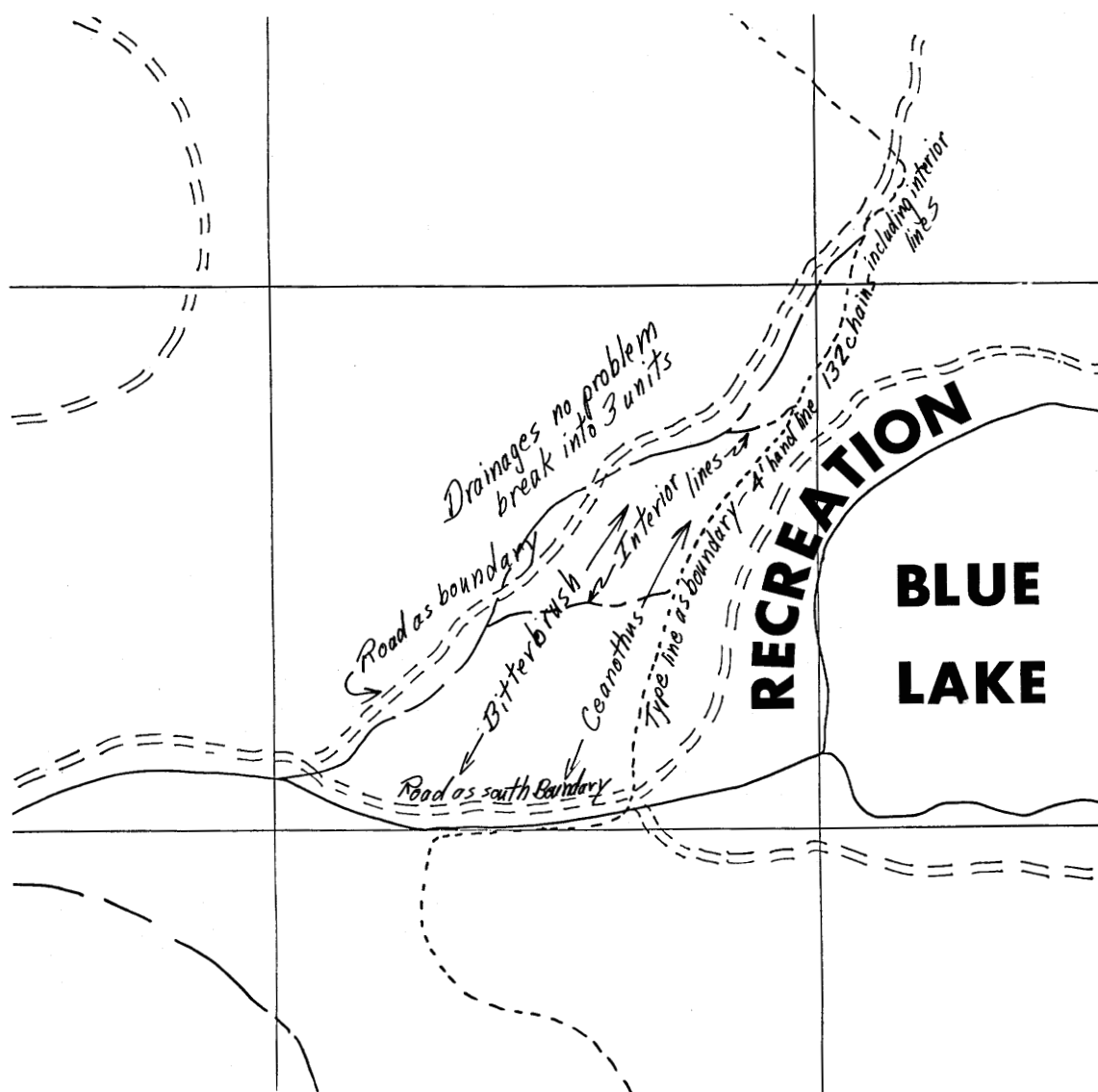


Figure 14.--Field notes on map concerning vegetation and firelines. Vegetation type line on west follows an old road along ridge, which makes construction of handline easy.



Figure 15.--Ponderosa pine with predominantly bitterbrush understory near bottom of the area. Needle drape in the bitterbrush will cause each plant to flare up; burners should be cautioned about this.



Figure 16.--Ponderosa pine with predominantly snowbrush ceanothus and greenleaf manzanita near the top of the unit. Although not visible here, true fir and Douglas-fir seedlings are becoming established.

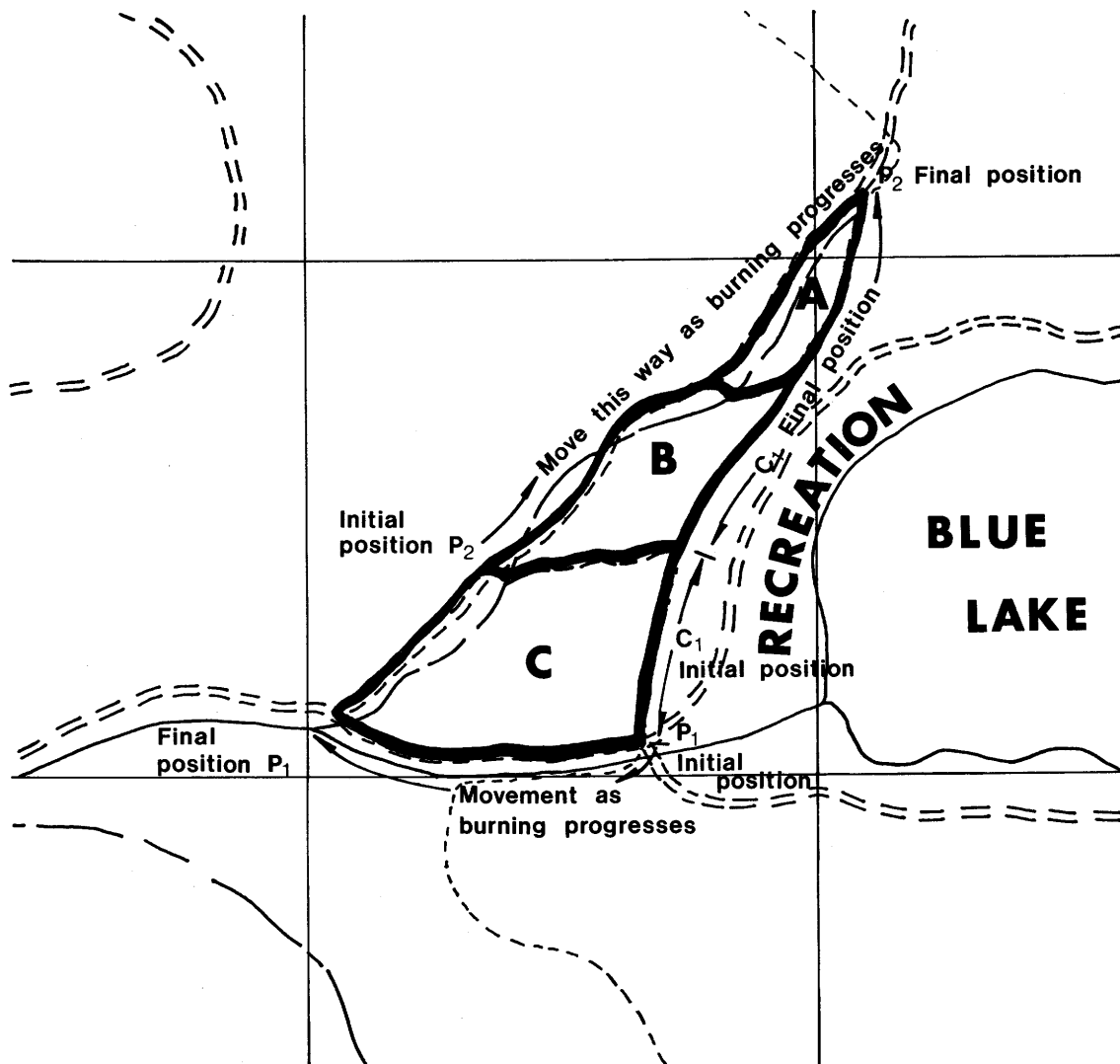


Figure 17.--Location of crews as burn progresses. Strip head fires will be used throughout the burn.

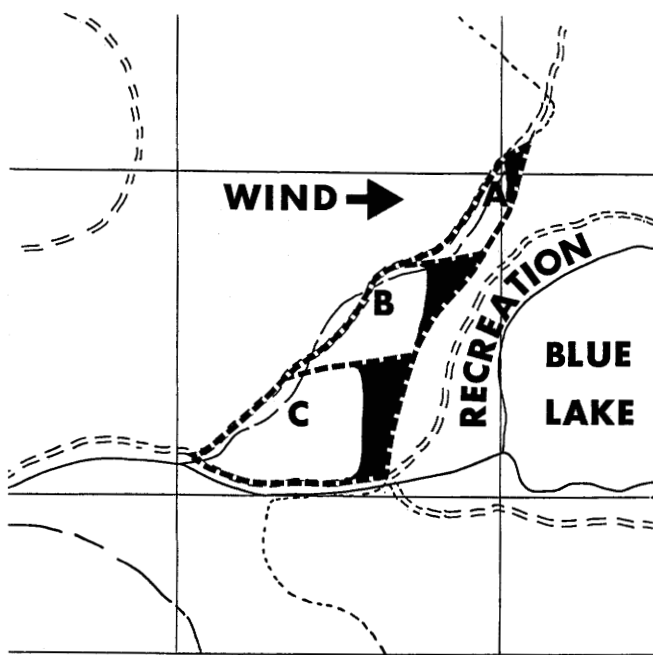
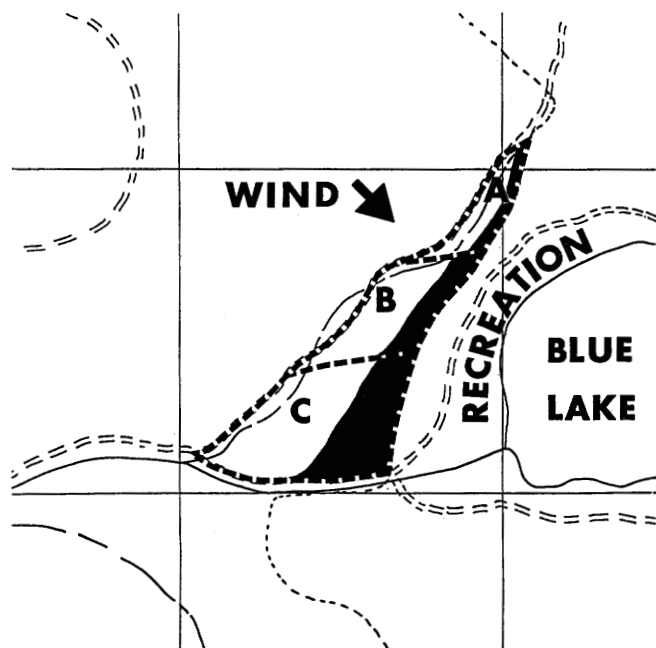
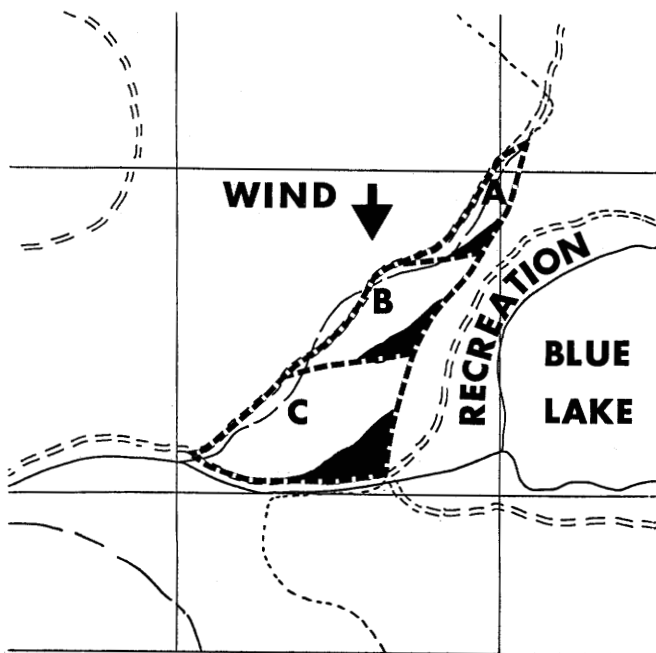


Figure 18.--A range of wind directions will satisfy prescribed burning needs. You can alter orientation of strip head fire to get satisfactory results.

SAMPLE

R6 PRESCRIBED BURNING PLAN

FOREST <u>Dechoco</u>		DISTRICT <u>Appalina</u>	FY- <u>1978</u>																											
TRI COMPARTMENT (NAME & NUMBER)		GRID NUMBER	BURN UNIT <u>Blue Lake</u>																											
LOCATION: <u>T 14 S, R 12 E, S 29</u>		GROSS AREA <u>228 acres</u>	NET AREA <u>228 acres</u>																											
I&E CONTACTS <u>KTVZ</u> <u>KBND, KGRL</u> <u>The Bend Bulletin</u>		APPROPRIATION(S)																												
		EAR PREPARED BY <u>I.M.A. Torch</u>	DATE																											
BURN AREA DESCRIPTION: DESCRIBE TREES & SHRUBS OVER 12 FEET TALL, SHRUBS & TREES UNDER 12 FEET, AND GRASSES AND FORBS (USE R6 COVER CARD #3 - ATTACH TO BURNING PLAN). ECOCLASS CODE(S) <u>CP-G1-11</u> TOPOGRAPHY _____ SLOPE <u>0-30%</u> ASPECT <u>WNW</u> SOIL TYPE(S) & DESCRIPTION <u>Pumice loamy sand</u> FUELS (NATURAL &/OR ACTIVITY) 0 - 1/4" SIZE CLASS <u>0.1-0.3</u> T/A SHRUBS <u>0.3-0.9</u> T/A TOTAL <u>9.6-15.3</u> T/A 1/4" - 1" SIZE CLASS <u>0.3-0.8</u> T/A HERBACEOUS <u>< 0.1</u> T/A 1" - 3" SIZE CLASS <u>0.2-2.8</u> T/A DUFF <u>DEBRIS 5.2-14.4</u> T/A R6 FUEL CLASSIFICATION <u>Albini</u> 3" + SIZE CLASS _____ T/A SURFACE FUEL DEPTH <u>0.5</u> FT NFDR FUEL MODEL <u>K</u> <u>10</u>																														
MANAGEMENT GOALS OF THIS BURN																														
<table border="0" style="width:100%;"> <tr> <td style="width:30%;">OBJECTIVES OF BURN</td> <td style="width:20%;">(CHECK)</td> <td style="width:50%;">(SPECIFICS)</td> </tr> <tr> <td>HAZARD REDUCTION</td> <td><u>x</u></td> <td><u>Reduce 1,10 & 100 hr fuels to 1 ton each</u></td> </tr> <tr> <td>SILVICULTURE</td> <td><u>x</u></td> <td><u>Kill or catface <1% of larger pine</u></td> </tr> <tr> <td>SITE PREPARATION</td> <td>_____</td> <td>_____</td> </tr> <tr> <td>WILDLIFE HABITAT</td> <td><u>x</u></td> <td><u>Top kill 90% of shrubs; get 30% bitterbrush</u></td> </tr> <tr> <td>RANGE MANAGEMENT</td> <td>_____</td> <td><u>sprouting</u></td> </tr> <tr> <td>INSECT/DISEASE CONTROL</td> <td>_____</td> <td>_____</td> </tr> <tr> <td>SPECIES MANIPULATION</td> <td><u>x</u></td> <td><u>Kill 90% of D-fir and true fir regeneration</u></td> </tr> <tr> <td>OTHER</td> <td><u>x</u></td> <td><u>Expose <20% mineral soil</u></td> </tr> </table>				OBJECTIVES OF BURN	(CHECK)	(SPECIFICS)	HAZARD REDUCTION	<u>x</u>	<u>Reduce 1,10 & 100 hr fuels to 1 ton each</u>	SILVICULTURE	<u>x</u>	<u>Kill or catface <1% of larger pine</u>	SITE PREPARATION	_____	_____	WILDLIFE HABITAT	<u>x</u>	<u>Top kill 90% of shrubs; get 30% bitterbrush</u>	RANGE MANAGEMENT	_____	<u>sprouting</u>	INSECT/DISEASE CONTROL	_____	_____	SPECIES MANIPULATION	<u>x</u>	<u>Kill 90% of D-fir and true fir regeneration</u>	OTHER	<u>x</u>	<u>Expose <20% mineral soil</u>
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BURNING PRESCRIPTION SEASON <u>Fall</u> TEMPERATURE (RANGE) <u>55°</u> to <u>75°</u> F WIND DIRECTION: _____ TIME OF DAY _____ PM RH (RANGE) _____ to _____ % Mi/ _____ PREFERRED _____ W DAYS SINCE RAIN <u>3-7</u> WIND SPEED (RANGE) <u>2</u> to <u>10</u> MPH ACCEPTABLE <u>SW to N</u> FUEL MOISTURES: 1 HR TL <u>5-8</u> %, 10 HR TL <u>5-10</u> %, 100 HR TL <u>5+</u> %, 1000 HR TL <u>10+</u> %, DUFF Lower <u>30%</u> , SHRUB <u>50- to 100%</u> , HERBACEOUS <u>50-100</u> % FLAME LENGTH: MAXIMUM <u>5(80%)</u> AVERAGE <u>3-4</u> FLAME HEIGHT <u>3</u> ft ALLOWABLE SCORCH HT (FT): CROWN <u>20</u> , BOLE <u>5</u> NFDR DATA: BI <u>50</u> , ERC <u>75</u> , IC _____, SC <u>5</u> FIRING PATTERN <u>Strip headfire</u> IGNITION METHOD <u>Drip torch</u>																														
LOGISTICAL INFORMATION CHAINS LINE TO CONSTRUCT: TRACTOR _____ HAND <u>132</u> OTHER (SPECIFY) _____ TOTAL <u>132</u> CHAINS LINE TO FIRE: EXTERIOR <u>132</u> INTERIOR _____ TOTAL _____ MANPOWER NEEDS: UNIT PREPARATION <u>8x8</u> BURNING _____ 3x8 HOLDING <u>8x8</u> MOPUP _____ 4x8 EQUIPMENT NEEDS: UNIT PREPARATION <u>None</u> BURNING <u>None</u> HOLDING <u>3 pumpers x 8 hrs</u> MOPUP <u>2 pumpers x 8 hrs.</u>																														
BURN SUMMARY DATE BURNED _____ TIME OF DAY _____ DAYS SINCE RAIN _____ SEAS. PRECIP TO DATE _____ IN. ACTUAL WEATHER: TEMP _____ RH _____ WIND SPEED & DIRECTION _____ NFDR BI _____ FUEL MOISTURES: 1 HR _____ 10 HR _____ 100 HR _____ 1000 HR _____ BRUSH _____ HERBACEOUS _____ FIRE BEHAVIOR: ROS _____ CH/HR, AVERAGE FLAME LENGTH _____ FT, HEIGHT _____ FT SCORCH HEIGHT: BOLE _____ FT, CROWN _____ FT OTHER OBSERVATIONS (If additional space is needed, use additional sheet) _____ _____ _____																														
PLAN PREPARED BY: <u>I.M.A. Torch</u> DATE _____ PLAN REVIEWED BY: <u>I. M. Weried</u> DATE _____ PLAN APPROVED BY: <u>Von Bacation</u> DATE _____																														

NOTE: ATTACH MAP OF BURN AREA

Figure 19.--The written prescribed burning plan. Maps and necessary instructions and information will be attached.

Your reconnaissance has included estimates or measurements of fuel loads. You have estimated fuel loads from photo series such as those by Maxwell and Ward (1976) or from some you have developed to meet specific needs. You have measured dead and down fuels, as well as the duff, by the planar intersect method (Brown 1974).

Before proceeding with other aspects of planning, you formulate specific objectives of the burn:

Reduce dead and down fuel loads to:

- 1 ton per acre for 1-h TL class,
- 1 ton per acre for 10-h TL class,
- 1 ton per acre for 100-h TL class,
- 2 tons per acre of duff;
- expose less than 20 percent of mineral soil;
- top-kill 90 percent of shrubs;
- obtain 30-percent sprouting of bitterbrush;
- kill or catface less than 1 percent of larger pine; and
- kill 90 percent of Douglas-fir and true fir understory in top part of burn.

Using input from several resource staff members, you prepare the EAR for the burn. Preparation and approval take some time, and it is important to get started early. Your notes from discussions with various resource people will help remind you of crucial points to cover.

Having clearly stated your objectives, you are ready to design the prescription to meet the burning objectives with the fuel loads you have measured or estimated. The final integrating factor of the prescription is the fire itself. You select a 20-foot (6-m) crown scorch height as desirable. Albini (1976, p. 65) says a 5-foot (1.5-m) flame length will give scorch heights from about 15 to 25 feet (4.6 to 7.5 m), depending on the wind. The flame length should correspond to about a 3-foot (0.9-m) flame height. You think you can hold to these flame sizes on 80 percent of the area; this would allow for occasional flareups where shrubs, saplings, or dead and down fuel concentrations ignite. You find Albini's (1976) nomograms helpful. You select Albini's model "10 Timber (Litter & Understory)" and obtain estimates of flame length, rate of spread, and fire intensity for given fuel moisture contents, windspeeds, and slopes (fig. 20). You can now write a prescription that will meet your requirements.

The prescription allows for a range of values in most variables, as some can be traded off against others to meet your objectives. You arrive at the following set of prescription variables:

- Maximum flame length, 5 feet (1.5 m), 80 percent of area
- Maximum flame height, 3 feet (0.9 m), 80 percent of area
- Maximum crown scorch height, 20 feet (6.1 m)
- 1-h TL dead fuel moisture, 5-8 percent MC
- 10-h TL dead fuel moisture, 5-10 percent MC
- 100-h TL dead fuel moisture, over 5 percent MC
- Lower duff moisture, over 30 percent MC
- Wind, 2-10 mi/h (3-16 km/h) in stand.

Your prescription is complete; you must now estimate the logistics required to prepare for and conduct the burn and to mop up afterwards. The estimates of lines to be prepared are on your field map (fig. 14). You estimate that a crew of eight

10. TIMBER (LITTER & UNDERSTORY) - LOW WINDSPEEDS

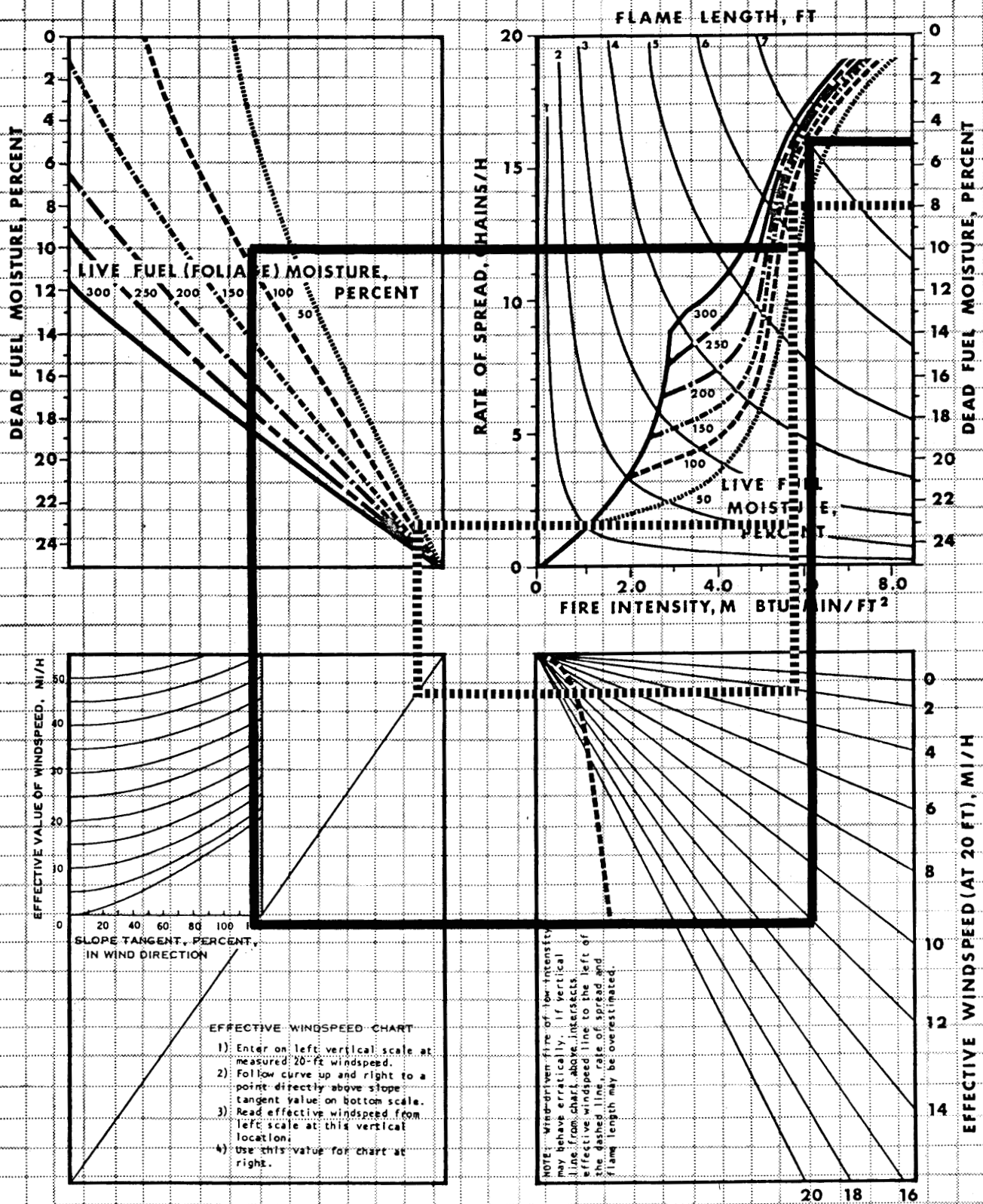


Fig. 20.--Under the least severe conditions (8-percent MC of 1-h timelag fuels, 2-mi/h (3.2-km/h) wind, and no slope), you could expect head fire flame lengths to be about 2 ft (0.6 m) and rate of spread about 1.5 chains (30 m) per hour (dashed line). Under the most severe conditions within the prescription (5-percent MC of 1-h timelag fuels, 10-mi/h (16-km/h) wind, and 30-percent slope) you could expect flame lengths of 6 ft (1.8 m) and a rate of spread of 12 chains (241 m) per hour (solid line).

can prepare the firelines in 1 day, since you have selected old roads and rocky drainages as firelines. You estimate your needs for burning and holding crews and for mopup. All the needed resources are entered on the burning plan.

The burning plan is essentially complete; now you need a system to monitor conditions on the site--a weather station. If you have the facilities, a dummy (temporary) NFDRS station should be installed, perhaps at a midelevation position on the site where readings can be taken daily. A hygrothermograph is good for 24-hour readings; a hygrothermoaerograph is even better (Fischer et al. 1969) for recording wind variation throughout the day and night. Each locale has its own wind peculiarities; the more you know about them, the safer will be the burning. You may supplement the weather station by using fuel moisture sticks and maximum-minimum thermometers at higher and lower elevations in the stand. As a check against predicted MC of different fuel-size classes, upper and lower duff, or foliage, you may have the weather observer collect samples for actual MC determinations. The observer can collect samples in sealed plastic bags or soil moisture cans. The samples can be transported to the office, weighed, oven-dried at 160°F (70°C) for 2 to 3 days, and reweighed.^{9/} (See appendix A for information on measuring moisture content.)

You are not able to prepare the area for burning this spring, so you plan for a fall burn--either a spring or fall burn could meet your prescription. You use your summer fire crews to prepare lines.

Fall arrives in mid-September. The first substantial rain falls, and measurements indicate that the burn area received 1.20 inches (3.0 cm) of rain on a Thursday. You alert all concerned parties of the possibility of burning on Monday or Tuesday, as the fire weather forecaster has predicted conditions that meet your prescription.

Weekend weather has been as predicted. On Monday morning you ask the fire weather forecaster for another spot weather forecast and then go into the field with your weather observer to check conditions on the site. The overnight low has been 40°F (5°C), and high humidity was 80 percent. Since the fire weather forecaster has predicted a high of 65° to 70°F (18° to 21°C) you quickly estimate by rule of thumb^{10/} that your humidity should reach a low of 30 to 35 percent in early afternoon. (See appendix B for estimating relative humidity from temperature changes.)

You radio headquarters that you plan to begin burning at 1100. Your dispatcher has instructions for whom to contact, including not only your personnel but radio and television stations, police and sheriff's departments, and other land management agencies.

The wind, as predicted, is from the west. You assemble your crews at the southeast corner of the unit for a complete briefing of firing and holding crews. A final check with the fire weather forecaster indicates no changes in predicted weather. At 1045, notify the dispatcher you are going to "put up smoke." You light a test fire and observe its behavior. The fire backs through the duff with flames less than 1 foot (0.3 m) in length, with occasional flareups as it engulfs fuel concentrations and needle drape in the shrubs. Strip head fires burn with flame lengths

^{9/} Percent moisture content is then calculated as:
$$MC\% = \frac{\text{Field weight} - \text{ovendry weight}}{\text{Ovendry weight}} \times 100.$$

Subtract the weight of the cans or bags from the field and oven-dry weights before doing the calculations.

^{10/} Procedure based on experience and common sense.

of 1 to 3 feet (0.3 to 0.9 m) in the duff, but large shrubs with needle drape occasionally produce flame lengths of 6 to 9 feet (1.8 to 2.7 m). You explain the variation to your crewmembers and tell them what you want the fire to look like. You instruct them, as they light the strip head fires by hand, to look ahead for potential hotspots and modify their lighting to get maximum area covered but keep flame length under 5 feet (1.5 m) 80 percent of the time. When the lighters come to a potential hotspot, they should allow fire to back through the fuel where possible and should straighten the fireline on future passes.

You make the decision to continue burning and request the two lookouts in the vicinity to notify you of any major changes in the weather. You disperse the holding crews to their original stations (fig. 17).

Burning begins nicely and by 1130 approximately 3 chains (60 m) into unit C have been burned. You now begin backfiring the eastern line of unit B, at the same time dispersing six of crew C₁ along this line. At noon, you are ready to fire interior line of unit C so that you can complete that unit in the day's burning time. Pumper P₁ moves to the midpoint of the south boundary road. By 1300, you begin backfiring the east line of unit A, moving five members of crew C₁ to patrol this line. You move pumper P₂ to the north end of unit A.

You periodically check with the burners to answer questions and suggest changes in their lighting procedures. As you move through the unit you make notes on weather, fire characteristics, fuel consumption, and other factors. You are carrying out the first phases of fire evaluation. Once all fires are well into the interior of the units, you begin rotating the burners and the holding crewmembers. Two holding crewmembers at a time are designated to eat lunch but to remain on their station.

Weather readings at 1400 indicate a temperature of 64°F (18°C) and a relative humidity of 35 percent. These components look good. The wind is shifting to the northwest, and you instruct the burners to begin shifting their firing lines to a more southwest-to-northeast orientation. You also instruct the burners on unit C to extend their backfires along the south road, as this will give added protection against further wind shift from the north and allow a widened black line against which to strip head fire. You move four holding crewmembers to the south road.

By 1630, unit A is burned out, and units B and C have 5 to 7 chains (100 to 140 m) yet to burn. By now six of the holding crew and the two pumpers are mopping up hotspots along the firelines. At 1715, burning of all units is complete. You notify the dispatcher and the lookouts that burning is completed and that a pumper will patrol the area throughout the night. The pumper will continue to mopup along the firelines. A relief pumper will relieve the pumper at midnight, and a four-person crew will work with a pumper on mopup the next day.

The next morning check on mopup in the area and complete your short-term evaluation of the fire. The evaluation may be extensive, with remeasurement of fuels and documentation of tree or shrub injury, or it may be a less intensive perusal of the apparent effects of the burn. As your prescribed burning program develops, you will probably spend less time per acre in evaluation as you will be better able to estimate fire effects. You complete the evaluation section of the burning plan and plan to reevaluate in the spring and the next fall. You decide the conditions and fire will be such that after today the fire prevention technician can assess any potential problems by early morning and midafternoon visits, as well as more visits should the weather become drier and windier.

You have now completed your first management-size burn on the forest.



Summary of Steps in a Successful Prescribed Burn

1. The general objectives of management for a given piece of land should come from overall land use planning and the basic philosophy of the organization.
2. A reconnaissance is necessary to decide if the unit needs treatment. Measurements and evaluation may be needed at this point.
3. General objectives of the treatment should be developed and should involve several resource disciplines.
4. A decision should be made on the tools to be used and specific objectives of the treatment delineated. An environmental analysis report may be prepared at this point.
5. A prescription that will meet the objectives should be developed. Several estimation techniques are available.
6. Written burning plans should be developed and reviewed.
7. Preparations must be made for burning.
8. The burn is conducted.
9. The burn is evaluated and mopped up.
10. Feedback on various steps of the planning process will aid in future burning.



Literature Cited

- Ahlgren, I. F., and C. E. Ahlgren.
1960. Ecological effects of forest fires. *Bot. Rev.* 26:483-533.
- Albini, Frank A.
1976. Estimating wildfire behavior and effects. USDA For. Serv. Gen. Tech. Rep. INT-30, 97 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.
- Alexander, M. E., and F. G. Hawksworth.
1975. Wildland fires and dwarf mistletoes: A literature review of ecology and prescribed burning. USDA For. Serv. Gen. Tech. Rep. RM-14, 12 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
- Allen, M. H., R. W. Berry, D. Gill, and others.
1968. Guide to prescribed fire in the Southwest. Southwest Interagency Fire Council, West. For. Fire Comm., West. For. and Conserv. Assoc. 58 p.
- Beaufait, W. R., G. E. Hardy, and W. C. Fisher.
1975. Broadcast burning in larch-fir clearcuts: The Miller Creek-Newman Ridge Study. USDA For. Serv. Res. Pap. INT-175, 53 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

- Beaufait, William R.
1966. Prescribed fire planning in the intermountain West. USDA For. Serv. Res. Pap. INT-26, 27 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.
- Bevins, Collin D.
1976. Evaluation of the slash fuel model of the National Fire-Danger Rating System. Master's thesis. Univ. Wash., Seattle. 104 p.
- Bollen, Walter B.
1974. Soil microbes. In Environmental effects of forest residues management in the Pacific Northwest, a state of knowledge compendium, p. B-1 to B-41. USDA For. Serv. Gen. Tech. Rep. PNW-24. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.
- Brown, James A., Kendall Snell, and David L. Bunnell.
1977. Handbook for predicting slash weight of western conifers. USDA For. Serv. Gen. Tech. Rep. INT-37, 35 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.
- Brown, James K.
1974. Handbook for inventorying downed woody material. USDA For. Serv. Gen. Tech. Rep. INT-16, 24 p., illus. Intermt. For. and Range Exp. Stn., Ogden, Utah.
- Burgy, R. H., and V. H. Scott.
1952. Some effects of fire and ash on the infiltration capacity of soils. Am. Geophys. Union Trans. 33:405-416.
- Davis, J. R., P. F. Ffolliott, and W. P. Clary.
1968. Fire prescription for consuming ponderosa pine duff. USDA For. Serv. Res. Note RM-115, 4 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
- Debano, L. F.
1969. Water repellent soils; a worldwide concern in management of soil and vegetation. Agric. Sci. Rev. 7:4-18.
- Debano, L. F., and J. S. Krammes.
1966. Water repellent soils and their relationship to wildfire temperatures. Int. Assoc. Sci. Hydrol. 11:14-19.
- Debano, L. F., L. D. Mann, and D. A. Hamilton.
1970. Translocation of hydrophobic substances into soil by burning organic litter. Soil Sci. Am. Proc. 34:130-133.
- Debell, D. S., and C. W. Ralston.
1970. Release of nitrogen by burning light forest fuels. Soil Sci. Soc. Am. Proc. 34:936-938.
- DeByle, N. V.
1973. Broadcast burning of logging residues and the water repellancy of soils. Northwest Sci. 47(2):77-87.
- Deeming, John E., Robert E. Burgan, and Jack D. Cohen.
1978. The National Fire-Danger Rating System - 1978. USDA For. Serv. Gen. Tech. Rep. INT-39. Intermt. For. and Range Exp. Stn., Ogden, Utah.
- Dell, John D.
1976. Fuels and fire management--prescribed fire use on the National Forests in the Pacific Northwest Region. Proc. 15th Annu. Tall Timbers Fire Ecol. Conf., p. 119-126. Tall Timbers Res. Stn., Tallahassee, Fla.

- Fischer, William C., William R. Beaufait, and Rodney A. Norum.
1969. The hygrothermoaerograph - construction and fire management applications. USDA For. Serv. Res. Note INT-87, 8 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.
- Green, Lisle R.
1977. Fuelbreaks and other fuel modification for wildland fire control. U.S. Dep. Agric., Agric. Handb. 499, 79 p. Washington, D.C.
- Hall, Frederick C.
1973. Plant communities of the Blue Mountains in eastern Oregon and southeastern Washington. R-6 Area Guide 3-1, 62 p. USDA For. Serv., Pac. Northwest Reg., Portland, Oreg.
- Hall, Frederick C.
1976. Fire and vegetation in the Blue Mountains--implications for land managers. Proc. 15th Annu. Tall Timbers Fire Ecol. Conf., p. 155-170. Tall Timbers Res. Stn., Tallahassee, Fla.
- Helvey, J. D., A. R. Tiedemann, and W. B. Fowler.
1976. Some climatic and hydrologic effects of wildfire in Washington State. Proc. 15th Annu. Tall Timbers Fire Ecol. Conf., p. 201-222. Tall Timbers Res. Stn., Tallahassee, Fla.
- Ingebo, P. A., and A. R. Hibbert.
1974. Runoff and erosion after brush suppression on the natural drainage watersheds in central Arizona. USDA For. Serv. Res. Note RM-275, 7 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
- Kozlowski, T. T., and C. E. Ahlgren, Eds.
1974. Fire and ecosystems. 542 p. Acad. Press: New York, San Francisco, London.
- Lewis, W. M.
1974. Effects of fire on nutrient movement in a South Carolina pine forest. Ecology 55:1120-1127.
- Lorenz, Ralph W.
1939. High temperature tolerance of forest trees. Univ. Minn. Agric. Exp. Stn. Bull. 141, 35 p. St. Paul, Minn.
- Martin, R. E.
1977. Prescribed burning for site preparation in the inland Northwest. Workshop on tree planting in the inland Northwest, 44 p. Wash. State Univ., Pullman.
- Martin, Robert E.
1978. Prescribed burning: decisions, prescriptions, strategies. 5th Natl. Conf. Fire and For. Meteorol., March 14-16, 1978, Atlantic City, N.J., p. 94-99, illus. Am. Meteorol. Soc., Boston, Mass.
- Martin, Robert E., Stuart E. Coleman, and Arlen H. Johnson.
1977. Wetline technique for prescribed burning firelines in rangeland. USDA For. Serv. Res. Note PNW-292. 6 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.
- Martin, Robert E., Charles T. Cushwa, and Robert L. Miller.
1969. Fire as a physical factor in wildlife management. Proc. 9th Annu. Tall Timbers Fire Ecol. Conf., p. 271-288. Tall Timbers Res. Stn., Tallahassee, Fla.

- Martin, Robert E., Dan D. Robinson, and Walter L. Schaeffer.
1976. Fire in the Pacific Northwest: Perspectives and problems. Proc. 15th Annu. Tall Timbers Fire Ecol. Conf., p. 1-23. Tall Timbers Res. Stn., Tallahassee, Fla.
- Maxwell, Wayne G., and Frank R. Ward.
1976. Photo series for quantifying forest residues in the: ponderosa pine type, ponderosa pine and associated species type, lodgepole pine type. USDA For. Serv. Gen. Tech. Rep. PNW-52, 73 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.
- Mobley, Hugh E., Robert S. Jackson, William E. Balmer, and others.
1977. A guide for prescribed fire in southern forests. USDA For. Serv. South. Reg., 40 p. Atlanta, Ga.
- Nelson, R. M.
1952. Observations on heat tolerance of southern pine needles. USDA For. Serv. Southeast. For. Exp. Stn. Pap. 14, 8 p. Asheville, N.C.
- Norum, Rodney A.
1977. Preliminary guidelines for prescribed burning under standing timber in western larch/Douglas-fir forests. USDA For. Serv. Res. Note INT-229, 15 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.
- Rothacher, Jack, and William Lopushinsky.
1974. Soil stability and water yield and quality. In Environmental effects of forest residues management in the Pacific Northwest, a state-of-knowledge compendium, p. D-1 to D-23, illus. USDA For. Serv. Gen. Tech. Rep. PNW-24. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.
- Schroeder, Mark J., and Charles C. Buck.
1970. Fire weather. A guide for application of meteorological information to forest fire control operation. U.S. Dep. Agric., Agric. Handb. 360, 229 p.
- Scott, V. H.
1956. Relative infiltration rates of burned and unburned upland soils. Am. Geophys. Union Trans. 37:67-69.
- Scott, V. H., and R. H. Burgy.
1956. Effects of heat and brush burning on the physical properties of certain upland soils that influence infiltration. Soil Sci. 82:63-70.
- Silen, Roy R.
1963. Lethal surface temperatures and their interpretation for Douglas-fir. Ph. D. thesis. Oreg. State Coll., Corvallis.
- Society of American Foresters.
1958. Forestry terminology. 97 p. Washington, D.C.
- Soeriaatmadja, R. E.
1966. Fire history of the ponderosa pine forests of Warm Springs Indian Reservation, Oregon. Ph. D. thesis. Oreg. State Univ., Corvallis. 132 p.
- Southern Forest Fire Laboratory.
1977. Southern forestry smoke management guidebook. USDA For. Serv. Gen. Tech. Rep. SE-10, 140 p. Southeast. For. and Range Exp. Stn., Asheville, N.C.
- Swanson, John Roger.
1974. Prescribed underburning for wildfire hazard abatement in second-growth stands of west-side Douglas-fir. Master's thesis. Univ. Wash., Seattle. 130 p.

- Tiedemann, Arthur R., and Glen O. Klock.
1976. Development of vegetation after fire, seeding, and fertilization on the Entiat Experimental Forest. Proc. 15th Annu. Tall Timbers Fire Ecol. Conf., p. 171-192. Tall Timbers Res. Stn., Tallahassee, Fla.
- U.S. Department of Agriculture, Forest Service.
1974. Fuel management planning and treatment guide: Prescribed burning guide. USDA For. Serv., North. Reg., 56 p. Missoula, Mont.
- U.S. Department of Agriculture, Forest Service.
[n.d.-a] Fuel management planning and treatment guide. Prescribed burning guide. North. Reg., 56 p. Missoula, Mont.
- U.S. Department of Agriculture, Forest Service.
[n.d.-b] Fuel management planning and treatment guide: Specific methods and procedures. North Reg., 50 p. Missoula, Mont.
- Volland, Leonard A.
1976. Plant communities of the central Oregon pumice zone. Reg. 6 Area Guide 4-2, 110 p. USDA For. Serv. Pac. Northwest Reg., Portland, Oreg.
- Wallace, Michael Wayne.
1976. The effects of fire on nutrient conditions in the *Pinus ponderosa* zone of central Oregon. Master's thesis. Univ. Wash., Seattle. 73 p.
- Weaver, Harold.
1959. Ecological changes in the ponderosa pine forest of the Warm Springs Indian Reservation in Oregon. J. For. 57(1):15-20.
- Weaver, Harold.
1961. Ecological changes in the ponderosa pine forests of Cedar Valley in southern Washington. Ecology 42(2):416-420.
- Weaver, Harold.
1967. Some effects of prescribed burning on the Coyote Creek test area. J. For. 65(8):552-558.
- Wright, H. A.
1974. Range burning. J. Range Manage. 27(1):5-11.



Additional References

- Ahlgren, C. E.
1959. Some effects of fire on forest reproduction in northeastern Minnesota. *J. For.* 57(3):194-200.
- Ahlgren, Clifford E.
1960. Some effects of fire on reproduction and growth of vegetation on northeastern Minnesota. *Ecology* 41(3):431-445.
- Ahlgren, Clifford E.
1966. Small mammals and reforestation following prescribed burning. *J. For.* 64(9):614-618.
- Ahlgren, Clifford E.
1974. Effects of fires on temperate forests: North Central United States. *In* Fire and ecosystems, p. 195-223. Acad. Press, New York.
- Aldon, Earl F.
1968. Moisture loss and weight of the forest floor under pole-size ponderosa pine stands. *J. For.* 66(1):70-71.
- Anderson, H. E.
1968. Fire spread and flame shape. *Fire Technol.* 4(1):51-58.
- Anderson, H. E.
1974. Appraising forest fuels--a concept. USDA For. Serv. Res. Note INT-187. Intermt. For. and Range Exp. Stn., Ogden, Utah.
- Anderson, Henry W.
1976. Fire effects on water supply, floods, and sedimentation. *Proc. 15th Annu. Tall Timbers Fire Ecol. Conf.*, p. 249-260. Tall Timbers Res. Stn., Tallahassee, Fla.
- Andrews, E. F.
1907. Agency of fire in propagation of longleaf pine. *Bot. Gaz.* 64: 497-508.
- Axelton, Elvera A. (Compiler).
1967. Ponderosa pine bibliography through 1965. USDA For. Serv. Res. Pap. INT-40, 150 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.
- Axelton, Elvera A.
1974. Ponderosa pine bibliography II: 1966-1970. USDA For. Serv. Gen. Tech. Rep. INT-12, 63 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.
- Barney, Richard J.
1971. Wildfires in Alaska--some historical and projected effects and aspects. *Proceedings--Fire in the northern environment--a symposium*, p. 51-60. USDA For. Serv. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

- Barrett, James W.
1965. Spacing and understory vegetation affect growth of ponderosa pine saplings. USDA For. Serv. Res. Note PNW-27, 8 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.
- Barrett, James W.
1970. Ponderosa pine saplings respond to control of spacing and understory vegetation. USDA For. Serv. Res. Pap. PNW-106, 16 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.
- Beadle, N. C. W.
1940. Soil temperatures during forest fires and their effect on the survival of vegetation. J. Ecol. 28:180-192.
- Beaufait, William R.
1960. Some effects of high temperatures on the cones and seeds of jack pine (*Pinus banksiana*). For. Sci. 6(3):194-199.
- Beaufait, William R.
1961. Crown temperatures during prescribed burning in jack pine. Mich. Acad. Sci. 1960 Pap. 46(1):251-257.
- Bendell, J. F.
1974. Effects of fire on birds and mammals. In Fire and ecosystems, p. 73-138. Acad. Press, New York.
- Bentley, J. R.
1967. Conversion of chaparral areas to grassland: Techniques used in California. USDA For. Serv. Agric. Handb. 328. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.
- Berndt, H. W.
1971. Early effects of forest fire on streamflow characteristics. USDA For. Serv. Res. Note PNW-148, 9 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.
- Biswell, H. H.
1959. Man and fire in ponderosa pine in the Sierra Nevada of California. Sierra Club Bull. 44:44-53.
- Biswell, H. H., H. R. Kallander, R. Komarek, and others.
1973. Ponderosa fire management: A task force evaluation of controlled burning in ponderosa pine forests of central Arizona. Tall Timbers Res. Stn. Misc. Publ. 2, 49 p. Tallahassee, Fla.
- Biswell, H. H., and A. M. Schultz.
1958. Manzanita control in ponderosa. Calif. Agric. 12:12.
- Biswell, H. H., W. O. Shepherd, B. L. Sauthwell, and T. S. Boggess, Jr.
1943. Native forage plants of cutover forest lands in the coastal plain of Georgia. Ga. Coastal Plain Exp. Stn. Bull. 37:1-43.
- Biswell, H. H., and J. E. Street.
1948. Wedgeleaf ceanothus, range brush: Increase studied and control method recommended. Calif. Agric. 2:3-12.
- Biswell, Harold H.
1960. Danger of wild fires reduced by prescribed burning in ponderosa pine. Calif. Agric. 14(10):5-6.
- Biswell, Harold H.
1974. Effects of fire on chaparral. In Fire and ecosystems, p. 321-364. Acad. Press, New York.

- Boldt, C. E., and J. L. Van Deusen.
1974. Silviculture of ponderosa pine in the Black Hills: The status of our knowledge. USDA For. Serv. Res. Pap. RM-124, 45 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
- Brackebusch, A. P.
1975. Gain and loss of moisture in large forest fuels. USDA For. Serv. Res. Pap. INT-173, 50 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.
- Brackebusch, Arthur P.
1973. Fuel management: a prerequisite not an alternative to fire control. J. For. 71(10):637-643.
- Brender, Ernst V., and Robert W. Cooper.
1968. Prescribed burning in Georgia's Piedmont loblolly pine stands. J. For. 66(1):31-36.
- Brown, J. K.
1970. Physical fuel properties of ponderosa pine floors and cheatgrass. USDA For. Serv. Res. Pap. INT-74, 16 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.
- Brown, J. H., K. M. Cook, F. G. Ney, and T. Hatch.
1950. Influence of particle size upon the retention of particulate matter in the human lung. Am. J. Public Health 40:450-459.
- Brown, James K.
1971. A planar intersect method for sampling fuel volume and surface area. For. Sci. 17(1):96-102.
- Buckman, Robert E.
1962. Two prescribed summer fires reduce abundance and vigor of hazel brush regrowth. USDA For. Serv. Lake States Exp. Stn. Tech. Note 620, 2 p. St. Paul, Minn.
- Buckman, Robert E.
1964. Effects of a prescribed burn on hazel in Minnesota. Ecology 45(3): 626-629.
- Byram, George M.
1948. Vegetation temperature and fire damage in the southern pines. Fire Control Notes 9(4):34-36.
- Byram, George M.
1954. Atmospheric conditions related to blowup fires. USDA For. Serv. Southeast. For. Exp. Stn. Res. Pap. 35, 31 p. Asheville, N.C.
- Byram, George M.
1958. Some basic thermal processes controlling the effects of fire on living vegetation. USDA For. Serv. Southeast. For. Exp. Stn. Res. Note 114, 2 p. Asheville, N.C.
- Chapman, Herman H.
1912. Forest fires and forestry in the Southern States. Am. For. 18(8): 510-517.
- Clevinger, W. R.
1951. S.W. Washington's legendary "big fire." Seattle Times Mag., October 28, p. 2.
- Cooper, C. F.
1960. Changes in vegetation, structure and growth of southwestern pine forests since white settlement. Ecol. Monogr. 30:129-164.

- Cooper, C. F.
1961. The ecology of fire. *Sci. Am.* 204(4):150-160.
- Cooper, R. W.
1971. The pros and cons of prescribed burning in the South.
For. Farmer 31(2):10-12, 39-40.
- Cordone, A. J., and D. W. Kelley.
1961. The influences of inorganic sediment on the aquatic life of streams.
Calif. Fish and Game 47(2):189-228.
- Countryman, Clide M.
1964. Mass fires and fire behavior. USDA For. Serv. Res. Pap. PSW-19,
53 p., illus. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.
- Cramer, Owen P.
1969. Disposal of logging residues without damage to air quality.
U.S. Dep. Commer. Weather Bur. Tech. Memo. 37, 8 p.
- Cramer, Owen P.
1974. Air quality influences. *In* Environmental effects of forest residues
management in the Pacific Northwest, p. F-1 to F-51. USDA For. Serv.
Gen. Tech. Rep. PNW-24. Pac. Northwest For. and Range Exp. Stn.,
Portland, Oreg.
- Cramer, Owen P., Ed.
1974. Environmental effects of forest residues management in the Pacific
Northwest: a state-of-knowledge compendium. USDA For. Serv. Gen. Tech.
Rep. PNW-24. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.
- Curtis, J. T., and R. Vogl.
1961. Prairie fire heats little below ground. *Sci. News* 79:152.
- Cushwa, Charles T., and Robert E. Martin.
1969. The status of prescribed burning for wildlife management in the
Southeast. North Am. Wildlife Conf., Washington, D.C., Trans., p. 420-8.
- Darley, E. F., F. R. Burleson, E. H. Mateer, and others.
1966. Contribution of burning of agriculture wastes to photochemical
air pollution. *J. Air Pollut. Control Assoc.* 16(12):685-690.
- Davis, Kenneth P.
1959. Forest fire control and use. 584 p. McGraw-Hill Book Co., Inc.,
New York.
- Davis, Laurence S., and Robert W. Cooper.
1963. How prescribed burning affects wildlife occurrence. *J. For.*
61(12):915-917.
- Davis, Laurence, and Robert E. Martin.
1960. Time-temperature relationships of test head fires and backfires.
USDA For. Serv. Southeast. For. Exp. Stn. Res. Note 148, 2 p. Asheville,
N.C.
- Day, Gordon M.
1953. The Indian as an ecological factor in the Northeastern forest.
Ecology 34(2):329-346.
- Debano, L. F., and R. M. Rice.
1971. Fire in vegetation management: its effect on soil. *Am. Soc.*
Civ. Eng., p 327-347. Bozeman, Mont.

- Deeming, John E., James W. Lancaster, Michael A. Fosberg, and others.
1972. National Fire-Danger Rating System. USDA For. Serv. Res. Pap. RM-84, 53 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
- Dell, John D., and Franklin R. Ward.
1971. Logging residues on Douglas-fir region clearcuts--weights and volumes. USDA For. Serv. Res. Pap. PNW-115, 10 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.
- Dodge, M.
1972. Forest fuel accumulation--a growing problem. Science 177(7):139-142.
- Donohue, L. R., and V. J. Johnson.
1975. Prescribed burning in the North Central States. USDA For. Serv. Res. Pap. NC-111, 8 p. North Cent. For. Exp. Stn., St. Paul, Minn.
- Droege, Henry F.
1976. Fire and environmental criteria. Proc. 15th Annu. Tall Timbers Fire Ecol. Conf., p. 261-264. Tall Timbers Res. Stn., Tallahassee, Fla.
- Duprey, R. L.
1968. Compilation of air pollutant emission factors. U.S. Dep. Health, Educ., and Welfare, Public Health Serv. Publ. 999-AP-42, 67 p.
- Dyrness, C. T., and C. T. Youngberg.
1957. The effect of logging and slash-burning on soil structure. Soil Sci. Soc. Am. Proc. 21:444-447.
- Eldridge, I. F.
1911. Fire problem on the Florida National Forest. Soc. Am. For. Proc. 6:166-170.
- Eyre, F. H., and R. K. LeBarron.
1944. The management of jack pine stands in the Lake States. USDA For. Serv. Tech. Bull. 863.
- Fahnestock, George R.
1960. Logging slash flammability. USDA For. Serv. Intermt. For. and Range Exp. Stn. Res. Pap. 58, 67 p. Ogden, Utah.
- Fahnestock, George R.
1968. Fire hazard from precommercial thinning of ponderosa pine. USDA For. Serv. Res. Pap. PNW-57, 16 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.
- Fahnestock, George R.
1976. Fires, fuels, and flora as factors in wilderness management: the Pasayten case. Proc. 15th Annu. Tall Timbers Fire Ecol. Conf., p. 33-70. Tall Timbers Res. Stn., Tallahassee, Fla.
- Fahnestock, George R., and J. H. Dieterich.
1962. Logging slash flammability after five years. USDA For. Serv. Intermt. For. and Range Exp. Stn. Res. Pap. 70, 15 p. Ogden, Utah.
- Fahnestock, George R., and Robert C. Hare.
1964. Heating of tree trunks in surface fires. J. For. 62(1):799-805.
- Feldstein, M., S. Duckworth, H. C. Wohlers, and B. Linsky.
1963. The contribution of the open burning of land clearing debris to air pollution. J. Air Pollut. Control Assoc. 13(11):542-545, 564.

- Ffolliott, Peter F., Warren P. Clary, and B. Baker, Jr.
1976. Characteristics of the forest floor on sandstone and alluvial soils in Arizona's ponderosa pine type. USDA For. Serv. Res. Note RM-308, 4 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
- Ffolliott, Peter F., Warren P. Clary, and James R. Davis.
1968. Some characteristics of the forest floor under ponderosa pine in Arizona. USDA For. Serv. Res. Note RM-127, 4 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
- Foiles, Marvin W., and James D. Curtis.
1973. Regeneration of ponderosa pine in the northern Rocky Mountain-Intermountain Region. USDA For. Serv. Res. Pap. INT-145, 44 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.
- Fritschen, Leo J., Harley Bovee, Konrad Buettner, and others.
1970. Slash fire atmospheric pollution. USDA For. Serv. Res. Pap. PNW-97, 42 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.
- Fritz, Emanuel.
1931. The role of fire in the redwood region. J. For. 29(5):939-950.
- Fritz, Emanuel.
1932. The role of fire in the redwood region. Univ. Calif. Agric. Exp. Stn. Circ. 323, 23 p.
- Fuchs, N. A.
1964. The mechanics of aerosols. p. 4. Pergamon Press, Oxford.
- Garren, Kenneth H.
1943. Effects of fire on vegetation of the Southeastern United States. Bot. Rev. 9(9):617-654.
- Gerstle, R. W., and D. A. Kemnitz.
1967. Atmospheric emissions from open burning. J. Air Pollut. Control Assoc. 17(5):324-327.
- Gipe, Donald.
1976. Response of range to burning. Proc. 15th Annu. Tall Timbers Fire Ecol. Conf., p. 25-32. Tall Timbers Res. Stn., Tallahassee, Fla.
- Gordon, Donald T.
1967. Prescribed burning in the interior ponderosa pine type of northeastern California: A preliminary study. USDA For. Serv. Res. Pap. PSW-45, 20 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.
- Gratkowski, Henry J.
1962. Heat as a factor in germination of seeds of *Ceanothus velutinus* var. *laevigatus* t. & g. Ph. D. thesis. Oreg. State Univ., Corvallis. 122 p.
- Green, Lisle R., and Harry E. Schimke.
1971. Guides for fuel-breaks in the Sierra Nevada mixed-conifer type. USDA For. Serv. Pac. Southwest For. and Range Exp. Stn., 14 p. Berkeley, Calif.
- Greene, S. W.
1931. The forest that fire made. Am. For. 37(10):583-584.
- Grelen, H. E., and V. L. Duvall.
1966. Common plants of longleaf pine-bluestem range. USDA For. Serv. Res. Pap. SO-23, 96 p. South. For. Exp. Stn., Atlanta, Ga.

- Grier, Charles C.
1972. Effects of fire on the movement and distribution of elements within a forest ecosystem. Ph. D. thesis. Univ. Wash., Seattle. 167 p.
- Haessler, W. M.
1965. Smoke detection by forward light scattering. *Fire Technol.* 11(1):43-51.
- Hakala, John B., Robert K. Seemel, R. A. Richey, and John E. Kurtz.
1971. Fire effects and rehabilitation methods--Swanson-Russian Rivers fires. *In Fire in the northern environment*, p. 87-99. C. W. Slaughter, Richard J. Barney, and G. M. Hansen, eds. USDA For. Serv. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.
- Hall, A. G.
1947. Four flaming days. *Am. For.* 53(12):540-542, 569-570.
- Hall, I. V.
1955. Floristic changes following the cutting and burning of a woodlot for blueberry production. *Can. J. Agric. Sci.* 35:143-152.
- Hall, J. Alfred.
1972. Forest fuels, prescribed fire, and air quality. USDA For. Serv. Pac. Northwest For. and Range Exp. Stn., 44 p. Portland, Oreg.
- Hall, J. D., and R. L. Lantz.
1969. Effects of logging on the habitat of coho salmon and cutthroat trout in coastal streams. *In Symposium on salmon and trout air streams*, 1968, p. 355-375. T. G. Northcote, ed. Univ. B.C., Vancouver.
- Hardison, John R.
1976. Fire and disease. *Proc. 15th Annu. Tall Timbers Fire Ecol. Conf.*, p. 223-234. Tall Timbers Res. Stn., Tallahassee, Fla.
- Harper, R. M.
1914. Geography and vegetation of northern Florida. *Fla. Geol. Surv.*, 6th Annu. Rep., p. 266-279.
- Hartman, Harold E.
1976. Forest land fire: Industry's enemy and management ally. *Proc. 15th Annu. Tall Timbers Fire Ecol. Conf.*, p. 127-134. Tall Timbers Res. Stn., Tallahassee, Fla.
- Hawes, Auston F.
1923. New England forests in retrospect. *J. For.* 21(3):209-224.
- Hedin, Al.
1976. Fire and environmental criteria. *Proc. 15th Annu. Tall Timbers Fire Ecol. Conf.*, p. 265-270. Tall Timbers Res. Stn., Tallahassee, Fla.
- Heinselman, M. L.
1969. Diary of the canoe country's landscape. *Nature* 20:2-13.
- Hendrickson, William H.
1972. Perspective on fire and ecosystems in the United States. *In Fire in the environment: Symposium proceedings*, Denver, May 1-5, 1972, p. 29-33. USDA For. Serv. FS-276.
- Heyward, Frank.
1938. Soil temperatures during forest fires in the longleaf pine region. *J. For.* 36(5):478-491.

- Hilmon, J. B., and Ralph H. Hughes.
1965. Forest Service research on the use of fire in livestock management in the South. Proc. 4th Annu. Tall Timbers Fire Ecol. Conf., p. 261-275. Tall Timbers Res. Stn., Tallahassee, Fla.
- Horton, K. W., and E. J. Hopkins.
1965. Influence of fire on aspen suckering. Can. Dep. For. Publ. 1095, 19 p.
- Howard, W. E., R. L. Fenner, and H. E. Childs, Jr.
1959. Wildlife survival on brush burns. J. Range Manage. 12:230-234.
- Hughes, Ralph H.
1966. Fire ecology of canebrakes. Proc. 5th Annu. Tall Timbers Fire Ecol. Conf., p. 149-158. Tall Timbers Res. Stn., Tallahassee, Fla.
- Humphrey, Robert R.
1963. The role of fire in the desert and desert grassland areas of Arizona. Proc. 2d Annu. Tall Timbers Fire Ecol. Conf., p. 45-61. Tall Timbers Res. Stn., Tallahassee, Fla.
- Isaac, L. A.
1943. Reproductive habits of Douglas-fir. Chas. Lathrop Pack For. Found. Univ. Wash., Seattle.
- Johnson, Arlen H., and Garrett A. Smathers.
1976. Fire history and ecology, Lava Beds National Monument. Proc. 15th Annu. Tall Timbers Fire Ecol. Conf., p. 103-116. Tall Timbers Res. Stn., Tallahassee, Fla.
- Johnson, C. M., and P. R. Needham.
1966. Ionic composition of Sagehen Creek, California, following an adjacent fire. Ecology 47(4):636-639.
- Kallander, Harry.
1969. Controlled burning on the Fort Apache Indian Reservation, Ariz. Proc. 9th Annu. Tall Timbers Fire Ecol. Conf., p. 241-250. Tall Timbers Res. Stn., Tallahassee, Fla.
- Kilgore, Bruce M.
1971. The role of fire in a giant sequoia-mixed conifer forest. Paper, AAAS, Philadelphia, Pa. 1971.
- Kilgore, Bruce M.
1974. Fire management in National Parks: An overview. Proc. 14th Annu. Tall Timbers Fire Ecol. Conf., p. 45-57. Tall Timbers Res. Stn., Tallahassee, Fla.
- Klock, G. O., and J. D. Helvey.
1976. Soil-water trends following wildlife on the Entiat Experimental Forest. Proc. 15th Annu. Tall Timbers Fire Ecol. Conf., p. 193-200. Tall Timbers Res. Stn., Tallahassee, Fla.
- Klukas, Richard W.
1972. Control burn activities in Everglades National Park. Proc. 12th Annu. Tall Timbers Fire Ecol. Conf., p. 397-425. Tall Timbers Res. Stn., Tallahassee, Fla.
- Komarek, E. V., Sr.
1967. Fire--and the ecology of man. Proc. 6th Annu. Tall Timbers Fire Ecol. Conf., p. 143-170. Tall Timbers Res. Stn., Tallahassee, Fla.

- Komarek, E. V., Sr.
1967. The nature of lightning fires. Proc. 7th Annu. Tall Timbers Fire Ecol. Conf., p. 5-41. Tall Timbers Res. Stn., Tallahassee, Fla.
- Komarek, E. V., Sr.
1969. Fire and animal behavior. Proc. 9th Annu. Tall Timbers Fire Ecol. Conf., p. 161-207. Tall Timbers Res. Stn., Tallahassee, Fla.
- Komarek, E. V., Sr.
1974. Further remarks on controlled burning and air pollution. Proc. 13th Annu. Tall Timbers Fire Ecol. Conf., p. 279-282. Tall Timbers Res. Stn., Tallahassee, Fla.
- Komarek, E. V., Sr., B. B. Komarek, and T. C. Carlisle.
1973. The ecology of smoke particulates and charcoal residues from forest and grassland fires: A preliminary atlas. Tall Timbers Res. Stn., Tallahassee, Fla.
- Korstian, C. F.
1937. Perpetuation of spruce on cut-over and burned land in the higher southern Appalachian Mountains. Ecol. Monogr. 7:125-167.
- Kurz, H.
1944. Secondary forest succession in the Tallahassee red hills. Fla. Acad. Sci. 7, 42 p.
- LeBarron, Russell K.
1957. Silvicultural possibilities of fire in northeastern Washington. J. For. 55(9):627-630.
- Lemon, Paul C.
1949. Successional responses of herbs in the longleaf-slash pine forest after fire. Ecology 30(2):135-145.
- Lindenmuth, A. W., Jr.
1962. Effects on fuels and trees of a large intentional burn in ponderosa pine. J. For. 60(11):804-810.
- Little, S.
1959. Silvical characteristics of pitch pine (*Pinus rigida*). USDA For. Serv. Northeast. For. Exp. Stn. Pap. 119, 22 p. Broomall, Pa.
- Little, S.
1964. Fire ecology and forest management in the New Jersey pine region. Proc. 3d Annu. Tall Timbers Fire Ecol. Conf., p. 34-59. Tall Timbers Res. Stn., Tallahassee, Fla.
- Little, S.
1967. Treatments needed to regenerate yellow-poplar in New Jersey and Maryland. USDA For. Serv. Res. Note NE-58, 8 p. Northeast. For. Exp. Stn., Broomall, Pa.
- Little, S.
1974. Effects of fire on temperate forests: Northeastern United States. Fire and Ecosyst. Repr., Acad. Press, New York.
- Little, S., and H. A. Somes.
1956. Buds enable pitch and shortleaf pines to recover from injury. USDA For. Serv. Northeast. For. Exp. Stn. Pap. 81, 14 p. Broomall, Pa.
- Long, E. C.
1888. Notes of some of the forest features of Florida, with items of tree growth in that state. Proc. Am. For. Assoc. Conf. 7:38-41.

- Lotti, Thomas, Ralph A. Klawitter, and W. P. LeGrande.
1960. Prescribed burning for understory control in loblolly pine stands of the Coastal Plain. USDA For. Serv. Southeast. For. Exp. Stn. Pap. 116, 19 p. Asheville, N.C.
- Lutz, H. J.
1956. Ecological effects of forest fires in the interior of Alaska. U.S. Dep. Agric. Tech. Bull. 1133, 121 p. Washington, D.C.
- Lynch, D. W.
1959. Effects of a wildfire on mortality and growth of young ponderosa pine trees. USDA For. Serv. Intermt. For. and Range Exp. Stn. Res. Note 66, 8 p. Ogden, Utah.
- Lynch, J. J.
1941. The place of burning in management of the gulf coast refuges. J. Wildl. Manage. 5:454-458.
- MacArthur, D. A.
1966. Particle sizes in bushfire smoke. Aust. For. 30:274-278.
- McIntosh, R. P., and R. T. Hurley.
1964. The spruce-fir forests of the Catskill Mountains. Ecology 45(2): 314-326.
- Maissurou, D. K.
1935. Fire as a necessary factor in the perpetuation of white pine. J. For. 33(4):373-378.
- Martin, Robert E.
1963. A basic approach to fire injury of tree stems. Proc. 2d Annu. Tall Timbers Fire Ecol. Conf., p. 151-162. Tall Timbers Res. Stn., Tallahassee, Fla.
- Martin, Robert E., and Arthur P. Brackebusch.
1974. Fire hazard and conflagration prevention. In Environmental effects of forest residues management in the Pacific Northwest: A state-of-knowledge compendium, p. G-1 to G-30, illus. USDA For. Serv. Gen. Tech. Rep. PNW-24. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.
- Martin, Robert E., and Charles T. Cushwa.
1966. Effects of heat and moisture on leguminous seed. Proc. 5th Annu. Tall Timbers Fire Ecol. Conf., p. 159-175. Tall Timbers Res. Stn., Tallahassee, Fla.
- Martin, Robert E., and Laurence S. Davis.
1961. Temperatures near the ground during prescribed burning. Mich. Acad. Sci. 1960 Pap. 46(1):239-249.
- Martin, Robert Edward.
1963. Thermal and other properties of bark and their relation to fire injury to tree stems. Ph. D. thesis. Univ. Mich., Ann Arbor. 267 p.
- Matthews, Robert P.
1976. Fire implications for land managers. Proc. 15th Annu. Tall Timbers Fire Ecol. Conf., p. 117-118. Tall Timbers Res. Stn., Tallahassee, Fla.
- Meland, Bruce R., and Richard W. Boubel.
1966. A study of field burning under varying environmental conditions. J. Air Pollut. Control Assoc. 16(9):481-484.

- Metz, L. J., and M. H. Farrier.
1971. Prescribed burning and soil mesofauna on the Santee Experimental Forest. *In* Prescribed burning symposium, p. 100-105. USDA For. Serv. Southeast. For. Exp. Stn., Asheville, N.C.
- Miller, Howard A.
1963. Use of fire in wildlife management. Proc. 2d Annu. Tall Timbers Fire Ecol. Conf., 2:19-30 (23, 33). Tall Timbers Res. Stn., Tallahassee, Fla.
- Miller, Margaret M., and Joseph W. Miller.
1976. Succession after wildfire in the North Cascades National Park complex. Proc. 15th Annu. Tall Timbers Fire Ecol. Conf., p. 71-84. Tall Timbers Res. Stn., Tallahassee, Fla.
- Morris, W. G.
1934. Forest Fires in western Oregon and Washington. *Oreg. Hist. Q.* 35: 313-339.
- Morris, William G.
1970. Effects of slash burning in overmature stands of the Douglas-fir region. *For. Sci.* 16(3):258-270.
- Morris, William G., and Edwin L. Mowat.
1958. Some effects of thinning a ponderosa pine thicket with a prescribed fire. *J. For.* 56(3):203-209.
- Muir, J.
1894. The mountains of California. 163 p. Houghton, Boston, Mass.
- Muir, J.
1901. Our national parks. p. 68-69, 291-292, 307-308. Houghton, Boston, Mass.
- Munger, Thornton T.
1911. The growth and management of Douglas-fir in the Pacific Northwest. USDA For. Serv. Circ. 175.
- National Air Pollution Control Administration.
1970. National inventory of air pollutant emissions 1968. *Natl. Air Pollut. Control Admin. Publ. AP-73*. U.S. Dep. Health, Educ., and Welfare.
- Nelson, Jack R.
1976. Forest fire and big game in the Pacific Northwest. Proc. 15th Annu. Tall Timbers Fire Ecol. Conf., p. 85-102. Tall Timbers Res. Stn., Tallahassee, Fla.
- Phillips, C. B.
1971. California aflame! September 22-October 4, 1970. *State Calif. Dep. Conserv., Div. For.* 73 p.
- Philpot, C. W.
1965. Temperatures in a large natural-fuel fire. USDA For. Serv. Res. Note PSW-90, 14 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.
- Philpot, C. W.
1968. Mineral content and pyrolysis of selected plant materials. USDA For. Serv. Res. Note INT-84, 4 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

- Philpot, C. W.
1970. Influence of mineral content on the pyrolysis of plant materials. For. Sci. 16(4):451-471.
- Pierovich, John M., Edward H. Clarke, Stewart G. Pickford, and Franklin R. Ward.
1975. Forest residues management guidelines for the Pacific Northwest. USDA For. Serv. Gen. Tech. Rep. PNW-33, 273 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.
- Place, I. C. M.
1955. The influence of seed-bed conditions on the regeneration of spruce and balsam fir. Can. For. Branch Bull. 117, 87 p.
- Quick, Clarence R.
1935. Notes on germination of ceanothus seeds. Madrono 3:135-140.
- Quick, Clarence R.
1959. Ceanothus seeds and seedlings on burns. Madrono 15:79-81.
- Quick, Clarence R.
1962. Resurgence of a gooseberry population after fire in mature timber. J. For. 60(1):100-103.
- Quirk, William A., and Dwane J. Sykes.
1971. White spruce stringers in a fire-patterned landscape in interior Alaska. In Fire in the northern environment--a symposium, p. 179-197, illus. USDA For. Serv. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.
- Robertson, William B.
1962. Fire and vegetation in the Everglades. Proc. 1st Annu. Tall Timbers Fire Ecol. Conf., p. 67-80. Tall Timbers Res. Stn., Tallahassee, Fla.
- Roe, Eugene I.
1963. Seed stored in cones of some pine stands, northern Minnesota. USDA For. Serv. Res. Pap. LS-1, 14 p. Lake States For. Exp. Stn., St. Paul, Minn.
- Rothermel, Richard C.
1972. A mathematical model for predicting fire spread in wildlands fuels. USDA For. Serv. Res. Pap. INT-115, 40 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.
- Rothermel, Richard C., and Hal E. Anderson.
1966. Fire spread characteristics determined in the laboratory. USDA For. Serv. Res. Pap. INT-30, 34 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.
- Rothermel, Richard C., and Charles W. Philpot.
1973. Predicting changes in chaparral flammability. J. For. 71(10):640-643.
- Sampson, A. W.
1944. Plant succession on burned chaparral lands in northern California. Calif. Agric. Exp. Stn. Bull. 685, 143 p.
- Sandberg, David V.
1974. Measurement of particulate emissions from forest residues in open burning experiments. Ph. D. thesis. Univ. Wash., Seattle. 165 p.
- Sandberg, David V., and Robert E. Martin.
1975. Particle sizes in slash fire smoke. USDA For. Serv. Res. Pap. PNW-199, 7 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

- Sandberg, D. V., and S. G. Pickford.
1976. An approach to predicting slash fire smoke. Proc. 15th Annu. Tall Timbers Fire Ecol. Conf., p. 239-248. Tall Timbers Res. Stn., Tallahassee, Fla.
- Schiff, Ashley L.
1962. Fire and water. 225 p. Harvard Univ. Press, Cambridge, Mass.
- Schimke, Harry E., and Lisle R. Green.
1970. Prescribed fire for maintaining fuel-breaks in the Central Sierra Nevada. USDA For. Serv. Pac. Southwest For. and Range Exp. Sta., 9 p. Berkeley, Calif.
- Schubert, Gilbert H.
1974. Silviculture of southwestern ponderosa pine: The status of our knowledge. USDA For. Serv. Res. Pap. RM-123, 71 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
- Schwartz, G. F.
1907. The longleaf pine in virgin forest--a silvical study. 135 p. John Wiley and Sons, New York.
- Scotter, George W.
1964. Effects of forest fires on the winter range of barren ground caribou in northern Saskatchewan. Can. Wildl. Serv., Wildl. Manage. Bull., Ser. 1, No. 18, p. 11.
- Scotter, George W.
1971. Fire, vegetation, soil, and barren-ground caribou relations in northern Canada. In Fire in the northern environment--a symposium, p. 209-230, illus. USDA For. Serv. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.
- Shantz, H. L.
1947. The use of fire as a tool in the management of the brush ranges of California. 156 p. Calif. State Board For., Sacramento.
- Sharp, Ward M.
1970. The role of fire in ruffed grouse habitat management. Proc. 10th Annu. Tall Timbers Fire Ecol. Conf., p. 47-61. Tall Timbers Res. Stn., Tallahassee, Fla.
- Shearin, A. T., Marlin H. Bruner, and N. B. Goebel.
1972. Prescribed burning stimulates natural regeneration of yellow poplar. J. For. 70(8):482-484.
- Show, S. B., and E. I. Kotok.
1923. Forest fires in California, 1911-1920, an analytical study. U.S. Dep. Agric. Circ. 243, 80 p.
- Show, S. B., and E. I. Kotok.
1924. Fire and the forest. U.S. Dep. Agric. Circ. 358, 20 p.
- Siggers, Paul V.
1934. Observations on the influence of fire on the brown spot needle blight of longleaf pine seedlings. J. For. 32(5):556-562.
- Smith, D. M.
1951. The influence of seedbed conditions on the regeneration of eastern white pine. Conn. Agric. Exp. Stn. Bull. 545, 61 p. New Haven.

- Smith, D. W.
1968. Surface fires in northern Ontario. Proc. 8th Annu. Tall Timbers Fire Ecol. Conf., p. 41-54. Tall Timbers Res. Stn., Tallahassee, Fla.
- Smith, J. Harry G., and David E. Gilbert.
1976. Rates of spread and fire damage to timber cover types in British Columbia. Proc. 15th Annu. Tall Timbers Fire Ecol. Conf., p. 135-154. Tall Timbers Res. Stn., Tallahassee, Fla.
- Smith, L. F.
1940. Factors controlling the early development and survival of eastern white pine (*Pinus strobus* L.) in central New England. Ecol. Monogr. 10:373-420.
- Sneeuwjagt, Richard John.
1974. Evaluation of the grass fuel model of the National Fire-Danger Rating System. Master's thesis. Univ. Wash., Seattle. 162 p.
- Spurr, Stephen H.
1954. The forests of Itasca in the 19th century as related to fire. Ecology 35(1):21-25.
- Stewart, O. C.
1951. Burning and natural vegetation in the United States. Geogr. Rev. 41(2):317-320.
- Stoddard, H. L.
1931. The bobwhite quail: Its habits, preservation and increase. 559 p. Chas. Scribner and Sons, New York.
- Stone, Edward C., Rudolf F. Grah, and Paul J. Zinke.
1972. Preservation of the primeval redwoods in the Redwood National Park. Am. For. 78, Part I, Vol. 4, p. 50-55; Part II, Vol. 5, p. 48-59.
- Stone, E. L., Jr.
1971. Effects of prescribed burning on long-term productivity of Coastal Plain soils. In Prescribed burning symposium proceedings, p. 115-129. USDA For. Serv. Southeast. For. Exp. Stn., Asheville, N.C.
- Sundahl, William E.
1966. Slash and litter weight after clearcut logging in two young-growth timber stands. USDA For. Serv. Res. Note PSW-124, 5 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.
- Sunquist, M. E.
1967. Effects of fire on raccoon behavior. J. Mammal. 48:673-674.
- Swan, Frederick R., Jr.
1970. Post-fire response of four plant communities in south-central New York State. Ecology 51(6):1074-1082.
- Swanson, John R.
1976. Hazard abatement by prescribed underburning in west-side Douglas-fir. Proc. 15th Annu. Tall Timbers Fire Ecol. Conf., p. 235-238. Tall Timbers Res. Stn., Tallahassee, Fla.
- Tarrant, Robert F.
1956. Changes in some physical soil properties after a prescribed burn in young ponderosa pine. J. For. 54(7):439-441.
- Tarrant, Robert F.
1956. Effects of slash burning on some physical soil properties. For. Sci. 2(1):18-22.

- Tervis, L., Jr.
1956. Effect of slash burn on forest mice. *J. Wildl. Manage.* 20:405-409.
- Trevett, M. F.
1962. Nutrition and growth of the lowbush blueberry. *Maine Agric. Exp. Stn. Bull.* 605, 151 p.
- Turner, James M., and Frederic R. Larson.
1974. Cost analysis of experimental treatments on ponderosa pine watersheds. USDA For. Serv. Res. Pap. RM-116, 12 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
- Udvardy, M. D. F.
1969. Dynamic zoogeography with special reference to land animals. Van Nostrand-Reinhold, Princeton, N.J.
- U.S. Department of Agriculture, Forest Service.
1936. Timber type maps of Oregon and Washington. *Pac. Northwest For. and Range Exp. Stn.*, Portland, Oreg.
- Van Wagner, C. E.
1968. The line intersect method in forest fuel sampling. *For. Sci.* 14(4): 20-26.
- Van Wagner, C. E.
1973. Height of crown scorch in forest fires. *Can. J. For. Res.* 3(3):373-378.
- Vines, R. G., L. Gibson, A. B. Hatch, and others.
1971. On the nature, properties, and behavior of bush-fire smoke. CSIRO Div. Appl. Chem. Tech. Pap. No. 1, 32 p.
- Vlams, J., H. H. Biswell, and A. M. Schultz.
1955. Effects of prescribed burning on soil fertility in second growth ponderosa pine. *J. For.* 53(12):905-909.
- Vogl, R. J.
1964. The effects of fire on bracken-grasslands. *Wis. Acad. Sci., Arts Lett.* 53:67-82.
- Vogl, R. J.
1964. The effects of fire on a muskeg in northern Wisconsin. *J. Wildl. Manage.* 28:317-329.
- Vogl, R. J.
1973. Smokey's mid-career crisis. *Sat. Rev. Sci.* 1(2):23-29.
- Vogl, R. J.
1974. Effects of fire on grasslands. *In Fire and ecosystems*, p. 139-194. Acad. Press, New York.
- Wagener, Willis W.
1955. Preliminary guidelines for estimating the survival of fire-damaged trees. USDA For. Serv. Pac. Southwest For. and Range Exp. Stn. Res. Note 98, 9 p. Berkeley, Calif.
- Wagener, Willis W.
1961. Past fire incidence in Sierra Nevada forests. *J. For.* 59(10):739-748.
- Wagener, Willis W., and H. R. Offord.
1973. Logging slash: Its breakdown and decay at two forests in northern California. USDA For. Serv. Res. Pap. PSW-83, 11 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

- Weaver, Harold.
1943. Fire as an ecological and silvicultural factor in the ponderosa pine region of the Pacific slope. J. For. 41(1):7-15.
- Weaver, Harold.
1947. Fire--nature's thinning agent in ponderosa pine stands. J. For. 45(5):437-444.
- Weaver, Harold.
1951. Fire as an ecological factor in the southwestern ponderosa pine forests. J. For. 49(2):93-98.
- Weaver, Harold.
1951. Observed effects of prescribed burning on perennial grasses in the ponderosa pine forests. J. For. 49(4):267-271.
- Weaver, Harold.
1952. A preliminary report on prescribed burning in virgin ponderosa pine. J. For. 50(9): 662-667.
- Weaver, Harold.
1955. Fire as an enemy, friend, and tool in forest management. J. For. 53(7):499-504.
- Weaver, Harold.
1956. Wild fires threaten ponderosa pine forests. Am. For. 62(2):28-29, 52-55.
- Weaver, Harold.
1957. Effects of prescribed burning in ponderosa pine. J. For. 55(2):133-138.
- Weaver, Harold.
1961. Implications of the Klamath fires of September, 1959. J. For. 57(8):569-572.
- Weaver, Harold.
1967. Fire and its relationship to ponderosa pine. Proc. 7th Annu. Tall Timbers Fire Ecol. Conf., p. 127-149. Tall Timbers Res. Stn., Tallahassee, Fla.
- Weaver, Harold.
1974. Effects of fire on temperate forests: Western United States. Fire and Ecosyst. Repr., Acad. Press, New York.
- Wells, C. G.
1971. Effects of prescribed burning on physical properties of soil. In Prescribed burning symposium, p. 86-97. USDA For. Serv. Southeast. For. Exp. Stn., Asheville, N.C.
- Wilson, Carl C., and John D. Dell.
1971. The fuels build-up in American forests: A plan of action and research. J. For. 69(8):471-475.
- Woodard, Paul M.
1974. Predicting crown slash weights in Douglas-fir. Master's thesis. Univ. Wash., Seattle. 94 p.
- Wooldridge, David D., and Harold Weaver.
1965. Some effects of thinning a ponderosa pine thicket with a prescribed fire, II. J. For. 63(2):92-95.

- Wright, Henry A., Carlton M. Britton, Robert L. Wink, and Bob Beckham.
1972. A progress report on techniques to burn dozed juniper. Proc. 12th Annu. Tall Timbers Fire Ecol. Conf., p. 169-174. Tall Timbers Res. Stn., Tallahassee, Fla.
- Zahner, Robert.
1958. Hardwood understory depletes soil water in pine stands. For. Sci. 4(3):178-184.
- Zasada, John C.
1971. Natural regeneration of interior Alaska forests--seed, seedbed, and vegetative reproduction considerations. *In* Fire in the northern environment--a symposium, p. 231-246. USDA For. Serv. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.
- Zinke, P. J.
1961. Physical and biological aspects of chaparral management. *In* Man, fire and chaparral, p. 21-25. Univ. Calif. Agric. Stn., Berkeley.
- Zontek, Frank.
1966. Prescribed burning on the St. Marks National Wildlife Refuge. Proc. 5th Annu. Tall Timbers Fire Ecol. Conf., p. 195-202. Tall Timbers Res. Stn., Tallahassee, Fla.



Appendix A

MEASURING MOISTURE CONTENT

Moisture content (MC) in percent is defined by the equation:

$$\text{MC, percent} = \frac{\text{Field weight} - \text{ovendry weight}}{\text{Ovendry weight}} \times 100.$$

Regardless of whether one measures the moisture content, estimates it from tables or fuel moisture sticks, or uses a moisture meter, the definition is the same. To measure fuel MC directly, we generally must collect samples and oven-dry them in the laboratory.

The procedures are as follows:

1. Collect each sample to represent the size, category, and position of the fuel for which you wish to measure moisture content. Soil cans sealed with masking tape or sealed plastic bags work well. Once you have the sample, protect it and container from excess heat and sun. Each container should be identified adequately: date, time, fuel component, etc.
2. Weigh samples in container as soon as practicable after collection; if tape has been used to seal the container, first remove and discard the tape. The weight will be the field weight with tare (can or bag).
3. Oven-dry the sample in the container at 160°F (70°C) for 2 days, longer if pieces of fuel are large. Until you know how long it takes, check samples each day until they reach an essentially constant weight. When the weight is constant, the sample is dry. Take only a few samples from the oven at a time, as they will pick up moisture from the air rapidly as they cool. Drying may also be done at 220°F (150°C), but some investigators think the higher temperatures may drive off volatile components, particularly in living material. Norum (1977) described use of a microwave oven to dry samples in about 30 minutes.
4. After you have obtained oven-dry weight including container (tare), empty the container and weigh it to get the tare weight.
5. Subtract tare weights from the field and oven-dry weights; then calculate moisture content percent by the equation above.
6. The sample recording form may be modified to fit your needs.

SAMPLE RECORDING FORM								
Forest _____			District _____			Unit _____		
Date _____			Sampler _____					
Sample description								
Date and time	Can no.	Sample	Tare wt., g	Field wt. w/tare, g	Ovendry wt. w/tare, g	Field wt., g	Oven-dry wt., g	MC, per-cent
6/15/78 1400	18 C	Upper duff	77.8	188.2	175.3	110.40	97.5	13



Appendix B

ESTIMATING RELATIVE HUMIDITY AS TEMPERATURE CHANGES

This rule-of-thumb method for estimating relative humidity as the temperature changes is based on the fact that relative humidity (RH) will roughly double as the temperature drops 20°F, and will drop to one-half its previous value as the temperature increases 20°F.

Example: At 8 a.m., temperature is 40°F and RH is 84 percent.

Expected high for the day is 80°F. What will the expected low RH be?

40°F to 60°F, RH drops to $1/2$ of 84% = 42%;

60°F to 80°F, RH drops to $1/2$ of 42% = 21%.

Example: At 1400, temperature is 90°F and RH is 30 percent.

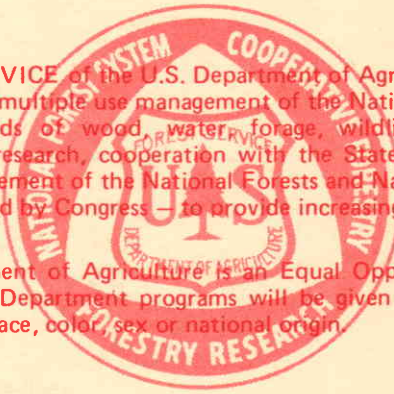
If temperature at 1800 is expected to be 70°F, what will RH be?

90°F to 70°F, double RH, $2 \times 30\% = 60\%$.

Steps to a successful prescribed burning program:

- Know the land management objectives
- Conduct reconnaissance and measurement
- Develop general objectives of treatment
- Decide on best tools to meet objectives
- Write specific objectives of treatment
- Estimate fire behavior for different burning conditions
- Develop prescription
- Plan and prepare carefully for burn
- Execute burn, modifying to meet objectives
- Conduct mopup as necessary
- Record evaluation of effects

If the fire is not accomplishing your objectives, modify burning. If it still does not do what you want, STOP BURNING! A prescribed fire burning in fuel that is too wet or too dry wastes resources and can lead to serious problems.



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