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Technical and Vocational Forestry and Forest Industries Training

B U R M A

Introduction to FOREST FIRE MANAGEMENT

based on the work of

J.G.Goldammer

UNITED NATIONS DEVELOPMENT PROGRAMME

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS ROME, 1986

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INTRODUCTION TO FOREST FIRE MANAGEMENT

Training Manual prepared for the Government of Burma

by

the Food and Agriculture Organization of the United Nations
acting as executing agency for
the United Nations Development Programme
based on the work of
J. G. Goldammer
Forest Fire Management Consultant

UNITED NATIONS DEVELOPMENT PROGRAMME
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Preface

The increasing occurrence of forest fires is one of the major disturbance factors of the forests of Burma. The wildfires have a considerable influence on forest degradation, soil depletion, erosion and changes in air quality, and they endanger the long-term planning goals of plantation establishment.

The improvement of training and the efficiency of personnel involved in forest fire management therefore must become one of the most urgent goals within the forest protection policy.

This manual on "Introduction to Forest Fire Management" is designed as a basic source of information for teachers at the Burma Forest School as well as for forest protection officers in the field. It has been prepared as a part of the FAO Technical and Vocational Forestry and Forest Industries Training in Burma.

The book covers the basic aspects of fundamentals of forest fire behaviour, fire prevention and control. A glossary of the most important wildland fire management terms is included. Text and illustrations are based on approved forest fire management publications; to promote the readability the citations of the sources are summed up in the appendix.

J. G. Goldammer
Consultant

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1. FUNDAMENTALS OF COMBUSTION AND FIRE BEHAVIOUR

1.1 PRINCIPLES OF COMBUSTION

Fire is a chemical reaction in which energy is released. When forest material burns there is a chemical combination of the oxygen in the air with wood, pitch, and other burnable elements in the fuel. In the forest several stages in the fire process are normally encountered - first the igniting spark, then a period of smoldering, and finally the more rapid combustion of fuels. The action of a fire throughout its life is governed by certain natural laws or principles of combustion, as they are termed here. An understanding of these principles is a basic step in judging the effect of various environmental factors on fire behaviour.

THE FIRE TRIANGLE

Three elements - heat, oxygen, and fuel - are required in proper combination before ignition and combustion will occur. If any one of the three is absent, ignition or combustion will not occur. Likewise, if the three elements are not in proper balance, there will be no fire. Variations in balance among heat, oxygen, and fuel govern the violence of the fire, and careful observation of these three essentials indicates to the firefighter whether the fire will only smolder and spread slowly or will flame brightly and travel rapidly. The task of the firefighter is to visualize the fire triangle as applied to forest conditions. The ease of ignition and rate of combustion are determined by the amount of heat, the availability of oxygen, and the type of fuel.

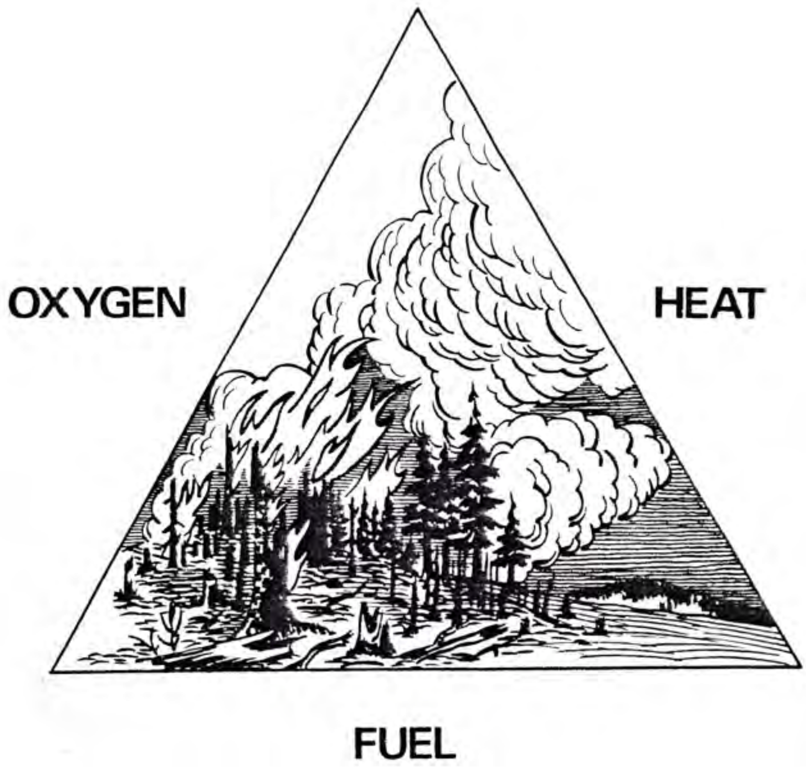

Fig.1: The fire triangle

HEAT

How much heat is required to ignite forest fuels? It is difficult to answer this question specifically because of the variations in the nature of forest fuels. Vegetative material, such as forest fuels, is high in carbon the substance is freely exposed to the air. During the forest fire season a large part of the vegetative matter in a forest - duff, dead limb wood, pine needles, tree branches, rotted logs, etc. - becomes dry enough to be ignited easily. Actual heat requirements for ignition of forest fuels varies from approximately 260°to 400°C. Many common ignition sources provide the required heat, including a burning match, a glowing cigarette, and a lightning bolt.

Ignition often depends upon the length of time that the fuel is exposed to heat. Dry pine needles may be ignited in a few seconds by the heat from a flaming match. Moist pine needles also may be ignited by a match if subjected to the heat for several minutes. When wood fuels are exposed to heat for a long period of time, the time required for ignition will be reduced.

The ease of ignition of forest fuels when exposed to heat for a considerable time has an important influence on fire behaviour. In a coniferous forest a hot fire burning in a tangle of down logs and dry limb wood may generate enough heat to transform the green tree crowns above the fire into an easily ignitible condition. All that is needed to cause the tree crowns to break into flame is a flying ember and a gust of wind. Similarly, a fire smoldering in a pile of leaves may generate enough heat to lower the normal ignition temperature. When the leaves are stirred up, the whole pile breaks into flame. The stirring of the pile lets in enough oxygen for the preheated leaves to be easily ignited.

Oxygen

Normally the atmosphere at elevations where forest fires occur contains about 21 percent oxygen. When the oxygen content of the air is reduced to less than 15 percent, most materials will not burn. Within the forest there is sufficient oxygen to permit ignition and combustion. However, some of the forest fuels may be arranged so that air, and consequently oxygen, is not available in sufficient amount to support a fire. In deep, tightly compacted duff only the top particles can get enough air to permit a fire to burn. In this situation a fire will burn from the top down with combustion taking place in each layer as it is exposed to the air. On the other hand, in a very loose layer of pine needles the entire mass is fairly well exposed to air and consequently combustion will take place rapidly.

When wind blows on a fire, a forced draft of oxygen is present to speed up the combustion process. In addition, as will be shown later, the wind has a physical reaction on the flames, often bending them into positions that create more favorable situations for the spread of the fire. Wind forces oxygen around fuel particles where the flow of air may be normally restricted.

FUEL

Under forest conditions fuel is a major variable in the fire triangle. Fuel constitutes the leg of the triangle that is often most difficult to evaluate properly. The firefighter must become acquainted with the general nature of forest fuels if he is to attain a thorough understanding of the principles of combustion. Ease of ignition and combustion of forest fuels depends mainly upon the kind of fuel (is it logging slash or dense duff in a green forest?), fuel continuity (is the fuel distributed more or less evenly over the area or only present in patches?), moisture content (does it feel damp when touched or does it crackle and appear very brittle?), and fuel temperature (is the fuel exposed to the heat of the sun or does it lie in cool shade?).

COMBUSTION

When fuels are heated to a given temperature, gases are produced which will ignite if combined with oxygen. When one observes a log fire, he will note that the flames may appear to be coming directly from the fuel. Actually, the flames come from the ignited gases emerging from the heated log.

The process of combustion is actually oxidation in which the combustible substance ignites with oxygen. There may be several stages to the oxidation process. Under certain conditions oxidation may be so slow that it is not accompanied by the heat and light normally associated with combustion. In this so-called "slow combustion" stage heat is dissipated very rapidly, in fact

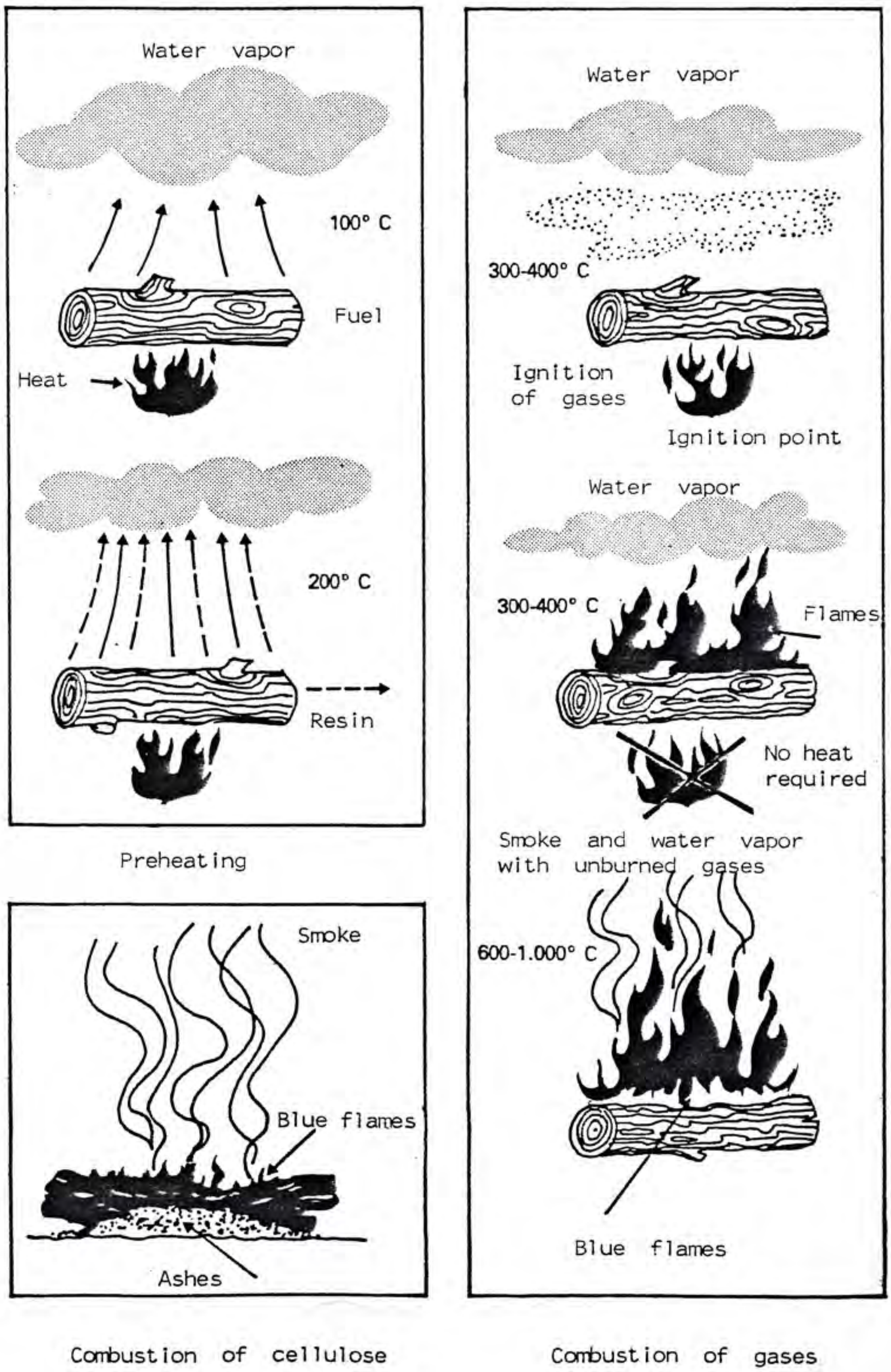

Fig.2: Phases of combustion process in forest fuels

nearly as fast as it is liberated; and as a result no appreciable rise in temperature occurs. "Slow combustion" is not common in forest fuels.

In forest fires two common stages of combustion are smoldering and flaming. In the smoldering stage heat is liberated and a rise in fuel temperature occurs. However, flame is absent or present only intermittently. Normally the absence of flame is caused by insufficient oxygen or by moisture in the fuels. Lack of oxygen or moisture in the fuels will slow up the oxidation process. When a fire is in the smoldering stage, all the elements of the fire triangle are present but not in a combination to permit rapid combustion.

When a fire is in the flaming stage, all the elements of the fire triangle - heat, oxygen, and fuel - are in proper combination for rapid oxidation to occur. Thus flame in itself provides a guide to an understanding of fire behaviour.

The flames of very hot fires may be observed intermittently in the smoke at a considerable distance above the fire. In some cases oxygen is consumed so rapidly near the base of the fire that combustion of the gases is incomplete. As these gases rise, they reach a fresh oxygen supply and break into flame. For this reason it may appear that the smoke of some fires is itself flaming.

Re-ignition of apparently dead fires is an important factor to be observed in the combustion process. The important element in re-ignition is heat. Although neither flames nor smoke may be observed, a fire can break out again if sufficient heat remains. Re-ignition occurs easily where fuels have been subjected to heat for a considerable length of time. To prevent re-ignition the good firefighter feels out fuels with his hands before leaving the area. If heat is still present, he knows that the control job is incomplete.

BREAKING THE FIRE TRIANGLE

In fire control operations the objective is to prevent combustion by breaking the fire triangle. The fire triangle is broken when any one of the heat, oxygen, and fuel legs is removed or altered to such an extent that combustion can no longer occur. Many methods may be employed in this process (figure 3). Use of water reduces heat: if a sufficient volume of water is applied, the fuel temperature can be lowered below the ignition point. Smothering with dirt reduces oxygen: if the air supply can be shut off until all fuels are thoroughly cooled, further combustion can be prevented. Building a line in which all inflammable material is removed from the path of the fire prevents further spread by robbing the fire of fuel.

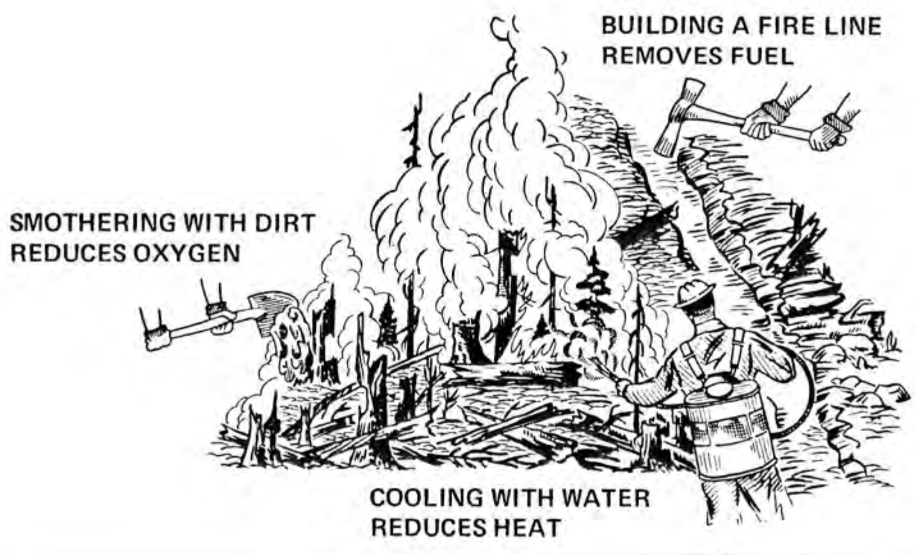

Fig.3: Breaking the fire triangle: In forest fire control the objective is to stop combustion by removing or altering one or more legs of the fire triangle.

Usually in forest firefighting combustion is reduced or stopped by attacking more than one of the three legs of the fire triangle. The actual method of suppression is often dictated by the available equipment and manpower. However, the most effective methods for each part of the fire and for each stage of the suppression operation can be determined by keen observation of the combustion process.

Reducing Heat

The principles of combustion indicate the best method of applying water to reduce heat. Since the objective is to reduce fuel temperature, water should be applied directly on the fuels being consumed. A common mistake is to apply water on the flames rather than the fuels. As explained previously, the flames are actually burning gases liberated by the heated fuels. If the liberation of these gases is to be stopped, the fuels themselves must be cooled by the water. If the water is applied on the flame, a large part of it will either miss its mark or be lost through vaporization.

Occasionally water may be used for other purposes than direct cooling of fuels. In a very hot fire accompanied by leaping flames the nozzle-man may not be able to get close enough to the fuels to apply water directly on the trouble spot. In such cases a fog nozzle should be used to knock down the flames. Fog performs a smothering function on the flaming gases by occupying air space with millions of finely divided particles of water. These water particles also assist in cooling the heated gases being liberated by the fuels. Once the flames have been knocked down the nozzle-man immediately returns to his primary job of thoroughly cooling the heated fuels that are generating inflammable gases.

Reducing Oxygen

Fires burning in forest fuels are difficult to smother completely. Soil thrown on burning forest material may retard combustion by shielding portions of the fuel surface from the air. Because of the porous nature of most soils, it is difficult to shut off completely the supply of oxygen in this manner. Throwing dirt on fires is nevertheless an important means of reducing the rate of combustion after which the control operation may be continued by attacking one of the other legs of the fire triangle.

In very fine fuels, such as dry grass, the oxygen supply may be reduced easily. Fuels of this nature do not retain heat for long periods, and therefore combustion may normally be checked by temporarily shielding the fuel surface from the air. For this reason fire swatters and shovelfuls of earth correctly applied are effective implements in smothering grass fires. Wherever larger accumulations of inflammable material, such as dead stems and leaves, lie beneath the stand of grass, there is danger of re-ignition. The understory material may hold enough heat to cause the fire to break out again as soon as an adequate supply of oxygen becomes available. This danger can be determined by careful observation of the fuel.

Removing Fuel

In forest fire control work the removal of fuel is the most common method of attacking the fire triangle. Actually this method does not prevent combustion in the area on fire. The fire continues to burn until the fuel is consumed or the combustion process is broken by some other means. However, removal of the fuel in the path of the fire does prevent the fire from spreading any further. Thus the fire triangle is broken indirectly.

The nature of the fuel removal operation is dictated by the influence of fuels on behaviour of the fire. A slowly advancing fire burning in sparse ground fuels may be checked simply by constructing a fire line down to mineral soil. However, a hot or a fast-running fire may require several other fuel removal operations. Snags which may cause spot fires may have to be felled. Thickets of reproduction or dry brush may have to be weeded out. Low-hanging limbs which may permit the build-up of a crown fire may have to be removed. Concentration of limbs and logs may have to be broken up. The objective throughout all these operations is to remove or to reduce the inflammable substance which may either allow the fire to build up in intensity or to continue to spread.

HEAT TRANSFER

The rate and amount of heat transferred influences the rate of spread and the intensity of a fire. Combustion cannot be sustained unless heat continues to be transferred. Heat transfer occurs by three means - radiation, convection, and conduction.

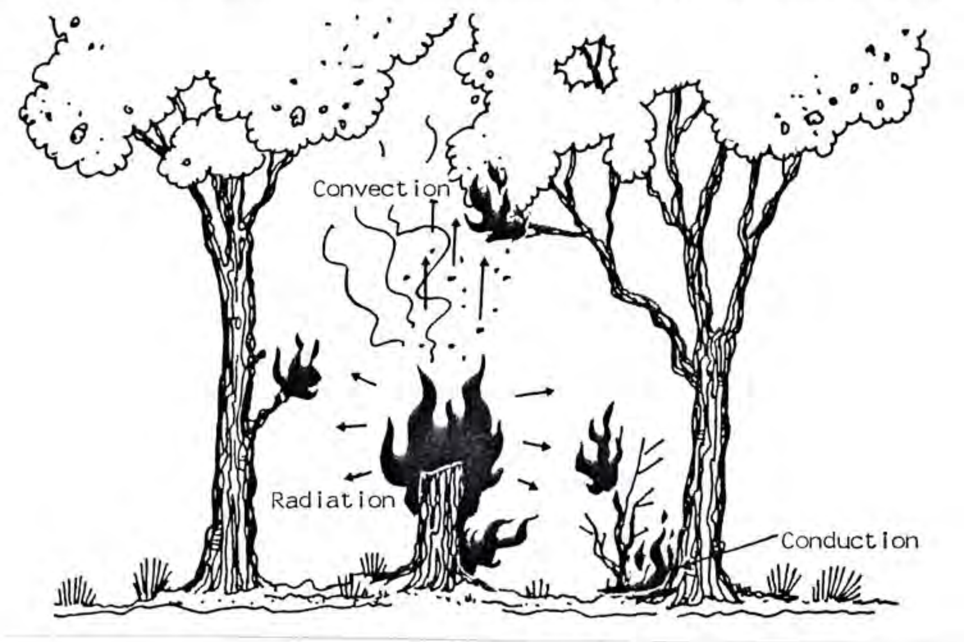

Fig.4: Heat transfer in forest fuels

Radiation

Radiation is a process by which heat energy is transmitted from its source to an object. Radiant heat is commonly known as an important means of warming the interiors of buildings. Heated pipes laid in the floor of a room release heat energy which is transmitted to objects and individuals. In forest fires radiation is an important means of transferring heat from a burning fuel to another fuel nearby.

Radiant heat transfer decreases inversely with the square of the distance from the fire (figure 5). If an object located 1 meter from the fire receives 100 heat units, then an object 2 feet from the fire will receive only 25 heat units, and an object 10 meters away only 1 unit. The actual number of heat units will vary according to the intensity of the fire, but the decrease of radiant heat according to distance from the source always will remain in the same ratio.

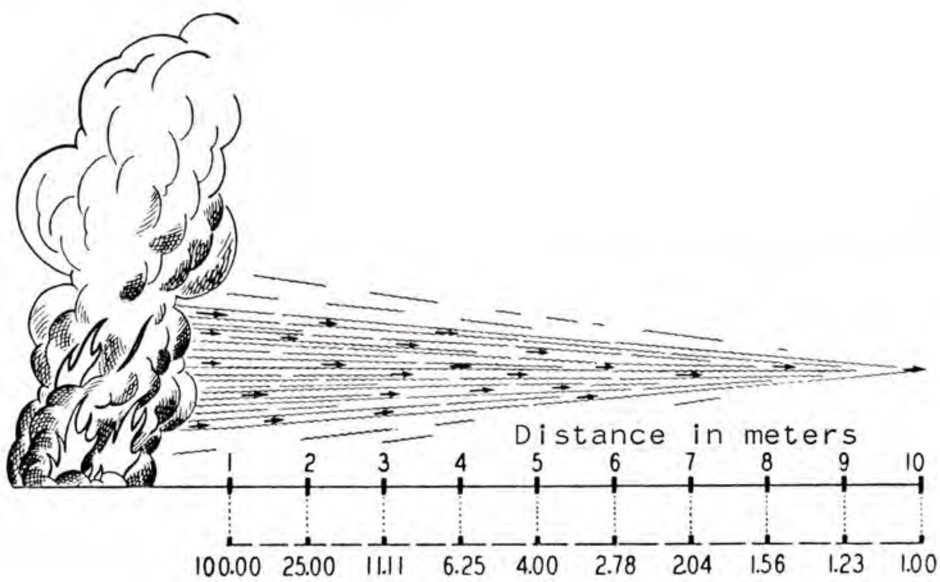

Fig.5: Radiant heat transfer decreases with the square of the distance from the fire

Radiant heat transfer plays an important part in fire behaviour. A pile of logs may create a hot fire because the burning logs radiate heat to each other. However, if these logs are separated and laid out a foot or two from each other, the fire will quickly die down. Separating the logs effectively reduces radiant heat transferred from one fuel unit to another. In firefighting, the laws governing radiant heat transfer can be used as a guide for suppression techniques. The location and width of fire lines must be governed in part by the rate of radiant heat transfer. Potentially hot fires and spots where dangerous flareups might occur can often be prevented by breaking up the fuels or, in other words, by reducing the radiant heat transfer between fuels.

Convection

Heat is also transferred through the movement of hot masses of air - a process called convection. The common hot air furnace used in homes takes advantage of the principle of heat transfer by convection. Air is easily heated and is capable of holding and transmitting heat. When forest fuels become heated by hot air masses moving from an adjacent fire, more favorable conditions are created for those fuels to be ignited and to burn.

Hot air masses have a tendency to rise because of their light weight in relation to cooler air masses. Kindling is placed at the bottom when a wood fire is lighted so that the fuels above may receive heat through convection. In a forest fire the fuels lying in the path of convection currents are heated and thus transformed into a more inflammable condition. The hot air mass rising from a surface fire transfers a large amount of heat to the tree crowns and brings them nearer to the ignition temperature (figure 6).

Fig.6

Tree crowns receive heat through convection currents rising from ground fires

When fires break out in tree crowns and other aerial fuels, heat transfer by convection is often increased. Sparks and burning embers from the burning tree crowns and snags will drop to start new fires in fuels on the ground. As these ground fires gain in intensity, more hot air masses rise through the aerial fuels and a type of chain reaction is created. For this reason firefighters are always alert to the danger of hot surface fires burning underneath a forest canopy. These surface fires must be cooled promptly, and fuel masses which are apt to create hot fires should be broken up.

Heat transfer through convection is increased by wind which moves hot masses of air ahead of the fire. Wind again performs a dual function by increasing the rate of combustion, thus creating more heat, and by accelerating the transport of hot air masses. When driven by wind, the hot convection currents may move closer to the ground fuels and create more inflammable conditions in the understory vegetation of the forest.

Fuels located above a fire on steep slopes also receive heat by the movement of convection currents up the slope. This is one more reason why fires often burn very rapidly up the sides of steep mountains. The fuels upslope are subjected to an accelerated rate of heating and drying.

Conduction

Wood is a poor conductor of heat. This is well illustrated by the fact that a wooden handle on a hot frying pan remains cool enough to be grasped by a bare hand. Because wood is such a poor conductor of heat, this method of heat transfer is relatively unimportant in evaluating forest fire behaviour.

KINDS OF FOREST FIRES

A useful and long accepted classification of fires is based on the degree to which fuels from mineral soil upward to treetops were involved in combustion. This is in effect a fire behaviour classification. This classifies all fires as ground, surface, or crown fires.

Ground Fire

A ground fire consumes the organic material beneath the surface litter of the forest floor. In many forest types, particularly in northern latitudes, at higher elevations, and in peat and swamp forests in the tropics, a mantle of organic material accumulates on top of the mineral soil. It may be identified as duff, raw humus, or peat. A fire spreading in and consuming such material is a ground fire. With very deep organic material, as in peat beds or bogs, under drought conditions the fire may penetrate several meters below the surface and travel entirely underground.

A ground fire may and often does follow a surface fire, depending on the moisture content of the organic layer. A true ground fire spreads within rather than on top of the organic layer. It is characterized by a slowly smoldering edge with no flame and little smoke. Ground fires are often hard to detect and are the least spectacular and slowest moving. But they are usually the most destructive of all fires. Per unit of perimeter they are usually, too, the most difficult to control.

Surface Fire

A surface fire is a fire that burns surface litter, other loose debris of the forest floor and small vegetation. This is the most common type of fire in timber stands of all species. It may be a mild, low-energy fire in sparse grass and pine needle litter, or it may be a very hot, fast-moving fire where slash, flammable understory shrubs, or other abundant fuel prevails. A surface fire may and often does burn up into the taller vegetation and tree crowns as it progresses. This is called "crowning out", but so long as it is sporadic in nature, the fire remains in the category of a surface fire.

Crown Fire

A crown fire is a fire that advances from top to top of trees or shrubs more or less independently of the surface fire. In dense conifer stands on steep slopes or on level ground, with a brisk wind, the crown fire may race ahead of the supporting surface fire. This is the most spectacular kind of forest fire. Since it is over the heads of ground forces it is uncontrollable until it again drops to the ground, and since it is usually fast-moving it poses grave danger to fire fighters and wildlife in its path. It is the most common cause of fire fighters becoming trapped and burned. A fire moving through the crowns of shrubs is also a crown fire. In most situations, however, the crown fire remains coupled to the surface fire. To distinguish the degree of independence from the surface fire, crown fires are often classed as "running" or "dependent".

Fire Combinations

In actual fire situations, these three kinds of fire may occur simultaneously and in all kinds of combinations. Surface fires are by far the most common, and nearly all fires start as such. A surface fire may spread into the crowns and develop into a

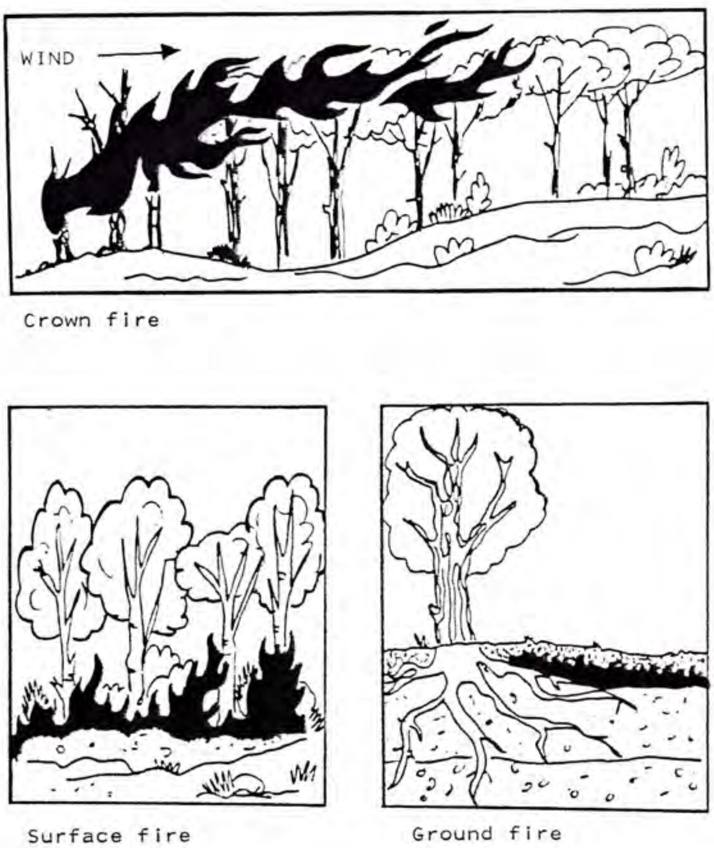

Fig.7: Kinds of forest fires

sweeping crown fire. A crown fire may drop to the ground and become a surface fire. Similarly, a surface fire may develop into a stubborn ground fire that may plague control forces for days or weeks. On a hot, dry, and windy afternoon, a rather innocuous-appearing ground fire may be fanned into a surface or crown fire. Figure 7 illustrates the basic nature of these three kinds of forest fires.

1.2 FOREST FUELS

Since natural forest fuels vary widely in their distribution, their physical characteristics, and their effect on fire behaviour, some means of classification is needed for systematic analysis. Fuels are here classified into three groups, based on vertical distribution and general properties: ground fuels, surface fuels, and aerial fuels.

GROUND FUELS

Ground fuels include all inflammable material lying on or immediately above the ground or in the ground. The principal materials are partially decomposed organic matter or duff and tree roots.

Duff

Duff is partially decayed vegetative matter on the forest floor. Duff seldom has a major influence on the rate of spread of a fire because normally it is moist and rather tightly compressed so that little of the surface is freely exposed to air. However, under extreme drought conditions the duff layer may dry out completely and become flammable even though the rate of combustion is slow. Under these conditions the whole duff layer

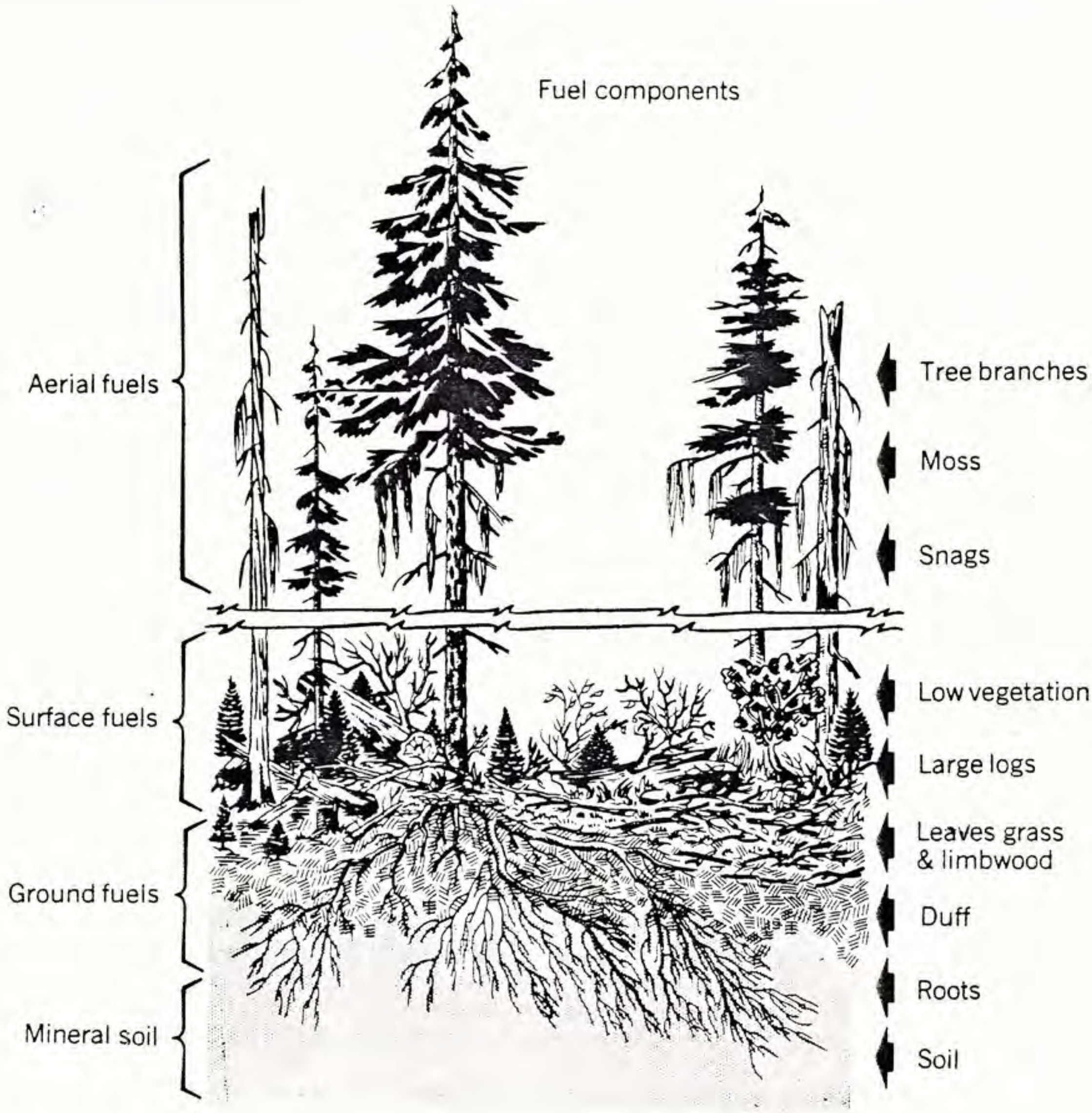

Fig.8: Principal components of ground fuels and aerial fuels

is consumed down to the mineral soil. Sometimes duff contributes to the rate of spread by furnishing a path for the fire to creep between patches of more inflammable material.

The smoldering characteristics of duff fires make them somewhat difficult to control. Fire lines dug down to mineral soil are required in duff areas. The only exception to this general rule can be made when examination by an expert fire man shows that the lower layers of duff are too wet or too tightly compressed to burn. Frequently duff fires inside a fire line are best mopped up by turning over the duff with a shovel, loosening the material for better exposure to air and allowing it to burn out. Water may be used effectively, but great care must be taken to stir the fuel to make certain that all particles are thoroughly soaked. Extinguishing duff fires by smothering with dirt is very difficult to accomplish.

Roots

Roots are not an important factor in rate of spread because greatly restricted air supply prevents rapid combustion. However, fires can creep slowly in roots - in fact some fires have escaped control because a root provided an avenue for the fire to cross the control line. The most inflammable roots are the large laterals stemming out from dead snags. Control of root fires is accomplished simply by cutting the root where it crosses the fire line. Mop-up of persistent fires may require complete excavation of roots.

SURFACE FUELS

Surface fuels include undecomposed dead leaves and needles, grass, fine dead wood, down logs, stumps and large limbs, and low brush and reproduction.

Tree Leaves and Fine Litter

Dead leaves or needles and other fine litter (bark and twigs <5 mm) on the ground constitute a highly flammable surface layer. It is the most common fuel in which surface fires spread in forest areas. Flammability depends on the physical characteristics of the fuel and on its arrangement and quantity rather than on differences in chemical composition. Among hardwood leaves, for example, oak leaves are especially flammable. There are several reasons: they are shed late, they curl tightly so have minimum contact with the soil, they resist wetting for a considerable period so are slow to weather, and they do not mat down readily. This results in high exposure of aerated edge and surface. However, oak leaves seldom carry over as flash fuel into the second growing season. Conifer needles persist much longer in the litter. On sandy soils and dry sites an undecomposed layer of several years of needle fall is common. Pine needles are shed in the two-to-five-needle clusters in which they grow. Thus pines produce a looser, more persistent, and more flammable litter than do other conifers that drop their needles singly. Because of their greater length and diameter and their resistance to decay, the needles of hard pines tend to develop deep, well-aerated layers of litter and therefore more dangerous fuel hazards. In contrast, spruce or Douglas-fir needles, while equally flammable intrinsically, shed their needles singly. Hence they come in close contact with the ground and are less persistent, forming a rather compact layer which ignites and burns slowly, more like a ground than a surface fuel.Dead needles or leaves attached to the branches are particularly flammable because they are fully exposed to the air and usually are not in direct contact with more moist materials on the ground. This is the major reason why logging slash with the leaves or needles still attached is so dangerous; the needles supply a highly combustible kindling material for ignition of coarser fuels.

Grass

Grass, weeds, and other small plants are important surface fuels influencing the rate of spread. The key factor in these fuels is the degree of curing. Succulent green grass acts as a fire barrier. During the course of a normal fire season grass goes through a curing process and gradually becomes drier and more inflammable. Finally the stems and leaves of the grass die due to lack of moisture and the major part of the cover becomes highly inflammable. Cured grass, if present in large and uniform volume, provides the most inflammable ground fuel found in the region. Grass and other small plants occur on the floor of almost all forests. Firefighters need to observe the volume and continuity of the grass cover. In dense forests where little sunlight reaches the ground, there is very little grass. In more open forests, such as mature pine stands, there may be a large amount. If a more or less continuous cover of dry grass occurs on the forest floor, the rate of spread of a fire will be governed largely by that cover rather than by the heavier fuels normally associated with a forest.

Fine Dead Wood

Fine dead wood consists of twigs, small limbs, bark, coniferous cones, and rotting material. Normally the fine dead wood classification is confined to material with a diameter of less than 5 cm. These fine dead ground fuels are among the most important of all materials influencing rate of spread and general fire behaviour in forest areas. Fine dead wood is ignited easily and often provides the main avenue for carrying fire from one area to another. It is the kindling material for larger heavier fuels. In areas where there is a great volume of fine dead wood, a fire rapidly develops tremendous heat. The effect would be much the same if a fireplace or stove were loaded with nothing except kindling. Timber stands that are decadent, fire-killed, or diseased, or that are heavily wind-thrown, usually have large amounts of fine dead wood on the ground. The greatest volume of fine dead wood usually is found in areas containing logging slash. Under dry conditions fires in such areas will burn violently, and the strong convection currents created by the intense heat will pick up burning embers and throw them out ahead, thus causing spot fires beyond the main fire front. In some areas the occurrence of fine dead wood may be spotty. Accumulations of this material may be found bunched up under an occasional tree or snag. In such cases the firefighter must be alert to the fact that a very hot fire may develop in these accumulations.

Down Logs, Stumps, and Large Limbs

Heavy fuels, such as down logs, stumps, and large limbs, require long periods of hot dry weather before they become highly inflammable. However, when such material reaches a dry state, very hot fires may develop. The most dangerous heavy fuels are those containing stringers of dry wood, shaggy bark, or many large cracks. Smooth-surfaced material is less flammable because it dries out more slowly, has little surface exposed to air, and contains less attached kindling fuel. Extremely hot fires may develop in piles of down logs and large limbs or in crisscrossed windfall because the various fuel components will radiate heat to each other. However, individual limbs and logs will not burn hotly unless the fire is supported by large accumulations of fine dead wood.

Low Brush and Reproduction

Low brush, tree seedlings, and small saplings are classified as ground fuels because they are so closely intermixed with the inflammable material on the forest floor. This understory vegetation may either accelerate or slow up the rate of spread of a fire. Normally, during the early part of a fire season the shading from understory vegetation prevents rapid drying of other ground fuels. However, as the season progresses continued high air temperature and low relative humidity will dry out both the fuel lying on the ground and the understory vegetation. When this stage is reached, much of the low vegetation, and especially small coniferous trees, become fire carriers. The understory vegetation in a forest often provides a link between ground fuels and aerial fuels. The crowns of small trees may catch on fire and in turn spread the fire to aerial fuels in the forest canopy. Thickets of reproduction or dead brush may provide the first means for a surface fire to flare up and spread into the crowns of the overstory trees.

AERIAL FUELS

Aerial fuels include all green and dead material located in the upper forest canopy. The main aerial fuel components are tree branches and crowns, bark, snags, moss, and high brush.

Tree Branches and Crowns

The live needles of coniferous trees are a highly inflammable fuel. Their arrangement on tree branches allows free circulation of air. In addition the upper branches of trees are more freely exposed to wind and sun than most ground fuels. These factors, plus the volatile oils and resins contained in coniferous needles, make tree branches and crowns important components in aerial fuels. Tree branches and crowns are flashy fuels which react quickly to changes in relative humidity. Crown fires seldom occur when relative humidity is high. However, coniferous needles will dry out quickly when exposed to hot dry air. The dryness of needles is influenced by the transpiration process in a tree.

When the ground is moist, trees are pumping a large amount of moisture into the air through the leaves. As the ground becomes drier, the transpiration process slows down and as a result leaves and branches become drier and more inflammable. Dead branches and needles on trees are an important aerial fuel. Concentrations of dead branches and needles such as found in insect- or disease-killed stands may cause a fire to spread from tree to tree. Likewise, concentrations of dead branches on the lower trunks of trees may provide an avenue for fires to spread from surface fuels into tree crowns. The most inflammable dead branches are those still containing needles. Fires in the upper crowns of trees are extremely difficult to control. The main control method must be aimed at suppressing the fire in surface fuels and, if possible, in preventing the fire from entering the tree crowns. Removal of limbs on the lower trunks of trees is one method of preventing crown fires.

Snags

Standing dead trees or snags are an important and dangerous fuel, as can be vouched for by experienced fire fighters. Standing dead timber maintains a low moisture content. As the bark and sapwood gradually decay, shaggy bark and punky surfaces are exposed which ignite readily from flying sparks or embers and from lightning strikes. Once ignited, the snag becomes a prolific source of flying embers which may start spot fires at considerable distances and may ignite adjoining snags during all active burning. Or the fire may smolder in the punky wood on the surface or inside a hollow tree until finally some of the top breaks off, scattering firebrands onto surface fuels below. The susceptibility of a snag to ignition increases with age. Fires in burning snags must be controlled promptly. Wherever possible the main control effort on the fire must be designed to prevent the blaze from getting into snags. When fires do become established in snags, the control method usually requires that the snags be felled. Snag-falling is especially important if shaggy bark is being carried from the burning trunk by wind or strong convection currents.

Tree Moss

Moss hanging on trees is the lightest and flashiest of all aerial fuels. Moss is important principally because it provides a means of spreading fires from ground fuels to other aerial fuels or from one aerial component to another. Like other light flashy fuels moss reacts quickly to changes in relative humidity. During dry weather crown fires may develop easily in heavily moss-covered stands. Control methods of moss fires are aimed primarily at breaking up ground fuels so as to prevent the fire from entering the tree crowns through the hanging moss. In addition, lower limbs containing tree moss should be removed at all danger spots.

Bark

In eucalypt forests, bark texture is as important as the arrangement of shrubs in the propagation of crown fires. Smooth-barked "gums" are less likely to carry flames into the crowns of trees than the fibrous-barked stringybarks and peppermints. Bark texture and arrangement also affect the potential of many eucalypt forests to spread burning embers and to start spot fires at distances greatly in excess of those observed in other parts of the world. The fibrous bark of stringybarks and peppermints may cause spotting downwind for several kilometres, while the larger but light candlebark streamers of many smooth-barked or half-barked species may be transported by convection updraughts and strong upper winds and deposited, while still in a flaming or smouldering condition, at very much greater distances.

Understory brush

In most forest types, various species of brush occur. In general, evergreen shrubs are much more flammable than deciduous species. Usually evergreen foliage contains volatile oils, and its moisture content remains generally lower than that of deciduous leaves. Crown fires in brush fuels ordinarily will not occur unless heavy ground fuels are present to develop the required heat. However, in some brush stands a high proportion of dead stems may create a sufficient volume of fine dead aerial fuels to permit very hot and fast-spreading crown fires. Key factors in evaluating the behaviour of fires in high brush are therefore the volume, arrangement, and general condition of ground fuels and the presence of fine dead aerial fuels.

FUEL CONTINUITY

Fuel continuity describes the distribution of fuels in a given area. Fuel continuity is an important fire behaviour factor because the distribution of fuels influences the potential area where a fire may spread as well as the rate of spread. If a dangerous fuel is uniformly distributed over an entire area, a high potential exists for a complete burn to occur at a rapid and uninterrupted rate of spread. However, if the fuel body is broken up by patches of bare ground or much less inflammable material, both the potential area of the burn and the rate of spread of the fire are affected. A wide range of fuel continuity conditions will be found in most forest areas. However, for the sake of simplicity in making fire behaviour estimates, two broad fuel continuity classes are recognized as follows:

Uniform fuels (figure 9) - include all fuels distributed continuously over the area being evaulated. Areas containing a network of stringers or blocks which connect with each other to provide a continuous path for the spread of fire are included in this classification.

Patchy fuels (figure 10) - include all fuels distributed unevenly over the area being evaluated. Definite breaks should be present, such as patches of rocky outcroppings or plots where the dominant vegetation is of much lower inflammability than the main fuel body.

UNIFORM FUELS

Fig.9: Uniform fuels are characterized by a continuous layer of inflammable ground cover

PATCHY FUELS

Fig.10: Patchy fuels are characterized by definite breaks in the ground cover which will reduce the rate of spread of a fire

FUEL QUANTITY

Measurements of fuel quantity are usually expressed as weight per unit area or height of the main fuel components. Both methods may be applied readily to grasslands, but in forests measurement by weight is most practicable. Fuel quantity or the weight of available fuel is usually expressed in tonnes per hectare. Grass height is measured in metres and may be related to tonnes per hectare for varying degrees of grass density. Observers soon become accustomed to estimating fuel quantities from the general appearance of the vegetation, but should measure samples from time to time to ensure that their estimates are accurate.

MOISTURE CONTENT AND THE CURING OF PLANT TISSUE

The moisture content* of plant tissue varies considerably with changes in seasonal weather conditions, the moisture content of the soil, the aspect and the stages that plants have reached in their life cycle. Variations may exist within the parts of a plant. In trees the moisture content of the sapwood is greater than that of heartwood. The moisture content of leaves and stems of plants ranges between 100% and 400% of the oven-dry weight, though this full range is not necessarily found within one species. In very lush vegetation, moisture content may be as high as 500% of oven-dry weight. The lowest limit necessary for plant survival is about 70% moisture content even for plants growing in a harsh arid environment.

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* Fuel moisture content - the amount of moisture in a fuel generally calculated as a percent of ovendry weight (M.C. %) as follows:

$$\text{M.C. \%} = \frac{(\text{Field weight}) - (\text{Ovendry weight}) \times 100}{\text{Ovendry weight}}$$

Grasses which complete their life cycle within a period of three to six months die when they reach maturity, or even earlier under drought conditions, and dry out rapidly when their roots cease drawing moisture from the soil. This process is termed curing. The process is related to physiological changes which take place in the plant and the rate of curing varies from species to species and with current climatic conditions.

MOISTURE CONTENT OF DEAD OR CURED MATERIAL

When vegetation dies or becomes cured it shrinks, but since it does not lose its basic cell structure it is capable of soaking up free water from rainfall. Deep litter layers and punky wood can reach values as high as 200% dry weight or more following a prolonged rainfall. Fine materials may reach the limit of their capacity to absorb rainwater within a few minutes; the process is much slower in large logs.

Since the cell walls of plants are hygroscopic, they are capable of taking in water vapour from the air in a process known as adsorption. In most dead plant material, fibre saturation point is reached when the moisture content is about 30% to 35% of dry weight. Normally fuels take up moisture by adsorption during the cool, still, humid conditions of night. Fuels dry by evaporation at rates depending on the air temperature and relative humidity of the atmosphere and the wind speed, in a process described as desorption. Desorption is usually at its maximum in the warmer, windier and drier conditions of daylight hours. Normally the rate of desorption exceeds that of adsorption and has to be taken into account when estimating the degree of fire danger, which is based on near equilibrium conditions in the early afternoon and does not take into account the fact that fuel moisture content is above equilibrium values in the early morning hours and is below these values in the late afternoon and evenings.

FUEL AVAILABILITY

As heat expended in driving out moisture delays the pre-heating and ignition of fuel, combustion rates vary inversely with fuel moisture content. Generally, a fuel moisture content of 20% to 25% of oven-dry weight in fine fuels is sufficient to prevent ignition or halt combustion. Strong winds may keep a fire burning at higher moisture contents than those quoted above.

Fuel availability is a term used to refer to the proportion of fuel, usually fine fuel, which will burn in a forest or grass fire. In forests, the upper part of the surface litter is normally drier than the lower part and is more likely to be consumed by fire. Thus it becomes possible to estimate the quantity of both total and available fuel and to make forecasts of fire behaviour depending on the quantity of available fuel. Fuel availability varies widely with fuel moisture conditions and with its thickness and geometry of arrangement. It also varies, to some extent, with the duration and intensity of the fire.

Because the availability of forest fuel is relatively low, only a small proportion of the total fuel is consumed by even a severe forest fire. In some forests the total dry weight of dead and living plant material may be as high as 500t/ha or more. Table 1 shows data derived from a dry sclerophyll forest in Victoria (Australia) containing trees to a height of 30 m. The total dry weight of plant matter was assessed at 265t/ha, but the amount of available fuel was only 10t/ha, plus some low percentage of scrub species and bark probably not exceeding 2-3t/ha.

Table 1: Example of the quantity of various sized fuel components in a dry sclerophyll eucalypt forest

Component	Weight (t/ha)
Fine fuel (or litter) < 6mm	10.0
Scrub species	10.8
Bark	27.3
Wood: 0.6 to 2.5 cm diameter	4.8
Wood: 2.5 to 12.5 cm diameter	46.0
Wood greater than 12.5 cm diameter	166.0
Total	264.9

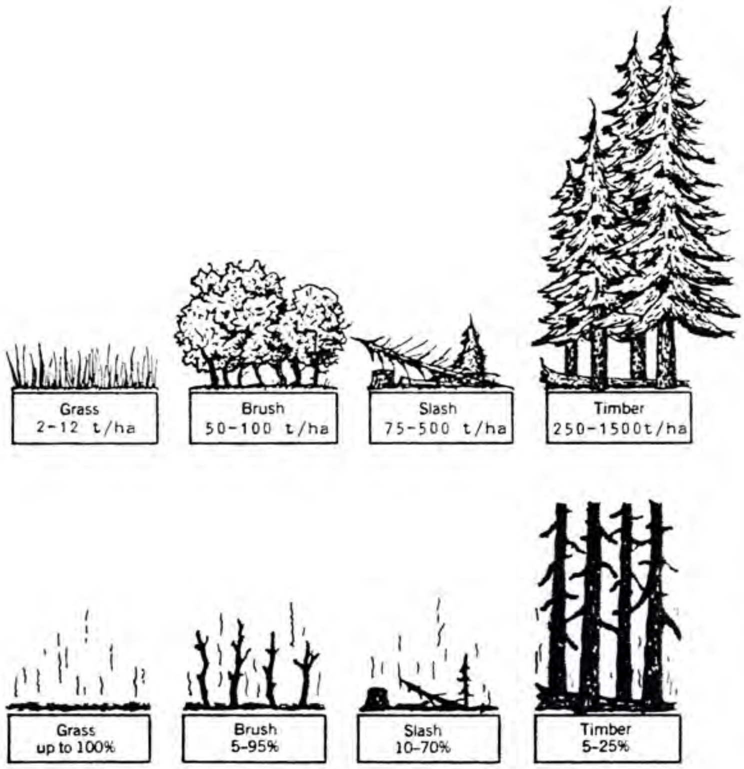

Fig.11: Fuel loading and fuel availability

1.3 INFLUENCE OF WEATHER AND TOPOGRAPHY ON FIRE BEHAVIOUR

Besides weather topography has a great influence on fire behaviour. Land masses influence the general climate of an area, but in addition differences in topography cause local variations in climate and day-to-day weather conditions. These variations in turn influence the character of forest growth and the inflammability of fuels.

Topography provides a useful and easily recognized indicator of fire behaviour. Fires often have distinctive behaviour characteristics according to aspect, elevation, position on slope, steepness of slope, and shape of the surrounding country. These topographic features are usually easy to identify in the field and thus are important factors in the evaluation of fire behaviour.

RELATIVE HUMIDITY AND TEMPERATURE

Relative humidity is most important as a fire-weather factor in the layer near the ground, where it influences both fuels and fire behaviour.* Near the ground, air moisture content, season, time of day, slope, aspect, elevation, clouds, and vegetation all cause important variations in relative humidity.

Since hourly and daily changes of relative humidity are normally measured in a standard instrument shelter, we will consider variations at that level and infer from our knowledge of surface

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* Relative humidity is the ratio, in percent, of the amount of moisture in a volume of air to the total amount which that volume can hold at the given temperature and atmospheric pressure.

temperatures what the conditions are near the surface around forest fuels.

A typical fair-weather pattern of relative humidity, as shown on a hygrothermograph exposed in a shelter at a valley station or one in flat terrain, is nearly a mirror image of the temperature pattern (figure 12). Maximum humidity generally occurs about daybreak, at the time of minimum temperature. After sunrise, humidity drops rapidly and reaches a minimum at about the time of maximum temperature. It rises more gradually from late afternoon through the night. The daily range of humidity corresponds to the daily range of temperature. Variations in the humidity traces within an air mass from one day to the next are usually small, reflecting mostly differences in temperatures. But over several days, there may be noticeable cumulative differences in humidity as the air mass gradually picks up or loses moisture.

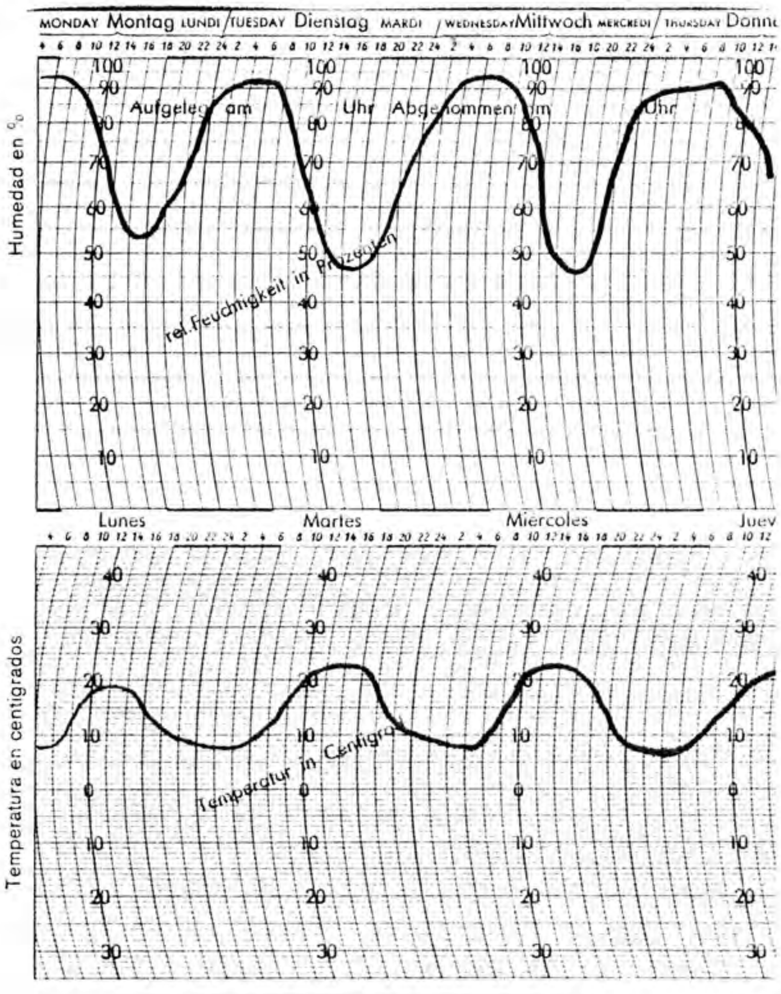


Fig.12

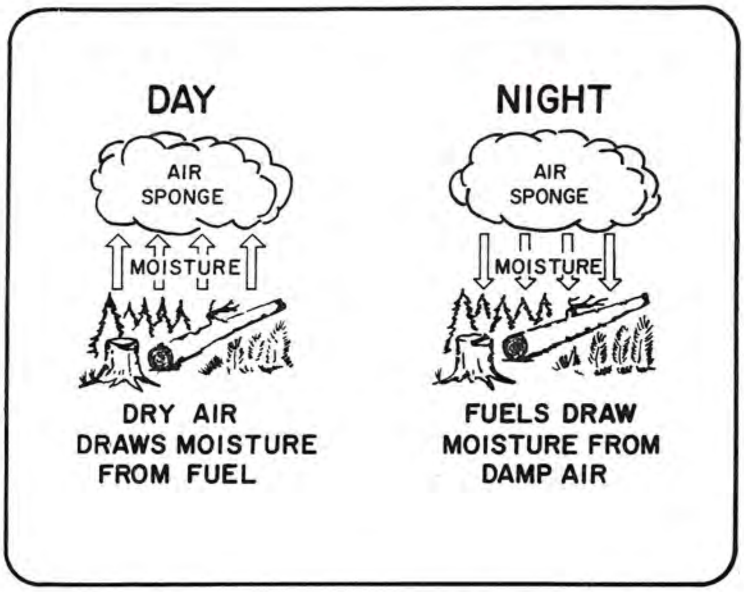


Fig.13: As air is heated, the relative humidity decreases. As it cools, the relative humidity increases. The amount of moisture in the air affects the fuel moisture content

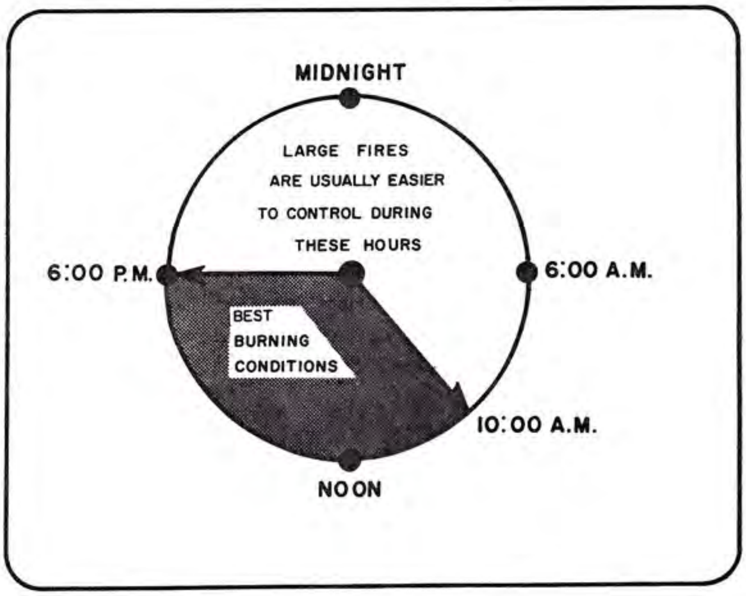


Fig.14: Fire suppression should not be stopped at night because fires are usually easier to control during hours of high relative humidity

FUEL MOISTURE

Once a fire has been started in natural fuels by an external heat source (match, lightning, biological activity etc.) it is the moisture content of the fuel which influences the heat side of the fire triangle and determines whether the fuel will continue to burn and the rate at which it will burn.

Moisture in the fuel reduces the combustion rate partly by absorbing the heat required to dry out the fuel (latent heat of vaporisation) but mainly by reducing the radiant emissions of the flames produced. Moisture also promotes partial combustion and enhances smoke formation so that the total amount of heat released is reduced.

The major effect of decreasing fuel moisture on fire behaviour is the increased ease of ignition. Fuels ignite more readily by flame contact and embers, thus increasing the probability and intensity of spotting.

At very low moistures very small embers are capable of igniting fires and so fires start easily from unusual sources such as carbon particles from faulty exhausts or sparks from power-line conductors striking together. Spot fires start easily from tiny embers and spotting becomes the dominant fire spread mechanism.

Also at low fuel moistures, flames produce high levels of radiant heat making it difficult and enervating to work close to the fire edge, even when flames are low. These conditions increase the chance of heat stress and heat exhaustion among fire fighters (see chapter 5.4).

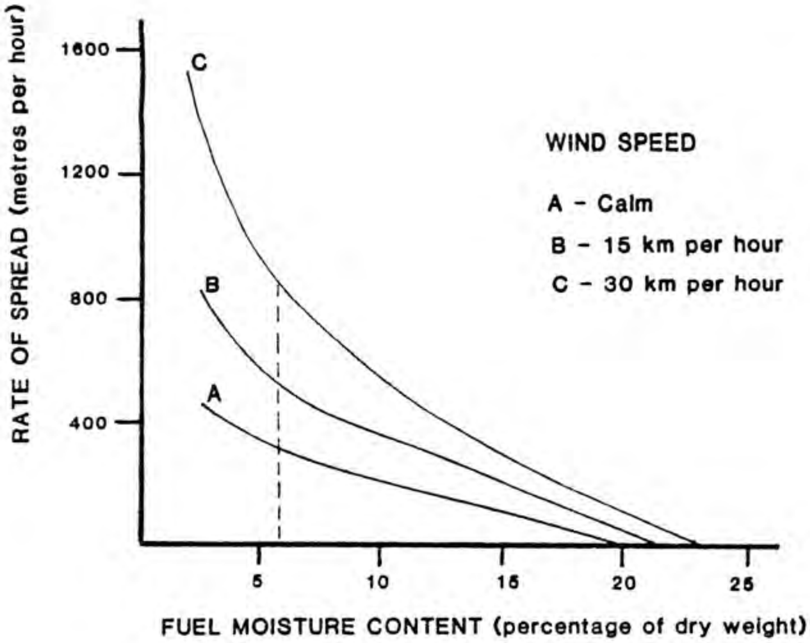


Fig.15: Effect of fuel moisture and wind speed on rate of fire spread (example of fire in eucalypt forest)

WIND

Wind provides oxygen to the fire triangle and it is the most important factor in determining fire behaviour in dry fuels. Any fire burning in a dry fuel on flat terrain will be relatively easy to control provided winds remain calm. Once the wind speed increases, the whole range of fire behaviour increases dramatically. Wind acts on a fire in the following ways:

(a) maintains the oxygen supply to the combustion zone;

(b) tilts the flames forward and provides more effective radiation and pre-heating to the unburned fuels;

(c) increases the chance of direct flame contact with fuels ahead of the fire;

(d) shifts the convection column ahead of the fire so that the convective energy of the fire reinforces and increases the wind speed in the flaming zone, providing additional momentum to fire spread;

(e) blows burning embers ahead of the fire and initiates the spotting process.

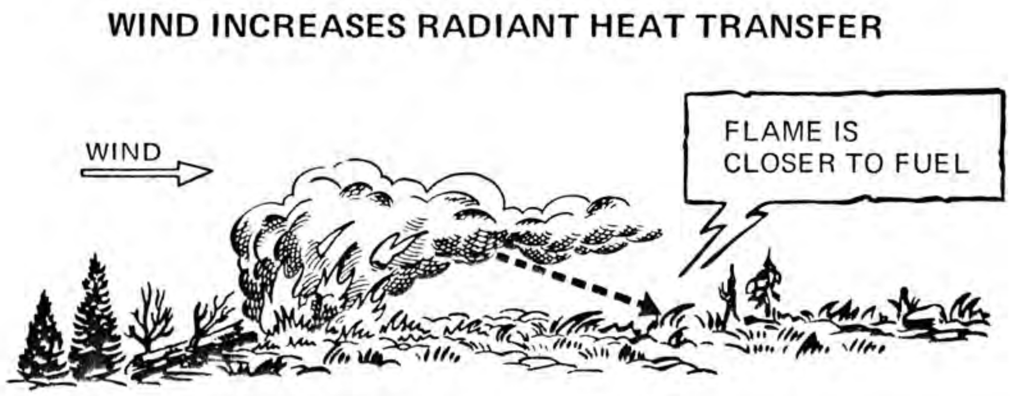


Fig.16: Wind bends over flames and thus provides more radiant heat to fuels immediately downwind from the fire

The relationship between wind speed and rate of forward spread in forest fuels is illustrated below (figure 17).

When the winds are light, less than 3 km/h, the convective updraft of the fire, particularly in heavy forest fuels, prevents the wind from bending the flames forward and there is no increase in rate of spread between wind speeds of 0 and 3 km/h. Above windspeeds of 3 km/h, the rate of spread of the fire increases very rapidly with further increases in wind speed.

Although the relationship is similar for different fuel types there are very big differences in the response to increasing wind speeds. Fires in light grassy fuels, for example, burn slowly under calm conditions but respond very quickly to changes in wind speed and their rate of spread increases much more dramatically as wind speed increases. Since the convective updrafts from fires in grass fuels are small by comparison with those in forest fuels, the rate of spread increases as soon as the wind speed increases.

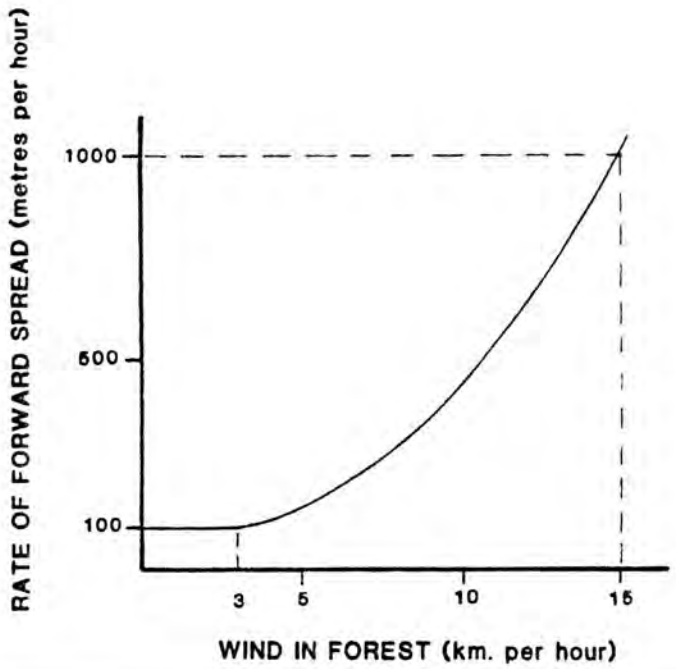


Fig.17: Relationship between wind speed and rate of forward spread in forest fuels

The wind speed near the ground is greatly influenced by:

- the height of vegetation (e. g. grass, scrub, forest)
- the density of forest cover
- the topography
- thermal currents from local heating or cooling
- the convective updraft (convection of the column).

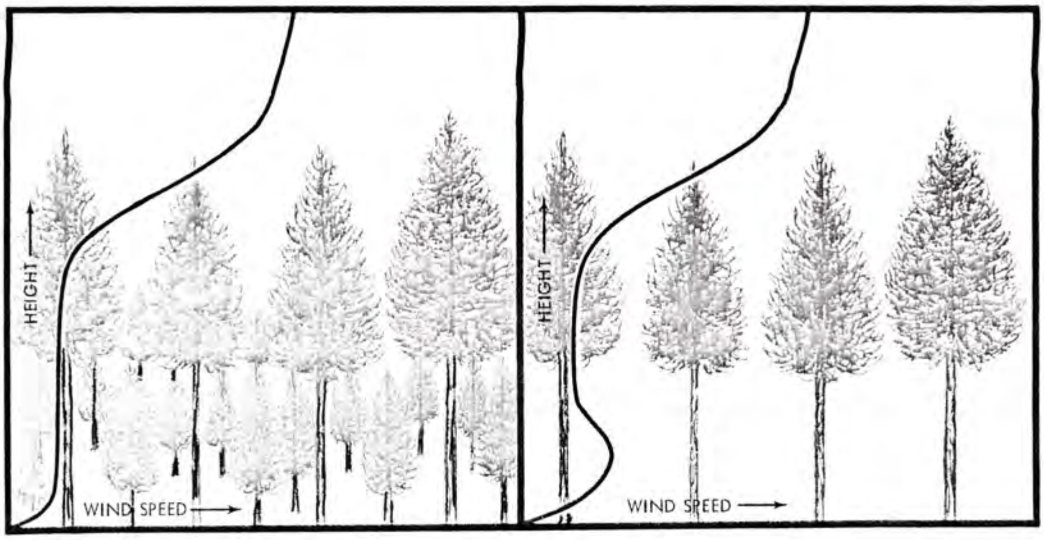


Fig.18: Vertical wind profiles in forest stands show that the crown canopy is very effective in slowing down wind movement. In stands with understory, the wind speed is nearly constant from just above the surface to near the tops of the crowns. Above the crowns, wind speed increases much like above level ground. In stands with an open trunk space, a maximum in wind speed is likely in the trunk space and a minimum in the crown area.

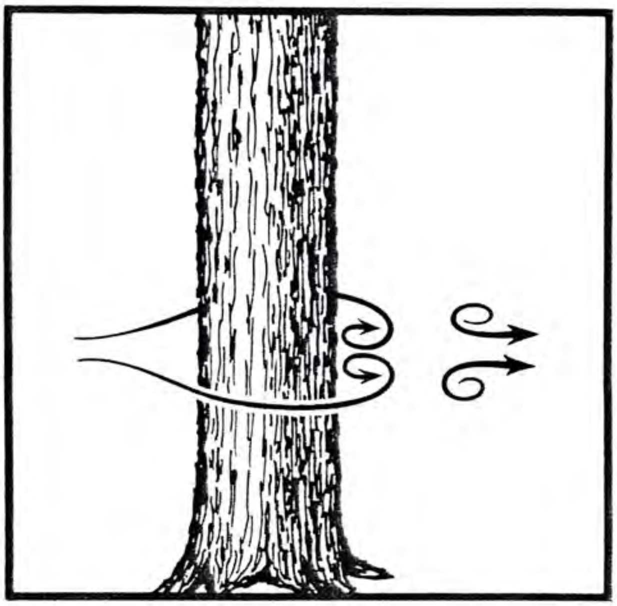


Fig.19: Wind-driven surface fires form local eddies in the lee of tree stems and create hotter and more persistent flames

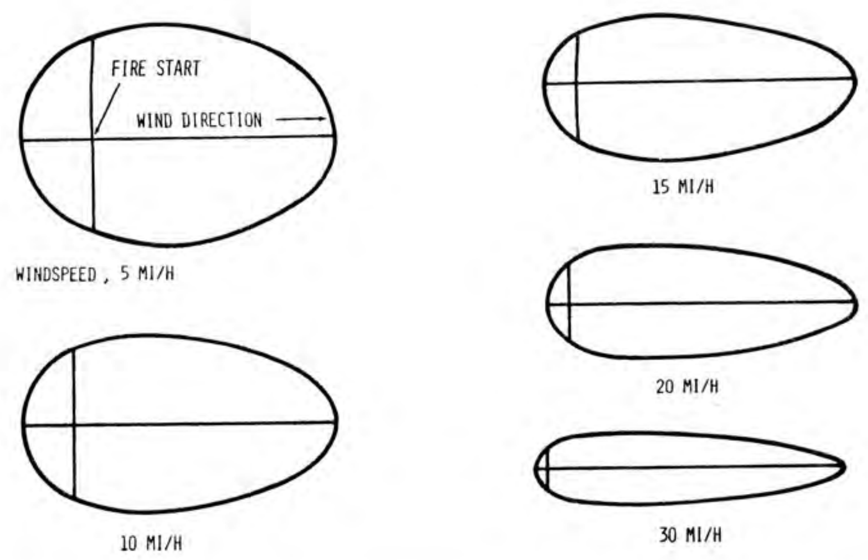


Fig.20: Fire shapes under different wind regimes. Note how the backing fire becomes less influential as windspeed increases.

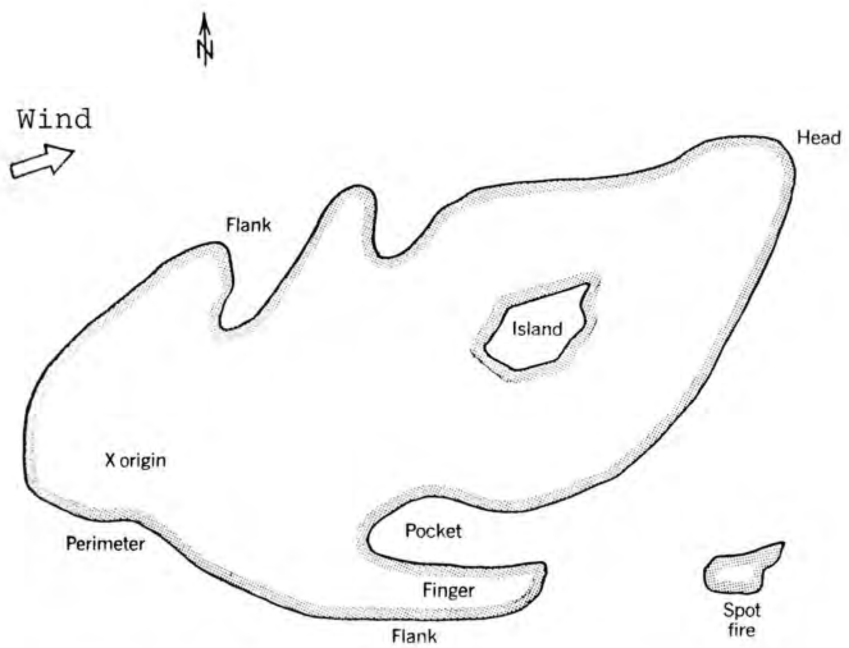


Fig.21: Description of fire shape

ASPECT

Aspect, sometimes referred to as exposure, describes the direction in which a slope faces. Fire conditions vary greatly according to aspect. These variations occur primarily because different amounts of sunshine and wind have a significant influence on fuel moisture and fire behaviour.

In general, in the northern hemisphere south and southwest slopes provide favorable conditions for the ignition and spread of fires. These slopes receive more direct sunshine (air and fuel temperatures are somewhat higher), and therefore fuels dry out rapidly (southern hemisphere: north and northwest slopes).

ELEVATION IN RELATION TO SURROUNDING COUNTRY

Mountain tops and valley bottoms have different burning conditions at various times during a 24-hour period. Under settled, mid-summer atmospheric conditions a daily interchange of air occurs between the valley bottoms and the mountain tops. During the day the air in the valley bottoms is much warmer than that near the mountain tops. Because of its light weight this heated air has a tendency to rise. At night when the heating by the sun discontinues, heavier cold air masses drain into the valley bottoms. As a result of this interchange, summer nighttime temperatures are usually lower in the valley bottoms than at the mountain tops.

The differences between valley bottoms and mountain tops are very important in evaluating fire behaviour. For about a 12-hour period from 8 a.m. to 8 p.m. valley bottoms have the most dangerous fire conditions. As night approaches the trend is reversed. Cool, moist air pours into the valley bottoms and the fire danger diminishes (Formation of night inversions).

The height of the top of night inversions, although it varies from night to night, is usually below the main ridges. The height of the warmest air temperature at the inversion top can be found by measuring temperatures along the slope. From this level, the temperatures decrease as one goes farther up or down the slope. At this level are both the highest minimum temperatures and the least daily temperature variation of any level along the slope. Here also are the lowest nighttime relative humidity and the lowest nighttime fuel moisture. Because of these characteristics of the average level of the inversion top, it is known as the "thermal belt". Within the thermal belt, wildfires can remain quite active during the night. Below the thermal belt, fires are in cool, humid, and stable air, often with downslope winds. Above the thermal belt, temperatures decrease with height.

Fig.22: The zone of warm nighttime temperatures near the top of the inversion is known as the thermal belt.

SLOPE

The slope of the ground affects the orientation of the fuel bed to the fire front and has a considerable influence on fire spread. The effect of slope is very similar to that of wind speed in that the angle between the flames and the fuel is reduced, increasing the radiant and convective pre-heating of fuels ahead of the fire and increasing the likelihood of direct flame contact. The effect of slope on rate of spread is illustrated below.

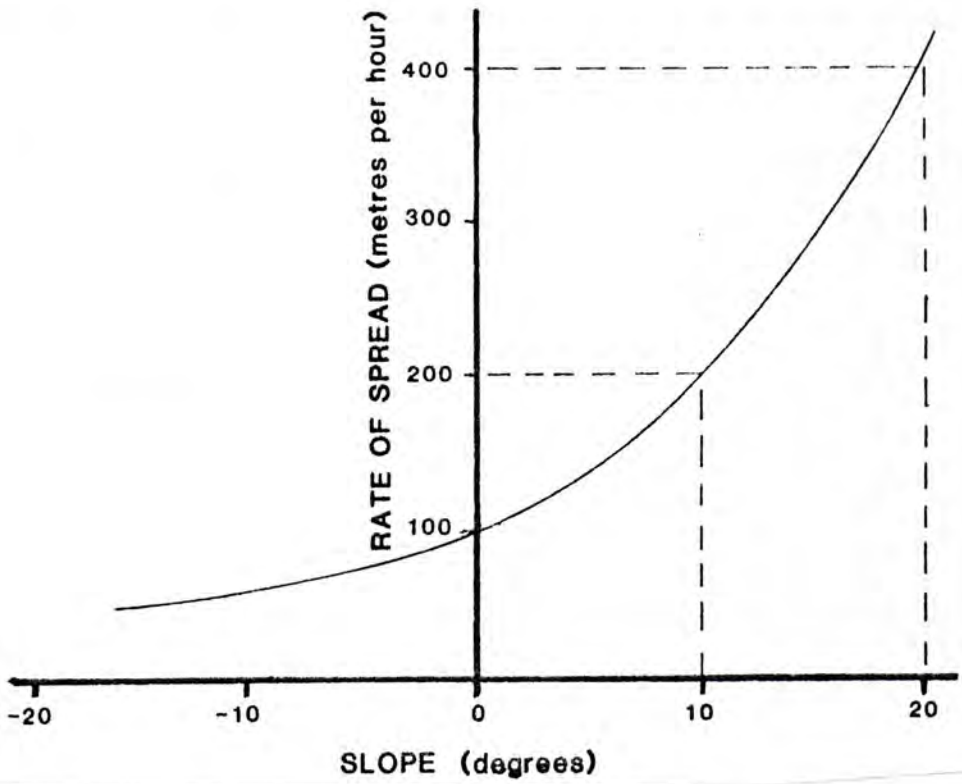


Fig. 23: The effect of slope on rate of fire spread

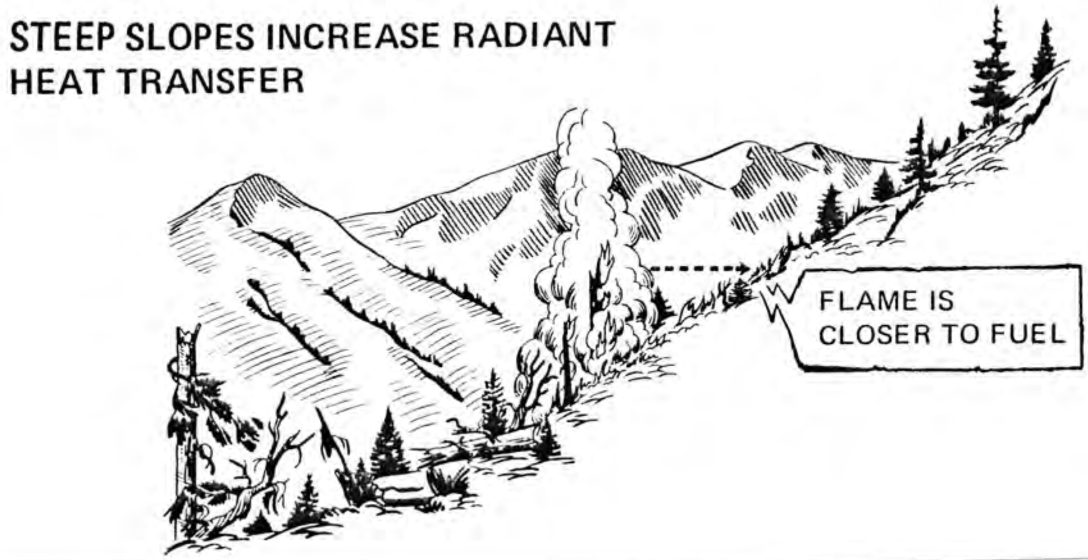


Fig.24: Fuels upslope from a fire receive more heat than fuels on the downslope side.

Fire behaviour at various positions on a slope may be influenced not only by aspect and elevation but also by the magnitude of the fuel body and topographic barriers. When a fire starts at the bottom of a slope, an entire mountainside of fuels may lie in its path. Once a fire starting at the base of a slope gains headway, the availability of a continuous fuel body makes a large burn possible. As shown in figure 26, a high percentage of fires starting at the base of a slope reach sizes of 5 ha or more. The fact that these fires are large in size probably means that they travel into the thermal belt, and in many cases into the upper slopes. The dangerous burning conditions in the thermal belt and at some periods of the day in the upper slopes may contribute to the large size of such fires.

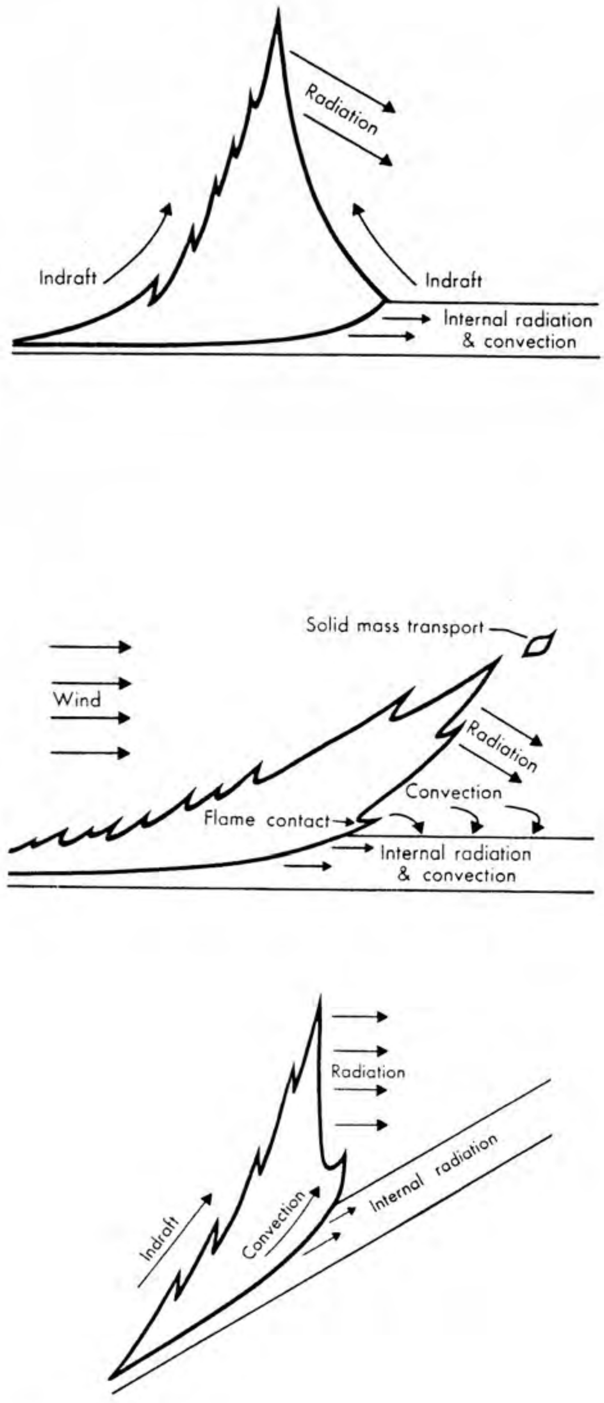


Fig.25: Flame shape and fire spread: No wind or slope (upper), wind-driven fire (middle) and slope-driven fire (lower).

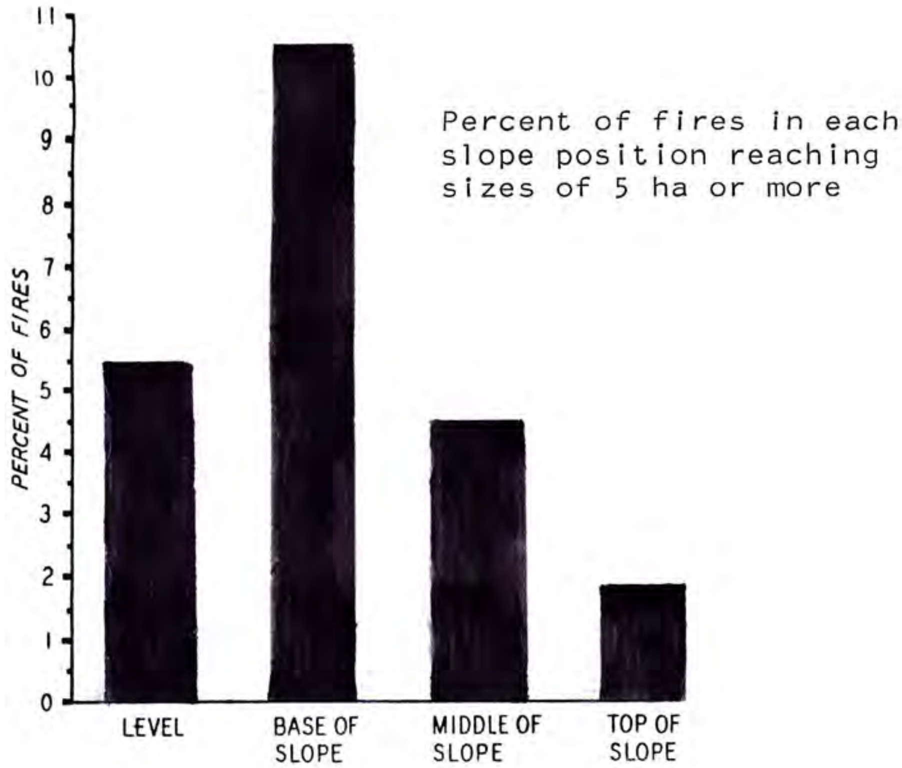


Fig.26: More fires starting at the base of slope reach large size because a greater fuel area is available for spread of the fire.

Fires running up a slope generally have a wedge shape similar to the shape of fires driven by strong winds (figure 27). Flames on the flanks of the fire will be pulled (under calm air conditions) inward by the intense heat. When fires reach the top of a slope, the flames usually will be bent back toward the rear of the fire (figure 28). This typical curling back of flames at the slope summit is caused by the natural rise of warm air on the opposite slope as well as the tendency of this air to be drawn toward the fire.

FIRES ON STEEP SLOPES HAVE A WEDGE SHAPE

Fig.27: Fires on steep slopes usually are characterized by a definite head, wedge shape, and flames on the flanks drawn inward.

FLAMES BEND BACK INTO THE FIRE AT THE TOP OF A SLOPE

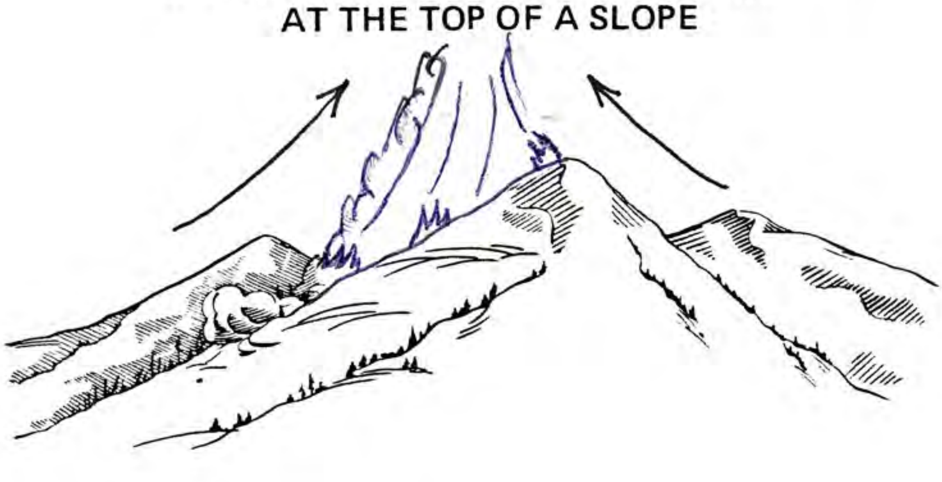


Fig.28: As a fire reaches a slope summit, the updraft from the opposite side of the mountain will bend flames into the burn.

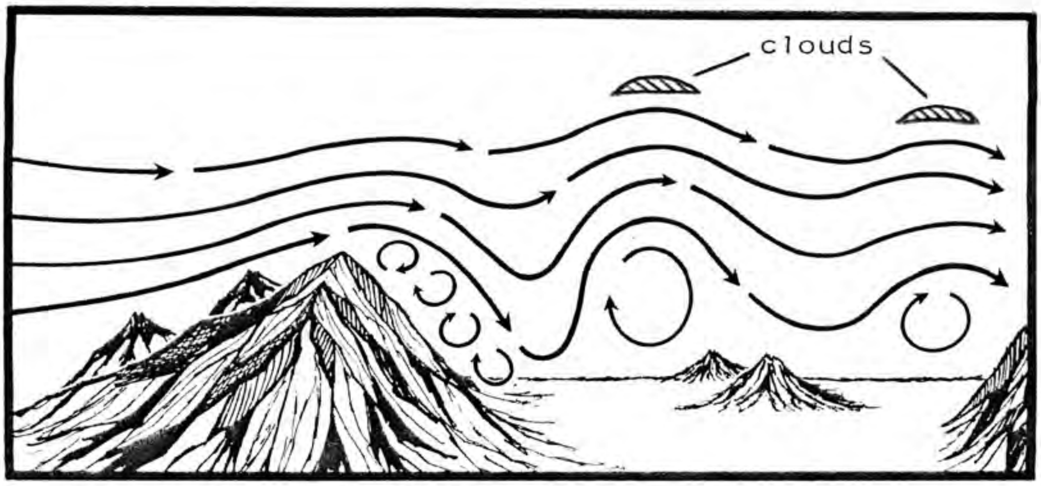


Fig.29: Mountain waves form when strong winds blow perpendicular to mountain ranges. Considerable turbulence and strong updrafts and downdrafts are found on the lee side. Crests of waves may be marked by lens-shaped wave clouds, but at times there may be insufficient moisture to form clouds.

Fires may travel rapidly downhill, especially at night when air masses are moving downslope. Fires may be expected to travel downhill whenever a temperature inversion is causing heavier air to flow into valley bottoms. Normally, this downslope spread of fires will be slower than the upslope spread except where strong winds accompany the inversion.

In forest areas a surface fire creeping downslope may create a dangerous situation for reburn in the tree crowns. Heat from the surface fire dries out the tree crowns as it moves downslope; and whenever conditions are favorable for an upslope movement of air, a crown fire is likely. This condition is most likely to occur on the day after a night movement of a fire downslope.

Steep slopes exert several physical effects on a fire. Burning material may roll downhill and start spot fires below the main fire. On steep slopes a vertical fire line running up and down the slope on the sides of a fire may be outflanked by a spot fire starting on the bottom of the slope (figure 30). Because of this possibility the flanks of fires on steep slopes cannot be considered safe until the lower slope portions have been thoroughly mopped up.

SPOT FIRES ON STEEP SLOPES
MAY OUTFLANK MAIN FIRE

Fig.30: The spot fire on the left of the fire line may burn rapidly upslope and outflank the main fire.

FIRES EASILY CROSS NARROW CANYONS

Fig.31: Fuels on the opposite slope from a fire in a narrow canyon are subjected to intense heat and flying embers.

SHAPE OF COUNTRY

In rugged mountainous areas the shape of the country is of great importance to the firefighter who must evaluate fire behaviour. Narrow canyons, side drainages, sharp ridges, and massive irregular slopes all have a bearing on the direction of travel, rate of spread, and general behaviour of fires. Experience in this region has shown the following topographic features to be of special importance:

Narrow canyons: Wind direction will normally follow the direction of the canyon. Wind eddies and strong upslope air movement may be expected at sharp bends in a canyon. Radiant heat transfer from one slope to another is great, and as a result fires may easily spot across the canyon (figure 31). Near the bottom of the canyon there is little difference between conditions on various aspects.

Wide canyons: Prevailing wind direction will not be altered to any great extent by the direction of the canyon. Cross-canyon spotting of fires is not common except in high winds. Strong differences will occur between general fire conditions on north and south aspects.

Box canyons: Fires starting near the base of box canyons will react similar to a fire in a stove (figure 32). Air will be drawn in from the canyon bottom creating very strong upslope drafts. These same conditions may occur at the head of narrow canyons and at the head of high mountain valleys.

Ridges: Fires burning along lateral ridges may change direction when they reach a point where the ridge drops off into a canyon (figure 33). This change of direction is caused by the flow of air in the canyon. In some cases a whirling motion by the fire may result from a strong flow of air around the point of a ridge.

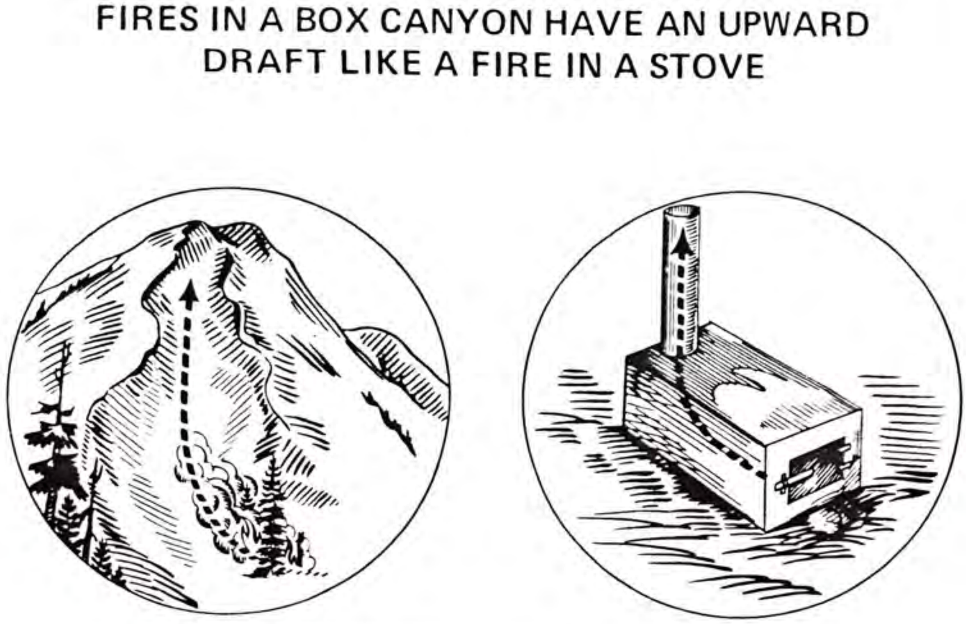


Fig.32: Box canyons and chimneys created by sharp ridges provide avenues for intense updrafts.

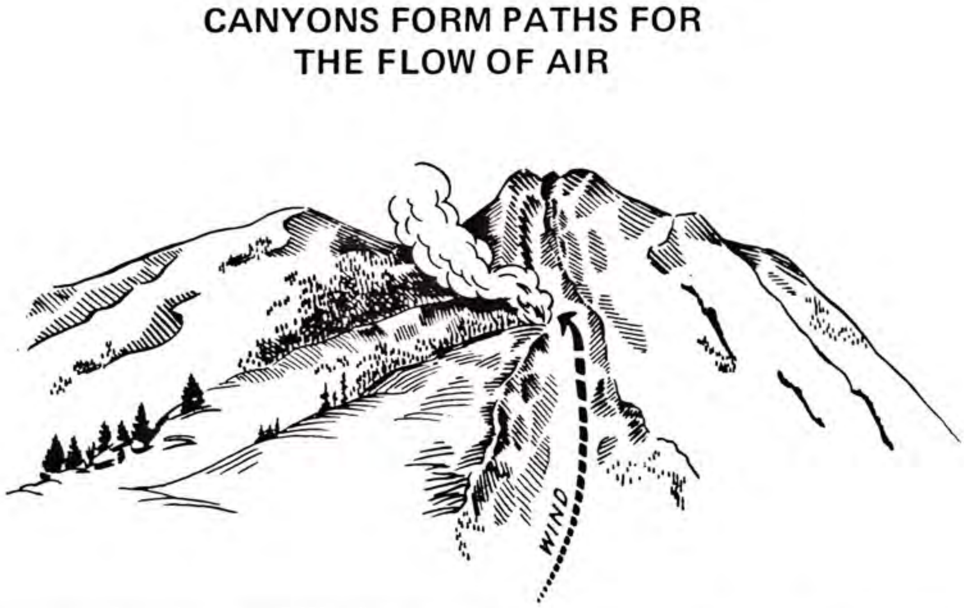


Fig.33: In narrow canyons wind may follow the direction of the canyon. Fires approaching a canyon on a lateral ridge may change direction when they reach the zone influenced by the air movement.

2. FOREST FIRE PREVENTION: HAZARD REDUCTION AND FUEL MANAGEMENT

Fire prevention concerns control of both fire risks and fire hazards. This chapter deals with the aspect of preventing fires through control of the quantity, arrangement, continuity, ignitability, or burning rate of forest fuels. Two principles are involved. First, the direct prevention of fires through hazard reduction means removal of fuels exposed to sources of high risk. Next comes an extension beyond the concept of mere prevention of ignitions to that of preventing or limiting spread following ignition or preventing the rapid build-up of heat energy. In terms of fire prevention the objective becomes prevention of large or uncontrollable fires rather than simply a reduction in the total number of fires.

With this broadened significance in mind, hazard reduction may be classified according to its intended purpose, as follows:

1. Removal of all ignitable fuel in limited areas of special risk. Examples: The cleared railway right-of-way. Or a zone kept clear of fuels around sawmill burner.

2. Removal of all fuel in a strip close to or around the source of risk in order to confine any fire that may be ignited to a small isolated area. Example: Cleanup of fuels or exposure of soil in a strip along roads; the purpose is both prevention of ignitions and containment.

3. Removal of fuel in a strip where the purpose is to exclude fire from a high-value or high-hazard area. Example: Firebreaks around a forest plantation.

4. Removal of fuels to reinforce natural breaks and to create new ones by which an area can be broken up into blocks to facilitate control of wildfires. Examples: Fuelbreaks in wildland fuels or a skeleton system of access roads and fire

breaks in plantations.

5. Breaking the vertical and horizontal continuity of fuels by silvicultural measures.

6. Use of prescribed burning, when coarse and intermediate fuels are moist, to safely remove flash fuels. The purpose is to reduce the energy output and the rate of spread of wildfires so that they will be much easier to control and will do less damage.

The main principles of fire break and fuelbreak construction, silvicultural measures, and prescribed burning are described in the following sections.

2.1 FIREBREAKS

A firebreak is defined as "any natural or constructed discontinuity in a fuelbed utilized to seggregate, stop, and control the spread of fire or to provide a control line from which to suppress a fire".

If the spread of fire depended solely on fuels being brought to ignition point by radiation or flame contact, firebreaks could be made quite narrow, varying perhaps from two to four times the greatest length of flames which could be expected in the horizontal plane. In some areas almost any narrow track would suffice, while a fast-spreading grass fire exposed to strong winds might require a minimum width of 30 m or more.

In many forest types airborne firebrands are likely to spread fires across a barrier of bare ground, so that the effects of both short and long distance spotting must be taken into account. In forests, spotting distances may range from a few metres to 20 km or more, depending on fuel and weather conditions and the characteristics of bark, the most important firebrand. In treeless grasslands spotting distances seldom exceed 100 m.

Constructing or burning firebreaks of sufficient width to ensure that all fires are stopped in agricultural and grazing areas is obviously not practicable, as the cost of construction and annual maintenance is high and land would have to be thrown out of production. Better opportunities for reducing fuel on a large scale are available in many forest areas without undue loss of productivity. Generally speaking, a reasonable compromise must be reached when applying theory to practice in the construction of firebreaks. The safety of fire fighters, local residents and the travelling public must be considered. While it is not practicable to set out specifications for their complete safety under all circumstances, radiation across roads and firebreaks should be taken into account.

Any area of bare ground or water which has the capacity to halt or divert a fire, or provide refuge for man or animals, can be regarded as a firebreak. Some, such as rivers, lakes, sandy wastes, bare rock or rainforest, are entirely natural. Others have been made by man for purposes other than those specifically connected with fire protection. Roads, railway easements, transmission line clearings, land under fallow and many of man's other works fall into this category. Even narrow cattle or sheep pads hold up fires under some conditions, and may be used as control lines for back-firing.

Locating and assessing the value of natural barriers is the starting point for planning a network of firebreaks or a scheme of fuel management. Some activities are then aimed at improving what already exists, such as making roads more effective as barriers or joining up disconnected but adjacent areas of bare ground, while others are directed at subdividing a district into small areas of risk.

Control of erosion is another factor to be considered. Ploughing or grading up steep slopes is not desirable, while grading on flat land involves the risk that the tracks may turn into watercourses during periods of high rainfall.

2.2 FUELBREAKS

Fuelbreaks are defined as "Generally wide (20-300 meters) strips of land on which the native vegetation has been permanently modified so that fires burning into them can be more readily controlled. Some fuelbreaks contain narrow firebreaks which may be roads or narrower hand-constructed lines. During fires, these firebreaks can quickly be widened either with hand tools or by firing out. Fuelbreaks have the advantages of preventing erosion, offering a safe place for firefighters to work, low maintenance, and a pleasing appearance."

REQUIREMENTS OF FUELBREAKS

Fuelbreaks seek to correct two conditions that have limited the effectiveness of present-day firefighting techniques: (a) the difficulty of quick, safe manning of critical parts of the fireline when needed; and (b) the need for widening many fire control lines before they can be used effectively.

Once fuelbreaks have been established, fire control plans can be developed for manning them during or soon after initial attack on a fire.

Fuelbreaks, when manned, are intended to help control fires under burning conditions that now hinder control in unbroken fuels on steep terrain. The wide breaks will not necessarily make stopping a rapidly moving fire possible when spot fires are starting well ahead of the main fire. The prepared breaks, however, can be used

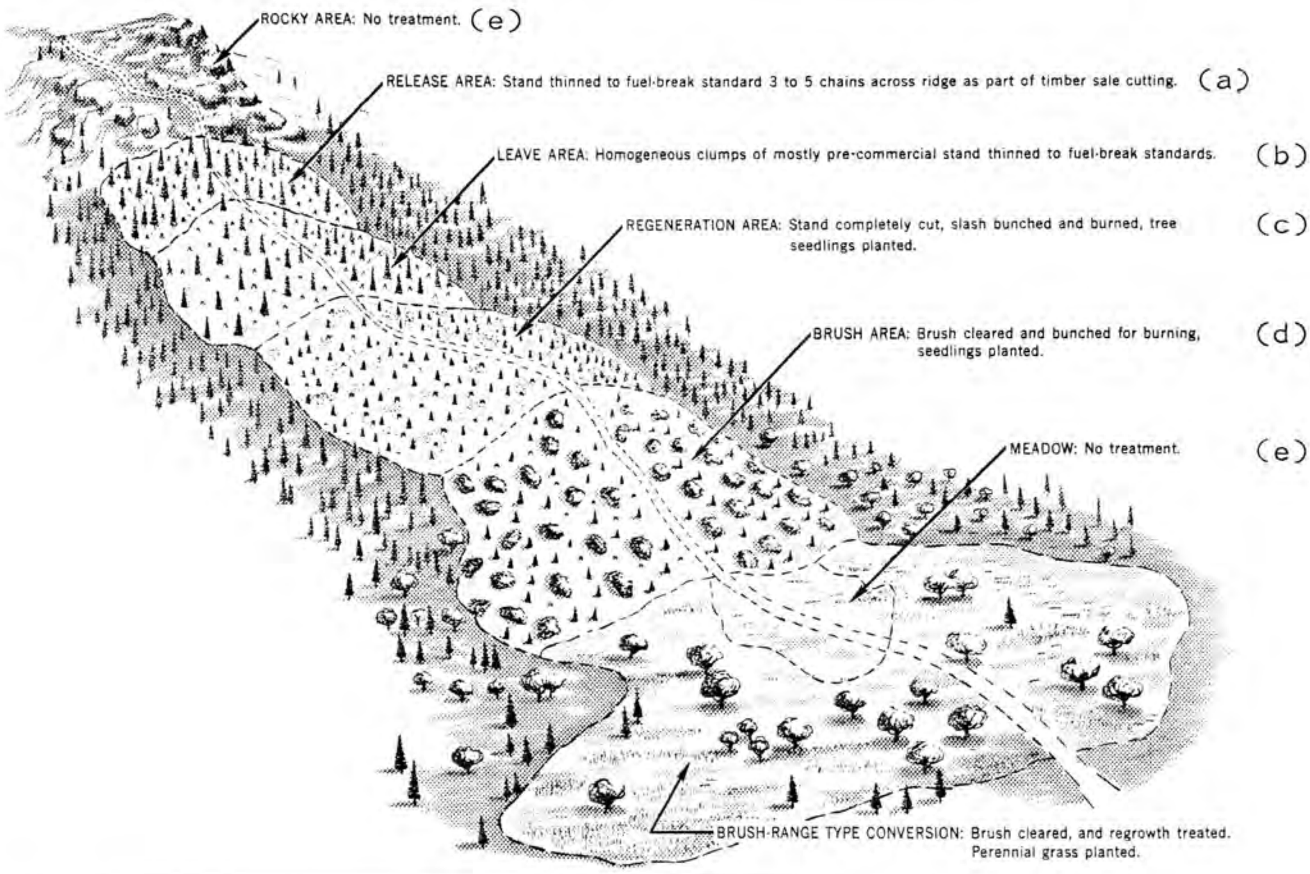


Fig.34

Forest Management activities that can help finance construction of fuelbreaks include (a) thinning in release area 60 to 100 m across a ridge as part of a timber sale; (b) thinning homogeneous clumps of mostly pre-commercial stand in a leave area; (c) cutting the stand in a regeneration area, bunching and burning slash, and planting trees; (d) clearing a brush area for burning, and then planting trees; (e) clearing brush, planting perennial grass, and controlling regrowth in a brush-range type conversion. In this model, meadows and rocky areas are left untreated.

to stop the lateral spread, thereby reducing the burned acreage, suppression costs, and resource damages.

Among the major requirements of a fuelbreak are these:

- A fuelbreak generally has a low-growing ground cover. This cover should protect the soil against erosion. It should have light-fuel volume so that the fire spread and the total heat output will be low. And it should produce few flying sparks or embers which may start spot fires across the break.

- Trees or shrubs or both should be present on a fuelbreak for esthetic purposes, but woody fuel must not be continuous. Individual trees and shrubs, or clumbs of trees and shrubs, should be spaced to prevent running crown fires within the break. Trees and shrubs should be pruned sufficiently high to prevent their ignition by burning ground fuels. Sound pines and some broadleaved trees are relatively fire resistant, and consideration should be given to leaving them on fuelbreaks. Good landscape design should be used to ensure a pleasing, esthetic appearance consistent with fire control objectives.

- Fuelbreaks, with safety zones as needed, provide safety for firefighting personnel and equipment under hazardous conditions. Safety zones should be wider than other parts of a fuelbreak. The fuel type on the fuelbreaks and safety zones must be of a kind which can be safely burned out for protection of personnel and equipment.

- Firelines are desirable within fuelbreaks and should be maintained so that they can be fired and held at the proper time. These interior firebreaks are kept clean to mineral soil during the fire season, in contrast to fuelbreaks, which have a permanent cover of vegetation.

- Fuelbreaks are made accessible to motorized and aerial equipment whenever possible. Places for helicopter touchdown spots or heliports, and for parking and turning vehicles will be designated.

- Sources of water for loading ground tankers or helicopters, or for grazing animals are provided.

FIRE CONTROL PLANNING

Fuelbreaks should be designed as an integral part of the preattack and presuppression inventory and fire control planning (see chapter 3). They and other planned improvements should be well meshed to provide the best possible fire control plan. This work should be coordinated with that of other protection agencies. The number and locations of fuelbreaks and the sizes of the intervening areas of natural fuels are determined by the fire control objectives together with the potential for large fires and damage. But the intervening areas must be kept as small as can be justified if the fuelbreaks are to help reduce the size of future fires.

Entire fuelbreak systems should be planned at one time. The planned work should include all breaks considered necessary in the long-range program, when the need for intensive fire control may be greater than now. The fuelbreak plan should be developed and coordinated with other resource improvement plants.

PRIORITY LOCATIONS

The first fuelbreaks to be built should be those of primary importance in helping prevent fires from sweeping for miles across country. These primary breaks commonly will be on prominent ridges that separate major drainages or sub-drainages, or they may be located to separate populated areas from unbroken fuel masses. They are not restricted to any specific topographic feature; they may be at the base of mountains, in bottoms of wide river drainages, or elsewhere.

Roadside clearing along fire control roads often will rank next in priority. Roadside fuelbreaks will ensure safer access, and they will make these accessible areas more usable as fire control lines.

Fuel hazard reduction work, which can be tied into fuelbreaks is essential. High priority should be accorded (a) residential areas, mountain communities, organizational camps, and similar areas where human safety, as well as investments, must be protected; (b) around groves of trees, either natural or planted, that have high economic, scenic, or historical value that cannot be replaced; and (c) around other areas with high investment in buildings and facilities.

All excess woody fuel which could burn if a fire occurred must be removed as the first step in building a fuelbreak. The objective is to leave a low volume of fuel with a low total heat output near the control line. Handcutting and burning or chipping of thinned brush and trees is an excellent way to clean up; bulldozing and burning or burying are alternate methods. Some areas can be prepared with prescribed fire (see chapter 2.4).

FACTORS AFFECTING WIDTHS

Each fuelbreak must be designed to fit the terrain, fuel, and expected weather conditions. The width will not be uniform; it will be wider at critical points, such as heads of draws and canyons, and narrower elsewhere. In selecting the widths of fuelbreaks, the forest manager must estimate the distance from the flame front necessary to prevent serious burns from radiated heat and direct ignition from radiation.

On a ridgetop, the crest will prevent direct radiation of heat from one side of a fuelbreak to the other. But because of eddying along the ridgetop, fuelbreaks of near minimum width must be manned with caution. On flat land, with no ridge-crest barrier for protection, the fuelbreaks must be wider (see figure 35).

Silvicultural methods

Following the principles of fuelbreak construction, fire hazard reduction in timber production areas is being attained by following silvicultural methods:

- Remove all merchantable high risk, damaged, and bark beetle killed and infested trees.
- Remove enough of the remaining merchantable overstory trees which have interlacing crowns to achieve a spacing that will result in a shaded fuelbreak of sound trees.
- Thin merchantable understory trees to a minimum spacing of 6 to 8 m or to a spacing of 2 m between crowns.
- Prune crop trees according to the forest management objectives. All other trees must be pruned to a height of at least 3 m, but not to exceed 50 percent of length of green crown.
- Remove all slash, brush, and other debris (methods being mentioned in the next paragraph).
- Favour less flammable hardwood species being mixed with highly flammable merchantable species.

Examples of fuelbreaks in timber production areas are shown in figure 35.

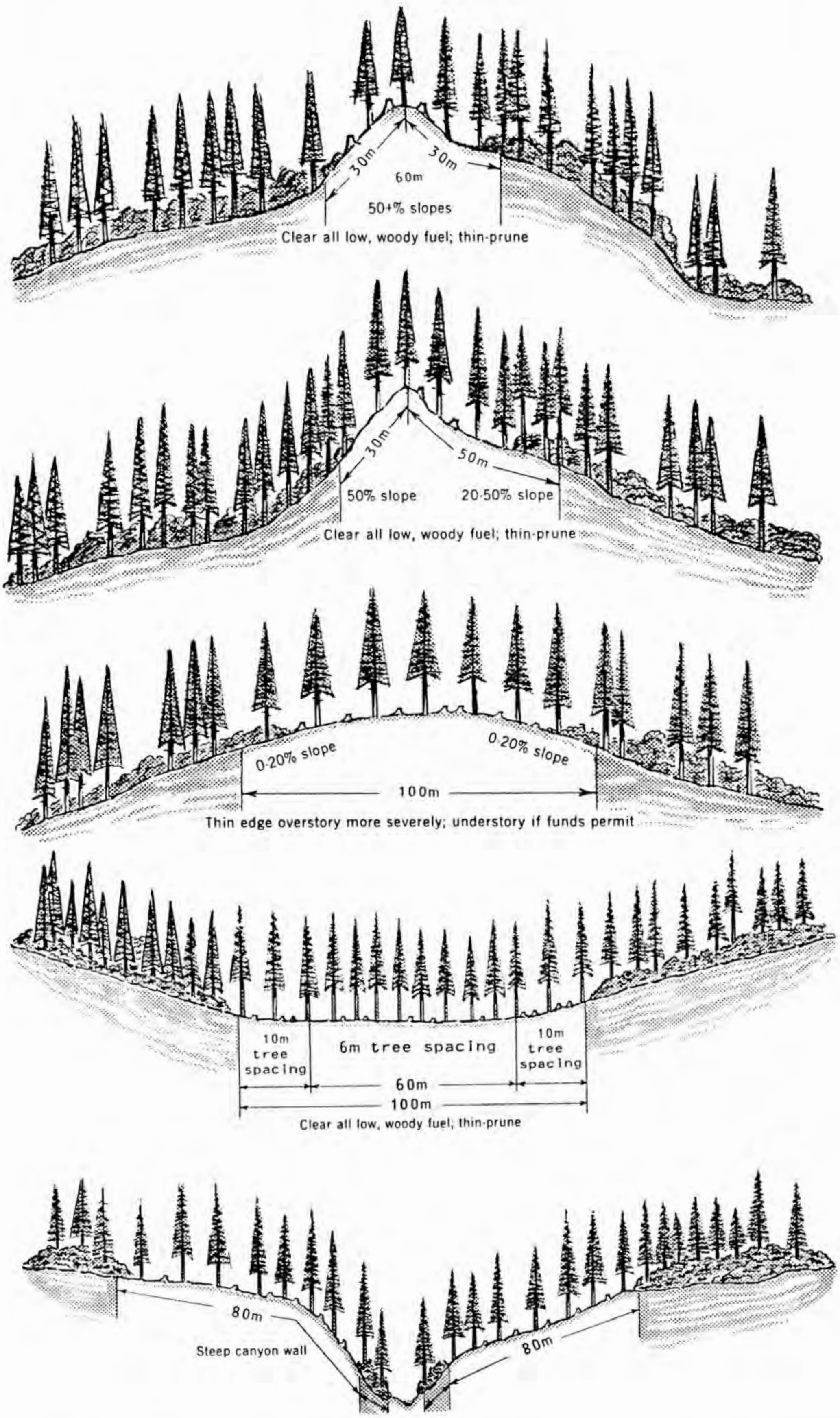


Fig.35: Fuelbreak widths on ridges, canyons, or on flat areas in timber

MAINTENANCE OF FUELBREAKS

If fuelbreaks are to serve their purpose they must be maintained. The ground cover must be kept to low volume. A ground cover is necessary to stabilize the soil and restrict growth of unwanted woody vegetation.

The aim in maintaining a low-volume ground cover is so that when it is ignited, it will burn with a low total heat output near the control line within a fuelbreak. This aim assumes that the cover on a fuelbreak will be flammable and that it will burn readily during critical fire periods.

A dry weight of 5 tons per ha has been arbitrarily set as the maximum volume of ground cover desired on a fuelbreak. A cover of grass, bear clover, or pine needles will be less than this volume on most sites in most years.

Even though bear clover and all grass covers are somewhat flashy fuels during dry weather, fire behaviour in this vegetation is predictable. And firefighters can more readily fire out control lines in this fuel than in other fuel types. The rapid burning of grass covers in many cases may be an advantage rather than a disadvantage. Fire control in the grass cover can be aided by establishing perennial grasses because they are less flammable than annuals during part of the year.

Different methods of fuelbreak maintenance are applicable: Mechanical treatment (hand labor, motor brush cutter, shredder), combination with other land-use practices (greenbelts or agroforestry, see para 2.3) and prescribed burning (see para 2.4).

2.3 PLANNED GRAZING

Hazard reduction and fuelbreak maintenance in open grassland-forest associations can be achieved by the integration of land-use practices into the forested land. As a part of agroforesty, the combination of production from trees and livestock grazing should be taken under consideration (figure 36).

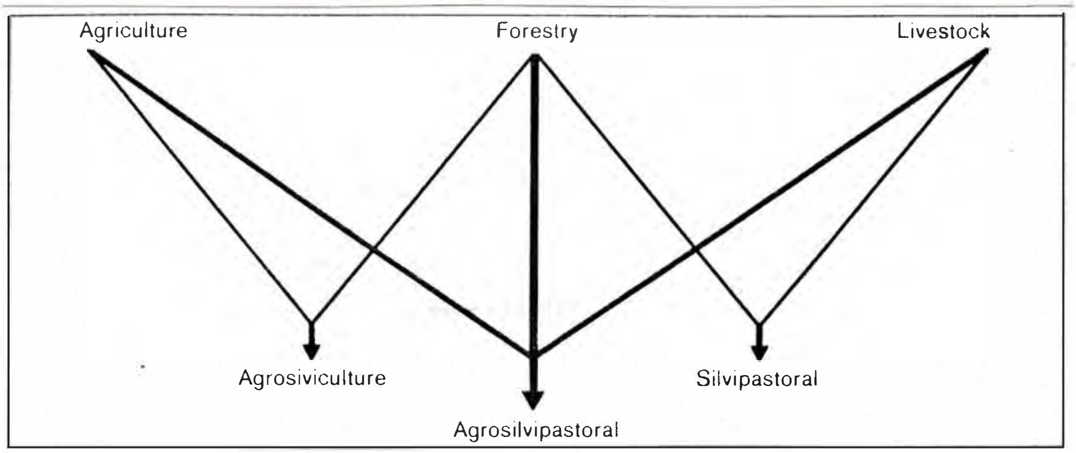


Fig. 36: Planned grazing is a part of two types of agroforestry.

Since in some forest types, grasses and herbs suitable for grazing form a natural part of the ground cover and in no way interfere with tree growth, it is a sound policy to make good use of this resource, provided this can be done without detriment to forest production.

From the aspect of fire prevention, it is in many instances an advantage to have animals grazing to prevent the build up of a large body of inflammable material, but for success the whole operation must be well planned and controlled. The animals need to be restricted to those fuelbreaks and areas where they will not damage young trees or prevent regeneration. This means either that they must be constantly tended or that the forest must be well fenced; in either case the costs involved need to be commensurate with the grazing values.

Above all else, the owners of stock must be prepared to support the protection policy, which at times may mean closure of the forest to grazing, either to secure regeneration or at times to avoid unnecessary risks of fires starting. If there is the slightest possibility that those holding the grazing rights will engage in uncontrolled burning of the forest in the hopes of increasing forage values, then the area is probably better left ungrazed. Grazing within the forest can be regarded as a protective measure and as wise resource use policy only if these principles are strictly observed.

The spacing of the trees on fuelbreaks or areas being grazed by livestock should be extended to up to 10 x 10 m, corresponding to 100 trees/ha as final stocking. In this final phase all trees should be pruned at least to a height of 6 m.

The animal husbandry (cattle, goats and sheep) have to be chosen according to the local conditions.

2.4 PRESCRIBED BURNING

In forested land fire can be used to reduce the quantity of fuel by prescribed burning. Prescribed burning is defined as the "Controlled application of fire to wildland fuels in either their natural modified state, under specified environmental conditions which allow the fire to be confined to a predetermined area and at the same time to produce the intensity of heat and rate of spread required to attain planned resource management objectives".

MANAGEMENT OBJECTIVES

Here the management objective under discussion is fuel reduction, planned to decrease the intensity of heat and rate of spread of any uncontrolled wildfire which may start or spread into the area. Other major uses of prescribed fire are wildlife habitat improvement and preparation of sites for planting and seeding.

A prescribed burn can be used for more than one purpose. A prescribed burn always reduces the fuel accumulation, and with a few modifications, a burn for hazard reduction can improve wildlife habitat. Almost any prescribed burn improves access and visibility.

IMPACT OF PRESCRIBED FIRE

Prescribed fires can be harmful as well as beneficial. They can contribute to changes in air quality and to loss of nitrogen and other nutrients, although to a much lesser degree than wildfires. Proper planning and execution are necessary to reduce any detrimental effects to air quality. The impact on all resources should be considered carefully - especially the impact on wildlife, aesthetics, and stream siltation.

Public opinion is another factor to consider since the general public is concerned about the deterioration of our environment. Smoke from prescribed fires, as well as wildfires, is highly visible.

Prescribed burning is a complex tool and should be used only by those trained and experienced in its use. Proper diagnosis and detailed planning are needed for each and every area.

EFFECTS ON VEGETATION

Many reasons for prescribed burning are concerned with reducing understory hardwoods and brush species along with the litter that adds to fuel buildup. This must be done by killing or consuming the understory without damaging the overstory.

Prescribed fire may injure or kill only part of a plant or the entire plant, depending on how intense the fire burns and how long the plant is exposed to the heat. In addition, the plant may have features - bark is the most obvious - that protect it from heat. Size of the tree stem is also a factor. Small trees of any species are generally easier to kill than the larger ones.

The thick bark of most pines, eucalypts and some tropical deciduous trees (teak) and other hardwoods have good insulating qualities, while the thin bark of most hardwoods is not as effective. Generally, this makes hardwood trees much more susceptible to fire injury than pines. Pine trees 10 cm in diameter and larger have bark thick enough to protect the stem from damage by most prescribed fires. However, the crowns are quite vulnerable to temperatures above 65° C. To reduce heat transfer by convection, adequate wind should be present to help dissipate the heat and keep it from rising into the overstory. Wind is also important in cooling crowns heated by radiation from the fire (see figure 37).

The temperatures of the air and vegetation at the time of burning are critical factors. A tree crown above a fire when the air temperature is 35°C would suffer about twice as much damage as a crown above the same fire in 5°C weather. The effect of high air temperature is recognized in using fire to control understory hardwoods. Summer burns generally kill more hardwood stems since less heat is needed to raise the plant temperature to the lethal level. Also, when plants are actively growing they are more easily damaged by prescribed fire. The least damage occurs with dormant season burns.

IMPORTANT WEATHER ELEMENTS

A general understanding of the separate and combined effects of several weather elements on the behaviour of fire is needed if the prescribed burner is to plan and execute a good burn. Wind, relative humidity, temperature, rainfall, and airmass stability are the more important elements to consider. These factors influence fuel moisture which must be given consideration in carrying out the prescription.

Wind

Prescribed fires behave in a more predictable manner when some wind movement is present. Ideal conditions occur when both windspeed and direction are steady. Onsite winds vary with density of the stand and crown height. The preferred range for windspeeds in the stand is 4 to 15 km/h for most fuel and topographic situations.

High windspeed will dissipate the heat of a backing fire resulting in less damage to the overstory than a fire backing into a low-speed wind. Windspeeds should be in the low to mid range when head fires are used. This way, high fire intensities caused by extreme rates of spread are prevented, yet enough wind is present to keep the heat from rising directly into tree crowns. Open areas with no overstory can be burned with little or no wind.

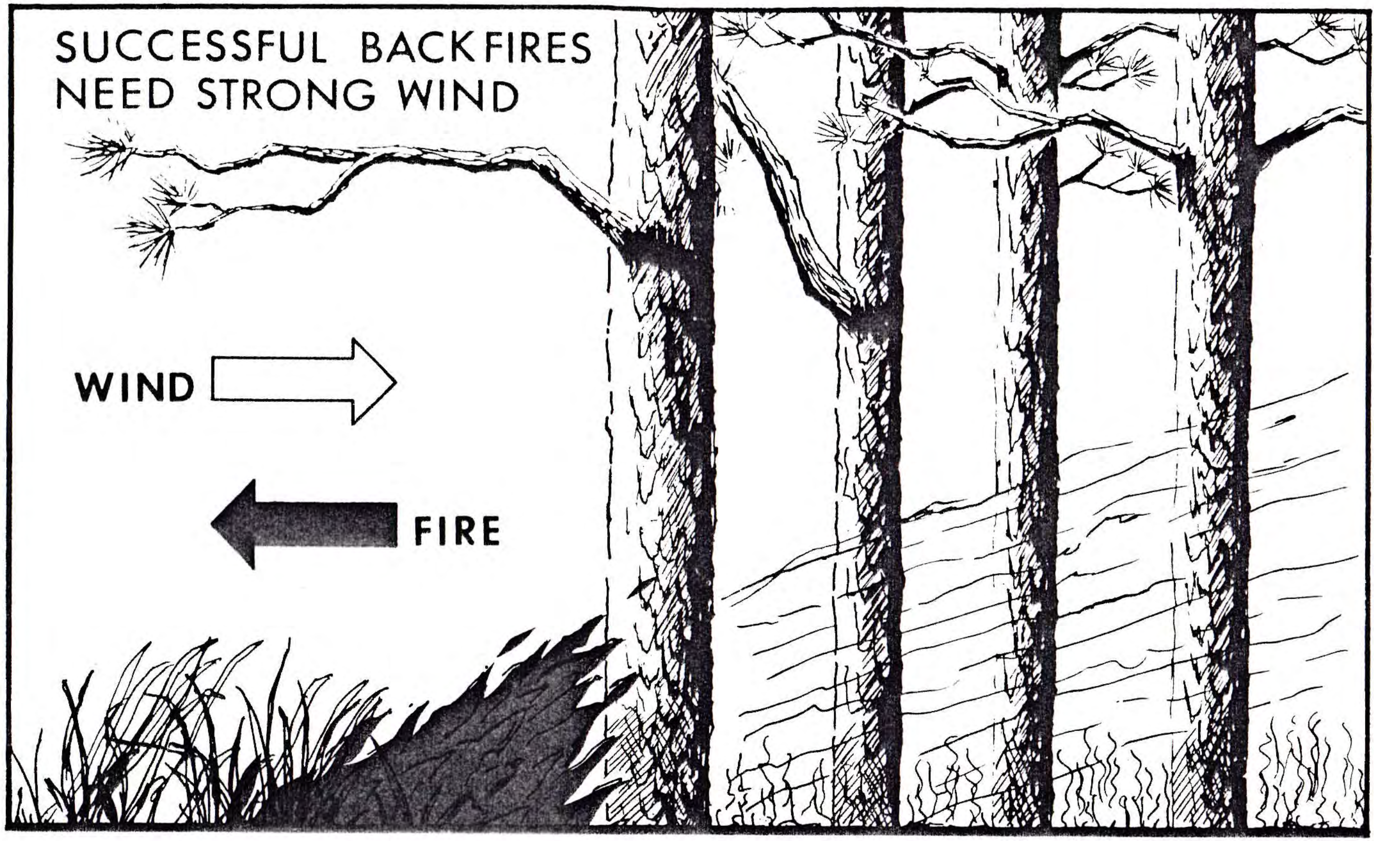


Fig.37: Successful backing fires need strong wind: Dispersed heat prevents crown scorch.

Relative Humidity

Preferred relative humidity for prescribed burning varies from 30 to 50 percent. Under special conditions, a wider range of relative humidities - as low as 20 percent and as high as 60 percent - can produce successful burns. When relative humidity is as low as 20 percent, prescribed burning is dangerous because fires are more intense and spotting is more likely - proceed only with adequate precautions. When the relative humidity is 60 percent or higher, fires may not burn an area completely or may not burn hot enough to accomplish the desired result.

The moisture content of fine fuel responds rather rapidly to changes in relative humidity. However, because there is a timelag involved for fuels to achieve equilibrium with the moisture condition of the surrounding atmosphere, and because previous drying or wetting regimes can influence fuel moisture, relative humidities by themselves cannot be relied upon completely for predicting the success or failure of a burn.

Temperature

Low air temperatures of 5°to 15°C are recommended for winter burning because there is less chance of raising foliage or stem tissue to lethal temperatures.

The effect of temperature on moisture changes in forest fuels is important. When sunshine falls on the fuels, there are wide differences between air and fuel temperature. Moisture moves readily from the warmer fuel to air, even though the relative humidity of the air may be high.

Rainfall

Sufficient rainfall is desired before the prescribed burn. To insure that the soil will be moist and deep organic layers will not be burned, the amount of rainfall required depends on the dryness conditions (which may be expressed by a drought index or a soil dryness index). Damp soil protects small tree roots and microorganisms. This is a general rule and certain situations may call for dry duff if the burn is to accomplish the specific objective of exposing mineral soil for seedbed preparation, or elimination of debris in site preparation.

Fine fuel moisture

Fine fuel moisture is not a weather element but is influenced by relative humidity, rainfall, and temperature. The preferred range of actual fine fuel moisture is from 7 to 20 percent. Burning when fuel moisture is below 5 percent may result in serious damage to young growth, overstory crowns, and even the soil. When fuel moisture is above 30 percent, fires tend to burn slowly and irregularly, resulting often in incomplete burns that do not meet the desired objectives. When very heavy fuel buildup is burned, moisture content should be near 20 percent to keep the fire from getting too hot.

Relative humidity can control moisture contents of fuels up to about 35 percent. Liquid moisture in the form of rain, snow, or dew must contact the fuel for moisture content to go above 35 percent and the increase depends on duration as well as amount of precipitation. For example, 20 mm of rain occurring in 2 hours will not produce as large a moisture gain as 20 mm falling over a 12-hour period. Different types of fuels may reach different moisture content levels under the same humidity conditions.

Because of natural variations, the moisture values recommended are only guidelines. On-the-ground knowledge of fuels must be incorporated into planning the prescribed burn.

Airmass stability

Atmospheric stability is the resistance of the atmosphere to vertical motion. A prescribed fire generates vertical motion by heating the air, but the strength of convective activity over a fire is affected by the stability of the airmass. Strong convective activity will increase the indrafts into the fire and may result in erratic fire behaviour.

When the atmosphere is stable, a small decrease in temperature occurs with an increase in altitude. Under very stable conditions, inversions may develop in which temperature actually increases with height (see chapter 1.3). Stable air tends to restrict convection-column development and produces more uniform burning conditions. However, combustion products are held in the lower layers of the atmosphere, especially under temperature inversions, and visibility may be reduced because of smoke accumulation.

When the atmosphere is unstable, there is a large decrease in temperature with height. Once air starts to rise, it will continue to rise and strong convective activity may develop over the fire. Strong convection over cleared areas burned for site preparation or slash disposal would be helpful in venting smoke into the upper atmosphere. Strong indrafts will help confine this type fire to its prescribed area. In extreme cases, the effect of airmass instability on fire behaviour may result in erratic spread rates, spotting, and crowning. A burn would no longer meet the prescription especially in standing timber, and might have to be terminated.

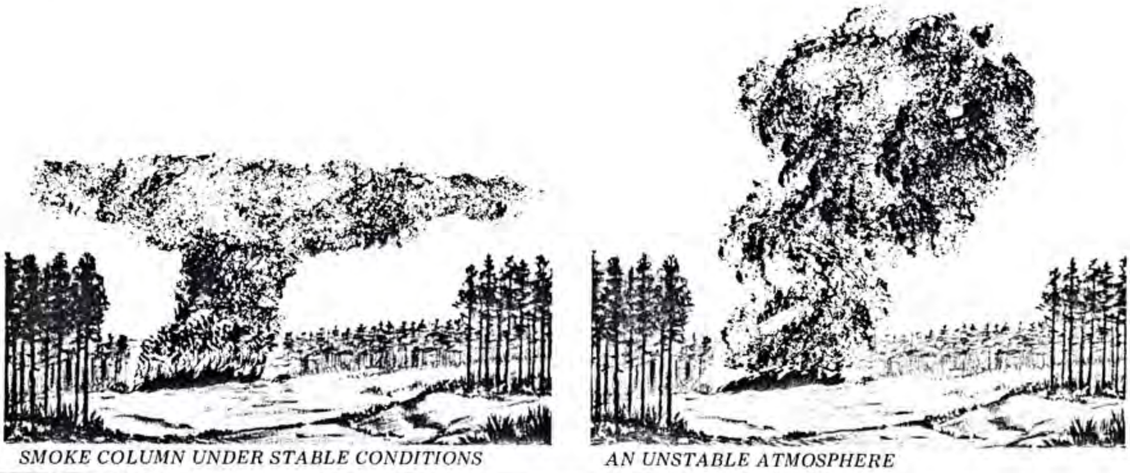


Fig.38: Development of smoke column under stable and unstable atmospheric conditions

TECHNIQUES OF PRESCRIBED FIRE

FIRING EQUIPMENT

The "drip torch" is the most widely used incendiary device. It consists of a fuel fount, burner arm, and igniter. A common mixture of liquid fuel is 4:1 to 2:1 diesel fuel to gasoline, the gasoline providing flash ignition to the diesel, and the diesel a longer burning flame to wildland fuels (see chapter 5.1 and figure 54).

IGNITION PATTERNS

Head Fire

The head fire technique (fire being driven by the wind) 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.

Boundary firelines should be wide enough to prevent the fire from jumping or spotting across the line.

Backing Fire

The backing fire (also called 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.

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.

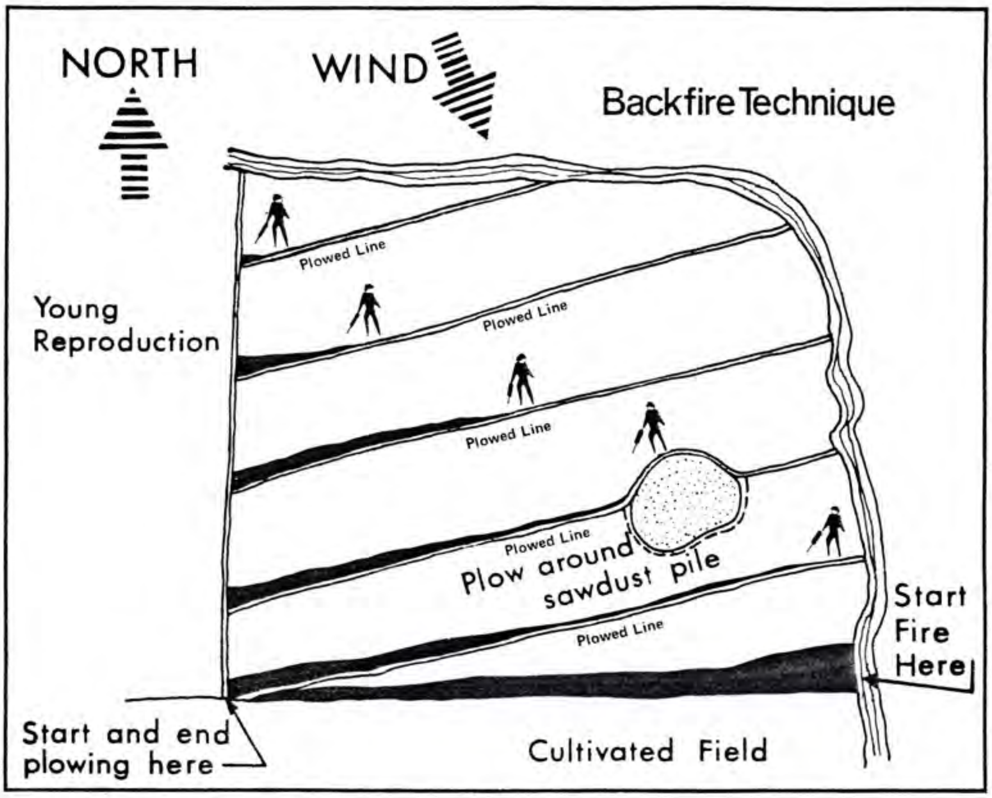


Fig.39: Backfire technique on flat terrain. On steep slopes the fire will be started at the ridge-top.

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

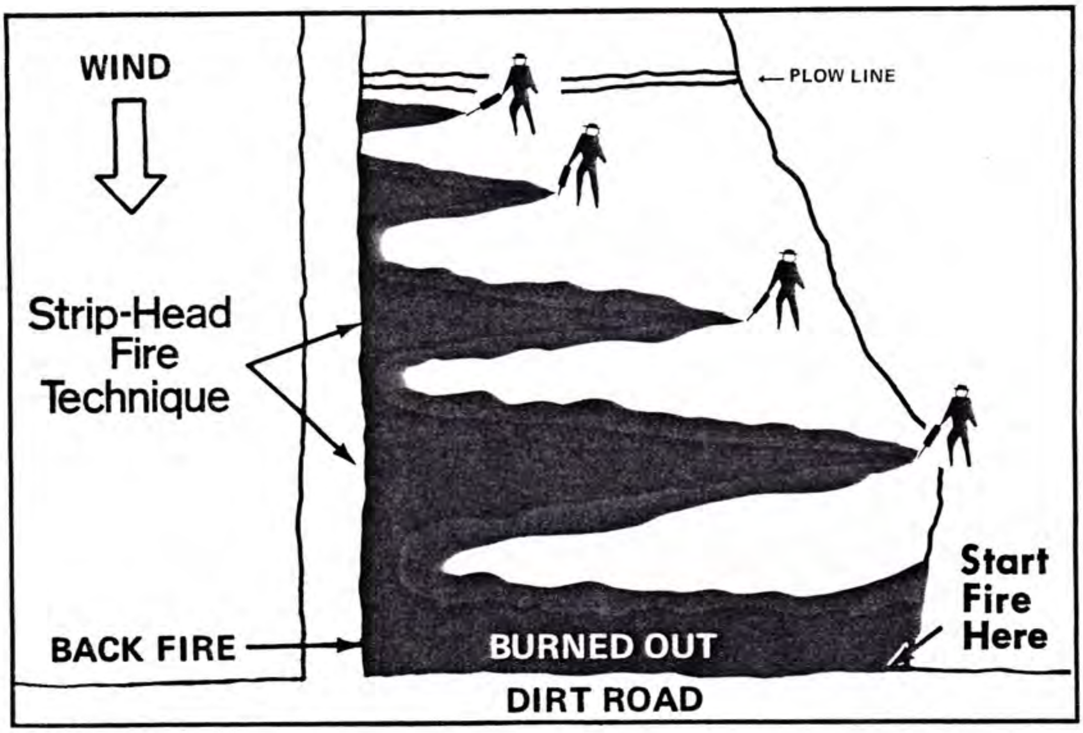


Fig.40: Strip-head fire technique

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 than 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.

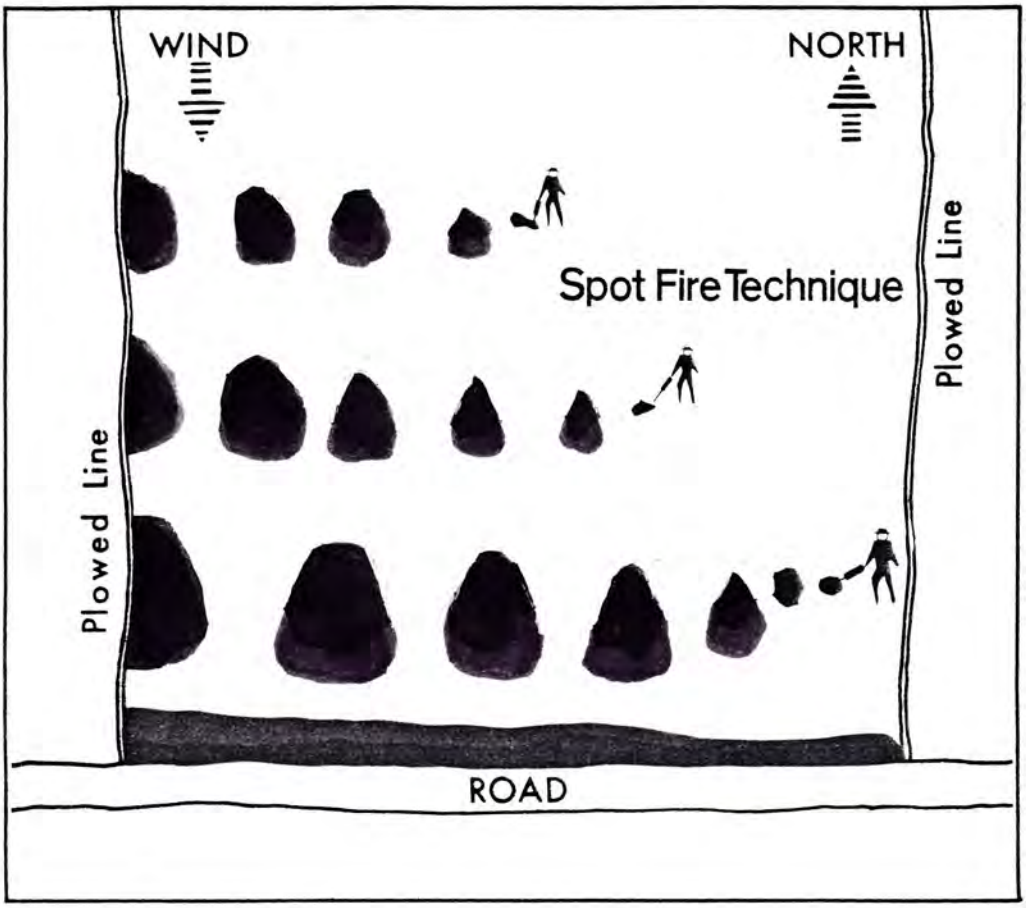


Fig.41: Spot(-head) fire technique

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" shape 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.

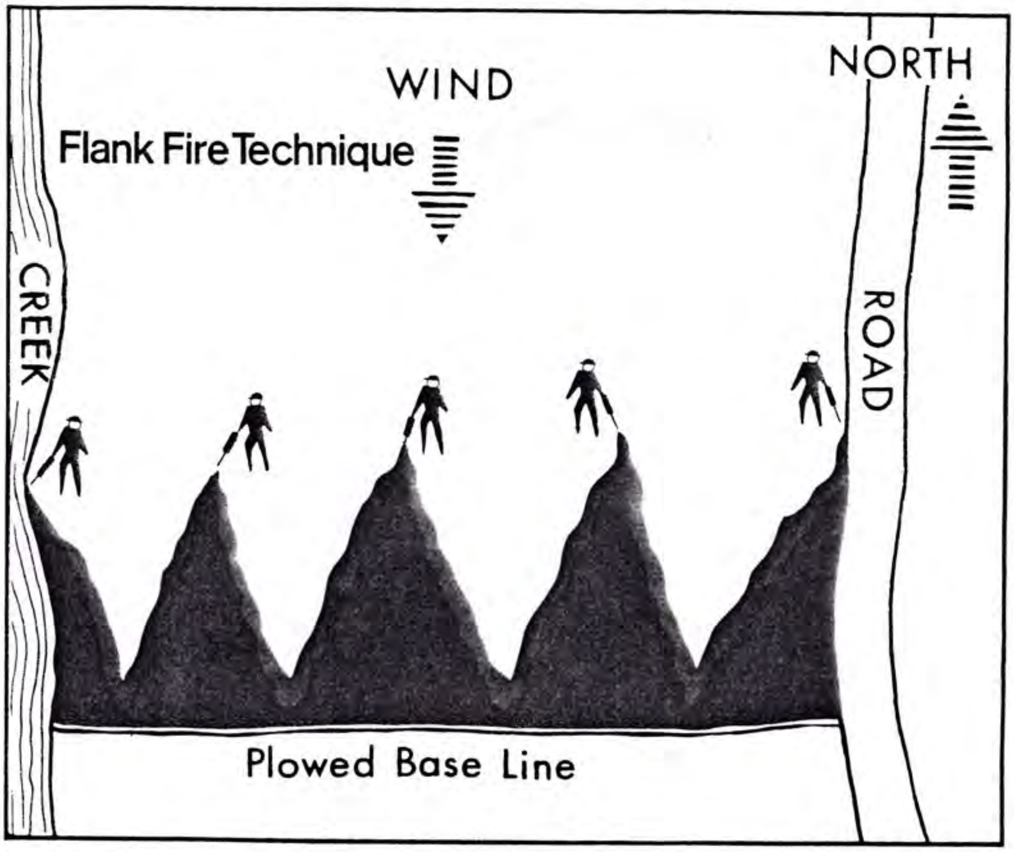


Fig.42: Flank fire technique

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.

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 the 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.

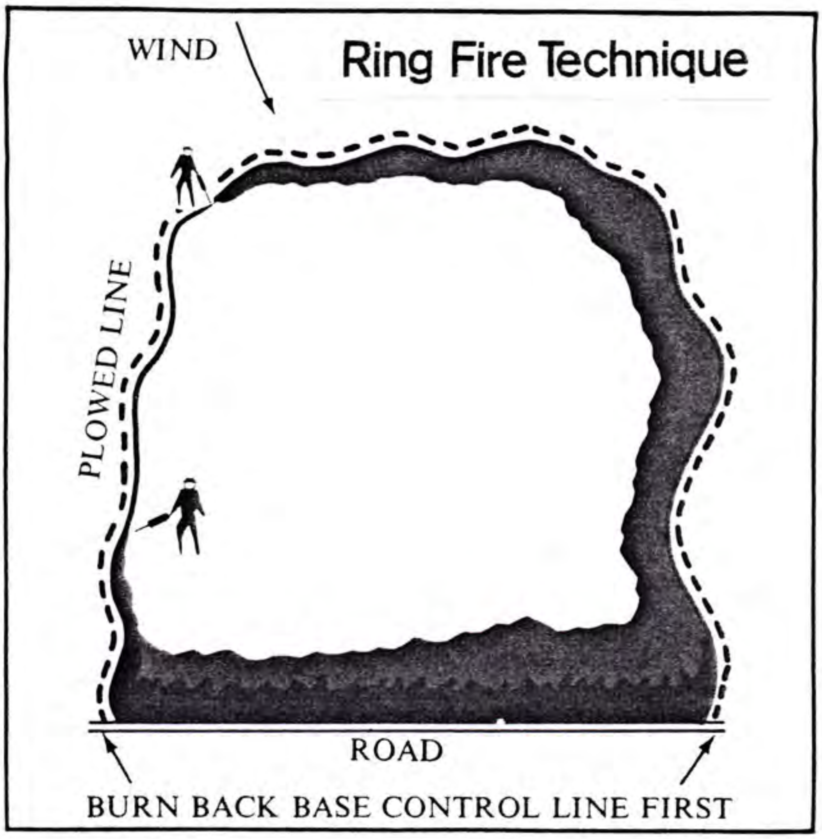


Fig.43: Center or ring fire technique

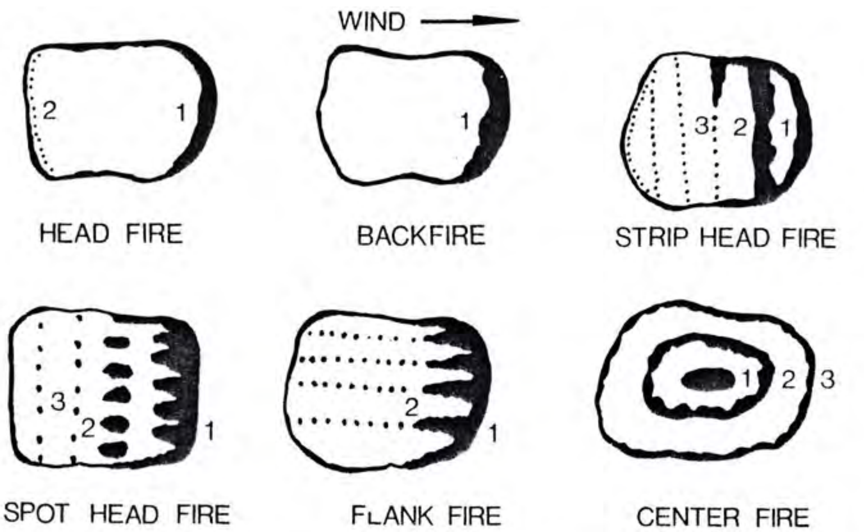


Fig.44: Quick guide to the various firing techniques. The numbers indicate the sequence of ignition.

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

Tab.2: Quick guide to the various firing techniques used in prescribed burning

3. PREATTACK PLANNING

Preattack planning is a system of collecting, recording and evaluating information relevant to wildland fire management. Preattack planning should be carried out within the forest districts. It contains the following information related to the administrative units (forest districts, forest sectors) and ecological units (preattack blocks):

Wildland information
Topography, vegetation types, fuel load, water sources, meteorological particularities (e. g. local wind and fog patterns).

Technical information
Localities of forest service fire crews and local fire brigades, equipment (communication, tool caches, fire trucks, water tenders, dozers, lookout towers), facilities for airborne control actions (helipads, heliponds, jump spots), control lines (fuelbreaks, firebreaks, greenbelts, and other barriers), access (roads, forest roads, skid and foot trails), safety islands, values-at-risk, smoke targets, travel time map.

Administrative information
Area of jurisdiction (fire agency), direct protection area (fire crews, fire brigades), communication, cooperators, detection system, ground attack plan, air attack plan, mobilization plan, logistics, mutual threat zones.

Most of this information may be figured on the district fire control map and more detailed on the preattack block maps. These maps should be based on a topographic map, showing the vegetation cover/fuel load type. Most of the other information like access, control lines, prescribed burned areas, water sources, helispots, jumpspots, heliponds, equipment locations and administrative boundaries are included by using symbols.

The preattack plan should be supplemented by oblique photos taken from an aircraft or neighbouring elevations. These photos show the main fire-problem sites of the preattack blocks and may be completed by hand-painted symbols/informations.

The preattack plan contains all information in wildland fire prevention and fire preparedness being essential for effective fire suppression.

Examples of a completed preattack block map (Mt. Hood National Forest, USA), the legend of symbols and one aerial oblique photo of a part of this block are shown in figure 45 and 46.

In initial attack on small fires, the preattack plan provides data on local fuels and topography, travel routes, road and trail conditions, helispot locations, and water sources. When a fire escapes initial attack, the system can contribute to fast and effective control action by followup forces. It is not a substitute for judgement, but it provides the fire command team with valuable information for strategy decisions. It can also reduce or eliminate confusion and many of the logistical problems of manpower and equipment organization and dispersal.

Fig.45: Example of a preattack block map and the legend of symbols (next page). Mt.Hood National Forest, USA.

R-6 PREATTACK LEGEND

◇ ◇ ◇	FUEL BREAK PROPOSED
◇-◇-◇	FUEL BREAK EXISTING
V V V	CONTROL LINE TRACTOR PROPOSED
~~V V V~~	CONTROL LINE TRACTOR EXISTING
>>>	WORK DIRECTION IF RESTRICTED
● ● ● ●	CONTROL LINE HAND PROPOSED
●-●-●-●	CONTROL LINE HAND EXISTING
XXXXXXX	BARRIER
XXX)(XXX	BREAK IN BARRIER
P101	POINT ON CONTROL LINE
H101	HELIPORT PROPOSED
O H102	HELIPORT EXISTING
H103	HELISPOT PROPOSED
⊕ H104	HELISPOT EXISTING
FC101	FIRE CAMP
SC102	SPIKE CAMP
■ T101	TRACTOR LOADING LOCATION
● W102	WATER SOURCE
W103	WATER HELICOPTER HOVERFILL
□ S104	STAGING AREA
⚓ BL105	BOAT LANDING
1102	EXISTING ROAD & NUMBER
A-101	AIRCRAFT LANDING STRIP (SHOW STOL IF APPLICABLE)
-412-	TRAIL
— —	COMPARTMENT BOUNDARIES (TRI)
IIIIIIII	BLOCK BOUNDARY

Legend to preattack block map (fig.45)

Fig.46: Aerial oblique photo of the same preattack block map (fig.45)

4. DETECTION AND REPORTING OF FIRES

The detection of a forest fire is the vital first step in action taken to control it. Organized detection of fires is ordinarily accomplished by means of one or more of the following conventional methods and facilities:

- Lookouts (lookout or detection towers and other detection structures) planned and designed for the purpose

- Forestry personnel on ground patrol over planned routes and specified times

- Forestry personnel in the normal course of their duties

- Aerial patrol over planned routes under specified circumstances and frequencies

- Prearrangement with local residents and cooperators

Unorganized information is supplied by any individual who happens to see the fire and recognizes that action to control it is needed.

Although lookouts have certain disadvantages, especially during periods of poor visibility, they provide a detection system which other methods could not supply. Evidence from reports of fires in many countries suggests that more fires are detected from lookouts than by other means. It appears, therefore, that lookouts provide the most efficient means of fire detection.

LOCATION OF LOOKOUTS

The observatory must be sufficiently elevated to provide unobstructed view from it over the treetops and any other local obstructions.

In flat country, this usually requires high towers which can clear the mature forest canopy. If the location is in a young stand, its height at maturity would be the proper criterion. Where the site is on a hill or ridge, clearing away of nearby obstructing trees may greatly reduce the height of tower necessary and may be preferable.

In mountainous terrain, the most important factor is usually the shape of the high point selected as the lookout site. A flattened top may require considerable tower elevation in order to gain a sufficient view down its slopes. If angles and distances are measured so that the profile of the top can be defined, it is not difficult to determine the exact height from which the desired view can be obtained with the minimum tower elevation.

The towers should be located to ensure the maximum area seen from the least number of points and to obtain accurate cross bearings, intercepting at a reasonable angle.

CONSTRUCTION OF LOOKOUTS

The style of buildings erected at a lookout point varies considerably. If the terrain falls away sharply on all sides from the observation point, there is little advantage to be gained by erecting a high structure. Towers 10-20 m high are quite frequently constructed on flat-topped hills to improve the view into nearby valleys. Towers 30-40 m are sometimes used on fairly flat terrain so that they may provide a view over the surrounding tree cover.

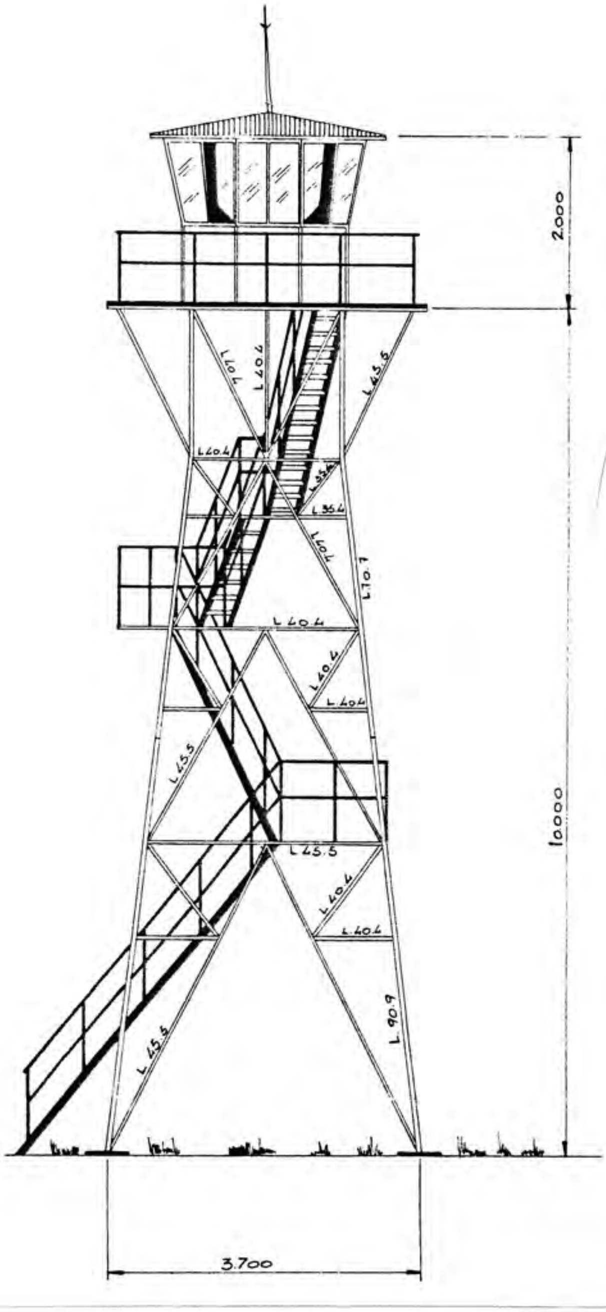


Fig.47: Design of a typical lookout tower with platform and observatory. Complete lightning protection must always be a standard requirement of exposed towers and other lookouts.

There may be no need to erect a building if a direction finder or alidade has been installed on a post, but protection against the weather is usually provided for the observer and the equipment he uses. Though the floor space in a cabin is generally fairly small, it should be sufficient for reasonable comfort. Occasionally cabins are made large enough to provide live-in accommodation, but mostly a separate building is supplied for this purpose.

Unobstructed view from inside the lookout observatory or cab requires windows from which the entire panorama can be seen with minimum obstruction. From the fire finder or alidade in the center of the cab or observatory, the view must be so little obstructed horizontally that a reading on any smoke in the panorama can be obtained by horizontal adjustment of the alidade. This means that the corner posts and the framing between windows must not create any obstruction of more than 10 to 15 cm. This not only assures that an azimuth reading can be taken on any smoke that may show up but also enables the observer to see all the territory from any position near the center of the observatory by simply moving his head slightly to change the angle of his view. Large-pane windows are also preferred.

EQUIPMENT AND DETERMINING THE LOCATION OF A FIRE

Furnishings and equipment within a cabin are arranged to facilitate detection, recording information and communication and to provide reasonable comfort for the observer. Binoculars are usually supplied, sometimes with special glasses to reduce glare and to help in discriminating between haze, cloud, dust and smoke. There are several methods of determining the bearings to an observed smoke.

A direction finder (alidade) is a simple device incorporating

- a compass face divided into 360°
- a sighting arm mounted to pivot on the centre of the compass face
- a peephole at one end of the sighting arm and a foresight at the other.

The inner circle contains a map of the surrounding area with the center being the lookout point itself.

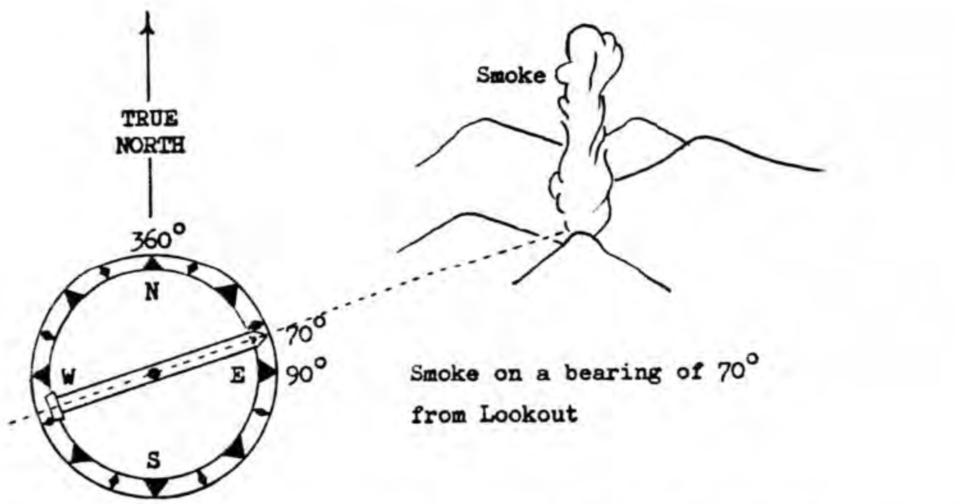


Fig.48: Determination of direction (bearing) to the fire

The direction finder must be permanently mounted in an elevated position so that North on the compass face (360°) is set at TRUE NORTH.

By sighting through the peephole and foresight, and turning the sighting arm so that the sights align directly with the <u>base</u> of the fire, the bearing, or direction of the fire from the observer, can be read off the compass face on the direction finder.

At least two bearings are needed from different lookout points before the location of a fire can be determined; a third bearing will help eliminate error. Observers do not need to be in view of each others positions, and may be as close as 1 or 2 km in hilly country, or as far apart as 20 or 30 km in flat country.

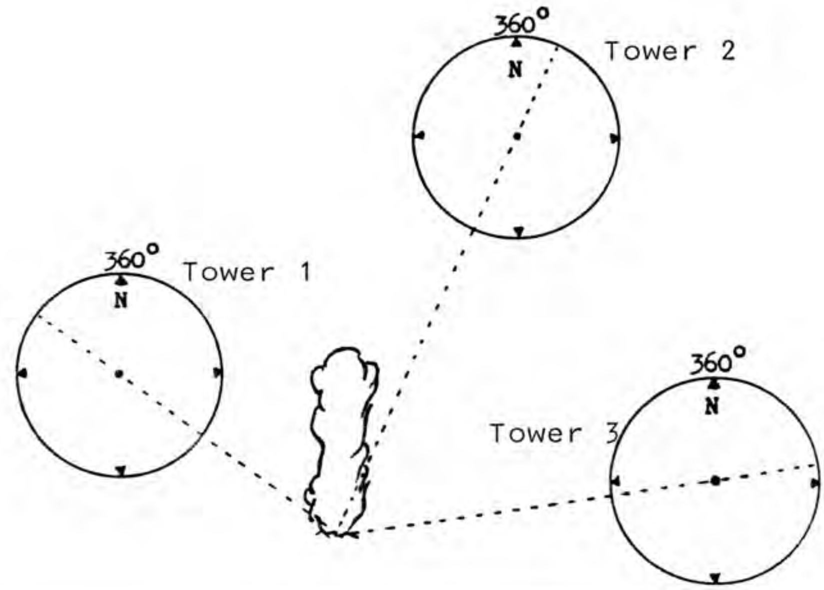


Fig.49: Determination of the location of the fire: bearing 1: 130° , bearing 2: 215°, bearing 3: 265°

Using the information provided by two or more observers, the officer on duty at the control centre is in a position to locate accurately the position of the fire, using maps and 360° transparent protractors. The maps need to be properly mounted, with a softwood edging surrounding the mounting. The protractors are glued to the map so that their centres coincide exactly with the positions of the different direction finders used by the observers.

Lengths of elastic string are fixed so that one end is anchored at the centre of each protractor. Each string should be long enough to stretch to the edge of the map mounting. When a bearing is provided by an observer, the string which is fixed to his location on the map is stretched across the map so that it passes through the appropriate bearing on the protractor. It is fixed in this position by pinning the free end to the soft edge of the mounting. When two bearings have been fixed on the map, the point at which the strings intersect is the location of the fire (figure 50). A high degree of accuracy can be reached where the observers are close to being at right angles to the fire.

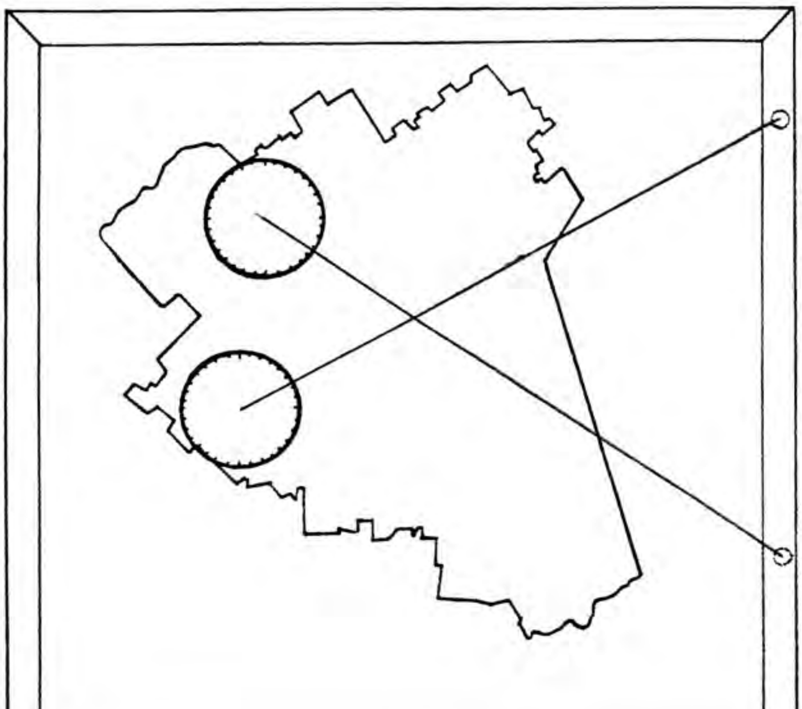


Fig.50: Fire location map

Communications may be provided by telephone or radio or both. If electricity is not available from a mains supply, batteries may be located in the cabin. If battery charging is required, it is usual to locate the charger and batteries in a separate structure near the base of the fire tower.

A record book is provided for the observer to record, in chronological order, information concerning weather, the location of fires and the passing of messages.

The location of instruments for recording weather depends largely on how convenient it is to get in and out of the lookout. Though it is desirable to install thermometers in a meteorological screen at ground level, they are sometimes placed in a shaded position outside the cabin, reasonably accessible to the observer. A device for measuring wind speed and direction is usually located on a pole, in a position close enough to the cabin for the observer to make observations.

5. FOREST FIRE CONTROL

5.1 EQUIPMENT

The fire triangle described in chapter 1 gives special significance to the physical jobs for which fire tools are employed. For combustion to proceed, fuel, oxygen, and a temperature above the kindling point must combine and be maintained. It is the fire fighter's job to break up this combination, which he does by the aid of tools. He removes fuel to separate it from sources of heat, and so to limit or localize the burning process, or he works at limiting the available oxygen or at reducing the temperature of the burning fuels below the kindling point. All fire-fighting tools might be classified according to which of these three functions they facilitate most.

The most efficient serve more than one function. Digging, cutting, and scraping tools employed in building fire line are devoted almost entirely to removing fuels from exposure to kindling temperatures. Flappers and beaters of various kinds depend chiefly for their effect on the temporary exclusion of oxygen, though they function also to some extent in dissipating heat. Tools used for applying dirt or sand to a fire function in the same way, but with a more pronounced dual effect in lowering temperatures of the burning fuel. Equipment used to apply water carries out a truly dual function in excluding oxygen and in rapidly lowering the temperature of the burning fuel. Backfiring equipment performs the function of eliminating fuels from the path of the main fire, just as cutting and digging tools do, but it adds to the heat energy being released. All mechanized equipment performs one or more of these functions. The only difference is in the method of performance and in the replacement of manpower by motor power.

HAND TOOLS

A great variety of hand tools, particularly digging and cutting tools, are being used in fire control operations. However, only a few have found a place as standard fire equipment among most forest fire agencies. Some are standard commercial items developed for nonfire purposes; some are adaptations of commercial items, and some have been developed specifically for fire control use. Those used most commonly are illustrated in figure 51. A brief description of each tool and of its use follows, referenced to its number in the figure.

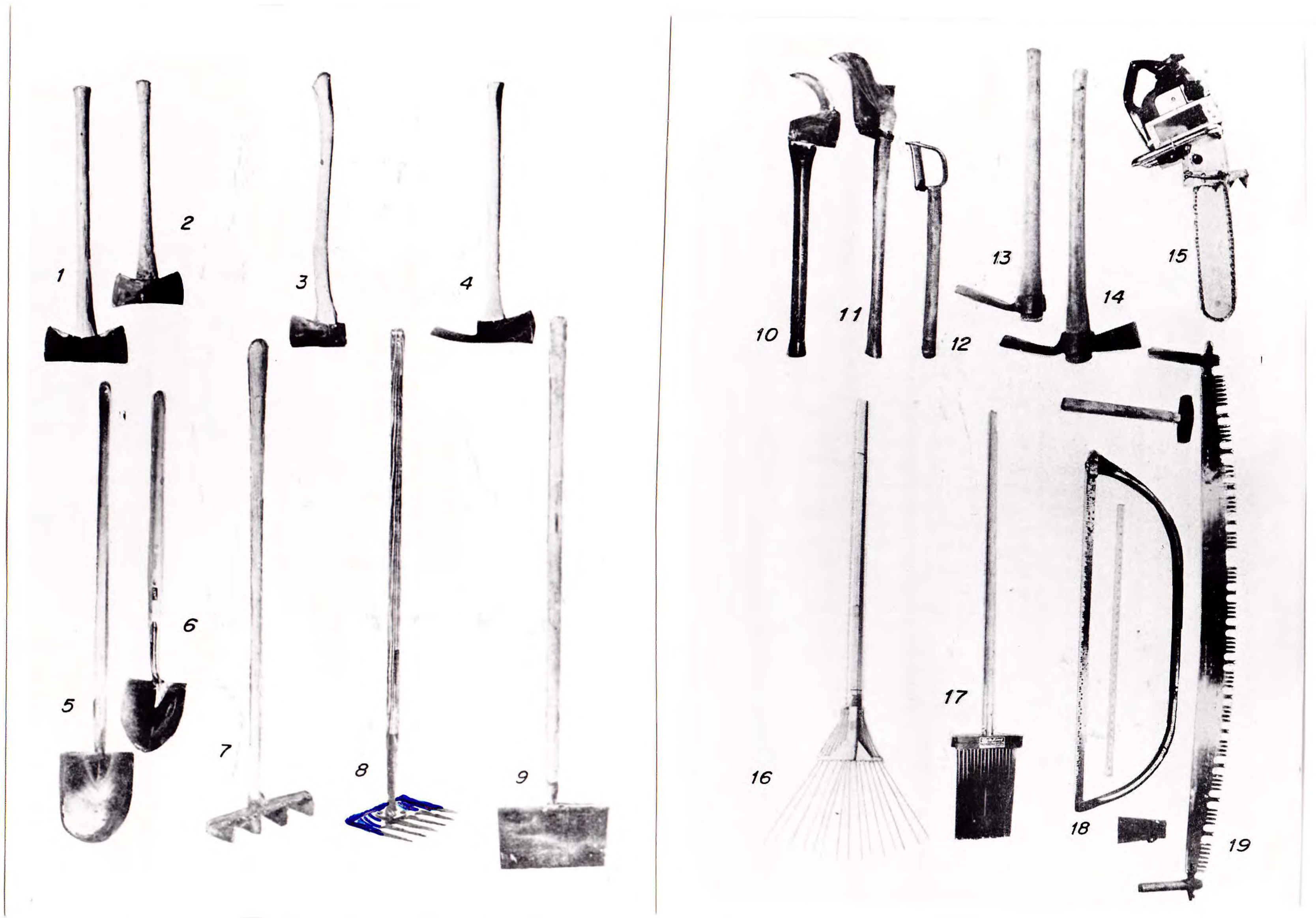


Fig.51: Common hand tools used in firefighting

Ax (1,2,3): There are many types, sizes, and weights of axes, which are the prime hand-operated cutting tool (single-bitted or poleaxes and double-bitted axes).

Pulaski Tool (4): The "Pulaski" (developed in the USA) successfully combines a cutting with a digging tool, which makes it highly versatile. It weighs approximately 2,5 kg with a 1,5 kg head and is specifically designed for fire suppression use.

Shovel (5,6): Edge-sharpened near the point, well-balanced, and strongly made, a shovel is a most versatile, simple, and durable tool, almost universally used. It can be used to dig, scrape, throw dirt, and cut to some extent. When scraping and cutting become important uses, the sharpened edge may be carried well up on one or both sides. It is usually not, however, used as a primary line-construction tool but more commonly as a supplement to other digging and cutting tools. It is much used and is particularly effective in throwing dirt to check a running fire or in digging out or burying burning material. There are many kinds and sizes of shovels, but the round-point, long-handled type is the most common. Item 6 is specifically designed for fire use and is the lightest yet most effective shovel for all-around use.

Council Rake, or Rich Tool (7): Essentially, this tool consists of four heavy mowing-machine sickle-bar blades riveted to a 1-inch piece of angle iron which is attached to a handle. This tool is highly efficient for trenching work in light brush, duff, and small roots and can be used for cutting, digging, or raking.

McLeod or Cortic Tool (8): This is a combination heavy-duty rake and hoe for cutting matted litter and duff and clearing loose surface materials. It needs to be supplemented in rocky soils or brushy cover. The tool is specifically designed for fire work. It has long been a standard tool in California but has found increasing use throughout the ponderosa pine types. In Australia it has proved highly useful in creating fire lines in eucalypt forests.

Swatter, or Flap (9): This tool consists of a piece of heavy belting mounted with a long handle. It is effective and widely used in beating out (smothering) fires in grass and similar light fuels.

Brush Cutter (10,11,12): There are various types of brush cutters, of which three are illustrated. They are strictly single-purpose cutting tools designed to cut smaller stems than can be efficiently handled with an ax.

Grub Hoe (13) and Mattock (14): There are many variations of these ancient tools. They are effective in fire-line digging and about the last word in durability, simplicity, and economy. The grub hoe is a straight digging tool.

The mattock has a narrow but thick cutting blade on the back good for roots, and its weight (up to 3,5 kg) makes it effective (but fatiguing to use) in heavy duff and rooty ground.

Broom Rake (16,17): These items have been developed to provide a light but effective tool for use in light litter, leaf, and needle fuels. The broom rake (16), which can be readily adjusted for width and stiffness of the teeth, is particularly effective.

Saws (15,18,19): There are many types and sizes of saws, including power chain saws. Single purpose: cutting larger tree stems.

FIRELINE PLOWS

One of the most commonly used pieces of mechanical equipment is the fireline plow. It is essentially an adaption of the familiar farm plow. The purpose of the plow in forest fire work is like that of many other tools, to break the fuel continuity by clearing a line or furrow down to mineral soil. To be more effective in this task, the farm plow has been modified and strengthened to meet the rugged conditions of forest and wildland, to widen the furrow it produces, and to allow it to be attached to a wide range of vehicles used in the forest. Fireline plows range from self-contained or sulky units that must be towed behind a tracked or wheeled tractor or truck, to hydraulically operated units attached as an integral part of the prime mover. Normally, the depth of furrow of hydraulic plows can be controlled and the unit can be lifted clear of the ground when not building firelines.

In order to widen the furrow so that the result is an effective fire guard, most fireline plows are designed so that the blade throws the sod and soil to either side creating a flat bottomed furrow with earth mounds on each side.

Obviously, the more the terrain resembles farm land, the more effective a plow will be in building fireline. Best results are obtained in relatively level, open, sandy, or loam sites. On the opposite side of the scale, plows are seldom effective in steep, rocky terrain or in dense bush or underbrush. As with any other type of fire equipment, the best plow units are those that are sturdy and simple, easily transported, and readily attached to their prime mover. The depth of plow blade penetration must be readily adjustable and the plow must be capable of riding over rocks, stumps, or other obstacles without damage and without serious disruption to its building continuous line. The unit should also be capable of reversing without difficulty. This is often necessary when the vehicle becomes bogged down and a new start or direction is required. The sulky-type plows have a disadvantage in this regard whereas those attached to the vehicle may be lifted out of the soil to facilitate reversing. Since, as was said earlier, the fireline plow is an adaptation of the farm plow, many variations have arisen from the fertile minds of local fire "equipmenteers". Many of these are, of course, particularly adapted to meet local conditions and if one is interested in acquiring a good plow for a certain region it is usually wise to begin by looking at what has been developed locally.

USE OF WATER AND FIRE CHEMICALS

Because of its high specific heat and natural abundance, water makes a superb extinguishing agent. Applied to the reaction zone, water absorbs heat and lowers the heat of combustion; applied to fuels, it raises the heat of preignition. And once converted to steam, it smothers the reaction zone even as it lowers the amount of heat produced, thereby diminishing the convective flow that might expel it. It is particularly effective in urban environments where, with ventilation under control, the expanding, penetrating, and smothering powers of steam can be exploited. In wildland environments steam is less useful: it cannot be confined.

The efficiency of water can be improved by chemical additives. Flame inhibiting chemicals may be used in two ways, as suppressants or as retardants. When applied directly to the flame they are being used as suppressants; when applied in the path of a moving flame front to stop fire spread, they are being used as retardants.

Suppressants may be short-term or long-term chemicals in liquid, gas or powdered form. Retardants are generally liquids of the long-term variety. Retardants that are presently in use remain effective after all the water has evaporated. They inhibit flaming combustion by chemical action and remain effective until washed away.

Wetting and Thickening Agents

The efficiency of water can be improved by additives that reduce its surface tension (wetting agents) or that increase its viscosity (thickening agents). By reducing surface tension a wetting agent increases the amount of surface area available for a given volume of water, improves the ability of water to coat rough surfaces, and diminishes the viscosity of the water. The increase in surface area means that more heat can be absorbed more rapidly. Reduced surface tension (the tendency of water to bead) allows treated water to penetrate into deeply furrowed logs burning by glowing combustion and to insinuate into deep mats of grass and needles. Reducing viscosity enhances the movement of water through hoses, with more water moved for less work.

Making water thinner improves its rate of heat absorption, but reduces its heat absorbing capacity. Where high heat absorption is needed, thickening agents are used. A wetting agent can reduce the height of a layer of water by half; thickening agents can congeal that layer up to 20 times its normal height. The increased viscosity which results means that thickening agents must be combined with water at the nozzle, not pumped through a hose. But they have advantages. Viscous fluids adhere better to fuel surfaces, coat and smother reaction surfaces, absorb greater quantities of heat, and penetrate better into the reaction zone. When delivered by aircraft such mixtures will not so readily dissipate during their descent and will better penetrate forest canopies. Such mixtures are known as gels or slurries, and the thickening agent is a clay (like bentonite) or a gum (like Gelgard). The rheological properties of gumthickened slurries are generally superior, but the mixtures more costly.

Phosphates and Sulphates

Chemicals used as fire retardants that contain relatively inexpensive, fertilizer-grade ammonium phosphates are known as liquid phosphate concentrates. They inhibit flaming and glowing combustion even when considerably diluted by water and are known as long-term retardants.

Long-term retardants are chemicals that have the ability to inhibit the spread of flame through chemical reactions between the products of combustion and the applied chemicals. Water is used as a dispersing agent for these chemicals, but these materials will be effective flame inhibitors after the water has evaporated.

Ammonium phosphates are also available in a dry, powdered, or crystalline form which, when dissolved in water, are equally as effective retardants as those made from liquid concentrate and water.

Water solutions of ammonium sulfate salt can also be used as long-term retardants. This salt is usually found as a dry fertilizer in crystalline form. Ammonium sulfate does a good job of inhibiting flaming combustion, but is not effective against glowing combustion.

PORTABLE WATER PUMPS

Two main types of pumps are used in forest fire fighting: centrifugal and positive displacement. A centrifugal pump has no valves, pistons or plungers. Making use of centrifugal force, it consists primarily of a vaned disc or impeller which receives water at its centre and discharges it from its perimeter. The impeller rotates in a casing or volute. Two or more pump chambers may be mounted on the same drive shaft. The output of these pumps may be connected in parallel or in series to obtain extra volume or pressure. These are known as multi-stage centrifugal pumps. Centrifugal pumps are not in themselves self-priming, i. e. they will not exhaust air from a suction hose. Priming may be effected in various ways - by means of a positive gear or piston pump, by filling specially designed pump housings with water or by means of an exhaust ejector operated by the engine.

The main advantages of centrifugal pumps are simplicity of operation, a minimum of moving parts, lack of close tolerances, ability to handle dirty and abrasive material, high volume at low pressures and the fact that the output can be cut off abruptly at the nozzle without damage to the pump and without the need for a pressure relief valve. Maintenance and repair costs are low. Pumps of this type have a longer life than positive displacement types. The disadvantages of centrifugal pumps are that they are not selfpriming, are generally larger than an equivalent positive displacement pump and have a relatively low maximum pressure unless multi-stage construction is employed.

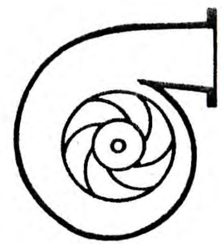
Positive displacement pumps are those in which energy is imparted to the water by displacement between the plunger or rotor and the case of the pump, the moving parts making an air- or water-tight joint with the casing. They are self-priming, as they will withdraw air from the suction hose when in good condition. They include force, lift, bucket and plunger, and rotary pumps.

BACKPACK PUMPS

The simplest and most portable water pumping outfit - for its size - is the common backpack pump. It consists of a 20 liters tank (metal, plastic) or a collapsible bag (rubber, plastic), a short length of hose, a hand-operated pump, and a nozzle adjustable to a straight stream or spray (figure 53). Operated by a skilled man, it is the most efficient, flexible, and economical of all water pumping equipment.

Centrifugal Pumps

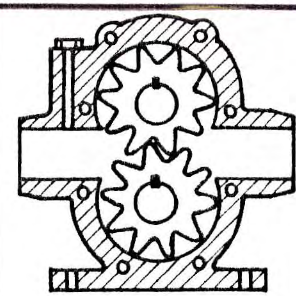
Advantages	Disadvantages
- Pressure can be changed by adjusting rpm. - Volume can be changed by adjusting psi and rpm. - Relief valves not required. - Dirty water and small particles can be passed without damage. - Refill performance good.	- More power required for higher pressures. - Primer usually required. - To avoid heating bypass is required when no water is moved.



CENTRIFUGAL

Positive Displacement Pumps

Advantages	Disadvantages
- Higher pressures can usually be produced with less power. - Primers usually are not required.	- Damaged by dirty water. - Relief valve required. - Fixed output and psi performance not easily changed.



POSITIVE DISPLACEMENT

Fig.52: Centrifugal and positive displacement pumps: Advantages and disadvantages

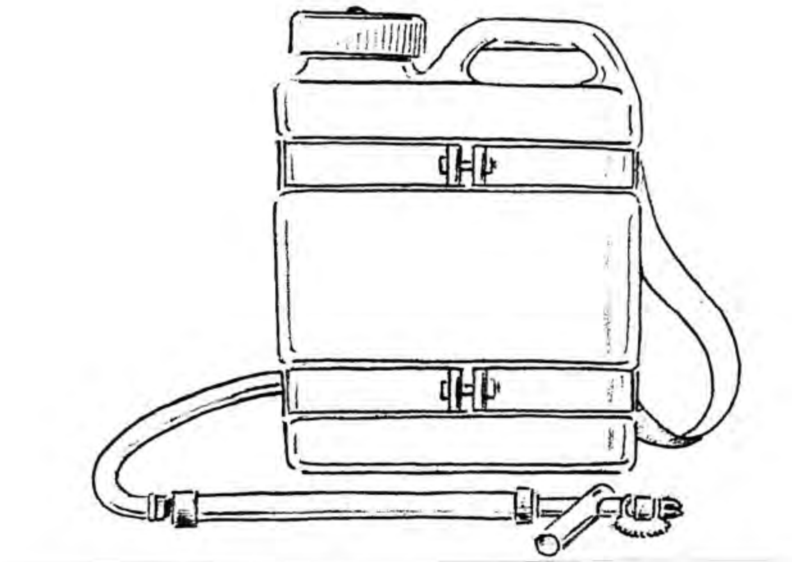


Fig.53: Backpack pump (20 1)

HOSES AND NOZZLES

As with the pumps themselves, there have been numerous developments in the hose used with them. The suction hose is a semi-rigid hose about three to four meters in length with a foot valve and strainer on the intake end. It is usually somewhat larger in diameter than the outlet hose. The latter has been designed to provide effective transport of water yet be light in weight to facilitate transport to the fire. For many years the type most used was a lightweight woven linen hose. One of its major advantages was in its ability to remain wet through seepage. This reduced the likelihood of its being burned should it come in contact with burning embers or be subjected to high levels of heat radiation near the fireline. Linen hose has now been largely replaced by hoses made with synthetic fabrics. Hoses having a smooth impermeable inner lining such as rubber are able to deliver more water because of reduced friction loss but they lose the ability to remain wet. This type of hose is generally used where it is not likely to be close to the fire. Another type, the lined percolating hose, was designed to combine the advantages of the linen hose and the lined hose. The lining has small slits in it to allow enough water to seep through to keep the outer jacket wet.

There are also many variations in such ancillary equipment as couplings, nozzles, and valves. In some countries, threaded couplings have largely given way to what is known as quick-connect couplings. These can be connected with a simple twist and have the added advantage of being interchangeable, that is, having neither male nor female fittings. Originally most fittings were brass, but in recent years other materials such as aluminum and high-strength plastics have been used, partly to reduce the weight of the fittings and partly because of the high cost of brass.

Commonly used nozzles consist of a barrel with a set of interchangeable tips of various orifice size. Different diameter tips will give different patterns of spray and different droplet sizes and an operator is able to select the most desirable effect for the particular fire situation. The larger the nozzle orifice diameter, the greater the volume of water being delivered and the less the nozzle pressure, hence the less the length of stream. For light surface fires, a fine spray is more effective than a straight stream whereas the latter is more effective when dealing with a fire in heavier fuels. At times a wide variety of fuel types are encountered on the same fire segment and, to meet this challenge, variable stream nozzles have been designed. Using these nozzles, an operator is able to change the application rate from a straight stream to a fine spray or to anything in between at the turn of a dial. The so-called fog nozzle where a high pressure fog is produced has not been found effective against wildfires. A portion of the fog tends to drift away from the target in the wind and, in addition, the entrained air with the high pressure fog may actually fan the fire.

GROUND TANKERS

Two varieties of ground tankers are recognized: the slip-on unit and the integral unit. A slip-on unit consists of a tank and pump assembly that can be removed from or added to a vehicle as a single unit. In part the device represents an adaptation to the seasonal nature of fire control. A pickup truck, for example, may be converted to a ground tanker during fire season and then returned to duty as a general purpose vehicle when fire season ends. In part, too, the slip-on unit reduces the costs of purchasing special fire vehicles. Trucks designed for other purposes can be converted easily by inserting a prepackaged assembly. The intergral unit, by contrast, has the pump built into the engine system of the vehicle and the water tank constructed as part of the entire body. Most dual-purpose engines are of the integral variety. Both slip-on and integral unit engines can substitute chemical retardants or wetting agents for simple water.

AIRCRAFT

Aircraft are used to reconnoiter fires, to deliver firefighters, and to drop supplies, retardants, and ignition devices. In general two types of aircraft are recognized: fixed wing (airplane) and rotary wing (helicopter). Within each category aircraft are differentiated according to the payload they can carry. Fixed wing aircraft are used for heavy payloads carried over long distances, and for reconnaissance when long observation periods are required. Some light aircraft have been adapted for aerial ignition, and others for infrared mapping. Most air tankers began as surplus military aircraft, generally of World War II vintage. As the planes have aged, other aircraft of civilian origin, such as the DC-6, have been adapted to aerial attack. One plane, the CL-215 manufactured by Canadair, has been designed specifically for fire control. This plane has a special scooping device that allows to fill up the interior tank with water while in flight. Other civilian and military planes, the C-130 "Hercules" and the C-160 "Transall", can be outfitted with a pressurized "Modular Airborne Fire Fighting System" (USA) or a "Fire Fighting Kit" which simply works by gravity (Federal Republic of Germany).

BACKFIRING TOOLS

Backfiring or burning-out is a frequently used fire control technique (see chapter 5.2). One of the most commonly use manual devices is the drip torch which has been described in chapter 2.4. A number of other torches are available, some having backpack tanks for the fuel and some pressurized. Solid fuel ignition devices (mostly fusees) are also used in backfiring. The burning period is usually limited to about 10 minutes, but they have the advantage of not requiring a supply of flammable fuel.

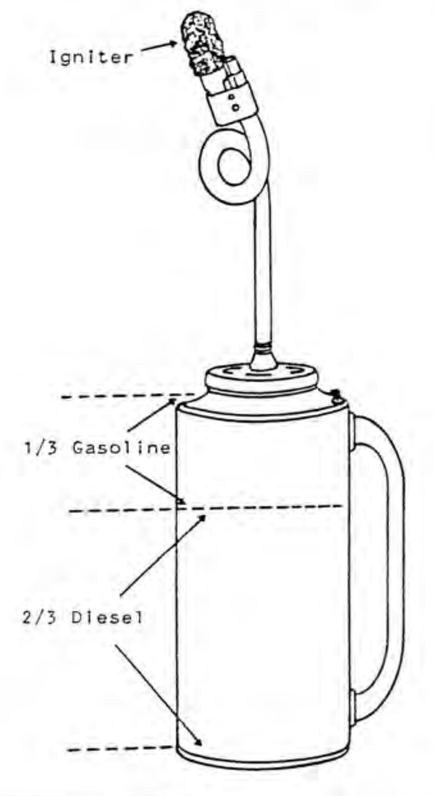


Fig.54: Drip torch

5.2 FIRE SUPPRESSION METHODS

There are three methods of bringing a forest fire under control: direct attack on the burning fire edge, parallel attack by constructing a fireline close by and parallel to the fire edge, and indirect attack by locating control lines a considerable distance from the fire edge and burning out all intervening fuel.

DIRECT ATTACK

Direct attack, as its name implies, is the suppression of combustion of the actively burning fire front. Direct attack involves suppressing flames by cooling the fuel with water, chemicals, or dirt and then scraping a line completely around the fire edge. Direct attack is normally used on very small fires that can be suppressed and completely mopped up as a unit, on low-intensity fires where heat and smoke do not preclude workers remaining at the fire edge, and on the rear of more intense fires where the smoke is being blown into the burned area. Because direct attack is always undertaken in a relatively high radiation environment, it is physically demanding work and crews must be rotated often. It is, however, the most positive method of control, leaving a cold line behind it, as well as the safest method of control because of the proximity of the burned-over area, and direct attack is the method of choice when fire behaviour permits it. Direct attack is most feasible when water handling apparatus is available since water is a much more effective flame suppressant than dirt.

PARALLEL ATTACK

Parallel attack is used whenever the fire is too intense for direct attack or when the fire edge is so irregular that direct attack would result in excessive length of line. In parallel attack a fireline is constructed as near to the fire edge as possible while still allowing for crew comfort and ensuring that the line can be completed before the arrival of the fire. A wider fireline is needed in a parallel attack since flame suppression is not undertaken as the fire meets the line. Parallel attack requires that the line be fired out as the work progresses or that firefighters be dropped off to patrol the line to ensure that it is not breached when the main fire hits it. Parallel attack requires a larger force per unit of held line than does direct attack, but this is compensated for by the fact that the easier working conditions make it possible to sustain productivity for longer periods, and because the line may often be shorter than that required in a direct attack. Heavy equipment such as fire plows and bulldozers usually use parallel attack since it is difficult for them to work directly on the fire edge without the risk of scraping or throwing burning material outside the fireline. This form of attack is often used on the flanks of intense fires, but it is potentially dangerous in these situations since an unexpected wind shift can turn a flank into the head of the fire with not enough distance between the fire and the line to permit the crew an orderly withdrawal.

INDIRECT ATTACK

Indirect attack is used when the fire is too intense for safe use of any other method or when the values protected are insufficient to justify a large firefighting expenditure. In indirect attack the firefighter force is withdrawn to roads, trails, fuelbreaks, or natural barriers and all fuel within this connected network is burned out. Indirect attack trades off increased area burned

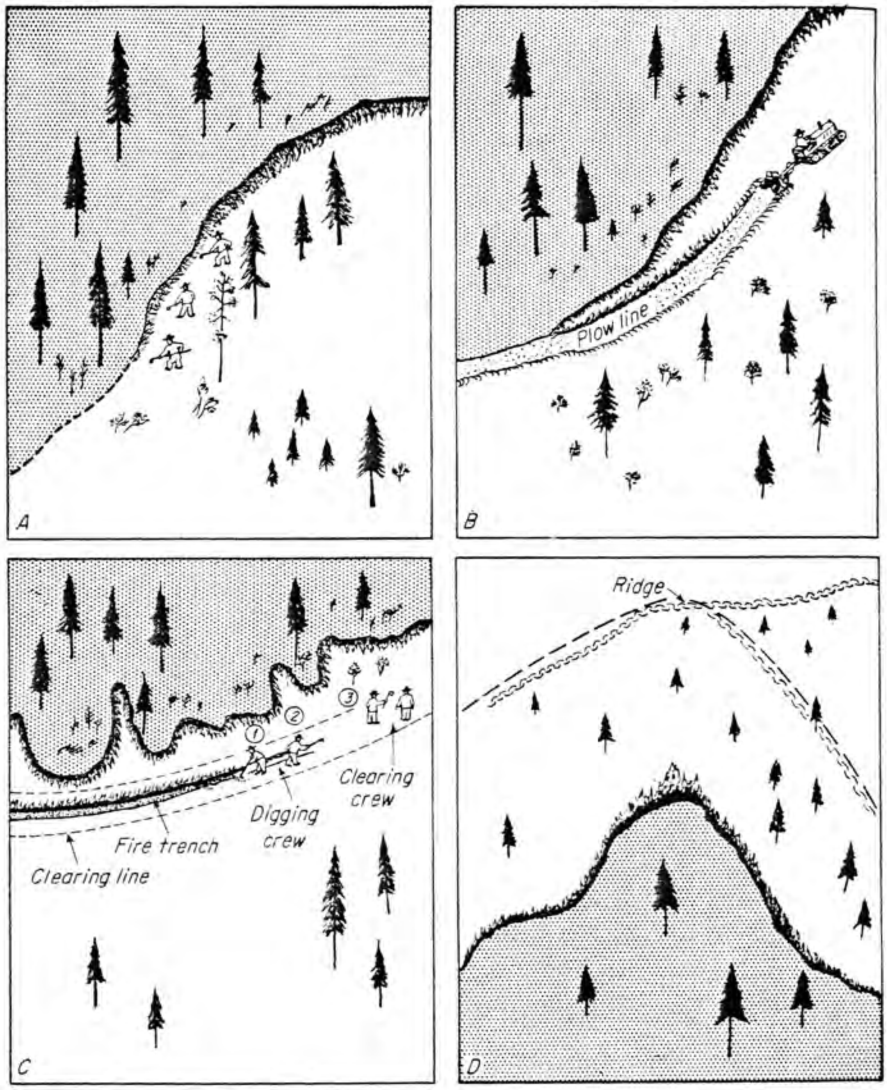


Fig.55

Methods of control line construction. A: Direct method. B: Parallel method. C: Indirect method used with irregular fire edge to shorten control line and make it easier to hold. D: Indirect method employed to take advantage of a better control-line position and to anticipate fire spread.

against reduced cost of operation. It is the least certain of success of the three methods since it usually requires the longest firelines and requires the most time. Long firelines mean more potential places for breakover and longer times mean more chances for unanticipated weather changes. If all intervening fuels cannot be burned clean, either because adverse weather makes backfiring too dangerous or because easing burning conditions precludes the spread of backfires, then nothing has been accomplished and the main fire still remains to be controlled. In the worst possible case, when backfires have been lit but fail to spread as anticipated, firefighters will have two fires rather than one to suppress. Successful indirect attack requires experienced personnel thoroughly knowledgeable about weather and fire behaviour in similar fuel and topographic situations.

CREW ORGANIZATION METHODS IN CONTROL LINE ESTABLISHMENT

Whether a fire line is being established during direct attack or by the parallel or the indirect method, crews should work systematically, for greater personal safety and more efficient line production. This is particularly necessary in thick scrub, but even in open country, where men and machines have ample space to manoeuvre, they should follow orderly procedures.

A group of men who have had no previous experience of fire line construction with hand tools tend to bunch together or walk past the men ahead in search of a new section. If space is limited a man may obstruct the work of the others and possibly injure them with the tool he is carrying. It is preferable that each man maintain the same relative position in the line as he assumed at the start of the job. There are two ways of doing this, known as the step-up method and the one-lick method.

Step-up method

To illustrate the step-up method, let it be assumed that a trail has to be constructed through an area of bush and that each man has a similar job of work, such as raking litter to one side. The crew members then space themselves along the proposed line of trail, so that each man has a section of say 15 m (figure 56). When an individual reaches the end of the work available to him, he calls out "step-up". This signal is repeated all along the line and each man then steps forward until he finds some fresh work to do. The leader in front, who is deciding the direction of the trail or following a previously marked line, will probably go forward to the extent of several sections and those who follow will either find an entirely new unraked section or take over some partly raked section. As passing is not necessary, each man retains his position in the crew. The man at the end of the line has a difficult and responsible job as he has to make sure that the line is cleared down to mineral soil and is of sufficient width.

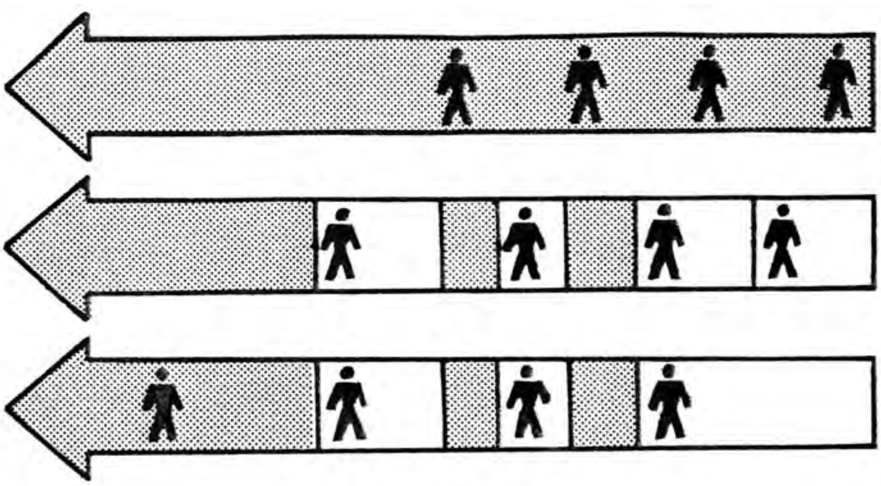


Fig.56: Step-up method

One-lick method

The one-lick method is used where the work of establishing a trail requires the use of a variety of hand tools. The first man might carry an axe to mark the trail. He may be followed by a man with a brush-hook, and then another man may have a hoe to chop out tussocks, of grass. He could be followed by a raker who prepares a rough trail and a second raker who completes the trail down to bare earth. The idea is to provide tools in suitable proportions so that the men work steadily forward. If the crew is well organised and each man does his share, fire line construction is completed to a satisfactory standard with a minimum of effort.

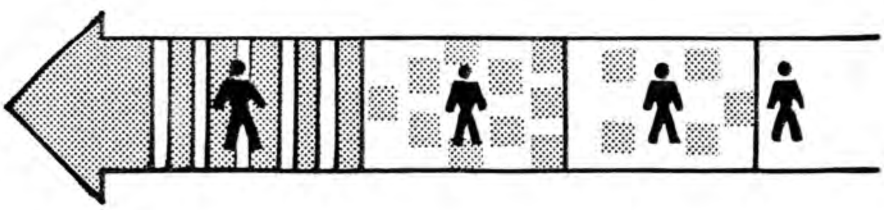
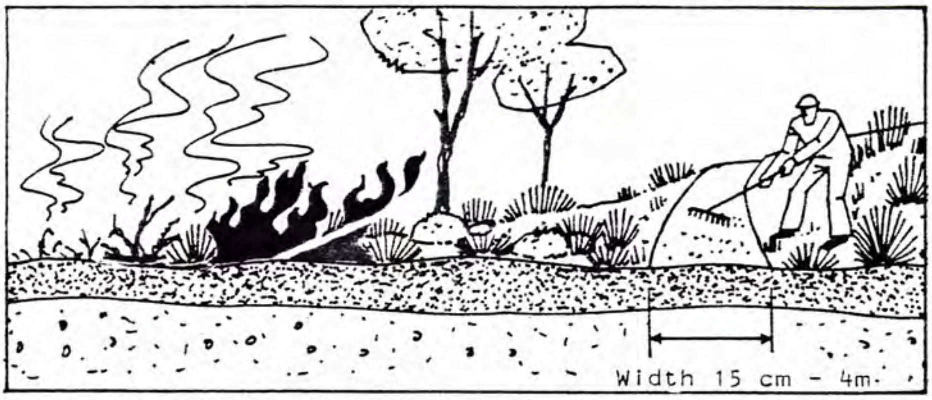
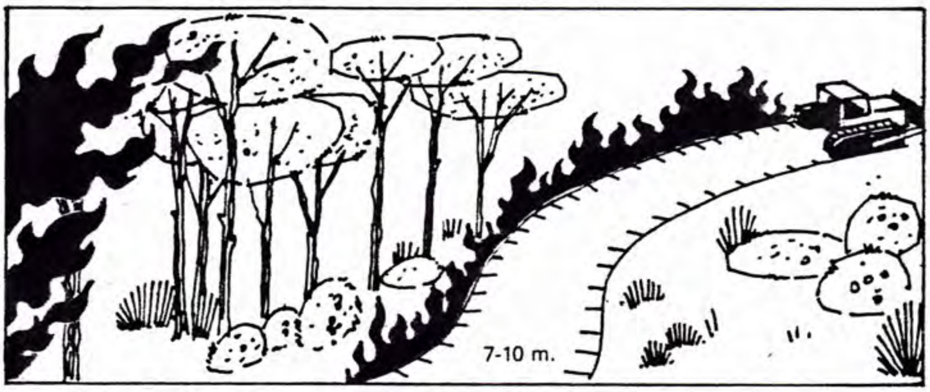


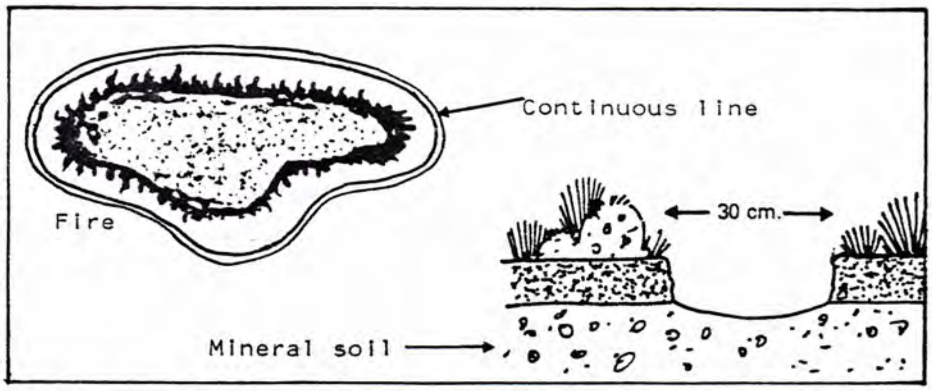
Fig.57: One-lick method



Surface fire



Crown fire



Ground fire

Fig.58: Characteristics of control lines

These principles not only apply to the construction of fire lines with hand tools. The advantage of applying the one-lick method with other equipment generally leads to more efficient working. If two or more tankers are worked in tandem on a sector of a grass fire, the tanker in front should be responsible for reducing some of the severity of the fire by a quick pass, while the tankers following would be expected to extinguish the fire. The same principle could be applied to the use of two bulldozers so that the one in front partly clears a trail and the other completes the job. Various combinations of men and machines can use the one-lick method provided that each piece of equipment is used effectively.

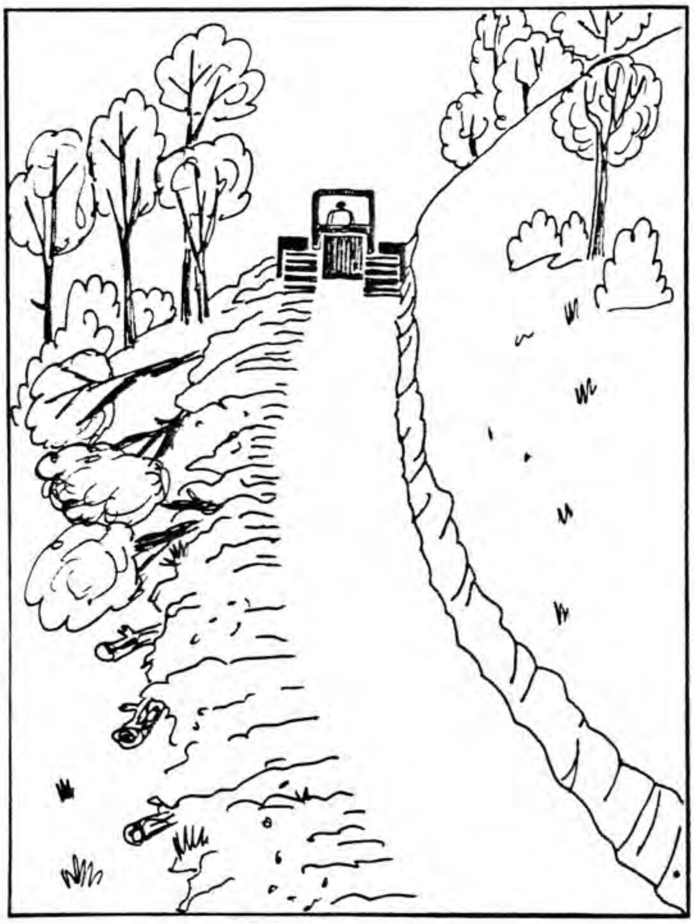
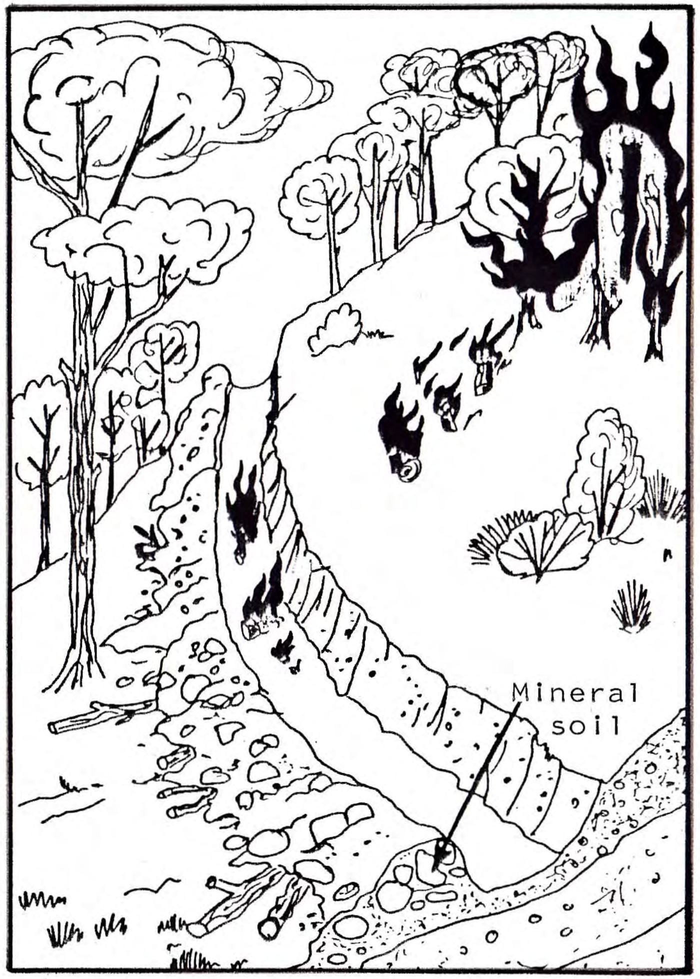


Fig.59

Covering of forest fuel with mineral soil on outer side of control line



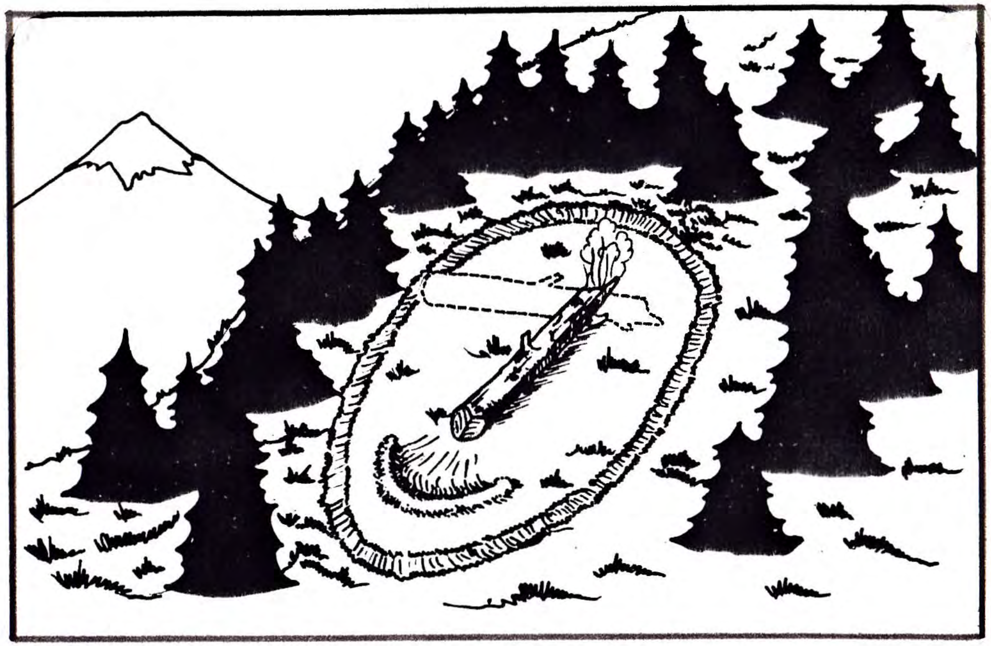


Fig.60 + 61

"V" trench in steep terrain generally stops most small rolling material.

Burning logs have to be turned parallel with the slope to prevent rolling (dotted lines show log's original position).

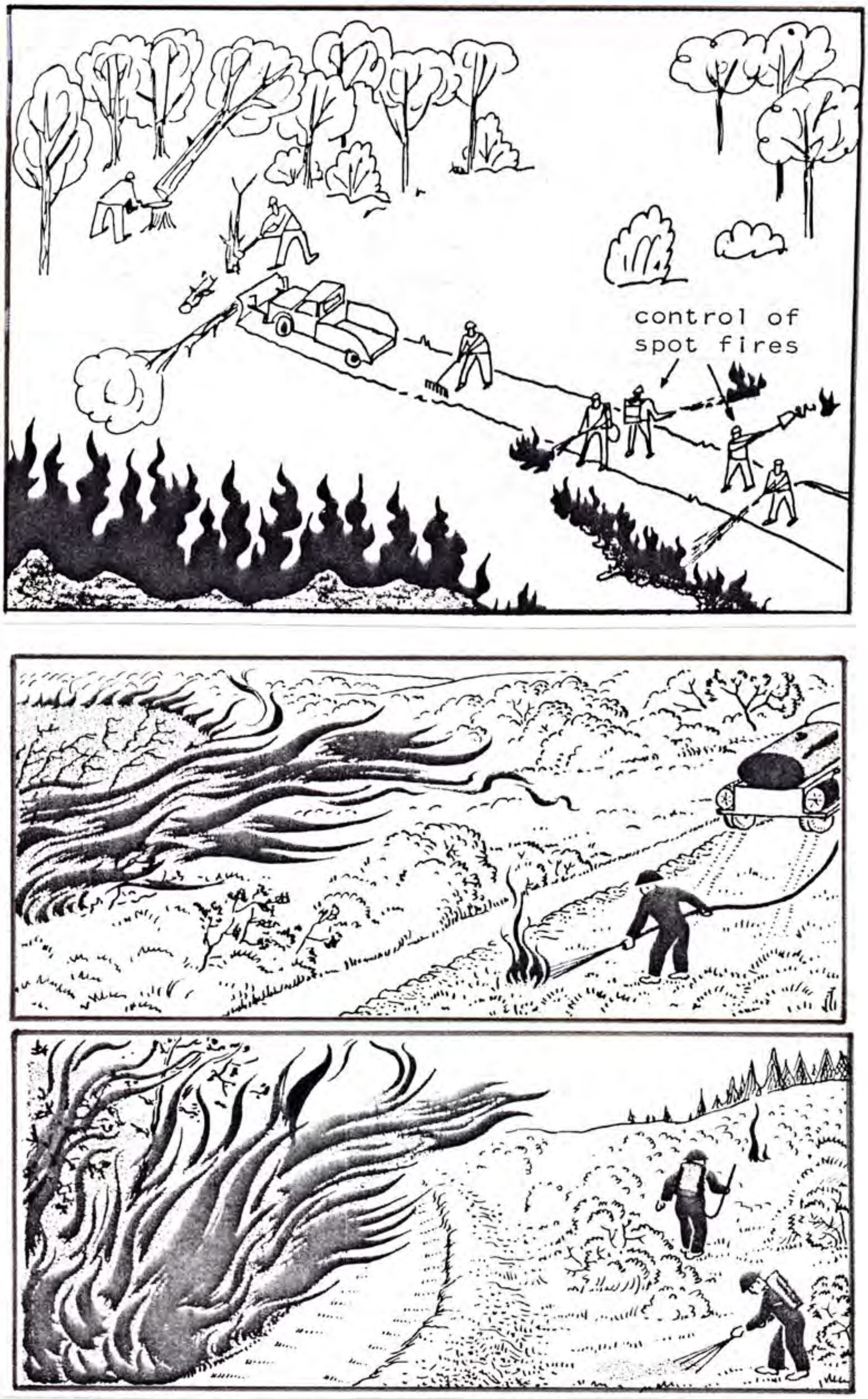


Fig.62-64: Fireline construction and control of spot fires beyond the line (backpack pumps or ground tankers)

BACKFIRING

Backfiring in fire suppression is the process of intentionally starting a fire in advance of a head fire or along the forward flanks of a rapidly spreading fire. The decision to backfire is a serious one, not to be undertaken lightly. Backfiring always involves the sacrifice of additional burned area and often involves an increased safety risk for firefighters. The decision to backfire should be based on careful calculation of the probability of success, not out of blind desperation or as a last resort when all else has failed. It is better to simply hang on to the flanks of a fast running fire and wait for weather conditions to improve than it is to accelerate the fire's spread by unsuccessful backfiring.

Backfiring is most successful in light, uniform fuels. Heavy fuels increase the danger of spot fires and, because of their longer burning times, increase the number of firefighters needed to hold each unit length of line. Patchy fuels make it difficult to obtain a clean burn when burning against the wind from a cleared fireline. Backfiring success is inversely proportional to wind velocity and backfiring against adverse winds greater than five meters per second should be strictly avoided.

Backfiring is usually undertaken under two quite different circumstances: when trying to stop, slow, or break up the head of a fast running fire, or when trying to obtain a clean burn between a line or natural barrier and a quiescent fire whose perimeter is too long or too ragged for direct attack to be feasible. Since quite different tactics and techniques are required for each situation, they are discussed separately.

With a fast running headfire, spotting is the main concern. In order to hold the fire successfully the backfire must be burned clean at least twice the spotting distance of the headfire at the time the two meet. If the spotting distance cannot be estimated,

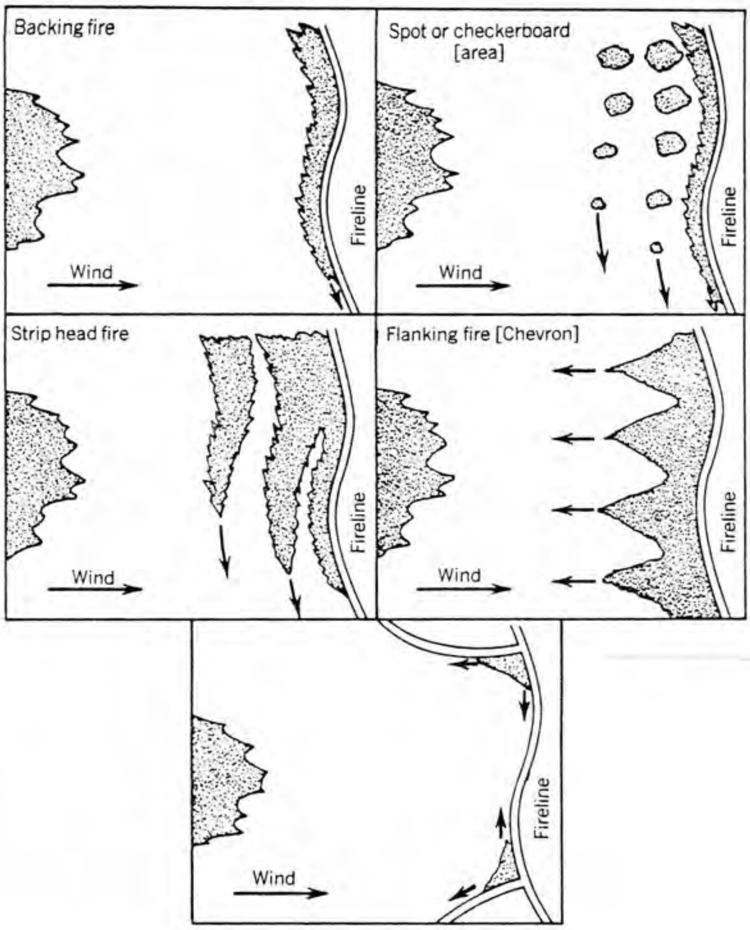


Fig.65

Backfiring techniques. Fundamentally, there are two techniques: strip firing (upper left) and spot firing (upper right). These methods can be arranged in various ways. Strips may be placed accross the head or flanks, or run parallel to the direction of the fire spread. As with any mode of attack, a system of anchor points is essential (bottom).

the backfire must be planned to be burned back from the line at least 30 meters. If at all possible, it is preferable to set the backfire between two firelines and allow the intervening strip to burn out before the arrival of the headfire. This avoids the extreme convective turbulence that occurs when two active fires merge and greatly reduces the chance of fire spotting over the line. Backfiring should never be undertaken unless there is an adequate firefighting force to assure control of the set fire. A backing fire alone will seldom spread fast enough to provide an adequate safety strip within reasonable time limits and it is usually necessary to resort to strip headfires, flanking fires, or spot firing to gain the necessary area. If the backfire is lost before the main fire arrives, the situation is worse than it would have been with no firefighting effort whatever.

In mountainous terrain, the preferred location for backfiring is a short distance below the crest of the ridge opposite the slope where the main fire is burning. This location allows the set fire to run upslope, takes advantage of any upslope winds that may be present, and also uses the upslope component of the lee eddy that is formed whenever a strong wind blows across a ridge. This not only lets the backfire spread faster and thus create a wider barrier in a shorter time, it makes it more likely that the convection column will merge with that of the main fire at a greater distance from the line and thus reduce the probability of spot fires downwind.

Backfiring is a line building technique that uses combustion rather than a shovel to remove fuel from the path of the fire. In backfiring, just as in hand line construction, it is necessary to have the line securely anchored to avoid having it breached or flanked. Again, as in hand line construction, it is possible to anchor a backfire by starting in one spot and firing the line out in two directions simultaneously. This is not always possible in mountainous terrain since backfires must generally be carried downhill to avoid rapid uphill runs that can hook and threaten

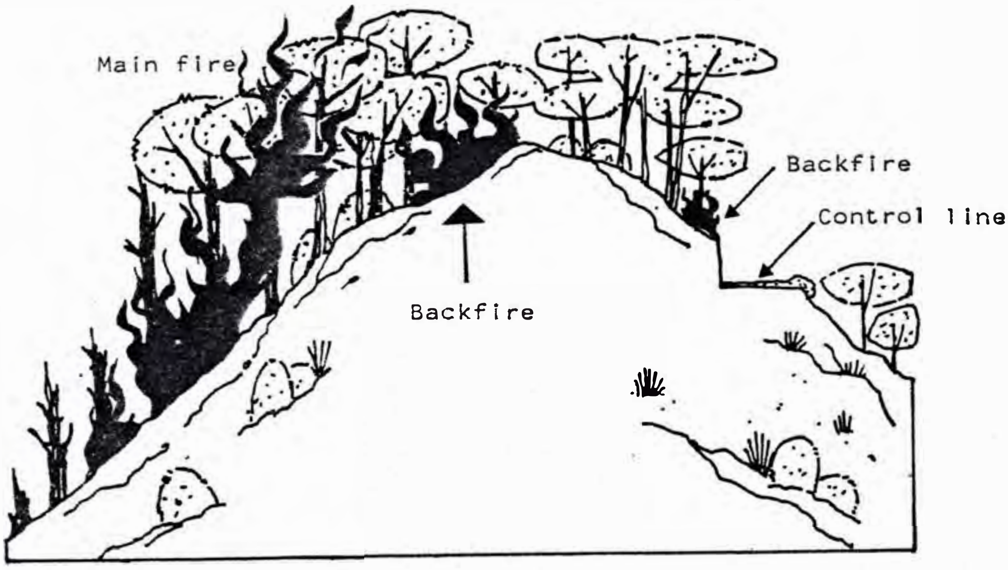
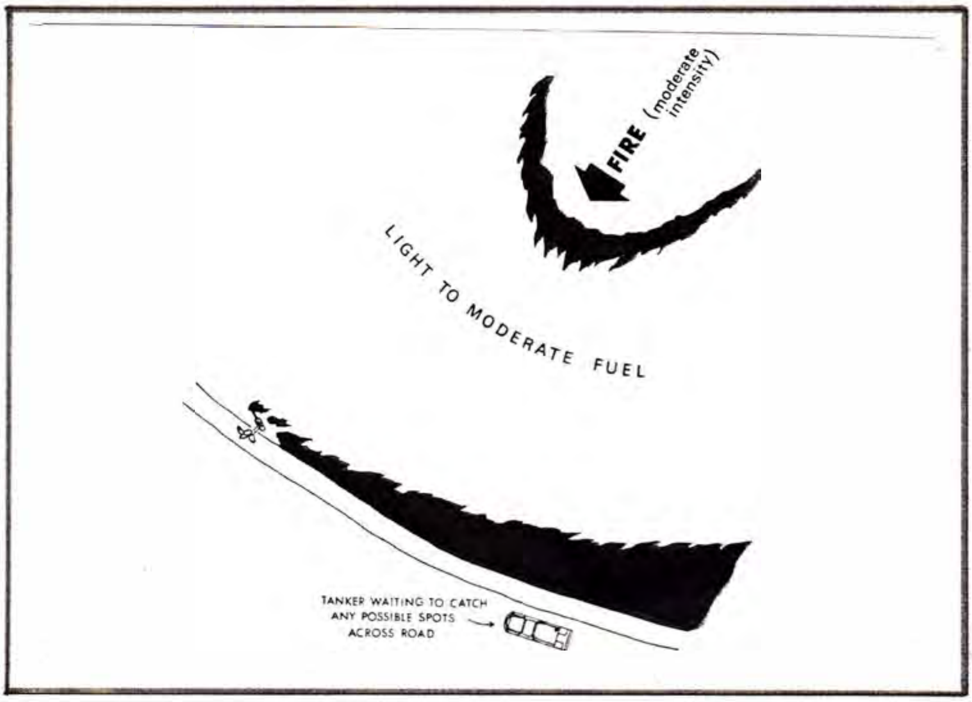


Fig.66: Backfiring in mountainous terrain

Fig.67-69: Backfiring from control lines (upper) and from road (bottom)



the fireline above. Consequently, when the fireline crosses a saddle or narrow valley it is usually necessary to split the firing and holding crews and fire downhill from both sides. This is a dangerous and delicate maneuver and must be done carefully with experienced people in charge at all times.

An even more dangerous technique called blowhole firing is used to break up the runs of fast moving fires burning with narrow fronts in light fuels. In blowhole firing one or more torchmen string fire at right angles, to the fireline, starting at the line and moving towards the main fire. When he has advanced as far as safely possible, the torchman returns to the line by crossing in front of the newly created backfire. When the main fire arrives, one or more V-shaped areas will have been burned out and serve to split the head fire and blunt its force. The technique is dangerous because the torchman has fire between himself and the fireline throughout the operation.

5.3 FIRE CONTROL ORGANIZATION

Fire control organizations are shown in figures 70 to 73. The figures represent a fairly typical range from the simple arrangements for small fires to those applicable to large fires. In addition to the command (coordinating and directing) and suppression (all firefighting) functions, other functions must be performed on any fire regardless of size: Planning (collection, analysis and evaluation of fire-related information), logistics (procurement, maintenance, distribution of personnel and equipment) and finance (payrolls, contracts, fiscal duties).

5.4 SAFETY

An understanding of the basic principles of fire behaviour is vitally important for all forest fire fighters. Equally important

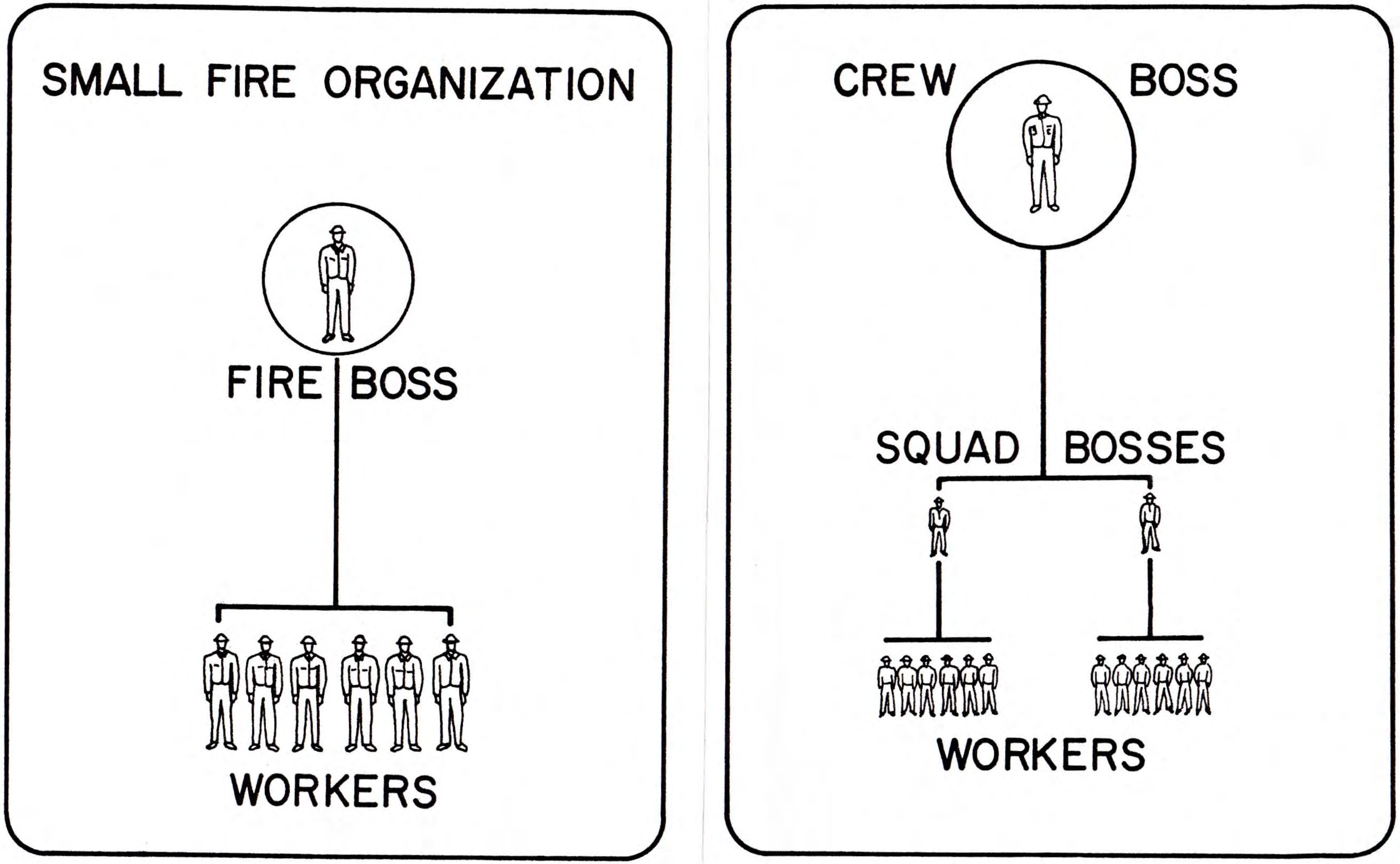
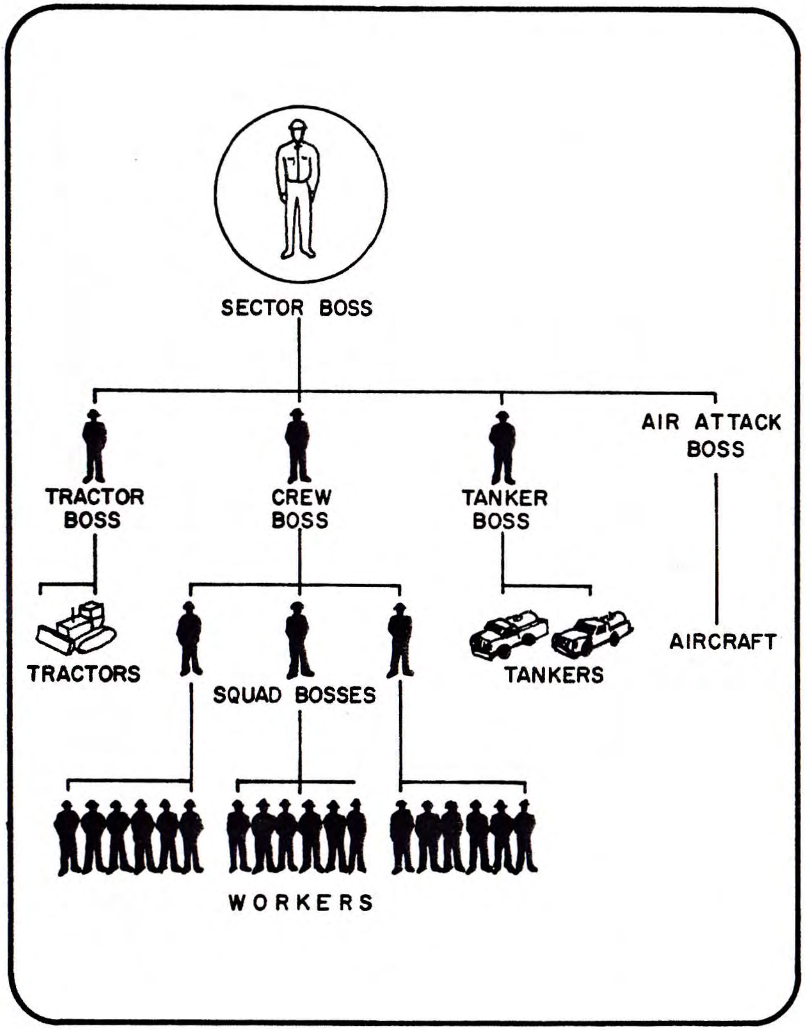


Fig.70+71: Small fire organization



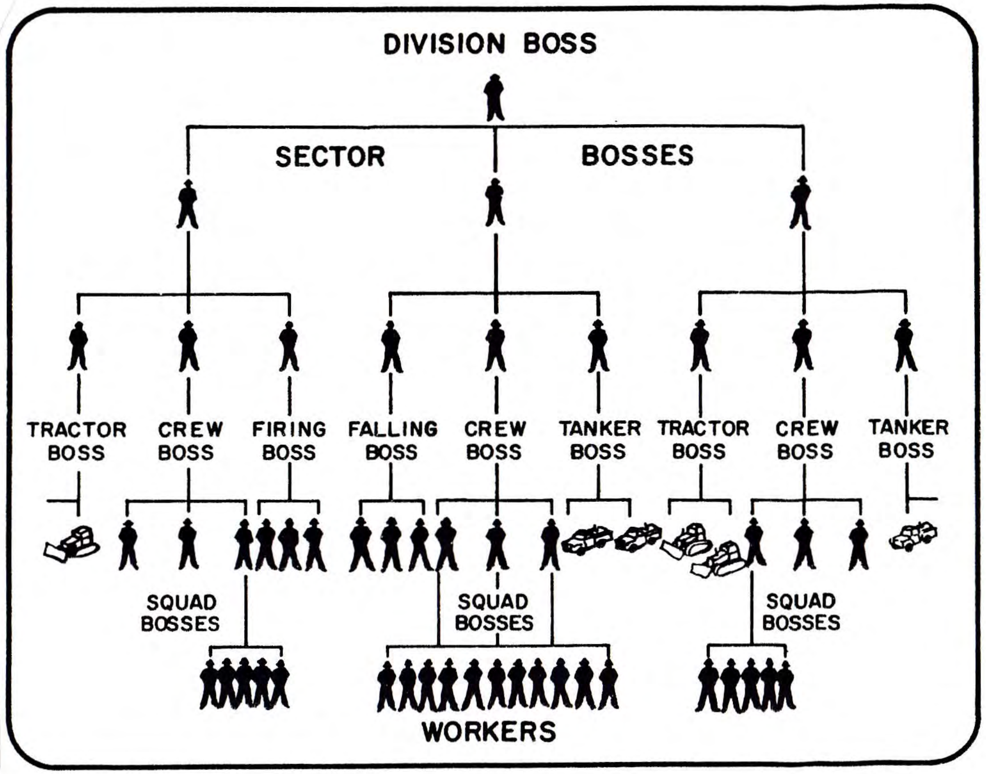


Fig.72+73: Large fire organization

is an understanding of the circumstances and conditions which can lead to sudden changes in fire behaviour. These sudden changes, even under moderate weather conditions, are often the main factors contributing to deaths, accidents, and near misses, among fire fighters.

Although most lives are lost on days of extreme fire danger many forest fire fighters die when the fire danger is only moderate to high. An analysis of the US Forest Service records of 125 wildland fires involving 236 fatalities, and 66 nearmiss situations also involving a substantial number of personnel, revealed the associated fire behaviour characteristics listed in table 3. Just over 50 percent of the incidents involved a sudden increase in fire intensity or other change in fire behaviour associated with a fire moving rapidly upslope or with a sudden wind shift.

Tab. 3: Fire behaviour situations associated with fatalities and nearmisses (USA)

	%
1. Fire ran upslope	29.6
2. Sudden wind shift (increased fire spread)	20.8
3. Headfire made rapid run	13.6
4. Fire spotted across line (often followed by uphill run)	9.6
5. Fire ran downslope	6.4
6. Flare up in heavy fuel	4.8
7. Downdraught large cumulus cloud (thunderstorm downdraughts)	4.0
8. Increased fire activity from wake turbulence (helicopters and airtankers)	0.8
9. Unchanged fire behaviour situations	
(a) equipment failure	0.8
(b) other (heart attack, electrocution)	9.6
	100.0

High-risk fires are typically small fires, or small portions of large fires; they burn in fine fuels rather than heavy; they occur under sudden wind shifts rather than strong but steady winds, and concentrate on steep slopes or topographic chimneys. Many fatalities have occured on fires considered under control, or fires that burned under routine circumstances until the fire suddenly flared up explosively. Fine fuels, variable winds, and steep topography make for fires that can respond quickly to environmental changes. When a fire burns in conditions that have two or three of these elements, its risk can be exceptionally high.

The hazards of the fire are greater than its flames, however. Even working next to an intense radiant heat source or within smoke - a common condition of direct attack methods - can lead to heat stress, dehydration, and in certain cases a degree of carbon monxide poisoning.

PROTECTIVE DEVICES

Clothing and other devices can protect firefighters by separating them from the fire to a limited extend.

Clothing

Undershirts, shirts and pants should always be worn to provide insulation against radiant heat from fire. Underwear should be made of cotton, both for adequate vapour passage and the avoid the danger of skin burns from melting acrylics should embers burn unnoticed through the outer clothing. The shirt should be longsleeved and worn with the sleeves down and buttoned. Canvas pants are often worn when working in heavy brush or thorn scrub, whereas lightweight cotton is more comfortable when working in light fuels. The pants should always be loose fitting, especially around the thighs.

Special flame-resistant clothing (synthetic aromatic polyamide fiber, e. g. Nomex, Aramid or Sulfon T.) offers additional protection against the likelihood of a flashover in clothes. Upon continous exposure to flame such fibers char rather than melting or burning to ash. Bright yellow in colour, fire shirts improve the visibility of a firefighter. Cotton or wool are also acceptable as shirt materials. Most synthetics and blends containing more than 15 percent nylon or polyester should be strictly avoided since they can melt and produce serious burns when exposed to embers or direct flame contact. The ubiquitous American "Blue Jeans" have no place on the fireline since radiant heat is conducted through the material directly to the skin.

Footwear

Boots should be high-topped, of good quality leather with nonslip tread soles. Two pair of socks should be worn; an outer pair of wool and an inner pair of light cotton. This combination keeps the foot dry by passing moisture through to the wool sock and reduces friction by adding a second interface between the boot and the feet and ankles.

Hard hat

The hard hat is the single most important protective device and should be required of every firefighter regardless of the fuel type in which the fire is burning. They are usually made of aluminium, fiberglass or plastic compositions.

Other

Work gloves and protective goggles are also recommended. Emergency fire shelters offer a further degree of protection.

Basically, the shelter consists of highly reflective aluminium foil being packed so that it can be worn on the waist. When trapped, the victim lies prone to the ground, feet facing the oncoming flames and envelops himself in the shelter with the reflective side out.

Equipment can also provide a temporary shelter. Vehicles can protect against a rapidly moving flaming front; even glass windows will cut radiant heat in half. The air inside the cab may become foul because of smoldering debris, but the vehicle will not flame for many minutes - long enough for the fire front to have passed by - and the gas tank will not explode unless it has been mechanically ruptured. Parking in a clearing or road further lessens heat stress. Less satisfactory are tractors. The cab is unshielded, but many operators have survived entrapment by clearing an area, placing the tractor within it, and taking refuge behind the blade. Again, it is only the flaming front against which one needs immediate protection. What is calculated to worsen the situation is simply to run. To run directly away from a fire is usually worse than to run through it, to run upslope worse than to traverse. The need for safety islands to provide a protected area and for lookouts to give ample time to get to such sites is obvious.

FIREFIGHTING HAZARDS

Heat

When heat and hard work combine to drive the body temperature up, the temperature-regulating mechanism begins to fail and the firefighter faces serious heat stress disorders. During strenuous activity a firefighter will lose 0.5 grams per second or 1.5 liters per hour of body fluids from the lungs and as perspiration. This amounts to a maximum cooling rate of 290 calories per second. If the heat absorbed by the body, including heat produced by muscular activity, exceeds this value, the body temperature will rise at a rate of approximately 1°C per 63,000 calories of excess heat. Since vigorous exercise produces about 150 calories per second within the body and exposure to full sunlight contributes another 50, any absorbed radiation or convected heat from the fire above 90 calories per second will eventually be evidenced by increased body temperature and heat sickness. The first symptoms are usually a mild headache, dizziness, and profuse perspiration. These can be alleviated by increasing fluid intake. Fireline workers should drink deeply and often. The normal sweating rate for firefighters is something over 1/2 liters per hour and can exceed 2 liters per hour under extreme heat loads. Dehydration up to five percent of body weight can be tolerated but losses beyond this will accelerate and aggravate heat stress symptoms. If too much salt is lost in perspiration, severe cramps in the legs and abdomen will result. Normal salt intake (20-30 grams per day) is sufficient to prevent heat cramps under normal fireline conditions and salt tablets are not necessary unless the noon meal is skipped or consists solely of fruit, candy, or other salt-free substances. If body fluids are not replenished following the onset of heavy perspiration, or if heat loads accumulate sufficient to raise the body temperature by 2 ° C, heat stroke is likely to occur. During heat stroke perspiration ceases, the skin becomes hot, dry, and reddish, breathing is rapid and shallow, body temperature rises rapidly, and the victim is quickly unconscious or delirious. Heat stroke is extremely dangerous, often resulting in death or permanent brain damage. The victim should be kept as cool as possible with the skin moistened frequently, and evacuation to a hospital should be initiated promptly.

Heat Stress Disorder	Cause	Symptoms	Treatment
Heat cramps	Failure to replace salt lost in sweating.	Painful muscle cramps.	Drink lightly salted water or lemonade; tomato juice, or "athletic" drinks; stretch cramped muscle.
Heat exhaustion	Failure to replace water and salt lost in sweating.	Weakness, unstable galt, or, extreme fatigue; wet, clammy skin; headache, nausea, collapse.	Rest in shade and drink lightly salted fluids.
Dehydration exhaustion	Failure to replace water losses over several days.	Weight loss and excessive fatigue.	Drinks fluids and rest until body weight and water losses are restored.
Heat stroke	Total collapse of temperature regulating mechanisms.	Hot skin; high body temperature (41° C or higher); mental confusion, delirium, loss of consciousness, convulsions.	Rapidly cool victim immediately, either by immersing in cold water or soaking clothing with cold water and fanning vigorously to promote evaporative cooling. Continue until temperature drops below 39° C. Treat for shock if necessary once temperature lowered. Heat stroke is a medical emergency. Send for medical help and begin treatment at once. Brain damage and death result if treatment is delayed.

Tab. 4: Recognizing and treating heat stress disorders

Carbon Monoxide

Carbon monoxide is a product of incomplete combustion. It is formed when there is too little oxygen in the fire environment to allow complete oxidation of carbon to carbon dioxide, or when the oxidizing gases are cooled quickly below their reaction temperatures. Carbon monoxide yields from forest fires range from 10 to 250 grams of CO per kilogram of fuel burned with the higher amounts found in high-intensity, rapidly spreading fires where oxygen supply is limiting, and in fires with a high proportion of smoldering material. Carbon monoxide production in smoldering combustion is about 10 times that in flaming combustion.

Although it takes relatively high concentrations (800+ppm) of carbon monoxide in the environment to cause unconsciousness and death (within several hours), research and experience show that low-level carbon monoxide poisoning can impair alertness, judgment, vision, and the ability to move quickly.

Consequently, workers doing direct attack at the fire front should be rotated every couple of hours and limited to one hot line assignment per day whenever possible. The greatest danger of carbon monoxide to forest firefighters is its insidiousness. Firefighters may feel that they are functioning perfectly long after their mental acuity has deteriorated to a point where they are a danger to others as well as themselves.

Burns

The principal cause of incapacitation and death in flame burns typical of those suffered by forest firefighter fatalities is thermal overload, similar to heat stroke but occuring in a much shorter time frame. Studies have shown that, for exposures lasting less than 30 seconds, 100 percent of the firefighters are totally incapacitated by total thermal loads (radiation plus convection) of 18,000°C-sec (1000°C for 18 sec, 18,000°C for 1 sec or any similar combination), 50 percent are totally incapacitated at 15,000 °C-sec, and no instances of total incapacitation can be expected at 9500°C-sec or less. To put these figures in a more familiar context, consider a line fire in light fuels with a flame temperature of 1000°C and a flame height of 3 meters. A firefighter running toward, through and away from such a fire at 5 meters per second would receive the equivalent of 2000° C-sec while approaching and leaving the flames. Thus survival could be expected to be certain if travel through the flames took less than 7.5 seconds and if clothing is not alight and skin not exposed to the fire. Few fires in light fuels have large flame depths. The typical residence times for fires (length of time it burns in any one spot) in common fuel types are shown in table 5.

Fuel Type	Residence time (sec)
Fine grass (annual pastures)	5
Coarse tropical grass, stubble	10
Pine needles and twigs	100
Eucalypt litter	130
Logging slash	over 600

Tab. 5: Typical residence times for fires in common fuel types.

In most firefighter fatalities, however, the unsuccessful strategy has been to try to run away from the fire and to continue running until exhaustion or the radiant heat load from the fire front fells the victim and allows the flame front to pass over him or her. Under these conditions both the radiant heat load and the residence time of the victims in the flame front exceed the maximum survival time.

Of course the best way to avoid such draconian measures as running through walls of flame is to stay out of situations where such measures become necessary.

Therefore the "Ten Standard Firefighting Orders" and the "Thirteen Situations that Shout Watch Out" have always to be kept in mind as the principles of safe firefighting practices.

THE TEN STANDARD FIREFIGHTING ORDERS

1. Keep informed on FIRE WEATHER conditions and forecasts.
2. Know what your FIRE is DOING at all times - observe personally, use scouts.
3. Base all actions on current and expected BEHAVIOUR of FIRE.
4. Have ESCAPE ROUTES for everyone and make them known.
5. Post LOOKOUTS when there is possible danger.
6. Be ALERT, keep CALM, THINK clearly, ACT decisively.
7. Maintain prompt COMMUNICATION with your men, your boss, and adjoining forces.
8. Give clear INSTRUCTIONS and be sure they are understood.
9. Maintain CONTROL of your men at all times.
10. Fight fire aggressively but provide for SAFETY first.

THE 13 SITUATIONS THAT SHOUT WATCH OUT!

1. YOU - in heavy cover with unburned fuel between YOU and FIRE.

2. YOU - in country you have not seen in daylight.

3. YOU - feel weather getting hotter and drier.

4. YOU - feel like taking a nap near fireline.

5. YOU - cannot see main fire and YOU are not in communication with anyone who can.

6. YOU - notice the wind change.

7. YOU - in an area where terrain and/or cover make travel slow.

8. YOU - are getting frequent spot fires over your line.

9. YOU - are building a line downhill toward a fire.

10. YOU - have been given assignment and instructions not clear to you.

11. YOU - are attempting to make a frontal assault on a fire with tankers.

12. YOU - on a hillside and rolling fire can ignite fuel below you.

13. YOU - are in an area were YOU are unfamiliar with local factors influencing fire behaviour.

6. GLOSSARY

MAJOR CATEGORIES (DEFINITIONS) OF MAN-CAUSED FIRES

INCENDIARY - A fire deliberately set by anyone to burn vegetation or property not owned or controlled by that person and without consent of the owner or his agent. It is also called arson in some areas whether a structure is involved or not.

CAMPFIRE - A fire started for cooking, warmth, or light that has spread sufficiently to require firefighting activity.

LAND OCCUPANCY FIRE - A fire started as a result of land occupancy for agricultural purposes, industrial establishment, construction, maintenance and use of rights-of-way, and residences, except use of equipment and smoking.

EQUIPMENT USE FIRE - A fire caused by any and all mechanical equipment other than railroad operations.

LUMBERING FIRE - A fire resulting from lumbering except one caused by smokers.

RAILROAD FIRE - A fire resulting from any operation or activity of a common carrier railroad, except smoking.

SMOKING - A fire caused by smokers from matches, lighters, tobacco, or other smoking material.

MISCELLANEOUS FIRE - A fire of known cause that cannot be properly classified under any of the eight standard causes of fires.

WILDLAND FIRE MANAGEMENT TERMS

AERIAL FUELS - The standing and supported forest combustibles not in direct contact with the ground and consisting mainly of foliage, twigs, branches, stems, bark, and vines.

BACKFIRE - A fire set along the inner edge of a control line to consume the fuel in the path of a forest fire and/or change the direction of force of the fire's convection column. NOTE: Doing this on a small scale and with closer control, in order to consume patches of unburned fuel and aid control-line construction (as in mopping-up) is distinguished as burning out = firing out, clean burning.

BACKING FIRE - Generally, a fire front spreading against the wind. However, a fire front spreading downhill with the wind would also be termed a backing fire if the angle of the flames, with respect to the unburned fuels, was more than 90 degrees. A fire spreading on level or downward sloping ground with no wind is a backing fire.

BARRIER - Any obstruction to the spread of fire, typically an area or strip devoid of combustible material.

BASELINE - In prescribed burning, the initial line of fire, usually set as a backing fire along a road, stream, or firebreak, which serves to contain subsequent burning operations.

BLACKLINE - Preburning of fuels adjacent to a control line before igniting a prescribed burn. Blacklining is usually done in heavy fuels adjacent to a control line during periods of low fire danger to reduce heat on holding crews and lessen chances for spotting across control line. In fire suppression, a blackline denotes a condition where there is no unburned material between the line and the fire edge.

BROADCAST BURNING - Allowing a prescribed fire to burn over a designated area within well-defined boundaries for reduction of fuel hazard, as a silvicultural treatment, or both.

BRUSH FIRE - A fire burning in vegetation that is predominantly shrubs, brush, and scrub growth.

BUMPUP METHOD - = moveup, step-up, functional
A progressive system of building a fireline on a wildfire without changing relative positions in the line. Work is begun with a suitable space, such as 15 feet (5 m), between workers. Whenever one worker

overtakes another, all of those ahead move one space forward and resume work on the incompleted part of the line. The last worker does not move ahead until the work is complete in his space. Forward progress of the crew is coordinated by a crew leader.

CENTER FIRING - A method of broadcast burning in which fires are set in the center of the area to create a strong draft; additional fires are then set progressively nearer the outer control lines as indraft builds up so as to draw them in toward the center.

CHEVRON BURN - A prescribed burning technique used in hilly areas to fire ridge points or ridge ends. Lines of fire are started simultaneously from the apex of a ridge point, and progress downhill.

CONFINE A FIRE - To restrict the fire within determined boundaries established either prior to the fire or during the fire.

CONTAIN A FIRE - To take suppression action as needed which can reasonably be expected to check the fire's spread under prevailing conditions.

CONTROL A FIRE - To complete control line around a fire, any spot fires therefrom, and any interior islands to be saved; burn out any unburned area adjacent to the fire side of the control lines; and cool down all hot spots that are immediate threats to the control line, until the line can reasonably be expected to hold under foreseeable conditions.

CONTROL LINE - A comprehensive term for all the constructed or natural fire barriers and treated fire edges used to control a fire.

CONTROL TIME - Elapsed time from the first work on a fire until holding the control line is assured. NOTE: Sometimes still measured only from the time of containing a fire.

COUNTER FIRE - Fire set between main fire and backfire to hasten spread of backfire. Also called draft fire. The act of setting counter fires is sometimes called front firing or strip firing. In European forestry synonomous with backfire.

CREEPING FIRE - A fire spreading slowly over the ground, generally with a low flame.

CROWN FIRE - A fire that advances from top to top of trees or shrubs more or less independently of the surface fire. Sometimes crown fires are classed as either running or dependent, to distinguish the degree of independence from the surface fire.

CROWN OUT - With reference to a forest fire, to rise from ground level and begin advancing from tree top to tree top. To intermittently ignite tree crowns as a surface fire advances.

CROWN SCORCH - Browning of the needles or leaves in the crown of a tree or shrub caused by heat from a fire.

DEAD FUELS - Fuels having no living tissue in which the moisture content is governed almost entirely by atmospheric moisture (relative humidity and precipitation), air temperature, and solar radiation.

DIRECT ATTACK - = direct fire suppression = direct method
Any treatment of burning fuel, e. g. by wetting, smothering, or chemically quenching the fire or by physically separating the burning from unburned fuel.

DISCOVERY TIME - Elapsed time from start of fire (known or estimated) until the time of the first discovery.

DISPATCHER - A person employed to receive reports of discovery and status of fires, confirm their locations, take action promptly to provide the firefighters and equipment likely to be needed for control in first attack, send them to the proper place, and support them as needed.

DOZER LINE - = cat line
Fireline constructed by a bulldozer.

DRAPED FUELS - Needles, leaves, and twigs that have fallen from tree branches and have lodged on lower branches or brush. A part of aerial fuels.

DRIP TORCH - A hand-held apparatus for igniting prescribed fires by dripping flaming fuel on the materials to be burned. The device consists of a fuel fount, burner arm, and igniter. The fuel used is generally diesel or stove oil with gasoline added.

DUFF - Forest floor material composed of the L (litter), F (fermentation), and H (humus) layers in different stages of decomposition.

EARLY BURNING - Prescribed burning early in the dry season before the leaves and undergrowth are completely dry or before the leaves are shed, as an insurance against more severe fire damage later on.

EDGE FIRING - A method of broadcast burning in which fires are set along the edges of an area and allowed to spread inward. Cf. CENTER FIRING

ELAPSED TIME - The total time taken to complete any step(s) in fire suppression. NOTE: Generally divided chronologically into discovery time, report time, getaway time, travel time, attack time, control time, mop-up time, and patrol time.

ESCAPED FIRE - A fire which has exceeded initial attack capabilities.

FIRE BEHAVIOUR - The manner in which a fire reacts to the variables of fuel, weather, and topography. NOTE: Common terms used to describe fire behaviour include smoldering, creeping, running, spotting, and crowning.

FIRE BELT - A strip, cleared or planted with trees, maintained as a firebreak or fuelbreak.

FIREBREAK - Any natural or constructed discontinuity in a fuelbed utilized to segregate, stop, and control the spread of fire or to provide a control line from which to suppress a fire.

FIRECLIMATE - The composite pattern of weather elements over time that affect fire behaviour in a given region.

FIRE CLIMAX - = pyric climax
A (plant) community maintained by regular fires.

FIRE CYCLE - = fire rotation = return period
The length of time necessary for an area equal to the entire area of interest to burn; the size of the area of interest must be clearly specified.

FIRE DAMAGE - The detrimental effects of fire expressed in monetary or other units, including the unfavorable effects of fire-caused changes in the resource base on the attainment of organizational goals.

FIRE DANGER - The resultant, often expressed as an index, of both constant and variable danger factors affecting the inception, spread, and difficulty of control of fires and the damage they cause.

FIRE DANGER RATING - A fire management system that integrates the effects of selected fire danger factors into one or more qualitative or numerical indices of current protection needs.

FIRE DETECTION - The act or system of discovering and locating fires. Cf. FIRE DISCOVERY

FIRE DISCOVERY - The act of determining that a fire exists; does not include determining its location. Cf. FIRE DETECTION

FIRE FREQUENCY - The number of fires per unit time in some designated area. The size of the area must be specified (units--number/time/area).

FIRE HAZARD - A fuel complex, defined by volume, type condition, arrangement, and location, that determines the degree both of ease of ignition and of fire suppression difficulty.

FIRE INSURANCE TREE - A seed tree left as a precaution against regeneration being destroyed by fire.

FIRELINE - A loose term for any cleared strip used in control of a fire.

FIRELINE INTENSITY (Byram's Intensity) - The product of the available heat of combustion per unit area of ground and the rate of spread of the fire. The primary unit is kilowatts per metre of fire front.

FIRE MANAGEMENT - All activities required for the protection of burnable forest values from fire and the use of fire to meet land management goals and objectives.

FIRE PREVENTION - All activities concerned with minimizing the incidence of destructive fires.

FIRE PROTECTION - All activities to protect wildland from fire.

FIRE RETARDANT - Any substance except plain water that by chemical or physical action reduces the flammability of fuels or slows their rate of combustion, e. g., a liquid or slurry applied aerially or from the ground during a fire suppression operation.

FIRE RISK - The chance of fire starting, as affected by the nature and incidence of causative agencies; an element of the fire danger in any area. Cf. FIRE HAZARD

FIRE SEASON - The period(s) of the year during which fires are likely to occur, spread, and do damage to forest values sufficient to warrant organized fire control.

FIRE STORM - Violent convection caused by a large continuous area of intense fire, often characterized by destructively violent, surface indrafts, a towering convection column, long-distance spotting, and sometimes by tornado-like vortices.

FIRE SUPPRESSION - = fire control
All the work and activities connected with fire-extinguishing operations, beginning with discovery and continuing until the fire is completely extinguished.

FLAMING COMBUSTION - Luminous oxidation of the gases evolved from the decomposition of the fuel.

FLAMING FRONT - That zone of a moving fire where the combustion is primarily flaming. Behind this flaming zone combustion is primarily glowing. Light fuels typically have a shallow flaming front, whereas heavy fuels have a deeper front.

FLAMMABILITY - The relative ease with which a substance ignites and sustains combustion.

FLANK FIRE - A fire set along a control line parallel to the wind and allowed to spread at right angles to it, toward the main fire.
- A firing technique consisting of treating an area with lines of fire set into the wind which burn outward at right angles to the wind.

FLAREUP - Any sudden acceleration of fire spread or intensification of the fire or a part of the fire. Unlike blowup, a flareup is of relatively short duration and does not radically change existing control plans.

FLASH FUEL - = fine fuels
Fuels, e. g. grass, ferns, leaves, draped (i. e. intercepted when falling) needles, tree moss, punky wood, and some kinds of light slash, that ignite readily and are consumed rapidly by fire when dry. Generally characterized by a comparatively high surface-to-volume ratio. Cf. HEAVY FUELS.

FOREST PROTECTION - That branch of forestry concerned with the prevention and control of damage to forests arising mainly from the action of humans (particularly unauthorized fire, grazing and browsing, felling, fumes and smoke) and of pests and pathogens, but also from storm, frost, and other climatic agencies.

FOREST RESIDUE - The accumulation in the forest of living or dead mostly woody material that is added to and rearranged by human activities such as forest harvest, cultural operations, and land clearing.

FUEL - Combustible material.

FUELBREAK - Generally wide (20 - 300 meters) strips of land on which the native vegetation has been permanently modified so that fires burning into them can be more readily controlled. Some fuelbreaks contain narrow firebreaks which may be roads or narrower hand-constructed lines. During fires, these firebreaks can quickly be widened either with hand tools or by firing out. Fuelbreaks have the advantages of preventing erosion, offering a safe place for firefighters to work, low maintenance, and a pleasing appearance.

FUEL LOADING - The oven dry weight of fuel per unit area. Loading is further analyzed by fuel size. Loading or mass per unit area is usually expressed in tonnes/hectare.

FUEL MANAGEMENT - The act or practice of controlling the flammability and reducing the resistance to control of forest fuels through mechanical, chemical, biological, or manual means, or by fire, in support of land management objectives.

FUEL MOISTURE CONTENT - = fuel moisture
The water content of a fuel particle expressed as a percent of the ovendry weight of the fuel particle.

GLOWING COMBUSTION - Oxidation of a solid surface accompanied by incandescence, sometimes evolving flame above it.

GREENBELT - An irrigated, landscaped, and regularly maintained fuelbreak, usually put to some additional use (e.g., golf course, park, playground).

GROUND FIRE - Fire that burns the organic material in the soil layer (e.g. a "peat fire") and often also the surface litter and small vegetation. Cf. SURFACE FIRE, CROWNING FIRE.

GROUND FUEL - All combustible materials below the surface litter, including duff, tree or shrub roots, punky wood, peat, and sawdust, that normally support a glowing combustion without flame. Cf. AERIAL FUELS.

GROUND TANKER - = engine, pumper, firetruck
A vehicle equipped with tank, pump, and necessary tools and equipment for spraying water and/or chemicals on grass, brush, and timber fires.

HAND LINE - A fire line constructed with hand tools.

HEAD FIRE - = heading fire
Generally, a fire front spreading with the wind. However, a fire front spreading uphill against the wind (or with no wind) would also be termed a head fire if

the angle of the flames, with respect to the unburned fuels, was less than 90 degrees.

HEAT TRANSFER - The process by which heat is imparted from one body to another, through conduction, convection, or radiation.

HELD LINE - All the prepared control line that contains the fire until mopping up is completed. Excludes lost line, natural barriers not counterfired, and unused secondary lines.

HELITACK CREW - A crew of firefighters specially trained in the tactical and logistical use of helicopters for fire suppression.

HOTSHOT CREW - an intensively trained firefighting crew used primarily in hand line construction.

IGNITION PATTERN - The manner in which a prescribed fire is set, determined by weather, fuel, geographic, and other factors having influence on the fire and the job it is to do.

INDIRECT ATTACK - = indirect method = indirect fire suppression
A method of suppression in which the control line is located some considerable distance away from the fire's active edge. Generally done in the case of a fast-spreading or high-intensity fire and to utilize natural or constructed firebreaks or fuelbreaks and favorable breaks in the topography. The intervening fuel is usually backfired or burned out, but occasionally the main fire is allowed to burn to the line, depending on conditions.

INITIAL ATTACK - = first attack
The first action taken to suppress a fire, whether it be ground or air.

LADDER FUELS - Fuels which provide vertical continuity between strata. Fire is able to carry from surface fuels into the crowns of trees or shrubs with relative ease and help assure initiation and continuation of crowning.

LIGHTNING FIRE - A wildfire caused directly or indirectly by lightning.

LOOKOUT - A person designated to detect and report fires from a fixed vantage point (=lookout observer).
- A location and associated structures from which fires can be detected and reported (=lookout station).

- A member of a fire crew designated to observe the fire and warn the crew when there is danger of becoming trapped.

MASS FIRE - A fire resulting from many simultaneous ignitions that generates a high level of energy output.

MOPPING UP - = mopup
Making a fire safe after it has been controlled, by extinguishing or removing burning material along or near the control line, felling snags, trenching logs to prevent rolling, etc.

NATURAL BARRIER - Any area where lack of flammable material obstructs the spread of forest fires.

NATURAL FIRE - Any fire of natural origin, e. g., caused by lightning, spontaneous combustion, or volcanic activity.

NATURAL FUELS - Fuels resulting from natural processes and not directly generated or altered by forestry practices.

NONCOMMERCIAL - Forest land incapable of yielding crops of commercially useful wood because of adverse site conditions, or productive forest land withdrawn from commercial timber use through statute or administrative regulation.

ONE LICK METHOD - A progressive system of building a fire line on a wildfire without changing relative positions in the line. Each worker does one to several "licks", or strokes, with a given tool and then moves forward a specified distance to make room for the worker behind.

PARALLEL ATTACK - = parallel method
= PARALLEL FIRE SUPPRESSION
A method of suppression in which fireline is constructed approximately parallel to, and just far enough from, the fire edge to enable workers and equipment to work effectively, though the line may be shortened by cutting across unburned fingers. The intervening strip of unburned fuel is normally burned out as the control line proceeds but may be allowed to burn out unassisted where this occurs without undue delay or threat to the line.

PATROL - Generally, to travel over a given route to prevent, detect, and suppress fires.
- More specifically, to go back and forth vigilantly over a length of control line during and/or after construction to prevent breakaways, control spot fires, and extinguish overlooked hot spots.
- A person or group of persons who carry out patrol actions.

PILING AND BURNING - Piling slash resulting from logging and subsequently burning the individual piles.

PREATTACK - A planned, systematic procedure for collecting, recording, and evaluating prefire and fire management intelligence data for a given planning unit or preattack block. The planning phase is usually followed by a construction and development program integrated with other resources and activities.

PREATTACK BLOCK - A unit of forest land delineated by logical and strategic topographic features for preattack planning.

PREATTACK PLANNING - Within designated blocks of land, planning the locations of fire lines, base camps, water supply sources, helispots, etc.; planning transportation systems, probable rates of travel, and constraints of travel on various types of attack units; and determining what types of attack units likely would be needed to construct particular fire lines, their probable rate of line construction, topographic constraints on line construction, etc..

PRESCRIBED BURNING - Controlled application of fire to wildland fuels in either their natural or modified state, under specified environmental conditions which allow the fire to be confined to a predetermined area and at the same time to produce the intensity of heat and rate of spread required to attain planned resource management objectives.

PRESCRIBED FIRE - A fire burning within prescription. The fire may result from either planned or unplanned ignitions.

PRESCRIPTION - A written statement defining the objectives to be attained as well as the condition of temperature, humidity, wind direction and speed, fuel moisture, and soil moisture under which the fire will be allowed to burn, generally expressed as acceptable ranges of the various indices, and the limit of the geographic area to be covered.

PROGRESSIVE METHOD OF LINE CONSTRUCTION - A system of organizing workers to build fireline in which they advance without changing relative positions in line. There are two principal methods of applying the system: (1) the "moveup", "stepup", or "bumpup" (see bumpup) method, and (2) the "one lick" method (see entry).

PULASKI TOOL (USA) - A combination chopping and trenching tool widely used in fireline construction, which combines a single-bitted axe blade with a narrow adze-like trenching blade fitted to a straight handle.

PYROLYSIS - The thermal or chemical decomposition of fuel at an elevated temperature. This is the pre-combustion stage of burning during which heat energy is absorbed by the fuel which, in turn, gives off flammable tars, pitches, and gases.

RANGE FIRE - Any fire on rangeland where the main fuel is grass.

RAPPELLING - A technique of landing firefighters from hovering helicopters which involves sliding down ropes with the aid of friction producing devices.

RATE OF SPREAD - The relative activity of a fire in extending its horizontal dimensions. NOTE: Is expressed either as rate of increase of the fire perimeter, as a rate of increase in area, or as a rate of advance of its head, depending on the intended use of the information; generally in meters or hectares per hour for a specific period in the fires's history.

RESIDENCE TIME - The time required for the flaming zone of a fire to pass a stationary point; the width of the flaming zone divided by the rate of spread of the fire.

RESIDUE TREATMENT - Managing, manipulating, removing, or modifying forest residues. Treatments may involve piling, chipping, crushing, burning, burying, lopping, herbicide spraying of live residues, leaving for natural deterioration, removal, or a combination of these.

ROUGH REDUCTION - Reduction of the rough hazard, usually by prescribed burning.

RUNNING FIRE - A fire spreading rapidly, with a well defined head, Cf. CREEPING FIRE, SMOLDERING FIRE, CROWNING FIRE, SPOTTING FIRE.

SAFETY ISLAND - An area (usually a recently burned area) used for escape in the event the line is outflanked or in case a spot fire causes fuels outside the control line to render the line unsafe. In firing operations, crews progress so as to maintain a safety island close at hand allowing the fuels inside the control line to be consumed before going ahead. Safety islands may also be constructed as integral parts of fuelbreaks; they are greatly enlarged areas which can be used with relative safety by firefighters and their equipment in the event of blowup in the vicinity.

SHADED FUELBREAK - Fuelbreaks built in timbered areas where the trees on the break are thinned and pruned to reduce the fire potential yet retain enough crown canopy to make a less favorable microclimate for surface fires.

SLASH DISPOSAL - Treatment of slash to reduce the fire hazard or for other purposes.

SLIP-ON TANKER - A tank, a live hose reel or tray, an auxiliary pump, and an engine combined into a single one-piece assembly which can be slipped onto a truck bed or trailer.

SMOKE MANAGEMENT - The application of knowledge of fire behaviour and meteorological processes to minimize air quality degradation during prescribed fires.

SMOKE TARGET - An area that may be adversely affected by smoke from a prescribed burn.

SMOLDERING COMBUSTION - Combustion of a solid fuel, generally with incandescence and smoke but without flame. Cf. GLOWING COMBUSTION.

SMOLDERING FIRE - A fire burning without flame and barely spreading.

SPOT FIRE - Fire set outside the perimeter of the main fire by flying sparks or embers. Cf. SPOTTING FIRE

SPOTTING FIRE - = jumping fire
A fire that spreads by spot fires, the process being termed spotting.

STRIP BURNING - =parallel burning = strip firing
- Setting fire to a narrow strip of fuel adjacent to a control line and then burning successively wider adjacent strips as the preceding strip burns out.
- Burning only a relatively narrow strip or strips through an area of slash, leaving the remainder.
- Burning the slash on strips generally 100 to 300 feet (30 to 90 m) wide along roads or barriers so as to subdivide the slash area into blocks.

STRIP HEAD FIRING - Setting a line or series of lines of fire near and upwind of a firebreak so they burn with wind into the firebreak. A technique used to quickly burn out an area.

SUPPRESSION FIRING - The various applications or uses of fire to speed up or strengthen control action on wildfires. Many terms are used for various types of suppression firing: burning out, backfire, line firing, counter firing, burned strip, etc..

SURFACE FIRE - Fire that burns only surface litter, other loose debris of the forest floor, and small vegetation.

THERMAL BELT - An area of mountainous slope (characteristically the middle third) that typically experiences the least variation in diurnal temperatures and has the highest average temperatures and, thus, the lowest relative humidity. Its pressure is most evident during clear weather with light wind.

UNDERBURNING - Prescribed burning with a low intensity fire in activity-created or natural fuels under a timber canopy.

URBAN/WILDLAND INTERFACE - That line, area, or zone where structures and other human development meets or intermingles with undeveloped wildland or vegetative fuels.

VALUES-AT-RISK - Any or all of the natural resources or improvements which may be jeopardized if a fire occurs.

VISCOUS WATER - Water that contains a thickening agent to reduce surface runoff. Also called thick water. Thickened water tends to cling to burning fuels and to spread in layers that are several times thicker than plain water, thereby having an increased capacity to absorb heat, cool the fuel, and exclude oxygen.

WET LINE - A fire edge being contained by water and/or retardants but <u>not</u> by fireline. Cf. FIRELINE

WET WATER - Water containing a wetting agent.

WILDFIRE - Any fire occurring on wildland except a fire under prescription.

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8. APPENDIX

8.1 CALCULATION OF HEAT YIELD AND FOREST FIRE INTENSITY

The amount of heat energy produced by a fuel when it burns away completely is known as its heat of combustion. It is expressed in kilojoules per kilogram (kJ/kg) - where the kilojoule is the unit of energy and the kilogram the unit of mass.

Since fuels may vary greatly in the amount of moisture they contain, their heats of combustion are measured in terms of their weight when completely dry, i.e. in terms of their oven-dry weight. The heats of combustion of individual fuels are variable, but 20 000 kJ/kg is regarded as a fair average for the range of fuels most commonly consumed by forest. fires.

Natural fuel is never oven-dry, although the moisture content of fine fuels in a cured or dried-out condition may sometimes be as low as 2.5 - 3.0% of its oven-dry weight. Some of the heat from the burning of fuel is used in driving off the moisture contained in living cells, or is absorbed by dried-out material. Furthermore, fires produce smoke which consists mainly of unburnt tars and carbon. Therefore the heat output or yield from the burning of a natural fuel is somewhat less than that of the heat of combustion and is closely related to its current moisture content. As moisture content may vary considerably, it is necessary to assume an average value when assessing the effect of burning grass and forest fuels under natural conditions. The figure of 16 000 kJ/kg is generally taken as the average value for heat yield.

As well as the total energy released by the burning of fuels, the rate at which the energy is released - the power output - is of considerable importance in understanding fire behaviour. Whether the energy comes from an electric radiator, a flame or a burning log, the unit used for the expression of power output is the watt. As one watt is equivalent to one joule per second, it will be noted that the time factor is taken into account. Usually it is more convenient to express power in kilowatts (one kilojoule per second). As the power of most domestic electric radiators is one kilowatt, a ready-made means of appreciating the rate of heat output from active fire fronts is a available.

FIRE INTENSITY

The term, FIRE INTENSITY, refers to the rate at which energy, in the form of heat, is released in the flame zone of a going fire. Calculations of fire intensity are based upon three contributory factors

- the heat yield of the fuel involved
- the quantity of fuel available for burning
- the rate of forward spread of the fire.

Measurements are expressed according to the energy release over a unit length of the fire front. Current practice is to express the measurement in kilowatts per metre.

An assessment of fire intensity is essential in determining appropriate suppression strategies and in predicting fire behaviour.

Fire intensity can be calculated using the equation

$$I = \frac{Hwr}{600}$$

where, I = the fire intensity in kilowatts per metre
H = the heat yield in kilojoules per kilogram
w = the weight of available fuel in tonnes per hectare
r = the rate of forward spread in metres per minute.

As it was mentioned before, the average heat yield of forest fuels has been calculated close to 16 000 kilojoules per kilogram. The term "available fuel" refers to that fuel which would burn if fire got into the area. The amount of available fuel will vary between a few tonnes per hectare up to in excess of 30 tonnes per hectare.

The rate of forward spread of a fire is determined by the interaction of several variables, including the weight and type of available fuel, air temperature, relative humidity, wind speed and slope.

An Example of Fire Intensity in a Forest Fire

The example of fire intensity given below is calculated on the following fuel and weather conditions:

- Fuel Load: 20 tonnes per hectare
- Air Temperature: 32° Centigrade
- Relative Humidity: 20%
- Wind Speed: 25 kilometres per hour.

The rate of forward spread of a forest fire under these conditions would be around 18 metres per minute.

Using the equation:

$$\text{Fire Intensity} = \frac{\text{Heat Yield} \times \text{Fuel Load} \times \text{Rate of Spread}}{600}$$

$$= \frac{16000 \times 20 \times 18}{600}$$

$$= 9{,}600 \text{ kW/m (kilowatts per metre)}$$

The Effect of Uphill Slope

An uphill slope has the effect of increasing the rate of forward spread and, therefore, the intensity of a fire as follows:

- 5° slope increases forward spread/intensity by 33%
- 10° slope increases forward spread/intensity by 200%
- 20° slope increases forward spread/intensity by 400%

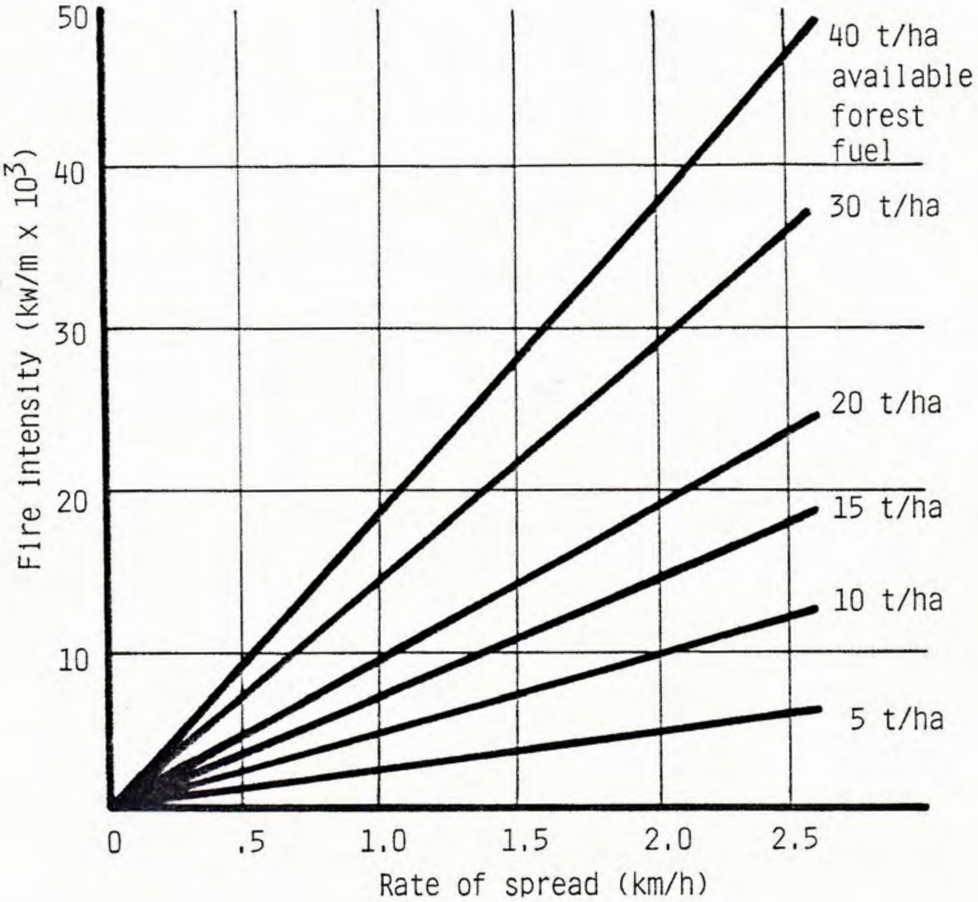
Applying these increases to the results of the fire intensity calculations above, we get:

- 5° slope would increase fire intensity to 12,800 kW/m
- 10° slope would increase fire intensity to 28,800 kW/m
- 20° slope would increase fire intensity to 48,800 kW/m

Difficulty is usually experienced in bringing fires under control when their intensity exceeds 4000 kW/m. The normal limits for prescribed burning are about 500 kW/m. Consequently, a firefighter can rapidly estimate fire intensity and associate it with the significant factor affecting fire behaviour.

An impression of the ranges of fire intensity that can be encountered in Australia may be gained from a study of figure 74. Extremes of the order of 30 000 kW/m can occur in grass fires; and of the order of 60 000 kW/m in forest fires.

Flame height and flame depth are two factors of great significance to the fire fighter. Both are related to fire intensity. For example, a fire with an intensity of 450 kW/m (towards the upper limit of prescribed burning) has a flame height of 1.2 m and a flame depth of around 2.5 m. It is spreading at 1.3 m/min. A much hotter fire spreading at 13.7 m/min in a 17.5 t/ha fuel type in eucalypts will have a flame height of 15 m and a flame depth of 27 m. A fire in a 25 t/ha fuel type spreading at 30 m/min will be a fully developed crown fire with a flame depth of at least 60 m.



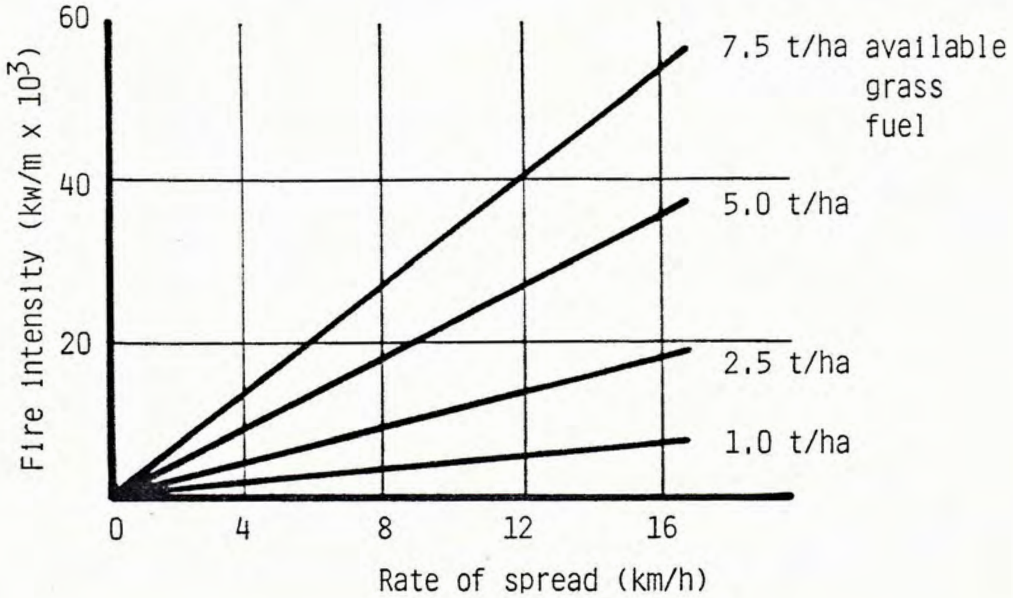


Fig.74: Range of fire intensities for forest fires and grass fires

8.2. SCHEMATIC DIAGRAM OF INTEGRATED FOREST FIRE MANAGEMENT