5

FOREST FIRE BEHAVIOUR

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5.1 General - Forest Fire Behaviour

The first step in every forest fire fighter's training is a knowledge of forest fire behaviour. There is no chance of being successful in the management of suppression activities without the knowledge of how a forest fire behaves.

Fire behaviour can be defined as the manner in which fuels ignite, flames develop, and the fire spreads and exhibits other phenomena.

How and why forest fire spreads is determined by a number of interrelated factors.

In order to predict fire behaviour it must be understood and known:

(i) what causes a fire;
(ii) how it will start;
(iii) will it continue burning;
(iv) in what direction and how fast will it spread;
(v) why will it burn the way it does; and
(vi) how frequently does it burn, and when does it burn.

This knowledge will enable fire fighters and managers to:

(i) develop a more effective and efficient forest fire pre-suppression and suppression plan, helping in the decision of when, where, and how to control a fire;
(ii) work safely; if dangerous situations can be recognised and avoided; and
(iii) train more efficient fire fighters in forest fire control.

5.2 Principles of Combustion

5.2.1 Fire triangle

All fires are the result of a chemical process that occurs when three essential elements

- FUEL, HEAT and OXYGEN -

are brought together in the necessary combination to support combustion. This combination of the three elements of fire is called the:

"FIRE TRIANGLE".

In a forest there is an abundance of fuel and air (oxygen) always present. To complete the triangle (= fire) only an addition of sufficient heat or a source of ignition is required.

If any one of these three elements can be eliminated, the fire can be put out. In forest fuels, the principal inflammable component is carbon. The reaction is very simply expressed : carbon plus oxygen gives carbon dioxide plus energy ($C + 0_2 = C0_2$ + heat energy).

THE FIRE TRIANGLE

The three elements of **the fire triangle** are:

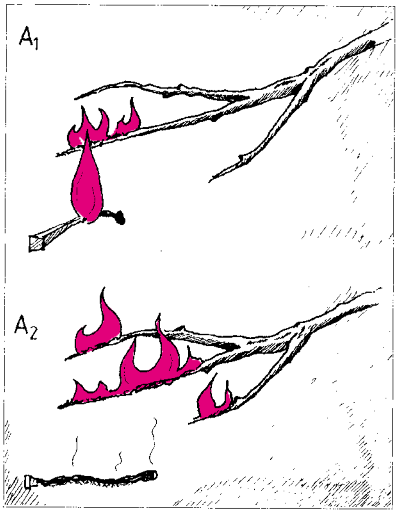
Oxygen - 21 percent of the air is oxygen. A reduction in oxygen to 15 percent extinguishes the fire. This can be done by smothering or covering - usually with sand (soil material) in the case of a wildfire, or swatters, sacks, branches, etc.

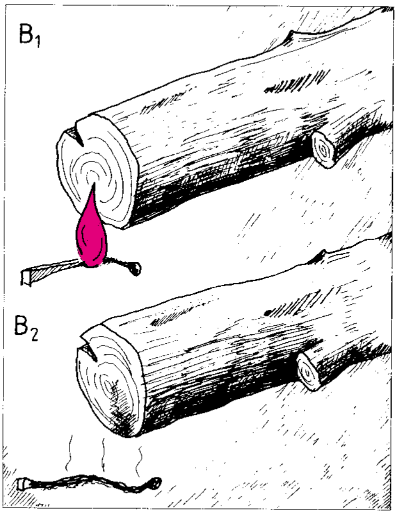
Fuel - wildfires are primarily controlled by working on the fuel side of the fire triangle. This is done by confining the fire to a definite amount of fuel by means of a fire line and natural barriers if they are available. By keeping all fire inside the line it is confined and controlled. The line is usually made by removing the surface fuel with tools or equipment so that the mineral soil is exposed, or by wetting down the width of the line with water.

Heat - in order to start a fire, fuel must be brought to the ignition temperature. If the heat drops below the ignition temperature, the fire goes out. Water is the most effective agent for this reduction of heat. Application of sandy soil also helps to reduce the heat.

5.2.2 Ignition temperature

Ignition temperature may be defined as the temperature of a substance at which it will ignite and continue to burn without any additional heat from another source. If a fuel stops burning when the heat which caused it to burn is removed from it, then the fuel has not reached its ignition temperature. The ignition point, or phase, when rapid combustion takes places varies with the type and condition of the fuel. The ignition temperature ranges from between 220 - 250°C depending on the particular fuel. For example:





A. A match is applied to a small twig. The twig begins to burn and continues burning after the match is taken away from it.

B. A match is held under a dry log. The log begins to burn but stops burning as soon as the match is removed from it. In these two examples it can be seen that one match would raise the temperature of a small twig to its ignition point, but one match could not cause a log to reach its ignition temperature. The size of the fuel in relation to the heat applied is important in determining whether or not the fuel will reach its ignition temperature.

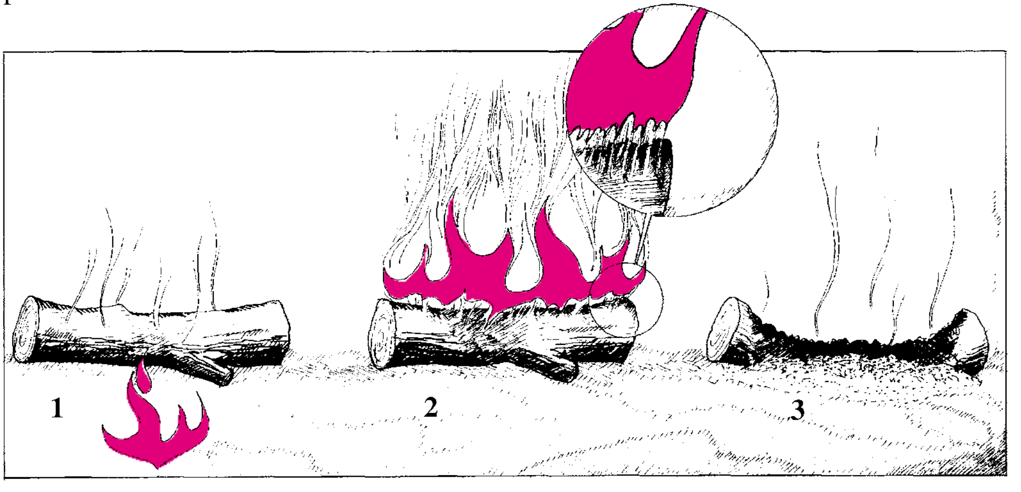
More units of heat must be applied to a large size fuel than to a small size fuel in order to make it reach its ignition temperature. Another factor which determines whether or not a fuel will reach its ignition temperature is the moisture content of the fuel. A wet log will take longer to reach the ignition temperature than a dry log.

Some of the sources of heat which cause forest or grass fires are:

(i) flames (e.g. match);
(ii) embers (e.g. cigar);
(iii) electrical sparks from man made sources;
(iv) lightning; and
(v) friction (forest machines, trains, etc.).

5.2.3 Phases of combustion

Combustion is possible if sufficient heat is present to attain the ignition temperature of the particular fuel.



In forest fires, all fuels undergo the following three phases of burning. The completion of these three phases will only occur if all three elements of the fire triangle are present, and if enough heat is applied.

Phase 1 - Pre-heating

This is the phase where fuels are dried, heated, and partially distilled, but where no flame exists. In this phase the temperature of the fuel is being raised to the ignition point (temperature), which is roughly 220 - 250°C for most wildfire fuels.

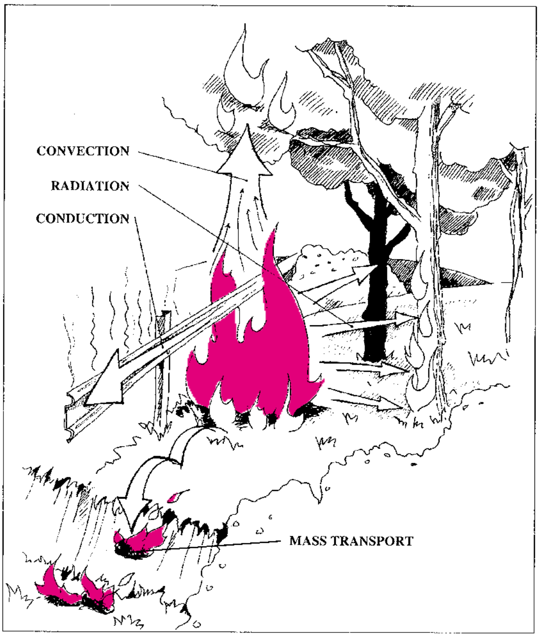
Phase 2 - Fuel breakdown (gaseous phase)

This is the phase where the pre-heated fuel breaks down into two fuels; gases and charcoal. The fuel has been brought to its ignition temperature and if an ignition source is present, flames appear above the fuel. At this phase the gases are burning, but the fuel itself is not yet glowing.

Phase 3 - Combustion (charcoal phase)

This is the third and last phase of burning. Before this phase, the fuel has already been broken down into two fuels, gases and charcoal, by the process of fuel breakdown. During the phase of combustion the gases from the fuel burn off with a flame, which is clearly visible, and the charcoal burns without a flame. The fuel is consumed and ashes are left. Wildfire fuels in this phase can cause spotfires if a wind causes mass transport, or if the burning fuels break apart and roll downhill.

5.2.4 Heat transfer

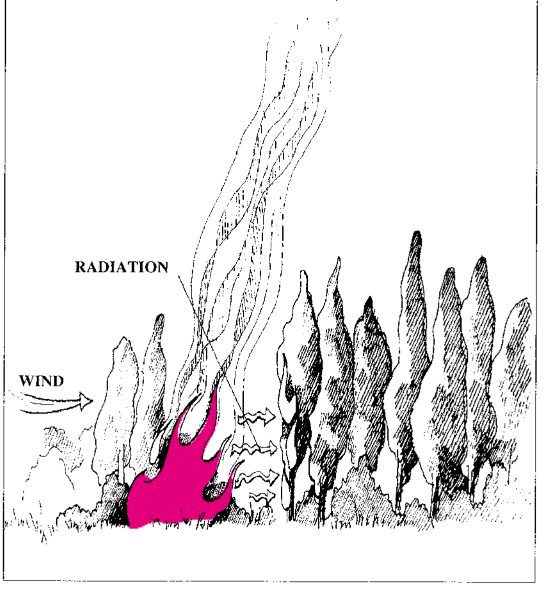


Heat is a form of energy that can be moved or transferred from one substance to another. Heat transfer influences the fire to behave the way it does. Fires spread by different methods of heat transfer.

Four different methods of heat transfer can be discussed:

(i) Radiation.
(ii) Convection.
(iii) Conduction.
(iv) Mass transport.

Radiation is the transfer of heat through space, in any direction, at the speed of light. It does not need the movement of hot air. The intensity of the heat, however, decreases by the square of the distance from the object to the source.



Radiation is the main means by which fuels ahead of a "flame front" are pre-heated. That is, the heat radiated from the flames pre-heats the unburnt fuel to its ignition temperature and causes it to burn.

A large fire (with high flames) will pre-heat and ignite fuels faster than a small one. Since radiation causes the pre-heating of new fuel, it is an important cause of the spreading of surface fires. Radiation may pre-heat fuels across a fuel break and contribute to the fire jumping the fuel break.

Radiation is important to fire behaviour since it:

(i) enables a surface fire to spread; and
(ii) may contribute to a fire jumping a fuel break.

The term **convection** refers to the transfer of heat by the movement of hot air and other heated gases. The smoke rising above a fire is evidence of the upward movement of hot air and gases. A fast rising convection column indicates that the fire is burning intensely.

Convection forms heated air and smoke gases that spread heat in any direction, depending on the movement of the air. In a forest fire, fuels are pre-heated when they come into contact with this hot air and smoke gases. Convection contributes to the spread of fire.

A rising convection column may carry hot embers and fire brands from an existing fire aloft. These heat sources drop back to the ground and may cause spot fires should they land on a suitable fuel.

Convection also causes "torching" and contributes to the start of a crown fire, although this is a rare occurrence in tropical forests.

To summarise, convection is important to fire behaviour because it contributes to:

(i) the spread of fires;
(ii) spot fires;
(iii) torching;
(iv) the starting of crown fires; and
(v) the rapid spread of fires up a slope.

Conduction refers to the transfer of heat within a fuel or from one fuel to another by direct contact. Wood is originally a poor conductor of heat, but metal is a good conductor. Although this method of heat transfer is important in building structures, it has little relation to wildfires.

Mass transport is a principal method of heat transfer in wildfires. It is primarily related to contact and it may be caused by the rolling, or falling, of ignited fuels and embers. Mass transport can occur when burning fuels roll down a slope into a new fuel, or when burning fuels (embers, branches, etc.) drop from above to ignite ground fuels.

Main Factors Influencing Fire Behaviour

There are three main factors which influence fire behaviour:

(i) Fuel.
(ii) Weather.
(iii) Topography.

5.3.1 Fuel

Fuel is any organic material that will ignite and burn, either living or dead, in the ground, on the ground, or in the air. It must be remembered that fuel forms one side of the fire triangle. It is important to be familiar with certain properties and characteristics of the fuel, which can include the:

(i) size of fuel;
(ii) fuel arrangement;
(iii) volume of fuel;
(iv) fuel type and fuel type pattern; and
(v) fuel condition.

In analysing any fire situation, all five of the above fuel factors must be taken into account.

Size of fuel

The size of a fuel is an important factor in determining the rate of combustion of the fuel. If the pieces of fuel have a large surface area exposed per unit volume, the rate of combustion is less than that of small pieces.

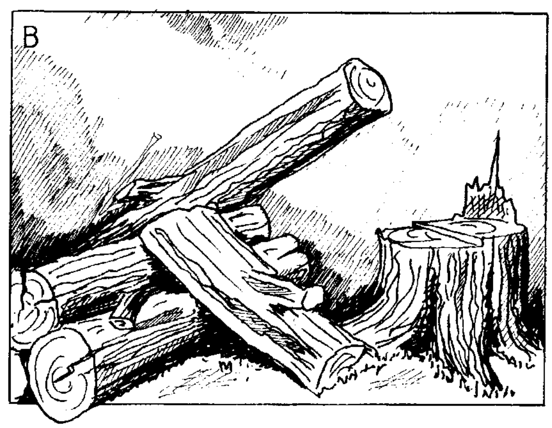
A. Light (fine) fuels are twigs, leaves, grass, small branches, pine needles, etc.

Light fuels pick up moisture quickly and give it off quickly. Light fuels, such as dry grass, need very little heat to reach ignition temperature. Once the grass begins to burn it will burn very quickly.

Therefore, light fuels are referred to as being fast-burning fuels.

B. Heavy (coarse) fuels are large fuels such as logs, stumps, standing trees, etc. In comparison, a heavy fuel takes in moisture slowly and gives it up slowly. Large fuels need much more heat to reach ignition temperature than a light fuel.

Heavy fuels are therefore referred to as being slow-burning fuels. Heavy fuels continue to burn for a much longer time.



FIRE SPREADS FASTER IN FINE FUELS THAN IN HEAVY FUELS.

Fuel arrangement

The type and size of the fuel determines, in part, how a fire burns. The way in which the fuel is arranged also has an important influence on fire behaviour.

To a large extent, fuel arrangement determines the:

(i) rate of fire spread and burning;
(ii) direction of the fire spread;
(iii) rate of evaporation of moisture; and
(iv) rate of oxygen supply for burning.

Fuel arrangement is the relationship of all the combustible materials in the horizontal and vertical planes from mineral soil to the ground layer. The arrangement of fuel affects the rate of evaporation of moisture, the rate of oxygen supply and burning, and the rate and manner in which fire will spread. The arrangement of fuel affects the amount of air that can pass around it.

The horizontal arrangement of individual pieces of fuel affects the rate of the fire spread, and its intensity. Fuels which are far apart burn slowly and the fire spreads slowly from one piece of fuel to another. If the pieces are close together, they will burn with great intensity and the heat produced will cause the fire to spread more rapidly. Fine fuels which are closely arranged, such as grasses, are easily ignited because very little heat is lost by conduction. Each piece is small and more or less independent, thus it will heat up and dry out rapidly.

The vertical arrangement of fuels affects the rate of spread and the type of fire which results. Combustible fuels that are continuous from the ground to the tops of the trees may "torch". That is, they may burn individually from the ground to the tree top (or crown) and may then spread through the tree tops in advance of the surface fire. The continuity and density of the crowns will have a strong bearing on whether a crown fire will continue or drop down to become a surface fire. Where there is a definite separation between the surface fuels and the crowns the possibility of a fire climbing to the tree tops is minimised.

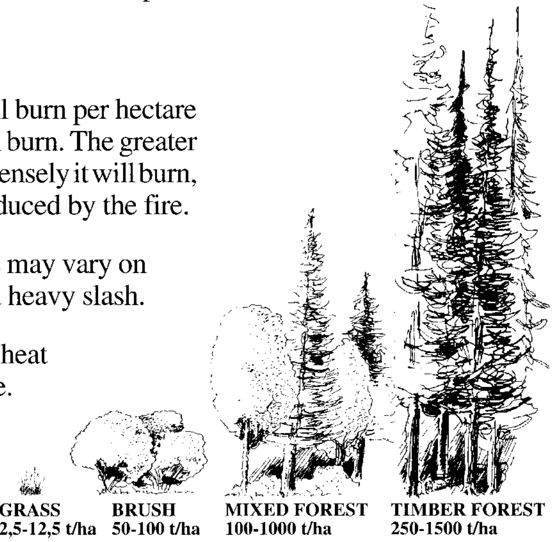
Volume

The volume of the available fuel that will burn per hectare affects the intensity with which a fire will burn. The greater the volume of fuel per hectare the more intensely it will burn, and the greater will be the total heat produced by the fire.

The amount (volume) of fuel per hectare may vary on a wide scale, between a light grass and a heavy slash.

The volume of fuel determines the total heat that can be developed during a given fire.

The total heat volume plays a big part in the spread of the fire.



THE VOLUME OF FUEL REFERS TO THE AMOUNT OF FUEL PER HECTARE

High volumes of fuel usually require more work in line construction than low volumes.

If a fire were burning in a light accumulation of surface fuel it would be relatively easy to control. A fire burning in a heavy accumulation of surface fuel would be fairly hot. This fire would be intense fire, and much more difficult to control.

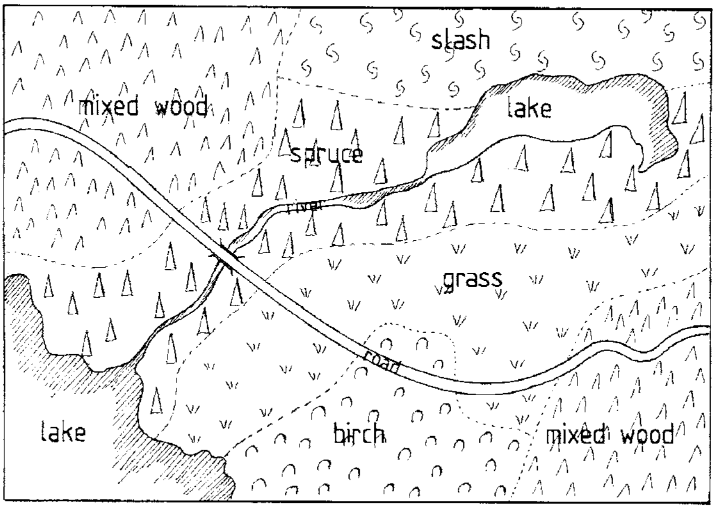
Fuel type and fuel type pattern

Fuel type refers to the general classification of forest cover type, i.e. grass, bush, mixed forest, conifer, hardwood, slash, etc.

Fuel type pattern refers to the arrangement of barriers and the different types of fuel.

Fire spreads more rapidly in certain types than in others, depending on the season.

For example, poplar stands and other hardwoods usually form good barriers, but pine and other conifer barriers seldom do.



The fuel type pattern shows where the different types of fuel and barriers are located in an area.

Fuel condition

Fuel moisture is a prime factor in judging the burning capability of fuel. It is a product of past and present weather events. Forest fuels obtain their moisture from:

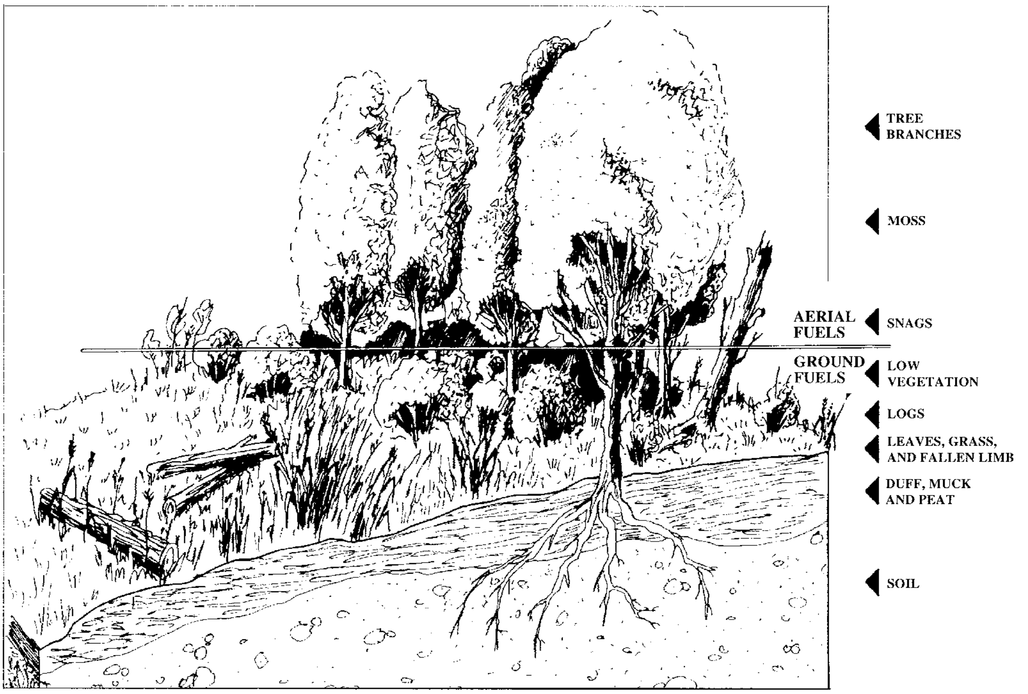
(i) the atmosphere;
(ii) precipitation; and
(iii) the ground.

There is a relationship between the relative humidity and the moisture in fuels. When the relative humidity is high the moisture in forest fuels tends to be high, and when the relative humidity is low the moisture content is low. Precipitation, or rain, has an obvious effect on the moisture content of forest fuels.

When the fuel moisture is high fires are difficult to start, and when the fuel moisture is low fires start easily and spread rapidly. Temperature, humidity, wind, the precipitation season, the time of day, and the topographic location all have either a direct or an indirect bearing on the fuel moisture at a given time. Fuel moisture changes more rapidly in dead fuels than in living fuels.

Ground and aerial fuels

Fuels are classified by location as ground or aerial fuels. Each of these classes is then evaluated for arrangement, size, volume, and moisture content.



Ground fuels are those lying on, immediately above, or in the ground. They may be either dead or living materials, including duff, roots, branches, dead leaves and needles, grass, fine deadwood, logs, slash, brush, and small trees.

Duff is the partially decayed vegetative matter lying on the soil. In a forest it may be several centimetres to one metre deep and it creates the humus soil beneath it. It may be only a light layer of decaying vegetable matter, such as grass. Usually duff is inflammable, but burns slowly. Dead leaves and needles that are loosely arranged and not in contact with the ground are most inflammable. If they are still attached to the branch and freely exposed to the air they are especially inflammable.

With grass, weeds, and maize the key factor is the stage of drying. Succulent green grass is a good fire barrier, but as it gradually dries it becomes increasingly inflammable. Twigs, dead needles, leaves, small branches, bark, and rotting materials are classed as fine deadwood. It is ignited easily and provides the kindling for larger fuels.

Logs, stumps, and large branches are heavy fuels which require long periods of dry conditions before they become highly inflammable. When they do become dry, they can develop very hot fires. Low brush and small trees may either slow down or accelerate the spread of fire, depending on the species and its drying stage.

Peat fires are a hazard in certain areas. Peat contains oxygen and supports slow-burning fires when it becomes dry enough to kindle. It burns down to the depth at which moisture is found.

Aerial fuels consist of tree branches, crowns, snags, and high brush. They are physically separated from the earth and from each other and air can circulate around the fuel particles. They may be green or dead and they form the canopy of the forest or tall brush.

The live needles of evergreen trees are highly inflammable because their arrangement on the branches allows for the free circulation of air and they contain oil and resins susceptible to ignition.

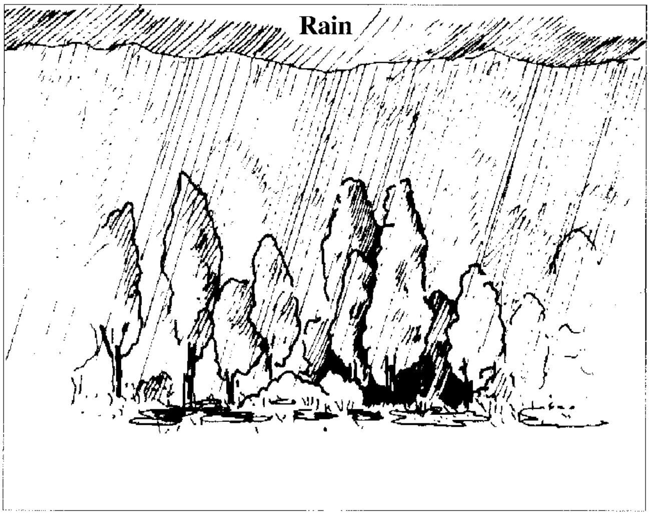
Tree crowns react quickly to the relative humidity, and it is rare for a crown fire to occur with a high relative humidity. Crown fires do not occur unless sufficient ground fuels are underneath to trigger the action or unless the area is close enough to another fuel type that can furnish enough heat to start combustion. There must also be sufficient wind to maintain a crown fire.

In some stands, a sufficient amount of dead stems and branches may be present to allow for a fast spreading crown fire.

5.3.2 Basic weather factors

A true analysis of fire behaviour cannot be made on the basis of one weather factor alone. Actual fire behaviour is the result of many factors acting together in various ways. The basic weather factors which we should take into account in wildfires are:

(i) precipitation;
(ii) wind;
(iii) temperature; and
(iv) relative humidity.



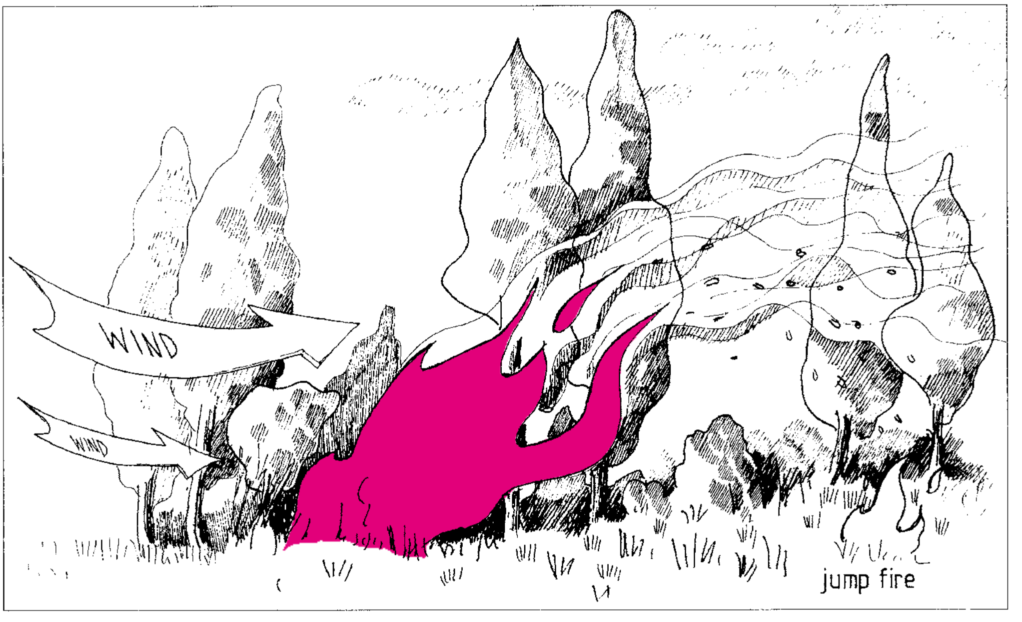
Precipitation in the form of rain, dew, or heavy fog must be taken into account. All these factors may be referred to as precipitation.

Like relative humidity, rain influences the moisture content of the fuels. The large or heavy fuels are more likely to hold their moisture content longer.

Suppose that two days ago, 10-20 mm of rain fell on the region. Humidity is now 30% and wind speed is high. In the case of a fire, the fine (light) fuels will most likely burn completely. Heavy fuels may char but will not burn very easily with a flame. The fire will die down at night when the relative humidity rises and the wind speed drops.

This is because the recent rainfall contributed to the difference in the forest fire behaviour between the heavy and light fuels. Fine fuels lose their moisture more rapidly. The heavy fuel will not burn easily because it contains a lot of moisture. The increased relative humidity at night increases the moisture content of the fine fuels, thus causing the fire to die down. This is also the reason why very few fires occur early in the morning.

Wind is a major factor in determining fire behaviour. It affects the rate at which a fuel dries, it increases the supply of oxygen, influences the pre-heating of fuels, and may carry burning brands or embers forward, causing jump fires or spot fires. The pressure of heavy wind may bend the convection column towards the ground, permitting rapid pre-heating and drying of the fuels ahead of the fire and allowing the fire to spread rapidly in that direction. Wind also influences the moisture content of the fuel (fuel condition). If the wind speed is high, a forest fuel will dry out much faster than it would if the speed were low. The principal result of wind is that it influences both the rate and the direction of fire spread.



Wind speed is at its maximum during the day, or in the afternoon, and will drop down in the evening. That is why fire fighting is most difficult during daytime, as a fire can spread very quickly. It is always safe to assume that if the wind speed doubles, the speed of a fire's spread in the direction of the wind will more than double.

In addition to carrying fire brands to a new fuel where they can start spot fires, the wind has two other important and direct effects on fire behaviour, it:

(i) influences direction of spread; and
(ii) influences rate of spread.

This is because the wind bends the convection column and the flame from the fire and increases the oxygen supply.

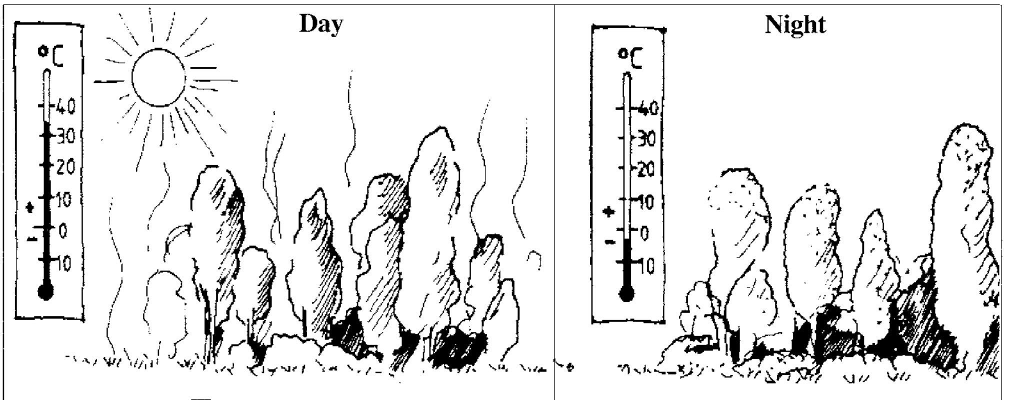
Wind can carry burning embers across a narrow fuel break, thereby causing the fire to jump the fuel break. This is not however the only way that a surface fire can jump a narrow fuel break. If the fuel is relatively dry it could occur due to radiation, to spot fires, or to direct contact of flames with the fuel on the other side if the wind bends the flames and convection column.

The fire fighter should be constantly aware of the winds in the vicinity of fire.

If an anemometer is not available, wind velocity in the forest can be estimated by observing the surroundings, as shown in the following table.

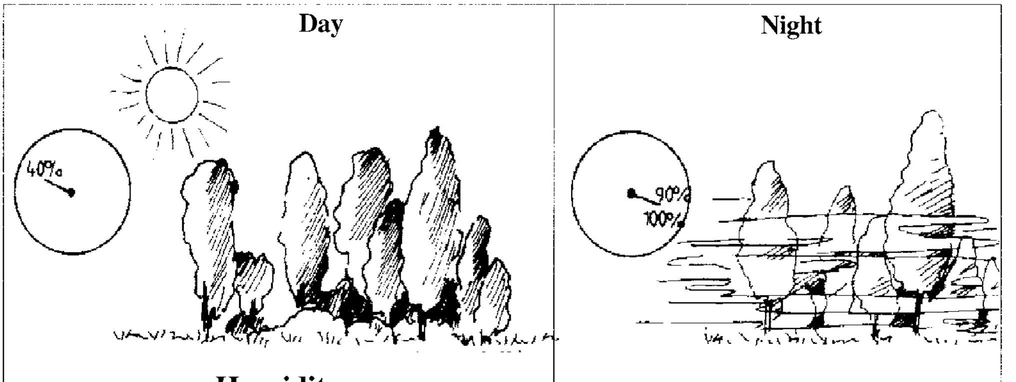
Modified Beaufort scale for estimating wind speed

Wind class	Range of speed m/s	Nomenclature
1	0 - 1.5	**Very light** - smoke rises nearly vertically. Leaves of quaking aspen in constant motion; small branches of bushes sway; slender branchlets and twigs of trees move gently; tall grasses and reeds sway and bend with wind; wind vane barely moves.
2	1.5 - 3	**Light** - trees of pole size in the open sway gently; wind felt distinctly on face; loose scraps of paper move; wind flutters small flags.
3	3 - 5	**Gentle breeze** - trees of pole size in open sway very noticeably; large branches of pole size trees in the open toss; tops of trees in dense stands sway; wind extends small flags; a few crested waves form on lakes.
4	5 - 8	**Moderate breeze** - trees of pole size in open sway violently; whole trees in dense stands sway noticeably; dust is raised in the road.
5	8 - 11	**Fresh** - branchlets are broken from trees; inconvenience is felt in walking against wind.
6	11 - 14	**Strong** - tree damage increases with occasional breaking of exposed tops and branches; progress impeded when walking against wind; light structural damage to buildings.
7	14 - 17	**Moderate gale** - severe damage to tree tops; very difficult to walk into wind; significant structural damage occurs.
8	17	**Fresh gale** - intense stress on all exposed objects, vegetation, buildings; canopy offers virtually no protection; wind flow is systematic in disturbing everything in its path.



Temperature

Temperature is the third basic weather factor which should be taken into account. The temperature influences the condition of forest fuel, as its main effect is to dry the fuel. Temperature also has a very direct affect upon the fire fighters themselves. It is more uncomfortable and tiring to fight fires in excessive heat.



Humidity

Relative humidity is an indicator of the percentage saturation of the air at the prevailing temperature. Therefore, if the relative humidity is high it means there is a high amount of moisture in the air. The amount of moisture in the air affects the amount that is in the fuel.

Wet fuels, and most green fuels, do not burn freely. If, for instance, the relative humidity is 80%, the fuel is less inflammable than it would be if the relative humidity were, for instance, 20%.

Some rules of thumb

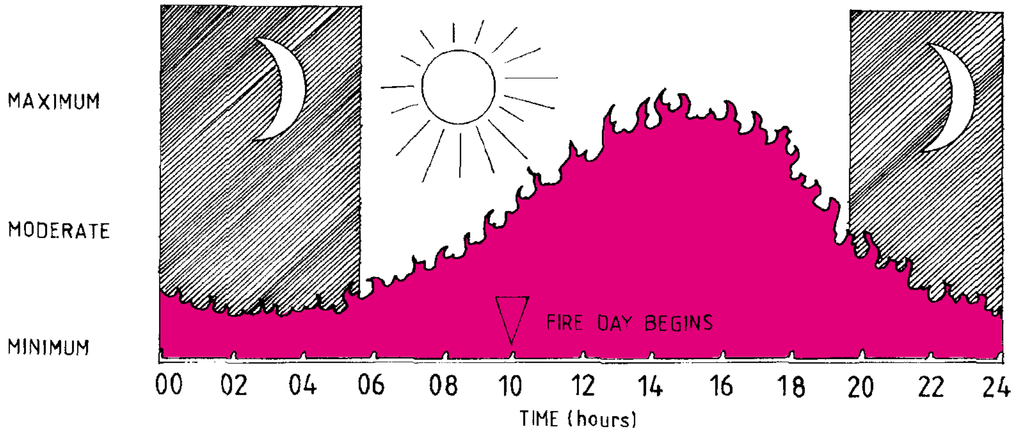
(i) For every 20°C decrease in temperature the relative humidity is doubled, and for every 20°C increase in temperature the relative humidity is lowered by one half.
(ii) Around 30 % relative humidity is the ordinary danger point for wildfires.
(iii) When the relative humidity is above 30 % fires are not too difficult to handle, but below 30 % wildfires are generally more difficult to control.
(iv) Relative humidity varies according to the time of day, it is highest in the morning, around dawn, and lowest in the afternoon.

5.3.3 The changing influences of weather

Two natural conditions influence the weather which, in turn, influences fire behaviour. These are:

(i) time of day; and
(ii) seasonal changes.

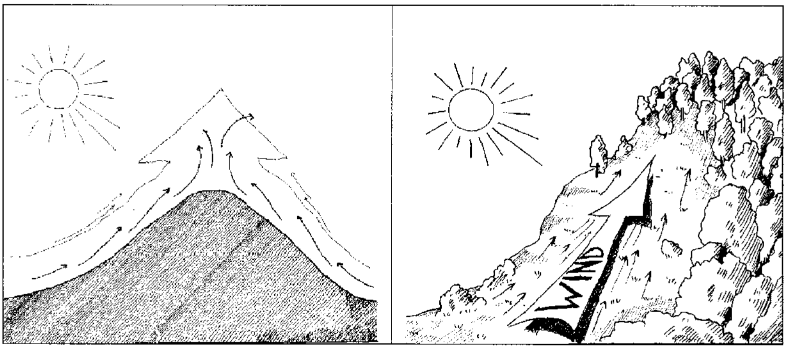
Time of Day



The same fire may burn very differently at different times of the day. The time of day influences wind, relative humidity, and temperature. We have seen that the greatest fire danger exists when the wind speed is high, relative humidity is low, and the temperature is high.

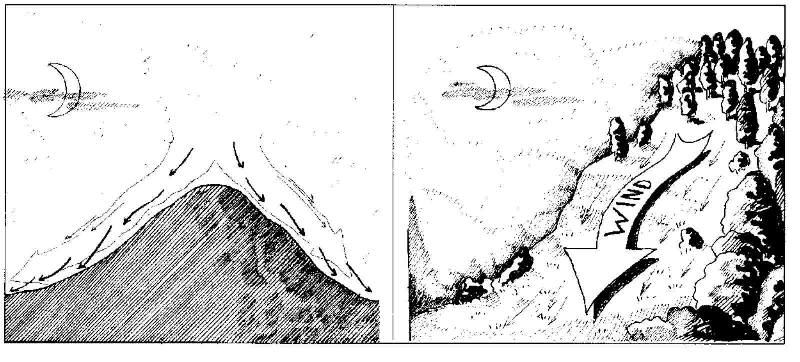
The greatest fire danger during the day is roughly between 10 a.m. and 6 p.m.

The wind speed is high, relative humidity is low and the temperature is high.



The lowest fire danger exists between about 2 a.m. and 6 a.m.

The relative humidity is high, the wind speed is low and the temperature is low.



Seasonal changes

The natural cycle of the season also influences fire behaviour. Each season has a different effect on the available moisture and the condition of forest fuels.

In a tropical forest, the fuels dry out during the dry season and are green during the rainy season. Dead fuels are more inflammable than green ones and thus form a high hazard condition. The season affects the drying time of the fuels, the temperature, and the relative humidity of the air.

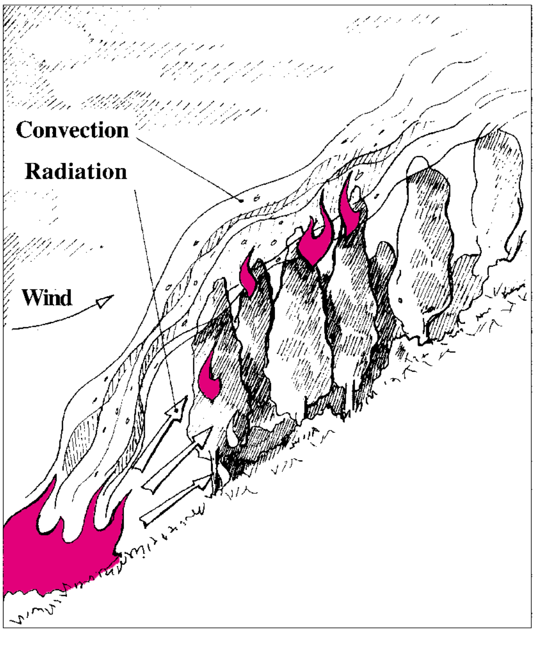
5.3.4 Topography

A knowledge of topography is important to understanding fire behaviour. Topography is the third major factor which determines how a fire will burn, where it will burn, and why it burns the way it does.

The term "topography" refers to the physical features of the earth's surface. Topographical information tells us whether the land is hilly or flat, whether there is a presence or absence of water (lakes, dams, rivers, streams, etc.), where there are cliffs, swamps, and so on.

Slope

Slope has a great influence on fire behaviour. A fire will burn much faster uphill than it will on a level surface or downhill. When the ground is sloping the convection column and the flame front is much closer to a new fuel. The convection column and the radiation of heat from the spread of the fire downhill is much slower than on a flat surface, but an uphill fire will always spread faster than on flat land. The speed of the fire spreading uphill will depend on the degree of the slope. The spreading is faster as the hill gets steeper.



The slope influences fire behaviour in two ways:

(i) the rate of fire spread; and
(ii) the direction of fire spread.

Natural barriers

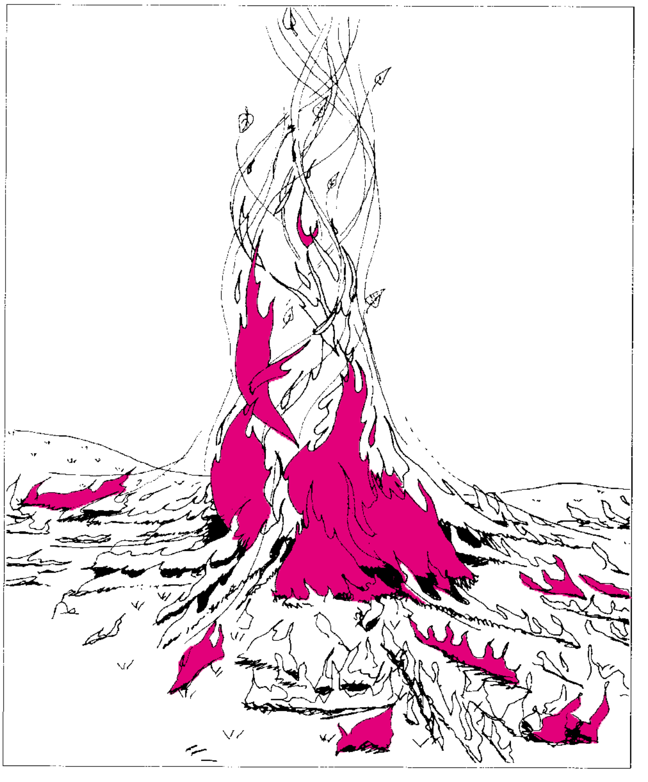
Topography can be a natural barrier, and / or a hindrance to the fire. For example, a fire burning at ground level spreads to the shores of a large lake. The wind blows towards the lake. When the fire reaches the lake it will probably burn itself out.

As well as lakes, dams and rivers, roads, cliffs, and swamps may serve as effective natural fire barriers. The presence or absence of natural barriers is therefore an important topographical factor.

5.4 Rate of Spread

The rate of spread in forest fires is variable, and depends on the following interacting factors:

(i) fuel quantity;
(ii) fuel moisture content;
(iii) fuel type and dispersal;
(iv) wind direction and speed;
(v) slope of ground; and
(vi) weather conditions.



5.5 Torching

When the weather is dry enough for individual tree crowns to be easily ignited, but there is not sufficient wind to sustain a crown fire, the resulting phenomenon is called torching. Torching is always a danger signal to the firefighters as it means that any increase in wind may result in a crown fire, and also because needle clusters, small pieces of bark, and other material may be lifted above the burning tree and cause spot fires some distance away.

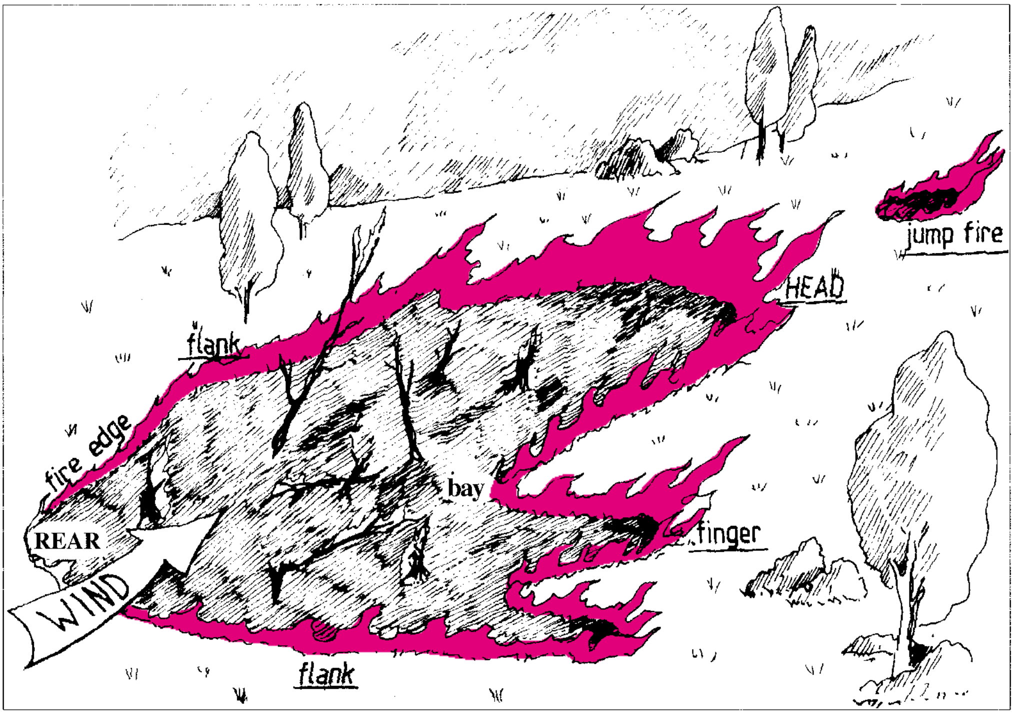
5.6 Large Fire Behaviour

On average, five to ten percent of all forest fires grow to a large size. These are the fires that cause the most damage, often reaching catastrophic proportions. Many large fires are the result of adverse conditions of weather and topography. "Adverse" may also include conditions too tough for the strength of the initial attack forces for the particular fire. The initial attack force is not usually strong enough to combat worse than average conditions.

The transition from a small fire to a large fire regime is typically sudden, sometimes only 15-30 minutes. This transition to convective dominance is marked by an increase in fire intensity (particularly by fuels burning well inside the fire edge), an increase in draught, the production of black smoke indicating incomplete combustion of the flame gases, and often an increase in the amount and distance of spot fires.

A blow-up is a sudden increase in fire intensity and an increase in the rate of spread, or both, that probably multiplies the existing control plans. Blow-ups are often the result of violent convection, and they may have some characteristics of a firestorm . When fires have reached extreme fire behaviour the combustion chain has usually become so strong that it cannot be broken by conventional fire-fighting methods. It is then necessary to plan the control for the changing conditions, and to try to anticipate the place and time at which the changes will occur. In the meantime, only part of the perimeter may be tenable for the fire control forces.

5.7 Parts of a Forest Fire



Head -The head is the most rapidly spreading part of a fire's perimeter. It is usually driven by the wind, the uphill effects of a slope, or is determined by the fuel arrangement or the fuel type pattern. The head often burns very intensely, and may move forward at a dangerously fast rate.

Finger - A finger is a long narrow tongue of fire projecting from the main fire body. Each finger has its individual "head" and "flanks". This fire pattern usually results from the fuel and slope conditions.

Bay - That part of a fire edge usually between two or more fingers, where fire spread is slower because of the fuel or slope conditions.

Rear - That part of the fire edge opposite to the fastest spreading side is referred to as the rear of the fire. It usually burns with a slow rate of spread, and is easier to handle than other parts of the fire.

Flanks - The sides, or parts, of the fire's perimeter roughly parallel to the main direction of spread are called the flanks. They are designated left or right as viewed facing the head of the fire from the rear. The flanks do not generally burn as intensely, nor spread as rapidly, as the head.

The edge - The fire edge is the boundary of a fire at any given moment. It can be active, burning with varying intensity, or completely extinguished. The fire edge must not be confused with a fire line, which is a natural or constructed line along which fire fighters undertake control action.

Other terms

Other terms commonly used to describe the conditions of a forest fire are "hot spot", "smudge", and "jump fire". Their definitions are as follows:

Hot spot - A very active part of a fire's edge is referred to as a hot spot. The fire burns more intensely and spreads more rapidly than the adjacent section of the fire's edge. It may constitute a local threat to fire line construction efforts.

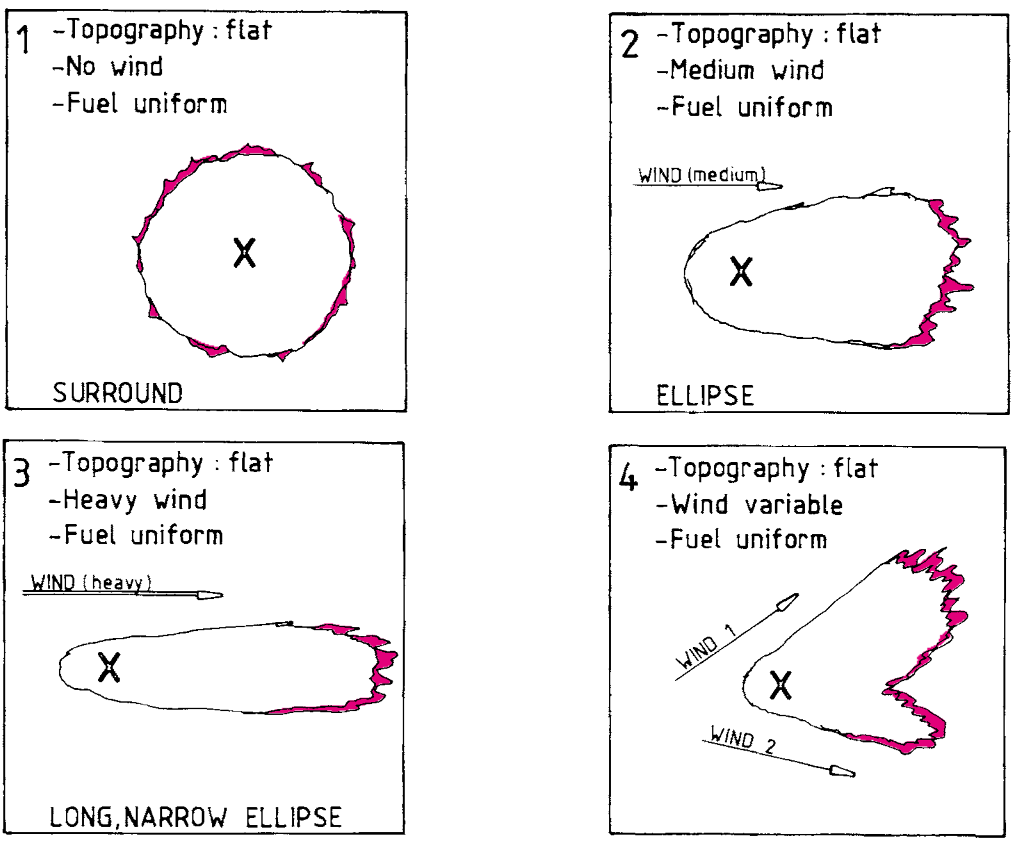
Smudge - A spot in a fire, or along a fire's perimeter, which has not yet been extinguished, and which is producing smoke. A term commonly used during the patrol stage of a fire.

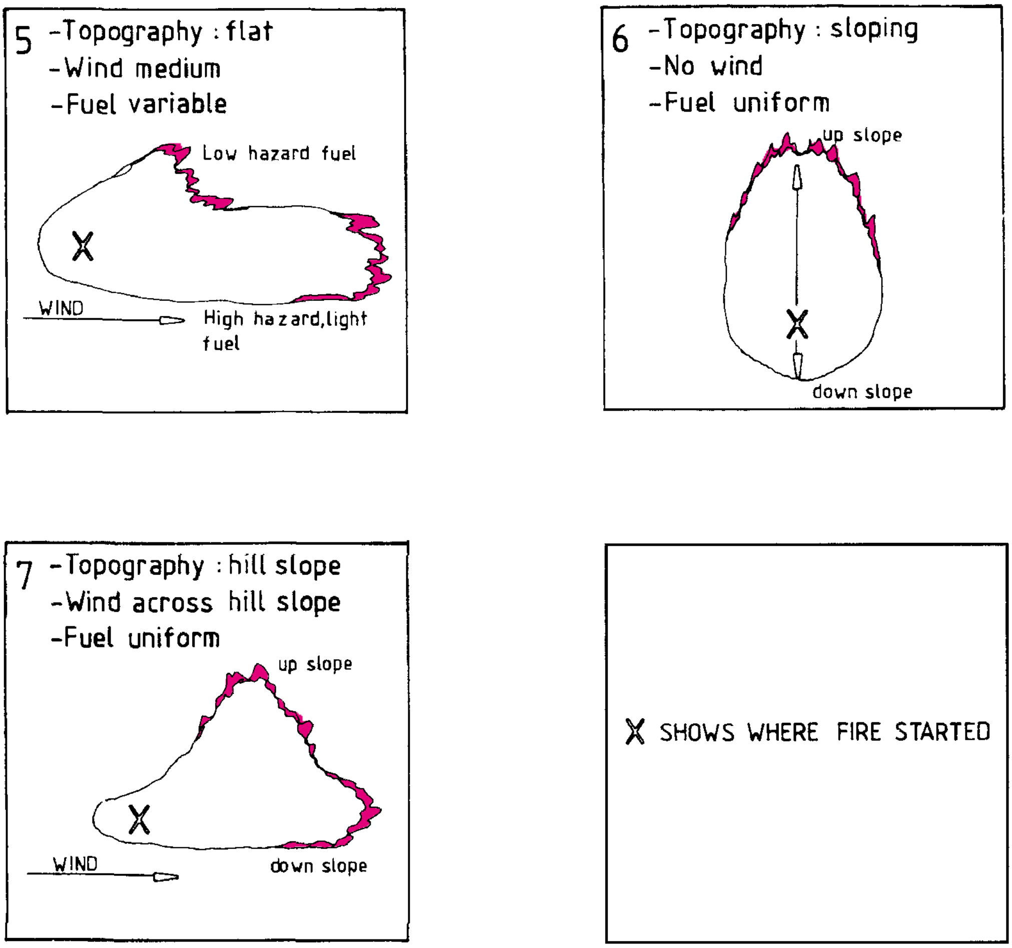
Jump fire - Jump fires occur in advance of the main fire and are started by burning sparks or embers carried from the main fire by air currents. They are also often referred to as spot fires. When a fire jumps immediately across an established fire line the new fire may also be referred to as a jump fire.

5.8 Form of Forest Fires

The factors which influence the form of a forest fire are:

(i) wind, especially the speed of the wind;
(ii) differences in fuel; and
(iii) topography.





5.9 Types of Fire

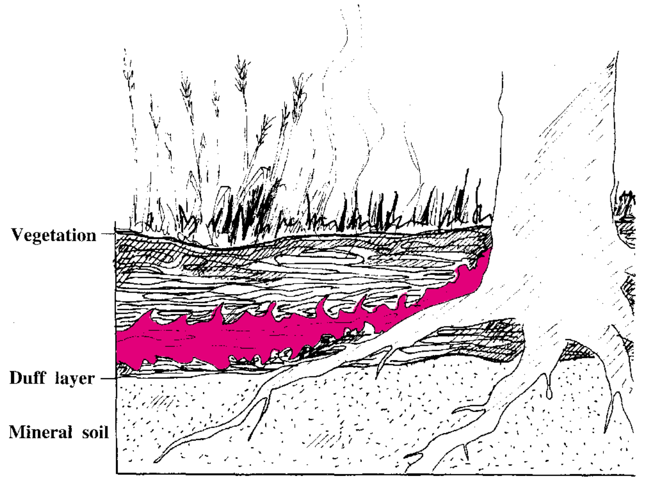
There are three fuel layers in the forest: the sub-surface, surface, and crown .

A forest fire can burn in one or any combination of these layers. However, most fires occur and burn in the surface fuel. Occasionally, surface fires, burning intensely, will spread to the crowns of the trees. Here, the fire will travel through the tree tops at a high rate of spread but will eventually return to the surface fuel layer. Under certain circumstances, the fire will burn beneath the surface fuels in the sub-surface layer. Here it can lie dormant, burning slowly, waiting to be fanned once again into a surface fire and, from there, leaping upwards to become a fast moving crown fire under favourable fuel and weather conditions.

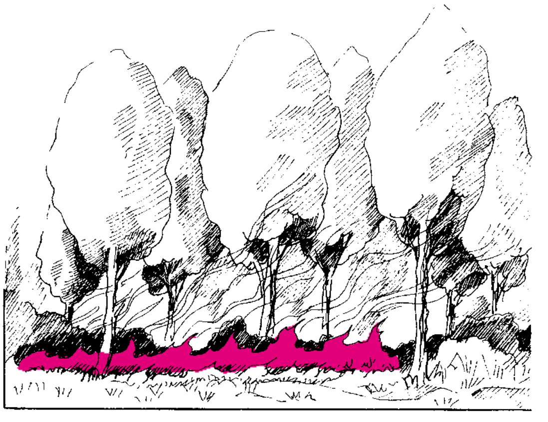
In this respect, the three main types of forest fires encountered are:

(i) sub-surface fires;
(ii) surface fires; and
(iii) crown fires.

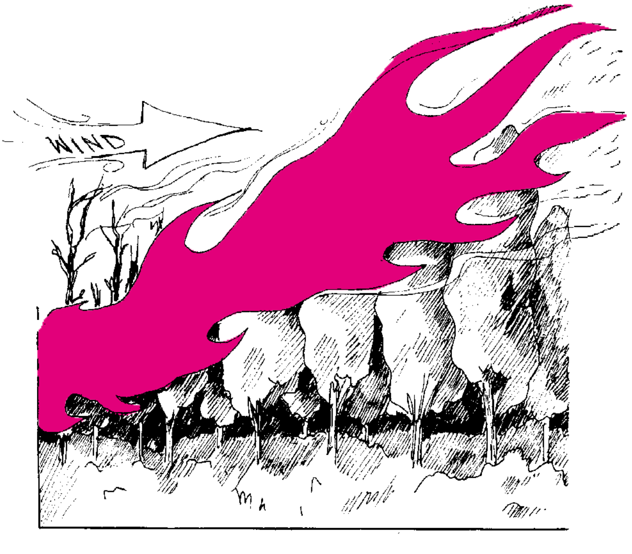
A sub-surface fire burns in the organic material under the surface litter and, by itself, will spread slowly. The depth to which it burns will vary with the depth of the decomposed and partially decomposed vegetation, and with the drought conditions. It may be from several centimetres to one metre deep. The sub-surface fire can present control problems because of the difficulty in locating the fire's edge and extinguishing it.



A surface fire is a fire which burns in the fuel on the surface of the ground. This category would include burning slash, brush, grass and surface litter (twigs, dry leaves, needles, and other undecomposed material), or anything which burns on the surface of the ground.



A crown fire develops from a surface fire where the type, volume, and vertical arrangement of fuels will carry the fire and gases from the surface into the crown fuel layer. Such an arrangement of fuels presents a "stepladder" effect. The crown fire burns independently of fire burning on the surface and advances from tree top to tree top with the leading edge outrunning the surface fire below. The crown fire usually occurs in conifer stands with a continuous crown cover. Fires burning in the crown layer are extremely difficult to control and spread quite rapidly.



However, in tropical forest, there is a very rare chance of a crown fire taking place. Crown fires are an indication of explosive fire conditions. A crown fire may start in the following manner:

- Currents of rising hot air and other gases from a surface fire produce a convection column.

- If this convection column touches the crowns, it will pre-heat them.

- The convention column may also carry burning leaves and branches up to the pre-heated crowns, setting them on fire.

- Once the crown of one tree begins to burn, it may set the crowns of trees next to it on fire. A wind will cause the spread of fire from crown to crown and the crown fire will spread ahead independently of the surface fire below.

5.10 Classification of Fires

Small fires

A "small" fire is one that has not yet built up to serious proportions of intensity and spread. It can be controlled with the forces of hand by initial or direct attack. Generally, small fires have a size from a few acres to ten hectares. Small fires are normally only surface fires.

Medium fires

Medium fires are of serious intensity, depending on the fire fuel and weather conditions. They can burn both as a surface and a crown fire. Suppression tactics can be by direct or indirect attack. A medium fire is about 40 hectares to 100 hectares in size.

Large fires

Five to ten percent of all wildfires in a given area grow to a large size. These are the fires that do the most damage, often reaching catastrophic proportions. Many large fires are a result of adverse conditions of weather and topography. In large fires, the size, distribution, and arrangement of the fuel particles are relatively unimportant, it is the total fuel volume that is important. The fighting tactic for large fires is mostly indirect, because there is no chance to make a direct attack.

5.11 Fire Behaviour Rules of Thumb

Both the rate of spread and the flame height will vary linearly with fuel loading in the same fuel type. For example, when fuel loading doubles, the rate of spread and flames will also double. This rule is strictly accurate only in fuelbeds that are near their optimum packing ratio and in which the degree of compaction is not greatly affected by loading.

For very fine fuels such as grasses and reeds the rate of spread increases more rapidly in relation to loading. For example, the spread rate triples when loading doubles, whereas in very large fuels or densely packed fuelbeds the spread rate is little affected by loading.

Fuel moisture content

At a fuel moisture content below 5 percent, fires in fine and large fuels tend to spread at an equal rate. At a fuel moisture content between 5 and 15 percent, fires in fine fuels spread more rapidly than those in large fuels. At a fuel moisture content above 15 percent, fires in heavy fuels will continue to burn and spread, whereas those in fine fuels will extinguish themselves.

Wind

The rate of spread will double for each 4 metre per second increase in the wind speed. This rule is valid for fires in loosely compacted surface litter. Grass fires increase their rates of spread faster than this, particularly at higher wind speeds, whereas fires in heavy or compacted fuel are less affected.

Slope

(i) The rate of spread doubles at 10 degrees increase in slope.
(ii) The rate of spread doubles again at 15 degrees increase in slope up to 30 degrees and for every 10 degrees thereafter.
(iii) The rate of spread can increase ten fold on slopes above 35 degrees.

Actually, the effect of the slope on the fire spread is a function of the packing ratio of the fuelbed. Consequently, fires in loosely packed fuels such as grass are affected more than those in dense duff.