Rural Firefighting

Study Guide

Vegetation Fire Environment

RFVFE1

Status of this Document

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Contents

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Study Guide Introduction

Overview

Welcome to the Vegetation Fire Environment, supporting unit standard 14564, Demonstrate Knowledge of the Fire Environment on Vegetation Fire Behaviour version 4. Information on demonstrating knowledge of vegetation fires is not covered in this study guide but is included in 3285 Working Safely at Vegetation Fires.

In this course, you will learn the basic level awareness about the effects of the fire environment factors on vegetation fire behaviour. This will enable you to manage a crew at a vegetation fire incident effectively and safely. It will also help you to make informed decisions about wildfire control and prescribed burning.

Course objectives

The general objective for this course is to review the vegetation fire environment and its influences on fire behaviour.

Theory

There are four theory sections comprising the fire environment:

- topography
- fuels
- weather
- combined effects of the fire environment.

There is an accompanying workbook with exercises on the subject matter. The study guide and workbook are taught by distance education.

How this is assessed

There is a written assessment for this course. You will be assessed on the theory outlined in this study guide.

Additional information

For more information on the Fire Weather Index (FWI) System refer to the Student Guide for Unit Standard 14556 - Apply Fire Weather Index (FWI) System Data for Fire Preparedness Measures.

For a comprehensive set of definitions see the Rural Fire Management Glossary of Terms at www.nrfa.org.nz.

Vegetation Fire Environment

Section objective

The general objective for this section is to describe the vegetation fire environment and its influences on fire behaviour.

Section 1: Overview

Fire environment definition

The Glossary of New Zealand Rural Fire Management defines the fire environment as:

'*The surrounding conditions, influences and modifying forces of topography, fuel and fire weather that determine fire behaviour'*.

The fire environment describes the conditions surrounding a fire that determine the way the fire will behave.

The fire environment factors of topography, fuel and weather interact in many ways to determine fire behaviour, and it is important to consider the theory of the science of fire behaviour together with local knowledge and experience.

It is essential we learn to predict fire behaviour for safe, effective and efficient fire control.

This means we need to understand how fire interacts with its environment.

Components

The components of the fire environment are:

- topography
- fuel
- weather.

The way these three components interact with each other determines the fire environment for a particular area.

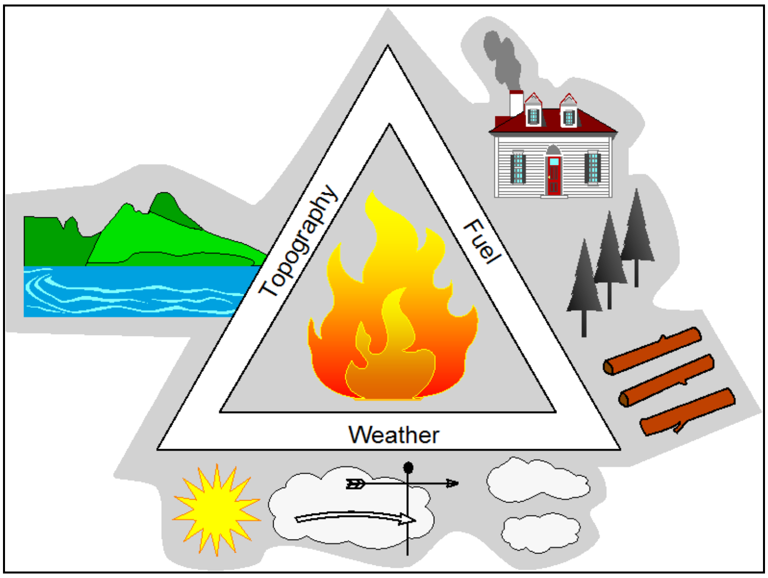


Figure 1 – The fire environment triangle (after Countryman 1972).

Topography

Topography can vary significantly over an area, but changes very slowly over time.

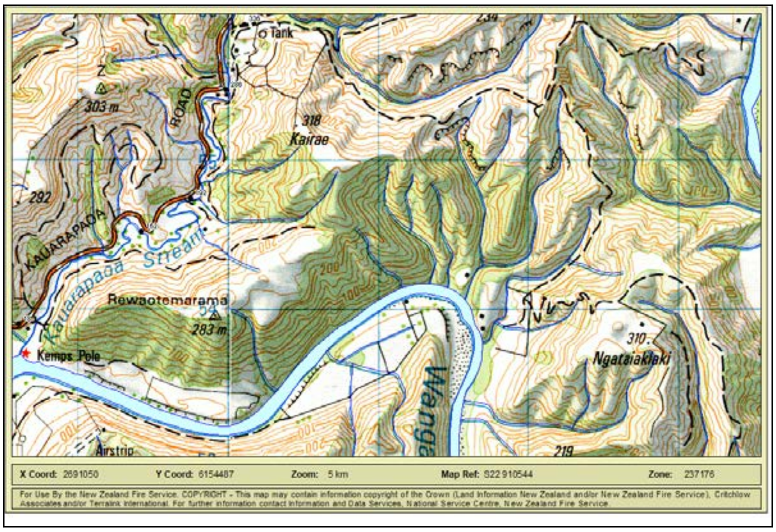


Figure 1.1 – Topography

Fuel

Fuel components can vary over an area, but also over time. For example, the moisture content of dead fuels changes due to the effect of weather conditions. Also as vegetation grows (e.g. plantation forest fuels) the fuel types and properties can change.

Figure 1.2 – Fuel

Weather

The weather is the most variable component, changing rapidly over both area and time.

Fire's effect on the environment

Fire is considered a local heat source. As such, it influences and modifies the fire environment. The intensity and convection column (smoke) created by the fire can dominate the environment. The extent of the fire's influence varies with fire intensity. For example, a very large or intense fire may over-ride its environment, resulting in unpredictable/erratic fire behaviour.

Environment's effect on fire

The environment in which the fire is burning changes over time. Most changes in fire behaviour occur as the fire moves over the terrain, and moves from one fuel type to another as time passes. Abrupt changes can occur when a fire moves vertically from one fuel layer to another, such as when a surface fire escalates into forest crowns. Also when it moves from one type of vegetation to another, for example, from grass into gorse. Changes in weather conditions can also affect how a fire is burning.

Predictions

Fire behaviour is the interaction of the environment components with each other and with the fire. Since fire behaviour varies according to the environment, it is not an exact science. Firefighters can acquire sufficient skill in predicting fire behaviour to allow safe, effective and efficient control and use of fire.

Experience and training in relation to fire behaviour and the fire environment will develop this skill. This allows us to determine:

- how to fight fire safely
- where to attack the fire
- what tools will be effective
- when to request more resources
- when to pull back for SAFETY.

Fuel condition

Fuel condition refers to how well a fuel usually burns; this depends on the fuel type and the environmental conditions. It refers to the; 'dead to live ratio' or 'degree of curing' which describes to the amount of dead fuel present. In forest fuels, the state of green leaves or needles and slash fuels changes to a drier, more flammable state as these fuel die or 'cure' to become red/brown in colour.

The same happens in grasses and other plants which have a seasonal cycle of curing as the vegetation dies off through summer. Sometimes the term fuel condition may also refer to the state of decomposition of larger woody fuels, which can undergo a change from a 'solid' or 'sound' condition to being rotten as they decay over time.

Section 2: Topography

Definition

Topography is the shape and orientation of the land surface. It is the most static of the three major factors that influence fire behaviour.

Topography changes very slowly over time, but can change rapidly over an area.

Influences

Topography influences:

- fuel characteristics such as type or structure
- weather micro-climates and resulting fuel moisture contents
- the direction and speed at which a fire may spread
- the general behaviour of a fire.

Factors

To predict fire behaviour, we need to consider the following factors in relation to topography:

- elevation
- slope
- aspect
- shape of surrounding terrain
- barriers to fire spread.

For practical purposes we'll consider each factor separately, though each is constantly influenced by the others.

Risks for firefighters

There are risks for firefighters associated with different topography. Working:

- uphill of the fire may cause exposure to smoke or being run over by the fire due to faster upslope rate of spread (ROS)
- on a hill side may result in unstable footing or being hit by dislodged material
- in rugged terrain may hinder ease of access
- in rugged terrain may reduce situational awareness since the firefighter may not be able to see the fire
- in unfamiliar territory could have unknown dangers such as mine shafts or sink holes.

Effects on fire behaviour summary

Topography has numerous direct and indirect influences on fire behaviour:

- elevation influences the local climate and hence fuel type and condition, and wind exposure
- slope influences the rate of spread and intensity of fire
- aspect influences the fuel condition
- shape of terrain influences the direction, rate of spread and intensity of a fire
- barriers to fire spread can contribute to restricting the spread of a fire.

Elevation

Effect

Elevation influences the general climate of an area and the vegetation types of an area.

We measure elevation (or altitude) in metres above sea level and consider in relation to the surrounding country.

Influences

Generally, temperature decreases with elevation and relative humidity (RH) increases.

Solar heating may influence the daily air flow between mountain ranges and valley floors. During a hot, calm day warm air rises, causing upslope draughts. If this air is heated rapidly, the upslope draught can cause air turbulence and whirlwinds. At night the airflow generally reverses, bringing cooler air back downslope to the lower lying areas.

Higher elevations may be more exposed to the prevailing wind whereas lower elevations may be more sheltered. Wind strength can increase considerably as the prevailing airflow is forced up and over, between or around elevated terrain.

Rainfall will be greater on the windward side of elevated terrain.

Vegetation growth and decomposition is generally slower at higher elevations. Colder temperatures also lead to more dead fuel (frost covering) at higher elevations. This leaves a higher than normal proportion of dead fuels with slower drying rates of fuels due to cooler conditions.

Elevation influences the micro-climate and hence fuel type and condition.

Figure 2.1 – Elevation and vegetation

Slope

Definition

Slope is the degree to which a surface tends upwards or downwards.

Gradient is the degree to which a surface departs from the horizontal.

Measurement

For fire behaviour purposes, slope is usually measured in degrees from the horizontal. It can be assessed visually, measured using a clinometer or determined from a topographical map.

The distance between the elevation contour lines indicates the steepness of the slope.

On the map, the closer the contour lines are together the steeper the slope. Contours are usually 20 metres apart on a 1:50,000 topographical map.

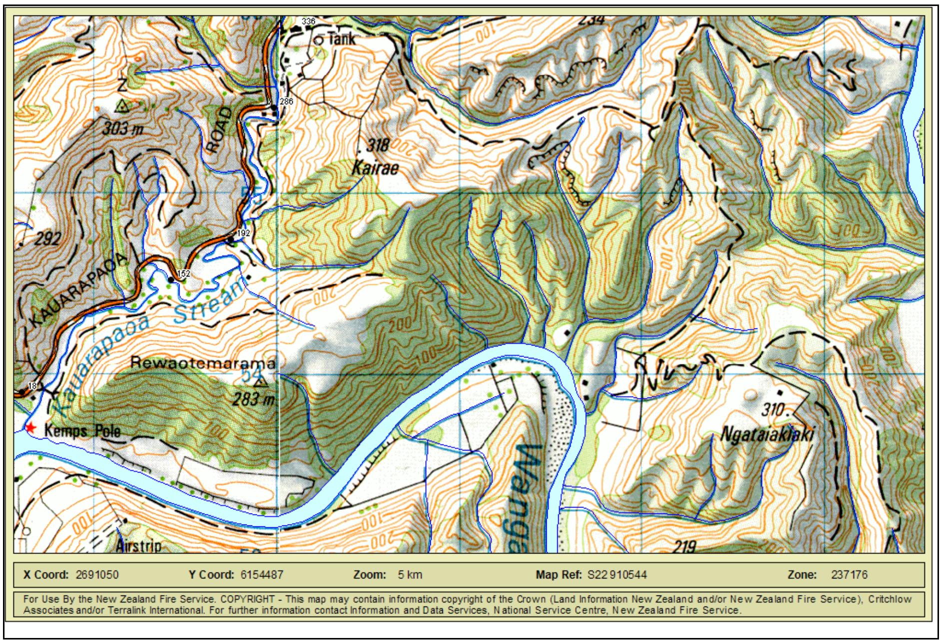


Figure 2.2 – Topographical map

Steepness

Slope steepness affects the rate of fire spread and fire intensity. Fire burns more rapidly and intensely upslope, than on level ground.

The upslope effect is similar to that of wind reducing the angle between the flames and unburnt fuel ahead of the fire. This increases the rate of radiant and convective pre-heating of those fuels, which increases the rate of spread (ROS) and therefore the level of fire intensity.

Steep slope

The steeper the slope the more likely a fire will burn upward in a narrow, elliptical shape, with a high intensity head fire.

The rapid movement of the fire may cause strong in-draughts on the flanks.

This increases the rate of heating of unburnt fuels ahead of the flame fronts.

Flames may directly bathe fuels ahead of the fire on very steep slopes.

Together these can add up to exceptionally high rates of fire spread.

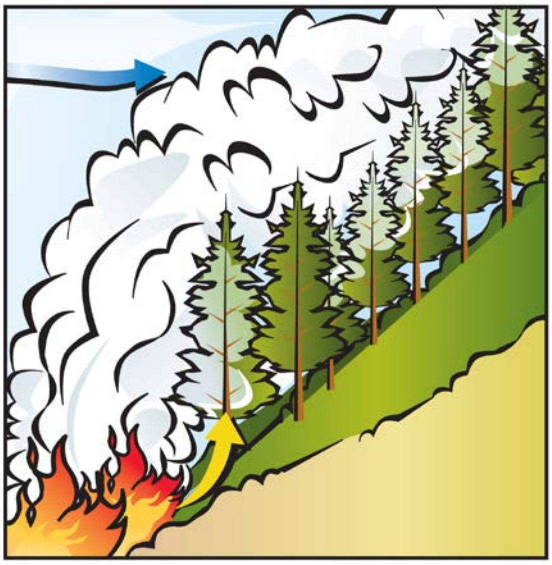


Figure 2.3 –Sloping ground scenario

Upslope changes

As a general rule:

On a 10° slope, ROS can be up to double that on level ground.

On a moderate 20° slope, ROS can be up to four times faster, than on level ground.

On a steep 30° slope, ROS can be up to six times faster than on level ground.

Downslope

Fires generally burns slower down a slope.

Lee slope

A lee slope is the part of a hill or dune, which is sheltered or turned away from the wind. On a lee slope, with the wind crossing over a rounded top ridge or hill, the airflow can follow the lay of the land and increase downslope fire spread. Wind flow across a steep narrower ridge top can result in formation of a lee slope eddy, and upslope winds in the opposite direction to the prevailing wind flow. Due to turbulent effects, lee slopes are also a favoured area for fire whirl formation.

Other considerations

Slope steepness influences the rate of spread and intensity of a fire. In mountainous country, the effect of a downslope wind can override the effect of slope.

Föhn winds are a type of dry downslope wind that occur in the lee of a mountain range. These winds bring warm and dry air over mountains on the leeward side, which can result in increases in temperature and decreases in relative humidity that can significantly impact fire behaviour.

To a lesser extent, downslope breezes at night can cause a fire to move downslope quicker than normal.

Aspect

Definition

Aspect is the direction a slope faces in relation to its exposure to the sun (north, south, east or west).

In the southern hemisphere, solar heating from the sun's rays is most intense on northern and western aspects, with the land surface and vegetation receiving considerably more heating and drying than eastern and southern aspects.

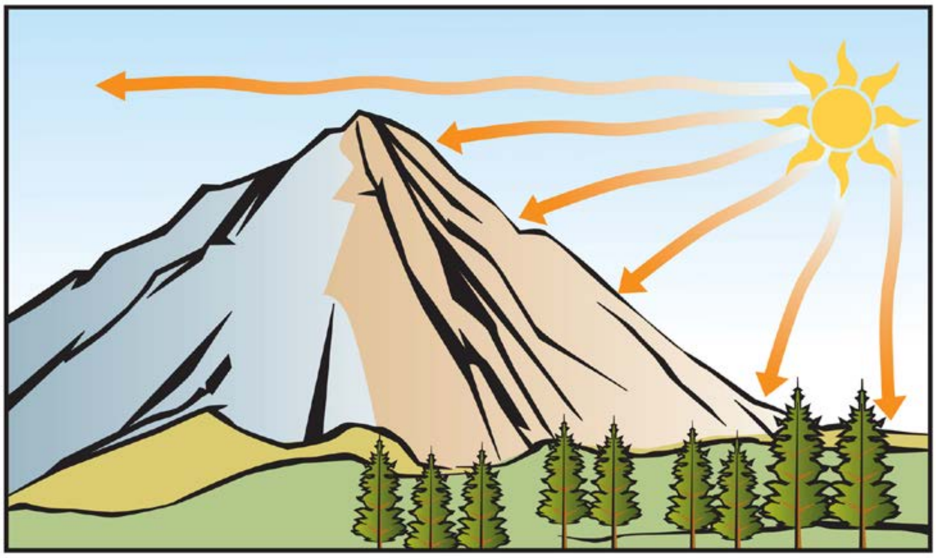


Figure 2.4 – Aspect

The more perpendicular the sun's rays are as they strike the surface the greater the intensity of solar heating..

Key influences

Generally the vegetation on northern and western aspects will be drier than that on the more cool and moist southern and eastern aspects.

Temperatures will be higher and relative humidity lower on areas with a northern or western aspect than on a southern or eastern aspect as a result of differences in exposure to solar radiation during the day.

Vegetation and soils on northern and western aspects will dry out more rapidly and fuel moisture content will be lower. The vegetation is therefore generally more flammable, with a greater potential for ignition and rapid fire spread, than vegetation on other aspects.

Solar heating of northern and western aspects will also generate greater upslope winds and turbulence.

Shape of the Terrain

Definition

Terrain is the shape of the land.

In rugged terrain, the shape of landforms is of great importance in predicting fire behaviour. Valleys, gullies, flat or level land, intersecting drainages and irregular slopes can all have an influence on the direction and rate of fire spread, and fire behaviour in general.

Topography has a mechanical effect on local winds, affecting wind direction and speed. Like water, wind flows along the lowest and easiest path, following the contours of the land and increasing speed as it funnels through narrow passages.

Figure 2.5 – Different Terrain

Valleys

Local winds can increase in speed along a valley floor.

In a narrow valley, the wind's speed increases as it funnels along the valley floor. It can flow in either direction.

Figure 2.6 – Wind in Valleys

Ridges and forks along the valley disrupt the airflow causing strong eddies and turbulent local winds.

In steep narrow valleys, spot fires can occur across faces due to turbulent wind conditions.

Shading and native vegetation in the bottom of deep narrow valleys may limit any influences from the aspect.

Sharp Ridges

Strong airflow over sharp ridges can create very erratic wind behaviour and turbulence on the lee side of the ridge.

Figure 2.7 – Sharp ridges

If there is an opposing airflow opposite the fire, the airflow may be sufficient to stop the fire going over and down the ridge.

As any fire approaches a ridge top it can rapidly increase in rate of spread and intensity under the combined influence of slope and a greater exposure to wind. Also embers can be carried from ridge tops to unburnt fuels on the lee side, or even onto downwind ridges or faces of slopes.

Rolling Country

Strong airflow over rolling country can cause faster downslope fire spread on the lee side.

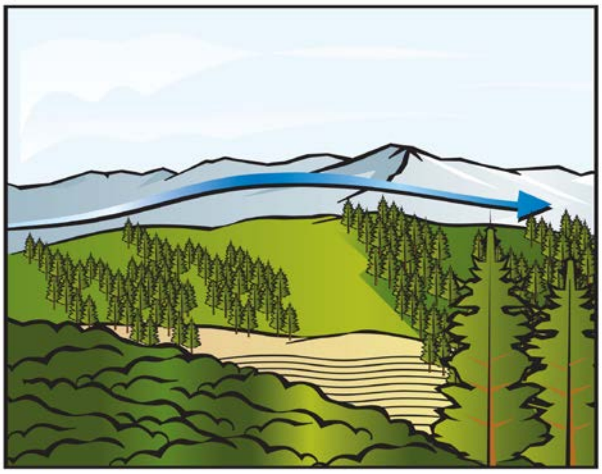


Figure 2.8 – Round hills

Chimney effect

On steep terrain, the slope effect can combine with the wind, funnelling into any depression, resulting in strong up-draughts.

The funnel effect directs the movement of fire into a narrow rising path eg. a saddle or steep gully.

The fire's rate of spread (ROS) and intensity increase rapidly, like a chimney in a fireplace.

Even comparatively shallow gullies running up a slope can create a chimney effect.

Figure 2.9 – Chimney effect

Barriers to fire spread

Definition

Barriers to fire spread are any obstruction that could either slow down or stop the spread of fire. This is typically an area devoid of combustible material or with a less flammable fuel type.

Natural or man-made barriers to fire spread, can have a significant effect on fire behaviour.

Natural barriers

Natural barriers include:

- landslides and barren areas such as scree slopes
- rivers and riverbeds, streams, lakes, swamps, and the ocean
- shaded and wet gully bottoms
- less flammable types of vegetation (natives).

Manmade barriers

Manmade barriers include:

- roads/railways
- firebreaks
- cultivated land.

The shape of the land can have a positive or negative influence on fire containment efforts. For example, steep terrain with a barren strip along the ridge can help contain the fire spread. However, there is a safety threat to firefighters on such a ridge.

Effect

Natural and man-made barriers can contribute to the containment of a fire.

Barriers can affect the spread of fires:

- directly through the absence of fuels, or by having fuels that have reduced burning potential than adjacent fuels
- indirectly through change in local winds.

Barriers to fire spread can reduce a fire's rate of spread or change the direction of spread and intensity. This can aid in the containment of the fire.

The effectiveness of barriers may depend on fire intensity and spotting potential, as well as time of year and seasonal conditions.

Section 3: Fuels

Definition

Fuels are any material such as dead and live vegetation which can be ignited and sustain fire.

Importance

Of the three major factors that influence vegetation fire behaviour – (topography, fuel and weather), fuel has the most significant influence on fire behaviour.

Fuel burns and generates the energy, rate and level of intensity of the fire.

In short, no fuel, no fire!

Fire Development

The process of combustion consists of three more or less distinct but overlapping phases:

Preheating phase	Unburnt fuel is raised to its ignition temperature and volatile gases are produced.
Gaseous or flaming phase	The flammable gases escaping from the fuel are ignited in the presence of oxygen and produce heat and light energy.
Charcoal or smouldering phase	The presence of flammable gases above the fuel is too low to support a persistent flame. The residual solid fuel burns away slowly.

Fuel varies by season and location. It can be manipulated to modify fire behaviour. Also fuels are the only fire environment factor that can easily be modified.

In daylight hours, fuel temperature constantly changes. Fuel moisture also needs to be driven off first. Sunlit fuel can be heated by solar radiation, which is many times more flammable than cool, shaded fuels.

Fuel Type

Definition

"An identifiable association of fuel elements of distinctive species form, size, arrangement and continuity that will exhibit characteristic fire behaviour under defined burning conditions."

A fuel type exhibits similar fire behaviour under similar burning conditions, based on the physical fuel characteristics of the vegetation..

Figure 3.1– Fuel Type

Layers of vegetation fuels

Classification

Fuels vary widely in distribution, type, physical characteristics, amount available for combustion, and their effect on fire behaviour.

Therefore, they can be classified on the basis of their vertical structure and general properties for analysis and communication.

Categories

There are three commonly recognised layers of fuels or categories:

1. Crown fuels, including ladder fuels.
2. Surface fuels.
3. Ground fuels

This categorisation helps distinguish the type of fire and corresponding burning fuel layer.

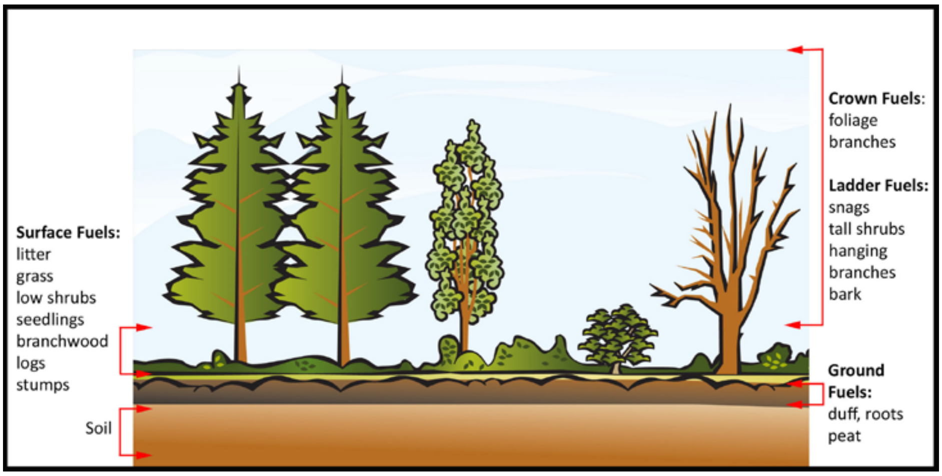


Figure 3.2– Fuel layers

Crown fuels

Crown fuels are aerial fuels not in direct contact with the ground surface. Examples include foliage, twigs, branches, lichens of trees and high scrub.

Crown fuels include ladder fuels. Ladder fuels are the lower living or dead branches of scrub or unpruned trees.

These ladder fuels provide vertical continuity between the surface and aerial fuels, thus contributing to the ease of fire spread into tree crowns.

Surface fuels

Surface fuels are the combustible materials in contact with the ground surface, lying above the duff layer between the subsurface fuels and the ladder fuels. Examples include litter, low and medium sized shrubs, seedlings, grasses, and fallen dead matter.

Ground fuels

Ground fuels are the decomposed organic materials below the surface litter, such as duff, roots, peat or buried wood.

These fuels normally support smouldering or glowing combustion in subsurface fires, which can be anything from a few centimetres to more than a metre deep.

In drought conditions, the moisture content of these fuels may be very low, contributing to prolonged mop-up and difficult fire extinguishment.

Figure 3.3 – Forest fuels usually contain all three fuel layers

Fuel Properties

The properties of fuel are:

- arrangement
- size and shape
- continuity/pattern
- quantity/load
- moisture content
- chemical composition.

Fuel arrangement

Definition

Fuel arrangement is the way individual pieces of fuel lie in relation to one another and their distribution over an area, both horizontally and vertically.

Vertical arrangement

Vertical arrangement is the spacing of fuels from ground level to the canopy top. It affects the rate of fire development and fire spread, but more importantly dictates the type of fire in forest fuels.

When the vertically arranged fuels are continuous, fire spreads from the ground to the crowns very rapidly. The fuels above are preheated and ignited by the convection of heat, from burning fuels below or ladder fuels carry fire into the crowns.

A definite separation between surface fuels and aerial fuels, with no ladder fuels, minimises the possibility of a fire spreading into the crowns. This separation requires a high intensity fire to ignite the aerial fuels.

Vertical arrangement

Assessing the fuel arrangement along with the fuel moisture content is important to predict potential fire behaviour.

Elevated and aerated fire fuels dry more rapidly than more compacted surface fuels. As a result, they ignite readily and burn more rapidly, leading to an increase in:

- Flame heights
- Rates of spread (ROS)
- Fire intensity.

Figure 3.4 – Vertical fuel arrangement

Horizontal arrangement

Horizontal arrangement is the spacing between individual fuel elements/particles on the ground.

It affects the rate of fire spread and ability for fire to spread.

If fuels are spaced too far apart, the ability for fire to spread can be hindered.

Figure 3.5 –Horizontal fuel continuity

Continuity	Continuity refers to the distribution of fuel across the landscape. Fuels can be referred to as patchy, due to rock outcrops or bare ground or uniform if they form a continuous cover across an area. When fuels are patchy or separated, fire may not be continuous and can therefore be less intense with irregular spread.

Fuel size and shape

Definition

Fuel size and shape refers to the size and thickness or diameter of the vegetation elements. There are three broad classifications: fine, medium and coarse fuels.

The size and shape of fuels affects their wetting and drying rates and exposure to heat and ignition sources.

Drying rate

Fuel particles with a small diameter, or high surface area compared to their volume will dry rapidly e.g. pine needles or leaves.

Conversely, the greater the diameter or the lesser the surface area for its volume, the slower the rate of drying for the fuel particle with an increased ability to retain moisture. e.g. large logs or stems.

Fine fuels

Fine fuels have a large surface area in relation to their volume. They lose moisture and dry out very easily. Dry or dead fine fuels ignite easily, carry fire and are consumed rapidly. Examples include: cured grass, leaves, needles, small twigs.

The duration of burning is minimal and the fine fuels carry fire to, and pre-heat, the surrounding heavier fuels.

Medium fuels

These are the fuels that are too large to be ignited until after the leading edge of the fire front passes, but small enough to be completely consumed. Examples include branches and loosely compacted duff material. Dead elevated medium size fuels can dry quicker than those on the ground.

Coarse fuels

Course fuels are large diameter woody or deep organic materials that have a small surface area proportionate to their volume. Examples include logging slash, wind-felled trees, trunks, deep-seated peat. They are normally difficult to ignite and burn more slowly than fine or medium fuels. A mixture of fine and coarse fuels is often needed to maintain the spread of a fire through heavy fuels.

Coarse fuels need considerable exposure to prolonged drying conditions to lower the moisture content enough to sustain combustion. Once ignited, the heavy fuels burn slowly although can burn for long periods of time (days to weeks).

Figure 3.6 – Mixture of fuels

Summary

Fuel size/shape influences the rate of drying, ease of ignition, and the amount and rate of fuel consumption. Fine fuel ignites and burns easily and is essential to fire spread.

Fuel Load

Definition

Fuel load refers to the amount (or weight) of fuel present in an area. It is generally expressed in tonnes per hectare (t/ha).

Fuel load is usually highly variable. The amount present directly affects fire intensity, since a fire's energy output is in direct proportion to the weight of fuel consumed.

Available fuels

These are the quantity of fuel that will burn in a fire. The amount that burns depends on the fuel's dryness and amount of live and dead fuel in the area. Not all the fuels will burn under given conditions.

The amount of fuel available to burn varies with the moisture content of the fuel. Shortly after rain, only the top layers of the ground fuels may burn. When the deeper fuel layers dry out, they become available to burn.

During normal weather, the live foliage of scrub and trees can retain sufficient moisture to prevent them from burning.

Under extreme drought and low fuel moisture conditions, most fuels become available for combustion (including live fuels).

To evaluate the fuel load in a given area, consider the type, size, arrangement, moisture content and amount of dead and live fuels. This is particularly significant when there is a mixture of vegetation types within the area assessed for fuel load. Fuel load contributes to fire intensity.

Figure 3.7 – Fuel load

Fuel Moisture Content

Definition

Fuel moisture content represents the amount of water that is present in fuel expressed as a percentage of the fuel's dry weight. Fuel moisture can vary from less than 5% in dry dead fuels, to more than 200% in live vegetation. Typically, the moisture content of dead fuels needs to fall below 30% before it will ignite and burn.

Critical importance

Fuel moisture is the most important characteristic affecting fire behaviour since it determines the ease of ignition, rate of burning, and the amount of fuel consumed.

Fuels with low moisture content ignite and burn easily, and are burned more completely.

Figure 3.8 – Fuel moisture content

Reasons

To burn, fuel must be dry. Heat and wind help dry out moist fuels.

The heat of a fire is sufficient to dry the unburned fuels ahead of the fire enough to ignite.

Fine fuels dry easily.

Fuels with low moisture content:

- ignite easily
- burn rapidly/easily

Fuels with a high moisture content, particularly heavy fuels:

- take a long time to dry
- are hard to ignite.

The moisture content of dead fuels depends on the surrounding atmospheric conditions.

The moisture content of living vegetation varies little except under conditions of extreme drought. Drought reduces the moisture content by placing the plant under stress.

Chemical composition

Some fuels burn more readily because of flammable oils, waxes, resin etc. in their chemical composition. Examples include pine foliage, manuka, eucalypts, manoao, turpentine scrub, and gorse. Fuels with a higher pressure/concentration of volatile chemicals burn with greater fire intensity and higher flames.

Section 4: Weather

Importance

New Zealand weather is variable and difficult to forecast. However, a general knowledge of air temperature, relative humidity, wind and rainfall will help explain the weather influence on fire behaviour.

Temperature

Definition

Temperature is defined as “the degree of hotness or coldness of a substance”. The sun’s energy heats the earth’s surface and the air above it as it passes over the land. The temperature of the air is called the ambient or dry-bulb temperature.

Importance

Temperature directly influences fire behaviour by raising the temperature of fuels closer to their ignition temperature. Temperature also indirectly affects the way fires burn because it influences other factors, such as relative humidity, wind, and fuel moisture levels.

Higher temperatures dry fuels faster. They ignite more easily than shaded fuels.

Relative Humidity

Definition

Relative humidity (RH) is the amount of moisture in the air compared with the amount of moisture the air is capable of holding at that temperature. It is expressed as a percentage.

Water retention depends on air temperature. Warm air holds more moisture than cold air.

Influences

The amount of moisture in the air influences the rate of wetting and drying of fine fuels, and therefore their ease of ignition, rate of burning and fire intensity.

The moisture content in the air is measured by relative humidity. At a relative humidity (RH) of 100%, the air is fully saturated and moisture falls out of the air as rain or dew. RH values of 20% are considered low and below 10% very low. However, the range of RH values experienced in different parts of the country will vary.

Variations

Relative humidity varies daily with the temperature, as shown in figure 4.1.

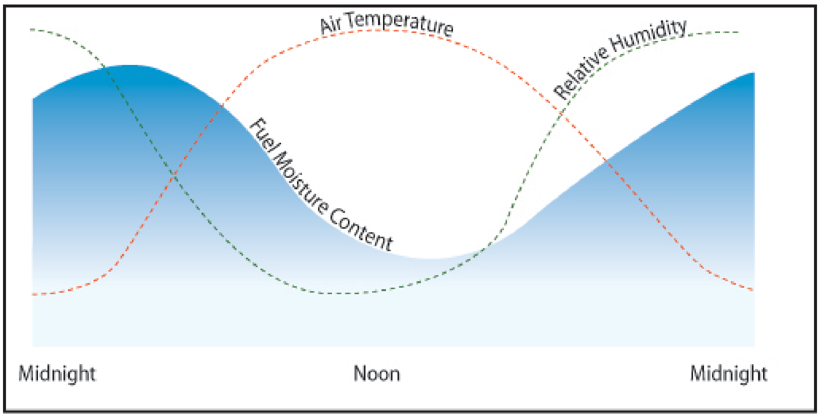


Figure 4.1 – RH variations

Night variations

The daily trends in temperature and relative humidity are important.

RH normally increases overnight to reach a maximum around dawn. However, if temperature remains high and relative humidity low overnight, the fire can remain active.

Fine fuels

The moisture content of fine fuels will increase and decrease rapidly in response to the rise and fall of RH.

Low RH values in the middle of the day can produce low fine fuel moisture content in the mid-afternoon, increasing the potential for combustion.

Monitoring

It is important to monitor the RH at a fire, as any decrease or increase provides another indicator of increasing or decreasing fire activity.

Summary

Relative Humidity is a key indicator of the moisture content of fine fuel, and therefore the ease of ignition, rate of burning and fire intensity.

Surface Wind and Turbulence

Definition

Wind is the horizontal or near-horizontal movement of air from, for example, high to low pressure, warm to cooler aspects (upslope/downslope wind), warm land to cooler water and vice versa (land-sea breeze).

Influence

The ability to predict wind speed and direction is crucial to effective incident management, as these are the major factors that determine the rate of spread and direction of a fire.

Surface winds

Surface winds tend to blow in a series of gusts and lulls with fluctuations in direction. This irregular motion is known as turbulence, which may be either mechanical or thermal.

Airflow over land is similar to the flow of water.

Surface friction with the land surface or vegetation produces mechanical turbulence in the airflow.

Mechanical turbulence increases with both wind speed and the roughness of the ground surface. Obstructions such as buildings, variations in topography, shelterbelts etc produces mechanical turbulence.

Thermal turbulence is associated with atmospheric instability and convection and generally extends higher into the atmosphere as a result of surface heating of the air (heated air rises from the land surface and is replaced by cooler air).This vertical air movement obstructs wind flow resulting in turbulence.

Summary

Wind strength, as with slope, has a significant influence on the direction in which the fire spreads, as well as the rate of spread (ROS) and fire intensity.

Wind Speed

Wind speed

Wind speed is usually measured in km/h for fire danger rating. Wind speed is usually measured at a height of 10 m in the open.

Wind acting on the fire may be different from that measured elsewhere due to the sheltering effect of vegetation or terrain. For example it may be higher on exposed ridge tops, and lower in valley bottoms or in forest or other dense vegetation.

Without instruments to accurately measure wind speed, reference to the Beaufort Wind Scale will be of assistance. Originally a naval invention, the scale has been adapted for use on land. The land observation version is illustrated below.

Wind direction is the direction from which wind is blowing i.e.; NW (270 degrees) indicates that the wind is blowing from NW to SE.

Note: Hand held wind observations need to be adjusted for the 10 m height (x1.5). Wind measurements should also be averaged over a period (preferably 10 minutes) to reduce the influence of wind gusts.

Beaufort Wind Scale for estimating 10 - m open wind speed over land

Beaufort Wind Force	Descriptive term	10 - m wind speed --km/h--	Observed wind effects
0	Calm	< 1	Smoke rises vertically.
1	Light air	1 to 5	Direction of wind shown by smoke drift but not by wind vanes.
2	Light breeze	6 to 11	Wind felt on face; leaves rustle; ordinary vanes moved by wind.
3	Gentle breeze	12 to 19	Leaves and small twigs in constant motion; wind extends light flags.
4	Moderate breeze	20 to 28	Wind raises dust and loose paper; small branches are moved.
5	Fresh breeze	29 to 38	Small trees in leaf begin to sway; crested wavelets form on inland waters.
6	Strong breeze	39 to 49	Large branches in motion; whistling heard in telephone wires; umbrellas used with difficulty.
7	Moderate gale	50 to 61	Whole trees in motion; inconvenience felt when walking against wind.
8	Fresh gale	62 to 74	Breaks twigs off trees; generally impedes progress.
9	Strong gale	75 to 88	Slight structural damage occurs (e.g., TV antennas and tiles blown off).
10	Whole gale	89 to 102	Seldom experienced inland; trees uprooted; considerable structural damage.

Note: Fire behaviour predictions in this guide are based on head fire rate of spread in fully cured standing grasslands (Fire Behaviour Prediction System Fuel Type O-1b) on flat to undulating terrain, assuming a fuel load of 3.5 t/ha, a Fine Fuel Moisture Code of 93.2, and the midpoint of the wind speed range associated with each Beaufort Wind Force. Use of the guide is at the reader's sole risk.

Figure 4.2 – Beaufort Chart

Topographical Effects on Wind

Influence	A hill, or any other topographic obstacle, will interfere with the flow of wind, changing the wind's speed, direction and turbulence. Gorges funnel wind and significantly increase wind speeds, whereas wind slows down in broad, open areas.
Mountains	Mountains represent the maximum degree of surface roughness and provide the greatest friction to airflow by forcing winds to go around or over them.
Ridges	The wind flow on the lee side of hills or ridges may create an eddy flow back up the hill in the direction opposite to the prevailing wind flow. How the airflow behaves is influenced by ridge shape, and wind speed and direction. Rounded top ridges tend to disturb airflow least. Sharp ridges produce significant turbulence and eddy on the lee side.
Slopes	Generally, wind speed will progressively increase up a slope to the crest of the hill due to compression and exposure to the prevailing wind flow. Daily heating and cooling of slopes can create local wind patterns. When the temperature at higher elevations decreases at night. the cooler air sinks and flows down the slope; as the day warms the slopes, the warmed air will move upslope.

Slopes

The downslope evening breeze may cause a fire to spread more quickly downhill.

Combined with the catchment shape of a valley system these localised upslope winds are generally light, but can produce up valley winds. The downslope winds can become very strong at the narrowing base of the valley system.

Figure 4.3 – Topography

Föhn Winds

Definition

A föhn wind is a warm, dry, and often strong and gusty wind that occurs on the leeward side of a mountain range.

Moist air passing over high mountain ranges cools and loses moisture on the windward side through precipitation as it is forced to higher altitudes. As it descends to the lowlands on the leeward side of a range, the dry air heats up and arrives as a strong, gusty, dry wind. The fohn wind often precedes the passage of a cold front.

Canterbury Nor'wester

A well known example is the Canterbury Nor'wester, where the airflow descending from the Southern Alps flowing over the Canterbury plains is warmer and drier than on the West Coast.

Other examples

Wanganui / Manawatu in a NE airflow

Hawkes Bay / Wairarapa in a NW airflow

Nelson in a SW airflow and

West Coast in an easterly airflow

Summary

Föhn winds are strong, warm and dry.

Coastal Effects on Winds

Influence

Because New Zealand is essentially a long, narrow land mass surrounded by oceans, it is essentially a maritime climate. There are few parts of the country that are not affected to some degree by winds generated by the interaction of land and sea temperatures.

Wildfires adjacent to coastal areas or large lakes can be radically affected by the changing wind patterns.

Onshore winds/ Sea breeze

Land heats more quickly than the ocean.

Warm air rises from the land before the sea temperature rises. Cooler air then flows onshore from the ocean to replace the warm air displaced above the land surface.

Onshore winds:

- appear in late morning (or early to mid afternoon)
- strengthen during the afternoon
- flow considerable distances inland
- carry cooler, moister air.

Onshore winds are also referred to as sea breezes.

A sea breeze is significant to fire behaviour because it may:

- strengthen the prevailing wind
- produce a wind on an otherwise calm day
- reverse the wind direction.

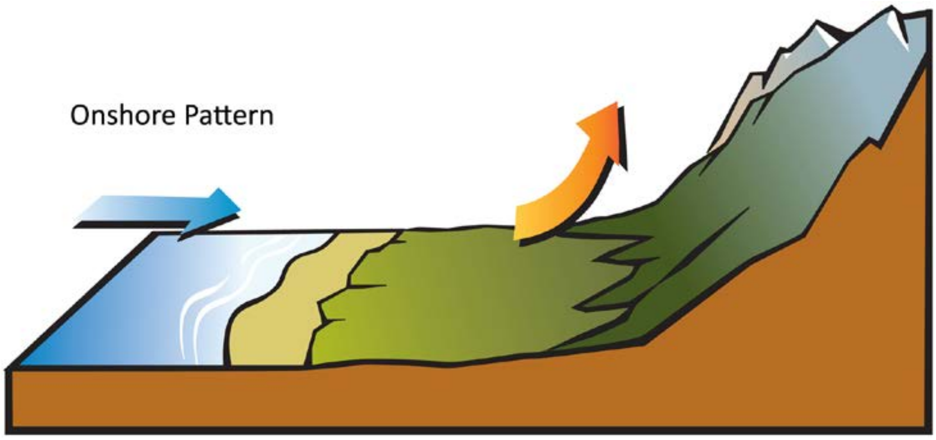


Figure 4.4 – Onshore pattern

Offshore winds/ Land breeze

Offshore winds are created by air cooling over the land in the evening. Air then flows off shore to the ocean. This is sometimes called a 'land breeze'.

These winds develop mainly at night.

They are usually less vigorous than sea breezes and affect smaller areas of the coastal strip. This wind is warmer and drier than the air it replaces.

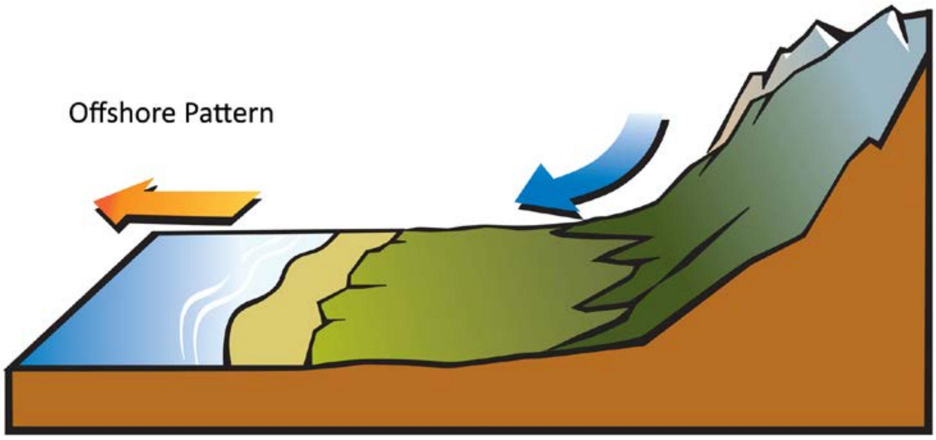


Figure 4.5 – Offshore pattern

Upper Atmosphere Winds

High altitudes

Fire behaviour can be affected by wind conditions up to 3,000 metres above ground level.

This is seen when a column of rising smoke is dispersed in one direction at a higher level only. Wind speed normally increases with the height above the ground.

Even with very little surface wind, strong upper atmosphere winds can create updraughts that can increase the fire intensity. In lee of mountain range, air flow can form waves these lee waves can result in strong upper atmosphere winds reaching the surface.

Atmospheric Stability

Definition

This is defined as "the resistance of the atmosphere to vertical motion."

Warm air rises and as it rises it expands and cools and sinks again. This creates a cycle of vertical motion.

Surface winds, temperature and relative humidity are the most commonly considered weather factors when evaluating fire danger.

Less obvious, but also important, is the effect of an unstable atmosphere.

Unstable atmosphere

Unstable atmospheric conditions increase the rate of vertical air movement, with cooler air from high altitudes coming down to ground level to replace the rapidly rising warmer air.

This creates gusty and turbulent surface winds in a narrow band around the fire perimeter.

These conditions increase fire intensity, and fire behaviour can become very erratic due to the vertical air movement and gusty/turbulent surface winds.

Indicators of an unstable atmosphere include a cloudless day, cumulus type smoke column above the fire, and dust whirls.

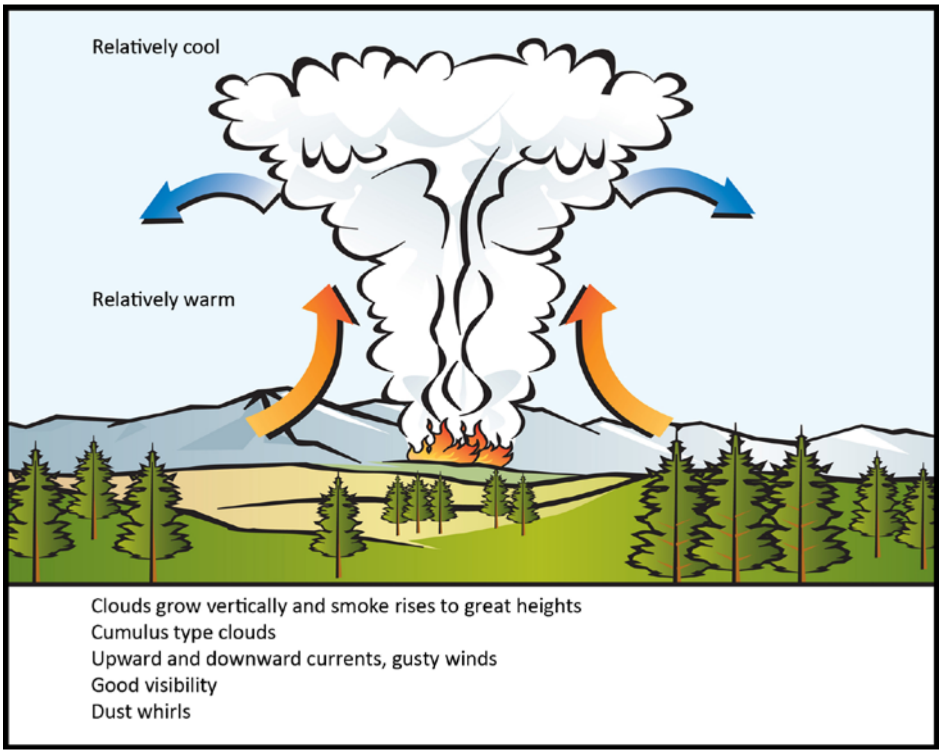


Figure 4.6 – Unstable atmosphere

Stable atmosphere

Under stable conditions the atmosphere resists vertical motion while under unstable conditions the atmosphere favours vertical motion.

A stable atmosphere is putting a "lid' on air movement, restricting the ability of air to rise: This:

- causes smoke to be trapped and spread out horizontally
- winds to be generally light and steady.

The affect restricts fire development, resulting in lower fire intensity and more predictable fire behaviour.

Caution Breaking of an inversion can cause rapid change from stable to unstable atmosphere conditions and a dramatic increase in fire activity as indicated by increasing in wind and vertical development of the smoke column.

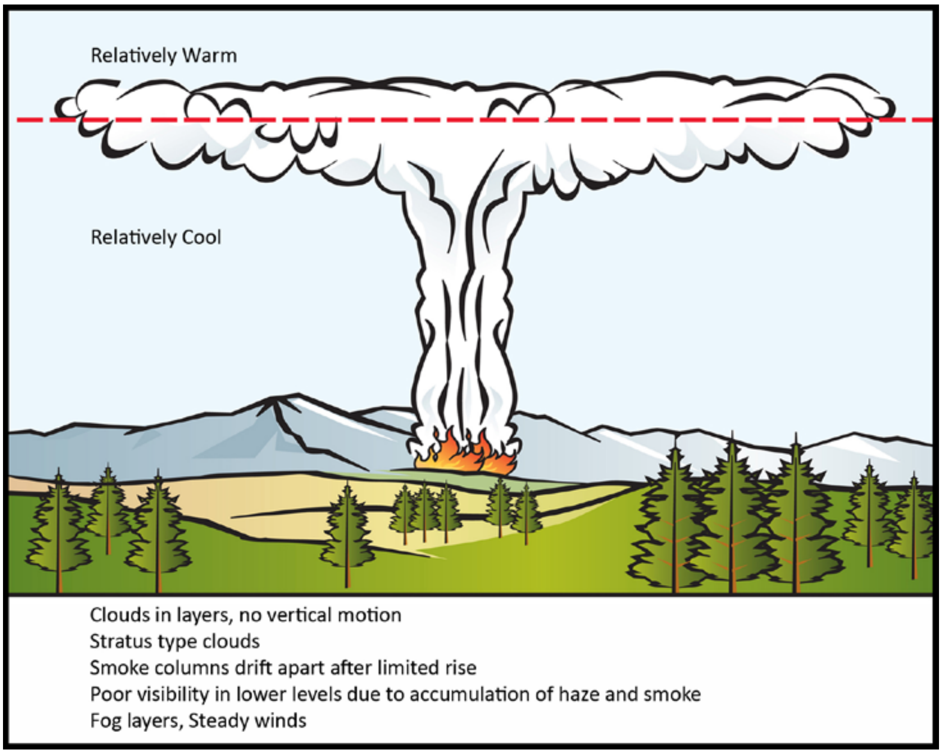


Figure 4.7 – Stable atmosphere

Whirlwinds

Indication

Whirlwinds, including dust whirls or fire whirls, usually indicate unstable atmospheric conditions.

Occurrence

They occur on a hot calm day when the surface of one area is hotter than adjacent land. This heating causes the warmer air to rise vertically and be replaced with cooler surrounding air.

A whirlwind occurs when these warm, vertical air movements are interrupted by a large obstacle or an updraught in a gully. The air spins upward until it loses its energy.

Fire whirls

Fire whirls are whirlwinds that develop within a fire area characterised by uneven burning.

Fire whirls are narrow twisting plumes of flame.

These can carry burning material considerable distances.

With small fires they persist for only a few seconds before dying out and re-forming.

Large fires can produce fire whirls that travel down the flank of a fire for several minutes picking up loose burning material and scattering them outside the fire perimeter.

More persistent fire whirlwinds commonly occur on the lee slopes of hills and near ridge crests.

Precipitation

Definition

Precipitation is the release of moisture from the atmosphere. It is normally in the form of rain although can include snow, hail, drizzle and dew.

Effect

Rainfall – or lack of it – directly affects the moisture content of fuels.

A prolonged dry spell dries out fuels making them especially susceptible to fires.

Continuous rain over a long period enables large/coarse dead fuels and the duff layer to absorb water.

Heavy rain over a short period tends to run off the land or fuel surface, especially when the ground is dry.

Light, occasional rainfall dampens the dead fine fuels. However, these quickly dry out with a dry wind and sunshine.

Coarse, dead fuels and the deep duff layer need significant amounts of rain to stop them from burning. They also need a long dry period to make them combustible.

A few millimetres of rain in one day will dampen fine fuels, but more than 25 mm over a couple of days may be required to dampen heavy fuels.

Consider the duration as well as the amount of rain.

Clouds and Thunderstorms

Formation

For clouds to form and precipitation to develop, the atmosphere must be saturated so that some of the moisture condenses and falls out. Saturation point is reached by lowering air temperature. The most common way that this happens is through lifting of the air mass.

Indicators

Cloud types are an indicator of wind patterns, atmospheric stability and moisture content.

High altitude clouds moving in a different direction to the wind direction at ground level indicates a potential shift in wind direction.

Without clouds, solar radiation is high and surface temperatures of dead fuels can rise higher than the ambient air temperature, by as much as 20 degrees.

Cloudless skies are often associated with an unstable atmosphere which, combined with high fuel temperatures, can lead to erratic fire behaviour.

With continuous cloud cover, fuel temperatures are closer to the air temperature, and fuel moisture content may be higher than in the absence of sunlight.

Thunderstorms

A thunderstorm is a violent local storm that is often accompanied by lightning. It represents extreme convective activity produced at a result of an unstable atmosphere.

They are usually triggered by some form of atmospheric lifting where warm air near the surface is raised into the atmosphere, such as lifting by air flowing over mountainous topography (orographic lifting), frontal activity (frontal lifting), or by heating from below (thermal lifting).

In addition to lighting and sometimes rain or hail, they can be associated with strong downdrafts that can produce erratic fire behaviour if a thunderstorm passed near a going fire.

Figure 4.8 – Clouds

Diurnal Weather Variations

Daily

The full 24 hour daily period needs to be considered to completely assess the weather effects on potential fire behaviour. Monitor daily weather trends.

Temperature is usually higher and relative humidity lower during the day than at night. Winds tend to be stronger during the day.

As a result, fuels are dry and burn more vigorously during mid to late afternoon.

Night time and the early hours of the morning are often the most effective suppression times for large fires. Fire conditions are more stable and the cooler environment is better for firefighters (although night time firefighting can raise other risks/safety issues that need to be considered).

However, normal temperature weather patterns do not always occur:

- under föhn wind conditions, temperatures can remain high and RH low so that fires continue to burn actively overnight
- frontal passages can bring about a change in air mass with different temperature and RH and wind direction resulting in changes in fire behaviour.
- upslope/downslope winds, there can be local variation on wind speed and direction in hill/valleys due to night and day changes in temperature. .This can influence more dominant downslope wind during early morning and stronger upslope winds during the afternoon.

Seasonal effects

Fire behaviour potential varies with the season of the year. Seasons affect the fire climate, as well as the condition of the vegetation, hours of sunlight per day, and the moisture content of fuels.

The generally accepted high fire risk season is the spring and summer period from October to April. However, fires can occur throughout the year.

Heavy frosts and clear winter days can dry out fuels resulting in an ‘out of season’ fire.

A wet spring or summer increases vegetation growth. This can dry out in autumn, producing a greater than normal volume of cured fuels.

Drought

Definition

Drought is an extended period of time of lower than average rainfall.

Effects

Combined with the drying effects of wind, high temperatures and low relative humidity, drought dries out fuels and increases the potential for fires.

Prolonged drought

Prolonged drought is usually considered as a period of more than 50 days without substantial rainfall. However, shorter term droughts may occur is some parts of the country e.g. West Coast after 2 to 3 weeks without significant rain. Serious fires are likely to occur during these conditions.

Additional effects include:

- heavy (coarse) fuels dry out
- deep duff layers and sub-surface fuels dry out
- moisture content in living vegetation reduces
- fire can become deep seated and burn well below ground level.

Soil type

Soil type, especially soil drainage can contribute to drought conditions.

Sandy or pumice soil with good drainage dries out faster because it does not retain or store water well. Clay soils or those with high amounts of organic material (e.g. peat) retain moisture for longer.

Water table levels

Low water table levels indicate the long-term effects of drought.

Rivers, streams and other water sources may run low, or dry out altogether.

When the water table is low, rain filters quickly into the soil, leaving the surface and sub-surface fuels to dry rapidly.

Trees are deprived of water and their foliage dries out. They can then be more susceptible to crown fires.

Maps

Weather forecasting is neither simple nor exact. Meteorologists consider and evaluate many factors before making predictions. The atmosphere is complicated and patterns constantly change, sometimes very quickly.

Reading weather maps provides an indication of local weather conditions.

The two main weather map types are:

- Situation map, showing current weather situation
- Forecast map, showing the projected situation.

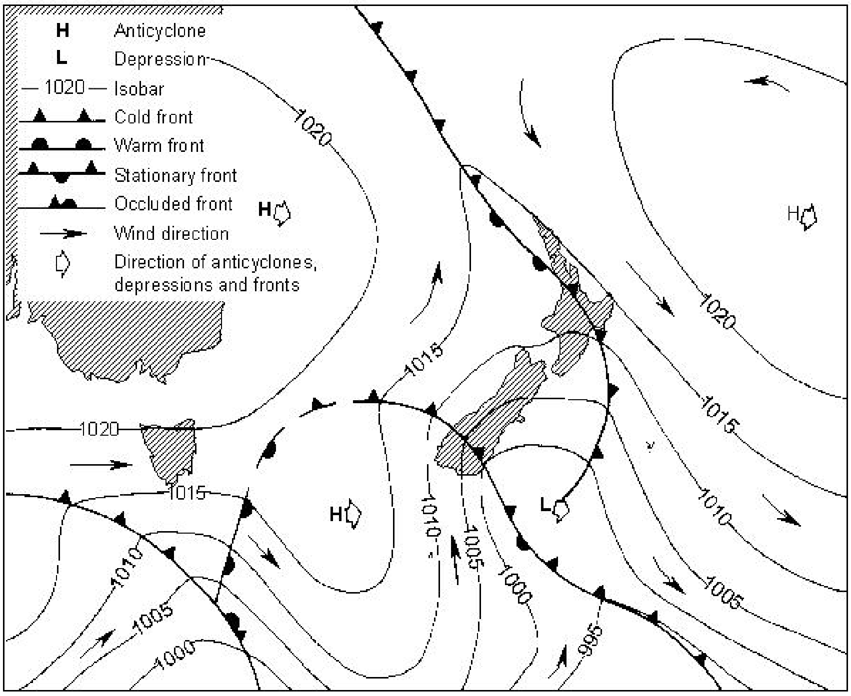


Figure 4.9– Weather map

Atmospheric pressure (Isobars)	The effect of gravity on an air mass creates atmospheric pressure. Pressure usually decreases with altitude. Atmospheric pressure is represented by isobars lines drawn on a weather map connecting places with equal atmospheric pressure. The air pressure at sea level (e.g. hectopascals) is recorded beside each isobar. From these, the forecaster determines regions of: • high pressure – anticyclones and ridges • low pressure – depressions and troughs. Isobars tend to be closer together towards low pressure centres and wider apart around high pressure centres. Isobars indicate wind direction and strength. Winds blow almost parallel to the isobars. The distance between the isobars indicates the wind speed. When they are close together the winds are strong; when isobars are widely spaced winds are light. **Note**: With your back to the wind, high pressures are to your left and low pressures to your right
Anticyclone (Highs)	An anticyclone is an area of high pressure depicted as 'H' on the weather map. Anticyclones generally move from west to east, spreading from the Tasman Sea on to NZ, bringing generally settled weather with light, variable winds. In the Southern Hemisphere, air flows anti-clockwise around an anticyclone.
Depression (Lows)	A depression is an area of low pressure depicted as 'L' on a weather map. Depressions usually move towards the east or southeast, often under the dominance of a strong anticyclone over the Tasman Sea. Depressions can bring fronts with strong winds, clouds and rain. In the Southern Hemisphere, air flows clockwise around a depression. .

Frontal systems

Fronts are the boundary between air masses with different temperature and moisture characteristics. Warm and cold fronts on a weather map show the lines along which the warm and cold air masses are moving.

Warm Front

A warm front forms as warm air cools and forms clouds by passing over colder air. Light rain usually falls and the temperature rises following passage of the front.

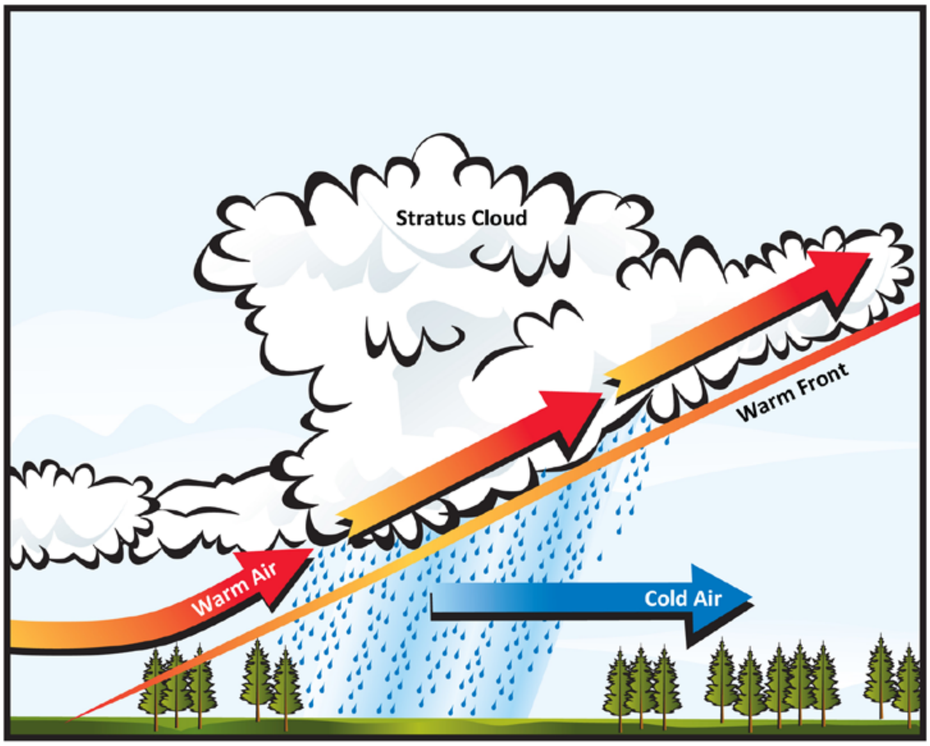


Figure 4.10 – Warm Front

Cold Front

Cold fronts occur when cold air flows under warm air, lifting it to form heaped cumulus cloud and often heavy rain. Cold fronts can advance at up to 35 to 50 kilometres an hour.

Cold fronts can be preceded by strong and gusty, hot, dry winds (föhn)

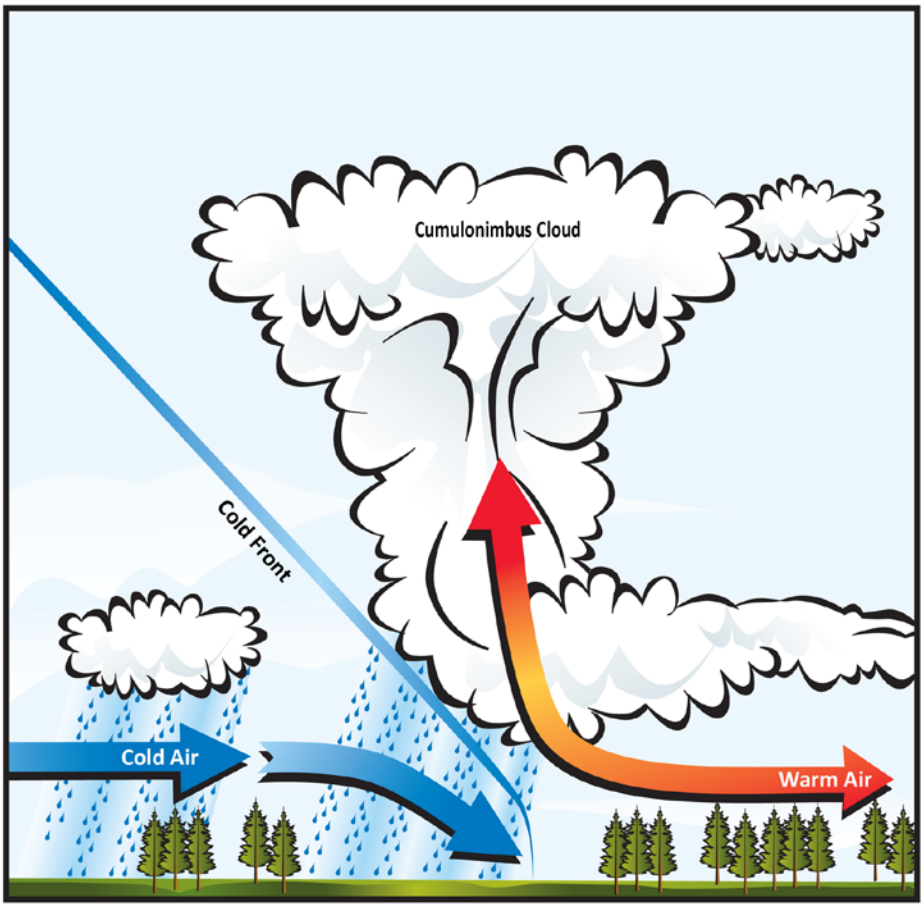


Figure 4.11 – Cold Front

Weather patterns associated with fronts can be predicted as events.

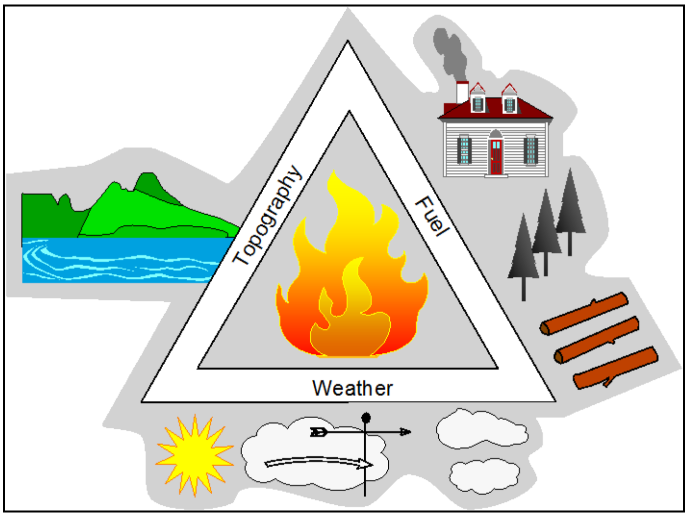
Interaction of factors

No two vegetation fires behave in the same manner.

Fires are classed as wind driven, fuels driven, or topography driven.

The fire environment factors interact in many ways to determine fire behaviour, and blending the theory of the science of fire behaviour with local conditions is something of an art.

The possible combinations of the three influencing factors of topography, fuels and weather are so variable that to predict 'standard fire behaviour' for all vegetation fires would be extremely misleading.



To understand why a fire is burning like it is, or to predict the ways a fire may behave, requires an understanding of all the influencing factors in the fire environment and how they interact with each other (not just considered in isolation).

The current level and condition of each influence needs to be known, together with predicting likely changes that may occur in the future.

The primary forces that cause the behaviour of vegetation fires to change are wind speed, slope and fuel variations.

Fire that is moving across a range of topographic features will change speed and direction as dictated by the combination of the factors of:

- slope steepness
- wind speed and direction, and

  the amount, agreement, conditions and dryness of available fuels.

Where these key factors become more aligned, the fire intensity will increase and conversely, where they are less aligned, the fire intensity will decrease.

The following factors need to be carefully considered in your assessment of potential fire behaviour:

- topography-immediate area and surrounding area
- fuels- currently involved and in path of fire
- weather- current and expected.

A change in any one factor of the fire environment can influence a change in another factor, and in turn the behaviour of a fire, sometimes with serious safety consequences.

In many cases where a sudden change in fire behaviour has occurred, the indicators or change in one or more of the fire environment factors, went unnoticed or the consequences of a change were not understood by the personnel involved.

The primary forces that cause fire behaviour to change are wind, slope and fuel variations.

This may occur as a major change in a single factor (wind speed) or a combination of minor changes in multiple factors. Minor changes in multiple factors may go unnoticed until fire changes align the fire behaviour reacts.

The Fire Day

10 am to 6 pm- All factors of fire intensity are at their highest. The air and fuels are dry, temperature is high, wind is strong, and the sun and heat are most unfavourable, for the control efforts. Spot fires start easily. All fires are at their point of strongest resistance to control.

6 pm to 4 am-The wind moderates, the air cools, relative humidity rises and fuels cool and begin to absorb moisture from the air. These conditions, gradually increase throughout the night until the fire reaches its lowest ebb about 4 am.

4 am to 6 am- The fire activity remains low until shortly after dawn. It may stop running especially in low places and gullies. During this time and the preceding period (6 pm to 4 am) the most effective control work can be done on the fire, and less effort is required.

6 am to 10 am- Shortly after dawn the fire begins to increase in intensity. Small pockets may start to smoulder, the slow burning and moving fires begin to flame up, and gradually, separate fires join together in a solid front. The wind rises, humidity decreases, air temperature rises and firefighting becomes increasingly difficult.

It is important to note with the above that this refers to a ‘standard’ daily temperature and wind weather pattern. Where this is not the case (e.g. föhn wind overnight with no cooling and recovery of RH in the evening), the above pattern is not true/will not occur.