PROCEDURE

Energy storage systems

IS4-SOPb

Introduction

When to use	This document describes the procedures to follow when dealing with a fire or physical damage to energy storage systems (ESS). These systems are modern storage batteries usually with a lithium or nickel base. These procedures must be followed for any incident which results in an emergency response by Fire and Emergency New Zealand. ESS systems can be found in: • electric vehicles • residential or commercial installations, or • electricity supply authority installations, (substations) This procedure must be read alongside the guidance in the IS4 suite of policy and guidance, as well as the training modules on Learning Station: • Electricity 1: How electricity works • Electricity 2: Working safely around electricity.
Vehicles Background	There has been an increasing number of incidents involving these systems of batteries, resulting in property damage and a potential safety hazard to responding crews. Electric vehicles are becoming more common, and the range is extending to heavier vehicles, (busses and trucks). Lithium or nickel based batteries are found in three types of vehicles: • hybrid electric (HEV) • plug-in hybrid (PHEV) and • electric vehicles (EV), increasingly seen on New Zealand roads. These vehicles may operate on a combination of petrol/diesel engine plus electric motor, or be 100% electric. The high voltage electric component can be between 200 and 800 volts DC.
Static battery background	Energy storage systems made up of lithium or nickel based batteries can also be found in buildings. These installations support electricity supply in part or wholly “off-grid” installations. These can be part of solar/wind and water generated power storage systems. ESS are also used as storage for off-peak (cheaper) power. This is then used as peak power supply support. These can be very large installations and can be found in: • residential housing • commercial/industrial buildings • electricity supply authority infrastructure (substations). **Note:** There is also an increasing number of lithium or nickel based batteries in small appliances, electric toys, mobility scooters and electric bikes. The hazards are the same for these size batteries.

Hazards	Lithium and nickel based batteries present a hazard when damaged physically or electrically. A situation involving chemical breakdown inside the battery, called **thermal runaway,** can occur. This causes the battery cells to overheat, releasing toxic and volatile fumes, and sometimes igniting and/or causing vapour explosion. Once thermal runaway occurs, damaged cells can induce failure in other cells within the battery. The heat and vapour pressure created as the batteries break down means battery casings can rupture violently. This is not the battery content exploding, but the vapours creating an overpressure rupture. These vapours are highly toxic and flammable. Vapour build-up can create a potentially explosive situation. Level two and breathing apparatus will be required if there is any suspicion of battery failure in motor vehicle accidents, and for any fire scenario involving any size lithium or nickel based battery. There is a risk of PPE and respiratory protection equipment (BA) contamination, requiring decontamination. The mix of contaminants cannot be reliably defined, but one possible vapour and liquid contaminant is **hydrofluoric acid**. This acid has very toxic and corrosive properties. See Post incident considerations/requirements below. **Note:** The lack of industry standards makes it impossible to reliably determine what toxic and hazardous substances may be present during battery breakdown. Using the possibility of hydrofluoric acid as the default contaminant will give sufficient guidance for PPE and hazard management.

Pre-incident planning

Fixed battery installations	Uninterruptable power supplies (UPS) are used in many business and some residential locations, to avoid computer and control equipment failing in power outage situations. Where operational plans are being developed for a location, knowledge of any battery storage is to be recorded in the hazards section of the Site Report. Tactical Plan scenarios should consider issues if the installation is damaged, threatened or involved in fire, flooding or other damage. Increasingly, power supply retailers are considering local suburb based battery support in the form of battery substations for peak power demand management. This uses off peak power stored in the batteries to balance the peak load demand on a daily basis. **Note:** Where power suppliers are using peak demand management with battery installations, areas are to ensure stations have at least a generic site report for managing the situation.
Mobile battery installations	Battery storage is lithium or nickel based, and this presents a hazard when attending motor vehicle accidents where the batteries can be damaged by impact or fire. Damaged batteries may not show any visual sign of damage, but may already be in a thermal runaway event. Early monitoring with thermal imaging and/or gas detection is desirable, but may not be achievable. Vigilance is required if monitoring equipment cannot be deployed on the first response vehicles.

Operational considerations

Assessing the situation

On arrival, crews approaching the incident should be mindful of the potential for a lithium or nickel based battery to be onsite, or on-board, and possibly involved in the incident.

Where the presence of large storage batteries is suspected or known, and damage has or is likely to have occurred, breathing apparatus (BA) should be worn from the start of scene assessment through all phases of stabilising the incident.

Residential and commercial installations of batteries can also be charged by:

- solar panels (photovoltaic cells/PVs)
- wind turbines
- an electric vehicle (i.e. homes-back-fed from the charge in the vehicle).

Power for charging batteries may not be from a reticulated mains power supply. Crews need to be aware of the continuous supply from any non-reticulated power generation, for example solar, wind, or small hydro power.

Any battery involved in an incident will still have stranded energy (power) in it, depending on the state of charge the battery was in at the time of the incident. There is also a risk of electrocution on any battery storage system, be it a fixed installation or in a motor vehicle, even after the incident is contained.

There may be a requirement to evacuate the area surrounding the vehicle or installation. These large battery installations can, if in a thermal runaway, release toxic and volatile fumes. Once they are venting, there is no way of predicting if or when fire may develop, and there is the risk of vapour explosion.

Initial actions

Water is currently the medium used for fire suppression.

Thermal runaway either pre-fire, or during a fire, can only be halted by cooling with copious amounts of water. Temperatures of up to 100°C can be generated, at which point the battery may start to vent and the vapours ignite.

Larger batteries systems will require large quantities of water to reduce the heat as quickly as possible, and pre-planning will dictate whether direct attack on an installation or exposure protection is the preferred approach.

Gas detectors will trigger on the carbon monoxide, which is a signature gas emitted by batteries in breakdown. Repeated monitoring may be required.

A thermal imaging camera (TIC) should be used and the battery should be continuously monitored to check stability. If temperature starts to rise, further water should be applied to reduce the heat.

Note: See the Hazards section for notes on PPE.

Monitoring

Any lithium or nickel based battery has the potential to reignite after initial fire suppression.

Gas detectors should be used to monitor carbon monoxide (CO) levels. Increased CO is a signature indicator of battery failure. A rise in CO values may indicate that the battery is failing.

Thermal imaging cameras (TIC) should be used to check and monitor battery stability.

Cooling may be required if temperatures start to rise. Monitoring (up to 5 days) may be required after the incident is contained. See Handover considerations below.

Handover considerations

When fire suppression has been completed, a handover to the owner or other agency needs to include safety information about:

- the risk of thermal runaway and possible ignition/re-ignition. This can be up to five days
- stranded energy still in the battery and the risk of electrocution from any damaged cabling
- the battery being stored outside, and kept at least 15 metres away from any other combustible material.

Safety considerations

Crew	• Identify if batteries are involved • Level 2 PPE and BA to be worn until scene is contained • TIC to be used to check and monitor battery stability • Approach from up wind to reduce risk of contamination.
People	• Public safety from toxic fumes • Risk of electrocution • Risk of re-ignition after initial fire suppression • Consider evacuation of area surrounding incident.
Environment	• Location of incident and surrounding properties • Downwind contamination risks from smoke • Contaminated run off from fire suppression may need to be contained • Pollution control notifications to be made.

Post-incident considerations/requirements

Decontamination	After the incident, decontamination will be required by G7-1 SOP Post fire decontamination procedure for Chemical fire. **Note:** The lack of industry standards makes it impossible to reliably determine what toxic and hazardous substances may be present during battery breakdown. Using the possibility of hydrofluoric acid as the default contaminant will give sufficient controls for decontamination.

Related information

Also refer to the following

Policy and procedures

- IS4-POP Electricity hazard management
- G7-POP Decontamination
- IS4-SOP Working safely around electricity
- IS4-GD Working safely around electricity
- G7-SOP Decontamination
- G7-1-SOP Post fire decontamination

YouTube video - Lithium battery in thermal runaway (https://www.youtube.com/watch?v=24fYrV2vCPk)

Document information

Owner	National Operations Manager
Last reviewed	27 September 2018
Review period	Every second year

Record of amendments

Date	Brief description of amendment
August 2018	Created

Fire Research and Investigation Unit
Specialist Fire Investigators Update
Issue 24 11 September 2018

Lithium-ion Batteries

Over recent times the Fire Research and Investigation Unit (FRIU) have been made aware of the increasing number of fires involving lithium-ion batteries.

The FRIU has been undertaking work to raise the awareness nationally of the health and safety dangers to Fire and Emergency New Zealand (FENZ) personnel for fires involving these products, how fires in such battery arrangements may impact on operational firefighting activities and to identify the extent of the problem.

In the fullness of time hopefully there will be more to come from FENZ on this, but in the interim, to protect **your** health and safety and to enable the FRIU to begin to get a handle on the size of this emerging problem we ask that:

1. Beware of the toxic nature of the fumes and by-products these batteries can produce. When on fire, these batteries produce Hydrogen Fluoride gas, forming corrosive and penetrating Hydrofluoric Acid with and potentially without moisture. Obviously very careful handling of such batteries, by-products and decontamination or disposal of say gloves exposed to these products needs to be considered.
2. Batteries that have been involved in fire can reignite several hours after extinguishment so should be moved to a safe place away from combustibles and to avoid accidental exposure by people to poisonous or corrosive battery residue.

"Lithium batteries emit highly toxic Hydrofluoric Acid gases under thermal runaway conditions. This gas is a chemical agent that affects the nervous system and is highly corrosive. Breathing Hydrofluoric Acid fumes will affect the nervous system, respiratory tract, lungs and impair the cardiovascular system. Symptoms may have delayed onset.

Air Services Australia (who provide aviation firefighting services at many airports in Australia) advise their staff that "any clothing or PPE that may have come in contact with electrolyte should be appropriately laundered or disposed of".

Until specific direction is issued by Fire and Emergency NZ Operations on decontamination of PPE, Specialist Fire Investigators are advised to apply current decontamination and laundering process marking the affected PPE as contaminated with Hydrofluoric Acid. If in doubt, discontinue use of the PPE until further advice is provided.

Use appropriate methods to handle such debris maybe like a shovel to pick it up, suitable gloves and/or consider disposing of gloves that may have been exposed to the Hydrofluoric Acid.

3. All fires involving lithium batteries and/or charging arrangements be reported through to Energy Safety (ES) even you don't have all the product detail available, the same as should be happening with any other electrical type fire in electrical appliances or infrastructure i.e. building wiring etc. A link to ES is in the SMS reporting system or use worksafe.govt.nz.

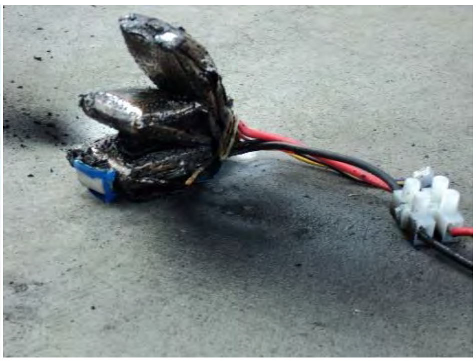
4. All fires involving lithium-ion type batteries, as well as been reported to ES, please report to your FRMO, so we can collect accurate data on these events. Please collect as much information as possible i.e. make, model, serial number, processes used at the time, age etc. to help inform the issue ahead of us.

5. FRMO's should advise the FRIU of such events with the relevant details.

6. If you are transporting the remains of whole or partial lithium-ion batteries, as a minimum make sure they are stored well away from other combustibles and preferably in a metal box like and old metal ammo tin or similar.

7. Undertake a dynamic risk assessment to ensure safe handling practices and the wearing of appropriate PPE, especially respiratory protection is in place.

It is anticipated that there will be more information surrounding lithium-ion type batteries and fires to come, so please treat this advice as an interim measure until it is either supported or replaced.



A lap top and battery pack that has failed as further examples of lithium-ion type batteries

Please distribute this notice through your areas to ensure operational staff are aware of this issue and required actions.

For other Specialist Fire Investigators Updates click here: SFI Updates

Published: 11/09/2018, Last Updated: 11/09/2018 | Category: Operational, Risk Reduction

Fire Research and Investigation Unit

Specialist Fire Investigators Update

June 17 Issue 19

SPECIAL EDITION Battery Safety:

LiPo (Lithium) Battery Safety Guide

Lithium Polymer or LiPo batteries are a great new way of storing energy for portable devices from cell phones, home electronics to RC hobby battery packs used in cars, boats and flight. They're great because they can store 350% (approximately) more energy than a typical NiCd/NiHm battery pack and weigh 10% - 20% less. They can also discharge much more current than a NiCd/NiHm battery, and can be fully charged in about an hour. LiPo batteries also don't develop memory or voltage depression characteristics like NiCd/NiHm batteries, and do not need to be discharged before being charged.

However, incorrect charging, impact damage and other mishandling of these batteries can lead to fire, explosions and toxic smoke inhalation. There are safety guidelines for charging and handling LiPo battery packs. Another good resource for information is LiPo battery info.

LiPo Safety

There are plenty of warnings on safety measures needed when charging LiPo batteries. LiPo batteries are made from volatile materials and if not looked after and charged/discharged at correct "C" rating as well as charge voltage, they can heat up and in some cases explode. There are plenty of videos on YouTube with LiPo packs exploding and releasing toxic gases including the Fire Research and Investigation Unit (FRIU) warning page on our website.

We recommend people use a fire proof LiPo safety bag or other fire proof container when they are charging, discharging, or storing LiPo batteries. When they explode LiPo batteries can generate an intense fireball at very high temperatures which can ignite nearby combustibles. Batteries may show signs of swelling prior to rupture. Below is a Safety Alert following a LiPo battery fire in New Zealand.

At any fire where you believe a battery may be involved in the ignition, ensure you document make/model of battery and charger if being used, ask about the history of the battery (usage, damage, recharging) and let Energy Safety (ES) know.

Hazard Alert - Lithium Polymer Bat

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Fire Research and Investigation Unit

Specialist Fire Investigators Update

Issue 19 June '17

Battery Issues:

MiniMax Charger: A recent multi-million dollar loss fire in Auckland attributed the cause as a faulty MiniMax Charger unit. These units have Lithium Cobalt Technology.


The FRIU has an increasing number of issues reported to us regarding suspected origin and cause of fires in all types of batteries.

A fire at an electrical wholesalers was believed to have originated from smoke alarm batteries that had been removed from redundant alarms. The hypothesis was that the batteries had shorted against other battery bodies causing overheating and igniting adjacent combustibles.

The FRIU attempted to reproduce this by creating direct shorts across battery terminals as shown below, however under the conditions tested the maximum temperatures achieved for 9 volt batteries were only in the vicinity of 90°C. One test of a 6 volt battery achieved a maximum temperature in the vicinity of 92°C. The temperatures were measured using a hand held infra-red thermometer.

YouTube, amongst other sites, contains information suggesting that disposal of 9 volt batteries with exposed terminals have caused serious structure fires. The FRIU findings don't preclude this from happening, only that we were unable to replicate conditions that would confirm this. NFPA Battery Info N:\FR&IU\Information and Knowledge\Reported fire trends\Batteries\NFPA 9 volt battery safety leaflet.pdf

To assist in determining any emerging trends, it is vital that all fires involving or suspected as being caused by any sort of battery be reported to both Energy Safety and to the FRIU.

Provided here is a link to the most common types of Lithium-ion batteries on the market to assist in knowledge of these products.

http://batteryuniversity.com/learn/article/types_of_lithium_ion

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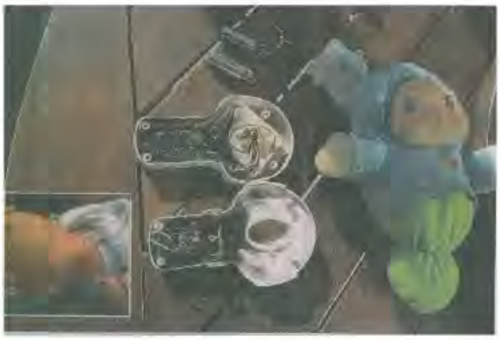
Playskool Lullaby Gloworm Toy



A recent media article reported a complaint by parents that this product allegedly burnt their baby when the batteries overheated. There has not yet been a formal recall by the supplier or Energy Safety, so just a heads up on this potential issue.

Electrical inspectors have expressed some doubt as to whether the heat damage suffered by the toy could have been caused by the dry cell batteries from the toy.

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If you become aware of any apparent fire trend; or you encounter a fire cause that you believe may have national implications, please let the FRIU know ASAP.

Fire.Investigation@fire.org.nz

Many thanks from the FRIU team.

Fire and Emergency New Zealand

National Notice

034/2018

SUBJECT	**Operational instruction for working around batteries**
DATE	27 September 2018
TO	All personnel
FROM	Paul Turner, National Operations Manager
STATUS	Operational instruction

Action

1. Read and discuss the IS4 SOPb Energy storage systems procedure.
2. Complete the Electricity modules in Learning Station and make sure the OSM task is recorded in SMS.
3. Action the energy storage systems procedure listed in our guideline when batteries are involved in incidents.

Summary

The energy storage systems industry is relatively new. The industry is characterised by larger size batteries with lithium or nickel based contents.

We are aware that currently there is a lack of a standard approach to battery construction and contents. However, we do know they contain toxic and corrosive compounds – particularly in larger batteries. These compounds can be released if the battery is damaged either electrically or physically, whether the damage can be seen or not.

Monitoring batteries known to be involved and following the correct procedure when working around them is important, including:

- wearing correct Level two PPE and BA, and
- decontamination.

National Operations is monitoring the industry and increasing our contact with those responsible for setting the appropriate standards for battery use and control authorities.

Current situation

Lithium and nickel based batteries are increasingly being used to power vehicles and to support electricity distribution. There are no standards for the content, importing or sale of many of these batteries, even in larger sizes. Common uses are in vehicles including buses and refuse trucks at present. Use in homes, businesses, and support for the electrical distribution industry is also growing.

The issue for us, is that lithium and nickel based batteries can add risks if they are damaged including:

- fire
- electric shock from retained energy
- hazardous chemical leaks and/or explosions.

The industry is in the early stages of setting standards for the control and use of batteries in energy storage systems. This industry is separated from the hand held and small format battery industry, although the hazards and controls are the same no matter what size the battery.

We have developed IS4 SOPb Energy storage systems procedure to provide guidance for personnel when batteries are involved in incidents we respond to.

Looking ahead	We know technology around batteries and energy storage systems is evolving. National Operations is engaging with electrical industry participants, as part of an industry interest working group, to define and recommend any controls to lead and manage the hazards associated with energy storage systems. As we have more information, we will review our operational instructions and update the procedures.
Contacts	For more information, contact Keith Pedley National Operations Advisor Plant and Equipment at Keith.Pedley@fireandemergency.nz
	End of notice.

E1-1-4-7 Thermal imaging cameras (TICs)

Scope	This operational requirement applies to thermal imaging cameras (TICs) suitable for identifying heat sources relating to fire situations and for search and rescue.

Requirements

The following are the mandatory requirements for a thermal imaging camera for use by the New Zealand Fire Service:

General	• designed for use in interior structural firefighting • capable of single-handed operation • able to be started up whilst wearing structural firefighting gloves • microbolometer sensor • an image capable of being viewed in varying levels of light whilst the operator is wearing a breathing apparatus mask • re-chargeable battery packs – lithium-ion or nickel-metal hydride preferred • battery charging module/s suitable for mounting in a vehicle (24 Volt) capable of charging two batteries simultaneously, one of which will be fitted to the camera.
Vision	• field of view no less than 50° diagonal • able to clearly detect a person at not less than 50m in daylight • colour image enhancement • data input/output socket or alternative means to allow download of images • still photography capture.
Temperature	• dynamic range of not less than 500^{0}C • spot temperature measurement • ambient temperature measurement • able to operate in a 60 °C environment for one hour • able to operate in an environment greater than 60 °C for short periods • over temperature warning • external components, including hands free carrying facility, made from flame resistant materials.
Batteries and start up	• battery status indicator displaying the operational life of the battery • operational battery life of at least 1.5 hours • battery recharge time less than the operational life of the battery • spare battery pack • battery charging module for office use (240 Volt) • fully operable in 10 seconds or less from a fully off state • simple one-action start up procedure

Health and safety/ ergonomics	• the equipment should be impact and vibration resistant and able to withstand an impact from a one metre drop • operational weight, including batteries, not exceeding 2.0 kg • shielded for electromagnetic and radio frequency interference for emissions to EN 50081-2:1992 and for immunity to EN 50082-1:1992, or similar standards.
Portability and durability	• hands-free carrying facility i.e. carry strap, lanyard • hard shell carry case for storage of camera and accessories • Sealed to prevent ingress of water and dust to BS EN 60529:1992 IP65 or similar standard.
Other	• training manual, on video or compact disk, detailing features & operation, and care and maintenance regime, to be supplied with each camera.

E3-2 Prepare BA torch for use

BA Service Hub	Firefighter	Tips

BA Service Hub

Streamlight Vantage 180 (orange) BA torches ordered from Phillips & Smith Ltd.

1. Receive torch packs
2. Remove helmet clip and discard
3. Fit batteries, add Dräger hose clip #3358835
4. Issue BA torch

Firefighter

4A. Collect BA torch

5. Use the hose clip to attach BA torch to shoulder harness

BA torch securely fitted

Tips

Note:
CR123A lithium batteries can be sourced free from your Dräger technician (PASS alarm batteries)

Attach the BA torch to the right shoulder harness, 2nd loop from the bottom

Important
Ensure the hose clip is attached to the harness, for the torch to sit firmly

Alternatively, attach the BA torch upside down in the hose clip

Use a cable tie to secure the BA torch to the torch clip

NEW ZEALAND FIRE SERVICE

National Notice 3/2011

SUBJECT	**SAFETY NOTICE – Photovoltaic Solar Panels**
DATE	18 January 2011
TO	Operational Personnel
FROM	Brian Davey, National Manager Operational Standards
STATUS	Safety Notice

Background

Photovoltaic solar panel arrays (PV systems) are becoming more common power sources for buildings. PV systems:

- generate DC voltage and use inverters to transform this into AC voltage
- may generate up to 600V DC with large current flows.

Electrical shock hazard

Many photovoltaic panels cannot be switched off or isolated, creating an ongoing electrical shock hazard near:

- the panels
- the wiring between the panels and the battery/inverter.

Identification

PV panels are shown at the front of the adjacent image. Grid connected PV systems will have a notice on the switch board indicating dual supply (this will usually include the location of the inverter).

PV systems should not be confused with solar panels used for heating water or other fluids (seen to the back of this image) which only present heat hazards.

Image from www.ecobob.co.nz

Photovoltaic Solar Panel Array

PV systems consist of panels (usually on the roof), the inverter (usually inside the building), and cabling which joins the two.

Some PV systems also have a charger controller and batteries before the inverter.

Isolation switches

Check for "Shutdown procedure" located near the inverter or meter box and follow these instructions.

If there is no shutdown procedure, then, locate and switch off the AC isolation switch (and PV array isolator if fitted) on the output of the inverter which will stop the PV power supply to the building.

Fire in panels

If the panels are on fire <u>do not attempt to extinguish</u> – allow to burn out, while protecting exposures.

During operations

When a PV system is present at an incident the OIC Fire will:

- ensure all crews are informed that there is a PV system and to treat it as live at all times
- isolate the output from the PV system if practicable and required for operations (the panel side of the system will still be live)
- consider covering the PV panels to reduce the power output from the panels if operationally necessary (note: caution will still be required as residual light may still generate power)
- recognise the potential hazard of PV panels falling if the fixings are damaged (for example by fire or wind).

End of notice

Station Officer Programme

Study Guide

Specific Incidents

WHAKARATONGA IWI FIRE EMERGENCY NEW ZEALAND

Status of this Document

This document is issued by Fire and Emergency New Zealand.

Recommendations for Change:
Training encourages and welcomes feedback on all its materials.

Recommendations for changes to this material should be sent to Training using the Training Feedback Form on The Portal.

Document Title: **Station Officer Programme – Specific Incidents**

Published: **1 July 2007** **Amended: 8 May 2012; October 2013; October 2017; February 2019**

If you wish to copy or reproduce any of the material in this document, please contact:

Fire and Emergency New Zealand
Team Leader, Learning and Development
Training
PO Box 2133
Wellington 6140

Contents

Course Introduction

What is the aim of this course	The aim of this course is to further your knowledge of some specific incident types and your role in them as an officer.
What is in this course	The course consists of a theory section and at least one practical session. **Theory:** There are three theory modules in this course: 1. Hazardous substances 2. Terrorist incidents. 3. Clandestine laboratories. 4. Background to vegetation fire behaviour.
Why you need to know this	While every incident will be unique, there are some specific incidents for which it would be useful for you to have some prior general knowledge.
How this course is taught	The theory part of this course is delivered by distance education. Read through the study guide and complete the activities and assignments when prompted. The activities and assignments are located in your specific incidents workbook. There is one assessed assignment that will count towards your final mark.

Hazardous Substances

Section Objective

The objective of this section is for you to understand the legislation, operational and safety considerations when responding to Hazardous Substance emergencies.

Why you need to know this

The Fire and Emergency New Zealand Act 2017 mandates that Fire and Emergency New Zealand (FENZ), (as one of the primary functions) responds to, and make safe hazardous substances incidents.

How this is taught

This module delivered by distance education (this study guide and workbook).
The sections cover:

- Relevant legislation
- Operational Management in New Zealand

Read this study guide in conjunction with H1 TM (the Hazardous Substances Technical Manual) and M1 TM (the Command and Control Technical Manual) and the Qualified Firefighter Career hazardous material study guide as a refresher where needed.

Relevant legislation

The two main pieces of legislation that govern Fire and Emergency New Zealand's response to a hazardous substance emergency are The Fire and Emergency New Zealand Act 2017 and the Hazardous substances and new organisms Act 1996.

The Fire Emergency New Zealand Act 2017 (the Act)

Section 11 Main functions of FENZ
(1) FENZ must carry out the main functions specified in subsection (2).
(2) The main functions are—

(a) to promote fire safety, including providing guidance on the safe use of fire as a land management tool; and
(b) to provide fire prevention, response, and suppression services; and
(c) to stabilise or render safe incidents that involve hazardous substances; and
(d) to provide for the safety of persons and property endangered by incidents involving hazardous substances; and
(e) to rescue persons who are trapped as a result of transport accidents or other incidents; and
(f) to provide urban search and rescue services; and
(g) to efficiently administer this Act.

The Act gives FENZ powers to respond to HAZSUBS incidents. Under **section 39** it states that:
If a hazardous substance emergency occurs, the authorised person responding to the emergency may do 1 or more of the following:
(a) endeavour by all practicable means—

(i) to stabilise or render safe the hazardous substance emergency:
(ii) to save lives and property in danger:

(b) direct any person to stop any activity that may contribute to the emergency:
(c) request any person, either orally or in writing, to take any action to prevent or limit the extent of the emergency:
(d) direct any person to leave any place in the vicinity of the emergency:
(e) direct any person to refrain from entering the vicinity of the emergency.

(2) If this section applies, the authorised person has the powers of an enforcement officer under the Hazardous Substances and New Organisms Act 1996 relating to the hazardous substance emergency until the arrival of an enforcement officer.

The Act states that a hazardous substance emergency means the release or potential accidental release of any hazardous substance from any building or other premises, or from any container or pipe, or from any means of transport (whether motorised or not).

Section 40 - Power to destroy or dispose of any by-product
An authorised person may destroy or dispose of any by-product after rendering safe a hazardous substance emergency or other substance emergency, if—
(a) the owner of the hazardous substance, other substance, or by-product cannot readily be contacted or identified; or
(b) the authorised person reasonably considers that it is not appropriate or feasible to transfer the by-product to another authority; or
(c) the authorised person reasonably considers it necessary or appropriate to destroy or dispose of the by-product.

Hazardous Substances and New Organisms Act 1996 (HSNO)

The Fire Emergency New Zealand Act 2017 generally empowers Authorised persons to manage all hazardous substances incidents. Consequently, FENZ officers should seek to operate under The Fire Emergency New Zealand Act 2017 in preference to any other legislation. If FENZ arrives at an incident and an emergency has already been declared under the Hazardous Substances and New Organisms Act 1996 (HSNO), there are certain powers an enforcement officer has that FENZ Officers need to be aware of. For example, the power to take samples for evidence, which FENZ personnel would not need to do but might be directed to do so to assist an Enforcement Officer.

Section 135 extends the definition of Enforcement Officer to cover any employee, volunteer, or contractor of Fire and Emergency New Zealand exercising powers under the Fire and Emergency New Zealand Act 2017.

It is important to note that Enforcement Officers can declare an emergency when they have reasonable grounds to believe that an emergency exists. Until the emergency is over, they have wide-ranging powers for managing it.

If FENZ responds to a hazardous substances emergency, it should be treated as an emergency under the FENZ Act. No other agency can declare a HSNO emergency until FENZ emergency is closed.

If FENZ arrives to find that another agency has already responded and declared an emergency under the HSNO Act, the OIC may elect to deal with the emergency under the FENZ Act. The HSNO emergency then ends (an example might be when a threat to life or property exists, and the OIC deems that it is not being dealt with).

The HSNO emergency may be reinstated after FENZ emergency ends, this allows enforcement officers to take any steps necessary to prevent the incident from recurring.

In some situations, it may be more appropriate for another agency to take the lead. The circumstances under which an officer may believe it is more appropriate that an emergency is dealt with by another agency using the HSNO Act may be the following:

- When a special approval is required as part of the emergency, such as resource consent for the clean–up or removal of a contaminant.
- If the incident will be over a long timeframe, for example, over a number of days.
- Where specialised contractors have to be brought in, for example, drillers and excavators.
- If FENZ is in a situation where it may have to justify any of its actions to an enquiry or court on technical grounds, as required under the HSNO Act.

Summary

Where the hazardous substance emergency is outside the standard resources of FENZ, for example, where the incident is of a criminal or terrorist nature, then the emergency should be dealt with by another agency under the HSNO Act.

Other legislation that can impact the management of a hazardous substances Emergency:

• Hazardous Substance and New Organism Regulations 2001 concerning:

- packaging
- disposal
- tracking
- personnel qualifications
- emergency management
- identification.

• Resource Management Act 1991
• Land Transport Dangerous Goods 2005 Rule 45001/1 and 2010 Rule 45001/2
• Maritime Rule part 24A: Carriage of Cargoes—Dangerous Goods
• International Maritime Dangerous Goods Code
• Workplace exposure standards and acute exposure guideline levels
• Health Act 1956.

Glossary of terms

Contaminant
Any substance—whether gaseous, liquid, or solid—that may adversely affect the health and safety of people, property, or the environment.

Emergency
Includes a hazardous materials emergency.

Hazardous substance
A hazardous substance is:

- as defined in Section 2 of the Hazardous Substances and New Organisms Act 1996
- any infectious or radioactive substance that may damage human, animal, or plant health.

Dangerous goods
These include:

- substances or articles that have the properties described in Table A of Properties and Classification of Dangerous Goods for Land Transport (available online)
- packaging and empty containers that have not been cleaned after containing dangerous goods.

Hazardous substances emergency
The release, or potential accidental release, of any hazardous material amounting to a contaminant from any:

- premises
- container or pipe
- means of transport (whether motorised or not).

Managing hazardous substance incidents

The initial approach to the event/Approaching a hazard
When approaching a hazard, keep yourself and your crew members safe at all times. To keep yourself and other firefighters safe:

- ensure that you are upwind, uphill, and upstream of the hazard
- never drive through clouds or spills
- stay a safe distance from the hazard.

Position vehicles so that:

- you can enter and leave the area easily
- you are facing the way out
- you have left enough space to provide decontamination.

To find the recommended safe distances for outdoors, refer to the Initial Emergency Response Guide

To decide what are safe distances indoors, consider:

- what the material is
- how dense any vapour is
- the types of air conditioning or air management systems
- the kind of structure and who is in it.

Safety concerns on arrival

Consider the following safety factors when arriving at an incident. Do not rush in to provide help to injured people. Your priorities should be preservation of self, team, others, victims.

- Stop any unsafe activities.
- Plan before acting.
- Isolate the area.
- Make sure you and others are only exposed to the hazard for as short a time as possible.
- Stay as far away from the hazard as possible.
- Use cover to protect yourself and others.
- Select the right kind of PPE for the job.
- Treat all material as hazardous until proven otherwise.
- Appoint a Safety Officer.
- Consider appointing a Hazard Control Officer.
- Observe hazards and whether local conditions change.
- Don't underestimate small events.
- Be aware of the atmosphere (wind, rain, etc.).
- When ready, provide a thorough situation report to Comcen.

Size-up

As with a structure fire or any other incident, the officer must undertake a comprehensive size-up to gain situational awareness. Due to the exposure concerns, a full 360 size up may not always be physically possible so the officer may initially need to rely on information gathering from witnesses, hazard placarding and prior knowledge of the site/location to form an incident picture.

Potential for escalation

As OIC, you should aim to move from being reactive to being proactive. At the start, you will respond to the incident as it develops, but you also need to predict how the incident will progress and bring in the resources you may need accordingly. You need to do this as quickly as possible, but it can be difficult when you are also dealing with immediate actions. It is a good idea to delegate tasks so that you have time to think about the incident and how it might develop. To help you predict incident development, ask yourself questions like:

- What could make this situation get worse?
- How bad could it get?
- What might happen if it gets to that stage?

Refer to the NZFS Command and Control Technical Manual for more information.

Securing the scene

To control an incident and protect the public, you need to secure the scene, isolating the area involved, this is done using zones and cordons as necessary.
Refer to the Initial Emergency Response Guide for cordon and zone areas specific to various hazardous substance groups.

Resolving the incident

The basic principles of dealing with any HAZSUBS incident are to apply RECEO and ICIM:

- Isolate
- Contain
- Identify
- Make Safe (& Decontaminate.)

The relationship between these two models is illustrated below

Isolate

To isolate an area, you need to decide what area is affected or at risk. You then need to isolate the area and remove everyone from it. When you arrive at an incident that involves a hazardous substance, you need to set up a hot zone as soon as possible. The first crew at the incident sets up the hot zone. When more firefighters and resources arrive, you can set up control zones. Control zones will isolate the area further.

Contain

Containing a leak or spill refers to preventing the spill or exposure from escalating and can be achieved in a number of methods including
Blocking drains
Building dams or barriers using soil or absorbent
Relying on bunded areas

Identify

As you approach an incident, you may find several things that will help you to identify a substance. Think about all the information you have. Weigh-up your information carefully. Don't rely on a single piece of evidence or information. Possible sources of information include:

- details from the caller
- equipment that can detect, identify and monitor substances
- operational or emergency response plans
- containers at the scene
- manifests, shipping papers, and safety data sheets
- markings on buildings, vehicles, or containers
- the type of area or the kinds of structures there
- placards
- people in the area
- witnesses.

For more information on identifying hazardous substances refer to H1-TM

Make Safe

Once you have identified the hazardous material, you can select the appropriate methods to make the situation safe; this could be as simple as righting a container or decanting the contents then applying absorbent or diluting as necessary but may require the assistance of a specialist contractor. Gas clouds can be left to dissipate or forcibly ejected using a PPC fan.

Decontamination

For information specific to decontamination see H1-TM

Module 2: Terrorist Incidents

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Workbook Activity 1

Turn to your workbook and complete the questions in Activity 1.

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Workbook Activity 2

Turn to your workbook and complete the questions in Activity 2.

Module 4: Background to vegetation fire behaviour

What is in this module

This course provides sufficient information to equip you with a basic understanding of vegetation fire behaviour. It also covers the fundamentals of fire danger prediction.

Why you need to know this

While Fire and Emergency urban personnel may be primarily concerned with structural fires within urban areas, there will inevitably be a need, from time to time, to attend vegetation fires of varying sizes. In central city areas these may be limited to small incidents in parks and reserves. On the urban-rural interface, however, these incidents are likely to be larger in scale, more frequent.

To manage a vegetation fire incident effectively and safely, or to assist rural firefighters with the management of larger scale incidents, you must have a base-level awareness of vegetation fire behaviour. This course provides that base level.

Module objective

The objective of this module is for you to be able to explain the basics of vegetation fire behaviour.

How this is taught

This module is taught by distance education (this study guide and workbook).

The sections cover:

- The fire environment.
- Fire behaviour.
- Fire danger and the weather index system.
- Operational management in New Zealand.

The fire environment

Section objective

The objective of this section is that for you to be able to explain the factors involved in the fire environment.

Definitions

'Fire Environment' is defined in the Glossary of New Zealand Rural Fire Management terminology as:

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

In simple terms it can be described as those conditions surrounding a fire that determine the way the fire will behave.

Prediction of fire behaviour is essential for safe and effective control and use of fire. This requires an understanding of the interactions of fire with its environment.

The fire environment consists of three major components:

- Topography
- Fuel
- Air mass or weather.

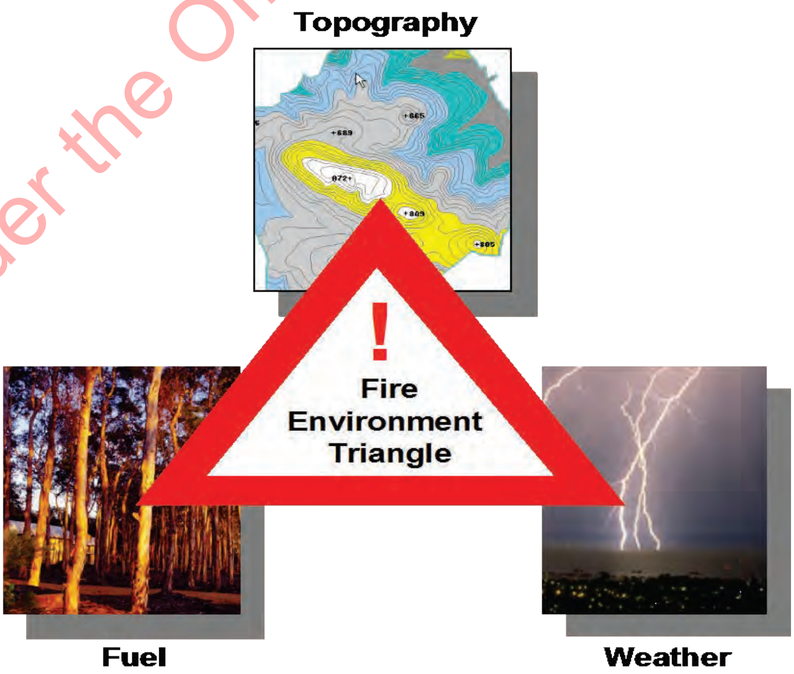


Figure 3.1: The fire environment

Critical inter-relationship

Topography can vary significantly over an area, but changes very slowly over time. Fuel components can vary over an area and also over time. The moisture content of dead fuels will change due to the effect of weather conditions. The weather is usually the most variable component, changing rapidly in both area and time.

The interaction of these three components with other conditions determines the fire environment for a particular area.

Fire can be considered as a local heat source. As such, it influences and modifies the fire environment. Because a fire creates high temperatures, it can dominate the environment. The extent of the fire's influence varies with fire intensity.

Most changes in fire behaviour occur as the fire moves over the terrain and/or 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.

Fire behaviour is the interaction of the fire environment components with each other and with the fire.

It is possible for firefighters to acquire sufficient skill in predicting fire behaviour to allow safe and efficient control and use of fire. Development of this skill comes from experience and from training in the fundamentals of fire behaviour and the fire environment.

Each of these key components is dealt with in more detail on the following pages.

Topography

Definition

The term 'topography' refers to the shape and orientation of the land surface.

Of the three major factors which influence vegetation fire behaviour – topography, fuels and weather – topography is the most static and, therefore, the most predictable. It changes very slowly over time but can vary significantly over an area.

Topographical factors

Topographical factors influence:

- fuel type and density
- micro-climates
- the direction and speed at which a fire may spread
- the general behaviour of a fire.

Topographical factors continued

Topographic factors that need to be considered are:

- elevation
- slope
- aspect
- shape of surrounding terrain
- barriers to fire spread
- topographical influences on fire behaviour.

Elevation

Two broad factors that need to be considered are the elevation of an area above sea level, or altitude, and the elevation in relation to the surrounding country.

Elevation influences the general climate of an area, and in turn this influences the vegetation type/s. It is a factor that needs to be considered in determining potential fire behaviour for a particular area.

The key influences of elevation on climate and fuels are as follows:

- Generally, temperature decreases with elevation and relative humidity increases
- Solar heating may influence the daily flow of air between mountain ranges and valley floors. During a hot, calm day warm air rises, causing up-slope draughts. If this air is heated rapidly, the up-slope draught can cause air turbulence and whirlwinds. At night, the airflow generally reverses, bringing cooler air back down the slope to the lower lying areas
- Wind strength can increase considerably as the prevailing airflow is forced up and over or around elevated terrain. Rainfall will be greater on the windward side of elevated terrain
- Vegetation growth is generally slower at higher elevations and is slower to decompose, leaving a higher than normal proportion of dead fuels. Slower drying rates of fuels can be expected.

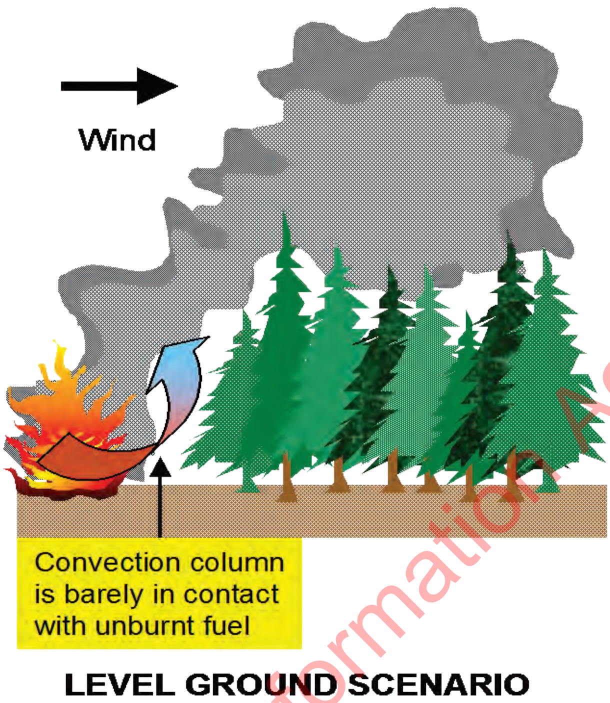
Elevation influences the microclimate and hence fuel type and condition.

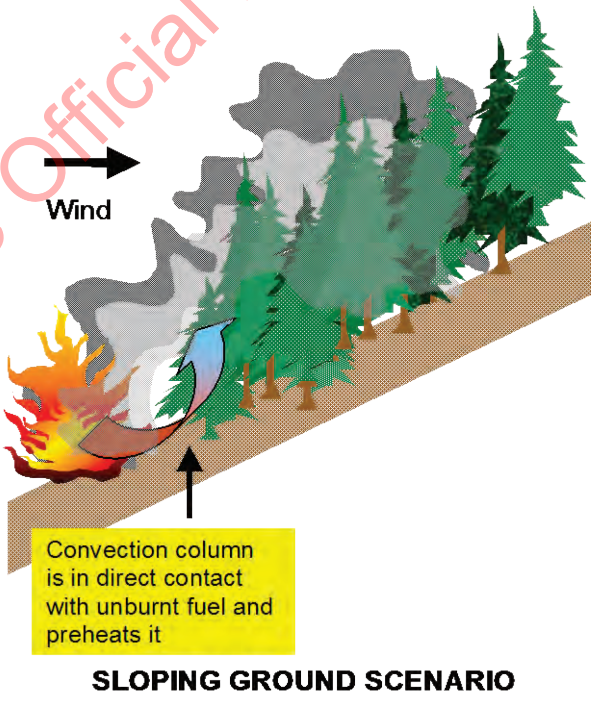
Slope

Slope is simply the upward and downward inclination of the land's surface in relation to the horizontal. For fire behaviour purposes, slope is measured in degrees from the horizontal and can be assessed visually or by reference to a topographical map. On a map, the closer the contour lines, the steeper the slope.

Slope steepness has a decided effect upon fire behaviour in that it affects the rate of fire spread and fire intensity, i.e. fires burn more rapidly and intensely upslope than downslope or on level ground.

The effect is similar to that of wind, and reduces the angle between the flames and fuel upslope of the fire. This increases the rate of radiant and convective pre-heating of those fuels and this in turn increases the rate of spread (ROS) of a fire.





Figures 3.2 and 3.3: Effect of slope on fire

Steep slope effects

- The steeper the slope, the more likely a fire will drive upward in a wedge shape forming a narrow, high-intensity head fire. This rapid movement of the fire may cause strong in-draughts on the flanks
- The rate of fire spread on a 10-degree slope can be one and half times faster than on level ground. On a 20-degree slope, the rate of spread can be three times faster, and on a 30-degree slope, it can be six times faster than a fire on level ground
- Wind blowing directly upslope further reduces the angle of flames and increases the rate of pre-heating of fuels. The flames may directly bathe fuels ahead of the fire, and exceptionally high rates of fire spread can occur
- Potential for spotting through convection carrying firebrands upslope. Burning material can roll downhill and cause upslope 'fire runs'.

Downslope effects

- Fires generally burn slowly down a slope, but 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
- In mountainous country the effect of a downslope wind can override the effect of slope (e.g. hot and dry fohn winds – see later in this module)
- Strong down slope winds may drive fire downslope, reversing the normal slope effect of fire spread. To a lesser extent, breezes at night can cause a fire to move downslope quicker than normal.

Mid-slope effects (thermal belt)

The thermal belt is a narrow horizontal belt of warm air captured midway up the slopes within a land basin, predominantly when the basin shape of an area doesn't have a natural opening for air drainage. Under calm conditions over a 24 hour period, this belt generally receives the highest temperature and the lowest relative humidity. Consequently, fuels within the thermal belt are likely to have a lower fuel moisture content than the fuels above or below it. When fire enters this thermal belt it develops a more intensive fire behaviour pattern with fires often remaining quite active at night.

Slope influences the rate of spread and intensity of a fire.

Aspect

Definition

'Aspect' refers to the direction a slope faces in relation to its exposure to the sun (e.g. 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 east and south aspects.

The greater the slope, the smaller the angle of the sun's rays as they strike the surface, and consequently the greater the intensity of solar heating.

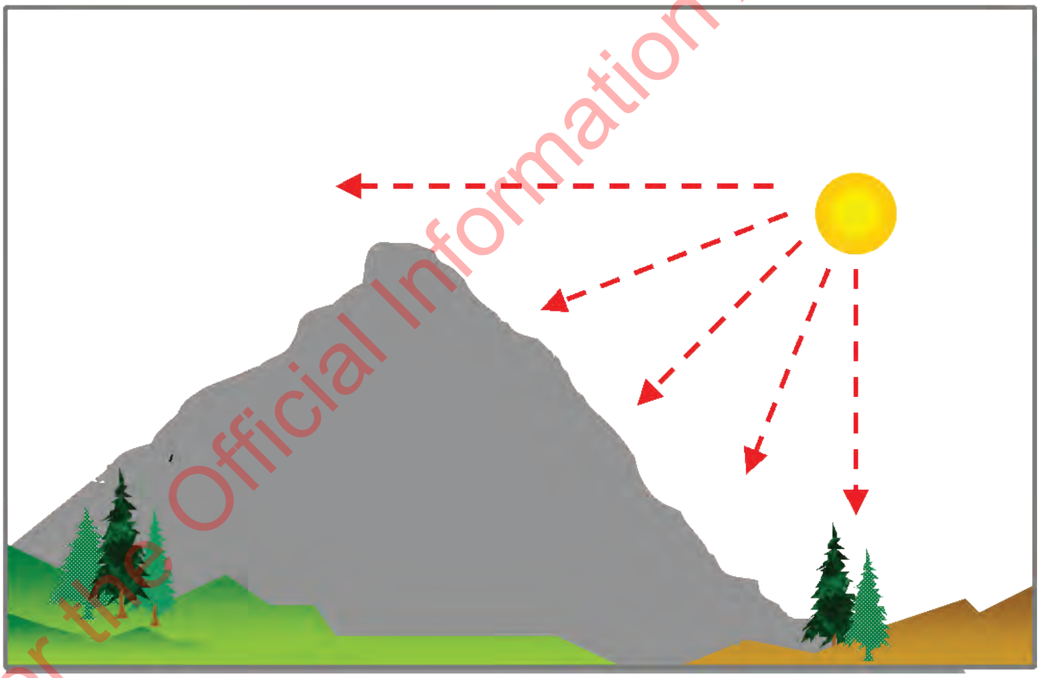


Figure 3.4: Effects of aspect on solar heating

Key influences of aspect

- Generally, northern and western aspects have greater vegetation growth, and often will have different vegetation to cooler, moister southern and eastern aspects
- Vegetation and soils on northerly aspects will dry out more rapidly, and fuel moisture content will be lower
- Vegetation on northerly aspects is more flammable, with a greater potential for ignition and rapid fire spread than vegetation on other aspects
- Temperatures will be higher and relative humidity lower on areas with a northern or western aspect than on a southern or eastern aspect. This is due to differences in exposure to solar radiation during the day
- Solar heating of northerly aspects will generate upslope winds and turbulence.

Aspect influences the fuel condition.

Terrain

Lay of the land

In rugged terrain the shape of landforms are of great importance in predicting fire behaviour. Valleys, gullies, canyons, intersecting drainages and irregular slopes can all have a bearing on the direction and rate of fire spread, and fire behaviour in general (e.g. spotting, firewhirls).

Topography has a mechanical effect on local winds. Local topographical features affect 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.

Valleys

- A wide valley will generally not affect the direction of the prevailing wind. However, local winds can increase along a valley floor
- In narrow valleys the wind can funnel along the valley floor, increasing in speed
- Ridges and forks along the valley will disrupt the airflow causing strong eddies and turbulent local winds
- In steep narrow valleys, spot fires can occur on the opposing face because of short distances associated with radiant heat and turbulent wind conditions
- Aspect has little effect on drying fuels in the bottom of deep narrow valleys, due to shading.

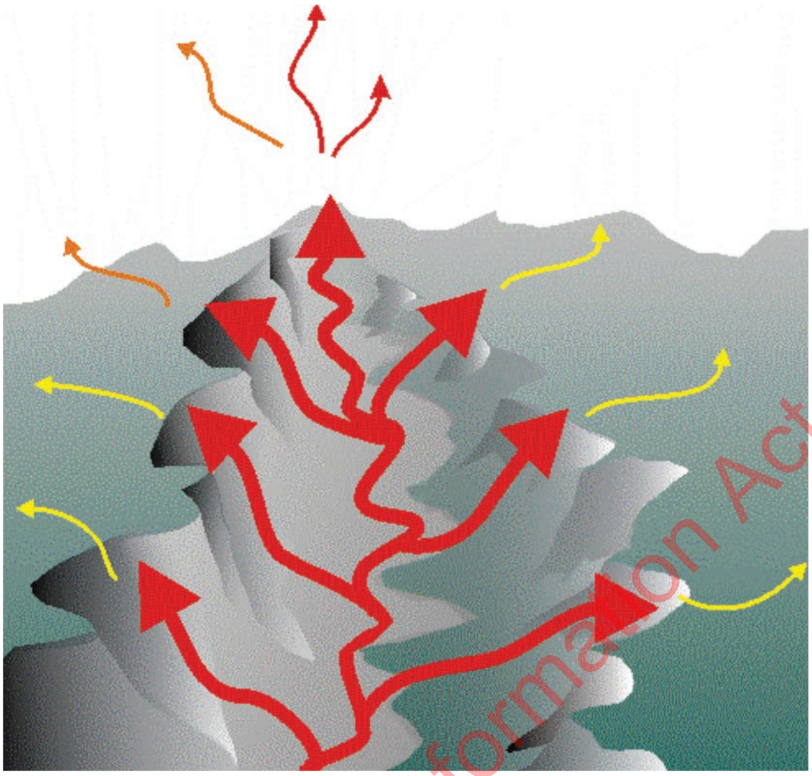


Figure 3.5: Typical effects on wind due to valley topography

Ridges

- Strong airflow over sharp ridges can create very erratic wind behaviour on the lee side of the ridge, causing turbulent upslope winds and eddies
- Strong airflow over rounded top high points may follow the lay of the land and cause rapid downslope fire spread on the lee slope
- With an opposing upslope airflow (from the other side of the ridge from a 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 intensity and rate of spread under the combined influence of slope and a greater exposure to wind.

Figure 3.6: Air flow over rounded ridge tops following the shape of the ground

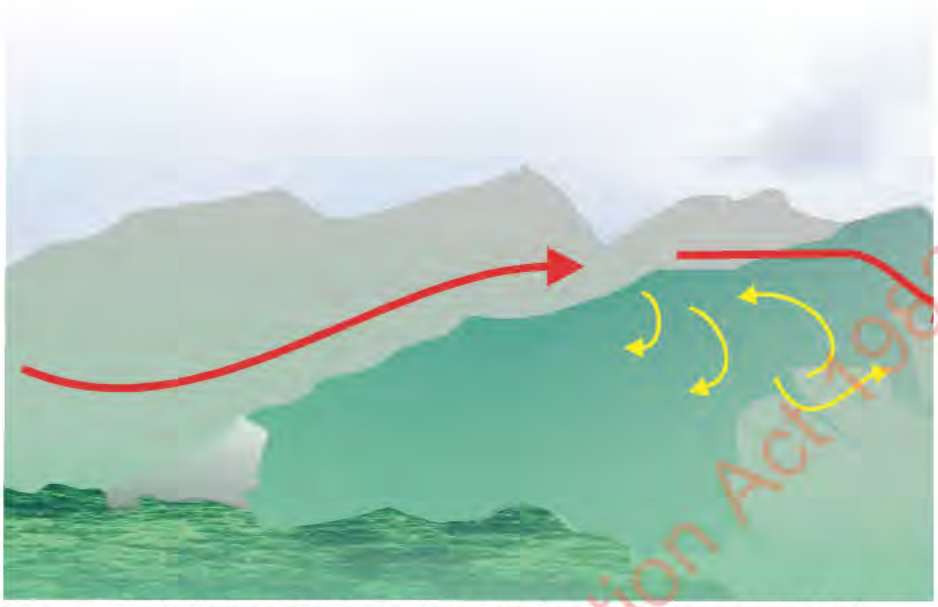


Figure 3.7: Air flow over sharp ridges creating turbulence on lee side

Chimney effect

In steep terrain, a combination of the slope effect and wind channelling into any depression in land shape will result in strong up-draughts. This funnelling effect directs the movement of fire into a narrow rising path. The fire's rate of spread (ROS) and intensity will increase rapidly, just as in a chimney fire

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

The shape of the terrain influences the direction rate of spread and intensity of fire.

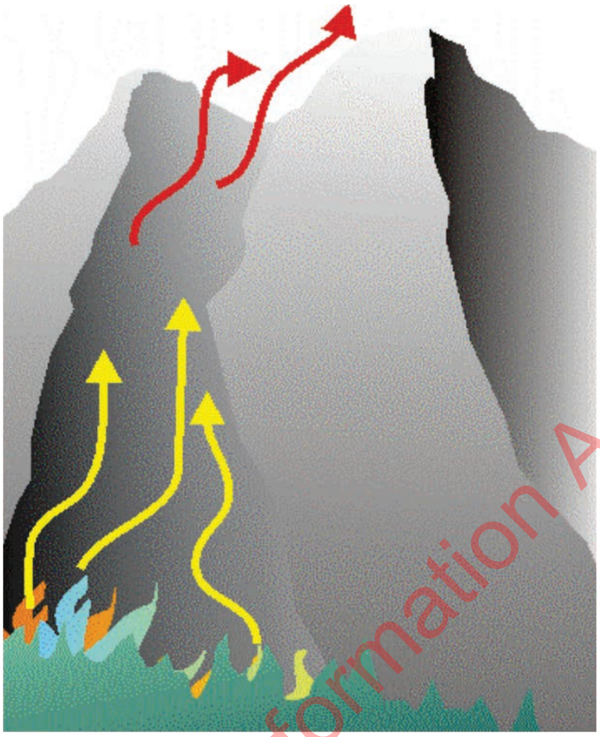


Figure 3.8: Chimney effect

Barriers to fire spread

Natural or man-made barriers to fire spread, such as areas devoid of vegetation, can have a significant effect on fire behaviour. Barriers may affect the spread of fires in two ways:

1. Directly, through the absence of fuels or by having fuels that differ in their characteristics from the adjacent fuels
2. Indirectly, through modification of relative humidity or local winds

Barriers to fire spread can change a fire's intensity, rate of spread or direction of spread. They can, therefore, aid the containment of fire spread by being utilised as fire breaks or fuel reduction areas.

The shape of the land can influence fire spread to either the advantage or disadvantage of fire containment efforts. For example, steep terrain with a barren strip along the ridge may be of more assistance to the containment of fire spread than flat open land with contiguous fuels.

Similarly, certain physical features can act as barriers to fire spread.

Natural barriers may include:

- Landslides and barren areas
- Rivers, streams, lakes, swamps, and the ocean
- Bottom of gullies (only when shaded and wet)
- Terrain shape (ridges).

Man-made barriers include:

- Roads/railways
- Firebreaks
- Cultivated land.

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

Summary

In summary:

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

Safety issues

Dangerous situations arising from topographical considerations are:

- working uphill of a fire
- working on a hillside
- working in rugged terrain
- working in unfamiliar territory.

Fuels

Overview

Like topography, the fuel component of the fire environment can vary over an area, but can also vary considerably over time. It is influenced by weather and by seasonal changes, and it is also the one component that can be manipulated to influence or modify the behaviour of vegetation fires.

The ignition, build-up, and behaviour of fire depend on fuels more than any other single factor. It is the fuel that burns and generates the energy with which the firefighter must cope. This largely determines the rate and level of intensity of that energy. Other factors that are important to fire behaviour (i.e. moisture, wind etc), must always be considered in relation to fuels. In short, no fuels – no fire!

Fuel temperature is much more variable than air temperature. It is the fuel temperature that determines its moisture content and flammability. Even though the air temperature and relative humidity may be stable over the fuel bed, the fuel bed can be highly variable in surface temperature and thus highly variable in flammability. Fuel in daylight hours is constantly changing from cool to hot and back to cool. Sunlit fuel is often heated to 90 degrees Celsius by solar radiation and becomes many times more flammable than cool, shaded fuels.

Classes of vegetation fuels

Fuels vary widely in distribution, type, physical characteristics, amount available for combustion, and their effect on fire behaviour. Because of this, a simple means of classification can be made on the basis of their vertical structure and general properties for analysis and communication etc.

Four categories or layers of fuel are commonly recognised:

- aerial (or crown) fuels
- ladder (or bridge) fuels
- surface fuels
- ground (or sub-surface) fuels.

Aerial (or crown) fuels

Aerial fuels are the standing and supported fuels not in direct contact with the ground (e.g. foliage, twigs, branches etc. of trees and high scrubs).

Ladder (or bridge) fuels

Ladder fuels are the lower branches, and/or the dead fuel hung up in the lower branches, of scrub or unpruned trees.

These are the fuels that provide vertical continuity between the surface and aerial fuels, thus contributing to the ease of torching and crowning (e.g. tall shrubs, small size trees, bark flakes, draped needles, tree lichens).

Surface fuels

Surface fuels are the combustible materials lying above the duff layer between the ground fuels and the ladder fuels. They may consist of litter, low and medium sized shrubs, seedlings, grasses, and fallen dead matter.

Ground (or sub-surface) fuels

Ground fuels are the decomposed organic materials below the surface litter. They include duff, roots, peat, buried wood etc. These are the fuels that normally support smouldering or glowing combustion in ground or sub-surface fires, and can be anything from a few centimetres to more than a metre deep.

The moisture content of these fuels may be very low in drought conditions.

Placing fuels into the categories as named above is a somewhat artificial separation. The main emphasis of this categorisation is in distinguishing the type of fire and the corresponding fuel layer it is burning in (e.g. ground fire, surface fire, crown fire).

Figure 3.9: The four recognized fuel types
(Source – NZFS 2005)

General fuel properties

There are basically six main properties or characteristics of fuels that affect fire behaviour:

- fuel arrangement
- fuel size/shape
- fuel type
- fuel quantity/fuel load
- fuel moisture content
- availability for combustion.

Fuel arrangement

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.

Fuels that are elevated and well aerated lose more moisture from evaporation than fuels that are tightly compacted. For example, loosely arranged, continuous fine fuel will dry more readily, and hence burn more readily and intensely, than tightly packed fine fuel. Compaction also affects the oxygen available for combustion – the more compact the arrangement, the less oxygen is available.

Assessing the fuel arrangement along with the fuel moisture content are important factors in predicting potential fire behaviour. Elevated, dry fine fuels will burn readily and rapidly, leading to an increase in:

- flame heights
- rates of spread
- fire intensity.

Fuel arrangement can be broadly explained as the horizontal and vertical arrangement, and distribution of fuel.

Horizontal arrangement

This is the spacing between fuels on the ground. It affects the rate of fire spread and fire intensity. When fuels are touching or close together, fire can build up to a high intensity then spread evenly at a steady rate.

Continuity refers to distribution over an area. It is a relative term and refers to the percent area covered with fuel. Fuels can be referred to as 'patchy' (e.g. due to rock or bare ground outcrops etc.) or as 'uniform'. When fuels are patchy or separated, fire will not be continuous and, therefore, less intense with irregular spread.

Vertical arrangement

This is the spacing of fuels from ground level to the treetops. It also affects the rate of fire development and fire spread, but more importantly dictates the type of fire that results.

When the vertically arranged fuels are contiguous, fire will spread from the ground to the crowns very rapidly as the fuels above preheat and ignite through the convection of heat.

A definite separation between surface fuels and aerial fuels (no ladder fuels) minimises the possibility of a fire spreading into the crowns. The greater the separation between the surface and aerial fuels, the greater the fire intensity required for a surface fire to ignite the aerial fuels.

Fuel arrangement influences the ability for fire to spread.

Fuel size and shape

Fuel size and shape means the size and thickness or diameter of the vegetation element.

The smaller the diameter, or greater the surface area for its volume (e.g. pine needles), the greater the rate of drying that can occur. Conversely, the greater the diameter or the less the surface area for its volume (e.g. a large log), the slower the rate of drying with an increased ability to retain moisture.

Since all of the heat required to raise fuels to their ignition temperature must go through their surface, those fuels with a higher surface area to volume (SAV) will be preheated and burn more readily than those with a lower SAV. Simply put, the smaller the fuel, the easier it is to ignite and burn.

Broad classifications are:

- fine (or flash) fuels
- medium (or intermediate) fuels
- heavy (or coarse) fuels.

Fine (or flash) fuels

These have a large surface area in relation to their size or volume and therefore lose moisture and dry out very easily. Dry fine fuels ignite easily, carry fire and are consumed rapidly (e.g. cured grass, fallen leaves, needles, small twigs). Dead fine fuels also dry very quickly.

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

Medium (or intermediate) 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 (e.g. scrub trunks and branches, juvenile forest).

They have potential for a rapid rate of fire spread, with an added problem of residual burning (taking longer to consume the fuel) compared to fine fuels.

Heavy (or coarse) fuels

These are large diameter woody or deep organic materials that have a small surface area proportionate to the volume (e.g. logging slash, wind-felled trees, mature forest, and deep-seated peat). They are normally difficult to ignite and burn more slowly than fine or medium fuels. A mixture of fine fuels is often needed to maintain the spread of a fire.

Considerable exposure to drying conditions is needed to lower the moisture content enough to sustain combustion. Once on fire, the heavy fuels can take considerable time to be consumed.

Fuel size/shape influences the rate of drying, ease of ignition, and the amount and rate of fuel consumption.

Fuel type	Fuel type, by definition, is an identifiable association of fuel elements of distinctive species, form, size, arrangement, or other characteristics that will exhibit similar characteristics of fire behaviour under specified burning conditions.
Chemical composition	Some fuels have higher heat of combustion values because of oils, waxes, resin etc. in their chemical composition. Basically, fuel type is an association of fuel elements that burn in a similar manner under the same burning conditions. **A fuel type exhibits similar fire behaviour under similar burning conditions.**
Fuel quantity/fuel load	Fuel quantity/fuel load means the amount (or weight) of fuel in an area that a fire may burn. Generally expressed in tons per hectare (t/ha), it 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. The type, size, arrangement, and amount of dead and live fuels need to be taken into account when evaluating the fuel load of a given area. This is particularly significant when a mixture of vegetation types is present within the area to be assessed for fuel load. Total fuel load is not nearly as important as the 'available fuel', which is the quantity of fuel that would actually be consumed under the conditions prevailing at the time. **Fuel load contributes to available fuel.**

Fuel moisture content

Fuel moisture content represents the amount of water that is present in fuel, expressed as a percentage of the fuel's oven-dry weight.

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.

Key points with respect to fuel moisture:

- Moisture must be evaporated from or driven from fuels before the fuel temperature can be raised to ignition point.
- Heat energy is needed to evaporate fuel moisture, and raise the fuel temperature.
- Exposure of fuels to solar radiation and air with low relative humidity is the predominant means of lowering fuel moisture.
- Fine fuels will lose fuel moisture very quickly under low relative humidity conditions and, conversely, will gain moisture rapidly with high relative humidity.
- Exposure of fuels to the heat of a fire will drive sufficient moisture out of the fuel so as to attain the fuel ignition point.
- Fuels with low moisture content will ignite easily and maintain combustion more readily than fuels with higher moisture content.
- Fuels with a high moisture content (particularly heavy fuels) need long exposure to heat to lower their moisture content and to then reach ignition point. Conversely, the fine fuels require minimal exposure to heat to lower their moisture content.
- Dead fuels can have a lower moisture content given exposure to drying conditions. The smaller the size, and the more elevated and aerated the fuel, the shorter the drying period required to lower its moisture content
- Generally speaking, the moisture content of living vegetation will vary little except under conditions of extreme drought. Drought will accelerate the natural processes of curing of annual vegetation (e.g. grasses, weeds).

Fuel moisture content contributes to fuel availability.

Available fuels

Depending on how dry the fuel is, and/or the dead/live amount, not all of the fuel in an area (the total fuel load) will burn under given conditions. The amount or weight of fuel that will burn under given conditions is called the 'available fuel,' that is, the weight of fuel available to burn under those conditions.

Key points with respect to available fuel:

- this is the quantity of fuel that will burn in a fire
- the amount of fuel available to burn varies with the moisture content of the fuel. For example, shortly after rain, only the top layers of the ground fuels may burn. As the deeper fuel layers dry out they become available to burn
- during moist weather, the foliage of scrub and trees retains sufficient moisture to protect them from fire
- under extreme drought and low fuel moisture conditions, most fuels become available for combustion.

Available fuels influence fuel consumption and fire intensity.

Fuel influences on fire behaviour

Fuels influence fires in a number of ways:

- four categories or layers of fuel are recognised
- fuel arrangement influences the ability for fire to spread
- fuel size/shape influences the rate of drying, ease of ignition, and the amount and rate of fuel consumption
- a fuel type exhibits similar fire behaviour under similar burning conditions
- fuel load contributes to available fuel
- fuel moisture content contributes to available fuel
- available fuels influence fuel consumption and fire intensity.

Safety issues

Associated 'Dangerous Situations':

- working in unburned vegetation
- working where you can't see the fire
- working where spot fires are occurring.

The effects of weather

Majors factors

The major factors affecting New Zealand's weather are its geographical position and its terrain. New Zealand is mountainous and narrow, extending from latitude 34 degrees south to 48 degrees south. It lies in the westerly wind belt between the subtropical anticyclone belt to the north and the depression belt to the south, and is dominated by a maritime climate.

As the New Zealand weather is so variable and difficult to forecast, it is important for fire control personnel to have a basic understanding of the weather elements, the weather systems and general weather forecasting. This will assist towards providing a general understanding of the most variable component of the fire environment – the constantly changing weather systems.

Of the three factors of the fire environment – topography, fuels and weather – weather is the most variable and hence it is a significant factor to monitor. It varies greatly in time and space, varying over short distances with changes in topography and fuels, and changing daily, hourly, even minute by minute and, of course, by season. These changes are reflected in such weather elements as temperature, wind, relative humidity, cloud cover, precipitation and air stability.

Air temperature

Temperature is defined as 'the degree of hotness or coldness of a substance'. Because the sun's energy heats the earth's surface through solar radiation, the temperature of the air is the result of the exchange of heat between the air and the surfaces it passes over, and is commonly referred to as the ambient or dry-bulb temperature.

- Temperature indirectly affects the way fires burn because it influences other factors, such as relative humidity, wind, and fuel moisture levels.
- Fuels receive heat by direct solar radiation and from the surrounding air mass.
- Fuels exposed to high temperature are warmer than fuels exposed to lower temperature. They ignite more easily than shaded fuels.

Air temperature is an indicator of the amount of solar heating received.

High temperatures contribute to the drying and pre-heating of fuels.

Atmospheric pressure

The effect of gravity on the air mass results in atmospheric pressure. At the outer limits of the atmosphere the air has very low atmospheric pressure. At sea-level, however, air is compressed by all the air above it, resulting in much higher pressures – i.e. pressure decreases with altitude.

- The normal pressure at sea-level, or 'standard atmospheric pressure' has a value of 1013 hectopascals (hPa is equivalent to millibars, mb).
- The atmosphere expands and contracts as it heats and cools as a result of different amounts of solar heating received by the earth's surface. This causes atmospheric pressure to rise and fall in different places.
- On weather maps, isobars (lines) are drawn through points of equal pressure.
- An area of relatively high pressure is known as an 'anticyclone' or high. The bigger it is, the slower it tends to move.
- An area of low-pressure is called a 'depression' or low. It forces colder air inwards and upwards, forming clouds.
- Differences in atmospheric pressure cause air to flow from one place to another – from high to low pressure.
- In the southern hemisphere, air circulates anti-clockwise around areas of high pressure and clockwise around low pressure areas.
- The closer the isobars are together, the faster the wind speed (although several other factors also influence wind speed and direction, notably terrain, especially mountain ranges).

Relative humidity

Relative humidity is the amount of moisture in the air compared with the amount of moisture the air is capable of holding.

The capacity of the air to hold water vapour depends on air temperature – the lower the temperature, the less capacity, and the warmer the air, the more moisture it can hold. Generally, as the temperature rises humidity decreases, and vice versa. Relative humidity has daily variations with a maximum at dawn and a minimum during the afternoon, coinciding with minimum and maximum air temperatures.

- Air holds moisture like a sponge. Atmospheric moisture is measured as relative humidity (R/H). When the air is saturated, its relative humidity is 100 percent. Extremely dry air can have a reading near zero.
- Relative humidity affects the flammability of fuels because water vapour is continuously exchanging between the atmosphere and dead fuels. Dead fuels give up moisture to a dry atmosphere, and absorb moisture from a humid atmosphere.
- The moisture content of fine fuels will increase and decrease following the influence of the daily rise and fall of relative humidity. Low relative humidity in the mid-day period will lead to a low fine fuel moisture content in mid-afternoon. Low relative humidity indicates an increase in the potential for ignition of fine fuels.
- The 24 hour pattern of temperature and relative humidity is important. If temperature remains high and relative humidity low overnight, fine fuels will gain very little moisture. This can mean a fire will continue to burn at a high intensity overnight.
- When relative humidity is below 60 percent, fire spread can be rapid. When below 30 percent, fire intensity can be extreme.

Relative humidity is a key indicator of fine fuel moisture content.

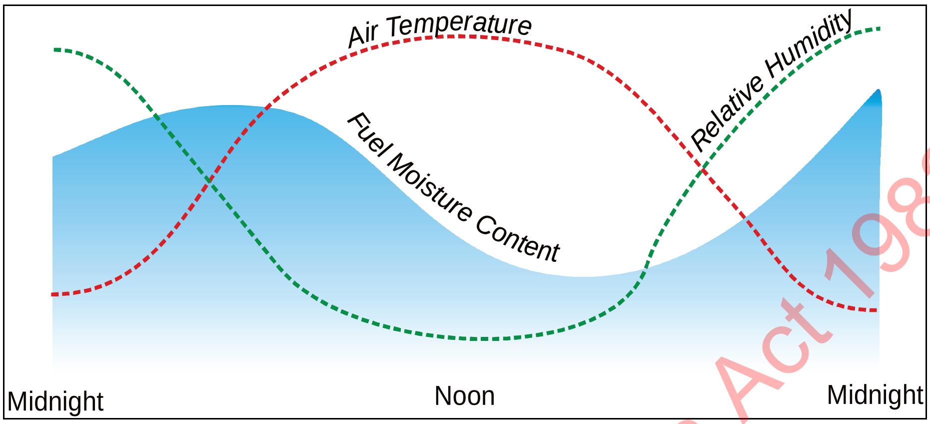


Figure 3.10: The 24 hour pattern of temperature and relative humidity

Frontal systems

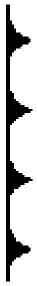
A body of air usually more than 1,000 km across and which has generally uniform characteristics is called an air mass. The distinct boundary where two air masses come together is called a front. Frontal zones, where air masses merge, are regions of considerable weather activity.

Warm front

A warm front occurs when warm air is advancing and displacing colder air.

- The warm air moves over the cold air, cooling as it does so, to form a layer of stratus cloud.
- Light persistent rain may fall, and the temperature will rise as the front passes.

Cold front



A cold front occurs when cold air advances and displaces warmer air.

- The cold air lifts the warm air to form heaped cumulus clouds that can produce heavy rain.
- Squalls may precede the front.

Cold fronts are important to fire behaviour because:

- Strong and gusty erratic winds generally precede them.
- Winds frequently change direction sharply as the cold front passes.

Cold fronts can be preceded by strong and gusty, hot, dry winds.

Occluded front

An occluded front/occlusions is when a cold front overtakes a warm front.

As an occluded front passes by, rain will become patchy and wind will ease.

Stationary front

A stationary front is one that has stopped moving. There is some temperature change or shift in wind direction either side of a stationary front.

Weather patterns

Weather patterns that accompany warm and cold fronts can be predicted as a sequence of events. This standard sequence is illustrated on the diagram overleaf.

This also illustrates the variety of cloud formation that will allow the practised eye to determine (along with other signs) the stage of frontal advance.

Wind

The atmosphere is in continual motion as a result of unequal heating over the surface of the earth. This motion is reflected in the winds we see and feel. Air always moves in response to differences in air pressure; it moves from areas of high pressure to areas of lower pressure. As it moves, its speed and direction are governed by factors such as the amount of pressure difference between high and low pressure areas, the rotation of the earth, and friction between the air and the surface of the earth.

Clearly, the ability to predict wind behaviour is crucial to effective incident management.

The weather patterns discussed above are illustrated on the weather map given below.

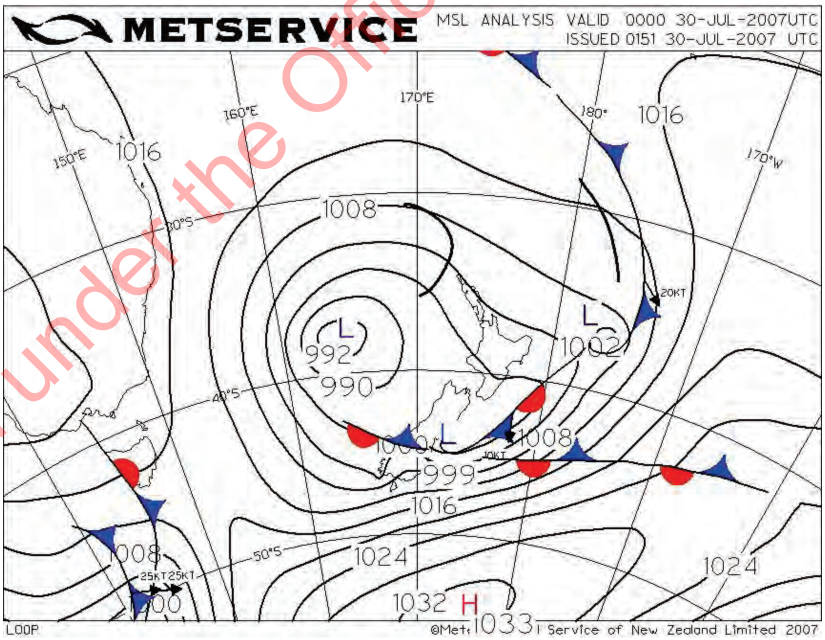


Figure 3.11: Weather map
(Source – Meteorological Service of New Zealand)

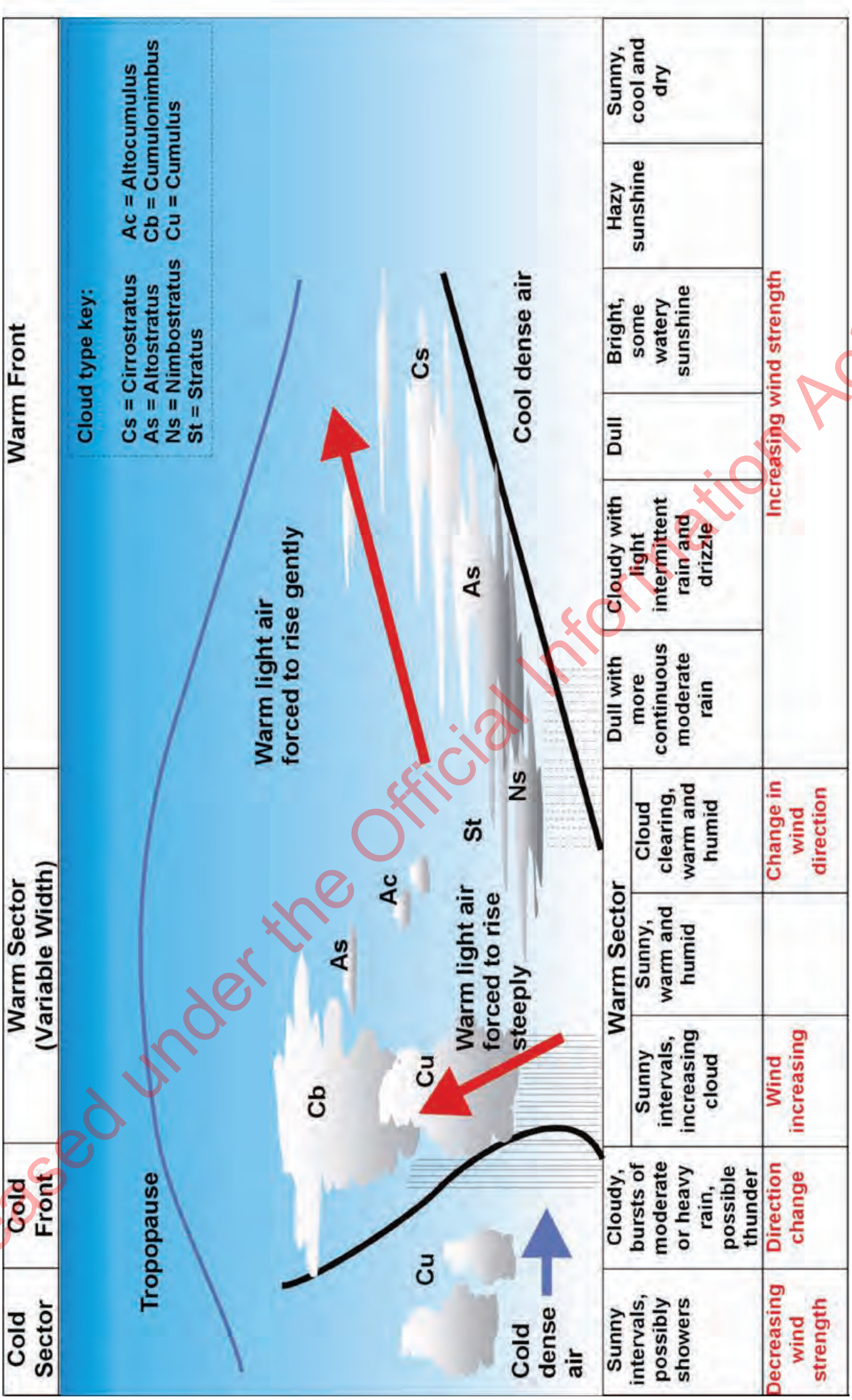


Figure 3.12: Weather patterns accompanying advance of warm and cold fronts

Cloud formations

Recognition

The ability to recognise cloud formations and understand their place in frontal advance is extremely valuable in understanding the potential effects of weather on wildfire fire behaviour. Shown below are examples of the principal cloud formations.

High level clouds: Cirrus

Cirrus clouds are ice clouds. They can look like delicate white feathers or streamers. They are always more than three miles up where the temperature is below freezing, even in summer. Wind currents twist and spread the ice crystals into wispy strands.

High-level clouds: Cirrostratus

Cirrostratus are sheet-like, high level clouds composed of ice crystals. Though cirrostratus can cover the entire sky and be up to several thousand feet thick, they are relatively transparent, as the sun or the moon can easily be seen through them. These high-level clouds typically form when a broad layer of air is lifted by large-scale convergence.

Sometimes the only indication of their presence is given by an observed halo around the sun or moon. Halos result from the refraction of light by the cloud's ice crystals. Cirrostratus clouds, however, tend to thicken as a warm front approaches, signifying an increased production of ice crystals. As a result, the halo gradually disappears and the sun (or moon) becomes less visible.

Mid-level cloud: Alto Cumulus

Altocumulus may appear as parallel bands (top photograph) or rounded masses (bottom photograph). Typically, a portion of an altocumulus cloud is shaded, which distinguishes them from the high-level cirrocumulus.

Altocumulus clouds usually form by convection in an unstable layer aloft, which may result from the gradual lifting of air in advance of a cold front. The presence of altocumulus clouds on a warm and humid summer morning is commonly followed by thunderstorms later in the day.

Mid-level clouds: Altostratus

This is a denser version of cirrostratus. It has a thin, watery layer which forms a coloured ring (corona) around the sun and moon. Altostratus has a more uniform and diffuse coverage where it is difficult to detect individual elements or features. Sunlight is often visible through these clouds as in this picture. Altostratus clouds form when a front of warm, moist air meets a body of cold, dry air. If these clouds thicken precipitation is likely.

Mid-level clouds: cumulus	These clouds are associated with fair and maybe blustery weather. The warming of the atmosphere evaporates moisture on the ground causing warm, moist air to rise, which condenses to form small 'packets' or 'rolls' of cloud. Fair weather cumulus clouds have a height that is similar to their width. They rarely produce precipitation, but can if they merge to form cumulus congestus cells.
Low-level clouds: nimbostratus	Nimbostratus are dark, low-level clouds accompanied by light to moderately falling precipitation. Low clouds are primarily composed of water droplets since their bases generally lie below 6,500 feet (2,000 meters). However, when temperatures are cold enough, these clouds may also contain ice particles and snow.
Low-level clouds: stratus	This is a low-altitude, damp, grey cloud which often overcasts the entire sky. It may veil mountains, and usually has an even base. Similar to simple ground fog but is found higher and is more dense (contains more water vapour). Stratus cloud is found particularly at high latitudes (e.g. Northern Europe), and is commonly seen shrouding the flanks of mountains in morning until the midday sun dissipates the cloud. It often brings rain or drizzle. Stratus clouds often form when a front of warm, moist air meets a body of cold, dry air.
Clouds with vertical development: cumulonimbus	These clouds are also known as thunderstorms. Especially strong upward convection associated with extreme instability in the atmosphere can lead to the nearly explosive vertical development of these clouds. While their bases range from near the ground to about 6,500 feet, their tops can extend well into the region of the high clouds.

Turbulence

Surface winds often vary considerably in both speed and direction over short intervals of time. They 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 in nature:

- Airflow is similar to the flow of water
- Surface friction produces mechanical turbulence in the airflow
- Mechanical turbulence increases with both wind speed and the roughness of the ground surface
- Thermal turbulence is associated with atmospheric instability and convection, and generally extends higher into the atmosphere as a result of surface heating.

Topographic effects on winds

A hill – or any other topographic obstacle – will interfere with the flow of wind, changing the wind's speed, direction and turbulence. Generally, wind speed will progressively increase up a slope to the crest of the hill as the wind from lower elevations is compressed by the wind above it and is forced to speed up. 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.
Mountains represent the maximum degree of surface roughness and provide the greatest friction to airflow by forcing winds to go around or over them.
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 eddies on the lee side
- Gorges funnel wind through with increased wind speeds.

Valley and mountain winds

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.

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

The downslope evening breeze may allow a fire to travel more quickly downhill.

Daily heating and cooling of slopes can create local wind patterns.

Fohn winds

A fohn (or foehn) 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 through precipitation as it is forced to higher altitudes. As it descends to the lowlands on the leeward side of a range, it heats up and arrives as a strong, gusty, dry wind.

A well-known example is the Canterbury 'Nor'wester' where the airflow descending from the Southern Alps to flow over the Canterbury Plains is warmer and drier than when it commenced on the West Coast. Other examples include:

- Wanganui/Manawatu in a NE airflow
- Hawkes Bay/Wairarapa in a NW airflow
- Nelson in a SW airflow
- West Coast in an Easterly airflow.

The fohn effect often precedes the passage of a cold front.

Fohn winds are strong, warm and dry.

Coastal effects on winds

Because New Zealand is essentially a long, narrow landmass isolated 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.

Firefighters need to understand that wildfires adjacent to coastal areas can be radically affected by the changing patterns of coastal winds.

Onshore winds – sea breezes

Land heats more quickly than the ocean. Consequently, warm air begins to rise from the land surface earlier during the day than from the sea. Cooler air from the ocean then begins to move ashore to compensate for the displacement over the land.

Onshore winds are likely to appear in the late morning and strengthen during
the afternoon. These winds can penetrate considerable distances inland. They will carry cooler, moister air.

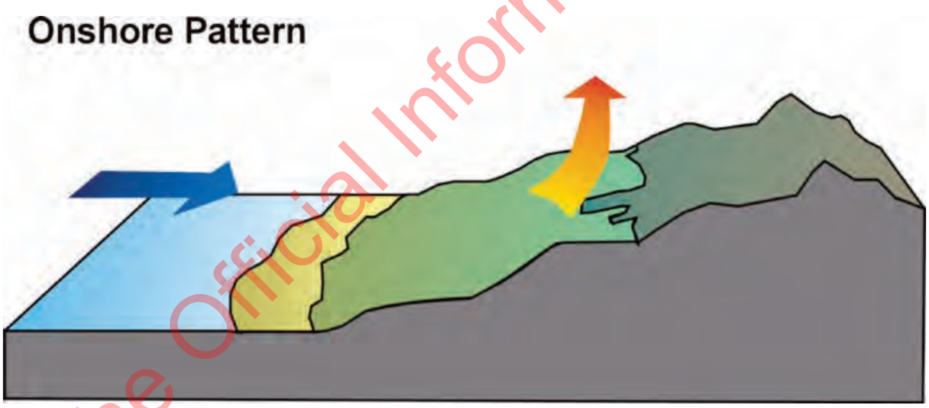


Figure 3.13: Onshore wind development

Onshore winds

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

- Produce a wind on an otherwise calm day
- Strengthen the prevailing wind
- Reverse the wind direction.

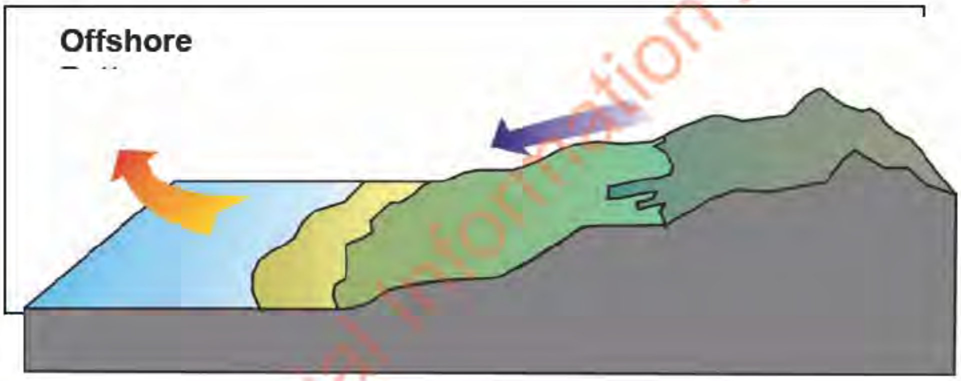
Offshore winds – land breezes

Off-shore winds are created by the reversal of the temperature differential between land and sea temperatures caused by daylight heating. These winds develop mainly at night. They are usually less vigorous than sea breezes and affect smaller areas of the coastal strip.

A land breeze is significant to fire behaviour because it is:

- Warmer than the air it replaces
- Drier than the air it replaces.

Local breezes can significantly influence fire behaviour.



Upper atmosphere winds

Fire behaviour can be affected by wind conditions 300 – 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. Even with very little surface wind, fast upper atmosphere winds will create updraughts that can increase the fire intensity.

Atmospheric instability

Atmospheric instability may:

- 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
- Create gusty and turbulent surface winds in a narrow band around the fire perimeter
- Increase fire intensity, and cause fire behaviour to become very erratic along its perimeter.

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

An unstable atmosphere generates turbulent surface winds.

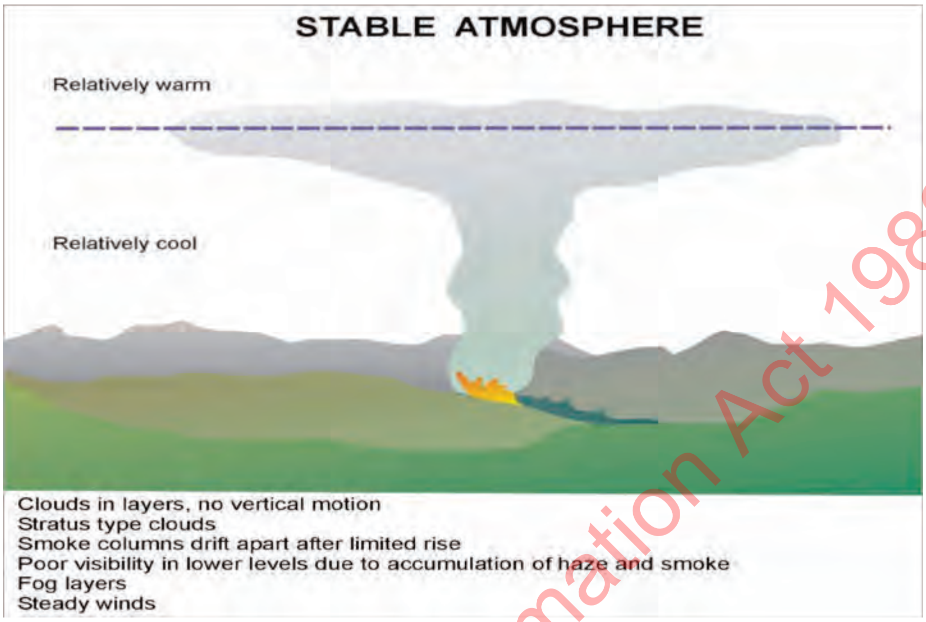


Figure 3.15: Stable atmosphere conditions

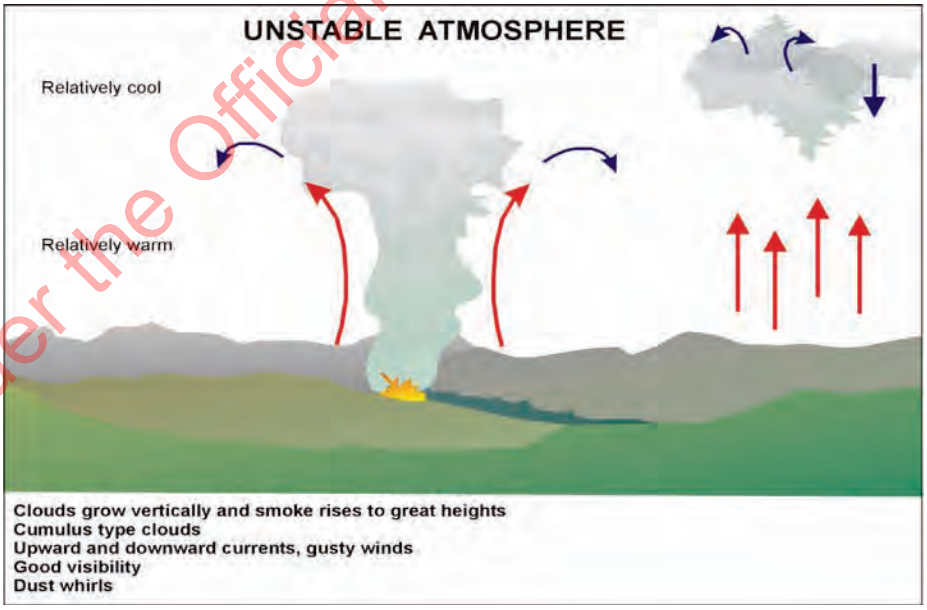


Figure 3.16: Unstable atmosphere conditions

Whirlwinds – including dust whirls or fire whirls

These usually indicate unstable atmospheric conditions. They are most prevalent on a hot calm day when the surface of the land has been heated to a higher temperature than adjacent areas or adjacent vegetation. This heating causes the warmer air to rise vertically, with cooler air from the surrounding area replacing it.

If these warm, vertical air movements are interrupted by a large obstacle or an updraught in a gulley, turbulence can occur – causing the air to whirl around and upward until it expends its energy.

Whirlwinds can also develop within a fire area of uneven burning. This is potentially more dangerous as the whirlwind (or fire whirl) can carry burning material considerable distances.

Fire whirls are narrow twisting plumes of flame. With small fires they persist for only a few seconds before dying out and re-forming. Large fires can produce fire whirls that can travel down the flank of a fire for several minutes – picking up loose burning material and scattering it outside the fire perimeter. More persistent fire whirlwinds commonly occur on the lee slopes of hills and near ridge crests.

Whirlwinds are an indicator of unstable atmosphere.

Key points with respect to winds

- Wind speed has significant influence on the rate of fire spread
- Dry wind creates a continual flow of air with a lower moisture content than that of the fuel it surrounds. It increases the rate at which fuels release their moisture
- Wind pressure can bend the rising heat and smoke from a fire towards the ground, causing fuels ahead to heat and dry, thus generating rapid fire spread in that direction
- Wind increases the oxygen supply and speeds up the rate of combustion. It can also carry burning material forward to start spot fires ahead of the main fire
- The type of vegetation alters the effect of wind – e.g. in a forest with a heavy ground cover of trees, wind speed at ground level may be reduced to as little as 30 percent of the wind speed in the open
- Wind speeds directly affect the behaviour of a fire in grasslands and other types of exposed surface fuels.

Local topographical features affect 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.

For the Fire Weather Index System, wind strength is measured in kilometres per hour, 10 metres above ground level, and averaged over a 10 minute period.

If the 10 metre wind measurement can't be taken, the ground level reading is multiplied by 1.5 to give the upper wind measurement.

Key points with respect to winds continued

Without instruments to read accurately, 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 strength (as with slope) has a significant influence on the direction in which the fire will travel, the rate of fire spread (ROS), and fire intensity.

Beaufort Term	Average Speed kms/hr	Observable Effects
0 = calm	<1	Smoke rises vertically
1 = light air	1-5	Direction of wind shown by smoke drift but not by wind vanes
2 = light breeze	6-11	Wind felt on face, leaves rustle; ordinary vanes moved by wind.
3 = gentle breeze	12-19	Leaves and small twigs in constant motion; wind extends light flags.
4 = moderate breeze	20-28	Wind raises dust and loose paper; small branches are moved
5 = fresh breeze	29-38	Small trees in leaf begin to sway; crested wavelets form on inland waters.
6 = strong breeze	39-49	Large branches in motion; whistling heard in telephone wires, umbrellas used with difficulty.
7 = moderate gale	50-61	Whole trees in motion; inconvenience felt when walking against wind
8 fresh gale	62-74	Breaks twigs off trees; generally impedes progress.
9 = strong gale	75-88	Slight structural damage occurs (e.g. TV antennas and tiles blown off)
10 = whole gale	89-102	Seldom experienced inland; trees uprooted; considerable structural damage.
11 = storm	103-110	Widespread damage.
12 = hurricane	120+	Widespread severe structural damage.

Figure 3.17: Representation of the Beaufort Scale

Precipitation

Rain

Precipitation is essentially the liquid and solid forms of atmospheric moisture that falls from the sky. It is commonly experienced as rain and snow, sometimes with drizzle and hail. Rainfall – or lack of it – directly affects the condition of fuels. A prolonged dry spell will considerably reduce the moisture content of most fuels, making them especially susceptible to fires.

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

Heavy rain over a short period tends to run off the land surface, especially when the ground layer is dry and resists water penetration.

Rain continued

Substantial rain is needed for heavy, dead fuels and the deep duff layer fuels to absorb enough moisture to stop them from burning. Conversely, a substantial dry period is needed to expel moisture from heavy and deep fuels to dry them out sufficiently for combustion.

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.

Light, occasional rainfall dampens the dead fine fuels that carry a fire, but a dry wind and sunshine will quickly dry them enough to be easily combustible.

Consider the duration as well as the amount of rain.

Clouds

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.

'Thermal lifting' or convection is the result of local surface heating that causes the air to rise and become cooler.

When air is forced up the windward side of hills and mountain ranges, 'orographic lifting' occurs which causes the air to cool and clouds to develop.

'Frontal lifting' occurs as air is forced up the slope of warm or cold fronts.

Cloud indicators

Cloud types are an indicator of wind patterns:

- High altitude clouds moving in a different direction to the wind direction at ground level indicates a potential shift in wind direction at ground level
- 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
- With continuous cloud cover, fuel temperatures are closer to the air temperature, and fuel moisture content will be higher
- Cloudless skies are often associated with an unstable atmosphere, which, combined with high fuel temperatures, can lead to extreme fire behaviour.

Thunderstorms

A thunderstorm is a violent local storm accompanied by lightning. It represents extreme convective activity in the 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).

Day and night weather patterns

The day and night (24 hour) effect of weather patterns needs to be considered for a complete assessment of the weather effects on potential fire behaviour.

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 in the mid-afternoon.

Some evenings can maintain warm temperatures, low relative humidity and strong winds (e.g. effect of a fohn wind).

Night 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.

Monitor daily weather trends.

Seasonal effects

Fire danger varies with the season of the year. Seasons affect the condition of the vegetation, the number of hours of sunlight per day, and the moisture content of fuels. The generally accepted high fire risk season is the spring – summer period from October to April.

Suitable burning conditions can prevail during other times of the year, given
seasonal effects such as:

- Heavy frosts and clear winter days can cure vegetation and dead fuels to a low moisture content, making them available for burning. This often results in so-called 'out of season' fires
- A wet spring considerably increases vegetation growth, particularly grasses. These fine fuels dry out in summer months, leaving a greater than normal volume of cured fuels
- A wet summer with good growth followed by a dry winter also produces high volumes of fuels.

Fuel moisture content can be low throughout the year.

Drought

Drought is an extended period of time with much lower than average rainfall. Combined with the drying effects of wind, high temperatures and low relative humidity, lack of rain reduces the moisture content in vegetation, dead fuels and soils, and the volume of fuels available to burn increases.

The effects of low rainfall are:

- light vegetation dies and dries out
- medium size fuels dry out
- litter on forest floors dries out.

Prolonged drought is generally regarded as a period of more than 50 days without substantial rainfall. Serious fires are likely to occur during these conditions. Additional effects are:

- heavy (coarse) fuels, normally damp, 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.

Low water table levels indicate the long-term effects of drought. When the water table is low, rain filters quickly into the soil, leaving the surface and sub-surface fuels to dry rapidly. Trees may also be deprived of water. Under these conditions the moisture content of foliage will be less than normal and tree crowns more flammable and susceptible to crown fires.

Drought conditions increase fuel availability.

Fire behaviour

Section objective

The objective of this section is for you to be able to explain what is meant by fire behaviour and the factors that impact on it.

Overview

Fire behaviour is the reaction of fire to the environment.

The fire environment is the surrounding conditions that determine the behaviour of fire. To understand fire behaviour, it is necessary to understand fire development and the effects of the fire environment.

Fire development

- Combustion
- Types of fire
- Parts of a fire
- Fire patterns
- Fire intensity
- The combined effects of the fire environment.

Fire development

Ignition

The fundamental principles for combustion of vegetation to take place are:

- There must be sufficient fuel of an appropriate size and arrangement.
- This fuel must be dry enough to support continued combustion.
- There must be an ignition agent present.

There are three basic elements to combustion and flame production – fuel, oxygen, and heat.

Combustion

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

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

The colour of smoke produced can be used as a rough guide to burning conditions. The following table illustrates the general principles.

Grey	Dense white	Black
Moist fuel	Very moist fuel	Dry fuel
Moderate intensity	Mild intensity	High intensity

Copper-bronze
Very dry fuel
Severe intensity

Heat transfer

Heat transfer refers to the processes by which heat energy produced through combustion is transmitted to unburnt fuels. There are four recognised mechanisms of heat transfer:

- Convection – transfer of heat by the actual movement of hot air upwards.
- Conduction – transfer of heat through solid matter (too slow to be important in spreading surface fires as wood is a poor conductor of heat. Will contribute to spreading of sub-surface fires).
- Radiation – transfer of heat in straight lines from warm surfaces to cooler surroundings (this is the principal means by which fire preheats unburnt fuel ahead of a spreading fire).
- Ember Transport – transfer of heat as a result of burning material being transported by the wind or by rolling downhill or by being carried aloft in the fire's convection column or by a fire whirl (commonly called spotting).

Heat transfer = convection, conduction, radiation and ember transport.

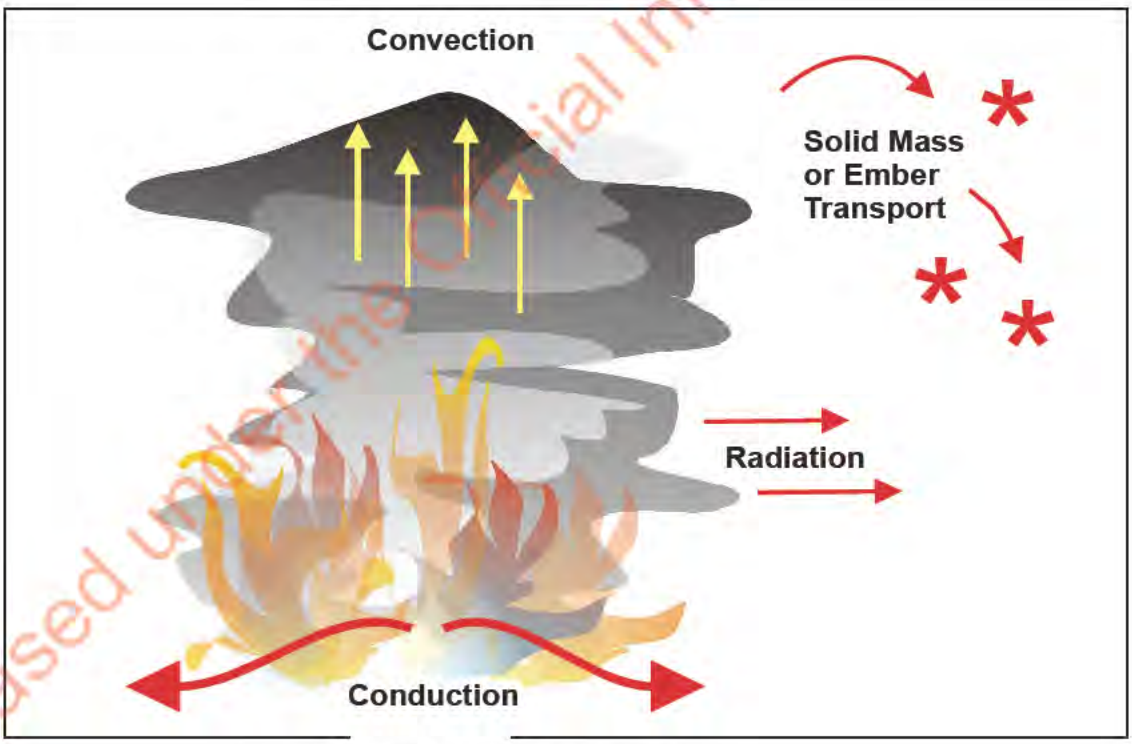


Figure 3.18: Forms of heat transfer

Types of fire

Factors

The three primary factors of the fire environment influence the intensity and the rate of spread of a vegetation fire (i.e. topography, fuels, and weather).

Fire can be broadly classified as being driven predominantly by one of the following:

- wind
- fuels
- topography.

Fire type corresponds to the fuel layer in which the fire is burning. Vegetation is categorised as one of:

- aerial fuels
- ladder fuels
- surface fuels
- ground or sub-surface fuels.

Key points with respect to fuels:

- Although fire can burn in any one, or a combination of these layers, most fires occur and burn in the surface fuels.
- Occasionally, intensely burning surface fires spread to the aerial fuels.
- Under certain circumstances fire burns beneath ground level in the ground or sub-surface fuels.

Within these types of fuels three primary types of fire occur:

- crown fire
- surface fire
- ground fire.

Crown fire

A crown fire involves burning of aerial fuels. All crown fires develop from a surface fire. The aerial fuels become involved in fire because either:

- ladder fuels carry a fire up into the crowns (this can occur even in low intensity fires), or
- convection from a high intensity surface fire bridges the gap to the aerial fuels.

An active or independent crown fire advances through the aerial fuels more or less independently of the surface fire. It needs continuous aerial fuels to support its forward movement.

These fires occur in extreme conditions, usually with the support of a strong, gusty wind or steep slope. They normally only travel short distances, dropping burning embers that ignite surface fuels. On a steep face, contiguous aerial fuels can extend up the entire slope.

An intermittent or dependent crown fire spreads upwards through ladder fuels. This occurs where there are gaps in the aerial fuels, and no high winds are present to support lateral spread.

These fires need continual support from a surface fire. Individual trees can torch almost instantaneously in a spectacular but isolated crown burn.

Surface fire

A surface fire involves the fuels at and immediately above ground level.

Ground fire

A ground fire burns in the organic materials under the surface litter and in the root systems.

The extent to which these sub-surface organic materials will burn and smoulder varies with the moisture content, and the depth of decomposed and partially decomposed vegetation. This can range from a few centimetres to a metre or more.

Ground fires occur in indigenous forests, peat swamps, coastal vegetation and other areas with deep or buried organic material. The moisture content of these fuels may be very low in drought conditions and fire may spread for some distance underground without any visible signs on the surface, making it difficult to locate.

Types of fires are: crown, surface, and ground.

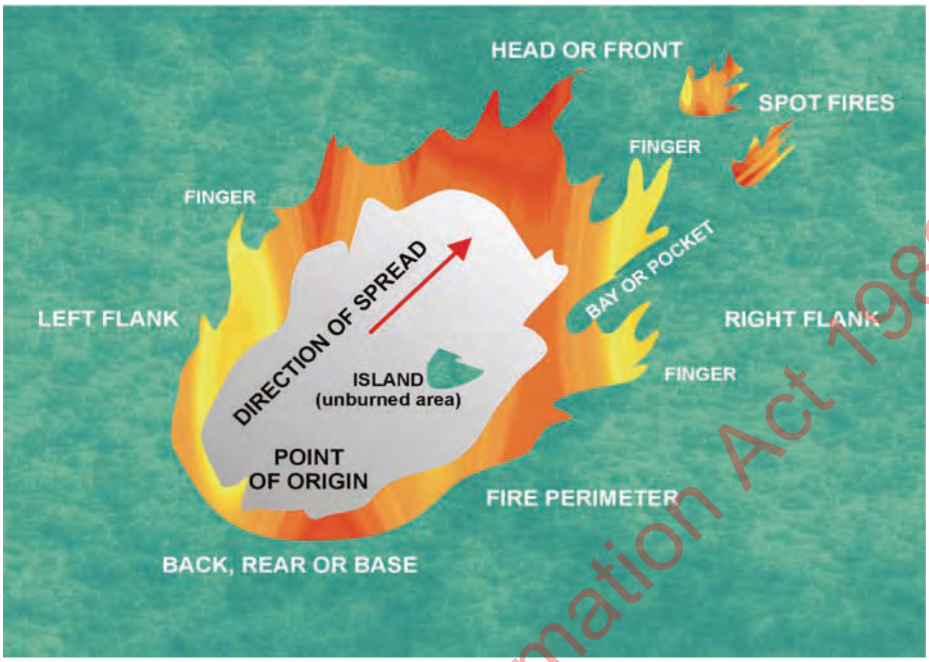


Figure 3.19: Parts of a fire

Parts of a Fire

Description

The 'anatomy' of a fire is as follows:

- Fire perimeter – the entire edge or boundary of a fire.
- Bay(s) – a marked indentation in the fire perimeter, usually located between two fingers.
- Finger(s) – a long narrow extension of the fire perimeter.
- Flanks or Sides – those portions of the fire perimeter that are between the head(s) and back or base of the fire which are roughly parallel to the main direction of spread.
- Head or Front – that portion of fire perimeter having the greatest rate of spread and frontal fire intensity which is generally on the downwind and/or upslope side of the fire.
- Back, Rear or Base – that portion of the fire perimeter opposite the head; the slowest spreading part of the fire.
- Island(s) – an area of unburnt fuels located within the fire perimeter.
- Spot Fire – a fire ignited by fire brands being carried outside the main fire perimeter by air currents, gravity and/or by fire whirls.

Description continued

Fires can also be described by their relationship or orientation to the edge of the fire with respect to wind. A moving fire will have all sections of the perimeter fitting into one of three classes – heading, backing and flanking fire.

Heading fire

This is where the flames are blown towards the fuel. The fuel bed is ignited at the top and the fire progressively burns down into the lower layers. Sometimes the bottom of the fuel bed may remain unburned and may rekindle later.

Backing fire

These move into the wind with flames leaning over the burnt ground. These fires ignite the fuel bed at or near the base and burn slowly but very efficiently, leaving little residue.

Flanking fire

In a flanking fire, the fire edge is generally parallel to the direction of the wind.

This means the flames will lean, more or less, along the flank. The major characteristics of a flanking fire is that it will become, by turns, a heading fire
and a backing fire in response to changes in wind direction.

Fire patterns

The shape or pattern of a fire depends on:

- wind direction
- topography
- fuel arrangement.

The simplest pattern will develop when a fire starts on flat ground, with an even fuel distribution, and on a calm day. The fire perimeter will move out evenly from the ignition point in a circular pattern. Fire spread is slow under these conditions.

Under the influence of wind, the fire's convection column is deflected towards the fuels.

Slope has the effect of bringing the convection column closer to the fuels.

Wind and slope both increase the rate of preheating ahead of the fire. The fire soon takes on an elliptical shape with the pointed end travelling the quickest, propelled by the wind and/or rising slope.

Caution – Strong dry winds blowing down or across slope may override the slope effect, with fire travelling faster downhill or across the slope. Lulls in the wind will allow the fire to return to periodic uphill runs.

Fire pattern depends on: wind direction, slope, fuel arrangement.

Frontal fire intensity

Frontal fire intensity

This is the rate of energy or heat released, per meter of perimeter, per second, in the flame zone of the forward moving section of the fire.

Fire intensity, in simple terms, is the amount of heat released by the fuel as it burns. It is calculated using a combination of the amount of fuel that is available to burn, and the rate of spread of the fire.

Fire intensity is a major factor in determining how difficult a fire is to control. Calculating frontal fire intensity helps determine the suppression effort that will be required to contain a fire and warns of impending danger to firefighters. It can indicate that the suppression efforts needed are beyond the capabilities of ground crews.

Bryram's formula

I = Hwr

I = Frontal fire intensity (in kilowatts per meter)

H = Heat of combustion (standard value of 18500 kJ per kg of fuel)
w = Fuel consumed (weight as kg per m^2)
r = Rate of speed (meters per second)

For example: A fire is burning 4 tonnes of fuel per hectare and spreading at 100 meters per hour.

H = 18500 kJ/kg
w = 4 tonnes per hectare
There are 1000kg in 1 tonne, and 10000m^2 in 1 hectare, so,
= 4000/10000 = 0.4kg/m^2
r = 100 meters per hour
There are sixty seconds in a minute and sixty minutes in an hour, so,
100/60/60 = 0.028m/s

I = 18500 x 0.4 x 0.028 = 207.2 kW/m

Frontal fire intensity may limit fire suppression efforts.

The chart on the following page shows estimated flame height in relation to frontal fire intensity and Fire Danger Class Interpretation.

Fire Danger Class and Frontal Fire Intensity	Description of Probable Fire Potential and Implications for Fire Suppression	Nominal Max. Flame Height
EXTREME >8000 kW/m	Out of control fire run. The situation should be considered 'explosive'. Violent physical behaviour of conflagrations or firestorms are a certainty (e.g. rapid spread rates, crowning in forests, medium to long range mass spotting, firewhirls, towering convection columns, great walls of flame). As a result, fires pose an especially grave threat to persons and their property. Breaching of roads and firebreaks occurs with regularity as fires sweep across the landscape. Extreme fire behaviour presents serious control problems. Direct attack is rarely possible given the fire's ferocity – except immediately after ignition –and should only be attempted with the utmost caution. Generally, suppression action should not be attempted until burning conditions subside. The only effective and safe control action that can be taken until the fire run expires is at the back and along the flanks.	3.6+ metres
VERY HIGH 4000 – 8000 kW/m	Extremely vigorous surface fire or crown fire. Burning conditions have become critical. As the likelihood of intense surface fires is a distinct possibility, torching and intermittent crowning in forests can take place. Direct attack on the head of a fire by ground forces is feasible for only the first few minutes after ignition has occurred. Otherwise, any attempt to attack the fire's head should be limited to helicopters with buckets, or to the use of fixed-wing aircraft – preferably dropping long-term chemical fire retardants. Focus on indirect attack. Suppression efforts will be restricted to flanks and base. Until the fire weather severity abates, resulting in a subsidence of the fire run, the uncertainty of successful control exists.	2.6 to 3.5 metres
HIGH 2000 – 4000 kW/m	High vigorous surface fire. Running or vigorous surface fires are most likely to occur. Any fire outbreak constitutes a serious problem. Control becomes gradually more difficult if it is not completed during the early stages of fire growth following ignition. Water under pressure (from ground tankers or fire pumps with hose lays) and bulldozers are required for effective action at the fire's head. Control efforts on fires head may fail. Machinery formed fire lines required.	1.4 to 2.5 metres
MODERATE 500 – 2000 kW/m	Moderately vigorous surface fire. From the standpoint of moisture content, fuels are considered to be sufficiently receptive to sustain ignition and combustion from both flaming and most non-flaming (e.g. glowing) firebrands. Creeping or gentle surface fire activity is commonplace. Control of such fires is comparatively easy but can become troublesome as fire damages can still result and fires can become costly to suppress if they are not attended to immediately. Direct manual attack around the entire fire perimeter by firefighters with only hand tools and back-pack pumps is possible. Hand constructed fire lines may be challenged.	Up to 1.3 metres
LOW <500 kW/m	Low vigour surface fire. New fire starts are unlikely to sustain themselves due to surface moisture fuel conditions. Ignitions may take place near large and prolonged or intense heat sources (e.g. campfires, windrowed slash piles). However, the resulting fires generally do not spread much beyond their point of origin, and if they do, control is easily achieved. Constructed hand lines should hold. Direct attack on fires by ground crews is possible. Mop-up or complete extinguishment of fires that are already burning may still be required provided there is sufficient dry fuel to support	No visible flame

	smouldering combustion.	
N.B. The above notes should not be used as a guide for firefighter safety. Fires can be potentially dangerous or life-threatening at any level of fire danger!		

Combined effects of the fire environment

No two vegetation fires behave in the same manner.

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 as it is or to predict how a fire may behave, it is necessary to understand all of the influencing factors in the fire environment.

The current level and condition of each influence needs to be known, together with likely changes in the next hour or so.

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

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

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

- Slope steepness
- Wind speed and direction
- The amount of pre-heating the fuel is receiving.

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

Each aspect (N, S, E, W) has a peak heating period as well as a time of warming and a time of cooling. As the fuel is warming, it becomes more flammable. As the fuel is getting less sun and cooling with time, the fuel becomes less flammable.

Fuel temperature

Fuel temperature is much more variable than air temperature and it is the fuel's temperature that determines its moisture content and flammability.

Fuel in daylight hours is constantly changing from cool to hot and back to cool. Sunlit fuel is often heated to 90 degrees Celsius by solar radiation and becomes many times more flammable than cool, shaded fuels. Fuels under these conditions can be said to be 'hot' fuels.

Details need to be noted on:

- Topography – immediate area and surrounding area
- Fuels – currently involved and in path of fire
- Weather – current and expected.

Effects of the fire

It is also important to consider the effects of the fire itself on the fire environment. 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 most 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.

No two vegetation fires behave exactly the same.

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

Environment factors must be constantly monitored.

The fire day

10 am to 6 pm

This is the heat of the day. During this time, all factors of fire intensity are at their highest. Air is dry, fuels are dry, temperature is high, wind is strong, and the sun and heat are most unfavourable to the control forces. Spot fires start easily. All fires are at their point of strongest resistance to control.

6 pm to 4 am

As early evening comes, the wind moderates, the air cools, relative humidity rises, and fuels cool and begin to absorb moisture from the air. These conditions, which are favourable to fire control, gradually increase throughout the night until the fire reaches its lowest ebb about 4 am.

4 am to 6 am

The fire remains low until shortly after dawn, or around 6 a.m. It may stop running especially in low places and gullies. During this and the preceding period from 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 or between 6 and 7 am the fire begins to increase in intensity. Small pockets begin to smoulder, creeping fire begins to flame up, and gradually, the broken pieces join together in a solid front. The wind rises, humidity decreases, air temperature rises, and firefighting becomes increasingly difficult.

Summary

Fire behaviour

Shown below are the key areas for understanding fire behaviour.

- Phases of combustion: pre-heating, gaseous, charcoal
- Heat transfer: convection, conduction, radiation, and ember transport
- Types of fire: crown, surface, ground
- Key parts of the fire: head, flanks, base
- Fire pattern depends on: wind, direction, slope, fuel arrangement
- Frontal fire intensity may limit fire suppression efforts
- No two vegetation fires are the same
- The primary forces that cause fire behaviour to change are: wind, slope and fuel temperature variations
- Fire environment factors need to be monitored. Details are needed on topography (immediate and surrounding area), fuels (currently involved and in path of fire), and weather (current and expected)
- Key indicators for increase in fire intensity include fire moving into steeper terrain, intermittent trees torching, fire moving into an area with more fuels available, fire moving into alignment with slope, wind direction and hot fuels, decreasing relative humidity, and an increase in wind speed
- Associated dangerous situations are unknown fire size and speed, spot fires occurring, and working uphill or downwind of a fire.

Information to note

Information about both the fire environment and fire behaviour should be noted and recorded as part of the record of fire incidents:

- Weather (temperature, humidity, wind speed and direction, rainfall)
- Topography (altitude, aspect, slope, landscape features including barriers)
- Fuel (type, size, volume, arrangement, moisture content)
- Ignition source
- Type, shape, size and direction of fire
- Fire intensity.

It is essential that information about suppression tactics and their efficacy is also recorded.

Records are essential in identifying how to improve fire prevention and response planning for the future.

Fire danger and the Fire Weather Index System

Section objective

The objective of this section is for you to be able to explain how the fire weather index system works and how to interpret the codes.

Fire danger

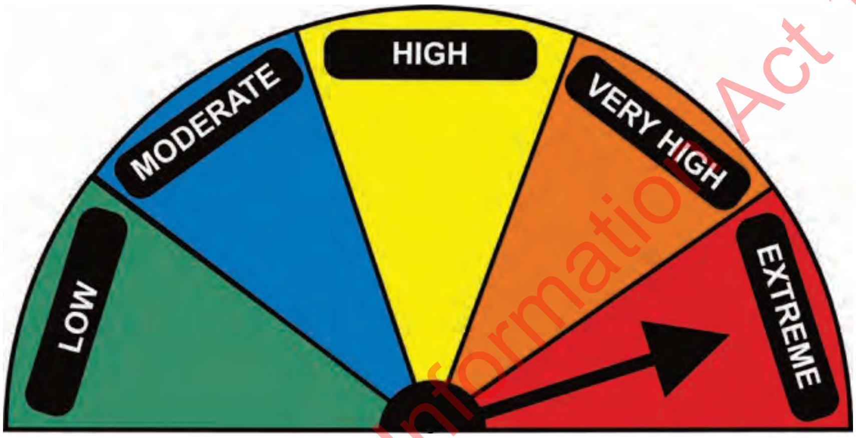


Figure 3.20: Fire danger indicator

Rating

Fire danger refers to an assessment of both fixed and variable factors of the fire environment that determine the ease of ignition, rate of spread, difficulty of control, and impact of wildland fires.

Fixed fire danger factors are those that change only slowly over time but can vary from place to place (e.g. topography, fuel types). Variable factors are those that vary from time to time (throughout the day, and from day to day) at any given place (e.g. temperature, relative humidity, wind, precipitation, fuel moisture).

A fire danger rating system should supply an objective answer to the question:

'What is the probability of a fire starting, spreading and doing damage today?'

Use of the NZFDRS

The NZFDRS provides information that assists others in making intelligent and informed decisions about:

- fire prevention (inform public, determine likelihood of fire, close areas at risk etc.)
- levels of preparedness and the suppression resources needed to keep fire losses to a minimum
- wildfire control (fire suppression response and resources)
- planned burning (plan and conduct controlled burns, issue or cancel burn permits)

Information

The Fire Weather Index (FWI) System is the first major sub-system for the Canadian Forest Fire Danger Rating System (CFFDRS) that was evaluated during the late 1970s for its suitability for use in New Zealand. This system proved suitable for rating fire danger for this country and was introduced nationally for the 1980-81 fire season.

The Fire Weather Index (FWI) System consists of six components that provide relative numerical ratings for various aspects of ignition potential and fire behaviour and are based solely on selected weather inputs.

The weather readings that are taken at noon standard time (1 pm daylight saving time) are:

- air temperature (taken in the shade)
- relative humidity (taken in the shade)
- wind speed (an average over 10 minutes taken at 10 metres above ground level)
- rainfall (for the previous 24 hours).

These readings are used to rate fire danger at the mid-afternoon peak between 2 pm and 4 pm.

Note: If the 10 metre height speed wind measurement cannot be obtained, a wind speed reading taken at 1.2 metres above the ground is multiplied by a factor of 1.5 to provide a good estimate of the 10 metre height wind speed measurement.

FWI Components

The first three components of the FWI system are fuel moisture codes that represent the moisture content of:

- Fine surface litter – Fine Fuel Moisture Code (FFMC).
- Loosely compacted duff – Duff Moisture Code (DMC).
- Deep compact organic matter – Drought Code (DC).

They act as book-keeping systems that add moisture after rain and subtract some for each day's drying.

The other three components are fire behaviour indices. The three moisture codes, together with wind, are linked to form two indices that represent:

- rate of fire spread – Initial Spread Index (ISI), based on wind speed and FFMC
- amount of fuel available to burn – Build Up Index (BUI) based on DMC and DC.

A combination of the ISI and BUI values create the third fire behaviour index that represents:

- a measure of fire intensity – Fire Weather Index (FWI).

Interpreting the codes and indices

To interpret the system, the three fuel moisture codes and three behaviour indices need to be understood.

Each fuel moisture code is a numerical rating relating to the dryness of the fuel, and each fire behaviour index is a numerical rating related to likely fire behaviour. The scales start at zero and, except for the Fine Fuel Moisture Code which has a maximum value of 101, all are open-ended.

Low ratings indicate high moisture content and ratings rise as moisture content decreases. Ratings rise as fire weather becomes more severe.

Fine Fuel Moisture Code

The FWI system evaluates fuel moisture content and relative fire behaviour using past and present weather effects on ground level fuels. The moisture codes reflect the effects of daily fuel moisture gains and losses.

FFMC is a numerical rating of the moisture content of surface litter and other cured fine fuels. It is an indicator of the relative ease of ignition and flammability of fine fuels.

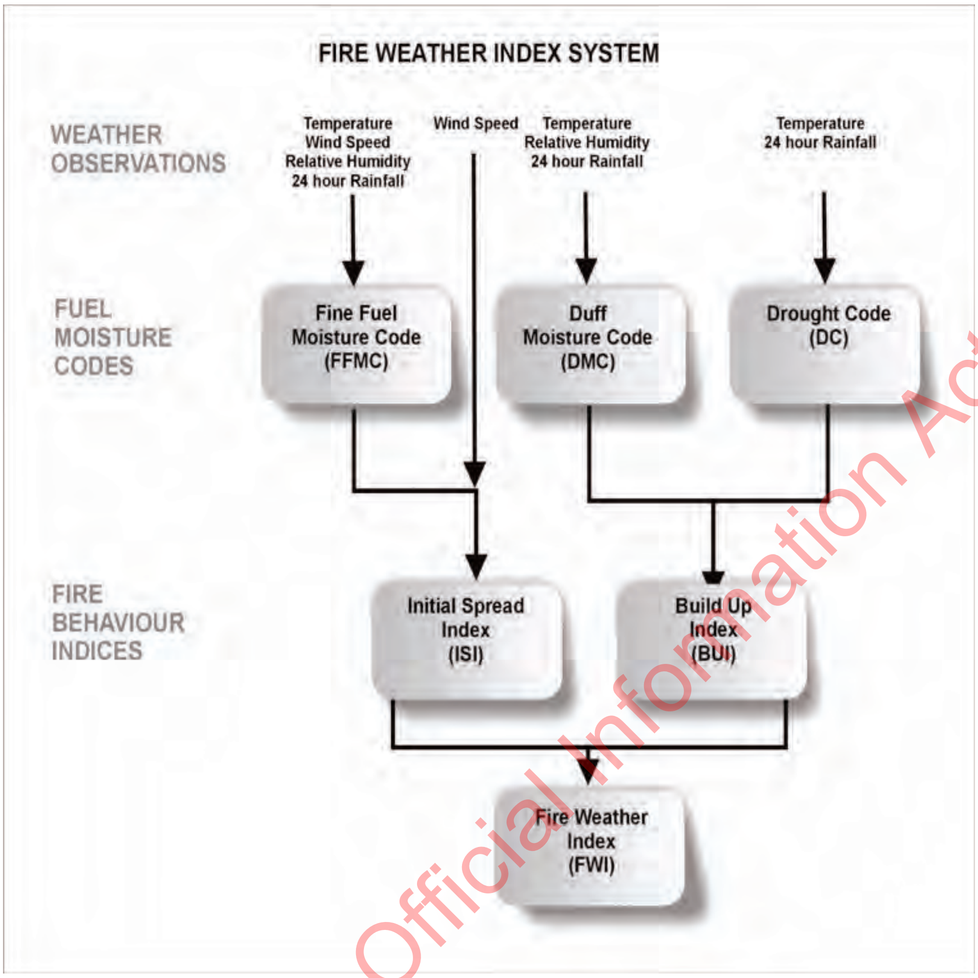


Figure 3.21: The Fire Weather Index System

Fine Fuel Moisture Code continued

The moisture content of fine fuels is very sensitive to the weather. Even a day of rain or fine and windy weather will significantly affect the FFMC rating. The system uses a time lag of two-thirds of a day to accurately measure the moisture content in fine fuels.

The FFMC rating is on a scale of 0 to 101. Any figure above 70 is high, and above 90 is extreme.

Duff Moisture Code

DMC is a numerical rating of the average moisture content of loosely compacted organic layers of moderate depth. The code indicates the depth that fire will burn in moderate duff layers and medium size woody material.

Duff layers take longer than surface fuels to dry out, but weather conditions over the previous couple of weeks will significantly affect the DMC. The system applies a time lag of 12 days to calculate the DMC.

A DMC rating of more than 30 is dry, and above 40 indicates that intensive burning will occur in the duff and medium fuels.

Prescribed burning should not be carried out when the DMC rating is above 40.

Drought Code

Drought Code (DC) is a numerical rating of the moisture content of deep, compact, organic layers.

It is a useful indicator of seasonal drought and shows the likelihood of fire involving the deep duff layers and large logs.

A long period of dry weather (about 52 days) is needed to dry out these fuels and affect the DC.

A DC rating of 200 is high, and 300 or more indicates that fire will involve deep sub-surface and heavy fuels.

Prescribed burning should not be carried out when the DC rating is above 300.

Fire behaviour indices

The three behaviour indices are relative to the fuel moisture codes. They indicate what a fire is likely to do.

The lower the fuel moisture content, the higher the fuel moisture codes, and the higher the fire behaviour indices – and the more active the fire will be.

Initial Spread Index

ISI is a numerical rating indicating the rate of spread of a fire in its early stages. It is calculated from the FFMC rating and the wind speed.

The open-ended ISI scale starts at zero. A rating of 10 indicates a high rate of spread and a rating of 16 or more indicates an extremely rapid rate of spread.

Build Up index

BUI is an indicator of the amount of fuel that is available for combustion, indicating how the fire will develop after initial spread. It is calculated from the Duff Moisture Code and the Drought Code.

The BUI scale starts at zero and is open-ended. A rating above 40 indicates a high level of fuel available for combustion. A rating above 60 is extreme.

Fire Weather Index – FWI

The information from the ISI and BUI is combined to provide a numerical rating of fire intensity – The Fire Weather Index. The FWI indicates the likely intensity of a fire. The graphs below illustrate how the indices are combined to give a rating for the differing environments of forest and grasslands.

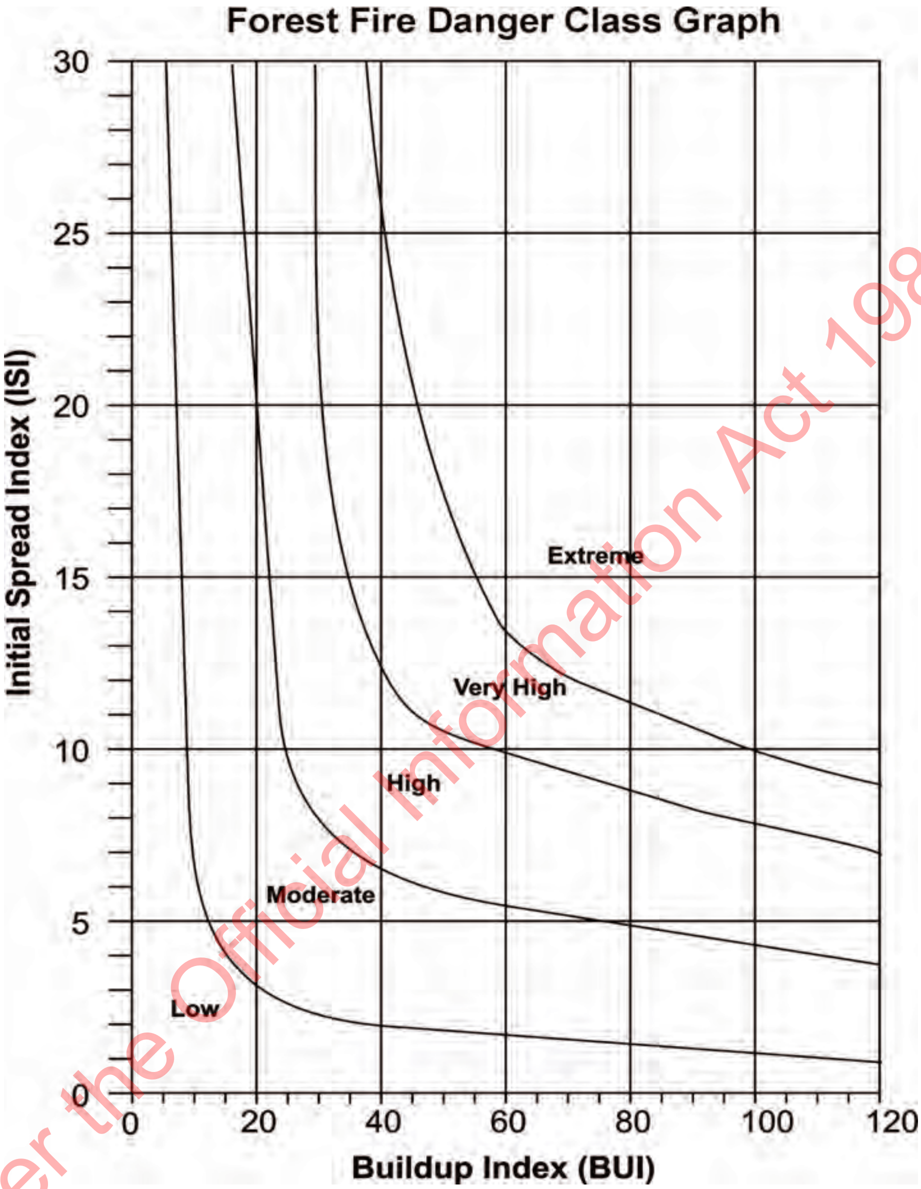


Figure 3.22: Forest Fire Danger Prediction

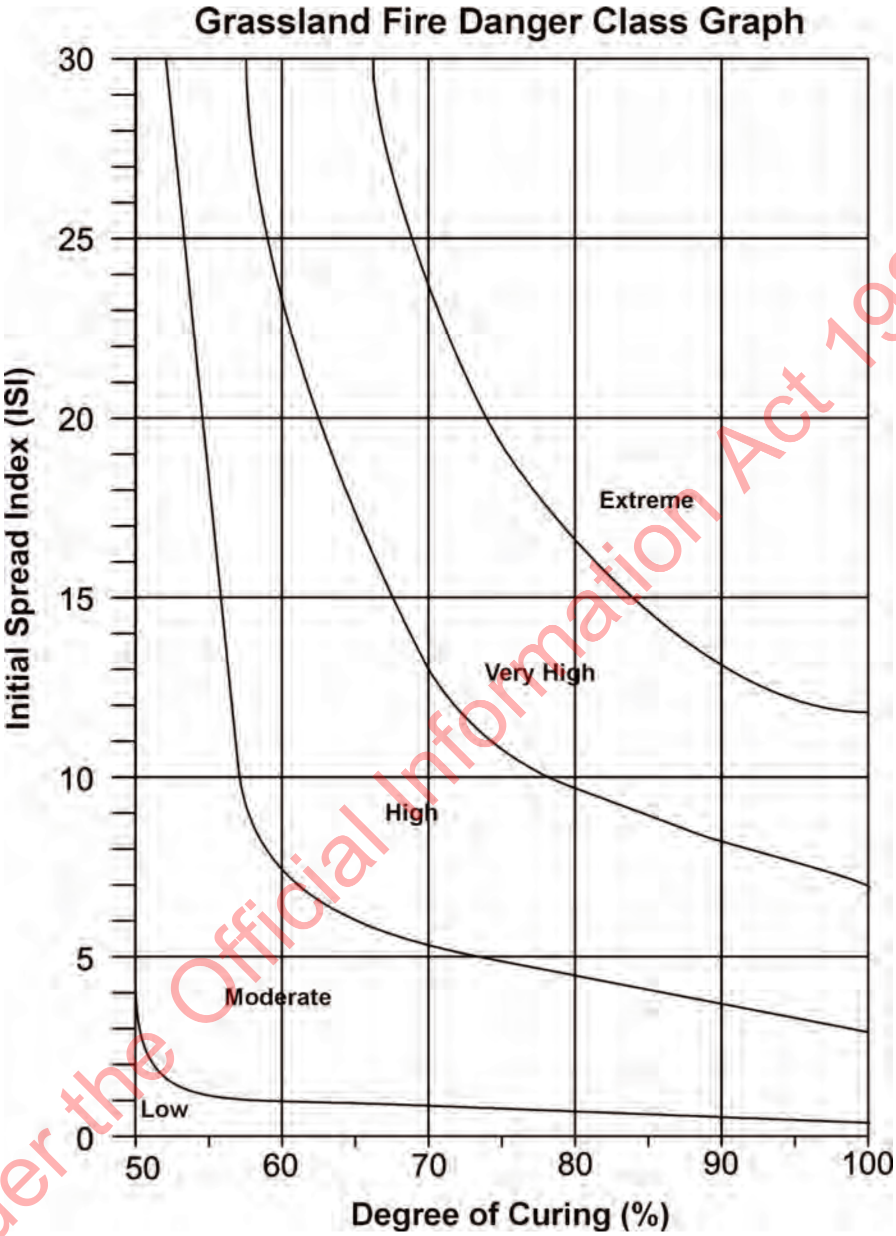


Figure 3.23: Grassland fire prediction

Interpreting the Information

The fuel moisture codes (FFMC, DMC and DC) indicate which fuels will be involved and their ease of ignition. This will vary during the season. Each code must be considered to assess its potential burning characteristics.

Example 1: **FFMC = 86 DMC = 25 DC = 120**

These numeric values indicate that:

- Fine fuels will ignite easily
- Fire will involve the fine fuels and to a limited extent the medium and duff layer fuels
- Fire will not become deep-seated.

Example 2: **FFMC = 94 DMC = 45 DC = 320**

These numerical values indicate that:

- Fine fuels will ignite extremely easily
- Fire will involve all fuel levels
- Extreme fire behaviour is likely.

The fire behaviour indices (ISI, BUI and FWI) indicate the likely initial spread, total fuel availability and potential fire intensity.

Example 3: **ISI = 5 BUI = 120 FWI = 21**

These numeric values indicate:

- Slow initial spread
- High volume of fuel available for combustion
- Potentially high level of fire intensity.

In general terms this is a hot, but slow-moving fire – the type of fire likely to occur on a windless day in mid-summer after a long, dry period.

Example 4: **ISI = 25** **BUI = 10** **FWI = 21**

Note: this example has the same FWI as in Example 3.

These numeric values indicate:

- Extremely fast initial spread
- Low volume of fuel available for combustion
- Potentially high level of intensity in fine fuels.

In general terms this is a fast-moving fire involving the fine fuels only. It is likely to be either a fire in early spring or late autumn when medium and heavy fuels have high moisture content and winds are strong, or after rain on a day with strong winds.

Operational management in New Zealand

Section objective

The objective of this section is for you to be able to explain the main points of the legislative foundation which governs how vegetation fires are managed.

Overview

It is essential that Fire and Emergency urban personnel (especially officers) have an understanding of the way in which the response to wildfires is organised and structured.

Legislative foundation

The manner in which vegetation fires will be managed is governed by Fire and Emergency New Zealand Act 2017 section 43.

Department of Conservation

The Minister of Conservation is the rural fire authority for the considerable areas administered by the Department. These areas often include a one-kilometre fire safety zone around conservation areas. Specified DOC personnel have been Authorised as Rural Fire Officers under the Fire and Emergency New Zealand Act 2017.

Fire and Emergency urban

The inevitable overlap of urban and rural responses means that Fire and Emergency officers (career and volunteer) need to possess a level of understanding and practical skill in order to:

- manage the low-level vegetation fire incidents for which they will have primary responsibility
- contribute effectively in a command role, under the interim Command and Control policy, when contributing to the management effort directed by the Incident Controller for larger scale incidents.

Where Fire and Emergency urban personnel provides the first response to a rural fire Section 43 of the Fire and Emergency New Zealand Act provides the necessary powers for Fire and Emergency urban crew to take any action that is considered necessary. Once aRura; Fire Officer arrives, the incident control will be determined according to the Interim Command and Control Policy.

Officers must be thoroughly aware of their responsibilities as set out under *Operational instruction S2*. This is given below.

Fire and Emergency personnel publications

Fire and Emergency personnel must:

- Familiarise themselves with the Fire and Emergency New Zealand Act 2017.
- Familiarise themselves with fire plans relevant to their area.
- Familiarise themselves with any Operational Service Agreement (OSA) and sections 145 to 148 of the Fire and Emergency New Zealand Act relevant to their area
- Operate according to the fire plan including policies and procedures for fire control.
- Understand the Fire and Emergency Interim Command and Control policy.

Pre-fire planning

Local procedures should include:

- liaison with the rural Officers
- hiring of plant, plant machinery and aircraft
- monitoring the Fire Weather Index data

Actions at the incident

Local procedures must include:

- assessing the fire
- assessing and identifying the environmental, cultural and commercial risks
- assessing potential fire spread
- providing water supplies
- upgrading the response
- establishing communications
- arranging incident ground safety
- evacuating endangered people or stock
- providing personnel
- appointing Safety Officer(s)
- providing relief crews and refreshments.

Local procedures

It will be seen from the above that considerable emphasis is placed upon local procedures. These will of course vary considerably, and the onus is therefore upon the individual officer to take the time and trouble to become entirely familiar with these.

Workbook Activity 3

Turn to your workbook and complete the questions in Activity 3.

Assignment 5

Congratulations, you have reached the end of this study guide.

In the back of your workbook there is an assignment to be completed. Remember to take a copy of your work before sending the assignment together with the completed workbook to your Programme Manager.

This is a marked assignment and will contribute to your final course results, so take your time with it.

All the questions in the assignment need to be answered.