HIGHFIRE RISK PROJECT RESEARCH DISSEMINATION PROGRAM

TRAINING MATERIAL

INTRODUCTION

There has been a significant amount of new science conducted on bushfires in the past decade. This has expanded our knowledge of the drivers of the major events that have catastrophic impacts on our communities.

There has been so much new learning introduced to the industry that the national training curricula have fallen behind.

This material is intended to be part of the research dissemination effort arising from research undertaken by the HighFire Risk Project.

HFR looked at understanding the drivers of wildifire risk in and around Australia's high country. The project was far more productive than expected, and has produced a large volume of ground-breaking research into fire weather and fire behaviour of international importance.

HFR has shown that established understanding of fire behaviour and training and procedures in use by fire agencies failed to pick up many of the drivers of catastrophic wildfires.

It is of vital importance that the results of the latest research finds its way into training programs, otherwise we will fail in our mission when the next catastrophic occurs.

Phase 1 of HFR was under the auspices of the Bushfire CRC, with funding from the Federal Government for three years. It was a joint research program between UNSW@ADFA and ACTESA.

Phase 2 of HFR is now run out of UNSW@ADFA, with collaboration from ACTESA and a wide range of international researchers. It is not associated with the BushfireCRC.

This research dissemination project is a collaboration between HFR and ESA Training and staff of AFAC.

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www.highfirerisk.com.au

A NOTE ON THE FORMAT OF THIS DOCUMENT

This document is fundamentally three targeted training documents interleaved into one. This is done to present the draft content for review. In final version it would be disaggregated.

KEY LEARNING OUTCOME

Detailed learning outcome.

Required level - B=i,, A=i,, F=i; References: [numbers in square brackets]

GENERAL AWARENESS

Content as required.

OPERATIONAL

Content as required.

EXPERT

Content as required.

Where:

Training is aimed at:

[B] Basic firefighters, staff of support agencies, etc.

[A] Advanced fire officers, Duty Meteorologists, & Air Observers

[F] Fire Behaviour Analysts, Severe Weather Meteorologists & Field Observers.

For each detailed learning outcome, a required level of training is assigned to B, A and F...

[G] General Awareness

[O] Operational

[E] Expert

CONTENTS

GENERAL FIRE CONCEPTS: The ruggedness of the landscape affects fire behaviour.

Methods for calculating landscape ruggedness, and the three main categories of ruggedness that result (rugged, undulating and flat).

Required level - B=O, A=E, F=E; References: [12]

GENERAL AWARENESS

OPERATIONAL

The behaviour of a major fire will reflect the type of terrain on which it is burning: flat, undulating or rugged.

The Situation Unit will alert crews if there are safety issues arising from the terrain.

EXPERT

The primary measure of ruggedness at a site for fire work is the range of elevation within a 1.5km radius of that site. Flat terrain in defined as an elevation range of less than 150m within that radius. Undulating terrain is where the local elevation range is between 150m and 300m. Rugged terrain is where the local elevation range exceeds 300m. In Australia the maximum range is over 1100m west of Mt Kosciusko.

The HighFire risk website contains maps of terrain ruggedness for a large number of 1:100,000 topographic maps sheet tiles. See http://www.highfirerisk.com.au/maps/index.htm. These have been mathematically derived from raw elevation data from the Shuttle Radar Topography Mapping mission (v2, Geoscience Australia). The three categories are a good indication of which type of fire behaviour to expect.

GENERAL FIRE CONCEPTS: The ruggedness of the landscape affects fire behaviour.

The ways that fires can evolve over flat terrain, and the suppression opportunities that result.

Required level - B=O, A=E, F=E; References: [12]

GENERAL AWARENESS

OPERATIONAL

On flat terrain, elliptical, wind-driven fires are the norm, and fire crews are skilled at methods of containing these fires. A pinching of the headfire from an anchor point near the point of origin is typical. Strategies and tactics can be successfully managed in the field.

EXPERT

The spread of the fire is easy to predict using established fire spread meters, algorithms or spreadsheets. The rate of spread, intensity, spotting potential and ratio of fire length to width are useful parameters. Guidance on that ratio can be derived from Pasquill's Index.

Reliable local weather observations are often not available. However the lack of terrain modifiers in flat terrain for weather make it valid to extrapolate from the nearest "official" weather sources or to use BoM NexGen gridded data.

GENERAL FIRE CONCEPTS:
The ruggedness of the landscape affects fire behaviour.

The ways that fires can evolve over undulating terrain, and the suppression opportunities that result.

Required level - B=O, A=E, F=E

GENERAL AWARENESS

OPERATIONAL

On undulating terrain fire crews have different skills, centred around suppression opportunities when fires back down leeward slopes. They also recognise the dangers of the hot fire runs up the windward slopes and resulting spotting.

There is a need to have fire analysts assessing the complexities of fire behaviour, especially in relation to timing and spotting potential.

EXPERT

The spread of an escalated fire may potentially be beyond the skill of most officers without Fire Behaviour Analyst training. Predictions require good data on slope and aspect, fuel type and loading and site weather.

GENERAL FIRE CONCEPTS:
The ruggedness of the landscape affects fire behaviour.

The ways that fires can evolve over rugged terrain, and the suppression opportunities, or lack of opportunities, that result.

Required level - B=O, A=E, F=E; References: [1], [3], [9]

GENERAL AWARENESS

OPERATIONAL

On rugged terrain we are now learning that fires on rugged terrain act as they would on undulating terrain until they have escalated past a certain scale, when the vertical air flows induced by the terrain act to make suppression difficult if not impossible. Such fires only decay when they leave the rugged terrain.

Incident objectives must focus on preventing fire escalation, and its subsequent coupling with the atmosphere.

When a fire becomes very large or plume-driven it is up to the Situation Unit to assess the safety issues that result and to review incident objectives and strategies.

EXPERT

It is essential that analysis of escalated fires on rugged terrain considers new research into the interactions of terrain and weather.

Among the factors to consider are:

- Foehn winds
- Low-level jets
- Mountain wind waves
- Thermal winds
- Subsidence inversions
- Thermal belts
- Wind channelling
- Fire channelling

This especially concerns computer systems, whose inner workings may not be obvious to the user.

GENERAL FIRE CONCEPTS: A fire's scale determines what drives a fire's behaviour.

The five main fire scales, their properties, their threats and the options for them to persist, escalate or decay during a work shift.

Required level - B=G, A=E, F=E; References: [2]

GENERAL AWARENESS

The size of a fire influences how it behaves.

OPERATIONAL

Fires fall into one of five size classes. Small fires are only on their site of origin. Medium fires have spread onto the surrounding landform. Large fires are onto adjacent landform elements. Very large fires are on a number of landform elements. As each landform element presents different weather and slope effects, the more such elements are involved the more complex the fire becomes. Very large fires respond to different components of the weather than do smaller fires. If a very large fire escalates it can become an extreme or plume-driven fire.

Small and medium fire respond only to surface conditions, and are termed surface fires.

Large and very large fires may respond to conditions up to the mixing depth, and are termed mixed fires.

Extreme fires may respond to conditions across the troposphere, and are termed coupled fires.

A local landform element may be important for a medium fire but "lost in the wash" for a very large fire. Thus crew need to know the context of their sector.

EXPERT

The transition model is a tool for quantifying the likelihoods of a fire changing its scale during an operational shift. It gives initial estimates of the probabilities of a fire

- Decaying
- Escalating
- Remaining in its current scale
- Causing significant damage

This is based on the Fire Danger Rating and the largest fire currently on the landscape.

GENERAL FIRE CONCEPTS:
A fire's scale determines what drives a fire's behaviour.

Techniques for assessing the probabilities of a fire's persistence, escalation or decay during a work shift.

Required level - B=G, A=E, F=E; References: [2]

GENERAL AWARENESS

Over any shift, a fire may decay (or go out), it may persist at its current scale or it may escalate into a large scale. It is possible to estimate the probabilities of these transitions.

OPERATIONAL

It is essential to understand the options for how a fire's size class may evolve over the current work shift.

Note that initial suppression on a very large fire may break it up into a series of large and medium fires, but these may merge the next time that FDI goes up.

It is important to only use achievable objectives in an Incident Action Plan, so obtaining valid probabilities from the Planning Section is vital.

EXPERT

Initial assessment of the likelihoods must be on the basis of an endorsed process. The HFR Transition model is the best currently available, but may not be endorsed.

The initial estimates need to be varied on the basis of:

- Operational effectiveness or difficulties.
- Local weather issues.

GENERAL FIRE CONCEPTS: The interaction of wind & terrain is a fundamental concept for understanding fire behaviour.

That while wind and slope are both critical drivers of a fire spread, they are not independent.

Required level - B=O, A=E, F=E; References: [8], [9], [11]

GENERAL AWARENESS

Care must be taken when factoring wind and slope into estimates of fire behaviour. If the situation is complex, ask someone with higher skill levels to do the estimations.

OPERATIONAL

The appropriate mathematical techniques need to be applied to finding the correct solution to combining wind and slope vectors for fire spread.

Recent research is showing how it is important to use correct techniques when both slope and wind are driving fire spread. Without wind a fire will accelerate upslope. Without slope a fire will accelerate downwind. in complex terrain the balance of these two forces varies from time-to-time and from place-to-place.

Wind-terrain interactions are also significant. When air flow is blocked by terrain the air flow can be complex and may produce quite different weather to the unimpeded weather, in the form of deflected wind, accelerated wind, drier air and turbulence. Some of these effects can be broad-scale, others very localised. More than one effect can be present.

In some cases wind will be accelerated upslope, and the slope may have no direct effect on rate of spread.

EXPERT

When taken on their own, it is straightforward to estimate the effects of slope or wind on fire behaviour. When wind and terrain interact the results may be difficult to predict. There are two elements to this:

- Firstly, both wind and slope seek to push a fire in certain directions, and their combined effect may be mathematically challenging.
- Secondly, wind is affected by slope, and care must be taken to correctly weight these into the resultant fire spread prediction.

These calculations are best done in a pre-tested computer system which needs to be validated.

GENERAL FIRE CONCEPTS:
The interaction of wind & terrain is a fundamental concept for understanding fire behaviour.

The various forms of interactions of wind and terrain: lee-slope eddies, wind channelling, fire channelling, thermal winds, low-level jets and general wind-terrain interactions.

Required level - B=G, A=E, F=E; References: [1], [3], [4], [9]

GENERAL AWARENESS

There will be various localised wind and terrain interactions influencing winds throughout the day. Not all of these may be noticed from general observations, requiring access to detailed weather data by the Situation Unit instead.

OPERATIONAL

Lee-slope eddies occur at the top of a ridge, when the upslope wind separates from the ground when the lee slope begins. After descending and re-attaching the air flow back upslope, in the opposite direct to the prevailing wind. These eddies are dominant when wind speeds exceed 20 km/hr. Below that speed they may or may not be present. Above 30 km/hr they are almost certain.

Wind channelling occurs when the prevailing winds blow across a steep valley. Some air flow is deflected down into the valley, and may then flow sideways, up or down the valley. Thus fires influenced by these winds may move in unexpected directions.

Thermal winds occur in rugged terrain when solar heating occurs on some slopes and not on others. Heated air rising over the former may be replaced by cooler air from the latter. This can produce circulations within valleys. These localised winds are dominant when prevailing winds are light, especially at night. Through the day, heating of the various aspects in a gully will change, as will the heating of a mountain range change between morning and evening.

Low-level jets occur when night-time inversions separate prevailing winds from the friction caused by rugged terrain. These stronger winds may be experienced by high ground that sticks up through the inversion.

General wind-terrain interaction involves wind accelerating up windward slopes, deflecting around side slopes and forming eddies on lee slopes. Subtle changes in prevailing wind direction may shift specific sites into quite different local wind fields, causing major changes in local fire behaviour.

EXPERT

The Situation Unit must ensure that, as is needed for the incident, a suitable weather observation network is put in place , on and around the fireground, augmented by aerial and ground observers and access to internet data.

Some of the events that may be detected require consideration be given to issuing watchouts or Red Flag Warnings.

GENERAL FIRE CONCEPTS:
The interaction of wind & terrain is a fundamental concept for understanding fire behaviour.

Methods for obtaining data on terrain attributes.

Required level - B=O, A=E, F=E

GENERAL AWARENESS

OPERATIONAL

Terrain data for operational purposes can estimated from published topographic maps. While the aspect of the side of a ridge will be rather constant, its slope value will depend on the scale at which you measure it – the finer you examine it, the greater the possible range of value will be. This scale should resolve details of about 5% of the headfire width. For most fires 1:25,000 topographic maps will suffice.

EXPERT

Understanding wind-terrain interaction generally requires a model – ranging from a complex computer-intensive one to a simple look-up table one. However these do not handle turbulence or eddies in moderate wind regimes, reducing their usefulness.

Terrain data should be of a resolution between 25m and 100m. Topographic maps are useful for basic work, while data from state agencies or the Shuttle Radar Topographic Mapping mission can be used in computer models. Initial data on wind should come from the BoM NexGen system, otherwise nesting wind-terrain interaction analyses are needed – e.g. "the NW winds are deflected around the ranges, becoming locally NNW winds, which interact with the ridge to form a lee eddy where the fire is".

A range of key parameters for wind – terrain interaction may be accessed from www.highfirerisk.com.au/maps/index.htm .The wind regimes are an important attribute:

- Terrain exposed to prevailing winds.
- Terrain prone to lee-slope eddies, depending on prevailing winds.
- Terrain prone to wind channelling.

GENERAL WEATHER: Vertical air flow and the vertical structure of the atmosphere are important for escalated fire.

Obtaining and interpreting an Aerological Diagram.

Required level - B=G, A=O, F=E; References: [3], [13]

GENERAL AWARENESS

It is important that the vertical structure of the atmosphere is reflected in fire strategies for that shift. This is a technical area carried out by the Situation Unit.

OPERATIONAL

Aerological Diagrams are useful way of plotting the data obtained from weather balloon flights. These are very detailed and not intuitive. Behind training, these are the most valuable tool for fire managers and analysts. They should be analysed by Situation Unit staff. Operations Unit senior officers benefit from a familiarity with them. They are posted on the web by a number of services, including BoM.

EXPERT

The tool "Using an Aerological Diagram" should be understood (see http://www.highfirerisk.com.au/tools/aerological.pdf). The on-line tool http://www.highfirerisk.com.au/extras/aerological.htm or equivalent tools can be used to simplify analysis of the Diagrams.

Derived products include:

- Ventilation Index, a combination of mixing layer depth and surface wind speed, which estimates the likely dispersal of smoke. Detailed guidance is also available from BoM models of smoke dispersion available on the registered user pages.
- Lifted Index, an index derived from the temperature (T) difference between ambient and lifted air at the 500 hPa level, is a measure of thunderstorm potential. 500 hPa is a higher level than is used for fire indices, but is relevant to violent pyro-convection. Intermediate values suggest that storms will form if there is a lifting mechanism present – such as a mountain range or an approaching cold front.
- Dry storm potential can be estimated from T and dew point (DP) data from 850 hPa and 700 hPa levels. While general guidance only is possible, the guidance should also reflect the storm potential derived from the lifted index.
- The mid-level Haines Index is a measure of the potential for the atmosphere above a fire to couple with the fire and cause it to escalate. HI is also derived from T and DP data from 850 hPA and 700 hPa levels. Also known as the Lower Atmosphere Stability Index (LASI), it can also be derived from higher layers over mountainous

regions. HI is restricted to between 2 and 6, with 6 indicating a high fire growth potential generally equivalent to a FDI over 40.

- The Continuous Haines Index bypasses the range restriction of HI. CH is open ended, but should not exceed 13. It is best interpreted in terms of percentiles of the site's climatology, which often means a value of 10 corresponds to a dangerous 95% value.
- Fuel moisture content can be estimated, but does need a value for Drought Factor. FDI can then also be estimated.

GENERAL WEATHER:
Vertical air flow and the vertical structure of the atmosphere are important for escalated fire.

Obtaining and interpreting internet data on vertical air flow.

Required level - B=G, A=O, F=E; References: [1]

GENERAL AWARENESS

Vertical air flow, either rising or descending, can affect a fire's behaviour.

OPERATIONAL

Neither surface weather reports nor Aerological Diagrams directly indicate vertical air flow. However it is imperative that those managing large or very large fires in rugged landscapes have access to the implications of information about vertical air flow. The Situation Unit must interpret this information.

EXPERT

The available options for obtaining this information are:

- Deducing the conditions under which vertical air flow may occur from the information at hand, such as surface heating, converging air flows seen in MSLP charts, heating by a fire, etc.
- Discussions with the duty fire weather forecaster. Forecasters have access to numerical weather models which can depict vertical air flow systems above a certain size. They may have an appreciation of whether general conditions are conducive to the formation of smaller-scale processes such as mountain wind waves.
- Field observations of the manifestations of vertical air flow – such as cloud formations.

GENERAL WEATHER:
Vertical air flow and the vertical structure of the atmosphere are important for escalated fire.

Field detection of vertical air flow.

Required level - B=G, A=E, F=E; References: [3], [4], [10]

GENERAL AWARENESS

Looking at the structure of the smoke plume and nearby clouds reveals a lot about the atmosphere's stability, an important indicator of the potential for dangerous fire behaviour.

OPERATIONAL

Established fire training refers to stability and compares smoke plumes under stable and unstable conditions. This vertical flow is induced by the heat from the fire, and is clearly seen. However additional intelligence can be gathered from the details of plume structure, and new terms have been introduced to allow reporting of these details. For example, a report of a high cauliform towering pyro-Cu clearly indicates the potential for development of a pyro-Cb.

Other forms of vertical air flow can be detected. As examples, foehn winds may produce foehn arches, foehn walls and foehn gaps, and mountain wind waves may produce standing altocumulus lenticularis clouds.

EXPERT

Various tools are available to aid in interpreting smoke plumes:

"Interpretation of Smoke Plumes" on-line at http://www.highfirerisk.com.au/tools/smoke.pdf.

and "The Smoke Spotters Guide" on-line at http://www.highfirerisk.com.au/tools/tool6_v2.pdf.

A wide range of fire and weather elements that field observers should look out for are discussed in "Checklist for Fire Observers" on-line at http://www.highfirerisk.com.au/tools/events.pdf.

Observations might come from general field staff, field observers, air operations or from remote sensing sources. The latter includes aircraft, UAVs, satellite imagery and weather radar.

Some observed or reported features require consideration be given to issuing watchouts (e.g. Mountain wind wave) or Red Flag Warnings.

GENERAL WEATHER:
Vertical air flow and the vertical structure of the atmosphere are important for escalated fire.

The mixing layer.

Required level - B=G, A=O, F=E

GENERAL AWARENESS

There will frequently be an inversion some kilometres above the ground, that separates the ground from the prevailing weather, especially winds. It controls how well smoke disperses away from a fire. Daytime heating can cause this to breakdown, leading to rapid escalation of fire danger. Field staff should always watch out for this.

OPERATIONAL

The air above the ground, in general terms gets cooler as you get higher. Below the cloud base the dry adiabatic lapse rate applies, while above it the saturated adiabatic lapse rate applies. This is the case right through the troposphere (the lowest layer of the atmosphere), except for the very lowest part, adjacent to the ground. At night radiative heat loss to space makes the ground surface cool, also cooling the air that comes into contact with it. Thus, except for during the heat of the afternoon, the air gets warmer above the ground. This is the mixing layer, and is a form of inversion. It develops overnight and breaks down during the late morning. That breakdown is due the ground warming up and also turbulent mixing caused by air flowing above the inversion. This turbulence is the cause of wind gustiness in the morning.

If this inversion is in place it will limit the dispersion of smoke from fuel reduction burns. The depth of the inversion and the wind speed under it are the key controlling factors in dispersion.

EXPERT

There are two good sources of information about the mixing layer.

Firstly Aerological Diagrams, generally flown in the morning, give a feel for the maximum development of the mixing layer. The maximum heating adiabats on the Diagram also indicate what will happen when the daytime heating breaks down the mixing layer.

Secondly NexGen provides maps of mixing depth. There is currently some inconsistency within NexGen as to whether it shows the current depth or the maximum depth.

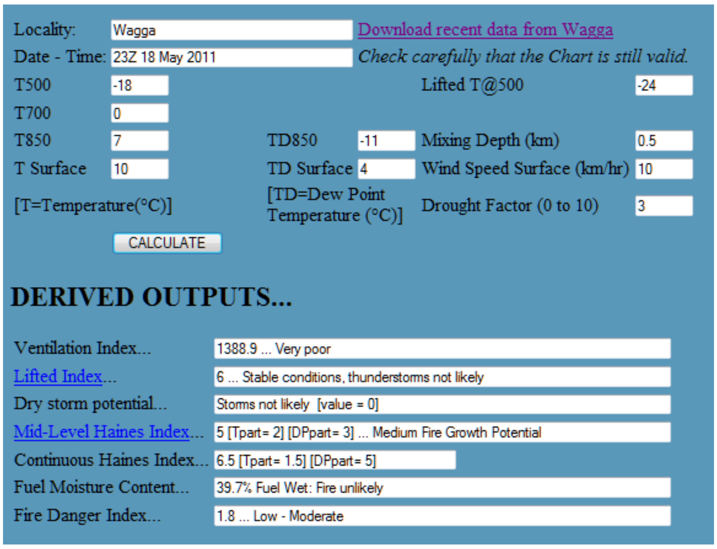

Figure 1. Analysis of an Aerological Diagram.

GENERAL WEATHER: Vertical air flow and the vertical structure of the atmosphere are important for escalated fire.

Key air flows around and within a fire's plume.

Required level - B=G, A=O, F=E; References: [3], [4]

GENERAL AWARENESS

Winds are deflected around strong smoke plumes – keep alert to unexpected wind flows.

OPERATIONAL

Air flow in and around a plume is complex and variable. A weak fire simply injects smoke into the surrounding air, which moves away with the wind.

When a medium fire forms a noticeable plume, it is trying to punch upwards through a horizontal air flow. As this happens some of the air flow is deflected upwards and some is deflected around the plume.

A large fire will generate a stronger plume, which will cause greater deflection. In the lee of the plume there will be recurved eddies as the deflected air tries to re-establish equilibrium.

Low whispy plume.	Raised columnar plume.	Pyro-Cu plume.

The depth of the flaming zone will be of the same order as the height above ground within which the rising plume resists mixing with the surrounding air, and thus also causes greatest deflection. This reflects the thermal expansion within the rising plume as it seeks to re-establish equilibrium with its surroundings.

For a very large fire these effects start to have the capacity to locally dominate weather.

If the plume resists mixing up to the lifting condensation level, then violent pyro-convection can develop, leading to an extreme fire.

If this happens the plume acts like a solid object in its effects of local surface weather outside the plume. Within the plume localised turbulent circulations dominate.

Strengthening convection may require consideration be given to issuing watchouts or Red Flag Warnings (Conditions conducive to plume-driven fire).

EXPERT

The task of watching for complex local winds around a fire's plume is best done by Operations staff at the Sector level. However if this becomes a critical issue then field observers must be tasked to assist.

Reports from Operations Section staff or field observers of watchout conditions will require in-depth analysis of the potential for worsening of the situation.

SPECIFIC HIGH COUNTRY WEATHER: Foehn winds are important in southeast Australia.

The types of foehn winds and the conditions for their formation.

Required level - B=G, A=O, F=E; References: [1], [3], [4], [10]

GENERAL AWARENESS

A prominent barrier ridge – aligned across the prevailling wind flow – can have a major impact on weather downwind through two processes, collectively called Foehn Winds. Firstly, it may block the low level air mass, with upper level air flowing down on the lee side. Secondly it may raise low level air (in passing over the ridge), causing the air to lose moisture through precipitation. When it descends it is warmer and drier than it was upwind of the ridge. Additionally the downward descent may accelerate the air flow.

OPERATIONAL

Operations Officers should check daily weather forecasts and briefings for foehn wind potential whenever they are operating downwind of ranges or prominent ridgelines. If there is such a potential then they need to work with Situation Unit to ensure that a suitable situation observation program is in place.

EXPERT

Situation Unit analysts should refer to current Aerological Diagrams to assess foehn potential. This involves (a) looking to see what happens to air that is lifted up to the barrier height and then descended again, or (b) air that flows across the top of a barrier and then descends to the fire ground's elevation. The effect of radiation inversions needs to be considered.

SPECIFIC HIGH COUNTRY WEATHER: Foehn winds are important in southeast Australia.

The impact of a foehn wind on surface fire weather.

Required level - B=G, A=E, F=E; References: [1], [3], [4], [10]

GENERAL AWARENESS

Foehn winds can produce a rapid escalation of fire danger.

OPERATIONAL

The two types of foehn wind will only form when the winds are aligned across the ridge. At a site downwind, there may be a sudden onset of foehn conditions as winds back ahead of an approaching cold front. These may produce rapid increases in FDI – thirty-fold increases over thirty minutes have been recorded.

This increase may happen within the normal interval specified for taking fire ground weather observations. Thus when foehn winds may occur, the weather observation interval must not exceed 30 minutes.

Consideration may be given to issuing watchouts or Red Flag Warnings (Foehn wind).

EXPERT

The two types of foehn wind will only form when the winds are aligned across the ridge. At a site downwind, there may be a sudden onset of foehn conditions as winds back ahead of an approaching cold front.

This increase may happen within the normal interval specified for taking fire ground weather observations. Thus when foehn winds may occur, the weather observation interval must not exceed 30 minutes.

For prediction work three tasks must be considered.

Firstly the general isobarically-driven winds need to be determined, from the MSLP chart, to see if they may be aligned normal to the terrain.

Secondly the ability of wind shifts to take the situation into or out of foehn conditions. Guidance on wind direction variability may be sought from Pasquill's Index.

Thirdly consideration may be given to issuing watchouts or Red Flag Warnings (Foehn wind).

SPECIFIC HIGH COUNTRY WEATHER: Subsidence inversions and nocturnal low-level jets can invert the diurnal weather cycle.

The formation of a subsidence inversion and its potential impacts on surface fire weather.

Required level - B=G, A=O, F=E; References: [1], [3], [4]

GENERAL AWARENESS

As a high pressure cell forms and approaches from the west, it can have some complex impacts on surface weather.

OPERATIONAL

The thermal expansion of middle layers of the air can push warm, dry air downwards towards the surface. The highest ground, above say 1500m ASL, will be impacted by this first. Upper air frequently has very low dew point temperatures, unaffected by the evaporation of water from the surface. Thus even though the temperature at these heights may be much lower than in the lowlands, the relative humidity can be very low – say 10%.This can reduce fuel moisture content to dangerous conditions. If, as is common on high ground, the wind speeds are elevated, then the FDI can be elevated as well.

Most importantly this often happens between midnight and sunrise, inverting the typical daily FDI cycle. Records show that this can happen on between one day in six and one day in nine. Thus over the course of a campiagn fire it is very likely to happen.

EXPERT

The prerequisite conditions for a subsidence inversion are:

- Generally dry, fine weather.
- Approaching high pressure system.
- Terrain above c.1500m ASL.

Confirming their onset requires monitoring BoM AWS data feeds. Due to the imprecision of the “1500m ASL” parameter, there may be a need to install an AWS near the fireground to be sure of onset.

Consideration may be given to issuing watchouts or Red Flag Warnings (Dew point depression event).

SPECIFIC HIGH COUNTRY WEATHER:
Subsidence inversions and nocturnal low-level jets can invert the diurnal weather cycle.

The formation of a low-level jet and its potential impact on surface fire weather.

Required level - B=G, A=O, F=E; References: [1], [3], [4]

GENERAL AWARENESS

Low-level jets are a process that can produce higher than expected wind speed over high ground, especially at night.

OPERATIONAL

An inversion often forms at the lifting condensation level. Without friction from the ground, winds blowing above the inversion may be much stronger than those below it. The band of higher winds is termed a jet, and these occur at lower levels than most.

If the lifted inversion is at about the maximum terrain height, high points on the terrain may protrude through the inversion, and experience stronger winds.

Operations staff in the field must be wary of this when working at night, as it may be difficult to detect a low-level jet unless you deliberately look for it.

EXPERT

It is difficult to detect a low-level jet. Available sources of information are limited to AWS data from alpine sites and Aerological Diagrams. Field observations in rugged terrain at night close to a fire are potentially dangerous to do.

Most likely a Sector Leader will report unexpectedly strong winds. This could be viewed as a watchout (Low-level jet) and require follow-up actions for verification and ensuring crew safety.

SPECIFIC HIGH COUNTRY WEATHER: When prevailing winds exceed 25km/hr lee-eddy winds may become important.

The potential wind regimes around rugged terrain and the prevailing weather that can produce them.

Required level - B=G, A=E, F=E; References: [1], [3], [4], [8], [12]

GENERAL AWARENESS

As discussed elsewhere, as winds pass over complex terrain, their speed and direction can be significantly modified. These wind-terrain interactions can, in part, be predicted, but only under certain circumstances. The lee of a ridge is where winds are least predictable.

OPERATIONAL

Operations staff must always monitor the setting within which they must work. In complex terrain, a key uncertainty in this arises from the interaction of wind with terrain. As winds pass over or around terrain obstacles, there may be major and dynamic variations in local wind speed and direction. Remember that wind and slope are both dominant drivers of the speed and direction of spread of a headfire.

In the light winds required for fuel reduction burning it is not possible to reliably predict local winds. On-site, routine observations are essential.

In the stronger winds that may be driving an escalated wildfire, it is likely that rugged lee-slopes will be carrying lee-slope eddies. It must always be remembered that somewhere on the side of a hill there may be a dynamic transition between windward and leeward wind fields.

There is also a need to be watchful for wind channelling. If the prevailing winds pass over the top of an incised valley, some of the air flow is deflected downwards into the valley and sideways. The direction of deflection is determined by friction (forced channelling) or, in the case of large valleys, pressure gradients (pressure-driven channelling).

Wind – terrain interactions thus may modify wind direction and speed, or may alter the general wind regime. Where needed Operations Section should issue a watchout or Red Flag Warning (Wind change).

EXPERT

It is essential that staff in a Situation Unit consider the potential wind fields. Key possibilities are:

- Light winds where wind direction is little affected by terrain, and winds accelerate on exposed faces and decelerate on leeward faces.

- Moderate winds, where winds may or may not be deflected by terrain. Field observations are essential.
- Strong prevailing winds – over 25 km/hr – will produce dominant lee-slope eddies.

It must also be remembered that major terrain features may alter the wind flow before localised wind-terrain interactions are factored in. Thus a WNW wind may become a NW on the lee of a major ridge system, and this is the wind that is affected by localised interactions with a prominent hilltop.

Analysts need to continually monitor the balance between prevailing winds, wind terrain interactions, thermal winds and wind channelling.

Consideration should be given to issuing a watchout (Wind change at fire) if winds become variable or erratic.

SPECIFIC HIGH COUNTRY WEATHER:
When prevailing winds exceed 25km/hr lee-eddy winds may become important.

The conditions for dominance of lee-slope eddies.

Required level - B=G, A=E, F=E; References: [4], [8]

GENERAL AWARENESS

When winds freshen, the winds on the lee of ridges may switch to blow upslope.

OPERATIONAL

During operations on the lee-side of landforms, operations staff must monitor the wind field. This is because sudden changes in winds may occur.

The critical factor is whether the prevailing wind speed exceeds 25 km/hr. This may happen because of the diurnal cycle of wind speed, especially when the overnight inversion boils off. It may also happen due to synoptic freshening, or under the influence of approaching weather systems. Extra care is required if a wind change is part of such a system. It is feasible that on a windward site, for example, a reversal of the prevailing wind direction accompanied by a freshening of the wind speed could result in an additional switch to a lee-eddy field and no overall change in wind direction on the ground, but major changes in plume behaviour and spotting footprint.

EXPERT

In general terms the formation of a lee-slope eddy requires undulating or rugged terrain. The lee slope should generally be above 10˚, but this varies with prevailing wind speed. The aspect should be opposite to the wind direction to within about 50˚. Long runs with continuous slope and aspect values are able to support stronger eddies than complex slopes. Under some situations eddies are stationary, in others they roll over the terrain.

Eddies always have a separation point, where they stop following the terrain and rise up to loop back. Outside the eddy there may be prevailing winds or channelled winds (depending on where it lies in the toposequence).

When wind speeds are assessed as able to produce lee-slope eddies, consideration should be given to issuing a watchout (Wind change at fire).

SPECIFIC HIGH COUNTRY WEATHER:
When prevailing winds exceed 25km/hr lee-eddy winds may become important.

The implications of the dominance of lee-slope eddies for fire behaviour.

Required level - B=G, A=O, F=E; References: [4], [8]

GENERAL AWARENESS

General fire training suggests that fires burn most intensely on the windward faces of ridges. This is because slope and wind effects are acting in unison to accelerate the fire. Lee-slope eddies also act in unison with the slope. The perhaps unexpected resulting intensity may appear rapidly.

OPERATIONAL

Operations staff must be wary of lee-slope eddies. They may appear rapidly, they may behave erratically, and they may produce intense fire behaviour.

Established fire training indicates that after a wind-driven uphill run a fire will abate when it enters a downhill run, with wind and slope opposing. The uphill runs is where spotting is most likely to start, and a spotfire on the lee-slope should be mild.

However, if a lee-slope eddy is present, that spotfire will experience a wind-driven uphill run, equally likely to produce spotting. Observations of extreme fires show that fires may leap-frog across complex landscapes as a series of such runs, making containment lines ineffective and jeopardising crew safety.

Consideration should be given to issuing watchouts or Red Flag Warnings (Wind change).

EXPERT

As, in general terms, intense fire runs are the most likely to produce spotting, both the windward and leeward runs may produce spot fires for some distance downwind that reflects the fire danger index. As a rule of thumb, the spotting distance is less than 2 hours level ground forward spread. Lofted embers flow with the prevailing wind. Thus if conditions are severe enough for the windward run to produce medium range spotfires, these may occur near the bottom of the lee-slope eddy, and thus produce a major uphill run on the leeward side, which is equally able to spot onto adjacent landform elements. This leapfrog-style fire spread negates control lines and jeopardises fire crew safety.

SPECIFIC FIRE BEHAVIOUR: Fire channelling is a major factor in rugged landscapes.

The process of fire channelling, and the setting within which it forms.

Required level - B=G, A=O, F=E; References: [1], [3], [4], [9]

GENERAL AWARENESS

Fire channelling occurs when, during conditions of elevated FDI, fire enters a lee-slope eddy or a valley eddy.

With the severity of the fire weather and the thermal heating within the eddy two things ensue: (1) embers are shed from the top of the eddy, igniting the landscape for some distance downwind; and (2) the fire within the eddy expands sideways, expanding the area affected by process 1 as well.

OPERATIONAL

On windy days with low fuel moisture levels in rugged terrain there is a real risk of fire channelling on lee-slopes. If a headfire or fire flank enters a lee-slope, the following will be seen, and operations staff should be alert for these signs:

- A dense column of orange and black smoke will form just over the ridgetop.
- This column will move sideways away from the main fire.
- Spotfires will start downwind of that column.

This is a trigger for a Red Flag Warning (Fire Channelling event}.

EXPERT

Recent research has explained how fire channelling works. The main conditions are:

- Rugged landscape, as indicated in the on-line maps on the HFR website. This carries with it a range of interactions between terrain and air flow.
- A lee-slope aligned to within 40˚ of the reverse of the wind direction – i.e. for a westerly wind (270˚), an aspect from 50˚ to 130˚.
- A lee-slope above 10˚ slope.
- Ambient winds above 25 km/hr. Under these conditions lee-slope eddy winds dominate.

If a fire enters a site that meets these conditions, then fire channelling must be considered. Note that there may be other, as yet unidentified, prerequisites.

Should a fire channelling event be observed or inferred then a Red Flag Warning must be issued.

SPECIFIC FIRE BEHAVIOUR:
Fire channelling is a major factor in rugged landscapes.

The potential consequences of fire channelling.

Required level - B=O, A=E, F=E; References: [3], [4], [9]

GENERAL AWARENESS

Fire channelling has been linked to many of the notable fatal fires in Australia and the US.

OPERATIONAL

If you hear a warning of fire channelling occurring in your sector, it is imperative that your crews focus on safe egress only. This is a Red Flag Warning situation (Fire Channelling event}.

Operations personnel are unlikely to detect fire channelling occurring – it will be field or aerial observers who do so. Make sure that they are tasked to do this during fires in rugged landscapes with ambient winds over 25 km/hr and low fuel moisture content.

EXPERT

Should a fire channelling event be initiated, the subsequent fire evolution will involve:

- Intense spotting downwind of the flank of the event, for up to 6km, with all spots attaining headfire intensities and rates of spread and rapidly merging.
- A vortex of dense smoke within the lee-slope eddy, with a major, dense, orange-coloured plume emerging from the flank. This is diagnostic.
- The flank of that vortex expanding, laterally with respect to the prevailling wind, at up to 6 km/hr. Note that this takes the spotting zone, above, with it, resulting in fire spreading in two directions at once.

A major expansion of the flaming zone results – it may be some kilometres wide. This creates a convection column that maintains its thermal expansion (and thus prevents mixing with the surrounding air) up to the lifting condensation level. Should this occur, then a violent pyro-convection event will ensue.

SPECIFIC FIRE BEHAVIOUR: Deep flaming may result from elevated rates of spread, wind changes or fire channelling.

How deep flaming may form.

Required level - B=G, A=E, F=E; References: [3], [4] ,[5], [6], [12]

GENERAL AWARENESS

A key indicator of dangerous fire conditions is the depth of the flaming zone. In normal fire operations this is measured in up to tens of metres. In wildfires the flaming zone may be hundreds of metres deep. However in extreme fires it may be kilometres wide.

OPERATIONAL

Deep flaming may form, at times of elevated FDI, when any of the following occur:

1. The rate of spread of a headfire is extreme.
2. A wind change, making a flank the new, extremely broad headfire.
3. Fuel moisture content approaches zero with frequent, rapdily coalescing spotting.
4. Fire channelling.

Deep flaming means that the depth of the flaming zone is of the same scale as its width. Any observation of this must lead to issuing watchouts (Deep flaming) or Red Flag Warnings (Conditions Conducive to plume-driven fire).

EXPERT

Studies of deep flaming events have shown the common elements behind their ferocity.

In normal fire behaviour we need to consider the residence or burn-out time of a headfire. The distance travelled by the headfire in that time is the flaming depth. Clearly when the FDI and fuel loads are high enough this will produce deep flaming.

It is also well established that when a wind change hits a fire, it may activate a flank fire to become a new headfire with significant greater width. This is commonly the result of a cold front hitting a fire driven by pre-frontal weather.

Dense spotfires under very low FMC conditions can rapidly amalgamate, producing a high effective rate of spread (although without a headfire).

A common mechanism for produce dense spotfires is a fire channelling event. In these the two-directional fire spread makes it a far more effective producer of deep flaming than the other mechanisms.

The other major mechanism is abrupt surface drying events, where dry middle level mixes down, either mechanically or through fire forcing.

It is the task of Situation Unit analysts to monitor the full set of circumstances. They all involve elevated FDI, and in varying ways strong winds. The terrain aspect of fire channelling is also important. Atmoshperic stability must also be monitored.

Any prediction of deep flaming forming must lead to issuing watchouts (Deep flaming) or Red Flag Warnings (Conditions conducive to plume-driven fire).

SPECIFIC FIRE BEHAVIOUR:
Deep flaming may produce an extreme fire event.

The consequences of deep flaming.

Required level - B=G, A=E, F=E; References: [2], [3], [4], [5], [6]

GENERAL AWARENESS

In the worst circumstances, deep flaming may cause an extreme fire. Should happen crew safety becomes paramount, and incident objectives need to reflect only the need to protect lives.

OPERATIONAL

Deep flaming is a sign of serious fire behaviour. Should it happen, then all aspects of fire suppression will become more difficult, increasing the need to revise incident strategies. Crew safety also becomes increasingly difficult to guarantee.

In the worst case an extreme, or plume-driven, fire will result. Should this happen the fire will stop responding to surface weather, fuel loads or terrain. Instead middle level winds will drive it for as long as the terrain stays rugged and the atmospheric instability supports mixing down of dry air from aloft.

Deep flaming may well be detected by operations resources, but it must be reported immediately. The likelihood of an extreme fire forming would trigger consideration of a Red Flag Warning (Conditions conducive to plume-driven fire). The IAP would also need review, especially for the safety of crews in affected sectors.

EXPERT

The most extreme form of deep flaming is when this scale exceeds the distance to the cloud base, when violent pyro-convection may occur. This is called an extreme fire. This plume-driven fire is then extremely dangerous and unstoppable. The resulting fire thunderstorm may make the situation very complex, with downburst winds, tornadoes and ember storms.

SPECIFIC FIRE BEHAVIOUR: Extreme fires produce violent pyro-convection.

The conditions for formation and behaviour of violent pyro-convective events.

Required level - B=G, A=O, F=E; References: [3], [4], [6]

GENERAL AWARENESS

In the worst case, an extreme fire may produce a thunderstorm in its plume, with serious consequences for fire crews.

OPERATIONAL

On a day of elevated FDI, the lifting condensation level, also called the cloud base, may be over 5km above the ground. In general terms the burning of vegetation releases a lot of water vapour which may form a cloud within the plume, called a pyro-cumulus or pyro-cu.

A rising smoke plume will resist mixing with the air that it passes through for a distance broadly equal to the flaming depth. If the resistance is still occurring when the cloud base is reached, then a fire thunderstorm may result. Such a cloud is called pyro-cumulonimbus or pyro-Cb.

Pyro-Cbs are dominated by the heat released as the water vapour condenses and freezes (the latent heat). This may be up to three times the heat release of the fire. This is now a coupled fire-atmosphere event, and its movement is determined by the upper level winds pushing on the plume.

Within the plume, conditions are extremely violent and disconnected from the prevailing weather outside. Fire suppression is impossible and a Red Flag Warning (Plume-driven fire) must be issued.

EXPERT

There are two key requirements to look out for.

Firstly there must be deep flaming, to allow the convection column to reach the lifting condensation level before mixing with the surrounding air.

Secondly there must be sufficient instability for the column to continue rising once it passes the convective cap at the LCL. The cap may be passed if the additional heating on the ground moves a trace of a lifted parcel of air past it.

SPECIFIC FIRE BEHAVIOUR: Extreme fires produce violent pyro-convection.

Surface weather events associated with the passage of a pyro-convective plume.

Required level - B=G, A=O, F=E; References: [3], [5], [6]

GENERAL AWARENESS

Conditions under a pyro-convective plume are extremely life-threatening.

OPERATIONAL

Under a pyro-convective plume, the only operational imperative is to have fire crews evacuated or inside secure shelter.

Sheltering crews experience extreme fire conditions, severe ember attack, localised strong to gale-force winds and reduced oxygen levels. Burn-over times may be over half an hour even in light fuels. The important point to note is there will not be a headfire pass by, rather there will be spotfires, ember attack, possible tornado impact, fireballs, gale-force indraft winds, and finally a steady consolidation of fire elements under light winds until things abate. It may not be safe to leave when the shelter become uninhabitable.

The plume will pass over any point at a speed of up to 35 km/hr, determined by upper winds.

EXPERT

The impact of a pyro-convective plume reflects the events that it produces as it moves over the landscape. Information on these events can be sourced from Operations Section staff, the public over social networks, the media and field observers. Remote sensing sources, such as weather radar and airborne linescanning if available are vital.

The correct assessment of these events is essential for timely and appropriate response and recovery actions.

SPECIFIC FIRE BEHAVIOUR: Violent pyro-convection may involve a pyro-cumulonimbus, pyro-tornadogensis and ember storms.

The phenomena associated with pyro-Cbs, including ember storms, lightning and tornadoes.

Required level - B=G, A=O, F=E; References: [3], [4], [5], [6]

GENERAL AWARENESS

A pyro-Cb is a true thunderstorm, and may have any of the features and threats to safety of a severe thunderstorm.

OPERATIONAL

A pyro-Cb may exhibit many of the features of a true thunderstorm:

1. Tornadoes.
2. Very large fire whirls.
3. Lightning.
4. Downburst fronts and squalls.

They may move at up to 65 km/hr, as determined by weather radar. Fire whirls are attached to the ground, but may leave the burnt area, carrying fire with them. Fire tornadoes are attached to the base of a pyro-Cb, and may lift-off from the ground repeatedly as they travel. They may be filled with fire and embers. They produce surface winds of over 250 km/hr, and have vertical air flow of over 150 km/hr. They are a major hazard to fire aviation. Lightning has, on a number of occasions, started new fires over 20km downwind. Downbursts can produce rapid changes in fire spread, endangering fire crews.

Pyro-Cbs may exceed 15 km in height and reach into the upper atmosphere.

Operations Officers need to carefully consider the implications of these features for the safety of crews and the public. There should be a Red Flag Warning (Plume-driven fire) in place.

EXPERT

Near real-time remote sensing data from weather radar and weather satellites are the key tools for detecting the formation of a pyro-Cb. Field or air observers can only assess this if they are over 10km distant from the fire.

The thunderstorm’s movements should be tracked using weather radar, and forecast tracks developed and used for operational planning.

SPECIFIC FIRE BEHAVIOUR: Ember storms are different to ember attack, and are associated with unusual combustion processes.

The formation, behaviour and consequences of an ember storm.

Required level - B=G, A=O, F=E; References: [3], [4], [5]

GENERAL AWARENESS

Ember storms may form around violent pyro-convective events. They involve a sheet of embers, about a metre deep, blowing across the ground. Crews need to consider safety as a priority.

OPERATIONAL

Ember storms are a direct result of the weather *within* an extreme fire plume. With strong winds and near zero fuel moisture content it is easy for embers to form and to blow across the ground. They form a layer about one metre deep, and any object that sticks up into that layer is attacked by these embers and potentially ignited. Compact surface fuel layers (such as eaten-out paddocks) may not ignite. An ember storm results in numerous spot fires that rapidly merge. The embers flow like a river, following a path of least resistance. This is a primary cause of seemingly indiscriminate house loss patterns. Urban features such as gardens and mulch beds, when ignited, can produce new embers re-invigorating the ember storm.

EXPERT

Research is still underway into ember storms. However we do know something of operational use:

- They are associated with deep flaming, but not headfires.
- They can be detected in multispectral linescanning imagery.
- They typically cover around 2 to 10 square kilometres, and move with the convective event across the landscape, at up to 35 km/hr.
- However within the storm wind speeds may reach much higher values.
- Primary embers come into the urban area from adjacent broadacre landuses. Secondary embers are created by mulch beds, gardens, etc in the urban area. Tertiary embers are produced by burning houses.
- In the absence of a wind change, the winds coming from burnt ground for the next six hours foster ember creation. New house ignitions are possible throughout this phase.

If an ember storms occurs, Situation Unit analysts need to review the potential timing with Operations Section staff.

SPECIFIC FIRE BEHAVIOUR: Eruptive fire growth and its threats.

Eruptive fire is acceleration upslope in a dangerous manner, including in canyons.

Required level - B=G, A=O, F=E; References: [14]

GENERAL AWARENESS

When wind-driven headfires lean strongly upslope they can experience eruptive growth, where they continue to accelerate upslope, threatening fire crews. A particularly dangerous form of this occurs in canyons.

OPERATIONAL

As wind speeds increase, the headfire leans downwind more strongly. When winds are blowing upslope this can bring the headfire close to the surface fuel layer. It is possible for the flames to then attach to the surface, as it is easier for convection to push upslope then vertically.

Typically this requires a slope of at least 30˚, and strong winds.

This attachment results in extensive sheets of flame. In a forest this may stay underneath the canopy, as may its smoke. Further, the headfire rate of spread may continue to accelerate, ultimately exceeding the egress speed of any crews on foot. The speed of onset is such that even pre-arranged egress routes have been jeopardied. These outbreaks may start from a minor breakaway, and typically reach the ridgetop in a matter of minutes. The deep flaming makes survival on foot in a burn-over difficult.

There will typically be no time for a watchout to be issued.

A canyon typically consists of a steep floor and precipitous sidewalls. The geometry of this is significant, as it constricts the attached flame, assisting the eruptive acceleration.

EXPERT

As eruptive fire events are localised and short-lived, there is little role for an analyst, apart from a safety message in shift-change briefings where wind and slope values are above those specified. Field observers may recognise the potential for fire to spread onto terrain elements where eruptive spread might occur, and should then talk to operations staff, especially affected sector leaders.

FIRE MANAGEMENT: Field and aerial observers are vital for detecting fire escalations.

The set of events that field staff need to look for.

Required level - B=G, A=E, F=E; References: [3], [4], [5], [9], [10], [12]

GENERAL AWARENESS

Unusual fire weather and fire behaviour must be reported up to ensure that any threats to crew safety are acted on.

OPERATIONAL

If unusual fire weather or fire behaviour events are noticed, then Operations Section staff must:

- Ensure crew safety.
- Assess the need for watchouts or Red Flag Warnings.
- Work with Situation Unit staff to ensure a full observational network is in place. This network involves observations, analysis and reporting.

EXPERT

In order operate safely, especially in rugged landscapes, there is a need to augment the traditional weather monitoring systems with field or aerial observers looking for a range of phenomena. This can be aided by Situation Unit analysts using remote sensing to the same goal. These phenomena include:

- Fire channelling.
- Deep flaming.
- Violent pyro-convection.
- Mountain wind waves.
- Foehn winds.
- Low-level jets.
- Wind change at the fire.
- Nocturnal dew point depression event.
- Abrupt surface drying.
- Eruptive fire growth.
- Thermal belt.
- Convergence zone.
- Thunderstorm activity.

FIRE MANAGEMENT: Detection should be followed by specific watchouts and Red Flag Warnings.

The system of watchouts and Red Flag Warnings that may arise from detection of key events.

Required level - B=G, A=E, F=E; References: [3], [4], [5], [9], [10]

GENERAL AWARENESS

If dangerous conditions arise, then a watchout or Red Flag Warning may be issued. Crew members must follow directions.

OPERATIONAL

Operations staff may:

- Detect conditions that generate a need for a watchout or a Red Flag Warning, these are then passed up to the IMT, but may cause immediate local actions as well.
- Recommend the issuing of a watchout or a Red Flag Warning.
- Need to act on a watchout or Red Flag Warning that has been issued by the IMT. This may be due to observations made by the Situation Unit.

EXPERT

If any of the key fire weather or fire behaviour phenomena are observed, it may at times be prudent for the IMT to issue a watchout or a Red Flag Warning. The function of a Red Flag Warning is to clearly indicate the emergence of a dangerous situation requiring immediate action.

Each of these has associated with it a level of urgency and response required.

FIRE MANAGEMENT: Escalated fires in rugged landscapes may resist suppression until they leave those landscapes.

The landscape setting within which crews are operating.

Required level - B=O, A=E, F=E; References: [12]

GENERAL AWARENESS

Crews involved in suppression operations in rugged landscapes must always be safety conscious.

OPERATIONAL

If a fire has escalated it is, in part, because the FDI is elevated. It may also be due to fuel or slope. In rugged terrain there is also likely to be contribution from the interaction of terrain and the weather, and in particular vertical air flow. These drivers are not represented in the Fire Danger system in any way, but it is because of these elements that an escalated fire in rugged terrain will resist suppression.

This is worth repeating – escalated fires in Australia's rugged landscapes on days of elevated fire danger have never been put out. These fire go out when they leave the rugged terrain (and after up to 10km to decelerate) or when the weather abates or rains.

Thus it is imperative for fire crews to know when they are operating in rugged landscapes. For southeast Australia and Tasmania there are maps of these available on the HighFire Risk website.

EXPERT

The Situation Unit must understand the landscape within which a fire is burning. If the terrain is rugged, this must be reflected in the IAP.

It is essential to carefully assess the incident objectives for an escalated fire in rugged terrain. If the fire is unlikely to be suppressed, then the IAP must reflect this. The IAP must also reflect the potential for dangerous conditions to arise.

FIRE MANAGEMENT: Predicting fire spread must include these concepts.

Methods of incorporating key events and landscape setting into predictions of fire spread.

Required level - B=G, A=O, F=E; References: [2]

GENERAL AWARENESS

There are circumstances within which fires will do unexpected things.

OPERATIONAL

When suppressing escalated fires or when working in rugged terrain, Operations Section staff may make use of fire spread predictions issued by the Situation Unit. It is important to ensure that the inputs to those predictions accurately reflect the conditions on the ground.

EXPERT

Almost all fire behaviour prediction systems in use are based on a Fire Danger Index or equivalent. These do not incorporate the key interactions between rugged terrain and weather that act to produce extreme fires.

It is important not to base key decisions on inappropriate information.

FDIs assume that fire danger is a continuum – i.e. as the weather gets worse the FDI smoothly rises in response, as vice versa.

The additional drivers tend to be discrete – they are either active or not. Thus the first step towards fire prediction are a series of questions. For example, if the flame depth exceeds the lifting condensation level, then a pyro-Cb may form, and then the spread will reflect the upper winds only. A rectangular area aligned downwind, 15km wide and 25km wide is then the area under threat.

FIRE MANAGEMENT:
A simplified FDI formulation is vital for rapid assessment.

Simple methods of calculating fire danger and fire behaviour.

Required level - B=O, A=E, F=E; References: [7]

GENERAL AWARENESS

Fire danger can change quickly in response to changing conditions.

OPERATIONAL

In the field, crew leaders and sector leaders who are monitoring their weather may occasionally need to rapidly assess whether there is a crew safety risk emerging. A circular slide rule may be used for this, but many are not comfortable using these and often they do not have one. Web and mobile phone apps are now available for the same purpose.

It is also now known that FDI is proportional to wind speed divided by fuel moisture content. Thus if the wind picks up the FDI goes up in roughly the same ratio. Equally if the fuel dries out the FDI goes up. Fuel dryness reflects the difference between temperature and relative humidity. If this difference approaches 40, the fuel is completely dry and fire behaviour can become catastrophic creating deep flaming.

EXPERT

As for “Operations”

FIRE MANAGEMENT: A range of nocturnal processes must be considered: subsidence inversions, jets, thermal belt, Foehn winds.

Detecting a subsidence inversion using an on-site AWS, hand-held weather meters, internet data sources and pressure charts.

Required level - B=G, A=E, F=E; References: [4]

GENERAL AWARENESS

Occasionally, in rugged or high country, relative humidity may plummet overnight, creating rapid and unexpected increases in fire intensity. You should always be alert for this.

OPERATIONAL

In most cases, relative humidity will vary in a predictable manner, reaching minima in the afternoon and maxima overnight, just before sunrise. However there may be cases where subsidence inversions cause overnight RH minima, mainly between midnight and sunrise. As these are poorly forecast, it is imperative that operations officers remain vigilant for these, especially in high country. Even a half-hourly weather reporting schedule may not pick-up their early stages of onset. At large burn-off operations, operations section should always have at least one person reporting weather on a schedule and when changes occur. This could involve hand-held meters or properly installed automatic weather stations.

EXPERT

Subsidence inversions are predictable. They require a large high pressure cell overhead, and often occur on adjacent nights. Analysts need to discuss the situation with the duty forecaster.

It is highly recommended that expert staff are tasked to the Situation Unit if a subsidence inversion is in place over a fireground or is forecast to be so. They must be tasked to monitor the onset and effects of subsidence inversions. Analysts must be familiar with the synoptic weather patterns locally associated with subsidence inversion development. They are best detected in Aerological Diagrams.

Field observers need to assess the impact of winds flowing over the ranges, especially from the point of view of where they are reaching the surface. Field observers should also monitor surface fire weather.

Consideration may be given to issuing watchouts or Red Flag Warnings.

FIRE MANAGEMENT:
A range of nocturnal processes must be considered: subsidence inversions, jets, thermal belt, Foehn winds.

Issuing a Red Flag Warning regarding a subsidence inversion.

Required level - B=G, A=E, F=E; References: [3], [4]

GENERAL AWARENESS

When a subsidence inversion causes relative humidity to plummet, and fire behaviour to escalate, there may be a watchout or Red Flag Warning issued by the IMT. This indicates that safety is compromised by the fire behaviour escalation.

OPERATIONAL

Should fire behaviour escalate too far, the IMT should issue a watchout or Red Flag Warning for a dew point depression event. At this time all strategies and tactics are to be re-assessed by operations section. For instance, a backburn in alpine areas might immediately become a crown fire, and should be delayed until dew points rise again in the morning. These events are variable, but typically start around midnight, and can last for up to twelve hours.

EXPERT

Analysts need to understand that subsidence inversions typically impact terrain over 1500m ASL, and this commences around midnight and lasts for up to 12 hours. However they are currently poorly understood and may be quite different to that. They are associated with the core of large high pressure cells. This implies an association with continental air masses, thermal belts and light overnight winds.

FIRE MANAGEMENT:
A range of nocturnal processes must be considered: subsidence inversions, jets, thermal belt, Foehn winds.

Detecting a low-level jet using an on-site AWS, hand-held weather meters, internet data sources and pressure charts.

Required level - B=G, A=O, F=E; References: [3], [4]

GENERAL AWARENESS

OPERATIONAL

Low-level jets can be inferred by the presence of strong winds on high ground, especially overnight. This needs confirmation from meteorological services.

In conditions in which a low-level jet has been forecast it is imperative that Planning and Operations sections work closely to ensure safety in the field.

Field observers and Sector Leaders should routinely monitor and report general fire weather, but especially winds. They should use either hand-held weather meters or properly installed automatic weather stations. The Situation Unit staff should look at these reports for an indication of both (a) signs of an inversion within the elevation range on the fireground, and (b) anomalously high wind speeds on higher ground.

EXPERT

Low-level jets can be forecast, based on a synoptic air flow that is strongest at about the height of the main local range systems. Numerical weather models may indicate an event through the patterns of wind speed at 850 hPa. Note that they may not show up in surface weather products, due to the poor resolution of high ground in these models.

Analysts need to discuss the situation with the duty forecaster.

It is highly recommended that expert staff are tasked to the Situation Unit if a low-level jet is in place over a fireground or is forecast to be so. They must be tasked to monitor the onset and effects of low-level jets. Analysts must be familiar with the synoptic weather patterns locally associated with low-level jet development. They are best detected in Aerological Diagrams.

Field observers need to assess the impact of winds flowing over the ranges, especially from the point of view of where they are reaching the surface. Field observers should also monitor surface fire weather.

Consideration may be given to issuing watchouts or Red Flag Warnings (Wind change).

FIRE MANAGEMENT:
A range of nocturnal processes must be considered: subsidence inversions, jets, thermal belt, Foehn winds.

Issuing a watchout regarding a low-level jet or a possible Red Flag Warning.

Required level - B=G, A=E, F=E; References: [3], [4]

GENERAL AWARENESS

Some weather conditions that may occur overnight can produce dangerous fire behaviour.

OPERATIONAL

If a low-level jet watchout is issued by the Planning Officer in consultation with the Operations Officer, Sector Leaders working on high ground need to be wary and must monitor fire weather at thirty minute intervals (using a hand-held weather monitor or portable AWS). Any significant changes in fire danger should be discussed with the Operations Officer immediately.

If a low-level jet causes a Red Flag Warning to be issued, it will be on the basis of conditions conducive to the formation of a plume-driven fire. It will be issued by the Planning Officer in consultation with the Operations Officer, all Operations staff and especially Sector Leaders should then review safety needs. The Operations Officer would need to ensure that fall-back IAP elements are at hand to activate immediately should a sudden change in conditions occur.

EXPERT

The Situation Unit leader needs to be able to assess reports from the field or from analysts and the risks indicated by those reports, and to make recommendations to the Planning Officer regarding the need to react to those reports.

The Planning Officer needs to be able to confidently decide whether to issue watchouts or Red Flag Warnings, and to prepare alternative incident strategies that reflect the risks posed by low-level jets on the fireground.

FIRE MANAGEMENT:
A range of nocturnal processes must be considered: subsidence inversions, jets, thermal belt, Foehn winds.

Detecting a foehn wind using satellite imagery, field observations, an on-site AWS, hand-held weather meters, internet data sources and pressure charts.

Required level - B=G, A=E, F=E; References: [3], [4], [10]

GENERAL AWARENESS

Foehn wind events can be detected by the weather and cloud patterns that they generate.

OPERATIONAL

In conditions in which a foehn wind has been forecast it is imperative that Planning and Operations sections work closely to ensure safety in the field.

Situation Unit staff must be tasked to monitor the onset and effects of foehn winds. Field observers must be familiar with the cloud patterns associated with foehn winds. Analysts must be familiar with the synoptic weather patterns locally associated with foehn wind development.

EXPERT

It is highly recommended that expert staff are tasked to the night shift Situation Unit if a foehn wind is in place over a fireground or is forecast to be so.

Foehn events can be forecast, based on a synoptic air flow that is perpendicular to the main local range systems. Numerical weather models will indicate an event through the patterns of forecast temperature, relative humidity, rainfall and winds. Note that they may not show up in dew point products. Vertical flow products (either velocity or dP/dt) may show these events clearly.

Analysts need to (1) assess vertical air flow; (2) review satellite imagery for cloud patterns and (3) discuss the situation with the duty forecaster.

Air observers need to review the regional cloud pattern and its dynamics.

Field observers need to assess the impact of winds flowing over the ranges, especially from the point of view of where they are reaching the surface. They also need to assess the large-scale fluctuations on wind direction which may cause foehn winds to switch on or off suddenly. Field observers should also monitor surface fire weather.

Consideration may be given to issuing watchouts or Red Flag Warnings (Foehn wind).

FIRE MANAGEMENT:
A range of nocturnal processes must be considered: subsidence inversions, jets, thermal belt, Foehn winds.

Issuing a watchout regarding a foehn wind or a possible Red Flag Warning.

Required level - B=G, A=O, F=E; References: [3], [4], [10]

GENERAL AWARENESS

Watchouts or warnings relating to foehn winds refer to an event that could cause sudden changes in temperature, relative humidity and winds, resulting in rapid surges in fire danger.

OPERATIONAL

If a foehn wind watchout is issued by the Planning Officer in consultation with the Operations Officer, Sector Leaders need to be wary and must monitor fire weather at ten minute intervals (using a hand-held weather monitor or portable AWS). Any significant changes in fire danger should be discussed with the Operations Officer immediately.

If a foehn wind Red Flag Warning is issued by the Planning Officer in consultation with the Operations Officer, all Operations staff and especially Sector Leaders will need to review safety needs. The Operations Officer will need to ensure that fall-back IAP elements are at hand to activate immediately should a sudden change in conditions occur.

EXPERT

The Situation Unit leader needs to be able to assess reports from the field or from analysts and the risks indicated by those reports. They also need to make recommendations to the Planning Officer.

The Planning Officer needs to be able to confidently decide whether to issue watchouts or Red Flag Warnings (Foehn winds), and to prepare alternative incident strategies that reflect the risks posed by foehn winds on the fireground.

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Ref 3: McRae, R. (2009). Checklist for Fire Observers. (unpublished).

Ref 4: Guidelines on Red Flag Warnings and Watchouts for Fire Crews operating in Rugged Landscapes. (unpublished).

Ref 5: Dold, J, Weber, R, Gill, M, Ellis, P, McRae, R & Cooper, N. (2005). *Unusual Phenomena in an Extreme Bushfire. 5th Asia-Pacific Conference on Combustion*, The University of Adelaide.

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Ref 9: Sharples, J., McRae, R. & Wilkes, S. (in press). Wind-terrain effects on the propagation of wildfires in rugged terrain: fire channelling. *International Journal of Wildland Fire...*

Ref 10: Sharples, Jason J., Graham A. Mills, Richard H. D. McRae, Rodney O. Weber, 2010: Foehn-Like Winds and Elevated Fire Danger Conditions in Southeastern Australia. *J. Appl. Meteor. Climatol.*, **49**, 1067–1095.

Ref 11: Sharples, J.J. (2008). Review of formal methodologies for wind-slope correction of wildfire rate of spread. *IJWF*, 2008, **17**, 179-193.

Ref 12: McRae, R.H.D., Sharples, J.J. & Weber, R.O. (2007). Are big fires inevitable*? AFAC 2007 Conference presentation.*

Ref 13: See Mills, G.A. & McCaw, L. (2010). Atmospheric Stability Environments and Fire Weather in Australia – extending the Haines Index. *CAWCR Technical Report* No. **20**.

Ref 14 Viegas, D.X., Pita, L.P., Ribeiro, L. & Palheiro, P. (2005). Eruptive Fire Behaviour in Past Fatal Fire Accidents. Eighth International Wildland Fire Safety Summit, Missoula, MT.

RESOURCES

Tool 1: Interpretation of Smoke Plumes (Poster)

http://www.highfirerisk.com.au/tools/smoke.pdf

Tool 2: Using an Aerological Diagram

http://www.highfirerisk.com.au/tools/aerological.pdf

Tool 3: How to Model Wildfires

http://www.highfirerisk.com.au/tools/tool3b.pdf

Tool 5: Non-diurnal Weather

http://www.highfirerisk.com.au/tools/tool5.pdf

Tool 6: Smoke Spotter's Guide

http://www.highfirerisk.com.au/tools/tool6_v2.pdf

Tool 7: Elements to Consider When Modelling Wildfires

http://www.highfirerisk.com.au/tools/tool7.pdf

Tool 8: The Continuous Haines Index

http://www.highfirerisk.com.au/tools/c_haines_flierA4.pdf