Fire Behaviour Case Study: Mt Cook Station Fire, 16 January 2008

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Front cover image:
Mount Cook Station Fire during the blow up on Thursday 17 January 2008 at 0630 hours (Image courtesy of Richard McNamara, Dept. of Conservation, Aoraki/Mount Cook).

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SUMMARY

On the afternoon of Wednesday, 16 January 2008, a fire was ignited on farmland on the eastern side of Lake Pukaki in South Canterbury. This fire escaped initial attempts at containment and went on to burn an area of 756 hectares. The fire burnt actively for the next two days, during which periods of extreme fire behaviour were witnessed due to hot, dry windy conditions and heavy fuel loadings. At the time the fire occurred, there was a Prohibited Fire Season in place banning the lighting of fires, although no restrictions on other activities were imposed. A subsequent fire investigation identified the cause of the fire as heat transfer from a chainsaw igniting light grass fuels.

A single point ignition occurred in 100% cured grass on flat ground along the Braemar-Mt Cook Station road edge, from which the fire then spread into heavily forested areas on rolling to steep terrain. The fire was fanned by strong winds that hampered efforts to bring it under control. Aerial attack was the preferred fire suppression option, as the site was remote and had difficult terrain with poor vehicle access. The fire continued to burn slowly overnight, but flared up the following morning, jumping control lines. It burned in wilding pines, scrub, matagouri and pasture grass. Due to high intensity fire behaviour, the suppression strategy was to let the fire burn in the heavy fuels and contain it once it reached lighter fuels.

At its height, more than 60 personnel fought to contain the 14 km perimeter of the blaze. Their efforts, combined with a change in weather and fuel type, allowed the fire to be contained on the third day, 18 January 2008. Mop-up to extinguish numerous hotspots within and outside the burn area occurred over the following four days. Significant rainfall occurred on day seven (23 January), which extinguished hotspots and reduced the re-ignition potential of heat-scorched fuels. The fire was declared controlled on 22 January (a week after the original ignition), but was not officially declared out until 9 February 2008.

The fire was significant in that it was the largest wildfire to have occurred in the South Canterbury Rural Fire District for more than a decade. It was also the most expensive fire for the District due to the large amount of aerial resources involved. At its peak 11 helicopters were used, as the location and terrain made it virtually impossible for ground resources to fight the blaze. The fire burned predominantly within dense stands of wilding pines with high fuel loads. Fires in this fuel type are rare in New Zealand so that little is known regarding fire behaviour in wilding pine forests. The fire was devastating to the Mount Cook Station trophy hunting farm and neighbouring Braemar Station, with the owners suffering the loss of livestock (elk, thar, chamois, sheep and deer), fencing, grazing and associated revenue. Power lines were also damaged by the fire, resulting in significant economic impacts when power was cut to Mount Cook Village.

The most appropriate New Zealand models against which to compare observed fire behaviour were those for immature and mature pine plantations and ungrazed pasture. However, none of these models performed particularly well, as they overestimated headfire spread and intensity due to fuel type differences, as well as topographic and weather factors. The scarcity of observations of head fire locations during the fire's main runs also made comparisons of observed and predicted fire spread difficult. Recording times when the headfire reached major landmarks would have greatly assisted in predicting headfire rates of spread. Documentation of wildfires is invaluable for fire management and for testing and validating existing fire behaviour models. Regardless of the few fire behaviour observations, the Mount Cook Station fire provides valuable information on fuel hazard and fire behaviour in wilding pines.

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Introduction

This report describes the fire environment factors and fire behaviour during the Mount Cook Station fire that occured in January 2008. It includes past weather conditions and details on the topography, fuels, weather and fire danger condidtions experienced during the main runs of the fire. Fire behaviour reconstructed from observations is also compared with that predicted using current models for predicting fire behaviour in New Zealand fuels.

The Mount Cook Station fire occurred within the Mackenzie District of the South Island of New Zealand (latitude -43.90º, longitude 170.18º) at an altitude of 546m (Map 1). The fire was situated between Lakes Tekapo and Pukaki and the nearest townships included Mount Cook, Lake Tekapo and Twizel. There were three nearby fire weather stations located within 20 km of the point of origin at Mt Cook, Tekapo and Pukaki. The Mackenzie region is a popular tourist spot, known for its lakes and New Zealand's highest mountain, Aoraki/Mount Cook. This region is also popular for its many recreational activities such as boating, fishing, climbing, tramping, 4WD safaris and hunting. The world's highest freshwater salmon farm is also located nearby in the hydro-electric canal that links Lakes Tekapo and Pukaki.

The Mount Cook Station fire was significant in that it was one of the largest experienced in South Canterbury Rural Fire District (burning 756 ha), it involved heavy use of aerial resources, and little is known about the fire behaviour in the major fuel type involved (wilding pines). Wilding pines are generally considered weeds in New Zealand, transforming grassland and/or shrubland into conifer forest. Wilding pines spread from established plantations (typically of lodgepole (*Pinus contorta)*, Corsican (*P. nigra*) or radiata pine (*P. radiata)* and Douglas fir (*Pseudotsuga menziesii*)) by wind-blown seed and establish themselves in unwanted areas.

The spread of wilding pines has created problems for land managers attempting to control wilding spread, and also for fire managers concerned about the increased fire hazard. An increase in fuel loads, extreme fire behaviour, potential difficulty of suppression and greater threats to life and property are expected with increased wilding spread in the landscape. Leaving the fire to burn as a means of wilding pine control was not an option in this case, as the fire threatened neighbouring properties and, as the Rural Fire Authority for the area, it was the responsibility of the South Canterbury Rural Fire District to protect life and property at threat from the fire.

On the afternoon of Wednesday 16 January 2008, the Mount Cook Station fire quickly developed near the northern end of the Braemar-Mount Cook Station Road side (Map 2). A point ignition occurred on flat ground adjacent to the road edge in grass that was 100% cured. At the time of ignition, a new fenceline was under construction along the road edge. A fire investigation subsequently identified the cause as heat transfer from a chainsaw involved in the fenceline construction igniting cured grass fuels. At the time of the fire there was a Prohibited Fire Season in place across South Canterbury with a ban on lighting fires, but no restrictions on access or other activities were imposed.

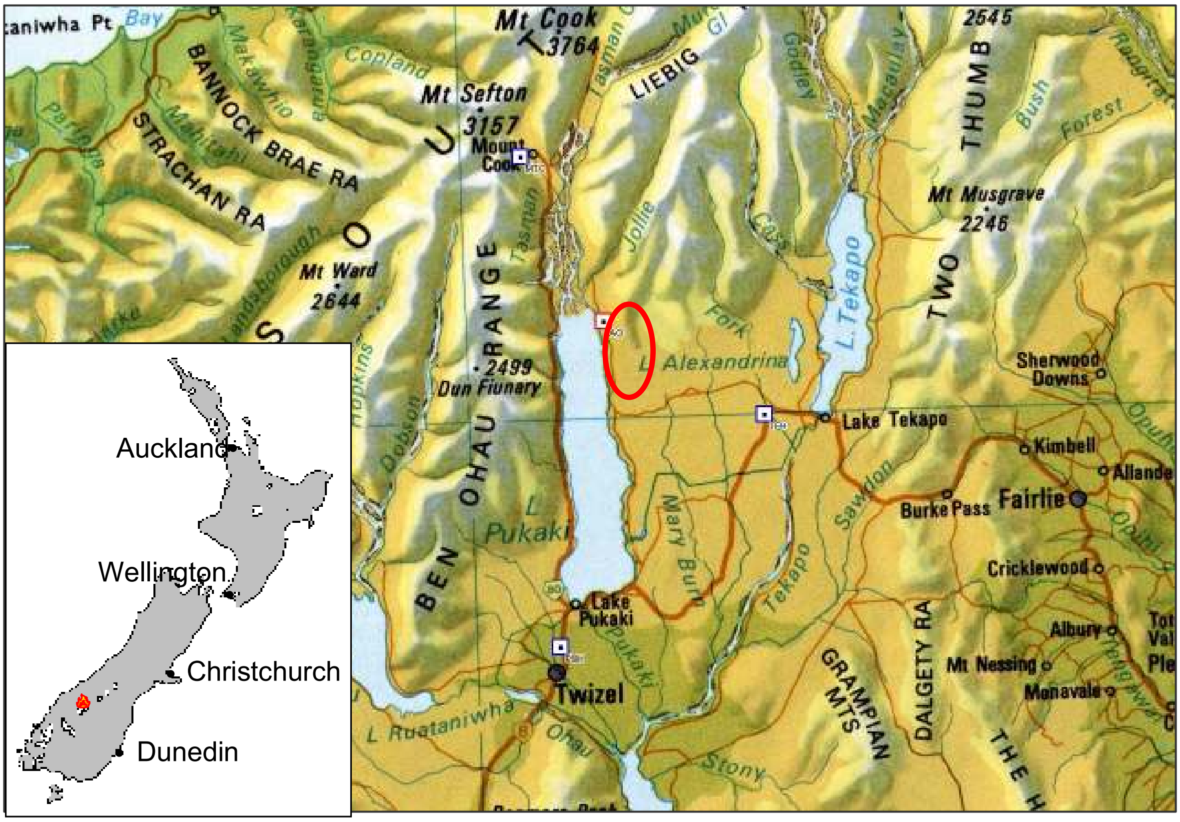
The fire was fanned by strong northwest winds and progressed quickly up a small hill crest in grass and litter fuels. It then became well established once the initial fire crested the short slope and spread into dense wilding pine stands. Extreme fire behaviour occurred in the heavy wilding fuels, where periods of intermittent torching and crowning with flame heights of 20+ m above the trees were observed. Fire behaviour in lighter grass fuels was less extreme, resulting in easier control of the spreading fire along the flanks and head once it had reached open pasture.

The fire burnt a total area of 756 hectares, mostly on Mount Cook Station, with 46 hectares of the neighbouring Braemar Station burnt (Figures 1 & 2). The main fire runs occurred in the first 24 hours, but the fire continued to burn over the next seven days. Dry conditions experienced at the time of the fire caused a number of spot fires and deep-seated burning. Patches of unburnt fire-cured vegetation within the fire area also posed a risk of re-ignition. Conditions eased on 18 January (day 3), so that the fire was contained and mop-up began, allowing resources to be scaled down. Occasional flare-ups and breaches of control lines occurred in the subsequent days, until significant rain fell on 22 January (day 7) extinguishing any remaining hotspots. However, monitoring continued for a further 18 days, and the fire was not officially declared out until 9 February, 24 days after it initially started.

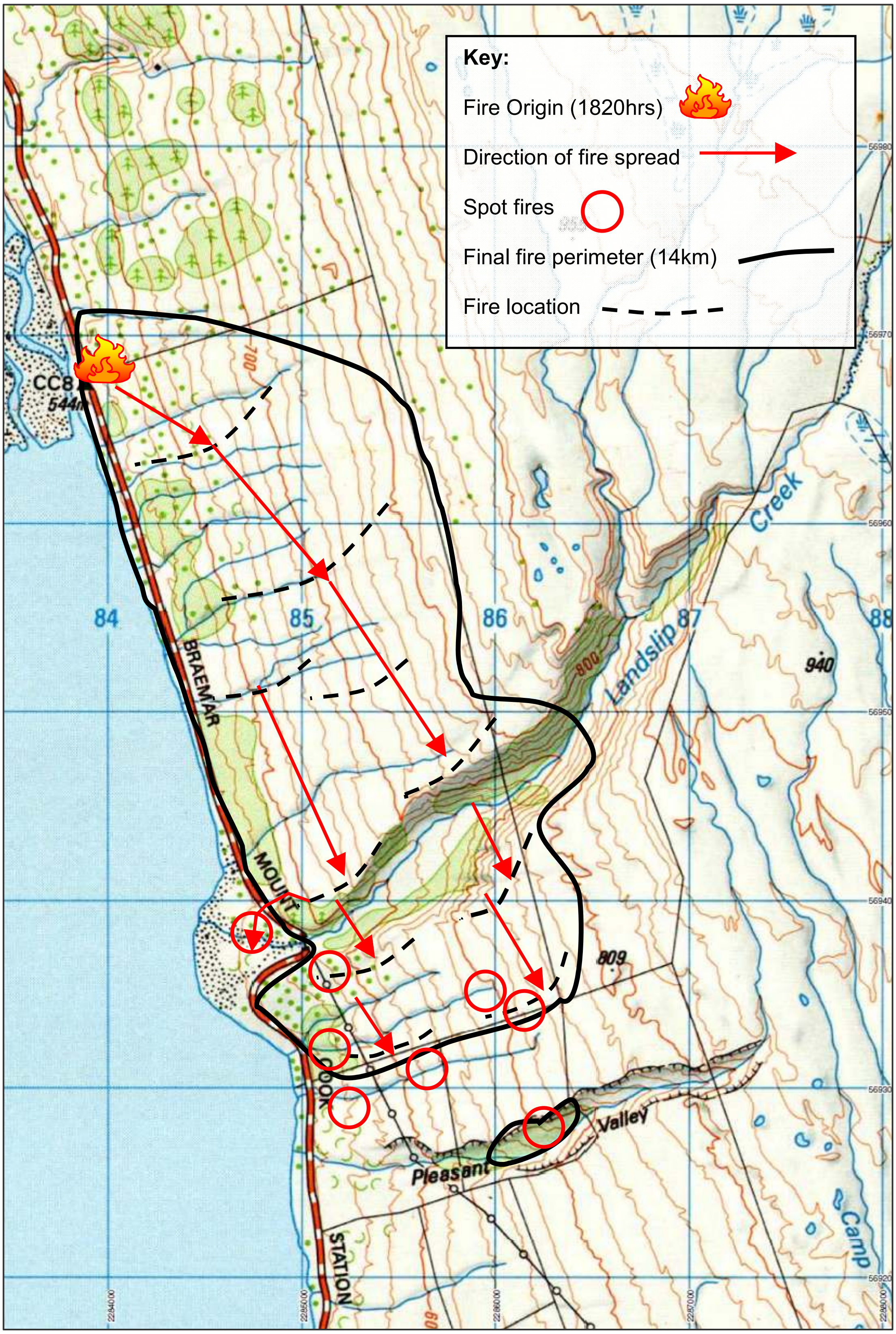
Due to the fire's remoteness and difficult terrain, aerial attack was the major suppression strategy used. Heavy fuels, steep terrain and extreme fire behaviour meant that it was too dangerous to undertake widespread ground attack. Quick aerial suppression of the Mt Cook fire was considered necessary to protect life and property in the path of the fire. The costs associated with fighting the fire were therefore high (~$800,000), but damages could have been much greater without the early response and aerial suppression effort. The fire killed a number of livestock, including trophy hunting animals. It also damaged fences, grazing areas and powerlines. Power was cut off causing problems for the Mount Cook village and surrounding areas. The fire threatened a number of homesteads downwind of the fire, and also conservation resources on the ridges above. At one stage the fire was also considered to have the potential to spread to Lake Tekapo Township. Fortunately, no lives or homes were lost, although several near-miss incidents were reported during fire suppression.

Figure 1. Looking north over the Mount Cook Station fire area (Photograph: C Miles, Tekapo Helicopters Ltd.).

Figure 2. Looking south over the fire area (Photograph: R McNamara, DOC).



Map 1. Location of the Mount Cook Station fire and nearby towns
(Source: MapToaster Topo, Sheet 2, scale 1:1 million).



Map 2. Location of point of ignition, fire runs and final perimeter of the Mt Cook Station fire (Source: MapToaster Topo, NZMS 260 Sheet H37, scale 1:32,250 approx.).

Fire Chronology

Day 1 – Wednesday, 16 January 2008

On Wednesday 16 January, at 1832 hours[1], a fire burning on Mount Cook Station was reported to the New Zealand Fire Service Communications Centre (via the 111 emergency phone system). The fire started between the hours of 1820 and1830 in a strip of 100% cured grass along the side of Braemar-Mount Cook Station Road that had been sprayed to control the spread of young wilding pines (Figure 3). A new fenceline was being constructed along the road edge. The fire was determined to have started from a hot chainsaw coming into contact with dry grass fuels. The fire was fanned by strong northwesterly winds, and spread upslope away from the road in a southeast direction. The fire spread quickly up the first rise in grass and litter fuels. Once the fire had reached the first crest, it quickly became well established in mature wilding pine trees. Local farm workers attempted to put out the fire but they were unable to contain it due to its rapid development.

By 1844 hours the first suppression resources were responding, with a pump, tanker and auxiliary appliance enroute to the fire. Within approximately 30 minutes of the initial escape (1905 hours), the first helicopter (Tekapo Helicopters) was on site and began monsoon bucket work. Fire brigades from Lake Tekapo and Twizel, and rural fire units from Burkes Pass and Twizel, were dispatched. Another 111 call was received at 1918 hours reporting that 400 hectares (1000 acres) of forest was on fire and another 125 ha (500 acres) was likely to be burnt in the next couple of hours. The Principal Rural Fire Officer for the South Canterbury Rural Fire District was contacted around 1950 hours and authorised a further deployment of three helicopters from nearby Glentanner airfield that was 5 km away from the fire. With only three hours of light remaining, the objective was to use as many aerial resources as available to attack the fire with the aim of stopping the fire before it crossed Landslip Creek (see Map 2). Fire appliances from Lake Tekapo and Twizel arrived at the scene at 1953 hours. Initial attack resources concentrated on the base of the fire and pinching off the eastern flank, along the ridgeline between Lake Pukaki and Lake Tekapo.

Figure 3. The fire began along the Braemar-Mt Cook Station roadside in light, cured grass fuels (Right photograph: D Stackhouse, NZ Fire Service).

[1] All times used in this report are in New Zealand Daylight Savings Time (DST) unless stated as local standard time (NZST).

Figure 4. Helicopters were a major resource used in initial attack (Photographs: R McNamara, DOC).

The fire was mainly burning above the road in the terraces of wilding pines. There were considerable fire suppression resources onsite, especially aircraft. Aircraft were chosen as the main suppression resource as downed powerlines, heavy smoke conditions, extreme fire behaviour, dense fuels and difficult terrain hampered ground fire resources (Figure 4). A total of nine helicopters, one fixed wing aircraft, four appliances and 40 staff were in attendance by 2218 hours.

Crews witnessed intermittent crowning (with maximum flame heights of 20+ m above 15 - 20 m tall trees) when the fire hit patches of dense wilding pines and matagouri, then dropped back down as it reached more open areas of grass and matagouri. Aircraft and ground crews worked on the fire perimeter until they were stood down at 2200 hours (due to poor light). By this time the fire area was estimated to cover about 105 hectares (significantly less than the area ha initially reported in the 111 phonecall). One night crew monitored the fire overnight and were to initiate evacuation if required. A Regional Incident Management Team (RIMT) was deployed from Canterbury, who worked throughout the night to develop an Incident Action Plan for the following day.

Overnight, low intensity fire behaviour was observed by the night crew. The fire backed against the wind and burned in the surface fuels of the dense wilding pines and in the lighter grass fuels. There was the occasional flare-up of individual trees. The fire also burned downslope in light grass fuels and matagouri scrub back towards the Braemar-Mount Cook Station road. Along this road, the fire crept towards Landslip Creek. It was hoped the fire's progress could be stopped by cutting it off at Landslip Creek before it reached the neighbouring Braemar Station.

Day 2 – Thursday, 17 January 2008

During the early hours of Thursday morning, fire behaviour decreased due to an increase in relative humidity and a decrease in temperature. However, the north westerly wind continued to fan the fire. Overnight crews monitored the fire spreading 200 m towards Landslip Creek between 0300 and 0400 hours. Powerlines were in the path of the fire, and as a precautionary measure the power was shut off at 0349 hours. Power cuts affected the Glentanner airfield and Mount Cook village. By 0600 hours, the fire size was estimated to be 300 hectares. The Incident Management

Team undertook an aerial reconnaissance of the fire perimeter to identify the extent of the fire area, values at risk and containment opportunities.

Suppression started at 0600 hours with the objective of containing the fire on the north side of Landslip Creek. Resources consisted of 11 helicopters and one fixed wing aircraft working on the fire perimeter, while ground crews worked with heavy machinery on constructing firebreaks along the flanks. The fire control strategy was again based around aerial operations due to access and safety concerns. North westerly winds were predicted to gust to 70-80 km/h during the morning, with a southerly change by midday. A transition from a back or flank fire to a head fire for the north and eastern flanks was expected with the forecasted wind change. As a precautionary measure, construction of a firebreak and retardant drops was commenced in these areas.

Fire activity began to increase around 0630 hours as the wind speed and temperature increased. The fire spread into scrub and 15-year old wilding pines on the terrace above the northern side of Landslip Creek. The north westerly winds continued to increase, and the fire jumped control lines south of Landslip Creek, burning into heavier fuels (Figure 6). The copper/bronze smoke column from the previous day had pre-heated the wilding pine forest south of Landslip Creek so that the fuels were tinder dry before the blow up occurred. Some of the most severe burning occurred close to the road near the bridge in an area of exceptionally dense wilding pines. Crews witnessed continuous crowning in the wilding pine stand, with flame heights of 20 – 40 m above the trees (as opposed to intermittent torching the day before). It is possible that much of the spotting observed in the open grasslands directly to the south originated from this area. The fire also spotted across the road into scrub near the outlet of Landslip Creek into the lake (see map 2).

Figure 5. The fire jumped Landslip Creek and burnt into dense wilding pine stands (Photograph: R McNamara, DOC).

The wind developed to around 40 km/h and the fire also jumped Landslip Creek into grasslands and windrows (of heaped scrub and wilding pines) in the more open country to the south (Figure 5 & 6). Mass ember transport from areas of dense wilding pines into the open grasslands and windrows resulted in several spot fires occurring between 400 – 1500 m in front of the head fire, and as far south as Pleasant Valley (see Map 2). Burning rabbits and possums were also observed to cause short-range spotting ahead of the fire into the grassland. Aircraft managed to contain spot fires as they broke out of forest fuels and into open grasslands.

A number of properties were threatened by the advancing fire. Stock were moved out of the fire's path, and plans made to evacuate Braemar homestead. Estimates of where the fire could have spread on day two were 8 km south, past Braemar Station and threatening Guide Hill Station. A second scenario involved a forecasted wind change from the south, which would have pushed the fire back through the heavily forested area at the north end of the fire towards Mount Cook Station homestead and possibly the Lake Alexandrina settlements.

Fire suppression was required at 0716 hours to protect Braemar Station, as fire intensity increased and spotting occurred ahead of the fire. The fire crossed into grazed grass, tussock, scrub and wilding pines on the Braemar property and farmers were desperately trying to move stock out of the fire's path. Fortunately, fire behaviour in grazed pasture was less extreme, resulting in a reduction in escapes and the fire did not reach the homestead. By midday the wind eased and the fire was contained. The turning point was when the wind strength dropped, as prior to this the thick smoke made it difficult to get water on to the actively burning areas of the fire. At its height, 70 personnel (including Incident Management Team, IMT), 11 helicopters and one fixed wing aircraft were involved in fighting the fire.

Figure 6. The fire jumped Landslip creek in the early hours of the morning of day 2. (Photographs: C Miles, Tekapo Helicopters Ltd).

At 1347 hours, crews on the ground were involved with putting out hotspots along the road edge. Ground crews worked with heavy machinery consisting of two diggers and one bulldozer on the north flank completing an initial firebreak. Work had begun on a containment line on the north side of Landslip Creek. Two diggers working on the south flank constructed a firebreak along the southern ridge of Landslip Creek. A crew and smokechaser completed a containment line along the south boundary of the spot fire in Pleasant Valley. Hand crews working along the Mt Cook Station-Braemar road secured the western perimeter (lake edge). Aircraft were reduced to six; however, at times there were breakouts and additional aircraft were called in to deal with these situations.

By 1800 hours, the area burnt was approximately 500 ha, with numerous hotspots present. The fire extended from just above the top of the lake in the north to about 1 km south of Landslip Creek. It had mostly burned down to the Braemar-Mt Cook Station Road along the western flank, and extended 1.5 - 2.0 km above the lake edge towards the east. The spot fire located in Pleasant Valley to the south of the main fire was approximately 20 ha in size.

During the day there was urgency to construct a northern firebreak and widen this with retardant drops in response to a forecasted southerly wind shift. This wind change had the potential for further increased fire activity in heavier fuels if the fire spread into thick wilding pines and advanced towards Mount Cook Station. Fortunately, this forecasted wind shift did not eventuate. By the end of day two, the fire was considered 80% contained and ground resources were to remain for the next 48 hours with reduced aircraft support.

Day 3 – Friday, 18 January 2008

Fire behaviour overnight was expected to reduce following settled weather and cool temperatures. An infra-red camera was first used to survey the fire ground early in the morning. It confirmed the security of the fire perimeter and assisted in determining the best allocation of resources. Aerial and ground suppression recommenced at 0700 hours with seven helicopters, one fixed wing, seven earth moving machines and 80 personnel (including IMT). Aircraft provided aerial support to protect ground resources from flare ups as they developed containment lines (Figure 7). A fire investigator also arrived and commenced investigation into the origin and cause of the fire.

Figure 7. Earthmovers constructing a firebreak and aerial resources continued to help ground crews when required (Photographs: R Barclay, NRFA & J McCaughans, Aorangi Rural Fire Team).

During the day firefighters made good progress on containing the fire. Weather conditions on site at 1300 hours were fine, with light winds from the southwest at 1.5 km/h, temperature 26.4 ºC and relative humidity 38%. Fire behaviour was expected to remain relatively benign throughout the day, with little change to temperature and relative humidity with the southerly wind flow. Several earthmovers completed the firebreak in the area north of the point of ignition and construction of the firebreak along the southern ridge of Landslip Creek by two diggers was also completed. Crews also worked with the Alpine Power Company to replace powerlines and 20 power poles to get power reinstated. Farmers also began work within the burn area to repair damage to fences.

By the end of the day, the fire encompassed approximately 700 hectares with a 14 km perimeter (Figure 11). The fuels involved were wilding pine of mixed ages and density (some areas 800 stems/ha), matagouri scrub, tussock and slash piles. Extreme fire behaviour exhibited in heavy wilding pine fuels on the first two days resulted in numerous large, deep-seated hotspots that still required suppression on day 3 and over subsequent days. At this stage, containment lines were 90% complete. Fire behaviour overnight was expected to be benign due to increasing relative humidity and decreasing temperature and wind speed.

However, there was continued urgency for containment of the fire with a forecasted wind shift back to northwest conditions on day 4 indicating the potential for increased fire activity. Burning within the fire area had been patchy, with substantial pockets of unburnt or partially scorched vegetation providing significant re-burn potential (Figure 8). Numerous large deep-seated hotspots also remained within the fire area that required ongoing assessment and suppression by ground resources to complete containment and mop-up (Figure 9).

Figure 8. Pockets of unburnt vegetation within the burn area (Photograph: J McCaughans, Aorangi Rural Fire Team).

Days 4 to 7 – Saturday 19th to Tuesday 22nd January
Ongoing use of ground resources was required to complete containment lines and dampen down hotspots (Figure 10). Aircraft provided aerial support to ground crews when requested. The infra-red camera was used each morning, and identified three critical areas containing numerous hotspots that required major suppression effort to extinguish: the eastern end of Landslip Creek, slash piles in Pleasant Valley, and the northern perimeter. The fire continued to burn within the containment lines in wilding pine, matagouri, tussock, slash piles and lighter grass fuels on the eastern and southern perimeter.

On day four, the onsite weather conditions at 1000 hours were 22 ºC, 30% relative humidity, with light southerly winds at 3.6 km/h. A maximum of 27 ºC was expected, with low relative humidity and winds tending more northeasterly in the afternoon, resulting in increasing fire behaviour. The Alpine Power Company advised that the power was restored at 1400 hours. Extra response was required when a fire escape occurred at 1436 hours in the area outside of the bulldozed containment line along the northern perimeter. Three additional helicopters where dispatched and a Cresco aircraft put on standby. A second escaped occurred and was also extinguished by helicopters. These two escapes were contained by extending the firebreaks with heavy machinery and additional retardant drops from the Cresco aircraft. Retardant drops along the eastern portion of the northern perimeter were also made to further improve the containment line in this area. By the end of the day four containment lines were 95% complete. A firebreak around the fire perimeter had been completed and anchored to the roadway. Only a small area at the top end of Landslip Creek remained without containment lines due to the nature of the terrain hindering the establishment of a machine firebreak. Aerial operations were expected to be further scaled down.

Figure 9. Ground resources involved in extensive mop-up (Photograph: J McCaughans, Aorangi Rural Fire Team).

Figure 10. Hot spots occasionally flared up due to the weather and required aerial suppression (Photographs: J McCaughans, Aorangi Rural Fire Team).

On day five, the infra-red camera survey confirmed the progress of crews working in the three critical areas. Ground and aerial suppression numbers were reduced to four diggers, 64 personnel and three helicopters to support crews. The Incident Management Team was also scaled back, with local members of the Regional IMT remaining on site. The operation was further scaled down on day six, with the Incident Control Point moved from the Department of Conservation offices in Twizel to Braemar Station. About 20 fire fighters on site targeted five key areas with three helicopters and three excavators. A significant flare-up on the northeast corner at 1900 hours required at least 10 drops of water from a helicopter. Overnight, fire behaviour diminished as a total of 6 mm of rain fell. Rainfall continued throughout day seven, and a total of 22 mm had fallen at Braemar before the southerly wind change occurred at 1430 hours.

The rain reduced burning and smouldering of hot spots outside the forest canopy and fine fuels. The infra-red scan on day seven at 0700 hours showed good progress on hotspot extinguishment, although some areas remained in Pleasant Valley, Landslip Creek, and along the eastern and northeastern flanks of the fire. These were single points or small clusters of smouldering fire activity and deep-seated burning. The critical area continued to be the northeastern corner in heavily forested fuels. Access to hotspots in forested areas on the northern part of the eastern flank was difficult for vehicles due to slippery conditions. By 1430 hours, 17 out of 23 (75%) hot spots identified had been extinguished. However, fuels were expected to begin to dry again with the northwesterly wind forecasted to return the following day (day 8).

By the end of day seven at 1951 hours, the incident was declared contained and demobilisation of crews was underway. All significant resources had left the site and returned to their respective home locations. One smokechaser and five personnel remained on site. Ongoing infra-red camera monitoring and a move into a long term weather monitoring programme was planned from day eight as fuels were expected to dry out with the further warm dry conditions forecasted in the coming days. The fire was officially declared out when no remaining hotspots were found by an infra-red camera on Saturday 9 February, 24 days after it initially started.

Figure 11. The fire was still active during the early hours of the morning on day 2 (Photograph: R. McNamara, DOC).

Fire Environment

Details of the fire environment are important to relate to observed fire behaviour. The fire environment is described as "the surrounding conditions, influences and modifying forces of topography, fuel and fire weather that determine fire behaviour" (Countryman, 1972).

Topography

The topography of the fire area was characterised by moderately steep terrain, with the slopes rising at 15º to 20º from the lakeshore as a series of terraces to the main ridgeline between Lakes Pukaki and Tekapo. This steep terrain made vehicle access within the fire area difficult. There were some major barriers to fire spread, including the Braemar-Mt Cook Station Road, Lake Pukaki and old earth breaks along fencelines within the fire area. Landslip Creek also presented a significant natural barrier, although it was breached through spotting (Map 2 & Figure 14).

Ignition occurred alongside the Braemar-Mt Cook Station Road, in an area exposed to the north westerly wind at the base of a short slope. The fire spread upslope and across steep undulating terraces between the point of origin (POI) and Landslip Creek. The elevation of the POI was approximately 540 m above sea level. The eastern flank of the fire reached an upper limit of about 760 m above sea level. The fire jumped Landslip Creek and spread into rolling terrain to the south that was more open and flatter country compared to north of Landslip Creek.

Figure 12. The fire started along the roadside and travelled up steep rolling terrain that had an initial slope of around 15º.

Figure 13. Man-made barriers to prevent fire spread (Photographs: R Barclay, NRFA; R Gardner, SCRFD; D Stackhouse, NZFS; and R McNamara, DOC).

Figure 14. It was hoped the fire spread would be stopped by the natural barrier of Landslip Creek (Photographs: T Barr, DOC).

Fuels

Fuels covering the fire area were predominantly wilding pines of various ages and densities, and open pasture grasslands. These were the two key fuel types involved for predicting rates of spread and intensities. Other fuels involved in the fire included grazed pasture grasses, scattered tussock grasses, matagouri, bracken fern and windrows of cleared scrub and wilding pines. The major factors affecting fire behaviour were high levels of available fuels, changes in fuel loads and mixed fuel types.

The area of origin contained a 20 m strip of grass along the road side that had been sprayed to control the spread of young wilding pines. Grass fuels along this strip were approximately 20-30 cm tall and 100% cured. The young wildings within this strip were also desiccated due to the chemical spray. Neighbouring unsprayed grass was considered 80-90% cured, while tussock and pasture grasses at higher elevations (600 m) were around 60% cured (Figure 16). Fuel moisture samples taken as part of the fire investigation found the grass from within the area of origin to have a moisture content of 23%, desiccated grass along the roadside to be 17%, and mixed live and dead grass fuels at higher elevations 115% (Stackhouse, 2008).

The fire travelled up slope from the point of origin in the cured grass fuels along the road side, into wilding pines that were less than 10 m tall (Figure 15 & Map 2). Ahead of the fire and above the first crest, the wilding cover became more continuous, taller and denser. The wilding pines were estimated at 800 to 1000 stems per hectare with an average stem base of 500 mm and fuel loads of 25 - 30 t/ha. There was a mix of wilding tree species present that were 15-20 m tall. These were dominated by Corsican pine *(Pinus nigra*) which made up about 90% of the wildings, with the remainder being mainly Larch (*Larix decidua*). The needle litter layer underneath the canopy was up to 3-4 cm deep, duff a futher 3-4 cm deep, and the uppermost soil layer contained high levels of organic matter with the presence of intact pine cones. Some areas had a total litter/duff layer of up to 10 cm deep.

Figure 15. Ignition occurred in grass fuels along the roadside, and the fire then travelled upslope into wilding pines. (Photograph: D Stackhouse, NZ Fire Service).

Figure 16. Grass fuels were considered 80-90% cured. (Photograph: R Barclay, NRFA).

Litter fuel moisture samples taken under the wildings during the fire investigation on day 3 had a moisture content of 47%, although the uppermost litter layer (top 1-2 cm) was likely to have been considerably drier than this (Stackhouse, 2008). The wilding pine forests had continuous ladder fuels made up of numerous thin branches that collected layers of dead needles, allowing the fire to travel up the trees easily. There were the occasional open spaces within the wilding forest where scrub, tall rank grass and bracken ferns were found. These resulted in the fire exhibiting periods of intermittent (rather than continuous) crown fire behaviour.

To the north towards Mount Cook Station homestead (and away from the fire's point of origin), the wilding cover was denser than the areas to the south and very difficult to walk through (Figure 17 & 19). Estimates of wilding pines in this area were 600 to 1800 stems per hectare and fuel load of at least 30 t/ha. Underneath the wildings were deep litter and duff layers (5-30 cm deep) which were moderately dry (Figure 18). The fire back burned into the wind in this area of unburnt wildings. This area was a concern for fire containment due to presence of a significant dead fuel component. As a precautionary measure, a dozed firebreak and retardant drops were carried out in this area due to a forecasted southerly wind change that could have spread the fire into these heavier fuels.

From the point of origin to the south along the Braemar-Mt Cook Station Road, the fire backed or flanked along and towards the road in more open grass and matagouri scrub (1.0-1.5 m tall), with scattered young wildings (1-2 m tall). Just to the south across Landslip Creek, another dense stand of wildings was present. This area also had very high available fuel loads and the fire burnt so fast and hot through this area that white ash was present and no deep-seated fires occurred. The fire also spotted across the Braemar-Mt Cook Station Road into an area containing scrub near the mouth of Landslip Creek.

At elevations above 760 m (Figure 20 & Map 2), the wilding cover became patchy and shorter in stature (less than 8 m tall). This area was a mix of young wilding pines, scrub and open tussock grassland. The fire ran in fingers through these areas due to the broken and patchy nature of the fuels. Fire behaviour was of lower intensity due to the reduction in fuel loads (3 - 10 t/ha).

The area of wilding pine cover ended south of Landslip Creek (halfway between Landslip Creek and Pleasant Valley), becoming open pasture grassland with scattered scrub (Figure 21). From here onwards the fuel loading was reduced (3 - 10 t/ha). The fire's spread was halted when it came into contact with a grazed paddock. The Pleasant Valley area contained grass (15 cm tall) and patchy matagouri. The areas between Landslip Creek and Pleasant Valley also contained windrows of piled slash resulting from the clearing of scattered scrub and wildings.

Figure 17. The northern end of the fire ground was covered in dense stands of wilding pines (Right photograph: R McNamara, DOC).

Figure 18. Tall dense wilding stands contained deep litter and duff layers.

Figure 19. The dense wilding stands contained dense elevated dead fuels.

Figure 20. At higher elevations, dense wilding pine stands gave way to lighter fuels comprising grasslands and scattered scrub (Photographs: R McNamara, DOC and J McCaughan, Aorangi Rural Fire Team).

Figure 21. To the south of Landslip Creek, the wilding pine cover gave way to open grass and scrubland (Photographs: R Gardner, SCRFD and R Barclay, NRFA).

Fire Weather

The point of origin of the fire was located within 20 km of the nearest fire weather stations at Mount Cook village and Tekapo Military Camp; a third Remote Automatic Weather Station (RAWS) was also located at Pukaki Aero (Map 1). These fire weather stations are monitored by the National Rural Fire Authority (NRFA)[i]. Another automatic station, the Mount Cook Electronic Weather Station (EWS) monitored by NIWA[ii] ws the closest to the POI (Table 1). However, this and the Mount Cook RAWS were not considered representative of the weather conditions at the fire site as they are closer to the main divide so are sheltered from the W/NW winds and receive more rainfall from the westerly spill-over rain events (Figure 22). Wind speeds recorded at the Pukaki RAWS were also thought to be generally lower than those observed at the fire area. It is sited in a sheltered location at the bottom end of the lake, compared to the fire site on the eastern side of Lake Pukaki which is more exposed to the full unabated westerly and northwesterly winds. The Tekapo RAWS was therefore considered most likely to reflect the onsite weather conditions in the lead up to and during the fire.

A number of additional rainfall monitoring stations were also located nearby (Table 1) from which data were available from within the National Climate Database (CliFlo)[ii] maintained by NIWA. The nearest rain gauge at Braemar Station (station number 4629) was located 10 km directly downwind from the fire's point of origin.

Weather data from the Tekapo RAWS and rainfall data from the Braemar raingauge were therefore used to analyse the fire weather leading up to and during the fire. Refer to Appendix A (Table 8) for the daily raw weather data using the closest weather stations to the fire during the main runs.

Table 1. Summary of the closest weather stations to the Mount Cook Station fire's point of origin (latitude -43.899 and longitude 170.184).

NETWORK	AGENT	STATION NAME	LAT	LONGT	DIST (km)	TYPE
H30921	4629	Lake Pukaki, Braemar	-43.983	170.2	9.5	rain
H40022	4968	Lake Pukaki, Guide Hill	-44.0	170.233	12.0	rain
H30706	18125	Mt Cook EWS	-43.736	170.096	19.6	all
NRFA	TEK	Tekapo	-44.0	170.4	20.3	fire
NRFA	MTC	Mount Cook	-43.73	170.08	20.7	fire
NRFA	PKA	Pukaki Aero	-44.23	170.11	37.6	fire

Pre-fire weather

A prohibited fire season was imposed from Saturday 22 December 2007 over the inland area of the South Canterbury Rural Fire District due to dry conditions and a very high fire danger. Much of the previous year had been drier than average (based on 10- and 90-year monthly rainfall totals) (Figure 23). Monthly rainfalls for the period January-April 2007 were below average, May and June about average, July and August again below average, but September and October significantly higher than the average. Rainfall in November and December, immediately leading up to

[i] https://portal.fire.org.nz/fwsys/fire_weather/
[ii] http://cliflo.niwa.co.nz/

the fire, was significantly lower than average with only around a third of the normal rainfall received.

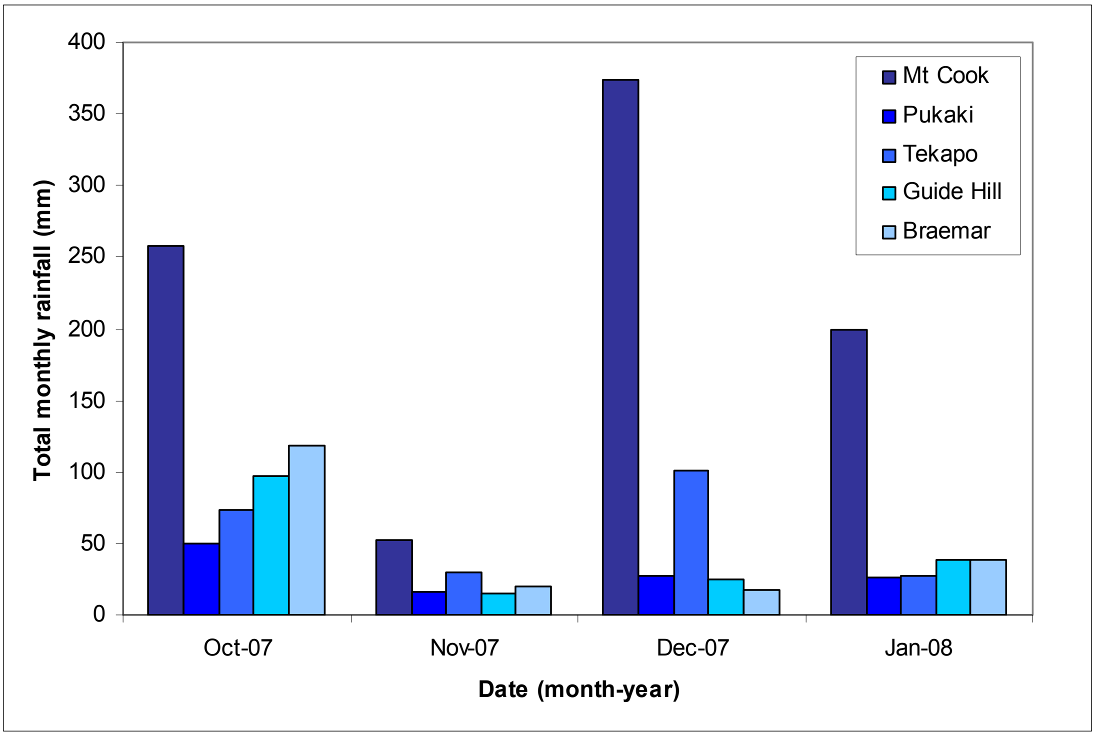


Figure 22. Total monthly rainfall for October 2007 to January 2008 from nearby weather stations (Source: NRFA fire weather and NIWA climate databases).

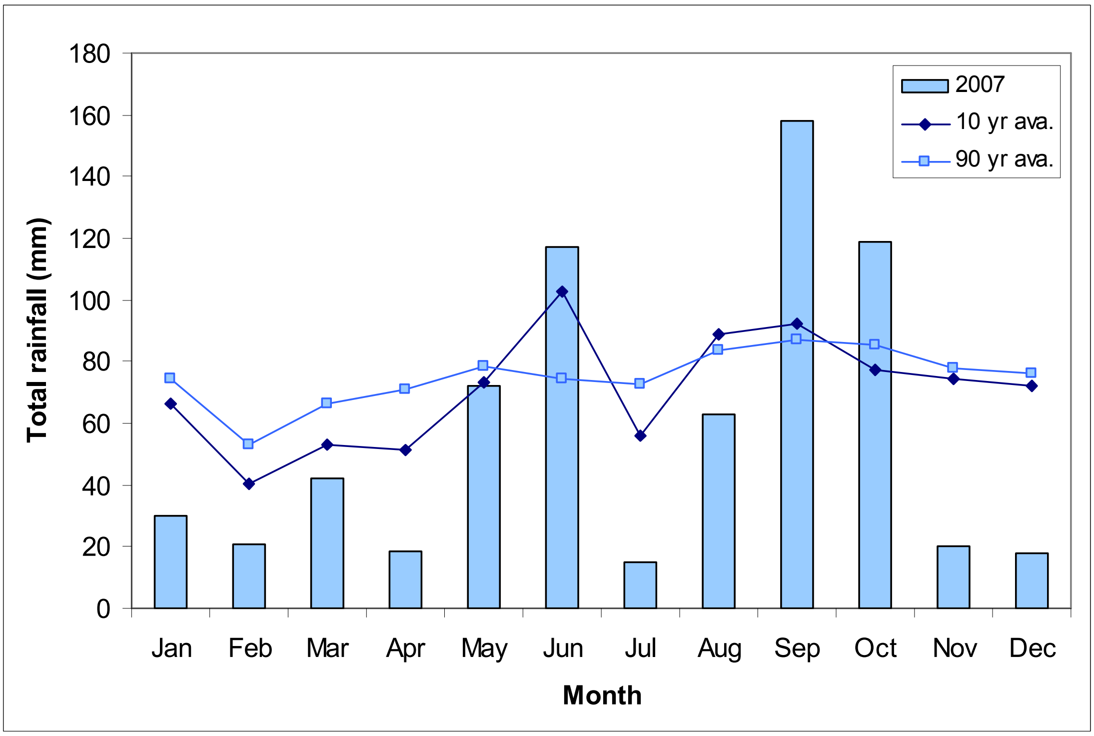


Figure 23. Monthly rainfall totals (mm) for 2007 compared with long-term averages over 10 years (1998 – 2008) and 90 years (1918 – 2008) at Braemar Station (agent no. 4629) (Source: NIWA climate database).

From November 2007 there were few significant rainfall events, so that fuels were progressively drying out over the months leading up to the fire (Figure 24). The Duff Moisture Code (DMC), Drought Code (DC) and Buildup Index (BUI) components of the Fire Weather Index (FWI) System steadily increased from November to the day of the fire (16 January 2008). The only major rainfall event prior to the fire occurred on 28 December 2007 (18 days before ignition), when 11 mm of rain fell lowering all of the fire weather indices (Table 2 & Figure 24). However, these indices continued to climb in the absence of further rain until 1 mm fell on 15 January 2008. This rain event had no effect on the fire weather indices so that they were very high when the fire occurred (FFMC 93.1, DMC 103, DC 432, ISI 10.6, BUI 129 & FWI 36.5).

The DMC, DC and BUI, in particular, indicated the presence of high available fuel loads within soil organic layers and woody fuels, and the potential for deep-seated burning and mop-up problems. The very high FFMC value also indicated extremely dry fine fuels susceptible to ignition. The moderately high ISI and FWI values also indicate the potential for rapid fire development, high fire intensity and significant control problems.

The last major rain events occurred on 22 and 23 of January 2008, where significant rain fell (7 mm and 31 mm respectively). These two rain events significantly reduced the fire weather indices (FFMC 66.6, DMC 27, DC 329, ISI 5.6, BUI 45 & FWI 13.6), and aided considerably in the fire's mop-up and extinguishment.

Daily fire weather observations

The major weather factors contributing to fire behaviour were hot, dry and windy conditions. Weather conditions on the day were hot and dry with strong winds, and the daily FWI System codes and indices indicated the potential for extreme fire behaviour.

During the fire (16 to 22 January), daily temperatures at 1200 hours ranged between 17 ºC and 23 ºC (averaging 21 ºC over the 7 days) (Table 2). Relative humidity ranged from 30% to 86% (averaging 44% over the 7 days). Wind speeds ranged from 9 km/h to 40 km/h (averaged 16 km/h over the 7 days). Wind direction observed at the Tekapo RAWS was frequently from the west or southeast during the burn period.

The daily FFMC peaked at 93 on the day the fire broke out, and remained very high (above 89) until it rained on the 22 January (Table 2 and Figure 24). The DMC, DC and BUI continued to climb during the fire event in the absence of rain, peaking at 119, 470 and 146 respectively by 21 January. The DC value, which high, is not particularly extreme for this part of the country where it can reach as high as 800 – 1000. However, the DMC and BUI values are very high and indicate very dry conditions and significant amounts of available fuel, and potential for extreme fire behaviour and difficult fire control and extinguishment.

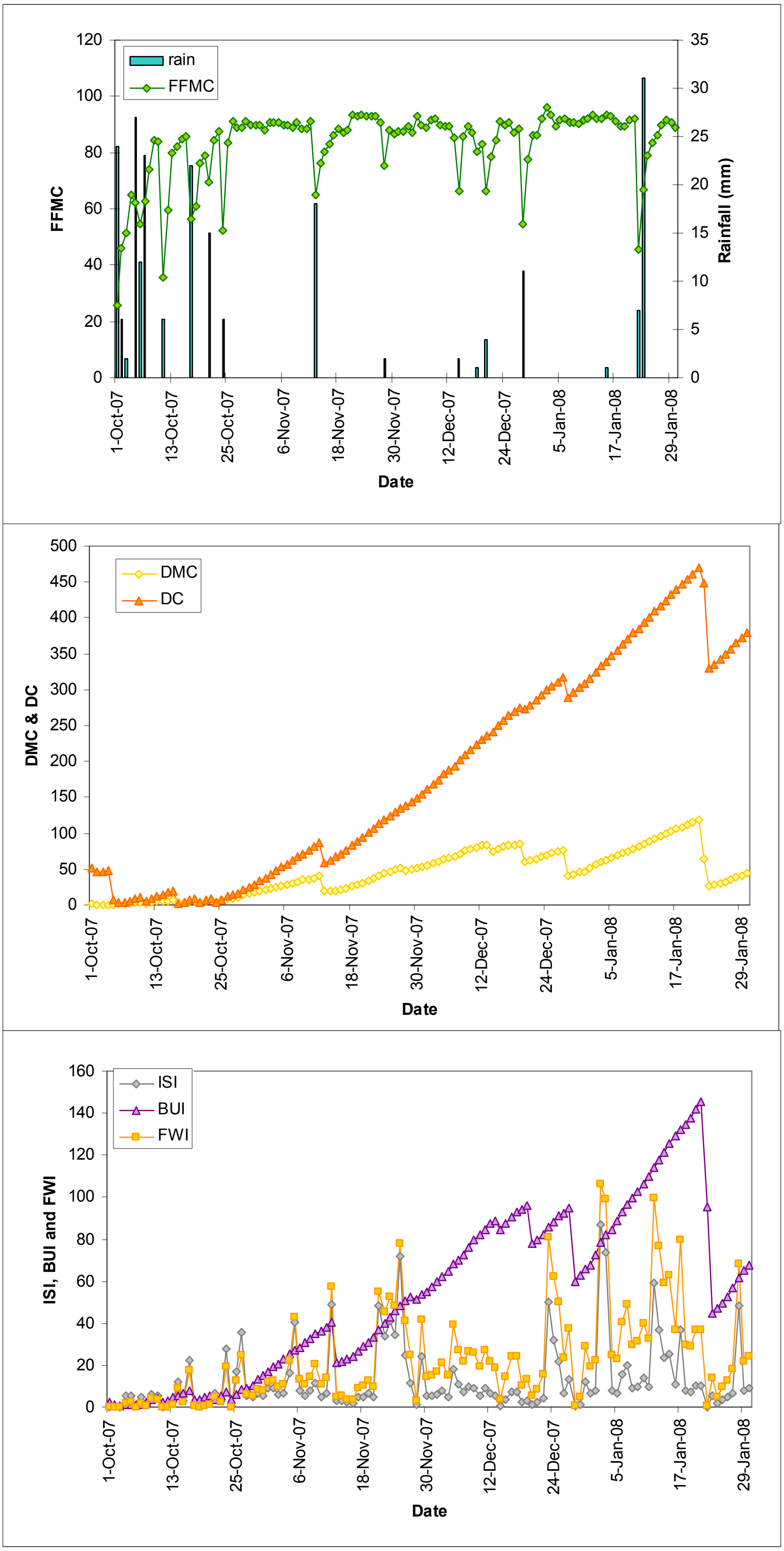


Figure 24. Daily rainfall and FWI System values (DMC, DC and BUI) for the period leading up to and during the Mt Cook Station fire (October 2007 to January 2008), based on weather data from the Tekapo RAWS and Braemar rainfall (Source: NRFA & NIWA).

Table 2. Daily weather and FWI System values for the Mt Cook Station fire, based on Tekapo station fire weather and Braemar rainfall (Source: NRFA & NIWA).

Date	Temp (ºC)	RH (%)	Wind dirn (deg)	Wind spd (km/h)	Rain (mm)	FFMC	DMC	DC	ISI	BUI	FWI
28/12/2007	12.2	39	105	7.5	**11.0**	54.7	40	289	0.4	60	0.8
29/12/2007	18.1	43	114	7.7	0	77.7	43	296	1.4	63	4.8
30/12/2007	18.5	45	272	30.8	0	86.3	45	303	11.9	66	28.9
31/12/2007	14.1	61	187	19.6	0	86.2	47	309	6.6	68	19.4
1/01/2008	22.7	23	140	6.1	0	91.8	51	316	7.6	72	22.1
2/01/2008	26.8	12	262	42.9	0	96.3	56	325	86.8	78	106.5
3/01/2008	20.9	29	265	53.8	0	93.4	59	332	73.4	82	98.8
4/01/2008	16.8	53	196	14.4	0	89.2	61	339	7.9	84	24.7
5/01/2008	24.6	29	121	5.0	0	91.6	65	347	6.9	89	23.1
6/01/2008	23.4	29	225	20.2	0	91.9	69	355	15.5	93	40.7
7/01/2008	24.7	45	267	28.5	0	90.8	72	363	20.1	96	48.7
8/01/2008	22.3	41	135	12.5	0	90.8	75	371	9.0	100	29.4
9/01/2008	21.1	43	188	14.9	0	90.4	78	379	9.7	103	31.2
10/01/2008	16.5	23	212	18.1	0	91.8	81	385	13.8	106	40.0
11/01/2008	22.2	30	154	11.4	0	91.8	84	393	9.9	110	32.7
12/01/2008	24.7	23	265	43.5	0	93.3	89	401	59.4	114	99.9
13/01/2008	23.8	37	283	36.8	0	92.1	92	409	36.8	118	76.5
14/01/2008	19.8	29	55	27.9	0	92.1	95	416	23.7	121	59.2
15/01/2008	21.8	15	261	26.3	**1.0**	93.2	100	424	25.4	125	62.5
16/01/2008	**23.1**	**30**	**137**	**9.2**	**0**	**93.1**	**103**	**432**	**10.6**	**129**	**36.5**
17/01/2008	**21.8**	**41**	**268**	**39.5**	**0**	**91.1**	**106**	**440**	**36.8**	**132**	**79.5**
18/01/2008	**17.3**	**50**	**150**	**13.7**	**0**	**89.1**	**108**	**446**	**7.6**	**135**	**29.5**
19/01/2008	**20.1**	**39**	**175**	**12.1**	**0**	**89.3**	**111**	**454**	**7.2**	**138**	**28.7**
20/01/2008	**24.6**	**29**	**136**	**12.4**	**0**	**91.8**	**115**	**462**	**10.3**	**142**	**36.8**
21/01/2008	**24.1**	**32**	**261**	**12.1**	**0**	**91.8**	**119**	**470**	**10.2**	**146**	**36.9**
22/01/2008	**17.8**	**86**	**218**	**10.7**	**7.0**	**45.5**	**65**	**449**	**0.2**	**95**	**0.4**
23/01/2008	**15.2**	**32**	**267**	**50.2**	**31.0**	**66.6**	**27**	**329**	**5.6**	**45**	**13.6**
24/01/2008	15.9	56	197	9.2	0	79.0	28	336	1.6	47	4.7
25/01/2008	16.8	58	134	13.3	0	83.6	30	343	3.4	49	9.6
26/01/2008	18.5	51	137	12.7	0	86.1	32	350	4.7	52	12.9
27/01/2008	20.4	33	209	9.8	0	89.7	35	357	6.7	57	17.8
28/01/2008	21.5	28	271	44.7	0	91.6	39	365	48.4	61	68.2
29/01/2008	20.5	43	121	10.7	0	90.6	42	372	8.0	65	21.7
30/01/2008	19.3	52	239	17.6	0	88.9	44	379	8.9	68	23.9
31/01/2008	20.4	56	228	11.3	0	88.2	46	387	5.8	71	18.0
1/02/2008	22.6	40	279	31.3	0	89.5	49	394	19.2	74	41.9
2/02/2008	12.7	67	157	8.8	2.0	71.7	45	399	1.0	70	3.9
3/02/2008	21.0	28	50	7.0	0	87.3	48	406	4.1	74	14.2
4/02/2008	9.5	93	147	15.4	0	79.7	48	411	2.4	74	9.2
5/02/2008	12.9	61	184	17.8	1.0	79.2	49	416	2.6	76	9.9
6/02/2008	21.8	29	88	8.4	0	89.2	52	423	5.8	80	19.3
7/02/2008	24.2	24	117	9.0	0	92.6	56	430	9.7	85	28.5
8/02/2008	25.5	15	145	4.9	0	95.1	61	438	11.2	90	32.3
9/02/2008	**20.0**	**33**	**175**	**5.4**	**0**	**93.1**	**64**	**444**	**8.8**	**94**	**27.9**
10/02/2008	16.9	66	176	6.0	0	87.6	65	450	4.1	95	16.4
11/02/2008	20.8	53	79	12.5	4.0	71.8	48	445	1.2	75	5.1
12/02/2008	20.0	53	0	9.0	4.0	66.7	36	439	0.9	60	2.9

Synoptic charts

The synoptic chart at 1250 hours NZST on 16 January 2008 (Figure 25a) indicated a warm front approaching the South Island with westerly winds, followed by a cold front. For 17 January, the synoptic chart at 0051 hours indicated that the warm front had passed and that the cold front, which had split into two, was approaching the fire area with a change to southerly or southwesterly winds.

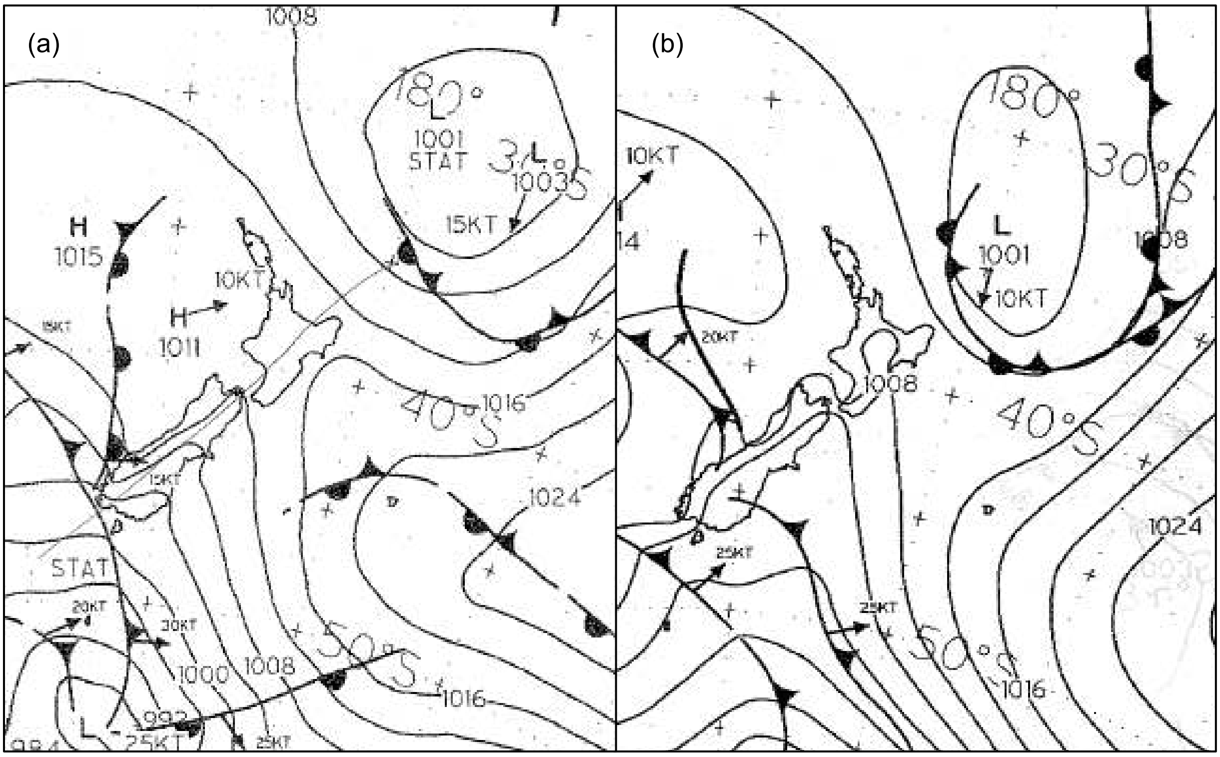


Figure 25. Synoptic charts issued on **(a)** the 16th and **(b)** 17th of January (Source: Meteorological Service of New Zealand Ltd 2008).

Hourly weather observations and onsite measurements

The weather observations from Tekapo RAWS and rainfall from the Braemar rain gauge were regarded as a close representation of the weather conditions experienced at the fire site during the fire (Figures 26 – 28). The main fire runs occurred within the first 24 hours. Refer to Appendix B for tables of the hourly weather conditions during the main run of the fires and over the following days of mop up.

<u>Day 1 – Wednesday 16 January 2008:</u>

Weather data from the Tekapo RAWS (Figure 26) show conditions at the time of ignition (approximately 1820 DST) were hot and dry (27 ºC and 14% relative humidity). During the main run of the fire, the temperature was decreasing and relative humidity began to increase. However, relative humidity still only reached a high of 40% overnight and it wasn't until the evening of day 2 that the relative humidity fully recovered with the south westerly wind change. Wind speed at 1800 hours averaged 43 km/h from the west (Figure 27), resulting in high ISI and FWI values of 62.6 and 107.2 respectively (Figure 28). The hourly FFMC of 93.8 and elevated degree of grass curing (100%) meant that the fine grass fuels were very dry and easy to ignite. During the main run of the fire, the wind continued to blow from the west with high speeds (40-45 km/h), although these reduced during the early hours of the morning to under 10 km/h. Observations on the fireground indicate that the wind was funnelling down the Pukaki valley and across the fire site in a northwesterly (rather than westerly) direction.

Day 2 – Thursday 17 January:
In the early hours of the morning, temperature increased and relative humidity decreased with the continuing northwesterly conditions. The wind fluctuated between northwest and west with wind speeds increasing from 7 to 40 km/h. At approximately 0630 hours, suppression resources observed a flare-up they described as an "area explosion" north of Landslip Creek in a stand of wilding pines. The increase in wind speed resulted in the fire taking off again, jumping Landslip Creek and spotting across the Braemar-Mount Cook Road and also between and into Pleasant Valley.

From a fire danger perspective, the weather conditions during the early hours of the morning were right for extreme fire behaviour. Between the hours of 0600 and 0700 (DST), the temperature was steadily increasing to about 20 ºC, relative humidity was 35-41%, and the wind speed reached 39 km/h from the northwest, resulting in an FFMC of 93, ISI of 11-45 and FWI of 37-89. By 0800 hours the Incident Control Point was notified that the southern flank and flare-up along the lake edge were under control, as the fire front had reached lighter fuel loads in a grazed paddock. A southerly wind change was expected at 1400 hrs but arrived later in the evening (2200 hours), which brought cooler temperatures (8 ºC) and higher humidity (90%).

Day 3 – Friday 18 January:
Conditions improved on day three with cooler temperatures, increased relative humidity and lower wind speeds (Appendix B Table 13). Hourly FFMC, ISI and FWI continued to decrease from the early hours of the morning until 1200 noon. The weather conditions over this period allowed fire crews to finish containment lines and target hotspots to minimise risk of flare-ups.

Days 4 to 7 – Saturday 19 to Tuesday 22 January:
Overnight and early on day 4, the wind changed back to a southwesterly then westerly direction (Appendix B Table 14). Between 0600 hours and 1400 hours, temperatures increased from 5º C to 21º C, and relative humidity decreased from 91% to 33%. The wind speed fluctuated between 6 km/h and 15km/h. The hourly FFMC increased from 82.9 to 85.6, ISI increased from 2.6 to 5.7 and FWI from 13.8 to 24.6. The fire weather conditions and subsequent fire danger resulted in two escapes at 1415 and 1446 hours.

For the following days (days 5 - 6), high temperatures and low relative humidities resulted in high FWI System values and the continued need for ground resources to target hotspots and undertake prolonged mop-up. At the end of day 6 (at 2300 hours), rain began to fall with a southwesterly wind change and continued to fall throughout day 7 (Appendix B Table 15 & 16). The fire was considered contained on day 7 due to the cool, wet conditions which significantly reduced the moisture content of fine fuels (reducing ignition potential) and duff layers in forested areas (reducing the need for suppression of remaining hotspots). However, the fire was not officially declared out until 9 February due to weather returning to warmer temperatures, lower relative humidity and an absence of rainfall.

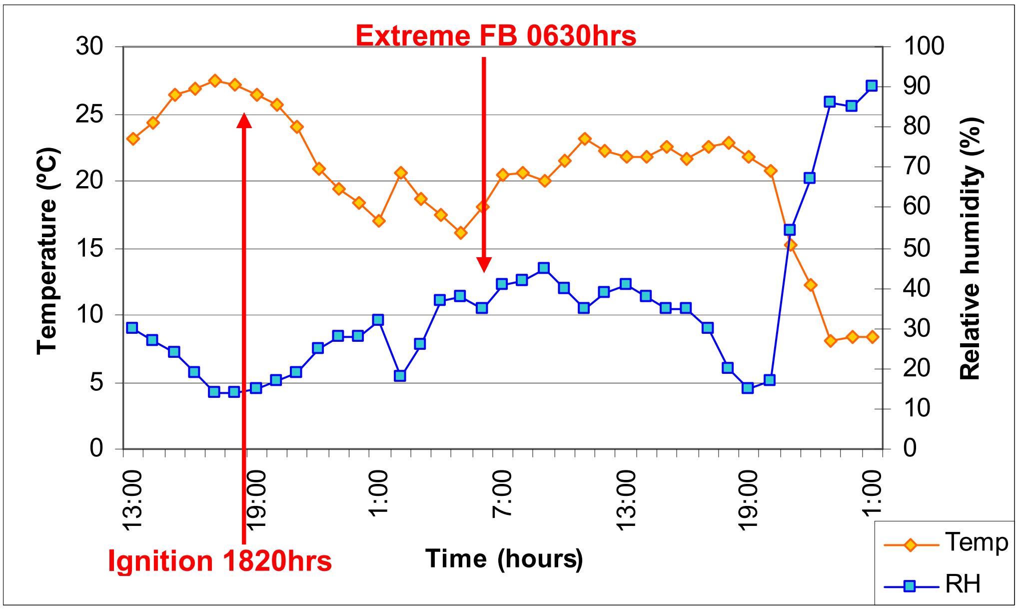


Figure 26. Hourly temperature and relative humidity for the period including the main fire runs (beginning 1300 hours on January 16), from the Tekapo RAWS (Source: NRFA).

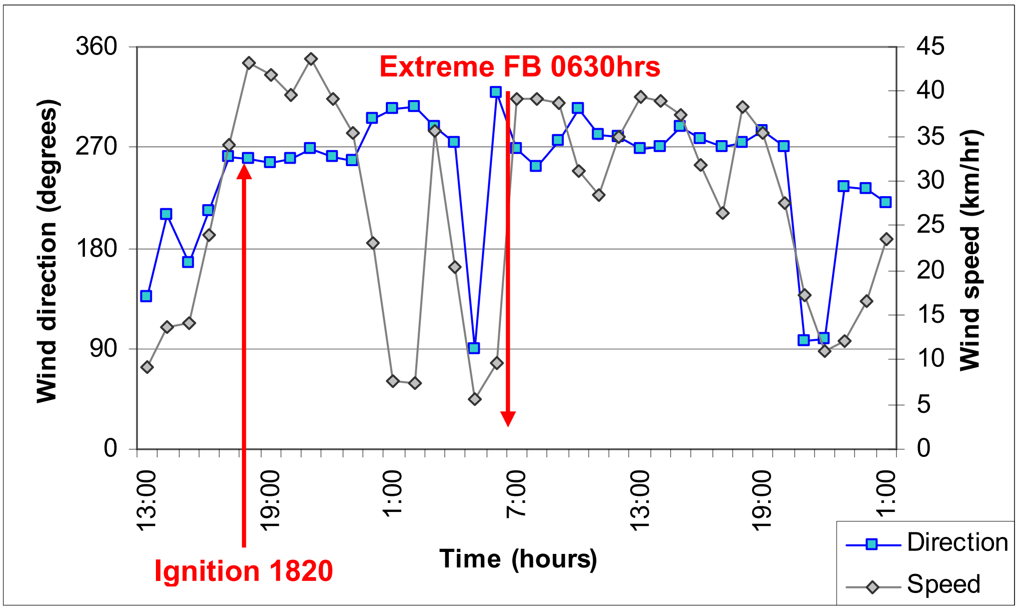


Figure 27. Hourly wind speed and direction for the period including the main fire runs (beginning 1300 hours on January 16), from the Tekapo RAWS (Source: NRFA).

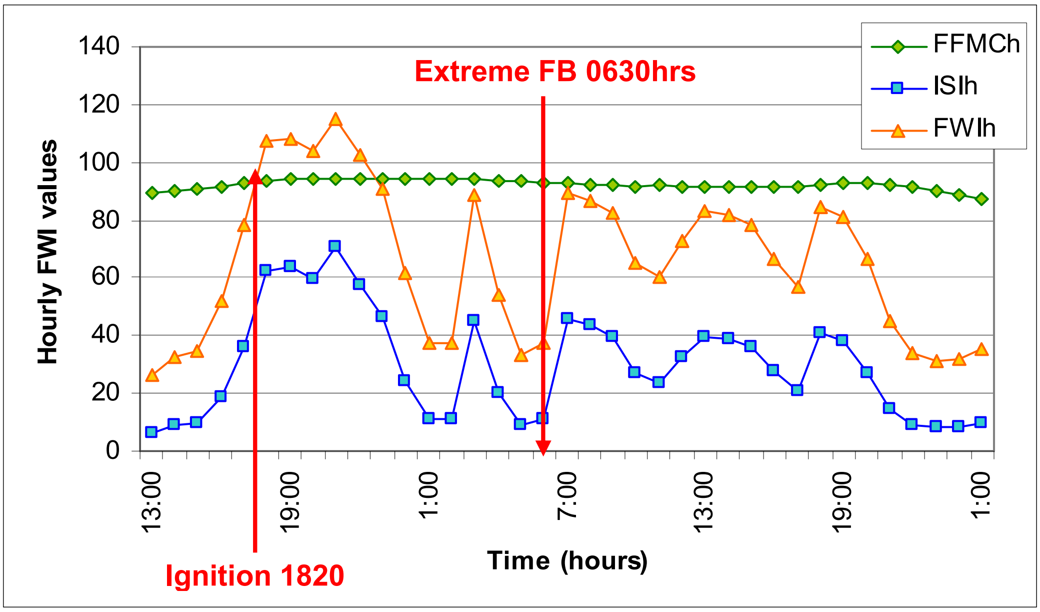


Figure 28. Hourly Fire Weather Index (FWI) System values for the period including the main fire runs (beginning 1300 hours on January 16), based on data from the Tekapo RAWS and Braemar rainfall (Source: NRFA & NIWA).

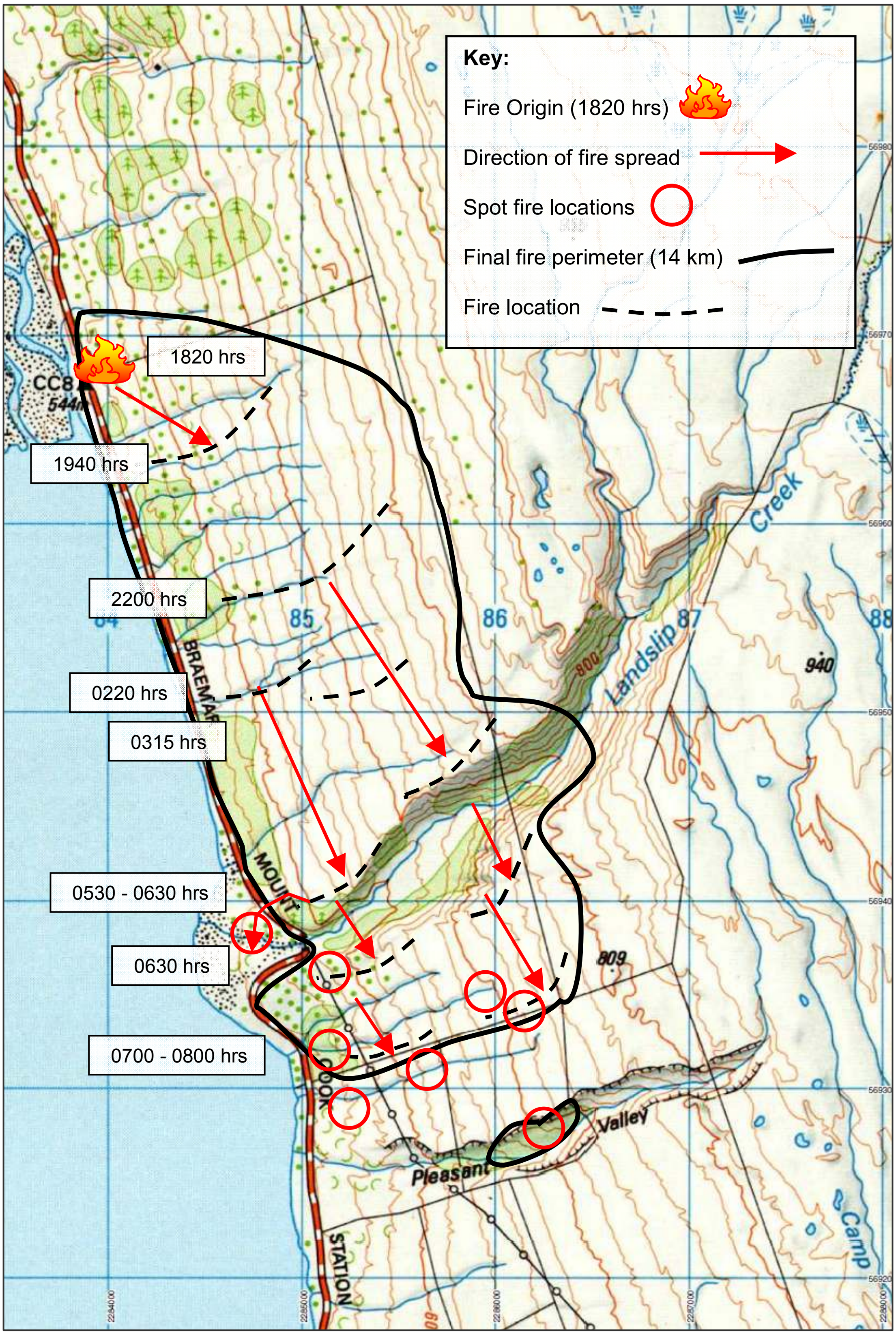
Fire Behaviour Observations

The main fire runs occurred within the first 24 hours (Map 3), but the fire continued to burn over the next 7 days. Burning was patchy due to the nature of the wilding fuels, with the fire consuming approximately 70% of the fuel within the fire area.

Observations:

- From the ignition point along the Braemar-Mount Cook Road at 1820 hours, the fire spread uphill and across slope in a southeasterly direction (with the generally northwest wind) through rank grass, bracken fern and quickly spread into thick wilding pines.
- Ground resources that arrived on the scene observed intermittent crowning in wilding pines at 1940 hours. At higher elevations, the fire ran in fingers above the terraces due to a reduction in fuel continuity, with open grass fuels and scattered scrub interspersed with areas of denser wildings.
- At one stage the Tekapo Township and military camp were potentially at risk, had the fire continued to be fanned by strong northwest winds and the number of aerial resources been less during initial attack.
- At the end of day one (2200 hours), resources were stood down due to poor light. The fire had spread a distance of 1.7 km and continued to travel towards Landslip Creek overnight and into the early hours of the morning. During this time the fire also back-burned into the wind away from the point of ignition, and the western flank of the fire spread downslope back towards the roadside.

- Night crews observed the fire 1.6 km away from the bridge at 0220 hours and 1.4 km by 0315 hours.
- The fire eventually reached Landslip Creek on day two between the hours of 0530 and 0630, spreading a further 1.3 km; it had been hoped to stop the fire's spread here.
- Wind activity picked up about 0630, resulting in the fire spotting across Landslip Creek and into a dense wilding pine stand where intense fire behaviour was observed. The fire also spotted over the road into scrub fuels near the mouth of Landslip Creek.
- The fire also ran down into the Landslip Creek gully/streambed and up the southern side into more wilding trees. Fire activity in the wilding pine stands was observed to be hot and fast mostly involving the surface layer, ladder fuels and torching into the tree crowns.
- These two breakouts showed extreme fire behavior and caused numerous spot fires ahead of the main fire between Landslip Creek and Pleasant Valley. Spot fire distances ranged from 100 m to 800 m, the largest in Pleasant Valley at a distance of about 1.5 km. Some of these spot fires were observed to be caused by rabbits and possums.
- This fire threatened a number of properties, including Braemar, Guide Hill and Tasman Downs homesteads (if the fire had continued to travel in a southerly direction), and Mount Cook homestead to the north (with a forecasted southerly wind shift).
- The fire was controlled due to a combination of suppression efforts, weather conditions and change of fuel type (from heavy forest fuels to light, grazed grass fuels).
- Dry conditions experienced at the time caused burning in a number of deep-seated hotspots, especially in windrows; these dry conditions over the following days resulted in numerous flare-ups.
- The mop up operation took four days to complete following containment of the fire, finishing on day seven (23 January).
- The fire was officially declared out 25 days after ignition, on 9 February 2008. The fire was estimated to have burnt a total area of 756 ha, of which 46 ha was on the neighbouring property.



Map 3. Location of the main fire runs that occurred within the first 24 hours (Source: MapToaster Topo, NZMS 260 Sheet H37, scale 1:32,250 approx.).

Analysis of Fire Behaviour

Although only limited observations of the fire's spread were available for the main runs of the fire that occurred within the first 24 hours, the fire behaviour observed is worthy of further analysis. It is difficult to accurately determine rates of spread based on recollections after the event, unless fire behaviour observations were accurately recorded by a dedicated observer. However, the observations made by fire personnel present during this period, together with information from photographs and fire log records have been used to reconstruct the general pattern of spread of the fire. Approximate times the fire reached specific locations were used to determine estimates of fire spread rates for comparison against those predicted by available fire behaviour models.

Observed fire behaviour

Observed rates of spread and fire intensity were determined using observations obtained from personnel interviewed regarding the location of the head fire at different times, and distances the fire travelled over these periods as measured from a topographic map.

Observed rates of fire spread for the main fire runs over the first 24 hours were generally between 400 – 600 m/h (Table 4). However, there were periods where rates of spread were higher, particularly in the case of runs 9 & 10 (800 – 1200 m/h) associated with the fire spotting across Landslip Creek and "taking off" again around 0630 hours on day two. The fuel loads used to calculate observed fire intensity for wilding pine stands were 25 and 30 t/ha, with 5 t/ha for grasslands (Table 4). Estimated fire intensities from observations ranged from 300 – 3000 kW/m for grasslands and 1500 – 18,000 kW/m for wilding pine stands.

Figure 29. The fire was eventually controlled by 0800 hours when it burnt into a paddock of grazed pasture (Photograph: C. Miles, Tekapo Helicopters Ltd).

Predicted fire behaviour

There were a mix of fuel types involved in the main fire runs, ranging from dense wilding pine stands to less dense wildings with patches of scrub, bracken fern and grasses, to more open tussock and pasture grasslands with scattered scrub, wilding pines and windrows. In terms of fire behaviour, there were two key fuel types that carried the fire: wilding pine stands and open pasture grasslands. As there is no specific model currently available in New Zealand for estimating fire behaviour in wilding pines, fire behaviour in these fuel types was predicted using models contained within both the New Zealand Fire Behaviour Prediction (FBP) System (Pearce and Anderson 2008), and Canadian FBP System (Forestry Canada Fire Danger Group 1992), on which the New Zealand models are based.

Weather and fire danger conditions at the time of the fire runs for use in fire behaviour predictions were calculated from conditions recorded by the Tekapo RAWS and rainfall observations from the Braemar Station rain gauge (Table 3). Around the time of ignition (1820 - 1832 hours), the hourly FWI readings were extreme, with an FFMC of 94 that stayed above 90 throughout the main run of the fire (see Table 2 page 24). The hourly ISI of 63 and FWI of 108 both remained at extreme levels during the main runs. As a result, the fire exhibited extreme fire behaviour in the wilding pines producing high intensity runs.

The current New Zealand models available for the two major fuel types involved were ungrazed pasture (natural/standing grasslands) and, in the case of wilding pines, two forest models were chosen: mature (20+ yrs) and immature (11-20 yrs) pine forest (both these pine models predict the same rates of spread as the inputs are the same but the difference between them is the fuel load). All three New Zealand models predicted significantly higher spread rates and intensities than those observed during the fire (Table 5), especially when slope effects were also included. The predicted fuel loads for mature and immature pine (using a BUI of 129) were 26 and 34 t/ha respectively (Appendix C Table 17). Thus these fuel loads were relatively similar to those used for observed fire intensity calculations.

Figure 30. Cutover area north of Landslip Creek where the fire spotted over the road and Landslip Creek (Photograph: A Jackson, NRFA).

Rates of spread were also calculated using the Canadian models for the immature (C-3) and mature (C-4) lodgepole pine fuel types, which most closely relate to the New Zealand wilding pine fuel type. Lodgepole pine (*Pinus contorta*) is a common wilding species in New Zealand and, although not the dominant species present at Mt Cook, is similar in fuel structure to the wilding fuels present. However, these Canadian fuel type models predicted even faster rates of fire spread compared to the New Zealand models (ranging from 420 – 6190 m/h on flat ground), due to the very high ISI values (30 – 60+) observed during the main runs of the fire (see Table 3).

Observed versus predicted

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For the first major run (run 1), the fire travelled a distance of approximately 600 m in 80 mins from the ignition point along the roadside in grass fuels, up and across the slope in dense wilding pine stands, to the area where intermittent crowning was observed by initial ground crews at 1940 hours. The rate of fire spread was estimated to be 450 m/h, and the head fire intensity calculated to be between 5600 - 6750 kW/m (Table 4) depending on the fuel type (and associated available fuel load) used.

Run 2 was from where the intermittent crowning was observed by the first arriving crews to where the fire was estimated to be when crews were stood down at 2200 hours. The rate of spread over this run was calculated to be 600 m/h (using a distance of 1400 m and 140 mins), and the calculated head fire intensity ranged between 7500 - 9000 kW/m (Table 4).

Run 3 was the total distance travelled from the point of ignition at 1820 hours to where crews were stood down at 2200 hours (a total distance of 1700 m). The rate of spread over this run was calculated at 460 m/h, with an intensity ranging from 3750 to 5600 kW/m (Table 4).

For runs 1 to 3, using the fire behaviour models for immature and mature pine, the predicted rate of spread ranged from 1900 to 5500 m/h depending on the slope used (Table 6), considerably faster than those observed. Predicted head fire intensities were also considerably higher than those estimated from observed spread, ranging between 25,000 and 73,000 kW/m for immature pine and 33,000 to 94,000 kW/m for mature pine (Table 6).

Estimates of average flame lengths during these runs were 10 -15 m, which are equivalent to intensities of about 38,000 – 94,000 kW/m. Intensities for the maximum reported flame lengths during these runs (25 m above 15 m tall trees) would be even greater still (in excess of 280,000 kW/m). The observations of intermittent crowning tend to agree more with intensities derived from observed spread rates (up to 9000 kW/m) compared with predicted intensities (in excess of 25,000 kW/m) where fully developed crown fires would be expected.

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Runs 4 to 7 occurred overnight and into the early hours of the morning on day 2 as the fire continued to burn towards Landslip Creek. Runs 4 and 5 were the observations of the night crew, and runs 6 & 7 were the distances the fire travelled from the time of the night crew observations to the approximate time the fire reached Landslip Creek. The observed rates of spread ranged from 150 m/h to 450 m/h, with fire intensities ranging from 1500 to 6750 kW/m for immature and mature pine and 300 to 1000 kW/m using the ungrazed pasture model (Table 3).

The predicted rates of spread during this time ranged from 400 m/h to 3000 m/h using the immature and mature pine models, and 1500 m/h to 10,000 m/h using the ungrazed pasture model (Table 6). Predicted fire intensity ranged from 9500 to 54,000 kW/m using the immature and mature pine models, and 5000 to 21,000 kW/m using the ungrazed pasture model (Table 6).

Runs 8 to 13 occurred when fire activity picked up due to the wind increasing in speed (from 7 to 40 km/h) between the hours of 0500 and 0700. The fire was initially north of Landslip Creek, but spotted across the road into scrub fuels, and also over Landslip Creek into an area of dense wilding pine. Observations were unclear whether this occurred as a two-stage jump or by spotting into two separate areas from the same general source (cut-over area in Figure 29). Further to the east, the fire also spread across Landslip Creek into wilding pine stands.

The rates of spread and intensities for runs 8 to 13 ranged from 200 to 1200 m/h and 2500 to 18,000 kW/m (using the immature and mature pine models respectively) (Table 4). The predicted rates of spread were calculated at 400 to 5500 m/h using both immature and mature pine models (Table 5). Predicted fire intensities calculated ranged from 5000 to 73,000 kW/m for immature pine and 6500 to 94,000 kW/m using the mature pine model (Table 6).

During the high intensity crown fire runs (8 - 10), continuous crowning (as opposed to intermittent torching) was observed (Figure 30 & 31). Flame heights of 20 – 40 m were observed in this run, also reflective of the very high fire intensity (in excess of 175,000 kW/m). Intensities estimated using observed maximum flame lengths of 60 m (including flames above trees 15 – 20 m tall) would be even higher still (in excess of 800,000 kW/m).

Figure 31. Mount Cook Station fire crowning in dense wilding pines soon after “jumping” Landslip Creek (Photograph: R Hands, SCRFD).

Table 3. Summary of fire weather conditions used in fire behaviour calculations for each major run (Source: Tekapo RAWS (NRFA) and Braemar rain (NIWA)).

Run	Time (DST)	Temp (°C)	RH (%)	Wind Dir (º)	Wind spd (km/h)	FFMCh	ISIh	FWIh	DMC	DC	BUI
16 January 2008											
1	1820 - 1940	26.4	15.3	258	41.6	94.2	61.9	106.6	103.3	431.9	129.3
2	1940 - 2200	23.5	20.3	263	40.8	94.5	62.7	107.2			
3	1820 - 2200	24.8	18.0	261	41.5	94.3	62.9	107.4			
17 January 2008											
4	0220 - 0315	19.7	22.0	298	21.5	94.0	28.0	62.9			
5	0220 - 0350	18.9	27.0	290	21.1	93.8	25.2	60.0			
6	0350 - 0600	17.2	36.7	227	11.9	93.4	13.3	41.5			
7	0220 - 0600	18.2	30.8	255	15.7	93.6	19.2	50.1			
8 & 9	0600 - 0630	18.0	35.0	319	9.7	93.2	10.9	37.2			
10	0630 - 0700	20.5	41.0	268	39.1	92.7	45.4	89.2			
11 & 12	0630 - 0800	20.6	41.5	261	39.2	92.6	44.4	88.0			
13	0600 - 0800	19.7	39.3	280	29.3	92.8	33.2	71.1			

Table 4. Observed rates of fire spread (m/h) and fire intensity (kW/m) for major fire runs, based on available fuel load from New Zealand models.

Run	Time (DST)	Observed rate of spread: Distance (m)	Interval (min)	ROS (m/h)	Fire Intensity (kW/m): Immature Pine 11-20 years[i]	Mature Pine 20+ years[ii]	Ungrazed pasture[iii]
16 January 2008							
1	1820 - 1940	600	80	450	5625	6750	1125
2	1940 - 2200	1400	140	600	7500	9000	1500
3	1820 - 2200	1700	220	464	5625	3750	1125
17 January 2008							
4	0220 - 0315	200	57	211	2500	3000	500
5	0220 - 0350	200	90	133	1560	1750	315
6	0350 - 0600	1100	150	440	5625	6750	1125
7	0220 - 0600	1300	220	355	4375	5250	875
8	0600 - 0630	310	30	620	7500	9000	1500
9	0600 - 0630	400	30	800	10000	12000	2000
10	0630 - 0700	600	30	1200	15000	18000	3000
11	0630 - 0800	640	90	427	5625	6750	1125
12	0630 - 0800	530	90	353	4375	5250	875
13	0600 - 0800	400	120	200	2500	3000	500
	Max	1700	220	1200	15000	18000	3000
	Min	200	30	133	1560	1750	315

[i] Based on estimated available fuel load of 25 t/ha for young wildings
[ii] Based on estimated available fuel load of 30 t/ha for denser wildings
[iii] Based on estimated available fuel load of 5 t/ha for grass and scrub areas

Table 5. Summary of predicted rates of spread (m/h) for the two key fuel types using the NZ models for Immature pine (Mature pine had same ROS) and Ungrazed pasture grass.

Run ID	Time interval (DST)	Observed ROS (m/h)	Predicted rate of spread (m/h): Immature pine, age 11-20 (model: IP 11-20)			Ungrazed pasture (model: O-1b)		
			flat ground	15º Slope	20º Slope	flat ground	15º Slope	20º Slope
16 January 2008								
1	1820 - 1940	450	1937	4009	5538	8571	17741	24508
2	1940 - 2200	600	1938	4011	5541	8599	17797	24586
3	1820 - 2200	464	1940	4015	5546	8632	17866	24680
17 January 2008								
4	0220 - 0315	211	1123	2323	3210	3651	7556	10438
5	0220 - 0350	133	1076	2228	3077	3498	7240	10002
6	0350 - 0600	440	1076	2228	3077	3498	7240	10002
7	0220 - 0600	355	719	1489	2057	2419	5007	6917
8 & 9	0600 - 0630	620 & 800	387	801	1107	1484	3072	4243
10	0630 - 0700	1200	1820	3768	5205	7091	14678	20276
11 & 12	0630 - 0800	427 & 353	1807	3740	5167	6974	14435	19941
13	0600 - 0800	200	1395	2888	3989	4656	9638	13314
	Max		1940	4015	5546	8632	17866	24680
	Min		387	801	1107	1484	3072	4243

Table 6. Summary of predicted fire intensity (kW/m) for the two key fuel types using the NZ models for Immature pine, Mature pine and Ungrazed pasture grass.

Run ID	Predicted fire intensity (kW/m): Immature pine, age 11-20 (model: IP 11-20) [i]			Mature Pine, age 20+ (model: C-6) [i]			Ungrazed pasture (model: O-1b) [ii]		
	flat ground	15º Slope	20º Slope	flat ground	15º Slope	20º Slope	flat ground	15º Slope	20º Slope
16 January 2008									
1	25429	52634	72709	32764	67815	93681	17618	36466	50375
2	25447	52670	72759	32786	67861	93745	17674	36582	50535
3	25467	52712	72818	32813	67916	93821	17742	36723	50730
17 January 2008									
4	14739	30507	42143	18990	39306	54298	7504	15532	21456
5	14132	29250	40407	18208	37687	52061	7190	14882	20558
6	14132	29250	40407	18208	37687	52061	7190	14882	20558
7	9446	19552	27009	12171	25191	34799	4972	10292	14217
8 & 9	5083	10520	14533	6549	13555	18725	3050	6314	8722
10	23903	49474	68344	30797	63744	88057	14576	30170	41677
11 & 12	23727	49111	67843	30571	63277	87411	14335	29670	40987
13	18319	37916	52378	23603	48853	67486	9571	19810	27366
Max	5083	10520	14533	6549	13555	18725	3050	6314	8722
Min	25467	52712	72818	32813	67916	93821	17742	36723	50730

[i] Using fuel loads based on a BUI of 129 (Pearce & Anderson 2008).
[ii] Based on height and cover (Pearce and Anderson 2008).

Suppression

This fire was costly for the South Canterbury Rural Fire District due to the involvement of a large number of aerial and ground resources. The fire cost about $800,000 but could have easily cost more without the quick response of numerous aerial attacks. The fire was remote and the terrain difficult, so aerial attack was the major resource used for suppression.

Resources deployed on day one were crews and equipment from the Department of Conservation, Twizel and Tekapo Volunteer Fire Brigades, Burkes Pass Rural Fire Team, plus 11 helicopters (of which six were initially used), one fixed wing, and local and Regional Incident Management Team personnel (Table 8). The location and difficult terrain made it impossible for ground resources to fight the blaze; instead a number of helicopters equipped with monsoon buckets were used.

On day two, suppression crews hoped to stop the fire's spread before it neared Braemar Station, downwind of the fire. The aim was to cut it off at Landslip Creek. However, the fire jumped Landslip Creek and then threatened stock and the neighbouring property on Braemar Station. At its height, more than 60 personnel, 11 helicopters and one fixed wing aircraft fought to contain the 14 km perimeter of the blaze. The fire would have likely destroyed the Braemar homestead if aircraft and machinery hadn't been used to control the fire and the fire's spread halted as it ran into a paddock of grazed pasture. Suppression efforts, aided by changes in fuel type and weather, helped contain the fire. By the evening of the second day, most of the fire that was burning was under control.

Prolonged mop-up began in the days that followed, with efforts turned to completing containment lines and putting out hot spots. Firefighters, heavy machinery and aircraft targeted hot spots located with an infra-red camera. The decision to use the Infra-red camera early (day three) aided significantly in making decisions about where to target resources to extinguish hot spots efficiently. The fire was contained when 7 mm and 31 mm of rain fell seven and eight days after ignition, and was officially declared out on 9 February, 25 days after ignition.

Table 7. Suppression resources used during the course of the Mount Cook Station fire.

Resources	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Helicopters	11 (6 used)	11	6	5	2	2	1
Fixed wing	1	1		1			
Heavy machinery	1	5	7	7	8	5	2
Ground crew	20	43	34	49	44	18	12

Safety

This was a challenging incident, as the site was remote and access was complicated by a dead end road and heavy forest fuels on steep terrain. Although there were a handful of near miss incidents, the fact that there was only one minor injury can only support that competencies of the fire crews were adequate.
A number of hazards were identified in the safety plan during the incident. The first safety concern was a forecasted change in wind direction from northwest to southerly winds on 17 January. Had the northern perimeter of the fire not been contained by a firebreak and retardant drops, the base of the fire could have become a new head fire with this wind change. A potential wind change would have resulted in the fire burning through thick dense wilding pines towards Mt Cook Homestead. The second safety concern was when fire behaviour increased on 17 January, so that it jumped the natural barrier (Landslip Creek) and headed south towards the Braemar Homestead. Fortunately, the fire was contained due to a decrease in wind strength and a change in fuel type to lighter fuels.

Other potential safety issues included very hot, deep-seated burning within the fire area and care was needed with possible ground collapse due to burnt out stumps and underground roots. Care was also needed while working in the fire area with burning spars overhead, and working around numerous heavy machinery and aircraft. There were multiple aircraft working on the fire that had to work around thick smoke and each other, along with possible sightseeing aircraft.

Figure 32. Ground crews involved in extensive mop-up within the burn area. (Photograph: J. Mc Caughans, Aorangi Rural Fire Team).

Discussion and Conclusions

The rates of spread and fire intensities observed during the main runs of the Mount Cook Station fire were significantly lower than those predicted using current New Zealand and Canadian fire behaviour models. At times the predicted rates of spread based on the FWI conditions were ten times greater than those observed. The differences are largely due to the fuel type (wilding pine) compared to that assumed when using associated models (commercial pine plantation). The differences between observed and predicted fire behaviour were due to variation in the local fire environment factors that did not necessarily fit with the underlying assumptions of the selected models. For fire managers, it is important to understand the assumptions of the fire behaviour models being used, and to modify them based on local knowledge of the fire environment. The likely reasons for the differences between observed and predicted fire behaviour are due to the combined effects of the three fire environment factors:

1. Topography
The differences between observed and predicted fire behaviour in the wilding pine and grassland fuels could be due to the topography. The fire travelled across slope due to the wind not blowing directly upslope. The fire behaviour models predict rates of spread on flat ground or directly upslope, so that the rates of spread observed would not be as fast as those predicted for fires burning directly upslope. The terrain also consisted of a series of terraces so that the slope would have comprised a series of steep rises with flatter areas in between. This would have resulted in periods of more rapid spread as the fire ran up the steeper sections, followed by periods with slower spread in the flatter areas. In contrast, the predicted spread rate is based on a single average slope calculated over the entire length of each fire run. However, the rates of spread using level ground should have been closer to those observed. Even for those runs where the slope was close to 0 degrees, observed rates of spread were still significantly less compared to those predicted for flat ground.

2. Weather
Observed and predicted fire behaviour in the wilding pine and grassland fuels could be different due to the wind. The wind speed and direction on the fireground were likely to have been different from those measured at the nearest weather stations. The wind onsite appears to have been more north-northwesterly compared with the more westerly winds recorded at the Tekapo weather station, which was considered the most representative of wind conditions on the fire ground. However, there were few onsite weather measurements made during the main runs of the fire to corroborate these differences. If wind speeds were lower onsite than recorded by the nearest RAWS then this might explain why observed rates of spread were slower than those predicted.

3. Fuels
The differences in observed and predicted fire behaviour in the wilding pine could be due to the effect of fuels. The stand structure in the wilding pines was denser, with much higher fuel loads compared to either the immature or mature commercial pine plantation models used in New Zealand. The denser fuel structure would likely have had an effect on reducing the wind speed reaching the fire at ground level, as tree density would reduce wind speed and therefore the fire's rate of spread (Barry & Chorley 2003, Johnson & Miyanishi 2001, Lalic *et al*. 2003). The fire behaviour models are based on pure fuel complexes that are continuous across the landscape, and at times the wilding stands were patchy (this was evident by the observations of intermittent crowning). Intermittent crowning was likely due to other fuels present

carrying the fire such as matagouri, tussock, pasture grass and bracken fern. Predicted rates of spread would have also been for fully developed crown fires. Similarly, the Canadian fuel models probably do not accurately reflect the fuel structure of New Zealand wilding pines. They are based on different wilding species (lodgepole pine) from those present at Mt Cook (Corsican pine and larch), so would likely have different structure and fuel loads that resulted in different fire behaviour predictions. In particular, the Canadian models appear to be based on fuels with more open structure than the areas of denser, more continuous wilding pines at the fire site, and therefore predict faster fire spread rates.

Observed rates of spread were also slower than that predicted using the grassland models. This may have been due to fire spread into patches of dense matagouri or other scrub slowing the rate of spread down due to wind reduction effects and slower combustion in heavier fuels. However, comparisons using the NZ scrub model still predict rates of spread higher than those observed in these areas.

The most appropriate New Zealand models against which to compare observed fire behaviour were those for immature and mature pine plantations and ungrazed pasture. However, none of these models performed particularly well, as they overestimated headfire spread and intensity due to fuel type differences, topographic and weather conditions. It was difficult to make comparisons with predicted headfire spread as few observations were made of the location and timing of the fire's main runs. More observations of when the headfire reached major landmarks would have greatly assisted in predicting headfire rates of spread.

Wildfire documentation is especially important to increase our understanding of fire behaviour in a fuel type that is becoming increasingly common in New Zealand. There is a clear need for research in wilding pines to better understand and predict fire behaviour in this fuel type. Documentation of wildfires is also invaluable for testing and validating existing fire behaviour models. Regardless of the few fire behaviour observations made, the Mount Cook Station fire still provides valuable information on fire behaviour for this fuel type.

Figure 33. The fire backed into the dense wilding pine stands during the early hours of day two (Photograph: C Miles, Tekapo Helicopters Ltd).

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- Kerry Ellem (Regional Incident Management Team)
- Russell Barclay (ex Department of Conservation; now Manager Rural Fire, National Rural Fire Authority, Dunedin)
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- Dave Stackhouse (NZ Fire Service, Christchurch)
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- Christchurch City Council/City Care
- Selwyn District Council
- Selwyn Plantation Board
- Waimakariri District Council
- Ashburton District Council
- Timaru District Council
- NZ Defence, Burnham/Tekapo
- NZ Fire Service, Twizel, Tekapo, Ashburton, Rakaia
- Mt Cook Industrial Fire Brigade
- Whitestone Contracting Ltd

APPENDICES

Weather Station Key:

MTC	- NRFA fire weather station at Mt Cook
MTC + 4629 rain	- Mt Cook with rain data from Braemar rain gauge
MTC + 4698 rain	- Mt Cook with rain data from Guide Hill rain gauge
18125 (0800 rain)	- Mt Cook EWS using hourly rain values at 0800hrs
18125 (1200 rain)	- Mt Cook EWS using hourly rain values at 1200hrs
PKA	- NRFA fire weather station at Pukaki Aero
PKA + 4629 rain	- Pukaki Aero with rain data from Braemar rain gauge
PKA + 4698 rain	- Pukaki Aero with rain data from Guide Hill rain gauge
TEK	- NRFA fire weather station at Tekapo
TEK + 4629 rain	- Tekapo with rain data from Braemar rain gauge
TEK + 4698 rain	- Tekapo with rain data from Guide Hill rain gauge

Weather Parameters Key:

Temp (ºC)	- Temperature measured in degrees Celsius
RH (%)	- Relative Humidity as a percentage
Wdir (degrees)	- Wind Direction measured in degrees (0-359)
Wspd (km/h)	- Wind Speed measured in kilometres per hour
Rain (mm)	- Rainfall measured in millimetres
FFMC	- Fine Fuel Moisture Code
DMC	- Duff Moisture Code
DC	- Drought Code
ISI	- Initial Spread Index
BUI	- Build up Index
FWI	- Fire Weather Index
Forest FDC	- Forest Fire Danger Class
Grass FDC	- Grassland Fire Danger Class
Scrub FDC	- Scrubland Fire Danger Class

List of figures and tables:

Appendix A – Daily Fire Weather records

Table 8. Summary of 1200 (NZST) daily fire weather readings for 16 & 17 January 2008 from Tekapo, Pukaki, Mt Cook RAWS and Mt Cook EWS (18125), using their own rainfall or rainfall from nearby rain gauges (Source: NRFA and NIWA).

Station	Temp (ºC)	RH (%)	Wind Dir (Deg)	Wind Spd (km/hr)	Rain (24hr)	FFMC	DMC	DC	ISI	BUI	FWI	Forest FDC	Grass FDC	Scrub FDC
Wednesday, 16 January 2008														
TEK	23.1	30	137	9.2	0	90.65	65.94	466.87	7.48	97.46	25.51	VH	H	E
TEK + 4629	23.1	30	137	9.2	0	93.15	103.28	431.89	10.65	129.27	36.54	E	VH	E
TEK + 4968	23.1	30	137	9.2	0	91.03	62.57	411.70	7.89	90.69	25.55	VH	H	E
PKA	24.9	28	13	7.3	0	91.89	104.47	609.91	8.11	146.29	31.76	E	H	E
PKA + 4629	24.9	28	13	7.3	0	92.02	118.97	467.93	8.26	145.47	32.10	E	VH	E
PKA + 4968	24.9	28	13	7.3	0	90.76	69.88	445.75	6.91	100.41	24.50	H	H	E
MTC	21.1	39	114	10	0	85.40	14.35	14.63	3.68	13.95	4.81	L	H	E
MTC + 4629	21.1	39	114	10	0	89.41	87.62	531.62	6.52	124.11	25.86	VH	H	E
MTC + 4968	21.1	39	114	10	0	88.09	53.72	528.94	5.40	85.69	18.92	H	H	E
18125 +1200	22.2	36	114	10.1	0	86.27	14.67	14.86	4.18	14.26	5.54	L	H	E
18125 + 0800	15.2	90	247	8.6	14.2	30.05	6.96	6.44	0.01	6.53	0.00	L	H	E
Thursday, 17 January 2008														
TEK	21.8	41	268	39.5	0	90.70	68.88	474.50	34.66	101.08	69.47	E	E	E
TEK + 4629	21.8	41	268	39.5	0	91.13	106.22	439.51	36.85	132.43	79.53	E	E	E
TEK + 4968	21.8	41	268	39.5	0	90.85	65.52	419.33	35.42	94.23	68.32	E	E	E
PKA	24.7	32	297	21.7	0	91.94	108.29	618.06	16.87	150.61	51.39	E	E	E
PKA + 4629	24.7	32	297	21.7	0	92.07	122.79	476.08	17.19	149.31	51.88	E	E	E
PKA + 4968	24.7	32	297	21.7	0	91.45	73.70	453.90	15.73	104.84	43.29	E	E	E
MTC	14.8	89	247	9	13	31.69	6.96	6.37	0.01	6.53	0.00	L	L	L
MTC + 4629	14.8	89	247	9	0	81.90	88.00	537.99	2.22	124.92	11.61	M	M	E
MTC + 4968	14.8	89	247	9	0	81.61	54.11	535.31	2.14	86.38	9.19	M	M	E
18125 +1200	22.2	36	114	10.1	0	86.26	14.41	14.86	4.18	14.01	5.48	L	L	L
18125 + 0800	15.2	90	247	8.6	1.6	67.90	13.95	21.30	0.90	13.72	0.65	L	M	H

Appendix B – Hourly Fire Weather records

Table 9. Hourly RAWS readings on 16 January 2008. Source NRFA

Time (DST)	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400
(NZST)	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300
Hourly Temperature (ºC)												
TEK	23.1	24.3	26.4		27.4	27.2	26.4	25.7	24	20.9	19.4	18.4
PKA	24.9	27.2	28.6	29.7	30.3	30.1	29.2	28	24.9	23.8	21.7	20.2
MTC	21.1	23.9	25.2	25.2	24.9	24.5	22.8	20.7	19.9	19.2	18.9	19.6
Hourly Relative humidity (%)												
TEK	30	27	24		14	14	15	17	19	25	28	28
PKA	28	23	17	13	13	12	14	15	19	20	25	28
MTC	39	29	25	24	25	25	26	27	29	29	27	23
Hourly Wind direction (degrees)												
TEK	137	210	167		261	259	257	259	269	262	258	295
PKA	13	39	29	48	21	295	333	319	283	268	22	339
MTC	114	32	3	0	350	324	317	332	328	335	316	326
Hourly Wind speed (km/hr)												
TEK	9.2	13.7	14		34.1	43.3	41.8	39.6	43.7	39.1	35.3	23
PKA	7.3	9.1	15	19.6	23.5	26	16.2	16.9	22	24.6	4	2.9
MTC	10	12	19	23	20	15	15	13	12	13	10	16

Table 10. Hourly weather readings recorded at Tekapo RAWS and Braemar (4692) rainfall on 16 January 2008 (Source: NRFA and NIWA).

Time (NZST)	Time (DST)	Temp (ºC)	Relative humidity (%)	Wind direction (degrees)	Wind direction	Wind speed (km/hr)	Rainfall (mm)	Hourly FFMC	Hourly ISI	Hourly FWI
0900	1000	18.2	40	232	SW	4.4	0	88.56	4.35	19.50
1000	1100	20.4	32	36	NE	5.6	0	88.91	4.86	21.12
1100	1200	21.6	33	97	E	8.2	0	89.23	5.81	23.95
1200	1300	23.1	30	137	SE	9.2	0	89.67	6.50	26.21
1300	1400	24.3	27	210	SSW	13.7	0	90.23	8.83	32.28
1400	1500	26.4	24	167	SSE	14	0	90.92	9.90	34.82
1500	1600	26.9	19	214	SW	24.05	0	91.82	18.67	52.30
1600	1700	27.4	14	261	W	34.1	0	92.91	36.15	78.04
1700	**1800**	**27.2**	**14**	**259**	**W**	**43.3**	**0**	**93.77**	**62.57**	**107.24**
1800	**1900**	**26.4**	**15**	**257**	**WSW**	**41.8**	**0**	**94.28**	**63.69**	**108.33**
1900	2000	25.7	17	259	W	39.6	0	94.51	59.50	104.21
2000	2100	24	19	269	W	43.7	0	94.56	70.69	114.91
2100	2200	20.9	25	262	W	39.1	0	94.48	57.82	102.52
2200	2300	19.4	28	258	WSW	35.3	0	94.30	46.53	90.48
2300	2400	18.4	28	295	WNW	23	0	94.15	24.53	61.86
2400	0100	17	32	304	NW	7.6	0	93.96	11.01	37.34

Table 11. Hourly weather readings recorded at Tekapo RAWS and 4692 rainfall on 17 January 2008 (Source: NRFA and NIWA).

Time (NZST)	Time (DST)	Temp (ºC)	Relative humidity (%)	Wind direction (degrees)	Wind direction	Wind speed (km/hr)	Rainfall (mm)	Hourly FFMC	Hourly ISI	Hourly FWI
0100	0200	20.6	18	307	NW	7.3	0	94.01	10.92	37.14
0200	0300	18.7	26	288	WNW	35.6	0	93.94	45.00	88.74
0300	0400	17.5	37	274	W	20.3	0	93.58	19.80	54.24
0400	0500	16.1	38	89	E	5.6	0	93.33	9.12	32.98
0500	0600	18	35	319	NW	9.7	0	93.16	10.94	37.19
0600	0700	20.5	41	268	W	39.1	0	92.75	45.44	89.23
0700	0800	20.6	42	253	WSW	39.2	0	92.38	43.33	86.81
0800	0900	20	45	275	W	38.7	0	91.96	39.83	82.63
0900	1000	21.5	40	304	NW	31.2	0	91.83	26.80	65.27
1000	1100	23.2	35	282	WNW	28.4	0	91.88	23.44	60.17
1100	1200	22.3	39	280	W	35	0	91.81	32.37	73.10
1200	1300	21.8	41	268	W	39.5	0	91.67	39.80	83.22
1300	1400	21.8	38	271	W	39	0	91.65	38.74	81.91
1400	1500	22.5	35	288	WNW	37.3	0	91.70	35.81	78.20
1500	1600	21.6	35	277	W	31.9	0	91.75	27.47	66.77
1600	1700	22.6	30	271	W	26.5	0	91.80	21.08	56.82
1700	1800	22.9	20	274	W	38.3	0	92.30	40.95	84.62
1800	1900	21.8	15	284	WNW	35.3	0	92.90	38.31	81.38
1900	2000	20.8	17	271	W	27.6	0	93.21	27.13	66.27
2000	2100	15.2	54	97	E	17.2	0	92.48	14.51	44.98
2100	2200	12.3	67	98	E	10.9	0	91.59	9.31	33.73
2200	2300	8	86	234	SW	12.1	0	90.24	8.16	30.88
2300	2400	8.4	85	233	SW	16.6	0	89.02	8.60	31.98
2400	0100	8.4	90	221	SW	23.6	0	87.61	9.99	35.33

Table 12. Hourly weather readings recorded at Tekapo RAWS and 4692 rainfall on 18 January 2008 (Source: NRFA and NIWA).

Time (NZST)	Time (DST)	Temp (ºC)	Relative humidity (%)	Wind direction (degrees)	Wind direction	Wind speed (km/hr)	Rainfall (mm)	Hourly FFMC	Hourly ISI	Hourly FWI
0100	0200	8.9	90	219	SW	20.8	0	87.63	8.70	32.25
0200	0300	8.4	92	224	SW	16.8	0	86.37	5.95	24.88
0300	0400	6.9	95	230	SW	15.7	0	85.12	4.73	21.14
0400	0500	7.7	95	231	SW	15.5	0	84.02	4.03	18.82
0500	0600	8.3	94	208	SSW	12.3	0	83.15	3.06	15.33
0600	0700	8.5	93	220	SW	11.8	0	82.47	2.74	14.07
0700	0800	10	88	205	SSW	15	0	82.12	3.08	15.40
0800	0900	11.3	77	228	SW	11	0	82.17	2.53	13.24
0900	1000	13.4	68	235	SW	12.3	0	82.31	2.75	14.12
1000	1100	13.9	59	198	SSW	8.3	0	82.59	2.33	12.39
1100	1200	16.8	51	155	SSE	9.1	0	83.09	2.58	13.45
1200	1300	17.3	50	150	SSE	13.7	0	83.62	3.49	17.04
1300	1400	18	44	179	S	13.5	0	84.26	3.76	18.02
1400	1500	19	41	149	SSE	15	0	84.96	4.46	20.41
1500	1600	19.8	40	133	SE	17.8	0	85.65	5.65	24.14
1600	1700	19.9	37	149	SSE	20.7	0	86.35	7.22	28.60
1700	1800	19	41	142	SE	24.2	0	86.79	9.17	33.59
1800	1900	18.3	43	151	SSE	21.5	0	87.07	8.33	31.49
1900	2000	17	47	146	SE	25.5	0	87.17	10.32	36.32
2000	2100	14.3	59	155	SSE	21	0	87.11	8.17	31.09
2100	2200	12.2	67	252	WSW	14.5	0	86.86	5.68	24.24
2200	2300	11.1	72	239	WSW	11.3	0	86.53	4.61	20.91
2300	2400	10.3	75	247	WSW	7.5	0	86.19	3.63	17.54
2400	0100	9.4	79	222	SW	9.9	0	85.75	3.85	18.34

Table 13. Hourly weather readings recorded at Tekapo RAWS and 4692 rainfall on 19 January 2008 (Source: NRFA and NIWA).

Time (NZST)	Time (DST)	Temp (ºC)	Relative humidity (%)	Wind direction (degrees)	Wind direction	Wind speed (km/hr)	Rainfall (mm)	Hourly FFMC	Hourly ISI	Hourly FWI
0100	0200	7.7	84	249	WSW	8.8	0	85.22	3.39	16.66
0200	0300	6.9	88	265	W	9.7	0	84.59	3.25	16.15
0300	0400	6.6	88	248	WSW	7.9	0	84.05	2.76	14.26
0400	0500	5.8	89	254	WSW	10.4	0	83.51	2.91	14.86
0500	0600	5.4	91	250	WSW	9.9	0	82.93	2.64	13.76
0600	0700	5.9	90	242	WSW	7.9	0	82.48	2.25	12.15
0700	0800	9.4	84	210	SSW	6.9	0	82.32	2.10	11.48
0800	0900	12.3	73	205	SSW	8.8	0	82.37	2.32	12.46
0900	1000	14.9	62	190	S	6.4	0	82.60	2.12	11.57
1000	1100	16.2	60	121	ESE	13	0	82.92	3.08	15.50
1100	1200	18.9	44	125	SE	9.3	0	83.64	2.80	14.43
1200	1300	20.1	39	175	S	12.1	0	84.51	3.62	17.67
1300	1400	20.9	33	232	SW	18.3	0	85.57	5.73	24.57
1400	1500	22.1	33	198	SSW	14	0	86.48	5.25	23.09
1500	1600	21.9	36	148	SSE	18.7	0	87.17	7.33	29.11
1600	1700	23	34	172	S	10.3	0	87.80	5.25	23.11
1700	1800	22.1	36	146	SE	17	0	88.26	7.87	30.54
1800	1900	21.9	38	151	SSE	14.8	0	88.57	7.36	29.18
1900	2000	21.2	38	181	S	10	0	88.79	5.96	25.25
2000	2100	18.8	48	237	WSW	11.8	0	88.83	6.57	27.02
2100	2200	14.3	63	254	WSW	15.2	0	88.48	7.41	29.33
2200	2300	13	63	254	WSW	18	0	88.14	8.13	31.23
2300	2400	13	65	252	WSW	9.5	0	87.85	5.08	22.57
2400	0100	13	66	238	WSW	8.1	0	87.57	4.55	20.87

Table 14. Hourly weather readings recorded at Tekapo RAWS and 4692 rainfall on 20 January 2008 (Source: NRFA and NIWA).

Time (NZST)	Time (DST)	Temp (ºC)	Relative humidity (%)	Wind direction (degrees)	Wind direction	Wind speed (km/hr)	Rainfall (mm)	Hourly FFMC	Hourly ISI	Hourly FWI
0100	0200	10.6	74	220	SW	11.8	0	87.10	5.13	22.72
0200	0300	10.5	74	246	WSW	9.2	0	86.70	4.25	19.87
0300	0400	10.8	76	253	WSW	19.4	0	86.23	6.65	27.24
0400	0500	10.8	77	250	WSW	14.4	0	85.82	4.88	21.94
0500	0600	9	81	244	WSW	8.1	0	85.39	3.34	16.64
0600	0700	12.2	69	0	N	6.6	0	85.32	3.07	15.61
0700	0800	15.1	63	38	NE	5.4	0	85.37	2.91	14.98
0800	0900	18.2	52	94	E	3.3	0	85.55	2.69	14.08
0900	1000	20	46	125	SE	8.5	0	85.93	3.68	17.86
1000	1100	22	43	117	ESE	7.5	0	86.39	3.73	18.06
1100	1200	23.2	37	125	SE	13.1	0	87.07	5.46	23.74
1200	1300	24.6	29	136	SE	12.4	0	88.01	6.02	25.67
1300	1400	25.8	24	129	SE	12.4	0	89.07	7.01	28.49
1400	1500	26.9	21	192	SSW	17.7	0	90.20	10.77	37.94
1500	1600	27.2	21	167	SSE	12.7	0	91.07	9.48	34.89
1600	1700	27.3	21	141	SE	18	0	91.82	13.76	44.43
1700	1800	26.6	25	153	SSE	25.6	0	92.20	21.29	58.36
1800	1900	25.3	32	151	SSE	21.4	0	92.25	17.35	51.42
1900	2000	24.6	32	156	SSE	10.5	0	92.30	10.09	36.36
2000	2100	20.7	46	242	WSW	16.9	0	91.96	13.28	43.44
2100	2200	17.8	50	258	WSW	18.8	0	91.51	13.72	44.36
2200	2300	16.2	51	245	WSW	16.8	0	91.11	11.71	40.06
2300	2400	16.9	55	221	SW	9.6	0	90.71	7.69	30.36
2400	0100	14.3	60	241	WSW	11.8	0	90.20	8.00	31.17

Table 15. Hourly weather readings recorded at Tekapo RAWS and 4692 rainfall on 21 January 2008 (Source: NRFA and NIWA).

Time (NZST)	Time (DST)	Temp (ºC)	Relative humidity (%)	Wind direction (degrees)	Wind direction	Wind speed (km/hr)	Rainfall (mm)	Hourly FFMC	Hourly ISI	Hourly FWI
0100	0200	13.9	60	256	WSW	15.8	0	89.73	9.15	34.08
0200	0300	13.1	63	258	WSW	18.5	0	89.23	9.75	35.54
0300	0400	12.3	70	260	W	15.6	0	88.62	7.72	30.43
0400	0500	11.6	73	245	WSW	13.6	0	88.03	6.41	26.82
0500	0600	12.2	72	243	WSW	6.6	0	87.61	4.24	20.03
0600	0700	13.6	72	235	SW	6.1	0	87.24	3.92	18.93
0700	0800	15.6	58	229	SW	6.5	0	87.24	4.00	19.21
0800	0900	20	49	91	E	6	0	87.32	3.95	19.02
0900	1000	23	30	117	ESE	6.2	0	88.01	4.41	20.58
1000	1100	24.7	29	143	SE	8.3	0	88.74	5.44	23.92
1100	1200	23.1	33	171	S	4.2	0	89.11	4.67	21.45
1200	1300	24.1	32	261	W	12.1	0	89.56	7.40	29.82
1300	1400	26.1	28	147	SSE	6.9	0	90.12	6.17	26.34
1400	1500	26.9	23	122	ESE	7.5	0	90.83	7.05	28.84
1500	1600	26.7	27	140	SE	11.5	0	91.27	9.18	34.43
1600	1700	25.4	32	263	W	14	0	91.38	10.57	37.79
1700	1800	24.3	38	115	ESE	11.8	0	91.43	9.53	35.30
1800	1900	23.8	40	73	ENE	7.4	0	91.46	7.67	30.54
1900	2000	23.2	43	302	WNW	2.2	0	91.43	5.87	25.44
2000	2100	21.6	53	218	SW	8.2	0	91.08	7.57	30.27
2100	2200	21.8	49	194	SSW	4.7	0	90.92	6.20	26.41
2200	2300	18.5	81	31	NNE	17	0.4	80.96	2.97	15.52
2300	2400	17	90	85	E	5.5	1.4	55.73	0.39	2.10
2400	0100	16.7	86	7	N	3.8	0	56.68	0.39	2.08

Table 16. Hourly weather readings recorded at Tekapo RAWS and 4692 rainfall on 22 January 2008 (Source: NRFA and NIWA).

Time (NZST)	Time (DST)	Temp (ºC)	Relative humidity (%)	Wind direction (degrees)	Wind direction	Wind speed (km/hr)	Rainfall (mm)	Hourly FFMC	Hourly ISI	Hourly FWI
0100	0200	16.1	94	213	SSW	4.7	0.2	54.32	0.33	1.56
0200	0300	15	94	231	SW	15.1	0.2	52.33	0.46	2.62
0300	0400	15	95	237	WSW	7.8	0	52.80	0.33	1.58
0400	0500	14.7	95	252	WSW	8.2	0.2	50.70	0.27	0.94
0500	0600	14.8	94	219	SW	12.3	0	51.36	0.36	1.80
0600	0700	14.8	96	239	WSW	7	0	51.75	0.29	0.99
0700	0800	15.4	96	178	S	0.5	0.2	49.44	0.16	0.54
0800	0900	16	94	207	SSW	5.6	1	39.12	0.04	0.13
0900	1000	16.1	94	134	SE	6.7	2.2	23.65	0	0
1000	1100	16.7	92	117	ESE	8.2	1.2	19.17	0	0
1100	1200	16.9	89	92	E	2.4	1.2	15.86	0	0
1200	1300	17.8	86	218	SW	10.7	0	18.13	0	0
1300	1400	17.8	85	187	S	13.4	0	20.67	0	0
1400	1500	13.9	95	204	SSW	62.6	3.2	11.54	0	0
1500	1600	12.5	94	176	S	28	4.8	5.58	0	0
1600	1700	12.6	97	137	SE	6.1	3.4	2.72	0	0
1700	1800	13.5	90	245	WSW	3.2	0	3.78	0	0
1800	1900	14.2	85	291	WNW	3.5	0	5.32	0	0
1900	2000	14.8	79	235	SW	2.3	0.2	6.57	0	0
2000	2100	14.4	85	73	ENE	2.1	0	7.96	0	0
2100	2200	11.8	88	229	SW	18.7	0	9.92	0	0
2200	2300	11.5	86	240	WSW	16.2	0	11.99	0	0
2300	2400	10.9	84	250	WSW	16.8	0	14.23	0	0
2400	0100	10.8	83	227	SW	10.1	0	16.21	0	0

Appendix C – Fire Behaviour Analysis

Table 17. Fire behaviour models and inputs used for fire behaviour calculations.

		Observed fuel load (t/ha)	Available fuel load (t/ha)	Height (m)	Cover (%)	Curing (%)
NZFDRS Fuel Types						
IP 11-20	Immature pine, age 11-20	25	26.3[i]			
C-6	Mature Pine, age 20+	30	33.8[i]			
O-1b	Ungrazed pasture	5	4.1[ii]	0.20	90	85
CFFDRS Fuel Types						
C-3	Mature jack or lodgepole pine		37.5[iii]			
C-4	Immature jack or lodgepole pine		37.5[iii]			
O-1b	Natural (standing) grass		3.0[iv]			85

Table 18. Weather readings used to calculate fire behaviour for each run (Source: Tekapo RAWS (NRFA) and Braemar rain gauge (NIWA)).

Run ID	Time (DST)	10m-Wind Speed	FFMC	DMC	DC	ISI	BUI
16th January 2008							
1	1820 - 1940	41.6	94.2	103.3	431.9	62.4	129.3
2	1940 - 2200	40.8	94.5			62.8	
3	1820 - 2200	41.5	94.3			63.4	
17th January 2008							
4	0220 - 0315	21.5	94.0			22.0	
5	0220 - 0350	21.1	93.8			21.2	
6	0350 - 0600	11.9	93.4			12.5	
7	0220 - 0600	15.7	93.6			15.6	
8 & 9	0600 - 0630	9.7	93.2			10.9	
10	0630 - 0700	39.1	92.7			45.1	
11 & 12	0630 - 0800	39.2	92.6			44.1	
13	0600 - 0800	29.3	92.8			27.6	

[i] Based on BUI of 129 (Pearce & Anderson 2008)
[ii] Based on grass height and cover (Pearce and Anderson 2008)
[iii] Based on BUI (FCFDG 1992)
[iv] Based on assumed standard grass fuel load (FCFDG 1992)