Fire Technology Transfer Note

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Fire Behaviour Case study
Waiomu, 28 January 2008

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Importance of documenting wildfires

There are many reasons why documenting wildfires is important and should form a key part of any fire management organisation's procedures. One reason is benefiting the researcher, by contributing fire behaviour data from "real world" conditions to improve existing (or develop new) fire behaviour models and fire danger rating systems. The individual or an organisation can also benefit from documenting wildfires, as the information can be used to:

- Validate and improve organisational procedures, e.g. readiness and response levels suited to the fire danger conditions;
- Analyse fire suppression resource productivity and effectiveness, and to improve cost-effectiveness of resources;
- Identify factors contributing to incidents, and to develop improved procedures to minimise these risks in future. The focus should not only be limited to fatality or serious harm incidents, but also focus on lessons to be learned from "near miss" events on large and small wildfires (or prescribed burns);
- Improve organisational and individual knowledge by providing a source of information for training materials, fire debriefs, fire investigations and fire statistics.

The extent of information and level of detail collected during and after a fire event will vary depending upon the purpose of the investigation, resources available and the aspects being examined (e.g., fire behaviour analysis, aerial suppression study, safety incident). Fire suppression personnel are usually first on scene and therefore in the best position to record a few simple, yet key aspects of a fire's chronology which enable a case history to have some substance. Fire researchers (and senior fire personnel) can play an important role in the compilation, analysis and write-up of wildfire case studies.

Introduction

This report investigates vegetation fire behaviour at the Waiomu Fire on the 28th of January 2008. It looks at how the prediction and observation of fire behaviour can assist in fire suppression planning. The information was collected as part of as a case study for the Intermediate Fire Behaviour qualification. The case study describes the interaction between the fire environment factors of fuels, weather and topography to determine the fire behaviour observed at the 2008 Waiomu fire. This case study also demonstrates the use of the recently released “Fire Behaviour Toolkit” calculator, and how it can be used to compare observed versus predicted fire behaviour. It is also a good example that not all case studies need to be prepared by researchers, but can also be useful for operational staff and fire suppression planning.

Waiomu is one of a number of small settlements on the west coast of the Coromandel Peninsula. The Coromandel has relatively high average temperatures by NZ standards and moderate/high annual rainfall (NIWA 2009). The peninsula has a range of vegetation types including pasture, scrub, pine plantation forest and mature native broadleaf/podocarp forest. Topography is generally rolling near the coast with steeper country in the Coromandel Ranges.

Figure 1. Location of Waiomu on the Coromandel Peninsula.

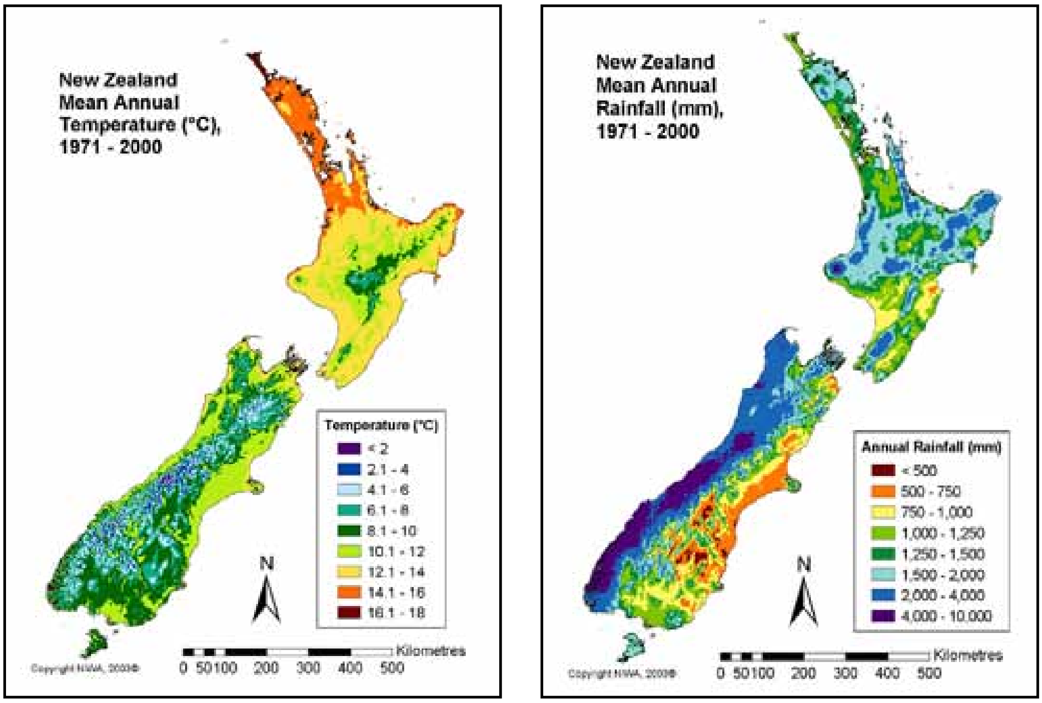


Figure 2. NIWA Climate Maps showing mean annual temperature and mean annual rainfall across NZ (from www.niwa.co.nz).

Overview of the incident

Summary of fire chronology and suppression efforts

On the afternoon of 28th of January 2008 a fire was reported via the emergency 111 system to the NZ Fire Service fire communications centre at 1640 DST. The origin of the fire was on the edge of the Waiomu settlement, approximately 2 km inland from the coastal road (SH25) that follows the western side of the Coromandel Peninsula. It is believed that the fire was started by a faulty fridge in a small building in the area of the fire origin (Twyford and Atkinson unpub. 2008). The fire began as the result of an electrical fault within a structure igniting the building and subsequently escaping to the nearby vegetation. The fire made a major run during the late afternoon before being contained latter that evening.

Initial attack on the 28th was started by the Tapu Volunteer Fire Brigade crew but this was soon replaced by helicopter attack. On the 29th January, three DOC crews carried out mop up of the perimeter using water from portable dams on the spur supplied by the helicopters. Many hot spots were found but there was no further spread of the fire. On the 30th January, two DOC crews continued with mop up of hotspots mostly by dry fire fighting with some use of Rega packs. A few hotspots were found throughout the day but there was no further fire spread. During the 31st January – 3 February, DOC crews continued to patrol fire line.

The following is a brief summary of events as documented in the NZ Fire Service Station Management System incident report, the Department of Conservation (DOC) fire log and the situation summary section of the Incident Action Plans.

Table 1. Summary of events on the afternoon of the 28th of January 2008.

Time (DST)	Description
1640	Smoke was reported via 111 call.
1644	Second 111 caller reports fire in the scrub.
1658	Tapu Volunteer Fire Brigade crew arrived at fire and commence fire suppression around the building where the fire had started.
1659	2nd Tapu Volunteer Fire Brigade in attendance.
1713	Tapu crews report the dwelling totally destroyed and requested Rural Fire Officer and helicopter assistance.
1719	Thames NZ Fire Service crew in attendance.
1725	2nd Thames NZ Fire Service crew in attendance.
1730	Fire reported spreading up onto and along spur.
1730	Helicopter arrives.
1735	Deputy Principal Rural Fire Officer (DPRFO) from DOC arrives to take over control of the incident.
1740	Incident Controller (IC) obtains an overview of the fire ground from a helicopter fly over. The main fire was slowing as the head fire was burning down slope into a steep gully, however a spot fire of about 50m x10m was establishing on the other side of the gully.
1830 approx.	DOC fire crew arrive and focus on air support and keeping public away from air operations.
2007	NZ Fire Service crews return to station.
2011	Three helicopters now working on fire.
2045	Incident Controller hands over control to DOC Area staff to attend another incident.
2124	Tapu Volunteer Fire Brigade stand down, leave to DOC and helicopters.
2210	Helicopters stood down, no sign of further fire spread.

Fire behaviour observations summary and fire ground map

The fire initially spread relatively slowly from the building as it burnt through long grass, until it became established in mixed kanuka/native vegetation surrounding the buildings at 1644. Once established in this vegetation, intensity started to increase and the fire spread along the northern side of the spur. At 1740 the Incident Controller obtained an overview of the fire-ground and observed that the head of the fire had reached a point (see Figure 3) where the spur starts to descend into a small steep gully (not obvious from the contours on the topo map) with an estimated flame height of 3-4 m and flame length of 6-8 m (12,776-23,879 kW/m using Byram's formula, as recommended by Pearce & Anderson 2004). The main head fire appeared to be decreasing in intensity as it descended into the small gully. The incident controller also observed a spot fire of about 50 x 50 m recently established on the other side of the gully from the main fire, approximately 600 m from the fire origin and 150 m ahead of the main head fire. This equates to an observed average rate of spread of 750 m/h from the time the fire was first reported in the scrub to the time of the aerial overview was obtained by the incident controller.

After this overview was obtained, an aggressive direct helicopter attack with three helicopters was focussed on the spot fire and also on the lower back-burning areas near the fire origin, to prevent possible rapid uphill runs though unburnt fuel parallel to the main fire run. Further spread was limited before the fire was bought under control around 2120. The total area burnt was 8.6 ha.

The backing fire heading to the southwest was observed to be burning slowly downhill and into the wind with flame lengths typically of 1 m or less, except on occasion where the fire flared and candled into the canopy of pines and kanuka. The flare-ups in this area were short-lived as the heat from them was driven back into the burnt out area by both slope and wind.

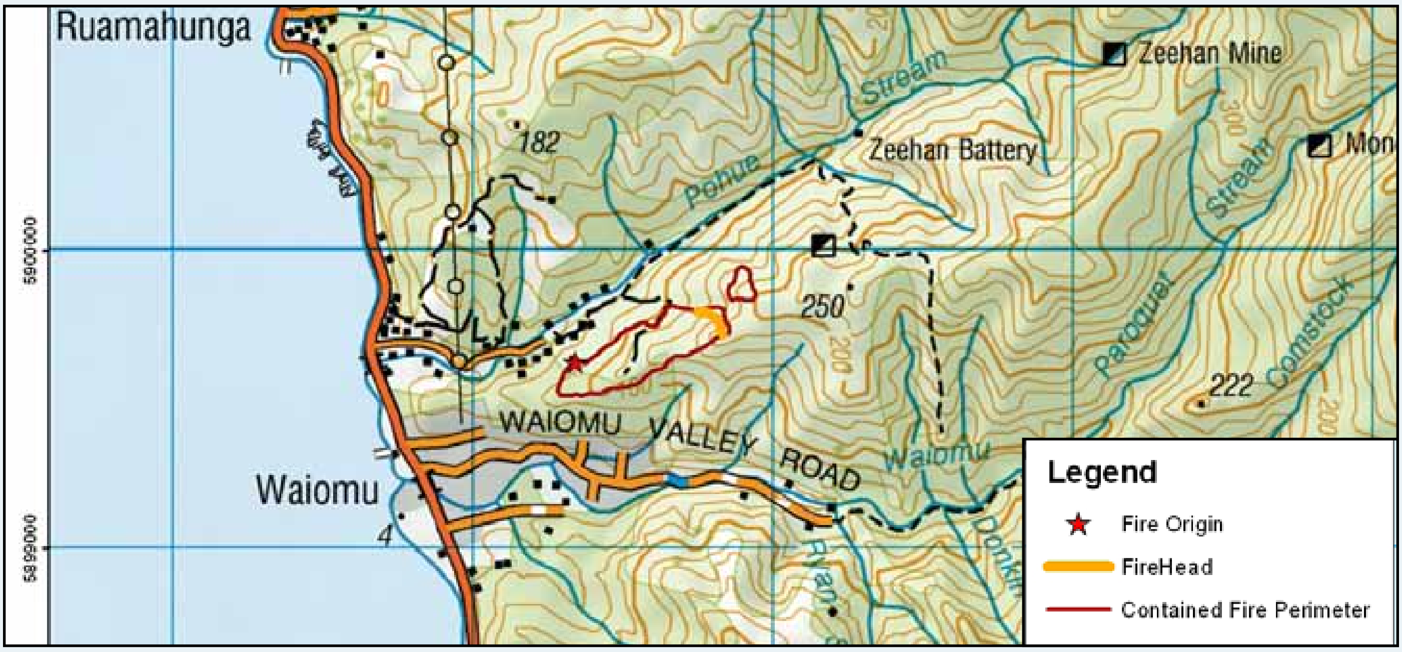
Topography

Slope

Slope steepness had a significant impact on fire spread, in either increasing (upslope) or reducing (downslope) fire spread rate, intensity and flame lengths. Slope correction factors for determining the effect of slope steepness on fire spread were obtained from Pearce and Anderson (2004).

The fire origin was mid-slope on the side of the spur with a slope averaging 16º (slope correction factor of 2.2) rising to the north-northeast for 1800 m from the fire origin with the exception of a small narrow gully not evident on the topo map. The slope leading down into this small gully was estimated to be about 10º

Figure 3. Topographic map indicating the fire's point of origin, spread to 1740h and final fire perimeter.



(slope correction factor of 0.5). Similar or slightly larger gullies are shown on the topo map at 750 m and 1300 m from the fire origin. Beyond 1800 m the spur flattens out for about 300 m before rising at 20º (slope correction factor of 2.9) for 400 m up to one of the main ridgelines of the ranges.

To the south-southeast and northwest of the spur where the main run of the fire burnt, the slope descends at as much as 30º and 20º respectively (slope correction factor of 0.25).

Aspect

North and northwest facing slopes receive greater solar radiation per unit of surface area making them warmer and drier. South facing slopes receive less solar radiation and are generally cooler and wetter. The Waiomu fire started on the side of a spur, having a north-northwest aspect, meaning the site would be warmer and drier, thus increasing the probability of ignition and resulting rate of spread and fire intensity. The head fire moved up onto, then headed up the northwest side of the spur, but there was limited spread on the right flank of the fire on the cooler, damper south side of this spur.

Elevation

This fire site was close to sea level with elevation ranging from 70 to 200 m. The hills to the east of the fire site rise up to form the Coromandel Ranges at an elevation of 600–800 m above sea level. Waiomu is situated approximately half way up the Coromandel Peninsula on the western side. At this point the peninsula is about 31 km wide. To the west of the peninsula is the Firth of Thames which is about 20 km wide. With broken land / water, the effect of sea breezes or katabatic winds is likely to be minimal, and there would be virtually no cooling or precipitation due to the low elevation at this site. Wind speeds at higher elevations are likely to have been stronger due to increased exposure, and if the fire had been allowed to travel further up the spur toward the ridgeline then this is likely to have increased rates of spread.

Shape of the terrain

The shape of terrain can significantly effect wind direction and speed. The shape of the terrain in the immediate vicinity is likely to have generally sheltered the valleys from the wind from many directions although there is also potential for the valleys to act as wind tunnels if the wind is from the right direction. Sheltering of the valleys from the wind would not only reduce the wind effect on the flame front, but is also likely to have reduced the drying effect of the wind on the vegetation in these areas prior to the fire. The Coromandel Ranges are situated to the east of Waiomu. These ranges were likely to have provided a slight rain shadow from rain coming from the east where much of the summer rain comes from (pers. obs).

Photos (Robert Anderson) showing aerial suppression and backing fire burning down hill and into the wind.

Physical barriers to fire spread

There was a 4x4 track of about 2.5 m wide up onto the spur but this was not sufficient to stop the spread of the fire as it was too narrow to be an effective fire break and there was patchy vegetation of about 0.5 m on the track that may have carried the fire. It is not known what width of fire break would have been required at this point as the intensity was not known, but based on the observed flame length of 6-8 m a fire break of 9-12 m wide would have been required using on the 1.5 times flame length rule of thumb as recommended by Pearce & Anderson (2004). There were no other barriers to fire spread within the immediate vicinity of the area burnt.

Fuels

“The ignition, build-up and behaviour of fire depends on fuels more than any other single factor” (Brown & Davis 1973). The vegetation in and surrounding the area burnt in the Waiomu fire was variable but can be described as manuka/kanuka scrub or kanuka/broadleaf-podocarp native mix. Scattered through both types of vegetation were occasional exotics such as *Pinus radiata* and *Eucalyptus* species appearing as individuals emergent above the low canopy.

Manuka/kanuka

Manuka/kanuka was dominant on top of the spur and on parts of the spur with a north or northwest aspect, and was typically about 2.5m tall. Manuka (*Leptospermum scoparium*) leaves are dotted with oil glands (Eagle 1986), and are also narrow and small in size giving them a high surface area-to-volume ratio making them burn readily and rapidly. In addition to the highly flammable leaves, manuka has stringy bark that adds to the fuel available. Supporting this, Fogarty (2001) found manuka to be the most flammable of over 40 native NZ tree and shrub species.

Kanuka (*Kunzea ericoides*) also has small leaves with high surface area-to-volume ratio. Kanuka retains considerable amounts of elevated dead fuel in the form of tiny dead branches with very low moisture retention making them highly flammable and very effective ladder fuels. These characteristics increase rate of spread and fire intensity (Wilson 1993). These small branches are used by people familiar with the bush to start fires when it is or has been raining. Fogarty (2001) found kanuka was considered to be the second most flammable native NZ shrub species.

The “Field Guide to Fire Behaviour in NZ Fuel Types” (Pearce & Anderson 2004) estimates that the fuel available to a fire from 2.5 m tall scrub is about 26 t/ha.

Photos (Robert Anderson) showing typical fuel types involved.

Kanuka/broadleaf and podocarp mix
Further away from the areas occupied by the manuka/kanuka already described, manuka was gradually replaced by broadleaf species toward the gullies and the vegetation canopy height increased from 2.5 m to 4 m (not including occasional emergent trees). Broadleaf species toward the gullies included species such as hangehange (*Geniostoma rupestre*), *Coprosma macrocarpa*, red matipo (*Myrsine australis*) and *Psudopanax* species. These or similar related species are listed in Fogarty (2001) as either low flammability or low/moderate flammability. The vegetation height increased to about 5 m in the gullies. The broadleaf species were particularly common in the understory under the taller vegetation. The low flammability broadleaf species were also more prevalent in areas where the drying effect was inhibited by topography, eg. southern aspects and lower parts of the gullies. It is also believed that tall canopy kanuka forest such as that found closer to the gullies has better moisture retention (Pearce et al. 2004) due to shading of litter and less elevated fine, dead fuel.

The “Field Guide to Fire Behaviour in NZ Fuel Types” (Pearce & Anderson 2004) estimates that the fuel available to a fire from 5 m tall scrub is approximately 33 t/ha. [NB. Fogarty & Pearce (2000) caution the use of model data for scrub fuel estimation above 3.5 m due to limited data in this range]. Available fuel load is likely to be lower where broadleaf vegetation is more prevalent, due to containing less fine dead fuel, thereby resulting in lower fire intensity than purer manuka/kanuka scrub.

Broadleaf and podocarp
Approximately 1800 m up the spur from the fire origin the vegetation changes from manuka/kanuka scrub to broadleaf/podocarp forest, where the spur enters the Coromandel Forest Park. This fuel type is much less flammable than manuka/kanuka scrub, and lower rates of fire spread and intensities would be expected. This vegetation type may not even carry fire unless extended dry periods have been experienced. Based on fuel dryness at the time of the fire (as depicted by the FWI System’s Buildup Index, BUI), the available fuel load is estimated at about 14 t/ha (Pearce & Anderson 2004).

Weather

Situation
The situation for all NZ issued at 06:19pm Monday 28-Jan-2008 showed a ridge of high pressure over the Tasman Sea extending onto northern NZ. A front moving across the lower South Island overnight was weakening as it moved north. The forecast for the following 6-12 hours was for fine weather, with light southwesterly winds of 10–15 km/h, temperature high of 23 °C and relative humidity (RH) of 55%.

Selection of RAWS and weather recordings
The nearest remote automated weather stations (RAWS) are located at Whangamata, Waikawau Bay and Whitianga. However these are on the opposite side of the Coromandel ranges to Waiomu and would be expected to be significantly different from the fire site due to the influence of these ranges on the weather. Hunua RAWS, about 45 km to the west was selected as the most representative of the fire site because it would not be as effected by the topography of the Coromandel Ranges which are likely to have provided a slight rain shadow from rain from the east as well as effecting wind. To support this theory, the Whangamata RAWS received 75.8 mm of rainfall and Hunua 19 mm in the month of January leading up to the Waiomu fire. At both stations almost all of this January rain occurred during winds from an easterly direction. The effect of the Coromandel Ranges is also reflected in the differences in wind speeds and Drought Code (DC) values at the two sites (Table 2).

In addition to the weather recordings available from the Hunua RAWS, the DOC incident log records a weather reading taken from the Staging Area at Waiomu at 2045 as “SW 15 knots (28 km/h) , RH 15%, Temp 23.5°C”. This situation where temperature (in degrees Celsius) is greater than RH is known as “crossover”, and is an indication of extreme fire behaviour potential, especially in conjunction with strong wind and/or slope. Initially the reliability of the very low RH in a coastal area was questioned; however DOC staff recall the RH being very low and RH readings as low as 11% have been recorded at Coromandel (Pearce 1996).

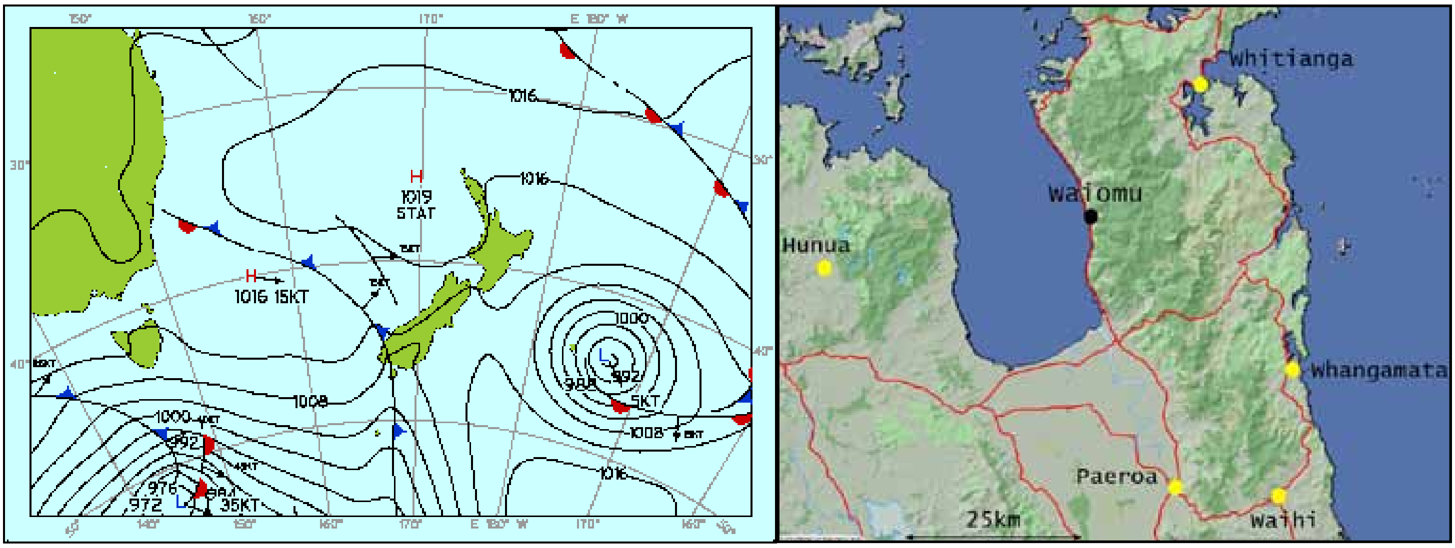


Figure 4 (left) Forecasted weather for NZ Valid at: 7:00 pm 28 Jan 2008 NZDT; (right) Location of Waiomu on the Coromandel Peninsula, also showing surrounding Remote Automatic Weather Stations.

Table 2. Daily fire weather outputs from RAWS in the vicinity of the Waiomu fire-ground.

STATION NAME	FOREST	SCRUB	GRASS	FFMC	DMC	DC	ISI	BUI	FWI	TEMP	RH	DIR	WSP	RN24	GC%
Whangamata	M	E	M	87	18	155	3.6	28	7.2	23.5	67	60	6	0.0	60
Waihi Gold	M	E	M	88	23	259	4.7	38	10.8	23.6	61	46	8	0.0	60
Whitianga Aero										24.0	64			0.0	50
Waikawau Bay	M	E	M	87	19	172	5.8	30	11.3	24.9	56	270	14	0.0	60
Paeroa	V	E	L	89	70	513	7.7	105	26.9	24.0	56	290	15	0.0	50
Hunua East	H	E	H	88	39	352	6.7	61	18.4	26.0	64	25	16	0.0	70

Table 3. Hourly fire weather recordings from the Hunua RAWS for 28th January 2008 (source: NZFS Firenet).

Time (NZST)	Temp (°C)	RH (%)	Dir (deg)	Wsp (km/h)	Rain (mm)	FFMC	ISI	FWI
12:00	26.0	64	25	16	0	84.2	4.2	12.5
13:00	27.7	41	240	7	0	85.3	3.2	10.2
14:00	25.5	51	157	6	0	85.7	3.1	10.2
15:00	25.8	40	259	12	0	86.5	4.8	14.4
16:00	26.4	35	252	12	0	87.4	5.5	16.0
17:00	24.7	38	234	18	0	88.0	7.8	20.5
18:00	22.7	48	247	15	0	88.1	6.8	18.6
19:00	20.0	59	210	12	0	88.0	5.8	16.6
20:00	18.4	69	172	8	0	87.7	4.6	13.9
21:00	17.5	77	247	7	0	87.2	4.1	12.6
22:00	17.0	80	281	1	0	86.7	2.9	9.5
23:00	15.9	85	251	6	0	86.0	3.3	10.6

Fuel moisture codes
Fine Fuel Moisture Code (FFMC) represents the moisture content of surface litter and fine dead fuels and indicates the ease of ignition and flammability of fine fuels. As with all moisture codes in the Fire Weather Index (FWI) System, higher codes indicate lower moisture levels. At the time of ignition (1640 DST = 1540 NZST), a FFMC value of 87.4 from the Hunua RAWS (Table 2) indicates that the fine fuels were dry and that ignition would be almost certain to occur if fine fuels receive firebrands, but it is below the FFMC threshold of 92 where spot fires become common (Pearce et al. 2004). However, when the FFMC is recalculated based on the noon FFMC of 86 from the day prior and the fire weather readings recorded at Waiomu (SW 28 km/h, RH 15%, Temp 23.5°C), a FFMC value of 94 is obtained, which would warn of the potential for high rates of spread and likely spot fires when the fire is moving with the slope or wind.

Duff Moisture Code (DMC) represents moisture levels in loose duff layers to moderate depth and medium-sized dead woody material, and the likelihood that these materials will burn. A DMC value of 39 is moderately high, and indicates that most of the duff layer will probably burn.

The Drought Code (DC) represents moisture levels in deep compacted organic matter layers and heavy fuels. A DC value of 352 is also moderately high, and indicates that if there are heavy fuels or subsurface fuels such as peat present some underground burning will probably occur, and increased mop-up may be required.

Fire behaviour indices
A Buildup Index (BUI) value of 61 indicates high fuel availability (Pearce et al. 2004), especially in scrub dominated vegetation where there is an absence of heavy fuels and the majority of fuels are fine or medium size classes.

An Initial Spread Index (ISI) of 7.8 from the Hunua RAWS would be associated with moderate rates of fire spread, with values of greater than 10 being considered high (Pearce et al. 2004). However when the ISI is recalculated based on the fire weather readings recorded at Waiomu (including a wind speed of 28 km/h), a value of 31 is obtained which would be associated with extremely rapid rates of spread.

At the time of the main fire run the Fire Weather Index (FWI) was 20.5 indicating moderately high potential fire intensity, however when this is adjusted using the ISI calculated from the fire ground weather readings, a FWI of 52 is achieved which is an indicator of extreme fire intensity.

The Forest and Grassland Fire Danger Classes for the day of the fire were both rated as “High”. However, the Scrubland Fire Danger Class which is more relevant to the fuel types present was “Extreme” if either the Hunua RAWS data or fire-ground observations were used, meaning that if a fire establishes a high intensity fire that is difficult to control can be expected.

Haines index
The Haines Index is a combined representation of atmospheric stability and humidity. An index value of 2 indicates stable humid air, whereas the maximum value of 6 represents unstable dry conditions. A high intensity fire is more likely to occur when uplift of heat from the fire is encouraged by already unstable atmospheric conditions. A weather report obtained on January 28th from MetConnect showed a forecasted Haines Index of 5, which indicates a moderate potential for dry unstable conditions to aid fire development.

Predicted Fire Behaviour

The influence of topography, vegetation and weather described above with the assistance of the NZ Fire Behaviour Prediction (FBP) System is used to provide the following prediction of fire behaviour.

General
High rates of spread and high fire front intensities, especially on uphill fire runs along spurs and ridges where:
- greater drying has occurred;
- higher wind speeds occur;
- vegetation/fuel is light, comprising mainly fine fuels with high amounts of dead, elevated material, i.e.

predominately manuka/kanuka;
- spot fires may occur.

See Appendix for predicted fire behaviour worksheets from the NZ Fire Behaviour Toolkit.

Specific
The head fire is expected to be fast moving and intense going up spurs or ridgelines. Flank fires will be burning down from these spurs and ridgelines, and will have lower rates of spread and intensities burning downhill and into vegetation of lower flammability, i.e. progressively less manuka/kanuka and more broadleaf species in valleys. The lower rates of spread due to the slope and lower flammability (broadleaf) fuels on the flank fires, in combination with the high length-to-breadth ratio associated with strong wind, will result in a long narrow fire following the main spur.

Backing fires are likely to be of low intensity, burning downhill and into the wind at low spread rates (<100 m/h) and with low flame lengths (<2 m). However, fire may burn slowly down and along a slope until it is below unburnt vegetation, which could result in further rapid uphill runs. Note - Broken terrain may affect wind flow and make fire behaviour vary from the predictions above.

The duff layer will probably burn in most areas, and if there are heavy woody fuels or subsurface fuels below the ground some consumption of these fuels will likely occur. This will mean that a thorough mop-up will be required.

Table 4. Summary of predicted fire behaviour from the NZ Fire Behaviour Toolkit. Also see Appendix 1 - Fire behaviour worksheet from the NZ Fire Behaviour Toolkit. Note: Required fire break effectiveness is based on rule of thumb of 1.5 x flame length as recommended by Pearce & Anderson (2004).

Fire run	Outputs	Prediction with RAWS data	Prediction with fire-ground weather
1. Manuka/kanuka scrub 2.5 m tall, 16º slope	ROS Intensity Flame length Required fire break width	3756 m/h 48,536 kW/m 11.1 m 16.7 m	10,086 m/h 130,328 kW/m 17.5 m 26.3 m
2. Broadleaf/ podocarp, 0º slope	ROS Intensity Flame length Required fire break width	19 m/h 133 kW/m 0.7 m 1.1 m	706 m/h 14,037 kW/m 3.9 m 5.9 m
3. Broadleaf/ podocarp, 20º slope	ROS Intensity Flame length Required fire break width	55 m/h 380 kW/m 1.2 m 1.8 m	2018 m/h 48,536 kW/m 6.3 m 9.5 m

Discussion

The fire weather readings from the various surrounding RAWS showed large variations. These variations can greatly effect the outputs from the NZ Fire Behaviour Prediction System which highlights the importance of selecting the RAWS data that is most relevant to the site, and not just the nearest. Although the Hunua RAWS is considered to be most relevant to Waiomu, the weather observations recorded from the site were significantly different and using this weather information in the fire behaviour predictions results in much more severe fire behaviour being predicted. This highlights the importance of monitoring and accurately recording the weather on or very near to the fire-ground. At this fire, multiple weather readings should have been recorded to ensure that accurate information was collected and used to inform the Incident Action Plan (IAP), as a single reading from one site at one time may not be representative of the weather across the fire-ground or for the duration of the main run of the fire.

The fire's observed rate of spread (ROS) estimated at 750 m/h was lower than those predicted by the NZ Fire Behaviour Toolkit (see Table 4). The possible reasons for these differences are likely to be that:

- The calculation of the observed ROS is an average that includes the fire's initial period of acceleration from a point ignition, whereas the fire behaviour predictions assume the fire spreads at its equilibrium ROS immediately from ignition. The period of acceleration before a fire reaches its maximum potential ROS for the conditions is variable, but 30 minutes or more is common, especially in medium to heavy fuels (McArthur 1968, Cheney & Gould 1997). Although the observed average ROS was 750 m/h, the fire would have initially spread more slowly and then reached speeds much greater than this at its peak.
- In general, a fire will take longer to reach its potential ROS and intensity in stronger winds (Cheney & Gould 1997).
- The width of the fire was reduced by a combination of topography and fuels. Fires with narrow heads may spread at rates well below their potential for the conditions (Cheney & Gould 1997, Anderson et al. 2008).
- The fuels through which the fire burned may have varied, both in terms of fuel type and physical properties, resulting in changes in fire behaviour that are not accounted for in individual predictions based on a single fuel type in which fuel properties are assumed to remain constant.
- Minor changes in topography (e.g. slope and aspect) have influenced the fire's ROS that are not accounted for in individual predictions based on single topographic (i.e. slope) scenarios.
- The single recorded weather reading may not have been representative of the overall fire weather on the fire-ground.
- Fire weather, particularly wind speed and direction, but also temperature and RH, are likely to have changed over the fire prediction period, resulting in changes in ROS that are not accounted for in predictions based in weather conditions assumed to remain constant over the prediction period.
- "No model can fully account for all of the variables that affect fire behaviour" (Anderson et al. 2008).

The forecast and observed fire behaviour show that the aggressive attack with multiple helicopters was justified despite the fire size being relatively small at 8.6 ha. If it was not brought under control quickly, the fire had the potential to spread rapidly toward the Coromandel Forest Park and cover a much larger area, resulting in more mop-up effort and burning a much greater area. Based on the high potential fire intensity and rapid perimeter growth rates predicted, it would have been prudent to have further aircraft on standby to assist should the fire not have been contained at or near to the small gully where the Incident Controller observed the head at 1740. If the fire was not contained at this point, the direct attack may have had to be replaced with an indirect attack.

On the 28th of January, the threat to houses on the fringes of Waiomu was limited because the head fire travelled away from the settlement driven primarily by wind and slope. The backing fire burning towards the houses on the fringes was burning down slope and into the wind and was of low intensity with a low ROS, meaning that it would have taken a long time to reach any of the houses of Waiomu and it would have been relatively easy to defend buildings if the fire reached them. However, if the fire perimeter had not been bought under control, and a change to strong north through easterly winds had occurred in the following days, then the fire could have been pushed downhill with head fire intensities that would have made defence of buildings difficult.

Direct attack with aircraft was effective despite the spread rates and intensities predicted from the average slope indicating that direct attack on the head of the fire should have been ineffective. The effectiveness of this direct attack on the head of the fire is likely to be because the direct attack was implemented as the fire intensity dropped briefly while the fire made a short downslope run into the small gully. Despite this gully being so small that it is not clear from the topographic maps of the area, it was clearly an important factor controlling this fire, showing that attention to details of the terrain can be useful in identify opportunities for effective control strategies. The difficulty in identifying or detecting these small features from a topo map highlights the value of obtaining a good overview of the fire-ground.

Spot fires are important considerations in fire suppression as they pose a risk to firefighter safety and increase the difficulty of controlling a fire. The NZ Fire Behaviour Toolkit does not currently predict spot fires or their distances. However, the combination of fuel types (manuka/kanuka scrub), high fire intensity, low RH and high FFMC (of 94) based on fire-ground weather recordings, indicate that spot fires would be likely to occur, and in this case there was a spot fire estimated a distance of 150 m upwind of the head fire. This risk of spot fires should be noted and fire crews and incident management teams should be warned of this risk.

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Fire Name Waiomu with RAWS data **Prepared by** Rory Renwick

Date 28/01/2008 5:00 p.m.

INPUTS	1	2	3
Prediction Start Time (hh:mm)	**05:00 p.m.**		
Prediction Finish Time (hh:mm)			
Dry Bulb Temp (°C)	**24.7**	**24.7**	**24.7**
Relative Humidity (%)	**38**	**38**	**38**
Wind Speed (km/h)	**15**	**12**	**12**
Wind Direction (deg)	**234**	**234**	**234**
Fine Fuel Moisture Code	**88**	**88**	**88**
Initial Spread Index [ISI]	**6.8**	**5.8**	**5.8**
BuildUp Index [BUI]	**61**	**61**	**61**
Slope (deg)	**16**	**0**	**20**
Slope Correction Factor	**2.2**	**1.0**	**2.9**
Initial Spread Distance (m)	**0.1**	**1792**	**2094**
Elapsed Time (min)	**28**	**900**	**30**
Fuel Type	**Scrub - Kanuka/Manuka**	**Podocarp/Broadleaf**	**Podocarp/Broadleaf**
Live Crown Base Height (m)			
Degree of Curing (%)			
Fuel Height (m)	**2.5**		
Cover (%)			
PRIMARY OUTPUTS			
Rate of Spread (m/h)	**3756**	**19**	**55**
Available Fuel Load (t/ha)	**26**	**14**	**14**
Head Fire Intensity (kW/m)	**48536**	**133**	**380**
Flame Length (m)	**11.1**	**0.7**	**1.2**
Type of Fire	**S**	**S**	**S**
SECONDARY OUTPUTS			
Head Spread Distance (m)	**1753**	**286**	**27**
Back Spread Distance (m)	**39**	**16**	**0**
Total Spread Distance (m)	**1792**	**2094**	**2121**
Back Rate of Spread (m/h)	**84**	**1**	**0**
Back Fire Intensity (kW/m)	**1091**	**7**	**2**
Fire Area (ha)	**65.3**	**207.1**	**212.6**
Perimeter Length (m)	**3851**	**5349**	**5419**
Perimeter Growth Rate (m/h)	**8252**	**51**	**140**
Length/Breadth Ratio	**3.9**	**1.7**	**1.7**
Warnings			

Fire Behaviour Prediction Worksheet

NZ Fire Behaviour Toolkit

Fire Name Waiomu with Field weather

Prepared by Rory Renwick

Date 28/01/2008 5:00 p.m.

INPUTS	1	2	3
Prediction Start Time (hh:mm)	**05:00 p.m.**		
Prediction Finish Time (hh:mm)			
Dry Bulb Temp (°C)	**23.5**	**23.5**	**23.5**
Relative Humidity (%)	**15**	**51**	**51**
Wind Speed (km/h)	**28**	**28**	**28**
Wind Direction (deg)	**225**	**225**	**225**
Fine Fuel Moisture Code	**94**	**94**	**94**
Initial Spread Index [ISI]	**30.7**	**30.7**	**30.7**
BuildUp Index [BUI]	**61**	**61**	**61**
Slope (deg)	**16**	**0**	**20**
Slope Correction Factor	**2.2**	**1.0**	**2.9**
Initial Spread Distance (m)	**0.1**	**1870**	**2165**
Elapsed Time (min)	**11**	**25**	**60**
Fuel Type	**Scrub - Kanuka/Manuka**	**Podocarp/Broadleaf**	**Podocarp/Broadleaf**
Live Crown Base Height (m)			
Degree of Curing (%)			
Fuel Height (m)	**2.5**		
Cover (%)			
PRIMARY OUTPUTS			
Rate of Spread (m/h)	**10086**	**706**	**2018**
Available Fuel Load (t/ha)	**26**	**14**	**14**
Head Fire Intensity (kW/m)	**130328**	**4909**	**14037**
Flame Length (m)	**17.5**	**3.9**	**6.3**
Type of Fire	**S**	**S**	**S**
SECONDARY OUTPUTS			
Head Spread Distance (m)	**1849**	**294**	**2018**
Back Spread Distance (m)	**20**	**0**	**0**
Total Spread Distance (m)	**1870**	**2165**	**4183**
Back Rate of Spread (m/h)	**111**	**1**	**0**
Back Fire Intensity (kW/m)	**1431**	**8**	**2**
Fire Area (ha)	**53.2**	**102.7**	**383.6**
Perimeter Length (m)	**3905**	**4694**	**9072**
Perimeter Growth Rate (m/h)	**21301**	**1533**	**4377**
Length/Breadth Ratio	**5.2**	**3.6**	**3.6**
Warnings			