A Fire Danger Climatology for New Zealand

A final report summarising
research completed under the project
"Fire Danger Climatology Analyses and Tools".

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Abstract/Executive Summary

- Although not having one of the worst fire climates in the world, New Zealand still experiences around 2500 vegetation fires each year that burn around 7000 ha of rural lands. Strong winds, high temperatures, low humidities and seasonal drought can combine to produce dangerous fire weather situations. To effectively manage this risk, New Zealand fire managers require a knowledge of these extremes and their likelihood of occurrence, in relation to long-term averages of fire weather and fire danger conditions.

- The principal objective of the project was to extend and improve the New Zealand fire climatology analysis undertaken by Pearce (1996). This was the first study to undertake an assessment of fire danger in New Zealand's climate regions, and summarised long-term averages and extremes of fire weather and fire danger rating system components for 20 weather station locations around New Zealand. The present study involved updating of the analysis to include more recent data (to May 2002), and extending the 1996 analysis to include data from at least 90 of the 177 weather stations contained within the National Rural Fire Authority's (NRFA) fire weather network.

- The study comprised three main steps: compilation of a database of daily fire weather records for each weather station by replacing missing or erroneous values with suitable data from appropriate substitute stations; recalculation of Fire Weather Index (FWI) System and associated fire danger class values from the completed weather input datasets; and statistical analysis of long-term average and extreme (min/max) values of weather and fire danger components for each weather station.

- In total, some 20,000 weather values were required to be substituted to complete the more than 535,000 records (1464 years) of weather and fire danger components for the 127 weather stations that had greater than 5 years of record available. The final number of stations for which datasets were completed and analysed was significantly higher than originally thought (85-100). However, the data quality issues encountered highlight a number of problems with weather station maintenance, as well as the accuracy and completeness of data contained within the NRFA's present fire weather archive.

- The principal output from the analysis is a summary table for each of the 127 stations containing the long-term average and extreme values of each of the weather and FWI System components summarised by month, fire season and year. In addition, the summary tables include fire danger class frequencies for Forest and Scrubland vegetation types, also by month, fire season and year.

- Summary statistics for each station were used to identify the individual weather stations and geographic regions with the most severe fire climates. Stations in Marlborough and Canterbury demonstrated the highest values of the three fire climate severity measures contrasted.

- The compilation of a comprehensive database of daily fire weather and fire danger information for 127 of the 179 weather stations for which data was available was the other major output from the analysis. This database is an essential component of associated research being conducted by both Forest Research and NIWA on prediction of fire season severity. In its own right, it also provides an extremely useful tool for the NRFA and fire managers in making more informed fire management decisions on prevention, preparedness, and prescribed burning activities.

- The analytical methodology used during the analysis was automated within a statistical software routine so that, in future, regular updates of the database and associated statistical analyses can be conducted more easily. It is suggested that this updating be conducted annually or, at the very least every 5 years, to maintain the accuracy and utility of the database and to minimise the workload required to repeat the analyses.

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Introduction

Although not having one of the worst fire climates in the world, New Zealand still experiences around 2500 vegetation fires each year that burn around 7000 ha of rural lands[1]. Strong winds, often associated with high temperatures, low humidities and seasonal drought, can combine to produce dangerous fire weather situations. To effectively manage this risk, New Zealand fire managers require a knowledge of these extremes and their likelihood of occurrence, in relation to long-term averages of fire weather and fire danger conditions.

A better description of New Zealand's fire climate will enable rural fire authorities, and the National Rural Fire Authority (NRFA), to increase the focus of fire prevention and mitigation activities. In particular, fire managers will be better able to predict severe fire seasons in advance so that prevention programmes and preparedness systems can be implemented in a timely and effective manner. Use of the fire danger climatology and associated analytical tools will also lead to more effective and efficient use of equipment, and ultimately a reduction in the incidence and consequences of rural fires.

Scope of the Study

The principal objective of the project was to extend and improve the New Zealand fire climatology analysis undertaken by Pearce (1996). This study was the first to undertake an assessment of fire danger in New Zealand's climate regions, and summarised long-term averages and extremes of fire weather and fire danger rating system components for 20 weather station locations throughout New Zealand. However, the complexity of New Zealand's topography results in a large number of regional and micro-climates, so that there is a need to extend this study to a greater number of locations to better understand the variability of New Zealand's fire climate. The installation of remote automatic weather stations as part of the NRFA's fire weather station network (predominantly since 1995) has also meant that the required data are now available for a much greater number (170+) of locations (see Fig. 1). In addition, these stations are located in more remote rural locations where vegetation fires are likely to occur, as opposed to populated centres (airport locations) where the majority of stations used in the earlier analysis were located. The definition of a fire danger class criteria for scrub fuels and ongoing development of models for determining the degree of curing of grasslands mean that it is now possible to conduct analyses of fire danger class frequencies for Scrubland and potentially Grassland, thereby extending the analysis of Forest fire dangers included in Pearce (1996). A further six years of data (to May 2002) was also available to update the original analyses, so that a more representative long-term dataset for the original 20 stations can now be utilised.

Background

Assessment of the effect of fire weather (and other fire environment factors of fuel and topography) on potential fire occurrence and fire behaviour is assisted by the use of the New Zealand Fire Danger Rating System (NZFDRS) (Fig. 2a), which is based on the Canadian Forest Fire Danger Rating System (CFFDRS). The NZFDRS is used by New Zealand fire authorities to assess the probability of a fire starting, spreading and doing damage. New Zealand's adoption and continued adaptation of the CFFDRS has been described by Fogarty *et al*. (1998).

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[1] From statistics produced by the NRFA based on the Annual Return of Fires form completed by New Zealand fire authorities.

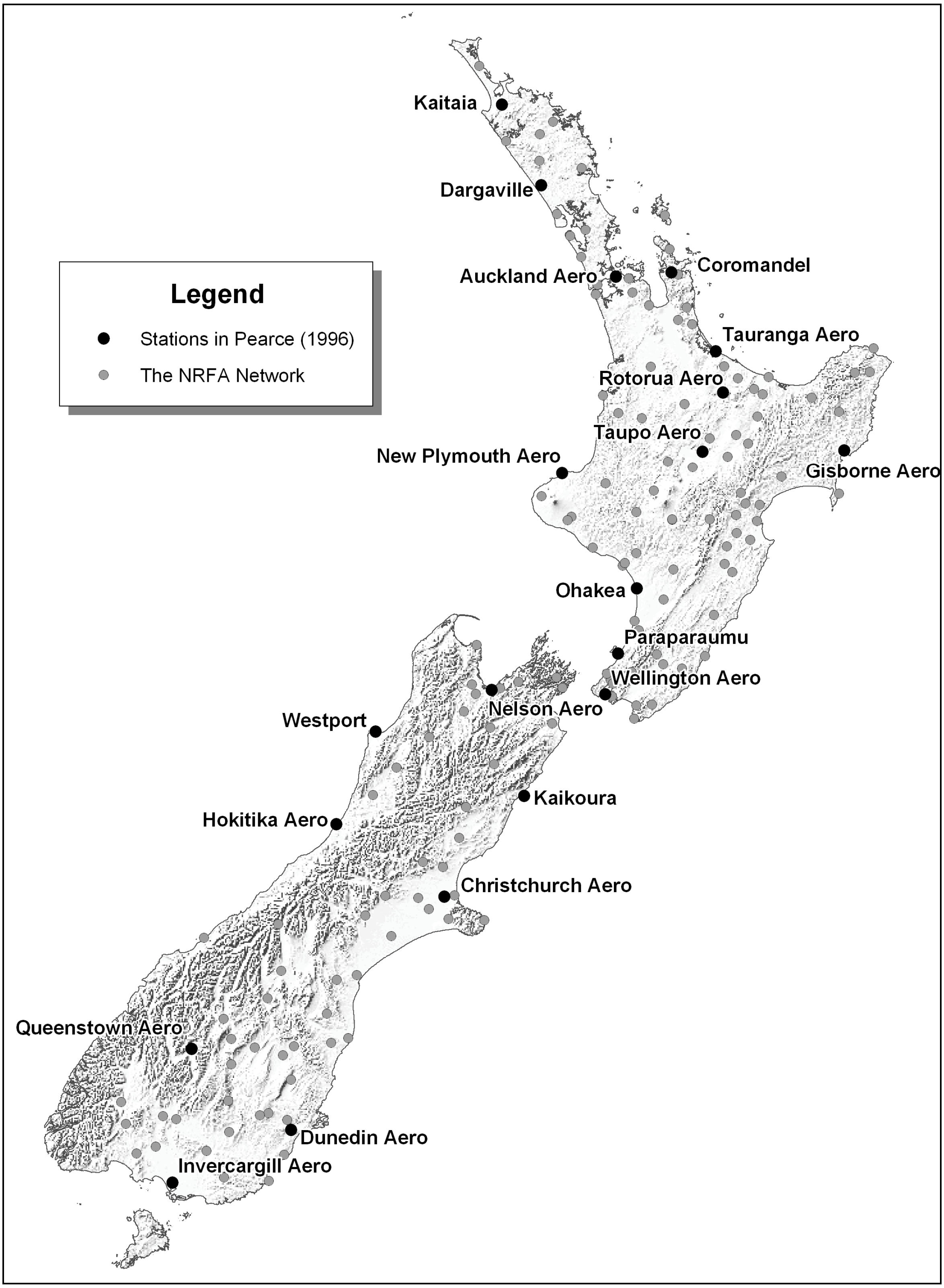

Figure 1. Weather stations (•) included in the fire danger climatology analysis of Pearce (1996), and current station coverage (•) included on the National Rural Fire Authority's (NRFA) fire weather monitoring network.

The Fire Weather Index (FWI) subsystem of the CFFDRS was adopted by the former New Zealand Forest Service in 1980. Based solely on weather observations, the FWI System (Fig. 2b) provides numerical ratings of relative ignition potential and fire behaviour which can be used as guides in a wide variety of fire management activities including (after Alexander 1992a):

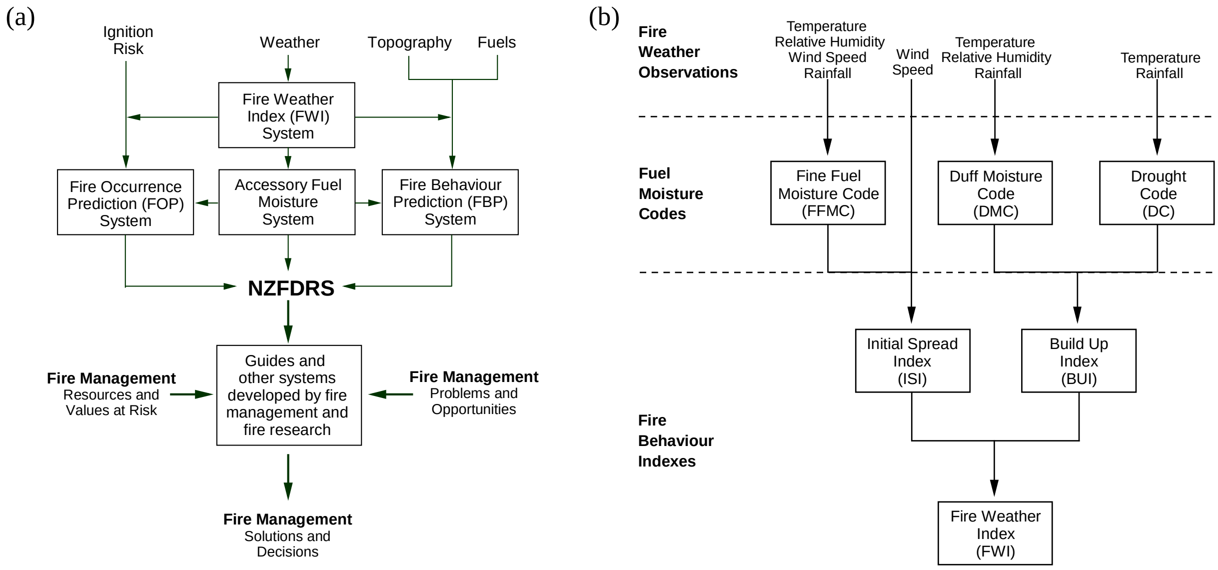

Figure 2. Simplified structure diagrams for **(a)** the New Zealand Fire Danger Rating System (NZFDRS), illustrating the linkage to fire management actions (after Fogarty *et al*. 1998); and **(b)** the Fire Weather Index (FWI) System (after Anon. 1993).

- prevention planning (e.g., informing the public of pending fire danger, regulating access and risk associated with public and industrial use of forest and rural areas);
- preparedness planning (e.g., level of readiness and prepositioning of suppression resources);
- detection planning (e.g., lookout manning and aerial patrol routing);
- initial attack dispatching;
- suppression tactics and strategies on active wildfires; and
- prescribed fire planning and execution.

Daily observations made at noon local standard time of temperature, relative humidity, wind speed, and 24-hour accumulated rainfall recorded by a network of remote automatic weather stations located around the country are used to compute values of the three fuel moisture codes and three fire behaviour indexes. These may be determined from tables (e.g., Anon. 1993) or by computer calculation (Van Wagner and Pickett 1985).

In the NZFDRS, the FWI codes and indices are also used to determine the fire danger class for Forest, Grassland and Scrubland using the criteria defined by Alexander (1994). The ISI and BUI components of the FWI System are used to determine Forest fire danger, while the Grassland criteria uses the ISI component, a standard fuel load of 3.5 t/ha and an assessment of the Degree of Curing[2] that has taken place in the grassland fuel complex. The new Scrubland model (Pearce 2001) uses the ISI and a standard fuel loading of 20 t/ha to predict fire danger class. As the ISI and BUI are based solely on weather inputs (see Fig. 2b), they can readily be calculated from historical weather data. However, the Degree of Curing must currently be supplied directly by the user, usually based on a visual estimate, although a study investigating alternative methods for determining curing over broad areas is being conducted by the fire research programme at Forest Research (Baxter and Woodward 1999, Baxter 2000). Potential relationships with FWI System fuel moisture codes (i.e., DMC, DC and/or BUI) may allow retrospective estimation of Degree of Curing and, thus, determination of the Grassland fire danger class from climatological records.

[2] The Degree of Curing represents “the proportion of cured and/or dead material in a grassland fuel complex expressed as a percentage (%) of the total” (Alexander 1994), and is used in recognition of the significant effect grass curing has on fire behaviour and, in particular, potential fire spread.

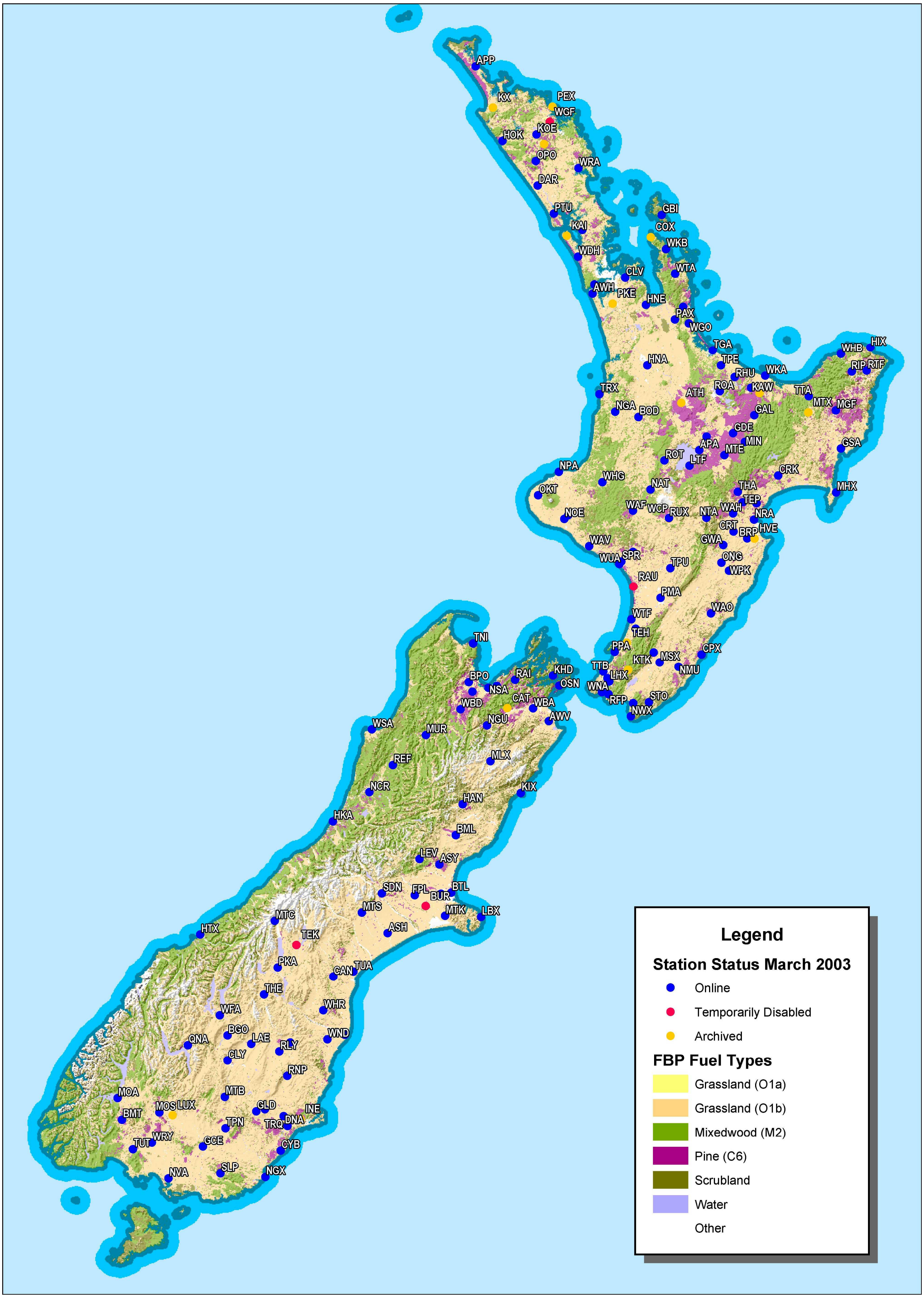

Figure 3. Network of fire weather monitoring stations administered by the National Rural Fire Authority (NRFA), including station status as at March 2003. Station names are indicated by the 3-letter codes (e.g., Le Bons Bay, LBX).

The remote automatic weather station network is at the heart of the New Zealand fire weather monitoring system run by the NRFA. At the commencement of the study this network comprised 157 weather stations, including 111 owned by rural fire authorities for which data are downloaded and archived by the NRFA, together with another 46 stations for which data were provided by the Meteorological Service of NZ Ltd (MetService) (see Fig. 3)[3]. The weather data provided by this fire weather network are used to calculate the daily FWI System components and related fire danger ratings, which are then circulated to fire authorities and the general public via the NRFA's Fire Weather Reporting System (FWSYS). Within New Zealand, there is also a more extensive weather observation network maintained by the National Institute of Water and Atmospheric Research (NIWA), that includes MetService stations plus a much greater number of stations monitoring climatic and other environmental conditions. Data from this network is archived within the National Climate Database administered by NIWA.

While production of climatological summaries for the standard weather elements are commonplace (e.g., NZMS 1983a), analyses of fire danger are much less routine (Nikleva 1973, Tapper *et al*. 1993). Despite a clear need being expressed for such analyses (Valentine 1978, p. 35, Alexander 1992b), few New Zealand examples of fire climate studies exist. In trialling the FWI System prior to its introduction, Valentine (1978) compared fire season climatologies for British Columbia and New Zealand, and Cooper and Ashley-Jones (1987) used fire danger class frequencies, determined over several fire seasons, to investigate the economics of fire prevention activities. Pearce (1996) has undertaken the most comprehensive analysis conducted to date, producing a fire climatology for 20 weather stations and presenting long term average and extreme values for both weather inputs and fire danger components in a summary table for each station. This database was extended in 1998 to investigate the potential impact of the 1997/98 El Nino event on regional fire dangers (Anon. 1998, Pearce 1998), and in 2001 to further illustrate the use of severity ratings to compare and predict fire season conditions (Majorhazi and Pearce 2001). The Pearce (1996) data was also used by Pearce and Hawke (1999) to determine the length of data record required for further fire climatology analyses and they found, like others (e.g., Simard 1972, Main *et al*. 1982), that 10 years data was sufficient for fire climatology studies. This diverges significantly from standard climatological practice, where 20 or 30 years of data is typically used to produce climate 'normals'.

Based on the example of Simard and Valenzuela (1972) from Canada, the emphasis of the Pearce (1996) analysis was on describing fire danger in various parts of the country using the climate regions of NZMS (1983b) (Fig. 4). As well as indicating seasonal trends in fire danger values, the study also enabled comparison of fire climates in different parts of the country using measures of fire season severity based on FWI (Harvey *et al*. 1986). However, it did not compare the severity of individual fire seasons for particular stations, as has been done using Monthly (MSR) and Seasonal Severity Ratings (SSR) in Canada (Stocks 1971), and no attempt was made to define fire climate regions using the FWI System as has been done in Canada (Simard 1973). Both these objectives form part of the closely aligned NZFSC-funded project undertaken by NIWA (Heydenrych *et al*. 2001, Heydenrych and Salinger 2002, Gosai *et al*. 2003). Based on the results of a pilot study (Salinger *et al*. 1999), the NIWA project aims to identify large scale global and regional climate factors influencing fire season severity as a basis for improving fire danger forecasts. As part of another NZFSC-funded project, Landcare Research (Leathwick and Briggs 2001) also used FWI data from the NRFA's fire weather network to produce fire climate layers for input into the NRFA-led New Zealand Wildfire Threat Analysis System project.

The high value of fire climatological information for fire management is evidenced by the vast number of studies and wide variety of applications illustrated in the literature. A significant

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[3] Observations from an additional 20 stations (including 14 rural fire authority and 6 MetService stations) had been discontinued for a variety of reasons (e.g., station closure or relocation), but are archived by the NRFA.

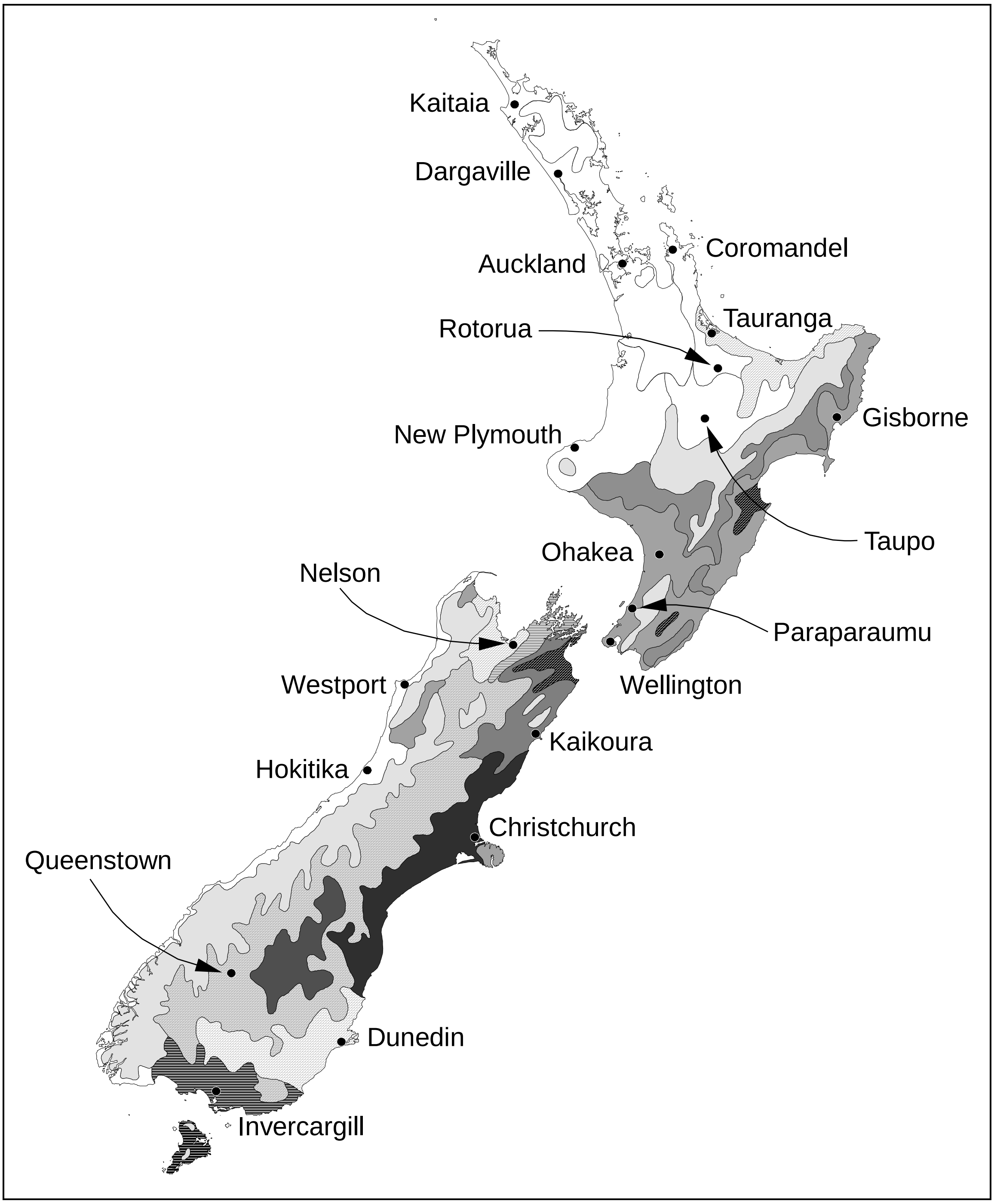

Figure 4. New Zealand climate regions (after NZMS 1983b) and weather stations included in the fire danger climatology analysis of Pearce (1996).

number of these studies have attempted to use fire climatologies to describe fire activity (Cheney 1976, Haines *et al*. 1980, Harrington *et al*. 1983). However, fire danger climatologies have also been used to illustrate seasonal trends in fire danger (McAlpine 1990), to determine length of fire season (Wotton and Flannigan 1993), and to delineate fire climate zones (Simard 1973). They have also been used to define impacts of El Nino-Southern Oscillation events (Williams 1998) and climate change (Wotton *et al*. 1998). Perhaps more importantly, fire climatologies have also been used to develop systems to assist with the full range of fire management activities, including prevention (OMNR 1989, Borger 1997), preparedness (Gray and Janz 1985, Fogarty and Smart 1994), fire suppression (Andrews *et al*. 1998, Fogarty and Slijepcevic 1998), and prescribed fire planning (Furman 1979, Andrews and Bradshaw 1990).

Pilot Study to Determine Minimum Length of Record

Early in the database compilation phase of the main study it was recognised that data quality and length of available record had the potential to limit the number of stations that could practically be included in the final analyses. The extra work required to complete station datasets because of missing and/or incomplete records meant that the effort expended on this had to be balanced against the time available to undertake the analyses. It also appeared that many of the stations had insufficient length of record to allow accurate statistical analysis, either as a result of only recently being installed or due to prolonged periods of missing data. The previous study by Pearce (1996) had indicated that, in contrast with standard climatological practice where 20 or 30 years of data is typically used to produce climate 'normals', 10 years of data was sufficient for analysis of fire danger ratings. This length of record was expected to be available for only a relatively small proportion of the stations, so that the minimum acceptable length of record and number of stations affected needed to be fully determined. A decision was therefore made to undertake an analysis to determine the impact of minimum length of record on station numbers, using weather stations from the central North Island as a case study.

Data for 26 weather stations in the central North Island region (Waikato/Bay of Plenty/Hawkes Bay) were investigated in this case study (Table 1). This included data for 20 stations from the NRFA Fire Weather archive and a further 6 Meteorological Service of New Zealand Ltd. (MetService) stations. Of the 6 MetService stations, 3 had previously been used in the Pearce

Table 1. Weather stations used in the central North Island case study.

Station Code	Station Name	Length of Record (years)	Dataset Quality (% complete)	Station Type	Source
ROA	Rotorua Aero	37	99.1	Met	Pearce (1996), Moore *et al*. (2002)
TGA	Tauranga Aero	31	100	Met	Pearce (1996), Moore *et al*. (2002)
APA	Taupo Aero	25	99.8	Met	Pearce (1996), Moore *et al*. (2002)
HNA	Hamilton Aero	10	97.7	Met	Moore *et al*. (2002)
TPE	Te Puke	10	99.9	Met	NRFA
WKA	Whakatane Aero	10	99.2	Met	Moore *et al*. (2002)
ATH	Athol	9	99.0	NRFA	Moore *et al*. (2002)
TTA	Toatoa	8	100	NRFA	Moore *et al*. (2002)
MTE	Matea	8	100	NRFA	Moore *et al*. (2002)
GDE	Goudies	8	99.9	NRFA	Moore *et al*. (2002)
HNE	Hunua East	7	83.6	NRFA	NRFA
OMT	Omataroa	7	100	NRFA	Moore *et al*. (2002)
TAH	Tahorakuri	7	89.8	NRFA	Moore *et al*. (2002)
WPK	Waipukurau	7	100	NRFA	Moore *et al*. (2002)
TEP	Te Pohue	6	98.0	NRFA	NRFA
HNW	Hunua West	5	94.6	NRFA	NRFA
KAW	Kawerau	5	100	NRFA	Moore *et al*. (2002)
GAL	Galatea	5	100	NRFA	Moore *et al*. (2002)
RHU	Rotoehu	5	100	NRFA	Moore *et al*. (2002)
THA	Te Haroto	5	97.0	NRFA	NRFA
BRP	Bridge Pa	4	99.8	NRFA	NRFA
WGO	Waihi Gold	3	99.2	NRFA	NRFA
MIN	Minginui	3	100	NRFA	NRFA
ROT	Rotoaira	3	99.9	NRFA	NRFA
LTF	Lake Taupo Forest	3	100	NRFA	NRFA
TWA	Tarawera	<1	99.0	NRFA	NRFA
Total/ Average	**26**	**8.9**	**98.3**		

(1996) fire danger climatology study and only required updating of records from December 1995 through to May 2002. The other 3 stations required compilation of all available records; however, with minimal missing data, this was readily achieved through substitution from the NIWA Climate Database. In all cases, the length of record available for these 6 stations exceeded 10 years (range 10-37 years). Of the 20 stations from the NRFA archive, datasets for 10 locations were compiled relatively easily with only minimal missing data and value correction. A dataset for a further station could be compiled despite moderate amounts of missing or incorrect data requiring substitution. One station was immediately discounted due to it being recently relocated from a previous site and only having a very short length of record (<1 year) at this new location. Three stations were discounted due to large amounts of missing or incorrect data, while a further 5 stations were considered to have insufficient length of record (only 3 or 4 years) available.

In total, 65% of the stations investigated (17 of 26) within the central North Island region had sufficient length (>5 years) and quality of record (>95% complete) for further analysis (Table 2). Of these, only 6 stations (all MetService) had greater than 10 years of record available for statistical analysis, while a further 11 stations (all NRFA) had 5-9 years of suitable record.

Assuming that the age of stations and quality of the data in other parts of the country was similar to that in the central North Island, it could therefore be expected that only 35-40 (mainly MetService) stations would have greater than the 10 years of record required to meet the recommendation of Pearce (1996). With a further 65-75 stations likely to have 5-9 years of adequate data available, it was deemed that it would be necessary to relax this minimum length of record requirement to meet the original target of 90 stations included in the study proposal. Use of a minimum length of record of 5 years would result in around 100-115 of the 177 stations for which data was available being used in the subsequent fire danger climatology analyses.

An additional 30-40 stations could also be expected to have 3-4 years of record available and potentially could also be included in statistical analyses. However, these stations were considered a lower priority than those with longer periods of record, and should only be analysed if time were available. Where possible, records for these stations (plus the 20-50 stations with incomplete datasets and/or <3 years record) should be checked and databases compiled so that they can more readily be added to for inclusion in future analyses.

In an effort to maximise the number of stations included in the current analysis, a decision was therefore made to relax the minimum length of record criteria to 5 years. Emphasis would be placed on completing the datasets for stations that met this requirement.

Table 2. Summary of data availability (quality and length of record) for weather stations used in the central North Island case study.

Length of Record (years)	**Dataset Quality (% complete)**				
	>98	**95-98**	**90-95**	**<90**	**Total**
>15	3	-	-	-	3
10-15	2	1	-	-	3
5-9	10	1	*1*	*2*	14
1-4	*5*	-	-	-	5
<1	*1*	-	-	-	1
Total	21	2	1	2	**26**

Methodology

Calculation of Fire Weather Index (FWI) System codes and indices and subsequent fire danger ratings requires a continuous daily record for each of the input weather elements. These comprise 1200 noon NZST observations of temperature, relative humidity, wind speed (and direction), and 24-hour accumulated rainfall (see Fig. 2b). This daily (and in many cases, hourly) fire weather information is recorded by the network of fire weather monitoring stations around the country which are downloaded daily and archived by the National Rural Fire Authority (NRFA). A copy of all available data from this national fire weather data archive was obtained from the NRFA in May 2002, and was combined with datasets from several other sources (e.g., Pearce 1996, Moore *et al*. 2002) to provide the starting point for compilation of a database of daily fire danger information and subsequent statistical analysis. The principal steps involved in the study were:

1. weather database compilation – data quality assessment, station selection, data accuracy checking and data substitution;
2. fire danger database creation – calculation of FWI System components and fire danger classes;
3. statistical analysis and output table production.

<u>1. Weather database compilation</u>

The database obtained through combining data from the various sources included weather datasets for a total of 179 stations (see Appendix 1). Within the NRFA fire weather archive, the required weather input data were available for 177 weather stations from the date of installation of each station up to May 2002 or, in a few cases, to the date of decommissioning of the station. Data was also available for a further two stations used in the original study by Pearce (1996) and subsequently by Moore *et al*. (2002).

Data quality assessment

One of the major issues encountered in the original study by Pearce (1996) was that of data quality, and datasets for the 179 weather stations available for the present analysis were again of considerably varying length and quality. Datasets from the NRFA fire weather archive in particular contained significant problems with missing and/or incomplete records and erroneous values. It was therefore necessary to assess the datasets for individual weather stations to determine their suitability for inclusion in the analysis.

The quality of data was determined by producing simple summary statistics for each individual station dataset. These statistics included data counts, mean, and maximum and minimum values for each of the weather elements of temperature, relative humidity, wind speed and rainfall; wind direction was not considered as it is not used in FWI calculations. Data counts, in particular, were used to determine the length of record available and general completeness of each station dataset.

Station selection

Using the methodology employed in the case study conducted on stations from the central North Island, the stations were ranked on the basis of their length of record available and completeness (quality) of this record. This was used to determine the order in which station datasets were processed. A length of record/data quality matrix was also prepared (Table 3) to identify the minimum length of record to be used and likely number of stations to be included in the subsequent analyses. Stations with the greatest length of record (more than 10 years) and highest data quality (>98%) were completed first. Subsequently, datasets for all stations with greater than 5 full calendar years of record were completed regardless of their data quality to provide an adequate number of stations.

Table 3. Summary of data availability (quality and length of record) for all fire weather stations for which data was available.

Length of Record (years)	Dataset Quality (% complete)				
	>98	95-98	90-95	<90	Total
>15	13	5	2	1	21
10-15	5	6	4	2	17
5-9	58	13	12	13	96
1-4	*27*	*8*	*2*	*3*	40
<1	*3*	-	*2*	-	5
Total	106	32	22	19	**179**

Data accuracy checking

In addition to using data counts of each of the weather elements to identify the number of individual weather values or entire daily records missing within each station dataset, station summary statistics were used to verify data accuracy. Maximum and minimum summary statistics were used to identify obvious data errors and, together with mean values, were also compared against climate normals published by the NZ MetService (i.e., NZMS 1983a) and monthly summaries produced by NIWA and MetService (e.g., NIWA 2003, MetSocNZ 2003). Clearly erroneous values were deleted for replacing with appropriate substitute data. Questionable values that could not be verified against published information were subjectively compared with data from nearby stations, and were retained if deemed to be reasonable or deleted if still considered dubious. Similarly, periods of repeated values present within many of the datasets were also deleted for substitution.

Data substitution

At the completion of the data checking phase, a list of dates for which data were missing was compiled for each weather station. The availability of data from a wide variety of sources, including appropriate[4] alternate stations within the NRFA Fire Weather archive and NIWA's National Climate Database, meant there were several options for completing these missing station records. These included, in order of preference (after Pearce 1996), substitution with values from:

(i) existing 1200h values for the selected station from the NIWA database;
(ii) where 1100h and 1300h records were available from the NIWA database for the selected station, by the averaging of these values for each of the elements;
(iii) where only one of either the 1100h or 1300h records for the selected station were available from the NIWA database, the use of the 1300h values or, if unavailable, the 1100h values;
(iv) substitution with records from an appropriate neighbouring station contained in either NIWA's Climate Database or the NRFA's Fire Weather station network, using the substitution criteria outlined in steps (i)-(iii) above;
(v) for periods of missing data of up to three days, averaging data for the preceding and following days;

[4] The "appropriateness" of adjacent stations was determined from a combination of proximity, elevation, assessment of microclimates based on the climate regions identified by NZMS (1983b) and fire climate zones recently described by NIWA (Heydenrych and Salinger 2002), and identified alternates for stations contained in the NRFA fire weather network.

(vi) in the case of temperature, use of 0800h and 1200h data from an appropriate station in the NIWA database for a period of at least a month either side of the missing data to calculate the average rate of change, and adjustment of the 0800h values by this amount; or

(vii) for relative humidity, use of 0800h and 1200h data from an appropriate station in the NIWA database for dry-bulb and dew-point temperatures to adjust 0800 hr values as above, and calculation of the estimated relative humidity from derived 1200 hr dry-bulb and dew-point temperatures.

Similarly, rainfall records available for many of the stations included in the analysis were also incomplete. As only 0800h or 0900h synoptic rainfall data is available for stations archived in NIWA's Climate Database, and averaging of data for the days before and after missing values is not valid in the case of rainfall, fewer options for completing rainfall records were available. However, there are many more stations on the NIWA network that collect rain data than are available for the other weather elements, so that the methods used, again in order of preference (after Pearce 1996), were:

(i) replacement of the original data with data for the selected station from the NIWA database, with apportionment across 24-hour periods to 1200h if possible based on preceding and subsequent days; or

(ii) substitution with records from the closest appropriate neighbouring station contained in either NIWA's Climate Database or the NRFA's Fire Weather station network.

Where suitable replacement data could not be located for a particular station, the complete year or years containing the period of missing data was removed from the final analysis. Wherever possible, all datasets were also updated to include data covering the same period up to May 2002.

2. Fire danger database creation

The completion of the data quality checking and substitution phase resulted in production of a fire weather input database for each weather station.

FWI calculation

Calculation of FWI System components for each station, using the equations of Van Wagner and Pickett (1985), was possible once this continuous record of weather inputs had been established. Where available, start-up values obtained from the original NRFA datasets were used to commence calculations. In other cases, start-up values were obtained from the most appropriate alternate station that included data for the start-up period. In many cases, it was recognised that a period of 'build-up data' prior to the start of the first full calendar year of record would be discarded from the subsequent statistical analysis. The effect of the start-up values would also be reduced by averaging of the resulting fire danger data over many years, so that while important, these start-up values were not critical to the final analysis.

Often included with commercial FWI calculation software, the Daily Severity Rating (DSR) is a numerical measure which rates the daily fire severity at a particular station based on the FWI value[5]. Severity ratings can be calculated for any desired period by simply summing the individual DSRs and then dividing by the number of days in the chosen time period, e.g., Weekly (WSR), Monthly (MSR) or Seasonal Severity Ratings (SSR) (Harvey *et al.* 1986). In

[5] Not to be confused with Days Since (Significant) Rain, the Daily Severity Rating (DSR) is determined directly from FWI and therefore relates to fire intensity. It is designed so that the impact of the FWI is reduced at low values but rises sharply as FWI increases, thus better reflecting control difficulty and the amount of work required to suppress a fire as fire intensity increases (Van Wagner 1987).

this study, as in the previous analysis of Pearce (1996), the Cumulative Daily Severity Rating (CDSR) was determined by summing the individual daily DSR values for each year of record, and these were then averaged over that period to provide an objective measure by which the severity of fire dangers at individual stations could be compared.

Fire danger class computation

Using the derived FWI values for each station, the fire danger classes for each day of record were determined by calculating the potential head fire intensity and allocation of a descriptive term to values using the fuel type criteria and intensity ranges specified by Alexander (1994):

LOW	L	≤ 10 kW/m
MODERATE	M	10 - 500 kW/m
HIGH	H	500 - 2000 kW/m
VERY HIGH	VH	2000 - 4000 kW/m
EXTREME	E	≥ 4000 kW/m

In the case of the Forest fuel type, this was carried out by inputting the calculated Initial Spread Index (ISI) and Buildup Index (BUI) components of the FWI System into the appropriate equations for fire intensity using the conifer plantation fuel model (C-6) from the Canadian Fire Behaviour Prediction (FBP) System (Forestry Canada Fire Danger Group 1992). In recent times, a new fire danger class criteria for Scrubland fuels has been produced (Anon. 2000, NZ Fire Research 2000) and subsequently refined based on the results of experimental burning trials (Pearce 2001). In this Scrubland criteria, the fire danger class is determined from the ISI component (which is itself based on Fine Fuel Moisture Code (FFMC) and wind speed) and a standard fuel load[6].

For the Grassland fuel type, fire intensity and the resultant fire danger class are determined from the ISI component, a standard fuel load[7], and an assessment of the Degree of Curing of grassland fuels, using the natural/standing grass (O-1b) fuel type from the FBP System (Forestry Canada Fire Danger Group 1992). As historical grassland Degree of Curing information was not universally available, it was not possible to calculate the Grassland fire danger class. Visual observations of grass curing have only routinely been included within the NRFA's Fire Weather archive since mid-1996 (and then not for all stations), and no curing information is available prior to this. However, methods for assessing the effect of weather and seasonal conditions on the curing of grassland areas are being investigated as part of the Fire Research programme's grassland curing project (Pairman *et al*. 1995, Baxter and Woodward 1999, Baxter 2000), and in the future it is hoped that these will enable the retrospective estimation of the Degree of Curing and determination of the Grassland fire danger class for these climatological records.

3. Statistical analysis and output table production

On completion of a database of weather inputs and FWI System codes and indices for each station, an analysis of long-term descriptive statistics was carried out using the S-Plus statistical software package (Insightful Corporation, Seattle, Washington). Statistical analysis involved calculation of monthly, seasonal and annual mean, median and extreme (maximum and minimum) values for each of the weather and fire danger components for each weather station. Computation of fire danger class frequencies for Forest and Scrubland was achieved by counting and averaging the data for each period of analysis by fire danger class. These statistics were then output as a summary table for each weather station.

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6 Assumed to be 20 t/ha for Scrubland (Pearce 2001).

7 Assumed to be 3.5 t/ha for Grassland (Alexander 1994).

Results and Discussion

Summary tables

Tabular summaries were produced for 127 of the 179 stations for which data was available, and these are contained as Appendix 2. This equated to all stations for which greater than 5 full years of record were available. The tabular summaries for each station follow the same general format as that used by Pearce (1996), with long-term average and extreme values for each of the weather and FWI System components summarised for each month, the fire season months (Oct-Apr) and year as a whole (see Fig. 5a). The summary tables also include fire danger class frequencies for both the Forest and Scrubland vegetation types, also by month, fire season and year (see Fig. 5b). As noted previously, it was not possible to determine Grassland fire danger class frequencies due to a lack of Degree of Curing information.

As in the previous analysis of Pearce (1996), it was also decided to include summaries for the 'fire season' as a distinct analysis period (*cf*. individual months and the year as a whole). Defined as the seven month period from October 1 to April 30, the 'fire season' can often provide a more meaningful indicator of the general fire climate of a region for the period when fires most commonly occur than either the annual or individual monthly values. However, in many parts of the country, fires can occur in any month of the year, and there is a danger in only considering a calendar-based 'fire season'. The production of a comprehensive fire danger database provides an opportunity to test the validity of current fire season start and end dates, and to better redefine a more appropriate period where necessary.

However, at odds with the Pearce (1996) study, the long-term average values contained for each of the weather elements and FWI System components within the summary tables are expressed as both a *median* value as well as the more common *mean* (average) value. The arithmetic mean is the average obtained by summing the individual values and dividing by the number of values, whereas the median is the middle value when data are arranged in order of magnitude (Pearce 1996). At the time, Pearce (1996) questioned the validity of using the mean as a long-term averaging measure, noting that the mean can be strongly influenced by extreme values. For this reason, 20- or 30-year periods are commonly used for the determination of climatological 'normals' (e.g., for temperature or rainfall). In addition, Van Wagner and Pickett (1985) have commented that the FWI System components (and the FWI itself, in particular) "are not considered suitable for averaging" and "the DSR is the function of FWI specifically designed for averaging". For wind speed, rainfall, and FWI System components such as the ISI and FWI, there is a much greater occurrence of low values than higher ones, so that their frequency distributions are skewed to the left; similarly, the distribution of FFMC values is skewed to the right towards higher values[8]. In these cases, the median is a more robust measure of central tendency than the mean, and this is likely to improve as the number of values (i.e., length of record) decreases. As many of the station datasets included in the study comprised less than 10 years of record, let alone 20 or 30 years, a decision was made to include the median value along with the mean for each of the weather elements and FWI System components within the summary tables in an attempt to improve the estimate of long-term averages.

Despite the shorter lengths of record and use of substitute data, the resulting summary statistics for individual stations agreed well with those found for the same stations used in the 1996 study, and also with long-term averages for the weather elements published elsewhere (NZMS 1983a, 1986). (Table 4). The addition of extra years to the length of record in the present study has

[8] Where a frequency distribution is more normally distributed (i.e., bell-shaped), as in the case of temperature or relative humidity, there is likely to be little difference between the calculated mean and median values.

Station name and code

Period of record (in full calendar years)

Length of record (in whole years)

Station Name: Christchurch Aero, CHA **Period: 1 Jan 1961 - 31 Dec 2001** **Length of Record: 41 years**

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	**YEAR**	FIRE SEASON
Temperature, degrees Celsius														
Mean	20.1	19.8	18.0	15.4	12.1	9.1	8.7	10.2	12.6	15.2	16.9	18.8	**14.7**	17.7
Median	20.0	19.0	17.7	15.0	12.0	8.9	8.0	10.0	12.0	15.0	16.1	[illegible]	**14.4**	17.2
Max	35.0	[illegible]	[illegible]	30.0	25.0	22.0	18.8	21.1	24.0	[illegible]	[illegible]	[illegible]	[illegible]	39.0
Min	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.4	2.2	[illegible]	[illegible]	[illegible]	[illegible]	2.7
Relative Humidity														
Mean	57	59	62	65	70	74	74	68	63	[illegible]	[illegible]	[illegible]	[illegible]	59
Median	58	60	63	66	70	74	74	69	63	58	57	58	**64**	60
Max	100	100	100	100	100	100	100	100	100	100	100	100	**100**	100
Min	7	12	13	19	22	21	28	20	16	13	9	12	**7**	7
Wind Speed, km/h														
Mean	22.0	20.6	19.3	17.1	15.5	13.2	14.1	16.7	19.0	[illegible]	[illegible]	[illegible]	[illegible]	20.6
Median	22.2	20.4	18.5	15.8	13.0	11.1	13.0	14.8	18.5	[illegible]	[illegible]	[illegible]	[illegible]	20.4
Max	59.3	59.3	61.1	70.4	55.6	59.0	63.0	63.0	66.7	[illegible]	[illegible]	[illegible]	[illegible]	70.4
Min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	[illegible]	[illegible]	[illegible]	[illegible]	0.0
24-hr Rainfall, millimeters														
Mean	1.4	1.4	1.8	1.8	1.8	2.0	2.5	2.0	1.4	1.4	1.6	1.4	**1.7**	1.6
Median	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**	0.0
Max	110.4	36.8	[illegible]	82.1	36.8	69.3	77.0	76.8	41.0	43.0	56.5	79.5	**110.4**	110.4
Min	0.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**	0.0
Monthly Rainfall, millimeters														
Mean	43.7	39.5	[illegible]	[illegible]	[illegible]	[illegible]	78.8	60.5	43.3	44.8	49.0	43.9	**52.4**	47.2
Max	138.9	109.9	[illegible]	[illegible]	[illegible]	[illegible]	399.6	171.0	109.2	137.8	117.5	148.7	**399.6**	196.1
Min	7.8	4.9	3.4	6.8	12.0	1.7	1.0	1.6	[illegible]	2.4	9.8	9.0	**1.0**	2.4
Seasonal Rainfall, millimeters														
Mean													**628.6**	330.3
Max													**953.4**	506.4
Min													**306.0**	157.7
Fine Fuel Moisture Code, FFMC														
Mean	81.5	80.8	77.5	75.4	70.0	64.4	63.6	69.3	[illegible]	[illegible]	[illegible]	[illegible]	**74.6**	79.0
Median	85.7	85.2	83.9	82.6	78.6	72.5	72.2	77.8	[illegible]	[illegible]	[illegible]	[illegible]	**82.0**	84.6
Max	98.1	98.1	95.2	92.9	92.5	91.4	90.5	91.7	[illegible]	[illegible]	[illegible]	[illegible]	**98.1**	98.1
Min	11.7	5.6	1.4	0.0	0.6	0.0	0.0	0.0	[illegible]	[illegible]	[illegible]	[illegible]	**0.0**	0.0
Duff Moisture Code, DMC														
Mean	34.7	40.3	28.4	22.0	11.2	4.5	3.1	5.9	11.7	19.5	25.0	30.7	**19.6**	28.6
Median	29.7	33.8	22.5	17.9	8.0	2.9	2.3	4.8	10.4	15.0	20.9	27.9	**13.5**	23.3
Max	102.7	163.6	104.8	93.8	86.6	23.1	22.0	27.3	55.2	94.7	100.7	110.3	**163.6**	163.6
Min	2.9	2.8	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.4	0.7	**0.0**	0.0
Drought Code, DC														
Mean	375.8	458.0	445.8	414.0	322.5	226.1	153.7	115.6	103.1	129.2	190.1	284.2	**267.1**	326.7
Median	377.6	450.8	436.1	416.8	308.4	218.2	120.9	90.5	72.8	98.7	178.0	274.5	**245.9**	312.1
Max	741.6	795.2	800.7	785.4	792.6	604.5	533.5	382.7	407.2	508.5	544.0	731.8	**800.7**	800.7
Min	6.0	168.9	36.4	29.9	22.8	0.7	0.1	0.0	0.7	2.2	5.8	25.5	**0.0**	2.2
Initial Spread Index, ISI														
Mean	9.4	7.8	6.7	4.6	3.1	2.0	2.0	3.1	5.2	7.3	8.8	9.3	**5.8**	7.7
Median	6.3	5.7	4.4	3.1	1.9	1.2	1.2	2.0	3.4	4.6	5.5	6.1	**3.2**	5.0
Max	105.5	116.1	124.0	59.8	39.6	84.8	50.8	56.4	92.4	126.2	120.6	144.8	**144.8**	144.8
Min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**	0.0
Buildup Index, BUI														
Mean	54.4	63.6	47.5	37.4	19.7	8.1	5.5	9.3	16.1	26.3	35.4	46.3	**30.6**	44.2
Median	48.5	56.8	39.8	31.6	14.6	5.5	4.1	7.5	14.2	21.1	31.3	43.6	**22.0**	37.6
Max	142.8	211.3	148.2	132.3	134.6	38.3	39.0	37.0	58.0	129.2	132.0	142.7	**211.3**	211.3
Min	5.5	5.5	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.9	1.3	**0.0**	0.0
Fire Weather Index, FWI														
Mean	19.7	18.8	14.2	9.7	4.6	1.9	1.5	3.3	6.9	11.4	14.9	18.2	**10.4**	15.3
Median	16.6	15.9	10.7	7.0	2.4	0.6	0.5	1.3	4.1	7.8	11.1	14.8	**5.4**	11.5
Max	121.8	122.9	115.3	67.3	59.5	65.4	24.7	37.6	77.9	130.3	102.7	130.8	**130.8**	130.8
Min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**	0.0
Daily Severity Rating, DSR														
Max	133.72	135.91	121.32	46.81	37.68	44.42	7.91	16.73	60.56	150.58	98.82	151.69	**151.69**	151.69
Monthly Severity Rating														
Mean	7.85	[illegible]	[illegible]	[illegible]	0.90	0.26	0.16	0.49	1.65	3.66	5.36	7.09	**3.53**	5.56
Max	24.64	[illegible]	[illegible]	[illegible]	3.55	2.68	0.74	1.86	8.06	26.53	18.50	18.78	**27.07**	27.07
Min	1.60	[illegible]	[illegible]	[illegible]	0.01	0.01	0.00	0.04	0.04	0.19	1.00	0.31	**0.00**	0.19
Cumulative Daily Severity Rating, CDSR														
Mean													**1299.55**	1194.01
Max													**2894.70**	2849.74
Min													**406.49**	384.68

Long-term average and extreme values for <u>individual months</u>

Long-term average and extreme values for <u>all months</u> of the year

Long-term average and extreme values for <u>"fire season" months</u> (Oct-Apr)

Long-term average and extreme values for <u>daily (24-hr) rainfall</u>

Long-term averages and extremes for <u>monthly rainfall totals</u>

Long-term average and extremes for <u>annual and fire season rainfall totals</u>

Long-term maximums for <u>individual daily DSR</u> values

Long-term averages and extremes for <u>MSR (monthly averages</u> of DSR values)

Long-term averages and extremes for <u>CDSR (cumulative DSR values</u> totaled) for all or fire season months

Figure 5a. Example of summary output table containing summary statistics for weather elements and FWI System components, with descriptive comments on statistics and format.

Station name and code

Period of record (in full calendar years)

Length of record (in whole years)

Station Name: Christchurch Aero, CHA **Period: 1 Jan 1961 - 31 Dec 2001** **Length of Record: 41 years**

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	**YEAR**	FIRE SEASON
Forest Fire Danger Class (FFDC) Frequency														
Low														
Mean	5.0	4.6	9.7	12.0	21.5	27.5	30.0	25.6	18.0	12.8	8.0	6.7	**181.3**	58.8
Max	14	13	26	28	31	30	31	31	30	30	19	26	**234**	91
Min	0	[illegible]	0	0	12	11	21	12	0	0	0	0	**122**	21
Moderate														
Mean	9.9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.1	9.6	11.9	12.1	9.9	**102.6**	76.4
Max	19	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	19	19	19	20	20	**148**	101
Min	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0	1	5	4	**69**	48
High														
Mean	7.5	6.9	5.4	3.5	1.0	0.2	0.0	0.2	1.8	3.8	5.2	6.7	**42.3**	39.1
Max	15	12	14	10	6	4	1	3	10	9	14	13	**70**	63
Min	2	1	0	0	0	0	0	0	0	0	0	[illegible]	**18**	18
Very High														
Mean	3.5	3.0	2.1	1.0	0.2	0.0	0.0	0.0	0.4	[illegible]	[illegible]	[illegible]	[illegible]	16.6
Max	7	8	7	5	2	0	0	0	3	[illegible]	[illegible]	[illegible]	[illegible]	32
Min	0	0	0	0	0	0	0	0	0	[illegible]	[illegible]	[illegible]	**6**	6
Extreme														
Mean	5.0	3.9	3.1	1.2	0.2	0.0	0.0	0.0	0.2	1.4	2.3	4.3	**21.8**	21.4
Max	19	18	13	9	2	0	0	0	4	19	13	18	**56**	56
Min	0	0	0	0	0	0	0	0	0	0	0	0	**4**	4
Scrub Fire Danger Class (SFDC) Frequency														
Low														
Mean	2.4	2.5	4.2	4.6	7.3	9.8	10.6	7.6	5.2	4.0	3.6	3.0	**64.9**	24.3
Max	7	6	12	12	18	21	20	18	17	10	9	8	**91**	36
Min	0	0	0	0	1	0	0	0	0	0	0	0	**40**	12
Moderate														
Mean	0.0	0.0	0.0	0.1	0.1	0.2	0.1	0.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.1
Max	0	0	0	2	1	1	2	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2
Min	0	0	0	0	0	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0
High														
Mean	0.8	0.8	1.9	2.2	3.8	6.1	5.3	4.1	1.9	1.4	1.3	1.1	**30.8**	9.6
Max	3	3	5	6	8	12	12	8	5	5	5	6	**50**	18
Min	0	0	0	0	0	2	1	0	0	0	0	0	**20**	4
Very High														
Mean	1.9	1.5	2.6	3.6	5.3	5.1	6.0	4.3	3.4	2.5	2.3	2.0	**40.4**	16.4
Max	6	4	7	10	10	9	12	8	7	6	7	6	**53**	27
Min	0	0	0	0	1	1	0	0	0	0	0	0	**28**	10
Extreme														
Mean	25.9	23.4	22.3	19.5	14.4	8.8	9.0	15.0	19.5	23.1	22.8	24.8	**228.5**	161.9
Max	31	27	30	28	22	21	19	27	30	31	28	31	**272**	185
Min	18	19	12	9	4	1	1	6	8	15	16	14	**188**	142

Long-term average and extreme counts (frequencies) for each fire danger class for individual months

Long-term average and extreme counts for all months of the year

Long-term average and extreme counts for "fire season" months (Oct-Apr)

Figure 5b. Example of summary output table containing summary statistics for Forest and Scrubland fire danger class frequencies, with descriptive comments on statistics and format.

resulted in some minor changes to annual rainfall totals, CDSR and the combined number of days of Very High and Extreme Forest fire danger (VH+E FFDC) over those produced in the Pearce (1996) study; however, maximum temperature values were unchanged. In spite of the different observation times for fire danger rating (1200h NZST) and synoptic climatological reporting (0800/0900h NZST), the differences in maximum recorded temperatures and annual rainfall totals between both previous studies and published long-term climate normals (NZMS 1983a, 1986) are also not significant.

Length of record

The 127 stations for which datasets were summarised included 21 stations with records exceeding 15 years, 17 stations with 10-15 years of record, and a further 86 stations with 5-9 years of record. As such, the number of stations completed represents a significant increase over the number (85-105) estimated based on the central North Island case study. However, it is less than the number of stations indicated by the data availability (length of record and data quality) survey completed during the early part of the study (see Table 3). This indicated that datasets for 134 stations with greater than 5 years of record could potentially be completed. This difference is partly as a consequence of increased periods of missing or erroneous data becoming apparent for several stations during the database compilation, resulting in one or more complete years being omitted from the analysis. Similarly, the limitation of the resulting FWI datasets to only include complete calendar years resulted in several stations failing to have 5 or more full years of record.

Table 4. Comparison of selected summary statistics between the present study, the 1996 analysis (Pearce 1996) and published climate normals (NZMS 1983a, 1986).

Station	Name	Length of Record (years)			Annual Rainfall (mm)			Max Temp. (°C)			CDSR		VH+E FFDC (days)	
		Present Study	1996 Study	Climate Normals	Present Study	1996 Study	Climate Normals	Present Study	1996 Study	Climate Normals	Present Study	1996 Study	Present Study	1996 Study
KX	Kaitaia	39	33	32	1361	1356	1418	29.0	29.0	30.5	403	428	8.9	10.0
DAR	Dargaville	23	17	38	1176	1177	1248	27.8	27.8	32.1	199	188	1.9	2.2
AKL	Auckland	35	29	19	1109	1106	1150	28.0	28.0	28.9	418	413	7.6	7.8
COR	Coromandel	21	17	19	1916	1860	1904	29.0	29.0	28.4	212	204	1.5	1.1
ROA	Rotorua	37	31	18	1432	1428	1491	29.0	29.0	29.8	223	226	2.0	2.1
NPA	New Plymouth	26	20	37	1435	1433	1529	26.0	26.0	30.3	172	89	1.4	0.0
TGA	Tauranga	31	25	68	1214	1233	1349	29.0	29.0	33.3	398	369	7.5	6.6
NSA	Nelson	39	33	40	1022	979	986	33.0	33.0	36.3	520	519	10.1	10.1
APA	Taupo	25	19	32	992	1003	1178	30.0	30.0	33.0	228	224	3.0	2.9
GSA	Gisborne	39	33	44	1012	1009	1058	37.0	37.0	38.1	1029	1046	32.5	33.1
KIX	Kaikoura	37	31	32	824	839	888	31.0	31.0	33.0	429	392	5.5	4.3
OHA	Ohakea	32	32	41	912	912	916	30.0	30.0	31.1	592	601	13.3	13.7
PPA	Paraparaumu	39	33	36	1024	1031	1054	28.0	28.0	29.4	307	310	3.6	3.9
WNA	Wellington	41	35	21	997	1011	1240	29.0	29.0	31.1	888	881	18.7	17.6
WSA	Westport	31	26	37	2224	2274	2192	26.0	26.0	28.6	58	61	0.0	0.0
HKA	Hokitika	37	31	18	2852	2843	2783	29.0	29.0	27.5	43	43	0.0	0.0
CHA	Christchurch	41	35	38	629	620	666	39.0	39.0	41.6	1300	1282	39.0	39.1
QNA	Queenstown	23	17	13	827	783	805	27.0	27.0	34.1	328	293	6.0	4.6
DNA	Dunedin	38	32	19	700	683	659	33.0	33.0	34.5	485	495	7.3	7.6
NVA	Invercargill	41	35	42	1093	1093	1037	29.0	29.0	32.2	157	159	0.5	0.3

Notes:

1. Max T = maximum recorded daily temperature; CDSR = Cumulative Daily Severity Rating; VH + E FFDC = combined number of days of VERY HIGH and EXTREME Forest fire danger.
2. The 1996 and present studies use 1200h NZST observations *cf.* climate normals based on 0800/0900h NZST synoptic observations.

It was also due in part to the duplication of station locations, as in the case of Dargaville (DAR and DV), Waiouru (RUX and WCP), Molesworth (MLX and MOL) and Lauder (LAE and LAU), where the records were combined to produce a single dataset in each case. Four stations were eliminated from the analysis as a result of this duplication, and KAW and TWA, which are in fact the same station following a recent relocation, could also potentially be combined, although TWA was not considered here due to having less than 1 complete year of record.

Data quality

Significant problems were encountered during the study with incomplete and/or erroneous data. During the database compilation phase, in excess of 20,000 records were substituted to complete the more than 535,000 records (1464 years) of weather (and resulting fire danger components) for the 127 weather station datasets. On average, these datasets were 94% complete (see Appendix 1), which was very close to the data quality of all 177 stations for which data was originally available. However, this data quality estimate does not include the erroneous or repeated values which were subsequently found to require substitution. The average length of record for the 127 stations analysed was 11.5 years (see Appendix 1), compared with 8.9 years for all 179 stations for which data were originally available.

Particular data quality issues found within the NRFA's Fire Weather archive included missing data, incomplete records and erroneous values for both weather input data and derived fire danger ratings. These data quality issues could not be attributed to a single problem, but occurred as a result of a variety of factors including faulty sensors and/or dataloggers, communication problems associated with data downloading, and database management and archiving. In most cases, problems with missing weather data could be relatively easily rectified through substitution from alternative stations; however, this is time consuming and not always practicable due to station availability, proximity, elevation and microclimate differences between stations, and prolonged periods of missing data. In the case of erroneous weather values, the data recorded was typically incorrect either as a result of the recording of an incorrect value (unreasonably high/low values, e.g., temperatures of +60°C or -20°C, or -2°C at 1200 noon in midsummer) or an error flag (e.g., -6999) or, in some cases, recording of data in the incorrect column (e.g., swapping of wind speed and direction, or FWI values being transposed into weather data columns). In many cases, it also appeared that starting values for the first day of operation of a station had been extended for a prolonged period for whatever reason, so that in some cases the data record showed in excess of 6 months of repeated values. This particular problem seemed to affect a large number of stations in the Fire Weather archive. When it was rectified, the actual period of record for which accurate data was available was often significantly shorter than at first thought. In addition, several stations had insufficient length of record (i.e., less than 5 years) to allow accurate statistical analysis, either as a result of only recently being installed or due to prolonged periods of missing weather data. Derived FWI values also contained similar problems with repeated records, significant periods of non-calculation (recorded as zeros or left blank), and subsequent restarting of calculations using new start-up values.

The need to more closely scrutinise the NRFA's Fire Weather archive datasets as a result of these data quality issues added significantly to the workload associated with this database compilation phase. This issue of data quality within the NRFA archive also needs to be carefully considered in any current or future applications that utilise this database, such as the NRFA's own Fire Weather Monitoring System (FWSYS) or NZ Wildfire Threat Analysis System (WTAS). Improved methods of error flagging and alternate data substitution within the NRFA's FWSYS are therefore required to reduce these problems in future.

Statistical analysis

Once the data quality and substitution issues were overcome, the creation of the fire danger database from the resulting weather datasets and subsequent statistical analysis phases of the study were completed relatively easily. The analytical methodology used during the statistical analysis was automated within a statistical software package (S-Plus) so that regular updates of the database and associated statistical analyses can be conducted more easily in future. It is suggested that this updating be conducted annually or, at the very least every 5 years, to maintain the accuracy and utility of the database, and to minimise the workload required to repeat the analyses. With 17 of the stations included in the present study comprising 4 years of record (and an additional 11 having 3 years of record) to December 2001, significant potential already exists to extend the analysis by simply bringing the datasets up to date (to May 2003). This increasing data availability, combined with new stations being added to the network each year, provides further incentive for regularly updating the database and repeating this analysis.

Application of the fire climatology - comparison of fire climate severity

The study by Pearce (1996) included a comparison of the relative severity of fire climates in different parts of the country, based on two measures of severity determined from station summary statistics – the Cumulative Daily Severity Rating (CDSR) (Harvey *et al*. 1986) and combined frequency of days falling into the VERY HIGH and EXTREME fire danger classes for Forest (VH+E FFDC) (after Alexander 1994). Although limited to 20 stations, this comparison provided significant insight into the extremes of fire danger experienced at these locations.

Along similar lines, the summary statistics for each of 127 stations included in the present analysis were used to identify the individual weather stations and geographic regions with the most severe fire climates. In addition to using the CDSR and VH+E FFDC severity measures, the comparison also included the combined frequency of days of VERY HIGH and EXTREME fire danger for Scrubland (VH+E SFDC) as a third measure of fire severity. Each station was ranked using each of these three measures separately, and then the rankings for each station were averaged to determine an overall measure of fire climate severity. The results of this analysis are included as Tables 5-7.

Table 5 contains the severity rankings for individual stations, and lists Awatere Valley (AWV), Woodbourne Aero (Blenheim) (WBA) and Molesworth (MLX/MOL) in Marlborough as three of the 5 stations with the most severe fire climates. Christchurch Aero (CHA) and Castle Point (CPX) were the other two stations in the top 5, the latter more as a result of the windiness of the site compared to seasonal dryness as the principal factor at the other locations[9]. At the other end of the scale, the 7 stations with the least severe fire climates included Opouteke (OPO) in Northland, Marco (WHG) in Taranaki, Athol (ATH) in the Waikato, Waimarino Forest (WAF) in Wanganui/Manawatu, and all three stations – Westport (WSA), Hokitika Aero (HKA) and Haast (HTX) – from the South Island's West Coast. In general, these stations are also characterised by the highest annual rainfalls.

Similarly, Table 6 contains the severity rankings for individual stations grouped on a regional basis, illustrating the wide range in severity that exists among stations from the same geographic regions. For example, the severity rankings for Waitangi Forest (WGF) in Northland rank it in the top 20 most severe locations in the country, whereas Opouteke (OPO) less than 50 km away ranks in the bottom 10 stations. This demonstrates the significant microclimatic variability that exists within each region of the country, and across New Zealand as a whole.

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[9] High DSR values, and hence high CDSR, can result from high temperature, low relative humidity, strong winds and/or seasonal dryness, as represented by the individual and combined influences of these weather elements on the FWI System fuel moisture codes and fire behaviour indexes (Majorhazi and Pearce 2001).

Table 5. Ranking of fire climate severity for individual stations included in the fire climatology analysis, based on the average of rankings for long-term average Cumulative Daily Severity Rating (CDSR), and days of VERY HIGH and EXTREME (VH+E) fire danger class for Forest (FFDC) and Scrubland (SFDC). The length of record (years) and annual rainfall (mm) for each station are also included for comparative purposes.

No.	Station	Region	Length of Record (years)	CDSR	VH+E FFDC (days)	VH+E SFDC (days)	Annual Rainfall (mm)	Rank CDSR	Rank FFDC	Rank SFDC	Average Rank
1	AWV	Marlborough	7	1770	49.4	293.6	583	3	1	1	1.7
2	WBA	Marlborough	10	1491	41.7	275.6	792	4	4	2	3.3
3	CHA	Canterbury	41	1300	39	268.9	629	7	5	5	5.7
4	MLX/MOL	Marlborough	5	1103	42.6	261.2	611	13	3	10	8.7
5	CPX	Wairarapa	10	2166	21.5	257.6	1016	1	16	12	9.7
6	DNP	Otago	7	1265	35.8	255.3	555	8	6	16	10.0
7	NRA	Eastern	10	1048	29.4	269.7	907	14	13	4	10.3
8	GSA	Eastern	39	1029	32.5	268.1	1012	15	11	6	10.7
9	BML	Canterbury	7	1416	49.4	247.6	542	6	1	25	10.7
10	FPL	Canterbury	8	1187	30.5	256.6	661	11	12	14	12.3
11	WNA	Wellington	41	888	18.7	273.8	997	20	20	3	14.3
12	RNP	Otago	5	1774	33	239.8	518	2	10	34	15.3
13	THE	South Cant'y	10	1235	35.8	237.9	533	10	6	36	17.3
14	WFA	Otago	7	1004	33.6	241.7	778	16	8	29	17.7
15	LAE/LAU	Otago	6	1485	33.6	232.7	463	5	8	45	19.3
16	WPK	Eastern	7	817	26.6	248.4	751	22	14	24	20.0
17	PMA	Wang/Man	5	619	16.6	258.6	858	30	21	11	20.7
18	OHA	Wang/Man	32	592	13.3	268.1	912	31	28	6	21.7
19	WGF	Northland	8	534	11.8	267.2	1342	35	33	8	25.3
20	NWX	Wairarapa	7	954	23	231.7	1092	19	15	48	27.3
21	THA	Eastern	5	725	20.4	235.2	900	25	18	40	27.7
22	WKA	CNI	10	480	11.4	257.1	1338	42	34	13	29.7
23	CRK	Eastern	5	635	15.2	236.4	1135	27	24	38	29.7
24	TUA	South Cant'y	10	591	12	245.4	770	32	32	27	30.3
25	LBX	Canterbury	7	987	10.5	236	810	17	37	39	31.0
26	KWK	Eastern	7	744	16.4	231.3	1172	24	22	49	31.7
27	BUR	Canterbury	5	763	15.4	230.8	612	23	23	51	32.3
28	NMU	Wairarapa	8	644	20.1	228.1	1061	26	19	53	32.7
29	NSA	Nelson	39	520	10.1	248.5	1022	38	38	23	33.0
30	HAN	Canterbury	5	834	21	220.2	915	21	17	62	33.3

No.	Station	Region	Length of Record (years)	CDSR	VH+E FFDC (days)	VH+E SFDC (days)	Annual Rainfall (mm)	Rank CDSR	Rank FFDC	Rank SFDC	Average Rank
31	SDN	Canterbury	8	960	15	222.3	1056	18	25	58	33.7
32	PTU	Northland	8	448	9	250.4	1223	44	41	21	35.3
33	KX	Northland	39	403	8.9	255.2	1361	52	43	17	37.3
34	MSX	Wairarapa	10	564	14.4	226.3	1072	33	26	54	37.7
35	WAH	Eastern	6	558	12.3	231.3	1085	34	31	49	38.0
36	MHX	Eastern	7	431	9.2	241.7	1096	46	40	29	38.3
37	BTL	Canterbury	8	522	10.9	232.8	520	37	36	44	39.0
38	AKL	Auckland	35	418	7.6	250.1	1109	50	46	22	39.3
39	TGA	CNI	31	398	7.5	253.8	1214	54	47	18	39.7
40	HIX	Eastern	7	403	6.1	256.1	1528	53	51	15	39.7
41	MOS	Southland	5	1114	11.2	210.2	854	12	35	74	40.3
42	DNA	Otago	38	485	7.3	240.5	700	41	49	32	40.7
43	NTA	Wang/Man	8	634	13.2	216.1	918	28	29	67	41.3
44	KAW	CNI	5	420	7.4	241.6	1485	49	48	31	42.7
45	KIX	Marlborough	37	429	5.5	246.6	824	47	56	26	43.0
46	LIS	Wang/Man	5	440	6.4	238.2	931	45	50	35	43.3
47	ASH	Canterbury	7	523	12.8	218.5	697	36	30	65	43.7
48	TRQ	Otago	8	619	5.5	232.3	660	29	56	47	44.0
49	RHU	CNI	5	467	9.8	229	1646	43	39	52	44.7
50	APP	Northland	7	359	5.2	252.9	1243	58	61	19	46.0
51	ASY	Canterbury	8	511	13.4	208.3	966	39	27	76	47.3
52	PPA	Wellington	39	307	3.6	263	1024	65	73	9	49.0
53	WRA	Northland	10	299	4.1	240.3	1349	68	68	33	56.3
54	WUA	Wang/Man	23	309	2.9	242.7	1099	64	78	28	56.7
55	QNA	Otago	23	328	6	221	827	63	53	60	58.7
56	OUA	South Cant'y	10	296	4.4	232.6	804	70	63	46	59.7
57	STO	Wairarapa	6	381	8.3	203	1238	55	44	80	59.7
58	TNI	Nelson	8	1259	3	191.4	1671	9	75	95	59.7
59	TEP	Eastern	6	370	8.1	202.5	1436	56	45	83	61.3
60	BMT	Southland	8	494	5.1	202.6	1099	40	62	82	61.3

No.	Station	Region	Length of Record (years)	CDSR	VH+E FFDC (days)	VH+E SFDC (days)	Annual Rainfall (mm)	Rank CDSR	Rank FFDC	Rank SFDC	Average Rank
61	GAL	CNI	5	410	9	192.2	1250	51	41	93	61.7
62	CAN	South Cant'y	7	424	6.1	196.9	559	48	51	87	62.0
63	HIR	Nelson	8	333	6	204.2	1185	59	53	79	63.7
64	RFP	Wellington	7	329	4	218.9	1336	61	69	63	64.3
65	RAU	Wang/Man	6	252	1	251.9	811	77	98	20	65.0
66	RTF	Eastern	7	302	3.9	221.3	2417	66	71	59	65.3
67	WAO	Wang/Man	6	328	4.4	214.2	920	62	63	71	65.3
68	INE	Otago	5	331	3	218.4	763	60	75	66	67.0
69	WRY	Southland	7	368	5.4	199	829	57	58	86	67.0
70	WDH	Auckland	5	250	5.2	218.6	1215	79	59	64	67.3
71	APA	CNI	25	228	3	233.9	992	85	75	43	67.7
72	GDE	CNI	8	292	4.3	213.8	1316	71	66	72	69.7
73	ROA	CNI	37	223	2	235.2	1432	86	86	41	71.0
74	WTA	Waikato	10	253	2.3	223.4	1904	75	81	57	71.0
75	TPU	Wang/Man	5	283	4.2	205.6	881	72	67	77	72.0
76	CLV	Auckland	7	269	3.4	213.2	1257	74	74	73	73.7
77	CDT	Auckland	8	296	2	216.1	1317	69	86	67	74.0
78	PAX	Waikato	10	252	2.8	215.9	1351	76	80	69	75.0
79	WAX	Wellington	6	215	0.8	237	922	90	99	37	75.3
80	RAI	Marlborough	5	302	4.4	190.6	2041	67	63	96	75.3
81	COR	Waikato	21	212	1.5	233.9	1916	92	94	42	76.0
82	HNA	Waikato	10	238	2.9	208.7	1400	82	78	75	78.3
83	NOE	Taranaki	10	215	1.9	220.9	1159	91	88	61	80.0
84	KHD	Marlborough	8	239	2.2	205.4	1579	81	82	78	80.3
85	MGF	Eastern	7	251	5.8	172.2	1349	78	55	108	80.3
86	HAU	Wairarapa	6	269	3.8	186.2	1360	73	72	99	81.3
87	KAI	Northland	5	215	5.2	177.4	1305	89	59	105	84.3
88	NPA	Taranaki	26	172	1.4	224.1	1435	102	96	56	84.7
89	MTE	CNI	8	223	4	186.1	1513	87	69	101	85.7
90	KOE	Northland	7	172	0.8	224.3	1457	103	103	55	87.0

No.	Station	Region	Length of Record (years)	CDSR	VH+E FFDC (days)	VH+E SFDC (days)	Annual Rainfall (mm)	Rank CDSR	Rank FFDC	Rank SFDC	Average Rank
91	OSN	Marlborough	8	232	2.2	190.6	1277	84	82	96	87.3
92	OKT	Taranaki	5	209	0.8	214.6	1552	94	99	70	87.7
93	DAR/DV	Northland	23	199	1.9	201.7	1176	95	88	84	89.0
94	HWT	Wairarapa	7	236	2.2	180.8	1655	83	85	103	90.3
95	GCE	Southland	10	217	1.5	193.1	882	88	94	90	90.7
96	DOV	Nelson	8	194	1.6	200.1	1141	96	93	85	91.3
97	LUX	Southland	10	240	1.9	160.6	1279	80	88	113	93.7
98	CYB	Otago	7	176	1.3	192.1	729	100	97	94	97.0
99	TAH	CNI	7	174	0.7	194.3	1278	101	105	88	98.0
100	OMT	CNI	7	180	0.4	193.8	1740	97	110	89	98.7
101	RIP	Eastern	7	210	0.3	192.9	3189	93	113	91	99.0
102	TPN	Otago	7	152	2.2	163.9	781	109	82	111	100.7
103	SLP	Southland	7	180	1.9	156.6	1273	98	91	115	101.3
104	WAV	Taranaki	6	124	0.2	202.9	1056	113	115	81	103.0
105	HNW	Auckland	5	165	0.8	177	1200	105	99	106	103.3
106	LNX	Wang/Man	10	167	0.8	180.5	1160	104	103	104	103.7
107	WTF	Wang/Man	7	156	0.3	192.9	917	108	113	91	104.0
108	NVA	Southland	41	157	0.5	189.6	1093	107	108	98	104.3
109	GBI	Auckland	7	147	0.7	186.2	1531	110	105	99	104.7
110	MOA	Southland	10	163	1.8	153.9	1514	106	92	116	104.7
111	TUT	Southland	7	178	0.6	171	1132	99	107	109	105.0
112	MAT	Northland	5	139	0.4	172.6	1599	111	110	107	109.3
113	HNE	Auckland	6	127	0	181.1	1196	112	116	102	110.0
114	WGM	Waikato	5	78	0.8	142.2	2022	120	99	121	113.3
115	TPE	CNI	10	118	0.4	153.2	1488	115	110	117	114.0
116	PKE	Auckland	10	118	0	163	1311	114	116	112	114.0
117	TTA	CNI	8	85	0	170.4	2717	118	116	110	114.7
118	NAT	Wang/Man	5	86	0	149.8	1950	117	116	118	117.0
119	MAH	Auckland	6	88	0	147.8	1533	116	116	119	117.0
120	RUX/WCP	Wang/Man	10	75	0.5	129.6	1663	121	108	123	117.3
121	WSA	West Coast	31	58	0	156.7	2224	123	116	114	117.7
122	OPO	Northland	6	80	0	136.4	1681	119	116	122	119.0
123	HKA	West Coast	37	43	0	144	2852	125	116	120	120.3
124	WHG	Taranaki	7	66	0	120.8	2032	122	116	125	121.0
125	ATH	Waikato	9	48	0	122.9	1681	124	116	124	121.3
126	WAF	Wang/Man	5	40	0	117.8	1613	126	116	126	122.7
127	HTX	West Coast	8	29	0	104.4	3624	127	116	127	123.3

Table 6. Fire climate severity statistics for individual weather stations summarised by region and island Severity measures include the Cumulative Daily Severity Rating (CDSR), and number of days of VERY HIGH and EXTREME (VH+E) fire danger class for Forest (FFDC) and Scrubland (SFDC). The length of record (years) and annual rainfall (mm) for each station are also included for comparative purposes.

Station/Region (no. stations)	Length of Record (years)	CDSR	VH+E FFDC (days)	VH+E SFDC (days)	Annual Rainfall (mm)
KX	39	403	8.9	255.2	1361
DAR/DV	23	199	1.9	201.7	1176
WRA	10	299	4.1	240.3	1349
WGF	8	534	11.8	267.2	1342
PTU	8	448	9	250.4	1223
APP	7	359	5.2	252.9	1243
OPO	6	80	0	136.4	1681
MAT	5	139	0.4	172.6	1599
KOE	7	172	0.8	224.3	1457
KAI	5	215	5.2	177.4	1305
Northland (10)	***11.8***	**285**	***4.7***	***217.8***	**1374**
AKL	35	418	7.6	250.1	1109
CDT	8	296	2	216.1	1317
CLV	7	269	3.4	213.2	1257
GBI	7	147	0.7	186.2	1531
MAH	6	88	0	147.8	1533
WDH	5	250	5.2	218.6	1215
HNW	5	165	0.8	177	1200
PKE	10	118	0	163	1311
HNE	6	127	0	181.1	1196
Auckland (9)	***9.9***	**209**	***2.2***	***194.8***	**1297**
COR	21	212	1.5	233.9	1916
HNA	10	238	2.9	208.7	1400
WTA	10	253	2.3	223.4	1904
PAX	10	252	2.8	215.9	1351
ATH	9	48	0	122.9	1681
WGM	5	78	0.8	142.2	2022
Waikato (6)	***10.8***	**180**	***1.7***	***191.2***	**1712**
ROA	37	223	2	235.2	1432
TGA	31	398	7.5	253.8	1214
APA	25	228	3	233.9	992
TPE	10	118	0.4	153.2	1488
WKA	10	480	11.4	257.1	1338
TTA	8	85	0	170.4	2717
MTE	8	223	4	186.1	1513
GDE	8	292	4.3	213.8	1316
OMT	7	180	0.4	193.8	1740
TAH	7	174	0.7	194.3	1278
KAW	5	420	7.4	241.6	1485
GAL	5	410	9	192.2	1250
RHU	5	467	9.8	229	1646
CNI (13)	***12.8***	**284**	***4.6***	***211.9***	**1493**
GSA	39	1029	32.5	268.1	1012
WPK	7	817	26.6	248.4	751
KWK	7	744	16.4	231.3	1172
WAH	6	558	12.3	231.3	1085
TEP	6	370	8.1	202.5	1436
NRA	10	1048	29.4	269.7	907
THA	5	725	20.4	235.2	900
HIX	7	403	6.1	256.1	1528
MHX	7	431	9.2	241.7	1096
CRK	5	635	15.2	236.4	1135
RTF	7	302	3.9	221.3	2417
MGF	7	251	5.8	172.2	1349
RIP	7	210	0.3	192.9	3189
Eastern (13)	***9.2***	**579**	***14.3***	***231.3***	**1383**

Station/Region (no. stations)	Length of Record (years)	CDSR	VH+E FFDC (days)	VH+E SFDC (days)	Annual Rainfall (mm)
NPA	26	172	1.4	224.1	1435
NOE	10	215	1.9	220.9	1159
WHG	7	66	0	120.8	2032
WAV	6	124	0.2	202.9	1056
OKT	5	209	0.8	214.6	1552
Taranaki (5)	**10.8**	**157**	***0.9***	***196.7***	**1447**
WUA	23	309	2.9	242.7	1099
OHA	32	592	13.3	268.1	912
RUX/WCP	10	75	0.5	129.6	1663
LNX	10	167	0.8	180.5	1160
NTA	8	634	13.2	216.1	918
RAU	6	252	1	251.9	811
WTF	7	156	0.3	192.9	917
WAO	6	328	4.4	214.2	920
WAF	5	40	0	117.8	1613
LIS	5	440	6.4	238.2	931
NAT	5	86	0	149.8	1950
PMA	5	619	16.6	258.6	858
TPU	5	283	4.2	205.6	881
Wang/Man (13)	**9.8**	**306**	***4.9***	***205.1***	**1126**
MSX	10	564	14.4	226.3	1072
CPX	10	2166	21.5	257.6	1016
NMU	8	644	20.1	228.1	1061
HWT	7	236	2.2	180.8	1655
STO	6	381	8.3	203	1238
HAU	6	269	3.8	186.2	1360
NWX	7	954	23	231.7	1092
Wairarapa (7)	**7.7**	**745**	***13.3***	***216.2***	**1213**
WNA	41	888	18.7	273.8	997
PPA	39	307	3.6	263	1024
RFP	7	329	4	218.9	1336
WAX	6	215	0.8	237	922
Wellington (4)	**23.3**	**435**	***6.8***	***248.2***	**1070**
North Island (80)	**11.1**	**359**	**6.4**	**212.4**	**1346**
NSA	39	520	10.1	248.5	1022
TNI	8	1259	3	191.4	1671
HIR	8	333	6	204.2	1185
DOV	8	194	1.6	200.1	1141
Nelson (4)	**15.8**	**576**	***5.2***	***211.1***	**1255**
KIX	37	429	5.5	246.6	824
KHD	8	239	2.2	205.4	1579
OSN	8	232	2.2	190.6	1277
AWV	7	1770	49.4	293.6	583
WBA	10	1491	41.7	275.6	792
RAI	5	302	4.4	190.6	2041
MLX/MOL	5	1103	42.6	261.2	611
Marlborough (7)	**11.4**	**795**	***21.1***	***237.7***	**1101**
HKA	37	43	0	144	2852
WSA	31	58	0	156.7	2224
HTX	8	29	0	104.4	3624
West Coast (3)	**25.3**	**44**	***0.0***	***135.0***	**2900**
CHA	41	1300	39	268.9	629
SDN	8	960	15	222.3	1056
FPL	8	1187	30.5	256.6	661
BTL	8	522	10.9	232.8	520
ASY	8	511	13.4	208.3	966
BML	7	1416	49.4	247.6	542
ASH	7	523	12.8	218.5	697
LBX	7	987	10.5	236	810
BUR	5	763	15.4	230.8	612
HAN	5	834	21	220.2	915
Canterbury (10)	**10.4**	**900**	***21.8***	***234.2***	**741**

Station/Region (no. stations)	Length of Record (years)	CDSR	VH+E FFDC (days)	VH+E SFDC (days)	Annual Rainfall (mm)
THE	10	1235	35.8	237.9	533
OUA	10	296	4.4	232.6	804
CAN	7	424	6.1	196.9	559
TUA	10	591	12	245.4	770
South Cant'y (4)	***9.3***	**636**	***14.6***	***228.2***	**667**
QNA	23	328	6	221	827
DNA	38	485	7.3	240.5	700
LAE/LAU	6	1485	33.6	232.7	463
TRQ	8	619	5.5	232.3	660
CYB	7	176	1.3	192.1	729
TPN	7	152	2.2	163.9	781
WFA	7	1004	33.6	241.7	778
DNP	7	1265	35.8	255.3	555
RNP	5	1774	33	239.8	518
INE	5	331	3	218.4	763
Otago (10)	***11.3***	**762**	***16.1***	***223.8***	**677**
NVA	41	157	0.5	189.6	1093
LUX	10	240	1.9	160.6	1279
GCE	10	217	1.5	193.1	882
MOA	10	163	1.8	153.9	1514
BMT	8	494	5.1	202.6	1099
TUT	7	178	0.6	171	1132
WRY	7	368	5.4	199	829
SLP	7	180	1.9	156.6	1273
MOS	5	1114	11.2	210.2	854
Southland (9)	***11.7***	**346**	***3.3***	***181.8***	**1106**
South Island (47)	**12.3**	**644**	**13.5**	**213.7**	**1026**
National (127)	**11.5**	**463**	**9.0**	**212.9**	**1228**
Minimum	5	29	0	104.4	463
Maximum	41	2166	49.4	293.6	3624

Table 7 presents a summary of the regional averages contained in Table 6, and ranks the fire climate severity for each region using the same methodology employed in Table 5. It confirms that Marlborough and Canterbury have the most severe fire climates, followed by Otago and South Canterbury, and that on average the West Coast, Taranaki and Waikato have the least severe fire climates. Interestingly, it also depicts significant differences between the North and South Islands, when the data for individual stations are summarised on this basis. On average, South Island stations have significantly higher fire climate severity, experiencing some 13.5 days each year of VH+E Forest fire danger (and have a CDSR of 644) compared with 6.4 days (and a CDSR of 359) for North Island stations.

The number of days of VH+E Scrubland fire danger is not significantly different between the two islands. However, the very high frequency of days of VH+E fire danger for Scrubland is in itself a concern, with on average some 213 days (58%) each year being experienced in these classes. This contrasts with recognised norms, where around 15%-25% of days might typically be expected to fall into these classes (Alexander 1994). In comparison, VH+E Forest fire danger was found here to occur on average on 9 days (2.5%) per year, although this ranged from 0% to 13.5% across the stations included in the study. The high frequency of days of VH+E Scrubland fire danger poses questions regarding the usefulness of this criteria to fire managers, and suggests that further changes may still be required to the underlying fire behaviour models to increase its practicality.

Table 7. Ranking of regional fire climate severity based on stations included in the fire climatology analysis, using the average of rankings for long-term mean Cumulative Daily Severity Rating (CDSR) and number of days of VERY HIGH and EXTREME (VH+E) fire danger class for Forest (FFDC) and Scrubland (SFDC). The average length of record (years) and annual rainfall (mm) for each region are also included for comparative purposes.

No.	Region	No. Stations	Length of Record (years)	CDSR	VH+E FFDC (days)	VH+E SFDC (days)	Annual Rainfall (mm)	Rank CDSR	Rank FFDC	Rank SFDC	Average Rank
1	Canterbury	10	10.4	900	21.8	234.2	741	1	1	3	1.7
2	Marlborough	7	11.4	795	21.1	237.7	1101	2	2	2	2.0
3	Otago	10	11.3	762	16.1	223.8	677	3	3	6	4.0
4	South Cant'y	4	9.3	636	14.6	228.2	667	5	4	5	4.7
5	Eastern	13	9.2	579	14.3	231.3	1383	6	5	4	5.0
6	Wellington	4	23.3	435	6.8	248.2	1070	8	7	1	5.3
7	Wairarapa	7	7.7	745	13.3	216.2	1213	4	6	8	6.0
8	Nelson	4	15.8	576	5.2	211.1	1255	7	8	10	8.3
9	Northland	10	11.8	285	4.7	217.8	1374	11	10	7	9.3
10	Wang/Man	13	9.8	306	4.9	205.1	1126	10	9	11	10.0
11	CNI	13	12.8	284	4.6	211.9	1493	12	11	9	10.7
12	Southland	9	11.7	346	3.3	181.8	1106	9	12	15	12.0
13	Auckland	9	9.9	209	2.2	194.8	1297	13	13	13	13.0
14	Waikato	6	10.8	180	1.7	191.2	1712	14	14	14	14.0
15	Taranaki	5	10.8	157	0.9	196.7	1447	15	15	12	14.0
16	West Coast	3	25.3	44	0.0	135.0	2900	16	16	16	16.0
	South Island	**47**	**12.3**	**644**	**13.5**	**213.7**	**1026**				
	North Island	**80**	**11.1**	**359**	**6.4**	**212.7**	**1346**				
	National	**127**	**11.5**	**463**	**9.0**	**212.9**	**1228**				

Other uses of the fire climatology

Analysis of historical weather and fire danger data from the network of remote automatic weather stations provides a better description of New Zealand's fire climate, and will enable rural fire authorities (and the New Zealand Fire Service Commission via the National Rural Fire Authority) to make more informed fire management decisions on prevention, preparedness, and prescribed burning activities. This will lead to improved fire risk management, more effective and efficient use of equipment and resources, and ultimately a reduction in the incidence and consequences of rural fires.

In addition to these general outcomes, the development of a comprehensive fire danger climatology and associated tools will also result in a number of more specific outcomes, many of which have been highlighted in previous sections. These include improved awareness among fire managers of the fire climate component of their fire environments, and an ability for fire managers and scientists alike to test and improve fire mitigation measures by:

- highlighting extremes of fire weather
- comparing fire climates at different locations
- defining fire climate regions
- indicating seasonal trends in fire danger
- validating and providing FWI station start-up values
- defining length of fire season
- providing fire danger class frequencies
- testing and validation of fire danger rating system basis (e.g., fire danger class criteria)
- allowing fire season comparison
- describing potential impacts of ENSO events and climate change
- improving firefighter safety
- improving fire danger forecasting and prediction of fire season severity
- indicating likely level of fire activity
- improving timing of prevention activities
- imposition of fire season restrictions and status (e.g., permit issue, forest closures)
- predicting resource requirements and fire suppression budgets
- providing input for economic analyses of prevention and preparedness systems (e.g., initial attack guides)
- highlighting of resource effectiveness issues (e.g., effect of wind on aircraft)
- defining "windows" for prescribed burning

The production of the fire climatology also provides a better understanding of rural climates in general, and there are a number of potential non-fire uses for the data, for example, in agriculture, horticulture and forestry (e.g., windthrow).

To maximise the utility of the updated and extended fire climatology database, it is also proposed to develop a number of analytical tools, including methods for comparing and predicting fire season severity and determining the likelihood of specific fire weather conditions occurring for individual weather stations. The database is an essential component of associated research being conducted by both Forest Research and NIWA on prediction of fire season severity, and development of the first of these analytical tools, a method for predicting fire season severity by comparison with past seasons, by Forest Research is currently underway as part of a joint Contestable Fund project.

Conclusion

This study has significantly contributed to the knowledge and understanding of New Zealand's fire climate by providing summaries of fire weather and fire danger ratings for 127 rural weather station locations. These summaries provide detailed descriptions of the long-term average and extreme conditions experienced at each location for individual months, the fire season and year as a whole. As such, they provide a wealth of information that can be used by fire managers in developing and improving their fire management decision making.

The compilation of a comprehensive database of daily fire weather and fire danger information for 127 of the 179 weather stations for which data was available represents the other major output from the analysis. This database is an essential component of associated research being conducted by both Forest Research and NIWA on prediction of fire season severity. In its own right, it also provides an extremely useful tool for the NRFA and fire managers in making more informed fire management decisions on prevention, preparedness, and prescribed burning activities. It is therefore essential that this database be incorporated with the NRFA's FWSYS database, and then regularly updated and maintained via improved data management and quality control.

The methodology used during the statistical analysis has been automated so that regular updates of this study can be conducted more easily in future. It is suggested that this updating be conducted annually or, at the very least every 5 years, to maintain the accuracy and utility of the database and to minimise the workload required to repeat the analyses. Significant potential already exists to further expand the number of stations included in future analyses by simply bringing the existing datasets up to date. This increasing data availability provides incentive for regularly updating the database and repeating the analyses, which will ultimately result in an even better description of New Zealand's fire climate.

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Appendices

Appendix 1. Summary of Data Availability for Individual Weather Stations.

Station Code[a]	Station Name	Region	Start Date	End Date	Length of Record[b] (years)	Dataset Quality[c] (% complete)
KX	Kaitaia Observatory	Northland	01/01/63	30/05/02	39	99.8
DAR	Dargaville	Northland	01/01/79	28/05/02	23	83.2
DV	Dargaville	Northland	01/01/79	28/05/02	2	73.7
WRA	Whangarei Aero	Northland	01/01/92	28/05/02	10	97.0
WGF	Waitangi Forest	Northland	13/12/92	27/08/01	8	99.2
PTU	Pouto	Northland	01/12/93	28/05/02	8	94.8
APP	Aupouri Peninsula	Northland	20/11/94	28/05/02	7	96.6
OPO	Opouteke	Northland	13/10/95	28/05/02	6	99.9
MAT	Matawaia	Northland	24/10/95	22/03/01	5	98.9
KOE	Kaikohe	Northland	30/11/94	01/05/02	7	98.0
KAI	Kaipara	Northland	28/07/96	28/05/02	5	91.0
HOK	Hokianga	Northland	29/11/96	17/12/01	4	67.2
PEX	Purerua	Northland	09/01/95	12/01/99	4	87.5
AKL	*Auckland Aero*	*Auckland*	*01/01/67*	*30/05/02*	*35*	*100.0*
CDT	Cornwallis Depot	Auckland	18/11/93	28/05/02	8	98.8
CLV	Clevedon Coast	Auckland	05/10/94	28/05/02	7	94.8
GBI	Great Barrier Island	Auckland	06/07/94	28/05/02	7	91.8
MAH	Mahurangi	Auckland	23/10/95	28/05/02	6	98.1
WDH	Woodhill	Auckland	27/07/96	28/05/02	5	99.3
HNW	Hunua West	Auckland	16/07/96	28/05/02	5	94.6
PKE	Pukekohe	Auckland	30/09/91	30/05/02	10	84.6
HNE	Hunua East	Auckland	24/01/95	28/05/02	6	83.6
AWH	Awhitu	Auckland	14/07/99	28/05/02	2	99.4
COR	*Coromandel*	*Waikato*	*01/01/79*	*01/05/00*	*21*	*100.0*
HNA	Hamilton Aero	Waikato	02/10/91	28/05/02	10	97.7
WTA	Whitianga Aero	Waikato	01/01/92	28/05/02	10	95.9
PAX	Paeroa	Waikato	01/10/91	28/05/02	10	91.3
ATH	Athol	Waikato	03/11/92	28/05/02	9	99.0
WGM	Whangamata	Waikato	22/03/96	28/05/02	5	94.9
NGA	Ngapaenga	Waikato	04/12/97	28/05/02	4	94.6
BOD	Bodley Road	Waikato	08/06/97	28/05/02	4	92.5
WGO	Waihi Gold	Waikato	30/05/98	28/05/02	3	99.2
COX	Cape Colville	Waikato	30/09/91	16/06/93	1	99.8
WKB	Waikawau Bay	Waikato	16/07/97	28/05/02	4	91.1
TRX	Port Taharoa	Waikato	25/02/97	28/05/02	4	85.7
ROA	Rotorua Aero	CNI	01/01/65	28/05/02	37	99.1
TGA	Tauranga Aero	CNI	01/01/71	28/05/02	31	100.0
APA	Taupo Aero	CNI	01/01/73	28/05/02	25	99.8
TPE	Te Puke	CNI	01/10/91	28/05/02	10	99.9
WKA	Whakatane Aero	CNI	01/01/92	28/05/02	10	99.2
TTA	Toatoa	CNI	12/11/93	28/05/02	8	100.0
MTE	Matea	CNI	18/10/93	28/05/02	8	100.0
GDE	Goudies	CNI	18/10/93	28/05/02	8	99.9
OMT	Omataroa	CNI	22/11/94	28/05/02	7	100.0
TAH	Tahorakuri	CNI	01/01/95	28/05/02	7	89.8
KAW	Kawerau	CNI	26/08/96	28/05/02	5	100.0
GAL	Galatea	CNI	06/03/96	28/05/02	5	100.0
RHU	Rotoehu	CNI	06/03/96	28/05/02	5	100.0
MIN	Minginui	CNI	02/07/98	28/05/02	3	100.0
LTF	Lake Taupo Forest	CNI	01/09/98	28/05/02	3	100.0
ROT	Rotoaira	CNI	31/07/98	28/05/02	3	99.9
TWA	Tarawera	CNI	21/02/02	28/05/02	1	99.0
GSA	Gisborne Aero	Eastern	01/01/63	28/05/02	39	97.0
WPK	Waipukurau	Eastern	17/08/94	28/05/02	7	100.0
KWK	Kaiwaka	Eastern	11/08/94	28/05/02	7	99.0
WAH	Waihau	Eastern	02/11/95	28/05/02	6	99.0
TEP	Te Pohue	Eastern	23/09/95	28/05/02	6	98.0
NRA	Napier Aero	Eastern	30/09/91	28/05/02	10	96.0
THA	Te Haroto	Eastern	27/08/96	28/05/02	5	97.0
HIX	Hicks Bay	Eastern	18/09/94	28/05/02	7	94.0

Station Code	Station Name	Region	Start Date	End Date	Length of Record (years)	Dataset Quality (% complete)
MHX	Mahia	Eastern	14/10/94	28/05/02	7	92.0
CRK	Cricklewood	Eastern	26/08/96	28/05/02	5	92.0
RTF	Porapora	Eastern	02/12/94	28/05/02	7	82.0
MGF	Mangatu Forest	Eastern	03/12/94	28/05/02	7	79.0
RIP	Ruatoria	Eastern	29/11/94	28/05/02	7	74.0
BRP	Bridge Pa	Eastern	25/02/97	28/05/02	4	99.8
ONG	Ongaonga	Eastern	22/10/97	28/05/02	4	96.8
CRT	Crownthorpe	Eastern	19/03/99	28/05/02	2	98.0
MTX	Motu	Eastern	01/10/91	25/10/94	2	93.3
HVE	Havelock North	Eastern	30/09/91	23/05/94	2	90.0
GWA	Gwavas	Eastern	21/10/97	28/05/02	4	96.4
NPA	New Plymouth Aero	Taranaki	01/01/76	28/05/02	26	94.2
NOE	Normanby	Taranaki	30/09/91	28/05/02	10	94.4
WHG	Marco	Taranaki	31/07/94	28/05/02	7	99.6
WAV	Waverly	Taranaki	30/10/95	28/05/02	6	99.2
OKT	Okato	Taranaki	15/12/96	28/05/02	5	95.2
ELT	Eltham	Taranaki	10/10/00	28/05/02	1	99.5
WUA	Wanganui Aero	Wang/Man	01/01/79	28/05/02	23	96.0
OHA	Ohakea	Wang/Man	01/01/61	23/06/96	32	75.9
RUX	Waiouru Aero	Wang/Man	01/10/91	28/05/02	10	93.2
WCP	Waiouru Camp	Wang/Man	12/01/95	30/04/02	7	72.1
LNX	Levin	Wang/Man	01/10/91	28/05/02	10	76.9
NTA	Ngamatea	Wang/Man	22/10/93	28/05/02	8	98.9
RAU	Raumai	Wang/Man	24/12/95	28/05/02	6	78.3
WTF	Waitarere Forest	Wang/Man	28/07/94	28/05/02	7	95.4
WAO	Waione	Wang/Man	09/10/95	28/05/02	6	98.4
WAF	Waimarino Forest	Wang/Man	27/04/96	28/05/02	5	98.3
LIS	Lismore	Wang/Man	05/09/96	28/05/02	5	98.2
NAT	National Park	Wang/Man	28/04/96	28/05/02	5	96.6
PMA	Palmerston North Aero	Wang/Man	10/07/96	28/05/02	5	90.8
TPU	Tapuae	Wang/Man	06/09/96	28/05/02	5	66.5
SPR	Spriggins Park	Wang/Man	16/10/97	28/05/02	4	93.9
MSX	East Taratahi	Wairarapa	01/10/91	28/05/02	10	93.0
CPX	Castle Point	Wairarapa	01/10/91	01/05/02	10	90.3
NMU	Ngaumu	Wairarapa	04/11/93	28/05/02	8	99.3
HWT	Holdsworth Station	Wairarapa	22/08/94	28/05/02	7	99.2
STO	Stoney Creek	Wairarapa	19/09/95	28/05/02	6	96.5
HAU	Haurangi	Wairarapa	01/10/95	28/05/02	6	94.8
NWX	Ngawihi	Wairarapa	16/11/94	28/05/02	7	94.8
WNA	Wellington Aero	Wellington	01/01/61	28/05/02	41	99.4
PPA	Paraparaumu	Wellington	01/01/63	28/05/02	39	90.7
RFP	Rimutaka Forest Park	Wellington	03/08/94	28/05/02	7	94.2
WAX	Chatham Island	Wellington	28/11/95	28/05/02	6	90.9
BEL	Belmont	Wellington	24/11/97	28/05/02	4	91.3
TEH	Te Horo	Wellington	05/09/92	04/12/97	4	85.9
LHX	Lower Hutt	Wellington	28/02/97	28/05/02	4	96.7
KTK	Kaitoke	Wellington	24/11/97	28/05/02	4	95.9
TTB	Titahi Bay	Wellington	02/05/98	28/05/02	3	97.6
NSA	Nelson Aero	Nelson	01/01/63	28/05/02	39	95.1
TNI	Totaranui	Nelson	05/11/93	28/05/02	8	99.1
HIR	Hira	Nelson	07/12/93	28/05/02	8	96.8
DOV	Dovedale	Nelson	29/12/93	28/05/02	8	94.7
MUR	Murchison	Nelson	30/03/98	28/05/02	3	100.0
BPO	Big Pokororo	Nelson	07/12/98	28/05/02	3	99.3
WBD	Western Boundary	Nelson	06/10/99	28/05/02	2	98.6
KIX	Kaikoura	Marlborough	01/01/65	28/05/02	37	96.1
KHD	Keneperu Head	Marlborough	25/10/93	28/05/02	8	99.1
OSN	Opua Bay	Marlborough	10/12/93	28/05/02	8	99.1
AWV	Awatere Valley	Marlborough	02/09/94	28/05/02	7	98.3
WBA	Woodbourne Aero	Marlborough	01/01/92	28/05/02	10	92.3
RAI	Rai Valley	Marlborough	10/10/96	28/05/02	5	97.4
MLX	Molesworth	Marlborough	01/10/92	28/05/02	5	71.5
CAT	Cat Creek	Marlborough	08/10/96	06/10/00	4	99.6
NGU	Ngaruru	Marlborough	20/02/98	28/05/02	3	90.4
MOL	Molesworth	Marlborough	24/06/97	04/12/97	0	92.7

Station Code	Station Name	Region	Start Date	End Date	Length of Record (years)	Dataset Quality (% complete)
HKA	Hokitika Aero	West Coast	01/01/65	28/05/02	37	94.3
WSA	Westport	West Coast	01/01/71	28/05/02	31	96.4
HTX	Haast	West Coast	09/04/93	28/05/02	8	87.7
REF	Reefton	West Coast	25/07/99	28/05/02	2	98.4
NCR	Nelson Creek	West Coast	01/12/99	28/05/02	2	95.1
CHA	Christchurch Aero	Canterbury	01/01/61	28/05/02	41	97.4
SDN	Snowdon	Canterbury	19/12/93	28/05/02	8	99.6
FPL	Darfield	Canterbury	19/12/93	28/05/02	8	99.2
BTL	Bottle Lake	Canterbury	19/12/93	28/05/02	8	97.8
ASY	Ashley	Canterbury	19/12/93	28/05/02	8	96.7
BML	Balmoral	Canterbury	06/11/94	28/05/02	7	99.6
ASH	Ashburton Plains	Canterbury	21/09/94	28/05/02	7	99.6
LBX	Le Bons Bay	Canterbury	16/11/94	28/05/02	7	98.3
BUR	Burnham	Canterbury	16/09/96	28/05/02	5	86.0
HAN	Hanmer	Canterbury	16/07/96	28/05/02	5	86.1
LEV	Lees Valley	Canterbury	08/11/97	28/05/02	4	94.3
MTS	Mount Somers	Canterbury	16/06/98	28/05/02	3	96.3
MTK	Motukarara	Canterbury	15/08/99	28/05/02	2	98.3
THE	Tara Hills	South Canty	01/10/91	28/05/02	10	98.0
OUA	Oamaru Aero	South Canty	01/10/91	28/05/02	10	93.2
CAN	Cannington	South Canty	24/02/94	28/05/02	7	97.6
TUA	Timaru Aero	South Canty	01/01/92	28/05/02	10	93.0
MTC	Mount Cook	South Canty	07/11/00	28/05/02	1	100.0
PKA	Pukaki Aero	South Canty	08/02/00	28/05/02	1	100.0
WHR	Waihaorunga	South Canty	09/02/00	28/05/02	1	100.0
TEK	Tekapo	South Canty	24/05/96	2/3/98+	1	42.3
QNA	Queenstown Aero	Otago	01/01/79	28/05/02	23	95.8
DNA	Dunedin Aero	Otago	01/01/64	28/05/02	38	90.4
LAE	Lauder	Otago	01/10/91	28/05/02	6	71.2
TRQ	Traquair	Otago	04/11/93	28/05/02	8	99.3
CYB	Glenledi	Otago	24/08/94	28/05/02	7	99.9
TPN	Tapanui	Otago	21/08/94	28/05/02	7	99.8
WFA	Wanaka	Otago	11/03/94	28/05/02	7	96.6
DNP	Dansey Pass	Otago	20/08/94	28/05/02	7	99.9
RNP	Rock and Pillar	Otago	22/02/96	28/05/02	5	99.9
INE	Invermay	Otago	01/10/91	04/12/97	5	62.7
CLY	Clyde	Otago	19/09/97	28/05/02	4	98.8
DPS	Deep Stream	Otago	04/02/98	28/05/02	3	97.0
MTB	Mount Benger	Otago	01/12/98	28/05/02	3	95.1
BGO	Bendigo	Otago	31/01/00	28/05/02	2	98.5
NGX	Nugget Point	Otago	01/09/99	28/05/02	2	98.1
GLD	Glendhu	Otago	16/08/00	28/05/02	1	95.2
WND	Windsor	Otago	06/02/01	28/05/02	0	99.8
RLY	Ranfurly	Otago	19/02/01	28/05/02	0	99.6
LAU	Lauder	Otago	24/02/97	04/12/97	0	90.8
NVA	Invercargill Aero	Southland	01/01/61	28/05/02	41	96.4
LUX	Lumsden	Southland	01/10/91	28/05/02	10	92.7
GCE	Gore	Southland	01/10/91	28/05/02	10	91.3
MOA	Manapouri Aero	Southland	30/09/91	28/05/02	10	90.5
BMT	Blackmount	Southland	04/11/93	28/05/02	8	98.5
TUT	Tuatapere	Southland	15/08/94	28/05/02	7	100.0
WRY	Wreys Bush	Southland	16/08/94	28/05/02	7	97.3
SLP	Slopedown	Southland	05/10/94	28/05/02	7	93.1
MOS	Barn Hill	Southland	09/10/96	28/05/02	5	94.8
Stations completed			**127**		**11.5**	**94.4**
All stations			**179**		**8.9**	**94.2**

Notes:

a. Data for stations indicated in itallics (i.e., AKL, COR) are from Pearce (1996); data for all other stations were obtained from the NRFA Fire Weather archive. Stations indicated in bold depict those stations included in the final analyses for which summary tables were produced.

b. Length of record in full calendar years (1 Jan - 31 Dec).

c. Dataset quality (% complete) based on counts of missing values; does not include erroneous or repeated values found subsequently.

Appendix 2. Fire Climate Summaries for Individual Weather Stations by Region.