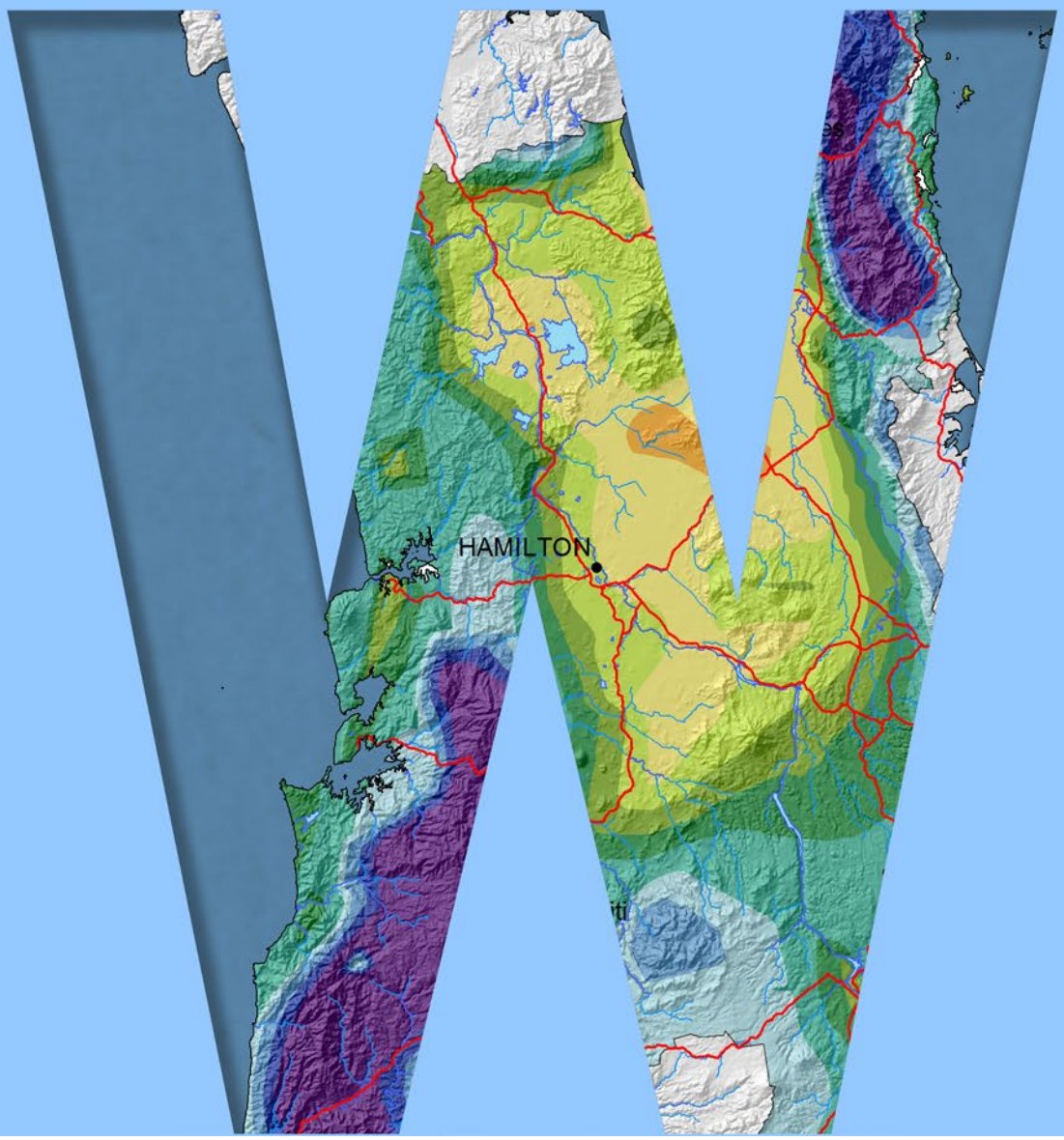
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Taihoro Nukurangi

THE CLIMATE AND WEATHER OF WAIKATO

2nd edition

P.R. Chappell



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Note to Second Edition

This publication replaces the first edition of the New Zealand Meteorological Service Miscellaneous Publication 115 (7), written in 1974 by W.J. Maunder. This edition incorporates more recent data and updated methods of climatological variable calculation.

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SUMMARY

Waikato exhibits a range of climates due to the variety of landscapes in the region. The northern coastal areas of Coromandel Peninsula and the Hauraki Plains have different climatic characteristics to the high altitude areas around Taupo and Tongariro National Park in the south of the region. It can be very windy in exposed areas, but low elevation inland parts of the region are more sheltered. Mountain ranges cause rainfall anomalies which are directly related to elevation. However, rainfall is generally plentiful year-round. An east-west gradient of bright sunshine is observed, with more sunshine in the east than the west of the region.



INTRODUCTION

The Waikato region (Figure 1) extends from Coromandel Peninsula in the north to Mt Ruapehu in the south, and is defined here as the region administered by the Waikato Regional Council, and also includes Tongariro National Park (Mt Ruapehu). The region covers a large portion of the central North Island's west coast, with a number of harbours offering shelter from the predominant southwest swells. On the east coast, Coromandel Peninsula extends to the north with white sandy beaches and Kauri forests, and shelters the Firth of Thames.

The landscape setting of the region varies significantly, which has an impact on the region's climate. Low elevation and northern coastal settings in the Thames-Coromandel District give way to extensive pasture and hill country for the majority of the region, which supports large dairy farms and plantation forestry. The Central Plateau rises near Taupo, with an alpine desert landscape surrounding the volcanoes of Tongariro National Park.

All numbers given in the following tables are calculated from the 1981-2010 normal period (a normal is an average or estimated average over a standard 30-year period), unless otherwise stated.

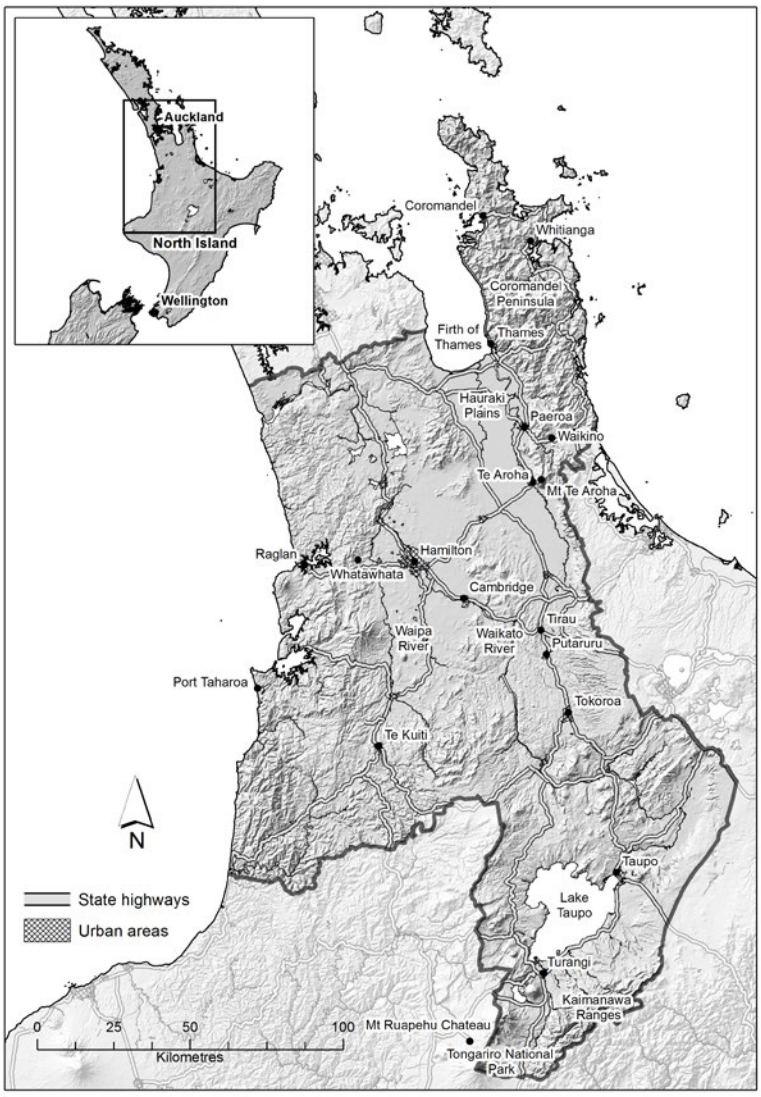


Figure 1. Map of Waikato region, with locations of places mentioned in the text, tables, and figures.





TYPICAL WEATHER SITUATIONS IN WAIKATO

Fine weather spells

Prolonged spells of fine weather of five or more days in the Waikato region are usually associated with either a single anticyclone moving slowly across the New Zealand area or a series of anticyclones, when the troughs of low pressure between the anticyclones are so weak that there are no showers associated with them as they pass over the region. An example of this type of situation, which occurs more often in late summer/early autumn than in other seasons, is shown in Figure 2, which indicates the location of the anticyclone centres at noon from 18-27 February 1969. Specifically, an anticyclone which was centred over Tasmania on the evening of the 17th moved to the central Tasman Sea by the 19th and initiated a fine spell in the region which lasted for 9 days. The anticyclone remained almost stationary over the central Tasman Sea for several days, and during the period 19-27 February 1969 the weather in the Waikato region was sunny with virtually no rain.

Another situation associated with a spell of fine weather occurred during August 1961, as shown in Figure 3. This event caused a succession of sunny days and frosty nights with relatively low mean wind speeds.

Showery periods

A sequence of unsettled weather during July 1969 is illustrated in Figure 4. This type of weather sequence may be found at any time of the year but is more common in winter. In these situations, a belt of high pressure extends from eastern Australia to the area to the north of New Zealand, while south of about 50°S a series of deep depressions moves steadily eastwards, the southeasterly air stream between the high and low pressure systems being

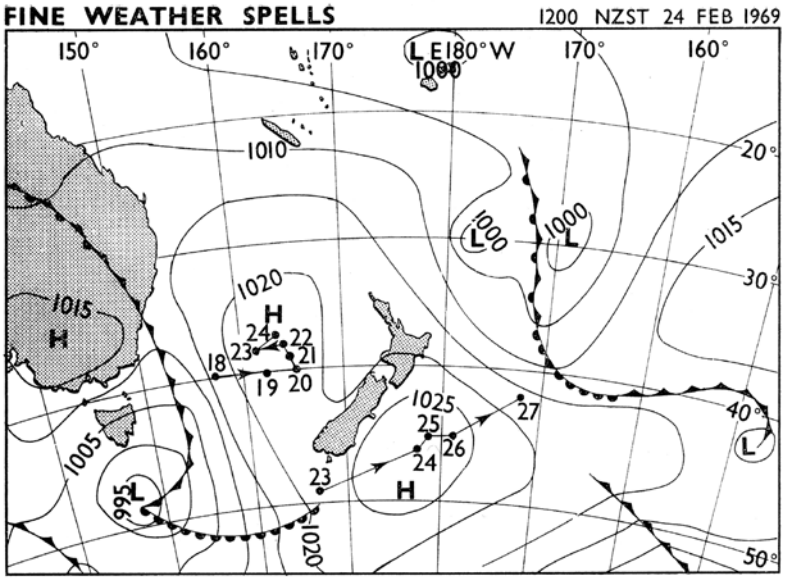


Figure 2. Anticyclone replacement causing fine weather in Waikato.

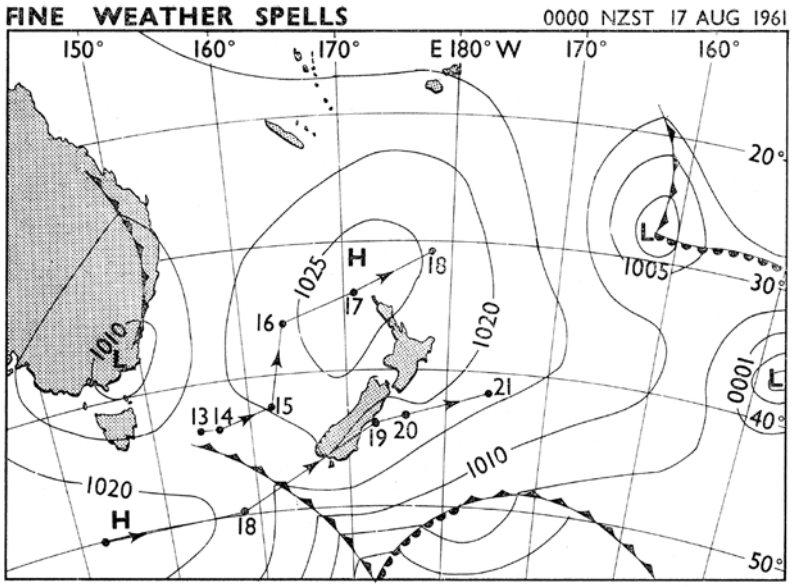


Figure 3. Stationary anticyclone causing fine weather in Waikato.

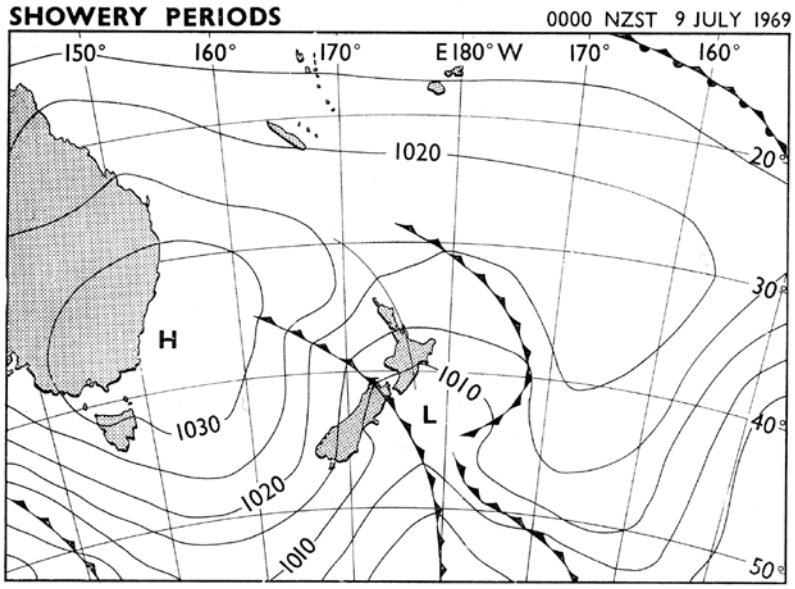


Figure 4. Showery periods in Waikato region.

'punctuated' with frontal systems. As these systems cross New Zealand a period of rain is usually experienced in places exposed to the west, but little if any rain reaches districts east of the main ranges.

A somewhat similar pattern for 23 September 1961 is shown in Figure 5. In this case a belt of relatively high pressure lies north of the Tasman Sea and New Zealand, while low pressure systems are passing eastwards in the far south, giving a strong air stream over New Zealand from directions between northwest and west-south-west. Showers in this air stream are usually intensified by the orography of the Waikato region and showery weather will often occur over the whole region. Cold fronts, often present in such air streams, also cause an increase in the intensity of the showers as they cross the region. Showery periods of this nature usually last several days. In this case significant amounts of rain occurred on several of the days between 22 and 28 September 1961.

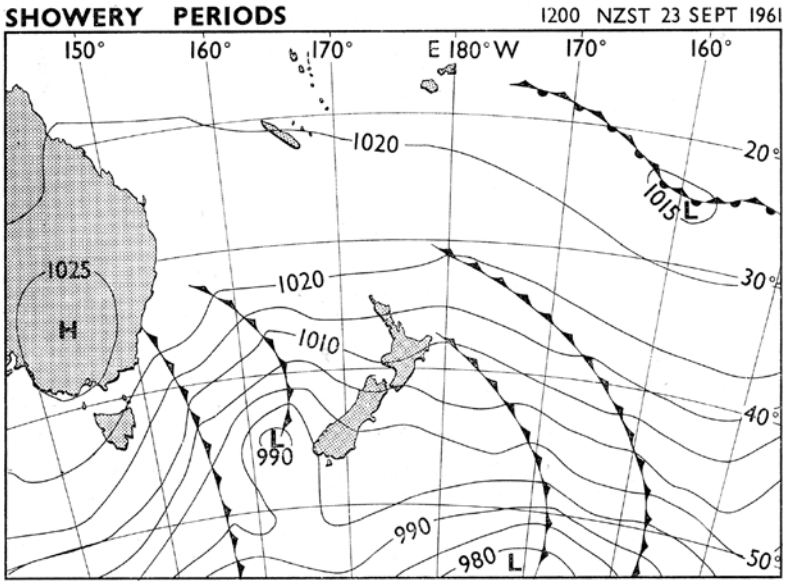


Figure 5. Showery periods in Waikato region.

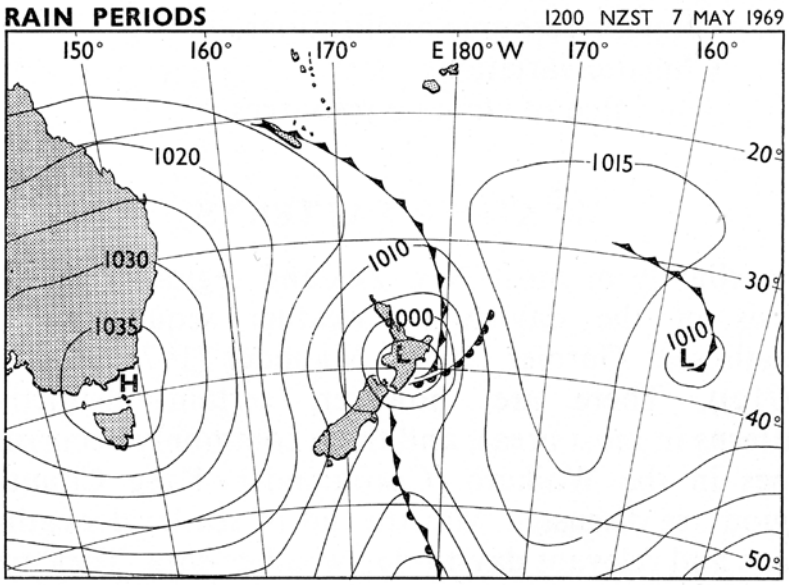


Figure 6. Pressure systems causing rainy periods in Waikato region.

Periods of moderate to heavy rain

When a depression crosses the North Island from the northwest to the southeast, periods of moderate to heavy rain often occur in the Waikato region. A typical situation of this type for 7 May 1969 is shown in Figure 6. In this case, a depression had formed over the north Tasman Sea and deepened as it moved towards the southeast. At 6 am on the 7th the centre was near New Plymouth and by midnight the depression was some 650 km south-east of National Park. During the 3 days 5-7 May 1969 considerable rain falls were recorded in the region.

Another example of a situation producing periods of moderate to heavy rain is given in Figure 7. In this case a deep depression moved from near the New South Wales coast to the area south of the South Island, and an associated frontal system crossed New Zealand from the west giving a brief period of moderate to heavy rain in areas exposed to the west.

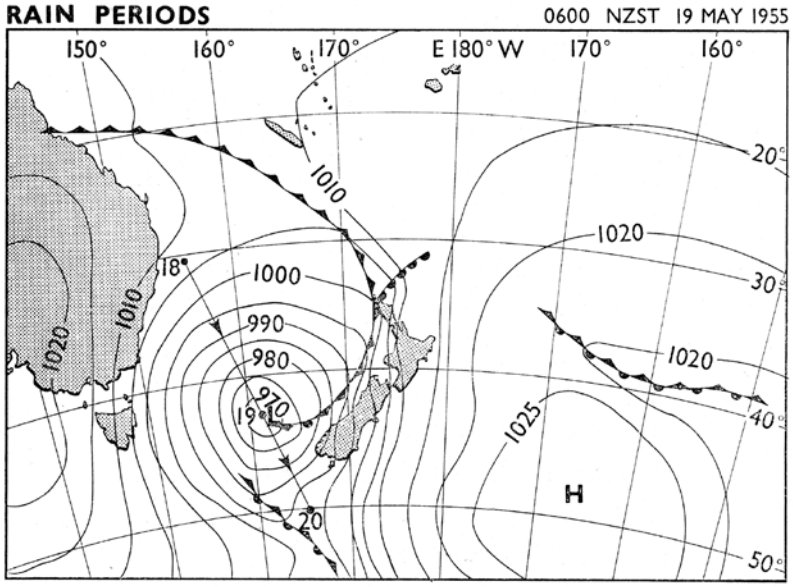


Figure 7. Depression causing rain in Waikato region.

The tropical cyclone season in the southern hemisphere lasts from November to April. Tropical cyclones reaching northern New Zealand and still retaining true cyclonic characteristics, such as a warm core, are extremely rare. However, storms of tropical origin (which may never have been fully developed tropical cyclones) affect Waikato about once or twice each year, mainly between the months of December and April. They usually bring heavy rain and strong easterly winds. Ex-tropical storms generally affect the Coromandel Peninsula more significantly than the rest of the Waikato region.

One example of an ex-tropical cyclone that affected the Coromandel Peninsula was ex-tropical cyclone Fergus, in December 1996. All major Coromandel roads were closed by slips and flooding as the storm battered the area. A State of Emergency was declared for the Thames-Coromandel District, as well as parts of the Hauraki District and the Matamata-Piako District. Hundreds of holiday makers were trapped by flood waters and had to seek shelter in Civil Defence centres.

Figure 8a-e shows, by months, the tracks of tropical cyclones which made landfall in New Zealand during the period between 1970 and 2010.

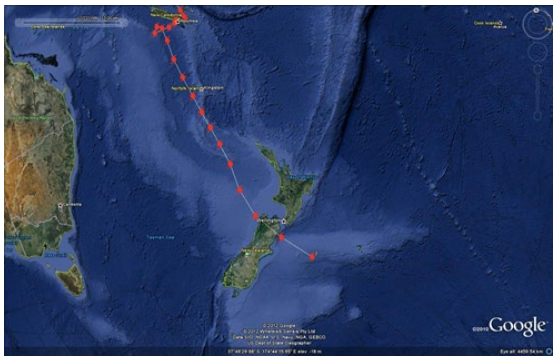


Figure 8a. Tropical cyclones which made landfall in New Zealand during December, 1970-2010. Source: Southwest Pacific Enhanced Archive of Tropical Cyclones (SPEArTC; Diamond et al., 2012)

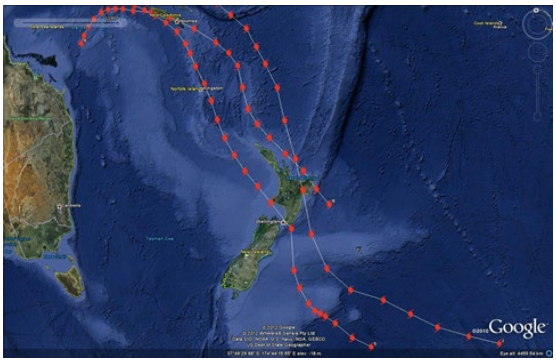


Figure 8b. Tropical cyclones which made landfall in New Zealand during January, 1970-2010. Source: SPEArTC (Diamond et al., 2012)

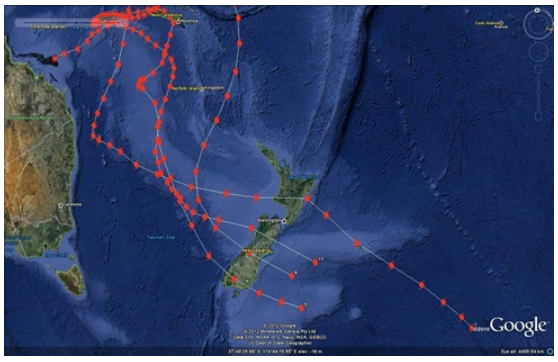


Figure 8c. Tropical cyclones which made landfall in New Zealand during February, 1970-2010. Source: SPEArTC (Diamond et al., 2012)

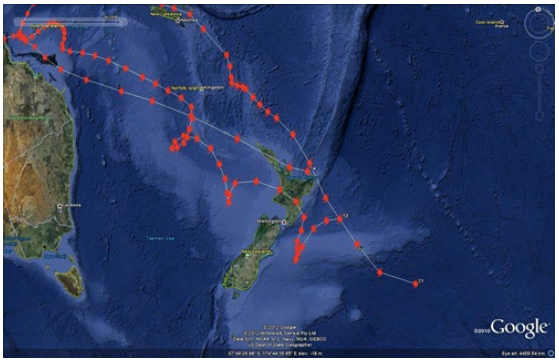


Figure 8e. Tropical cyclones which made landfall in New Zealand during April, 1970-2010. Source: SPEArTC (Diamond et al., 2012)

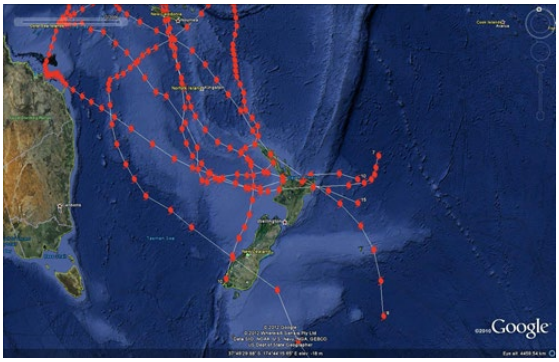


Figure 8d. Tropical cyclones which made landfall in New Zealand during March, 1970-2010. Source: SPEArTC (Diamond et al., 2012)



CLIMATIC ELEMENTS

Wind

Northerly or westerly air flows are common over most of the region, although as in all areas of New Zealand the specific prevailing and strong wind direction in any locality is determined largely by local topography. Figure 9 shows mean annual wind frequencies of surface wind based on hourly observations from selected stations. Exposed sites such as Mt Te Aroha and Port Taharoa have a higher percentage of strong winds than more sheltered sites, such as Hamilton.

Mean wind speed data (average wind speeds are taken over the 10 minute period preceding each hour) are available for several sites in Waikato, and these illustrate the several different wind regimes of the region. Coastal areas (e.g. Port Taharoa) tend to be windier throughout the year compared with sheltered inland areas (e.g. Paeroa). Areas at higher elevations (e.g. Mt Ruapehu Chateau) are generally windier than low-lying sites. Table 1 gives mean monthly and annual wind speeds for selected stations in Waikato.

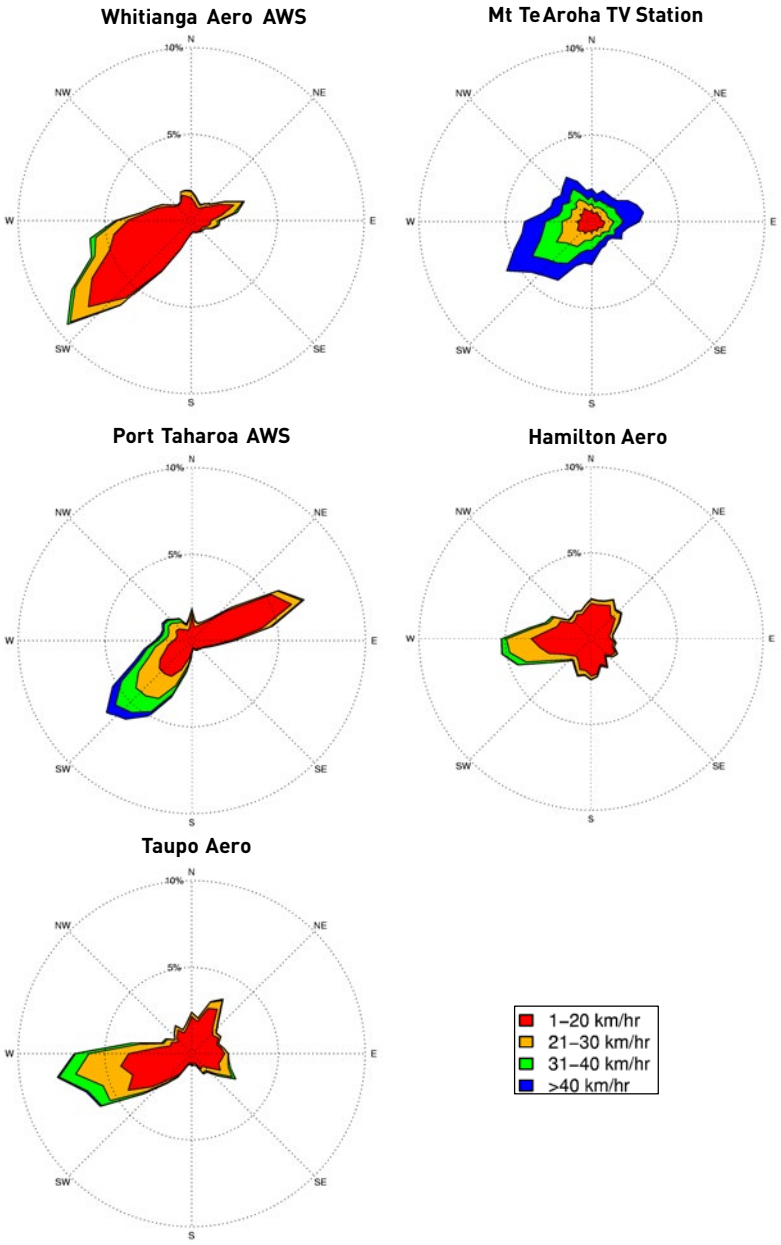


Figure 9. Mean annual wind frequencies (%) of surface wind directions from hourly observations at selected Waikato stations. The plots show the directions from which the wind blows, e.g. the dominant wind direction at Whitianga is from the southwest.

Table 1. Mean monthly/annual wind speeds (km/hr) for Waikato sites.

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Whitianga Aero AWS	12	12	11	10	11	11	11	12	12	14	14	13	12
Paeroa AWS	9	9	8	7	8	8	9	9	10	10	10	9	9
Port Taharoa AWS	15	15	15	15	17	18	16	17	17	20	19	17	17
Hamilton AWS	11	10	10	9	9	10	10	11	11	13	13	12	11
Taupo AWS	13	12	12	11	12	13	12	13	12	15	15	14	13
Mt Ruapehu, Chateau EWS	14	13	14	13	15	16	16	15	15	16	15	14	15

Spring is generally the windiest season throughout the region. Summer and autumn are the seasons where the greatest number of light wind days is recorded. Table 2 gives the seasonal proportion of strong and light winds as a percentage of the annual total. For example, of all strong winds recorded at Hamilton, 17% occurred in summer, 10% in autumn, 29% in winter and 44% in spring. In compiling this table a strong wind was defined as having a mean wind speed of at least 31 km/hr.

Table 2. Seasonal percentages of strong winds or calms (%) for Waikato sites.

Location		Summer	Autumn	Winter	Spring
Whitianga Aero AWS	Strong	17	14	36	33
	Light	25	25	25	25
Paeroa AWS	Strong	15	15	44	27
	Light	25	25	25	25
Port Taharoa AWS	Strong	19	24	28	29
	Light	26	25	25	24
Hamilton AWS	Strong	17	10	29	44
	Light	25	25	25	25
Taupo Aero	Strong	17	26	27	30
	Light	25	25	25	25
Mt Ruapehu, Chateau 2	Strong	20	23	27	31
	Light	25	25	25	24

Table 3. Average wind speed (km/hr) for selected hours.

Location	00	03	06	09	12	15	18	21
Whitianga Aero AWS	9	9	8	10	16	17	14	10
Paeroa AWS	6	6	6	8	13	14	11	7
Port Taharoa AWS	17	17	17	16	19	20	19	17
Hamilton AWS	8	7	7	9	14	16	14	9
Taupo AWS	12	10	10	11	15	16	15	14

Table 4. Average number of days per year with gusts exceeding 63 km/hr and 96 km/hr for selected stations.

Location	Gusts >63 km/hr	Gusts >96 km/hr
Whitianga Aero AWS	32	0.2
Paeroa AWS	23	1.6
Hamilton AWS	17	0.2
Taupo AWS	26	0.1

Table 5. Highest recorded gusts at selected Waikato stations, from all available data.

Location	Gust (km/hr)	Direction (°)	Date
Whitianga Aero AWS	100	NE	20/06/2002
Paeroa AWS	124	E	29/11/1998
Hamilton Aero	111	WSW	2/08/1982
Taupo AWS	109	W	10/10/2006
Mt Ruapehu Chateau EWS	130	SE	19/06/2006

Diurnal variation in wind speed is well-marked, with greatest wind speeds occurring in the early part of the afternoon. This is because at that time of day heating of the land surface is most intense and stronger winds aloft are brought down to ground level by turbulent mixing. Cooling at night generally restores a lighter wind regime. Table 3 gives average wind speeds at three-hourly intervals for selected stations.

Winds can be strong and gusty at times, especially in coastal areas. Whitianga has the highest number of gusts per year that are greater than 63 km/hr, but Paeroa has the highest number of gusts per year that exceed 96 km/hr (Table 4). In comparison, Hamilton is more sheltered.

Although gale force winds can occur in any month, they are most frequent in winter. The highest gust recorded in the region was 130 km/hr at Mt Ruapehu Chateau on 19 June 2006. Maximum gusts recorded at different stations in the region are listed in Table 5.

Rainfall

Rainfall distribution

Rainfall patterns in the region are closely related to elevation, and exposure to the predominant air flows (westerly and northeasterly). The distribution of the Waikato region's median annual rainfall is shown in Figure 10. Areas with high annual rainfall over 2000 mm (Coromandel Ranges, Central Plateau south of Lake Taupo, hill country west of Te Kuiti) provide a stark contrast to areas which receive around 1100 mm of rain per year, that is the area east of Hamilton and the Hauraki Plains, as well as east of Taupo.

Seasonal influences on rainfall distribution are also quite well defined. Table 6 lists monthly rainfall normals and percentage of annual total for selected stations. This table shows a clearly defined winter rainfall maximum. Monthly percentages of the annual rainfall total are fairly consistent across the Waikato region, with around 31% of annual rainfall expected in the winter months from June to August, and around 22% of rain in the summer months from December to February.

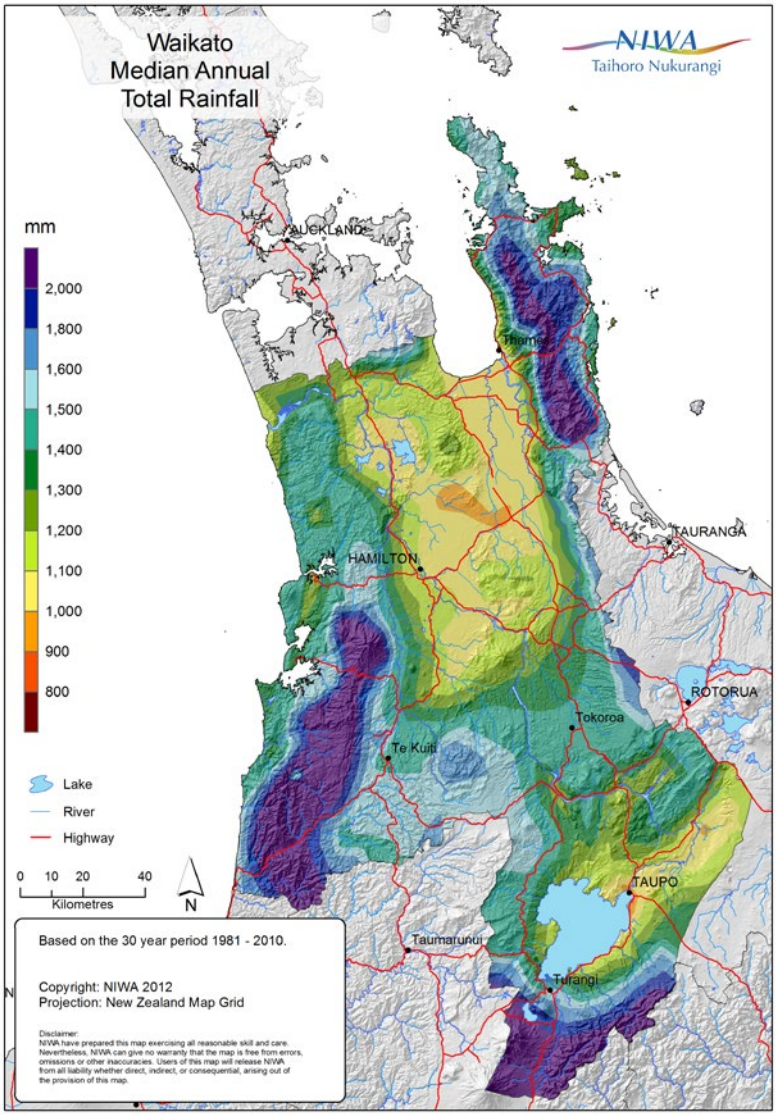


Figure 10. Waikato median annual total rainfall, 1981-2010.

Table 6. Monthly/annual rainfall normals (a; mm); percentage of annual total for each month (b; %)

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Whitianga Aero AWS	a	82	112	139	152	171	205	242	196	169	139	104	129	1840
	b	4	6	8	8	9	11	13	11	9	8	6	7	
Thames 2	a	65	70	78	104	90	120	148	124	96	93	74	81	1141
	b	6	6	7	9	8	10	13	11	8	8	6	7	
Hamilton, Ruakura EWS	a	69	62	71	67	117	102	116	73	85	91	101	118	1072
	b	6	6	7	6	11	9	11	7	8	8	9	11	
Te Kuiti EWS	a	100	93	87	104	134	149	164	140	130	138	117	140	1496
	b	7	6	6	7	9	10	11	9	9	9	8	9	
Taupo AWS	a	78	69	65	68	75	93	96	87	82	86	68	94	960
	b	8	7	7	7	8	10	10	9	8	9	7	10	
Mt Ruapehu Chateau EWS	a	189	167	174	180	233	258	263	241	271	280	236	268	2759
	b	7	6	6	7	8	9	10	9	10	10	9	10	

The distribution of monthly rainfall is shown in Figure 11. The 10th percentile, 90th percentile, and mean rainfall values for each month are shown along with maximum and minimum recorded values for several stations.

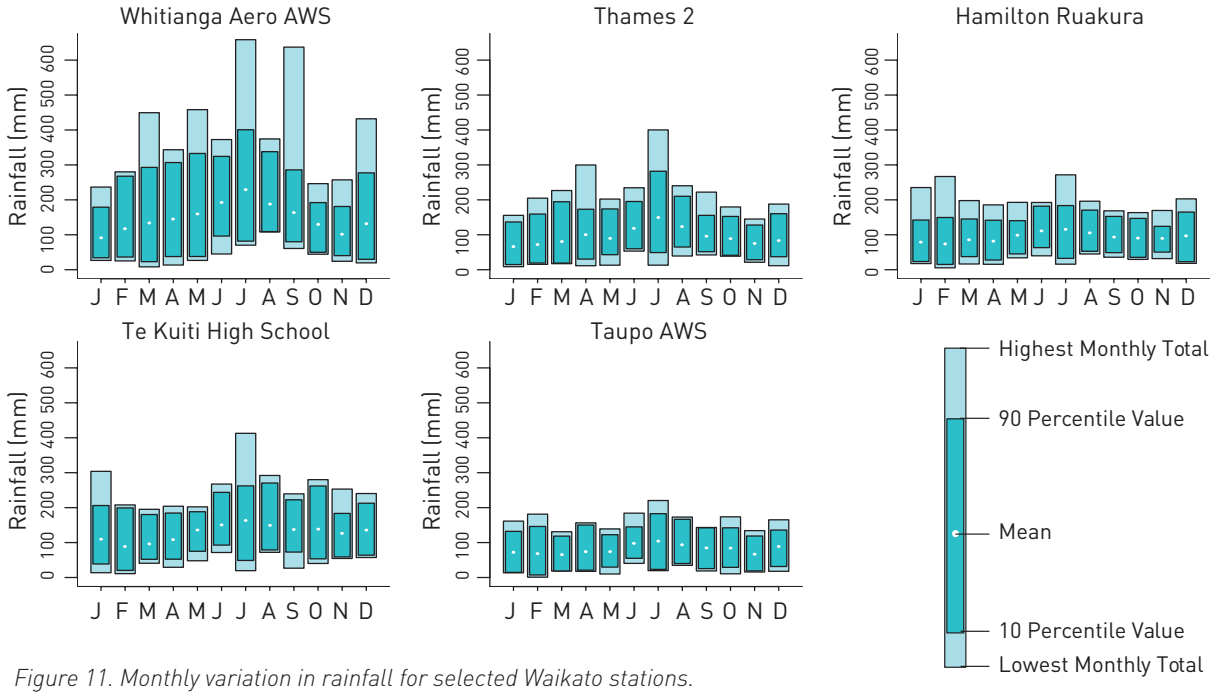


Figure 11. Monthly variation in rainfall for selected Waikato stations.



Rainfall variability over longer periods is indicated by rainfall deciles, as given in Table 7. The 10th percentile values show the accumulated rainfalls that will normally be exceeded in nine out of ten years, while the 90th percentile values indicate the accumulated falls that will normally be exceeded in only one year in ten. The table includes periods from one month to twelve months; each period over one month begins with the month stated. For example, using the table for Whitianga, for three months it can be seen that in the three month period beginning in April, 304 mm or more of rainfall can be expected in nine years in ten, while a total of 713 mm should occur in only one year in ten.

Table 7. Rainfall deciles for consecutive months.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Whitianga Aero AWS												
1 month												
10th	34	36	23	38	38	96	82	109	80	50	40	30
90th	179	268	293	307	333	324	401	338	286	192	181	277
3 months												
10th	192	164	256	304	317	362	388	335	273	196	213	181
90th	680	645	708	713	974	951	943	766	478	568	525	507
6 months												
10th	604	615	726	764	709	725	690	632	555	469	451	479
90th	1217	1281	1459	1643	1647	1509	1397	1214	1033	944	1031	1090
12 months												
10th	1077	1144	1155	1154	1281	1268	1354	1479	1221	1280	1247	1251
90th	2329	2296	2263	2211	2239	2200	2269	2250	2221	2398	2378	2461
Hamilton AWS												
1 month												
10th	23	11	20	31	58	89	64	68	41	45	42	32
90th	127	182	138	203	152	198	229	209	176	161	174	162
3 months												
10th	135	139	177	237	295	285	232	221	215	203	194	157
90th	319	402	444	453	526	554	463	437	411	422	424	370
6 months												
10th	434	467	549	562	549	523	511	450	387	374	340	358
90th	767	837	898	889	894	832	830	730	785	754	763	785
12 months												
10th	1048	1022	997	919	969	973	968	1037	1030	1072	1013	1043
90th	1498	1478	1469	1509	1620	1597	1587	1519	1576	1550	1542	1493
Taupo AWS												
1 month												
10th	15	7	19	21	30	55	23	40	25	29	19	31
90th	132	146	119	150	122	145	183	167	142	142	119	136
3 months												
10th	101	111	143	165	211	196	156	166	154	156	146	136
90th	318	359	320	308	413	384	370	356	330	327	327	387
6 months												
10th	290	364	395	388	392	367	409	372	326	286	272	290
90th	648	627	631	656	652	659	647	621	719	642	659	663
12 months												
10th	768	750	747	747	760	789	805	782	769	785	796	781
90th	1208	1167	1162	1150	1267	1250	1252	1251	1276	1285	1205	1272

Rainfall frequency and intensity

The average number of days each year on which 0.1 mm or more of rain is recorded varies from around 160 days in western and southern parts of the region (e.g. Raglan and Taupo) to over 200 days in eastern areas (e.g. Whitianga). Taupo also exhibits the lowest number of rain days, at 112 days per year. The 0.1 mm rain days and 1 mm wet days show the same geographic variability. Table 8 lists the average number of days per month with 0.1 mm and 1 mm of rain for selected stations.

Table 8. Average monthly rain days and wet days for Waikato region; a: 0.1 mm rain day, b: 1 mm wet day.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Whitianga Aero AWS	a	11	12	15	18	20	22	23	22	19	16	14	14	205
	b	9	9	10	11	13	14	15	16	13	11	10	10	140
Thames 2	a	10	9	11	13	17	18	18	19	17	17	14	13	176
	b	7	6	8	9	11	13	13	13	12	11	9	9	122
Hamilton Ruakura	a	11	9	11	12	15	17	17	18	16	16	14	13	169
	b	8	7	8	8	11	13	13	13	12	12	11	10	126
Raglan Karioi	a	10	9	10	11	15	19	17	18	15	14	12	12	163
	b	8	7	8	9	13	15	15	15	13	12	10	10	134
Taupo AWS	a	10	9	10	11	13	17	18	17	15	14	12	13	160
	b	7	7	7	8	8	11	12	12	11	10	8	9	112

Heavy rainfalls can occur in Waikato with the passage of depressions from the northwest or southeast, and with northeasterly flows between ridges of high pressure to the east and troughs over the Tasman Sea. Intense rainfalls also occur with thunderstorms. In Table 9, maximum short period rainfalls for periods of 10 minutes to 72 hours with calculated return periods are given for several stations. Also listed in this table are the maximum rainfalls expected in 2, 5, 10, 20, and 50 years. Depth-duration frequency tables for Waikato locations are available from NIWA's High Intensity Rainfall Design System (HIRDS). HIRDS uses the index-frequency method to calculate rainfall return periods. For more information on methods and to use the tool, see www.hirds.niwa.co.nz.

Table 9. Maximum recorded short period rainfalls and calculated return periods from HIRDS.

Location		10min	20min	30min	1hr	2hrs	6hrs	12hrs	24hrs	48hrs	72hrs
Thames 2	a	12	21	30	60	71	91	102	131	190	209
	b	6	11	19	68	39	17	7	7	16	15
	c	9	13	17	25	33	52	70	94	111	123
	d	12	17	22	32	43	68	91	122	145	161
	e	14	21	26	38	51	81	109	146	173	192
	f	17	25	31	45	61	96	129	173	205	227
	g	21	31	38	56	76	120	161	215	255	282
Hamilton Ruakura	a	16	28	35	43	45	62	83	102	107	107
	b	9	29	37	25	10	8	11	10	6	4
	c	11	15	18	24	30	43	54	68	80	88
	d	14	19	22	30	38	55	69	87	103	113
	e	16	22	26	36	45	65	82	103	121	134
	f	19	26	31	42	53	76	96	120	142	157
	g	23	32	38	51	65	93	117	148	175	192
Te Kuiti High School	a	21	30	38	57	69	85	104	147	150	182
	b	35	40	51	77	70	34	28	48	16	21
	c	10	14	17	22	29	45	58	76	96	110
	d	13	18	22	29	38	56	73	94	119	136
	e	16	22	26	35	45	66	84	108	137	157
	f	19	25	30	41	52	77	97	124	157	180
	g	23	32	38	51	64	93	117	148	187	214
Taupo NZED	a	13	19	25	41	61	88	105	112	156	164
	b	11	11	14	17	35	38	31	14	31	24
	c	8	12	15	22	29	44	57	74	89	98
	d	10	15	20	30	38	56	72	92	109	121
	e	12	19	24	36	45	66	83	105	126	139
	f	15	22	29	43	54	77	96	120	143	159
	g	19	28	36	55	67	94	116	143	171	189

a: highest fall recorded (mm)
b: calculated return period of a (years)
c: max fall calculated with ARI 2 years (mm)
d: max fall calculated with ARI 5 years (mm)
e: max fall calculated with ARI 10 years (mm)
f: max fall calculated with ARI 20 years (mm)
g: max fall calculated with ARI 50 years (mm)

Recent extreme events in Waikato

Waikato has experienced numerous extreme weather events, with significant damage and disruption caused by flooding and high winds (e.g. Figure 12). The events listed below are some of the most severe events to have affected the Waikato region between 1980 and 2012.

11-16 April 1981: A deep depression to the north and an anticyclone to the south caused a strong easterly flow over the eastern Waikato region. Torrential rain and high winds hit the Coromandel Peninsula and the Hauraki Plains. Half of Waikino Township was destroyed by flooding. Paeroa and Thames were severely inundated and over 2000 people were

evacuated, causing a Civil Defence Emergency (CDE) to be declared in the area. The total flood damage cost in the Paeroa area was over $44 million 2010 dollars.

16-17 February 1985: A CDE was declared in the Thames area after heavy rain caused flooding and landslides. All major roads in Coromandel Peninsula were closed. Major rivers in the area flooded, and people were isolated by floodwaters and slips. 164 people were evacuated in Te Aroha, while three people were killed in a debris flow and a woman drowned in floodwaters.

8-20 July 1998: Successive depressions moved east from the Tasman Sea over the country, causing heavy rainfall and flooding throughout the Waikato region. Lake Taupo rose to its highest level in 40 years, causing erosion to the foreshore. Extremely high river levels were experienced on the Waikato and Waipa Rivers, leading to extensive flooding downstream of Hamilton. In total, over 11,300 ha of farmland were flooded. A number of people were evacuated across the region, and damage to property was severe.

18-21 June 2002: A weather bomb struck the eastern Waikato region. Two weeks after the storm some areas were still without power or water. Roads were closed due to slips and flooding, and considerable damage was done to property. A CDE was declared in Tirau and Putaruru due to extensive flooding, causing evacuations, school closures, and a water shortage for 18,000 people. 500 people on the Coromandel Peninsula were evacuated. Insurance payouts for the event totalled over $29 million 2008 dollars.

26 July – 3 August 2008: Three storms hit the country over one week. The first storm caused power to be cut to 20,000 homes on the Coromandel Peninsula and the Hauraki Plains. Roads were closed due to slips and flooding, and damage to the town of Te Aroha was particularly severe. The second storm was longer-lasting, causing additional flooding, road closures, and damage on the Coromandel Peninsula and the Hauraki Plains. In the Coromandel, 20 schools were closed due to the storm. In Te Aroha, almost every property suffered damage due to extremely high winds. The third storm caused more flooding in already saturated areas, and rivers rose further. A number of people died as a result of the storms, in car accidents and from drowning.



Figure 12. Waikato River flooding near Mercer, August 2008.

Periods of low rainfall

Periods of fifteen days or longer with less than 1 mm of rain on any day are referred to as 'dry spells'. Dry spells are common in Waikato during the summer and early autumn. There is usually one, and frequently two, such periods each year between December and March. The average duration of a dry spell is about 20 days. The longest recent dry spell between three key sites in Waikato (Whitianga Airport, Hamilton, and Taupo) was 33 days recorded in Hamilton, from 24 January 1999 to 25 February 1999. During this dry spell, 19 consecutive days were without any rain. Other long dry spells include 30 days at Taupo from 1 February to 1 March 2000, of which 13 consecutive days were without any rain, and 30 days at Whitianga Airport from 14 November to 13 December 1999, all of which were without any rain.

Temperature

Sea surface temperature

Monthly mean sea surface temperatures off the west coast of Waikato region and Coromandel Peninsula are compared with mean air temperature for Hamilton in Figure 13. There is a six to eight week lag between the minima of land and sea temperatures, with west coast sea surface temperatures being slightly cooler than those off the east coast for most of the year. Figure 14 shows the mean sea surface temperatures for the New Zealand region for February and August, which are the warmest and coolest months with respect to sea surface temperatures.

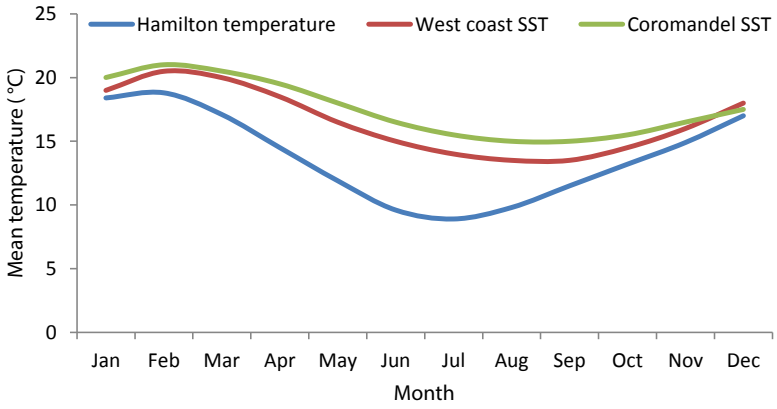


Figure 13. Mean monthly land (Hamilton Ruakura) and sea surface temperatures (west coast and Coromandel).

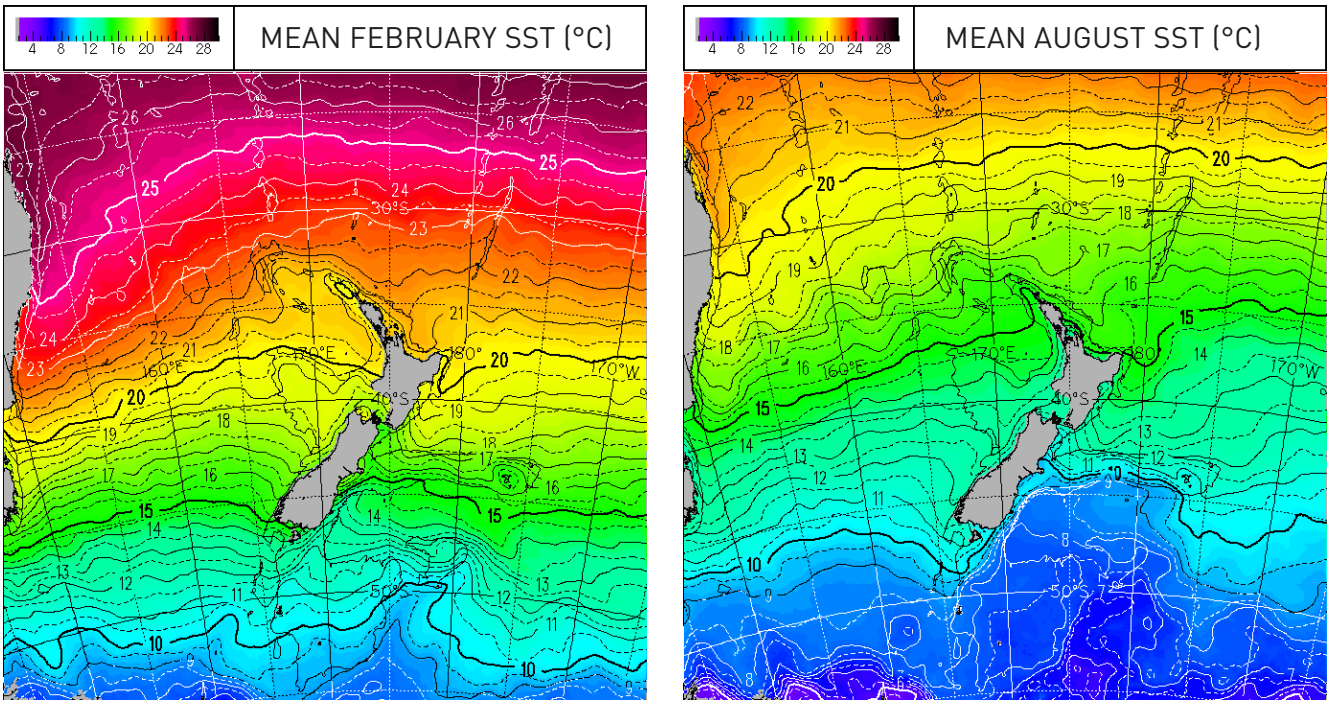


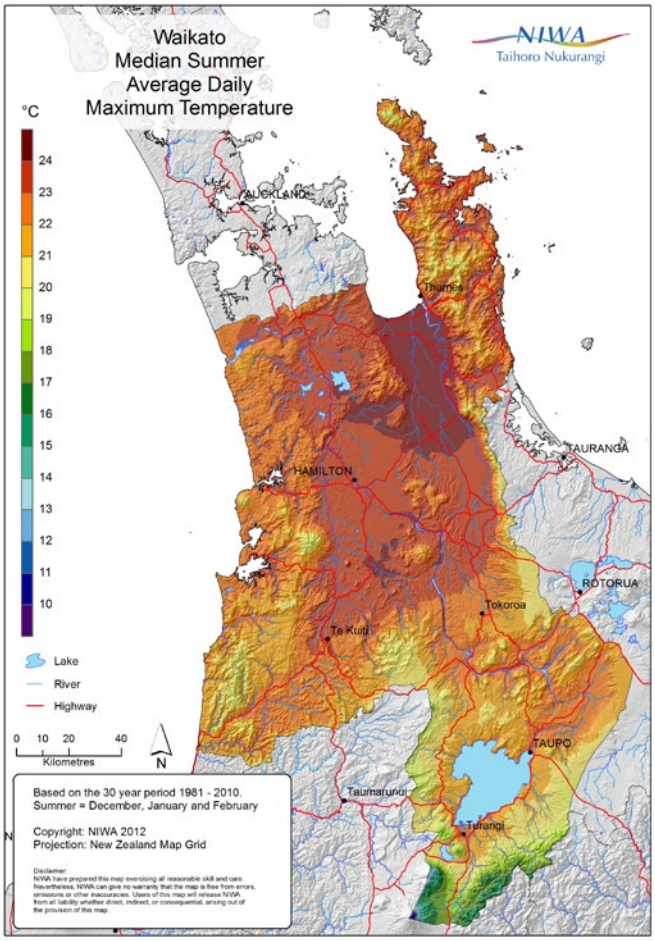
Figure 14. Monthly mean sea surface temperatures (°C) for: a) February; b) August. Source: NIWA SST Archive, Uddstrom and Oien (1999).



Air temperature

In general, the Waikato region is characterised by relatively warm temperatures in the summer (20-25°C mean daily maximum temperature, Figure 15a) and relatively cold temperatures during the winter (0-8°C mean daily minimum temperature, Figure 15b). However, in the high country of Tongariro National Park, conditions are appreciably colder, especially in the winter; with temperatures often well below freezing. Figure 16 shows that median annual average temperature in the Waikato region varies with elevation and latitude. Low-lying areas around the Hauraki Plains and north of Hamilton have a mean annual temperature of around 14°C, whereas the area around Taupo has a mean annual temperature of around 11°C, and higher elevation areas in Tongariro National Park and the Kaimanawa Ranges have a mean annual temperature of less than 8°C. Figure 17 gives the monthly temperature regime (highest recorded, mean monthly maximum, mean daily maximum, mean, mean daily minimum, mean monthly minimum, and lowest recorded) for selected sites in Waikato.





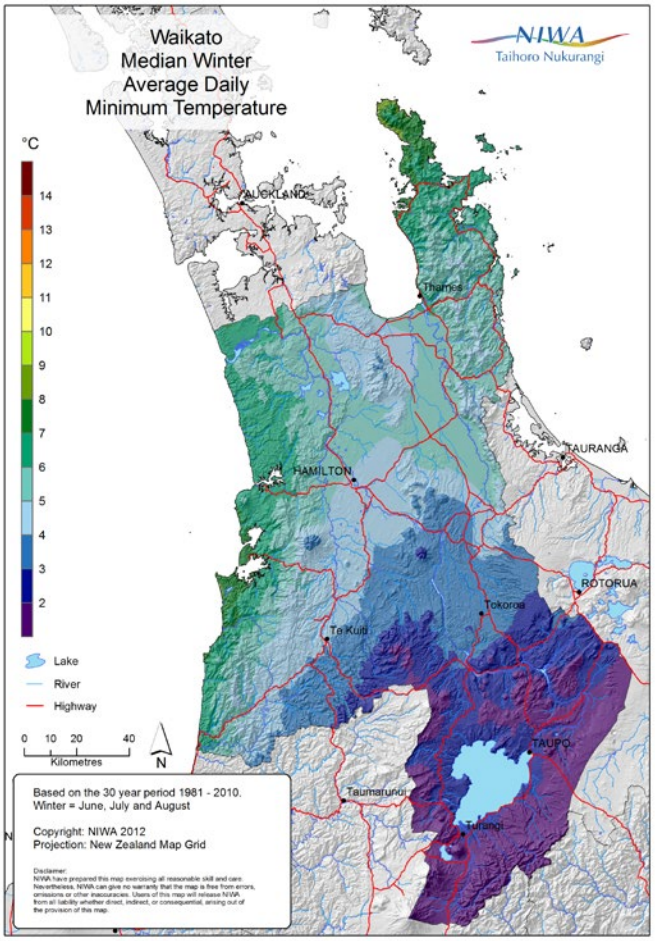


Figure 15. a) Left: Waikato median summer average daily maximum temperature; b) Right: Waikato median winter average daily minimum temperature.

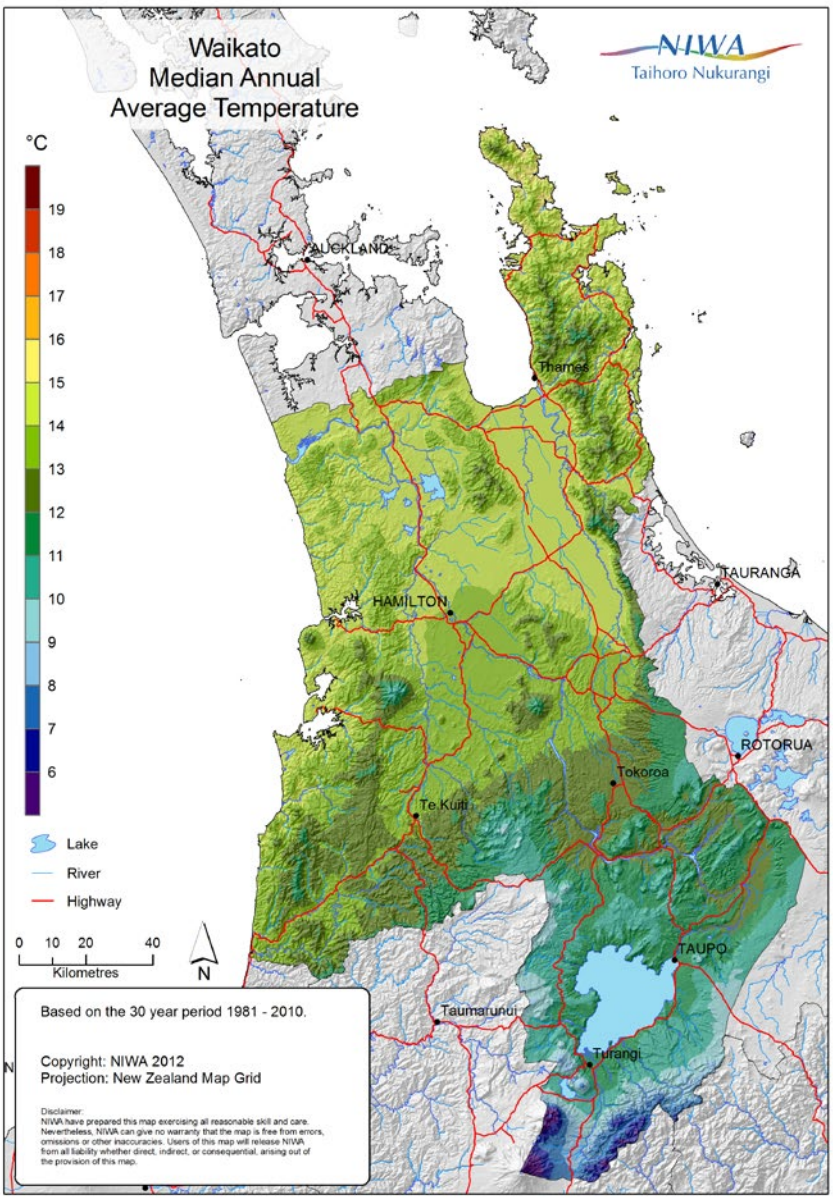


Figure 16. Waikato median annual average temperature, 1981-2010.

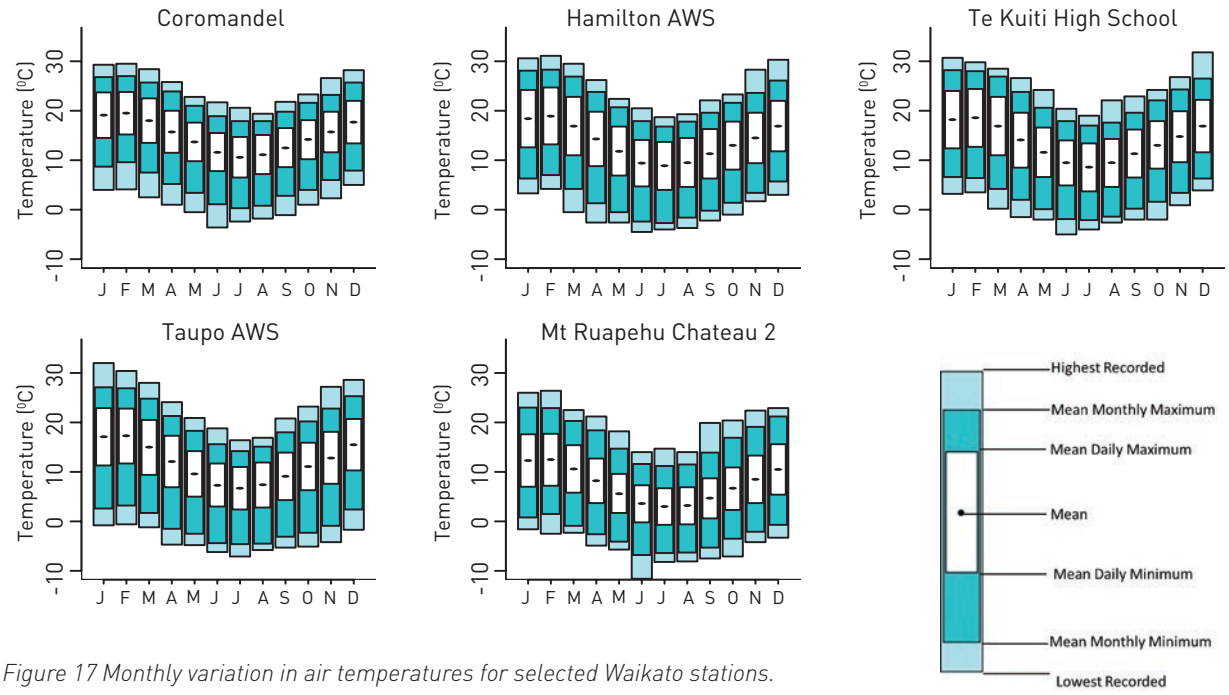


Figure 17 Monthly variation in air temperatures for selected Waikato stations.

The diurnal temperature range for Hamilton is moderate. Table 11 and Figure 18 show mean hourly temperatures for Hamilton AWS for January and July. From this, it can be seen that the average daily range for January is 9.7°C and for July it is 6.9°C.

Table 10. Average daily temperature range (Tmax - Tmin, °C) for Waikato sites.

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Whitianga Aero AWS	10.1	9.5	9.8	9.9	9.1	8.9	8.9	8.9	9.1	8.7	8.9	9.2	9.2
Thames 2	10.1	9.6	9.7	9.4	8.6	8.3	8.3	8.2	8.4	8.4	8.8	8.9	8.9
Port Taharoa AWS	7.6	7.8	8.0	7.3	6.6	6.3	6.8	6.6	6.7	6.5	7.0	6.8	7.0
Hamilton AWS	11.9	11.8	11.9	11.5	10.4	9.7	10.2	10.2	10.1	10	10.4	10.6	10.7
Taupo AWS	11.3	11.1	10.8	10.4	9.3	8.6	8.9	9.2	9.5	9.4	10.4	10.3	9.9
Mt Ruapehu Chateau EWS	11.0	10.5	9.9	9.1	7.9	7.3	7.4	7.5	8.3	8.7	10.0	9.9	9.0

Compared with some other parts of the country, the diurnal temperature range for Hamilton is relatively moderate. Table 11 and Figure 15 show mean hourly temperatures for Hamilton AWS for January and July.

Table 11. Mean hourly temperatures at Auckland Airport in January and July.

hrs	00	01	02	03	04	05	06	07	08	09	10	11
January	15.3	14.9	14.3	14.2	13.9	13.5	14.1	16.0	17.7	19.3	20.5	21.3
July	7.1	6.9	6.6	6.4	6.3	6.2	6.1	6.1	6.1	7.5	9.2	10.6
hrs	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
January	22.2	22.8	23.0	23.1	22.9	22.1	21.3	19.9	18.0	17.1	16.3	15.6
July	11.6	12.5	12.9	12.8	12.7	11.6	10.1	9.3	8.7	8.1	7.7	7.4

The highest maximum temperature in Waikato is 34.8°C, recorded at Waihi on 30 January 1988. The extreme minimum temperature of -13.6°C was recorded at the Mt Ruapehu Chateau in July 1937, which is the lowest temperature on record for the North Island. These extreme temperatures compare to national extremes of 42.4°C and -25.6°C.

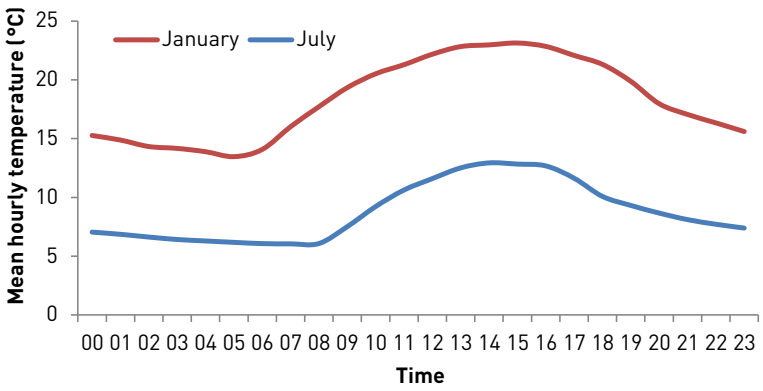


Figure 18. Mean hourly temperatures at Auckland Airport, January and July.

Earth Temperatures

Earth (soil) temperatures are measured once daily at 9 am at several Waikato locations. Earth temperatures are measured at varying depths and are important, amongst other things, for determining the growth and development of plants. Different plants have different rooting depths and as such, earth temperatures are routinely monitored at 10, 20, 30, 50, and 100 cm depths. Table 12 lists mean monthly earth temperatures for a number of standard depths.

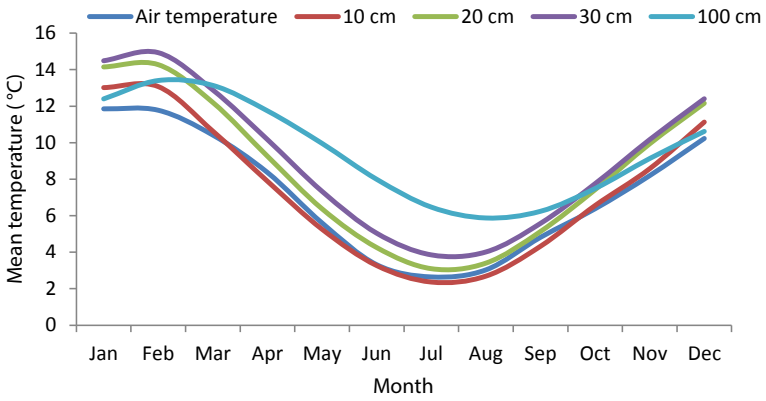


Figure 19. Average monthly 9 am earth temperatures for different depths and mean 9 am air temperature at Mt Ruapehu Chateau.

In the Waikato region, earth temperatures, like air temperatures, vary spatially. The sites at higher elevations and further south, such as Taupo and Mt Ruapehu Chateau, exhibit significantly cooler 9 am earth temperatures than sites at lower elevations and further north, such as Coromandel and Hamilton. Figure 19 shows how earth temperatures change throughout the year at Mt Ruapehu Chateau, compared with air temperature. The temperature cycle for 100 cm depth is more damped and lagged than at shallower depths.

Table 12. Mean 9 am earth temperatures at different Waikato locations, with station elevations.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Coromandel (100 m)	10cm	21	20	18	15	13	11	10	10	12	14	17	19	15
	20cm	22	22	20	17	14	12	11	11	13	15	18	20	16
	30cm	22	22	20	17	15	13	11	12	13	16	18	20	17
	100cm	20	20	20	18	17	15	13	13	14	15	17	18	17
Hamilton, Ruakura (40 m)	10cm	19	18	17	14	11	9	8	9	10	13	15	17	13
	20cm	20	20	19	16	13	11	9	10	12	14	17	19	15
	30cm	20	20	19	16	13	11	10	10	12	14	16	18	15
	100cm	18	19	19	18	16	14	12	12	12	14	15	17	15
Te Kuiti High School (54 m)	10cm	19	19	17	14	11	9	7	8	11	13	16	18	13
	20cm	21	21	19	16	13	11	9	10	12	14	17	19	15
	30cm	21	21	20	17	14	12	10	11	12	15	17	19	16
Taupo NZED (376 m)	10cm	18	18	15	12	9	7	5	6	8	11	14	16	12
	20cm	20	20	17	13	10	8	7	8	10	13	16	18	13
	50cm	20	20	18	14	11	9	7	8	10	13	16	18	14
Mt Ruapehu Chateau 2 (1097 m)	10cm	13	13	11	8	5	3	2	3	4	7	9	11	7
	20cm	14	14	12	9	6	4	3	3	5	7	10	12	8
	30cm	14	15	13	10	7	5	4	4	6	8	10	12	9
	100cm	12	13	13	12	10	8	6	6	6	7	9	11	10

Frosts

Frost is a local phenomenon and its frequency of occurrence can vary widely over very small areas. Areas most likely to be subjected to frost are flat areas, where air is not able to drain away on calm nights, and valleys, where cold air is likely to drift from higher areas.

There are two types of frost recorded. Air frosts occur when air temperature measured in a screen by a thermometer 1.3 m above the ground falls below 0°C. Ground frosts are recorded when the air temperature 2.5 cm above a clipped grass surface falls to -1.0°C or lower. Both types of frosts are common in the inland parts of the Waikato, but less common in coastal areas of the Coromandel Peninsula (see 'Coromandel' entry in Table 13). Table 13 lists for selected sites the mean daily grass minimum and extreme grass minimum temperatures and the average number of days each month with ground and air frosts. Data on air temperatures (mean daily, monthly minima, and extreme minima) can be obtained from Figure 17.



Photo: ©mychillybin.co.nz/Mark Ewington

Table 13. Occurrences of frosts and grass minimum temperatures in Waikato.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Coromandel	a	12.8	13.5	11.8	9.3	7.5	5.6	4.4	4.9	6.6	8.3	9.9	11.6	8.8
	b	3.0	1.4	0.0	-2.0	-4.4	-6.2	-5.9	-4.2	-4.0	-1.4	-1.4	2.2	
	c	0.0	0.0	0.0	0.2	0.6	3.0	4.6	2.5	1.1	0.3	0.0	0.0	12.4
	d	0.0	0.0	0.0	0.0	0.0	1.1	1.9	0.6	0.2	0.0	0.0	0.0	3.8
Hamilton, Ruakura	a	8.9	9.3	7.7	5.3	2.9	1.1	-0.1	1.0	2.5	4.5	6.3	8.0	4.8
	b	-2.9	-1.8	-5.2	-8.3	-8.7	-10.0	-9.4	-8.7	-7.6	-6.7	-5.4	-3.4	
	c	0.1	0.1	1.0	3.1	7.7	11.4	15.0	11.8	7.9	3.4	1.0	0.4	62.9
	d	0.0	0.0	0.0	0.2	2.2	5.8	7.2	4.1	1.3	0.1	0.0	0.0	21.0
Taupo NZED	a	8.4	8.7	7.3	4.4	2.4	0.7	-0.4	0.2	1.7	3.4	5.3	7.4	4.1
	b	-5.6	-5.7	-5.2	-5.6	-9.6	-9.1	-9.6	-10.2	-9.1	-8.2	-6.8	-6.4	
	c	0.4	0.3	1.0	2.9	7.0	11.5	15.3	13.1	8.6	5.7	2.1	0.8	68.8
	d	0.0	0.0	0.1	0.5	3.2	8.2	10.6	7.2	3.7	1.2	0.4	0.0	35.2
Mt Ruapehu Chateau 2	a	5.5	5.5	3.6	1.8	-0.7	-2.3	-2.3	-2.5	-1.1	0.9	2.0	4.0	1.2
	b	-3.7	-5.2	-6.1	-10.1	-9.1	-12.2	-11.6	-12.5	-10.5	-9.9	-8.2	-5.9	
	c	1.9	1.0	4.6	11.2	13.3	13.7	18.2	19.2	15.7	8.1	7.3	3.4	117.5
	d	0.5	0.2	1.8	4.7	8.0	15.7	14.6	18.0	11.0	7.0	3.6	1.5	86.5

a: mean daily grass minimum (°C)
b: lowest grass minimum recorded (°C)
c: average number of ground frosts per month
d: average number of air frosts per month

Sunshine and Solar Radiation

Sunshine

In the Waikato region, an east-west gradient of bright sunshine hours is observed (Figure 20). The Coromandel Ranges and the ranges to the south receive the most bright sunshine hours per year (>2100 hours). Sunshine hours are also high for the area east of Taupo (~2025 hours). This declines to around 1950 hours near Hamilton and Tokoroa, and the lowest bright sunshine hours received in the Waikato region is the hill country around Te Kuiti (~1800 hours). Figure 21 shows the monthly mean, maximum, and minimum recorded bright sunshine hours for selected sites in Waikato.

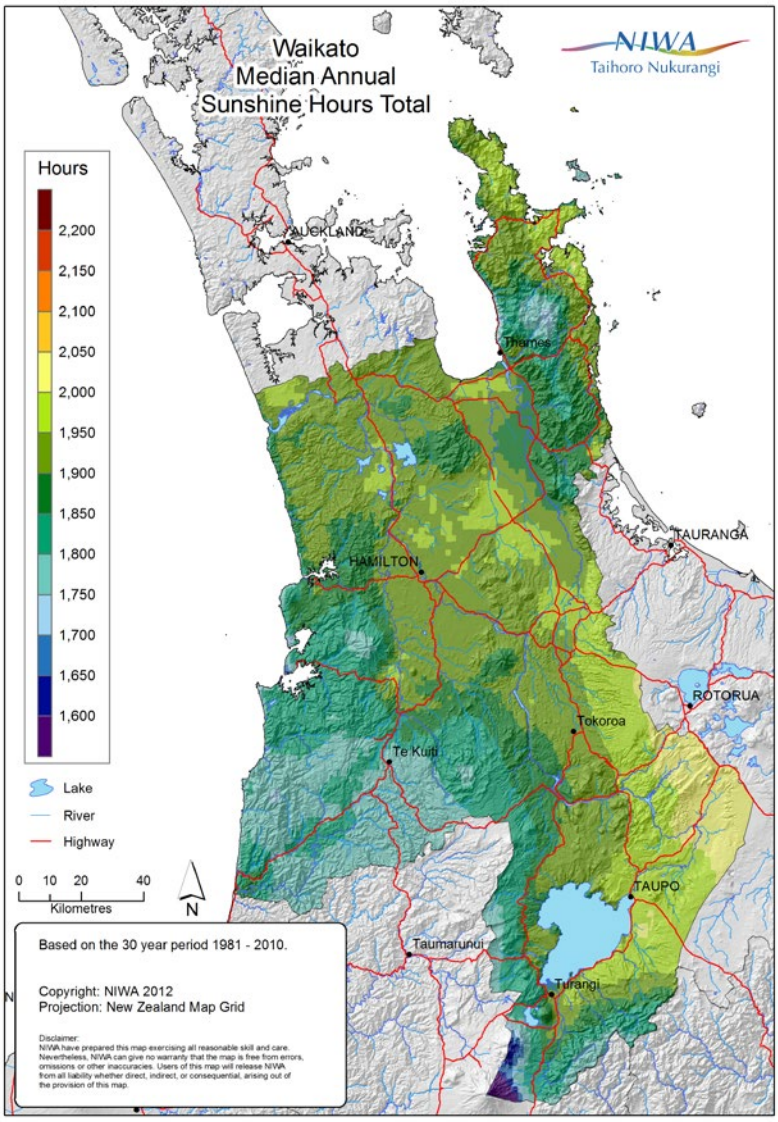


Figure 20. Median annual sunshine hours for Waikato, 1981-2010.

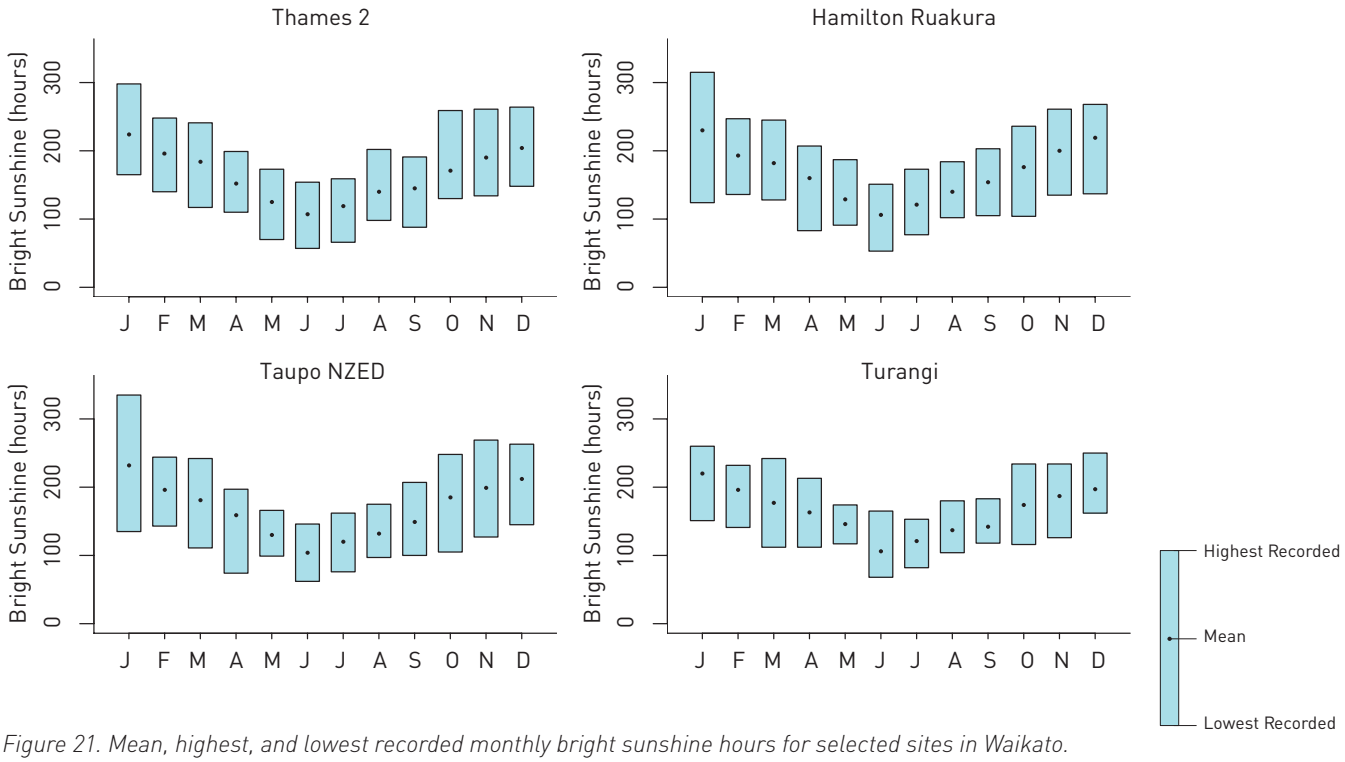


Figure 21. Mean, highest, and lowest recorded monthly bright sunshine hours for selected sites in Waikato.

Solar radiation

Solar radiation records are available for a number of sites in Waikato, but only a few sites have a long record (>10 years). Solar radiation is presented for Whitianga, Paeroa, and Whatawhata for 1981-2010. Insolation is at a maximum in December and January and a minimum in June. Table 14 shows mean daily solar radiation (global) for each month for these three sites.

Table 14. Mean daily global solar radiation (MJ/m²/day) for Waikato sites.

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Whitianga Aero AWS	21	18	15	11	8	6	7	9	13	17	20	21	14
Paeroa AWS	22	19	15	11	8	6	7	9	13	16	19	21	14
Whatawhata	19	16	14	10	7	5	6	8	10	14	16	18	12

UV (Ultra-violet radiation)

Ultra-violet radiation (UV) measurements are not available for any stations in the Waikato region. Table 15 and Figure 22 show the mean monthly UV Index at Leigh, the closest site to the Waikato region, compared with Lauder, a site in the lower South Island. Leigh records higher UV levels than Lauder throughout the year due to Leigh's northern location, although at both sites, summer months record significantly higher UV levels than winter months. Figure 23 shows an example of a UV forecast for Hamilton, and indicates the levels of UV and times of the day where sun protection is required.



Table 15. Mean daily maximum UV Index at Leigh and Lauder.

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Leigh	12.2	10.7	8.4	5.1	2.8	1.8	1.9	3.0	4.8	7.2	9.8	11.5	6.6
Lauder	10.4	8.9	6.0	2.9	1.3	0.8	0.9	1.7	3.3	5.2	7.9	10.0	4.9

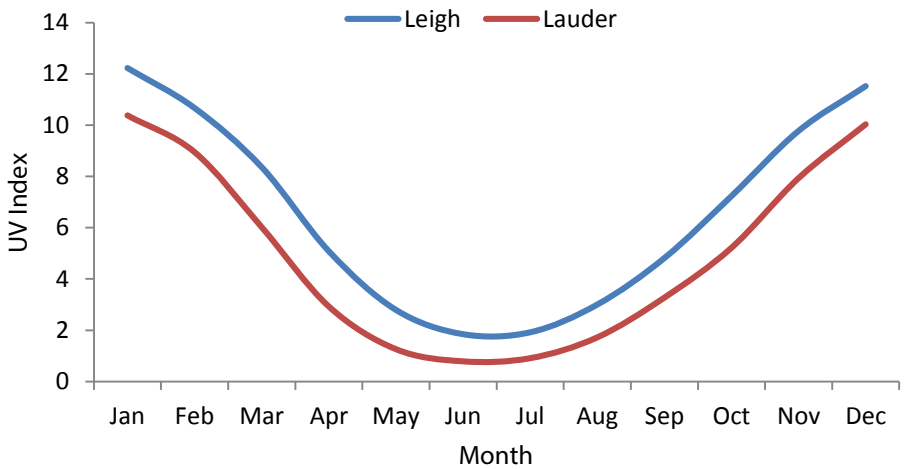


Figure 22. Mean monthly maximum UV Index at Leigh and Lauder.

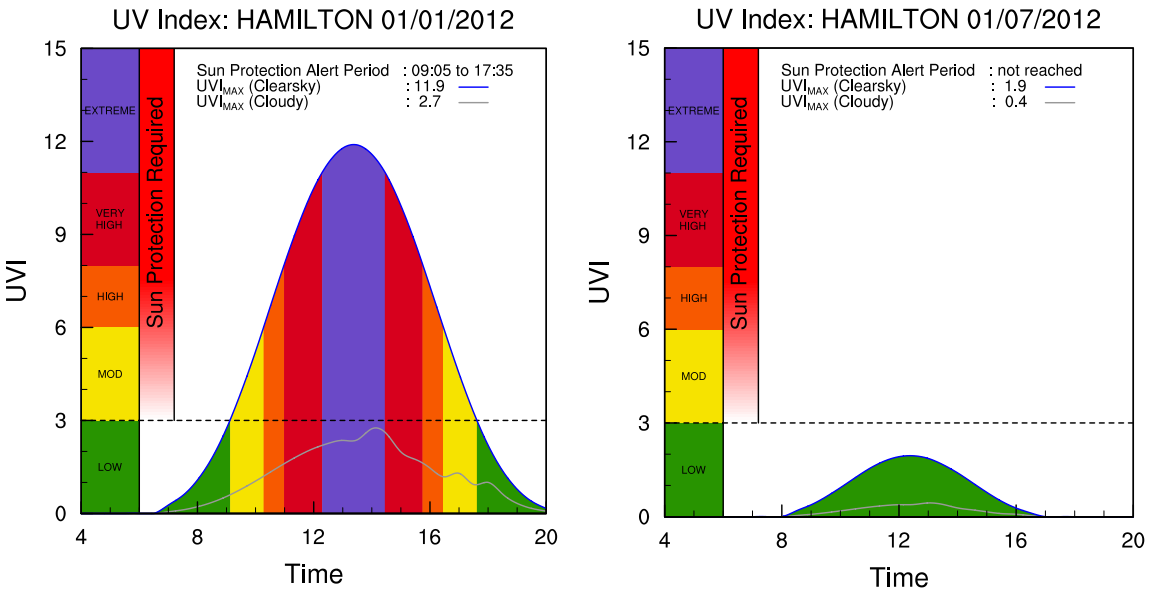


Figure 23. UV Index forecast for Hamilton, January and July. Source: https://www.niwa.co.nz/our-services/online-services/uv-and-ozone

Fog

The most common type of fog in the Waikato region is radiation fog, formed when the air cools to its dew-point on clear nights, allowing the water vapour in the air to condense. Another type of fog sometimes seen in the region is 'steaming fog'. This forms, normally on cold nights, when the water vapour evaporating off lakes and rivers condenses as it rises into the cool air, giving the impression of steam rising off the water surface. Fogs also sometimes form when the humidity of the air near the ground has been raised by falling rain.

The frequency of fog varies widely over the Waikato region, ranging from an average of 50 days with fog per year at Taupo to an average of once every five months in Coromandel. Although fog can occur at any time of the year it is recorded most frequently between March and August. The average number of days per year with fog for selected stations in the Waikato region is listed in Table 16.



Photo: ©mychillybin.co.nz/Myles Andrews

Table 16. Average number of days each year with thunder, fog, and hail, from all available data.

Location	Thunder	Fog	Hail
Coromandel	6	0.4	2
Hamilton, Ruakura	10	38	2
Te Aroha	5	19	2
Te Kuiti High School	8	28	1
Taupo NZED	4	50	1
Mt Ruapehu, Chateau 1	1	10	1

Severe convective storms

Thunderstorms

In Waikato thunderstorms occur throughout the year, and have a maximum frequency in the winter months when cold, unstable air masses cross the region. Average annual frequencies for selected stations are given in Table 16, and range from 10 in Hamilton to only one per year at Mt Ruapehu Chateau. At some of the stations, it is likely that not all the thunderstorms are detected. The heavy rain, lightning, hail, wind squalls, and rare tornadoes which can occur with thunderstorms will sometimes cause severe local flooding, disruption of electrical and electronic equipment, and damage to trees, crops, and buildings.

Hail

There is no significant difference in days with hail throughout the region, the number of which are low (1-2 days per year). As with thunderstorms, an unknown number of hail falls will escape detection at some of the stations. Hail is most likely over the six months from June to November. Table 16 gives the average number of days per year on which hail is reported at selected stations.

Tornadoes

Tornadoes are rapidly rotating columns of air extending from the base of a cumulonimbus cloud, and have in New Zealand a damage path typically 10-20 m wide and 1-5 km long. The small size (compared to tornadoes in the USA), their short lifetimes, and the sparse population of much of New Zealand must result in an unknown number of tornadoes not being reported. During the period 1981-2012, 8 damage-causing tornadoes were reported in the Waikato region. One particularly severe tornado event was on 17 October 2008, when a tornado swept through Cambridge in the early morning. The tornado brought down trees and power lines, including an 80 year old oak tree. More than 100 houses had lost or damaged roofs, with major damage to 15-20 houses. Many cars were also damaged. The tornado caused a water main to burst, which flooded several rooms in the Oakdale Rest Home. In addition, 3500 customers lost power for a number of hours. Following the tornado, about $10 million worth of insurance claims were made.

Sea swell and waves

Much of the swell that affects the west coast of New Zealand originates in the ocean to the south of Australia. On the west coast of the Waikato region, the most frequent swell direction is from the southwest, occurring nearly 40% of the time (Gorman et al., 2003). The frequency of swells less than one metre is about 20%, while swell over two metres occur approximately 35% of the time. Heavy southwest swells are particularly noticeable in winter and spring.

On the east coast of Waikato (Coromandel Peninsula), swells from a northeasterly direction tend to predominate. These can originate from tropical cyclones well to the north of New Zealand or from anticyclones far to the east. Of all swells observed on the eastern coast the frequency of those less than one metre is 50%, while for those greater than two metres is 5% (Gorman et al., 2003).

There is a known relationship between steady wind speed and wave heights over the open sea. The most probable wave heights for a given wind speed over a typical fetch length in New Zealand coastal waters of about 500 km are given in Table 17.

Table 17. Generated wave heights associated with specific wind speeds. Assumes a fetch length of 500 km with unlimited wind duration.

Wind speed (km/hr)	Associated wave height (m)
10	0.5
20	1
30	2
40	3
50	4
75	7
100	11
125	13+





DERIVED CLIMATOLOGICAL PARAMETERS

Apart from elements such as temperature and rainfall which can be measured directly, it has been found that parameters computed from several elements, have some important uses especially in industry. Parameters which define the overall suitability of the climate for agriculture, horticulture, architectural and structural designs, and contracting, etc., are vapour pressure, relative humidity, evapotranspiration (leading to soil water balance), degree-days (thermal time), and rainfall extremes. Some of these and their uses are discussed in the following paragraphs. Short-term high intensity rainfalls have been covered previously.

Vapour pressure and relative humidity

Vapour pressure and relative humidity are the two parameters most frequently used to indicate moisture levels in the atmosphere. Both are calculated from simultaneous dry and wet bulb thermometer readings, although a hygrograph may be used to obtain continuous humidity readings.

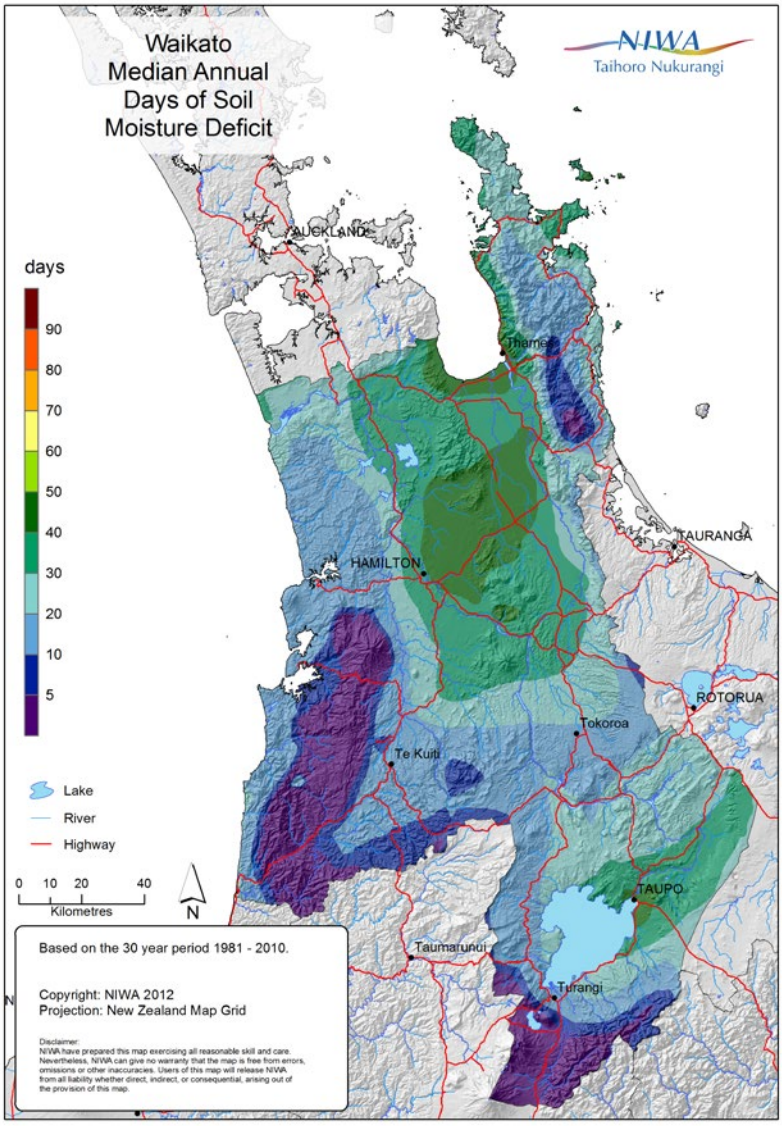


Figure 24. Waikato median annual days of soil moisture deficit, 1981-2010.

Table 18. Mean monthly/annual 9 am vapour pressure (hPa) for selected Waikato sites.

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Coromandel	17.2	17.8	16.6	14.8	13.1	11.6	10.8	11.1	12.0	12.8	13.8	15.8	13.9
Paeroa AWS	16.9	17.3	15.8	14.6	12.7	10.9	10.2	10.7	11.9	12.6	13.5	15.6	13.6
Hamilton AWS	16.6	16.9	15.2	13.9	12.0	10.2	9.6	10.3	11.6	12.4	13.2	15.5	13.1
Te Kuiti High School	16.4	16.3	15.3	13.3	11.6	10.3	9.3	9.9	11.1	12.3	13.4	15.4	12.9
Taupo Aero	14.1	14.4	13.3	11.8	10.3	8.9	8.2	8.6	9.5	10.3	11.2	13.1	11.1
Mt Ruapehu Chateau 2	11.3	11.5	10.6	9.2	7.9	7.0	6.5	6.7	7.3	8.2	8.8	10.1	8.8

Table 19. Mean monthly/annual 9 am relative humidity (%) for selected Waikato sites.

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Coromandel	80	84	83	84	87	89	89	86	82	80	78	78	83
Paeroa AWS	81	84	86	88	91	91	91	89	84	83	79	80	86
Hamilton AWS	81	82	83	83	85	88	87	87	84	85	81	81	84
Te Kuiti High School	78	81	84	86	88	90	89	87	82	81	78	78	83
Taupo Aero	77	80	80	82	86	87	87	84	81	79	76	78	82
Mt Ruapehu Chateau 2	81	83	83	85	89	92	90	87	82	80	79	80	84

Vapour pressure is the part of total air pressure that results from the presence of water vapour in the atmosphere. It varies greatly with air masses from different sources, being greatest in warm air masses that have tropical origins and lowest in cold, polar-derived air masses. Vapour pressure can be important in determining the physiological response of organisms to the environment (very dry air, especially if there is a pre-existing soil moisture deficit, can cause or increase wilting in plants). Average 9 am vapour pressures for several stations are given in Table 18.

Relative humidity is high in all seasons, but there is a peak in winter, as shown in Table 19. In general, there is no discernible difference in relative humidity between sites.

Evapotranspiration and soil water balance

Evapotranspiration is the process where water held in the soil is gradually released to the atmosphere through a combination of direct evaporation and transpiration from plants. A water balance can be calculated by using daily rainfalls and by assuming that the soil can hold a fixed amount of water with actual evapotranspiration continuing at the maximum rate until total moisture depletion of the soil occurs. The calculation of water balance begins after a long dry spell when it is known that all available soil moisture is depleted or after a period of very heavy rainfall when the soil is completely saturated. Daily calculations are then made of moisture lost through evapotranspiration or replaced through precipitation. If the available soil water becomes insufficient to maintain evapotranspiration then a soil moisture deficit occurs and irrigation becomes necessary to maintain plant growth. Runoff occurs when the rainfall exceeds the soil moisture capacity (assumed to be 150 mm for most New Zealand soils). The Waikato region is comparatively well served by frequent rainfalls in winter, but due to high evapotranspiration and a minimum of rainfall, soil moisture levels in summer are frequently such that irrigation or watering is necessary.

Mean monthly and annual water balance values are given in Table 20, for a number of sites in Waikato. It can be seen from this table that eastern parts of Waikato have about 34 days between November

Table 20. Mean monthly/annual water balance summary for a soil moisture capacity of 150 mm.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Coromandel	DE	48	33	10	2	0	0	0	0	0	0	4	33	129
	ND	11	8	3	1	0	0	0	0	0	0	1	7	31
	RO	29	32	53	91	76	172	199	165	123	57	47	54	1098
	NR	1	1	2	4	7	12	12	12	8	4	2	2	66
Paeroa AWS	DE	80	55	29	5	1	0	0	0	0	0	11	40	221
	ND	17	13	9	3	1	0	0	0	0	0	3	9	57
	RO	9	12	2	22	27	115	154	79	40	21	9	12	503
	NR	0	0	0	1	3	11	12	11	5	3	1	1	48
Hamilton AWS	DE	51	50	26	7	1	0	0	0	0	0	8	24	167
	ND	12	13	8	4	1	0	0	0	0	0	2	6	46
	RO	2	12	1	16	44	109	120	98	49	39	8	8	508
	NR	0	1	0	1	5	12	13	13	6	4	1	1	58
Te Kuiti High School	DE	20	27	13	2	0	0	0	0	0	0	0	3	65
	ND	5	8	5	1	0	0	0	0	0	0	0	1	20
	RO	20	8	9	35	96	135	141	121	82	66	35	38	788
	NR	1	1	1	3	9	14	13	13	9	6	3	3	76

DE is the average amount of soil moisture deficit in mm
ND is the average number of days per month on which a soil moisture deficit occurs
RO is the average amount of runoff in mm
NR is the average number of days per month on which runoff occurs

and April when there is insufficient soil moisture to maintain plant growth without irrigation, but only 13 days in western areas (Te Kuiti). There is adequate moisture available to maintain plant growth between May and October. Figure 24 shows region-wide variability in days of soil moisture deficit per year.

The Waikato region experienced a major drought between November 2007 and March 2008. Severe soil moisture deficits (more than 130 mm of deficit) were present in the region. Numerous locations in the region experienced record or near-record low rainfall during January, including the lowest recorded January rainfall at Ruakura since records began in 1906 (4 mm, 4% of normal January rainfall). The combination of hot and dry conditions meant that dairy farmers continued drying off dairy stock, and sheep farmers had to sell stock early. The stock feed situation remained very low in drought-stricken areas, and the price of feed significantly increased. Water restrictions were also in place for both urban and rural areas. Rainfall in April 2008 ended the severe and significant soil moisture deficits in the region. This drought dramatically affected production from pastoral agriculture in the western North Island, with economic costs of at least $1 billion, and the Ministry of Agriculture and Forestry reporting an 11% fall in sheep numbers due to the drought. Figure 25 shows the soil moisture deficits reached at Ruakura and Te Kuiti over the drought period, compared to normal soil moisture deficit conditions for the same time of year at Ruakura (soil moisture deficit from October to May averaged from 1981-2010).

Potential evapotranspiration (PET) has been calculated for Thames, Hamilton, Te Kuiti, and Taupo, using the Penman method (Penman, 1948). The monthly mean, minimum, and maximum PET values are listed in Table 21. These values were calculated from all available data.

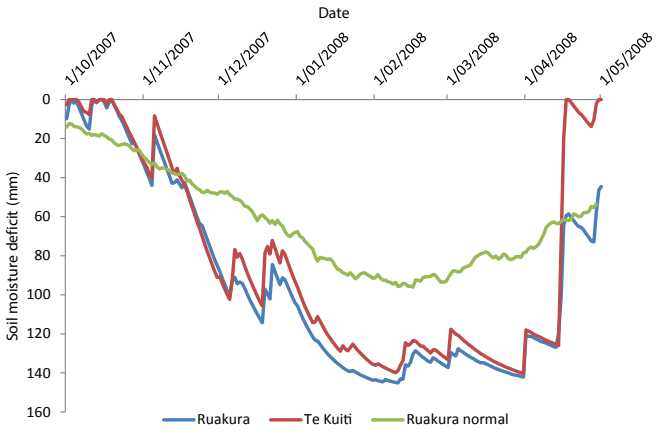


Figure 25. Soil moisture deficit at Ruakura and Te Kuiti during the November 2007 to March 2008 drought, compared with normal soil moisture deficit conditions for the same time of year at Ruakura (1981-2010).

Table 21. Penman calculated maximum, mean, and minimum monthly potential evapotranspiration (mm), as well as total mean annual PET.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Thames 2	Max	170	130	111	68	43	30	34	48	73	113	138	164	
	Mean	145	117	97	60	36	23	28	41	61	93	117	138	954
	Min	118	106	83	45	24	15	19	23	37	60	94	107	
Hamilton, Ruakura	Max	147	119	96	54	34	20	26	39	59	86	118	138	
	Mean	127	102	82	47	25	16	19	33	52	79	103	122	807
	Min	109	85	70	38	21	11	14	27	43	65	90	103	
Te Kuiti High School	Max	139	106	87	48	25	15	20	36	54	83	102	127	
	Mean	119	98	77	43	23	12	16	29	48	73	93	110	740
	Min	104	85	67	35	18	9	14	25	41	64	84	96	
Taupo NZED	Max	173	120	98	55	35	21	25	36	63	93	126	147	
	Mean	135	106	82	47	26	16	19	31	52	82	107	126	829
	Min	107	94	69	38	21	11	14	26	42	62	83	103	

Degree-day totals

The departure of mean daily temperature above a base temperature which has been found to be critical to the growth or development of a particular plant is a measure of the plant's development on that day. The sum of these departures then relates to the maturity or harvestable state of the crop. Thus, as the plant grows, updated estimates of harvest time can be made. These estimates have been found to be very valuable for a variety of crops with different base temperatures. Degree-day totals indicate the overall effects of temperature for a specified period, and can be applied to agricultural and horticultural production. Growing degree-days express the sum of daily temperatures above a selected base temperature that represent a threshold of plant growth. Table 22 lists the monthly totals of growing degree-day totals above base temperatures of 5°C and 10°C for sites in the Waikato region.

Cooling and heating degree days are measurements that reflect the amount of energy that is required to cool or heat buildings to a comfortable base temperature, which in this case is 18°C. Table 23 shows that the number of cooling

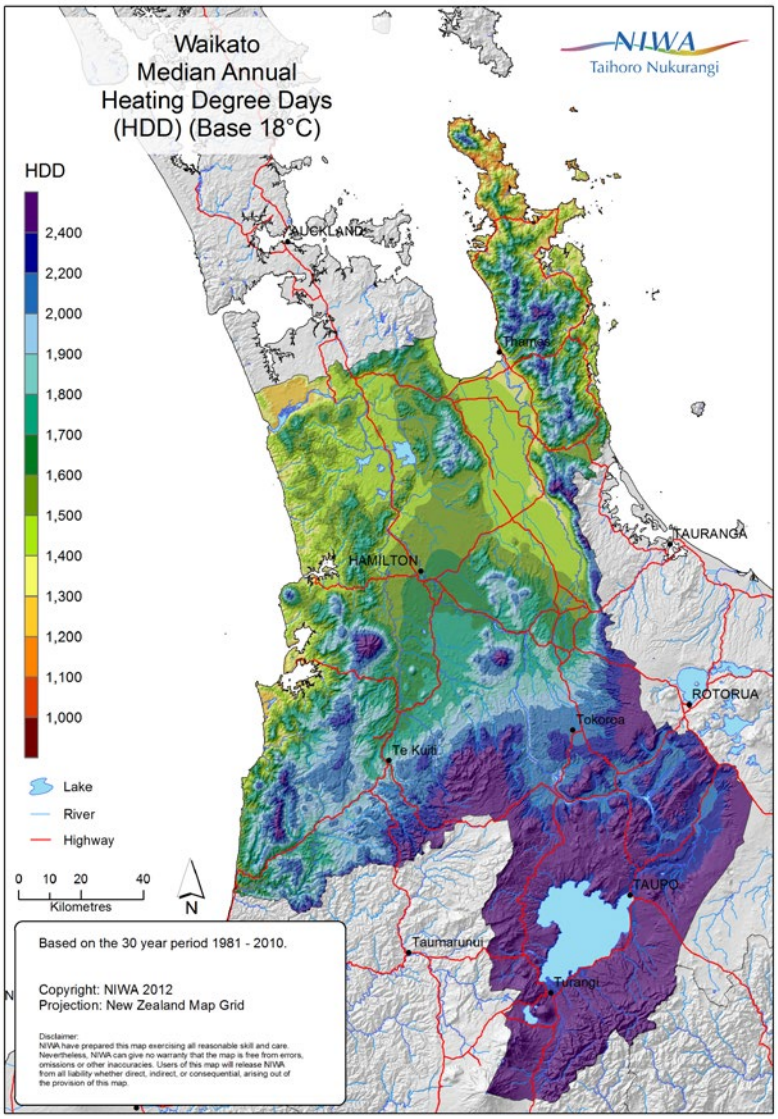


Figure 26. Median annual heating degree days for Waikato, 1981-2010

Table 22. Average growing degree-day totals above base 5°C and 10°C for selected Waikato sites, from all available data.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Coromandel	5°C	439	410	403	320	267	194	175	189	227	284	323	393	3624
	10°C	284	268	248	171	114	60	43	46	81	129	173	238	1856
Paeroa AWS	5°C	448	419	391	307	245	172	153	172	219	272	310	395	3502
	10°C	293	278	236	159	98	51	37	39	75	119	160	240	1784
Hamilton Ruakura	5°C	400	377	367	275	198	126	110	142	184	245	288	355	3068
	10°C	245	235	213	127	60	25	16	23	48	93	139	200	1424
Te Kuiti High School	5°C	412	383	373	274	195	123	104	137	187	251	293	368	3101
	10°C	257	242	218	126	57	22	13	20	48	98	144	213	1458
Taupo NZED	5°C	380	350	329	225	142	79	57	81	131	201	257	332	2564
	10°C	225	209	174	81	26	8	2	5	18	58	109	178	1094
Mt Ruapehu Chateau 2	5°C	221	213	167	94	43	9	7	5	25	59	100	164	1107
	10°C	75	78	40	9	2	0	0	0	1	2	10	38	255

degree days reach a peak in summer in Waikato, where there is a higher demand for energy to cool building interiors to 18°C. Conversely, heating degree days reach a peak in winter, where the demand for energy to heat buildings to 18°C is highest. Figure 26 shows region-wide variability in the number of heating degree days per year. The number of heating degree days tends to be lower in low elevation coastal areas, compared with areas further inland and at higher elevations.

Table 23. Average cooling (CDD) and heating (HDD) degree-day totals with base 18°C for selected Waikato sites, from all available data.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Coromandel	CDD	47	48	27	5	1	0	0	0	0	0	3	20	152
	HDD	11	6	27	75	137	196	228	214	163	120	71	30	1276
Paeroa AWS	CDD	57	59	25	7	1	0	0	0	0	0	3	25	177
	HDD	11	7	36	90	159	219	250	231	171	131	84	33	1425
Hamilton Ruakura	CDD	28	32	17	3	0	0	0	0	0	0	2	11	94
	HDD	31	23	53	118	206	266	296	261	206	159	103	59	1780
Te Kuiti High School	CDD	35	35	19	3	0	0	0	0	0	0	2	15	109
	HDD	26	19	49	119	208	269	301	266	203	152	99	50	1760
Taupo NZED	CDD	20	20	7	0	0	0	0	0	0	0	1	7	54
	HDD	43	36	82	166	261	317	356	326	259	202	134	77	2259
Mt Ruapehu Chateau 2	CDD	0	0	0	0	0	0	0	0	0	0	0	0	0
	HDD	182	154	237	301	379	449	464	464	399	351	291	240	3912



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