

IN THE MATTER of the Resource Management
Act 1991

AND

IN THE MATTER of a Board of Inquiry appointed
under s146 of the Resource
Management Act 1991 to
consider an application by
Mighty River Power Limited for
resource consents to construct,
operate, and maintain a wind
farm at Turitea

EVIDENCE OF MICHAEL JAMES SALINGER

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INTRODUCTION

- 1. My name is Michael James Salinger. I am an Honorary Research Fellow of the School of Geography, Geology and Environmental Sciences, University of Auckland. I have 34 years' professional experience in many aspects of climate research.**

- 2. I have a Doctorate in Physical Geography from Victoria University of Wellington, specialising in New Zealand climate and climate change. I have an M.Phil in Environmental Law from the University of Auckland. I am a Companion of the Royal Society of New Zealand, a member of the Meteorological Society of New Zealand, and President of the Commission for Agricultural Meteorology for the World Meteorological Organization. I was one of the lead authors for the Fourth Report of the Inter-Governmental Panel on Climate Change (IPCC).**

- 3. My field of expertise relates to all aspects of climate, with a particular interest in climate variability and change. This includes regional and district climates in New Zealand, their extremes, short and long-term variability and climate change, which includes rainfall.**

- 4. My most recent experience relevant to the Turitea proposal includes work for the Manukau City Council on storm rainfall across the city, including under scenarios of climate variability and change for the 2050s and 2090s, and similar work for the Hastings City Council.**

- 5. I confirm that I have read and am familiar with the Code of Conduct for Expert Witnesses in the Environment Court Consolidated Practical Note (2006). I agree to comply with this Code of Conduct and my evidence has been prepared in compliance with this Code.**

PURPOSE AND SCOPE OF EVIDENCE

- 6. My evidence covers the following matters in relation to climate and rainfall in the area of the proposed wind farm:**

- a. Estimation of the annual and seasonal rainfall across the Turitea Wind Farm;
- b. Estimation of the average recurrence interval high intensity rainfalls for 2-10 years;
- c. Evaluation of visibility;
- d. Seasonal to interannual variation in rainfall due to climate variability;
- e. Long term trends in temperature, rainfall and wind because of climate change.

RAINFALL

7. Annual and seasonal rainfall has been assessed using rainfall data from the vicinity of the proposed wind farm. Except for one site, the data was obtained from the NIWA National Climate Database. The data from the Turitea Dam location was obtained from the Palmerston North City Council rain-gauge monitoring site near the Upper dam in the lower Turitea stream catchment.

Table 1. Rainfall stations used to estimate rainfall for the proposed Turitea Wind farm area.

Station	Network No.	Latitude °S	Longitude °E	Elevation (metres)	Source
AgResearch*	E05363	-40.38	175.61	34	NIWA
Turitea 1	E05463	-40.42	175.67	83	NIWA
Turitea 2 *	E05464	-40.43	175.66	131	NIWA
Turitea Dam		-40.43	175.88	280	PNCC
Makomako*	D05471	-40.46	175.73	158	NIWA
Kahuterawa Watershed	E05463	-40.47	175.62	N/A	NIWA

* Longer term rainfall monitoring.

8. Monthly and annual rainfall data were compared between the shorter term sites to those with longer term records. From ratios of monthly and annual rainfalls over the same periods of records, rainfall normals for the period 1971 – 2000 were calculated. These are given in Table 2.

Table 2. Calculated normals for monthly, seasonal and annual rainfall (mm) for the period 1971-2000 for rainfall stations near the Turitea Wind Farm area.

	J	F	M	A	M	J	J	A	S	O	N	D	Annual
AgResearch*	65	62	74	76	94	87	94	82	83	91	78	83	967
		210			244			263			252		
Turitea 1	98	65	65	91	105	129	131	101	86	102	104	126	1203
		289			261			361			292		
Turitea 2*	82	90	93	93	132	119	128	111	111	115	88	109	1272
		281			318			358			314		
Turitea Dam	89	86	102	105	130	121	130	114	115	125	108	115	1340
		290			337			365			348		
Makomako*	103	100	114	114	145	156	159	135	139	150	133	127	1573
		330			373			450			422		
Kahuterawa	113	110	128	129	162	162	170	146	149	162	141	143	1715
Watershed		366			419			478			452		

* Normals provided for these sites by NIWA. Others have been calculated.

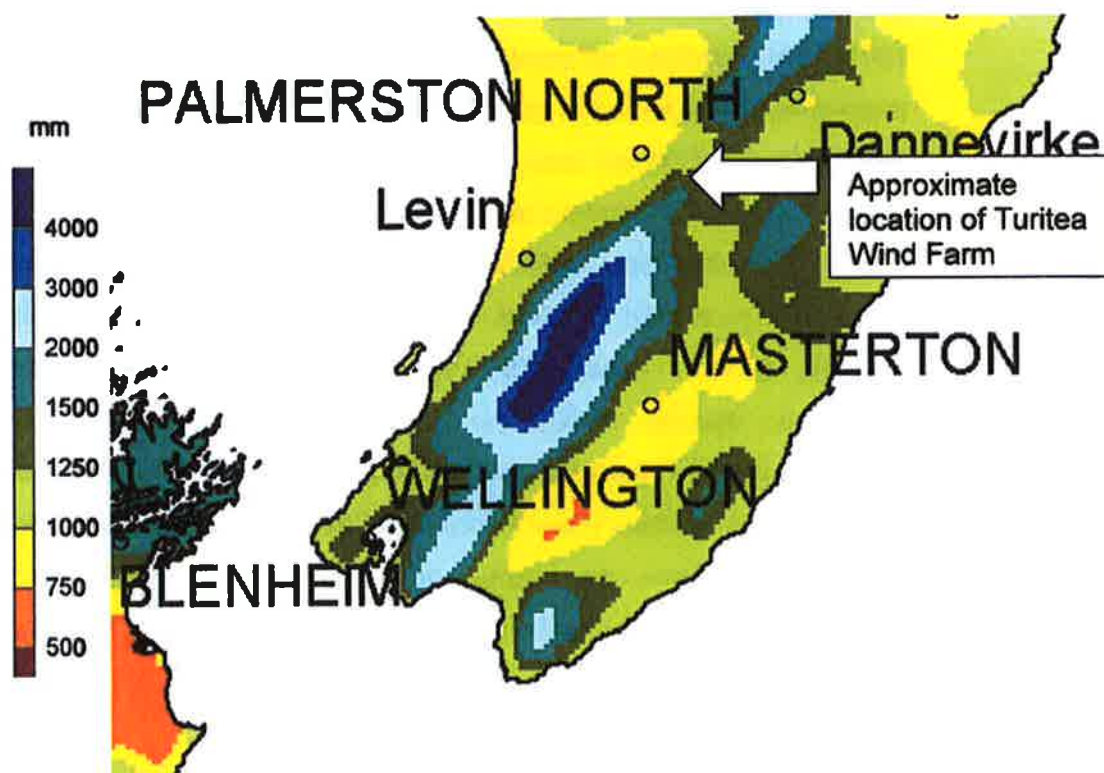


Figure 1. Median annual rainfall in millimetres, 1971-2000 (Source: NIWA, 2004).

9. Annual rainfall (Table 2 and Figure 1) varies from just over 1300 mm in the north of the proposed wind farm site to about 1800 mm in the south. There is an increase in rainfall from about 1300 mm in the northwest to 1600 mm in the northeast, and from 1700 mm in the southwest to 1800 mm in the south and southeast. Summer is the season with the least rainfall, ranging from about 290 mm to 370 mm, and winter has the most, from 340 mm to 500 mm. The northern end of the Tararua Ranges has lower elevations, and therefore seasonal and annual rainfall amounts are lower than those recorded to the south in the middle part of the Tararua Ranges.
10. The heaviest falls occur with the approach of an active frontal system preceded by a moist northwest airflow.
11. Rainfall intensities for two locations for Turitea have been calculated by two methods: the first used the HIRDS version 2 software developed by NIWA. This provides estimation for any point in New Zealand where there is not a long enough rainfall history. Such longer term records do not exist for the Turitea area. These are given in Table 3. The second method examined monthly maximum daily rainfall for the three sites Turitea 2, Turitea Dam, and Makomako. Turitea 2 is on the western fringe, with a period of record from January 1967- February 1992. Records at the Turitea Dam commenced in November 2003. Makomako records cover the period from November 1957 to September 2007. The last site can be taken as fairly representative of the proposed Turitea Wind Farm area, being at moderate elevation (158 metres above sea level), and with higher rainfall than the Manawatu flatlands to the west of the Tararua Ranges. These are given in Table 4.

Table 3. Rainfall intensity rates, in millimetres for various average recurrence intervals (ARIs) for durations from 10 minutes to 72 hours (3 days). Calculations are based on HIRDS software.

Turitea Dam: Latitude 40° 26' S, Longitude 175° 53' E

ARI	Duration									
	10m	20m	30m	60m	2h	6h	12h	24h	48h	72h
2	6.9	9.5	11.6	16.0	21.5	34.4	46.2	62.1	75.6	84.9
10	10.7	14.4	17.1	23.0	30.6	48.1	64.0	85.1	101.6	112.7
20	13.0	17.3	20.4	27.1	35.9	55.9	74.0	98.0	115.9	127.9
30	14.7	19.4	22.7	30.0	39.5	61.3	80.9	106.8	125.6	138.2
40	16.1	21.0	24.6	32.2	42.4	65.6	86.4	113.8	133.3	146.3
50	17.3	22.5	26.2	34.2	44.9	69.3	91.1	119.7	139.8	153.0
60	18.3	23.7	27.7	35.9	47.1	72.5	95.1	124.9	145.4	159.0
70	19.3	24.9	28.9	37.4	49.1	75.4	98.8	129.5	150.4	164.2
80	20.1	25.9	30.1	38.8	50.9	78.0	102.1	133.7	155.0	169.0
100	21.7	27.9	32.2	41.4	54.1	82.7	108.0	141.2	163.1	177.5
125	23.5	30.0	34.6	44.1	57.6	87.8	114.5	149.3	171.9	186.7
150	25.1	31.9	36.7	46.6	60.7	92.3	120.2	156.5	179.6	194.7

Turitea South: Latitude 40° 30' S, Longitude 175° 39' E

ARI	Duration									
	10m	20m	30m	60m	2h	6h	12h	24h	48h	72h
2	8.4	12.3	15.4	22.7	31.4	52.5	72.7	100.5	126.4	144.5
10	12.8	18.3	22.6	32.4	44.4	73.2	100.2	137.4	169.4	191.5
20	15.5	21.9	26.8	37.9	51.8	84.7	115.7	157.8	192.9	217.0
30	17.4	24.4	29.8	41.8	56.9	92.8	126.3	171.9	209.0	234.3
40	18.9	26.4	32.1	44.9	61.0	99.1	134.7	183.0	221.6	247.9
50	20.3	28.1	34.2	47.5	64.5	104.5	141.8	192.3	232.2	259.3
60	21.4	29.7	35.9	49.8	67.5	109.2	148.0	200.5	241.5	269.2
70	22.5	31.1	37.6	51.9	70.2	113.5	153.6	207.8	249.7	278.1
80	23.5	32.3	39.0	53.8	72.8	117.3	158.7	214.5	257.2	286.1
100	25.3	34.6	41.7	57.2	77.2	124.2	167.7	226.4	270.6	300.3
125	27.2	37.2	44.6	60.9	82.1	131.7	177.5	239.2	284.9	315.6
150	29.0	39.4	47.2	64.2	86.4	138.3	186.1	250.5	297.5	329.0

Table 4. Average maximum 1-day rainfall rates, in millimetres for each month of the year, and for average recurrence intervals of 1, 2, 5 and 10 years derived from the three sets of station records

SITE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	1- YR	2- YR	5- YR	10- YR
	Turitea 2	31	29	32	28	35	34	27	23	27	30	25	32	61	71	84
Turitea Dam	35	36	20	22	31	24	24	29	31	36	27	25	68	76		
Makomako	38	38	36	35	39	35	38	30	36	39	36	39	70	81	94	103

12. The 2-year average recurrence interval (ARI) daily intensity fall ranges from 62 mm to 100 mm, and the 10-year ARI fall from 85 mm in the north to 137 mm in the south. Comparable 3 day averages range from

85 to 145 mm for a 2-year ARI, to 113 to 192 mm for a 10-year ARI. Therefore the sedimentation ponds being used during the construction period would need to be large enough to cope with these volumes of runoff.

13. The monthly and annual, 2, 5 and 10-year average maximum daily rainfall rates in millimetres are shown in Table 4. The monthly average maximum daily rainfall rates. For any individual month, daily maximum rainfall rates varied from 23 to 36 mm in the Turitea sites, and 30 to 39 mm in the wetter Makomako site. Slightly higher monthly daily maximum rainfall rates would be expected in the south of the proposed wind farm area. Analyses of these records suggest 2 year ARI 1-day rainfall rates of between 71 and 81 mm, which compares satisfactorily with the HIRDS derived values of 62 and 100 mm respectively for the drier and wetter parts of the wind farm area. Comparable 10 year ARI 1-day rainfall rates for the two sites with longer records are both 103 mm, which compares with the HIRDS values of 85 mm in the north, and 137 mm in the south. This comparison suggests that the HIRDS derived 1-day intensities may be slightly low for the northern area, but a good estimate of daily rates for the southern part of the wind farm area.

VISIBILITY

14. Assessing the clarity of the atmosphere from Palmerston North through meteorological factors can be achieved by two methods: direct observations of visibility made at Palmerston North Airport, and statistics on occurrence of fine days in Palmerston North from direct measurements of bright sunshine hours.

15. Direct observations of visibility are available from Palmerston North Airport between 1 January 1965 and 13 May 1998. These observations were made by Air Traffic Control staff in the control tower, and are visibility measurements, in kilometres. Distances of various landmarks and geographic features from the airport are measured on a

topographic map, and these are used as markers. The visibility is estimated from the most distant marker which is just visible from the control tower. As the readings are made when the various markers are no longer visible, the readings are conservative. These measurements have been made every hour during daylight observations when the airport is open. The results from 64995 hourly observations are given in Table 4.

Table 4. Percent frequency of visibility measured at Palmerston North Airport 1 Jan 1965 – 13 May 1998, from hourly observations. Data obtained from the NIWA National Climate Database.

Visibility (kilometres)	Frequency	Percent frequency
> 99 km	507	0.8
> 90 km	834	1.3
> 80 km	1663	2.6
> 70 km	5211	8.0
> 60 km	7090	10.9
> 55 km	9222	14.2
> 50 km	21831	33.6
> 40 km	27444	42.2
> 30 km	34613	53.2
> 20 km	50940	78.3

16. The data show that in New Zealand visibility is very good. However, in the Manawatu area the atmosphere does have some haziness and cloud, except on very clear days. This will make some objects on a skyline less visible. As the view of visibility for Palmerston North Airport is judged by when the marker is just barely visible, then for a skyline object to be clearly visible will have to be at the upper end of the visibility range. For these purposes a visibility distance of an object at 55 km or more would depict a very clear atmosphere. Table 4 shows that such a visibility is attained or exceeded 14 percent of the time at Palmerston North Airport.

17. Visibility was also assessed by examination of bright sunshine hours measured at a number of nearby locations. Fine days were assessed

as a day when 80 percent or more of the possible daily sunshine. Days with less sunshine are indicative of partly cloudy to cloudy and overcast conditions when skyline views will be less clear. These statistics are shown in Table 5. The data show that for autumn, winter and spring between 15 to 17 percent of the days are very clear and sunny. This increases to 20 percent in summer.

Table 5. Days with approximately 80 percent or more of the possible daily bright sunshine, after Burgess 1987.

Station	Spring	Summer	Autumn	Winter
Ohakea	20	26	23	20
AgResearch	15	20	16	17
Dannevirke	14	19	19	13

Table 6. Percentage of days without any sunshine, after Burgess 1987

Station	Spring	Summer	Autumn	Winter
Ohakea	6	5	7	13
AgResearch	8	6	13	15
Dannevirke	9	8	12	14

18. Both direct observations of visibility at Palmerston North Airport, and measurement of bright sunshine hours give a guide to the frequency of occurrence of very clear conditions at Palmerston North. These observations indicate that a very clear environment will occur about 15 percent of the time in autumn, winter and spring, and about 20 percent of the time in summer months.

CLIMATE VARIABILITY AND CHANGE

19. New Zealand climate varies with two key natural cycles that operate over timescales of years (El Niño-Southern Oscillation, ENSO) and decades (Interdecadal Pacific Oscillation, IPO). Trends and variations in local climate over the next decades will be a combination of these natural climate variations and those resulting from increases in greenhouse gas emissions.

20. The El Niño/Southern Oscillation (ENSO) is a natural feature of the global climate system. El Niño events occur irregularly, about 3 to 7 years apart, typically becoming established around April or May and persisting for about a year thereafter. In El Niño years, New Zealand tends to experience stronger and/or more frequent west to southwest winds, and enhanced rainfall in the south and west of the South Island. La Niña events bring roughly the opposite changes: weaker westerly winds occur in summer, with more northerly quarter winds at other times, and there is usually enhanced rainfall in the north and east.

21. The Interdecadal Pacific Oscillation, or IPO, is a Pacific-wide natural fluctuation in the climate, which causes abrupt "shifts" in Pacific circulation patterns that persist for decades. There are two phases, positive and negative. The positive phase produces more westerly quarter winds over the country, with generally wetter conditions in the west and south. In the negative phase, with weaker westerlies over the country, more easterlies and north easterlies occur over northern New Zealand, with increased tropical disturbances.

22. Global warming effects are expected to accumulate during the 21st century, and enhance already observed changes in regional climate that have affected many physical and biological systems. Expected changes out to 2100 for New Zealand include: increases in westerly winds, increases in temperature of between 0.5 and 3.5°C, decreases in frost risk, wetter in the west and drier in the east, increases in the frequency of extreme daily rainfalls and sea level rises averaging 4 cm/decade. However, over a single decade these changes are likely to be overwhelmed by the natural variations discussed above. In particular, rainfall changes are likely to be overridden by ENSO climate impacts.

CLIMATE VARIABILITY

23. In the next few years, over the construction period of the proposed wind farm, ENSO will be the largest mechanism causing variability in

the Manawatu region. Analysis of the present IPO status suggests that the climate is now in the negative phase, and likely to remain in this state for the next decade or so.

24. The El Niño is a natural feature of the climate system. The term was originally used by fishermen for the occasional warming of waters along the Peruvian coast, which typically happens around Christmas. The warming extends out along the Equator from the South American coast to the central Pacific. It is accompanied by large changes in the tropical atmosphere, lowering pressures in the east and raising them in the west, in what is known as the “Southern Oscillation”. In the late 1960’s and early 1970’s, scientists realised that El Niño and the Southern Oscillation were linked, with one component in the ocean and the other in the atmosphere. This became known as ENSO. A convenient way of measuring ENSO is in terms of the east-west pressure difference, the Southern Oscillation Index, or SOI, which is a scaled form of the difference in mean sea-level pressure between Tahiti and Darwin. A graph of the SOI over the past 30 years is shown in Figure 2.

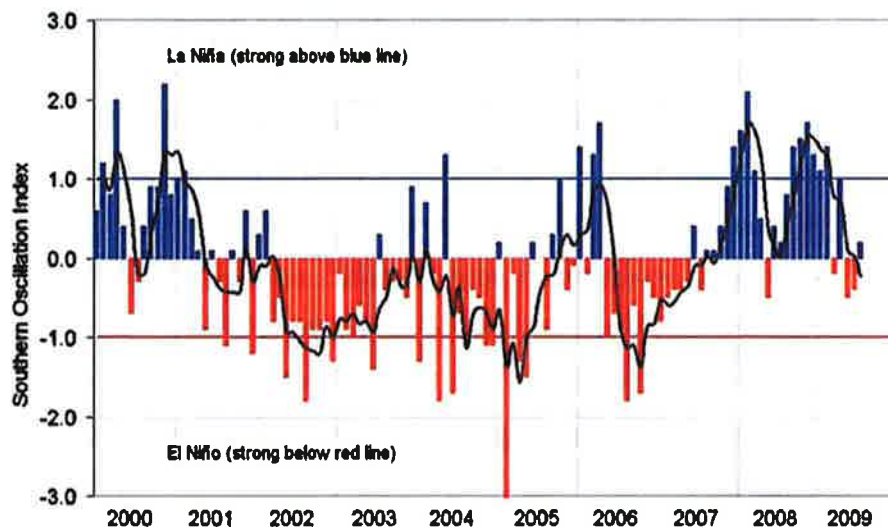


Figure 2. Southern Oscillation Index. Monthly values of the Southern Oscillation Index (SOI), a measure of changes in atmospheric pressures across the Pacific, and the 3-month mean (black line). (Source: NIWA, New Zealand Climate Update, July 2009).

25. ENSO may be thought in terms of a slopping back and forth of warm surface water across the equatorial Pacific Ocean. The trade winds, blowing from the east towards the west, normally help to draw up cool water in the east and to keep the warmest water in the western Pacific. This encourages low air pressures in the west and high pressures in the east. An El Niño event is when the warm water "spills out" eastwards across the Pacific, the trade winds weaken, pressures rise in the west and fall in the east. Eventually, the warm water retreats to the west again and "normality" is restored. The movements of water can also swing too far the other way and waters become unusually cool near South America, resulting in what is termed a "La Niña", where the trade winds are unusually strong while pressures are unusually low over northern Australia.

26. El Niño events occur irregularly, about 3 to 7 years apart, typically becoming established around April or May and persisting for about a year thereafter. The ENSO cycle is an example of a positive feedback system, where a small change in the trade winds can change Equatorial sea temperatures to encourage a larger change in the trade winds that changes sea temperatures even more, and so on, into a full-blown El Niño or La Niña.

27. New Zealand does not lie directly in any of the high-impact regions, but its climate is significantly affected by changes in the atmospheric circulation (winds). In El Niño years, New Zealand tends to experience stronger and/or more frequent west to southwest winds, bringing relatively cool conditions, with below average land and sea surface temperatures. In spring and summer, increased westerlies lead to increased risk of drought in eastern areas, while in winter, increased southerlies often bring more cold stormy conditions, both to the land and the surrounding ocean. La Niña events bring roughly the opposite changes, with weaker westerlies in summer, and more northerly quarter winds, usually associated with enhanced rainfall in the north

and east of the North Island, and dry conditions in some western regions, especially in the South Island. Land and ocean temperatures tend to be above average during a La Niña. There is a tendency for slow-moving anticyclones to position themselves just east of New Zealand, while depressions over the north Tasman Sea can bring enhanced rainfall especially to the northern half of the North Island.

28. Natural rainfall variability in the Manawatu region is not high, compared with some regions of New Zealand. On an annual basis the coefficient of variability, a measure of the annual variability, is 13 percent for the environs of the proposed windfarm. This compares with 19 percent for Auckland, and 22 percent for Christchurch. On a seasonal basis, the rainfall variability ranges from a maximum of 30 percent in summer, to about 26 or 27 percent for the remainder of the year.

Table 7. Percent difference in seasonal rainfall for the El Niño and La Niña phases of ENSO,

Site	Summer	Autumn	Winter	Spring
El Niño				
Windfarm area	105	100	90	105
Turitea 2	102	109	93	103
Makomako	116	86	95	101
La Niña				
Windfarm area	100	98	115	110

Turitea 2	103	92	118	104
Makomako	83	99	115	117

29. The differences in rainfall for the two phases of ENSO are shown in Table 7. For El Niño seasons, there is a slight tendency for wetter conditions in spring and summer, and definitely drier months in El Niño winters. With La Niña events, autumns are certainly drier and winter and spring seasons normally wetter.

30. In my view, the differences expected from this climate variability during the period proposed for construction of the wind farm will have minimal effect on expected rainfall levels.

CLIMATE CHANGE

31. Global warming is expected to continue during the 21st century, and to enhance already observed changes in regional climate. The global scale projections presented in the IPCC 4th Assessment Report published in 2007 include a global average surface warming of 1.1°C to 6.4°C, an increases in mean annual rainfall in some regions and decreases in others, a contraction of snow cover, and a global mean sea-level rise ranging from 0.18 to 0.59 m (with a caveat of a further 0.1–0.2 m in the upper ranges if the major ice sheets melt faster than 1993–2003 rate due to rising temperatures). The range of likely temperature increases and other changes is related to uncertainties about the future levels of greenhouse gases emitted into the atmosphere, and to differences between different climate model projections of future climate. Based upon global climate model output as used in the IPCC 4th Assessment Report, a downscaling to New Zealand conditions has been completed, based largely upon statistical models, but some use has been made of dynamical downscaling using the NIWA regional climate model. The most likely changes out to 2100 for New Zealand include increases in average temperature of between

0.5 and 5.5°C. As temperature increases, the water holding capacity of the atmosphere increases. With this the intensities of design rainfall extremes increase for a particular duration. For a specific rainfall intensity, the recurrence interval (return period) reduces.

32. Recently, the IPCC Fourth Assessment provided climate projections based on scenario analysis for the period 2090–2099 relative to 1980–1999 (Mullan et al., 2008). These global projections have been “downscaled” with the purpose of having region-specific climate projections across New Zealand associated with the IPCC emission scenarios. Projected New Zealand climate changes are given for six greenhouse gas emission scenarios. Changes are specified for 2040 (2030–2049 average), and for 2090 (2080–2099 average), relative to the climate of 1990 (1980–1999 average).

33. Temperature changes for the Manawatu region are indicated in Table 8, from Ministry for the Environment (MfE 2008) report on climate change prepared by NIWA. This indicates the range not only across the models analysed, and but also across the various emissions scenarios. The A1B projections were rescaled by the quoted IPCC global temperature changes to cover the other 5 illustrative scenarios. The values given in Table 8 are averages over all grid-points within the regional council region. Averaging over all models and all 6 illustrative emissions scenarios gives a Manawatu-average warming of 0.8–1.1°C by 2040 and 1.8–2.3°C by 2090.

Table 8. Projected changes in seasonal and annual mean temperature (in °C) from 1990 to 2040 and to 2090, for the Manawatu area, from MfE 2008. The average change, and the lower and upper limits (in brackets), over the 6 illustrative scenarios are given.

	Summer	Autumn	Winter	Spring	Annual
2040	1.1 [0.2, 2.3]	1.0 [0.2, 2.6]	0.9 [0.2, 2.2]	0.8 [0.0, 1.9]	0.9 [0.2, 2.2]
2090	2.3 [0.9, 6.0]	2.2 [0.6, 5.3]	2.1 [0.5, 5.0]	1.8 [0.3, 4.9]	2.1 [0.6, 5.3]

Note: This table covers the period from 1990 (1980-1999) to 2040 (2030–2049) and to 2090 (2080–2099), based on downscaled temperature changes for 12 global climate models,

re-scaled to match the IPCC global warming range for 6 illustrative emission scenarios (B1, A1T, B2, A1B, A2, and A1F1).

34. The estimated range in seasonal and annual precipitation change over the 6 illustrative SRES scenarios, for Paraparaumu over the two periods from 1990 to 2040 and from 1990 to 2090 is shown in Table 9. This was the only location given in MfE 2008 relevant to the Manawatu. Generally there is a slight increase in rainfall, which is more marked in winter. For the 2040s and 2090s this amounts to 4 and 9 percent respectively in winter. There is little change in summer rainfall.

Table 9. Projected changes in seasonal and annual precipitation (in %) from 1990 to 2040 and to 2090, for Paraparaumu, from MfE 2008. The average change, and the lower and upper limits (in brackets), over the 6 illustrative scenarios are given.

	Summer	Autumn	Winter	Spring	Annual
2040	0 [-21, 13]	4 [-3, 14]	4 [-1, 13]	2 [-5, 14]	2 [-3, 10]
2090	-1 [-38, 16]	2 [-12, 14]	9 [0, 26]	2 [-15, 26]	3 [-7, 14]

Note: This table covers the period from 1990 (1980-1999) to 2090 (2080-2099), based on downscaled precipitation changes for 12 global climate models, re-scaled to match the IPCC global warming range for 6 indicative emission scenarios.

35. The annual-average rainfall change has a pattern of decrease up to 3% by 2040 and 5% by 2090, in the mean. While summer and autumn show an increase by 2040, in winter and spring the pattern is reversed. A general decrease is expected by 2090, although the percentage changes are smaller than for the winter and spring seasons. These distinct seasonal differences are a new result, not apparent in the smaller sample of models used in the previous studies. However, it is worth to note that there is still a lot of variability between models.

36. A warmer atmosphere can hold more moisture (about 8% more for every 1°C increase in temperature), so there is an obvious potential for heavier extreme rainfall under global warming. The Intergovernmental Panel on climate Change (IPCC) in its Fourth Assessment concluded that more intense rainfall events are “very likely over most areas”. The mountainous nature of New Zealand, with its starkly contrasting rainfall climates, makes it difficult to be sure if this situation is universally applicable across the country. Any change in the mix of circulation patterns will have a major impact on the spatial distribution of precipitation.

37. Recent climate model simulations confirm the likelihood that heavy rainfall events will become more frequent. The MfE guidance manual

(2008) suggests empirical adjustments, shown in Table 10, that can be applied to estimate a range of possible changes in extreme rainfall under global warming for a particular site. For example, for Manawatu the worst case (most severe) end of the range for 2100 indicates that a rainfall amount with a return period of 50 years under the current climate would have a return period of less than 10 years (AEP>0.10) by 2100. Design storm intensity rates increase by between 0.8 and 19.4 percent for the 2040s and 2 and 46 percent by the 2090s. Thus the intensity (mm/h) for the mid-range scenarios increases by 3.4 to 7.7 percent for the 2040s and 7.5 to 17.2 percent for the 2090s.

Table 10. Factors for use in deriving extreme rainfall information for preliminary scenario studies (screening assessments) from MfE (2008).

ARI (years)	2	5	10	20	30	50	100
Duration							
< 10 minutes	8.0	8.0	8.0	8.0	8.0	8.0	8.0
10 minutes	8.0	8.0	8.0	8.0	8.0	8.0	8.0
30 minutes	7.2	7.4	7.6	7.8	8.0	8.0	8.0
1 hour	6.7	7.1	7.4	7.7	8.0	8.0	8.0
2 hours	6.2	6.7	7.2	7.6	8.0	8.0	8.0
3 hours	5.9	6.5	7.0	7.5	8.0	8.0	8.0
6 hours	5.3	6.1	6.8	7.4	8.0	8.0	8.0
12 hours	4.8	5.8	6.5	7.3	8.0	8.0	8.0
24 hours	4.3	5.4	6.3	7.2	8.0	8.0	8.0
48 hours	3.8	5.0	6.1	7.1	7.8	8.0	8.0
72 hours	3.5	4.8	5.9	7.0	7.7	8.0	8.0

Note: This table recommends *percentage* adjustments to apply to extreme rainfall *per degree Celsius of warming*, for a range of average recurrence intervals (ARIs.). The percentage changes are mid-range estimates per degree Celsius and should only be used in a preliminary scenario study. The entries in this table for a duration of 24 hours are based on results from a regional climate model driven for the A2 SRES emissions scenario. The entries for 10-minute duration are based on the theoretical increase in the amount of water held in the atmosphere for a 1°C increase in temperature (8%). Entries for other durations are based on logarithmic (in time) interpolation between the 10-minute and 24-hour rates.

38. The broad pattern of expected New Zealand changes includes increased westerly winds. Over the next decade this is likely to be slight. An increase in severe wind risk is possible by the 2040s and likely by the 2090s. Up to a 10% increase in the strong winds (>10m/s, top 1 percentile) by 2090 is the projection in MfE 2008.

CONCLUSION

39. The methods I have described allow estimation of annual and seasonal rainfall in the proposed area of the windfarm. This ranges from an annual value of 1300 mm in the north, to just over 1800 mm in the south. Winter is the wettest season, with summer being the driest.
40. From two methods of estimation of high intensity rainfalls, the 2-year average recurrence interval (ARI) daily intensity fall ranges from 62 mm to 100 mm, and the 10-year ARI fall from 85 mm in the north to 137 mm in the south. For any individual month, daily maximum rainfall rates varied from 23 to 36 mm in the Turitea sites, and 30 to 39 mm in the wetter Makomako site. 2 year ARI 1-day rainfall rates of between 71 and 81 mm, and comparable 10 year ARI 1-day rainfall rates for the two sites with longer records are both 103 mm, which compares with the HIRDS values of 85 mm in the north, and 137 mm in the south. This comparison suggests that the HIRDS derived 1-day intensities may be slightly low for the northern area, but a good estimate of daily rates for the southern part of the wind farm area.
41. Measurements of visibility in the area indicate that for about 15 percent of the time there are very clear skies with visibility of more than 55 kilometres. This increases to close to 20 percent during summer months. However, for about 22 percent of the time visibility 20km away is substantially obscured. There is good correlation with sunshine hours for the area, which shows between 6 and 15 percent of days without any sunshine.
42. Rainfall displays variability in the Manawatu area, but this is naturally low, being about 13 percent on an annual basis, with highest variability in summer (30 percent) and lower variability at other times of the year (25-27 percent).
43. ENSO causes some variability in rainfall, with El Niño events giving higher summer rainfall and lower winter rainfall, and La Niña events lower autumn rainfall but increased winter and spring rainfall.

44. Global warming, because of increases in anthropogenic increases in greenhouse gases is expected to warm the climate of the Manawatu during the 21st century. Mid-range scenario warmings of about 1 and 2°C are expected for the 2040s and 2090s respectively with a slight increase in rainfall. Winter is the season with the most increase in rainfall.
45. A warmer atmosphere can hold more moisture (about 8% more for every 1°C increase in temperature), so as the climate warms the likelihood of high intensity rainfall increases.
46. Westerly winds are likely to increase during the century. The implications for the wind farm area are for stronger westerlies with up to a 10 percent increase in strong winds by the 2090s.

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