IN THE MATTER	of the Resource Management Act 1991
AND	
IN THE MATTER	of applications to the **WAIKATO DISTRICT COUNCIL** and **WAIKATO REGIONAL COUNCIL** by **WEL NETWORKS LTD** for resource consents to authorise the establishment, operation and maintenance of 28 wind turbines for the generation of electricity and associated activities on the Wharauroa Plateau near Te Uku

STATEMENT OF EVIDENCE OF DR ANDREW KIRKLAND WRIGHT

1. INTRODUCTION

Qualifications and experience

1.1 My name is Andrew Wright, I am a Renewable Energy Engineer with Hydro Tasmania Consulting ("HTC") which is based in Hobart, Tasmania.

1.2 I hold a Bachelor of Engineering (Mechanical, with Honours) from Monash University, Australia (2000) and a PhD from the University of Newcastle, Australia (2005). My post-graduate work involved the study of various aspects of the aerodynamics and operation of wind turbines, and I am the lead author on related articles published in the internationally recognised, peer-reviewed journals, "Wind Engineering" [1], and "Journal for Wind Engineering and Industrial Aerodynamics" [2].

1.3 Since October 2005, I have worked for Hydro Tasmania Consulting, servicing a variety of clients. HTC is an international consulting firm which provides expert engineering and environmental services in the areas of renewable energy, power engineering and environmental and catchment management. HTC has developed comprehensive Wind Atlases in various regions of Australia, New Zealand and the Pacific, and conducted other site prospecting, monitoring, wind resource and energy

---

1 A. K. Wright, D. H. Wood, "Yaw Rate, Rotor Speed and Gyroscopic Loads on a Small Horizontal Axis Wind Turbine", Wind Eng. 31 (2007), 197-209(13)

2 A. K. Wright, D. H. Wood, "The starting and low wind speed behaviour of a small horizontal axis wind turbine", J. Wind Eng. & Ind. Aero. 92 (2004), 1265-1279

production estimates at more than 55 sites of varying terrain across Australia, China, India, South Korea, New Zealand, PNG, and the Pacific Islands.

1.4 I have extensive involvement in leading, preparing and reviewing energy estimates for proposed wind farms in Australia, New Zealand, China, India, and other locations in the Pacific Region. I also have significant experience in providing technical guidance on operational wind farms, including assessments of energy generation and the assumptions used in deriving energy estimates.

Involvement in the project

1.5 I have been involved with the preparation of energy estimates for the Te Uku project since February 2006. I visited the site in March 2006 as part of our wind resource assessment process and to identify the optimum site for the new 50m mast location. I am also familiar with methodologies and results of the site-identification studies and pre-feasibility energy estimates for the Te Uku project produced for WEL Networks by my colleagues at HTC from mid-2005.

Expert Witness Code of Conduct

1.6 I have been provided with a copy of the Code of Conduct for Expert Witnesses contained in the Environment Court's Consolidated Practice Note 2006 [2006] NZRMA 357. I have read and agree to comply with that Code. This evidence is within my area of expertise, except where I state that I am relying upon the specified evidence of another person. I have not omitted to consider material facts known to me that might alter or detract from the opinions that I express.

Purpose and scope of evidence

1.7 The purpose of my evidence is to provide an overview of the wind resource on the Wharauroa Plateau, and explain how it has been assessed. I also address some minor issues raised by PB Power's review of HTC's shadow flicker report.

1.8 My evidence will address the following matters:

(a) The standard methodologies that the wind industry uses to determine the wind resource and estimate the energy output of a proposed wind farm (Section 3);

(b) The site identification studies undertaken by HTC for WEL Networks (Section 4);

(c) The results of HTC's energy estimates for the Te Uku project, and the methodology followed (Section 5);

(d) Provide comments on some aspects of the submission presented by Mr. Cox which relate to my field of practices (Section 6); and

(e) The PB Power review of HTC's shadow flicker report (Section 7).

2. SUMMARY OF MY EVIDENCE

2.1 In section 3, I describe the standard methods used by industry to estimate the wind resource and energy output of a proposed wind farm, from initial site identification studies through to the business case. A typical project development will involve the following steps:

(a) Site identification based on regional wind resource assessments.

(b) Preliminary wind data from a nearby source, but often acquired at a height well below typical wind turbine hub heights.

(c) Investment in high quality wind measurement equipment at the project site.

(d) Analysis of the measured wind resource, ideally at least one year of data, with an estimate of the long-term wind resource at the site based on a reference wind data source.

(e) Modelling of the wind resource and energy across the entire wind farm, and estimates of wind farm losses.

2.2 In section 4, I summarise the initial site identification studies which HTC conducted on behalf of WEL Networks, which provided a preliminary assessment of the wind resource across many areas of the North Island of New Zealand, and in particular the Waikato Region. The results of this study suggested that the Wharauroa Plateau site has an excellent potential for wind farm development relative to other sites in the Waikato Region, and relative to other sites on the North Island in general.

2.3 In section 5, I explain the wind resource assessments and energy estimates which HTC have provided for the Te Uku project. These have been conducted according internationally accepted methodologies, and have considered all available and relevant wind data sources acquired in the vicinity of the proposed wind farm.

2.4 In section 6, I provide a commentary on Mr. Cox's evidence regarding the wind resource at the Te Uku project site. I conclude that his estimate of the wind resource at the Te Uku site is inaccurate, and that his calculations of likely wind farm output underestimate the energy output of the Te Uku project by a significant amount.

2.5 In section 7, I provide some minor clarifications required to address issues raised by PB Power's peer review of HTC's shadow flicker assessment of the Te Uku site. These clarifications have no affect on the conclusion that shadow flicker at existing residences will be within international best practice limits and is unlikely to be problematic.

3. WIND RESOURCE ASSESSMENT AND ENERGY ESTIMATE METHODOLOGY

3.1 In this section I briefly describe the standard methods used by industry to estimate the wind resource and energy output of a proposed wind farm, from initial site identification studies through to the business case, as a basis for considering the appropriateness of the methodology adopted at the Te Uku site.

3.2 The feasibility of a wind farm development is typically very sensitive to the wind resource, particularly in regions such as New Zealand where wind energy is competing on a relatively level playing field with other forms of energy. As a result, the initial site selection process, and pre-feasibility studies for a potential wind farm usually place a high emphasis on finding locations with a good wind resource, and then verifying this wind resource.

3.3 The wind resource verification process is usually incremental, with the extent of wind monitoring increasing as the project is developed. It is a time consuming exercise, with the complete cycle of seasonal data gradually acquired and made available for assessment.

3.4 The wind resource at a specific site can be assessed at the most basic level by considering factors such as the surrounding topography and elevation of the site, the vegetation, and anecdotal evidence by locals.

3.5 Many regions of the world are now covered by "wind resource maps" available in the public domain. Consultants are often engaged by developers to produce detailed wind resource maps of specific regions, and preliminary estimates for a potential site using either local weather station data, or modelled wind data developed from historic synoptic weather data and local terrain information. The main use of such studies is to provide an indication of whether a site should be investigated further, typically by installing wind monitoring equipment.

3.6 Prospective wind farm developers will often install or have access to data from a low-level monitoring mast at or near the site. This provides some indication of the wind resource, although it is important to note that the extrapolation of wind speeds from a low level, say below 50m, up to a hub-height of 80m can give misleading results.

3.7 Wind data at a height above ground level near to the proposed hub-height of the wind turbines is an essential requirement for an accurate energy estimate. To capture seasonal effects, at least a full year of data is ideal.

3.8 The average long-term wind resource of the site is estimated by comparing the measured site data with a multi-year record of "reference" data. The reference data is often a local weather station, or if no suitable source of long-term measured data is available, modelled wind data developed from historic synoptic weather data and local terrain information can be used. By correlating the available site data with the long-term reference data, the long-term wind resource estimate is based on the actual measured data, adjusted to account for the year to year variability of the wind.

3.9 Wind speed variations across a site can be modelled by industry standard software packages such as WAsP. Inputs into the modelling include the estimated long-term wind speed and direction distributions at the monitoring mast, topographic data, surface roughness maps, a wind turbine layout, and a wind turbine power curve. The wind resource and the annual energy output at each turbine location are calculated. Wake losses, electrical losses, turbine availability, and other loss factors are applied to estimate the total wind farm output per year.

3.10 For sites with variations in wind resource across the wind turbine locations, such as large wind farm, or sites with complex terrain, additional monitoring masts provide further confidence in wind speed estimates across the site. For sites with complex terrain, sophisticated non-linear wind flow models are sometimes used, and alternative measurement techniques such as lidar or sodar (which are laser and sound emitting devices) can be employed.

4. NEW ZEALAND NORTH ISLAND SITE IDENTIFICATION

4.1 In this section, I describe initial site identification studies carried out by HTC for WEL Networks. The findings of these studies are confidential, however, a summary of the results in relation to the Te Uku project is provided here.

4.2 In 2005, WEL Networks engaged HTC to identify potential wind farm sites on the North Island. HTC's approach to this site identification project involved mesoscale meteorological modelling of the wind resource across the areas of interest, which initially included 39 potential sites across a number of regions, including the Waikato. This technique employs large-scale synoptic weather data and local topographic and vegetation data to model meteorological parameters such as wind speed and wind direction, which are then used to “map” the wind resource

4.3 The initial phase of this investigation was conducted by HTC without prior knowledge of WEL Network’s interest in the Te Uku site. A number of priority sites were identified based on the estimated wind resource, potential wind farm size, transmission issues, access, vegetation, proximity of houses, and land tenure. The Wharauroa Plateau received a high ranking, and was recommended as a high priority site to investigate. No other site in the Waikato Region was ranked higher.

4.4 After reviewing the preliminary results of the site identification study, WEL Networks informed HTC of their interest in the Wharauroa Plateau. Subsequent analysis of measured hub-height wind data acquired on the Wharauroa Plateau has confirmed that the wind resource at the site is suitable for wind farm development. This is discussed further below.

5. TE UKU WIND RESOURCE ASSESSMENT AND ENERGY ESTIMATE

5.1 This section outlines the methodology of HTC’s wind resource assessments and energy estimates for the Te Uku project.

5.2 HTC completed a wind resource assessment and energy estimate for the 28 turbine layout used in the consent application in July 2006, and updated this assessment in March 2007 when the application was filed. The output calculated in the March 2007 update is used in the consent application in evidence given by Mr Burchett and relied on by others. This report was based on approximately 2 years of wind monitoring data from 50m above ground level on the Wharauroa Plateau, and 2.5 months of 80m hub-height data.

5.3 Subsequent to the consent application, in April 2007, HTC revised the March energy estimates. This resulted in a slight difference between numbers that were used at the time of consent application, and the numbers presented here.

5.4 HTC will be engaged by WEL to further update energy estimates in May 2008, when a full year’s data from the new 50m mast location becomes available.

Methodology

5.5 WEL Networks has acquired wind speed and direction measurements at three locations within the proposed Te Uku project area – an original 50m mast, a nearby 80m mast located on the Wharauroa Plateau, and a new 50m mast located at the northern end of the proposed site. The original 50m mast was moved in May 2007 to the new northern location. These masts are maintained by PB Power. Measurement of the wind resource is addressed in the evidence of Mr Andrew Kerley of PB Power.

5.6 HTC has physically inspected the 80m mast installation and the original 50m mast, and has reviewed installation reports and supporting documentation on these masts. HTC has reviewed the quality of the data, and is satisfied that the measured wind speeds and directions are an accurate representation of the actual wind speeds at the 80m mast location.

5.7 Previous long-term wind resource estimates have considered the Port Taharoa, Hamilton, and Auckland Airport weather stations as sources of long-term reference data. However, these locations are a significant distance (all >30km) from the Te Uku project site, and are subject to different wind regimes. For this reason, mesoscale meteorological modelling of the wind resource using synoptic weather data from 1994-2007 is used to generate the long-term reference data source.

5.8 Mesoscale meteorological modelling uses large-scale synoptic weather data based on satellite and observational records available as far back as 1948. Using the input synoptic data and local topographic and vegetation data, a time series of wind speed and direction at low-level heights can be generated, which can then be used as a long-term reference data source.

5.9 HTC uses the reference data source, and the measured wind speed and direction data from the 50m mast and 80m mast to calculate long-term average wind speeds at the mast location. Wind speeds are extrapolated to 80m above ground level (hub height) where 50m masts are used. At each update of the energy estimate, the latest wind speed data is used, so each update uses a longer period of site data and thus produces an estimate with less uncertainty.

5.10 Using the methodology set out above, the April 2007 energy estimate reported an estimated average long term wind speed at the 80m mast location of over 8 m/s. Preliminary analysis of data acquired at the 80m mast location since that report shows no significant change in this estimate.

5.11 The wind resource at each wind turbine location has been estimated using WAsP, which is a standard software package for modelling wind farm energy output. Inputs to this process included the wind resource estimate, a contour map and roughness map, wind turbine power curves provided by the manufacturer, and the consent application layout. Estimates of wake losses, electrical losses and wind turbine availability are based on HTC's past experience, and are typical for a wind farm in New Zealand.

5.12 In the March 2007 update used for the consent application, and the April 2007 revision, the wind resource estimate from the 80m mast has been used to estimate the wind resource at all 28 wind turbines. Based on this information, and use of industry standard methodologies, the estimated long-term wind speed at the 80m mast is over 8 m/s, and the average of all wind turbine locations is over 8 m/s.

5.13 In future updates, the wind resource estimate from the new 50m mast location, extrapolated to 80m, will be applied to approximately half of the 28 wind turbines. This assignment is based on an assessment of the topography at each turbine site, and the distance from the mast locations. This will be updated in May 2008 when a full year of data is available from the new 50m mast location.

Energy estimate

5.14 Using the consent application layout as revised in April 2007, the energy estimate gives an average wind farm output of 261 GWh/yr, metered at the connection to the network and assuming Vestas V90-3MW turbines. The estimated contribution to this output from the different wind turbines varies from 8.1 GWh/yr from turbine 23, up to 10.9 GWh/yr from turbine 15. The output of Turbine 29 is now calculated at 10.7 GWh/yr. I note these numbers are slightly different to those used by WEL due to the revision of the March report used by WEL as noted in paragraph 5.2 above.

5.15 When the new 50m mast location is included in the analysis in May 2008, the energy estimate for the wind farm may change. This is a normal and expected part of the incremental wind resource verification process. HTC has provided WEL Networks with analysis of the uncertainties involved in assessing the wind resource, and has provided confidence levels for the energy estimates, which model the potential for change in the energy estimates as more data becomes available.

5.16 The international standard used in design of large wind turbines is IEC61400-1. Wind turbine manufacturers typically obtain certification for their machines from a certifying agency who have independently assessed the design of the wind turbine against wind conditions defined by IEC61400-1. Based on average wind speeds, there are three classes within these standards to which a wind turbine may be certified – an IEC Class I wind turbine being the most robust and suitable for high wind sites.

5.17 The average annual wind speeds measured and predicted at the Te Uku project suggest a mix of IEC Class I and Class II wind turbines are appropriate for the site. In other words, some locations are subject to average wind speeds higher than the defined limit for a Class II machine. However the final decision on wind turbine suitability needs to condition a range of factors in addition to average wind speed, and will also involve the input of the manufacturer. These aspects have been addressed in the main evidence of Mr Walter and Mr Burchett.

6. COMMENT ON ASPECTS OF MR COX'S EVIDENCE

6.1 In this section, I provide a commentary on Mr. Cox's evidence regarding the wind resource at the Te Uku project site, in particular the average annual wind speed estimate and energy estimate methodology.

6.2 In reference to his analysis of estimated wind farm output, Mr. Cox states: *"I have done this using wind data from a site 10km south west of the plateau but corrected for the plateau's elevation and position".* He then goes on to assume an average annual wind speed of 6.12m/s, and states "I have chosen a day that is representative of the average".

6.3 HTC's estimates consider all available wind data acquired at this site, including data from the 80m mast for December 2006 to the February 2007, and from the original 50m mast for April 2005 – April 2007. Future updates will also consider the new 50m mast location. Based on this information, the consent application layout as revised in April 2007, and use of industry standard methodologies accepted worldwide, the estimated long-term wind speed is over 8m/s, which will be discussed in more detail by Mr Kerley.

6.4 It is noted that different methodologies and data analysis techniques will generally produce marginally different wind resource estimates. However Mr. Cox's estimated average annual wind speed of 6.12 m/s is well below measured and predicted 80m wind speeds across the site, and well below the bounds of a plausible long-term 80m wind speed at the site.

6.5 Given that the energy derived from wind is proportional to the cube of the wind speed, the estimated energy output of the wind farm is very sensitive to wind speed. Therefore, the difference between Mr Cox's wind speed and the actual wind speed at the site is very material to project value.

6.6 Mr. Cox makes no mention of the fact that wind speed typically increases in velocity at higher altitude above ground level, within the height of a modern large wind turbine. Therefore, measurements of average wind speed close to ground level are almost always significantly lower than the corresponding wind speed at a typical wind turbine hub-height of 80m above ground level. Measurements within several metres of ground level are a very unreliable indicator of wind resource at hub-height, even at the location where the measurement is made.

6.7 In the best of circumstances, high quality weather station wind data from a site 10km from the wind farm, at a lower elevation and closer to the coastline, could be used to provide a rough estimate of wind speed at the Wharauroa plateau. However, even a well developed estimate made by this method could over-estimate or under-estimate the actual wind speed by a significant amount.

6.8 For example, the NIWA Port Taharoa weather station data is acquired at 10m above ground level and is located approximately 40km from the site. This weather station was found to have a significantly different wind regime than the Te Uku project site, and any estimates based on this data source would be subject to great uncertainty.

6.9 Mr Cox states that "NIWA's data shows there is nowhere on the north or south islands of New Zealand that have a 9m/s average wind". NIWA data is typically acquired at a height well below modern wind turbine hub-heights – such as the 10m Port Taharoa data – so the typical increase in wind speed with altitude up to turbine hub-height needs to be considered when quoting NIWA data in this manner.

6.10 Wind data measured at three locations across the actual wind farm, at multiple heights up to 80m, conclusively show a significantly higher wind resource for the Te Uku project than is assumed by Mr. Cox's energy estimate.

6.11 Furthermore, the method applied by Mr. Cox to estimate the energy output of the wind farm based on his wind resource estimate is very much unconventional, and a number of questionable assumptions are applied. In Section 3 I outlined the standard way the energy at a potential wind farm is assessed by professionals working in the wind industry. And while variations to this method can be envisaged, the method outlined in my evidence has been accepted by the wind industry worldwide because it is the most reliable way to estimate the energy output of a wind farm.

6.12 Considered overall, I would characterise the method applied by Mr. Cox as very unreliable.

7. **SHADOW FLICKER – COMMENT ON PB POWER REPORT**

7.1 The Shadow Flicker report "Te Uku Wind Farm Shadow Flicker Assessment", by G Neilson of Hydro Tasmania Consulting (HTC), 28th September 2006 was reviewed by PB Power for the Waikato District Council in November 2007. This review concluded that: *"PB concurs with the findings of the Report; that shadow flicker experienced by the current surrounding residences is within the limits of international best practice and is unlikely to be problematic for the associated residents."* The review raised some queries, which are listed and addressed below.

7.2 At page [1] of the PB Power review, PB Power raise the following query: *"HTC describe a spatial model that calculates the relative position of the sun, turbines and houses for every minute of the year. This general approach is considered typical and is employed by a number of industry standard software packages however, we note HTC do not specifically mention the software package used for their study."*

7.3 I can confirm that the software used to calculate shadow flicker was developed 'in-house' and was verified against Garrad Hassan's "WindFarmer" software and manual calculations (including sun position and the intersection of a line and a plane). Graeme Neilson, author of the HTC Shadow Flicker report is well qualified for this assessment as he was a co-developer of the GH Windfarmer software and specifically developed the shadow flicker portion of Windfarmer. The equations for calculating shadow flicker are well known and straightforward.

7.4 At page [2] of the PB Power review, PB Power raise the following query: – *"Page 1, third bullet point: The Report implies that the WTG rotor disk needs to be perpendicular to the line joining the WTG to the shadow receptor for shadow flicker to be possible. A perpendicular orientation is the worst-case situation, but flicker can still be experienced in other orientations, albeit with a lesser duration per day."*

7.5 I can confirm that the HTC Report makes the *assumption* that the rotor disk is perpendicular to the line joining the WTG and the shadow receptor as a conservative assumption rather than this needing to be the case. PB Power are correct when they say "A perpendicular orientation is the worst-case situation, but flicker can still be experienced in other orientations, albeit with a lesser duration per day say this is the worst case." HTC has merely taken the more conservative assumption.

7.6 At page [2] of the PB Power review PB Power raise the following query:*"Page 5 and 6: The numbering of the wind turbines does not match between the map in Figure 2-1 and the list of coordinates in Table 2-1."*

7.7 I can confirm that the numbers in the table are a typographical error. These should correspond to the numbers used in the figure. The actual positions are unchanged and the results of the analysis are unaltered. The actual number sequence should be:

Turbine	**East(m)**	**North(m)**
1	2682481	6364588
2	2682973	6364380
3	2684167	6364871
4	2682666	6365172
5	2684267	6365389
6	2683980	6365664
7	2684291	6366001
8	2683122	6366020
9	2683757	6366180
10	2684207	6366368
11	2684038	6367260
12	2683891	6367601
13	2682191	6367615
14	2683003	6367824
15	2683904	6368186
16	2682817	6368184
17	2682292	6368363
18	2682854	6368720
19	2682434	6368937
20	2681884	6368545
21	2681732	6369194
23	2683458	6365142
24	2684186	6368714
25	2683096	6365611
26	2683615	6365800
27	2684057	6366836
28	2683751	6368793
29	2683397	6369721

7.8 At page [2] of the PB Power review, PB Power raise the following query: *"Page 7, Table 2-2: There is a discrepancy between the maximum flicker range specified in Table 2-2 (1500m) and in the last paragraph on Page 6 (range sufficient to include the three residences would be several kilometres)".*

7.9 I can confirm that the value of 1500m listed in Table 2-2 is incorrect, and does not reflect the actual parameters used in the calculations. The maximum range of shadow flicker was arbitrarily set at a distance to include the three selected residences (>3800m). In actuality, as the distance between the wind turbine and the residence increases, the shadow becomes more diffuse and less intense. Therefore, this is a conservative assumption.

7.10 At page [2] of the PB Power review, PB Power raise the following query: *"Page 7, Table 2-3: The distances from houses to the closest wind turbines appear to be incorrect. When calculated using the coordinates from Tables 2-1 and 2-2, the approximate distances are*:

Residence 144 3800m (against 4500m in Table 2-3)

Residence 175 2100m (against 1800m in Table 2-3)

Residence 201 2100m (against 1500m in Table 2-3)"

7.11 It appears that PB Power have reviewed a slightly out of date version of the report that quotes incorrect distances from these residences. HTC have subsequently issued a further revision of that report (which has the same date and revision number) and the only difference between the reports are these distances. I have forwarded the correct version of the report to PB Power for their review and that report is attached to this evidence at **Appendix A**. I can confirm that the revised report released by HTC on 28/09/2006 provided the correct values, verified by GIS, and as stated below:

Residence 144, 3750m

Residence 175, 2200m

Residence 201, 2100m

Andrew Wright
January 2008

Appendix A
HTC Shadow Flicker Report