Department of the Environment,
Heritage and Local Government

Irish National Annex to the Wind Eurocode (EN1991-1-4)

Derivation of the Wind Map

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Ove Arup & Partners Ltd
13 Fitzroy Street, London W1T 4BQ
Tel +44 (0)20 7636 1531 Fax +44 (0)20 7755 2150
www.arup.com

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Contents

1 Introduction

Arup has been appointed to aid in the development of the Irish National Annex (NA) of the Eurocode, wind actions section. As part of this study, a new contour map illustrating the basic 50 year return period design wind speed in Ireland has been prepared. This contour map is based on historical wind records from sixteen weather stations across Ireland, supplied by the Irish Meteorological Service (Met Éireann). The map details the 10-min mean wind speed at sea level (z_o = 0.03 m) which has a probability of 0.02 of being equalled or exceeded in any one year.

Extreme value analyses of historical wind records have been undertaken for the purpose of deriving design wind speeds. Recordings at regular intervals, both hourly and daily, made at meteorological stations around Ireland have been utilized.

Correction factors were applied to the historical wind records based on the exposure of the weather station and variation in terrain roughness by direction. The records were separated based on variation in instrument type and/or location. Given the significant topography in Ireland, and the impact of the near and far field terrain on wind speed recordings (such as mountains, valleys, cliffs and coast) topography correction factors were also considered.

This technical report has been prepared to illustrate the results of the wind study. The following three sections detail preliminary investigation procedures and summarize the methods employed in correcting the weather station records. Section 5 and 6 detail the methods of analysis used in the generation of the design wind speed map to be used in the Irish NA.

2 Weather Station Auditing

Daily maximum gust speeds and hourly maximum mean speeds for period up to and including 2005 were analysed using extreme value analysis techniques. Pictorial documents and historical auditing reports were accessed from the Met Éireann data archives for each of the weather stations. The information contained within these reports was used to evaluate:

- Changes in surroundings over time (i.e. construction of subdivisions, tree growth, etc.)
- Changes to anemometer location (i.e. the movement from a sheltered location to a less sheltered location)
- Changes to anemometer height and/or type (i.e. Dines pressure tube anemometer to Vaisala rotating-cup anemometer)

A general procedure is adopted for analysing the hourly-mean and daily-gust wind speeds from each of the anemometers to derive design wind speeds;

- **Data Quality:** Check quality of measurements for each anemometer and separate or remove inconsistent data records.
- **Exposure Correction:** Transpose wind records from each anemometer (considering an elevation, terrain, and topographical correction) to be consistent with open country terrain (Engineering Sciences Data Unit (ESDU) z_0 = 0.03 m).
- **Extreme Value Analysis:** Carry out extreme value statistical analysis and assess directionality using discrete wind records.
- **Design Wind Speed Map:** Review predicted design gust and mean wind speed for each anemometer and generate contours which account for local topography.

The following sections describe in detail each of the above steps and provide a final summary of the wind speeds to be used in design.

2.1 Weather Stations

Sixteen weather stations (with anemometers) have been considered in this analysis, the geographical locations of which are shown in Figure 1. The wind records analysed consisted of hourly mean wind speeds and daily gust speeds taken over a range of ten to sixty years (shortest record - Knock airport, longest record - Shannon airport).

The effective height of the anemometers was taken as 10 m, with the one exception being Malin Head whose effective height was taken as 22 m for periods of recording after March 1963.

The Dine pressure-tube anemometer was the standard instrument of measurement of the gust and mean wind speeds up to the 1990's when they were replaced by Vaisala or Vector rotating-cup anemometers (as shown in Table 1 with the date of commissioning of the anemometer shown as YYYYMMDD). Trial separation of the mean and gust wind speeds by anemometer recording type revealed small variations and therefore it was considered necessary to separate the mean and gust data records and carry out independent analyses based on the anemometer type.

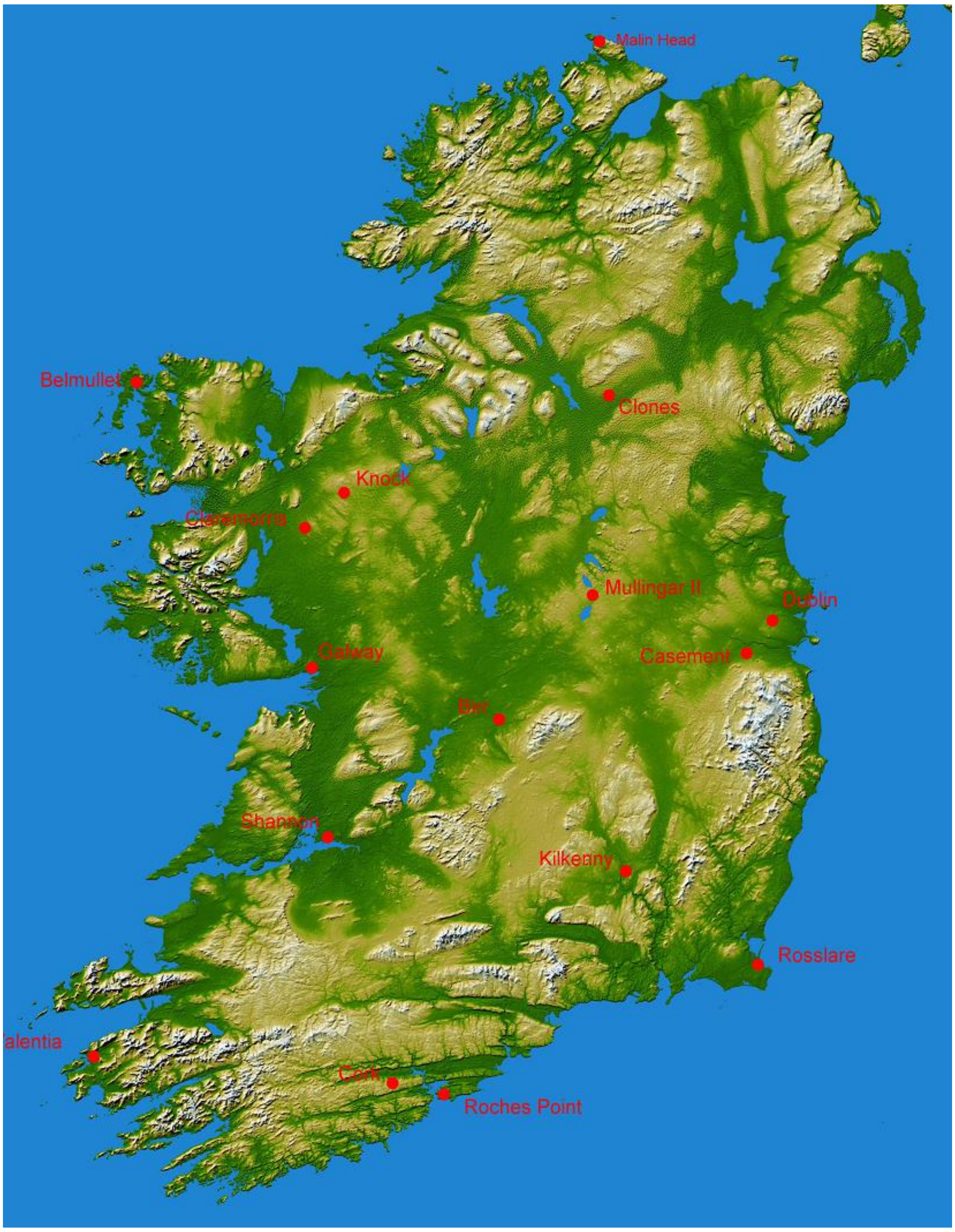

Figure 1 – Weather stations.

	DINES	VAISALA	VECTOR	Other Change
Belmullet	19560901			
Birr	19541001		19980624	
Casement	19670113	19910901		location change (19991122)
Claremorris	19500101		19950912	
Clones	19510101		19970612	
Cork	19620101	19910201		location change (19951031)
Dublin	19411101	19940101		location change (19870701)
Galway	19810101			
Kilkenny	19570601		19980622	
Knock	19960731		19970201	
Malin Head	19550501			height change (19630301)
Mullingar	19500101		19960610	location change (19731107)
Rosslare	19561201			
RochesPoint	19551201	19920701		
Shannon	19450901	19900409		
Valentia	19920101	19990215		

Table 1 – Basic metadata for the sixteen weather stations.

3 Topographical Assessments

The wind speeds measured by the anemometers are a result of not only the strength of the winds but also the elevation of the site and the surrounding terrain and topography. A rough upwind terrain will act to slow wind speeds down and a large mountain or a steep cliff may act to steer or accelerate the winds. Accounting for the upwind topography allows wind speeds measured at an anemometer to be transposed to a reference terrain at standard height. This transposition allows for the like-for-like comparison of anemometers in close proximity and provides a basis for comparing design wind speeds (i.e. reference wind speed, open-country, at 10 m height above sea level, 50-year return period).

Two methods of assessing the upwind terrain roughness were utilized, the first employing the widely accepted Deaves and Harris log-law wind model of the atmospheric boundary layer, as defined in Engineering Sciences Data Unit (ESDU) Item 01008, the second using the UK methodology as proposed and developed by Nick Cook and included in the BRE-Ve software package.

A topographical assessment was carried out for two cases, Casement Aerodrome (Wicklow Mountains to the south) and Valentia (Kerry mountains to the east). Topographic corrections, in terms of wind speed-ups and directional steering, were assessed using MS-MICRO.

In addition to a terrain and topographic correction, the wind records were also corrected for altitude. These correction methodologies are described in further detail in the sections below.

3.1 Terrain Assessments

The atmospheric boundary layer model used in the ESDU analyses is that developed by Deaves and Harris and takes account of varying surface roughness with fetch. Surface roughness length is characterised by a typical z_o, consistent with the model used in ESDU. The method takes account of the varying terrain roughness with fetch at 30 degree sectors about the origin of the anemometer.

A detailed survey of terrain roughness was carried out for each anemometer using satellite imagery, OSI TrailMaster, and aerial photography. This analysis was completed for twelve sectors of wind direction and to a distance in excess of 40 km away from the anemometer. For each sector and patch of terrain a typical roughness coefficient, z_o, was assigned.

Two assessments of the terrain were made, a best-guess estimation and a conservative estimation. The conservative estimation considered a rougher upwind terrain which resulted in higher factors to be applied to the wind records. The gust speed correction factor is less sensitive to terrain changes (due to the balance between gain/loss of turbulence and loss/gain of kinetic energy over a rough/smooth surface) and therefore in areas very sensitive to terrain changes it is more ideal to analyse gust speeds.

For illustration purpose, Figure 2 shows an aerial photo of the Dublin Airport anemometer and the z_o assessments for the 90° direction.

Figure 2 - Satellite image of Dublin.

RWDI-Anemos was commissioned to carry out BRE-Ve terrain assessments for four anemometer sites (Birr, Casement Aerodrome, Dublin Airport, and Shannon Airport). The BRE-Ve terrain assessment, used for a UK site, provides automatic corrections for surface roughness in 30 degree sectors to a distance of 200 km, using the Building Research Establishment database of ground roughness. This is done in two phases: "near field" - site to 50 km (1 km resolution) and "far field" – 50 km to 200 km (4 km resolution). For use in Ireland the assessment requires the user to input terrain roughness lengths. Similarly to the ESDU methodology, the assessment of roughness length was made using satellite imagery and/or aerial photos.

The terrain assessments carried out are representative of the current day surface roughness. The wind speeds from previously less developed areas (no nearby houses or large scale trees) are conservatively represented by these terrain correction factors.

3.2 Topographic Assessments

The topography of surrounding terrain can significantly affect wind speed measurements by either providing shelter to the anemometer site or by accelerating winds. For instance, the Wicklow Mountains located to the southwest of Dublin, as shown in the contour image in Figure 3, affect the measurements recorded at Casement Aerodrome and, to a less extent, at Dublin Airport. When the oncoming wind direction is coincident with the mountains much of the flow moves outwards to pass on either side of the mountains or accelerate over the top, hence modifying the apparent wind directions and accelerating the wind flow.

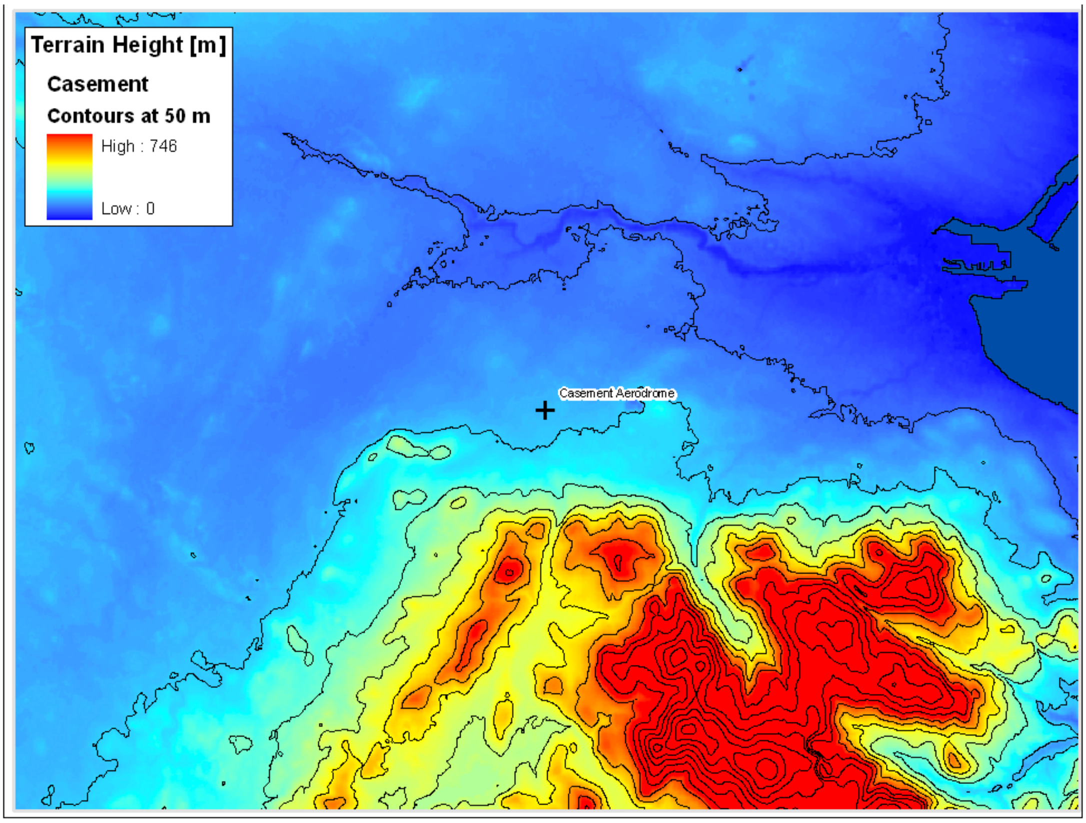

Figure 3 - Contour image of hills/mountains to the southwest of Dublin.

Depending on the size of the hills, mountains, valleys, cliffs, etc., topographic effects can be difficult to correct. The natural topography of Ireland is quite rugged and mountainous, resulting in a number of local areas being sheltered from various directions and suffering from accelerated flow from other directions. One way to correct for these topographic effects is to carry out a topographic assessment using internationally recognized software.

RWDI-Anemos was commissioned to carry out MS-Micro topographic assessments for two anemometer sites (Valentia and Casement Aerodrome). At Casement Aerodrome the speed-up factors due to the mountainous topography were on average about 5% (from the critical mountainous directions). The directional steering factors were negligible and were therefore not further incorporated in the analysis.

The speed-up factors for Valentia were in some cases up to about 45% and about 20 degrees directional steering. As the theoretical background in these topographic modelling programs is uncertain in significantly topographic areas, applying factors as large as these to the wind records is questionable. Therefore the design wind speeds predicted and corrected at Valentia were treated with caution.

The proximity of cliffs and valleys in the immediate vicinity of the anemometer can have a significant effect on wind speed measurements. Minor effects of these obstacles can be specifically accounted for, however, for some directions wind speeds need to be discounted as correction methods are impractical and utilizing wind records from these directions may result in an overestimation of the design wind speed.

Reviewing satellite imagery and photographs of the local anemometers permitted the categorization of proximity effects (i.e. cliffs, mountains, obstructions, etc.). These regions were identified to help categorize directions from which the obstructions may have affected the resulting design wind speeds.

3.3 Altitude Factor

The design wind speed is defined at an elevation of reference which is the mean sea level. Therefore, wind speeds assessed at each of the anemometers needs to be corrected to account for the effect of the increase in elevation of the anemometer relative to sea level.

The elevation above sea level for each anemometer site was provided by Met Eireean. Based on these elevations a correction factor, referred to as altitude factor (S_A), was estimated as recommended in International Standards, and used in the Eurocode. The altitude factor follows the form:

$$S_A = 1 + 0.001 * A$$

Where A is the elevation above sea level in metres.

The map shown in Figure 4 shows the altitude factor for each of the anemometer sites.

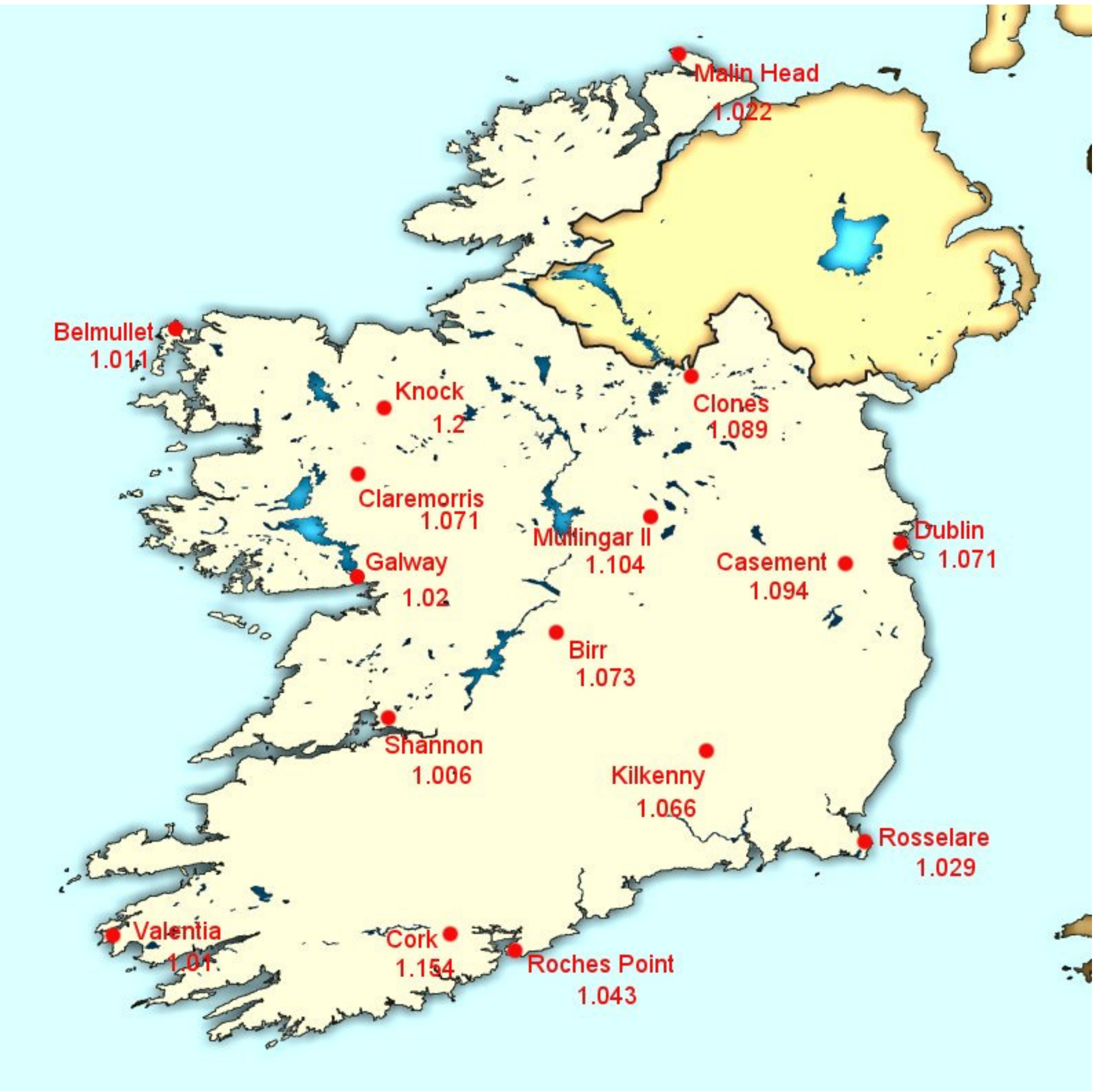

Figure 4 - Altitude factors (S_A).

The terrain correction factors (including the altitude corrections) for the gust and mean wind speeds for all anemometers and each wind direction are given in Appendix A. These correction factors are multiplied to wind speeds measured at the anemometer sites to resolve the design wind speeds for a standard open country terrain roughness (z_o = 0.03 m) and standard elevation (i.e. sea level).

4 Inspection of the Wind Record

4.1 General Analyses

Wind records were scanned for statistical outliers. An outlier was defined as a wind speed that was either greater than 100 m/s (a wind speed which would be unheard of in the Irish climate), or a wind speed which was greater than 20 m/s (mean) and three times greater than both the previous and post hourly (mean) recording (wind speeds such as these would be attributed to local thunderstorm behaviour).

Contrary to the typical necessity of removing numerous statistical outliers from manual recorded wind records, only one mean hourly measurement, from all anemometer stations, was defined as an outlier and was removed from subsequent analysis.[1]

The outlying wind record was a mean hourly value of 99 knots occurring on the 29th of January in 1999 in Birr. No mention of a severe storm occurring in the region can be traced from any media source nor do any of the other wind records from adjacent anemometer sites contain significantly high wind speeds. Therefore the high wind speed was considered to be a true outlier (possibly caused by a fault in the equipment).

Wind records were also scanned for anomalies such as; data gaps (as a result of anemometer faults), or step-changes (as a result of anemometer change or change in the recording method.

In Ireland, and the majority of synoptic wind climates the parent wind distribution, irrespective of wind direction, is well represented by the Weibull distribution (Cook, 1990). It is an underlying assumption of the extreme value analysis procedures employed in this study that the wind speeds are of a Weibull form. Therefore histograms of parent wind speeds were reviewed to ensure that the wind records (daily gusts and hourly means) were from a Weibull distribution.

Probability distributions of wind speeds were reviewed to determine directions from which the anemometer was sheltered.

4.2 Seasonal Analysis

Wind records were separated into seasons categorized by the following:

- Autumn = September, October, November
- Winter = December, January, February
- Spring = March, April, May
- Summer = June, July, August

The strongest wind speeds across Ireland were shown to occur in the late winter or early spring months. The wind speeds in the summer months are approximately 75% as strong as those in the winter. The current British Standard for Wind Loading (BS6399-2) provides seasonal factors that can be used in the design of temporary structures. It is not the intention of this current piece of work to provide seasonal factors to be used in conjunction with the Irish design wind speed map.

[1] Recent analysis of a wind record from a Middle Eastern Airport has revealed over 100 statistical outliers in a 20 year data record.

5 Extreme Value Analysis Procedure

The cumulative probability distribution of the wind speed measurements is most closely modelled by the Weibull distribution of the form:

$$P_V = 1 - \exp\left[-(V/c)^k\right]$$

Where *c* and *k* are empirical constants for a best fit to individual data sets and P_V is defined as the probability that a velocity will be less than a velocity *V*. Theoretically, for a set of data conforming to a Weibull distribution the cumulative distribution function of the extremes will converge towards a Fisher-Tippett Type I distribution of the form:

$$P_x = \exp\left[-\exp(-y)\right]$$

Where the reduced variate y, is given by:

$$y = -\ln[-\ln(P_x)]$$

And P_x is the probability that an extreme value will be less than a value x in any one year.

The extreme value x is equated to the wind velocity (mean or gust) squared to ensure a rapid convergence to the extreme value distribution.

Two methods of extreme value analysis were carried out in this assessment; a modified Gumbel analysis (annual maximum data), and a Harris Independent Storms (using the maximum '2.4 x years of data' wind speeds from independent storms). These methods of analyses are valid for both daily gust and hourly mean wind speeds.

In the assessment the design wind speeds predicted using the two methods of analysis were compared for consistency.

5.1 Analysis of Annual Maxima Data

Gumbel (1954) gave an easily usable methodology for fitting recorded annual maxima to the Type 1 Extreme Value distribution. In this method of analysis the following procedure is adopted:

- The largest wind speed in each calendar year of the wind record is extracted
- The series is ranked in order of smallest to largest: 1,2,…m…to N
- Each value is assigned a probability of non-exceedence, p, according to $p = m(N+1)$
- A reduced variate y is formed
- The wind speed V^2 is plotted against y and a line of 'best-fit' is drawn

This probabilistic analysis is used to provide design wind speeds for various return periods, with a greater confidence associated with shorter return period events.

To account for the greater confidence in these shorter return period events a probability weighted least squares methodology (giving appropriate weighting to each wind record based on confidence levels) is adopted (as proposed by Harris). The probability positions depend on the rank, m, and the number of wind records. Based on the plotting positions the mode and dispersion of the statistical fit is derived, this fit is referred to as a modified Gumbel.

Cook (1985) suggests a minimum of 20 consecutive years of wind records is required to ensure reliable results when employing a modified Gumbel analysis. Following the separation of the wind record based on anemometer type and location there were no wind records from the Vaisala anemometers which satisfied this 20 year minimum, therefore the predictions were treated with caution.

One fault of the Gumbel method is that the maximum wind speeds are chosen from each 'calendar year', as opposed to each 'storm year', giving rise to the situation where yearly maximums occurring on the 31st of December one year and the 1st of January in the following year could both be kept. Theoretically these two wind speeds could be related and associated with the same storm generating event. The inclusion of both of the wind speeds results in a conservative estimate of the design speed.

5.2 Analysis of Individual Storm Data

Originally explained by Cook (1985) and later modified by Harris (1998), the method of analysis, as recommended in ESDU, makes use of wind speed maxima taken from independent storms of the same mechanism. The advantage of this method is that many more wind records are available to define the mode and dispersion parameters of a distribution, leading to a greater confidence in the estimation of design wind speeds. Only seven years of wind data are needed to permit a reasonable estimate of the design winds (Cook, 1985).

A period of storm separation of three days was considered. Therefore the smaller values of pairs of wind records separated by three days or less were deleted to ensure that only *independent* storm maxima were retained.

The procedure for analysing the independent storm data is similar to that for the yearly maxima except that the calculation of the reduced variate is modified. The probability that the extreme value will not be exceeded in any one year is based on the rank of the wind speed compared to the total number of storms (taken as 2.4 x years of data). The plotting positions are again modified based on probability weighted least squares. This probabilistic analysis is used to provide design wind speeds for various return periods, with a greater confidence associated with shorter return period events.

5.3 Discussion of analysis

For the methods of analyses outlined above, there is an amount of uncertainty in the estimation and the precision of the design wind speed estimates. These estimates depend on both the quality and the length of the wind record.

In some cases recorded wind maxima can fall outside confidence limits. There are three common reasons accounting for these obscure wind records. Firstly, the value may originate from a storm with a different mechanism. Secondly, the event may have a smaller probability of occurrence than the analysis would indicate, due to the finite record length not containing other intermediate storm events which would occur eventually. Thirdly, the value could be associated with a manual recording/rounding error.

The methodology of the Harris probability least squares prevents individual events from skewing the design wind speed prediction substantially.

Due to the short length of some of the wind records, and given the greater reliability in the prediction of the mode rather than the design wind speed itself; the directional design wind speeds were calculated using a general directional dispersion parameter and the individually calculated mode. In the majority of cases this resulted in a level of conservatism added to the design wind speeds.

The general dispersion parameter was derived by taking the natural log of the average number of storms by direction. The number of storms from each direction for each station was determined by counting the downward crossings of a specified threshold in the time histories of the mean wind speeds, and then averaged for all anemometer sites. Dispersion parameters representative of the wind climate in Ireland (shown in Figure 5), were derived.

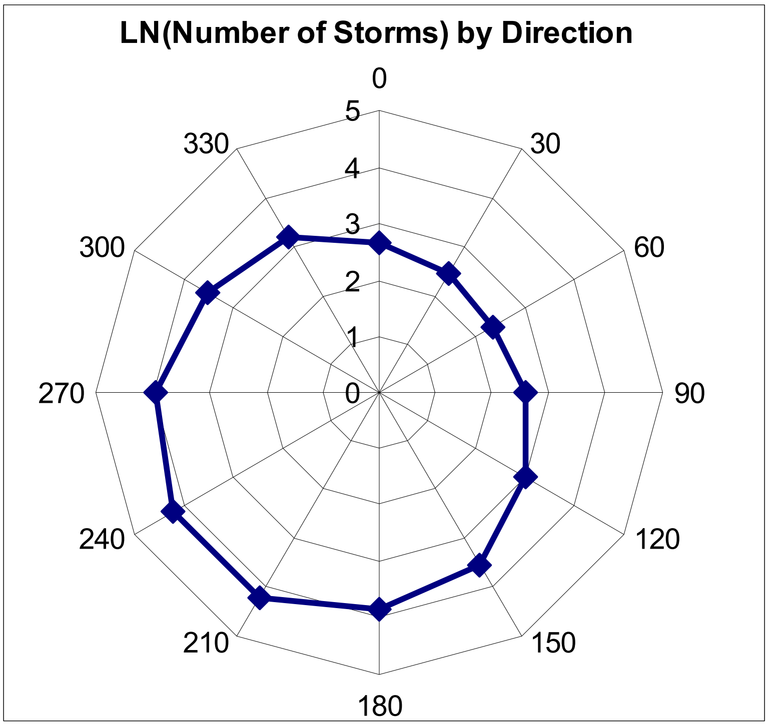

Figure 5 – Directional dispersion parameters for Ireland.

6 Wind Map for Ireland

6.1 Mean and Gust Wind Speeds

Over the last 40 years there has been an increasing tendency to use mean speeds rather than gust speeds in predicting extreme wind speeds. The use of mean speeds over gust speeds has been favoured because of the theoretical statistical stability of measurement of means speeds and the known problems with interpreting and comparing gust speed records from different anemometer and recording systems. Statistical variation and random measurement problems tend to result in over-predictions of extremes. On the other hand gust speeds are much less sensitive to changes or estimates of terrain roughness and site exposure and prediction reliability should be of less concern with longer data records.

The extreme value analyses described above were carried out on both the hourly mean and the daily gust wind speeds. Due to the variations in the design wind speed predictions from the three anemometer types (Dines, Vector and Vaisala) each anemometer was treated independently, and a correction factor was applied to the design wind speed predictions. The mode predictions from the Vaisala anemometer were uniformly 10% lower than the predictions from the Dines anemometer. The Vector anemometer predictions were a further 6% lower. This difference in the modal predictions was similar for both the hourly mean wind speeds and the daily gust speeds. The Vaisala anemometer was taken to be the most robust and accurate of the three anemometer types and therefore the Dines and the Vector wind speed predictions were downward and upward corrected by 10% and 6% respectively.

The mean and gust design wind speeds were then derived for the anemometers based on the predicted mode and the general dispersion parameter by direction (separated by anemometer type, height change and/or anemometer re-location). These directional design wind speeds (in 30^{o} segments) were corrected for terrain and in some cases, topography.

6.2 Directionality of the Design Winds

'Direction factors' are applied to a site specific design wind speed to enable designers to carry out a more accurate assessment of wind loading of a structure. Without the inclusion of direction factors in a design assessment there is the high probability of over-design.

Direction factors were derived by dividing each independent directional design wind speed by the maximum directional design wind speed. Direction factors similar to those used for the UK NA have been proposed for the Irish NA for two reasons; firstly, because minimal difference was found between the directional factors between the UK and Ireland and secondly because the topography in Ireland was considered to be significant and not fully represented by the sixteen anemometers used in this analysis. The recommended direction factors are shown in Figure 6.

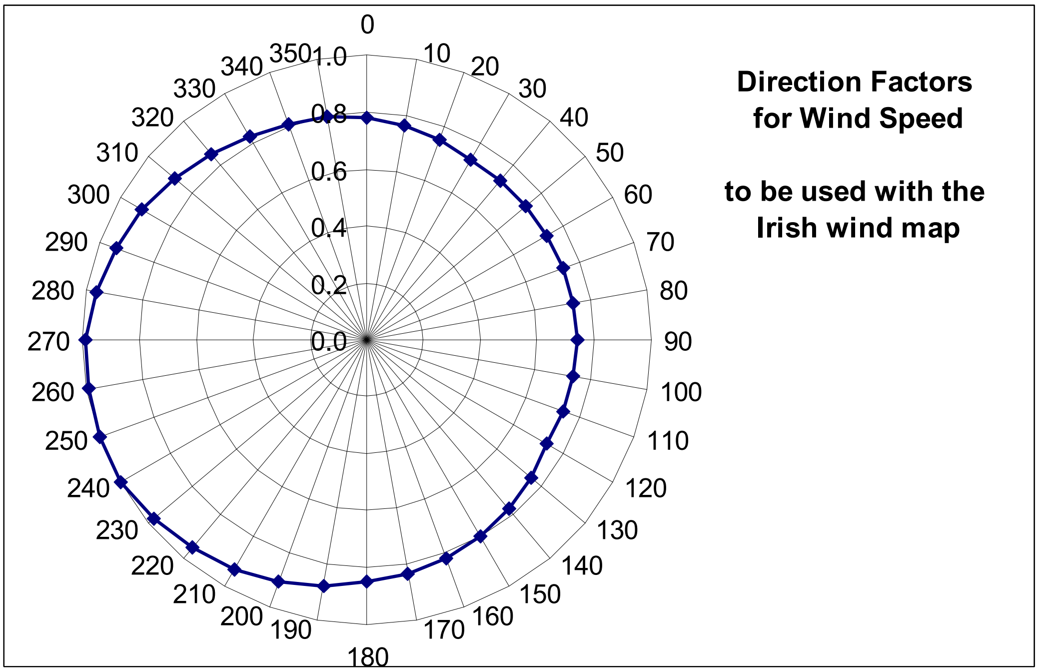

Figure 6 - Direction factors for wind speeds, to be used with the Irish NA wind map.

6.3 Design Wind Map for Ireland

The hourly mean directional wind speeds for all anemometers were converted into 10-min mean wind speeds using a 1.06 conversion factor, as used in generating the wind map of the UK NA.

The design gust speeds were converted to hourly mean design speeds by applying an average gust factor of 1.67. This was shown to be conservative as the average gust factor for the sixteen stations (based on the 50-year design wind speed predictions) was shown to be 1.73. These hourly-mean design speeds were than converted into 10-min means using the 1.06 conversion factor.

The 10-min mean design wind speeds were then plotted on the map of Ireland and contour lines were drawn to fit, as shown in Figure 7.

Shown in Figure 8 are the Irish and the UK NA wind maps plotted together.

The design speeds across Ireland are not too dissimilar from those specified in the BS6399-2 wind map, increased by 6% to account for the hourly-mean to 10-min mean conversion. The numerical values of the mean hourly directional design wind speeds according to the wind map are shown in Appendix B.

Using the contours from the Irish NA wind map the recommended design wind speeds were compared with the wind speeds predicted in the extreme value analyses (as shown in Appendix C for the various anemometer types). There were only a few minor aberrations where the extreme value analysis results for certain directions were larger than recommended design speeds.

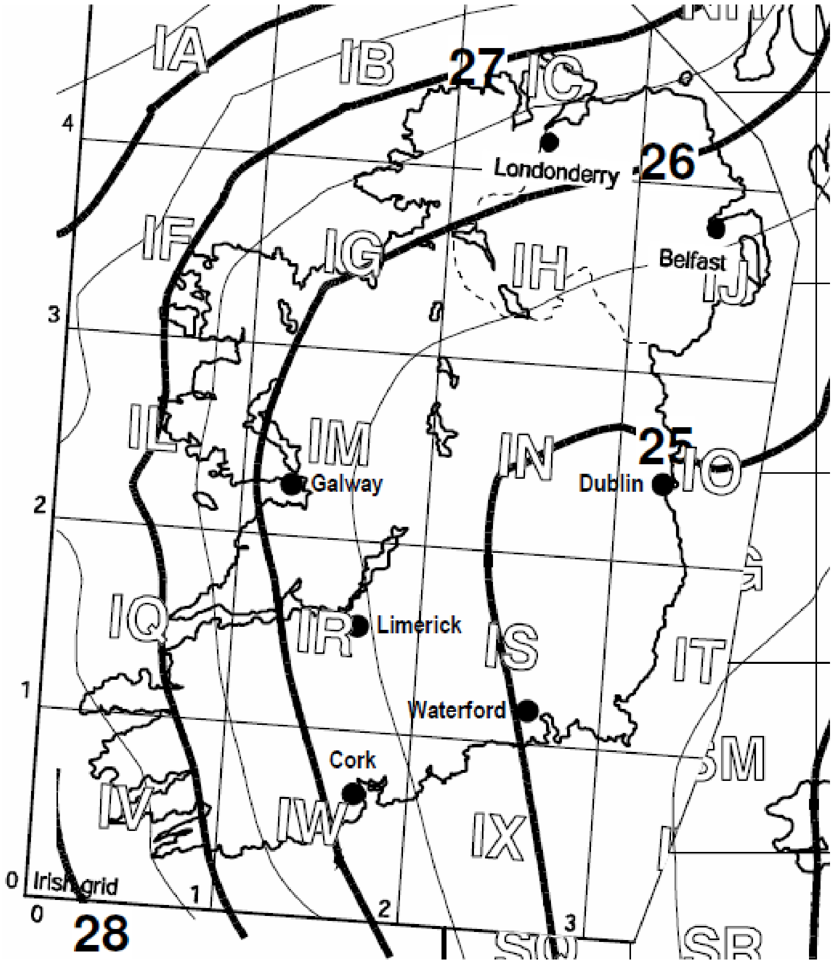

Figure 7 – Proposed Irish NA design wind speeds (10-minute mean).[2]

[2] The extreme value predictions from the following stations (for particular directions) were taken as guidance only when forming the design wind speed contours. The following notes were detailed in the station audits.

- Belmullet: 'Overall the exposure of the current site is not ideal as it is contaminated by trees and shrubs in the nearby surroundings.'
- Clones: 'Fir trees NW have a major impact on the readings. Ground around the station slopes steeply S. Site is within SW-NE lowland corridor.'
- Galway: 'Town has a substantial effect on the anemometer readings.'
- Malin Head: 'Cliffs from 0^o -120^o potentially distort the airflow.'
- Rosslare: 'The site is on a NE facing cliff (17m). Cliffs to the S and SW cause some minor wind distortion.'
- Valentia: 'The observatory is surrounded by hills with just a few gaps; the winds are less strong and more turbulent than they would be otherwise. The anemometer is situated on a strongly sloping ground.'

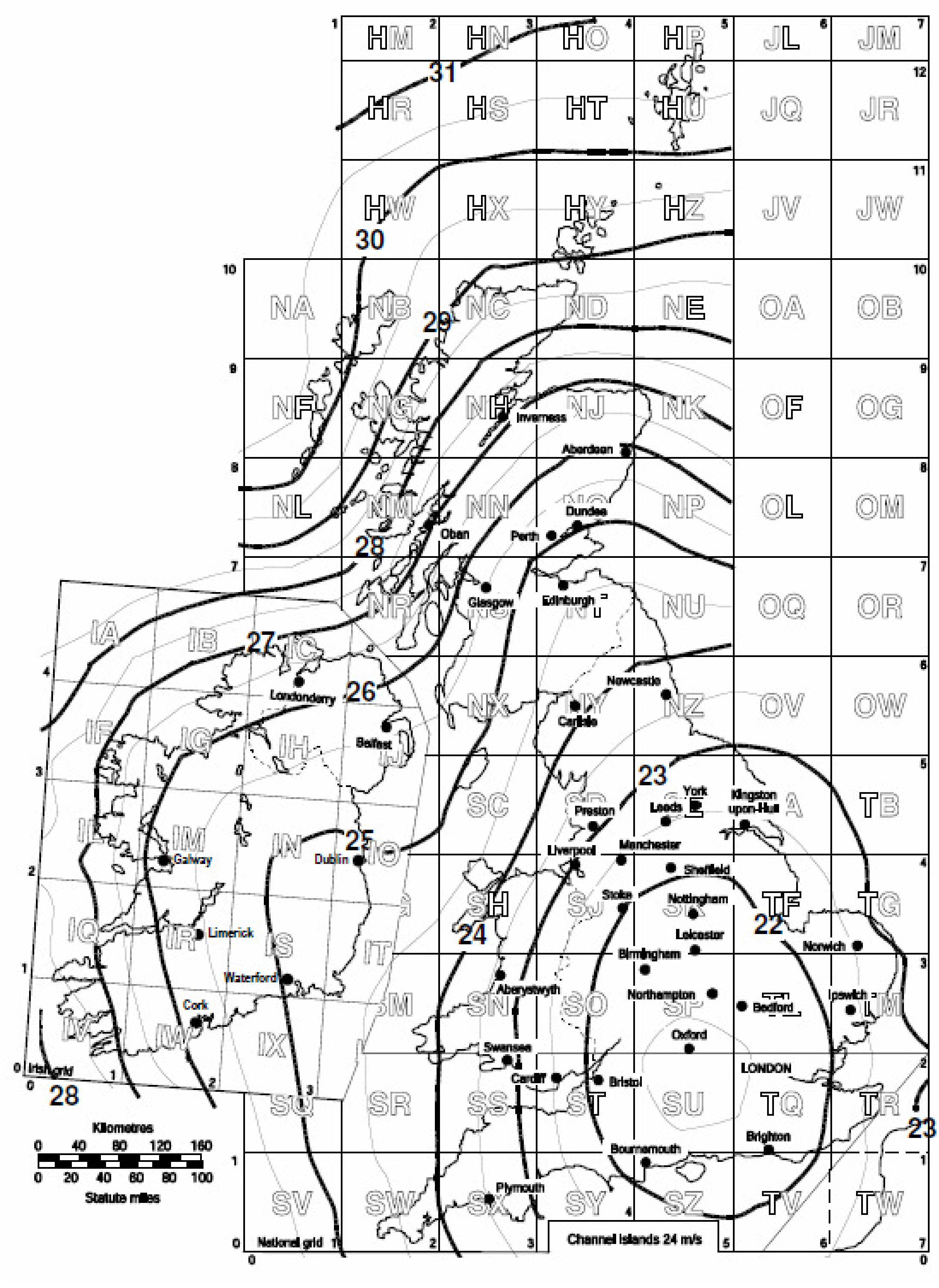

Figure 8 – Proposed Irish and UK NA design wind speeds (10-minute mean).

7 Summary

An extensive study has been carried out to assess the wind speeds around Ireland. Long-term wind records from sixteen weather stations were used in the assessment. The daily gust speeds and the hourly mean speeds from three anemometer types (Dines pressure-tube, Vaisala rotating-cup, Vector rotating-cup) were used in the study.

The 50-year 10-min mean wind speeds at 10 m height in open country terrain, appropriate for the design of structures in Ireland have been assessed and a design wind map to be used with the Irish National Annex to the Eurocode has been proposed.

The design wind speeds compare well with those specified in the BS6399-2 wind map (increased by 6% to account for the hourly-mean to 10-min mean conversion).

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APPENDIX A – correction factors (altitude and terrain)

MEAN	0	30	60	90	120	150	180	210	240	270	300	330
Belmullet	0.919	0.913	0.964	0.900	0.907	0.803	0.812	0.927	0.890	0.888	0.906	0.914
Birr	1.066	1.053	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.086	1.086
Casement	1.006	1.011	1.031	0.967	1.033	1.019	1.042	0.883	0.864	0.914	0.975	0.980
Claremorris	0.934	0.934	0.934	0.934	0.934	1.020	0.972	0.934	0.934	0.934	0.934	1.008
Clones	1.031	1.031	1.031	1.031	1.031	1.031	1.031	1.063	1.063	1.063	1.063	1.063
Cork	0.884	0.855	0.839	0.842	0.871	0.799	0.811	0.867	0.867	0.867	0.845	0.837
Dublin	0.913	0.968	0.979	0.893	0.902	0.975	1.101	1.025	0.956	0.898	0.895	0.895
Galway	1.212	1.210	1.210	1.186	1.163	1.113	1.017	1.030	1.107	1.266	1.243	1.228
Kilkenny	1.013	1.018	1.022	1.026	1.030	1.081	1.021	0.938	0.938	0.938	0.938	0.938
Knock	0.797	0.797	0.797	0.797	0.797	0.893	0.893	0.893	0.856	0.789	0.789	0.797
Malin Head	0.700	0.695	0.695	0.695	0.695	0.862	0.823	0.798	0.813	0.822	0.768	0.740
Mullingar	0.924	0.945	0.951	0.947	0.962	0.960	0.942	0.906	0.906	0.906	0.906	0.906
Rosslare	0.906	0.959	0.959	0.734	0.734	0.734	0.734	0.734	0.734	0.919	0.924	0.875
RochesPoint	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756
Shannon	0.950	0.935	1.015	1.075	0.953	0.936	0.895	0.913	0.866	0.926	0.929	0.903
Valentia	0.985	1.028	1.010	1.019	1.012	0.989	0.934	0.973	0.934	0.870	0.880	0.858

GUST	0	30	60	90	120	150	180	210	240	270	300	330
Belmullet	0.945	0.942	0.971	0.947	0.953	0.918	0.907	0.950	0.930	0.930	0.938	0.943
Birr	0.958	0.954	0.931	0.931	0.931	0.931	0.931	0.931	0.931	0.931	0.962	0.962
Casement	0.958	0.966	0.981	0.941	0.975	0.964	0.985	0.906	0.898	0.913	0.939	0.941
Claremorris	0.934	0.934	0.934	0.934	0.934	0.970	0.948	0.934	0.934	0.934	0.934	0.962
Clones	0.969	0.969	0.969	0.969	0.969	0.969	0.969	0.983	0.983	0.983	0.983	0.983
Cork	0.882	0.875	0.860	0.862	0.871	0.834	0.840	0.866	0.866	0.866	0.863	0.860
Dublin	0.931	0.955	0.953	0.907	0.917	0.950	1.022	0.993	0.961	0.925	0.923	0.923
Galway	1.073	1.072	1.072	1.062	1.053	1.031	0.987	0.989	1.020	1.098	1.087	1.080
Kilkenny	0.966	0.968	0.970	0.972	0.974	0.998	0.969	0.937	0.937	0.937	0.937	0.937
Knock	0.822	0.822	0.822	0.822	0.822	0.856	0.856	0.856	0.841	0.818	0.818	0.822
Malin Head	0.838	0.829	0.829	0.829	0.829	0.897	0.892	0.846	0.853	0.857	0.844	0.839
Mullingar	0.911	0.923	0.926	0.924	0.932	0.931	0.923	0.905	0.905	0.905	0.905	0.905
Rosslare	0.928	0.958	0.958	0.860	0.860	0.860	0.860	0.860	0.860	0.950	0.953	0.921
RochesPoint	0.881	0.881	0.881	0.881	0.881	0.881	0.881	0.881	0.881	0.881	0.881	0.881
Shannon	0.981	0.974	1.010	1.032	0.963	0.965	0.954	0.953	0.931	0.959	0.960	0.951
Valentia	1.001	1.005	0.999	1.011	1.007	0.988	0.954	0.976	0.954	0.926	0.942	0.931

APPENDIX B – directional design wind speeds at each anemometer site

Site Name	Map 10-Min Mean Wind Speed (m/s)	Hourly-Mean Wind Speeds by Direction (m/s)											
		0	30	60	90	120	150	180	210	240	270	300	330
Belmullet	27.0	19.9	18.6	18.6	18.8	18.6	20.4	21.7	23.7	25.5	25.2	23.2	20.9
Birr	25.0	18.4	17.2	17.2	17.5	17.2	18.9	20.0	21.9	23.6	23.3	21.5	19.3
Casement	25.0	18.4	17.2	17.2	17.5	17.2	18.9	20.0	21.9	23.6	23.3	21.5	19.3
Claremorris	26.0	19.1	17.9	17.9	18.2	17.9	19.6	20.8	22.8	24.5	24.3	22.3	20.1
Clones	25.4	18.7	17.5	17.5	17.7	17.5	19.2	20.4	22.3	24.0	23.7	21.8	19.6
Cork	25.7	18.9	17.7	17.7	17.9	17.7	19.4	20.6	22.5	24.2	24.0	22.1	19.9
Dublin	25.0	18.4	17.2	17.2	17.5	17.2	18.9	20.0	21.9	23.6	23.3	21.5	19.3
Galway	26.0	19.1	17.9	17.9	18.2	17.9	19.6	20.8	22.8	24.5	24.3	22.3	20.1
Kilkenny	25.0	18.4	17.2	17.2	17.5	17.2	18.9	20.0	21.9	23.6	23.3	21.5	19.3
Knock	26.0	19.1	17.9	17.9	18.2	17.9	19.6	20.8	22.8	24.5	24.3	22.3	20.1
Malin Head	27.0	19.9	18.6	18.6	18.8	18.6	20.4	21.7	23.7	25.5	25.2	23.2	20.9
Mullingar	25.0	18.4	17.2	17.2	17.5	17.2	18.9	20.0	21.9	23.6	23.3	21.5	19.3
Rosslare	25.0	18.4	17.2	17.2	17.5	17.2	18.9	20.0	21.9	23.6	23.3	21.5	19.3
RochesPoint	25.7	18.9	17.7	17.7	17.9	17.7	19.4	20.6	22.5	24.2	24.0	22.1	19.9
Shannon	25.8	19.0	17.8	17.8	18.0	17.8	19.5	20.7	22.6	24.3	24.1	22.1	20.0
Valentia	27.0	19.9	18.6	18.6	18.8	18.6	20.4	21.7	23.7	25.5	25.2	23.2	20.9

APPENDIX C.1 – design wind speed predictions (Dines pressure-tube anemometer)

EVA PREDICTIONS (mean)	0	30	60	90	120	150	180	210	240	270	300	330
Belmullet	22.0	21.7	20.4	17.6	19.0	18.5	23.1	27.7	25.7	24.4	23.6	21.2
Birr	14.5	14.1	15.1	15.4	18.6	18.5	18.3	17.4	18.9	19.1	18.6	15.7
Casement	14.8	15.9	19.3	19.3	21.1	23.5	29.0	24.2	21.8	21.8	17.5	15.1
Claremorris	17.0	16.1	16.6	18.0	17.6	18.1	19.1	21.0	20.4	22.2	21.7	19.8
Clones	20.8	17.1	16.0	16.1	19.3	22.0	22.5	23.3	21.3	21.6	24.2	22.6
Cork	18.4	15.4	16.6	19.7	20.4	20.6	19.4	22.7	21.0	18.5	22.0	20.4
Dublin	15.2	18.2	16.5	14.3	17.4	21.0	22.2	24.5	25.3	22.6	19.3	15.2
Galway	18.8	16.6	19.1	19.8	20.5	21.1	18.1	20.7	25.3	29.3	23.9	21.7
Kilkenny	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Knock	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Malin Head	21.9	20.1	19.3	21.9	20.9	24.4	24.4	23.4	25.3	25.9	23.7	22.1
Mullingar	12.4	13.1	14.4	14.2	16.1	18.7	18.2	17.0	18.1	17.4	15.9	13.3
Rosslare	18.5	22.3	20.9	15.7	16.0	17.0	17.9	18.2	16.0	13.0	14.7	15.7
RochesPoint	19.1	15.5	19.5	16.3	17.9	19.7	21.2	20.7	19.3	23.8	27.5	24.5
Shannon	17.4	15.6	17.3	21.9	21.5	22.2	20.3	20.9	22.7	23.4	22.3	18.4
Valentia	19.7	21.0	17.1	19.7	20.3	20.0	20.2	24.6	23.2	22.4	17.5	16.2

EVA PREDICTIONS (gust)	0	30	60	90	120	150	180	210	240	270	300	330
Belmullet	21.1	19.7	17.4	15.9	19.0	18.6	24.1	28.2	26.8	27.1	24.9	22.2
Birr	14.9	13.6	14.2	13.7	18.1	19.8	19.2	19.5	21.7	21.5	20.8	17.3
Casement	13.7	14.9	16.3	17.1	18.3	21.2	26.0	23.6	22.3	22.8	19.8	16.1
Claremorris	17.7	14.8	14.4	16.1	17.5	18.4	20.5	21.8	20.7	24.0	23.4	20.5
Clones	19.4	15.6	15.4	15.6	18.7	20.9	22.5	22.4	21.9	22.8	25.0	21.3
Cork	16.6	14.5	14.2	16.7	18.2	20.0	20.6	21.7	20.4	19.3	23.0	20.5
Dublin	13.4	14.7	13.4	11.8	16.1	19.9	21.9	23.8	24.8	23.2	19.1	16.8
Galway	18.0	14.2	16.4	18.0	18.6	21.2	20.5	22.7	27.0	29.3	24.8	22.9
Kilkenny	16.8	13.7	13.0	14.0	15.2	18.9	22.3	21.7	21.0	22.8	21.6	19.2
Knock	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Malin Head	19.6	15.3	14.2	18.3	19.9	21.0	20.8	21.1	23.9	24.1	23.8	20.8
Mullingar	14.3	12.6	14.2	13.8	13.3	17.1	16.2	17.5	19.8	19.0	19.0	16.6
Rosslare	16.4	18.1	16.5	14.2	15.7	17.5	19.1	21.0	20.3	17.4	17.0	17.1
RochesPoint	16.6	13.1	16.8	16.9	19.2	21.9	25.0	24.2	21.7	23.6	26.1	22.3
Shannon	16.6	14.8	14.6	16.7	18.5	21.2	22.0	22.2	24.7	24.9	23.1	18.3
Valentia	18.4	20.3	15.7	21.0	23.0	25.1	25.2	28.2	25.0	26.1	22.7	18.3

APPENDIX C.2 – design wind speed predictions (Vaisala rotating-cup anemometer)

EVA PREDICTIONS (mean)	0	30	60	90	120	150	180	210	240	270	300	330
Belmullet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Birr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Casement	12.6	13.7	16.0	16.9	18.8	20.8	24.0	20.6	20.0	19.9	15.7	13.0
Claremorris	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Clones	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cork	16.7	13.7	16.1	18.5	18.7	18.9	15.5	20.6	18.9	18.3	19.5	16.8
Dublin	15.1	17.9	17.9	17.7	18.4	19.9	20.3	22.0	23.0	21.4	17.4	15.7
Galway	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Kilkenny	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Knock	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Malin Head	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mullingar	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rosslare	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RochesPoint	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Shannon	14.8	15.2	15.6	18.0	19.1	20.0	18.0	17.9	21.0	22.1	19.4	15.4
Valentia	19.0	17.2	16.5	19.3	20.2	19.0	18.0	22.6	21.4	20.4	17.9	15.9

EVA PREDICTIONS (gust)	0	30	60	90	120	150	180	210	240	270	300	330
Belmullet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Birr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Casement	11.9	13.3	15.4	14.9	16.1	18.4	21.7	20.8	21.2	19.6	16.3	13.4
Claremorris	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Clones	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cork	14.8	10.9	13.4	16.3	15.9	19.7	18.8	20.8	18.3	18.6	19.8	17.1
Dublin	13.2	15.0	14.9	15.5	16.2	19.4	19.8	22.1	22.9	23.1	17.9	17.1
Galway	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Kilkenny	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Knock	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Malin Head	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mullingar	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rosslare	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RochesPoint	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Shannon	14.6	14.0	12.7	14.2	16.3	18.9	19.7	19.7	23.7	24.0	20.0	16.4
Valentia	19.8	16.0	15.6	20.0	23.2	22.5	21.7	24.8	23.3	22.6	20.5	17.7

APPENDIX C.3 – design wind speed predictions (Vector rotating-cup anemometer)

EVA PREDICTIONS (mean)	0	30	60	90	120	150	180	210	240	270	300	330
Belmullet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Birr	12.6	12.1	13.6	14.4	16.7	16.6	17.3	16.4	16.3	15.0	15.1	15.4
Casement	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Claremorris	16.4	15.3	14.9	15.4	14.7	16.1	17.9	19.7	18.5	19.8	17.3	15.0
Clones	14.0	14.6	12.9	13.9	17.6	19.3	19.5	19.5	17.4	18.7	20.2	17.2
Cork	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dublin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Galway	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Kilkenny	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Knock	14.0	11.3	10.9	12.6	13.7	17.6	19.4	19.9	18.8	18.7	17.6	16.8
Malin Head	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mullingar	9.5	10.1	11.8	12.3	13.0	15.7	15.7	14.9	14.9	14.4	13.1	11.0
Rosslare	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RochesPoint	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Shannon	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Valentia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

EVA PREDICTIONS (gust)	0	30	60	90	120	150	180	210	240	270	300	330
Belmullet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Birr	12.5	11.9	12.4	11.4	15.3	16.7	17.3	16.8	17.4	18.1	16.5	15.8
Casement	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Claremorris	17.6	12.8	12.9	13.8	15.8	15.6	19.5	19.7	17.8	21.3	18.2	14.8
Clones	14.8	14.6	12.2	12.9	16.6	18.6	19.7	19.9	18.0	19.4	21.6	16.6
Cork	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dublin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Galway	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Kilkenny	17.2	10.9	13.1	11.5	13.6	17.9	20.6	19.7	20.0	20.0	18.1	15.3
Knock	13.6	10.2	9.9	12.7	15.0	16.4	19.7	21.3	21.3	19.8	20.0	18.2
Malin Head	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mullingar	10.2	11.1	11.2	12.0	11.5	14.4	14.5	15.8	17.1	15.8	16.1	12.8
Rosslare	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RochesPoint	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Shannon	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Valentia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0