Project Report
Republic of Ireland – Wind Atlas 2003

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Sustainable Energy Ireland,
Glasnevin,
Dublin 9.

ESBI Consultants
18-21 St. Stephen's Green,
Dublin 2.

Contents

(Report to be accompanied by full set of maps)

Prepared by: M. Brower

G. Ewing

P. McCullen

Executive Summary

This report presents the results of a wind-mapping project conducted by ESBI International, with TrueWind Solutions under a contract with Sustainable Energy Ireland. Using its MesoMap system, TrueWind has produced GIS data files of mean wind speed and power at heights of 50 m, 75 m, and 100 m above ground, on a 200 m grid covering the Republic of Ireland and points up to 20 km offshore on a 400m grid. From these individual digital county wind resource maps are produced.

The method is based, inter alia, on the use of a historical world weather dataset compiled for intervals of six hours at all atmospheric levels. Analysis is then performed using nested grids of successively finer mesh size to simulate conditions down to a grid size of 1km. The mesh size is further reduced using a second model having regard to local land elevation, land cover and roughness and a comparison is made between the predicted wind characterisation and those measured at a range of meteorological sites across the country to minimise the residual differences between predicted and actual mean values encountered.

The results confirm that Ireland has a very significant wind resource, particularly offshore, at exposed points along the coasts, and on hilltops and ridges throughout the island and especially in the western part of the country. The predicted mean wind speed and power in many such locations is in the range of 8 to 10 m/s, which would suffice to support economical wind energy projects. Lowlands and valleys are somewhat less windy, with mean wind speeds predicted to be in the range of 6 to 7.5 m/s.

The report also describes the validation of the maps carried out by TrueWind Solutions using data from Met Eireann, private developers and other sources. The data indicate very good agreement with the MesoMap predictions. With the initial model results, which were generated without reference to surface wind data, the predicted mean speed at 50 m averaged about 3% above the measured (extrapolated to the same height), and the root-mean-square discrepancy was about 0.4 m/s or 5% after accounting for uncertainty in the data. The last stage of model runs was then repeated with amended settings to increase the wind shear and reduce the near-surface wind speed at less windy sites. This eliminated the average bias and reduced the model-only rms discrepancy to about 0.2 m/s or 2.5%. The r^2 correlation coefficient between the predicted and measured/extrapolated mean wind speeds was 88%.

The results are held on digital databases that support geographical information output and 12 national and 405 county paper map plates showing mean wind speed contours, contours of power density, diurnal seasonal and directional effects at heights of 50, 75, 100m above ground in both unconstrained and constrained forms.

The marine wind resource is mapped in a similar way to a distance of approximately 15km from the coast involving 156 plates.

Based on the experience of producing the Wind Atlas a number of conclusions are reached and corresponding recommendations are made to facilitate future similar work.

The wind atlas provides a basis for informed strategic decision making related to resource distribution and efficient development.

PMcC1404

1. Introduction

This report outlines the application of meso scale wind modelling in the development of Wind Atlas 2003 for the Republic of Ireland (A corresponding but separate project is underway for Northern Ireland). The project was commissioned by Sustainable Energy Ireland (SEI) as part of its policy to assist informed strategic decision making where the development of Ireland's sustainable energy resources are concerned.

The project was undertaken by ESBI in collaboration with True Wind Solutions during 2002-2003 and the output for each county is provided to SEI in geographical information system and paper map format for general use. Instructions for use of the individual county data bases are contained on the CD for the particular county. The digital maps are compatible with the 1:50000 scale 'Discovery' series of maps produced by Ordnance Survey Ireland. The paper maps are re-scaled to fit A3 sized sheets depending on the size of the particular county with the scale and national grid shown for the nearshore resource paper maps a uniform scale of 1 : 150000 is adopted.

2. Background

In 1996-7 as part of the input to Ref.(1), ESBI and the UK Energy Technology Support Unit (ETSU) estimated the extent of the wind resource of the Republic of Ireland using methodology that had already been applied in Scotland, Northern Ireland and parts of England based on the NOABL wind model developed in the United States. In the Irish application the model was applied at a height of 45m above ground. It utilised a 1km square grid of points for which calculations were made based on input from Met Eireann stations and an averaged wind rose for the whole country. Corrections were made for directionality and slopes. The initial theoretical resource was calculated for the whole land area, from this the feasible resource was derived by deducting areas subject to arbitrary constraints such as particular land cover, slopes > 10^o, buffer zones surrounding built up areas, lakes etc. Finally the accessible resource was estimated by deducting environmentally sensitive areas (again on an arbitrary basis) and areas where the mean wind speed was below 7m/sec which was then deemed to be the commercially viable threshold wind speed bearing in mind rates payable under the first Alternative Energy Requirement (AER) scheme. This enabled contours of mean wind speed to be plotted using a 0.5m/sec. interval and these in turn could be used to screen out and quantify the average projected power and energy values for key sites for individual clients, including some local authorities and commercial clients.

During the period 1997-2001, feedback reaching the Renewable Energy Information Office via a series of seminars that involved representatives of local planning authorities, wind farm developers, consultants and others, together with the publication of Refs. 2, 3 led to an emphasis on the need for county based wind resource mapping for planning purposes. This would take account, where possible, of the wind measurements being made at heights above the standard meteorological height by developers and others at prospective wind farm sites. New methods of analysis were also becoming available and the (then) Dept. of Energy issued an Enquiry dated Sept. 2001 that invited tenders for the determination of the onshore commercially accessible wind energy resource on a national and a county basis, in the form of both the unconstrained theoretical resource and the feasible commercial resource constrained by physical limitations. At that point it was stipulated that the analysis should determine

- Unconstrained theoretical resource.
- Feasible commercial resource constrained by physical limitations.
- Onshore commercially accessible wind energy resource on a national and county basis.

and that the input should

- Use a meso scale atmospheric model with measured wind energy parameters and verifiable field data
- Use 500m buffer around settlements
- Use 100m buffer along main roads, railways, HV lines
- Delete rivers, lakes, canals, reservoirs
- Delete areas with mean wind speed < 7.0m/sec.
- Secure best reliable fit between meso scale model and field data
- Provide commercial resource maps to identify transmission network
- Be compatible with 1 : 50,000 scale OSI mapping
- Be compatible with common Geographic Information Systems
- Allow for addition of other restrictions by Planning Authorities leading to the following output
  - Digital coloured map of each county
  - Resolution on grid of at least 1km x 1km
  - Annual mean wind speed distribution at 0.25m/sec intervals
  - Wind power density distribution (W/m2)
  - Wind power class and direction distribution
  - Typical Diurnal/Seasonal wind patterns
  - Roughness classes
  - Description of analysis method for resource prediction

The Department delegated administration of the project to Sustainable Energy Ireland. ESBI, in association with TrueWind Solutions of Albany, New York, was the successful tenderer and implementation commenced in May 2002 on an eleven month schedule which reflected a number of further changes.

3. Methodology

3.1 Mesomap System

At the core of the MesoMap system is MASS (Mesoscale Atmospheric Simulation System), a numerical weather model that has been developed over the past 20 years both as a research tool and to provide commercial weather forecasting services. MASS embodies the fundamental physics of the atmosphere including conservation of mass, momentum, and energy, as well as the moisture phases, and it contains a turbulent kinetic energy module that accounts for the effects of viscosity and thermal stability on wind shear. As a dynamical model, MASS simulates the evolution of atmospheric conditions in time steps as short as a few seconds. This creates great computational demands requiring the use of powerful workstations and multiple parallel processors. However, MASS can be coupled to a faster model, WindMap, a high-resolution mass-consistent wind flow model. Depending on the size and complexity of the region and requirements of the client, WindMap may be used to increase the spatial resolution of the MASS simulations.

3.2 Databases

The MASS model uses a variety of online, global, geophysical and meteorological databases. The main meteorological inputs are reanalysis data, rawinsonde data, and land surface measurements. The reanalysis database – the most important – is a gridded historical weather data set produced by the US National Center for Environmental Prediction (NCEP) and National Center for Atmospheric Research (NCAR). The data provide a snapshot of atmospheric conditions around the word at all levels of the atmosphere in intervals of six hours. Along with the rawinsonde and surface data, the reanalysis data establish the initial conditions as well as updated lateral boundary conditions for the MesoMap simulations. However, the model itself determines the evolution of atmospheric conditions within the region based on the interactions among different elements in the atmosphere and between the atmosphere and the surface. Because the reanalysis data are on a relatively coarse, 200 km grid, the MesoMap system is run in several nested grids of successfully finer mesh size, each taking as input the output of the previous nest, until the desired grid scale is reached. The outermost grid typically extends several thousand kilometers.

The main geophysical inputs are elevation, land cover, vegetation greenness (normalized differential vegetation index, or NDVI), soil moisture, and sea-surface temperatures. The elevation data normally used by MesoMap were produced by the US Geological Survey in a gridded digital elevation model, or DEM, format from a variety of data sources. * The US Geological Survey, the University of Nebraska, and the European Commission's Joint Research Centre (JRC) produced the land cover data in a cooperative project. The land cover classifications are derived from the interpretation of Advanced Very High Resolution Radiometer (AVHRR) data – the same data used to calculate the NDVI. The model translates both land cover and NDVI data into biophysical parameters such as surface roughness, albedo, emissivity, and others. The nominal spatial resolution of all of these data sets is 1 km. Thus, the standard output of the MesoMap system is a 1 km gridded wind map, although higher resolution maps can be produced if the necessary topographical and land cover data are available.

* The US Defence Department's high-resolution Digital Terrain Elevation Data set is the principal source for the global 1km grid elevation. Gaps in the DTED data set were filled mainly by an analysis of 1:1,000,000 scale elevation contours in the Digital Chart of the world (now called VMAP). For Ireland the Ordnance Survey 50m grid digital terrain model was used (See 5.1), giving a much higher resolution.

3.3 Computer and Storage Systems

The MesoMap system requires a very powerful set of computers and storage systems to produce wind resource maps at a sufficiently high spatial resolution and with a fast turnaround time. To meet this need TrueWind Solutions has created a distributed processing network consisting of 94 individual Pentium II processors and 2.5 Terabytes of hard disk storage. Since each processor simulates a sequence of days independently from the others, a project can be run on this system 50 times faster than would be possible with any single processor. To put it another way, a typical MesoMap project requiring 2 CPU-years of processing can be completed in just 2 weeks. The typical project also generates around 500 GB of data.

3.4 The Mapping Process

The MesoMap system creates a wind resource map by simulating weather conditions over 366 days selected from a 15-year period. The days are chosen through a stratified random sampling scheme so that each month and season is represented equally in the sample. Each simulation generates wind and other weather variables (including temperature, pressure, moisture, turbulent kinetic energy, and heat flux) throughout the model domain, and the information is stored at hourly intervals. When the runs are finished, the data files are compiled and summarized in a variety of formats, including most importantly colour-coded maps of mean wind speed and power density at various heights above ground and databases containing wind frequency distribution parameters. The results are then compared with available land surface and ocean surface wind measurements, and if significant discrepancies are observed, adjustments can be made to the wind maps or the runs may be repeated with a different model configuration to iron out any shortcomings.

3.5 Accuracy of the Method

TrueWind has compared the MesoMap predictions with high-quality measurements from tall towers in several regions and climates.[1] These comparisons indicate that the standard error in mean wind speed is usually 7% or less once the uncertainty in the data are removed. One or more of the following factors, which are listed in approximate order of decreasing importance, usually drives the errors:

- Variations in topography and land cover not resolved at the model grid scale
- Errors in the land cover data bases
- Finite sample size
- Errors in the meteorological data

The first is usually the most important. With a sufficiently high resolution at both the MASS and WindMap scales, it has been found that the model-only standard error can usually be reduced to around 3-7%. What resolution is "sufficiently high" depends on several factors including the complexity of the terrain and whether there are any land-ocean boundaries within the domain being mapped. Even where a higher resolution is clearly desirable, however, budgetary and schedule considerations may limit the ability to reduce the grid spacing of the model runs.

Errors in the land cover data, and especially the translation to surface roughness, are the next most common problem. These errors can usually be reduced or eliminated by applying site-specific adjustments to the surface roughness based on field surveys and aerial photography. (The method is described in Section 5 below).

The finite sample size (366 independent days) introduces an error margin of, typically, 3-4%. However the uncertainty can be larger where the wind speed frequency distribution is unusually broad – for example, if the wind resource varies greatly by season.

Errors in the meteorological data are probably of little concern in most developed countries, but may be significant in developing countries where data collection is relatively sparse.

4. Programme & Progress

4.1 Scope Changes

The client introduced a number of changes in scope as the project got underway. This involved a number of trials with different possible presentation formats. Because of the range of windspeeds encountered in Ireland it was decided that mean windspeeds and power densities should be mapped respectively over the ranges.

- 7.5m/sec – 0.25m/sec intervals – 15m/sec.
- 500W/m2 – 50W/m2 intervals – 3000W/m2

on the constrained resource maps and that, apart from built-up areas and electricity network at 38kV and above, all subsequent deletions in respect of manmade selective restrictions applied to infrastructure, transportation, designated areas, central and local communication systems would be made by or for individual competent authorities to yield the Accessible/Commercial Wind Resource in their respective counties.

4.2 Critical Path Schedule

Although much of the third stage of the project is repetitive in that similar information is being generated for 27 different counties from the master dataset, there were a number of critical activities without whose timely completion the whole project could get out of control. In fact an 800 activity critical path network had been submitted with the tender and following contract negotiation a number of revisions were made at the project inception stage. It was recognised that particular areas of time sensitivity would include acquisition of

1. Ordnance Survey Digital Mapping data to match the 1 : 50000 Discovery Series maps
2. Ordnance Survey Digital terrain model showing relief
3. Relevant ground roughness data, particularly in respect of Forestry
4. Wind measurement data from individual developers and others
5. Interfacing of data (incl. co-ordinate system changes)
6. Numerical modelling on a national basis
7. Recreating GIS files and output on a county basis.

The overall effects of these and a number of unanticipated issues are discussed below. These include

(1) The OSI digital mapping was delivered on time but was found to be in 239 separate 20 x 20km “tiles” that had to be “stitched” together to form a complete mapping. The county boundaries, lakeshores, and high water line on the coast all had to be reconfigured to ensure that the lines were accurate, contained no digital discontinuities and that county boundaries digitally joined high water lines for example as the vector shapes created in the geographic information system could otherwise collapse. (It was later found that an error in the particular layer of GIS data dealing with lakes, as received from OSI, contained a fault of this kind that took some time to resolve).

(2) The OSI digital terrain model which gives x, y national grid coordinates at 50m centres and a corresponding z, vertical level value, were found to be incomplete as one approached the Border with Northern Ireland. The extent of this problem had not been notified at the time of delivery of the original data and caused delay during the processing by Truewind. It was found that this work was in fact still being updated for OSI by external contractors and special arrangements were made for them to deliver their product directly to ESBI.

(3) A feature of the OSI material was that it stopped directly on the Border leaving a notional cliff edge of up to some hundreds of metres in some locations. This would of course affect the wind model and it was necessary to purchase the corresponding Northern Ireland digital terrain data which covers the areas north and south of the Border. This introduced its own difficulties due to the time taken in dealing with OSNI copyright procedures and the fact that the data is produced in tiles using a coded format quite different from the xyz format used by OSI. These difficulties were resolved and the information was used to smooth the model output in the Border counties of the Republic. (The project had originally been bid on the basis that a single whole island DTM would be used where this problem would not have arisen).

The amount of digital data handled during this project was extremely large and the level of resolution represents a significant step change over that which was available before the project was carried out. The ongoing work was dependent on the constant input of high quality information from a number of sources. It was a source of delay and concern wherever the standard of digital mapping information was found to be deficient for any reason. Specifically this occurred in relation to

- Unavailability of unified set of map tiles
- Partial unavailability of digital terrain model
- Non continuous vector boundaries between counties and at junctions between counties and high water coast line marking edge of local authority jurisdiction at coast
- Initial unavailability of an accurate vector high water line
- Difficulty in treatment of lake and reservoir boundaries
- Non standard digital terrain data set for Northern Ireland
- Disruption of OSI services (due to flooding and a power failure at Phoenix Park following damage to main cable at critical times)
- Incomplete ESB digital network node data set covering some transformer station locations.

These difficulties were compounded by the fact that freshly sourced material was in part being used extensively to support the subconsultants calculations in the United States as well as locally. Constant vigilance was necessary to ensure that ‘fixes’ for these problems could be rapidly developed and implemented. In this respect staff of O.S.I., and and its contractors, together with Truewind and ESBI cooperated closely to implement solutions once the particular difficulty was identified. It did however entail considerable additional effort and delayed the project somewhat.

5. Project Application

5.1 Wind Maps

The maps show the predicted mean wind speed at a heights of 50 m – 100 m above ground level and also show the predicted mean wind power density at the same heights. The mean speed and power describe different aspects of the wind resource, and both can be useful in different ways. The mean speed is the easier for most people to relate to and is consequently the more widely used. However, it does not directly measure the power-generation potential in the wind. Some experts regard the mean wind power, which depends on the air density and the cube of the wind speed, as a more accurate indicator of the wind resource when assessing wind project sites. Generally speaking, commercial wind power projects using large turbines require a mean speed of at least 7 m/s or mean power of at least 400 W/m^2. Small turbines are designed to operate at lower wind speeds, and may be useful at mean speeds (at 30 m height) as low as 5-6 m/s.

The wind speed map depicts a widely varying wind resource. The main factors affecting the resource are distance from the coast, exposure above the surrounding terrain, and land cover (which determines surface roughness). In central Ireland the predicted mean wind speed at 50 m generally ranges from 6.5 to 7.5 m/s; relatively sheltered areas may be below 6 m/s. Approaching the west coast, and particularly in open areas with few trees, wind speeds of 7-8 m/s are projected. Higher wind speeds are predicted (and experienced) on many hills and mountains and especially in the western half of the country. With respect to the offshore resource, wind speeds are predicted to be somewhat higher on the western side than in the Irish Sea, in part because the prevailing westerly winds are diminished after crossing the land.

The wind power map shows a similar pattern. The wind power density in the central part of Ireland is typically 300-500 W/m^2. Power values above 500 W/m^2 are found in the western part of the country and on exposed hilltops. Offshore, the resource is predicted to be from 600 to over 800 W/m^2.

The data files referred to in this report include the predicted speed and power at 50, 75 and 100 m heights above ground. The predicted wind shear exponent generally ranges from 0.18 to 0.21 in open areas on land and from 0.26 to 0.30 in forested or sheltered areas. Offshore, the predicted shear exponent is about 0.11 off the west coast and 0.13 in the Irish Sea. The higher shear on the eastern side reflects not only the frictional effect of the land, but also more frequent thermal stability in the boundary layer.

It should be emphasized that the mean wind speed or power over a period at any particular location may depart substantially from the predicted values, especially where the elevation, exposure, or surface roughness differ from that assumed by the MesoMap system. The accuracy of the elevation and roughness should be verified in areas where wind projects are being considered, and wind resource estimates should ultimately be confirmed by measurements. Section 6 provides guidelines on the use of the maps.

For this project, digital terrain elevation data on a 50 m grid spacing from Ordnance Survey Ireland (OSI) was used. Gaps in coverage near the Border were filled with similar data from Ordnance Survey Northern Ireland. The elevation map was then resampled using bilinear interpolation to the final 200 m grid scale. To define the surface roughness, roughness contours were prepared from the CORINE land cover database by ESBI International, amplified in forest areas, by a forest growth database produced by the Irish Forest Service. Upwards of one thousand sample observations of ground roughness were made throughout Ireland to validate the process.

The MASS model was run over nested grids at three grid scales: 30 km, 8 km, and 2 km and subsequently the Windmap model was run at a grid scale of 200 m.

5.2 Map Validation and Adjustments

The wind maps were initially produced without reference to any surface wind data. To assess the maps' accuracy, the 50 m height mapped wind speed values were compared with data from 34 monitoring stations throughout the region. They included 14 stations maintained by Met. Eireann, as well as one UK station, Orsay Lighthouse, located across the North Channel in Scotland. The instruments at most of the met service stations were mounted on towers or buildings at the standard height of 10 or 12 m, except Malin Head, which was at 21 m. In addition data for 19 stations owned by private developers was available; tower heights for these stations ranged from 10 m to 50 m. Unlike the met stations, which with few exceptions were located in lowlands and valleys, the privately owned towers were located mainly on hilltops of possible interest for wind energy projects. The core ten year period of interest was 1990-9 inclusive.

It is useful to note that ten years of hourly data reported from one meteorological station gives rise to 82,600 values from which a distribution and mean value is determined. Thus what appears as a single point source is in fact much wider in that it forms part of a simultaneous set that reflects the wind behaviour during the decade of measurement. Wind patterns can oscillate and drift over the years so that some differences between short term and long term measurements are always to be expected, independent of those induced by changes in ground roughness to which measurements made at 10m height (meteorological stations) are particularly vulnerable.

The available periods of measurement varied widely among the stations. Almost 30 years of annual mean speed values, starting in 1972, were available for the Meteorological Eireann stations. In contrast, most of the privately owned towers were monitored for only a year or two in the early or middle 1990s before being dismantled. It was necessary to ensure Summer/Winter time and US/European recording conventions are treated consistently in privately recorded data. Where possible, adjustments were made to the mean speeds recorded at the short-term stations using regressions against nearby met stations. However the accuracy of these adjustments was in some cases limited by the poor correlation between the currently available short-term and long-term station data and apparent fluctuations or trends in the long-term data. Where this occurred the data from the private sites was discarded. The significance of this problem should reduce with time as more data of higher quality is collected by private developers.

The validation was carried out in the following steps:

1. Station locations were verified and adjusted, if necessary, by comparing the quoted elevations and station descriptions against the elevation and land cover maps. Where there was an obvious error in position, the station was migrated to the nearest point with the correct elevation or other characteristic.
2. The observed mean speed and power were extrapolated to a common reference height of 50 m using the power law. For those privately owned stations that had multiple levels of instruments, the measured wind-shear exponent was used. For particular Met Eireann stations, the shear exponent was derived from WASP analyses reported in the European Wind Atlas, which took into account localized influences on the measured wind speed (such as nearby buildings) at these stations. The shear exponent for the remaining stations was estimated from the surrounding land cover and topography. The average shear exponent for the privately owned stations was 0.18, with a range of 0.10 to 0.23; the average for the met stations was 0.21, with a range of 0.10 to 0.28.
3. The error margin for each data point was then estimated as a function of two factors: the tower height and the number of years of measurement. Although these are not the only sources of uncertainty, they are the most easily quantified.

   The tower height enters the equation because of uncertainty in the wind shear. An error margin in the shear equal to 15% of the estimated shear exponent was assumed; for example, if the estimated shear was 0.2, the error margin was assumed to be 0.03.

   The number of years of measurement affects the reliability of the long-term mean wind speed estimate. The wind speed measured over a short period may not be representative of long-term conditions. An indicative guide in the wind industry is that a mean speed based on one year of data will be within 10% of the true long-term mean with 90% confidence. This translates into a standard error of 6% for one year of data. It was assumed that the annual mean fluctuates randomly with a normal distribution, and thus the error margin varies inversely with the square root of the number of years.

   The two uncertainties were then combined in a least-squares sum as follows:

$$(1)\quad e = \sqrt{\left(\left(50/H\right)^{0.15a} - 1\right)^2 + \left(\frac{0.06}{\sqrt{N}}\right)^2}$$

   where H is the height of the anemometer, α the estimated shear exponent, and N the number of years of measurement. For example, if the mean speed for a 10 m tower with a two-year record was 4.6 m/s, and the estimated shear was 0.18, then the estimated 50 m speed would be 6.1 m/s with a standard error of 6.1%, or 0.4 m/s.

   This equation shows that, as might be expected, that the dominant source of uncertainty for the met stations is the extrapolated wind shear, whereas the dominant source of uncertainty for the privately owned stations is their relatively short period of record.

4. Next, the predicted and measured/extrapolated speed and power were compared, and the map bias (map speed or power minus measured/extrapolated speed or power) was calculated for each point. The results were then displayed in a scatter plot, which allows the quick identification of outlying points and reveals the overall quality of the match between prediction and measurement.

Table 1 summarizes the results. Figure 1 shows a scatter plot comparing the data against both the preliminary and final maps. For the preliminary map, the predicted mean wind speeds were on average about 0.3 m/s higher than the measured/extrapolated values. The corresponding root-mean-square discrepancy was 0.5 m/s, or about 6% of the average speed. The RMS discrepancy reflects errors both in the model and the data, however, and therefore tends to overstate the true error in the predicted mean wind speed. The true error can be estimated by subtracting (in a least-squares sense) the standard error of the data (e_{DATA}) from the total RMS discrepancy (e_{TOTAL}), as follows:

$$(2)\quad e_{MODEL} \approx \sqrt{e_{TOTAL}^2 - e_{DATA}^2}$$

This equation assumes that the errors in the model and data are random, normally distributed, and independent of one another. Using this equation, the speed error for the model alone (preliminary results) is found to be 0.4 m/s, or 5% of the average speed.

The scatter plot shows that most of the high bias in the preliminary results occurred at stations with relatively low wind speeds, which were mainly met stations in the central part of Ireland such as Kilkenny and Birr. It is possible that problems in measuring equipment or tree growth/buildings nearby, could be causing anomalously low readings under low wind conditions at some of these stations; and indeed some of the data exhibit a rather high incidence of calms and low speeds that does not follow a normal frequency distribution. The wind shear at these stations could also be higher than estimated. Nevertheless, it seemed prudent to rerun the final stage of the mapping process with modified settings to increase the nocturnal stability and shear, and hence lower the near-surface wind speed, at the less windy stations.

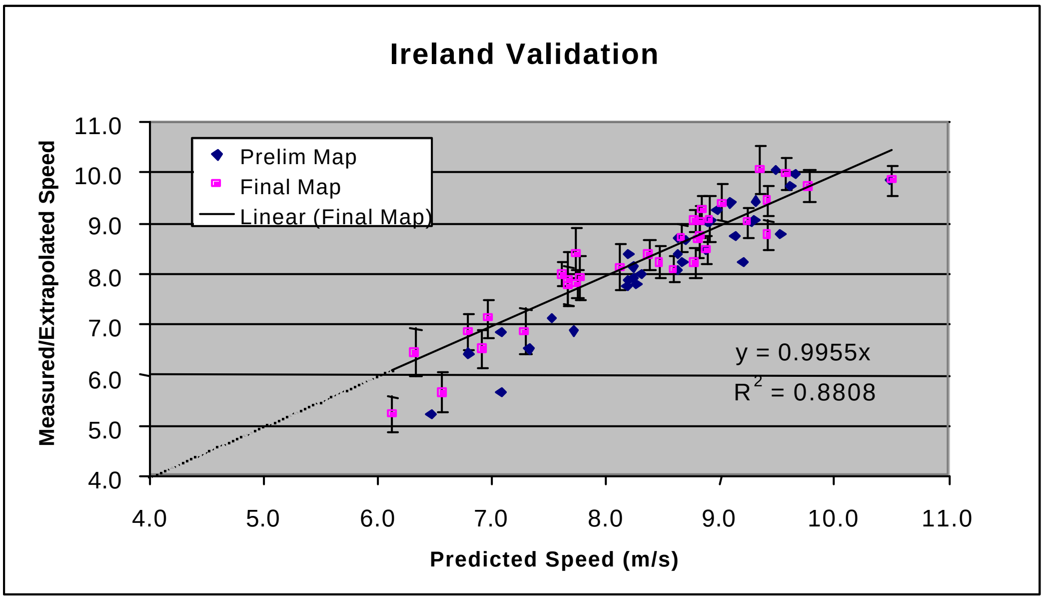
The result is shown in the last two columns of Table 1 and in the square dots in Figure 1. Error bars have been added to show the error margin of the data calculated using Equation 1. The average bias of the final map is now near zero, while the root-mean-square discrepancy has been reduced to 0.4 m/s, or 5%. This is only slightly higher than the average error margin of the data, and thus the model-only error is just 0.2 m/s, or about 2.5%.

The linear trend line, which is forced through the origin, confirms that the average measured/extrapolated speed nearly equals the predicted, while the r^2 correlation coefficient of 88% shows that the model explains the vast majority of the variance in the observed wind resource. Thus concluded the second or analytical stage of the project.

Table 1. Comparison of measured/extrapolated and predicted mean wind speeds at 50 m.

Station Name	Anem. Height (m)	Obs. Speed (m/s)	Shear Exp.	Obs. Speed at 50m (m/s)	Est. Error Margin (m/s)	Prelim. Map (m/s)	Prelim. Map Bias (m/s)	Final Map (m/s)	Final Map Bias (m/s)
Orsay Lighthouse	10	8.0	0.10	9.4	0.3	9.3	-0.1	9.4	0.0
Malin Head	21	8.3	0.10	9.1	0.2	8.9	-0.1	8.8	-0.3
Proprietary	34.5	9.5	0.10	9.8	0.3	10.5	0.6	10.5	0.7
Proprietary	30	7.1	0.30	8.2	0.3	8.7	0.4	8.5	0.3
Proprietary	25	9.2	0.13	10.1	0.5	9.5	-0.6	9.4	-0.7
Proprietary	41	9.5	0.23	10.0	0.3	9.7	-0.3	9.6	-0.4
Proprietary	41	8.4	0.18	8.7	0.3	8.6	-0.1	8.7	-0.1
Bellmullet	12	6.9	0.16	8.7	0.3	8.7	0.0	8.8	0.1
Clones/	10	4.1	0.28	6.4	0.5	6.8	0.4	6.3	-0.1
Proprietary	30	9.0	0.15	9.7	0.3	9.6	-0.1	9.8	0.0
Proprietary	30	7.5	0.17	8.2	0.3	9.2	1.0	8.8	0.6
Proprietary	50	8.0	0.25	8.0	0.2	8.3	0.3	7.6	-0.4
Mullingar	12	4.6	0.24	6.5	0.4	7.3	0.8	6.9	0.4
Dublin	12	5.2	0.22	7.1	0.4	7.5	0.4	7.0	-0.2
Casement	10	5.9	0.22	8.4	0.5	8.2	-0.2	7.7	-0.7
Birr	10	3.6	0.28	5.6	0.4	7.1	1.4	6.6	0.9
Proprietary	30	7.8	0.15	8.4	0.3	8.6	0.2	8.4	0.0
Shannon Apt.	12	5.0	0.22	6.8	0.4	7.1	0.2	6.8	-0.1
Kilkenny	12	3.5	0.28	5.2	0.3	6.5	1.3	6.1	0.9
Proprietary	40	9.0	0.18	9.4	0.4	9.1	-0.3	9.0	-0.4
Rosslare	10	5.8	0.21	8.1	0.5	8.2	0.1	8.1	0.0
Proprietary	40	8.9	0.18	9.3	0.3	9.0	-0.3	8.8	-0.4
Proprietary	30	8.1	0.21	9.0	0.3	8.9	-0.1	8.8	-0.2
Proprietary	30	7.7	0.19	8.5	0.3	8.9	0.4	8.9	0.4
Proprietary	40	7.6	0.17	7.9	0.5	8.2	0.3	7.7	-0.2
Valentia Obs	12	5.7	0.23	7.9	0.4	8.2	0.3	7.8	-0.1
Cork Airport	12	5.8	0.20	7.8	0.4	8.2	0.4	7.7	-0.1
Proprietary	40	8.5	0.13	8.8	0.3	9.5	0.7	9.4	0.6
Proprietary	40	7.9	0.10	8.1	0.3	8.6	0.5	8.6	0.5
Proprietary	10	6.9	0.17	9.1	0.5	9.3	0.2	8.9	-0.2
Roches Point	12	6.3	0.15	7.8	0.3	8.3	0.5	7.7	-0.1
Claremorris	12	4.6	0.28	6.9	0.4	7.7	0.9	7.3	0.4
Proprietary	30	8.3	0.17	9.0	0.3	9.3	0.2	9.2	0.2
Proprietary	30	8.0	0.18	8.8	0.3	9.1	0.4	8.8	0.1
Average (m/s)				**8.3**	**0.3**	**8.5**	**0.3**	**8.3**	**0.0**
RMS Discrepancy (m/s)							**0.5**		**0.4**
Model-Only Error (m/s)							**0.4**		**0.2**

Figure 1



With regard to the diurnal graphs it may be noted that nocturnal stability has the effect of reducing turbulence and friction between different atmospheric layers. This reduction in friction however strengthens the influence of the force acting on the atmosphere due to the rotation of the earth (Coriolis force) giving rise to an oscillating increase in wind speed with height which is proportional to the latitude of the particular point on the earth's surface. There is evidence of this in the project diurnal windspeed distributions between heights of 50m and 100m. While good agreement was obtained between measured and projected distributions at the lower heights there were no field measurement records accessible for the relevant period at heights of 100m or more as diurnal data from instruments originally attached to tall structures such as television masts and shipyard cranes were no longer available. This is a matter for future attention as the influence of sustained nocturnal winds at height will affect the capacity factors of future large turbines in a positive way.

Following correction of a slight problem (originally identified in the diurnal data) arising from the way in which rawinsonde and surface data were assimilated into the model for midnight and midday (allowing for local summer time) the hourly means were renormalized as well. The projected mean wind speeds for each day and hour of the synthesised year reflect this correction. The projected mean annual values as mapped are also derived from corrected figures.

6. Guidelines for use of the Maps

The following guidelines may be useful for interpreting and adjusting the wind speed estimates, especially in conjunction with the accompanying data files. The data files provide not only the predicted mean wind speed and power at any point on the map; they also indicate the elevation and surface roughness assumed by the model for each point. These data can be used to adjust the predicted wind speed following the methods described below.

1. The maps assume that all locations are free of obstacles that could disrupt or impede the wind flow. “Obstacle” does not apply to trees if they are common to the landscape, since their effects are already accounted for in the predicted speed. However, a large outcropping of rock or a structure would pose a local obstacle, as would a nearby shelterbelt of trees or a building in an otherwise open landscape. As a rule of thumb, the effect of such obstacles extends to a height of about twice the obstacle height and to a distance downwind of 10-20 times the obstacle height.

2. Generally speaking, points that lie above the average elevation within a 200×200 m grid cell will be somewhat windier than points that lie below it. A rule of thumb is that every 100 m increase in elevation will raise the mean speed by about 1 m/s. This formula is most applicable to small, isolated hills or ridges in otherwise flat terrain.

3. The roughness of the land surface – determined mainly by vegetation cover and buildings – up to 1-2 kilometers away has an important impact on the wind resource. If the roughness is much lower than that assumed by MesoMap, the mean wind speed should be adjusted upward. Typical values of roughness range from 0.01 m in open, flat ground without significant trees or shrubs, to 0.1 m in land with few trees but some smaller shrubs, to 1 m or more for areas with many trees or buildings. These values are only indirectly related to the physical size of the vegetation; they are actually scale lengths used in meteorological equations governing the structure of the boundary layer.

   An approximate speed adjustment *in the direction of the roughness difference* can be calculated using the following equation:

$$\frac{v_2}{v_1} \approx \frac{\log\left(h_{ibl} / z_{01} \right)}{\log\left(h / z_{01} \right)} \times \frac{\log\left(h / z_{02} \right)}{\log\left(h_{ibl} / z_{02} \right)}$$

   for $h_{ibl} > h$. The parameters v_1 and v_2 are the original and adjusted wind speeds at height h (in meters above the effective ground level), while z_{01} and z_{02} are the model and actual surface roughness values (in meters). The parameter h_{ibl} is the height to which the roughness difference is assumed to have an effect on the wind speed; except in the case of nearby roughness changes, it could be considered the average boundary layer depth. A typical value would be 500 m. As an example, suppose the land cover data used by the model showed an area to be forested in all directions with an estimated roughness value of 1 m, whereas in fact the land was fairly open in all directions with an estimated roughness value of 0.1 m. For h = 65 m and h_{ibl} = 500 m, the above formula gives

$$\frac{v_2}{v_1} \approx \frac{\log\left(500/1\right)}{\log\left(65/1\right)} \times \frac{\log\left(65/0.1\right)}{\log\left(500/0.1\right)} = 1.13$$

implying the predicted wind speed should be increased by about 13%.

This formula assumes that the wind is in equilibrium with the new surface roughness from the height of interest (in this case 65 m) to the height of the boundary layer (500 m). When going from high roughness to low roughness (such as from forested to open land), the clearing should be at least 1 km wide for the benefit of the lower roughness to be fully realized. However, when going from low to high roughness, the reduction in wind speed may be felt over a much shorter distance. For nearby roughness changes, a lower value of h_{ibl} should be used. For this and other reasons, the formula should be applied with caution. Where doubts arise, users are urged to obtain the advice of a qualified consulting meteorologist.

7. County Resources

Having computed the values of mean wind speed, power density and other characteristics for each point on the national 200m grid the subsets lying within each county boundary were extracted. (In order to produce smooth contours for each county it is necessary of course to include parts of the adjoining counties in the process so that the contours harmonise at the boundary lines). Directionality, diurnal effect and seasonal values were computed from the data set contained within the particular county boundary, thus the wind rose for a particular county is calculated from the data set appropriate to that county alone. All of the variables are calculated for the three heights of interest giving 324 maps and 324 graphical diagrams. Diurnal effects are most marked at the lower heights.

The fact that mean wind speed contours are closed vector shapes permits an evaluation of the wind resources available in each county to be made and costed. In a similar way the cost implications of decisions to exclude particular areas from wind farm development on particular grounds can be made. Thus a mechanism exists for ranking counties in terms of resource value, levels of development value permitted and contribution to national renewable energy goals.

The production of individual county resource memoirs was outside the scope of the current report.

8. Contour Intervals

The original specification had called for a contour interval of 0.25m/sec. in the wind speed maps. As the range of wind speeds in Ireland is quite high (0-15m/sec) this implied the use of a colour palette of sixty colour gradations on the paper maps. The possibility of using a larger interval implying fewer colours was examined at length but in the end the client opted for the original arrangement. The correspondence between mean windspeed and power density is non linear as the latter is proportional to the air density and cube of the windspeed. These are computed individually for each grid point and contoured on a county basis.

In the wind power density formula $p_m = 0.5\rho Vm^3$

(p_m = mean power density)

ρ = Air density

Vm = mean wind speed

The mean wind speed is simply derived from a summation of windspeed values divided by the number of observations over the time period. The mean power is half the summation of the cubes of each of these windspeeds multiplied by the air density at that place and time divided by the number of observations. Some cube values have a disproportionate effect on the outcome relative to others. In the model the calculation takes the Weibull distribution and air density into account before making the summation.

The contour interval was finalised at $100W/m^2$ (on a plane orthogonal to wind flow). The colour banding gives a broad correspondence with the mean wind speed.

9. Other Mapped Data

While it was originally intended to buffer out key infrastructure, certain natural features and sensitive areas, as indicated at the outset, the client decided that this should be left to the individual local planning authorities who could also incorporate key designated areas within their respective administrative areas.

The electrical network at 38kV, 110kV, 220kV and 400kV (incl. transformer stations) was incorporated, apart from congested urban areas and some locations for which digital information was not yet readily available. The network is, of course, undergoing continuous renewal and development and the data provided is best treated as indicative. At client request 20kV medium voltage transformers were shown where digitally mapped. (These are gradually replacing the circa 80,000 10kV transformers mostly in rural areas but this will take upwards of two decades or more to complete). As noted on the maps the existence of a power line does not necessarily imply the ability to accept a connection for windpower input as each application is evaluated individually.

The final product utilises no Ordnance Survey Information other than

- Coast line and border
- Towns as per 1 : 50,000 mapping
- County boundaries
- National Grid
- Lake shorelines

Thus the clients ongoing exposure to OSI royalties should be minimal.

It was somewhat astonishing to discover that no administrative boundary lines have been agreed (or dispensed with) between U.K. and Republic of Ireland for the Foyle Estuary and Carlingford Lough. It is understood that these areas are now the subject of discussion.

10. Conclusions

Onshore Resource

(1) Using the MesoMap system, highly detailed wind resource maps and data files have been produced for the Republic of Ireland. The results confirm that Ireland has a very good wind resource. Sites with a sufficient mean wind speed to support economical wind projects are predicted to be found on hilltops and mountaintops throughout the country, in open areas with few trees in the western part of the country, on exposed points near the coasts,

and offshore. The preliminary MesoMap results agreed very closely with data from 34 wind monitoring stations, apart from some overestimation of the resource at less windy stations in the central part of the country. However the revised model runs eliminated the overall bias, resulting in an estimated standard error of prediction versus measurement of about 2.5%.

(2) The results show mean wind speed, power density, directionality diurnal and seasonal effects at each of the required heights (50m, 75m, 100m) as calculated from the county data set on a grid of 200m spacing. In order to attain smooth contours along the county boundaries this implies inclusion of some predicted values from outside the county area. This grid spacing is five times finer than the 1km grid specified at the outset and produces maps of correspondingly higher resolution.

(3) The analysis points to a need to check trends evident in the results arising from particular meteorological stations where slowly changing conditions may be affecting the recorded mean wind speeds.

(4) The value of high quality measured records at potential wind farm sites and other locations (communication masts) where records from higher than normal levels can be obtained is important for calibration purposes. (In seeking calibration data for this project, no fewer than 28 different organisations in relevant areas were approached but at that point very few had any medium term records available).

(5) The undertaking of such an analysis and production of maps is a major task. Revision and updating is readily possible but should only be comtemplated if collection of reliable input information can be organised beforehand.

(6) In general the output shows the value of the three dimensional nature of the wind resource and its potential for capture by taller wind turbines than have been used heretofore. It also shows that diurnal effects are moderated with increasing height.

(7) The geographic information systems used provide a platform for quantifying in financial terms the annual value of the wind resource transiting each county and the financial implications of planning, zonation policy, network status, and other issues that impact on the resource. It now becomes possible to produce more informed county and other development plans than heretofore.

(8) The production of the results was not altogether assisted by the shortcomings noted in respect of digital data supplied by Ordnance Survey (Ireland) where unexpected difficulties arose in particular areas. However full recognition must be given to the efforts of individual survey staff in rectifying these difficulties when they had been brought to their notice.

(9) The consultants are not altogether convinced that dependence on 27 county planning authorities to incorporate appropriate local planning constraints uniformly on the mapping will result in this being done in a uniform and timely way and the absence of such maps would negate a key objective of the study.

(10) It would be useful to carry out wind measurements where the opportunity arises on tall fixed structures e.g. communication masts etc. to obtain more data for Ireland at or near 100m height.

Marine Resource

(11) Over the sea, data is produced for heights of 50m, 75m, 100m at a grid spacing of 400m, which is also finer than originally specified.

(12) The marine resource is presented in the area currently subject to Foreshore Licencing (i.e. within the old 12 mile limit. It is understood that legislation providing for licencing of projects outside this area is currently in preparation). As shown the deductions made between the unconstrained resource and the constrained resource reflect anchorages, shipping routes and the areas notified in Reference (3). As noted, no formal interstate boundaries have yet been agreed for Lough Foyle or Carlingford Lough.

No reduction has been made in respect of wreck sites, bathymetry or proximity to coast.

(13) Clearly the wind resource associated with Ireland's economic zone lying outside the 12 mile limit will be many times that between that limit and the coast. Quantification of this resource was outside the scope of the current study.

(14) The offshore wind regime for the Republic has been mapped without reference to sea bed contours or surface features other than the coastal and island highwater lines and designated danger areas, or other features listed in Notices to Mariners. The national grid and lines of latitude and longitude may be plotted but no Admiralty digital data has been used in the project so there should be minimal client liability to royalties. Where it is desired to add information on underwater features such as cables, sand banks, shallows or buoyage etc. arrangements should be made with U.K. Hydrographer of the Navy in respect of copyright and royalty payments.

11. Recommendations

(1) The GIS information and maps should receive wide dissemination to planning authorities, statutory bodies, developers and general public so that the nature of the resource can inform strategic thinking and public policy where development of the country's renewable energy resource is concerned. It is suggested that this is best attained when the extent and nature of the resource is revealed to all stakeholders.

(2) As the material necessarily reflects input data gathered over a particular period it can be expected that there will be some change over time due to differing meteorological patterns, changes in ground cover and roughness, and better quality of measurements and this should be borne in mind.

(3) It is not expected however that these changes will have the effect of varying the results presented here by more than a few percent. The merits of a better spread of input measurements from developer's site records should be examined as a prelude to any future revision of the mapping. One method by which this might be attained would be the introduction of a requirement for the submission of such data (of appropriate quality) for a period as a consequence of obtaining a power sale agreement at a particular site. In addition SEI might liaise with Met. Eireann to ensure that, where records are being taken at regional airports and by harbour companies, these reach an adequate standard and are retained, if necessary by SEI or on its behalf so that they may be used in future reassessments.

(4) Where industries, or semi state bodies or universities have been making wind records in compliance with EPA obligations or for research purposes it is recommended that they be invited to register the existence of such records, where possible to make them at the standard 10m above, ground level or above and where such programmes are terminated the results may be placed at the disposal of SEI possibly in cooperation with Met. Eireann but at reasonable cost.

(5) It is suggested that SEI arrange for the provision of a central service to local authorities where in exchange for Development Plan data submitted by these authorities in a specified format, SEI will arrange to have locally determined constraints incorporated on the database and maps in the interest of maintaining progress and national uniformity.

(6) It is recommended that consideration be given at a future date to mapping and quantifying the wind resource associated with Ireland's economic zone lying beyond the 12 mile limit.

(7) SEI should liaise with Marine Institute to ensure that wind data from unmanned marine buoys is available for future updating of the marine wind resource.

12. Acknowledgements

In submitting this report ESBI – TrueWind staff have pleasure in placing on record their indebtedness to the following who contributed to the formulation and implementation of the project.

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University College Dublin: R. Watson

Teagasc (Johnstown Castle): B. Coulter

Wind Farm Developers: Saorgus Energy, Airtricity, B9 Energy, DP Energy

UK Meteorological Office

Met. Eireann.

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2. "Micrositing with Mesomap", Brower, M., Bailey, B., Zack, J., Proceedings of Windpower 2002, American Wind Energy Association
3. "Offshore Electricity Generating Stations – Note for Intending Developers", Dept. of Communications, Marine and Natural Resources (2000)
4. European Wind Atlas (Commission of the European Communities). Riso National Laboratory, Denmark (1989).

Appendix A

On Shore Map Listing

Ref. No.	Title	Status	Height (m)
	Carlow		
M001	Mean Wind Speed	Unconstrained	50
M002	Distribution Map	Constrained	50
M003		Unconstrained	75
M004		Constrained	75
M005		Unconstrained	100
M006		Constrained	100
M007	Mean Power Density	Unconstrained	50
M008	Distribution Map	Constrained	50
M009		Unconstrained	75
M010		Constrained	75
M011		Unconstrained	100
M012		Constrained	100
G001	Directional/Seasonal/	Unconstrained	50
G002	Diurnal Mean Wind Speed	Unconstrained	75
G003	Distribution Graphs	Unconstrained	100
	Cavan		
M013	Mean Wind Speed	Unconstrained	50
M014	Distribution Map	Constrained	50
M015		Unconstrained	75
M016		Constrained	75
M017		Unconstrained	100
M018		Constrained	100
M019	Mean Power Density	Unconstrained	50
M020	Distribution Map	Constrained	50
M021		Unconstrained	75
M022		Constrained	75
M023		Unconstrained	100
M024		Constrained	100
G004	Directional/Seasonal/	Unconstrained	50
G005	Diurnal Mean Wind Speed	Unconstrained	75
G006	Distribution Graphs	Unconstrained	100

(Prefix to all maps and graphs : ESBI 4Y103A)

Ref. No.	Title	Status	Height (m)
	Clare		
M025	Mean Wind Speed	Unconstrained	50
M026	Distribution Map	Constrained	50
M027		Unconstrained	75
M028		Constrained	75
M029		Unconstrained	100
M030		Constrained	100
M031	Mean Power Density	Unconstrained	50
M032	Distribution Map	Constrained	50
M033		Unconstrained	75
M034		Constrained	75
M035		Unconstrained	100
M036		Constrained	100
G007	Directional/Seasonal/	Unconstrained	50
G008	Diurnal Mean Wind Speed	Unconstrained	75
G009	Distribution Graphs	Unconstrained	100
	Cork		
M037	Mean Wind Speed	Unconstrained	50
M038	Distribution Map	Constrained	50
M039		Unconstrained	75
M040		Constrained	75
M041		Unconstrained	100
M042		Constrained	100
M043	Mean Power Density	Unconstrained	50
M044	Distribution Map	Constrained	50
M045		Unconstrained	75
M046		Constrained	75
M047		Unconstrained	100
M048		Constrained	100
G010	Directional/Seasonal/	Unconstrained	50
G011	Diurnal Mean Wind Speed	Unconstrained	75
G012	Distribution Graphs	Unconstrained	100

(Prefix to all maps and graphs : ESBI 4Y103A)

Ref. No.	Title	Status	Height (m)
	Donegal		
M049	Mean Wind Speed	Unconstrained	50
M050	Distribution Map	Constrained	50
M051		Unconstrained	75
M052		Constrained	75
M053		Unconstrained	100
M054		Constrained	100
M055	Mean Power Density	Unconstrained	50
M056	Distribution Map	Constrained	50
M057		Unconstrained	75
M058		Constrained	75
M059		Unconstrained	100
M060		Constrained	100
G013	Directional/Seasonal/	Unconstrained	50
G014	Diurnal Mean Wind Speed	Unconstrained	75
G015	Distribution Graphs	Unconstrained	100
	Dublin		
M061	Mean Wind Speed	Unconstrained	50
M062	Distribution Map	Constrained	50
M063		Unconstrained	75
M064		Constrained	75
M065		Unconstrained	100
M066		Constrained	100
M067	Mean Power Density	Unconstrained	50
M068	Distribution Map	Constrained	50
M069		Unconstrained	75
M070		Constrained	75
M071		Unconstrained	100
M072		Constrained	100
G016	Directional/Seasonal/	Unconstrained	50
G017	Diurnal Mean Wind Speed	Unconstrained	75
G018	Distribution Graphs	Unconstrained	100

(Prefix to all maps and graphs : ESBI 4Y103A)

Ref. No.	Title	Status	Height (m)
	Galway		
M073	Mean Wind Speed	Unconstrained	50
M073	Distribution Map	Constrained	50
M075		Unconstrained	75
M076		Constrained	75
M077		Unconstrained	100
M078		Constrained	100
M079	Mean Power Density	Unconstrained	50
M080	Distribution Map	Constrained	50
M081		Unconstrained	75
M082		Constrained	75
M083		Unconstrained	100
M084		Constrained	100
G010	Directional/Seasonal/	Unconstrained	50
G020	Diurnal Mean Wind Speed	Unconstrained	75
G021	Distribution Graphs	Unconstrained	100
	Kerry		
M085	Mean Wind Speed	Unconstrained	50
M086	Distribution Map	Constrained	50
M087		Unconstrained	75
M088		Constrained	75
M089		Unconstrained	100
M090		Constrained	100
M091	Mean Power Density	Unconstrained	50
M092	Distribution Map	Constrained	50
M093		Unconstrained	75
M094		Constrained	75
M095		Unconstrained	100
M096		Constrained	100
G022	Directional/Seasonal/	Unconstrained	50
G023	Diurnal Mean Wind Speed	Unconstrained	75
G024	Distribution Graphs	Unconstrained	100

(Prefix to all maps and graphs : ESBI 4Y103A)

Ref. No.	Title	Status	Height (m)
	Kildare		
M097	Mean Wind Speed	Unconstrained	50
M098	Distribution Map	Constrained	50
M099		Unconstrained	75
M100		Constrained	75
M101		Unconstrained	100
M102		Constrained	100
M103	Mean Power Density	Unconstrained	50
M104	Distribution Map	Constrained	50
M105		Unconstrained	75
M106		Constrained	75
M107		Unconstrained	100
M108		Constrained	100
G025	Directional/Seasonal/	Unconstrained	50
G026	Diurnal Mean Wind Speed	Unconstrained	75
G027	Distribution Graphs	Unconstrained	100
	Kilkenny		
M109	Mean Wind Speed	Unconstrained	50
M110	Distribution Map	Constrained	50
M111		Unconstrained	75
M112		Constrained	75
M113		Unconstrained	100
M114		Constrained	100
M115	Mean Power Density	Unconstrained	50
M116	Distribution Map	Constrained	50
M117		Unconstrained	75
M118		Constrained	75
M119		Unconstrained	100
M120		Constrained	100
G028	Directional/Seasonal/	Unconstrained	50
G029	Diurnal Mean Wind Speed	Unconstrained	75
G030	Distribution Graphs	Unconstrained	100

(Prefix to all maps and graphs : ESBI 4Y103A)

Ref. No.	Title	Status	Height (m)
	Laois		
M121	Mean Wind Speed	Unconstrained	50
M122	Distribution Map	Constrained	50
M123		Unconstrained	75
M124		Constrained	75
M125		Unconstrained	100
M126		Constrained	100
M127	Mean Power Density	Unconstrained	50
M128	Distribution Map	Constrained	50
M129		Unconstrained	75
M130		Constrained	75
M131		Unconstrained	100
M132		Constrained	100
G031	Directional/Seasonal/	Unconstrained	50
G032	Diurnal Mean Wind Speed	Unconstrained	75
G033	Distribution Graphs	Unconstrained	100
	Leitrim		
M133	Mean Wind Speed	Unconstrained	50
M134	Distribution Map	Constrained	50
M135		Unconstrained	75
M136		Constrained	75
M137		Unconstrained	100
M138		Constrained	100
M139	Mean Power Density	Unconstrained	50
M140	Distribution Map	Constrained	50
M141		Unconstrained	75
M142		Constrained	75
M143		Unconstrained	100
M144		Constrained	100
G034	Directional/Seasonal/	Unconstrained	50
G035	Diurnal Mean Wind Speed	Unconstrained	75
G036	Distribution Graphs	Unconstrained	100

(Prefix to all maps and graphs : ESBI 4Y103A)

Ref. No.	Title	Status	Height (m)
	Limerick		
M145	Mean Wind Speed	Unconstrained	50
M146	Distribution Map	Constrained	50
M147		Unconstrained	75
M148		Constrained	75
M149		Unconstrained	100
M150		Constrained	100
M151	Mean Power Density	Unconstrained	50
M152	Distribution Map	Constrained	50
M153		Unconstrained	75
M154		Constrained	75
M155		Unconstrained	100
M156		Constrained	100
G037	Directional/Seasonal/	Unconstrained	50
G038	Diurnal Mean Wind Speed	Unconstrained	75
G039	Distribution Graphs	Unconstrained	100
	Longford		
M157	Mean Wind Speed	Unconstrained	50
M158	Distribution Map	Constrained	50
M159		Unconstrained	75
M160		Constrained	75
M161		Unconstrained	100
M162		Constrained	100
M163	Mean Power Density	Unconstrained	50
M164	Distribution Map	Constrained	50
M165		Unconstrained	75
M166		Constrained	75
M167		Unconstrained	100
M168		Constrained	100
G040	Directional/Seasonal/	Unconstrained	50
G041	Diurnal Mean Wind Speed	Unconstrained	75
G042	Distribution Graphs	Unconstrained	100

(Prefix to all maps and graphs : ESBI 4Y103A)

Ref. No.	Title	Status	Height (m)
	Louth		
M169	Mean Wind Speed	Unconstrained	50
M170	Distribution Map	Constrained	50
M171		Unconstrained	75
M172		Constrained	75
M173		Unconstrained	100
M174		Constrained	100
M175	Mean Power Density	Unconstrained	50
M176	Distribution Map	Constrained	50
M177		Unconstrained	75
M178		Constrained	75
M179		Unconstrained	100
M180		Constrained	100
G043	Directional/Seasonal/	Unconstrained	50
G044	Diurnal Mean Wind Speed	Unconstrained	75
G045	Distribution Graphs	Unconstrained	100
	Mayo		
M181	Mean Wind Speed	Unconstrained	50
M182	Distribution Map	Constrained	50
M183		Unconstrained	75
M184		Constrained	75
M185		Unconstrained	100
M186		Constrained	100
M187	Mean Power Density	Unconstrained	50
M188	Distribution Map	Constrained	50
M189		Unconstrained	75
M190		Constrained	75
M191		Unconstrained	100
M192		Constrained	100
G046	Directional/Seasonal/	Unconstrained	50
G047	Diurnal Mean Wind Speed	Unconstrained	75
G048	Distribution Graphs	Unconstrained	100

(Prefix to all maps and graphs : ESBI 4Y103A)

Ref. No.	Title	Status	Height (m)
	Meath		
M193	Mean Wind Speed	Unconstrained	50
M194	Distribution Map	Constrained	50
M195		Unconstrained	75
M196		Constrained	75
M197		Unconstrained	100
M198		Constrained	100
M199	Mean Power Density	Unconstrained	50
M200	Distribution Map	Constrained	50
M201		Unconstrained	75
M202		Constrained	75
M203		Unconstrained	100
M204		Constrained	100
G049	Directional/Seasonal/	Unconstrained	50
G050	Diurnal Mean Wind Speed	Unconstrained	75
G051	Distribution Graphs	Unconstrained	100
	Monaghan		
M205	Mean Wind Speed	Unconstrained	50
M206	Distribution Map	Constrained	50
M207		Unconstrained	75
M208		Constrained	75
M209		Unconstrained	100
M210		Constrained	100
M211	Mean Power Density	Unconstrained	50
M212	Distribution Map	Constrained	50
M213		Unconstrained	75
M214		Constrained	75
M215		Unconstrained	100
M216		Constrained	100
G052	Directional/Seasonal/	Unconstrained	50
G053	Diurnal Mean Wind Speed	Unconstrained	75
G054	Distribution Graphs	Unconstrained	100

(Prefix to all maps and graphs : ESBI 4Y103A)

Ref. No.	Title	Status	Height (m)
	Offaly		
M217	Mean Wind Speed	Unconstrained	50
M218	Distribution Map	Constrained	50
M219		Unconstrained	75
M220		Constrained	75
M221		Unconstrained	100
M222		Constrained	100
M223	Mean Power Density	Unconstrained	50
M224	Distribution Map	Constrained	50
M225		Unconstrained	75
M226		Constrained	75
M227		Unconstrained	100
M228		Constrained	100
G055	Directional/Seasonal/	Unconstrained	50
G056	Diurnal Mean Wind Speed	Unconstrained	75
G057	Distribution Graphs	Unconstrained	100
	Roscommon		
M229	Mean Wind Speed	Unconstrained	50
M230	Distribution Map	Constrained	50
M231		Unconstrained	75
M232		Constrained	75
M233		Unconstrained	100
M234		Constrained	100
M235	Mean Power Density	Unconstrained	50
M236	Distribution Map	Constrained	50
M237		Unconstrained	75
M238		Constrained	75
M239		Unconstrained	100
M240		Constrained	100
G058	Directional/Seasonal/	Unconstrained	50
G059	Diurnal Mean Wind Speed	Unconstrained	75
G060	Distribution Graphs	Unconstrained	100

(Prefix to all maps and graphs : ESBI 4Y103A)

Ref. No.	Title	Status	Height (m)
	Sligo		
M241	Mean Wind Speed	Unconstrained	50
M242	Distribution Map	Constrained	50
M243		Unconstrained	75
M244		Constrained	75
M245		Unconstrained	100
M246		Constrained	100
M247	Mean Power Density	Unconstrained	50
M248	Distribution Map	Constrained	50
M249		Unconstrained	75
M250		Constrained	75
M251		Unconstrained	100
M252		Constrained	100
G062	Directional/Seasonal/	Unconstrained	50
G063	Diurnal Mean Wind Speed	Unconstrained	75
G064	Distribution Graphs	Unconstrained	100
	Tipperary North		
M253	Mean Wind Speed	Unconstrained	50
M254	Distribution Map	Constrained	50
M255		Unconstrained	75
M256		Constrained	75
M257		Unconstrained	100
M258		Constrained	100
M259	Mean Power Density	Unconstrained	50
M260	Distribution Map	Constrained	50
M261		Unconstrained	75
M262		Constrained	75
M263		Unconstrained	100
M264		Constrained	100
G065	Directional/Seasonal/	Unconstrained	50
G066	Diurnal Mean Wind Speed	Unconstrained	75
G067	Distribution Graphs	Unconstrained	100

(Prefix to all maps and graphs : ESBI 4Y103A)

Ref. No.	Title	Status	Height (m)
	Tipperary South		
M265	Mean Wind Speed	Unconstrained	50
M266	Distribution Map	Constrained	50
M267		Unconstrained	75
M268		Constrained	75
M269		Unconstrained	100
M270		Constrained	100
M271	Mean Power Density	Unconstrained	50
M272	Distribution Map	Constrained	50
M273		Unconstrained	75
M274		Constrained	75
M275		Unconstrained	100
M276		Constrained	100
G068	Directional/Seasonal/	Unconstrained	50
G069	Diurnal Mean Wind Speed	Unconstrained	75
G070	Distribution Graphs	Unconstrained	100
	Waterford		
M277	Mean Wind Speed	Unconstrained	50
M278	Distribution Map	Constrained	50
M279		Unconstrained	75
M280		Constrained	75
M281		Unconstrained	100
M282		Constrained	100
M283	Mean Power Density	Unconstrained	50
M284	Distribution Map	Constrained	50
M285		Unconstrained	75
M286		Constrained	75
M287		Unconstrained	100
M288		Constrained	100
G071	Directional/Seasonal/	Unconstrained	50
G072	Diurnal Mean Wind Speed	Unconstrained	75
G073	Distribution Graphs	Unconstrained	100

(Prefix to all maps and graphs : ESBI 4Y103A)

Ref. No.	Title	Status	Height (m)
	Westmeath		
M289	Mean Wind Speed	Unconstrained	50
M290	Distribution Map	Constrained	50
M291		Unconstrained	75
M292		Constrained	75
M293		Unconstrained	100
M294		Constrained	100
M295	Mean Power Density	Unconstrained	50
M296	Distribution Map	Constrained	50
M297		Unconstrained	75
M298		Constrained	75
M299		Unconstrained	100
M300		Constrained	100
G074	Directional/Seasonal/	Unconstrained	50
G075	Diurnal Mean Wind Speed	Unconstrained	75
G076	Distribution Graphs	Unconstrained	100
	Wexford		
M301	Mean Wind Speed	Unconstrained	50
M302	Distribution Map	Constrained	50
M303		Unconstrained	75
M304		Constrained	75
M305		Unconstrained	100
M306		Constrained	100
M307	Mean Power Density	Unconstrained	50
M308	Distribution Map	Constrained	50
M309		Unconstrained	75
M310		Constrained	75
M311		Unconstrained	100
M312		Constrained	100
G077	Directional/Seasonal/	Unconstrained	50
G078	Diurnal Mean Wind Speed	Unconstrained	75
G079	Distribution Graphs	Unconstrained	100

(Prefix to all maps and graphs : ESBI 4Y103A)

Ref. No.	Title	Status	Height (m)
	Wicklow		
M313	Mean Wind Speed	Unconstrained	50
M314	Distribution Map	Constrained	50
M315		Unconstrained	75
M316		Constrained	75
M317		Unconstrained	100
M318		Constrained	100
M319	Mean Power Density	Unconstrained	50
M320	Distribution Map	Constrained	50
M321		Unconstrained	75
M322		Constrained	75
M323		Unconstrained	100
M324		Constrained	100
G080	Directional/Seasonal/	Unconstrained	50
G081	Diurnal Mean Wind Speed	Unconstrained	75
G082	Distribution Graphs	Unconstrained	100

(Prefix to all maps and graphs : ESBI 4Y103A)

Appendix B

On Shore Map Conventions

1. Mean Wind Speeds (m/sec) at heights of 50m, 75m, 100m above ground level.

1.1 Unconstrained Range: 2m/s to 15+m/s at 53 No. coloured contour intervals of 0.25 m/sec.

1.2 Constrained Range 7.5m/s to 15+m/s at 33 no. coloured contour intervals of 0.25 m/sec.

2. Mean values of wind power density W/m^2 at heights of 50m, 75m, 100m above ground level.

2.1 Unconstrained Range $0W/m^2$ to $3000+W/m^2$ at 61 no. coloured contour intervals of 50 W/m^2.

2.2 Constrained Range $500W/m^2$ to $3000+W/m^2$ at 51 no. coloured contour intervals of 50 W/m^2.

3. Graphical Distributions

3.1 Directionality: Derived for each level from distribution of projected mean wind speed over 16 segments of the 360^o compass, utilising true North as reference and data points arising within the particular county of interest only.

3.2 Seasonality: Derived for each level from 3 monthly distribution of projected mean wind speed utilising data points arising within the particular county of interest only. The projected mean annual value is also shown on these diagrams.

3.3 Diurnal (day/night) Distribution: Derived for each level from the projected hourly values of mean wind speed for each hour of the projected 24 hour average day in the projected year, utilising data points arising within the particular county of interest only.

4. Features

4.1 Built up (urban) areas shown pale grey on constrained maps. Lakes and rivers shown dark blue.

4.2 Power Lines shown thus.

Voltage	Line Colour	Station Symbol	Colour
400kV	Black (solid)	Square	Black
275kV	Not applicable	Not applicable	-
220kV	Red (solid)	Square	Red
110kV	Red (broken)	Triangle	Red
38kV	Black (solid)	Circle	Red
33kV	Not applicable	Not applicable	-
20kV	Not shown	Diamond	Black

5. Designated Areas

Areas designated by others for particular purposes e.g. National Parks, Special Areas of Conservation, National Heritage Areas, Local Authority designated areas, Archaelogical areas, World Heritage Sites that might constrain or assist wind resource development are, at client request, omitted from this edition.

6. National Grid

Easting and Northing lines forming 10km grid squares shown to match Ordnance Survey 1 : 50,000 scale 'Discovery' series maps.

7. County Boundaries, Coastline (High Water line)

Shown black with adjoining counties shown pale grey.

Appendix C

Near Shore Map Listing

Whole Coastline

Ref. No.	Subject/Location	Status	Height (m)
NS001	Mean Windspeed	Unconstrained	50
NS002	Distribution : Nearshore :	Constrained	50
NS003	Whole Coastline : Republic	Unconstrained	75
NS004	of Ireland	Constrained	75
NS005		Unconstrained	100
NS006		Constrained	100
NS007	Mean Windspeed	Unconstrained	50
NS008	Distribution : Nearshore :	Constrained	50
NS009	Whole Coastline : Republic	Unconstrained	75
NS010	of Ireland	Constrained	75
NS011		Unconstrained	100
NS012		Constrained	100

Coastal Blocks

Ref. No.	Subject/Location	Status	Height (m)
NSA01	Mean Windspeed	Unconstrained	50
NSA02	Distribution : Nearshore :	Constrained	50
NSA03	Block A	Unconstrained	75
NSA04	South Down –	Constrained	75
NSA05	North Dublin	Unconstrained	100
NSA06		Constrained	100
NSA07	Mean Windspeed	Unconstrained	50
NSA08	Distribution : Nearshore :	Constrained	50
NSA09	Block A	Unconstrained	75
NSA10		Constrained	75
NSA11		Unconstrained	100
NSA12		Constrained	100

Coastal Blocks

Ref. No.	Subject/Location	Status	Height (m)
NSB01	Mean Windspeed	Unconstrained	50
NSB02	Distribution : Nearshore :	Constrained	50
NSB03	Block B	Unconstrained	75
NSB04	North Dublin –	Constrained	75
NSB05	North Wexford	Unconstrained	100
NSB06		Constrained	100
NSB07	Mean Windspeed	Unconstrained	50
NSB08	Distribution : Nearshore :	Constrained	50
NSB09	Block B	Unconstrained	75
NSB10		Constrained	75
NSB11		Unconstrained	100
NSB12		Constrained	100
NSC01	Mean Windspeed	Unconstrained	50
NSC02	Distribution : Nearshore :	Constrained	50
NSC03	Block C	Unconstrained	75
NSC04	Wexford East –	Constrained	75
NSC05	Waterford	Unconstrained	100
NSC06		Constrained	100
NSC07	Mean Windspeed	Unconstrained	50
NSC08	Distribution : Nearshore :	Constrained	50
NSC09	Block C	Unconstrained	75
NSC10		Constrained	75
NSC11		Unconstrained	100
NSC12		Constrained	100

Coastal Blocks

Ref. No.	Subject/Location	Status	Height (m)
NSD01	Mean Windspeed	Unconstrained	50
NSD02	Distribution : Nearshore :	Constrained	50
NSD03	Block D	Unconstrained	75
NSD04	Waterford – East Cork	Constrained	75
NSD05		Unconstrained	100
NSD06		Constrained	100
NSD07	Mean Windspeed	Unconstrained	50
NSD08	Distribution : Nearshore :	Constrained	50
NSD09	Block D	Unconstrained	75
NSD10		Constrained	75
NSD11		Unconstrained	100
NSD12		Constrained	100
NSE01	Mean Windspeed	Unconstrained	50
NSE02	Distribution : Nearshore :	Constrained	50
NSE03	Block E	Unconstrained	75
NSE04	South Cork	Constrained	75
NSE05		Unconstrained	100
NSE06		Constrained	100
NSE07	Mean Windspeed	Unconstrained	50
NSE08	Distribution : Nearshore :	Constrained	50
NSE09	Block E	Unconstrained	75
NSE10		Constrained	75
NSE11		Unconstrained	100
NSE12		Constrained	100

Coastal Blocks

Ref. No.	Subject/Location	Status	Height (m)
NSF01	Mean Windspeed	Unconstrained	50
NSF02	Distribution : Nearshore :	Constrained	50
NSF03	Block F	Unconstrained	75
NSF04	West Cork – South Kerry	Constrained	75
NSF05		Unconstrained	100
NSF06		Constrained	100
NSF07	Mean Windspeed	Unconstrained	50
NSF08	Distribution : Nearshore :	Constrained	50
NSF09	Block F	Unconstrained	75
NSF10		Constrained	75
NSF11		Unconstrained	100
NSF12		Constrained	100
NSG01	Mean Windspeed	Unconstrained	50
NSG02	Distribution : Nearshore :	Constrained	50
NSG03	Block G	Unconstrained	75
NSG04	North Kerry – West Clare	Constrained	75
NSG05		Unconstrained	100
NSG06		Constrained	100
NSG07	Mean Windspeed	Unconstrained	50
NSG08	Distribution : Nearshore :	Constrained	50
NSG09	Block G	Unconstrained	75
NSG10		Constrained	75
NSG11		Unconstrained	100
NSG12		Constrained	100

Coastal Blocks

Ref. No.	Subject/Location	Status	Height (m)
NSH01	Mean Windspeed	Unconstrained	50
NSH02	Distribution : Nearshore :	Constrained	50
NSH03	Block H	Unconstrained	75
NSH04	Galway – South Mayo (Inner)	Constrained	75
NSH05		Unconstrained	100
NSH06		Constrained	100
NSH07	Mean Windspeed	Unconstrained	50
NSH08	Distribution : Nearshore :	Constrained	50
NSH09	Block H	Unconstrained	75
NSH10		Constrained	75
NSH11		Unconstrained	100
NSH12		Constrained	100
NSI01	Mean Windspeed	Unconstrained	50
NSI02	Distribution : Nearshore :	Constrained	50
NSI03	Block I	Unconstrained	75
NSI04	West Galway – Mayo (outer)	Constrained	75
NSI05		Unconstrained	100
NSI06		Constrained	100
NSI07	Mean Windspeed	Unconstrained	50
NSI08	Distribution : Nearshore :	Constrained	50
NSI09	Block I	Unconstrained	75
NSI10		Constrained	75
NSI11		Unconstrained	100
NSI12		Constrained	100

Coastal Blocks

Ref. No.	Subject/Location	Status	Height (m)
NSJ01	Mean Windspeed	Unconstrained	50
NSJ02	Distribution : Nearshore :	Constrained	50
NSJ03	Block J	Unconstrained	75
NSJ04	North West Mayo	Constrained	75
NSJ05		Unconstrained	100
NSJ06		Constrained	100
NSJ07	Mean Windspeed	Unconstrained	50
NSJ08	Distribution : Nearshore :	Constrained	50
NSJ09	Block J	Unconstrained	75
NSJ10		Constrained	75
NSJ11		Unconstrained	100
NSJ12		Constrained	100
NSK01	Mean Windspeed	Unconstrained	50
NSK02	Distribution : Nearshore :	Constrained	50
NSK03	Block K	Unconstrained	75
NSK04	North Mayo – South Donegal	Constrained	75
NSK05		Unconstrained	100
NSK06		Constrained	100
NSK07	Mean Windspeed	Unconstrained	50
NSK08	Distribution : Nearshore :	Constrained	50
NSK09	Block K	Unconstrained	75
NSK10		Constrained	75
NSK11		Unconstrained	100
NSK12		Constrained	100

Coastal Blocks

Ref. No.	Subject/Location	Status	Height (m)
NSL01	Mean Windspeed	Unconstrained	50
NSL02	Distribution : Nearshore :	Constrained	50
NSL03	Block L	Unconstrained	75
NSL04	North West Donegal	Constrained	75
NSL05		Unconstrained	100
NSL06		Constrained	100
NSL07	Mean Windspeed	Unconstrained	50
NSL08	Distribution : Nearshore :	Constrained	50
NSL09	Block L	Unconstrained	75
NSL10		Constrained	75
NSL11		Unconstrained	100
NSL12		Constrained	100
NSM01	Mean Windspeed	Unconstrained	50
NSM02	Distribution : Nearshore :	Constrained	50
NSM03	Block M	Unconstrained	75
NSM04	North Donegal –	Constrained	75
NSM05	North Derry	Unconstrained	100
NSM06		Constrained	100
NSM07	Mean Windspeed	Unconstrained	50
NSM08	Distribution : Nearshore :	Constrained	50
NSM09	Block M	Unconstrained	75
NSM10		Constrained	75
NSM11		Unconstrained	100
NSM12		Constrained	100

Appendix D

Near Shore Map Conventions

1. Mean Wind Speeds (m/sec) at heights of 50m, 75m, 100m above ground level.

1.1 Unconstrained Range: 2m/s to 15+m/s utilising 53 No. coloured contour intervals of 0.25 m/sec.

1.2 Constrained Range 7.5m/s to 15+m/s utilising 33 no. coloured contour intervals of 0.25 m/sec.

2. Mean values of wind power density W/m^2 at heights of 50m, 75m, 100m above ground level.

2.1 Unconstrained Range 0W/m^2 to 3000+W/M^2 utilising 61 no. coloured contour intervals of 50 W/m^2.

2.2 Constrained Range 500W/m^2 to 3000+W/M^2 utilising 51 no. coloured contour intervals of 50 W/m^2.

3. Graphical Distributions

3.1 Directionality: Not applicable to blocks.

3.2 Seasonality: Not applicable to blocks.

3.3 Diurnal (day/night) Distribution: Not applicable to blocks.

4. Features

4.1 Coastal blocks divided into lettered areas off particular counties as follows:

A South Down – North Dublin

B North Dublin – North Wexford

C Wexford – East Waterford

D Waterford – East Cork

E South Cork

F West Cork – South Kerry

G North Kerry – West Clare

H Galway – South Mayo (Inner)

I West Galway – Mayo (Outer)

J North West Mayo

K North Mayo – South Donegal

L North West Donegal

M North Donegal – North Derry

4.2 Navigation channels and approach routes to ports and harbours shown indicatively only (Green). Marine traffic separation zones with indicative manouvering areas shown (Purple).

4.3 Dept. of Marine and Natural Resources/Dept. of Defence restricted areas shown (dark Blue and Red respectively) Anchorages shown (Purple). Bathymetry not shown.

4.4 Communication, powercables, submarine pipelines may not be shown in all instances. (Reference should be made to latest Admiralty Charts).

5. Designated Areas

Areas designated by others for particular purposes e.g. National Parks, Special Areas of Conservation, National Heritage Areas, Local Authority designated areas, Archaelogical areas, wreck sites, World Heritage Sites that might constrain or assist wind resource development are, at client request, omitted from this edition.

6. National Grid

Easting and Northing lines forming 10km grid squares shown to match onshore Ordnance Survey 1 : 50,000 scale 'Discovery' series maps. Scale of each block : 1 : 150000

7. County Boundaries, Coastline (High Water line)

Shown black with adjoining counties shown pale grey.

Appendix E

Specimen TrueWind Data Files

The data files produced by TrueWind following completion of the analytical modelling process comprise sets of numerical values that contain the following information arranged in the listed fields (Tables E.1 – E.8).

- **Table E.1 Main Database 50m Height (11 Fields x 26 x 10^6 points)**

  Point Identifier, Nat. Grid Coordinates, Longitude, Latitude, ground elevation, ground surface roughness, mean wind speed, mean power density, Weibull coefficients C, K relating to windspeed distribution. (200m x 200m grid).

- **Table E.2 Annual Wind rose Database 50m Height (86 Fields x 26 x 10^3 points)**

  Point Identifier, Nat. Grid Coordinates, Longitude, Latitude, File Identifier, Occurrence throughout year within each 22.5^o sector in terms of frequency, normalised wind speed, normalised power density, normalised Weibull C and Weibull K (400m x 400m grid).

- **Table E.3 Summer Seasonal Windrose Database 50m Height (86 Fields x 26 x 10^3 points)**

  Point Identifier, Nat. Grid Coordinates, Longitude, Latitude, File Identifier, Occurrence throughout year within each 22.5^o sector in terms of frequency, normalised wind speed, normalised power density, normalised Weibull C and Weibull K.

- **Table E.4 Autumn Seasonal Windrose Database 50m Height (86 Fields x 26 x 10^3 points)**

  Point Identifier, Nat. Grid Coordinates, Longitude, Latitude, File Identifier, Occurrence throughout year within each 22.5^o sector in terms of frequency, normalised wind speed, normalised power density, normalised Weibull C and Weibull K.

- **Table E.5 Winter Seasonal Windrose Database 50m Height (86 Fields x 26 x 10^3 points)**

  Point Identifier, Nat. Grid Coordinates, Longitude, Latitude, File Identifier, Occurrence throughout year within each 22.5^o sector in terms of frequency, normalised wind speed, normalised power density, normalised Weibull C and Weibull K.

- **Table E.6 Spring Seasonal Windrose Database 50m Height (86 Fields x 26 x 10^3 points)**

  Point Identifier, Nat. Grid Coordinates, Longitude, Latitude, File Identifier, Occurrence throughout year within each 22.5^o sector in terms of frequency, normalised wind speed, normalised power density, normalised Weibull C and Weibull K.

- **Table E.7 Seasonal Windspeed Variation 50m Height (22 Fields x 2.6 x 10^6 points)**

  Point Identifier, Nat. Grid Coordinates, Longitude, Latitude, Actual mean wind speed, mean power density, Weibull Coefficient C, Weibull K.

- **Table E.8 Diurnal Mean Windspeed Variation 50m Height (29 Fields x 26 x 10^3 points)**

  Point Identifier, Nat. Grid Coordinates, Longitude, Latitude, normalised mean hourly windspeed.

- **Power Density**

  It should also be noted that mean power density is a non linear function of both wind speed and air density. The fact that air density is one of the variables used within the Meso model when estimating wind speed makes it available for calculating power density also. Power density is the power level of the air stream per square metre of area of a vertical plane at 90^o to the direction of wind flow e.g. the disk area swept out by turbine blades. It is not directly related to a ground area except insofar as points having similar power density values may be grouped together and contoured for mapping purposes).

- **Repetition**

  Repetition of above data set occurs for heights of 75m and 100m above ground level.

Thus there is a very significant string of data associated with each grid point and only limited specimen examples can be given here. (The negative sign associated with Longitude merely denotes that the point lies west of Greenwich Meridian).

Table E.1 Extract from the Main Database file for 50m above ground level:

	X	Y	LONGITUDE	LATITUDE	ELEV	ROUGH	SPEED050	POWER050	WEIBC050	WEIBK050
	97100	300	-9.475	51.247	0	0.001	9.29	870	10.52	2.067
	91100	500	-9.56	51.248	0	0.001	9.29	874	10.52	2.073
	91300	500	-9.558	51.248	0	0.001	9.29	874	10.52	2.073
	91500	500	-9.555	51.248	0	0.001	9.29	874	10.52	2.073
	91700	500	-9.552	51.248	0	0.001	9.29	873	10.52	2.073
	91900	500	-9.549	51.248	0	0.001	9.29	873	10.52	2.073
	92100	500	-9.546	51.248	0	0.001	9.29	872	10.52	2.073
	92300	500	-9.543	51.248	0	0.001	9.29	872	10.52	2.072
	92500	500	-9.54	51.248	0	0.001	9.29	872	10.52	2.072
	92700	500	-9.538	51.248	0	0.001	9.29	872	10.52	2.072
	92900	500	-9.535	51.248	0	0.001	9.29	872	10.51	2.072
	93100	500	-9.532	51.248	0	0.001	9.29	872	10.51	2.072
	93300	500	-9.529	51.248	0	0.001	9.29	872	10.51	2.072
	93500	500	-9.526	51.248	0	0.001	9.29	871	10.51	2.072
	93700	500	-9.523	51.248	0	0.001	9.29	871	10.51	2.071
	93900	500	-9.52	51.248	0	0.001	9.29	871	10.51	2.071
	94100	500	-9.518	51.248	0	0.001	9.29	871	10.51	2.071
	94300	500	-9.515	51.248	0	0.001	9.29	871	10.51	2.071
	94500	500	-9.512	51.248	0	0.001	9.29	871	10.51	2.071
	94700	500	-9.509	51.248	0	0.001	9.29	871	10.51	2.071
	94900	500	-9.506	51.248	0	0.001	9.29	871	10.51	2.07
	95100	500	-9.503	51.248	0	0.001	9.29	871	10.51	2.07
	95300	500	-9.5	51.248	0	0.001	9.29	870	10.51	2.07
	95500	500	-9.497	51.249	0	0.001	9.29	870	10.51	2.07
	95700	500	-9.495	51.249	0	0.001	9.29	870	10.51	2.07
	95900	500	-9.492	51.249	0	0.001	9.29	870	10.51	2.069
	96100	500	-9.489	51.249	0	0.001	9.29	870	10.51	2.069
	96300	500	-9.486	51.249	0	0.001	9.29	870	10.51	2.069
	96500	500	-9.483	51.249	0	0.001	9.29	870	10.51	2.069
	96700	500	-9.48	51.249	0	0.001	9.29	870	10.51	2.069

Table E.2 Extract from the Annual Rose Database file for 50m above ground level:

	X	Y	LONGITUDE	LATITUDE	FILE	FREO 1	FREO 2	FREO 3	FREO 4	FREO 5	FREO 6	FREO 7	FREO 8
	89100	1100	-9.589	51.253	EI 500530 2430.JPG	3.42	2.62	2.43	3.71	5.73	4.58	3.87	3.85
	91100	1100	-9.561	51.253	EI 500540 2430.JPG	3.4	2.63	2.44	3.78	5.65	4.56	3.88	3.85
	93100	1100	-9.532	51.253	EI 500550 2430.JPG	3.35	2.64	2.47	3.94	5.52	4.54	3.87	3.84
	95100	1100	-9.503	51.254	EI 500560 2430.JPG	3.31	2.63	2.5	4.08	5.42	4.53	3.84	3.83
	97100	1100	-9.475	51.254	EI 500570 2430.JPG	3.25	2.62	2.55	4.24	5.32	4.5	3.83	3.83
	99100	1100	-9.446	51.255	EI 500580 2430.JPG	3.22	2.62	2.56	4.3	5.27	4.47	3.84	3.83
	85100	3100	-9.647	51.27	EI 500510 2420.JPG	3.41	2.65	2.39	3.45	5.85	4.71	3.86	3.9
	87100	3100	-9.619	51.27	EI 500520 2420.JPG	3.44	2.61	2.41	3.58	5.83	4.63	3.86	3.87
	89100	3100	-9.59	51.271	EI 500530 2420.JPG	3.45	2.6	2.42	3.61	5.84	4.62	3.86	3.87
	91100	3100	-9.561	51.271	EI 500540 2420.JPG	3.42	2.61	2.43	3.7	5.75	4.6	3.86	3.86
	93100	3100	-9.533	51.271	EI 500550 2420.JPG	3.35	2.62	2.48	3.92	5.56	4.56	3.85	3.84
	95100	3100	-9.504	51.272	EI 500560 2420.JPG	3.29	2.61	2.52	4.11	5.44	4.55	3.81	3.84
	97100	3100	-9.475	51.272	EI 500570 2420.JPG	3.27	2.6	2.54	4.17	5.41	4.55	3.79	3.84
	99100	3100	-9.447	51.273	EI 500580 2420.JPG	3.24	2.61	2.56	4.24	5.34	4.51	3.81	3.84
	101100	3100	-9.418	51.273	EI 500590 2420.JPG	3.14	2.6	2.61	4.41	5.21	4.41	3.86	3.84
	103100	3100	-9.389	51.273	EI 500600 2420.JPG	3.05	2.58	2.67	4.57	5.12	4.33	3.89	3.85
	69100	5100	-9.877	51.284	EI 500430 2410.JPG	3.5	2.53	2.17	2.84	5.85	5.23	3.84	4.14
	71100	5100	-9.848	51.285	EI 500440 2410.JPG	3.44	2.53	2.25	2.94	5.85	5.18	3.84	4.09
	73100	5100	-9.82	51.285	EI 500450 2410.JPG	3.42	2.53	2.29	3	5.84	5.13	3.84	4.06
	75100	5100	-9.791	51.286	EI 500460 2410.JPG	3.41	2.57	2.3	3.03	5.9	5.12	3.82	4.04
	77100	5100	-9.762	51.286	EI 500470 2410.JPG	3.4	2.63	2.3	3.06	5.98	5.08	3.81	4.02
	79100	5100	-9.734	51.287	EI 500480 2410.JPG	3.39	2.69	2.32	3.13	6.01	4.98	3.81	3.97
	81100	5100	-9.705	51.287	EI 500490 2410.JPG	3.38	2.71	2.34	3.18	6	4.91	3.82	3.95
	83100	5100	-9.677	51.287	EI 500500 2410.JPG	3.41	2.7	2.35	3.24	6.01	4.89	3.8	3.94
	85100	5100	-9.648	51.288	EI 500510 2410.JPG	3.45	2.67	2.36	3.35	6	4.85	3.79	3.92
	87100	5100	-9.619	51.288	EI 500520 2410.JPG	3.47	2.63	2.39	3.5	5.92	4.74	3.81	3.9
	89100	5100	-9.591	51.289	EI 500530 2410.JPG	3.46	2.6	2.42	3.62	5.85	4.65	3.84	3.87
	91100	5100	-9.562	51.289	EI 500540 2410.JPG	3.46	2.61	2.42	3.67	5.83	4.68	3.8	3.87
	93100	5100	-9.533	51.289	EI 500550 2410.JPG	3.42	2.61	2.45	3.84	5.72	4.7	3.76	3.86
	95100	5100	-9.505	51.29	EI 500560 2410.JPG	3.34	2.6	2.5	4.04	5.55	4.63	3.76	3.85

Table E.3 Extract from the Summer (June - August) Rose Database at 50m above ground level:

	X	Y	LONGITUDE	LATITUDE	FILE	FREQ 1	FREQ 2	FREQ 3	FREQ 4	FREQ 5	FREQ 6	FREQ 7	FREQ 8
	89100	1100	-9.589	51.253	FL_500530_2430_SUM.JPG	3.02	2.47	1.92	2.8	3.78	3.63	2.66	3.04
	91100	1100	-9.561	51.253	FL_500540_2430_SUM.JPG	2.96	2.47	1.95	2.89	3.73	3.59	2.66	3.08
	93100	1100	-9.532	51.253	FL_500550_2430_SUM.JPG	2.84	2.46	2.02	3.04	3.64	3.52	2.68	3.16
	95100	1100	-9.503	51.254	FL_500560_2430_SUM.JPG	2.71	2.46	2.1	3.13	3.59	3.47	2.71	3.23
	97100	1100	-9.475	51.254	FL_500570_2430_SUM.JPG	2.58	2.44	2.18	3.29	3.51	3.39	2.77	3.29
	99100	1100	-9.446	51.255	FL_500580_2430_SUM.JPG	2.57	2.41	2.18	3.4	3.45	3.35	2.81	3.28
	85100	3100	-9.647	51.27	FL_500510_2420_SUM.JPG	3.21	2.39	1.82	2.59	3.75	3.83	2.68	3
	87100	3100	-9.619	51.27	FL_500520_2420_SUM.JPG	3.11	2.45	1.88	2.67	3.82	3.72	2.67	3
	89100	3100	-9.59	51.271	FL_500530_2420_SUM.JPG	3.08	2.49	1.9	2.68	3.85	3.71	2.67	2.99
	91100	3100	-9.561	51.271	FL_500540_2420_SUM.JPG	3.01	2.48	1.93	2.77	3.79	3.65	2.67	3.04
	93100	3100	-9.533	51.271	FL_500550_2420_SUM.JPG	2.83	2.47	2.04	2.98	3.68	3.54	2.69	3.16
	95100	3100	-9.504	51.272	FL_500560_2420_SUM.JPG	2.65	2.46	2.16	3.11	3.62	3.46	2.74	3.27
	97100	3100	-9.475	51.272	FL_500570_2420_SUM.JPG	2.58	2.45	2.22	3.14	3.61	3.44	2.76	3.31
	99100	3100	-9.447	51.273	FL_500580_2420_SUM.JPG	2.57	2.42	2.22	3.27	3.53	3.38	2.8	3.29
	101100	3100	-9.418	51.273	FL_500590_2420_SUM.JPG	2.52	2.3	2.26	3.6	3.34	3.21	2.96	3.27
	103100	3100	-9.389	51.273	FL_500600_2420_SUM.JPG	2.47	2.15	2.35	3.89	3.18	3.02	3.17	3.26
	69100	5100	-9.877	51.284	FL_500430_2410_SUM.JPG	3.75	2.38	1.48	1.81	3.39	4.53	2.61	3.39
	71100	5100	-9.848	51.285	FL_500440_2410_SUM.JPG	3.73	2.28	1.57	1.88	3.43	4.55	2.55	3.28
	73100	5100	-9.82	51.285	FL_500450_2410_SUM.JPG	3.74	2.22	1.61	1.93	3.46	4.51	2.5	3.23
	75100	5100	-9.791	51.286	FL_500460_2410_SUM.JPG	3.67	2.27	1.64	2	3.49	4.49	2.56	3.19
	77100	5100	-9.762	51.286	FL_500470_2410_SUM.JPG	3.56	2.36	1.66	2.11	3.54	4.42	2.68	3.13
	79100	5100	-9.734	51.287	FL_500480_2410_SUM.JPG	3.44	2.39	1.69	2.27	3.61	4.26	2.74	3.05
	81100	5100	-9.705	51.287	FL_500490_2410_SUM.JPG	3.38	2.38	1.71	2.36	3.65	4.15	2.76	3.01
	83100	5100	-9.677	51.287	FL_500500_2410_SUM.JPG	3.36	2.42	1.71	2.41	3.7	4.13	2.76	3.01
	85100	5100	-9.648	51.288	FL_500510_2410_SUM.JPG	3.3	2.47	1.74	2.48	3.76	4.07	2.75	3.01
	87100	5100	-9.619	51.288	FL_500520_2410_SUM.JPG	3.18	2.49	1.82	2.59	3.82	3.89	2.71	3
	89100	5100	-9.591	51.289	FL_500530_2410_SUM.JPG	3.09	2.49	1.88	2.69	3.84	3.75	2.68	3
	91100	5100	-9.562	51.289	FL_500540_2410_SUM.JPG	3.07	2.49	1.88	2.75	3.83	3.78	2.7	3.02
	93100	5100	-9.533	51.289	FL_500550_2410_SUM.JPG	2.95	2.48	1.93	2.91	3.77	3.75	2.73	3.1
	95100	5100	-9.505	51.29	FL_500560_2410_SUM.JPG	2.75	2.46	2.07	3.07	3.68	3.6	2.75	3.21

Table E.4 Extract from the Fall (September to November) Rose Database at 50m above ground level:

	X	Y	LONGITUDE	LATITUDE	FILE	FREQ 1	FREQ 2	FREQ 3	FREQ 4	FREQ 5	FREQ 6	FREQ 7	FREQ 8
	89100	1100	-9.589	51.253	EI_500530_2430_FAL.JPG	2.89	2.69	1.86	2.25	3.9	3.78	4.99	4.73
	91100	1100	-9.561	51.253	EI_500540_2430_FAL.JPG	2.92	2.67	1.87	2.27	3.89	3.77	5	4.68
	93100	1100	-9.532	51.253	EI_500550_2430_FAL.JPG	2.95	2.62	1.92	2.32	3.91	3.76	4.98	4.59
	95100	1100	-9.503	51.254	EI_500560_2430_FAL.JPG	2.96	2.56	1.97	2.39	3.95	3.79	4.91	4.53
	97100	1100	-9.475	51.254	EI_500570_2430_FAL.JPG	2.94	2.49	2.02	2.49	4.03	3.77	4.82	4.5
	99100	1100	-9.446	51.255	EI_500580_2430_FAL.JPG	2.9	2.48	2.02	2.5	4.05	3.71	4.84	4.52
	85100	3100	-9.647	51.27	EI_500510_2420_FAL.JPG	2.74	2.83	1.75	2.18	3.79	3.86	4.92	4.84
	87100	3100	-9.619	51.27	EI_500520_2420_FAL.JPG	2.82	2.74	1.84	2.22	3.89	3.81	4.96	4.81
	89100	3100	-9.59	51.271	EI_500530_2420_FAL.JPG	2.84	2.7	1.88	2.24	3.94	3.8	4.95	4.81
	91100	3100	-9.561	51.271	EI_500540_2420_FAL.JPG	2.87	2.68	1.89	2.26	3.93	3.79	4.96	4.75
	93100	3100	-9.533	51.271	EI_500550_2420_FAL.JPG	2.93	2.61	1.93	2.35	3.94	3.8	4.91	4.62
	95100	3100	-9.504	51.272	EI_500560_2420_FAL.JPG	2.97	2.51	1.99	2.46	4	3.85	4.79	4.52
	97100	3100	-9.475	51.272	EI_500570_2420_FAL.JPG	2.98	2.47	2.01	2.52	4.03	3.88	4.72	4.49
	99100	3100	-9.447	51.273	EI_500580_2420_FAL.JPG	2.93	2.47	2.02	2.52	4.06	3.8	4.76	4.51
	101100	3100	-9.418	51.273	EI_500590_2420_FAL.JPG	2.81	2.45	2.02	2.58	4.19	3.63	4.76	4.59
	103100	3100	-9.389	51.273	EI_500600_2420_FAL.JPG	2.7	2.43	2.01	2.67	4.36	3.51	4.67	4.68
	69100	5100	-9.877	51.284	EI_500430_2410_FAL.JPG	2.76	2.66	1.45	2.09	3.47	3.91	5.04	5.18
	71100	5100	-9.848	51.285	EI_500440_2410_FAL.JPG	2.66	2.66	1.64	2.15	3.46	3.94	5.07	5.05
	73100	5100	-9.82	51.285	EI_500450_2410_FAL.JPG	2.62	2.66	1.74	2.19	3.45	3.9	5.1	4.98
	75100	5100	-9.791	51.286	EI_500460_2410_FAL.JPG	2.6	2.69	1.75	2.2	3.53	3.96	5.02	4.97
	77100	5100	-9.762	51.286	EI_500470_2410_FAL.JPG	2.6	2.76	1.72	2.18	3.66	4.02	4.9	4.98
	79100	5100	-9.734	51.287	EI_500480_2410_FAL.JPG	2.58	2.87	1.7	2.15	3.75	4	4.83	4.97
	81100	5100	-9.705	51.287	EI_500490_2410_FAL.JPG	2.57	2.94	1.7	2.12	3.76	3.96	4.81	4.96
	83100	5100	-9.677	51.287	EI_500500_2410_FAL.JPG	2.64	2.9	1.73	2.16	3.84	3.96	4.79	4.94
	85100	5100	-9.648	51.288	EI_500510_2410_FAL.JPG	2.74	2.8	1.79	2.21	3.92	3.94	4.79	4.91
	87100	5100	-9.619	51.288	EI_500520_2410_FAL.JPG	2.81	2.73	1.85	2.24	3.95	3.88	4.86	4.85
	89100	5100	-9.591	51.289	EI_500530_2410_FAL.JPG	2.85	2.69	1.88	2.26	3.96	3.83	4.91	4.81
	91100	5100	-9.562	51.289	EI_500540_2410_FAL.JPG	2.87	2.67	1.9	2.3	4	3.86	4.85	4.78
	93100	5100	-9.533	51.289	EI_500550_2410_FAL.JPG	2.91	2.59	1.94	2.4	4.05	3.91	4.76	4.69
	95100	5100	-9.505	51.29	EI_500560_2410_FAL.JPG	2.95	2.51	1.99	2.48	4.06	3.91	4.72	4.57

Table E.5 Extract from the Winter (December to February) Rose Database at 50m above ground level:

	X	Y	LONGITUDE	LATITUDE	FILE	FREQ 1	FREQ 2	FREQ 3	FREQ 4	FREQ 5	FREQ 6	FREQ 7	FREQ 8
	89100	1100	-9.589	51.253	EI_500530_2430_WIN.JPG	3.61	2.97	3.32	3.42	8.22	7.06	3.76	3.97
	91100	1100	-9.561	51.253	EI_500540_2430_WIN.JPG	3.59	3.02	3.32	3.52	8.07	7.08	3.75	3.96
	93100	1100	-9.532	51.253	EI_500550_2430_WIN.JPG	3.55	3.13	3.28	3.73	7.79	7.12	3.72	3.94
	95100	1100	-9.503	51.254	EI_500560_2430_WIN.JPG	3.5	3.25	3.23	3.95	7.56	7.16	3.68	3.92
	97100	1100	-9.475	51.254	EI_500570_2430_WIN.JPG	3.43	3.38	3.2	4.16	7.34	7.18	3.63	3.9
	99100	1100	-9.446	51.255	EI_500580_2430_WIN.JPG	3.4	3.4	3.23	4.17	7.3	7.17	3.63	3.91
	85100	3100	-9.647	51.27	EI_500510_2420_WIN.JPG	3.65	2.88	3.36	3.17	8.42	7.16	3.79	4.05
	87100	3100	-9.619	51.27	EI_500520_2420_WIN.JPG	3.63	2.91	3.33	3.29	8.4	7.07	3.77	4
	89100	3100	-9.59	51.271	EI_500530_2420_WIN.JPG	3.62	2.93	3.3	3.34	8.41	7.05	3.75	3.98
	91100	3100	-9.561	51.271	EI_500540_2420_WIN.JPG	3.6	2.98	3.3	3.44	8.25	7.07	3.74	3.97
	93100	3100	-9.533	51.271	EI_500550_2420_WIN.JPG	3.54	3.15	3.26	3.74	7.84	7.12	3.71	3.94
	95100	3100	-9.504	51.272	EI_500560_2420_WIN.JPG	3.46	3.32	3.19	4.05	7.51	7.17	3.65	3.91
	97100	3100	-9.475	51.272	EI_500570_2420_WIN.JPG	3.43	3.39	3.16	4.17	7.42	7.19	3.62	3.89
	99100	3100	-9.447	51.273	EI_500580_2420_WIN.JPG	3.41	3.41	3.19	4.18	7.36	7.18	3.62	3.89
	101100	3100	-9.418	51.273	EI_500590_2420_WIN.JPG	3.33	3.49	3.24	4.25	7.24	7.15	3.6	3.89
	103100	3100	-9.389	51.273	EI_500600_2420_WIN.JPG	3.24	3.61	3.26	4.35	7.13	7.14	3.55	3.86
	69100	5100	-9.877	51.284	EI_500430_2410_WIN.JPG	3.71	2.68	3.33	2.64	8.54	7.63	3.95	4.15
	71100	5100	-9.848	51.285	EI_500440_2410_WIN.JPG	3.61	2.81	3.3	2.75	8.53	7.61	3.87	4.21
	73100	5100	-9.82	51.285	EI_500450_2410_WIN.JPG	3.58	2.86	3.3	2.81	8.48	7.6	3.85	4.24
	75100	5100	-9.791	51.286	EI_500460_2410_WIN.JPG	3.57	2.89	3.3	2.84	8.59	7.52	3.8	4.21
	77100	5100	-9.762	51.286	EI_500470_2410_WIN.JPG	3.58	2.92	3.3	2.88	8.71	7.41	3.76	4.15
	79100	5100	-9.734	51.287	EI_500480_2410_WIN.JPG	3.61	2.91	3.32	2.95	8.69	7.34	3.74	4.11
	81100	5100	-9.705	51.287	EI_500490_2410_WIN.JPG	3.64	2.9	3.33	3	8.62	7.32	3.74	4.11
	83100	5100	-9.677	51.287	EI_500500_2410_WIN.JPG	3.63	2.95	3.33	3.05	8.67	7.25	3.72	4.07
	85100	5100	-9.648	51.288	EI_500510_2410_WIN.JPG	3.62	2.99	3.31	3.13	8.69	7.15	3.7	4.02
	87100	5100	-9.619	51.288	EI_500520_2410_WIN.JPG	3.62	2.98	3.3	3.25	8.57	7.08	3.71	3.99
	89100	5100	-9.591	51.289	EI_500530_2410_WIN.JPG	3.61	2.97	3.29	3.37	8.43	7.05	3.72	3.98
	91100	5100	-9.562	51.289	EI_500540_2410_WIN.JPG	3.6	3.05	3.27	3.45	8.38	7.05	3.68	3.96
	93100	5100	-9.533	51.289	EI_500550_2410_WIN.JPG	3.54	3.2	3.22	3.7	8.13	7.08	3.62	3.93
	95100	5100	-9.505	51.29	EI_500560_2410_WIN.JPG	3.47	3.33	3.18	3.99	7.73	7.14	3.61	3.91

Table E.6 Extract from the Spring (March to May) Rose Database at 50m above ground level:

	X	Y	LONGITUDE	LATITUDE	FILE	FREQ 1	FREQ 2	FREQ 3	FREQ 4	FREQ 5	FREQ 6	FREQ 7	FREQ 8
	89100	1100	-9.589	51.253	EL_500530_2430_SPR_1P	4.15	2.34	2.64	6.32	7.02	3.87	4.1	3.69
	91100	1100	-9.561	51.253	EL_500540_2430_SPR_1P	4.11	2.35	2.65	6.44	6.93	3.84	4.1	3.68
	93100	1100	-9.532	51.253	EL_500550_2430_SPR_1P	4.07	2.32	2.68	6.65	6.74	3.77	4.1	3.66
	95100	1100	-9.503	51.254	EL_500560_2430_SPR_1P	4.06	2.24	2.72	6.81	6.6	3.73	4.1	3.65
	97100	1100	-9.475	51.254	EL_500570_2430_SPR_1P	4.04	2.16	2.78	7.01	6.4	3.69	4.1	3.65
	99100	1100	-9.446	51.255	EL_500580_2430_SPR_1P	4	2.18	2.81	7.11	6.27	3.68	4.11	3.64
	85100	3100	-9.647	51.27	EL_500510_2420_SPR_1P	4.04	2.5	2.61	5.84	7.44	4.03	4.05	3.71
	87100	3100	-9.619	51.27	EL_500520_2420_SPR_1P	4.19	2.34	2.62	6.1	7.21	3.95	4.07	3.71
	89100	3100	-9.59	51.271	EL_500530_2420_SPR_1P	4.26	2.26	2.63	6.17	7.15	3.94	4.08	3.71
	91100	3100	-9.561	51.271	EL_500540_2420_SPR_1P	4.2	2.28	2.64	6.29	7.05	3.89	4.09	3.7
	93100	3100	-9.533	51.271	EL_500550_2420_SPR_1P	4.11	2.25	2.69	6.59	6.79	3.79	4.09	3.67
	95100	3100	-9.504	51.272	EL_500560_2420_SPR_1P	4.08	2.14	2.74	6.8	6.61	3.73	4.09	3.67
	97100	3100	-9.475	51.272	EL_500570_2420_SPR_1P	4.08	2.08	2.76	6.85	6.56	3.71	4.08	3.67
	99100	3100	-9.447	51.273	EL_500580_2420_SPR_1P	4.03	2.12	2.79	6.97	6.42	3.7	4.1	3.65
	101100	3100	-9.418	51.273	EL_500590_2420_SPR_1P	3.92	2.16	2.9	7.21	6.08	3.68	4.14	3.62
	103100	3100	-9.389	51.273	EL_500600_2420_SPR_1P	3.8	2.15	3.03	7.36	5.82	3.67	4.19	3.59
	69100	5100	-9.877	51.284	EL_500430_2410_SPR_1P	3.77	2.38	2.44	4.84	7.99	4.85	3.79	3.85
	71100	5100	-9.848	51.285	EL_500440_2410_SPR_1P	3.74	2.37	2.49	4.98	7.98	4.65	3.88	3.84
	73100	5100	-9.82	51.285	EL_500450_2410_SPR_1P	3.72	2.36	2.52	5.09	7.96	4.52	3.92	3.82
	75100	5100	-9.791	51.286	EL_500460_2410_SPR_1P	3.76	2.4	2.52	5.08	7.99	4.51	3.91	3.83
	77100	5100	-9.762	51.286	EL_500470_2410_SPR_1P	3.84	2.48	2.53	5.06	8.02	4.49	3.89	3.82
	79100	5100	-9.734	51.287	EL_500480_2410_SPR_1P	3.89	2.58	2.57	5.14	7.99	4.35	3.92	3.78
	81100	5100	-9.705	51.287	EL_500490_2410_SPR_1P	3.9	2.64	2.61	5.21	7.96	4.24	3.96	3.74
	83100	5100	-9.677	51.287	EL_500500_2410_SPR_1P	4	2.56	2.61	5.32	7.86	4.26	3.92	3.75
	85100	5100	-9.648	51.288	EL_500510_2410_SPR_1P	4.15	2.41	2.6	5.56	7.64	4.27	3.91	3.77
	87100	5100	-9.619	51.288	EL_500520_2410_SPR_1P	4.24	2.3	2.62	5.9	7.36	4.13	3.98	3.75
	89100	5100	-9.591	51.289	EL_500530_2410_SPR_1P	4.28	2.24	2.64	6.14	7.16	4	4.04	3.72
	91100	5100	-9.562	51.289	EL_500540_2410_SPR_1P	4.29	2.21	2.66	6.16	7.11	4.06	4	3.73
	93100	5100	-9.533	51.289	EL_500550_2410_SPR_1P	4.28	2.14	2.71	6.32	6.94	4.06	3.96	3.74
	95100	5100	-9.505	51.29	EL_500560_2410_SPR_1P	4.18	2.09	2.75	6.6	6.72	3.9	4	3.71

Table E.7 Extract from the Seasonal Variation Database file at 50m above ground level:

	X	Y	LONGITUDE	LATITUDE	WINSPEED050	WINPOWER050	WINWEIBC050	WINWEIBK050	SPRSPEED050
	97100	300	-9.475	51.247	10.99	1370.69	12.45	2.207	9.03
	91100	500	-9.56	51.248	11	1379.43	12.47	2.209	9.03
	91300	500	-9.558	51.248	11	1379.36	12.46	2.21	9.03
	91500	500	-9.555	51.248	11	1379.29	12.46	2.21	9.03
	91700	500	-9.552	51.248	11	1377.64	12.46	2.211	9.03
	91900	500	-9.549	51.248	11	1377.58	12.46	2.211	9.03
	92100	500	-9.546	51.248	11	1375.94	12.46	2.211	9.02
	92300	500	-9.543	51.248	11	1375.89	12.46	2.212	9.02
	92500	500	-9.54	51.248	11	1375.85	12.46	2.212	9.02
	92700	500	-9.538	51.248	11	1375.81	12.45	2.212	9.02
	92900	500	-9.535	51.248	10.99	1375.78	12.45	2.212	9.02
	93100	500	-9.532	51.248	10.99	1375.75	12.45	2.212	9.02
	93300	500	-9.529	51.248	10.99	1375.73	12.45	2.212	9.02
	93500	500	-9.526	51.248	10.99	1374.13	12.45	2.212	9.02
	93700	500	-9.523	51.248	10.99	1374.11	12.45	2.212	9.02
	93900	500	-9.52	51.248	10.99	1373.42	12.44	2.212	9.02
	94100	500	-9.518	51.248	10.99	1373.4	12.44	2.212	9.02
	94300	500	-9.515	51.248	10.99	1373.36	12.44	2.212	9.02
	94500	500	-9.512	51.248	10.99	1373.32	12.44	2.212	9.02
	94700	500	-9.509	51.248	10.99	1373.27	12.44	2.211	9.02
	94900	500	-9.506	51.248	10.99	1373.21	12.44	2.211	9.02
	95100	500	-9.503	51.248	10.99	1373.14	12.44	2.211	9.02
	95300	500	-9.5	51.248	10.99	1371.49	12.44	2.21	9.02
	95500	500	-9.497	51.249	10.99	1371.41	12.44	2.21	9.02
	95700	500	-9.495	51.249	10.99	1371.32	12.44	2.21	9.02
	95900	500	-9.492	51.249	10.99	1371.24	12.44	2.209	9.02
	96100	500	-9.489	51.249	10.99	1371.15	12.44	2.209	9.02
	96300	500	-9.486	51.249	10.99	1371.06	12.44	2.209	9.02
	96500	500	-9.483	51.249	10.99	1370.97	12.44	2.209	9.02
	96700	500	-9.48	51.249	10.99	1370.89	12.44	2.209	9.02

Table E.8 Extract from the diurnal Variation Database file:

	X	Y	LONGITUDE	LATITUDE	HOUR 1	HOUR 2	HOUR 3	HOUR 4	HOUR 5	HOUR 6	HOUR 7	HOUR 8	HOUR 9	HOUR10
	89100	1100	-9.589	51.253	0.979	0.966	0.972	0.995	1.009	1.013	1.01	1.009	1.01	1.013
	91100	1100	-9.561	51.253	0.979	0.966	0.972	0.995	1.008	1.013	1.01	1.009	1.01	1.013
	93100	1100	-9.532	51.253	0.979	0.966	0.972	0.995	1.008	1.013	1.01	1.009	1.01	1.013
	95100	1100	-9.503	51.254	0.978	0.966	0.973	0.995	1.008	1.013	1.01	1.009	1.01	1.013
	97100	1100	-9.475	51.254	0.978	0.967	0.973	0.995	1.008	1.013	1.01	1.009	1.01	1.012
	99100	1100	-9.446	51.255	0.978	0.967	0.973	0.995	1.007	1.013	1.01	1.009	1.01	1.012
	85100	3100	-9.647	51.27	0.979	0.964	0.971	0.995	1.009	1.014	1.011	1.009	1.011	1.014
	87100	3100	-9.619	51.27	0.979	0.965	0.972	0.995	1.009	1.014	1.01	1.009	1.01	1.013
	89100	3100	-9.59	51.271	0.978	0.965	0.972	0.995	1.009	1.014	1.01	1.009	1.01	1.013
	91100	3100	-9.561	51.271	0.979	0.966	0.972	0.995	1.009	1.014	1.01	1.009	1.01	1.013
	93100	3100	-9.533	51.271	0.978	0.966	0.973	0.995	1.008	1.013	1.01	1.009	1.01	1.013
	95100	3100	-9.504	51.272	0.978	0.967	0.973	0.995	1.008	1.013	1.01	1.009	1.01	1.013
	97100	3100	-9.475	51.272	0.978	0.967	0.973	0.995	1.008	1.013	1.01	1.009	1.01	1.012
	99100	3100	-9.447	51.273	0.978	0.967	0.973	0.995	1.008	1.013	1.01	1.009	1.01	1.012
	101100	3100	-9.418	51.273	0.978	0.967	0.973	0.995	1.007	1.013	1.01	1.009	1.01	1.012
	103100	3100	-9.389	51.273	0.978	0.968	0.973	0.995	1.007	1.013	1.01	1.009	1.01	1.012
	69100	5100	-9.877	51.284	0.978	0.962	0.968	0.993	1.01	1.016	1.015	1.011	1.011	1.014
	71100	5100	-9.848	51.285	0.978	0.962	0.969	0.994	1.01	1.016	1.014	1.01	1.011	1.014
	73100	5100	-9.82	51.285	0.978	0.962	0.969	0.994	1.01	1.016	1.014	1.01	1.011	1.014
	75100	5100	-9.791	51.286	0.978	0.962	0.969	0.994	1.01	1.016	1.013	1.01	1.011	1.013
	77100	5100	-9.762	51.286	0.978	0.963	0.969	0.994	1.01	1.016	1.013	1.01	1.011	1.013
	79100	5100	-9.734	51.287	0.978	0.963	0.97	0.994	1.01	1.015	1.012	1.01	1.011	1.013
	81100	5100	-9.705	51.287	0.978	0.963	0.97	0.995	1.01	1.015	1.012	1.01	1.011	1.014
	83100	5100	-9.677	51.287	0.978	0.964	0.97	0.995	1.009	1.015	1.012	1.01	1.011	1.013
	85100	5100	-9.648	51.288	0.978	0.964	0.971	0.995	1.009	1.014	1.011	1.009	1.01	1.013
	87100	5100	-9.619	51.288	0.978	0.965	0.972	0.995	1.009	1.014	1.011	1.009	1.01	1.013
	89100	5100	-9.591	51.289	0.978	0.965	0.972	0.995	1.009	1.014	1.01	1.009	1.01	1.013
	91100	5100	-9.562	51.289	0.978	0.966	0.972	0.995	1.009	1.014	1.01	1.009	1.01	1.013
	93100	5100	-9.533	51.289	0.978	0.966	0.972	0.995	1.008	1.013	1.01	1.009	1.01	1.013
	95100	5100	-9.505	51.29	0.978	0.967	0.973	0.995	1.008	1.013	1.01	1.009	1.01	1.012

Appendix F

Terrain Roughness Database

CORINE Ground Cover and Ground Roughness

Introduction

CORINE ground cover mapping was originally produced (1993) using interpretation of LANDSAT satellite imagery in an EU wide project. The project is described in a Final Report (December 1994) where the experience of the CORINE Team (Ireland) in applying the CORINE Technical Guide to Irish conditions was detailed. Thirty-four cover classes were used to describe the ground surface. None of these was, at that point, directed at describing or mapping the ground roughness from a wind modelling perspective but the broad relationship between roughness and land type/use/vegetation cover could readily be discerned. This working paper discusses the application of CORINE to surface roughness length estimation.

In assessing ground roughness for wind modelling purposes there are several factors to be borne in mind:

1. Seasonality

1.1 The roughness varies with the season depending on the amount of foliage present and on the type and size of crops.

1.2 It also varies from year to year depending vegetation pattern, crop type and on the gradual increase in tree height with age.

1.3 In terms of influence on mean wind speed the Winter/Spring winds are likely to be somewhat less affected by roughness than the Summer/Autumn wind statistics. It is the former winds that contribute most significantly to the mean annual wind speed.

2. Observer height

2.1 In assessing local surface roughness, ideally the observer should be positioned about 25-30m above ground to develop an uninterrupted view and impression of the surrounding countryside for rating purposes.

2.2 If observations have to be made at ground level this is probably best done during the winter when the absence of foliage permits the landscape to be viewed through roadside hedges and trees. Otherwise a false 'closed in' impression of the extent of bushes and trees can be gained.

3. Forestry

3.1 Tree felling and attributable new plantations alter the roughness in forested areas. It is important to note that on early 'Discovery ' series maps forest property lines could extend outside the areas actually afforested and may overstate the afforested area at the relevant time. This should not be a problem with the CORINE data however within its limits of resolution.

3.2 Forestry accounts for approximately 8% of the overall land cover of the Republic but the percentage rises where the upland and marginal areas are concerned due to the uneven spread involved. These are or often adjoin areas of significant wind resource.

Using the CORINE mapping three forest types are recognised and Coded 3.1.1 Coniferous, 3.1.2 Deciduous, 3.1.3 Mixed forest. Each of these is allocated a roughness length of 0.75.

To improve the quality of forest roughness information, further data on forest growth status was obtained from Irish Forest Service (IFS). This distinguished between areas of "mature" coniferous and deciduous forest both of which were assigned roughness 0.75, young forest, assigned roughness 0.25, and cleared forest assigned roughness 0.2 to account for brash cover left behind. Where uncertainty existed in the IFS data as to forest status the existing CORINE designation was allowed to stand.

As the Forest Service database was based on O.S.I mapping it was more crisp than that of CORINE where the boundaries between land cover areas tended to be somewhat more fluid.

Thus the roughness classification was based on CORINE for the general country side and IFS mapping for public and privately owned forest parcels, reverting to CORINE where IFS information was incomplete.

This allowed the following key roughness lengths to be mapped:

Table F1.1

Forest Roughness Lengths Z_o

Description	**Roughness**	**Source**
3.1.1 Mature Coniferous	0.75	Corine/IFS
3.1.2 Mature Deciduous	0.75	Corine/IFS
3.1.3 Mature Mixed	0.75	Corine/IFS
Young Forest	0.25	IFS
Cleared Forest	0.2	IFS
3.2.1 Rough natural grass land, scrub	0.15	Corine

4. Other Factors

4.1 The impact of roughness on mean wind speed is also influenced by directionality, relief, reflectivity, and significantly, by the upwind area over which given roughness prevails.

4.2 The representativeness of the synoptic meteorological stations where long term measurement have been made was determined originally during the European Wind Atlas project. The countryside surrounding a set of 10 stations was systematically assessed for ground roughness at various distances and directions from each station as part of the process of validating their 10 year wind records for inclusion in the original wind atlas data base. Certain other stations were excluded at the time for a variety of reasons.

5. Roughness Lengths

5.1 In using the roughness lengths (Z_o) and classes as used for the European Wind Atlas in combinations with the terrain cover types recognised for CORINE mapping purpose purposes it will be appreciated that there will in general be significantly fewer identifiable roughness lengths than terrain nomenclature types.

5.2 The roughness lengths follow a logarithmic scale over four orders of magnitude (1-0.0001) to describe the surface variation between built up city and open sea. Virtually all of the surface characteristics encountered in Ireland fall into the upper two of these giving 1.0< Z_o<0.01.

6. Methodology

The nomenclature (at Level 3) given in Annex 5 to the Final Report with descriptions is abbreviated as follows. These descriptions were matched with equivalent descriptions from the European Wind Atlas to allow the assignment of preliminary roughness length (Z_o) values as tabulated: (Table F1.2):

Table F1.2

CORINE Description	Roughness Length Z_o
1.1 Urban Fabric	
1.1.1 Continuous	1.0
1.1.2 Discontinuous	0.5
1.2 Industrial /Commercial/Transport	
1.2.1 Industrial /Commercial	0.4
1.2.2 Road/Rail networks & lands	0.03
1.2.3 Sea ports	0.03
1.2.4 Airports	0.03
1.3 Mine, Dump, Construction Sites	
1.3.1 Mineral, Extraction, Sites	0.15
1.3.2 Dump Sites	0.01
1.3.3 Construction Sites	0.1
1.4 Artificial, Non Agricultural, Vegetated Areas	
1.4.1 Green Urban Areas	0.1
1.4.2 Sport & Leisure facilities	0.1
2.1 Agricultural: Arable Land	
2.1.1 Non irrigated arable land	0.15

2.3 Agricultural; Pastures		
2.3.1	Pastures, with /without hedges	0.07
2.3.1.1.	Highly Productive grass lands (open)	0.05
2.3.1.2	Low productivity grass lands (closed)	0.07
2.3.1.3	Low productivity mixed, shrubby (closed)	0.1
2.4 Heterogeneous Agricultural		
2.4.1	Annual crops/permanent crops	0.05
2.4.2	Complex Cultivation (Small Units)	0.1
2.4.3	Mixed cover types, primarily agriculture	0.1
3.1 Forest		
3.1.1	Broad leaf (mature) Corine /IFS	0.75
3.1.2	Conifer (mature) Corine /IFS	0.75
3.1.3	Mixed Forest Trees, Bushes (mature) Corine /IFS	0.75
3.2 Scrub/ herbaceous		
3.2.1	Natural Grasslands	0.15
3.2.2	Moors/Heathland	0.07
3.2.4	Transitional Woodland scrub, Young Forest Corine /IFS	0.25
	Cleared Forest, Brash (IFS Overlay)	0.2
3.4 Open Spaces		
3.3.1	Beaches, dunes, sand	$3x10^{-4}$
3.3.2	Bare rocks	0.2
3.3.3	Sparse Vegetation	0.02
3.3.4	Burnt Areas	0.01
4.1 Wetlands (inland)		
4.1.1	Marshes	0.02
4.1.2	Peat bogs	0.02
4.2 Wetlands (coastal)		
4.2.1	Salt Marshes	0.02
4.2.3	Inter tidal flats	0.01

5.1	Inland Waters	
5.1.1	Rivers (=100m, wide)	$2x10^{-4}$
5.1.2	Water bodies (lakes, reservoirs)	10^{-4}
5.2	Marine Waters	
5.2.1	Coastal Lagoons	10^{-4}
5.2.2	Estuaries	10^{-4}
5.2.3	Sea	10^{-4}

(For application the full descriptions of Annex 5 should be referred to. Minimum areas identified 25Ha).

6.2 The predominating element observed in the Irish countryside using the Wind Atlas nomenclature is 'closed farm land' which has a roughness approaching 0.1 (Types 2.3.1, 2.4.2) while open farm land /crops (Type 2.4.1) has a roughness length of 0.05. A key issue for clarification therefore is the significance of using roughness values in this range on the mean wind speeds projected at the heights of interest (50-100m).

7. Sources of Differences

- CORINE is based on 25ha area elements ie 0.5kmx0.5km. Thus insitu observations are more accurate although they really need to be made by reference to a GPS co-ordination system giving a positional reference of perhaps ± 15m. (The fourth digit in CORINE classification is irrelevant in this context).
- On site estimations are descriptive of local countryside for a "visual bubble" perhaps 0.5-1km radius when viewed from the public road.
- If Co ordinates of a point are estimated from mileometer in a moving vehicle and 1:50 000 OSI Maps, it is felt that they can have an error of circa ± 0.5km.
- If a point falls outside precise area e.g within built up areas (towns) it may give a completely different surface designation and roughness number e.g. Town should read 1.0 but if the point is in surrounding countryside it might give 0.05.
- There is a significant difference between open farmland (0.05) and closed farmland (0.1) based on visual observation. With CORINE both types are shown as 2.3.1 having a roughness of 0.07 which is a compromise but may be seen as having a + 40% - 30% roughness difference relative to an observed value. This will not of course automatically affect wind speeds to this extent. The effect would depend on the area involved and height of interest.

8. Sensitivity of wind speed to Surface Roughness and Height

8.1 The sensitivity of mean wind speed results obtained at heights of 50m, 75m, 100m to surface roughness requires assessment together with the effect of different roughness values on long term local wind measurements where these were made at 10m, 30m or other heights above ground level. This has been tabulated and plotted as a series of curves based on wind records from representative high and low wind speed locations. (Belmullet and Kilkenny).

8.2 A important feature relates to the extent of ground area over which a given roughness can be taken to apply. The larger the area the larger the impact on mean wind speed at height. Thus it is the aggregate or integrated effects of the ground roughness drag on the winds that determines the outcome not the mere presence of a local patch of particularly rough ground.

8.3 In this case calculations were made for areas of 1,3,5 and 10 km radius and also for the extreme case of an unlimited radius (to test the upper limit of roughness effect). From observation in the field the most likely cases to be encountered in Ireland lie in the range 1-5km ie a typical field observation of ground roughness can be taken as being representative of an area within that range in Ireland.

8.4 The reference stations used were Belmullet to represent an exposed coastal site, and Kilkenny representing an inland site. Both had formed part of the suite of sites checked out for use in the European Wind Atlas at the relevant period.

8.5 Area of Uniform Roughness (Radius 1km - Tables F2.1, F2.2)

8.5.1 The mean wind speed curves for Belmullet and Kilkenny when the roughness area is taken to be of 1km radius are shown on Fig. 1.

8.5.2 In particular it may be noted that the effect on mean wind speed at heights of 50m and above is almost negligible. In the key roughness length range of 0.05-0.1 the variation in projected mean windspeed is of the order of 0.05m.sec on wind speeds the range from 5.5 m/sec to 9.6 m/sec.(1%-0.5%). This is insignificant given the uncertainties in the overall process. Thus the important conclusion is reached that where the surface area of roughness value is a circle of radius 1km it is of little significance whether a roughness length of 0.05 or 0.1 is used and a value of 0.07 would be quite representative for projected mean wind speeds at heights of 50m and above.

(At 30m height and below the question still requires some attention particularly at the more windy coastal sites).

8.6 Area of Uniform Roughness (Radius 3km – Table F3.1, F3.2)

8.6.1 The mean wind speed curves for Belmullet and Kilkenny when the roughness area in taken to be of 3km. radius are shown in (Fig.2).

8.6.2 The variation in mean wind speed with increasing roughness is more evident at lower height than for heights of 50m and above. The overall rates of variation are proportionally about the same for both Kilkenny and Belmullet sites in percentage terms. The mean windspeeds based on Kilkenny are of course significantly lower than for Belmullet at all heights.

The key area of interest centres on the roughness range of $0.05=Z_0=0.1$ and here the variation in projected mean wind speed is 0.15m/s on 5.2 – 6.35 (2.96-2.3%) for and 0.25m/s on 7.9-9.5 (3.2-2.6%) for at heights of 50-100m.

Thus the selection of a mean roughness of $Z_0=0.07$ would induce potential errors of ± .07m/sec (1.1%-1.5%) for Kilkenny and 0.125m/sec (1.3-1.6%) for Belmullet.

8.7 Area of Uniform Roughness (Radius 5km – Tables F4.1, F4.2)

8.7.1 The question was also examined for an area corresponding to a 5km radius and the results are plotted in Fig. 3. Here again the some general pattern may be seen. The variation in projected mean windspeed at heights of 50-100m and roughness lengths 0.05-0.1 is of the order ± 0.15 m/sec on wind speeds that range from 5.1 m/sec to 9.5 m/sec. This is closer to the case for the area based on 1km radius than that based on the 10km radius which is considered below.

8.8 Area of Uniform Roughness (Radius 10km – Table F5.1, F5.2)

The case having 10km radius of roughness area Fig. 4 was assessed in a similar way to that for radii of 5km. However this case produced results that were almost coincident with those for the unlimited roughness area (below).

Thus at the heights of interest the potential errors in mean wind speed that might arise from use of a mean roughness of 0.07 are projected to be ± 0.25m/sec on 7.1-9m/sec (3.5%-2.7%) for Belmullet and ± 0.125m/sec on 5.2-6.0m/sec (2.4%-2%) for Kilkenny.

These are tolerable given the other uncertainties involved.

8.9 Unlimited Area of Roughness (Tables F6.1, F6.2)

8.9.1 As an extreme case curves showing the influence of unlimited surface roughness area on projected mean wind speeds at heights 10,30,50,75,100m above ground level were plotted using linear scales Fig.5. As might be expected these show that in absolute terms the greater the roughness the greater the mean wind speed is reduced at any height and that the degree of reduction decreases with height. Clearly the Kilkenny based wind speeds are lower than these based on Belmullet.

8.9.2 It may be noted that for an "unlimited" area the effect of any roughness is significant e.g the loss of mean wind speed over the roughness length range broadly 0.03-0.15 equates to that over the much greater range of 0.15 to 0.5.

8.9.3 The key issue for investigation here is the range between Z_0=0.05 and 0.1. Here the slope of the curves is such that the wind speed variation is about ±0.125 m/s for all heights at Kilkenny, ± 0.25m/sec Belmullet. As the energy value is proportional to the cube of the wind speed it is important to get the roughness length as correct as possible.

8.9.4 This is less important for exposed sites (Belmullet) than more inland sites (Kilkenny) as the exposed sites are all in the economic speed range at the heights of interest 50-100m.while the inland sites are only in the speed range 5-6.25 m/sec.

9. Conclusions

9.1 Based on the above analysis it can be concluded that, for the heights of 50-100m used in this program and the areas of uniform surface roughness likely to be encountered in the Irish landscape, the CORINE mapping can be used to delineate these areas and that in the most common cases of open/closed farmland there is little diffence in whether roughness lengths of 0.05 or 0.1 are used and the mean value of 0.07 as targeted can be used without loss of accuracy.

9.2 For larger areas and lower heights and for greater roughness e.g over extensive forestry this might not be the case but this is not a problem in this case as large scale commercial forestry is reasonably well mapped and delineated and clear roughness length could be assigned using proprietary data made available by Irish Forest Service.

9.3 The two meteorological stations chosen (Belmullet, Kilkenny) represent a coastal and an inland site respectively and both were calibrated during the European Wind Atlas programme. They represent the upper echelon and lower echelon of Irish mean wind speed sites respectively. A more exhaustive analysis could be applied using the characteristics of other meteorological sites but as Belmullet and Kilkenny encompass the relevant range of speeds it is felt that this would be mere repetition and is outside the scope of the current work.

9.4 Areas of a given roughness in Ireland are well represented by the cases examined. Areas of uniform roughness having radii of 1-5km in a given upwind direction cover most cases.

The area having 10km radius might typically be encountered in flat parts of the country such as the Curragh in Co. Kildare or midland peat bogs and some other locations.

The “unlimited” area of roughness of Section 8.9 does not usually occur within of the Irish countryside except on the rare occasions when the country is blanketed by deep frozen snow.

10. Recommendations

10.1 In carrying out the wind velocity distribution analysis for heights of 50-100m above ground level, the ground surface roughness lengths that may be ascribed to the different pasture types which make up much of the land cover are:

0.05 for open highly productive grass lands

0.07 for closed low productivity grass lands

0.1 for closed shrubby mixed grass lands

The use of a mean value of roughness length of 0.07 appears to be acceptable unless the radius of the roughness area involved exceeds 5-10km.

10.2 The use of CORINE data augmented by that made available, on a limited basis, by Irish Forest Service provides the best current estimate of the roughness range and areol extent of forest cover as indicated in Table F1.1.

10.3 The remaining areas as identified on Table F1.2 are mostly of limited extent, apart from 3.2.2 moors/heathland and 4.1 Wetlands (incl. peat bogs) where the roughness lengths are low, and do not have a major impact in reducing mean windspeed.

10.4 In the Irish context the impact of the extent of areas of uniform roughness for the range of windspeeds and heights of interest shows that the sensitivity of mean wind speed, while more pronounced at inland sites than coastal (or upland) sites having higher wind speeds, may be regarded as not being unduly significant.

10.5 Thus for the period concerned, 1990-9 (inclusive), the use of CORINE land cover augmented by Irish Forest Services Data represents an acceptable overall basis for ascribing surface roughness distribution for use in the mean wind speed computation.

Table F2.1
Variation of Mean Wind speed with height and roughness length: Kilkenny: Radius of Area: 1km (Plotted Fig.1)

Roughness	Height (m)				
Length (m)	10	30	50	75	100
0.03	4.0	4.9	5.4	6.0	6.4
0.075	3.7	4.8	5.4	6.0	6.4
0.1	3.7	4.8	5.4	6.0	6.4
0.15	3.5	4.7	5.4	5.9	6.3
0.3	3.3	4.6	5.4	5.9	6.3
0.5	3.0	4.4	5.3	5.9	6.3

Table F2.2
Variation of Mean Wind Speed with height and roughness length: Belmullet: Radius of Area: 1km (Plotted Fig.1)

Roughness	Height (m)				
Length (m)	10	30	50	75	100
0.03	6.2	7.6	8.3	9.1	9.6
0.075	5.9	7.5	8.3	9.0	9.5
0.1	5.7	7.4	8.3	9.0	9.5
0.15	5.5	7.3	8.2	9.0	9.5
0.3	5.1	7.0	8.2	8.9	9.5
0.5	4.7	6.8	8.1	8.9	9.4

Table F3.1
Variation of Mean Wind Speed with height and roughness length: Kilkenny: Radius of Area: 3km (Plotted Fig.2)

Roughness	Height (m)				
Length (m)	10	30	50	75	100
0.03	4.0	4.9	5.4	6.0	6.4
0.075	3.7	4.7	5.3	5.9	6.3
0.1	3.6	4.6	5.2	5.8	6.2
0.15	3.4	4.5	5.1	5.7	6.2
0.3	3.1	4.2	4.9	5.5	6.0
0.5	2.9	4.0	4.7	5.4	5.9

Table F3.2
Variation of Mean Wind Speed with height and roughness length:
Belmullet: Radius of Area: 3km (Plotted Fig. 2)

Roughness Length (m)	Height (m) 10	30	50	75	100
0.03	6.2	7.6	8.3	9.1	9.6
0.075	5.8	7.2	8.0	8.8	9.4
0.1	5.6	7.1	7.9	8.8	9.4
0.15	5.3	6.9	7.8	8.6	9.3
0.3	4.9	6.5	7.4	8.4	9.1
0.5	4.5	6.2	7.1	8.1	8.9

Table F4.1
Variation of Mean Wind Speed with height and roughness length:
Kilkenny: Radius of Area: 5km (Plotted Fig. 3)

Roughness Length (m)	Height (m) 10	30	50	75	100
0.03	4.0	4.9	5.4	6.0	6.4
0.075	3.6	4.6	5.2	5.8	6.2
0.1	3.5	4.6	5.1	5.7	6.1
0.15	3.4	4.4	5.0	5.6	6.0
0.3	3.1	4.1	4.7	5.3	5.8
0.5	2.8	3.9	4.5	5.1	5.6

Table F4.2
Variation of Mean wind speed with height and roughness length:
Belmullet: Radius of Area: 5km (Plotted Fig. 3)

Roughness Length (m)	Height (m) 10	30	50	75	100
0.03	6.2	7.6	8.3	9.1	9.6
0.075	5.7	7.2	7.9	8.7	9.3
0.1	5.5	7.0	7.8	8.6	9.2
0.15	5.3	6.8	7.6	8.4	9.0
0.3	4.8	6.4	7.2	8.1	8.7
0.5	4.4	6.1	6.9	7.8	8.4

Table F5.1
Variation of Mean Speed with height and roughness length:
Kilkenny: Radius of Area: 10km (Plotted Fig. 4)

Roughness Length (m)	Height (m)				
	10	30	50	75	100
0.03	4.0	4.9	5.4	6.0	6.4
0.075	3.6	4.6	5.1	5.7	6.1
0.1	3.5	4.5	5.0	5.6	6.0
0.15	3.3	4.3	4.9	5.4	5.8
0.3	3.0	4.0	4.6	5.1	5.5
0.5	2.7	3.8	4.4	4.9	5.3

Table F5.2
Variation of Mean Wind Speed with height and roughness length:
Belmullet: Radius of Area: 10km (Plotted Fig. 4)

Roughness Length (m)	Height (m)				
	10	30m	50	75	100
0.03	6.2	7.6	8.3	9.1	9.6
0.075	5.6	7.1	7.9	8.6	9.1
0.1	5.5	6.9	7.7	8.4	9.0
0.15	5.2	6.7	7.5	8.2	8.8
0.3	4.6	6.2	7.0	7.8	8.3
0.5	4.2	5.8	6.7	7.4	8.0

Table F6.1
Variation of Mean Speed with height and roughness length: Kilkenny: Radius of Area>> 10km (Plotted Fig. 5)

Roughness Length (m)	Height (m)				
	10	30m	50	75	100
0.03	4.0	4.9	5.4	6.0	6.4
0.075	3.6	4.6	5.1	5.6	6.0
0.1	3.5	4.5	5.0	5.5	5.9
0.15	3.3	4.3	4.8	5.3	5.7
0.3	2.9	3.9	4.5	5.0	5.3
0.5	2.6	3.7	4.2	4.7	5.1

Table F6.2
Variation of Mean Speed with height and roughness length:
Belmullet: Radius of area>>10km: (Plotted Fig. 5)

Roughness Length (m)	**Height (m)**				
	10	**30**	**50**	**75**	**100**
0.03	6.2	7.6	8.3	9.1	9.6
0.075	5.6	7.0	7.8	8.5	9.0
0.1	5.4	6.9	7.6	8.3	8.8
0.15	5.1	6.6	7.3	8.0	8.5
0.3	4.5	6.0	6.8	7.5	8.0
0.5	4.1	5.7	6.4	7.1	7.6

References:

(1) Application of the CORINE nomenclature to the Land Cover of Ireland (in CORINE Land Cover Project (Ireland) – Final Report /December 1994)

(2) Annex 5 to above (Concise Nomenclature to Level 3 based on the Technical Guide to CORINE with agreed adoptions for Ireland – Tomlinson RW and Cruikshank M, School of Geosciences, Queens University Belfast.

(3) European Wind Atlas,Ch. 5.General Concepts.

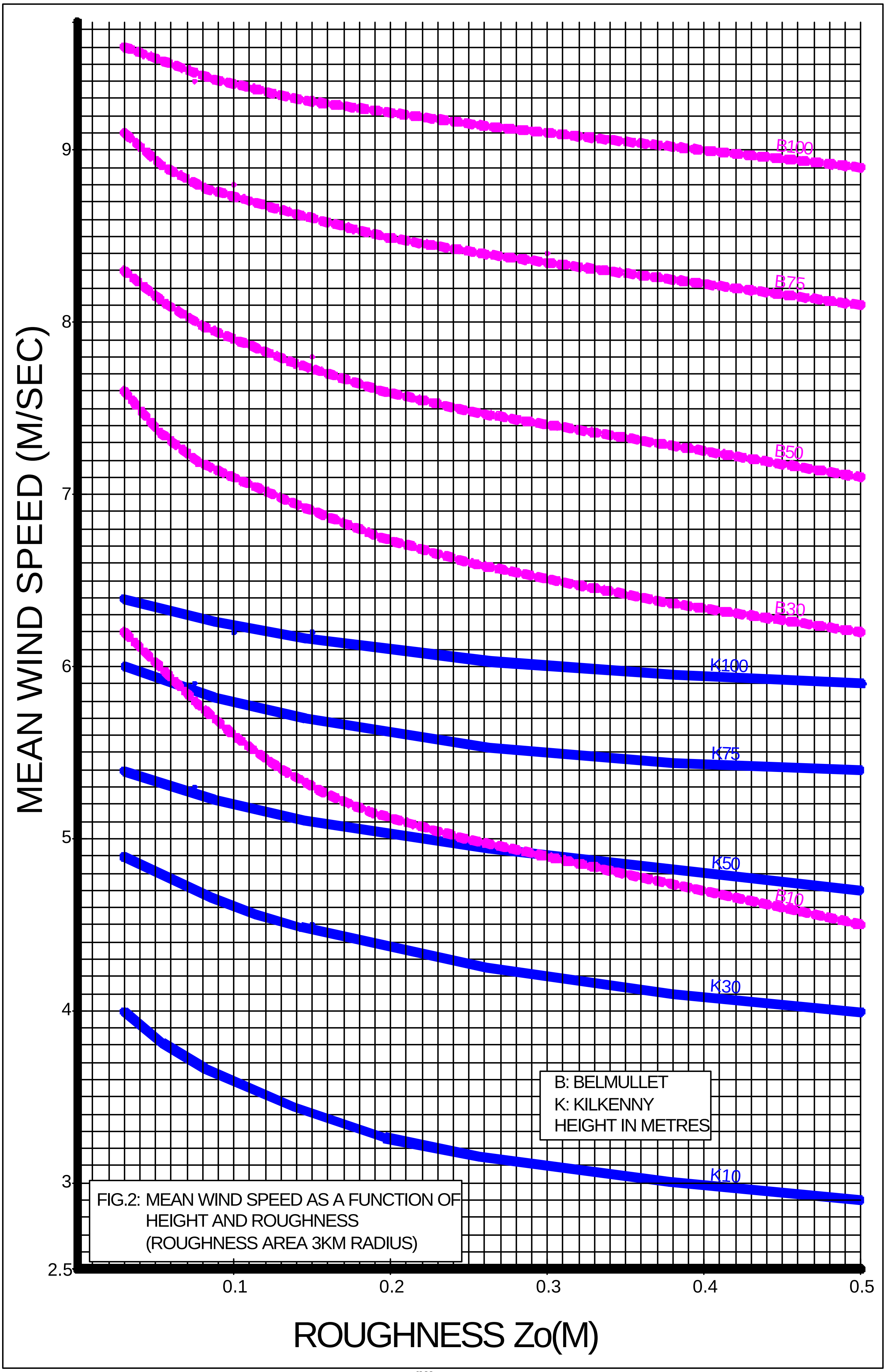

FIG.2: MEAN WIND SPEED AS A FUNCTION OF HEIGHT AND ROUGHNESS (ROUGHNESS AREA 3KM RADIUS)

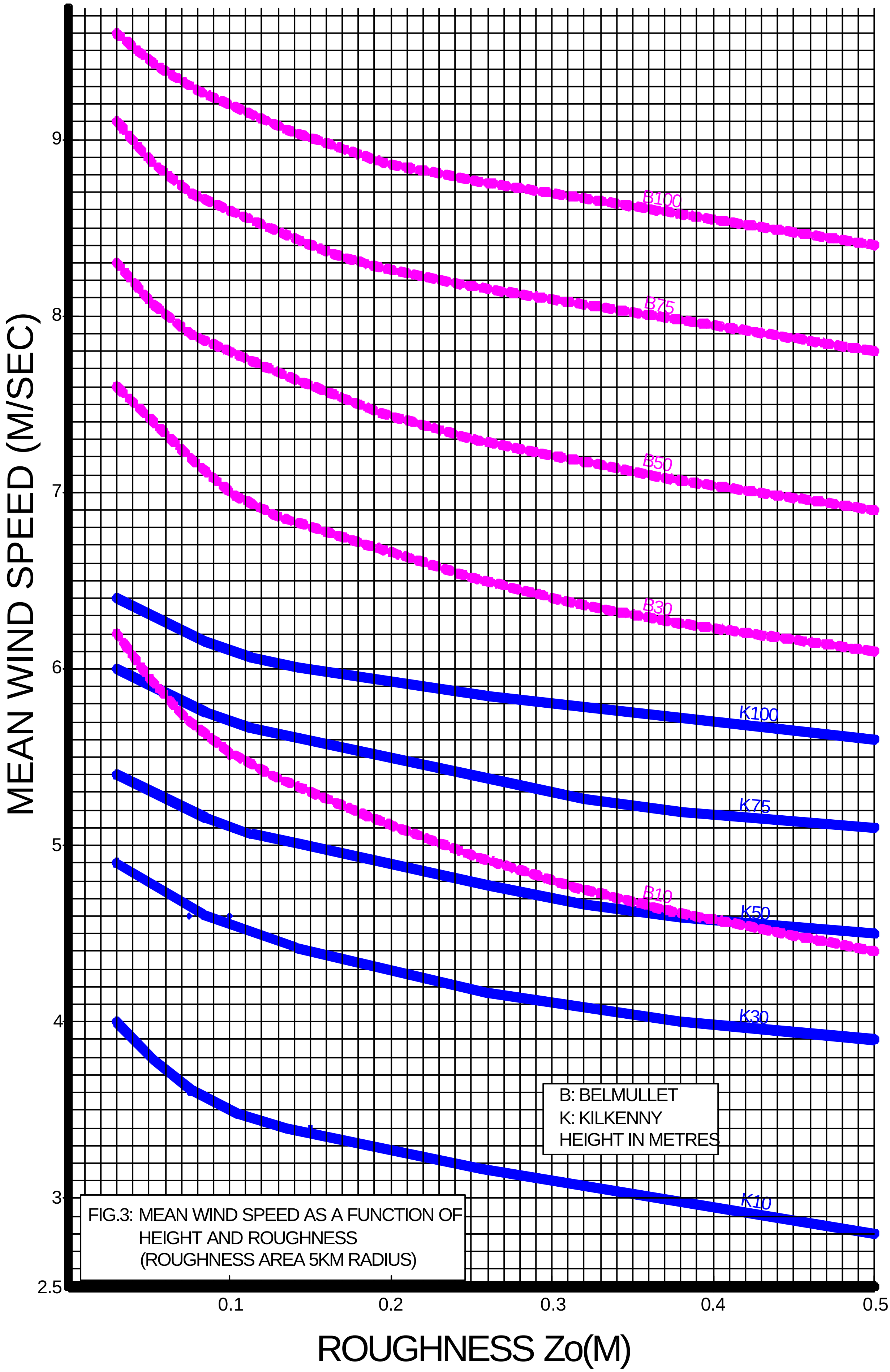

FIG.3: MEAN WIND SPEED AS A FUNCTION OF HEIGHT AND ROUGHNESS (ROUGHNESS AREA 5KM RADIUS)

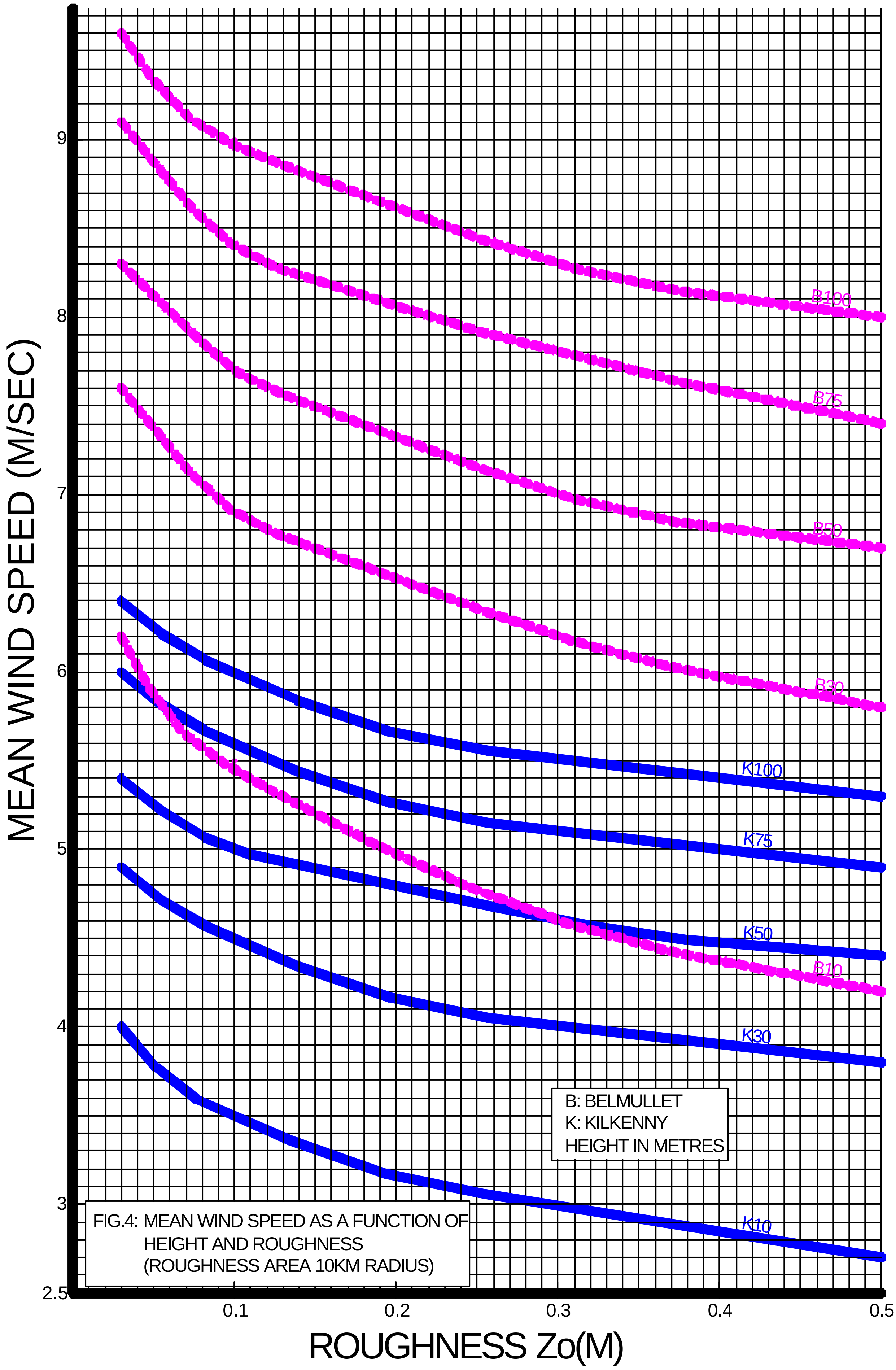

FIG.4: MEAN WIND SPEED AS A FUNCTION OF HEIGHT AND ROUGHNESS (ROUGHNESS AREA 10KM RADIUS)

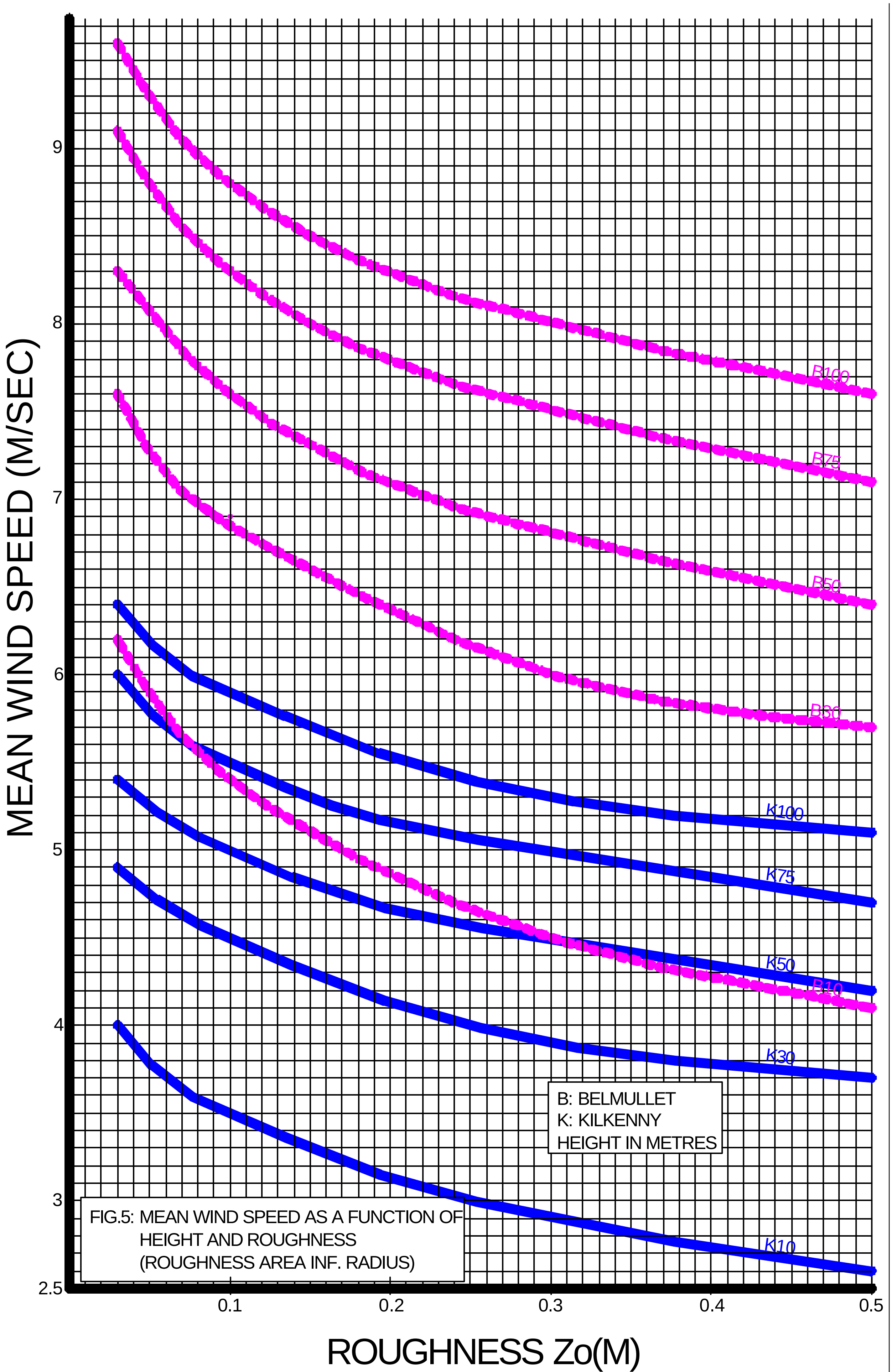

FIG.5: MEAN WIND SPEED AS A FUNCTION OF HEIGHT AND ROUGHNESS (ROUGHNESS AREA INF. RADIUS)