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Identifying tranquil environments and quantifying impacts

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ABSTRACT

The UK has recently recognized the importance of tranquil spaces in the National Planning Policy Framework. This policy framework places considerable emphasis on sustainable development with the aim of making planning more streamlined, localised and less restrictive. Specifically it states that planning policies and decisions should aim to "identify and protect areas of tranquillity which have remained relatively undisturbed by noise and are prized for their recreational and amenity value for this reason". This is considered by some (e.g. National Park Authorities) to go beyond merely identifying quiet areas based on relatively low levels of mainly transportation noise, as the concept of tranquillity implies additionally a consideration of visual intrusion of man-made structures and buildings into an otherwise perceived natural landscape. In the first instance this paper reports on applying a method for predicting the perceived tranquillity of a place and using this approach to classify the level of tranquillity in existing areas. It then seeks to determine the impact of a new build, by taking the example of the construction of wind turbines in the countryside. For this purpose; noise level measurements, photographs and jury assessments of tranquillity at a medium sized land based wind turbine were made. It was then possible to calculate the decrement of noise levels and visual prominence with distance in order to determine the improvement of tranquillity rating with increasing range. The point at which tranquillity was restored in the environment allowed the calculation of the position of the footprint boundary.

Keywords: Tranquillity, noise predictions, planning, landscapes

1. INTRODUCTION

Significant contributions in understanding the essential physical and psychological qualities of tranquil environments have been made [1,2] and these can be applied globally when characterizing restorative space. For the purposes of this study, the extent to which a place is considered to be tranquil is defined by how much individuals think a particular setting is a quiet, peaceful and attractive place to be, i.e., a place to get away from "everyday life." In common with many advanced economies in Europe and in the Far East the United Kingdom has lost vast tracts of green space both within the inner city and along the urban–rural fringe due to development activity. Despite still having around 27,000 public parks and gardens[3] the number of tranquil spaces in the UK is becoming seriously compromised and has prompted systematic research into tranquillity mapping.[4,5] This work has been conducted along with attempts to define and characterize "quiet areas" in response to the European Directive on the Assessment and Management of Environmental Noise END.[6] Although defining quiet areas in accordance with the END using purely acoustical measures is an important step in protecting tranquil spaces, there is a need to go further and integrate both aural and visual factors into an overall descriptor that will be sufficiently precise and practical.

Previous studies at the Bradford Centre for Sustainable Environments have largely focused on prediction and validation of tranquility ratings in city and country parks using the Tranquillity Rating Prediction Tool (TRAPT) which effectively combines acoustic and visual factors. Highly rated tranquil areas are likely to be restorative providing health and well being benefits as there was shown to be a close relationship between perceived tranquillity of a place and the degree of relaxation experienced [7]. This latest phase investigates how TRAPT can be used for planning purposes by considering firstly how it can be used to monitor the level of tranquillity in a changing situation and secondly how the tool can be used to assess the impact of a specific energy infrastructure project. Based on laboratory studies with participants covering a wide age range, statistically significant factors influencing perceived tranquillity of a place are the noise level and the percentage of natural and contextual features in the visual scene. The TRAPT formula relating these factors [7] is given by:

$$TR = 9.68 + 0.041\ NCF - 0.146\ L_{day} + MF \qquad (1)$$

Where TR is the predicted tranquillity rating on a 0 to 10 scale (0 is "least tranquil" and "10" is "most tranquil"), NCF is the percentage of natural and contextual features in the landscape and L_{day} is the equivalent constant A-weighted level of man-made noise during daytime (7:00am to 7:00pm). Contextual features include listed buildings, religious and historic buildings, landmarks, monuments and elements of the landscape, such as traditional farm buildings, that directly contribute to the visual context of the natural environment. It can be argued that when present, these visually cultural and contextual elements are as fundamental to the construction of 'tranquil space' as are strictly natural features (e.g. grass, shrubs, trees, water, rock etc). MF is a moderating factor that was added to the equation following an earlier study [8], and is designed to take account of the presence of litter and graffiti that would depress the rating, or natural water sounds that would improve it. This minor adjustment is designed to take account of the actual environmental conditions at the time of assessment and is unlikely to influence the calculated TR by more than ±1 scale point. TRAPT was used in a previous study to assess tranquillity in 8 green open spaces and the predictions were validated using a questionnaire survey of park visitors [7]. A further study was completed using a jury approach to rate tranquillity at 9 locations in a country park. Again it was possible to validate the predictions with average ratings from the jurors [9]. This paper describes and reports on a method of (a) determining and presenting existing levels of tranquillity for planning and monitoring purposes using tranquillity contours and (b) the effects on perceived tranquillity with distance from wind turbines. Of course the methodology could equally apply to a new road, building development, car park or pylons etc, and the example should prove useful in demonstrating how it could be used to meet the new requirements imposed by the National Policy Planning Framework (NPPF) [10]. This Framework requires that planning policies and decisions should aim to “identify and protect areas of tranquillity which have remained relatively undisturbed by noise and are prized for their recreational and amenity value for this reason”.

2. TRANQUILLITY SURVEYS

A useful initial approach is to identify the most likely tranquil and non-tranquil places in a defined area and calculate the corresponding range of Tranquillity Ratings, TR, [11] defined in equation (1) using:

- Noise maps (if available)
- Spot readings of A-weighted sound pressure levels throughout the area
- Noise predictions based on official noise prediction software
- Photographic survey of the percentage of natural and contextual features

2.1 Classification of tranquillity ratings

This survey method provides the expected range of tranquillity ratings in an area. To provide greater detail it is necessary to calculate the tranquillity rating throughout the chosen area using a grid sampling approach and to map the resulting levels of tranquillity using suitable contouring software.

To provide informative tranquillity maps it is necessary to provide an indication of the quality of the tranquillity rating e.g. acceptable and non-acceptable levels. It has been suggested that the following descriptors of tranquillity level should apply for urban parks and green spaces [11]:

<5 unacceptable

5.0 – 5.9 just acceptable

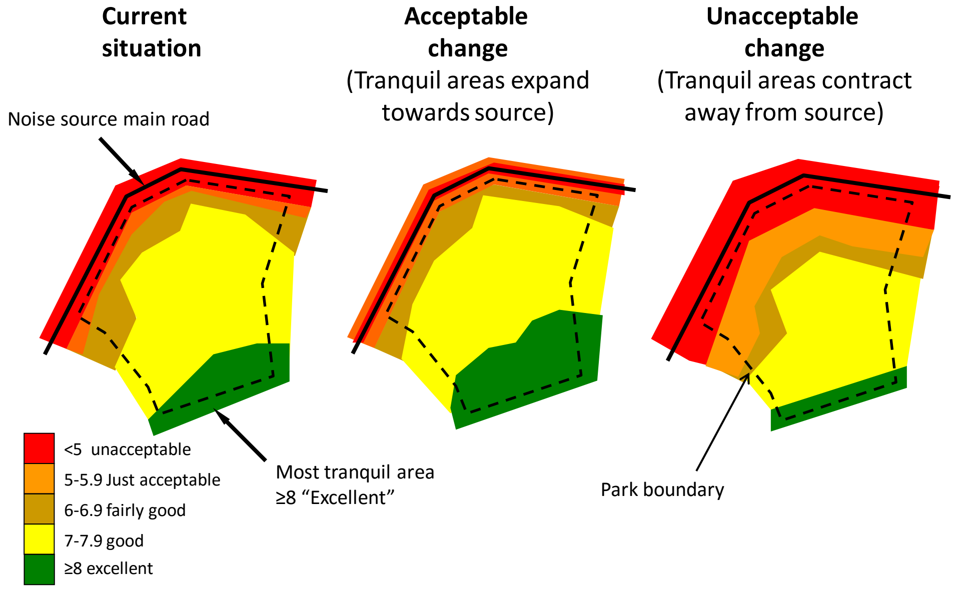
6.0 – 6.9 fairly good

7.0 – 7.9 good

≥ 8.0 excellent

Note that for countryside areas these limit values could be increased because expectations for tranquillity are likely to be higher.

To protect tranquil areas it would be useful to provide plots of tranquillity contours which can be monitored in order to indicate changes that might pose a threat. Figure 1 illustrates cases where the noise from traffic varies and indicates the corresponding changes in the areas of tranquil spaces of various qualities.



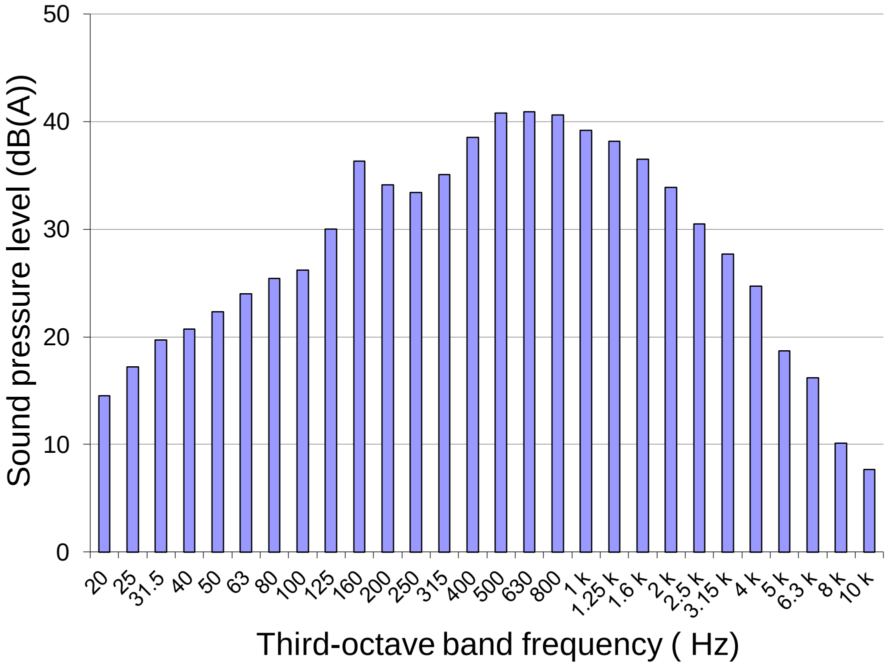
[Figure 1: Illustrative tranquillity rating contour plots for a park situated adjacent to a major urban road]

Of particular concern would be significant shrinkage of high quality tranquil areas that might be of particular benefit for local residents. The health and well-being benefits of such spaces has been reviewed previously [9,11].

3. IMPACT ASSESSMENT

3.1 Predicting tranquillity

The first stage involved collecting data in an around a wind farm located in Ovenden Moor in the district of Calderdale in West Yorkshire. The wind farm consisted of 23 turbines in 2 rows aligned approximately north-south with a ground to rotor tip height of approximately 50m. Each turbine has a rated output of 0.4 MW. The turbines were built on essentially flat ground at a height of 400m above sea-level with prevailing winds from the west. While aerodynamic noise produced by the moving blades was dominant it was possible to perceive some gearbox/generator noise at distances less than approximately 100m. Figure 2 shows the third octave band levels recorded at 95m and height of 1.2m over 30 sec with a wind speed <5m/s showing a broad peak centred at 630 Hz band and a significant low frequency component at 160 Hz.



[Figure 2: A-weighted third octave band levels at 95m from a wind turbine at Ovenden Moor]

3.1 Measurements and assessments

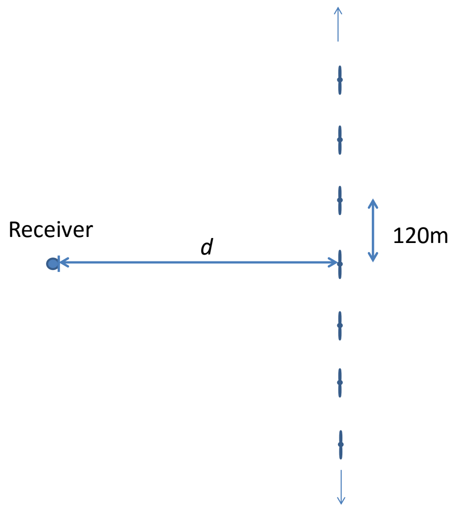
Tranquillity assessments were made at a distance of 95m from a turbine at the end of the most westerly row of turbines as part of a jury experiment previously reported [9]. Thirty participants took part and an average tranquillity rating on a 0 to 10 scale was obtained. A-weighted noise level measurements were made at a distance of 25 m and height of 1.2m from the same turbine under different conditions from wind speeds<0.5m/s, 3-5m/s and >6m to determine a typical reference level from which noise level predictions could be made at varying distances. The level ranged from 43dB (A) at the lowest wind speed to 57 dB(A) at the highest. A value of 55 dB(A) was selected for reference purposes though calculations were carried out additionally at 50 and 60 dB(A) for illustrative purposes. The measurement distance was considered sufficiently close to avoid significant contamination of measured noise levels by other turbines.

3.2 Predictions

To illustrate the calculation method predictions of tranquillity ratings were made for a single turbine and also for a row of turbines (wind farm). The variation with tranquillity is calculated at distances d to the turbine. The ground is assumed flat and grass covered and the turbine blades move in a vertical plane. From the analytical work [12] it can be assumed that the effective centre for the noise generation is at or close to the turbine hub at a height of 32m. The receiver is assumed to be at a height of 1.5m. The length of the turbine blades was 17m and the towers were 1.5m in diameter.

For the case of the row of wind turbines it was assumed that there are 11 turbines. The variation with tranquillity is calculated at distances d normal (right angle) to the centre turbine. Figure 3 shows and example of a linear array of wind turbines on flat ground. Figure 4 shows the assumed geometry of the wind farm examined.

[Figure 3: Example of a linear array of wind turbines on flat ground]



[Figure 4: Assumed geometry of wind farm based on Ovenden Moor installation]

3.2.1 Noise level variations

Using ISO 9613-2[13] the attenuation with A-weighted level distance is given for a single turbine by:

$$A = A_{div} + A_{gr} + A_{atm} \tag{2}$$

Where A_{div} is the hemispherical spreading term, A_{gr} is the ground attenuation and A_{atm} is the air absorption effect. For calculating the ground effect the average height of propagation was 16.8m. Air absorption was given a typical value of 2 dB per km. In this example a small positive wind blows from turbine to receiver as assumed in ISO 9613-2 i.e. between 1-5m/s measured at a height of 3-11m.

To obtain a realistic baseline condition the sound level at Ovenden Moor wind farm was measured at 25m from the turbine tower at the end of the line where there was little noise contamination from adjacent turbines. The average value was found to be 55 dB(A). Predictions of noise levels were carried out for the single turbine out to a distance of 2000m. In the case of the row of turbines predictions were made along the perpendicular bisector for each of the 11 turbines at distances out to over 2000m and the resulting noise levels added logarithmically to obtain overall levels.

3.2.2 Percentage of natural features

For the purposes of calculating the percentage of natural features it was assumed that the area swept out by each of the 11 turbine should be counted as a man-made feature together with the tower. Note that in part this is an attempt to take account of the fact that the blades are moving and therefore are likely to produce more visual impact than a stationary blade. Note also there may be access roads for turbine maintenance, fences, car parks and small buildings to house equipment. These are ignored in the following calculations in order to simplify calculations. Their presence would tend to reduce tranquility further but are unlikely to make a significant difference at distance say >200m.

The angle of view at the receiver position in the vertical plane is assumed to be ±20 deg and the area of sky above the horizon is not used in the calculation of NCF. Calculations are calculated over 360 degrees assuming contiguous photographs are taken at a height of 1.5m with the lens axis sweeping a horizontal plane.

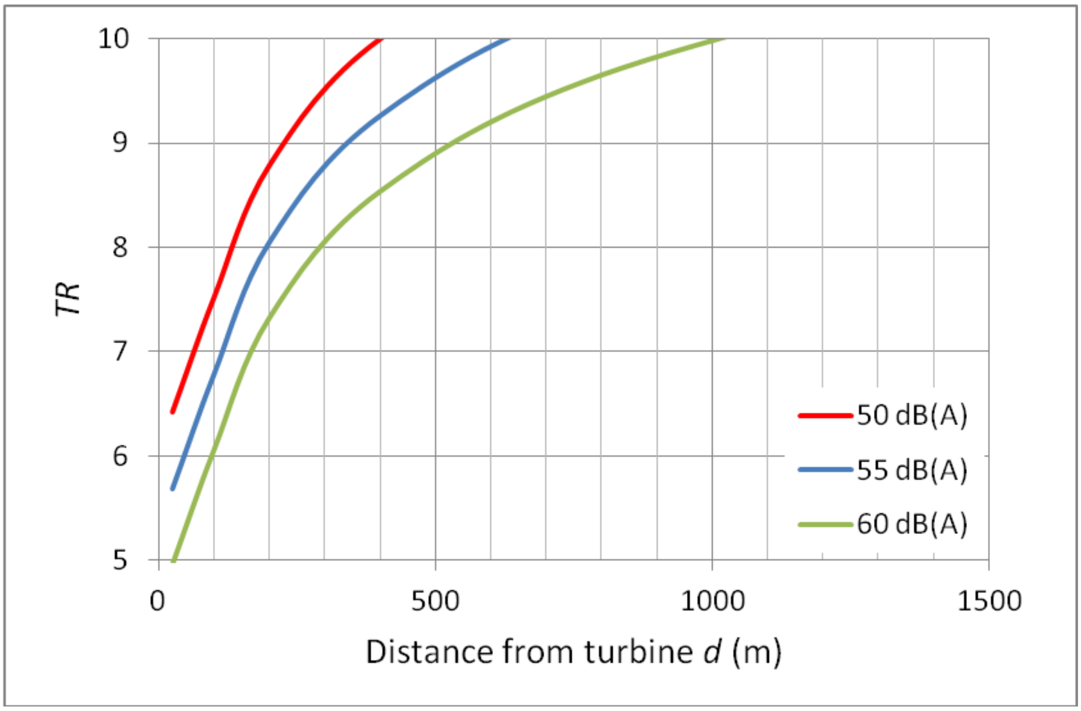
If N is the area with natural features and M is the total area of man-made features then NCF is given by:

$$NCF = 100\ N/(N + M) \qquad (3)$$

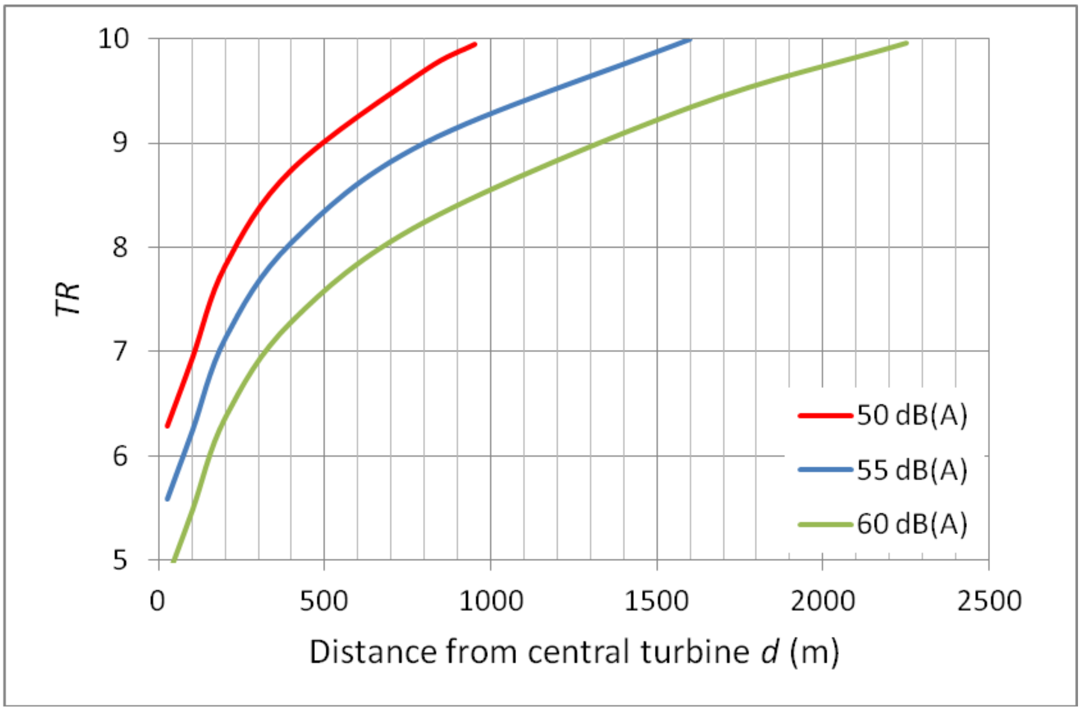
As mentioned previously at a receiver position the area presented by a single turbine is composed of the area swept out by the blades, and this was calculated as 908m^2, and tower with area 48m^2. Other turbines will present different areas due to effects of distance and the angle of view of the swept area.

3.3 Predicted impact on tranquillity

For distances from 25m to over 2500m the predicted tranquility rating TR was calculated from equation (1) using the results obtained following the approaches outlined in section 2 above. Figure 5 shows the predicted variation of TR with distance for a single turbine and Figure 6 the predictions for the row of turbines. In each case the blue curve shows the results assuming a measured level of 55 dB at 25m (i.e. as measured at Ovenden Moor wind farm). The red and green curves show the predicted trends for measured levels at 25m of 60 dB(A and 50 dB(A) respectively corresponding to higher and lower output sound powers respectively.

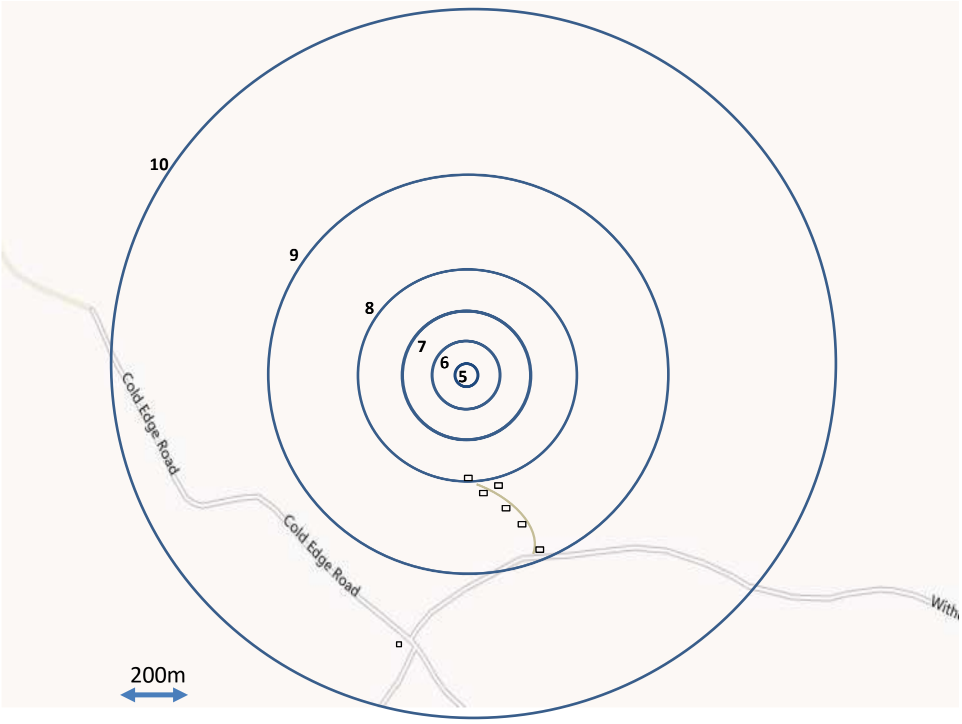


[Figure 5: Predicted variation of tranquillity rating (TR) with distance d from a single turbine for different noise levels recorded at 25m from the turbine tower]



[Figure 6: Predicted variation of tranquillity rating (TR) with distance d from a line of 11 turbines]

Assuming the nearest major road is at least 2 km away we may expect a noise level of less than 30dB(A) under low wind conditions and with NCF at 100% before the wind farm was installed then TR will be approaching 10. Note that Ovenden Moor is situated at a distance of 2.5 km from the A629. To restore to a TR of 10 for a line of turbines of mid power (blue curve) then a distance of over 1,600m is required. However for noisier turbines a larger distance of 2,250m is required. In the case of a single turbine the corresponding distance is predicted to be less than half this distance (1030m). For a relatively quiet line of turbines the distance would be lower at 950m. By computing the TR values at various points in the horizontal plane e.g. at grid nodes it is possible to produce TR contours around the installation which will give a useful overview of impact, or “footprint”, of the wind farm. Figure 7 illustrates this type of diagram for the case of a single turbine with a measured noise level of 60 dB(A) at a distance of 25m from the turbine. At each position in the ground plane it is assumed that the receiver is downwind of the turbine. In this way the maximum predicted impact is indicated at each position. Contours of tranquility rating TR are indicated from 5 to 10. Using appropriate software (e.g. GIS) this can be combined with a map of the terrain to indentify properties that are likely to be affected and the degree of impact.



[Figure 7: Contour plot for a single turbine of predicted tranquility rating TR at a height of 1.5m above the ground plane. In this hypothetical case residential properties are indicated by rectangles and traffic noise from minor roads with a very low traffic flow is negligible]

Note that currently an assessment method for limiting noise disturbance from UK wind farms sets a daytime noise level limit in quiet areas at between L_{A90} of 35 - 42dB (equivalent to an L_{Aeq} range of approximately 37 - 44 dB) [14]. With NCF set to 100% this equates to a TR of 7.7 to 8.4 which it can be argued is relatively low for a quiet rural area. At nighttime the permissible noise level is even higher i.e. an equivalent level of 45dB equating to a TR of 7.2. This may prove unacceptable to residents if windows are left open.

Clearly if background noise from other sources were present, e.g. noise from a motorway, then the distances from the wind farm to restore tranquility levels close to pre-installation values would be shorter. In addition natural sounds such as wind noise may also mask such low levels of man-made noise especially if wind speeds are higher than that assumed in these calculation i.e. >5m/s. A further point is that predictions of TR are relevant to daytime assessments outdoors. During nighttime sensitivity to noise is likely to increase, thus lowering the perceived tranquillity levels below predicted. Tonal effects and modulation noise from the turbines may also decrease perceived tranquillity. Atmospheric effects due for example to temperature inversions, may facilitate noise propagation beyond that predicted which would also reduce TR below expected levels. Note that the results of the jury experiment gave an average TR value of 5.0 [9] at a distance of 95m whereas in this example the predicted result is higher at 6.2. This is because in the real case the infrastructure to support the turbines would have reduced NCF e.g. gravel roads, fences, car park and small building. Figure 8 shows a view taken from the jury assessment location illustrating the type of infrastructure to be expected. In practice such constructions would be taken into account in the calculation of NCF.

Figure 8a and 8b: Views at assessment point in two opposing directions

[Figure 8a and b: Views at assessment point in two opposing directions]

4. DISCUSSION OF CONCLUSIONS

The UK has recently recognized the importance of tranquil spaces in the National Planning Policy Framework [10]. Specifically it states that planning policies and decisions should aim to “identify and protect areas of tranquillity which have remained relatively undisturbed by noise and are prized for their recreational and amenity value for this reason”. Using TRAPT both soundscape and landscape factors are taken into account in determining the perceived tranquillity of a place and can potentially be used for planning purposes. The level of man-made noise can be predicted using appropriate software and the percentage of natural and contextual features in the scene can be captured using photographic surveys. For a detailed analysis it will be necessary to sample over a grid of points in the area under investigation. This will then allow plots of tranquillity contours using appropriate software tools. Using contour maps it will be possible to identify quality tranquil spaces and regular updates of the maps will enable external threats to tranquillity to be identified and appropriate action taken. Note that in the past defining a footprint has proved problematic as in a previous study commissioned by CPRE [5] the assessment of wind farm impact was noted in their 1994 report as “.... loss of tranquillity is absolute within 1km of a wind-farm, and partial within 2 km of a wind-farm”. However, later the figure was revised down to 0.5 km though it was noted that the lower figure may well be an underestimate. It is unclear precisely how these assessments were made. As clearly revealed in the analysis the source strength and number of turbines will have an impact as well as the terrain where they are operating as this will affect sound propagation and visibility.

In a literature review of the human response to wind farm noise [15] it is clear that visual factors as well as noise exposure play a part in determining the impact of wind farms and in particular the degree of annoyance. More generally two important factors determining emotional response to objects and situations have been found to be pleasantness and arousal levels [16]. Where a situation is both visually and aurally pleasant and calming we can expect high levels of tranquillity such as is found in natural environments that are relatively uncontaminated with man-made noise. Such environments are likely to be restorative providing health and well-being benefits as has been demonstrated by the close relationship between levels of perceived tranquility and degrees of relaxation experienced [7,9]. The tranquillity rating prediction tool is therefore potentially appropriate for quantifying the impact of new constructions in the countryside and the example of a wind farm built in a tranquil area has been examined. The initial analysis allowed the "footprint" to be determined over a large area though further work is needed to consider impact in less tranquil areas and the effects of modulation noise, night time disturbance and atmospheric effects promoting sound propagation as well as visual effects produced by the moving blades not captured by a consideration of swept area alone.

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Figure captions:

Figure I: llustrative tranquillity rating contour plots adjacent to a major urban road

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Figure 3: Example of a linear array of wind turbines on flat ground

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Figure 5: Predicted variation of tranquillity rating TR with distance d from a single turbine for different noise levels recorded at 25m from the turbine tower

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