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What is the Real Background Noise?

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Abstract

A test that relies on background noise measurements related to wind speed may stand or fall on one or two decibels difference, yet the reality is that unattended outdoor measurements are highly variable and unpredictable. Measurements taken almost next to each other and at more or less the same time have been quite different. This paper considers what the noise v wind curve should look like and how it is made up of two separate data sets, one related to the wind and the other not. The paper considers exposure and shelter at noise measurement locations, noise sources and the effect of non-wind related noise. It also considers what the differences should be between night and day. Finally the paper looks at the limitations of the recorded data. Limitations of the equipment, results that are not typical of the measurement location and results that are typical of the measurement location but not elsewhere.

Introduction

A planning application assessed under ETSU-R-97 [1] or any test that relies on background noise measurements may stand or fall on one or two decibels difference in the background noise. So it is important both for developers (so that they can properly plan the development) and for residents (so that they can have adequate protection from noise) that the measurements are not only accurate but that they truly represent the “real” conditions at each location.

What is real is not so much a technical matter as a philosophical one. What is real can only be determined within the context of the question. Perhaps the best that can be done is to look at the technical background and describe a variety of “real” background noise levels and some that are clearly not real and many in between. It will be for the reader or perhaps the Inquiry or the court of law to decide which is the real background noise in the context of the particular circumstance being considered.

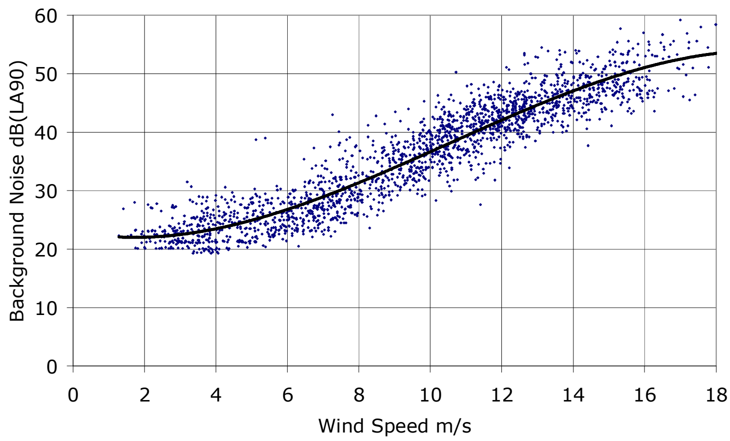
All the examples in this paper are taken from Environmental Statements for wind farms submitted in the belief that they represented the real noise level and its relationship to wind speed. All the noise levels in this paper are decibels as 10 minute LA90.

The Reality

In order properly to assess the impact of wind farm noise on noise sensitive neighbours the background noise has to be measured at a range of wind speeds and a graph of background noise level plotted against wind speed. The normal procedure is to measure wind and noise in 10 minute periods, the noise being measured at the sensitive properties and the wind measured on the wind farm site at a height of 10m above the ground.

The graph below in Fig 1 shows a typical result together with the best fit curve.

Fig 1



This all looks very neat and simple. The reality is that unattended outdoor measurements such as this are fraught with difficulty and can easily be affected by unexpected and unwanted data. In practice the results of these background noise measurements are highly variable and unpredictable.

The table below shows a summary of the background noise levels at the same residential location measured by two developers at different times.

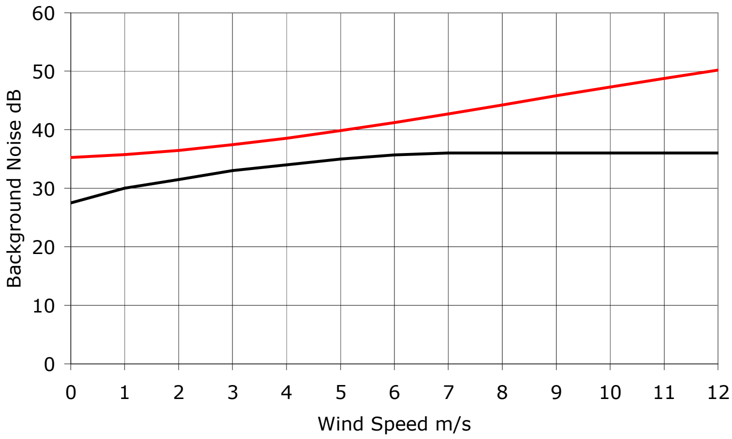
Table 1

Location II	6m/s	8m/s
Developer 1	38	42
Developer 2	32	34

Developer 1 might well have relied on its background noise measurements to design turbine noise levels of, say, 42dB at 6m/s and 44dB at 8m/s on the grounds that the background noise was not exceeded by more than 5dB. If the real background noise level is represented by Developer 2’s measurements then the turbine noise levels would exceed the background noise by 10dB and, if ETSU-R-97 was the standard in use, then it would not meet either the day or night time requirements resulting in a significant loss of amenity and perhaps nuisance to residents. On the other hand if Developer 1's measurements are the real ones then Developer 2 might have unnecessarily removed turbines from the preferred design to comply with the lower background noise so reducing the viability of the development.

At another residential location the noise levels are shown below. The graph shows two best fit curves for the location made by two developers.

Fig 2

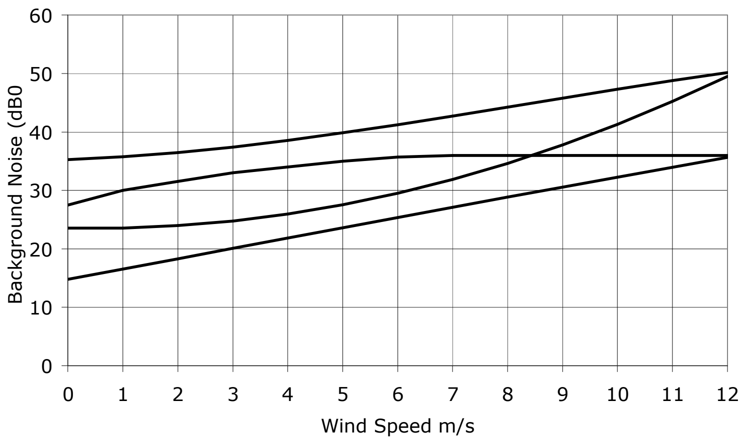


The interesting thing here is not only that this is the same site but the measurement positions were within a few metres of each other and the measurements were taken over almost the same period of time. They were taken over two week periods but were staggered by four days. In other words 72% of the measurements covered exactly the same period. The only differences are the equipment and the operator and the location of the anemometer mast.

How can it be possible that measurements taken almost next to each other and at more or less the same time are so different? It cannot be attributed to the anemometers being located on different hills because, even though the anemometers may be recording different wind speeds the measured noise levels must be almost identical. In fact, a closer examination shows that the noise levels reported at the same time were quite different. In one case about 10% of the noise levels were below 35dB and in the other about 50% were below 35dB.

The story of this unfortunate property does not end there because there were two other measurements taken at the same location about six months before in connection with two other wind farm applications. Fig 3 shows four curves, three of them taken at the same property and the fourth (the lowest curve) at the neighbouring one that was considered to have the same characteristics.

Fig 3



This shows an even wider divergence so that, at the wind speed likely to be the most sensitive for turbine noise (usually about 6m/s), there is a spread of around 15dB.

Regrettably such differences are the norm. At the six locations for which duplicate data is available only one has similar noise levels for two sets of data. To have such large discrepancies is not acceptable where decisions on whether a development should go ahead or not are at stake.

What Should The Curve Look Like?

The background noise graphs of the type shown in Fig 1 are familiar. The best fit curve has the flat S-shape.

The curve can be considered as being made up of two separate noise sources each consisting of a set of data. The first is a horizontal line consisting of noise that is not wind related (the NWR element). It may be inherent meter noise, streams, road traffic or any other continuous or varying noise other than that associated with the wind. Because it is not wind related the best fit curve for this first set of data must be horizontal.

The second noise source produces a set of data that is related to wind speed (the wind generated element).

Fig 4

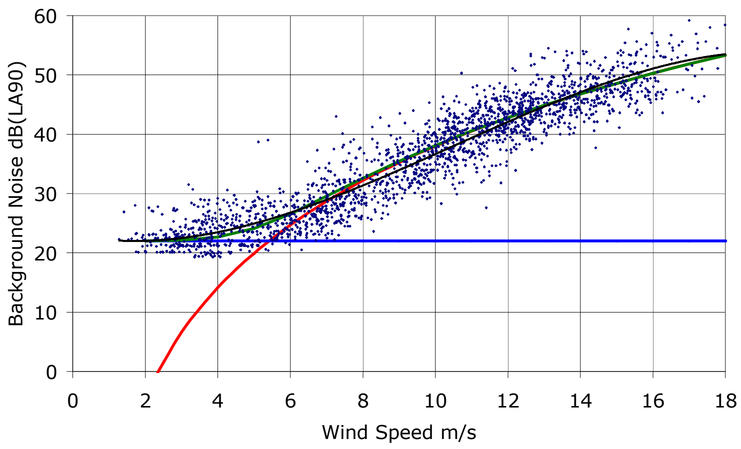


Fig 4 shows how these two elements go together to produce the typical best fit curve. Because of the way the curve is made up a second order polynomial is probably not sufficient to describe the position properly and a third order polynomial would be better.

The wind generated element can be described by:

$$L_1 = A \times \log(V) + C \; . \; . \; . \; . \; . \; . \; . \; \{1\}$$

Where L_1 is the 10 minute measured sound pressure level in dB(LA90), V is the wind speed at the noise measurement location and A and C are constants whose values depend on various factors to be discussed later in this paper. It is not proposed to define what "the wind speed at the noise measurement location" means in any further detail.

The NWR element can be described by:

$$L_2 = D. \; . \; . \; . \; . \; . \; . \; . \; .. \; . \; . \; . \; . \; \{2\}$$

Where L_2 is the 10 minute measured sound pressure level in dB(LA90) and D is a constant.

EXPOSURE AND SHELTER

Background noise measurements for wind farms are complicated by the fact that the wind measurement is made at a different place from the noise measurement. Taking two noise sensitive locations and assuming that the noise generating objects (trees, shrubs, grass and so on) are similar, if the wind speed were measured at the noise measurement locations there would be no difference in the graphs for a sheltered location down in a valley and for an exposed location on a hill. The fact that noise levels are, in practice, less at sheltered locations than at exposed locations is because of the difference in wind speeds between the two sites compared with the anemometer wind speed at the development site. The degree of exposure could be defined as the ratio of wind speed at the noise measurement location to the wind speed at the anemometer site. The smaller the ratio the less exposure or, conversely, the more the shelter.

For example if the degree of exposure is 0.75 then we can re-write equation 1 as:

$$L_1 = A \times \log(0.75 \times V_A) + C \; . \; . \; . \; . \; . \; . \; . \; \{3a\}$$

or

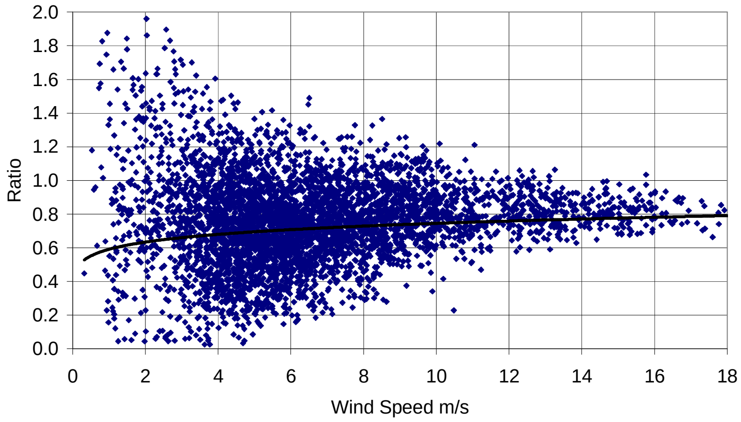
$$L_1 = A \times \log(V_A) + C - 0.125 \times A \; . \; . \; . \; . \; . \; . \; . \; \{3b\}$$

Where V_A is the 10m wind speed at the anemometer.

So the wind generated part of the curve can be considered as moving to the right with increasing shelter (as described by equation 3a) or moving down (as described by equation 3b). To be precise the left to right shift is only a linear movement if the X-axis is logarithmic. As the X-axis here is linear by convention the left and right shift is constrained by the Y-axis – data shifted to the left is "squashed" against the Y-axis.

In passing, it is worth considering an alternative possibility. It is well documented that the atmosphere becomes less stable at higher wind speeds – for example van den Berg [4] and van Lieshout [5] – so the relationship between wind speed at the noise measurement location and wind speed at the anemometer mast is velocity dependent. The graph in fig 5 shows the result of comparing the wind speed at a development site with that at another more sheltered location 3km away. The vertical axis is the ratio of the wind speed at the sheltered location to the wind speed at the development site.

Fig 5



The power trend line has the relation:

$$V/V_A = 0.6 \times V_A^{0.1} \; . \; . \; . \; . \; . \; . \; . \; . \; . \; \{4\}$$

showing increasing instability with wind speed. We can substitute the relationship in equation {4} into equation {1} as follows:

$$L_1 = A \times \log(0.6 \times V_A^{1.1}) + C \; . \; . \; . \; . \; . \; . \; . \; \{5a\}$$

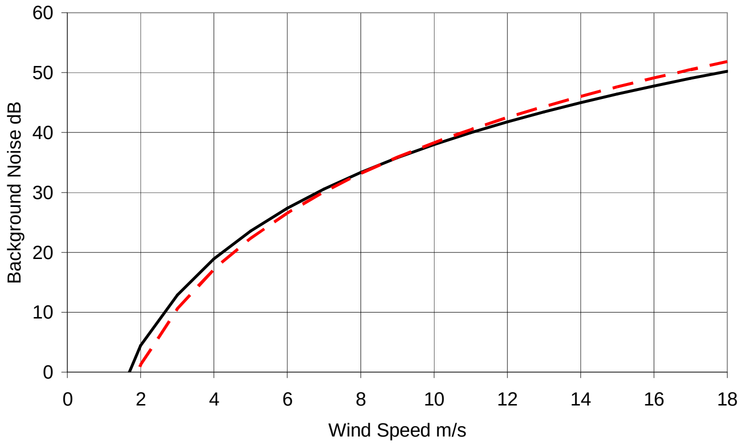
or

$$L_1 = 1.1 \times A \times \log(V_A) + C - 0.222 \times A \; . \; . \; . \; . \; . \; . \; . \; \{5b\}$$

As the degree of shelter increases the curve is therefore shifted down and becomes steeper – contrary perhaps to intuition.

Fig 6 below shows a comparison of the linear and power relationships for the set of data in Fig 5 The linear relationship (solid line) is 0.75 (as equation 3a) and the power relationship (broken line) is 0.1 (as equation 5a).

Fig 6



The differences here are small and there would be very little error if the shift were considered to be simply a shift of the wind generated curve up or down or right and left. However, that might not be the case in every circumstance.

Noise Sources

The value of C in equation 1 must also be dependent on the size, type and quantity of noise generating objects and how they are exposed to the wind. For example, trees might have a more significant quantity of noise generating components than grass but they might also be more exposed to the wind. To approach it with a broad brush the value of C will be higher for a location with trees and hedges than it will for an area with mown grass.

However, as with the degree of exposure, a shift of the wind generated curve up and down due to a change in the type and location of vegetation can be described alternatively as a shift to the right or the left.

VALUE OF A

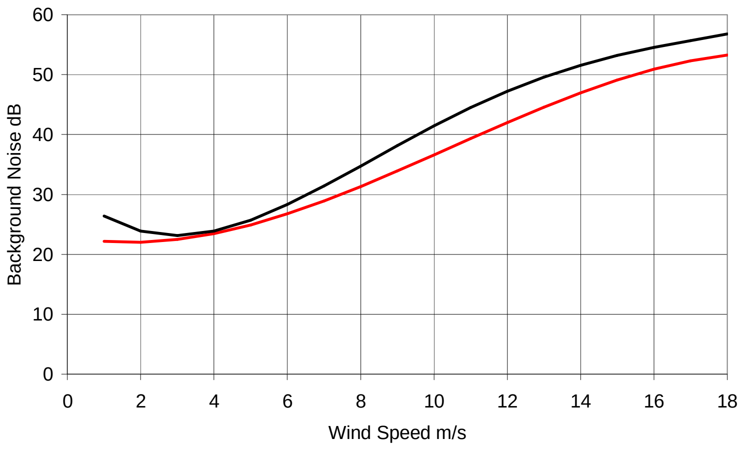
There does not appear to be any firm evidence to establish the value of A in equation 1 and indeed it may be dependent on the noise sources. In practice it is difficult to read from graphs of measured noise because of the flattening effect of the NWR element. An examination of a large number of graphs with low NWR elements suggest that it is normally between 40 and 60.

As described above and later, it may be that the curve is steeper in more sheltered or at night but the difference is probably small.

THE EFFECT OF THE NWR ELEMENT

Fig 7 shows the polynomials for two locations where noise has been measured simultaneously. One is exposed on the hill at an elevation only a little below the anemometer mast (the top, black, line) and the other is further down in the valley.

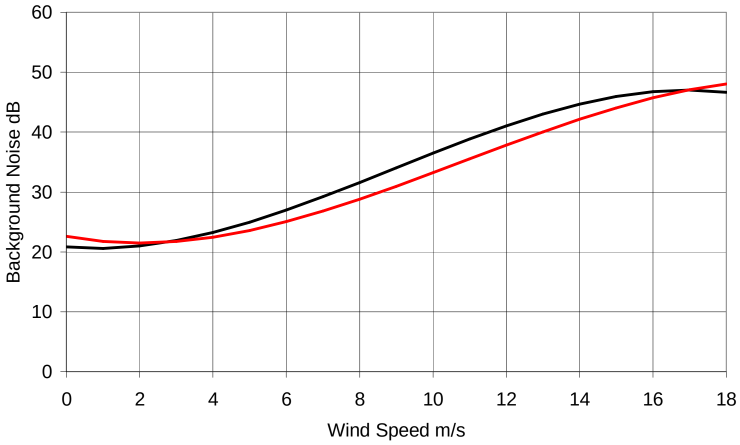
Fig 7



The measurements suggest that the NWR elements are similar in each case. The wind element simply moves up and down or right and left on the graph reflecting both the degree of exposure and shelter and the nature of the noise generating components. Because the NWR element does not move up or down and shifting it to the left or right makes no difference to it, it is better to consider that the whole curve moves horizontally.

Another example in Fig 8 shows why it may be better to consider that the wind curve moves horizontally. The graph below shows two polynomials of exactly the same set of noise data but plotted against wind speeds from two different anemometers that were 3km apart. The noise measurement location can be considered as more sheltered from one wind farm site than from the other.

Fig 8



Because the noise data is exactly the same for both curves, the position of the individual points in the scatter diagram can only move horizontally from left to right or vice versa. One best fit curve must therefore be considered as derived from the other by shifting to the right or left.

In summary the polynomial curve can be considered as shifting left or right according to:

> The degree of shelter at the noise measurement location as compared with the anemometer location.
>
> The nature and position of the noise generating objects at the noise measurement location.

Night and Day

Leaving aside the question of the difference in wind shear during the day and during the night for the moment, if the day and the night time noise graphs for a site are compared then the Wind generated element must be the same. Figure 9 is day time and figure 10 is night time at the same location. The NWR element of the graph alters the shape and height of the graph at lower and middle wind speeds. Unless the NWR element is particularly high it would not therefore significantly affect the curve at higher wind speeds.

Fig 9

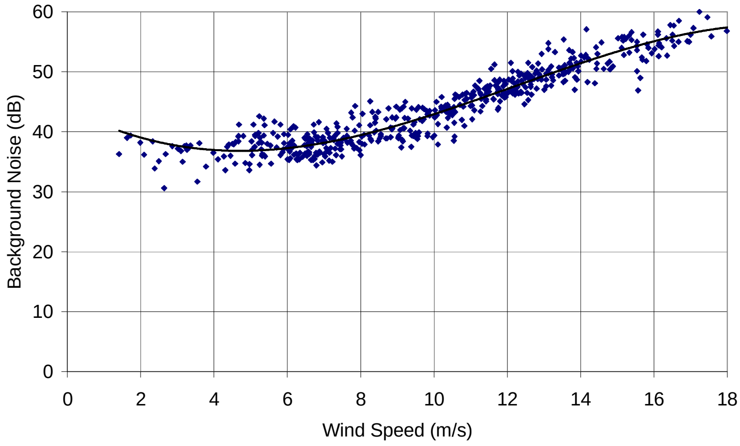
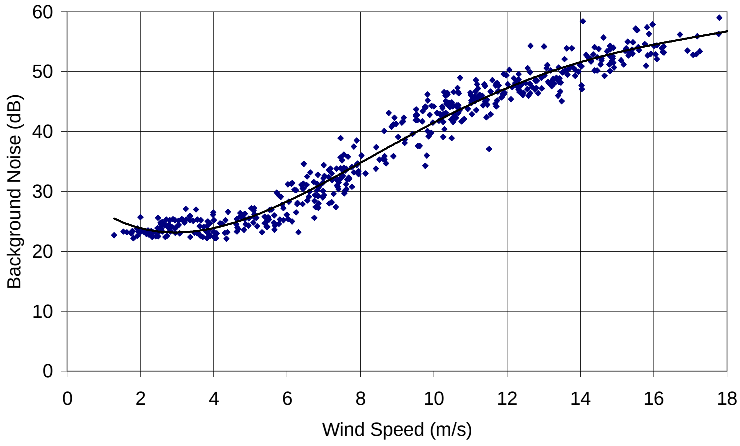
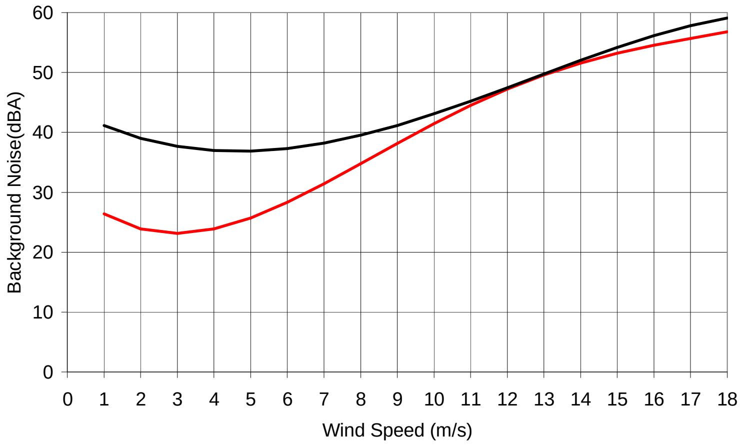


Fig 10



The differences are at the lower wind speeds. Where the wind element dominates there is little difference. This can be seen more clearly in Fig 11 which shows the day and the night measurements together.

Fig 11



This is as the measurements should be since the site is several hundred metres from a medium trafficked road.

If the wind shear is greater at night then the effect of this would be exactly the same as increasing shelter. That is to say there will be a tendency for locations to be more sheltered at night than during the day and so the night time wind generated element will tend to be shifted to the right compared with the day. Furthermore, if the power relationship in equation 5 is valid then the night curve could be steeper than the day curve.

Some Practical Examples

This section discusses some of the reasons why the actual or apparent measured noise levels may not be the real ones depending on the context and gives examples.

RESULTS THAT ARE NOT THE REAL NOISE LEVEL

Sometimes the noise levels apparently recorded by the equipment are not the actual environmental noise levels present at the time. Essentially this is a question of whether the equipment is the right equipment, whether it is being used correctly and whether it is operating without fault. All these issues ought to be obvious to the professional consultant. Nevertheless, because of the particular difficulty of this type of measurement, about one third of those submitted in Environmental Statements are probably faulty due to problems with equipment.

The first question is whether the equipment is fundamentally right for the job.

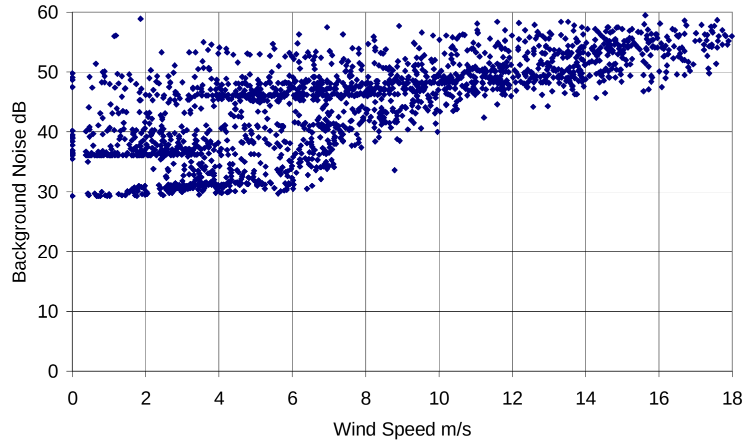
> What is the noise floor in dBA? It may not be enough to rely on the manufacturers data and, where possible, it is better to keep a record of the performance of individual items of equipment. Not only does this identify any shortcomings in the equipment but allows any changes in performance to be monitored. The actual noise floor of the instrument needs to be as low as possible but certainly it needs to appear to record noise below 20dBA to reduce distortion of the polynomial in low noise situations.

> The right windshield is essential. A study on improved windshields by Davis [2] was published at much the same time as ETSU-R-97. It recommends types of enhanced windshields that can be used. Such windshields are available commercially. A standard windshield has a self noise level proportional to the sixth power of the wind speed when measured in laminar flow [3]. What is more the self noise at a wind speed of 8m/s is 48dBA so that measurements in exposed places could easily be affected by wind on the windshield. It is almost impossible to identify the problem from the measurements because the wind shield noise can be considered as just another noise generating object at the measurement position. Perhaps an indicator is a steep curve close to the sixth power of velocity, but that might also be the real background noise in some circumstances.

The final issue here is that of faults in the equipment. All equipment develops faults at times and it is important to go through all the data sets when measurements are complete to look for anomalies that might indicate equipment faults. Anything showing unusual features would warrant further investigation.

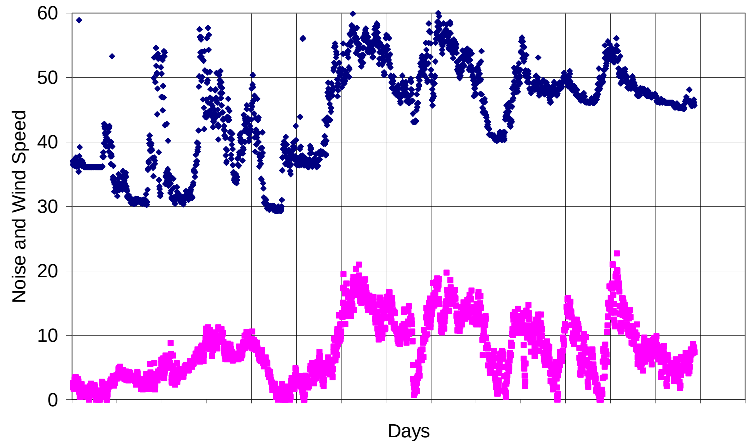
Figure 12 shows a curve containing banding.

Fig 12



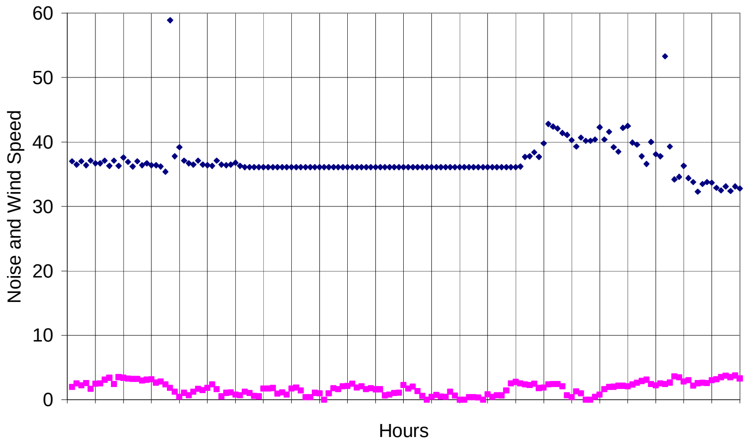
The banding may be due to a boiler flue, to plant or machinery in a farm. But it could also be an equipment problem. It is useful to plot all the data as a time series as shown in Fig 13.

Fig 13



There are a number of "suspicious" indicators here. On some of the first few days of the period when the wind was low the noise level dropped to 30dB at night. After day 6 when there was a big rise in wind speed the noise level never came back down to 30dB again even when the wind speed reduced to zero in the middle of the night. What seems to have happened is that the entire curve has shifted up by about 10dB. It cannot be that the wind shield was blown away because the noise level would still drop to 30dB when there was no wind. Further examination might suggest a problem with the meter. Fig 14 shows a closer look at day 1.

Fig 14



It can be seen that for ten hours the recorded level was exactly 36.1dB. The probability of this being the real noise level is very small and it is almost certainly some fault of the meter. Since this happened on the first day it puts the rest of the measurements under suspicion.

RESULTS THAT ARE REAL BUT NOT TYPICAL OF THE MEASUREMENT LOCATION

These can be the result of insufficient data or more particular a data set covering an insufficient range of wind speeds and wind directions. Alternatively it can be the result of noise sources measured at the measurement location that do not exist for the whole year or even for a substantial part of it. For example, measurements taken near sheep enclosures in the lambing season have resulted in raised noise levels.

Fig 15 shows an example where the amount of data at higher wind speeds is small. There is no way of knowing whether the polynomial is accurate or not but more measurements are needed over a larger range of wind speeds to be certain that something approaching the real noise level has been obtained.

Fig 15

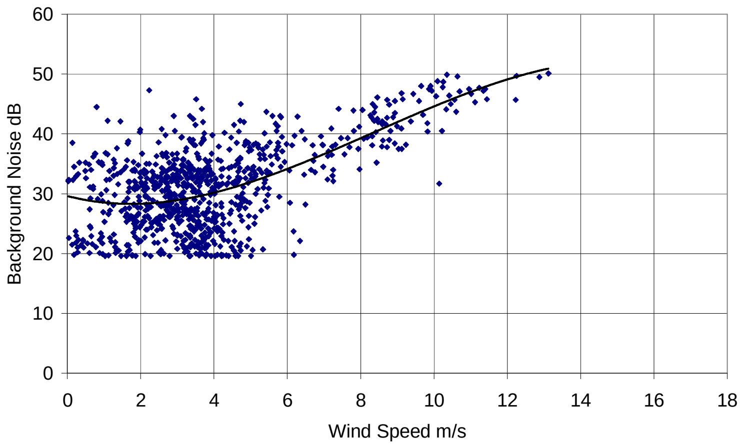
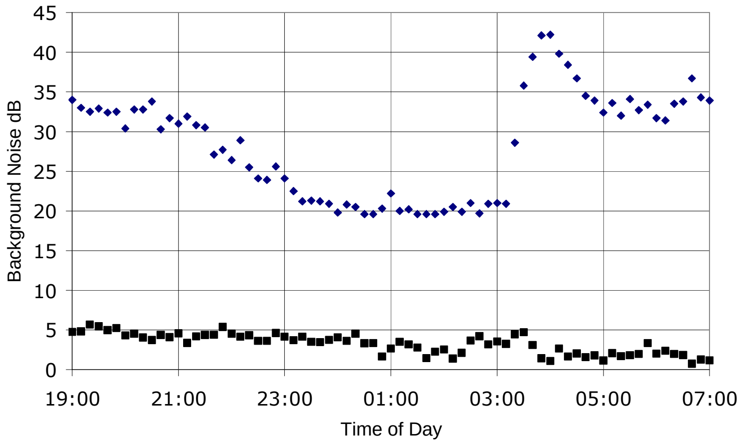


Fig 15 also shows another problem with the measurements. The thing that draws attention is the large spread at low wind speed. It is a night time measurement and this is unusual at night. It is instructive to look at the low wind speed data in a time series. This shows a picture of what is happening without the influence of wind. Fig 16 shows a detail of one typical night time period from early evening to morning. The bottom set of data is the wind speed.

Fig 16



From about 9 o'clock in the evening the noise level falls gradually to a minimum at 11pm and stays constant until 3.20 in the morning when it rises 22dB in the space of 30 minutes. This happens at the same time every morning unless it is particularly windy. Sunrise is about 4.15 at this location on this day. This is clearly the dawn chorus. The measured noise levels here are the real noise levels for period of the measurements but do not necessarily represent the normal night time situation throughout the year.

Boiler or other plant noise is another common source picked up. Boiler noise may be representative at a house (even in the summer hot water is required) but not necessarily all parts of the house.

Figure 17 shows an extreme case that was nevertheless presented as the real background noise level at a property.

Fig 17

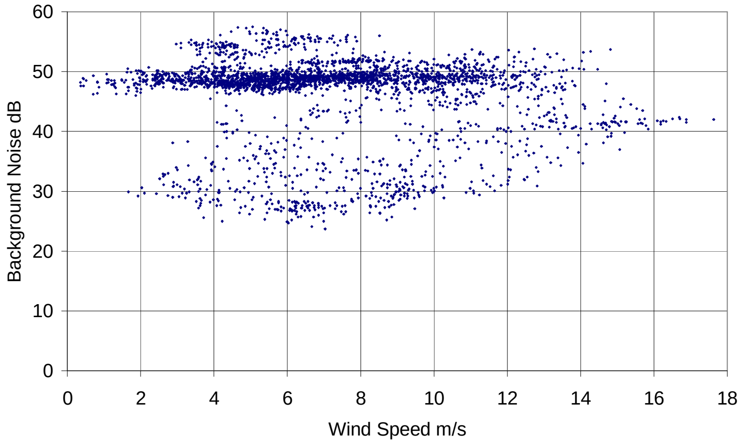
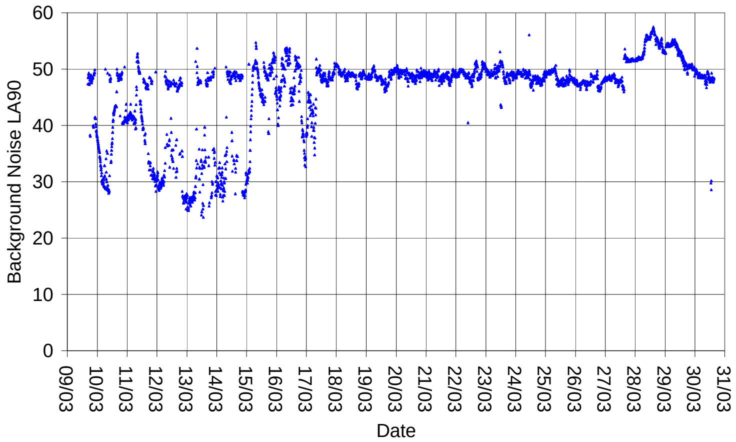


Fig 18 shows the same data as a time series.

Fig 18



On further investigation it was found that there was a generator at the property that was used at times during the day but turned off at night as can be seen in the first six days. A week into the measurement period the generator developed a fault and stayed on all the time.

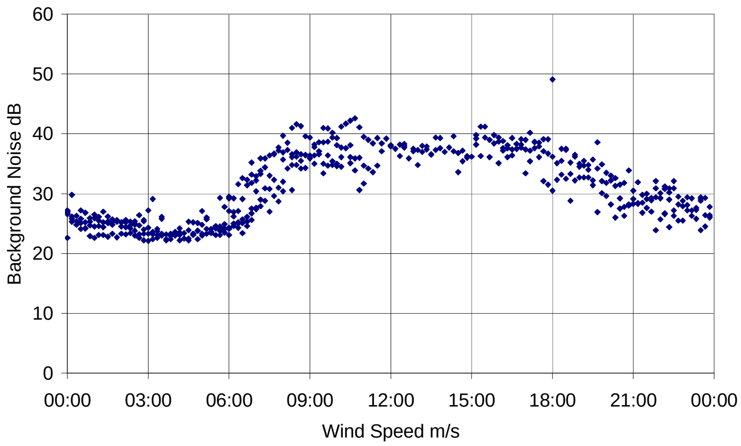
There is a further factor that is more unpredictable than anything else as far as measurements at a specific location are concerned. That is the variation of background noise with time of year. There is not enough information to be able to quantify this. There is no doubt however that variation does take place. Some trees and shrubs are more noisy in the autumn – like the beech. Others, like the Scots pine can be more noisy in the spring. But that is only part if the story because one group of trees can screen wind from another group in certain conditions so that the presence of some trees at certain times of year may reduce background noise. The location in Fig 8 has relatively low noise levels but is surrounded by deciduous trees and located on the edge of a large mature conifer plantation. In most conditions, the deciduous trees are sheltered from the wind by the coniferous forestry.

RESULTS THAT ARE TYPICAL OF THE MEASUREMENT LOCATION BUT NOT ELSEWHERE

Because it is usually impossible or unreasonable to make background noise measurements at every property likely to be affected by a wind farm development, measurements made at one location are regularly used as a proxy for another location. The fundamental questions to be answered in considering whether a set of data can be used as a proxy are "is the degree of shelter similar?" and "is the nature of noise generating objects similar?" This has to be a matter of individual judgement but the mere proximity of one location to another is not sufficient reason.

Many differences are obvious such as streams or livestock on farms. Another common difference is exposure to road traffic noise. This noise can usually easily be identified. At the location on Figs 9 and 10 the reason for the higher day time level is road traffic. If it is not certain whether this is the case all the data at wind speeds less than 4m/s can be plotted against time of day. The result is shown in Fig 19.

Fig 19



This shows the standard pattern of road traffic with a fairly constant noise level between 0900 and 1800hrs. The traffic then eases off gradually over the evening period and into the night until it rises quite steeply over about two hours in the morning.

A Special Case

Apart from the NWR and Wind generated elements there is another factor in some background noise measurements that is partly wind related but not wholly. This is water noise where the location is near the sea. Water noise in places such as the Atlantic coast of Europe whilst linked to local wind can also be significant even when there is no wind. Water noise from inland lakes or estuaries is largely related to the wind because it dies down quickly as the wind drops.

Is the Average the Real Background Noise?

All the above has tacitly assumed that the "real" background noise is defined by the best fit polynomial. This in itself is a considerable assumption. The normal practice with local authorities when assessing non wind related noise from industrial developments is to take a time of lowest background noise.

The most common example of this is when background noise is required at night in an area substantially affected by road traffic noise. The normal method of assessment is to compare the noise from the industrial development with the background noise level at the quietest part of a quiet night, that is to say a calm night when wind and weather conditions do not affect the noise level. It is not normal practice to average the background noise level over the whole eight hour night time period or over a range of weather conditions.

Similarly it would be more in accordance with normal practice to compare turbine noise at each wind speed with the lowest background noise at that wind speed. In practice the lowest 10 minute measured value would probably be unreasonable. It has been suggested that the level adopted should be the "L90 of the L90 readings". That is perhaps too extreme but more realistic might be one standard deviation below the average line.

Conclusions

Making the measurements is only half the task. Careful analysis of the results is essential to make sure that they are robust.

- Always plot and examine a time series.
- Does the data cover a large enough range of wind speed and direction?
- Does the polynomial produce a flat S that can be shown to be composed of a NWR component and a wind generated component?
- What is the level of the NWR element of the curve? Why is it at the position that it is?
- If it is not significantly affected by the NWR element, what is the noise level at 10m/s? Generally this will range from 35dB in a well sheltered area without many noise generating objects to 45dB in an exposed area with trees - bearing in mind that exposure is relative to the anemometer position. If it is outside this range is there a good reason?

Going back to Fig 3 it is of considerable concern that probably none of the four polynomial curves represents the real noise level in any useful sense.

Rules for Proxies

- The NWR element (streams, traffic, farm noise etc) should be similar.
- The nature and number of noise generating objects should be similar.
- The degree of shelter should be similar.

References

[1] ETSU-R-97 – The Assessment and Rating of Noise from Wind Farms
[2] Davis R (1996). Noise Measurements in Windy Conditions. ETSU-W-13-00386.
[3] Bruel and Kjaer data on UA0237
[4] G.P. van den Berg Effects of the wind profile at night on wind turbine sound JSV 2003
[5] Paul van Lieshout - Time Dependent Energy Calculations, BWEA 2004

Acknowledgements

The data used in this paper is all in the public domain and forms part of some of the many Environmental Statements that I have analysed over the last few years. I would like to thank all those who were out with their equipment in all weathers gathering the data in good faith only to have me pick it apart. Most of them probably know who they are but I have decided not to credit them individually for obvious reasons.