Proposed Wind turbine @ Inchmore, Drybridge, Buckie with proposed revised position, 97m from neighbouring monastery gable wall (closest point) and 39m from highway edge.

On each day for 1 week, as agreed by Environmental health department wind and noise levels were measured every 10minutes and data noted.
Measurements are listed on attached files.
Precision Gold sound level meter N05CC and weather station N96GY were used to collate noise levels and wind speeds.
The noise levels were recorded 49m North of the proposed wind turbine position, at the tree line in our own land, bordering the neighbouring monastery building which is a further 48m away from this point. The wind speed was recorded at the proposed position of the wind turbine, 97m form the monastery gable wall (closest point) and 39m from highway edge.
All measurements were taken with no road traffic passing, no farm animals in the field to the West and no activity from neighbours that could have added any extra noise.
There are trees surrounding the proposed site, to the north bordering the monastery, to the south and to the rear (East) previously wooded area which is self-regenerating, with closely rooted/dense young trees now >2m tall.

The noise levels from the proposed Kingspan KW6 wind turbine will be below the prevailing ambient noise and therefore virtually indistinguishable to a listener in the grounds of the monastery which is separated by 20-30m strip of trees & shrubs on the boundary with a narrow obstructed line of sight to the proposed position of the turbine. The obstructed line of sight is narrow due to the position of Inchmore house, outbuilding (shed/log store) and the tree line.
The ambient noise level is greater than Moray council's maximum of 38db for all wind speeds & directions above 2.7m/s
The wind turbines cut in speed (start-up) is 3.5m/s.
There is also evidence to support that the trees & shrubs positioned at the border will reduce noise, a belt of trees and shrubs 15-30m can reduce noise by 6 -10db.

The ambient/background noise above 7m/s is >60db's and the turbines noise level at 8m/s at the monastery 97m away would be approximately 40db (Kingspan Acoustic Noise Levels data sheet), considerably lower than the ambient noise levels.

The Kingspan KW6 turbine is a direct drive alternator, no gearbox and is the quietest MCS accredited domestic wind turbines of this size and type available on the market.

PRODUCT SPECIFICATION

ARCHITECTURE AND ROTOR
Type: Downwind, 360 degrees free yawing
Speed control: Self-regulating
Blades: 3 blades, passive coning and pitch control
Rotor diameter: 5.6m
Rated speed: 11m/s
Rotor thrust: 10kN

GENERATOR
Type: Brushless permanent magnet, direct drive
Output: Grid connect (300v), battery charging (48V)

TOWER
Type: Self-supporting monopole
Hub height: 9m, 11m and 15m (hinged or hydraulic tower)
3.5m x 3.5m x 0.9m (max) Pad Foundation
Root Foundations are also available

WEIGHTS
Wind turbine: 600kg

PERFORMANCE
Cut-in wind speed: 3.5m/s
Max wind speed (survival): Designed to Class 1 (70m/s), Tested to Class 2 (59.5m/s)
Rated Power: 5.2kW (at 11m/s measured at hub height)
Peak Power: 6.1kW
RAE: 8,949kWh as certified by TUV NEL (at 5m/s measured at hub height)

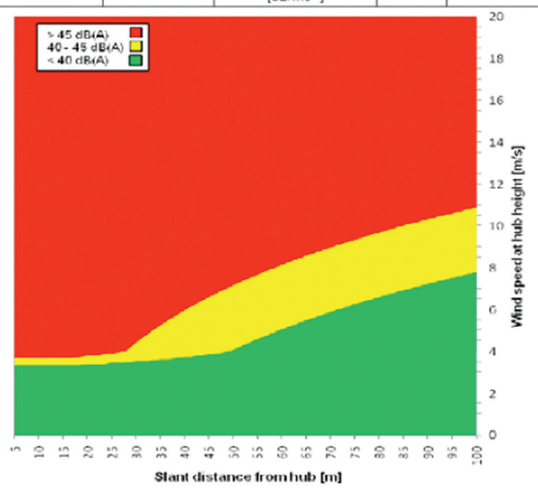
BUILD MATERIALS AND COLOURS
Frame: Galvanised steel, grey (not visible)
Towers: Galvanised steel, grey
Blades: Glass thermoplastic composite, black, white or grey
Covers: Plastic.

Black (RAL 9005) White (RAL 9003) Grey (RAL7000)

ACOUSTIC DATA

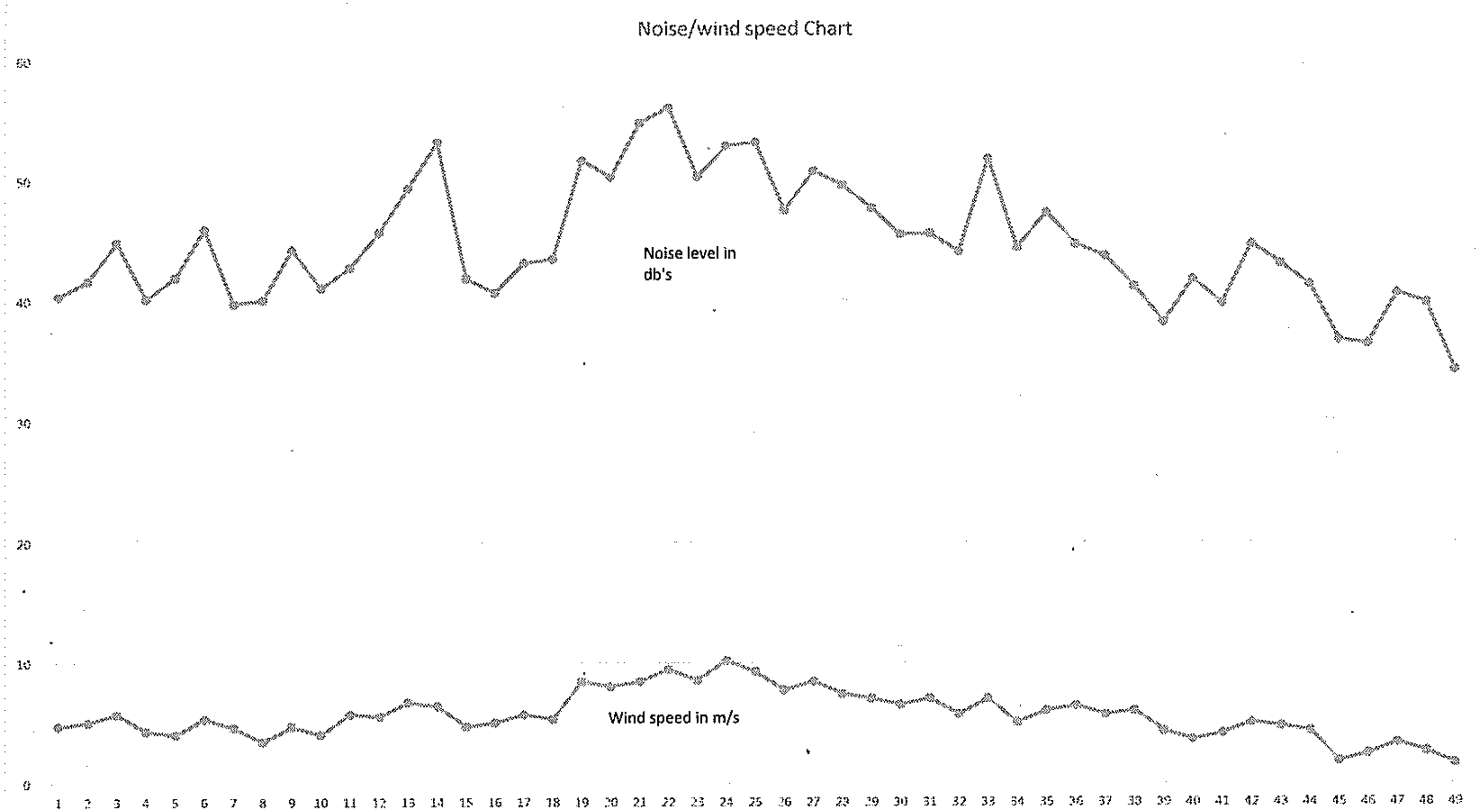
The following noise map is a declaration of the sound power level, including noise slope tested according to BWEA standard (29th Feb 2008) which amends IEC 61400-11 for the purposes of acoustic testing of small wind turbines.

Acoustic Noise Levels				
Turbine Make:	Proven Energy		Model:	P11
Noise Emission Level				Noise Penalty
Sound Power $L_{WA,8m/s}$	88.3 dB(A)	Noise Slope S_{dB} [dB/ms^{-1}]	1.62	NO



A full report is available upon request from wind.support@kingspan.com

11.23	40.4	4.8
11.33	41.7	5.1
11.43	44.9	5.8
11.53	40.2	4.4
12.03	42	4.1
12.13	46	5.4
12.23	39.8	4.7
12.33	40.1	3.5
12.43	44.3	4.8
12.53	41.1	4.1
13.03	42.8	5.8
13.13	45.7	5.6
13.23	49.4	6.8
13.33	53.2	6.5
13.43	41.9	4.8
13.53	40.7	5.1
14.03	43.2	5.8
14.13	43.5	5.4
14.23	51.7	8.5
14.33	50.3	8.1
14.43	54.8	8.5
14.53	56.1	9.5
15.03	50.3	8.6
15.13	52.9	10.2
15.23	53.2	9.3
15.33	47.5	7.8
15.43	50.8	8.5
15.53	49.6	7.5
16.03	47.7	7.1
16.13	45.5	6.6
16.23	45.6	7.1
16.33	44.1	5.8
16.43	51.8	7.1
16.53	44.4	5.1
17.03	47.3	6.1
17.13	44.7	6.5
17.23	43.7	5.8
17.33	41.2	6.1
17.43	38.2	4.4
17.53	41.8	3.7
18.03	39.8	4.2
18.13	44.7	5.1
18.23	43.1	4.8
18.33	41.3	4.4
18.43	36.7	1.9
18.53	36.4	2.5
19.03	40.6	3.4
19.13	39.8	2.7
19.23	34.2	1.7



9.35	51.7	5.8
9.45	48.7	6.5
9.55	58.9	5.4
10.05	66.3	6.1
10.15	57.6	5.8
10.25	60.2	5.1
10.35	54.7	5.4
10.45	60.8	6.8
10.55	51.1	4.8
11.05	64.2	7.8
11.15	57.3	5.4
11.25	60.7	6.1
11.35	59.6	5.8
11.45	64.1	7.1
11.55	67	8.5
12.05	56.5	5.4
12.15	64.7	6.8
12.25	68.7	7.1
12.35	62.8	7.1
12.45	54.7	5.8
12.55	55	5.4
13.05	61.9	7.1
13.15	53.7	3.4
13.25	56.9	4.4
13.35	64.4	5.4
13.45	63.3	4.8
13.55	60.7	6.1
14.05	66.3	6.5
14.15	60.5	5.8
14.25	66.7	6.1
14.35	63.5	6.8
14.45	62.7	5.4
14.55	61.4	5.9
15.05	62.6	6.5
15.15	63.7	7.1
15.25	60.3	5.4
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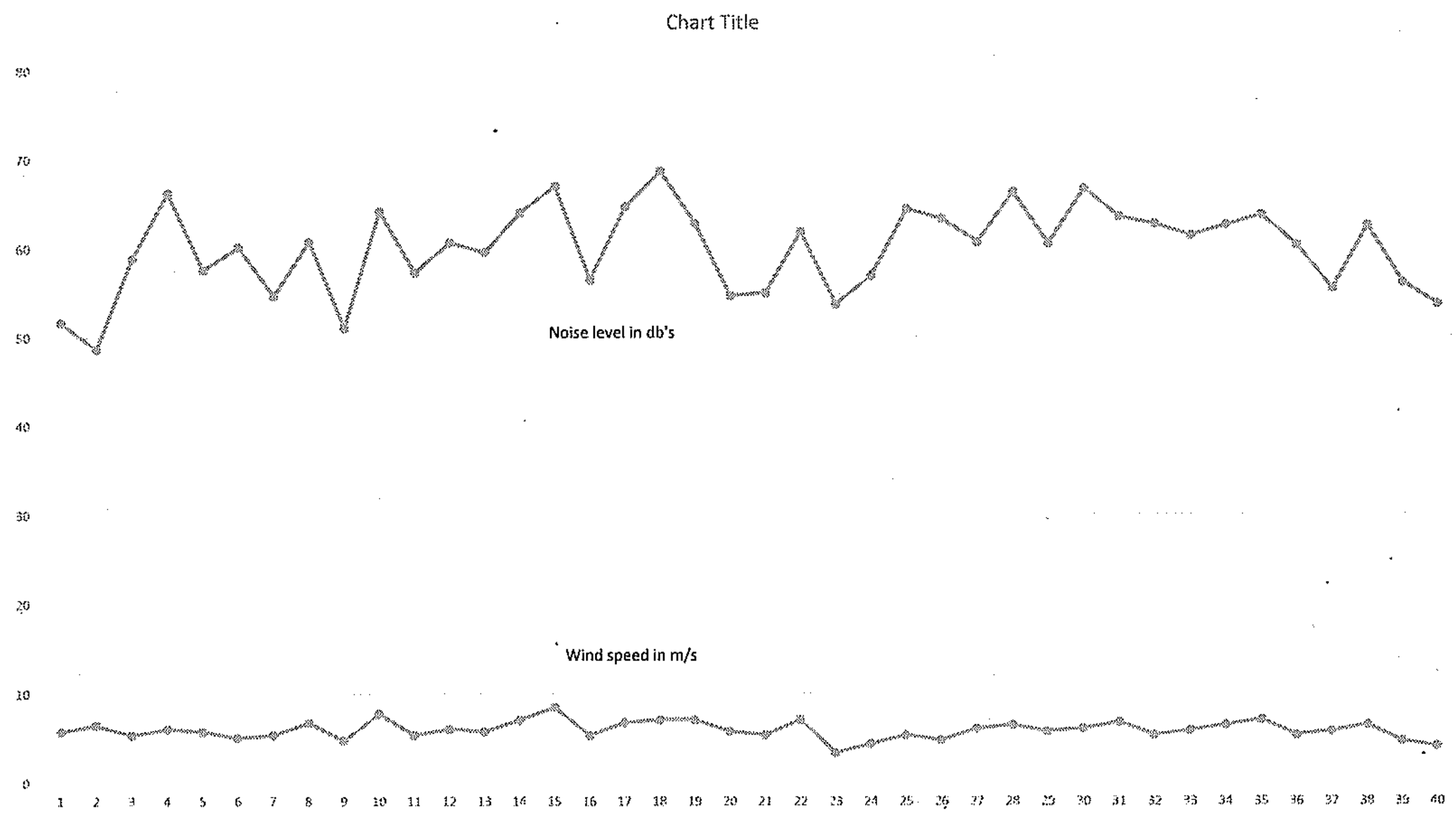
15.55	56.1	4.7
16.05	53.6	4.1



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11.45	44.1	3.1
11.55	45.3	4.1
12.05	48.8	4.1
12.15	43.5	3.4
12.25	51.8	2.7
12.35	48.6	1.4
12.45	47.4	2.7
12.55	43.6	1.4
13.05	39.5	1.4
13.15	49.5	2.1
13.25	41.8	2
13.35	38.3	1.7
13.45	36.2	1
13.55	39.1	2.1
14.05	37.4	1
14.15	35.8	1
14.25	36.2	0.7
14.35	35.1	1.6
14.45	38.7	2
14.55	37.5	0.7
15.05	57.4	1.4
15.15	34.8	0.7
15.25	33.6	1.7
15.35	42.1	2
15.45	37.2	1
15.55	36.8	1
16.05	34.6	1.4
16.15	36.8	1.4
16.25	36.2	1.7
16.35	35.1	0.7
16.45	38.6	1
16.55	37.8	0.7
17.05	34.6	1
17.15	35.7	0.7
17.25	37.3	1
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17.45	35.2	1
17.55	35.4	1
18.05	39.6	1.4
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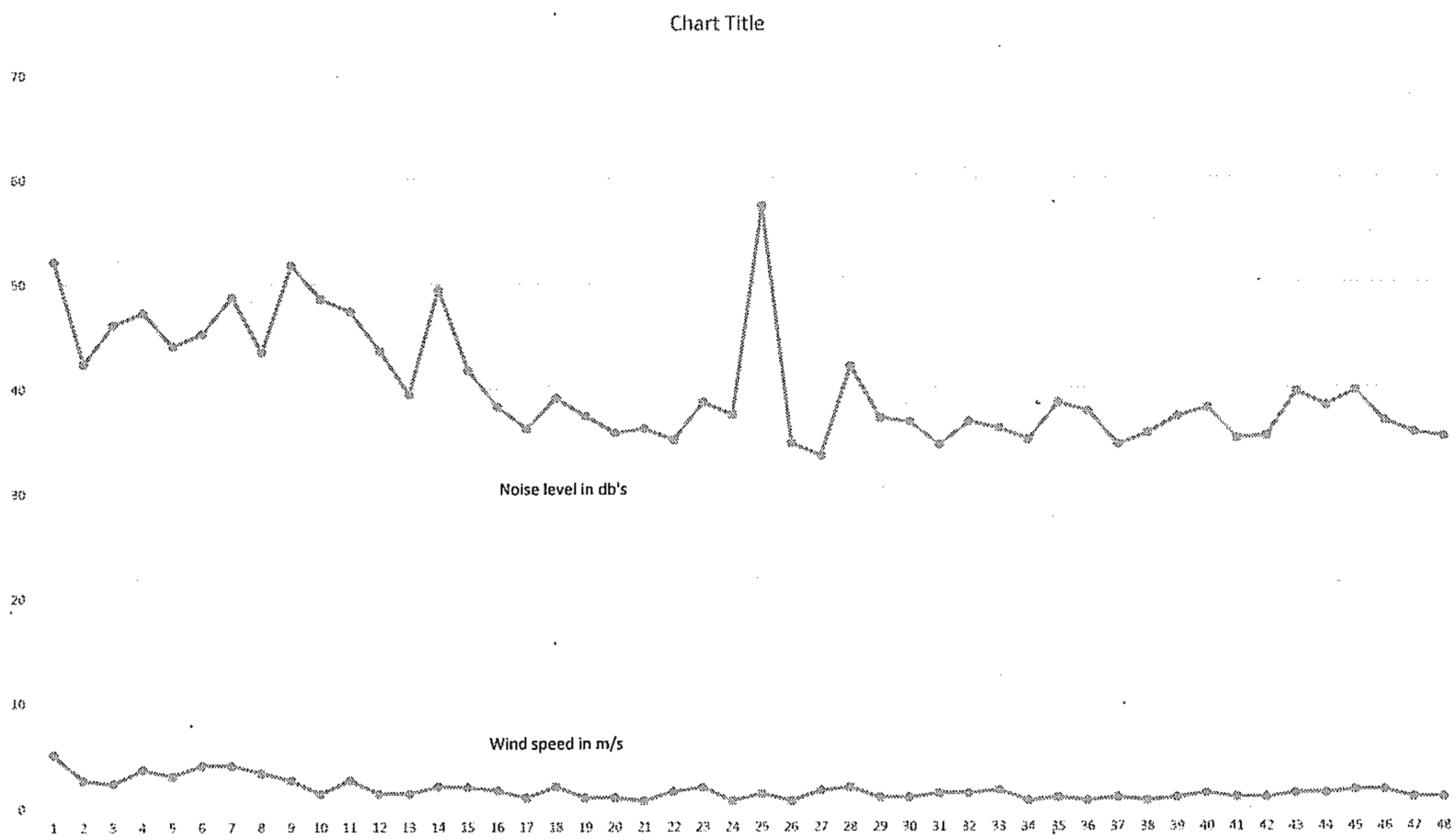
18.45	35.7	1
18.55	35.3	1



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11.40	35.9	2
11.50	34.6	1.7
12.00	41.3	1
12.10	37.1	1
12.20	34.7	1.4
12.30	40.4	1.7
12.40	33.6	1.4
12.50	32.5	2.5
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13.40	38.7	1.4
13.50	37.9	2
14.00	35.8	1.7
14.10	41.8	1
14.20	37.5	1.7
14.30	40.1	0.7
14.40	37.6	1.4
14.50	34.4	1
15.00	34.2	0.3
15.10	33.9	1
15.20	39.2	2.4
15.30	37.1	1.7
15.40	35.6	1
15.50	34	1.7
16.00	37.4	1.4
16.10	36.3	1.4
16.20	34.2	0.7
16.30	36.2	1
16.40	38.7	1.4
16.50	36.1	1.7
17.00	34.1	1.7
17.10	37.5	1.4
17.20	34.6	1.4
17.30	38.5	0.7
17.40	36.1	1.4
17.50	36.7	0.7
18.00	39.2	0.7
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18.20	35.3	0.7
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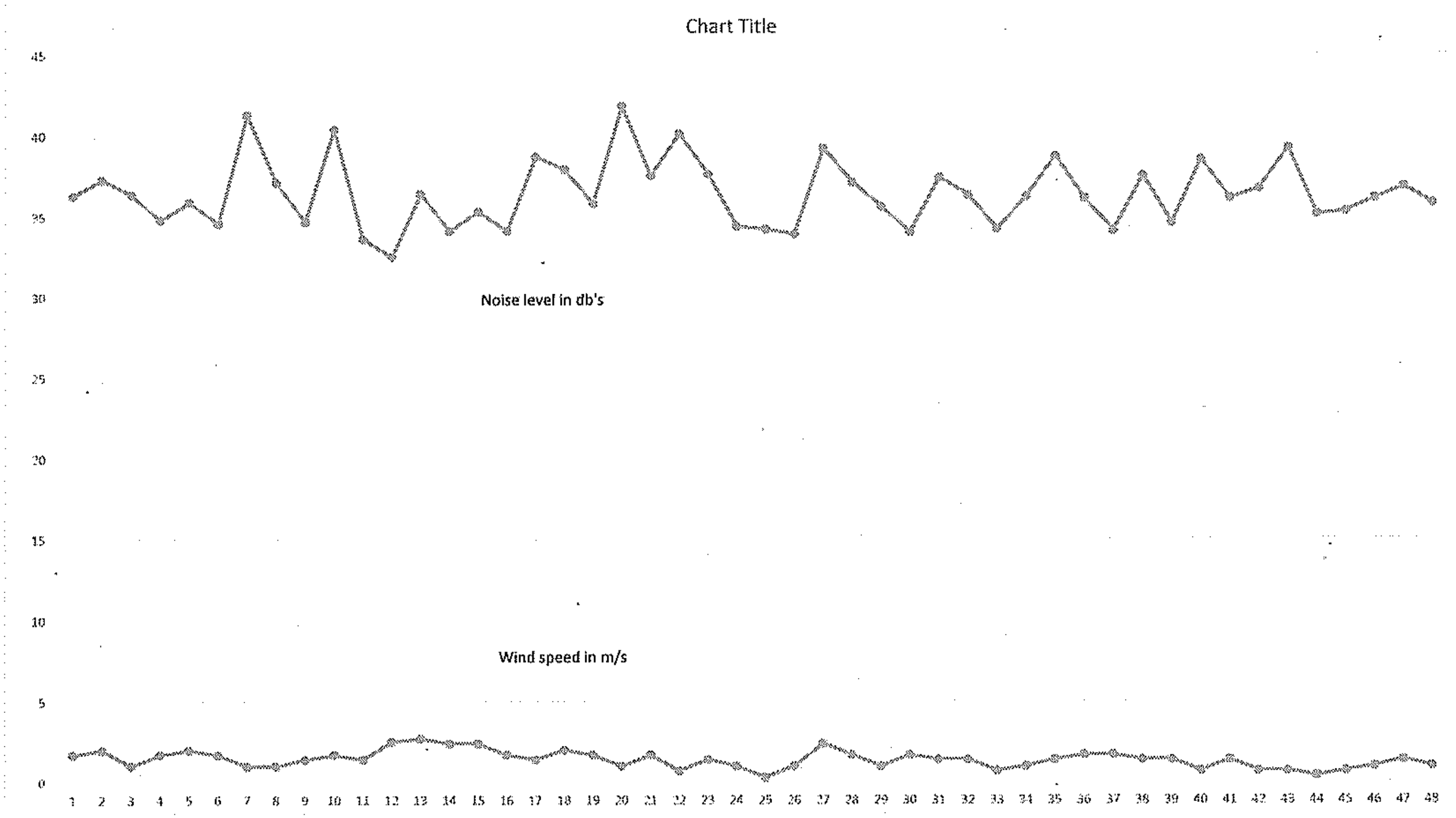

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9.50	41.6	1
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10.10	39.8	1
10.20	35.1	1
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11.30	36.7	2
11.40	37.8	1.7
11.50	38.6	2.4
12.00	41.5	2.7
12.10	43.1	2.7
12.20	40.2	3.4
12.30	43.3	3.1
12.40	42.1	3.1
12.50	40.1	2
13.00	40.6	2.4
13.10	41.5	2.4
13.20	44.2	3.1
13.30	43.1	3.4
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13.50	52.6	3.7
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14.10	43.4	4.1
14.20	45.9	3.7
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14.40	47.1	3.4
14.50	41.5	2
15.00	39.8	3.4
15.10	42.6	3.1
15.20	54.3	4.4
15.30	58	4.1
15.40	46.7	3.7
15.50	50.1	4.1
16.00	46.3	3.4
16.10	45.1	3.4
16.20	43.9	2.4
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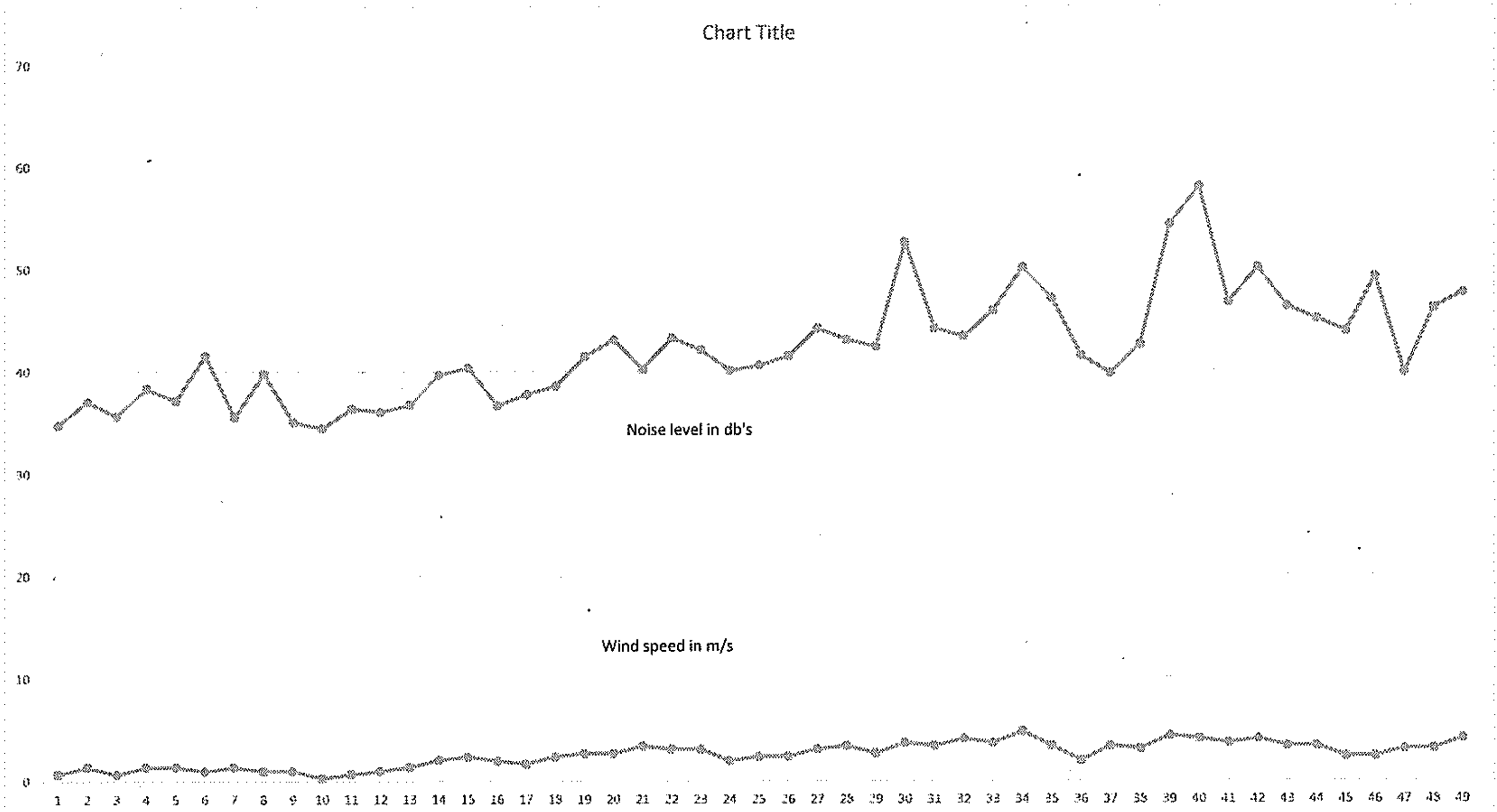
16.40	39.8	3.1
16.50	46.1	3.1
17.00	47.6	4.1



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8.40	44.5	3.1
8.50	47.4	3.4
9.00	40.3	2.7
9.10	46.2	3.1
9.20	47.9	3.1
9.30	45	3.4
9.40	42.6	2.7
9.50	45.2	3.7
10.00	42.4	2.4
10.10	42.2	2.7
10.20	43.7	2.7
10.30	45.1	3.4
10.40	46.6	2.7
10.50	44.9	3.1
11.00	44.6	2.7
11.10	47.2	2.7
11.20	45	3.7
11.30	45.7	3.7
11.40	47.9	3.1
11.50	44.9	2.4
12.00	45.8	3.1
12.10	44.1	3.1
12.20	45.3	3.7
12.30	37.6	2
12.30	45.1	3.1
12.40	43.1	2.7
12.50	41.7	2.4
13.00	38.1	2.4
13.10	35	2
13.20	40.1	2
13.30	42.4	2.4
13.40	39.1	1.7
13.50	44.3	2.4.
14.00	44.9	2
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14.20	45.9	4.1
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14.40	43.2	2.7
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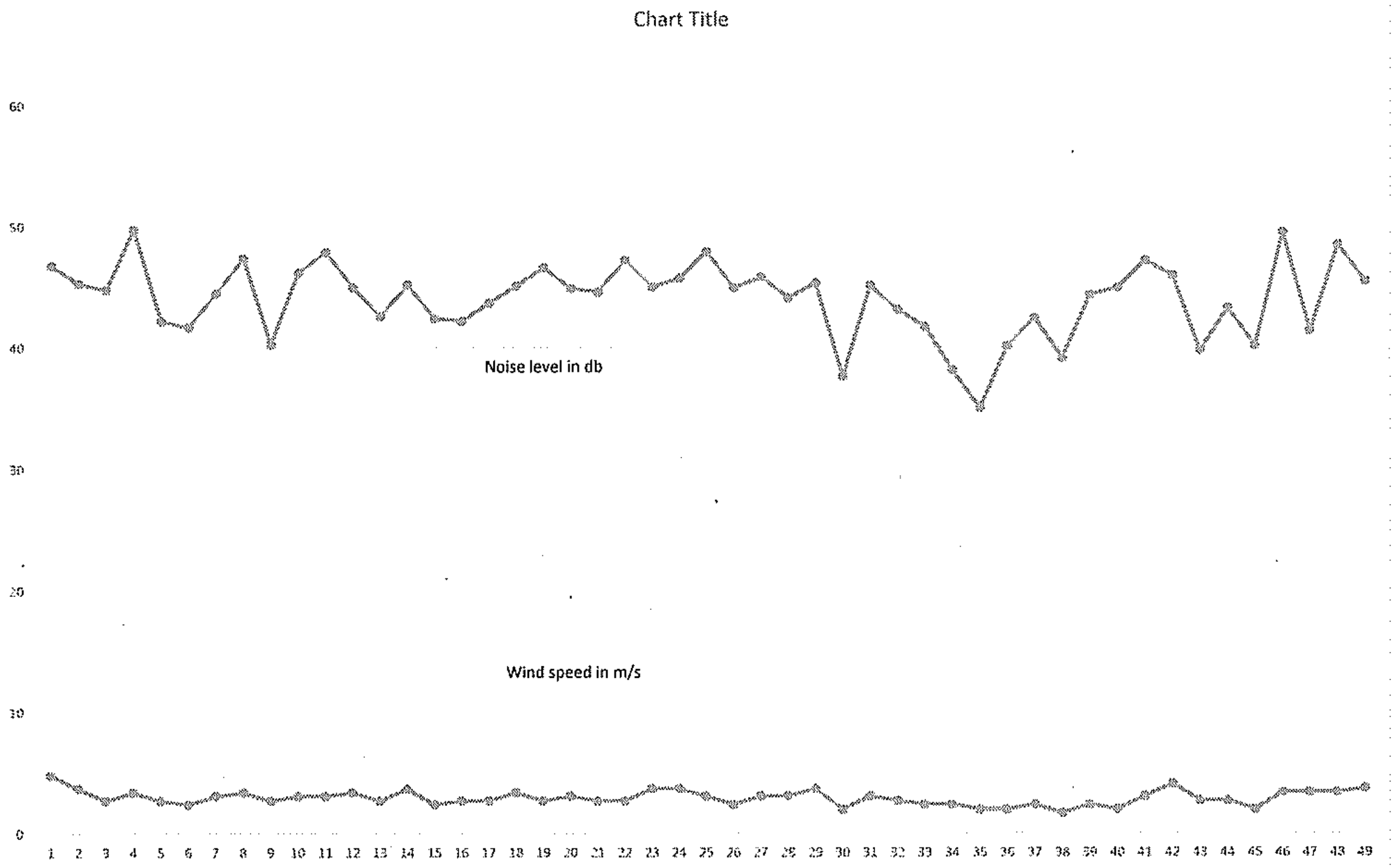

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10,50	46.7	4.4
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12.50	55.5	5.4
13.00	52.6	6.1
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13.30	52.3	4.8
13.40	51.1	5.1
13.50	54.3	4.8
14.00	53.9	5.8
14.10	54.9	3.7
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14.30	54.9	5.1
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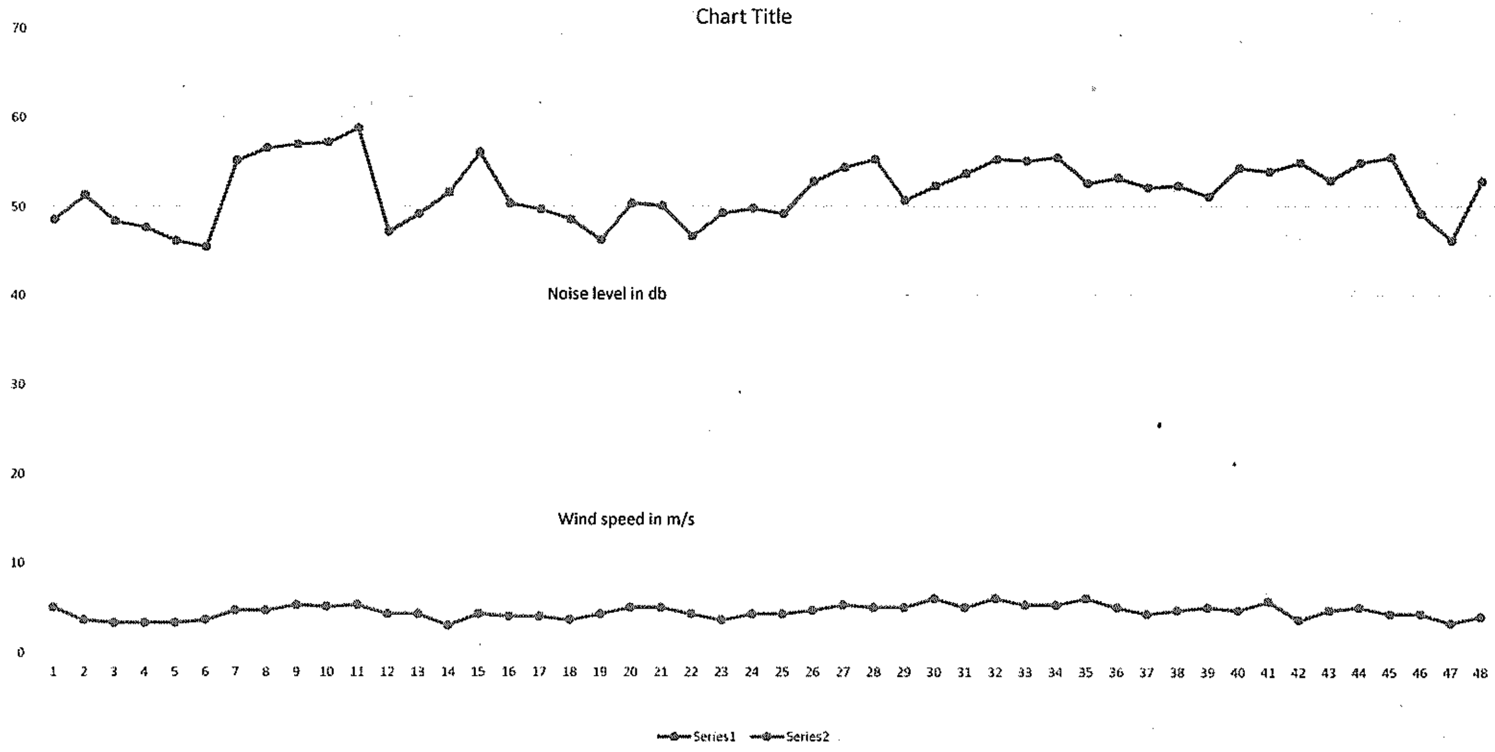

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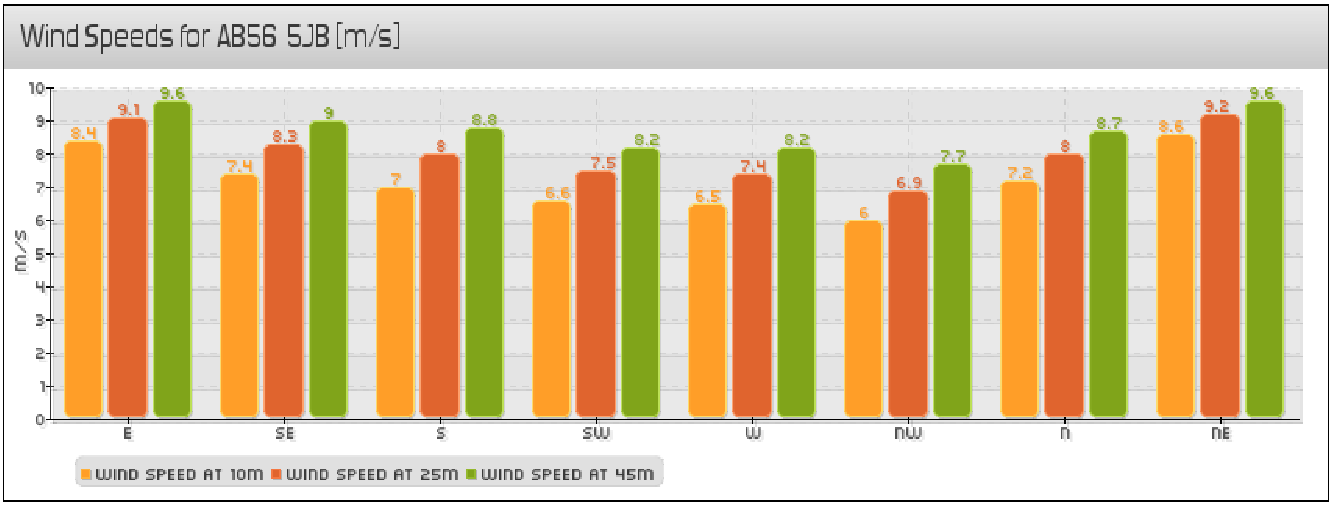
LOOKUP WIND SPEED

YOUR RESULTS FOR AB56 5JB



Wind Speed at 10m

6	7.2	8.6
6.5	8.3	8.4
6.6	7	7.4

Wind Speed at 25m

6.9	8	9.2
7.4	8.9	9.1
7.5	8	8.3

Wind Speed at 45m

7.7	8.7	9.6
8.2	9.4	9.6
8.2	8.8	9

Post Code

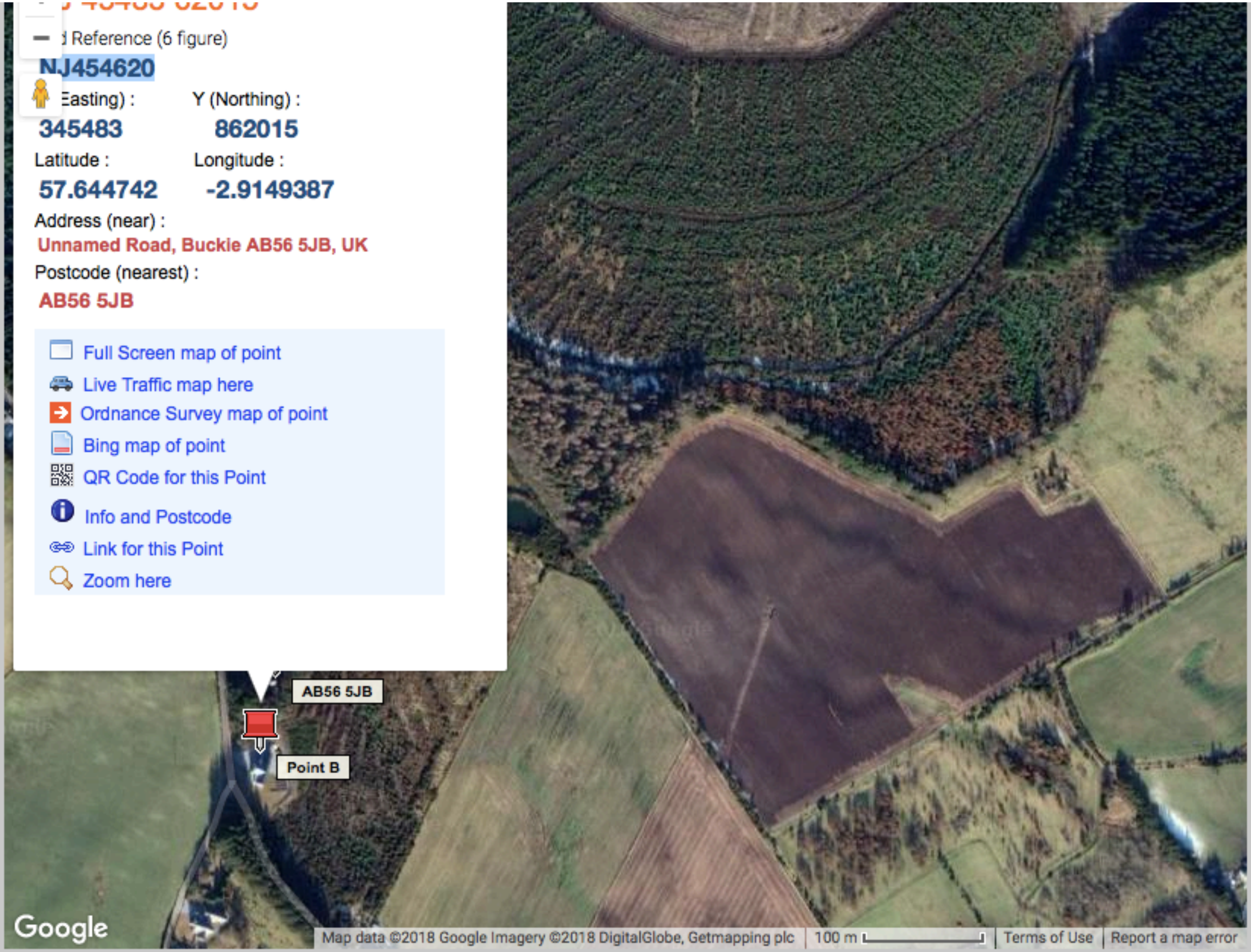
AB56 5JB | Go

Location (Road , Town) | Go

Grid Reference | Go

X (Easting) | Y (Northing) | Go

Lat | Long | Go



Link for All Points | Elevation Chart | Show Points on OS Map | Show Points on Mobile Map | Show Points on OpenStreetMap | Distance Matrix | Heatmap | Toggle Show Pin Labels |

Export Points to CSV | Export Points to Excel | Export Points to Google Earth (KML)

1 Find your property

Drybridge, Buckie AB56 5.

Draw Property Boundary

Remove Wind Speed

Delete Selected Shape

Measure Distance

2 Mark the boundary

Click the *'Draw Property Boundary'* icon above, then repeatedly click the map along your boundary line until you close the loop.

3 Check the wind speed

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;ITAL ISSUES

ɔw loud is a wind turbine ɛally?

By Editor | December 4, 2009

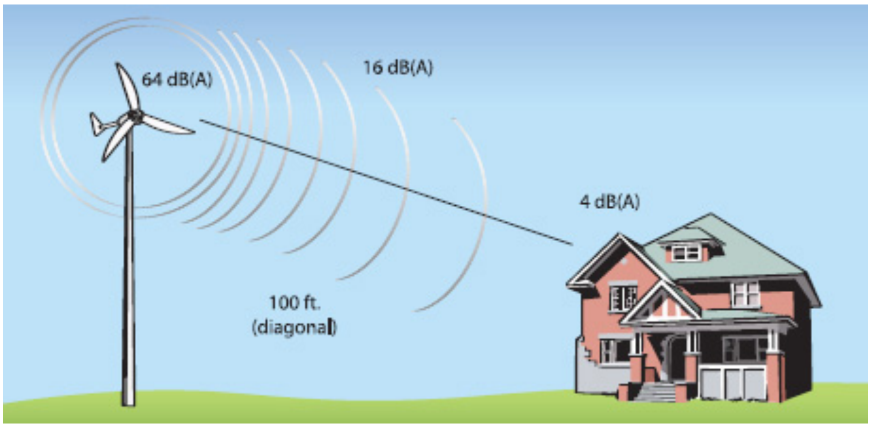
Modern small wind turbines have better insulation, lower rotation speeds, fewer moving parts, no gearboxes, and more efficient blades that make them much quieter than their ancestors. Today's small wind turbines emit sound that is barely discernible from ambient noise, even with a decibel (dB) meter. Sound from traffic, rustling trees, airplanes, and people in fact often sufficiently mask the dull, low, "white noise" sounds a small turbine can make at certain wind speeds. Only during short-term events like severe storms or utility outages do small wind turbines make distinctive sounds, but in these occurrences ambient sound levels increase as well.

To put this into further perspective, the sound made by the lanyard clasp on a flagpole line hitting its pole is far more "tonal" and distinguishable than any sound a small wind turbine makes, and is

WIND TALK PODCASTS

Windpower Editors Paul Dvorak and Michelle Froese interview the industry's biggest newsmakers and allow them to tell their less easily masked by ambient sounds.

Zoning policy should reflect ambient sound levels as well as occasions where no affected parties are located immediately outside a property boundary. Therefore, except during short-term events like storms and utility outages, a small wind system should be installed and operated such that sound pressure levels do not exceed the definition of "nuisance noise" as established by existing zoning code. or at the nearest dwelling, whichever is greater. Sound levels should always be measured downwind of the turbine to account for the canceling effect of the sound of the wind itself. If ambient sound levels exceed "nuisance" levels on certain occasions, such as during storms, sound level limits of small wind systems should also be given reprieve during these events which are out of everyone's control.



Sound waves are diluted with distance

Or, instead of singling out wind turbines in sound regulations, it may be more fair and administratively simple to use default sound/noise regulations that apply universally to other objects and appliances in a community. The small wind section of Wisconsin's (state-wide) zoning ordinance, for example, has no mention of sound because its designers chose to treat small wind turbines equally with other allowed devices/structures.

Also Keep in Mind

- Sound decreases significantly with distance from the source (including height – another good reason to allow tall towers). Doubling the distance from the turbine decreases the sound level by a factor of four. For example, sound level readings at 25ft. from the turbine hub drop by a factor of 4 at 50ft., and by a factor of 16 at 100ft. Noise intrusion across a property line from a turbine that is set back 100ft. or more is typically very limited.

- Turbine manufacturers are keenly aware of the public demand for quieter machines and have invested in new materials and designs to minimize sound. As a result, today's turbines operate at near-ambient sound levels.
- Only a few events or circumstances can cause a normal operating wind system to become audible, including utility blackouts (or a full battery bank for those models that incorporate batteries). Both situations are temporary, and in many cases (but not all), easily remedied by the owner by manually shutting down the turbine.
- Sound level test data for some turbines is available from the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL).7
- Requiring certified noise tests for a residential wind system is unnecessary given the lower sound emissions of today's turbines and that sound data is readily available from manufacturers. Such tests are also beyond the budget of any homeowner.
- "Noise" is a subjective term. Whether a person generally favors wind turbines or not can determine how he or she views a single, seemingly objective sound.
- The single best way to understand the nature of a turbine's sound is to visit an installation site. All turbines are a marginally different so be sure to visit a location with a similar wind resource and the same model turbine as is in question.

AWEA

ABOUT THE AUTHOR

Editor

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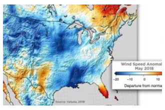

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Practical Care and Management

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Martin Dobson[1] and Jo Ryan

Arboricultural Advisory and Information Service

Summary

Noise, or unwanted sound, can be one of the most problematic environmental factors of both urban and rural areas; traffic noise in particular is a common problem. Noise attenuation can be achieved by increasing the distance between the noise source and hearer. However, very often this is not possible and other methods, such as erecting a solid barrier can be adopted. Where space permits, trees and shrubs can make effective noise barriers and at the same time be visually attractive. Based on published research, this Note makes recommendations and prescriptions for planting trees and shrubs to reduce noise and discusses the merits of various planting specifications.

The Problem of Noise

Few things are more irritating or tiring than continuous loud noise. And it isn't a new phenomenon. "Citizens of Rome perish for lack of sleep" wrote Juvenal, a satirist of the first century AD and in the same period Julius Caesar banned chariot traffic from the streets of Rome at night because it was too noisy! Traffic noise is an even greater problem today and has probably become the most widespread social irritant, especially in urban areas and near to roads carrying large volumes of traffic. It has been estimated that about 1 in 10 people live with an intrusive level of road noise (Huddart, 1990). Other sources of intrusive and persistent noise include trains, factories, airports and quarries to name a few.

The most effective way to minimize noise is to reduce it at source. However, this is often not possible and so the remaining options are to increase the distance from the source (which is frequently impractical) or to place a barrier between the source of noise and the hearer. A personal barrier (e.g. earmuffs) is acceptable in some situations as a last resort, but a reduction in noise for the public at large is preferable. Solid barriers such as fences or mounds of earth have frequently been used as sound barriers, but trees and shrubs can also be effective in reducing noise and have the advantage of being more attractive and less expensive. Trees may be used in conjunction with solid barriers, either as visual screens or to reduce their reflective properties.

What is Noise?

It may seem a naïve question, but understanding noise is fundamental to solving the problem of how it can be reduced. Noise is created by vibrations in the air which cause variations in air pressure. The result is waves which radiate from the source like waves on a pond caused by a stone. When a noise-induced wave (a sound wave) reaches the ear it causes the ear drum to vibrate. The vibrations are then converted to a nervous impulse transmitted to the brain, which registers the noise.

How is Noise Measured?

Any movements in the air perceptible to the human ear are classed as 'sound' and only when sound becomes uncomfortable or unacceptable, is it classed as noise. However, noise is a subjective phenomenon; what one person calls noise, another may not, which makes it difficult to categorise. Sound waves, however, have physical attributes that can be objectively measured by acoustical equipment. The unit of sound is expressed as the decibel (dB) and measures the sound pressure level. Most studies seem to have adopted the dB(A) scale, which weights the frequencies in sound to approximate human responses to loudness.

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A zero decibel level corresponds to the threshold of human hearing. An increase of 1 decibel is roughly equivalent to the smallest difference in loudness perceptible to the human ear and an increase of 10 decibels roughly corresponds to a doubling in the apparent loudness of a sound. Thus 20dB is twice as loud as 10dB but 30dB is four times louder than 10dB, and 40dB eight times louder, and so on. Most ordinary sounds fall in the range of about 25dB (as in a library) to 80dB (in a noisy street). Above a sound intensity of about 60dB sound becomes uncomfortable and would be considered 'noise'; at 120dB a noise becomes unbearably loud. The sound pressure levels of some common sounds, measured at close quarters, are shown in Table 1 below.

Table 1
Sound Pressure levels of some common sounds.

Sound	Decibels (dB)
Jet aircraft	120+
Car horn	110
Passing train	100
Chainsaw	100
Dog barking	92
Busy dual carriageway	72-78
Normal speech	48
Whisper	20
Threshold of hearing	0

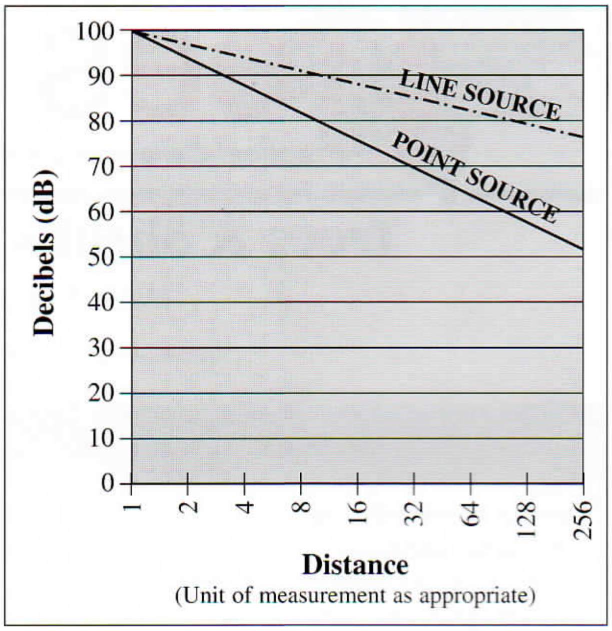

Figure 1
Effect of distance on noise reduction.

Reducing Noise

Sound is greatest nearest to the source and diminishes with distance - so, obviously, the further away you are, the less you will hear. This is because of 'geometric spreading' i.e. the further a sound wave travels the greater the dissipation of its energy, like ripples on a pond. Sound can originate from either a single point such as a chainsaw cutting wood (point source) or from a continuous activity, such as a stream of traffic (line source). Increasing the distance between you and a noise will reduce its loudness; there is a reduction of about 6dB when the distance from a point source is doubled and about 3dB when doubling the distance from a line source (Fig.1). For example, if the noise from road traffic (approximately 20m away) is 70dB, doubling the distance over a hard surface to 40m will reduce the noise by 3dB to 67dB.

Objects between the source and the hearer can also help attenuate noise, for example closing windows and doors or erecting a tall fence or wall. This is because most sound waves are significantly reduced when passing through solid objects or they are reflected off them; the density and area of an object presented to a sound largely determines the attenuation. On the other hand, fibrous and porous materials are able to absorb sound and hence may effectively reduce noise.

Sound travels *(propagates)* differently over various kinds of surfaces. Asphalt and concrete reflect virtually all incident sound at any angle, whereas grass covered surfaces interact with sound quite differently. Although the wave is still reflected, its phase is somewhat slower due to the interaction with the ground surface. As a result, sound travelling directly from a source to a listener is partly cancelled by this out-of-phase reflection, leaving the listener in a type of 'sound shadow'. The net effect is a reduction in sound levels near the ground. This change of phase can be explained literally at a grass roots level. It is thought that the roots of vegetation keep the soil surface open and the soil structure more porous, effectively making the ground a sound absorbing material.

One obvious way that trees may be useful is in reducing human perception of noise by creating a visual barrier between the source and the hearer. It has been suggested that people are less conscious of noise if they cannot see the source. Trees, then, might be useful in reducing the *perception* of noise by providing an aesthetically pleasing visual barrier, for example between houses and a nearby source of noise such as a road. The effect of trees as a visual barrier to reduce perception of noise is a subject which has not been fully studied. However, Aylor (1972) reports on one experiment which found a screen of trees with gaps in it to be more effective than a dense screen in making people *think* they were hearing relatively less noise. Correspondingly, a visually impenetrable screen of trees increased the subjects' perception of noise. This and more recent research suggest that people expect a visually opaque barrier to reduce noise more than it actually does (Watts, personal communication, TRL, Crowthorne). When this does not occur, the level of irritation is greater and the noise appears louder. Nevertheless, another study indicated that people would rather have an aesthetically pleasing barrier to screen a noise source from view, even if noise is not substantially reduced (Perfater, 1979).

surrounding noise. Masking noise may be useful in a situation where the noise is simply annoying rather than overwhelmingly loud.

Can Trees and Shrubs Reduce Noise?

Research has indicated that trees and shrubs can make a contribution to noise reduction. Usually, comparisons have been made between noise propagated over a grass surface and noise propagated through tree and shrub belts. The difference between the two is known as *insertion loss* and is the amount of noise reduction directly attributable to the trees. Published results on the effectiveness of tree and shrub barriers vary enormously, however, a review by Huddart (1990) shows that in some instances noise can be reduced by 6dB over a distance of 30 m where planting is particularly dense. Leonard and Parr (1970) and Reethof (1973) found that a dense belt of trees and shrubs between 15-30 m wide could reduce sound levels by as much as 6–10dB. Cook and Van Haverbeke (1972) also found reductions in noise level of 5–10dB for belts of trees between 15-30m wide.

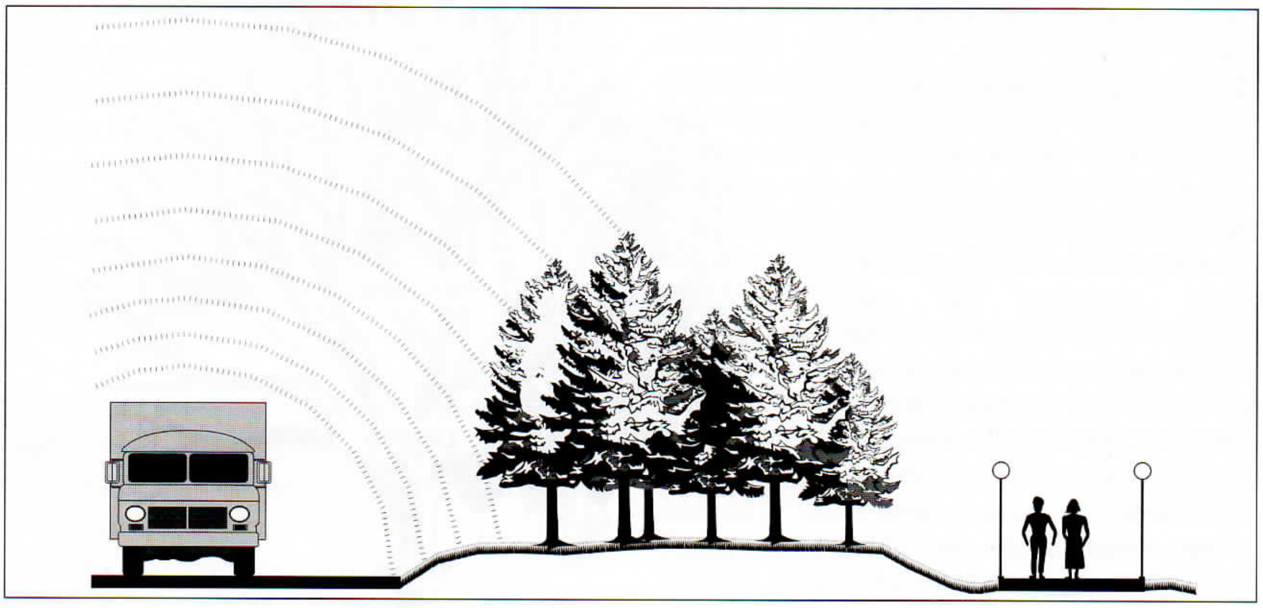

Figure 2
A visual barrier between the noise source and the hearer may help reduce the perception of noise.
(Source: Grey & Deneke, 1986)

Another way in which noise may be made less intrusive is through the masking effect created by the rustling of leaves, needles and branches in the wind. The sounds of birds and other animals associated with trees may also help to mask

It is difficult to generalise but a thick belt of densely planted trees and shrubs should provide a useful reduction in noise of several decibels although reductions will be significantly less than a purpose built noise barrier of the same height and length.

How Can Trees Reduce Noise?

Trees and shrubs can reduce noise levels, particularly at high frequencies (or pitch), whereas a reduction in low frequency noise levels can be attributed more to the effect of the ground.

The attenuation of sound by vegetation is commonly attributed to the processes of reflection, scattering and absorption. Reflection and scattering from the surfaces of leaves, branches, trunks and the ground can alter the phase of sound, which can cause interference in the sound waves and a reduction in noise level. Thus, the more surfaces: leaves, needles and branches there are within a tree belt, the better the reduction of noise will be, provided they are evenly distributed in the space between ground level and the tops of trees.

Foliage appears to be the most efficient part of a tree for scattering sound and it seems that large leaves are more effective than small leaves. Broadleaved trees with large leaves tend to reduce noise more than conifers that have needle-like leaves (Tanaka et al., 1979). However, since most broadleaved trees lose their leaves in winter, conifers may give better year-round noise reduction, although the most effective trees are likely to be broadleaved evergreens (e.g. holly, evergreen oak and eucalyptus). Low shrubs and/or hedges along the edge of a group of trees can improve sound reduction, particularly those on the side nearest the sound source. Nevertheless, during British winters people spend most time indoors, making the need for noise control less critical.

Whilst trees themselves do not absorb a great deal of noise (tree bark appears to be the most efficient part of a tree in noise absorption) the ground within a group of trees seems to have a relatively large noise absorbing capacity. Studies within woodlands have shown that the greatest noise reduction occurs near ground level. Trees help to keep the soil loose through the action of their roots exploring the soil, by the fall of leaf litter to form a soft humus layer, and because of the shading of trees which prevents soils becoming baked hard in hot, dry summers.

The developmental stage of the trees is important in relation to their effectiveness in noise control. Young (1.5–4.0m tall) and middle aged (4–10m tall) tree belts appear to be best (Kellomäki et al., 1976). Noise reduction tends to increase with tree height up to 10–12m after which attenuation decreases. This is probably a result of lower branches dying back through shading as trees get taller, opening the understorey and allowing sound to travel more easily. This implies that a noise barrier comprising both trees and shrubs should be managed to ensure that the density of branches and foliage (particularly from ground level to 10m) remains high.

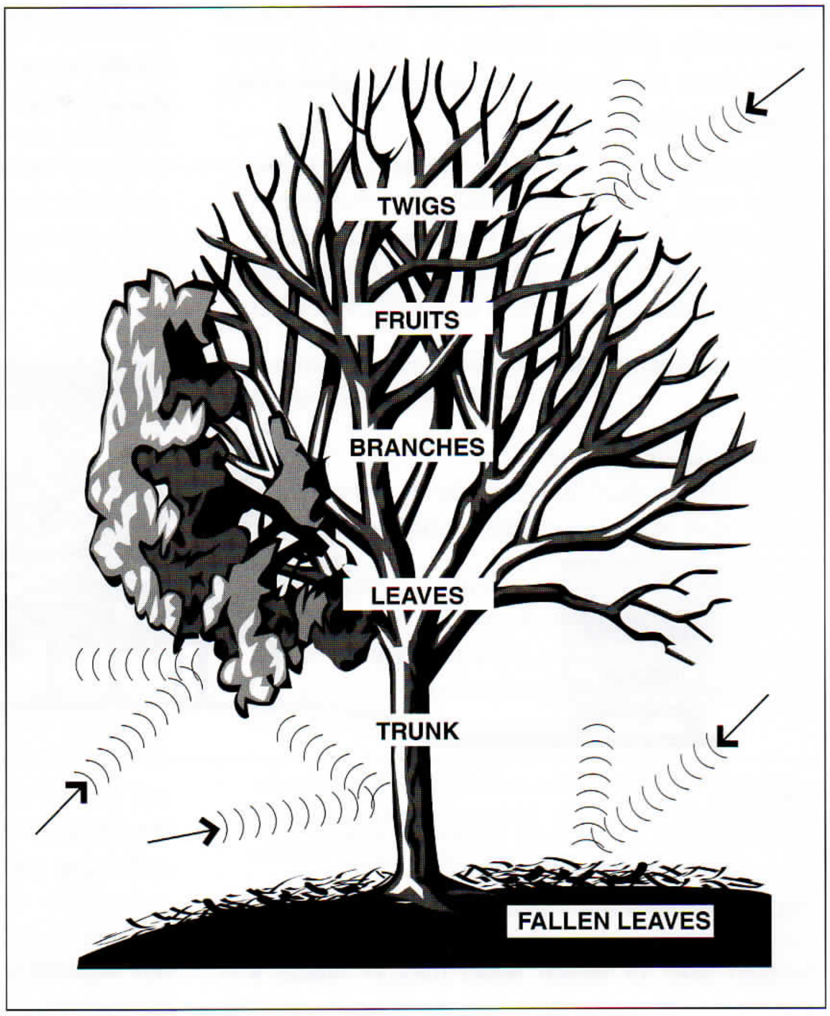

Figure 3
Illustration of how plants can attenuate sound. (Source: Grey & Deneke, 1986)

Does Size Matter?

Allowing trees to become too tall, resulting in gaps opening up in the understorey, will lessen their effectiveness. Kellomäki *et al.* (1976) found that noise attenuation by a stand of mature pines was less than in stands of any other species, or even clear cut areas. This may be due to the open structure exhibited by a group of mature trees combined with the reflection of sound downwards from the crowns of the trees.

Noise reduction is correlated with the width of a belt of trees, *i.e.* the wider it is, the greater the noise reduction. However, the amount of additional noise reduction declines with increasing distance. For example, from studies of traffic noise, Huddart (1990) found that a 10m wide strip of trees planted close to a road gave an attenuation of about 5dB more than the same width of grass whilst a strip of trees 20m wide only gave an attenuation of 6dB more than grass. This appears to be because the interior of a wide group of trees is relatively free of foliage and small branches, especially at lower levels, and therefore somewhat 'hollow', whereas narrow strips of trees, especially young conifers, have foliage and small branches throughout, from top to bottom. These compensating factors probably account for the smaller than expected differences in sound level attenuation between wide and narrow belts.

The length a tree and shrub belt extends may also influence its effectiveness in noise attenuation. Actual prescriptions are difficult however, as they will depend on the dimensions of the noise source, *i.e.* point or line source. Of more importance in noise attenuation is the actual *siting* of the barrier; a screen placed relatively close to a noise source is more effective than one placed close to an area to be protected. However, at midway between the source and receiver, noise reduction is least. Also, a barrier is most effective when trees and shrubs are combined with soft rather than hard ground surfaces, *i.e.* grass instead of tarmac or gravel. Hard surfaces tend to reflect noise with little or no attenuation.

To maximise noise attenuation

- A vegetation barrier should ideally form an irregular structure comprising:
  - Trees
  - Shrubs
  - Herb and
  - Litter layers
- Particular attention should be paid to:
  - Density
  - Height
  - Amount of foliage in the shrub layer
- Large-leaved deciduous species may be more effective at reducing noise during spring and summer but evergreens will provide better year-round attenuation.

Trees and Solid Barriers

Walls, fences, earth mounds and other solid barriers have proved useful as noise screens (Huddart, 1990). Whilst trees and shrubs have often been combined with solid barriers, for aesthetic purposes, relatively little thought has been given to the noise reducing capabilities of this combination. However, limited research has shown that a screen consisting of a solid barrier and trees/shrubs is no more effective for noise abatement than a solid barrier on its own.

Although planting trees may initially be more cost effective than erecting a solid barrier, it would incur more on-going management costs than a solid barrier. Tree and shrub belts, however, offer many **additional** benefits over conventional techniques of controlling noise. Tree belts may develop into more effective windbreaks and provide more protection from the glare of the sun than mounds or fences. In addition, trees can also help purify the air, stabilize embankments with their roots, provide habitats for wildlife, and improve the appearance of roads.

Where are Tree and Shrub Belts Useful?

In order to achieve a significant noise reduction of say, 6dB (corresponding to a reduction in loudness of about one third of the original level), a barrier consisting of trees and shrubs needs to be relatively wide (between 20-30m). Such barriers are therefore best suited to areas where land is freely available for planting. However, the cost of land may be extremely high and in many instances is the main argument against the use of vegetation as a noise barrier. Nevertheless, a narrow strip of densely planted trees and shrubs of about 10m wide could still give significant reductions in traffic noise level - of the order of 5dB (Huddart, 1990). For comparison, a 3m high solid barrier (e.g. a wall or a fence), erected on flat ground might be expected to give an attenuation of 15dB immediately behind it (Watts, Personal Communication, TRL). Motorways and trunk roads which often have a relatively wide verge, quarries or landfill sites, or industrial complexes could all benefit from having trees and shrubs planted around them. However, where the sound source is above the potential canopy height, as with aircraft or overhead roads, trees will be effective only very locally.

Another argument against the use of vegetation for noise barriers is the length of time taken for the barrier to become established. However, trees and shrubs can grow rapidly if appropriate stock is planted and attention is given to proper aftercare, particularly keeping trees free of weeds (Davies, 1987). If this is done, benefits should be noticeable within about 5 years.

Vegetated Solid Barriers

Willow walls, which have been pioneered on the continent, have recently been introduced into the UK. These 'living walls' generally consist of two parallel sets of posts which form the outer faces of the wall, between which willow branches are woven, in a similar way to a wicker basket, and as the weaving progresses the core is filled with soil. At each metre in height internal irrigation pipes are installed and lateral rods for structural support. The woven willow then produce new shoots on the outside and roots within the internal core, providing a total covering of foliage within the first year after construction. Construction should be during the dormant period (November to March) using live shoots, freshly cut, or kept in cold storage. A typical wall may have a basal width of about 2.5m and a height of 4.0m. Overall costs may be high; the willow requires cutting back annually but living walls may be a suitable option where space is limited, and where there needs to be a combination of 'greenery' and noise reduction. The level of noise reduction provided by willow walls is similar to the reduced level of a solid noise barrier of similar height, because the soil core prevents sound leakage. Unlike a tree belt which takes time to become established, the benefits of such vegetated barriers are immediately available.

Conclusions

There are several factors to be considered before deciding to create a tree and shrub barrier against noise. In each case, where possible, use trees that will develop dense foliage and relatively uniform vertical foliage distribution, or combinations of shrubs and taller trees to give this effect. Where the use of trees is restricted, use combinations of shrubs and tall grass or similar soft ground cover in preference to paved, tarmac or gravel surfaces to encourage absorption of noise rather than reflection.

Some other points to bear in mind are:

- noise is more effectively attenuated by *completely* screening the source from view. Although gaps and partial views through a barrier may create an *impression* of greater noise reduction, they will allow noise to penetrate.
- a noise barrier should be planted as close to the noise source as possible.
- widely spaced trees do not reduce noise effectively. Wide belts of high densities are required to achieve significant noise reductions.
- effectiveness is closely related to the density of stems, branches and leaves. Use trees with dense foliage and branches that reach close to the ground. Alternatively plant an understorey of dense shrubs or a surrounding hedge.
- where year-round noise screening is desired use broadleaved evergreens or a combination of conifer and broadleaved evergreen species.
- soft ground is an efficient noise absorber. Avoid hard surfaces - asphalt and concrete reflect virtually all incident sound at any angle. Cultivating ground before planting, and the addition of well-rotted organic matter to the soil surface may also help to reduce noise whilst vegetation becomes established.

Acknowledgments

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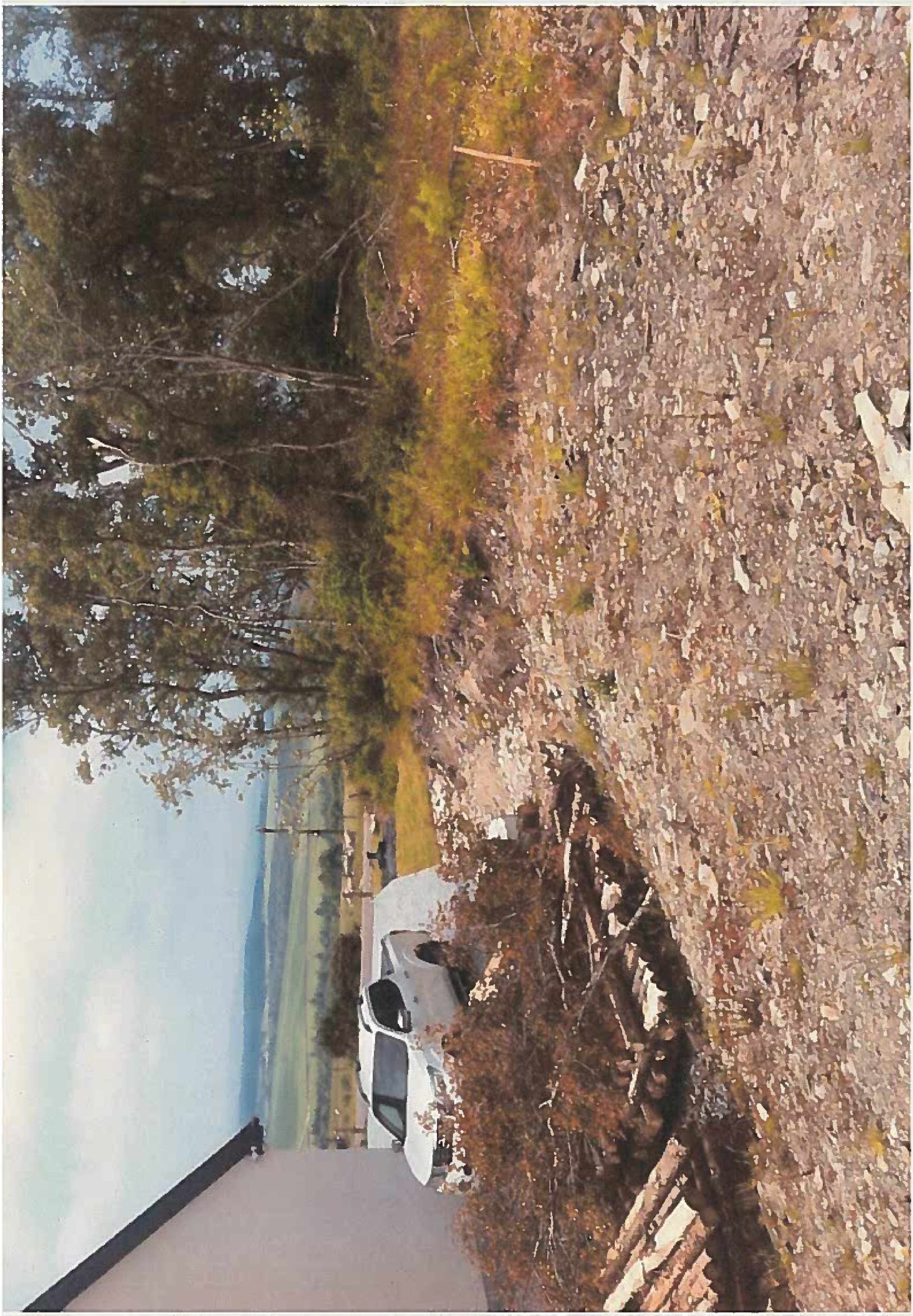

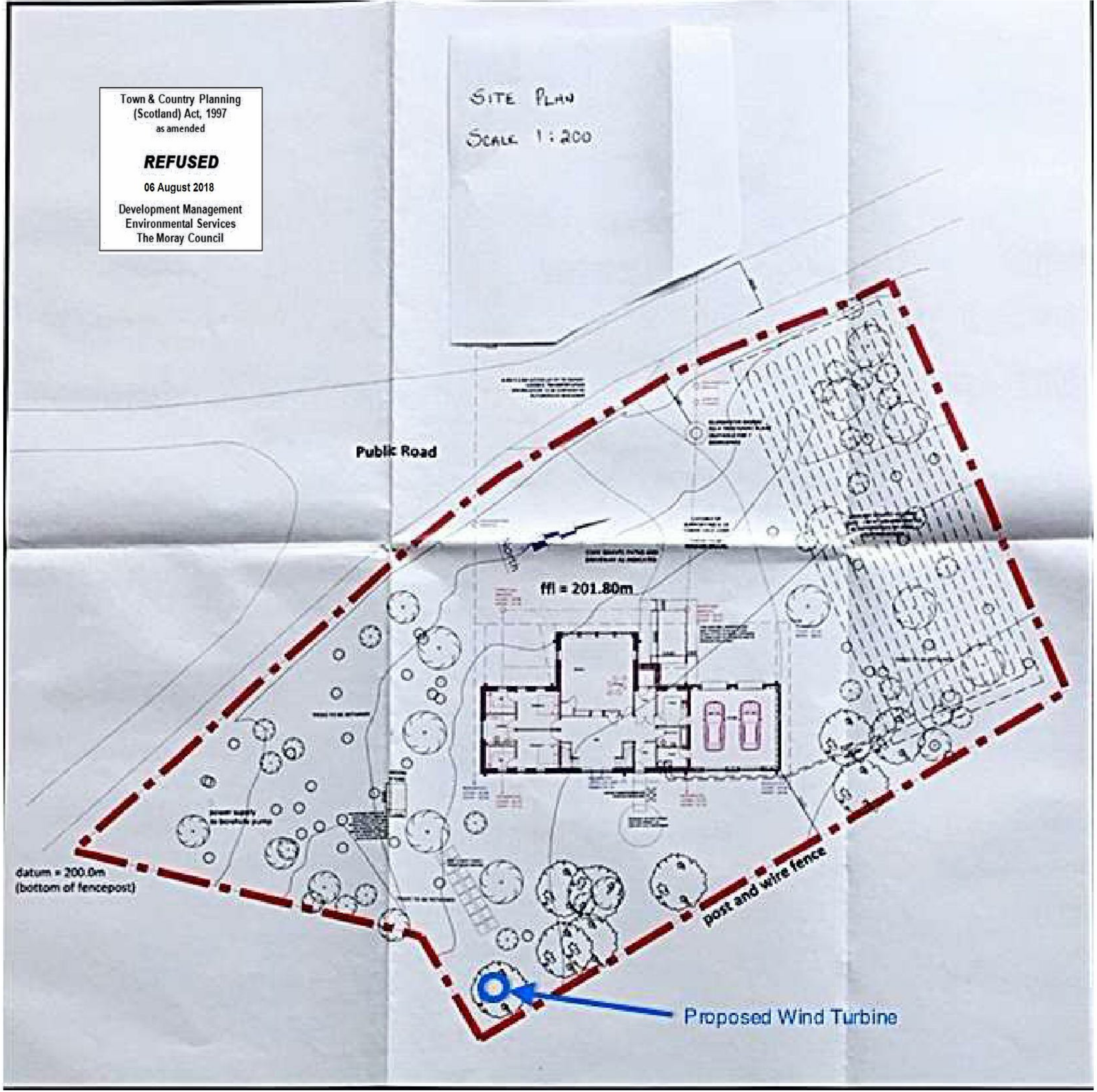

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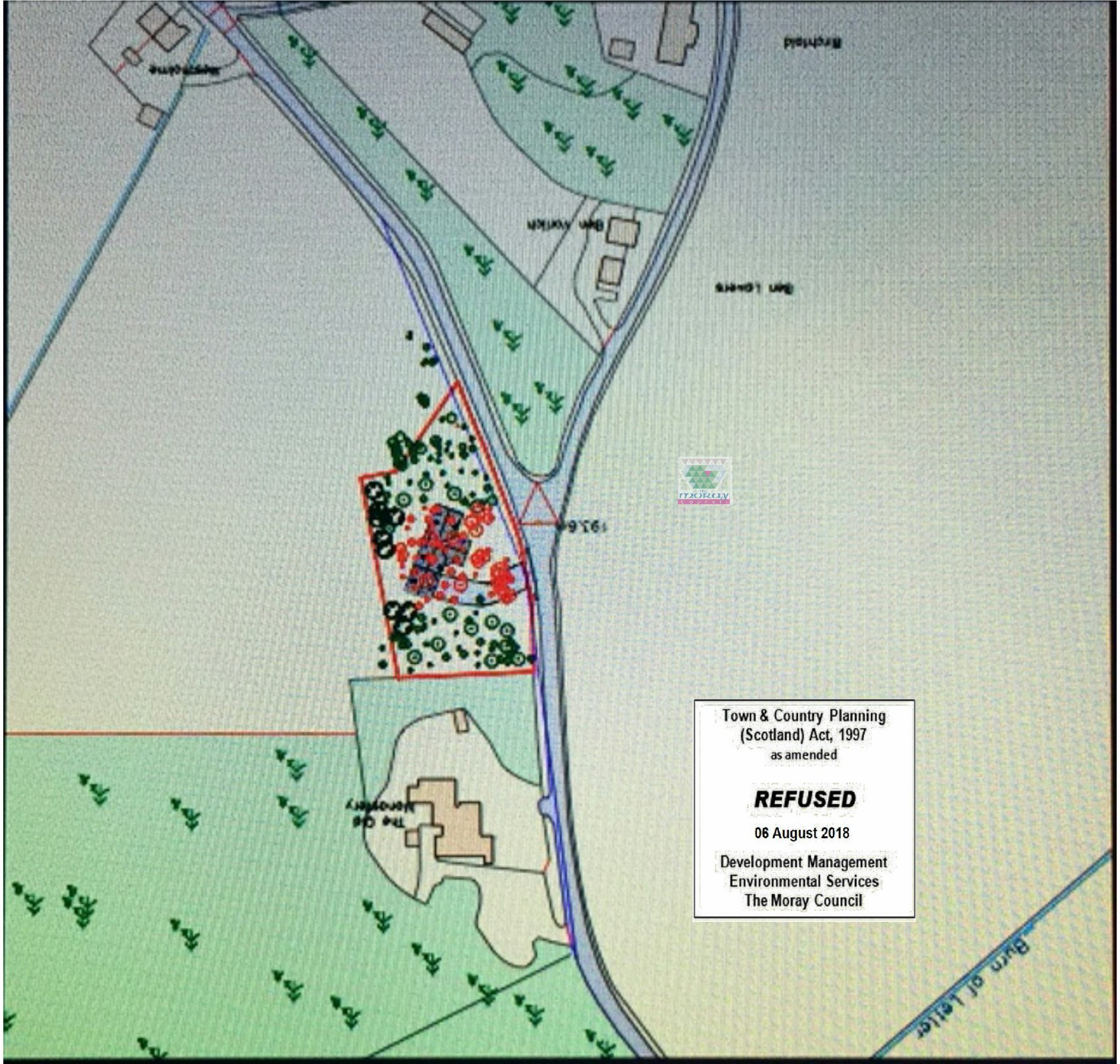
post and wire fence
Proposed Wind Turbine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