EDF Energy

Kellystown Wind Farm: Collision Risk Modelling Report

APPENDIX A8.4

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APEM

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Contents

List of Tables

Glossary

Term	Definition
Avoidance rate	It is acknowledged that birds take avoiding action when flying in the vicinity of turbines, either macro-avoidance (avoidance of an entire wind farm) or micro-avoidance (avoidance of individual turbines). To account for this 'an avoidance rate' is applied, based on guidance, to correct predicted collisions for each species.
Collision Risk Modelling	Collision Risk Modelling (CRM) is the process for predicting avian collisions likely to arise during the operational phase the development.
Collision Risk Zone	The Collision Risk Zone is the area within 500 m of the turbine layout. A flight which is within this zone (even if only partially) is considered to be at risk of collision.
Potential Collision Height	A flight which is at Potential Collision Height is one which is between the lowest and highest extent of a turbine rotor.
Vantage Point	A location from which Vantage Point Surveys were undertaken to determine flight activity.
Viewshed	The visible area at the lowest rotor swept height of a turbine model.

1. Executive Summary

This Collision Risk Modelling (CRM) Report details the methodology and results for CRM undertaken for the Kellystown Wind Farm. CRM has been undertaken following NatureScot guidance to predict collisions associated with the operational phase of the development and inform the impact assessment undertaken within the Environmental Impact Assessment Report.

CRM has been undertaken for target species which were present at sufficient levels to allow for robust modelling, using APEM's professional judgement. Species scoped into the CRM were: black-headed gull, common gull, herring gull, lesser black-backed gull, kestrel and peregrine.

CRM was undertaken for three proposed turbine models, which were based on real turbines. Following the precautionary principle, the predicted collisions for the Highest Risk Turbine should be used within the impact assessment.

Modelling was undertaken using the Band model, and followed two stages:

- **Stage 1**: calculating the number of birds flying through the rotors; and
- **Stage 2**: estimating the probability of a bird flying through the rotors being hit.

Stage 1 is a purely mechanistic calculation, to determine the number of birds present transiting through the rotors. Stage 2 incorporates the probability of a bird colliding with the rotors, and that birds will take avoiding action.

The results generated by running NatureScot's recommended approach for CRM moderate levels of predicted collisions for some target species; notably black-headed gull, common gull and herring gull. Peregrine and lesser black-backed gull collisions were also predicted, while no kestrel collisions were predicted.

2. Introduction

APEM Ltd (APEM) was commissioned by EDF Energy Ireland to undertake the Ornithology Environmental Impact Assessment (EIA) for the proposed Kellystown Wind Farm (hereafter referred to as 'the Site'). To support the impact assessment, Collision Risk Modelling (CRM) has been undertaken to determine the predicted collision mortality for Important Ornithological Features (IOFs) during the operational lifespan of the Development using data collected during Vantage Point Surveys (VPS) undertaken between 2021-2023, detailed in Appendix A7.1 and Appendix A7.2.

Predicted collisions have been calculated for a five-turbine layout and three different theoretical candidate turbine models, categorised as 'Highest', 'Moderate' and 'Lowest' risk. Categorisation has been undertaken based on the rotor diameter of the theoretical candidate turbine models, with the largest rotor assigned the highest risk, and the smallest rotor diameter assigned the lowest risk. Parameters to use for each theoretical turbine have been supplied to APEM by EDF and are real turbine specifications.

This report is a Technical Appendix to support the Ornithology Chapter of the EIA Report.

3. Methodology

CRM was undertaken using NatureScot (NS) guidance and using the recommended Band Model (Band *et al*., 2007). The NS methodology uses two approaches dependent on the flight activity of the species of interest (SNH, 2000). The 'Regular' model is used where species show predictable flight patterns, for example where a species follows a flightpath from a roost location to a preferred foraging location. The 'Random' model is used where a species activity is less predictable within the Site, for example birds foraging or displaying over a wide area. The Random model has been used to calculate collision risk for all species, as no species exhibited predictable flight patterns.

Collision Risk Modelling has been undertaken for species recorded within the Collision Risk Zone (the CRZ, a 500 m buffer of the turbine layout in line with SNH [2000] guidance) which were present at sufficient levels to allow for robust modelling, using APEM's professional judgement. **Table 1** outlines the target species recorded during Vantage Point Surveys within the CRZ. and outlines species which have been scoped in or out of CRM.

Table 1. Summary of Target Species Flights Recorded During VPS within the CRZ.

Species	Conservation Status*	Number of flights during Year 1 surveys	Number of flights during Year 2 surveys	No. of birds per flight	Include in CRM?
Mallard	Amber, SPA	3	2	1-4	No. Insufficient records available for a robust assessment of collision risk. In addition, the very small number of flights across two years indicate that collision risk for this species is negligible.
Swift	Red	0	3	1-2	No. Insufficient records available for a robust assessment of collision risk. In addition, the very small number of flights across two years indicate that collision risk for this species is negligible.
Lapwing	Red	0	1	1	No. Insufficient records available for a robust assessment of collision risk. In addition, the very small number of flights across two years indicate that collision risk for this species is negligible.
Golden plover	Red, Annex I	2	2	1-12	No. Insufficient records available for a robust assessment of collision risk. In addition, the very small number of flights across two years indicate that collision risk for this species is negligible.
Curlew	Red	1	0	11	No. Insufficient records available for a robust assessment of collision risk. In addition, the very small number of flights across two years indicate that collision risk for this species is negligible.
Black-headed gull	**Amber, SPA**	**92**	**7**	**1-128**	**Yes. Species recorded frequently within the CRZ, is an amber-listed species of conservation concern, and the Site has potential connectivity to SPA populations.**

Common gull	**Amber, SPA**	**82**	**21**	**1-140**	**Yes. Species recorded frequently within the CRZ, is an amber-listed species of conservation concern, and the Site has potential connectivity to SPA populations.**
Herring gull	**Amber, SPA**	**108**	**11**	**1-140**	**Yes. Species recorded frequently within the CRZ, is an amber-listed species of conservation concern, and the Site has potential connectivity to SPA populations.**
Lesser black-backed gull	**Amber**	**23**	**5**	**1-11**	**Yes. Species recorded frequently within the CRZ,and is an amber-listed species of conservation concern.**
Cormorant	Amber	3	2	1	No. Insufficient records available for a robust assessment of collision risk. In addition, the very small number of flights across two years indicate that collision risk for this species is negligible.
Grey heron	Green	11	12	1-2	No. This is not a species of conservation concern and has therefore been scoped-out of CRM.
Little egret	Green, Annex I	6	1	1	No. Insufficient records available for a robust assessment of collision risk. In addition, the very small number of flights across two years indicate that collision risk for this species is negligible.
Sparrowhawk	Green	27	31	1-2	No. This is not a species of conservation concern and has therefore been scoped-out of CRM.
Red kite	Red; Annex I	1	0	1	No. Insufficient records available for a robust assessment of collision risk. In addition, the very small number of flights across two years indicate that collision risk for this species is negligible.
Buzzard	Green	166	172	1-5	No. This is not a species of conservation concern and has therefore been scoped-out of CRM.
Kestrel	**Red**	**2**	**10**	**1**	**Yes. Species recorded frequently within the CRZ and is a red-listed species of conservation concern.**

Merlin	Amber; Annex I	1	0	1	No. Insufficient records available for a robust assessment of collision risk. In addition, the very small number of flights across two years indicate that collision risk for this species is negligible.
Peregrine	**Green, Annex I**	**41**	**32**	**1-4**	**Yes. Species recorded frequently within the CRZ and is listed on Annex I.**
Total		**569**	**312**		
** Annex I: listed on Annex I of the Bird's Directive, Red/Amber/Green: Birds of Conservation Concern in Ireland Classification, SPA: species is a designated feature of a nearby SPA and has potential connectivity to the Site.					

Table 2. Turbine Parameters used in CRM.

Turbine parameter	Unit	Lowest Risk Turbine	Moderate Risk Turbine	Highest Risk Turbine
Number of blades	N/A	3	3	3
Hub height	m	105	102.5	98
Rotor diameter	m	149.1	155	163
Minimum swept height	m	30.5	25	16.5
Maximum swept height	m	179.5	180	179.5
Maximum chord of rotor blade	m	4	4	4
Blade pitch	°	5	5	5
Average rotor speed	rpm	9.5	7.66	8.8
Average rotational period	seconds	6.52	7.84	6.82
Turbine operation time*	%	85	85	85
*This operational period of 85% is referenced from a report by the British Wind Energy Association (BWEA) (2007) which identifies the standard operational period of the wind turbines in the UK to be roughly 85%.				

Table 3. Species biometrics used in CRM*.

Species	Bird length (cm)	Bird wingspan (cm)	Flight speed** (m/s)	Avoidance rate*** (%)	Breeding season****	Non-breeding season*****
Black-headed gull	36	105	11.9	99.2%	April to August	September to March
Common gull	41	120	11.9	99.2%	April to August	September to March
Herring gull	60	144	12.8	99.5%	April to August	September to March
Lesser black-backed gull	58	143	11.9	99.5%	April to August	September to March
Kestrel	34	76	10.1	95%	March to mid-August	Mid-August to February
Peregrine	42	103	12.1	98%	March to mid-August	Mid-August to February

*Species biometrics are taken from Snow *et al*. (1998)
**Species flight speeds are taken from Alerstam *et al*. (2007), Bruderer & Bolt (2001) and Provan & Whitfield (2006)
***Species avoidance rates are taken from NatureScot (SNH, 2018) and Furness (2019)
****The breeding season for each species is taken from NatureScot guidance (SNH, 2014). All dates are inclusive.
*****Non-breeding seasons are the remaining months of the year

For each species scoped into the CRM, the risk of collision for an individual was calculated by estimating the likelihood of collision based on the characteristics of the birds and of the turbine parameters, using the Band et al. (2007) model. The model runs as a two-stage process:

- **Stage 1**: calculating the number of birds flying through the rotors; and
- **Stage 2**: estimating the probability of a bird flying through the rotors being hit.

Stage 1 is a purely mechanistic calculation, to determine the number of birds present transiting through the rotors. Stage 2 incorporates the probability of a bird colliding with the rotors, and that birds will take avoiding action.

3.1 Stage 1 – Number of birds flying through the rotors

This stage involves a number of sequential steps:

1. Identify a 'flight risk volume' V_w (m^3) which is the area of the Collision Risk Zone (the CRZ; a 500 m buffer of the turbine layout) multiplied by the diameter of the rotors:

$$V_w = Area_{CRZ} \times rotor\ diameter$$

2. The combined 'rotor swept volume' V_r (m^3) for the wind farm rotors is then calculated:

$$V_r = X\,\pi R^2\,(d + l)$$

where X is the number of turbines, R is rotor radius, d is the blade depth and l is the bird length of a species in metres.

3. The time taken for a bird to make a transit through the rotor and completely clear the rotors (t) is then calculated:

$$t = \frac{d + l}{v}$$

where d is the blade depth (m), l is the bird length (m) of a species and v (m/sec) is the speed of the bird through the rotor. Bird length and flight speed are provided in key literature. This equation assumes a straight line of flight through the rotors.

4. Estimate the bird occupancy n within the flight risk volume for each VP. This is the This is the number of birds present within the V_w, multiplied by the time spent flying at Potential Collision Height (PCH), within the period (per year, per breeding season, or per non-breeding season as outlined in Table 3) for which the collision estimate is being made. n is calculated as follows:

$$t^1 = \frac{\text{Flight time at PCH}}{\text{Observation effort}}$$
$$F = \frac{t^1}{\text{VP viewshed area}}$$
$$t_{risk} = F \times \text{CRZ area}$$
$$n = F \times \text{Available flight time in season}$$

5. Within this stage, a weighting adjustment can be applied to the value for bird occupancy n, which is intended to take account of the fact that flight observations are recorded from different vantage points (VPs), that the viewshed areas from each VP are different sizes (in terms of total hectarage), and that the combination of the areas seen from all VPs may not always incorporate the entire site being assessed. The unweighted value, n_{avg} is calculated using Equation 5:

$$n_{avg} = \frac{n_{\mathrm{VP1}} + n_{\mathrm{VP2}} + n_{\mathrm{VP3}} + n_{\mathrm{VP4}}}{4}$$

The weighting factor for each VP is worked out by the percentage cover of the viewshed of each VP within the CRZ (see Figures in Appendix 1), as well as the combined percentage coverage of the CRZ from all VPs (excluding any overlapping areas). This report includes calculations for both unweighted and weighted occupancy values. $n_{avg\_weighted}$ is calculated using Equation 6:

i) $Weighting = \frac{\mathrm{VP}_{Area}}{\mathrm{CRZ}_{Area}}$

ii) $Total_{Weighting}\ \left(\frac{Weighting_{\mathrm{VP1}}+Weighting_{\mathrm{VP2}}+Weighting_{\mathrm{VP3}}+Weighting_{\mathrm{VP4}}}{4}\right) \div$
$\%\ coverage\ of\ CRZ\ by\ combined\ viewsheds$

iii) $n_{avg\_weighted} = n_{avg} \div Total_{Weighting}$

6. The bird occupancy of the volume swept by the rotors (b) in birds-secs is then calculated:

$$b = n\left(\frac{V_r}{V_w}\right)$$

7. To calculate the number of bird transits through the rotors N, divide the total occupancy of the volume swept by the rotors in bird-secs by the transit time t:

$$N = \frac{b}{t}$$

Note in this calculation that the factor $(d + l)$ cancels itself out, so only assumed values need be used - it is used above to help visualise the calculation.

8. Finally, the number of bird transits are adjusted to correct for the proportion of time that turbines are operational. British Wind Energy Association (BWEA) (2007) which identifies the standard operational period of the wind turbines in the UK to be roughly 85%. Tn is therefore calculated as follows:

$$T_n = N \times 0.85$$

3.2 Stage 2 – Probability of a bird being hit when flying through the rotors

This stage uses data relating to bird and turbine parameters to calculate the likelihood of a bird being hit when flying through the turbine rotor. The turbine parameters used in the CRM are shown in **Table** 2. It should be acknowledged that there are many approximations used when calculating probability of collision, and that predicted collision rates give an indication of the risk with a presumed accuracy of around ±10%, rather than an exact figure.

Data relating to the likelihood of a bird being hit when flying through the rotor is derived from a spreadsheet available from NatureScot[1]. The outputs from this spreadsheet are provided for species modelled in Table 4, while the spreadsheet for black-headed gull is provided in Appendix 2.

[1] https://www.nature.scot/doc/wind-farm-impacts-birds-calculating-probability-collision

Table 4. Average Collision Probability for each Species and Turbine Model.

Species	Lowest Risk Turbine			Moderate Risk Turbine			Highest Risk Turbine		
	Probability of collision - upwind	Probability of collision - downwind	Average probability of collision	Probability of collision - upwind	Probability of collision - downwind	Average probability of collision	Probability of collision - upwind	Probability of collision - downwind	Average probability of collision
Black-headed gull	5.65%	4.15%	**4.90%**	5.21%	3.96%	**4.58%**	5.25%	3.81%	**4.53%**
Common gull	5.89%	4.38%	**5.14%**	5.42%	4.17%	**4.79%**	5.47%	4.03%	**4.75%**
Herring gull	6.42%	5.02%	**5.72%**	5.87%	4.70%	**5.28%**	5.98%	4.64%	**5.31%**
Lesser black-backed gull	6.54%	5.03%	**5.79%**	5.96%	4.70%	**5.33%**	6.09%	4.65%	**5.37%**
Kestrel	5.78%	4.01%	**4.89%**	5.27%	3.79%	**4.53%**	5.39%	3.69%	**4.54%**
Peregrine	5.79%	4.31%	**5.05%**	5.31%	4.08%	**4.69%**	5.39%	3.97%	**4.68%**
Collision probability assumes flapping flight for all species. This has been used based on the flight habits recorded during surveys, and also as a precaution as it increases probability of collision in comparison to gliding flight.									

Following Stage 1, the number of bird transits per year through the rotors (T_n) can be combined with the probability of a bird being hit when flying through the rotor to give a predicted collision risk per year (assuming no avoidance). An avoidance figure is applied to get a predicted number of collisions, and thus a likely mortality rate. Avoidance rates are taken from applicable literature including NatureScot (SNH, 2018) and Furness (2019). This stage also accounts for the proportion of time that turbines are likely to be operational. The modelling then provides an estimate of the number of collisions predicted for each species per annum and for the operational lifespan of the project (35 years), as presented in **Section 5**.

4. Baseline Survey Data

4.1 Viewshed Coverage and Survey Effort

VPS were undertaken for two years from four Vantage Point locations. The methods and full results of VPS are outlined in Appendices A7.1, A7.2 and A7.3. Viewshed coverage was calculated using GIS and was ground-truthed by surveyors in the field to confirm accuracy. Viewsheds were calculated for each turbine model and show the visible area from each Vantage Point at the lowest rotor swept height for each turbine model. In line with NatureScot (2017) guidance, 36 hours of VPS were undertaken from each VP during each season, giving a total of 144 hours survey effort across two years. **Table 5** outlines the viewshed coverage from each VP, which is illustrated in Figures (Appendix 1).

Table 5. VP Viewshed Coverage and Survey Effort.

Vantage Point	Viewshed coverage within 500m of the turbine layout at 30.5m – Lowest Risk turbine (ha)	Viewshed coverage within 500m of the turbine layout at 25m- Moderate Risk Turbine (ha)	Viewshed coverage within 500m of the turbine layout at 16.5m -Highest Risk Turbine (ha)	Survey effort (hours)
VP1	195.44 ha	183.45 ha	165.00 ha	144
VP2	194.26 ha	180.12 ha	152.06 ha	144
VP3	271.01 ha	262.61 ha	237.24 ha	144
VP4	201.64 ha	150.98 ha	81.94 ha	144
Total of viewshed areas	862.35 ha	777.17 ha	636.23 ha	
Area within the CRZ which is covered by at least one viewshed	325.45 ha	320.89 ha	295.58 ha	
Percentage coverage of CRZ by combined viewsheds	99.23%	97.84%	90.12%	

4.2 Flight activity of species scoped into CRM

VPS were undertaken between September 2021 and September 2023. The number of flight seconds at PCH (for each turbine model) within the CRZ for species scoped into the CRM is outlined in Table 6, Table 7 and Table 8.

Table 6. Species flight seconds at PCH of the Lowest Risk Turbine within the CRZ recorded at each Vantage Point.

Species	Season	Seconds at PCH within the CRZ recorded from VP1	Seconds at PCH within the CRZ recorded from VP2	Seconds at PCH within the CRZ recorded from VP3	Seconds at PCH within the CRZ recorded from VP4	Total
Black-headed gull	Non-breeding season: September to March	2,110	22,212	36,346	24,789	**85,457**
Common gull	Non-breeding season: September to March	1,095	3,963	4,194	18,552	**27,804**
	Breeding season: April to August	0	0	15,897	835	**16,732**
Herring gull	Non-breeding season: September to March	1,662	1,558	3,879	6,082	**13,181**
	Breeding season: April to August	303	50	20,603	1,077	**22,033**
Lesser black-backed gull	Non-breeding season: September to March	0	0	71	0	**71**
	Breeding season: April to August	144	421	2,222	43	**2,830**
Kestrel	Year round	93	0	0	0	**93**
Peregrine	Non-breeding season: mid-August to February	131	221	620	0	**972**
	Breeding season: April to August	2,475	2,453	2,222	114	**7,264**

Table 7. Species flight seconds at PCH of the Moderate Risk Turbine within the CRZ recorded at each Vantage Point.

Species	Season	Seconds at PCH within the CRZ recorded from VP1	Seconds at PCH within the CRZ recorded from VP2	Seconds at PCH within the CRZ recorded from VP3	Seconds at PCH within the CRZ recorded from VP4	Total
Black-headed gull	Non-breeding season: September to March	3,304	68,254	37,361	26,932	**138,851**
Common gull	Non-breeding season: September to March	2,144	57,865	4,357	19,517	**83,883**
	Breeding season: April to August	45	0	15,897	835	**16,777**
Herring gull	Non-breeding season: September to March	1,914	5,471	9,878	17,621	**34,884**
	Breeding season: April to August	303	75	2,0603	1,077	**22,058**
Lesser black-backed gull	Non-breeding season: September to March	0	218	192	660	**1,070**
	Breeding season: April to August	144	421	2,222	43	**2,830**
Kestrel	Year round	151	36	0	0	**187**
Peregrine	Non-breeding season: mid-August to February	187	266	620	0	**1,073**
	Breeding season: April to August	2,475	2,453	2,563	114	**7,605**

Table 8. Species flight seconds at PCH of the Highest Risk Turbine within the CRZ recorded at each Vantage Point.

Species	Season	Seconds at PCH within the CRZ recorded from VP1	Seconds at PCH within the CRZ recorded from VP2	Seconds at PCH within the CRZ recorded from VP3	Seconds at PCH within the CRZ recorded from VP4	Total
Black-headed gull	Non-breeding season: September to March	4,855	76,009	44,472	31,714	**157,050**
Common gull	Non-breeding season: September to March	6,640	58,477	14,739	23,322	**103,178**
	Breeding season: April to August	45	0	15,897	835	**16,777**
Herring gull	Non-breeding season: September to March	4,137	24,025	11,985	18,860	**59,007**
	Breeding season: April to August	303	75	21,329	1,077	**22,784**
Lesser black-backed gull	Non-breeding season: September to March	0	218	487	1,010	**1,715**
	Breeding season: April to August	156	421	2,222	43	**2,842**
Kestrel	Year round	151	0	155	0	**306**
Peregrine	Non-breeding season: mid-August to February	187	355	620	98	**1,260**
	Breeding season: April to August	0	218	487	1,010	**7,660**

5. Collision Risk Modelling Results

As detailed above, CRM is undertaken in two stages, with Stage 1 being to ascertain the number of bird flights through the rotors and Stage 2 being to ascertain the probability of a bird being hit by the rotors as it passes through.

5.1 Stage 1 - Number of birds flying through rotors

The first part of Stage 1 is defining the 'flight risk volume' V_w. This is derived by calculating the area within the CRZ (3,279,804 m^2) multiplied by the rotor diameter calculated at Step 1 (**Section 3.1**):

- V_w Lowest Risk Turbine $= 3{,}279{,}804\text{m}^2 \times 149.10\text{m} = 489{,}018{,}776.40\text{m}^3$
- V_w Lowest Risk Turbine $= 3{,}279{,}804\text{m}^2 \times 155.00\text{m} = 508{,}369{,}620.00\text{m}^3$
- V_w Lowest Risk Turbine $= 3{,}279{,}804\text{m}^2 \times 163.00\text{m} = 534{,}608{,}052.00\text{m}^3$

The 'rotor swept volume' V_r is then worked out based on the rotor swept area multiplied by the number of turbines, the depth of the rotor and the length of the bird. This is shown for the specified turbine models in **Table 9** and calculated using in Step 2 (**Section 3.1**). Also shown in **Table 9** is t, which is the time taken for a bird to pass through the turbine rotors, calculated using in Step 3 (**Section 3.1**).

Table 9. Rotor Swept Volume for each turbine and time taken for bird to pass through turbine rotor

Species	N149 V_r (m^3)	SG155 V_r (m^3)	N163 V_r (m^3)	t (secs)
Black-headed gull	380,628.81	411,348.36	454,905.91	0.37
Common gull	384,993.82	416,065.66	460,122.73	0.37
Herring gull	401,580.86	433,991.39	479,946.61	0.36
Lesser black-backed gull	399,834.86	432,104.47	477,859.88	0.38
Kestrel	378,882.81	409,461.44	452,819.19	0.43
Peregrine	385,866.83	417,009.12	461,166.09	0.37

$$t^1 = \frac{\text{Flight time at PCH}}{\text{Observation effort}}$$

$$F = \frac{t^1}{\text{VP viewshed area}}$$

$$t_{risk} = F \times \text{CRZ area}$$

$$n = t_{risk} \times \text{Available flight time in season}$$

The next step of the calculations (Step 4 [**Section 3.1**]) is to determine the bird occupancy n within the rotor swept volume. This is worked out individually for each VP and then averaged to find the mean occupancy across the site.

Occupancy n is then calculated through a number of stages outlined in Step 4 (**Section 3.1**) by dividing the flight time at PCH by a species from a VP by the observation effort, and then dividing that value by the viewshed area for each VP, multiplying this by the CRZ area, and finally multiplying this by the total hours the target species could be active.

The time a species could be active is defined as the product of the daylight hours (species modelled have been considered diurnal) within a year when the species could be present, in accordance with guidance as outlined in Table 3. Table 6, Table 7 and Table 8 show the periods when species were present during surveys. Species are assumed to be present during the operational phase during the same months they were recorded during baseline surveys. The figures calculated for occupancy, which is then converted into bird-seconds, are shown in Tables 10-12.

For example, for black-headed gull from VP1 for the Highest Risk Turbine:

$$t^1 = \frac{4{,}855 \text{ secs}}{81 \text{ hours}} = 0.017$$

$$F = \frac{t^1}{165\text{ha}} = 0.0001$$

$$t_{risk} = F \times \text{CRZ area} = 0.033$$

$$n = F \times 2024.5 = 67.00$$

n_{avg} is then calculated by taking the average of n for each VP.

Table 10. Occupancy n (bird-secs per season) for species modelled from each vantage point for Lowest Risk Turbine.

Species	Season	n VP1	n VP2	n VP3	n VP4	n_{avg}
Black-headed gull	Non-breeding season	24.58	251.07	305.38	379.94	**215.24**
Common gull	Non-breeding season	12.76	44.80	35.24	209.51	**75.57**
	Breeding season	0	0	203.03	13.68	**54.18**
Herring gull	Non-breeding season	19.36	17.61	32.59	68.68	**34.56**
	Breeding season	5.37	0.89	263.13	17.65	**71.76**
Lesser black-backed gull	Non-breeding season	0	0	0.60	0	**0.15**
	Breeding season	2.55	7.50	28.38	0.70	**9.78**
Kestrel	Year-round	1.33	0	0	0	**0.33**
Peregrine	Non-breeding season	1.27	2.23	4.68	0	**2.05**
	Breeding season	46.83	44.76	29.06	2.09	**30.68**

Table 11. Occupancy n (bird-secs) for species modelled from each vantage point for Moderate Risk Turbine

Species	Season	n VP1	n VP2	n VP3	n VP4	n_{avg}
Black-headed gull	Non-breeding season	4.01	83.03	323.95	406.20	**400.80**
Common gull	Non-breeding season	26.61	705.39	37.78	294.37	**266.04**
	Breeding season	0.85	0	209.53	18.27	**57.16**
Herring gull	Non-breeding season	23.76	66.69	85.65	265.77	**110.47**
	Breeding season	5.72	1.44	271.55	23.57	**75.57**
Lesser black-backed gull	Non-breeding season	0	2.66	1.66	9.95	**3.57**
	Breeding season	2.72	8.09	29.29	0.94	**10.26**
Kestrel	Year-round	2.30	0.56	0	0	**0.71**
Peregrine	Non-breeding season	1.93	2.90	4.83	0	**2.41**
	Breeding season	49.89	48.27	34.59	2.79	**33.89**

Table 12. Occupancy n (bird-secs) for species modelled from each vantage point for Highest Risk Turbine.

Species	Season	n VP1	n VP2	n VP3	n VP4	n_{avg}
Black-headed gull	Non-breeding season	67.00	1,097.61	426.85	881.28	**618.19**
Common gull	Non-breeding season	91.64	844.44	141.47	648.08	**431.40**
	Breeding season	0.94	0	231.94	33.67	**66.64**
Herring gull	Non-breeding season	57.09	346.93	115.03	524.09	**260.79**
	Breeding season	6.36	1.71	311.19	859.99	**294.81**
Lesser black-backed gull	Non-breeding season	0	3.15	4.67	28.07	**8.97**
	Breeding season	3.27	9.58	32.42	1.73	**11.75**
Kestrel	Year-round	2.56	0	1.83	0	**1.10**

Species	Season	n VP1	n VP2	n VP3	n VP4	n_{avg}
Peregrine	Non-breeding season	2.14	4.59	5.35	2.26	**3.58**
	Breeding season	55.48	57.18	39.11	5.15	**39.23**

Once a value for n and n_{avg} have been calculated for each VP, a weighting factor is used to account for the varying extents of coverage from each VP as well as the combined coverage from each VP not covering the entire CRZ. Weighted values for bird occupancy (n_{avg}) were calculated using the values for percentage cover outlined within Table 5.

The weighting factor is calculated as shown in Step 5 (**Section 3.1**).

Table 13. Values obtained for bird occupancy n_{avg} and $n_{(weighted)avg}$ (bird-secs) for each species and turbine model.

Species	Season	Lowest Risk Turbine		Moderate Risk Turbine		Highest Risk Turbine	
		n_{avg}	$n_{weighted\ avg}$	n_{avg}	$n_{weighted\ avg}$	n_{avg}	$n_{weighted\ avg}$
Black-headed gull	Non-breeding season	215.24	148.09	400.80	236.68	618.19	297.24
Common gull	Non-breeding season	75.57	48.39	266.04	145.15	431.40	194.69
	Breeding season	54.18	44.39	57.16	45.14	66.64	49.00
Herring gull	Non-breeding season	34.56	22.96	110.47	61.54	260.79	111.99
	Breeding season	71.76	58.45	75.57	59.35	294.81	123.15
Lesser black-backed gull	Non-breeding season	0.15	0.12	3.57	1.88	8.97	3.29
	Breeding season	9.78	7.52	10.26	7.63	11.75	8.31
Kestrel	Year-round	0.33	0.20	0.71	0.41	1.10	0.72
Peregrine	Non-breeding season	2.05	1.50	2.41	1.67	3.58	2.12
	Breeding season	30.68	20.08	33.89	21.31	39.23	23.30

The bird occupancy of the rotor swept volume b is then worked out as shown in Step 6 (Section 3.1) by multiplying n_{avg} by $\frac{V_r}{V_w}$.

An example is provided for black-headed gull for the Highest Risk Turbine:

$$618.19 \times \left(\frac{454905.91}{534608052}\right) \times 3600 = 1{,}839.69$$

The bird occupancy of the swept volume b is used to determine the number of bird transits through the rotors N by dividing b by the rotor transit time t (see Step 7, Section 3.1).

An example is provided for black-headed gull for the Highest Risk Turbine:

$$\frac{1{,}893.69}{0.37} = 5{,}168.56$$

The number of transits through the rotors N is then adjusted by a factor of 0.85[2] to obtain Tn, which accounts for likely wind turbine down time. Calculations for the number of transits through turbine rotors taking are shown in Tables 14-16.

An example is provided for black-headed gull for the Highest Risk Turbine:

$$5{,}168.56 \times 0.85 = 4393.27$$

Table 14. Rotor transits for each species associated with Lowest Risk Turbine.

Species	Season	Unweighted			Weighted		
		b	*N*	*Tn*	*b*	*N*	*Tn*
Black-headed gull	Non-breeding season	603.13	1,646.15	1399.23	414.96	1,132.57	962.68
Common gull	Non-breeding season	214.19	577.98	491.28	137.14	370.05	314.54
	Breeding season	153.55	414.35	352.19	125.80	339.46	288.54
Herring gull	Non-breeding season	102.18	284.32	241.67	67.87	188.86	160.53
	Breeding season	212.14	590.31	501.76	172.80	480.84	408.71
Lesser black-backed gull	Non-breeding season	0.44	1.14	0.97	0.37	0.95	0.81
	Breeding season	28.80	74.82	63.60	22.13	57.51	48.88
Kestrel	Year-round	0.93	2.16	1.83	0.56	1.30	1.10
Peregrine	Non-breeding season	0.44	1.14	0.97	0.37	0.95	0.81
	Breeding season	28.80	74.82	63.60	22.13	57.51	48.88

Table 15. Rotor transits for each species associated with Moderate Risk Turbine.

Species	Season	Unweighted			Weighted		
		b	*N*	*Tn*	*b*	*N*	*Tn*
Black-headed gull	Non-breeding season	1,167.51	3,186.54	2,708.56	689.44	1,881.72	1,599.46
Common gull	Non-breeding season	266.04	783.84	2,115.11	1797.85	427.65	1,153.97
	Breeding season	168.42	454.46	386.30	133.00	358.88	305.05
Herring gull	Non-breeding season	110.47	339.50	944.69	802.99	189.13	526.27
	Breeding season	75.57	232.25	646.25	549.32	182.40	507.55
Lesser black-backed gull	Non-breeding season	3.57	10.92	28.38	24.12	5.77	14.98
	Breeding season	10.26	31.39	81.56	69.33	23.34	60.63
Kestrel	Year-round	0.71	2.07	4.82	4.10	1.18	2.75

[2] This operational period of 85% is referenced from a report by the British Wind Energy Association (BWEA) (2007) which identifies the standard operational period of the wind turbines in the UK to be roughly 85%.

Species	Season	Unweighted			Weighted		
		b	*N*	*Tn*	*b*	*N*	*Tn*
Peregrine	Non-breeding season	2.41	7.13	19.52	16.59	4.93	13.50
	Breeding season	33.89	100.07	273.94	232.85	62.93	172.28

Table 16. Rotor transits for each species associated with Highest Risk Turbine.

Species	Season	Unweighted			Weighted		
		b	*N*	*Tn*	*b*	*N*	*Tn*
Black-headed gull	Non-breeding season	1,893.69	5,168.56	4,393.27	910.55	2,485.21	2,112.43
Common gull	Non-breeding season	1,336.68	3,606.92	3,065.88	603.25	1,627.81	1,383.64
	Breeding season	206.47	557.14	473.57	151.84	409.72	348.26
Herring gull	Non-breeding season	842.85	2,345.31	1,993.51	361.95	1,007.17	856.09
	Breeding season	952.80	2,651.27	2,253.58	398.02	1,107.53	941.40
Lesser black-backed gull	Non-breeding season	37.82	98.26	83.52	26.75	69.52	59.09
	Breeding season	37.82	98.26	83.52	26.75	69.52	59.09
Kestrel	Year-round	3.34	7.78	6.61	2.21	5.13	4.36
Peregrine	Non-breeding season	11.13	30.46	25.89	6.58	18.01	15.31
	Breeding season	121.82	333.49	283.47	72.36	198.08	168.37

5.2 Stage 2 - Probability of a bird being hit when flying through the rotors

Tables 17-19 provide the predicted collisions for each species modelled, for each turbine model. An average collision probability is applied within the CRM based on the collision probability travelling upwind and downwind. All CRM calculations were undertaken assuming flapping flight rather than gliding, which is precautionary and gives higher predicted collisions when compared to gliding flight behaviour. The collision probability spreadsheet for black-headed gull for the Highest Risk Turbine is included in Appendix 2.

The average probability of collision value from Table 4 is applied to T_n to determine the number of collisions before avoidance rates are applied. An avoidance rate is applied to this value using avoidance rates detailed in Table 3 to provide a predicted 'collisions per year' for each species and turbine model.

Table 17. Predicted collisions for each species for Lowest Risk turbine.

Species	Unweighted			Weighted		
	Collisions per year/season *(with avoidance)	Collisions per 35 years*	Number of years/seasons for one collision	Collisions per year/season (with avoidance)	Collisions per 35 years**	Number of years/seasons for one collision
Black-headed gull – non-breeding season/annual***	0.55	19.20	1.82	0.38	13.21	2.65
Common gull – non-breeding season	0.20	6.06	4.95	0.13	3.88	7.73
Common gull – breeding season	0.14	5.07	6.91	0.12	4.15	8.43
Common gull – annual	0.35	12.14	2.88	0.25	8.68	4.03
Herring gull – non-breeding season	0.07	2.07	14.47	0.05	1.38	21.78
Herring gull – breeding season	0.14	5.02	6.97	0.12	4.09	8.55
Herring gull - annual	0.21	7.44	4.70	0.16	5.70	6.14
Lesser black-backed gull – non-breeding season	<0.01	0.01	3562.95	<0.01	0.01	4278.65
Lesser black-backed gull – breeding season	0.02	0.64	54.31	0.01	0.50	70.67
Lesser black-backed gull – annual	0.02	0.65	53.50	0.01	0.50	69.52
Kestrel – annual****	<0.01	0.16	222.94	<0.01	0.09	371.23
Peregrine – non-breeding season	0.01	0.41	73.23	0.01	0.30	99.99
Peregrine – breeding season	0.20	7.17	4.88	0.13	4.69	7.46
Peregrine - annual	0.22	7.65	4.58	0.14	5.04	6.94

Species	Unweighted			Weighted		
	Collisions per year/season *(with avoidance)	Collisions per 35 years*	Number of years/seasons for one collision	Collisions per year/season (with avoidance)	Collisions per 35 years**	Number of years/seasons for one collision

*Seasons are based on NatureScot (SNH, 2014) guidance

**Thirty-five years is the proposed operational lifespan of the wind farm.

***Black-headed gull was only recorded during the non-breeding season.

****As kestrel was recorded extremely rarely, it was not considered necessary to calculate collisions by season.

Table 18. Predicted collisions for each species for Moderate Risk Turbine.

Species	Unweighted			Weighted		
	Collisions per year/season *(with avoidance)	Collisions per 35 years*	Number of years/seasons for one collision	Collisions per year/season (with avoidance)	Collisions per 35 years**	Number of years/seasons for one collision
Black-headed gull – non-breeding season/annual***	0.99	34.73	1.01	0.59	20.51	1.71
Common gull – non-breeding season	0.69	20.67	1.45	0.38	11.28	2.66
Common gull – breeding season	0.15	5.18	6.76	0.12	4.09	8.55
Common gull – annual	0.84	29.29	1.19	0.49	17.25	2.03
Herring gull – non-breeding season	0.21	6.36	4.72	0.12	3.54	8.47
Herring gull – breeding season	0.15	5.08	6.90	0.11	3.99	8.78
Herring gull - annual	0.36	12.50	2.80	0.23	8.12	4.31
Lesser black-backed gull – non-breeding season	0.01	0.19	155.57	0.00	0.10	294.66
Lesser black-backed gull – breeding season	0.02	0.65	54.13	0.01	0.48	72.81
Lesser black-backed gull – annual	0.02	0.87	40.15	0.02	0.60	58.38
Kestrel – annual****	0.01	0.38	92.39	0.01	0.22	162.17
Peregrine – non-breeding season	0.02	0.47	64.27	0.01	0.32	92.87
Peregrine – breeding season	0.22	7.64	4.58	0.14	4.81	7.28
Peregrine - annual	0.23	8.19	4.27	0.15	5.18	6.75

Species	Unweighted			Weighted		
	Collisions per year/season *(with avoidance)	Collisions per 35 years*	Number of years/seasons for one collision	Collisions per year/season (with avoidance)	Collisions per 35 years**	Number of years/seasons for one collision

*Seasons are based on NatureScot (SNH, 2014) guidance

**Thirty-five years is the proposed operational lifespan of the wind farm.

***Black-headed gull was only recorded during the non-breeding season.

****As kestrel was recorded extremely rarely, it was not considered necessary to calculate collisions by season.

Table 19. Predicted collisions for each species for Highest Risk Turbine.

Species	Unweighted			Weighted		
	Collisions per year/season *(with avoidance)	Collisions per 30 years*	Number of years/seasons for one collision	Collisions per year/season (with avoidance)	Collisions per 35 years**	Number of years/seasons for one collision
Black-headed gull – non-breeding season/annual***	1.59	55.72	0.63	0.77	26.79	1.31
Common gull – non-breeding season	1.17	34.95	0.86	0.53	15.77	1.90
Common gull – breeding season	0.18	6.30	5.56	0.13	4.63	7.56
Common gull – annual	1.34	47.07	0.74	0.66	23.03	1.52
Herring gull – non-breeding season	0.53	15.88	1.89	0.23	6.82	4.40
Herring gull – breeding season	0.60	20.94	1.67	0.25	8.75	4.00
Herring gull - annual	1.13	39.47	0.89	0.48	16.70	2.10
Lesser black-backed gull – non-breeding season	0.02	0.51	58.41	0.01	0.19	159.39
Lesser black-backed gull – breeding season	0.02	0.78	44.59	0.02	0.56	63.03
Lesser black-backed gull – annual	0.04	1.38	25.29	0.02	0.77	45.17
Kestrel – annual****	0.02	0.53	66.63	0.01	0.35	100.96
Peregrine – non-breeding season	0.02	0.73	41.26	0.01	0.43	69.81
Peregrine – breeding season	0.27	9.29	3.77	0.16	5.52	6.35

Species	Unweighted			Weighted		
	Collisions per year/season *(with avoidance)	Collisions per 30 years*	Number of years/seasons for one collision	Collisions per year/season (with avoidance)	Collisions per 35 years**	Number of years/seasons for one collision
Peregrine - annual	0.29	10.13	3.45	0.17	6.02	5.82

*Seasons are based on NatureScot (SNH, 2014) guidance

**Thirty-five years is the proposed operational lifespan of the wind farm.

***Black-headed gull was only recorded during the non-breeding season.

****As kestrel was recorded extremely rarely, it was not considered necessary to calculate collisions by season.

The output figures from stage 1 (bird transits through the rotors per year) and stage 2 (probability of a bird being hit while passing through the rotors) are multiplied to get an estimated collision/mortality rate per year in the absence of any avoidance. A species-specific avoidance rate is then applied to this value (**Table 3**). Unweighted and weighted results are detailed in **Tables 13-15** for each turbine model. When using the predicted collisions to support the impact assessment, the weighted values have been used.

6. Conclusion

The results generated by running NatureScot's recommended approach for CRM moderate levels of predicted collisions for some target species; notably black-headed gull, common gull and herring gull. In a worst-case scenario, for the Highest Risk Turbine, a black-headed gull and common gull collision is predicted approximately every year. A herring gull collision is predicted every 2.10 years. This would be equivalent to 26-27 black-headed gull, 23 common gull, and 16-17 herring gull collisions over the operational lifespan of the wind farm.

In a worst-case scenario, a peregrine collision is predicted every 5.82 years, or 6 collisions during the operational lifespan of the wind farm. A lesser black-backed collision is predicted every 45.17 years, and therefore it is likely that there would be a single collision during the operational lifespan of the wind farm. Predicted collision rates for kestrel are low, and therefore no collisions during the operational lifespan of the wind farm are predicted.

It is important to note that, as is always the case with a modelled approach, the collision risk model outputs are only considered to be indicative of the number of fatalities resulting from the proposed wind farm site and should be considered in conjunction with other impacts. For example, the outputs from the model do not take account of potential displacement of birds from the wind farm site, which would reduce collision risk.

It should be noted that the CRM results detailed above are a worst-case scenario, and that collision risk would be reduced if the Lowest Risk Turbine is selected. In addition, due to the VPS methodology, the predicted collisions are likely to be an overestimate.

Flights recorded during VPS were given a flight range and a flight duration, rather than splitting the flight into discrete height bands. For this reason, where a flight with recorded height range overlapped partially with the rotor swept height of a turbine, the entire flight duration was considered to have been at collision height and included in the model when calculating collision risk.

For example, where a flight was recorded at 0-40m, the entirety of the flight was considered at PCH for the Lowest Risk Turbine, which has a rotor swept height of 30.5-179.5m. Because of this, it is likely that a proportion of the flight seconds included at collision height within the model were in fact above or below rotor height, and therefore the predicted collisions will have been overestimated.

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Appendix 1 Figures

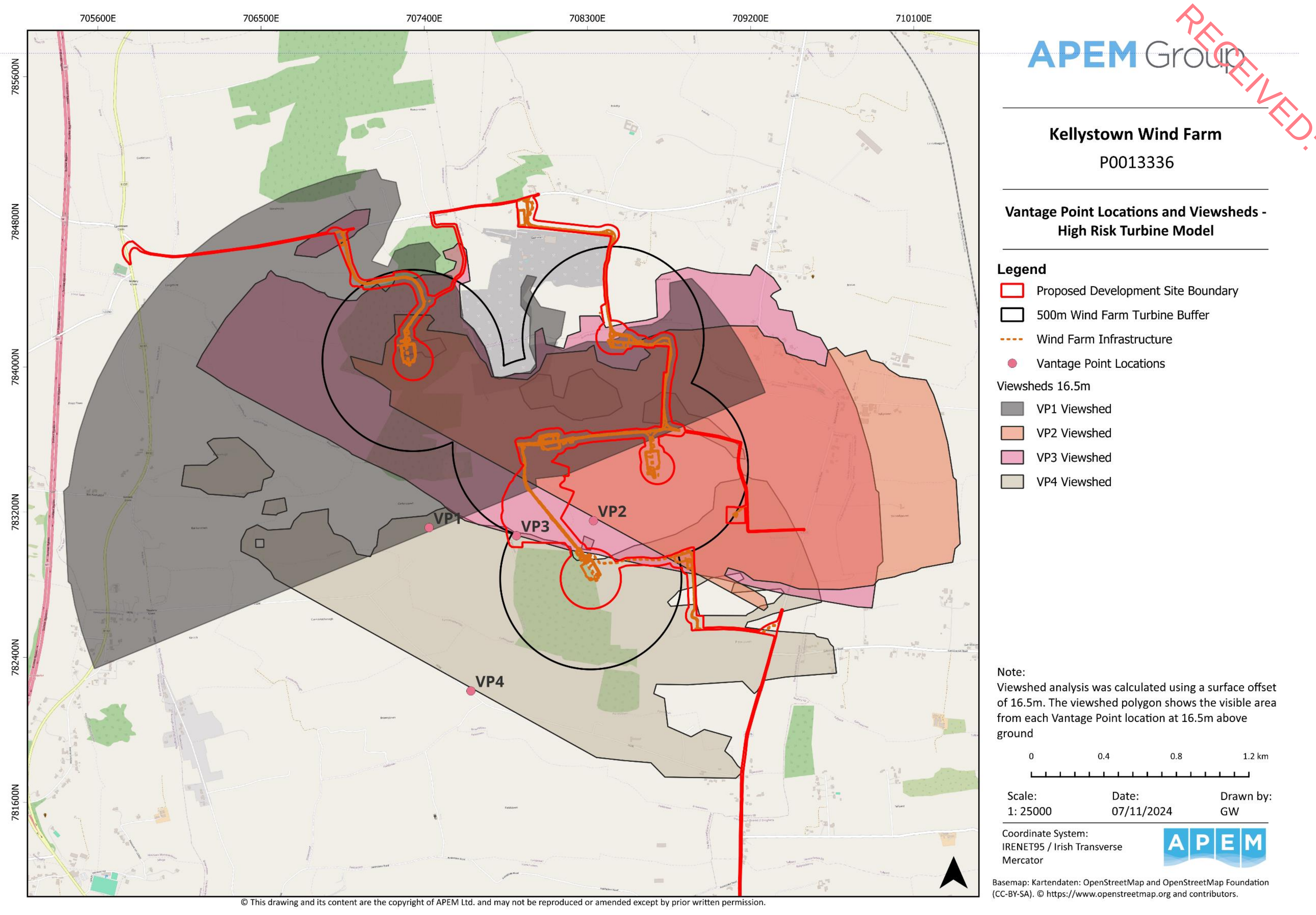

Figure 8.3.1. Vantage Points and Viewsheds – Highest Risk Turbine

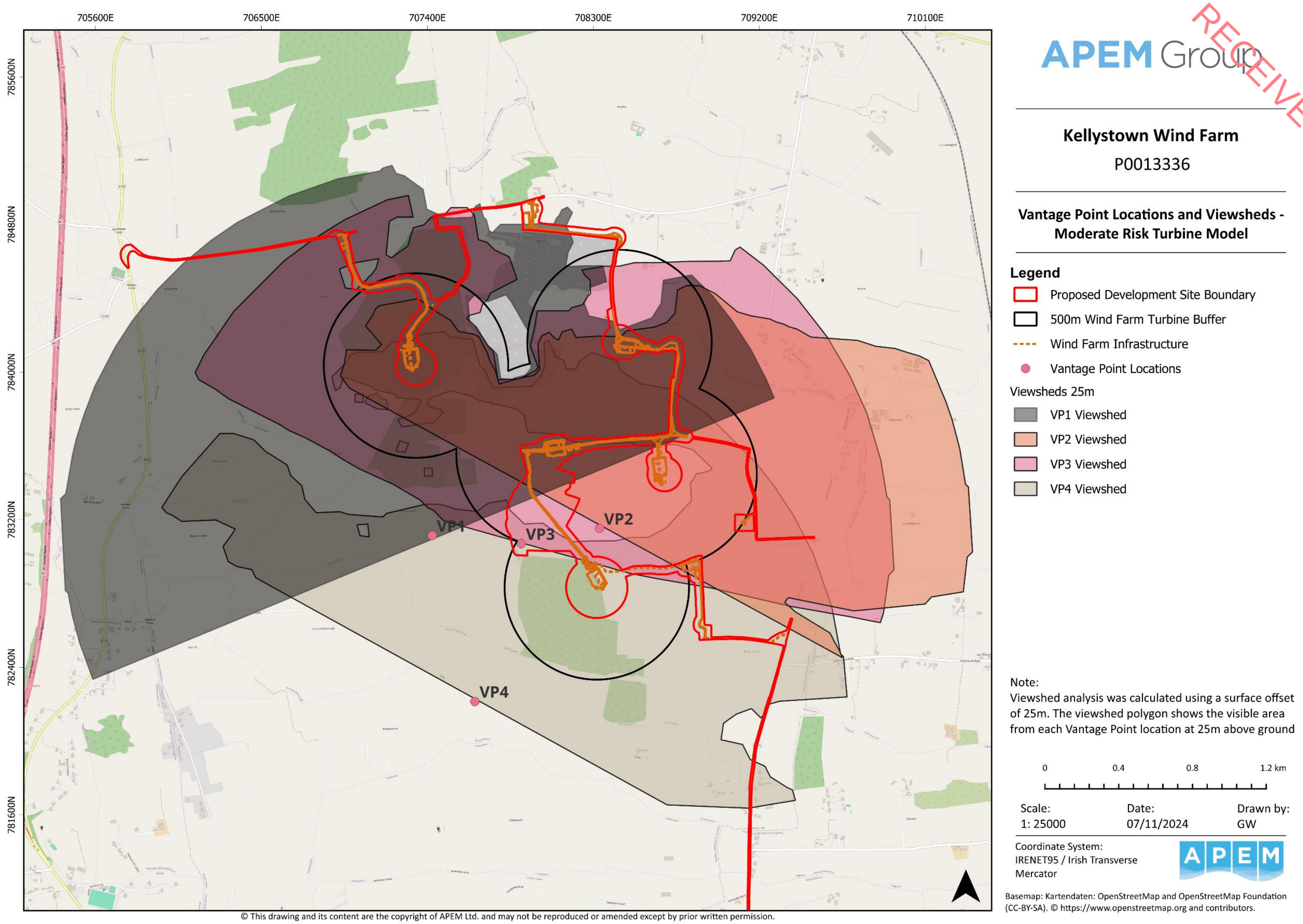

Figure 8.3.2. Vantage Points and Viewsheds – Moderate Risk Turbine

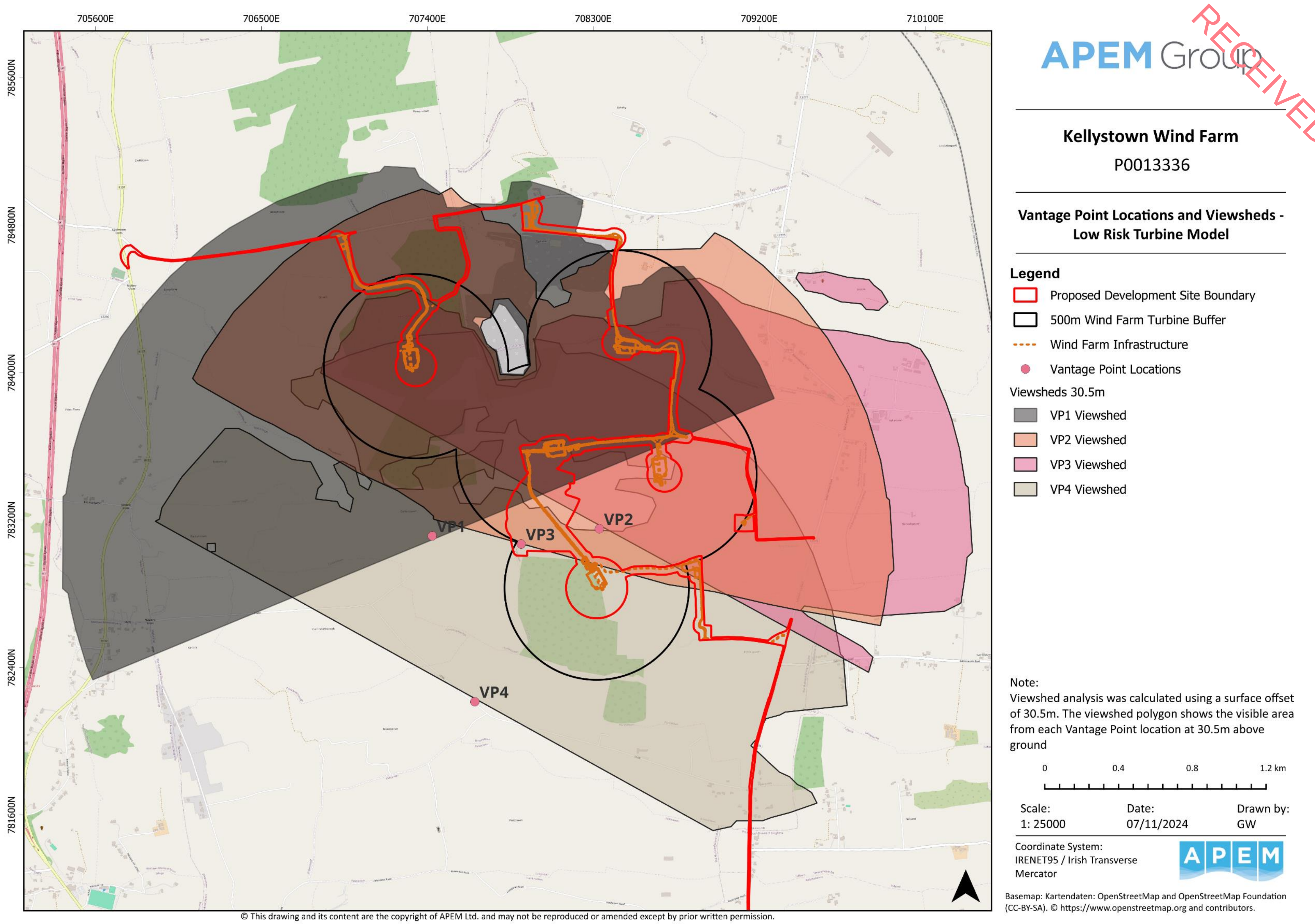

Figure 8.3.3. Vantage Points and Viewsheds – Lowest Risk Turbine

Appendix 2 Collision Probability Spreadsheet

CALCULATION OF COLLISION RISK FOR BIRD PASSING THROUGH ROTOR AREA										W Band	10/09/2024
K: [1D or [3D] (0 or 1)	1		**Calculation of alpha and p(collision) as a function of radius**								
NoBlades	3					Upwind:			Downwind:		
MaxChord	4	m	r/R	c/C	a	collide		contribution	collide		contribution
Pitch (degrees)	5		radius	chord	alpha	length	p(collision)	from radius r	length	p(collision)	from radius r
BirdLength	0.36	m	0.025	0.575	6.34	21.38	0.79	0.00099	20.98	0.78	0.00097
Wingspan	1.05	m	0.075	0.575	2.11	7.26	0.27	0.00201	6.86	0.25	0.00190
F: Flapping (0) or gliding (+1)	0		0.125	0.702	1.27	5.12	0.19	0.00237	4.63	0.17	0.00214
			0.175	0.860	0.91	4.35	0.16	0.00282	3.75	0.14	0.00243
Bird speed	11.9	m/sec	0.225	0.994	0.70	3.88	0.14	0.00322	3.18	0.12	0.00265
RotorDiam	163	m	0.275	0.947	0.58	3.11	0.11	0.00316	2.45	0.09	0.00249
RotationPeriod	6.82	sec	0.325	0.899	0.49	2.57	0.10	0.00309	1.94	0.07	0.00234
			0.375	0.851	0.42	2.17	0.08	0.00301	1.58	0.06	0.00219
			0.425	0.804	0.37	1.87	0.07	0.00293	1.31	0.05	0.00205
			0.475	0.756	0.33	1.63	0.06	0.00286	1.10	0.04	0.00193
Bird aspect ratio: b	0.34		0.525	0.708	0.30	1.46	0.05	0.00283	0.96	0.04	0.00187
			0.575	0.660	0.28	1.32	0.05	0.00280	0.85	0.03	0.00182
			0.625	0.613	0.25	1.19	0.04	0.00276	0.77	0.03	0.00177
			0.675	0.565	0.23	1.09	0.04	0.00271	0.69	0.03	0.00173
			0.725	0.517	0.22	0.99	0.04	0.00266	0.63	0.02	0.00169
			0.775	0.470	0.20	0.91	0.03	0.00260	0.58	0.02	0.00166
			0.825	0.422	0.19	0.83	0.03	0.00253	0.54	0.02	0.00163
			0.875	0.374	0.18	0.76	0.03	0.00246	0.50	0.02	0.00162
			0.925	0.327	0.17	0.70	0.03	0.00238	0.47	0.02	0.00160
			0.975	0.279	0.16	0.64	0.02	0.00230	0.44	0.02	0.00160
				Overall p(collision) =			**Upwind**	**5.25%**		**Downwind**	**3.81%**
								Average	**4.53%**		