Aviation Impact Assessment

Carrick Windfarm

19 October 2021

CL-5502-RPT-002 DG

www.cyrrus.co.uk

info@cyrrus.co.uk

Executive Summary

Cyrrus Limited has been engaged to provide guidance on aviation issues associated with Carrick Windfarm, the Proposed Development in South Ayrshire, south west Scotland. The Proposed Development is anticipated to comprise up to 13 wind turbines with a maximum blade tip height of 200m Above Ground Level (AGL).

Of the aviation stakeholders consulted at scoping, NATS (En Route) [NERL] indicated that it would object to the proposal due to turbines being visible to its Primary Surveillance Radar (PSR) at Lowther Hill. Glasgow Prestwick Airport (GPA) highlighted the cumulative impact caused by close proximity of the Proposed Development to the existing windfarms at Dersalloch and Hadyard Hill, as well as to the proposed Clauchrie windfarm. GPA therefore sought a better understanding of the impact on the mitigation capacity of its Terma Radar. Additionally, GPA requested that the Environmental Impact Assessment consider the impact on GPA's Instrument Flight Procedures (IFPs). The Ministry of Defence (MOD) raised no concerns that would lead to an objection but noted that the Proposed Development Site is within Tactical Training Area 20 (T), a military low flying area. As such, it requests that MOD accredited aviation safety lighting be fitted to the turbines.

Initial modelling of the GPA PSRs shows that Radar Line of Sight (RLoS) exists between all of the proposed turbines and the S511 and Terma Scanter 4002 PSRs. The GPA PSRs are likely to detect all the Proposed Development turbines; however, once it has been optimised by a Terma technician the GPA Terma should be capable of detecting the Proposed Development turbines and maintaining internal tracks on them (which are not displayed to the controller) whilst simultaneously tracking air targets passing over the Proposed Development. The optimisation process would be a one-off task for the Proposed Development with no requirement for further ongoing mitigation. The potential number of turbines in the vicinity of GPA is well within the Terma's concurrent internal track capacity . In other words, the inherent processing capabilities of the GPA Terma should be able to mitigate the impact of the Proposed Development turbines provided a Terma technician optimises the GPA Terma upon the erection of the Proposed Development's turbines. If for some reason the Terma PSR becomes unserviceable then the Radar Control Service would continue using Lowther Hill Secondary Surveillance Radar (SSR) data only, albeit with a minimum traffic separation increase from 5 Nautical Miles (NM) to 10NM.

Initial modelling of Lowther Hill PSR shows that 9 of the 13 turbines are in RLoS. Probability of Detection analysis indicates that turbines T01 to T09 would likely be detected and there is a possibility that turbine T10 would also be detected. Turbines T11, T12 and T13 are unlikely to be detected by Lowther Hill PSR.

There are no significant areas for concern specifically in relation to airspace or airspace users. The Proposed Development lies below a volume of uncontrolled airspace predominantly used by General Aviation and military aircraft. This Class G airspace extends from the surface to 5,500ft Above Mean Sea Level (AMSL). Above this airspace is a Class D portion of the Scottish Terminal Manoeuvring Area (TMA). The Class D airspace (specifically TMA-2) is under the control of Scottish Control (NERL), located at Prestwick Centre and is declared as a Transponder Mandatory Zone. Any aircraft entering this airspace from beneath (i.e. from below 5,500ft AMSL) should be carrying and using a serviceable transponder. Any loss of PSR coverage in this area should not impact to the provision of Air Traffic Services (ATS) within this airspace as there should be sufficient SSR coverage. The Proposed Development does fall within the

Tactical Training Area within Low Flying Area 20T within which military aircraft perform low flying as low as 100ft Minimum Separation Distance.

A standalone assessment of the IFPs associated with GPA has been conducted by Cyrrus and concludes that the turbines associated with the Proposed Development would have no impact on GPA's IFPs as currently published.

Where radar impacts result in an adverse impact on the ATS provided, mitigation may be required. A potential option for mitigating the impact on Lowther Hill PSR is to use an infill radar feed that does not have RLoS of the Proposed Development turbines but has adequate coverage over the Proposed Development to satisfy NERL Air Traffic Control requirements. It is likely that NERL only control the airspace from 6,000ft above the Proposed Development, delegating airspace in the vicinity of GPA from 5,5500ft to 6,000ft to GPA. Potential infill PSRs must optimally provide 2,000ft of additional PSR coverage below the base of NERL controlled airspace in the vicinity of the Proposed Development.

Great Dun Fell PSR has the lowest base of radar coverage, 3,500ft AMSL, in the vicinity of the Proposed Development. Cumbernauld can provide the required minimum coverage of 4,000ft AMSL. Both of these PSRs are integrated into NERL's Multi-Radar Tracking infrastructure.

Abbreviations

AGL	Above Ground Level
AIP	Aeronautical Information Publication
AMSL	Above Mean Sea Level
ANSP	Air Navigation Service Provider
ATC	Air Traffic Control
ATS	Air Traffic Service
CAA	Civil Aviation Authority
DTM	Digital Terrain Model
EIA	Environmental Impact Assessment
FIS	Flight Information Service
FL	Flight Level
GA	Glasgow Airport
GPA	Glasgow Prestwick Airport
IFP	Instrument Flight Procedure
IFT&E	Interagency Field Test and Evaluation
kt	knots
MOD	Ministry of Defence
NERL	NATS (En Route)
NM	Nautical Miles
PD	Probability of Detection
PLI	Public Local Inquiry
PSR	Primary Surveillance Radar
RCS	Radar Cross Section
RLoS	Radar Line of Sight
RNAV	Area Navigation
SPR	ScottishPower Renewables
SSR	Secondary Surveillance Radar
STAR	Standard Arrival
TMA	Terminal Manoeuvring Area
TMZ	Transponder Mandatory Zone
TOPA	Technical and Operational Assessment

Contents

EXECUTIVE SUMMARY 1
ABBREVIATIONS 3
CONTENTS 4
1. INTRODUCTION 7
1.1. Background 7
1.2. Effects of Wind Turbines on Aviation 7
1.3. Scoping Responses 7
1.4. Aviation Modelling Tasks 8
2. DATA 9
2.1. Carrick Windfarm 9
2.2. Radar Data 10
2.3. Analysis Tools 10
2.4. Terrain Data 10
3. GPA MODELLING 12
3.1. Radar Locations 12
3.2. Radar Line of Sight 13
3.3. RLoS – GPA S511 PSR 13
3.4. RLoS – GPA Terma PSR 15
3.5. Impact of Detected Turbines – GPA S511 PSR 16
4. NERL MODELLING 17
4.1. Radar Locations 17
4.2. Radar Line of Sight 17
4.3. RLoS – Lowther Hill PSR 18
4.4. Probability of Detection 19
5. AIRSPACE ANALYSIS 24
5.1. Overview 24
5.2. Provision of Air Traffic Services 25
5.3. Other Airspace Considerations 26
6. MITIGATION OPTIONS 30
6.1. Mitigation Requirement 30
6.2. GPA Mitigation – Terma Scanter 4002 30
6.3. NERL Mitigation – Potential Infill Radars 33
6.4. NERL Potential Infill Radars – Great Dun Fell PSR 34

6.5. NERL Potential Infill Radars – Cumbernauld PSR 36
6.6. NERL Potential Infill Radars – Glasgow PSR and Glasgow Terma 38
6.7. NERL Potential Infill Radars – Kincardine PSR 42
6.8. NERL Potential Infill Radar – Summary 43
A. ANNEX A – LOWTHER HILL PSR PATH PROFILES 44
A.1. Turbine T01 44
A.2. Turbine T02 44
A.3. Turbine T03 45
A.4. Turbine T04 45
A.5. Turbine T05 46
A.6. Turbine T06 46
A.7. Turbine T07 47
A.8. Turbine T08 47
A.9. Turbine T09 48
A.10. Turbine T10 48
A.11. Turbine T11 49
A.12. Turbine T12 49
A.13. Turbine T13 50

List of figures

Figure 1: Carrick Windfarm turbine layout 10
Figure 2: 3D view of turbines and terrain from south east 11
Figure 3: Locations of GPA Terma PSR and S511 PSR 12
Figure 4: Location of GPA PSRs and Carrick Windfarm 12
Figure 5: GPA S511 PSR RLoS to 200m AGL 13
Figure 6: GPA S511 PSR RLoS to 200m AGL – zoomed 14
Figure 7: GPA Terma PSR RLoS to 200m AGL 15
Figure 8: GPA Terma PSR RLoS to 200m AGL – zoomed 16
Figure 9: Location of Lowther Hill PSR and Carrick Windfarm 17
Figure 10: Lowther Hill PSR RLoS to 200m AGL 18
Figure 11: Lowther Hill PSR RLoS to 200m AGL – zoomed 18
Figure 12: Path loss profile between Lowther PSR and tip of turbine T01 19

Figure 13: Path loss profile between Lowther PSR and tip of turbine T11 20
Figure 14: Path loss calculation for turbine T01 21
Figure 15: Proposed Development in relation to nearby airports 25
Figure 16: Proposed Development in relation to the Scottish TMA and Glasgow Prestwick CTAs 25
Figure 17: Proposed Development in relation to Lower ATS Routes 26
Figure 18: Prestwick APPLE 2P RIBEL 2P STAR 27
Figure 19: UK AIP ENR 6.33 Scottish Control FIS sectors 28
Figure 20: Proposed Development in relation to PINS and UK Day Low Flying System 29
Figure 21: 500m inter-turbine spacing 31
Figure 22: GPA Terma PSR RLoS to 200m AGL – all turbines 32
Figure 23: Great Dun Fell PSR RLoS at 3,500ft AMSL 34
Figure 24: Great Dun Fell PSR RLoS at 3,500ft AMSL – zoomed 35
Figure 25: Cumbernauld PSR RLoS at 4,000ft AMSL 36
Figure 26: Cumbernauld PSR RLoS at 4,000ft AMSL – zoomed 37
Figure 27: Locations of Glasgow PSR and Glasgow Terma 38
Figure 28: Glasgow PSR RLoS at 4,000ft AMSL 39
Figure 29: Glasgow PSR RLoS at 7,000ft AMSL 40
Figure 30: Glasgow Terma RLoS at 7,000ft AMSL 41
Figure 31: Kincardine PSR RLoS at 4,000ft AMSL 42
Figure 32: Kincardine PSR RLoS at 6,500ft AMSL 43

List of tables

Table 1: Carrick Windfarm turbine coordinates 9
Table 2: Lowther Hill PSR PD results 22
Table 3: Lowther Hill PSR PD results with 5dB gain reduction 23

1. Introduction

1.1. Background

1.1.1. ScottishPower Renewables (SPR) is proposing the construction of a new onshore windfarm located within Carrick Forest, a commercial forest block of the Galloway Forest Park in South Ayrshire, south west Scotland. Carrick Windfarm, the Proposed Development, is anticipated to comprise up to 13 wind turbines with a maximum blade tip height of 200m Above Ground Level (AGL).

1.1.2. Cyrrus Limited has been engaged by WSP to provide guidance on aviation issues to support the Environment Impact Assessment (EIA) process for the project.

1.2. Effects of Wind Turbines on Aviation

1.2.1. Wind turbines are an issue for aviation Primary Surveillance Radars (PSRs) as the characteristics of a moving wind turbine blade are similar to that of an aircraft. The PSR is unable to differentiate between wanted aircraft targets and unwanted clutter targets introduced by the presence of turbines.

1.2.2. The significance of any radar impact depends on airspace usage in the vicinity of the Proposed Development and the nature of the Air Traffic Service (ATS) provided in that airspace.

1.3. Scoping Responses

1.3.1. Following publication of the Scoping Report[1] and requests for pre-application advice, responses have been received from the following aviation stakeholders:

- Glasgow Prestwick Airport (GPA);
- Ministry of Defence (MOD); and
- NATS (En Route) [NERL].

1.3.2. In GPA's response on 25 June 2020 it highlights that the close proximity of the Proposed Development to the existing windfarms at Dersalloch and Hadyard Hill, as well as to the proposed Clauchrie Windfarm, needs consideration in relation to cumulative impact and mitigation capacity. GPA also considers aviation lighting an important area and wishes the EIA to consider the impact on GPA's Instrument Flight Procedures (IFPs), both conventional and Area Navigation (RNAV), as published in the UK Aeronautical Information Publication (AIP).

1.3.3. MOD, in its response on 24 June 2020, has no concerns with the proposal but notes that the Proposed Development is within Tactical Training Area 20 (T), a military low flying area. As such, it requests that MOD accredited aviation safety lighting be fitted to the turbines.

[1] Carrick Windfarm Scoping Report, May 2020

1.3.4. In NERL's response on 23 June 2020 it objects to the proposal. A NATS Technical and Operational Assessment (TOPA)[2] issued for the Proposed Development anticipates an unacceptable technical impact on Lowther Hill radar.

1.4. Aviation Modelling Tasks

1.4.1. The aviation modelling tasks identified are:

- Determine the radar visibility of the Proposed Development to GPA's PSRs;
- Determine the radar visibility of the Proposed Development to NERL's PSRs; and
- Review the nature of the airspace in the vicinity of Carrick Windfarm to determine any potential impact on aviation.

[2] TOPA for Carrick Windfarm, NATS ref: SG29709, Issue 1, June 2020

2. Data

2.1. Carrick Windfarm

2.1.1. A design freeze layout for Carrick Windfarm, dated 20 September 2021, has been issued in the following file:

- Carrick_WTG_DF_210920.shp.

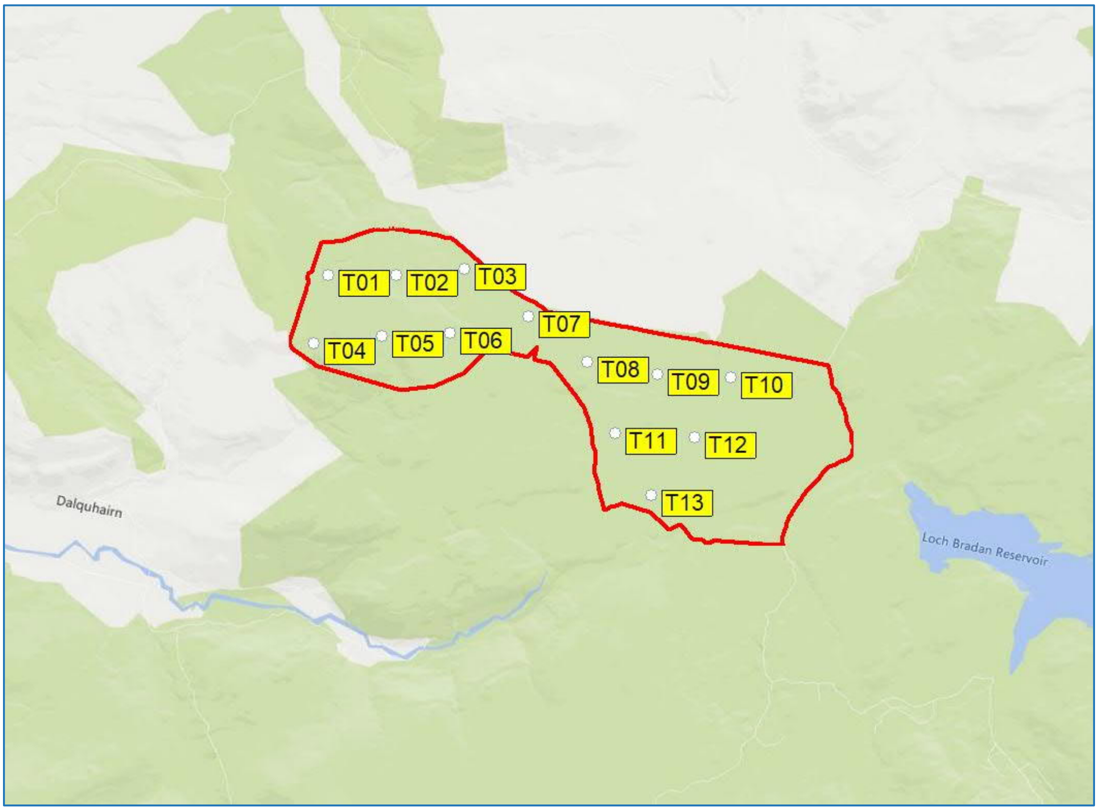
2.1.2. The Ordnance Survey National Grid coordinates for this proposed turbine layout, as used in the assessment, are listed in Table 1.

Turbine	Easting	Northing
T01	234298.12	599031.63
T02	235006.24	599144.20
T03	235700.54	599334.29
T04	234271.57	598307.66
T05	234967.00	598502.00
T06	235666.00	598647.00
T07	236449.00	598947.00
T08	237132.24	598584.10
T09	237884.62	598580.80
T10	238642.00	598676.00
T11	237545.78	597897.24
T12	238379.54	598000.00
T13	238031.61	597330.52

Table 1: Carrick Windfarm turbine coordinates

2.1.3. The 13 turbines are planned to have a blade (rotor) diameter of up to 170m and a maximum blade tip height of 200m AGL.

2.1.4. The proposed turbine layout used for the modelling is shown in Figure 1.



Microsoft® Bing™ screen shot reprinted with permission from Microsoft Corporation

Figure 1: Carrick Windfarm turbine layout

2.2. Radar Data

2.2.1. Radar parameters used in the assessment have been taken from data held on file by Cyrrus.

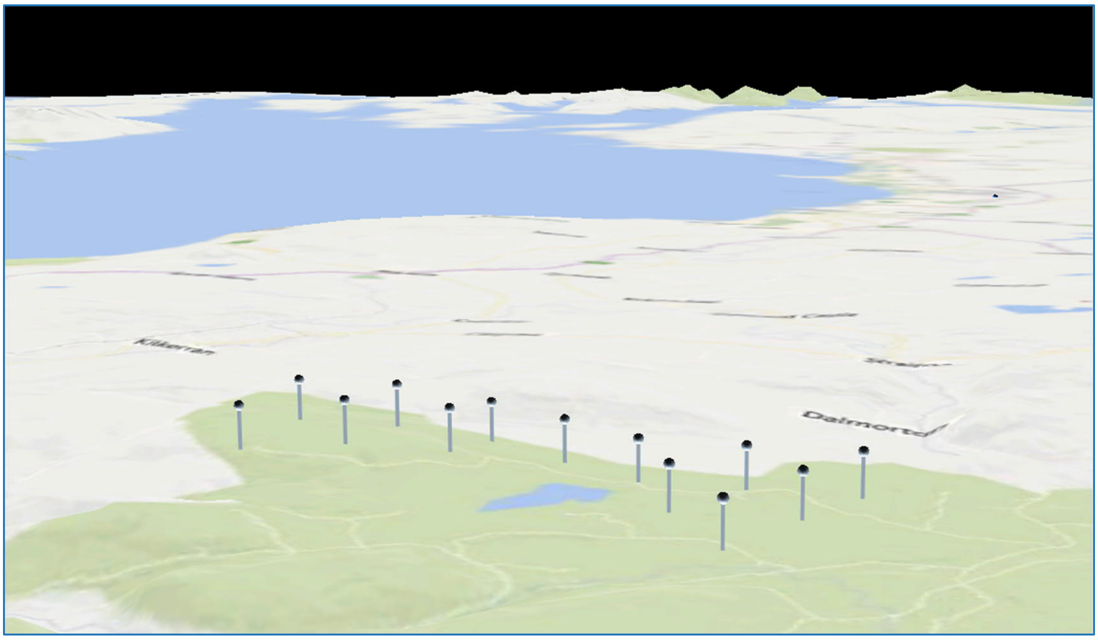
2.3. Analysis Tools

- ATDI ICS telecom EV v15.5.3 x64 radio network analysis tool;
- Global Mapper v21.1.1 Geographic Information System data processing utility;
- ZWCAD+ 2015 SP2 Pro v2015.05.26(27086) Computer Aided Design software.

2.4. Terrain Data

- 25m Digital Terrain Model (DTM)

2.4.1. A 3D view of the turbines and the terrain model is shown in Figure 2.



Microsoft® Bing™ screen shot reprinted with permission from Microsoft Corporation

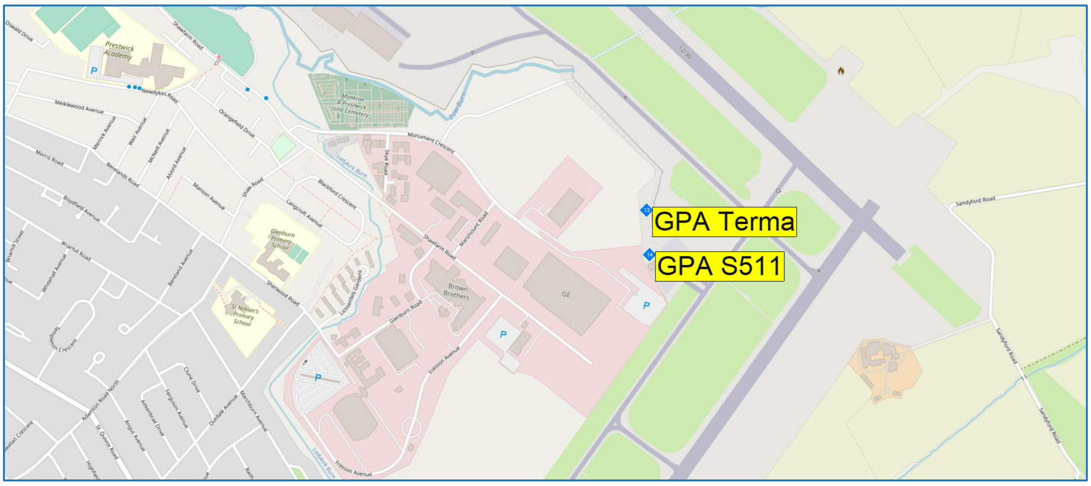
Figure 2: 3D view of turbines and terrain from south east

3. GPA Modelling

3.1. Radar Locations

3.1.1. There are two PSR facilities at GPA: a Marconi S511 radar used for planning purposes while a Terma Scanter 4002 radar is used for approach control. In addition, GPA is fed with Secondary Surveillance Radar (SSR) data from Lowther Hill radar. GPA is authorised to use SSR only in the event of PSR failure.

3.1.2. The locations of the two GPA PSRs are shown in Figure 3.



© OpenStreetMap contributors

Figure 3: Locations of GPA Terma PSR and S511 PSR

3.1.3. The nearest turbine within the Proposed Development area is approximately 26.9km (14.5 nautical miles (NM)) south of the GPA PSRs, as shown in Figure 4.

Microsoft® Bing™ screen shot reprinted with permission from Microsoft Corporation

Figure 4: Location of GPA PSRs and Carrick Windfarm

3.2. Radar Line of Sight

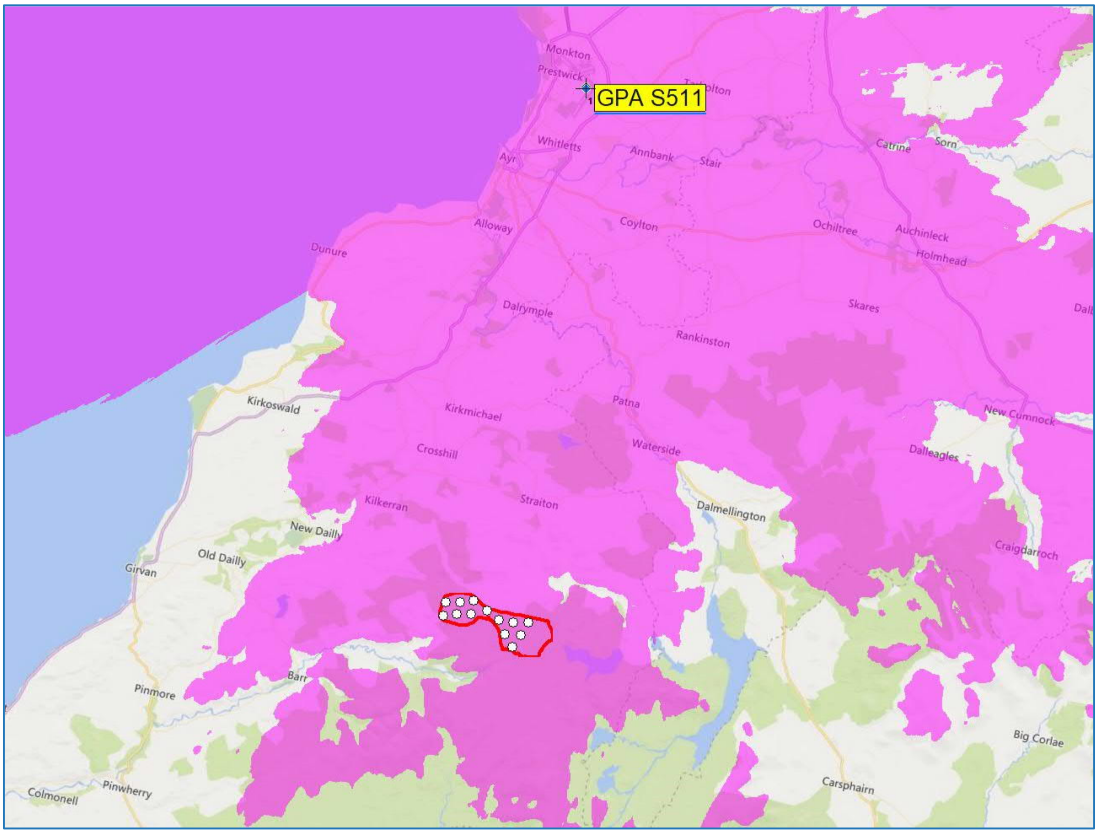
3.2.1. RLoS is determined from a radar propagation model (ATDI ICS telecom EV) using 3D DTM data with 25m horizontal resolution. Radar data is entered into the model and RLoS to the turbines from the radar is calculated.

3.2.2. Note that by using a DTM no account is taken of possible further shielding of the turbines due to the presence of structures or vegetation that may lie between the radars and the turbines. Thus, the RLoS assessments are worst-case results.

3.2.3. For PSR, the principal sources of adverse windfarm effects are the turbine blades, so RLoS is calculated for the maximum tip height of the turbines, i.e. 200m AGL.

3.3. RLoS – GPA S511 PSR

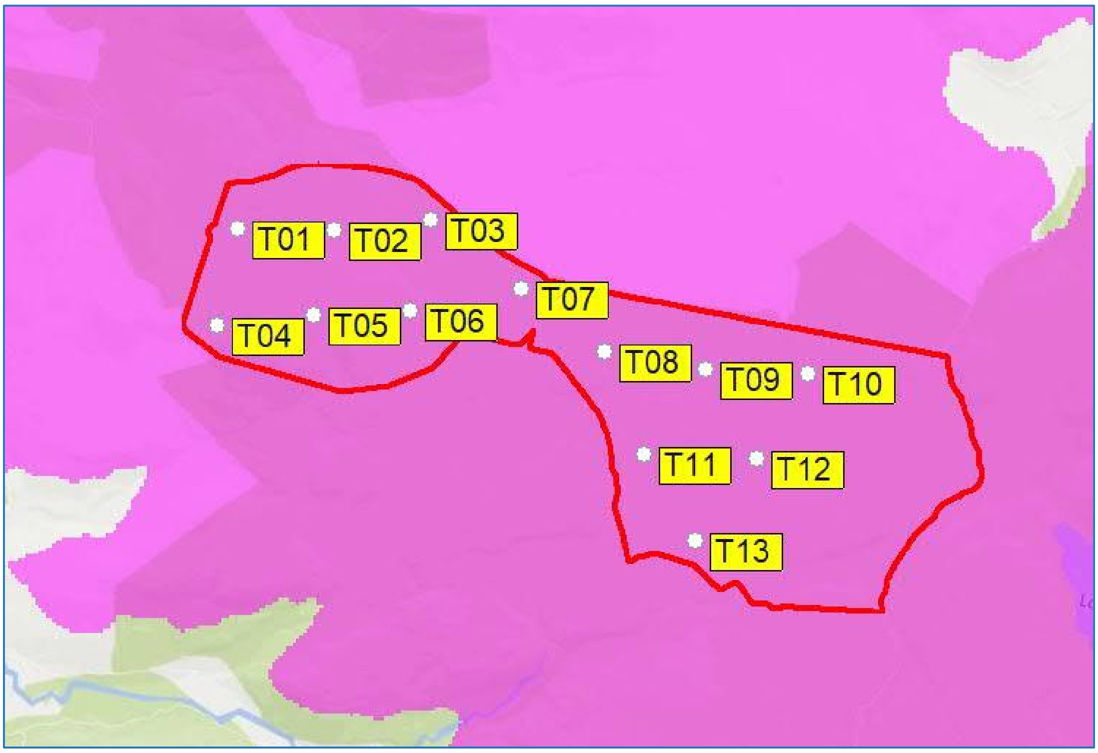
3.3.1. The magenta shading in Figure 5 illustrates the RLoS coverage from the GPA S511 PSR to turbines with a blade tip height of 200m AGL.



Microsoft® Bing™ screen shot reprinted with permission from Microsoft Corporation

Figure 5: GPA S511 PSR RLoS to 200m AGL

3.3.2. The zoomed view of the Proposed Development in Figure 6 shows that RLoS exists between the S511 PSR and the blade tips of all 13 turbines.



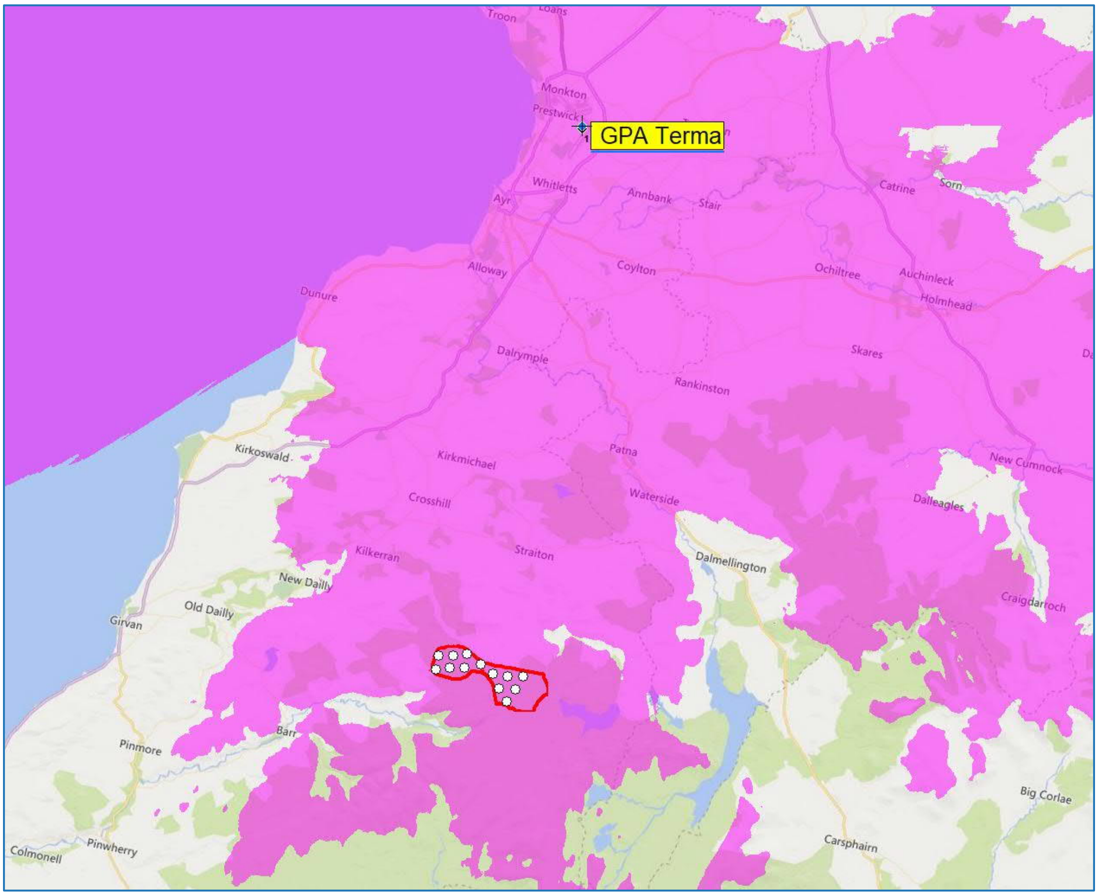
Microsoft® Bing™ screen shot reprinted with permission from Microsoft Corporation

Figure 6: GPA S511 PSR RLoS to 200m AGL – zoomed

3.3.3. Given that RLoS exists to all of the turbines, it can be assumed that the GPA S511 PSR will also detect all of the Carrick Windfarm turbines.

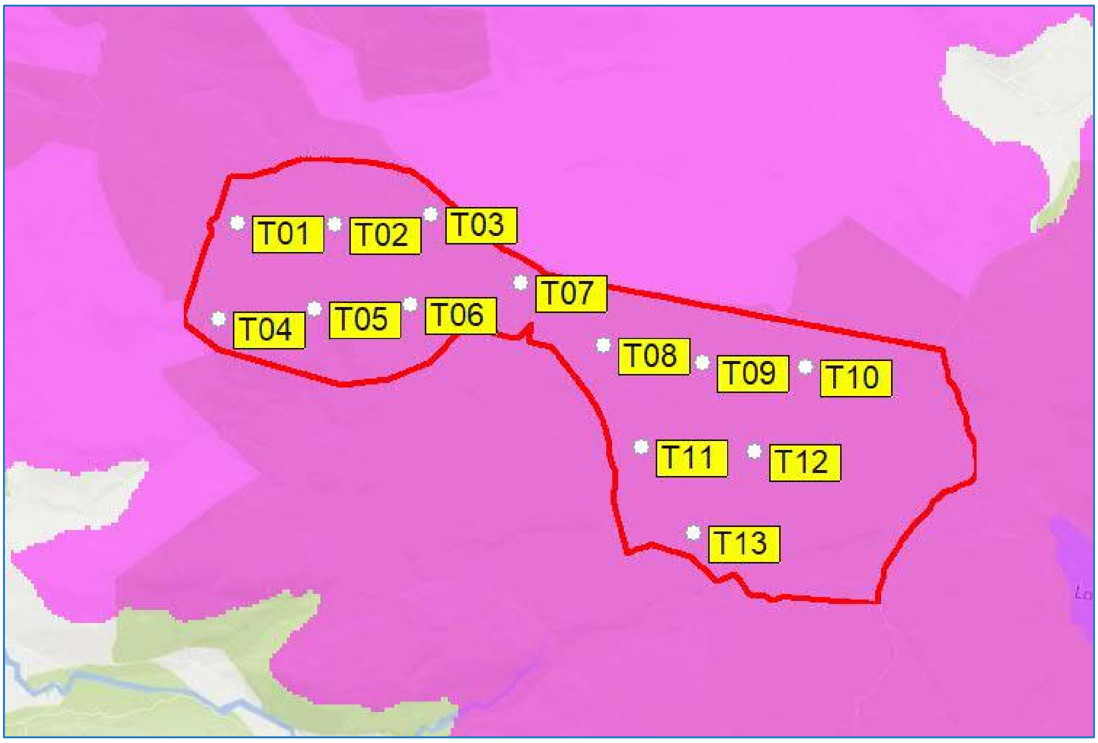
3.4. RLoS – GPA Terma PSR

3.4.1. The magenta shading in Figure 7 illustrates the RLoS coverage from the GPA Terma PSR to turbines with a blade tip height of 200m AGL.



Microsoft® Bing™ screen shot reprinted with permission from Microsoft Corporation
Figure 7: GPA Terma PSR RLoS to 200m AGL

3.4.2. The zoomed view of the Proposed Development in Figure 8 shows that, similarly to the S511 PSR, RLoS exists between the Terma PSR and the blade tips of all 13 turbines.



Microsoft® Bing™ screen shot reprinted with permission from Microsoft Corporation

Figure 8: GPA Terma PSR RLoS to 200m AGL – zoomed

3.4.3. Given that RLoS exists to all of the turbines, it can be assumed that the GPA Terma PSR will also detect all of the Carrick Windfarm turbines.

3.5. Impact of Detected Turbines – GPA S511 PSR

3.5.1. The GPA S511 PSR was installed in 1990, and today is primarily used as a planning radar. The newly installed Terma PSR is effectively a replacement for this legacy radar but is limited to a range of approximately 40NM, so the S511 may be used for traffic beyond this range. At the Public Local Inquiry (PLI) in respect of the Clauchrie Windfarm (DPEA reference WIN-370-3, May-June 2021), GPA acknowledged that the S511 PSR was at the end of its life and that once the Terma PSR was commissioned into service (scheduled to occur in Summer 2021), the Terma with the SSR feed from Lowther Hill would form the basis of GPA's air traffic service surveillance infrastructure.

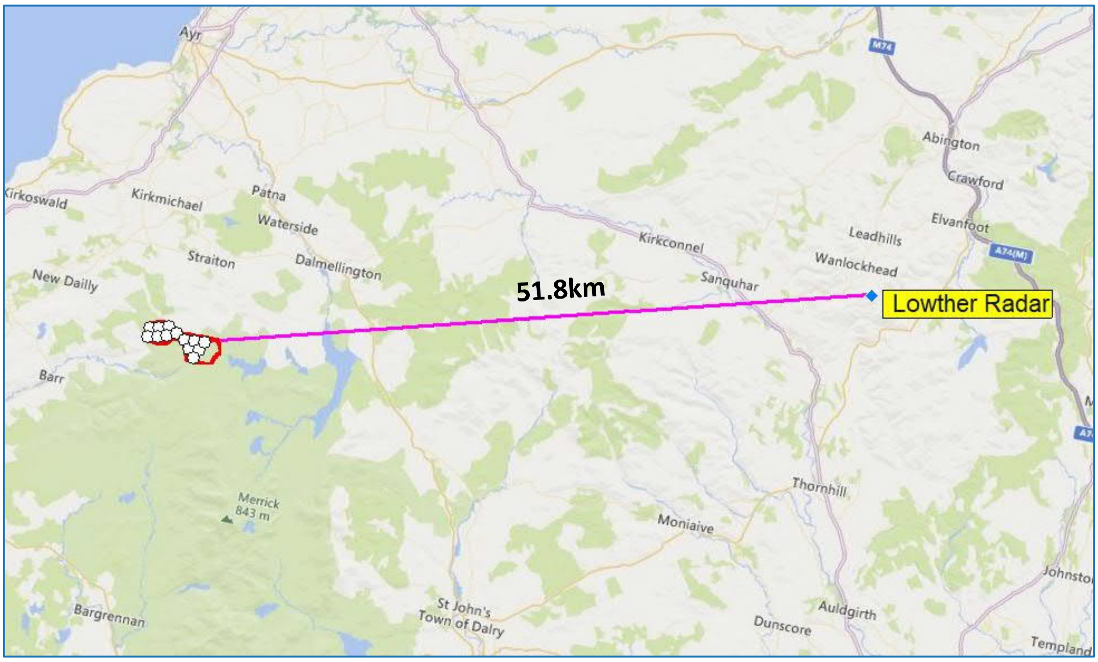
3.5.2. In the unlikely event that the Terma approach radar becomes unserviceable then the radar control service would continue using Lowther Hill SSR data only, albeit with a minimum traffic separation increase from 5NM to 10NM.

4. NERL Modelling

4.1. Radar Locations

4.1.1. In its TOPA, NERL identifies the en-route PSR at Lowther Hill as being technically impacted by the Proposed Development.

4.1.2. The nearest turbine within the Proposed Development area is approximately 51.8km (27.9NM) west of Lowther Hill PSR, as shown in Figure 9.



Microsoft® Bing™ screen shot reprinted with permission from Microsoft Corporation

Figure 9: Location of Lowther Hill PSR and Carrick Windfarm

4.2. Radar Line of Sight

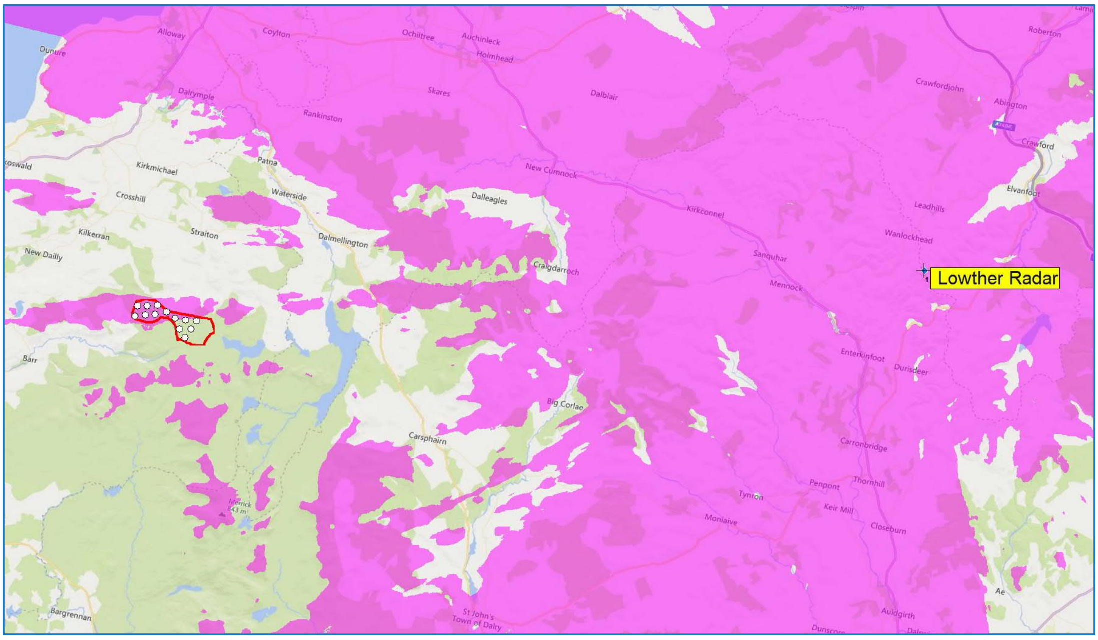
4.2.1. RLoS is determined from a radar propagation model (ATDI ICS telecom EV) using 3D DTM data with 25m horizontal resolution. Radar data is entered into the model and RLoS to the turbines from the radar is calculated.

4.2.2. Note that by using a DTM no account is taken of possible further shielding of the turbines due to the presence of structures or vegetation that may lie between the radars and the turbines. Thus, the RLoS assessments are worst-case results.

4.2.3. For PSR, the principal sources of adverse windfarm effects are the turbine blades, so RLoS is calculated for the maximum tip height of the turbines, i.e. 200m AGL.

4.3. RLoS – Lowther Hill PSR

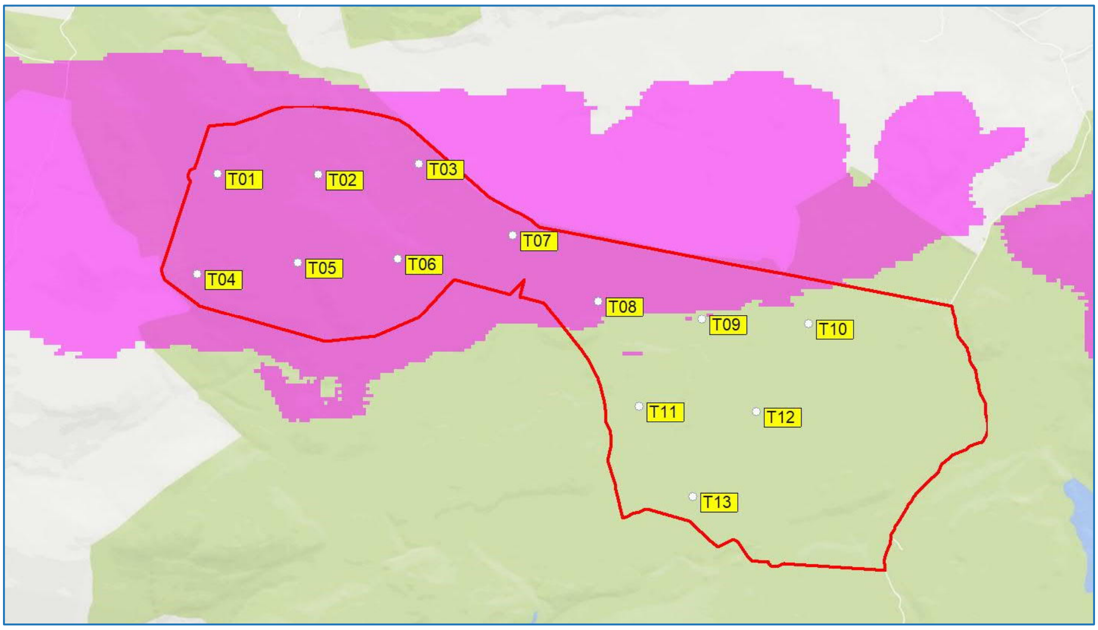
4.3.1. The magenta shading in Figure 10 illustrates the RLoS coverage from Lowther Hill PSR to turbines with a blade tip height of 200m AGL.



Microsoft® Bing™ screen shot reprinted with permission from Microsoft Corporation

Figure 10: Lowther Hill PSR RLoS to 200m AGL

4.3.2. The zoomed view of the Proposed Development in Figure 11 shows that RLoS exists between Lowther PSR and the blade tips of turbines T01, T02, T03, T04, T05, T06, T07 and T08. There is marginal RLoS to turbine T09 and no RLoS between Lowther PSR and turbines T10, T11, T12 and T13.



Microsoft® Bing™ screen shot reprinted with permission from Microsoft Corporation

Figure 11: Lowther Hill PSR RLoS to 200m AGL – zoomed

4.3.3. When no RLoS exists between a turbine and a radar it can generally be assumed that the radar will not detect the turbines. However, this can only be assured by analysis of path profiles between the radar and each turbine and conducting Probability of Detection (PD) calculations.

4.4. Probability of Detection

4.4.1. Using a radar propagation model, the actual path loss between Lowther PSR and various parts of each turbine can be determined.

4.4.2. Figure 12 illustrates the path loss profile between Lowther PSR and turbine T01.

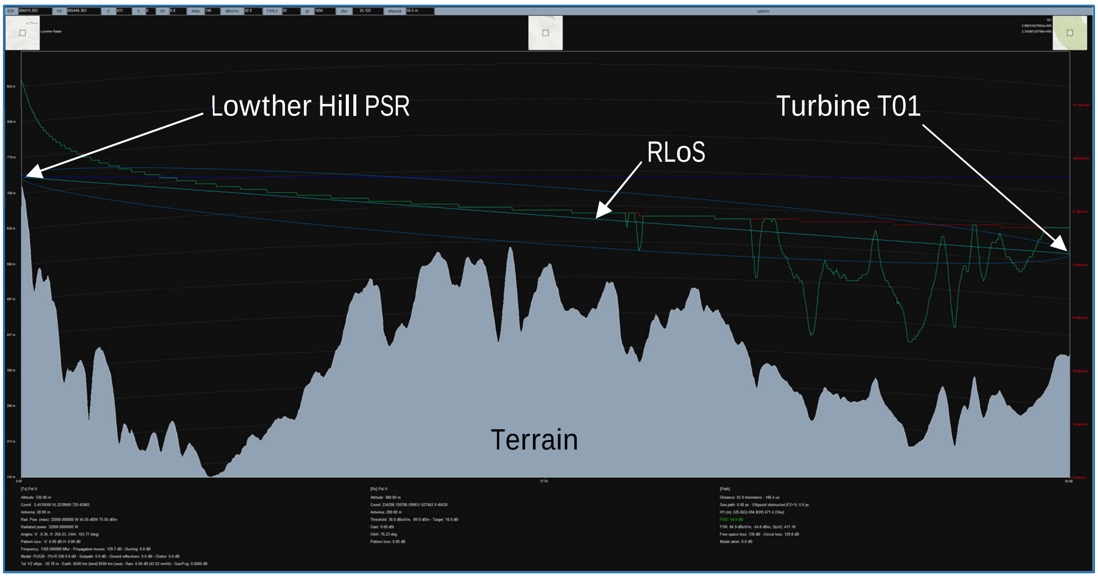


Figure 12: Path loss profile between Lowther PSR and tip of turbine T01

4.4.3. In Figure 12 the terrain, shaded grey, lies entirely below the path between the PSR and the turbine tip. Thus, Lowther PSR has uninterrupted RLoS to the tip of turbine T01 and it can be assumed that the PSR will detect the turbine.

4.4.4. Figure 13 illustrates the path loss profile between Lowther PSR and turbine T11.

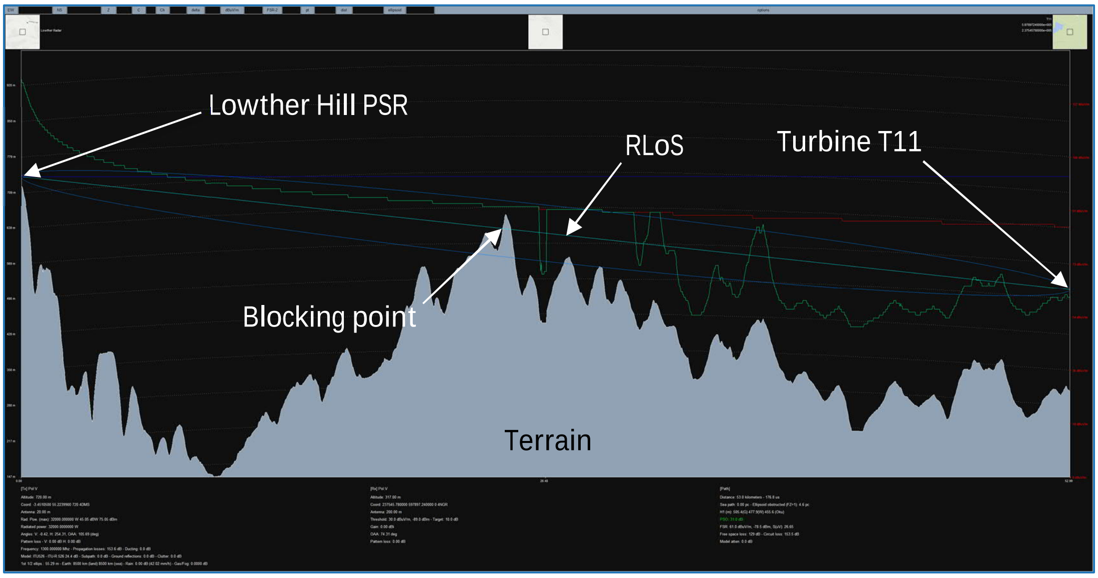


Figure 13: Path loss profile between Lowther PSR and tip of turbine T11

4.4.5. In this case a peak in the terrain penetrates the path between the PSR and the turbine tip. The indicated blocking point prevents Lowther PSR from having RLoS to turbine T11.

4.4.6. All of the path profiles between Lowther PSR and the 13 Carrick turbines are shown in Annex A at the end of this report.

4.4.7. Even when intervening terrain blocks RLoS between the radar and a turbine, the probability that the turbine will be detected by the radar is still dependant on several factors including the radar's power, radar signal path loss, the angle of antenna tilt and distance to the object.

4.4.8. The radar propagation model can determine the actual path loss between the PSR and various parts of the turbine. By knowing the PSR transmitter power, antenna gain, 2-way path loss, receiver sensitivity and the turbine Radar Cross Section (RCS) gain, the probability of the radar detecting the target (PD) can be calculated.

4.4.9. The static parts of the turbine (tower structure) are ignored in the calculation as these will be rejected by the radar Moving Target filter. In this refined model, 3 parts of the turbine blade are considered: the hub, the blade tip, and a point midway along the turbine blade. Each part of the turbine blade is assigned an RCS of $80m^2$ based on a blade length of 85m (half of 170m rotor diameter). Path loss calculations are made to all turbines. The received signal at the radar from each component part of the turbine is then summed to determine the total signal level.

4.4.10. The path loss calculation carried out for each turbine component is as follows:

Tx Power		dBm
+	Antenna Gain	dB
-	Path Loss	dB
+	RCS Gain	dB (60m^2 ~ +42.8dB)
-	Path Loss	dB
+	Antenna Gain	dB
=	Received Signal	dBm

4.4.11. The received signal is then compared with the radar receiver Minimum Detectable Signal level.

4.4.12. An example of the path loss calculation from Lowther PSR to turbine T01 is shown in Figure 14.

Radar 2-Way Path Loss Calculator

Data		
Tx Frequency	1300	MHz
Tx Power	50000	Watts
Antenna Gain	33	dBi
Rx Sensitivity	-125	dBm
Target		
RCS	80	m^2
Path Loss (1-way)	129.7	dB
Calculations		
Tx Wavelength	0.23	m
Tx power	76.9897	dBm
EIRP	109.9897	dBm
Power at Target	-19.7103	dBm
RCS Gain	42.77	dB
Power at Rx	-73.64	dBm
dB over Rx Threshold	51.36	dB

Figure 14: Path loss calculation for turbine T01

4.4.13. The two-way path losses from the turbine components are tabulated and combined to give total radar received signals from each turbine. The results are colour-coded to indicate the likelihood of detection. Radar returns >3dB above the detection threshold are coloured green as these values show a high probability of detection. Those between +3dB and -3dB are coloured yellow and indicate a possibility of detection. Between -3dB and -6dB, results are coloured orange to show only a small possibility of detection. Signals >6dB below the threshold of detection are shaded red as these values show that detection is unlikely.

4.4.14. Using this representation provides a ready visual comparison of different scenarios. The final result is shown in the final column (TOTAL) of each colour-coded chart.

4.4.15. The results of the PD calculations for each turbine are shown in Table 2.

Turbine ID	Turbine Nacelle Path Loss dB	Blade mid-point Path Loss dB	Blade Tip Path Loss dB	TOTAL dB over RX threshold
T01	131.9	129.7	129.7	55.09
T02	133.7	129.6	129.6	54.88
T03	148.7	141.0	131.9	47.02
T04	129.7	129.7	129.7	56.13
T05	129.6	129.6	129.6	56.33
T06	132.7	129.5	129.5	55.24
T07	147.9	137.7	129.3	52.25
T08	153.7	148.0	140.0	30.87
T09	159.1	153.9	146.2	18.49
T10	160.4	155.9	149.3	12.39
T11	160.8	157.7	153.6	4.30
T12	163.3	160.6	157.1	-2.45
T13	162.2	160.2	157.7	-3.05

Table 2: Lowther Hill PSR PD results

4.4.16. From Table 2 it appears that there is a high probability that all the turbines except T12 and T13 will be detected by Lowther PSR. There is a small possibility that turbines T12 will be detected and a possibility that T13 will be detected.

4.4.17. The above calculations are based on the optimum performance of the radar, however the gain of a radar antenna in the vertical axis is not uniform with elevation angle. The beam is a complex shape to minimise ground returns by having low gain at elevations close to the horizontal but having high gain at elevations just a few degrees above the horizon.

4.4.18. The Lowther Hill PSR antenna is a twin beam SREM-5 system with one pencil beam and one Cosec^2 beam. The combined beam pattern provides extra gain at low elevations when compared with a standard Cosec^2 radar.

4.4.19. Cyrrus does not hold data for the Lowther antenna Vertical Polar Diagram, however it is likely that the turbine tip elevations from Lowther PSR (approximately -0.4°) are below the peak elevation of the beam where gain is maximum. Any reduction in gain will further reduce the probability of turbine detection.

4.4.20. For example, it is not unreasonable to suggest a reduction in gain of 5dB at the turbine elevations. The revised PD calculation results incorporating this gain reduction are shown in Table 3.

Turbine ID	Turbine Nacelle Path Loss dB	Blade mid-point Path Loss dB	Blade Tip Path Loss dB	TOTAL dB over RX threshold
T01	131.9	129.7	129.7	45.09
T02	133.7	129.6	129.6	44.88
T03	148.7	141.0	131.9	37.02
T04	129.7	129.7	129.7	46.13

Turbine ID	Turbine Nacelle Path Loss dB	Blade mid-point Path Loss dB	Blade Tip Path Loss dB	TOTAL dB over RX threshold
T05	129.6	129.6	129.6	46.33
T06	132.7	129.5	129.5	45.24
T07	147.9	137.7	129.3	42.25
T08	153.7	148.0	140.0	20.87
T09	159.1	153.9	146.2	8.49
T10	160.4	155.9	149.3	2.39
T11	160.8	157.7	153.6	-5.70
T12	163.3	160.6	157.1	-12.45
T13	162.2	160.2	157.7	-13.05

Table 3: Lowther Hill PSR PD results with 5dB gain reduction

4.4.21. From Table 3 it now appears that turbines T12 and T13 are unlikely to be detected, there is a small possibility that turbine T11, and there is a possibility that turbine T10 will be detected.

5. Airspace Analysis

5.1. Overview

5.1.1. As already noted, the significance of any radar impact depends on airspace usage in the vicinity of the Proposed Development and the nature of the ATS provided in that airspace.

5.1.2. This section of the report will examine the potential impact to aviation, including civil and military operations.

5.1.3. The airspace surrounding the Proposed Development is contained in the UK AIP. The type (airspace classification), usage and dimensions are contained within various sections of the En-Route section of the AIP.

5.1.4. The airspace immediately above the Proposed Development consists of two types of airspace. The first portion is classified as Class G and extends from ground level to 5,500ft AMSL.

5.1.5. The Class G airspace is commonly referred to as 'uncontrolled airspace' and is predominantly used by General Aviation and military aircraft. There is no defined ATS within this area as it falls outside the support provided by Lower Airspace Radar Service units. Any services within the area are provided in accordance with CAP 774[3].

5.1.6. NERL provides Flight Information Services (FIS) within the area of the Proposed Development within Class G airspace. From the perspective of ATS delivery, two Air Navigation Service Providers (ANSPs) cannot be responsible for delivery of service within the same portion of airspace. More specifically, NERL has been designated the responsibility in this airspace with no mention of responsibility delegated to GPA.

5.1.7. The higher portion of airspace is a portion of the Scottish Terminal Manoeuvring Area (TMA) classified as Class D and managed by NERL. This extends from 5,500ft up to Flight Level (FL) 195 (atmospheric pressure equivalent of 19,500ft AMSL). This airspace contains Lower ATS routes and Instrument Flight Procedures (IFPs) associated with Glasgow Prestwick Airport.

5.1.8. The Class D airspace (specifically TMA-2) is under the control of Scottish Control (NERL), located at Prestwick Centre and is declared as a Transponder Mandatory Zone (TMZ) from 6,000ft AMSL to FL100 (approximately 10,000ft AMSL).

5.1.9. Class D airspace is commonly referred to as 'controlled airspace' and aircraft within it are under a Radar Control Service. A clearance from the controlling authority is required to enter the controlled airspace and control instructions are mandatory. It provides a 'known traffic' environment meaning that Air Traffic Control (ATC) is aware of all traffic operating within the designated airspace.

[3] CAP 774, UK Flight Information Services, Third edition, May 2017

5.2. Provision of Air Traffic Services

5.2.1. Figure 15 indicates the approximate location of the Proposed Development in relation to nearby airports. The nearest airports are GPA, approximately 15NM to the north, and Glasgow Airport, approximately 36NM to the north.

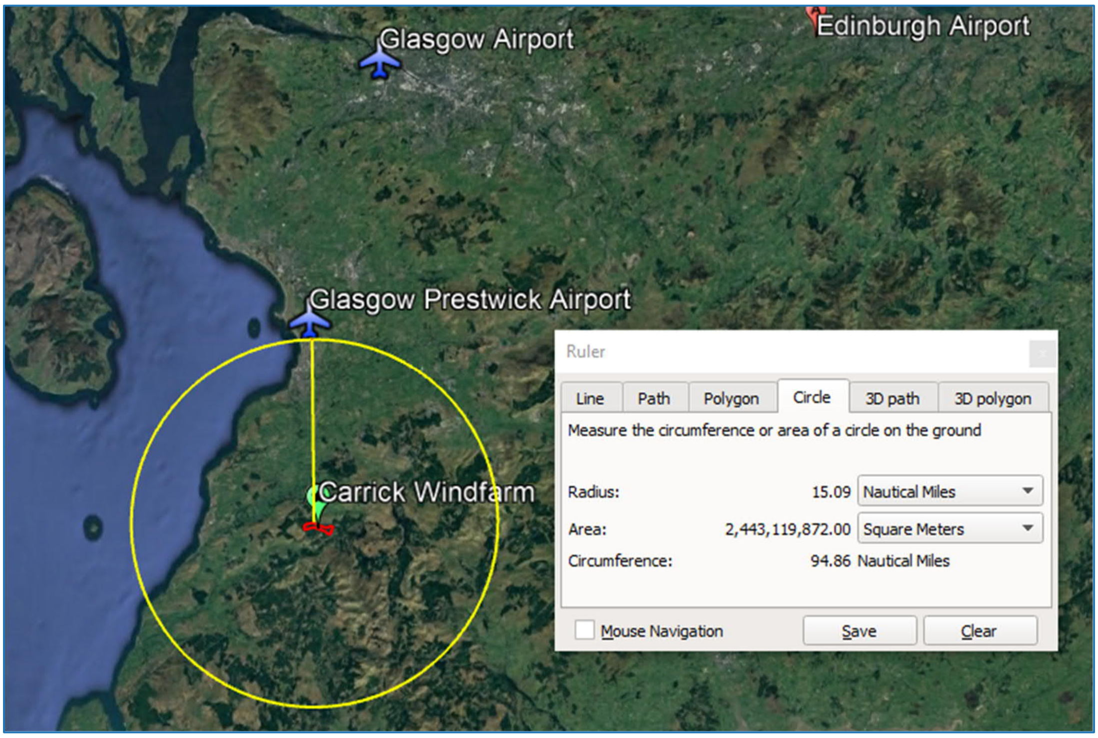


Figure 15: Proposed Development in relation to nearby airports

5.2.2. Figure 16 and Figure 17 depict the airspace and Lower ATS Route structure.

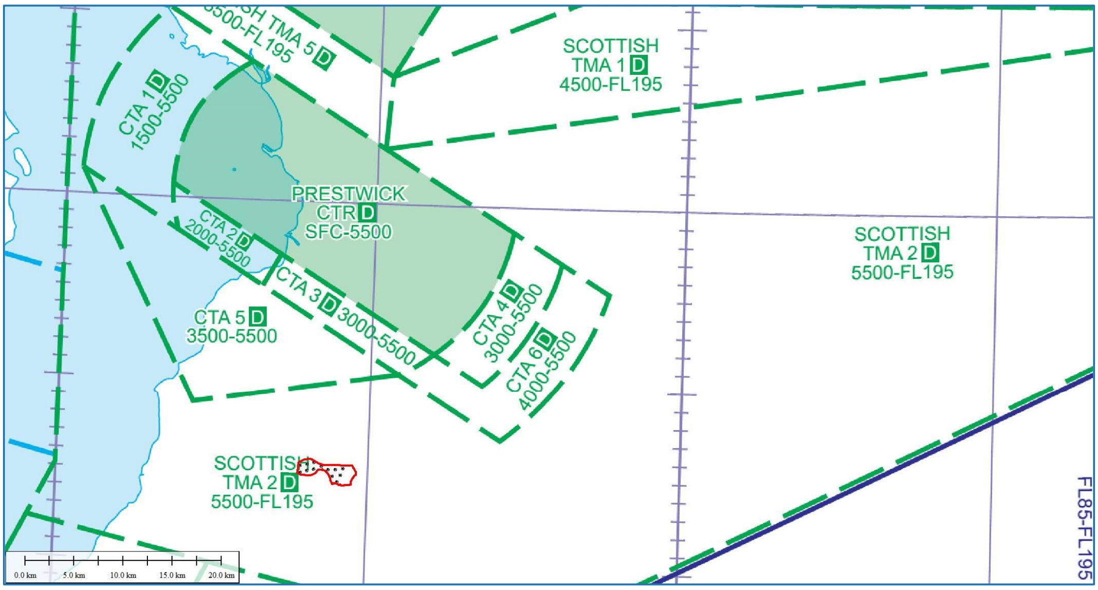


Figure 16: Proposed Development in relation to the Scottish TMA and Glasgow Prestwick CTAs

5.2.3. Figure 17 shows that the Proposed Development is laterally clear of any of the ATS Routes. The closest ATS Route is Z248, approximately 3.8NM north east of the nearest turbine.

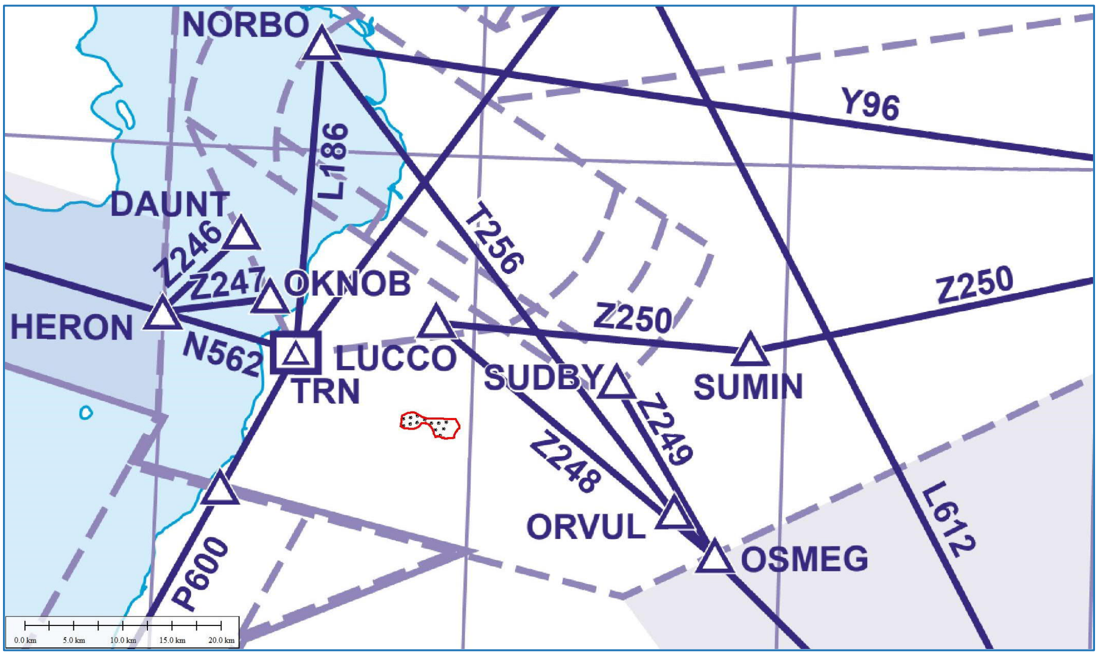


Chart reproduced with the permission of NATS (Services) Limited.

Figure 17: Proposed Development in relation to Lower ATS Routes

5.2.4. As the Transition Altitude in the Scottish TMA is 6,000ft, the lowest useable FL is FL70 (approximately 7,000ft AMSL). Aircraft at FL70 are contained within a TMZ therefore any aircraft entering the airspace from beneath (i.e. from 5,500ft AMSL) should be carrying and using a serviceable transponder. Any loss of PSR coverage in this area should not impact on the provision of ATS within this airspace as there should be sufficient SSR coverage.

5.2.5. As there is no direct conflict with ATS Routes or any controlled airspace, the focus of this report switches to those users of the uncontrolled airspace below 5,500ft AMSL with consideration to any potential impact.

5.3. Other Airspace Considerations

5.3.1. The Proposed Development is relatively close to GPA but does not impact directly upon the procedures associated with Glasgow Prestwick Airport. The Proposed Development is in close proximity (laterally) to the APPLE 2P RIBEL 2P Standard Arrival (STAR) as depicted at Figure 18. However, aircraft will be at FL70 as published and accordingly, the logic from paragraph 5.2.4 applies and, as stated in paragraph 5.1.7, aircraft will be managed by NERL.

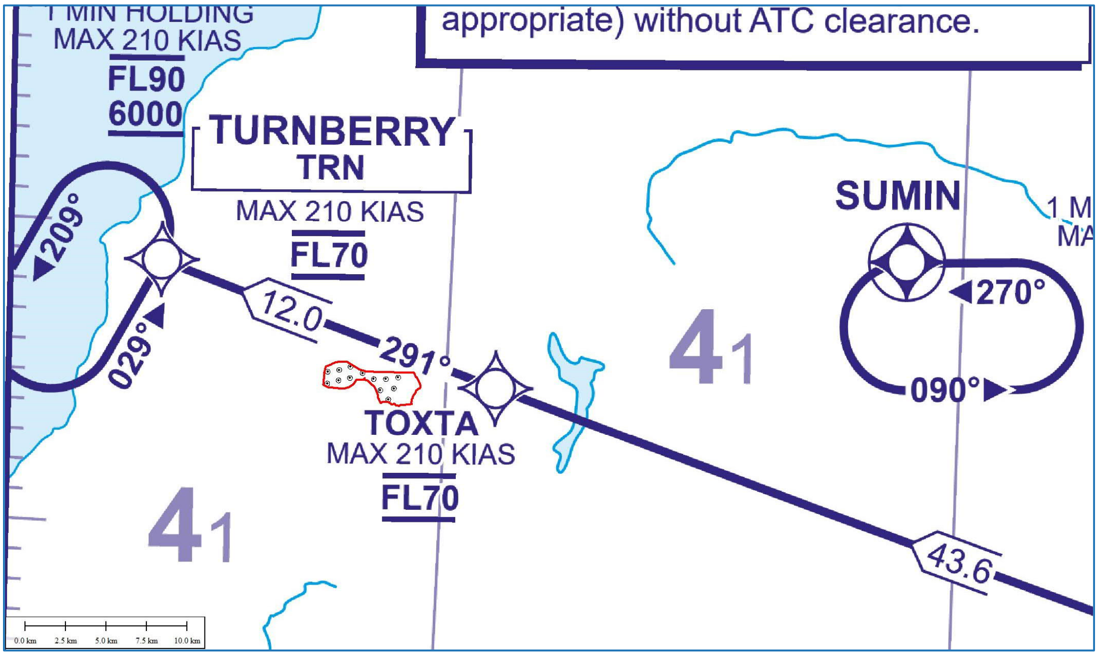


Chart reproduced with the permission of NATS (Services) Limited.

Figure 18: Prestwick APPLE 2P RIBEL 2P STAR

5.3.2. A standalone assessment of the IFPs associated with GPA has been conducted by Cyrrus and concludes that the turbines associated with the Proposed Development do not penetrate any of the design surfaces.

5.3.3. Figure 19 shows an area of the FIS chart extracted from the UK AIP under ENR 6-33. Although the GPA airspace is not depicted on this chart, the FIS area of responsibility excludes those under the responsibility of another ANSP as defined within the AIP. Figure 16 indicates GPA airspace in relation to the Proposed Development.

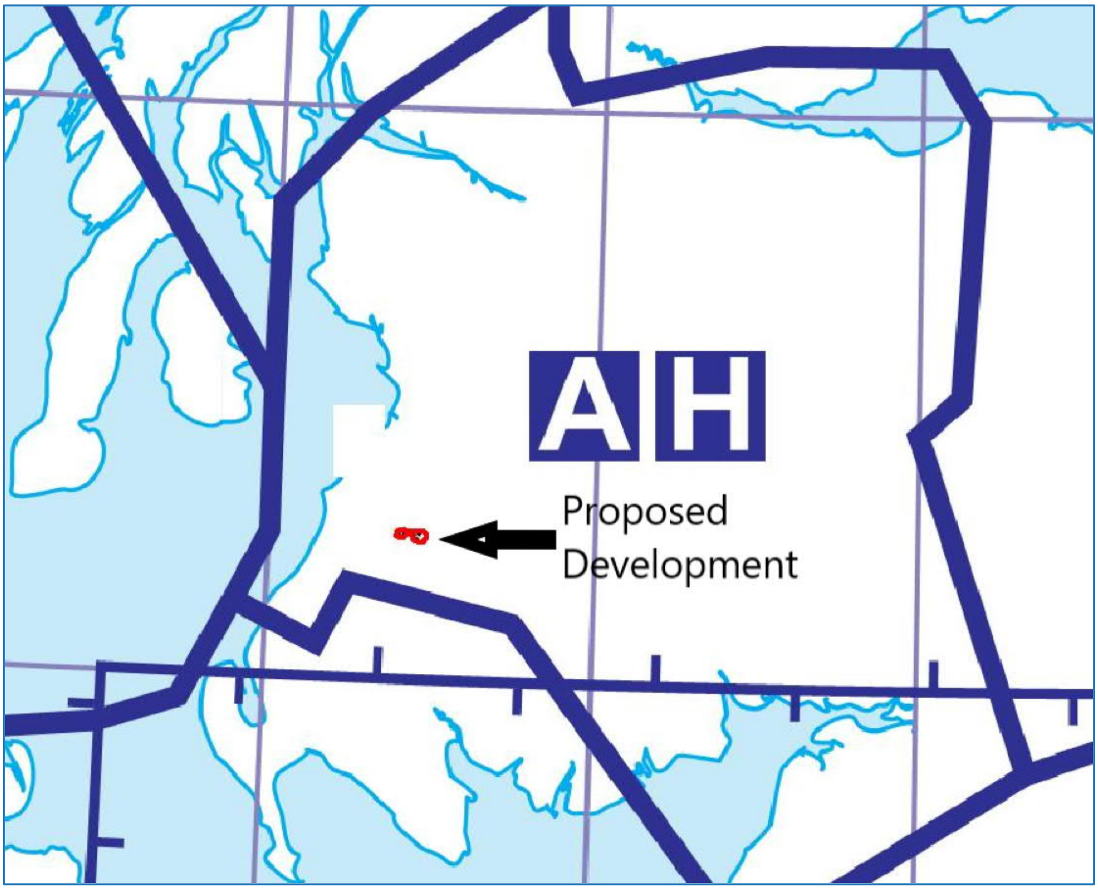


Chart reproduced with the permission of NATS (Services) Limited

Figure 19: UK AIP ENR 6.33 Scottish Control FIS sectors

5.3.4. The airspace covering the Proposed Development is defined as Sectors A and H. The services are described as:

- Sector A: An Information Sector with provision of service, FL55 (circa 5,500ft depending on atmospheric pressure) and below, between the times of 0800-2000 on radio frequency 119.875MHz.
- Sector H: Over the same area, provides a Control Service H24 from FL55 to FL245 (circa 5,500ft to 24,500ft) and an Information Service, FL55 and below, between the hours of 2000-0800 on radio frequency 124.500MHz.

5.3.5. The provision of service above ground in the vicinity of the Proposed Development is delegated to Scottish Control, who provide the service 24 hours per day throughout the year. GPA may not provide a service in that airspace without individual coordination and delegation by Scottish Control. As stated in paragraph 5.1.5, services are provided in accordance with CAP 774.

5.3.6. The nearest private airstrip depicted on the UK Visual Flight Rules chart is at Kilkerran, to the east of Turnberry. Kilkerran has a grass strip and is approximately 3NM north west of the Proposed Development boundary and is not licensed by the UK Civil Aviation Authority (CAA). The level of usage of this private airstrip is unknown.

5.3.7. Figure 20 indicates the Proposed Development in relation to the PINS (Pipeline Inspection Notification System) Areas and UK Day Low Flying System. It is contained within Area 20T (Area 2B at night). The 'T' indicates that this is a situated within the Tactical Training Area. Military aircraft do occasionally conduct tactical low flying training down to 100ft Minimum Separation Distance in this region. SPR has indicated that it will light the periphery Carrick Windfarm turbines with Infra-Red lights, in addition to lighting in accordance with Air Navigation Order Article 222. These Infra-Red lights would be illuminated in all hours of darkness, and not be subject to any Aircraft Detection Lighting System.

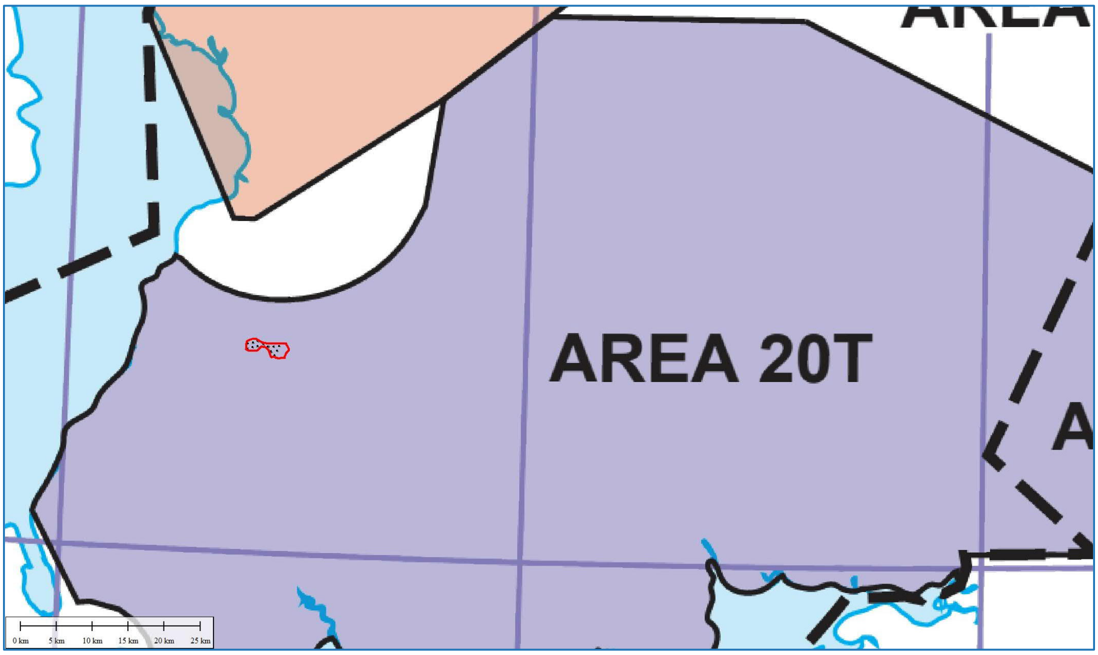


Figure 20: Proposed Development in relation to PINS and UK Day Low Flying System

6. Mitigation Options

6.1. Mitigation Requirement

6.1.1. Mitigation may be required where radar clutter generated by the Proposed Development's turbines has a detrimental impact on the ATS provided. Both NERL's and GPA's ATS may be impacted by the Proposed Development. If the impact on ATS provided is sufficiently detrimental, mitigation may be required. This section analyses the available mitigation options.

6.2. GPA Mitigation – Terma Scanter 4002

6.2.1. The newly installed GPA Terma Scanter 4002 PSR was introduced as a windfarm tolerant approach radar and is understood to have been funded through contributions from windfarm operators. The Terma PSR operates in the X frequency band (9GHz), unlike the majority of PSRs providing approach services which operate in the S band (2.8GHz). This means that the Terma antenna transmits a narrower beam with smaller range resolutions down to approximately 6m as opposed to 50m.

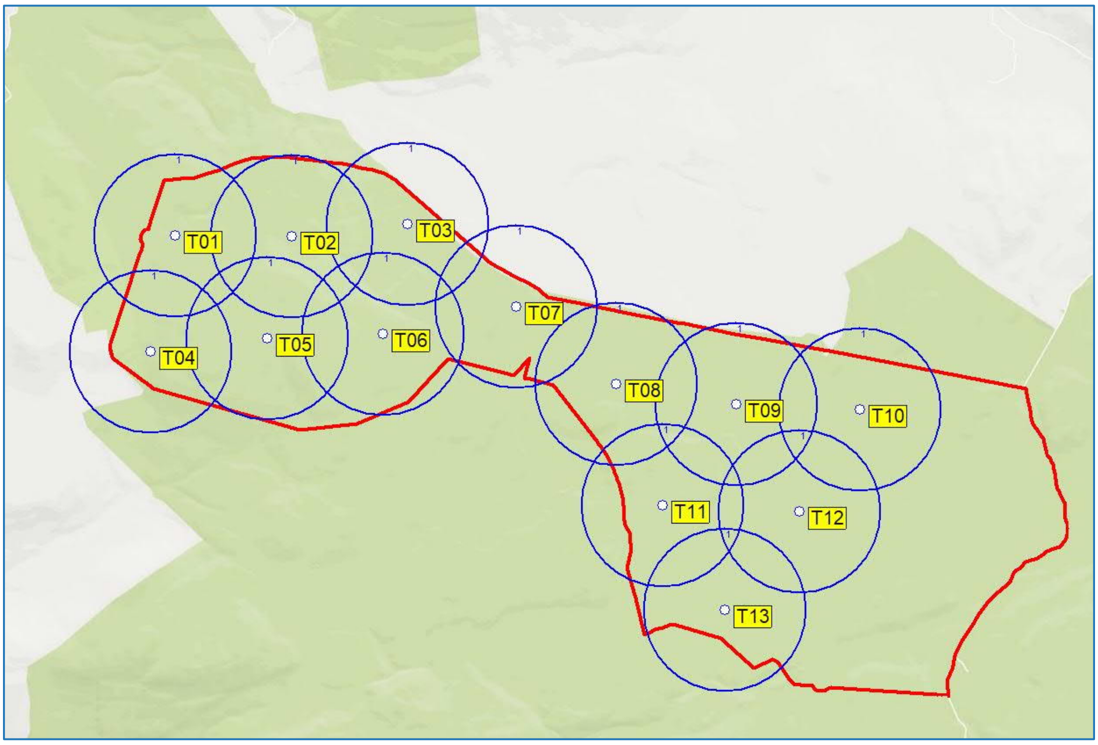
6.2.2. A white paper published in 2012, "Detection and Tracking of Aircraft over Wind Farms using SCANTER 4002 with Embedded Tracker 2", comprehensively presents the details and results of flight tests carried out over large offshore windfarms. The document describes how, for windfarms with an inter-turbine spacing of 500m or more, wind turbine clutter can be removed by allowing the turbine video to be extracted as plots to be used in the tracker and identified as static targets. Once established as static targets, they will have high association likelihood to new plots overlapping the track updated position, and thereby help consume wind turbine plots and lower the risk of track seductions.

6.2.3. During the Clauchrie PLI, in response to questions regarding the Terma Scanter 4002[4], Terma stated that the 2012 white paper was based on the first generation 4002 radar and that the latest Terma Scanter 4002 differs in several ways. However, Terma did state that "many of the principles described in the article are still valid and carried over in the latest design."

6.2.4. Mitigation of turbines will impact the PD for aircraft within the wind farm area because it is not possible to distinguish an aircraft from a turbine in the radar cell directly over each wind turbine. It therefore follows that the inter-turbine spacing will affect the level of PD impact. Although by itself it is not a guarantee of maintaining a satisfactory PD, an inter-turbine spacing of more than 500m should help to minimise the impact on PD.

[4] Terma response to questions regarding Terma SCANTER 4002 radar (Clauchre Windfarm Public Inquiry) email 18 June 2021

6.2.5. Blue circles of 500m radius centred on each turbine in Figure 21Error! Reference source not found. show that the Carrick turbines have an inter-turbine spacing that exceeds 500m.



Microsoft® Bing™ screen shot reprinted with permission from Microsoft Corporation

Figure 21: 500m inter-turbine spacing

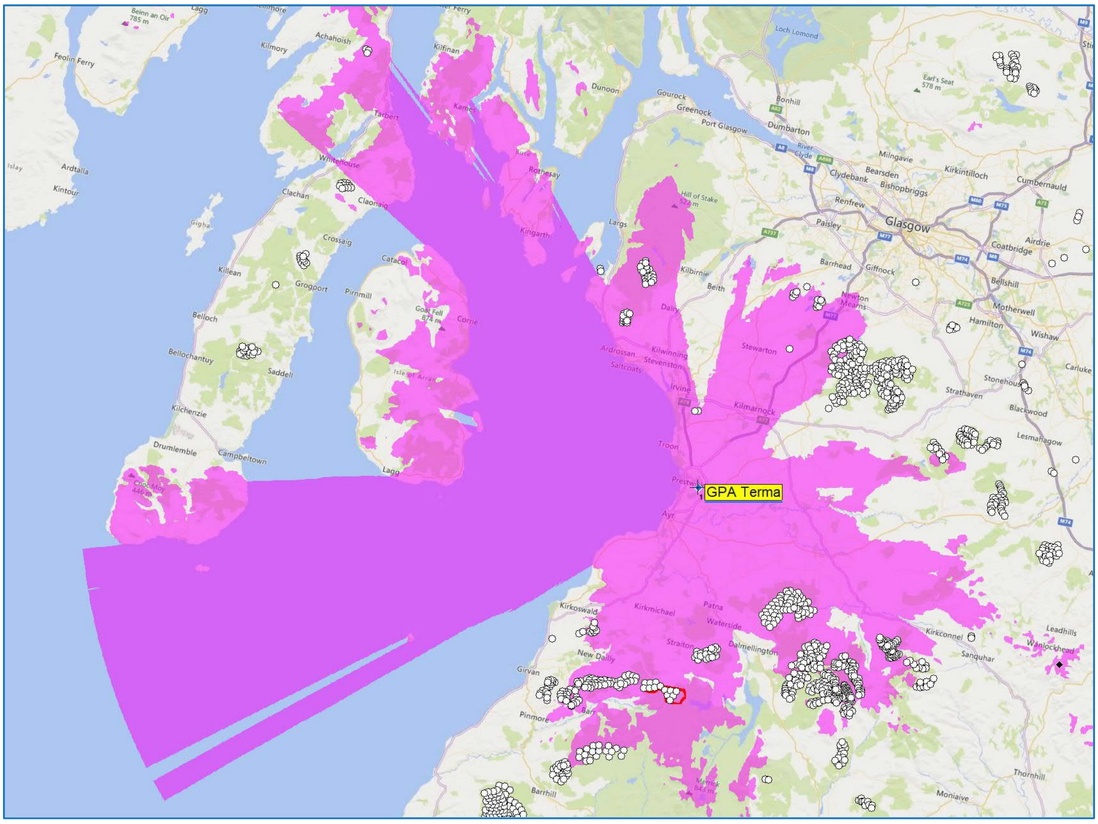
6.2.6. When a new windfarm becomes operational within the Terma radar coverage area that is in RLoS and detected, then, if necessary, the Terma radar can be re-optimised to filter out any clutter generated by the turbines. Individual turbine positions must be manually added to the radar's internal map so that the plots originating from turbines are identified as static targets. Once optimised, the GPA Terma should then be capable of detecting the Carrick turbines and maintaining internal tracks on them (which are not displayed to the controller) whilst simultaneously tracking air targets passing over the Proposed Development. Once the Carrick turbines have been optimised there should be no subsequent requirement for re-optimisation or mitigation unless the turbine sizes or locations are changed.

6.2.7. In their Scoping response on 25 June 2020, GPA expressed concern regarding the close proximity of the Proposed Development to the operational Dersalloch and Hadyard Hill windfarms, and the proposed Clauchrie windfarm, in terms of the cumulative impact on mitigation capacity.

6.2.8. The Terma PSR, as part of its commissioning process, has already undergone one-off optimisation to mitigate several visible windfarms, including Dersalloch and Hadyard Hill. During the Clauchrie PLI, radar video recordings were presented which contrasted the S511 and Terma PSRs' displays as seen by controllers. Clutter generated by Dersalloch and Hadyard Hill windfarms was clearly visible on the S511 display, together with additional clutter from weather, while the Terma display was by contrast entirely clutter-free.

6.2.9. As reported in the 2012 white paper, the Terma Scanter 4002 PSR can reportedly maintain more than 1000 concurrent internal tracks without a degradation to the display. It is reasonable to assume that the latest generation of the Scanter 4002 can maintain considerably more. With that in mind, an analysis of windfarms in the vicinity of GPA was undertaken using data on turbine obstacles 300ft AGL and over from the Area 1 Obstacles File (ENR 5.4), available on the UK Integrated Aeronautical Information Package website[5], and additional turbine data from consented windfarms and applied for developments.

6.2.10. The turbine data is imported into the radar model and the number of turbines within GPA Terma RLoS to 200m AGL is determined, as shown in Figure 22Error! Reference source not found..



Microsoft® Bing™ screen shot reprinted with permission from Microsoft Corporation

Figure 22: GPA Terma PSR RLoS to 200m AGL – all turbines

6.2.11. The total number of turbines within the 200m AGL coverage area is 549. This number is an overestimate of the actual turbines in RLoS as most of the turbine tip heights are less than 200m, but the total is presented here as a useful worst-case scenario figure.

6.2.12. The potential number of turbines in the vicinity of GPA is well within the Terma's concurrent internal track capacity. In other words, the inherent processing capabilities of the GPA Terma should be able to mitigate the impact of the Carrick turbines provided a Terma technician optimises the GPA Terma upon the erection of the Proposed Development's turbines.

[5] http://www.nats-uk.ead-it.com/aip/current/misc/ENR_5_4_2020_09_10.xls

6.3. NERL Mitigation – Potential Infill Radars

6.3.1. A potential option for mitigating the impact on Lowther Hill PSR is to use an infill radar feed that does not have RLoS of the Carrick Windfarm turbines but has adequate coverage over the Proposed Development to satisfy ATC requirements.

6.3.2. The base of controlled airspace immediately above the Proposed Development is 5,500ft AMSL in the Scottish TMA. As has been stated, this airspace is under the control of NERL, based at Prestwick Centre; however, airspace in the vicinity of GPA from 5,500ft to 6,000ft is delegated from NERL to GPA to enable vectoring and sequencing of traffic. Most of the traffic passing over Carrick Windfarm is likely to be inbound to GPA, so it is likely that NERL only control the airspace from 6,000ft above the Proposed Development. The airspace in the vicinity of the Proposed Development is discussed further in Section 5.

6.3.3. Cyrrus understands that NATS' units optimally require circa 2,000ft of additional PSR coverage below the base of NERL TMA controlled airspace to provide a safety buffer for controllers. This means that PSRs must be capable of detecting airborne targets at a minimum altitude of 4,000ft over Carrick Windfarm.

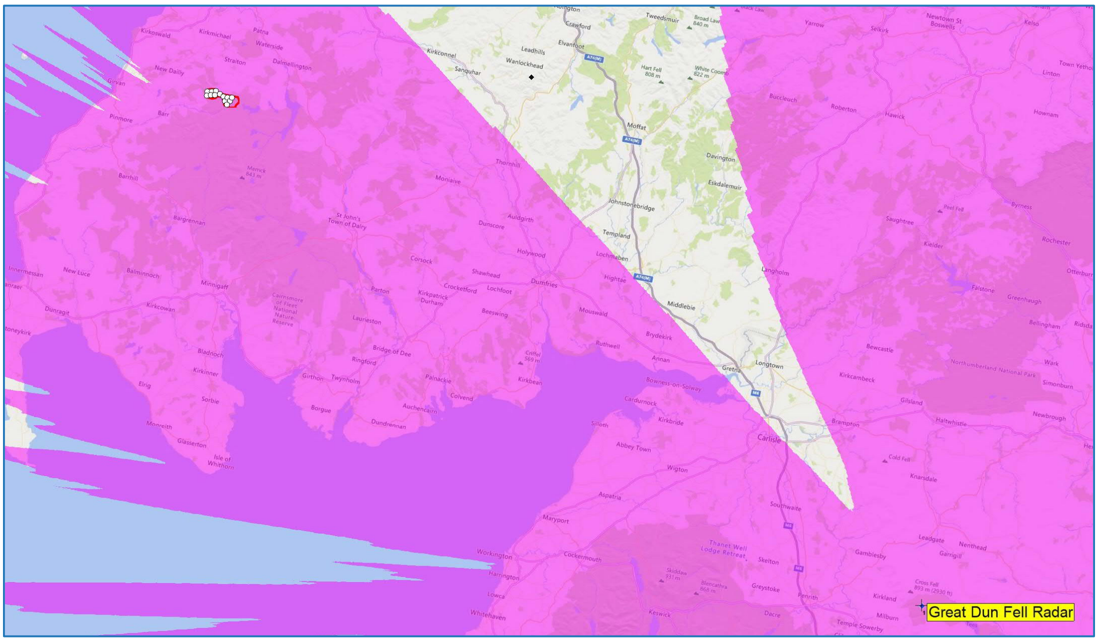
6.3.4. Surveillance coverage requirements in the terminal environment are summarised in the CAA document CAP 670[6]. Section 3: SUR 01 states that below Flight Level 100 (approximately 10,000ft AMSL) all TMAs shall have at least a single layer of coverage by a non-cooperative surveillance technique, i.e. PSR, together with data from a suitable co-operative surveillance technique (e.g. SSR). Redundancy is only required for the co-operative surveillance provision, e.g. in the form of dual SSR, which suggests that a single layer of infill PSR coverage is sufficient to provide coverage over a blanked area.

6.3.5. Candidate radars for infill coverage over Carrick Windfarm are Great Dun Fell PSR, Cumbernauld PSR, Glasgow PSR, Glasgow Terma PSR and Kincardine PSR.

[6] CAP 670, Air Traffic Services Safety Requirements, Issue 3 Amendment 1/2019, June 2019

6.4. NERL Potential Infill Radars – Great Dun Fell PSR

6.4.1. The closest turbine within the Proposed Development area is approximately 147.7km (79.8NM) north west of Great Dun Fell PSR. The magenta shading in Figure 23 illustrates the RLoS coverage for Great Dun Fell PSR at an altitude of 3,500ft.



Microsoft® Bing™ screen shot reprinted with permission from Microsoft Corporation

Figure 23: Great Dun Fell PSR RLoS at 3,500ft AMSL

6.4.2. It can be seen in Figure 23 that Great Dun Fell PSR can provide radar coverage down to an altitude of 3,500ft in the vicinity of the Carrick Windfarm turbines.

6.4.3. Historically, there has been a NERL requirement that infill coverage is extended to include a 5NM buffer on all the mitigated wind turbines. It is not known how strictly this requirement is currently being applied.

6.4.4. The zoomed view of the Great Dun Fell PSR 3,500ft coverage in Figure 24 includes 5NM circles centred on each turbine to illustrate where the buffer may be required to extend to.

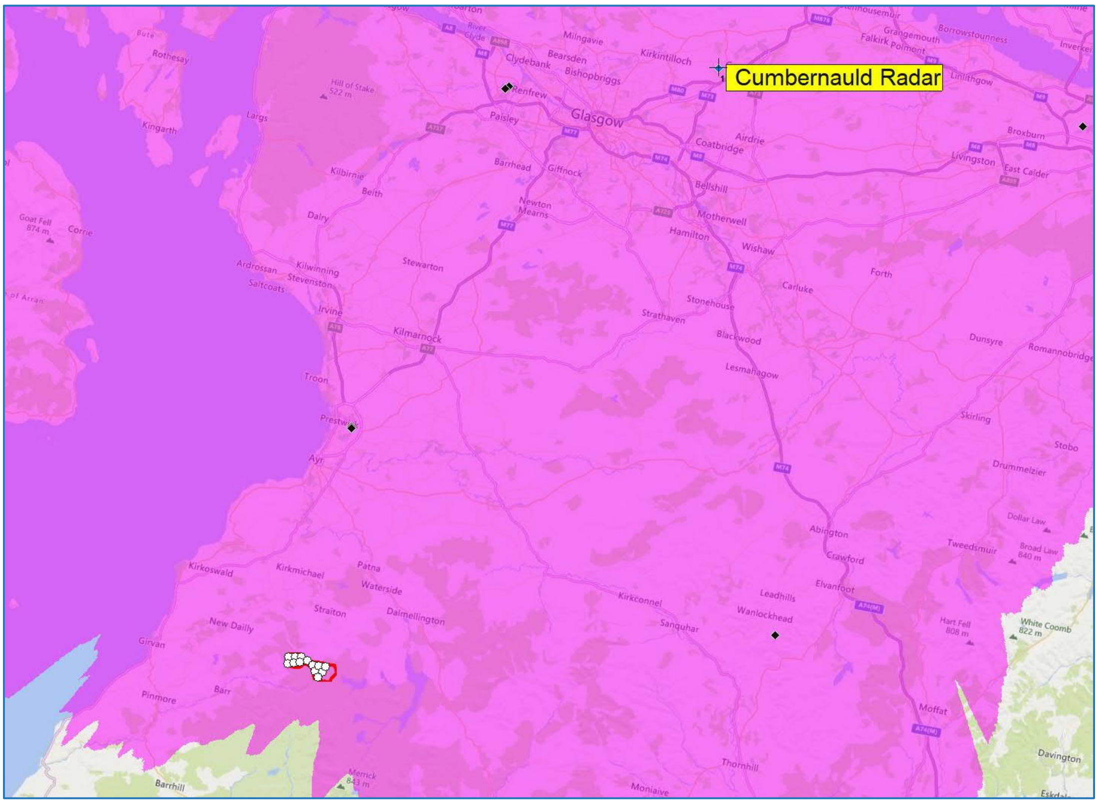
Microsoft® Bing™ screen shot reprinted with permission from Microsoft Corporation

Figure 24: Great Dun Fell PSR RLoS at 3,500ft AMSL – zoomed

6.4.5. Great Dun Fell PSR can provide coverage at 3,500ft AMSL over the Carrick Windfarm turbines that satisfies the 5NM buffer requirement.

6.5. NERL Potential Infill Radars – Cumbernauld PSR

6.5.1. The closest turbine within the Proposed Development area is approximately 82.2km (44.4NM) south west of Cumbernauld PSR. The magenta shading in Figure 25 illustrates the RLoS coverage for Cumbernauld PSR at an altitude of 4,000ft.

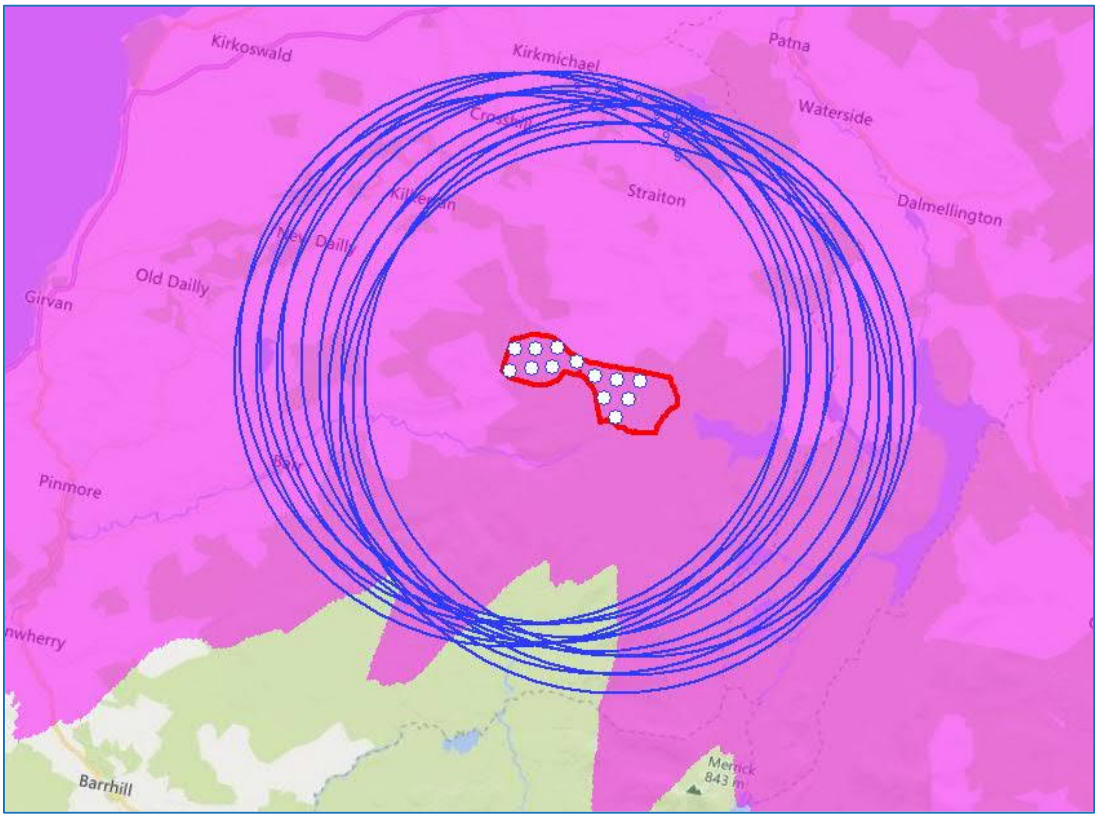


Microsoft® Bing™ screen shot reprinted with permission from Microsoft Corporation

Figure 25: Cumbernauld PSR RLoS at 4,000ft AMSL

6.5.2. It can be seen in Figure 25 that Cumbernauld PSR can provide radar coverage down to an altitude of 4,000ft in the vicinity of the Carrick Windfarm turbines.

6.5.3. The zoomed view of the Cumbernauld PSR 4,000ft coverage in Figure 26 includes 5NM circles centred on each turbine to illustrate where the buffer may be required to extend to.



Microsoft® Bing™ screen shot reprinted with permission from Microsoft Corporation

Figure 26: Cumbernauld PSR RLoS at 4,000ft AMSL – zoomed

6.5.4. As can be seen, coverage at altitude 4,000ft does not quite extend to 5NM south of the turbines.

6.5.5. Notwithstanding the 5NM buffer requirement, Cumbernauld PSR can provide a minimum of 4,000ft AMSL infill coverage over the Carrick Windfarm turbines.

6.6. NERL Potential Infill Radars – Glasgow PSR and Glasgow Terma

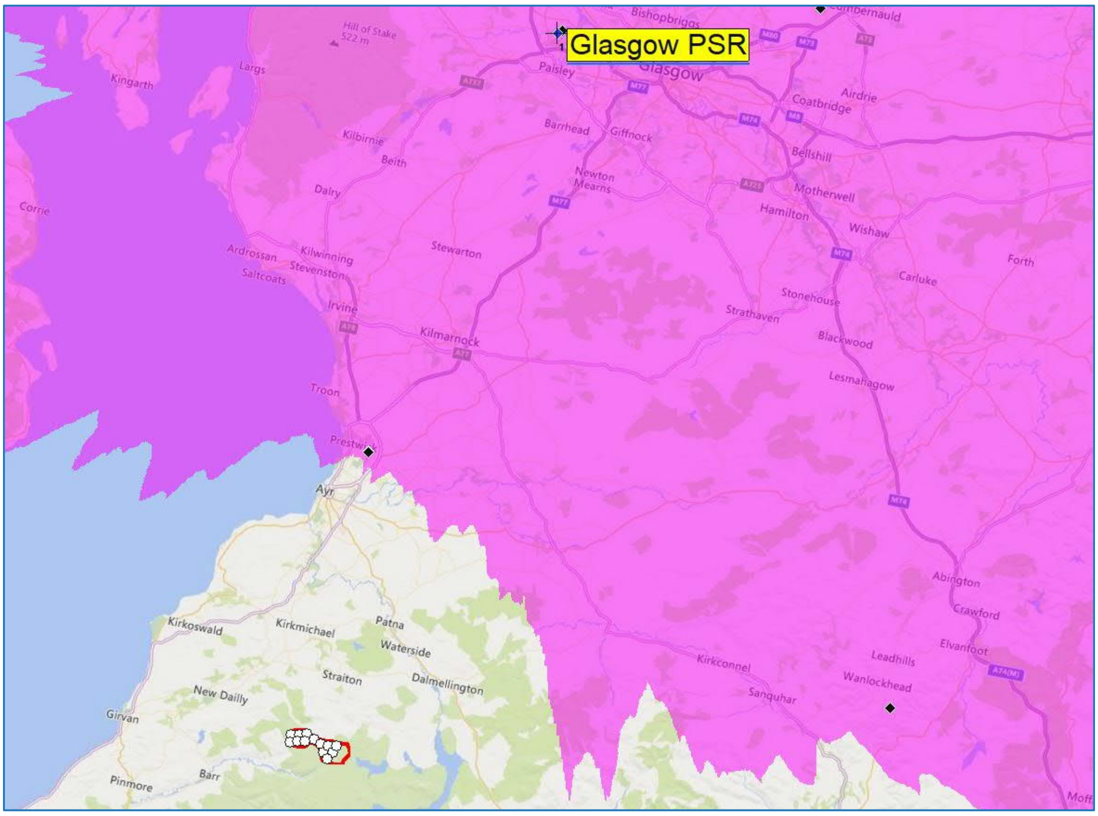
6.6.1. The locations of the Glasgow PSR and Glasgow Terma are shown in Figure 27.

Microsoft® Bing™ screen shot reprinted with permission from Microsoft Corporation

Figure 27: Locations of Glasgow PSR and Glasgow Terma

6.6.2. The closest turbine within the Proposed Development area is approximately 69.2km (37.4NM) south of the Glasgow radars.

6.6.3. The magenta shading in Figure 28 illustrates the RLoS coverage for Glasgow PSR at an altitude of 4,000ft.

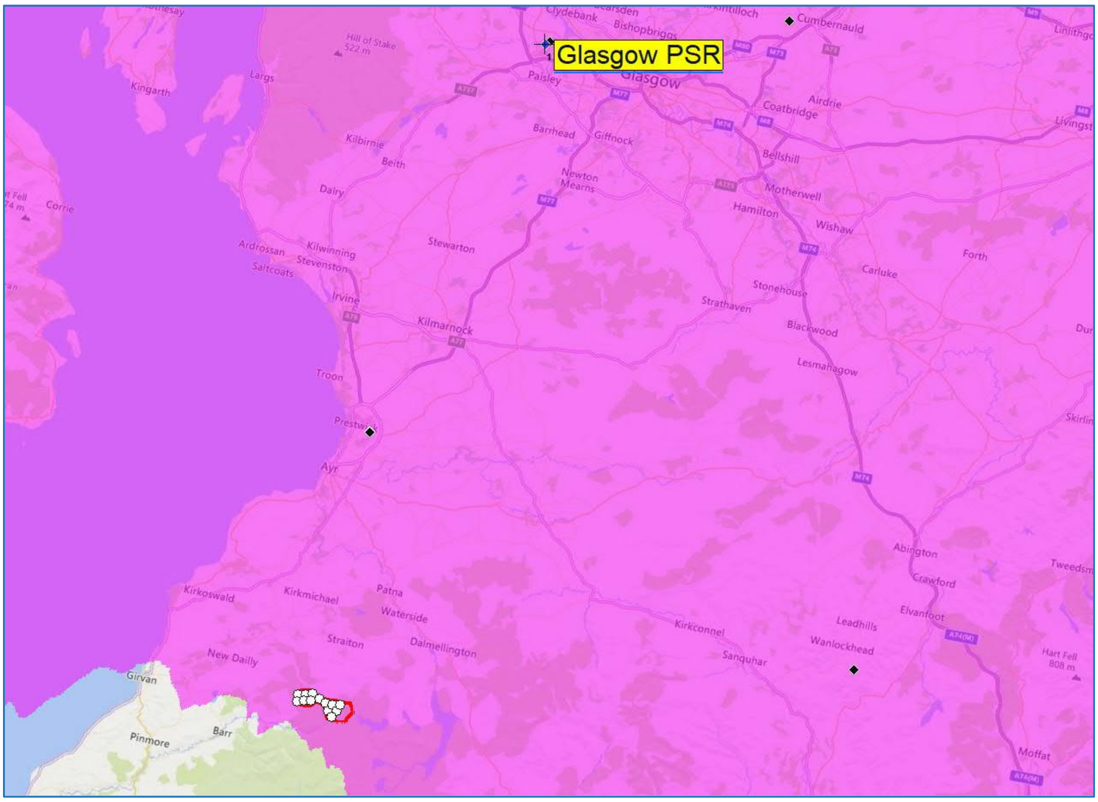


Microsoft® Bing™ screen shot reprinted with permission from Microsoft Corporation

Figure 28: Glasgow PSR RLoS at 4,000ft AMSL

6.6.4. It can be seen that Glasgow PSR cannot provide radar coverage down to an altitude of 4,000ft in the vicinity of the Carrick Windfarm turbines.

6.6.5. The base of Glasgow PSR coverage over the Carrick Windfarm turbines is 7,000ft AMSL, as shown by the magenta shading in Figure 29.

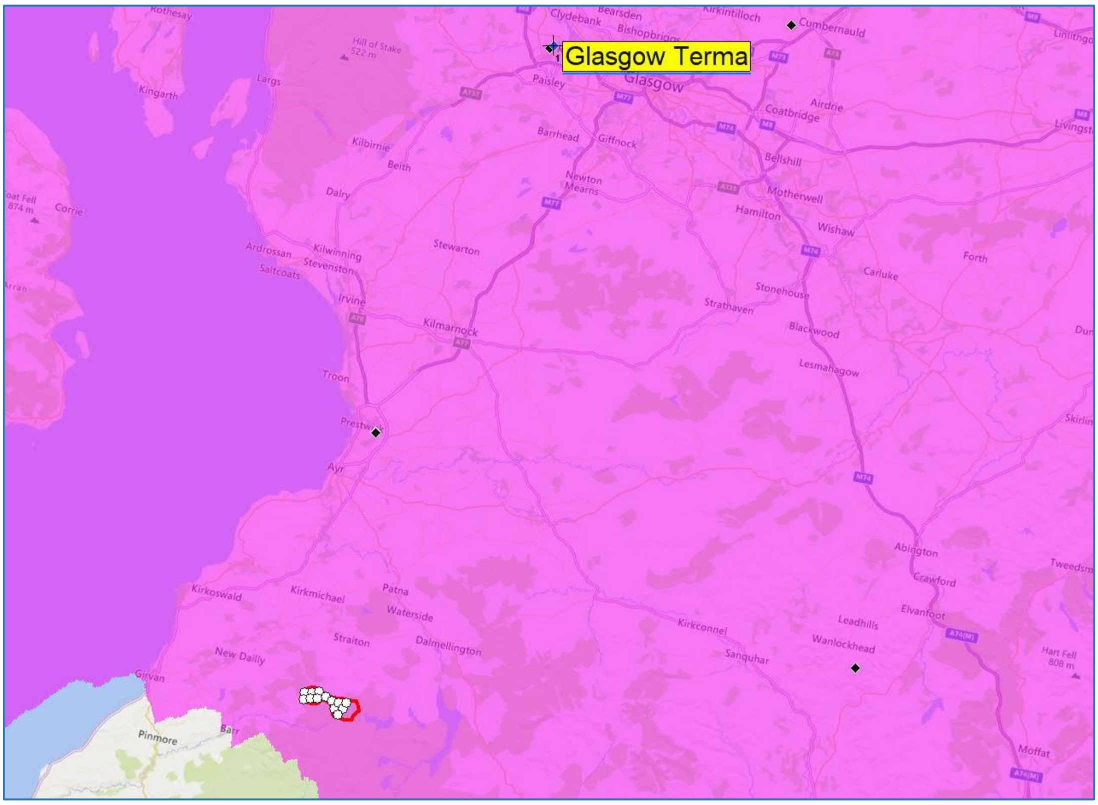


Microsoft® Bing™ screen shot reprinted with permission from Microsoft Corporation

Figure 29: Glasgow PSR RLoS at 7,000ft AMSL

6.6.6. The Glasgow Terma is sited in close proximity to the Glasgow PSR and thus has very similar RLoS coverage performance.

6.6.7. The magenta shading in Figure 30 shows the Glasgow Terma RLoS coverage at 7,000ft AMSL over the Carrick Windfarm turbines.



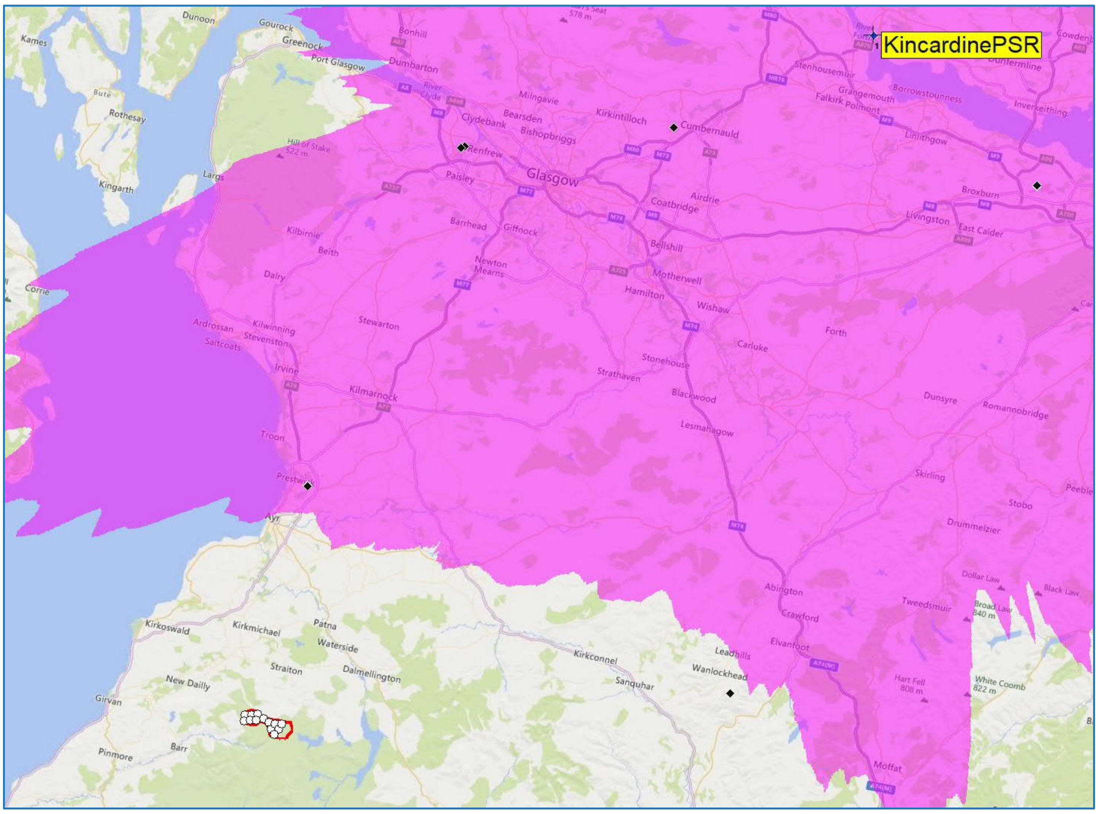
Microsoft® Bing™ screen shot reprinted with permission from Microsoft Corporation

Figure 30: Glasgow Terma RLoS at 7,000ft AMSL

6.6.8. It is unlikely that either Glasgow PSR or Glasgow Terma can provide the necessary required minimum infill radar coverage over the Carrick Windfarm turbines.

6.7. NERL Potential Infill Radars – Kincardine PSR

6.7.1. The closest turbine within the Proposed Development area is approximately 104.6km (56.5NM) south west of Kincardine PSR. The magenta shading in Figure 31 illustrates the RLoS coverage for Kincardine PSR at an altitude of 4,000ft.

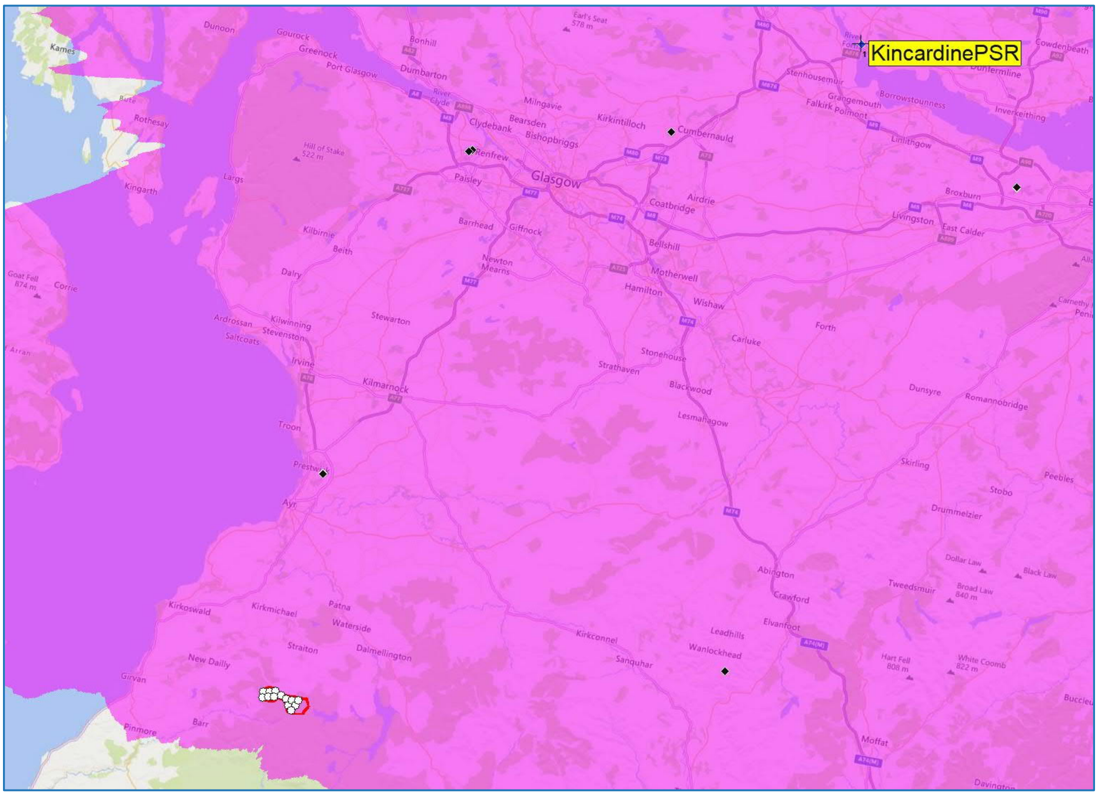


Microsoft® Bing™ screen shot reprinted with permission from Microsoft Corporation

Figure 31: Kincardine PSR RLoS at 4,000ft AMSL

6.7.2. It can be seen that Kincardine PSR cannot provide radar coverage down to an altitude of 4,000ft in the vicinity of the Carrick Windfarm turbines.

6.7.3. The base of Kincardine PSR coverage over the Carrick Windfarm turbines is 6,500ft AMSL, as shown by the magenta shading in Figure 32.



Microsoft® Bing™ screen shot reprinted with permission from Microsoft Corporation

Figure 32: Kincardine PSR RLoS at 6,500ft AMSL

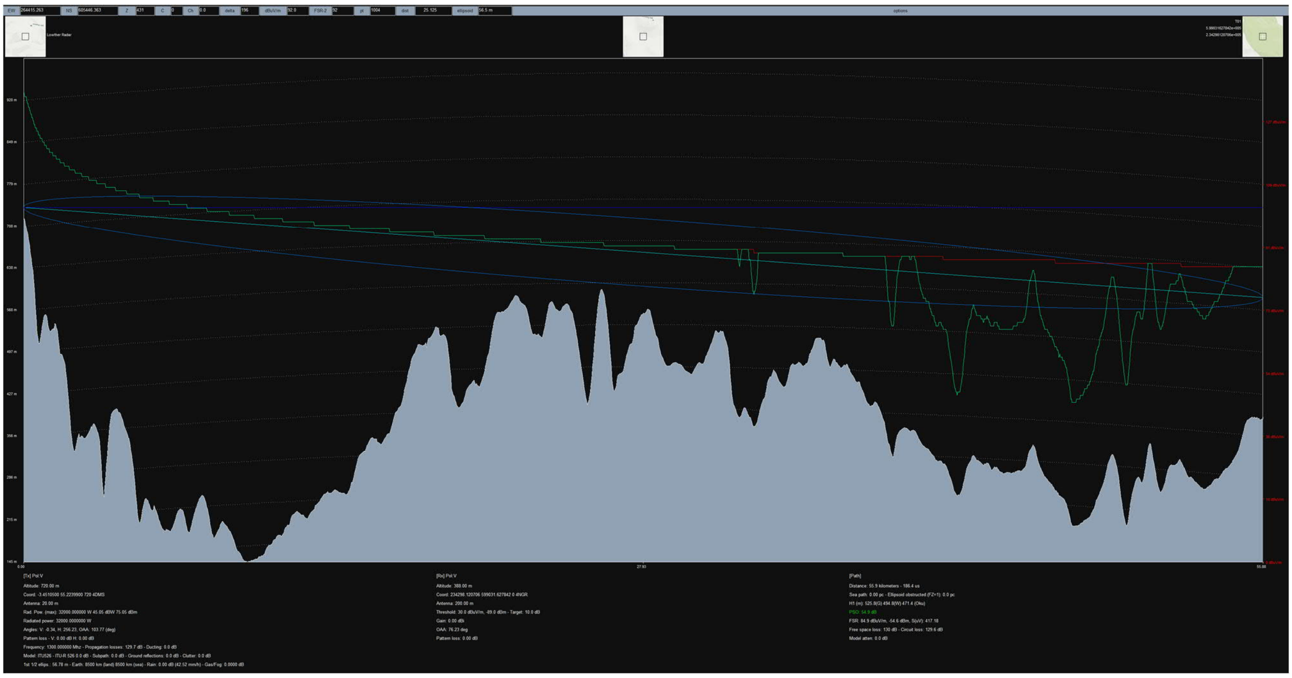
6.7.4. It is unlikely that Kincardine PSR can provide the necessary required minimum infill radar coverage over the Carrick Windfarm turbines.

6.8. NERL Potential Infill Radar – Summary

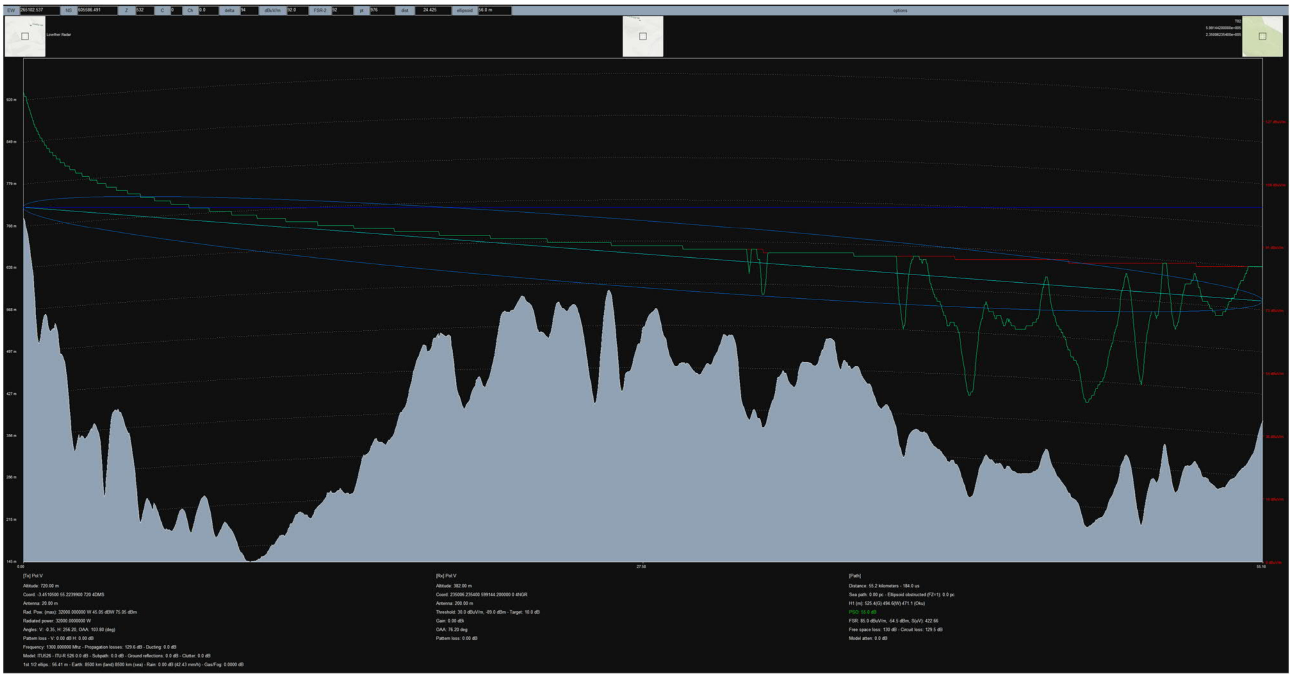
6.8.1. Great Dun Fell PSR has the lowest base of radar coverage, 3,500ft AMSL, in the vicinity of the Proposed Development. Cumbernauld can provide the required minimum coverage of 4,000ft AMSL. Both of these PSRs are integrated into NERL's Multi-Radar Tracking infrastructure.

A. Annex A – Lowther Hill PSR Path Profiles

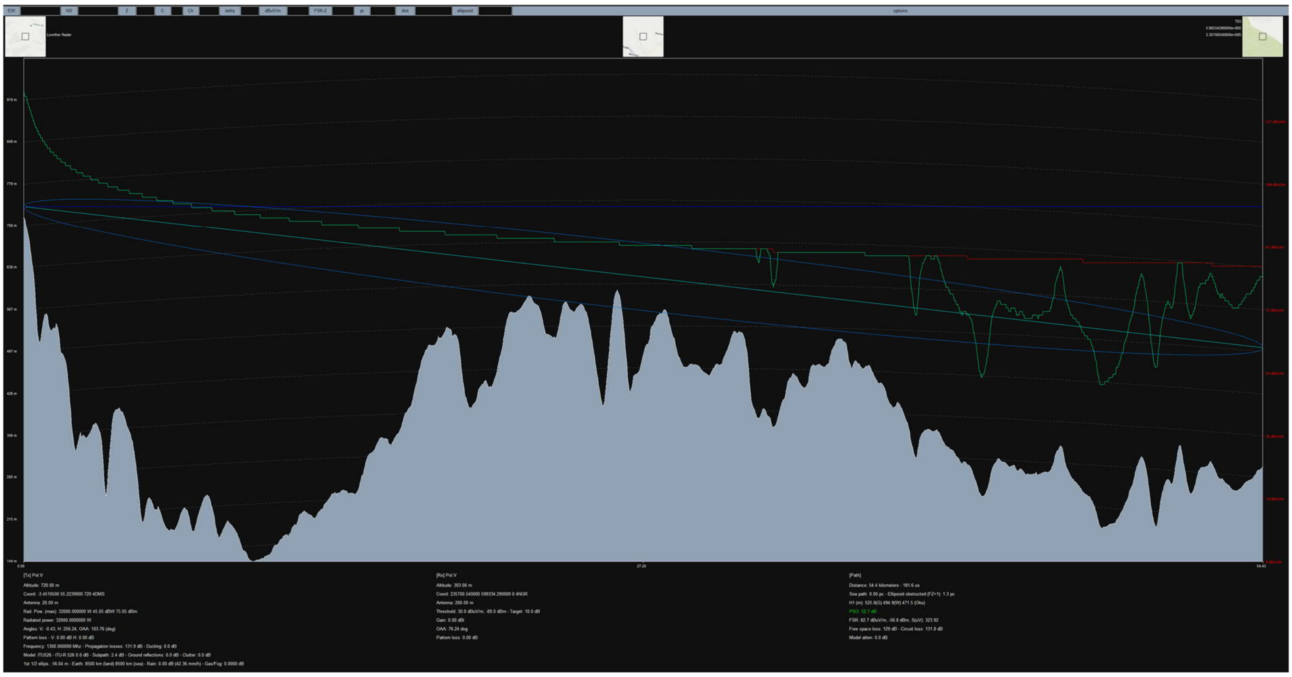
A.1. Turbine T01



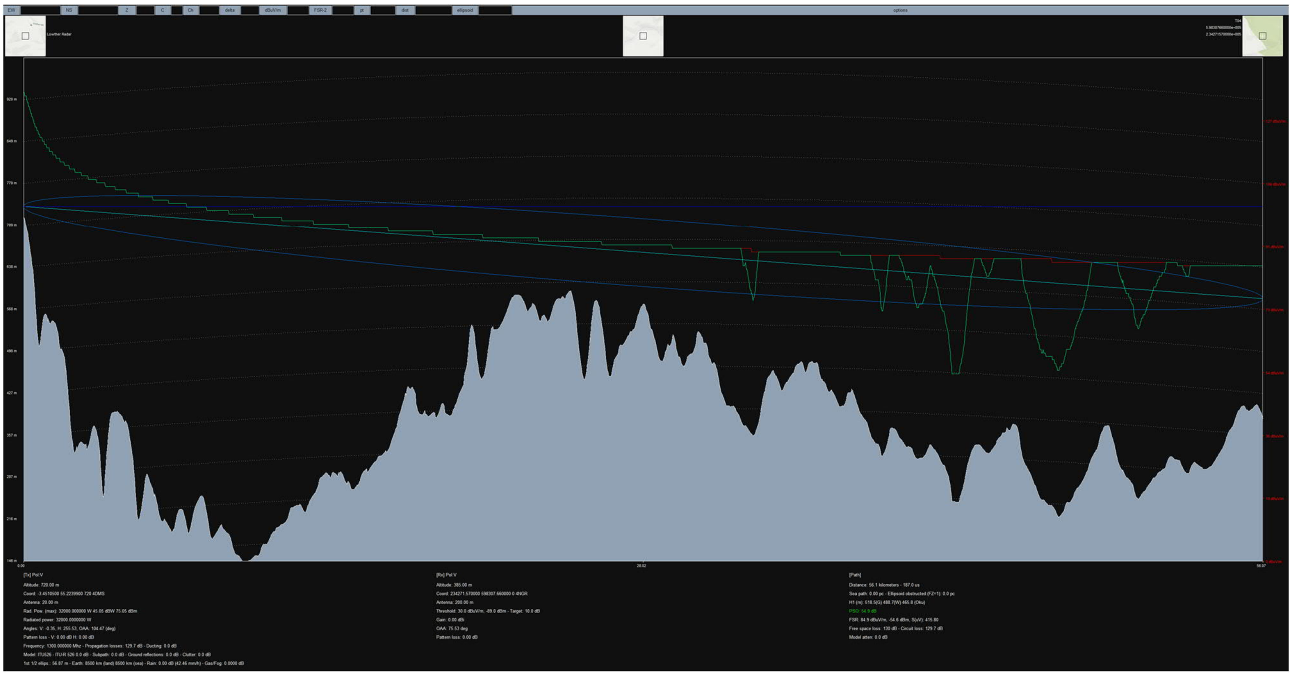
A.2. Turbine T02



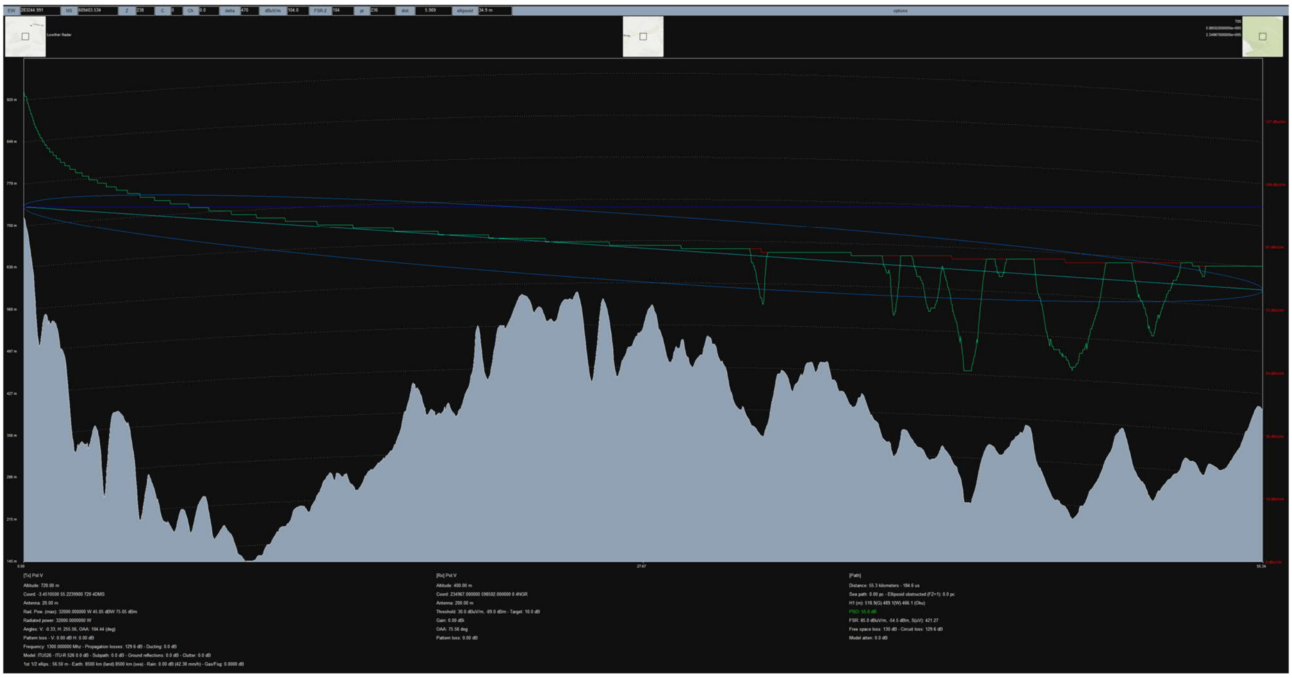
A.3. Turbine T03



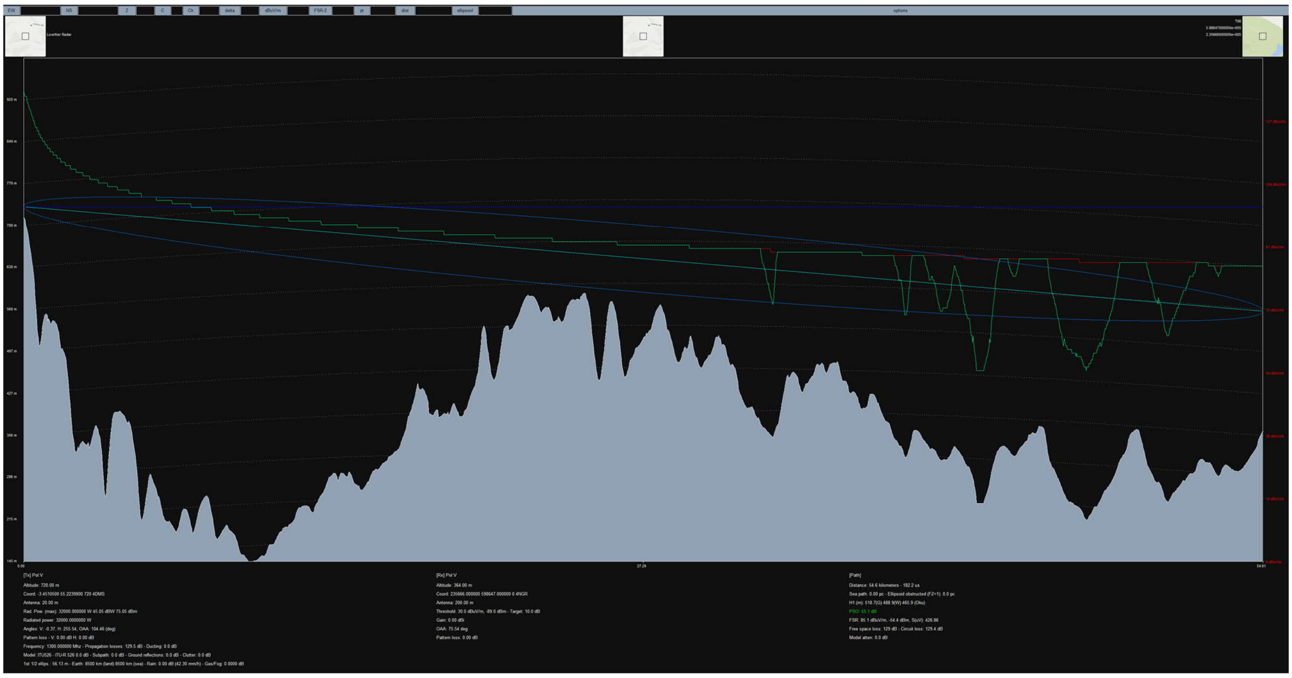
A.4. Turbine T04



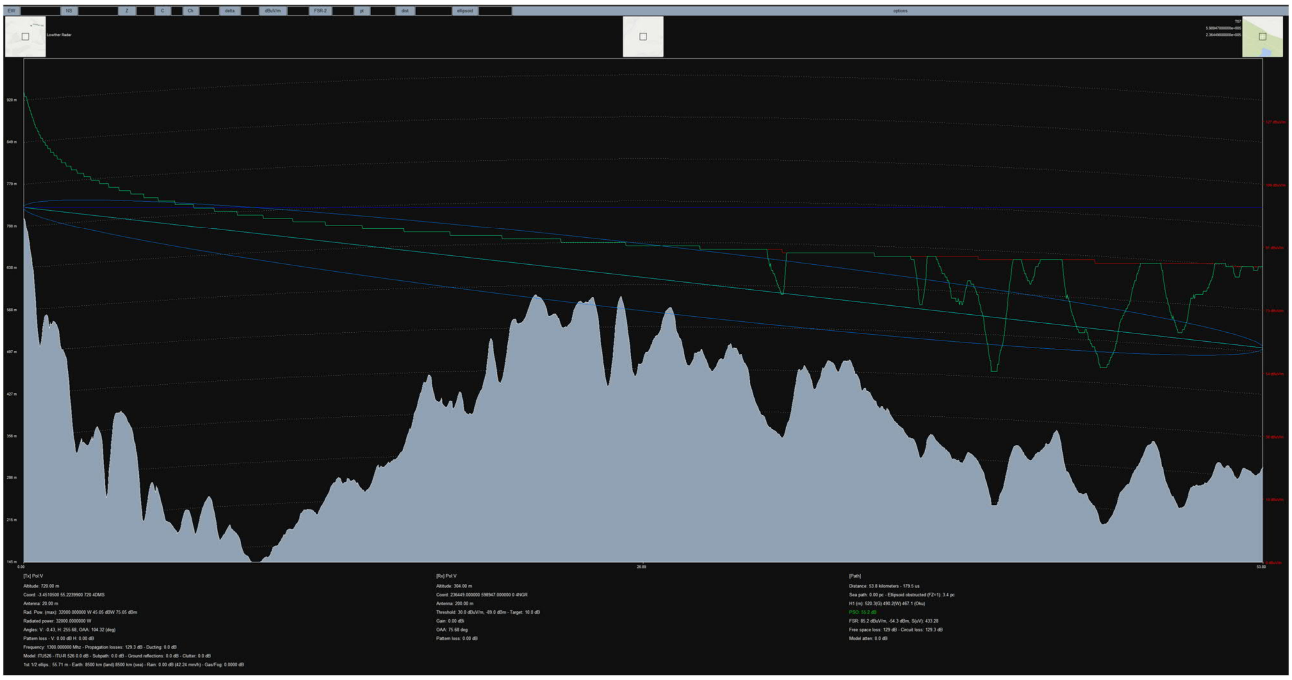
A.5. Turbine T05



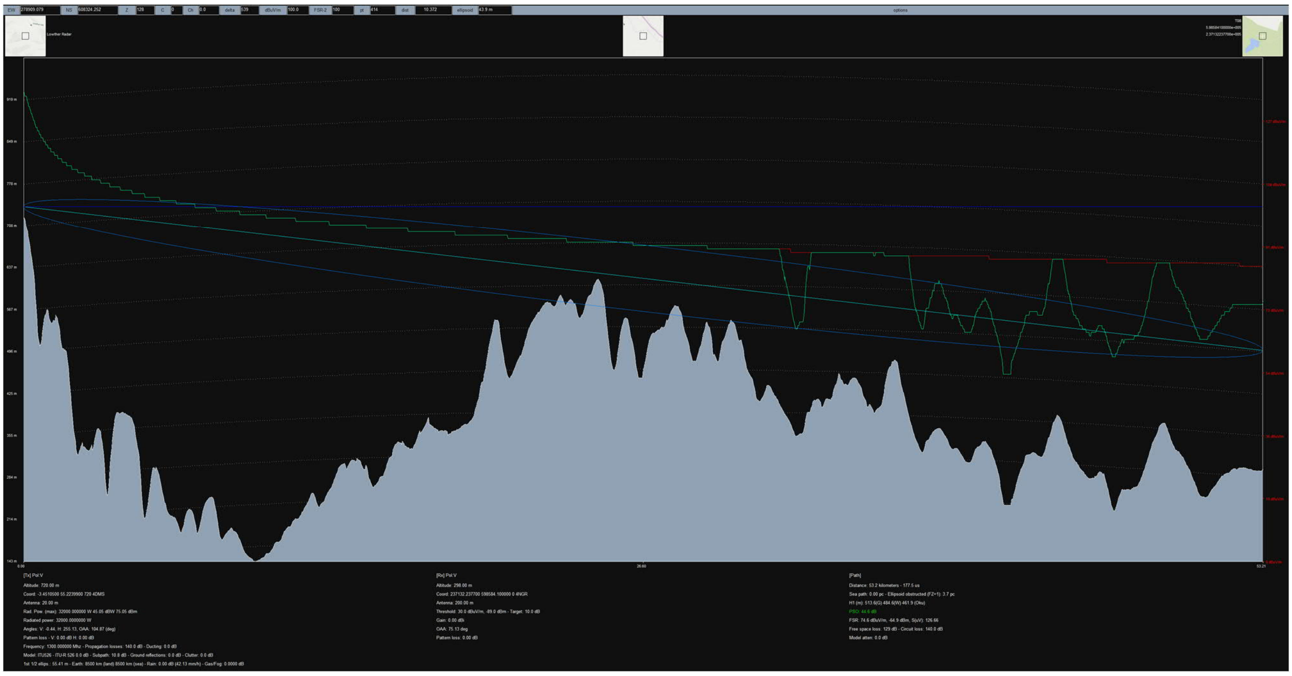
A.6. Turbine T06



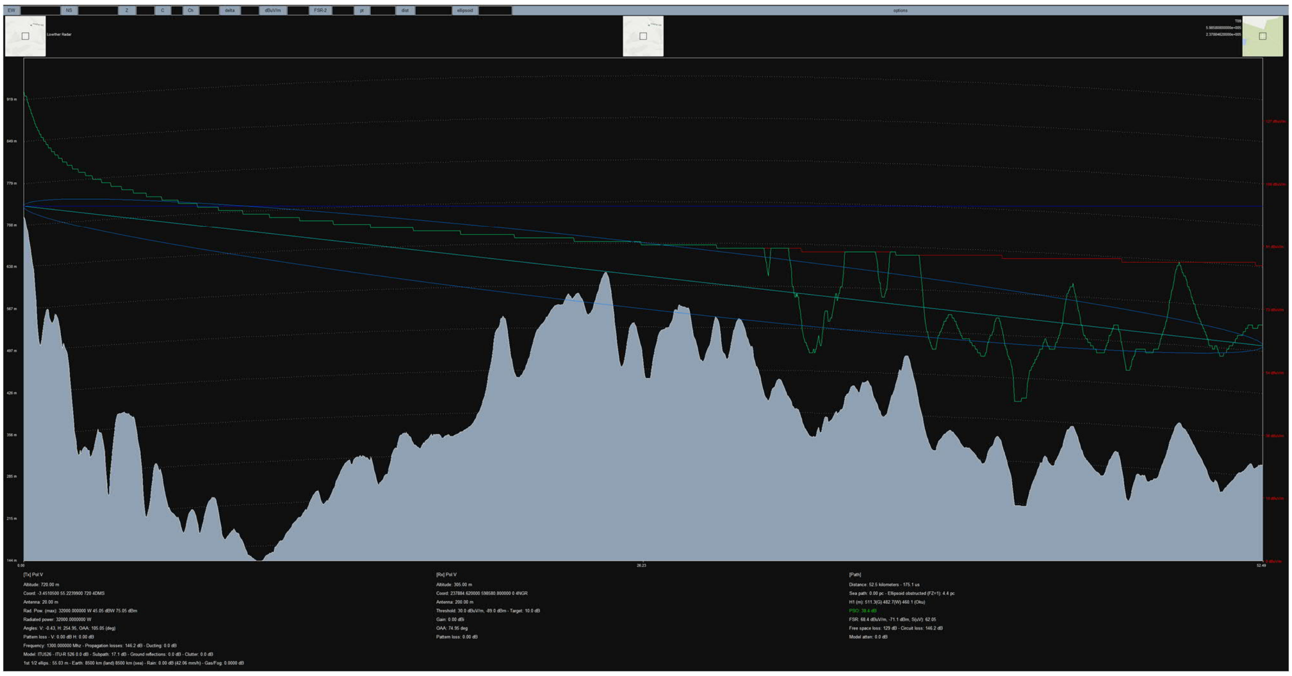
A.7. Turbine T07



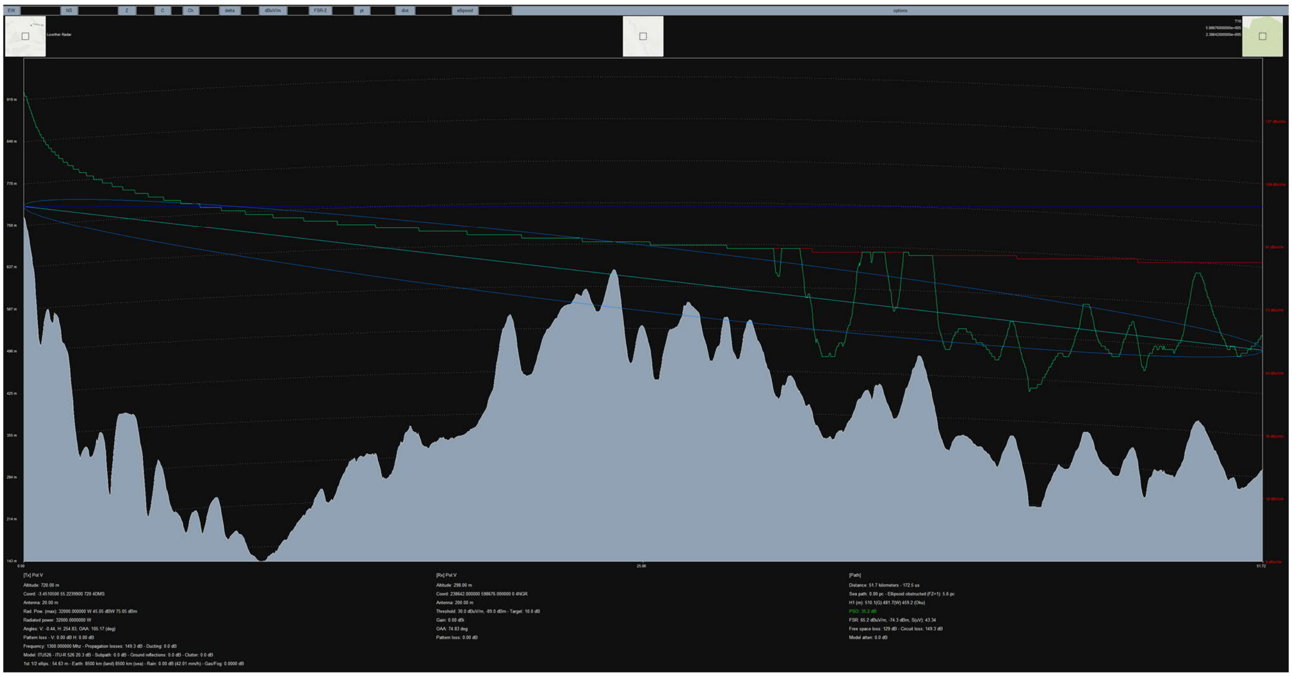
A.8. Turbine T08



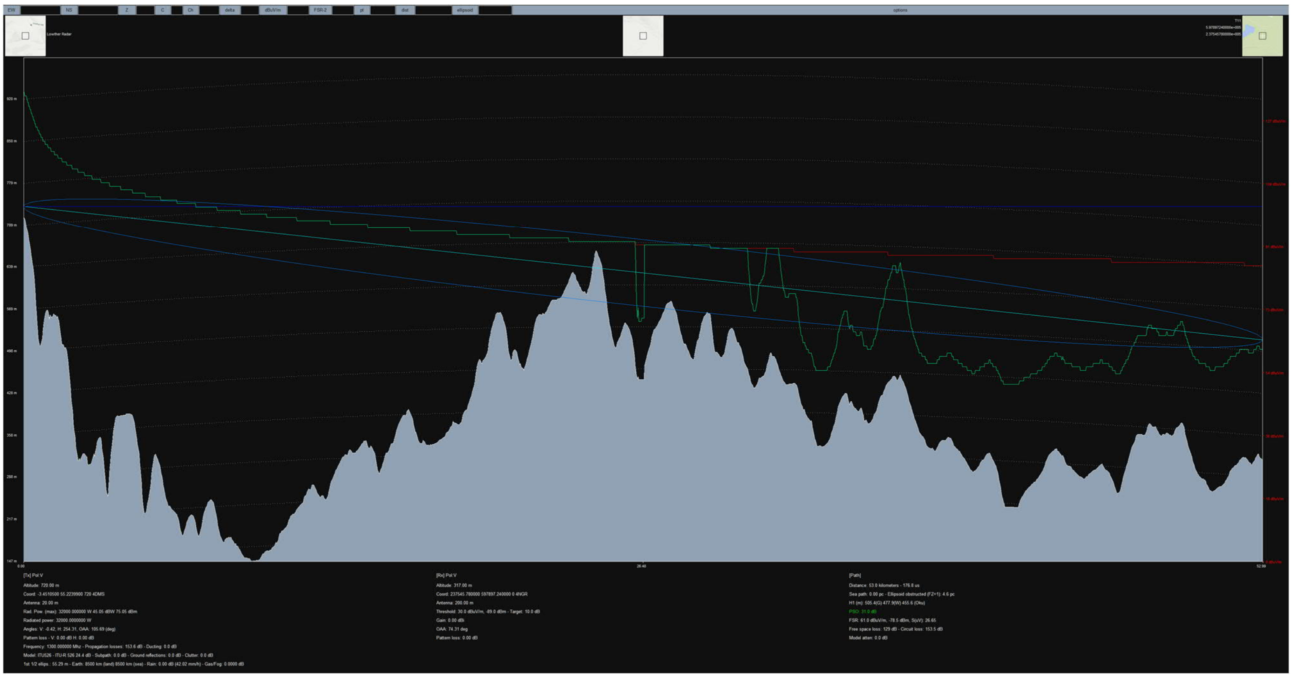
A.9. Turbine T09



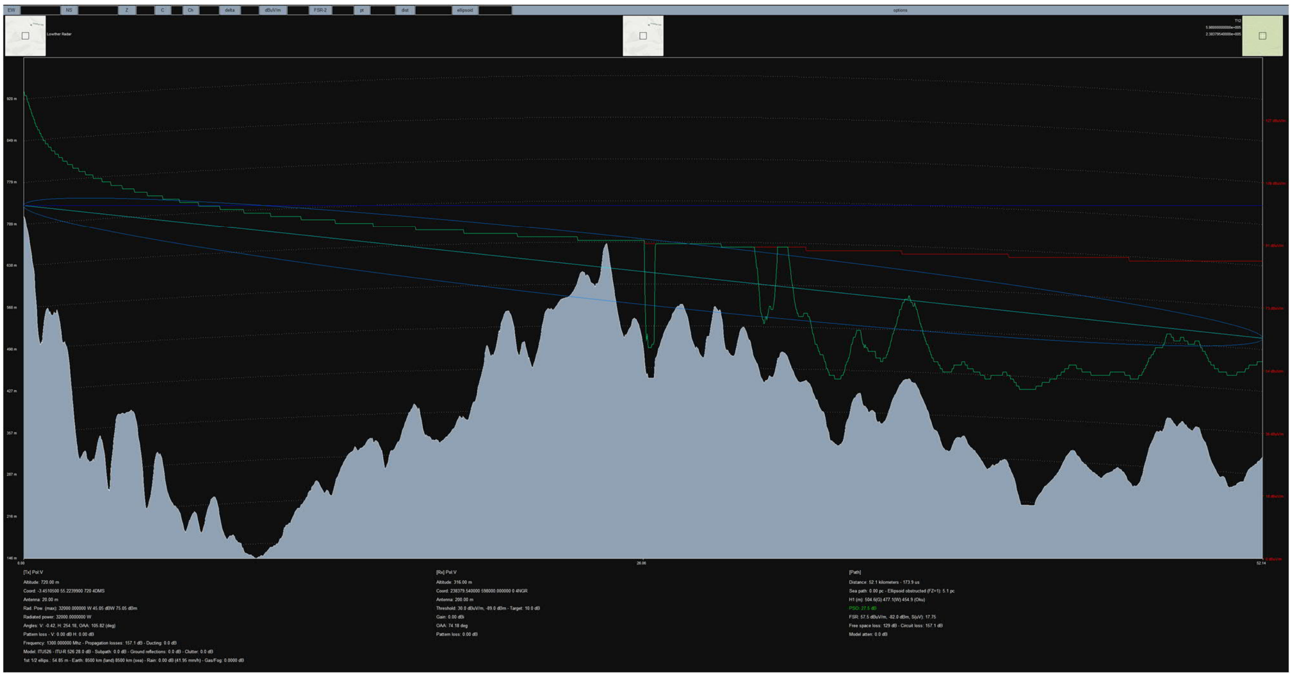
A.10. Turbine T10



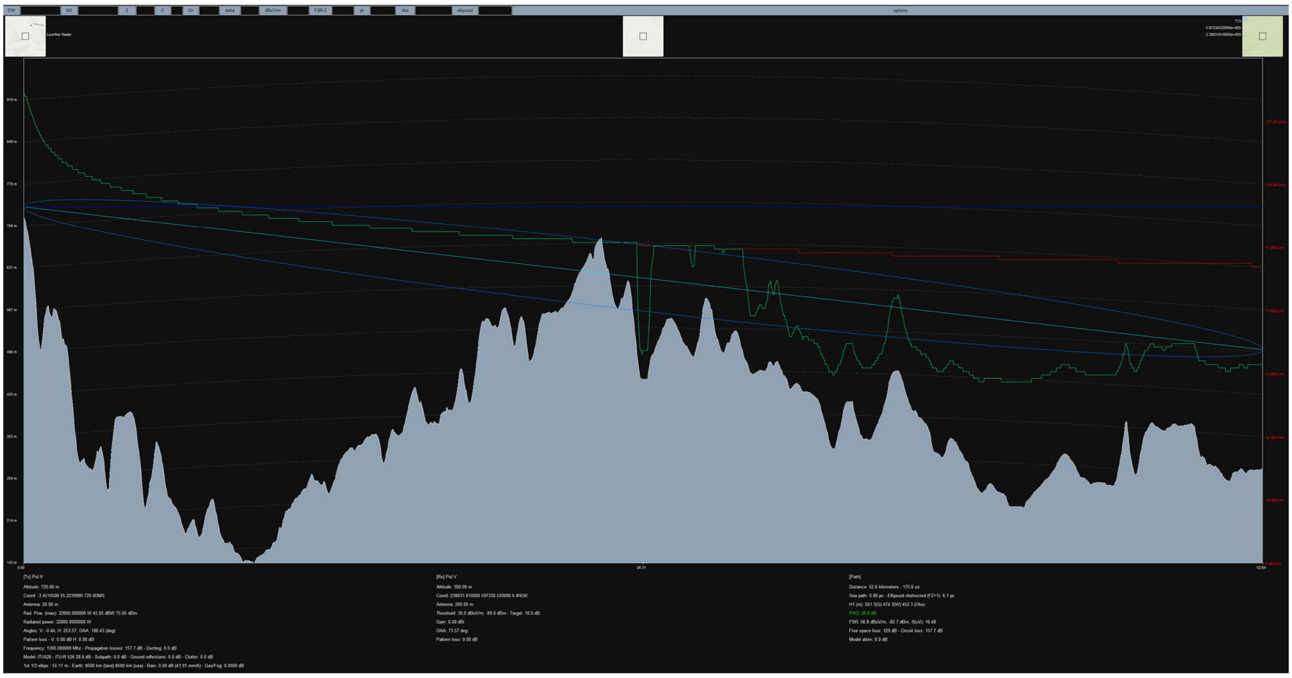
A.11. Turbine T11



A.12. Turbine T12



A.13. Turbine T13



This Page Is Intentionally Blank