GL Garrad Hassan

ICE THROW RISK ASSESSMENT
COLEBROOK SOUTH GE 1.6-100

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REVISION HISTORY

Issue	Issue date	Summary
A	4 March 2011	Draft issue for review
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1 INTRODUCTION

Garrad Hassan America, Inc (GL GH) has been contracted by BNE Energy Inc (the "Client") to undertake an assessment of the risk of ice fragments being shed from wind turbines and striking members of the public in the vicinity of three (3) GE 1.6-100 wind turbines model at the South Phase of the proposed Colebrook wind power project (the "Project").

The results of GL GH's assessment are presented in this Ice Throw Assessment report (the "Report").

2 ASSESSMENT SUBJECT

The proposed Project site is located in Litchfield County, Connecticut. The approximate site elevation is between 380 m to 440 m. The South Phase of the Project consists of three (3) 1.6 MW GE 1.6-100 wind turbines. The key parameters of the wind turbine model are summarized in Table 2-1 below.

Table 2-1: Wind Turbine Parameters

Wind turbine model	**GE 1.6-100**
Rated Power	1.6 MW
Rotor diameter	100 m
Hub height	100 m
Cut-in wind speed	3.5 m/s
Cut-out wind speed	25 m/s
Nominal rotor speed	16.2 rpm
Nominal tip speed	84.7 m/s

This assessment is focused primarily on the area surrounding each turbine. The Project layout is presented in Figure 2-1.

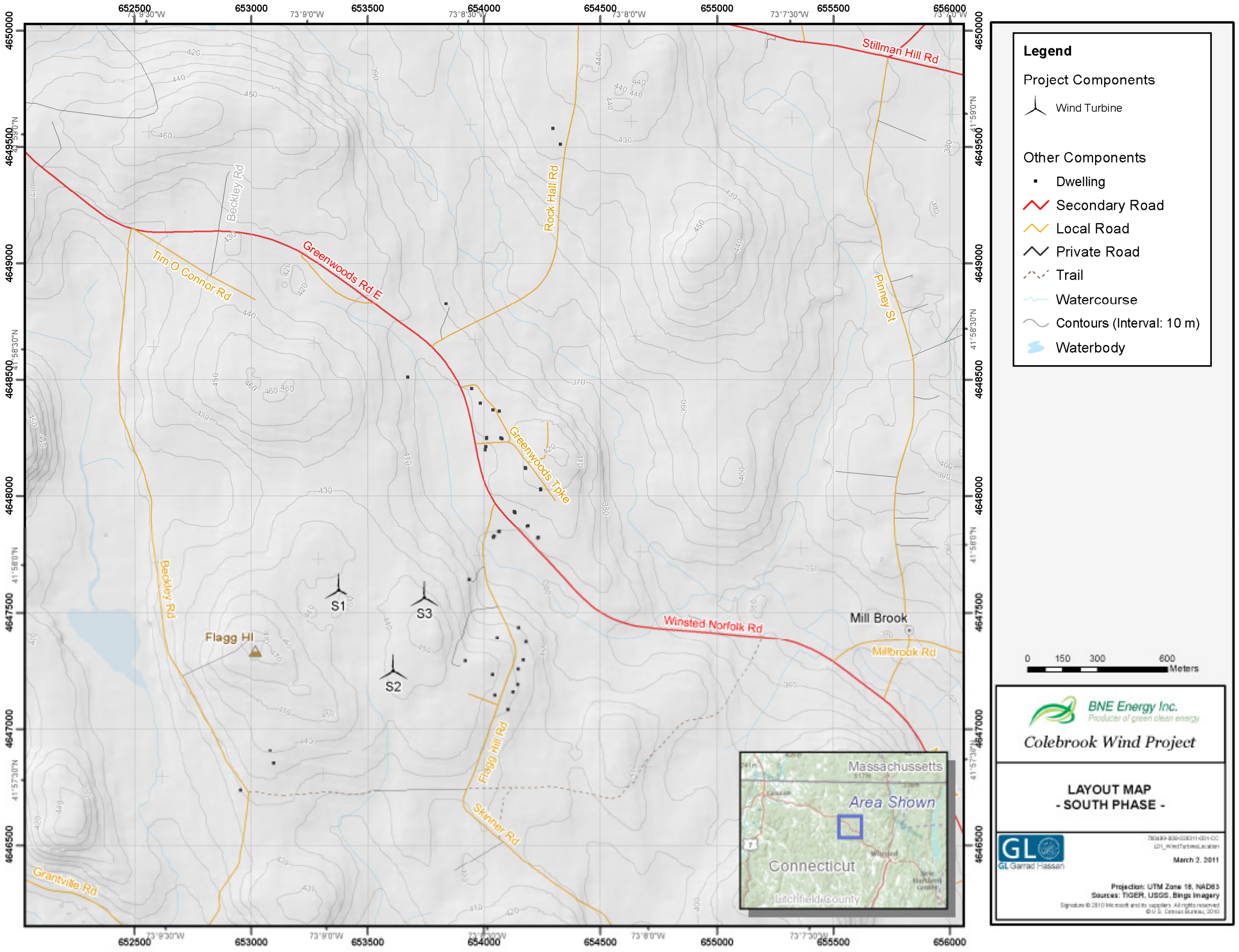

Figure 2-1: Project Layout – Colebrook South

3 ICE THROW ASSESSMENT METHODOLOGY

The assessment methodology that has been used in this Report is based on one developed by GL GH in conjunction with the Finnish Meteorological Institute and Deutsches Windenergie-Institut as part of a research project on the implementation of wind energy in cold climates (WECO). This research project was primarily funded by the European Union and also supported in part by the United Kingdom Department of Trade and Industry [1]. The guidelines for safety assessments in relation to ice throw were developed by GL GH in the WECO project and the work was summarized in a series of conference papers [3][4] and [5]. These guidelines have been applied to the Project site by considering the proposed turbine type, the terrain of the site and surrounding area, and assumptions for human presence in the surrounding area.

The overall approach is presented schematically in Figure 3-1 and is based on the following staged approach:

- Determine the periods when ice accretion on structures might occur, based on historical climatic observations.
- Within those periods, determine when the wind speed conditions are within the operational range of the wind turbines.
- Within the resultant periods, if applicable, exclude those periods when the wind turbines will be shut down automatically by the wind turbine control system or by remote operators.
- Based on an estimate from the above concerning the amount of icing, use guidelines to derive probability of fragments landing at distances from the turbines which are of interest.
- When information is available, estimate probability of members of the public being present within the distances from the turbine which are being considered.
- Derive combined probability of the public being hit by ice fragments.

It is our professional opinion that this methodology is sound and provides for an appropriate analysis of the Project.

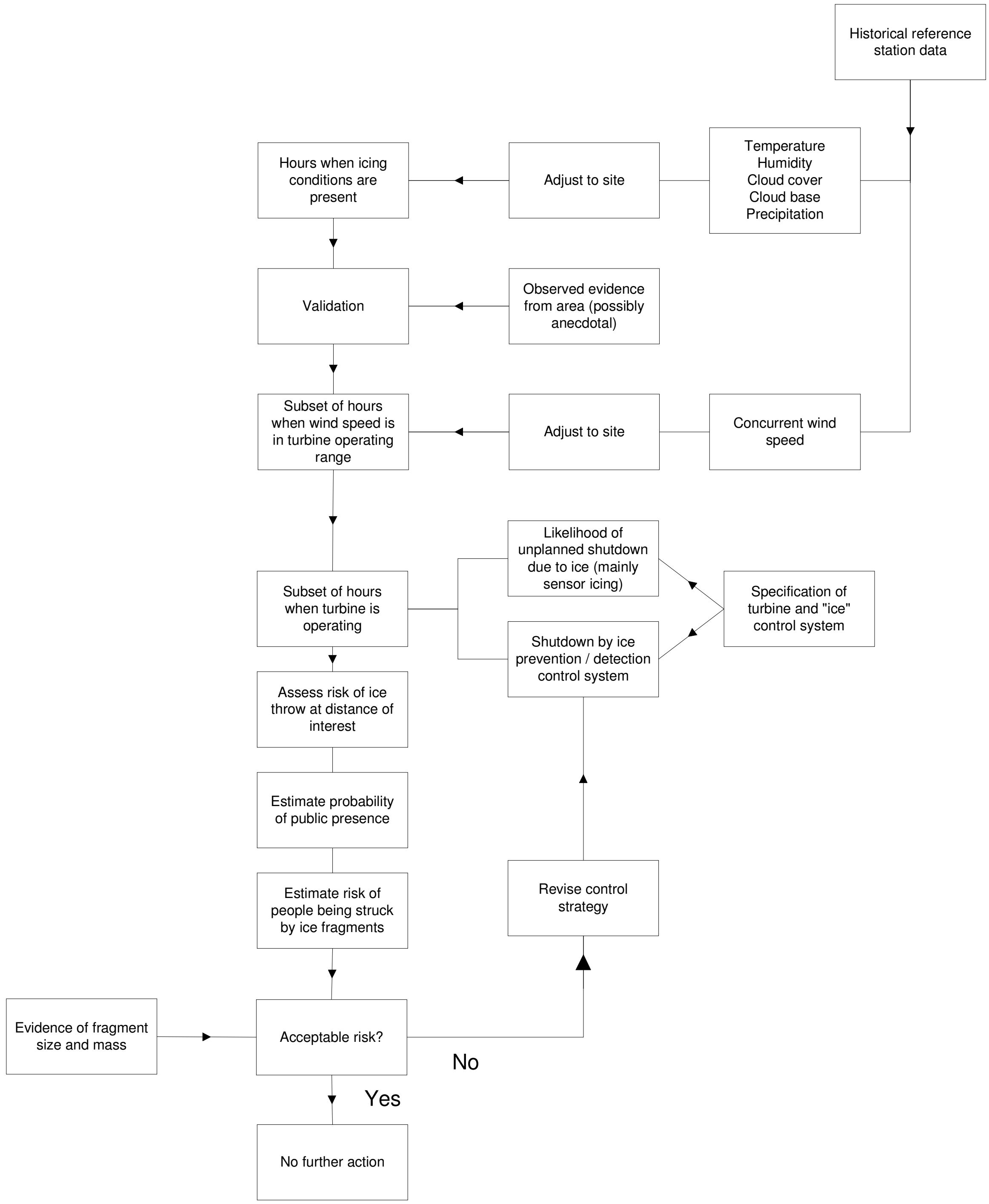

Figure 3-1: Ice Throw Risk Assessment Procedure

4 DATA SOURCES AND OTHER INPUTS

4.1 Wind Climate During Icing Events

The data were recorded using sensors mounted on the meteorological tower located on site. A wind speed and wind direction table of the icing period (November to March) derived from these measurements have been provided to GL GH by the Client [1] and were used as the base meteorological input for this study.

4.2 Control Methodologies

Ice detectors are typically mounted to the nacelle of a turbine or nearby meteorological towers and monitored by the wind farm control system, triggering an automatic or remote manual shutdown of the wind farm in the event that icing conditions are detected.

It is also generally accepted in the wind industry that any ice build up on the blades of an operating turbine will lead to additional vibration and to a loss of aerodynamic efficiency. This is caused by both mass and aerodynamic imbalances. All machines including the GE 1.6-100 are equipped with sensors, which will trigger the shutdown of the machine during these periods.

Depending on the results of the present Report, it may be recommended implementing a winter operating protocol that will curtail the operating of wind turbines in the event of icing and when extreme weather conditions present hazardous conditions to the general public. This will lead to either the operator or automatic controls shutting the system down under any of the following circumstances:

- The installed ice monitoring device(s) and heated wind sensors (installation subject to reliability testing) detect unsafe conditions that are present due to icing conditions.
- Ice accretion is recognized by the remote or on site operator.
- Air temperature, relative humidity and other meteorological conditions at the site that are conducive to ice formation.
- Air temperature is several degrees above 0°C following icing conditions.
- Any other weather conditions which appear to be unsafe.

During any of these events, turbines which present a safety risk to the public are to be placed in Pause mode, at which time the units become inoperative.

4.3 Assessment Guidelines and Data

The guidelines produced in the WECO project were based on a combination of numerical modeling and observations.

The numerical modeling involved Monte-Carlo simulations of a range of scenarios of ice building up on a wind turbine and being shed from the rotor blades. An updated set of simulations have been conducted for the Project study using the wind turbine parameters of the GE 1.6-100 model as defined in Table 2-1 and the wind regime measured at the site for the period from November to March.

In the modeling, further assumptions were required in regards to the aerodynamic properties of ice fragments. These assumptions were verified during the course of the WECO project by measuring the lift and drag characteristics of models of typical ice fragments in wind tunnels. Those coherent fragments collected from various icing events were irregular blocks shed from the leading edge of the rotor blades. Moulds were produced from these and replicas were cast for wind tunnel testing. No stable lifting situation was measured leading to a conclusion that the lift coefficient could be ignored. The drag coefficient meanwhile was measured to fall in the same range as was assumed in the modeling described above.

5 RESULTS OF ICE THROW ASSESSMENT

5.1 Numerical Simulation - Monte-Carlo Results

The results from the Monte Carlo analysis are shown in Figure 5-1 and Figure 5-2 for 1-kg ice fragments for each 30 degree direction sector. These figures represent the probabilities, given an ice fragment has been released, that any one ice fragment lands in one square meter of ground area, as a function of distance and direction from the turbine. It is proposed that the results shown in these figures are used in risk assessment at the Project site where detailed assessment is required.

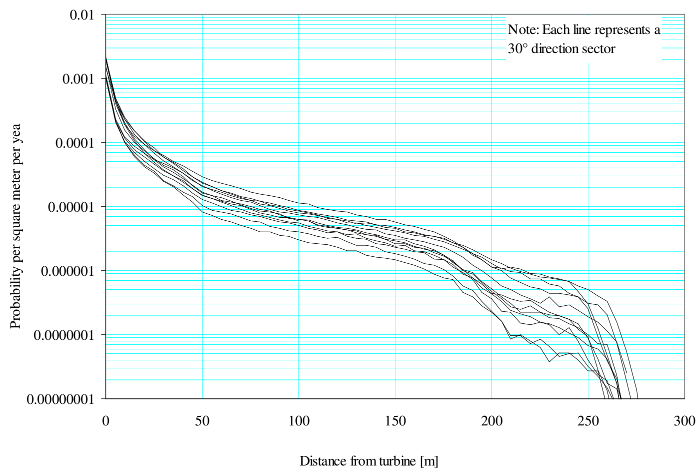

Figure 5-1: Calculated Probabilities of 1 kg Ice Fragment Throw Distances

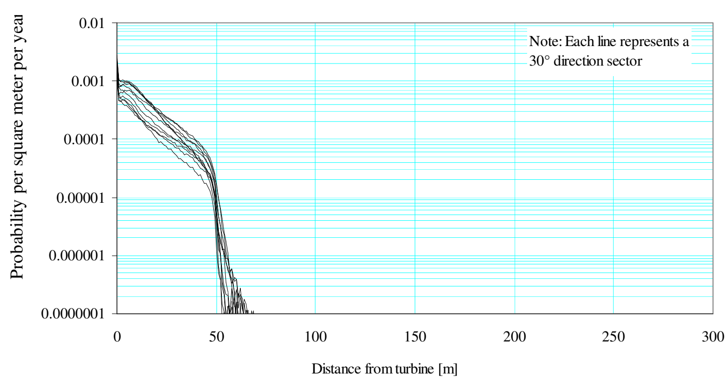

Figure 5-2: Calculated Probabilities of 1 kg Ice Fragment Drop Distances

5.2 Wind Turbine Icing

Ice can build up on wind turbine rotor blades when appropriate conditions of temperature and humidity exist, as it would on any structure that is exposed to the elements when appropriate conditions of temperature and humidity exist. When a wind turbine is stationary it is no more likely to suffer from ice accretion than a large stationary structure such as a building, tree or power line. Like such structures, accreted ice will eventually be released and fall directly to the ground.

When operating, which will be the case when the wind speed at the GE 1.6-100 wind turbine hub-height is in the range of 3.5 m/s to 25 m/s, ice can still build up on the rotor blades when appropriate conditions of temperature and humidity are present. In this case, observations suggest that higher ice accretion rates occur due to the relative velocity of the rotor blades. Any fragments will land directly below the wind turbine, in the plane of the wind turbine rotor, or downwind.

In situations when a risk is perceived due to icing of rotor blades, it is common that mitigation measures be taken either by automated or remote manual shutdown of the wind turbines. It is noted that remote monitoring and operation of wind farms is now standard practice in the industry.

5.3 Individual Risk

The results of the numerical modeling described in the Section 4.3 are shown in Table 5-1 below for an estimated 12 days of icing per year. The initiating probability (number of ice fragment potentially thrown per year per turbine) is calculated according to WECO guidelines by estimating a constant rate of ice accretion along the whole length and the leading edge of the turbine blades during periods of icing conditions. The typical range of ice thrown is taken to be the distance within which 90% of the ice throw or drop events would be expected to occur.

Table 5-1: Typical and Exceptional Ice Throw and Drop Ranges

	Throw		**Drop**	
Ice fragment weight [kg]	0.5	1	0.5	1
Number of ice fragment [per year]	3,600	1,800	3,600	1,800
Typical range [m] ([feet])	0-150 (0-492)	0-160 (0-525)	0-40 (0-131)	0-39 (0-128)
Impact probability	90%			
Exceptional range [m] ([feet])	150-265 (492-869)	160-285 (525-935)	40-120 (131-394)	39-104 (128-341)
Impact probability	10%			

All direction risk levels for ice throw and drop for 0.5 kg and 1 kg fragment weights considered are shown in Figure 5-3. These curves represent the risk level of one ever-present 1 m^2 area being struck by an ice fragment in the vicinity of the Project site turbines assuming 12 days of icing per year.

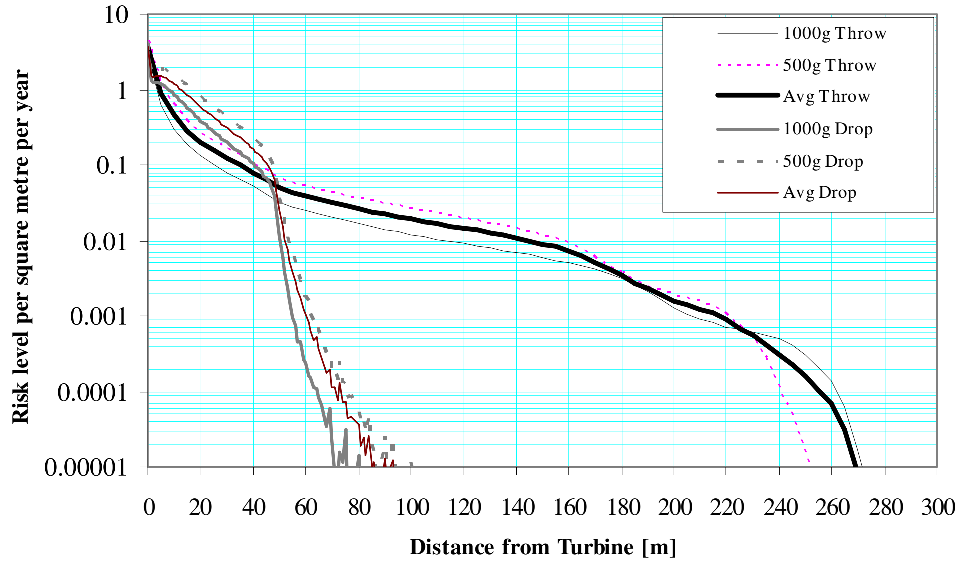

Figure 5-3: Ice Fragment Strikes Estimated Per m^2 Per Year

The level of risk of being hit by a 1 kg ice fragment thrown from the turbine as a function of distance from the turbine and direction is presented in Figure 5-4: .

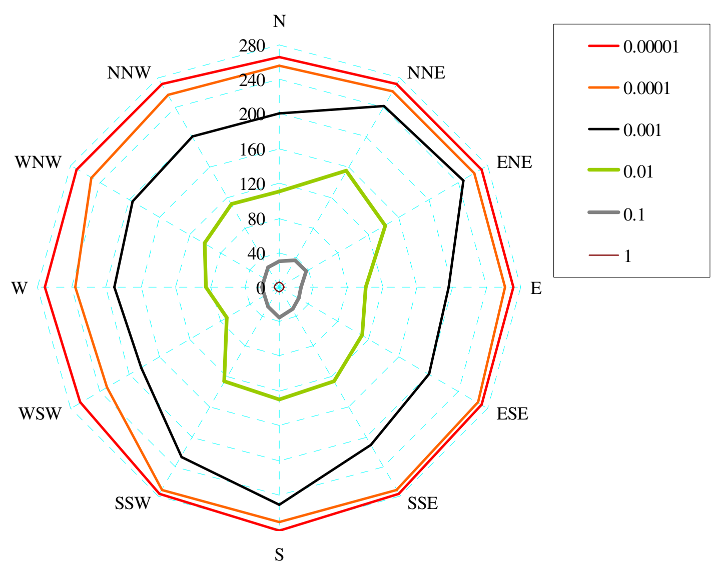

Figure 5-4: Risk level of 1-kg Ice Fragment Strikes Per m^2 by Direction and Distance (Ice Throw Scenario)

The level of risk being hit by a 0.5 kg ice fragment dropped from the turbine as a function of distance from the turbine and direction is presented in Figure 5-5

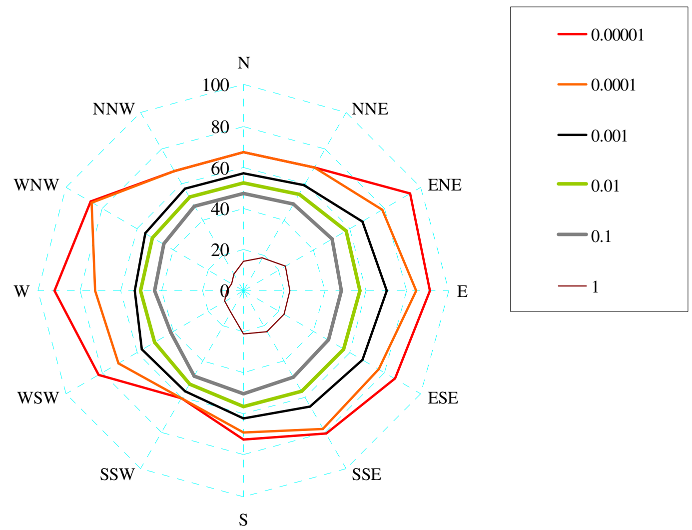

Figure 5-5: Risk level of 0.5-kg Ice Fragment Strikes Per m^2 by Direction and Distance (Ice Drop Scenario)

The results of the analysis indicate that the typical distance range (90% of time) of ice throw from the turbines is approximately 160 m (525 feet), and the typical distance range (90% of time) of ice drop from the turbines is approximately 40 m (131 feet). The results of the ice drop analysis indicate that the risk of a fragment of ice dropping and landing in a square meter a distance from the turbine drops sharply for distances beyond the overhang of the turbine considered (in this case 50 m).

More specifically, two (2) fixed points and one (1) portion of road with identified public use present a non nil risk level of being hit by an ice fragment. These two (2) points have been identified in Figure 5-6.

In the case of the portion of road (ID 6), it has been considered that one car per hour passes on the road at a speed of 50 km/h (approximately 30 mph). The plane area exposed to the risk is estimated to be 10 m² (approximately 100 square feet).

The following table shows the level of risk at these points assuming the wind turbines operate during icing conditions (12 icing days).

Table 5-2: Points with non nil Risk of Ice fragment Strike

ID	Feature	Closest Turbine	Distance [m] ([feet])	Ice fragment Strike
4	Dwelling	S3	206 (676)	Once in 512 years
5	Private Road	S3	203 (666)	Once in 1,069 years
6	Flagg Hill Road	S3	275 (902)	Once in 32,768 years

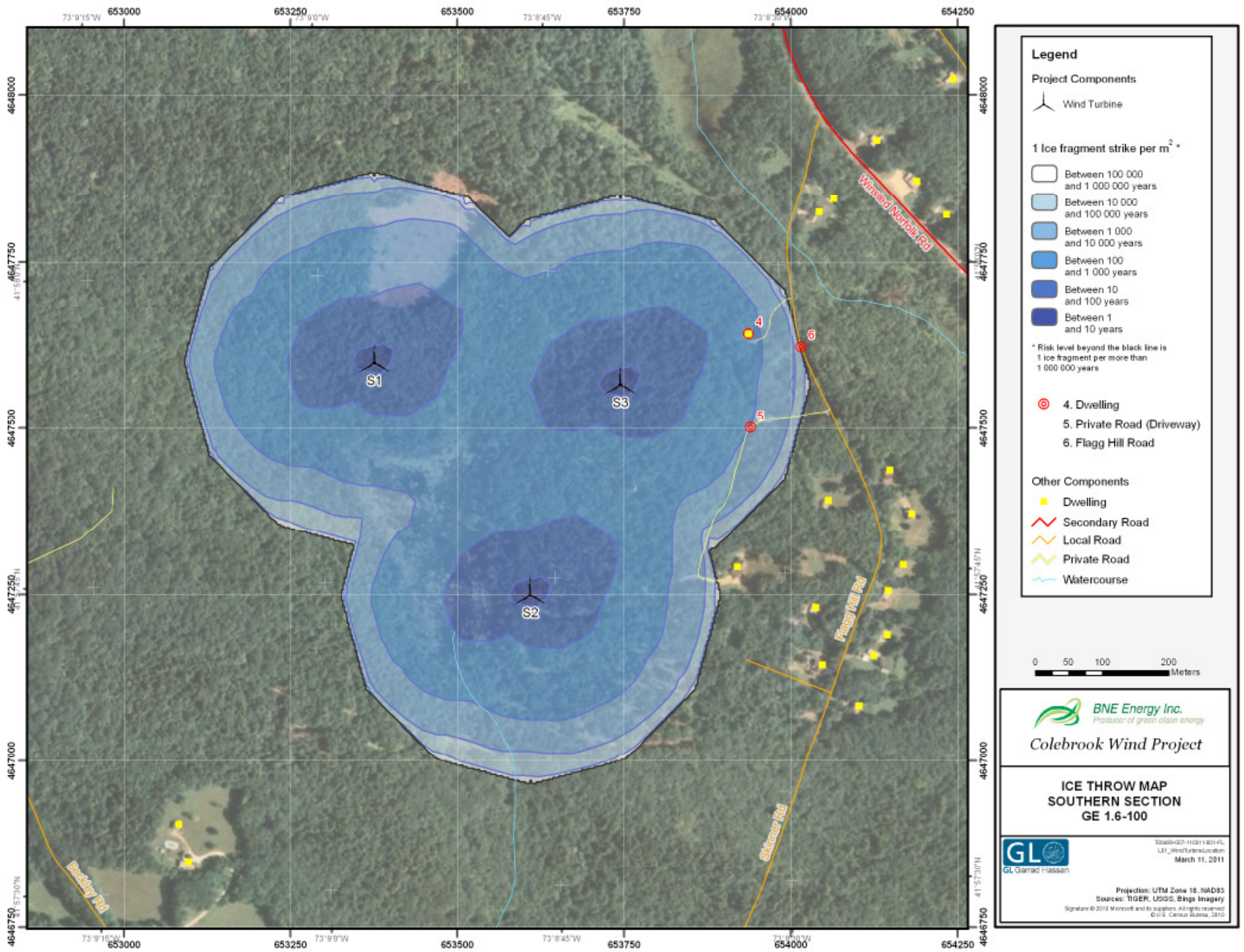

Figure 5-6: Risk Levels of Ice Fragment Strikes Per m^2 Per Year – Colebrook South

5.4 Ice throw Risk Mitigation

Ascertaining the estimated level of risk presented by icing on wind turbines within the lots not under control of the Project has required several assumptions. It is prudent that a control method be employed at the Project to eliminate the risk of potentially damaging ice fragments. This involves implementing a wind turbine control procedure when hazardous icing conditions are present.

The proposed procedures outlined in Section 4.2 should be sufficient to identify periods when icing is likely and to shut down turbines when unsafe conditions are present. The ice detectors as well as the monitoring of meteorological conditions provide a direct measurement of the likelihood ice is starting to build up and the point at which icing conditions cease. It is important that all associated equipment for this system be diligently maintained and that the remote operator shutdown procedure is satisfactorily implemented by personnel so that all turbines will be shut down in the event that ice is starting to build up.

It is recognized that a risk may occur on start up of a turbine after a prolonged period of shutdown during icing conditions. In such circumstances, ice fragments may be released or thrown from blades in the first period of operation. This issue needs to be addressed by a suitable pre-startup inspection and remote startup procedure. With the proposed procedure and a suitable pre-startup inspection and remote startup procedure, one can expect the ice build-up on the turbines to be no more than on any large stationary structure, with no risk of ice fragments being thrown from an operating rotor.

As an additional safeguard, the Client should post warning signs along property lines and access ways to turbine locations.

6 CONCLUSIONS

GL GH undertook an assessment of the risk of ice fragments being shed from wind turbines and striking members of the public in the vicinity of the turbines at the Project.

It is concluded that if the proposed procedure and suitable pre-startup inspection and remote startup procedure are followed, one can expect the ice build-up on the turbines to be no more than on any large stationary structure, with no risk of ice fragments being thrown from an operating rotor.

As with a large stationary structure, the risk remains of ice forming at a slow rate on the structure and dropping from the stationary turbine. In comparison to an operating turbine, only a small amount of ice is likely to form. As this thaws, there will be some wind blow effects on the lightest particles of ice. With a suitable operating protocol in place to prevent ice fragments from being thrown from the turbine, GL GH estimates that only very high winds (above 25 m/s) in a specific direction may cause fragments of any significant mass to be blown beyond 50 m of the turbine base. This is supported by the risk level calculations presented in Figure 5-3 and Figure 5-5.

At 50 m of the turbine base, the probability of falling ice fragment strike per square meter is approximately once in 124,671 years. Assuming 12 days of icing per year, this amounts to an individual risk from dropping ice for a stationary person present for all icing events located at 50 m of the turbine base of once in 40 years.

7 REFERENCES

[1] "Colebrook CT_Weibull Parameters-Frequency-WS for Nov till March_2011-2-3.xlsx" via email from G Zupkus, BNE, to C Sieg, GL GH, 9 Feb 2011.

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[5] C Morgan, E Bossanyi and H Seifert, "Assessment of safety risks arising from wind turbine icing", Proceedings of EWEC '97 conference, Dublin 1997.