Best Practice for Wind Power Project Acoustic Assessment British Columbia 2012

Ministry of Forests, Lands and Natural Resource Operations
Ministry of Energy, Mines and Natural Gas
Environmental Assessment Office

EXECUTIVE SUMMARY

The purpose of this document is to describe the common issues regarding sound from industrial wind turbine generators, and to recommend a best practice for conducting sound assessment of wind power projects. This document is intended to augment the Land Use Operational Policy - Wind Power Projects (the Policy). This document outlines recommended approaches and practices for the completion of a sound assessment that:

- meets the requirements and intent of the Policy,
- meets the requirements of the BC Clean Energy Projects Development Plan Information Requirements (DPIR) (MFLNRO 2011b), and
- provides sufficient technical analysis for reviewers to evaluate a project.

In addition to the development of this Best Practice, a Land Procedure – Acoustic Assessments for Wind Power Projects has been developed and is available at:

http://www.for.gov.bc.ca/Land_Tenures/tenure_programs/programs/windpower/index.html

These two documents are closely linked with the requirements for assessment influencing the investigative procedures, and vice-versa.

The Best Practice for Wind Power Project Acoustic Assessment makes recommendations in three areas:

- interpretation of the Policy criteria;
- requirements of assessment reports; and
- predictive modelling techniques.

Criteria

The Policy requires that sound emitted from wind turbines is not to exceed a maximum of 40 dBA on the outside of an existing permanently-occupied residence (not owned by the proponent) or the nearest property line of existing, undeveloped parcels zoned residential (not owned by the proponent) in existence at the time of application for a *Land Act* tenure to construct a wind farm (MFLNRO 2011).

The interpretation of the Policy for the assessment of sound levels from wind turbines is as follows:

- Where ambient conditions are 35 dBA or less:
  - Night-time criterion: L_{eq},9hr of 40 dBA between 10:00pm and 7:00am
  - Day-time criterion: L_{eq},15hr of 40 dBA between 7:00 am and 10:00 pm
  - Ambient conditions are to be assumed at 35 dBA for calculation purposes
- Where ambient conditions are shown to be greater than 35 dBA during either the day or night (except where another wind power project is present), a 5 dBA increment may be applied to a measured background sound level to determine the day or night criterion, to a maximum of 50 dBA.

TABLE OF CONTENTS

1. SOUND LEVEL CRITERIA FOR WIND TURBINES

The Land Operational Policy – Wind Power Projects (the Policy) requires that sound emitted from wind turbines not exceed a maximum of 40 dBA on the outside of an existing permanently-occupied residence (not owned by the proponent) or the nearest property line of existing, undeveloped parcels zoned residential (not owned by the proponent) in existence at the time of application for a *Land Act* tenure to construct a wind farm.

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    - Ambient conditions are to be assumed at 35 dBA for calculation purposes

Where ambient conditions are shown to be greater than 35 dBA during either the day or night (except where another wind power project is present), a 5 dBA increment may be applied to a measured background sound level to determine the day or night criterion, to a maximum of 50 dBA.

Environmental assessments and the consultations for a project may require consideration of sound effects on wildlife; and should be determined and addressed separately through the environmental assessment process. The predictive modelling exercise conducted for human receptors may be sufficient for any sensitive wildlife areas. Data regarding effects on wildlife should be discussed separately, as wildlife responses are less well defined, vary by species and should be addressed by the appropriate specialists.

2. DEFINITIONS

Ambient sound means all sound that exists in an area and are not related to a facility under study. Ambient sound may include sound from other existing industrial facilities, transportation sources, animals, and wind. Context for ambient sound should be defined for each project.

Attenuation means the reduction of sound intensity by various means (e.g., air, humidity, porous materials, etc.).

A-weighted sound level means the sound level as measured on a sound level meter using a setting that emphasizes the middle frequency components similar to the audible range of the human ear**.**

Daytime is defined as the hours from 07:00 to 22:00.

dB (decibel) is a unit of measure of sound pressure that compresses a large range of numbers into a more meaningful scale. Hearing tests indicate that the lowest audible pressure is approximately 2 x 10-5 Pa (0 dB), while the sensation of pain is approximately 2 x 102 Pa (140 dB). Generally, an increase of 10 dB is perceived as twice as loud.

dBA is the decibel (dB) sound pressure level filtered through the A filtering network to approximate human hearing response at low frequencies.

dBC is the decibel (dB) sound pressure level filtered through the C filtering network to include low frequency sound that, in sufficient amounts, can trigger annoyance in humans.

DPIR is the Development Plan Information Requirements which form the management plan for the Clean Energy program

Energy equivalent sound level (L_{eq})

The L_{eq} is the integrated average A-weighted sound level over a specified period of time. It is a single-number representation of the cumulative acoustical energy measured over a time interval. If a sound level is constant over the measurement period, the L_{eq} will equal the constant sound level where f is the fraction of time the constant level L is present.

Low Frequency Sound (LFS) is Sound in the range of frequencies from 0 to 250 Hz.

L_{90} is the ninetieth percentile sound level (L_{90}) - the sound level exceeded 90 percent of a specified time period. L_{90} is also known as the sound floor for ambient sound levels.

MFLNRO means the Ministry of Forests, Lands and Natural Resource Operations

Night-time Is defined as the hours from 22:00 to 07:00.

the Policy means the Land Use Operational Policy – Wind Power Projects

Receptor(s) means the outside of an existing permanently-occupied residence (not owned by the proponent) or the nearest property line of existing, undeveloped parcels zoned residential (not owned by the proponent) in existence at the time of application for a *Land Act* tenure to construct a wind farm.

3. GENERAL SOUND LEVEL MEASUREMENT REQUIREMENTS

Specific recommendations for the content and analysis for sound assessments of proposed and operating wind power projects are outlined in the following sections. Predictive assessments as well as compliance assessments share the recommended measurement requirements but have specific detail differences respecting predictive versus compliance situations.

Table 1: General Sound Measurement Requirements

#	Description	Predictive Specifications	Compliance Specifications
1	Sound level meter requirement	Type 1 or type 2	Type 1 or type 2
2	Measurement intervals	1 to 10 minutes	1 to 10 minutes, 10 minutes preferred
3	Measurement parameters	L_{90} (L_{eq} optional)	L_{eq} (L_{90} optional)
4	Frequency weighting	A-weighted (C-weighted also recommended)	A-weighted (C-weighted also recommended)
5	Frequency content	Octave band centre frequency	Octave band centre frequency
		1/3 octave band for tonality analysis	1/3 octave band for tonality analysis

6	Audio recording	For identification of abnormal sound events during unattended sound monitoring periods	A continuous recording at the sound level measurement microphone location (available as an on-board capability of the equipment) for identification of abnormal sound events during unattended sound monitoring periods and verification that wind incidence has not influenced the measurement
7	Microphone placement	At least 15 m from a façade or other reflecting surface	At least 15 m from a facade or other sound reflecting surface at the receptor of complaint
8	Microphone height	1-2 m above ground	1-2 m above ground
		Ground level accepted per IEC 61400-11 method	Ground level accepted per IEC 61400-11 method
9	Compliance only – Microphone wind screens		Use both primary and a secondary wind screen (7” foam or other type). Document performance of secondary screen in the field report
10	Minimum monitoring duration	Minimum 48 hour duration when other industry present, with 7 days preferred	Minimum 7 days, to obtain measurements during a variety of wind speeds, 14 days preferred

Sound assessments are to be completed by a qualified professional. The names and accreditation of the professionals completing the work along with their signature should accompany the report, or application.

3.1 Sound Assessment Report Requirements

Sound assessment report requirements are similar for predictive and compliance situations. Requirements for predictive sound assessment reports are listed in Appendix A, requirements for sound level compliance reports are listed in Appendix B.

4. PREDICTIVE ASSESSMENTS

General Information

The general approach is for assessments to focus on project operations only, although sound from construction activity should be considered from a qualitative view for consultation purposes.

Assessments, including baseline measurements, are to focus on summertime conditions – or seasonal conditions when people are more likely to have bedroom windows open at night. This represents the period of concern when outdoor sound has the greatest potential to travel inside the home and potentially affect sleep.

The turbine operation sound levels should be considered cumulatively with ambient conditions as well as with any existing wind power projects. The report should describe the relationship between the sound assessment, the project design and site conditions.

If the sound assessment is incorporated into a larger Environmental Assessment or Clean Energy Project (CEP) application, a concordance table should also be provided (See Appendix A). Where exceptions or alternative methods are used for the sound assessment, these should be highlighted in the concordance table to aid the reviewers in assigning internal resources.

Consistent with the Clean Energy Projects DPIR, sound assessments are to be completed by a qualified professional. The names and accreditation of the professionals completing the work along with their signature should accompany the report, or application.

Appendix A provides a template for the Predictive Sound Assessment Report and a report content checklist for staff to ensure consistency in report format (and Table of Concordance for EAO if needed).

4.1 Introduction and Project Site Description

All CEP applications will have a detailed project description. Portions of that description, as they relate to the sound assessment, should be reiterated in any stand-alone sound assessment document. Appropriate references to the sections containing the general project description should be made when the sound study is incorporated into a larger assessment.

Key elements of the Project Description that should be identified within the sound assessment are:

- Turbine layout
- Turbine specifications
- Substation specifications and location
- Wind power project tenured land boundary

The project description for the sound assessment also needs to summarize the operating conditions expected for the site. Note that for the assessment, the operating conditions to be assessed must assume the turbines are operating at maximum sound output 100% of the time and that receptors are downwind of all turbines at all times. The description of operating conditions at receptors will define the realistic conditions to be examined in the event compliance monitoring is required at a later date.

The description of operating conditions at receptors should include seasonal wind shear conditions or a description of the expected differences in wind /atmospheric conditions between the turbines and receptors. The text should answer the following questions:

- Will there be high wind shear or low ambient conditions at receptors when the turbines are operating at capacity more than 10% of the time at night, particularly in summer?
- Is a wind masking, a low wind shear condition or high ambient condition claimed?
- Will receptors be downwind of the turbines more than 10% of the time and what will the expected operating capacity be when downwind?

The distance from the tenure boundary that developers must search for potentially affected receptors is not specified, leaving the determination of who should be included in the assessment open to the tenure applicant. A set distance of 1500 m outside tenured lands, similar to other jurisdictions, would provide a simple limit on receptor identification while including receptors most likely to be affected based on sound attenuation distances. Another method of determining a "potential affected receptor" would be to determine the distance at which sound from a single turbine reduces to less than 20 dBA. Receptors outside this distance are unlikely to experience cumulative sound levels approaching the 40 dBA criteria.

Regardless of determination of sound methodology used, in the event of a complaint that requires Compliance Investigation, and subsequently a turbine or turbines is found be out of compliance, mitigation measures and direction to remove turbine(s) may result.

4.2 Existing Environment

A general description of existing sound sources that influence sound levels at the receptors should be provided.

If no baseline program is conducted for the assessment, the ambient should be assumed to be 35 dBA.

If normal ambient conditions suggest higher values than 35 dBA, a baseline sound survey should be conducted prior to the start of construction for a wind power project. Baseline values can be measured and agreed to prior to the submission of the full assessment and this would reduce the risk for developers when the need for special consideration of ambient conditions exists.

If there is a strong expectation that low ground level winds will occur when the turbines are operating at capacity, the baseline program could be delayed until after project approval, so that data can be "on-file" in the event of a sound complaint.

Where other industry is present or where and ambient adjustment is to be claimed, a baseline sound survey should be completed and included with the assessment. The survey should be conducted to be specific to each receptor, although an approach that establishes a representative baseline over an area can be considered. Representative conditions would be considered for receptors that have similar surroundings and existing sound sources (e.g. one location could suffice for three homes located along the same road in a wooded area).

4.3 Criteria

Technical standards that may be used to conduct sound measurements are as follows:

- ISO 1996-1 (CAN/CSA 2005)
- ASTM 1014 (ASTM 2008a)
- ANSI S12.9 part 2 (ANSI 2008)
- IEC 61400-11 (IEC 2006)

General expectations for sound measurement in relation to wind power projects are summarized in

Table . Variations from these expectations may be warranted based on the standard selected or site conditions. If variations are used, justification should be provided.

Microphone placement should be at least 15m from a building façade to reduce the measurement being influenced by activity at the house, as well as reduce potential sheltering and reflection effects. Placement farther from any structure is encouraged to address privacy issues, with the meter still in a relatively open area with free-field sound. Distances from structures may need to be closer than 15m so the microphone is placed in an area where there is the most open pathway between the future turbines and the measurement location.

Additional wind screens (7" foam or other secondary wind screens) should be considered, with the effects on meter performance to be documented and provided. Equipment calibration records, both lab and field, should also be provided.

In addition to sound level data, microphone height wind data for correlation of the sound levels with wind speeds are required. Measurements should be conducted during a period where the representative or realistic worst case atmospheric condition (e.g. greatest wind speed differentials) are likely to occur but also during a period when a variety of wind speed can be measured. Periods with heavy precipitation, recorded at the weather station or identified through sound recordings, should be excluded. Portable logging anemometers can be used.

4.3.1 Baseline Determination

The one or ten minute L_{90} sound level measurements should be analysed and summarized based on either microphone height wind speeds, or microphone height wind speeds normalized to 10m height per Formula 10 in the IEC 61400-11 standard (IEC 2006). The analysis of the data should be a validation exercise, excluding any extraneous sound event (e.g. technician activity), interference with the equipment, or ground level wind speeds sufficient to affect the wind protected microphone.

Once the L_{90} data has been validated then sorted by ground level wind speed, the baseline can be determined. There are two suggested ways to achieve this: the first based on relative wind speed conditions and the second based on a turbine sound power differential approach.

The first approach considers the identification of the worst case wind speed variations that occurs for at least 10% of the valid measurements. By comparing the ground level and meteorological station weather data for the entire period of measurement, periods of time with a high wind speed differential can be identified. The average of the corresponding L_{90} sound level measurements can then be used as a baseline value. This would require time synchronization of the data, but would allow for automated processing of the data using spreadsheet routines.

The second method to establish baseline uses a turbine sound power differential approach described in the NARUC study (NARUC 2011). In that method, the 10-minute L_{90} measurements are sorted by microphone height wind speed and averaged for each wind speed bin. Then the wind speeds are normalized for a 10m standard height using the IEC 61400-11 formulae. This data are then compared to the manufacturer supplied sound power from the proposed project turbine, also normalized to 10m height wind speeds. When the data for each wind speed bin are compared, the wind speed where the greatest difference between ambient L_{90} and the turbine sound power is the operating condition where the greatest impact is expected (the turbines would be the most dominant). An example is shown in Table 2.

Table 2 Example of Sound Power Differential Baseline Determination

Wind Speed at 10 m, m/s	Measured Overall L_{90}, dBA	Turbine Sound Power Level, dBA	Differential
4	27	95	68
5	29	99	69
6	**32**	**102**	**70**
7	35	104	69
8	38	104	66
9	41	104	63
10	45	104	59
11	48	104	56

From: NARUC 2011: Table 4.4.3.1 Comparison of Turbine Sound Power Levels to Measured Background Levels to Determine Critical Wind Speed.

4.4 Sound Level Predictions

All sound level predictions should be made using acoustic models capable of meeting the information requirements (no simplified calculations or 'rules of thumb'). Predictions are required for all project applications, regardless of whether receptors have been identified or not. Where no receptors are present, sound assessment will provide the basis for compliance in the event or future encroachment by residential lands.

Predictions are made for every identified receptor. Predictions are to be provided in $L_{eq,day}$ and $L_{eq,night}$ (dBA) for the project alone and for the project + ambient (cumulative sound level) for comparison with the criteria. Contour results are also expected, particularly when wildlife zones are required for the assessment or for addressing potential for future development.

Predictions are to include all proposed turbines and the project substation as a cumulative project sound level at a receptor. Sound from neighbouring wind farms should also be included or considered in the assessment. The extent for consideration of cumulative effects from existing and proposed wind power projects can be based on a straight distance from the receptor (5 km suggested), or based on the sound contribution from the turbines. Turbines that contribute at least 20 dBA at the receptor should be included in the cumulative sound level. Turbines predicted to contribute less than 20 dBA can be excluded. Other existing industry is to be considered part of the ambient sound levels.

Details on the accepted prediction methods are outlined in Section 6 Predictive Sound Assessment Modelling Requirements.

4.5 Determination of Compliance

Compliance with the Policy or the criteria determined in the assessment must be demonstrated in any application. A project is compliant when:

Predicted Project Sound Level + Ambient Sound Level < Criteria

Using this approach, the inclusion of ambient sound levels does effectively limit the amount of sound contributed by a project to be 38.4 dBA or less based on the logarithmic addition used:

38.4 dBA (Predicted Project Sound Level) + 35 dBA (Ambient Sound Level)= 40 dBA

If compliance is not demonstrated during the analysis, the developer has the option to fix the non-compliance as part of the project design and, therefore, the final sound assessment will comply. The layout used in the assessment should be consistent with the main application document and should be considered the final design. The second option, if a design change is not possible, is to provide a detailed mitigation plan.

4.6 Low Frequency Sound

An optional analysis is to provide an estimate of LFS, in the event it is warranted from the public consultation. The analysis should provide the prediction results in dBC and show the dBC-dBA value for each receptor. The dBC-dBA value can be used to demonstrate the low frequency sound content of sound from the turbines when conducting public consultation. Specific requirements for dBC values or LFS are not proposed. Differences of up to 10 dBA (WHO 1999) and 20 dBA (AUC 2012) are considered acceptable.

4.7 Mitigation Options and Analysis

If sound level predictions indicate that sound levels at a receptor may exceed the criteria under the operating conditions assessed, mitigation options will be applied.

Where the detailed measurement program demonstrates that sound levels are not compliant at the receptor, a mitigation plan must be included with the analysis.

Mitigation options other than shut-down and removal exist for industrial wind turbines and use of these modes may be considered as an acceptable solution by MFLNRO. Most turbine manufacturers offer reduced sound operating modes for their equipment. If use of these modes is suggested by the Tenure Holder as a potential mitigation option, a predictive modelling analysis on the expected sound reduction from use of these modes must accompany the compliance measurement report. The modelling analysis is to include an updated assessment model, with results matching the measured conditions, then the results after applying the reduced sound modes to the calculations. Prediction methods are to follow those in the Best Practices for Wind Power Project Acoustic Assessment, except where adjustments were made for predictions to best fit the measured site conditions.

The resulting mitigation plan forms a commitment by the Tenure Holder to use them. Any commitment must be clearly stated. For example, a generic statement such as “turbines 2, 3 and 4 will be curtailed at night” may be interpreted as turbines 2, 3 and 4 being shut off all night. A clearer statement would be “turbines 2, 3 and 4 will be placed into sound reduced operating mode 3, per the manufacturer specification attached, for wind speeds higher than 10m/s normalized to 10 m height". All manufacturer data regarding reduced sound modes should accompany the application.

Re-location or removal of the relevant turbines may still be required, if reduced sound modes do not result in sufficient sound control.

4.8 Summary

A summary section must be included in the Predictive Assessment that simply states that project will be compliant with the Policy and include any conditions that make it so.

4.9 Uncertainty and Prediction Confidence

The amount of uncertainty in the sound power levels used in the modelling as well as the prediction method used should be reported. Where uncertainties are identified, the assessment should discuss how each was considered or addressed in the assessment. For example, conservative selections for ground attenuation or terrain conditions could be made to address the +/- 3 dBA (at 1 km from source) uncertainty in the ISO 9613 method.

Given that the sound power data for the turbines ranges between +/- 1 and 4 dBA (2 dBA is common) and the uncertainty in the ISO 9613 method, which increases at distances further than 1 km, reporting results in partial decibels (e.g., 39.9 versus 40.1 dBA) is not statistically valid. When predictions are within +/- 1 dBA of the 40 dBA criteria, developers should provide a plan on how the prediction results will be validated. This will be in a form and structure of a Compliance Investigation Report for the most affected locations.

For sound measurements, the uncertainty in each measurement or data point is about +/- 1 or 2 dBA depending on the equipment used. The uncertainty in the result, particularly as compared to a compliance condition, is much higher as it is dependent on the degree of variance between the environmental conditions for the measurements and the environmental conditions desired/modeled as well as on the distance from the turbines to the house.

The amount of uncertainty in measurement is generally reduced by focusing on the conditions where the turbine sound is most likely to be audible or dominant and obtaining a sufficiently large data sample so the statistical significance of the data can be supported.

5. COMPLIANCE INVESTIGATIONS

General Information

A common thread throughout the existing compliance requirements in other jurisdictions and recent measurement studies is the need for measurement programs to relate sound measurements to the atmospheric conditions and wind turbine operating conditions during the measurements. To that end, the following compliance determination method looks to coordinate sound measurements with wind speed data and turbine operating conditions.

The described method focuses on sound from wind turbine operation only. Some types of complaints (e.g., pure tones, intermittent modulation) may require that specific subset of data be examined more closely and using different sound indicators. In these cases, the measurement and analysis plan must be discussed with MFLNRO prior to proceeding.

Appendix B provides a template for the Wind Power Project Sound Level Compliance Report (Compliance Report) which will be required by Authorizing Agency staff. Sound assessments are to be completed by a qualified professional. The names and accreditation of the professionals completing the work along with their signatures should accompany the report, or application.

5.1 Introduction, Purpose and Complaint Conditions

Provide a brief description of the purpose for the measurement program and description of the wind power project.

Include a detailed description of the complaint being investigated, and the resulting atmospheric and turbine operating conditions that relate to the complaint. Include any relevant meteorological or operating data for the time of the complaint and provide a map showing the wind projects and the receptor(s) under investigation.

5.2 Compliance Condition

Summarize the compliance conditions committed for the receptor from the original assessment if any. Include sound level criteria, atmospheric conditions and turbine operating conditions.

5.3 Measurement Methods

Technical standards that may be used to conduct sound measurements are as follows:

- ISO 1996-1 (CAN/CSA 2005)
- ASTM 1014 (ASTM 2008a)
- ANSI S12.9 part 2 (ANSI 2008)
- IEC 61400-11 (IEC 2006)

General expectations for sound measurement in relation to wind power projects are summarized in

Table . Variations from these expectations may be warranted based on the standard selected or site conditions. If variations are used, justification should be provided.

Microphone placement should be at least 15m from a building façade to reduce the measurement being influenced by activity at the house, as well as reduce potential sheltering and reflection effects. Placement farther from any structure is encouraged to address privacy issues, with the meter still in a relatively open area with free-field sound. Distances from structures may need to be closer than 15m so the microphone is placed in an area where there is the most open pathway between the future turbines and the measurement location.

Additional wind screens (7" foam or other secondary wind screens) should be considered, with the effects on meter performance to be documented and provided. Equipment calibration records, both lab and field, should also be provided.

In addition to sound level data, microphone height wind data for correlation of the sound levels with wind speeds are required. Measurements should be conducted during a period where the representative or realistic worst case atmospheric condition (e.g. greatest wind speed differentials) are likely to occur but also during a period when a variety of wind speed can be measured. Periods with heavy precipitation, recorded at the weather station or identified through sound recordings, should be excluded. Portable logging anemometers can be used.

5.3.1 Attach Calibration records

Wind speed data and turbine operations data for the period of measurement are required by the practitioner doing the detailed measurement program. The Tenure Holder, or designated operator, is to provide the acoustic practitioner with a summary of time periods when the relevant turbines were operating at 75% of sound power. If the data format is accessible and in a useable format, the actual turbine operating records would be a convenient way to identify the valid turbine operating condition time period. Alternately, as turbine manufacturer sound power data is provided at varying wind speeds or can be inferred from the turbine power generation curve, the corresponding hub height wind speed for 75% of sound power can be used to compare with hub height anemometer readings to identify the "valid" turbine operating condition time periods within the measurement period

5.4 Data Analysis

The data management for a detailed measurement program for wind turbine sound compliance determination includes a requirement to time synchronize and correlate the sound measurement data with ground level wind speeds and turbine operating conditions. In most cases, the data will be manageable through various database or spreadsheet programs.

If, at the end of seven days, the required weather conditions or turbine operating conditions did not occur, the measurement period must be extended by another 7 days, or a period of time as directed by MFLNRO, to increase the likelihood of gathering sufficient valid data. If operating and atmospheric conditions are believed to have occurred during the monitoring period, detailed data analysis can then begin.

The following steps are the preferred analysis method to be used to determine whether sufficient valid data has been gathered.

1. Assemble a full data set consisting of time stamped Leq data, corresponding ground level wind speeds and, if used, hub height wind speeds.
2. Filter the data set for ground level wind speeds above which wind incidence on the microphone influences the measurements. This is dependent on the performance capabilities of the individual equipment so supporting data must be available.
3. Filter the remaining data set for the desired operating conditions, using either time periods supplied by the Tenure Holder or the corresponding hub height wind speed when the turbines are operating at 75% capacity or higher and wind direction is toward the receptor.
4. Determine if the remaining data set is valid for the compliance determination. If at least three hours of valid data for the night (or day, depending on the nature of the complaint) period remains, a valid data set has been gathered.

5.5 Results

5. Compliance is then determined. If 90% of the data are at or below the assessment criteria, then sound levels at the receptor are considered to be compliant.
6. If the results do not indicate compliance, further analysis of the sound recordings will be used to determine if the turbine sound was dominant. If so, a mitigation plan must be developed. If unclear or background sound is dominant, further analysis or measurement is warranted to assess the wind turbine sound contribution.
7. Provide tables and graphs showing a comparative analysis of measured sound levels and turbine operating condition/wind speeds.
8. Show detail regarding the 90% compliance requirement

The 3-hour minimum amount of data is somewhat arbitrary, but is consistent with several studies based on 1-minute sampling.

The challenge with measurement programs is capturing data during the appropriate conditions. The 7-day period for measurement and 3hrs of valid data are viewed as minimum durations. Longer measurement periods (14 days is recommended) are preferred to provide greater potential for gathering valid data and give more confidence in the data set. The measurement duration needs to be balanced with cost of data management and the intrusion of having equipment on private property.

In the event the valid data set does not indicate compliance and the wind turbine generators are not heard to be the dominant sound on the audio recordings, further analysis may be requested to address the influence of background sound. Even though background levels may have been measured as part of the assessment, normal outdoor sound levels are variable, and an elevated background could result in the appearance of non-compliance for the turbines. There are three methods that can be used to address suspected background sound level issues. Selection of measurement method must be discussed with MFLNRO prior to proceeding.

The first method works best if the wind speed and direction of concern is common to operation of the wind power project, or monitoring can be planned with a high degree of likelihood that the desired operating conditions will occur. Measurements are conducted at 1-minute intervals over several hours in either the day or night period. When turbine operating conditions are appropriate (75% capacity and receptor downwind) the relevant turbines are turned on for ½ hour and then off for ½ hour at a time. The comparative sound levels will indicate the amount of influence the wind turbines have or the amount of sound contribution at the receptor. Compliance is then determined based on the amount of sound contribution in the original assessment.

The second method is to conduct a detailed measurement program as described above at an intermediate point between the receptor and the wind turbines, where the contribution of the turbine sound is dominant. The sound levels from the intermediate location is then propagated or used in a prediction calculation to estimate the contribution at the receptor. Caution is required with this method, particularly in extreme terrain conditions where valley effects may not be adequately addressed.

The final method is to conduct another detailed measurement program at the receptor with a second monitor set up at a topographically similar location at least 5 km from the nearest turbine (NARUC 2011). The second location acts as a representative baseline which is then subtracted from the sound levels at the receptor. Again, compliance is then determined based on the amount of sound contribution in the original assessment predicted at that receptor. The difficulty with this method is establishing a representative baseline location that would have the same local and hub height atmospheric conditions as well as similar topography. This method may not be suited to smaller or narrow valleys with the receptor below the ridgeline. Finding another location at the same relative elevation but far enough away from the turbines in the same valley may not be possible.

5.6 Mitigation Analysis

If sound level predictions indicate that sound levels at a receptor may exceed the criteria under the operating conditions assessed, mitigation options will be applied.

Where the detailed measurement program demonstrates that sound levels are not compliant at the receptor, a mitigation plan must be included with the analysis.

For compliance investigation as soon as non-compliance with the Policy criteria is identified, the Tenure Holder must curtail, either through reduced power generation or complete shut-down of the turbine(s) in question, until a mitigation plan is approved. If the non-compliance is related to a specific atmospheric condition or wind speed/direction, curtailment can be limited to those conditions.

Mitigation options other than shut-down and removal exist for industrial wind turbines and use of these modes may be considered as an acceptable solution by MFLNRO. Most turbine manufacturers offer reduced sound operating modes for their equipment. If use of these modes is suggested by the Tenure Holder as a potential mitigation option, a predictive modelling analysis on the expected sound reduction from use of these modes must accompany the compliance measurement report. The modelling analysis is to include an updated assessment model, with results matching the measured conditions, then the results after applying the reduced sound modes to the calculations. Prediction methods are to follow the Predictive Assessment direction in this document.

The resulting mitigation plan forms a commitment by the Tenure Holder to use them. Any commitment must be clearly stated. For example, a generic statement such as "turbines 2, 3 and 4 will be curtailed at night" may be interpreted as turbines 2, 3 and 4 being shut off all night. A clearer statement would be "turbines 2, 3 and 4 will be placed into sound reduced operating mode 3, per the manufacturer specification attached, for wind speeds higher than 10m/s normalized to 10 m height". All manufacturer data regarding reduced sound modes should accompany the application or are to accompany the compliance measurement report.

Re-location or removal of the relevant turbines may still be required, if reduced sound modes not result in sufficient sound control.

When reduced sound operating modes are proposed, the results of a prediction analysis showing the effective sound reduction at each affected receptor and demonstrating compliance must accompany the sound assessment.

a. If required, provide a description of the mitigation options (reduced sound modes, total curtailment)
b. Describe the options selected for the specific non-compliance
c. Provide the results of an updated assessment model based on the measurements
d. Provide the results of the predicted effectiveness of the mitigation selected

5.7 Sound Level Compliance Report

A summary section must be included in the Sound Level Compliance Report that definitely states whether the project is in compliance 90% of the time and if not what mitigation is required to bring it into compliance.

6. PREDICTIVE SOUND ASSESSMENT MODELLING REQUIREMENTS

6.1 Calculation Standards

The recommendations in this section focus on the use of models that employ the ISO 9613 calculation standard (ISO 1993, 1996) per the Policy. However, a general description of how the various parameters affect calculations is also provided as guidance when other calculation methods are used.

The preference is that the ISO-9613 standard (Parts 1 and 2) is continued to be used for assessments. While it is generally understood by practitioners that the accuracy (+/- 3 dBA) of the method diminishes at distances beyond 1000m from the sound source (ISO 1996) and the standard was never developed with wind power projects in mind, there are a number of comparative studies that indicate it is still a good assessment tool, when the model parameters are set to conservative values (Keliski 2009, Delaire 2011 and NARUC 2011). It is still the most commonly used calculation method.

Other calculation methods that may be used include the following:

- CONCAWE: this method published in 1978. It calculates sound propagation from a heavy oil facility and incorporates atmospheric conditions through the Pasquill stability classes in the calculations. (CONCAWE 1978)
- Harmosound: this is a European method that considers diffraction of sound by the atmosphere. It has not been widely implemented in commercially available software although it is growing in use in Europe. (Nota 2005)
- Nord2000: this is a proprietary Nordic calculation method that also considers atmospheric diffraction of sound but is not in common use. (Nord2000 2001)

In general, all outdoor sound propagation calculations take similar approaches. They start with the sound power of the source then provide attenuation coefficients for various parameters such as geometric spreading (distance), atmospheric absorption of sound, interaction of the sound wave with the ground, structures or barrier and vegetation.

All predictive modelling work should be accompanied by a discussion indicating where conservative measures have been used in the models to address the degree of uncertainty in modelling. The exact amount of uncertainty cannot be easily quantified, due to the number of parameters that enter into the calculations.

Should other appropriate standards for calculation of wind turbine sound propagation be developed, a description of the method and details on the calculation inputs should be provided with the assessment.

6.2 Predictive Models

A number of commercially available models have implemented the ISO 9613 calculation standard to varying degrees:

- Cadna/A by Datakustik GMBH
- SoundPLAN by SoundPLAN International LLC
- Predictor by Bruel and Kjaer

- WindPro by EMD International A/S
- WindFarmer by GL Garrad Hassan

Some model software packages also implement other calculation standards besides the ISO 9613 method (Cadna/A, SoundPLAN and Predictor). Both the model used and the calculation method selected should be specified in the assessment.

6.3 Wind Turbine Sound Power

Wind turbine sound power data should be provided by the manufacturer and attached to the assessment. The determination of sound power should reference the IEC61400-11 technical standard and spectral sound power relative to hub height wind speed should be provided.

Typically, sound power data is provided with an uncertainty factor for various wind speed from cut-in to shut-down. Only the maximum sound power output of the turbine should be used in the modelling to assess for compliance.

Generally, the uncertainty in the sound power data (usually +/- 1 or +/- 2 dBA) is not used in the assessment. If a project is particularly contentious, additional setback could be achieved by adding the uncertainty to the sound power. This may result in an overly conservative assessment and may adversely affect the economics of a project.

If there is a substation with the proposed project, sound power levels for the transformers should also be included.

Turbines should be modelled at hub height, as the centre of the sound source.

6.4 Geometric Spreading

The various standards all apply a standard reduction factor based on the attenuation of sound with distance from a source. These distances influence how the cumulative effect of multiple turbines is considered.

As cumulative assessment is required with the recommended approach, sound from all turbines should be considered at all receptors. For larger wind power projects, this may not be practical, as a high number of turbines contributing very low levels of sound can mathematically result in higher predictions that would not realistically occur. From a mathematical standpoint, this occurs when the contribution is more than 15 dBA below ambient or 20 dBA (it is less than 0.1 dBA change). However, all wind turbine generators that may affect a receptor need to be included in the assessment. For the purposes of wind power project assessment, turbines that contribute less than 20 dBA or are more than a set distance (5 km) from a receptor do not need to be considered. When the exclusion of turbines is based on distance, evidence demonstrating that sound from an individual turbine would be expected to be at least 15 dBA below ambient should be provided.

Assessments that limit the consideration of cumulative effects based on either turbine contribution or a set distance should highlight where conservative assumptions have been made in the remainder of the prediction calculations.

6.5 Atmospheric Absorption

The absorption of sound by the atmosphere in ISO 9613, Part 1 is a complex calculation based on 'typical' conditions. The two factors that affect the calculation the most are temperature and relative humidity. Calculations are referenced to atmospheric pressure as well although the relative air pressure does not significantly affect the results of the calculation. Most commercial sound model software only allows for selection of the temperature and relative humidity factors for the calculation.

Assessments should consider 'worst case summer season conditions' generally considered to be well represented by a temperature of 10 degrees Celsius and 70% Relative Humidity for the ISO 9613 calculations. It is the combination of these two factors that result in the least amount of attenuation (or allow the most propagation) of sound through the atmosphere (ISO 1996).

If values other than 10^0C and 70% humidity are used, justification for reducing the amount of conservatism in the predictive modelling should be provided.

6.6 Wind Speed and Direction

ISO 9613 assumes a house is downwind of all sources, regardless of direction. While seeming bit unrealistic for wind projects, research shows this is not unreasonable given that the high wind speed differentials can result in turbine sound not being influenced by wind direction (omni-directional) (NARUC 2011). Where modelling software allows for specific wind speeds or directions, these options should not be used to assess conditions over night-time or daytime periods. Also, statistical options (C_{met}) should not be used unless it is to help quantify conservatism in the modelling or potential seasonal average variations in weather conditions. Generally these are not required for a sound assessment to meet Policy requirements but may need to be examined as part of a larger environmental assessment.

Other calculation methods consider wind in specific ways, some in a single direction at a time or through the consideration of atmospheric stability. When these methods are used, a detailed explanation of how wind speed and direction are considered as well as identification of where conservative measures have been selected in the modelling should be provided. Predictions should be representative of high wind shear/speed differential (stable atmosphere) and downwind conditions.

6.7 Ground Conditions and Ground Cover

The interaction of the atmospheric sound wave with the ground will provide additional attenuation of sound within the first 10 m meters off the ground. This effect is the most pronounced in the first 5 m of height. This ground absorption is based on the ground conditions along the path of the sound, exclusive of physical barriers in the path of travel. The ISO 9613 calculation is based primarily on the ground condition in the vicinity of the source and receiver as shown in Figure 1. However, given that the turbine is an elevated sound source, it is the ground conditions near the receptor that dominate this effect. Therefore, ground conditions considered in the modelling should focus on the conditions in the vicinity of the receptor (Drew 2011).

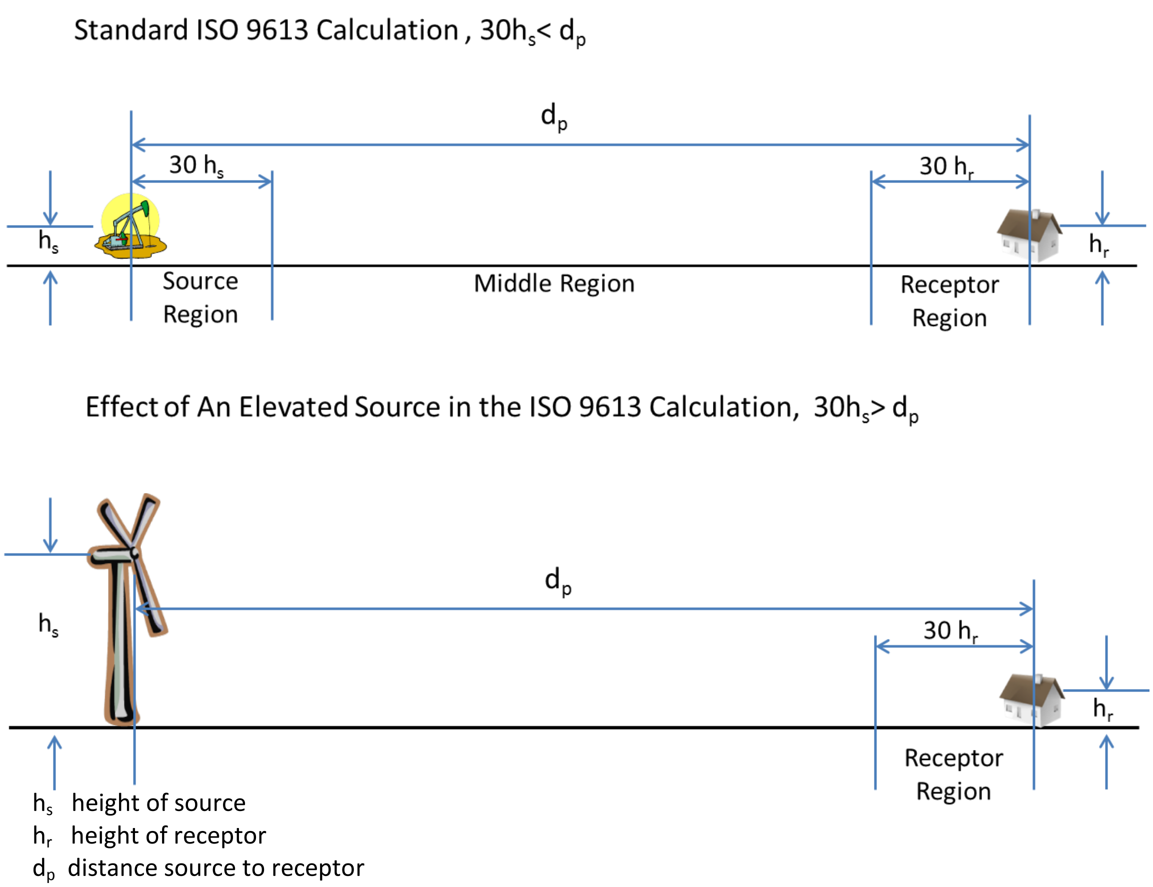

Figure 1: Illustration of Ground Absorption Calculation

For example, water and rock are reflective and should be treated as such in the model. Vegetated areas can be mixed to very absorptive. Mixed ground or gravel driveways and grassy yard should be considered as 0.5 or 50% at most (Keliski 2009, Delaire 2011). The ONMOE limit of 0.7 or 70% absorptive should be the highest accepted absorption value.

Ground cover such dense forest may have some attenuating effects; however, the height of the turbines may negate these effects based on the way sound travels and how calculations are conducted.

Consideration of trees as barrier to sound should be avoided, particularly if the area is likely to be identified as a future harvest area.

6.8 Terrain and Physical Barriers

Terrain is often considered in predictions but caution needs to be used depending on the calculation standard selected. The calculation methods available use a straight ray or diffracted ray approach where sound travels a defined path and any obstructions, whether natural terrain or man-made, trigger a separate barrier attenuation calculation. In ISO 9613, a "straight ray model", gently undulating terrain may be considered as a barrier, when the sound can actually arc over a slight rise with the movement of air as shown in Figure 2 (Drew 2011).

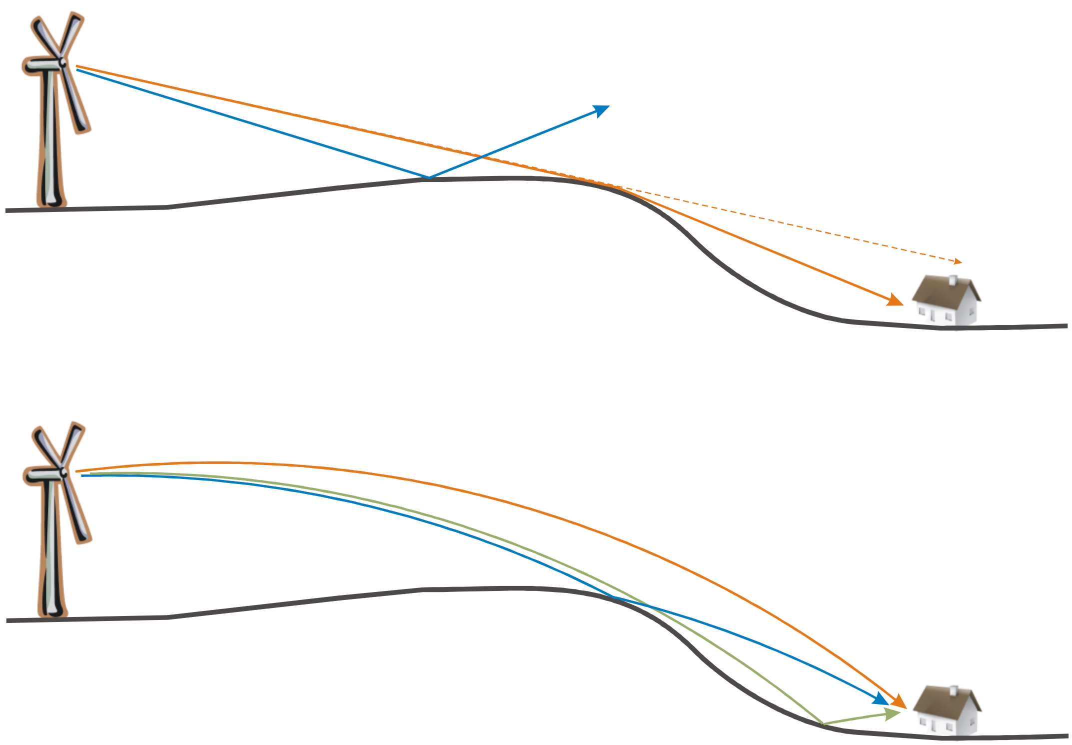

Figure 2: Model Treatment of Undulating Terrain

When terrain is considered in a sound assessment, only extreme terrain changes should be evaluated. Undulating terrain or partial shielding of turbines by terrain should be identified and the calculations structured so that barrier effects are not considered.

If more information is requested the complete background documents for the Best Practice for Wind Power Project Acoustic Assessment British Columbia 2012 and the Wind Power Project Draft Compliance Investigation Procedure for Wind Turbine Sound are available on the Land Tenures Branch website – link.

7. APPENDIX A – PREDICTIVE SOUND ASSESSMENT REPORT TABLE OF CONTENTS AND CONCORDANCE TABLE

Table of Contents:

1. Introduction
2. Project and Site Description
3. Existing Environment
4. Criteria
5. Sound Level Predictions
    a. Sound Sources
    b. Model parameters
    c. Results
6. Determination of Compliance
7. Low Frequency Sound (optional)
8. Mitigation
    a. Modified Sound Sources
    b. Modified Results
9. Summary

Concordance Table for Environmental Assessments or DPIRs:

Completing the following table will assist Ministry staff with reviewing and addressing the key issues with the project. Using the Provided (Y/N/P) column, proponents can indicate which information elements are included in the sound assessment by stating yes (Y), no (N) and partial (P) as appropriate.

Section	Information Requirement	Provided (Y/N/NA)	Comment	EA Reference
1	Introduction			
	Identification of qualified professionals			
2	Project description			
	Turbine locations			
	Turbine specifications			
	Substation details			
	Meteorological conditions			
3	Existing environment description			
	Measured baseline			
4	Receptors and criteria identified			
	Adjusted criteria used			
5a	Sound sources provided			
5b	Model Parameters detailed			
5c	Results at receptors			
	Contour results			

Section	Information Requirement	Provided (Y/N/NA)	Comment	EA Reference
6	Cumulative calculations and demonstration of compliance			
7	Low frequency sound analysis (optional)			
8a	Mitigation – sound source specifications			
8b	Mitigation – modified results			
9	Summary			

8. APPENDIX B - WIND POWER PROJECT SOUND LEVEL COMPLIANCE REPORT TABLE OF CONTENTS

1. Introduction and Purpose
    a. Provide a brief description of the purpose for the measurement program and description of the wind power project
2. Complaint Conditions
    a. Provide a detailed description of the complaint being investigated, and the resulting atmospheric and turbine operating conditions that relate to the complaint.
    b. Attach the resident completed complaint form
    c. Include any relevant meteorological or operating data for the time of complaint
    d. Provide a map showing the wind projects and the receptor(s) under investigation
3. Compliance Condition
    a. Summarize the compliance conditions committed for the receptor from the original assessment. Include sound level criteria, atmospheric conditions and turbine operating conditions.
4. Measurement Methods
    a. Provide a detailed description of the measurement program conducted, including equipment details, location of measurement(s)
    b. Cite any standard followed
    c. Provide details of how wind incidence on the microphone was managed
    d. Provide wind screen performance data
    e. Attach calibration records
5. Data Analysis
    a. Describe the data sorting and filtering conducted
    b. Describe the periods of valid turbine operation
    c. Provide detailed results for the validated data set
    d. Attach detailed summaries of sound measurement data
    e. Attach detailed summaries of ground level wind data
6. Results
    a. Provide tables and graphs showing a comparative analysis of measured sound levels and turbine operating condition/wind speeds
    b. Show detail regarding the 90% compliance requirement
7. Mitigation Plan (if required)
    a. If required, provide a description of the mitigation options (reduced sound modes, total curtailment)
    b. Describe the options selected for the specific non-compliance
    c. Provide the results of an updated assessment model based on the measurements
    d. Provide the results of the predicted effectiveness of the mitigation selected

8. Summary
9. References