4 AIRBORNE NOISE – BACKGROUND & METHODS

4.1 INTRODUCTION

The activities associated with the construction, operation, and decommissioning of the proposed offshore wind farm will generate noise both underwater and in-air. Underwater noise has been considered in Sections 6 through 9 of this Volume; the present section addresses airborne noise. Sound propagation modeling has been applied to predict airborne noise levels arising from the Project activities as received at nearby sensitive receptor locations. This assessment addresses noise disturbance with respect to impacts on humans in residential and recreational land use areas. The estimated received sound levels have been compared to the levels suggested as being acceptable in relevant regulations and guidelines.

This airborne noise assessment considered project activities with the greatest potential for human disturbance. The activities that were considered included the impact pile driving of the turbine foundations, the construction activities at both of the cable land fall areas, as well as the noise from the operating wind turbines. Airborne noise associated with impact hammer pile driving will be generated mostly by the physical striking of the hammer on the steel pile, which will dominate any noise that may be associated with hammer fluid exhaust. The airborne noise generated during pile driving decreases as the piling progresses and the length of pile exposed in the air decreases. Noise from the construction activities will be generated by the engines of the heavy equipment that will be used at the cable landfall areas. The operating turbines will generate noise mechanically through the components of the turbine nacelle (the gear box, generator etc.) and, more importantly, aerodynamically due to air flow effects arising from the rotation of the blades in the wind. Decommissioning activities are expected to employ similar types of equipment as used during the construction phase, resulting in similar expected noise footprints.

The proposed wind farm will not be located in the vicinity of populated areas; there is, however, a potential that noise from the project activities will be detectable on shore (within Naikoon Provincial Park) since airborne sound can propagate to long ranges when traveling across water. Airborne noise associated with the construction activities at the two cable landfall areas have also been considered due to their closer proximity to the residential communities of Tlell on Haida Gwaii, and Port Edward on the mainland.

Some basic airborne acoustic terminology is introduced in Section 4.2 below. Regulatory guidelines relevant to the assessment of impacts to humans from airborne noise follow in Section 4.3. The modelling methods that were used to estimate the airborne noise levels arising from each activity, as well as details of the model scenarios that were considered, are discussed Section 4.4. The model results are then presented in Section 5.1. Noise from anticipated project decommissioning activities is discussed in Section 5.2. Noise mitigation options are presented in Section 5.3, and the discussion and conclusions are found in Sections 5.4 and 5.5, respectively.

4.2 ACOUSTICS TERMINOLOGY

Sound is the result of mechanical vibrations that travel as waves through a fluid medium (*e.g.*, air or water) and generate a time-varying pressure disturbance. At a fixed receiver location, the pressure oscillates positively and negatively relative to the ambient pressure. Sound waves may be perceived by the human auditory system, or can be measured using an acoustic sensor.

Sound waves are typically described in terms of two characteristics: intensity and frequency. Intensity is measured in units of power-per-unit-area and frequency is measured in units of cycles-per-unit-time. The SI units of intensity and frequency are W/m^2 and Hz, respectively. Intensity describes the pressure wave amplitude while frequency describes how rapidly the pressure fluctuations occur. Low frequency sounds, such as distant rolling thunder, exhibit few pressure fluctuations per second, whereas the pressure oscillates many times a second for high frequency sounds such as a whistle. Sounds that are composed of essentially a single frequency are called tones. Most sounds are generally composed of a broad range of frequencies (“broadband” sound) rather than being pure tones. The loudness of a sound is related to its intensity; loudness, however, is a subjective term that refers to the perception of sound intensity rather than the intensity itself. Loudness also depends on the frequency and duration of sound. Pulsed sounds and sounds with very short durations (less than a few seconds) are sometimes called transient sounds. Sounds with longer durations are called continuous sounds.

Sound pressure and intensity are most commonly measured on the decibel (dB) scale. The logarithmic dB scale expresses a quantity relative to a predefined reference level. Sound pressure in dB is expressed in terms of the sound pressure level (SPL), L_P, as

$$L_P = 20\log_{10}(P/P_{ref}) \qquad \textbf{Eq. 1}$$

where P is the pressure amplitude and P_{ref} is the reference sound pressure. For airborne sound, the reference pressure is generally taken to be 20 μPa (1 μPa is equal to 10^{-6} Pa or 10^{-11} bar) as this is the lowest pressure that a normal human ear is capable of detecting.

The term “noise” generally refers to unwanted sound that interferes with the detection of other sounds and/or disturbs regular activities. Airborne noise levels naturally vary from place to place and over time. Levels of airborne background noise at a particular location depend primarily on the intensity and proximity of human activities, on the local topography and on local wind and weather conditions.

4.2.1 Continuous Noise

Continuous noise is characterized by gradual intensity variations over time; an everyday example would be engine noise from heavy equipment. The intensity of continuous noise is generally given in terms of the measured root-mean-square (*rms*) SPL. Given a measurement of the time varying sound pressure *p(t)* from a given noise source at some location, the *rms* SPL (symbol L_P) is computed according to the formula:

$$L_P = 10\log_{10}\frac{1}{T}\int_T p(t)^2\,dt / P_{ref}{}^2 \qquad \textbf{Eq. 2}$$

where *T* is the measurement period. The *rms* SPL is effectively the average sound intensity over the measurement period.

Continuous noise levels are also commonly expressed using the Equivalent Continuous Sound Level (symbol L_{eq}) which is the notional sound pressure level of a constant signal that would deliver the same total acoustic energy as the real time-varying noise over the same total duration. L_{eq} values are always accompanied by a time reference indicating the duration used.

4.2.2 Pulsed Noise

Transient or pulsed noise is characterized by brief, intermittent acoustic events with rapid onset and decay back to pre-existing levels (*i.e.*, within a few seconds). Noise from pile hammering is an example of pulsed noise. One acoustic metric used to describe transient noise is the peak SPL. The peak SPL (symbol L_{Pk}) is the maximum instantaneous sound pressure level measured over the pulse duration:

$$L_{Pk} = 20\log_{10}\left(\max|p(t)| / P_{ref}\right) \qquad \textbf{Eq. 3}$$

where *p(t)* is the instantaneous pulse pressure as a function of time, measured over the pulse duration $0 \leq t \leq T$. This metric is very commonly quoted for impulsive sounds but does not take into account the pulse duration or bandwidth of a signal.

The sound energy of a transient noise signal is also commonly expressed using the previously defined Equivalent Continuous Sound Level (symbol L_{eq}) which is the notional sound pressure level of a constant noise signal that would deliver the same total sound energy as that of the transient signal over the same total duration. A similar sound energy metric is known as the Sound Exposure Level (or SEL) which, in airborne acoustics, is the level of a constant signal of one second duration which contains the same sound energy as the total duration of the time varying signal. L_{eq} and SEL values are the same for transient signals that are 1 second in length.

4.2.3 Source Level and Transmission Loss

Acoustic waves radiate from noise sources and the sound intensity generally decays with distance from the source. The dB reduction in sound level that results from propagation of sound away from an acoustic source is called transmission loss (TL). The loudness or intensity of a noise source is quantified in terms of the source level (SL), which is the sound pressure level referenced to some fixed distance from a noise source. In the source-path-receiver model of sound propagation, the received SPL at some receiver position is equal to the source level minus the TL along the propagation path between the source and the receiver (Richardson *et al*. 2005, p. 16). Received SPLs arising from a given noise source can be computed by combining acoustic source level measurements with transmission loss estimates. This is the method of modelling airborne sound propagation that has been applied in the present study.

4.2.4 1/3-Octave Band Analysis

It is often useful to analyze the distribution of power of a sound signal as a function of frequency. This may be done by examining the sound power at discrete frequency values, or the noise may be band-pass filtered to examine the sound power in a band of adjacent frequencies. In acoustics, 1/3-octave band analysis is a commonly used scheme for determining the frequency content of a broadband signal. The process of band-pass filtering rejects all sound power outside of a narrowly defined frequency range. In 1/3-octave band analysis, the recorded pressure time series is filtered into a series of adjacent band pass filters, each one third of an octave wide. These pass bands don’t overlap. The width of each 1/3-octave filter can also be expressed as approximately 23 % of the band center frequency. Standard center frequencies for 1/3-octave pass bands (in units of Hz) are given by the following formula:

$$f_c = 10^i / 10 \qquad i = 1, 2, 3... \qquad \textbf{Eq. 4}$$

where i is the band number (ISO 266-1975E). The low and high band limits, f_{lo} and f_{hi}, are equal to 89.1 % (= $2^{-1/6}$) and 112.2 % (= $2^{1/6}$) of the band center frequency, respectively. The SPL in the i^{th} 1/3-octave band (symbol $L_b^{(i)}$) may be computed from the power spectrum according to the following formula:

$$L_b^{(i)} = 10\log_{10}\left(\int_{flo}^{fhi} S(f)df\right) \qquad \textbf{Eq. 5}$$

where *S(f)* is the spectral power density (units of μPa^2/Hz) and *f* is frequency. Noise is customarily analyzed using several parallel 1/3-octave bands covering the frequency range of interest. The spectral power density is the squared acoustic pressure filtered into a series of adjacent bandpass filters of 1 Hz width and integrated over a certain period in time. It is normally computed via a Fourier Transform of the recorded pressure time series.

Propagation of sound is often modelled in 1/3-octave bands as well. Band pressure levels possess the convenient property that, when the power in all *n* bands is summed together, it equals the total SPL of the broadband signal:

$$L_P = 10\log_{10}\sum_n 10^{L_b^{(i)}/10} \qquad \textbf{Eq. 6}$$

The summing has to happen in linear space rather than logarithmic space, therefore, $10^{L/10}$ is taken to change from dB back into linear units. The advantage of 1/3-octave band modelling is that it can resolve the frequency dependent propagation characteristics of a particular environment and still be used to efficiently compute the overall sound pressure level for any receiver position.

4.2.5 A-weighting

Humans are capable of detecting sounds in the frequency range roughly between 20 Hz and 20 kHz (exact hearing limits are specific to each individual and are impacted by factors such as age). The human ear is not equally sensitive to sound at all frequencies, however, and the ear is most sensitive at around 1 kHz. For noise assessments considering human impacts, noise levels are typically frequency-weighted to reflect the relative sensitivity of the ear as a function of frequency. The frequency dependence of the ear's sensitivity varies with sound intensity; a few different weighting filters are in general use, known as A-, B-, and C-weighting. The most commonly applied filter which is relevant for the ranges of sound pressure levels in this assessment is known as A-weighting and is represented by the following function as defined in the International Standard IES 651 (1993-09):

$$W_A(f_n) = 20\log\left(\frac{R_A(f_n)}{R_{A,1000}}\right) \qquad \textbf{Eq. 7}$$

where

$$R_A(f)=\frac{12200^2 f^4}{(f^2+20.6^2)(f^2+12200^2)(f^2+107.7^2)^{1/2}(f^2+737.9^2)^{1/2}} \quad \textbf{Eq. 8}$$

and $R_{A,1000}$ is $R_A(f)$ for f = 1000 Hz. Here, f_n is the frequency of interest expressed in Hz.

The A-weighted sound pressure level is commonly referred to simply as “sound level” (symbol L_A) and is computed from the un-weighted sound pressure level, $L_p(f_n)$, and $W_A(f_n)$ as follows:

$$L_A(f_n)=L_p(f_n)+W_A(f_n) \quad \textbf{Eq. 9}$$

Sound levels are presented in ‘A-weighted decibels’ written as dBA. A-weighted L_{eq} values use the symbol L_{AEq}. Some typical sound levels measured at 1 m range are provided in Table 4-1 below.

Table 4-1 Examples of typical sound levels.

Sound Source	Level (dBA)
Quiet Room	30 dBA
Typical Living Room	40 dBA
Normal Conversation @ 1m range	55-65 dBA
Lawn Mower @ 1m range	88-94 dBA
Hairdryer @ 1m range	80-95 dBA
¼” Drill @ 1m range	92-95 dBA

4.3 REGULATORY BACKGROUND

Noise from construction and other anthropogenic activities occurring in British Columbia is mostly regulated through municipal or regional bylaws. These bylaws are often general in nature and do not define acceptable levels of noise for specific receptor settings and industrial activities. The World Health Organization’s (WHO) Community Noise Guidelines and the Province of British Columbia Ministry of Agriculture and Lands Land Use Operational Policy respectively provide specific noise level guidelines for human dwellings and parklands as well as for land based wind farms. These guidelines are described in the sections that follow and have been used in this assessment to determine potential impacts arising from project related airborne noise.

4.3.1 Tlell

Noise bylaws for the community of Tlell fall under the jurisdiction of the Skeena-Queen Charlotte Regional District. At time of writing, there are no bylaws that restrict airborne noise in this region (John Holland, Administrator/Planner, Skeena-Queen Charlotte Regional District, personal communication, 25-Aug-2008).

4.3.2 Naikoon Provincial Park

In-air noise restrictions for Naikoon Provincial Park are defined in the Park, Conservancy and Recreation Area Regulation of the British Columbia Park Act. The regulation states “except as authorized by a park officer, no person shall, between the hours of 11 p.m. and 7 a.m. the following day, operate or permit another person to operate any device that produces sound at a level which disturbs the peace and quiet of (a) an occupant of another campsite, or (b) persons in the park, conservancy or recreation area.” Disturbing noise levels are not quantified.

4.3.3 Port Edward

The District of Port Edward Noise Control bylaw No. 245, 1987 curtails the making or causing of noise, nuisance, or sounds within the Port Edward community. While unacceptable noise levels are not quantified within the bylaw, it generally states that “no person shall make or cause, or allow or permit to be made or caused, any noise in or on any property which disturbs or tends to disturb the quiet, peace, rest, enjoyment, comfort, or convenience of any person or persons in the neighbourhood or vicinity” of the district. The bylaw does, however, allow maintenance, repair, and construction activities to proceed between the hours of 7:00 a.m. and 9:00 p.m. of the same day. A permit allowing these activities to continue outside the specified time frame may be applied for, but the duration of noise causing activities is restricted to within a 48 hour period.

4.3.4 Province of British Columbia’s Wind Power Projects, Land Use Operational Policy

The Province of British Columbia regulates airborne wind turbine noise through land use operational policy Wind Power Projects on Crown Land. The policy states that wind energy projects “must be sited at locations where the wind turbine sound level will be reduced to a maximum of 40 dB (A-weighting) on the outside of an existing permanently-occupied residence (not owned by NaiKun Wind Development Inc. (the Proponent)) or the closest boundary of existing, undeveloped parcels zoned residential (not owned by the Proponent).” The 40 dBA requirement was chosen based on WHO guidelines for community noise (see section 4.3.5), and is limited to residential zones in existence at the time of application to construct a wind farm. The policy additionally asserts that wind turbine locations should be determined through modelling of turbine produced sound propagation. Worst case scenarios must be modelled using methodology that satisfies the internationally recognized noise prediction standard ISO-9613 (Part 2) Attenuation of sound during propagation outdoors, and specific characteristics of the proposed turbines and project site must be incorporated.

The policy further states that if the owner of a residence or residential parcel registers a complaint about wind turbine noise while the Project is in operation, the sound received at this location must be measured, recorded and submitted to the Regional Executive Director of the Ministry of Agriculture and Lands. If the measured received level exceeds the maximum permissible sound level of 40 dBA, the wind turbine(s) causing excessive noise must be identified and decommissioned. Turbines producing excessive noise due to mechanical malfunction or damage are excluded from this requirement but must cease operation until repairs are complete. If sound levels exceed 40 dBA due to loss of vegetation along the path of sound propagation, proof that levels have been elevated by the loss is required, and reasonable efforts must be made to replace the vegetation to increase noise dampening.

4.3.5 World Health Organization Community Noise Guidelines

The World Health Organization (WHO) provides recommendations for appropriate atmospheric noise levels in human dwellings and parklands in their publication: Guidelines for Community Noise. This document states that noise levels for indoor living spaces should be kept below 35 dB L_{Aeq} (16 hour time base) during the day and evening to avoid speech intelligibility hindering and moderate annoyance. For outdoor living areas, such as balconies and terraces, sound levels from continuous sources should be kept below 55 dB L_{Aeq} (16 hour time base) to avoid serious annoyance, and 50 dB L_{Aeq} (16 hour time base) to avoid moderate annoyance during daytime and evening hours. The WHO further recommends that noise levels in bedrooms be kept below 30 dB L_{Aeq} (8 hour time base) for continuous sound and 45 dB L_{Amax} for impulse events to avoid sleep disturbance. In addition, sound levels just outside living spaces should be kept below 45 dB L_{Aeq} (8 hour time base) and 60 dB L_{Amax} so people may sleep uninterrupted with windows open.

No quantitative recommendations for noise levels are provided for parklands, but the document asserts “existing large quiet outdoor areas should be preserved and the signal-to-noise ratio kept low.”

4.4 AIRBORNE NOISE MODELLING METHODS

4.4.1 INPM Model Description

Sound propagation modelling for wind farm construction and operation activities was performed to evaluate the extent of the area of potential impact using JASCO Applied Sciences’ atmospheric noise propagation model INPM. This model surpasses the ISO-9613 noise prediction standard recommended by the BC Land Use Operational Policy in terms of its sophistication and inclusion of physical phenomena affecting propagation. The ISO-9613 standard is empirically based and accounts in an approximate way for sound attenuation from geometric spreading, atmospheric absorption as a function of the gas composition and environment aspects such as the impedance of the ground and reflections from physical barriers. The standard is most accurate for moderate downwind atmospheric conditions and for ranges within 1 km from a noise source. The INPM model uses a numerical solution to an approximate form of the acoustic wave equation and more accurately incorporates the influences of atmospheric and ground properties on the sound propagation. INPM model estimates are valid at long ranges (*i.e.*, up to several tens of kilometres) from the source. Unlike the ISO standard, INPM fully accounts for real-life aspects of the propagation environment including a stratified (layered) atmosphere profile, terrain elevation and acoustic impedance, as well as air turbulence. The elevation and ground properties of the terrain enable the propagation model to account for reflections and absorption of the propagating sound field as the acoustic waves interact with the ground. This model also accounts for refraction and possible inversions in the atmosphere when representative atmospheric profile of the area is available from measurements or meteorological modelling, or to explore potential worst-case scenarios.

INPM uses a split-step Padé solution for the parabolic form of the wave equation to determine frequency dependent transmission losses as a function of range away from a source. This algorithm is considered on the cutting edge of atmospheric propagation modelling within the atmospheric modelling community. The split-step Padé solution is computationally faster than the finite-difference solution of the Parabolic Equation by approximately two orders of magnitude and is more accurate than the split-step Fourier solution for wide angle propagation. This approach is also superior to standard ray tracing models that can yield unrealistically large received sound level values due to caustics, which are computationally intensive to remove (Salomons, 2001). Further details on the theoretical basis of the split-step Padé algorithm can be found in Collins, 1993.

INPM computes acoustic fields by modelling transmission loss along evenly spaced radial traverses covering a 360 º swath from the source (so-called N×2-D modelling). Acoustic transmission losses were computed for each of the center frequencies for all 1/3-octave bands between 25 Hz and 4 kHz. Received sound pressure levels in each band were computed by applying frequency-dependent transmission losses to the corresponding 1/3-octave band source levels obtained from the literature.

4.4.2 Acoustic Environment

4.4.2.1 Ground Elevation

The ground elevation used in the modelling came from digital terrain elevation data (DTED) files acquired from the Shuttle Radar Topography Mission (SRTM), which successfully collected Interferometric Synthetic Aperture Radar (IFSAR) data over 80 percent of the landmass of the Earth between 60 degrees North and 56 degrees South latitudes in February 2000. The mission was co-sponsored by the National Aeronautics and Space Administration (NASA) and National Geospatial-Intelligence Agency (NGA). These data have a spatial resolution of approximately 100 m.

4.4.2.2 Ground Coverage

The INPM model takes into account the acoustic impedance of the ground. The relationship between the acoustic impedance of the ground and that of the atmosphere will dictate the ratio of the sound energy which is reflected to that which is absorbed into the ground. The acoustic impedance can be described using a single parameter, flow resistivity, within a known parameter, space (Delany, 1970). Flow resistivity values of 200 and 20,000 $kN \cdot s/m^4$ for land and water respectively were used for the modelling work presented in this report. These are typical values used for atmospheric propagation modelling (Sondergaard, 2005).

4.4.2.3 Wind Velocity Profiles

The atmospheric profiles used in the modelling were developed by acquiring data from the University of Wyoming, which had daily weather balloon launches from Annette Island, BC during the month of July 2007. These data, for every day of the month, were then averaged and smoothed. The resulting data can be seen in Figure 4-1. The pressure, temperature, and relative humidity profiles were used for all scenarios. The average wind speed was also used for all scenarios but was increased by a factor of 2 to give a value of approximately 10 m/s through the turbine cross-section. The wind direction was changed accordingly to force the direction of the wind to be toward land in order to give a worst case for all scenarios.

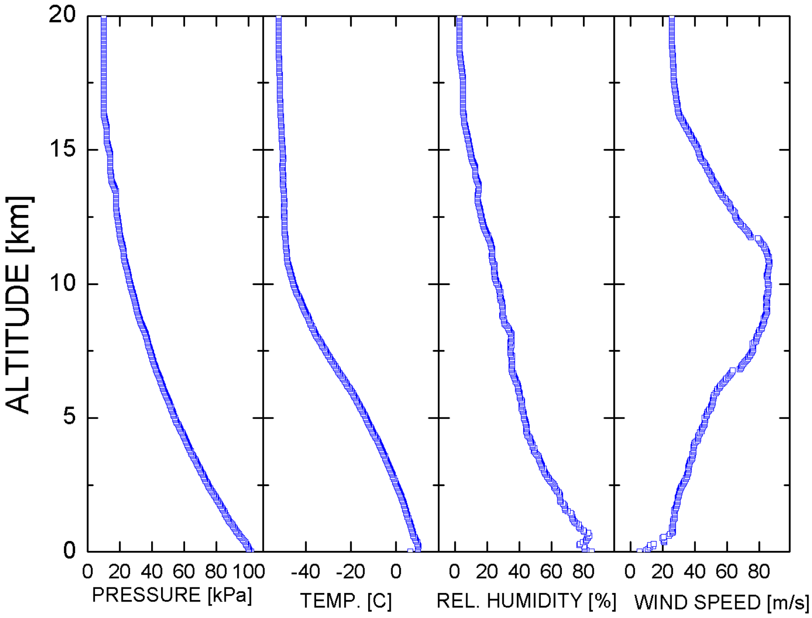


Figure 4-1 **Atmospheric profile pressure, temperature, relative humidity and wind speed data used for the in-air modelling.**

4.4.3 Model Scenarios

Table 4-2 provides a summary of the scenarios that were modelled to capture a precautionary estimate of the noise footprint associated with the relevant project activities. The scenarios considered were based on descriptions of the expected construction and operations activities outlined in the NaiKun Wind Development Project Description (Baird 2008). Table 4-2 summarizes the activities accounted for by each scenario, as well as each scenario's location. The subsections below provide more detailed information about the parameters used to model the noise sources associated with each activity. Source levels for the modeling were obtained from a literature review of measurements for similar equipment performing similar operations. The 1/3-octave band source levels that were used to model the noise for the equipment in each of the model scenarios are provided in the Appendix.

Table 4-2 **Construction and operations activities accounted for by each model scenario, as well as each scenario location.**

No.	Name	Location
1A	Tripod/Lattice Impact Pile Driving (550 kJ hammer energy)	Wind Farm Grid – Closest Turbine To Naikoon Park
1B	Monopile Impact Pile Driving (1200 kJ hammer energy)	Wind Farm Grid – Closest Turbine To Naikoon Park
2	Construction at Tlell Cable Landfall Area	Transmission Cable Corridor – Haida Link
3	Cable Shore Pull at Tlell Cable Landfall Area	Transmission Cable Corridor – Haida Link
4	Construction at Ridley Island Cable Landfall Area	Transmission Cable Corridor - SW Ridley Island
5	Cable Shore Pull at Ridley Island Cable Landfall Area	Transmission Cable Corridor - SW Ridley Island
6	Operating Wind Turbines	Wind Farm Grid

4.4.3.1 Construction

The construction phase of the Project as modelled comprises scenarios one through five. This section provides the details of each individual scenario setup.

Scenario 1A – Tripod/Lattice Impact Pile Driving (550 kJ ram energy):

Scenario 1A accounts for noise produced by impact hammer pile driving of a single support pile for the WTG substructures based on either a tripod (3 piles) or a lattice (4 piles) foundation type. The nearest sensitive receptor location for this scenario is along the East Beach of Naikoon Provincial Park, an area frequented for recreational purposes. East Beach follows the eastern coast of Graham Island between Rose Spit and Tlell, within Naikoon Provincial Park. Scenario 1A was modelled using acoustic parameters for a hydraulic impact hammer with 550 kJ of ram energy, located at the turbine site nearest to East Beach in Naikoon Park. This pile driving scenario will, under most conditions, yield higher received levels at Naikoon Park than any other pile location since the other turbine sites are further away from the shore. The 1/3-octave band source levels used for this scenario were derived from a published study of pile driving noise measured during the San Francisco - Oakland Bay Bridge East Span Seismic Safety Project (Thorson and Reyff, 2004). This reference presented airborne noise measurements collected at 100 m range from 2.4 m diameter steel pile that was driven using a hydraulic impact hammer with approximately 1000 kJ of hammer energy. The measured levels were decreased by 2.6 dB for this model scenario to account for the lower hammer energy of 550 kJ anticipated to install the tripod or lattice foundation piles. This 2.6 dB adjustment was derived based on the reasonable assumption that pulse energy from pile driving is linearly proportional to the ram energy used to hammer the pile (i.e., the decibel adjustment was 10 $\log_{10}$(550 kJ / 1000 kJ)). The levels were also back propagated to a range of 1 m from the source assuming spherical spreading. Table 4-3 summarizes the pile driving energy, pile diameter and location of the noise source that was assumed for this model scenario.

Impact hammer pile driving generates pulsed noise, as opposed to non-pulsed noise, and noise from this source was modelled in terms of single-impulse SEL (total pulse energy). The repetition rate of the pile driving pulses is expected to be approximately 2 seconds and the total time for driving a single pile is approximately 2 hours.

Table 4-3 Noise source specifications for scenario 1A.

Noise Source	Source Description	Location (m - UTM Zone 9)	Activity	Broadband SL (dBA @ 1 m)
Hydraulic Impact Hammer	Assuming 2-3 m hollow, steel piles, 550 kJ hammer energy	331288, 5984365	Pile Driving	128.1 dBA

Scenario 1B – Monopile Impact Pile Driving (1200 kJ ram energy):

Scenario 1B accounts for noise produced by impact hammer pile driving of a single support pile for the WTG substructures with a monopile foundation type. As for scenario 1A, the nearest sensitive receptor location for this scenario is along the East Beach of Naikoon Provincial Park. Scenario 1B was modelled using acoustic parameters for a hydraulic impact hammer with 1200 kJ of ram energy, located at the turbine site nearest to Naikoon Park. This pile driving scenario will under most conditions yield higher received levels at Naikoon Park than any other pile location since the other turbine sites are further away from the shore. The 1/3-octave band source levels used for this scenario were also derived from the San Francisco - Oakland Bay Bridge East Span Seismic Safety Project measurements (Thorson and Reyff, 2004). As described above, the measured levels were again adjusted to account for the difference in hammer energy. For this scenario the levels were increased by 0.8 dB to account for the increased anticipated hammer energy of 1200 kJ for the larger diameter piles. The levels were also back propagated to a range of 1 m from the source assuming spherical spreading. Table 4-4 summarizes the pile driving energy, pile diameter and location of the noise source that was assumed for this model scenario.

Impact hammer pile driving generates pulsed noise, as opposed to non-pulsed noise, and noise from this source was modelled in terms of single-impulse SEL (total pulse energy). The repetition rate of the pile driving pulses is expected to be approximately 2 seconds and the total time for driving a single pile is approximately 2 hours.

Table 4-4 Noise source specifications for scenario 1B.

Noise Source	Source Description	Location (m - UTM Zone 9)	Activity	Broadband SL (dBA @ 1 m)
Hydraulic Impact Hammer	Assuming 4.5-5 m hollow, steel piles, 1200 kJ hammer energy	331288, 5984365	Pile Driving	128.1 dBA

Scenario 2 – Construction at Tlell Cable Landfall Area:

Scenario 2 accounts for construction noise produced during the expected activities at the Tlell Cable Landfall Area. The nearest sensitive receptor location for this scenario is the residential area of Tlell. The activities accounted for in this scenario are trenching of the cable joining pit and site preparation for cable laying using heavy equipment appropriate for earthworks. This scenario assumed the use of one long reach tracked excavator (178 kW) for digging, a second tracked excavator (173 kW) for ground excavation and an additional tracked excavator idling. The source levels for the heavy equipment used in this construction scenario were obtained from the UK Department for Environment Food and Rural Affairs source level database (Defra, 2005). Table 4-5 presents the source levels and locations that were assumed for each piece of equipment included in this model scenario. The excavators were all placed at the same location and an aggregate source level was applied in the model.

Table 4-5 Noise source specifications for scenario 2.

Noise Source	Source Description	Location (m - UTM Zone 9)	Activity	Broadband SL (dBA @ 1 m)
Long Reach Tracked Excavator	178 kW	306141, 5938940	digging	97.3 dBA
Tracked Excavator	173 kW	306141, 5938940	ground excavation	96.0 dBA
Tracked Excavator	173 kW	306141, 5938940	idle	87.9 dBA

Scenario 3 – Cable Shore Pull Tlell:

Scenario 3 accounts for the cable shore pull activities at the Tlell Cable Landfall Area. The nearest sensitive receptor location for this scenario is the residential area of Tlell. This scenario assumed the use of two tracked excavators (173 kW), one performing ground excavation and one idling, as well as a cable ship sitting idle at a location offshore where the water is at least 5 m deep. The source levels for the heavy equipment used in this construction scenario were obtained from the UK Department for Environment Food and Rural Affairs source level database (Defra, 2005)), with the exception of the cable tow vessel, which used a reference obtained from a software package called SourceDB (sourceDB, DGMR) for a ship less than 1 ton. Table 4-6 presents the source levels and locations that were assumed for each piece of equipment included in this model scenario. The tracked excavators were both placed at the same landfall location and an aggregate source level was applied in the model.

Table 4-6 Noise source specifications for scenario 3.

Noise Source	Source Description	Location (m - UTM Zone 9)	Activity	Broadband SL (dBA @ 1 m)
Tracked Excavator	173 kW	306141, 5938940	ground excavation	96.0 dBA
Tracked Excavator	173 kW	306141, 5938940	idle	87.9 dBA
Ship	Less than 1 ton	310471, 5940605	idle	62.7 dBA

Scenario 4 – Construction at Ridley Island Cable Landfall Area

Scenario 4 accounts for noise produced during construction at the Cable Landfall Area on Ridley Island. As for Scenario 2, the activities accounted for in this scenario are trenching of the cable joining pit and site preparation for cable laying using one long reach tracked excavator (178 kW) for digging, a second tracked excavator (173 kW) for ground excavation and an additional tracked excavator idling. The source levels for the heavy equipment used in this construction scenario were obtained from the UK Department for Environment Food and Rural Affairs source level database (Defra, 2005). Table 4-7 presents the source levels and locations that were assumed for each piece of equipment included in this model scenario. The excavators were all placed at the same location and an aggregate source level was applied in the model.

Table 4-7 Noise source specifications for scenario 4.

Noise Source	Source Description	Location (m - UTM Zone 9)	Activity	Broadband SL (dBA @ 1 m)
Long Reach Tracked Excavator	178 kW	414687, 6007120	digging	97.3 dBA
Tracked Excavator	173 kW	414687, 6007120	ground excavation	96.0 dBA
Tracked Excavator	173 kW	414687, 6007120	idle	87.9 dBA

<u>Scenario 5 – Cable Shore Pull at Ridley Island Cable Landfall Area:</u>

Scenario 5 accounts for the cable shore pull activities at the Ridley Island Landfall site. As in Scenario 3, this scenario definition assumes the use of a tracked excavator (173 kW), a second tracked excavator idling, and a ship that is less than 1 ton. The source levels for the heavy equipment used in the construction scenarios were obtained from the UK Department for Environment Food and Rural Affairs source level database (Defra, 2005), with the exception of the cable tow vessel for which a reference from the software package SourceDB (SourceDB, DGMR) was used. Table 4-8 presents the source levels and locations that were assumed for each piece of equipment included in this model scenario. The tracked excavators were both placed at the same landfall location and an aggregate source level was applied in the model.

Table 4-8 Noise source specifications for scenario 5.

Noise Source	Source Description	Location (m - UTM Zone 9)	Activity	Broadband SL (dBA @ 1 m)
Tracked Excavator	173 kW	414687, 6007120	ground excavation	96.0 dBA
Tracked Excavator	173 kW	414687, 6007120	idle	87.9 dBA
Ship	Less than 1 ton	414219, 6006551	idle	62.7 dBA

4.4.3.2 Operations

Scenario 6 captures the operating noise of the entire wind farm grid. A layout of 110 Siemens 3.6 MW turbines has been assumed for this scenario. The Proponent is considering several different turbine models for the Project; if a larger turbine type (with power greater than 3.6 MW) was used however, fewer total turbines would be required to produce the same electrical power. The 110 turbine case that has been modelled here represents the greatest expected number of operating turbines and thus is the most conservative noise scenario. The net area of the wind farm will span an area of over 156 km^2. For Scenario 6 each turbine was modelled individually using a reference source from Danish Electronics Light and Acoustics, which compiled a test report (DELTA, 2006) based on measurements of source levels from the same turbine at wind speeds of 8 to 10 m/s through the axis of the turbine. The broadband sum of the aggregate sound field was computed from the results of the 110 model runs.

Table 4-9 Noise source specifications for scenario 6.

Noise Source	Source Description	Location (m - UTM Zone 9)	Activity	Broadband SL (dBA re 20µPa - m)
Wind Turbine	Siemens 3.6 MW, assuming 8 – 10 m/s wind speed	An array of 110 turbines, see layout in Volume 2 of this assessment report.	Rotating blades under normal operating conditions	94.0 dBA

5 AIRBORNE NOISE - RESULTS

5.1 SOUND LEVEL CONTOUR MAPS

The resultant acoustic noise footprints for all scenarios are presented in this section. These predictions have been designed to give the worst case results by setting the wind direction to be inland for all scenarios. Therefore, these results will show greater noise levels on land then would typically be measured during normal operating conditions.

5.1.1 Construction

The results for model Scenarios 1 through 5, which provide estimates of the airborne noise associated with the Project construction activities, are presented in Figure 5-1 through Figure 5-6 below. The maps represent the received sound pressure level in dBA.

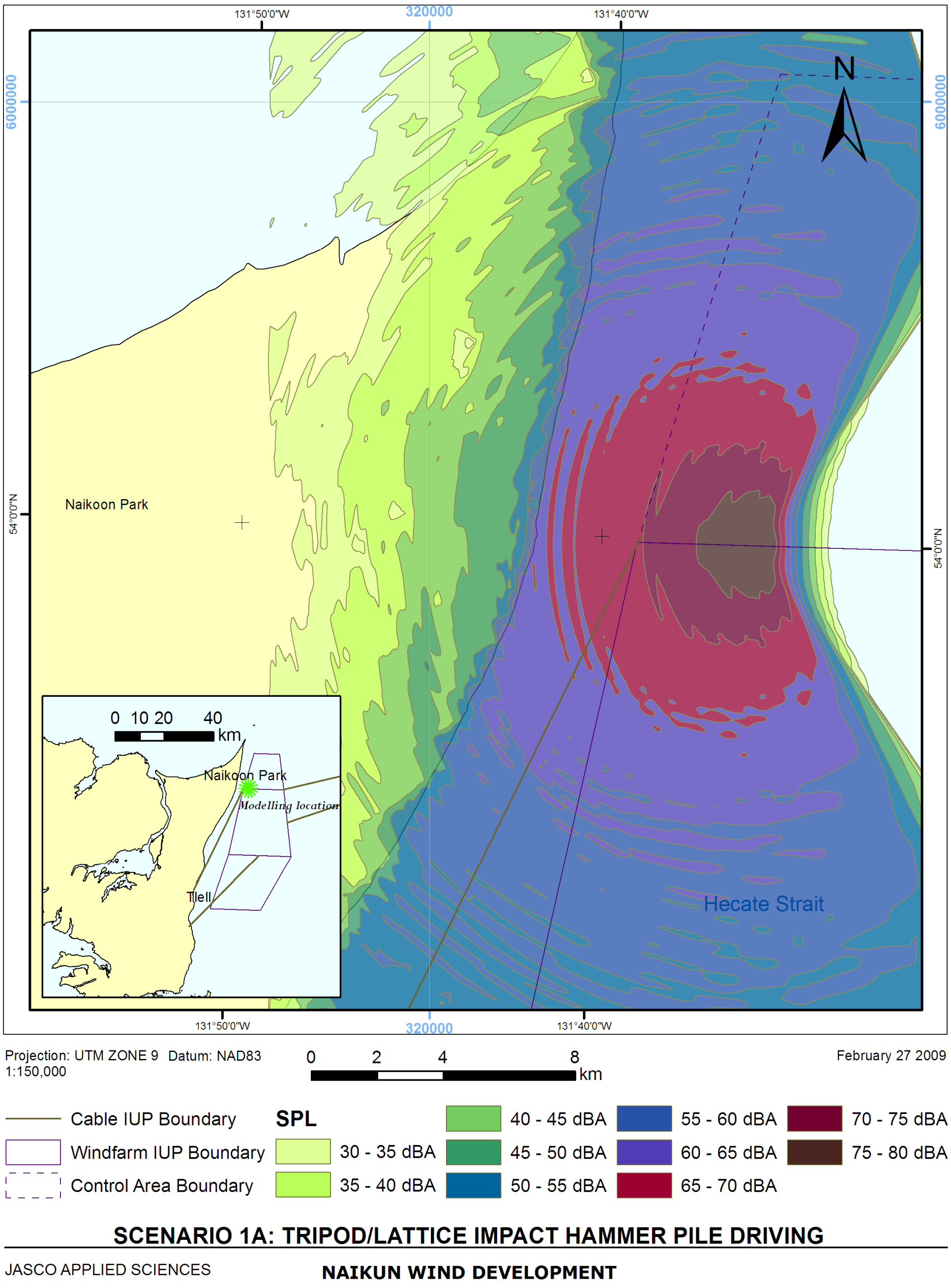


Figure 5-1 Map showing modelled noise contours for impact hammer pile driving of a 2-3 m diameter steel pile for a tripod or lattice foundation type (550 kJ hammer energy).

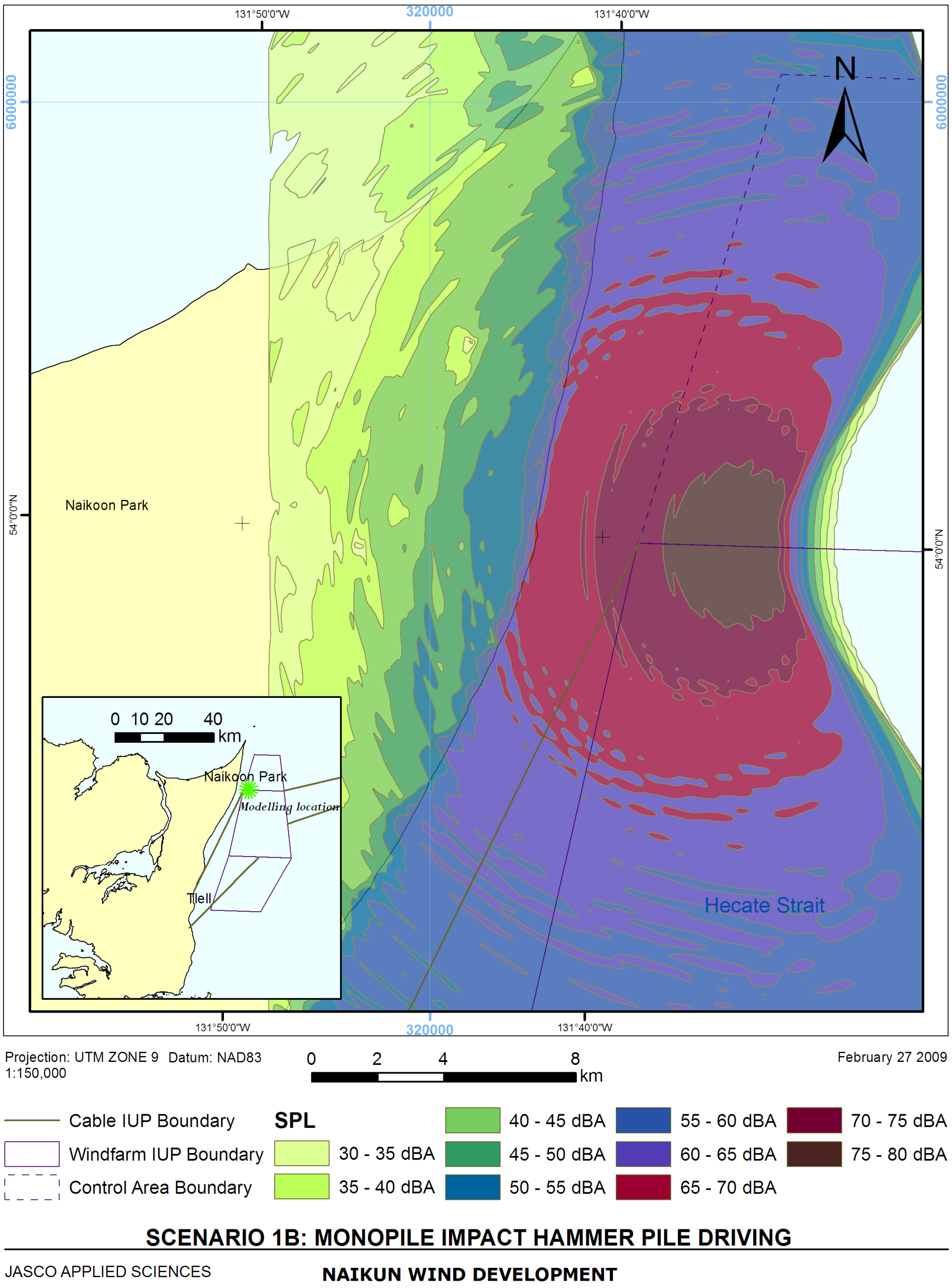


Figure 5-2 Map showing modelled noise contours for impact hammer pile driving of a 4.5-5 m diameter steel pile for a monopile foundation type (1200 kJ hammer energy).

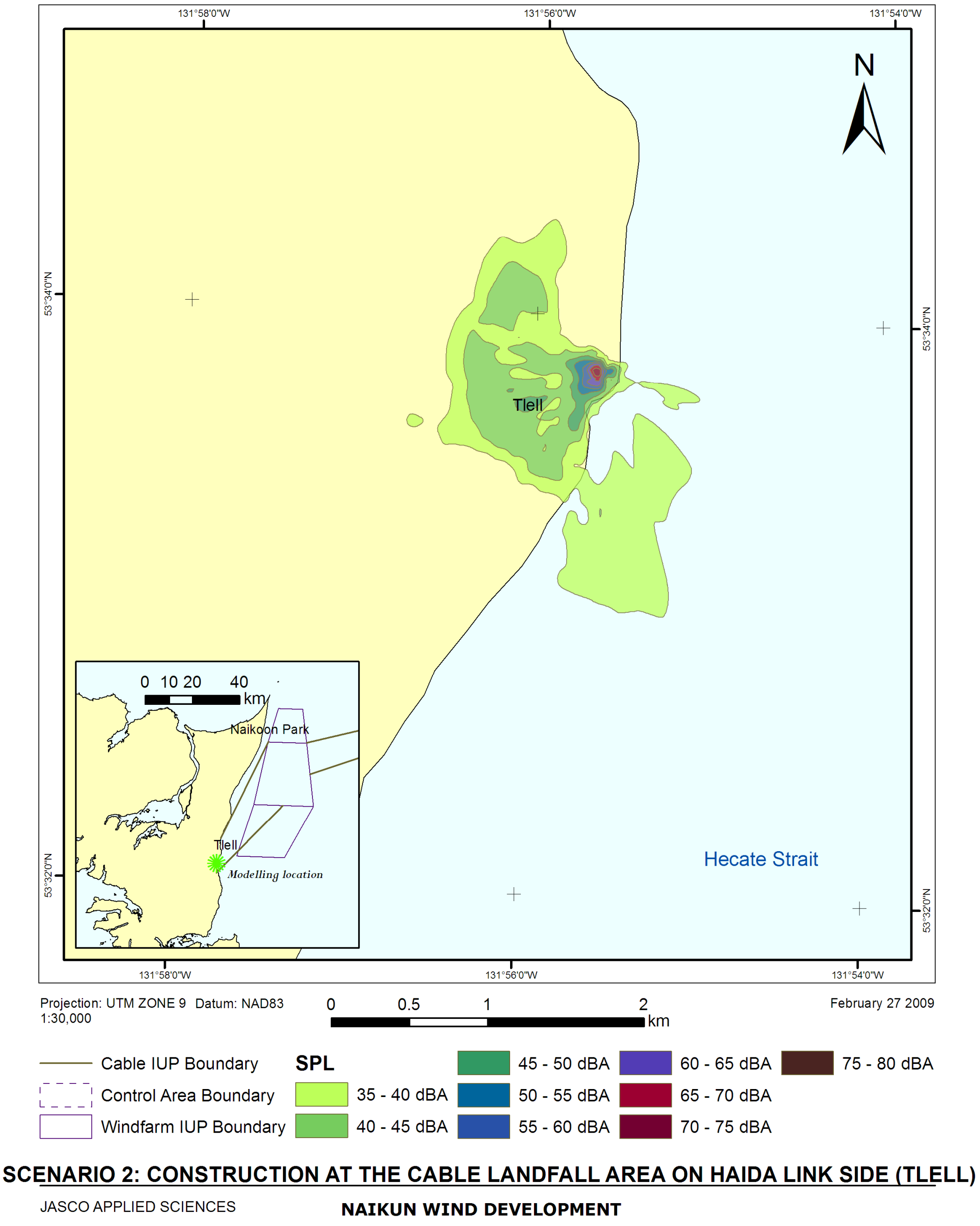


Figure 5-3 **Map showing modelled noise contours for site preparation at the Haida Link cable landfall area at Tlell.**

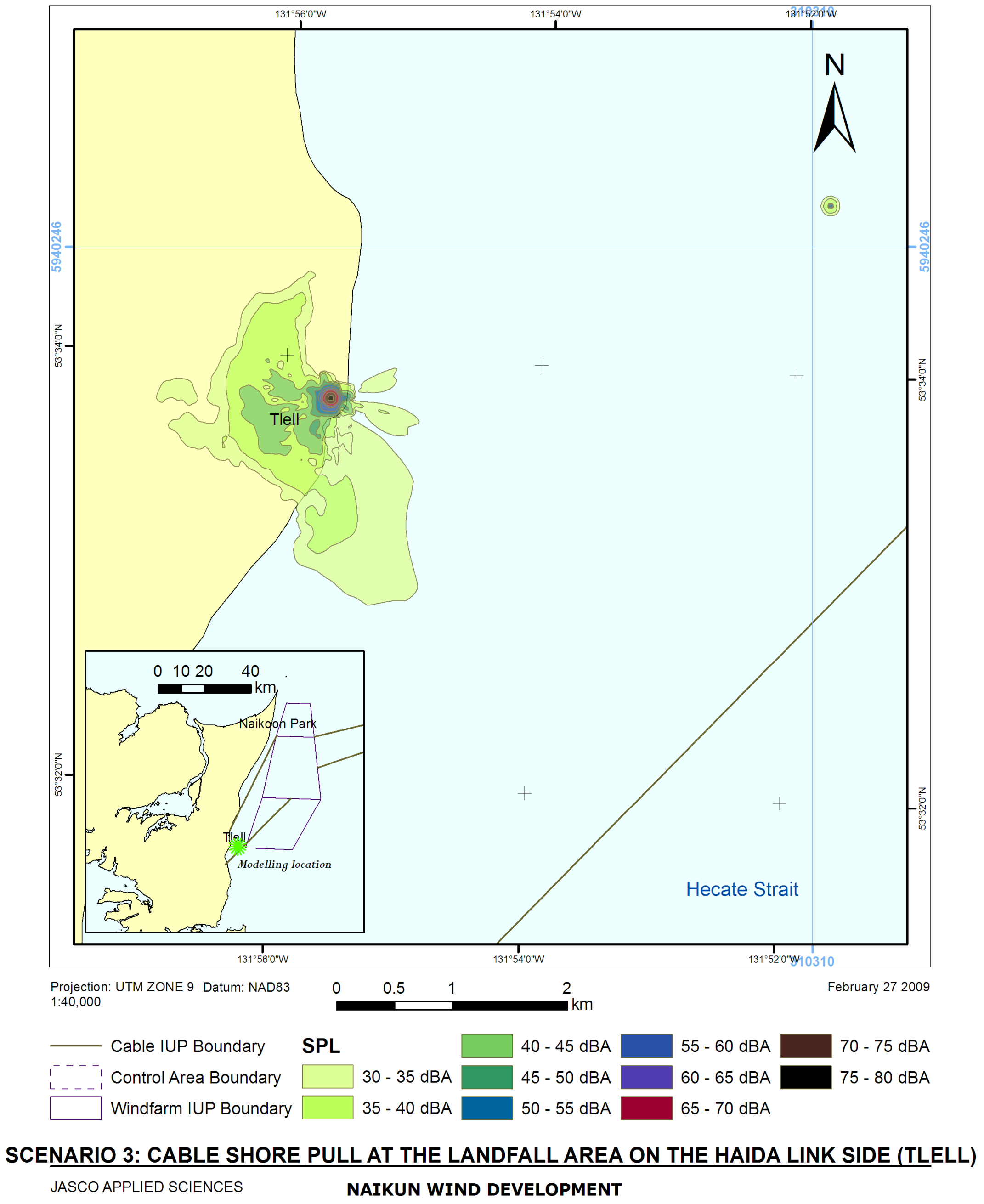


Figure 5-4 **Map showing modelled noise contours for the Haida Link cable shore pull at the landfall area at Tlell.**

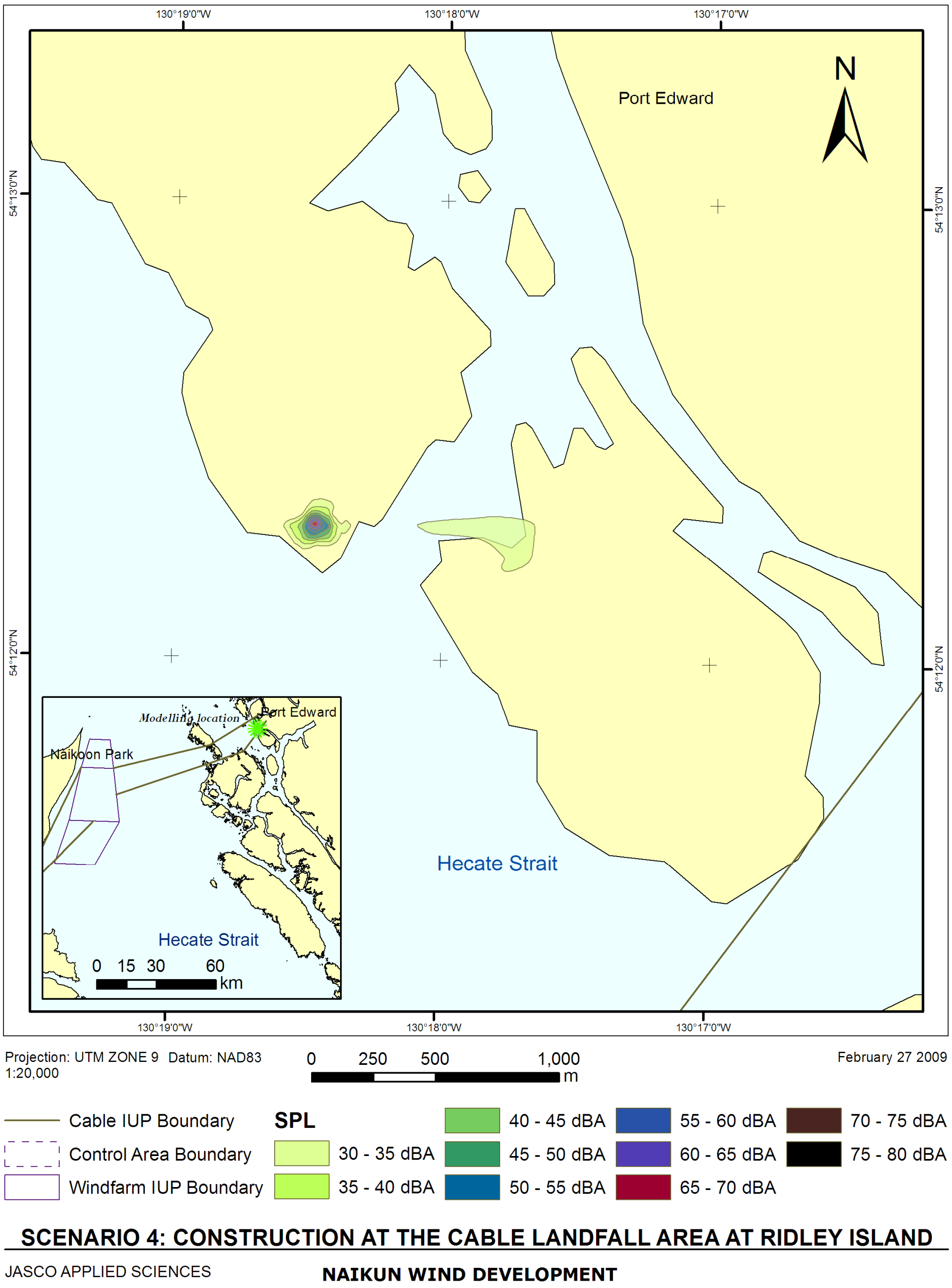


Figure 5-5 Map showing modelled noise contours for site preparation at the cable landfall area at Ridley Island.

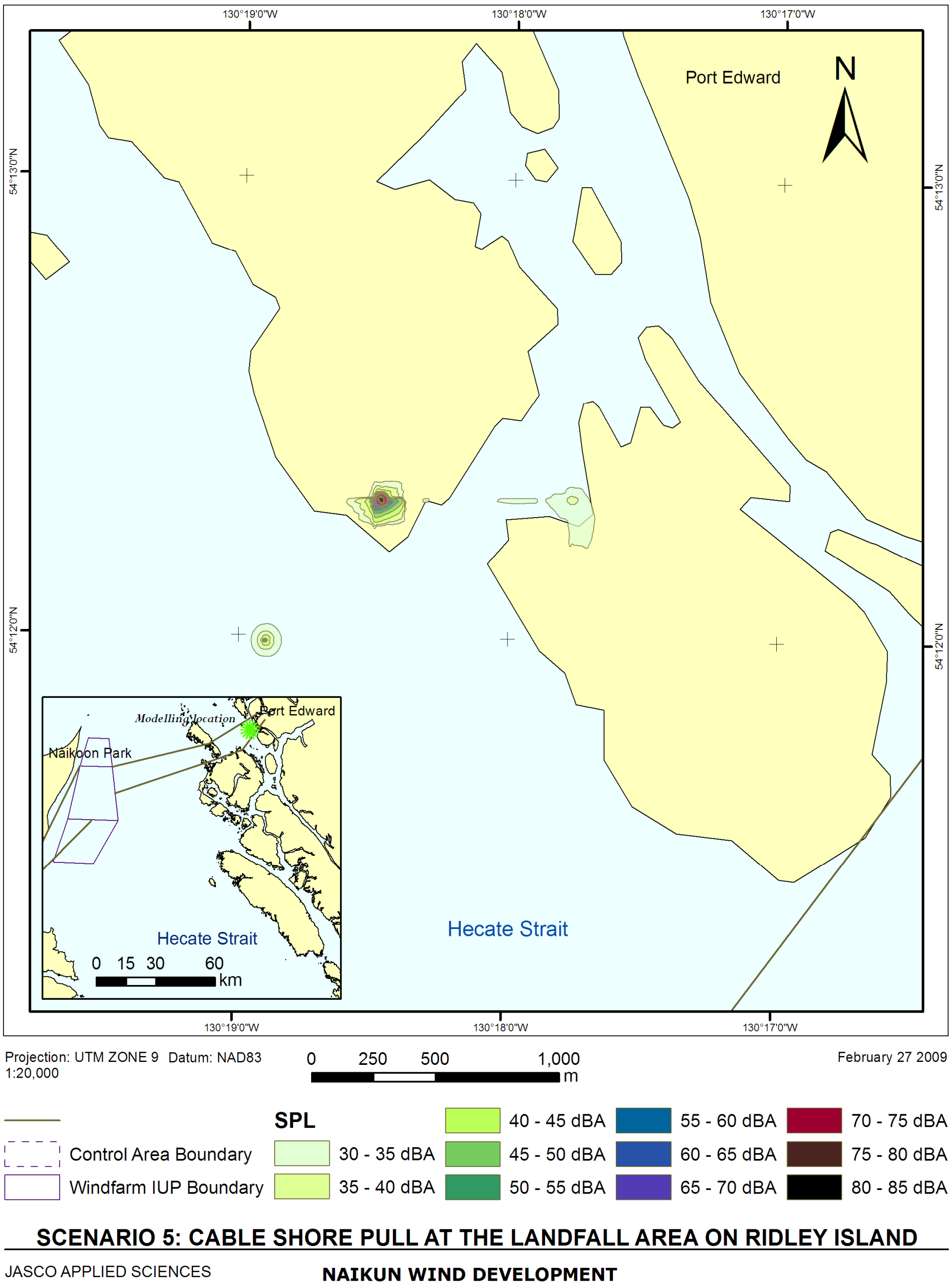


Figure 5-6 **Map showing modelled noise contours for the Haida Link cable shore pull at the landfall area at Ridley Island.**

5.1.2 Operations

The result for model Scenario 6, which estimates the airborne noise associated with the regular operations of the Project, are presented in Figure 5-7 below. Note that the 30-35 dB contour shows a sharp truncated boundary to the west where the contour reached the boundary of the computational model grid for this scenario. The edge of this contour would extend further to the west, but since it represents a level that is below the threshold of concern it is unnecessary to expand the modelled region.

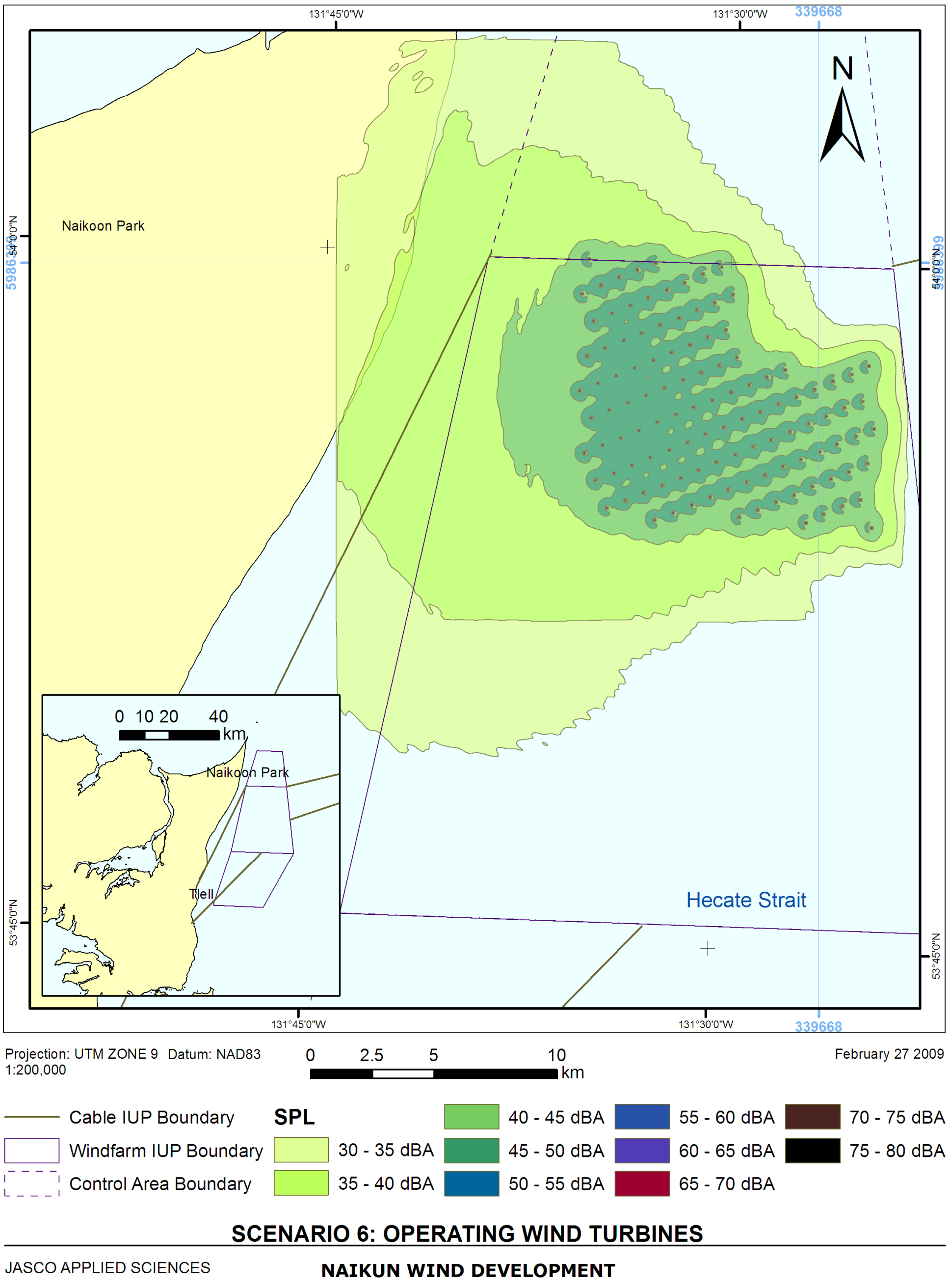


Figure 5-7 **Map showing modelled noise contours for the wind turbines under normal operating conditions.**

5.2 DECOMMISSIONING

Decommissioning of the NaiKun Offshore Wind Energy Project (the Project) will be carried out in compliance with federal and provincial legislation in place when the wind farm reaches the end of its life cycle. At time of writing, legislation indicating acceptable in-air noise levels produced by wind farm decommissioning activities is unavailable. It can be expected, however, that the type and usage of equipment for the construction and decommissioning stages will be largely the same (Nedwell and Howell 2004, MMS 2008, Pearson, Sea Breeze Energy Inc. 2004) and therefore the noise footprints will also be similar (Holberg Wind Energy GP Inc. 2004). Estimated noise levels associated with wind farm construction were presented in Section 5.1.1 and can be taken as a conservative forecast of decommissioning noise. However, the atmospheric noise caused by decommissioning will likely be lower since pile driving, the loudest source of in-air noise during construction, will not occur.

5.3 NOISE MITIGATION OPTIONS

General mitigation options to minimize noise effects are described below.

5.3.1 Pile Driving

Pile driving construction for the WTG foundations is generally expected to occur between April and September and to take approximately 2 hours per pile. Naikoon Park users may be temporarily exposed to elevated noise levels related to pile driving during this time. In-air noise from pile driving can be mitigated using a number of methods, some of which may however be unsuitable to the Project due to the offshore location. The following options for mitigating pile driving noise have been identified:

1. Schedule activities to minimize the presence of sensitive receptors during construction
2. Use the quietest available technology for the location, *e.g.* hydraulic or vibration pile drivers
3. Use noise reduction devices
4. Perform acoustic monitoring

Noise reduction can be accomplished by using a variety of devices in conjunction with a suitable pile driving technology. Some examples include noise curtains around the area of impact, shock absorbing pads, enclosures to reduce the discharge sound of the hammer’s air exhaust, and damping compound applied to hollow steel piles to reduce ringing noise. The pile driver operator or a noise control engineering company should be contacted to identify appropriate options should the noise from pile driving need to be reduced.

Acoustic monitoring should be performed at the closest receiver location at Naikoon Park to measure received levels of pile driving to validate the pile driving model noise estimate.

5.3.2 Land Based Construction

No specific mitigation is recommended for the land-based construction activities beyond the following general measures:

1. Avoid creating unnecessary or intrusive noise at the construction site
2. Perform constructions activities during daytime hours
3. Avoid or reduce construction noise at the source through use of appropriate operation and maintenance or modification / enhancement of construction equipment and processes – for example noise-producing project equipment and vehicles using internal combustion engines should be fitted with mufflers or other noise reducing features

5.3.3 Operating Wind Turbines

The quietest and most recently available turbine technology should be used to limit as much as possible the noise footprint associated with turbine operations.

5.4 DISCUSSION

The estimated received sound levels at the identified sensitive receptor locations for each model scenario are presented in Table 5-10 and Table 5-11 based on the sound level contour maps that were presented in the previous section.

Table 5-10 Estimated received sound levels for construction model scenarios 1 through 5.

Model Scenario	Description	Sensitive Receptor Location Considered	Predicted Sound Level
1A	Tripod/Lattice Impact Hammer Pile Driving	Naikoon Park, East Beach	< 60 dBA
1B	Monopile Impact Hammer Pile Driving	Naikoon Park, East Beach	< 65 dBA
2	Construction at cable landfall, Tlell	Tlell residential area	≤ 45 dBA
3	Cable shore pull, Tlell	Tlell residential area	≤ 45 dBA
4	Construction at cable landfall, Ridley Island	Port Edward residential area	< 30 dBA
5	Cable shore pull, Ridley Island	Port Edward residential area	< 30 dBA

Table 5-11 Estimated received sound levels for operations model scenario 6.

Model Scenario	Description	Sensitive Receptor Location	Predicted Sound Level
6	Operating turbines	Naikoon Park, East Beach	< 35 dBA

The highest predicted sound levels for the construction model scenarios occur in Scenarios 1A and 1B for the impact pile driving at the turbine site located nearest to East Beach in Naikoon Park. These levels are likely to be greater than the ambient noise levels at Naikoon Park (for which measurements are not presently available) and could be detectable by park users. It is noted, however, that this is a temporary noise source. It is expected that the pile driving will take less than one day per turbine site, and that the noise levels will be lower for turbine sites that are located further offshore.

The predicted sound levels for the remaining construction scenarios (2 through 5) at the cable landfall areas are all below the WHO guidelines for outdoor living spaces and for areas that are just outside living spaces.

The predicted sound levels for operations Scenario 6 indicate that the received levels at Naikoon Park will be below the 40 dBA guideline presented in the BC Land Use Operational Policy (LUOP) for residential land use areas. With the exception of a very small sliver of land along the coastline at the center of East Beach in Naikoon Park, the predicted sound levels with the park will be between 30 and 35 dBA while the turbines are operating under shoreward propagating wind conditions. The BC LUOP does not provide guidance for recreational land use areas, but the WHO recommends that indoor sound levels should be kept below 30 dBA for indoor sleeping conditions. It is assumed that levels slightly higher than this would be considered acceptable for sleeping conditions in a campground. Given that natural ambient noise conditions in the park are likely to be greater than 35 dBA, particularly while the wind is blowing (the only condition under which the turbines would be operating) due to rustling vegetation and noise from waves breaking at the shore, it can be argued that the modelled noise levels from the turbine operations would be acceptable to park users camping in the park lands.

It is noted that the wind conditions applied in the modelling were selected to present the worst- case sound propagation conditions to meet the guidelines of the BC LUOP. Thus shoreward propagating wind conditions were selected, with easterly winds being used for Scenarios 1 and 6. However, the statistical wind rose for the area presented in the Project Description section of this Application indicates that the dominant wind direction in the wind farm grid area does not favour shoreward propagation, that is, easterly winds favouring sound propagation toward Naikoon Park. In fact, the wind typically blows in this direction only approximately 4 % of the time. The majority of the time the sound levels reaching Naikoon Park from activities at the wind farm will be below those presented in this report.

5.5 CONCLUSIONS

This portion of the report has presented the results of an acoustic modeling study performed to estimate airborne noise levels at identified sensitive receptor locations from construction and operational activities associated with the Project. The study was carried out to assist in the assessment of impacts on humans occupying nearby residential and recreational land use areas. Advanced numerical sound propagation modelling techniques were employed to estimate airborne noise levels from project activities based on the best available source level and environmental data. Modelled activities included pile driving, construction at the cable landfall areas and the normal operation of the full set of WTGs. Six construction scenarios (also representative of decommissioning) and one operational scenario were modelled, and the results presented in tabular and contour map form.

The highest estimated airborne noise levels from this project were associated with impact hammer pile driving of the turbine substructure support piles, during the construction period. The estimated levels for each modelled activity fell within the range of acceptability as described in guidelines set-out by the World Health Organization and the British Columbia provincial policy for Wind Power Projects on Crown Land.

Although the noise modelling methods employed in this study are known to be accurate for predicting noise levels in the vicinity of industrial operations, inevitable uncertainty remains in the acoustic source levels and environmental parameters used as model inputs.

References

Baird, T. 2008. Project Description. Technical report prepared for NaiKun Wind Development by ODE Ltd. Document Number: 9131-PM.

Collins, M. D. 1993. A split-step Padé solution for the parabolic equation method. *Journal of the Acoustical Society of America*. 93: 1736-1742.

Defra – Department for Environment Food and Rural Affairs. 2005. Update of Noise Database for Prediction of Noise on Construction and Open Sites.

Delany, M. E. & Bazley, E. N. (1970). Acoustical properties of fibrous materials. *Applied Acoustics* **3**, 105.

DELTA (Danish Electronics Light and Acoustics) Test Repot. 2006. “Measurement of Noise Emission from a Siemens SWT-3.6-107 Wind Turbine Situated at Hovsore, Denmark”, performed for Siemens Wind Power A/S

Holberg Wind Energy GP Inc. 2004. Application for an Environmental Assessment Certificate for the Holberg Wind Energy Project – Northern Vancouver Island.

Minerals Management Service (MMS). 2008. Cape Wind Energy Project-Draft Environmental Impact Statement January 2008. Document Number: 2007-024

Municipal Council of the District of Port Edward. District of Port Edward Noise Control bylaw No. 245, 1987.

Nedwell, J. and D. Howell. 2004. A review of offshore wind farm related underwater noise sources. Technical report prepared by Subacoustech Ltd for COWRIE. Report Number 544 R 0308.

Pearson, D. Decommissioning Wind Turbines in the UK Offshore Zone. http://www.owen.eru.rl.ac.uk/Default.htm. Accessed August 2008.

Province of British Columbia. 1990. Park, Conservancy and Recreation Area Regulation (B.C. Reg. 180/90), Park Act.

Province of British Columbia Ministry of Agriculture and Lands. 2005. Wind Power Projects on Crown Land.

Salomons, E. M., 2001. Computational Atmospheric Acoustics, Kluwer Academic Publishers, Dordrecht, The Netherlands.

Sea Breeze Energy Inc. 2004. Environmental Assessment Application under the British Columbia Environmental Assessment Act: Proposed Knob Hill Wind Farm Vancouver Island, B.C.

Sondergaard, B., B. Plovsing. 2005. Noise From Offshore Wind Turbines. *Danish Environmental Protection Agency*. Project # 1016.

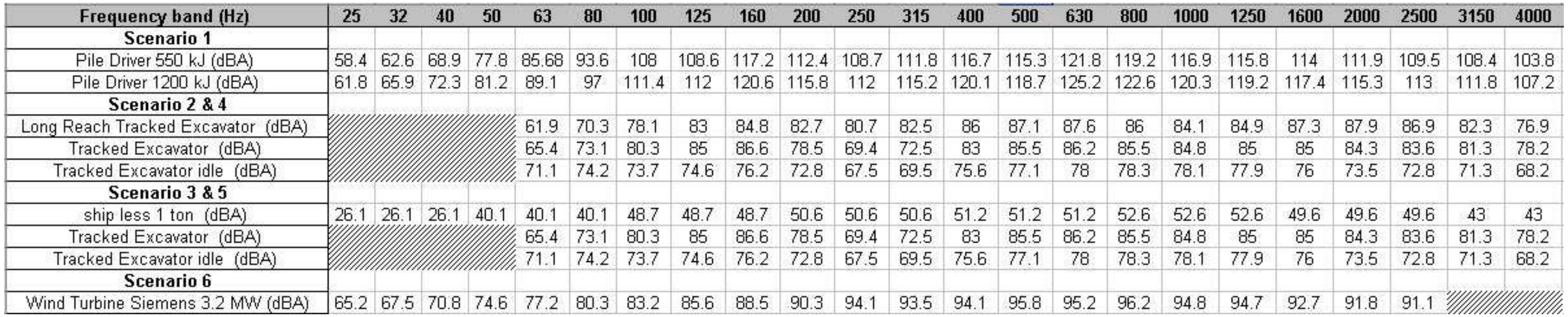
SourceDB, ver. 1.1. DGMR Consulting Engineers, The Hague, The Netherlands.

Thorson, P. and Reyff, J. A. 2004. San Francisco – Oakland Bay Bridge East Span Seismic Safety Project. Marine Mammal and Acoustic Monitoring for the Eastbound Structure. Prepared for Caltrans.

U of Wyoming, College of Engineering, 2006. Dept. of Atmospheric Science – weather, http://weather.uwyo.edu/upperair/sounding.html.

World Health Organization (WHO). 1999. Guidelines for Community Noise. Edited by: B. Berglund, T. Lindvall, and D.H. Schwela.

APPENDIX 4-1 A-WEIGHTED, 1/3-OCTAVE SOURCE LEVELS



Frequency band (Hz)	25	32	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000
Scenario 1																							
Pile Driver 550 kJ (dBA)	58.4	62.6	68.9	77.8	85.68	93.6	108	108.6	117.2	112.4	108.7	111.8	116.7	115.3	121.8	119.2	116.9	115.8	114	111.9	109.5	108.4	103.8
Pile Driver 1200 kJ (dBA)	61.8	65.9	72.3	81.2	89.1	97	111.4	112	120.6	115.8	112	115.2	120.1	118.7	125.2	122.6	120.3	119.2	117.4	115.3	113	111.8	107.2
Scenario 2 & 4																							
Long Reach Tracked Excavator (dBA)	▨	▨	▨	▨	61.9	70.3	78.1	83	84.8	82.7	80.7	82.5	86	87.1	87.6	86	84.1	84.9	87.3	87.9	86.9	82.3	76.9
Tracked Excavator (dBA)	▨	▨	▨	▨	65.4	73.1	80.3	85	86.6	78.5	69.4	72.5	83	85.5	86.2	85.5	84.8	85	85	84.3	83.6	81.3	78.2
Tracked Excavator idle (dBA)	▨	▨	▨	▨	71.1	74.2	73.7	74.6	76.2	72.8	67.5	69.5	75.6	77.1	78	78.3	78.1	77.9	76	73.5	72.8	71.3	68.2
Scenario 3 & 5																							
ship less 1 ton (dBA)	26.1	26.1	26.1	40.1	40.1	40.1	48.7	48.7	48.7	50.6	50.6	50.6	51.2	51.2	51.2	52.6	52.6	52.6	49.6	49.6	49.6	43	43
Tracked Excavator (dBA)	▨	▨	▨	▨	65.4	73.1	80.3	85	86.6	78.5	69.4	72.5	83	85.5	86.2	85.5	84.8	85	85	84.3	83.6	81.3	78.2
Tracked Excavator idle (dBA)	▨	▨	▨	▨	71.1	74.2	73.7	74.6	76.2	72.8	67.5	69.5	75.6	77.1	78	78.3	78.1	77.9	76	73.5	72.8	71.3	68.2
Scenario 6																							
Wind Turbine Siemens 3.2 MW (dBA)	65.2	67.5	70.8	74.6	77.2	80.3	83.2	85.6	88.5	90.3	94.1	93.5	94.1	95.8	95.2	96.2	94.8	94.7	92.7	91.8	91.1	▨	▨