Technical Data Report

Marine Acoustics (2006)

ENBRIDGE NORTHERN GATEWAY PROJECT

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Acronyms and Abbreviations

µPa .......................................................................................................................... micropascal
ABR .......................................................................................................................... auditory brainstem response
BP ............................................................................................................................. before present
CTD .......................................................................................................................... conductivity-temperature-depth
dB ............................................................................................................................. decibel
DFO ......................................................................................................................... Fisheries and Oceans Canada
digit/V ..................................................................................................................... digit per volt
GB ............................................................................................................................. gigabyte
GPS ............................................................................................................................ global positioning system
GSC .......................................................................................................................... Geological Survey of Canada
HP ............................................................................................................................ horsepower
Hz ............................................................................................................................ hertz
IUCN ....................................................................................................................... International Union for Conservation of Nature
kHz ........................................................................................................................... kilohertz
MONM ..................................................................................................................... marine operations noise model
TL .............................................................................................................................. transmission loss
OBH ......................................................................................................................... ocean-bottom hydrophone
Pa ............................................................................................................................ pascal
V/µPa ......................................................................................................................... volts per micropascal
VLCC ....................................................................................................................... very large crude carrier
## Glossary

<table>
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<th>Term</th>
<th>Definition</th>
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<td><strong>Acoustic pressure</strong></td>
<td>The deviation from the ambient hydrostatic pressure caused by a sound wave. Measured in Pa, µPa or bars (1 Pa = 10⁶µPa = 10⁻⁵ bar).</td>
</tr>
<tr>
<td><strong>Audiogram</strong></td>
<td>A curve of hearing threshold (sound pressure level, measured in decibels) as a function of frequency that describes the hearing sensitivity of an animal over its normal hearing range.</td>
</tr>
<tr>
<td><strong>Audiogram weighting</strong></td>
<td>The process of combining an animal’s audiogram and sound pressure levels to determine the sound pressure levels above the animal’s hearing threshold.</td>
</tr>
<tr>
<td><strong>Bathymetry</strong></td>
<td>Measurements of underwater depths</td>
</tr>
<tr>
<td><strong>Broadband level</strong></td>
<td>The total sound pressure level over a specified frequency range. It is calculated by summing the acoustic pressures in small frequency bands and converting to sound pressure level.</td>
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<tr>
<td><strong>Ensonified</strong></td>
<td>Filled with sound</td>
</tr>
<tr>
<td><strong>Geo-acoustic</strong></td>
<td>Relating to the acoustic properties of the seabed.</td>
</tr>
<tr>
<td><strong>Hydrostatic pressure</strong></td>
<td>The pressure, at any given depth in a static liquid, from the weight of the liquid plus any additional force acting on the surface. Measured in Pa, µPa or bars (1 Pa = 10⁶µPa = 10⁻⁵ bar).</td>
</tr>
<tr>
<td><strong>Propagation loss</strong></td>
<td>The reduction in sound level with distance from an acoustic source, subject to the influence of the surrounding environment. Measured in dB.</td>
</tr>
<tr>
<td><strong>Seabed piston-core data</strong></td>
<td>Data from seabed sediment samples collected by a piston corer. A piston corer is a hollow cylinder with a weight above that is lowered to the seabed. The hollow cylinder plunges into the seabed and fills with undisturbed sediment. The core is then brought to the surface and the sediment extracted. A piston inside the cylinder allows the collection of long samples.</td>
</tr>
<tr>
<td><strong>Sound pressure level (SPL)</strong></td>
<td>The logarithmic ratio of acoustic pressure to a reference pressure, typically 1 µPa (expressed as dB re 1 µPa), multiplied by 20: $SPL = 20\log_{10}\left(\frac{P}{P_{ref}}\right)$</td>
</tr>
<tr>
<td><strong>Source level</strong></td>
<td>The sound level referenced to 1 m from a point source. For sources that are physically larger than a few cm (ship propellers, for example), the spectrum is measured at some range, and a sound propagation model applied to correct it to 1 m from a point source. Vessel source levels are expressed in dB re 1µPa at 1 m.</td>
</tr>
<tr>
<td><strong>1/3-Octave band levels</strong></td>
<td>Frequency-resolved pressure or energy levels in frequency bands that are 1/3 of an octave wide (where an octave is a doubling of frequency).</td>
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1 Introduction

This report gives the results of underwater acoustics field and modelling studies carried out for the Enbridge Northern Gateway Project (the Project) by JASCO Research Ltd. (JASCO) as part of the Gateway Environmental Management (GEM) team. Field studies were done from September 28 to October 2, 2005 at several sites along existing tanker shipping routes to the Kitimat Terminal in British Columbia. The four primary goals of the field and modelling studies were:

- to measure ambient noise levels in the channels and sounds
- to measure acoustic transmission loss, i.e., the rate at which noise levels decrease with distance from sources such as vessels, in the respective underwater environments
- to identify marine mammal vocalizations, and other sounds of biological origin, that would help identify wildlife species
- to predict the extent of underwater ensonification produced by tankers for the shipping of oil and condensate

The ambient noise measurements, in Section 3, show existing noise conditions at several locations along the tanker routes and near the Kitimat Terminal. Transmission loss (TL) measurements, in Section 5, were acquired and used for ground-truthing the acoustic noise models. The spectral characteristics of recorded marine biological sounds, including marine mammal vocalizations, were examined to determine if they overlap with the sound frequencies produced by tanker and tug traffic. Those results are shown in Section 4. There is higher likelihood for effects when the sound frequencies produced by vessels coincide with the frequencies of the wildlife. Section 6 of this report contains a brief literature review of Geological Survey of Canada study papers describing the Douglas Channel geomorphology. The sediment descriptions from those studies were used to characterize the geoaoustic properties of sediments in the channels of the Kitimat fjord system. Finally, acoustic modelling was done to generate broadband noise level maps showing the underwater sound level distributions for a set of scenarios representing operations associated with the marine terminal and with project-related tanker and tug traffic between the Kitimat Terminal and open water.
2 Field Study

Ambient measurements and acoustic transmission loss (TL) measurements were made at four sites (see Figure 2-1). An autonomous ocean-bottom hydrophone (OBH) system was deployed to record sound levels for 13 hours at each of the measurement locations. The OBH system is described in Section 3. Deployment locations and water depths for the respective measurement sites are given in Table 2-1. These sites were chosen to be representative of the different acoustic environments encountered along the proposed shipping routes:

- **G1 – Principe Channel**: This is a steep-sided fjord environment with 3-km wide channel and water depths between 100 m and 200 m. The recorder deployment site was near Mink Trap Bay, close to midway between the ends of Principe Channel. The sound transmission loss characteristics in Principe Channel are expected to be similar to those in the outer reaches of Douglas Channel because bathymetry and channel width are similar at the two locations.

- **G2 – Caamaño Sound**: Caamaño Sound is the passageway from the protected waters of the channels between Kitimat and the open waters of Hecate Strait. The recorder site was on the north side of the Sound, about 10 km south of Dewdney Island where water depths were close to 214 m. This environment had the highest ambient noise levels because of its direct exposure to surface wind and wave noise originating from Hecate Strait.

- **G3 – Wright Sound**: Five large channels and passages lead into Wright Sound, which is about 5-km wide. The sound itself is deep and has uniform water depths between 450 m and 550 m. Many vessels pass through this sound because it is part of the Inside Passage. Consequently, ambient noise levels at this location varied with the numbers of vessel traffic in the sound. The recorder site was off Turtle Point at the northern tip of Gil Island at 90 m depth.

- **G4 – Emsley Creek Estuary**: The Emsley Creek Estuary is about 11 km from Kitimat Village on the west side of Douglas Channel in Kitimat Arm. The recording site was about 100 m offshore from the estuary in just 5 m of water. Ambient noise levels in the estuary were much lower than at the other three sites.

Transmission loss experiments were done at the four OBH deployment sites. The results are shown in Section 5. The TL experiments were typically done within the first five hours after OBH deployment at each site. The measurements were made using a calibrated acoustic projector operated from between 200 m and 10 km from the OBH. The OBH recorder stored up to 13 hours of data, so the remaining recording time was used to capture ambient and biological noise. The ambient noise recordings are shown in Section 3. Those recordings captured a selection of marine mammal vocalizations and other biological sounds.
Table 2-1 Sites Monitored with Ocean-Bottom Hydrophone Recording System

<table>
<thead>
<tr>
<th>Station</th>
<th>Site Name</th>
<th>Date</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Water Depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1</td>
<td>Principe Channel</td>
<td>Sept. 28, 2005</td>
<td>53º 26.375'</td>
<td>129º 56.328'</td>
<td>142</td>
</tr>
<tr>
<td>G2</td>
<td>Caamaño Sound</td>
<td>Sept. 29, 2005</td>
<td>52º 54.617'</td>
<td>129º 39.317'</td>
<td>214</td>
</tr>
<tr>
<td>G3</td>
<td>Wright Sound</td>
<td>Sept. 30, 2005</td>
<td>53º 19.592'</td>
<td>129º 17.401'</td>
<td>90</td>
</tr>
</tbody>
</table>

Figure 2-1 Sites Monitored with Ocean-Bottom Hydrophone Recording System
Ambient noise measurements at the four monitoring sites were made using JASCO’s OBH system. This system uses a preamplified RESON TC-4032 hydrophone having nominal sensitivity $-170 \pm 2$ dB re V/µPa in the 10 Hz to 20 kHz band. The hydrophone output is fed directly to a Marantz PMD660 digital recorder housed inside a pressure case. The recorder’s line input has nominal sensitivity $-98$ dB re digit/V and stores the 16-bit digital data directly onto an internal 4 gigabyte (GB) flash disk. The recorder’s frequency dependence in the 5 Hz to 20 kHz was calibrated in the laboratory before the field study. The overall system has usable dynamic range of about 85 dB spanning absolute acoustic levels approximately 77 dB re 1 µPa to 162 dB re 1 µPa in the frequency range 5 Hz to 20 kHz. The sound levels observed in this field study spanned most of the available dynamic range; ambient levels in the channels were as low as 82 dB re 1 µPa and some marine mammal vocalizations were as high as 155 dB re 1 µPa.

### 3.1 Principe Channel

The OBH was deployed at 11:00. The first nine hours of recording time at this site contain the TL study data. Ambient noise measurements at site G1 in Principe Channel (see Figure 2-1) were made for 3.5 hours from 20:30 on September 28 to 00:10 on September 29, 2005. The TL data acquired were not suitable for establishing the ambient noise conditions, primarily because of the noise produced by the support vessel. Useful ambient noise information was extracted from time periods during which the noise from the TL study was minimal. Figure 3-1 shows the spectral content of acoustic energy through the full 13-hour period of the Principe Channel acoustic recording. The lower spectrogram in this figure shows the detailed spectral features versus time and the upper figure shows the absolute root-mean-squared (RMS) sound pressure level in 1-minute intervals in the frequency bands: 10 Hz to 100 Hz, 100 Hz to 1 kHz, 1 kHz to 20 kHz, and the broadband level in the 10 Hz to 20 kHz band.

The low frequency noise below 30 Hz noted between 17:30 and 22:45 is a result of water flowing across the hydrophone during tide change, and is not of acoustic origin. This flow noise is also responsible for the 90 Hz narrow band noise seen at the same time. Flow noise dominates the real ambient acoustic levels below 100 Hz. A less apparent feature in the spectrogram is the approach of an unknown vessel starting at about 22:30. The narrow band lines in this time period are the tonal components and harmonics of propellers and engines of this vessel. The vessel noise increases in all bands through to the end of the recording.

The flow noise does not extend notably above 100 Hz so higher frequency ambient information is available. The noise in the 100 Hz to 1 kHz band reaches a low of 82 dB re 1 µPa during the ambient period at 20:15. Furthermore this band reaches its lowest level overall of 78 dB re 1 µPa in the noise lull at 14:45 during the transmission loss study. The broadband level at that time also reaches its overall lowest value of 84 dB re 1 µPa. This value is likely an upper limit for the true ambient conditions because it may also include some noise from the support vessel, which was at idle.
NOTE: Spectrogram and 1-minute RMS levels for 13 hours of acoustic recording at site G1 in Principe Channel, starting on September 28, 2005.

Figure 3-1 Spectrogram and Sound Pressure Levels of Acoustic Recording in Principe Channel, September 28

3.2 Caamaño Sound

The OBH was deployed at 15:00 on September 29, 2005 in Caamaño Sound about 10 km south of Dewdney Island where water depth was 214 m (Site G2, Figure 2-1). The TL study was completed in less than four hours, so more than 9 hours of the recording at this site were available for ambient measurements. Figure 3-2 shows the spectrogram and band levels versus time for the entire recording. The most prominent features observed during the ambient period of this recording are the killer whale (*Orcinus orca*) and mysticetes (baleen whales) vocalizations. Those vocalizations are discussed further in Section 4. Increased levels of flow noise up to a few hundred Hz are apparent between 17:00 and 21:00 on September 29 and between 00:40 and 01:00 on September 30. Flow noise increased measured levels by about 5 dB in all bands; however, this noise is not acoustic in origin. No nearby vessel noise signatures appeared during the ambient recording period.
NOTE: Spectrogram and 1-minute RMS levels for 13 hours of acoustic recording at site G2 in Caamaño Sound, starting on September 29, 2005.

**Figure 3-2 Spectrogram and Sound Pressure Levels of Acoustic Recording in Caamaño Sound, September 29**

With the exception of the periods of whale vocalization, the broadband noise level remained very close to 95 dB re 1 µPa through most of the ambient recording time period. The broadband acoustic energy was split evenly between the 100 Hz to 1 kHz and 1kHz to 20 kHz bands, both of which averaged 92 dB re 1 µPa. Less noise energy was measured below 100 Hz; the average level in the 10 Hz to 100 Hz band, excluding whale calls and flow noise, was just 82 dB.

The ambient noise field, excluding vocalizations, in Caamaño Sound differs from that measured in Principe Channel. The Principe Channel measurements showed nearly equal energy distribution between the 10 to 100 Hz, 100 to 1,000 Hz and 1 to 20 kHz bands. In Caamaño Sound the low frequency band is similar to that in Principe Channel, but the 100 to 1,000 Hz and 1 to 20 kHz bands are almost 10 dB louder. This additional energy is attributed to wind and wave noise that originated over larger unprotected areas of ocean.
3.3 Wright Sound

The OBH system was deployed in Wright Sound at 14:00 on September 30, 2005 off Turtle Point on the northern tip of Gil Island (Site G3, Figure 2-1). Figure 3-3 shows the spectrogram and 1-minute band levels for the entire 13-hour recording period from this location. The ambient noise measurement was started at 16:30, immediately after completing the TL study.

![Spectrogram and Sound Pressure Levels of Acoustic Recording in Wright Sound, September 30](image)

NOTE: Spectrogram and 1-minute RMS levels for 13 hours of acoustic recording at site G3 in Wright Sound, starting on September 30, 2005.

**Figure 3-3 Spectrogram and Sound Pressure Levels of Acoustic Recording in Wright Sound, September 30**

The acoustic recording at Wright Sound shows at least four notable vessel pass-bys including one during the TL study and at least three afterwards. There are several instances of aircraft overflight noise that are too brief to be visible in Figure 3-3. The field team saw the vessel, a sailboat under power, responsible for the noise signature at 15:45 pass within about 1 km of the recorder station. The whale calls at 19:00 and at other times in this recording are discussed in Section 4.

Vessel noise was detected in the acoustic recording for at least 9 hours out of the total 13-hour recording period. The ambient noise levels for frequencies less than 1 kHz in Wright Sound were dominated by...
vessel traffic noise. The ambient noise above 1 kHz was dominated by vessel noise only when the vessels were close. Nearly all of the marine mammal vocalizations occurred when vessel noise was lowest. The spectral content of the vocalizations was at its maximum in the 10 Hz to 1 kHz band. The minimum broadband ambient level was 83 dB re 1 µPa. This level occurred within half an hour of 19:00.

3.4 Emsley Creek Estuary

The Emsley Creek Estuary is on the west side of Douglas Channel about 11 km from Kitimat Village. The estuary is about 3 km across and is characterized by a shallow grassland shore, scattered with logs and wood debris. Figure 3-4 shows a photograph of the shoreline taken from the OBH deployment location. Water depth increases slowly with distance from shore for the first kilometre, reaching about 100 m at that distance. The depth then increases more rapidly to 200 to 250 m over the next few hundred metres.

Figure 3-4 Emsley Creek Estuary at High Tide
The ambient noise levels measured at the OBH location (Site G4, Figure 2-1) 100 m from shore in 5 m deep water were lower than in Principe Channel and Caamaño and Wright sounds. The lowest broadband levels approached 84 dB re 1 µPa (10 Hz to 20 kHz). The ambient noise levels in the 10 Hz to 100 Hz band were as low as 73 dB re 1 µPa. Levels in the 100 Hz to 1 kHz band and levels in the 1 kHz to 20 kHz band both reached as low as 77 dB re 1 µPa. Noise at these lowest levels is attributed to continuous click noise from fish or shrimp.

During the recording period five vessel pass noise events occurred. Four of these were distant low-level events that produced broadband levels less than 100 dB with spectral energy restricted to above 100 Hz. The fifth event however was a vessel pass that caused the 1-minute sound level average to exceed 120 dB. This event also had maximum spectral content at very low frequency, near 30 to 40 Hz.

NOTE: Spectrogram and 1-minute RMS levels during 13 hours acoustic recording on October 1 at site G4 at the Emsley Creek Estuary in 5-m-deep water (about 100 m from shore).

Figure 3-5 Spectrogram and Sound Pressure Levels of Acoustic Recording at Emsley Creek Estuary, October 1
4 Biological Noise

Various biological noises were observed in the recordings made at the four study sites. Many of these noises could not be recognized in terms of the specific species that produced them. Definite whale vocalizations and clicks, and possibly seal or sea lion noises were identified only in the Caamaño and Wright Sound recordings. The sounds that could not be identified as marine mammal in origin are discussed in Section 4.2. These sounds include for example, grunts, croaks, splashes and snaps.

4.1 Marine Mammals

Whale vocalizations and possibly seal and sea lion vocalizations were detected in the Caamaño and Wright Sound recordings. No certain identifications of marine mammal vocalizations were made at the Principe Channel or the Emsley Creek Estuary sites. Table 4-1 gives a description of marine mammal detections in Caamaño and Wright sounds.

Table 4-1 Marine Mammal Sounds in Caamaño and Wright Sounds, September 29 to 30

<table>
<thead>
<tr>
<th>Location and Date</th>
<th>Time</th>
<th>Description of Sounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caamaño Sound, September 29, 2005</td>
<td>18:26 – 18:27, 19:40, 23:50.</td>
<td>Sequences of multiple very low frequency calls: 15 to 40 Hz which could be fin, blue or minke whales which have similar vocalizations. The whales approached within a few hundred metres of the OBH at 21:40. Their vocalizations likely could be detected to tens of kilometres range if originating in the direction of open water (Figure 4-1).</td>
</tr>
<tr>
<td></td>
<td>18:20, 20:10, 21:05, and 03:00 Sept. 30</td>
<td>Six narrowband calls: 50 to 70 Hz. These vocalizations may be from the same animals producing the lower frequency calls at 15 to 40 Hz.</td>
</tr>
<tr>
<td></td>
<td>22:00 – 24:00</td>
<td>Killer whale calls, buzzes and echo clicks. A very intensive period of vocalizations from close range occurred between 21:11 and 21:25 (Figure 4-4).</td>
</tr>
<tr>
<td>Wright Sound, September 30, 2005</td>
<td>17:44:07</td>
<td>Tail slap on surface. Based on the time delay of the surface and bottom reflections, and depth of the hydrophone, the animal is estimated to have been within 4 km of the OBH system</td>
</tr>
<tr>
<td></td>
<td>17:45 – 17:57</td>
<td>Vocalizations below 3 kHz (Figure 4-2). Intermixed with flipper or tail slaps. The species is unknown. May be seals or whales.</td>
</tr>
<tr>
<td></td>
<td>18:19 – 21:39</td>
<td>60 Hz pulse vocalizations (Figure 4-3). At least five of these were received strongly. The species is unknown.</td>
</tr>
<tr>
<td></td>
<td>19:34</td>
<td>400 Hz – 250 Hz frequency downsweep vocalization lasting about 1 second. The species is unknown.</td>
</tr>
</tbody>
</table>

NOTE: Summary of Strong Marine Mammal Detections During Field Recordings on September 29, 2005 in Caamaño Sound and September 30, 2005 in Wright Sound.
Three types of very low frequency calls (below 100 Hz) were observed at both sites. These calls are described below and are attributed to baleen whales. One type may have been from sea lions.

The first type of low frequency vocalization is characterized by one-second acoustic pulses in the 15 to 40 Hz frequency range. These were often repeated in 10 to 20 seconds intervals. The pulses themselves were characterized by frequency downsweeps with dominant frequency near 25 Hz. The pulses sometimes occurred in pairs separated by 2 to 6 seconds and with slightly different dominant frequencies. Figure 4-1 shows an example of this type of vocalization received at Caamaño Sound at 21:35 on 29 September. It is believed that fin, minke or blue whales produced this call.

The second type of call was characterized by groan and frequency upsweep vocalizations dominant in the 50 Hz to 500 Hz range, and containing energy up to 3 kHz. These were observed to coincide with blow noise and tail slaps (Figure 4-2). Whales or sea lions could have generated these noises.

The third type of call is characterized by 50 to 70 Hz pulses. This type of call was observed only in Wright Sound and an example spectrogram is given in Figure 4-3. The species responsible for this call has not been identified but based on its low-frequency content it is likely a baleen whale.

Killer whale calls were detected in Caamaño Sound and Wright Sound (examples in Figure 4-4 and Figure 4-5). Echo clicks are the brief broadband 8 to 20 kHz pulses at left side of Figure 4-5, frequency warbles and downsweep calls between 300 Hz and 10 kHz, and narrow-band and broadband buzzes are all apparent in the 3.5 second time period shown in Figure 4-5.

NOTE: Baleen whale vocalizations at 21:35 on 29 September 2005 in Caamaño Sound.

Figure 4-1 Baleen Whale Vocalizations in Caamaño Sound, September 29
NOTE: Sounds from an unidentified marine mammal recorded in Wright Sound at 18:51 on September 30.

Figure 4-2  Unidentified Marine Mammal Sounds in Wright Sound, September 30
NOTE: A 60 Hz pulse vocalization received at 18:57 on September 30 at Wright Sound station.

**Figure 4-3** Low Frequency Vocalization at Wright Sound Station, September 30
NOTE: Simultaneous Killer Whale and Baleen (mysticete) whale vocalizations recorded in Caamaño Sound at 22:12 on September 29.

**Figure 4-4** Simultaneous Killer Whale and Baleen Whale Vocalizations in Caamaño Sound, September 29
NOTE: Example of killer whale sounds received in Wright Sound at 19:01 on September 30, 2005.

**Figure 4-5** Killer Whale Sounds in Wright Sound, September 30

### 4.2 Fish and Other Animals

Various noises are audible in the ambient noise recordings at all four OBH deployment locations. These range from clicks (in the 10 to 20 kHz range), squeaks (in the 1 kHz to 10 kHz range) and scratchy noises, buzzes, groans and claps (in the sub-1-kHz frequency range). Although clicks were apparent at all stations, the greatest concentration of non-mammalian biological sounds was received in the estuary environment. Figure 4-6 presents spectrograms of 7 seconds of data from the OBH during a quiet period (left figure) and during noisier period as a result of the pass-by of a vessel (right figure). The rate of occurrence of clicks does not appear to decrease when the vessel passes. The species responsible for these sounds is not known.
NOTE: Acoustic recordings from the Emsley Creek Estuary site showing strong clicks during a quiet period (left) and during a vessel pass-by (right). No notable difference in the rate of click occurrence is apparent.

**Figure 4-6** Recordings from Emsley Creek Estuary Show Strong Clicks during a Quiet Period and during a Vessel Pass-by
5 Acoustic Transmission Loss Measurements

5.1 Introduction

Acoustic transmission loss (TL) is the term used to quantify the decrease of sound level with distance from a sound source. Measurements of TL can be used to predict sound levels at distance from sound sources such as vessels if the source levels of the vessels are known. When sound levels are expressed in decibels (dB) then the relationship between source level (SL), TL and received level (RL) is given by the expression:

\[ RL = SL - TL \]

where TL is, by convention, expressed as a positive number. For example, if a tanker has a source level of 185 dB and the TL at 1 km from it is 50 dB, then the expected received level at 1 km from it will be 135 dB. For most underwater environments, sound TL depends on the sound frequency. Received levels at individual frequencies or in narrow frequency bands are determined by applying frequency-specific transmission losses to the corresponding frequency-specific source levels:

\[ RL(f) = SL(f) - TL(f) \]

where \( f \) is the frequency of sound. Broadband received levels are then computed by summing the narrow band received levels.

The method used in this study to measure TL(\( f \)) was to measure the RL(\( f \)) produced by a calibrated acoustic sound projector. A Lubell Labs LL-9162 acoustic projector was deployed at 4 m depth from the work vessel at distances between 200 m and 10 km from each of the OBH deployment sites. During deployment a multi-frequency sound signal was broadcast underwater. The signal consisted of five repetitions of a set of 21 single-frequency tones at 1/3-octave band centre frequencies between 200 Hz and 20 kHz. Each tone was 5 seconds long so the entire playback sequence for each deployment lasted 8 minutes and 45 seconds. A GPS record of broadcast location versus time was obtained for each deployment to reference the TL measurements to the corresponding source-receiver distance. The source level of the broadcast sound signal was monitored continuously using a RESON TC-4043 reference hydrophone (-201 dB re V/µPa) mounted 1 m directly above the projector. The spectrogram of the source waveform for a single sweep, measured on the reference hydrophone, is shown in Figure 5-1. Source levels at all 1/3-octave band centre frequencies were computed by averaging reference hydrophone measurements from the five sweeps at each location.

Received levels of the projector tones were obtained by computing the energy flux densities in 7-second time windows in narrow frequency bands near the broadcast frequencies. The 7-second time window was chosen to capture the full 5-second broadcasts and an additional 2 seconds of reverberation, which was quite apparent especially in Principe Channel. The tones received on the OBH were observed to have bandwidths of about 0.5% of the respective broadcast frequencies, which themselves were stable to less than 0.01%. The frequency spread of the received tones is attributed to Doppler shift as a result of the movement of the source vessel caused by drift and from surface swell. Source level measurements were obtained by computing energy flux density in 5-second time windows from the signals recorded from the
source reference hydrophone. The extended time window was not necessary for the source signal because its reverberation levels were not notable. Finally, TL was computed by subtracting the source level from the received level in decibels.

Transmission loss measurements for frequencies below 500 Hz were obtained by analyzing the noise produced by propeller cavitation from the work vessel. The signals broadcast from the Lubell Labs transducer included frequencies as low as 200 Hz, but it was found that the received signal levels at frequencies less than 500 Hz were sometimes not notably above ambient noise for longer-range measurements. The work vessel’s cavitation noise at frequencies as low as 30 Hz was easily observed on most recordings out to 10 km range and the variation in its level, about ±4 dB, was acceptable for the TL measurements below 500 Hz. A consistent method was used to produce a short pulse of high cavitation noise each time the work vessel reached the next station; the vessel speed was set at 5 knots as it approached the station. Once at station, the engine was reversed abruptly at half of full throttle until the work vessel came to a stop. The noise output characteristics of this procedure, referred to as a “hard reverse”, are evident in the spectrogram shown in the right pane of Figure 5-1.

NOTE: Spectrogram of tones from broadcast system used for TL study as measured on the reference hydrophone (left), and received on the OBH (right). The OBH spectrogram also shows the cavitation noise produced by work vessel performing a “hard reverse”.

Figure 5-1 Spectrogram of Broadcast System Tones for Transmission Loss Study, Measured on both Reference and Ocean-Bottom Hydrophones
5.2 Principe Channel

The TL study in Principe Channel was done off Mink Trap Bay, along the transect shown in Figure 5-2. TL data were computed from acoustic recordings of the sound projector and cavitation noise from the work vessel as described in Section 5.1. These data are plotted for frequencies 200 Hz to 15,840 Hz out to 6.4 km range in Figure 5-3. The TL is greatest for the highest frequencies. At 6 km from the OBH, the TL is 80 to 90 dB re 1 µPa for the high frequencies and 65 to 75 dB re 1 µPa for the low and mid-range frequencies.

NOTE: Transmission loss study transect at Principe Channel. The OBH position is identified by the red asterisk near the northwest end of the transect.

Figure 5-2 Transmission Loss Study Transect at Principe Channel
NOTE: Transmission loss versus range at centre frequencies of 1/3-octave bands between 200 Hz and 15,840 Hz in Principe Channel.

Figure 5-3  Transmission Loss versus Range in Principe Channel
5.3 Caamaño Sound

The TL study at Caamaño Sound was done on September 29, 2005, about 10 km south of Dewdney Island. The TL transect and OBH recorder position is shown in Figure 5-4. The TL results are given in Figure 5-5. The TL at this site was greatest for very low and very high frequencies with sound in the range of 1 to 2 kHz exhibiting the strongest propagation.

NOTE: Transmission loss study transect at Caamaño Sound location. The OBH position is identified by the red asterisk near the west end of the transect.

Figure 5-4 Transmission Loss Study Transect in Caamaño Sound
NOTE: Transmission loss versus range at centre frequencies of 1/3-octave bands between 20 Hz and 19,950 Hz in Caamaño Sound.

**Figure 5-5** Transmission Loss versus Range in Caamaño Sound
5.4 Wright Sound

The TL study in Wright Sound was done on September 30, 2005. The TL transect and OBH recorder position is shown in Figure 5-6. The TL results are given in Figure 5-7. The TL measurements in Wright Sound showed very high loss for the measurements made beyond 2.2 km. This is attributed to propagation across a very shallow region off Turtle Point that effectively blocked direct path acoustic energy from reaching the OBH.

NOTE: Transmission loss study transect at Wright Sound location. The OBH position is identified by the red asterisk near Turtle Point on Gill Island (bottom of figure).

Figure 5-6 Transmission Loss Study Transect in Wright Sound
NOTE: Transmission loss versus range at centre frequencies of 1/3-octave bands between 20 Hz and 19,950 Hz in Wright Sound.

Figure 5-7  Transmission Loss versus Range in Wright Sound

5.5  Emsley Creek Estuary

The TL measurements were made at Emsley Creek Estuary October 1, 2005 along the transect indicated in Figure 5-8. The TL results are given in Figure 5-9 and show notably different TL characteristics from the other three sites further west. The Emsley Creek Estuary site was characterized by very high TL for low frequencies and lower-than-normal TL for high frequencies. Sound energy below 50 Hz was attenuated by more than 80 dB for sources just 1 km offshore. In contrast, the corresponding loss at Caamaño Sound was just 60 to 70 dB. Transmission loss at 2 kHz at the Emsley Creek Estuary study site were less than 50 dB for the source range of 5 km. The corresponding loss at Caamaño Sound was over 60 dB. The high TLs observed for low frequencies result because the OBH was deployed in very shallow (5 m) water. Long wavelengths for low frequency sounds are forced to propagate partially in the seabed, where much greater loss is experienced. This is the case for all shallow environments.

Low TLs observed for high frequencies at the Emsley Creek Estuary study site are attributed to a low salinity layer of about 10-m thick near the surface. The low salinity surface layer exists through most of
Douglas Channel and is caused by fresh water input to the channel from the surrounding slopes and watersheds. Because the speed of sound in water increases with increasing salinity, the surface layer sound speed is lower than in the underlying water. The low-sound speed layer at the surface creates a surface sound channel or surface duct that can trap noise generated by sound sources near the surface. The low-salinity layer (sound duct) is about 10-m thick. Generally, the frequencies that can be trapped by a sound duct must have wavelengths a few times smaller than the thickness of the duct. The Emsley Creek Estuary site TL measurements showed that losses in the 1 to 5 kHz were more than 10 dB less than at other sites. This low loss is attributed to ducted propagation near the surface. The higher losses observed above 5 kHz are likely a result of the scattering of short wavelengths from surface roughness and this behaviour was observed at all sites. The ducted propagation effect was confirmed through acoustic model ground-truthing as discussed in Section 7. Figure 5-10 shows a cross section of modelled transmission loss versus depth and range at 2 kHz over the entire 5 km transect at Emsley Creek. In this figure, the source is at 4 m depth at the top left corner of the figure and the receiver is at the top right corner at 5 m depth. The model result clearly shows a region of intensified sound level (lower TL) near the surface.

NOTE: Transmission loss study transect at Emsley Creek Estuary. The OBH position is identified by the red asterisk in Emsley Cove.

Figure 5-8 Transmission Loss Study Transect at Emsley Creek Estuary
NOTE: Measured acoustic transmission loss versus range at centre frequencies of 1/3-octave bands between 20 Hz and 19,950 Hz along the transect across Kitimat Arm from Emsley Cove. Source depth was 4 m.

Figure 5-9  Transmission Loss versus Range along the Transect across Kitimat Arm from Emsley Cove
NOTE: Modelled transmission loss at 2 kHz over the 5 km transmission loss study transect at Emsley Creek. The figure shows transmission loss in a cross-section of the channel with the sound source at upper left. Low transmission loss near the surface is caused by ducted sound propagation in the low salinity surface layer.

**Figure 5-10**  Modelled Transmission Loss over the Transect at Emsley Creek
6 Geoacoustic Environment

Underwater sound propagation is influenced strongly by the geoacoustic parameters of the seafloor, which include the density, seismic P-wave and S-wave wave speeds and the seismic wave attenuation of the seabed materials. The acoustic TL model used to predict noise from tanker traffic can account for seabed geoacoustic parameters if the parameters are known. The Geological Survey of Canada (GSC) and Fisheries and Oceans Canada (DFO) have done detailed studies of the seafloor along the proposed tanker routes and have produced several reports describing the underlying sediment types and stratigraphy. The sediment descriptions given are suitable for ascribing the geoacoustic parameters for the present sediment types that are required by the acoustic model.

6.1 Sediment Basins in the Fjord System

The tanker traffic route passes through Kitimat Arm, Douglas Channel, Wright Sound, Squally Passage, Campania Sound and Caamaño Sound. These channels and sounds lie within the Kitimat fjord system which is characterized by deep steep-walled channels with relatively flat thick sediment bottoms. The sediments are of glaciomarine origin, deposited during the period of deglaciation between about 13,000 years before present (BP) to 10,000 years BP (Bornhold 1983). There are at least three different sedimentary basin types in the fjord system and the tanker routes pass over all three. The extents of the three basin types, referred to as the Kitimat, Gil and Maitland Basins, are shown in Figure 6-1. The Gil Basin extends from Kitkiata Inlet to Caamaño Sound. The Maitland Basin covers the region of Douglas Channel from Kitkiata to just north of the entrance to Devastation Channel. The Kitimat Basin lies immediately north of the Maitland Basin, and continues into the Kitimat estuary and delta. A morainal sill separates the Gil and Maitland Basins. The smaller Kitimat Basin is separated from the Maitland basin by morainal and bedrock sills.

The GSC and DFO carried out a series of oceanographic studies between 1977 and 1979 to characterize the sediment basins in the channels between Kitimat and the open ocean (Bornhold 1983). The studies used seismic profiling, low-frequency echosounding and coring to characterize the depositional layers that make up the basins. Additional radiocarbon dating of wood samples in cores was done to determine the respective times of deposition. The following text is a summary from the Bornhold report (Bornhold 1983).

Gil Basin sediments were deposited during the period of deglaciation between 13,000 and 12,000 years BP. The basin floor is made up of glacial and glaciomarine sediments. By around 12,000 years BP, the rate of glacial recede had slowed or stopped, with the glacial front near Kitkiata Inlet, and this allowed the morainal sill which now separates Gil and Maitland Basins to build up. The glacier later continued to recede until about 11,000 years BP, at which time it again slowed and created the sill that now exists between Maitland and Kitimat Basins. Also during this time, suspended sediments settled in Maitland Basin creating the mud and sandy muds that now constitute the floor of that basin. The sill at the north end of the Maitland Basin created a boundary to the Kitimat Basin, and the Kitimat Basin was eventually filled completely by glacial sediments as the glacier continued to recede north of Kitimat.
6.2 Geoacoustic Parameters of Basin Sediments

The top sedimentary layers in Gil and Maitland basins consist of 50 to 60 m of stratified surficial muds and sandy muds. The mud layers in Gil Basin overlie about 500 m of highly acoustically reflective sediments. In contrast, the underlying sediments of the Maitland Basin appear to be relatively acoustically transparent. There are some regions of Maitland Basin, particularly near its bounding sills, where reflective stratified sediments underlie the less reflective muds. Figure 6-2 contains a seismic reflection profile showing the stratigraphic layering near the main sill that separates Gil and Maitland basins. Gil Basin is to the left of the sill and Maitland Basin is to the right in this figure.

GSC and DFO performed refractive seismic studies to measure interval velocities in the sediments. An average interval velocity of 1,862 m/s was measured for the sediments layers beneath the surface mud layer and above bedrock.

Core samples in Maitland Basin showed that the transparent sediment layer is made up of olive, olive-grey and dark grey muds and sandy muds. Core samples were not collected in Gil Basin.

Hamilton (1980) provides a comprehensive cross-reference providing expected parameter values for compressional velocity, compressional attenuation coefficient and density for several sediment types. This reference has been used to ascribe the sediment parameters for Gil Basin, given in Table 6-1, and for Maitland Basin, given in Table 6-2. The parameters specified are layer densities in grams per cubic centimetre, compressional wave speed in metres per second (m/s), and compressional wave attenuation in decibels per wavelength. Approximate shear wave properties of the surface muds were derived from Hamilton’s regression equations (1976) from a compressional speed of 1,549 m/s for silt-clay. The shear
wave speeds derived this way are 310 m/s for Maitland Basin and 259 m/s for Gil Basin. The shear wave attenuation from these regression equations is 8.65 dB/m. The “highly reflective” sediments in Gil Basin have been represented by alternating layers of high and low density. Density change is proportional to acoustic impedance change, so a reflection is generated at each density-change interface.

NOTE: (a) surficial stratified sediments (b) transparent sediments (c) highly reflective sediments. Vertical axis shows two-way travel time in seconds. Figure is reproduced from the article by Bornhold (1983).

**Figure 6-2**  Seismic Reflection Profile across the Main Sill Separating Gil and Maitland Sedimentary Basins

**Table 6-1**  Geoacoustic Parameters for Gil Basin Sediments

<table>
<thead>
<tr>
<th>Depth below Seafloor (m)</th>
<th>Sediment Type</th>
<th>Density (g/cm$^3$)</th>
<th>Compressional Speed (m/s)</th>
<th>Attenuation (dB/λ)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Transparent muds and glaciomarine outwash</td>
<td>1.488</td>
<td>1,549</td>
<td>0.07</td>
</tr>
<tr>
<td>60 to 75</td>
<td>Highly reflective stratified glacial and glaciomarine sediments</td>
<td>1.5</td>
<td>1,862</td>
<td>0.5</td>
</tr>
<tr>
<td>75 to 90</td>
<td></td>
<td>1.2</td>
<td>1,862</td>
<td>0.5</td>
</tr>
<tr>
<td>90 to 105</td>
<td></td>
<td>1.5</td>
<td>1,862</td>
<td>0.5</td>
</tr>
<tr>
<td>105 to 120</td>
<td></td>
<td>1.2</td>
<td>1,862</td>
<td>0.5</td>
</tr>
<tr>
<td>120 to 180</td>
<td></td>
<td>1.5</td>
<td>1,862</td>
<td>0.5</td>
</tr>
<tr>
<td>180 to 560</td>
<td>Non-reflective stratified glacial and glaciomarine sediments</td>
<td>1.5</td>
<td>1,862</td>
<td>0.5</td>
</tr>
<tr>
<td>&gt; 560</td>
<td>Bedrock</td>
<td>2.5</td>
<td>3,000</td>
<td>0.1</td>
</tr>
</tbody>
</table>
### Table 6-2  Geoacoustic Parameters for Maitland Basin Sediments

<table>
<thead>
<tr>
<th>Depth below Seafloor (m)</th>
<th>Sediment Type</th>
<th>Density (g/cm³)</th>
<th>Compressional Speed (m/s)</th>
<th>Attenuation (dB/λ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 70</td>
<td>Stratified muddy sands and muds</td>
<td>1.596</td>
<td>1,579</td>
<td>0.1</td>
</tr>
<tr>
<td>70 to 550</td>
<td>Transparent, olive, olive-grey to dark grey sandy muds, soft muds and stiff muds</td>
<td>1.9</td>
<td>1,862</td>
<td>0.5</td>
</tr>
<tr>
<td>&gt; 550</td>
<td>Bedrock</td>
<td>2.5</td>
<td>3,000</td>
<td>0.1</td>
</tr>
</tbody>
</table>
7 Acoustic Modelling

A primary goal of this marine acoustic study is to predict noise levels that will be produced by loading and unloading operations at the Kitimat Terminal, and from project-related very large crude carrier (VLCC) and tug traffic along the route from the Kitimat Terminal to open ocean. A modelling approach has been used to satisfy this goal. The specific approach used in this study is the same as that used for the very large offshore development projects at Sakhalin Island, Russia. The Sakhalin projects are near feeding areas for western grey whales, which are thought to be highly sensitive to underwater noise (Hannay 2004). The marine operations noise model (MONM) used in this study is the same model as was used for the Sakhalin projects. The specific model and approach has been subject to expert review by an International Union for Conservation of Nature (IUCN) scientific panel (Reeve 2005).

To ensure accuracy of model predictions, MONM was ground-truthed against the field measurements of acoustic TL acquired as part of this study and discussed in Section 5. MONM was then applied to a set of scenarios that represent expected tanker operations at locations along the marine transportation routes. The scenario locations encompass the different environment types that will be exposed to project-related tug and VLCC noise. These locations were chosen based on their physical properties: bathymetry, channel width, and proximity to areas of particular sensitivity. Section 7.2 specifies the project-related vessel types and Section 7.3 defines the scenario locations and project-related vessel (tankers and tugs) configurations chosen for the present study.

The project-related tug and tanker source levels used for the model predictions were obtained from calibrated measurements on similar (surrogate) vessels to those discussed in Section 7.2. Modelling of received levels was done on the centre frequencies of consecutive 1/3-octave bands between 20 Hz and 5 kHz for each scenario. The model runs were performed out to distances of up to 50 km from the source position. The 1/3-octave band received levels were summed to compute broadband (20 Hz to 5 kHz) levels, and these were contoured to produce the sound level isopleth maps presented in Section 7.3.

7.1 Model Ground-Truthing

Underwater acoustic noise models can accurately predict noise levels over large areas near vessels and other operating marine equipment. The accuracy of model predictions is dependent on how well the geoacoustic environment of the ocean and seafloor can be specified. The most important parameters influencing underwater sound propagation are:

- bathymetry
- ocean sound speed variation with depth
- compressional and shear sound speed structure in the seafloor
- seabed density and compressional wave and shear wave attenuation coefficients of the seafloor.

Fitting model predictions of TL to real TL measurements can compensate for uncertainties in the input model parameters. The input parameters are adjusted to optimize the fit between model and data. The adjusted geoacoustic parameters can then be used with confidence to predict more accurately the noise levels for specific project-related vessel scenarios.
Section 7 of this report presents the results of dedicated TL measurements at four locations along the VLCC tanker route. The MONM acoustic model was ground-truthed against these TL data. Modelled TL results were computed for the known bathymetry at the TL study sites using the appropriate geoacoustic parameter profiles given in Section 6. Ocean sound speed profiles for the model runs were based on conductivity-temperature-depth (CTD) measurement profiles provided by ASL Ltd, which were made two weeks before the field TL study.

The match between measured and modelled TL was generally very good. The mean discrepancies between measured and modelled values were less than 5 dB at the Principe Channel and Wright Sound TL study sites over the frequencies 20 Hz to 5 kHz. However, systematic discrepancies were observed at the Caamaño Sound site; the Caamaño Sound TL measurements were less than the modelled values by a mean of 6 dB. These discrepancies were addressed by modifying the geo-acoustic profile at Caamaño Sound by reducing the sediment thickness to 5 m. This is a realistic change also because bedrock islands are abundant in Caamaño Sound, so the thick sediments of Maitland Basin were not representative of that location. This adjustment brought mean model results into close agreement with measurements. The model results at Emsley Creek Estuary were in good agreement with the measured values at all frequencies. The final model-data comparisons for all four sites are shown in Figure 7-1 to Figure 7-4.

### 7.1.1 Principe Channel

Plots of the comparisons between the modelled and measured TL data for the Principe Channel location at ranges of 200 m, 1,000 m, 2,500 m, 5,000 m and 6,500 m are shown in Figure 7-1. The source depth was 4 m and the receiver was at the sea bottom (142 m depth).

### 7.1.2 Caamaño Sound

Plots of the comparisons between the modelled and measured TL data for the Caamaño Sound site at ranges of 1,000, 5,000, 8,000 and 10,500 m are shown in Figure 7-2. The source depth was 4 m and the receiver was at the sea bottom (close to 214 m depth).

### 7.1.3 Wright Sound

A plot of the comparisons between the modelled and measured TL data for the Wright Sound location at 2,000 m range is shown in Figure 7-3. The source depth was 4 m and the receiver was on the sea bottom (90 m depth).

### 7.1.4 Emsley Creek Estuary

Plots of the comparisons between the modelled and measured transmission loss data for the Emsley Creek Estuary site at ranges of 1,000, 2,000, 3,000 and 5,000 m are shown in Figure 7-4. The source depth was 4 m and the receiver was at the sea bottom (5 m depth).
NOTE: Measured (red dash) and modelled (solid) transmission loss in Principe Channel in 1/3-octave bands between 20 Hz and 5 kHz at selected ranges.

Figure 7-1    Measured and Modelled Transmission Loss in Principe Channel
NOTE: Measured (red dash) and modelled (solid) transmission loss at Caamaño Sound in 1/3-octave bands between 20 Hz and 5 kHz for selected ranges.

**Figure 7-2** Measured and Modelled Transmission Loss in Caamaño Sound
NOTE: Measured and modelled transmission loss in 1/3-octave bands between 20 Hz and 5 kHz at 2 km range at Wright Sound.

**Figure 7-3**  Measured and Modelled Transmission Loss in Wright Sound
NOTE: Measured (red dash) and modelled (solid) transmission loss at Emsley Creek Estuary in 1/3-octave bands between 20 Hz and 5 kHz for selected ranges.

**Figure 7-4** Measured and Modelled Transmission Loss in Emsley Creek Estuary
7.2 Acoustic Source Levels

The predictive noise modelling approach requires representative frequency-dependent source levels for the project-related vessels included in the model scenarios. Surrogates for five types of vessel were included in the scenarios. The vessel surrogates are described below and their 1/3-octave band levels are shown in Figure 7-5 to Figure 7-8.

- **Tanker Underway** (see Figure 7-5): The source levels used as surrogate for VLCCs are based on measurements published for a generic tanker of length 240 m and unspecified power (Malme et al. 1989). The reported levels were measured with the tanker at full power transiting at 16 knots. To approximate a half-power setting that is more representative of project-related VLCC operations in the channel environments, 5 dB have been uniformly subtracted from all 1/3-octave band levels.

- **Tanker at Standby** (see Figure 7-6): The source levels are based on measurements of the bulk gravel carrier, Nelvana, at standby at Sechelt, British Columbia (MacGillivray et al. 2004). The broadband source level was 167.8 dB re 1 µPa at 1 m.

- **Escort Tug** (see Figure 7-7): the escort and anchor-handling tug, Katun, has been used as surrogate for the escort tugs in the model scenarios (Hannay 2004). The Katun is a large 67.6 m, 12,240 HP escort and anchor-handling tug.

- **Harbour Tug** (see Figure 7-7): source levels were obtained from measurements on a harbour tug as it escorted the 243 Nelvana bulk gravel carrier during berthing at the Sechelt gravel loading facility in British Columbia (MacGillivray et al. 2004). The tug displacement and horsepower were not determined.

- **Clamshell Dredge** (see Figure 7-8): Clamshell dredge source levels are from the clamshell dredge, Argilopotes, measured while operating in the Alaskan Beaufort Sea and reported in Miles et al. (1987). The broadband (50 to 3,160 Hz) source level of the Argilopotes was 161.2 dB re 1 µPa at 1 m. The unusual spectral characteristics of the band levels, presented in Figure 7-8, are due to 125 Hz harmonics attributed to vibrations from a winch system that lifted the bucket. The tone was not seen at 125 Hz in the original measurement and consequently the first notable energy appears at 250 Hz.
Figure 7-5  Source Levels for Tanker Underway at Half Power

Figure 7-6  Source Levels for Tanker at Standby

Figure 7-7  Source Levels for Escort and Harbour Tugs

Figure 7-8  Source Levels for Clamshell Dredge
7.3 Model Scenarios and Results

Six modelling scenarios were defined to represent the primary operations types involving project-related vessel traffic associated with shipping oil and condensate at the Kitimat Terminal. One additional scenario for dredging during construction activities was also considered. The scenarios include:

- berthing at the Kitimat Terminal with escort tugs
- tanker on standby at the Kitimat Terminal
- transit past an ecologically sensitive site (Kitkiata Inlet)
- transit through the channel (Principe Channel Site)
- transit through an enclosed Sound (Wright Sound)
- transit from a semi-enclosed sound through to open water (Caamaño Sound)
- dredging at the Kitimat Terminal

For each of these scenarios, an appropriate project-related vessel configuration is assigned. The configuration is based on a vessel requirements engineering assessment, which considered the safe steering of VLCCs from the Kitimat Terminal to open water. The project-related vessels involved in the scenarios include a tanker (VLCC surrogate), escort tugs and harbour tugs. The dredging construction scenario assumes a single clamshell dredge. The scenarios are described in the following sections.

7.3.1 Berthing at the Kitimat Terminal

Figure 7-9 presents the vessel configuration for docking the tanker (VLCC surrogate) at the Kitimat Terminal. This scenario includes two escort tugs and two harbour tugs. The escort tugs work near the bow and stern of the tanker and the harbour tugs work between the escort tugs. The tugs are expected to operate in high power mode as they hold the tanker alongside the berth while moorings are secured. Figure 7-10 presents the model results as noise level isopleths for unweighted broadband (20 Hz to 5 kHz) sound pressure in decibels referenced to $1 \mu Pa$. The receiver depth was set to 20 m; the model places the receiver on the sea bottom where the water is shallower than the specified receiver depth. Received levels of 125 to 130 dB re $1 \mu Pa$ reach the opposite side of Kitimat Arm directly across from the Kitimat Terminal but the sound levels deteriorate more rapidly along the channel. Figure 7-11 shows an expanded view of the model results. Sound levels of 120 dB extend to the mouth of the Kitimat Delta to the north of the Kitimat Terminal and to the tip of Coste Island to the south of the Kitimat Terminal, a distance of about 15 km.

7.3.2 Tanker on Standby while Moored at the Kitimat Terminal

The scenario shown in Figure 7-12 represents the noise levels produced by a tanker (VLCC surrogate) moored at the Kitimat Terminal on standby after moorings are secured. No propulsion systems are operating and no escort or harbour tugs are involved. Receiver depth is 20 m, or at the sea bottom if the water is shallower than 20 m. The received levels are notably lower in this scenario that for the berthing scenario presented above. Levels are unweighted, broadband (20 Hz to 5 kHz) sound pressure in decibels referenced to $1 \mu Pa$. In this scenario sound levels of 120 dB re $1 \mu Pa$ extend about 1 km from the Kitimat Terminal.
Figure 7-9  Vessel Geometry during Tug-Escorted Tanker Berthing at the Kitimat Terminal
Figure 7-10  Underwater Noise Level Isopleths for Tug-Escorted Tanker Berthing at the Kitimat Terminal
Figure 7-11: Expanded View of Underwater Noise Level Isopleths for Tanker Berthing at the Kitimat Terminal
Figure 7-12  Underwater Noise Level Isopleths for Tanker at Standby at the Kitimat Terminal
7.3.3 Transit Past Kitkiata Inlet

The planned vessel configuration during VLCC transits within Douglas Channel includes escort tugs leading and following the VLCC. The stern tug may be hooked up to assist with steering in bad weather or it may escort unconnected but in position for rapid assistance if needed. The leading tug will normally operate unconnected. Its primary purpose is to provide extra assistance in bad weather and act as backup in case of malfunctions of the VLCC or the other escort tug.

The vessel configuration for the Kitkiata Inlet transit scenario is shown in Figure 7-13. The tanker (VLCC surrogate) is positioned directly off the mouth of Kitkiata Inlet. The lead escort tug is positioned 0.5 nautical miles (926 m) in front of the tanker and the rear escort tug is 0.1 nautical miles (185 m) to the starboard of the tanker’s stern.

The received sound levels resulting from the model run for this scenario are presented in Figure 7-14 with an expanded view presented in Figure 7-15. Receiver depth is 20 m, or at the sea bottom if the water is shallower than 20 m. Levels are flat-weighted, broadband (20 Hz to 5 kHz) sound pressure in decibels referenced to 1 \(\mu\)Pa. Sound levels of 120 dB re 1 \(\mu\)Pa extend about 13 km from the tanker in the along-channel direction. The sound distribution across the channel is fairly uniform due to the constancy of the across-channel bathymetry at this location.

7.3.4 Transit Through Wright Sound

The VLCC will be required to make two acute turns through Wright Sound and will need to have escort tugs on hook to assist with manoeuvring these turns. Two major shipping channels converge in this area and many cruise ships, cargo ships, tugs, and ferries pass through this water. In this scenario, two escort tugs are positioned on hook to the tanker (VLCC surrogate) for steering assistance, while a third tug is present ahead of the tanker for traffic control thus four simultaneous noise sources have been modelled.

The model results are shown in Figure 7-16 and Figure 7-17. Receiver depth is 20 m, or at the sea bottom if the water is shallower than 20 m. Levels are flat-weighted, broadband (20 Hz to 5 kHz) sound pressure in decibels referenced to 1 \(\mu\)Pa. The noise propagates into the channels surrounding Wright Sound. However, the levels have decreased below 120 dB re 1 \(\mu\)Pa within a range of about 8 km from the tanker position.
Figure 7-13  Vessel Configuration Scenario for Kitkiata Inlet
Figure 7-14  Underwater Noise Level Isopleths for a Tug-Escorted Tanker in Douglas Channel off Kitkiata Inlet
Figure 7-15: Expanded View of Underwater Noise Level Isopleths for Tug-Escorted Tanker Transit Past Kitkiata Inlet in Douglas Channel
Figure 7-16  Vessel Configuration Scenario for Wright Sound
Figure 7-17 Underwater Noise Level Isopleths for Tug-Escorted Tanker Transit through Wright Sound
Figure 7-18  Expanded View of Underwater Noise Level Isopleths for Tanker Transit through Wright Sound
7.3.5 Transit Through Principe Channel

Throughout Principe Channel there will be two tugs providing free running escort to the VLCC. One tug will travel ahead of the VLCC at a distance of up to 1 nautical mile (1.85 km) clearing other traffic out of the path of the VLCC. The second tug will follow the VLCC at a distance of about 0.2 nautical mile (370 m) and will be prepared to hook up to the VLCC if needed for steering or other assistance. The rear tug will be slightly offset of the path of the VLCC.

The model results for the vessel surrogates are presented in Figure 7-20 and Figure 7-21. Receiver depth is 20 m, or at the sea bottom if the water is shallower than 20 m. Levels are flat-weighted, broadband (20 Hz to 5 kHz) sound pressure in decibels referenced to 1 μPa. Sound levels of 120 dB re 1 μPa extend about 10 km from the stern of the tanker (VLCC surrogate) in this scenario.

Figure 7-19  Vessel Configuration Scenario for Principe Channel
Figure 7-20  Underwater Noise Level Isopleths for Tug-Escorted Tanker Transit through Principe Channel
Figure 7-21 Expanded View of Underwater Noise Level Isopleths for Tanker Transit through Wright Sound
7.3.6 Transit Through Caamaño Sound

In this scenario, one tug will provide free running escort of the VLCC as it transits through Caamaño Sound heading out to open ocean in Hecate Strait. The escort tug is positioned 0.5 nautical miles off the VLCC’s port bow (Figure 7-22). This scenario is only anticipated to occur in good weather. In bad weather, the VLCC will use the more sheltered passage to open ocean through Principe Channel.

The model results for the vessel surrogates are presented in Figure 7-23 and Figure 7-24. The vessel propagates sound between the surrounding islands near Caamaño Sound, but it is attenuated by the shallow slopes around the islands. Receiver depth is 20 m, or at the sea bottom if the water is shallower than 20 m. Levels are flat-weighted, broadband (20 Hz to 5 kHz) sound pressure in decibels referenced to 1 μPa. Sound levels of 120 dB re 1 μPa extend about 20 km from the tanker (VLCC surrogate) position.

![Vessel Configuration Scenario for Caamaño Sound](image)

**Figure 7-22** Vessel Configuration Scenario for Caamaño Sound
Figure 7-23  Underwater Noise Level Isopleths for Tug-Escorted Tanker Transit through Caamaño Sound
Figure 7-24 Expanded View of Underwater Noise Level Isopleths for Tanker Transit through Caamaño Sound
7.3.7 Dredging at the Kitimat Terminal

This scenario represents the construction-related dredging at the Kitimat Terminal. It is anticipated that a clamshell dredge will be used for this operation. The 1/3-octave band source levels used are from the dredge ‘Argilopotes’ as measured in the Alaskan Beaufort Sea and reported in Miles et al. (1987). The broadband (50 to 3,160 Hz) source level of the Argilopotes was 161.2 dB re 1 µPa at 1 m. This scenario generates relatively low noise levels with the levels decreasing to ambient noise levels within 15 km range. Levels are flat-weighted, broadband (20 Hz to 5 kHz) sound pressure in decibels referenced to 1 µPa. Levels of 120 dB re 1 µPa are received to ranges of less than 1 km.
Figure 7-25 Underwater Noise Level Isopleths from Clamshell Dredge Operating at the Kitimat Terminal
8 Audiogram analysis

When considering the impact of anthropogenic noise on marine mammals and fish, it is important to take into account how sound is perceived differently by different species. Noise is more likely to affect an animal when it overlaps that its frequency range of best hearing sensitivity. For example, most baleen whales hear best at low frequencies whereas toothed whales hear best at mid to high frequencies. Thus, low frequency anthropogenic noise, e.g., from shipping, is more likely to affect baleen whales, who would perceive the noise as louder than toothed whales. Thus, different species of marine mammals and fish must be considered separately, because their hearing abilities are often very different.

The standard method for computing the loudness of sound as perceived by a particular species of marine mammal or fish is to weight the sound by its audiogram, which is the species-specific curve of hearing threshold versus frequency. Audiograms have been determined for several species based on laboratory measurements, using behavioural or auditory brainstem response (ABR) methods, or estimated from auditory system anatomy. When audiogram weighting is applied to broadband noise levels, the resulting sound levels are in units of “dB re threshold”, which is the decibel level of the noise above the animal’s hearing threshold. At sound levels less than 0 dB re threshold, noise is below the audible limit for a particular species and is therefore expected to be inaudible. Audiogram weighting is analogous to the “A-weighting” that is used for measuring the effect of in-air noise on human subjects.

For the current study, audiogram analysis was applied to three different types of fish (herring, salmon and flatfish) and three species of marine mammals (humpback whale, killer whale and Steller sea lion).

Audiograms used in the analysis were taken from the following sources:

- Enger (1967) (herring)
- Hawkins and Johnstone (1978) (salmon)
- Erbe (2002) (humpback whale)
- Erbe (2001) (killer whale)
- Kastelein et al. (2005) (Steller sea lion)
- Zhang et al. (1998) (sole)
- Chapman and Sand (1974) (dab)

Figure 8-1 shows plots of frequency versus hearing threshold for the audiograms that were used in this analysis. In each case, audiograms were linearly interpolated or extrapolated from the original source data into 1/3-octave bands, as shown in the figure. The flatfish audiogram is a composite of dab audiogram data below 200 Hz (from Chapman and Sand [1974]) and sole audiogram data above 200 Hz (from Zhang et al. [1998]). The Steller sea lion audiogram above 4 kHz is an average of the male and female audiograms taken from Kastelein et al. (2005). The remaining four audiograms were taken directly from the respective literature sources.

Noise levels above hearing threshold were calculated by subtracting species-specific audiograms from modelled 1/3-octave band noise levels. The weighted 1/3-octave band levels were then summed to yield noise levels relative to hearing threshold for each species of marine mammal and fish. Sound levels above hearing threshold were computed for each of the seven different model scenarios presented in Section 7.3.
of this report. For each model scenario, noise levels above hearing threshold were plotted on contour maps, which are provided in the appendix to this report. The contours on the maps show predicted noise levels above threshold in 5 dB increments from 20 dB to 105 dB (re threshold).

NOTE: Audiogram plots of hearing threshold versus sound frequency for selected marine mammals and fish. Black stars indicate measured data taken from the literature and blue stars show points that were interpolated or extrapolated from the measured data.

**Figure 8-1** Audiogram Plots of Hearing Threshold versus Sound Frequency for Selected Marine Mammals and Fish
9 References

9.1 Literature Cited


9.2 Internet Sites


http://www.eao.gov.bc.ca/epic/output/documents/p225/d19527/1106074391306_f1cb72def3e7482c9684ca1e2ee4ce40.pdf
Appendix A Audiogram-Weighted Sound Level Maps
A.1 Berthing at the Kitimat Terminal

Figure A-1 Berthing at the Kitimat Terminal – Herring
Figure A-2  Berthing at the Kitimat Terminal – Salmon
Figure A-3  Berthing at the Kitimat Terminal – Humpback Whale
Figure A-4  Berthing at the Kitimat Terminal – Killer Whale
Figure A-5  Berthing at the Kitimat Terminal – Steller Sea Lion
Figure A-6  Berthing at the Kitimat Terminal – Flatfish
A.2 Tanker Standby

Figure A-7 Tanker Standby – Herring
Figure A-8     Tanker Standby – Salmon
Figure A-9  Tanker Standby – Humpback Whale
Figure A-10  Tanker Standby – Killer Whale
Figure A-11  Tanker Standby – Steller Sea Lion
Figure A-12  Tanker Standby – Flatfish
A.3 Kitkiata Creek Transit

Figure A-13 Kitkiata Creek Transit – Herring
Figure A-14     Kitkiata Creek Transit – Salmon
Figure A-15  Kitkiata Creek Transit – Humpback Whale
Figure A-16  Kitkiata Creek Transit – Killer Whale
Figure A-17  Kitkiata Creek Transit – Steller Sea Lion
Figure A-18  Kitkiata Creek Transit – Flatfish
A.4 Principe Channel Transit

Figure A-19 Principe Channel Transit – Herring
Figure A-20  Principe Channel Transit – Salmon
Figure A-21  Principe Channel Transit – Humpback Whale
Figure A-22  Principe Channel Transit – Killer Whale
Figure A-23  Principe Channel Transit – Steller Sea Lion
Figure A-24  Principe Channel Transit – Flatfish
A.5 Wright Sound Transit

Figure A-25 Wright Sound Transit – Herring
Figure A-26    Wright Sound Transit – Salmon
Figure A-27  Wright Sound Transit – Humpback Whale
Figure A-28  Wright Sound Transit – Killer Whale
Figure A-29  Wright Sound Transit – Steller Sea Lion
A.6 Caamaño Sound Transit

Figure A-31 Caamaño Sound Transit – Herring
Figure A-32  Caamaño Sound Transit – Salmon
Figure A-33    Caamaño Sound Transit – Humpback Whale
Figure A-34  Caamaño Sound Transit – Killer Whale
Figure A-35  Caamaño Sound Transit – Steller Sea Lion
Figure A-36  Caamaño Sound Transit – Flatfish
A.7 Dredging at the Kitimat Terminal

Figure A-37  Dredging at the Kitimat Terminal – Herring
Figure A-38  Dredging at the Kitimat Terminal – Salmon
Figure A-39  Dredging at the Kitimat Terminal – Humpback Whale
Figure A-40  Dredging at the Kitimat Terminal – Killer Whale
Figure A-41  Dredging at the Kitimat Terminal – Steller Sea Lion
Appendix A: Audiogram-Weighted Sound Level Maps

Figure A-42  Dredging at the Kitimat Terminal – Flatfish