# <u>Woodfibre LNG Sponsored Fellowship Proposal</u>

## *Sound transmission from land into water: Implications for industry near and in Howe Sound*

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**<u>ABSTRACT</u>**

There have been many concerns raised with the expansion of industry on the West Coast of British Columbia, Canada. Many of these concerns stem from the worry about the impact that the noise, unwanted sound, from these new projects will have on the environment and the local wildlife. The transmission of construction and operation noise through coastal industrial sites has the potential to have a negative affect on marine ecosystems. Testing how these noises travel through the geology of the site is key to quantifying the implications these projects will have. The attenuation (i.e., decay) of the signal differs with rock type and the rocks physical such as density, porosity, and geologic structure (eg. fault fractures) that affect its velocity and strength. Similar studies have been conducted on individual samples, however no such study has been done to test the transmission from land into water, in Howe Sound near Squamish BC. This study consists of measuring, on site, the real-time travel and attenuation (i.e., decay) of noise signals both on-shore and into the near-shore marine environment with the use of seismic and hydrological sensors. This study will allow for a much better site-specific characterization of the potential acoustic disturbance from on-shore industrial and construction activities of proposed industry in Howe Sound. It will allow Woodfibre LNG and Squamish Oceanfront development to inform decisions on how to strategically place their operations on the site and surrounding area to minimize the potential disturbance to the ecology, environment, and water systems in Howe Sound.

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## Introduction

One of the most important and controversial issues in Western Canada is the proposed return of industry and expansion of existing industries. For example, Campbell River, Kitsault, Delta and Kitimat are areas in B.C with proposed industrial expansion site (BC Gov, 2015). Projects like these bring social and environmental benefits as well as issues, especially in small communities. Canada, and especially British Columbia, has a resource-based economy and demand for earth's natural resources is increasing, as suggested by the these proposed projects. The destination for the liquefied natural gas, or LNG, is the Asian market, and their demand is the driving force behind these projects (Vivoda, 2014). In order to mitigate negative impacts from the industrialization (i.e., air, water, and noise pollution), it is important that these processes are as well managed, accountable, and the proper assessments are completed.

Transporting industrial goods via water (e.g., container ships, tugs) is significantly more efficient than via land (e.g., trucks, trains:Collins, 2015). Several industries in coastal British Columbia, including forestry and the oil and gas shipping industry exploit the proximity of suitable land-based building sites to waterways. In addition, the population of coastal British Columbia is growing, increasing the number of dwellings on its shores (StatsCan, 2011). Therefore, development next to waterways in British Columbia continues to grow.

One of the many concerns of new coastal development is noise and how it affects marine wildlife. Herring deaths, for example, in a controlled setting, have been recorded when exposed to 180 dba, this noise level, although unlikely, has the potential to be generated by the installation of piling among other construction techniques (Doksaeter *et al* 2012; Table 1). Subsequently, during construction, land-based activities, including piling, and other constructional noise can impact wildlife if the frequencies are within damaging range (Radle 2007; Table 1). Subsequently, during operation on industrial sites, noise emitted from land-based activity has the potential to affect aquatic life, however little is known about the transmission of land-based noise into nearby bodies of water. In this study, I consider the effects of noise generated on land and its transmission into the ocean.

In Squamish, B.C., two large construction projects are proposed; a liquefied natural gas (LNG) processing site at what was previously the Woodfibre pulp mill (Figures 1 & 2) and an oceanfront development adjacent to downtown Squamish at Nexen Beach (Figure 1 & 3). Both sites are located on the shores of Howe Sound and at each site land based construction has the potential to transmit noise into the water. In this study, I concentrated on measuring the transmission and attenuation of land-based noise into Howe Sound at both sites.

Figure 1.
This map shows both the Woodfibre site (red) and the Nexen Beach site (yellow).

Figure 2.
This map shows the Woodfibre site, which is located in Howe Sound, near Squamish, British Columbia Canada. The blue line shows where the experiments took place.

Figure 3.
This map shows the Nexen Beach, which is located in Howe Sound, in Squamish, British Columbia Canada. The blue line shows where the experiments took place.

| Construction Equipment Noise Emission Levels | |
|---|---|
| Equipment | Typical Noise (dBA) 50ft from source |
| Backhoe | 80 |
| Ballast Tamper | 83 |
| Concrete Mixer | 85 |
| Crane, Mobile | 83 |
| Dozer | 85 |
| Jack Hammer | 88 |
| Pile Driver (Impact) | 101 |
| Pile Driver (Vibratory) | 95 |
| Pneumatic Tool | 85 |
| Rail Saw | 90 |
| Rock Drill | 85 |
| Roller | 85 |
| Shovel | 82 |
| Spike Driver | 77 |
| Tie Inserter | 85 |
| Truck | 84 |
| Compacter | 82 |
| Grader | 85 |

Table 1: This table is showing us the construction noise emissionsf rom various construction equipment in decibels (dB). This is noise that travels outside of any medium. Modified from Wightman, 2003. The Federal Highway Administration.

The two sites are located on similar types of geology and are both located within the Coast Mountains adjoining Howe Sound. Geologically the area falls within the 'Coast Plutonic Complex', which is characterized as granitic plutonic bedrock. Metasedimentary rock (e.g., phyllite, slate) crops out on the east/west side of the Woodfibre project site, although granodioritic bedrock dominates the area. Additionally for both sites, there is the possibility of volcanic units within the valley, all of which have different effects on acoustic transmission. At the Woodfibre site unconsolidated glacio-fluvial and glacial sediments tend to dominate surficial geology of the lower project site, although post-glacial colluvial deposits occur in the valley (WLNG Executive Summary 2014). The colluvial area extends within the cleared project site into Howe Sound, with a steep drop-off located a distance of a few hundred metres offshore. This is the same for both Woodfibre and Nexen Beach. The Nexen Beach areas include this type of geology in the form of large amount of cement, fill, and riprap.

The physical properties of rocks (density, porosity, geologic structure (e.g., faults, fractures)) have a large effect on acoustic velocity (Hardy 1972). For example, acoustic waves will travel much faster in denser rocks than in an unconsolidated medium such as soil. For example the speed of sound in unconsolidated sandstone is about 4,600 m/s and in denser Granite is close to 5950 m/s (Engineering Toolbox, 2014). The velocity of sound in different solid mediums is found in Table 2.

| **Medium** | **Velocity (m/s)** |
|---|---|
| Brick | 4179 |
| Concrete | 3200-3600 |
| Copper | 4600 |
| Diamond | 12000 |
| Gold | 3240 |
| Granite | 5950 |
| Hardwood | 3962 |
| Iron | 5130 |
| Lead | 1960-2160 |
| Silver | 3650 |
| Steel | 6100 |
| Titanium | 6070 |
| Water | 1433 |

Table 2: This table shows the speed of sound in different media. The numbers are not taking into account temperature, or in the case of water salinity. Modified from The Engineering Toolbox.

Noise transmissions act differently in water then they do in solids. In water the speed of sound is variant based on different variables such as temperature, salinity, and depth. For example, in warmer water the faster the speed of sound due to the accelerated movement of particles. Average temperature in Howe Sound, Squamish BC is around 8° Celsius which roughly translates to the speed of sound in water being 1448.8 m/s.
Signal propagation, transmission and attenuation are well studied in both solids (e.g., rock and soil) and liquids (water). However, there is very little data on noise propagation between the two mediums. Here, I devised an experimental set-up to investigate the transmission and propagation of onshore noise into water using two locations (Woodfibre and Nexen Beach) in Howe Sound area near Squamish, BC. This method of testing sound propagation allows us to investigate how acoustic

signals attenuates as they pass from on medium (land) to another (water). Preliminary results indicate that noise transmission from land to water could be a factor affecting the marine environment at Nexen Beach, with the potential for it to be a factor at Woodfibre dependent on the scale and scope of the selected construction equipment.

## METHODS

To accurately quantify the transmission and attenuation of an acoustic signal from land into water, we had to combine terrestrial and aquatic sensors. Specifically, we linked land-based geophones with marine-based hydrophones through a series of multi-track recorders (Table 3; Figure 4). We ran each recording device through a pre-amplifier to ensure capture of relevant frequencies. For each test, we started the recorders simultaneously, ensuring an accurate time stamp. The acoustic signal was initiated by firing a .22 caliber hammer-actuated Ramset HammerShot construction tool. This tool is comparable to a spike driver (Table 1). .

E*quipment*

| | |
|---|---|
| CR1 Hydrophone | Captures frequencies from below 1kz to 68kz and operates at wide range of temperatures. The CR1 hydrophone is a multi-purpose microphone. It is made for listening to both very loud noise (such as piling) and quieter noises such as cetaceans. The leads are 15m long. |
| 4.5HZ Geophone | Captures seismic frequencies from high kilohertz to low. The frequency response for this system drops of at around 2khz. The leads are 30m long. |
| Tascam DR44WL | Basic recorder with external and internal microphones. |
| USB DualPre | Amplifies the frequencies and is tailored to use with both frequencies. |
| Hammer activated Ramset HammerShot | A high-powered stud driver. 0.22 Caliber shot is around 140dB, somewhat is variable depending on the force of the hammer blow. |

Table 3: The equipment we used came recommended for the hydrophone set-up. We had to make sure that they would work for our geophones. We had to individually put together the cables. More specifics and procedural notes see Appendix A.





Figure 4. Equipment used in this study. Top left, TASCAM DR-44WL Recorder, top right, A.R.T USB Pre-Amplifier, bottom left RT Clark 4.5hz Geophone, and bottom right Cetacean Researchs CR1 Hydrophone.

## ***Analysis***

For the analysis of the signal we used a variety of different analysis software. We needed to have a program that could gives a view to the signal and produce workable data in the form of a CSV file. We used different programs for different stages of the analysis. We used the open source Praat and Sonic Visualizer to view the signal as a waveform, spectrogram, and to find the formants. We performed additional data analysis in Microsoft Excel.

## ***Experimental Set-up***

### *Woodfibre Set-up*

At the Woodfibre site, we arranged four hydrophones and two geophones in a line across an area designated to be the future site of the natural gas liquification tanks, shown as a blue line in figure 2. We used this type of set-up to record the signal as it passes from the source, which is G1 in the schematic, to the water, shown at H2. Sensors G1, G2, G3, and G4 were placed in the rock by drilling a ½" hole in the asphalt substrate using a rock drill. Bags of sand were also placed on top of the geophone sensors to muffle the outside noise that would otherwise mask the signal. The distances between the geophones were approximately 13 m apart with some variation due to the type of rock that was available. The input on the recorders were set to 50, the preamplifiers were set to a gain of 35 for this test, the level was set at 7.5, and mix was set at 5. The recorders were manually started simultaneously, allowing for direct time series comparison of the captured signals

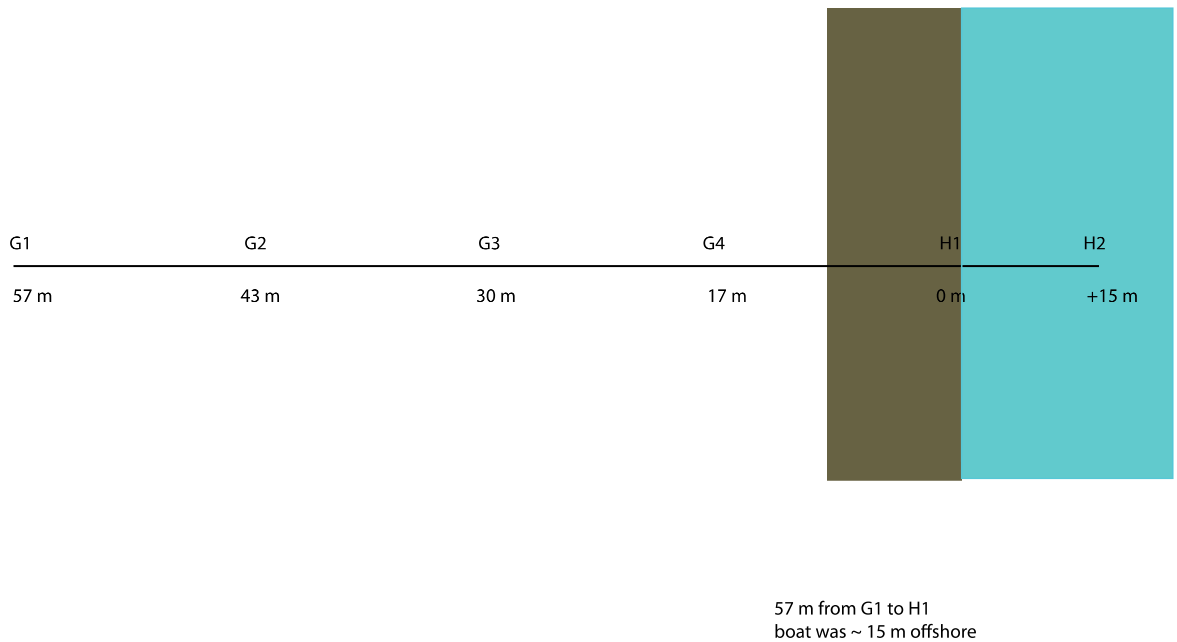


Figure 4: The schematic of the set-up at the Woodfibre LNG site. The brown coloration shows the dock and the blue indicates the water. Geophones are denoted as G1, G2, G3, and G4 and Hydrophones H1 and H2.

At G1 we produced the signal using a .22 caliber hammer shot. We used a boat to deploy H2 in the water at a depth of 5m, which was the depth that H1 was deployed off of the dock (noted in brown on Figure 4). Deploying the sensors at 5m kept the sensors below the surf zone to reduce interference from the waves. Waves can disrupt the transmission by moving the sensors in the water and the swell can make conditions for the equipment operators unsafe.

*Nexen Beach Set-up*

To capture the signal at Nexen Beach we used a total of five sensors. We used three geophones and two hydrophones; these were set up very similarly to the set-up at Woodfibre as shown in Figure 4.

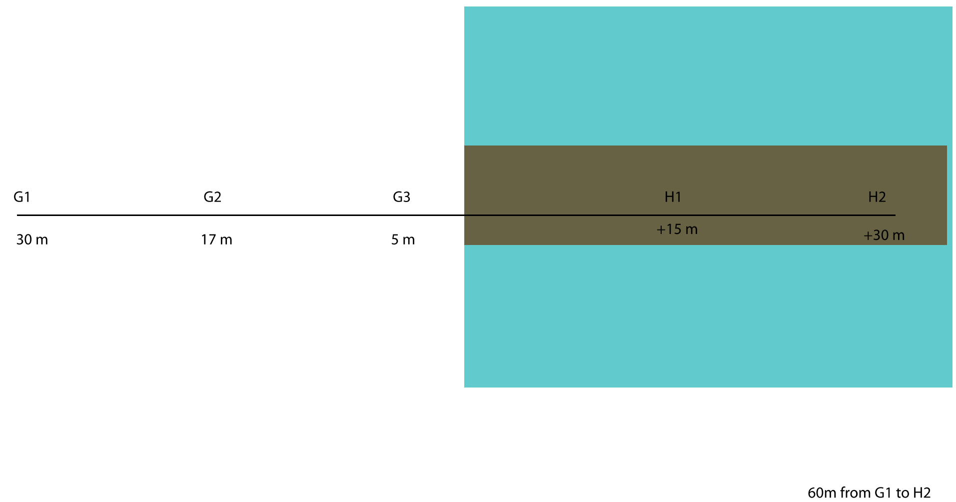


Figure 5: The schematic of the set-up at the Nexen Beach site. The color brown indicates the pier and blue indicates the water.

Like the set-up at the Woodfibre LNG site we used an array of sensors to capture the signal, geophones G1, G2, and G3 were placed on shore 30m, 17m and 5m, respectively. Hydrophones H1 and H2 were hung off of the pier (noted in brown) at a distance of 15m and 30m from shore. H1 and H2 were deployed at a depth of 5m. Setting them at this depth allowed the recording to take place below the surf zone to minimize the interference with the hydrophones. Again, to minimize interference with the geophones we drilled ½" holes into the asphalt substrate and covered them with sand bags.

The inputs, level, and mix on the recorder and preamps were set at gain of 35 for this test, the level was set at 7.5, and mix was set at 5, which allowed the data to be the consistent. We simultaneously started the recorders, which allowed us to obtain time data for the signal to pass through each individual sensor. We produced the signal at G2 using a .22 caliber hammer shot.

## RESULTS

We performed the experiments on the proposed Liquefied Natural Gas facility site at Woodfibre on the west side of Howe Sound and the second at Nexen Beach, on the shore of Howe Sound in the town of Squamish BC. We produced the signal using the Ramset Hammer Shot, which is comparable to the spike driver in Table 1.

### *Nexen Beach Tests*

At Nexen Beach, we detected an acoustic signal at G1, G2, G3, and H1 but not at H2. An example of the acoustic signal passing through sensor H1, the hydrophone that was deployed 15m from the shore (Figure 6). We found a signal amplitude of approximately 0.1 mV in the water.  Figure 6 below is the signal passing through H1, which is 37m away from the initial shot. As is pictured the waveform of the signal peaks at just below 0.1 mV.  The signal is interpreted as a sinusoidal wave, smooth repetitive oscillation; common for this type of acoustic signal.

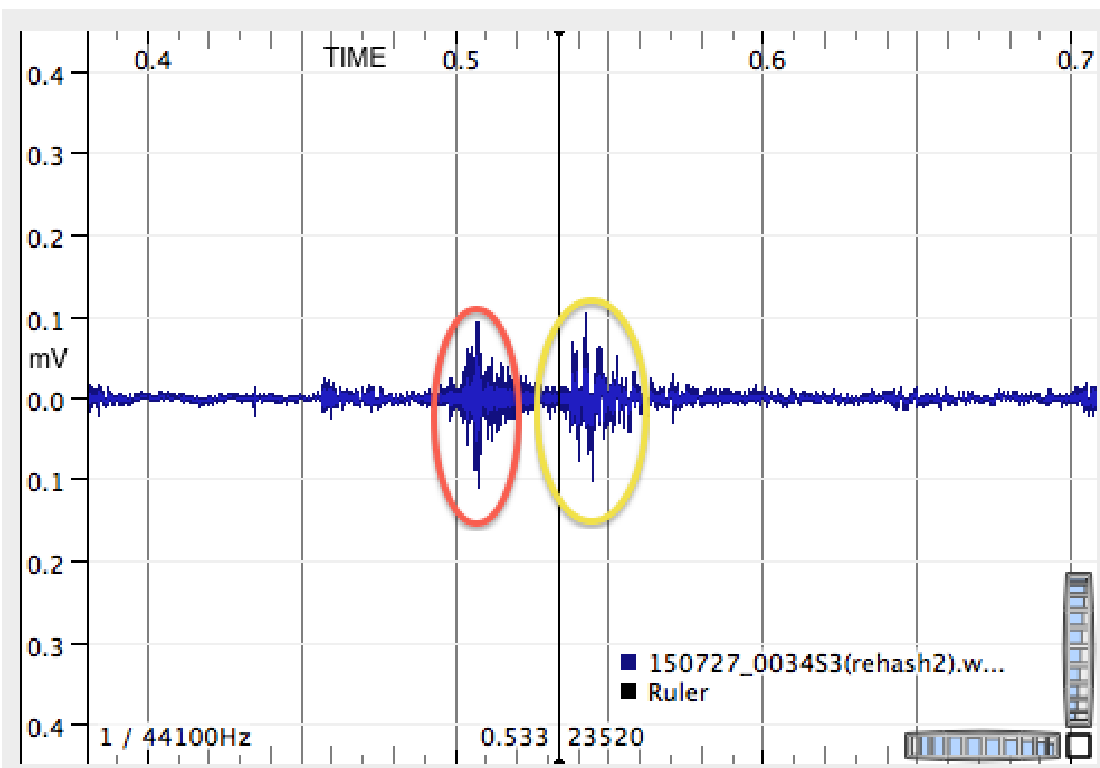


Figure 6: The signal as a waveform when it passes through H1 at a depth of 5m. We see the amplitude as mV (millivolts) on the Y-axis and time on the X-axis. The red oval is showing the initial signal and the yellow is showing it as it goes past. This image was modified from Sonic Visualizer.

Looking at the signal as a waveform tells us some about the signal we are looking at but there are many ways to view a sound. Below (Figure 7) is an image of a waveform and a spectrogram, a representation of the spectrum of frequencies through time.

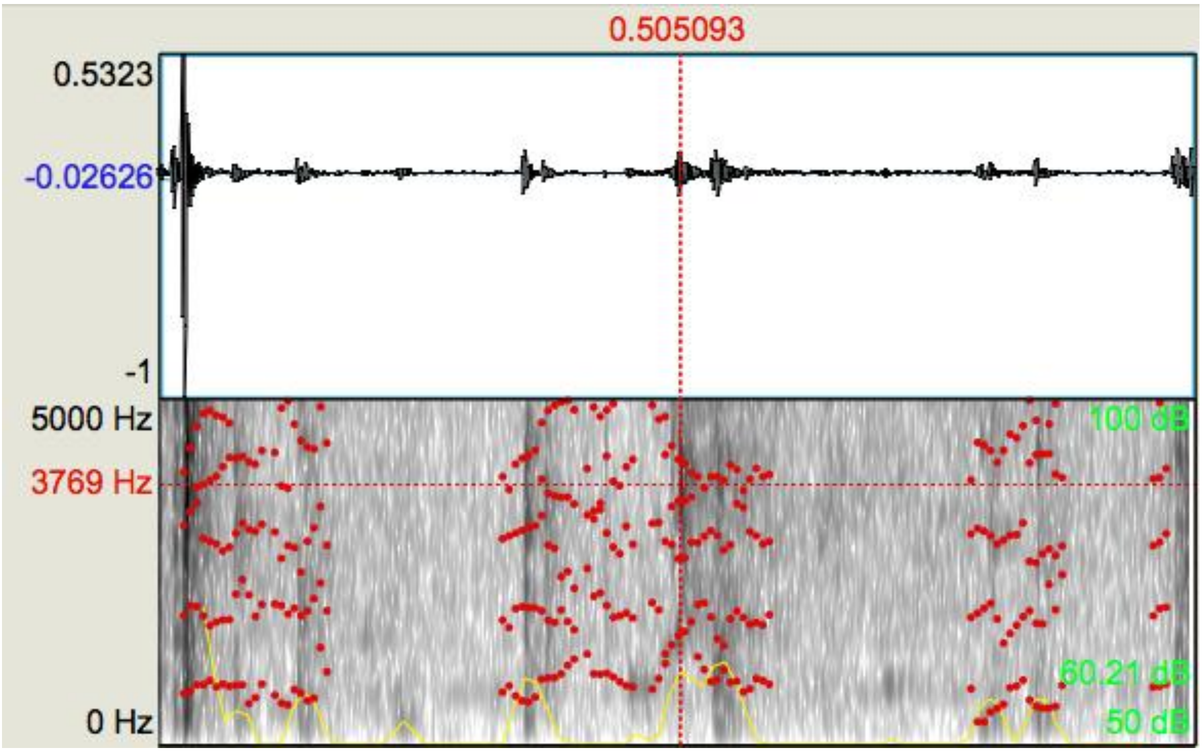


Figure 7: This image is showing a waveform of the signal as well as the spectrogram. Axes are showing Hertz (hz) and time. The grey background is the different frequencies, the darker the color the greater the frequency. The red dots are the formants, which is showing us the bands in the frequencies. The yellow line in the image is the waveform (figure 6). The decibels are shown as the green letters from 50dB to 100dB.

Looking at the spectrogram in Figure 7 the signal from H1 is seen as a series of red dots. The dots represent formants, showing the range of peak amplitude in the frequency spectrum. We can see bands by the lines of red dots they form on the spectrogram; the bands are formed by the red dots themselves in a series. For this particular site we can see that the frequencies and signal stay lower than 5000hz or 5khz, which is considered to be low. We also see dB (decibels), represented in the green lettering. Shown at the intersection of the red crosshairs that the signal is at 60.21dB, indeed higher than the ambient site noise of 50dB. This spectrogram shows the formants and frequencies but fails to show us any distinct high/low frequencies in decipherable color, for this we use figure 8. In Figure 8 we see a higher range of frequencies denoted in the brighter red colors as shown in the black oval and the Hz is shown the y-axis on the left of the figure. The difference between lower and higher frequencies could have effects on different species of animals in

Howe Sound. This is dependent on the levels that these frequencies present themselves. Therefore, the louder the sound the larger the effect.

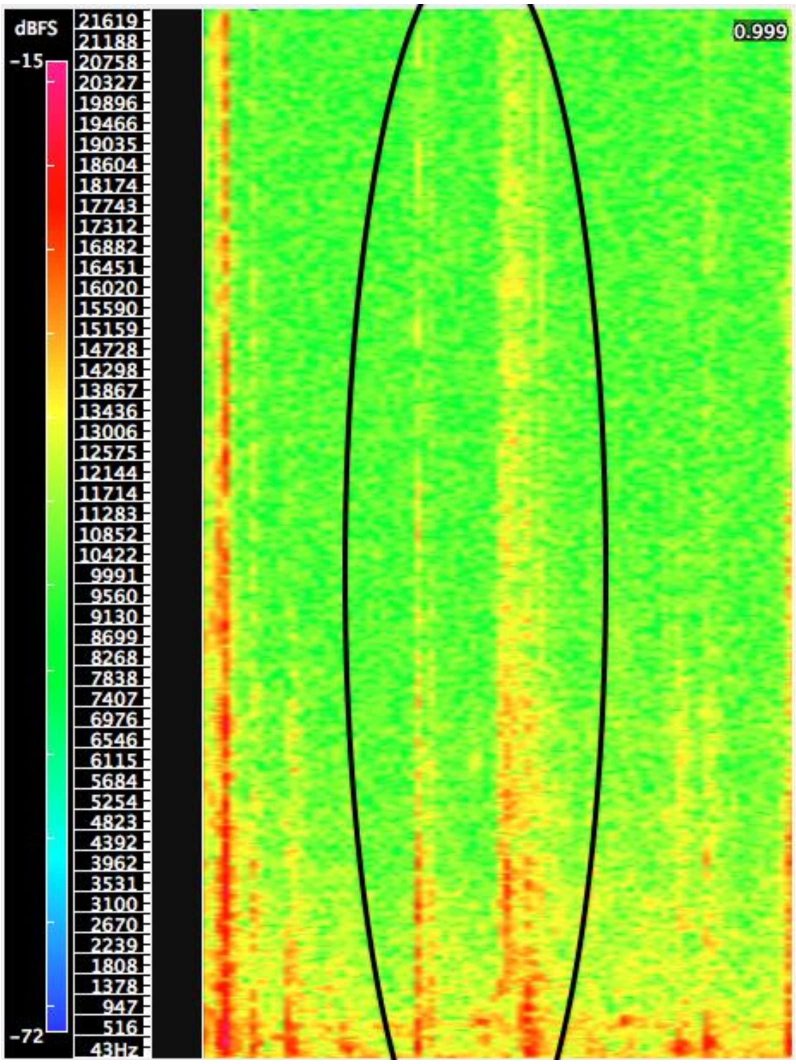


Figure 8: A spectrogram of the signal using Sonic Visualizer. The lower frequencies are in the warmer colors and the cooler colors are the lower frequencies.

We then took the data from all the sensors and plotted them on one graph to create a time series as the signal passes through G1, G2, G3 and H1 (colors denoted on side of graph). We see that the max amplitude is larger then 1 millivolt, although in reality this number could be much greater. What's interesting to observe is the difference in amplitude of the signal from sensor to sensor. The signal occurs in less then a 10th of a second. The amplitude at G1 is the largest, as stated before, and most prominent even though the signal was produced at G2. We see that G2, in red, is much lower, which could've been caused by the either a malfunction in equipment or the concrete in which it was located. However, G3, which is denoted in green, signal was much smaller and actually appears behind the rest of the data. This could be due to the rocks where it was placed being unconsolidated large sized beach pebbles.

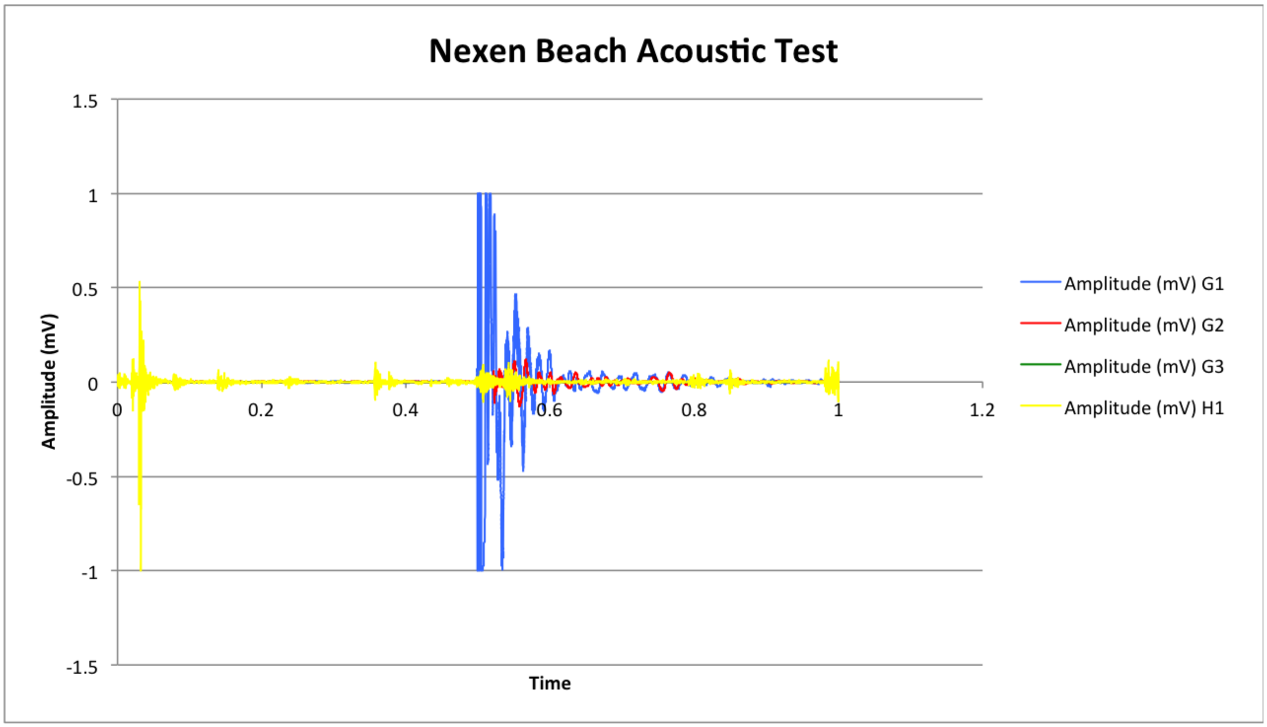


Figure 9: This graph shows us that the signal travels through the site, in all the sensors, and into the water where it has the possibility to cause issues. The data from G3 doe's not appear as the signal is to low.

## Woodfibre LNG Tests

The tests we ran at the Woodfibre LNG site were set up in very similar way to the ones at Nexen Beach. However, with our hydrophones, H1 and H2 in figure 4, we were unable to find any significant data in the analysis phase. This was due to the fact that the ambient noise, the regular noise in the water, was too great. However, there are conclusions you can draw from this result.

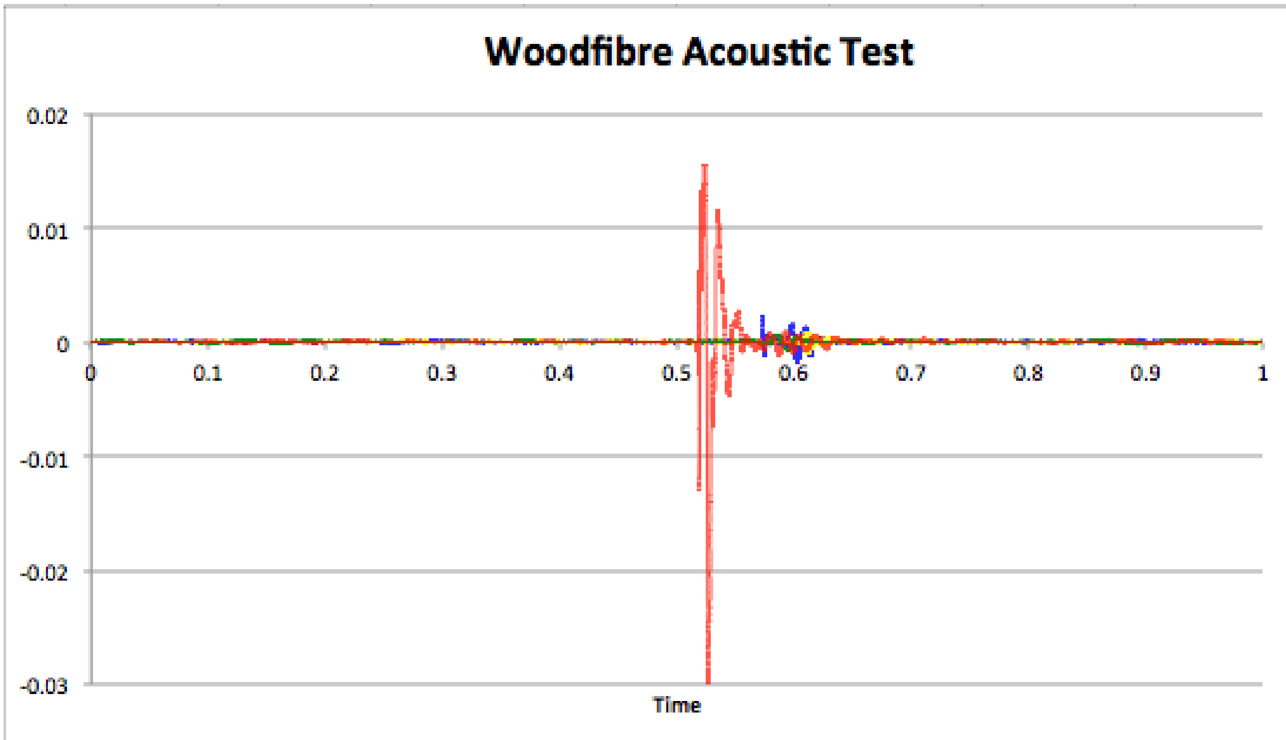


Figure 10: The signal as it passes through the Geophones at the Woodfibre site. We can see every signal at different amplitudes. G1 is denoted in blue, G2 in yellow, G3 in green, and G4 in red. The shot was initiated at G3.

The red waveform is the signal passing through G4. Geophone G4 was placed close to the water at 17m onshore. The signal appears to be just over 1mV, this is a low number. The signal was initiated at G3 during this test but G3 did not have the strongest signal, this could've been for various reasons such wither the pre-amp having malfunctioned or a change in the geology.

The time shows us that the signal passed through all sensors in less then a $10^{th}$ of a second. The areas that the geophones were placed in ground were all asphalt, which helped the transmission pass more easily as is evident by the difference in amplitude at G4.

In the water we did find interference on the hydrophone data, which during analysis we found that it was ambient noise from the area. Sources of this noise could be output from the sites hydro plant, who's outflow could be the reason for the noise in the data. However, just because there is not a signal in the data doe's not mean that it was not there.

## Discussion

As the results suggest the land-initiated noise signal does appear to be present in the water at Nexen Beach. The signal travels from the source, at G2, which means that any construction or work on that site has the potential to cause disturbances. The signal from the HammerShot is considerably smaller then the potential signal from a much larger or more powerful tool.  Due to the make up of the site the values of the amplitudes can be different. When it is, for example, concrete-to-concrete the signal can transmit much quicker then from concrete to loose, unconsolidated rocks, such as, riprap like what found at G3 at Nexen Beach. Although the Hammershot was not loud or powerful enough to produce any damaging numbers but that is a small tool that produced a relatively small signal. A larger tool would definitely produce a larger signal (Table 1) and, given that the sound does transmit from land into the water, could cause environmental damage.

This could also be inferred for the Woodfibre site, although in our experiment we did not find a signal in the water. The acoustic conditions of the near shore environment were loud enough to mask the signal. However, there could be other factors involved in not finding the signal such as a malfunction in the hydrophone or the off levels on the equipment.  What we're looking at is the noise that H1 picked up off of the dock at the Woodfibre site. The ambient noise from the site was loud enough to mask any signal. If there was to be a signal it would've appeared between 5:08 and 5:09 on the X-axis.

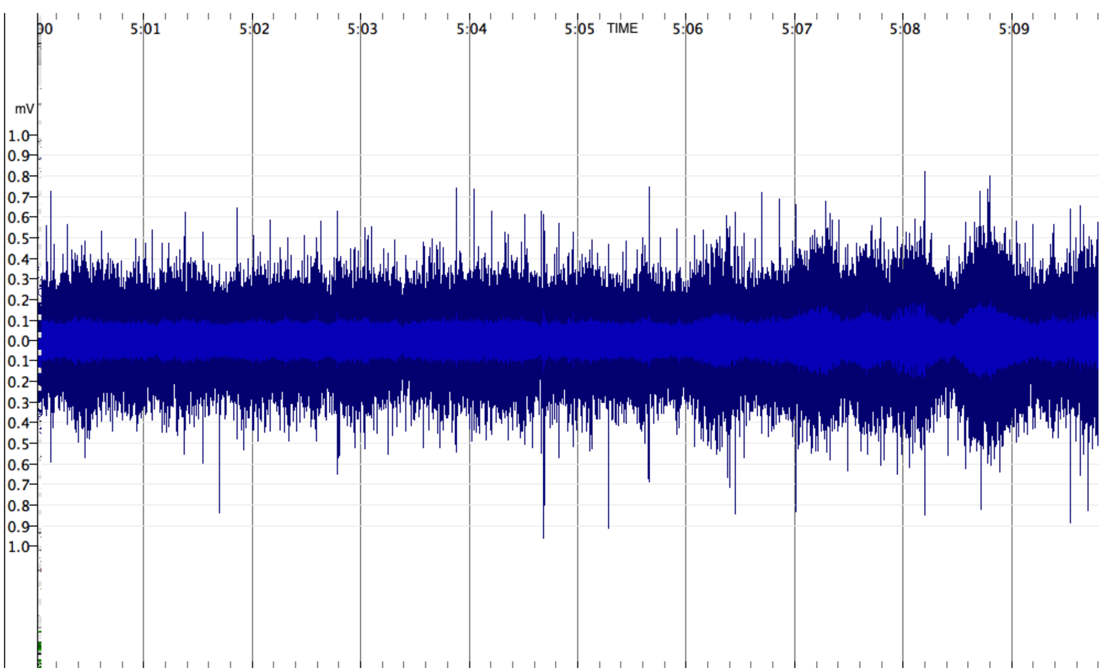


Figure 11: This figure is showing us the waveform from H1 at the Woodfibre site. There is no distinct signal, even after analysis we could not distinguish about the ambient, normal water noise, and any signal.

With the knowledge gained from the preliminary runs of this experiment, we have the base to run better, more sophisticated experiments that could give more compelling results. However, we have successfully set up a system and collected preliminary results that would warrant further testing of this experiment at the sites, or more new proposed sites. After this study we can say that the disturbance created by our experiment shows the potential for these signals to be heard by aquatic life. Although, with a larger signal the possibility for the disturbance to cause harm or divert marine populations.

This study was to test out the experiment and to investigate whether or not the construction and operational noise had the potential was transmitted into water. We have found that this is the case for the Nexen Beach site with the potential to also occur at the Woodfibre site. To collect stronger, more compelling results we would want to find out how much noise is made from larger equipment, the industrial noise just in the water, and then also how to mitigate the issues of industry noise.

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# Appendix

## Equipment

Finding the perfect system was important and the most important thing to make the experiment work. Here is a list of the equipment we used.

2 CR1 Hydrophone set-ups
4 4.5hz Geophones set-ups
1 Ramset 22-Caliber Shot plus extra shots
6 XLR cables
4 Dual USB Preamplifiers
4 Tascam DR44WL recorders

### CR1 Hydrophone

To record the sound under water we needed a hydrophone that would work within the frequency ranges we were looking to find. The CR1 Hydrophone from Cetacean Research in Seattle Wa, was a good choice because its specifications fall within what we required. It captures frequencies from below 1kz to 68kz and operates at wide range of temperatures. The CR1 hydrophone is a multi-purpose microphone. It is made for listening to both very loud noise (such as piling) and quieter noises such as cetaceans. To use the hydrophone the ¼ inch lead plugs into the DualPre. The frequency response stays even at even until it reaches the higher frequencies. The leads are 15m long.

### 4.5 HZ Geophone

To capture the transmission within the rocks we needed a microphone that would pick up seismic signals. We chose 4.5hz Geophones from R.T. Clark in Oklahoma City, OK. The specifications on these were almost exactly the same as the CR1's, which helped us keep the integrity of the experiment. The frequency response for this system drops of at around 2khz. The leads are 30m long.

### ART Dual-Pre

Turn the power on however DO NOT turn on phantom power as this could possibly overload and blow out he sensor. All the cables have to lead into the corresponding plugs (eg. Left to left to sensor) Set the dial to the exact gain and after running the data you can adjust accordingly on your next test run.

### TASCAM DR-44WL

Turn it on and select the channel for the external microphone. Channel 3 and 4 are the correct ones. The leads for the sensor have to lead into the bottom plug-ins. To start the recording process turn on record then hit it again to begin. To stop recording either hit record again or hit the stop button. The stop button will make sure the recording is saved and stopped. It is important to catalog the recordings so we will take a few minutes between tests to make sure this is done.

*All of the equipment needs to be set to the same gain, level, and input.

Setting up the System

To set up each system there needs to be 1 DualPre, 1 XLR cable, 1 TASCAM recorder, and one sensor/microphone. The microphone plugs into the input on the DualPre, then the ¼ inch end of the XLR plugs into the corresponding (left or right) monitor output. The male end of the XLR will then plug into the same corresponding female plugin on the TASCAM. It is important that all the dials are turned to the same number i.e. gain, input, and level.