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PREDICTED SOUND LEVELS ASSOCIATED WITH CONSTRUCTION ACTIVITIES AT KYLEAKIN

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1 INTRODUCTION

This note looks at the acoustic impact of construction activities at the Marine Harvest site at Kyleakin, Isle of Skye. Construction will consist of onshore building activity and an extension of an existing pier. The site looks out into the Inner Sound of Raasay and has two acoustic sensitivities:

- The high levels of sound close to the site may impact on marine animals, particularly mammals; and
- The UK MoD have test and evaluation ranges (BUTEC and Rona) to the north of the construction site and high levels of sound may interfere with their operations.

This document will set out these construction activities and list the possible sound levels they may produce in the water. The sound levels that may impact the BUTEC range are set out and a management procedure suggested to minimise the impact of construction activities on range activities.

In this document the term Source Level (SL) is used to describe the sound level radiated from a sound source. In many areas of underwater acoustics this is defined as the sound level referred to a distance of one metre, i.e. it would be the sound level at one metre from an equivalent point source. In many applications, this is not a physically possible measurement because of the size of the sound source but it is a convenient metric to use when carrying out acoustic modelling. This metric arose from the sonar field where the sound source is often small.

The use of one metre becomes even more meaningless when considering an extended sound source such as a pile and many reports use the sound level referred to 10 metres instead. Where reporting the work of others we have used the units from the original work. For modelling purposes the conversion factor is 20 dB. For an excellent discussion on this problem see Section 6.2 in Robinson (2014).

2 SITE CONSTRUCTION AND SOUND LEVELS

2.1 Pile Driving

The ‘Marine Works Description’ document (Rea, 2016) for this project lists the use of vibro-piling and impact piling driving sheet piles (14”/356mm) and some large diameter tubes (1.22 m dia), but does not indicate the size of the impact hammer to be used.

Note that there is no reliable, published method of relating noise in the water to pile size, pile type or hammer energy. Matuschek & Betke(2009) suggest in Figure 2 that the source level rises with 20*Log_{10}(diameter), with the source level for a 1 m pile used as the reference. However, it is not possible to relate the reference level to an absolute level in other applications. For this note generic figures derived from published work will be used to estimate the expected sound field. Note that there is insufficient published data covering a variety of pile sizes and types and for different environments to be able to set out a “typical” shallow water source level for pile driving.

Many measurements have been made of pile driving noise but the majority are measurements made during the construction of offshore windfarms. This involves driving very large (Typically 4-6 metres diameter) circular piles in open water. This data is not applicable to this project, which will be driving small cylindrical and sheet piles close to shore.

Matuschek and Berke (2009) reported data for a 1 metre diameter pile and showed a peak level of 183dB re 1uPa at a range of 750 metres. Rodkin and Pommerenck (2014) provided data for a variety of piles being struck by an impact hammer. This included data for four types of sheet pile:

Table 2-1: Sheet Pile Impact Sound Levels

Pile type	Water depth (m)	Peak sound level @ 10 metres
12” H pile - thin	<5	190 dB re 1uPa
12” H pile - thick	~5	200 dB re 1uPa
14” H pile - thick	6	208 dB re 1uPa
24” AZ pile	~15	205 dB re 1uPa

Unpublished data from sheet piling operations using impact piling during the Nigg Fabrication Yard development in the Cromarty Firth in 2014 gave peak sound levels around 205dB re 1uPa at a distance of 29 metres from the pile. At 750 metres the highest sound level was 167dB re 1uPa.

The spectrum of piling noise shows peak energy between 100 Hz and 2 kHz depending on the type of pile, hammer and seabed.

There is very little applicable data published on vibro-piling but it has been suggested that noise levels are typically 15-20 dB less than impact piling for the same pile size. Thalheimer et al (2014) reported on vibro-piling used to strengthen the bank of a waterway and showed a sound level of 155dB re 1uPa at a distance of 32 metres from a driven pile in a water depth of 2 metres. Rodkin and Pommerenck (2014) reported a peak sound level of 165dB re 1uPa at a distance of 10 metres from a 12" H pile being driven in 5 metres of water. They also reported the peak sound level of 182dB re 1uPa from a 24" AZ pile at 10 metres distance being driven in 15 metres of water.

Unpublished data from the Nigg Fabrication Yard development recorded a highest peak sound level from vibro-piling of 159dB re 1uPa at 750 metres compared with 167dB re 1uPa for impact piling of the same type of sheet pile.

Rodkin and Pommerenck (2014) suggest that for vibro piling the Sound Exposure Level (SEL) is only 15dB below the peak level.

All authors commented on the unpredictable variability of the peak sound levels which could vary by up to 10dB during each pile insertion and from pile to pile.

2.2 Dredging

The 'Marine Works Description' document (Rea, 2016) sets out that dredging will either use trailing suction hopper dredger (THSD) or backhoe dredging (BHD). THSD operations use a ship deploying a suction hose onto the seabed to suck up the seabed material. This hose is dragged slowly across the seabed as the ship moves. BHD operations use a bucket deployed from a crane either on shore or from a ship. The bucket is then dragged across the seabed to gather material which is then hoisted on board.

Jones and Martin (2015) provide a summary of the known sounds from these two types of dredging. Both methods are deployed from a ship which will itself put sounds into the water as it operates. Figure 1 in Jones and Martin (2015), reproduced from Robinson et al (2011), shows the operating noise from 7 dredgers presented as third-octave source levels. These range from 160 up to 180dB re 1uPa^2 m^2 over the range 50Hz to 10kHz. Note that the quoted source level is the dipole source level. For acoustic modelling the monopole source level is required and this is typically 6dB lower. The dredging operation does not increase the noise above the low frequency levels from the ship but above 2 kHz there can be a significant increase in level with an increase of 30dB observed from one ship at 16kHz.

There is less information on backhoe dredging noise levels. Only two studies were identified by Jones and Martin (2015) and they caution that different methodologies were used to calculate the source levels presented. The highest source level measured was 179dB re 1uPa @ 1m and was a wideband measurement that occurred when the dredge was extracting sediment. Most of the measurements were lower than this and were in the range 162 to 175dB re 1uPa @ 1m.

Observations during dredging for the Nigg Fabrication Yard development suggested that vessel noise was the dominant noise source. The dredging involved a THSD and a tug dragging a plough to loosen the seabed. Above the vessel noise were occasional loud transients as the plough or suction hose struck a seabed obstruction. At 600 metres range the ship noise peaked at 150dB re 1uPa while the impact transients peaked at 160dB re 1uPa. These transients were observed at an average rate of one per 10 minute period.

2.3 Vessel Movements

There are many vessel movements within the immediate area as ships enter and leave Kyle of Lochalsh and also transit around Skye. It is unlikely that vessel movements associated with the construction site and/or operation of the site will add significantly to this general noise level. However, any construction/operational vessel movements from/to the north may need to route away from the BUTEC Range area.

2.4 Rock Placement

From personal observation (Ed Harland) at other similar construction sites the only activity that could generate significant amounts of underwater noise is the dumping of boulders from a tipper truck into the water or up against sheet piles. There are no documented noise levels from such activities, but it will be a one-off transient for each load, extended in time and mostly with medium frequency content. It is unlikely to have peak amplitudes that could cause concern for animal safety.

3 MITIGATION MODELLING

3.1 Impact Piling

From the data presented above the worst case sound level for impact piling is 208 dB re 1uPa at 10 metres (Rodkin & Pomerenck, 2014). This project will use the same size pile (14” or 356mm). The data from Matuschek and Berke (2009) suggests that for a one metre pile the sound level will be very similar. Since the same hammer energy will be used to strike the combi pile and Robinson (2014) suggests that the hammer energy is the main factor affecting the sound level in the water, the assumption is made that this level will be applicable to this type of pile as well.

Using the standard propagation loss formula of:

$$PL = SLF * Log_{10}(R) + \alpha * R$$

Where:

- PL is the propagation loss in dB;
- SLF is the spreading loss factor;
- R is the range in metres; and
- α is the attenuation factor in dB/metre.

The Spreading Loss Factor (SLF) provides the loss due to spreading of the wave as it propagates through the water. For open water where spherical spreading of the wave-front is likely, SLF is 20. In very shallow water where the wave interacts with the sea surface and seabed the loss can be less due to reflections of the wave constraining the spreading. If the seabed is rigid and flat and the sea surface is also flat then cylindrical spreading is a better approximation and SLF is then 10. A widely-used approximation for shallow water with a seabed that is not flat or rigid is to use an SLF of 15 (e.g. Robinson (2014)).

It would be better to model the acoustic path in more detail in order to get a better approximation of propagation loss taking into account seabed sediments, surface roughness, bathymetry, vertical and horizontal sound velocity profiles and the effect of the islands. However, at the present state of acoustic model development this level of modelling is not possible. It is possible to leave out some of the complexities such as the effect of the islands and horizontal sound velocity structuring of the water. But this makes the modelling less accurate and it is then questionable whether the results are any better than the approximation used here. Since it is likely that the simple approximation will provide a worst case i.e. highest possible sound level, then the SLF=15 approximation has been used in this note.

The attenuation factor is a combination of viscosity effects and interaction between the acoustic wave and salt molecules within the sea water. The loss occurs in the water column and is not affected by the seabed or sea surface. At low frequencies the effect is very small and can be ignored (e.g. at 1 kHz there is a loss of just 0.05 dB at 1 km) but at high frequencies the attenuation can be a major contributor to propagation loss (e.g. 35 dB/km at 100 kHz). The effect of this term is to progressively remove higher frequency components as the wave propagates. At the short ranges considered for impact on marine mammals the contribution of this term is generally ignored as most of the energy from piling or dredging is concentrated at lower frequencies.

Based on the assumption that the α*R term is negligible then the predicted sound levels at various ranges are:

250 metres	185 dB re 1µPa
500 metres	182.5 dB re 1µPa
750 metres	180 dB re 1µPa.

When judging environmental impact the SEL is often used instead of peak pressure. The sound exposure is given by:

$$E = \int_{t1}^{t2} p^2(t)dt$$

The SEL is then given by:

$$SEL = 10 * \log_{10}\left(\frac{E}{E_0}\right)$$

Where E_0 is a reference exposure, usually taken as 1 µPa^{2}s.

The calculation of SEL requires a time interval which is usually taken as the length of the pulse in the water. This is very dependent on the type of piling and the acoustic environment. The calculation is usually made from measured pulses in the water. However, from published data the SEL is typically 25 dB below the peak level from impact piling so at 500 metres range the possible SEL would be 157.5dB re 1µPa^{2}s.

3.2 Vibro Piling

Taking the worst case from the data discussed above the sound level will be 182 dB re 1 µPa at a range of 10 metres (Rodkin and Pommerenck, 2014). Based on an SLF of 15 this will give the following sound levels at various ranges:

250 metres	161 dB re 1µPa
500 metres	156.5dB re 1 µPa
750 metres	154 dB re 1 µPa.

Note that the fundamental frequency of vibro piling, typically around 25 Hz, will not propagate in shallow water. However, it will enter the seabed and may propagate over significant distances.

3.3 Dredging

If a THSD dredger is used then the sound generated in the water will be that of a typical ship of the size used. This will typically be in the range 155-175dB in third-octave bandwidths across the frequency range 100Hz to 2kHz (Robinson et al, 2011). The transients identified during the Nigg dredging peak at around 160dB re 1µPa @ 1m.

For ship-based backhoe dredging the worst case source level will be 179dB re 1uPa @ 1m. This results in the following sound levels at various ranges:

250 metres	158 dB re 1µPa
500 metres	153.5dB re 1 µPa
750 metres	151dB re 1µPa.

For shore based backhoe dredging the levels will be lower because the machinery noise will not be coupled into the water but it is not possible to estimate the reduction compared with ship-based dredging.

3.4 Other Activities

The only other construction activity that could produce sound levels in the water that could impact the marine environment would be if blasting needs to be employed both on land or sea. If this should prove necessary then a separate sound level report will be necessary.

3.5 Recommendation

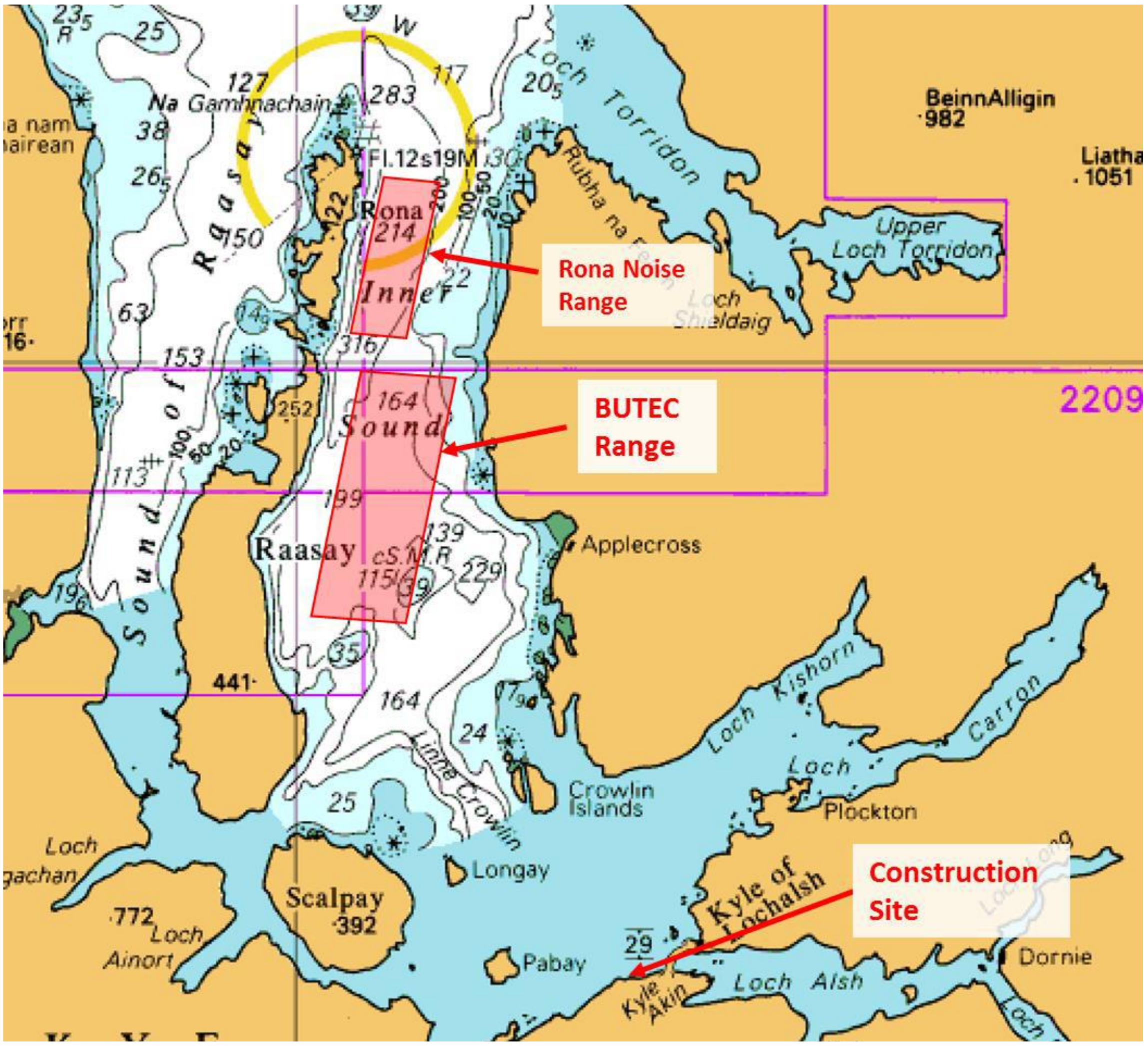
The figures given here are based on inadequate information because of the paucity of published data. It is important that the actual levels in the water are checked once work commences to ensure an optimum mitigation strategy is in place.

4 BUTEC RANGES

4.1 Location

The BUTEC range is described in a data sheet (BUTEC, 2016) available from QinetiQ. The range is located in the Inner Sound of Raasay to the north of the proposed construction site. Figure 4-1 shows the layout of the area. The range is used by the UK MoD “to track ships, submarines and vehicles with a tracking accuracy better than 3 metres within the range area”.

A second range associated with BUTEC is the Rona Noise Range. No details of the exact location of this range could be found but it is believed to be located in the area shown in Figure 4-1.



Rona Noise Range

BUTEC Range

Construction Site

Figure 4-1: BUTEC and Rona Ranges

The BUTEC range consists of 24 hydrophones and associated underwater telephone systems located on the seabed within a designated area within the Inner Sound as shown in Figure 4-2.

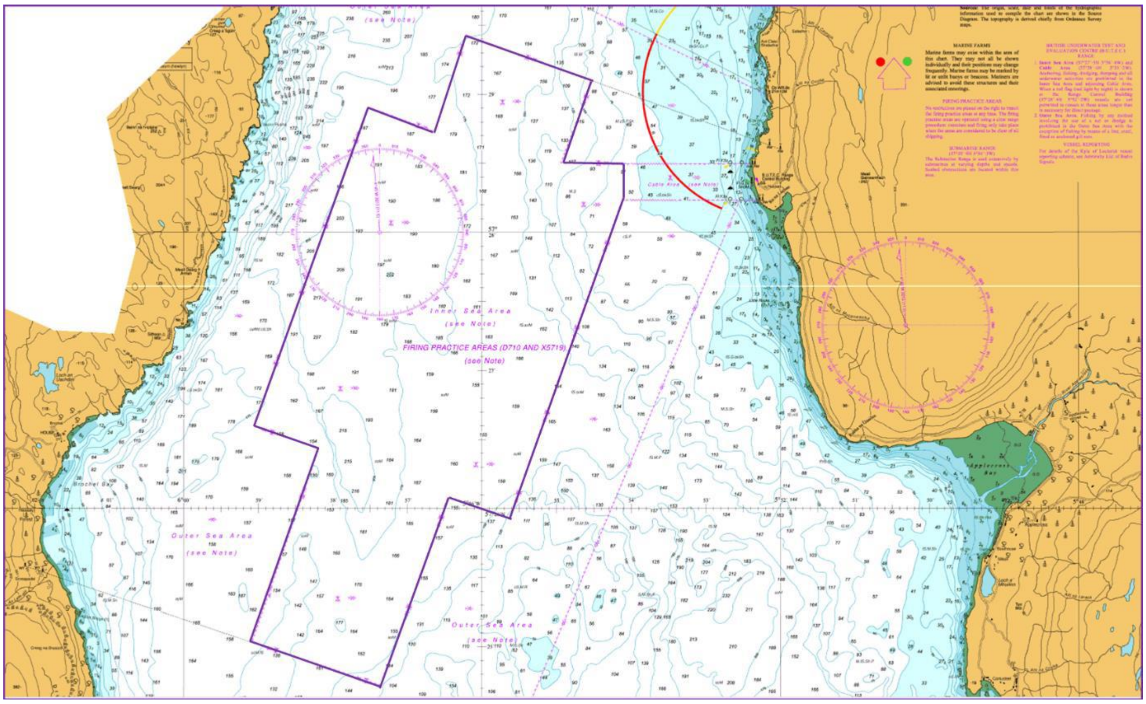


Figure 4-2: Location of BUTEC Range

The hydrophones are deployed within the box outlined in purple (the Inner Sea Area (ISA)) in Figure 4-2. There is a further range area outside of this box (the Outer Sea Area) which can also be used by exercise participants but at reduced tracking accuracy. The nearest point of the ISA to the construction site is 19.5km. Note that most of the ISA is obscured from the construction site by the Crowlin Islands as shown in Figure 4-1. There is a narrow passage between the Crowlin Islands and the mainland and this path is 22km from the construction site to the central part of the ISA.

The Rona Noise Range also uses hydrophones deployed on the seabed and is used to measure the noise emitted by vessels passing across the range. No details of this range or its exact location could be found but a submarine range area is declared on the Admiralty charts so it is likely that the hydrophones are located within this area. This area is shown in Figure 4-3. This area links into the top of the BUTEC Outer Sea Area. Assuming that the Rona range is similar to other noise ranges then it is likely that it will consist of an array of hydrophones spread across the seabed in a regular array.

There is no direct path from the construction site to the Rona range area but the least obstructed path is through the passage between the Crowlin Islands and the mainland and is 29km in length. It is likely that the path to the hydrophones will be longer and the diffraction angle will be greater with increased path loss.

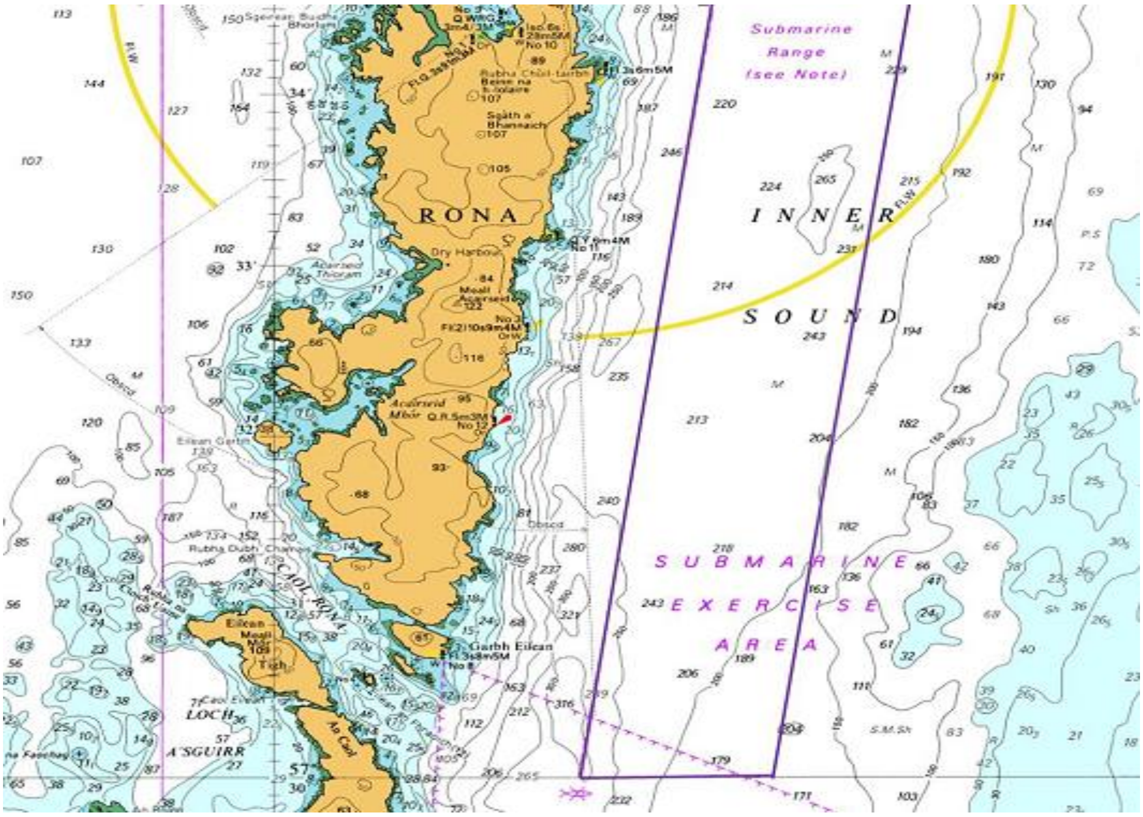


Figure 4-3: Likely Location of the Rona Noise Range

4.2 Acoustics - Tracking

The acoustics of the BUTEC tracking range are described in a data sheet (BUTEC, 2016) available from QinetiQ. The tracking range requires that any vessel to be tracked carries an acoustic pinger. These have a recommended source level of 193dB re 1uPa @ 1m and operate on one of five frequencies:

Table 4-1: BUTEC Tracking Pinger Frequencies

Channel	Frequency
Victor	11 kHz
Whisky	14 kHz
X-Ray	17 kHz
Yankee	20 kHz
Zulu	23 kHz

The pingers can operate with repetition rates of 0.8, 1.6 or 3.2 seconds, depending on the application. The transmission consists of a main pulse followed by a secondary pulse spaced in time by an amount dependent on the depth of the pinger.

The application note implies that the tracking receivers are sea-state noise limited and that the range can track with s/n ratios above 19dB. The receiver bandwidth is given as 4kHz.

4.3 Acoustics - Users

While the range is tracking users, the users may also be employing underwater acoustics as part of the test. These may include the following:

- Torpedo homing - Typically in the range 25-50kHz;
- Surface ship sonar - MF sonar in the range 3-8kHz / LF sonar in the range 1-2kHz; and
- Airborne sonar - Dipping sonar in the range 3-10kHz / Sonobuoys in the range 10-1500Hz.

4.4 Acoustics - Rona

There is no published information on the acoustics of the Rona noise range. However, assuming it is like other noise ranges, it will consist of an array of sensitive hydrophones just above the seabed. The frequency range of interest is likely to be 10Hz to 20kHz, although given the more specialised nature of this range the upper frequency limit may be significantly higher than this.

5 BUTEC MODELLING

Detailed modelling of the acoustic path between the construction site and the various parts of BUTEC is not possible. No existing models will accurately model the vertical and horizontal range-dependency required. Even approximate modelling will require a knowledge of the Sound Velocity Profile (SVP) along the acoustic path. The SVP data could not be obtained within the timescales of this report so assumptions have been made to ensure the worst case is addressed.

The frequency range of interest is very wide-ranging. The construction activities are likely to generate most noise at low frequencies but will have content going up to tens of kilohertz.

As shown above propagation loss is given by:

$$PL = SLF * Log_{10}(R) + \alpha * R$$

Where:

- *PL* is the propagation loss in dB;
- *SLF* is the spreading loss factor;
- *R* is the range in metres; and
- α is the attenuation factor in dB/metre.

For the purpose of this report an SLF of 15 will be used for frequencies up to 4kHz and an SLF of 20 for frequencies above 4kHz. In reality the losses are likely to be higher than this because of the obstruction of the Crowlin Islands and the shallows that surround them. It is also assumed that the sound velocity is constant across the area. However, there is one important exception to this assumption. In the spring and early summer there is possibility of a surface duct forming which will have the effect of reducing the SLF down to 10 as the waves will be trapped close to the surface and the loss will be closer to cylindrical spreading. This effect has a lower cut-off frequency which is typically around 1kHz.

It must also be remembered that in a complex area such as this with many islands and strong currents it is possible for the sound velocity to vary horizontally as well as vertically. This will have the effect of introducing horizontal refraction, i.e. the waves will be bent horizontally, which may mean that more of the southern end of the range area receives the direct path from the construction site.

Values for the attenuation factor are taken from Urick (1975). This factor varies with frequency and rises with increasing frequency. At 17kHz, the centre frequency of the BUTEC pinger range, it is typically around 3dB/km. Over a 20km path this adds 60dB to the propagation loss. At 1kHz the attenuation factor is typically around 0.05dB/km so there is only 1dB of additional attenuation on a 20km path.

Based on the above assumptions, the path loss to the southern end of the BUTEC range ISA will be 65 dB for frequencies below 1kHz. At the pinger frequencies used on

BUTEC it will be 146dB. For the Rona range the path loss for frequencies below 1kHz will be 68dB.

These losses can be altered by a number of factors and these are discussed below.

5.1 Factors that can increase path loss

Variations in the SVP can increase path loss.

Obstruction by the Crowlin Islands will significantly increase the path loss across most of the range areas.

If the factors affecting velocity of sound are frequency dependent then pulses which contain a wide band of frequencies will be increasingly distributed in time and the peak amplitude will be progressively reduced compared with the predicted figures. This effect is often seen below 1kHz.

5.2 Factors that can reduce path loss:

Horizontal variation in sound speed can bend the waves around the islands.

At low frequencies the sound may travel through the seabed rather than the water column and emerge some distance away. It is not possible to predict when, where or if this will occur.

A surface duct will trap sound near the surface and reduce the path loss.

5.3 Impact Piling

Using the level identified above we get a sound level at the southern end of the BUTEC ISA of 143dB re 1uPa. This represents the worst possible case and the actual level is likely to be significantly lower than this.

5.4 Vibro Piling

Using the levels identified above for vibro piling will give a level at the southern end of the ISA of 114dB re 1µPa. Again, this is very much the worst possible case.

5.5 Dredging

From levels shown above, the incremental sound due to dredging will not be heard at the BUTEC range. The impact transients will have a peak level of 95dB re 1uPa.

Note that at the pinger frequencies all noise sources will be below ambient noise and will not affect the tracking operation on the range.

5.6 Rona Modelling

There is no direct path to the Rona range so sound will arrive there by scattering from the seabed or shoreline. At low frequencies there may be a path via the substrate. It is not possible to model these paths using any existing acoustic model.

This means it is not possible to accurately predict the sound levels they will receive at their hydrophones. All we can say is that it will be less than that predicted using the simple models. Based on the levels predicted for impact and vibro piling it is very unlikely that the Rona hydrophones will receive signals via the in-water acoustic path. However, noise via the path through the seabed cannot be ruled out.

6 BUTEC MANAGEMENT

In the light of the above an arrangement needs to be put into place to allow construction activities to continue without impinging on the operation of the Ranges. The construction activities will not affect the range tracking. However, the low frequencies may impinge on the use of the BUTEC range area by units using low-frequency sonar, such as some frigates and aircraft dropping sonobuoys, so liaison with the range staff is important.

It must be noted that the short timescales for this report preclude detailed discussions with the BUTEC Range operator. These must take place before implementing this plan.

The Range normally publishes its programme in advance in the local newspaper so this will give guidance on when difficulties may arise.

A suggested procedure would be to contact Range Operations each morning to confirm their programme for the day and to get any changes to the programme for the following days. In the event of sensitive activities taking place on the Range it may then be necessary to negotiate time allocations for the construction activity.

During the early stages of construction work, particularly the piling work, it will be necessary to liaise with the Range acoustic team so they can use their hydrophones to measure the sound levels across the whole Range area and across the frequency range of interest to them to ascertain whether the construction activities are causing problems. This will need to be repeated as construction progresses as noise levels may change. This should apply to both the BUTEC and Rona ranges.

Vessels approaching and leaving the construction site should, where possible, route to the west of Raasay and Rona to avoid increased noise levels over the Range.

These arrangements need to be discussed with the Range management team before construction starts so that effective lines of communication can be established and both parties understand the difficulties each face.

7 REFERENCES

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We have used our reasonable endeavours to provide information that is correct and accurate and have discussed above the reasonable conclusions that can be reached on the basis of the information available.

8 APPENDICES

8.1 APPENDIX A (SITE MAPPING)

See separate document attached