Galway Harbour Company

Galway Harbour Extension

Environmental Impact Statement

Chapter 10

Noise & Vibration

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10 NOISE AND VIBRATION

10.1 INTRODUCTION

This chapter addresses the noise and vibration impacts of the proposed development. This chapter has been prepared by Biospheric Engineering Ltd.

There are three sections to this chapter:

- Airborne Noise
- Underwater Noise
- Vibration

The sections dealing with Airborne and underwater noise both refer to noise levels in decibels. It is important to remember that sound pressure is actually measured in Pascals. In order to avoid dealing with a very large range of numbers, i.e. from 0.00002 Pascals to 20,000 Pascals the logarithmic decibel scale is used. This simplifies the same range of numbers, by setting up a logarithmic scale based on a reference pressure.

For historical and scientific reasons the reference pressure chosen for airborne noise is not the same as that chosen for underwater noise. This means that there is no DIRECT relationship between decibels in air and decibels in water. This point will be clarified separately in each section, but can lead to confusion. The reader should bear in mind that:

decibels in Air ≠ decibels in water

10.1.1 Airborne noise and A weighting

International convention has determined that airborne noise uses a reference pressure of 20 µPa by convention. Airborne noise levels are therefore correctly quoted as say, 55 dB re 20 µPa.

Because the human ear is not equally sensitive to all frequencies, a weighting system has been adopted to reflect the human perception of noise. This scale is known as “A” weighting and noise levels measured to this scale are quoted in dBA re 20 µPa. Non-weighted values are known as linear weighted values.

A typical range of airborne noise levels is outlined on the following table:

Airborne Noise Levels		
Noise type	**Level (dBA) re 20 µPa**	**Comment**
	140	Threshold of pain
Airport	125	Jet Takeoff
	120	Uncomfortably loud
Construction Site	115	Pneumatic Drill
Disco or Rock Concert	110	
Motorway	90	Heavy Truck Passing
Very Busy Pub	85	Voice has to be raised to be heard Conversation difficult
Busy Restaurant	70	
Business Office	65	Normal Conversation Possible
0.5 km from busy roadway	55	Daytime
	40	Birds Chirping in countryside
Library	35	Clock ticking
	35	Quiet countryside, no wind
	20	Whisper at 1 metre
	0	Threshold of hearing

Table 10.1.1 - Airborne Noise Levels

10.2 AIRBORNE NOISE

The proposed development can be examined under the following phases:

- Construction Phase
- Operation Phase

The construction phase is of limited duration and will require some significant noise generating activities, for short periods. The operational phase is an ongoing phase with vessel noise similar to the existing, albeit in a different location.

The different phases give rise to different noise control measures. The operating phase will be a 24/7 operation requiring noise control at night and limiting impacts on amenities and wildlife. The construction phase is however a relatively short duration and will be carried out mainly by day so there is a balance between limiting noise and extending/shortening the duration of the phase. The noise control measures to be adopted must also be tailored to the activity. In either case we are dealing with noise levels that are in the ‘nuisance’ or ‘annoyance’ category rather than elevated noise levels that could have health or hearing implications.

10.2.1 Airborne noise impacts

Noise may have various effects on human beings exposed to it ranging from discomfort and annoyance to various psychological and pathological conditions. The degree to which it affects people depends on its nature and intensity, its duration, the frequency and time of its occurrence, the activity being undertaken by different individuals at the time of exposure, and their degree of sensitivity. Noise can be measured by way of its sound energy and frequency characteristics. However, sound measurement does not necessarily give a guide to what is noise - noise is subjective and depends on the factors mentioned above.

The susceptibility of people to noise, and the level of annoyance they experience, varies widely; indeed the degree of annoyance is dependent on the quality of the sound and the recipient's attitude towards it. Measurable psychological and pathological effects have been shown to be attributable to noise. They include effects on health, sleep, communications, working efficiently, industrial accidents and mental stress.

The levels of noise attributable to the proposed development are such that significant health effects outside the site boundary (such as occupational deafness, etc) can be ruled out. Impacts such as interference with sleep, communications and mental stress must however be examined as part of this study.

10.2.2 Acceptable Noise Levels

The "acceptable" level of noise arising from industrial activity in Ireland is determined by the Environmental Protection Agency. They licence a diverse range of activities from waste management facilities to power plants and many different industrial sites. Their guidance for licenced activities is based on World Health Organisation standards and best international practice. The levels adopted by the Environmental Protection Agency have been used by the Department of Environment, Heritage and Local Government to set levels for all significant developments in Ireland.

In summary the Environmental Protection Agency limits for industrial activity are as follows:

Daytime	55 dBA re 20 μPa
Night time	45 dBA re 20 μPa

These levels are recognised as striking a reasonable balance between competing land uses such as industrial activity and residential amenity.

10.2.2.1 Sleep Disturbance Criteria

The World Health Organisation recommendation for noise levels in a bedroom for an undisturbed nights rest are 30 dBA. Allowing for noise attenuation through an open window in the room, this equates to a level of 45 dBA outside the building. The Environmental Protection Agency have set a general night time noise limit of 45 dBA (externally) as an acceptable night time noise level for all activities they licence. The Environmental Noise Directive, while not stating explicit limits, adopts criteria requiring a 10 dB lower level at night, similar to the 55 dBA (daytime) and 45 dBA (nighttime) criteria adopted by the Environmental Protection Agency. 45 dBA re 20 μPa would therefore appear to have international acceptance as a threshold level.

10.2.2.2 Environmental Noise Directive

In 2002, Directive 2002/49 relating to the assessment and management of environmental noise was adopted by the European Parliament and Council. This Directive guides activities on noise in Member States of the EU.

The directive describes environmental noise as "unwanted or harmful outdoor sound created by human activities, including noise emitted by means of transport, road traffic, rail traffic, air traffic, and from sites of industrial activity" (Directive 2002/49/EC, article 3). Ambient or environmental noise covers long-term noise, from transport and industry sources, as distinct from noise caused by neighbours, construction sites, etc.

One of the features of the Directive is the introduction of the Lden noise criteria. This criteria is used to assess noise on a round the clock basis (day, evening & night) and provides penalties for noise created during the evening and night periods. The Environmental Noise Directive has been implemented in Ireland by the Environmental Noise Regulations 2006 (SI 140/2006).

The Lden criteria is in use for road traffic and rail noise control in Ireland and adopted in this study.

10.2.2.3 Construction Noise

Construction noise is a special case because of the temporary nature of its activities. A certain amount of noise is inherent in all types of building and it can never be completely eliminated. Many items of plant and equipment can be effectively silenced but there are also many other items of equipment that are not so easily silenced, e.g. rock breaking or pile driving equipment.

The problems of site noise control can often be complex and there are a number of practical implications including the pace of the works if unduly restrictive noise conditions are imposed. Practical noise reduction measures such as those outlined in British Standard 5228 *Code of practice for Noise Control on Construction and Open Sites*, can be implemented. The hours of work for noisy activities can be limited to avoid interference with residential amenity. It is not usual to impose a numerical noise limit on construction activity as equipment may need to operate near the site boundary for short periods and thus not be able to comply with a fixed numerical noise limit.

Noise (and vibration) from blasting is another particular case. The Department of Environment, Culture and Local Government have set limits for quarry operations in the Guidance for Quarries and Ancillary Activities issued to Planning Authorities under section 260 of the Planning and Development Act 2000.

The only published construction noise limits by a government agency in Ireland are those adopted by the National Roads Authority (NRA) for the construction of road schemes. These guidelines set maximum noise levels for different times of day.

NRA Construction Noise Limits		
Day & Time	LAeq (1 hr) dB re 20 µPa	LpA (max) slow dB re 20 µPa
Monday to Friday 07:00 to 19:00 hrs	70	80
Monday to Friday 19:00 to 22:00 hrs	60	65
Saturday 08:00 to 16:30 hrs	65	75
Sundays and Bank Holidays 08:00 to 16:30 hrs	60	65
All other Times	-	-

Table 10.2.1 - NRA Construction Noise Limits

L_{eq} Shorthand for ‘equivalent continuous noise level’, which is a parameter that calculates a constant level of noise with the same energy content as the varying acoustic signal being measured. The Leq is an energy mean of the noise level averaged over the measurement period and often regarded as an average level. It is good practice to state the time period over which measurements were taken.

L_pA	Sound Pressure (A-weighted) in dB re 20 µPa. LpA (max) refers to a maximum A weighted sound pressure level.

The noise controls set out above represent best international practice and will form the core of the measures to be included as contract conditions for the construction of this project.

10.2.2.4 Traffic Noise

Traffic noise levels are governed under the Environmental Noise Directive. The criteria used by the NRA is the Lden criteria with a design goal of 60 dbA re 20 µPa. The Lden criteria will be used in this chapter.

10.2.2.5 Railway Noise

Railway noise is also governed under the Environmental Noise Directive. The threshold set under the Directive is relatively high (60,000 trains per year) so the Directive is not primarily applicable. There is also a Commission Decision of 23 December 2005 relating to rolling stock noise with specific limits for pass-by noise and standing noise from locomotives and rolling stock. The limits for pass-by noise apply at 80 km/hr, which is not applicable to the proposed development.

The issue of noise from rail freight is a complex one and subject to an ongoing action programme at EU level. Due to the huge volume of static and rolling infrastructure that has to be modified allied to the fact that rail investment has a long life means that definitive limits for rail freight yards have not yet been determined. The Lden criteria while not directly applicable is in compliance with the intention of the Directive and will be used in this chapter.

10.2.3 Existing Background Noise Levels

Regular noise monitoring is carried out by Galway Harbour Company as part of the companies environmental management programme. This monitoring is currently carried out at 2 locations (N1 and N2) on a six monthly basis. In addition to this data monitoring was carried out at 3 other locations as part of the baseline monitoring for this study. The monitoring locations are as follows:

Figure 10.2.1 - Noise Monitoring Locations

Noise levels at the locations are significantly influenced by transport noise associated with a busy city centre location. Galway Airport is located east of the city but the flight-path includes an area close to the site, resulting in significant aircraft noise on an intermittent basis. The main railway line linking Galway with Dublin bounds the existing enterprise park to the north and the Lough Atalia road, which is one of the main traffic routes through Galway City, runs to the west-northwest of the site.

These noise sources result in a reasonable noise level at all times over the 24 hour period. The noise level increases during “working hours” (i.e. 8am to 6pm), during which the level is determined by activities on the enterprise park, i.e. traffic specifically entering or leaving the area, equipment operating in or associated with adjoining industries and loading/unloading activities in the enterprise park.

Noise levels at the noise sensitive locations are also to a significant extent determined by traffic, in particular the Docks and Grattan Road (Frenchville) areas.

10.2.3.1 Background Noise Measurements

A series of background noise measurements relating to the measurement locations outlined above have been carried out since 2004. Routine measurements are carried out at location N1 (Mellows Park) and N2 (Harbour Enterprise Park) and reported to Galway City Council. Additional measurements including all 5 locations have been taken during both day and night periods in 2004, 2007, 2011 and 2013. A summary of the range of noise levels is contained in Tables 10.2.2 to 10.2.7.

As can be seen from the tables the noise levels are quite varied, but if we focus on the L90 levels at the noise sensitive locations the baseline noise figures emerge. L90 is the noise level that is exceeded statistically for 90% of the time (L10 is the level exceeded for 10% of the time) and while there have been some changes over the years, the L90 level at Mellows Park is consistently in the region of 40 to 45 dBA during the day, dropping to 40 dBA or below at night. The level at the Docks (Dun Aengus Apartments) is in the region of 50 to 55 dBA during the day with only a modest reduction at night. A similar daytime level is experienced at Frenchville/Grattan Road but the night time level at this location drops to about 35 dBA.

Taking a conservative approach we therefore estimate the nightime background noise level at Mellows Park to be 40 dBA and a level of 35 dBA at Grattan Road. These two locations are the critical night time noise sensitive locations, particularly during the construction phase.

Background Noise Level Measurements 16/17th August 2004					
Location	Start time	Duration	L_{Aeq} dB(A)	L_{A10} dB(A)	L_{A90} dB(A)
Mellows Park	12.21	30m	37	36	30
	21.24	15m	34	36	30
Existing	21:15	24:45	44	-	-
Enterprise Park	10.59	30m	46	48	37
Ballyloughane	11.42	30m	50	51	33
Beach	21.00	15m	46	47	36
Existing Docks	13.08	30m	60	60	55
	21.48	15m	56	57	48
	01.07	10m	48	48	43
Grattan Road	17.02	30m	60	64	53
Frenchville	22.23	15m	65	68	37

Table 10.2.2 - Background Noise Level Measurements 16/17th August 2004

Background Noise Level Measurements 24th April 2007					
Location	Start time	Duration	L_{Aeq} dB(A)	L_{A10} dB(A)	L_{A90} dB(A)
Mellows Park	15.31	30m	55	43	39
	22.53	15m	43	44	36
Ballyloughane	14.55	30m	53	53	41
Beach	22.30	15m	48	48	39
Existing Docks	16.20	30m	60	62	55
	23.17	15m	63	64	55
South Park	16.55	30m	70	74	49
Grattan Road	23.43	15m	61	57	41

Table 10.2.3 - Background Noise Level Measurements 24th April 2007

Background Noise Level Measurements 20/21st December 2011					
Location	Start time	Duration	L_{Aeq} dB(A)	L_{A10} dB(A)	L_{A90} dB(A)
Mellows Park	11.43 0.49	90 10	48 44	49 45	44 42
Existing Enterprise Park	13.49 1.10	90 10	63 59	61 61	49 45
Ballyloughane Beach	11.13 0.22	30 10	52 39	55 40	47 37
Existing Docks	15.36 1.24	30 10	57 48	56 50	46 47
Grattan Road Frenchville	16.4 1.38	30 10	68 57	73 54	52 33

Table 10.2.4 - Background Noise Level Measurements 20/21st December 2011

Background Noise Level Measurements 29th May 2013					
Location	Start time	Duration	L_{Aeq} dB(A)	L_{A10} dB(A)	L_{A90} dB(A)
Mellows Park	10:15 00:32	90 15	48 41	49 43	42 38
Existing Enterprise Park	12:02	90	62	62	47
Ballyloughane Beach	09:38 00:07	30 15	48 40	47 41	40 38
Existing Docks	15:22 00:58	30 15	53 48	56 48	47 44
Grattan Road Frenchville	16:44 01:17	30 15	57 49	60 47	48 39

Table 10.2.5 - Background Noise Level Measurements 29th May 2013

Noise Level Measurements 2005-2013 Mellows Park (compiled from quarterly reports)			
Year	L_{Aeq} dB(A)	L_{A10} dB(A)	L_{A90} dB(A)
2005 average	48.8	48.5	43.3
2006 average	49.5	52.0	43.5
2007 average	50.3	50.7	43.5
2008 average	51.5	52.9	47.6
2009 average	48.0	51.3	45.5
2010 average	47.3	45.8	40.3
2011 average	48.0	49.0	44.0
2012 average	48.5	49.4	40.4
2013 average	50.0	48.6	43.3

Table 10.2.6 - Noise Level Measurements 2005-2013 Mellows Park (compiled from quarterly reports)

Noise Level Measurements 2005-2013 Galway Harbour Enterprise Park (compiled from quarterly reports)			
Year	L_{Aeq} dB(A)	L_{A10} dB(A)	L_{A90} dB(A)
2005 average	56.5	58.5	53.8
2006 average	56.8	58.8	51.5
2007 average	63.5	64.2	55.2
2008 average	63.8	66.5	52.8
2009 average	59.2	61.8	52.7
2010 average	53.9	54.5	40.5
2011 average	63.0	61.0	49.0
2012 average	62.6	63.1	52.5
2013 average	64.1	62.7	48.1

Table 10.2.7 - Noise Level Measurements 2005-2013 Galway harbour Enterprise Park (compiled from quarterly reports)

10.2.3.2 Existing Noise Sources

Noise in the existing Docks area is dominated by traffic noise during the day and early evening. At night however traffic levels die down and port related activity begins to dominate the noise climate. In order to estimate the noise emissions due to port related activity noise models have been created of the existing Dock area and of the proposed development.

Port related noise comprises ship manoeuvring and cargo unloading. Due to the tidal nature of the existing Docks operation ships carrying oil are unloaded on a 24 hour basis in order to minimise the turnaround time in port. This results in the noise from shipping activity becoming dominant at night when traffic related noise dies down.

The loading/unloading of scrap metal results in noise levels in the order of 70 to 75 dBA with noise peaks in excess of 90 dBA. (as measured 24/11/2010).

The existing noise levels are determined by city activities such as traffic, port activity, industrial and commercial activity and general noise sources related to human activity. The noise levels at noise sensitive locations near the proposed development have been measured and are outlined above. In order to assess the potential impact of the proposed development noise prediction models of the development (existing and proposed) have been prepared.

10.2.4 Airborne Noise Prediction Model

The noise prediction model chosen was constructed using Bruel & Kjaer “Predictor” Package. The Predictor software package is a comprehensive acoustic modelling system.

The program calculates the received noise level from specified sources, propagated via intermediate obstacles and media, based on national and international standards. Consequences of noise reduction measures can be rapidly assessed and it is possible to compare calculated, measured and permitted values.

Model data is held in a database of the Predictor model. The type of items in a model include ground contours, sound sources, objects and sound receivers. Each item has positional information, including its location, dimensions on the ground and height. The base area is superimposed upon a 2-D topographical map, the background which is used to align each item in the model relative to an actual survey of the area under study.

Models can be prepared for different times of day and calculated to predict the sound pressure levels at the receiver points. The calculation for each model is done with a specific calculation method like ISO 9613.1/2 (Acoustics – Attenuation of sound during propagation outdoors).

10.2.4.1 Calculation Standards

The ISO calculation method is implemented in Predictor as two separate modules. ISO 9613-1/2 industry and ISO 9613-1/2 road traffic. Predictor also includes a rail noise prediction model based on the RMR/SRM II van de Reken en Meetvoorschriften Railverkeerslawaai '96 (RMR-2006) Dutch standard. Due to the complex modelling algorithms employed in the different standards it is best practice to model each transport mode separately.

The following standards are used in the ISO industry calculation method:

1. ISO 9613-1 Acoustics – Attenuation of sound during propagation outdoors. Part 1: Calculation of the absorption of sound by the atmosphere;
2. ISO 9613-2 Acoustics – Attenuation of sound during propagation outdoors. Part 2: General method of calculation;

As traffic noise is dominant during the daytime the noise due to unloading bulk cargo is not considered. Oil cargos however are discharged on a 24 hour basis and night time represent the worst case scenario for modelling purposes. The Sound Power Levels of the sources used to create the model are derived from a series of measurements taken at the existing Docks area while oil tanker vessels such as the “Galway Fisher” were entering, berthing, discharging and leaving the Docks and from a database of road traffic noise measured previously by Biospheric Engineering Ltd. Due to the use of the pilot boat and the slow engine speeds used during manoeuvring the most significant noise is that generated when discharging a cargo of diesel/petrol. This is also partly due to the proximity of the ship to the dockside during discharge.

In addition to investigating the impact of shipping noise, traffic noise on the approach roads to the development and construction noise have been modelled. As a reference point the existing traffic noise and the Do Nothing port noise have also been modelled.

10.3 UNDERWATER NOISE

This section addresses the underwater noise impact of the proposed development in the inner part of Galway Bay. This evaluation was undertaken to assess potential impacts on the important Salmon and eel fisheries in Galway and the impact on marine mammals (seals and cetaceans) in the bay area. Baseline data for this section is based on monitoring carried out by Biospheric Engineering Ltd.

Salmon is a migratory species and Salmon smolts come down the river in the March/May period and go to sea for a period of one to several years. Eels are also migratory and elvers (small eels) come from the sea to begin their freshwater life around the same time. There is some scientific evidence that both species have an avoidance reaction to low frequency underwater noise (Sand, et al. (2000), Knusden, et al. (1994)). The frequency region of concern coincides with the lower end of a frequency range that can be generated by shipping and construction activities. It is important to note that these species are sensitive to particle velocity. No data exists to carry out an evaluation using particle velocity so this chapter is based on sound pressure.

During the construction phase, dredging (including rock blasting where required), pile driving and the construction of the proposed berthing area will generate significant underwater noise. This type of noise although of limited duration has the potential to cause damage to the species of concern. The potential impact needs to be assessed and in order to do so is necessary to address the issues of:

- The behaviour of noise underwater
- The hearing of fish
- The hearing of marine mammals
- The reaction of fish and marine mammals to noise
- The potential underwater noise sources generated by the proposed development

For reasons outlined later in this chapter fish species (Salmon & Eels) are the species of concern during the operational phase of this development, whereas marine mammals are of more concern during the construction phase.

10.3.1 Behaviour of Sound Underwater

In order to assess the impact of underwater noise on the species of concern it is necessary to explain the difference between the behaviour of noise in air and noise underwater. In particular it is necessary to explain the different measurement levels and the impact of these levels.

Noise propagates through a medium in the form of waves consisting of compressions and rarefactions which are detected by a receiver as changes in pressure. As with all wave motion the three basic components that define wave motion are amplitude, wavelength and frequency. All three are related but change depending on the medium in which the wave is propagating. Most receivers are sensitive to sound pressure, which is measured in micropascals (μPa). Standard atmospheric pressure is 101.3 kPa so the pressure changes due to noise in air are very small.

The range of pressure changes due to typical noise sources varies over a very wide range. The threshold of hearing in air is generally taken to be 20 μPa, whereas sonic booms and large guns can generate pressure changes of the order of 10,000 Pa. This large range of pressure changes has led to the adoption of the decibel scale using ratios of pressures to present noise measurements. Due to the logarithmic nature of the decibel scale the numbers become more manageable and generally range from 0 to 140 as outlined in section 10.1.

Unfortunately for the lay person the pressure ratio chosen for noise measurements in water is different from the noise ratio chosen for noise measurements in air. Noise measurements in water are usually expressed against a reference pressure of 1 μPa, whereas noise measurements in air are usually expressed against a reference pressure of 20 μPa. This difference in reference pressures means that it is not correct to compare underwater sound pressures with sound pressures in air.

Based on the above it should be obvious that 100 dB in air is not the same as 100 dB in water, primarily because of the differences in reference measurements. How do we make meaningful comparisons between an underwater noise and a noise in air? There are two factors to be taken into consideration (a) the difference in reference pressure, and (b) the difference in impedance in air and water (= ρc, where ρ is the density of the medium and c is the velocity of sound in it) (Sharland 1972).

In air the sound pressure level is referred to 20 μPa, while in water the sound pressure level is referenced to 1 μPa. Given the equation for dBs, the conversion factor for $dB_{air} \rightarrow dB_{water}$

$$dB = 20(p_{water}/1\ \mu Pa) = 20 \log 20 = +26\ dB$$

Therefore a pressure comparison between air and water differs by 26 dB.

The characteristic impedance of water is about 3600 times that of air; the conversation factor for a sound intensity in air vs. water is 36 dB.

$$10 \log (3600) = 36 \text{ dB}$$

The simplified conversion factor of dB in air to dB in water is therefore:

$$36 + 26 = 62 \text{ dB}$$

This simplified conversion simply relates underwater sounds to those in air. How a fish or marine mammal perceives or reacts to an underwater sound may be very different from its reaction to airborne sounds. For some fish and marine mammals, there are audiograms available, i.e. we know their hearing range. For those that we do not have audiograms for, it is generally assumed, however that animals can hear the ranges of sounds that they produce.

When evaluating the possible effects of sound pressures impinging on fish and marine mammals, it is therefore important to know the nature of the dB scale and appreciate that sound pressures in air and water should not generally be compared due to the very different properties of the two media.

Sound speed and wavelength are two related parameters which differ significantly in water and air. The speed of a wave is the rate at which vibrations propagate through the medium. Wavelength and frequency are related by:

$$\Lambda = c/f$$

Where Λ = wavelength, c = speed of sound in the medium, and f = frequency.
The speed of sound in seawater is approximately 1500 m/s while the speed of sound in air is approximately 340 m/s. Therefore a 10 Hz noise in the water has a wavelength of 150 metres whereas a 10 Hz noise in air has a wavelength of 34 metres. The importance of the increase in wavelength is apparent when we look at the propagation of noise in shallow water.

10.3.2 Propagation losses Underwater

The audibility of an underwater sound is determined by the strength of the source, the propagation efficiency, the ambient noise, and the hearing sensitivity of the subject's species. Noise levels produced by human activities in underwater environments are determined not only by the source power but by the local sound transmission conditions. A moderate level source transmitting over an efficient path may produce the same received level at a given range as our higher level source transmitting through an area where the sound is attenuated rapidly. In deep water, depth variations in water properties strongly affect sound propagation. In shallow water interactions with the surface and bottom have strong effects.

Absorption loss is another form of loss which involves a process of conversion of acoustic energy into heat and thereby represents a true loss of acoustic energy to the medium in which the propagation is taking place. The absorption losses are generally much less than the spreading losses and for distances of up to 10 kilometres in deep water can generally be ignored. It is not proposed to consider absorption losses in this study as (i) they are much less significant than spreading losses and (ii) ignoring the absorption losses will result in an additional factor of safety as the estimated received noise level will be overestimated by the extent of the absorption losses.

The zone of acoustic influence for a given source of man-made noise can vary in radius tenfold or more, depending on operating site and depth, and on seasonal with changes in water properties. Hence, sound transmission measurements, analyses, and model predictions are necessary to estimate the potential radius of acoustic influence of noisy human activities.

Etter (2013) defines shallow water as being characterized by numerous encounters with both the sea surface and the sea floor. Differences in propagation are driven by differences in the structure and composition of the seafloor. In the common shallow water bottom sediments; sand silt and mud, compressional speeds are greater than that of the overlying water column. Sound energy penetrates the bottom and losses are caused by mechanisms such as compressional wave absorption in the sediment and conversion of part of the incident energy to shear waves. Roughness of the ocean surface and bottom are perturbing effects that increase attenuation by causing more energy to be directed into the bottom.

With long range propagation in shallow water, the acoustic energy strikes the boundaries at small grazing angles leading to reflection back into the water column. At short range, the acoustic energy is reflected from the boundaries at almost normal incidence leading to multiple reflections with consequent multiple losses at the boundaries. This leads to significant attenuation close to the source which can be seen in measurements of passing vessels.

In shallow water, the propagation can be regarded as normal mode propagation where the water column is treated as a waveguide (with lossy boundaries). The solution to the wave equation is such that it consists of a finite sum of normal modes, each with a cut-off frequency below which it cannot propagate. No sound can propagate at frequencies below the cut-off frequency (fc) for the first node:

$f_c = (c_w/4D) \div \sqrt{(1-c_w^2/c_s^2)}$

Where c_w is the sound speed in water, D the water depth and c_s the sound speed of the bottom. The manifestation of the cut-off frequency is that in depths around 10m frequencies below 100 Hz will not propagate. This is an important consideration when it is known that a considerable portion of the energy associated with activities such as pile driving and blasting are at low frequencies.

The primary characteristic of acoustic signals in shallow water is the prevalence of multi-path arrivals. i.e. direct path, first surface reflection, first bottom reflection etc. The complexity of the arrival path results in constructive and destructive interference patterns arising. In order to have a full constructive addition the rays need to be perfectly reflected from the sea surface and the seabed which rarely occurs in nature. As the destructive patterns arise more frequently this results in a significant propagation loss.

The combination of these factors results in significant losses close to the source in shallow water. These losses cannot easily be modeled so the net result is that models tend to overestimate received noise levels close to the source in shallow water.

In order to calculate noise levels resulting from a particular source it is necessary to work out the transmission loss and the absorption loss. A sound wave travelling from point A to point B diminishes in amplitude or intensity, as it spreads out in space, is reflected, and is absorbed. If the source level the (at a 1 m) is 160 dB re- 1 µPa, the received level at range 1 km may be only 100 dB re-1 µPa. In this case transmission loss is 60 dB.

A major component of transmission loss is spreading loss from a point source in uniform medium (water or air), sound spreads outward as spherical waves. *Spherical* spreading implies that intensity varies inversely with the square of the distance from the source. Thus, transmission loss due to spherical spreading is given in dB by 20 (R/R_o), where Ro the reference range, normally 1 m. With spherical spreading, sound levels diminish by 6 dB when the distance is doubled and by 20 dB when distance increases by a factor of 10. Spherical spreading applies in the “free field” situation, i.e. the deep ocean.

Cylindrical spreading sometimes occurs when their medium is non-homogeneous. In shallow water, sound reflects from the surface and bottom. At some distance from the source that is long compared to water depth, various reflected waves combine to form a cylindrical wave. Such a wave may be imagined by picturing a short metal can (such as a 200 gram tin of salmon!). The top and bottom of the can correspond to the water surface and ocean bottom, and the curved outer surface is the cylindrical wave front. With cylindrical spreading, their sound intensity varies inversely with distance from the source. A simplified but useful equation for a transmission loss with cylindrical spreading is given by

$$TL = 20 \log R_1 + 10 \log (R/R_1),\ R > R_1$$

Where R_1 is the range at which spherical spreading stops and cylindrical spreading begins. For ranges $<R_1$, transmission loss is spherical. The preceding equation can be rewritten as

$$TL = 10 \log R_1 + 10 \log R,\ R < R_1$$

With cylindrical spreading, sound levels diminish by 3 dB when distance doubles and by 10 dB when distance increases tenfold. Thus, levels diminish much more slowly with increasing distance with cylindrical than with spherical spreading. Cylindrical spreading may apply in the case of shallow water, if the boundaries are highly reflective or in the case of ocean channel propagation.

When the source and receiver are close to the surface, the surface reflection of the sound interacts strongly with direct sound radiation. The reflected sound is out of phase with the direct sound. If the source has strong tonal or narrow band-width components, this phenomenon produces an interference pattern. This phenomenon, the Lloyd mirror effect is strongest with low-frequency tones and in calmer sea conditions.

A third type of spreading known as *dipole* type spreading can occur in sheltered water. When the sea surface is not too rough, it creates an interference pattern in the underwater sound field. This pattern is caused by constructive and destructive interference between the direct and surface reflected sound and is called the *Lloyd mirror* or *dipole* effect. With dipole type spreading

$$TL = 40 \log R_1$$

In general the spreading law for sound propagation in the sea is not simple, not only because of the reflection at the boundaries, but also because of the refraction that takes place due to sound gradients.

As sound travels, some power is absorbed by the medium, giving rise to absorption losses. In dB, such losses vary linearly with distance travelled, and absorption loss can be described as x dB/km. Absorption losses depend strongly and frequency, becoming greater with increasing frequency. Scattering losses also very linearly with distance, but result from different physical mechanisms. These losses are in addition to the spherical, cylindrical or other spreading losses previously mentioned.

The terms “deep” and “shallow” water are relative terms when referring to propagation losses. “Deep” water generally refers to the open ocean where spherical propagation is the norm and considerable distances are involved. “Shallow” water in the literature generally refers to the continental shelf and offshore area where depths are less than 200 metres. In the case of Galway Harbour we are dealing with extremely shallow water. The water depth at spring tides in the area of interest is typically 5 to 6 metres.

Sound transmission in shallow water is highly variable and site specific because it is strongly influenced by the acoustic properties of the bottom and surface as well as by variations in sound speed within the water column (Richardson et. al., 1995). With shallow water sound transmission the combination of environmental factors makes it difficult to develop accurate theoretical models. The theory must be combined with site-specific empirical data to obtain reliable propagation predictions.

When the water is very shallow (as in this case) sound propagation may be analysed using mode theory. Mode theory predicts that, if the effective water depth is less than $\lambda/4$, waves are not matched to the duct and very large propagation losses occur (λ for a 10 Hz wave in seawater is of the order of 150 metres as outlined above). The situation at Galway Harbour is further complicated by the existence of a water saturated sediment that does not act as a reflecting boundary for all the sound energy and the complex mixing zone where the fresh Corrib water meets the saline harbour water.

It is possible to make reasonable propagation predictions from simple formulas and numbers of such formulas have been developed for deep water. Urich (1983) describes the Marsh and Schulkin (1962) model which was based on a large number of measurements in "shallow" water from 100 Hz to 10,000 Hz.

With a shallow source, the source and its reflected image become a dipole source with a vertical directionality (Urich 1983). In deep water with both a shallow source and a shallow receiver, spreading loss may be as much as 40 log R, versus the 20 log R expected from spherical spreading. In shallow water, the shallow source dipole effect introduces an additional 10 log R spreading loss (Grachev 1983, quoted in Richardson et. al. (1985)), increasing the loss from ~ 15 log R to ~ 25 log R. A similar interference effect occurs when the receiving location is within ¼ wavelength of the surface, (At 6 metres depth this impacts all frequencies under 63 Hz). Thus, propagation from a shallow source to a shallow receiver in shallow water will show a spreading loss of ~35 log R.

The spreading loss is therefore a complex issue, can vary significantly in magnitude and has a significant impact on propagation losses. Under certain conditions the losses could be as high as 40 log R1 but it is likely that site conditions will reduce this rate somewhat. In order to be certain of the appropriate spreading loss to apply in each case it must be verified with site specific measurements.

10.3.3 Background Noise Levels Underwater

Ambient noise is the background noise, there is no single source, point or otherwise. In the ocean, ambient noise arises from the wind, waves, surf, ice, organisms, earthquakes, distant shipping, volcanoes, fishing boats, and more. At any one place and time, several of these sources are likely to contribute significantly to ambient noise. In this source-path-receiver model, and ambient noise is present in the medium (water or air) along the path, and it is present at any receiver location.

Ambient noise varies with season, location, time of day, and frequency it has the same attributes as other sounds, including transient and continuous components, tones, hisses, and rumbles. It is measured in the same units as other sounds. However, in measuring ambient noise, it makes no sense to use a reference distance from the source. There is no one source.

Wenz (1962) presented a graph of ambient noise spectra in the ocean attributable to many sources and spanning five decades of frequency from 1 Hz to 100 kHz. This graph shows the wind dependence of ambient sounds plus the typical contributions of many other sources. Low frequency noise (1-20 Hz) is caused largely by surface waves (especially in shallow water) and turbulent pressure fluctuations. However, biological sources, distant shipping, earthquakes, and other seismic activities are also major contributors to low frequency ambient noise. Wenz noted that shallow water noise levels are "…about 5 dB greater than corresponding deep water levels at the same frequency and same wind speed,"

The ambient noise level in Galway Harbour (as determined in this study) is consistent with the Wentz curve, albeit the shallow water noise levels are higher than deeper water levels.

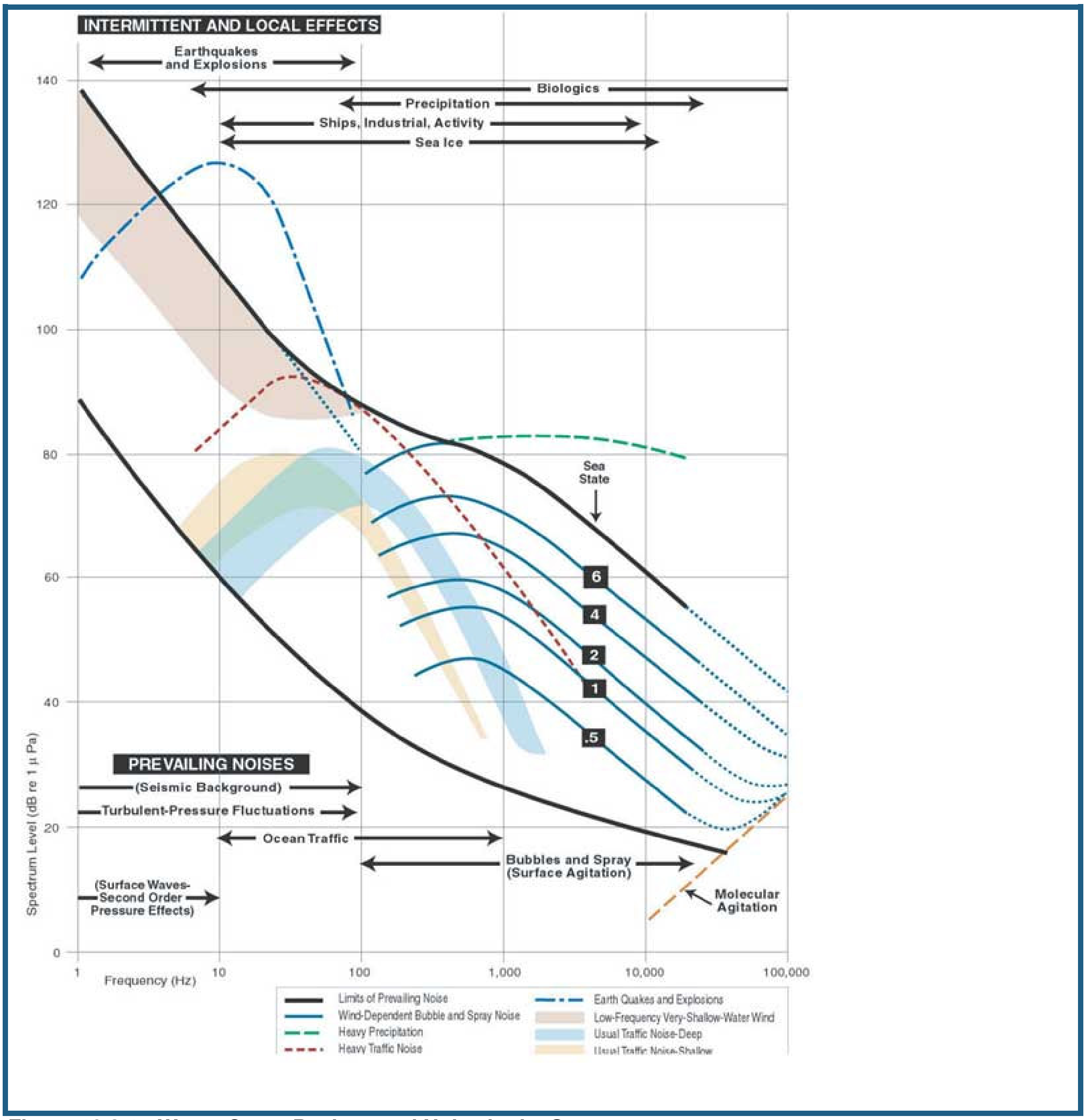

Figure 10.3.1 - Wentz Curve Background Noise in the Sea

10.3.4 Hearing of Fish

Most of the body tissues of a fish are almost the same density as water, so that, the fish will vibrate in a similar manner to the particles in the water. There will however be some differential motion between the fish and the surrounding water. This motion varies along the length of the fish depending upon the distance from the sound source, so there are differential displacements at various points on the body. Consequently, there are advantages in having a long lateral line in which the particle displacement system is subjected to differential stimulation.

Fish hearing in general is different from that of terrestrial organisms and operates in two ways. Most fish hear with a primitive version of the terrestrial inner ear (located in the skull of fish) and with the lateral line system that runs the length of each side of the fish and is often extensively branched in the area of the head. The inner ear and lateral line system are collectively called the acoustico-lateralis system. The lateral line system of fish is extremely sensitive to close range pressure changes.

The sensitivity of the lateral line system seems particularly well suited to sensing the movements of nearby fish, such as in schooling behaviour, the irregular movements of a potential prey, or the approach of a predator. The lateral line system appears to function most effectively in the near field, i.e. relatively close to the fish.

The inner ear of fish does not have a cochlea as in terrestrial vertebrates; rather there are three symmetrically paired structures with associated bony otoliths. The otoliths in both salmon and eels are hard structures composed of calcium carbonate and have a density of about 3 kg/m^{3,} (Jobling 1995). Most of the fish body has the same density as the surrounding water, (varies around 1.03 kg/m^{3,}) (Kempe's 1991) and during the passage of a sound wave the ossicilatory particle displacements in fish tissues will be similar to those of water molecules. The mechanism for a hearing is the differential displacement of high-density otholiths relative to their low-density bodies of fish (about the same density as water), resulting in bending of sensory hair cells that line the otholiths. This mechanical stimuli is then converted to electrical stimuli in the hair cells body and sent to the brain via the auditory nerve for processing. (Jobling 1995)

The gas bladder appears to respond to sound pressure by pulsating in sympathy with the passing sound wave. The pulsations caused by the sound pressure create a secondary near-field within the body of the fish close to the inner ear. The particle displacements so produced are then re-radiated through the tissues to the inner ear where they can be detected. Thus, the gas bladder may function as a pressure transducer and sound amplifier, but there are significant differences between species as to its effectiveness.

The hearing ability of fish such as salmonoids and flatfish is limited in bandwidth and intensity threshold compared to other fish. Atlantic salmon (Salmo salar) are functionally deaf above 380 Hz (Hawkins and Johnstone 1978). These fish lack the physical connection between their swim bladder and inner ear that other fish possess (Hawkins 1986). Fish with this latter type of hearing are most sensitive to particle velocity since the otholiths essentially respond to particle displacement (Hawkins and MacLennan 1976). In fact, the swim bladder probably does little to enhance hearing in salmon (Enger 1981).

Compared to humans, salmonoids have poor hearing on the basis of perceivable frequency range and sensitivity to sound pressure. Human infants are capable of detecting sounds from 20-20,000 Hz, and at sound pressure levels much lower than that of salmonoids. For example, a human would require about 40 dB re-1 µPa sound pressure level to hear a 160 Hz pure tone, while a salmonoid would require about 100 dB. Therefore, the salmonoid requires close to a thousand fold difference in sound pressure level to hear the same 160 Hz tone.

The hearing of the European eel (Anguilla anguilla) was studied by Jerko et al. (1989) who found that the upper audible frequency limit in the eel was about 300 Hz. At low frequencies the relevant stimulus parameter was particle motion. At higher frequencies within the audible range the swim bladder conveyed an auditory advantage for stimuli with a high ratio between pressure and particle motion. An auditory function of the swim bladder in this species therefore indicates an efficient transmission channel for the swim bladder pulsations between the bladder and the ear.

As pointed out earlier the hearing ability based on particle displacement is a highly localised ability and apart form short term close range impacts is not of material interest to this study. The proposed harbour development is located over a kilometre from the entrance to the river and so near field effects are not significant.

10.3.5 Hearing of Marine Mammals

10.3.5.1 Cetaceans

Cetacean ears are similar in structure to most mammalian ears; the basic structure comprises three auditory ossicles, a tympanic membrane linked via eustacian tube to a cochlea and semi-circular canals. In cetaceans however the outer ear is equipped with circular constrictor muscles. Particular adaptations are evident to permit detection of high frequency sounds and to facilitate stereoscopic ranging in an underwater environment (Fraser et al, 1960). The fact that sounds travels much faster underwater requires rapid processing of the difference in detection times of a sound in each ear to carry this out.

It has been suggested that cetacean ears may be less vulnerable to acoustic damage than those of terrestrial mammals. However, there is no direct evidence to support this contention. The middle and inner ears of cetaceans are located outside the cranium and are enclosed in two dense bony capsules. These bones are massive by comparison to homologous structures in terrestrial mammals and may be an adaptation to withstand pressure changes during diving.

There are two main groups of cetaceans: odontocete or toothed whales and mysticete or baleen whales, the species likely to feature in Galway Bay all belong to the former group. Toothed whales communicate at moderate to high frequencies (1-20 kHz) and also have highly developed echolocation systems operating at high and very high frequencies (20-150kHz).

Although closely related to each other, the odontocetes and the mysticetes produce different calls and probably produce the calls using very different mechanisms. In general the calls produced by odontocetes tend to be high in frequency and shorter duration than those produced by mysticetes (Popper et al, 1997).

Vocalisations by odontocetes can be assigned to three types; tonal whistles, pulsed sounds and echolocation clicks. There have been no reported whistle sounds from porpoises, whereas the dolphin family have such a variety of whistles that relatively small variations in whistles may indicate behavioural states (Caldwell et al, 1990). Most whistles are produced at frequencies below 20,000 Hz.

Pulsed calls are produced by the repetition of pulses, which are broadband in their frequency content (tens to thousands of Hz in odontocetes) and of very brief duration (milliseconds). When produced in rapid succession (>20/s) the human ear cannot separate the individual pulses and the sounds are perceived as complex moans, growls, barks or screams. It is likely that odontocetes perceive the individual pulses because the species that have been tested are capable of perceiving individual echolocation pulses that are produced at much higher repetition rates (600/s) (Ridgeway, 1983, quoted in Popper above)

Odontocete species have the ability to use sound to orient in their environment and to locate food by listening for the echoes of high-frequency clicks that the animal directs at the target just as bats do (echolocation). Echolocation sounds are higher frequency and may range from 16-20 kHz to over 100kHz. The sounds are short and may include frequency-modulated sweeps. The frequency and amplitude of the echolocation click varies and apparently depends on the background noise and target distance.

Dolphins and porpoises produce their different calls using their nasal sacs, associated muscles and muscular nasal plugs. A special fatty tissue region in the melon of the head helps to concentrate acoustic energy, allowing the animal to direct the energy in a narrow beam. This is different from other mammals which utilise the larynx to produce sound.

10.3.5.2 Hearing of Pinnipeds

Harbour and Grey seals belong to the Phocidae (true seals) family and do not have an external ear. Most phocids produce only simple mate-attraction calls and mother-pup calls. Because most of their mating behaviour occurs in the water, the phocids tend to produce more underwater vocalisations than in-air vocalisations.

Phocinid seals have essentially flat audiograms from 1 kHz to 30-50 kHz, with thresholds between 60 and 80 dB re 1 µPa. Harbour Seals can detect underwater sounds up to 180 kHz if it is sufficiently loud, however their sensitivity drops off significantly above 60 kHz.

Otters spend much of their time in water, but underwater sounds have not been studied. Airborne sounds of adults include whines, whistles, growls, soft cooing sounds, chuckles and snarls. When stressed otters may utter harsh screams. The sounds produced are in the human range of audibility, with sounds in the range 3-5kHz. There is no published data on the hearing of a eurasian otter, but as they spend less time in the water than pinnipeds it can be assumed that their hearing underwater is unlikely to be as sensitive as that of a pinniped's.

The hearing ranges of the Salmon, the Eel, Cetacean species and Pinnipeds are compared on Figure 10.2. For the purposes of this study we are particularly interested in the High-Frequency Cetaceans, which include both Common and Bottlenose Dolphins and Porpoises. Low Frequency Cetaceans such as the baleen whales are less likely to appear in the inner bay area and are included in the data for completeness only.

It is immediately apparent that the frequency range of the Salmon and Eel are limited to the low frequency (less than 600 Hz) end of the spectrum. The sensitivity of the Salmon is relatively flat over the frequency range 10 Hz to 150 Hz and decreases rapidly at higher frequencies (Knudsen 1992). The sensitivity of the eel increases up to 80 Hz and decreases rapidly at higher frequencies, It is apparent from the graph that the frequencies of most interest are those below 630 Hz for the "fish" species.

Marine Mammals however have a much higher range of hearing. Bottlenose dolphins can hear sounds as low as 40 Hz. However, the sensitivity at these low frequencies is poor. In contrast, the high frequency hearing abilities of most odontocetes are exceptionally good. This is related to their use of high-frequency sound for echolocation. In the mid-frequency range where odontocetes have their best sensitivity, their hearing is very acute.

Phocinid seals have essentially flat audiograms from 1 kHz to 30-50kHz, with hearing thresholds between 60 and 85 dB re 1 µPa. Harbour seals are reported to be able to detect sound at very high frequencies, up to 180 kHz. However, above 60 kHz sensitivity is poor and different frequencies cannot be discriminated. (Richardson, et al, 1995)

A simplified interpretation of the hearing thresholds would indicate that marine mammals have "better" hearing in that they can hear over a wider range of frequencies and at lower intensities than the fish.

In the audiograms presented in Figure 10.3.2 four sound types are marked A, B, C, and D.

<u>Sound A</u>
70 dB re 1 µPa at 10 Hertz. This sound is below the threshold of all species and is not audible to either fish or marine mammals.

<u>Sound B</u>
130 dB re 1 µPa at 100 Hertz. This sound is above the threshold of all species and is audible to both fish to marine mammals.

Sound C
110 dB re 1 µPa at 1000 Hertz. This sound is above the threshold of all marine mammal species and is audible marine mammals. At 1000 Hertz the frequency is too high for Salmon or Eels to hear the sound so it is inaudible to these species.

Sound D
70 dB re 1 µPa at 100,000 Hertz. This sound is above the frequency threshold of all species except the high frequency cetaceans and is not audible to both fish or marine mammals with low frequency or mid frequency hearing ability.

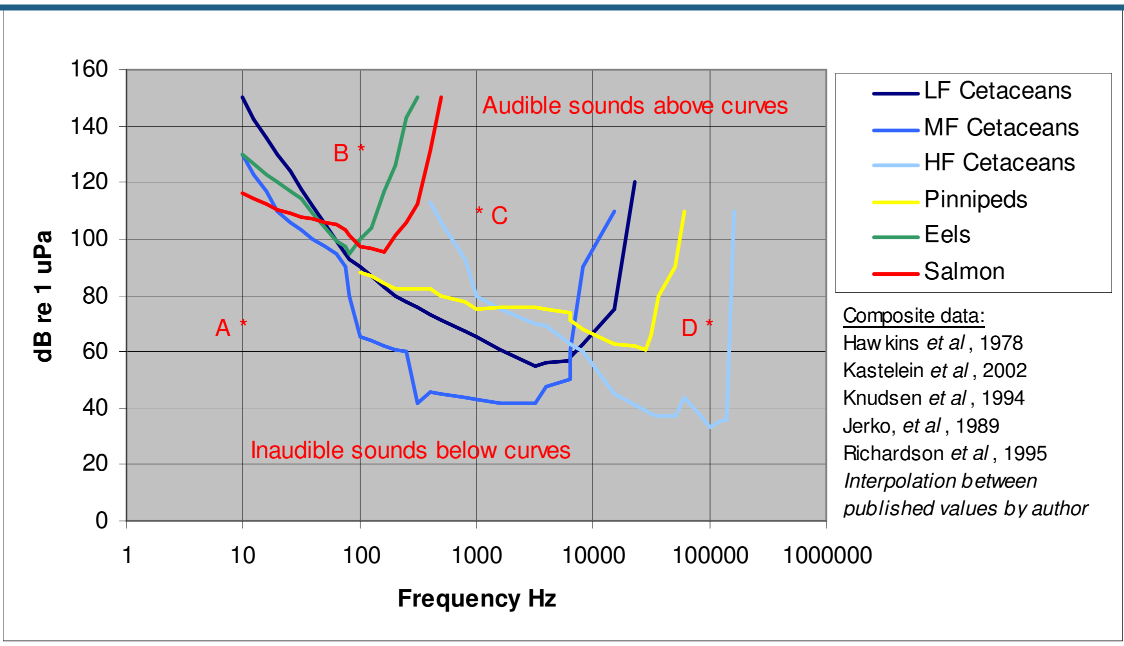

Figure 10.3.2 - Hearing Thresholds Marine Species

10.3.5.3 Avian Hearing

Birds hearing in air appears to be secondary to vision for sensing threats. Bird hearing is generally in the range 1 to 4 kHz with decreasing sensitivity to higher and lower frequencies, which is broadly similar to the human hearing range. Humans have more sensitive hearing than birds generally and birds gathering in flocks are somewhat accustomed to natural background noise. Many species live in urban environments with high levels of noise and there is both anecdotal and research evidence indicating that birds habituate to elevated noise levels.

Considerable research effort has gone into the effects of low flying military aircraft on nesting birds. Birds have a natural startle response and it is necessary to separate biologically significant disturbance from other forms. Incubating birds can be startled from a nest by a loud sound and return after an interval. If that interval is too long the eggs/young can die. Awbrey and Bowles (1990) found that startle responses by nesting raptors were short and did not result in a risk to the nest.

The noise levels associated with this project can be generally described as 'continuous' construction noise and the noise levels in air have been modeled and evaluated for impact on humans. With appropriate mitigation there will not be a significant impact and it is reasonable to infer the same applies to bird populations. Blasting noise is however a case where a startle response may result in a short term startle response. In order to minimise the risk to nesting birds in particular it is planned (other than in exceptional circumstances) to limit blasting to one blast per day.

10.3.6 Impact Thresholds for Marine Fauna

10.3.6.1 RECOVERABLE/ NON RECOVERABLE INJURY

Extreme levels of underwater noise can cause fatalities or non-recoverable injury and such noise levels occur close to very loud sources. As noise propagates out from a source, some of the energy is dissipated and the impacts are lessened. At some point, recoverable injury such as a temporary threshold shift (TTS) may be caused. This is defined as a temporary change in hearing capability which returns to normal after a period. Permanent Threshold Shift (PTS) is a permanent hearing impairment and thus a non-recoverable injury.

Further from the source, a zone may exist where the noise from the source is such that it prevents communication or detection capability for predators or prey and may directly or indirectly impact an animal. This ‘Disturbance Zone’ is one in which the animal is disturbed to an extent that it reacts in some way. Reactions can have behaviourally significant consequences, for example if breeding is interfered with.

Beyond this is a zone in which animals can hear underwater noise from the source and in some cases react to it but the consequences are not significant when viewed in the context of the conservation status of local populations.

Sound Exposure Level (SEL) is a measure of energy that incorporates both sound pressure level and duration. The spectral content can also be taken into account by an M-weighting, which is a frequency weighting to allow for the functional hearing bandwidths of different marine mammal groups.

10.3.6.2 TEMPORARY THRESHOLD SHIFT

There are limited scientific data available on underwater noise levels in general and this is particularly the case regarding injury and disturbance thresholds. For example, no data exist on the onset of Permanent Threshold Shift (PTS) in marine mammals. A review by Southall et al. (2007) proposed a PTS threshold of 6 dB above the unweighted Sound Pressure Level (SPL) and 15 dB above the M-weighted SEL.

Natural biological variations of up to 10 dB in an individual’s hearing capability can occur for many reasons. The Report of the Expert Hearing Group on Hearing Disability assessment set a minimum threshold of 20 dB (SPL) in threshold shift as the onset of disability. A threshold shift of 6 dB (SPL) in marine mammals can therefore be regarded as a conservative approach.

Some scientific data are available on recoverable injury and audibility thresholds for different species. These data was used by Southall et al. (2007) to develop metrics for potential impacts on marine mammals. Southall et al. propose SPL criteria of 230 dB re 1 µPa (peak broadband level) for PTS onset in cetaceans and 218 dB re 1 µPa for pinnipeds. TTS onset is expected at 224 dB re 1 µPa (peak broadband level) and 212 dB re 1 µPa for cetaceans and pinnipeds respectively (Finneran et al., 2002; Southall et al., 2007). The SEL criteria proposed are TTS onset at 183 dB re 1 µPa2-s for cetaceans and 171 dB re 1 µPa2-s for pinnipeds, and PTS onset is expected at 15 dB additional exposure.

The Southall criteria for High frequency cetaceans (Harbour Porpoise) were based on an extrapolation of data for Mid frequency cetaceans. Kastelein et al (2012) found that for relatively small threshold shifts (<15 dB), recovery is quick (within ~60 minutes). In most cases reduced hearing for such a short time period (if it does not occur many times per day) may have little effect on the total foraging period of a porpoise, particularly at low frequencies. With species such as Harbour Porpoise likely to move away from significant noise sources they are unlikely to repeatedly expose themselves to high noise levels in this way.

The greatest risk to bird life from this project is the risk of a diving bird being close to an underwater blast. Other activities generating noise may disturb bird life to a greater or lesser extent but are unlikely to have fatal consequences. The available evidence on the risk to diving birds during blasting indicates that unless the birds are very close to the source of the blast no injuries are likely. For this reason Terns and Gulls are not considered as being at risk from underwater noise.

Yelverton et al.l (1973) investigated far field underwater blast effects on mammals and birds and found that ducks subjected to 234 dB re 1uPa peak and 225 dB 1 uPa2-s SEL when submerged were not harmed. The corresponding levels for ducks on the surface were 230 dB re 1uPa peak and 220 dB 1 uPa2-s SEL. The explanation for the higher levels required to cause injury at the surface was based on the fact that most of the vital organs were located above the water surface. Stemp (1985) has stated that there is no evidence of high underwater sounds affecting diving birds.

There are no available data on disturbance to diving birds due to underwater noise levels. Doorling and Therrien (2012) indicate that diving birds may not hear well underwater. Startle responses and behavioural changes are therefore likely to be determined by airborne noise levels rather than underwater noise levels.

10.3.6.3 DISTURBANCE CRITERIA

Behavioural disturbance is difficult to quantify as reactions are highly variable and context specific making them less predictable Southall et al., (2007). SPL fails to account for the duration of the exposure, but it is the metric that has most often been estimated during disturbance studies (Southall et al., 2007). These values were based on those for multiple pulse sounds for all species, except for the harbour porpoise where all of the studies reviewed in Southall et al. (2007) were classified as non-pulses (intermittent or continuous sounds that can be tonal, broadband or both. Finneran and Jenkins (2012) have proposed SEL based criteria for disturbance which do take account of the duration of the exposure. These criteria are precautionary as only a small number of controlled studies have been performed, few field studies estimate received levels and a limited number of species are represented. The long-term implications of these behavioural responses have also not been determined.

Recent research on noise sensitive marine mammals indicates that disturbance/displacement is of shorter duration than previously reported, Thompson et. al (In Press) and while disturbance may take place at relatively low received levels the disturbance is context specific and distant sources may result in moderating reactions, De Ruiter et al (2013).

Hawkins and Popper (2012) have reviewed exposure metrics for fish species. The current US criteria of Peak SPL 206 decibels dB re 1 µPa, SELcum 187 dB re 1µPa2-s for fishes above 2 grams and SELcum 183 dB re 1µPa2-s for fishes below 2 grams need to be viewed in the light of more recent studies indicating that these thresholds are too conservative. Halvorsen et al. (2011) indicate the thresholds may be 20 dB below those found in better controlled studies.

In spite of the recognition that fish sense underwater noise as PV, no guidelines exist on PV exposure and very few data are available on PV levels. This significant data gap will be addressed in the forthcoming report which will set out ‘risk categories’ of High, Medium or Low within specific zones based on available studies. This categorisation of risk has been adopted for this report in relation to disturbance.

Due to historical reasons, underwater noise levels are referenced against a pressure of 1 µPa therefore noise levels in air are not directly comparable with noise levels underwater. The concept of M-weighting was introduced by Southall et al., (2007) to take into account the spectral characteristics of underwater noise and their potential impact on marine mammals in particular. Southall et al., (2007) introduced 5 categories of marine mammal thresholds, Low Frequency Cetaceans, Mid Frequency Cetaceans, High Frequency Cetaceans, Pinnipeds in Air and Pinnipeds underwater and proposed different M-weighting curves for each category.

Due to the shallow waters surrounding this development no Low Frequency Cetaceans are considered to be close enough to the proposed development to be at risk from underwater noise. In the unlikely event that any Low Frequency Cetaceans approach the risk area, mitigation measures will be implemented in a similar fashion to other Marine Mammals but the risk is not otherwise considered further in this section. In line with best international practice, Finneran & Jenkins (2012) and NOAA (2013), consideration is given to Cetaceans, Phocids and Mustelids separately rather than limiting consideration to Cetaceans and Pinnipeds as general classes of Marine Mammal.

Proposed Underwater Noise Exposure Criteria					
Species	**Single Pulse**	**Multiple Pulse**	**Nonpulse**	**Disturbance**	**Reference**
Mid Frequency Cetaceans					
Sound Pressure Level	224 dB re 1uPa (peak)(flat)	224 dB re 1uPa (peak)(flat)	224 dB re 1uPa (peak)(flat)	140 dB re 1uPa (peak)(flat)	Southall *et al*, 2007
Sound Exposure Level	183 dB re 1uPa2-s (M weight)	183 dB re 1uPa2-s (M weight)	200 dB re 1uPa2-s (M weight)		Southall et al, 2007
High Frequency Cetaceans					
Sound Pressure Level	224 dB re 1uPa (peak)(flat)	224 dB re 1uPa (peak)(flat)	224 dB re 1uPa (peak)(flat)		Southall *et al*, 2007
Sound Exposure Level	183 dB re 1uPa2-s (M weight)	183 dB re 1uPa2-s (M weight)	195 dB re 1uPa2-s (M weight)	120 dB re 1uPa2-s (M weight)	Finneran & Jenkins 2012
Phocids (in water)					
Sound Pressure Level	212 dB re 1uPa (peak)(flat)	212 dB re 1uPa (peak)(flat)	212 dB re 1uPa (peak)(flat)		Southall *et al*, 2007
Sound Exposure Level	171 dB re 1uPa2-s (M weight)	171 dB re 1uPa2-s (M weight)	188 dB re 1uPa2-s (M weight)	100 dB re 1uPa2-s (M weight)	Finneran & Jenkins 2012
Phocids (in air)					
Sound Pressure Level	143 dB re 20uPa (peak)(flat)	143 dB re 20uPa (peak)(flat)	143 dB re 20uPa (peak)(flat)		Southall *et al*, 2007
Sound Exposure Level	129 dB re 20uPa2-s (M weight)	129 dB re 20uPa2-s (M weight)	129 dB re 20uPa2-s (M weight)	100 dB re 20uPa2-s (M weight)	Finneran & Jenkins 2012

Table 10.3.1 - Proposed Underwater Noise Exposure Criteria (Part 1 of 2)

Proposed Underwater Noise Exposure Criteria					
Species	**Single Pulse**	**Multiple Pulse**	**Nonpulse**	**Disturbance**	**Reference**
Mustelids (in water)					
Sound Pressure Level	212 dB re 1uPa (peak)(flat)	212 dB re 1uPa (peak)(flat)	212 dB re 1uPa (peak)(flat)		Finneran & Jenkins 2012
Sound Exposure Level	171 dB re 1uPa2-s (M weight)	171 dB re 1uPa2-s (M weight)	188 dB re 1uPa2-s (M weight)	100 dB re 1uPa2-s (M weight)	Finneran & Jenkins 2012
Mustelids (in air)					
Sound Pressure Level	143 dB re 20uPa (peak)(flat)	143 dB re 20uPa (peak)(flat)	143 dB re 20uPa (peak)(flat)		Finneran & Jenkins 2012
Sound Exposure Level	129 dB re 20uPa2-s (M weight)	129 dB re 20uPa2-s (M weight)	129 dB re 20uPa2-s (M weight)	100 dB re 20uPa2-s (M weight)	Finneran & Jenkins 2012
Fish (0.1 kg)					
Sound Exposure Level	195 dB re 1 uPa2-s PTS onset			187 dB re 1 uPa2-s PTS onset	Popper *et al.* (1997)
Fish (1.0 kg)					
Sound Exposure Level	200 dB re 1 uPa2-s PTS onset			192 dB re 1 uPa2-s PTS onset	Popper *et al.* (1997)
Diving Birds					
No specific data is available on injury thresholds or behaviour of diving birds exposed to underwater noise					

Table 10.3.2 - Proposed Underwater Noise Exposure Criteria (Part 2 of 2)

The above criteria will be used to quantify the effect of existing and proposed noise emissions on the species of interest.

10.3.7 Underwater Noise Propagation in Galway Bay

Galway Bay is a complex area to model accurately. Due to the extremely shallow water depth, the mixture of fresh and saline water and the significant temperature variations sound speed varies significantly. The shallow depth also significantly limits transmission of low frequency sound.

Due to the difficulties in modelling noise transmission an empirical method was devised. Using known or constant sources, transmission loss was measured across the bay. Two methods were chosen; (a) using the noise log from an approaching vessel that was travelling at a constant speed towards the monitoring location (low frequency source) and (b) use a constant output (high frequency) source at a fixed position to generate noise levels in the bay and monitor the levels to calculate the transmission loss.

10.3.7.1 Moving Vessel Noise

A vessel approaching the dock gates must maintain a reasonable speed in order to be able to steer through the narrow entrance. This is complicated by the River Corrib flowing at right angles to the course the vessel wishes to steer. As a result most vessels maintain a speed of between 1 and 2 knots, the minimum speed to maintain steerage.

10.3.7.2 LE Emer

A vessel familiar with the area would have a standard docking procedure to be followed. The vessel chosen for the test was the LE Emer, one of the naval vessels that regularly visits the port.

On the date of the survey, 23rd March 2005 the sea state was calm and noise levels were logged as the vessel passed the head of Nimmo's Pier until it entered the dock gates. Noise levels were measured every 1.14 seconds. The resulting log of noise levels is reproduced in Figure 10.3.3 below.

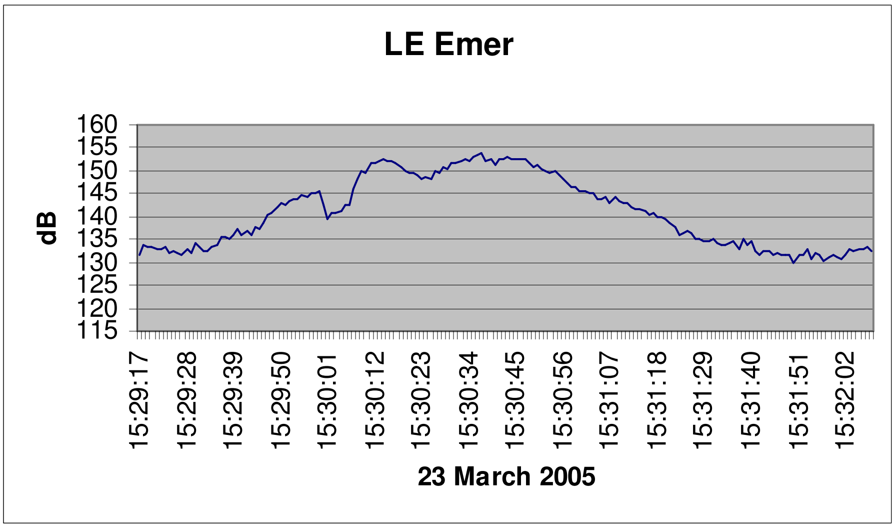

Figure 10.3.3 - Noise Level as LE Emer approaches the Existing Docks

With spherical spreading the expected difference for doubling of distance is 6 dB, for cylindrical spreading the expected difference is 3 dB. The difference is clearly greater than these values and is clearly impacted by the shallow water conditions and the fact that the source is close to (or on) the surface as outline in Section 1 in the section entitled "Behaviour of noise underwater" in these conditions as outlined in Richardson et.al. (1995) the expected loss equates to a 35 log R relationship and thus 10.5 dB per doubling of distance. The additional 1 dB attenuation can be due to localised effects and because it is an additional 1 dB, a 35 log R relationship is conservative.

10.3.7.3 Moving Vessel Noise (MV Conamara)

IMAR Survey Ltd carried out a shallow water seismic survey in Galway Bay. This involved the towing of an AAE200 seismic boomer astern of the MV Conamara. This seismic boomer represented a loud noise source that was used for a series of measurements as MV Conamara tracked an east-west tramline just south of the monitoring station. See Figure 10.3.5 for locations of vessels.

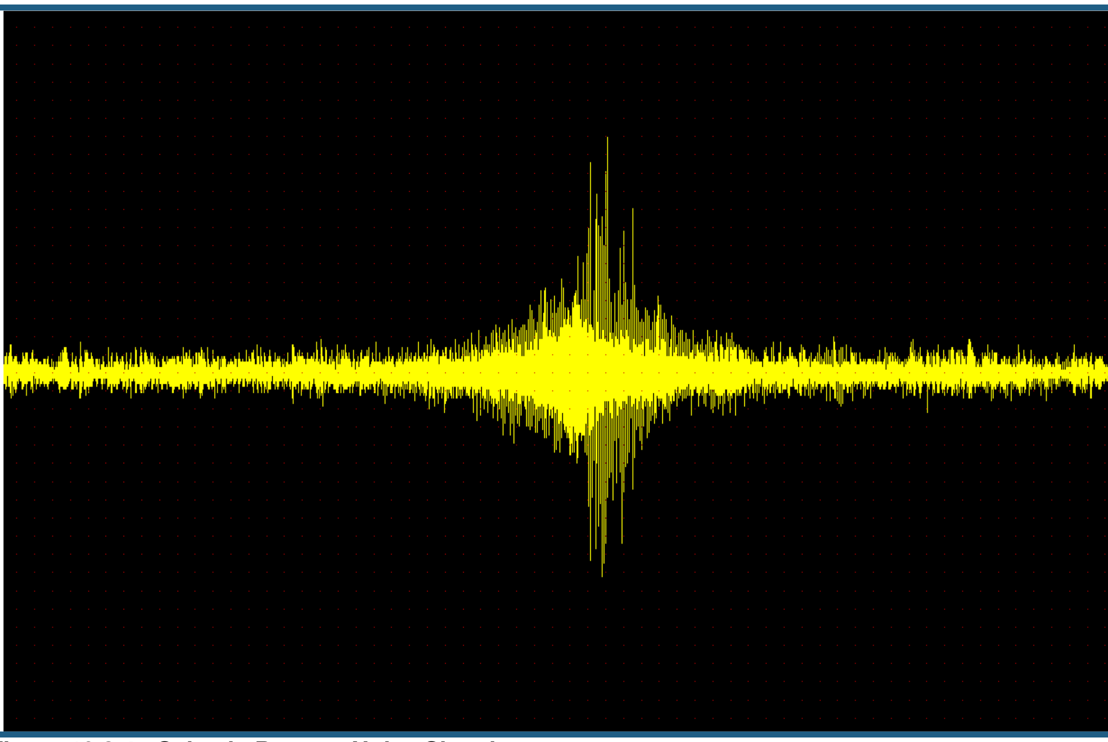

Figure 10.3.4 - Seismic Boomer Noise Signal

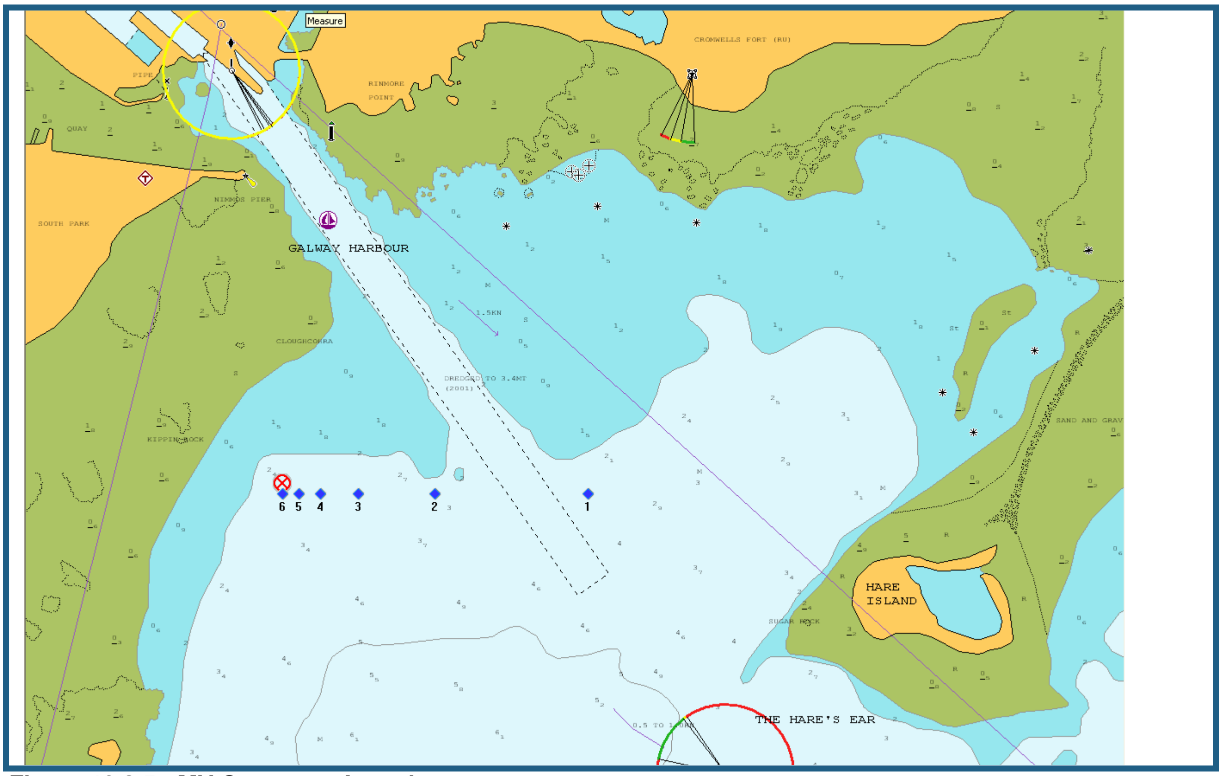

Figure 10.3.5 - MV Conamara Locations

The locations and received sound level for the run is reported in Table 10.3.3 below.

Noise Readings from MV Conamara			
MV Conamara Position	**Distance from receiver m**	**dB re 1 uPa**	**Difference**
1	640	81.8	12.3
2	320	94.1	11.4
3	160	105.5	10.8
4	80	116.3	11.6
5	40	127.9	10.8
6	20	138.7	0

Table 10.3.3 - Noise Readings from MV Conamara

The readings are consistent with the survey using LE Emer in that the attenuation for each doubling of distance is of the order of 10-12 dB per doubling of distance, which indicates a spreading loss of 35 Log R_1.

10.3.7.4 Fixed Source Survey

A series of tests was carried out on 5th April 2007. This test differed from the precious two tests in that a known high frequency noise source was anchored at a fixed location and noise measurements were taken on a transit across the bay.

The noise source was a Teledyne Benthos Model ALP-365 Flexi-Pinger. This underwater beacon features user-selectable frequencies, acoustic outputs and pulse repetition rates and provides a constant reliable output The Model ALP-365 has a frequency range of 25 kHz to 40 kHz, a pulse length of 4 milliseconds at a repetition rate of 0.5 to 2.0 seconds. The acoustic output can be varied from 162 dB re 1 µPa to 177 dB re 1 µPa.

Due to the acoustic output of the pinger the following protocol was observed for the survey:

- Check for the presence of marine mammals for 30 minutes prior to survey.
- None observed, pinger set to minimum output and deployed at dock gates for 25minutes
- Pinger relocated to survey location and deployed for 5 minutes
- Pinger set to maximum output for duration of survey
- Watch kept for marine mammals during survey, none observed

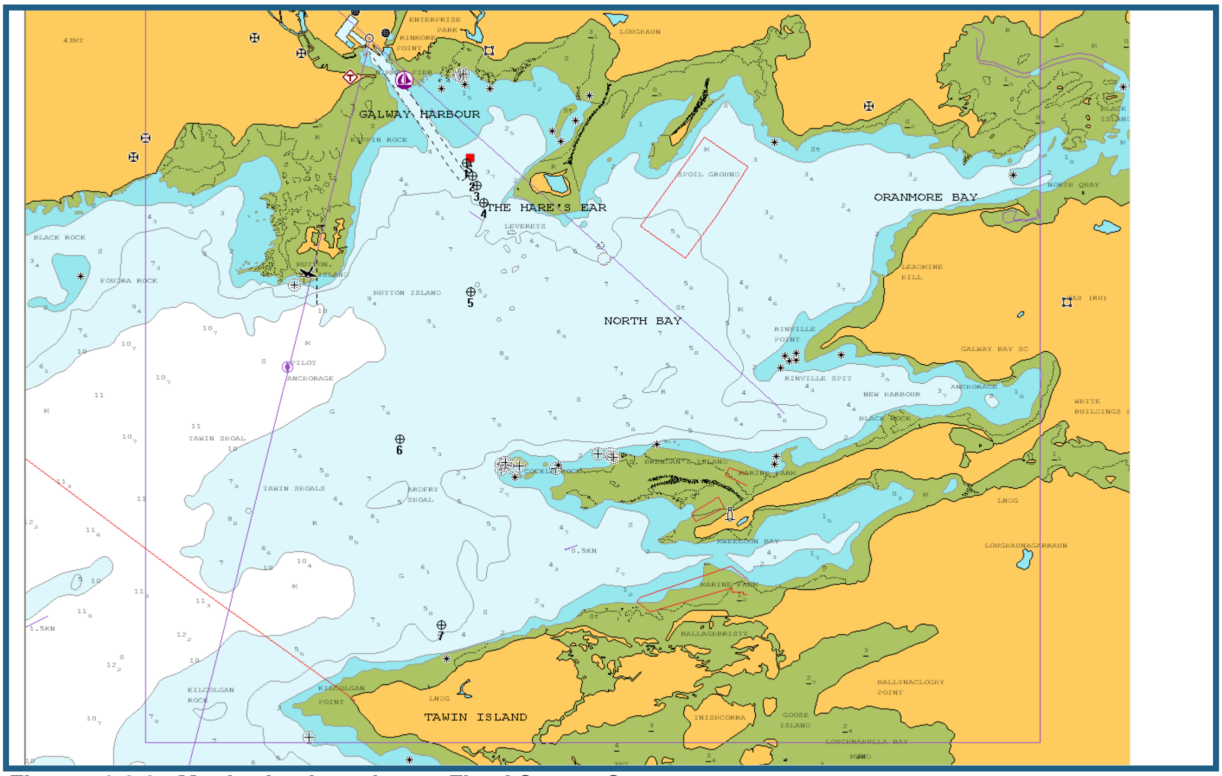

Figure 10.3.6 - Monitoring Locations – Fixed Source Survey

In order to determine transmission loss across the bay, the pinger was located in the area where deepening of the channel will take place using blasting. With the pinger in place noise levels were measured at locations across the bay. The measured noise levels are reported on the following table:

Results from Fixed Source Survey		
Location	**Distance from Receiver meters**	**dB re 1 µPa**
2	53	108
3	152	95
4	388	88
5	1113	80.5
6	2410	64
7	3887	54.5

Table 10.3.4 - Results from Fixed Source Survey

The results are plotted on Figure 10.3.7 along with a 35 Log R slope. While not giving an exact correlation, there is good agreement and the results are consistent with those obtained on the other two surveys.

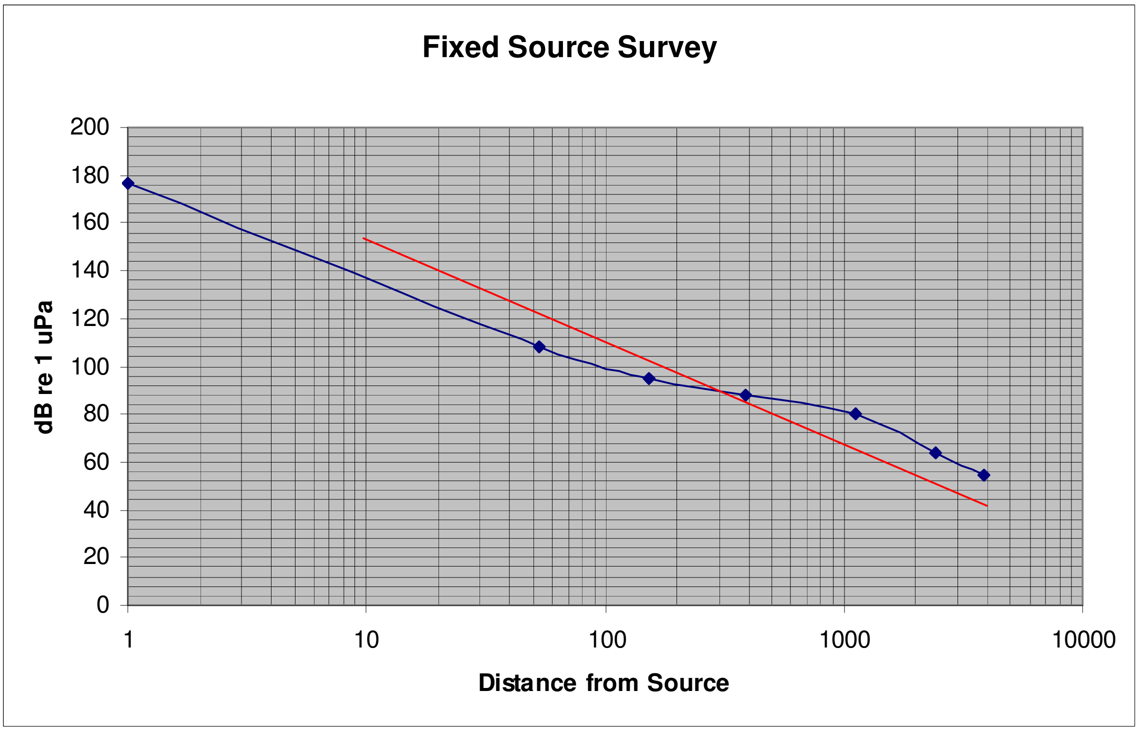

Figure 10.3.7 - Fixed Source Survey Attenuation Plot

The 35 Log R relationship is supported by the literature research for shallow water.

10.4 POTENTIAL SIGNIFICANT IMPACTS – AIRBORNE NOISE

The potential impacts of the project have been separated into Airborne Noise impacts and Underwater Noise impacts.

10.4.1 Airborne Noise

In order to determine the quantum of potential impacts the following scale has been devised:

10.4.1.1 Major

Noise levels in excess of a statutory/standard/guideline limit value is considered to be a Major Negative Impact. A significant reduction in the current impact on sensitive receptors is considered to be a Major Positive Impact.

10.4.1.2 Moderate

Noise Levels likely to cause disturbance at sensitive locations is considered to be a Moderate Negative Impact. A reduction on current impact is considered to be Moderate Positive.

10.4.1.3 Minor

Noise levels in excess of ‘Do-Nothing’ but unlikely to cause disturbance or cause any changes to current perception are considered as Minor Negative and Minor Positive respectively.

10.4.1.4 Negligible

No change in noise levels at sensitive locations

10.4.2 Construction Phase

The construction method statement is outlined in Chapter 3 of this document. The principal noise generating elements of the construction phase are:

- Lagoon Wall and lagoon construction
- Dredging Works
- Quay wall construction including pile-driving
- Traffic Noise During Construction (will be dealt with in the next section)

10.4.2.1 Lagoon Construction

The principal activity during this phase will be the transport and placement of material on site, in particular rock armour and consolidating and levelling the material in the lagoons. The principal noise sources during this phase will be dumper trucks, loaders and bulldozers. From our database of construction equipment and reference to B.S. 5228 Noise and Vibration Control on Construction and open sites, a noise prediction model has been prepared. The result of this model can be seen in figure 10.4.1.

As can be seen from the model the noise level for a typical scenario will be in the order of 45 dBA at the site perimeter. At various stages of construction some noisy equipment will need to operate at the site boundary. In these instances noise levels at the site boundary could reach 70 dBA. The received noise level at any of the noise sensitive locations will be below daytime background levels so the potential impact will be negligible.

Figure 10.4.1 - Lagoon Construction Noise Model

10.4.2.2 Dredging Works

As outlined in Chapter 3 there are 2 stages to the dredging operation.

- Trailer Suction Hopper Dredging (TSHD)
- Backhoe Dredging

10.4.2.3 Trailer Suction Hopper Dredging

The mechanics of operation of this equipment are described in Chapter 3. The operation of this type of dredger is the first stage of dredging, where soft, silty material in the upper layers to be dredged is suctioned into a vessel and discharged via a pipeline into one of the lagoons. The nature of the vessel is such that the noise levels are similar to a tanker (fuel or bitumen) discharging cargo. The main engine is required to drive the vessel and additional noise sources are related to pumping the material into the lagoon. The mode of operation means that on closest approach to the lagoon (and the noise sensitive locations) will involve either main engine propulsion or pumping discharge noise.

The noise prediction model has been prepared on a worst case scenario where both sources are operating. The noise prediction model for the TSHD dredging stage of construction is presented in Figure 10.4.2 TSHD Dredging Noise Model.

The noise sensitive locations are Mellows Park and Frenchville. From the background noise measurement data, noise levels are lower at Mellows Park during the day, so this becomes the sensitive location during the day time. At night background noise levels at Frenchville reduce due to lower road traffic volumes. The proposed dredging operation takes place closer to this location so Frenchville becomes the sensitive location at night time. As can be seen from the plot the noise level is in the order of 45 dBA at Frenchville, when operating close inshore. Night time background noise levels are in the order of 40 dBA at Frenchville . Given that noise levels in a bedroom with an open window are 10dB less than the external level, the operation of the TSHD at night will result in a Minor impact in this area.

Figure 10.4.2 - TSHD Dredging Noise Model

As can be seen from the plot the Lden noise level is in the order of 45 dBA at Frenchville, when operating close inshore. Should night time dredging be required night time noise levels are 39 dBA . Given that noise levels in a bedroom with an open window are 10dB less than the external level

10.4.2.4 Backhoe Dredging

Backhoe dredging probably involves a smaller dredging vessel, but requires the support of barges, which are themselves significant noise sources. The operation of the backhoe dredger also involves the excavation of consolidated material or in some cases rock. The dredged material has also to be double handled, i.e. loaded into and out of the barges. This inevitably will result in considerably more noise than the TSHD process. Database data for different dredging activities indicates that for both airborne and underwater noise backhoe dredging is noisier than TSHD bu about 10 dB.

The requirement for backhoe dredging will be further offshore than the areas requiring TSHD. This will result in a greater separation between source and receiver for the vast majority of the work. In order to cater for a worst case scenario, the source has been placed close to shore to determine the worst case impact.

The noise prediction model for the Backhoe dredging stage of construction is presented in Figure 10.4.3 Dredging Noise Model.

Noise levels in the order of 50 dB Lden are predicted at noise sensitive locations. This does not present any difficulty during the day. In a worst case scenario noise levels could reach 46 to 48 dBA at Frenchville and Mellows Park at night. Noise levels of this order have the potential to cause disturbance at night so the potential impact is classed as moderate.

Figure 10.4.3 - Backhoe Dredging Noise Model

10.4.2.5 Quay Wall Construction including Pile-Driving

This phase will comprise the construction of the berthing facility and also some of the breakwater and lagoon containment structures. The pile driving activity will require, in a worst case scenario, impact pile driving of circular piles and impact driving of sheet piling. Pile driving is by its nature a very annoying airborne noise source. The impact sound produced is normally accorded a penalty in any airborne noise assessments. The energy required to drive large piles generates significant noise and the model is based on database noise emissions for impact driving of 900mm steel piles on the construction closest to shore. A limited quantity of larger piles will be required further from the shore and sensitive locations. The 900mm pile close to shore represents a worst case scenario.

Figure 10.4.4 - Pile Driving Noise Model

The noise prediction for this activity is Lden of 55dBA at noise sensitive locations and Lnight values of 55 to 60 dBA. The impact in this case is Major.

10.4.3 ROAD TRAFFIC NOISE

10.4.3.1 Existing Road Traffic Noise

The traffic noise models are based on traffic predictions produced in Chapter 13 of this document. Due to the nature of road traffic noise small changes in road traffic levels do not result in significant changes in road traffic noise levels. In fact it requires a doubling of traffic volumes to effect a 3dB increase in road traffic noise levels.

As a means of comparing road traffic noise associated with the development with potential changes in noise levels due to the development a number of road traffic noise models have been prepared. As outlined above, the greatest impact will be at locations close to the proposed development. For this reason the scope of the modeling was limited to 4 roads close to the development.

- Bóthar na Long
- Lough Atália Road to the junction with Fairgreen Road
- Lough Atália Road to the junction with College Road
- Dock Road to the south of the harbour access junction

Traffic levels for the various scenarios were provided by the traffic consultants and noise models were prepared using the Predictor ISO 9613 Road Traffic calculation.

Road traffic was not modeled out to Mellows Park or Frenchville. The traffic model was limited geographically to the existing docks area and noise levels at 5 properties were given particular consideration:

- The Radisson Hotel (being representative of properties along Lough Atáila Road)
- The Harbour Hotel
- Cé na Mara apartments facing the port
- DockGate Apartments
- Dún Aengus Apartments

In order to validate the noise prediction model short term noise measurements were made at these five locations on three occasions, 20th, 25th and 30th May 2011. The model was in general agreement with the predicted noise levels as

Road Traffic Noise (Lden) Model validation		
Location	2011 Prediction	2011 Measured
Radisson Hotel	61	59
Harbour Hotel	69	68
Cé na Mara Apartments	53	51
DockGate Apartments	59	61
Dún Aengus Apartments	41	45

Table 10.4.1 - Road Traffic Noise (Lden) Model validation

The baseline model is based on 2011 road traffic levels and is reproduced in Figure 10.4.5.

Figure 10.4.5 - Baseline Traffic Noise Model

10.4.3.2 Construction Road Traffic Noise

Construction road traffic volumes were obtained from the traffic consultants and a noise prediction model was developed. This road traffic includes the movement of materials on to the site and the movements associate with construction workers coming and going from work. The model output is illustrated at Figure 10.4.6.

Figure 10.4.6 - Construction Traffic Noise Model

The impact of the construction traffic is outlined in Table 10.4.2. In order to compare like with like, the 2011 predicted levels are compared to the construction related traffic noise prediction. This approach is followed for the remaining traffic scenarios. The only significant change in noise levels is at the Radisson Hotel where the change can be considered moderate. A similar impact can be expected at other properties on Lough Atália Road with decreasing impact for properties further back from the road edge.

Road Traffic Noise (Lden) Construction Road Traffic		
Location	2011 Predicted	Construction Traffic
Radisson Hotel	61	63
Harbour Hotel	69	70
Cé na Mara Apartments	53	53
DockGate Apartments	59	59
Dún Aengus Apartments	41	41

Table 10.4.2 - Road Traffic Noise (Lden) Construction Road Traffic

10.4.3.3 Operational Phase Traffic Noise

The 2016 road traffic was modelled using 2 scenarios, the scenario with the development and the Do Nothing scenario. The results of the model output are illustrated in Figure 10.4.7 and Figure 10.4.8. The noise impact is compared in Table 10.4.3.

10.4.3.3.1 2016 Do Nothing

Figure 10.4.7 - 2016 Road Traffic Do Nothing

10.4.3.3.2 With Development

Figure 10.4.8 - 2016 Road Traffic with Development

As can be seen from Table 10.4.3, the difference between the 2016 road traffic noise prediction with and without development is in the order of 1 dB which is within the margin of error for the prediction model. The scale of the impact of road traffic noise emanating from the development in 2016 is therefore considered negligible.

Road Traffic Noise (Lden) 2016 Road Traffic		
Location	2016 Do Nothing	2016 With Development
Radisson Hotel	63	64
Harbour Hotel	67	68
Cé na Mara Apartments	54	54
DockGate Apartments	58	59
Dún Aengus Apartments	45	46

Table 10.4.3 - Road Traffic Noise (Lden) 2016 Road Traffic

10.4.3.4 2031 Road Traffic Noise

A similar exercise was carried out for 2031

10.4.3.4.1 2031 Do Nothing

Figure 10.4.9 - 2031 Road Traffic Do Nothing

10.4.3.4.2 2031 with Development

Figure 10.4.10 - 2031 Road Traffic with Development

As can be seen from Table 10.4.4, the difference between the 2031 road traffic noise prediction with and without development is in the order of 1 dB which is within the margin of error for the prediction model. The scale of the impact of road traffic noise emanating from the development in 2031 is therefore considered negligible.

Road Traffic Noise (Lden) 2031 Road Traffic		
Location	2031 Do Nothing	2031 With Development
Radisson Hotel	63	64
Harbour Hotel	68	68
Cé na Mara Apartments	54	54
DockGate Apartments	59	59
Dún Aengus Apartments	45	46

Table 10.4.4 - Road Traffic Noise (Lden) 2031 Road Traffic

10.4.4 Rail Traffic Noise

Rail traffic noise including the handling of freight is modeled using the RMR 2006 method as outlined in section 10.2.4. The rail link is twin line but the rail traffic comprises a single track use. The siding has a complex geometry due to a turn at high level off the main line and an incline to link the port level with the mainline level.

As outlined in section 10.2.2.4 the Lden is used as the noise criteria. Due to the volume of rail traffic associated with the development there are unlikely to be in excess of any statutory limits on noise levels from the operation.

Two of the most significant noise sources associated with slow moving rail freight traffic noise are the braking technology used on freight vehicles and corrugation of the track on curved track sections. Due to the geometry of the siding required for this development, these two factors have significant potential to exacerbate noise emissions from the rail operation. The impact of these sources is likely to result in screeching and grinding type noises which are beyond the scope of any model.

'Wheel squeal' arises when the wheel-sets of a vehicle are mounted in bogies or towards the end of a two-axle vehicle, they will be mounted parallel to each other, although there may be some yaw compliance incorporated. When negotiating a curve neither axle will lie on a curve radius, and some lateral creepage of the wheel tread over the railhead will take place. Some designs of bogie are now being applied that are capable of steering or being steered around curves. Rudd (1976) has estimated that squeal will occur when the track radius of curvature is less than 100 times the vehicle or bogie wheelbase. Generally a bogie with 2m wheelbase will squeal on a curve tighter than 200m radius. All proposed track curve radii are greater than 200m in this development to minimise squeal.

A models was prepared using the standard RMR algorithm with a 1.5m high noise barrier located on the eastern side of the track from where it separates from the mainline to where it joins the new port development at grade, i.e. for the full incline.

The noise model is presented in Figures 10.4.11 and an examination of noise levels at Mellows Park indicates a significant benefit in installing the barrier.

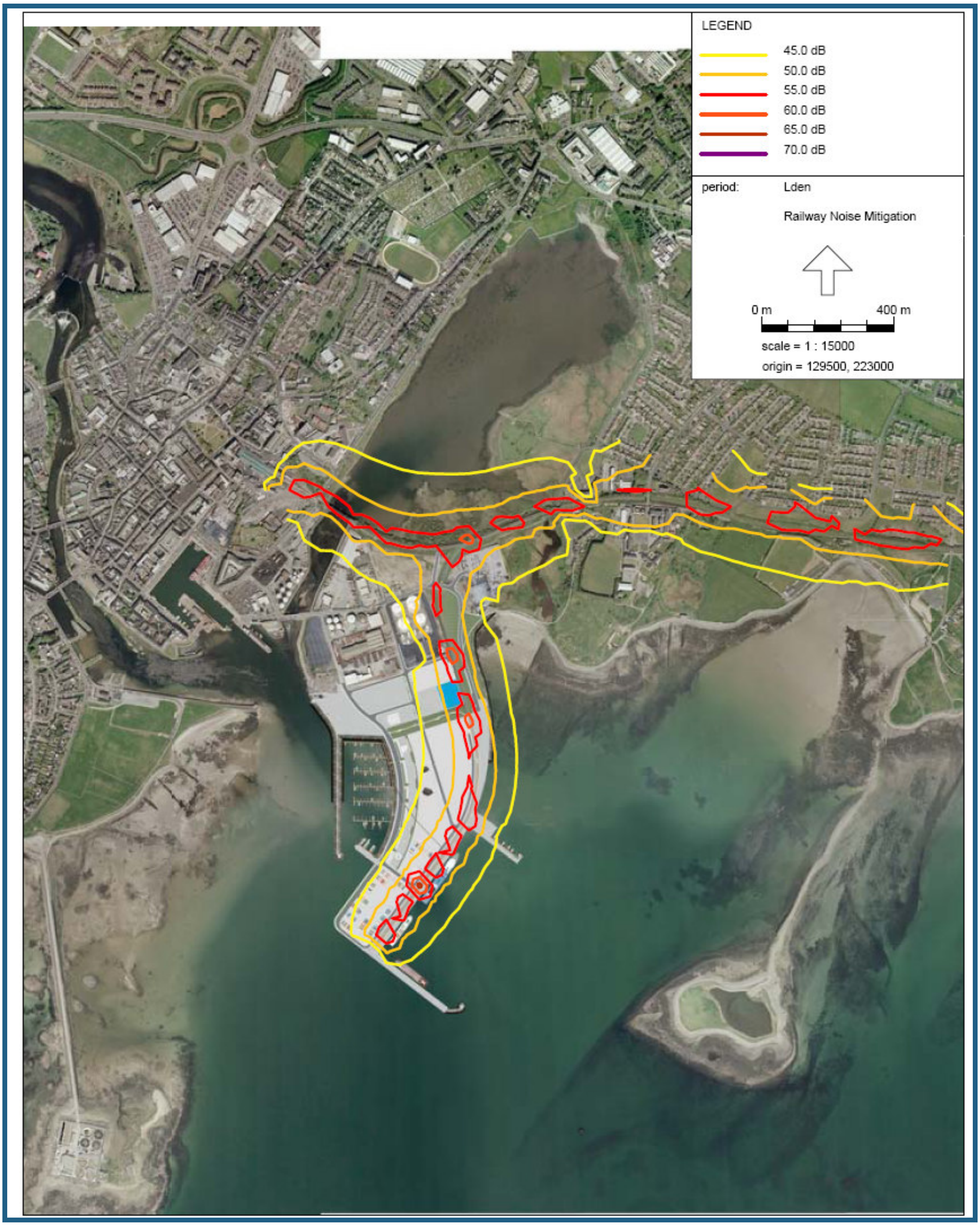

Figure 10.4.11 - Rail Noise with barrier

10.4.5 Operational Shipping Noise

The operational phase of the development will see the relocation of the shipping activity from the existing docks area to the new port area. This will significantly increase the separation between noise sources and receivers and will have major positive impacts.

Current port traffic is predominantly tankers of fuel or bitumen. Tankers tend to be noisy ships due to the pumping required to transfer their cargo. Research has shown that noise levels from cargo ships generally increases with the size of the vessel. This relationship does not hold however for tankers as can be seen in Figure 10.4.12. As can be seen in the chart for Bulk Carriers, Container and General Cargo ships the sound power level increases linearily with the capacity of the vessel. In the case of Tankers however the sound power level is constant for all vessel capacities.

What this means in practice is that with the capability of handling bigger Tankers, the sound power level of individual vessels will not increase and by relocating the berthage to the new port, the noise sources are further removed from the sensitive receptors. Additional benefits include the reduction in loading noise from scrap metal vessels. Noise prediction models comparing the current and proposed scenarios are presented below.

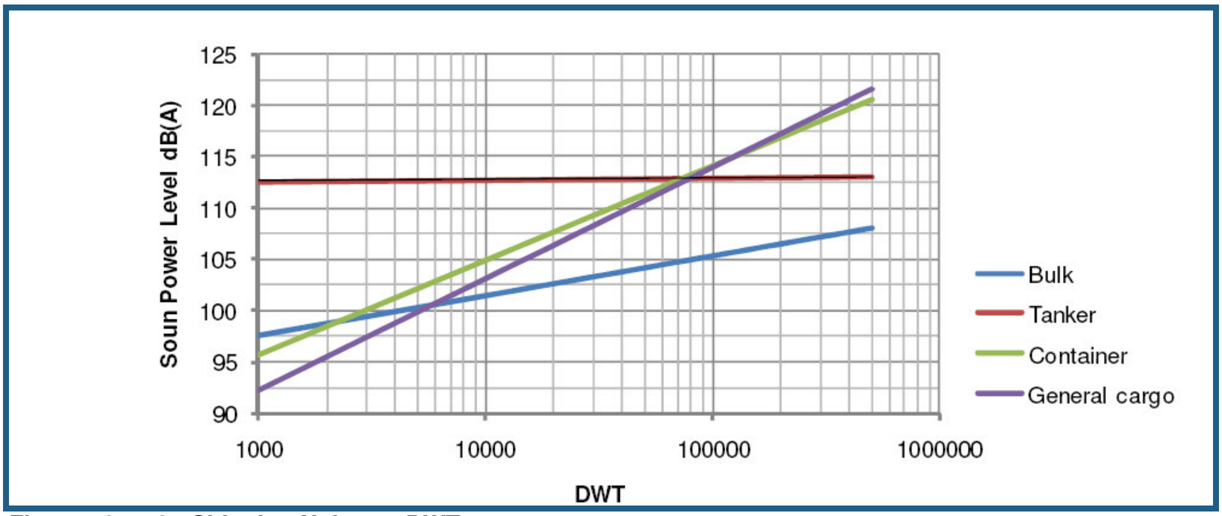

Figure 10.4.12 - Shipping Noise vs DWT

DWT: Dead Weight Tonnage

10.4.5.1 Operational Noise Do Nothing Scenario

In this case the model is based on one 4000T tanker in port

Figure 10.4.13 - Operational Noise Do Nothing

10.4.5.2 Operational Noise with Development

In this case the model is based on a worst case scenario of having a 15,000T Tanker, a 35,000T Tanker and a Cruise Ship berthed at the new port. Based on the number of vessels expected (refer to Chapter 2, port traffic) in 2031, approximately 135 due to the increasing size of vessel. This will result in a 'most likely' scenario of 1 ship being berthed at a time rather than the worst case of 3 large vessels contained in the model.

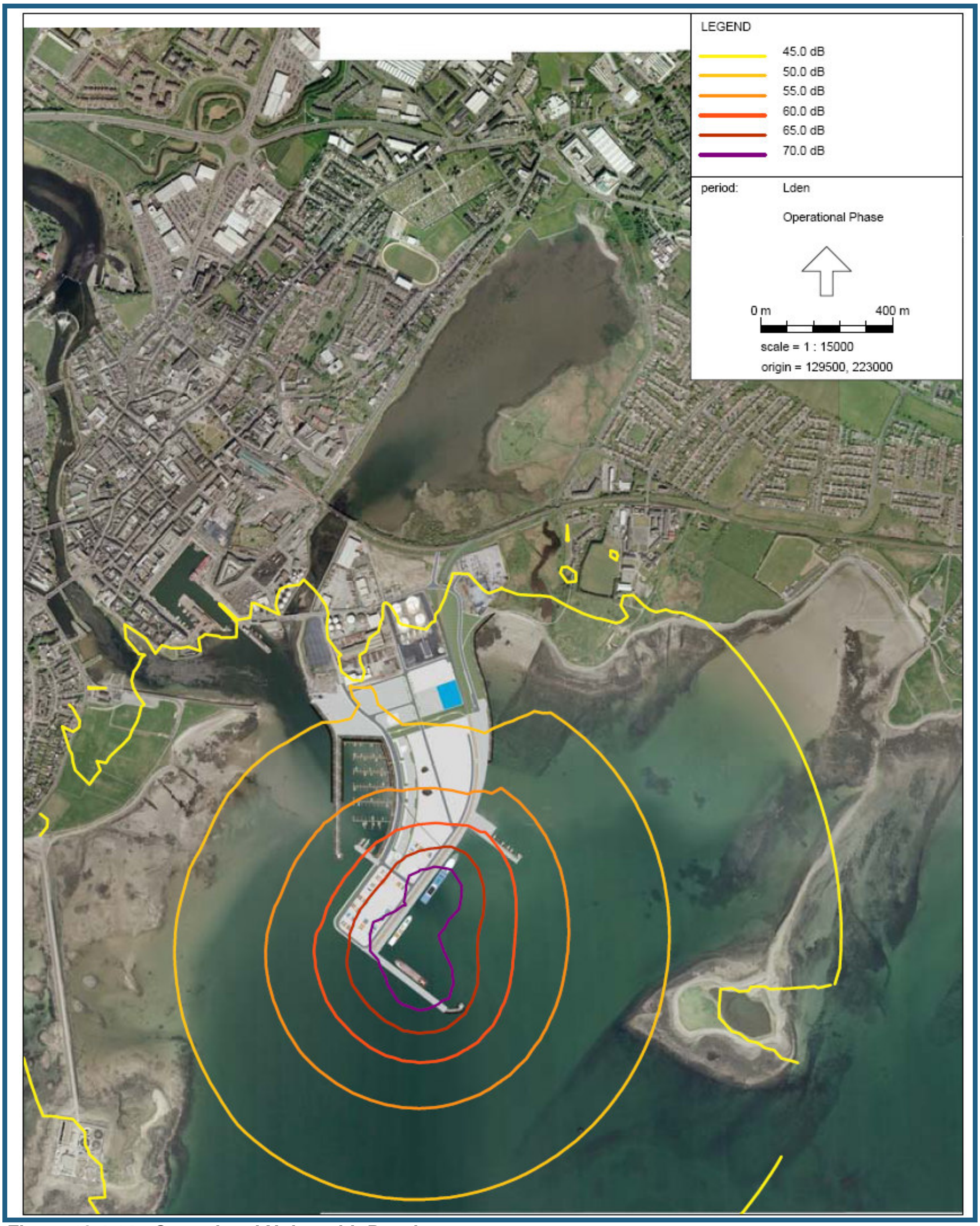

Figure 10.4.14 - Operational Noise with Development

The comparison of noise levels is outlined in Table 10.4.5. As can be seen from the table there is a significant reduction in noise levels in the existing docks area. This will result in a major positive impact for this area.

With regard to Mellows Park, the model predicts a worst case noise level increase from shipping to a level of 40 dBA. The existing background noise level at Mellows Park (as outlined in section 10.2.3.1) is 45 dBA during the day and 40 dBA at night. This means that the worst case noise level will be lower than background during the day and equal to background levels at night. At night in a bedroom with an open window the worst case prediction is for a noise level of 30 dBA which is within the WHO guideline for no disturbance. In any other case, i.e. 2 ships unloading in port simultaneously the impact will be 3 dB less. The impact is classed as negligible at Mellows Park for this reason.

At Frenchville the background noise levels are 52 dBA by day and 35 dBA at night. There is a negligible impact during the day and as with Mellow's Park the impact at night is classed as negligible.

Shipping Noise (Lden)		
Location	**Do Nothing**	**With Development**
Harbour Hotel	53	31
Cé na Mara Apartments	66	39
DockGate Apartments	64	36
Dún Aengus Apartments	46	43
Mellows Park	30	40
Frenchville	33	39

Table 10.4.5 - Shipping Noise (Lden)

10.4.6 Potential impact of Airborne Noise on Fauna

Airborne noise was modelled extensively in the Environmental Impact Statement. The most intense noise will arise due to impact pile driving and the airborne noise contours arising from this are shown in the figure below. Noise levels at the nesting sites on Mutton and Hare Island are in the order of 55 dBA. This represents a worst case noise level but will not arise during the nesting or pupping season as pile driving will not be carried out during the period April-July inclusive. A noise level of 55 dBA is extremely unlikely to generate a startle response at any sensitive location as traffic noise, passing boats or overhead flights by aircraft regularly generate this level of noise without adverse effect.

10.4.6.1 PHOCIDS & MUSTELIDS

The airborne noise disturbance thresholds for Phocids and Mustelids is in the order of 100 dB M weighted. The M weighting in air is almost directly equivalent to the 'B' weighting for human hearing. At low frequencies the difference between A weighting and B weighting is less than 30 dB so even in a worst case scenario the M weighted noise level will rise to 85 dBA, well below the threshold for disturbance.

10.4.6.2 NESTING BIRDS

Terns and other ground nesting birds show great loyalty to nesting sites. The noise levels associated with this project are below the threshold for disturbance.

10.5 POTENTIAL SIGNIFICANT IMPACTS - UNDERWATER NOISE

In order to determine the quantum of potential impacts the following scale has been devised:

- **Non-recoverable Injury**

Noise levels in likely to cause a permanent injury to sensitive species.

- **Recoverable Injury**

Noise Levels likely to cause a temporary but recoverable injury to sensitive species for example Temporary Threshold Shift.

- **Disturbance**

Noise levels likely to cause disturbance to a sensitive species. This criteria is further divided into radii of less than 100m (close to the source), less than 1 kilometer and greater than 1 kilometer. For impact assessment purposes the likelihood of disturbance is categorized as either 'high', 'Medium' or 'Low' in each of these distance bands.

- **Negligible**

No change in noise levels impacting sensitive locations/species

10.5.1 Underwater Noise Source Levels

Quoted (peak) source levels for underwater noise sources are quoted in dB re µPa at 1 metre. This is a 'notional' figure extrapolated from far field measurements as it is not practicable to measure sound levels at 1m from an active source such as a ship or a piledriver. Measurements are taken in what is known as the far field and extrapolated back to a notional 1m from the idealised point source. It is usual to take measurements at several hundred metres or kilometres and extrapolate the measured levels to what has become known as a 1m source level. This is illustrated in Figure 10.5.1.

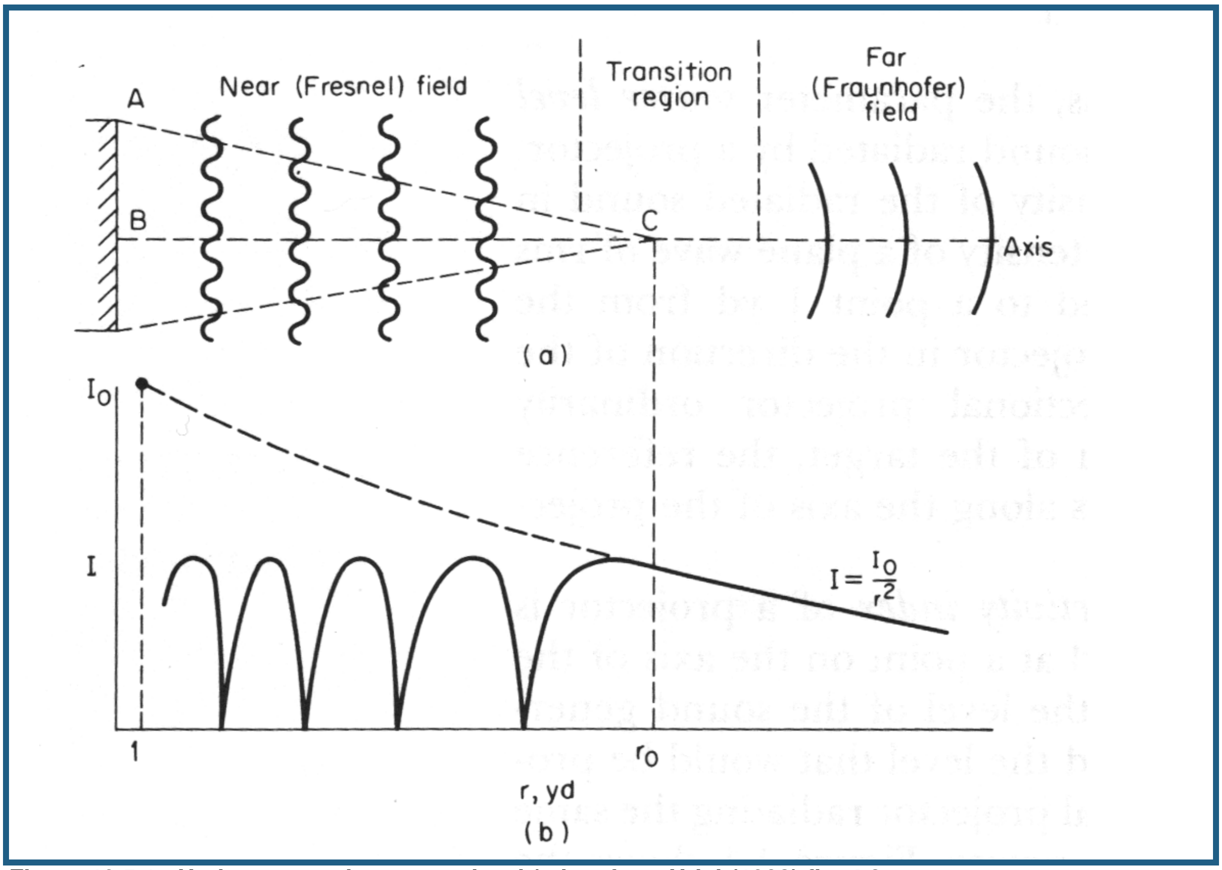

Figure 10.5.1 - Underwater noise source level (taken from Urich(1983) fig. 4.2

This apparently high value for the source level can lead to erroneous conclusions about the impact on marine mammals and fish for the following reasons:

Far field source levels do not apply in the near field of the array where the sources do not add coherently; sound levels in the near field are, in fact, lower than would be expected from far field estimates.

Source level calculations are generally based on theoretical point sources with sound propagating equally in all directions. This is not easily replicated in real world conditions.

The majority of published data for underwater sources is based on deep water exploration. Sound propagation in shallow water is significantly more complex and sound does not propagate as efficiently as it would in deep water.

As indicated previously underwater noise is referenced to a different pressure value so decibels underwater do not correspond to decibels in air. A table of typical underwater noise levels is set out below.

Typical Underwater Noise Levels Heathershaw et.al. (2001)		
Noise type	Level (dBA) re 1 µPa SPL (rms)	Comment
Undersea earthquake	272	Magnitude 4 on the Richter scale
Lightning strike on sea surface	250	Random events during storm at sea
Fin Whale	200	Vocalizations: pulses, moans
Container ship	198	274m long at 23 knots
Humpback Whale	192	Fluke & flipper slaps
Super tanker	190	340m long at 20 knots
Blue Whale	188	Vocalization, low frequency moans
Right Whale	187	Vocalizations, impulsive signal
Offshore Drilling Rig	185	MV Kulluk
Large Offshore Dredger	185	MV Aquarius

Table 10.5.1 - Typical Underwater Noise Levels Heathershaw et.al. (2001)

10.5.2 Construction Phase

The construction method statement is outlined in Chapter 3 of this document. The principal underwater noise generating elements of the construction phase are:

- Dredging Works
- Quay wall construction including pile-driving
- Underwater blasting noise

10.5.2.1 Dredging Works

As outlined previously there are two phases to the dredging process, an initial dredge using a Trailer Suction Hopper Dredger (TSHD) to remove silty material and a second phase using a backhoe dredger to remove consolidated material. Underwater noise from dredging has been extensively investigated by Robinson et al (2011) in the context of marine aggregate extraction. The data for TSHD dredgers is comprehensive as this is the type of equipment used for this purpose. There is very little published data for backhoe dredger operation.

A Trailer Suction Hopper Dredger uses a pump to 'suck' in material and discharge it to shore. This type of dredging can generate noise from mechanical equipment and from material movement. Robinson et al. (2011) calculated the source level of six dredging vessels and found that the material noise increased significantly with higher gravel content. For a dredger of the scale required for this project (99m long, 2,700m3 capacity) extracting sand, the source level was estimated at 183 dB re 1 µPa.

de Jong et al. (2011) found that measurements on 7 different Trailer Suction Hopper Dredgers yielded results in the range 133 dB and 185 dB re 1 µPa2 m2 depending on aspect ratio and activity, including transiting. The maximum levels only occurring during dredging activity.

A Backhoe dredger usually comprises a barge with a large excavator mounted on it excavating from the seabed and discharging into a transport barge. Backhoe dredgers are usually used for stiff sediments or rock excavation and make most noise when dragging rock from the seabed and depositing it into the barge. The duty cycle is such that this elevated noise level arises for about 50% of the time with lower noise levels when preparing to dig and while the barge is being emptied. In order to model a worst case scenario, the plant is assumed to be dragging all the time while operating.

Source levels are taken from a large (3,434-hp, using a 25-yd3 (18-m3) bucket) backhoe dredge, removing gravel and fractured rock in New York Harbour. Overall dimensions of the dredge were: 200 ft (61 m) long, 57 ft (17.4 m) wide, with a draft of 7 ft (2.1 m). This scale of dredger is larger than what will be required for the Galway Harbour Extension (~50m x 15 per Tobin Engineers) and represents a worst case scenario.

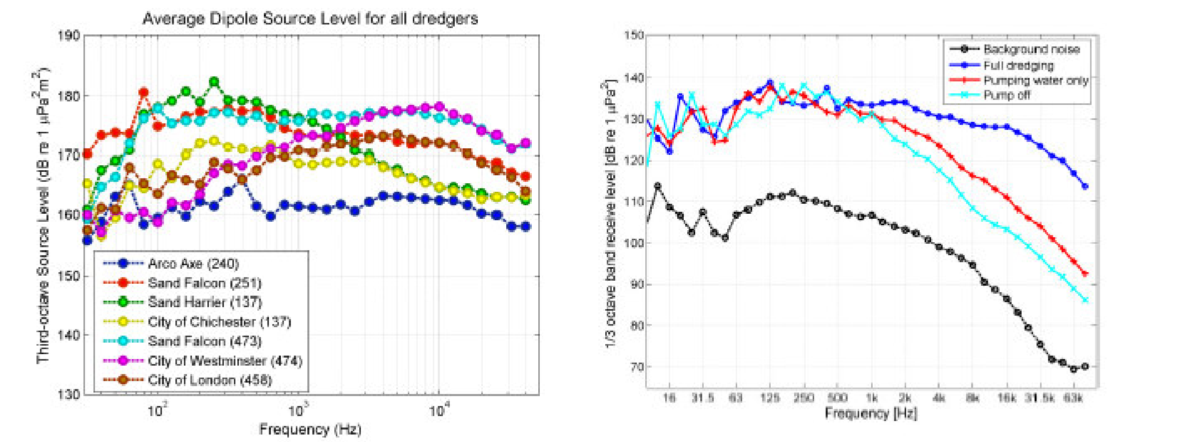

Figure 1.1 One-third-octave band Source Level data measured for six vessels from the UK whilst they were full dredging (left), and the Received Levels for one dredger (Sand Falcon) at a range of 100 m for a range of operating conditions (right).

Figure 10.5.2 - Underwater Noise from TSHD (Robinson et.al. 2010)

10.5.2.2 Pile Driving

There are essentially 3 types of pile driving used in construction; (a) Impact pile driving, (b) Vibratory pile driving and (c) auger piles. Auger piling comprises a drilling process where the pile effectively ‘lines’ the excavated hole until the desired depth is reached, it is suited for soft ground which is easily extracted. Auger piles provide a relatively quiet means of installing piles where ground conditions are suitable. Vibratory pile driving is normally used for sheet piles which are thin overlapping sheets and is similar to rock-breaking in implementation. A hydraulic driver provides small vibratory movement to the pile in combination with a static weight which forces the pile through the ground. Traditional impact pile driving comprises the use of a drop weight or equivalent force transmitting a downward blow to the pile until target resistance is met. It is the noisiest form of piling.

Underwater noise levels arising from pile driving have been extensively studied, in particular for the installation of offshore wind turbines. While the data for offshore wind-farms is useful it must be put in context. Offshore windfarms are typically installed on 4 to 6m diameter piles in relatively deep water. The energy required to drive a pile is proportional to the square of the diameter of the pile. In this project we are proposing to use piles of 900 to 1200mm in diameter with a consequent reduction in source level.

For pile driving the criteria is generally quoted with reference to SEL. This is due to the impulsive nature of the sound and more accurately reflects the total energy transmitted to the water body in pile driving.

Noise source level data for piling is quite complex as different parameters are often reported. One of the most widely accepted sources of information on pile driving noise levels is the Compendium of Pile Driving Sound Data compiled by Reyff (2007). This compendium reports 10m peak sound pressure levels of 208 to 210 dB re 1 µPa for 0.9 to 1.5m diameter piles when impact driven and 175 to 182 dB re 1 µPa for sheet piles when driven by a vibratory driver. The reduction in noise level is due to the lower energy required to drive a sheet pile and the change in driver to a vibratory machine.

A report prepared by URS Consultants for construction work in Darwin Harbour indicates a spectrum level in the range 185-210 dB re 1 µPa for a 1.5m impact pile driver with a peak frequency in the 200 to 500 Hz region.

10.5.2.3 Underwater Blasting Noise

Underwater blasting will be required at the New Harbour to remove some rock at the deep water berths and for providing a 'key' for the piles required to construct the quay walls and sections of the breakwaters. The explosives will be placed in drilled holes to fragment rock into pieces suitable for pile driving or subsequent excavation by dredge. In order to fragment the rock sufficiently a reasonably high blast ratio of explosive to rock cube. It is important to note that the explosives will be placed in drilled holes with appropriate stemming. Charges used in this manner lose most of their energy fracturing the rock and thus produce smaller pressure changes than unconfined charges.

Much of the literature regarding underwater blasting noise relates to unconfined blasting for seismic surveys, oil and gas infrastructure demolition or military purposes. The empirical data needs to be adopted for commercial blasting practices.

Peak overpressure for unconfined explosions can be approximated by the following formula developed by Ross (1987), Barrett (1996) based on earlier work by Cole (1948):

$$P_{max} = f(W^{0.27}R^{-1.13})$$

Where:

P = peak overpressure in Pa
W = weight of explosive per delay in kg
R = distance between blast and receiver

f = an experimentally derived constant
= 1.55 x10^7 for emulsion type explosives

On this project charge per hole will be limited to 10 kg per hole. The P_{max} therefore for a 10 kg maximum instantaneous charge (MIC) is 225 dB re 1 µPa.

This Nedwell et al (1992) have demonstrated that the pressure wave for a confined blast is at least 10dB lower than that of an unconfined blast, in fact the attenuation is closer to 20 dB at higher frequencies. The source level for a 10 kg MIC confined blast can be conservatively stated to be (SPL) 225 dB re 1 µPa at 1m.

SPL — Sound Pressure Level, at a given point is defined as SPL = $10\log10(p_{rms}/p_{ref})2$

10.5.3 Operation Phase

Underwater noise from shipping is regarded as a significant problem at European and a global level. Shipping noise has increased with the volume of motorized shipping traffic over the past

100 years. The impact of this increasing level of marine noise is subject to considerable research effort to both quantify the levels and reduce noise at source by design.

In relation to the proposed development it is necessary to assess operational underwater noise under a number of headings:

10.5.3.1 Noise Frequency

As outlined in Section 10.3 shipping noise needs to be assessed for the impact on the salmon and eel species in the longer term. In this respect we are focusing on frequencies below 625 Hz, in particular frequencies below 300 Hz.

Shipping noise can create disturbance in this frequency range as is evident from the noise emission characteristics of diesel engines as outlined in Bies & Hansen (2003) and Collier (1997). Shipping traffic is divided into commercial and leisure traffic as follows:

10.5.3.1.1 <u>LARGE COMMERCIAL VESSELS</u>

Shipping traffic will increase in gross tonnage terms but will be carried by fewer vessels. This results in a net decrease in vessel transits in and out of the port. Current vessel size is limited to about 5000T whereas the new Port will be able to handle vessels of over 20,000T. Vessel traffic to the port (in terms of vessels) peaked in 2005 with 432 vessels entering and leaving the port, current traffic is in the order of 180 vessels per year. Under the projections in the EIS the number of vessels entering the port in the 2035 (medium scenario) will be 107. While the vessels will be larger, there will be a net reduction in the number of vessels entering and leaving the bay and a reduction in vessels anchoring waiting for access to the port. This combined reduction will result in a decrease in overall underwater noise levels.

New et al. (2013) developed a mathematical model simulating a proposed more than six-fold increase (from 70 to 470 vessels) in shipping traffic from Nigg, a port in the Moray Firth cSAC on the resident population of Bottlenose Dolphins in the Firth. The model simulated the complex social, spatial, behavioural and motivational interactions of the dolphins. In spite of a more than six-fold increase in vessel traffic, the dolphins behavioural time budget, spatial distribution and motivations and social structure remained unchanged. They concluded that if increased commercial traffic is the only escalation in anthropogenic activity, then the dolphins response to disturbance is not biologically significant.

10.5.3.1.2 <u>FISHING BOAT TRAFFIC</u>

There are two types of fishing boat operating in Galway Bay; small inshore boats which stay within 5 miles of their home port and larger fishing vessels operating offshore and landing fish or coming to Galway for repairs or inspection.

The local fishing fleet is almost exclusively engaged in shrimp, lobster or crab fishing. From discussions with BIM, the fishery is at its maximum potential and it is unlikely that the local fishing fleet will expand significantly in terms of the number of vessels or fishing effort. The local fleet is spread around the bay with about 10 boats based in Galway, 3 at Bearna, 10 at Spiddal and a few operating from Maree, Ballynacourty, Kinvara and Ballyvaughan. The total fleet numbering about 30 boats.

The larger fishing boats operate from Rosaveal and Inishmore and come from other fishing ports for supplies, inspections and repairs. Currently about 60 boats of this type visit the harbour each year. It is expected that this number may double over time.

10.5.3.1.3 POTENTIAL SEA PLANE TRAFFIC

There is currently a proposal to operate a sea plane from Galway; this was the subject of a separate planning application by a third party. The operation of a seaplane from the port does not form part of this application.

Seaplane noise is generally airborne as there are no moving parts below the waterline. Underwater noise sources would comprise hull flow noise, structure-borne noise and refracted noise from the engine. Traffic levels will be low and it is not considered significant in the context of overall underwater noise levels.

10.5.3.1.4 LEISURE CRAFT TRAFFIC

The Inner Galway Bay area has 7 main access points for leisure craft; Galway Harbour with up to 50 craft, The Claddagh with 25, Bearna with 20, Spiddal with 20 most of which are sailing vessels, Rinville Bay with 80, the majority of which are sailing vessels, Kinvarra with 25 and Ballyvaughan with 20. These numbers are based on counts of vessels in harbours undertaken by Biospheric Engineering in August 2013. Aggregate numbers are therefore in the order of 150 motorised vessels and 100 sailing vessels. At a conservative estimate, there are probably that number again ashore which take to the bay occasionally.

While sailing vessels generally use sail power, it is normal for these vessels to use engine power when entering and leaving port so the total number of leisure craft are considered.

Apart from the Volvo Race or similar events, the annual blessing of the boats at the Claddagh is probably the biggest boating event on Galway Bay. The opening and closing of the dock gates leads to situations where several boats come and go together. Lusseau et al. (2012) found that leisure boat deployment is in the order of 3% with a peak of 5% in the months of June, July and August, which would tie in with casual observations of leisure craft on Galway Bay.

In general, traffic levels are light and underwater noise levels are only elevated for short periods when a craft is in a particular area. The noise level from a small craft has been studied by Evans et al.(1992) and from their data, a source level for small craft has been estimated for a fishing vessel (above) and a 'typical' leisurecraft based on a 6m boat with a 90 HP engine. These noise levels have been considered in the underwater noise model. The model is based on a trebling of leisure craft with the construction of the western marina and the conversion of the inner dock, the majority of which will be sailing vessels.

10.5.3.2 Noise Intensity

The new port is designed to accommodate larger vessels and intuitively the noise from larger vessels will result in an increase in intensity. In order to quantify this increase we must refer to the literature and estimate the impact.

10.5.3.3 Temporal impacts

The introduction of 24-hour access to a deep water berthing facility, providing access to larger vessels will result in a reduction in berthing times and a reduction in the number of vessels required transporting the equivalent amount of cargo. By reducing the total number of vessels and taking in larger single loads of cargo the impact of vessel noise is reduced on a temporal basis.

10.5.3.4 Increase in Vessel size

The size of the vessel using the port facilities is expected to increase from the current maximum of 5,000 Tonnes to a typical vessel of circa 25,000 Tonne. This will result in a considerable increase in engine size. Modern vessels however are being constructed to stricter noise limit values and may thus be quieter than historical research would indicate. This provides a factor of safety in the calculations which follow.

Urick (1983) groups the radiated noise from shipping into three main classes; Machinery noise, Propeller noise and Hydrodynamic noise. The three classes are distinguished by the frequency spectrum of the noise source. The machinery noise is described by Urick as complex and "subject to variations in level and frequency with changing conditions of the vessel".

Machinery noise is a function of the fundamental frequency of each piece of machinery, such as the diesel engine, the generator, the main drive motor, the reduction gears, the drive shafts and the propeller. An example would be the propeller shaft rate multiplied by the number of propeller blades.

Cavitation noise is speed dependant and is generated at higher frequencies at slower speeds. He indicates that at speeds of less than 2 knots cavitation noise is not a significant contributor to overall noise levels.

Under normal circumstances, hydrodynamic noise is likely to be only a minor contributor to radiated noise, and is apt to be masked by machinery and propeller noises. Under exceptional circumstances, such as when a structural member or cavity is excited into resonant source, (such as a "singing" propeller) hydrodynamic noise becomes a dominant noise source in the spectrum in which it occurs. (Urick 1983). We are therefore primarily concerned with the machinery noise of slow moving vessels in this study.

The speed/power dependence of the radiated noise of surface vessels has been documented in several sources. (Urick 1983), (Collier, 1997), Arveson et.al., 2000) and (Wales et.al., 2002). Urick's data is based on World War 11 data and is acknowledged by himself to be unreliable for freighters and tankers.

Richardson et.al. (1995) cite several examples from the published literature and state that broadband source levels for "small" ships are 170 to 180 dB re 1 μPa at 1m. They include data from several super tankers and their reference to "small" ships relates to vessels of less that 180 metres in length (about 30,000 Tonnes displacement).

Arveson et.al. (2000) examined the radiated noise of MV Overseas Harriette, a bulk cargo ship of 25,515 tons [25,923 Tonnes] and found tonal frequencies from the ships service diesel generator, main engine firing rate and propeller blade rate harmonics due to cavitation.

At low frequencies they found that the ships service diesel generator radiated a series of 6-Hz harmonics, in particular at 24 Hz and 30 Hz that were independent of ship speed. The diesel engine firing rate is a function of the engine rpm and the number of cylinders. On a 6 cylinder diesel engine running at 100rpm a firing rate of 10 Hz is achievable. The propeller cavitation noise is unlikely to be significant source at low speeds.

The result of the measurements and calculations carried out by Arveson et.al. (2000) indicate a broadband source level for the MV Overseas Harriette as follows:

Shipping Noise from 25,000T Cargo vessel		
Ship Speed RPM	knots	Broadband noise level dB re 1 µPa at 1 m
68	8	178
86	10	180
105	12	184
122	14	190
140	16	192

Table 10.5.2 - Shipping Noise from 25,000T Cargo vessel

It is anticipated that the noise level will reduce from these values with further reductions in speed. In a worst case scenario however a large 25,000 Tonne vessel can be considered to have a weighted noise emission level of 189 dB re 1 µPa at 1 m in the inner bay area. While this is above the disturbance threshold any such disturbance will be of short duration as the vessel will either continue to move out the bay or stop at the quay wall.

10.5.4 Propagation and Receiver Levels

As discussed in Section 10.3.8 and measured experimentally, the propagation losses in the Galway Bay area follow a 35 log R relationship. This can be attributed to the factors outlined in Section 10.2.1 Behaviour of noise underwater and defined in Richardson et.al (1995). The near fields effects (close to the source) is likely to distort the propagation estimate. Based on the measurements taken on the LE Emer's passage over the area it is reasonable to assume zero attenuation within 30 metres of the source and shallow water attenuation based on a 35 log R relationship from there to the receiver.

The inner Galway Bay area is a complex soundscape due to the shallow depth and complex salinity and temperature profile of the water. In order to provide conservative estimates of the safe separation distances for fish and marine mammals for the various stages of construction a 20 Log R relationship has been used. This provides a considerable factor of safety in estimating the received noise levels from each of the activities. A calculation of received underwater noise levels is presented in graphical form in Appendix 10.2.

10.5.5 Piling

There are three fundamental types of pile driving technology: impact pile diving, vibratory pile driving and auger piling. Impact pile driving comprises striking the pile with a piling head that generally uses potential energy from a falling weight to drive the pile. The resulting noise is a series of impacts at approximately one second intervals. Vibratory pile driving uses low frequency vibration to 'vibrate' the pile into place. The resulting noise takes the form of a low frequency buzz. Auger pile driving generally comprises a drilling type process where a hole is drilled into which the pile is lowered. The resulting noise is similar to a drilling type noise. Auger piling is not proposed on the Galway Port project.

Considerable measurement of noise from piling from offshore wind farms have been reported in the literature, the most notable feature of which are the high noise levels attributable to impact pile driving of very large diameter piles. For large offshore turbines, the pile diameters can be up to 6m with underwater noise levels in the order of 250 dB re 1 µPa. These piles are driven in open water by large sea-going vessels and in most cases, seal scaring devices are deployed in the area, leading to a combination of very loud noise sources concentrated in a small area. This type of activity is not directly comparable to pile driving for harbour construction where the pile diameter is much smaller and the activity is carried out from land or from jack up barges.

For the Galway Harbour Extension, the construction will comprise a combiwall system comprising tubular 'King' piles of either 900mm or 1.2m in diameter with three sheet piles in between. The piles will be driven into crushed rock to a depth of 2.5 to 3.0m as indicated on drawing numbers 2139-2142 & 2139-2143.

Piling will comprise a mix of impact piling and vibratory piling (vibropiling) depending on ground conditions. The expected average rate of installation is 4 tubular piles and 12 sheetpiles per day, a quantity that will vary depending on ground and weather conditions. The estimated time to install a tubular pile is in the order of 30 minutes and each sheet pile is estimated to take 6 minutes on average to vibrate into place. A considerable amount of time each day is taken up with relocating and aligning the pile driver and handling the piles. This non-piling time serves a useful function in reducing the overall noise emissions from the activity.

Noise source level data for piling is quite complex as different parameters are often reported. One of the most widely accepted sources of information on pile driving noise levels is the Compendium of Pile Driving Sound Data compiled by Reyff (2007) . This compendium reports 10m peak sound pressure levels of 208 to 210 dB re 1 µPa for 0.9 to 1.5m diameter piles when impact driven and 175 to 182 dB re 1 µPa for sheet piles when driven by a vibratory driver. The reduction in noise level is due to the lower energy required to drive a sheet pile and the change in driver to a vibratory machine.

A report prepared by URS Consultants for construction work in Darwin Harbour indicates a spectrum level in the range 185-210 dB re 1 µPa for a 1.5m impact pile driver with a peak frequency in the 200 to 500 Hz region.

10.5.6 Shallow Water Noise Model

As outlined above, noise propagation in shallow water is complex in particular close to the source. The use of source level data indicates a high noise level close to the source which does not actually arise. Until better models are developed, the concept of all noise sources being reduced to a single point in space requires this to happen. The noise levels predicted close to the source are therefore considerably overestimating the actual received noise levels.

It is difficult to model underwater noise in shallow water in a simplified manner due to the number of variables involved. Marsh and Schulkin (1962) validated a shallow water model with about 100,000 measurements. Greatest errors are likely close to the source as the model was optimised for long range transmission (Urick et al. 1968). The model is based on water depths of up to 200m and surface bottom interactions are seriously underestimated in very shallow (<20m) water due to (a) cut-off frequency and (b) higher grazing angles close to the source resulting in greater absorption in the sediments.

Schlulkin and Mercer (1985) reviewed the model and proposed some revisions and the near field anomaly term has been adjusted for propagation over mud in the model used as the basis of the calculations for this project.

The model for this project takes account of each of the sources on a case by case basis with frequency dependence built into the propagation model. The received level for each receiver type is corrected as appropriate using a type specific weighting. In order to simplify the discussion the sources are considered in three groups; impulsive sounds from blasting and pile driving, continuous noise from construction activities and noise from shipping.

10.5.6.1 Noise Model Results

Noise Model Results are presented in Appendix 10.2, with the category of impact indicated on the figure for each impacted species, i.e. Piling Noise levels impacting on Pinnipeds indicating the zones in which Permanent Injury, Temporary Injury and Disturbance are likely to occur.

Appendix 10.3 comprises impact radii plots illustrating the radius in which the various impacts occur for different sources.

These figures indicate that for pile driving an exclusion zone of 64m is required, for dredging a zone of up to 128m for dredging and 1 km for blasting activities in order to avoid any possibility of temporary injury to marine fauna. The limiting factor being the impact on Pinnipeds in all cases. The following tables show the relevant information.

Underwater Noise Impacts – Blasting and Impulsive Piledriving impact range (m)								
Activity	**PTS Onset Non-recoverable**	**TTS Onset Recoverable**	**Disturbance <100m**		**Disturbance <1000m**		**Disturbance >1000m**	
			Animal	**Population**	**Animal**	**Population**	**Animal**	**Population**
Cetaceans								
Dolphin	19	100	H	L	M	L	L	L
Harbour Porpoise	16	90	H	L	M	L	L	L
Phocids								
Common Seal	100	500	H	L	M	L	L	L
Grey Seal	100	500	H	L	M	L	L	L
Mustelids								
Otter	90	500	H	M	M	L	L	L
Fish								
Salmon	18	no data	H	L	M	L	L	L
Lamprey	18	no data	H	L	M	L	L	L
Eel	18	no data	H	L	M	L	L	L
Diving Birds								
Cormorant	no data	no data	H	L	M	L	L	L
Great Northern Diver	no data	no data	H	M	M	L	L	L
Red-Breasted Merganser	no data	no data	H	M	M	L	L	L

Table 10.5.3 - Underwater Noise Impacts – Blasting and Impulsive Piledriving impact range (m)

Underwater Noise Impacts – Construction Activities impact range (m)								
Activity	**PTS Onset Non-recoverable**	**TTS Onset Recoverable**	**Disturbance <100m**		**Disturbance <1000m**		**Disturbance >1000m**	
			Animal	**Population**	**Animal**	**Population**	**Animal**	**Population**
Cetaceans								
Dolphin	13	75	H	L	L	L	L	L
Harbour Porpoise	55	300	H	M	M	L	L	L
Phocids								
Common Seal	60	350	H	M	M	L	L	L
Grey Seal	60	350	H	M	M	L	L	L
Mustelids								
Otter	55	100	H	M	M	L	L	L
Fish								
Salmon	95	no data	H	L	M	L	L	L
Lamprey	95	no data	H	L	M	L	L	L
Eel	95	no data	H	L	M	L	L	L
Diving Birds								
Cormorant	no data	no data	H	L	M	L	L	L
Great Northern Diver	no data	no data	H	M	M	L	L	L
Red-Breasted Merganser	no data	no data	H	M	M	L	L	L

Table 10.5.4 - Underwater Noise Impacts – Construction Activities impact range (m)

Underwater Noise Impacts – Shipping Traffic impact range (m)								
Activity	**PTS Onset Non-recoverable**	**TTS Onset Recoverable**	**Disturbance <100m**		**Disturbance <1000m**		**Disturbance >1000m**	
'dno' indicates does not occur			**Animal**	**Population**	**Animal**	**Population**	**Animal**	**Population**
Cetaceans								
Dolphin	dno	dno	H	L	L	L	L	L
Harbour Porpoise	dno	dno	H	L	L	L	L	L
Phocids								
Common Seal	dno	<2	H	L	L	L	L	L
Grey Seal	dno	<2	H	L	L	L	L	L
Mustelids								
Otter	dno	<2	H	L	L	L	L	L
Fish								
Salmon	2	no data	H	L	L	L	L	L
Lamprey	2	no data	H	L	L	L	L	L
Eel	2	no data	H	L	L	L	L	L
Diving Birds								
Cormorant	no data	no data	M	L	L	L	L	L
Great Northern Diver	no data	no data	M	L	L	L	L	L
Red-Breasted Merganser	no data	no data	M	L	L	L	L	L

Table 10.5.5 - Underwater Noise Impacts – Shipping Traffic impact range (m)

10.6 VIBRATION

10.6.1 Introduction

This development has the potential to cause vibration from 2 sources; underwater blasting and construction traffic. The impact from construction traffic is likely to be of the order of less than 2 mm/s peak particle velocity in close proximity to operating heavy construction machinery. Levels from blasting could be higher than this if uncontrolled.

10.6.2 Vibration Sensitive Locations

There are no residential areas close enough to the proposed development to warrant any concern regarding vibration. Due to the isolated nature of the site there is no significant issue regarding vibration from construction machinery or traffic. There are 3 areas of potential concern regarding underwater blasting vibration.

- Sensitive structures on the Galway Harbour Enterprise Park
- Ground nesting birds (in season)
- Commercial Shelfish areas in Galway Bay

10.6.3 Vibration Design Criteria

Blasting can give rise to vibration, audible noise, and flyrock. The levels of vibration caused by blasting are well below those which can cause structural damage to properties. Nonetheless, vibration transmitted through the ground can 'shake' buildings and people and may cause nuisance.

Professional control of drilling and blasting operations can ensure through the design of the layout of the workings, that blasts are designed to minimise impact on sensitive areas. Use of the "delayed detonation" blasting technique, whereby the blast takes place in a series of timed small explosions rather than a single large blast, helps to minimise the vibration levels.

The EPA recommends that to avoid any risk of structural damage to properties in the vicinity of the blast, the vibration levels from blasting should not exceed a peak particle velocity of 12 millimetres per second as measured at a receiving location when blasting occurs at a frequency of once per week or less. In the event of more frequent blasting, the peak particle velocity should not exceed 8 mm/second.

10.6.4 Sensitive Structures in the Harbour Area

The Galway Harbour Enterprise Park has both bitumen and a fuel storage tank farms located in close proximity to the proposed development. Both sites are fully bunded, but because any spillage is regarded as having a major impact the sites are regarded as particularly vibration sensitive and appropriate mitigation measures will be applied.

10.6.5 Ground nesting birds

Vibration levels from underwater blasting are of very short duration and can be controlled to low levels. There will however be a short period each year where if blasting is required to be carried out some mitigation may be required.

10.6.6 Commercial shell-fishing

Commercial fishing in Galway Bay comprises fishing for prawns and commercial oyster rearing. In both cases the animals habitat is the bottom of the water column. The separation distance between the site and the oyster farming in particular indicates that any impact will be negligible. There is the potential however for some disturbance to prawns in the area between Mutton Island and Hare Island. The disturbance due to vibration levels is however likely to be less than that resulting from changes to water flow which are dealt with in Chapter 7.

10.7 MITIGATION

10.7.1 Introduction

The approach taken to mitigation on this project is based on the best practice hierarchical approach. This approach can be summarised as follows:

10.7.1.1 Prevention

Where possible the final design has engineered low noise and vibration solutions into the design. In the initial design stages a significant quantity of rock was to be removed by blasting and excavation. By re-designing the location and orientation of the proposed development to take maximum advantage of the sediment thickness, the quantity of rock to be excavated has been minimised.

Once the final layout was determined the staging of the construction works were examined. In the event of pile driving and blasting (to key in the piles) taking place close to Nimmo's Pier significant noise levels could arise in the lower parts of the River Corrib.

In order to minimize impact on migrating fish and the seal pupping season, no blasting or pile driving will take place from April until July inclusive.

10.7.1.2 Reduction

Where it has not been possible to prevent impacts, steps have been taken to reduce the impact through minimisation of cause of impact at source, abatement at source or abatement at the receptor. An example of this type of measure is the imposition of a limit on the maximum instantaneous charge in any underwater blast to minimise underwater noise and vibration impacts. A comprehensive environmental monitoring and management programme is proposed as part of the project development.

10.7.1.3 Remedy/Offset

Where residual impacts remain, that cannot be prevented or reduced, remedial or compensatory action is taken.

10.7.2 Construction Phase

The primary concern during the construction phase are the blasting and pile driving processes. Mitigation measures will be driven by the principle of reduction at source. In this regard trial blasting will be carried out prior to the commencement of production blasting to confirm the optimum blast ratio for the process, to test the effectiveness of the proposed mitigation measures and to provide initial monitoring data for the blasting events.

The mitigation measures proposed are based on international best practice in particular that adopted by the Canadian authorities (Anon), and the American authorities (Anon 1991), (Anon

2006) and British Standard 5607 *Code of practice for the safe use of explosives in the construction industry.*

- A test programme to develop from small charges to the maximum charge weight per delay interval for production will be carried out and reported to the planning authority prior to the commencement of production blasting.

- Details of volume and length of all blasting agents, detonation cord, and explosives will be limited to the minimum necessary to conduct the work in a manner that is efficient, safe for workers and protective of aquatic and marine organisms. Initiation of explosive charges should be conducted with the minimum length of detonation cord possible but will preferably utilise shock tube detonation where possible.

- The charge weight per delay, location, diameter, spacing and burden between borings, placement of explosives within borings, stemming, maximum length of stemming and the location of the detonator within the boring will be recorded for each blast and reported to the planning authority. A full blast report including climatic and sea conditions and any incidents occurring during blasting (including misfires) will be reported to the planning authority on a quarterly basis.

- All drilling and blasting will require the preparation of a detailed method statement outlining:
    - The location and route of any submerged cables, power or service lines
    - The effect of climatic and sea conditions on the operation
    - Shipping both commercial and leisure
    - Site geological conditions
    - Environmental conditions including the protection of marine life
    - Proximity of structures and residential areas
    - Proposed exclusion zones
    - Explosive type, detonation method, transport, storage, charging and dealing with misfires
    - The removal of material pre and post blasting.
    - Monitoring and reporting measures to be implemented during the course of the works

- All blasting will take place in daylight hours and sea state 0 to sea state 3. Where possible blasting will take place at low tide conditions.

- All explosives used will be detonated using a delayed detonation technique with a minimum delay of 25 milliseconds between detonations.

- The maximum instantaneous charge permitted in any blast will be 10 kg of explosive.

- The timing of all blasting operations will be such as to minimise the impact on marine animals, including smolt migration, seal pupping etc.

- Details of the policing of the exclusion zone for blasting, a detailed Marine Mammal Watch Plan including the provision of Marine Mammal Observers for the blasting programme will be submitted to the Parks & Wildlife Service for agreement prior to the commencement of blasting

- All shock tubes and detonation cord or electric wires will be recovered and removed after each blast.

- After loading a charge in a hole, the hole will be backfilled (stemmed) with clean imported angular stemming material. The stemming material shall be uniform, crushed, angular stone. The stemming material shall be within the range 1/20 to 1/8 of the borehole diameter being confined. The stemming material shall not be acceptable if it contains more than 10% fines. Stemming material shall be placed a minimum vertical length of three borehole diameters above the placed charge within sound rock. A standard procedure of logging the hole and placing the explosives shall be established to resolve and verify the proper placement of stemming material. Records of the above shall be held on site for inspection until the conclusion of the blasting operations.

- Due to the complex nature of the inner bay and the significant flow of fresh water from the Corrib it is not likely that mitigation measures such as the use of air-curtains will be effective due to the currents involved.

Underwater noise levels to be monitored in accordance with the proposals in the EMF and to be agreed with the National Parks and Wildlife Service prior to the construction period with particular emphasis on the smolt and eel migration period.

Vibration levels during underwater blasting to be recorded at the following locations:

Galway Harbour Enterprise Park at a location to be agreed with the operators of the storage tanks

Mutton Island at a location to be agreed with Galway City Council.

Dredging works will be carried on a round the clock basis. TSHD operations will not give rise to any significant noise levels. The operation of the backhoe dredger needs to be carefully controlled to avoid operation at night close inshore. The full extent of operation will not be clear until the TSHD dredging is complete and the dredge management plan must be revised to take account of night time noise levels.

Pile driving noise is such that it cannot be permitted during nigh time hours, i.e. 11pm to 7 am. The pile driving equipment can however operate on a round the clock basis provided no pile driving is carried out during night hours.

10.7.3 Residual Impacts

The mitigating effect of relocating the port to the New Harbour cannot be overstated. The noise levels, particularly at night time, will reduce considerably in the existing docks area. The provision and use of shoreside electricity could significantly reduce ship noise emissions in the future.

10.7.3.1 Noise Levels at the Existing Docks

Beneficial

Noise levels at the existing docks area will remain at current levels due to traffic and city centre noise sources. Noise levels due to shipping will reduce significantly and in particular night time shipping noise levels will in effect be eliminated.

10.7.3.2 Noise levels at residential areas at Renmore & Southpark

Minor Adverse

Minimal increase in noise levels which will generally mean that the New Harbour activity will be inaudible based on current noise levels at these locations. It is possible that on a very calm night, with no traffic noise the port will be audible out of doors at these locations. This impact is unlikely to occur other than on a few occasions during the year.

10.7.3.3 Underwater Noise Levels at the New Port

Localised minor adverse impacts but not on a biologically significant scale.

Noise levels due to shipping at the new port will be limited in time and geographical extent. The operational noise levels due to shipping will not cause any level of disturbance at any sensitive sites.

10.8 CONCLUSIONS

The overall impact of the proposal will be to reduce the underwater noise levels in the existing harbour area. There will be an increase in the intensity of the underwater noise levels at the new harbour area due to larger vessels. The impact of these increased intensity levels is mitigated by the fact that the elevated levels will be of shorter duration as docking, entering and leaving the port will be quicker and less vessels will be required for an equivalent throughput of cargo.

Operating noise levels due to the proposed development are below the level that has the potential to cause any hearing damage to fish or marine mammal species in the long term. Significant mitigation measures will be employed during the construction phase to avoid potential impacts on these species.

The proposed noise level due to larger vessels using the new port facility will be comparable with existing noise levels at the head of Nimmo's pier in both intensity and temporal effect. It is possible that shipping noise could create an avoidance response in both fish and marine mammal species for a short time while a vessel is berthing. The impact of this avoidance response will be short term (minutes) and of no critical significance.

With the proposed noise and vibration mitigation measures in place no significant long term impact on marine life in the bay is expected.

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