Central Rhyl Coastal Defences

Environmental Statement Volume 2: Technical Appendix 13 - Noise and Vibration

September 2021

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Central Rhyl Coastal Defences

Environmental Statement Volume 2: Technical Appendix 13 - Noise and Vibration

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Contents

Appendix 13.1 – Construction Plant List

This appendix presents the plant lists for each construction activity and the associated information which has assisted in the construction noise predictions. Where possible, noise levels have been taken from Appendix C of the BS 5228-1:2009+A1:2014. Appendix D of the BS 5228-1:2009+A1:2014 has been used in situations where an item of plant was not available in Appendix C of the BS 5228-1:2009+A1:2014.

A.1 Scour Protection Enabling (Section A to D)

Phase	Plant Description	BS 5228-1:2009+A1:2014 plant reference	Sound pressure level at 10 dB(A)	Number of units	% on time per typical hour
1	HP Tractor +Trailer	D.9 Ref 50	71.0	1	20
	Excavator	C.4 Ref 17	71.0	1	90
	Excavator for pile installation/ removal	C.3 Ref 24	74.0	2	90
	Concrete mixer trucks	C.4 Ref 20	80.0	1	20
	Vibration hammer	C.3 Ref 8	88.0	3	25
	Hydraulic submersible pump (mounted on trailer)	C.4 Ref 29	80.0	2	50
	Lighting power generator	C.4 Ref 86	65.0	1	40
2	Angle Grinder	C.4 Ref 93	80.0	2	20
	Hand held pneumatic breaker	C.1 Ref 6	83.0	1	75
	Compressor for breaker	C.4 Ref 94	74.0	1	25
	Concrete mixer	C.4 Ref 23	75.0	1	25

A.2 Scour Protection Works (Section A to D)

Phase	Plant Description	BS 5228-1:2009+A1:2014 plant reference	Sound pressure level at 10 dB(A)	Number of units	% on time per typical hour
1	Excavator	C.4 Ref 17	71.0	2	100
	8 Wheeled road wagon	C.4 Ref 53	77.0	2	75

Phase	Plant Description	BS 5228-1:2009+A1:2014 plant reference	Sound pressure level at 10 dB(A)	Number of units	% on time per typical hour
	Hydraulic submersible pump (mounted on trailer)	C.4 Ref 29	80.0	1	75
	Lighting power generator	C.4 Ref 86	65.0	2	40

A.3 Revetment and Promenade Enabling Works (Section E to H)

Phase	Plant Description	BS 5228-1:2009+A1:2014 plant reference	Sound pressure level at 10 dB(A)	Number of units	% on time per typical hour
1	Hi ab lorry	D.7 Ref 121	77.0	1	75
	Angle Grinder	C.4 Ref 93	80.0	1	75
2	Excavator with hydraulic hammer	C.1 Ref 9	90.0	2	40
	8 Wheeled road wagon	C.4 Ref 53	77.0	3	25
	Diamond Saw	C.4 Ref 93	75.0	2	50
3	Excavator	C.4 Ref 17	71.0	1	75
	Dozer	C.2 Ref 10	80.0	1	75
	Roller	C.5 Ref 25	75.0	1	75
	8 Wheeled road wagon	C.4 Ref 53	77.0	1	75

A.4 Beach works

Phase	Plant Description	BS 5228-1:2009+A1:2014 plant reference	Sound pressure level at 10 dB(A)	Number of units	% on time per typical hour
1	Breaker mounted on excavator	C.1 Ref 9	90.0	2	70
	Vibratory piling rig	C.3 Ref 8	88.0	2	90
	Concrete mixer truck	C.4 Ref 8	80.0	1	20
	Dump truck (tipping fill)	C.2 Ref 30	79.0	2	75

Phase	Plant Description	BS 5228-1:2009+A1:2014 plant reference	Sound pressure level at 10 dB(A)	Number of units	% on time per typical hour
	Truck mounted concrete pump + boom arm	C.4 Ref 29	80.0	3	90
	Lighting power generator	C.4 Ref 86	65.0	2	40

A.5 Promenade works (Section E to H)

Phase	Plant Description	BS 5228-1:2009+A1:2014 plant reference	Sound pressure level at 10 dB(A)	Number of units	% on time per typical hour
1	120t crawler crane	C.4 Ref 52	75.0	1	50
	Concrete mixer truck	C.4 Ref 20	80.0	1	30
	Excavator	C.4 Ref 10	66.0	1	75
	Site dumper	C.2 Ref 30	79.0	1	75
	HP Tractor +Trailer	D.9 Ref 50	71.0	1	50
	Poker vibrator	C.4 Ref 33	78.0	1	30
	Lighting power generator	C.4 Ref 86	65.0	1	30
2	Excavator	C.4 Ref 10	66.0	1	75
	Dozer	C.2 Ref 10	80.0	1	30
	Dump truck (tipping fill)	C.2 Ref 30	79.0	1	75
	Roller	C.5 Ref 25	75.0	1	30
	Hi ab lorry	D.7 Ref 121	77.0	1	75

A.6 Revetment Installation (Section E to H)

Phase	Plant Description	BS 5228-1:2009+A1:2014 plant reference	Sound pressure level at 10 dB(A)	Number of units	% on time per typical hour
1	120t crawler crane	C.4 Ref 52	75.0	1	100
	Concrete mixer truck	C.4 Ref 20	80.0	1	30
	Excavator	C.4 Ref 10	66.0	1	75
	Hi ab lorry	D.7 Ref 121	77.0	1	75

Phase	Plant Description	BS 5228-1:2009+A1:2014 plant reference	Sound pressure level at 10 dB(A)	Number of units	% on time per typical hour
	Roller	C.5 Ref 25	75.0	1	75
	HP Tractor +Trailer	D.9 Ref 50	71.0	1	100
	Truck mounted concrete pump + boom arm	C.4 Ref 29	80.0	1	50
	Lighting power generator	C.4 Ref 86	65.0	2	40
2	Concrete mixer truck	C.4 Ref 20	80.0	1	30
	Excavator	C.2 Ref 5	66.0	1	75
	Site dumper	C.2 Ref 30	79.0	1	75
	HP Tractor +Trailer	D.9 Ref 50	71.0	1	50

A.7 Promenade finishing works

Phase	Plant Description	BS 5228-1:2009+A1:2014 plant reference	Sound pressure level at 10 dB(A)	Number of units	% on time per typical hour
1	Concrete mixer truck	C.4 Ref 20	80.0	1	30
	Excavator	C.4 Ref 10	66.0	1	75
	Site dumper	C.2 Ref 30	79.0	1	75
	Lorry with lifting boom	C.4 Ref 53	77.0	1	75
	Poker vibrator	C.4 Ref 33	78.0	1	30
	Lighting power generator	C.4 Ref 86	65.0	2	40
2	Lorry with lifting boom	C.4 Ref 53	77.0	1	50
	Mini tracked excavator	C.4 Ref 68	65.0	1	50
	Lighting power generator	C.4 Ref 86	65.0	1	75
	Directional drill	C.4 Ref 96	77.0	1	75
	Road planer	C.5 Ref 7	82.0	1	75
3	Concrete mixer truck	C.4 Ref 20	80.0	1	30

Phase	Plant Description	BS 5228-1:2009+A1:2014 plant reference	Sound pressure level at 10 dB(A)	Number of units	% on time per typical hour
	Site dumper	C.2 Ref 30	79.0	1	75
	Lorry with lifting boom	C.4 Ref 53	77.0	1	75
	Lorry with lifting boom	C.4 Ref 53	77.0	1	30
	Poker vibrator	C.4 Ref 33	78.0	1	30
	Lighting power generator	C.4 Ref 86	65.0	1	30

A.8 Compounds and Access

Phase	Plant Description	BS 5228-1:2009+A1:2014 plant reference	Sound pressure level at 10 dB(A)	Number of units	% on time per typical hour
Quay street Compound	Excavator	C.2 Ref 5	76	1	75
	Site dumper	C.2 Ref 30	79.0	1	75
	Power for site cabins	C.4 Ref 76	61.0	2	100
	Lorry with lifting boom	C.4 Ref 53	77.0	1	10
	Lighting power generator	C.4 Ref 86	65.0	3	25
Install Central Access	Excavator	C.2 Ref 5	76	1	75
	Site dumper	C.2 Ref 30	79.0	1	75
	Lorry with lifting boom	C.4 Ref 53	77.0	1	100
	Breaker mounted on excavator	C.1 Ref 9	90.0	1	75
	Wheeled loader	C.2 Ref 28	76.0	1	50
	Lighting power generator	C.4 Ref 86	65.0	3	25
Install West Access	Excavator	C.2 Ref 5	76	1	75
	Site dumper	C.2 Ref 30	79.0	1	75
	Lorry with lifting boom	C.4 Ref 53	77.0	1	75
	Lorry with lifting boom	C.4 Ref 53	77.0	3	25
	Wheeled loader	C.2 Ref 28	76.0	1	25

Phase	Plant Description	BS 5228-1:2009+A1:2014 plant reference	Sound pressure level at 10 dB(A)	Number of units	% on time per typical hour
	Lighting power generator	**C.4 Ref 86**	**65.0**	**1**	**75**
Compound re-establishment	**Excavator**	**C.2 Ref 5**	**76**	1	75
	Site dumper	**C.2 Ref 30**	**79.0**	**1**	**75**
	Power for site cabins	**C.4 Ref 76**	**61.0**	**2**	**100**
	Lorry with lifting boom	**C.4 Ref 53**	**77.0**	**1**	**10**
	Lighting power generator	**C.4 Ref 86**	**65.0**	**3**	**25**
	Water pump	**C.2 Ref 45**	**65.0**	**2**	**10**

A.9 Haul Road Assumptions

The following haul road assumptions have been considered and incorporated into the construction activities L_{Aeq} presented in Table 13:10 of the main noise and vibration chapter. The assumptions are based on different geographical sections of the scheme. The prediction methodology has been based on the BS 5228-1:2009+A1:2014 'Method for mobile plant using a well-defined route (e.g haul roads). All vehicle movements have been assumed to be long wheeled base lorries. The BS 5228-1:2009+A1:2014 plant reference is: Table C.11, reference 10

Construction activity	Section	Total number of movements per day	L_{Aeq} at 10m
Rock toe works	**Section A**	8	67
	Section B	13	72
	Section C	4	61
	Section D	14	73
Revetment and promenade works			
	Section F	1	47
	Section G	11	70
	Section H	3	60
Revetment beach works			
	Section E	**1**	43
	Section F	1	51
	Section G	2	55
	Section H	1	51

Construction activity	Section	Total number of movements per day	L_{Aeq} at 10m
Promenade works			
	Section E	2	57
	Section F	11	70
	Section G	14	72
	Section H	9	69
Revetment installation			
	Section E	3	59
	Section F	7	67
	Section G	12	71
	Section H	7	67
Promenade finishing works			
	Section E	1	50
	Section F	3	58
	Section G	4	61
	Section H	3	58

Appendix 13.2 – SeaQuarium Noise Assessment

Central Rhyl Coastal Defences

SeaQuarium Noise Assessment

September 2021

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Central Rhyl Coastal Defences

SeaQuarium Noise Assessment

September 2021

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1 Introduction

1.1 Project background

1.1.1 Overview

The Central Rhyl Coastal Defences Scheme (herein referred to as 'the Scheme') is a design and build scheme being delivered by Balfour Beatty Civil Engineering Limited (BB) for Denbighshire County Council (DCC). Mott MacDonald Ltd (Mott MacDonald) has been commissioned by BB to support with the development and delivery of the Scheme.

The Scheme, located in the central area of Rhyl waterfront, Denbighshire, North Wales, is dependent on obtaining sufficient funding and comprises coastal defence works in the form of scour protection, stepped concrete revetment, promenade raising, sea wall works, access and promenade improvements, and associated tie-in works.

Rhyl is a Victorian coastal resort and the largest town in Denbighshire, with a well-established history as a tourist destination. There are ongoing and future plans to regenerate Rhyl to enhance its appeal to tourists and investors; however, the coastal defences for the Central Rhyl frontage are deteriorating and there is the risk that this integral asset for Rhyl's regeneration could be lost without intervention.

Historically, Central Rhyl has been protected from coastal flooding by hard engineered defence structures constructed from at least the 1900s. These comprise a series of stepped revetments, recurve walls and vertical walls in various states of repair. The existing defences no longer meet acceptable performance standards and are known to be deteriorating.

The existing promenade in the area of the Scheme can become inundated during storms, causing flooding of the promenade and surrounding areas. In the future this will be exacerbated by the effects of climate change, which is predicted to increase both the frequency and magnitude of flooding. The existing coastal defences and promenade require improvements to safeguard the area from overtopping with consideration given to the potential effects of climate change.

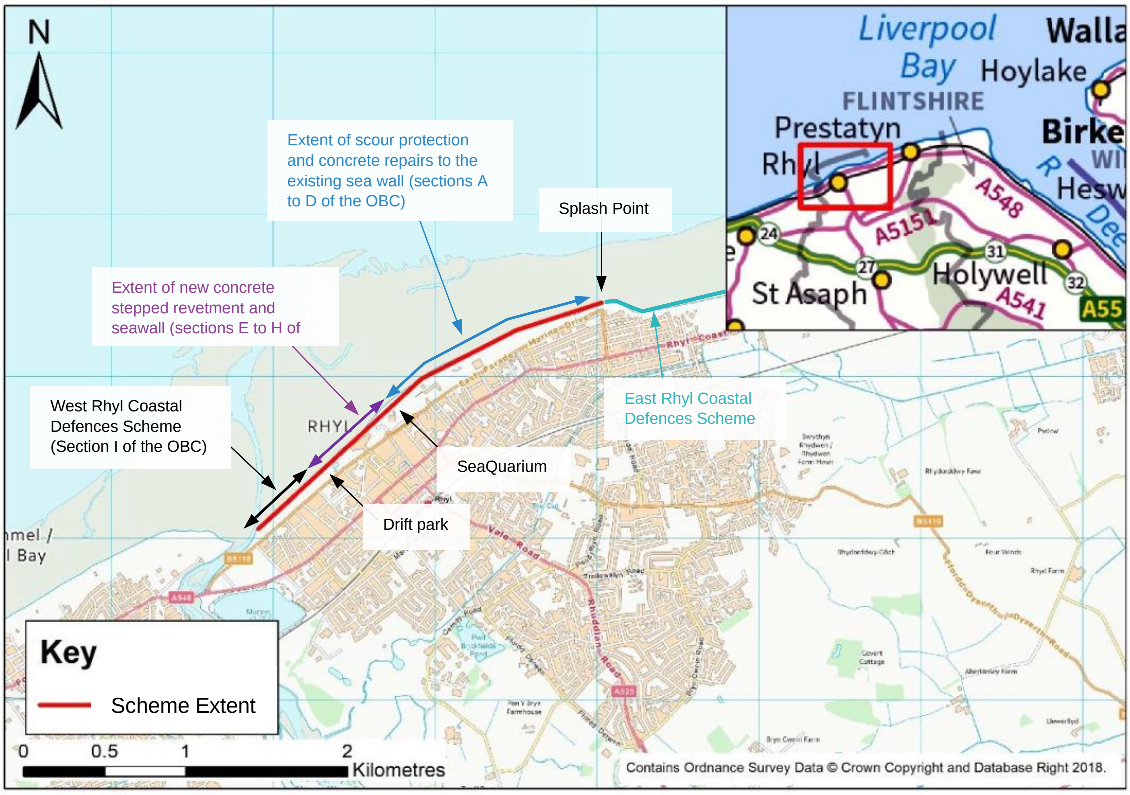
Subject to funding, this Scheme aims to improve the existing coastal defences to provide increased flood and erosion protection to people and property in Rhyl along with supporting local regeneration, achieving wider community benefits alongside flood risk management.

1.1.2 Scheme location

The Scheme is located along the coastal frontage of the town of Rhyl, North Wales. It extends from approximately 400m east of the mouth of the River Clwyd, to just west of Splash Point (and the start of the East Rhyl Coastal Defence Scheme, which was under construction at the time of writing this report). Figure 1.1 presents the approximate extent of the Scheme as outlined by the Central Rhyl Coastal Defences Outline Business Case (herein referred to as the "OBC") (DCC, 2019)[1]

[1] Denbighshire County Council, 2019. Central Rhyl Coastal Defence Scheme Outline Business Case.

Figure 1.1: Scheme Location and sections at per the Central Rhyl Coastal Defences Outline Business Case



Source: Central Rhyl Coastal Defence Schemes Outline Business Case, DCC, October 2019. Additional annotations by Mott MacDonald 2021

As shown in Figure 1-1 as part of the OBC, the Scheme was split into nine sections along its length: Sections A – I, with Section A at the eastern end and Section I at the western end.

The western end of the Scheme (i.e. west of Drift park and OBC Section I) is the location of the West Rhyl Coastal Defences Scheme. The West Rhyl Coastal Defences Scheme was constructed in 2015, and no further works are proposed at this location.

1.1.3 Scheme proposals

The Scheme is to include the following key coastal works:

- The construction of approximately 1.45km of scour protection and concrete repairs, from Splash Point to the SeaQuarium (sections A to D of the OBC, see Figure 1-1). The scour protection will consist of boulders being placed at the base of the existing coastal defence structures.
- The construction of approximately 750m of new concrete stepped revetment, from the SeaQuarium to opposite Drift Park (sections E to H of the OBC, see Figure 1-1).
- New pedestrian beach accesses through the proposed revetments to replace the existing ones and extension of existing beach accesses through the rock armour scour protection.
- The extension of outfalls and protection works to existing outfalls that would be covered by the new revetment.

The Scheme also includes the following works to the promenade:

- Raised promenade from the SeaQuarium to opposite Drift Park.
- New seawalls at the back of the promenade from the SeaQuarium to opposite Drift Park, .

- New flood gates for access points through the new rear seawalls between the SeaQuarium and opposite Drift Park.
- New retaining structures where appropriate at the back of the promenade between the SeaQuarium and opposite Drift Park,to accommodate level differences between the raised promenade and adjacent land.
- New ramps or steps to provide access to raised promenade between the SeaQuarium and opposite Drift Park.

1.2 Purpose of this report

Rhyl SeaQuarium is an aquarium located adjacent to the promenade. One of the attractions within the SeaQuarium is the outdoor seal exhibit called “Seal Cove”.

The purpose of this report a noise assessment on the potential impacts of construction on the SeaQuarium.

This assessment considers the following:

- Details of the construction activity that may produce underwater noise;
- The sensitivity of identified aquatic receptors;
- The distance from the construction activity at which various effect levels arise; and
- Mitigation to control the adverse effects.

The study is based upon construction information available at the time of the assessment which has been augmented with assumptions where the information is incomplete; peer-reviewed literature on the sensitivity of animals, particularly references (Popper, et al., 2014) for fish and (National Marine Fisheries Service, 2018) for mammals; and estimates of the underwater noise levels that will be produced.

Although the assessment is primarily concerned with underwater noise impact for the aquarium, the potential impact of airborne noise for seals that may be out of the water at the Seal Cove pools is also considered.

2 Construction activity producing vibration

Vibration from the construction activity can be transmitted through the ground and then be reradiated as underwater noise into the tanks and aquaria. The vibrations can also cause sedimentary disturbance which may cloud the water and the noise can also directly affect animals in the water.

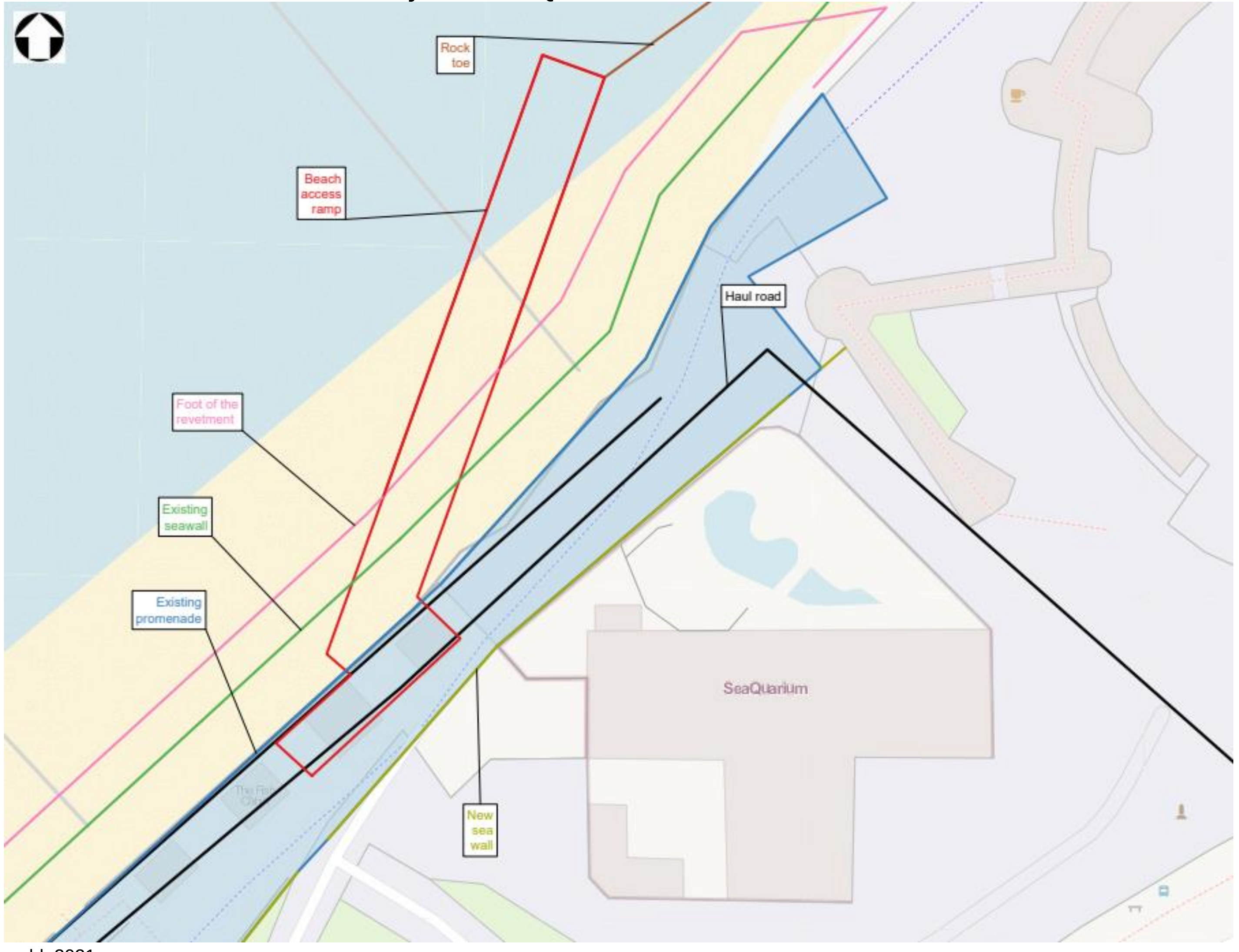
The construction activity that is expected to produce the highest levels of vibration and underwater noise comprises breaking the surface of the promenade between the SeaQuarium and the existing sea wall, relaying this surface at a higher level and piling along the line of the sea wall. Each of these activities is considered separately in the analysis below. Figure 2.1 illustrates the construction activities within the vicinity of the SeaQuarium. The construction activities included in the assessment are summarised in Table 1.

Table 1: Summary of construction activity likely to produce highest levels of underwater noise

Construction Activity	Construction plant	Assumptions	BS 5228-2:2009+A1:2014 reference
Initial Promenade works	Jackhammer	Force of 14kN and a blow rate of 1800 per minute.	N/A
Concrete stepped revetment beach works	Drop hammer	Nominal strike rate of 1.43 seconds, 15 minutes of piling required per pile and 8 piles per day.	Table D.8 Reference C19
Concrete stepped revetment beach works	Vibratory pile driver	15 minutes of piling required per pile and 8 piles per day.	Table D.10 Reference C44
Promenade finishing works	Bomag vibratory roller	Rolling will be needed for a daily total of 2 hours.	N/A

Source: Mott MacDonald, 2021

Figure 2.1: Construction activities within the vicinity of the SeaQuarium



Source: Mott MacDonald, 2021

3 Underwater Noise Impact Criteria

3.1 Introduction

Fish and marine mammals can detect underwater sound either through the mechanism of a sound pressure wave, particle motion/velocity or a combination of both (Nedelec, et al., 2016; Popper & Hawkins, 2019). Species vary in their sensitivity to underwater sound and the range over which they can detect and respond to it (National Marine Fisheries Service, 2018; Popper, et al., 2014).

One of the predominant factors that influences noise impact for fish in particular is the presence or absence of a gas bladder (also referred to as a swim bladder) in the body, its anatomical location within the fish and whether it is connected to the hearing organs known as otoliths[2] (Popper, et al., 2014). Those fish species without a gas bladder are commonly thought to be able to detect only particle motion, whilst those with a gas bladder are able to detect sound pressure to varying degrees based on the connectivity of the gas bladder with the otoliths. While the presence of a gas bladder can increase acoustic sensitivity, via transmission of sound energy to the otolithic organs if they are connected, it also increases the susceptibility of fish to injury from underwater noise (Popper & Hawkins, 2019).

Marine mammals have been classified into hearing groups that depend on their generalised hearing range (National Marine Fisheries Service, 2018). These groups are low, mid, and high frequency cetaceans (which include whales, dolphins and porpoises) and Phocidae and Otariidae pinnipeds (which include seals and sea lions).

The ears of sea turtles appear to be adapted to detect sound in water with retention of air in the middle ear, an indication that they are able to detect sound pressure (Popper, et al., 2014).

A list of the typical species in these hearing groups is also provided in Table 2 including a representative list of species that are likely to be represented among the aquarium exhibits.

Table 2: Categorisation of acoustic dependent species in Welsh waters[3]

Categories	Relevant species	SeaQuarium species
Fish: No swim bladder (Particle motion detection)	Common Dab (*Limanda limanda*) Lemon sole (*Microstomus kitt*) Thornback ray (proxy little skate) (*Raja clavata*) River lamprey (*Lampetra fluviatilis*) Sea lamprey (*Petromyzon marinus*)	Turbot Hawfish Wolf fish
Fish: Swim bladder is not involved in hearing (particle motion detection)	Atlantic salmon (*Salmo salar*) Sea trout (*Salmo trutta*)	Clownfish Pufferfish Tang Lionfish Cowfish Sea bass Wrasse Seahorse
Fish: Swim bladder involved in hearing (primarily pressure detection)	Herring (*Clupea harengus*) Whiting (*Merlangius merlangus)* Atlantic cod (*Gadus morhua*) European eel (*Anguilla anguilla*)	Moray eels Pollack

[2] Otoliths are structures located in the inner ear cavity of all teleost fish and serve as a balance organ and also aid in hearing.

[3] Several of these species are occasional visitors to Welsh waters rather than being part of the resident populations

Categories	Relevant species	SeaQuarium species
	European sprat (*Sprattus sprattus*)	
Sea turtles		Terrapins[4]
Low frequency (LF) cetaceans (Baleen whales) 7 Hertz (Hz) to 35kHz	Minke Whale (*Balaenoptera acutorostrata*)	None
Mid frequency (MF) cetaceans (dolphins, toothed whales, beaked whales, bottlenose dolphins) 150Hz to 160kHz	Bottlenose dolphin (*Tursiops truncatus*)	None
High frequency (HF) cetaceans (true porpoises, *Kogia*, river dolphins, *Cephalorhynchid*) 275Hz to 160kHz	Harbour porpoise (*Phocoena phocoena*)	None
Phocid pinnipeds (PW) (true seals)	Grey seal (*Halichoerus grypus*)	Harbour seal (*Phoca vitulina*)

Source: Popper et al, 2014, NMFS, 2018 and Mott MacDonald, 2021

Although fish have been grouped by the influence of a gas bladder on hearing, the species within a group may have differing sensitivities to underwater noise. For example, herring have specialised hearing apparatus linking the auditory system to the swimbladder increasing their hearing range. Such apparatus is absent in gadiformes (cod, haddock) and European eels, however, it is noted that the swimbladder still plays some role in hearing for these species. The groupings described in Table 2 have informed hearing thresholds for relevant species within this assessment.

No cetaceans or otariid pinnipeds are expected to be exhibits in the aquarium so these species are not considered further in this assessment.

3.2 Units to describe exposure

Acoustic pressure is the scalar variation in underwater pressure about a mean value and has units of Pa but is conventionally converted to a decibel scale with a reference value p_0 of 1 x 10^{-6} (1μPa). That is, a pressure variation p becomes a pressure level L using the formula $L = 20\log\left(\frac{p}{p_0}\right)$. Particle velocity is a vector quantity (having both value and direction) and has units m/s or mm/s. Velocity is one of several entities that can be used to express particle motion (as displacement, velocity, or acceleration) but these are all directly related to each other through differential calculus. Away from the surface, sea-bed and acoustic sources, the acoustic pressure and particle velocity are directly proportional to each other. Moreover, as there is currently a paucity of data on the sensitivity of fish or mammals to particle motion (Nedelec, et al., 2016), all criteria in this assessment are expressed in terms acoustic pressure and not particle motion, although it is recognised that some species are sensitive to particle velocity in particular.

Acoustic pressure varies continuously with time so no single-number entity can be used to fully describe noise. Statistical quantities are therefore often used to describe sources such as dredging noise. These include the root-mean-square (rms) pressure which can also be converted to a decibel quantity L_{rms} also with reference unit of 1μPa.

Criteria for the effect of noise on fish are expressed in terms of unweighted sound pressure. However, some of the criteria for the effect of noise on mammals are expressed in terms of weighted sound pressure, notably the sound exposure level (SEL) for exposure over 24 hours $L_{E,24h}$ where the weighting reflects the relatively low sensitivity to noise at very low and very high frequencies. In these cases, a frequency weighting network (loosely analogous to an audio

[4] Please note that the turtles in the aquarium are terrapins, a freshwater species, rather than a sea turtle. However, these criteria have been used as a proxy in the absence of other data.

graphic equaliser with pre-set frequency dependent gain) is applied before the conversion to decibels is made. This is similar to the A-weighting that is applied to determine the effect of noise on people in air. The SEL (weighted or otherwise) is expressed in dB with a reference unit of $1\mu Pa^2s$.

3.3 Effects of noise exposure

At the lowest noise levels there is no known effect on fish or marine mammals. As noise levels increase the effect ranges from changes in behaviour, temporary threshold shift in hearing (TTS), permanent threshold shift in hearing (PTS), barotrauma injury and death.

Potential effects on behaviour include impacts on ability to communicate, detection of predators and prey and may be on both the individual, or, in the wild, at the population level. In response to anthropogenic noise, fish have been observed to change swimming behaviour and show a startle reaction, although under repeated exposure to similar sounds habituation has also been observed (Popper, et al., 2014).

Hearing loss may be temporary, producing a temporary threshold shift (TTS) or permanent, producing a permanent threshold shift (PTS). These threshold shifts are increases in the threshold of audibility of sound which is the minimum sound pressure level of a sound able to evoke an auditory sensation. A TTS is a reversible shift resulting from a temporary change in sensory hair cells or damage to the auditory nerves. Sensory hair cells are renewed in fish so are replaced when damaged whereas this is not the case for mammals. In all TTS cases normal hearing is eventually restored when exposure to high amplitude noise ceases although there may have been temporary behavioural effects caused by reduced hearing fidelity while hearing sensitivity was reduced. However, in PTS cases normal hearing is not restored and the reduced hearing fidelity may impact the ability to communicate and ability to detect predators and prey.

Barotrauma is a result of rapid pressure changes that produce tissue injury. The pressure changes can cause blood gases to come out of solution or produce rapid changes in gas volumes damaging surrounding tissue. The effects can lead to lethal injury or delayed mortality depending on the severity of the pressure change and the sensitivity of the animal (Halvorsen, et al., 2012). In some cases, although not directly producing lethal injury itself the barotrauma effect can lead to a decrease in fitness, leaving the animal vulnerable to predation or disease (Caspar, et al., 2012).

3.4 Noise impact criteria

Criteria for effect thresholds for underwater noise are presented in noise exposure guidance for fish (Popper, et al., 2014) and marine mammals (National Marine Fisheries Service, 2018) respectively, although for continuous noise for fish these are predominantly qualitative. These criteria are reproduced in Table 4 for transient or impact noise such as that produced by piling and in

Table 5 for non-transient noise such as that produced by pumps or vibration from traffic outside the aquarium. Relative risk is given for animals at three distances from the source defined in relative terms as near (N) – typically tens of metres, intermediate (I) – typically hundreds of metres and far (F) – typically thousands of metres.

For animals in captivity the noise levels at which impacts arise may be expected to be similar to wild animals, although some habituation may have arisen for noise at relatively low sound pressure levels due to pumps and aeration equipment in the water as well as any sound or vibration produced by visitors. While this habituation may affect the levels at which behavioural changes arise, it would not be expected to affect the noise levels at which TTS, PTS or mortality arise as the mechanisms involved are predominantly physiological as set out above. Whilst the noise impact criteria discussed above refer to relative risk in terms of typical distance from the source as near, intermediate or far, as sound pressure levels fall with distance from a source, these terms are not directly relevant to the aquarium where the sound pressure level will be similar at all locations within a given tank. Instead, an indication of relative risk may be inferred from the table because sound pressure levels from a source are low at large distances (F), higher at intermediate distance (I) and highest at low distances (N). Thus, an effect arising in open water at distance (N) would be associated with relatively high sound pressure levels in the aquarium, an effect at distance (I) would be associated with lower sound pressure levels and an effect at distance (F) would be associated with low sound pressure levels.

Where the rms sound pressure levels are given in dB re 1μPa it will be noted that the quantitative criteria are specified for periods of 48 hours and 12 hours. This does not mean that the animal needs to be exposed to the noise source for these periods, rather this is the averaging time for the exposure and there is a trade-off between exposure level and duration whereby a halving of exposure duration is approximately equivalent to a 3dB change in level. That is 170 dB for 48 hours is equivalent to 173 dB for 24 hours, 176 dB for 12 hours, 179 dB for 6 hours etc.

While criteria for mammals are given in technical guidance (National Marine Fisheries Service, 2018) for TTS and PTS there are no criteria for behaviour changes or mortality. However, it would be expected that the onset of behaviour changes would arise at only levels that are lower than the onset of TTS and that mortality and potential mortal injury would arise only at levels that are higher than the onset of PTS. For non-impulsive noise (such as pumps) the threshold is given only as the weighted sound exposure level over 24 hours.

The weighting functions for the PTS/TTS thresholds were derived by the NMFS from available data describing the hearing abilities and effects of noise on marine mammals. They are characterised by a generic band-pass filter with frequency f given by the formula

$$W(f) = C + 10\log_{10}\left\{\frac{(f/f_1)^{2a}}{[1+(f/f_1)^2]^a[1+(f/f_2)^2]^b}\right\}$$

where the values of the coefficients are given in Table 3.

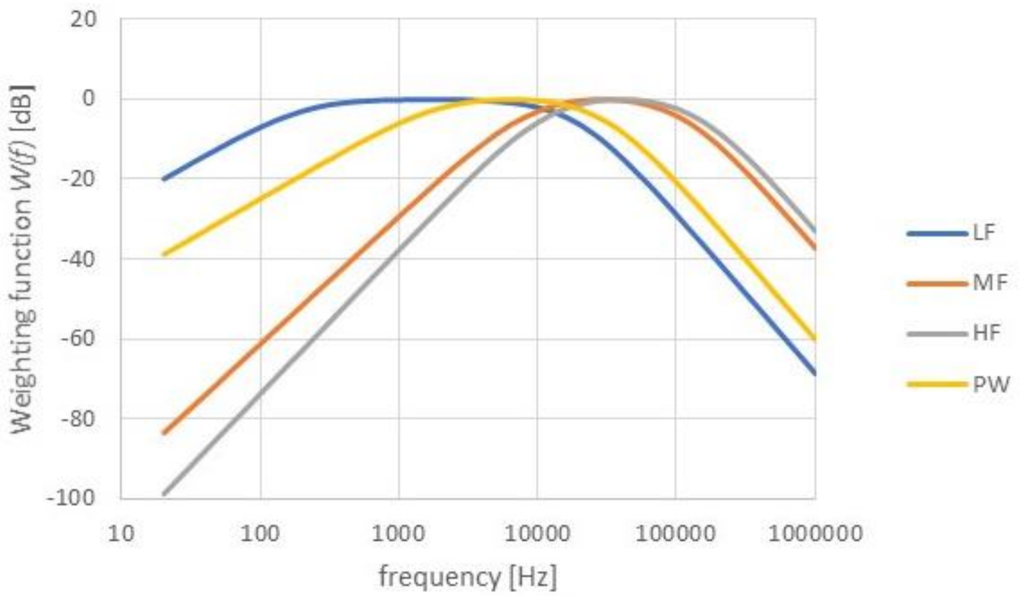
Table 3: Coefficient values for phocid pinniped weighting function

Hearing group	a	b	f_1 [kHz]	f_2 [kHz]	C [dB]
Phocid pinnipeds (PW)	1.0	2.0	1.9	30	0.75

Source: NMFS, 2018

The shape of these weighting functions given in Figure 3.1 shows how each weighting function attenuates low frequency and high frequency components but that the pass-band (where the filter gain is 0dB, i.e. unity gain) differs for each hearing group although, for the purposes of the assessment of underwater noise on the aquarium, only the phocid pinniped hearing group weighting function (PW) is of importance.

Figure 3.1: Gain W(f) of the mammal hearing groups – PW are the phocid pinnipeds



Source: Mott MacDonald, 2021

Table 4: Impact (transient) noise effect criteria for fish and phocid pinnipeds

Animal type	Mortality and potential mortal injury	Recoverable injury/PTS	TTS	Masking	Behaviour
Fish: no swim bladder (particle motion detection)	> 219 dB SEL_{cum} or >213 dB L_{pk}	> 216 dB SEL_{cum} or >213 dB L_{pk}	>> 186 dB SEL_{cum}	(N) Moderate (I) Low (F) Low	(N) High (I) Moderate (F) Low
Fish: swim bladder is not involved in hearing (particle motion detection)	210dB SEL_{cum} or >207dB L_{pk}	203dB SEL_{cum} or >213 dB L_{pk}	>186 dB SEL_{cum}	(N) Moderate (I) Low (F) Low	(N) High (I) Moderate (F) Low
Fish: swim bladder is involved in hearing (particle motion detection)	207 dB SEL_{cum} or >207dB L_{pk}	203dB SEL_{cum} or >213 dB L_{pk}	186dB SEL_{cum}	(N) High (I) High (F) Moderate	(N) High (I) High (F) Moderate
Sea turtles	210 dB SEL_{cum} or >207 dB L_{pk}	(N) High (I) Low (F) Low	(N) High (I) Low (F) Low	(N) High (I) Moderate (F) Low	(N) High (I) Moderate (F) Low
Phocid Pinnipeds (PW)	>PTS threshold	185dB $L_{E,PW,24h}$ or 218 dB L_{pk}	170dB $L_{E,PW,24h}$ or 212dB L_{pk}	< TTS threshold	< TTS threshold

Source: Popper et al., 2014 and NOAA 2018

Table 5: Shipping and continuous noise effect criteria for fish and phocid pinnipeds

Animal type	Mortality and potential mortal injury	Recoverable injury/PTS	TTS	Masking	Behaviour
Fish: no swim bladder (particle motion detection)	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) High (I) High (F) Moderate	(N) Moderate (I) Moderate (F) Low
Fish: swim bladder is not involved in hearing (particle motion detection)	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) High (I) High (F) Moderate	(N) Moderate (I) Moderate (F) Low
Fish: swim bladder is involved in hearing (particle motion detection)	(N) Low (I) Low (F) Low	170 dB L_{rms} for 48h	158 dB L_{rms} for 12h	(N) High (I) High (F) High	(N) High (I) Moderate (F) Low
Sea turtles	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) High (I) Moderate (F) Low	(N) Moderate (I) Moderate (F) Low
Phocid Pinnipeds (PW)	> PTS threshold	201 dB $L_{E,PW,24h}$	181 dB $L_{E,PW,24h}$	< TTS threshold	< TTS threshold

Source: Popper et al., 2014 and NMFS, 2018

4 Underwater Construction Noise in the aquarium

Estimates of underwater construction noise have been produced by using a finite difference model, Findwave, to solve the general field equation for an elastic medium. Findwave is a three-dimensional modelling package capable of simulating the dynamic behaviour of sources, soil and rock, buildings, generating output vibration and noise signals in the time domain. The software predicts the vibration of structures, re-radiated noise and ground borne propagation of vibration at acoustic frequencies and has previously been used in the prediction of vibration and groundbourne noise from a wide range of applications including railways and construction works.

The Findwave model includes the following assumptions:

- The exercise involves applying a vertical displacement as a filtered Dirac function (low-pass filtered at 282Hz) to simulate construction plant and modelling the rms pressure level across the site at a range of levels.
- Results are obtained in terms of rms pressure at two levels, the level of the Seal Cove pools and the level of the aquarium tanks.
- The internal layout of the aquarium was not known at the time of the modelling and so the assumed dimension of the tanks are: 2.8m x 9.8m x 3.8m high with 75mm thick glass sides. For the purposes of the model they are arranged in two rows of four.
- It is assumed that the floor of the aquarium building is a 200mm thick concrete slab and that this constitutes a raft foundation.
- For the Seal Cove pools the results presented are for the worst-case location. For the tanks the results are for a point near the corner of the worst affected tanks, looking at the two rows of tanks separately.
- Based on the geotechnical survey information (Geotechnics Limited, 2021), for the purposes of the model it has been assumed that the soil is very gravelly sand down to 5m, gravelly silty sand below 5m, gravelly sandy silt below 6.8m and slightly sandy gravelly clay below 10m.
- The algorithm has assumed that the soil loss factor was 0.1, rising at higher frequencies.
- For the water, surface tension was included, along with viscosity. The gravitational effect which produces surface waves on water was not modelled, however.
- Across the land, the algorithm generates Rayleigh waves, body waves and shear waves as well as the various interface waves.
- The boundaries of the model are a "perfectly matched layer", and inspection of the time-domain impulses shows no influence from any boundary reflections.

Four plant items (to represent the worst-case underwater noise levels) have been modelled. The plant items selected have been informed by information provided in BS5228 part 2, the code of practice for noise and vibration control on construction and open sites, part 2: vibration. The modelled plant comprise:

- A jackhammer of the type that might be used for breaking out the existing promenade. It is assumed that the jackhammer produces a force of 14kN and operates at a rate of 1800 blows per minute for a period of 2 hours.
- A drop hammer at the foot of the revetment. Reference C19 from table D.8 (summary of historic case history data on vibration levels measured during sheet steel piling, from

BS5228; It is assumed that piling will be at a nominal strike rate of 1.43s between strikes with 15 minutes of piling required per pile and 8 piles per day giving a total number of 10,288 strikes per day;

- A vibratory pile driver at the foot of the revetment. Reference C44 from table D.10 (summary of historic case history data on vibration levels measured during use of vibratory pile drivers, from BS5228. It is assumed the vibratory piling will be needed for 15 minutes per pile and for 8 piles per day giving a total vibropiling duration of 2 hours; and
- A Bomag type BW100 vibratory roller for surface reinstatement works on the promenade. It is assumed that rolling will be need for a daily total of 2 hours.

Use of the haul road is not considered explicitly as only low levels of vibration are anticipated for a compacted granular material forming a new road surface.

Underwater noise levels for this construction activity are shown in Table 6. Levels are reported for the nearest and furthest Seal Cove pools and for the nearest and furthest tanks. The levels shown in the tables include the unweighted peak level L_{pk} in dB re 1μPa, the unweighted cumulative sound exposure level SEL_{cum} in dB re 1μPa^{2}s, and the phocid pinniped weighted sound exposure level $L_{E,PW}$ in dB re 1μPa^{2}s for transient noise sources (the jackhammer and for impact piling) and the unweighted root mean square level over 24 hours $L_{rms,24h}$ in dB re 1μPa and phocid pinniped weighted sound exposure level $L_{E,PW}$ in dB re 1μPa^{2}s for the vibropiling and road rolling continuous source. These values are reported because they are directly comparable to the effect criteria levels set out in Table 4 for impact noise and in

Table 5 for continuous noise.

Table 6: Underwater noise levels for construction activity

	Jackhammer for breaking out			Impact piling drop hammer			Vibropiling		Rolling*	
Location	**L_{pk} [dB]**	**SEL_{cum} [dB]**	**$L_{E,PW}$ [dB]**	**L_{pk} [dB]**	**SEL_{cum} [dB]**	**$L_{E,PW}$ [dB]**	**$L_{rms,24h}$ [dB]**	**$L_{E,PW}$ [dB]**	**$L_{rms,24h}$ [dB]**	**$L_{E,PW}$ [dB]**
Near pool	159	191	164	160	178	148	121	134	151	171
Far pool	147	181	151	151	171	139	117	130	140	160
Near tank	149	186	153	143	163	133	105	118	147	165
Far tank	143	179	148	136	156	125	95	108	142	160

* Although rolling is not usually considered to be an impulsive vibration source, the unweighted underwater peak levels are predicted to be 190, 178, 180 and 174 dB L_{pk} re 1mPa for the near pool, far pool, near tank and far tank respectively. These values are high enough to be considered against the Table 7 criteria for peak sound levels. This analysis is included in Table 8.

Source: Mott MacDonald, 2021

5 Underwater noise impact

The noise level estimates set out in Table 6, together with the criteria at which PTS and TTS arise (see Table 4 for impact noise and

Table 5 for continuous noise) have been used to assess the potential impact on fish and aquatic mammals in the aquarium. Table 7 shows the thresholds and expected construction noise levels for breaking and for impact piling and Table 8 shows the thresholds and expected construction noise levels for vibropiling and road rolling. The near tank values are reported for fish and sea turtles[5] and the near pool values are reported for the phocid pinnipeds as these are the expected locations for each type of animal where the worst-case noise exposures will arise. Where the literature does not provide noise levels for effects but instead presents qualitative criteria (such as for continuous noise for fish), professional judgement has been used to determine what the calculated noise levels would be in comparison with an underwater source based on an assumption that noise attenuates with distance as it propagates away from the source. This enables the qualitative assessment of risk to be produced based on the expected noise levels and qualitative criteria.

Table 7: Effect criteria (onset thresholds) for fish and mammals, dB re 1μPa for L_{rms} and dB re 1μPa^{2}s for $L_{E,PW}$ and assessment of risk for breaking and for impact piling

Hearing group	Weighting	Recoverable injury for fish/PTS for mammals	TTS threshold	Level expected breaking out	Level expected impact piling	Risk of harm
Fish: no swim bladder (particle motion detection)	None	> 216 dB SEL_{cum} or > 213 dB L_{pk}	>> 186 dB SEL_{cum}	186 dB SEL_{cum} and 149 dB L_{pk}	163 dB SEL_{cum} and 143 dB L_{pk}	Low risk (TTS threshold >> cumulative level) and peak is below threshold
Fish: swim bladder is not involved in hearing (particle motion detection)	None	203 dB SEL_{cum} or >207 dB L_{pk}	> 186 dB SEL_{cum}	186 dB SEL_{cum} and 149 dB L_{pk}	163 dB SEL_{cum} and 143 dB L_{pk}	Low risk (TTS threshold > cumulative level) and peak is below threshold
Fish: swim bladder is involved in hearing (particle motion detection)	None	203 dB SEL_{cum} or >207 dB L_{pk}	186 dB SEL_{cum}	186 dB SEL_{cum} and 149 dB L_{pk}	163 dB SEL_{cum} and 143 dB L_{pk}	Moderate risk (TTS threshold same as cumulative level) but peak is below threshold
Sea turtles*	None	(N) High (I) Low (F) Low	(N) High (I) Low (F) Low	Equivalent to being in (I) or (F) field based on noise levels		Low
Phocid pinnipeds	PW	218 dB L_{pk} 185 dB $L_{E,PW}$	212 dB L_{pk} 170 dB $L_{E,PW}$	159 dB L_{pk} and 164 dB $L_{E,PW}$	160 dB L_{pk} and 148 dB $L_{E,PW}$	Low (peak and SEL levels less than threshold)
*Please note that the turtles in the aquarium are terrapins, a freshwater species, rather than a sea turtle. However, these criteria have been used as a proxy in the absence of other data.						

Source: Popper et al., 2014 and NOAA 2018 and Mott MacDonald, 2021

[5] Please note that the turtles in the aquarium are terrapins, a freshwater species, rather than a sea turtle. However, these criteria have been used as a proxy in the absence of other data.

Table 8: Effect criteria (onset thresholds) for fish and mammals, dB re 1µPa for L_{rms} and dB re 1µPa^{2}s for $L_{E,PW}$ and assessment of risk for vibropiling and rolling

Hearing group	Weighting	Recoverable injury for fish/PTS for mammals	TTS threshold	Level expected vibropiling	Level expected rolling	Risk of harm
Fish: no swim bladder (particle motion detection)	None	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	105 dB $L_{rms,24h}$ equivalent to being in (F)	147 dB $L_{rms,24h}$ equivalent to being in (I)	Low
		> 213 dB L_{pk} – see Table 4			180 dB L_{pk} see note * of Table 6	Low
Fish: swim bladder is not involved in hearing (particle motion detection)	None	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	105 dB $L_{rms,24h}$ equivalent to being in (F)	147 dB $L_{rms,24h}$ equivalent to being in (I)	Low
		>207dB L_{pk} – see Table 4			180 dB L_{pk} see note * of Table 6	Low
Fish: swim bladder is involved in hearing (particle motion detection)	None	170 dB rms for 48h (equivalent to 173 dB rms for 24h)	158 dB rms for 12h (equivalent to 161 dB rms for 24h)	105 dB $L_{rms,24h}$	147 dB $L_{rms,24h}$	Low
		>207dB L_{pk} – see Table 4			180 dB L_{pk} see note * of Table 6	Low
Sea turtles	None	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	105 dB $L_{rms,24h}$ equivalent to being in (F)	147 dB $L_{rms,24h}$ equivalent to being in (I)	Low
Phocid pinnipeds	PW	201 dB $L_{E,PW}$	181 dB $L_{E,PW}$	134 dB $L_{E,PW}$	171 dB $L_{E,PW}$	Low
		218 dB L_{pk} see Table 4	212 dB L_{pk} see Table 4		180 dB L_{pk} see note * of Table 6	Low

Source: Popper et al., 2014; NMFS, 2018 and Mott MacDonald

Table 7 shows the risk of harm to all fish and phocid pinnipeds is low because the expected underwater noise levels are no higher than the threshold at which a temporary threshold shift arises, with the exception of fish where the swim bladder is involved in hearing. In this case the risk due to peak noise levels is low, but for breaking out the cumulative exposure matches the TTS threshold. There is therefore a risk of temporary threshold shift for these fish, particularly if the exposure continues for more than the 2-hour period in a day that was included in the assumptions. This is therefore a potentially significant adverse effect for the most sensitive fish.

As masking and behavioural thresholds are at lower levels than the TTS threshold, and because exposures are in some cases are at or only just below the TTS threshold, it is likely that the fish and phocid pinnipeds would be subject to noise that would likely cause them to exhibit behavioural changes, although the ways that this would become manifest are not known. However, it is noted that some aquarium animals did exhibit a response to recent demolition activity on the promenade[6] which would be consistent with underwater noise for construction activity producing such an effect as set out in the analysis above.

[6] Pers. Comm. With aquarium managers

For the vibropiling and rolling Table 8 shows that the risk of harm is low for all animals including both the effect of prolonged exposure when compared with the L_{rms} thresholds and for peak exposure compared with the L_{pk} thresholds set out in Table 4 for transient noise.

6 Airborne noise impact on seals

The assessment set out above has focussed on the underwater noise impact on fish and the pinnipeds. However, the seals at Seal Cove will spend some time out of the water and it is therefore necessary to consider the potential airborne noise impact of construction activity.

While the construction activities that were expected to produce groundborne vibration (and hence underwater noise levels in the pools and tanks) were set out in Table 1, different construction activities may produce airborne noise including works at greater distances from the aquarium. These activities include:

- Ground excavation/earthworks;
- Breaking up brick foundations and concrete;
- Sheet steel piling;
- Mixing and pumping concrete;
- Distribution of material; and
- Road planning.

The auditory weighting function for airborne noise and the airborne noise PTS/TTS thresholds for pinnipeds differ from the weighting function and threshold used for underwater noise. For airborne noise the weighting function is given by Houser et al., (2017) (based on the US Navy Tactical Training Theatre Assessment and Planning [TAP] program) as

$$W(f) = k + 20\log_{10}\left\{\frac{b^2 f^2}{(a^2+f^2)(b^2+f^2)}\right\}$$

where the values of the coefficients are given in Table 9.

Table 9: Coefficient values for phocid pinniped weighting function in air

Hearing group	k	a [Hz]	b [Hz]
Phocid pinnipeds (PA)	0	75	30 000

Source: Houser, 2017

The SEL thresholds for TTS and PTS are also given by Houser et al., (2017) (also based on the US Navy TAP program) as set out in Table 10 in dB with a reference pressure of 20μPa^{2}s as 20μPa is the customary reference pressure for sound levels in air.

Table 10: Weighted SEL thresholds for TTS and PTS for phocid pinnipeds in air

	Non-impulsive SEL threshold dB re 20mPa^{2}s		Impulsive SEL threshold dB re 20mPa^{2}s	
Animal type	**TTS**	**PTS**	**TTS**	**PTS**
Phocid Pinnipeds (PA)	131	145	129	144

Source: Houser, 2017

Predictions for the airborne noise levels were made for each of the construction activities set out above at offset distances that represent the shortest distance between each construction activity and the Seal Cove. The predictions were made for all plant involved in the activity but weighted first in octave bands from 125Hz to 8kHz for the predominant noise source for each activity. The octave band levels were then weighted in accordance with the phocid pinniped weighting function in air and then combined to produce an RMS sound pressure level for a 12-hour working day using the % on-time for each activity. The RMS sound pressure levels were then converted to an SEL. The results of this are shown in Table 11. A screening correction of 10dB has been applied to all construction activity because the aquarium boundary wall will fully obscure the works except piling (for which no correction is applied) and excavator mounted breaking (for which a 5dB, partially obscured activity has been applied). It is possible, however, that the aquarium boundary wall will provide greater screening (noise reduction) that these figures suggest.

Table 11: Phocid pinniped weighted SEL values for construction activity

Activity	Distance [m]	% on time	Screening correction [dB]	SEL [dB re dB re (20mPa^2)s]
Dump Truck tipping fill	628	25	10	78
Breaking up brick foundations : Breaker mounted on excavator	40	75	10	116
Dump Truck tipping fill	626	75	10	85
Dump Truck tipping fill	808	75	10	81
Sheet steel piling – vibratory : Vibratory piling rig	64	25	0	111
Breaking up concrete : Hand-held pneumatic breaker	64	75	10	105
Pumping concrete : Truck mounted concrete pump + boom arm	64	75	10	104
Miscellaneous : Angle grinder (grinding steel)	10	75	10	119
Breaking up brick foundations : Breaker mounted on excavator	10	40	10	125
Ground excavation/earthworks: Dozer	10	100	10	129
Breaking up brick foundations : Breaker mounted on excavator	38	70	5	126
Mixing concrete : Concrete mixer truck	10	30	10	114
Ground excavation/earthworks: Dozer	10	30	10	122
Pumping concrete : Truck mounted concrete pump + boom arm	10	30	10	117
Mixing concrete : Concrete mixer truck	10	30	10	113
Mixing concrete : Concrete mixer truck	10	50	10	116
Road planing : Road planer	10	75	10	123
Distribution of material : Dump truck (tipping fill)	10	30	10	116

Source: Mott MacDonald 2021

A further activity that will produce noise at Seal Cove is the operation of the haul road immediately adjacent to the aquarium (see Figure 2.1). The phocid pinniped airborne noise weighted SEL associated with this is 114 dB based on 171 vehicles movements over 60 days.

The SEL values for airborne noise in Table 11 may be compared with the airborne noise criteria in Table 10. The highest predicted SEL value is 129 dB (ground excavation/earthworks) which matches the TTS criterion for impulsive noise and is 2 dB below the criterion for non-impulsive noise. All other works, including the haul road, are below the TTS threshold and well below the

PTS threshold, although the ground-breaking works is at 126 dB is also close to the TTS threshold.

Without further mitigation there is thus a risk of reaching the TTS threshold for seals remaining above the water during ground excavation/earthworks and during ground-breaking works. These are therefore potentially significant adverse effects.

7 Uncertainty

Several assumptions were made in the determination of the potential impact of underwater construction noise on the animals set out in Table 2, above. In the section that follows, the impact of departures from these assumptions is considered in terms of its potential to change the assessment outcome.

- *Sensitivity of the animals.* The criteria at which effects arise are taken directly form peer-reviewed literature and there is low risk that these could be incorrect for animals in the wild, but any change in sensitivity for captive animals is unknown, although there is no reason to believe that captive animals should be more sensitive to TTS and PTS than wild animals. There is therefore low risk of change to the assessment outcome associated with this factor.
- *Modelling assumptions.* A list of these was set out in Section 4. Erroneous assumptions could increase or decrease noise levels in comparison with the predictions. There is moderate risk of change to the assessment outcome if these assumptions are erroneous, particularly for the construction activity that produces the highest noise levels (jackhammer breaking for the nearest tanks) and for the species where the exposure is closest to the TTS threshold (fish where the swim bladder is involved in hearing through particle motion detection).
- *Plant.* Only four plant items have been considered in this analysis, jackhammer breaking, impact piling, vibropiling, and rolling. These are expected to produce the highest vibration levels. The precise details of the plant that will be used are not yet know and there is some risk of change to the assessment outcome if these plant assumptions are erroneous.
- *Haul road surface.* A compact granular surface is not expected to produce vibration that approaches the levels expected for rolling operations but any discontinuities or irregularities in the surface would tend to increase vibration levels and hence underwater noise levels. There is therefore some risk of change to the assessment outcome if the haul road surface is not free of significant defects and if a large number of vehicles uses the haul road on a daily basis.

Assumptions were also made in the determination of potential impact of airborne construction noise. The implications that these assumptions have in terms of assessment outcome are as follows:

- *Sensitivity of the animals.* As for underwater noise, the criteria at which effects arise are taken directly form peer-reviewed literature and there is low risk that these could be incorrect for animals in the wild, but any change in sensitivity for captive animals is unknown although there is no reason to believe that captive animals should be more sensitive to TTS and PTS than wild animals. There is therefore low risk of change to the assessment outcome associated with this factor.
- *Modelling assumptions.* Spherical propagation over hard or soft ground as appropriate has been used with phocid pinniped weighting applied to the spectrum of the predominant plant item in each case. The barrier insertion loss of 5dB or 10dB is a conservative estimate of noise reduction that would be provided by the aquarium wall and no provision has been made for a reduced exposure if the seals entered the water instead of staying out of the water during construction activity. There is therefore low risk of change to the assessment outcome associated with this factor.
- *Plant.* The plant on-time assumptions are set out in Table 11. If plant are operated for more time within a 12 period than shown, then noise levels increase by 3dB with every doubling of the on-time. Conversely, if plant are operated for only part of time shown then noise levels decrease by 3dB for every halving of the on-time. There is therefore moderate risk of a

change in assessment outcome associated with this factor if plant are operated for a greater proportion than the stated on-time or for more than a 12-hour day, although this risk can be controlled.

- *Cumulative impact.* The seals are exposed to other sounds in addition to the construction noise over a 24-hour period and some construction activity may arise at the same time as other construction activity. The current exposure levels are unknown but there is no reason to expect that these will approach the TTS threshold unless there is significant amplified music or sustained, loud crowd sounds. Where construction activities take place simultaneously there is a risk that the impact of the compound sources is greater than the louder of the two sources, although this does not apply if the louder sound is 10dB, or more, greater than the cumulative effects of all other sounds. Without control of sequencing of the work there is low to moderate risk of a change of assessment outcome associated with this factor, although this risk can be controlled.

8 Conclusion (Mitigation)

The assessment presented above demonstrates that underwater noise from construction activity presents a low risk of injury to either fish or phocid pinnipeds with notable exceptions but there is a reasonable expectation of a change in behaviour due to underwater noise. This is predominantly due to cumulative exposure over periods of several hours rather than the peak sound pressure levels. The exceptions are that the most sensitive fish, at the nearest receptor locations, may be exposed to noise approaching the TTS threshold and this is therefore a potentially significant adverse effect.

Underwater noise levels increase as the distance between the construction activity and the aquarium decreases. It follows that greatest exposures will arise for works close to the aquarium and which are sustained for several hours each day.

No criteria have been considered or presented for the risk that vibration would cause a sedimentary disturbance, potentially clouding or contamination of the exhibition water.

The following mitigation measures are recommended:

- There should be very close liaison between the contractors and the aquarium so that aquarium staff can closely monitor the animals' behaviour, feeding etc. at the times when construction activity is closest to the aquarium, particularly at the times when construction includes breaking of the existing promenade surface which seems to be the activity that poses the greatest risk.
- Underwater noise levels should be monitored during construction to determine if there is any correlation between any behavioural change and noise levels. This will be particularly beneficial if construction starts at a relatively remote location getting closer to the aquarium as it would provide an early indication of the potential impact.
- If there is an indication that construction activity would reach the TTS thresholds then consideration should be given to (a) locating the most sensitive species to the most remote tanks and (b) limiting the construction activity that produces the highest underwater noise levels to only a proportion of the working day – noting that all other factors being equal, cumulative noise levels reduce by 3dB for each halving of construction time although noting also that reduced hours of working on a given day also prolongs the number of days involved to achieve the same outcome.
- All tanks should be cleaned to remove sedimentary deposits as far as is reasonably practicable to reduce the risk of sedimentary disturbance produced by vibration.
- Vibration levels at the aquarium and water quality should both be monitored when construction activity is close to the aquarium to establish if any clouding of the water is associated with groundborne vibration.

There is low risk of injury for seals in Seal Cove during construction activity where the TTS threshold is not exceeded but as it is approached the seals may exhibit a behavioural change including spending more time in the water than normal. There is a risk of reaching the TTS threshold for seals remaining above the water during ground excavation/earthworks and during ground-breaking works. These are therefore potentially significant adverse effects and the following mitigation measures are therefore recommended:

- There should be very close liaison between the contractors and the aquarium so that aquarium staff can closely monitor the animals' behaviour, feeding etc. at the times when construction activity is closest to the aquarium, particularly at the times when construction includes breaking of the existing promenade surface which seems to be the activity that poses the greatest risk.

- Airborne noise levels should be monitored during construction to determine if there is any correlation between any behavioural change and noise levels and this will be particularly beneficial if construction starts at a relatively remote location getting closer to the aquarium as it would provide an early indication of the potential impact.
- If there is an indication that construction activity would reach the TTS thresholds then consideration should be given to limiting the construction activity that produces the highest underwater noise levels to only a proportion of the working day – noting that all other factors being equal, cumulative noise levels reduce by 3dB for each halving of construction time although noting also that reduced hours of working on a given day also prolongs the number of days involved to achieve the same outcome.

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