20.0 Underwater Noise

Introduction

20.1 This Subsea Noise Technical Chapter presents the results of a desktop study considering the potential Brief to Temporary[1] effects of underwater noise on the marine environment from the proposed berth expansion, dredging and breakwater extension at Stranraer Marina, Dumfries and Galloway, Scotland. The entirety of the activities proposed to be undertaken will, hereafter, be referred to as the “proposed development”.

20.2 Further detail on the proposed development can be found in **Chapter 2 of Volume 1.**

20.3 This chapter contains the description of the methods and the results of the underwater noise modelling. The results from this chapter have informed the assessments in **Chapter 13, Fish Ecology and Chapter 14, Marine Mammals of Volume 1**. Thus, this chapter only deals with calculating the likely ranges to exceedance of sound thresholds for marine mammals and fish, while the impact assessment for significance of effects is located in the relevant ecology chapters (**Chapter 13, Fish Ecology and Chapter 14, Marine Mammals of Volume 1**).

20.4 The sediment within the area is mainly silty gravelly clay overlying a bedrock of sandstone. Water properties in the area are relatively stable given the lack of major river outflows and good mixing due to tidal actions.

20.5 The proposed development includes a range of noisy activities where especially dredging, vibro piling and impact pile driving can pose a risk to the integrity of the auditory systems of fish and aquatic mammals.

20.6 This chapter provides an overview of the potential effects due to underwater noise from the proposed development on the surrounding marine environment based on the Southall et al. 2019[2], NMFS/NOAA 2024[3] and Popper et al. 2014[4] frameworks for assessing impact from noise on marine mammals and fish.

20.7 Consequently, the primary purpose of the underwater noise assessment is to predict the likely range of onset for potential physiological and behavioural effects due to increased anthropogenic noise because of the proposed development.

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[1] Brief Effects are those lasting less than a day; and Temporary Effects are those lasting less than a year. (EPA, 2022) p.51:

[2] Southall, B. L., Finneran, J. J., Reichmuth, C., Nachtigall, P. E., Ketten, D. R., Bowles, A. E., . . . Tyack, P. L. (2019). Marine Mammal Noise Exposure Criteria: Updated Scientific Recommendations for Residual Hearing Effects. 45(2)

[3] National Oceanic and Atmospheric Administration. (2024). 2024 Update to: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 3.0). Silver Spring: National Marine Fisheries Service.

[4] Popper, A. N., Hawkins, A. D., Fa, R. R., Mann, D. A., Bartol, S., Carlson, T. J., . . . Tavolga, W. N. (2014). Sound Exposure Guidelines for Fishes and Sea Turtles. Springer.

Competency Statement

Rasmus Sloth Pedersen, Senior Scientist (Acoustics)

20.8 Rasmus is an underwater acoustics specialist with 9 years' commercial experience following his research-focused MSc in biology and bioacoustics. He now specialises in modelling of emitted noise from a range of manmade sound sources including piling, dredging, echosounders and seismic surveys. Rasmus has delivered consultancy services to projects worldwide (incl. Ireland, Norway, Sweden, Germany, the United Kingdom and the USA), as well as developed or codeveloped and implemented multiple source models and propagation models (dBSea, Roger's, Weston's, raytracing, parabolic equation, normal modes) for underwater noise assessments. Daily work with marine noise impact assessments and source modelling forms the core of Rasmus' current work. Rasmus has strong field experience from former roles as a commercial diver, rope access technician, marine mammal & seabird observer and PAM-technician, meaning he has considerable understanding of many aspects of the industrial and scientific parts of the marine sector. His breath of experience with underwater acoustics and background in bioacoustics and programming means that Rasmus quickly can accommodate local needs for modelling and build bespoke solutions. Rasmus additionally has experience with machine learning and has produced applications for bat call classification and habitat classification, methods that are readily applicable to cetacean or marine sounds.

Guidance on Noise Exposure

Introduction

20.9 To determine the potential spatial range of injury and disturbance, assessment criteria have been developed based on a review of available evidence including national and international guidance and scientific literature. The following sections summarise the relevant assessment criteria and describe the evidence base used to derive them.

Frameworks and Assessment Criteria

20.10 Underwater noise has the potential to affect marine life in different ways depending on its noise level and characteristics. Assessment criteria generally separate sound into two distinct types, as follows:

- **Impulsive sounds** which are typically transient, momentary (less than one second), broadband, and consist of high peak sound pressure with rapid rise time and rapid decay (ANSI, 2005; ANSI, 1986; NIOSH, 1998)[5]. This category includes sound sources such as seismic surveys, impact piling and underwater explosions. Additionally included here are sounds under 1 second in duration with a weighted kurtosis over 40 (see note below*).

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[5] ANSI. (1986). S12.7-1986 Method for Measurement of Impulsive Noise. American National Standards Institute.
ANSI. (2005). S1.13-2005 Measurement of Sound Pressure Levels in Air. American National Standards Institute.
NIOSH. (1998). Criteria for a Recommended Standard: Occupational Noise Exposure. National Institute for Occupational Safety and Health.

- **Non-impulsive** (and continuous) sounds which can be broadband, narrowband or tonal, momentary, brief or prolonged, continuous or intermittent and typically do not have a high peak sound pressure with rapid rise/decay time that impulsive sounds do (ANSI, 1995; NIOSH, 1998)[6]. This category includes sound sources such as continuous vibro-piling, running machinery, some sonar equipment and vessels. Additionally included here are sounds over 1 second in duration with a weighted kurtosis under 40 (see note below*).

20.11 * Note that the European Guidance: "Monitoring Guidance for Underwater Noise in European Seas, Part II: Monitoring Guidance Specifications"[7] includes sonar as impulsive sources (see Section 2.2 of guidance). However, the guidance suggests that "all loud sounds of duration less than 10 seconds should be included" as impulsive. This contradicts research on impact from impulsive sounds suggesting that a limit for "impulsiveness" can be set at a kurtosis[8] of 40 (Martin & Klaus Lucke, 2020)[9] See examples in (**Appendix 20.1, Volume 2, Impulsiveness**).

20.12 This latter criterion (kurtosis >40) has been used for classification of impulsive versus non-impulsive sound sources. The justification for departing from the MSFD criterion is that the Southall et al. 2019 and the Popper et al. 2014 framework limits are based on the narrower definition of impulsive as given in "Impulsive sounds" above.

20.13 There is scope for some sounds to be classified as both impulsive and non-impulsive, depending on the criteria applied. Examples are pulses from sonar-like sources that can contain very rapid rise times (<0.5ms), sweep a large frequency range and have high kurtosis. However, given that the scientific work carried out to identify impulsive thresholds were done with "pure" impulses (from a near instantaneous event), sonar-like sounds are sometimes not included in this impulsive category. This argument ignores that sounds used for establishing the non-impulsive thresholds (often narrowband slowly[10] rising pulses), are markedly less impulsive (lower kurtosis, narrower bandwidth) than what is sometimes seen in pulses from sonar-like sources and are thus also not representative for all sonar-like pulses.

20.14 Given impulsive sound's tendency to become less impulsive with increased range, a minimal range can be established where the noise is no longer impulsive (here kurtosis <40 is used) (**Appendix 20.1, Volume 2, Impulsiveness**). This range is established using raytracing, but as the effect varies with exact depth and range of source and receiver, the transition range to non-impulsive used for exposure modelling is doubled from the modelled range where kurtosis goes below 40 (and is thus a conservative approach).

[6] ANSI. (1995). S3.20-1995 Bioacoustical Terminology. American National Standards Institute.
[7] MSFD Technical Subgroup on Underwater Noise. (2014). Monitoring Guidance for Underwater Noise in European Seas, Part II: Monitoring Guidance Specifications. European commission.
[8] Statistical measure of the asymmetry of a probability distribution.
[9] Martin, S. B., & Klaus Lucke, D. R. (2020). Techniques for distinguishing between impulsive and non-impulsive sound in the context of regulating sound exposure for marine mammals. 147(4).
[10] Slowly in this context is >10ms – slow relative to the integration time of the auditory system of marine mammals.

20.15 The acoustic assessment criteria for marine mammals and fish in this chapter has followed the latest international guidance (based on the best available scientific information), that are widely accepted for assessments in the UK, Europe and worldwide (Southall, et al., 2019; Popper, et al., 2014; NMFS, 2024).

Methodology Used for Assessment

Effects on Marine Mammals

20.16 Underwater noise has the potential to affect marine life in different ways depending on its noise level and characteristics. Richardson *et al.* (1995)[11] defined four zones of noise influence which vary with distance from the source and level, to which an additional zone has been added "zone of temporary hearing loss". These are:

- The zone of audibility: This is defined as the area within which the animal can detect the sound. Audibility itself does not implicitly mean that the sound will affect the animal.
- The zone of masking: This is defined as the area within which sound can interfere with the detection of other sounds such as communication or echolocation clicks. This zone is very hard to estimate due to a paucity of data relating to how animals detect sound in relation to masking levels (for example, humans can hear tones well below the numeric value of the overall sound level). Continuous sounds will generally have a greater masking potential than intermittent sound due to the latter providing some relative quiet between sounds. Masking only occurs if there is near-overlap in sound and signal, such that a loud sound at e.g., 1000Hz will not be able to mask a signal at 10,000Hz[12].
- The zone of responsiveness: This is defined as the area within which the animal responds either behaviourally or physiologically. The zone of responsiveness is usually smaller than the zone of audibility because, as stated previously, audibility does not necessarily evoke a reaction. For most species there is very little data on response, but for species like harbour porpoise there exists several studies showing a relationship between received level and probability of response (Graham IM, 2019; Sarnoci´nska J, 2020; BOOTH, 2017; Benhemma-Le Gall A, 2021)[13]. This zone is quantified here with the use of behavioural thresholds (**Table 20-2** & **Table 20-4**).

[11] Richardson, W., Greene, C., Malma, C., & Thomson, D. (1991). Effects of Noise on Marine Mammals.
[12] The exact limit of how near a noise can get to the signal in frequency before causing masking will depend on the receivers' auditory frequency resolution ability, but for most practical applications noise and signal frequencies will need to be within 1/3rd octave to start to have a masking effect.
[13] Graham IM, M. N. (2019). Harbour porpoise responses to pile-driving diminish over time.
Sarnocinska (2020). Harbor Porpoise (Phocoena phocoena) Reaction to a 3D Seismic Airgun Survey in the North Sea.
BOOTH, C. H. (2017). Using the Interim PCoD framework to assess the potential impacts of offshore wind developments in Eastern English Waters on harbour porpoises in the North Sea. Natural England.
Benhemma-Le Gall A, G. I. (2021). Broad-Scale Responses of Harbor Porpoises to Pile-Driving and Vessel Activities During Offshore Windfarm Construction.

- The zone of temporary hearing loss: The area where the sound level is sufficient to cause the auditory system to lose sensitivity temporarily, causing loss of “acoustic habitat”: the volume of water that can be sensed acoustically by the animal. This hearing loss is typically classified as Temporary Threshold Shift.
- The zone of injury / permanent hearing loss: This is the area where the sound level is sufficient to cause permanent hearing loss in an animal. This hearing loss is typically classified as Auditory Injury (AUD INJ). At even closer ranges, and for very high intensity sound sources (e.g., underwater explosions), physical trauma or acute mortal injuries are possible.

20.17 For this study, it is the zones of injury (AUD INJ) that are of primary interest, along with estimates of behavioural impact ranges. To determine the potential spatial range of injury and behavioural change, a review has been undertaken of available evidence, including international guidance and scientific literature. The following sections summarise the relevant thresholds for onset of effects and describe the evidence base used to derive them.

Thresholds for Marine Mammals

20.18 The zone of injury in this study is classified as the distance over which a fleeing marine mammal can suffer AUD INJ (Auditory Injury) leading to non-reversible auditory injury. Injury thresholds are based on a dual criteria approach using both un-weighted L_P (maximal instantaneous SPL, Sound Pressure Level) and marine mammal hearing weighted SEL (Sound Exposure Level). The hearing weighting function is designed to represent the sensitivity for each group within which acoustic exposures can have auditory effects. The categories include:

- Low Frequency (LF) cetaceans: Marine mammal species such as baleen whales (e.g. minke whale Balaenoptera acutorostrata).
- High Frequency (HF) cetaceans: Marine mammal species such as dolphins, toothed whales, beaked whales and bottlenose whales (e.g., bottlenose dolphin Tursiops truncatus and white-beaked dolphin Lagenorhynchus albirostris).
- Very High Frequency (VHF) cetaceans: Marine mammal species such as true porpoises, river dolphins and pygmy/dwarf sperm whales and some oceanic dolphins, generally with auditory centre frequencies above 100 kHz) (e.g., harbour porpoise Phocoena phocoena).
- Phocid Carnivores in Water (PCW): True seals, earless seals (e.g., harbour seal Phoca vitulina and grey seal Halichoreus grypus); hearing in air is considered separately in the group PCA.
- Other Marine Carnivores in Water (OCW): Including otariid pinnipeds (e.g., sea lions and fur seals), sea otters and polar bears; in-air hearing is considered separately in the group Other Marine Carnivores in Air (OCA).
- Sirenians (SI): Manatees and dugongs. This group is only represented in the NOAA guidelines.

20.19 These weightings are used in this study and are shown in **Figure 20-1**. It should be noted that not all of the above hearing groups of marine mammals will be present in the area, but all hearing groups are presented in this chapter for completeness.

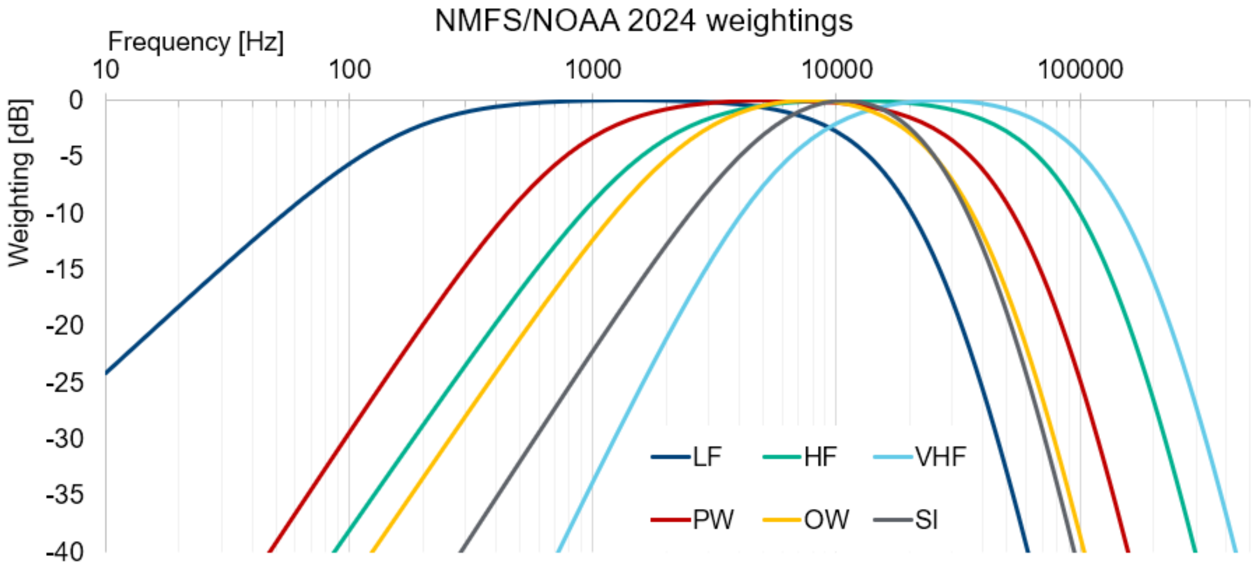

Figure 20-1: Auditory weighting functions for seals, whales and sirenians (National Oceanic and Atmospheric Administration, 2024).

20.20 Both the criteria for impulsive and non-impulsive sound are relevant for this study given the nature of the noise from the activities. The relevant AUD INJ and TTS criteria proposed by NMFS/NOAA 2024 are summarised in **Table 20-1.**

Table 20-1: AUD INJ and TTS onset acoustic thresholds (NMFS, 2024).

Hearing Group	Parameter	Impulsive [dB]		Non-impulsive [dB]	
		AUD INJ	TTS	AUD INJ	TTS
Low frequency (LF) cetaceans	L_P, (unweighted)	222	216	-	-
	SEL, (weighted)	183	168	197	177
High frequency (HF) cetaceans	L_P, (unweighted)	230	224	-	-
	SEL, (weighted)	193	178	201	181
Very high frequency (VHF) cetaceans	L_P, (unweighted)	202	196	-	-
	SEL, (weighted)	159	144	181	161
Phocid carnivores in water (PCW)	L_P, (unweighted)	223	217	-	-
	SEL, (weighted)	183	168	195	175
Other marine carnivores in water (OCW)	L_P, (unweighted)	230	224	-	-
	SEL, (weighted)	185	170	199	179
Sirenians (SI) (NOAA only)	L_P, (unweighted)	225	219	-	-
	SEL, (weighted)	186	171	186	180

Disturbance to Marine Mammals

20.21 The noise thresholds for disturbance of marine mammals are not as mature as the AUD INJ and TTS thresholds and several different approaches exist. We use a conservative but realistic approach based on a review of Danish and UK guidance documents as well as scientific reviews.

20.22 The general approach reflects the approach recommended by the Danish guidance (Danish Centre for Environment and Energy, 2021)[14], by a review submitted to the JNCC (Joint Nature Conservation Committee) of the UK (Nedwell, et al., 2007)[15] and by a review for Natural Resources Wales (Sinclair, Kazer, Ryder, New, & Verfuss, 2023)[16]. These all recommend or acknowledge the use of a weighted received level along with a hearing capability specific threshold.

20.23 Using 21 suitable studies from these reports we have arrived at hearing group specific thresholds (**Table 20-2**) to determine behavioural disturbance levels for non-impulsive noise (assumed to be noise with a kurtosis <40). These thresholds are compared to the range where the hearing group weighted received level exceeds the relevant threshold.

Table 20-2: Disturbance criteria for marine mammals used in this assessment, based on Danish and UK guidance.

Effect	LF	HF	VHF	PCW	OCW
Behavioural disturbance, non-impulsive, SPL [dB]	118	92	95	108	110

20.24 Given the considerable variation in the data (up to 40dB where both mild disturbance and severe disturbance was included) we have opted to select a conservative value of either the 10th percentile value of the matching normal distribution or the minimal value, whichever is greater[17] (**Figure 20-2**).

[14] Danish Centre for Environment and Energy. (2021). Thresholds for behavioural responses to noise in marine mammals. Aarhus: Aarhus Universitet.
[15] Nedwell, D. J., Turnpenny, A., Lovell, J., Parvin, S., Workman, R., Spinks, J., & Howell, D. (2007). A validation of the dBht as a measure of the behavioural and auditory effects of underwater noise. subacoustech
[16] Sinclair, R., Kazer, S., Ryder, M., New, P., & Verfuss, U. (2023). Review and recommendations on assessment of noise disturbance for marine mammals. Bangor: Natural Resources Wales.
[17] Where there is large variation the 10th percentile of the matching normal distribution might be unrealistically low.

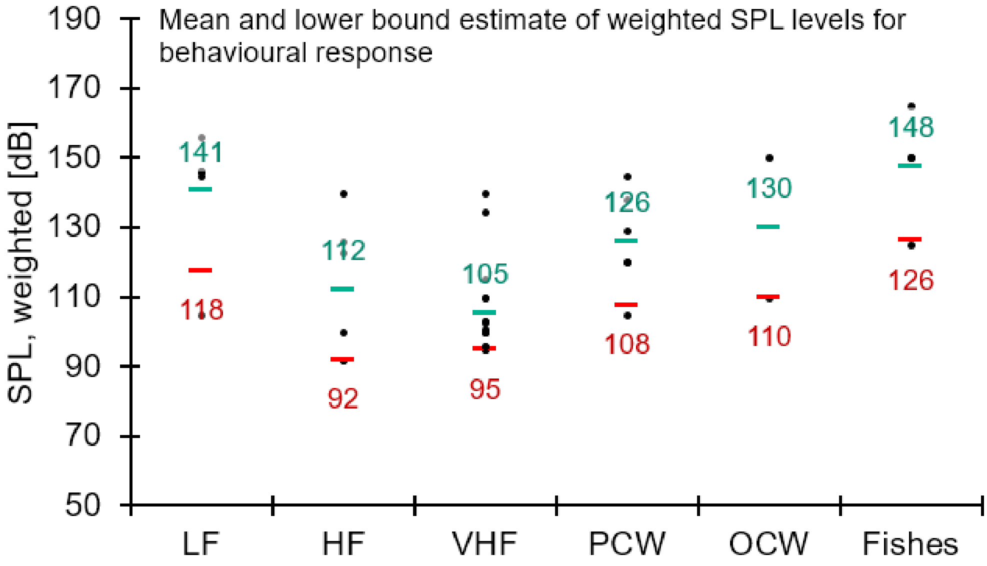

Figure 20-2: Data and behavioural disturbance thresholds. Mean values are green lines/values, while red lines/values are 10th percentile values or the minimal value, whichever is greater.

20.25 This approach to disturbance threshold is more suitable than fixed value thresholds such as the often applied "Level B Harassment level" of the NMFS (National Marine Fisheries Service, 2005)[18] which neglects to account for sources outside the hearing range of animals, but might underestimate behavioural effects for noise near the most sensitive regions of a species' hearing.

Injury and Disturbance to Fishes

20.26 The injury criteria used in this noise assessment are given **Table 20-3 and Table 20-4** for impulsive noise and continuous noise respectively. L_P criteria are assessed against unweighted received levels and SEL/SPL criteria presented in the tables are assessed against weighted received levels.

20.27 It's important to clarify that this lack of weighting for fishes reflects a lack of scientific consensus about the best method for applying frequency dependence to received levels for fishes, rather than a statement that fishes can hear all frequencies equally. Fishes generally cannot hear above 10kHz, and if they can, the sensitivity is generally very poor (**Figure 20-3,** (Nedwell, Edwards, Turnpenny, & Gordon, 2004)[19]). We therefore add a simple weighting prior to assessment against the fishes thresholds. This simple weighting would subtract 70dB from all noise above 10kHz, reflecting the decrease in sensitivity of the best-hearing fishes around this frequency (**Figure 20-3**).

[18] National Marine Fisheries Service. (2005). Scoping report for NMFS EIS for the National Acoustic Guidelines on Marine Mammals. National Marine Fisheries Service.
[19] Nedwell, D. J., Edwards, M. B., Turnpenny, D. A., & Gordon, D. J. (2004). Fish and Marine Mammal Audiograms: A summary of available information.

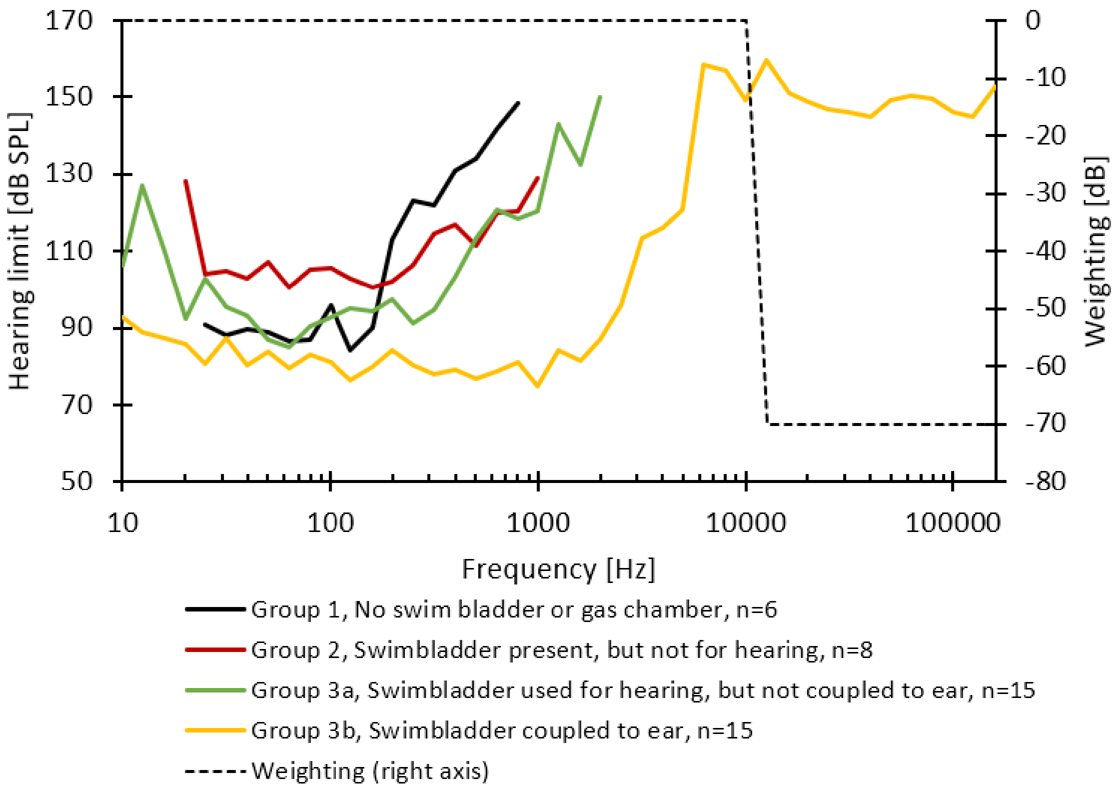

Figure 20-3: Generalised hearing thresholds for fishes grouped by the presence of a swim bladder and its role in hearing. Groups reflect categories proposed by Popper et al. 2014.

20.28 Physiological effects relating to injury criteria are described below (Popper, et al., 2014) (further explanation in equivalent section on marine mammals, paragraph 20.16):

- Mortality and potential mortal injury
- Recoverable injury ("AUD INJ" in tables and figures)
- Temporary Threshold Shift (TTS)

20.29 Popper et al. 2014 does not set out specific TTS limits for L_P and for disturbance limits for impulsive noise for fishes. Therefore publications: "Washington State Department of Transport Biological Assessment Preparation for Transport Projects Advanced Training Manual"[20] , "Canadian Department of Fisheries and Ocean Effects of Seismic energy on Fish: A Literature review"[21] on effects of seismic noise on fish and (Nedwell, et al., 2007)[22] on use of dB(audiogram-weighted) are used to determine limits for these:

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[20] WSDOT. (2020). Washington State Department of Transport Biological Assessment Preparation for Transport Projects Advanced Training Manual, CH 7. Washington State Department of Transport.
[21] Worcester, T. (2006). Effects of Seismic Energy on Fish; A Literature Review. Dartmouth, Canada: Department of Fisheries and Oceans, Bedford Institute of Oceanography.
[22] Nedwell, D. J., Turnpenny, A., Lovell, J., Parvin, S., Workman, R., Spinks, J., & Howell, D. (2007). A validation of the dBht as a measure of the behavioural and auditory effects of underwater noise. subacoustech.

- The criteria presented in the Washington State Department of Transport Biological Assessment Preparation for Transport Projects Advanced Training Manual (WSDOT, 2020). The manual suggests an un-weighted sound pressure level of 150dB SPL (assumed to be duration of 95 % of energy) as the criterion for onset of behavioural effects, based on work by (Hastings, 2002). Sound pressure levels in excess of 150dB SPL are expected to cause temporary behavioural changes, such as elicitation of a startle response, disruption of feeding, or avoidance of an area. The document notes that levels exceeding this threshold are not expected to cause direct permanent injury but may indirectly affect the individual fish (such as by impairing predator detection). It is important to note that this threshold is for onset of potential effects, and not necessarily an 'adverse effect' threshold. The threshold is implemented here as either single impulse SEL or 1 second SEL, whichever is greater.
- Nedwell et al. 2007 suggests 50-90dB(ht) for fishes, which if adjusting for absolute hearing sensitivity (c. 75dB SPL, **Figure 20-3** at 1000Hz) becomes 125-165dB.
- Taken together with the cautious approach from paragraph 20.21 to 20.25, this yields a weighted limit of 126dB SPL for fishes for non-impulsive noise (**Figure 20-2**), where the weighting is a -70dB weighting applied to frequencies above 10kHz.
- The report from the Canadian Department of Fisheries and Ocean "Effects of Seismic energy on Fish: A Literature review on fish" (Worcester, 2006) found large differences in response between experiments. Onset of behavioural response varied from 107-246dB L_P, the 10th percentile level for behavioural response was 160dB L_P (rounded to nearest 5dB to reflect large variation in data).
- Thus, the behavioural threshold for fishes for impulsive sound is 160dB L_P/150dB SPL, and for non-impulsive sound 126dB SPL.

20.30 *Note that while there are multiple groups of fish presented, we have used the thresholds of the more sensitive group for all fish thus covering all fishes (203/186 AUD INJ/TTS for impulsive sound & 222/204 AUD INJ/TTS for non-impulsive sound). These lower thresholds also cover "Eggs and Larvae".*

Table 20-3: Criteria for onset of injury to fish and sea turtles due to impulsive noise. For this assessment the lowest threshold for any group is used for all groups (shown in bold).

Type of animal	Unit	Mortality and potential mortal injury [dB]	Recoverable injury (AUD INJ) [dB]	TTS [dB]	Behavioural [dB]
Fish: no swim bladder (particle motion detection) Example: Sharks.	SEL	219[1]	216[1]	186[1]	150[3]
	L_P	213[1]	213[1]	193[2]	160[2]
Fish: where swim bladder is not involved in hearing (particle motion detection). Example: Salmonoids.	SEL	210[1]	203[1]	186[1]	150[3]
	L_P	207[1]	207[1]	193[2]	160[2]

Type of animal	Unit	Mortality and potential mortal injury [dB]	Recoverable injury (AUD INJ) [dB]	TTS [dB]	Behavioural [dB]
Fish: where swim bladder is involved in hearing (primarily pressure detection). Example: Gadoids (cod-like).	SEL	207[1]	**203[1]**	**186**	**150[3] [SPL]**
	L_P	207[1]	**207[1]**	**193[2]**	**160[2]**
Sea turtles	SEL	210[1]	(*Near*) High* (*Mid*) Low (*Far*) Low	-	-
	L_P	207[1]		-	-
Eggs and larvae	SEL	210[1]	(*Near*) Moderate (*Mid*) Low (*Far*) Low	-	-
	L_P	207[1]		-	-

[1] (Popper et al. 2014) table 7.4, [2](Worcester, 2006), [3](WSDOT, 2020)

* Indicate (range) and risk of effect, e.g., "(Near) High", meaning high risk of that effect when near the source.

20.31 Where Popper et al. 2014 present limits as ">" 207 or ">>" 186, we have ignored the "greater than" and used the threshold level as given.

20.32 Relevant thresholds for non-impulsive noise for fishes relating to AUD INJ, TTS, and behaviour are given in **Table 20-3** with behavioural disturbance thresholds in **Table 20-4**.

Table 20-4: Criteria for fish (incl. sharks) due to non-impulsive noise from Popper et al. 2014, (table 7.7) as well as behavioural threshold.

Type of animal	Unit	Mortality and potential mortal injury	Recoverable injury (AUD INJ) [dB]	TTS [dB]	Behavioural [dB]
All fishes	SEL	(*Near*) Low (*Mid*) Low (*Far*) Low	222[†]	204[†]	126 [SPL]

[†]Based on 48 hours of 170dB SPL and 12 hours of 158dB SPL

Site Environment

20.33 The following sections are based on information from the project description, from earlier projects in the area and written communication within the project team (includes updates to site boundary and sound source specifications). Where data is from public databases, the references are given in the text.

Development Area

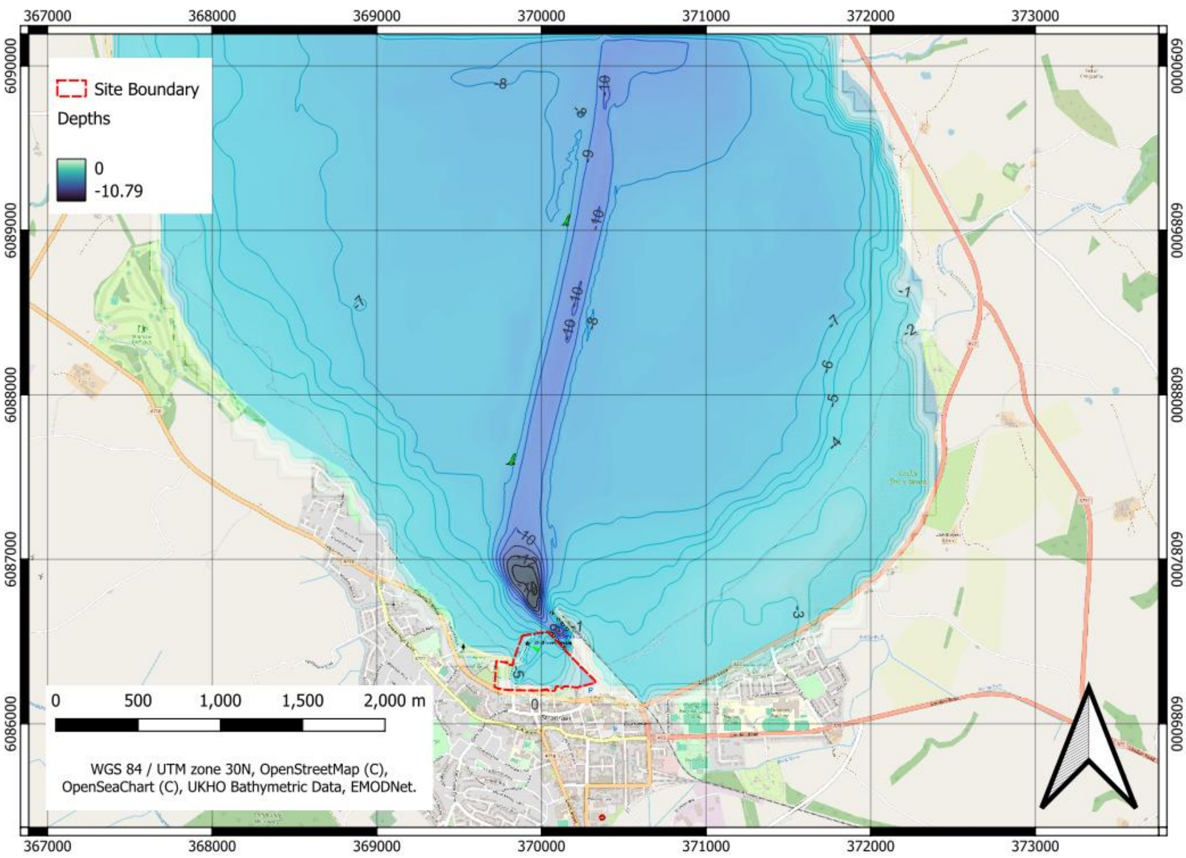

Figure 20-4: Overview of site boundary and southern end of Loch Ryan. Depths are for MHWS c. 1.7m above mean water level.

Water Properties

20.34 Water properties were determined from historical data for the area. Where a range of values are expected or observed, the value resulting in the lowest transmission loss was chosen for a more conservative assessment (more noise at range). Thus, this also covers seasonal variation.

- Temperature: 15°C – maximal summer temperature given by a range of weather services[23].
- Salinity: 33.1psu – minimal general salinity for Scottish marine waters[24].
- Soundspeed profile: Assumed generally uniform as a conservative measure and given generally shallow water (a typical summer sound speed profile would increase transmission loss by refracting sound towards the sediment).

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[23] https://www.seatemperature.org/europe/united-kingdom/stranraer.htm, https://seatemperature.net/current/united-kingdom/stranraer-scotland-united-kingdom-sea-temperature, https://en.climate-data.org/europe/united-kingdom/scotland/stranraer-6676/

[24] https://marine.gov.scot/sma/assessment/salinity-0

Sediment Properties

20.35 Sediment properties are based on sediments given in **Table 20-5**.

20.36 Sediment types are informed by the “Folk 7-class Classification” from EMODnet Geology[25] (European Commision, 2024)[26], from borehole samples by British Geological Survey (BGS) (British Geological Survey, 2023)[27] and two sediment ground investigation reports associated with this development. A sediment model (Ainslie, 2010)[28] was used to derive the acoustic properties of the sediment from the grain size.

Table 20-5: Sediment Properties.

Folk Sediment name	**Sediment type (ISO 14688-1:2017)**	**Density [kg/m³]**	**Soundspeed [m/s]**	**Grain size [mm] (nominal)**
Sandy mud	Medium Silt	1544	1541	0.0104

Source Noise Levels

20.37 Underwater noise sources are usually quantified in dB scale with values generally referenced to 1μPa pressure amplitude as if measured at a hypothetical distance of 1m from the source (called the Source Level). In practice, it is not usually possible to measure at 1m from a source, but the metric allows for comparison and reporting of different source levels on a like-for-like basis. In reality, for a large sound source, this imagined point at 1m from the acoustic centre does not exist. Furthermore, the energy is distributed across the source and does not all emanate from an imagined acoustic centre point. Therefore, the stated sound pressure level at 1m does not occur for large sources. In the acoustic near-field (i.e. close to the source), the sound pressure level will be significantly lower than the value predicted by the back-calculated source level (SL).

Source Models

20.38 The noise sources and activities investigated during this assessment are summarised in **Table 20-6**.

20.39 Impact piling noise levels are based on the “Taranis”, an inhouse model validated against recorded levels from piles of diameter 0.5-9m across a wide range of sediments (**Appendix 20.2, Volume 2**).

20.40 Note that:

- The source level changes during a pile installation (here c. 20dB), the impact piling model accounts for this and the loudest blows are used as representative for the installation and used as basis for further modelling as a conservative measure.

[25] https://drive.emodnet-geology.eu/geoserver/gtk/wms
[26] European Commision. (2024, 02 27). European Marine Observation and Data Network (EMODnet). Retrieved 02 27, 2024, from EMODnet Product Catalougue: https://emodnet.ec.europa.eu/geonetwork/srv/eng/catalog.search#/home
[27] British Geological Survey. (2023, 05 11). Geology Viewer. Retrieved 05 11, 2023, from British Geological Survey: https://geologyviewer.bgs.ac.uk
[28] Ainslie, M. A. (2010). Principles of Sonar Performance Modeling. Heidelberg: Springer.

- Source levels above 20,000Hz are extrapolated based on the trend at lower frequencies.

Table 20-6. Summary of Sound Sources and Activities Included in the Subsea Noise Assessment.

Equipment	Source level [SPL] (as used in model)	Primary decidecade bands (-20dB width)	Source model details	Impulsive/non-impulsive
Dredging vessel	191dB SPL	10-2,500Hz	Based on generic dredging vessel (installed power <30 MW, sandy or finer sediment).	Non-impulsive
Impact piling	212dB SEL 244dB L_P 212dB SPL (1 blow/sec assumed)	10-4,000Hz	"Taranis" (**Appendix 20.2, Volume 2**) Tubular steel pile, length 20m, diameter 1 m, wall thickness 0.02m. Hammer: 500kJ rating)	Impulsive
Rock dumping	-	-	Covered by proxy (Dredging vessel)	Non-impulsive
Sheet piling	194dB SPL	10-12,500Hz	Based on recordings of >80 installations	Non-impulsive

Equipment

20.41 This section presents details on each sound source individually.

Dredging Vessel

20.42 A generic dredging vessel (<30 MW installed power, sandy or finer sediment) has been modelled. The broadband level is 191dB SPL with the main energy (-20dB width) from 10-2,500Hz (**Figure 20-5**).

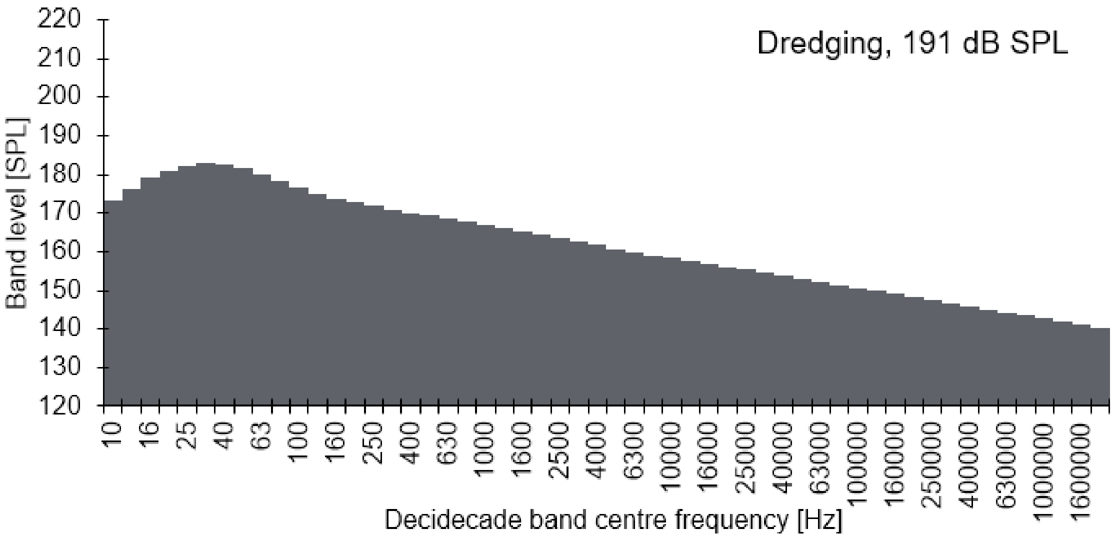

Figure 20-5. Band levels for dredging.

Impact Piling

20.43 The impact piling broadband level is 212dB SEL (single blow) with a modelled maximal blow rate of 1 blow/second meaning the SPL is also 212dB. The peak pressure level modelled is 244dB L_P. Most of the energy is (-20dB width) is within 10-4,000Hz (**Figure 20-6**). Level below 20Hz are given as a single value by the model and has been spread out across the three included bands below 20Hz (10, 12.5 & 16 Hz).

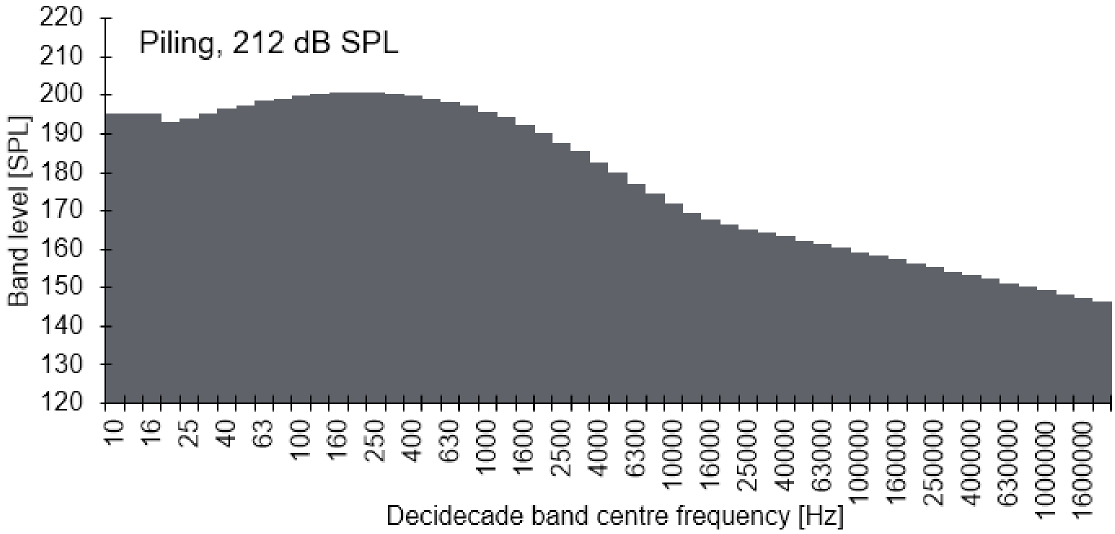

Figure 20-6. Impact piling source band levels.

Rock Dumping

20.44 The rock dumping or placement noise associated with the extension of the breakwater is assumed covered by the modelling of the dredging vessel as these are active in the same area and because the dredging noise is likely much louder than the actual rock dumping/placement, (JIP, 2020)[29] found no noticeable difference in sound levels during rock placement, and the vessel was the main source of noise throughout.

Sheet Piling

20.45 Sheet piling source band levels are based on over 80 recordings of vibratory sheet piling. As the recorded sheet piling noise shows no clear dependence on sediment, sheet pile dimension or driving power, the model is based on the 90th percentile band values for all recorded instances.

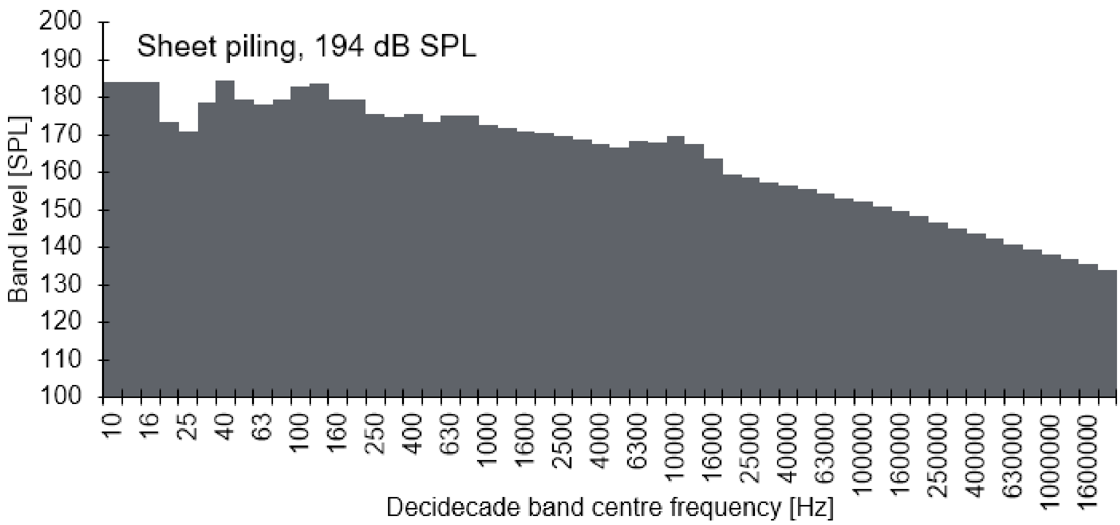

Figure 20-7. Sheet piling source band levels.

Sound Propagation Modelling Methodology

20.46 There are several methods available for modelling the propagation of sound between a source and receiver ranging from very simple models that assume spreading according to a $10x\log_{10}$(range) or $20x\log_{10}$(range) relationship, to full acoustic models (e.g., ray tracing, normal mode, parabolic equation, wavenumber integration and energy flux models). In addition, semi-empirical models are available which lie somewhere in between these two extremes in terms of complexity (e.g., (Rogers, 1981; Weston, 1971))[30].

[29] JIP. (2020). Review on existing data on underwater sounds produced by the oil and gas industry. E&p Sound & Marine Life Programme.
[30] This model is compared to measurements in the paper (Rogers, 1981) describing it and is capable of accurate modelling in acoustically simpler scenarios. Simpler meaning shallow in relation to the wavelengths and with no

20.47 For acoustically simpler scenarios, such as this one, where the sediment is relatively uniform and mostly flat or where great detail in the sound field is not needed, the simpler models are preferred over the higher numerical models and are routinely used for these types of assessments. For this assessment, we have used the "Roger's" model (Rogers, 1981), which is suitable to depths of c. 200m and generally softer sediments.

20.48 This model will tend to underestimate the transmission losses (leading to estimates greater than actual impact), primarily due to the omission of surface roughness, wind effects and shear waves in the sediment.

Modelling Assumptions/Limitations

20.49 The main assumptions made for the modelling are:

- Animals fleeing the area will not return within a 24-hour period.
- Animals flee for up to 2 hours, after which they will be up to 10.8km and 3.6km away for marine mammals and fish, respectively.
- A soft start where the impact hammer is running at lower blow energy is a feasible and practical option for the piling installation.
  The assumed soft start will achieve a reduction compared to the modelled level of 10 dB by a combination of reduced blow energy and blow rate, e.g.:
  - Reduce blow rate and blow energy to 33% of the modelled (0.33 Hz blow rate & 15 kJ blow energy).
  - Reduce blow rate only (to 0.1 Hz).
  - Reduce blow energy to 5 kJ.
  - This soft start is modelled for 15 minutes and for 30 minutes (the JNCC recommendation for impact piling).
- Results assume a transition from impulsive (kurtosis >40) to non-impulsive (kurtosis <40) at some distance from the source (source, sediment and depth dependant). This means that for the impact piling, at ranges greater than 1500 m the received noise will have become non-impulsive. After the transition to non-impulsive noise the noise is assessed against the non-impulsive thresholds. This assumption is also applicable for the assessment of behavioural disturbance.

Exposure Calculations

20.50 To compare modelled levels with the two impact assessment frameworks (NOAA 2024 & Popper et al. 2014) it is necessary to calculate received levels as exposure levels (SEL), weighted for marine mammals and

significant sound speed gradient in the water column.
Rogers, P. H. (1981). Onboard Prediction of Propagation Loss in Shallow Water. Washington DC: Naval Research Laboratory.
Weston, D. E. (1971). Intensity-Range Relations in Oceanographic Acoustics. Teddington: Admiralty Research Laboratory.

unweighted for fishes. For ease of implementation, sources have generally been converted to an SPL source level, meaning converting to SEL from SPL from a number of events or from a duration.

20.51 To convert from SPL to SEL, the following relation can be used:

$$SEL = \text{SPL} + 10 \cdot Log_{10}(t_2 - t_1) \quad (1)$$

20.52 Or, where it is inappropriate to convert SEL from one event to SEL cumulative by relating to the number of events as:

$$SEL_{n\ events} = SEL_{single\ event} + 10 \cdot Log_{10}(n) \quad (2)$$

20.53 And SPL from SEL:

$$SPL = SEL_{single\ event} + 10 \cdot Log_{10}\left(\frac{n}{t_2 - t_1}\right) \quad (3)$$

20.54 As an animal swims away from the sound source, the noise it experiences will become progressively more attenuated. The cumulative fleeing SEL is derived by logarithmically adding the SEL to which the mammal is exposed as it travels away from the source. This calculation is used to estimate the approximate minimum start distance for an animal in order for it to be exposed to sufficient sound energy to result in the exceedance of a threshold, or to check if a set exclusion zone is sufficient for an activity (e.g. will an exclusion zone of 500m be sufficient to prevent exceeding an AUD INJ threshold). It should be noted that the sound exposure calculations are based on the simplistic assumption that the animal will continue to swim away at a constant speed. The real-world situation is more complex, and the animal is likely to move in a more varied manner, but at higher speeds than what is modelled. Depending on the actual behaviour the exposure of the individual animal might not reflect what has been modelled, but given the modest swimming speeds assumed, there is a low likelihood that a real animal would have higher exposure than what has been modelled. Reported swim speeds are summarised in **Table 20-7** along with references.

20.55 For this assessment, we used a swim speed of 1.5m/s for marine mammals, and 0.5m/s for fishes (including sharks).

20.56 For very long fleeing durations, the ambient sound itself can exceed the thresholds, e.g., an ambient sound level of 122.4dB, weighted for the VHF group, will exceed the non-impulsive TTS threshold of 161dB SEL after 2 hours' exposure[31]. For this assessment, we consider fleeing durations of 2 hours (7,200 seconds, allowing 10,800m of fleeing), meaning that weighted levels of 122.4dB SPL will exceed the VHF group's non-impulsive TTS threshold in the fleeing model.

Table 20-7: Swim speed examples from literature Summary of Sound Sources and Activities Included in the Subsea Noise Assessment.

Species	Hearing Group	Swim Speed (m/s)	Source Reference
Harbour porpoise	VHF	1.5	Otani et al., 2000
Harbour seal	PCW	1.8	Thompson, 2015

[31] 122.4dB SPL + 10*log$_{10}$(3600 seconds) = 161dB SEL, TTS non-impulsive threshold for the VHF group is 161dB SEL.

Grey seal	PCW	1.8	Thompson, 2015
Minke whale	LF	2.3	Boisseau et al., 2021
Bottlenose dolphin	HF	1.52	Bailey and Thompson, 2010
White-beaked dolphin	HF	1.52	Bailey and Thompson, 2010
Basking shark	Fish (unweighted)	1.0	Sims, 2000
All other fish groups	Fish (unweighted)	0.5	Popper et al., 2014
Sea turtles	Fish (unweighted)	0.56-0.84 & 0.78-2.8	(F, P, E, & GR, 1997; SA, 2002)

Results and Assessment

20.57 Results are presented here as the geographical "risk range" to an auditory threshold (AUD INJ/ TTS/ Behavioural), as given in **Table 20-1** to **Table 20-4**.

20.58 A given risk range specifies the expected range, within which, a fleeing receiver would exceed the relevant threshold. Risk ranges are given for the 95th percentile value of all results for that source/activity and receiver combination.

20.59 Several result types are presented for each activity to inform this assessment and to provide flexibility in mitigation:

- "1 second exposure risk range":
  This is the range of acute risk of impact from the activity (a one second exposure) and is presented to indicate instantaneous risk and for comparison with other studies. This assumes a stationary animal (during the 1-second exposure) with all equipment operating at full power and does not include a soft start.
- "Minimal starting range for a fleeing animal with no soft start":
  The minimal range a fleeing animal needs to start fleeing from to avoid being exposed to noise exceeding its TTS/AUD INJ threshold. Animals are moving in a straight line away from the source at a constant speed of 1.5m/s (0.5m/s for fish, including sharks).
- "Minimal starting range for a fleeing animal with a 15 min soft start, where the impact piling is running at -10dB, compared to full power":
  The minimal range a fleeing animal needs to start fleeing from to avoid being exposed to noise exceeding its TTS/ AUD INJ threshold. Animals are moving in a straight line away from the source at a constant speed of 1.5m/s (0.5m/s for fish, including sharks).
- "Minimal starting range for a fleeing animal with a 30 min soft start":
  The minimal range a fleeing animal needs to start fleeing from to avoid being exposed to noise exceeding its TTS/ AUD INJ threshold. Animals are moving in a straight line away from the source at a constant speed of 1.5m/s (0.5m/s for fish, including sharks).
- "Behavioural response range":
  The range at which the behavioural limit for the marine mammals or the fishes (including sharks) is exceeded.

Assumptions and Notes on Results

20.60 The results should be read while keeping the following in mind:

- Results are rounded up to the nearest two significant digits. This can lead to apparent overlaps in risk ranges.

- The modelling resolution of ten metres means that were results are lower than this “<10” is stated to mean “below ten metres”.
- Were risk ranges are large (often the case for TTS risk ranges), an increase in soft start duration will not be effective to lower the TTS risk range. This is due to the logarithmic nature of transmission losses:
  For a marine mammal that starts fleeing at 500m range:
  - Increasing the soft start from 0 to 10 minutes allows a marine mammal to swim an additional 900m (1.5m/s * 600 seconds), from 500m range to 1400m range.
    This result in in a c. 6.5dB reduction in received level for the animal.
  - Increasing the soft start from 10 to 20 minutes allows the animal to swim an additional 900m, from 1400m range to 2300m range.
    This results in in a c. 3.5dB reduction in received level for the animal.
  - And for 20 to 30 minutes (2300 to 3200m), the reduction is c. 2dB.
- As the impulsive noise transitions to non-impulsive noise with increased ranges, the appropriate behavioural threshold for the assessment changes from 160dB to 92-126dB (a likely >10-fold increase in range). This means that there are large ranges of disturbance, but should be considered in relation to, for example, the radiated noise from common vessels, which will exceed this threshold to ranges of 500-10000m (assuming 160-180dB SPL source level).
- Animals are modelled as fleeing in straight lines. Where sites are very confined, the maximal risk ranges will be restricted by line-of-sight ranges (and cut short where they meet land).
- Modelling assumed a maximal fleeing time of 7200 seconds (2 hours). This allows for 10.8km of fleeing for marine mammals (3.6km for fish).
- Modelling is limited to a range of 5km from the source.
- Results are only given in relation to the behavioural thresholds (SPL) and TTS/ AUD INJ thresholds for sound exposure level (SEL).

Results tables

Impact piling

20.61 The impact piling has the potential to cause mild disturbance to 4.3 - 4.6 km for marine mammals and to 4.2 km for fishes (**Table 20-8**).

Table 20-8: Behavioural Disturbance Ranges for impact piling noise.

Condition	**LF**	**HF**	**VHF**	**PW**	**OW**	**Fishes**
Behavioural disturbance ranges [m]	4500	4300	4300	4600	4600	4200

20.62 Ranges for risk of TTS from exposure with no soft start are below 900m for all hearing groups except the VHF group which has a risk range extending to 1600m (**Table 20-9**). With a 30-minute soft start these ranges reduce to below 520m for all groups except the VHF group whose risk range is 1500m.

20.63 Risk of TTS from peak pressure levels extend to 1km for fishes, 650m for the VHF group and below 50m for the remaining groups.

Table 20-9: TTS Risk Ranges for impact piling noise.

Condition	LF	HF	VHF	PW	OW	Fishes
1 seconds' exposure [m]	280	20	290	190	50	60
Fleeing receiver, no soft start [m]	810	350	1600	860	580	450
Fleeing receiver, 15 min soft start (-10dB) [m]	520	60	1500	470	200	420
Fleeing receiver, 30 min soft start (-10dB) [m]	520	60	1500	470	190	420
Peak pressure level [m]	50	<10	650	50	<10	1000

20.64 Ranges for risk of AUD INJ with no soft start are below 500m for all hearing groups except the VHF group which has a risk range extending to 880m (**Table 20-10**). With a 30-minute soft start these ranges reduce to below 200m for all groups.

20.65 Risk of AUD INJ from peak pressure extends to 350m for the VHF group, 200m for Fishes and <10m for the remaining groups.

Table 20-10: AUD INJ Risk Ranges for impact piling noise.

Condition	LF	HF	VHF	PW	OW	Fishes	Fishes Mortality
1 seconds' exposure [m]	80	<10	30	20	<10	<10	<10
Fleeing receiver, no soft start [m]	410	20	880	310	60	90	30
Fleeing receiver, 15 min soft start (-10dB) [m]	160	<10	250	70	<10	20	<10
Fleeing receiver, 30 min soft start (-10dB) [m]	160	<10	190	70	<10	20	<10
Peak pressure level [m]	<10	<10	350	<10	<10	200	200

Dredging (incl. Rock Dumping)

20.66 The dredging (and rock dumping/placement) have potential to cause mild disturbance to 3.1-4.4km for marine mammals and to 1500m for fishes (**Table 20-11**).

Table 20-11: Behavioural Disturbance Ranges for dredging noise.

Condition	LF	HF	VHF	PW	OW	Fishes
Behavioural disturbance ranges [m]	3100	4400	4400	4300	4100	1500

20.67 Ranges for risk of TTS are below 30m for all hearing groups (**Table 20-12**).

Table 20-12: TTS Risk Ranges for dredging noise.

Condition	LF	HF	VHF	PW	OW	Fishes
1 seconds' exposure [m]	<10	<10	<10	<10	<10	<10
Fleeing receiver, no soft start [m]	30	<10	30	<10	<10	<10

20.68 Ranges for AUD INJ are below 10m for all gearing groups (**Table 20-13**).

Table 20-13: AUD INJ Risk Ranges for dredging noise.

Condition	LF	HF	VHF	PW	OW	Fishes
1 seconds' exposure [m]	<10	<10	<10	<10	<10	<10
Fleeing receiver, no soft start [m]	<10	<10	<10	<10	<10	<10

Vibratory Sheet Piling

20.69 The sheet piling (vibratory piling only) has potential to cause mild disturbance up to 4.7km for marine mammals and to 1.1km for fishes (**Table 20-14**).

Table 20-14: Behavioural Disturbance Ranges for vibratory sheet piling noise.

Condition	LF	HF	VHF	PW	OW	Fishes
Behavioural disturbance ranges [m]	2100	4700	4700	4300	4200	1100

20.70 Ranges for risk of TTS are below 30m for all hearing groups, except for the VHF hearing group (porpoises) where the TTS risk range extend to 230m (**Table 20-15**).

Table 20-15: TTS Risk Ranges for vibratory sheet piling noise.

Condition	LF	HF	VHF	PW	OW	Fishes
1 seconds' exposure [m]	<10	<10	30	10	<10	<10
Fleeing receiver, no soft start [m]	30	20	230	30	20	<10

20.71 Ranges for AUD INJ are below 10m for all gearing groups (**Table 20-16**).

Table 20-16: AUD INJ Risk Ranges for vibratory sheet piling noise.

Condition	LF	HF	VHF	PW	OW	Fishes

1 seconds' exposure [m]	<10	<10	<10	<10	<10	<10
Fleeing receiver, no soft start [m]	<10	<10	<10	<10	<10	<10

Mitigation

Impact piling

20.72 The results show that a 15-minute soft start for piling can decrease the AUD INJ risk ranges for the VHF group to 250m which is within the often-used 500m exclusion zone practical for observation by a qualified MMO. All other groups have risk ranges shorter than this. A 30-minute soft start will reduce risk ranges further (to ≤190m) and mean that animals outside the northeast pier and breakwater will be outside the risk of AUD INJ.

20.73 A minimum of 15 minutes' soft start including no observed marine mammal, by a qualified MMO, within 250m for impact piling is thus recommended as mitigation.

Dredging (incl. rock dumping)

20.74 No mitigation is needed for dredging to reduce TTS or AUD INJ risk to marine mammals and fishes.

Vibratory Sheet Piling

20.75 No mitigation is needed for dredging to reduce TTS or AUD INJ risk to marine mammals and fishes.

Cumulative Effects

20.76 The impact piling will be the activity with the loudest underwater noise profile by a large margin, meaning any other noise source will be insignificant in comparison and hence, are not contributing to cumulative effects.

20.77 Dredging, rock dumping and vibratory sheet piling are similar in noise level to large vessels. For animals in between the dredging/rock dumping and a large vessel, there could be an increased risk of exceedance either to 1.4-2 times the range or from shorter exposure duration (by a factor of 0.5-0.7). This variation in increase in range or decrease in exposure time is dependent on both the proximity to the sound sources and the propagation loss from the sources to the animal, which will vary with location and time.

Operational Noise

20.78 The planned increase in marina berthing (c. 70 currently to c. 250) is expected to lead to an increase in vessels. If a high uptake of berthing spots is assumed with an equal increase in vessel activity, the noise levels in the harbour might be expected to rise by c. 6 dB for longer term averages. However, vessels are limited by the speed limit of 10 knots[32], meaning noise emissions will be low for all small vessels. An area north of Stranraer Harbour is designated as a zone of "unrestricted speed", in this area we might expect behavioural disturbance to <200 m of marine mammals (regardless of number of berths). Note that vessels at high speed will tend to be further apart to maintain safe navigation, limiting the density of vessels in this high-speed area.

20.79 All leisure vessels will be emitting far less noise than the commercial vessels and ferries already operating in the area (such as nearby Stena Line Belfast-Cairnryan and P&O Ferries Larne-Cairnryan). The noise contribution from sailing and small motor vessels will be negligible. There is mention of possible berthing superyachts, these are expected to be very occasional and less noisy than the modelled dredging vessel. This means that the project is not expected to increase the biologically relevant underwater noise emissions from the harbour or its associated activities.

20.80 Additional information about small leisure vessel noise emissions and their effects on marine mammals see the study "Start-Up Boat Numbers at Whiteness Marina"[33] which concludes no significant impact on behaviour on the bottlenose dolphins of the Moray Firth SAC with up to 500 berths.

Summary and Conclusions

Impact piling

20.81 There will be a negligible risk of hearing injury to marine mammals and fishes (AUD INJ thresholds) from impact piling subject to a 30-minute soft-start (-10dB). This is valid provided a qualified Marine Mammal Observer verifies the absence of marine mammals prior to piling start within the harbour walls or to 500m (JNCC standard mitigation for impact piling).

20.82 Risk ranges for temporary hearing impact (TTS) will likely extend to 1500m for the VHF hearing group (harbour porpoises), and <520m for the remaining marine mammals and fishes, in a direction directly north – limited by the space and line-of-sight between the breakwater and the eastern solid pier.

Dredging and Rock Dumping

20.83 There is a negligible risk of auditory effects on marine mammals and fishes from dredging and rock dumping, with TTS possible for marine mammals very near the activity (<30m).

Sheet Piling

20.84 There is a negligible risk of auditory effects on marine mammals and fishes from vibro piling of sheet piles, with TTS possible for marine mammals near the activity (<200m, i.e. extending to the centre of the marina).

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[32] Tarbert [Harris] DG v1 (Stranraer Statutory Harbour Authority General Directions for Navigation 2023)
[33] David, J. A. (2008). Start-up boat numbers at Whiteness Marina. WPC.

Operational Noise

20.85 The increase in noise after project completion will be negligible, given the main type of additional vessel traffic will be hobby/leisure craft.

Glossary

Term	Meaning
Decibel (dB)	A relative scale most commonly used for reporting levels of sound. The actual sound measurement is compared to a fixed reference level and the "decibel" value is defined to be $10 \cdot \log_{10}$(“actual”/”reference”), where (“actual”/”reference”) is a power ratio. The standard reference for underwater sound pressure is 1 micro-Pascal (µPa), while 20 micro-Pascals is the standard for airborne sound. The dB symbol is often followed by a second symbol identifying the specific reference value (i.e. re 1 µPa).
Grazing angle	A glancing angle of incidence (the angle between a ray incident on a surface and the line perpendicular to the surface).
Auditory Injury (AUD INJ)	A total or partial permanent loss of hearing caused by some kind of acoustic trauma. AUD INJ results in irreversible damage to the sensory hair cells of the ear and thus, a permanent reduction of hearing acuity.
Temporary Threshold Shift (TTS)	Temporary loss of hearing as a result of exposure to sound over time. Exposure to high levels of sound over relatively short time periods will cause the same amount of TTS as exposure to lower levels of sound over longer time periods. The mechanisms underlying TTS are not well understood, but there may be some temporary damage to the sensory cells. The duration of TTS varies depending on the nature of the stimulus, but there is generally recovery of full hearing over time.
Sound Exposure Level (SEL)	The cumulative sound energy in an event, formally: “ten times the base-ten logarithm of the integral of the squared pressures divided by the reference pressure squared”. Equal to the often seen “L_E” or “dB SEL” quantity. Defined in: ISO 18405:2017, 3.2.1.5
Sound Pressure level (SPL)	The average sound energy over a specified period of time, formally: “ten times the base-ten logarithm of the arithmetic mean of the squared pressures divided by the squared reference pressure”. Equal to the deprecated “RMS level”, “dB_{rms}” and to L_{eq} if the period is equal to the whole duration of an event. Defined in ISO 18405:2017, 3.2.1.1
Peak Level, Peak Pressure Level (L_P)	The maximal sound pressure level of an event, formally: “ten times the base-ten logarithm of the maximal squared pressure divided by the reference pressure squared” or “twenty times the base-ten logarithm of the peak sound pressure divided by the reference pressure, where the peak sound pressure is the maximal deviation from ambient pressure”. Defined in ISO 18405:2017, 3.2.2.1

Source Level (SL)	Taken here to mean the level (SEL/SPL/L_P) at 1 meter range. If not otherwise stated, it is assumed the source is omnidirectional (equal level in all directions). For sources larger than 1m in radius, the Source Level is back calculated to 1m.
Decidecade	Refers to a set step in frequency, similar to “one-third-octave”, defined as a ratio of $10^{0.1}$ ≈ 1.259 (one third octave is 21/3 ≈ 1.260). Used interchangeably with “3rd octave”.
Noise	Sound that is irrelevant, unwanted, or harmful to the organism(s) in question. Noise is often detrimental, but not necessarily so.
Kurtosis	A statistical measure of “peakedness” of a distribution (of e.g. pressure values in a sound pulse). Defined in ISO 5479:1997

Acronyms/Abbreviations

Term	Meaning
LF	Low Frequency (Cetaceans)
HF	High Frequency (Cetaceans)
VHF	Very High Frequency (Cetaceans)
MF	Mid Frequency (Cetaceans) – **DEPRECATED** only for reference to NOAA/NMFS 2018 groups
OW/OCW	Otariid pinnipeds/Other Carnivores in water (refers to the same weighting and animal groups)
PW/PCW	Phocid pinnipeds
NMFS	National Marine Fisheries Service
RMS	Root Mean Square
SEL	Sound Exposure Level, [dB]
SPL	Sound Pressure Level, [dB]
L_P	Peak Pressure Level, [dB]
SL	Source Level [dB]
TTS	Temporary Threshold Shift
PTS	Permanent Threshold Shift – **DEPRECATED**, see “AUD INJ”
AUD INJ	Auditory Injury (synonymous with deprecated “PTS”)
c.	Circa, i.e., approximately
MMO	Marine Mammal Observer https://jncc.gov.uk/our-work/marine-mammal-observer-training/

Units

Unit	Description
dB	Decibel (Sound)
Hz	Hertz (Frequency)
kHz	Kilohertz (Frequency)
kJ	Kilojoule (Energy)
km	Kilometre (Distance)
km^2	Kilometre squared (Area)
m	Metre
ms	Millisecond (10^{-3} seconds) (Time)
ms^{-1} or m/s	Metres per second (Velocity or speed)
kn	Knots (speed), 1 kn = 0.514 m/s, 1 m/s = 1.944 kn
µPa	Micro Pascal
Pa	Pascal (Pressure: newton/m^2)
psu	Practical Salinity Units (parts per thousand of equivalent salt in seawater, weight-based)
kg/m^3	Specific density (of water, sediment or air)
Z	Acoustic impedance [$kg/(m^2 \cdot s)$ or $(Pa \cdot s)/m^3$]

Units will generally be enclosed in square brackets e.g.: “[m/s]”