7. Underwater Noise

AIS vessel movement counts recorded for 14-day period in August 2023

Locations from which demolition and construction activities that would generate underwater noise were modelled

The underwater noise ES chapter reports on the outputs of underwater noise modelling undertaken for various construction and demolition activities that will generate underwater noise. It also reports on the changes in background sound levels due to the additional number and greater size of vessels that will access the site once the proposed development is operational.

The effects of underwater noise on marine ecology are reported in the Marine Ecology chapter.

Existing Conditions

The existing underwater noise climate is predominantly dominated by vessel noise from vessels transiting in and around the Fal Estuary. Vessel data from the UK government data service platform and from CCTV images around Falmouth Docks were reviewed to understand existing background sound levels.

Demolition and Construction

Various activities during the demolition and construction stage of the proposed development will generate noise underwater. The worst-case activities were modelled, from worst-case locations around the site:

- Capital dredging using a backhoe dredger;
- Demolition of the Northern Arm using a hydraulic hammer; and
- Impact pile driving (with soft-start methodology) to install new structures (modelled with and without a bubble curtain).

Capital dredging has been modelled as a continuous source of sound during this phase of construction. Impact piling and demolition would produce impulsive sound.

The impact of the underwater noise is assessed based on whether the activity causes an increase in underwater noise level above the background sound levels in the environment. Where activities would cause an increase in underwater noise, the consequences for marine animals (fish and mammals) are assessed based on injury criteria (relating to the cumulative sound exposure level predicted over a given length of time). For impulsive sounds, the peak sound pressure levels are also compared with published thresholds for effects on animals.

Operation

It is assumed that there would be 11 additional cruise vessels and 12 additional cargo vessels visiting Falmouth Docks per year once the proposed development is in place. This is calculated to be approximately an additional 15 hours/year during which animals could be disturbed from underwater noise associated with vessels. Additional boat movements will therefore contribute intermittent noise which will not have a discernible effect on the noise climate.

7 Underwater Noise

7.1 Introduction

7.1.1 This chapter reports on the underwater noise modelling study undertaken for the demolition and construction stage and operational stage of the proposed development. It reports on the predicted change in underwater noise as a result of the proposed development and the predicted distances over which secondary ecological receptors may be impacted.

7.1.2 This chapter reports on the predicted magnitude of change in underwater noise only, and does not report on the effect of this change in noise climate on marine ecological receptors – this is reported on in Chapter 9: Marine Ecology, using outputs from the noise modelling.

7.1.3 This chapter is supported by the following technical appendix within ES Volume 2:

- Technical Appendix 7.1 – Underwater noise modelling: Falmouth Docks Development.

7.1.4 The assessment has been informed by the following legislation, policies and published guidance:

- International Legislation:
  - There are no international agreed standards for the assessment of underwater noise. Usual practise is to assess based on criteria available in published literature as set out below.
- National Legislation and Policy:
  - In the Marine Strategy Part One (HM Goverment 2012)[1] the UK set out the following high-level, qualitative description of what the marine environment should look like when Good Environmental Status is achieved for Underwater Noise:
  - Loud, low and mid frequency impulsive sounds and continuous low frequency sounds introduced into the marine environment through human activities do not have adverse effects on marine ecosystems.
  - Human activities potentially introducing loud, low and mid frequency impulsive sounds into the marine environment are managed to the extent that no significant long-term adverse effects are incurred at the population level or specifically to vulnerable/threatened species and key functional groups.
  - Continuous low frequency sound inputs do not pose a significant risk to marine life at the population level, or specifically to vulnerable/threatened species and key functional groups, for example through the masking of biologically significant sounds and behavioural reactions.
  - The UK aims that loud, low and mid frequency impulsive sounds and continuous low frequency sounds introduced into the marine environment through human activities are managed to the extent that they do not have adverse effects on marine ecosystems and animals at the population level.
- National guidance and published literature:
  - Standards for reporting underwater sound:
    - A general background on underwater sound and the accepted terminology and metrics are provided in The Good Practice Guide No. 133 for Underwater Noise Measurement by the National Physics Laboratory (NPL, 2014)[2]. The reader is referred to this document for details of terminology related to underwater noise used in this chapter, not already described in this chapter.
  - Criteria for underwater noise impacts on marine mammals:
    - The latest Southall et al. (2019)[3] guidance criteria have been used for assessing impacts of underwater noise on marine mammals in this assessment. These update the earlier NOAA (2016) criteria.
  - Criteria for underwater noise impacts on fish:
    - The guidance of Popper, *et al*. (2014)[4] have been used in this study for assessing the potential impacts of anthropogenic sound on fish from different sources.

7.2 Consultation

7.2.1 Table 7-1 summarises the key EIA Scoping Opinion responses and any separate consultations that have been undertaken with respect to the underwater noise assessment.

Table 7-1: Summary of Consultation

Consultee /Date of Consultation	Summary of Comments	Summary of Action Taken and Where in this Chapter Comments are Addressed
Falmouth Harbour Authority Scoping Opinion received 11 Sep 2023	Marine ecology - Table 9-1 does not consider noise and disturbance from vessel movement, piling and dredging. In addition, are there additional effects to consider associated with the removal of bedrock that would need to be considered. Have the methodologies been assessed at this stage or are they included within the definition of dredging? Further clarification in additional to use of backhoe dredger would be useful to enable full understanding	Consideration of noise associated with removal of bedrock via backhoe dredger is considered in this ES chapter. The potential for underwater noise disturbance associated with the vessel movements are considered in this ES chapter. The effects of underwater noise from these activities on marine receptors is reported in ES Chapter 9: Marine Ecology.
Marine Management Organisation Scoping Opinion received 25 October 2023	Please specify what kind of piling will be proposed in your ES. Underwater noise (UWN) generated during percussive piling operations has the potential to cause physiological harm and affect behaviour in fish. Fish responses to noise are in-part related to the anatomy of their hearing mechanisms. The presence of a swim bladder enhances hearing sensitivity as the bladder acts as a pressure transducer, converting sound pressure to particle velocity. Those species where the swim bladder is near to or connected to the ear have increased hearing sensitivity and thus greater vulnerability to underwater noise impacts. The MMO recommends that the impacts of underwater noise and vibration on fish are scoped into the impact assessment.	Details of piles, and piling schedule are provided within ES Chapter 4: Proposed Development Description and ES Chapter 5: Demolition and Construction Description. Underwater noise modelling has been completed and reported on in this ES chapter, with effects on marine receptors reported in ES Chapter 9: Marine Ecology. The impacts of underwater noise and vibration on fish are reported on in Chapter 9: Marine Ecology.
Marine Management Organisation	Please ensure you consider the following key points when undertaking UWN modelling as part of the UWN impact assessment for fish:	Underwater noise modelling has been completed and, where required, ES Chapter 9: Marine

[1] HM Government. (2012). Marine Strategy Part One: UK Initial Assessment and Good Environmental Status.
[2] National Measurement Office, Marine Scotland, The Crown Estate, Robinson, S. P., Lepper, P. A., & Hazelwood, R. A. (2014). Good Practice Guide for Underwater Noise Measurement. NPL Good Practice Guide No. 133, ISSN: 1368-6550, 2014.
[3] Southall, B. L., Finnerman, 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. Aquatic Mammals, 45(2), 125-232.
[4] Popper, A. N., Hawkins, A. D., Fay, R. R., Mann, D. A., Bartol, S., Carlson, T. J., . . . Tavolga, W. N. (2014). Sound Exposure Guidelines for Fishes and Sea Turtles: A Technical Report prepared by ANSI-Accredited Standards Committee S3/SC1 and registered with ANSI. Springer and ASA Press. Springer and ASA Press.

Table 7-1: Summary of Consultation

Consultee / Date of Consultation	Summary of Comments	Summary of Action Taken and Where in this Chapter Comments are Addressed
Scoping Opinion received 25 October 2023	i. Fish species with spawning or nursery grounds in the area, and those species that are known to migrate through the Fal should be classified into one of the four categories based on the hearing capabilities and presence/absence of a swim bladder. ii. Please also refer to Popper *et al.* (2014) for sound exposure guidelines on noise thresholds for mortality, potential mortal injury and recoverable injury, temporary threshold shift (TTS) and behavioural responses for fish for impulsive noise (e.g., percussive piling) and continuous noise (e.g., vibro piling). iii. The underwater noise assessment should be presented using appropriate unweighted metrics, supported by underwater noise modelling or by case studies of a similar nature to support conclusions made on the likelihood and significance of impacts to fish from piling. iv. The modelled/predicted impact ranges for underwater noise should be discussed in the context of the width of the Fal Estuary to determine the likelihood of an acoustic 'barrier' to fish movement and migration. v. If concurrent/simultaneous piling activity is proposed, this should also be included in the modelling or considered when sourcing supporting case study information. vi. The timing of piling and dredging works should be provided, together with a description of the number and size of the piles, typical duration of installation (per pile), and the number of piles to be installed per day, so that any overlap in construction and dredging activities with the spawning and migratory periods of fish can be identified.	Ecology, assesses the effects on fish using the Popper *et al.* (2014) criteria. Details of piles, and piling schedule are provided within ES Chapter 4: Proposed Development Description and ES Chapter 5: Demolition and Construction Description.

7.3 Assessment Scope

7.3.1 The assessment of the modelled underwater sound levels has been carried out using a combination of source level estimation for the activities concerned, underwater sound propagation modelling and comparison of the results against the published criteria as outlined in Section 7.6. To assess potential changes in disturbance to marine fauna in the area, vessel noise which contributes to the background noise levels in Falmouth harbour has been estimated based on AIS ship track data, and changes in background sound levels predicted based on the changes in the number of vessels once the proposed development is operational.

Technical Scope

7.3.2 The technical scope of the assessment has considered the following:

- The noise climate generated by construction and demolition activities, such as pile driving for the new dock, rock removal and dredging for the new berths;
- Changes in noise climate relating to operation of the proposed development, specifically the increased vessels sizes and numbers;
- The extent to which the change in noise climate could potentially affect marine receptors, providing information on injury thresholds and distances over which exceedances of the thresholds may occur – this information has then been used in ES Chapter 9: Marine Ecology, to assess the effects of the change in noise climate on specific marine receptors that occur within the zone of influence;

Spatial Scope

7.3.3 The study area for the assessment of underwater noise comprises the whole of the Fal estuary, extending westwards to Penryn and northwards along Carrick Roads to Loe Beach. Eastward the model reaches to St Mawes and the seaward boundary is the mouth of the estuary, between Pendennis Point and St Anthony Head. The study area was determined by means of locations where noise from the proposed development would be expected to be heard and covers an area of up to 5.1 km from the site boundary, Figure 7-1.

Temporal Scope and Assessment Scenarios

7.3.4 The assessment has considered impacts arising during the demolition and construction stage, which are expected to be temporary and short-term (up to 5 years) in nature, and from the operational stage, which are expected to be permanent and long-term in nature (i.e. more than 10 years).

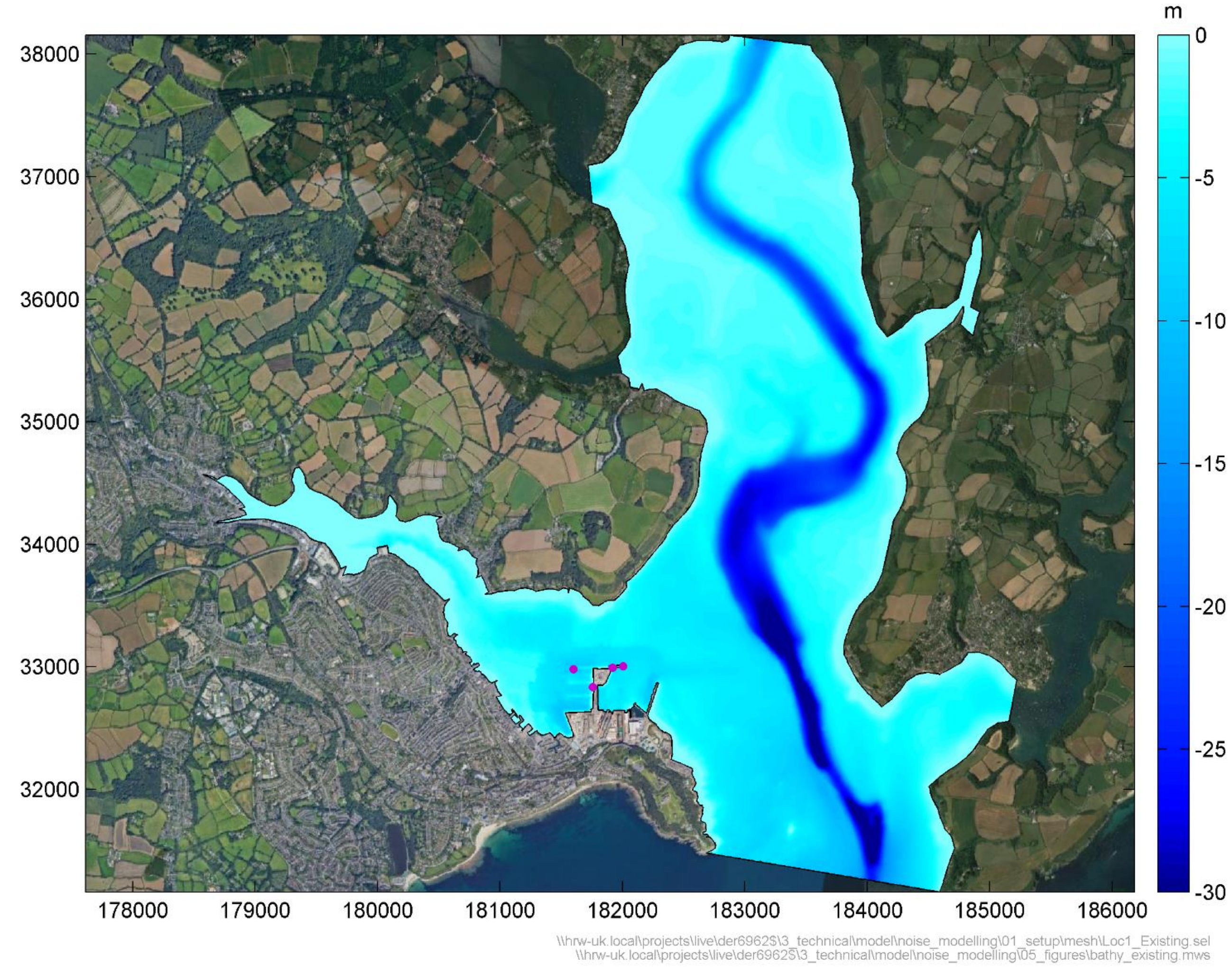

Figure 7-1: Model extent and bathymetry used for the underwater noise modelling

7.4 Baseline Characterisation Method

Desk Study

7.4.1 In order to establish the existing baseline for underwater noise conditions in the study area, relevant data were reviewed and assessed. The data sets and associated sources can be summarised as follows:

- Vessel AIS data were sourced from the UK government data service platform (environment.data.gov.uk) which holds anonymised AIS data for 2011 to 2019 (MMO, 2019)[5].
- Report by A&P[6] using AIS data and CCTV images to assess the shipping activity around Falmouth Docks.

7.4.2 Ambient sound levels in the region will predominantly be caused by the presence of motorised vessels. The annual mean baseline noise levels were modelled using records of vessel movements in the region, including AIS data and the A&P report. The Ross method, obtained from the RANDI-3.1 model (Breeding et al., 1996), was used which estimates the source level (SL_s) for moving vessels at discrete frequencies (f_n) based on their hull length (l_s) and velocity (v_s). This model is described in ES Volume 2: Technical Appendix 7.1 (Section 3.1).

7.4.3 The anonymised MMO (2019) AIS data were processed for each vessel type using a cell-crossing algorithm to generate heat maps of annual averaged source level on a grid covering the Fal Estuary, with a grid resolution of 50x50 m. The MMO (2019) AIS data did not provide detailed information on the vessel speed, so an estimated speed of 6 knots was defined for all vessels within the estuary (which is the speed limit within the harbour). This assumption closely matched the average speed calculated across all of the tracks with respect to the start and finish times and distance travelled. Using a constant vessel speed is likely to overestimate the average sound levels in some regions, but should be an upper estimate due to the speed limit of 6 knots within the harbour, so is considered a conservative estimate in terms of potential sound levels.

7.4.4 Using the AIS data, grids of the annual mean sound pressure levels were generated for each vessel type recorded in the AIS data. Estimates of the source levels for the different types of vessel were calculated and assessed in terms of the distance from the vessel that behavioural disturbance to marine mammals may occur.

Field Study

7.4.5 Not applicable to this assessment.

7.5 Assessment Method

Methodology

7.5.1 The assessment consisted of underwater noise modelling for the construction and demolition works, using HR Wallingford underwater sound propagation model, UnaCorda. In addition, sound metrics (e.g. cumulative sound exposure level (SEL_{cum})) were modelled for marine mammals and fish and compared against the relevant impact criteria.

Demolition and Construction Stage

7.5.2 The impacts of demolition and construction activities on the underwater noise environment and on secondary receptors (i.e. marine animals) were assessed using a modelling study. Two models were used:

- An underwater sound propagation model (UnaCorda) – to predict the 3D sound propagation from each noise source;
- An agent-based model of animal movement (HydroBoids) – used to predict the cumulative sound exposure level of marine animals whilst fleeing from the noise source and provide areas where impact thresholds may be exceeded.

7.5.3 For a detailed description of the model and its set up, refer to ES Volume 2: Technical Appendix 7.1.

Activity Source Levels and Durations

7.5.4 The demolition and construction stage of the proposed development includes various activities which will generate noise underwater. These include:

- demolition of the existing Northern Arm, using wire saws and potentially a hydraulic hammer or other rock breaker. Of these, the hydraulic hammer is likely to be the loudest sound source and therefore this was selected and modelled to represent the worst case noise from demolition;
- capital dredging for the new berths using a backhoe excavator; and
- pile driving to install the new dock structures.

7.5.5 The underwater sound propagation for each of these activities has been modelled using HR Wallingford's underwater noise model, UnaCorda.

7.5.6 The noise model was run for the locations shown in Figure 7-2, which are considered worst case locations, and the activities modelled for each location are shown in Table 7.2.

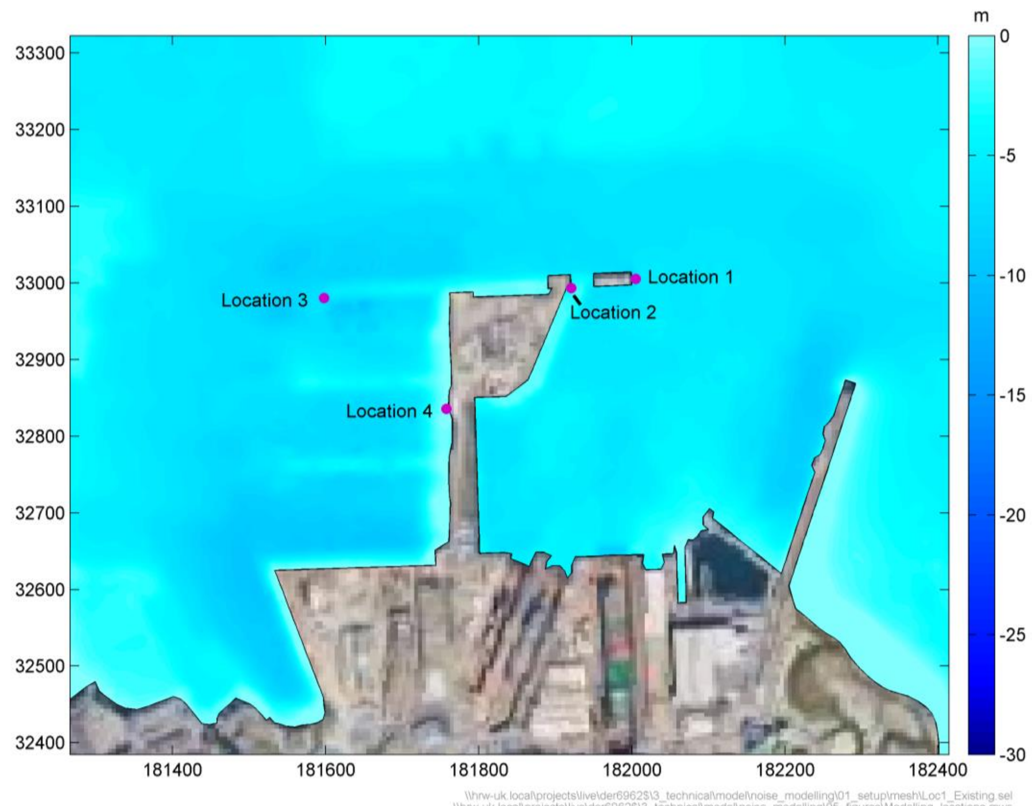

Figure 7-2: Locations used for underwater noise modelling

Table 7-2: Noise activities modelled at each location

Location	Name	Activities modelled
1	Northern Arm	Demolition with hydraulic hammer
2	Western Wharf	Backhoe dredging Percussive pile driving with soft start Percussive piling with soft start and potential mitigation scenario
3	Queens wharf	Percussive piling with soft start Percussive piling with soft start and potential mitigation scenario
4	FLOW deck	Backhoe dredging

5 environment.data.gov.uk

6 A&P. (2024). FDEC Traffic Analysis Report (Falmouth).

Table 7-2: Noise activities modelled at each location

		Percussive pile driving with soft start Percussive piling with soft start and potential mitigation scenario

Demolition

7.5.7 Various demolition activities will be required, in particular around the existing Northern Arm of the docks, which is due to be removed. It is expected that the loudest of these will be the use of a hydraulic hammer to break up any of the structure remaining underwater after cutting and block removal has been completed. The source level for this activity was adapted from Connell et al (2023)[7] with a source level of 192 db re1μPa^2. It is anticipated that the hydraulic hammer will only be needed for short periods, totalling up to one hour in any twenty-four hour period, and that other demolition noises will be quieter, see Table 7-3.

Table 7-3: Input parameters for the Northern Arm demolition

Parameter	Value
Source level (SL)	192 dB re 1μPa2
Duration (t)	1 hour in 24 hours

Dredging

7.5.8 It is understood that a pontoon mounted backhoe dredger will be used for the capital dredging for the new berths. Measured sound levels for various activities performed by a backhoe dredger were summarised by Jones and Marten (2016)[8]. Source levels were predicted to vary between 154 and 179 dB re 1 μPa at 1 m from the source. Whilst dredging is considered here as a continuous noise, it will vary considerably through time. For the current study, results are presented for a source level of 175 dB re 1 μPa which is considered to be an upper (worst case) estimate for the average source level for the daily dredging activity. It is understood that dredging will potentially be carried out for 24 hours out of every day, see Table 7-4.

Table 7-4: Input parameters for the backhoe dredging

Parameter	Value
Source level (SL)	175 dB re 1μPa
Duration (t)	24 hours

Percussive Pile driving

7.5.9 The proposed development requires numerous piles to be installed as part of the new dock structures. Piles will be installed initially by vibro-piling, to reduce noise[9]. However, it is anticipated that percussive piling will also be necessary due to the nature of the rock in the area. Piles are up to 1.32 m in diameter. It is assumed that for percussive piling, a hammer energy of 300 kJ will be used, suitable for the pile size to be installed.

7.5.10 The source level of pile driving can be estimated based on the hammer energy. De Jong & Ainslie (2008)[10] identified that the hammer energy (E) of the pile driver is a more reliable indicator of source level than the pile diameter. Using De Jong and Ainslie (2008), the source level for the pile driving was calculated to be 210 dB re 1μPa^{2}m^{2}s.

7.5.11 A soft start procedure was used for the animal modelling, in which the initial sound source level was decreased, then increased back to the full source level given in Table 7-5 over the first 20 minutes of the simulation. An additional mitigation option for the noise from pile driving is to use a bubble curtain, which was also modelled to predict it's effectiveness.

Table 7-5: Input parameters for the percussive piling

Parameter	Value
Source level (SL)(soft start)	210 dB re 1μPa2
Source level (SL)(mitigation scenario)	200 dB re 1μPa2s
Duration (t)	4 hours

Bed parameters

7.5.12 The geo-acoustic properties of the sea bed sediment influence how sound is refracted and attenuated as it propagates underwater. Particle size distributions provided by Ramboll[11] for the Falmouth Docks area, showed a mixture of mud, sand and gravel. The emitted sound will propagate over a large area and the sediment type will vary spatially across the region. Insufficient data were available to create a detailed map of the bed sediment stratigraphy in the area away from the dredging activity. A conservative approach was therefore adopted using the assumption of a homogeneous sandy bed type across the whole estuary. Under this assumption, the acoustic properties of the seabed within the region were estimated based on data of Jenson et al (2000)[12] which describes empirical predictions of seafloor properties based on remotely measured sediment impedance in a variety of sediments. The sound propagation properties used are given in Table 7-6.

Table 7-6: Physical properties of the bed sediment (sand) as input into the UnaCorda model

Physical Property	Value
Density (kg/m3)	1,900
Sound speed (m/s)	1,650
Attenuation coefficient (dB/λ)	0.8
Source: HR Wallingford using information from Jensen et al. (2000)	

Estimation of Peak Sound Pressure Level

7.5.13 For underwater pile driving noise or other activities where there are multiple sound impulses over an extended period of time (e.g. seismic surveys or percussive piling), the SEL_{cum} metric is usually the greater of the two metrics in terms of distance to TTS or PTS for marine mammals. This is due to the cumulative effect of integrating the energy dosage over time using the SEL_{cum} metric. The potential impacts on marine mammals are, therefore, primarily assessed in this report in terms of the SEL_{cum} metric. However, following the guidance of Southall et al (2007)[13], SPL_{peak} should also be considered.

7.5.14 An estimate of the SPL_{peak} was calculated for the present study assuming that the empirical constants are similar to those calculated by Lippert et al., 2015[14] for a study of pile driving during construction of three offshore wind farms. The three cases showed similar linear relationships between SEL and SPL_{peak}, with the worst case used for the present study, written as:

$$SPL_{peak} = 1.43\ SEL_{ss} - 44.0$$

where SEL_{ss} is the modelled single strike SEL.

7.5.15 This approach is considered to be a practical option for assessing the impact due to SPL_{peak} in this instance.

Fleeing animal model inputs

7.5.16 Modelling for fleeing animals was undertaken using agent-based modelling. At the start of the agent-based model simulations, agents (mammals) were initialised at the positions of the noise model mesh nodes across the whole model domain. At the onset of the activity generating the noise, it was assumed the animals swam away from the sound source at a swim speed of 1.5 m/s. Since it is not known what water depth the animals will be swimming at, the maximum SEL through the water column was used in the calculations to be conservative.

[7] Connell, S. C., Koessler, M. W., & McPherson. , C. R. (2023). Santos Barossa Darwin Pipeline Duplication: Acoustic Modelling for Assessing Marine Fauna Sound Exposure. Document 02954, Version 2.0. Technical report by JASCO Applied Sciences for Santos.
[8] Jones, D., Marten, K., & Harris, K. (2016). Underwater sound from dredging activities; establishing source levels and modelling the propagation of underwater sound. CEDA dredging days.
[9] Ramboll. (2023). Falmouth Docks Developement - Construction and Demolition Methodology Technical Note.
[10] de Jong, C., & Ainslie, M. A. (2008). Underwater sound due to the piling activities for the Q7 Off- shore wind park. TNO report MON- RPT-033-DTS-2007-03388.
[11] J0710_PSD_Analysis.csv provided by Ramboll on 15/01/2024
[12] Jenson, F., Kuperman, W., MB, P., & Schmidt, H. (2000). Computational Ocean Acoustics. New York: Springer-Verlag.
[13] Southall, B. L., Bowles, A. E., Ellison, W. T., Finneran, J. J., Gentry, R. L., Greene Jr, C. R., . . . Tyack, P. L. (2007). Marine mammal noise exposure criteria: Initial scientific recommendations. Aquatic Mammals, 33, 521.
[14] Lippert, T., M. Galindo-Romero, A.N. Gavrilov, and O. von Estorff. 2015. Empirical estimation of peak pressure level from sound exposure level. Part II: Offshore impact pile driving noise. Journal

7.5.17 A summary of the main parameters used in the fleeing animal modelling is given in Table 7-7.

Table 7-7: Parameters used in fleeing animal model

Parameter	Value used
Animal swim speed	1.5 m/s
3D sound levels used	Through-depth maximum
Mammal weightings used	Southall et al. (2019)[15]

Operational Stage

7.5.18 The potential impacts of the operational stage of the proposed development on the underwater noise are considered in regard to the number of additional vessels projected to visit the development. A desk assessment has been undertaken to assess these areas.

7.6 Assessment Criteria

7.6.1 The impact of the underwater noise is assessed based on whether the proposed activity causes an increase in underwater noise level above the background levels expected within the environment. Where activities are predicted to cause an increase in underwater noise, the consequences for marine animals are assessed based on injury criteria relating to the cumulative sound exposure level predicted for that activity over a given timescale. For impulsive sounds, the peak sound pressure levels are also compared with published thresholds. A summary of the thresholds is provided below, with details given in ES Volume 2: Technical Appendix 7.1. The effects on marine receptors, taking these thresholds into account are reported on in ES Chapter 9: Marine Ecology.

Marine Mammal Threshold Shift Criteria

7.6.2 The hearing frequency range of marine mammals is wide, and each species will differ slightly in the frequency of greatest sensitivity. Southall et al (2019)[16] divided marine mammals into four distinct groups based on their known, or assumed, auditory ranges – low-frequency cetaceans, high-frequency cetaceans, very-high-frequency cetaceans and pinnipeds (in air and in water). For each mammal group, the hearing range of the animals was accounted for using weighting factors (or M-weightings) to the received level sound at each centre frequency (f) of the third-octave sound spectrum. The M-weightings vary with frequency for the different hearing groups defined and are shown in Figure 7-3.

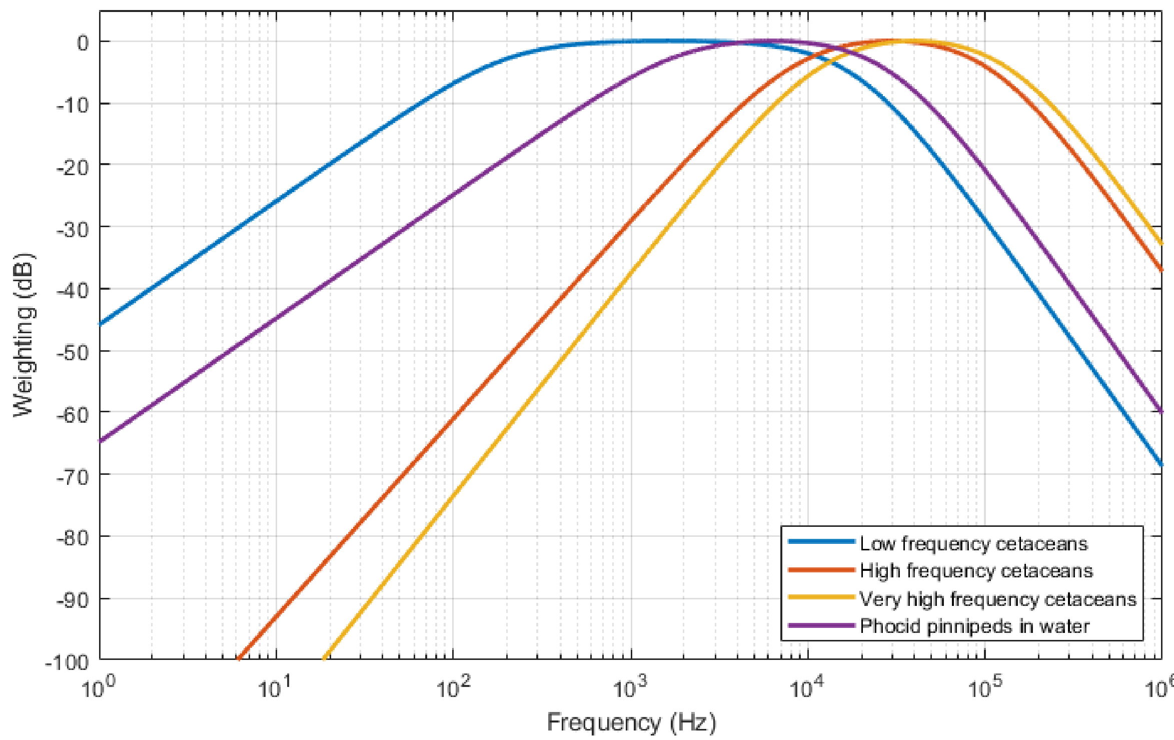

Figure 7-3: M-weightings for mammals using the assessment criteria of Southall et al. (2019)

7.6.3 The marine mammals thresholds for TTS and PTS are given in Table 7-8 for impulsive sounds (e.g. percussive piling and demolition works) for both the SEL_{cum} and SPL_{peak} metrics. Table 7-9 shows the impact thresholds for continuous noise sources (e.g. dredging).

Table 7-8: Weighted impact criteria for marine mammal injury from impulsive sounds

Hearing Group	TTS threshold		PTS threshold	
	SPL_{peak} (dB re 1 µPa)	SEL_{cum} (dB re 1 µPa²s)	SPL_{peak} (dB re 1 µPa)	SEL_{cum} (dB re 1 µPa²s)
Low-Frequency (LF) Cetaceans	213	168	219	183
High-Frequency (HF) Cetaceans	224	170	230	185
Very high-Frequency (VHF) Cetaceans	196	140	202	155
Phocid pinnipeds in water (PW)	212	170	218	185

[15] Southall, B. L., Finnerman, 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. Aquatic Mammals, 45(2), 125-232.

[16] Southall, B. L., Finnerman, 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. Aquatic Mammals, 45(2), 125-232.

Table 7-8: Weighted impact criteria for marine mammal injury from impulsive sounds

Adapted from NOAA (2016)[17] and Southall et al. (2019). Peak pressure is RMS dB re 1 µPa unweighted values; SEL_{cum} units are dB re 1 µPa²s, weighted for hearing range of the various categories and the SEL_{cum} accumulation period is 24 hours

Table 7-9: Weighted impact criteria for marine mammal injury from continuous sounds

Hearing Group	TTS threshold	PTS threshold
	SEL_{cum} (dB re 1 µPa²s)	SEL_{cum} (dB re 1 µPa²s)
Low-Frequency (LF) Cetaceans	179	199
High-Frequency (HF) Cetaceans	178	198
Very high-Frequency (VHF) Cetaceans	153	173
Phocid pinnipeds in water (PW)	181	201

Adapted from NOAA (2016) and Southall et al. (2019) SEL_{cum} units are dB re 1 µPa²s, weighted for hearing range of the various categories and the SEL_{cum} accumulation period is 24 hours

Fish Threshold Shift Criteria

7.6.4 The guidance for noise impacts on fish by Popper *et al.* (2014)[18] is based on whether a particular fish species primarily detects the sound pressure component of a noise, the particle motion component or a combination of both. Fish, eggs and larvae are divided into four categories based on their physiology, with those having swim bladders involved in hearing regarded as the most sensitive to noise impacts.

7.6.5 For each fish category, the defined thresholds for mortality, recoverable injury and TTS caused by impulsive sound are given in Table 7-10. For non-impulsive (continuous) noise, such as shipping noise and drilling, sound exposure thresholds are less well defined, largely being categorised as high, moderate or low potential impact (Popper *et al.* 2014)[19], as shown in Table 7-11.

7.6.6 For fish with a swim bladder, Smith *et al*. (2006) (in Popper *et al*., 2014) found that exposure to a continuous noise with an RMS of 170 dB re 1 µPa over a 48 hour period could cause recoverable injury in goldfish (*Carassius auratus*). Another study (Amoser and Ladich 2003)[20], in (Popper *et al*., 2014) suggested that 12 hours exposure to an RMS sound pressure level of 158 dB re 1 µPa could cause TTS in goldfish and catfish (*Pimelodus pictus*).

Table 7-10: Impulsive sound criteria for fish

Category	Mortality or potential mortal injury	Recoverable injury	TTS
Fish: No swim bladder	>219 dB SELcum OR >213 dB SPLpeak	>216 dB SELcum OR >213 dB SPLpeak	>>186 dB SELcum
Fish: Swim bladder not involved in hearing	210 dB SELcum OR >207 dB SPLpeak	203 dB SELcum OR >207 dB SPLpeak	>186 dB SELcum
Fish: Swim bladder involved in hearing	207 dB SELcum OR >207 dB SPLpeak	203 dB SELcum OR >207 dB SPLpeak	186 dB SELcum
Eggs and larvae	210 dB SELcum OR >207 dB SPLpeak	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low

Notes: Adapted from Popper et al. (2014) and Popper and Hawkins (2019)[21]. Peak and RMS sound pressure level dB re 1 µPa; SEL dB re 1 µPa2s. SELcum = Cumulative sound exposure level accumulated over a 24 hour period assuming stationary animals

Table 7-11 : Non-impulsive (continuous) noise impact criteria

Category	Mortality or potential mortal injury	Recoverable injury	TTS	Masking	Behaviour
Fish: No swim bladder	(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 not involved in hearing	(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 involved in hearing	(N) Low (I) Low (F) Low	170 dB RMS for 48 hours	158 dB RMS for 12 hours	(N) High (I) High (F) High	(N) High (I) Moderate (F) Low
Eggs and larvae	(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

Notes: Adapted from Popper et al. (2014). RMS sound pressure levels dB re 1 µPa. All criteria are presented as sound pressure even for fish without swim bladders since no data for particle motion exist. Relative risk (high, moderate, low) is given for animals at three distances from the source defined in relative terms as near (N), intermediate (I) and far (F)

7.7 Assumptions and Limitations

7.7.1 The exact equipment to be used for demolition, dredging and pile driving is not known. Therefore, it was necessary to make assumptions regarding the equipment used based on a reasonable worst case scenario and the resulting source levels. The assumed source levels are described in Section 7.5.

7.7.2 The duration of each activity (e.g. the time and number of strikes taken to install a pile, the dredging durations) is also uncertain at this point. The assumptions about duration of activities, for the purpose of calculating the cumulative sound exposure levels of animals, were taken to represent worst case (i.e. dredging for 24 hours a day; piling for up to 4 hours in 24 hours).

7.7.3 The locations of the modelled sound that have been selected represent the worst case in terms of sound propagation distance. For much of the demolition and construction stage, the activities will be carried out in more sheltered areas (such as within the dock basin, where the jetties prevent the sound propagating in most directions).

7.8 Baseline Conditions – Existing Underwater Noise Climate

7.8.1 The underwater noise climate is predominantly dominated by vessel noise from those vessels transiting in and around the Fal Estuary.

7.8.2 As described in ES Volume 2: Technical Appendix 7.1, noise generated by vessels is generally low frequency (<100 Hz). The fact that the vessels are generally moving also means the highest sound

[17] NOAA. (2016). Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing: Underwater Acoustic Thresholds for Onset of Permanent and Temporary Threshold Shifts. National Oceanic and Atmospheric Administration, Technical Memorandum NMFS-OPR-55.

[18] Popper, A. N., Hawkins, A. D., Fay, R. R., Mann, D. A., Bartol, S., Carlson, T. J., . . . Tavolga, W. N. (2014). Sound Exposure Guidelines for Fishes and Sea Turtles: A Technical Report prepared by ANSI-Accredited Standards Committee S3/SC1 and registered with ANSI. Springer and ASA Press. Springer and ASA Press.

[19] Popper, A. N., Hawkins, A. D., Fay, R. R., Mann, D. A., Bartol, S., Carlson, T. J., . . . Tavolga, W. N. (2014). Sound Exposure Guidelines for Fishes and Sea Turtles: A Technical Report prepared by ANSI-Accredited Standards Committee S3/SC1 and registered with ANSI. Springer and ASA Press. Springer and ASA Press.

[20] Amoser, S., & Ladich, F. (2003). Diversity in noise-induced temporary hearing loss in otophysine fishes. Journal of the Acoustics Society of America, 113, 2170–2179.

[21] Popper, A. N., & Hawkins, A. D. (2019). The importance of particle motion to fishes and invertebrates. The Journal of the Acoustical Society of America, 143(1), 470-488.

levels occur over a relatively short duration at any one location as the vessel passes close to any sensitive receivers, leading to lower cumulative levels than for a stationary sound source and stationary receptors. The cumulative sound exposure level from existing vessels is therefore predicted to be well below the sensitivity thresholds for marine mammals and is unlikely to cause temporary or permanent threshold shift. However, the Fal is a busy estuary in terms of commercial, military and recreational vessels, many of which are of a large size with potentially high source levels. It is therefore necessary to assess the potential for behavioural disturbance for the existing baseline and how this might change following the completion of the proposed development.

7.8.3 Port service craft and recreational craft have the highest numbers of vessels recorded in terms of time visiting the area. Tankers also spend similar amounts of time in and around the estuary, but are less present close to the site, presumably because they do not tend to moor at the berths. In terms of sound pressure level (Figure 7-4), the larger commercial and military vessels contribute the most (i.e. Passenger, tankers, cargo and military vessels). The passenger vessels are present in relatively high numbers and tend to follow a well-defined course along the channel, resulting in the highest annual mean source levels out of all vessel types concentrated along the shipping channel.

7.8.4 Source levels for the different vessel types, with the assumption of 6 knot cruising speed, were calculated using the Ross formulae as shown in Table 7-12. Using these source levels, the approximate distances from the vessel to the 120 dB marine mammal behavioural threshold for continuous sounds were calculated (also shown in the table). These distances were calculated using a simple spreading transmission loss method (RL=SL-15log10(range), where RL is received level and SL is source level) and represent the maximum distance to low level disturbance threshold for marine mammals. For the larger commercial vessels, the distances in most cases extend beyond the limits of the deep water channel which indicates that minor disturbances of marine mammals will occur throughout most of the estuary width during the passage of the larger vessels.

7.8.5 The amount of time for a vessel to travel from the estuary mouth to the dock (a distance of 3-4 km), at an assumed speed of 6 knots, is around 15-20 minutes. Based on this, and the current levels of vessel activity for cargo and passenger vessels, it is estimated that there is potential for behavioural disturbances to marine animals in relation to vessel noise for approximately 50 - 60 hours per year.

Table 7-12: Approximate vessel source levels at assumed speed of 6 knots and potential marine mammal disturbance radii during transit

Vessel type	Length range (m)	Mean length (m)	Calculated source level min-max (and mean) (dB)	Potential distance to 120 dB* (m)
Unknown	10 – 229	88	141 - 171 (160)	23 - 2497 (490)
Non-Port service craft	14 – 28	18	143 - 150 (146)	36 - 94 (51)
Port service craft	15 - 42	19	144 - 153 (146)	40 - 166 (55)
Dredging or underwater ops	15 - 130	61	144 - 164 (157)	40 - 910 (284)
High Speed Craft	15 - 102	50	144 - 162 (155)	40 - 616 (213)
Military or Law enforcement	23 - 201	105	148 - 169 (162)	72 - 1947 (645)
Passenger	23 - 229	126	148 - 171 (164)	72 - 2497 (864)
Cargo	24 - 292	122	148 - 174 (164)	76 - 4120 (820)
Tankers	75 - 324	120	159 - 176 (164)	385 - 5195 (798)
Fishing vessels	9 - 20	12	140 - 147 (142)	20 - 59 (30)
Recreational vessels	1 - 52	23	120 - 155 (148)	1 - 225 (72)
Excellence-class cruise ship**	-	345	177	6013

*range calculated assume spherical spreading formula with the for RL=SL-15log10(range)

**Excellence-class cruise ships are planned

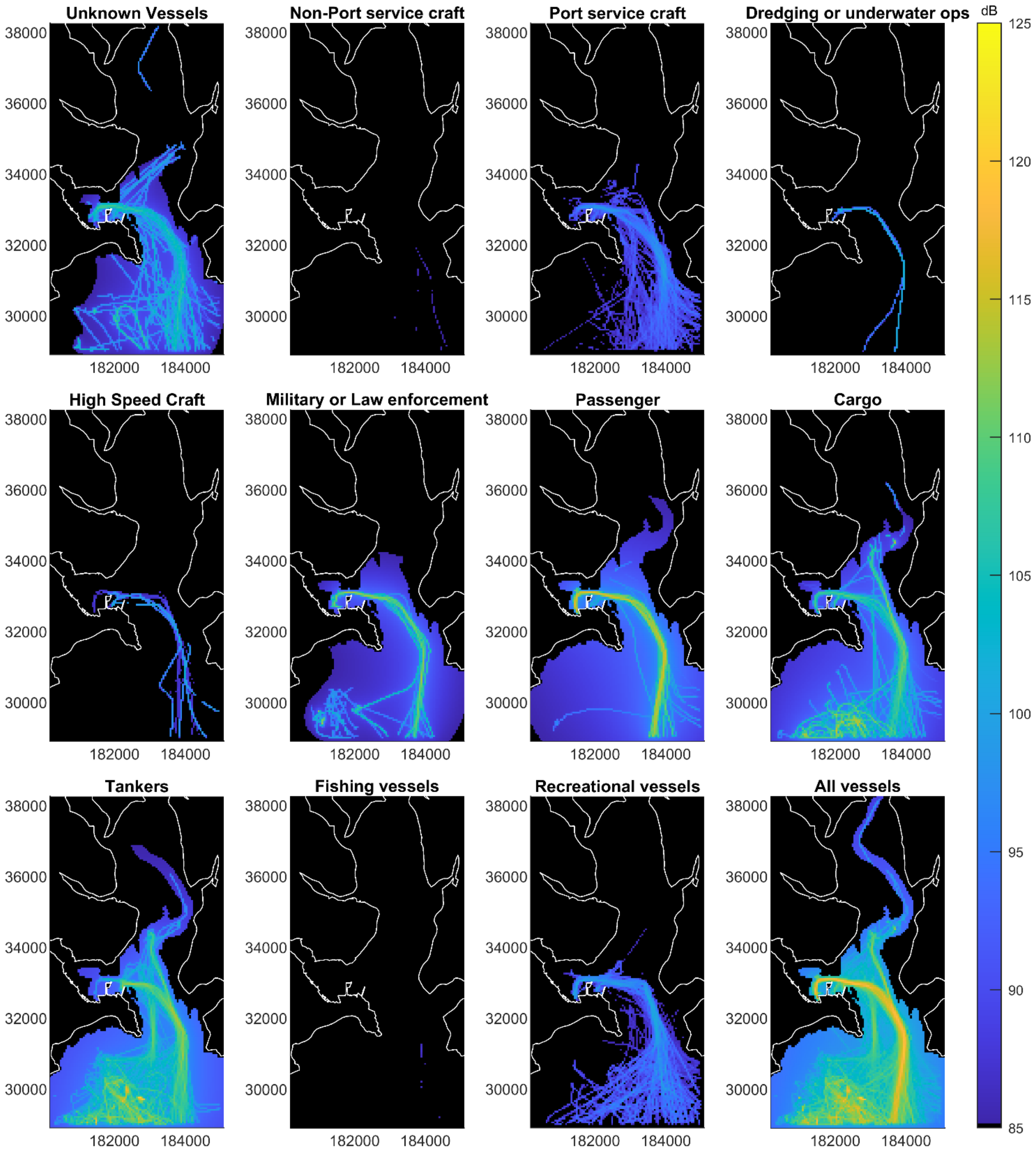

Figure 7-4: Modelled annual mean sound pressure level for each vessel type (sound levels are cropped in water depths under 10 m mean high water springs)

Source: Modelled sound levels using MMO AIS data[22]

7.9 Predicted Change in Noise Climate

Demolition and Construction impacts

Demolition with a hydraulic hammer

7.9.1 Demolition of the existing Northern Arm at the site may require a hydraulic breaker attached to an excavator to break up the concrete structure for removal. Other demolition methods, such as wire cutting and removal of sections by backhoe are expected to be quieter than the hydraulic hammer and therefore are not modelled. In the modelling it was assumed that the hydraulic hammer is used for a maximum of one hour in any 24 hour period.

7.9.2 Figure 7-5 shows the predicted broadband sound field for the demolition activity noise source. Sound levels decrease with distance from the source, with the broadband SEL dropping below 150 dB re 1μPa²s approximately 1 km away.

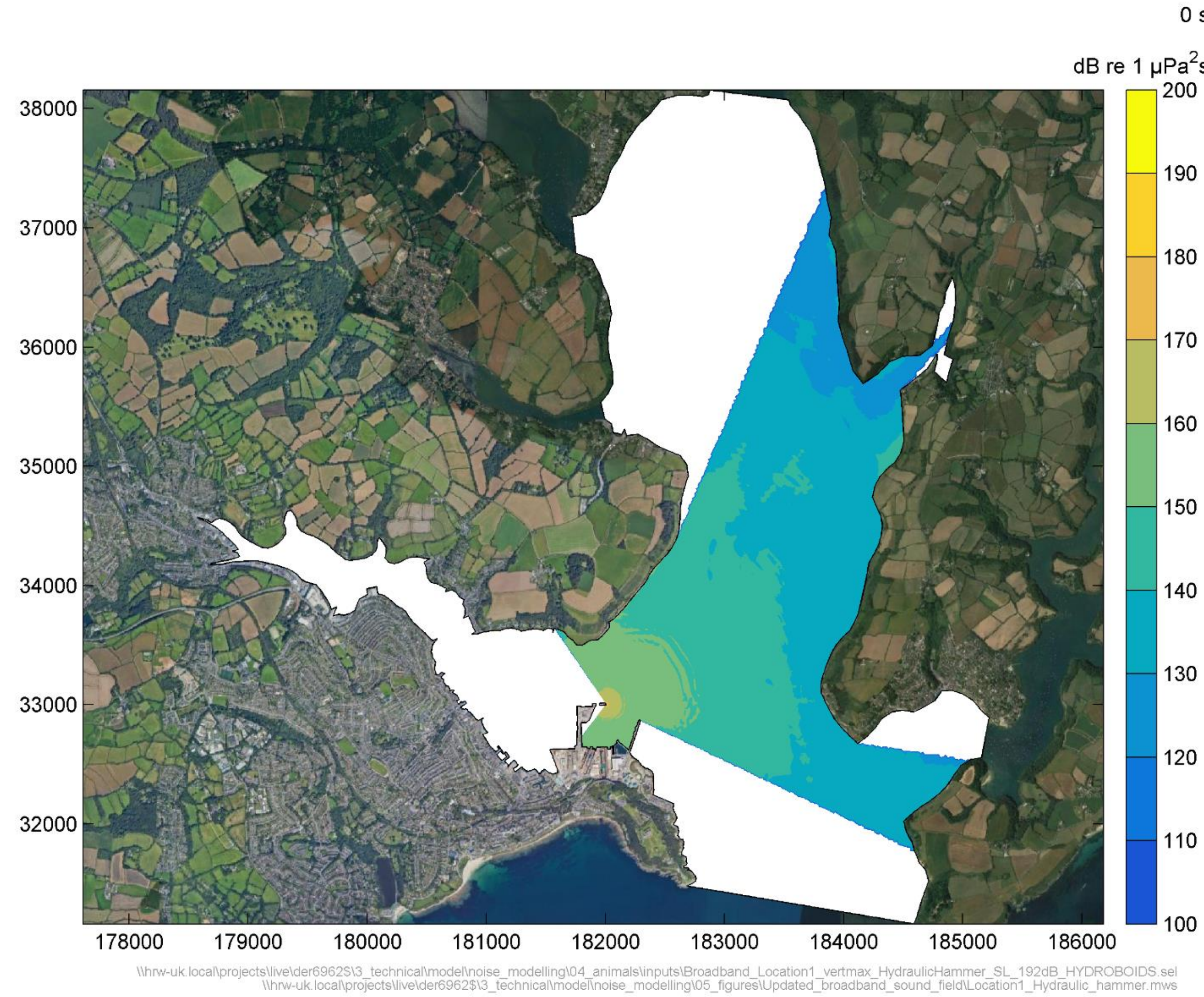

Figure 7-5: Predicted single strike SEL sound field for demolition at Location 1 using a hydraulic hammer (worst case scenario)

Source: Uses Google Earth imagery

Distances to impact threshold for marine mammals

7.9.3 Table 7-13 shows the predicted distances to the impact thresholds for the mammal groups. In most cases it is predicted that the areas predicted to exceed the SEL_{cum} PTS thresholds are within 400 m of the noise source and would mostly apply to any animals between the noise source and the shoreline (or Eastern Breakwater). The exception is for the very high frequency cetacean hearing group, for which the area above the PTS threshold extends northward and eastward across almost the whole width of the estuary. TTS thresholds were predicted to cover wider areas for all hearing groups.

22 environment.data.gov.uk

Table 7-13: Predicted distances to impact threshold for different mammal hearing groups (demolition of the Northern Arm, Location 1)		
	TTS	**PTS**
LF cetaceans (SEL_{cum})	3,000 m	400 m
HF cetaceans (SEL_{cum})	400 m*	0 m
VHF cetaceans (SEL_{cum})	3,800 m	1,700 m
Pinnipeds (SEL_{cum})	2,400 m	400 m*
LF cetaceans (SPL_{peak})	4 m	2 m
HF cetaceans (SPL_{peak})	1 m	0 m
VHF cetaceans (SPL_{peak})	40 m	20 m
Pinnipeds (SPL_{peak})	4 m	2 m

* Threshold exceedance would only occur for animals between the noise source and the shoreline, where fleeing is restricted.

Distances to impact threshold for fish

7.9.4 Impact distances are given for the two most sensitive hearing groups, fish with swim bladders involved in hearing (Category 3) and fish with swim bladders not involved in hearing (Category 2) (note that only the mortality threshold differs between these two groups). Fish may flee on exposure to noise, or may display other behaviours, such as swimming to the seabed. To cover the range of potential behaviours, fish are modelled as fleeing or stationary. The distances to impact thresholds for the demolition activity are shown in Table 7-14.

Table 7-14: Maximum distances from the sound source to impact radii for fish (demolition of the Northern Arm, Location 1)			
	TTS	**Recoverable Injury**	**Mortality**
Fleeing (SEL_{cum}) (swim bladder involved in hearing)	400 m*	0 m	0 m
Fleeing (SEL_{cum}) (swim bladder not involved in hearing)	400 m*	0 m	0 m
Stationary (SEL_{cum}) (swim bladder involved in hearing)	3,300 m	160 m	60 m
Stationary (SEL_{cum}) (swim bladder not involved in hearing)	3,300 m	160 m	40 m
SPL_{peak}	-	8 m	8 m

*Threshold exceedance occurs only for animals between the noise source and the shoreline, where fleeing is restricted.
**For SPL_{peak} only mortality and injury thresholds are available, and are equal.

Dredging

7.9.5 Backhoe dredging to create the deeper berths for the proposed Falmouth Dock Development was modelled for the north corner of the Western Wharf because this location is worst case in terms of spatial impact, with "lines of sight" extending past the Eastern Breakwater into the Percuil River, as well as to the north east and north west. Dredging for the FLOW deck was also modelled (see ES Volume 2: Technical Appendix 7.1). Backhoe dredging is assumed to be continuous, with the cumulative sound exposure calculated over 24 hours.

Broadband sound field

7.9.6 Figure 7-6 shows the predicted worst-case single sound pressure levels for the backhoe dredging activity noise source. Sound levels decrease with distance from the source, with the sound pressure levels sound dropping below 130 dB re 1µPa approximately 1 km away.

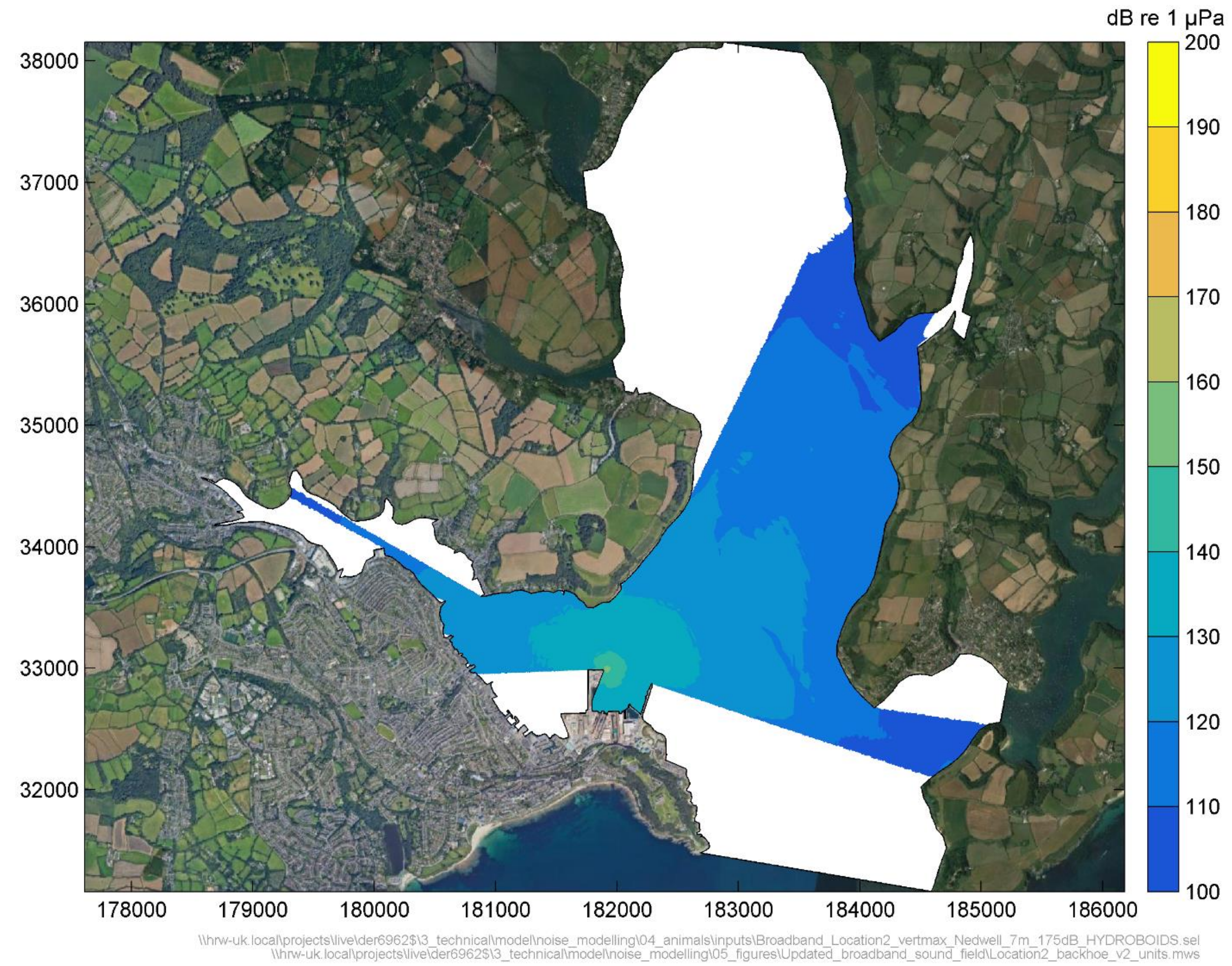

Figure 7-6: Predicted SPL sound field for backhoe dredging at Location 2 (worst case scenario)

Source: Uses Google Earth imagery

7.9.7 The underwater noise relating to backhoe dredging was modelled at two locations; the Western Wharf (Location 2) and the FLOW deck (Location 4) berths.

Percussive Pile driving

7.9.8 Sound propagation from percussive piling was assessed for three locations (Western Wharf (Location 2), Queen's Wharf (Location 3) and FLOW deck (Location 4)). In all cases, a soft-start procedure was included in the assessment of impacts on mammals. The distances over which animals may be affected vary slightly by location (see ES Volume 2: Technical Appendix 7.1), but the extent of the impacts are sufficiently similar that they are considered together here.

Broadband sound field

7.9.9 Figure 7-7 shows the predicted single strike SEL sound field for the percussive piling noise source at the Western Wharf location. Sound levels decrease with distance from the source, with the single strike SEL sound dropping below 170 dB re $1\mu Pa^2 s$ approximately 600 m away and below 160 dB re $1\mu Pa^2 s$ approximately 1,750 m away.

7.9.10 It is noted that the location selected for modelling this activity is the worst case in terms of spatial extent, because the "lines of sight" are longest from this point in all directions. Piling further south will impact smaller areas and the existing structures provide a sheltering effect. An indicative area for piling at the south of the Western Wharf is given in Figure 7-8. This shows only the areas that would be expected to have noise related to the activity, and has not been modelled at this location.

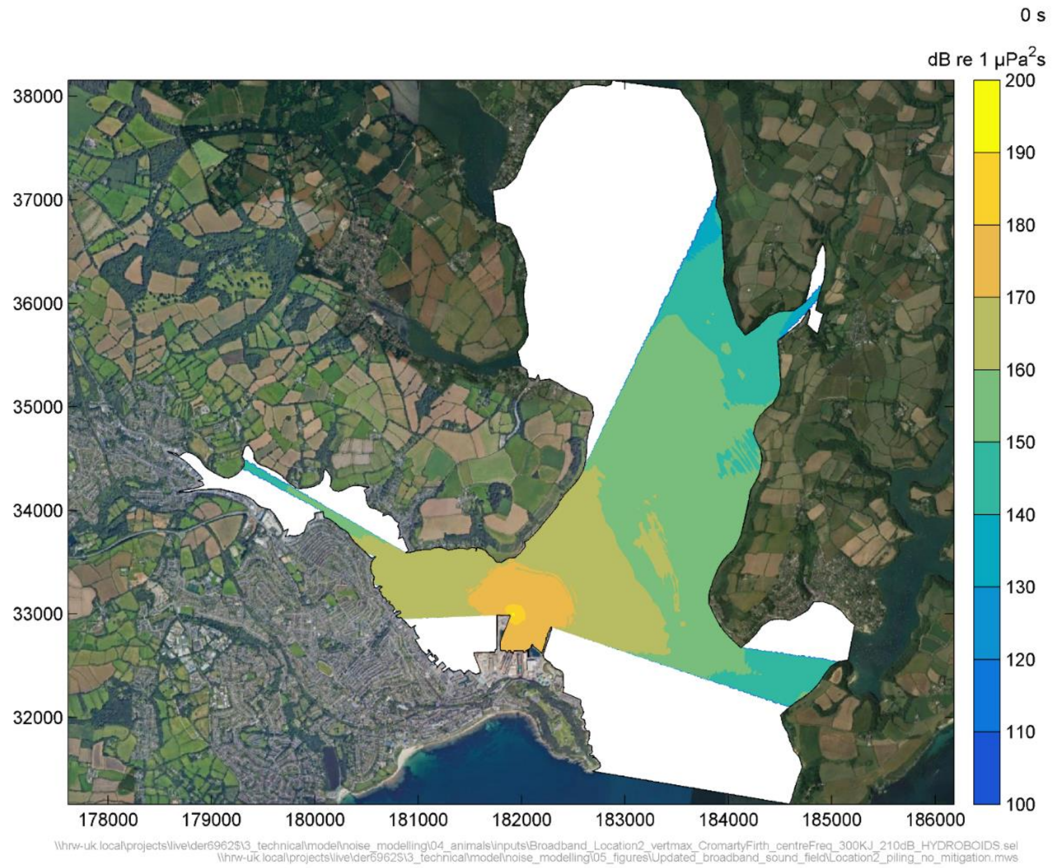

Figure 7-7: Predicted single strike SEL sound field for percussive piling at Location 2 (worst case scenario)

Source: Uses Google Earth imagery

Figure 7-8: Indicating how the spatial extent of the noise field would change with percussive piling further to the south on the Western Wharf (note indicative only, modelling not undertaken for this location)

Source: Uses Google Earth imagery

Distances to impact threshold for marine mammals

7.9.11 The maximum predicted distances to the impact thresholds for the mammal groups across all modelled locations are shown in Table 7-15.

Table 7-15: Maximum distances to impact threshold for different mammal hearing groups (percussive piling, including soft-start procedure, for all locations)

	TTS	PTS
LF cetaceans (SEL_{cum})	3,600 m	2,000 m
HF cetaceans (SEL_{cum})	1,300 m	650 m*
VHF cetaceans (SEL_{cum})	4,100 m	2,000 m
Pinnipeds (SEL_{cum})	3,100 m	1,100 m
LF cetaceans (SPL_{peak})	130 m	120 m
HF cetaceans (SPL_{peak})	30 m	20 m
VHF cetaceans (SPL_{peak})	1,300 m	630 m
Pinnipeds (SPL_{peak})	170 m	120 m

*Threshold exceedance occurs only for animals between the noise source and the shoreline, where fleeing is restricted.

Distances to impact threshold for fish

7.9.12 Impact distances are given for the most sensitive hearing group, fish with swim bladders involved in hearing (Category 3) and also for fish with swim bladder not involved in hearing (Category 2). Fish may flee on exposure to noise, or may display other behaviours, such as swimming to the seabed. To cover the range of potential behaviours, fish are modelled as fleeing or stationary. The distances to impact thresholds for the percussive piling activity are shown in Table 7-16.

Table 7-16: Distances from the pile to impact radii for fish (percussive piling, maximum of three locations)

	TTS	Recoverable Injury	Mortality
	R_{max}	R_{max}	R_{max}
Fleeing (SEL_{cum}) (swim bladder involved in hearing)	1,500 m	660 m*	650 m*
Fleeing (SEL_{cum}) (swim bladder not involved in hearing)	1,500 m	660 m*	650 m*
Stationary (SEL_{cum}) (swim bladder involved in hearing)	4,100 m	1,700 m	1,300 m
Stationary (SEL_{cum}) (swim bladder not involved in hearing)	4,100 m	1,700 m	940 m
SPL_{peak}	-	650 m	650 m

*Threshold exceedance occurs only for animals between the noise source and the shoreline, where fleeing is restricted.

**For SPL_{peak} only mortality and injury thresholds are available, and are equal.

7.10 Construction schedule

7.10.1 The underwater noise modelling reported in this chapter assumes that the dock development happens in series, with different wharfs and structures constructed separately and hence the underwater noise predicted for each of the activities should not occur at the same time. It is possible however, that a parallel construction programme will be used, with different activities occurring in different locations at the same time. The potential parallel construction programme is described in detail in ES Chapter 5: Demolition and Construction Description.

7.10.2 Under the parallel programme detailed in Figure 5-1 of ES Chapter 5, demolition of the Northern Arm of the Western Wharf occurs concurrently with dredging for the North Wharf/Queens Wharf. Piling and demolition activities do not overlap.

7.10.3 The underwater noise modelling presented here as separate activities can still be considered worst case because:

- Piling and demolition activity under the parallel programme will not occur at the same time.

- Dredging may overlap with piling or demolition activities, but the sound levels and impact footprint for dredging was predicted to be relatively small (behavioural impacts and possible limited TTS exceedance). Therefore, in areas affected by noise from both dredging and another percussive noise generating activity, the dredging noise will be almost indistinguishable in terms of sound exposure level.
- Sound from dredging may propagate into areas that are sheltered for the other piling or construction activities. This will create an effect area that is a composite of the two modelled activities, with a larger affected area than for just a single activity (e.g. Figure 7-9); however the area would be no greater than the total area for the two activities if they were carried out separately. The total duration of noise would also be shorter than if each activity were carried out at separate times.

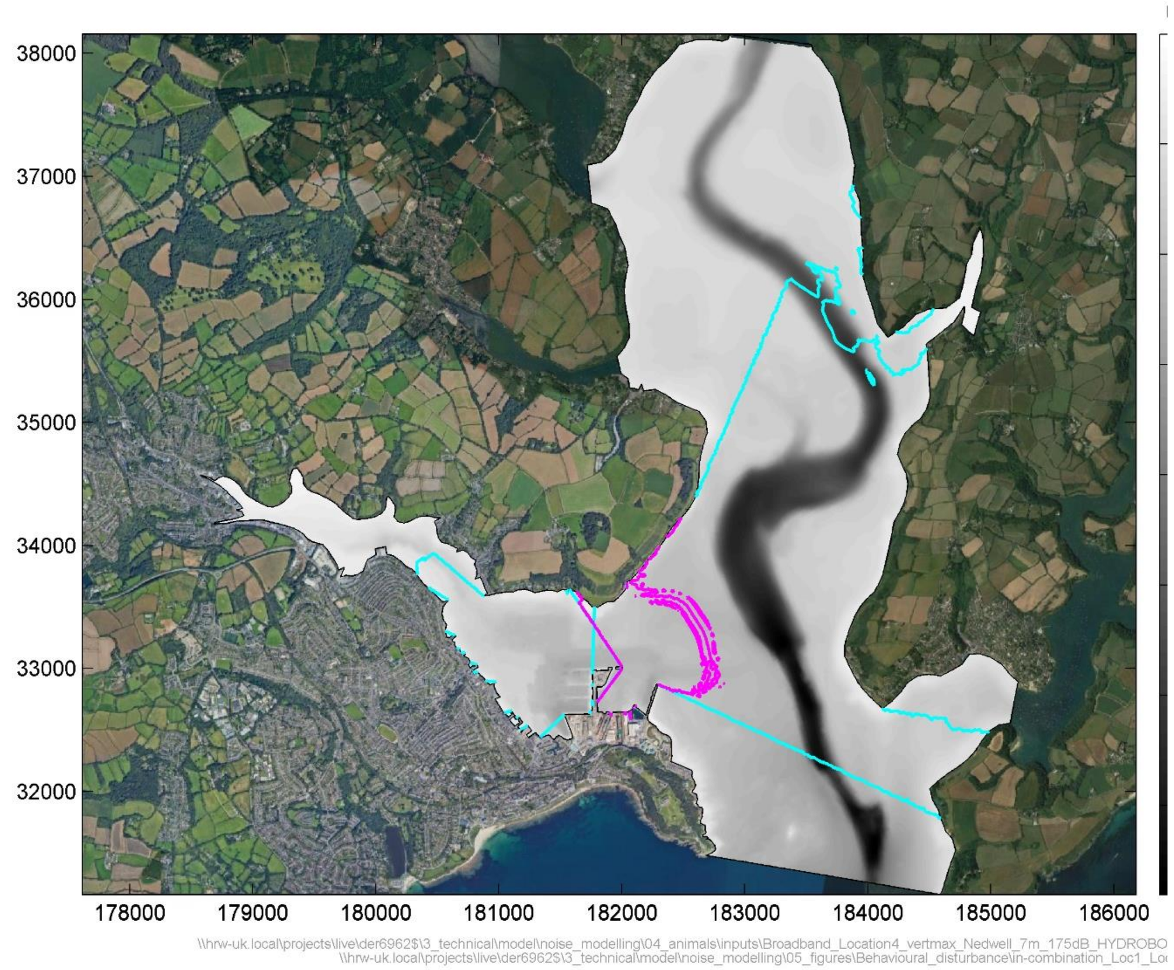

Figure 7-9: The in-combination behavioural disturbance contours for marine mammals considering demolition on the Northern Arm (Location 1) and backhoe dredging at the FLOW deck (Location 4)
Source: Uses Google Earth imagery

7.10.4 There will be other in-combination construction activities, however as these will be on land and emit no or low level noise into the underwater environment they are not considered here. ES Volume 2: Technical Appendix 7.1 shows the parallel programme for the underwater noise related activities only.

7.11 Mitigation

7.11.1 The use of a bubble curtain is a potential option to mitigate the impacts of noise caused by pile driving. A bubble curtain could reduce the sound levels outside of the bubble curtain by around 10 dB re 1μPa^{2}s, therefore reducing the cumulative sound exposure levels of animals. However, it's effectiveness is reduced if animals do not have a direct escape route away from the sound source, along with logistical constraints in certain marine environments. Other mitigation measures include the use of marine mammal observers or passive acoustic monitoring. The most appropriate mitigation measure for the proposed development is considered in Chapter 9: Marine Ecology, based on the predicted magnitude of change in underwater noise (reported in this chapter), and the effect on the specific marine ecological receptors.

Operational Stage Changes

7.11.2 The planned increases in vessels in the future baseline are only envisaged for cargo (i.e. commercial freight) and passenger vessels. Some reduction in tender vessels is anticipated due to the ability of the large passenger vessels to moor at the berths, but the reduction in numbers is not known, so the possible reduction in sound level is not considered here. The expected increases in vessel type are provided in ES Chapter 4: Proposed Development Description. It is expected that there will be 11 Excellence-class cruise ships docking at Falmouth per year, which are 345 m in length. There will also be an additional 12 cargo vessels docking at Falmouth per year, which typically are between 60 and 100 m in length. These numbers are multiplied by two to give the number of additional vessel movements through the estuary.

7.11.3 The amount of time for a vessel to travel from the estuary mouth to the dock (a distance of 3-4 km), at an assumed speed of 6 knots, is around 15-20 minutes. The amount of additional time per year that animals may be disturbed within the deeper areas of the estuary, assuming 11 passenger and 12 cargo vessels visits (i.e. 46 transits through the estuary in total) is therefore of the order of 15 hours/year combined. This is in addition to the current levels of vessel activity, which for combined passenger and cargo vessels is estimated to be around 50 - 60 hours (based on measured numbers of vessels). It is noted also that the predicted source levels for the Excellence-class cruise ships are higher than the other (smaller) vessels, with distances of disturbance of up to around 6 km from the vessel at 6 knots (in deep water). The levels of behavioural disturbance are therefore likely to be more pronounced for the larger vessels, but below injury thresholds.

7.11.4 Additional boat movements at the proposed development will therefore contribute intermittent noise to the underwater environment. It is not expected that this will have a discernible effect on the noise climate.