Submitted to:

Steven Rayner
HaskoningDHV UK Ltd
Rightwell House
Bretton
Peterborough
PE3 8DW
UK

E-mail: steven.rayner@rhdhv.com
Website: www.royalhaskoningdhv.com

Submitted by:

Tim Mason
Subacoustech Environmental Ltd
Unit 2, Muira Industrial Estate
William Street
Southampton
SO14 5QH
UK

Tel: +44 (0)23 80 236 330

E-mail: tim.mason@subacoustech.com
Website: www.subacoustech.com

Underwater Noise Impact Assessment – South Bank, Tees Estuary

Tim Mason

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1 Introduction

1.1 Project background and scope

South Tees Development Corporation (STDC) is proposing to construct a new quay at South Bank (Tees estuary) to support its landside proposals for general industry and storage or distribution uses within part of the South Industrial Zone. Some parts of the development of this new facility will require works that could generate underwater noise in the adjacent River Tees. This has the potential to affect river or marine species that are present in this stretch of the river.

The general layout of the site, in reference to the river, is shown in Figure 1-1. The River Tees at this location is approximately 300 m wide.

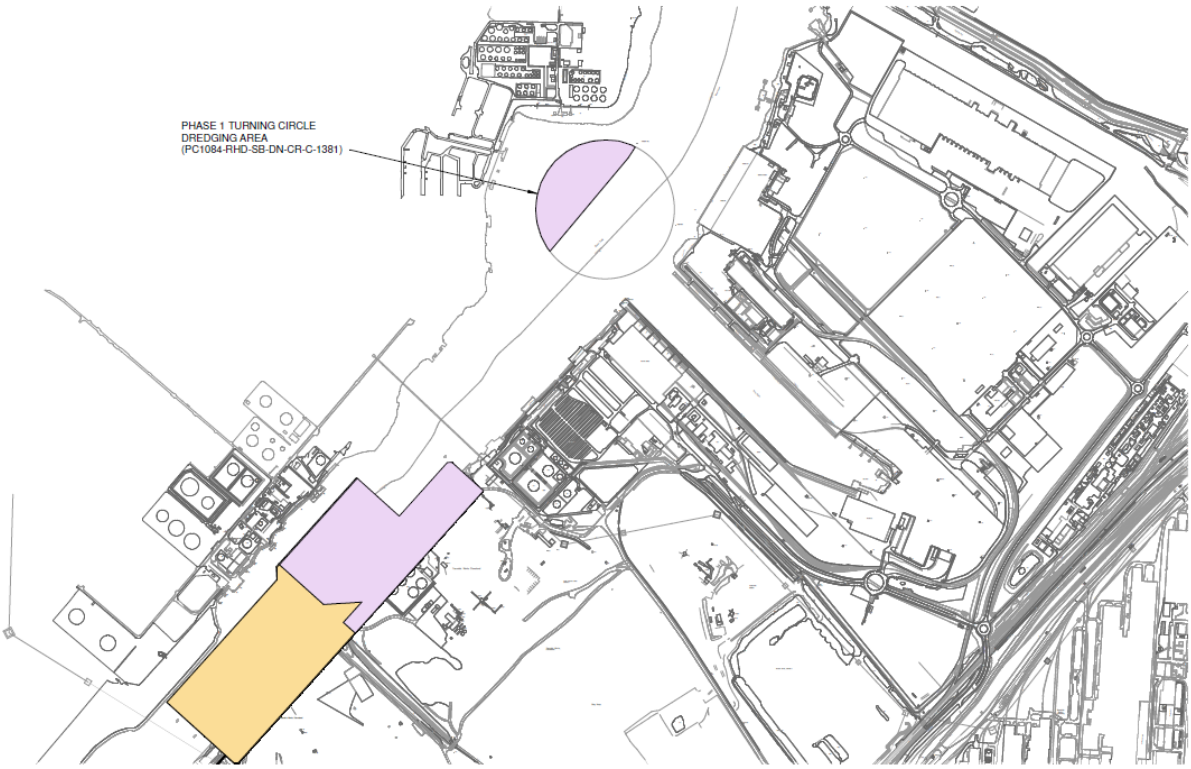

Figure 1-1 Overview site plan of South Bank development on the River Tees (NTS)

This technical note reviews the risk of transmission of underwater noise into the river from a piled quay wall and the potential impacts of this noise on the sensitive receptors present in the river. The species of interest are salmon, sea trout, eel, lamprey and smelt. There is the potential presence of seals in the river and these will also be considered.

1.2 Introduction to underwater acoustics

The following basic acoustical concepts provide the basis of this assessment.

1.2.1 Decibels and sound pressure level (SPL)

The decibel (dB), by which a level of sound is described, is a ratio measure and as such requires a reference sound pressure to compare with the noise level under consideration. In underwater noise this is conventionally 1 micropascal (1 µPa), as a minimum pressure level that could be present. Noise levels presented in this technical note are all referenced to this value and are thus a sound pressure level (SPL) “re 1 µPa”. Please note that this is different to the reference used for airborne noise, which is 20 µPa, and airborne and underwater noise levels should not be directly compared.

SPL is normally used to characterise noise and vibration of a continuous nature such as drilling, boring, or background sea and river noise levels. To calculate the SPL, the variation in sound pressure is measured over a specific time period to determine the root-mean square (RMS) level of the time varying acoustic pressure. The SPL_{RMS} can therefore be considered to be a measure of the average unweighted level of the sound over the measurement period. The SPL is calculated using the following formula where p is the sound pressure in Pascals (Pa), and p_{ref} is the reference sound pressure, which is typically 1 µPa for underwater sound as noted above.

$$SPL = 20 \log_{10}\left(\frac{p}{p_{ref}}\right)$$

Other measures include the 'peak' or 'peak-to-peak' SPL, which are relevant for impulsive noise as is expected for percussive piling. These are described below.

The attenuation of sound in the water as it propagates from the noise source must be considered in an impact assessment. As the measurement or receiver point moves away from the source, the sound pressure measured will decrease due to spreading. To standardise all source levels, regardless of where they are measured, they are referred back to a conceptual point 1 m away from the point of origin of the noise. Consequently, source levels should be presented with units of 'dB re 1 µPa @ 1 m'.

Unless stated otherwise, all noise levels referenced in this document are "re 1 µPa".

1.2.2 Peak sound pressure level (SPL_{peak})

Peak SPLs are often used to characterise transient sounds from impulsive sources, such as percussive impact piling and seismic airgun sources. SPL_{peak} is calculated using the maximum variation of the pressure from positive to zero within the wave. This represents the maximum change in positive pressure (differential pressure from positive to zero) as the transient pressure wave propagates.

A variation of this is the peak-to-peak SPL ($SPL_{peak\text{-}to\text{-}peak}$) where the maximum variation of the pressure from positive to negative within the wave is considered. Where the wave is symmetrically distributed in positive and negative pressure, the peak-to-peak level will be twice the peak level, or 6 dB higher.

1.2.3 Sound Exposure Level (SEL)

The SEL sums the acoustic energy over a measurement period, and effectively takes account of both the SPL of the sound source and the duration for which the sound is present in the acoustic environment. Where the RMS can be thought of as an average noise level, the SEL is accumulative exposure and its value will increase in time where the noise level continues. Where the SPL is a measure of the average level of the noise, the SEL sums the cumulative noise energy.

The SEL is used in contemporary underwater noise assessments to estimate the potential impact by noise on marine species by both Southall *et al.* (2019)[1] for marine mammals and Popper *et al.* (2014)[2] for fish, in terms of adverse effects on hearing and injury.

[1] Southall B L, Finneran J J, Reichmuth C, Nachtigall P E, Ketten D R, Bowles A E, Ellison W T, Nowacek D P, Tyack P L (2019). *Marine Mammal Noise Exposure Criteria: Updated Scientific Recommendations for Residual Hearing Effects*. Aquatic Mammals 2019, 45(2), 125-232, DOI 10.1578/AM.45.2.2019.125.
[2] Popper A N, Hawkins A D, Fay R R, Mann D A, Bartol S, Carlson T J, Coombs S, Ellison W T, Gentry M B, Løkkeborg S, Rogers P H, Southall B L, Zeddies D G, Tavolga W N (2014). *Sound exposure guidelines for fishes and sea turtles. Springer Briefs in Oceanography*. DOI 10. 1007/978-3-319-06659-2.

1.3 Proposed activities

This technical note considers a proposed new quay wall, which will be installed using percussive piling in the worst case. It will require up to 1.3 km worth of piles at South Bank. All piles will be driven on land. The closest piling is approximately 20 m from the river edge. There are no piling works proposed within the water.

The driving activity is predicted to take a maximum of 10 minutes per pile, with one pile driven per day at a rig. There could potentially be four rigs in use at the site at any one time and thus there is a worst case of up to 40 minutes of piling per day.

The activities required to undertake the above works will generate noise, and this has the potential to be transmitted as underwater noise into the surrounding water to the adjacent River Tees. The piles to be used for the quay wall are understood to be driven with a percussive technique.

2 Noise levels affecting the River Tees

2.1 Baseline noise levels

The baseline noise level in the river or other body of water is dependent on the existing natural or anthropogenic noise sources. In an entirely natural setting, the ambient noise is affected by: the water conditions, including the turbulent free-flowing water and the surface over which it flows, such as loose gravel; weather-dependent or tidal movement of the water surface; and bubbles. In some locations marine or river life will also contribute to the overall soundscape. Any vessels present will increase the noise level in the water significantly, as can some industrial units and any other machinery in the water. Due to the flow of water, in the absence of any man-made noise, the higher water flow rate in rivers tends to make them noisier overall than open sea.

Subacoustech Environmental undertook baseline underwater noise measurements in 2014[3] at a location just to the north-east of the opening to Tees Dock, which showed background levels generally between 103 dB and 115 dB re 1 µPa SPL_{RMS}, in the absence of any clear anthropogenic noise sources such as passing vessels. Measurements typically were seen to increase to 130 and 150 dB SPL_{RMS} with passing vessels, which was not uncommon. Although only a snapshot was possible, approximately two hours on each of two consecutive days, it gives a reasonable expectation of the sorts of noise levels that are typically found in this location on the River Tees.

2.2 Noise associated with piling equipment

The piling is proposed to be undertaken with a percussive technique. These piles will be installed on the bank of the river with no part of the pile or machinery in contact with the water. The nearest point of pile installation is approximately 20 m away from the River Tees. In order for the sound to be transmitted to the River Tees, where the sensitive species are present, the energy produced by the piling must be transmitted from the piling rig, into the surrounding ground and from there into the water.

The prediction of sound production and transmission from percussive pile driving is well studied and Subacoustech has undertaken numerous campaigns to measure the underwater noise present in the water around piling over the last 15 years. However, these are almost entirely where the piling and monitoring are both directly in the water, giving a direct ‘line of sight’ between the noise source and receiver location. In the case of the piling at South Bank, all piling will be on land.

Sound propagates most efficiently via a single, uninterrupted medium. Where it must pass through multiple media (i.e. mixed sand/silt and water), then the transmission of noise is reduced. In the situation at South Bank, vibration is transferred from the pile and hammer and distributed into the substrate, and out into the river. Situations involving groundborne noise transmission are complex due to the variety and layers of media. Every situation is different and the calculation of how, and how much, noise is transmitted is much more difficult than a simple calculation of transmission directly through air or water. The ground type in every situation must be taken into account. As such, it is most accurately identified by direct measurement. When it comes to prediction, the detail of analysis in calculation should be commensurate with the level of risk, and this relates to the level of noise present at source (i.e. the noise-generating activity) and the sensitivity of the receptor.

Due to the complexity of the groundborne noise transmission calculation, reference is made to measurements of other similar machinery used directly in water as a worst case. Measurements of percussive piling by a river have been taken by Subacoustech Environmental[4] from a survey in the

[3] A Collett, T Mason (2014). *York Potash Project Harbour Facilities: Underwater Noise Impact Assessment*. Subacoustech Environmental report number E473R0205

[4] F Midforth, S East (2016). *Monitoring of underwater noise prior to and during piling operations on the River Thames*. Subacoustech Environmental report number E541P0201.

River Thames with percussive piling of tubular piles, similar to those to be installed for the proposed combi-wall at South Bank, using a BSP CX-85 pile driving hammer. A summary of measurements is given in Table 2-1. Due to number of piles monitored and measurements taken, an overall average at these ranges is given.

Range	SPL_{peak}	$SPL_{RMS,0.125s}$	SEL_{ss}
100 m	189 dB	172 dB	166 dB
200 m	178 dB	161 dB	155 dB
300 m	173 dB	156 dB	150 dB
400 m	170 dB	154 dB	147 dB

Table 2-1 Measurements of underwater percussive piling, in water, in the River Thames, City of London, 2016

The largest (worst case) piling hammer assumed to be used at South Bank is an IHC S150, which is larger than the one used in the piling above and could lead to an increase of approximately 2 dB more than the measured noise levels above, using the correction noted by Bellman *et al.* 2000[5].

It must be reiterated that the measured noise levels presented in Table 2-1 were taken in the water, with the piling equipment also operating directly in the water. The piling at South Bank will occur on land.

Although every groundborne to underwater noise transmission situation is different, an example is offered to show the difference that this transition can make. In 2017, Subacoustech sampled the underwater noise produced by percussive piling to install sheet piles on the beach at Hill Head, near Portsmouth[6]. The River Meon was approximately 200 m from the piling and the noise levels were measured in the river. Based on previous measurements of similar equipment piling directly in the water, it was found that the piling noise (during piling on the beach) measured in the River Meon was 5 dB lower than the piling in the water. It is recognised that this is a rather different situation to that here; however the 9 m layer of made ground that the pile will be driven into at South Bank, rather than the consolidated material on the coast at Hill Head, groundwater and the river, would lead to greater losses (reductions) in noise at South Bank than for the River Meon example.

5 dB is therefore suggested as the minimum loss in noise level expected between the working area and the river. Table 2-2 shows conservative noise level predictions across the River Tees, based on Table 2-1, taking into account the 2 dB maximum noise level increase for the larger hammer that could be used and 5 dB attenuation by the piling on land.

Range	SPL_{peak}	$SPL_{RMS,0.125s}$	SEL_{ss}
100 m	186	169	163
200 m	175	158	152
300 m	170	153	147
400 m	167	151	144

Table 2-2 Predictions of underwater noise levels during percussive piling in the River Tees

[5] Bellmann M. A., Brinkmann J., May A., Wendt T., Gerlach S. & Remmers P. (2020) *Underwater noise during the impulse pile-driving procedure: Influencing factors on pile-driving noise and technical possibilities to comply with noise mitigation values*. Supported by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit (BMU)), FKZ UM16 881500. Commissioned and managed by the Federal Maritime and Hydrographic Agency (Bundesamt für Seeschifffahrt und Hydrographie (BSH)), Order No. 10036866

[6] T Mason (2018). *Transmission of noise into water from coastal piling at Hill Head, Hampshire*. Subacoustech Environmental report number P211R0101

3 Assessment criteria

The focus for impacts on underwater receptors in the River Tees is fish, specifically salmon, sea trout, eel, lamprey and smelt. The sensitivity criteria used to assess these species will be representative of effects on any other fish species within the river. There is the potential for grey and common seals to be present. These species will be considered in outline.

3.1 Fish

The effects of noise on fish have been assessed using criteria from Popper *et al*. (2014)[2], which gives specific criteria for various stimuli. The following criteria are relevant for impulsive (percussive) pile driving noise:

Fish	**Mortality & potential mortal injury**	**Recoverable injury**	**TTS**	**Masking**	**Behaviour**
Swim bladder	>219 dB SEL_{cum} or >213 dB peak	>216 dB SEL_{cum} or >213 dB peak	>>186 dB SEL_{cum}	(N) Moderate (I) Low (F) Low	(N) High (I) Moderate (F) Low
Swim bladder not involved in hearing	>210 dB SEL_{cum} or >207 dB peak	203 dB SEL_{cum} or >207 dB peak	>186 dB SEL_{cum}	(N) Moderate (I) Low (F) Low	(N) High (I) Moderate (F) Low
Swim bladder involved in hearing	>207 dB SEL_{cum} or >207 dB peak	203 dB SEL_{cum} or >207 dB peak	186 dB SEL_{cum}	(N) High (I) High (F) Low	(N) High (I) High (F) Moderate

Table 3-1 Summary of the qualitative effects on fish from impulsive pile driving sources (Popper et al. 2014) (N=Near field, I=Intermediate field, F=Far field)

Of the species under consideration, it is understood that the most sensitive to sound, salmon and sea trout, have a swim bladder that is not involved with hearing. Thus, the second category will be used, although numerically the difference between this and the most sensitive category will not have a material effect on the assessment.

Additionally, Woodbury and Stadler (2008)[7] and more recently Caltrans (2015)[8] referenced a noise level of 150 dB 1 µPa SPL (RMS assumed) for behavioural response for fish. Although Popper *et al*. (2019)[9] state concerns with this figure, including that the basis for it is unknown, or exactly what behaviour it relates to, in the absence of any alternative numerical criteria for behavioural effects, the noise levels produced by piling will be compared to this.

3.2 Marine mammals

The Southall *et al*. (2019) paper[1] on the effects of underwater noise on marine mammals is effectively an update of the previous Southall *et al*. (2007) criteria and gives identical thresholds to those from the NMFS (2018) guidance for marine mammals. The Southall *et al*. (2019) guidance grouped marine mammals into groups of similar species and applied filters to the unweighted noise to approximate the hearing sensitivity of the wider receptor group. Of these groups, only phocid carnivores in water (true seals) are potentially significant in this location.

[7] Woodbury, D., & Stadler, J. (2008). *A proposed method to assess physical injury to fishes from underwater sound produced during pile driving*. Bioacoustics, 17, 289–297.
[8] Caltrans (2015). *Technical guidance for assessment and mitigation of the hydroacoustics effects of pile driving on fish.* p. 532. Sacramento, CA.
[9] Popper AN, Hawkins AD. *An overview of fish bioacoustics and the impacts of anthropogenic sounds on fishes*. J Fish Biol. 2019;1–22. https://doi.org/10.1111/jfb.13948

Southall *et al*. (2019) gives individual criteria based on whether a noise source is considered impulsive or non-impulsive. The piling noise is considered non-impulsive as it is a steady state noise. The Southall *et al*. (2019) criteria used for assessing marine mammals is presented in Table 3-2, and presents unweighted SPL_{peak} and weighted cumulative sound exposure criteria (SEL_{cum}) for both permanent threshold shift (PTS), where unrecoverable hearing damage may occur, and temporary threshold shift (TTS), where a temporary reduction in hearing sensitivity may occur in individual receptors.

Group	PTS criteria	TTS criteria
Phocid carnivores in water (PCW)	218 dB SPL_{peak} re 1 µPa	212 dB SPL_{peak} re 1 µPa
	185 dB SEL_{cum} (weighted) re 1 μPa^2s	170 dB SEL_{cum} (weighted) re 1 μPa^2s

Table 3-2 Assessment criteria for seals from Southall et al. (2019) for impulsive noise.

Note that these criteria must have a weighting reduction applied to any noise level to account for the species group.

4 Assessment

4.1 Fish

Based on the criteria defined in Popper *et al.* (2014), the lowest quantitative threshold in respect of a piling sound sources is for potential TTS in the most sensitive species. This threshold is 186 dB SEL_{cum} exposure over multiple pulses from percussive piling.

For the cumulative exposure calculations, a stationary animal calculation has been used. This assumes that the receptor, when exposed to high noise levels, will remain in place for a worst-case estimation of exposure. This is a worst-case assumption as the receptors are migratory and expected to be highly mobile and are unlikely to remain static in the water near to the noise source, and would move away in the event of a noise that would be considered disturbing or hazardous. An assumption has been used that the receptor remains in the middle of the river closest to the piling for 10 minutes, considered to be a worst case for the length of time that a pile could take to be driven.

The noise level identified as the maximum expected in the river from percussive piling is 159 dB SEL_{ss} in the middle of the river, at 150 m from directly opposite the piling. Based on the above assumption, this is equivalent to 185 dB SEL_{cum}. As this is under the lowest quantitative threshold, and itself expected to be a significant over-estimation of the actual noise exposure to an individual, no risk of any injury or temporary threshold shift to even the most sensitive species of fish from noise from percussive piling on land is anticipated. The lowest SPL_{peak} threshold, 207 dB, is more than 20 dB higher than the level predicted at 100 m and is unlikely that a fish could be exposed to this level at any position in the river.

It should be noted that this noise level is directly opposite a piling location in the River Tees and will attenuate further up or down the river. This level of 158 dB SPL_{RMS} at 200 m is somewhat higher than the background noise levels that have been found in the River Tees in the South Bank location. This was of the order of 105 dB to 115 dB SPL_{RMS} at lowest, but often subject to levels of up to 150 dB SPL_{RMS} when vessels pass, or other noise sources are present. Based on the predicted piling noise levels at the greatest distance in Table 2-2 (151 dB SPL_{RMS} at 400 m), the noise level at the furthest 'line of sight' of the piling (around Middlesbrough Dock) using a reasonable estimation for noise attenuation in the water (15.log(r) geometric spreading), the noise level would drop to 139 dB SPL_{RMS}. This would still be above the background noise levels and thus likely to be audible.

The noise level predicted at the opposite side of the river (~300 m), 153 dB SPL_{RMS}, is slightly over the behavioural reaction threshold of 150 dB SPL_{RMS}. As this threshold is only for a "behavioural reaction" rather than the somewhat stronger response of aversive behaviour that would lead to an effective barrier

in the river, and the relative insensitivity of the fish under consideration, it is thought that the noise from piling on land is unlikely to impede their passage during piling.

It is worth noting that any motorised vessel present in the river will produce noise levels considerably in excess of background noise and be of a similar order or greater than the noise level produced during this construction activity for much of the stretch of river on which South Bank lies.

4.2 Marine mammals

The potential presence of seals is noted. Any individual marine mammal is unlikely to be in the vicinity of South Bank or remain there for extended periods, but for the purposes of an assessment, it has been assumed that an individual would remain stationary for half an hour in the middle of the river directly opposite the piling location.

Based on a predicted noise level of 159 dB SEL_{ss} at 150 m from a pile, this is approximately equivalent to 85 dB SEL_{cum} re 1 μPa^2s (unweighted), as for the fish assessment. Using the sound exposure level metric required by Southall *et al.* (2019), to correctly assess risk of injury (PTS or TTS) to marine mammals, a weighting should be applied to each species hearing group. For seals (phocid carnivores) exposed to percussive piling noise at this range, the weighting is approximately equivalent to 21 dB, which means that the cumulative exposure would be 164 dB SEL_{cum} (PCW). This is 6 dB lower than the assessment criteria for TTS for impulsive noise for seals shown in Table 3-2 and 21 dB below the PTS threshold, despite the worst case assumptions applied.

The lowest SPL_{peak} threshold of 212 dB (unweighted) for TTS in seals is 26 dB higher than the noise level predicted at 100 m and is not expected to be reached at any position in the river during piling.

5 Conclusions

The potential impact of underwater noise produced by the percussive piling activities of the proposed quay wall at South Bank on fish (salmon, sea trout, eel, lamprey and smelt) and seals in the River Tees has been assessed. All piling will be undertaken on land, out of the water. Due to the complexity of the propagation of sound through the ground and into water, assumptions based on measured data have been made to estimate a conversion factor between source-to-receiver direct transmission and indirect transmission from piling on land. Based on criteria for potential injury to fish (Popper *et al.* 2014) and phocid carnivores (Southall *et al.* 2019), the risk from noise passing through the bank and into the River Tees and adversely affecting sensitive receptors is unlikely, even under highly precautionary assumptions.

Noise levels during piling will be below those that could potentially cause temporary threshold shift (short-term adverse effects on hearing) of fish or marine mammals, even under worst case conditions. The noise levels are predicted to reach approximately 153 dB SPL_{RMS} directly opposite the piling, based on previous measurements of piling noise in similar conditions. This is slightly above the suggested threshold for behavioural reactions of fish, noting that there is significant caution in the generalised use of this threshold.

The species under consideration are recognised as not being highly sensitive to noise. As the percussive piling, the noisiest expected activity, is expected to occur for up to 10 minutes a day, in up to four locations, the risk of any potential impacts, behavioural or otherwise, from piling on land is unlikely to lead to a barrier to passage for these species. The majority of the day would be subject to normal background noise conditions.

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