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PROPOSED PORT TERMINAL AT
FORMER TILBURY POWER STATION

TILBURY2

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VOLUME 6 PART B

ES APPENDIX 17.A: MONITORING BACKGROUND NOISE AND MODELLING OF CONSTRUCTION NOISE AT TILBURY DOCKS

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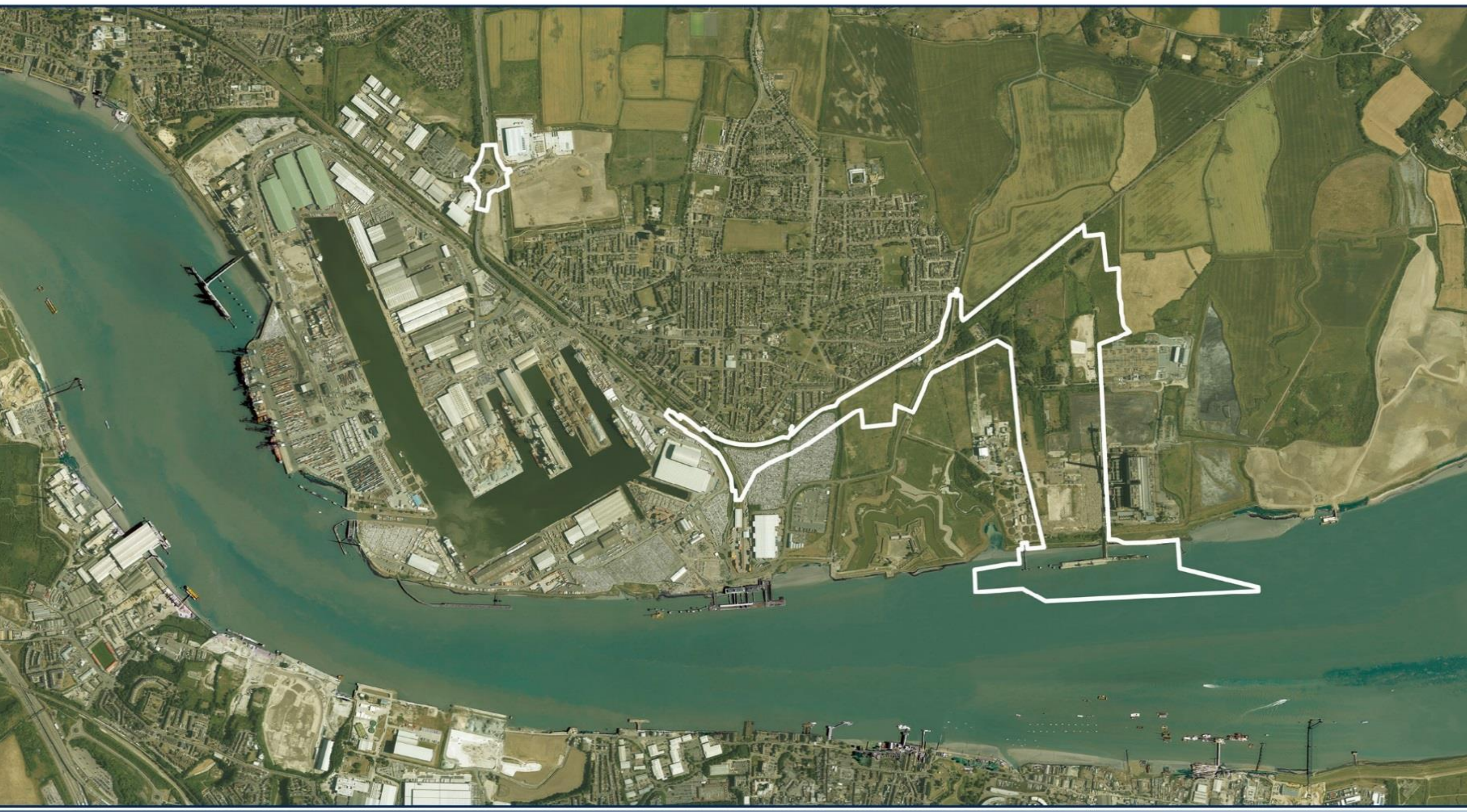

TILBURY2

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Monitoring background noise and modelling of construction noise at Tilbury Docks

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1 Introduction

Major development works have been proposed at the former Tilbury Power Station jetty, a part of Tilbury Docks in the Thames Estuary. The development of the site will involve impact piling operations to extend the existing jetty in the River Thames. These piling operations have the potential to generate underwater noise that could cause an impact on marine mammals and fish in the area.

To assess the potential environmental impact of works at the site, Subacoustech Environmental Ltd has undertaken a background noise survey from the existing Tilbury Power Station jetty to provide a baseline for noise levels in the area. In addition to this, underwater noise modelling has been carried out to ascertain noise levels that would surround the proposed jetty location during construction operations and ranges at which these could occur.

This report presents the results obtained from the background noise survey, the assessment criteria in respect of impacts on marine mammals and fish, and the modelling outputs for piling at the Tilbury Power Station jetty site.

2 Underwater noise

Sound travels much faster in water (approximately 1,500 ms^{-1}) than in air (340 ms^{-1}). Since water is a relatively incompressible, dense medium, the pressures associated with underwater sound tend to be much higher than in air. As an example, background noise levels in the sea of 130 dB re 1 µPa for UK coastal waters are not uncommon (Nedwell *et al.*, 2003a and 2007). It should be noted that stated underwater noise levels should not be confused with the noise levels in air, which use a different scale.

2.1.1 Units of measurement

Sound measurements underwater are usually expressed using the decibel (dB) scale, which is a logarithmic measure of sound. A logarithmic scale is used because rather than equal increments of sound having an equal increase in effect, typically a constant ratio is required for this to be the case. That is, each doubling of sound level will cause a roughly equal increase in “loudness”.

Any quantity expressed in this scale is termed a “level”. If the unit is sound pressure, expressed on the dB scale, it will be termed a “Sound Pressure Level”. The fundamental definition of the dB scale is given by:

$$Level = 10 \times \log_{10}\left(\frac{Q}{Q_{ref}}\right)$$

where Q is the quantity being expressed on the scale, and Q_{ref} is the reference quantity.

The dB scale represents a ratio and, for instance, 6 dB really means “twice as much as…”. It is, therefore, used with a reference unit, which expresses the base from which the ratio is expressed. The reference quantity is conventionally smaller than the smallest value to be expressed on the scale, so that any level quoted is positive. For instance, a reference quantity of 20 µPa is used for sound in air, since this is the threshold of human hearing.

A refinement is that the scale, when used with sound pressure, is applied to the pressure squared rather than the pressure. If this were not the case, when the acoustic power level of a source rose by 10 dB the Sound Pressure Level would rise by 20 dB. So that variations in the units agree, the sound pressure must be specified in units of root mean square (RMS) pressure squared. This is equivalent to expressing the sound as:

$$Sound\ Pressure\ Level = 20 \times \log_{10}\left(\frac{P_{RMS}}{P_{ref}}\right)$$

For underwater sound, typically a unit of one micropascal (1 μPa) is used as the reference unit; a Pascal is equal to the pressure exerted by one Newton over one square metre; one micropascal equals one millionth of this.

Where not defined, all noise levels in this report are referenced to 1 μPa.

2.1.2 Sound pressure level (SPL)

The sound pressure level (SPL) is normally used to characterise noise and vibration of a continuous nature such as drilling, boring, continuous wave sonar, or background sea and river noise levels. To calculate the SPL, the variation in sound pressure is measured over a specific period to determine the Root Mean Square (RMS) level of the time varying und. The SPL can therefore be considered a measure of the average unweighted level of sound over the measurement period.

Where SPL is used to characterise transient pressure waves such as that from seismic airguns, underwater blasting or impact piling, it is critical that the period over which the RMS level is calculated is quoted. For instance, in the case of pile strike lasting, say, a tenth of a second, the mean taken over a tenth of a second will be ten times higher than the mean taken over one second. Often, transient sounds such as these are quantified using “peak” SPLs.

2.1.3 Peak sound pressure level (SPL_{peak})

Peak SPLs are often used to characterise sound transients from impulsive sources, such as percussive impact piling and seismic airgun sources. A peak SPL 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 further variation of this is the peak-to-peak SPL 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.

2.1.4 Sound exposure level (SEL)

When assessing the noise from transient sources such as blast waves, impact piling or seismic airgun noise, the issue of the duration of the pressure wave is often addressed by measuring the total acoustic energy (energy flux density) of the wave. This form of analysis was used by Bebb and Wright (1953, 1954a, 1954b and 1955), and later by Rawlins (1987) to explain the apparent discrepancies in the biological effect of short and long-range blast waves on human divers. More recently, this form of analysis has been used to develop criteria for assessing the injury range from fish for various noise sources (Popper *et al.*, 2014).

The sound exposure level (SEL) sums the acoustic energy over a measurement period, and effectively takes account of both the SPL of the sound source and the duration the sound is present in the acoustic environment. Sound Exposure (SE) is defined by the equation:

$$SE = \int_0^T p^2(t)dt$$

where p is the acoustic pressure in Pascals, T is the duration of the sound in seconds, and t is the time in seconds. The SE is a measure of the acoustic energy and, therefore, has units of Pascal squared seconds (Pa^2s).

To express the SE on a logarithmic scale by means of a dB, it is compared with a reference acoustic energy level (${p^2}_{ref}$) and a reference time (T_{ref}). The SEL is then defined by:

$$SEL = 10 \times \log_{10}\left(\frac{\int_0^T p^2(t)dt}{P^2{}_{ref}T_{ref}}\right)$$

By selecting a common reference pressure P_{ref} of 1 µPa for assessments of underwater noise, the SEL and SPL can be compared using the expression:

$$SEL = SPL + 10 \times \log_{10} T$$

where the SPL is a measure of the average level of broadband noise, and the SEL sums the cumulative broadband noise energy.

This means that, for continuous sounds of less than one second, the SEL will be lower than the SPL. For periods greater than one second, the SEL will be numerically greater than the SPL (i.e. for a sound of ten seconds duration, the SEL will be 10 dB higher than the SPL, for a sound of 100 seconds duration the SEL will be 20 dB higher than the SPL, and so on).

Weighted metrics for marine mammals have been proposed by the National Marine Fisheries Service (NMFS) 2016 and Southall *et al.,* 2007. These assign a frequency response to groups of marine mammals, and are discussed in detail in the following section.

2.2 Analysis of environmental effects

2.2.1 Background

Over the past 20 years it has become increasingly evident that noise from human activities in and around underwater environments can have an impact on the marine species in the area. The extent to which intense underwater sound might cause an adverse impact in a species is dependent upon the incident sound level, sound frequency, duration of exposure and/or repetition rate of an impulsive sound (see for example Hastings and Popper, 2005). As a result, scientific interest in the hearing abilities of aquatic species has increased. Studies are primarily based on evidence from high level sources of underwater noise such as blasting or impact piling, as these sources are likely to have the greatest environmental impact and therefore the clearest observable effects, although there has been more interest in chronic noise exposure over the last five years.

The impacts of underwater sound on marine species can be broadly summarised as follows:

- Physical traumatic injury and fatality;
- Auditory injury (either permanent or temporary); and
- Disturbance.

The following sections discuss the agreed criteria for assessing these impacts in species of marine mammal and fish.

2.2.2 Criteria to be used

The main metrics and criteria that have been used in this study to assess environmental effect come from two key papers covering underwater noise and its effects:

- The National Marine Fisheries Service guidance (NMFS, 2016) for marine mammals; and
- Sound exposure guidelines for fishes and sea turtles by Popper *et al.* (2014).

At the time of writing, these present the most authoritative criteria for assessing environmental effects for use in impact assessments.

2.2.2.1 Marine mammals

Until recently, Southall *et al.* (2007) has been the source of the most widely used criteria to assess the effects of noise on marine mammals. The criteria from Southall *et al.* (2007) are based on M-Weighted

SELs, which are generalised frequency weighting functions to filter underwater noise data to better represent the levels of underwater noise various marine species are likely to be able to hear. The authors group marine mammals into five groups, four of which are relevant to underwater noise (the fifth is for pinnipeds in air). For each group, an approximate frequency range of hearing is proposed based on known audiogram data, where available, or inferred from other information such as auditory morphology. Southall *et al.* (2007) proposed a series of noise level threshold criteria, covering auditory injury, TTS (temporary threshold shift, a short-term reduction in hearing acuity) and behavioural avoidance.

Recently, NMFS (2016) was published, and was co-authored by many of the same authors from the Southall *et al.* (2007) paper. This paper effectively updates the Southall *et al.* 2007 criteria for assessing the risk of auditory injury.

Similarly, to Southall *et al.* (2007), the NMFS (2016) guidance groups marine mammals into functional hearing groups and applies filters to the unweighted noise to approximate the hearing sensitivity of the receptor. The weightings applied are different to the “M-weightings” used in Southall *et al*. The hearing groups given in the NMFS (2016) are summarised in Table 2-1 and Figure 2-1. A further group for Otariid Pinnipeds is also given in the guidance for sea lions and fur seals but this has not been used in this study as those species of pinnipeds are not found in this region.

Hearing group	Example species	Generalised hearing range
Low Frequency (LF) Cetaceans	Baleen Whales	7 Hz to 35 kHz
Mid Frequency (MF) Cetaceans	Dolphins, Toothed Whales, Beaked Whales, Bottlenose Whales (including Bottlenose Dolphin)	150 Hz to 160 kHz
High Frequency (HF) Cetaceans	True Porpoises (including Harbour Porpoise	275 Hz to 160 kHz
Phocid Pinnipeds (PW) (underwater)	True Seals (including Harbour Seal)	50 Hz to 86 kHz

Table 2-1 Marine mammal hearing groups (from NMFS, 2016)

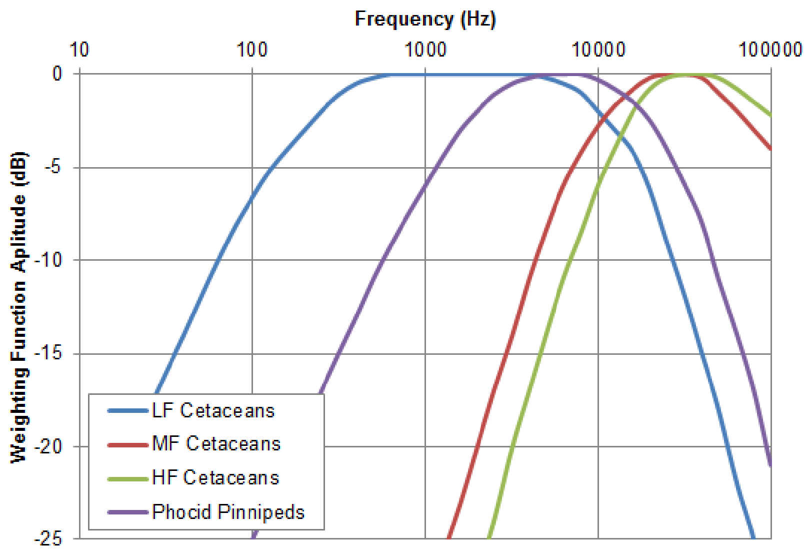

Figure 2-1 Auditory weighting functions for low frequency (LF) cetaceans, mid frequency (MF) cetaceans, high frequency (HF) cetaceans, and phocid pinnipeds (PW) (underwater) (from NMFS, 2016)

NMFS (2016) presents single strike, unweighted peak criteria (SPL_{peak}) and cumulative (i.e. more than a single sound impulse), weighted 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.

Table 2-2 presents the NMFS (2016) criteria for onset of risk of PTS and TTS for each of the key marine mammal hearing groups.

NMFS (2016)	**Unweighted SPL_{peak} (dB re 1 µPa)**	**Weighted SEL_{cum} (dB re 1 µPa^{2}s)**	
	Auditory injury (PTS)	**Auditory Injury (PTS)**	**TTS (Temporary Threshold Shift)**
Low Frequency (LF) Cetaceans	219	183	168
Mid Frequency (MF) Cetaceans	230	185	170
High Frequency (HF) Cetaceans	202	155	140
Phocid Pinnipeds (PW) (underwater)	218	185	170

Table 2-2 Criteria for assessment of auditory injury and TTS in marine mammals (NMFS, 2016)

Where SEL_{cum} are required, a fleeing animal model has been used. This assumes that the animal exposed to high noise levels will swim away from the noise source. For this a constant fleeing speed of 1.5 ms^{-1} has been assumed, which is a cruising speed for a harbour porpoise (Otani *et al.*, 2000). These are considered ‘worst case’ as marine mammals are expected to be able to swim much faster under stress conditions. The model assumes that a fleeing receptor stops if it reaches the coast before the noise exposure ends. The PTS and TTS criteria and results for low frequency cetaceans have been included for completeness although it is understood that species in this functional group are not considered a concern for this project.

Criteria for disturbance or behavioural reaction effects in marine mammals are in development by NMFS. For this assessment, thresholds as single strike SEL have been derived from data presented in Southall *et al.* (2007) for mid frequency and Lucke *et al.* (2009) for high frequency cetaceans. The disturbance threshold for seals is as per TTS. Criteria have not been presented for low frequency cetaceans, as these species are not generally present in the area.

Hearing group	**Behavioural reaction SEL re 1 µPa^{2}s**
Mid Frequency (MF) Cetaceans	160 dB
High Frequency (HF) Cetaceans	145 dB

Table 2-3 Criteria for assessment of disturbance/behavioural reaction in marine mammals

It is worth noting that the behavioural criteria are based on a limited dataset and behaviour will be highly context dependent.

2.2.2.2 Fish

The large variation in fish species leads to a greater challenge in production of a generic noise criterion, or range of criteria, for the assessment of noise impacts. Whereas previous assessments applied broad criteria based on limited studies of fish not present in UK waters (e.g. McCauley *et al.*, 2000), the publication of Popper *et al.* (2014) provides an authoritative summary of the latest research and guidelines for the assessment of fish exposure to sound.

The Popper *et al* (2014) study groups species of fish into whether they possess a swim bladder, and whether it is involved in its hearing. In the same way as NMFS (2016) the guidance gives specific criteria, as both SPL_{peak} and SEL_{cum} values, for a variety of noise sources. This assessment has used the criteria given for pile driving noise on fish where their swim bladder is involved in hearing, as these are the most conservative. The modelled criteria are summarised in Table 2-4. Similarly, to marine mammals for SEL_{cum} results, a fleeing animal model has been used assuming a receptor flees from the source at a constant rate of 1.5 ms^{-1} based on data from Hirata (1999).

Type of animal	Mortality and potential mortal injury	Impairment	
		Recoverable injury	**TTS (Temporary Threshold Shift)**
Fish: no swim bladder	>219 dB SEL_{cum} or >213 dB SPL_{peak}	>216 dB SEL_{cum} or >213 dB SPL_{peak}	>>186 dB SEL_{cum}
Fish: swim bladder is not involved in hearing	210 dB SEL_{cum} or >207 dB SPL_{peak}	203 dB SEL_{cum} or >207 dB SPL_{peak}	>186 dB SEL_{cum}
Fish: swim bladder involved in hearing	207 dB SEL_{cum} or >207 dB SPL_{peak}	203 dB SEL_{cum} or >207 dB SPL_{peak}	186 dB SEL_{cum}

Table 2-4 Criteria for assessment of mortality and potential mortal injury, recoverable injury and TTS in species of fish (Popper et al, 2014)

It is worth noting the use of “greater than” and “much greater than” in these criteria. The limited data available for the calculation of these figures leads to a significant uncertainty, especially with the less sensitive fish species, as to what could cause such effect, and so the guidance is restricted to effectively a statement that the effect is likely to occur at noise exposures greater than that stated, without being able to define the level. The consequence in this assessment, in respect to fish, is that the calculated contours are expected to be somewhat conservative and are therefore are likely to overstate the risk.

Popper *et al* also consider behavioural effects in fish, which are defined as “substantial change in behaviour for the animals exposed to a sound. This may include long-term changes in behaviour and distribution, such as moving from preferred sites for feeding and reproduction, or alteration of migration patterns.”

The Popper *et al* (2014) guidelines conclude that there is insufficient data available to apply quantitative thresholds for behavioural effects on fish. Therefore, the behavioural effects for fish in this study have been considered qualitatively.

3 Baseline noise survey

A survey of the prevailing underwater noise levels was undertaken to establish a baseline of existing noise levels. A static, long-term underwater noise monitor was installed between 28th June and 12th July 2017 to continuously record noise levels. This period covered both spring and neap tides.

The approach and methodolgy was designed in accordance with the guidelines provided in the NPL Good Practice Guidelines (2014).

3.1 Methodology

3.1.1 Location

Noise monitoring equipment was installed from a gantry between the main jetty and a small pier to the east. The location was chosen as it allowed for the hydrophone to be deployed away from structures in the water without presenting a risk to navigation.

The location is highly tidal with a tidal range of over 7 metres on the highest spring tides. The location chosen is on the inside of a bend in the river away from the main shipping channel the areas with the fast tidal stream to minimise the effect of water flow over the hydrophone.

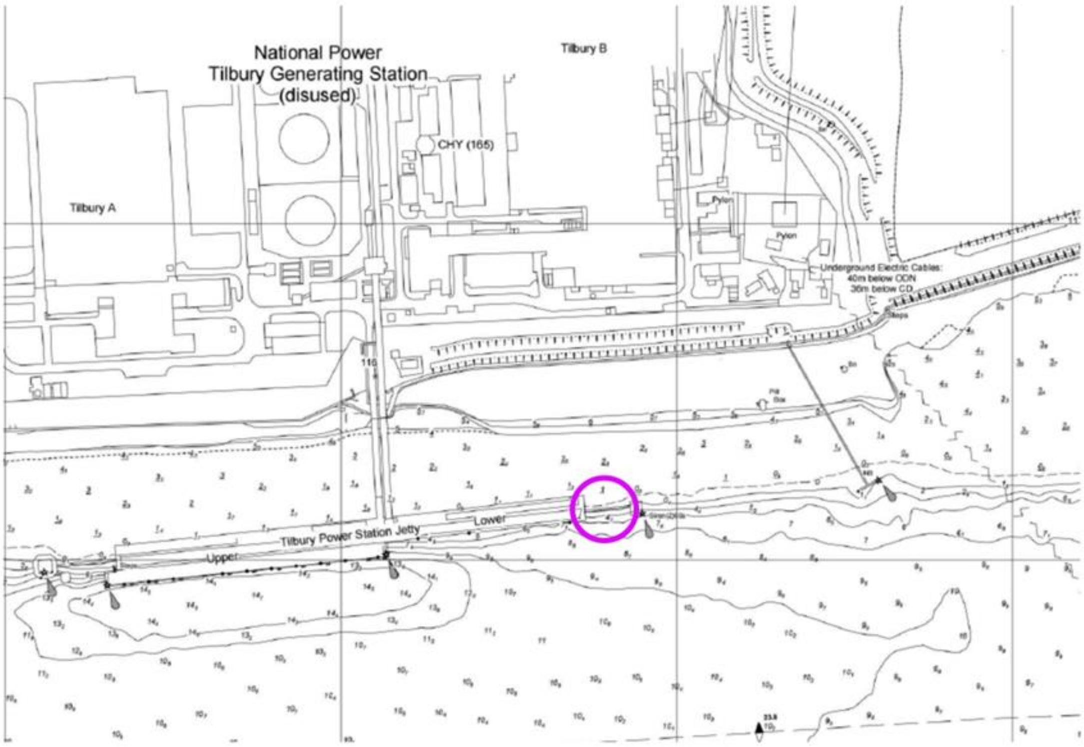

Figure 3-1 Location of baseline acoustic recorder. Image from Port of London Authority hydrographic survey

3.1.2 Equipment

The baseline noise assessment was undertaken using, a fully calibrated Ocean Sonics icListen HF-RB9 (Serial No. 1445) digital hydrophone. The hydrophone is a self-contained package consisting of a (Reson) transducer, battery, digital processing and recording system. The hydrophone was calibrated by the manufacturer within the past 2 years and calibrated prior to deployment on site using a laboratory pistonphone. The calibration certificate is given in Appendix B.

The hydrophone was configured to continuously log processed FFT data every second using a sampling rate of 32 kS/s. In addition, raw audio data (.wav) was recorded for 1 minute every 10 minutes at a sampling rate of 512 kS/s.

3.1.3 Deployment

The hydrophone was suspended on a line from the gantry with a 10 kg mass at the end of the line approximately one metre below the hydrophone. The arrangement was lowered into the water until the weight was firmly bedded in the sediment. The slack was then taken up and the line tided off. The mooring line both above and below the hydrophone was contained within a ribbed plastic sleeve to eliminate the effects of cable strum caused by hydrodynamic flow over the line under tension.

3.2 Results

The 1 second FFT data was processed to produce 10 second RMS values plotted as a time history in Figure 3-2. RMS values were used in accordance with the NPL 2014 guidelines as baseline noise is not expected to be impulsive in nature. Plotted alongside the noise data is the hourly tidal forecast data for Tilbury Docks published by the Port of London Authority.

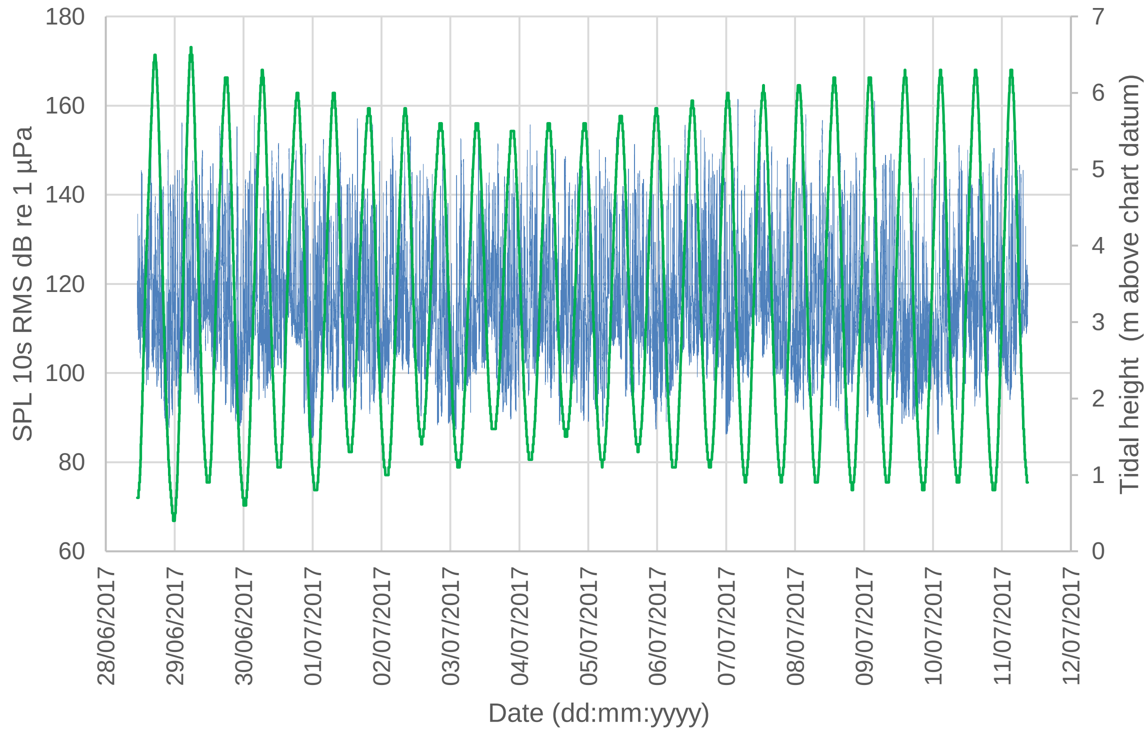

Figure 3-2 Underwater noise levels (10 second RMS SPLs) measured from Tilbury Power Station Jetty between 10:00 on 28/06/2017 and 08:00 on 11/07/2017

Baseline noise level is generally dependent on a mix of the movement of the water and sediment (especially in shallow water), weather conditions and shipping. There may also be a component of biological noise from marine mammal and fish vocalisation, as well as an element from invertebrates too.

In this instance, noise levels showed a high degree of variability and little correlation with tide height or tidal range. This is consistent with regular (but not continuous) vessel traffic transiting the area being the dominant contributor to average noise levels. The quietest periods were generally associated with night times and this is likely to be due to a reduction in vessel traffic.

The minimum, maximum and average noise levels for each day throughout the measurement period are presented in Table 3-1 and Table 3-2 below.

Date	28/06	29/06	30/06	01/07	02/07	03/07	04/07
Maximum dB $SPL_{RMS,10s}$	154.7	156.1	157.8	157.1	153.0	155.1	155.7
Minimum dB $SPL_{RMS,10s}$	87.8	88.1	85.4	85.5	88.4	87.3	88.4
Mean dB $SPL_{RMS,24hr}$	123.1	126.3	125.3	124.9	125.0	123.3	124.7

Table 3-1 Background noise levels sampled during the baseline noise survey (week 1)

Date	05/07	06/07	07/07	08/07	09/07	10/07	11/07
Maximum dB $SPL_{RMS,10s}$	152.9	155.7	161.5	158.0	161.1	151.1	152.2
Minimum dB $SPL_{RMS,10s}$	87.4	86.2	86.4	87.2	87.7	86.2	94.0
Mean dB $SPL_{RMS,24hr}$	123.8	125.6	126.4	125.1	122.5	124.4	124.3

Table 3-2 Background noise levels sampled during the baseline noise survey (week 2)

4 Piling noise modelling

4.1 Introduction

Modelling has been carried out using the INSPIRE underwater noise modelling software to ascertain noise levels from proposed piling operations in the River Thames at Tilbury.

The modelling considered four scenarios: two locations at high and low tide, which typically lead to the maximum and minimum noise propagation conditions, respectively. Tidal data was obtained from the Port of London Authority. The high tide modelling was undertaken at Mean High Water Springs (MHWS) and low tide at Mean Low Water Springs (MLWS). These are 6.4 m above LAT and 0.5 m above LAT respectively. The two locations are as follows:

East	West
51.4495° LAT 0.3922° LON	51.4495° LAT 0.3802° LON

Table 4-1 Piling location coordinates used in modelling

Modelling was undertaken assuming a 3.5 m diameter monopile with a maximum hammer blow energy of 555 kJ and also with a 610 mm pile with a blow energy of 74 kJ.

The actual piles and blow energy to be used was unknown at the time of modelling and as such the estimated blow energies was chosen as representative of maximum energies that may typically be used based on Subacoustech Environmental’s experience on similar projects. The locations used are the most eastern and western piling locations for the construction works.

Piling durations of one hour and a blow rate of one strike per second have been assumed in the modelling. As above, data specific to the Port of Tilbury project is not available, but these parameters are representative of similar piling projects seen by Subacoustech Environmental in the River Thames and other locations.

The outputs from the INSPIRE modelling are presented as maximum impact range tables and contour plot figures based upon absolute, unweighted noise levels and weighted noise levels for low, mid and high frequency cetaceans in as well as for phocid pinnipeds. Weightings for marine mammals are taken from the National Marine Fisheries Service (NOAA) in the United States (NMFS, 2016). Also highlighted is the range at which Popper *et al*, 2014 criteria of 186 dB SEL re 1 µPa^{2}s for temporary threshold shift in fish is exceeded.

4.2 INSPIRE Modelling

Subacoustech’s INSPIRE model has been used in this study. INSPIRE is a semi-empirical, range dependent propagation model that is built on a large amount of measured data from a range of piling projects in UK waters. It takes full account of bathymetry and tidal conditions.

INSPIRE was previously used to model potential noise levels from piling on the River Thames for the Tideway project. Measurements were taken during the subsequent pile installations and the results were found to be in good agreement (within 1-2 dB) with the INSPIRE predictions giving confidence to the use of INSPIRE in this case.

4.3 Source levels

Underwater noise propagation modelling requires knowledge of the source level, which is the theoretical noise level at 1 m from the noise source. Subacoustech have undertaken numerous measurements of in-water impact piling and for piles on this scale have developed a sound level model based on the pile diameter and blow energy used during a piling operation. For smaller piles and have been shown to be primary factors when comparing piling operations and the subsequent subsea noise levels produced.

Figure 4-1 source level curve fit to the measured data. This holds well for the smaller pile sizes, although when considering the pile sizes in excess of 4 m the calculation is more complex. Note also that the curve shows the noise level in $SPL_{peak\text{-}to\text{-}peak}$, whereas the value used in the modelling against the NMFS and Popper *et al* criteria are in SPL_{peak}. For this noise type the SPL_{peak} is approximately 6 dB lower than the $SPL_{peak\text{-}to\text{-}peak}$.

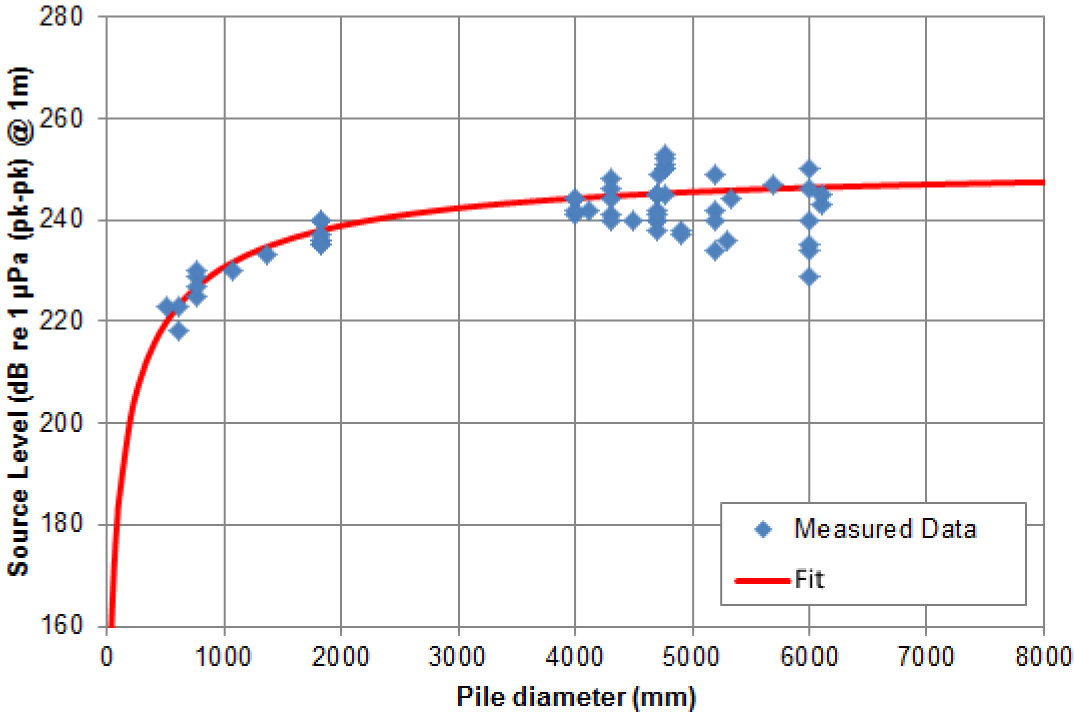

Figure 4-1 Pile diameter vs source level estimator, where line-of-fit is aligned conservatively near the top of the measured data

The predicted source noise levels used in the modelling are given in Table 4-2. An additional conversion factor is used to determine the equivalent SEL for a pile strike, based on Subacoustech's database of measured noise levels from piling events.

	Source Level	
	SPL_{peak}, re 1 µPa	SEL, re 1 µPa²s
3.5 m Pile, 555 kJ	238.8 dB	212.3 dB
610 m Pile, 74 kJ	217.2 dB	187.1 dB

Table 4-2 Source noise levels (unweighted) used in modelling

5 Modelling Results

5.1 3.5 m Piles

The range outputs for the underwater noise modelling of the larger 3.5 m piles are outlined in the following sections in respect of the two modelled locations, and tidal depths. The maximum, minimum and mean ranges at which the various criteria are reached are identified. Due to the shape of the river, the minimum is typically limited to the point at which the transect reaches the nearest riverbank. The maximum range will always be in an unrestricted transect directly up or downstream from the piling location. All contour plots are presented in 7Appendix A.

5.1.1 *Marine mammals – permanent threshold shift (PTS)*

The following tables show the SPL_{peak} and SEL_{cum} ranges for marine mammals, modelled to the criteria NMFS (NOAA) 2016 criteria detailed in section 2.2.2. The SEL_{cum} exposure ranges assume that the animal flees from the noise at a speed of 1.5 m/s, and the range represents the distance that the animal must be at the start of piling in order to not exceed the criteria.

LF cetacean	East				West			
	Unweighted SPL_{peak} 219 dB		Weighted SEL_{cum}, 183 dB threshold		Unweighted SPL_{peak} 219 dB		Weighted SEL_{cum}, 183 dB threshold	
Tide	MHWS	MLWS	MHWS	MLWS	MHWS	MLWS	MHWS	MLWS
Max	40	40	3550	2800	40	40	3900	3250
Min	30	30	150	100	30	30	150	100
Mean	35	35	859	719	35	35	747	642

Table 5-1 Range in metres for low frequency cetaceans – PTS thresholds

MF cetacean	East				West			
	Unweighted SPL_{peak} 230 dB		Weighted SEL_{cum}, 185 dB threshold		Unweighted SPL_{peak} 230 dB		Weighted SEL_{cum}, 185 dB threshold	
Tide	MHWS	MLWS	MHWS	MLWS	MHWS	MLWS	MHWS	MLWS
Max	20	20	50	50	20	20	100	50
Min	10	10	50	50	10	10	50	50
Mean	15	15	50	50	15	15	51	50

Table 5-2 Range in metres for mid frequency cetaceans – PTS thresholds

HF cetacean	East				West			
	Unweighted SPL_{peak} 202 dB		Weighted SEL_{cum}, 155 dB threshold		Unweighted SPL_{peak} 202 dB		Weighted SEL_{cum}, 155 dB threshold	
Tide	MHWS	MLWS	MHWS	MLWS	MHWS	MLWS	MHWS	MLWS
Max	160	140	4050	3250	160	150	4550	3800
Min	140	110	150	100	140	110	150	150
Mean	153	132	900	772	153	138	783	689

Table 5-3 Range in metres for high frequency cetaceans – PTS thresholds

Pinn.	East				West			
	Unweighted SPL_{peak} 218 dB		Weighted SEL_{cum}, 185 dB threshold		Unweighted SPL_{peak} 218 dB		Weighted SEL_{cum}, 185 dB threshold	
Tide	MHWS	MLWS	MHWS	MLWS	MHWS	MLWS	MHWS	MLWS
Max	50	50	1750	1400	50	50	1900	1450
Min	40	40	150	100	40	40	150	100
Mean	45	45	593	472	45	45	528	433

Table 5-4 Range in metres for phocid pinnipeds – PTS thresholds

In all cases the weighted SEL_{cum} criteria set lead to the greatest ranges compared to the equivalent SPL_{peak}. Over the shorter ranges (<100 m) the depth of water has a negligible effect on sound propagation, greater propagation loss is evident at low tide and increased ranges.

The minimum ranges are limited by the nearest river bank. The maximum ranges are limited by the distance to the bend in the river at Cliffe Pools to the east of the site.

5.1.2 *Marine mammals – temporary threshold shift (TTS)*

The following tables show the modelled ranges within which a receptor receives exposure sufficient to cause TTS. As with the PTS, the range represents the distance that an animal must be from the noise source at the commencement of piling, before fleeing, for it to receive the stated dose.

LF cetacean	East		West	
	Weighted SEL_{cum}, 168 dB threshold		Weighted SEL_{cum}, 168 dB threshold	
Tide	MHWS	MLWS	MHWS	MLWS
Max	4450	3850	4950	4350
Min	150	100	150	150
Mean	929	800	805	712

Table 5-5 Range in metres for low frequency cetaceans – TTS thresholds

MF cetacean	East		West	
	Weighted SEL_{cum}, 170 dB threshold		Weighted SEL_{cum}, 170 dB threshold	
Tide	MHWS	MLWS	MHWS	MLWS
Max	2100	1650	2300	1800
Min	150	100	150	100
Mean	659	527	586	483

Table 5-6 Range in metres for mid frequency cetaceans – TTS thresholds

HF cetacean	East		West	
	Weighted SEL_{cum}, 140 dB threshold		Weighted SEL_{cum}, 140 dB threshold	
Tide	MHWS	MLWS	MHWS	MLWS
Max	4450	3900	5000	4400
Min	150	100	150	150
Mean	931	804	807	714

Table 5-7 Range in metres for high frequency cetaceans – TTS thresholds

Pinniped	East		West	
	Weighted SEL_{cum}, 170 dB threshold		Weighted SEL_{cum}, 170 dB threshold	
Tide	MHWS	MLWS	MHWS	MLWS
Max	4150	3350	4650	3950
Min	150	100	150	150
Mean	908	780	789	695

Table 5-8 Range in metres for phocid pinnipeds – TTS thresholds

The maximum ranges for marine mammals in respect of TTS are up to 5000 m for High Frequency Cetaceans (e.g. harbour porpoise), which largely encompasses the stretch of the River Thames between the bends at Cliffe Pools and the entrance to the existing Port of Tilbury.

The limitations in these results are the same as those identified for the PTS modelling: minimum ranges will not be greater than the distance to the nearest river bank and maximum ranges will not be greater than the distance from piling to the east to Cliffe Pools. Beyond this, line-of-sight will be lost and exposures will drop.

5.1.3 <u>Marine mammals – behavioural effects</u>

Avoidance/behavioural reaction in marine mammals for MF and HF cetaceans has been modelled using criteria derived from Southall *et al.* (2007) and Lucke *et al.* (2009). MF cetaceans are predicted to show avoidance behaviour at ranges up to 3,420 m from the piling. HF cetaceans are predicted to show avoidance behaviour out to 5,000 m from the piling, which encompasses the east-west stretch of the River Thames with effective line-of-sight to the piling. It should be noted that this is based on a single strike SEL as opposed to the cumulative SEL used for the TTS and PTS criteria above.

5.1.4 <u>Fish – PTS and TTS</u>

Results of the underwater noise modelling in respect of fish criteria as presented in Popper *et al.* 2014 are given in Table 5-9 and Table 5-10 below. All thresholds are unweighted and for the most sensitive species, i.e. those with a swim bladder.

Fish	East				West			
	Unweighted SPL_{peak} >207 dB		Unweighted SEL_{cum}, 203 dB threshold		Unweighted SPL_{peak} >207 dB		Unweighted SEL_{cum}, 203 dB threshold	
Tide	MHWS	MLWS	MHWS	MLWS	MHWS	MLWS	MHWS	MLWS
Max	90	80	200	150	90	80	250	200
Min	80	70	50	50	80	70	50	50
Mean	85	75	131	103	85	75	129	103

Table 5-9 Range in metres for fish (swim bladder involved in hearing) – recoverable injury thresholds

In accordance with the criteria in Popper *et al.* (2014), risk of recoverable injury in fish is limited to within 250 m at high tide, for the most sensitive fish species, and where line-of-sight is maintained for the duration of the piling. For fish species without a swim bladder, any range of impact is likely to be somewhat less than this, although a precise threshold has not been defined in the literature.

Fish	East		West	
	Unweighted SEL_{cum}, 186 dB threshold		Unweighted SEL_{cum}, 186 dB threshold	
Tide	MHWS	MLWS	MHWS	MLWS
Max	3300	2600	3600	3000
Min	150	100	150	100
Mean	832	694	726	621

Table 5-10 Range in metres for fish (swim bladder involved in hearing) – TTS thresholds

Risk of TTS in the most sensitive category of fish, where the species has a swim bladder connected to their hearing (e.g. herring), temporary, recoverable effects on the fishes' hearing could occur at most at 3,600 m from the piling, at high spring tides. This is worst case, where less sensitive species are expected to be at lower risk and have consequently a lower range over which a risk is posed.

5.1.5 Fish – behavioural effects

As stated in section 0, for effects where insufficient data exist to make recommendations for thresholds Popper *et al.* (2014) gives an indication of the relative risk of the effect. In each case three overarching distances for source are given along with a relative risk rating.

The three qualitative distances given are "near", "intermediate", and "far"; Popper *et al* (2014) states that "while it would not be appropriate to ascribe particular distances to effects because of the many variables in making such decisions, "near" might be considered to be in the tens of meters from the source, "intermediate" in the hundreds of meters, and "far" in the thousands of meters." These ranges are each given a risk rating or either "high", "moderate", or "low". The ratings are again split into noise type (in this case, pile driving) and type of fish.

Table 5-11 summarises the qualitative impacts for pile driving given by Popper *et al* (2014) for fish with swim bladders involved with their hearing, which are most sensitive. Table 5-12 shows the results from the two remaining categories, "no swim bladder" and "swim bladder not involved in hearing", which are less sensitive to sound.

Effect	**Near ranges**	**Intermediate ranges**	**Far ranges**
Behavioural	High risk	High risk	Moderate risk

Table 5-11 Summary of the qualitative impacts on fish with swim bladder involved in hearing (most sensitive)

Effect	**Near ranges**	**Intermediate ranges**	**Far ranges**
Behavioural	High risk	Moderate risk	Low risk

Table 5-12 Summary of the qualitative impacts on other species of fish

5.2 610 mm Piles

The range outputs for the underwater noise modelling of the smaller 0.61 m piles is outlined in the following sections in respect of the two modelled locations, and tidal depths. The maximum, minimum and mean ranges at which the various criteria are reached are identified. Given the small ranges, contour plots are of little benefit and are not presented.

Measurements undertaken by Subacoustech have demonstrated that impact piling of sheet piles generates similar underwater noise levels to small tubular piles (600-800 mm).

5.2.1 *Marine mammals – permanent threshold shift (PTS)*

The following tables show the SPL_{peak} and SEL_{cum} ranges for marine mammals, modelled to the criteria NMFS (NOAA) 2016 criteria detailed in section 2.2.2. The SEL_{cum} exposure ranges assume that the animal flees from the noise at a speed of 1.5 m/s, and the range represents the distance that the animal must be at the start of piling in order to not exceed the criteria.

LF cetacean	East				West			
	Unweighted SPL_{peak} 219 dB		Weighted SEL_{cum} 183 dB threshold		Unweighted SPL_{peak} 219 dB		Weighted SEL_{cum} 183 dB threshold	
Tide	MHWS	MLWS	MHWS	MLWS	MHWS	MLWS	MHWS	MLWS
Max	<10	<10	20	15	<10	<10	20	15
Min	<10	<10	10	10	<10	<10	10	10
Mean	<10	<10	17	13	<10	<10	16	13

Table 5-13 Range in metres for low frequency cetaceans for impact piling of a 610 mm pile – PTS thresholds

MF cetacean	East				West			
	Unweighted SPL_{peak} 230 dB		Weighted SEL_{cum} 185 dB threshold		Unweighted SPL_{peak} 230 dB		Weighted SEL_{cum} 185 dB threshold	
Tide	MHWS	MLWS	MHWS	MLWS	MHWS	MLWS	MHWS	MLWS
Max	<10	<10	<10	<10	<10	<10	<10	<10
Min	<10	<10	<10	<10	<10	<10	<10	<10
Mean	<10	<10	<10	<10	<10	<10	<10	<10

Table 5-14 Range in metres for mid frequency cetaceans for impact piling of a 610 mm pile – PTS thresholds

HF cetacean	East				West			
	Unweighted SPL_{peak} 202 dB		Weighted SEL_{cum} 155 dB threshold		Unweighted SPL_{peak} 202 dB		Weighted SEL_{cum} 155 dB threshold	
Tide	MHWS	MLWS	MHWS	MLWS	MHWS	MLWS	MHWS	MLWS
Max	<10	<10	115	85	<10	<10	120	90
35Min	<10	<10	40	30	<10	<10	40	35
Mean	<10	<10	75	57	<10	<10	72	58

Table 5-15 Range in metres for high frequency cetaceans for impact piling of a 610 mm pile – PTS thresholds

Pinniped	East				West			
	Unweighted SPL_{peak} 218 dB		Weighted SEL_{cum} 185 dB threshold		Unweighted SPL_{peak} 218 dB		Weighted SEL_{cum} 185 dB threshold	
Tide	MHWS	MLWS	MHWS	MLWS	MHWS	MLWS	MHWS	MLWS
Max	<10	<10	<10	<10	<10	<10	<10	<10
Min	<10	<10	<10	<10	<10	<10	<10	<10
Mean	<10	<10	<10	<10	<10	<10	<10	<10

Table 5-16 Range in metres for pinnipeds for impact piling of a 610 mm pile – PTS thresholds

The maximum PTS impact ranges is 120 m for SEL_{cum} HF cetaceans at the West pile. For all MF cetaceans and pinnipeds the impact range for PTS is very small.

5.2.2 Marine mammals – temporary threshold shift (TTS)

The following tables show the modelled ranges within which a receptor receives exposure sufficient to cause TTS. As with the PTS, the range represents the distance that an animal must be from the noise source at the commencement of piling, before fleeing, for it to receive the stated dose.

LF cetacean	East		West	
	Weighted SEL_{cum} 168 dB threshold		Weighted SEL_{cum} 168 dB threshold	
Tide	MHWS	MLWS	MHWS	MLWS
Max	1650	1300	1800	1400
Min	150	100	150	100
Mean	576	456	514	421

Table 5-17 Range in metres for low frequency cetaceans for impact piling of a 610 mm pile – TTS thresholds

MF cetacean	East		West	
	Weighted SEL_{cum} 170 dB threshold		Weighted SEL_{cum} 170 dB threshold	
Tide	MHWS	MLWS	MHWS	MLWS
Max	50	50	50	50
Min	50	50	50	50
Mean	50	50	50	50

Table 5-18 Range in metres for mid frequency cetaceans for impact piling of a 610 mm pile – TTS thresholds

HF cetacean	East		West	
	Weighted SEL_{cum} 140 dB threshold		Weighted SEL_{cum} 140 dB threshold	
Tide	MHWS	MLWS	MHWS	MLWS
Max	2700	2150	2900	2350
Min	150	100	150	100
Mean	751	614	661	556

Table 5-19 Range in metres for high frequency cetaceans for impact piling of a 610 mm pile – TTS thresholds

Pinniped	East		West	
	Weighted SEL_{cum} 170 dB threshold		Weighted SEL_{cum} 170 dB threshold	
Tide	MHWS	MLWS	MHWS	MLWS
Max	250	200	300	200
Min	100	50	100	50
Mean	164	125	156	123

Table 5-20 Range in metres pinnipeds for impact piling of a 610 mm pile – TTS thresholds

As with PTS, TTS ranges for MF cetaceans and pinnipeds are comparatively small and the maximum range is 2900 m for HF cetaceans.

5.2.3 Marine mammals – behavioural effects.

Avoidance/behavioural reaction in marine mammals for MF and HF cetaceans has been modelled using criteria derived from Southall *et al.* (2007) and Lucke *et al.* (2009). MF cetaceans are predicted to show avoidance behaviour at ranges up to 100 m from the piling. HF cetaceans are predicted to show avoidance behaviour out to 900 m from the piling, this extends across the width of the River Thames at the site. It should be noted that this is based on a single strike SEL as opposed to the cumulative SEL used for the TTS and PTS criteria above.

5.2.4 Fish – PTS and TTS

Results of the underwater noise modelling in respect of fish criteria as presented in Popper *et al.* 2014 are given in Table 5-21 and Table 5-22 below. All thresholds are unweighted and for the most sensitive species, i.e. those with a swim bladder.

Fish	East				West			
	Unweighted SPL_{peak} >207 dB		Weighted SEL_{cum} 203 dB threshold		Unweighted SPL_{peak} >207 dB		Weighted SEL_{cum} 203 dB threshold	
Tide	MHWS	MLWS	MHWS	MLWS	MHWS	MLWS	MHWS	MLWS
Max	<10	<10	<10	<10	<10	<10	<10	<10
Min	<10	<10	<10	<10	<10	<10	<10	<10
Mean	<10	<10	<10	<10	<10	<10	<10	<10

Table 5-21 Range in metres for fish (swim bladder involved in hearing) for impact piling of a 610 mm pile – recoverable injury thresholds

Fish	East		West	
	Weighted SEL_{cum} 186 dB threshold		Weighted SEL_{cum} 186 dB threshold	
Tide	MHWS	MLWS	MHWS	MLWS
Max	<10	<10	<10	<10
Min	<10	<10	<10	<10
Mean	<10	<10	<10	<10

Table 5-22 Range in metres for fish (swim bladder involved in hearing) for impact piling of a 610 mm pile – TTS thresholds

5.2.5 Fish – behavioural effects

The criteria identified in section 2.2.2.2 for fish behavioural effects is qualitative for pile driving and makes no distinction for different pile sizes therefore the risks identified for 3.5 m piles also apply for 610 mm piles. Given the reduction in noise levels the ranges identified for near field (tens of metres) intermediate (hundreds of metres) and far field (thousands of metres) would be expected to be lower for a 610 mm pile but the available literature does not allow for this to be quantified.

5.3 Discussion

All species of fish and marine mammal have their own weightings and thresholds, and based on these the greatest ranges of impact are modelled for the HF cetaceans (i.e. harbour porpoises). The LF cetaceans have the next highest ranges, although species falling in this category (see Table 2-1) would be rare in the location of concern.

For both pile sizes, the ranges of impact are typically slightly higher for the piling position furthest to the west, although the difference overall between the ranges calculated for the eastern and western extent is small. Similarly, the greatest noise propagation is found at high tide, with deeper water leading to larger ranges.

The cumulative SEL exposure criteria are calculated assuming that, over the piling duration, the animal flees from the noise in a straight line. As a worst-case scenario, if the animal reaches the coast, it remains in this position and continues to be exposed. However, it is not unreasonable to assume that, in practice, an animal would seek shelter or turn a corner in the river, and losing ‘line-of-sight’ to the noise source would substantially reduce the level of exposure. The calculation methodology therefore is somewhat conservative.

The River Thames at the site is up to 1 km in width. During installation of the larger piles the large ranges would likely deter fish and marine mammals from entering or passing through the area. The greatest PTS impact ranges with the smaller piles does not extend to the mid-point of the river and it would seem likely that species less sensitive to acoustic pressure (such as salmon and trout) may still be able to pass during installation however, this is highly context specific and depend on the biological imperative of the animals.

It is worth noting that the impacts will be limited to the period in which piling occurs, and this is likely to represent only a few hours of any given day.

6 Other underwater noise consideration

Other noise sources have been considered qualitatively as impact ranges are expected to be considerably smaller than those predicted for piling. In each case the range at which the noise level will drop below 140 dB is indicated. 140 dB was selected as it is between the maximum and average baseline noise level and as such provides an indication of the range at which the noise level falls within the range of levels that might be typically expected in the area. Ranges to the average baseline levels (123 dB re 1 µPa) are also included and in all cases the noise levels are unweighted and the ranges are therefore considered conservative.

6.1 Sheet piling

It is intended that sheet piling will be undertaken during the construction works. Detailed information regarding the installation methods were not available at the time of this study.

In the experience of Subacoustech, sheet piles are typically installed using a combination of vibro piling and, if required, impact piling. Vibro-piling has not been considered in detail and noise levels are generally very low in comparison to percussive piling. Previous studies have shown that percussive piling used to install sheet piles generates similar underwater noise levels to a small tubular pile (600-800 mm).

It is considered reasonable to use the modelling results from the 610 mm piles as an indicative measure of the likely impact of percussive piling of sheet piles until more detailed information is available.

Noise levels from vibro piling wound be expected to fall below 140 dB re 1 µPa within 870 m of the works.

6.2 Dredging

During the construction phase of the project, it is anticipated that dredging will be undertaken in addition to piling to make the jetty more accessible to larger vessels.

Underwater noise from dredging is highly dependent on the method used. For maintaining depths close to existing structures, backhoe dredging is commonly used. This method typically utilises an excavator mounted on a barge with all machinery located above the deck level.

Underwater noise from backhoe dredging is caused by noise from engines or hydraulic power units radiating through the hull of the barge into the water. As such, noise levels would be expected to be similar to a small vessel and below the noise levels produced by larger vessels underway which frequently transit the area. Noise levels would be expected to drop below 140 dB re. 1µPa within 20 m and below the average baseline noise level within 140 m.

For this reason, noise from backhoe dredging is unlikely to be significant and detailed modelling of backhoe dredging has not been undertaken.

Suction dredging does generate higher noise levels than backhoe dredging but is not considered to be a significant contributor to overall noise levels. Noise levels from suction dredging would be expected to drop to below 140 dB re 1µPa with 250 m and below average baseline noise with 1,500 m.

6.3 Operational

During operation, additional vessel traffic at the jetty will present an additional contribution to existing noise levels. The significance of this contribution is dependent on the size of vessel, number of additional vessel movements and the time vessels spend moored alongside the jetty. None of these is known at the time of the study and a qualitative review has been undertaken.

The River Thames is a busy commercial waterway with significant levels of existing vessel traffic. When vessels are alongside the jetty noise will be produced and radiated into the water from engines at idle or ancillary equipment such as generators and pumps. Noise levels from vessels alongside are expected to be significantly below the levels from existing traffic and so have negligible effect on the average noise levels except in the immediate vicinity (tens of metres) of the vessel. Noise levels from a stationary vessel would typically be expected to drop below the average baseline noise level within 120 m.

The additional noise resulting from vessel movements to and from the jetty is also expected to have minimal effect on the average noise levels in the river. A doubling of all vessel movements would be required to produce a 3 dB increase in average noise levels. Given the existing high levels of traffic, including large vessel manoeuvring in and out of the lock gates, the contribution from additional traffic to and from the jetty is unlikely to result in a significant increase in average noise levels. A more detailed study would be required to confirm or quantify this.

7 Summary and conclusions

Subacoustech Environmental has undertaken a study to assess existing baseline noise levels and the effect of impact piling noise during construction of the new port at Port of Tilbury. This report presents the results of the underwater noise measurements and modelling undertaken to ascertain the magnitude of these impacts to appropriate criteria.

The level of underwater noise from the installation of piles during construction has been estimated by using the INSPIRE underwater noise model. The modelling considers a wide variety of input parameters including bathymetry, hammer blow energy, pile size and the movement of a receptor species. INSPIRE has been previously used to estimate the level of noise from piling on the River Thames and subsequent measurements were in good agreement.

Two representative locations were chosen at the east and west of the site to give spatial variation. At each location, piles of 3.5 m and 610 mm were installed with a maximum hammer blow energy of 555 kJ and 74 kJ respectively were modelled. Ranges at each piling location were found to be similar for each pile size.

The modelling results were analysed in terms of relevant noise metrics to assess the impacts of the predicted impact piling noise on marine mammals (NMFS, 2016) and fish (Popper *et al.*, 2014). The receptors were broken down in terms of 'functional hearing groups' as per NMFS (2016) and Popper *et al*. (2014), and a summary of the ranges of impact for permanent threshold shift (PTS) and temporary threshold shift (TTS), underwater from piling, are given below for the worst case (3.5 m) piles:

Marine mammals

- Low frequency cetaceans (e.g. baleen whales): PTS could occur up to 3,900 m and TTS could occur up to 4,950 m from the piling.
- Mid frequency cetaceans (e.g. common dolphin): PTS could occur up to 100 m and TTS could occur up to 2,300 m from the piling.
- High frequency cetaceans (e.g. harbour porpoise): PTS could occur up to 4,550 m and TTS could occur up to 5,000 m from the piling.
- Pinnipeds (e.g. harbour seal): PTS could occur up to 1,900 m and TTS could occur up to 4,650 m from the piling in water.

Disturbance or avoidance effects are modelled to occur in mid-frequency and high frequency cetaceans at 3,420 m and 5,000 m range respectively. Avoidance in pinnipeds is modelled at 2,050 m, as per the TTS range. It should be noted that behavioural effects are highly context dependent.

Ranges for the smaller (610 mm) piles were considerably smaller and extend to 100 m for MF cetaceans and 900 m for HF cetaceans.

Fish

Fish species are highly varied and impact ranges have been modelled based on the species with the most sensitive hearing, those for which their swim bladders are associated with hearing (e.g. herring). These impact ranges are summarised below for the larger (3.5m) pile:

- Fish (swim bladder involved with hearing): recoverable injury could occur up to 250 m and TTS could occur up to 3,600 m from the piling.

As these impact ranges are associated with the most sensitive species of fish, they represent the worst case. Other species will be expected to have lower impact ranges.

Potential behavioural effects have been considered qualitatively for fish. At intermediate ranges (of the order of hundreds of metres from the piling) at least a moderate risk of behavioural effects exists. Beyond this a low risk exists, although there is a moderate risk for the most sensitive species of fish.

For the smaller (610 mm) pile TTS and PTS is only likely in the immediate vicinity of the pile (<10m)

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Appendix A Modelling results: contour plots

A.1 Marine mammals, 3,500 mm pile, eastern location

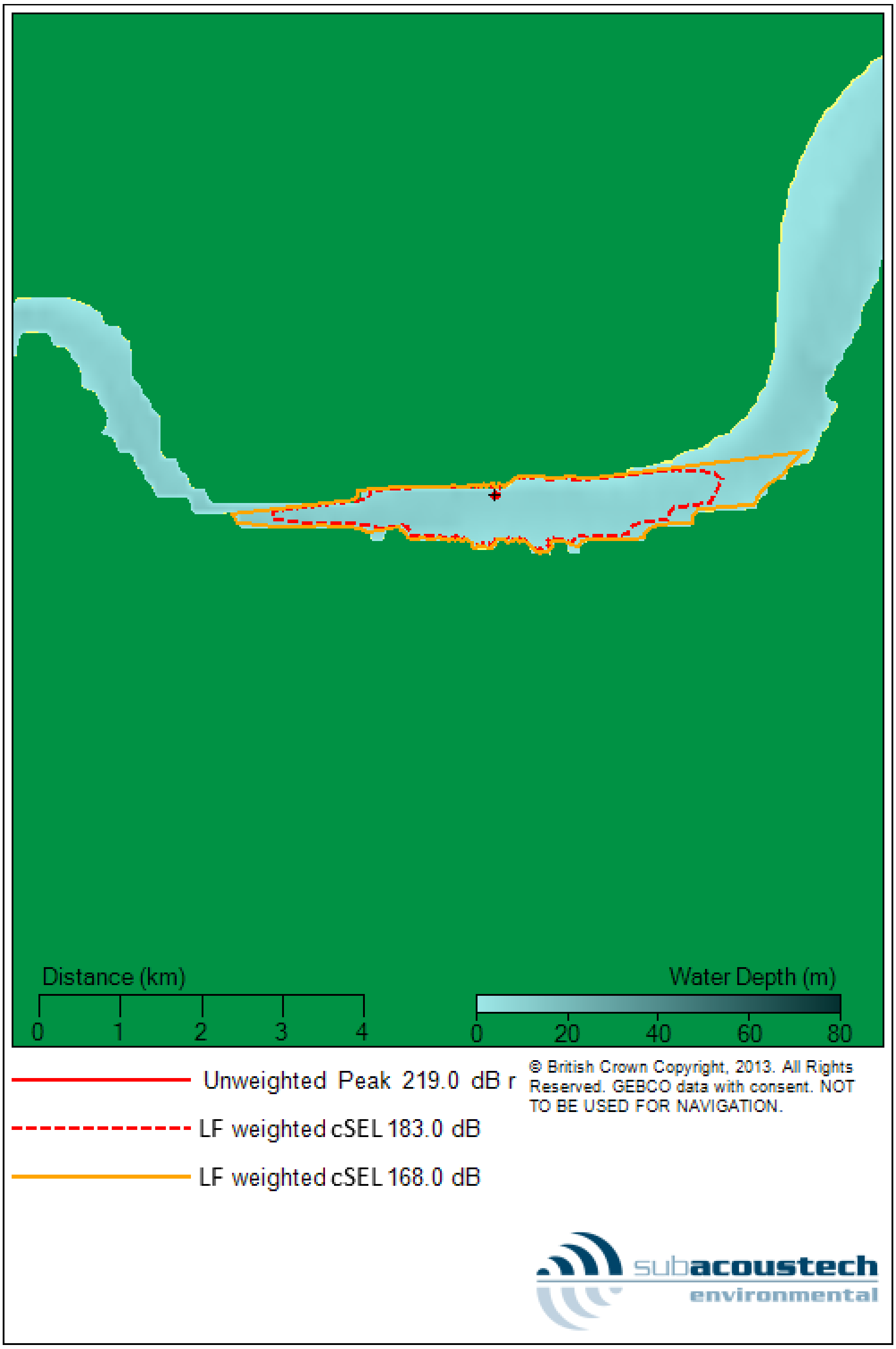


Figure 7-1 Low frequency cetacean weighted model of piling at low tide at the eastern location (3.5 m pile)

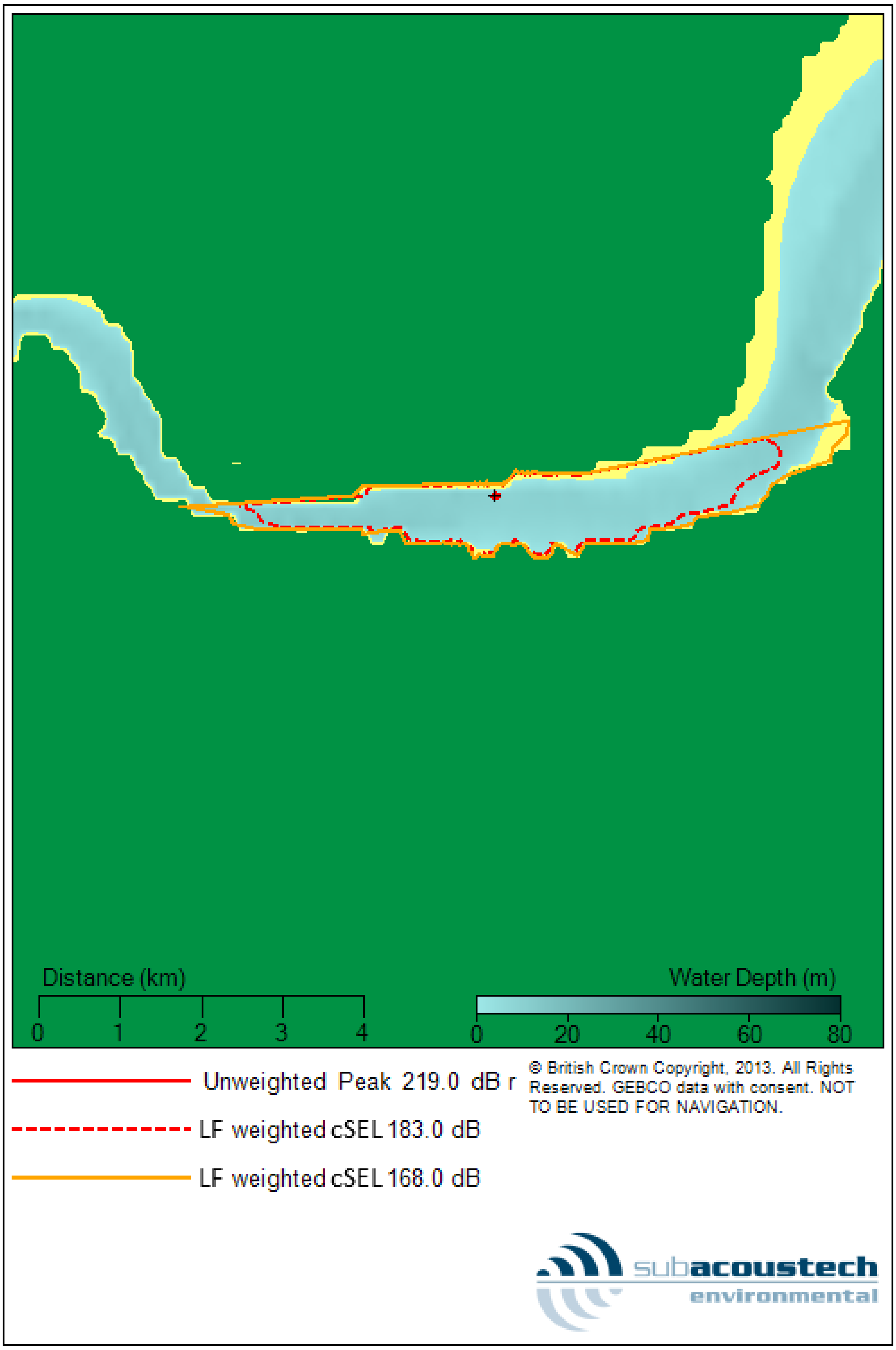


Figure 7-2 Low frequency cetacean weighted model of piling at high tide at the eastern location (3.5 m pile)

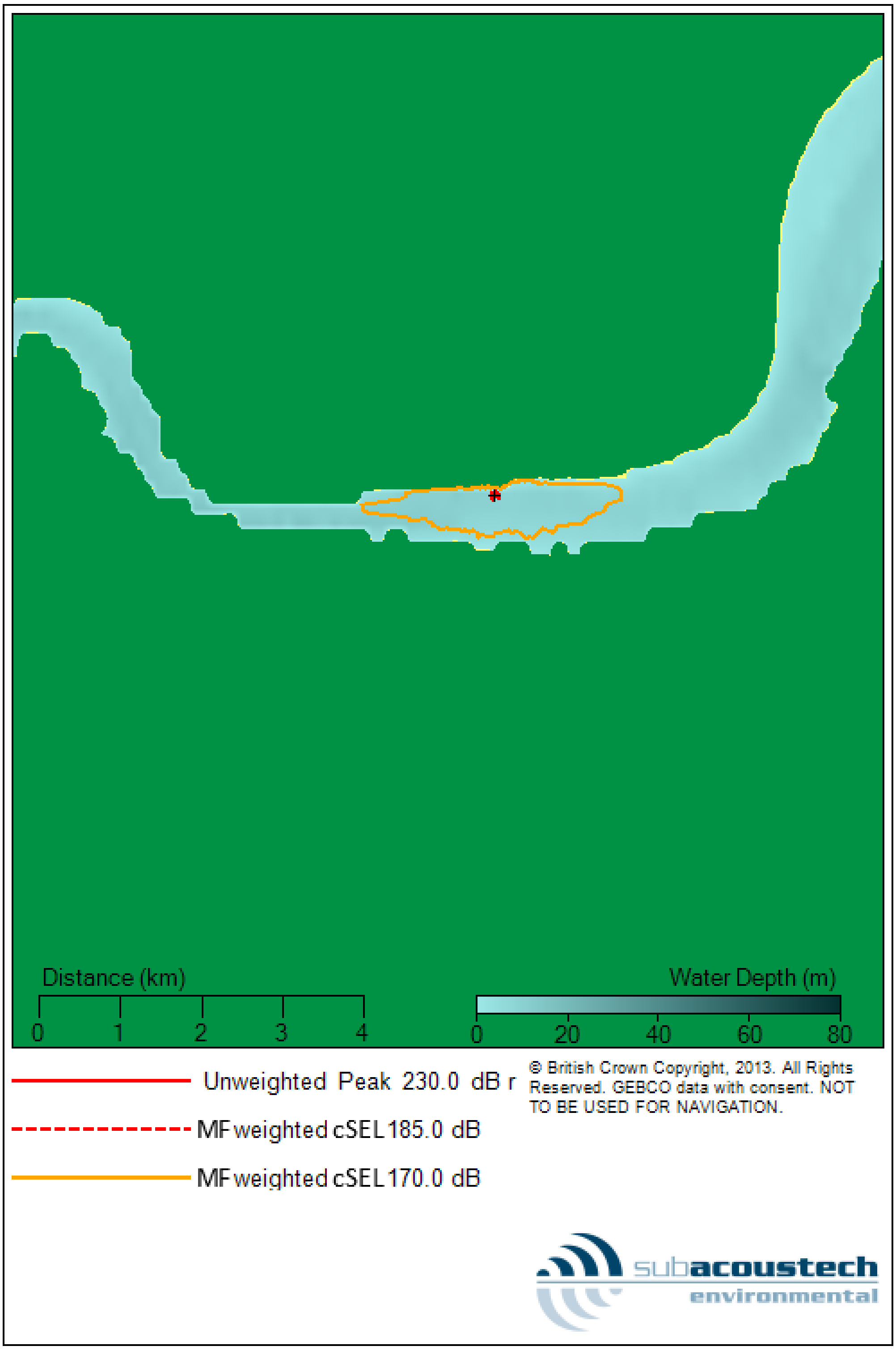


Figure 7-3 Mid frequency cetacean weighted model of piling at low tide at the eastern location (3.5 m pile)

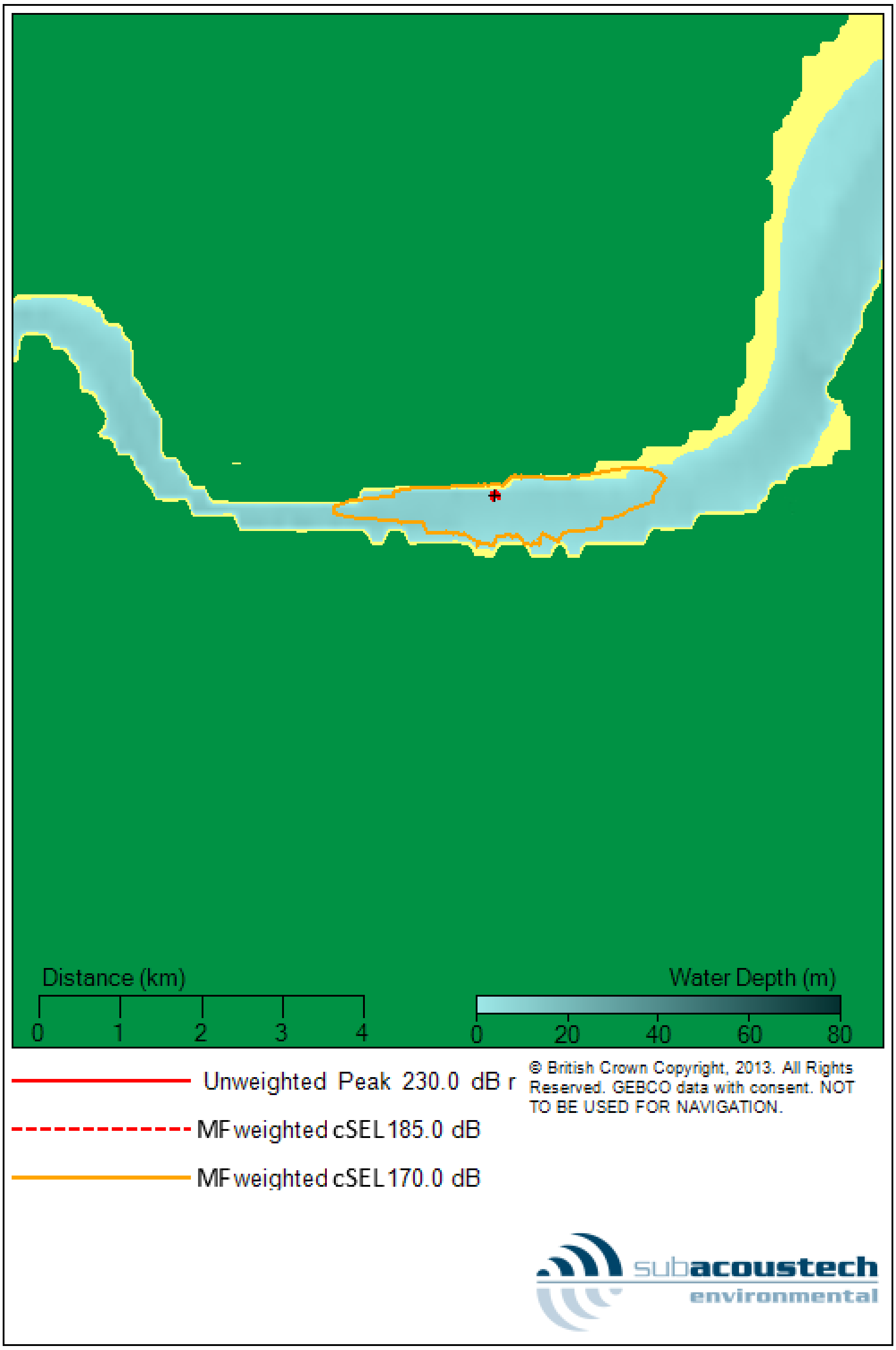


Figure 7-4 Mid frequency cetacean weighted model of piling at high tide at the eastern location (3.5 m pile)

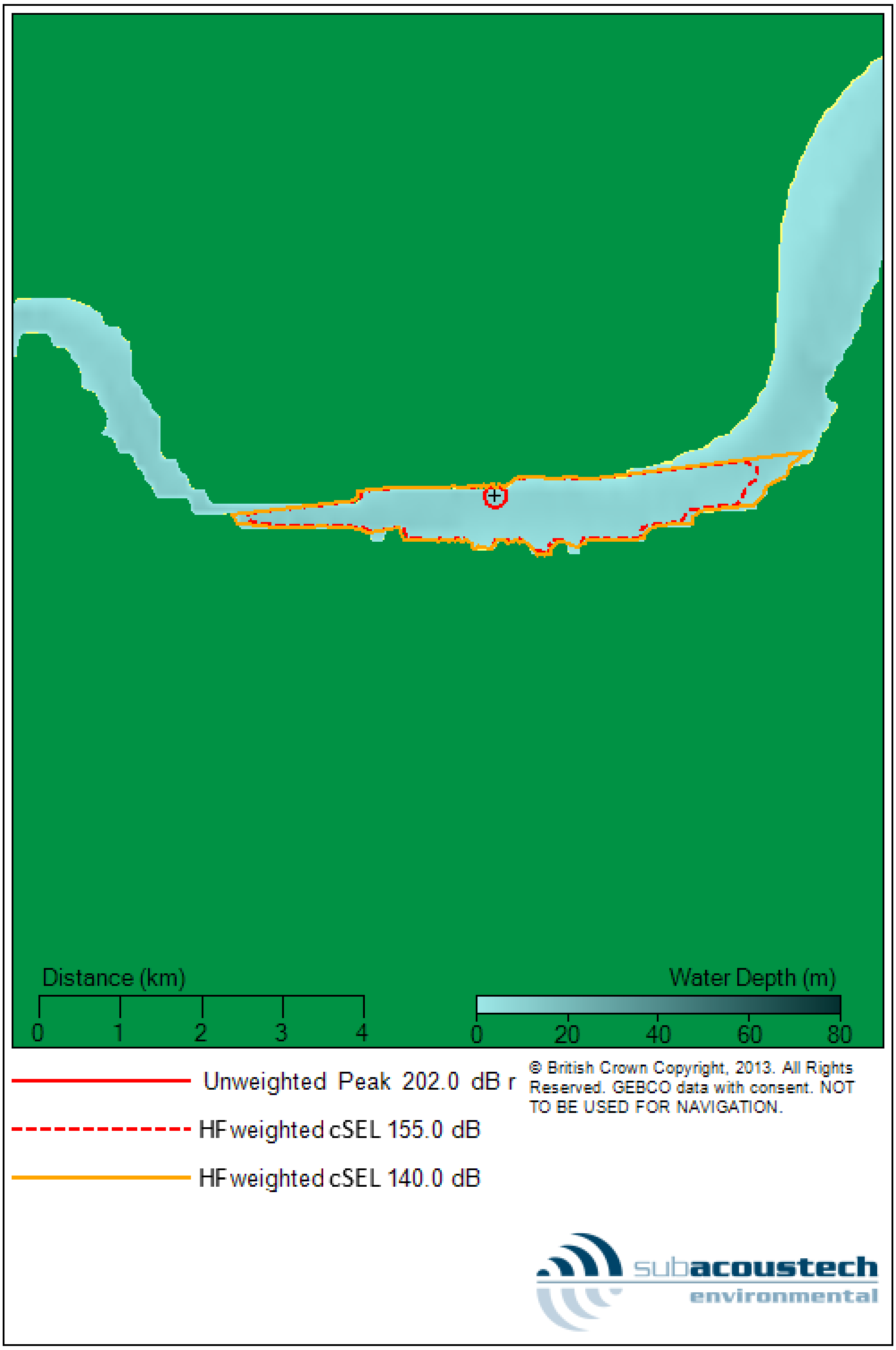


Figure 7-5 High frequency cetacean weighted model of piling at low tide at the eastern location (3.5 m pile)

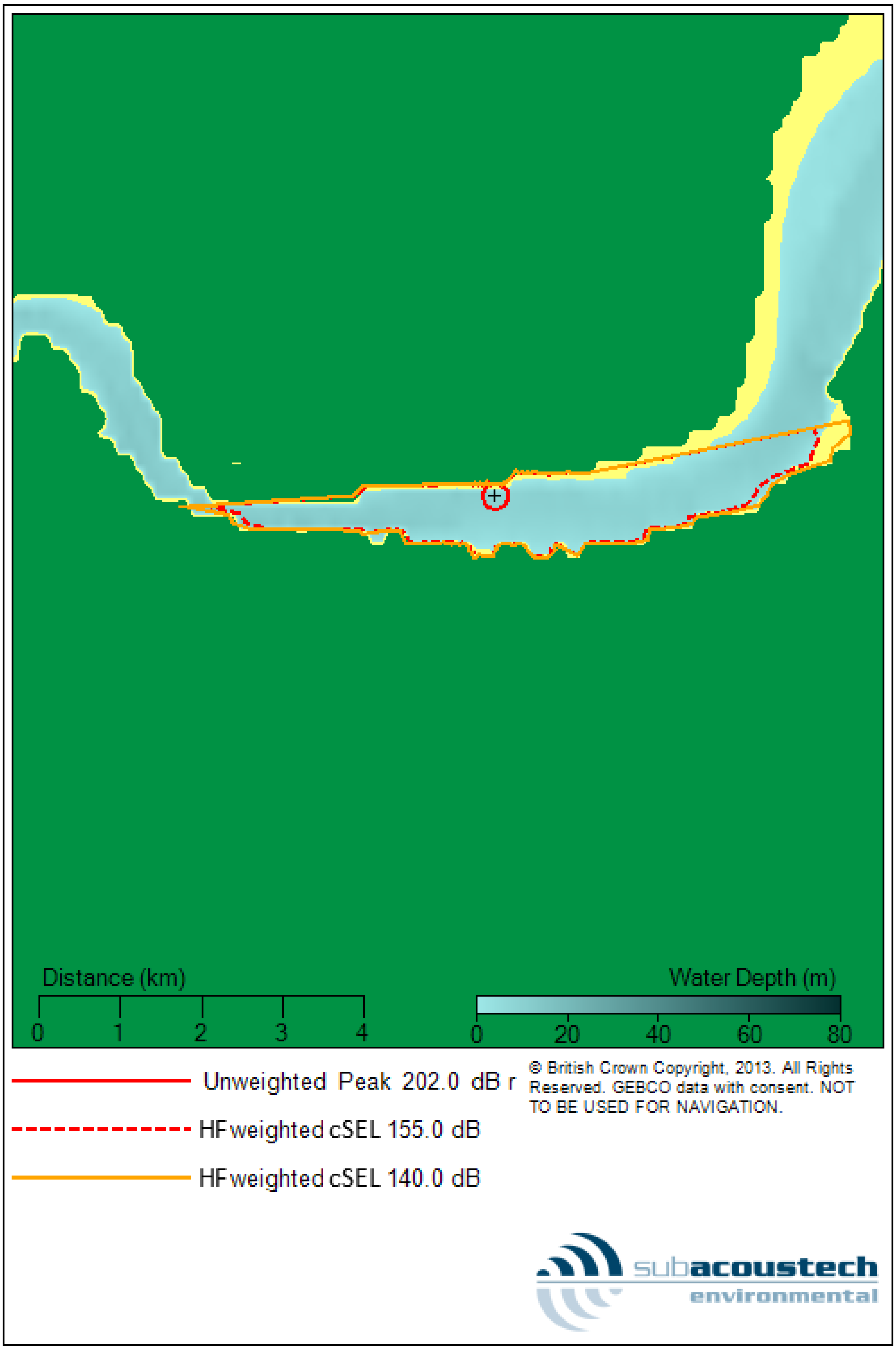


Figure 7-6 High frequency cetacean weighted model of piling at high tide at the eastern location (3.5 m pile)

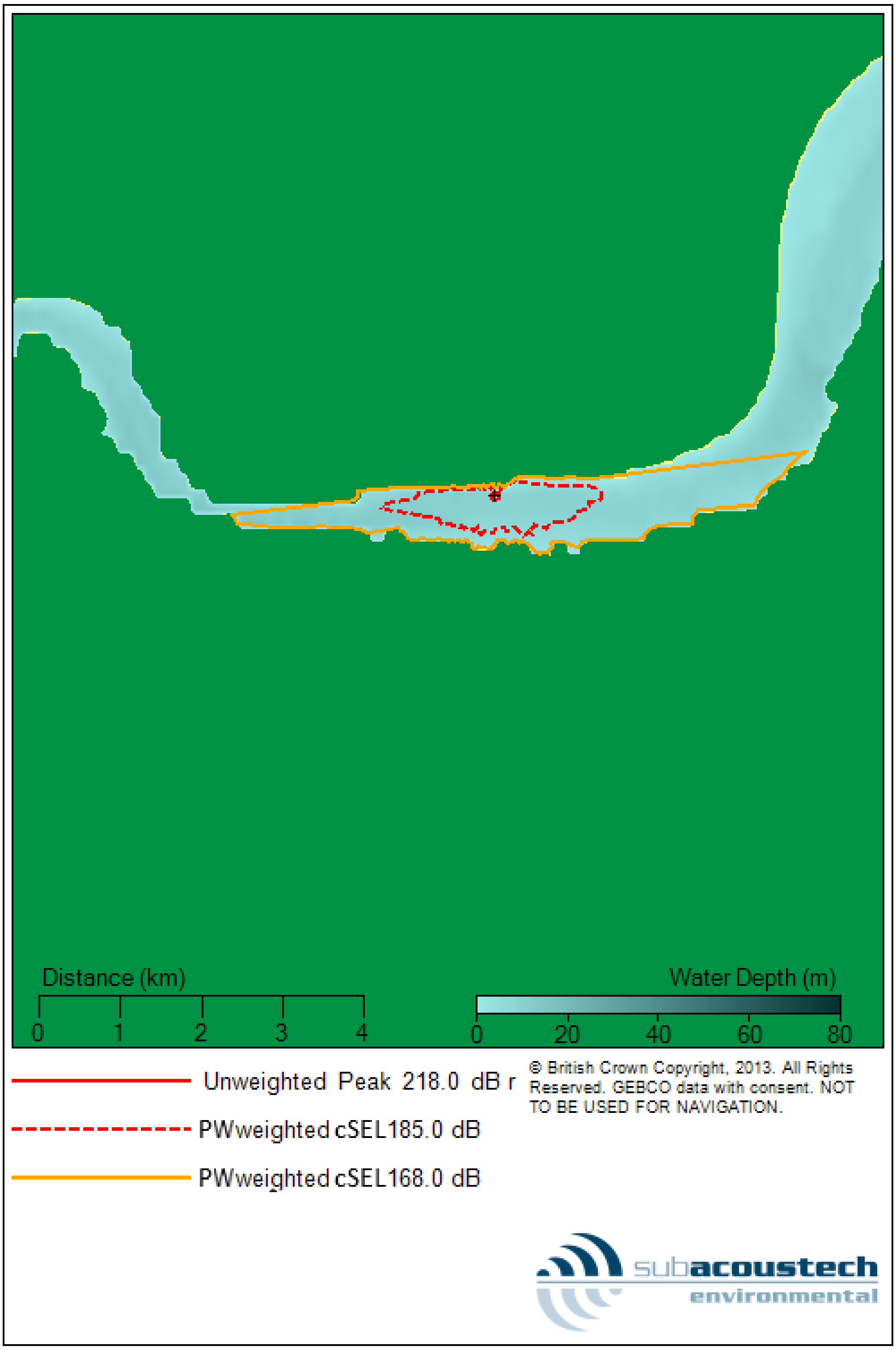


Figure 7-7 Phocid pinniped weighted model of piling at low tide at the eastern location (3.5 m pile)

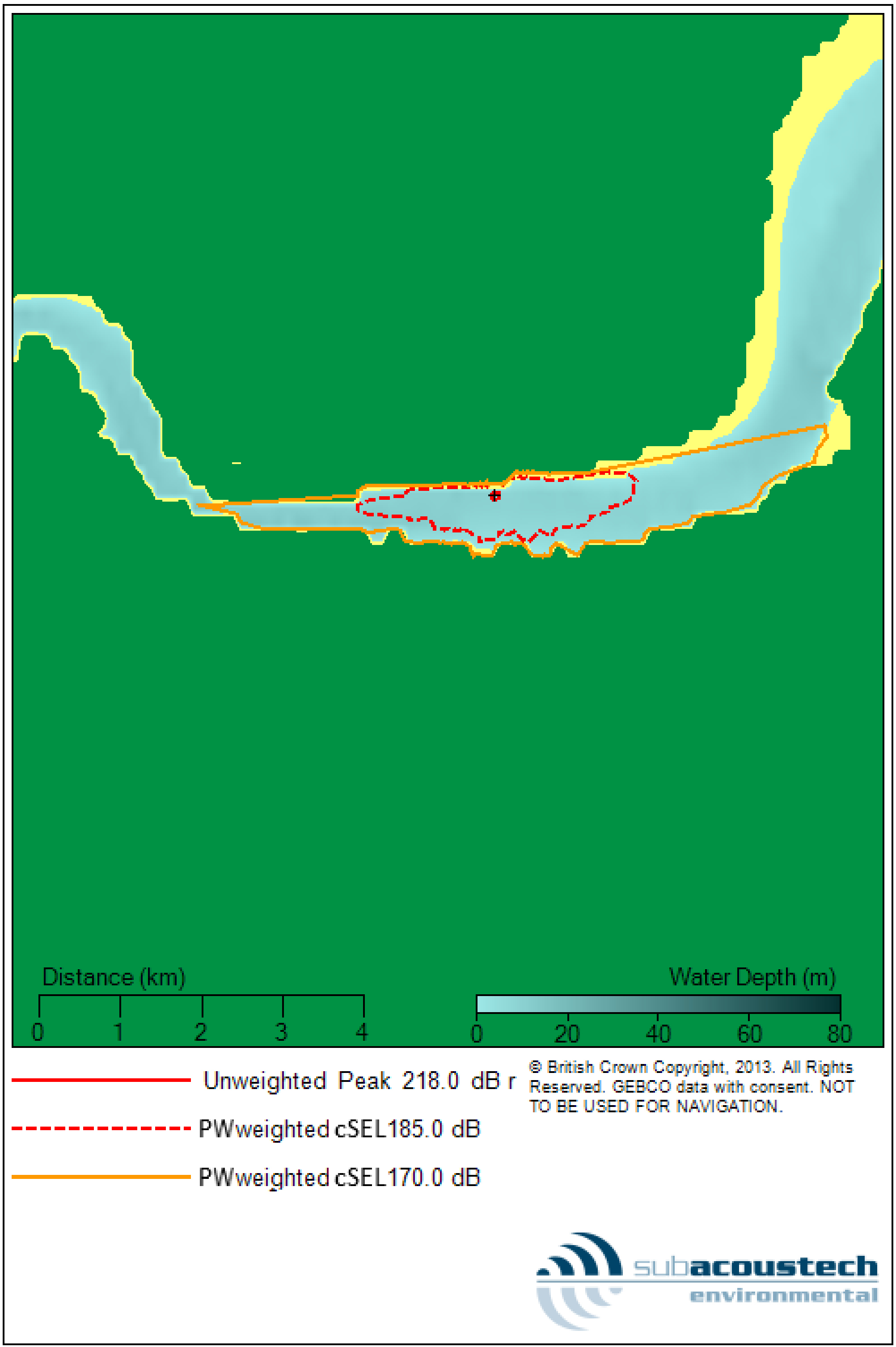


Figure 7-8 Phocid pinniped weighted model of piling at high tide at the eastern location (3.5 m pile)

A.2 Marine mammals, 3,500 mm pile, western location

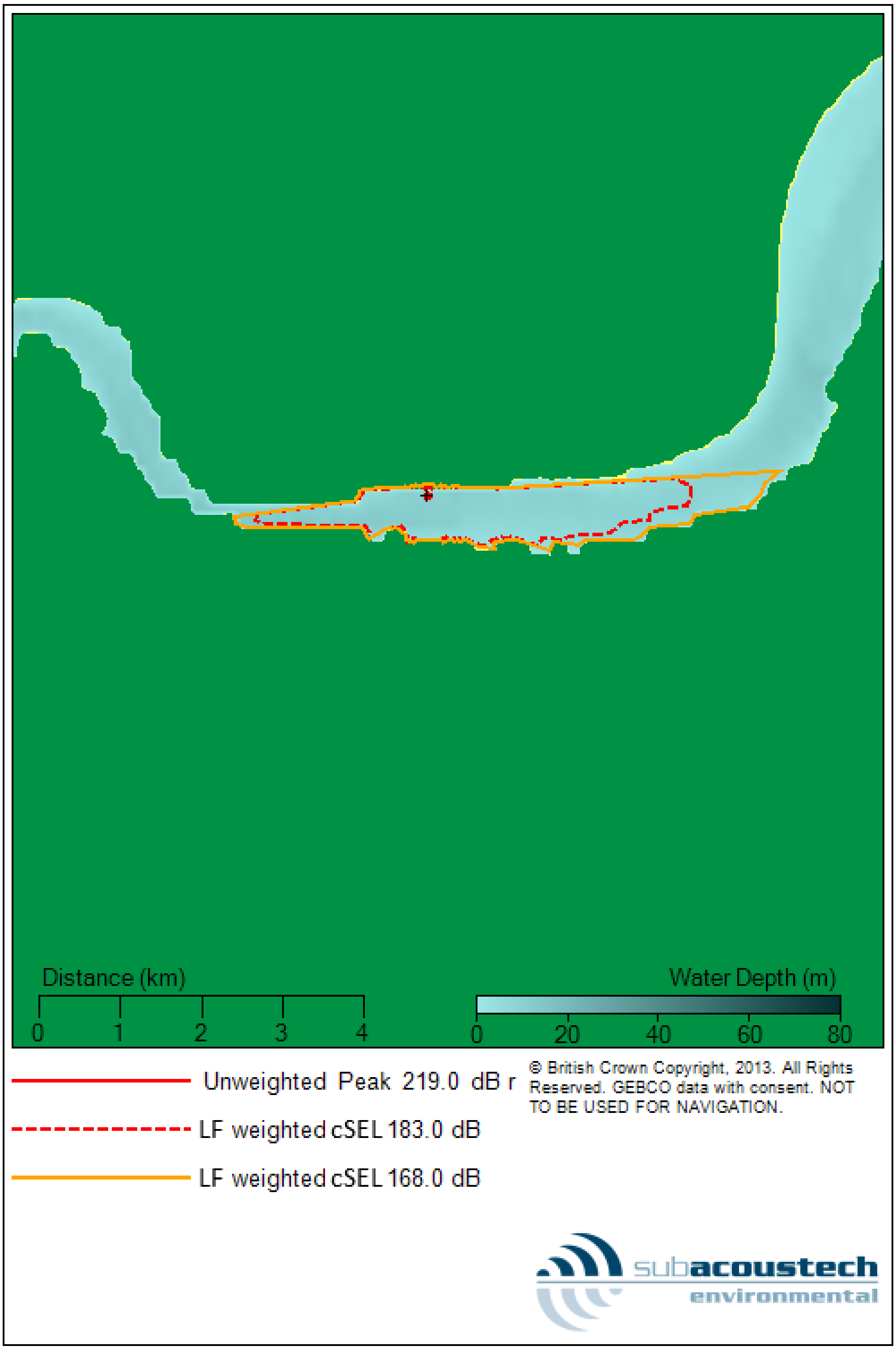


Figure 7-9 Low frequency cetacean weighted model of piling at low tide at the western location (3.5 m pile)

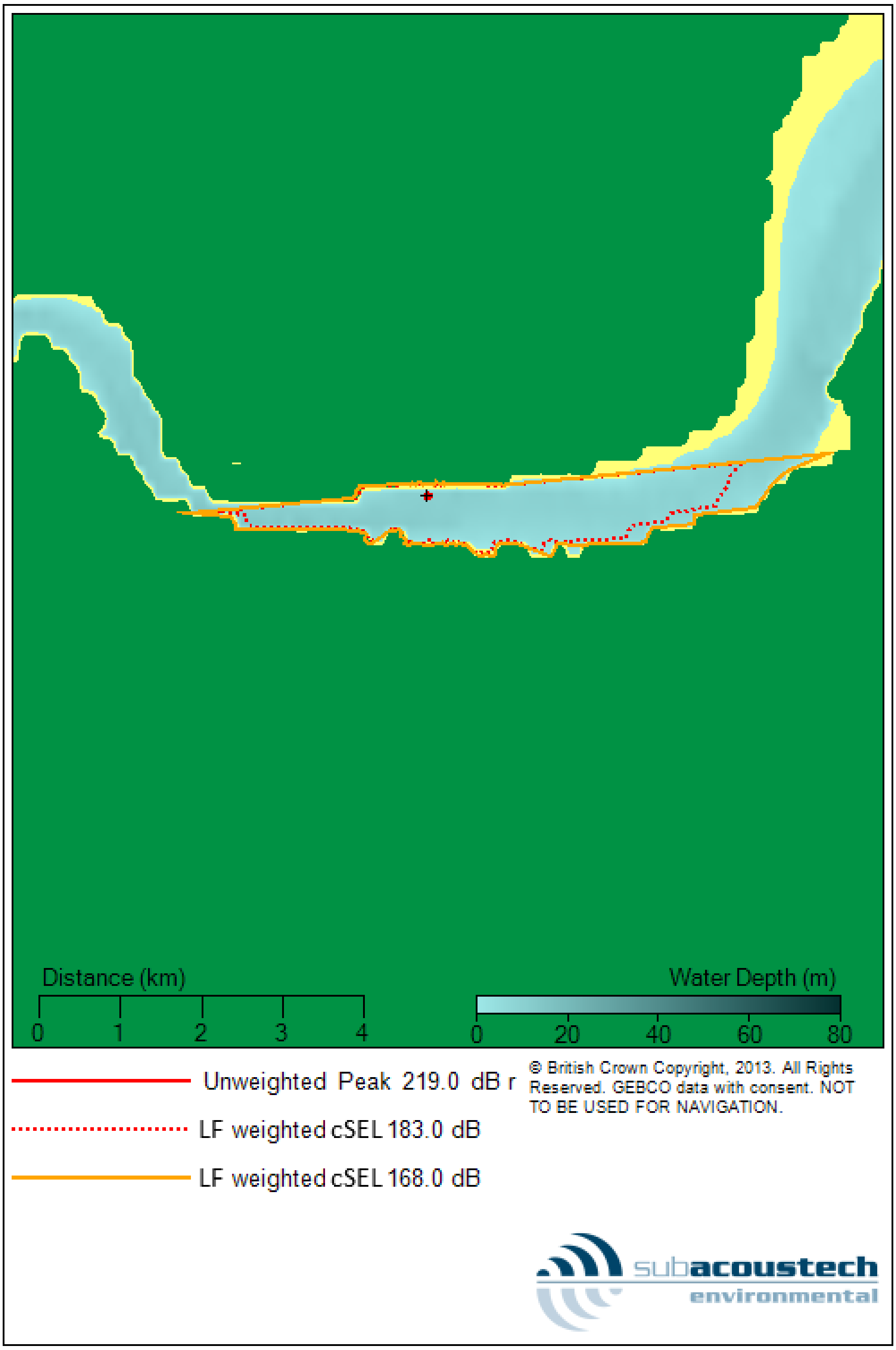


Figure 7-10 Low frequency cetacean weighted model of piling at high tide at the western location (3.5 m pile)

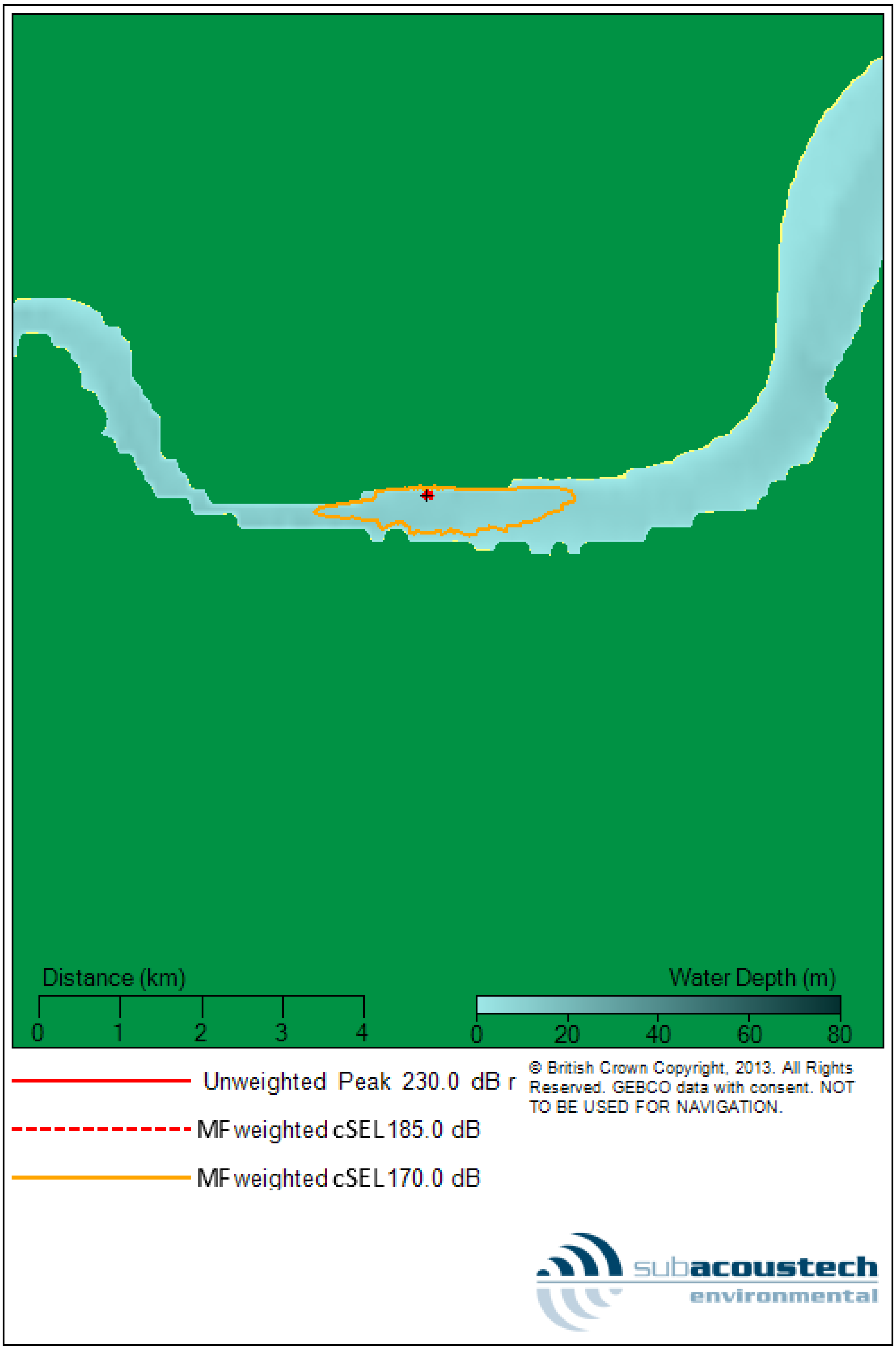


Figure 7-11 Mid frequency cetacean weighted model of piling at low tide at the western location (3.5 m pile)

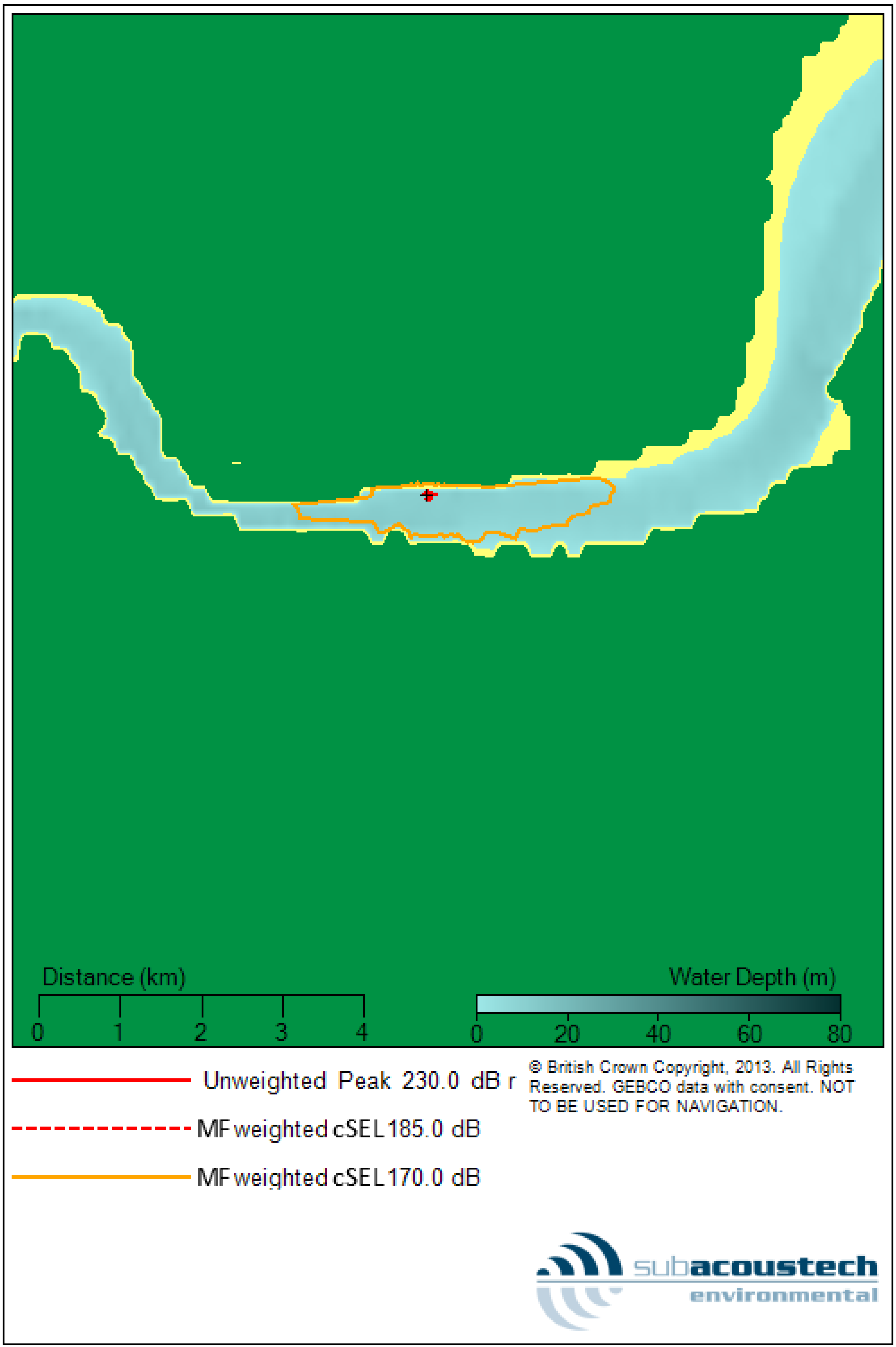


Figure 7-12 Mid frequency cetacean weighted model of piling at high tide at the western location (3.5 m pile)

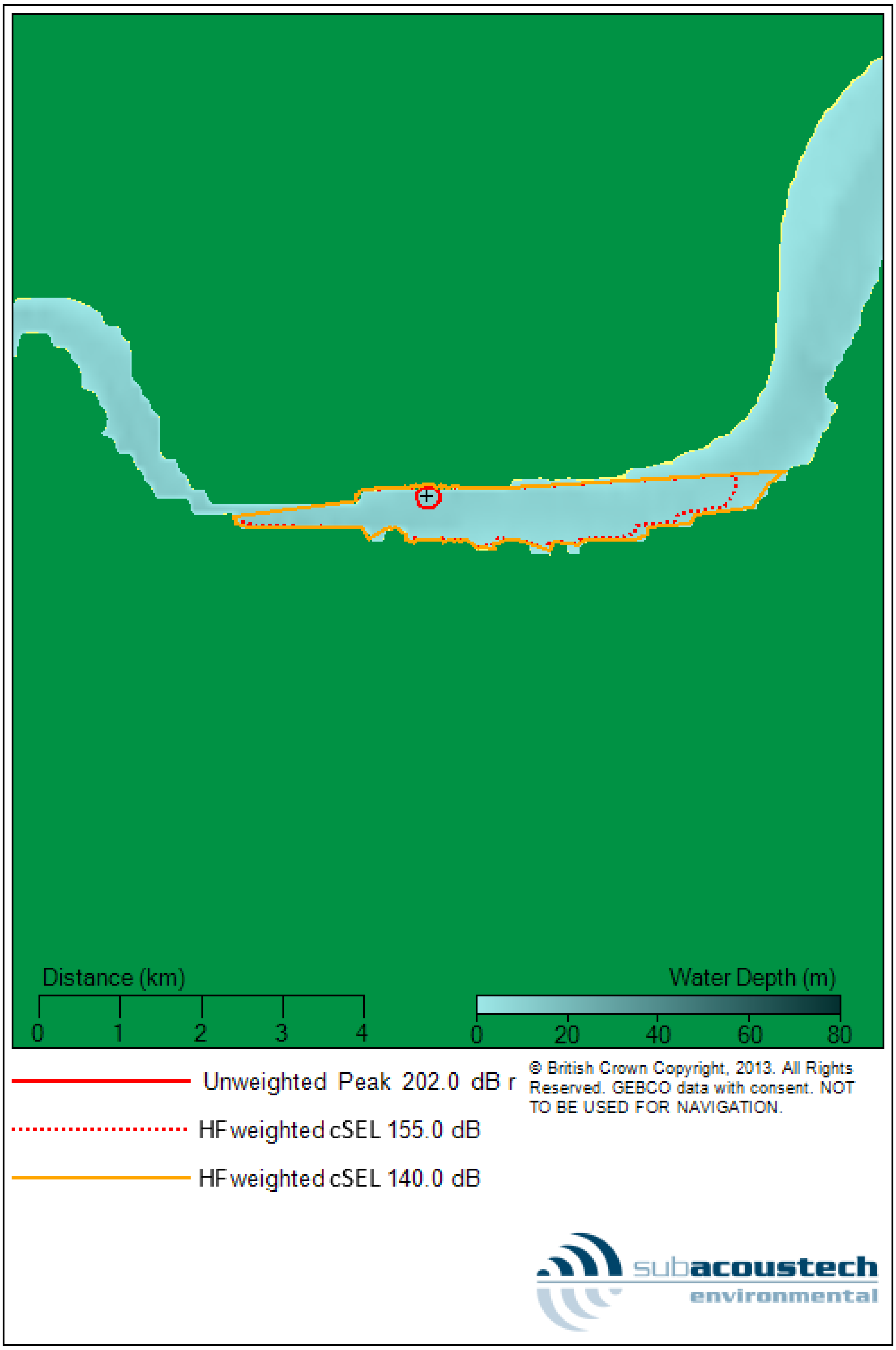


Figure 7-13 High frequency cetacean weighted model of piling at low tide at the western location (3.5 m pile)

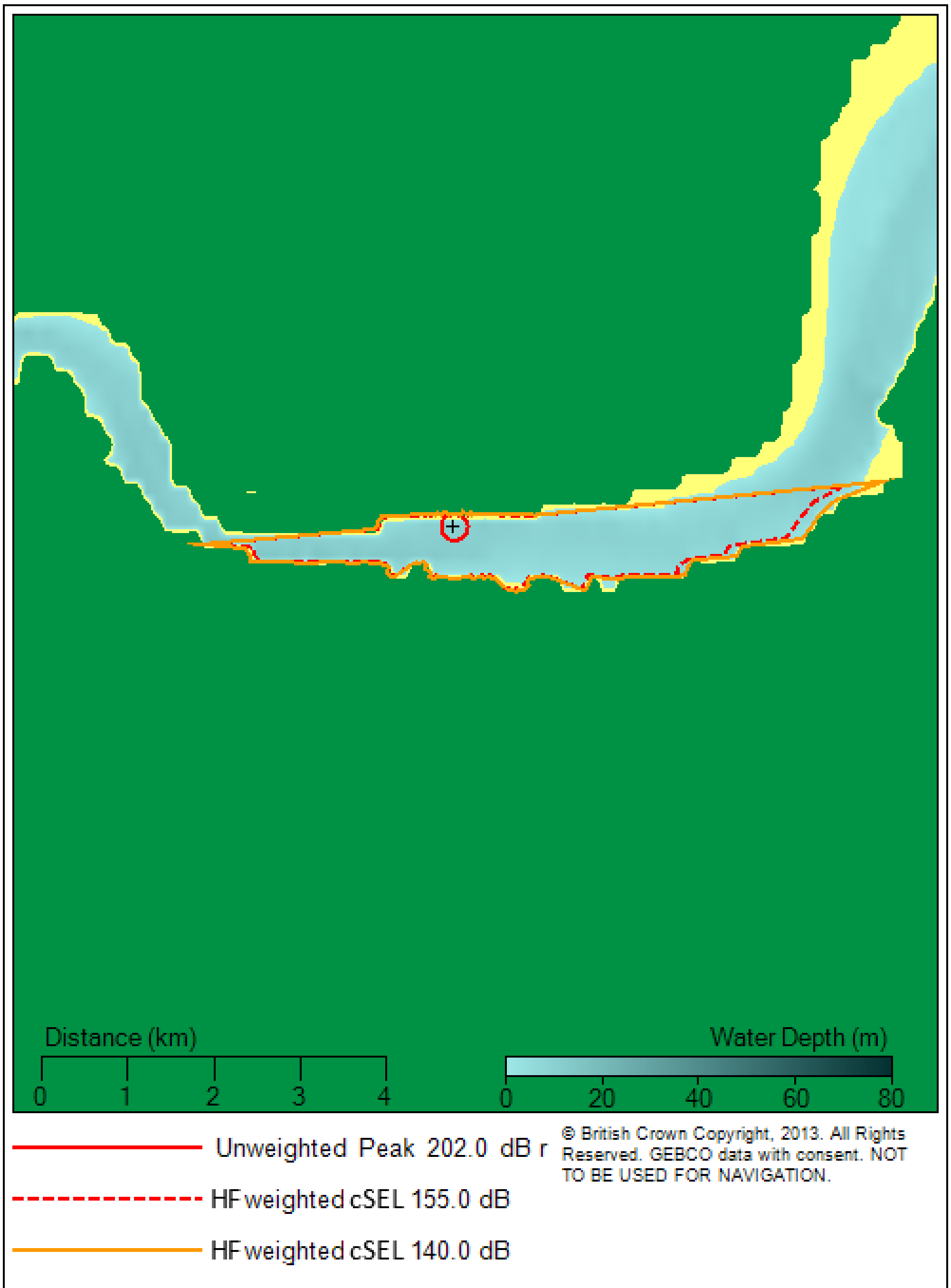


Figure 7-14 High frequency cetacean weighted model of piling at high tide at the western location (3.5 m pile)

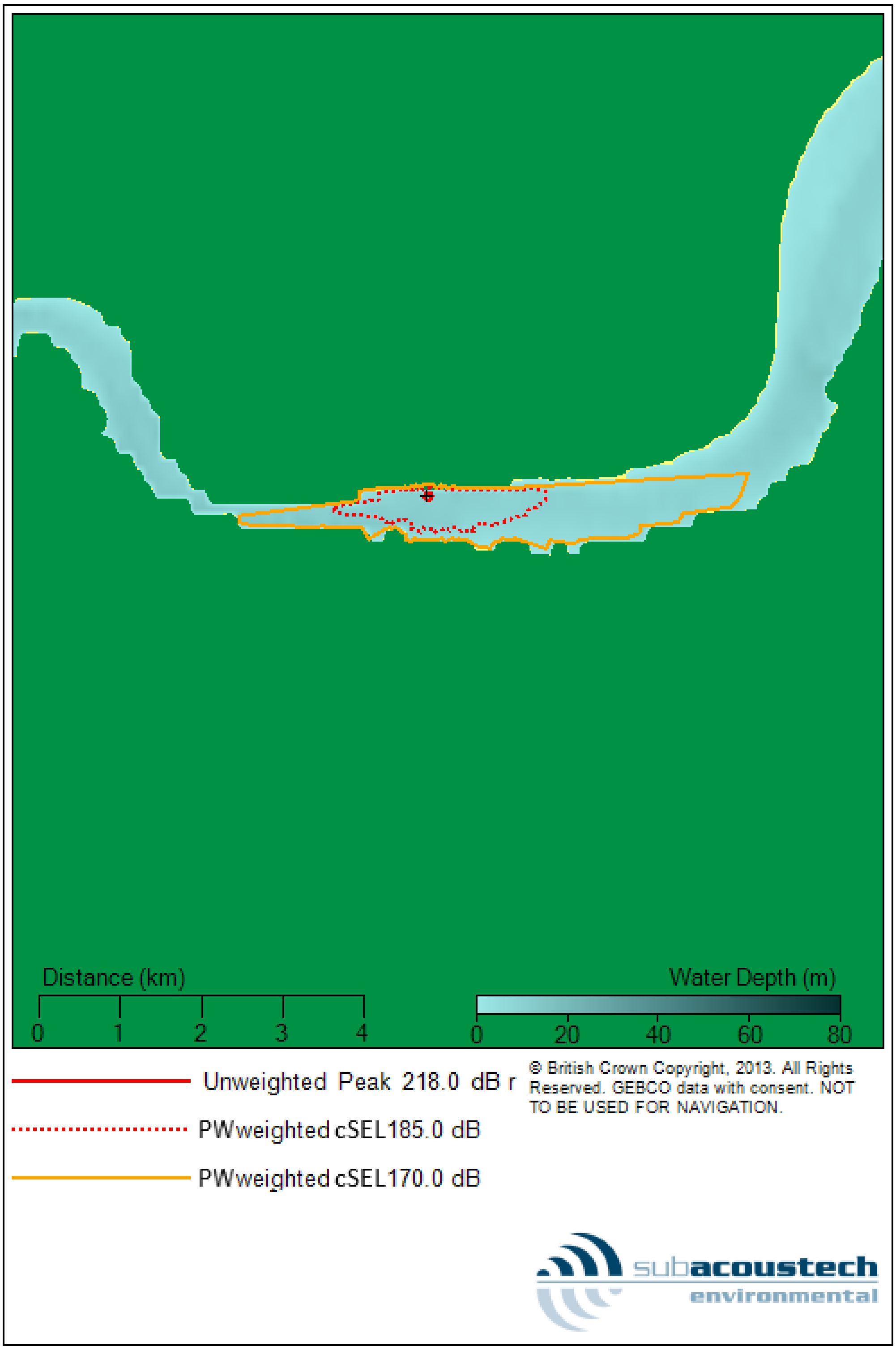


Figure 7-15 Phocid pinniped weighted model of piling at low tide at the western location (3.5 m pile)

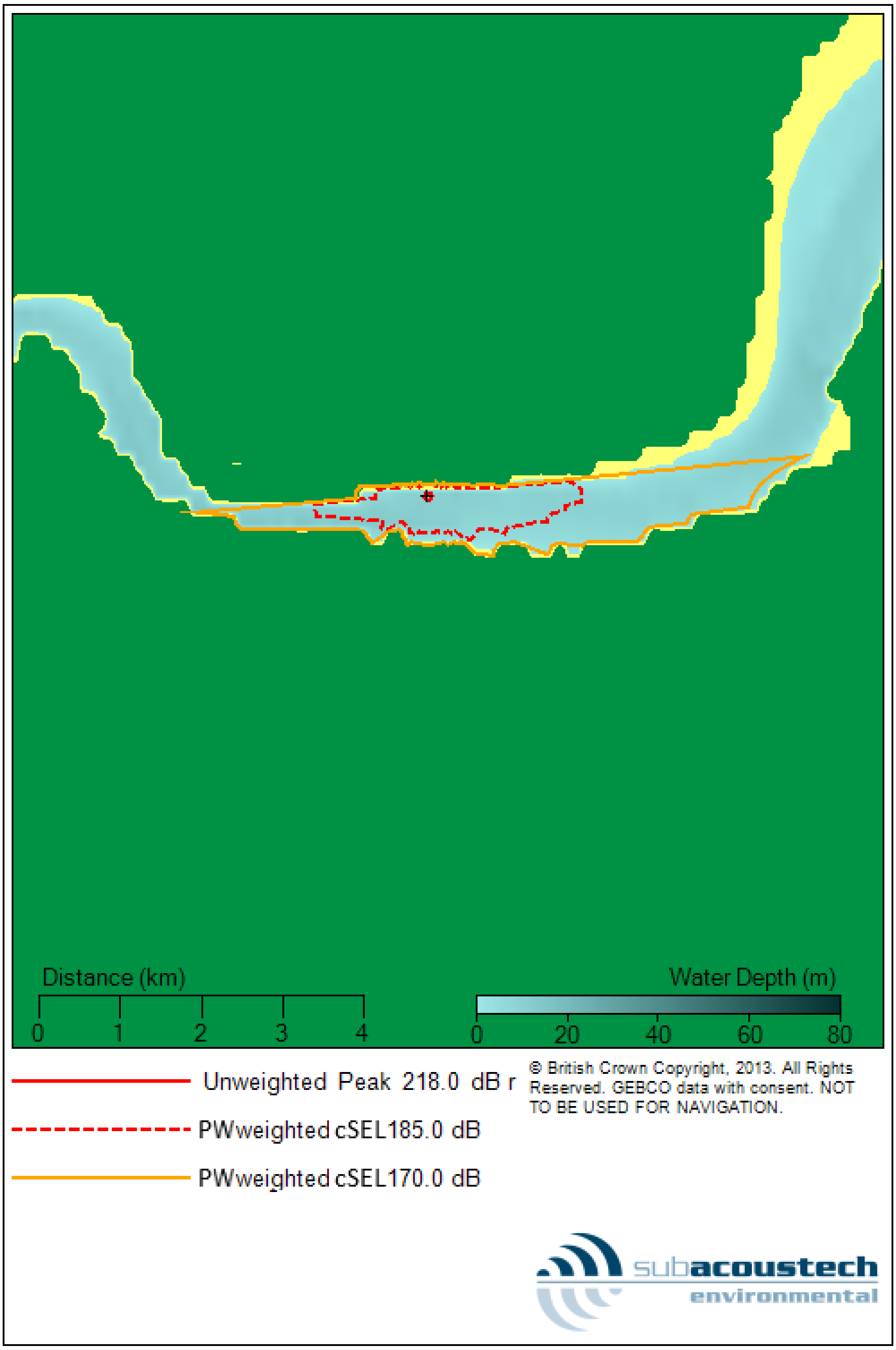


Figure 7-16 Phocid pinniped weighted model of piling at high tide at the western location (3.5 m pile)

A.3 Fish, 3,500 mm pile, eastern location

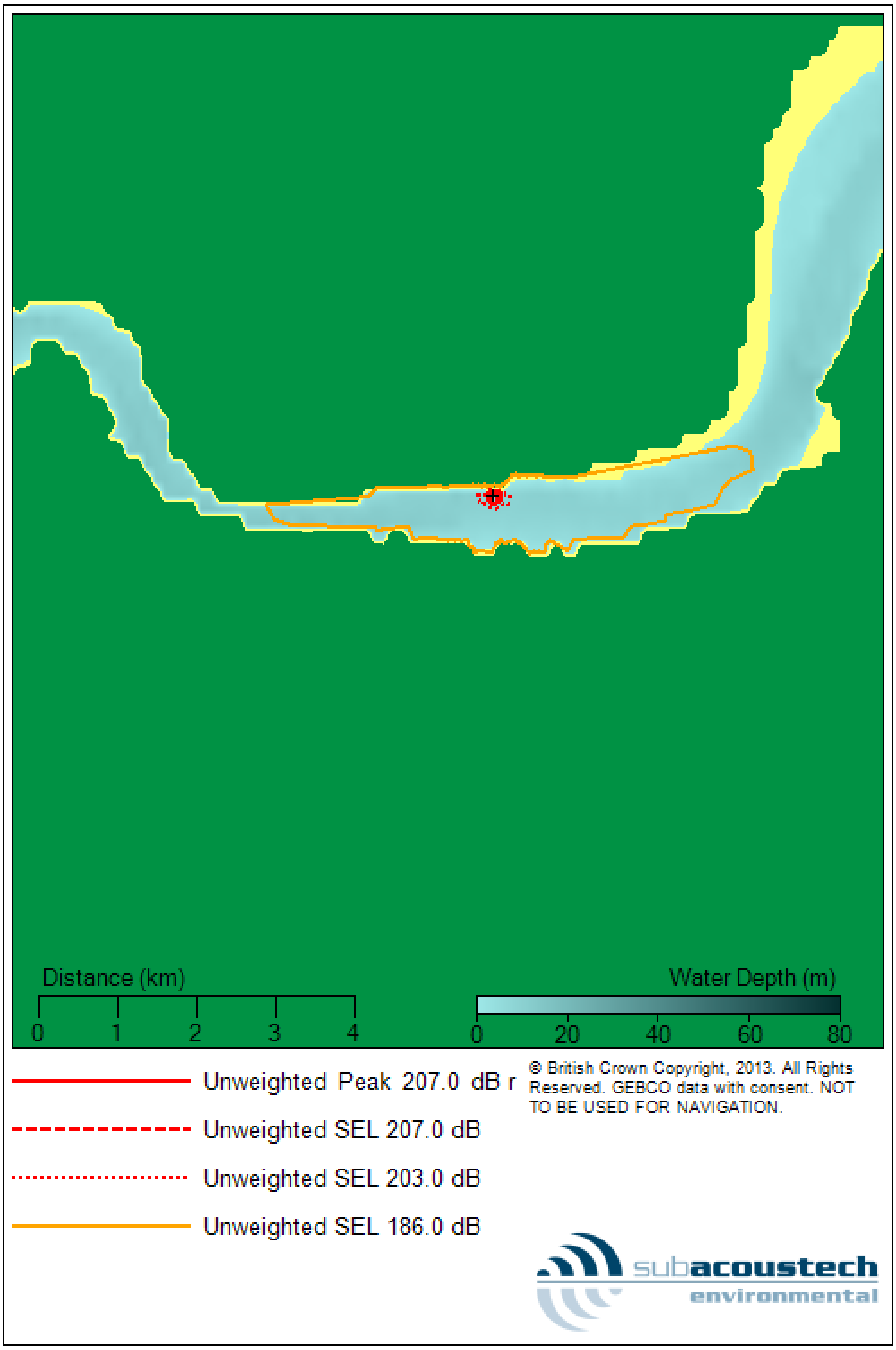


Figure 7-17 Fish model of piling at high tide at the eastern location (3.5 m pile)

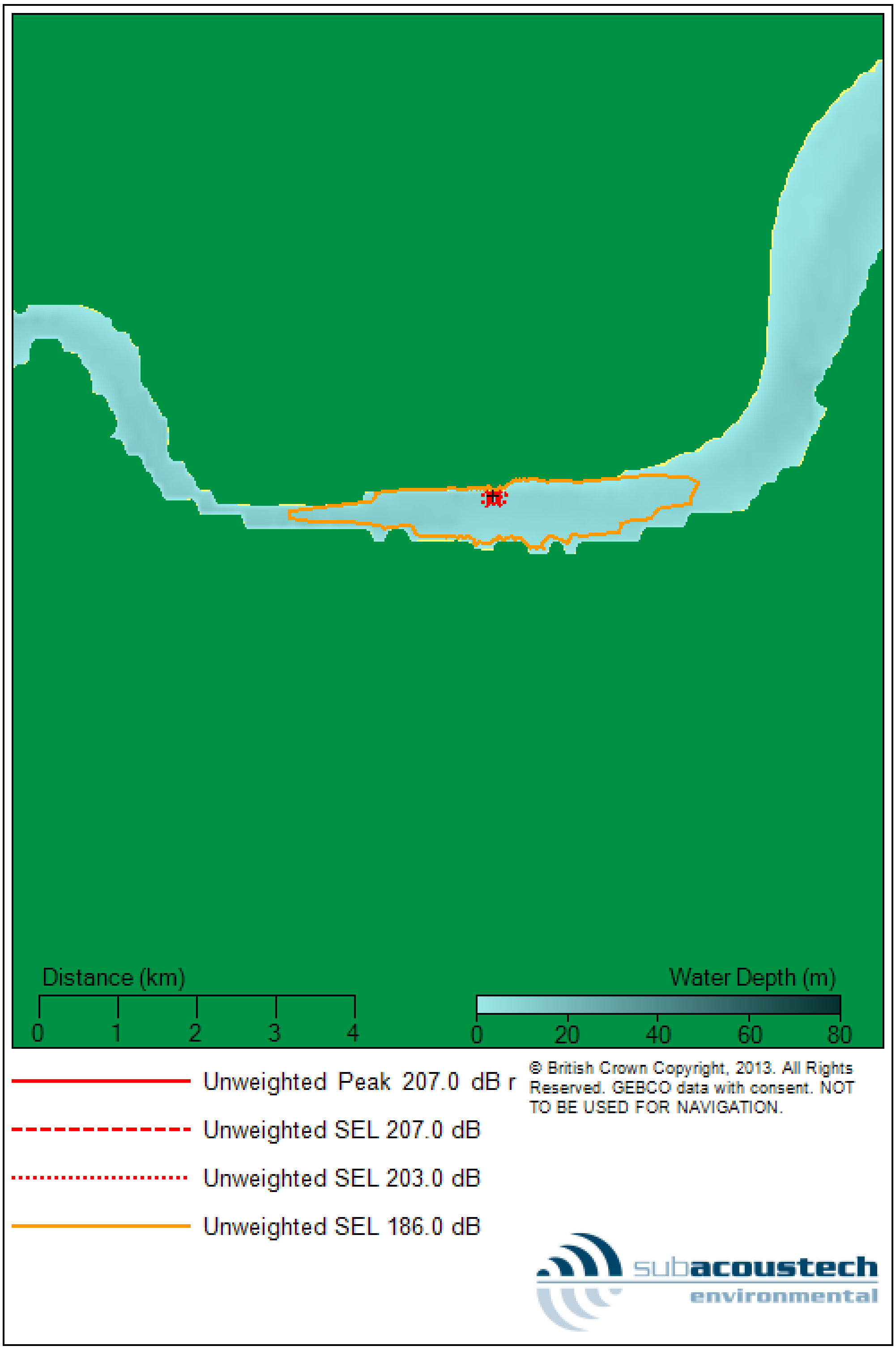


Figure 7-18 Fish model of piling at low tide at the eastern location (3.5 m pile)

A.4 Fish, 3,500 mm pile, western location

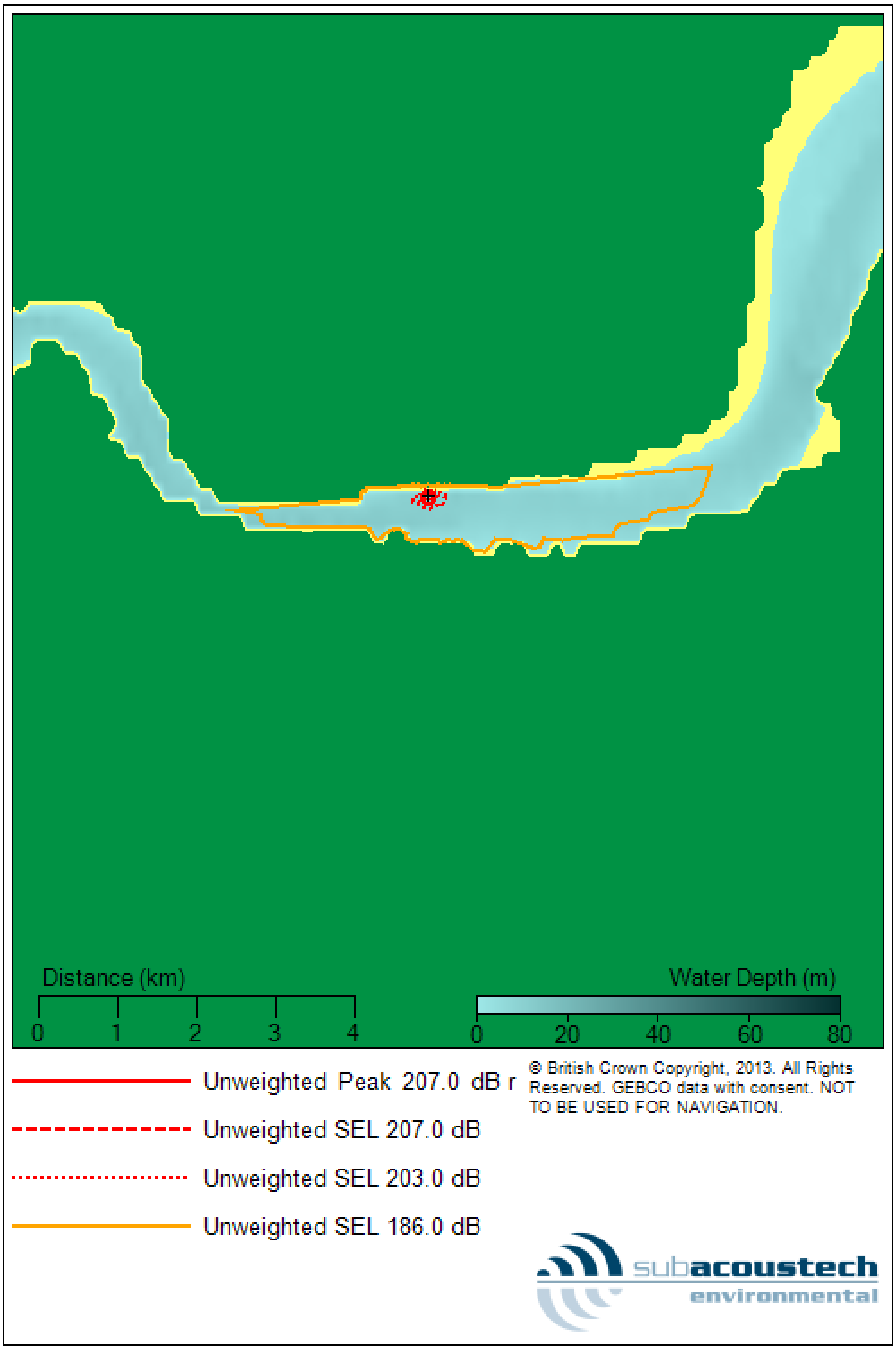


Figure 7-19 Fish model of piling at high tide at the western location (3.5 m pile)

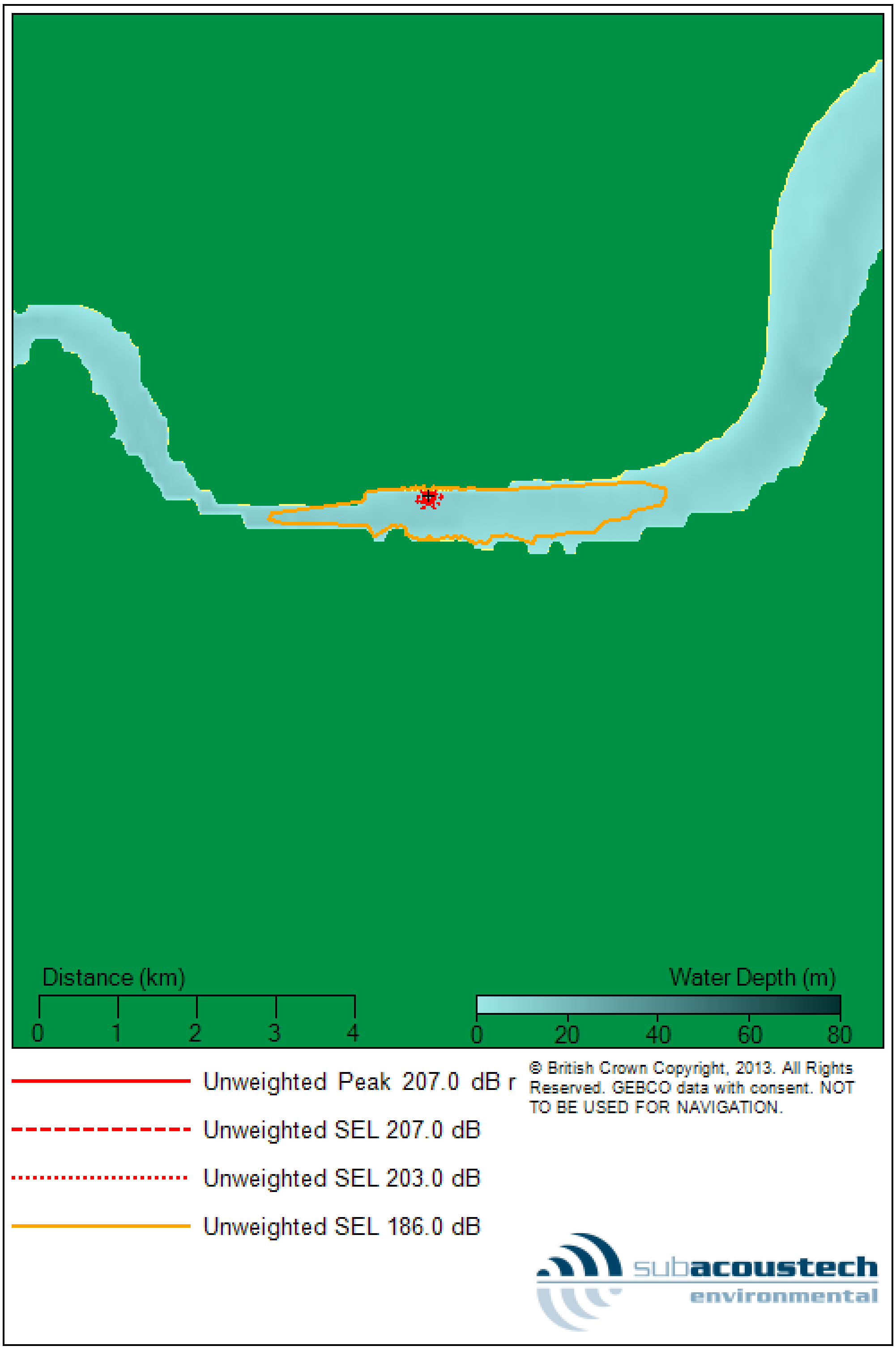


Figure 7-20 Fish model of piling at low tide at the western location (3.5 m pile)

A.5 Marine mammals, 610 mm pile, eastern location

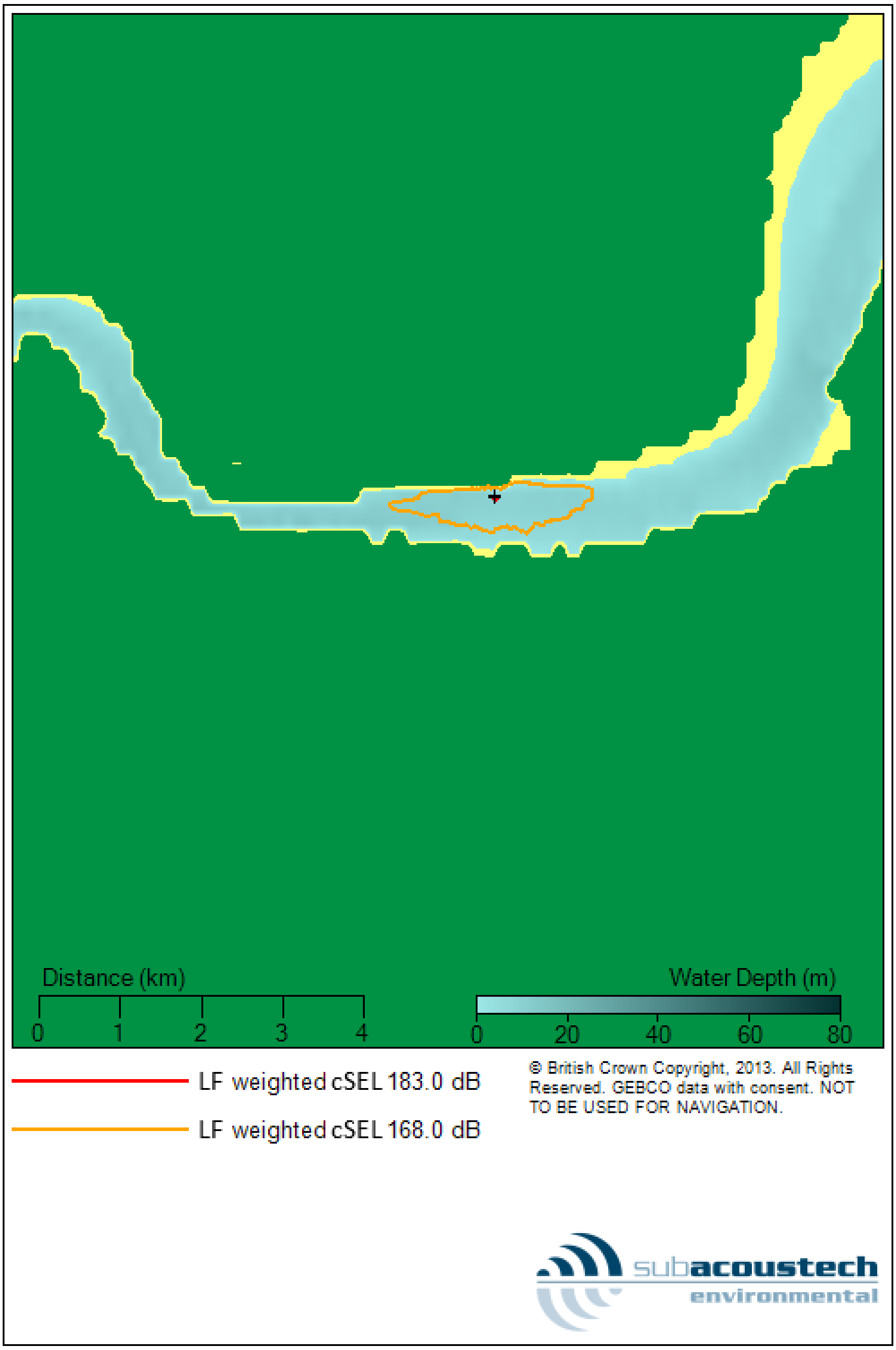


Figure 7-21 Low frequency cetacean weighted model of piling at low tide at the eastern location (610 mm pile)

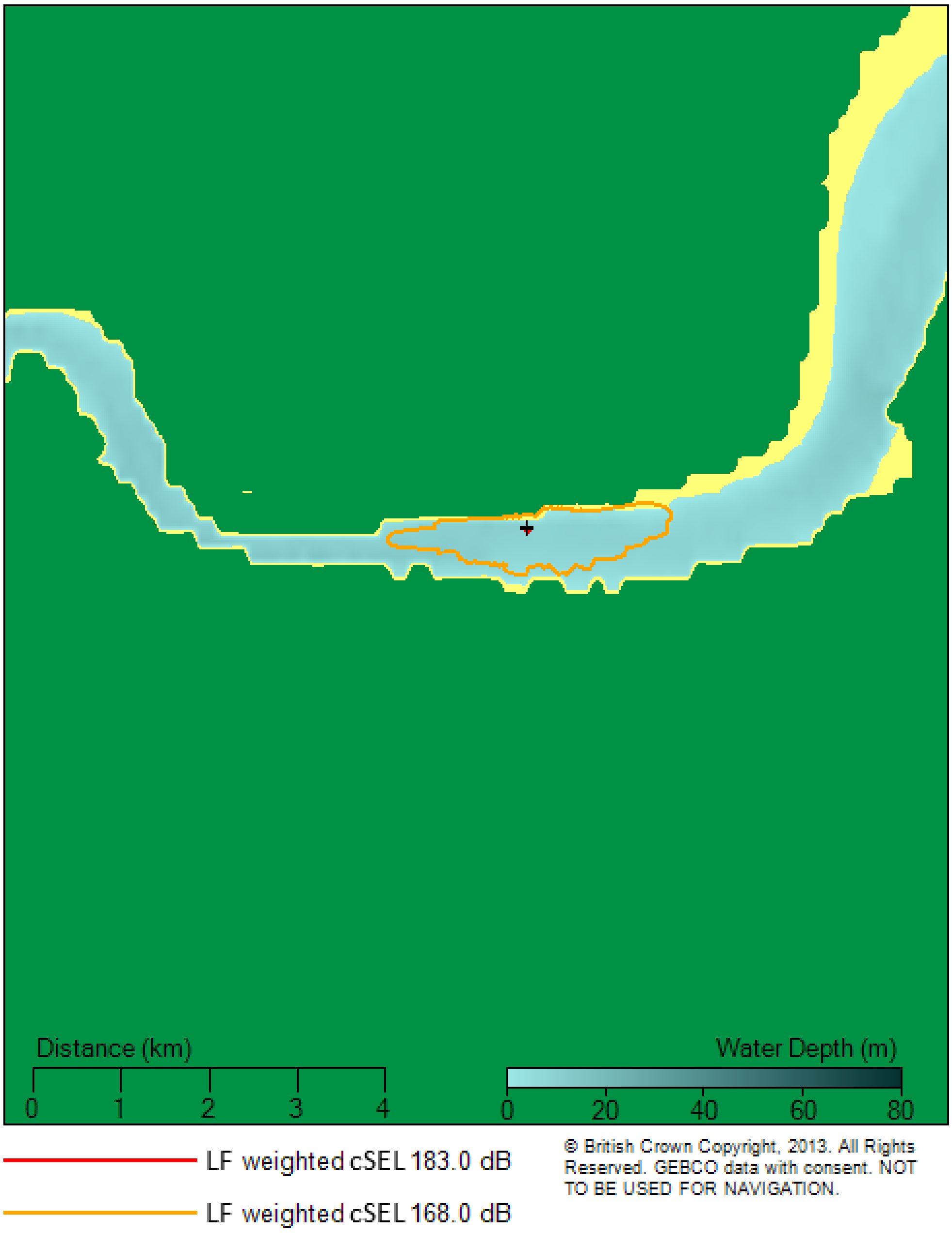


Figure 7-22 Low frequency cetacean weighted model of piling at high tide at the eastern location (610 mm pile)

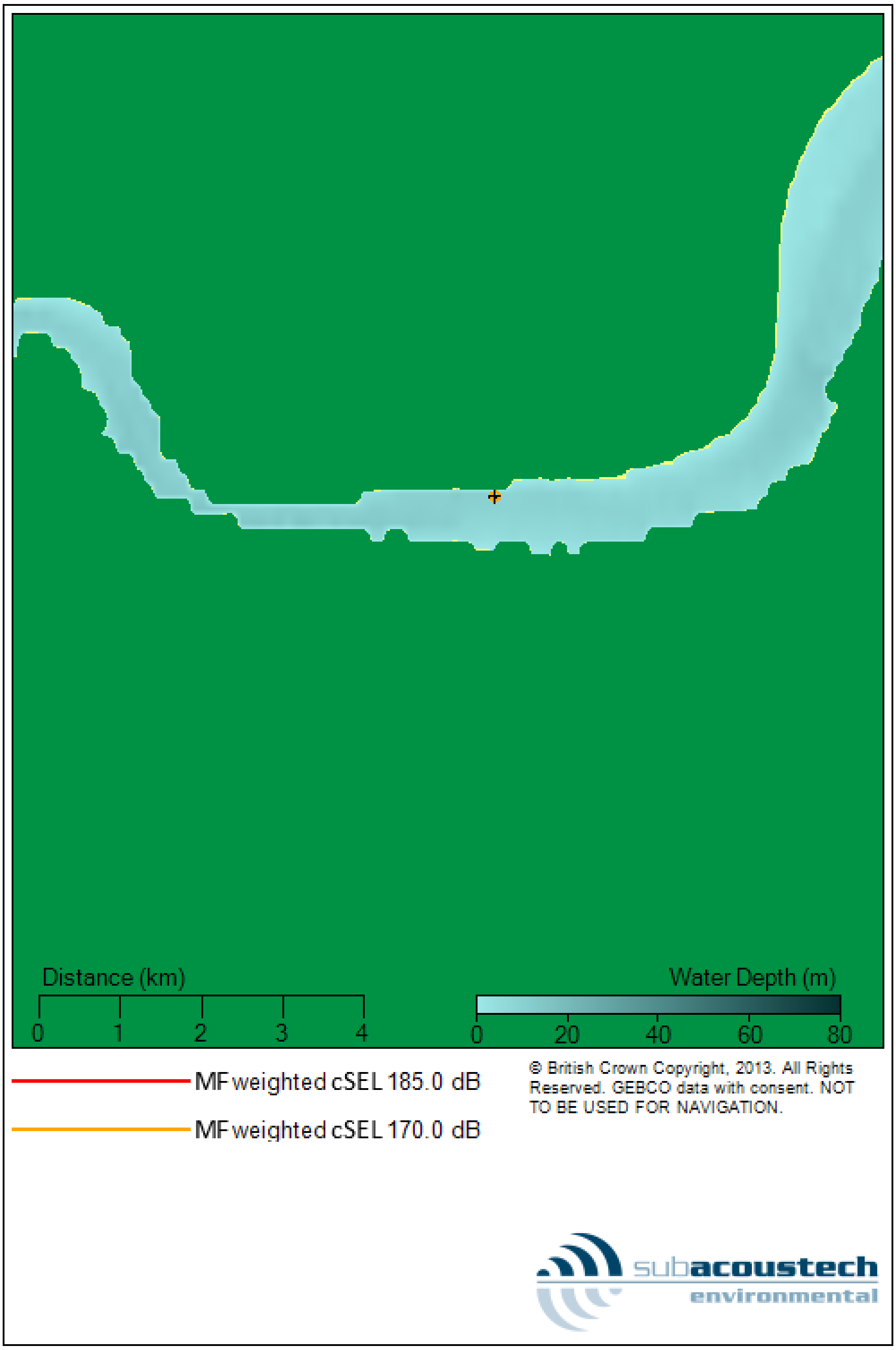


Figure 7-23 Mid frequency cetacean weighted model of piling at low tide at the eastern location (610 mm pile)

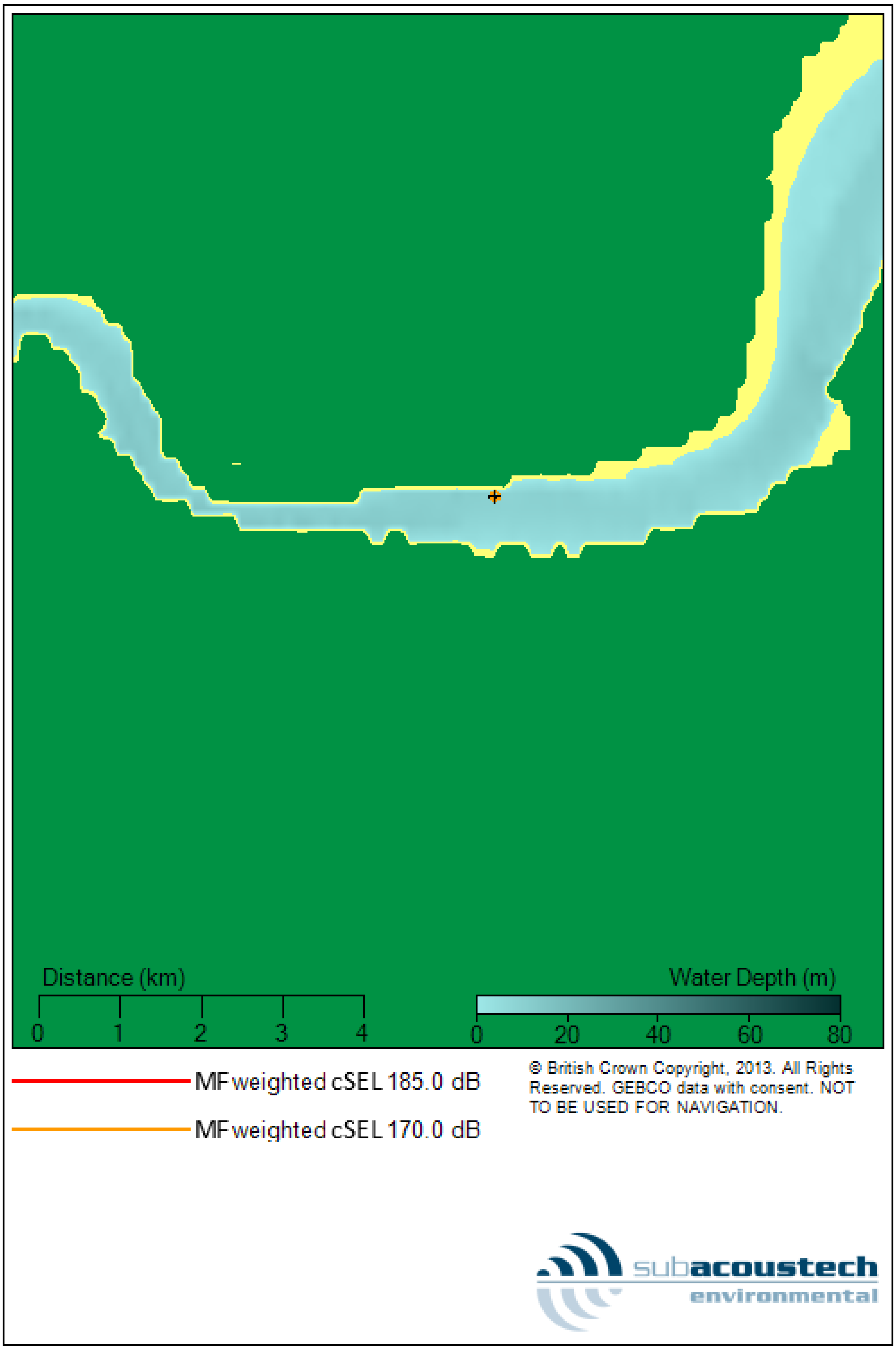


Figure 7-24 Mid frequency cetacean weighted model of piling at high tide at the eastern location (610 mm pile)

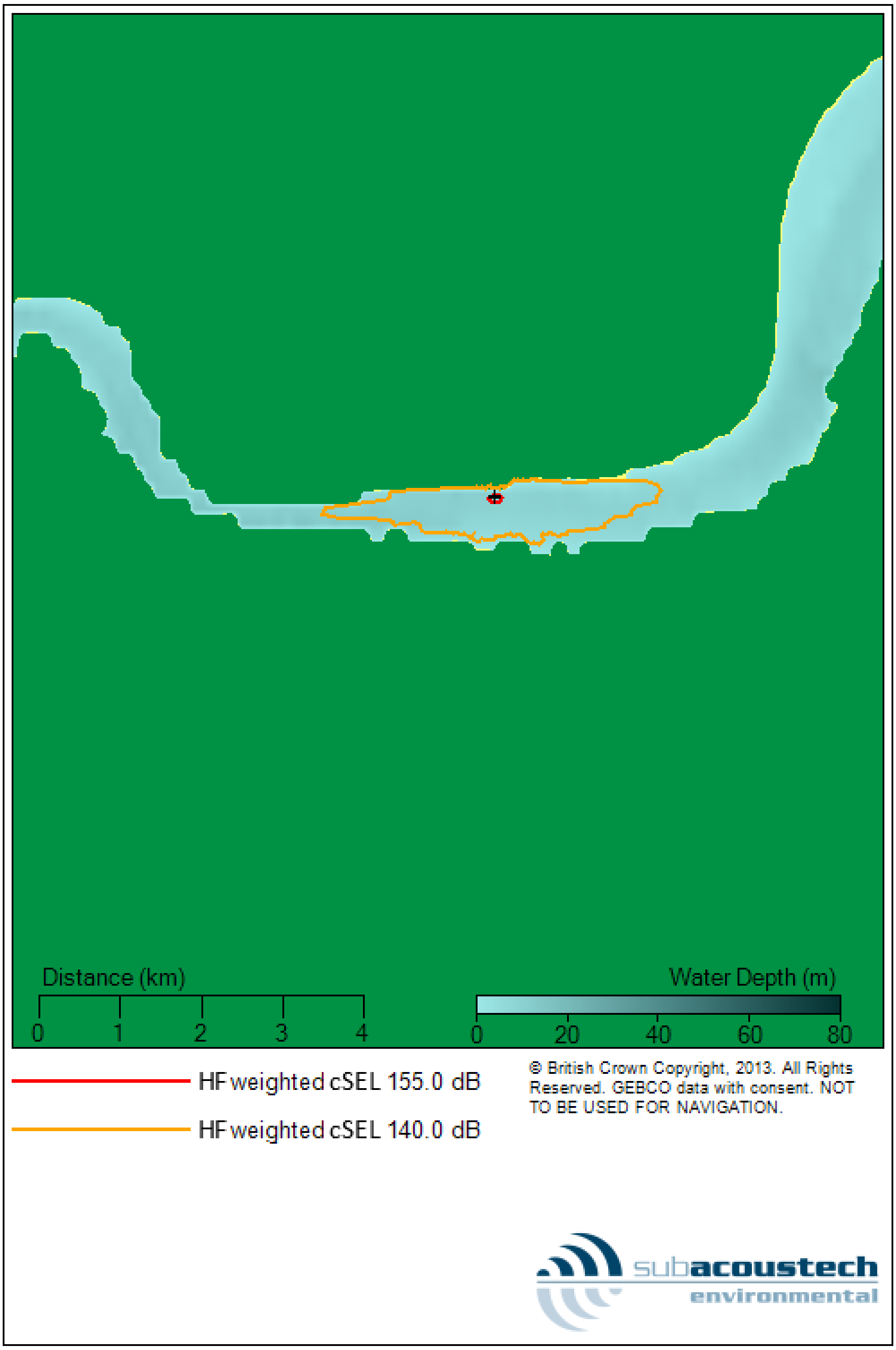


Figure 7-25 High frequency cetacean weighted model of piling at low tide at the eastern location (610 mm pile)

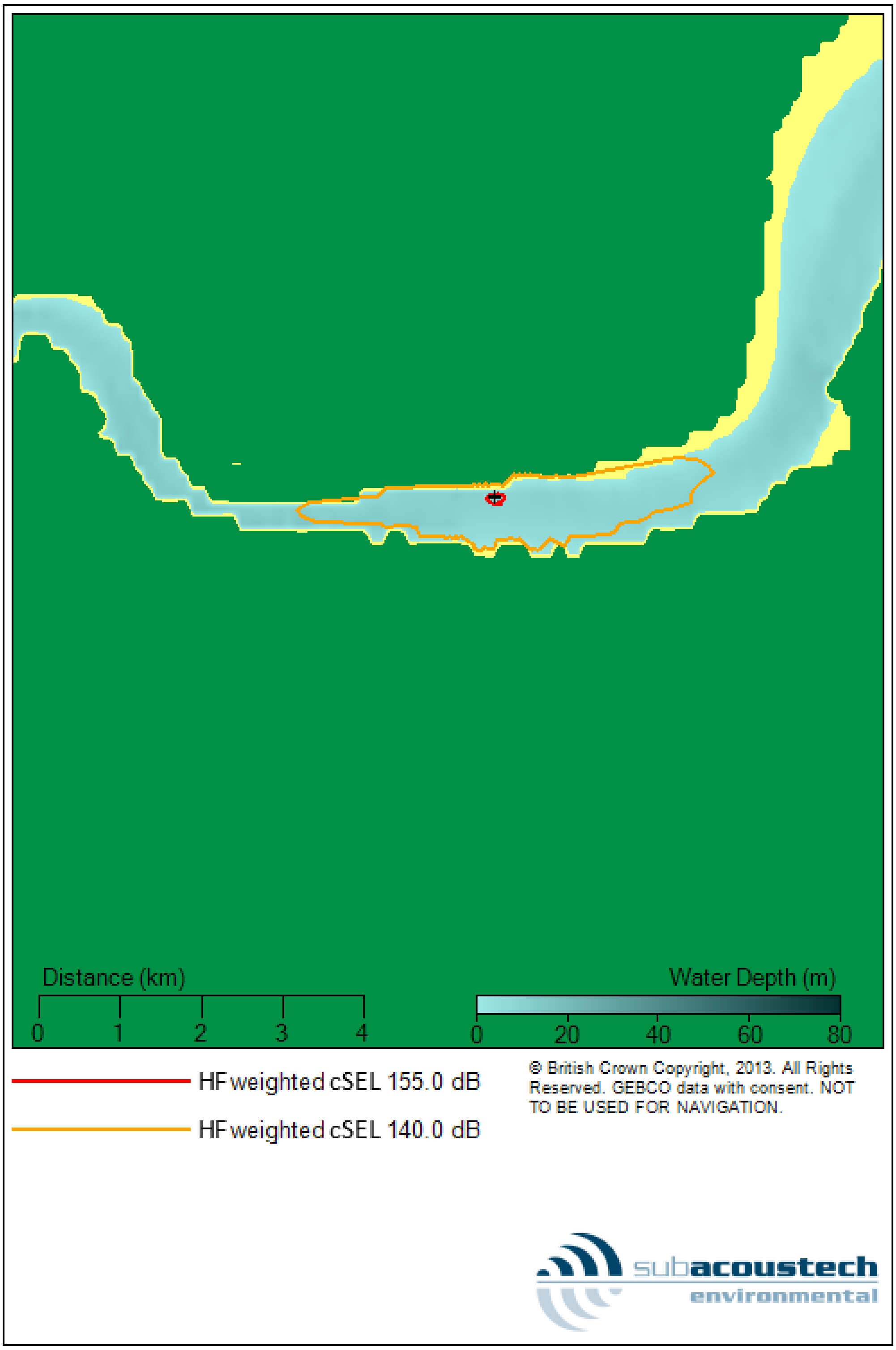


Figure 7-26 High frequency cetacean weighted model of piling at high tide at the eastern location (610 mm pile)

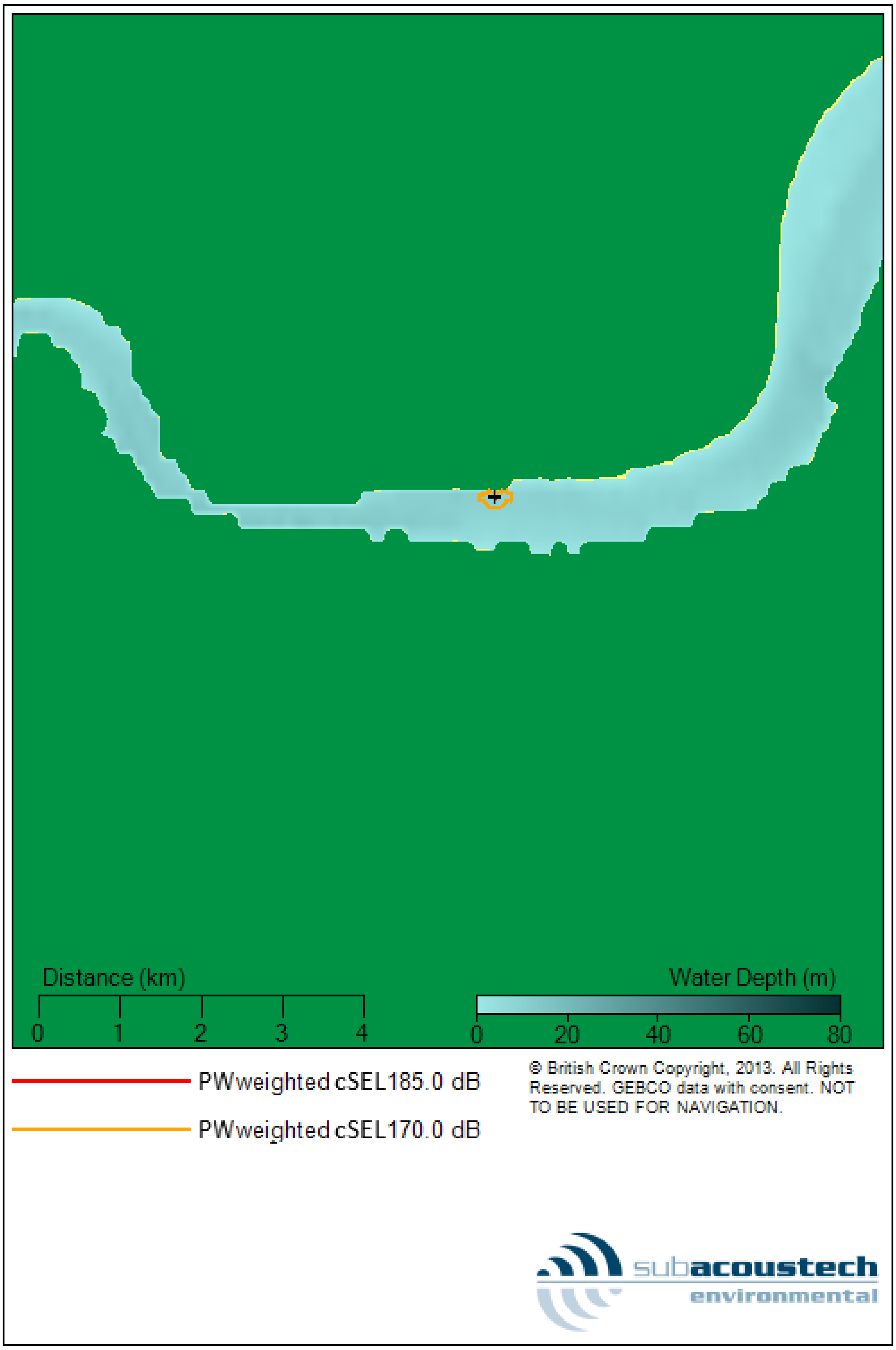


Figure 7-27 Phocid pinniped weighted model of piling at low tide at the eastern location (610 mm pile)

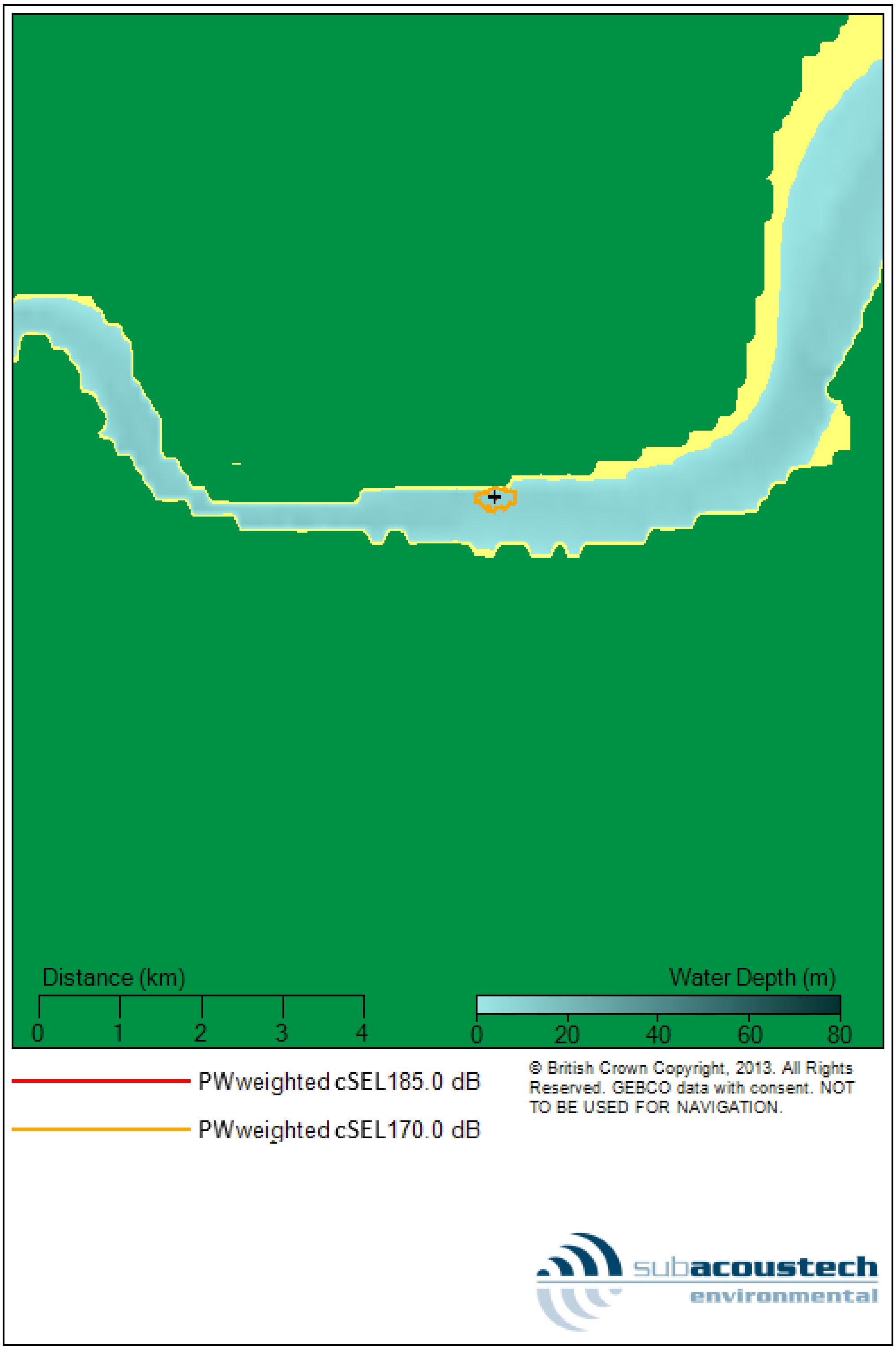


Figure 7-28 Phocid pinniped weighted model of piling at high tide at the eastern location (610 mm pile)

A.6 Marine mammals, 610 mm pile, western location

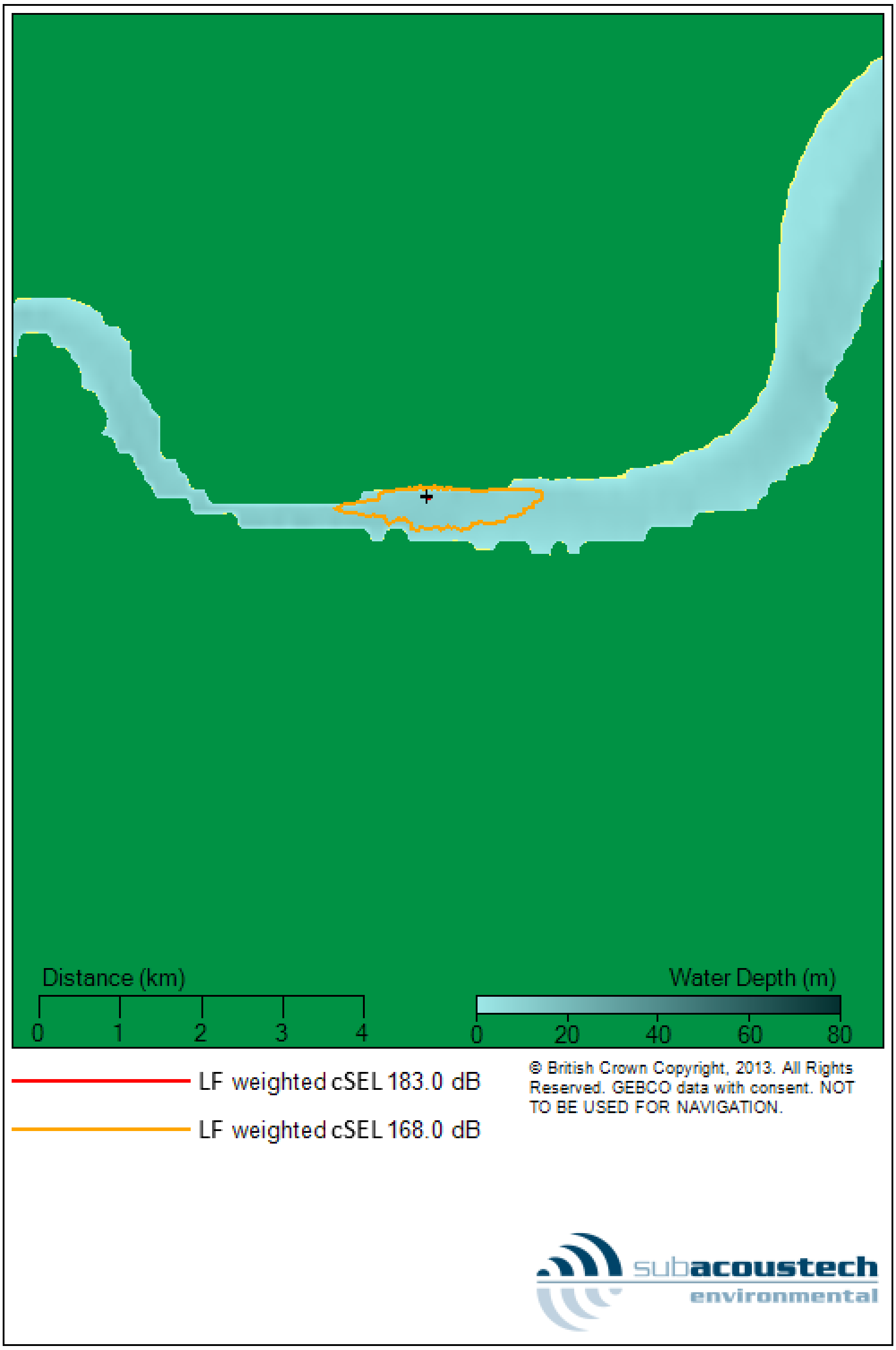


Figure 7-29 Low frequency cetacean weighted model of piling at low tide at the western location (610 mm pile)

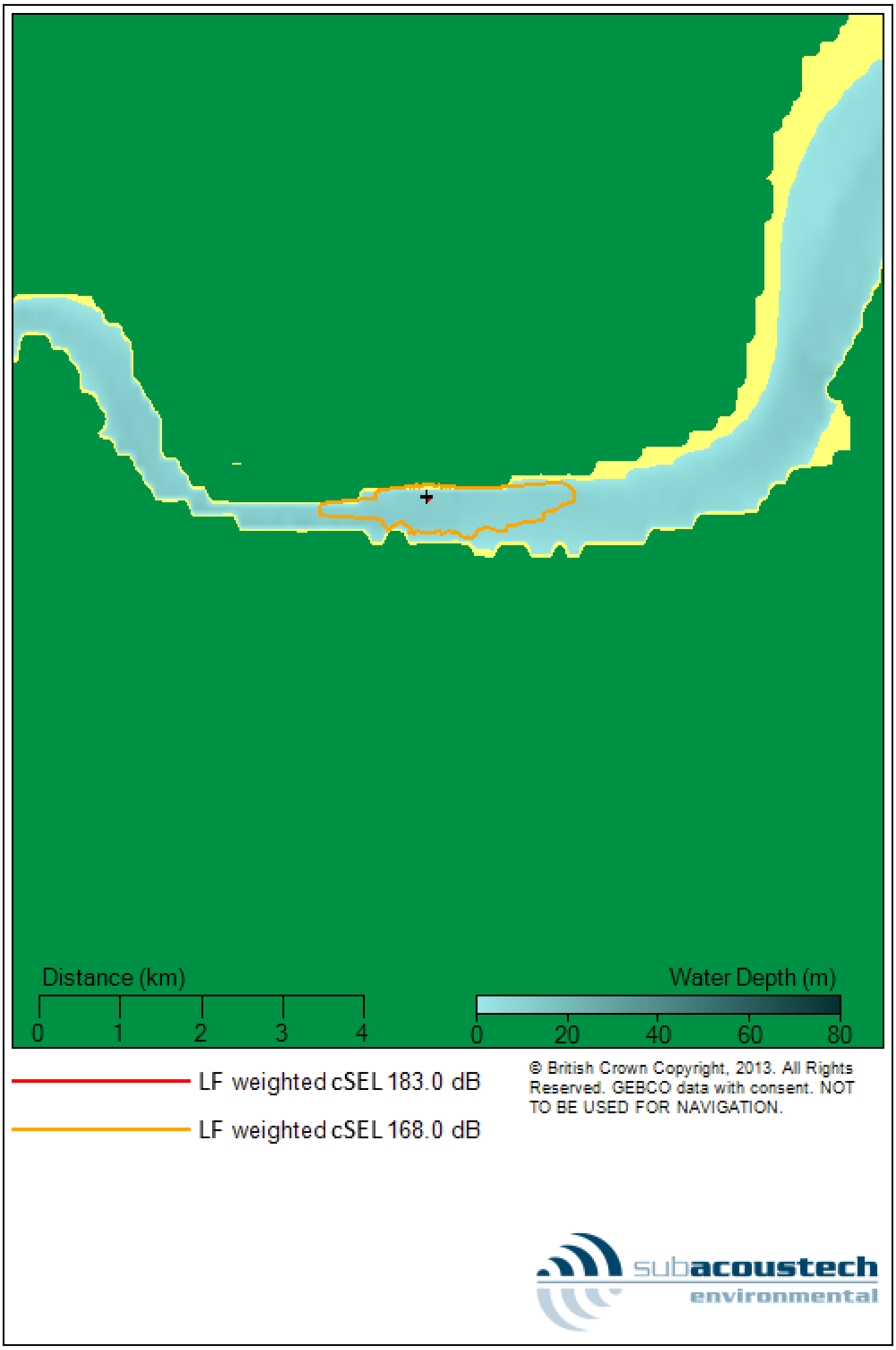


Figure 7-30 Low frequency cetacean weighted model of piling at high tide at the western location (610 mm pile)

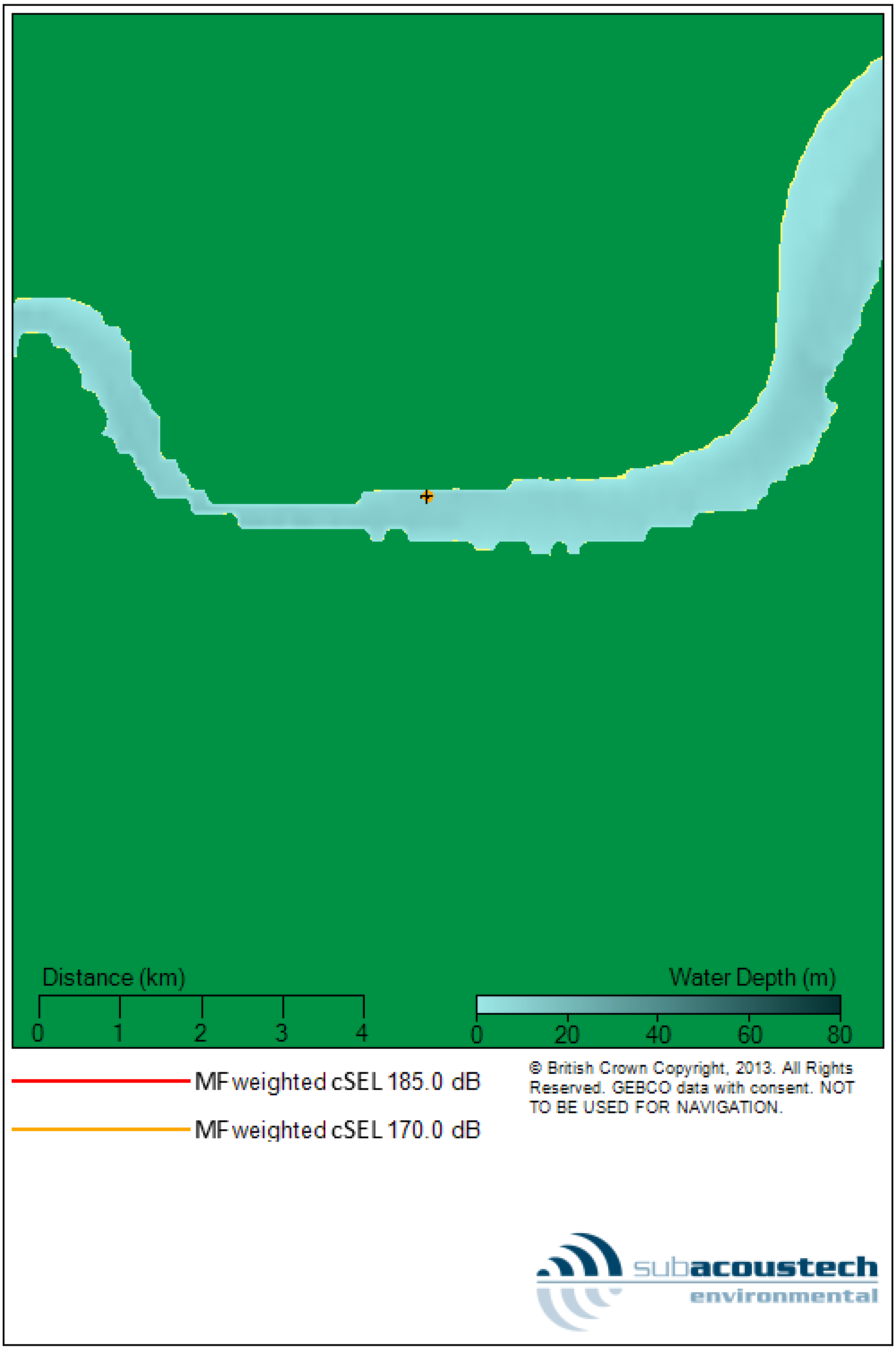


Figure 7-31 Mid frequency cetacean weighted model of piling at low tide at the western location (610 mm pile)

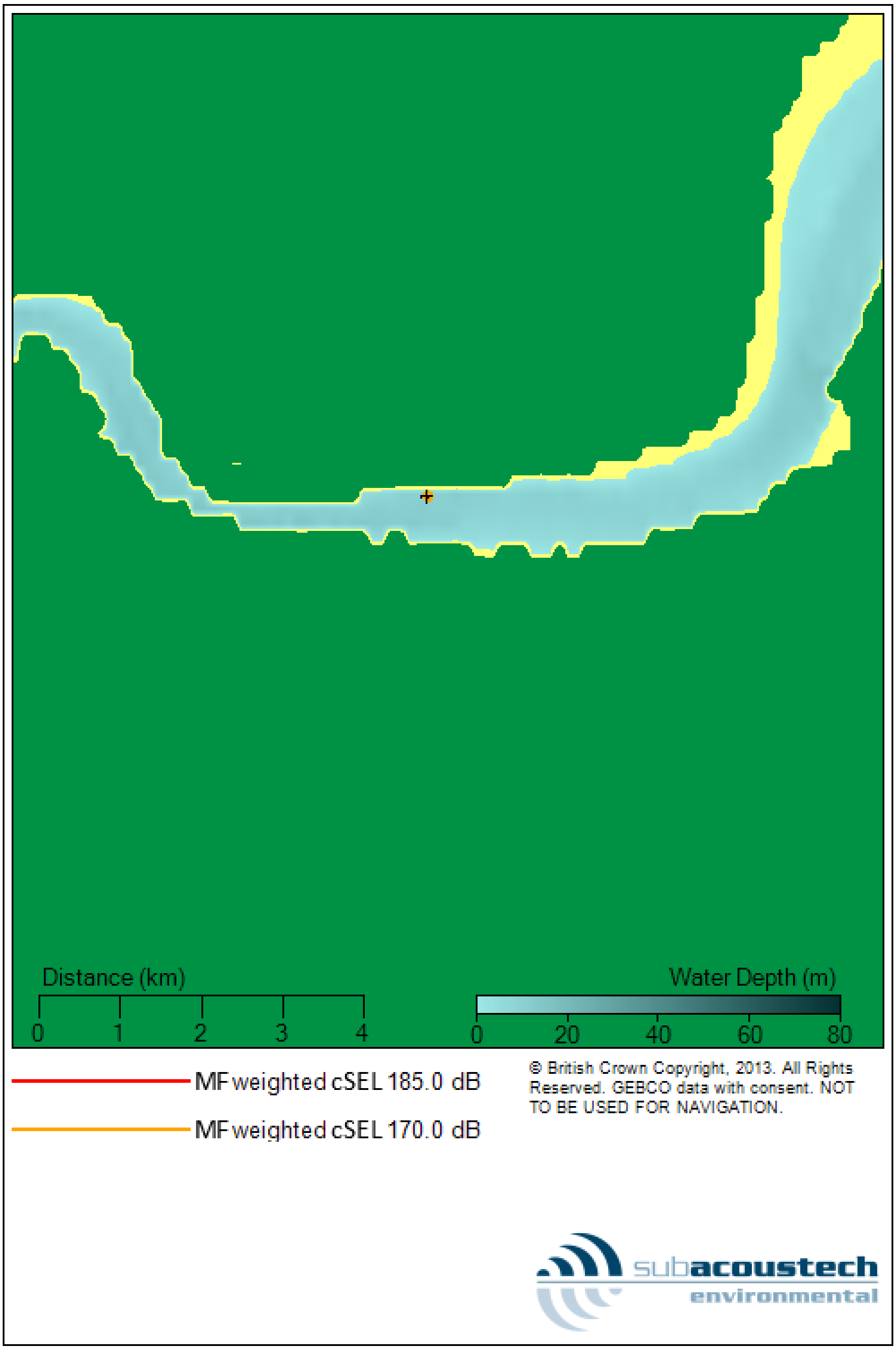


Figure 7-32 Mid frequency cetacean weighted model of piling at high tide at the western location (610 mm pile)

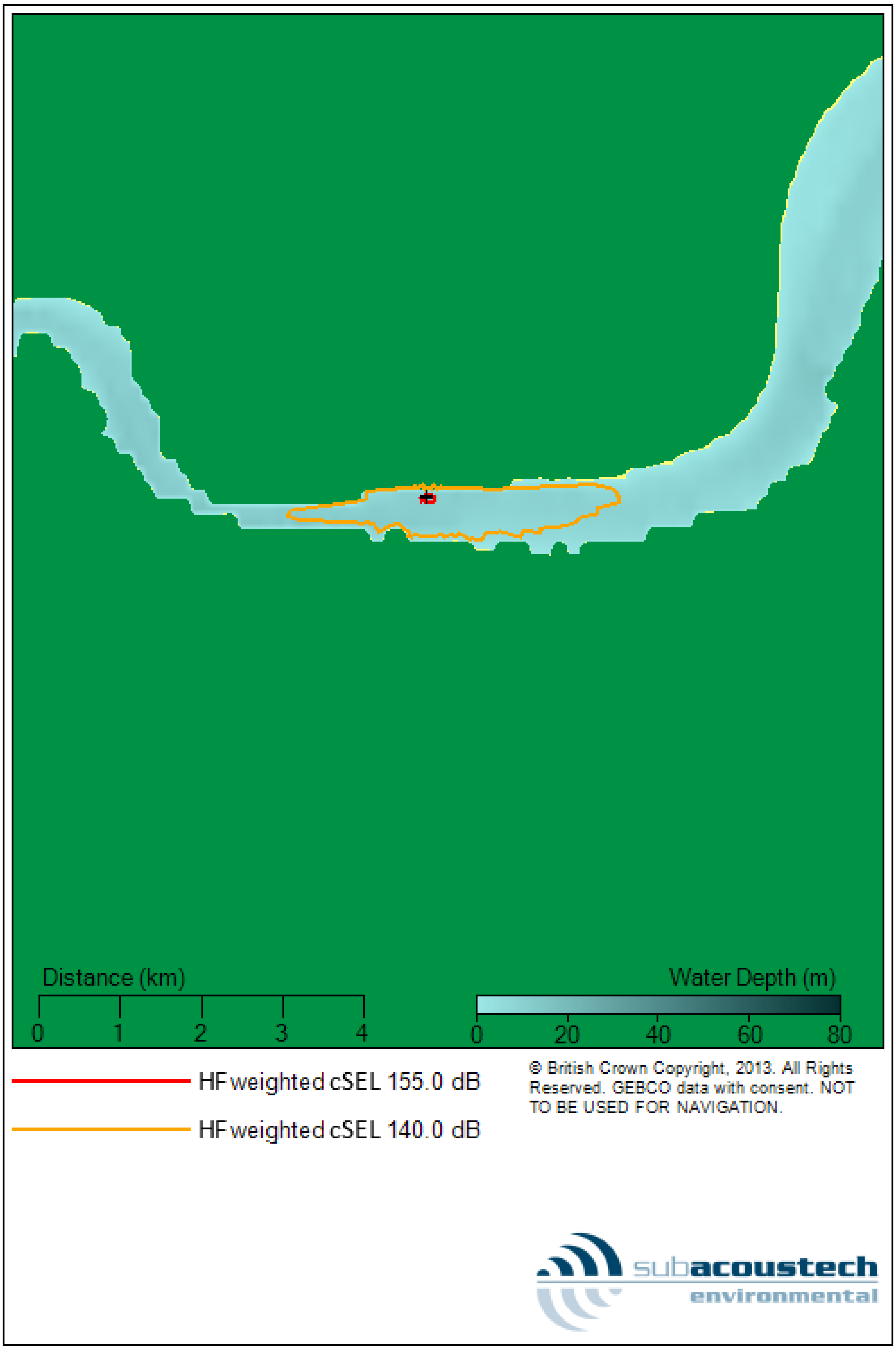


Figure 7-33 High frequency cetacean weighted model of piling at low tide at the western location (610 mm pile)

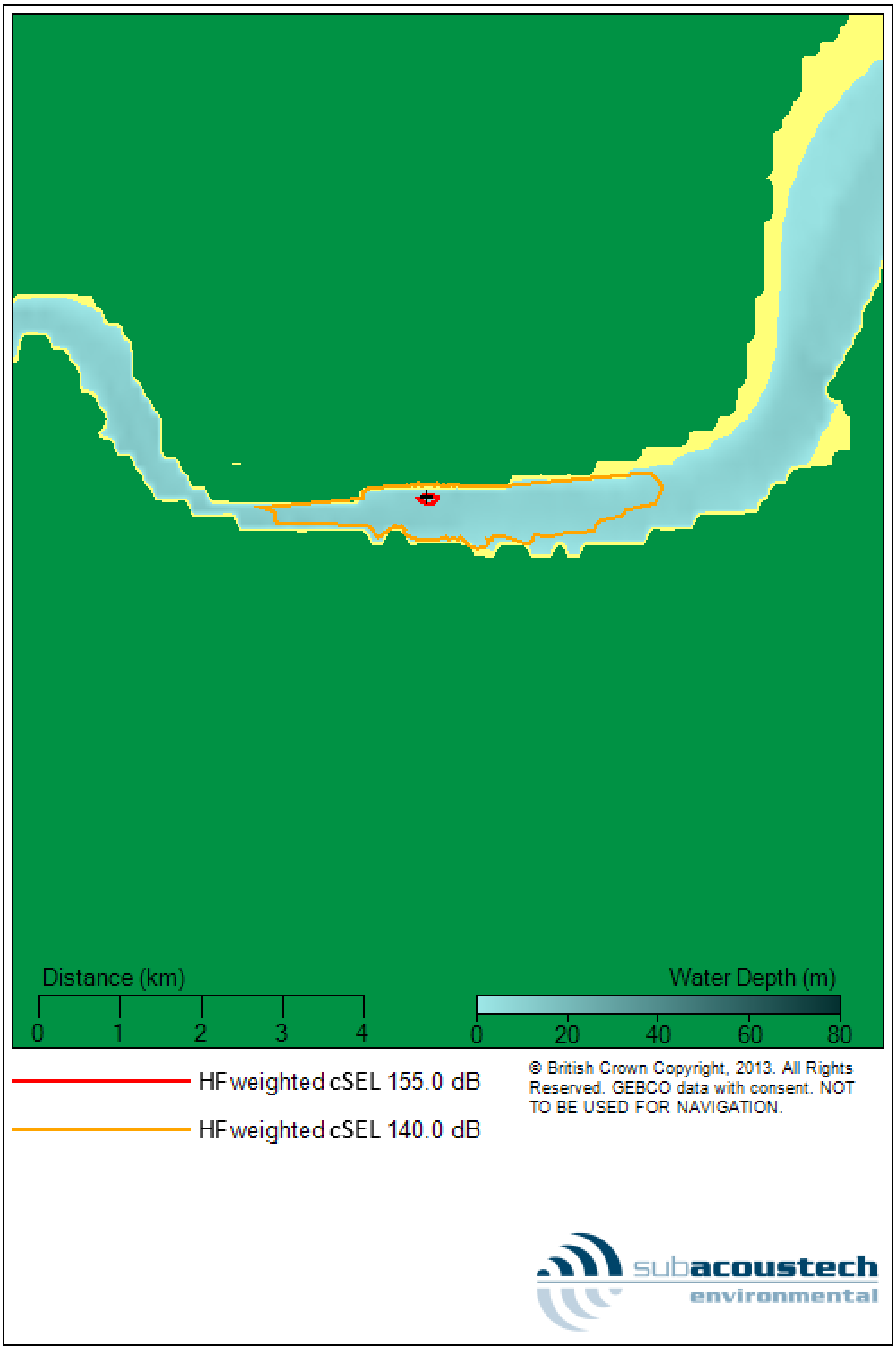


Figure 7-34 High frequency cetacean weighted model of piling at high tide at the western location (610 mm pile)

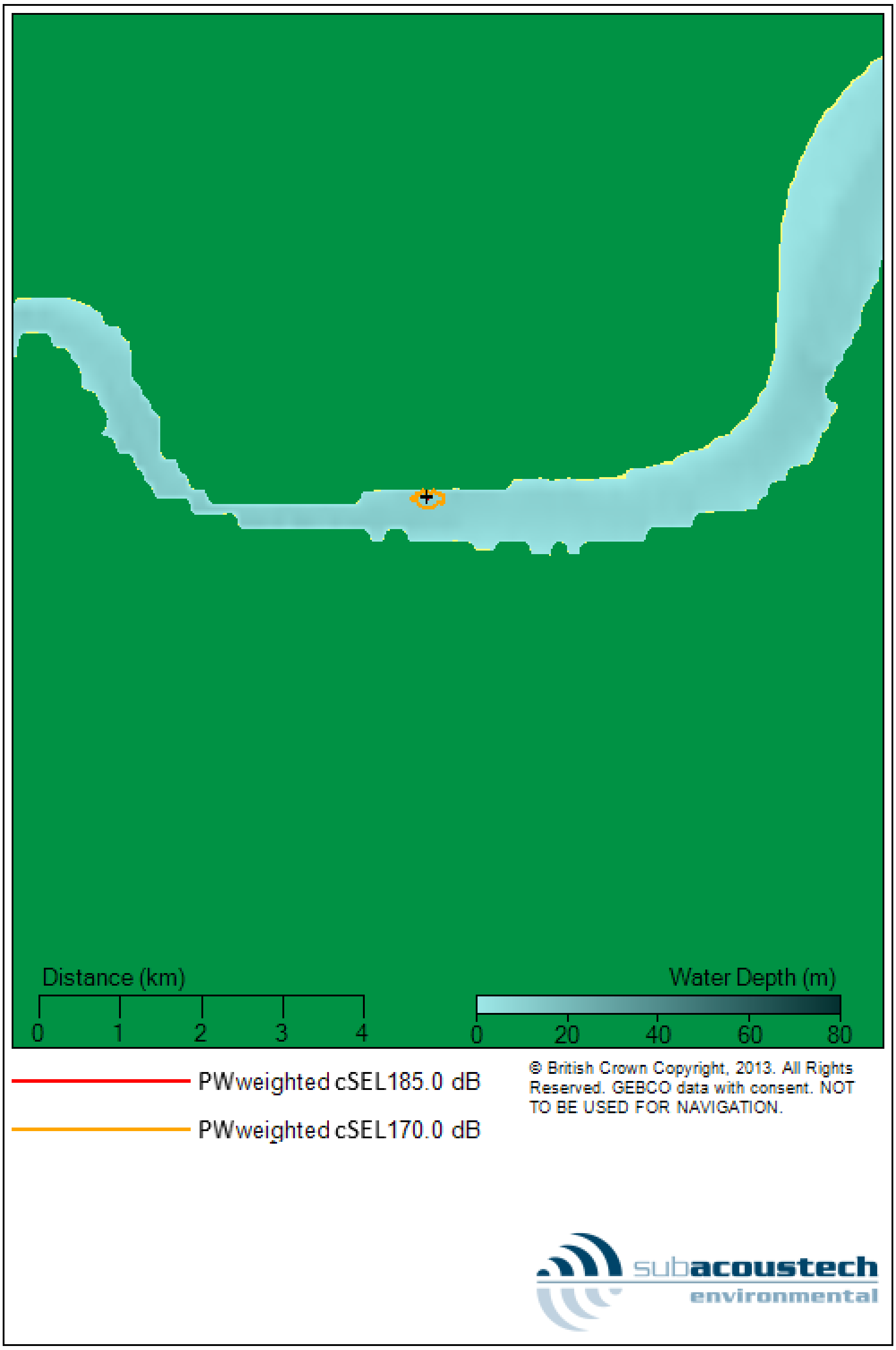


Figure 7-35 Phocid pinniped weighted model of piling at low tide at the western location (610 mm pile)

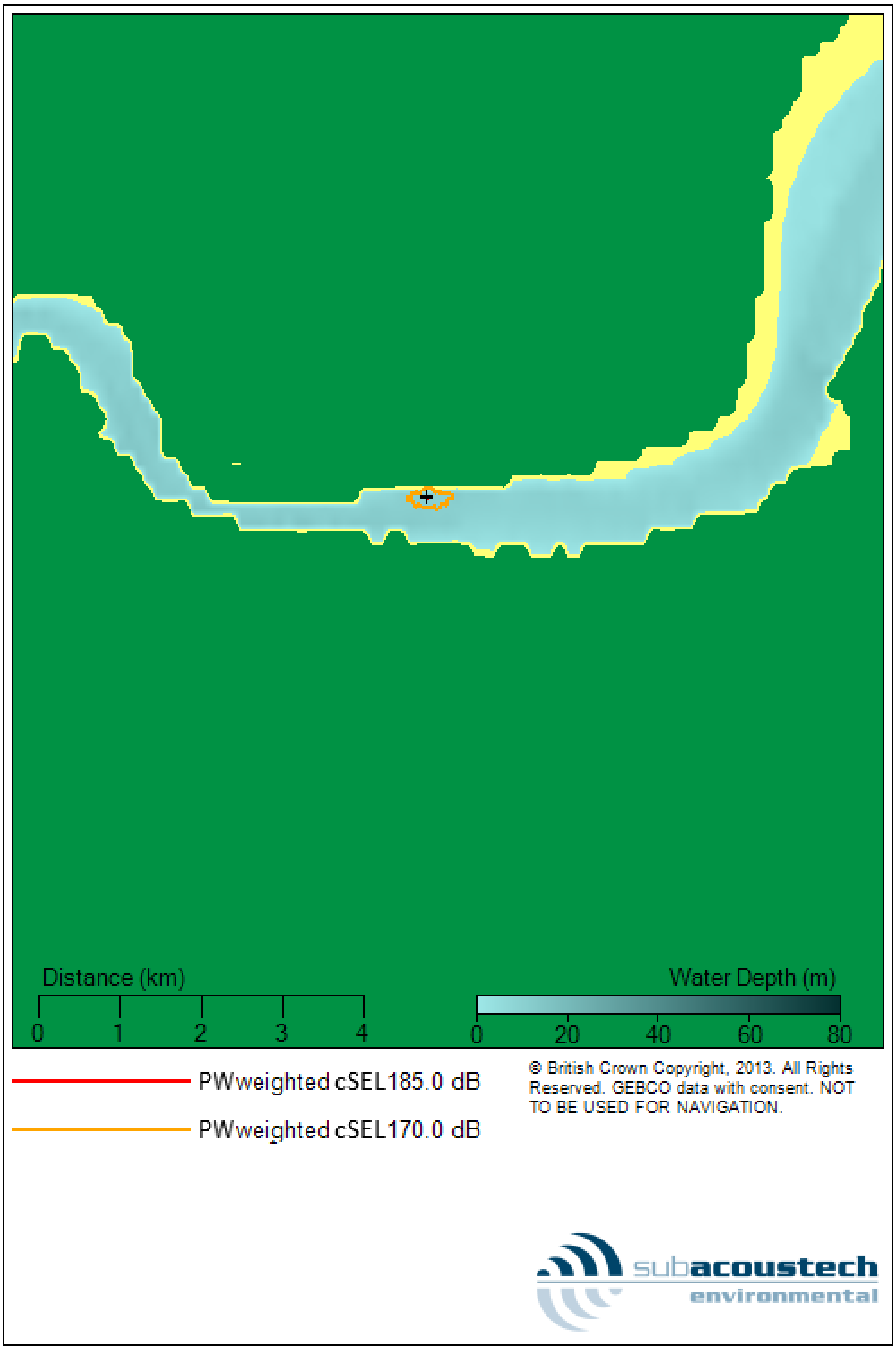


Figure 7-36 Phocid pinniped weighted model of piling at high tide at the western location (610 mm pile)

A.7 Fish, 610 mm piles, east and west locations

The contours for fish with 610 mm piles are too small to effectively display at the scale of plot.

Appendix B Hydrophone calibration certificate

Ocean Sonics

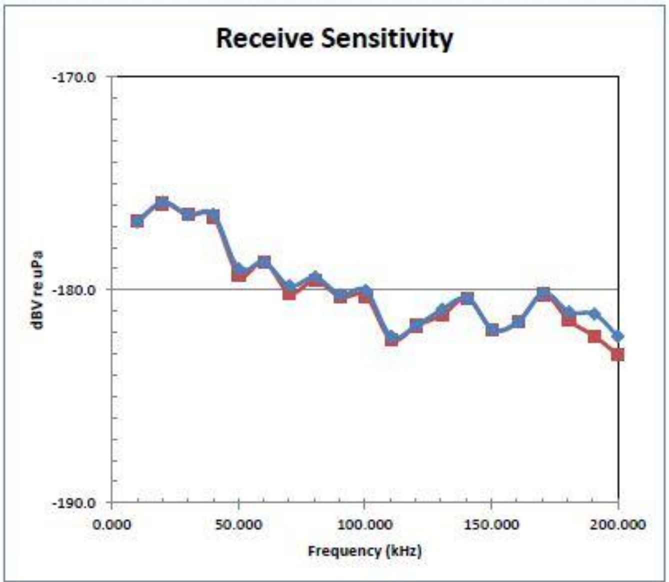
Certificate of Calibration

Ocean Sonics, Ltd.

Calibration Certificate Number: **C3698**

Test Result:	10 kHz to 100 kHz:	-178 ± 2.2
	10 kHz to 200 kHz:	-179 ± 3.2

Model Number	RB9-ETH	Projector Manufacturer	Ocean Sonics
Serial Number	1445	Projector Model	TH2-SER-4F
Manufacture Date	26-May-2016	Projector Serial	2210
Measurement Date	27-May-2016	Measurement Distance	1 m
Certificate Date	27-May-2016	Projector Mode	Wideband
Sensitivity @ 26 Hz	-178.7 dBV re µPa	Output Level	129.7 dB re µPa @ 1.0 m
Case Type	Plastic	Reference Manufacturer	Ocean Sonics
Element Manufacturer	Reson	Reference Model	SB2-ETH
Element Model	TC4059	Reference Serial	1387
Element Serial	5114020	Preamp Manufacturer	Ocean Sonics
Preamp Model	300434-01	Preamp Model	300419-01
Calibrated By	S.MacLean	Preamp Serial	261
Work Order Number	W1390	Preamp Gain	30 dB
Test Type	RX Sensitivity	ADC Manufacturer	Ocean Sonics
Test Proecdure	Complex RMS	ADC Model Number	04-300423-01
Test Location	Tank #2, 1 m	ADC Serial Number	261



Frequency	Sensitivity [dBV re µPa]	
kHz	0 deg	90 deg
10.0	-176.8	-176.8
20.1	-175.9	-175.9
30.1	-176.5	-176.5
40.2	-176.6	-176.5
50.2	-179.3	-179.0
60.2	-178.7	-178.7
70.3	-180.1	-179.8
80.3	-179.6	-179.4
90.4	-180.3	-180.2
100.4	-180.3	-180.0
110.4	-182.3	-182.2
120.5	-181.7	-181.7
130.5	-181.2	-180.9
140.5	-180.4	-180.4
150.6	-181.8	-181.9
160.6	-181.5	-181.5
170.7	-180.2	-180.1
180.7	-181.4	-181.0
190.7	-182.2	-181.1
200.0	-183.1	-182.2

Ocean Sonics Ltd. Great Village, Nova Scotia Certificate of Calibration v 1.02 © 2015

Report documentation page

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Document No.	Draft	Date	Details of change
P203R0101	01	03/08/2017	Initial writing and Atkins review
P203R0102	02	08/08/2017	Minor corrections and addition of section 5
P203R0103	-	11/08/2017	Addition of 610 mm piles, issued to client.
P203R0104	-	01/09/2017	2.5 m piles revised to 3.5 m. Updated TTS criteria for 610 mm piles. Additional detail included for other noise sources.
P2030105	-	13/09/2017	Minor revisions and clarifications

Originator’s current report number	P203R0105
Originator’s name and location	F Midforth; Subacoustech Environmental Ltd.
Contract number and period covered	P203; July 2017 – September 2017
Sponsor’s name and location	Port of Tilbury London Limited.
Report classification and caveats in use	COMMERCIAL IN CONFIDENCE
Date written	July 2017
Pagination	Cover + i + 64
References	
Report title	Monitoring background noise and modelling of construction noise at Tilbury Docks
Translation/Conference details (if translation, give foreign title/if part of a conference, give conference particulars)	
Title classification	Unclassified
Author(s)	Fergus Midforth, Tim Mason, Sam East
Descriptors/keywords	
Abstract	
Abstract classification	Unclassified; Unlimited distribution