BAS-210 0034 Rev 0

Darwin Underwater Noise Modelling Assessment

Santos Darwin Pipeline Duplication Project

Prepared for Santos

25 January 2023

Project Number: TN21068-1

DOCUMENT CONTROL					
Version	**Description**	**Date**	**Author**	**Reviewer**	**Approver**
0	Internal Draft	11/07/2022	IW/LA	GB	
1	First Issue – Draft for client review	13/07/2022	IW/LA	KT/RW	GB
2	Second Issue- updated with client comments	28/07/2022	GB	LM	GB
3	Third Issue- updated with Santo's comments	13/10/2022	GB	PI	GB
4	Fourth Issue- updated with Santo's comments	16/12/2022	GB		GB
5	Fifth Issue- updated two images	25/01/2023	IW		GB

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1 Introduction

This report summarises the outcomes of an underwater noise modelling study undertaken for Santos' proposed Darwin Pipeline Duplication Project (the Project).

1.1 Aim

The aim of this study is to model predicted underwater noise levels from construction activities (i.e. sheet piling and dredging) associated with the Project.

1.2 Scope

The report includes a summary of the methods and results of underwater noise modelling undertaken for the Project. It focuses on sheet piling and dredging as these are the most significant sources of underwater noise identified for the Project.

1.3 Applicable Documents

The following project document was used in support of the underwater noise study:

- EEN20291.007 – Santos Barossa PTS Underwater Noise Technical Note_0_220404.

References used for the underwater noise study are given in Appendix A and abbreviations and acronyms are given in Appendix B.

2 Project Background and Noise Sources

2.1 Overview

The Darwin Pipeline Duplication (DPD) Project is associated with the Barossa gas field development in northern Australia. The DPD Project involves the construction of a new pipeline running parallel to and approximately 50-100m from the existing Bayu-Undan to Darwin pipeline through Darwin Harbour and to the Darwin LNG facility (beach valve location). Some sections of the pipeline route through Darwin Harbour will be trenched using dredging vessels prior to pipelay (as shown in Figure 2-1). The pipeline will come ashore through a trenched shore crossing at the DLNG facility which may require the installation of a cofferdam.

2.2 Construction Overview

The following construction activities will be undertaken for the Project:

- Sheet piling may occur in the supratidal zone at the shore crossing site.
- Trenching activities using a dredger will occur in some sections along the pipeline route through the harbour.
- Rock breaking (hydraulic hammering) in areas of surficial rock.
- Laying of pipe on the seabed and within trenched area.

The most significant underwater noise sources are as follows:

- **Sheet Piling:** Steel sheets may be piled to create a cofferdam wall on the mudflats using a vibratory hammer. Sheet piling is not planned to take place at high tide or at night-time. As a result, the cumulative impacts from sheet piling have been determined using the hammer energy source level multiplied by the frequency over a maximum duration of eight hours (thus by adding it cumulatively over 480 minutes) over a 24-hour period.
- **Dredge Vessel:** Trenching will be undertaken in trenching zones by utilising a Trailing Suction Hopper Dredge (TSHD), a Cutter Suction Dredge (CSD) and a Backhoe Dredge (BHD) depending on the area. The following indicative 24-hour cycle times have been used to inform modelling:
    - **TSHD**: Cycle times are dependent on distance from spoil ground. On average it is expected that 3 hours will be spent dredging, 2 hours will be spent in transit/spoil dump repeated over period of 24 hours.
    - **CSD**: The CSD will have two cycles over a 24-hour period, with each cycle consisting of 10 hours of cutting and 2 hours of downtime.
    - **BHD – Hydraulic Hammering and Digging:** Rock breaking (hydraulic hammering) using a BHD. Indicative 24-hour cycle consisting of two cycles of 4 hours hammering, 4 hours of downtime followed by 4 hours of digging have been used to inform modelling.

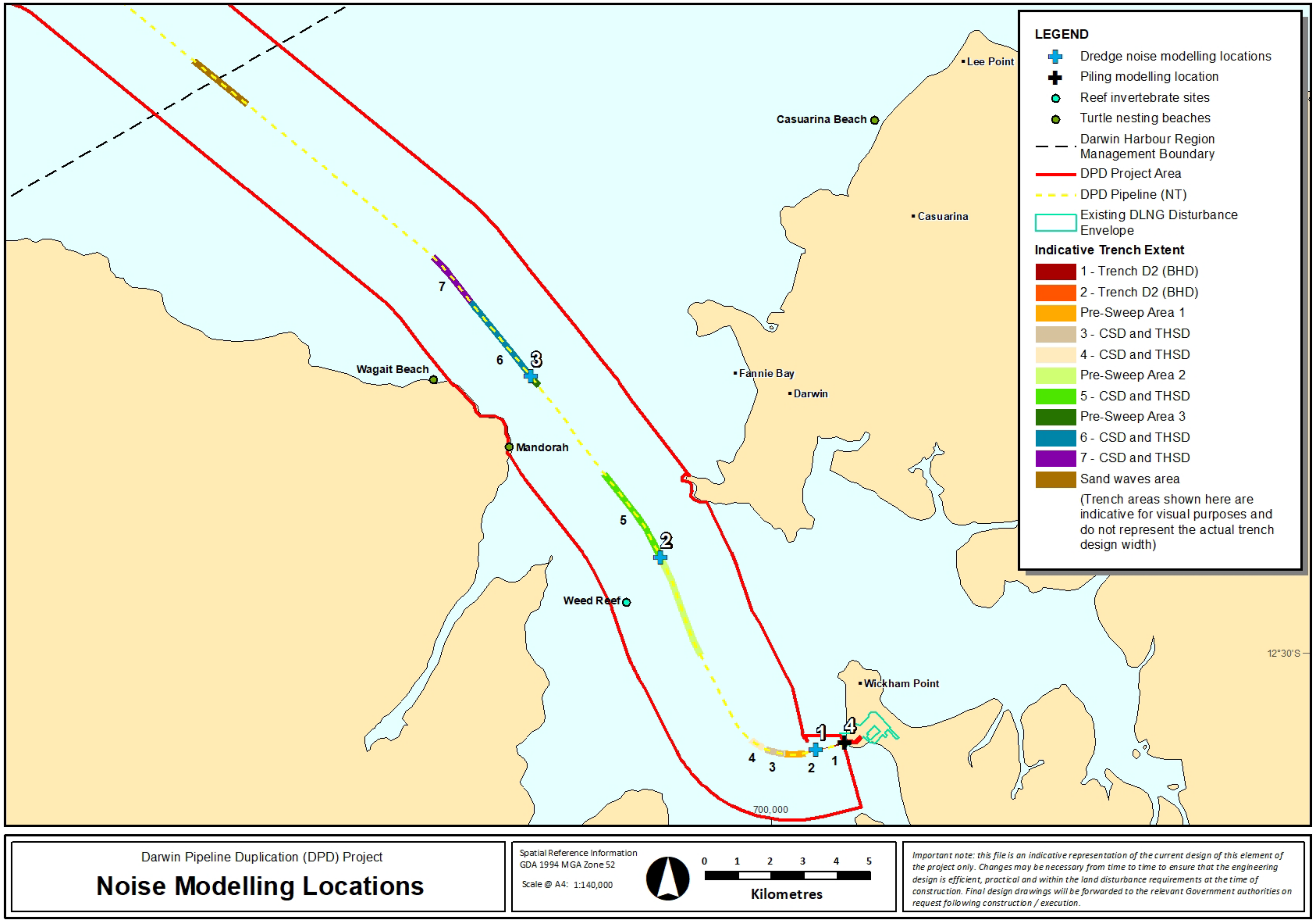

Figure 2-1 : Project Area and Trench and Noise Modelling Locations (source: RPS)

3 Underwater Noise

The ocean soundscape consists of naturally produced sounds and anthropogenically generated noise. Natural underwater sound occurs from marine life and events such as waves, storms, and underwater earthquakes. Anthropogenic noise results from activities such as piling, vessel traffic, seismic exploration, marine construction, and military activities.

The ambient underwater soundscape tends to be consistent and widespread across large areas of ocean, however, noise generated by anthropogenic activities can often be localised. If sufficiently loud, noise may be detrimental to certain marine species under some circumstances. The degree of impact is influenced by many factors, including the sound's duration, amplitude, and frequency; the distance between the sound source and marine life; the total time that the marine life is exposed to the sound and the sensitivity of marine life to the site-specific combination of these factors.

A two-year underwater noise measurement program [31] was undertaken by the Centre of Marine Science and Technology (CMST) between 2012 – 2015. The mean and minimum noise spectrum levels provided in the report are between 90 and 60 dB re 1µPa^2/Hz they are similar to the ambient sea noise in Australian waters given in Figure 3-1.

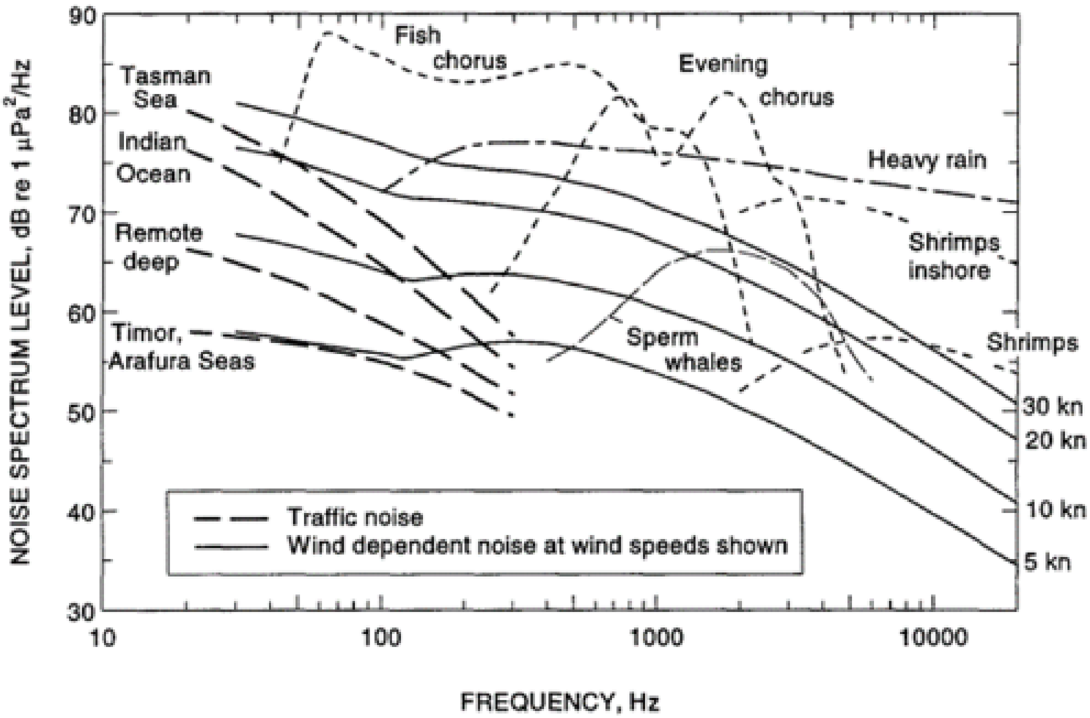

Figure 3-1 : Ambient Sea Noise in Australian Waters [6]

Sound travels further in the ocean than in air due to the natural duct created between the sea surface and the seabed, and the refractive properties of the water column. Additionally, the higher sound speeds in water result in longer wavelengths than in air, which result in low frequencies travelling further before they are absorbed to levels below ambient noise levels.

In shallow continental shelf water (< 200 m deep)[1], sound attenuates a lot faster than in the deeper, open ocean as the natural duct created between the sea surface and the seabed is very narrow,

[1] In the field of ocean acoustics, "shallow water" commonly refers to coastal waters extending from the shoreline out to the edge of the continental shelf to a depth of about 200 m, where the seafloor slope increases.

resulting in the acoustic pressure wave reflecting multiple times off the seabed and surface, with every reflection resulting in the pressure wave losing energy. Additionally, in very shallow water, low frequencies below a (depth dependant) cut off frequency attenuate very quickly, thus not having any impact at distance from the source.

4 Marine Fauna

4.1 Species of Interest

The conservation significant species with the highest likelihood of occurrence in the Project area are listed in Table 4-1. Fish are also included due to their potential commercial and recreational value.

Table 4-1 : Marine Fauna – Species of Interest for this study

Marine Fauna Type	Species
Cetaceans (high frequency dolphins)	• Indo-Pacific Humpback • Australian Snubfin • Spotted Bottlenose
Turtles	• Flatback • Olive Ridley • Hawksbill • Leatherback • Green • Loggerheads
Sirenians (SI)	• Dugong
Fish	• Various fish, sharks, and rays (including sawfish)

4.2 Assessment Criteria

Research has found that the noise levels at which Temporary Threshold Shift (TTS) and Permanent Threshold Shift (PTS) occur is dependent on whether the noise being generated is classed as impulsive or non-impulsive.

The definition of these two categories is as follows:

- **Impulsive** – sounds produced are typically transient, brief (less than one second), broadband and consist of high peak pressure with rapid rise time and rapid decay [2]. This noise source is associated with activities such as pile driving, seismic activities and underwater blasting and results in some of the most powerful sounds produced underwater [26], [27].
- **Non-impulsive** – sounds produced can be broadband, narrowband, or tonal, brief or prolonged, continuous or intermittent and typically do not have the high peak sound pressure with rapid rise / decay times that impulsive sounds do [2]. This type of noise source is associated with activities such as dredging, vessel noise, drilling and some construction activities.

See section 5.2 for a classification of the noise sources used in the study.

The assessment criteria for each fauna type are divided into noise levels that may result in TTS, PTS and behavioural disturbance (see Table 4-2). To determine the levels at which TTS and PTS occurs the study has relied on the following:

- **Dolphins**. For dolphins, the threshold levels for TTS and PTS for high frequency cetaceans as defined in Southall et al [1] and NOAA's 'Technical Guidance for Assessing the Effects of

Anthropogenic Sound on Marine Mammal Hearing' [2] respectively, are appropriate for this study. Behavioural threshold levels from NOAA's ESA Section 7 [2] have been used. Peak SPL levels at which PTS and TTS are provided for dolphins (see [1] and [2]) where peak levels of 230 and 224 dB re 1µPa are given for the onset of PTS and TTS respectively.

- **Sirenians**. For sirenians, the threshold levels for TTS and PTS for Sirenians as defined in Southall et al [1] and NOAA's 'Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing' [2] respectively, are appropriate for this study. Behavioural threshold levels from NOAA's ESA Section 7 [2] have been used.
- **Turtles.** The TTS and PTS criteria for turtles were taken from Criteria and Thresholds for U.S Navy Acoustics and Explosive Effect Analysis [22]. As there is a paucity of data regarding behavioural responses of turtles to non-impulsive sources a risk-based approach proposed by Popper et al [5] has been adopted. Using this approach, the risk is evaluated at three distances from the source defined in relative terms as near (N), intermediate (I), and far (F).
- **Fish.** The fish threshold criteria were taken from Popper et al [5] . Due to the paucity of data for behavioural responses a relative risk (high, moderate, low) as proposed by Popper et al [5] has been adopted. Using this approach, the risk is evaluated at three distances from the source defined in relative terms as Near (N) (scale of 10's of metres), Intermediate (I) (scale of 100's of metres), and far (F) (scale of 1000's of metres).

Note: Behavioural disturbance levels are not based on cumulative exposure or SEL[2], but rather on a Root Mean Square (RMS) Sound Pressure Level (SPL[3]).

Table 4-2 : Behavioural Disturbance, TTS and PTS Onset Thresholds (24-hour)

Marine Fauna Type	Marine Hearing Groups	Hearing Bandwidth	Noise Type	SEL_{24hour} (Weighted) dB re 1µ Pa^2.s		SPL Possible Behavioural Disturbance dB re 1µ Pa
				TTS	PTS	
Dolphins	High Frequency (HF)	150 Hz to 160 kHz	Non-Impulsive	178	198	120
			Impulsive	170	185	160
Sirenians	SI	100 Hz to 50 kHz	Non-Impulsive	186	206	120
			Impulsive	175	190	160
Turtles	N/A	100 Hz to 2 kHz	Non-Impulsive	200	220	Relative risk*
			Impulsive	189	204	166
Fish	N/A	100 Hz to 1 kHz	Non-Impulsive	Relative risk*		Relative risk*
			Impulsive	186	203	

* High, Moderate, Low.

2 Sound exposure levels (SEL) is the cumulative level of energy contained within underwater noise and is typically used to assess health and welfare impacts. This is also referred to as the "noise dose".

3 Sound Pressure Level (SPL) is the measure of the amplitude of acoustic pressure compared to 1 µPa.

5 Methodology

5.1 Overview

The desktop study has been undertaken using a computer noise model to simulate underwater noise emissions. The underwater software calculation kernel[4] utilises the Monterey Miami Parabolic Equation (MMPE [36]) which was developed by the University of Miami and Naval Postgraduate School Monterey in the USA. The model can predict transmission loss from multiple noise emission sources simultaneously in both broadband and narrowband frequency ranges.

Underwater propagation models require inputs including bathymetric data, geo-acoustic information, and oceanographic parameters to produce three-dimensional (3D) estimates of the acoustic field at any depth and distance from the source. As with any model, the quality of the prediction is directly related to the quality of the environmental information used in the model.

5.2 Noise Sources

The selection of noise sources has been based on the best information available from the project. The noise sources were selected in collaboration and with the project team. The sources selected were based on the best possible match to the activities and equipment provided at the time. The noise source levels used for modelling have therefore been calculated based on a combination of project data and source levels from an in-house database of underwater noise sources which have been developed from publicly available data. All source levels include overall and spectral levels.

5.2.1 Sheet Piling Noise Source Level

The action of driving a sheet pile into the seabed excites bendy[5] waves in the sheet pile that propagate along the length of the pile and transfer into the sea and seabed (see Figure 5-1). The compression component of the wave propagates into the ocean, while both compression and transverse components propagate into the seabed. Once in the seabed, the energy will then propagate outwards as compression and shear waves. Vibratory piling generates pulses that have rapid rise time and rapid decay and can therefore be considered as impulsive. They can also be considered as non-impulsive as the acoustic signal has sufficient duration to overcome starting transients and reach a steady-state condition [2]. Field data from 57 projects [33] show that levels from vibrational piling are highly variable and cannot be summarized into one level for a certain type of pile. This is due to several factors such as hammer size and pile type water depth, geotechnical conditions, and topography. As a result, a conservative approach has been taken and the vibratory hammer has been classed as an impulsive source as the threshold criteria for impulsive sources are stricter than non-impulsive sources.

The Project may use a vibratory hammer to drive the sheet piles if a cofferdam is required to be built. The frequency of a vibratory hammer is a lot higher than that of a hydraulic hammer with hammering frequencies ranging from 1,600 to 2,500 Hz.

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[4] The MMPE kernel used in this study has been rigorously tested at SWAM [32] and has undergone infield verification for both deep and shallow water.

[5] Bendy wave is a wave that comprises of a compression wave and a transverse wave.

The vibratory hammer specifications that have been used to calculate the source levels for modelling are given in Table 5-1.

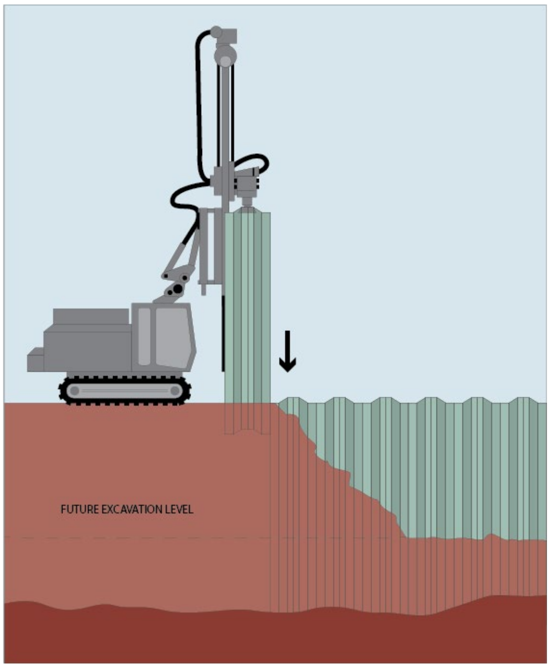

Figure 5-1 : Sheet piling using a vibratory hammer

Table 5-1 : Vibratory hammer specifications (based on 416L ICE) and modelled source level (SEL)[6]

Parameter	Value	SEL dB re 1µPa^2.s @ 1m	SPL Peak dB re 1µPa @ 10m
Eccentric moment kgm	23	165[6]	189[7]
Max. centrifugal force kN	645		
Max. frequency rpm	1600		
Max. amplitude mm	19.6		
Max. static line pull kN	400		
Max. oil flow L/min	359		
Dynamic weight kg	2350		
Total weight kg	3900		
L x W x H *) mm	2546 x 490 x 1566		

[6] Steel Sheet Pile [33] SWL calculated using 10*log10(2*pi*r) for approximated attenuation.

[7] Based on measured sheet pile levels at 10 m [33].

Parameter	Value	SEL dB re 1µPa^2.s @ 1m	SPL Peak dB re 1µPa @ 10m
Recommend. Power pack	400 series		
Recommended clamp	100TU		

Table 5-1 gives the sheet piling source level (SEL) for the vibratory hammer energy. Sheet piling is not planned to take place at high tide or at night-time. The cumulative impacts from sheet piling have been determined using the hammer energy source level multiplied by the frequency over a maximum duration of eight hours (thus by adding it cumulatively over 480 minutes) to give an overall cumulative SEL[8], as shown in Table 5-2.

Table 5-2 : Sheet piling noise source level

Parameter	Cumulative SEL $_{24\ hour}$
Source Level (SL)	227 dB re 1µPa^2.s @ 1m[8]

Note: If vibratory hammering only occurs during the low tide period, it has been assumed maximum of eight hours of driving will be undertaken.

The measured peak levels at 10m, as given in Table 5-1, are significantly less than the peak levels for the onset of PTS and TTS peak levels given in section 4.2. As a result, peak levels are not considered further in the assessment as sheet piling peak levels will be less than the threshold levels at ranges very close to the pile.

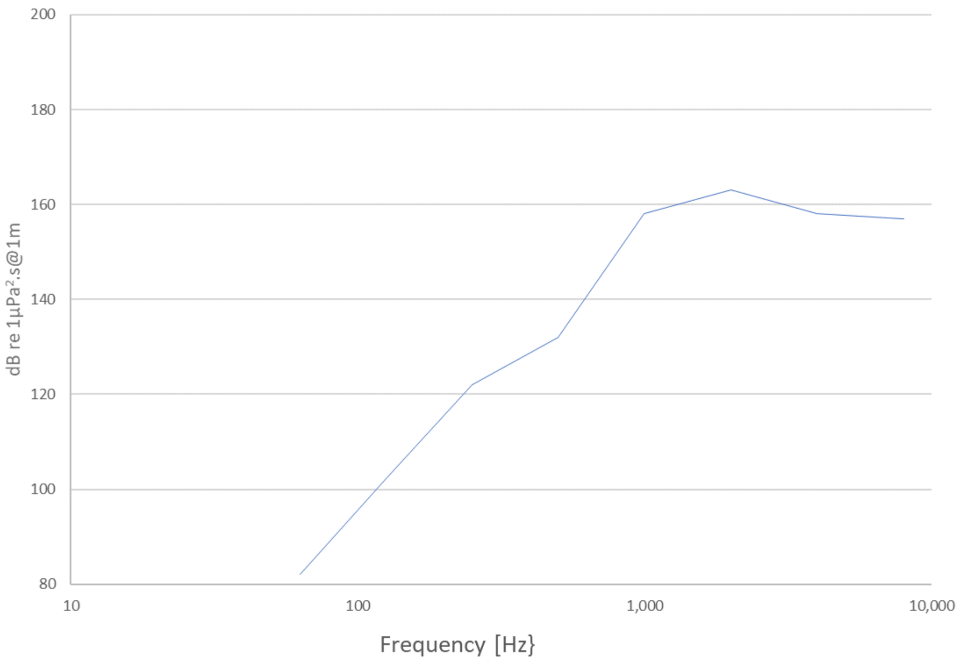

Figure 5-2 : Vibratory Hammer Sheet Piling source characteristics.

[8] 10*log10(N) where N is the number of minutes.

5.2.2 Dredging Noise Source Level[9]

Dredging is an underwater excavation activity used to increase the water depth, carried out by gathering up bottom sediment and disposing of the material at an approved spoil ground. Dredgers are non-impulsive noise sources.

The Project will use a TSHD, CSD and a BHD for trenching purposes. Dredging noise levels can vary significantly and are dependent on several factors including dredger design, equipment used, type of material being dredged and bathymetry. As RPS's 2022 pipeline route benthic habitat survey report [35] indicates that the pipeline route sediment consists of mud, gravel and sand, with sand being the predominate sediment, the dredging noise sources have been selected based on measurements undertaken of dredgers removing unconsolidated aggregate and sand [37].

Underwater noise measurements have been recorded from the CSD *Athena* conducting dredging operations at Walker Shoal in the East Arm of Darwin Harbour for the INPEX Ichthys project, as presented in Salgado-Kent et al [31]. These results have been reviewed but considered unlikely to be representative of CSD trenching operations for the DPD Project for the following reasons:

- Walker Shoal comprised areas of extremely high-strength conglomerate material (rock) which required special techniques to remove [39]. Some areas of rock were found to have had unconfined compressive strength (UCS) of 50 MPa to ~80 MPa; INPEX therefore determined that traditional dredging techniques, suitable for material strengths up to 30-50 MPa, could not be used [39].
- The CSD Athena was fitted with a specially modified cutting head (heavier with more teeth than a standard cutting head) to allow this high-strength rock to be removed [39]. The Athena was chosen on the basis that it was one of the few CSDs powerful enough to drive this cutting head [39].
- The DPD Project trenching areas does not comprise rock greater than 50 MPa and a conventional cutting head is considered sufficient to break up the rock encountered.

The equipment used and geology encountered during Ichthys project Walker Shoal dredging is therefore not considered representative for the DPD Project and CSD noise measurements in [31] have been used to inform the CSD source level used in this report.

A description of the dredging activities for the project are as follows:

- A TSHD uses a head suction pipe with nozzles connected to a high-pressure water installation to loosen the material on the seabed. The resulting lower pressure in the pipe lifts the material discharging it into a hopper. The SEL for the TSHD is based on a cycle time of dredging for 3 hours followed by 2 hours spent in transit/spoil dump repeated over period of 24 hours.
- A CSD is a vessel that includes a cutter head used to loosen the material and a suction mouth, inlet and pump used to mobilise the material from the seabed through piping into a hopper. The SEL for the CSD have been based on the cycle time of 10-hours of cutting and 2 hours of downtime repeated over 24 hours.
- A BHD will be used for digging and rock breaking. BHD noise was modelled in a rock-breaking phase (considered to be the noisiest activity undertaken by the BHD), whereby rock-breaking alternates with removal of broken rock via digging separate to the digging activities. The SEL

[9] Note: proposed equipment might not necessarily be the actual project equipment but are used as proxy sources reflective of actual equipment used by project.

for the BHD have been based on the cycle time of two cycles of 4 hours hammering, 4 hours of downtime followed by 4 hours of digging. As hydraulic hammering is impulsive, the exposure due to rock breaking has been calculated separately from the digging activity which has been modelled as non-impulsive noise.

The project dredge locations are shown in Figure 2-1 and the source levels used for modelling of dredging activities is given in Table 5-3.

Table 5-3 : Dredging noise source

Dredger Type	SPL[10] [dB re 1µPa @ 1m]	Reference Figure
TSHD [37]	184	**Figure 5-3**
CSD [37]	182	**Figure 5-4**
BHD (Digging) [26]	175	**Figure 5-5**

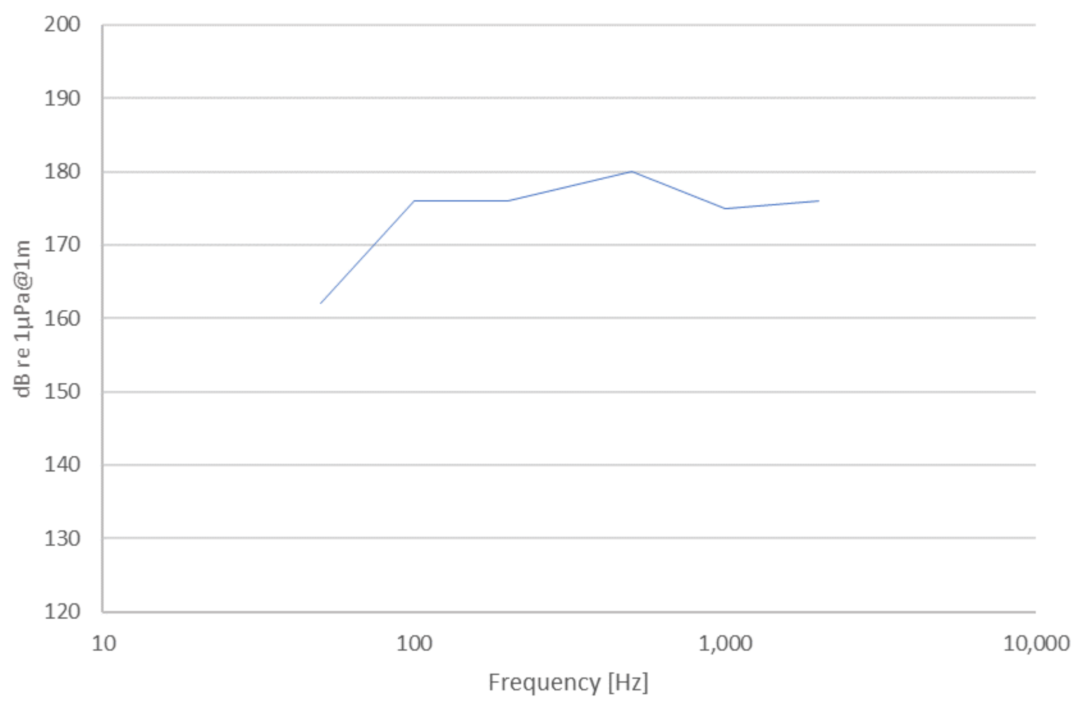

Figure 5-3 : TSHD noise source characteristics (at frequencies higher than reported a 20 dB/decade decay rate is assumed)

[10] Sound Pressure Level Root Mean Square.

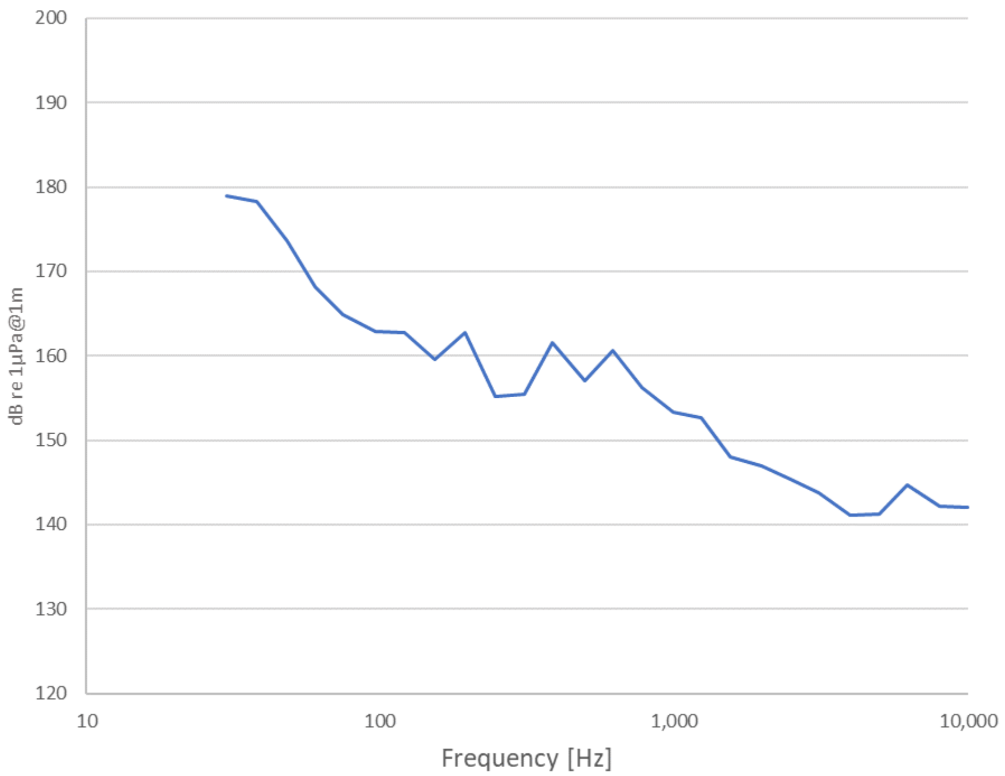

Figure 5-4 : CSD noise source characteristics

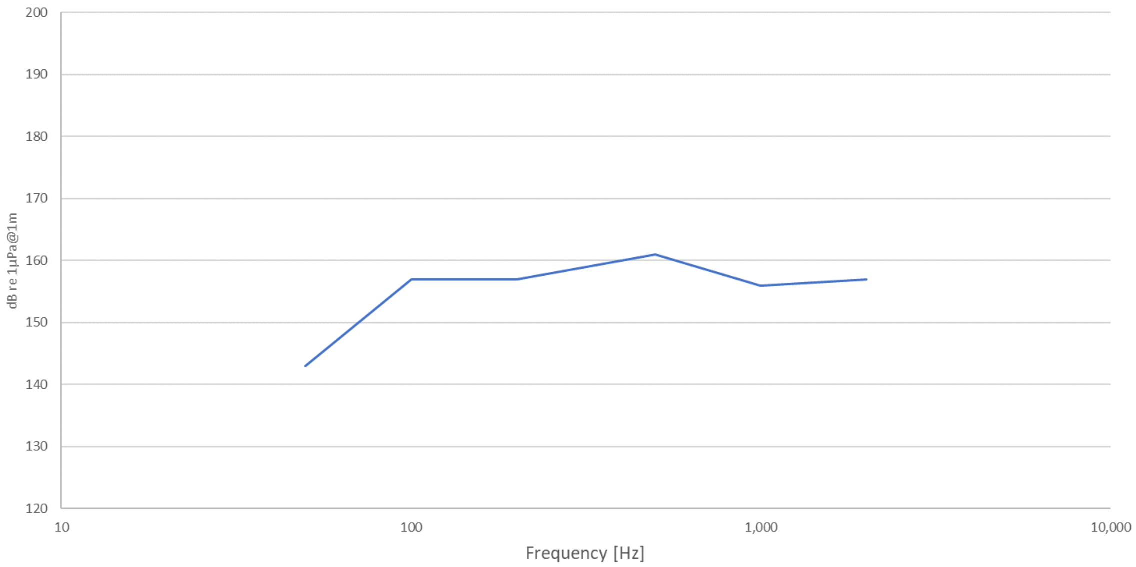

Figure 5-5 : BHD noise source characteristics (at frequencies higher than reported a 20 dB/decade decay rate is assumed)

5.2.3 BHD with Hydraulic Hammer

No publicly available underwater noise information could be found for hydraulic hammers. As a result, it has been assumed that the hydraulic hammer will have very similar levels to that of the vibratory hammer and the source levels in section 5.2.1 adopted as shown in Table 5-4.

Table 5-4 : Hydraulic Hammer noise source

Dredger Type	Cumulative SEL $_{24\ hour}$	Reference Figure
BHD Hydraulic Hammer	227 dB re 1µPa^2.s @ 1m	**Figure 5-2**

5.3 Noise Source Locations

Table 5-5 and Figure 2-1 gives the modelled noise source locations. For locations 1, 2 and 3, the source was positioned approximately halfway in the water column between surface and seabed.

Hydraulic sheet piling, if required, will be undertaken on the mud flats where there is no or very little water. As noise from the sheet piling can travel through the mud and reradiate into the water a noise source at Location 4 was placed 1m below the mud layer simulated in the model.

Table 5-5 : Noise Source model locations (MGA zone 52)

	Location Name	Easting	Northing
Location 1	Dredge Location 1	701366	8614382
Location 2	Dredge Location 2	696636	8620225
Location 3	Dredge Location 3	692710	8625712
Location 4	Sheet Pile Location	702240	8614600

5.4 Modelled Scenarios

Table 5-5 provides a summary of the modelled scenarios for each location and the 24 hour cycle time that was used to calculate exposure levels.

Notes:

- Noise sources are all static in the model.
- All model scenarios to SEL 24hour are at MSL. MSL was selected by the Project as Darwin harbour experiences extreme tidal ranges and high and low tide water levels occur for only a short period of time across a 24 hour period (or across spring-neap tidal cycle). A MSL therefore provides a more realistic representation of cumulative $SEL_{24\ hour}$ exposures as the water levels fluctuate around MSL over a 24 hour period.

Table 5-6 : Noise Model Scenarios

	Scenario	Water Depth [m]	Cycle Times within a 24 Hour periods
Location 1	BHD (Digging)	6	Two x 4 hours of digging over 24 hours during rock-breaking phase.
	BHD (Hydraulic Hammer)		Two x 4 hours hammering over 24 hours during rock-breaking phase.

	Scenario	Water Depth [m]	Cycle Times within a 24 Hour periods
Location 2	TSHD	17	3 hours dredging and 2 hours transit/spoil dump.
Location 3	TSHD	18	3 hours dredging and 2 hours transit/spoil dump
	Concurrent operations - TSHD and CSD		TSHD (3 hours dredging and 2 hours transit/spoil dump). CSD (10 hours of cutting and 2 hours downtime).
Location 4	Sheet Piling	0	8 hours over 24 hours.

5.5 Bathymetry

The bathymetry applied to the model was sourced from Geoscience Australia [38]. The bathymetry extended up to 20km from Darwin Harbour and 31km from the Project location. As shown in Figure 5-6, the water depth within the bathymetry which has been applied to the model is shallow (between 0m and ~25m).

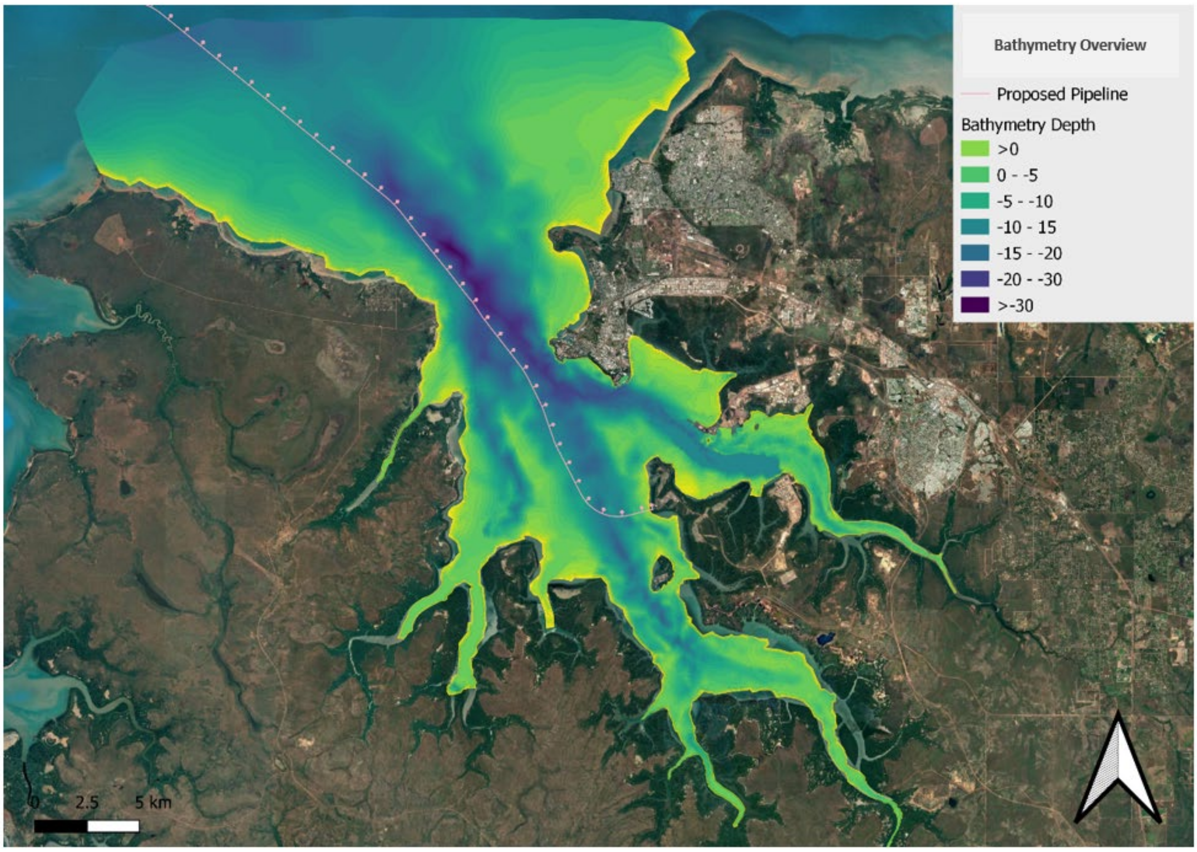

Figure 5-6 : Bathymetry (Mean Australian Sea Level)

5.6 Seabed Types

RPS's 2022 pipeline route benthic habitat survey report [35] shows that the pipeline route sediment consists of mud, gravel and sand, with sand being the predominant sediment. As a result, sand has been selected to represent the seabed for the study area with geo-acoustic properties as shown in Table 5-7. This is also a conservative approach as sand is more reflective in shallow water environments (i.e. shallow grazing angles) than limestone and other hard materials which absorb more of the energy of the pressure wave with each reflection [34]. This phenomenon is due to the properties of harder materials (such as limestone and calcarenite) where on reflection, the pressure wave at low grazing angles, excites both a compression and shear waves thus removing more energy from the wave. Sand on the other hand, excites only a compressional wave on reflection and therefore absorbs less energy.

Table 5-7 : Seabed geo-acoustic properties used in the model [34]

Type	Sound Speed (m/s)	Density (g/cm³)	Sound attenuation (dB/m/kHz)		Shear Speed (m/s)
			Compression	Shear	
Fine to medium sand	1774	2.05	0.374	0	0

5.7 Sound Speed Profile

The noise sources and a large proportion of the study area is in shallow water (<20m). The temperature profile through the water column has therefore been assumed to be isothermal (as sound speed profiles are not readily available). The sound speed profile used for modelling is for a constant water temperature of 28°C and a constant salinity of 27 parts per thousand (ppt), which are the mean values for water temperature and salinity in Darwin Harbour [11].

5.8 Hearing Threshold Weighting Curves

Hearing weighting curves used in the study are based on NOAA's technical guidance [2] for marine mammal species and the 2017 US Navy Acoustics and Explosive Effects report [22] for sirenians, fish and turtles. See Appendix F for a more detailed overview of the hearing curves.

5.9 Model Limitations

The following limitations apply to the noise modelling:

- **Reflection** – Specular reflection due to rough seabed surface and wave action is not accounted for in the model.
- **Airborne noise** – A small component of the airborne noise generated above the sea surface will be transferred into the water column. The levels from airborne noise will be a lot lower than for noise generated underwater. They will therefore not make a material difference to the outcomes of the underwater noise study.
- **Temperature, Salinity and Sound Speed Profiles** – The model has assumed negligible variation in sea temperature or salinity. It is assumed that the water column is isothermal (i.e. constant temperature) because the water depth in the modelling area is relatively shallow. Variation in the sound speed profile has been limited to the effects of water column pressure.

Technical Note on the impact of salinity, temperature and change of sound speed profile in shallow water:

- The Project area is in an acoustically shallow water environment (i.e. Depth <200 m [28]). In these environments sound is propagated to a distance by repeated reflections from both the surface and the bottom. In water that is acoustically shallow the acoustic characteristics of the surface and seabed are the most significant transmission paths. As a result, the interaction of the acoustic wave with the surface and the bottom becomes important for predicting received levels. As the project is in a very shallow environment and in an area where there is no major influx of cooler water or any other cooling effect the stratification of the water column won't be significant, and refraction will minimal.
- **Temperature**: In shallow water environments temperature affects the acoustic impedance between the water and seabed interface [29]. Water temperature has a cubic effect on sound speed and an increase or decrease in sound speed affects the efficiency of sound reflections. Due to uncertainty of the Projects schedule a mid-range temperature was appropriate.

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[11] Darwin harbour water temperature ranges between 23°C in June-July and 33°C in October-November. Salinity ranges between 25 parts per thousand (ppt) and 29 ppt. See reference [25].

- **Salinity**: Salinity, when compared to temperature, has a far smaller effect on sound speed. Additionally, salinity does not have an impact on absorption [30]. Salinity therefore does not affect the absorption of the acoustic wave or the sound speed profile (note it will only make a marginal difference to the sound speed profile in deep water). As a result, a change in salinity will not affect the predicted outcomes.

6 Noise Model Results and Discussion

6.1 Location 1 – BHD

Section 6.1.1 presents the ranges of predicted disturbance to each hearing group from the BHD (i.e. non-impulsive source) at Location 1, and section 6.1.2 gives the predicted disturbance to each hearing group from the BHD using a hydraulic hammer (i.e. rock breaking) at Location 1.

6.1.1 Location 1 – BHD Digging

Table 6-1 provides the ranges at which TTS and PTS is expected to exceed the threshold for each hearing group for BHD digging activity at Location 1 (as defined in section 5.4), and the estimated disturbance ranges. These ranges are as follows:

- TTS exceedances are between <50m and 151m.
- PTS exceedances are predicted to be <50m.
- Behavioural disturbance risks for turtles and fish have been assessed as Low in the nearfield (i.e. scales of 10s of metres) as defined in [5].
- Behavioural disturbance for dolphins and dugongs is predicted to occur within 454m from the BHD.

Appendix B, section B.1 provides the TTS and PTS noise maps and Appendix C, section C.1 contains the behavioural noise maps for all the hearing groups. Appendix D, section D.1 and Appendix E, section E.1 provides the maximum received levels with distance graphs.

Table 6-1 : Behavioural disturbance, TTS and PTS Onset threshold ranges for BHD Digging (non-impulsive) at Location 1 (MSL)

Hearing Group	$SEL_{24\ hour}$ (Weighted) Threshold [dB re 1µ Pa².s]		Distance [m]		SPL Behavioural [dB re 1µ Pa]	Distance [m]
	TTS	PTS	TTS	PTS		
Turtle	200	220	<50	<50	RISK	10's of metres
Dugongs	186	206	200	<50	120	454
Dolphins	178	198	145	<50	120	454
Fish	RISK		10's of metres	10's of metres	RISK	10's of metres

6.1.2 Location 1 – BHD with Hydraulic Hammer

Table 6-2 provides the ranges at which TTS and PTS is expected to exceed the threshold for each hearing group for BHD using a hydraulic hammer during rock-breaking phase at Location 1 (as defined in Section 5.4), and the estimated disturbance ranges. These ranges are as follows:

- TTS exceedances are between <50m and 200m.
- PTS exceedances are predicted to be <50m.

- Behavioural disturbance risks for fish have been assessed as Moderate in the nearfield (10's of metres) as defined in [5].
- Behavioural disturbance for turtles is predicted to occur at 151m from the BHD with Hydraulic Hammer activity.
- Behavioural disturbance for dolphins and dugongs is predicted to occur at 100m from the BHD with Hydraulic Hammer activity.

Appendix B, section B.1 provides the TTS and PTS noise maps and Appendix C, section C.1 contains the behavioural noise maps for all the hearing groups. Appendix D, section D.1 and Appendix E, section E.1 provides the maximum received levels with distance graphs.

Table 6-2 : Behavioural disturbance, TTS and PTS Onset threshold ranges for BHD with Hydraulic Hammer at Location 1 (MSL)

Hearing Group	$SEL_{24\ hour}$ (Weighted) Threshold [dB re 1µ Pa².s]		Distance [m]		SPL Behavioural [dB re 1µ Pa]	Distance [m]
	TTS	PTS	TTS	PTS		
Turtle	189	204	<50	<50	166	151
Dugongs	175	190	200	<50	160	100
Dolphins	170	185	151	70	160	100
Fish	186	201	100	<50	RISK	100's of metres

6.2 Location 2 – TSHD

Table 6-3 provides the ranges at which TTS and PTS is expected to exceed the threshold for each hearing group for the TSHD activity at Location 2, and the estimated disturbance ranges. These ranges are as follows:

- TTS exceedances are between 131m and 303m.
- PTS exceedances are predicted to be <50m.
- Behavioural disturbance risks for turtles and fish have been assessed as Low in the nearfield (10's of metres) as defined in [5].
- Behavioural disturbance for dolphins and dugongs is predicted to occur at 1,667m from the TSHD.

Appendix B, section B.3 provides the TTS and PTS noise maps and Appendix C, section C.3 contains the behavioural noise maps for all the hearing groups. Appendix D, section D.3 and Appendix E, section E.3 provides the maximum received levels with distance graphs.

Table 6-3 : Behavioural disturbance, TTS and PTS Onset Threshold Ranges for TSHD at Location 2 (MSL)

Hearing Group	$SEL_{24\ hour}$ (Weighted) Threshold [dB re 1µ Pa^2.s]		Distance [m]		SPL Behavioural [dB re 1µ Pa]	Distance [m]
	TTS	PTS	TTS	PTS		
Turtle	200	220	131	<50	RISK	10's of metres
Dugongs	186	206	170	<50	120	1,667
Dolphins	178	198	303	<50	120	1,667
Fish	RISK		10's of metres	10's of metres	RISK	10's of metres

6.3 Location 3 – TSHD

Table 6-4 provides the ranges at which TTS and PTS is expected to exceed for each hearing group for TSHD at Location 3, and the estimated disturbance ranges. These ranges are as follows:

- TTS exceedances are between 120m and 303m.
- PTS exceedances are predicted to be <50m.
- Behavioural disturbance risks for turtles and fish have been assessed as Low in the nearfield (10's of metres) as defined in [5].
- Behavioural disturbance for dolphins and dugongs is predicted to occur at 2,273m from the TSHD.

Appendix B, section B.4 provides the TTS and PTS noise maps and Appendix C, section C.4 contains the behavioural noise maps for all the hearing groups. Appendix D, section D.4 and Appendix E, section E.4 provides the maximum received levels with distance graphs.

Table 6-4 : Behavioural disturbance, TTS and PTS Onset Threshold Ranges for TSHD at Location 3 (MSL)

Hearing Group	$SEL_{24\ hour}$ (Weighted) Threshold [dB re 1µ Pa².s]		Distance [m]		SPL Behavioural [dB re 1µ Pa]	Distance [m]
	TTS	PTS	TTS	PTS		
Turtle	200	220	120	<50	RISK	10's of metres
Dugongs	186	206	200	<50	120	2,273
Dolphins	178	198	303	<50	120	2,273
Fish	RISK		10's of metres	10's of metres	RISK	10's of metres

6.4 Location 3 – TSHD and CSD

Table 6-5 provides the ranges at which TTS and PTS is expected to exceed for each hearing group for concurrent TSHD and CSD at Location 3, and the estimated disturbance ranges. These ranges are as follows:

- TTS exceedances are between 160m and 350m.
- PTS exceedances are predicted to be <50m.
- Behavioural disturbance risks for turtles and fish have been assessed as Low in the nearfield (10's of metres) as defined in [5].
- Behavioural disturbance for dolphins and dugongs is predicted to occur at 3,181m from the TSHD and CSD activities.

Appendix B, section B.5 provides the TTS and PTS noise maps and Appendix C, section C.5 contains the behavioural noise maps for all the hearing groups. Appendix D, section D.5 and Appendix E, section E.5 provides the maximum received levels with distance graphs.

Table 6-5 : Behavioural disturbance, TTS and PTS Onset Threshold Ranges for TSHD and CSD at Location 3 (MSL)

Hearing Group	$SEL_{24\,hour}$ (Weighted) Threshold [dB re 1μ Pa².s]		Distance [m]		SPL Behavioural [dB re 1μ Pa]	Distance [m]
	TTS	PTS	TTS	PTS		
Turtle	200	220	160	<50	RISK	10's of metres
Dugongs	186	206	210	<50	120	3,181
Dolphins	178	198	350	<50	120	3,181
Fish	RISK		10's of metres	10's of metres	RISK	10's of metres

6.5 Location 4 – Sheet Piling

Table 6-6 provides the ranges at which TTS and PTS is expected to exceed for each hearing group for Sheet Piling at Location 3, and the estimated disturbance ranges. These ranges are as follows:

- TTS exceedances are between <50m and 85m.
- PTS exceedances are predicted to be <50m.
- Behavioural disturbance risks for fish have been assessed as low in the nearfield (10's of metres) as defined in [5].
- Behavioural disturbance for turtles, dolphins and dugongs is predicted to occur at <50m from the Sheet Piling.

Appendix B, section B.6 provides the TTS and PTS noise maps and Appendix C, section C.6 contains the behavioural noise maps for all the hearing groups. Appendix D, section D.6 and Appendix E, section E.6 provides the maximum received levels with distance graphs.

Table 6-6: Behavioural disturbance, TTS and PTS Onset Threshold Ranges for Sheet Piling at Location 4

Hearing Group	$SEL_{24\ hour}$ (Weighted) Threshold [dB re 1µ Pa².s]		Distance [m]		SPL Behavioural [dB re 1µ Pa]	Distance [m]
	TTS	PTS	TTS	PTS		
Turtle	189	204	<50	<50	166	<50
Dugongs	175	190	<50	<50	160	<50
Dolphins	170	185	<50	<50	160	<50
Fish	186	201	<50	<50	RISK	10's of metres

6.6 Behavioural Ranges for LAT, MSL and HAT

Darwin Harbour can experience large tidal swings, with up to 8m between Low Astronomical Tide (LAT) and Highest Astronomical Tide (HAT), although typically tidal ranges are approximately 6m between spring low and high tides, and approximately 2m between neap low and high tides.

Table 6-7 presents the behavioural ranges for LAT, MSL and HAT which have been given as these are representative of likely behavioural disturbances for a point in time[12] for turtles, dugongs, and dolphins.

The highest differential behavioural ranges between LAT and HAT were found to be at Location 2 and Location 3 where the water is deeper

Note: Low risk ratings in Table 6-7 are for nearfield (10's of metres) distances while Moderate risk ratings are for intermediate (100's of metres) distances as defined in [5].

Table 6-7: Behavioural disturbance Threshold Ranges for all locations for LAT, MSL and HAT.

Receptor Type	Sound Pressure Level (SPL) Behavioural Threshold (dB re 1µ Pa)	Threshold Range (metres) for tidal state		
		LAT	MSL	HAT
Location 1 – BHD (digging)				
Turtle	RISK	10's of metres	10's of metres	10's of metres
Dugong	120	303	454	909
Dolphin	120	303	454	909
Fish	RISK	10's of metres	10's of metres	10's of metres
Location 1 – BHD (hydraulic hammering)				
Turtle	166	<50	151	302
Dugong	160	<50	100	200
Dolphin	160	<50	100	200
Fish	RISK	10's of metres	10's of metres	100's of metres
Location 2 – THSD				
Turtle	RISK	10's of metres	10's of metres	100's of metres
Dugong	120	1,450	1,667	20,000

[12] A MSL provides a more realistic representation of cumulative $SEL_{24\ hour}$ exposures as the water levels fluctuate around MSL over a 24 hour period. The HAT and LAT $SEL_{24\ hour}$ exposures ranges are therefore not included in the study

Receptor Type	Sound Pressure Level (SPL) Behavioural Threshold (dB re 1µ Pa)	Threshold Range (metres) for tidal state		
		LAT	MSL	HAT
Dolphin	120	1,450	1,667	20,000
Fish	RISK	10's of metres	10's of metres	100's of metres
Location 3 – THSD				
Turtle	RISK	10's of metres	10's of metres	100's of metres
Dugong	120	1,515	2,273	17,878
Dolphin	120	1,515	2,273	17,878
Fish	RISK	10's of metres	10's of metres	100's of metres
Location 3 – THSD and CSD				
Turtle	RISK	10's of metres	10's of metres	100's of metres
Dugong	120	3,000	3,181	20,000
Dolphin	120	3,000	3,181	20,000
Fish	RISK	10's of metres	10's of metres	100's of metres
Location 4 – Sheet Piling				
Turtle	166	<50	<50	N/A
Dugong	160	<50	<50	N/A
Dolphin	160	<50	<50	N/A
Fish	RISK	10's of metres	10's of metres	10's of metres

7 Conclusion

An underwater noise model has been developed to predict potential noise levels at distance from noise sources associated with the Project. The noise sources modelled in the report are representative of the Project design and construction. As noted in sections 5.1 and 5.2 the noise sources have been selected based on the best information available at the time of the study. Even so the information available in the public domain shows that noise sources with similar specifications can vary depending as described in section 5.2.

APPENDIX A Reference Documents

[1] Southall et al, Marine Mammal Noise Exposure Criteria: Updated Scientific Recommendations for Residual Hearing Effects, Aquatic Mammals 2019, 45(2).

[2] Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing, National Oceanic and Atmospheric Administration (NOAA), July 2018. And ESA Section 7 Consultation Tools for Marine Mammals on the West Coast (webpage), 27 Sep 2019. https://www.fisheries.noaa.gov/west-coast/endangered-species-conservation/esa-section-7-consultation-tools-marine-mammals-west.

[3] Criteria and Thresholds for Adverse Effects of Underwater Noise on Marine Animals, Science Applications International, May 2000.

[4] Casper, B.M., 2006, The hearing abilities of elasmobranch fishes. Graduate Theses and Dissertations, University of South Florida.

[5] A. Popper, et al, 2014, Sound Exposure Guidelines for Fishes and Sea Turtles, ANSI, ASA S3/SC1.4TR-2014.

[6] D. Cato, Ambient Sea Noise in Australian Waters, Fifth International Congress of Sound and Vibration, 1997.

[7] Dunlop et al, 2017, Determining the behavioural dose-response relationship of marine mammals to air gun noise and source proximity, Journal of Experimental Biology (2017) 220, 2878-2886.

[8] Cavanagh et al, 2000, 'Criteria and Thresholds for Adverse Effects of Underwater Noise on Marine Animals for injury' , AFRL-HE-WP-TR-2000-0092.

[9] McCauley RD, et al, 2000,'Marine Seismic Surveys: analysis and propagation of air-gun signals and effects of exposure on humpback whales, sea turtles, fishes and squid'. R99-15, Perth Western Australia.

[10] Whiting, S. D., 2003, Marine mammals and marine reptiles of Darwin Harbour, proceedings of the Darwin Harbour Public Presentations, Darwin Harbour Plan of Management.

[11] McCauley et al, 'Marine Seismic Surveys- A study of Environmental Implications' APPEA Journal 200, pg 692-708 and McCauley RD, et al, 2000,'Marine Seismic Surveys: analysis and propagation of air-gun signals and effects of exposure on humpback whales, sea turtles, fishes and squid'. R99-15, Perth Western Australia

[12] Arons, A.B. 1954. Underwater Explosion Shock Wave Parameters at Large Distances from the Charge. J. Acoust. Soc. Am. Volume 26, Issue 3, pp. 343-346

[13] Keevin, K.M., Hempen, G.L, 1997. The Environmental Effects of Underwater Explosions with Methods to Mitigate Impacts. U.S. Army Corps of Engineers, St. Louis, Missouri

[14] Koschinski, S. 2011. Underwater Noise Pollution from Munitions Clearance and Disposal, Possible Effects on Marine Vertebrates, and its Mitigation. Marine Technology Society Journal Volume 45, Issue 6, pp. 80-88

[15] Rogers, P.H. 1977. Weak-shock solution for underwater explosive shock waves. J. Acoust. Soc. Am. Volume 62, Issue 6, pp. 1412-1419

[16] Southall et al. 2007. Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations. Aquatic mammals Volume 33, Issue 4, pp. 411-521

[17] Yelverton, T.Y, D.R. Richmond, E.R. Fletcher and R.K. Jones. 1973 Safe distances from underwater explosions for mammals and birds. DNA 3114T Rep. from Lovelace Foundation for Medical Education and Research, Alburquerque, NM, for Defense Nuclear Agency, Washington, DC. 67p NTIS AD-766952

[18] Young, G.A. 1991. Concise Methods of Predicting the Effects of Underwater Explosions on Marine Life.

[19] Whiting, S. D., 2003, Marine mammals and marine reptiles of Darwin Harbour, proceedings of the Darwin Harbour Public Presentations, Darwin Harbour Plan of Management.

[20] Gaspin,J.B, 1983, Safe Swimmer Ranges from Bottom Explosion (technical report 83-84)

[21] https://dosits.org/science/advanced-topics/shallow-water-propagation/

[22] J.J Finneran and A.K. Jenkins. Criteria and Thresholds for U.S. Navy Acoustics and Explosive Effects Analysis (April 2017)

[23] Review on existing data on Underwater Sounds From Pile Drive Activities – E&P Sound & Marine Life Program – Sept 2020

[24] Criteria and Thresholds for U.S. Navy Acoustic and Explosive Effects Analysis

[25] Padovan, A.V. 2003. Darwin Harbour water and sediment quality. pp. 5–18 in Darwin Harbour Region: current knowledge and future needs. Proceedings of public presentations hosted by the Darwin Harbour Advisory Committee at the Northern Territory University, Darwin, on 11, 19 and 26 February 2003. Department of Infrastructure, Planning and Environment, Darwin, Northern Territory.

[26] Reine, K. J., D. G. Clarke, and C. Dickerson. 2012. Characterization of underwater sounds produced by a hydraulic cutter head dredge fracturing limestone rock.

[27] Young, G.A. 1991. Concise Methods of Predicting the Effects of Underwater Explosions on Marine Life.

[28] Urick, 'Principals of Underwater Sound'.

[29] Kinsley, Frey, Coppens and Sanders, 'Fundamentals of Acoustics'.

[30] Fisher and Simmons, J.Acous.Soc. AM, 62, 558 (1977.)

[31] Salgo-Kent etal, Report on a two year underwater noise measurement program: Before, During and after dredging activities in Darwin Harbour, 2012 – 2015,CMST 1122.

[32] Journal of Computational. Acoustics 9, pp. 243-285.

[33] Technical Guidance for the Assessment of Hydroacoustic Effects of Pile Driving on Fish, Caltrans, 2020.

[34] Computational Ocean Acoustics, Finn Jensen, William Kuperman, Michael Porte.

[35] RPS Pipeline Benthic Survey Report, AU213002038.001, Sept 2022.

[36] http://oalib.hlsresearch.com/PE/MMPE/mmpeintro.html

[37] Thomsen F, McCully SR, Wood D, White P, 2011. A generic investigation into noise profiles of marine dredging in relation to the acoustic sensitivity of the marine fauna in UK waters, MEP F 08/P21

and Measurements of underwater noise arrising from marine aggregate dredging operations, MEP F 09/P108.

[38]https://data.gov.au/data/dataset/complete-bathymetry-grid-of-darwin-harbour-from-various-surveys-onboard-the-matthew-flinde-2011

[39] INPEX Browse Ltd, 2011. Ichthys Gas Field Development Project: supplement to the draft environmental impact statement. Report prepared by INPEX Browse Ltd., Perth, Western Australia, for the Commonwealth Government, Canberra, ACT, and the Northern Territory Government, Darwin, Northern Territory.

APPENDIX A Abbreviations, Acronyms and Symbols

dB	Decibel
CMST	Centre of Marine Science and Technology
HAT	Highest Astronomical Tide
HF	High Frequency
Hz	Hertz
kHz	Kilo Hertz
LAT	Lowest Astronomical Tide
LE,24h	Sound Exposure Level Cumulative 24 hours
LF	Low Frequency
LPK	Peak Sound Pressure Level
M	Metre
MASDP	Middle Arm Sustainable Development Precinct
MSL	Mean Sea Level
ms	Milliseconds
NOAA	National Oceanic and Atmospheric
Pa	Pascals
PTS	Permanent Treshold Shift
RMS	Root Mean Square
s	Seconds
SEL	Sound Exposure Level [dB re 1µPa^2.s]
SELcum	Cumulative Sound Exposure Level
SL	Source Level [dB re 1µPa @ 1m] or [dB re 1µPa^2.s @ 1m]
SPL	Sound Pressure Level [dB re 1µPa]

TTS	Temporary Treshold Shift
µPa	Micro Pascal
µPa2-s	Micro Pascal Square Second
W(f)	Weighting function

APPENDIX B
PTS and TTS Contours

B.1 Location 1 – BHD

Figure 7-1 :Location 1 – BHD (Digging) TTS and PTS Contours for Turtles (MSL)

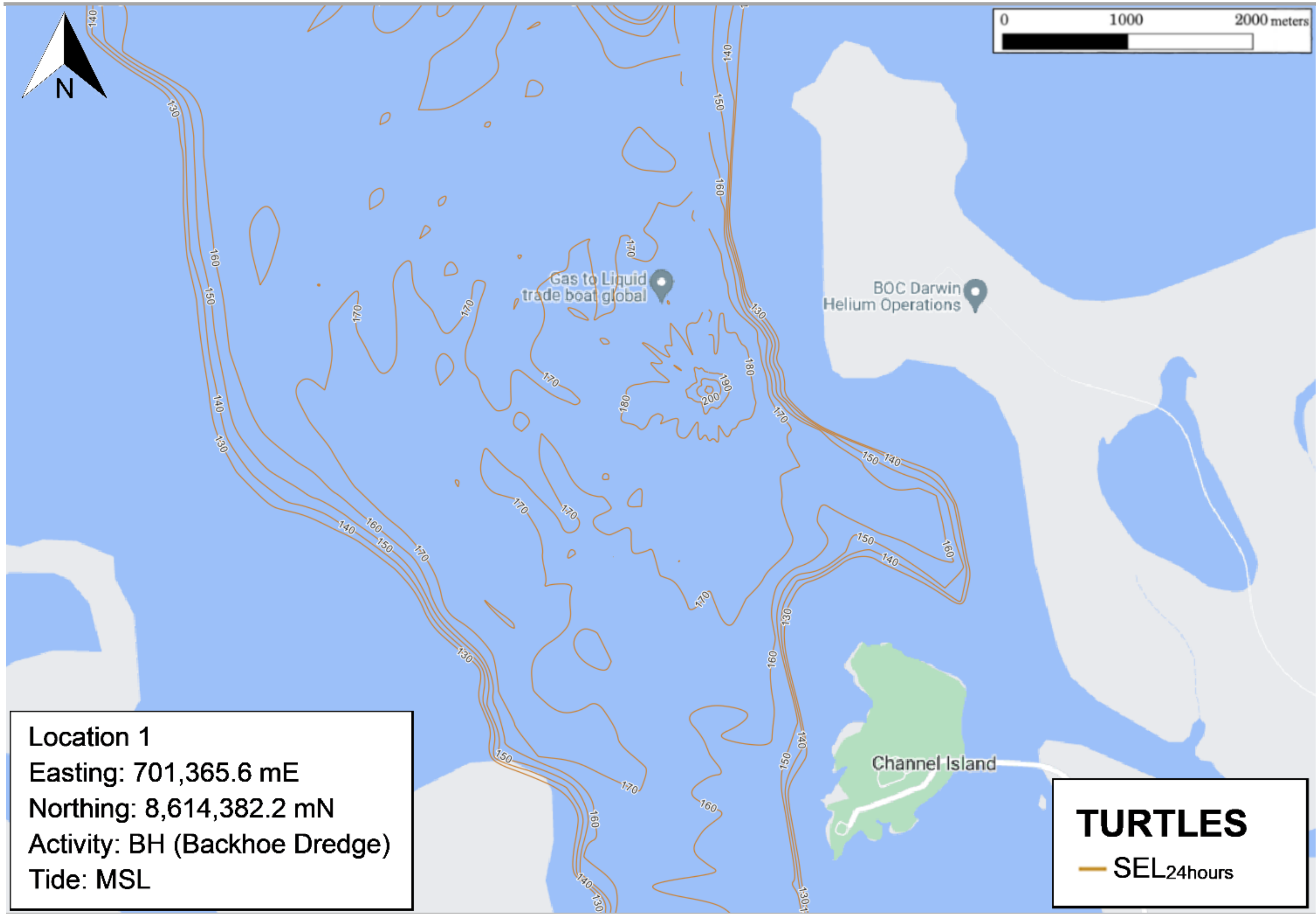

Figure 7-2 : Location 1 – BHD (Digging) SEL$_{24\ hours}$ Contours for Turtles (MSL)

Figure 7-3 : Location 1 – BHD (Digging) TTS and PTS Contours for Dolphins (MSL)

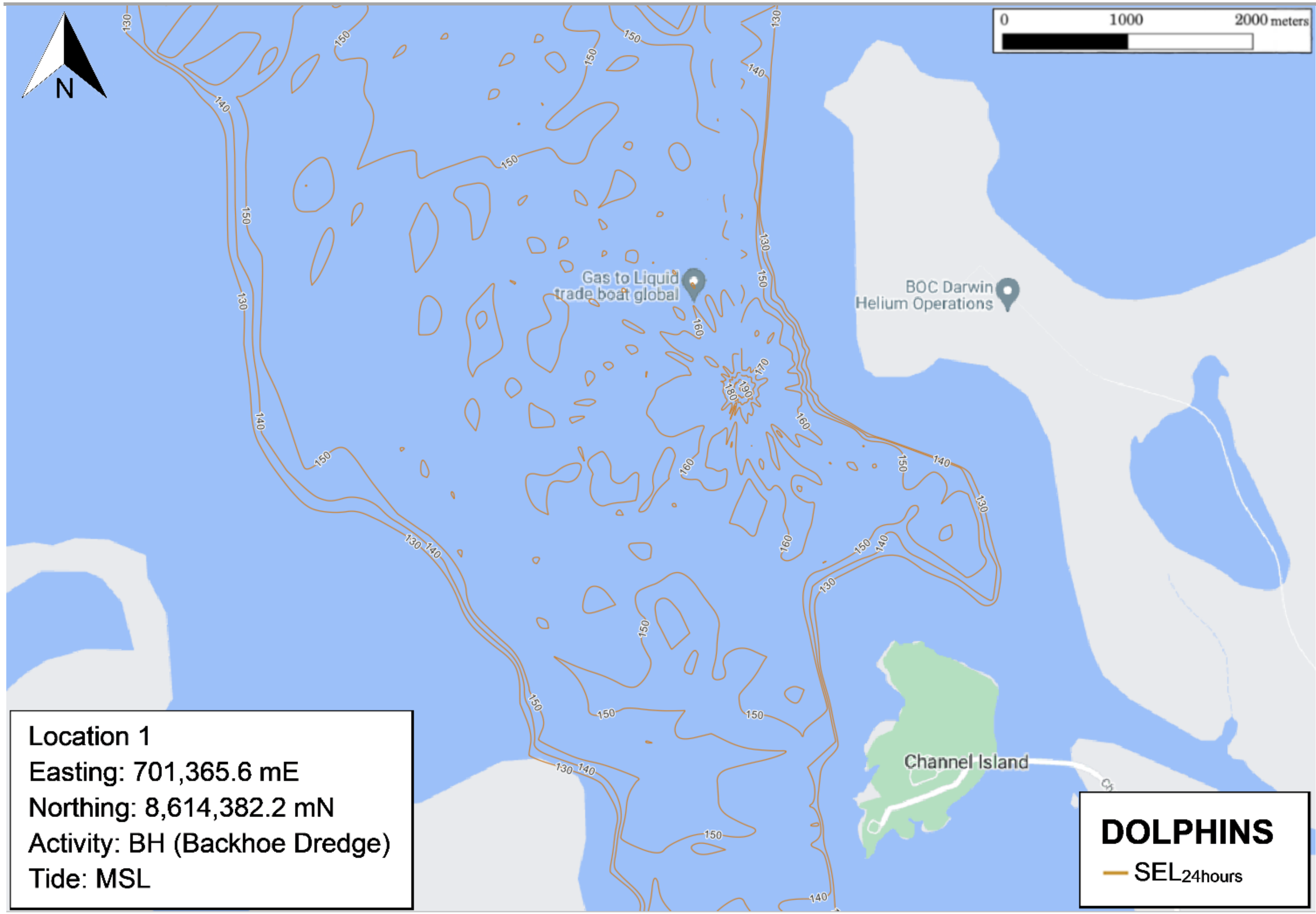

Figure 7-4 : Location 1 – BHD (Digging) SEL$_{24\ hours}$ Contours for Dolphins (MSL)

Figure 7-5 : Location 1 – BHD (Digging) TTS and PTS Contours for Sirenians (MSL)

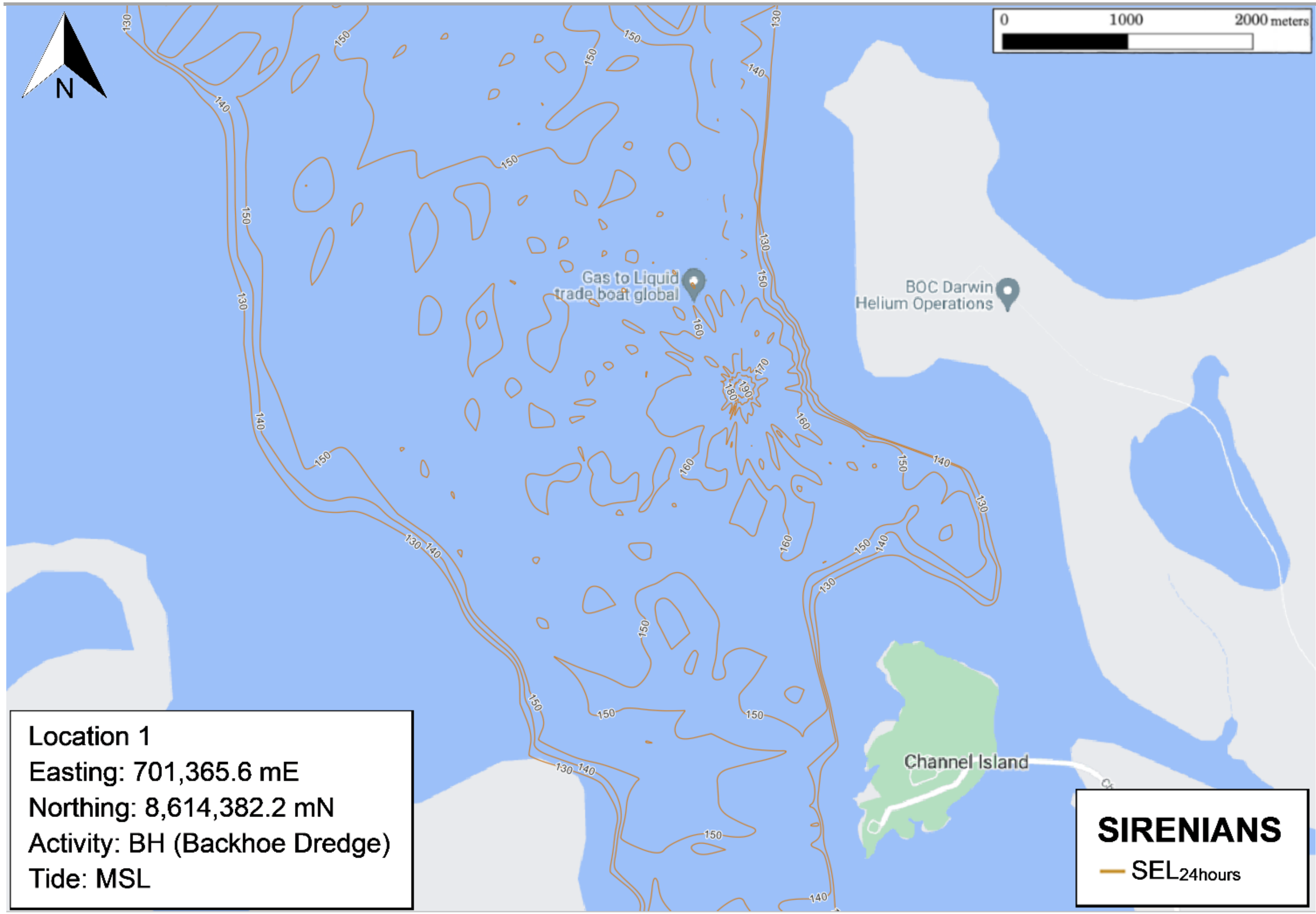

Figure 7-6 : Location 1 – BHD (Digging) $SEL_{24\ hours}$ Contours for Sirenians (MSL)

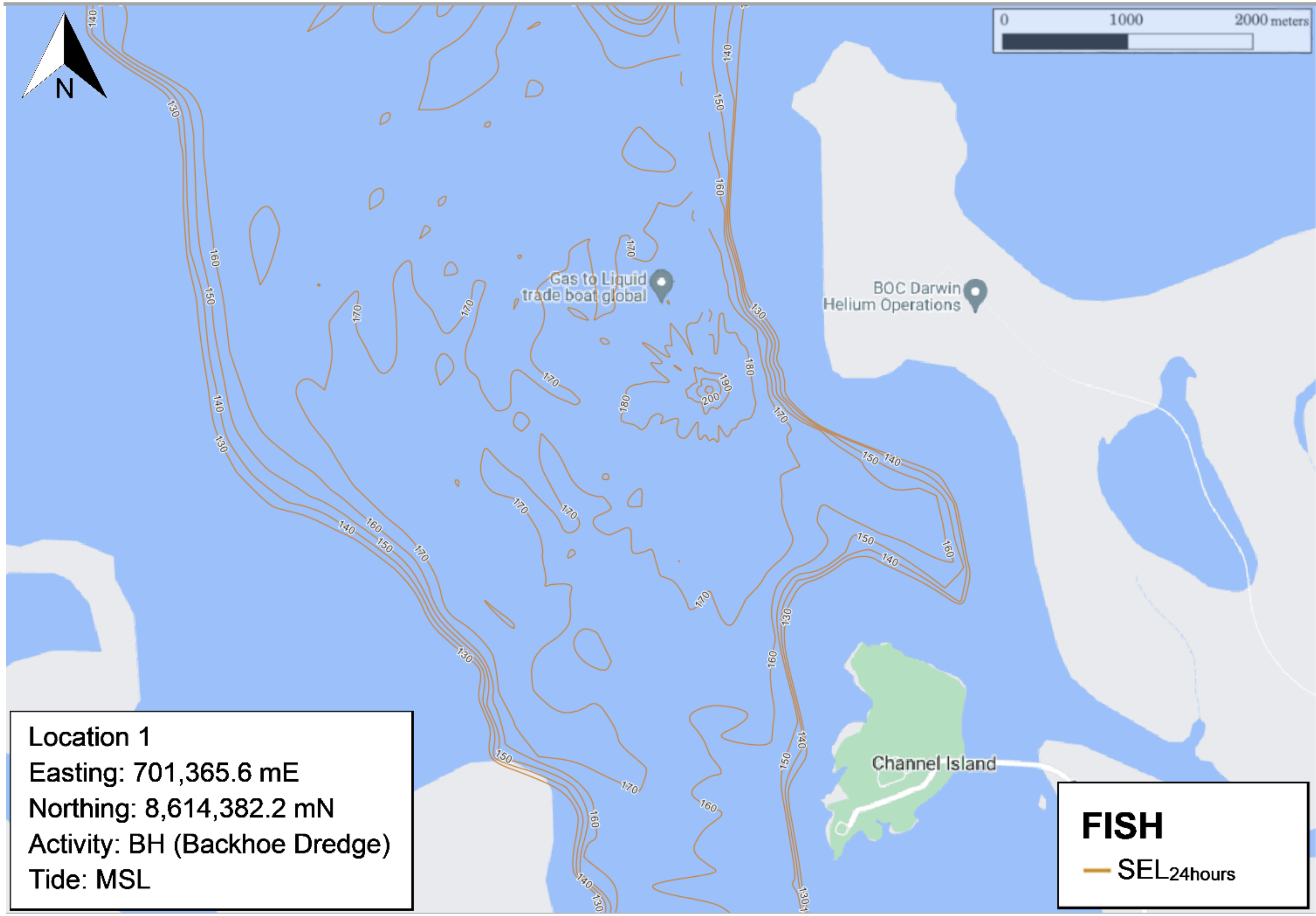

Figure 7-7 : Location 1 – BHD (Digging) $SEL_{24\ hours}$ Contours for Fish (MSL)

B.2 Location 1 – BHD (Hammer)

Figure 7-8 :Location 1 - BHD (Hammer) TTS and PTS Contours for Turtles (MSL)

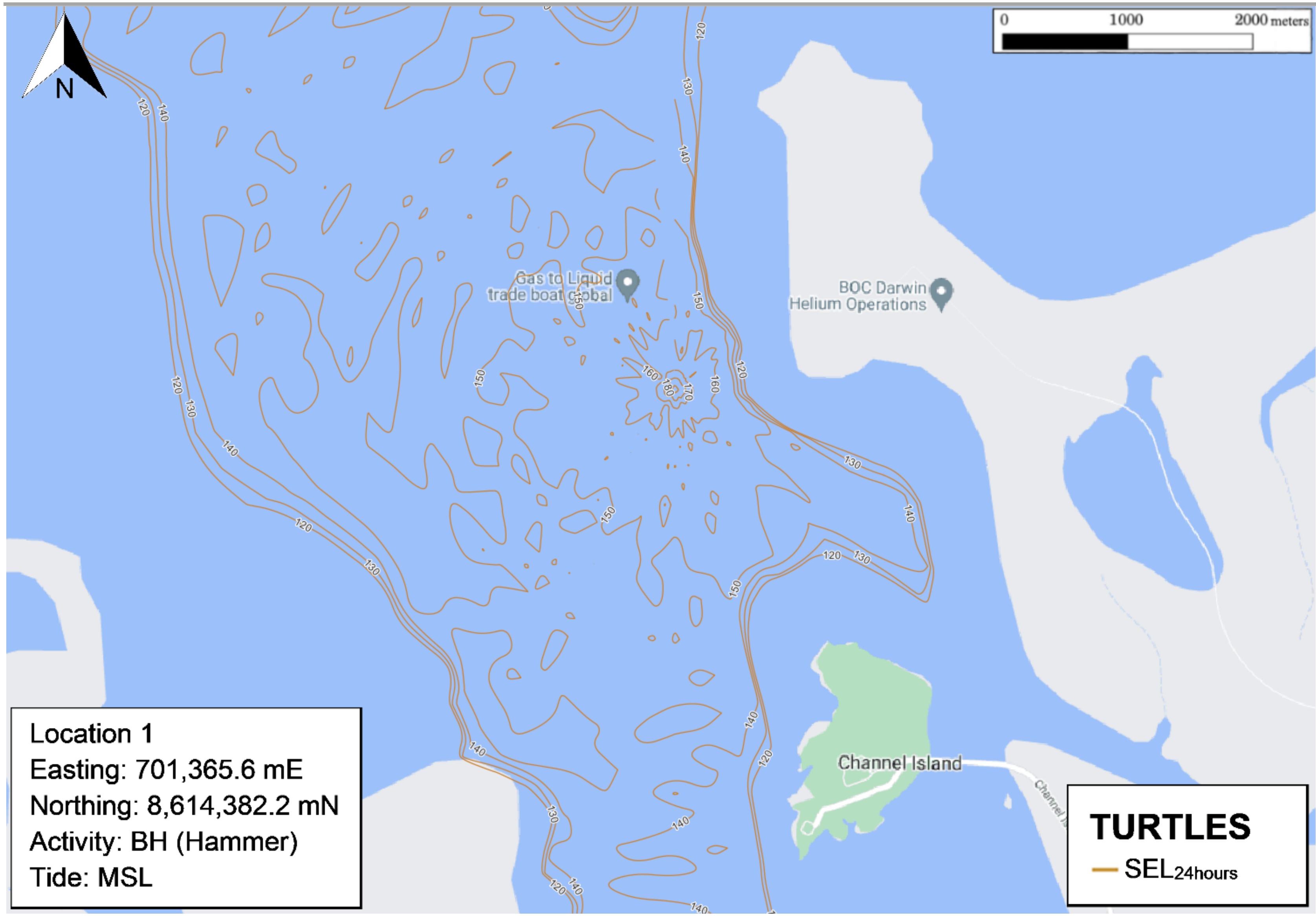

Figure 7-9 : Location 1 – BHD (Hammer) SEL$_{24\ hours}$ Contours for Turtles (MSL)

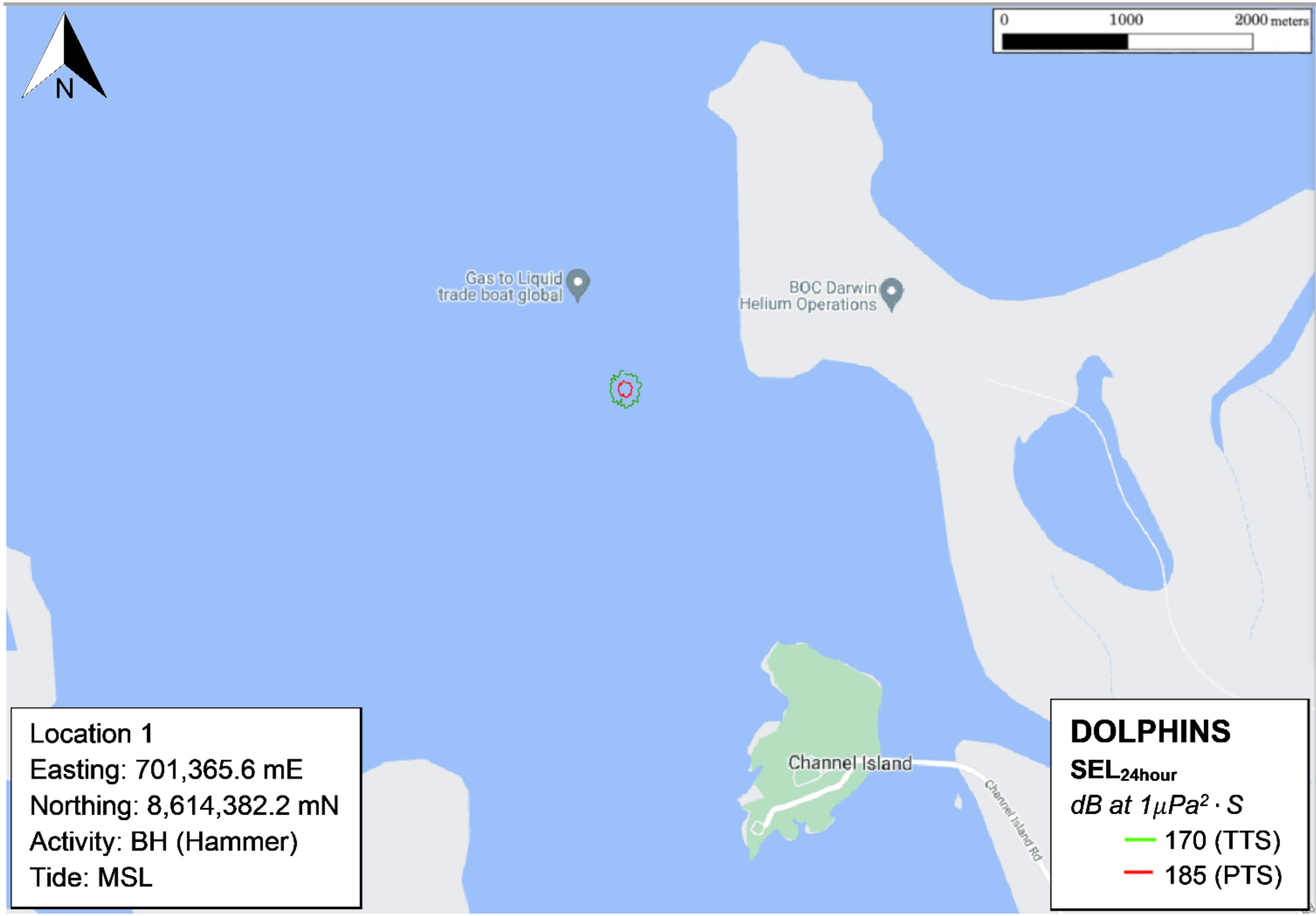

Figure 7-10 : Location 1 – BHD (Hammer) TTS and PTS Contours for Dolphins (MSL)

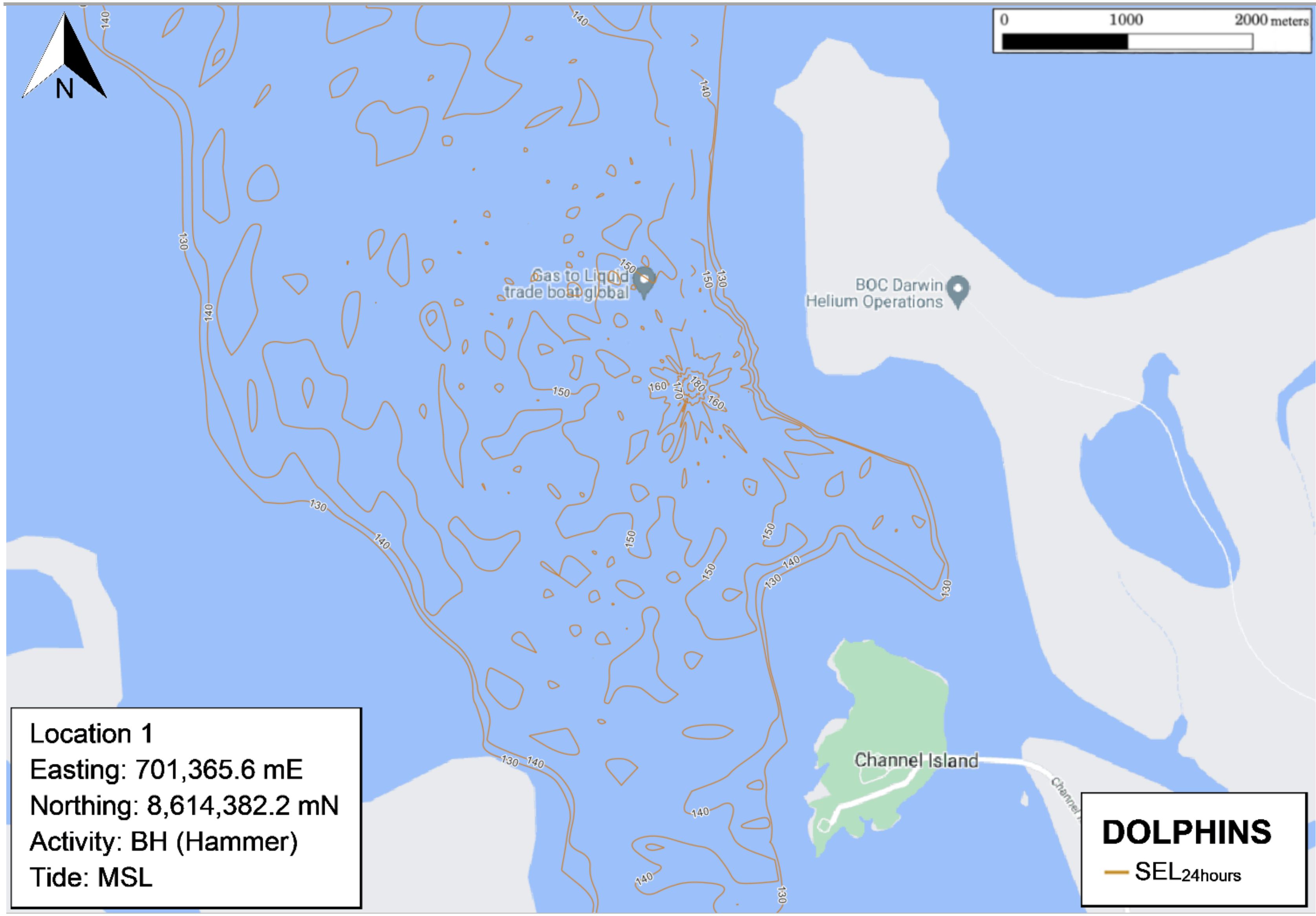

Figure 7-11 : Location 1 – BHD (Hammer) $SEL_{24\ hours}$ Contours for Dolphins (MSL)

Figure 7-12 : Location 1 – BHD (Hammer) TTS and PTS Contours for Sirenians (MSL)

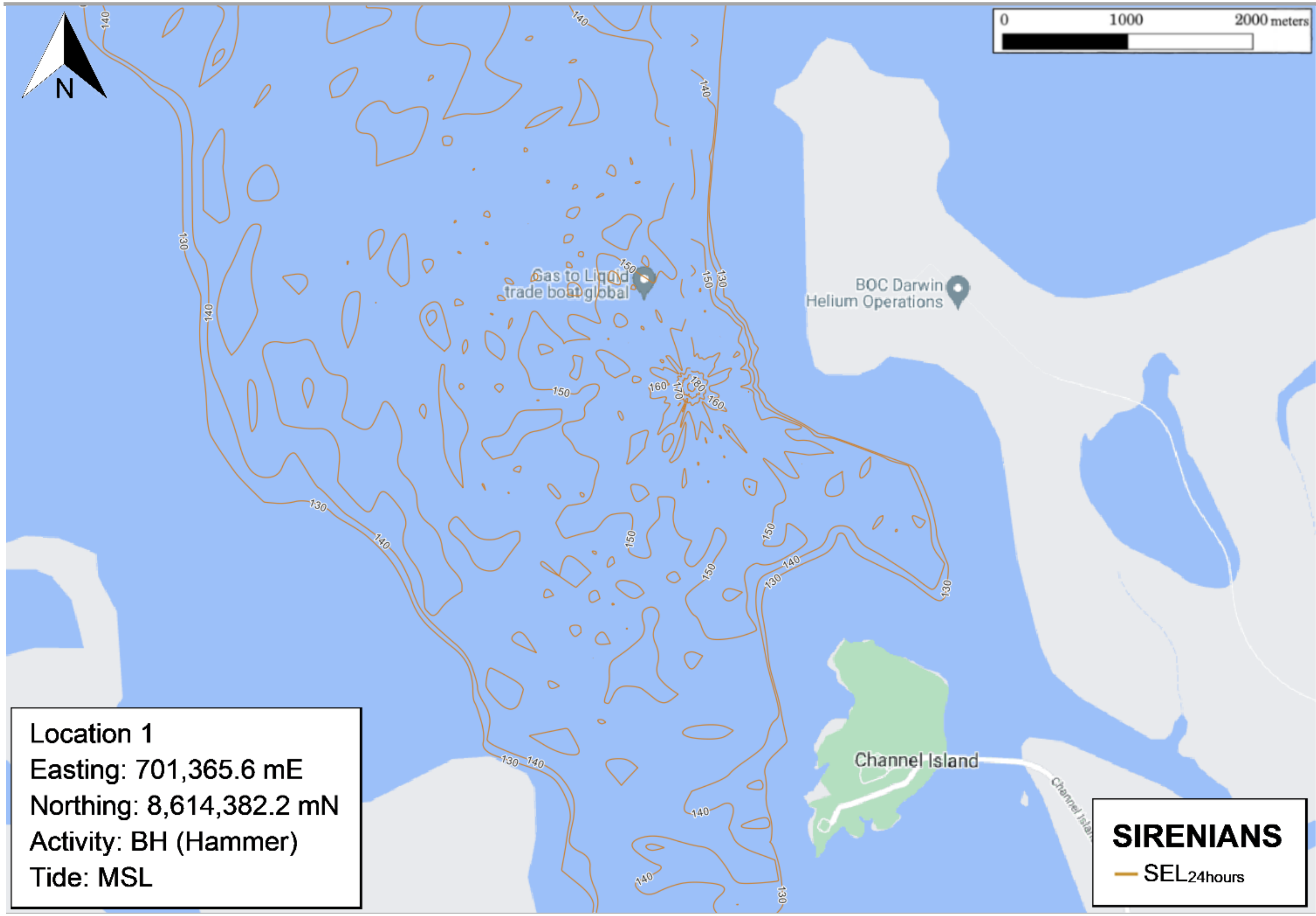

Figure 7-13 : Location 1 – BHD (Hammer) $SEL_{24\ hours}$ Contours for Sirenians (MSL)

Figure 7-14 : Location 1 – BHD (Hammer) TTS and PTS Contours for Fish (MSL)

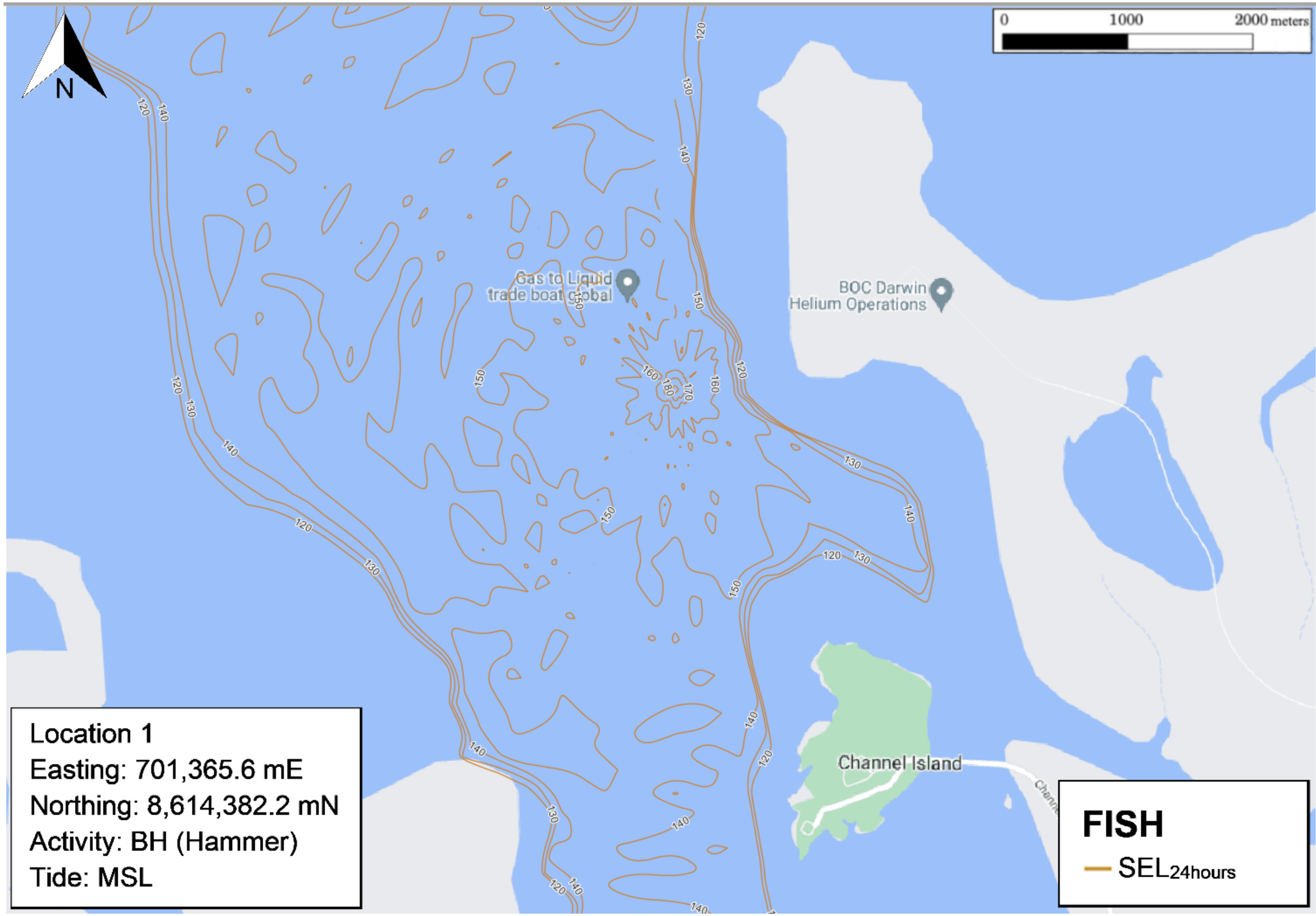

Figure 7-15 : Location 1 – BHD (Hammer) SEL$_{24\ hours}$ Contours for Fish (MSL)

B.3 Location 2 – TSHD

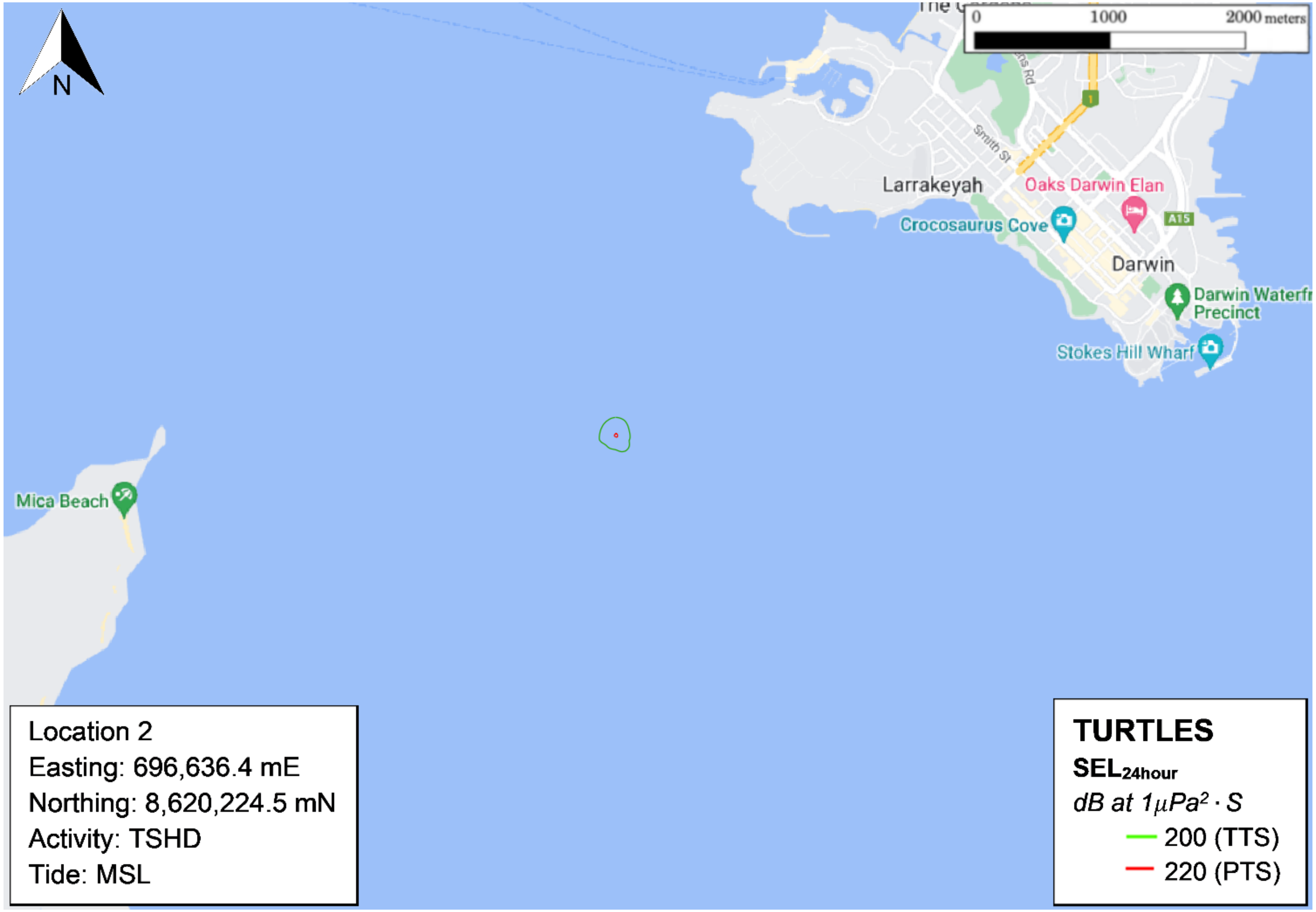

Figure 7-16 :Location 2 – TSHD TTS and PTS Contours for Turtles (MSL)

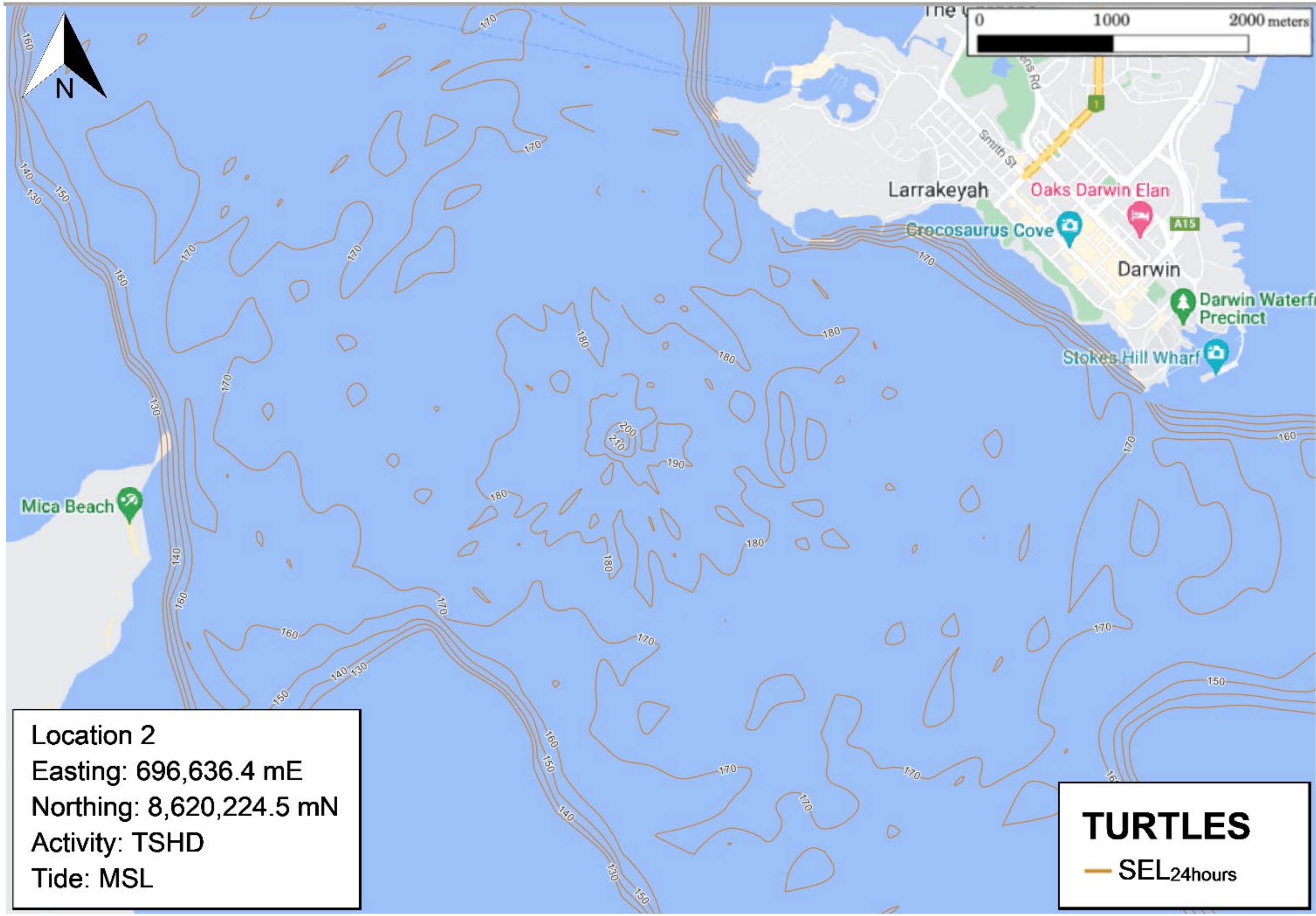

Figure 7-17 : Location 2 – TSHD $SEL_{24\ hours}$ Contours for Turtles (MSL)

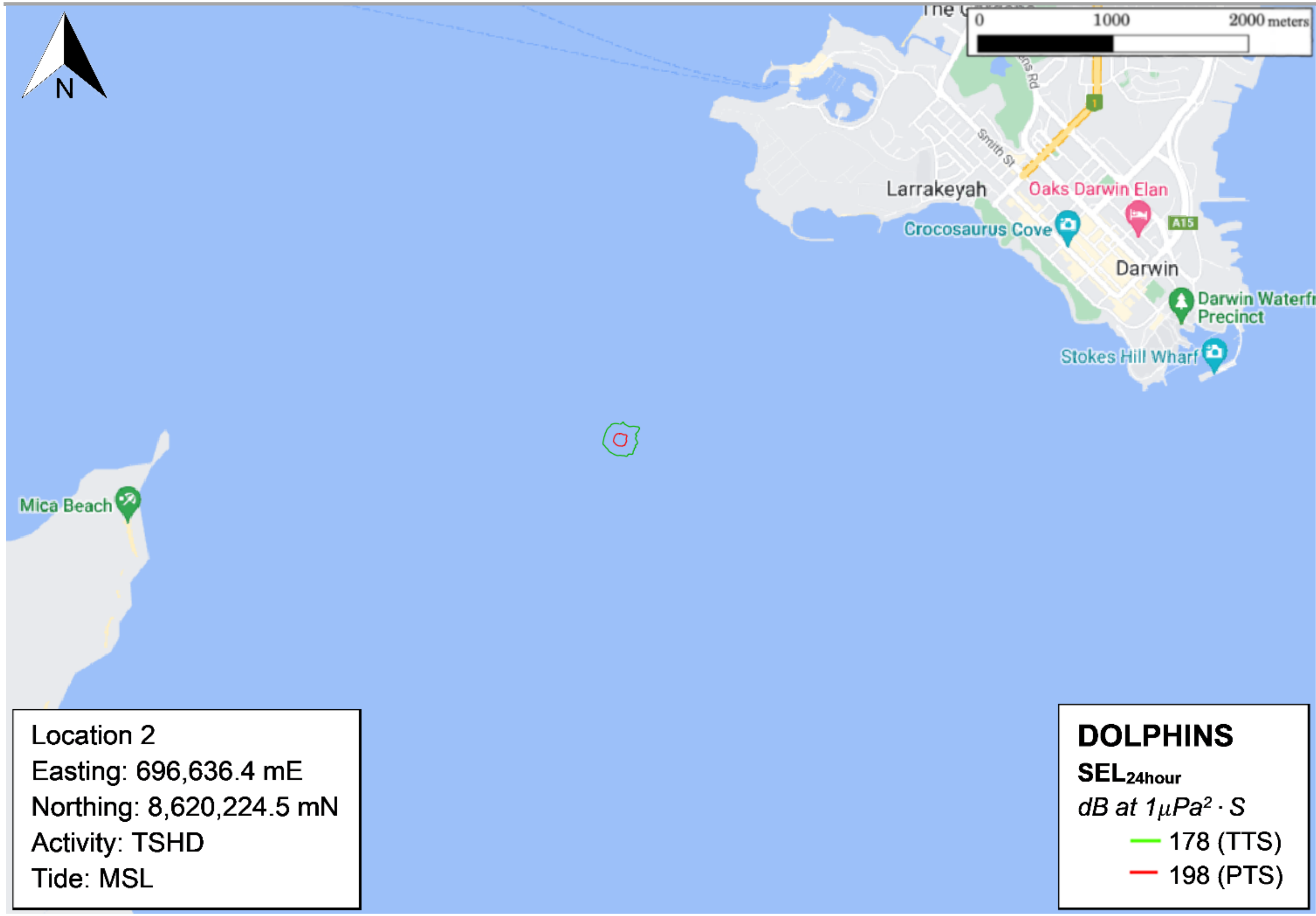

Figure 7-18 : Location 2 – TSHD TTS and PTS Contours for Dolphins (MSL)

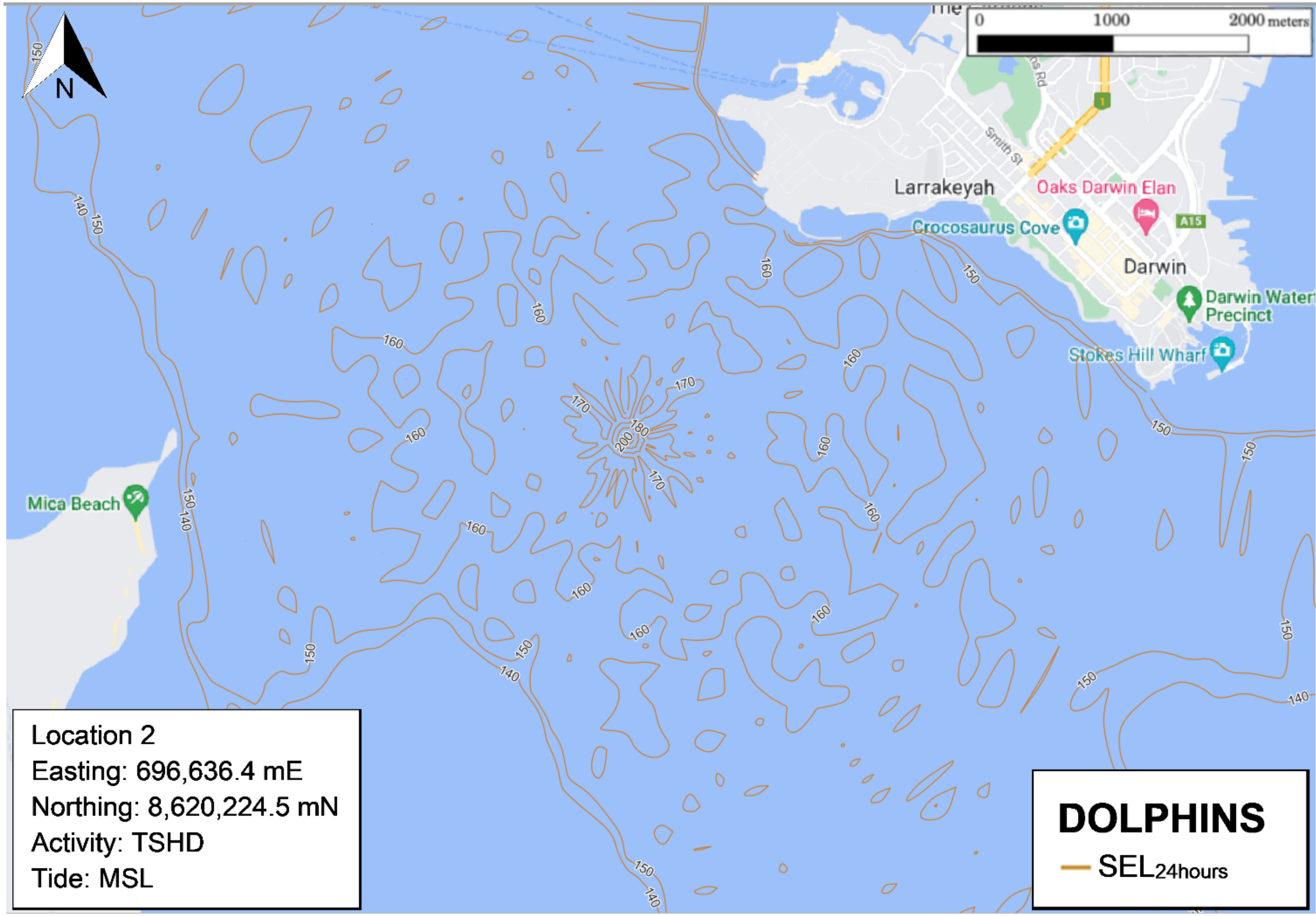

Figure 7-19 : Location 2 – TSHD $SEL_{24\ hours}$ Contours for Dolphins (MSL)

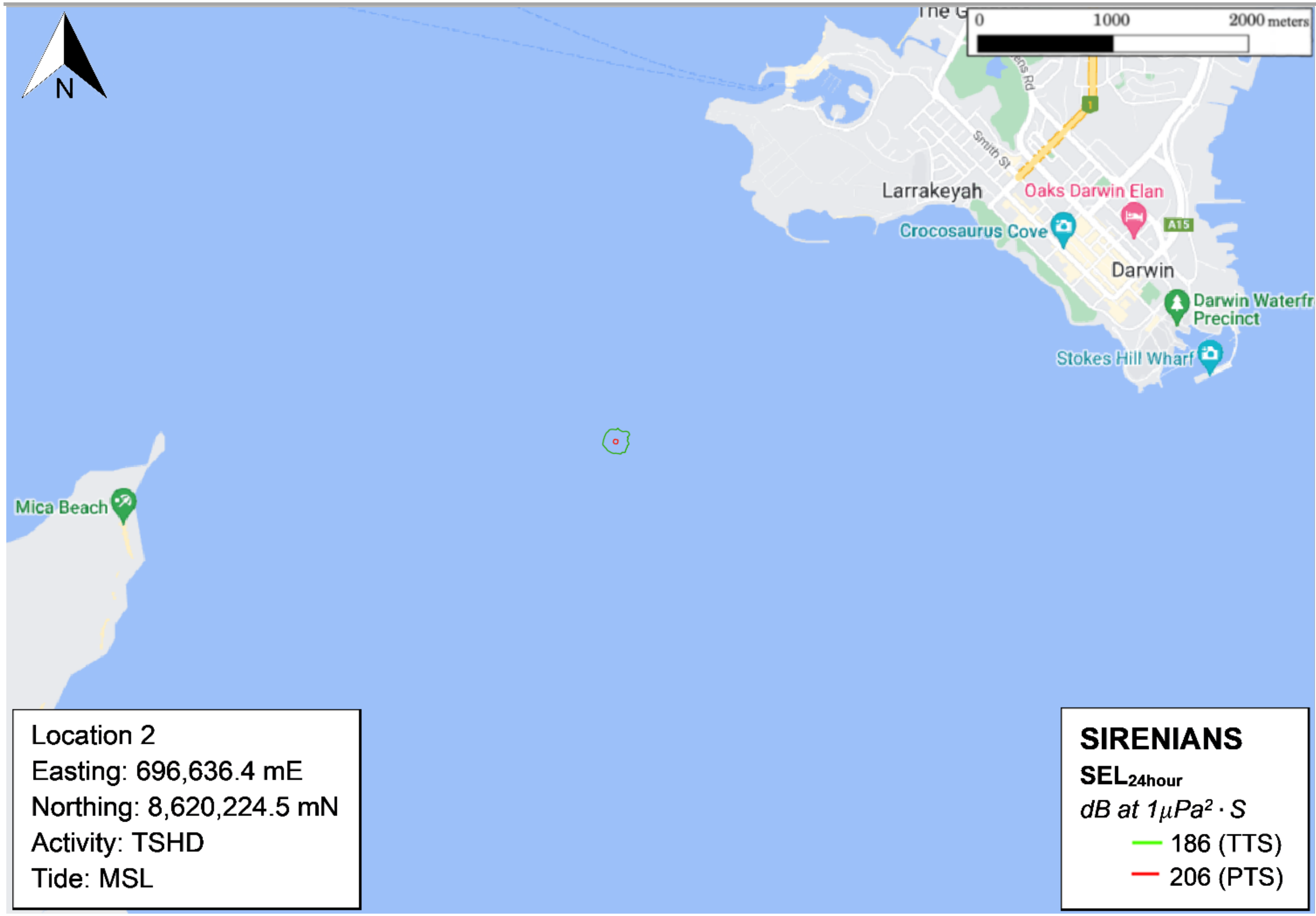

Figure 7-20 : Location 2 – TSHD TTS and PTS Contours for Sirenians (MSL)

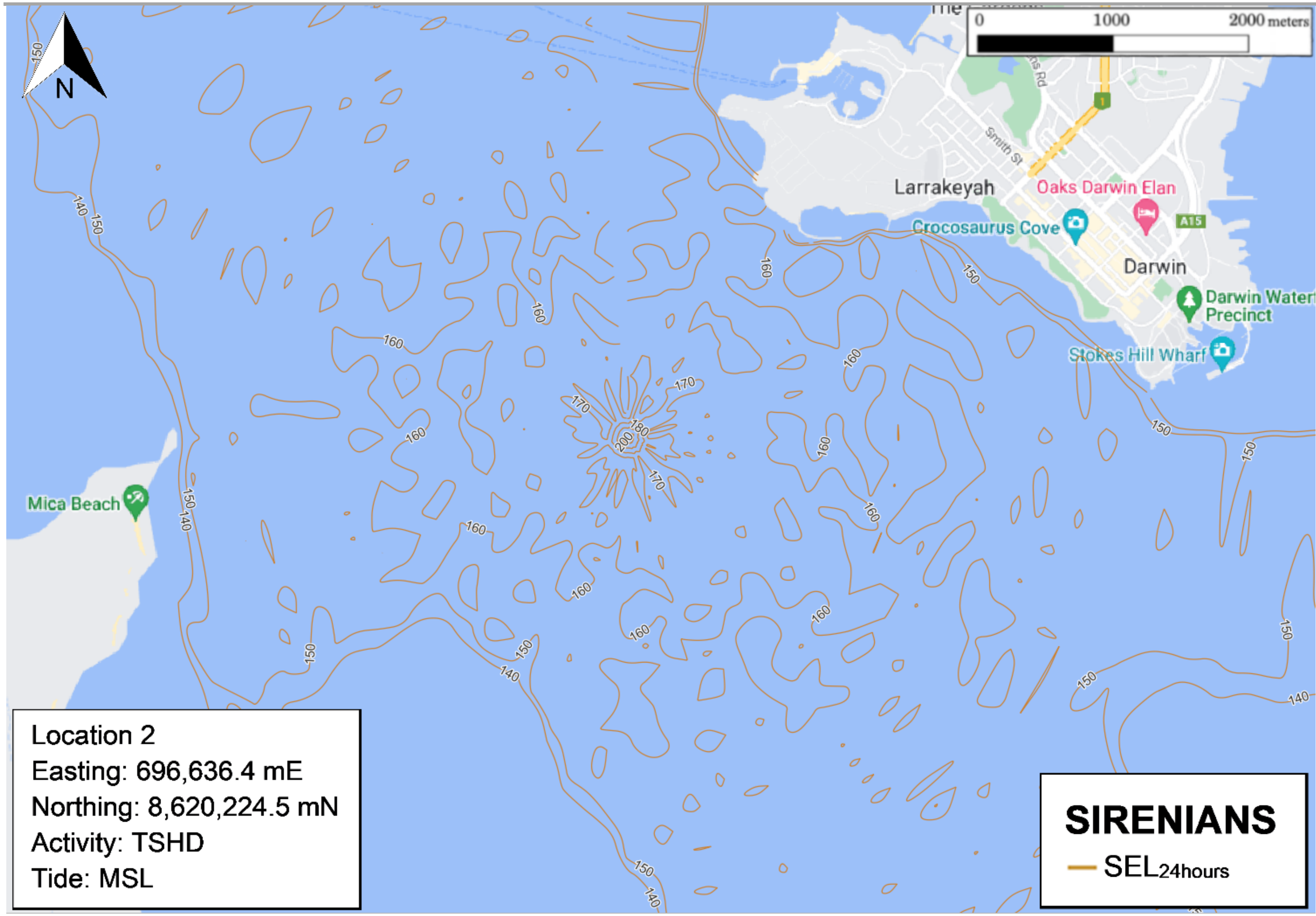

Figure 7-21 : Location 2 – TSHD $SEL_{24\ hours}$ Contours for Sirenians (MSL)

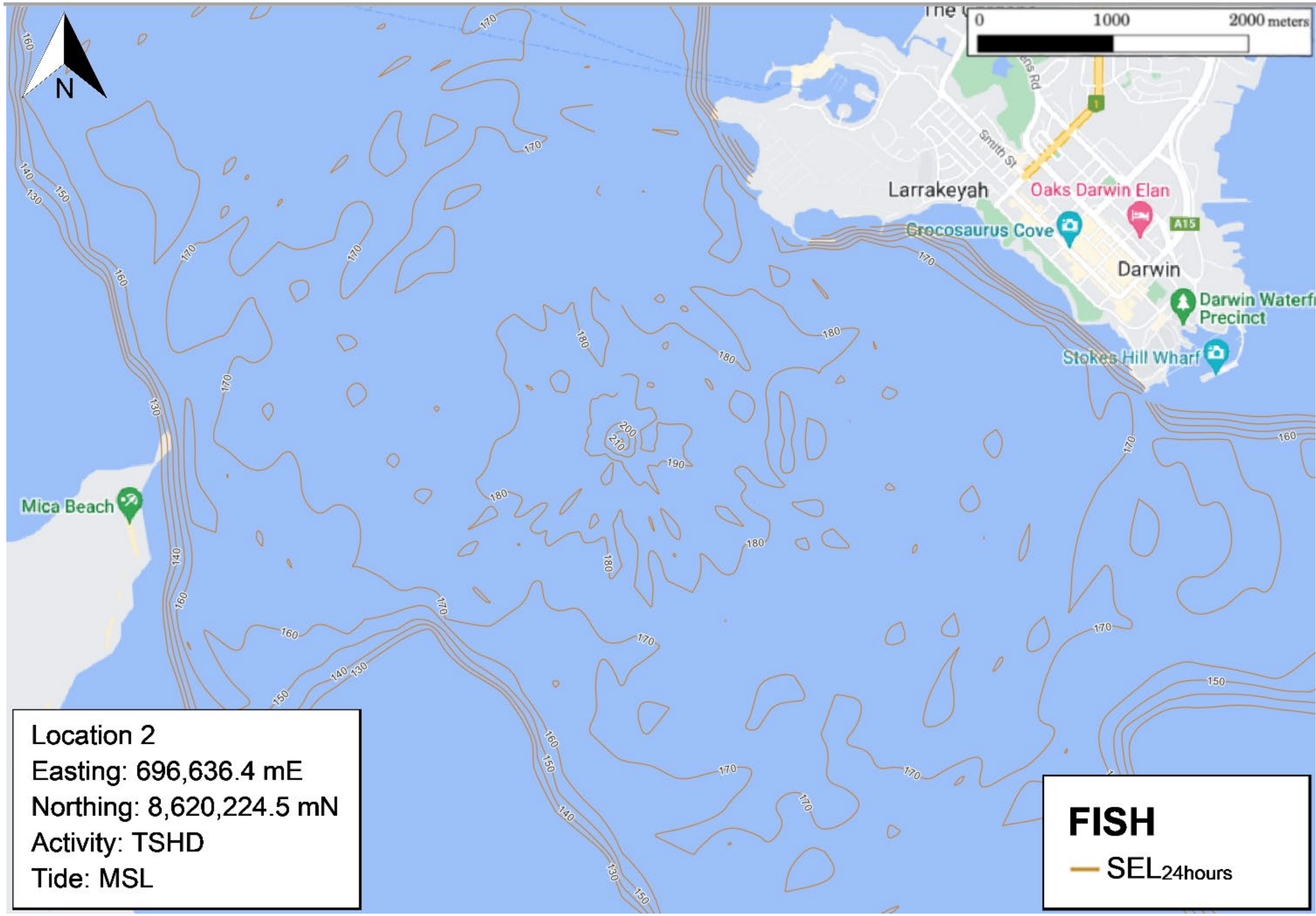

Figure 7-22 : Location 2 – TSHD $SEL_{24\ hours}$ Contours for Fish (MSL)

B.4 Location 3 – TSHD

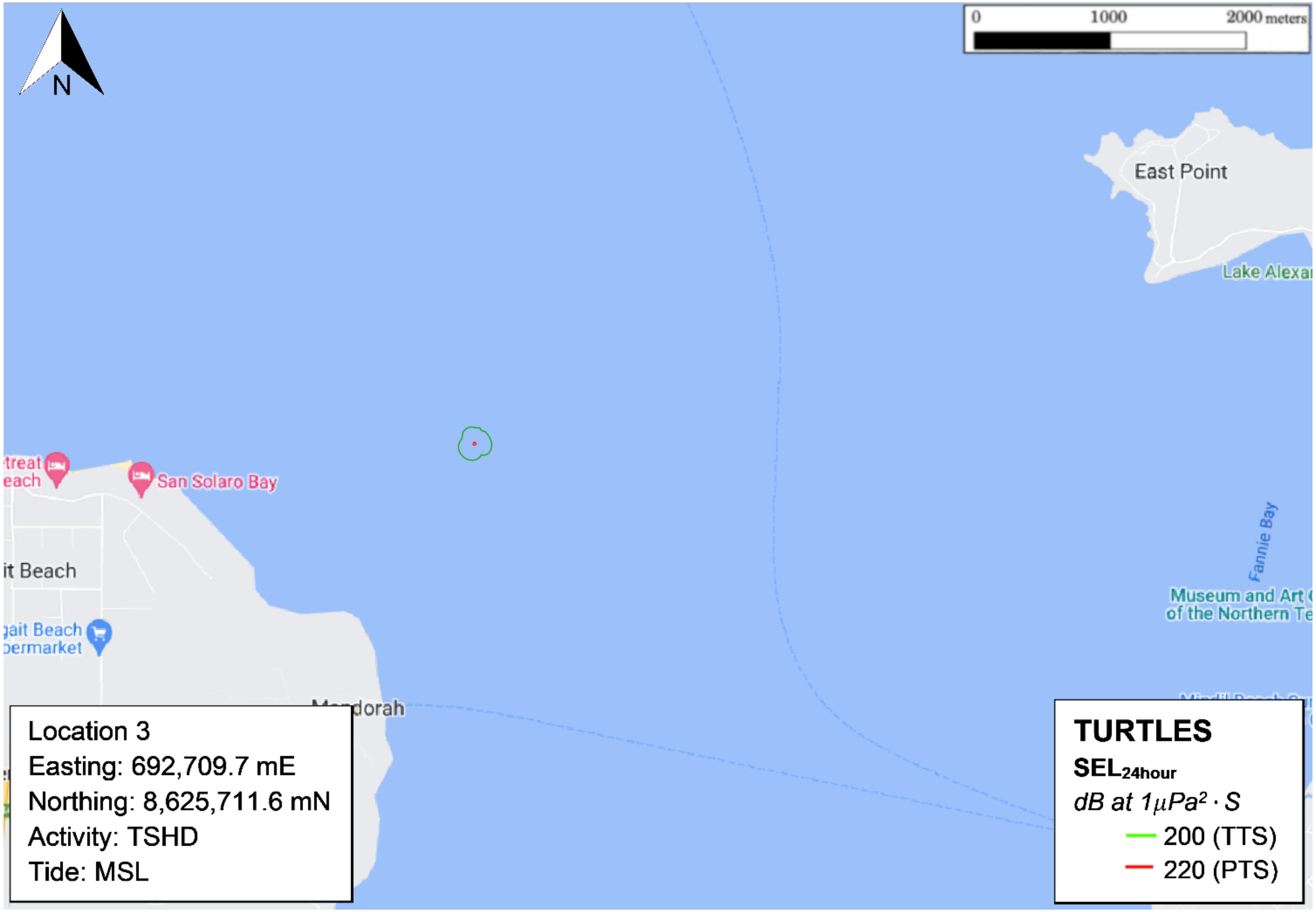

Figure 7-23 :Location 3 – TSHD TTS and PTS Contours for Turtles (MSL)

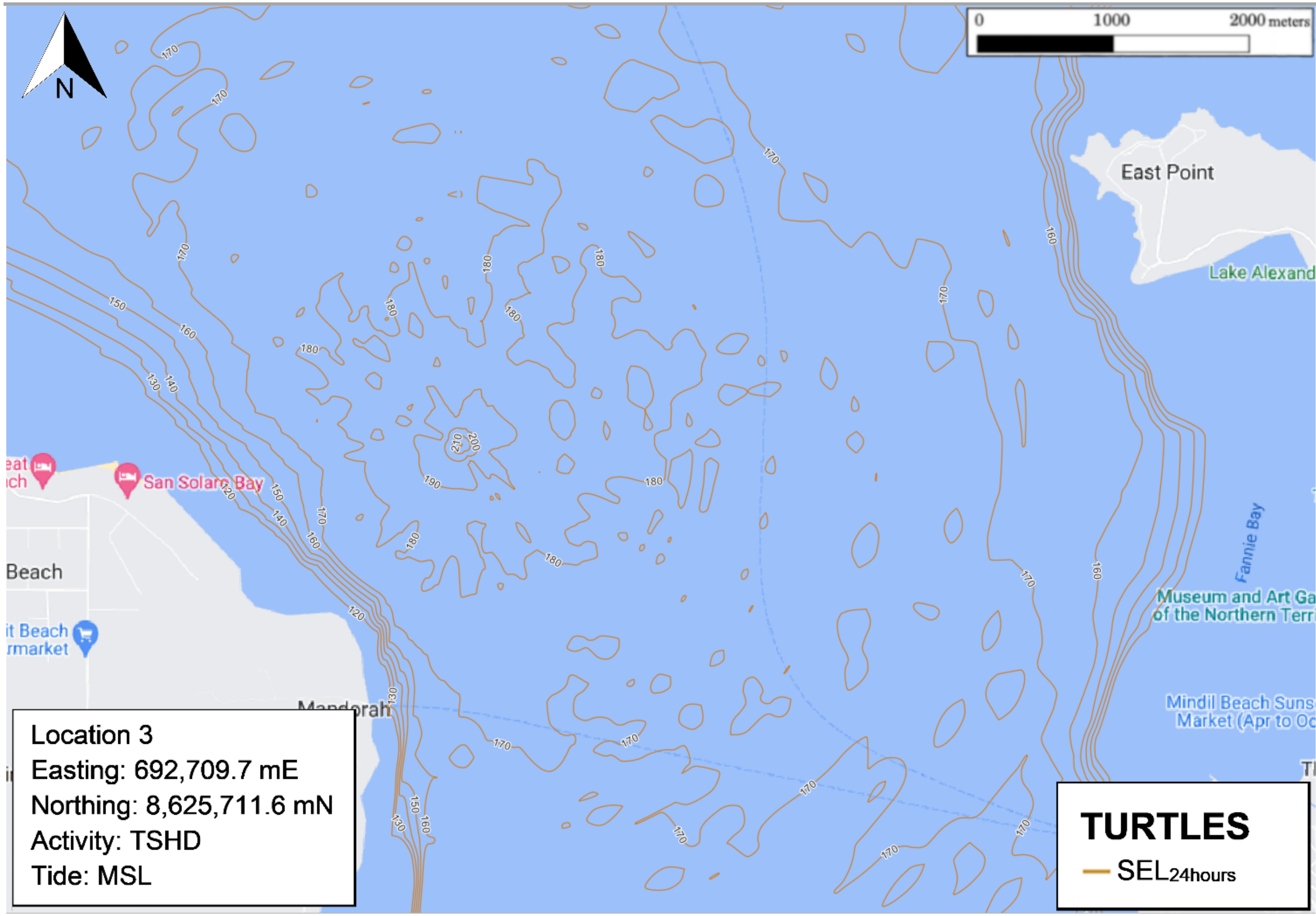

Figure 7-24 : Location 3 – TSHD $SEL_{24\ hours}$ Contours for Turtles (MSL)

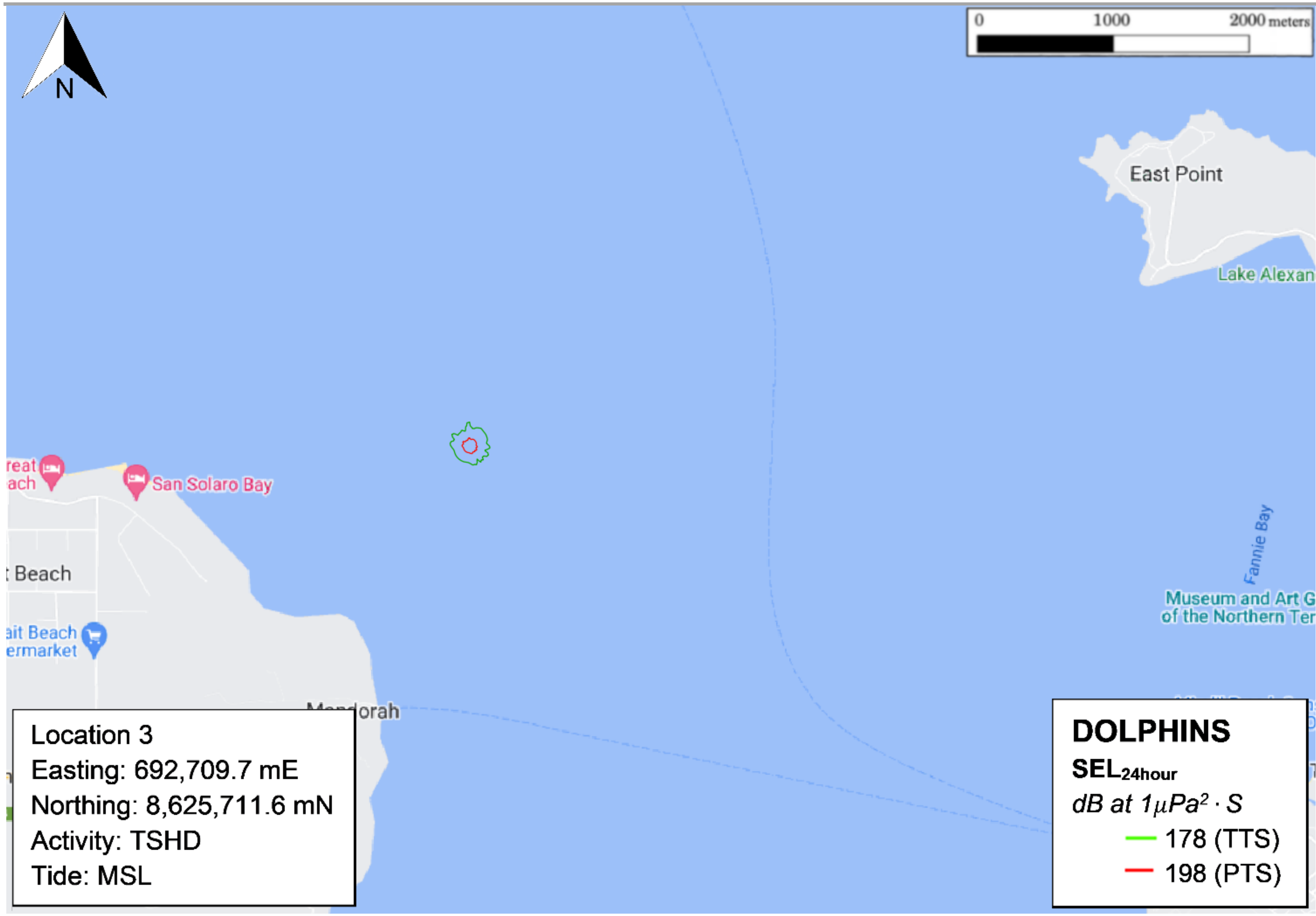

Figure 7-25 : Location 3 – TSHD TTS and PTS Contours for Dolphins (MSL)

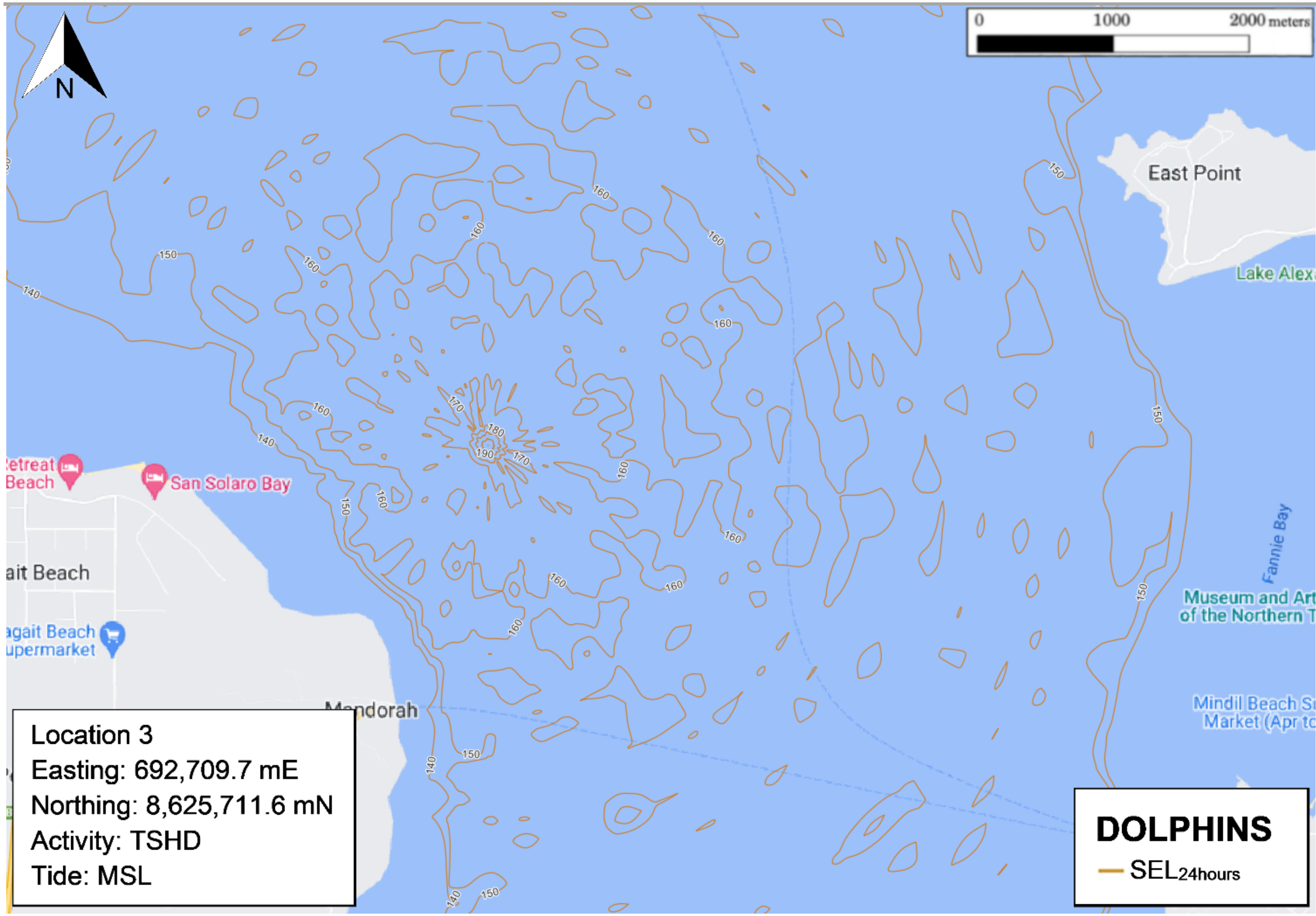

Figure 7-26 : Location 3 – TSHD SEL$_{24 \text{ hours}}$ Contours for Dolphins (MSL)

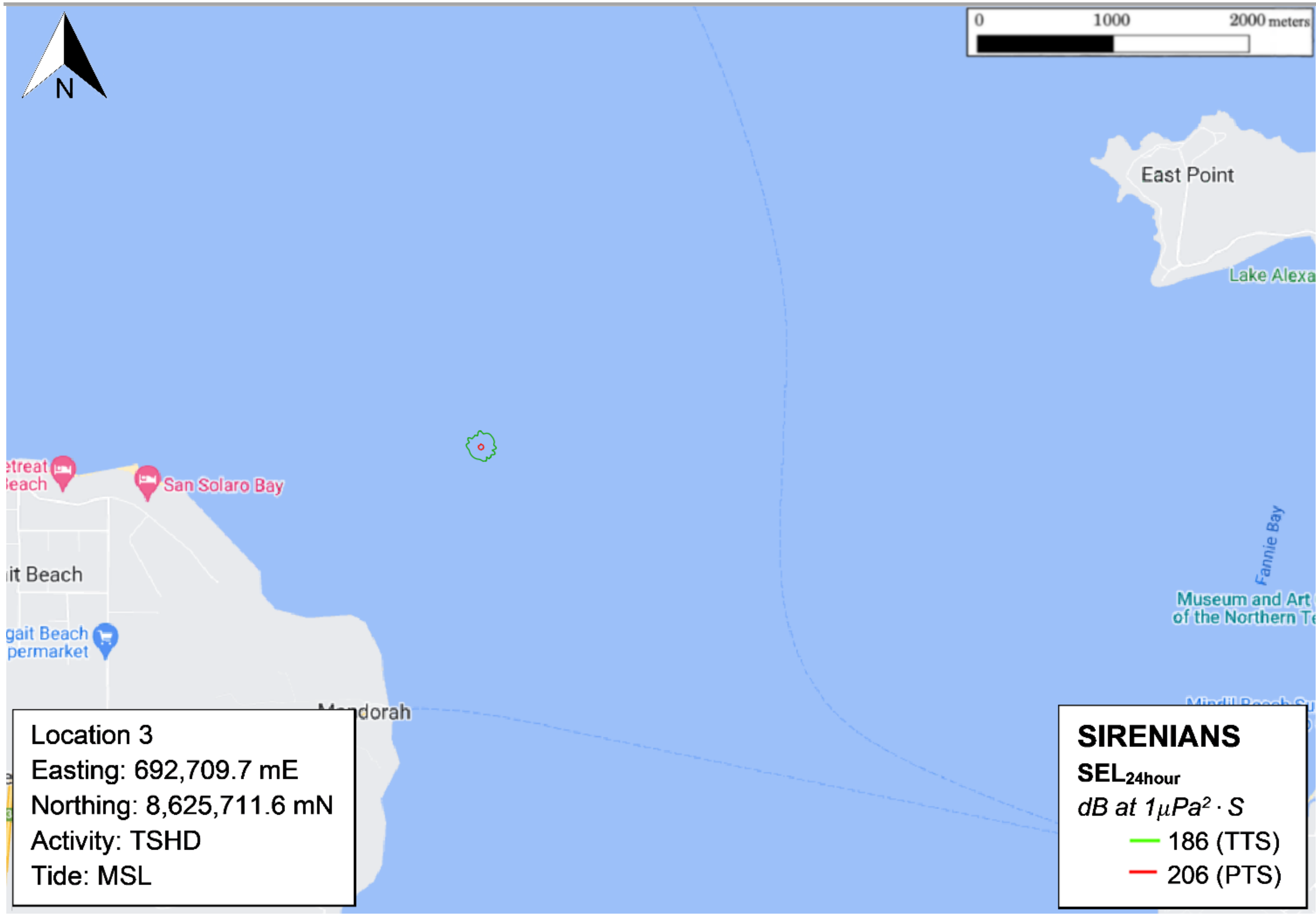

Figure 7-27 : Location 3 – TSHD TTS and PTS Contours for Sirenians (MSL)

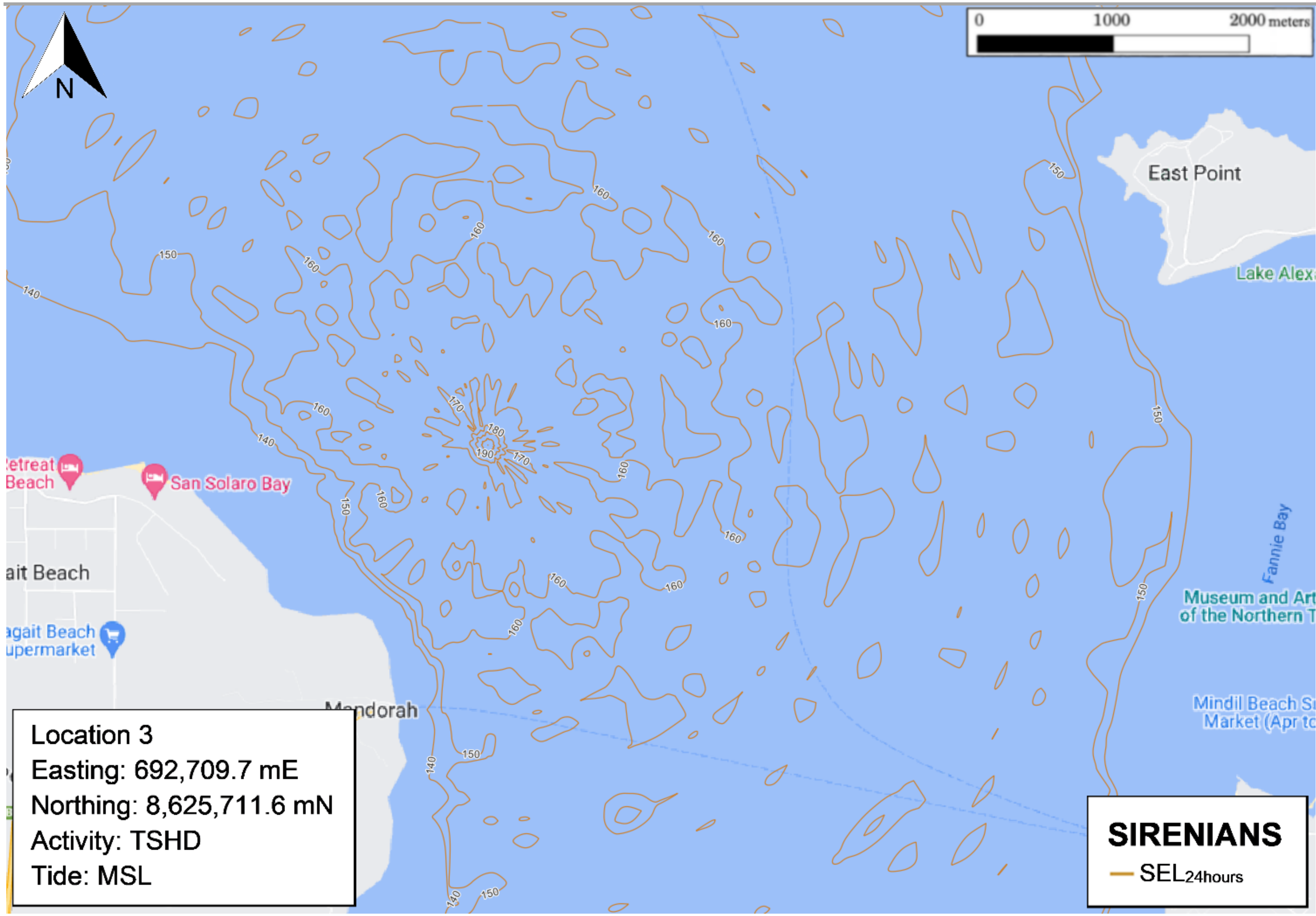

Figure 7-28 : Location 3 – TSHD $SEL_{24\ hours}$ Contours for Sirenians (MSL)

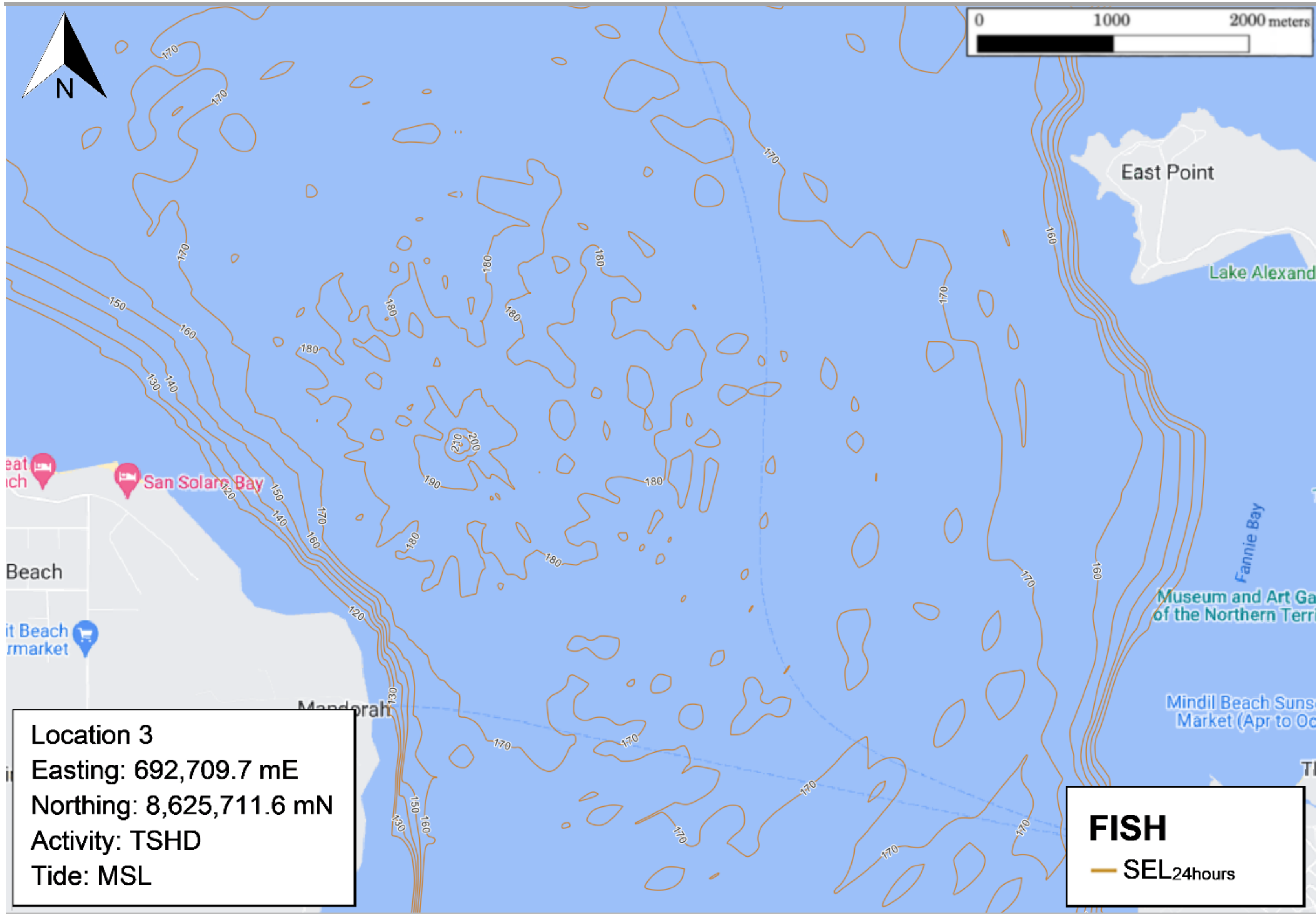

Figure 7-29 : Location 3 – TSHD $SEL_{24\ hours}$ Contours for Fish (MSL)

B.5 Location 3 – TSHD and CSD

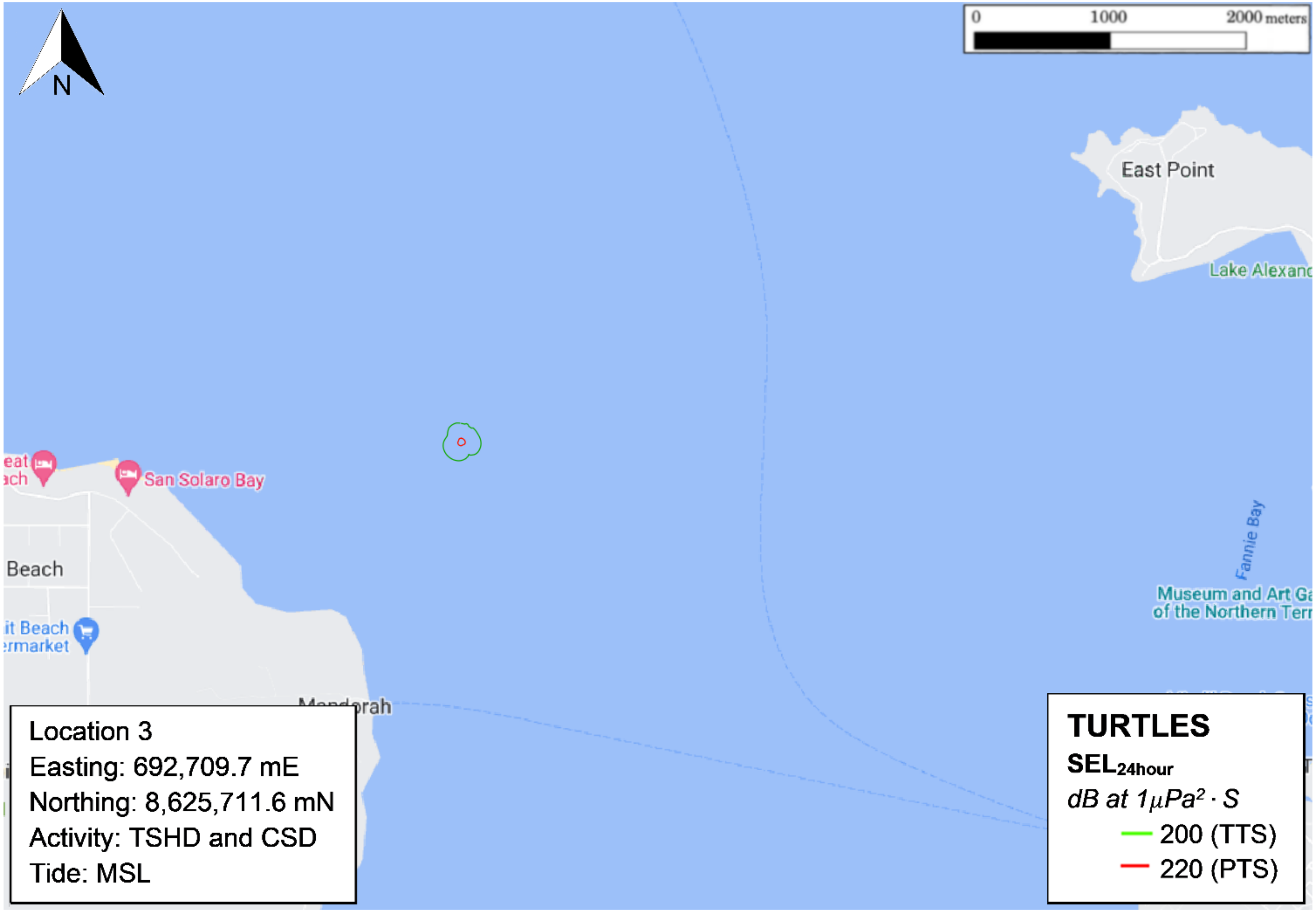

Figure 7-30 :Location 3 – TSHD and CSD TTS and PTS Contours for Turtles (MSL)

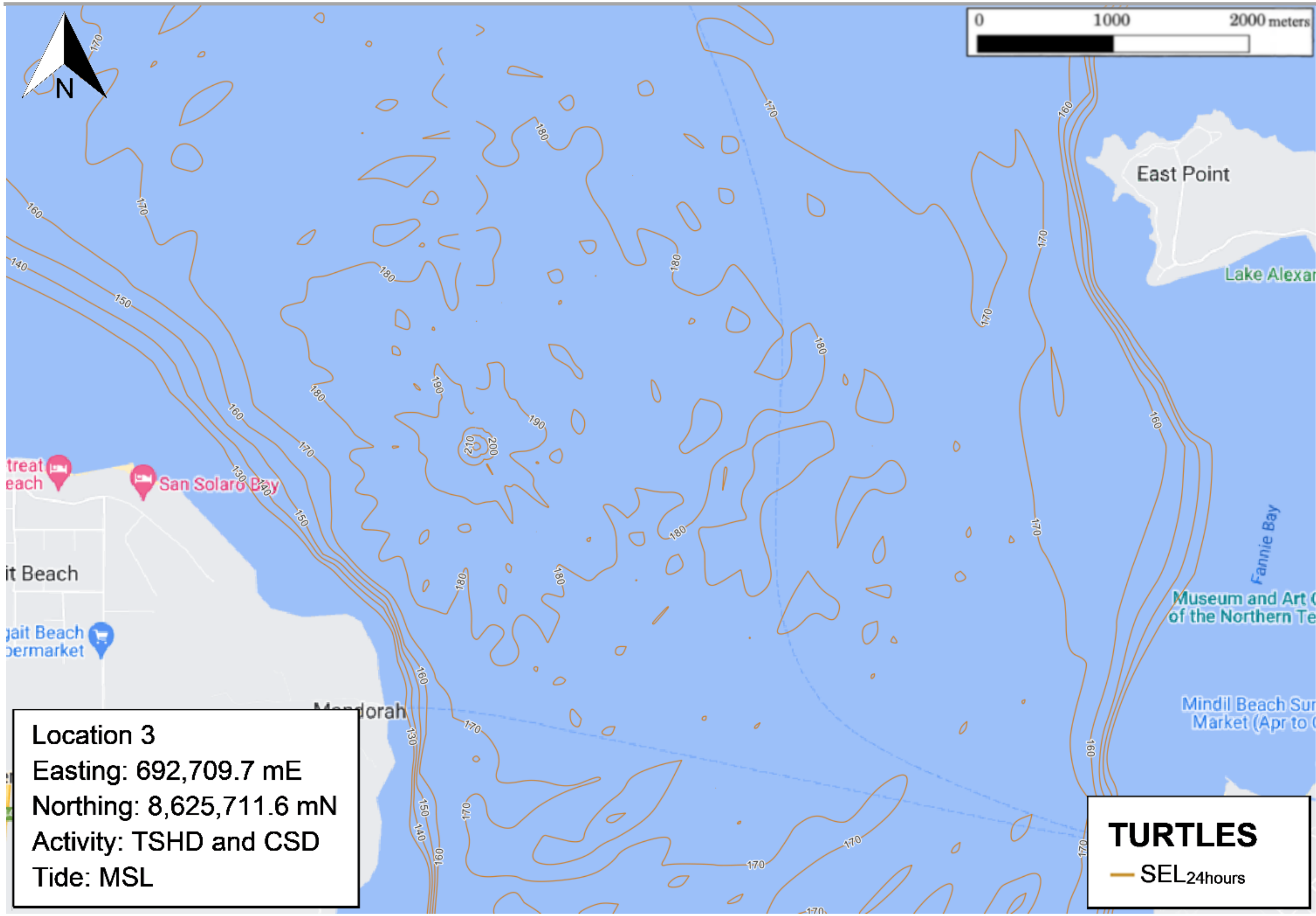

Figure 7-31 : Location 3 – TSHD and CSD $SEL_{24\ hours}$ Contours for Turtles (MSL)

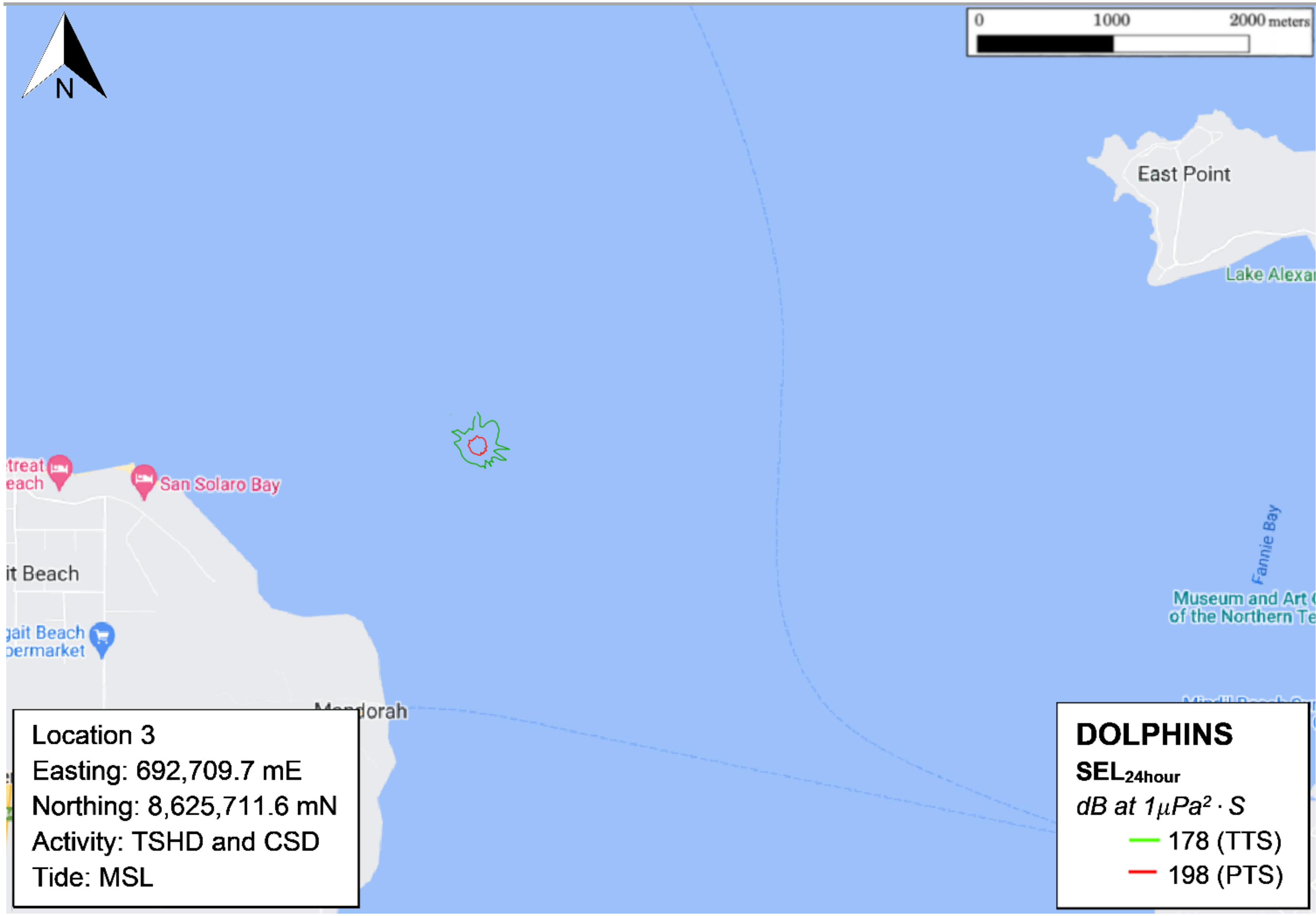

Figure 7-32 : Location 3 – TSHD and CSD TTS and PTS Contours for Dolphins (MSL)

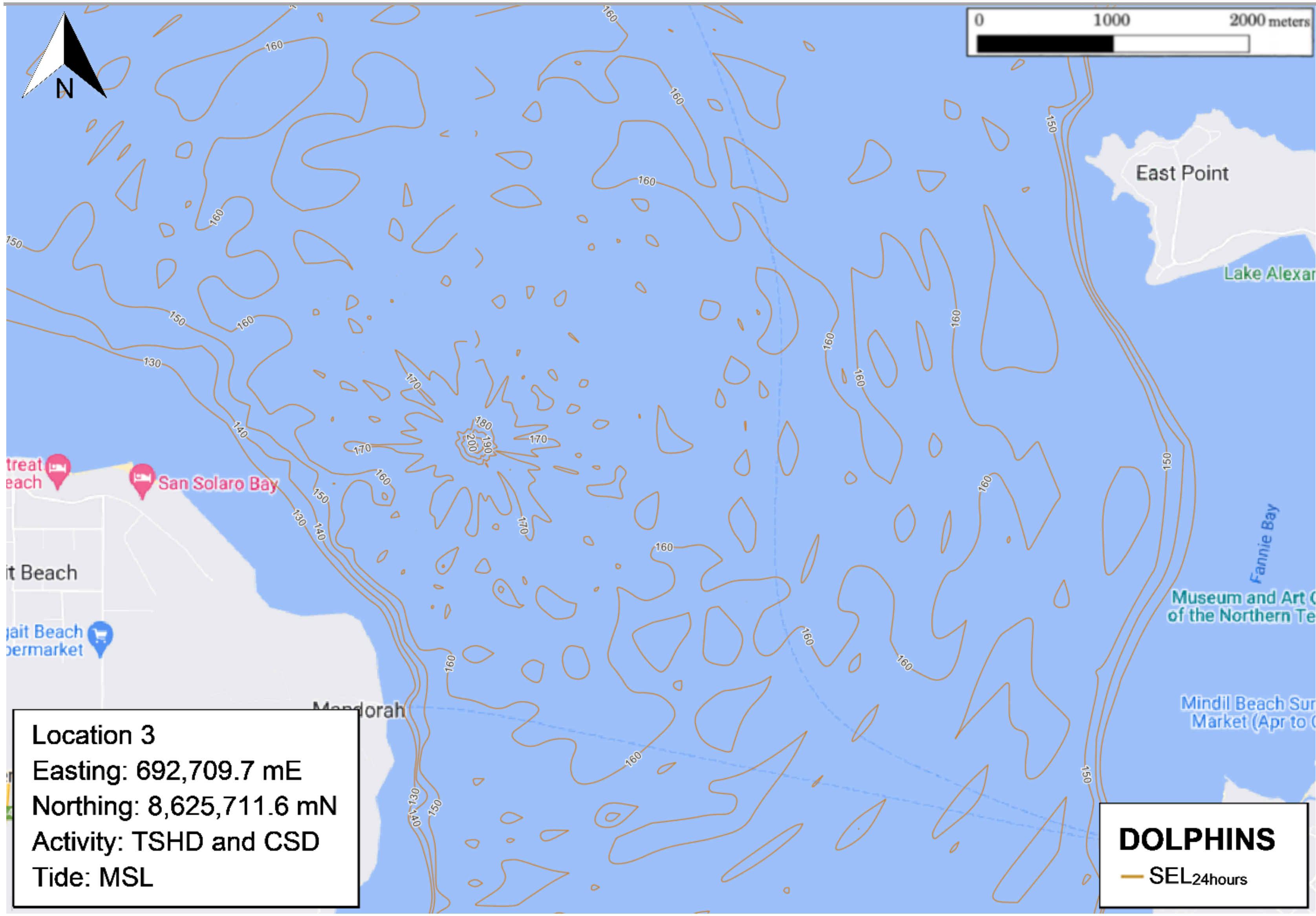

Figure 7-33 : Location 3 – TSHD and CSD $SEL_{24\ hours}$ Contours for Dolphins (MSL)

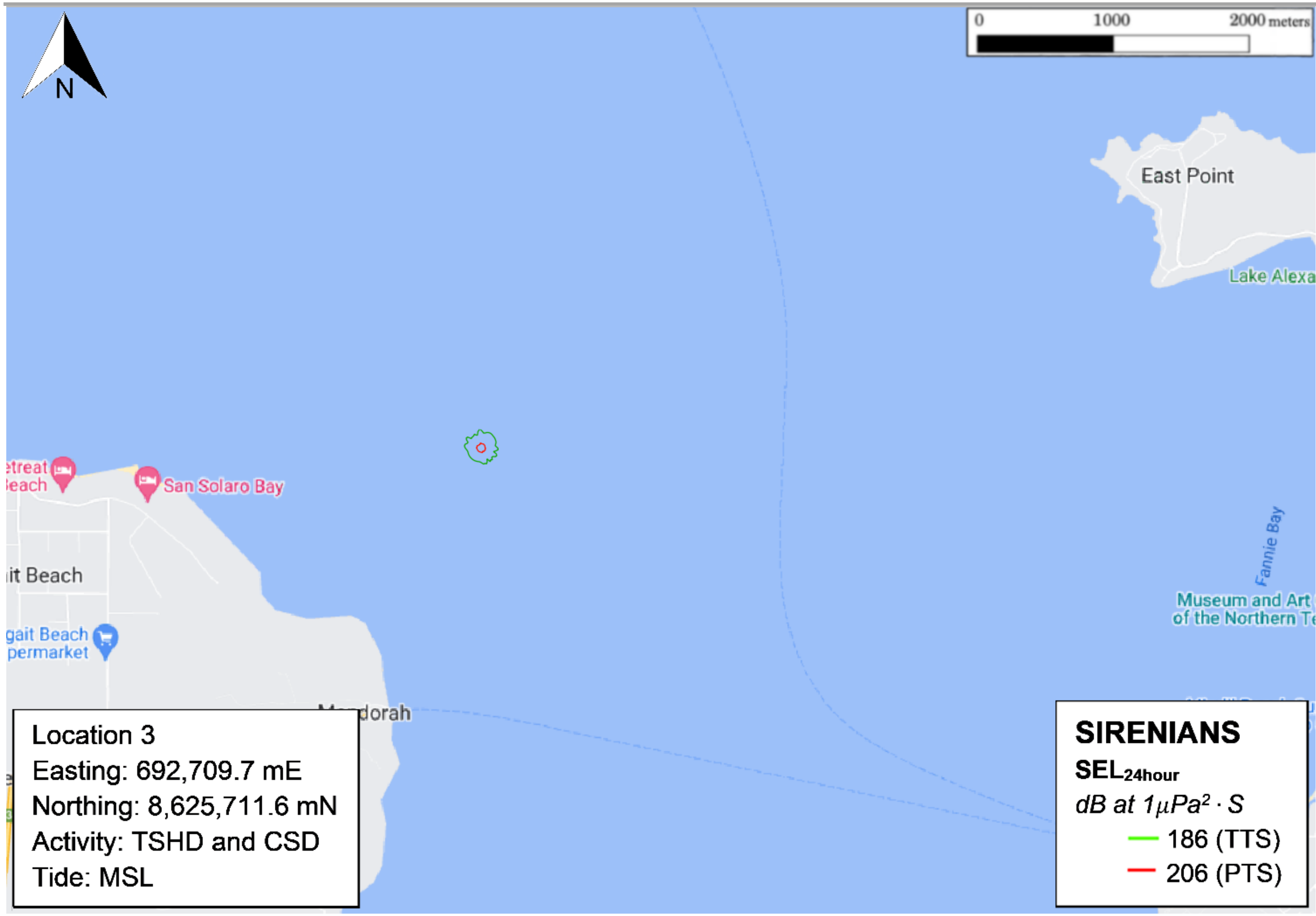

Figure 7-34 : Location 3 – TSHD and CSD TTS and PTS Contours for Sirenians (MSL)

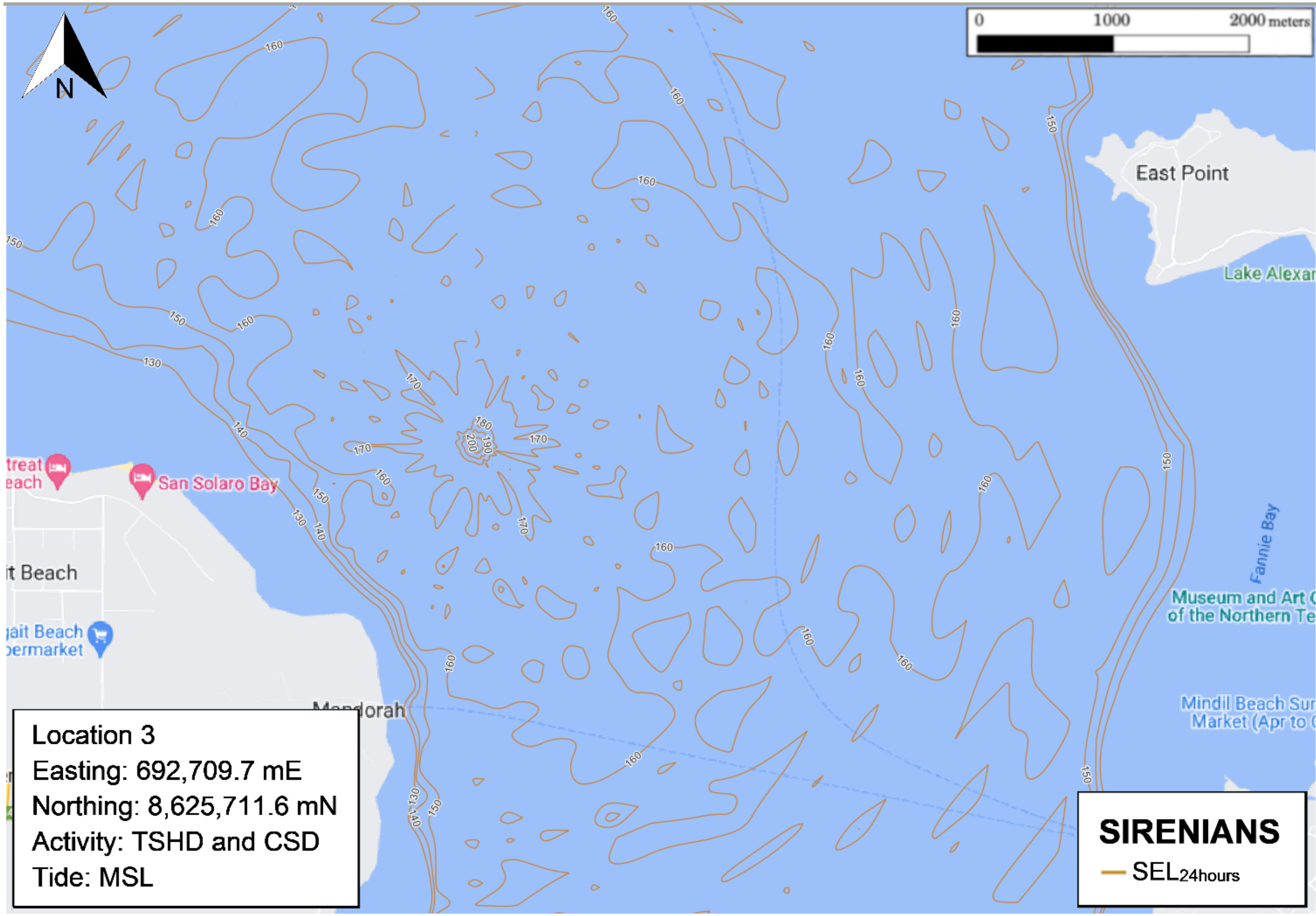

Figure 7-35 : Location 3 – TSHD and CSD $SEL_{24\ hours}$ Contours for Sirenians (MSL)

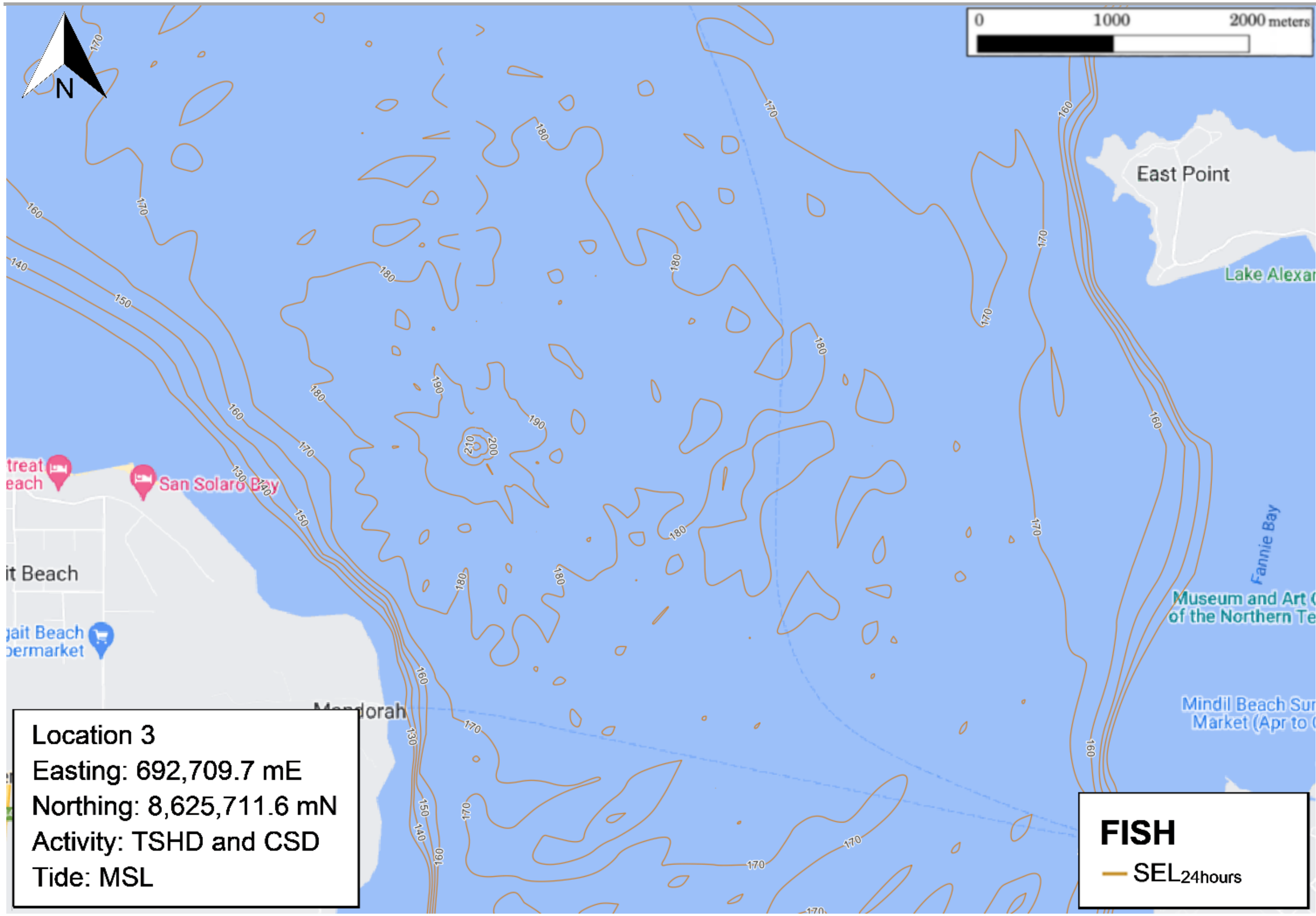

Figure 7-36 : Location 3 – TSHD and CSD $SEL_{24\ hours}$ Contours for Fish (MSL)

B.6 Location 4 – Sheet Piling

Figure 7-37 :Location 4 – Sheet Piling TTS and PTS Contours for Turtles (MSL)

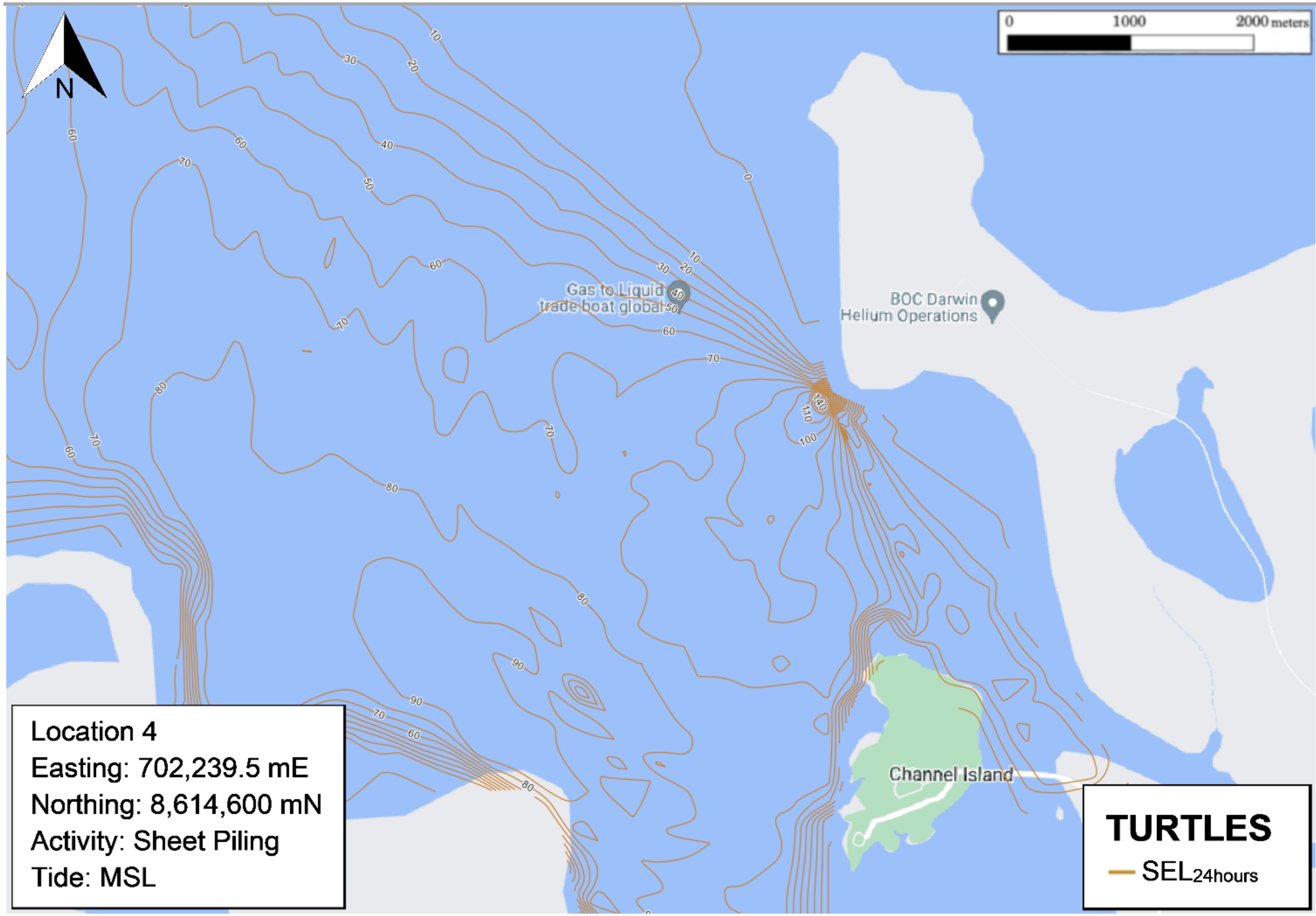

Figure 7-38 : Location 4 – Sheet Piling SEL$_{24\ hours}$ Contours for Turtles (MSL)

Figure 7-39 : Location 4 – Sheet Piling TTS and PTS Contours for Dolphins (MSL)

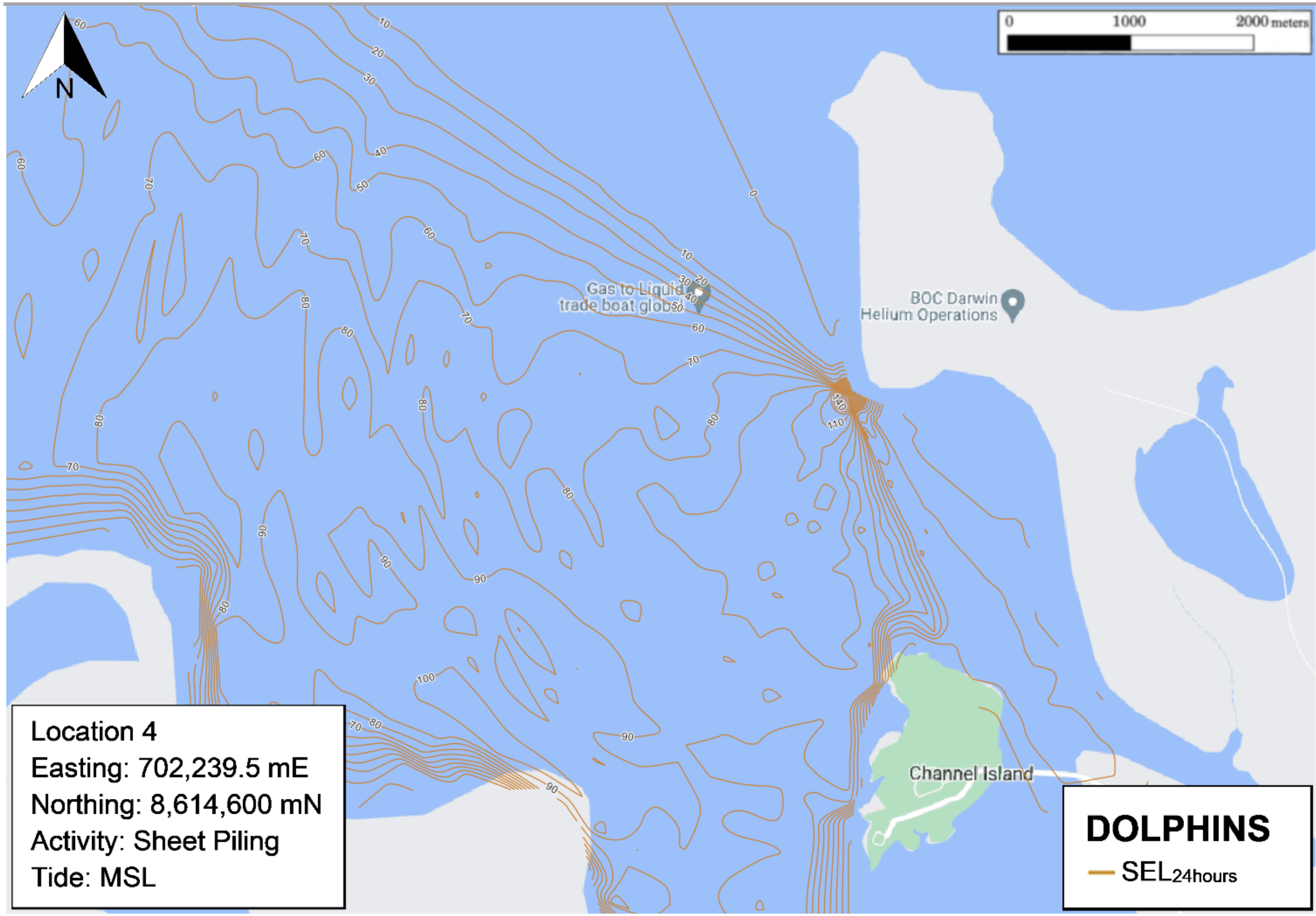

Figure 7-40 : Location 4 – Sheet Piling $SEL_{24\ hours}$ Contours for Dolphins (MSL)

Figure 7-41 : Location 4 – Sheet Piling TTS and PTS Contours for Sirenians (MSL)

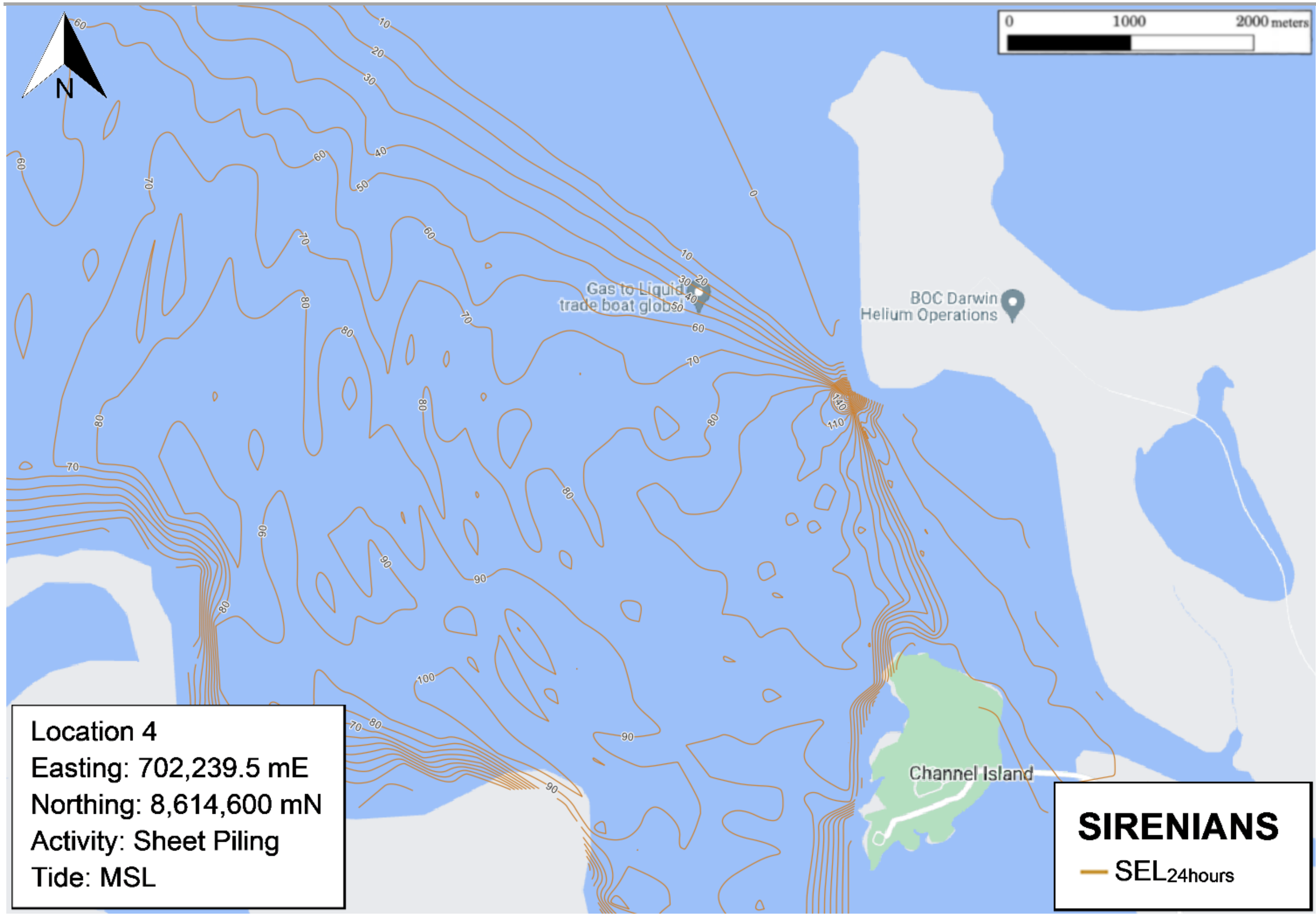

Figure 7-42 : Location 4 – Sheet Piling $SEL_{24\ hours}$ Contours for Sirenians (MSL)

Figure 7-43 : Location 4 – Sheet Piling TTS and PTS Contours for Fish (MSL)

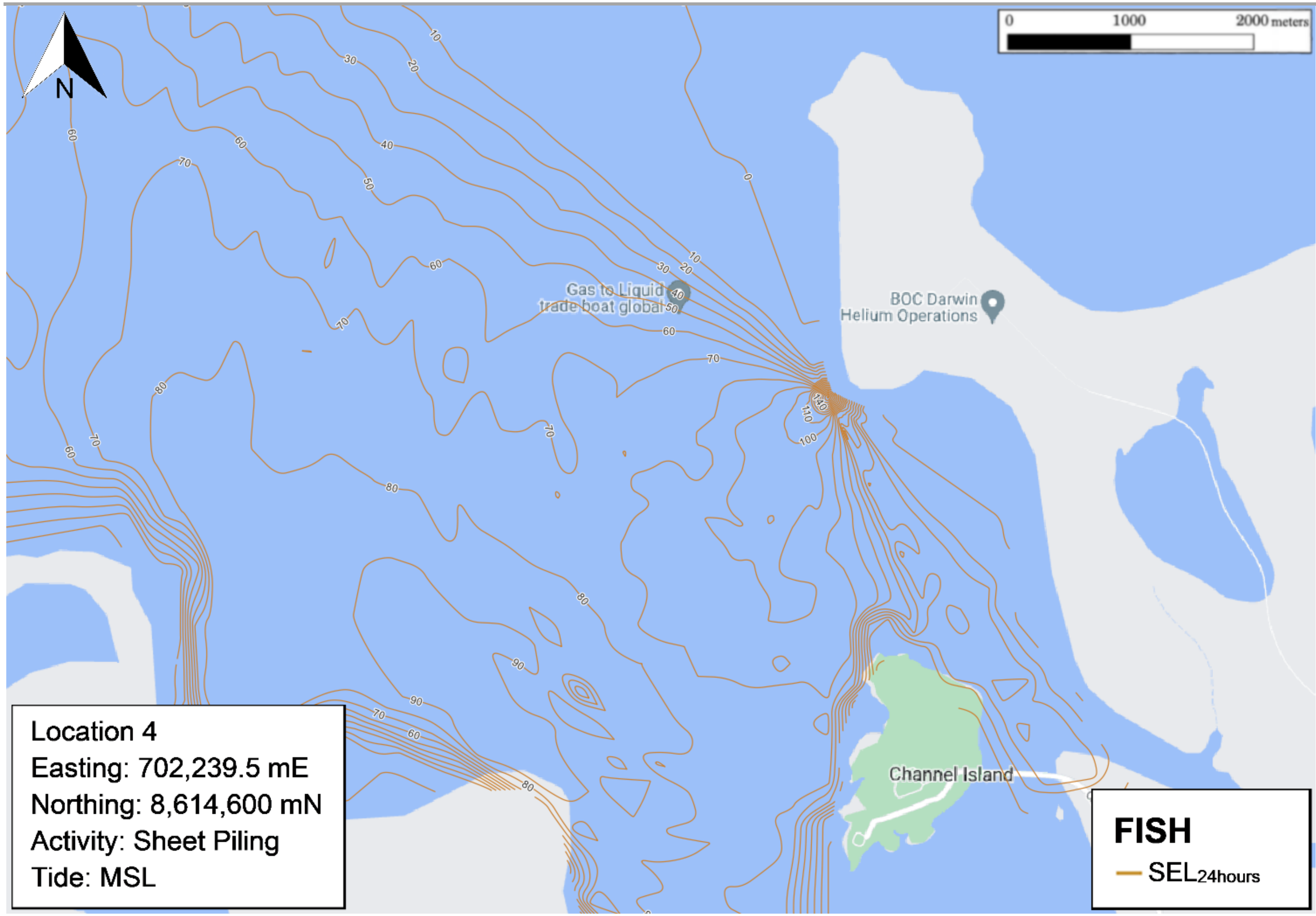

Figure 7-44 : Location 4 – Sheet Piling $SEL_{24\ hours}$ Contours for Fish (MSL)

APPENDIX C

Behavioural Contours

C.1 Location 1 – BHD

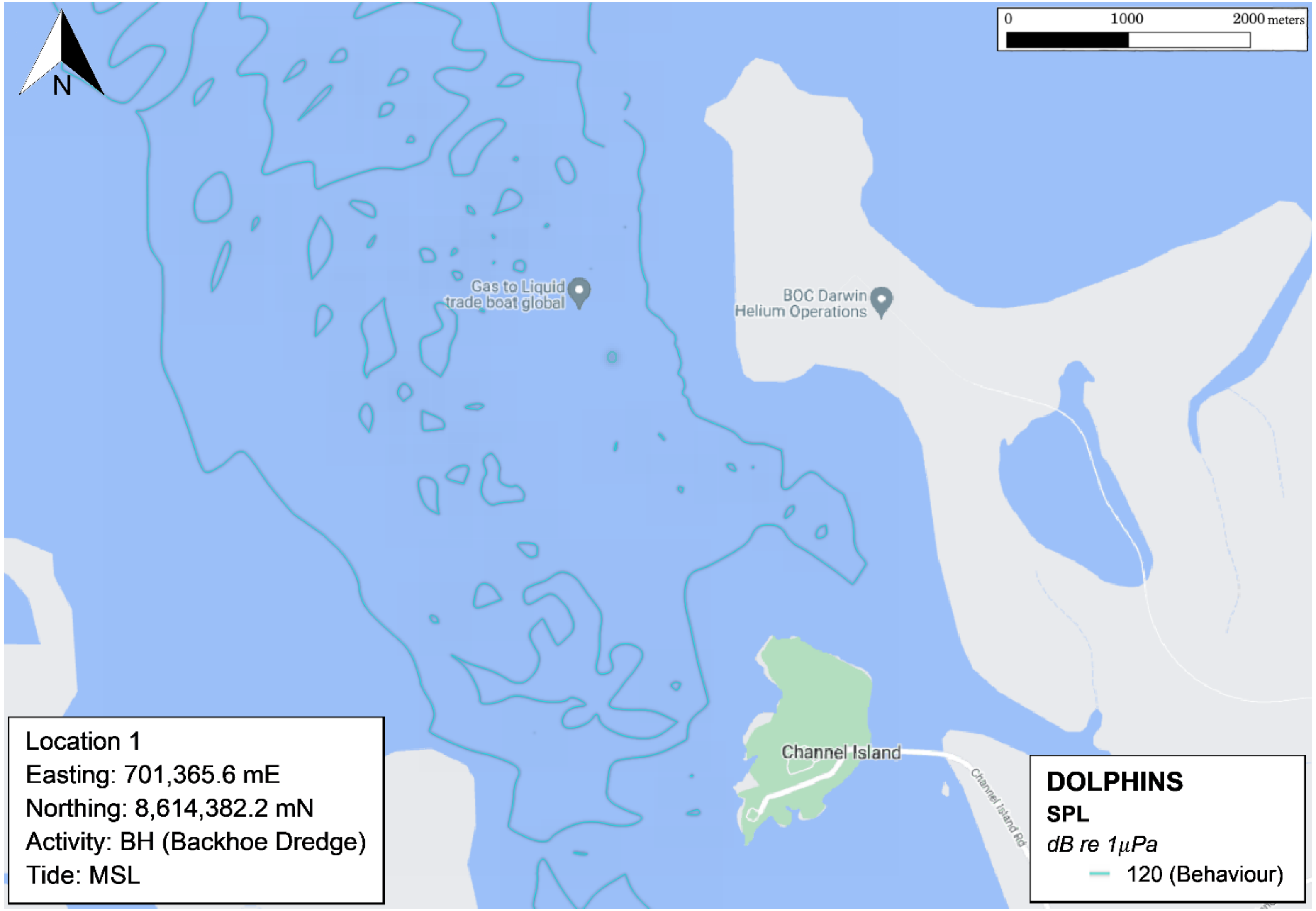

Figure 7-45 : Location 1 – BHD Behavioural Contours for Dolphins (MSL)

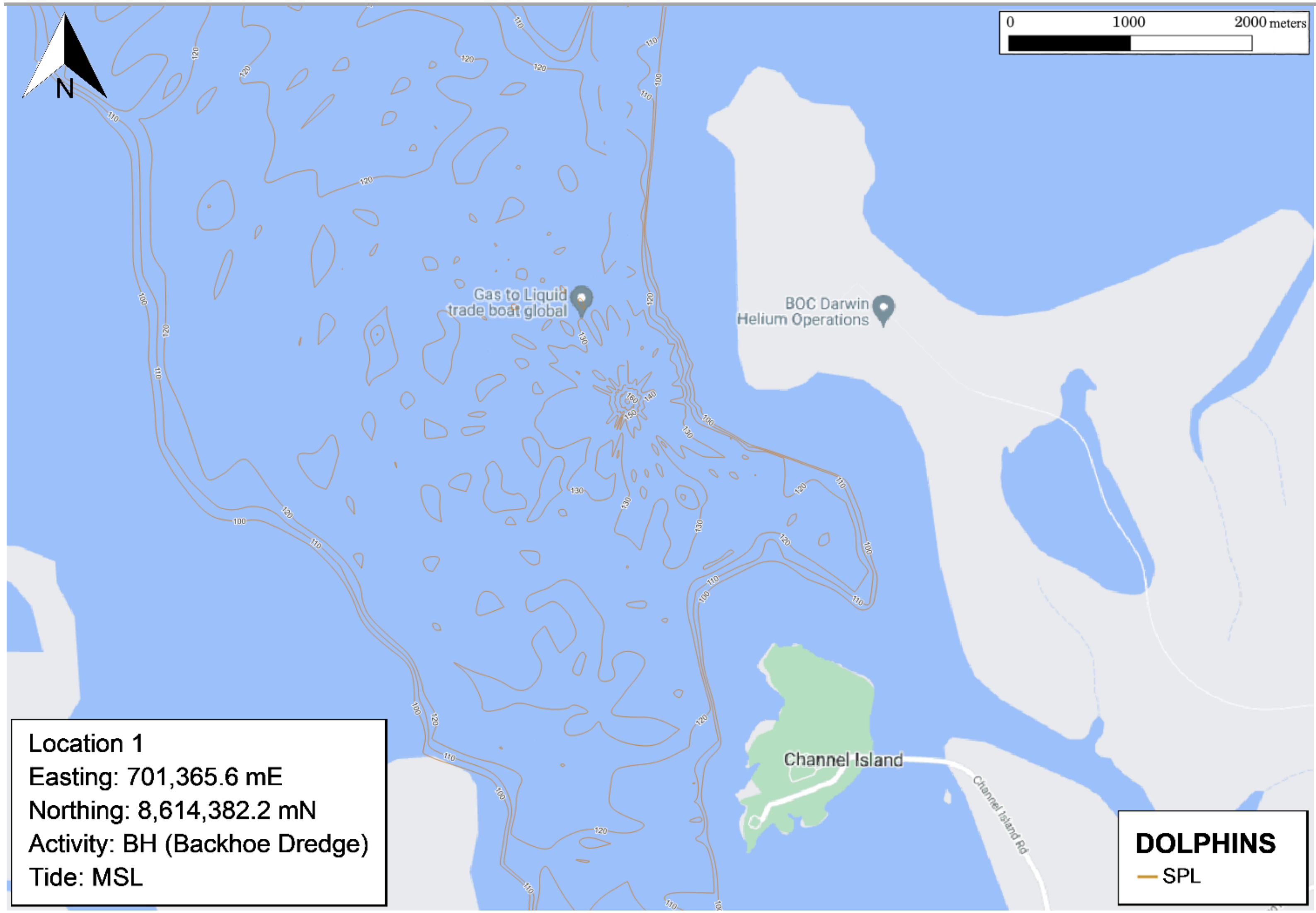

Figure 7-46 : Location 1 – BHD SPL Contours for Dolphins (MSL)

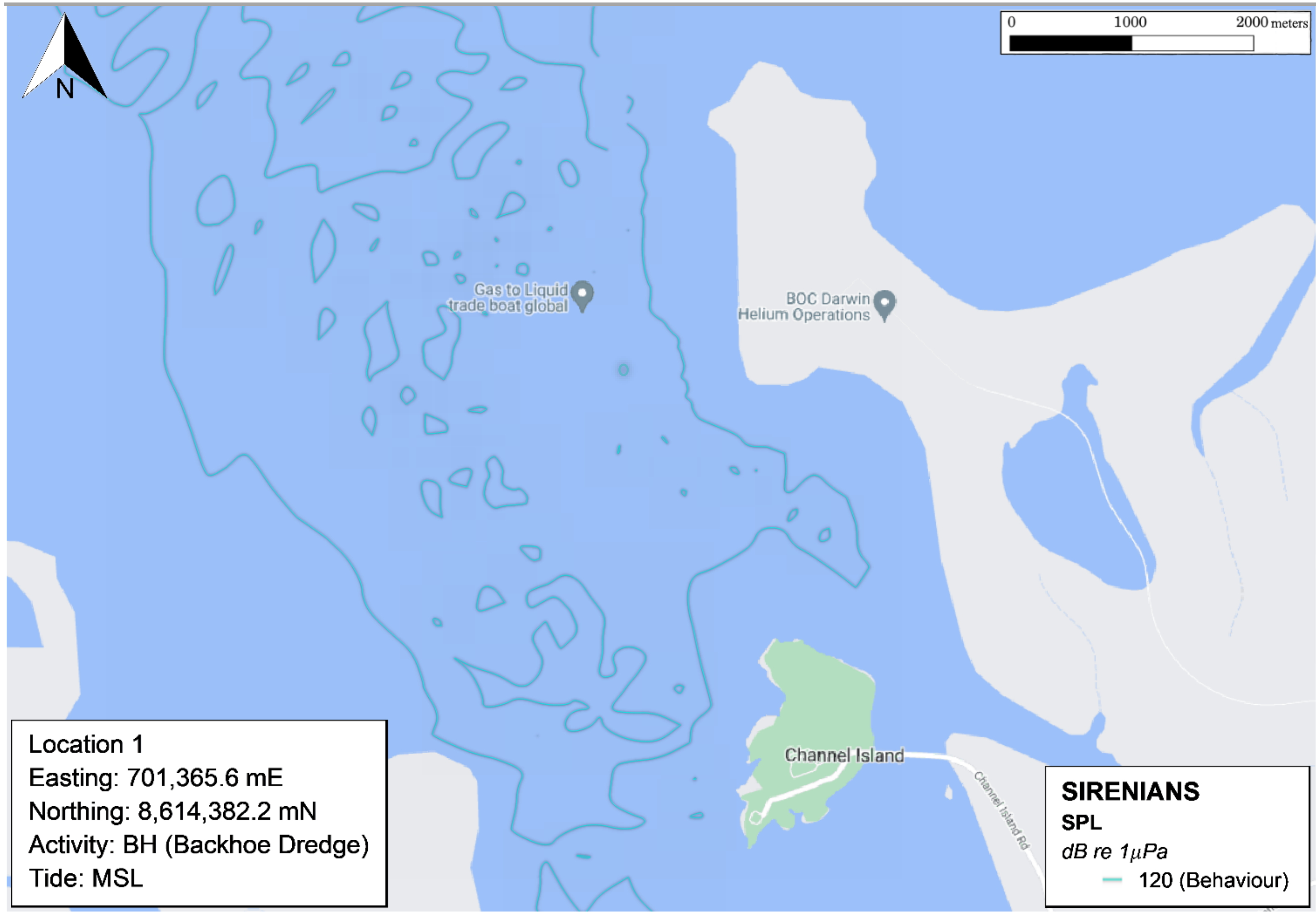

Figure 7-47 : Location 1 – BHD Behavioural Contours for Sirenians (MSL)

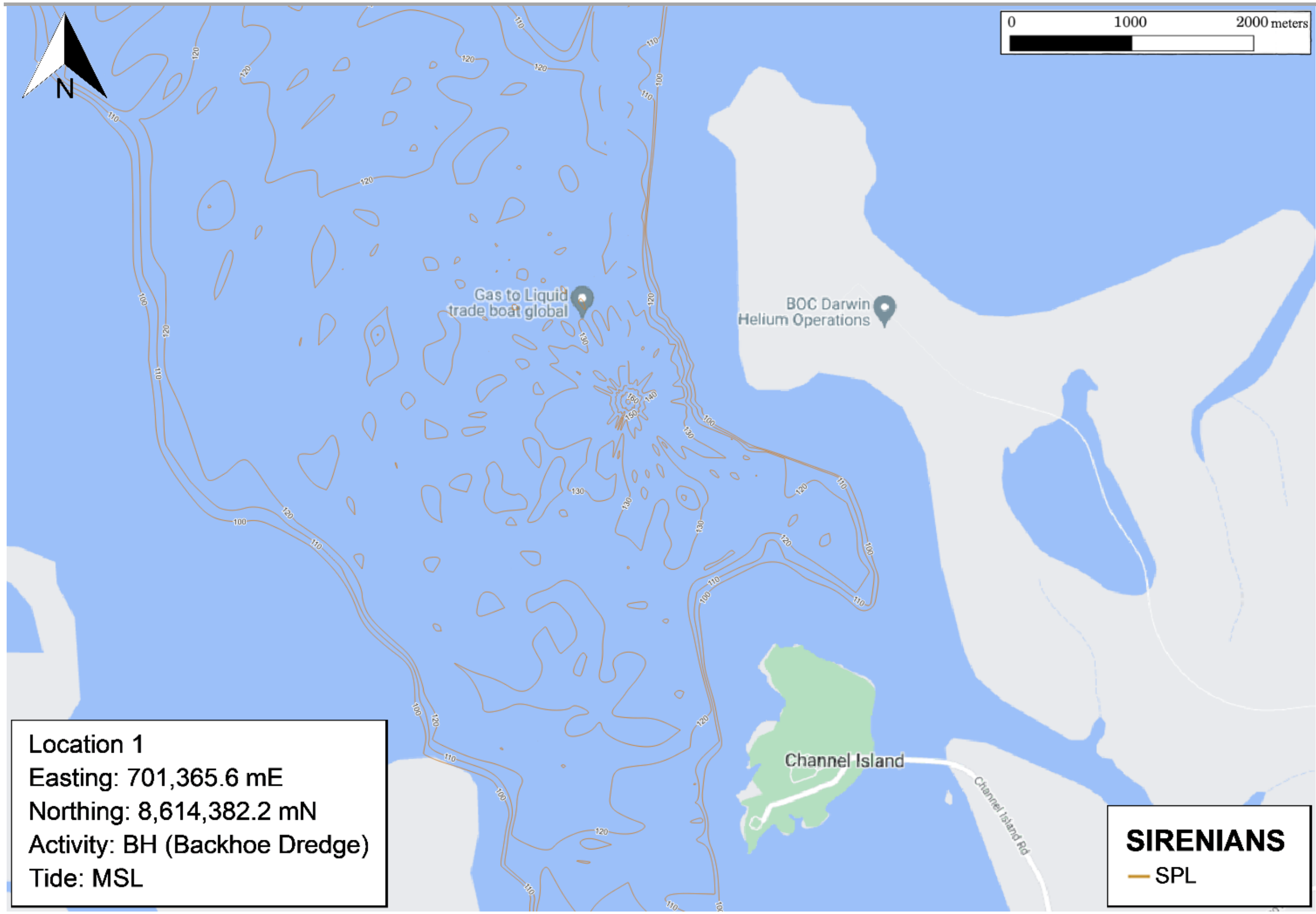

Figure 7-48 : Location 1 – BHD SPL Contours for Sirenians (MSL)

C.2 Location 1 – BHD (Hammer)

Figure 7-49 :Location 1 – BHD (Hammer) Behavioural Contours for Turtles (MSL)

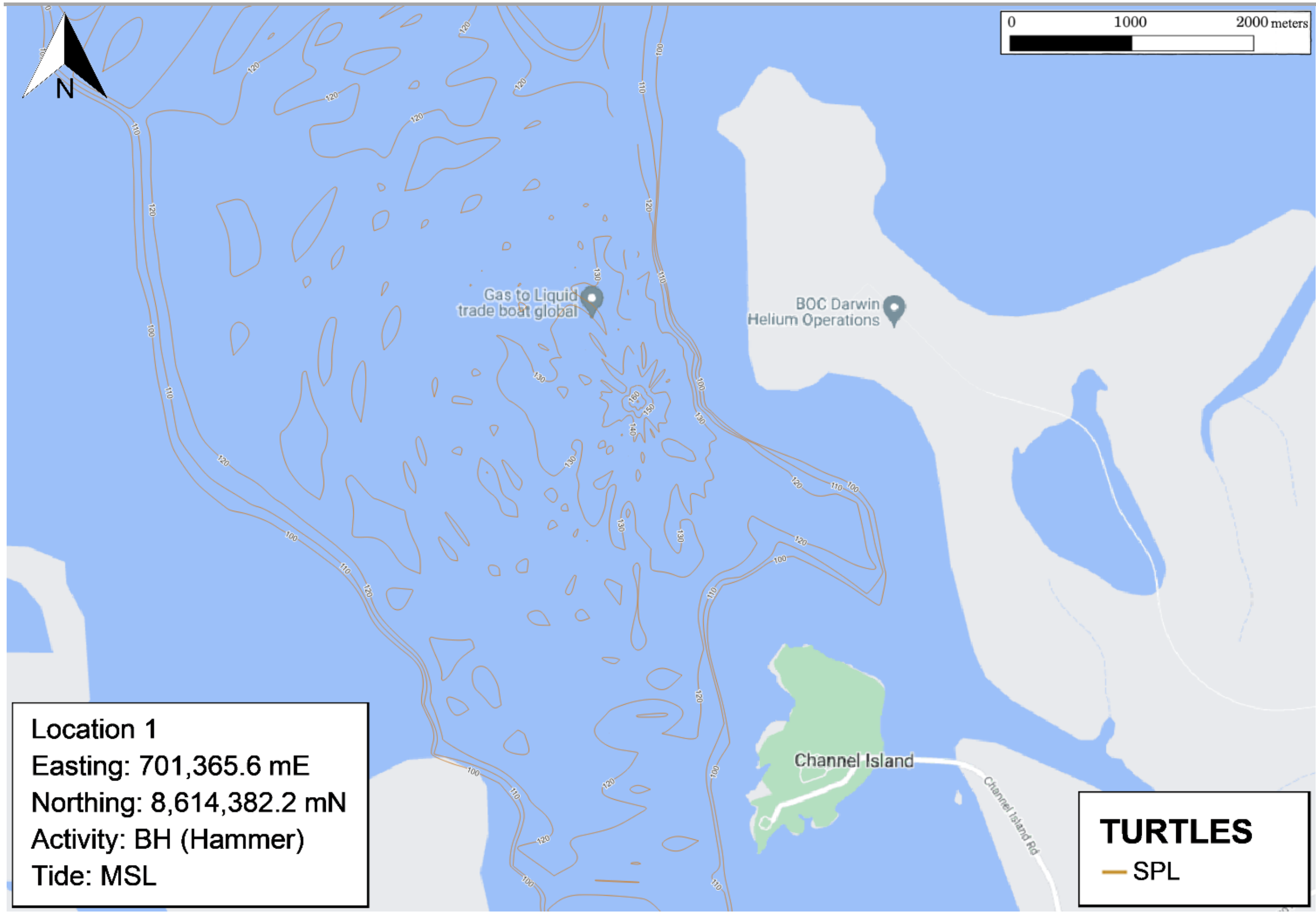

Figure 7-50 : Location 1 – BHD (Hammer) SPL Contours for Turtles (MSL)

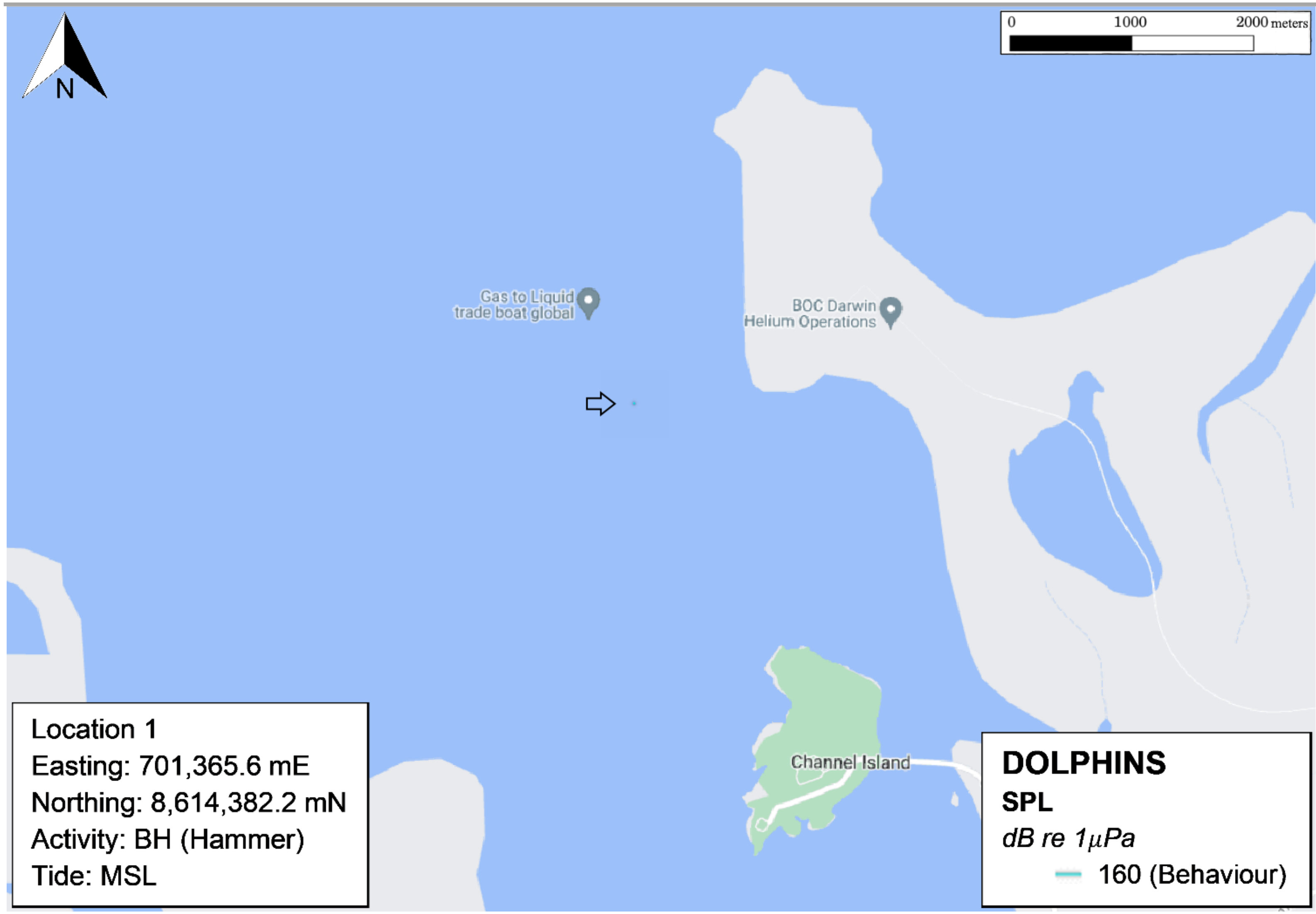

Figure 7-51 : Location 1 – BHD (Hammer) Behavioural Contours for Dolphins (MSL)

Figure 7-52 : Location 1 – BHD (Hammer) SPL Contours for Dolphins (MSL)

Figure 7-53 : Location 1 – BHD (Hammer) Behavioural Contours for Sirenians (MSL)

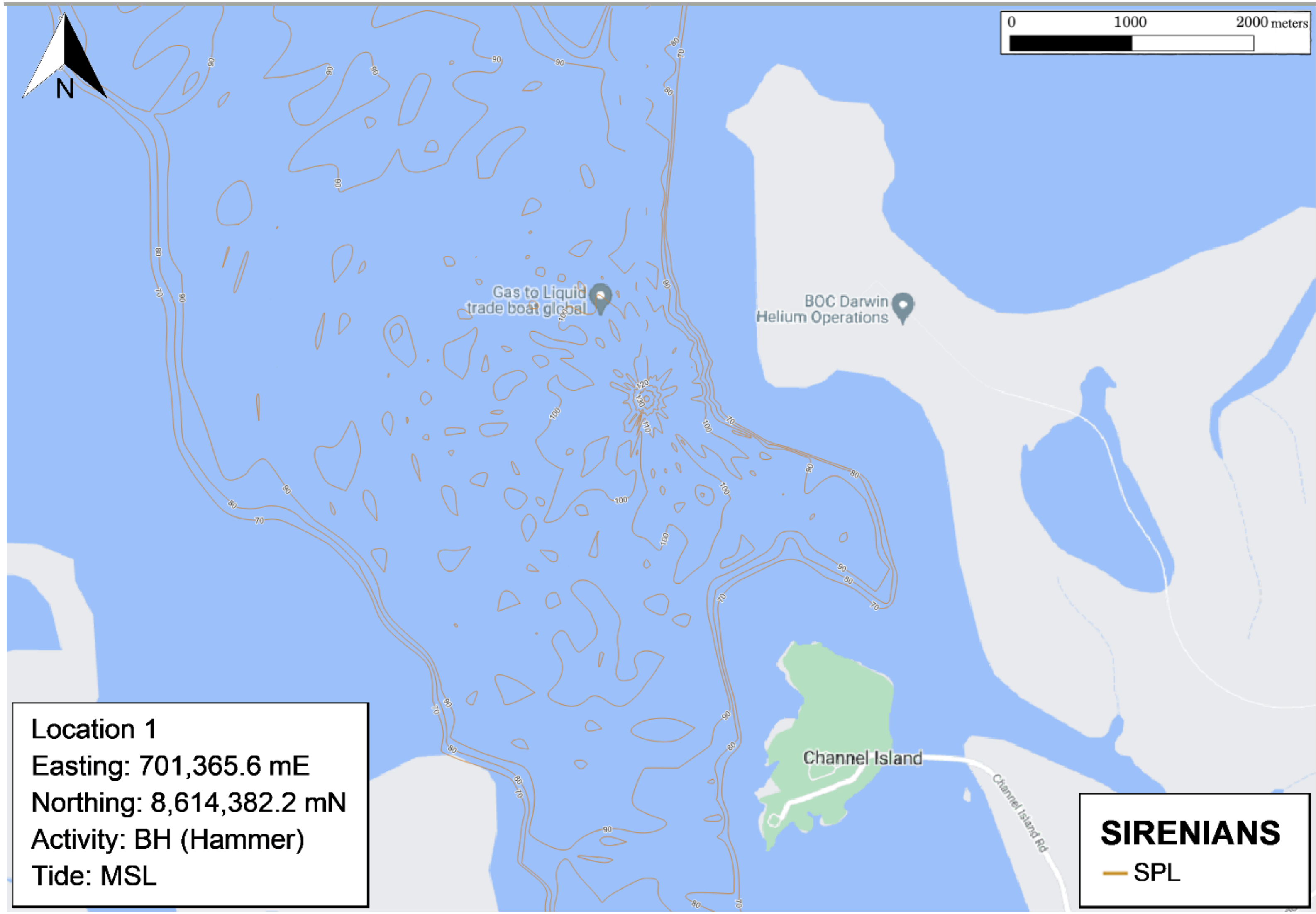

Figure 7-54 : Location 1 – BHD (Hammer) SPL Contours for Sirenians (MSL)

C.3 Location 2 – TSHD

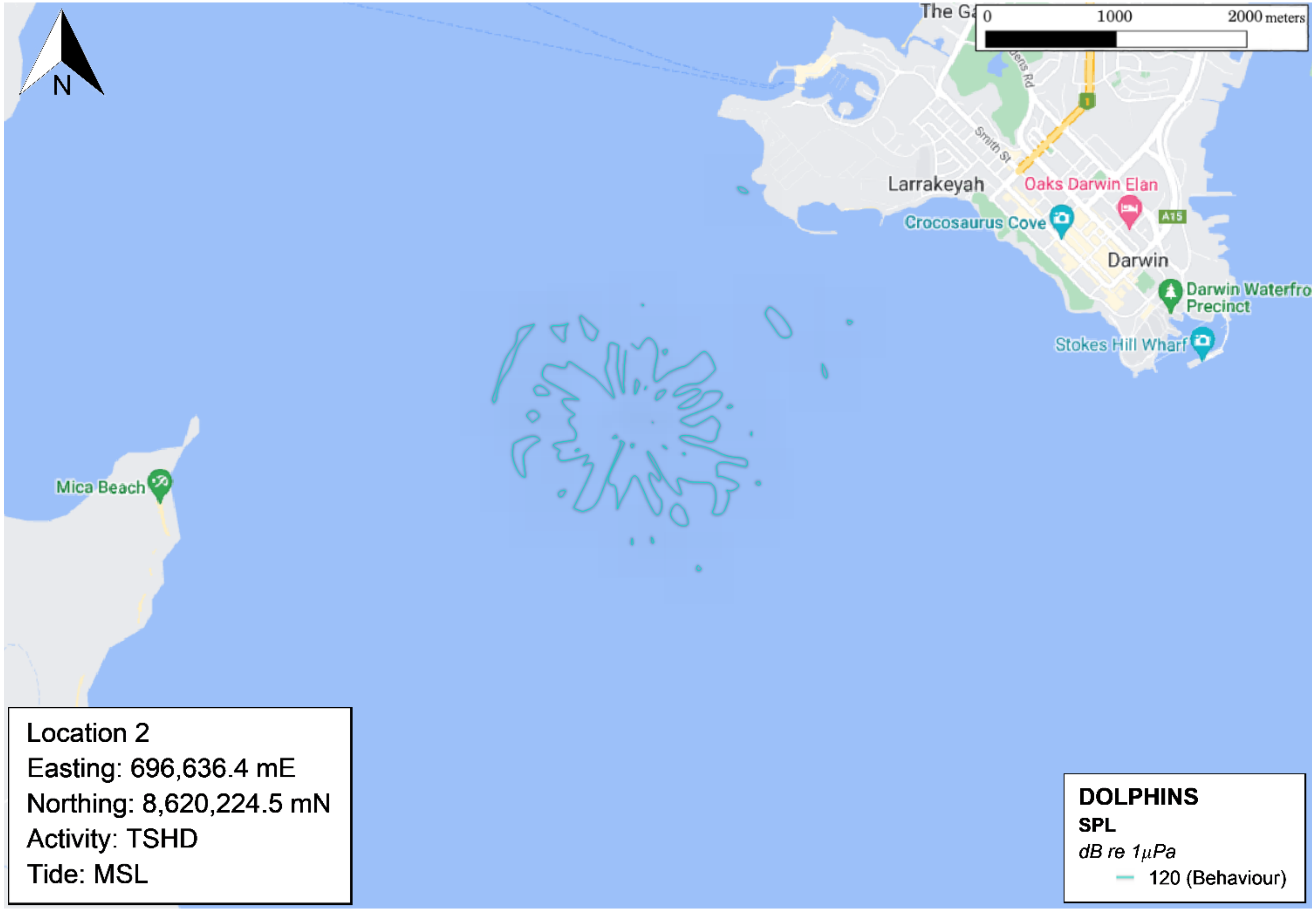

Figure 7-55 : Location 2 – TSHD Behavioural Contours for Dolphins (MSL)

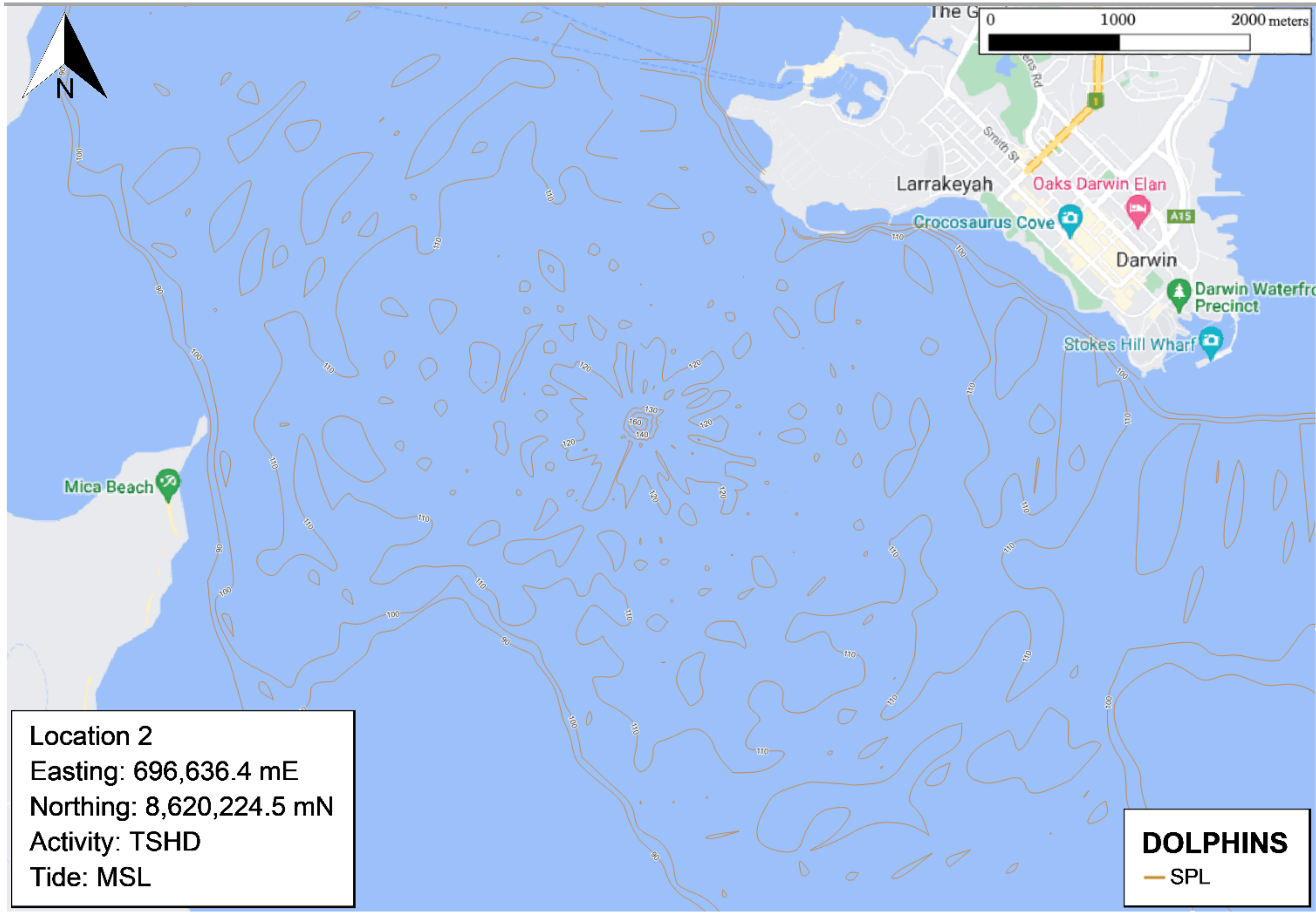

Figure 7-56 : Location 2 – TSHD SPL Contours for Dolphins (MSL)

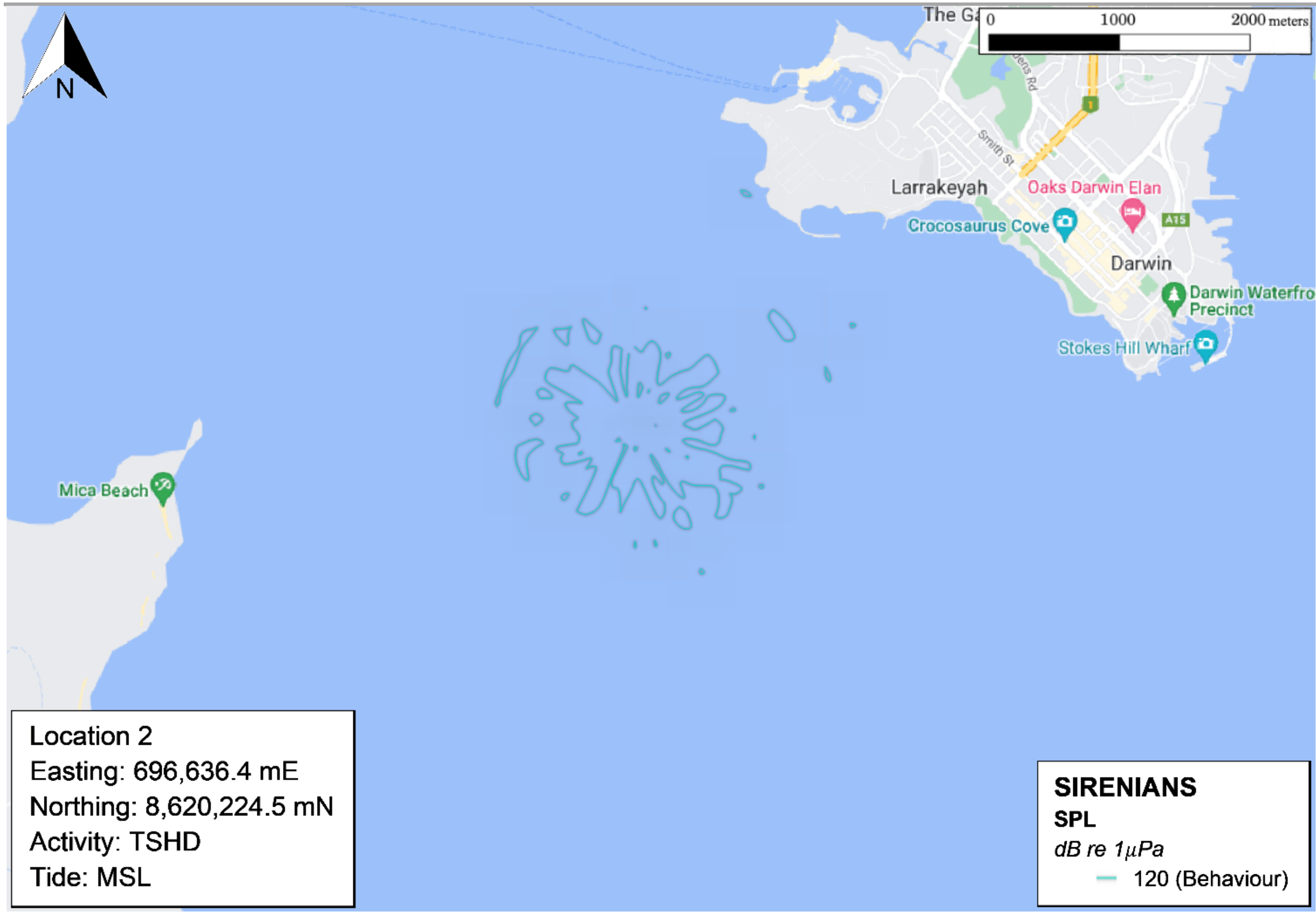

Figure 7-57 : Location 2 – TSHD Behavioural Contours for Sirenians (MSL)

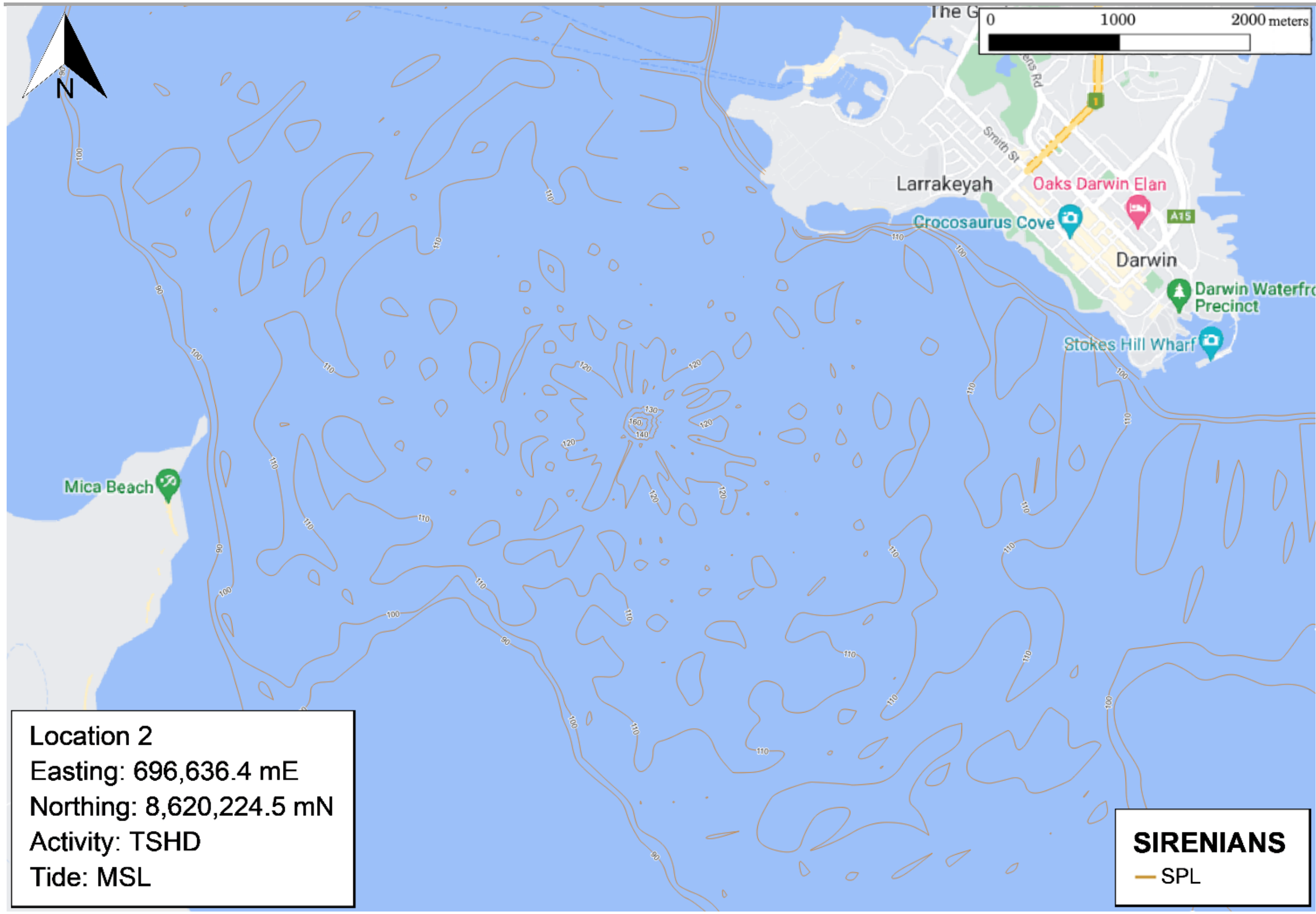

Figure 7-58 : Location 2 – TSHD SPL Contours for Sirenians (MSL)

C.4 Location 3 – TSHD

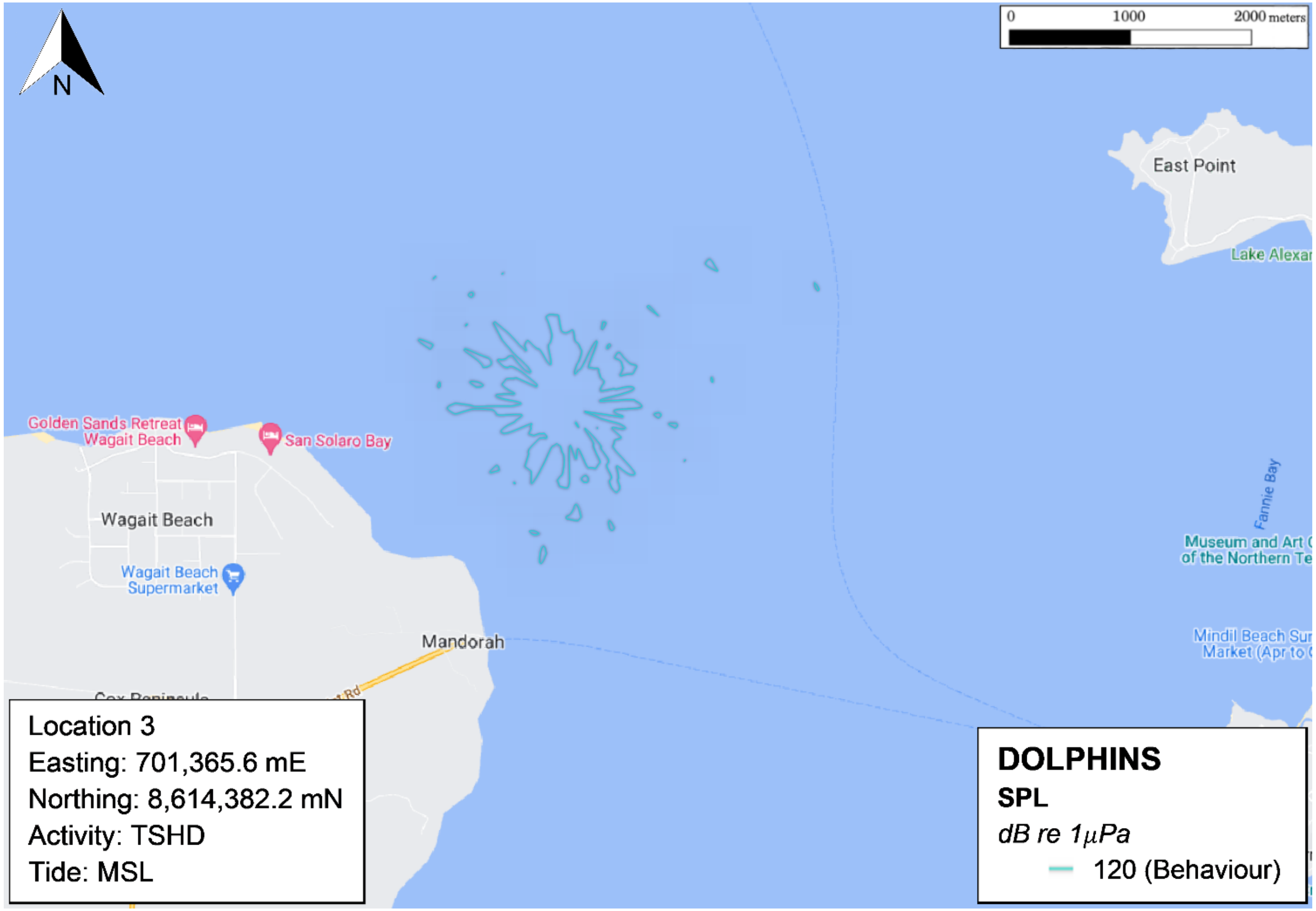

Figure 7-59 : Location 3 – TSHD Behavioural Contours for Dolphins (MSL)

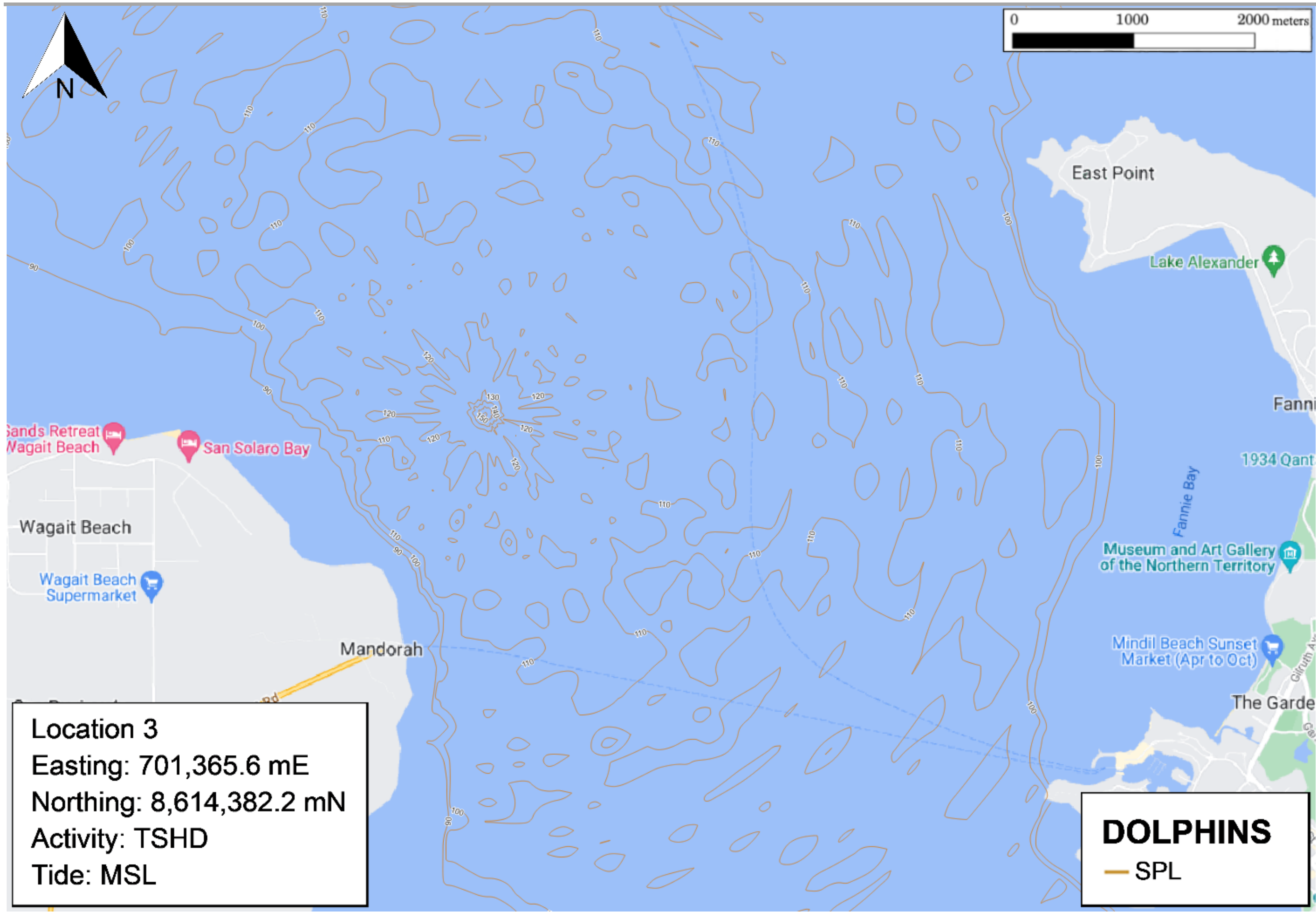

Figure 7-60 : Location 3 – TSHD SPL Contours for Dolphins (MSL)

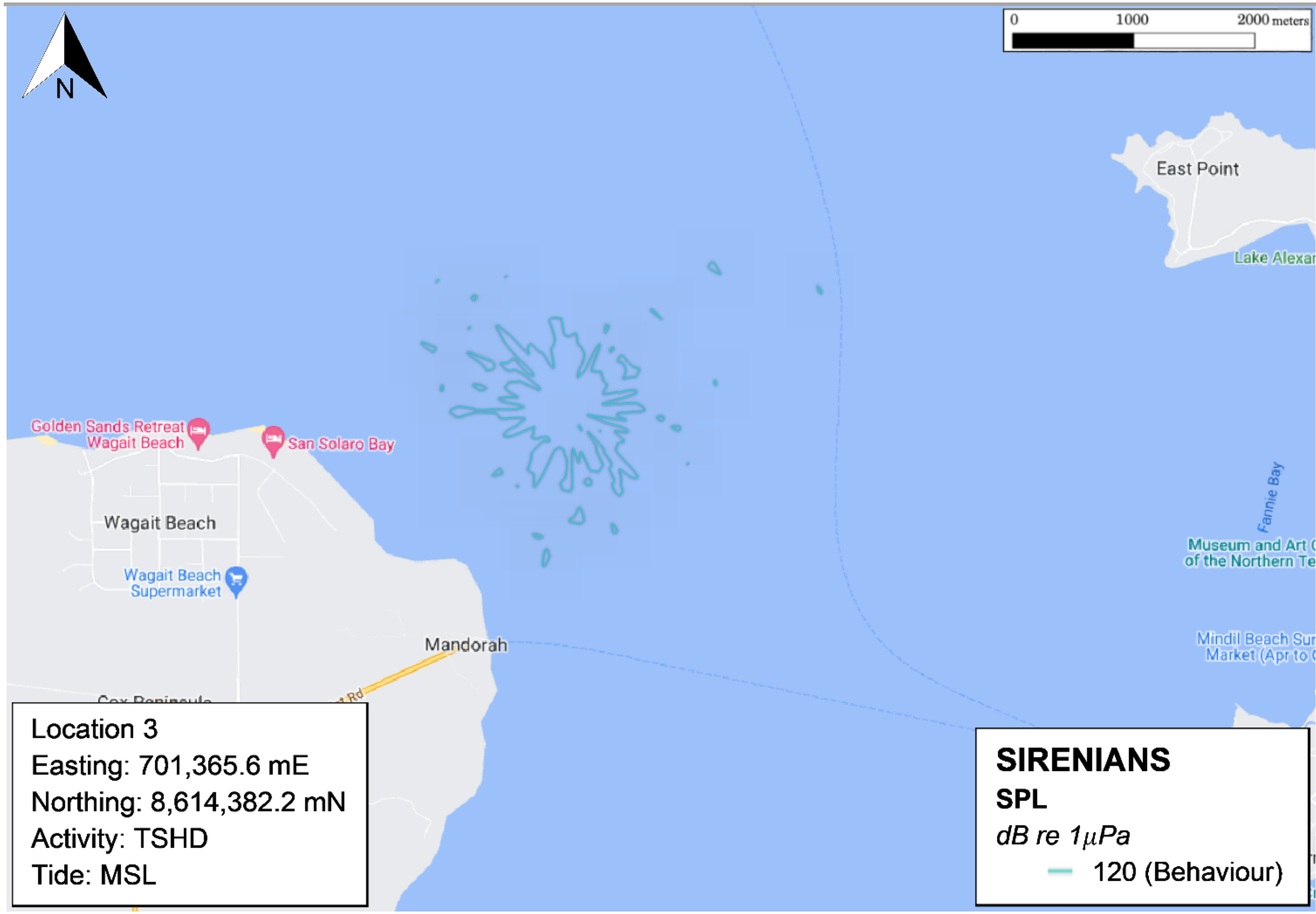

Figure 7-61 : Location 3 – TSHD Behavioural Contours for Sirenians (MSL)

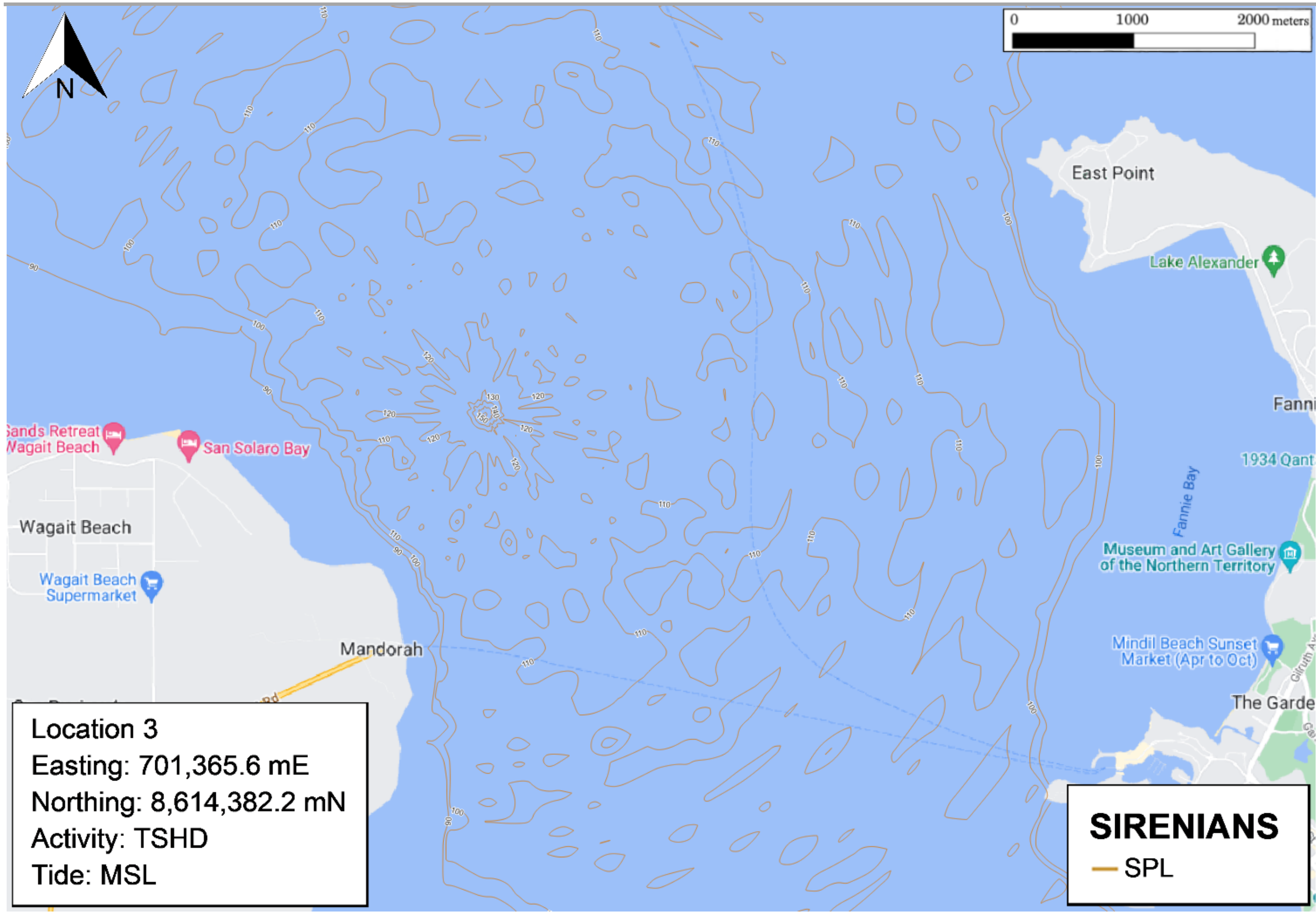

Figure 7-62 : Location 3 – TSHD SPL Contours for Sirenians (MSL)

C.5 Location 3 – TSHD and CSD

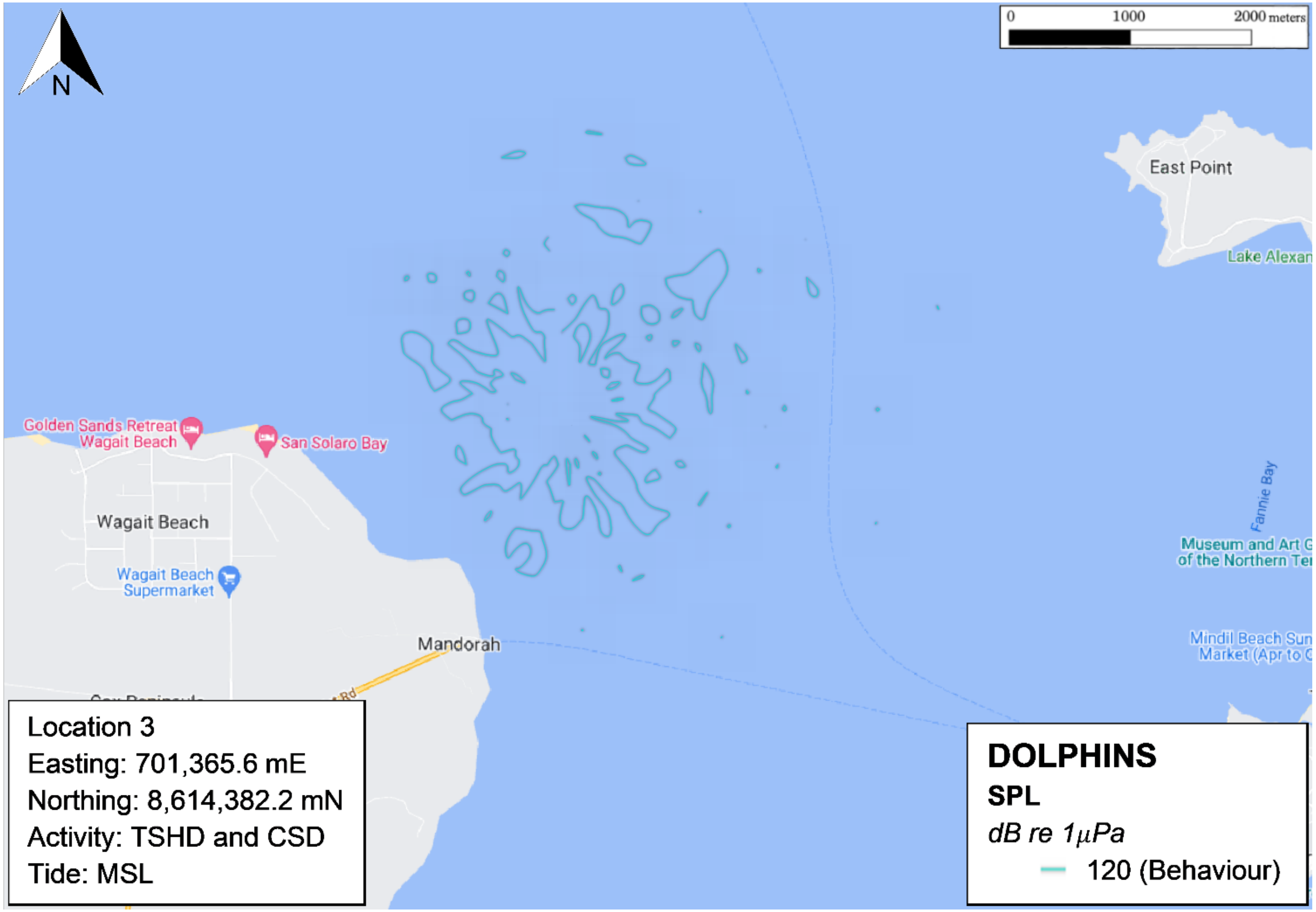

Figure 7-63 : Location 3 – TSHD and CSD Behavioural Contours for Dolphins (MSL)

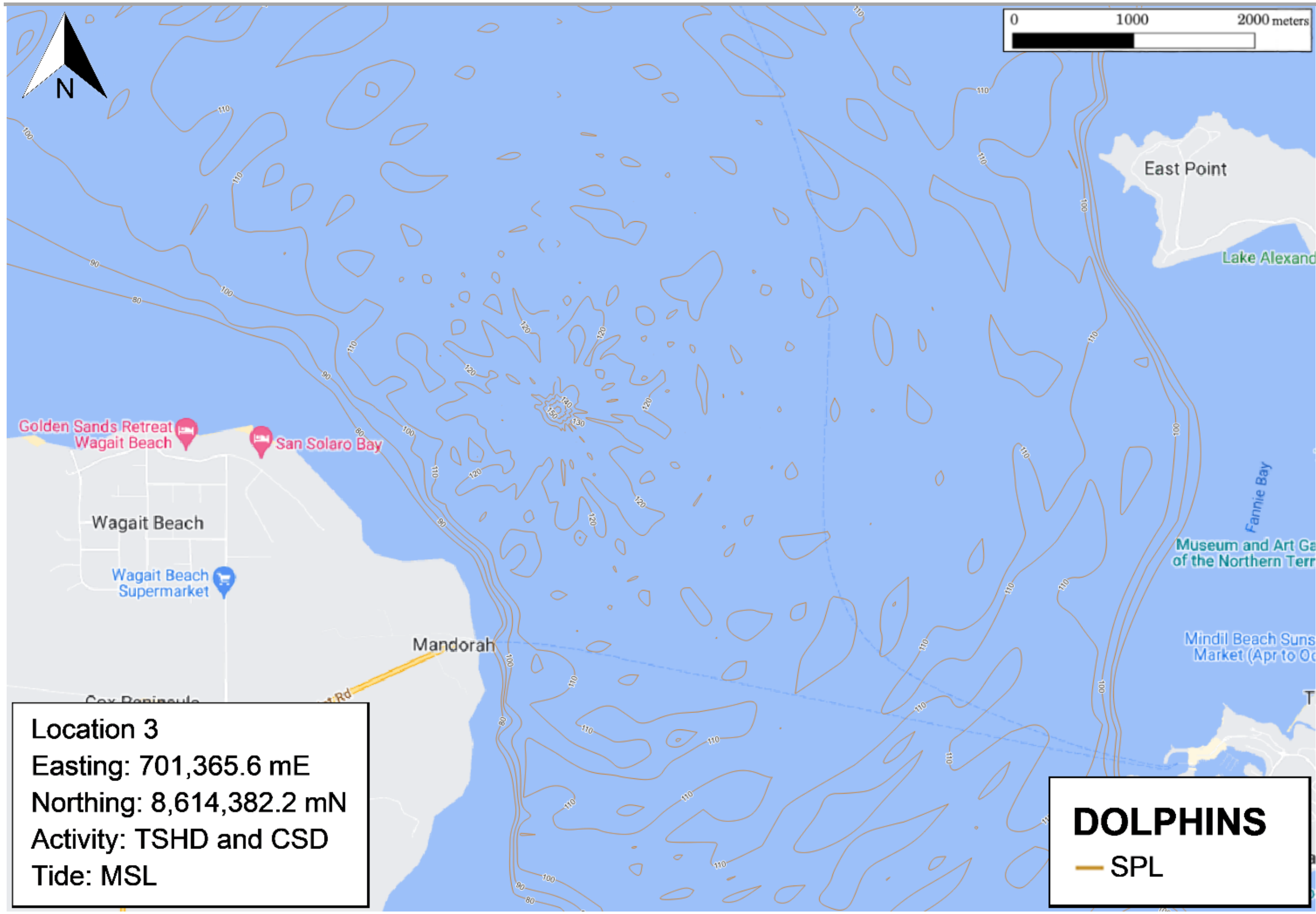

Figure 7-64 : Location 3 – TSHD and CSD SPL Contours for Dolphins (MSL)

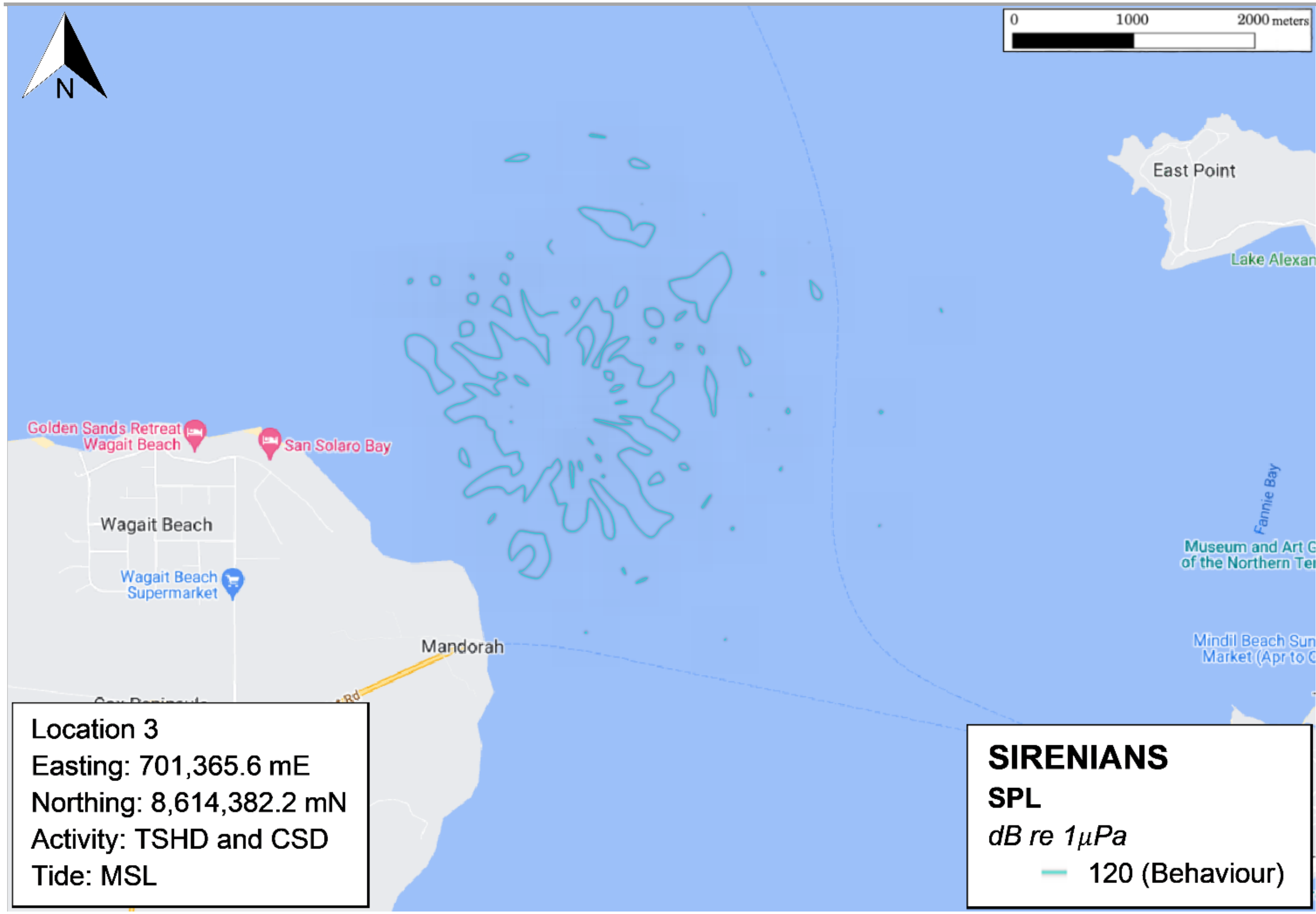

Figure 7-65 : Location 3 – TSHD and CSD Behavioural Contours for Sirenians (MSL)

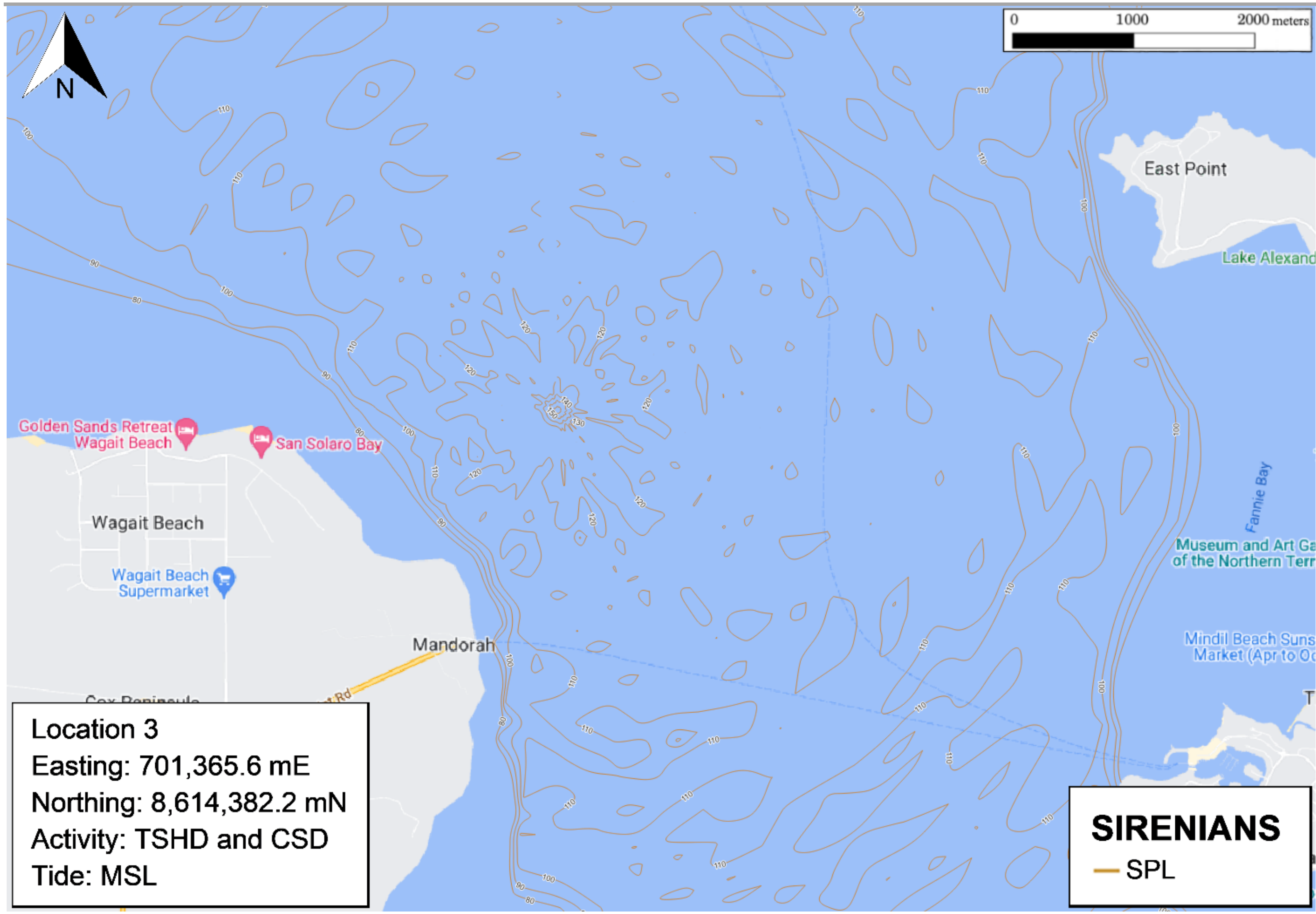

Figure 7-66 : Location 3 – TSHD and CSD SPL Contours for Sirenians (MSL)

C.6 Location 4 – Sheet Piling

Figure 7-67 :Location 3 – Sheet Piling Behavioural Contours for Turtles (MSL)

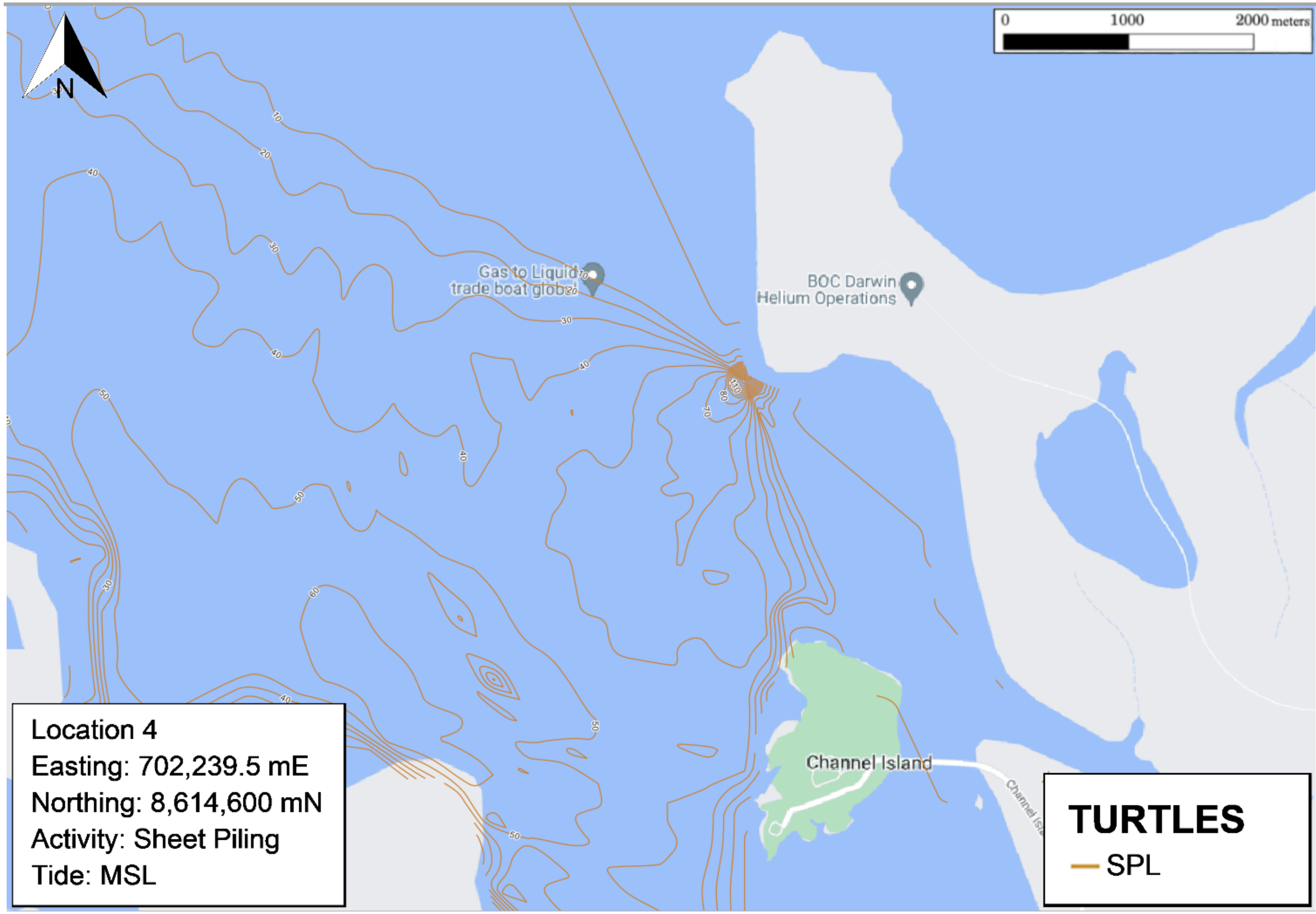

Figure 7-68 : Location 3 – Sheet Piling SPL Contours for Turtles (MSL)

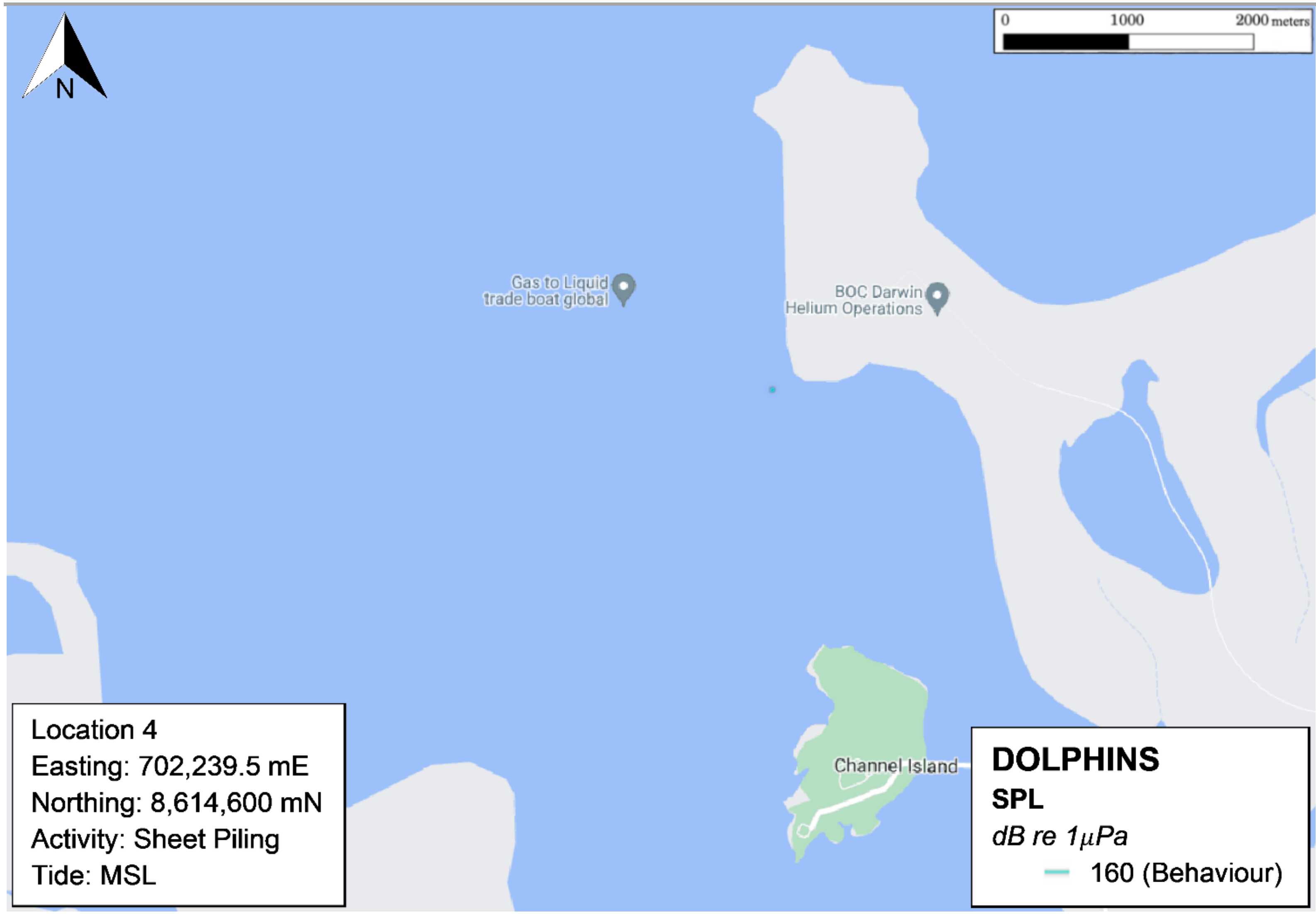

Figure 7-69 : Location 3 – Sheet Piling Behavioural Contours for Dolphins (MSL)

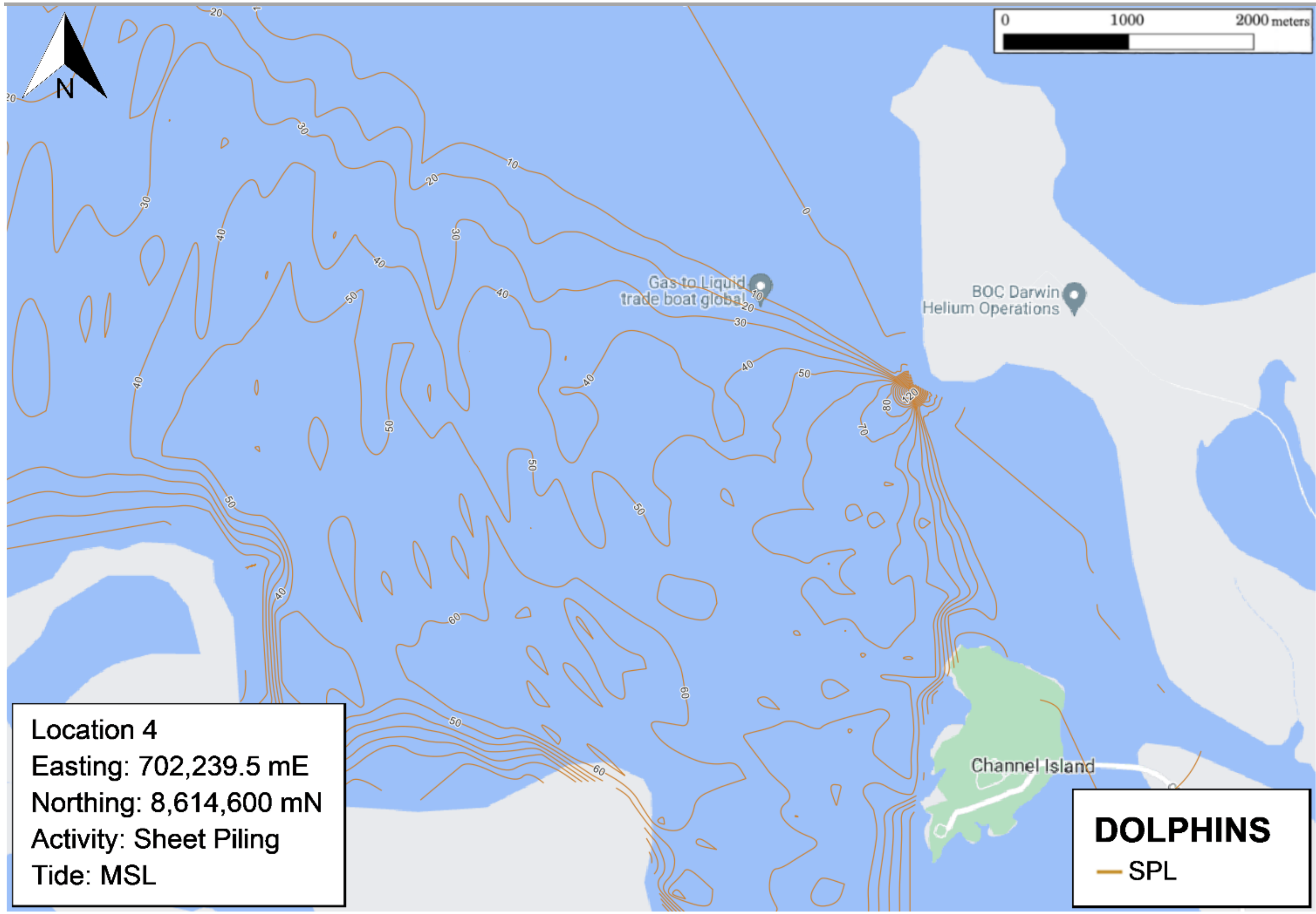

Figure 7-70 : Location 3 – Sheet Piling SPL Contours for Dolphins (MSL)

Figure 7-71 : Location 3 – Sheet Piling Behavioural Contours for Sirenians (MSL)

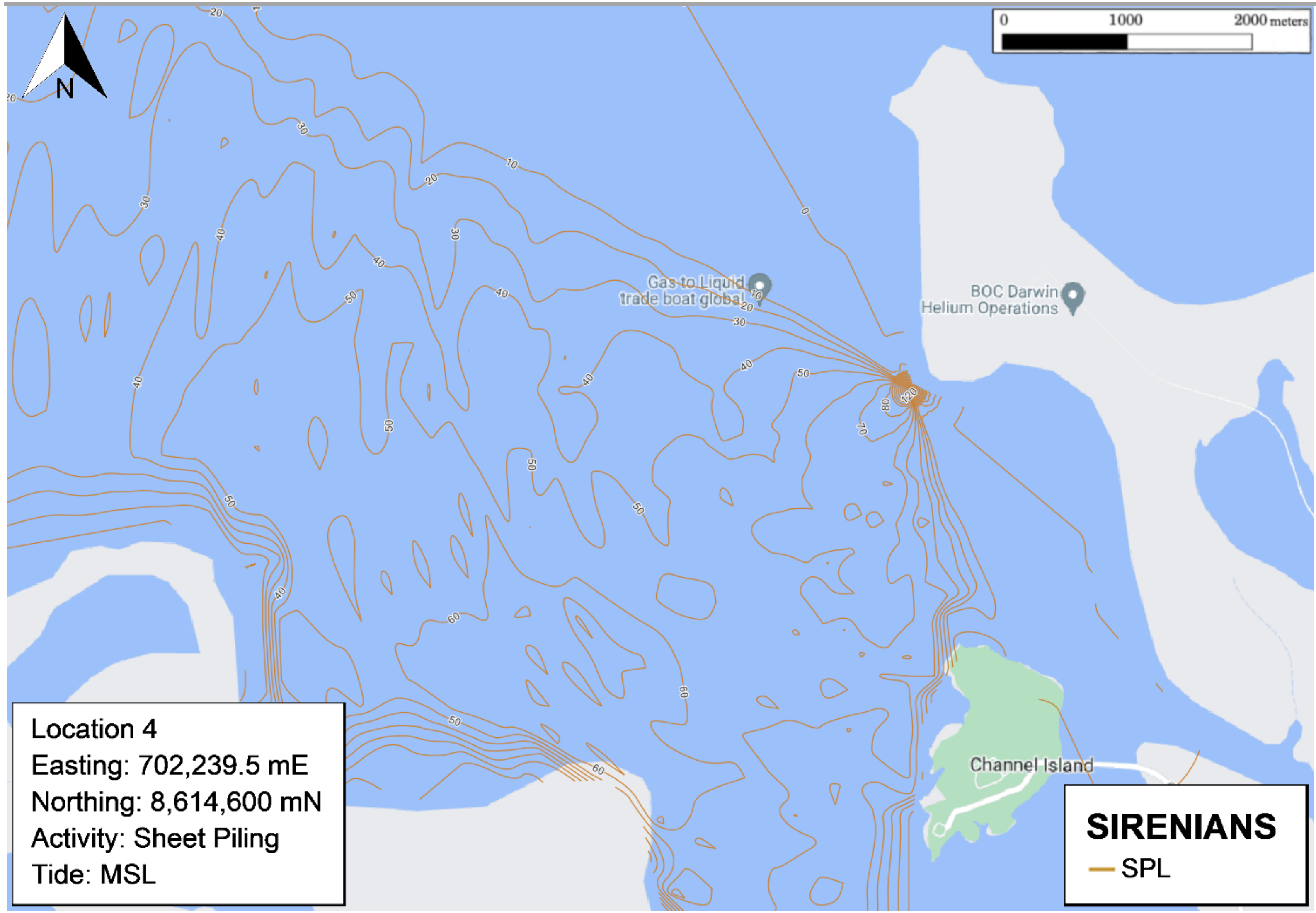

Figure 7-72 : Location 3 – Sheet Piling SPL Contours for Sirenians (MSL)

APPENDIX D
TTS and PTS Ranges

D.1 Location 1 – BHD (Digging)

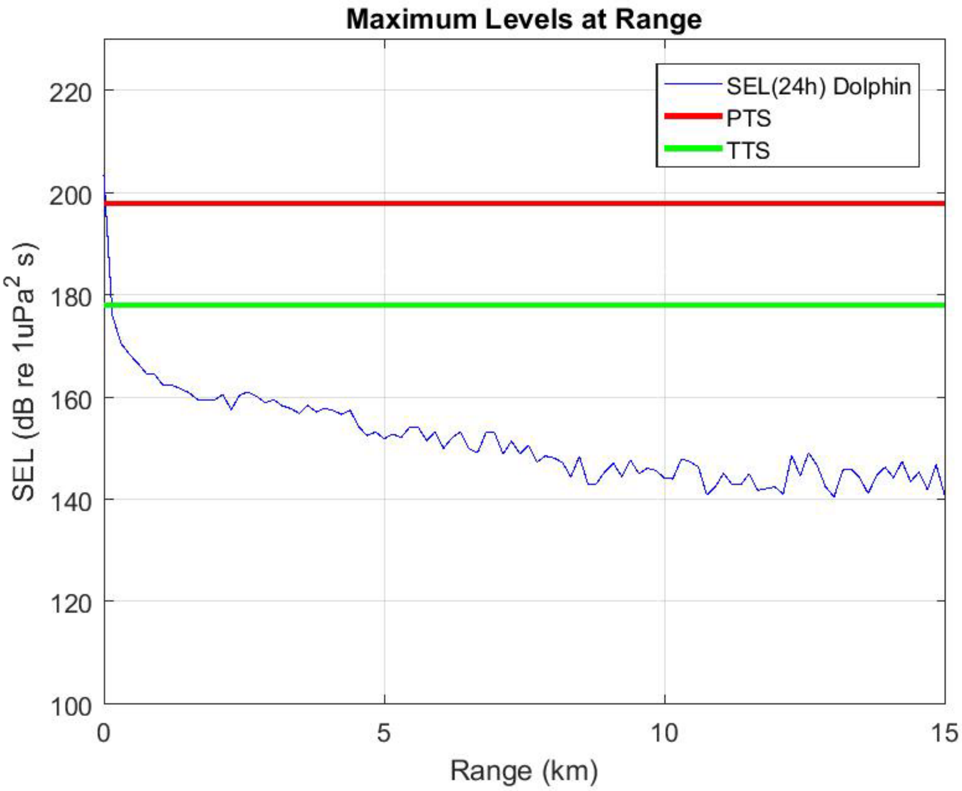

Figure 7-73 : MSL BHD (Digging) Location 1 maximum cumulative SEL with distance for Dolphin

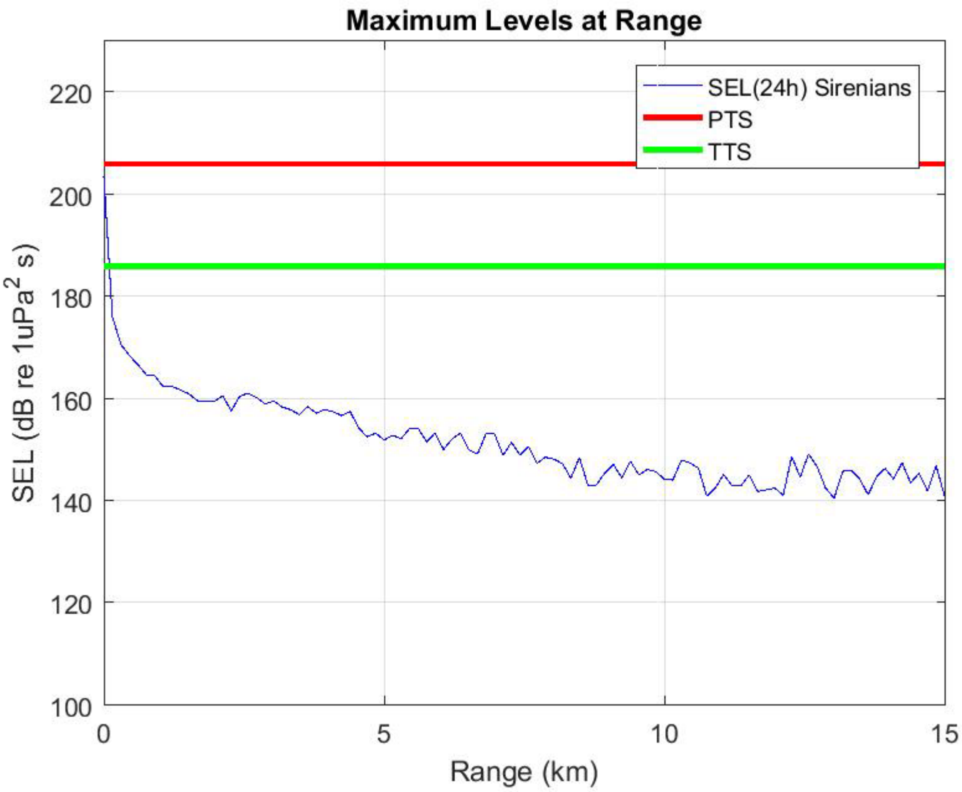

Figure 7-74 : MSL BHD (Digging) Location 1 maximum cumulative SEL with distance for Dugongs

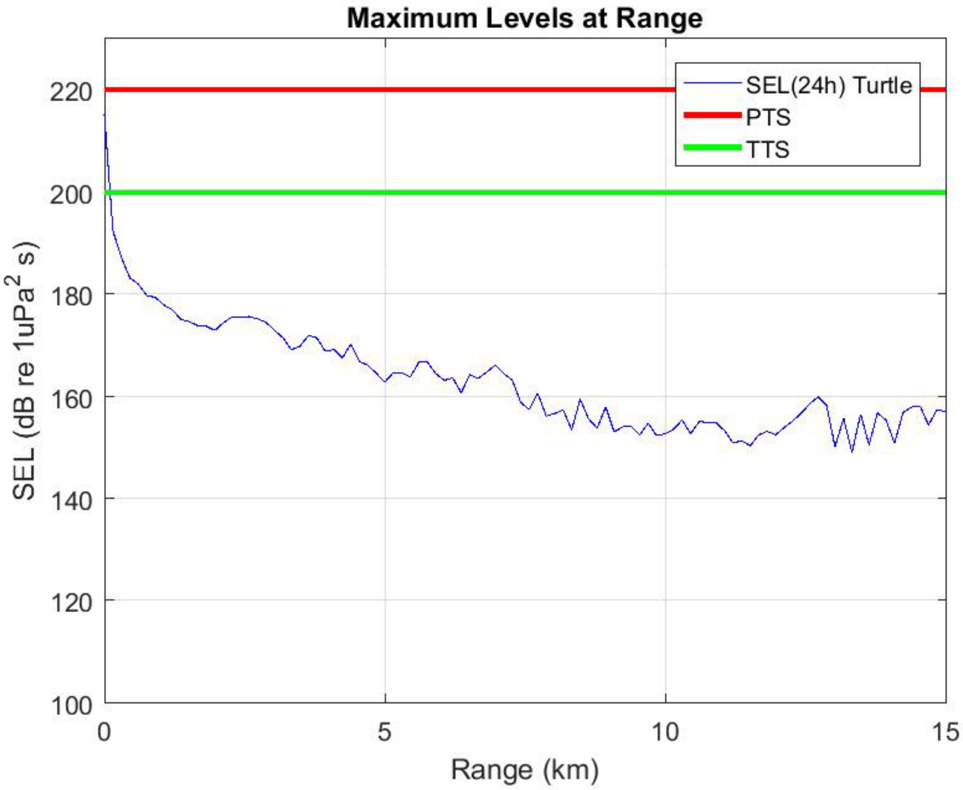

Figure 7-75 : MSL BHD (Digging) Location 1 maximum cumulative SEL with distance for Turtles

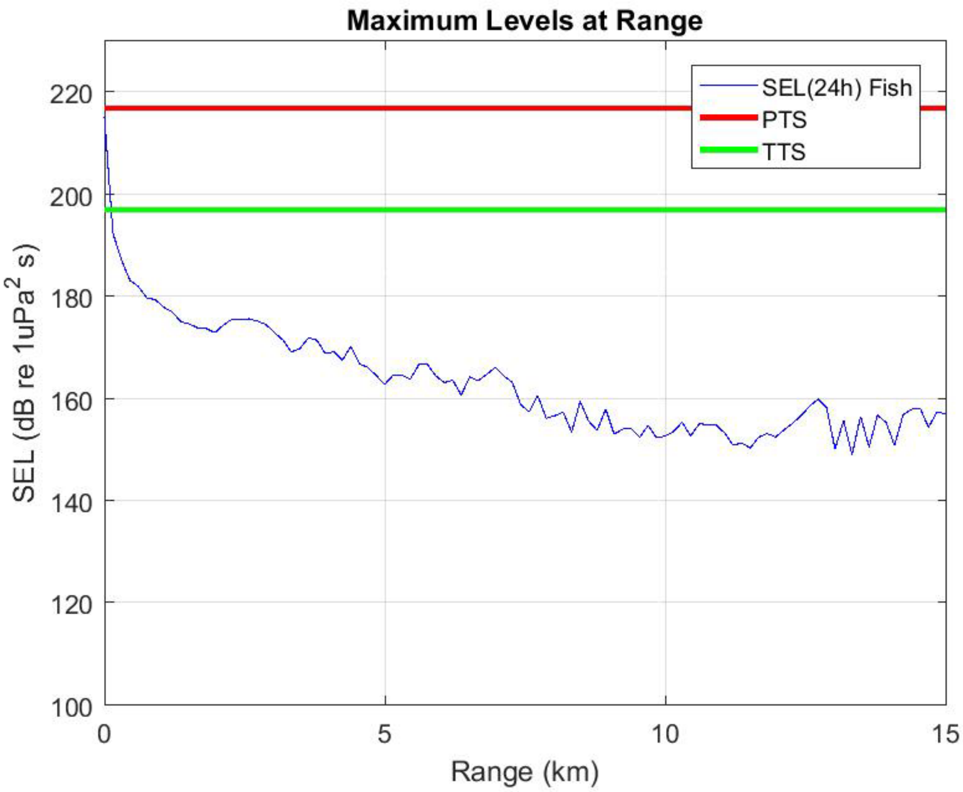

Figure 7-76 : MSL BHD (Digging) Location 1 maximum cumulative SEL with distance for Fish

D.2 Location 1 – BHD with Hydraulic Hammer

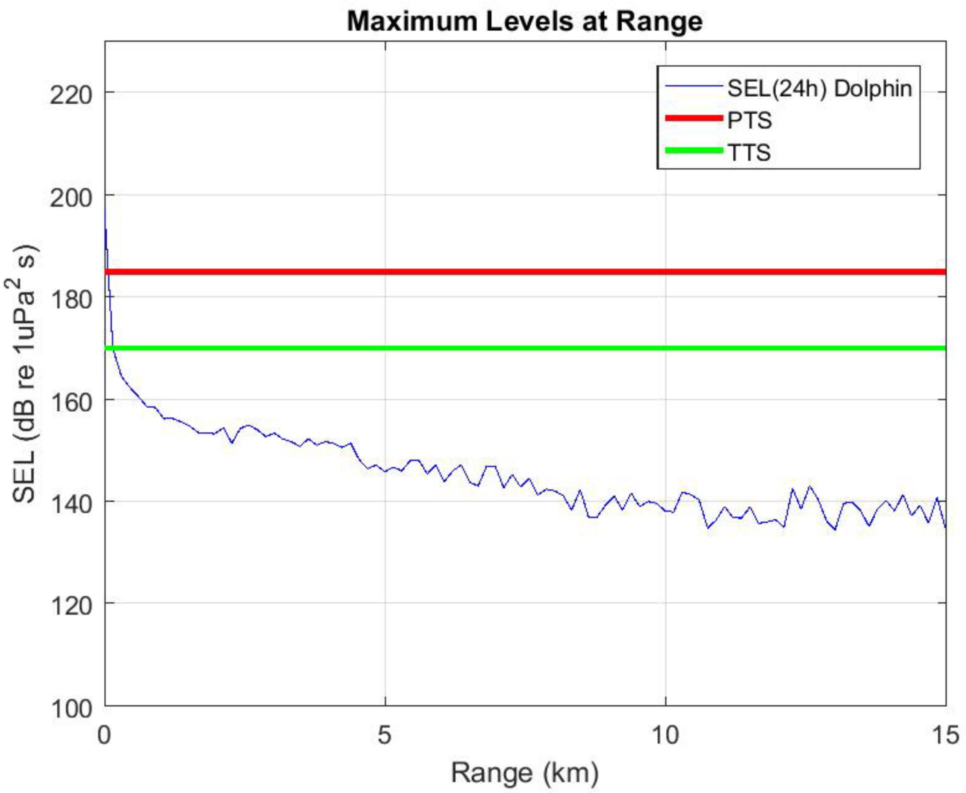

Figure 7-77 : MSL BHD (Hydraulic Hammer) Location 1 maximum cumulative SEL with distance for Dolphin

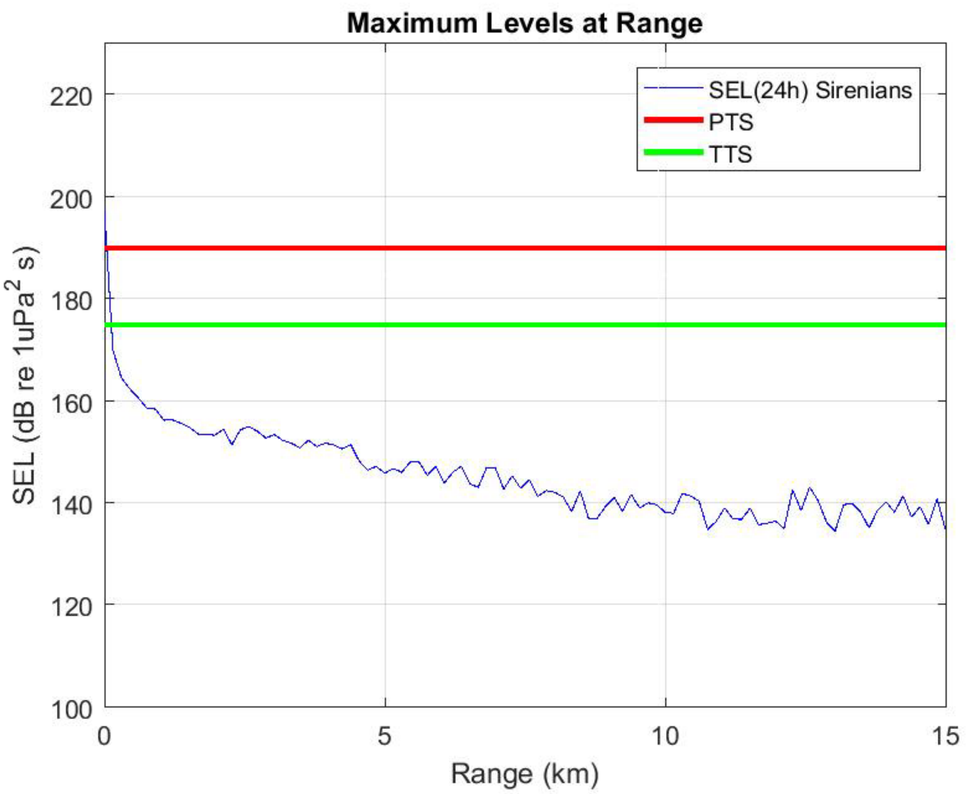

Figure 7-78 : MSL BHD (Hydraulic Hammer) Location 1 maximum cumulative SEL with distance for Dugongs

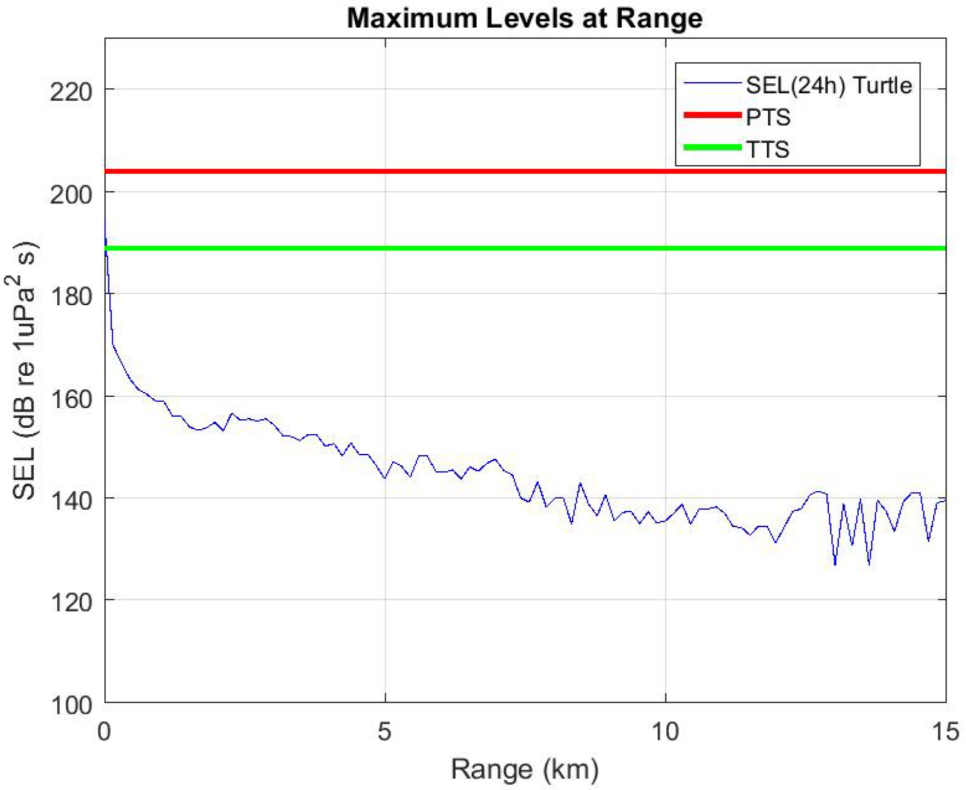

Figure 7-79 : MSL BHD (Hydraulic Hammer) Location 1 maximum cumulative SEL with distance for Turtles

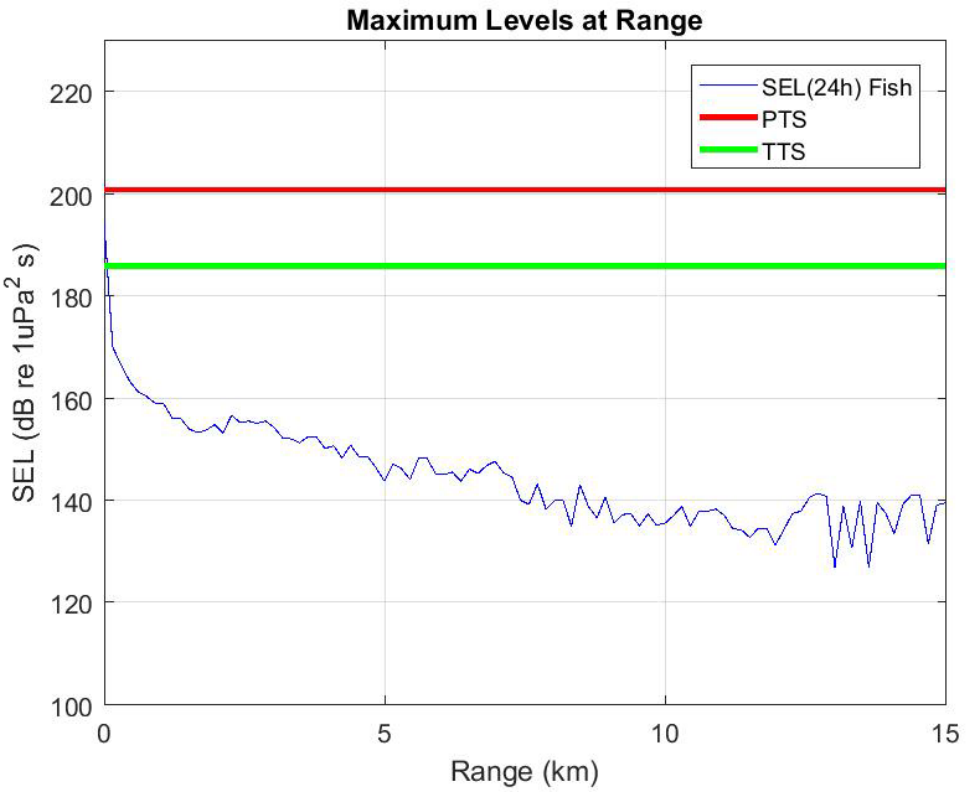

Figure 7-80 MSL BHD (Hydraulic Hammer) Location 1 maximum cumulative SEL with distance for Fish

D.3 Location 2 – TSHD

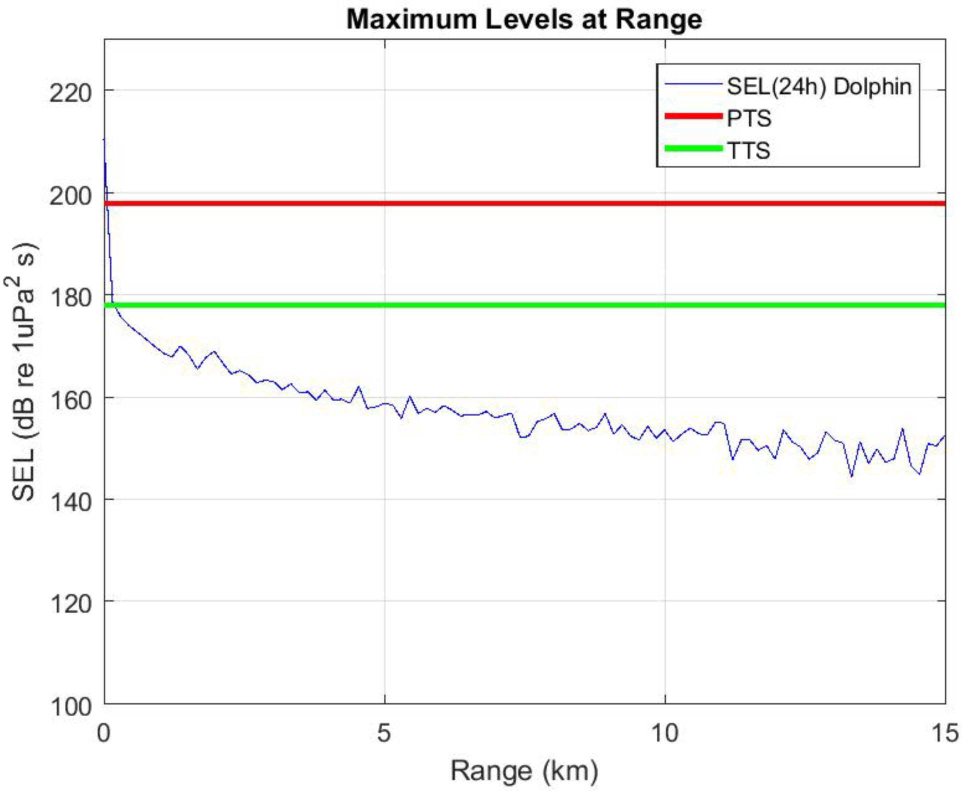

Figure 7-81 : MSL TSHD Location 2 maximum cumulative SEL with distance for Dolphin

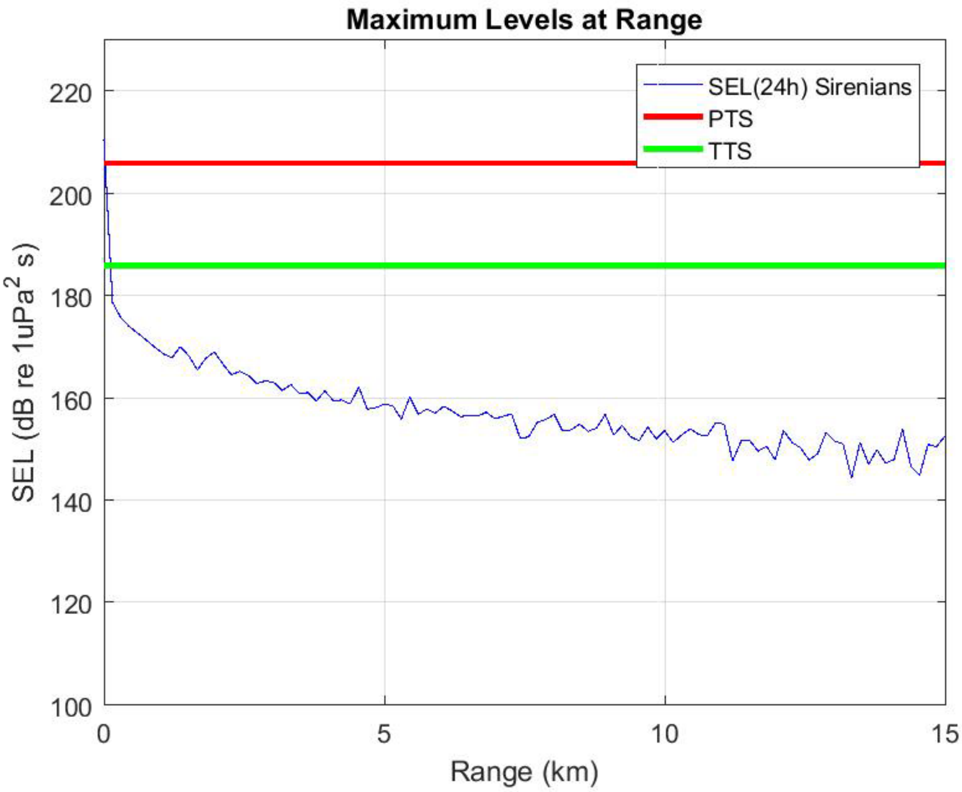

Figure 7-82 : MSL TSHD Location 2 maximum cumulative SEL with distance for Dugongs

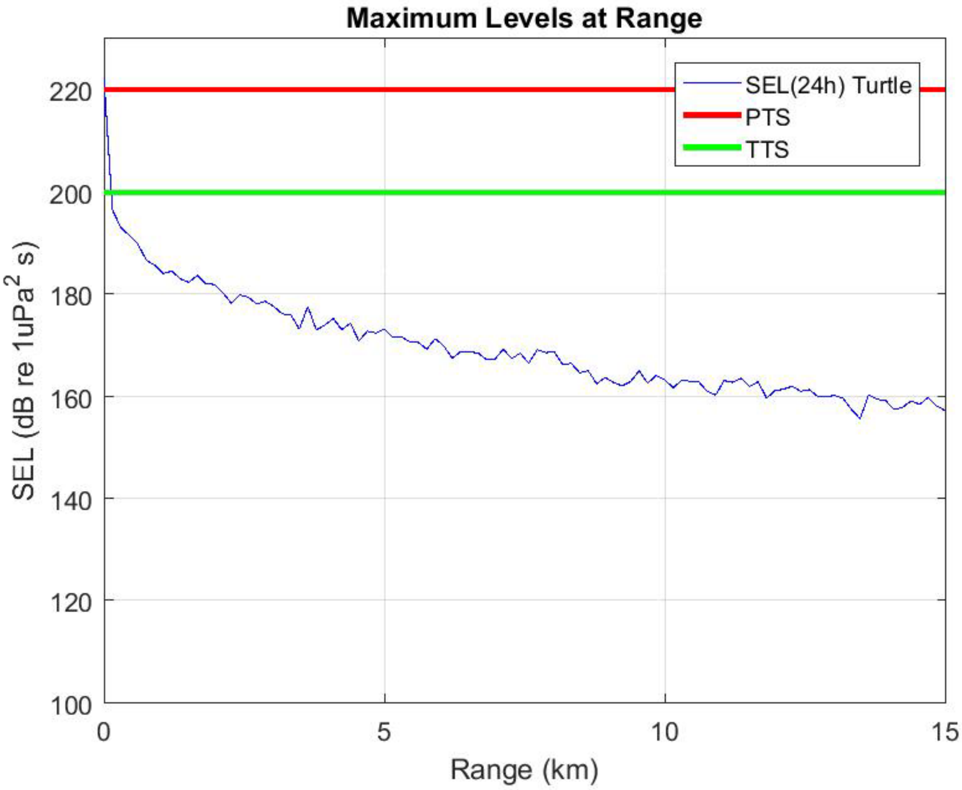

Figure 7-83 : MSL TSHD Location 2 maximum cumulative SEL with distance for Turtles

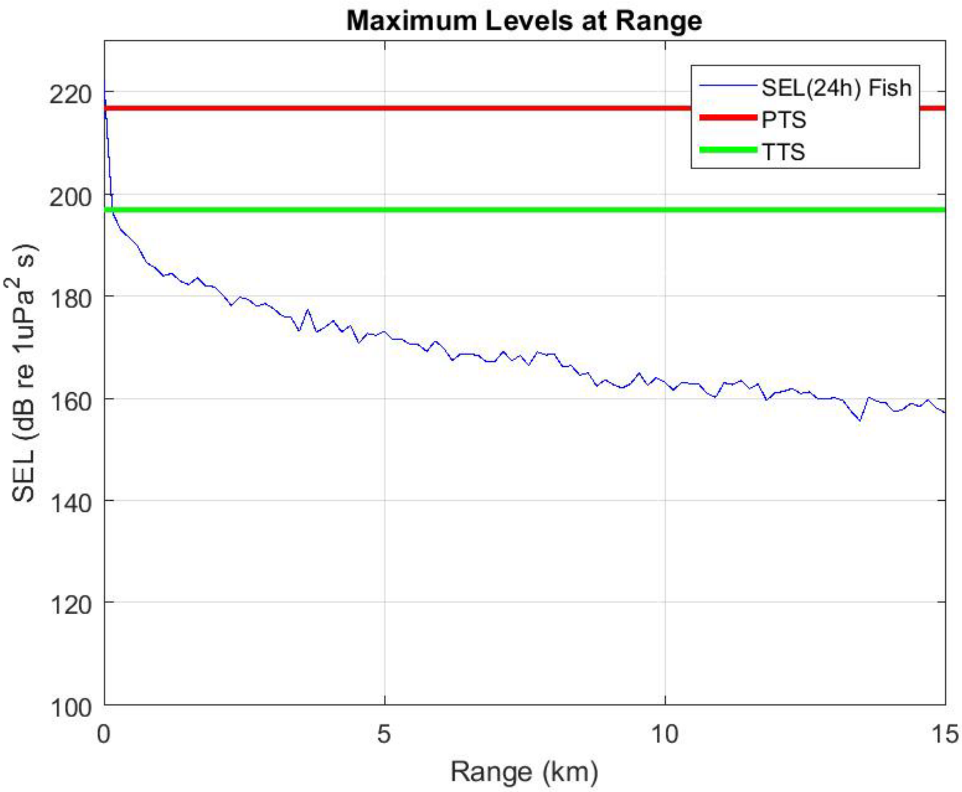

Figure 7-84 : MSL TSHD Location 2 maximum cumulative SEL with distance for Fish

D.4 Location 3 – TSHD

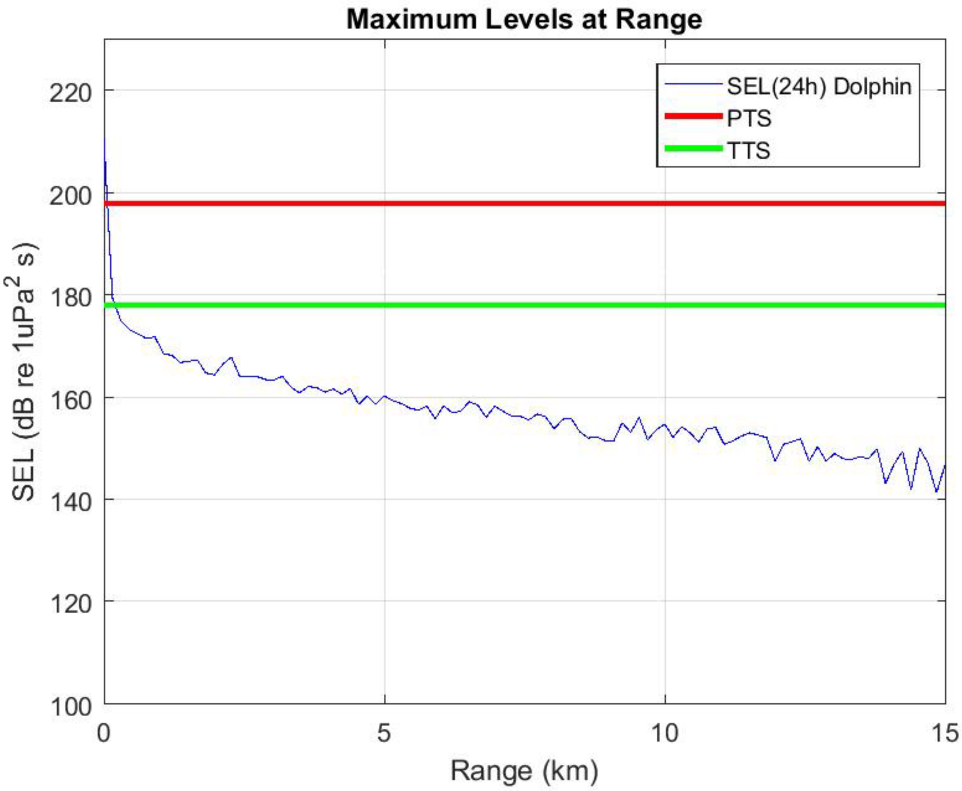

Figure 7-85 : MSL TSHD Location 3 maximum cumulative SEL with distance for Dolphin

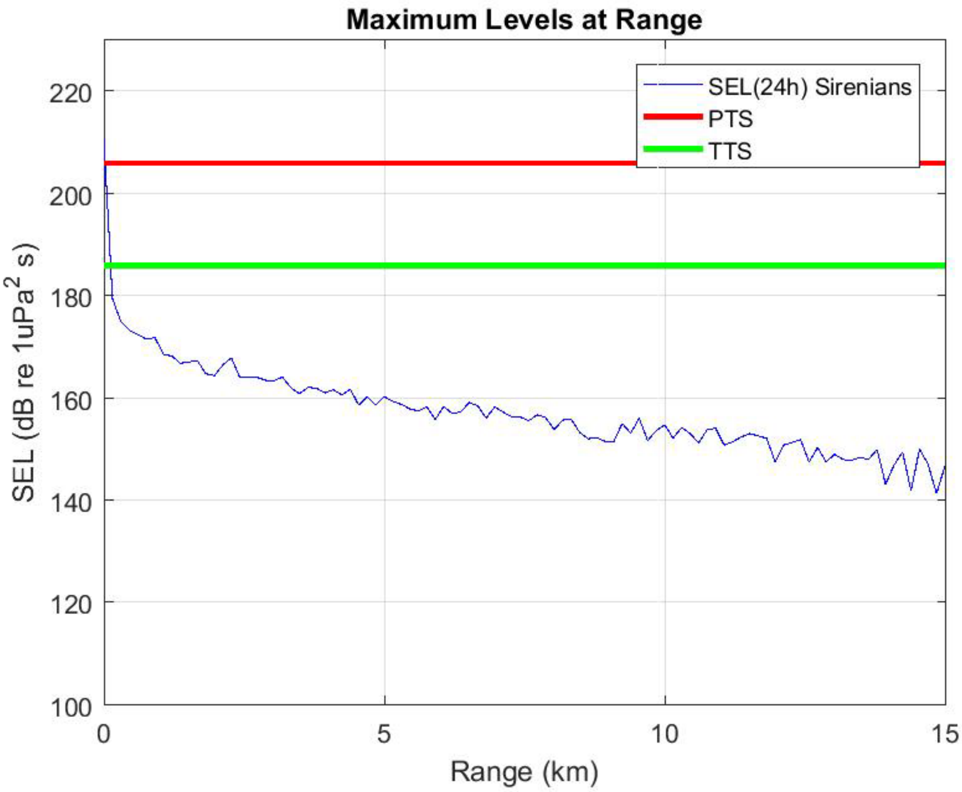

Figure 7-86 : MSL TSHD Location 3 maximum cumulative SEL with distance for Dugongs

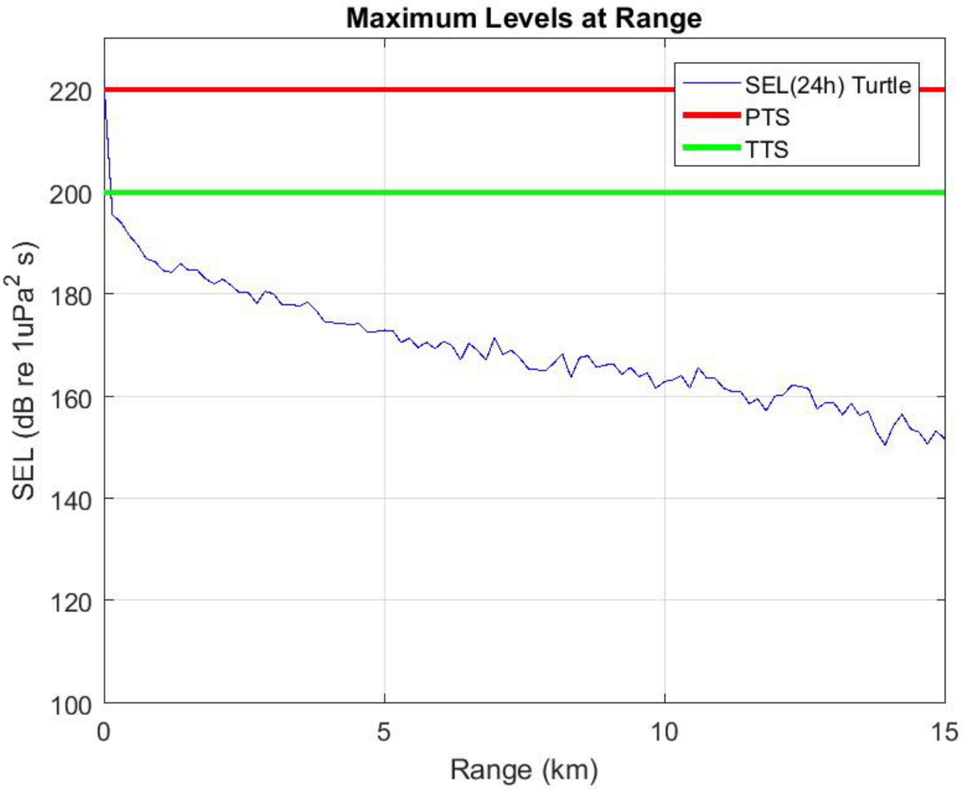

Figure 7-87 : MSL TSHD Location 3 maximum cumulative SEL with distance for Turtles

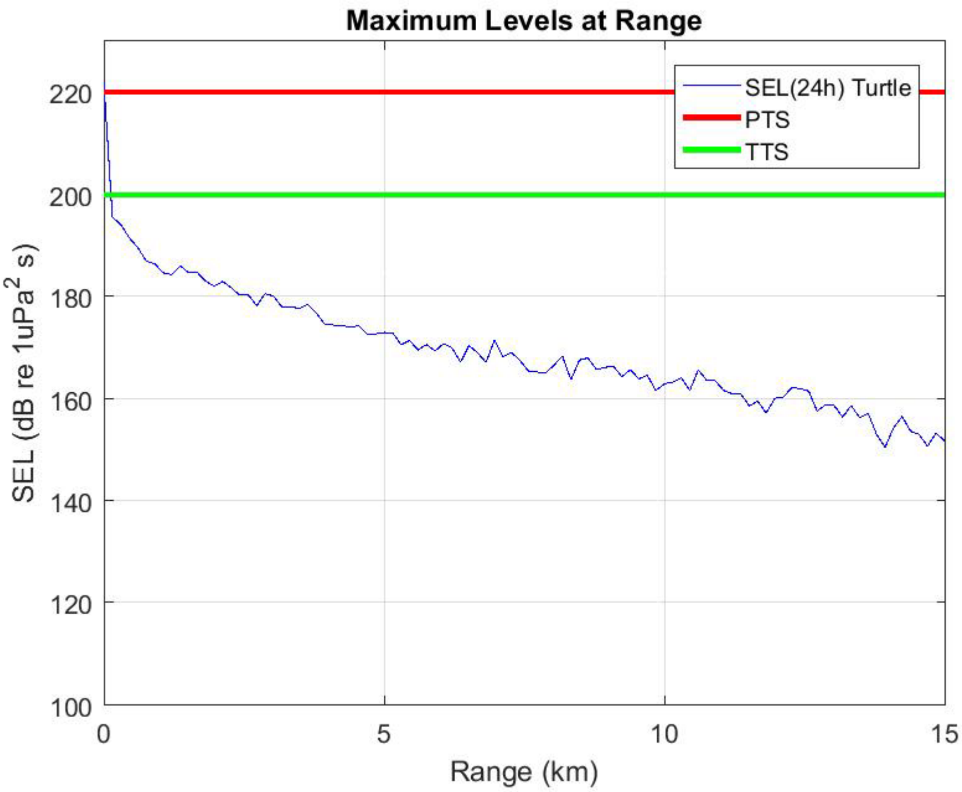

Figure 7-88 : MSL TSHD Location 3 maximum cumulative SEL with distance for Fish

D.5 Location 3 – Cumulative – TSHD and CSD

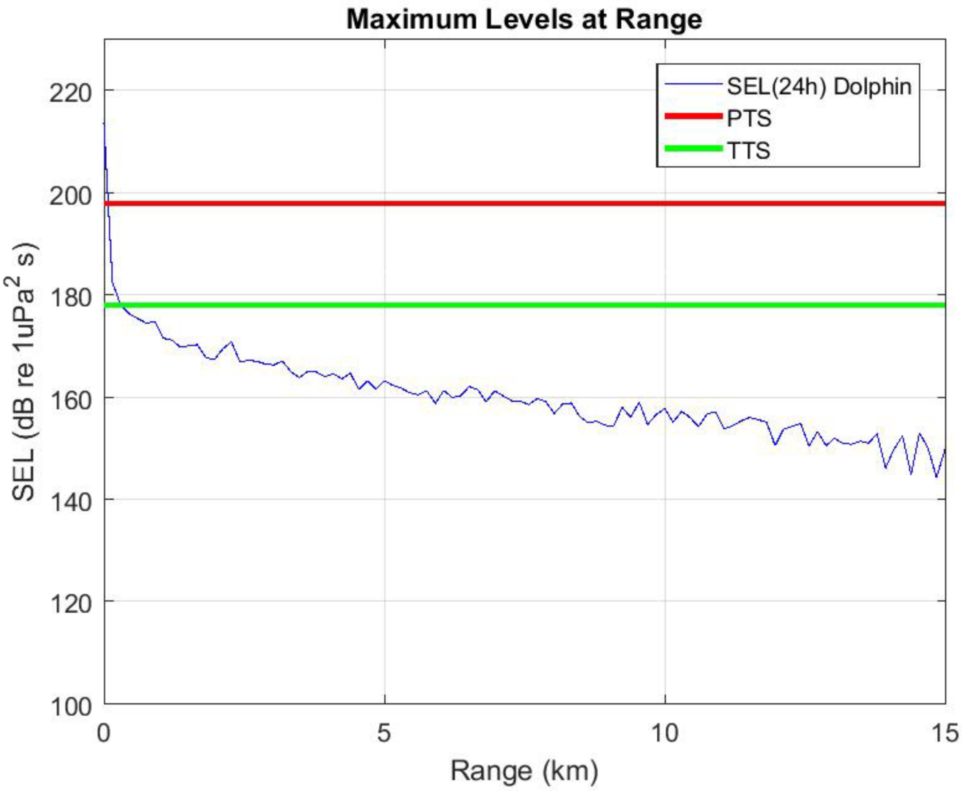

Figure 7-89 : MSL TSHD and CSD Location 3 maximum cumulative SEL with distance for Dolphin

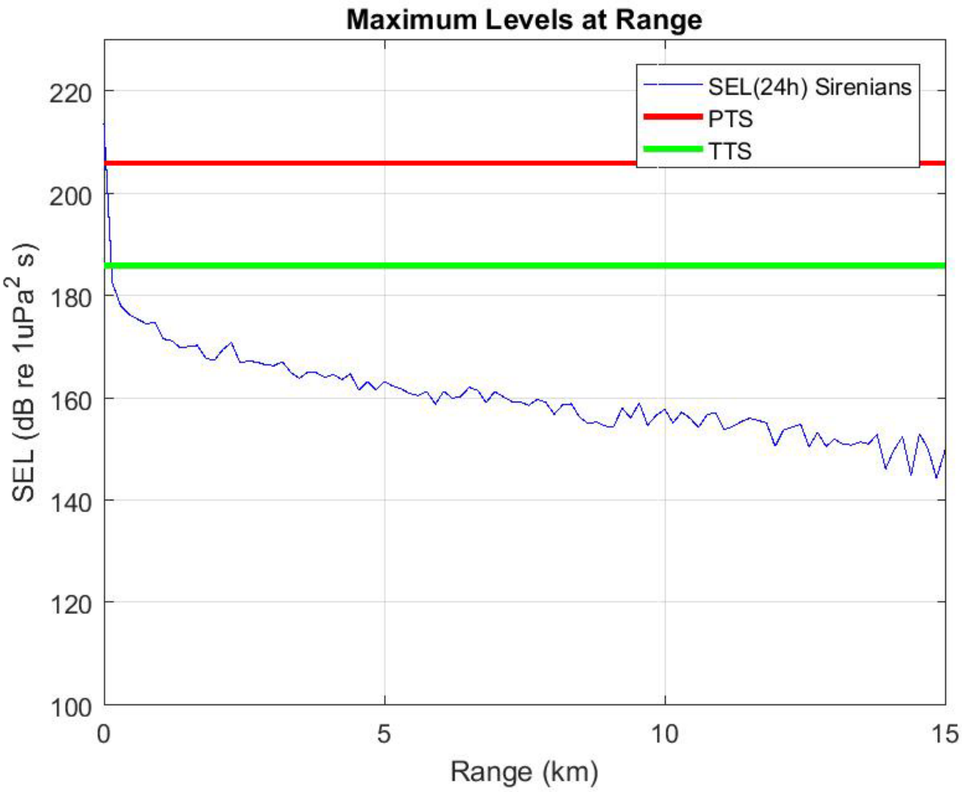

Figure 7-90 : MSL TSHD and CSD Location 3 maximum cumulative SEL with distance for Dugongs

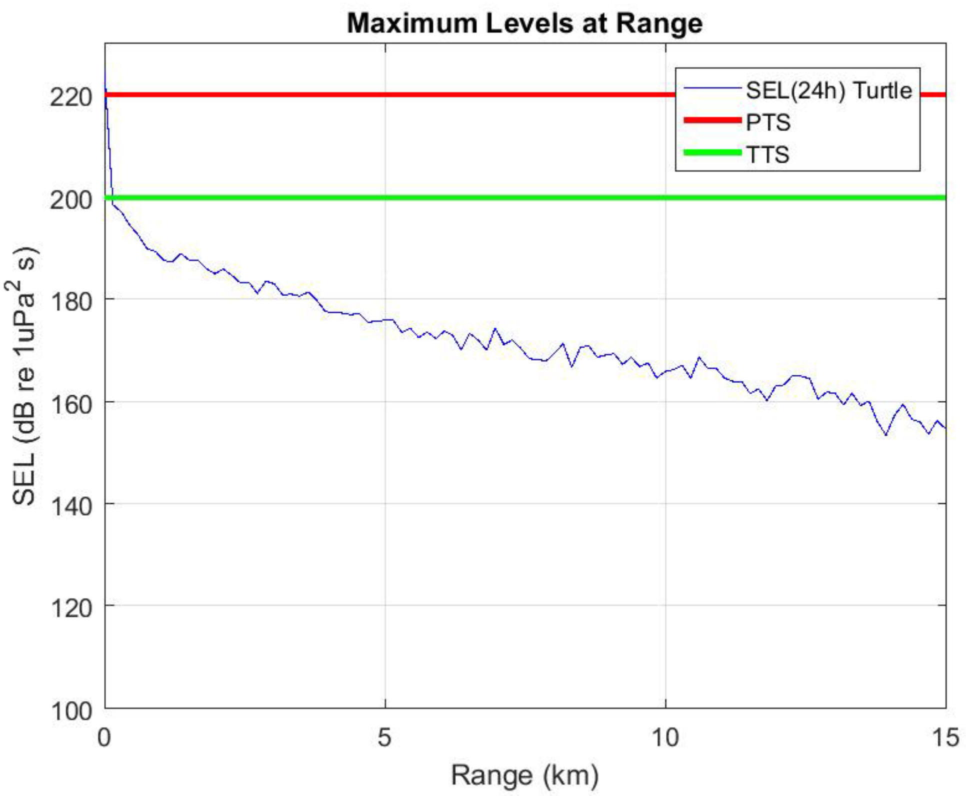

Figure 7-91 : MSL TSHD and CSD Location 3 cumulative SEL with distance for Turtles

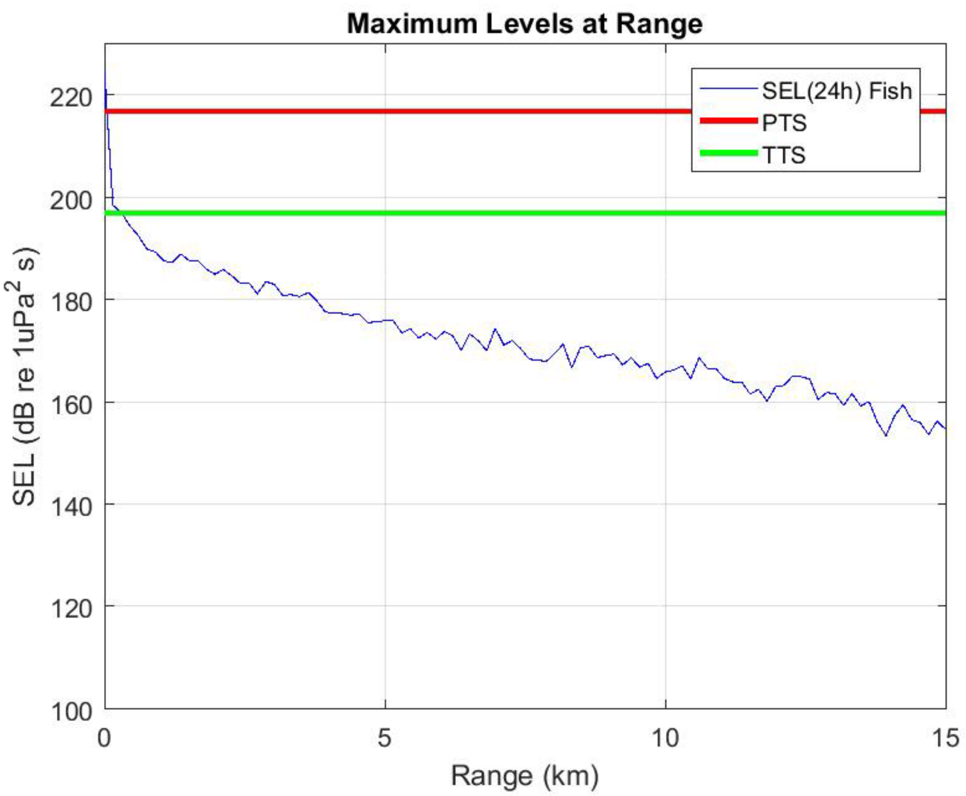

Figure 7-92 : MSL TSHD and CSD Location 3 maximum cumulative SEL with distance for Fish

D.6 Location 4 – Sheet Pile Driving (Mud Flat)

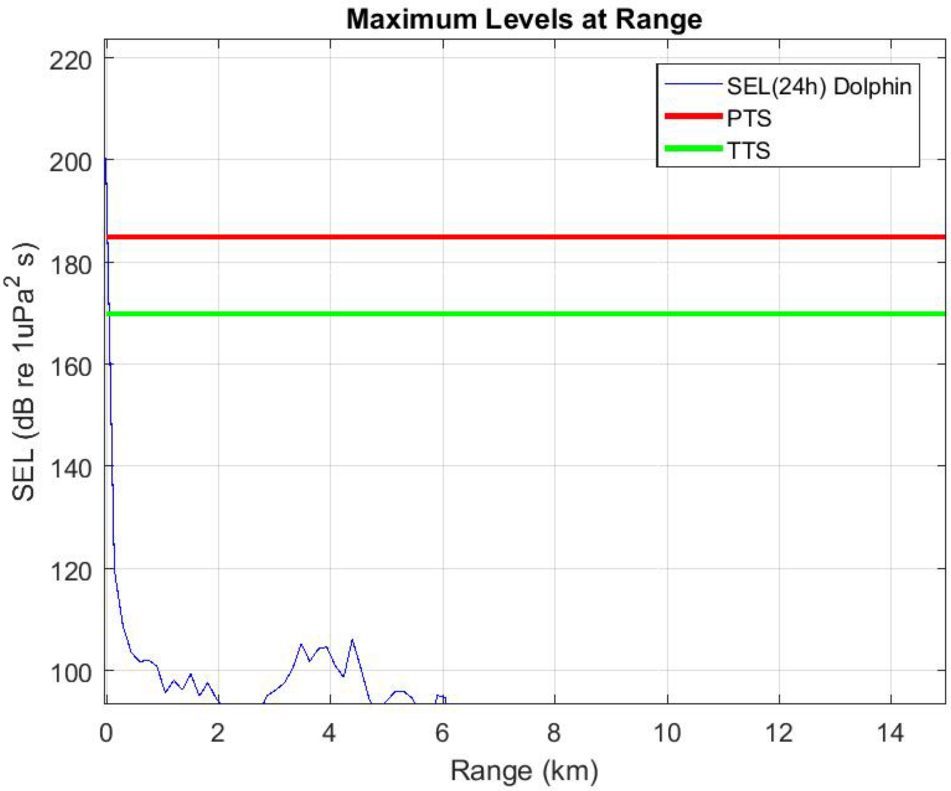

Figure 7-93 : Sheet Pile Driving maximum SEL with distance for Dolphins

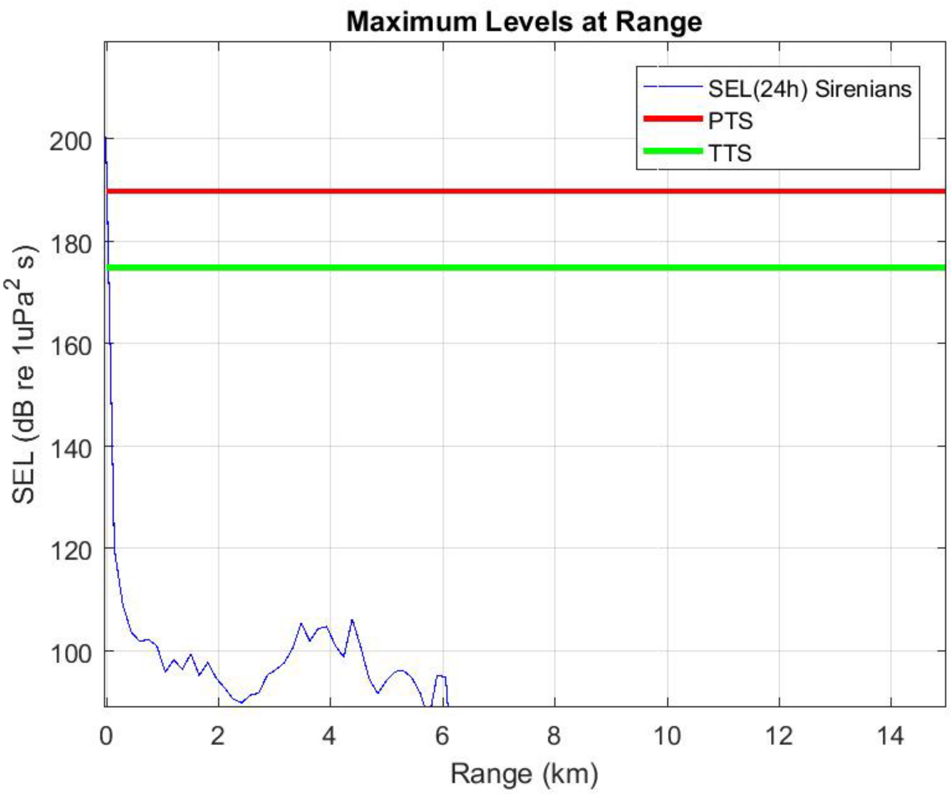

Figure 7-94 : Sheet Pile Driving maximum SEL with distance for Dugongs

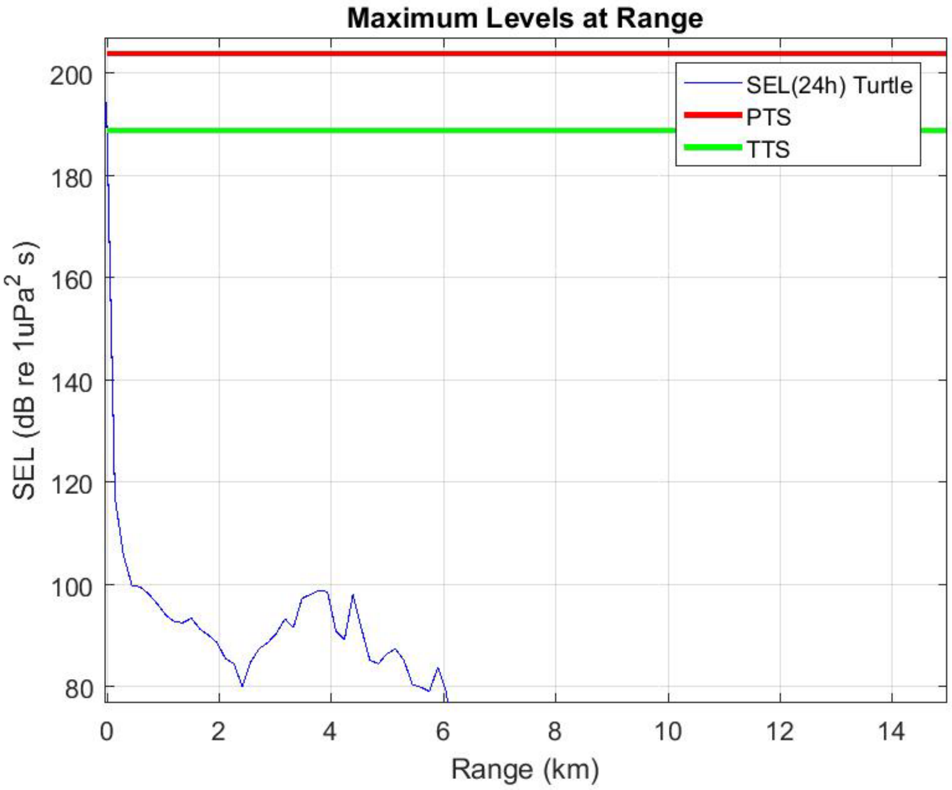

Figure 7-95 : Sheet Pile Driving maximum SEL with distance for Turtles

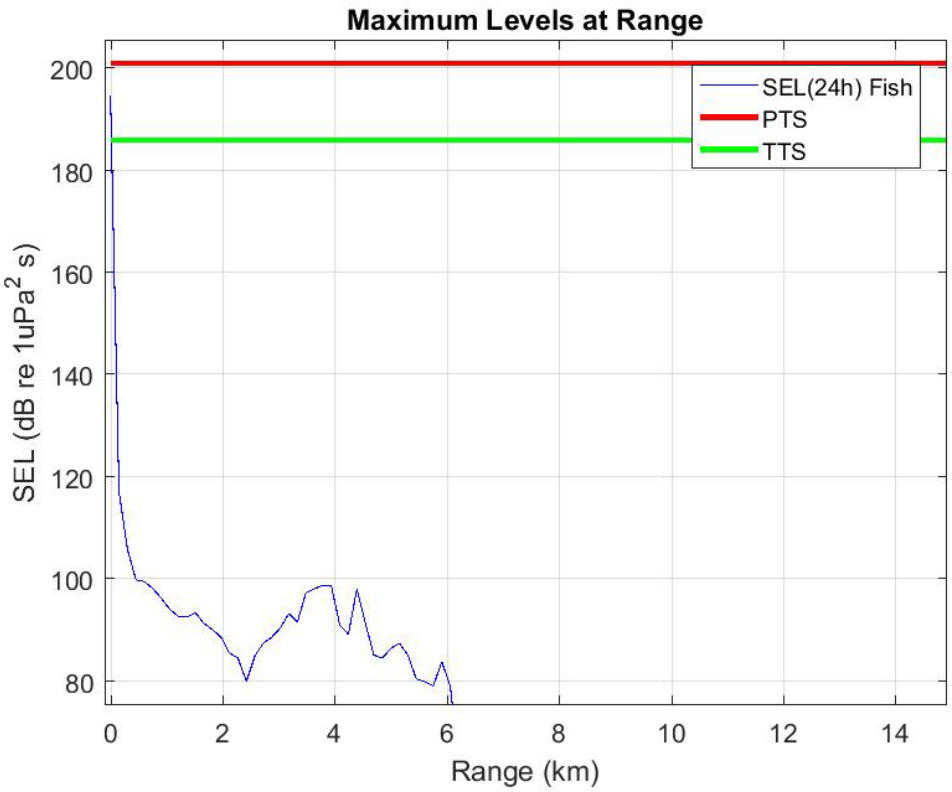

Figure 7-96 : Sheet Pile Driving maximum SEL with distance for Fish

APPENDIX E
Behavioural Ranges

E.1 Location 1 – BHD (Digging)

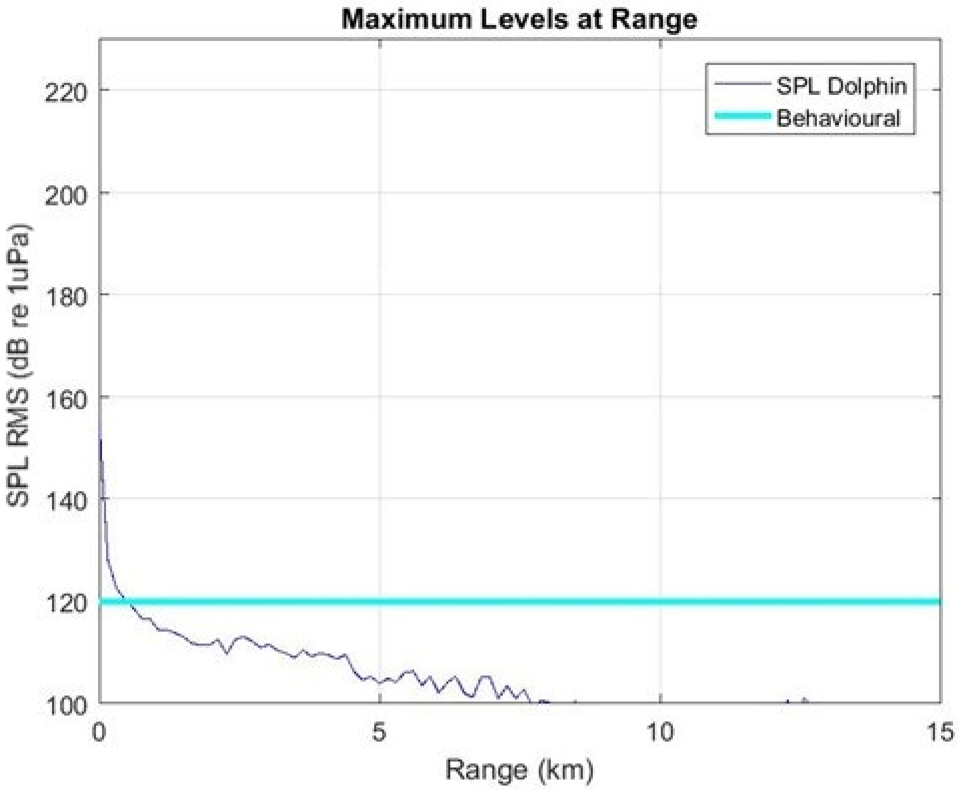

Figure 7-97 : MSL BHD (Digging) Location 1 maximum behavioural distance for Dolphin

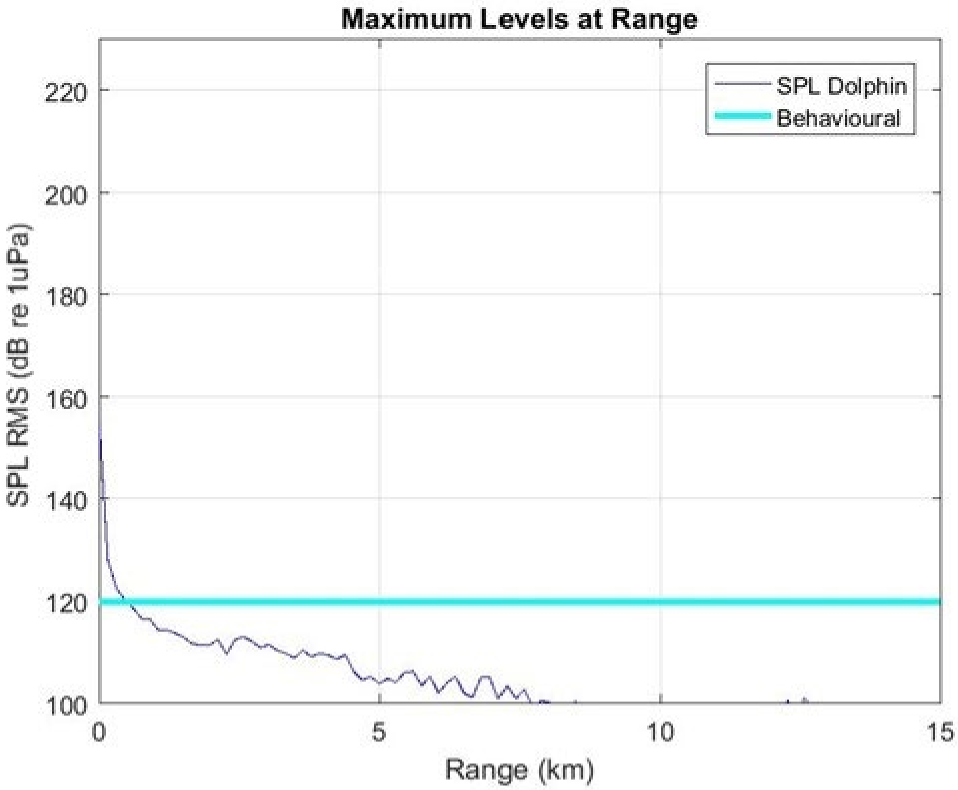

Figure 7-98 : MSL BHD (Digging) Location 1 maximum behavioural distance for Dugongs

E.2 Location 1 – BHD with Hydraulic Hammer

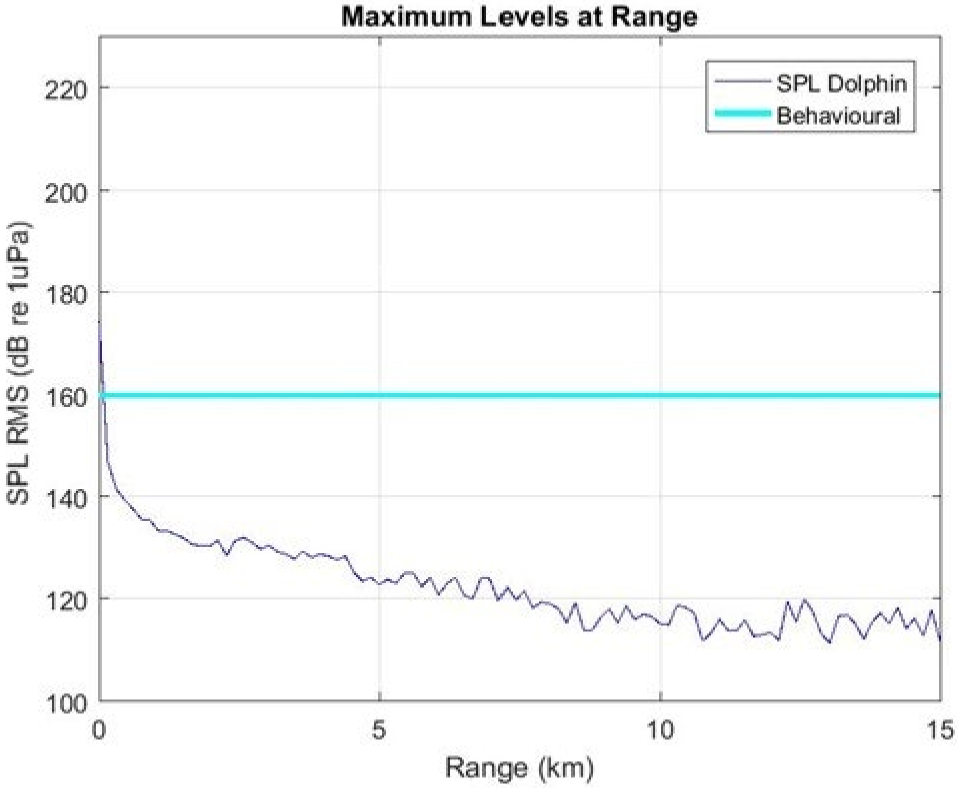

Figure 7-99 : MSL BHD (Hydraulic Hammer) Location 1 maximum behavioural distance for Dolphin

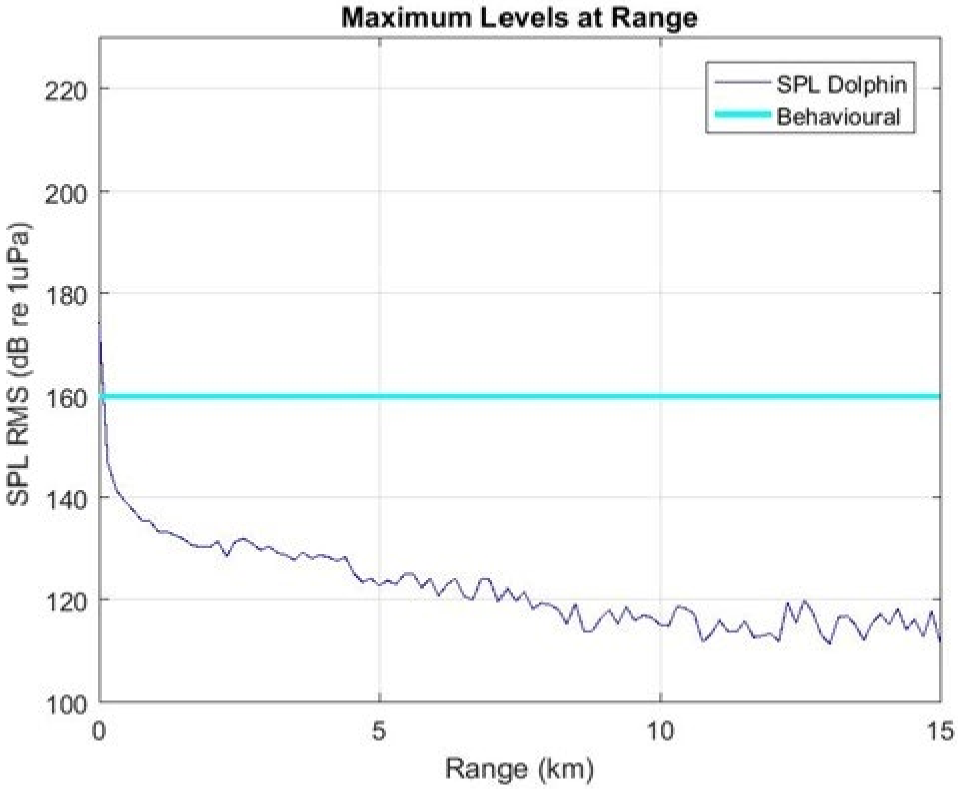

Figure 7-100 : MSL BHD (Hydraulic Hammer) Location 1 maximum behavioural distance for Dugongs

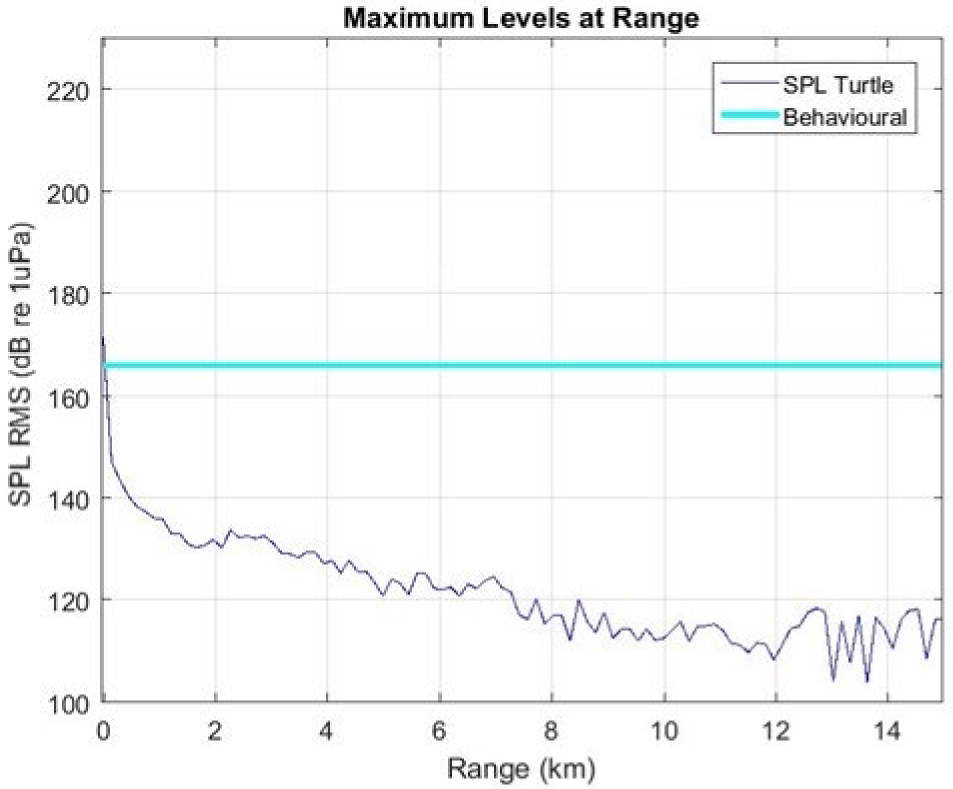

Figure 7-101 : MSL BHD (Hydraulic Hammer) Location 1 maximum behavioural distance Turtles

E.3 Location 2 – TSHD

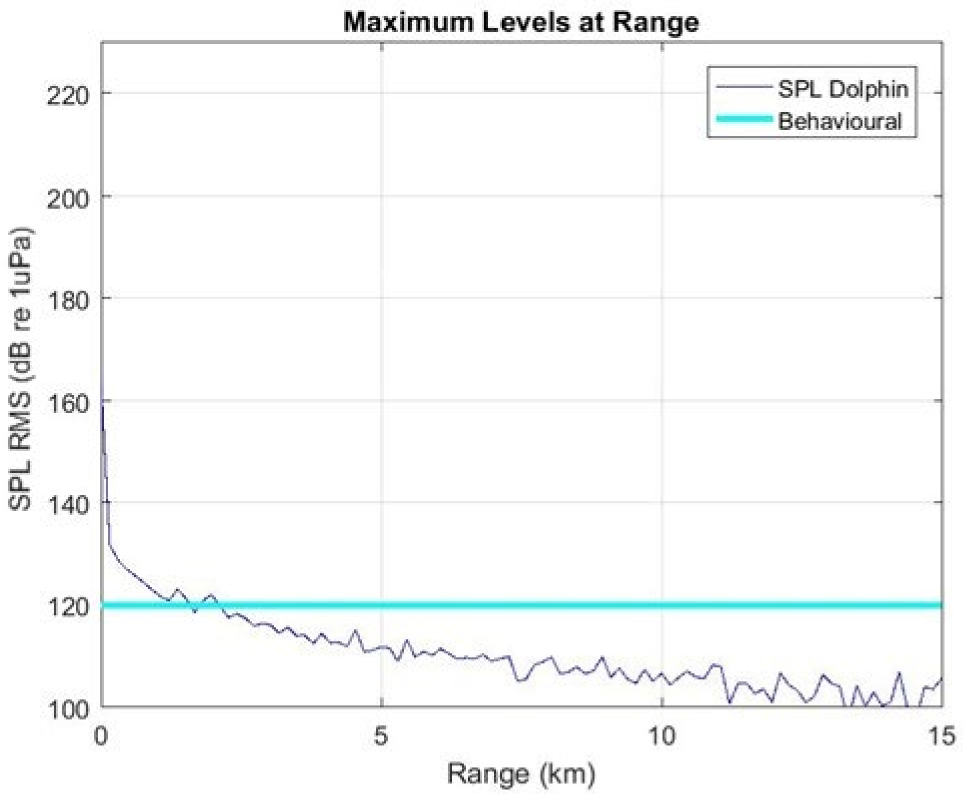

Figure 7-102 : MSL TSHD Location 2 maximum behavioural distance for Dolphin

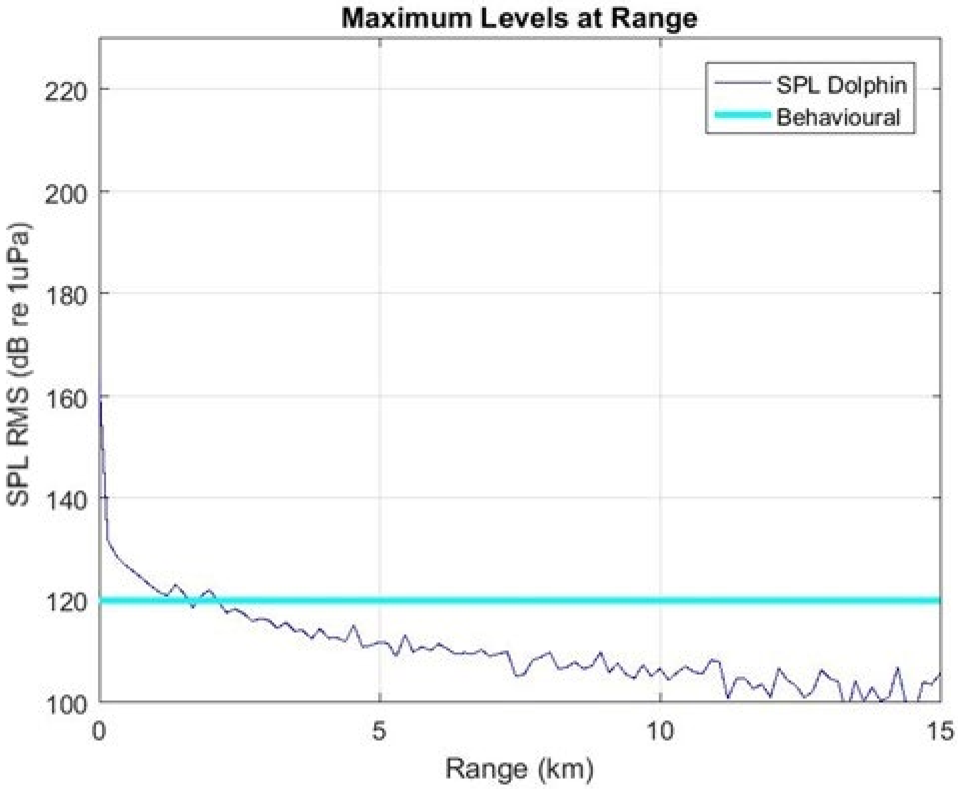

Figure 7-103 : MSL TSHD Location 2 maximum behavioural distance for Dugongs

E.4 Location 3 – TSHD

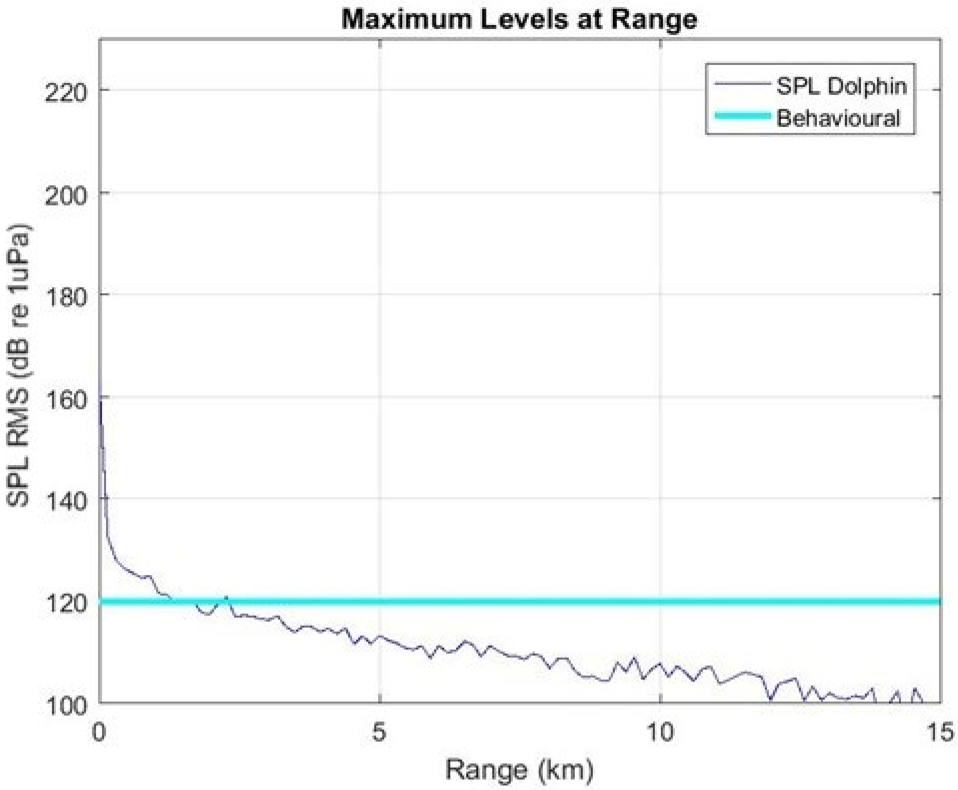

Figure 7-104 : MSL TSHD Location 3 maximum behavioural distance for Dolphin

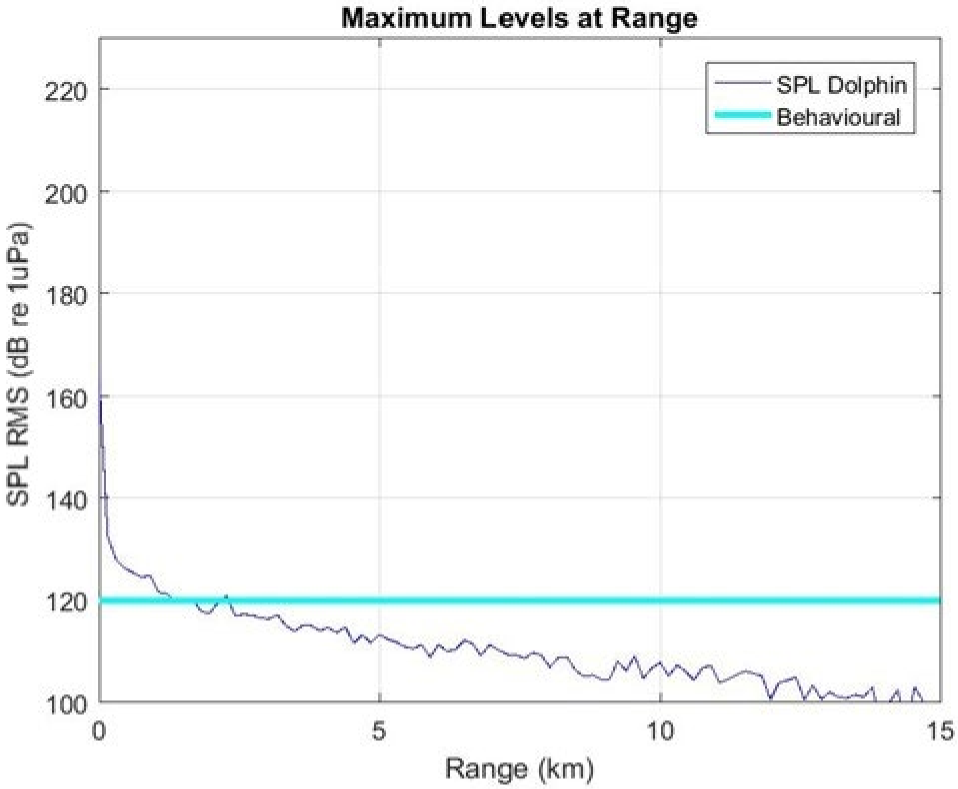

Figure 7-105 : MSL TSHD Location 3 maximum behavioural distance for Dugongs

E.5 Location 3 – Cumulative – TSHD and CSD

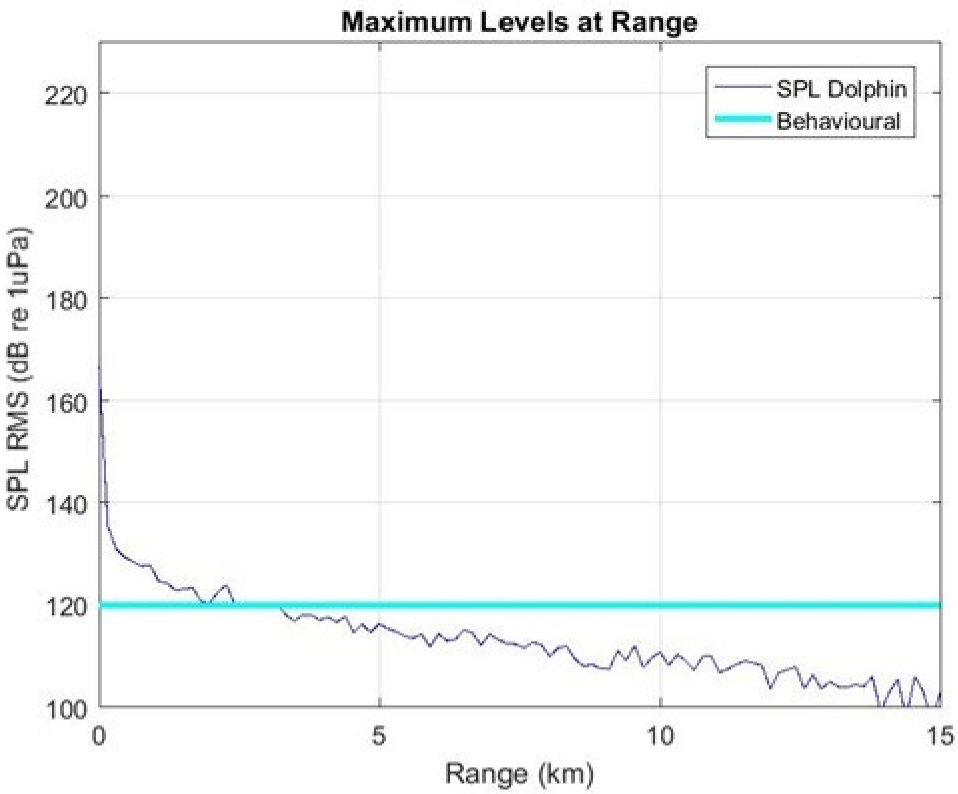

Figure 7-106 : MSL TSHD and CSD Location 3 maximum behavioural distance for Dolphin

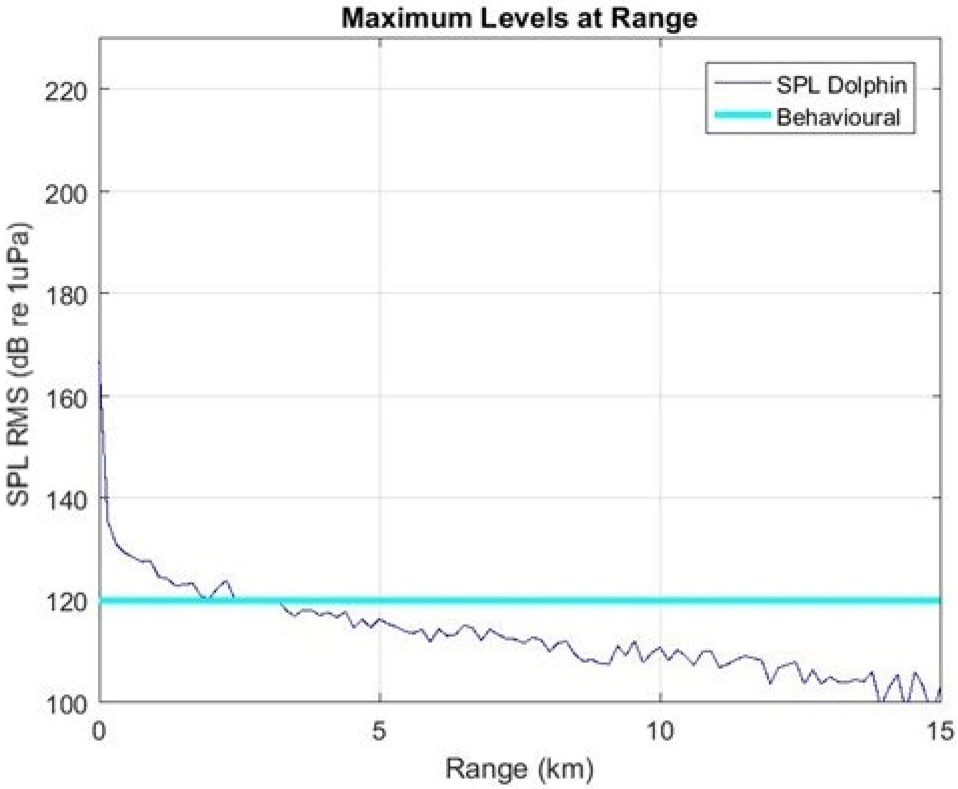

Figure 7-107 : MSL TSHD and CSD Location 3 maximum behavioural distance for Dugongs

E.6 Location 4 – Sheet Pile Driving (Mud Flats)

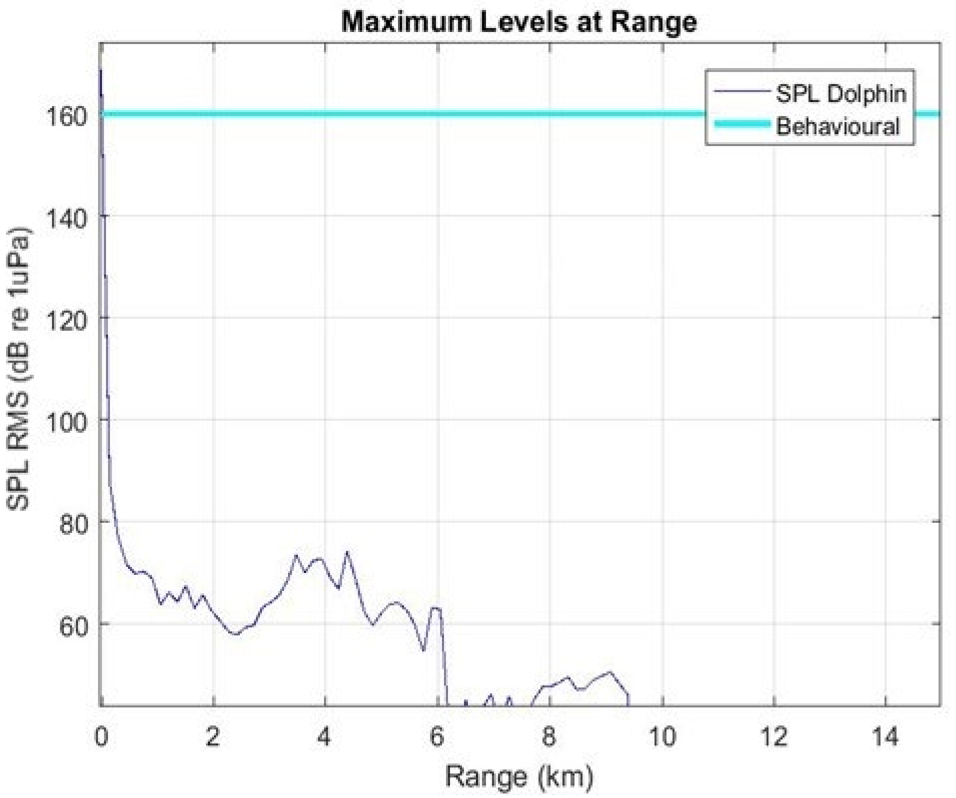

Figure 7-108 : Sheet Pile Driving behavioural distance for Dolphins

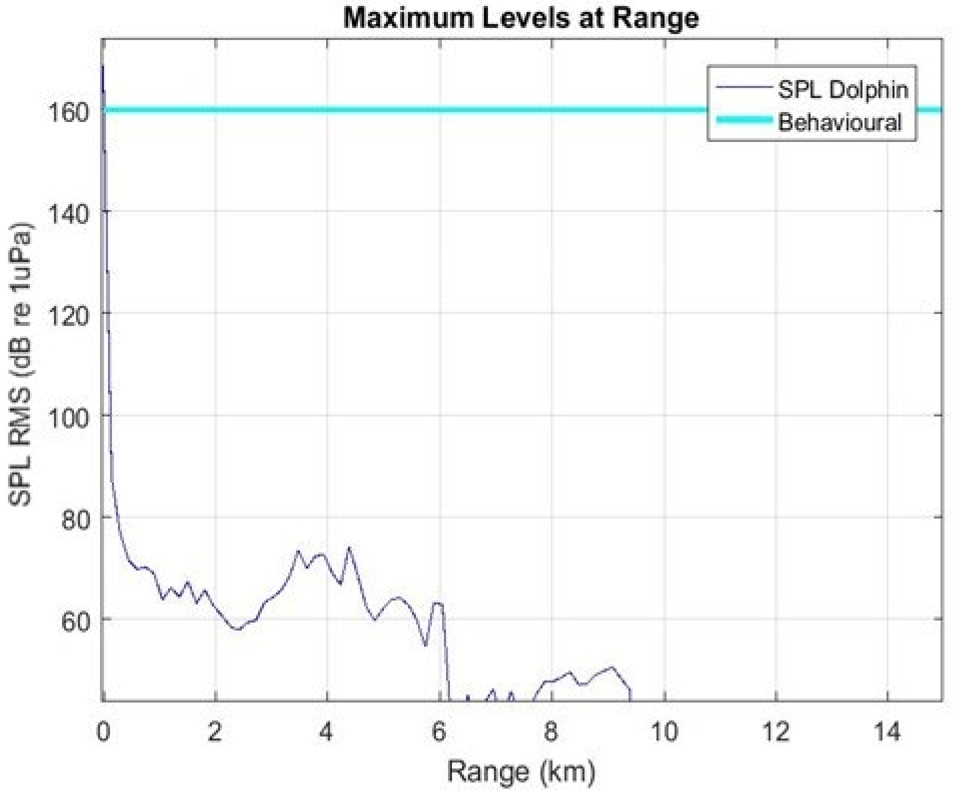

Figure 7-109 : Sheet Pile Driving behavioural distance for Dugongs

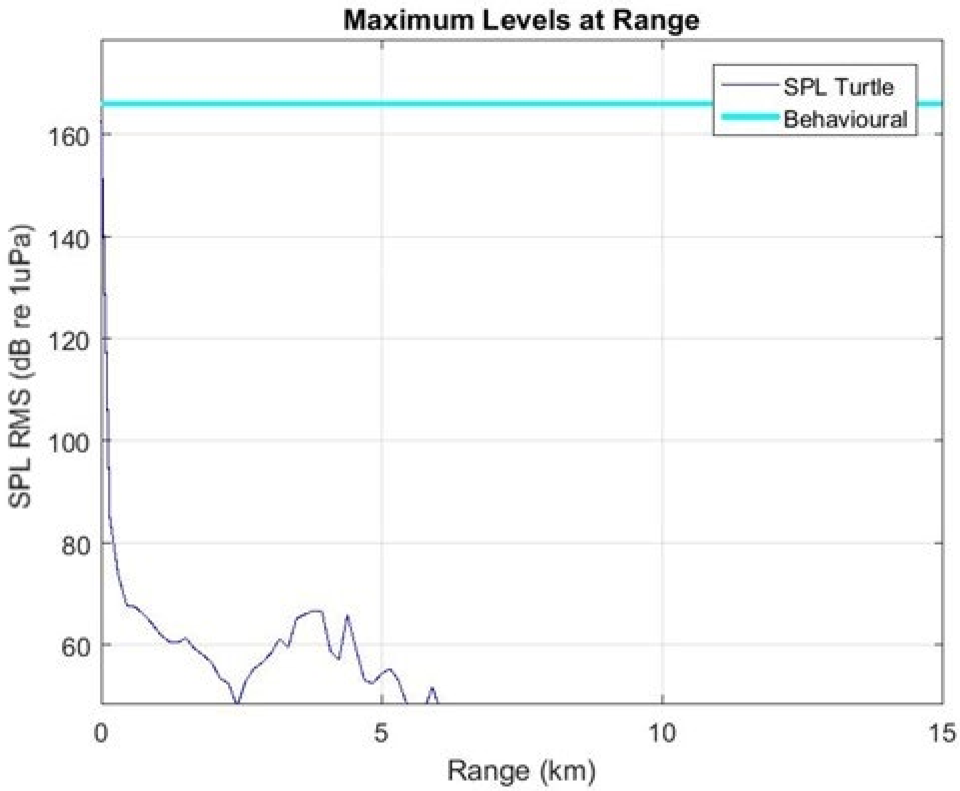

Figure 7-110 : Sheet Pile Driving behavioural distance for Turtles

APPENDIX F

Summary of Auditory Weighting and Exposure Function Parameters

Note: All of the following equations use SI units: Pascals, metres, seconds, and kilograms. For clarity, units are not included in every equation and constant.

Hearing Group	a	b	f_1 (kHz)	f_2 (kHz)	C (dB)	K (dB)
Low-frequency (LF) cetaceans	1.0	2	0.2	19	0.13	179
High-frequency (HF) cetaceans	1.6	2	8.8	110	1.20	177
Very High-frequency (HF) cetaceans	1.8	2	12	140	1.36	152

* Equations associated with Technical Guidance's auditory weighting ($W_{aud}(f)$) and exposure functions ($E_{aud}(f)$):

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

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

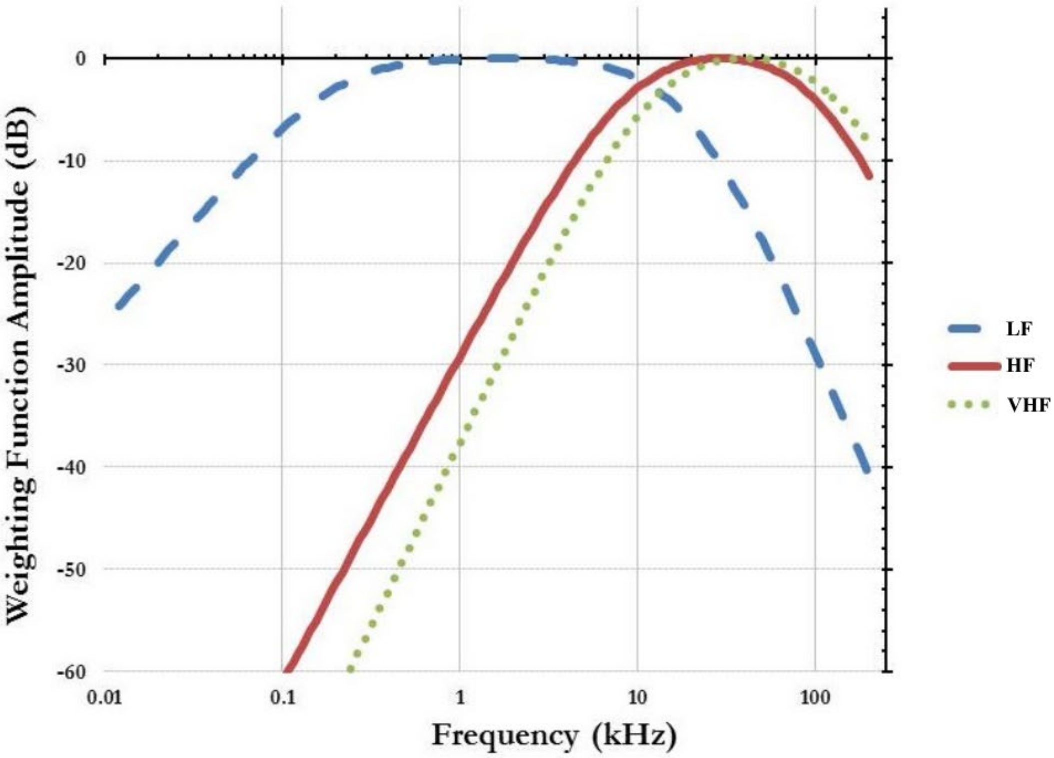

Figure 7-115: Hearing Sensitivity Curves for Cetaceans

Functional Hearing Group	K	a (Hz)	b (Hz)
Sea Turtles	0	10	2,000

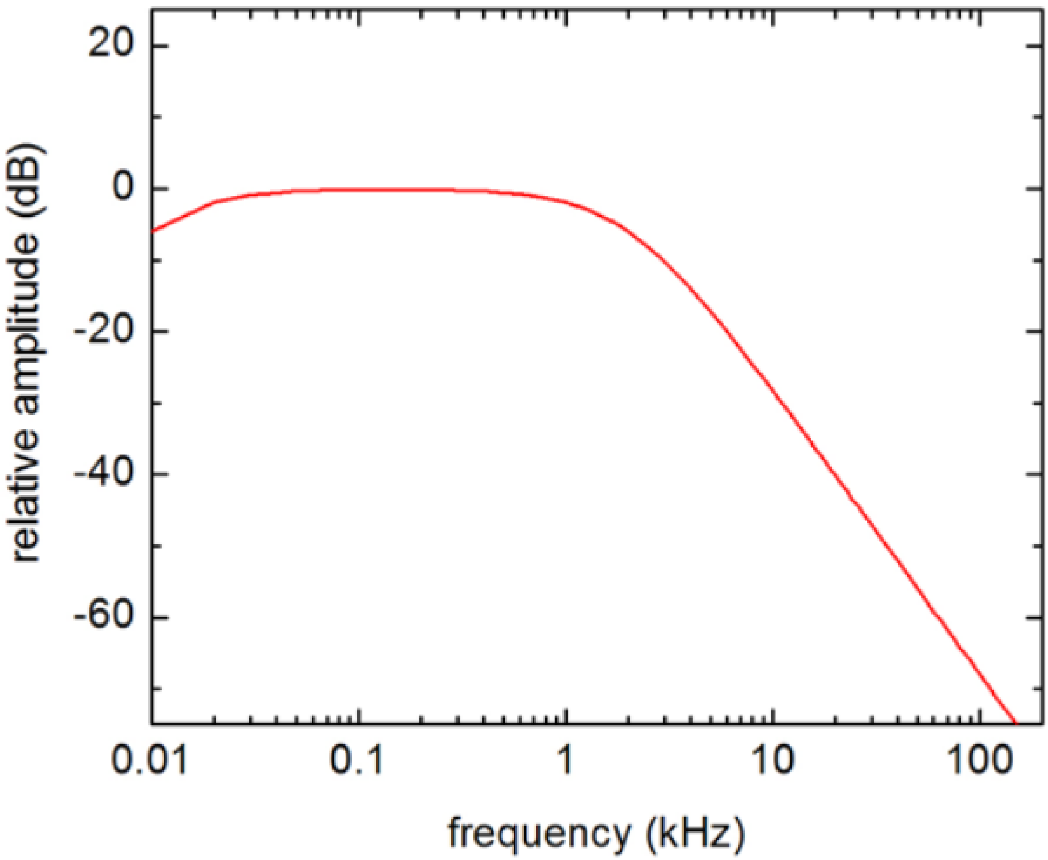

Figure 7-116: Hearing Sensitivity Curve for Turtles

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