Appendix 25

Assessment of Underwater Noise Effects

Styles Group
Underwater Acoustics

ASSESSMENT OF UNDERWATER NOISE EFFECTS

PERCUSSIVE PILE DRIVING AND CAPITAL DREDGING

PREPARED FOR

Northport Limited

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Executive summary

Northport Limited has engaged Styles Group to undertake an underwater acoustic assessment to inform resource consent applications involving reclamation at the eastern end of the current port, the creation of additional berthage and associated dredging activities (**the project**).

This report describes the methods and outputs of the underwater noise modelling and compares them with recognised international guidelines for noise effects in marine species. This information has then been used to inform the marine ecology and marine mammal impact assessment by Coast & Catchment and Cawthron Institute, respectively. This report does not provide any discussion of effects associated with underwater noise but instead establishes an information basis for the reports from Coast & Catchment and Cawthron. Management recommendations for protecting marine mammal species are also contained entirely within the reports from Cawthron.

Noise criteria

We have adopted the thresholds set out in the marine mammal acoustic technical guidance (revised in 2018) from the National Marine Fisheries Service of the U.S. Department of Commerce. This guidance has been extensively used around New Zealand and the world for underwater noise assessments. In the absence of specific guidance on underwater noise effects criteria in New Zealand, the adoption of overseas standards and peer-reviewed research is common.

For fish, we relied on the 2014 American National Standards Institute (ANSI) accredited guidelines for injuries that could lead to fatality and hearing loss. Those are the two noise-related impacts that current research can reliably link to negative effects on an individual or population net fitness.

Types of noise thresholds and species assessed

Permanent threshold shift (**PTS**), temporary threshold shift (**TTS**), risk of various behavioural responses, auditory masking and overall audibility were assessed (i.e., modelled) for a range of species. Threshold shifts are changes in hearing thresholds following some noise exposure and can either be temporary (i.e., return to normal hearing after a period of time) or permanent (i.e., hearing never returns). Specifically, bottlenose dolphins, common dolphins, killer whales, Bryde’s whales, New Zealand fur seals and leopard seals were investigated.

Fishes were assessed as two key groups: fish with swim bladders and fish without swim bladders. The distinction between these groups was made because the effects thresholds differ between. The assessment was done in the context of 6 months of ambient sound data from the area.

Results for marine mammals

No risk for permanent hearing loss (PTS) was identified from capital dredging. No risk for TTS beyond 1m is expected for marine mammals exposed to noise from the dredging using either a trail-suction hopper dredger (**TSHD**), a cutter-suction dredger (**CSD**) or backhoe dredger (**BHD**) in this case.

The modelling suggests that there is a risk for PTS occurring for dolphin species (within 26m), leopard seals (145m) and baleen whales, such as Bryde's whales (475m) during percussive piling. There is also a risk of TTS for all marine mammal species investigated within a maximum range of 1348m (for Bryde's whales) and a minimum range of 111m (for NZ fur seals). Dolphin species (including killer whales) will be at risk of TTS to some degree within 183m from the percussive piling source. Leopard seals will be at risk of TTS onset within 765m.

Low severity behavioural changes in marine mammals may occur during the percussive piling within 2047m. The risk for more severe behavioural effects occurring in marine mammals is within 969m. The ranges within which behavioural effects may occur are smaller for the capital dredging. There is a 50% risk of low severity behavioural responses occurring within 1055m for Bryde's whales and 451m for dolphin species. Behavioural response risks for any marine mammal are not expected beyond 1635m.

Auditory masking effects may occur within a maximum range of 2914m from the percussive piling source. This is based on the leopard seal which is the most sensitive to auditory masking of all species investigated. However, more than 50% of an animal's listening space[1] will be reduced within approximately 1397m (leopard seal), 1334m (fur seal), 1295m (bottlenose or common dolphin), 1279m (killer whales) or 1983m (Bryde's whale) from the percussive-piling source.

Auditory masking effects from the capital dredging are also expected but over smaller ranges than for the percussive piling. For example, the maximum range within which leopard seal's listening space begins to reduce is 1190m, 578m or 591m when exposed to noise from an operating TSHD, CSD or BHD, respectively.

Results for fish

No risk for TTS beyond 1m is expected for fishes exposed to noise from the capital dredging in this case.

The modelling suggests that fishes with swim bladders risk recoverable injury if within 78m of percussive piling. Fishes without swim bladders may be exposed to that same risk of injury within 40m of the full-power percussive piling. Risk for the potential onset of TTS in all fishes (regardless of their anatomy) may occur within a conservative 317m of the full-power

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[1] In simple terms, the area within which the animal can hear a biologically important sound signal.

percussive piling. These distances assume minimal movement of fishes during their exposure to piling noise.

Overall Conclusion

The reclamation and associated works at the eastern end of Northport will expose marine mammals and fish to acoustic-related disturbances that are either physiological or behavioural. Those risks are highest for the percussive piling but will occur over a limited range and not extend beyond the harbour entrance.

1.0 Introduction

Styles Group has been engaged by Northport Limited (**NPL**) to undertake an underwater acoustic assessment of the proposed construction works associated with reclamation at the eastern end of the current port, the creation of additional berthage and associated dredging activities (**the project**).

This report should be read in conjunction with the application site plans, the Assessment of Environment Effects (**AEE**), the Assessment of Effects on Marine Mammals prepared by the Cawthron Institute (Clement 2022) and Coast & Catchment (Kelly & Sim-Smith 2022). A glossary of acoustical terms used within this document is attached as Appendix A.

2.0 The project

NPL is proposing to expand its existing facilities to increase its freight storage and handling capacity to support the future freight needs of the upper North Island.

The specific construction activities investigated in this report are:

- Capital dredging to enlarge and deepen the existing swing basin and to enable construction of the new 520m long wharf (including the consented, but not yet constructed 270m long Berth 4) on the northern face of the proposed reclamation (**the reclamation**).
- Sheet piling on the eastern edge of the proposed reclamation.
- Construction of a new tug jetty.

NPL is seeking resource consents to authorise works for the project.

From an underwater noise perspective, the proposed percussive piling and capital dredging works are the two construction activities that pose the highest risk to marine animals. This advice provides a specific assessment of those activities to inform the determination of the appropriate mitigation strategies by the relevant technical specialists.

A full description of the project is provided in the AEE.

2.1 Potential noise receivers

Cawthron have identified six specific marine mammal species as occurring more commonly along the Whangarei coastline and therefore more likely to be affected by the project (Clement 2022). Those species are bottlenose dolphins, common dolphins, killer whales, Bryde's whales, New Zealand fur seals and leopard seals. Several offshore species (Humpback whales, southern right whales, pilot whales, sperm whales, false killer whales and blue whales) were also identified, although their occurrence inside the Whangarei Harbour are far more unlikely. All the offshore species fall under the same M-weighted thresholds as the six commonly occurring species.

Several species of fish and invertebrates occur within the Whangarei Harbour entrance (Kelly & Sim-Smith 2022). This assessment considers the impacts on fishes with and without swim bladders.

Invertebrates have not been specifically considered in this assessment because of the lack of noise exposure guidelines.

2.2 Scope of this assessment

The purpose and scope of this underwater noise assessment is to:

i. Model the underwater piling and dredging noise associated with the reclamation.

ii. To assess the potential extent of hearing threshold shifts (both permanent and temporary), behavioural responses and auditory masking in marine mammals

iii. To assess the potential extent of hearing threshold shifts and injury in fishes.

This assessment has been prepared to inform the assessment of effects on fish and marine mammals, respectively undertaken by Coast & Catchment (the **Coast & Catchment Assessment**) and the Cawthron Institute (the **Cawthron Assessment**).

The Coast & Catchment Assessment and Cawthron Assessment considers the results from the acoustic modelling and impact zones in the context of available literature, their respective qualifications and experience, and the relevant objectives and policies of the Regional Coastal Plan. These assessments also provide recommendations on the appropriate monitoring and mitigation methods.

3.0 Underwater noise and effects modelling

We prepared underwater noise models of the Whangarei harbour entrance, centred around Northport. Figure 1 displays the extent of the modelled area.

A full technical discussion of the methodology for the underwater noise modelling, including details on the source levels, propagation models and environmental inputs is set out in Appendix D. We do not replicate that here, other than the brief summary below.

The key aspects of the modelling exercise include:

- Empirical source level data were used. Measurements were of 914mm steel piles being driven using a BSP HH16-1.2 hammer (percussive), 212 kJ/blow, up to 1700 strikes per day.

- The noise models incorporated bathymetry, sound speed and seafloor composition.

- The propagation modelling used a combination of parabolic equations and ray tracing in the modelling software dBSea.[2]

- The resulting noise contours were used to assess PTS, TTS, behavioural risks and auditory masking. General audibility ranges were also considered as the theoretical maximum area for which the potential onset of any noise impact, of any severity, may occur.

- Mortality, injury (both recoverable and permanent) and TTS were assessed for fishes exposed to the highest percussive-piling noise. Behavioural impacts and masking effects were not assessed because of the lack of data on the relationship between contextualised behavioural responses and corresponding noise levels for piling or dredging.

Figure 1: Map of the study area

The blue dotted line represents the extent of the underwater noise models.

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[2] dBSea is an advanced propagation modelling software by dBSea Ltd in the United Kingdom.

Please refer to Appendix D for further detail, including the criteria for the assessment of noise effects on marine mammals and fishes, along with the rationale for why certain impacts were assessed.

4.0 Results: marine mammals

This section sets out the noise modelling results for percussive piling and capital dredging using a TSHD, CSD and BHD, providing ranges for:

- Potential onset of permanent threshold shift (PTS) (percussive piling only).
- Potential onset of temporary threshold shift (TTS).
- Distances at which 75, 50, 25 and 0% listening space reduction (LSR) occurs for each the species of interest.
- Distances at which the potential onset of behavioural responses may occur.
- Distances within which audibility of the activity will be possible.
- Cumulative noise effects.

Appendix E provides contour maps for each activity.

4.1 Percussive piling

In this case, the cumulative SEL (***SELcum***) levels were above the peak (***Lpk***) levels for all functional hearing groups investigated. The *Lpk* levels are not reported on for this reason.

Table 6: Ranges for the potential onset of permanent threshold shift (PTS) for the four functional hearing groups of cetaceans.

Species	**Critical Range (m)**
Bryde's Whales (LF)	475
Killer Whales, Bottlenose Dolphins, Common Dolphins (MF)	26
Leopard Seals (PW)	145
Fur Seals (OW)	0

4.1.1 Temporary Threshold Shifts

In this case, the *SELcum* levels were above the *Lpk* levels for all functional hearing groups investigated. The *Lpk* levels are not reported on for this reason.

Table 7: Ranges for the potential onset of temporary threshold shift (TTS) for the four functional hearing groups of cetaceans.

Species	Critical Range (m)
Bryde's Whales (LF)	1348
Killer Whales, Bottlenose Dolphins, Common Dolphins (MF)	183
Leopard Seals (PW)	765
Fur Seals (OW)	111

4.1.2 Behavioural effects

Table 8: Distances at which the potential onset of behavioural responses may occur from the percussive piling.

The use of these two threshold values, their origin, and meaning are provided in the methods, contained in Appendix D.

Species	Threshold	
	140dB	**160dB**
All Species	2047m	969m

4.1.3 Auditory masking

Table 9: Distances at which 75, 50, 25 and 0% listening space reduction (LSR) occurs for of each the species of interest.

Species	**Critical Distance (m)**			
	75% LSR	**50% LSR**	**25% LSR**	**0%LSR**
Humpback Whale	171m	1065m	1983m	2851m
Killer Whale	330m	1279m	2040m	2828m
Bottlenose/Common Dolphin	402m	1295m	2204m	2782m
Fur Seal	619m	1334m	2232m	2841m
Leopard Seal	693m	1397m	2430m	2914m

4.1.4 Audibility ranges

Table 10: Distances within which audibility is possible

Species	Maximum Audibility Range (maximum)
Humpback Whale	3028m (5844m)
Killer Whale	2825m (5857m)
Bottlenose/Common Dolphin	3029m (5859m)
Fur Seal	3027m (5843m)
Leopard Seal	3020m (5847m)

4.2 Trail-suction-hopper dredging

4.2.1 Temporary Threshold Shifts

A noise model of the operation of the TSHD while dredging was prepared to understand the noise levels from the noisiest activities. The noise sources present during the TSHD operation are water pumps, engines, propellors, pipes and the draghead extracting sandy/gravel sediments.

Noise levels beyond 1m from the source are not expected to induce TTS within any of the functional hearing groups of marine mammals during dredging.

4.2.2 Behavioural effects

Table 11: Distances at which 75, 50, 25 and 0% risk of low and moderate behavioural responses for each of the species of interest may occur.

Species	Behavioural Response	Risk isopeth (m)			
		75%	**50%**	**25%**	**0%**
Killer Whale **Bottlenose Dolphin** **Common Dolphin**	Low (minor changes in respiration rates, swimming speeds/direction)	327	451	544	935
	Moderate (moderate to extensive changes in swimming speeds/direction and/or diving behaviours, moderate or prolonged cessation of vocalisations, and/or avoidance)	171	245	324	585

Table 11: Distances at which 75, 50, 25 and 0% risk of low and moderate behavioural responses for each of the species of interest may occur.

Bryde's Whale	Low (minor changes in respiration rates, swimming speeds/direction)	884	1055	1202	1635
Fur Seal **Leopard Seal**	Low (minor changes in respiration rates, swimming speeds/direction)	Potential Onset: 1033m			
	Moderate (moderate to extensive changes in swimming speeds/direction and/or diving behaviours, moderate or prolonged cessation of vocalisations, and/or avoidance)	Potential Onset: 461m			

4.2.3 Auditory masking

Table 12: Distances at which 75, 50, 25 and 0% listening space reduction (LSR) occurs for of each the species of interest

Species	**Critical Distance (m)**			
	75% LSR	**50% LSR**	**25% LSR**	**0%LSR**
Humpback Whale	31	259	537	1081
Killer Whale	36	333	657	1055
Bottlenose/Common Dolphin	34	308	650	1027
Fur Seal	78	395	758	1102
Leopard Seal	134	420	828	1190

Note: N/A stands for Not Applicable.

4.2.4 Audibility ranges

Table 13: Distances within which audibility is possible

Species	Maximum Audibility Range* (m)
Humpback Whale	1228 (1542)
Killer Whale	1304 (1679)
Bottlenose/Common Dolphin	1290 (1668)
Fur Seal	1325 (1685)
Leopard Seal	1467 (1840)

*If land is reached within the Maximum Audibility Range, the limit is the coast.

4.3 Cutter-suction dredging

4.3.1 Temporary Threshold Shifts

Noise emissions from a complete dredging production cycle were evaluated. A noise model of the operation of the cutter head and dredging was prepared to understand the noise levels from the noisiest activities.

Noise levels beyond 1m from the source are not expected to induce TTS within any of the functional hearing groups of marine mammals during dredging.

4.3.2 Behavioural effects

Table 11: Distances at which 75, 50, 25 and 0% risk of low and moderate behavioural responses for each of the species of interest may occur.

Species	Behavioural Response	Risk isopeth (m)			
		75%	50%	25%	0%
Killer Whale **Bottlenose Dolphin** **Common Dolphin**	Low (minor changes in respiration rates, swimming speeds/direction)	168	202	290	422
	Moderate (moderate to extensive changes in swimming speeds/direction and/or diving behaviours, moderate or prolonged cessation of vocalisations, and/or avoidance)	58	90	138	293

Table 11: Distances at which 75, 50, 25 and 0% risk of low and moderate behavioural responses for each of the species of interest may occur.

Bryde's Whale	Low (minor changes in respiration rates, swimming speeds/direction)	425	503	577	621
Fur Seal **Leopard Seal**	Low (minor changes in respiration rates, swimming speeds/direction)	Potential Onset: 505m			
	Moderate (moderate to extensive changes in swimming speeds/direction and/or diving behaviours, moderate or prolonged cessation of vocalisations, and/or avoidance)	Potential Onset: 197m			

4.3.3 Auditory masking

Table 12: Distances at which 75, 50, 25 and 0% listening space reduction (LSR) occurs for of each the species of interest

Species	Critical Distance (m)			
	75% LSR	**50% LSR**	**25% LSR**	**0%LSR**
Humpback Whale	N/A	24	260	415
Killer Whale	N/A	34	236	403
Bottlenose/Common Dolphin	N/A	41	251	398
Fur Seal	N/A	70	263	434
Leopard Seal	N/A	101	327	578

Note: N/A stands for Not Applicable.

4.3.4 Audibility ranges

Table 13: Distances within which audibility is possible

Species	Maximum Audibility Range* (m)
Humpback Whale	742 (814)
Killer Whale	735 (815)

Table 13: Distances within which audibility is possible

Bottlenose/Common Dolphin	738 (810)
Fur Seal	735 (816)
Leopard Seal	804 (925)

*If land is reached within the Maximum Audibility Range, the limit is the coast.

4.4 Backhoe dredging

4.4.1 Temporary Threshold Shifts

We evaluated the noise emissions from the backhoe dredging, including operation of the BHD engine/generator, hydraulic rams, bucket impact and loading on the seafloor, barge loading and anchoring the spuds. A noise model of the bucket impact and loading was prepared to understand the noise levels of the noisiest activity.

TTS effects are not expected to incur beyond 1m of the source for any of the functional hearing groups of marine mammals. No TTS (or any injury) guidelines from aggregate dredging exist for fishes.

4.4.2 Behavioural effects

Table 14: Distances at which 75, 50, 25 and 0% risk of low and moderate behavioural responses for each of the species of interest may occur

Species	**Behavioural Response**	**Risk isopeth (m)**			
		75%	**50%**	**25%**	**0%**
Killer Whale **Bottlenose Dolphin** **Common Dolphin**	Low (minor changes in respiration rates, swimming speeds/direction)	178	185	263	368
	Moderate (moderate to extensive changes in swimming speeds/direction and/or diving behaviours, moderate or prolonged cessation of vocalisations, and/or avoidance)	57	93	135	259
Bryde's Whale	Low (minor changes in respiration rates, swimming speeds/direction)	398	468	514	608
Fur Seal	Low (minor changes in respiration rates, swimming speeds/direction)	Potential Onset: 377 m			

Table 14: Distances at which 75, 50, 25 and 0% risk of low and moderate behavioural responses for each of the species of interest may occur

Leopard Seal	Moderate (moderate to extensive changes in swimming speeds/direction and/or diving behaviours, moderate or prolonged cessation of vocalisations, and/or avoidance)	Potential Onset: 202 m

4.4.3 Auditory masking

Table 15: Distances at which 75, 50, 25 and 0% listening space reduction (LSR) occurs for of each the species of interest

Species	**Critical Distance (m)**			
	75% LSR	**50% LSR**	**25% LSR**	**0%LSR**
Humpback Whale	N/A	N/A	161	334
Killer Whale	N/A	N/A	146	304
Bottlenose/Common Dolphin	N/A	N/A	148	308
Fur Seal	N/A	N/A	172	343
Leopard Seal	N/A	N/A	236	591

Note: N/A stands for Not Applicable.

4.4.4 Audibility ranges

Table 16: Distances within which audibility is possible
The numbers in brackets indicate the maximum distance under certain conditions.

Species	**Maximum Audibility Range* (m)**
Humpback Whale	488 (528)
Killer Whale	413 (503)
Bottlenose/Common Dolphin	482 (527)
Fur Seal	534 (669)
Leopard Seal	936 (1218)

*If land is reached within the Maximum Audibility Range, the limit is the coast.

5.0 Results: Fish

5.1 Percussive piling

For fishes, the *Lpk* levels were above the *SELcum* levels and were therefore relied upon for determining the critical ranges for injury.

Table 17: Ranges for the potential onset of noise impacts from the percussive piling in fishes, based on the ANSI-Accredited guideline thresholds (Popper et al. 2014).

Species	Critical Range (m)
Injury (including recoverable and fatal) in fishes without swim bladders (particle motion detection)*	40
Injury (including recoverable and fatal) in fishes with swim bladders (particle motion and pressure detection)*	78
TTS (All fishes)**	317

* *Lpk* thresholds for fatal and recoverable injuries are the same and therefore grouped together in this assessment.

** The *SELcum* thresholds are the same for all fish-groups and therefore grouped together in this assessment.

6.0 Cumulative Noise Effects

We understand that there is potential for percussive piling and dredging to be undertaken simultaneously by NPL, or percussive piling by NPL during times when dredging is occurring as part of the neighbouring Channel Infrastructure dredging project (formerly Refining NZ). This is based on the assumption that Channel Infrastructure elects to give effect to the series of extant resource consents for dredging.

We have therefore assessed the potential for cumulative noise resulting from these activities occurring simultaneously. Assessment was undertaken by modelling the noise from percussive piling occurring within the project area while dredging occurred nearby.

The models show no additive effects in noise from the two noise sources. Cumulative noise effects are not expected.

7.0 Conclusion

The reclamation and associated works at the eastern end of Northport will expose marine mammals and fish to acoustic-related disturbances that are either physiological or behavioural. Those risks are highest for the percussive piling but will occur over a limited range and not extend beyond the harbour entrance.

8.0 Literature cited

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Appendix A Glossary of Terms

Acoustic waveguide	A medium or structure that guides sound waves by restricting the wave movement in one of more dimensions, resulting in the efficient transmission of the sound wave.
Ambient sound	Ambient sound is the total of all noise within a given environment, comprising a composite of sounds from sources near and far.
Biologically important signal	An acoustic signal that, once detected and perceived, provides the receiving animal some information that is important to its survival and/or reproductive output.
Critical band	The frequency band of sound, contained within a broadband noise spectrum, that contains the energy equal to that of a pure tone centred in the critical band and just audible in the presence of broadband noise (Erbe et al. 2016).
dB (decibel)	The basic measurement unit of sound. The logarithmic unit used to describe the ratio between the measured sound pressure level and a reference level of 1 micropascals (0 dB) (or 20 micropascals for airborne sound).
Detector	A detector is a computer program that automatically detects the presence or absence of a particular signal that the algorithm is trained to detect.
Halocline	A strong change in salinity in a body of water with depth, where the salinity is markedly different above and below the layer in which the salinity change occurs.
Power spectral density (PSD)	The dB level of the power spectrum, presented every 1 Hz.
Permanent Threshold Shift (PTS)	An increase in the threshold of hearing (i.e. the minimum sound intensity required for the receiver to detect a signal) at a specific frequency that does not return to its pre-exposure level over time., i.e., it is permanently altered.
Sub-lethal	Sub-lethal effects are biological (including ecological), physiological or behavioural effects on individuals that survive exposure to the invasive noise.
Sound pressure level (SPL)	The logarithmic unit used to describe the ratio between the measured sound pressure level and a reference level of 1 micropascals (0 dB) (or 20 micropascals for airborne sound). Unless stated otherwise, the SPL refers to the root-mean-square (rms) sound pressure.
Soundscape	Similar to ambient sound, the acoustic soundscape is the sum of multiple sound sources arriving at a receiver (whether animal or hydrophone).
SoundTrap (ST)	An autonomous underwater acoustic logger used in marine science research from Ocean Instruments New Zealand.
Sound exposure level	The dB level of the time integral of the squared pressure over the duration of the sound event, expressed as dB re 1 µPa^2•s.
Source level	The sound pressure level transmitted by a point-like source that would be measured at 1 metre distance, and expressed as dB re 1 µPa @ 1m.
Temporary Threshold shift (TTS)	An increase in the threshold of hearing (i.e. the minimum sound intensity required for the receiver to detect a signal) at a specific frequency that returns to its pre-exposure level over time.

Appendix B Source locations

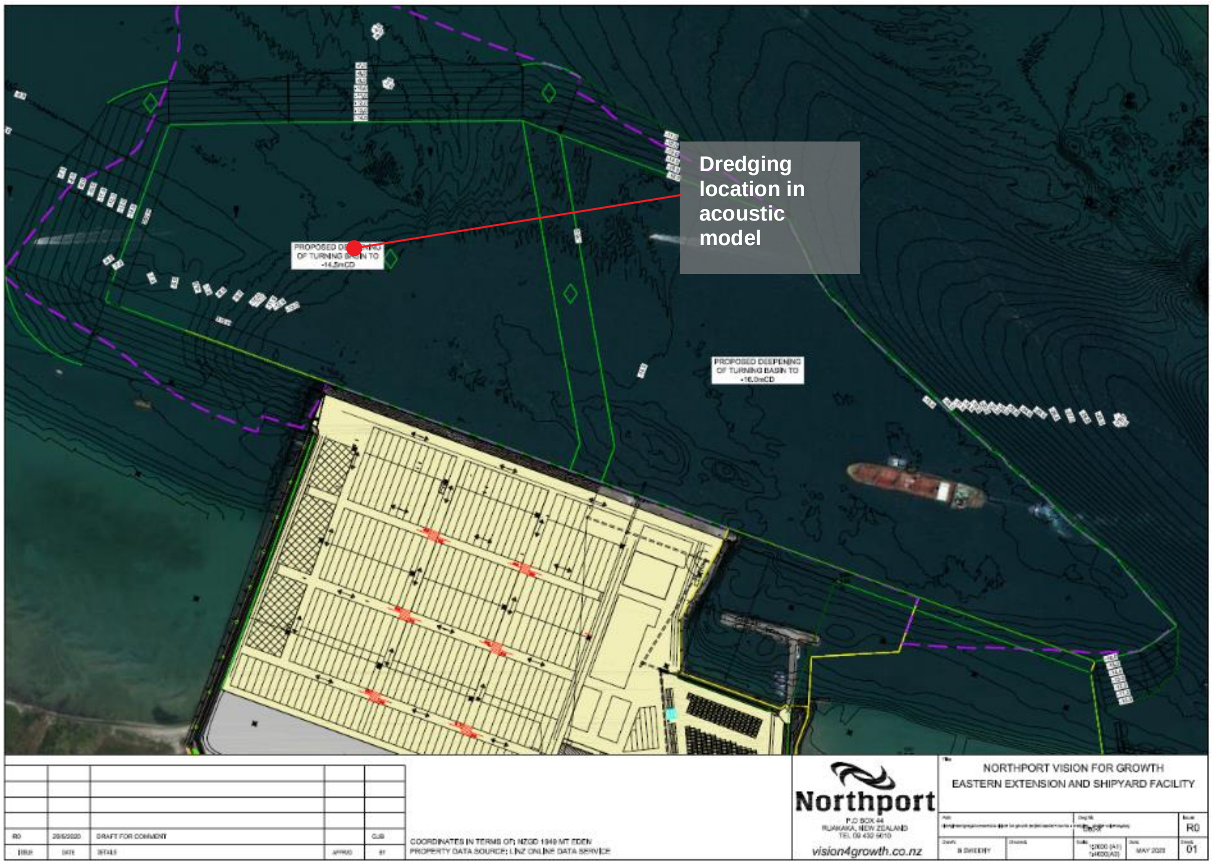
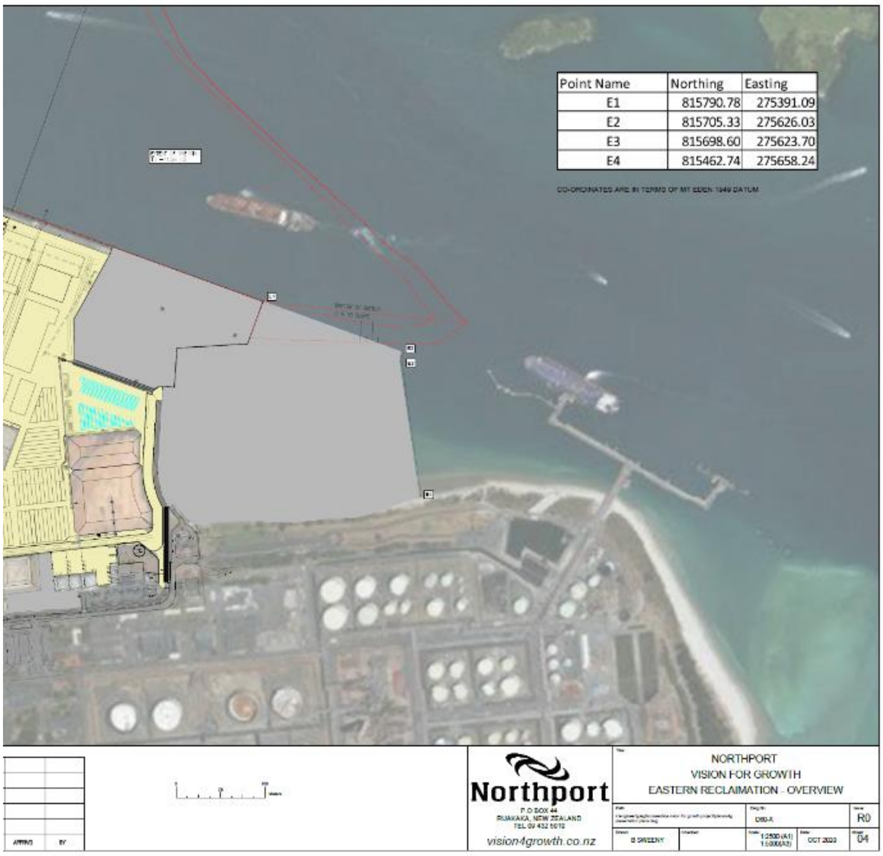


Figure 2: Extent of the capital dredging. Most of the dredging to occur to the west of the Site, where the acoustic model was based.



Point Name	Northing	Easting
E1	815790.78	275391.09
E2	815705.33	275626.03
E3	815698.60	275623.70
E4	815462.74	275658.24

CO-ORDINATES ARE IN TERMS OF MT EDEN 1949 DATUM

Figure 3: Locations of the percussive piling within the reclamation area

Appendix C The existing underwater soundscape

Marine mammals, fish and invertebrates depend on underwater sound for critical life processes. These processes include, but are not limited to, keeping group members together while navigating turbid coastal waters, communication between family members, locating prey during feeding, mediating mating behaviours, and avoiding predation (Duarte et al. 2021). Their ability to communicate and perceive biologically important sounds are directly related to the surrounding acoustic environment as signals must be audible over the background soundscape within some critical bandwidth. Coastal activities, including pile-driving, dredging, shipping, drilling, etc, can cause ambient sound levels over a wide frequency range to rise to the point where marine animals are unable to detect signals that are important to them. This masking effect can induce a range of sub-lethal impacts, from increased stress hormones and behavioural responses to total habitat avoidance and exclusion (Southall et al. 2007; Nowacek et al. 2007; Duarte et al. 2021). Underwater noise pollution can therefore degrade marine mammal habitats within sites where offshore activities take place.

Notwithstanding, not all areas/environments/regions are as suspectable to noise impacts because the physical environment changes. Generally, noise effects can only occur if the invading noise source is audible (audibility being a function of both the ambient soundscape and hearing thresholds of the listener). Therefore, to properly assess the maximum spatial extent of possible acoustic disturbance, the ambient soundscape must be fully considered and incorporated into the effects modelling (in the context of the species' hearing thresholds and critical bandwidths).

For this reason, among others, underwater noise monitoring at four locations near Northport has been occurring since June 2020.

Methodology

Monitoring sites and data acquisition

A SoundTrap recorder (ST300HF) was deployed near Passage Island opposite NPL. This location is one of four marine mammal monitoring sites maintained by NPL. This location was selected for the acoustic assessment because it was the closest to the proposed works. The sampling rate was 96 kHz and deployed at depths over 8m.

The hydrophone component of the SoundTrap recorders was calibrated by the manufacturer. Field-calibration checks before the initial deployment were undertaken using a calibrated piston phone (GRAS Type 42AA, SPL 114 dB re 20 µPa, nominal frequency range 250 Hz), and calibrated (using a Brüel & Kjaer Type 4231 Sound Calibrator) sound level meter (Brüel & Kjaer 2250 Type 1 SLM with a Brüel & Kjaer ½ inch condenser microphone Type 4189) and specialist acoustic software. Electronic calibration of the recorder component was undertaken at the start of every recording event by comparing a set of automated tones of known frequency and voltage amplitude to the full-scale response level provided by the manufacturer for the appropriate gain setting and verified using the piston phone.

Overview of analysis procedure

Ambient sound recordings from the SoundTrap recorder were processed in PAMScan[3]. The software processes audio for sound pressure levels (*SPL*s), power spectral densities (*PSD*s) and third octave level (*TOL*s). The equations for those are detailed by Merchant et al. (2015). For this assessment, the median *SPL*s in the third octave bands were needed for the behavioural, masking and audibility effects assessments. A full characterisation of the ambient soundscape was outside the scope of this assessment.

The levels themselves are provided in Figure 8 of Appendix D.

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[3] Propriety application.

Appendix D Methodology: underwater noise modelling

Sound Sources

Percussive piling

A range of pile sizes and types will be installed during the project, including H-section piles and sheet and solid steel piles with diameters between 25mm and 760mm. The acoustic models are based on the largest solid steel piles, as the sheet piles and smaller diameter piles require less energy from the hammer head to be driven (and therefore lesser noise emissions).

The source level for the effects modelling from the percussive piling was based on empirical source level measurements of 914mm diameter steel piles being installed using a percussive hammer (BSP HH16-1.2 hammer, 212 kJ/blow, up to 1700 strikes per day). Data were obtained using an array of hydrophones at various distances (between approximately 55 and 1700m) recording individual pulses over several hours.

The measurements were processed using an impulse signal detector designed to identify impulsive signals from passive acoustic datasets (based on that used by Pine et al. (2020)). The detector was customised specifically for the percussive piling being measured and the receiving environment. The sound exposure (SEL), peak pressure level (Lpk) and RMS sound pressure (L90) was calculated for each impulse (n=1762), over the pulse's T90 duration.

The relationship between the SEL and L90 was defined as

$$SEL = L90 + 10 \ \times Log_{10} + \ 0.458 \ dB$$

The 0.458 dB is to account for the lost energy either side of the 5% and 95% during the T90 calculation (i.e. $10 \times Log_{10}(0.9) = 0.458$ dB).

Empirical slope coefficients were established based on those data and used to obtain the frequency-dependent source levels.

The source levels used in this assessment are provided in Figure 4.

The percussive piling was modelled as point sources from within the reclamation area (refer to Appendix B).

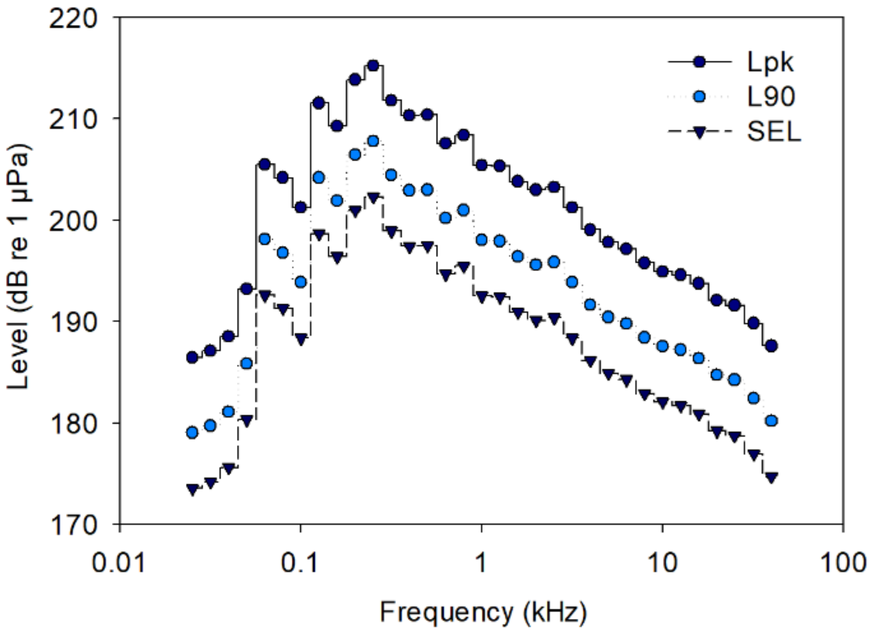

Figure 4 Source spectrum of the percussive piling used in the modelling. The *Lpk* is the peak levels, *L90* is the rms level calculated over the *T90* duration and *SEL* is sound exposure level calculated over the *T90* duration.

Capital dredging

The dredging operations will potentially use three types of dredgers: a trail-suction-hopper dredger (TSHD), a cutter-suction dredger (CSD) and a backhoe dredger (BHD). Based on the proposed dredging methodology provided by WSP[4], a TSHD or CSD will be used for the removal of soft clays while a BHD will be used to dredge sands.

The TSHD will be the vessel Albatros from Dutch Dredging. Because no specific noise levels from that particular vessel are readily available, we have based our modelling on a similar sized TSHD, the vessel City of Chichester. A table comparing the two TSHDs are provided in **Table 1**.

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[4] Auld M., Houba P., McManus K., Band N., Claassen D. 2021. Northport Ship Maintenance Facility Concept Design. Draft report by WSP (Ref 6-DV652.00) dated 11 January 2021.

Table 1: Summary comparing the Albatros and City of Chichester TSHDs.

Vessel	Length (m)	Capacity (m^3)	Total Power (kW)	Location	Citation
City of Chichester	72	1418	2720	UK	Robinson et al. 2011
Albatros	75	1860	2360	NZ	Dutch Dredging

We have based our modelling on large CSD and BHDs as the specific dredging equipment that will be used in the project has not yet been confirmed. Given the lack of details on the proposed CSD and BHD equipment, it was not possible to model actual acoustic data or recordings of the exact dredgers that will be used. Therefore, the source signal for each dredger type was based on published source spectra (from actual noise measurements) for similar dredging plant at different stages of their respective production cycles. Data were obtained from a single large BHD (BHD New York) and a large CSD (CSD Florida) were selected to represent the largest of the possible dredgers that could be used for the proposed works (Figure 5). Details on all dredgers used in the modelling are provided in **Table 1.**

The aim was to model a representative source signal for a complete production cycle (for example, the BHD digging and loading the barge, operating the cutter head of the CSD, or dredging sand/gravel while the TSHD was underway) and so the source levels for a range of typical operating configurations were considered. It is important to note that the measurement data obtained for each dredger are the cumulative noise level of all sources for that particular dredger during that particular production stage. For example, the source levels from the BHD under full dredging (i.e., bucket impact and digging) contain noise from the hydraulics and on-board generators, as well as any pumps.

Each dredger-type was modelled as a point source (refer **to Appendix B** for maps showing the dredging area). Details of the source signal are provided in **Table 2** and the source spectra are provided in Figure 6.

Table 1: Summary table of the different dredger types incorporated in the acoustic modelling

Dredger Type	Vessel	Length (m)	Capacity (m^3)	Total Power (kW)	Location	Citation
TSHD	City of Chichester	72	1418	2720	UK	Robinson et al. 2011

Table 1: Summary table of the different dredger types incorporated in the acoustic modelling

CSD	Florida	159	-	18938*	US	Reine et al. 2014
BHD	New York	61	18	2565	US	

*Total installed power.

Figure 5: Photographs of each of the dredging plant used to represent the possible dredging equipment for the project.

Table 2: Summary of high-level source characteristics for each dredging type in the acoustic modelling

Dredger Type	Vessel	Dredging Event	*RL*[1] Distance (m)	*TL*[2] model used to calculate *SL*	*SL*[3]	Peak Frequency (Hz)	Citation
CSD	Florida	Full Dredging[7]	152	15log(r)	175	300	Reine et al. 2014; Robinson 2015
BHD	New York	Engine/Generator noise	75	15log(r)	167	125	Reine et al. 2014
		Hydraulic Rams	60	15log(r)	164	2500	
		Bucket Impact and Filling	60	15log(r)	179	315	
		Barge Loading	60	15log(r)	166	100	
		Anchoring Spuds	75	15log(r)	167	1200	
		Engine/Generator noise	75	15log(r)	167	125	

[1] Received level (dB re 1 µPa).
[2] Transmission loss model used to back-calculate *SL* (Source Level).
[3] Broadband source level (dB re 1 µPa^2 m^2), un-weighted, averaged over a 1 sec time period.

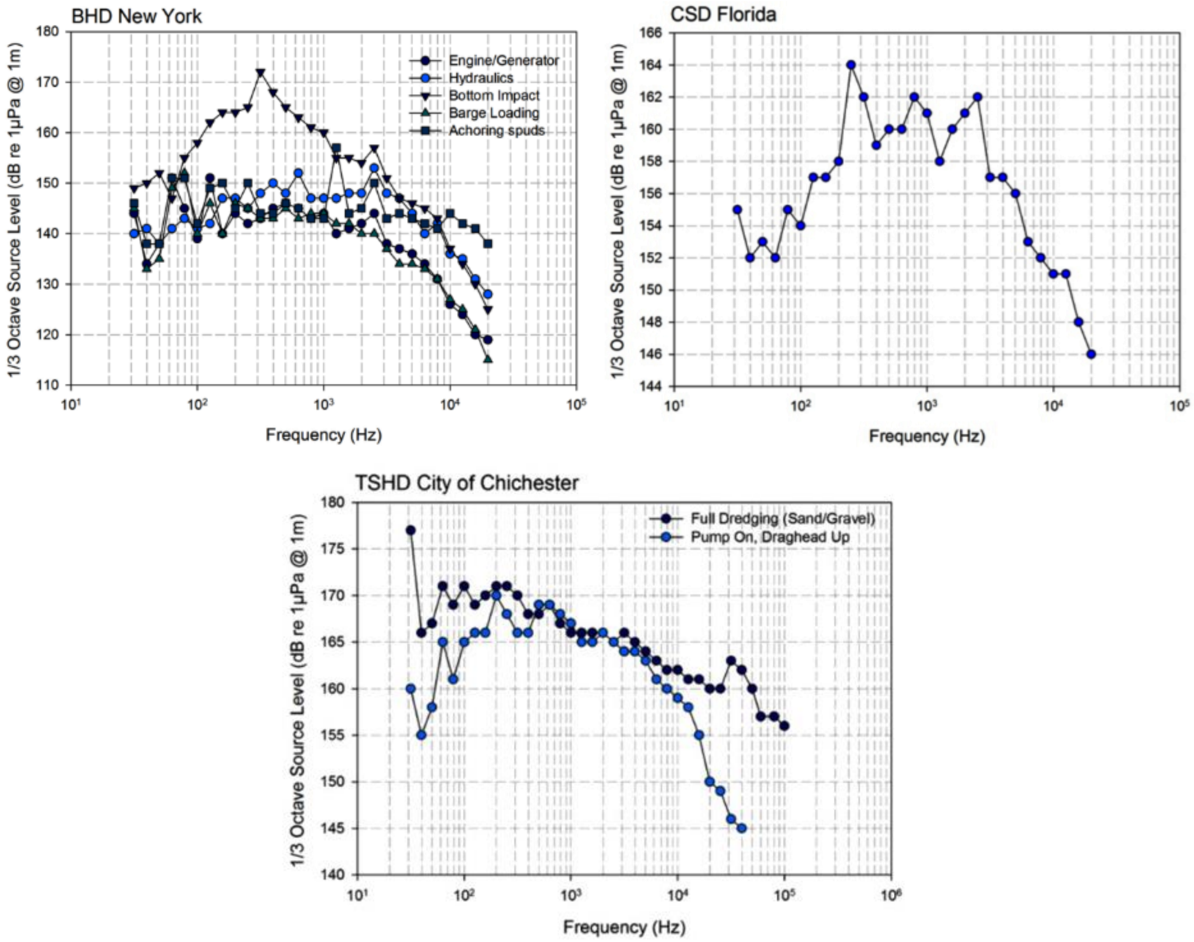

Figure 6: Third octave source spectra for each dredger modelled under different operating stages during a typical production cycle

Data sourced from Robinson et al. (2011) and Reine et al. (2014).

Bathymetry and hydrodynamics

Sound propagation within coastal waters typically follow a normal mode whereby a sound wave of a particular wavelength moves sinusoidally through an acoustic waveguide (i.e., the water column or seafloor) (Jensen 2011). However, sound propagation in shallow water is highly influenced by boundary effects and the extent of those effects is related to water depth, as well as the seafloor and surface roughness. Bathymetry data is therefore critical for any range-dependent propagation model.

The bathymetry dataset was provided by MetOcean Solutions and was the same dataset used for the hydrodynamic modelling[5] for the existing environment.

Sea-floor composition

The composition of the seafloor and sediments has a direct influence on the sound propagation as part of the ocean acoustic medium. Sediment type and seafloor roughness also influences the boundary effects through sound absorption, changes to compression wave velocities and reflections. These factors mean that the sound field at any given location from the sound source can be highly variable due to the changes in the seafloor compositions and geoacoustic properties. These factors can also mean the arrival times between the signal's multi-paths can also vary (which is also highly influenced by bathymetry). For waterborne signals, the surface layer of the seabed is more important but for ground-borne signals (both of which are present in pile-driving), the depth of the sediment layers is also of relevance, as the compression wave 'leaks' into the adjacent water column. The required geoacoustic model for the piling would therefore be a three-dimensional matrix with the surface layer being the seafloor and the water column interface and subsequent layers containing the depth-dependent compression wave speeds and densities.

The seafloor composition within Whangarei harbour entrance is relatively well studied compared to most, with a range of investigations being completed for other consent applications in recent years. The geoacoustic properties used in this study was built using sediment data obtained from Tonkin & Taylor in 2016 using a series of vibrocores up to 5m depth, beyond which consolidated sands were assumed (since the driven depths of the piles extend beyond 30m). The locations of the vibrocores are provided below (Figure 7), and were the same positions used in the acoustic model. The geoacoustic properties used in the modelling for the different sediment types are provided in Table 3.

For the areas west of the harbour entrance where no vibrocores were taken, the same properties were assumed for that area as core V2 near the shore and V3 in the channel (indicated in Figure 7).

Table 3: Geoacoustic properties for various sediment types within the project area

Sediment Type	Density (kg/m^3)	Compressional wave velocity (m/s)	Absorption (dB / lambda)
Sand-silt-clay	1600	1560	0.20

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[5] MetOcean Solutions. 2020. Hydrodynamic Modelling, report prepared for Northport. Dated September 2020.

Table 3: Geoacoustic properties for various sediment types within the project area

Sand-silt	1700	1605	1.0
Silty sand	1800	1650	1.1
Very fine sand	1900	1680	1
Fine sand	1950	1725	0.8
Coarse sand	2000	1800	0.9
Gravel	2000	1800	0.6

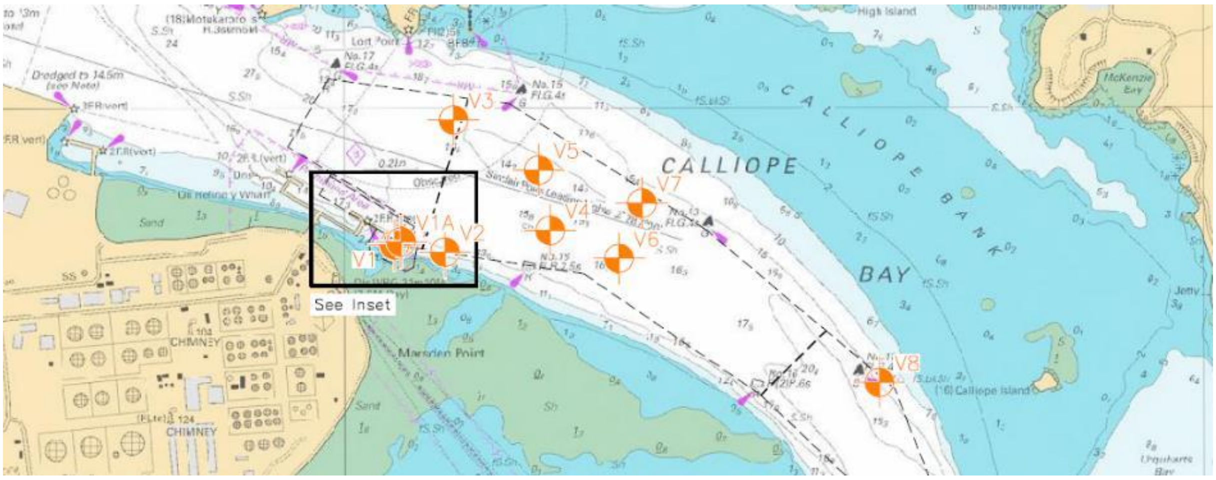

Figure 7: Borehole locations

Borehole log data for these locations were used in the noise model (taken directly from Tonkin & Taylor 2016) and presented in **Appendix F**.

Sound speed profiles

The speed of sound underwater is predominately dependent on temperature, density (salinity) and depth. In open water environments, such as the Hauraki Gulf, sea surface temperatures vary between seasons. Mixing down to 40m depth can occur during the winter months (Zeldis 2013) but during the summer the absence of that mixing gives way to thermo- and haloclines. Those temperature and salinity gradients change the speed of sound at those depths.

In high flow environments, such as the Whangarei harbour entrance, mixing can be year-round, with the currents and turbulent flows preventing stratification of the water column. We have therefore assumed an isovelocity propagation medium year-round, based on the sea surface temperature recorded from the study area during summer.

A simplified equation from Medwin & Clay (1998) was used to calculate the sound speed with depth.

Range-dependent propagation model

The underwater noise modelling was simply defined as:

$$SPL_{freq}(R) = SL_{freq} - PL_{freq}(R)$$

where SPL_{freq} at distance R was the predicted sound pressure level for some frequency bandwidth, SL_{freq} was the source level at that frequency band and PL_{freq} was the propagation loss over R for that frequency band.

The propagation loss (*PL*) was determined using a combination of range dependent parabolic equation (*PE*) and ray trace (*RT*) models, for frequencies below and above 1.4 kHz, respectively, for 72 radials over a 10m grid with 0.5m depth resolution. Since *RT* models are based on Snell's Law, it is applicable if a signal's wavelength is much less than the layer in which it is propagating. Therefore, ray tracing was only applied to frequencies above 1.4 kHz as the wavelengths beyond that frequency were far smaller than the water depth (since no stratification in the water column was assumed). The *PL* for three frequencies within each 1/3 octave band between centre frequencies 50 Hz and 32 kHz were calculated and then averaged within each bandwidth to represent the *PL* for a specific band. The 1/3 octave bands were chosen for the modelling as they are often used to represent the critical bandwidths in marine mammals[6] (Erbe et al., 2016; Pine et al. 2018).

Effects modelling for marine mammals

The overall objective of the acoustic modelling is to provide the acoustic footprint of the noisiest activity to inform an assessment of the potential impacts on marine animals.

Temporary Threshold Shifts

When a receiver is exposed to high noise levels over an extended period, the cells within the inner ear begin to fatigue and become less sensitive. Therefore, a change in the receiver's hearing threshold occurs, and the degree at which those thresholds change is referred to as a

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[6] This is done when the true critical bandwidths are unknown for the species of concern.

threshold shift. If hearing returns to normal after a certain time post-exposure, the threshold shift is temporary (termed TTS), but if not, then it is referred to as PTS. The amount of threshold shift depends on the duration of noise, rise times, duty cycles, sound pressure levels within the receiver's critical bandwidths' (i.e., the spectral composition of the noise) and, of course, the overall energy.

The noise criteria used for the establishment of TTS radii was from NMFS (2018), which has been used extensively around New Zealand for underwater noise assessments. For percussive piling, NMFS (2018) prescribes criteria for the potential onset of either PTS or TTS effects in both peak pressure (*Lpk*) or cumulative sound exposure level (*SELcum*) (termed a duel-metric threshold), whichever is the highest (Table 4). The *SELcum* metric is commonly used for assessing impulsive signals as it can incorporate the energy from multiple pulses and the overall exposure duration that an animal receiver would experience. The number of pulses and delay between them, for each pile (in the case of percussive piling) can therefore be incorporated to calculate the *SELcum*, unlike for the *Lpk*. Similarly, the duration of the dredging noise can also be incorporated to obtain the *SELcum* for comparison with the relevant criterion. In the case of multiple pulse sources, such as percussive piling, the dual-metric is particularly relevant as sometimes the *SELcum* values can be higher than *Lpk* levels for some marine mammal functional hearing groups, and therefore both must be considered.

Unlike the *Lpk*, the *SEL* criteria are to be cumulative over a 24-hr period and M-weighted.

The 24-hr *SELcum* was calculated by adding $10Log_{10}(n)$, where n=1700 strikes per 24hrs, to the modelled *L90* SPLs.

Table 4: NMFS (2018) auditory threshold criteria for the functional hearing groups relevant to **the VFG project**.

Functional Hearing Group	Non-Impulsive		Impulse			
	TTS Threshold	PTS Threshold	TTS Threshold		PTS Threshold	
	SEL* (weighted)	SEL* (weighted)	SEL* (weighted)	Peak SPL (unweighted)	SEL* (weighted)	Peak SPL (unweighted)
LF	179	199	168	213	183	219
MF	178	198	170	224	185	230
HF	153	173	140	196	155	202
OW	199	219	188	226	203	232
PW	181	201	170	212	185	218

* cumulative sound exposure levels over 24 hours.

Behavioural responses

There is a substantial amount of literature on the behavioural effects of noise on marine mammals and several studies on fish. Those include direct evidence-based studies, opportunistic studies or observations that have been summarised in several reviews (for example Richardson et al. 1995; Hildebrand 2005; NRC 2005; MMC 2007; Nowacek et al. 2007; Weilgart 2007; NAS 2017). Behavioural effects are highly varied and may include changes in swimming behaviours (directions and speeds), diving behaviours (durations, depths, surface intervals), time spent on the surface, respiration rates, fleeing the noise source and changes to vocalisations. Predicting the zones within which behavioural effects may be seen is the most difficult noise effect to quantify due their dependency on the context, species and location (see Ellison et al. 2012; Gomez et al. 2016 for reviews on the issue of context dependency on marine mammal behaviour).

Consequently, there is no widely accepted regulatory guidance on behavioural effects currently in existence as it is still a research problem. The only interim guidance for behavioural responses is a single unweighted decibel value of 120 dB re 1 µPa for continuous noise sources (applicable to the CSD and BHDs) and 140 or 160 dB re 1 µPa for impulsive noise sources (applicable to the pile driving) from NOAA (the National Oceanic and Atmospheric Administration in the US). However, for many noise sources, such as continuous dredging noise, they have not had wide-spread uptake (Gomez et al. 2016). One of the issues of using a single noise threshold for behavioural responses is that the data currently available are not very comparable (Nowacek et al. 2007; Southall et al. 2007; Eillison et al 2012; Gomez et al 2016). There is a limited relationship between the severity of the behavioural response and the received level of underwater noise (Gomez et al 2016).

Some underwater noise assessments in New Zealand still consider the 120 dB re 1 µPa contour, stating the reason being it is the only threshold for the onset of some behavioural response. However, because of the uncertainty in assessing the risk of behavioural effects within and between species (based on the highly contextual nature of behavioural effects), the application of a simplistic noise threshold for behaviours should be avoided (Faulker et al. 2018).

Recent studies assess behavioural zones based on the probability of occurrence using dose-response curves specific for the species of interest (Joy et al. 2019). Dose-response curves show the relationship between the probability of a behavioural effect occurring at a given level of noise exposure (Joy et al. 2019). The dose-response formulas have been used by the U.S. Navy (US Navy 2008, 2012) and the scientific community for several years, primarily for sonar, among other transducers, and explosions or airgun pulses.

Species-specific dose-response curves for percussive piling driving, however, have not been explicitly calculated and the U.S. Navy continues to recommend the existing NMFS risk criteria for the onset of behavioural responses from impact and vibratory pile driving (provided in Table 5).

Table 5: NMFS thresholds for the potential onset of behavioural responses from marine mammals.

Underwater Vibratory Pile Driving Criteria (Sound Pressure Level, dB re 1 µPa)	Underwater Impact Pile Driving Criteria (Sound Pressure Level, dB re 1 µPa)
120 dB rms[1]	160 dB rms[1]

[1]Note: Root mean square (rms) calculation for impact piling is based on the duration of the pulse defined by 90% of the cumulative energy in the impulse. The rms for vibratory piling is calculated over a duration that is representative of the piling, typically a few seconds in which the variation in noise levels is captured.

In the absence of specific dose-response curves for percussive piling, the step function threshold of 160 dB_{rms} re 1 µPa continues to be used. However, extensive reviews show most marine mammals respond to impulsive noise of varying levels between 140 and 180 dB_{rms} re 1 µPa, including large whales (Malme et al. 1983, 1984; HESS 1999; Woods et al. 2012). Probabilistic metrics applied at 10%, 50% and 90% of individuals having behavioural responses have been assumed above M-weighted 140, 160 and 180 dB_{rms} re 1 µPa, respectively (Woods et al. 2012).

Considering no general consensus on single value behavioural thresholds for percussive piling, the unweighted 140 and 160 dB_{rms} re 1 µPa step function thresholds have been used in this assessment. Being unweighted, they are more conservative.

For continuous noise sources, i.e. the CSD and BHD, however, dose-response curves were used. Recent studies provide a specific dose-response function and thresholds for southern resident killer whales exposed to continuous noise sources (Joy et al. 2019). The thresholds make use of the most up-to-date data for killer whales and behavioural effects (specifically those effects classed as low[7] or moderate[8] (respectively, a Southall severity score of 2-3 and 4-6 (Southall et al. 2007)). Briefly explained, the researchers took empirical studies on killer whales and noise (42 studies in total) and correlated the estimated received sound pressure levels with the behavioural response type (i.e. the Southall severity scores (Southall et al. 2007)) to get a regression curve (linear relationship). From there, two received levels that corresponded to the 50% probability of either a low or moderate behavioural response occurring was calculated. Dose-response curves for killer whales were then generated from those received levels.

The dose-response curve used in this assessment was calculated using:

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[7] Low behavioural responses are defined as minor changes in respiration rates, swimming speeds and direction (Joy et al. 2019).

[8] Moderate behavioural responses are defined as moderate to extensive changes in swimming speeds, direction and/or diving behaviours, moderate or prolonged cessation of vocalisations, and/or avoidance (Joy et al. 2019).

$$R = \frac{1 - \left(\frac{L - B}{K}\right)^{-A}}{1 - \left(\frac{L - B}{K}\right)^{-2A}}$$

where *R* was the risk from 0 to 1 (i.e. the probability of an effect occurring) at the noise level *L*, *B* was the basement received level (*RL*) at which the risk of an effect occurring is so low it does not warrant calculating, *K* was the *RL* increment above *B* at which there is 50% risk and *A* was a transition sharpness parameter (Joy et al. 2019). The *RL* at which there was a 50% risk of an effect was set at 129.5 (for a low response (Southall severity 2.5)) and 137.2 dB re 1 µPa (for a moderate response (Southall severity 5)) (Joy et al. 2019).

Since this method is based on more accurate data (and on killer whales, which is a species that occurs within Whangarei harbour and its entrance, with hearing biology similar to other delphinids), we applied the same method and assumptions to our data. However, for this assessment, we altered the basement received level, *B*, to be the averaged 1-min *SPL* of ambient noise over our monitoring period (between June and December 2020). This provided a conservative baseline level specifically related to the Whangarei harbour entrance that is more useful than the unweighted threshold level for continuous noises of 120 dB_{rms} re 1 µPa for all marine mammals.

For larger mystecete species, such as humpback whales (which have been seen inside the harbour on occasion) and Bryde's whales, the *RL* at which 50% risk of behavioural response occurring was set at 120 dB_{rms} re 1 µPa. This was because that level is the lowest level at which bowhead whales, another mystecete species and one of the only whales with estimated levels of exposure (from continuous noise), has been linked to a certain behavioural response (Southall et al. 2007). This is conservative. No assessment for moderate behavioural effects for mystecetes was done because we do not know what such a threshold would look like and is therefore too speculative to be meaningful. The same basement levels and transition sharpness values were applied.

Dose-responses functions were not used for pinnipeds. Data for leopard seals and fur seals (the two seal species considered in this assessment) are not available and therefore the step function approach was used and applied to both species. Southall et al. (2007) review studies showing pinnipeds responding to continuous noise, with individuals shown to react above 120 dB_{rms} µPa (Southall severity score 3[9]). Above 130 dB_{rms} re 1 µPa, the behavioural responses reviewed by Southall et al. (2007) are more moderate[10]. These unweighted thresholds were used to determine the potential onset for low and moderate severity behavioural responses in this assessment.

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[9] Such as alert behaviours, minor changes to swimming speeds, dive profiles or directions, changes to respiration rates, or minor cessation or modification of vocalisations (Southall et al. 2017, Table 4).

[10] Such as prolonged changes to swimming speeds, dive profiles, or directions, moderate shifts in distributions, prolonged cessation or modification of vocalisations (Southall et al. 2017, Table 4).

Auditory masking

Several species of marine mammals and fish are known to have hearing ranges that overlap with low-frequency anthropogenic noise – such as vessels or machinery such as renewable energy devices. For example, bottlenose dolphins (*Tursiops truncates*) and common dolphins (*Delphinus delphis*) have shown hearing sensitivities to signals as low as 100 Hz, while killer whales (*Orcinus orca*) show sensitivity down to 500 Hz (Hall & Johnson 1972; Popov & Klishin 1998; Szymanski et al. 1999). Therefore, auditory masking - the interference of a biologically important signal (such as vocalisations from conspecifics or predator/prey etc) by an unimportant noise that prevents the listener from properly perceiving the signal (Erbe 2008) – is expected to occur (Pine et al. 2019). Piling and dredging noise (along with other anthropogenic noise sources commonly seen in coastal waters) has the potential to interfere with an animal's ability to perceive their natural acoustic environment (Erbe et al. 2016; Popov & Klishin 1998). The inclusion of auditory masking in underwater noise effects assessments is best practice because behavioural effects generally occur at moderate levels of masking and thus understanding the spatial limits of masking is important (Pine et al. 2019).

We assessed auditory masking for marine mammals by quantifying the reduction in an animal's listening space. An animal's listening space is the immediate area (volume of ocean) surrounding it within which it can detect and perceive a biologically important signal. The listening space method was used instead of sonar equations in this case because the call structures of all the species of interest at the source are not well understood, while the listening space method is more sensitive to changes in the existing sound environment (Pine et al. 2018). Those changes could be better modelled using the empirical data collected between June and December 2020 at multiple sites within the study area.

As an animal receiver moves through the study area when waterborne construction activities are underway, the animal's listening space will decrease to a new, smaller listening space. The difference between the original and the smaller listening space under masking conditions is termed the listening space reduction (**LSR**).

The method for calculating the LSR is fully described by Pine et al. (2018) who define the LSR as:

$$LSR = 100\left(1 - 10^{-2\frac{\Delta}{N}}\right)$$

where *N* is the frequency-dependent *PL* slope coefficient and Δ is the difference between the perceived base ambient noise level NL_1 and anthropogenic noise level NL_2 at a given distance (NL_2 was the modelled sound pressure levels of either the percussive piling or dredging, as described above). The ambient noise levels were taken from the passive acoustic monitoring (as described in Appendix C). It is important to note that NL_1, being the perceived base ambient noise level, is the maximum of the listener's hearing threshold (audiogram value) and the ambient level inside a critical band, approximated herein by 1/3 octave bands (Erbe et al. 2016; Pine et al. 2018). Audiogram values for bottlenose dolphins and killer whales (reconstructed from Nedwell et al. 2004) were used to estimate hearing thresholds in each critical band. There are no audiograms available for the New Zealand fur seal or mystecete whales. Consequently, a Northern fur seal (*Callorhinus ursinus*) and leopard seal (*Hydrurga leptonyx*) audiogram (Nedwell et al. 2004) and modelled audiogram for the fin whale (Cranford & Krysl 2015) were used.

Using modelled audiograms requires special care, as they are based on the structure of the skull and no true hearing data is available (as AEP experiments, or behavioural audiograms, are not able to be done on mytecetes). However, their use in scientific studies occurs when no other data exists – as is the case with this assessment.

The PL slope coefficient was calculated by curve fitting the empirical PLs of each 1/3 octave band between 50 Hz and 32 kHz over a distance that represented the listener's maximum listening range under natural sound conditions. This was done using a simplified sonar equation without signal gain (to increase conservativeness):

$$SE = SL - PL - NL_1 - \ DT$$

where signal excess (**SE**) is set to zero to indicate detection onset, NL_1 was the 5th percentile ambient noise level and DT was the detection threshold (conservatively set at 10 dB for (Clark et al. 2009; Kastelein et al. 2013; Putland et al. 2017; Pine et al. 2018; Pine et al 2019)). This was done because the PL slope can have some range-dependence.

The empirical source levels, ambient levels and audiograms are provided in Figure 8.

The LSR was then calculated for each 1/3 octave band at each depth step – resulting in an LSR map for each band. Those maps were then overlaid on top of each other (forming a 3D matrix) and averaged through layers to provide an overall 2D LSR map for the project area (Pine et al. 2018).

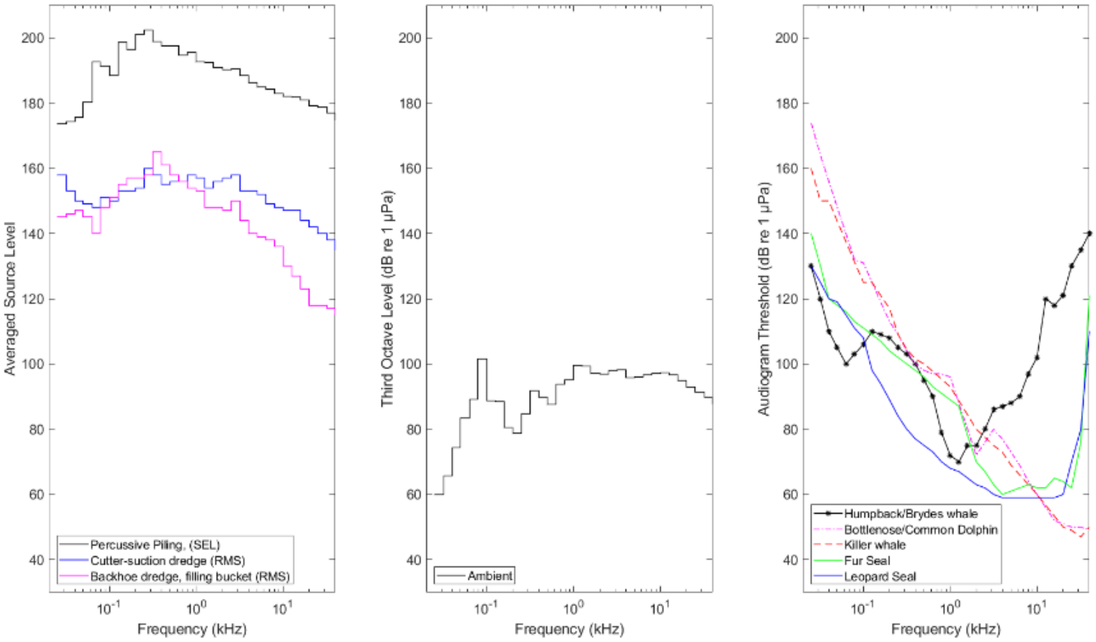

Figure 8: 1/3 Octave source levels for the piling and dredging (left panel), median 1/3 octave ambeint sound levels measured between June and December 2020 (middle panel) and species audiograms (right panel).

It is important to note the three important assumptions applied to the auditory masking model: (1) the listener exhibits omnidirectional hearing; (2) the sound propagation field is omnidirectional; and (3) no masking release mechanisms occurred. The exclusion of masking release is an important assumption as it means the results are likely to be conservative (i.e., has the potential to overstate true masking).

Marine fauna has evolved in a naturally noisy environment, with many natural sources (such as waves and conspecific or heterospecific vocalisations etc) active as effective maskers (Radford et al. 2014). It therefore stands to reason that they have evolved to counteract naturally occurring maskers, ensuring their vocalisations can be detected by a listener over the ambient noise level. Anti-masking strategies by the sender are predominately altering the call's characteristics, such as increasing call amplitude (Lombard effects), changing the spectral characteristics of the call (such as lowering or raising the fundamental or peak frequencies) to reduce spectral overlap, or altering the temporal dynamics of the call, such as increasing call rates or repetition (Radford et al. 2014; Erbe et al. 2016). There may also be repeating information at multiple frequencies within a call's harmonics (such as in some fish calls, graded structures in dolphin vocalisations and whale calls). In addition, masking release at the listener may occur when the call and masking noise are coming from different direction (termed spatial release from masking) or when the masking noise is amplitude modulated over a bandwidth much wider than the critical band of the listener (termed comodulation masking release) (Erbe et al. 2016). All these masking release mechanisms have been documented in marine mammals and fish, and thus the importance of this assumption.

Audibility ranges

In order for any noise effect to occur, the noise has to first be audible to a receiver. It is important to note, however, that simply detecting a noise source does not equate to an effect occurring. Notwithstanding, the limits of audibility do provide us a maximum area within which the risk of any effect occurring is theoretically greater than 1 %. By calculating the limits of audibility for each of the species of concern, it allows regulatory bodies to better understand the acoustic footprint of the proposed dredging for particular species or groups.

Audibility limits were calculated based on the hearing sensitivities of killer whales, common dolphins, bottlenose dolphins, New Zealand fur seals (approximated based on the Northern fur seal, being the closest phylogenetic relative to the NZ fur seal for which audiogram studies have been undertaken), leopard seals and baleen whales in the context of the ambient soundscape.

A conservative approach was taken – detection thresholds, auditory gain functions and directivity of hearing sensitivities have been left out of the calculations because they are unknown for the species of concern. Masking release mechanisms have also been left out for the same reason. The key assumption, therefore, is that detectability of the anthropogenic noise is omnidirectional[11] and directly relates to the difference between the ambient sound level, the anthropogenic noise and hearing thresholds at each critical band.

Effects modelling for fishes

Fish and invertebrates can be negatively impacted by anthropogenic noise, just as marine mammals. However, unlike marine mammals who have statutory protections in several countries, noise exposure criteria for fish are far more varied in their usefulness (Hawkins & Popper 2017). Data that establishes the expected severity of a certain effect following the exposure to some pressure levels are scarce. One of the only peer-reviewed guidance for the potential onset of noise effects (from a range of sources, including pile-driving) on fishes that has experienced some uptake internationally is the ANSI-accredited guidance from Popper et al. (2014). That guidance does provide useful guidelines (within the limitations and constraints) in gauging the spatial extent of potential impact. For percussive pile-driving, the criteria for various fish-groups are provided as decibel ranges. No guidance on vessel or dredging noise exists and have therefore fallen outside this assessments scope.

While thresholds are a good starting point, noise criteria for fishes should consider the biological significance of sound exposure (Hawkins et al. 2020). The biological significance of the sound exposure relates to whether the animal experiences an adverse effect in its life, i.e., is the invasive noise likely to cause significant physical, chemical or biological responses that

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[11] Also assumed in peer reviewed scientific publications, such as Pine et al. 2016; Pine et al. 2018; Pine et al. 2019; Putland et al. 2017; Stanley et al. 2018.

have real consequences for the net fitness of the individual or population (Hawkins et al. 2020). The only effect that can currently be directly linked to such an impact is mortality or severe injury that eventually may be fatal. Other biologically significant effects include PTS, TTS, sub-lethal injuries, behavioural and auditory masking but the relationship between the severity of those effects and exposure to noise is data deficient and still a research question (Hawkins et al. 2020). Notwithstanding, hearing loss (either permanent or temporary) is an impact that can impact an individual's net fitness because their perception of predators can be inhibited. We have therefore considered TTS risk in fishes from the percussive piling. Thresholds for the potential onset of TTS in fishes are provided in the ANSI-accredited guidelines. It is important to note those TTS guidelines were based on seismic airgun pulses and no data are available for TTS effects on fish from percussive pile-driving. The TTS thresholds are, therefore, considered conservative based on the shock wave from airgun pulses being higher energy, rise times and duration (through reverberation) than from percussive piling.

Multiple studies have been published that present noise exposure data and effects on fishes, but they suffer from a wide range of laboratory conditions, experimental methods, species and conclusions. Given the wide range of thresholds between research studies and the most recent review paper by Hawkins et al. (2020) maintaining the current state of knowledge does not alter the recommended thresholds within the ANSI-accredited guidance, we have adopted that guidance.

The ANSI-accredited thresholds used in this assessment are presented in Table 6 below.

Table 6: ANSI-accredited threshold criteria for mortality, recoverable injury and TTS (Popper et al. 2014)

Type of Fish	Mortality & potentially fatal injury	Recoverable injury*	TTS
No swim bladder (particle motion detection)	219 dB SEL_{cum} or 213 dB Lpk	216 dB SEL_{cum} or 213 dB Lpk	186 dB SEL_{cum}
Swim bladder is not involved in hearing (particle motion detection)	210 dB SEL_{cum} or 207 dB Lpk	203 dB SEL_{cum} or 207 dB Lpk	186 dB SEL_{cum}
Swim bladder involved in hearing (primarily pressure detection)	207 dB SEL_{cum} or 207 dB Lpk	203 dB SEL_{cum} or 207 dB Lpk	186 dB SEL_{cum}

*It is important to note that recoverable injury was deemed possible in controlled laboratory conditions therefore do not consider the fact some recoverable injuries could lead indirectly to mortality or reducing an animal's net fitness, even if temporarily (Popper et al. 2014).

Modelling cumulative noise effects

There exists a possibility of both percussive piling and dredging to occur at the same time. To test if cumulative noise effects may occur during these times, a simple scenario was constructed whereby two point-sources were modelled that represented the percussive piling and dredging.

Because the distances between the piling and dredging locations within NPL's project far exceed that of the neighbouring channel deepening project by Channel Infrastructure, the closest distance between the piling by NPL and dredging by Channel Infrastructure were used. This was approximately 400m (**Figure 9**).

BHD and CSD dredgers are the types to be used by Channel Infrastructure and the noise from the bucket-impact during the use of the large BHD *New York* was used. This was because it was the loudest phase of the production cycles between the two dredger types (**Figure 6**). The dredger was placed at the limits of their consented area.

The percussive piling was the same as that used in this assessment, placed near the edge of NPL's project area.

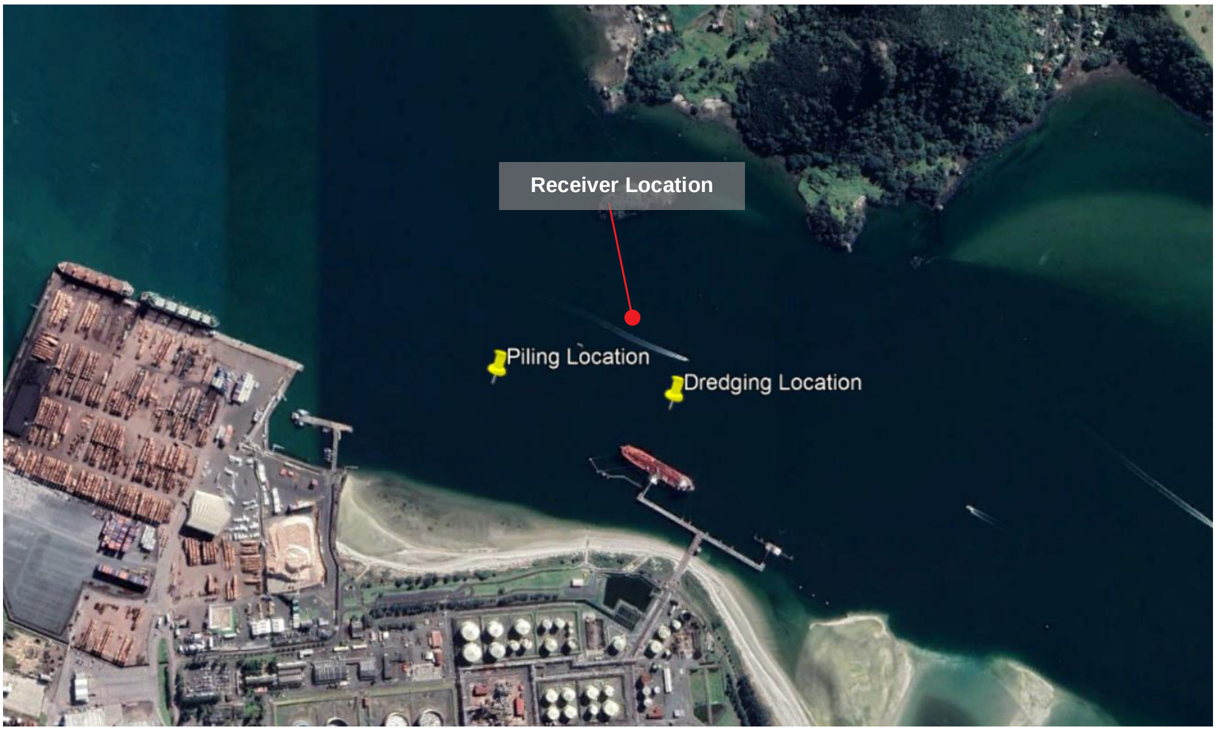

Figure 9 Locations of the percussive piling and dredger used in the cumulative noise modelling. The receiver location is where the modelled spectra were taken to test if any cumulative effects.

Three scenarios were modelled:

1. Dredging only, occurring at the Dredging Location in **Figure 9**.
2. Percussive piling only, occurring at the Piling Location in **Figure 9**.
3. Both the dredging and percussive piling together.

Results were compared from a single receiver location (**Figure 9**) from each of the three model scenarios and plotted in **Figure 10**.

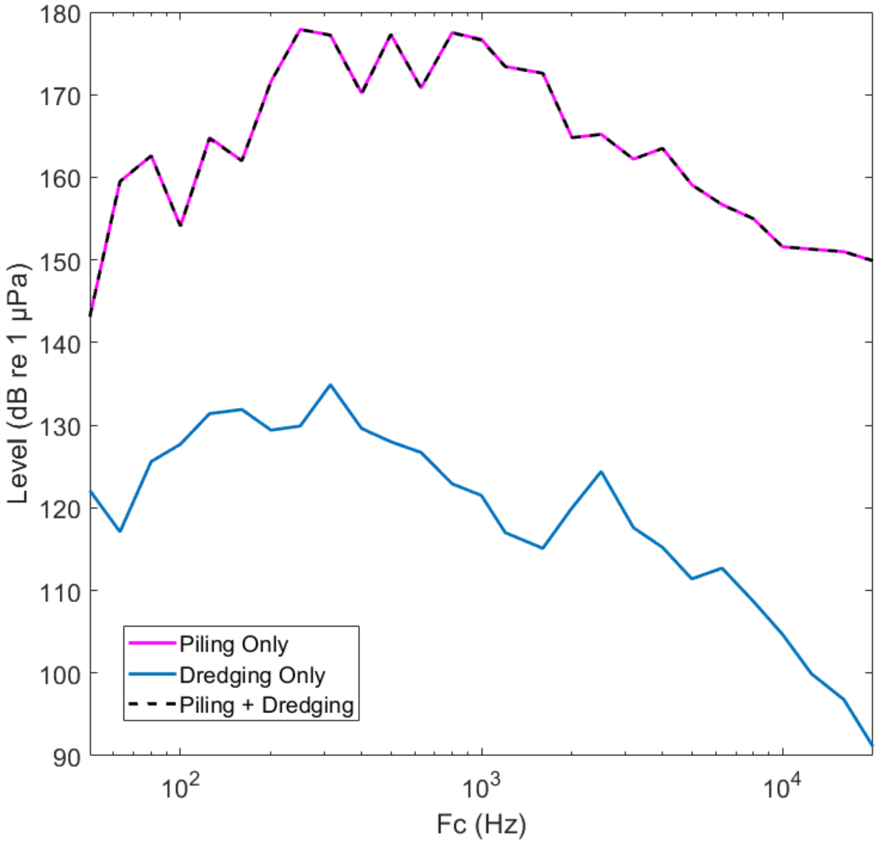

Figure 10 Received levels from each of the three scenarios modelled to test for cumulative effects.

The results show no cumulative noise effects from the dredging occurring at the same time as the percussive piling. This can be explained by the ranges and propagation pathways between the two sources and the substantial differences in the noise sources themselves (dynamics and amplitude).

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Appendix E Noise effects contours

Figure 11 Contours showing the ranges within which the potential onset of permanent threshold shift (PTS) for each functional hearing group of marine mamamls from the percussive piling within the reclamation area.

Figure 12: Contours showing the ranges within which the potential onset of temporary threshold shift (TTS) for each functional hearing group of marine mammals from the percussive piling within the reclamation area.

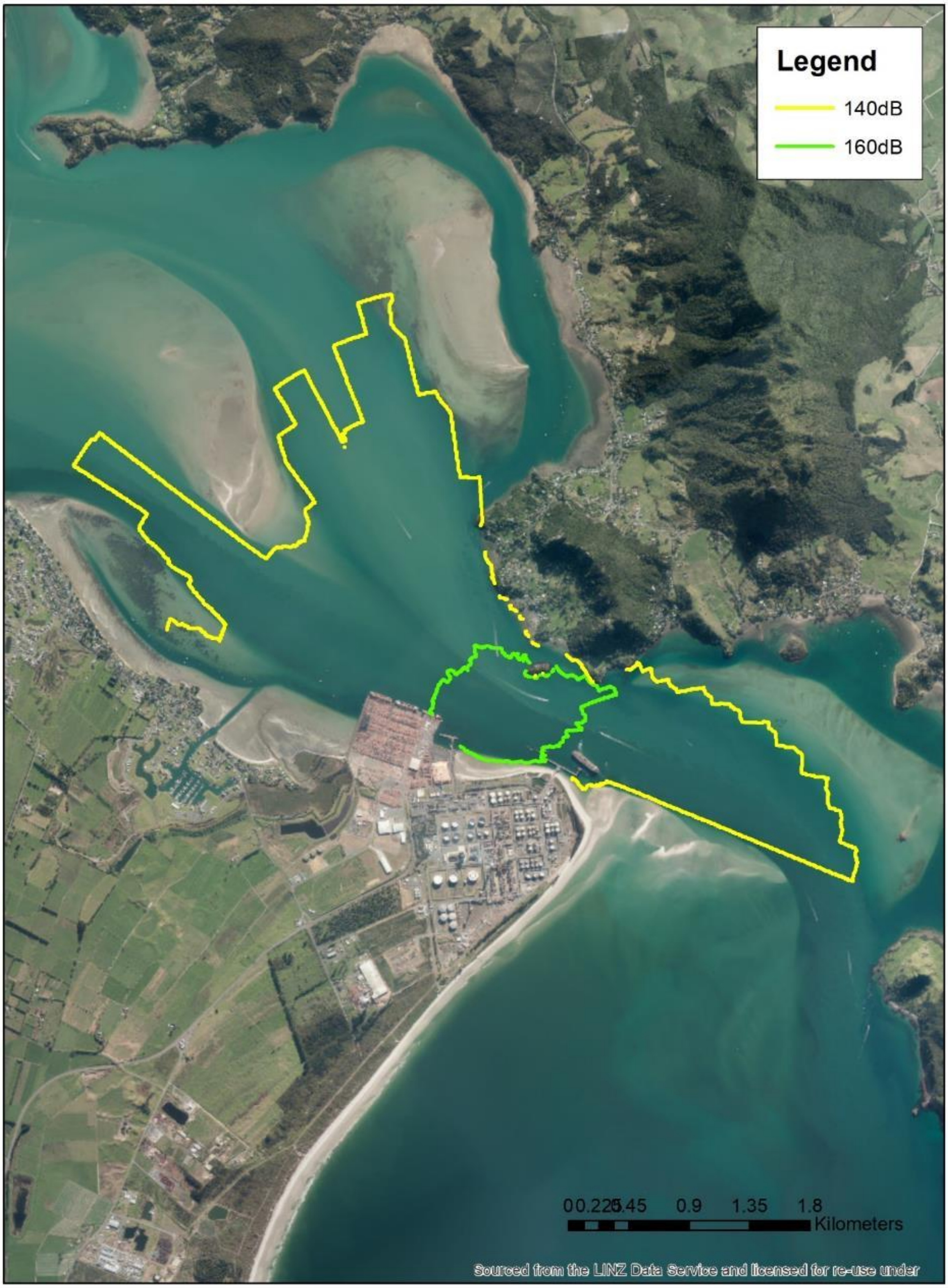

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Figure 13: Contours showing the ranges within which the potential onset of behavioural responses from the percussive piling within the reclamation area.

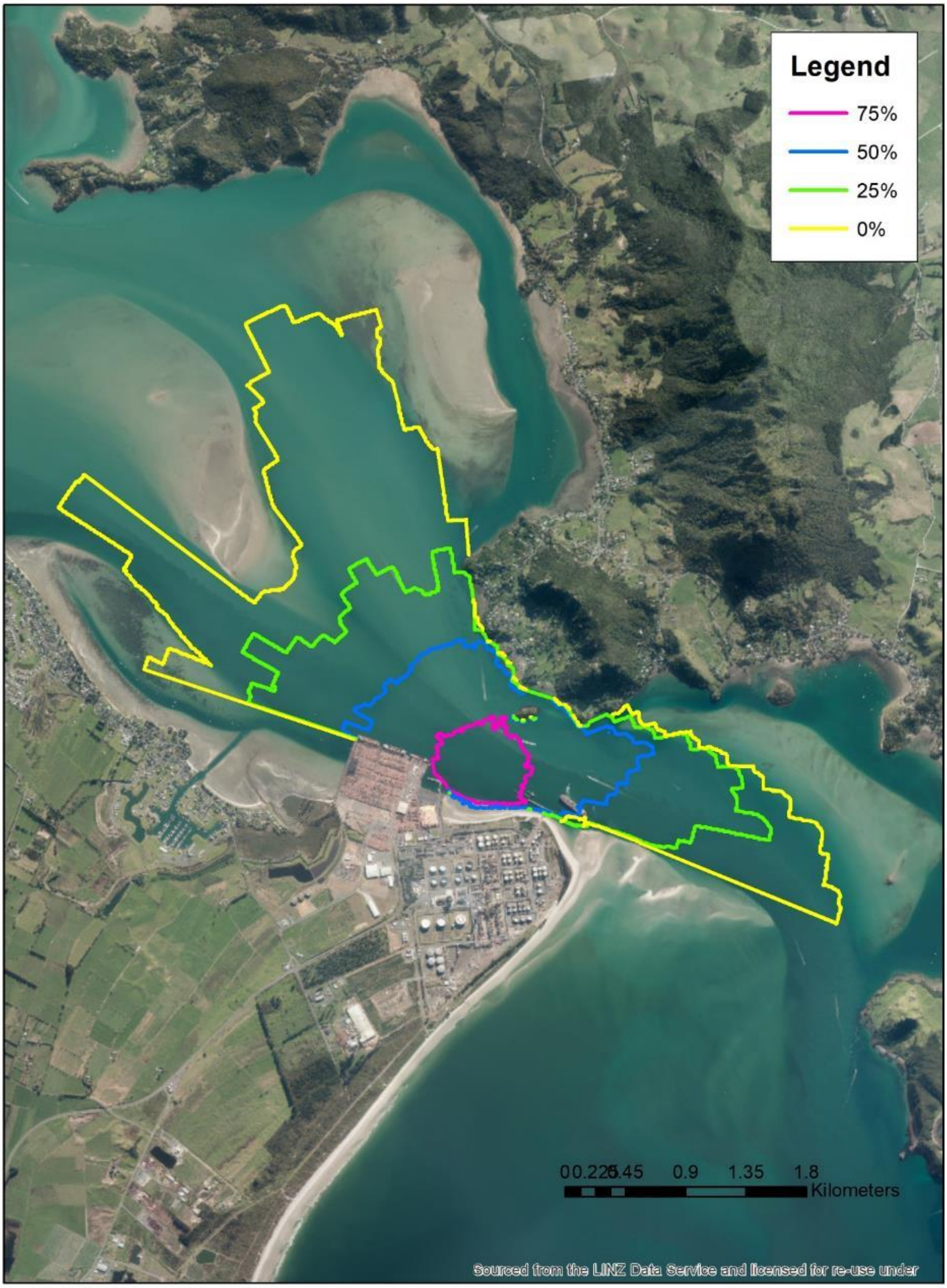

Figure 14: Map showing the extent of listening space reduction (LSR) for dolphins during the percussive piling within the reclamation area.

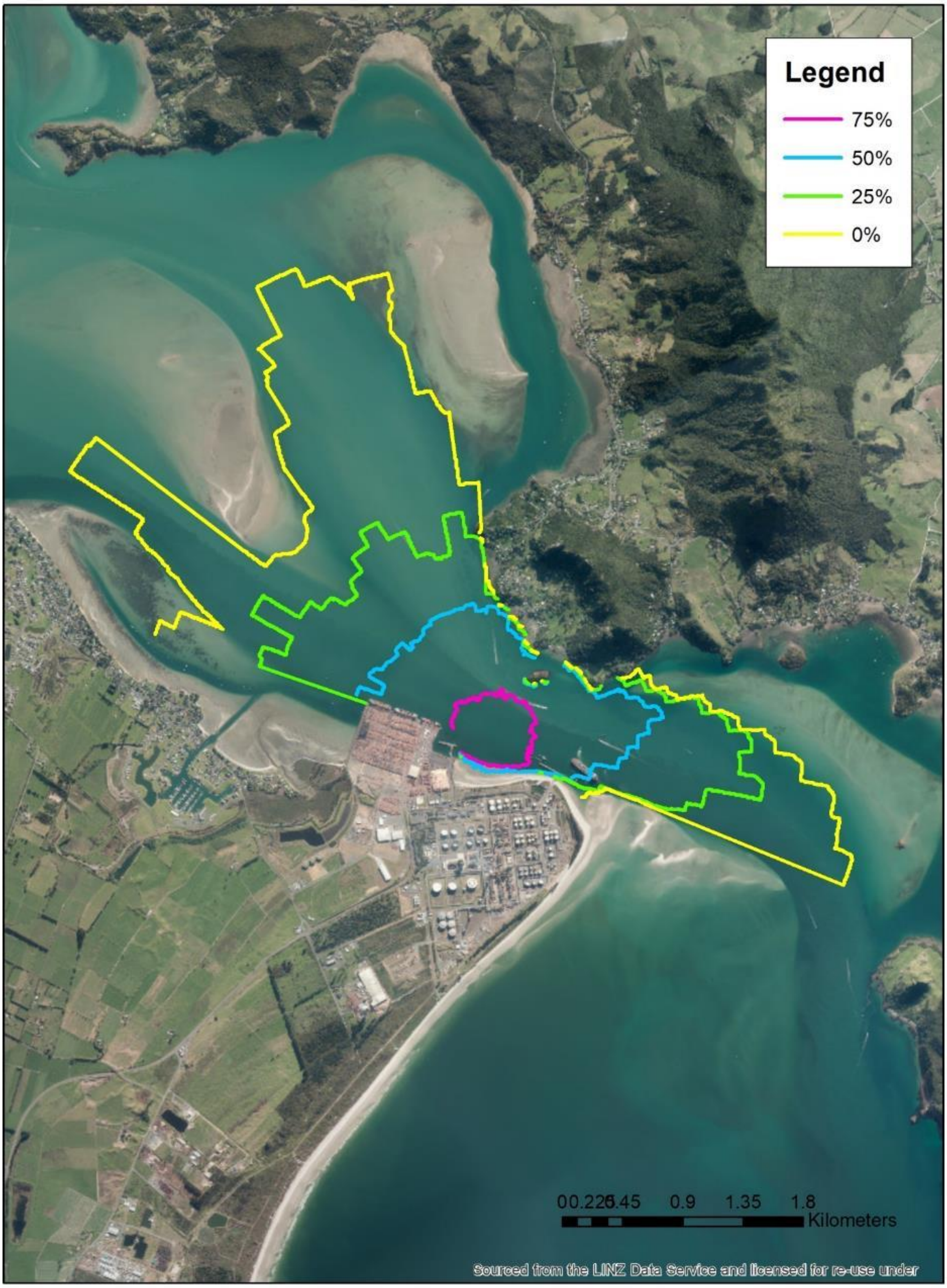

Figure 15: Map showing the extent of listening space reduction (LSR) for killer whales during the percussive piling within the reclamation area.

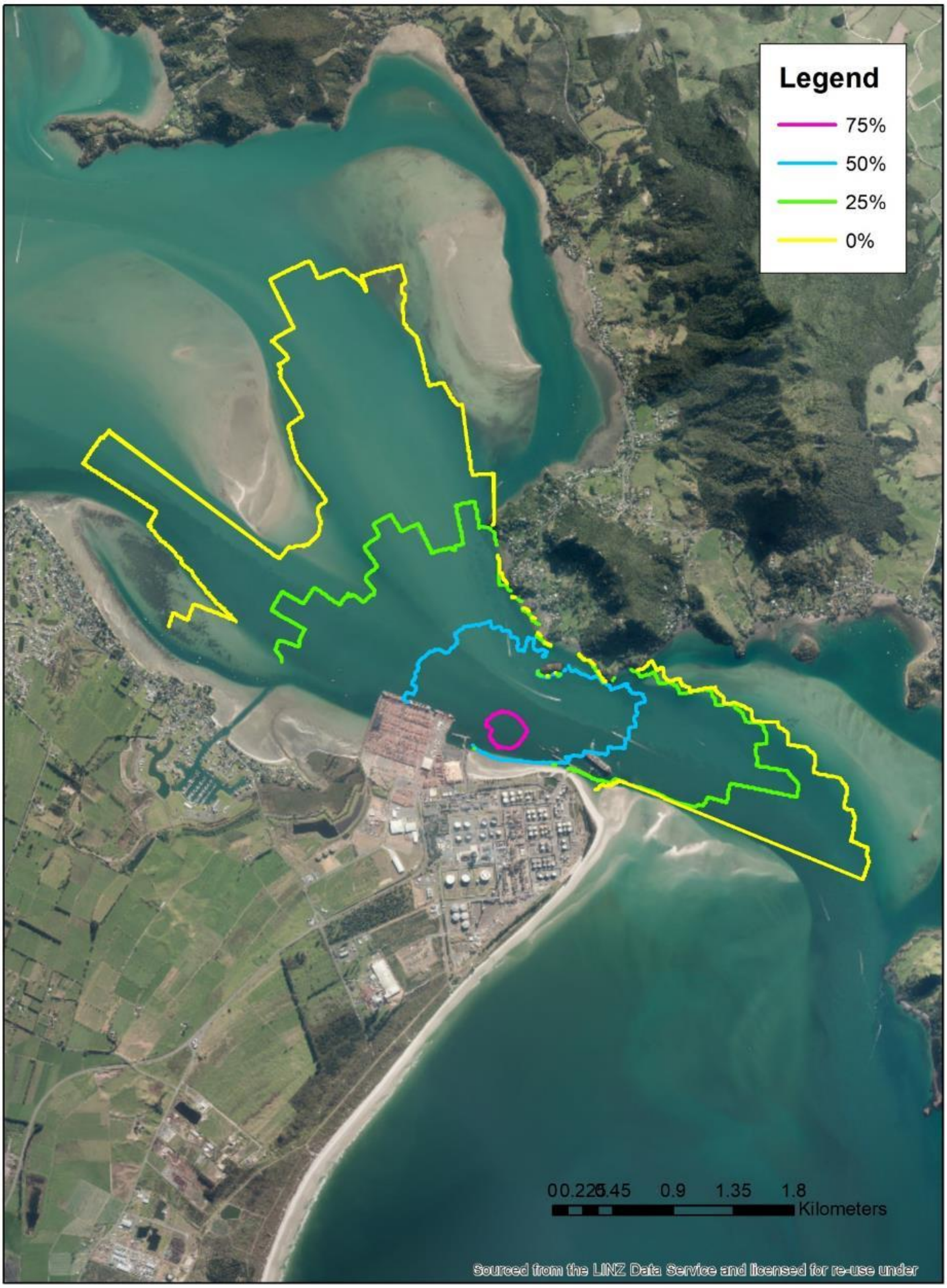

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Figure 16: Map showing the extent of listening space reduction (LSR) for mystecete whales during the percussive piling within the reclamation area.

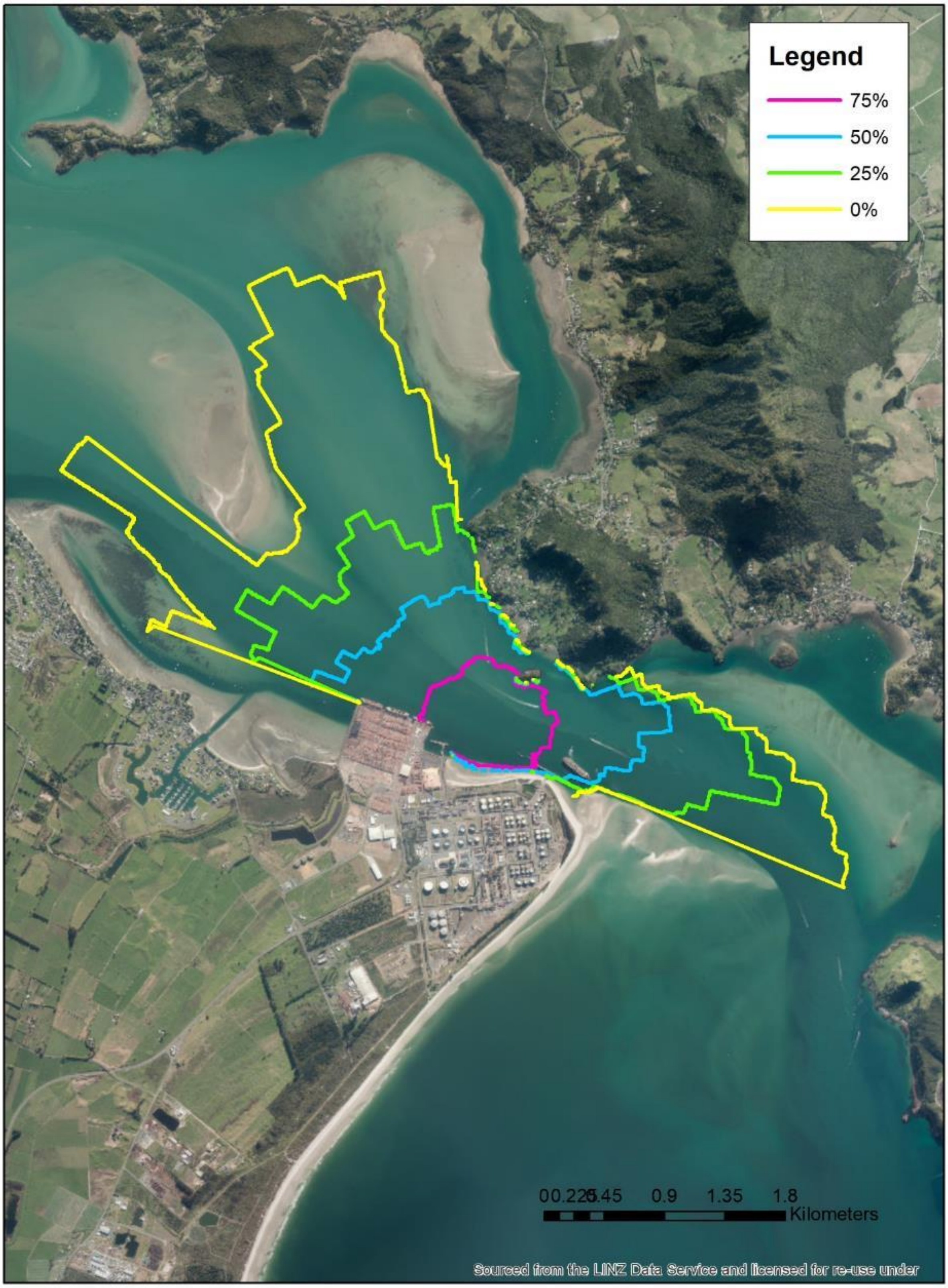

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Figure 17: Map showing the extent of listening space reduction (LSR) for fur seals during the percussive piling within the reclamation area.

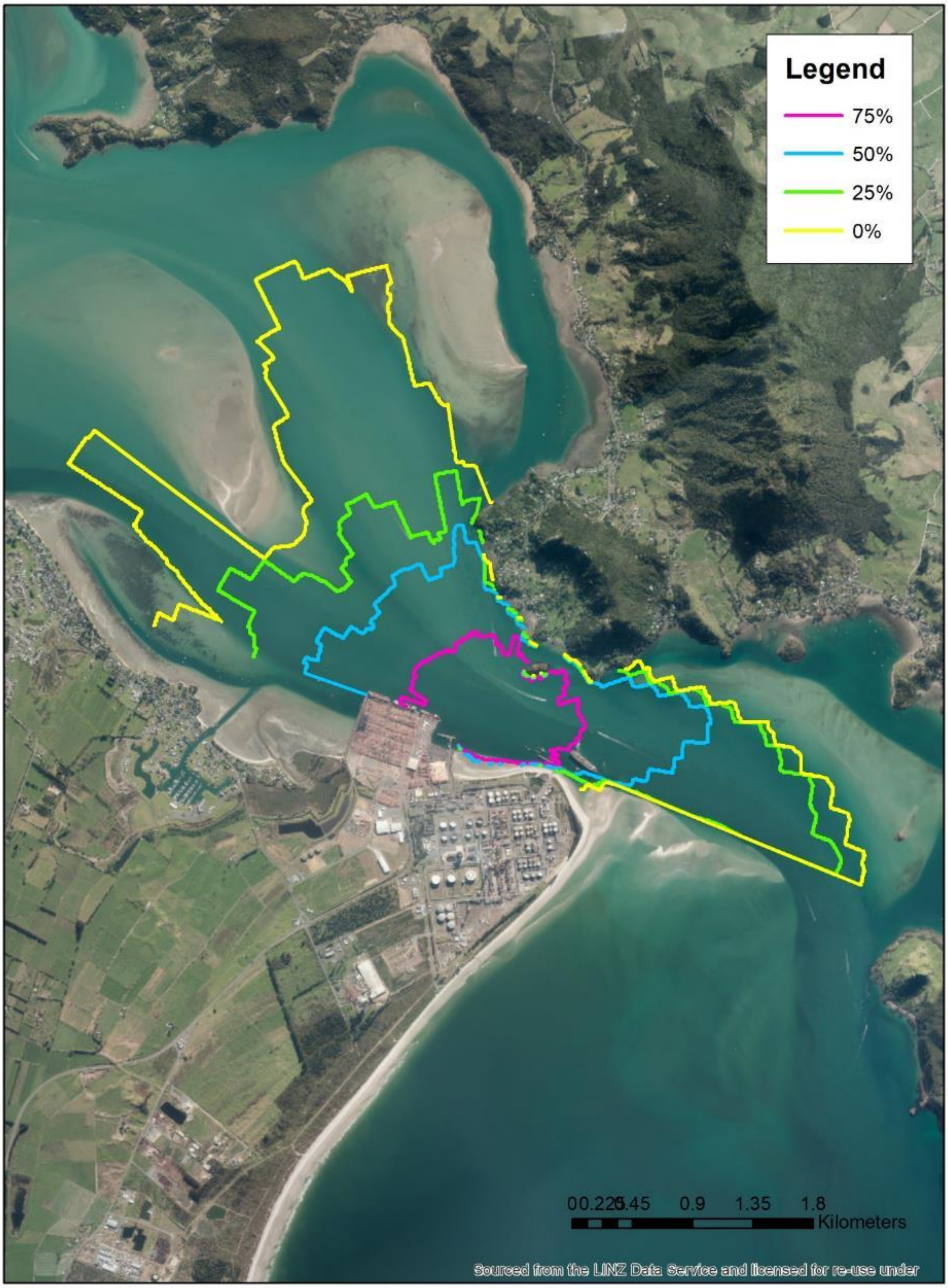

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Figure 18: Map showing the extent of listening space reduction (LSR) for leopard seals during the percussive piling within the reclamation area.

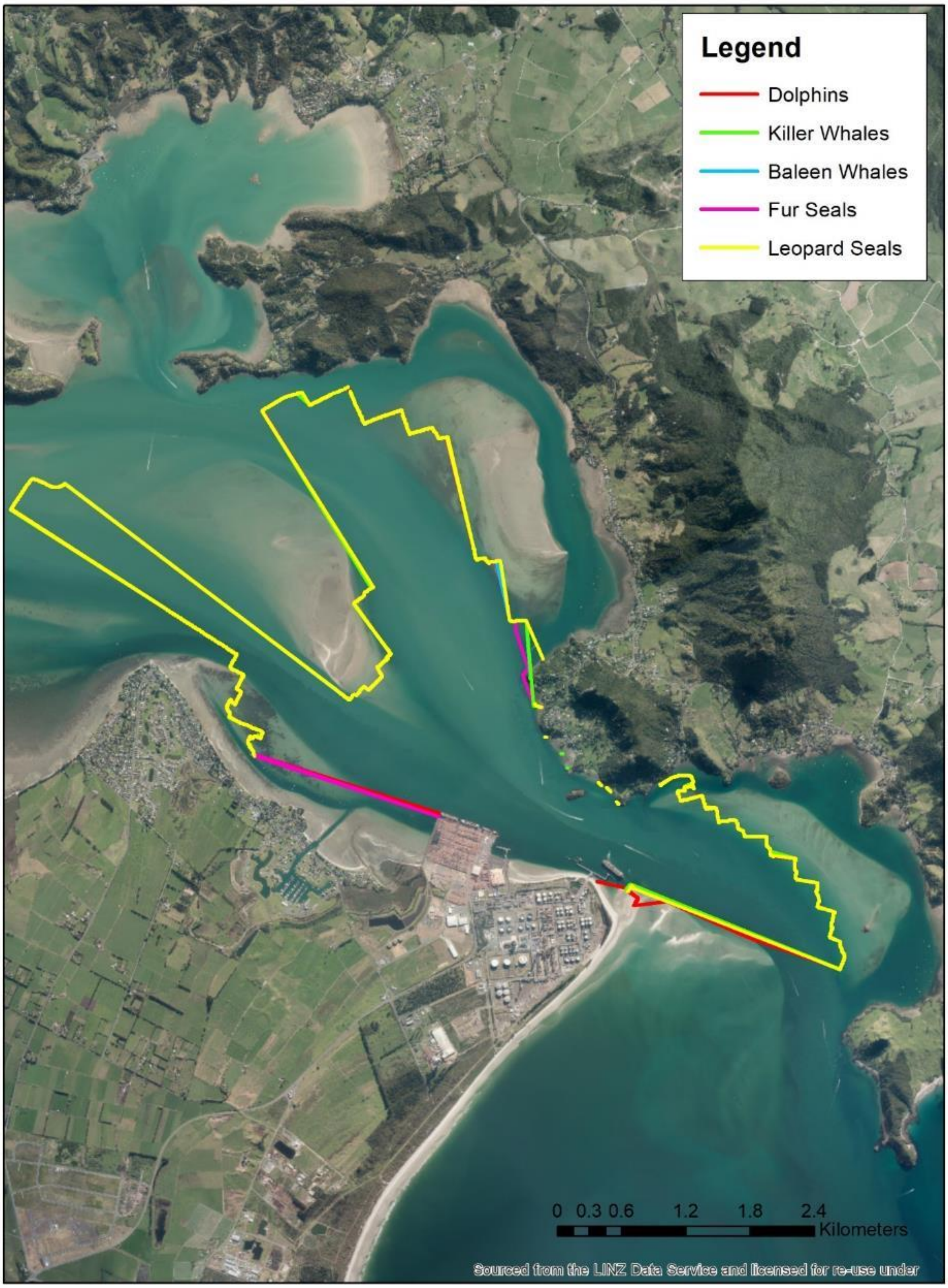

Figure 19: Plots showing the audibility limits for all species during the percussive piling in the reclamation area.

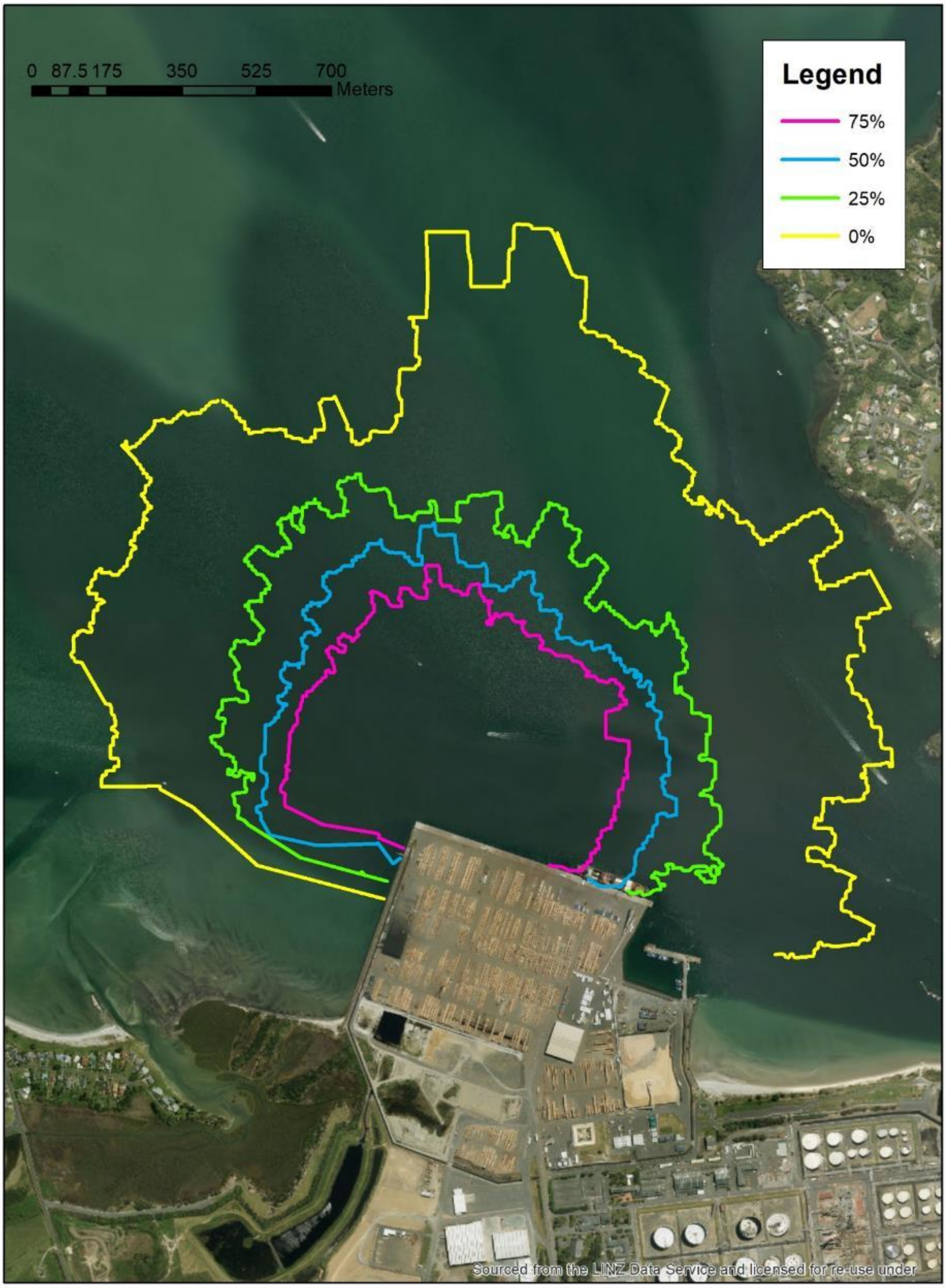

Figure 20 Low severity behavioural response risk for dolphin species during dredging using a TSHD dredger.

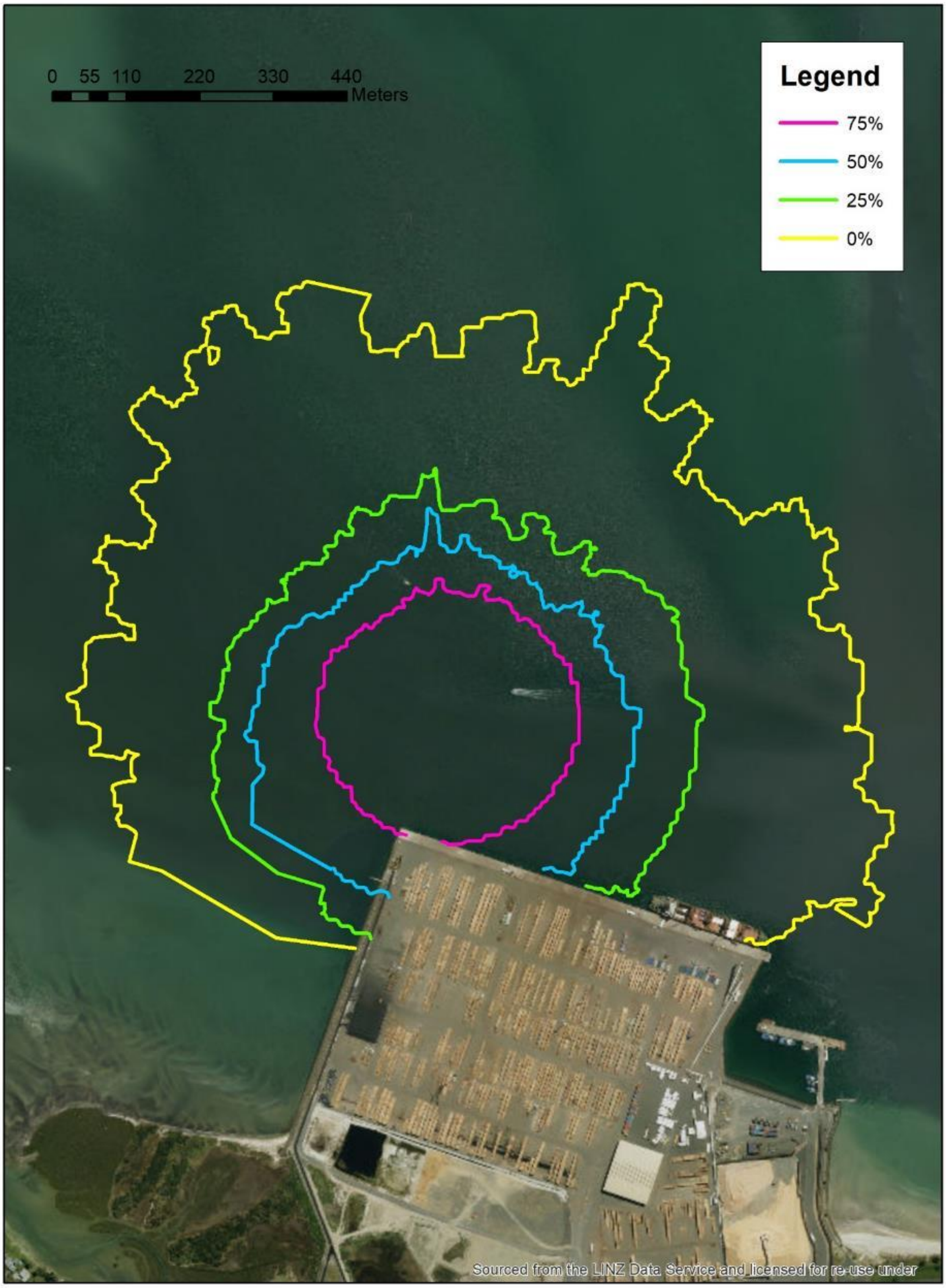

Figure 21 Moderate severity behavioural response risk for dolphin species during dredging using a TSHD dredger.

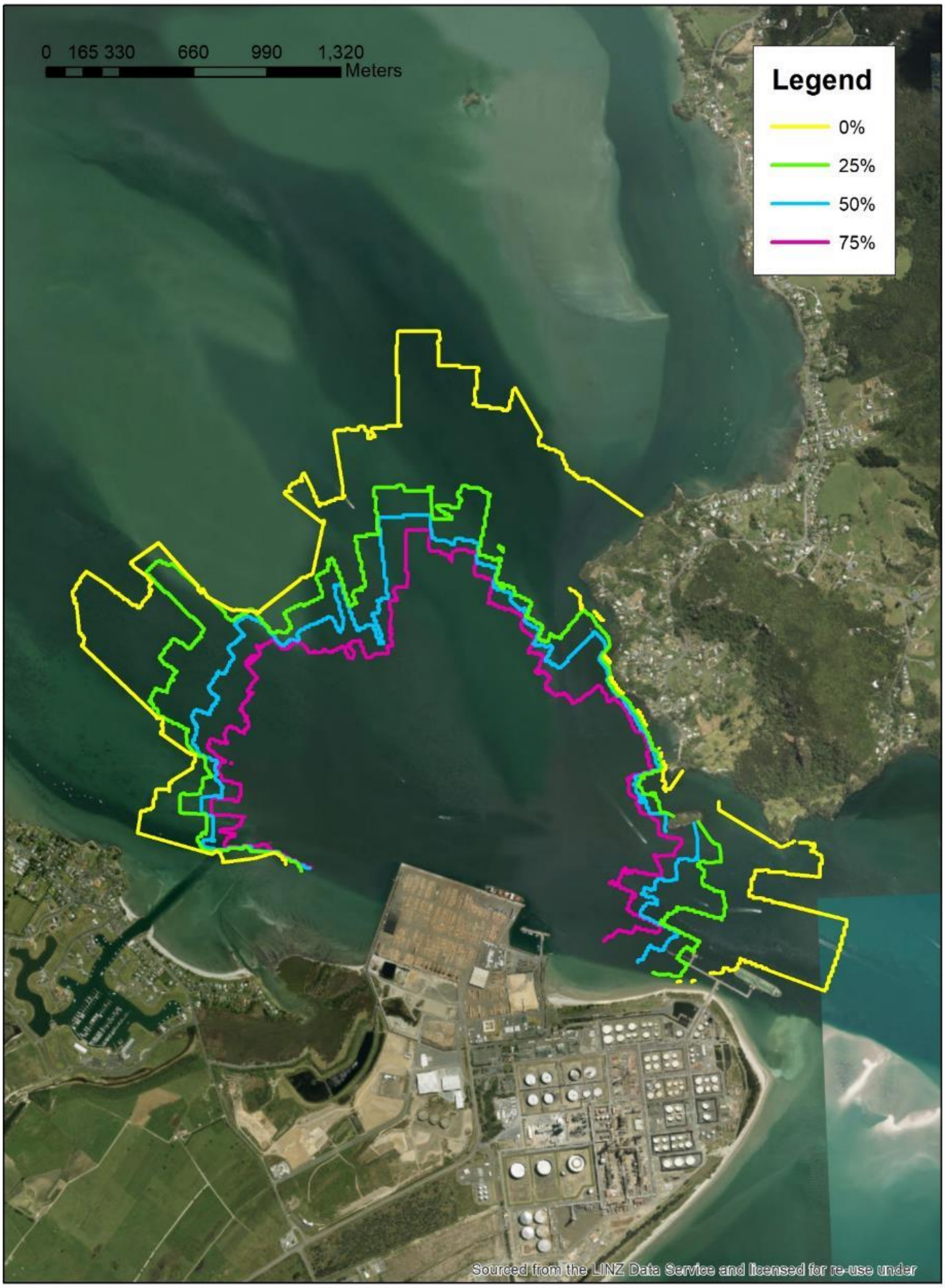

Figure 22 Low severity behavioural response risk for mystecete whales during dredging using a TSHD dredger.

Figure 23 Low and moderate severity behavioural response risk for seals (both fur and leopard seals) during dredging using a TSHD dredger.

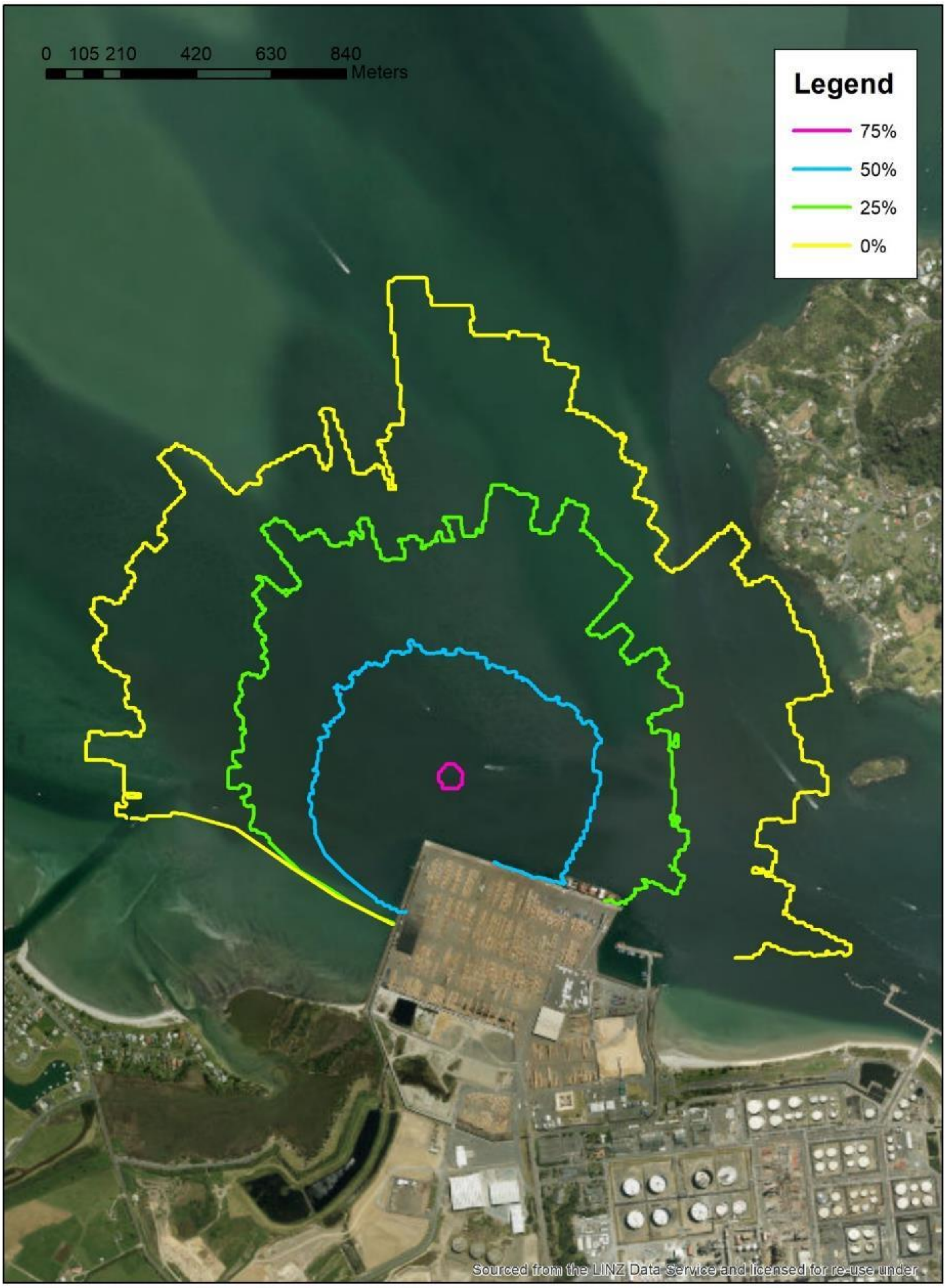

Figure 24 Map showing the extent of listening space reduction (LSR) for dolphins during dredging using a TSHD dredger.

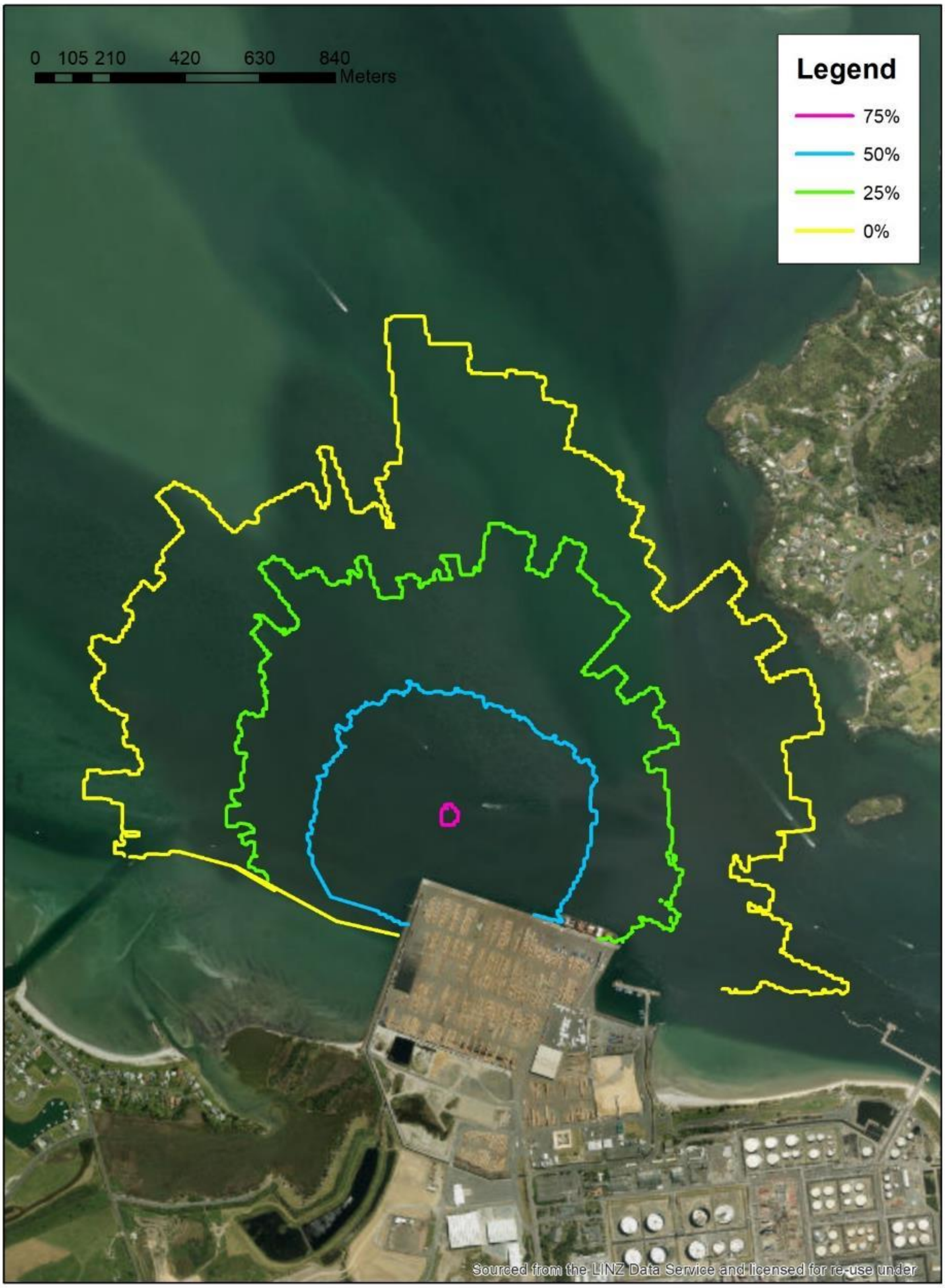

Figure 25 Map showing the extent of listening space reduction (LSR) for killer whales during dredging using a TSHD dredger.

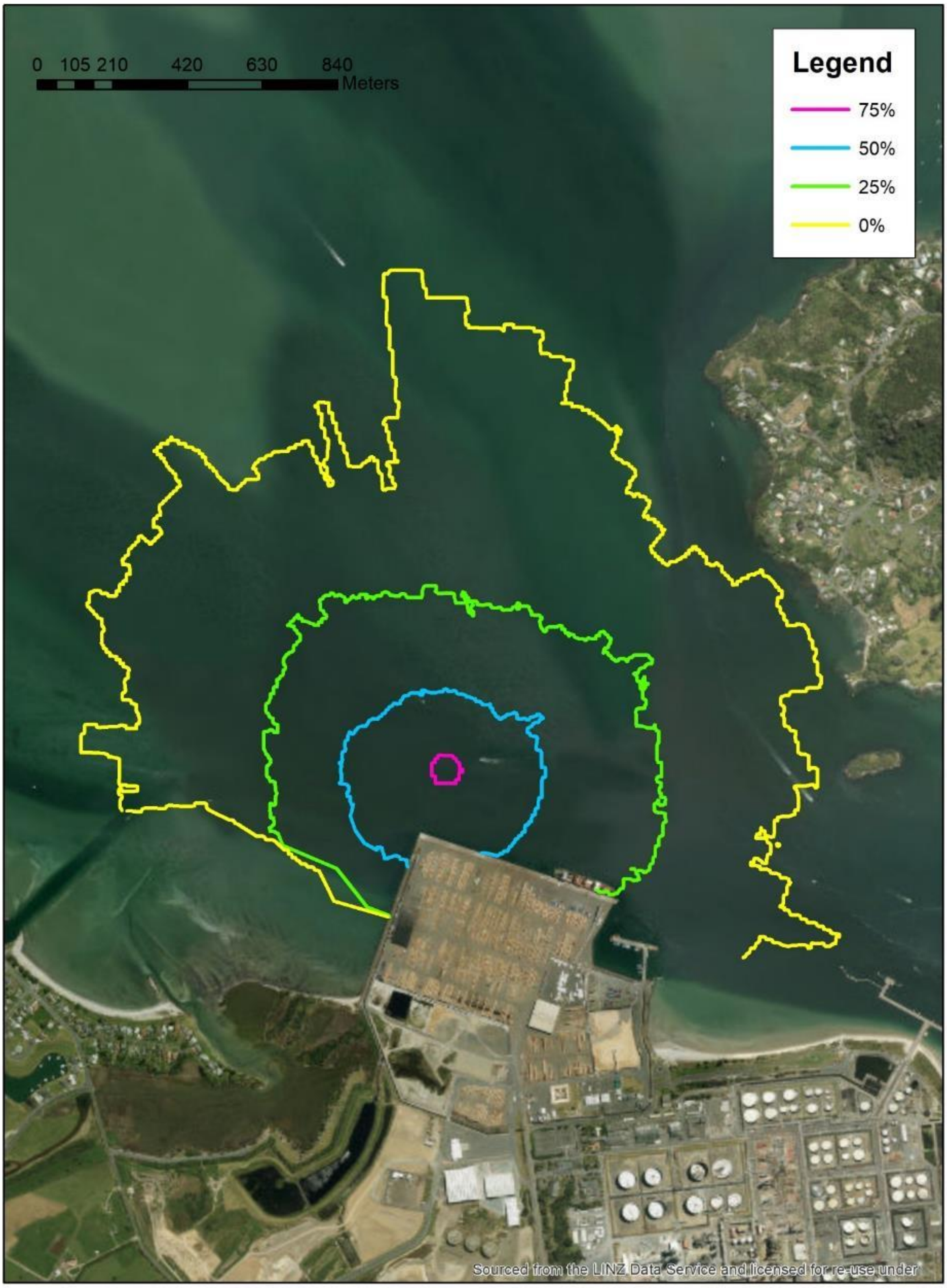

Figure 26 Map showing the extent of listening space reduction (LSR) for mystecete whales during dredging using a TSHD dredger.

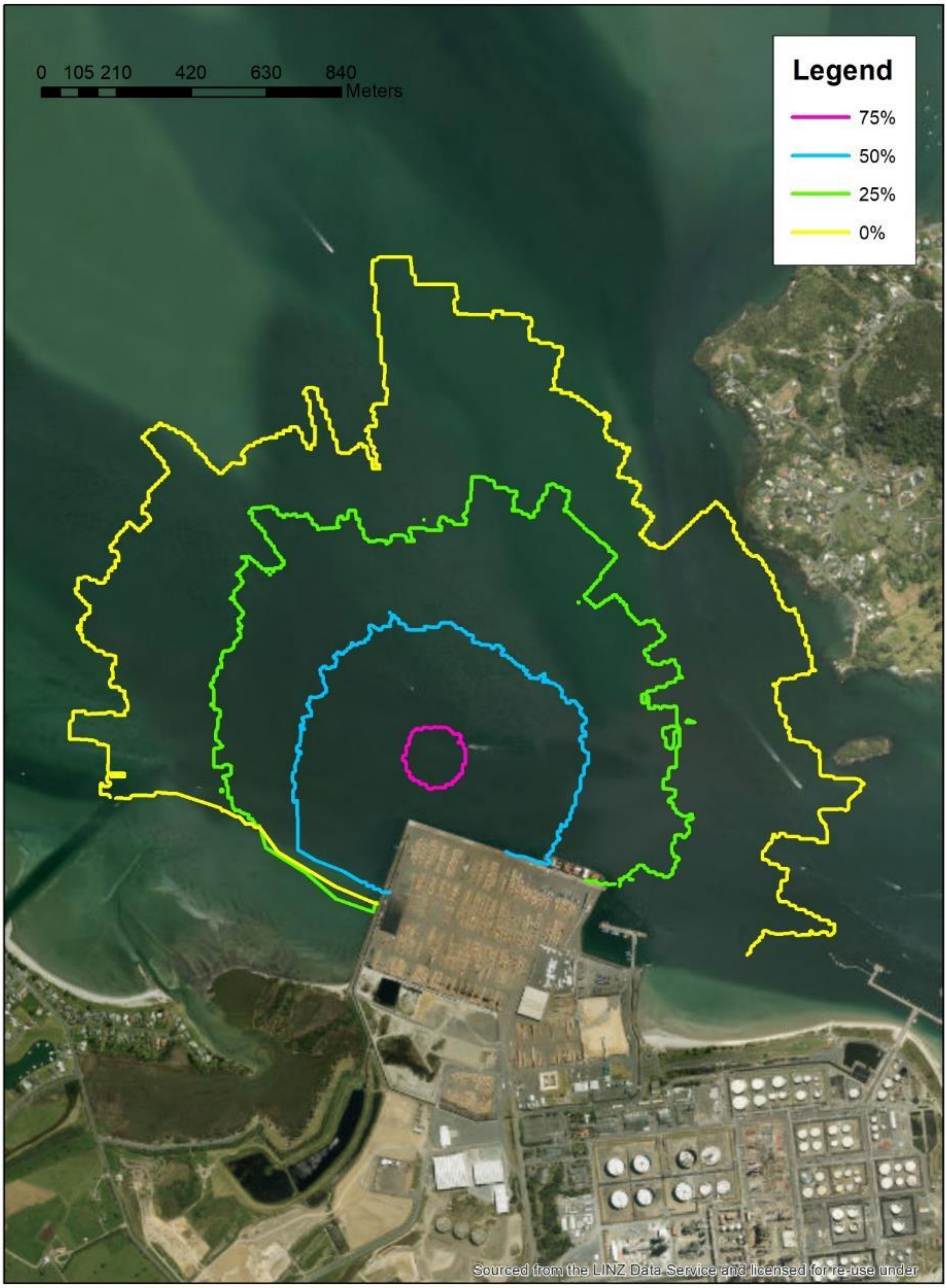

Figure 27 Map showing the extent of listening space reduction (LSR) for fur seals during dredging using a TSHD dredger.

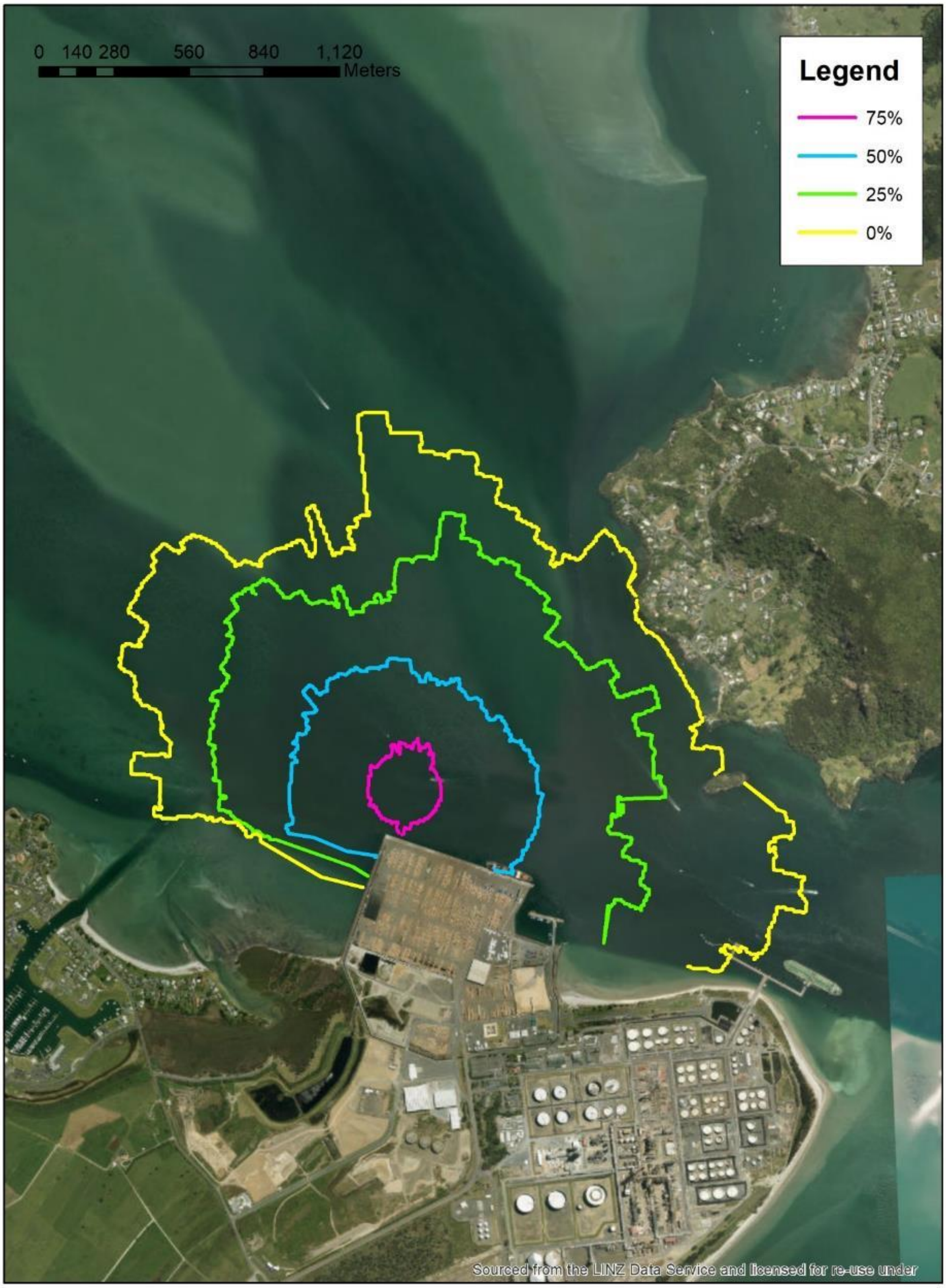

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Figure 28 Map showing the extent of listening space reduction (LSR) for leopard seals during dredging using a TSHD dredger.

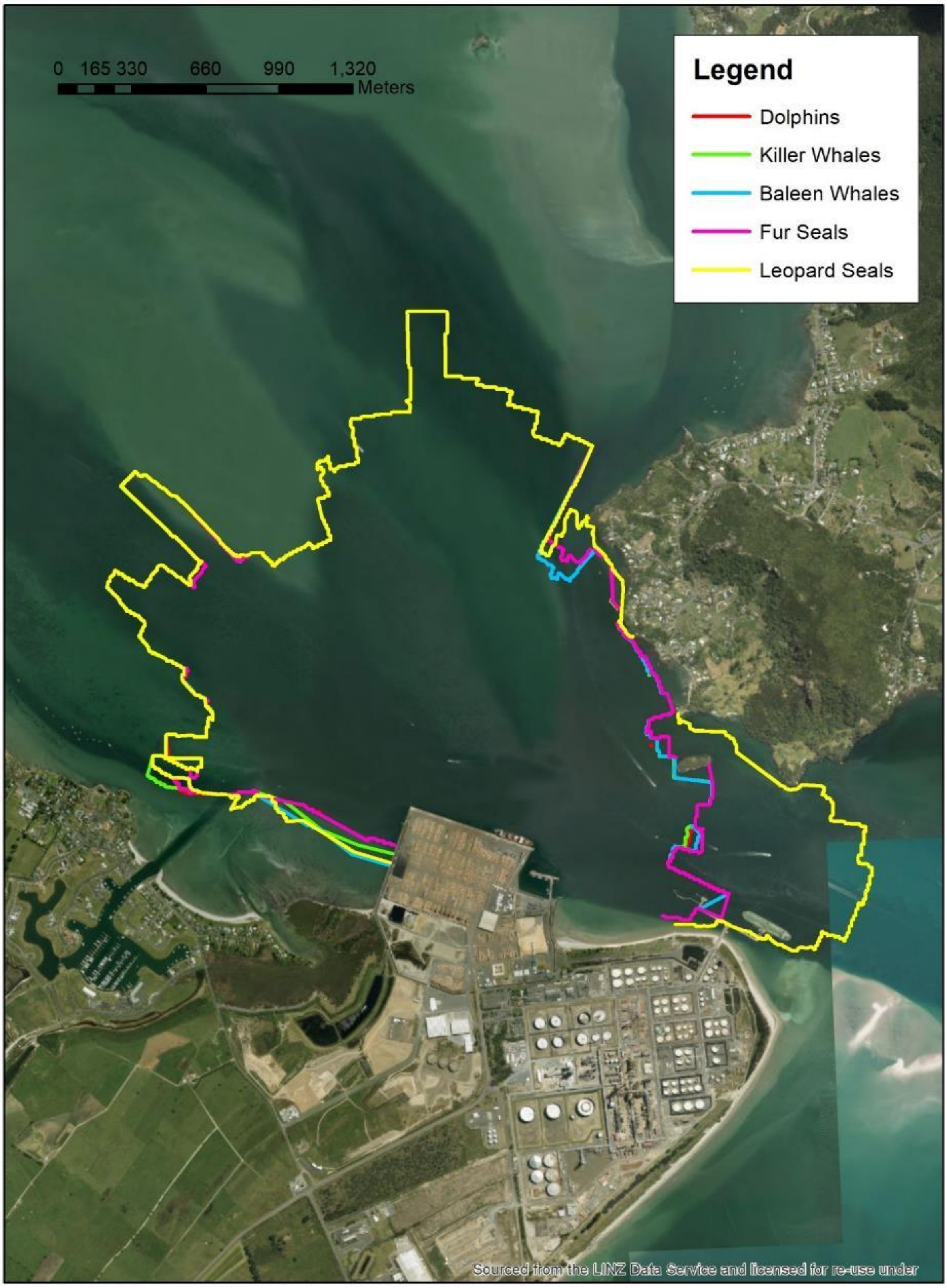

Figure 29 Plots showing the audibility limits for all species during dredging using a TSHD dredger.

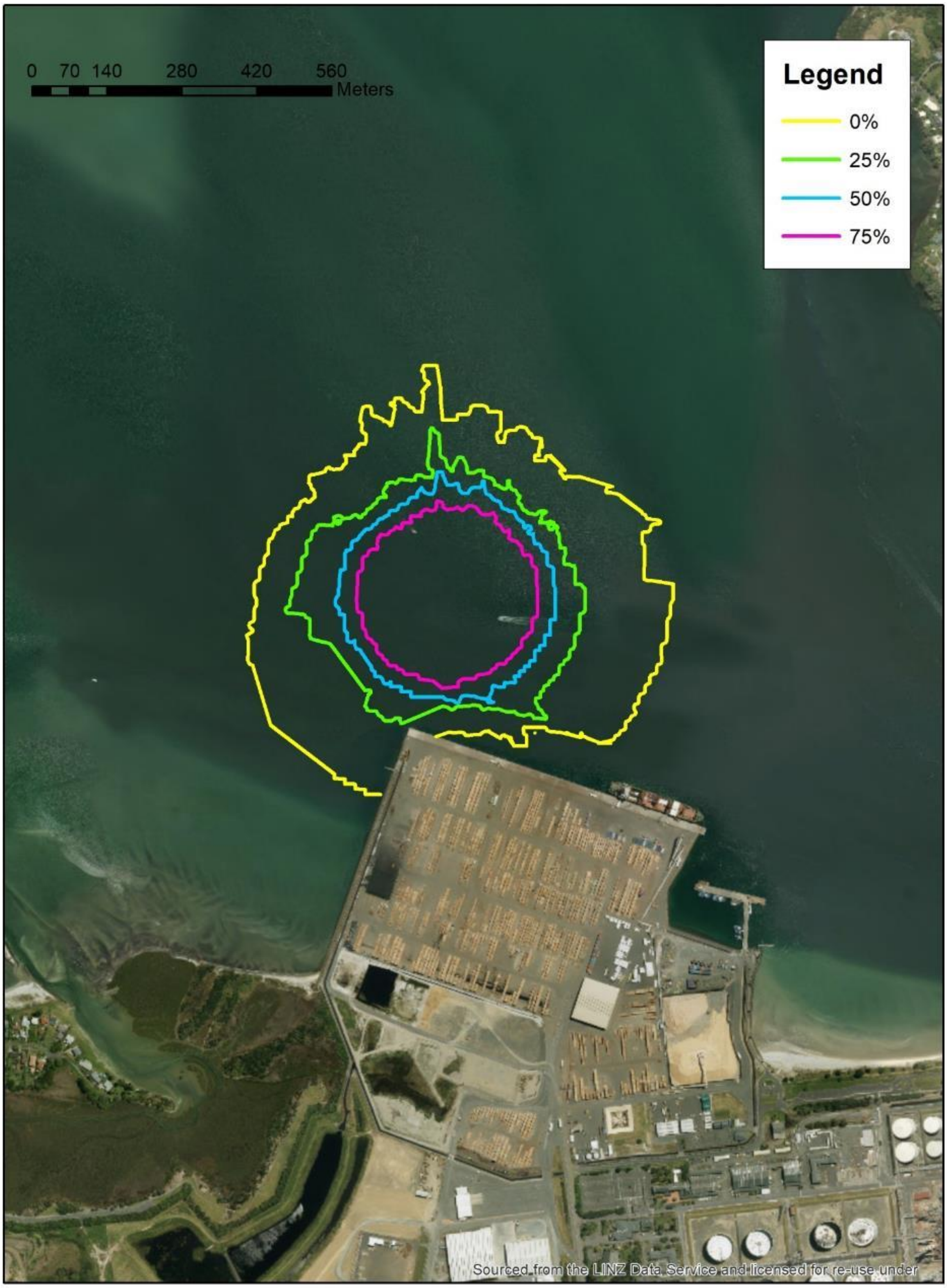

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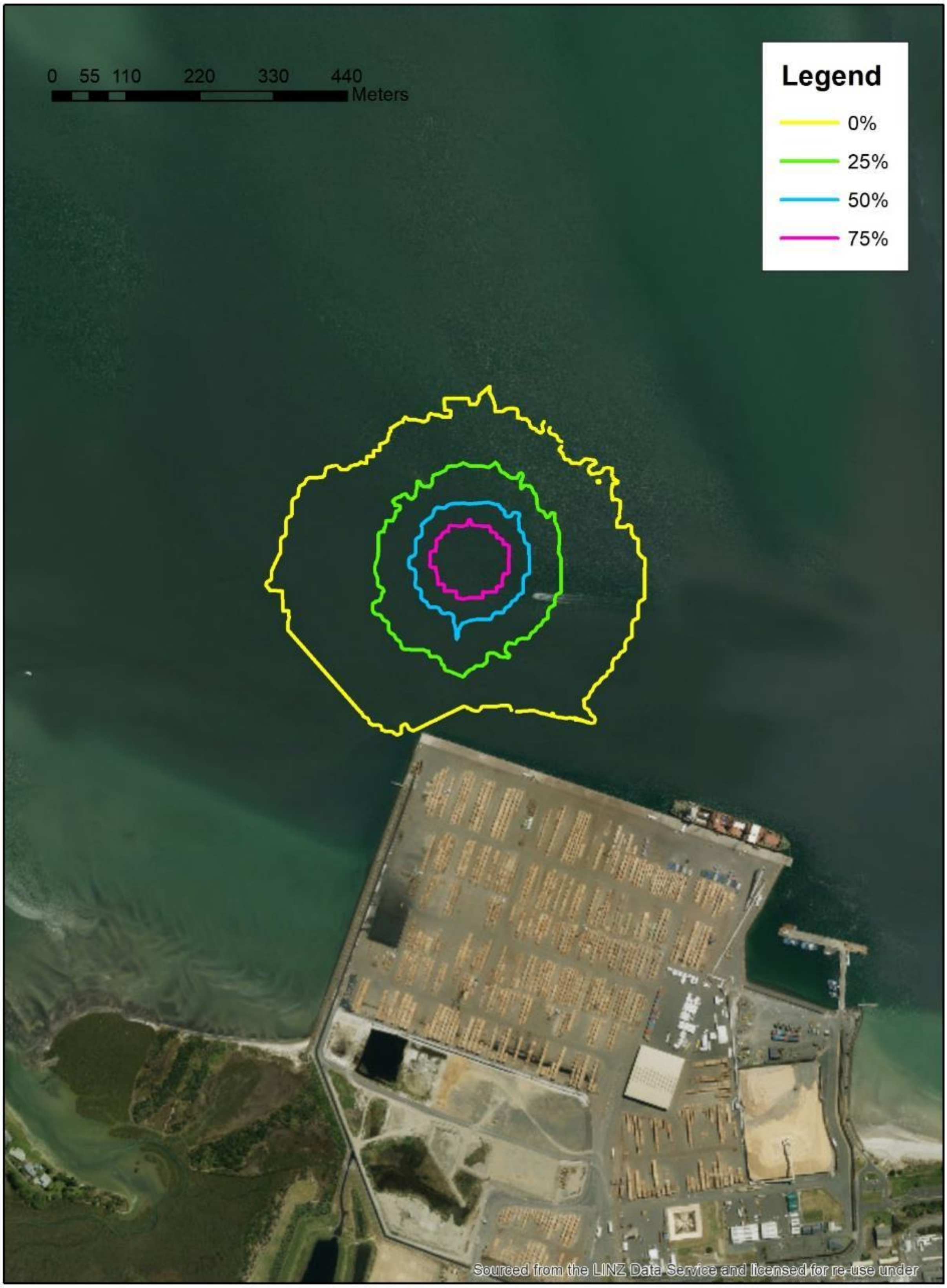
Figure 30: Low severity behavioural response risk for dolphin species during dredging using a cutter-suction dredger.



Sourced from the LINZ Data Service and licensed for re-use under

Figure 31: Moderate severity behavioural response risk for dolphin species during dredging using a cutter-suction dredger.

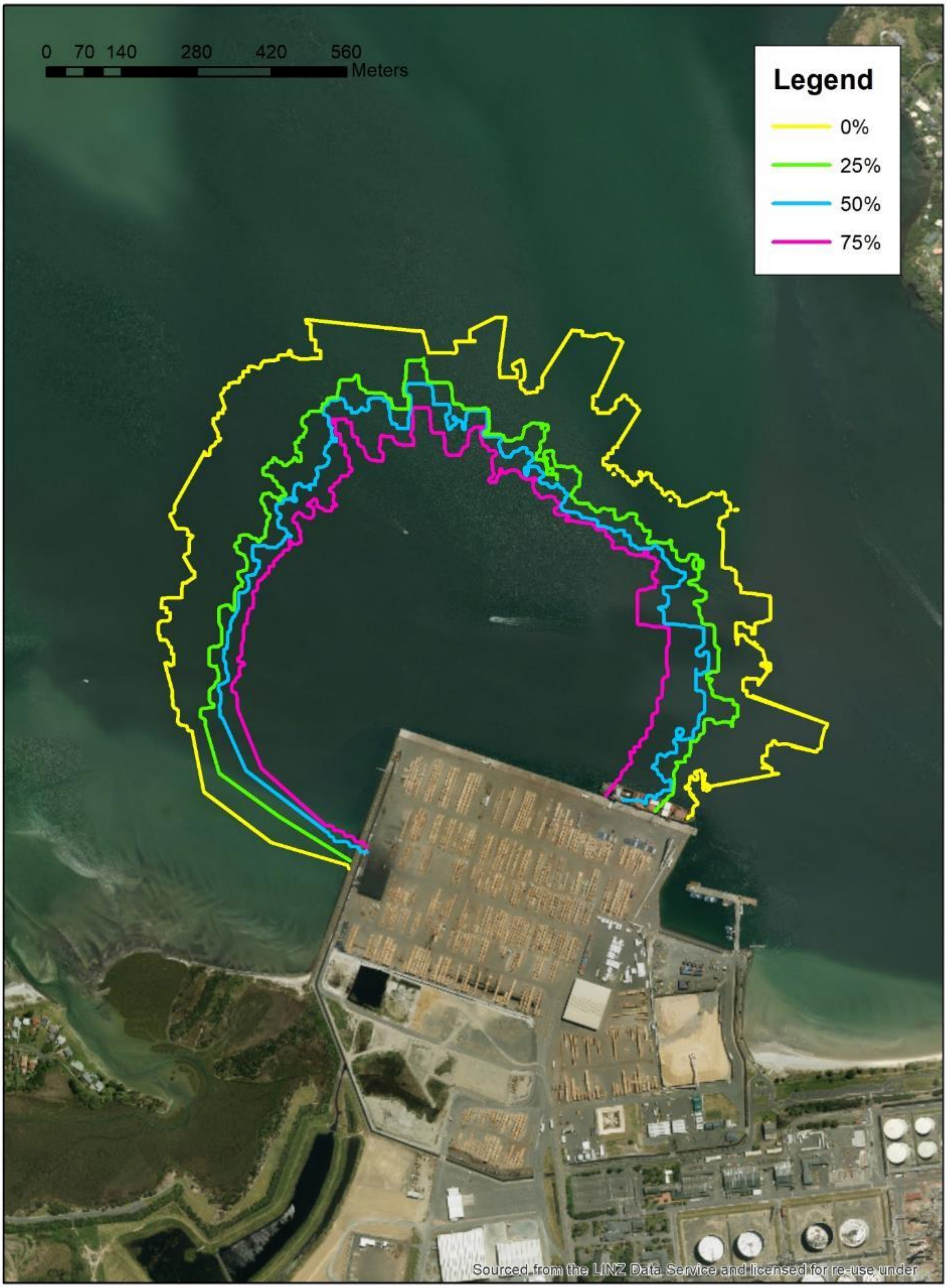


Figure 32: Low severity behavioural response risk for mystecete whales during dredging using a cutter-suction dredger.

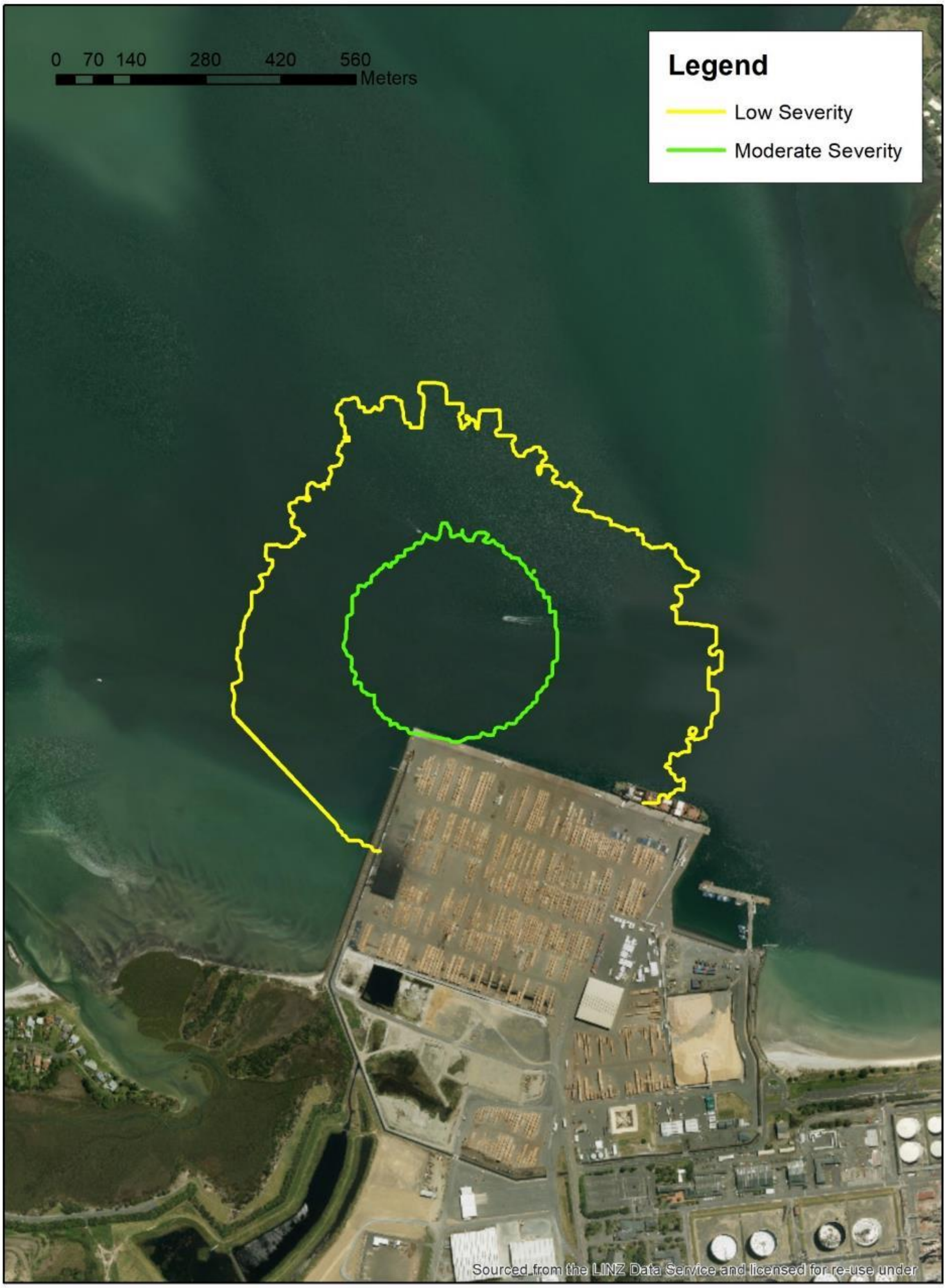


Figure 33: Low and moderate severity behavioural response risk for seals (both fur and leopard seals) during dredging using a cutter-suction dredger.

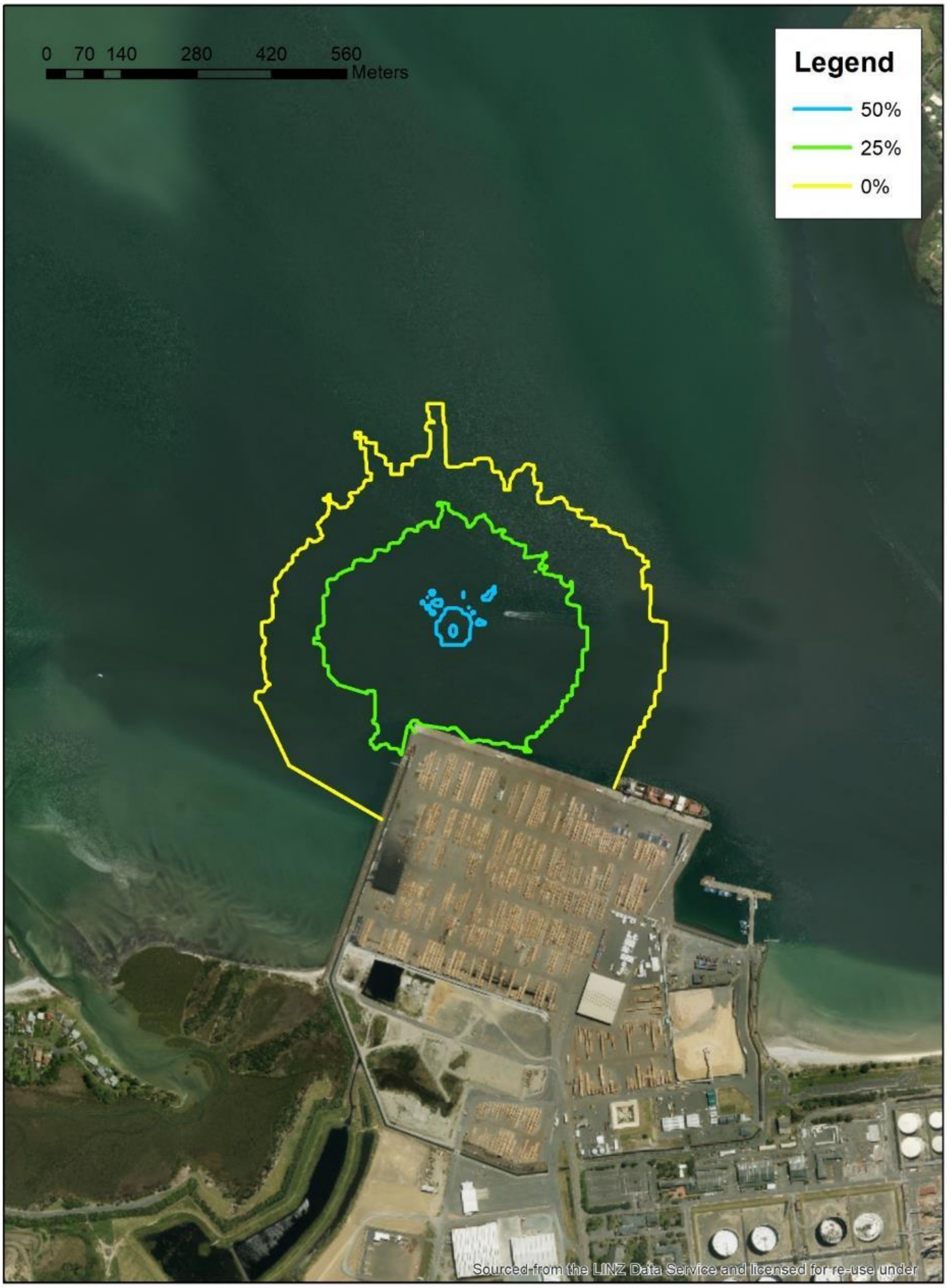


Figure 34: Map showing the extent of listening space reduction (LSR) for dolphins during dredging using a cutter-suction dredger.

Figure 35: Map showing the extent of listening space reduction (LSR) for killer whales during dredging using a cutter-suction dredger.

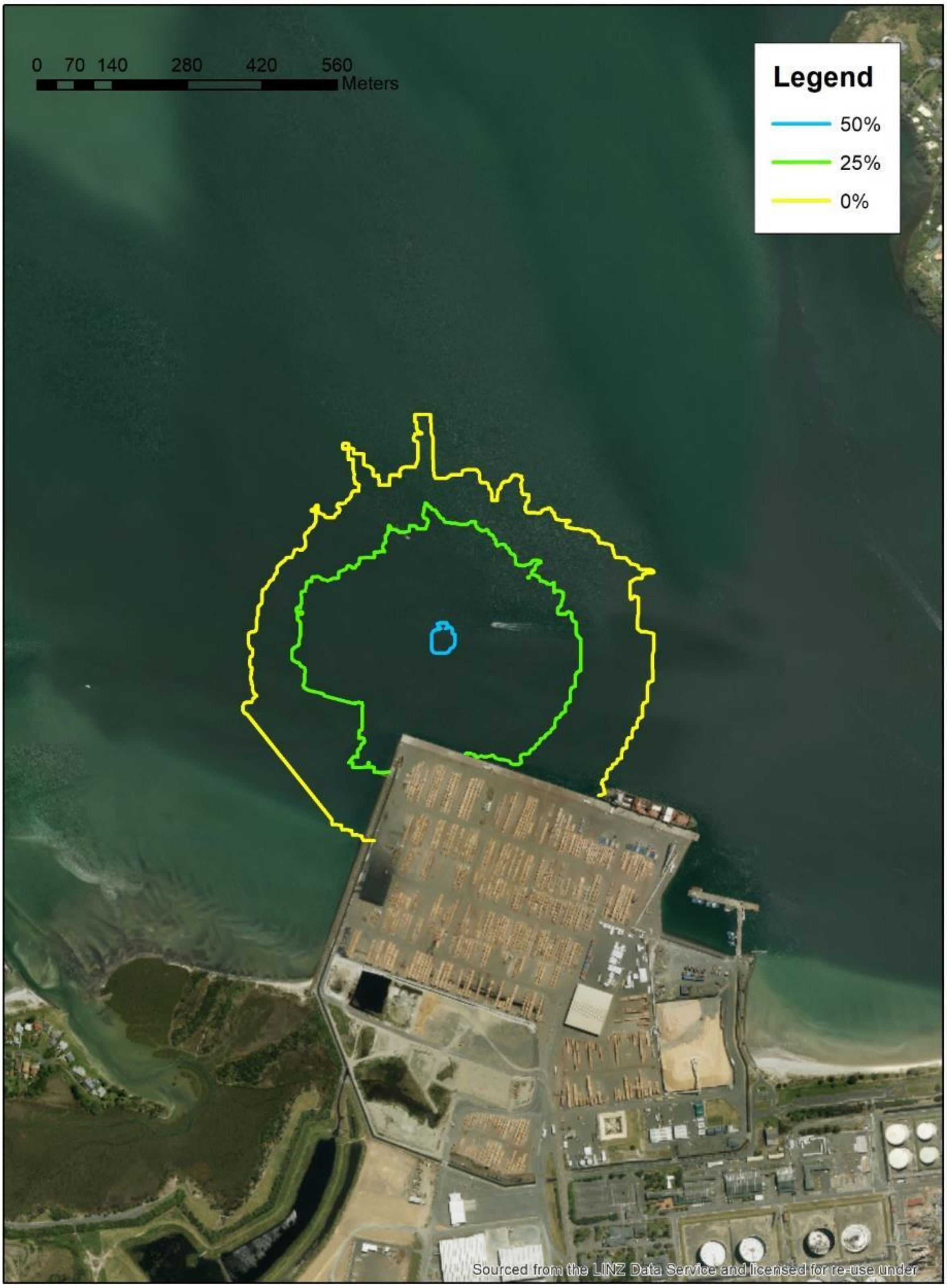


Figure 36: Map showing the extent of listening space reduction (LSR) for mystecete whales during dredging using a cutter-suction dredger.

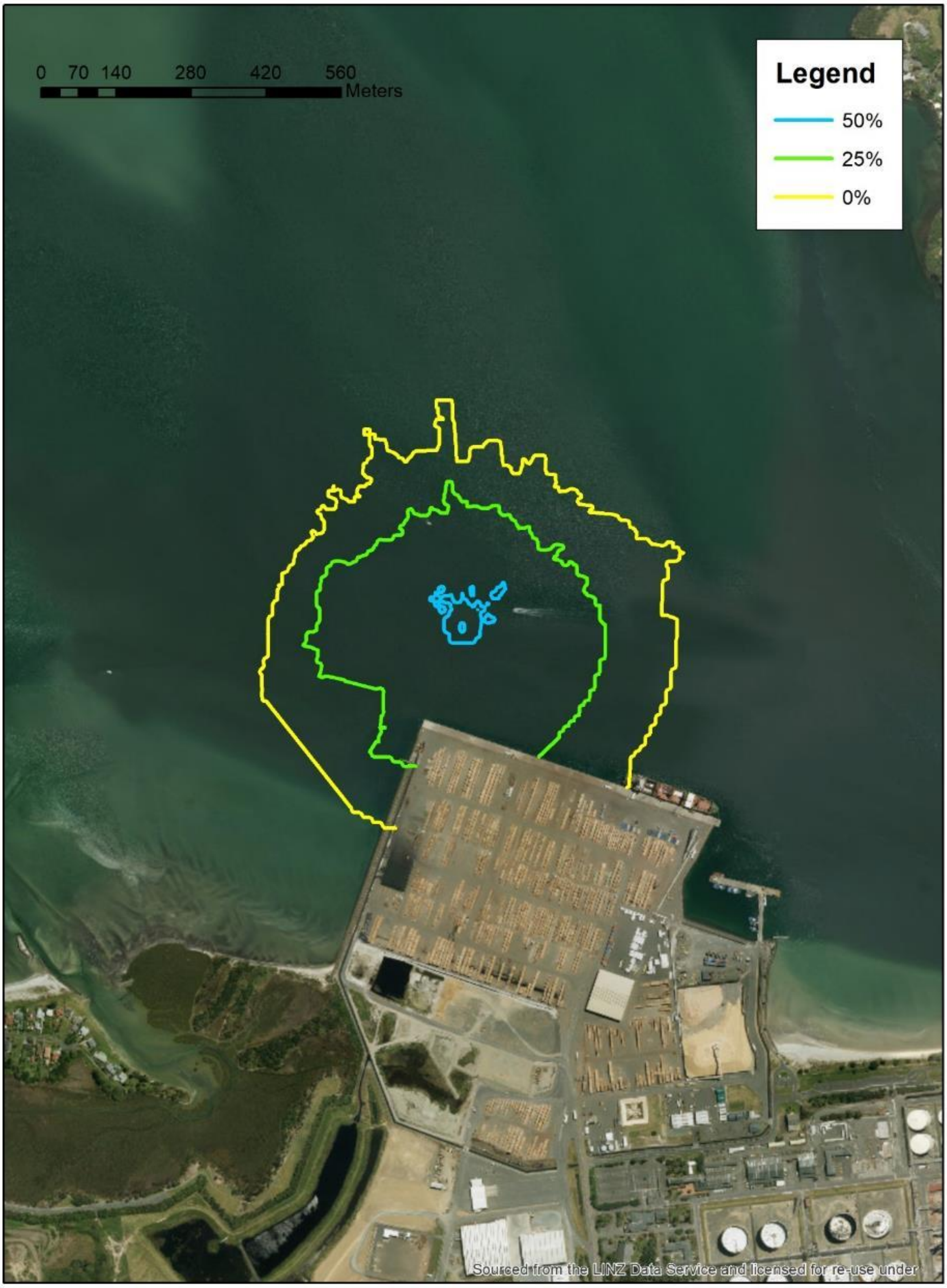


Figure 37: Map showing the extent of listening space reduction (LSR) for fur seals during dredging using a cutter-suction dredger.

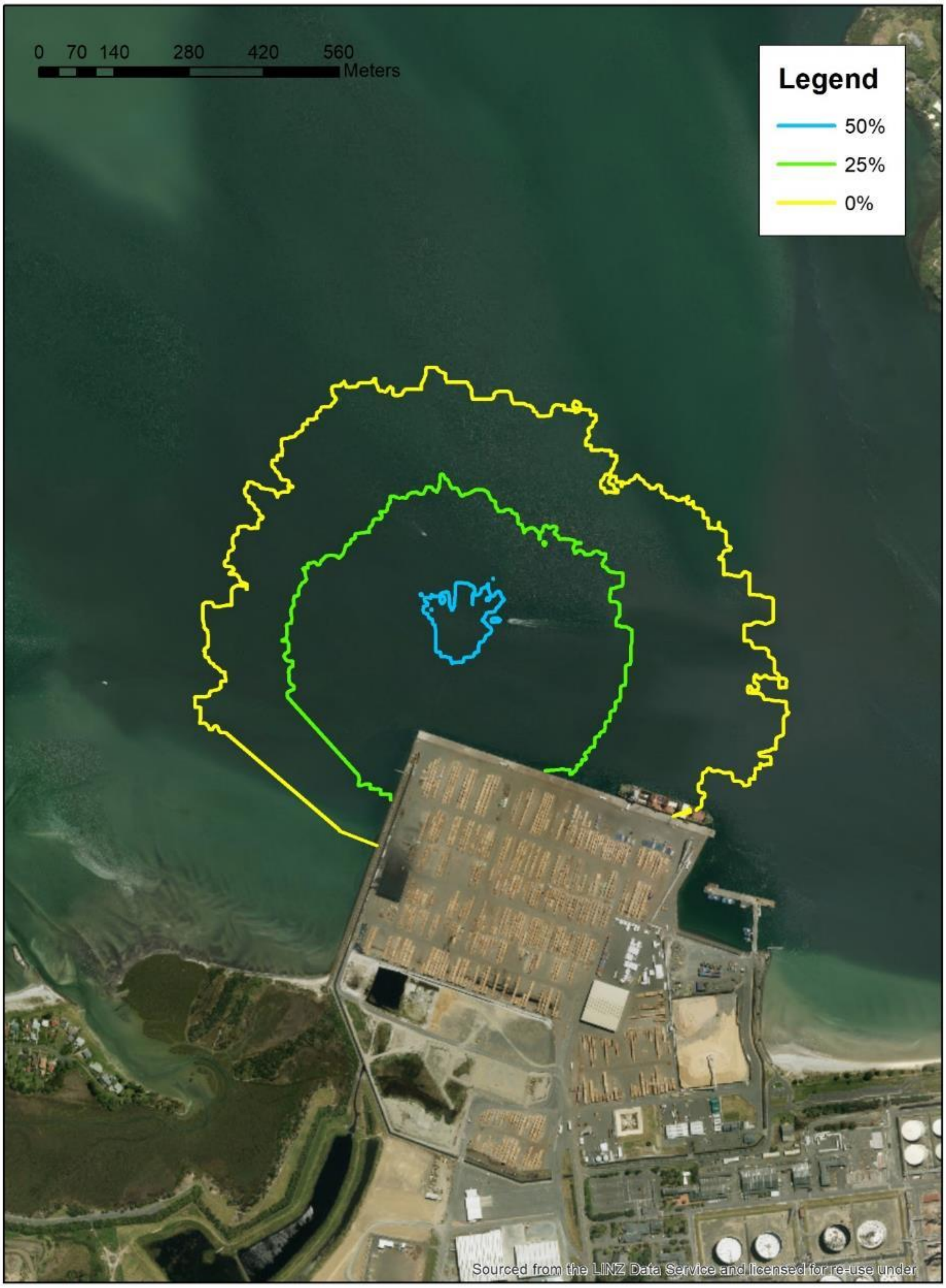


Figure 38: Map showing the extent of listening space reduction (LSR) for leopard seals during dredging using a cutter-suction dredger.

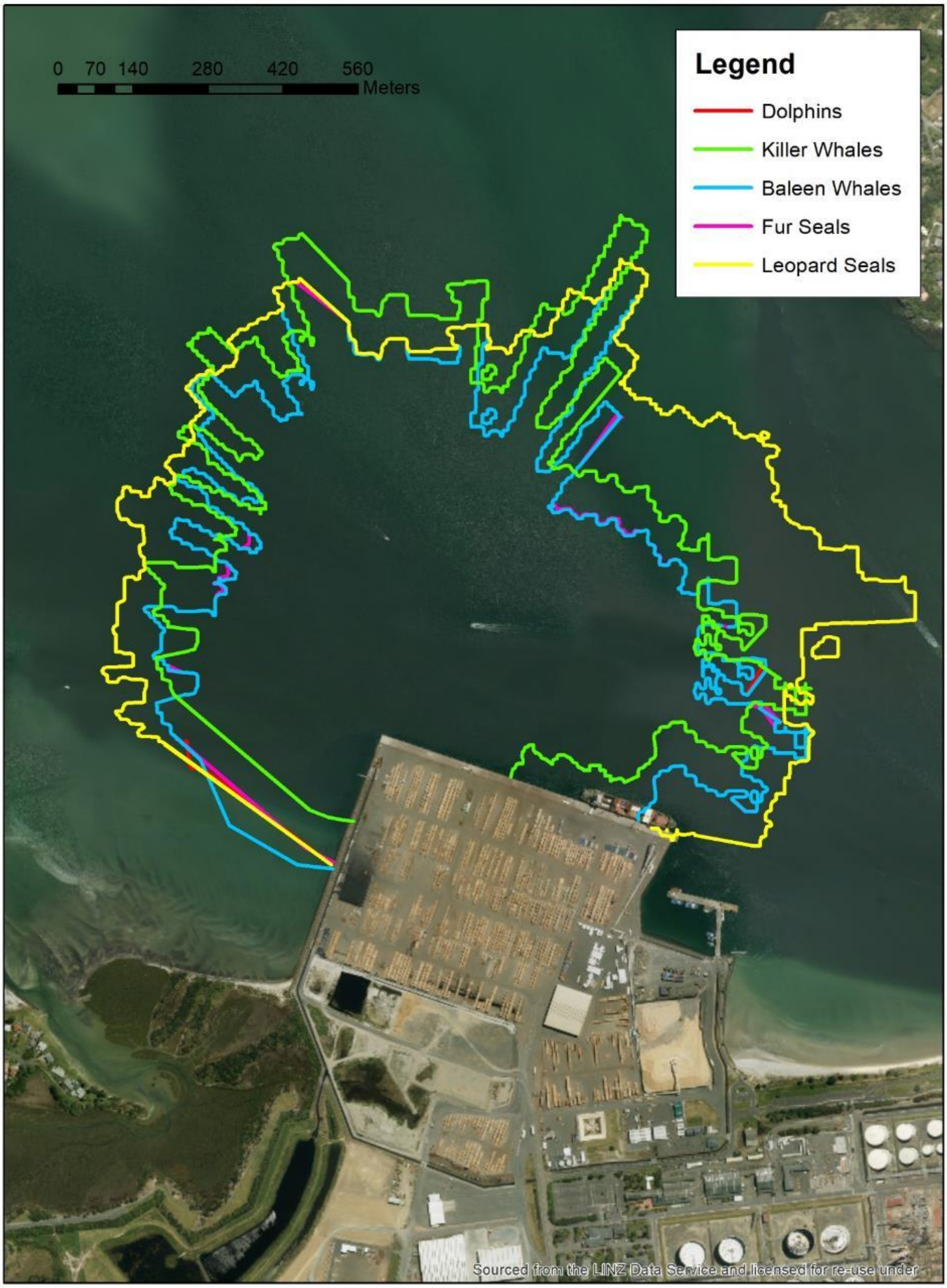


Figure 39: Plots showing the audibility limits for all species during dredging using a cutter-suction dredger.

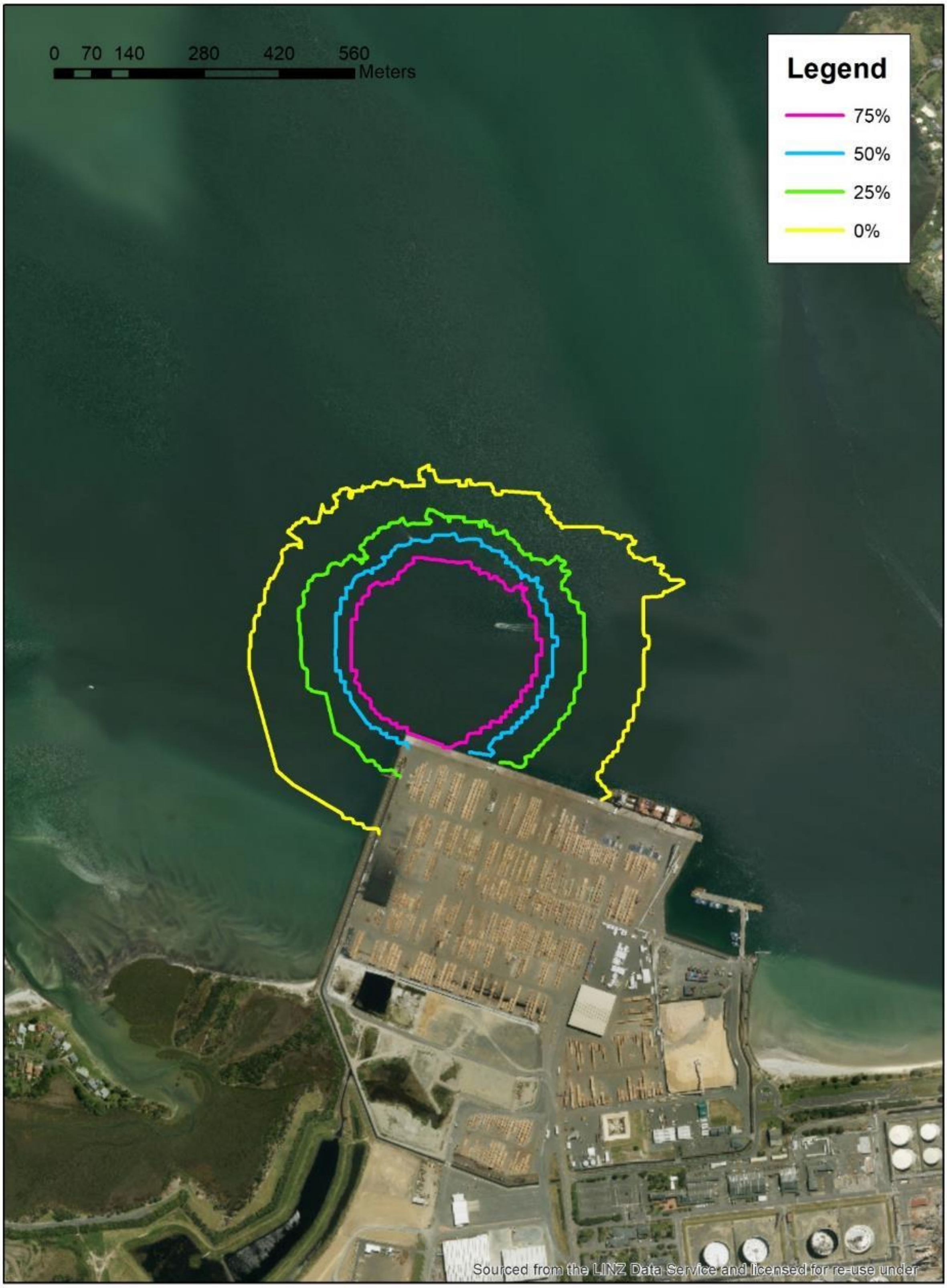


Figure 40: Low severity behavioural response risk for dolphin species during using a backhoe dredger.

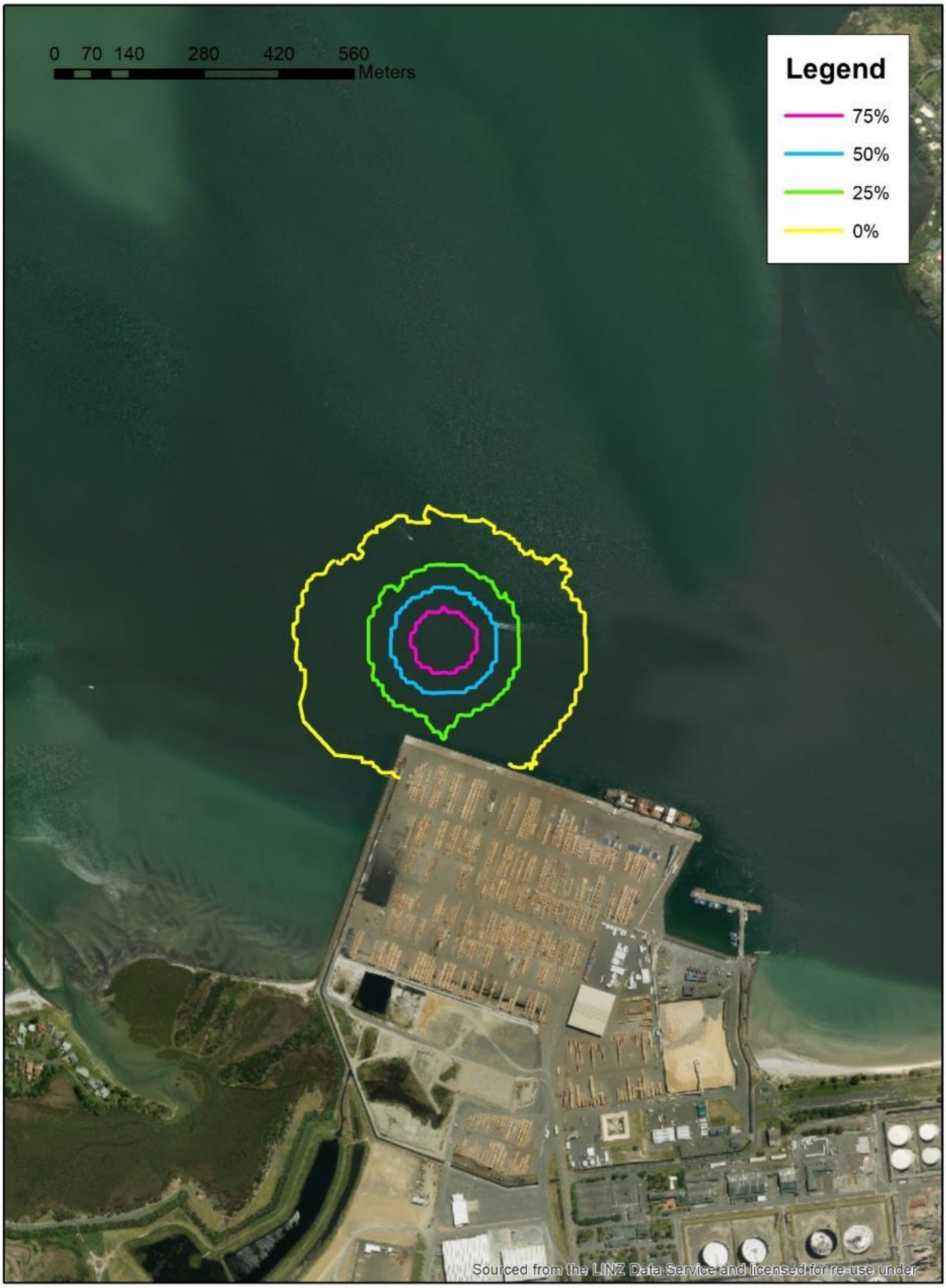


Figure 41: Moderate severity behavioural response risk for dolphin species during dredging using a backhoe dredger.

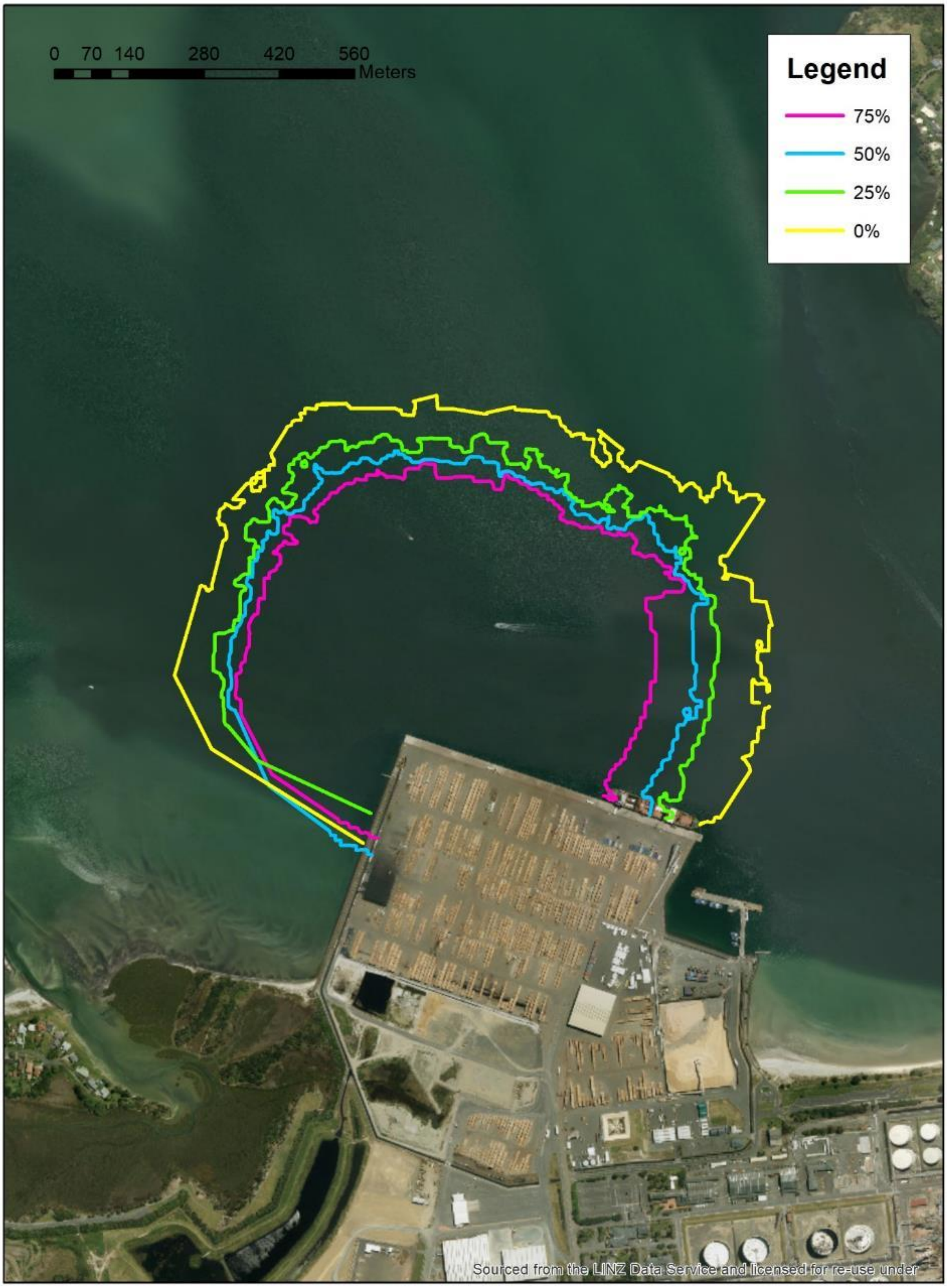


Figure 42: Low severity behavioural response risk for mystecete whales during dredging using a backhoe dredger.

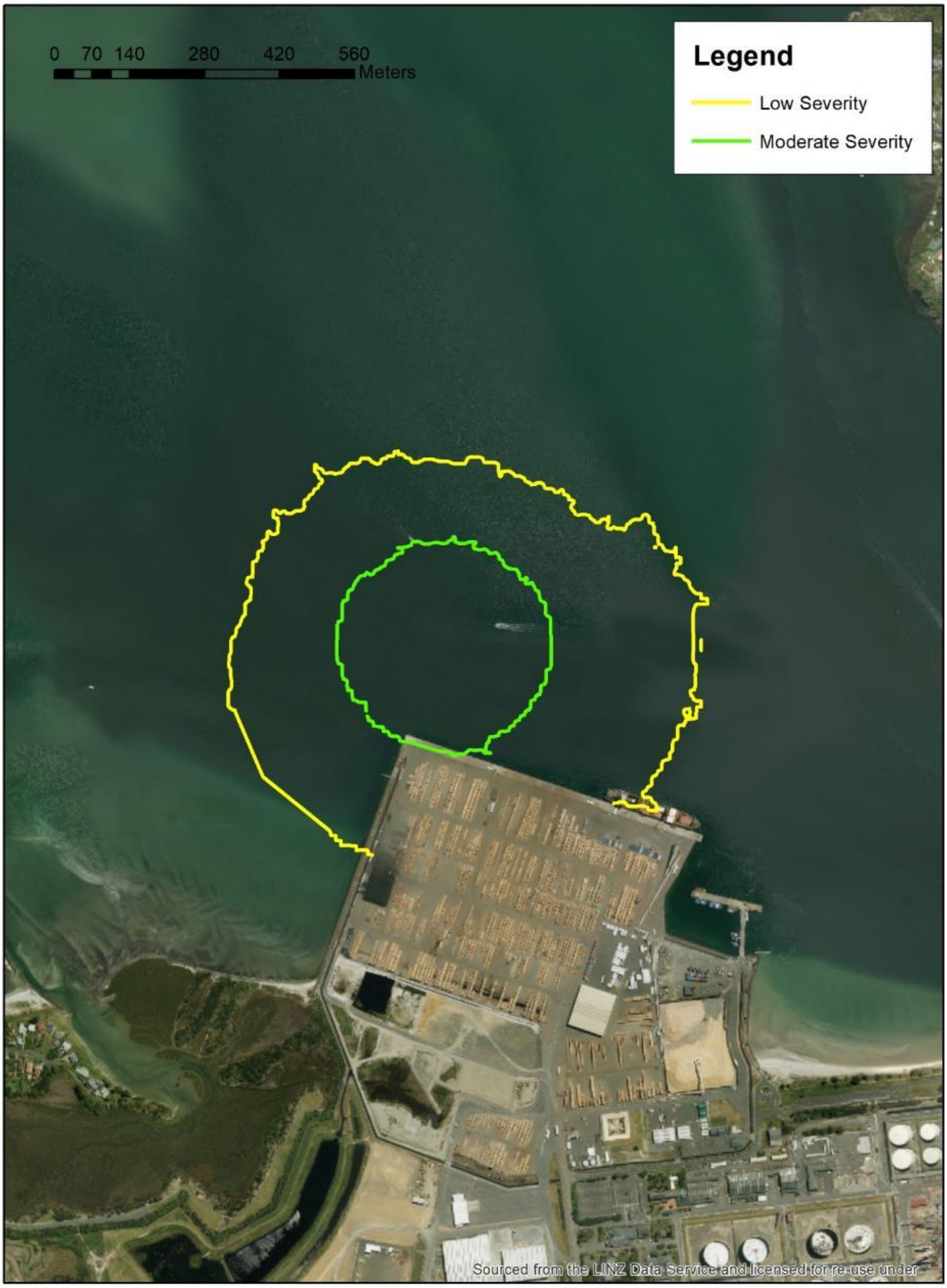


Figure 43: Low and moderate severity behavioural response risk for seals (both fur and leopard seals) during dredging using a backhoe dredger.

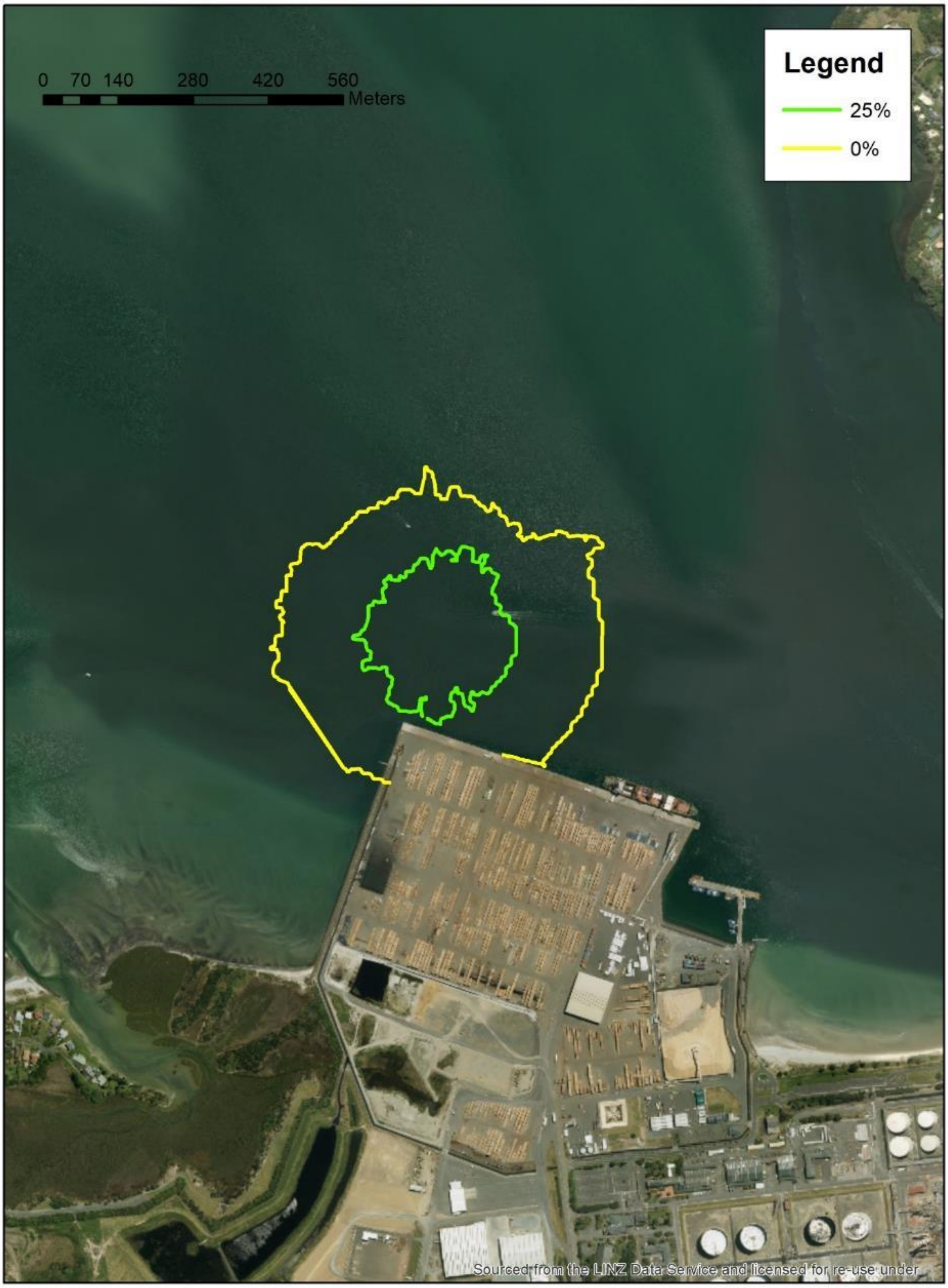


Figure 44: Map showing the extent of listening space reduction (LSR) for dolphins during dredging using a backhoe dredger.

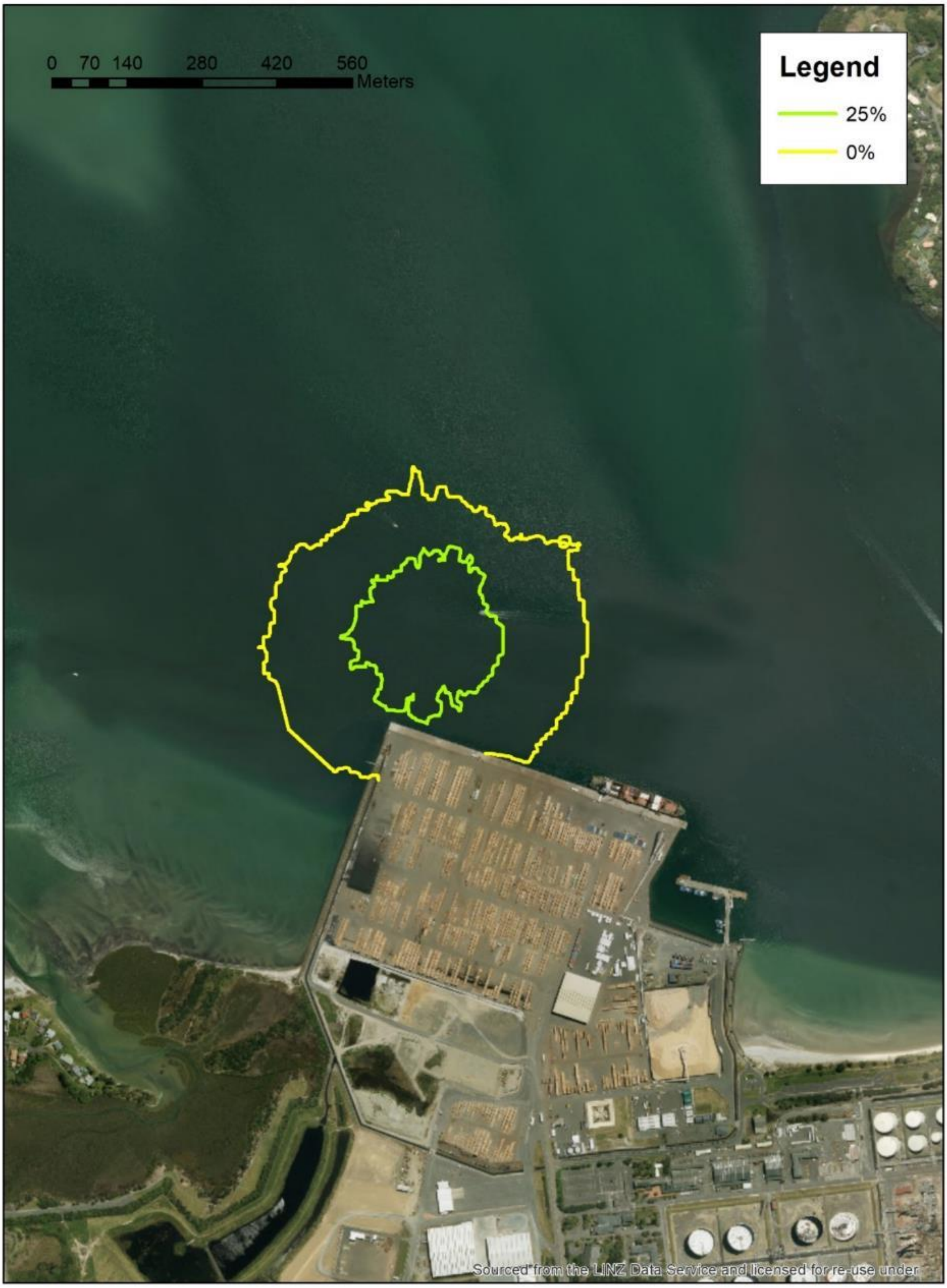


Figure 45: Map showing the extent of listening space reduction (LSR) for killer whales during dredging using a backhoe dredger.

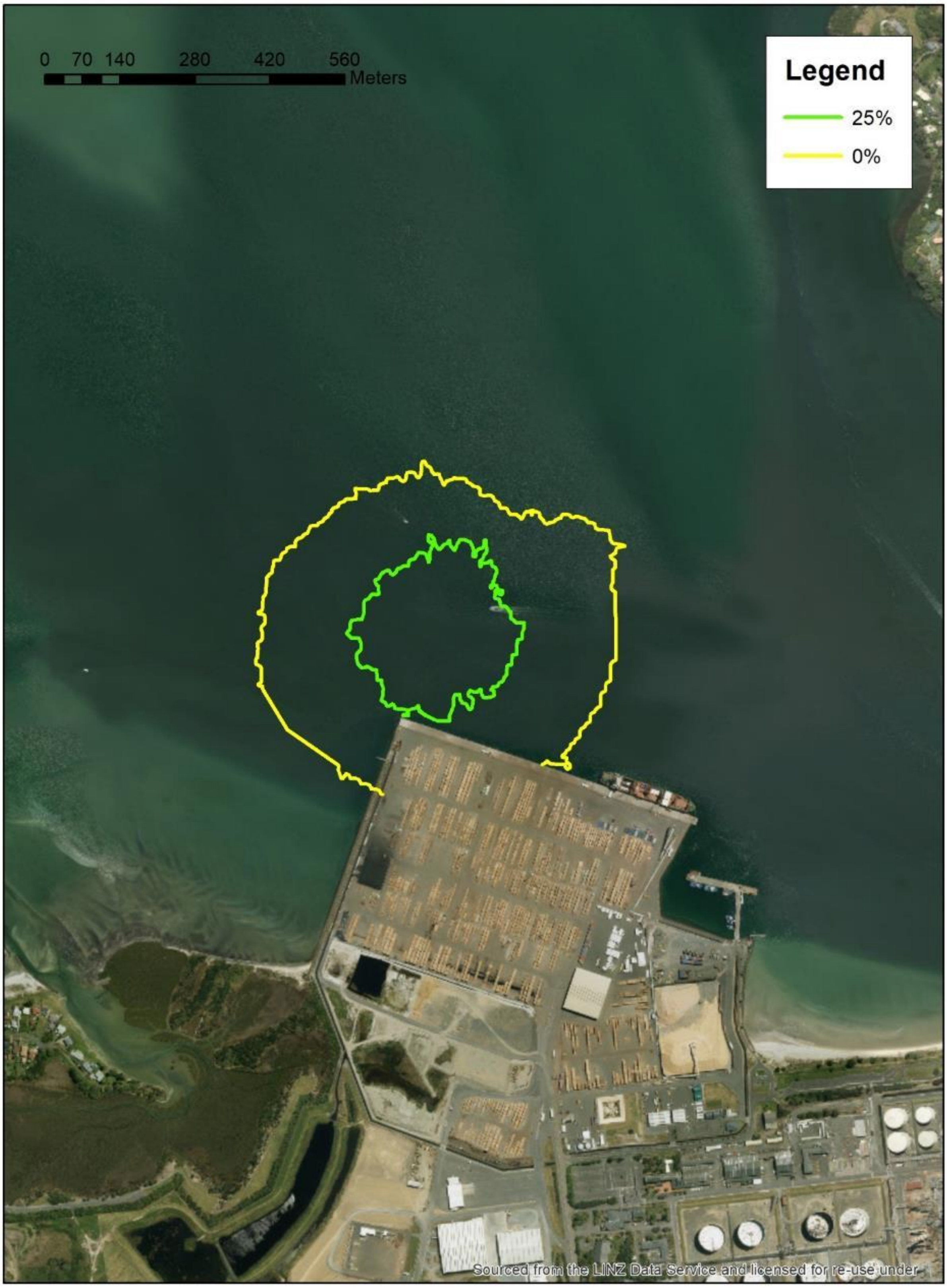


Figure 46: Map showing the extent of listening space reduction (LSR) for mystecete whales during dredging using a backhoe dredger.

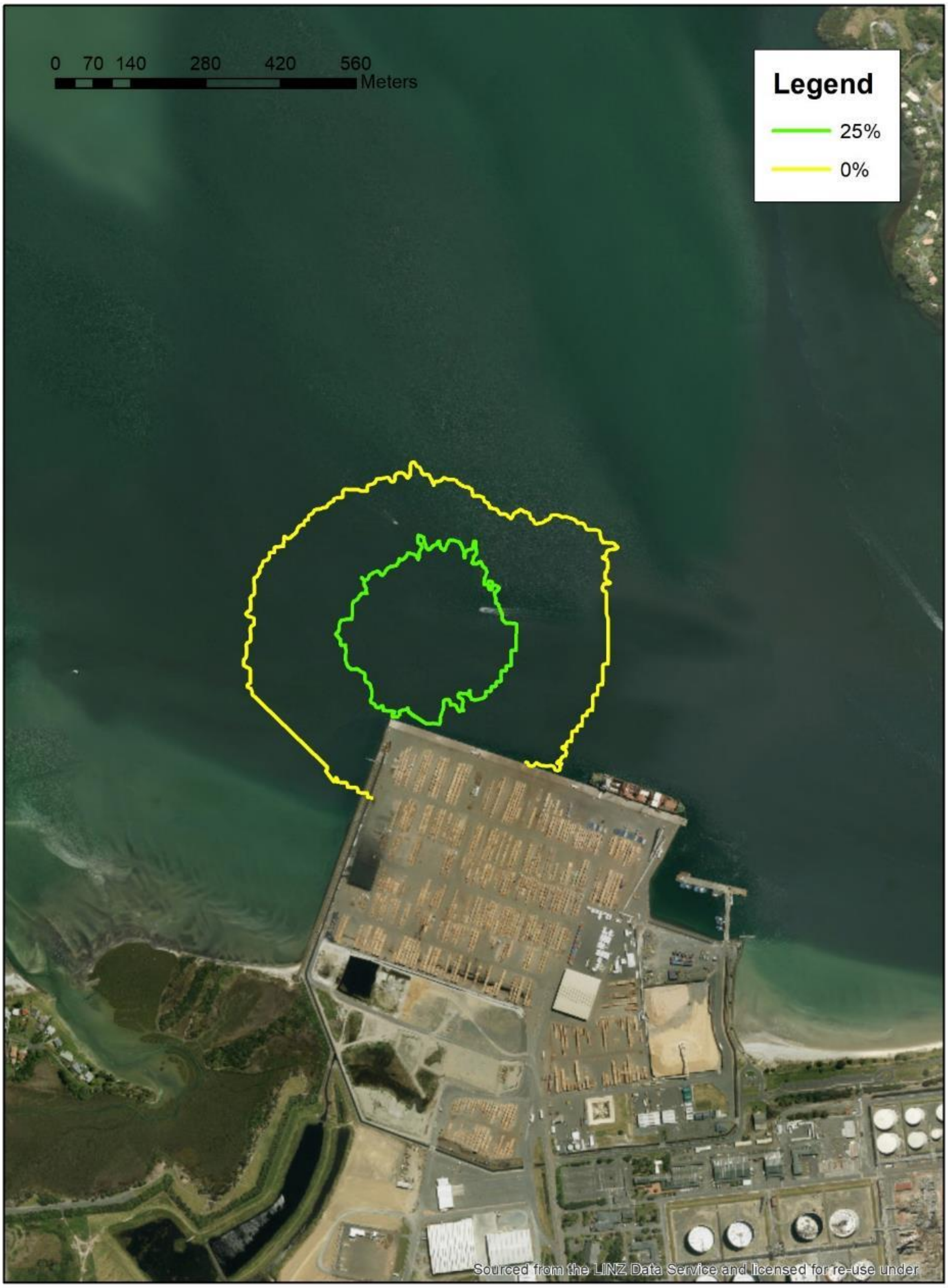


Figure 47: Map showing the extent of listening space reduction (LSR) for fur seals during dredging using a backhoe dredger.

Figure 48: Map showing the extent of listening space reduction (LSR) for leopard seals during dredging using a backhoe dredger.

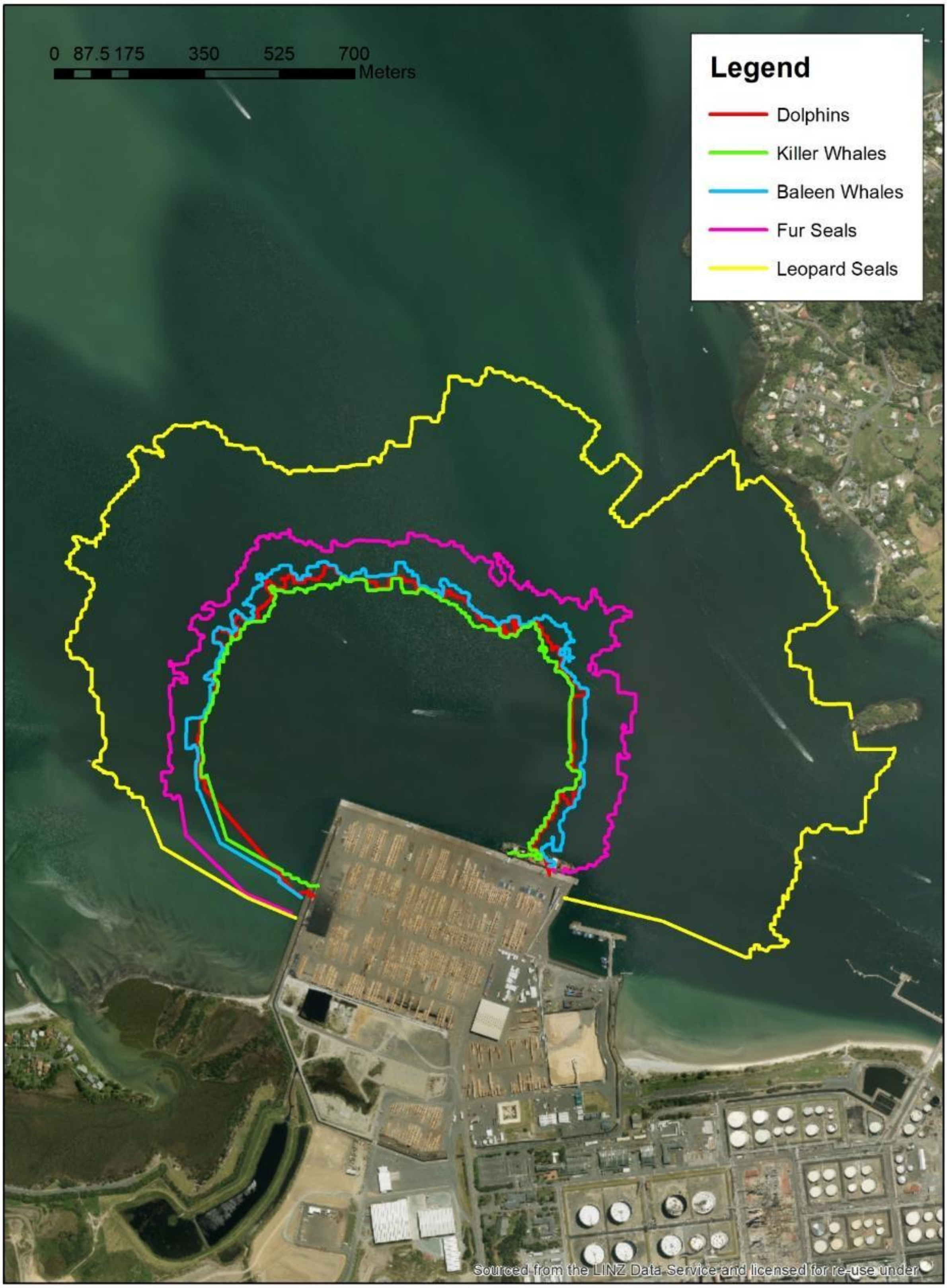


Figure 49: Plots showing the audibility limits for all species during dredging using a backhoe dredger.

Figure 50 Contours showing the ranges within which there is a risk of potential injury or TTS in fishes during the percussive piling.

Appendix F Vibro-core data sheets

Core-data showing the sediment type and depths used for locations V1 through V8. The locations match those from the figure below.

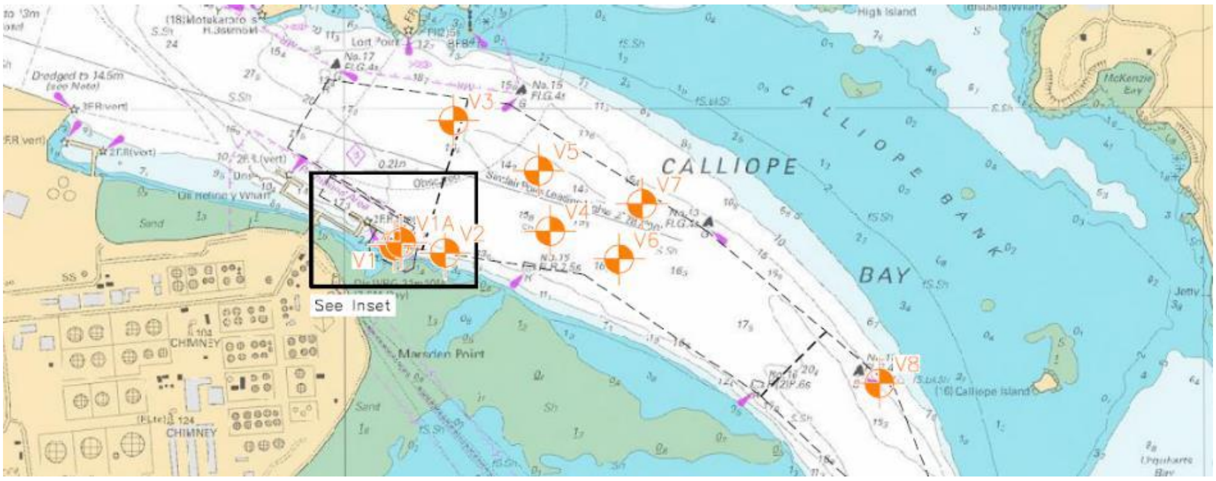
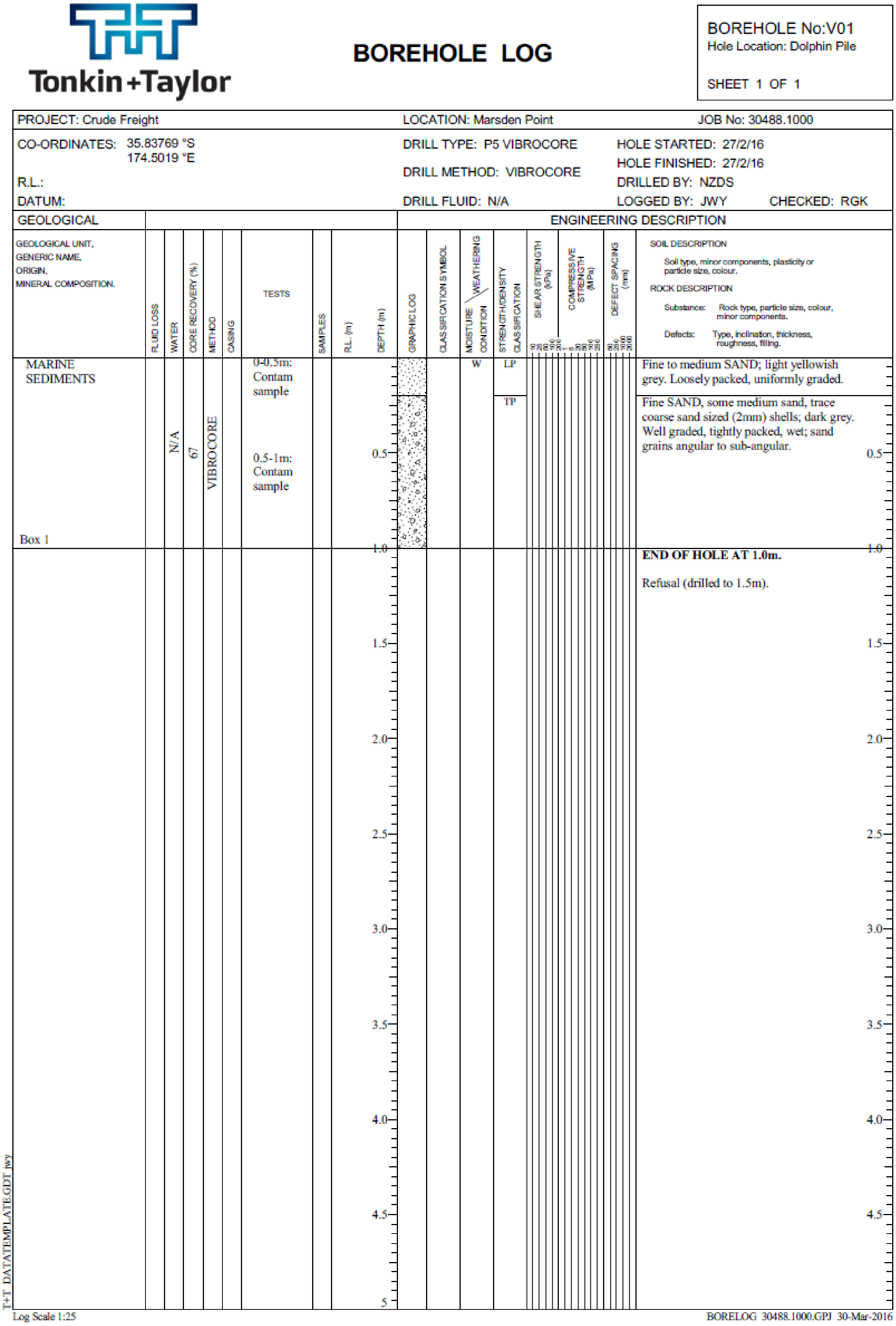


Figure 51: Borehole locations

Borehole log data for these locations were used in the noise model (taken directly from Tonkin & Taylor 2016).



Tonkin+Taylor

BOREHOLE LOG

BOREHOLE No:V01
Hole Location: Dolphin Pile

SHEET 1 OF 1

PROJECT: Crude Freight
LOCATION: Marsden Point
JOB No: 30488.1000

CO-ORDINATES: 35.83769 °S
174.5019 °E
R.L.:
DATUM:

DRILL TYPE: P5 VIBROCORE
DRILL METHOD: VIBROCORE
DRILL FLUID: N/A

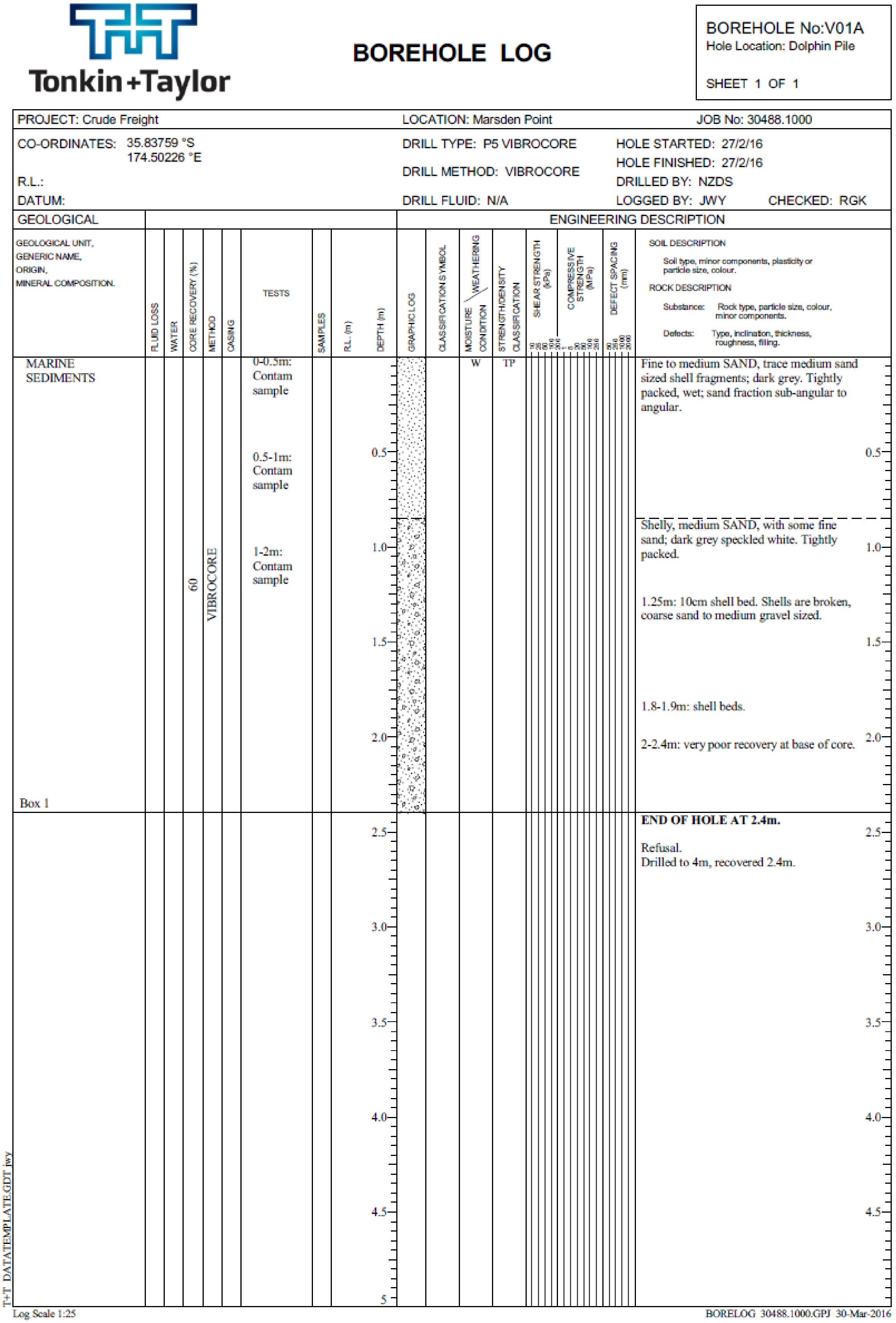
HOLE STARTED: 27/2/16
HOLE FINISHED: 27/2/16
DRILLED BY: NZDS
LOGGED BY: JWY
CHECKED: RGK

GEOLOGICAL										ENGINEERING DESCRIPTION							
GEOLOGICAL UNIT, GENERIC NAME, ORIGIN, MINERAL COMPOSITION.	FLUID LOSS	WATER	CORE RECOVERY (%)	METHOD	CASING	TESTS	SAMPLES	R.L. (m)	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	MOISTURE CONDITION / WEATHERING	STRENGTH/DENSITY CLASSIFICATION	SHEAR STRENGTH (kPa)	COMPRESSIVE STRENGTH (MPa)	DEFECT SPACING (mm)	SOIL DESCRIPTION Soil type, minor components, plasticity or particle size, colour. ROCK DESCRIPTION Substance: Rock type, particle size, colour, minor components. Defects: Type, inclination, thickness, roughness, filling.
MARINE SEDIMENTS Box 1		N/A	67	VIBROCORE		0-0.5m: Contam sample 0.5-1m: Contam sample						W	LP				Fine to medium SAND; light yellowish grey. Loosely packed, uniformly graded.
									0.5 1.0				TP				Fine SAND, some medium sand, trace coarse sand sized (2mm) shells; dark grey. Well graded, tightly packed, wet; sand grains angular to sub-angular.
									1.5 2.0 2.5 3.0 3.5 4.0 4.5 5								**END OF HOLE AT 1.0m.** Refusal (drilled to 1.5m).

T+T DATATEMPLATE.GDT jwy

Log Scale 1:25

BORELOG 30488.1000.GPJ 30-Mar-2016



Tonkin+Taylor

BOREHOLE LOG

BOREHOLE No:V01A
Hole Location: Dolphin Pile

SHEET 1 OF 1

PROJECT: Crude Freight
LOCATION: Marsden Point
JOB No: 30488.1000

CO-ORDINATES: 35.83759 °S
174.50226 °E
R.L.:
DATUM:

DRILL TYPE: P5 VIBROCORE
DRILL METHOD: VIBROCORE
DRILL FLUID: N/A

HOLE STARTED: 27/2/16
HOLE FINISHED: 27/2/16
DRILLED BY: NZDS
LOGGED BY: JWY
CHECKED: RGK

GEOLOGICAL
ENGINEERING DESCRIPTION

GEOLOGICAL UNIT,
GENERIC NAME,
ORIGIN,
MINERAL COMPOSITION.

FLUID LOSS | WATER | CORE RECOVERY (%) | METHOD | CASING | TESTS | SAMPLES | R.L. (m) | DEPTH (m) | GRAPHIC LOG | CLASSIFICATION SYMBOL | MOISTURE CONDITION | WEATHERING | STRENGTH/DENSITY CLASSIFICATION | SHEAR STRENGTH (kPa) | COMPRESSIVE STRENGTH (MPa) | DEFECT SPACING (mm)

SOIL DESCRIPTION
Soil type, minor components, plasticity or particle size, colour.
ROCK DESCRIPTION
Substance: Rock type, particle size, colour, minor components.
Defects: Type, inclination, thickness, roughness, filling.

MARINE SEDIMENTS

Box 1

Core recovery: 60
Method: VIBROCORE

Tests:
0-0.5m: Contam sample
0.5-1m: Contam sample
1-2m: Contam sample

Moisture condition: W
Strength/density classification: TP

Fine to medium SAND, trace medium sand sized shell fragments; dark grey. Tightly packed, wet; sand fraction sub-angular to angular.

Shelly, medium SAND, with some fine sand; dark grey speckled white. Tightly packed.

1.25m: 10cm shell bed. Shells are broken, coarse sand to medium gravel sized.

1.8-1.9m: shell beds.

2-2.4m: very poor recovery at base of core.

END OF HOLE AT 2.4m.

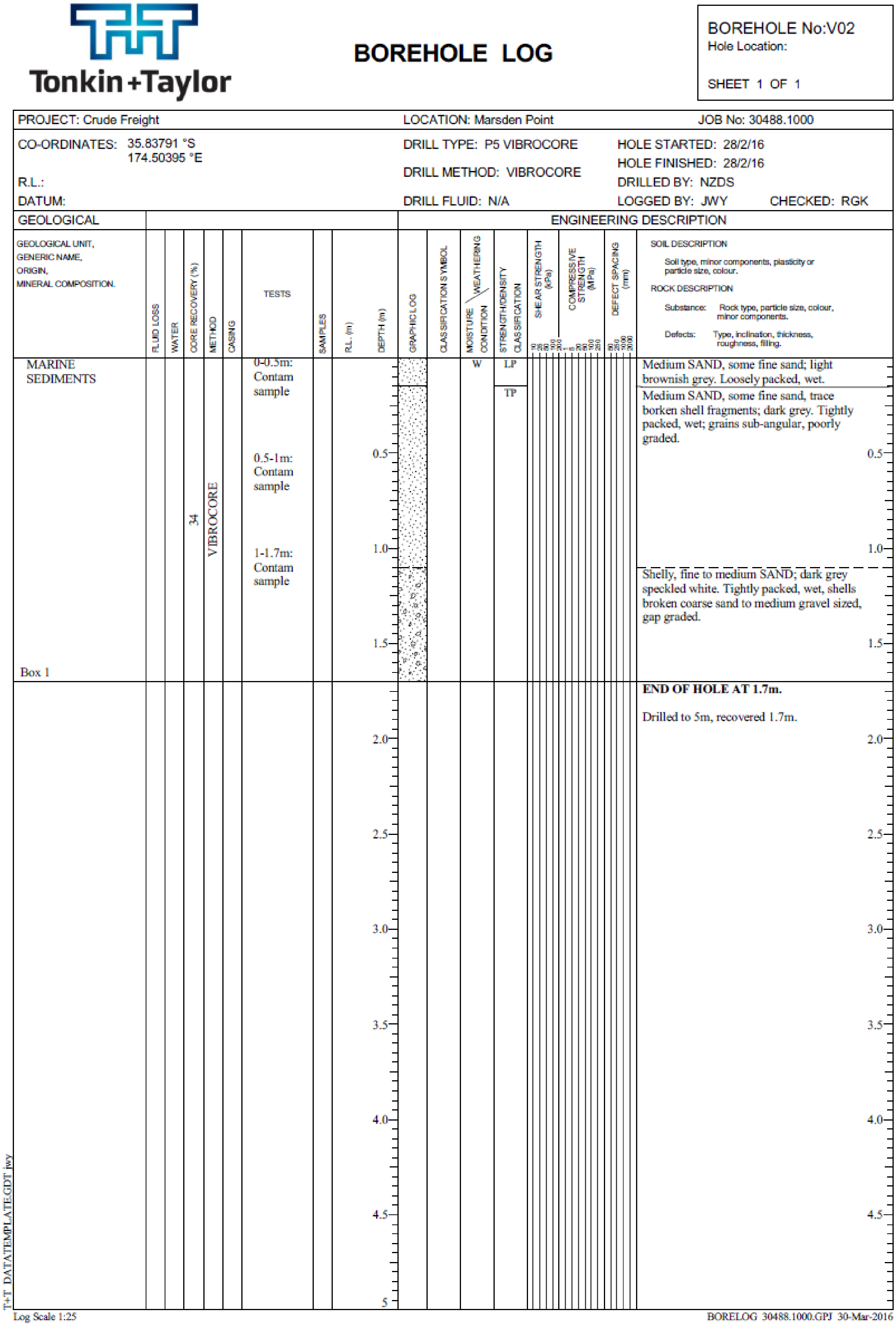
Refusal.
Drilled to 4m, recovered 2.4m.

Depth (m): 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5

T+T DATATEMPLATE.GDT jwy

Log Scale 1:25

BORELOG 30488.1000.GPJ 30-Mar-2016



Tonkin+Taylor

BOREHOLE LOG

BOREHOLE No:V02
Hole Location:
SHEET 1 OF 1

PROJECT: Crude Freight
LOCATION: Marsden Point
JOB No: 30488.1000

CO-ORDINATES: 35.83791 °S
174.50395 °E
R.L.:
DATUM:

DRILL TYPE: P5 VIBROCORE
DRILL METHOD: VIBROCORE
DRILL FLUID: N/A

HOLE STARTED: 28/2/16
HOLE FINISHED: 28/2/16
DRILLED BY: NZDS
LOGGED BY: JWY
CHECKED: RGK

GEOLOGICAL										ENGINEERING DESCRIPTION							
GEOLOGICAL UNIT, GENERIC NAME, ORIGIN, MINERAL COMPOSITION.	FLUID LOSS	WATER	CORE RECOVERY (%)	METHOD	CASING	TESTS	SAMPLES	R.L. (m)	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	MOISTURE CONDITION / WEATHERING	STRENGTH/DENSITY CLASSIFICATION	SHEAR STRENGTH (kPa)	COMPRESSIVE STRENGTH (MPa)	DEFECT SPACING (mm)	SOIL DESCRIPTION Soil type, minor components, plasticity or particle size, colour. ROCK DESCRIPTION Substance: Rock type, particle size, colour, minor components. Defects: Type, inclination, thickness, roughness, filling.
MARINE SEDIMENTS			34	VIBROCORE		0-0.5m: Contam sample						W	LP				Medium SAND, some fine sand; light brownish grey. Loosely packed, wet.
													TP				Medium SAND, some fine sand, trace borken shell fragments; dark grey. Tightly packed, wet; grains sub-angular, poorly graded.
						0.5-1m: Contam sample			0.5								
						1-1.7m: Contam sample			1.0								Shelly, fine to medium SAND; dark grey speckled white. Tightly packed, wet, shells broken coarse sand to medium gravel sized, gap graded.
Box 1									1.5								
									2.0								**END OF HOLE AT 1.7m.** Drilled to 5m, recovered 1.7m.
									2.5								
									3.0								
									3.5								
									4.0								
									4.5								
									5								

T+T DATATEMPLATE.GDT jwy

Log Scale 1:25

BORELOG 30488.1000.GPJ 30-Mar-2016

Tonkin+Taylor

BOREHOLE LOG

BOREHOLE No:V03
Hole Location: Inner Harbour

SHEET 1 OF 1

PROJECT: Crude Freight
LOCATION: Marsden Point
JOB No: 30488.1000

CO-ORDINATES: 35.83374 °S
174.5043 °E
R.L.:
DATUM:

DRILL TYPE: P5 VIBROCORE
DRILL METHOD: VIBROCORE
DRILL FLUID: N/A

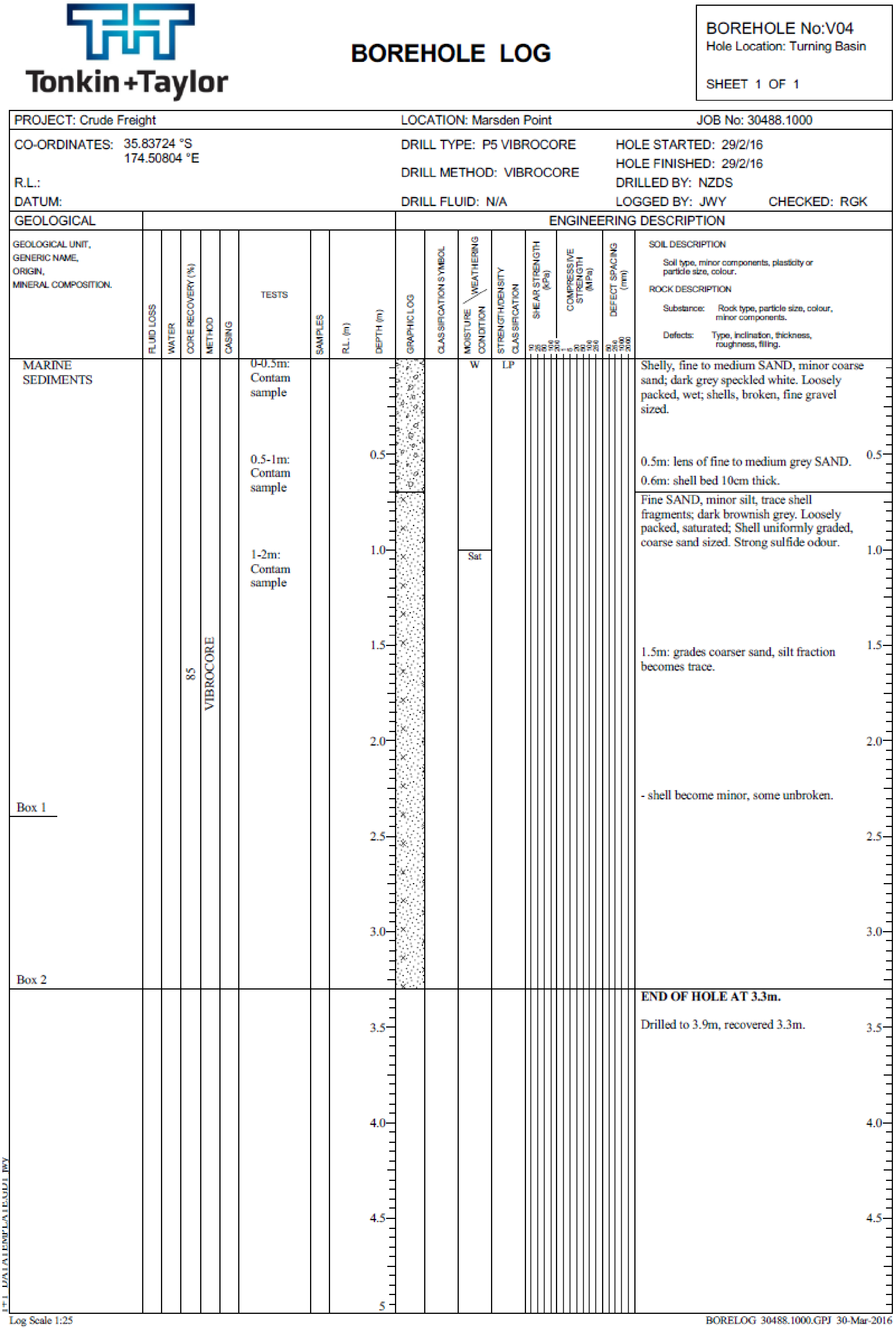
HOLE STARTED: 25/2/16
HOLE FINISHED: 25/2/16
DRILLED BY: NZDS
LOGGED BY: JWY
CHECKED: RGK

GEOLOGICAL										ENGINEERING DESCRIPTION							
GEOLOGICAL UNIT, GENERIC NAME, ORIGIN, MINERAL COMPOSITION.	FLUID LOSS	WATER	CORE RECOVERY (%)	METHOD	CASING	TESTS	SAMPLES	R.L. (m)	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	MOISTURE CONDITION / WEATHERING	STRENGTH/DENSITY CLASSIFICATION	SHEAR STRENGTH (kPa)	COMPRESSIVE STRENGTH (MPa)	DEFECT SPACING (mm)	SOIL DESCRIPTION Soil type, minor components, plasticity or particle size, colour. ROCK DESCRIPTION Substance: Rock type, particle size, colour, minor components. Defects: Type, inclination, thickness, roughness, filling.
						0-0.5m: Contam sample			0			W	LP				Fine SAND, minor medium sand and shells, trace silt; dark grey. Loosely packed, poorly graded, wet. Strong sulfide odour (anoxic decomposition).
						0.5-1m: Contam sample			0.5								
						1-2m: Contam sample			1.0								
			73	VIBROCORE					1.5				TP				Fine to medium SAND, minor shells; grey. Tightly packed, poorly graded, wet; sand grains, angular to sub-angular.
									2.0								Shelly medium SAND, minor fine sand; dark grey. Tightly packed, wet; shells grading coarser with depth (up to coarse gravel sized); sand, sub-angular.
Box 1									2.5								
Box 2									3.0								Shelly medium SAND; light greyish brown. Tightly packed, wet; shells, fine to medium gravel sized, typically broken. **END OF HOLE AT 2.9m.** Drilled to 4.0m, recovered 2.9m.
									3.5								
									4.0								
									4.5								
									5								

T+T DATATEMPLATE.GDT JWY

Log Scale 1:25

BORELOG 30488.1000.GPJ 30-Mar-2016



Tonkin+Taylor

BOREHOLE LOG

BOREHOLE No:V04
Hole Location: Turning Basin

SHEET 1 OF 1

PROJECT: Crude Freight
LOCATION: Marsden Point
JOB No: 30488.1000

CO-ORDINATES: 35.83724 °S
174.50804 °E
R.L.:
DATUM:

DRILL TYPE: P5 VIBROCORE
DRILL METHOD: VIBROCORE
DRILL FLUID: N/A

HOLE STARTED: 29/2/16
HOLE FINISHED: 29/2/16
DRILLED BY: NZDS
LOGGED BY: JWY
CHECKED: RGK

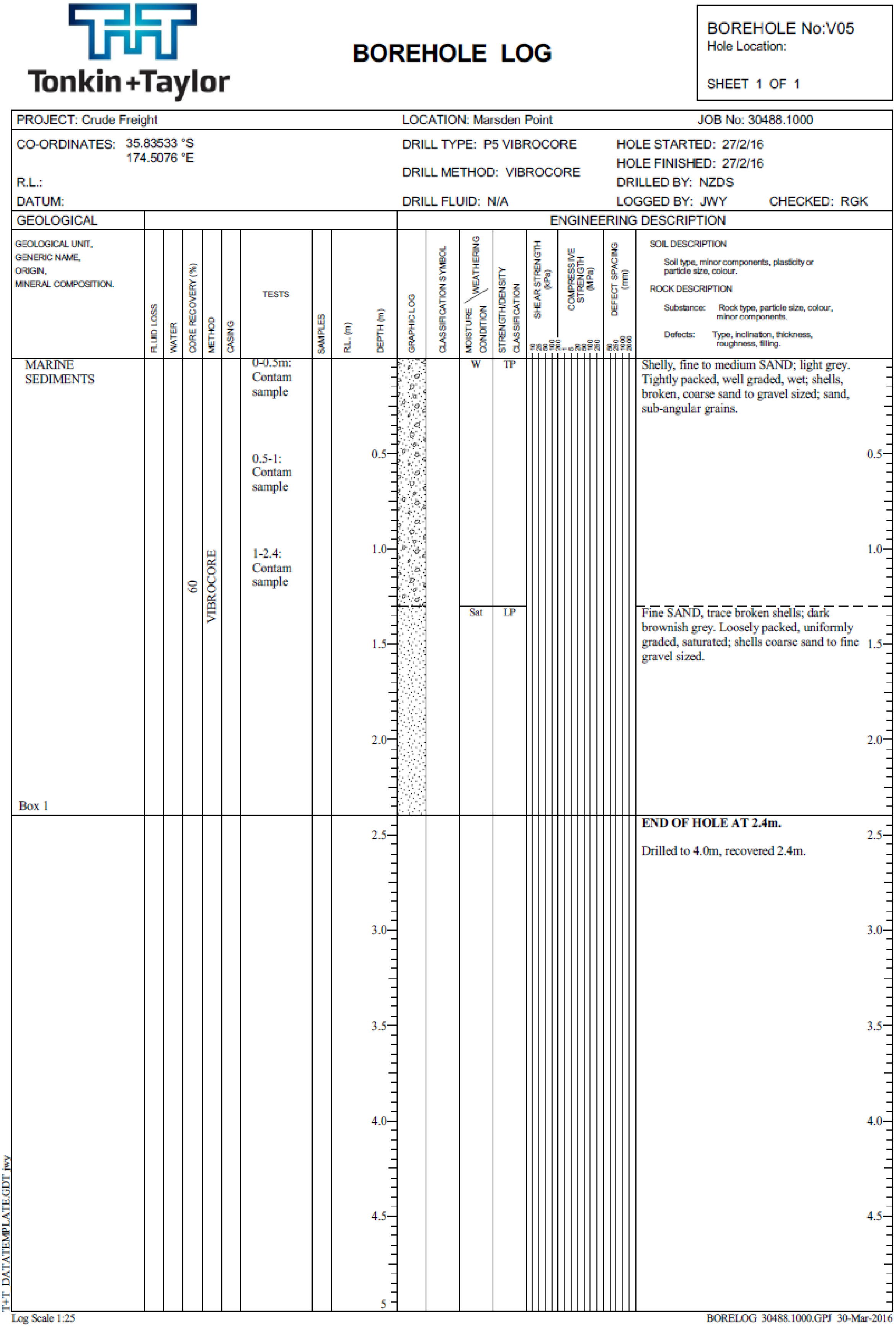
GEOLOGICAL UNIT, GENERIC NAME, ORIGIN, MINERAL COMPOSITION.	CORE RECOVERY (%)	METHOD	TESTS	DEPTH (m)	MOISTURE CONDITION	STRENGTH/DENSITY CLASSIFICATION	SOIL DESCRIPTION / ROCK DESCRIPTION
MARINE SEDIMENTS	85	VIBROCORE	0-0.5m: Contam sample	0	W	LP	Shelly, fine to medium SAND, minor coarse sand; dark grey speckled white. Loosely packed, wet; shells, broken, fine gravel sized.
			0.5-1m: Contam sample	0.5			0.5m: lens of fine to medium grey SAND. 0.6m: shell bed 10cm thick.
				0.7			Fine SAND, minor silt, trace shell fragments; dark brownish grey. Loosely packed, saturated; Shell uniformly graded, coarse sand sized. Strong sulfide odour.
			1-2m: Contam sample	1.0	Sat		
				1.5			1.5m: grades coarser sand, silt fraction becomes trace.
Box 1				2.3			- shell become minor, some unbroken.
Box 2				3.3			**END OF HOLE AT 3.3m.** Drilled to 3.9m, recovered 3.3m.

Columns also printed: FLUID LOSS, WATER, CASING, SAMPLES, RL (m), GRAPHIC LOG, CLASSIFICATION SYMBOL, WEATHERING, SHEAR STRENGTH (kPa), COMPRESSIVE STRENGTH (MPa), DEFECT SPACING (mm)

SOIL DESCRIPTION
Soil type, minor components, plasticity or particle size, colour.
ROCK DESCRIPTION
Substance: Rock type, particle size, colour, minor components.
Defects: Type, inclination, thickness, roughness, filling.

T+T DATATEMPLATE.GDT JWY

Log Scale 1:25
BORELOG 30488.1000.GPJ 30-Mar-2016



Tonkin+Taylor

BOREHOLE LOG

BOREHOLE No:V05
Hole Location:

SHEET 1 OF 1

PROJECT: Crude Freight
LOCATION: Marsden Point
JOB No: 30488.1000

CO-ORDINATES: 35.83533 °S
174.5076 °E
R.L.:
DATUM:

DRILL TYPE: P5 VIBROCORE
DRILL METHOD: VIBROCORE
DRILL FLUID: N/A

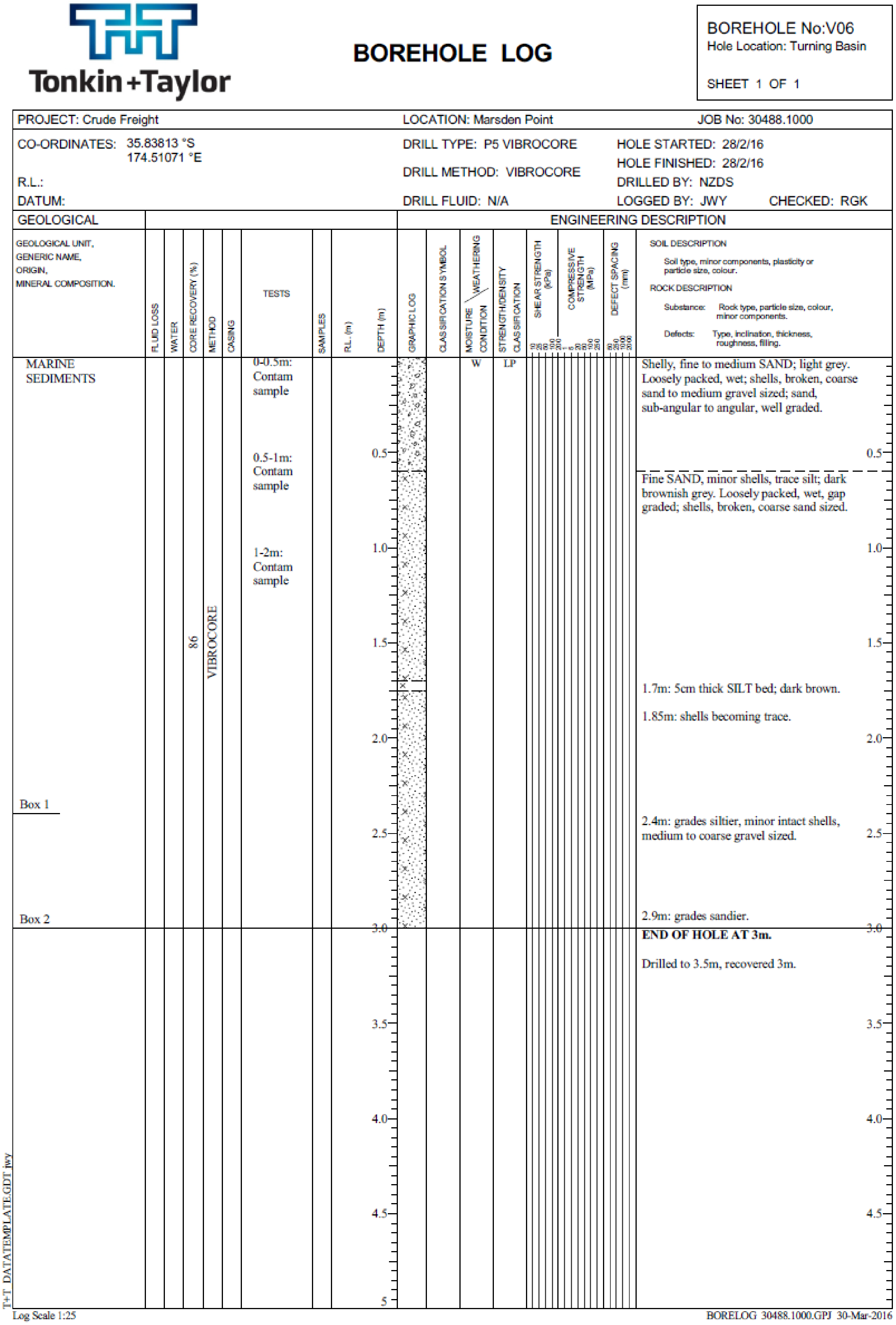
HOLE STARTED: 27/2/16
HOLE FINISHED: 27/2/16
DRILLED BY: NZDS
LOGGED BY: JWY
CHECKED: RGK

GEOLOGICAL										ENGINEERING DESCRIPTION							
GEOLOGICAL UNIT, GENERIC NAME, ORIGIN, MINERAL COMPOSITION.	FLUID LOSS	WATER	CORE RECOVERY (%)	METHOD	CASING	TESTS	SAMPLES	R.L. (m)	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	MOISTURE CONDITION / WEATHERING	STRENGTH/DENSITY CLASSIFICATION	SHEAR STRENGTH (kPa)	COMPRESSIVE STRENGTH (MPa)	DEFECT SPACING (mm)	SOIL DESCRIPTION Soil type, minor components, plasticity or particle size, colour. ROCK DESCRIPTION Substance: Rock type, particle size, colour, minor components. Defects: Type, inclination, thickness, roughness, filling.
MARINE SEDIMENTS			60	VIBROCORE		0-0.5m: Contam sample						W	TP				Shelly, fine to medium SAND; light grey. Tightly packed, well graded, wet; shells, broken, coarse sand to gravel sized; sand, sub-angular grains.
						0.5-1: Contam sample			0.5								
						1-2.4: Contam sample			1.0								
												Sat	LP				Fine SAND, trace broken shells; dark brownish grey. Loosely packed, uniformly graded, saturated; shells coarse sand to fine gravel sized.
									1.5								
									2.0								
Box 1																	
									2.5								**END OF HOLE AT 2.4m.** Drilled to 4.0m, recovered 2.4m.
									3.0								
									3.5								
									4.0								
									4.5								
									5								

T+T DATATEMPLATE.GDT jwy

Log Scale 1:25

BORELOG 30488.1000.GPJ 30-Mar-2016



Tonkin+Taylor

BOREHOLE LOG

BOREHOLE No:V06
Hole Location: Turning Basin

SHEET 1 OF 1

PROJECT: Crude Freight
LOCATION: Marsden Point
JOB No: 30488.1000

CO-ORDINATES: 35.83813 °S
174.51071 °E
R.L.:
DATUM:

DRILL TYPE: P5 VIBROCORE
DRILL METHOD: VIBROCORE
DRILL FLUID: N/A

HOLE STARTED: 28/2/16
HOLE FINISHED: 28/2/16
DRILLED BY: NZDS
LOGGED BY: JWY
CHECKED: RGK

GEOLOGICAL

ENGINEERING DESCRIPTION

GEOLOGICAL UNIT,
GENERIC NAME,
ORIGIN,
MINERAL COMPOSITION.

FLUID LOSS | WATER | CORE RECOVERY (%) | METHOD | CASING | TESTS | SAMPLES | R.L. (m) | DEPTH (m) | GRAPHIC LOG | CLASSIFICATION SYMBOL | MOISTURE CONDITION / WEATHERING | STRENGTH/DENSITY CLASSIFICATION | SHEAR STRENGTH (kPa) | COMPRESSIVE STRENGTH (MPa) | DEFECT SPACING (mm)

SOIL DESCRIPTION
Soil type, minor components, plasticity or particle size, colour.

ROCK DESCRIPTION
Substance: Rock type, particle size, colour, minor components.
Defects: Type, inclination, thickness, roughness, filling.

MARINE
SEDIMENTS

Box 1

Box 2

Core recovery: 86

Method: VIBROCORE

Tests:
0-0.5m: Contam sample
0.5-1m: Contam sample
1-2m: Contam sample

Depth (m): 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5

Moisture condition: W
Strength/density classification: LP

Shelly, fine to medium SAND; light grey. Loosely packed, wet; shells, broken, coarse sand to medium gravel sized; sand, sub-angular to angular, well graded.

Fine SAND, minor shells, trace silt; dark brownish grey. Loosely packed, wet, gap graded; shells, broken, coarse sand sized.

1.7m: 5cm thick SILT bed; dark brown.

1.85m: shells becoming trace.

2.4m: grades siltier, minor intact shells, medium to coarse gravel sized.

2.9m: grades sandier.

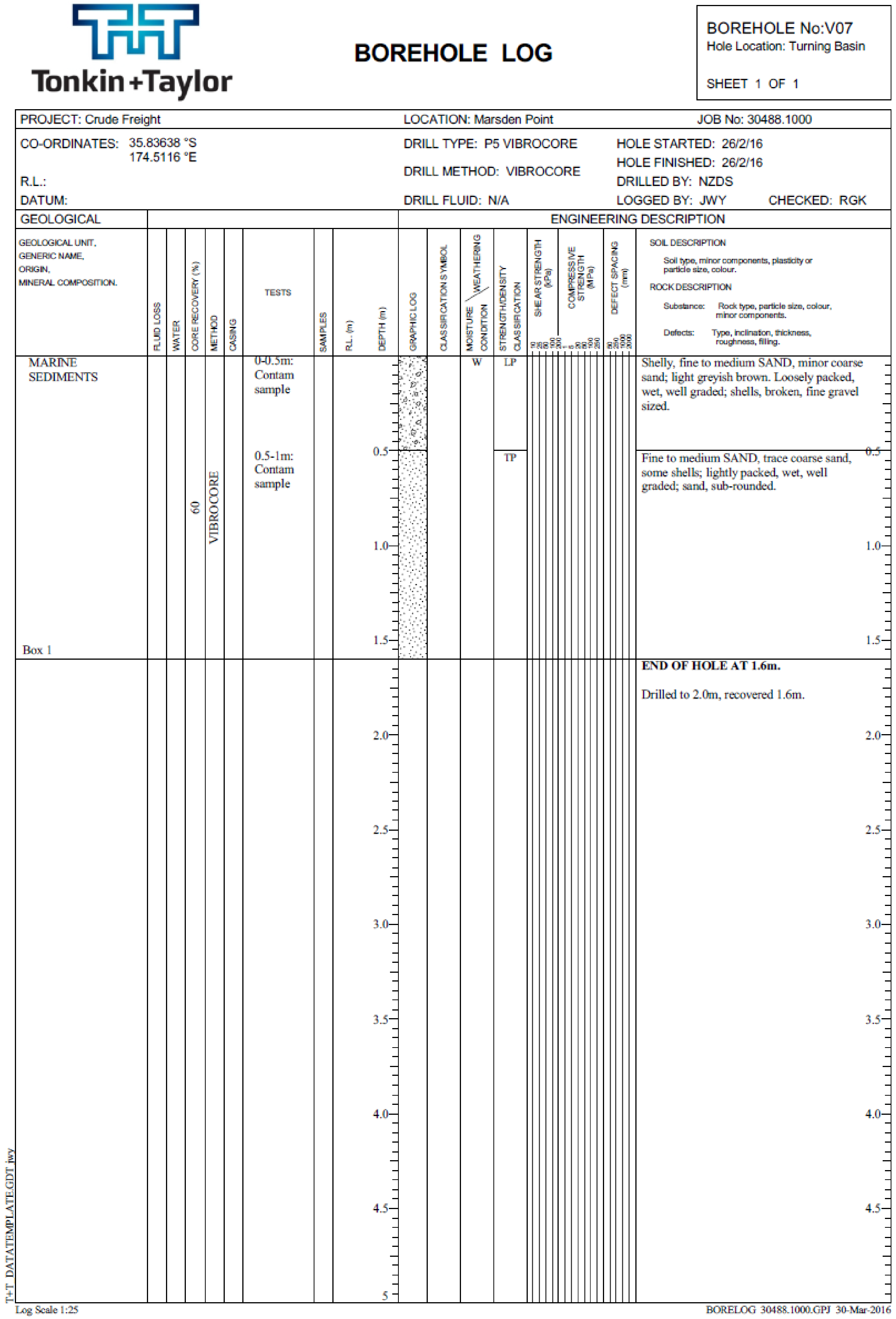
END OF HOLE AT 3m.

Drilled to 3.5m, recovered 3m.

T+T DATATEMPLATE.GDT jwy

Log Scale 1:25

BORELOG 30488.1000.GPJ 30-Mar-2016



Tonkin+Taylor

BOREHOLE LOG

BOREHOLE No:V07
Hole Location: Turning Basin

SHEET 1 OF 1

PROJECT: Crude Freight
LOCATION: Marsden Point
JOB No: 30488.1000

CO-ORDINATES: 35.83638 °S
174.5116 °E
R.L.:
DATUM:

DRILL TYPE: P5 VIBROCORE
DRILL METHOD: VIBROCORE
DRILL FLUID: N/A

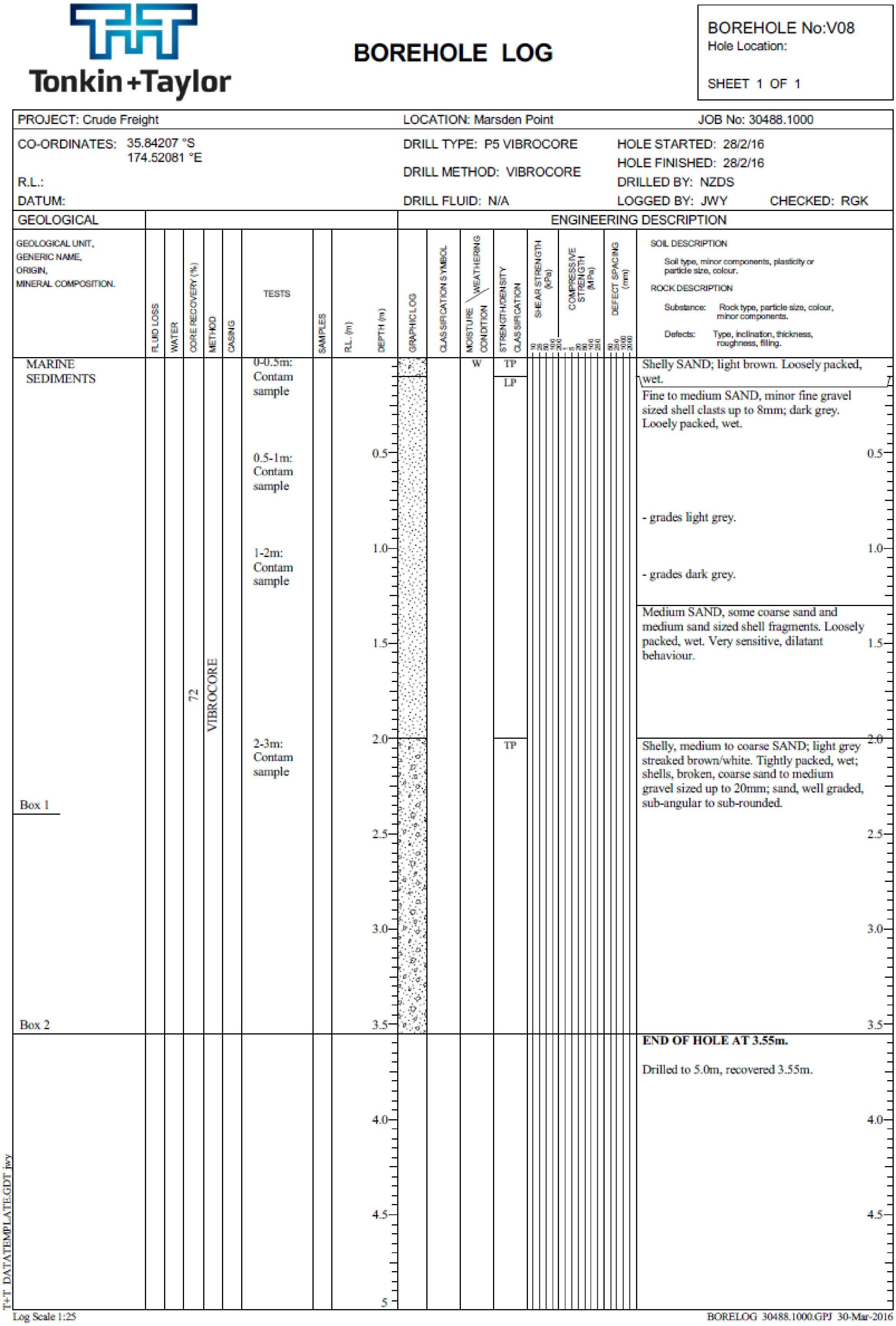
HOLE STARTED: 26/2/16
HOLE FINISHED: 26/2/16
DRILLED BY: NZDS
LOGGED BY: JWY
CHECKED: RGK

GEOLOGICAL UNIT, GENERIC NAME, ORIGIN, MINERAL COMPOSITION.	FLUID LOSS	WATER	CORE RECOVERY (%)	METHOD	CASING	TESTS	SAMPLES	R.L. (m)	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	MOISTURE CONDITION / WEATHERING	STRENGTH/DENSITY CLASSIFICATION	SHEAR STRENGTH (kPa)	COMPRESSIVE STRENGTH (MPa)	DEFECT SPACING (mm)	SOIL DESCRIPTION Soil type, minor components, plasticity or particle size, colour. ROCK DESCRIPTION Substance: Rock type, particle size, colour, minor components. Defects: Type, inclination, thickness, roughness, filling.
MARINE SEDIMENTS			60	VIBROCORE		0-0.5m: Contam sample						W	LP				Shelly, fine to medium SAND, minor coarse sand; light greyish brown. Loosely packed, wet, well graded; shells, broken, fine gravel sized.
						0.5-1m: Contam sample			0.5				TP				Fine to medium SAND, trace coarse sand, some shells; lightly packed, wet, well graded; sand, sub-rounded.
Box 1									1.0 1.5								
									2.0 2.5 3.0 3.5 4.0 4.5 5								**END OF HOLE AT 1.6m.** Drilled to 2.0m, recovered 1.6m.

T+T DATATEMPLATE.GDT jwy

Log Scale 1:25

BORELOG 30488.1000.GPJ 30-Mar-2016



Tonkin+Taylor

BOREHOLE LOG

BOREHOLE No:V08
Hole Location:

SHEET 1 OF 1

PROJECT: Crude Freight
LOCATION: Marsden Point
JOB No: 30488.1000

CO-ORDINATES: 35.84207 °S
174.52081 °E
R.L.:
DATUM:

DRILL TYPE: P5 VIBROCORE
DRILL METHOD: VIBROCORE
DRILL FLUID: N/A

HOLE STARTED: 28/2/16
HOLE FINISHED: 28/2/16
DRILLED BY: NZDS
LOGGED BY: JWY
CHECKED: RGK

GEOLOGICAL
ENGINEERING DESCRIPTION

GEOLOGICAL UNIT,
GENERIC NAME,
ORIGIN,
MINERAL COMPOSITION.

FLUID LOSS | WATER | CORE RECOVERY (%) | METHOD | CASING | TESTS | SAMPLES | R.L. (m) | DEPTH (m) | GRAPHIC LOG | CLASSIFICATION SYMBOL | MOISTURE CONDITION / WEATHERING | STRENGTH/DENSITY CLASSIFICATION | SHEAR STRENGTH (kPa) | COMPRESSIVE STRENGTH (MPa) | DEFECT SPACING (mm)

SOIL DESCRIPTION
Soil type, minor components, plasticity or particle size, colour.
ROCK DESCRIPTION
Substance: Rock type, particle size, colour, minor components.
Defects: Type, inclination, thickness, roughness, filling.

Geological unit	Core recovery (%)	Method	Tests	Moisture	Strength/density	Description
MARINE SEDIMENTS	72	VIBROCORE	0-0.5m: Contam sample	W	TP	Shelly SAND; light brown. Loosely packed, wet.
					LP	Fine to medium SAND, minor fine gravel sized shell clasts up to 8mm; dark grey. Looely packed, wet.
			0.5-1m: Contam sample			- grades light grey.
			1-2m: Contam sample			- grades dark grey.
						Medium SAND, some coarse sand and medium sand sized shell fragments. Loosely packed, wet. Very sensitive, dilatant behaviour.
			2-3m: Contam sample		TP	Shelly, medium to coarse SAND; light grey streaked brown/white. Tightly packed, wet; shells, broken, coarse sand to medium gravel sized up to 20mm; sand, well graded, sub-angular to sub-rounded.
Box 1						
Box 2						
						END OF HOLE AT 3.55m. Drilled to 5.0m, recovered 3.55m.

DEPTH (m): 0.5 – 1.0 – 1.5 – 2.0 – 2.5 – 3.0 – 3.5 – 4.0 – 4.5 – 5

T+T DATATEMPLATE.GDT jwy

Log Scale 1:25

BORELOG 30488.1000.GPJ 30-Mar-2016