APPENDIX A:

MARINE, DRILLING AND BLASTING MANAGEMENT PLAN: ROTHERA WHARF

PROJECT TITLE:

BAS Rothera Wharf Construction

Marine Drilling and Blasting Management Plan Rothera Wharf

Client:	**British Antarctic Survey**
Reference number:	
Issue Status:	Draft for CEE application use v3

	Name		**Date**	**Signature**
Prepared by:	J Cordon	BAM Ritchies	10 Jan 2018	[signature]
Checked by:				
Approved by:				

Contents

1 Introduction

As part of the upgrade to the Rothera Wharf for the British Antarctic Survey (BAS), it may be necessary to remove rock both directly adjacent to the sea, and on the seabed, to allow construction of the new wharf. Although subject to rock conditions at this location, it is anticipated that pre-treatment by drilling and blasting with explosives will be necessary to allow rock excavation to the design level.

This document describes the methods to be used to undertake this work and how the use of explosives will be controlled to prevent harm to the marine environment.

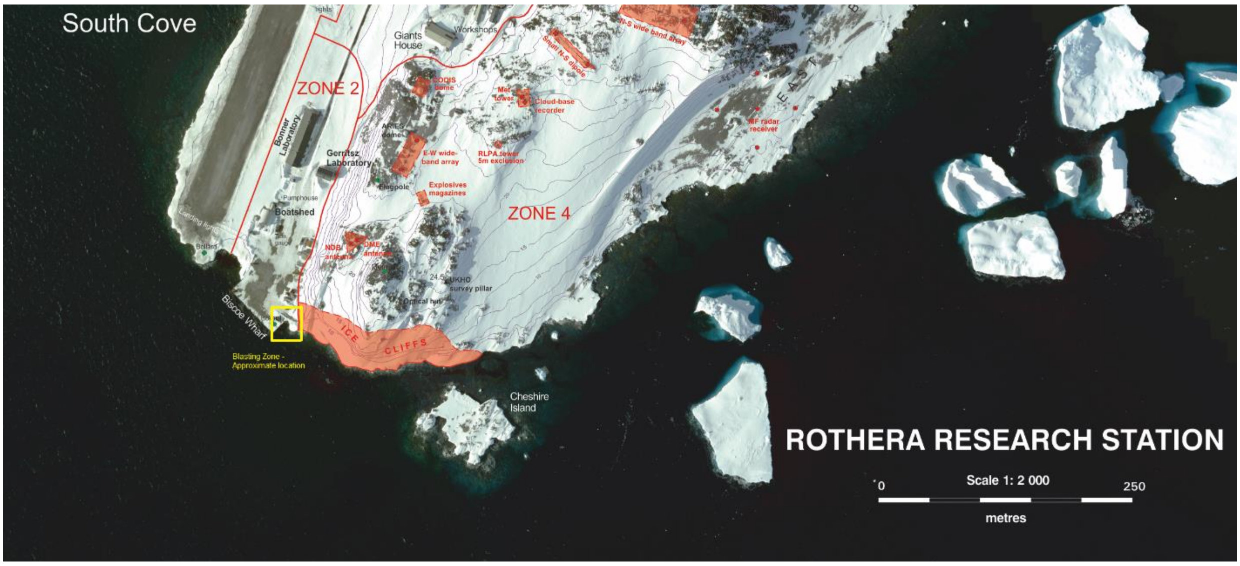


Figure 1 – Rothera Research Station showing the proposed blasting area.

This drilling and blasting process will be strictly controlled following BAM Ritchies blasting procedures and following the requirements of the UK Quarries Regulations 1999 as far as they can be applied to underwater blasting. The Quarries Regulations 1999 provide the strictest requirements currently in place and also ensure compliance with BS5607:1998 Code of practice for the safe use of explosives in the construction industry. In addition, the use of explosives will comply with British Antarctic Survey Code of Practice: Explosives, 3rd edition, 2007.

2 Design and Quantities

The rock to be removed by drilling and blasting for the wharf consists of three distinct parts, as follows:

1. Rock that can be drilled and charged from above the water, with a design level above the low water level. This is the same as land blasting, but is in close proximity to the marine environment. This is represented in orange in figure 2 and consists of approximately 300m^2, 1300m^3 of rock between +5.0 to +1.0mCD. These blasts also include the blasting of a trench down to -1.0mCD not directly adjacent to the water – see figure 3.

2. Rock that can be drilled and charged from above water, but has a free face in the water and a design level below the low water level. This consists of the lower slopes shown in red and the upper slopes shown in beige on figure 2 and consists of approximately 200m^2, 300m^3 of rock between +1.0 to c. -3.0mCD.

3. Rock that is entirely below water. This is represented in green on figure 2, though also includes the lower slopes shown in beige. This consists of approximately 180m^2, 100m^3 of rock between -3.0 to -8.0mCD shown in green plus 60m^2, 100m^3 of the lower slopes in beige.

For the purpose of drilling and charging, the methodology used for types 1 and 2 is the same as that used when blasting on land and is not repeated in this document (reference should be made to document 'Rothera Drill and Blast Management Plan'), however due to the very close proximity to the marine environment additional mitigation measures are required as discussed in section 5 of this document.

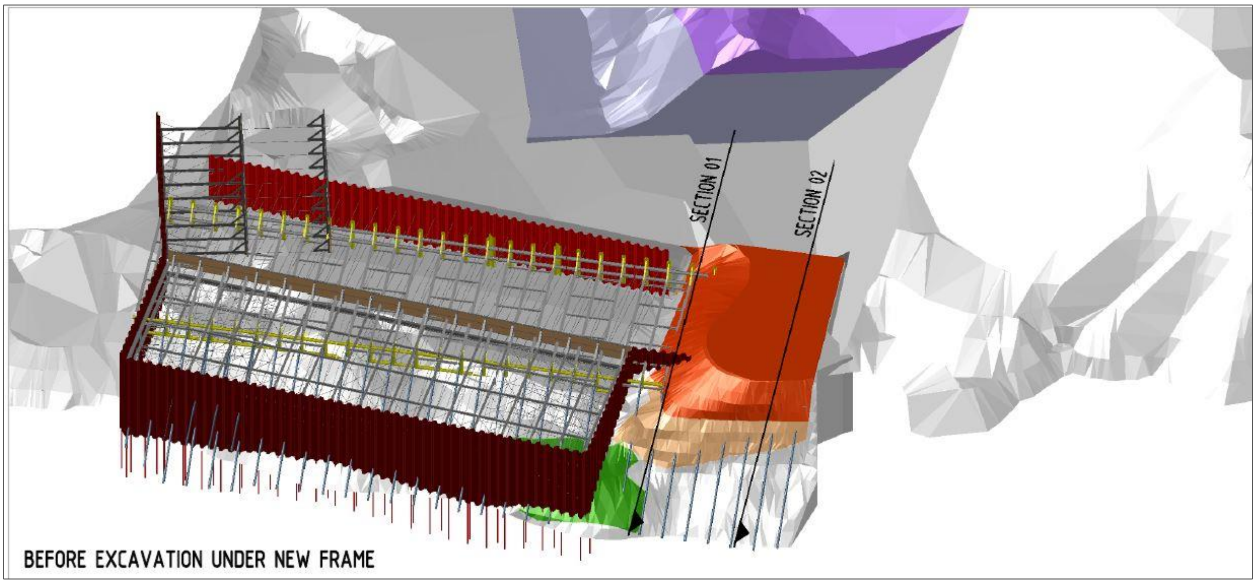


Figure 2 – 3D image showing areas to be blasted underwater and adjacent to the water shown in green, beige and orange.

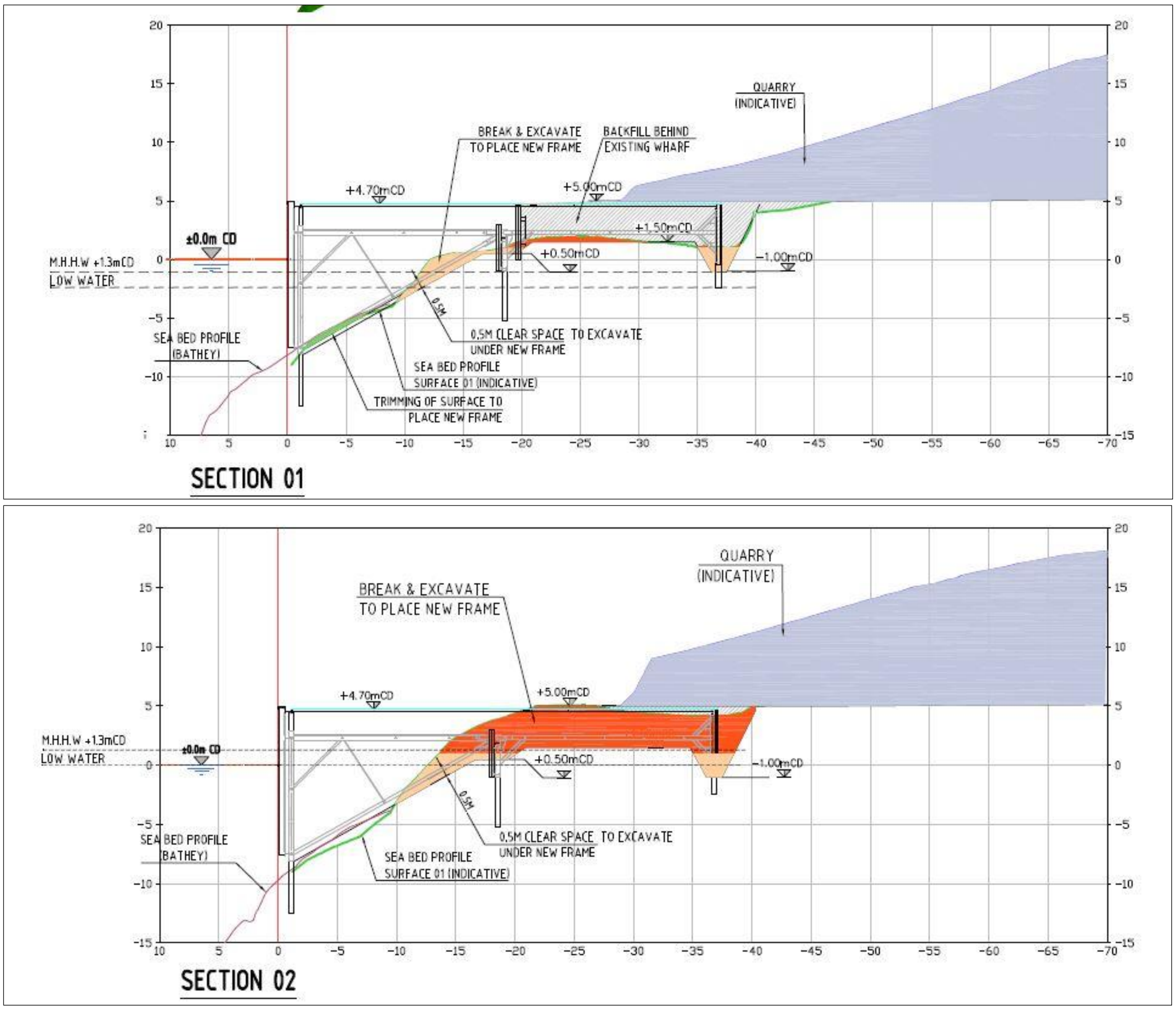


Figure 3 – Cross-sections showing the rock to be blasted.

3 Drilling and Blasting - Underwater

Drilling and charging is undertaken as a continuous process where each hole is drilled and then immediately charged before the drill rig repositions on the next hole, and therefore these activities are considered together as one process. Once sufficient holes are charged, the shot is fired and the process starts again.

This process will involve drilling blast holes using a tracked drill rig on a cantilever, or spudded working platform extending from the land adjacent to the wharf. The drill rig will be fitted with an extended centraliser that can be lowered below the water until it is close to the seabed, allowing the drill bit to collar into the sloping rock seabed. All drilling will be undertaken from this working platform. Charging of the holes with explosives will be carried out from the working platform using a guide tube, or casing, to guide the explosives as they are lowered the hole. Under normal circumstances divers will not be used.

Figure 4 - The above image shows a drill rig working from a cantilever platform. Although this image shows a working platform over the side of a barge, the same method can be used from adjacent land or an existing structure.

3.1 Blast Design

Blasting is required to reduce two areas of the seabed, one of 180m^2 and 100m^3 shown in green on figure 2, and a second area of approximately 60m^2 and 100m^3, the lower slopes shown in beige on figure 2.

The actual blasting parameters used during operations will be determined by environmental limitations, ground conditions, and experienced gained from previous blasts. An outline blasting specification will be prepared for each blast by the Shotfirer and approved by the Explosives Supervisor, and will include any maximum charge weights allowed for environmental mitigation measures. For marine blasting the actual charging is only known once drilling has been completed, but will be constrained by the outline specification limits.

In principle the blasting of the area will be carried out using a square / rectangular pattern of vertical holes over the design area. The actual design excavation location will be determined on-site in consultation with the Construction Manager and taking into account geological conditions.

Trial excavation should ideally be undertaken after the first blasts and at regular intervals afterwards to confirm the results of blasting and allow feedback to the blast design.

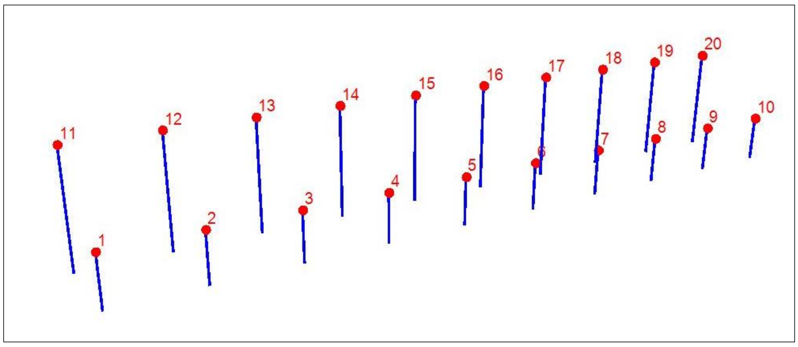


Figure 5 – Indicative 3D image of shot-holes on a 30 degree slope.

The following indicative blast parameters will be fine-tuned to meet the requirements of each blast.

Hole diameter	89mm
Burden (including spacing between rows)	2.0m
Spacing (between holes in the same row)	2.0m
Sub-grade drilling	1.0 to 1.5m
Drilling pattern	Square or rectangular
Number of holes per blast	Typically 10-20
Net rock depth above design	Variable 0 to 3.0m
Stemming	Minimum of 0.3m, though greater where water cover is less than 3m at the time of firing.
Type of explosive	Packaged Emulsion cartridges and cast boosters
Detonators	Non-electric 475/500ms delays
Surface Delays	non-electric connector detonators (eg.25ms and 42ms delays)
Maximum Instantaneous Charge (M.I.C.) - proposed	10 kg

It is anticipated that the total area to be blasted of 240m^2 will result in approximately 5-6 blasting events taking place over a one or two weeks (subject to weather and sea ice conditions).

3.2 Blast Specification

A blasting specification will be prepared for each blast. As a minimum this will include details of:

- All hole co-ordinates.
- Hole depths.
- Actual explosives, detonators and stemming used in each hole.
- Surface initiation timing diagram.
- Blasting Checklist completed during firing.
- Environmental monitoring results.

The blast specification will be signed as approved by the Shotfirer and Explosives Supervisor – roles as defined in the Quarries Regulations 1999.

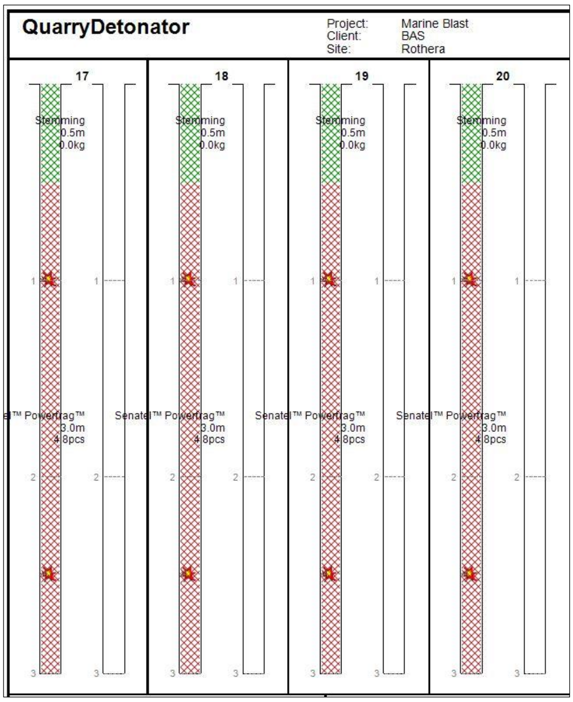


Figure 6 – Indicative charging diagram for a 2m rock thickness, with 1m sub-grade drilling, a 2.5m charge and 0.5m of stemming.

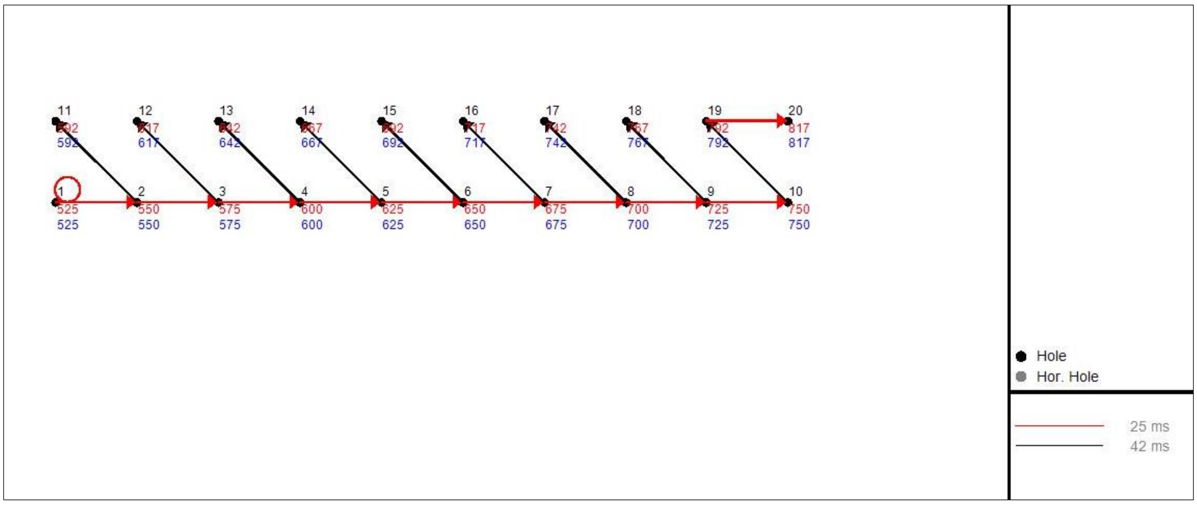


Figure 7 – Indicative initiation plan for 20 holes. The connector detonators would be on the landside with the in-hole detonator signal tubes leading into the shot-holes on the seabed. The times shown are in milliseconds with two detonators per hole.

3.3 Explosives

The following explosives types will be used:

- Packaged emulsion explosives (eg. Orica's Senatel Powerfrag, or similar) will form the main explosive charge.
- Cast boosters (primers) will be used to initiate/boost the packaged emulsion explosives.

Figure 8 - A packaged emulsion explosive and cast boosters.

These explosives have been selected for a number of reasons to minimise impact to the environment:

1. The explosives have been manufactured to a high standard of quality control in an explosives factory to have a good oxygen balance, minimising the production of harmful toxic emissions of NOx and excessive CO, CO_2. Some CO_2 will be released to the atmosphere.
2. These explosives contain no nitro-glycerine and deteriorate to a greater state of safety in the unlikely event of a misfire.
3. They are relatively insensitive during handling in relation to other explosives types, and are suitable for cold conditions.
4. They are waterproof and are available for use in underwater blasting.

Although most packaged emulsion explosives are detonator sensitive, cast boosters can be used to avoid pressure desensitisation in the underwater environment.

Non-electric detonators have been selected to initiate the explosives and to control the initiation sequence. These detonators are not affected by radio frequency hazards and are sufficiently robust for use in the process described below.

Figure 9 - Examples of non-electric detonators

Waste packaging from explosives must be burned on site in a controlled manner as this is the best means of disposal of potentially contaminated packaging in a safe manner. This is as per the HSE / CBI Guidance for the Safe Management of the Disposal of Explosives 2007 s11.2.3.5, as referenced in the UK Explosives Regulations 2014. This process is anticipated to have a minimal impact with the small size of the blasting operations. No other waste will be burnt during this process.

3.4 Preparing charges

Prior to loading, charges are prepared in PVC lay-flat tubing for ease of loading and to minimise the risk of misfires. These charge units are made up in a designated working area by the shotfirer.

- The number of charges inserted in any one tube is controlled by the practicality of length and weight but should not exceed 2.0m length, 10kg or the maximum instantaneous charge weight agreed.
- The detonator should be placed in the primer, which is then placed in the first unit of charge. If two detonators are being placed in the same unit, the second detonator should be placed either in the same primer, or a second primer near the top of the charge.
- The cartridges are then inserted into the lay-flat, making sure that they are all in contact with each other. The detonator signal tube running up inside the tube. The unit is then secured tightly with duct tape, very strongly at each end, though leaving exposed explosive clear where contact with further charges are required. The unit should be sufficiently competent to allow it to be lowered down the casing and shot-hole.
- Charges may only be prepared for the hole currently being drilled.
- Only sufficient explosives should be removed from the storage location to make up charges for the holes being charged that day. Packages should be opened and used one at a time as required.
- Records must be kept of the quantity of explosives and detonators placed in each hole.
- Explosives and initiation accessories will be kept separate until needed to make up charges. Made-up charges will be kept in the Shotfirer's preparation area until the shot-hole is ready for charging.

3.5 Hole Positioning

Prior to commencing drilling operations, a detailed plan is prepared of the intended hole positions as per the blast design. Each hole being assigned x and y co-ordinates and a target hole bottom position. The drilling plan is then overlaid with a series of set-up locations for the working platform allowing for a number of holes to be drilled from each set-up.

Next the working platform is positioned on a set-up location so that the target holes can be reached. The target drill positions are then marked by the surveyor on the platform. The rig is then set-up on the target position in-line with survey markers. The guide tube is lowered, or checked, to ensure that it is close to the seabed to ensure the hole can be collared on the rock slope. All holes are drilled vertically and the drill string is checked using an inclinometer to ensure that it is vertical prior to commencing drilling.

The Shotfirer verifies the rig is on the target position for the correct hole and marks this off on the plan. He also verifies that the drill string is vertical.

3.6 Drilling and Charging

Prior to commencing operations any loose material identified from surveys, or inspections, will be removed using a hydraulic excavator to leave a clean rock surface.

Holes will be drilled and charged using the following method:

1. The drill casing is lowered to the seabed, top of rock (TOR) and the casing length and the distance from the top of the casing to the reference level is recorded.

2. The DTH drill string is lowered down the casing and the hole drilled to the required level. Once completed, the drill string is removed and the shot-hole depth is confirmed using calibrated stemming rods or tape measure.

3. The driller confirms the shot-hole length and any other relevant information to the Shotfirer (eg. broken ground).

4. The Shotfirer charges the shot-hole with the pre-prepared charges by lowering the charges on their detonator shock tubes into the top of the casing down into the shot-hole. The shotfirer then checks the rise of the explosives in the hole. He may use the stemming rods to push the charges gently into the hole if required. Further charges are then added, checking the rise each time.

    - A minimum of two detonators should be used in any one shot-hole.

    - A record of the number of charges and detonators in each hole must be recorded by the shotfirer.

    - Any anomaly in the charging must be recorded.

5. Stemming (angular aggregate) is then poured into the hole to prevent the explosives floating free and to effectively confine the charge. The rise of this stemming should be confirmed.

6. The casing is now lifted clear of the seabed by approximately 2m, taking care not to damage the detonator shock tubes. A non-ferrous retrieval ring is then lowered down the outside of the casing to hook the signal tubes at the seabed. These are then pulled up to the working platform taking care to ensure the ends are not snagged on the casing.

7. The Shotfirer labels the tube and secure it to keep the signal tubes clear of the drill rigs and working platform. These tubes should be hand tight to prevent entanglement and avoid damage due to stretching.

The entire working area is considered a restricted area during charging operations with no-smoking or hot works permitted. Only personnel involved in the process may be present in the area.

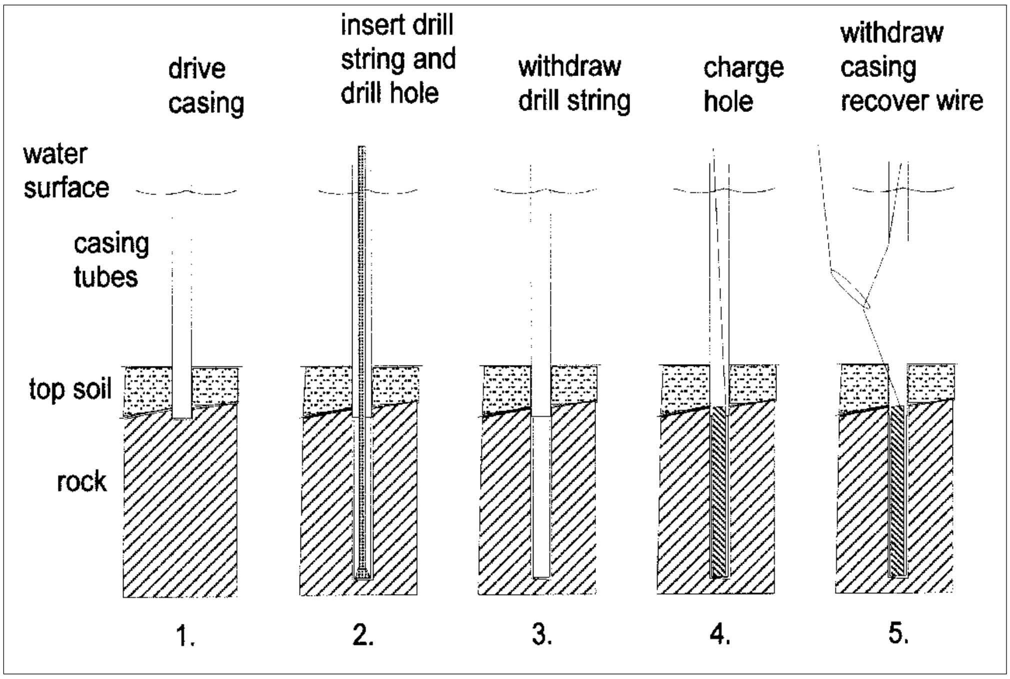


Figure 10 – Drilling and charging cycle.

Divers do not form part of normal operations. In the event that divers are required for any inspection or action involving explosives, a separate method statement and dive plan will be prepared and approved.

3.7 Initiation system

A system of advanced initiation will be used, where in-hole detonators have the same delay (eg. 500ms). The detonators tubes are then connected in sequence on-shore using connector detonator assemblies to control the initiation timing and ensure each hole is fired on a separate delay. This system ensures that all in-hole detonators are 'burning' through their delay element prior to the detonation of the first detonator in the sequence, preventing premature ground movement and misfire due to cut-offs. This control of the initiation timing ensures that the maximum instantaneous charge weight fired in any delay, and consequently the environmental impact, is kept to the minimum.

The first hole in the initiation sequence is connected to a firing line leading to a safe location. Surface delay detonators will be either laid on the wharf and covered with sand, or similar material, or placed on a firing board.

3.8 Blasting Protocol

The 'blasting protocol' refers to the actions undertaken to allow the shot to be charged and fired in such a way as not to harm personnel, marine fauna, equipment, air traffic, marine vessels and infrastructure. This protocol will be developed between BAM and BAS on-site to ensure all the necessary control measures and communications are in place to allow the blast to be charged and initiated safely. The blasting protocol is controlled by the 'Blast Controller', generally a supervisor who is appointed to that role and who controls all communications during the operations, and especially when firing the shot. Once all checks have been made, and it is safe to do so, the Blast Controller gives the Shotfirer permission to fire. Anyone can stop a blast by informing the Blast Controller, or in an emergency calling STOP, STOP, STOP on the radio channel. Only the Blast Controller can re-commence operations.

The Blast Controller records all actions during the firing procedure on a blast checklist. All personnel involved will receive instructions and training in their role in the firing procedure.

Appendix A gives an example of a blast checklist and the actions, checks and warnings to be undertaken at various times.

3.9 Explosives Storage and Transport

Explosives will be stored and transported as described in document 'Rothera Drilling and Blasting Management Plan'.

4 Blasting Control Measures

4.1 Prevention of rock projection

Flyrock is in general caused by having excessive energy projecting the rock rather than producing fragmentation and heave. Despite a high ratio of explosives to rock being used for underwater blasting, there will be no rock ejection from the water where a minimum of 3m of water cover is in place.

Where blasting is expected in shallower water depths, stemming levels are progressively increased to prevent ejection from the blast.

4.2 Preventing re-drilling into charged holes

Drilling operations are strictly controlled by the Shotfirer who will first confirm with the surveyor that the working platform is correctly positioned and then cross-check the drill rig set-up positions with the Driller before marking the hole 'as charged' on the specification as it charged. The rig will never be set-up on the same location once charged, even if the explosives have been removed from a hole.

No holes will be planned at closer separation than 2.0m when continuously drilling and charging. The Explosives Supervisor must be informed if the hole cannot be drilled within a tolerance 0.2m in any direction from the target position before continuing.

The drill string will be set-up vertically and checked using an inclinometer. A centraliser will be positioned close to the seabed to brace the drill string and prevent deviation during collaring on the slope.

4.3 Prevention of misfires

The following measures will be used to prevent misfires and the potential for leaving unexploded material in the marine environment:

- Two detonators per hole will be used, the second being a backup in case of failure. This is action considerably reduces the risk of misfire due to detonator failure (*BS5607: Code of Practice for the Use of Explosives in the Construction Industry).*

- Explosive charges will be prepared in lay-flat plastic tubes to avoid charge separation within the hole. Careful measurement of the charge depth in the blast hole with calibrated stemming rods will ensure there is no decoupling between these units.

- Where ground conditions are very poor and there is a risk of separation between made-up charge units, a detonator will be placed in each made-up charge.

- Explosive products will be selected that are resistant to dynamic pressure desensitisation.

- Appropriate initiation sequencing and advanced in-hole initiation used to avoid ground movement cutting detonator leads prior to initiation.

- Double checks of the surface system prior to firing.

- Prior to commencing drilling and charging operations the Explosives Supervisor will inspect the area and consult weather forecasts to determine if ice movements in the area are likely to occur. If in doubt operations should be postponed. The shotfirer will remain vigilant during operations and in the event of a change in conditions should either protect the initiation system from small ice, or fire the shot earlier if bergs pose a risk.

5 Environmental

There are a number of potential effects that blasting in the marine environment may have.

These are:

- Ground vibrations from the blasting affecting structures adjacent to the blast area.
- Peak pressure pulse in the water from the detonation of confined explosives charges have the potential to harm divers, marine fauna or diving birds. This may be caused when blasting under the water, or in close proximity to the water.

5.1 Vibration

For any specific site, the intensity of blast vibrations are related to the size of the charge fired, the distance from the blast site to the receiver, and the geological and topographical conditions at that location. Although the effect that specific geological and topographical conditions at Rothera will have on vibration attenuation is not known, it is possible to make outline predictions of the intensity of vibration levels at different distances for a given charge weight and use these predictions to guide the decision process.

At very close proximity to the blast - a few metres - it is permanent displacement rather than ground vibration that will have the controlling influence on structures. Beyond a few metres of the blast site the vibrations are transient with a small proportion of the explosive energy is transmitted into the rock mass as seismic waves.

It is possible to make predictions of the likely intensity of the vibrations at each location based on an empirical relationship derived by the US Bureau of Mines relating ground vibration to distance and charge weight, taking into account local geological factors, as follows:

$PPV = a\,(SD)^{b}$

Where:
PPV = peak particle velocity (mm/s)

SD = scaled distance = Distance (D in metres) ***/*** maximum instantaneous charge (MIC in kg)$^{1/2}$

a and **b** are dimensionless site factors,

The peak particle velocity predictions shown in the table below use site factors from the ISEE Blaster’s Handbook 18th Edition for predicting upper boundary limits for construction blasting. Values are given for anticipated maximum instantaneous charge weights for various sensitive receptors.

Indicative Blast Vibration Prediction
PPV = a(D/MIC^0.5)^b
where

PPV = Peak Particle Velocity (mm/s)
D = Distance from blast to sensitive location (m)
MIC = Maximum instantaneous charge (kg)
a and b = Site factors

All distances are approximate

ISEE Blaster's Handbook values

	Construction Upper Boundary
K	1730
B	-1.6

Sensitive Receptor	Description	Limit	Limit Source	M.I.C (kg)	10	15
		PPV (mm/s)		Distance (m)	PPV (mm/s)	PPV (mm/s)
NDB antenna	Planned to be moved	N/A				
DME antenna (to be moved)	Planned to be moved	N/A				
DORIS	Planned to be moved	N/A				
Sun Photometer	Can be removed if required dur	N/A	BAS MET & Science Co-ordinator			
GPS Receiver		N/A	Newcastle University	165	3.1	4.3
Optical Hut	SAOZ, Sun photometer logger	N/A	BAS MET & Science Co-ordinator	140	4.0	5.6
Optical Hut	AG spectrometer, OH imager, All sky cam, IR all sky cam	N/A	BAS Electrical Engineer	140	4.0	5.6
Memorial for SE Black and others		15-50	BS7385-2:1993 for buildings assumed	110	5.9	8.2
Memorial cross		15-50	BS7385-2:1993 for buildings assumed	110	5.9	8.2
Memorial KM Brown		15-50	BS7385-2:1993 for buildings assumed	110	5.9	8.2
Memorial NJ Armstrong and others		15-50	BS7385-2:1993 for buildings assumed	110	5.9	8.2
Memorial for sledge dogs		15-50	BS7385-2:1993 for buildings assumed	110	5.9	8.2
Memorial cairn ASPA		15-50	BS7385-2:1993 for buildings assumed	810	0.2	0.3
UKHO survey pillar		15-50	BS7385-2:1993 for buildings assumed	170	2.9	4.1
Flagpole		50	BS7385-2:1993 for buildings assumed	170	2.9	4.1
Explosives Magazine		N/A	Mobile steel structure	185	2.6	3.6
E-W wide band array		N/A	BAS Comms. Manager	190	2.5	3.4
ARIES Dome		N/A	BAS MET & Science Co-ordinator	225	1.9	2.6
RLPA tower		N/A	BAS Comms. Manager	275	1.4	1.9
CODIS dome		N/A	BAS Comms. Manager	270	1.4	1.9
MET tower		N/A	BAS MET & Science Co-ordinator	325	1.0	1.4
Cloud-base recorder		N/A	BAS MET & Science Co-ordinator	325	1.0	1.4
AWS		N/A	BAS MET & Science Co-ordinator	430	0.7	0.9
Small N-S dipole		N/A	BAS Comms. Manager	390	0.8	1.1
N-S wide band array		N/A	BAS Electrical Engineer	470	0.6	0.8
MF radar receiver (east beach)		N/A	BAS Electrical Engineer	475	0.6	0.8
MF radar receiver (Bransfield Hse)		N/A	BAS Electrical Engineer	540	0.5	0.6
MF radar transmitter (closest)		N/A	BAS Electrical Engineer	580	0.4	0.6
SkiYMet transmitter		N/A	BAS Electrical Engineer	620	0.4	0.5
SkiYMet radar masts		N/A	BAS Electrical Engineer	670	0.3	0.5
ASPA No.129		NA	Very remote to blast location	680	0.3	0.4
Tide gauge		N/A	BAS MET & Science Co-ordinator	90	8.2	11.3
Boatshed		15-50	BS7385-2:1993 for buildings	100	6.9	9.5
Bonnar Laboratory		15-50	BS7385-2:1993 for buildings	155	3.4	4.7
Bonner Lab. Science		N/A	BAS Science Leader	155	3.4	4.7
Gerritsz Laboratory		15-50	BS7385-2:1993 for buildings	150	3.6	5.0
Gerritsz Lab. Science		N/A	BAS Science Leader	150	3.6	5.0
Giants House		15-50	BS7385-2:1993 for buildings	300	1.2	1.6
Old Bransfield House		15-50	BS7385-2:1993 for buildings	350	0.9	1.3
Admirals House		15-50	BS7385-2:1993 for buildings	390	0.8	1.1
Bransfield House		15-50	BS7385-2:1993 for buildings	530	0.5	0.7
Fuel Tanks		NA	Very remote to blast location	560	0.4	0.6

Figure 11 – Predicted blast vibration levels at sensitive receptors

The relative sensitivity of structures and instrumentation has been discussed with the owners / managers of the sensitive receptors, but will be reconfirmed prior to blasting. The values in the table above show low predicted levels of vibration in relation to limit values. Blasting may need to be controlled if it coincides with sensitive construction activities

By monitoring blast vibration on-site, it is possible to check predictions against actual results and confirm compliance with agreed limits. Blast vibration monitoring will be undertaken for the purpose of both compliance and for later refinement of predictions once sufficient data has been gathered.

5.2 Pressure pulse in the water

Where explosives are fired in water, a pressure pulse is generated which attenuates with time and distance in a similar way to sound waves in air. In addition, gases are released into the water causing bubbles to form which oscillate and collapse and may cause negative pressures.

For charges suspended directly in a body of water a relationship exists between the peak pressure pulse, distance and charge weight as follows:

Peak pressure pulse $P_{unconfined} = 55x10^3\ (D/W^{1/3})^{-1.13}$

where W is the charge weight in kg, D the distance in metres and P the pressure in kpa.

For the Rothera project the explosives will be placed in holes drilled in the seabed and confined with stemming. Confining the explosives in this way has the effect of reducing the pressure pulse transmitted to the water. The level of the peak pressure pulse transmitted to the water is site specific and depends on factors such as geology and seabed topography, however there are reduction factors for confined explosives which can be applied following experience or published texts:

- Langefors & Kihlstrom 1963 suggests levels of 0.10 to 0.14 of the unconfined pressure pulse.
- Oriard 2005 suggests levels of 0.1 to 0.33 of the unconfined value.
- Actual project data from two projects gave measured average peak pressure of 0.08 (maximum 0.26) of that predicted for unconfined values (from 210 blasts).

Using the maximum value recorded by BAM Ritchies from 210 blasts and 326 measurements of $0.26{*}P_{unconfined}$ when the average value was $0.08{*}P_{unconfined}$ is considered conservative and comparative to the published texts.

Therefore Peak pressure pulse $P_{confined} = 14.3x10^3\ (D/W^{1/3})^{-1.13}$

Peak pressure in Kilopascals for different distances have been converted to dB using a reference level of 1µPa and are shown below.

P=H(D/W^	P=Peak pressure (kpa)	
	D=distance (m)	
	W= charge weight (kg)	
	H=55000*0.26 for confined	
kg	10	
m	Peak Pulse (Kpa)	Peak Pressure (dB) - ref 1x10^-6 Pa
100	187	225
200	85	219
300	54	215
400	39	212
500	30	210
600	25	208
700	21	206
800	18	205
900	16	204
1000	14	203
1100	12	202
1200	11	201
1300	10	200
1400	9	200
1500	9	199
1600	8	198
1700	8	198
1800	7	197
1900	7	197
2000	6	196
2100	6	196
2200	6	195
2300	5	195
2400	5	194

Figure 12 – Predicted pressure peak pressure pulse for underwater blasting.

As an alternative, following the approach shown in Australian Standard AS2187-2:2006, which suggests a limit of 40 KPa peak pressure for humans and animal exposure an exclusion zone of 1200m is calculated.

Where,

$P_{unconfined} = 55x10^3 (W^{1/3} /D)$ and $P_{confined} = P_{confined}$ *0.4. (P in Kpa, W in Kg and D in metres)

$P_{unconfined} = 55x10^3 (10^{1/3}/1200) = 99$ and $P_{confined} = 99 *0.4 = 39$ KPa (less than the limit value of 40KPa).

Guidelines for the use of explosives in or near Canadian fisheries waters Wright, D.G., and G.E. Hopky. 1998 suggests that 'No explosive is to be knowingly detonated within 500m of any marine mammal (or no visual contact from an observer using 7x35-power binocular).'

In a report by Aquatera 'Evaluation of the Environmental Impact on Marine Fauna of Underwater Noise Generated During Wharf Redevelopment and Extension Works at Rothera Research Station, Antarctica, v2 Jan 2018' marine fauna observation zones have been determined for blasting at 1200m for cetaceans, 600m for seals and 300m for birds.

Considering this Aquatera report as the most relevant project specific source, the plan is to implement a single 1200m observation / exclusion zone for simplicity, though should this zone be continuously occupied by less sensitive fauna, it may be necessary to introduce the three separate observation / exclusion zones for marine fauna of varying sensitivity.

5.3 Blasting Adjacent to the water

Where land blasting is undertaken in close proximity to a water body, some of the ground vibration will be transmitted across the land / water boundary into the water. Within the water this energy is transmitted as a pressure pulse similar to noise in the air and may cause harm or disturbance to marine fauna at very close proximities.

The following calculation has been made to predict the level of transmission into the water body based in part on Guidelines for the use of explosives in, or near Canadian Fisheries Waters – Wright and Hopky 1998 and the ISEE Blaster's Handbook 18th Edition. This assumes a perpendicular single boundary between the rock and water with no intermediate broken or weathered layers and as such can be considered conservative.

Equations from: Guidelines for the Use of Explosives In or Near Canadian Fisheries Waters - Wright and Hopky 1998

Step 1 Zw=DwCw Zr=DrCr

Equation B

Dw=	Density of water	1.0	gcm^{-3}	
Dr=	Density of rock#	2.70	gcm^{-3}	assumed
Cw=	Compressional wave vel in water	146300	cms^{-1}	
Cr=	Compressional wave vel in rock#	457200	cms^{-1}	assumed for granite

Zw=	146300
Zr=	1234440
Zw/Zr=	0.1185

estimate from Wright and Hopky

Step 2 Pw = 2(Zw/Zr)Pr/(1+(Zw/Zr))

Equation A

Pw=	Pressure in water kPa	
Zw=DwCw		0.1185
Zw=	Accoustic impedance water	146300
Zr=	Accoustic impedance rock	1234440

Pw= 0.212 *Pr

Step 3 Indicative Blast Vibration Prediction

ISEE Blasters PPV = a(D/MIC^0.5)^b

where

PPV = Peak Particle Velocity (mm/s)

D = Distance from blast to sensitive location (m)

MIC = Maximum instantaneous charge (kg)

a and b = Site factors

ISEE Blaster's Handbook values

	Construction Upper Boundary
a	1730
b	-1.6

M.I.C (kg)		15	
Distance (m)		PPV (mm/s)	PPV (cm/s)
2		4980.5	498.0
10		379.2	37.9

convert to cm/s

Step 4 Vr=2Pr/DrCr

therefore Pr=VrDrCr/2

2m 15kg	Pressure rock=	307405128	gcms2	30741	kpa
10m 15kg	Pressure rock=	23407719	gcms2	2341	kpa

Pw= 0.216 *Pr

2m 15kg	Pressure water=	6640	kpa
10m 15kg	Pressure water=	506	kpa

Step 5

Peak Pressure (dB)= 20 x log(P/P_0)

P_0 reference level 0.000001 Pa or 1µPa

For	2m 15kg	196	dB
For	10m 15kg	174	dB

Figure 13 Calculations relating to blasting adjacent to water

Although the calculations shown above indicate that levels of peak pressure will be below those that will cause harm, for the initial three blasts in this area closely adjacent to the water, the full marine fauna observation / exclusion zone(s) described above will be implemented. During these initial blasts, actual peak pressure levels will be measured using a hydrophone. If after this period actual levels are shown to be low it may be possible to reduce the marine fauna zone after seeking the approval of the BAM Environmental Manager.

5.4 Mitigation Measures for Underwater Blasting

In order to reduce the adverse environmental effect of blasting in the marine environment, a number of mitigation measures will be used, as follows:

- All explosives will be placed in shot-holes drilled in the seabed and confined in the holes with angular aggregate of approximately 1/12th hole diameter. A minimum of 0.3m length will be used, greatly reducing the pressure pulse released to the water.

- Short delay detonators will be used between holes to reduce the maximum charge weight fired and therefore the peak pressure pulse. The maximum instantaneous charge will therefore be that quantity fired in one hole, or deck within a hole, rather than the overall quantity in the blast.

- A marine fauna observation / exclusion zone and clearance protocol will be established with an exclusion zone of 1200m. This zone will be controlled by marine fauna observers at strategic viewpoints to ensure no mammals are present from 30 minutes before blasting, until 10 minutes after blasting. Any sightings of marine fauna in the water will re-set the 30 minute countdown. If sightings of marine fauna in the full 1200m zone are disruptive to operations, it may be necessary to implement the three separate recommended zones of 1200m for cetaceans, 500m for seals and 300m for birds.

- A hydrophone can be used to identify the presence of cetaceans in the area. Should cetaceans by identified in the area, close to the area, or getting closer (louder) then blasting would be postponed. When in doubt blasting is postponed. The users of the hydrophone will be trained in its use.

- A passive acoustic hydrophone(s) will be deployed to monitor peak pressure pulse levels during blasting operations and to verify predictions.

- A strict blasting protocol will be developed with communications between the marine fauna watch, the shotfirer and dive controllers to ensure the exclusion zone is clear.

- Blasting will only be undertaken when no divers are in the water within the Rothera area and no vessels are within 1200m, except project vessels and those used for marine fauna watches which will maintain a 200m minimum separation.

Some minor fish kill is a possibility.

6 Responsibilities

All BAM explosives activities will be controlled by an Explosives Supervisor, who will be appointed in writing by the Project Manager. This person will have sufficient experience and qualifications to be considered competent for the role as defined in the Quarries Regulations 1999. All other personnel involved in the use of explosives will be appointed by the Explosives Supervisor. These roles include:

- Shotfirer
- Blast Controller
- Sentry
- Marine Fauna Observer

It is the responsibility of the appointor to ensure that the appointees have suitable training, qualifications and experience to competently undertake that role and check that they are not a prohibited person if working with explosives. Records of these checks must be kept with the appointment – these may be in the form of training records, competency assessment forms, or copies of a CV and certificates.

The duties and responsibilities of each role must be included in the written appointment. Individuals may be appointed to several roles, but must follow the rules relating to the role they are undertaking irrespective of their employment job title.

6.1 Explosives Supervisor (ES)

The person appointed to organise and supervise all work involving the use of explosives.

Although more than one person may be appointed as Explosives Supervisor, only one may act in this role at any time. This is controlled by completion of the 'Explosives Supervisor Register' which is on display in the site office. This must be completed and then signed by the acting Explosives Supervisor and Project Manager.

Key Responsibilities:
- To ensure that explosives are handled and used in a manner that is without risk to the health and safety of personnel in the vicinity, and bring anything which may adversely affect this to the Project Manager's attention immediately.
- Preparing Shotfiring rules for the operation that are compliant with the BAS Explosives ACOP and Quarries Regulations as far as practicable. Ensuring that all personnel upon which shotfiring rules impose duties have received the latest copy and have understood, accepted and signed their copy of the rules. A copy of the signed acceptance should be kept.
- That the Quarries Regulations 1999, Part V Explosives are complied with as far as possible at this location.
- An adequate written blast specification is produced for each blast - prepared by themselves or the Shotfirer. This is evidenced by the Explosive Supervisor signing at least the cover sheet and proposed explosives loading sheets prior to charging operations commencing.
- Making all explosives appointments on site (except Explosives Supervisors).
- Equipment used for Shotfiring is suitable and safe.
- Checking that site conditions are in line with the blast specification before work with explosives begins.
- Explosives are only kept in the approved store unless they are being transported, or are being used, and accurate records are maintained.
- Providing feedback to the Project Manager of any information gained during blasting activities (experience gained from previous blasts) that may affect safety, other operations or planning / design.
- Implementation of the misfire procedure in the event of a misfire
- Defining the danger zone required. This may be a standard danger zone for blasting, but must be reconsidered for every blast when approving the blasting specification, or if notified of any change during charging notified by the Shotfirer. The extent of the danger zone and position of any safe areas must be notified to the Blast Controller before charging commences and prior to clearing the danger zone in the event of changes in conditions as a result of actual charging.

6.2 Shotfirers

Key Responsibilities:
- Preparing drilling plans for the driller.
- Surveying shots, or ensuring information provided by a separate surveyor is adequate for use preparing the blasting specification and to ensure that the driller can drill the holes in the correct location.
- Preparing an adequate blast specification as defined in the Quarries Regulations 1999.
- To prepare explosives for immediate use.
- Transporting explosives on-site.
- Prepare primers with detonators.
- Charge and stem holes as per the specification, or within the allowable variation. They must notify the Explosives Supervisor of any changes outside the allowable variation, or changes to any conditions since the approval of the specification.
- Maintain a strict record of hole charging so as to ensure that no hole is drilled on the same location twice.
- Link, connect or otherwise prepare the initiation system ready for firing.
- Inspect and test the initiation system as appropriate for the type being used.
- Liaise with the Blast Controller to ensure that the danger zone is clear before testing any live initiation system.
- Fire the shot from a safe designated location.
- Carryout post-blast inspections to check for misfires.

- Comply with The Quarries Regulations 1999, Part V Explosives relating to the storage, handling & use of explosives and instructions from the Explosives Supervisor.
- Check that equipment used for shotfiring is suitable and safe and site conditions are in line with the blasting specification before work with explosives begin.
- Maintaining security of explosives and control of the blast site as a restricted area.

6.3 Blast Controller

The Blast Controller's primary role is to ensure that the blasting danger zone is clear of personnel and secure, that the marine fauna exclusion zone is controlled during the blasting protocol, and to communicate directly with the shotfirer as per the blasting procedure to allow the safe firing of shots without risk of harm to personnel or fauna. It is not the role of the Blast Controller to determine the extent of the danger zone.

Blast Controller key responsibilities**:**

- To make any notifications and to place any signs as required in the blasting protocol.
- For each blast, to select sentries (previously appointed) and brief them of their location and specific duties for that blast. Ensure that they have a radio, and understand their specific duties. At this point ensure that the sentries understand who is acting as Blast Controller.
- Ensure that they are able to communicate with all the sentries and the shotfirer.
- To ensure that marine fauna observers are in position at the designated time and understand their area of responsibility and communications procedure.
- To ensure that no person is left in the danger zone once sentries are in position. Only the shotfirer and those personnel with specific duties in the clearance procedure enter the danger zone at this time.
- To only give the instruction to the shotfirer that he may fire the shot when the danger zone is secure and clear as per the agreed blasting protocol. The acting shotfirer is the only person allowed to enter the danger zone from this instruction until the 'all clear' is given by the shotfirer.
- Only communicate to the shotfirer when he may fire the blast, when there is no doubt in communications, or interference in communications of any sort.
- If anyone gives the STOP, STOP, STOP notice, ensure that the Shotfirer confirms this. If not, repeat the notice until the Shotfirer confirms. Once confirmed, investigate the cause and only recommence the procedure once safe.

6.4 General Rules

No person shall carry out any operation unless they are qualified and appointed to do so.

Everyone must report to their supervisor any accident or injury, defects in plant or equipment, hazards in your workplace.

All personnel will undergo a site induction as required by that individual site and sign-in / clock-in and out at the appropriate place at all times.

All personnel must follow site rules and wear appropriate PPE at all times.

All personnel should ensure that they are aware of the contents of the site specific risk assessment for drill and blast operations - maintained by the Explosives Supervisor.

6.5 Restricted Working Area

The area where explosives are being used should be controlled as a restricted area and be under the constant supervision of either the Shotfirer, or another appropriate person if no charging is being undertaken. Access to this area should be restricted to those personnel directly involved in the operations and with the permission of the Shotfirer (verbal permission is adequate).

Signs and or cones must be placed at the entrance to the blast area to warn people and prevent access to the blast site by unauthorised personnel and general traffic.

7 Permits and Licences

Approval is required from the UK Foreign and Commonwealth office for any blasting operations at Rothera. No other specific licences or permits are required, though activities will be undertaken so as to follow UK regulations as far as this is possible.

APPENDIX A

BLAST CHECKLIST TO BE COMPLETED FOR EACH BLAST PERFORMED - DRAFT

Programmed Time of Shot	
Date Fired:	
Time Fired:	
Blast Number:	
Location	
Number of Blast Holes:	
Total charge in kg :	
Maximum instantaneous charge kg	

Wind Speed	
Wind direction	
Cloud cover 8th	
Precipitation	
Visibility	
Sea State	

	Time	Clear	Name
24 Hours prior to blasting			
Notify BAS station leader			
Notify flight controller			
Notify shipping controller			
Notify dive controller			
60 minutes prior to blasting			
Notify BAS station leader			
Notify flight controller			
Notify shipping controller			
Notify dive master			
Notify fauna watch and monitoring controller			
Notify BAM construction Manager			
Radio check			
30 minutes prior to blasting			
Official Fauna Watch to commence (if fauna is spotted at any time the blast procedure re-starts at 30min)			
Notify dive master that diving operations must be completed			
15 minutes prior to blasting			
Give 'all ships warning Firing in 15 minutes' on VHF CH 16			
Positive confirmation from dive master that all divers are clear of the water			
On-land sentries to take up position			
Visual inspection that the exclusion zone is clear of vessels			
3 minutes prior to blasting			
Confirmation from shotfirer - ready to fire			
Give 'all ships warning Firing in 3 minutes' on VHF CH 16			
Check that land side sentries are in position and area secure			
Sound horn - 2 x 5 seconds			
Confirm with fauna watch that the area is clear			
Blasting and post blast			
Sound horn 30 seconds then fire			
Shotfirer checks that the shot has fired and radios the 'all-clear'			
Give 'all clear' to all vessels on VHF Ch 16 and 14			
Post blast fauna watch completed			

Comments

Checklist completed by: Blast controller	

APPENDIX B:

QUARRYING, DRILLING AND BLASTING MANAGEMENT PLAN: OPTION H

PROJECT TITLE:

BAS Rothera Wharf Construction

Quarrying, Drilling and Blasting Management Plan – Option H

Client:	**British Antarctic Survey**
Reference number:	
Issue Status:	rev4.3 for CEE

	Name		Date	Signature
Prepared by:	J Cordon	BAM Ritchies	09/01/2018	[signature]
Checked by:				
Approved by:				

Contents

1 Introduction

As part of the upgrade to the Rothera Wharf and other Rothera projects for the British Antarctic Survey (BAS), it will be necessary to source quarried rock materials locally at the Rothera base for use during the construction process. These quarried rock materials, principally for bulk fill and surface dressing material, will be sourced from a borrow pit within the footprint of the existing Rothera base. This process will involve drilling and blasting, load and haul, and rock processing, crushing and screening.

This document describes the methods to be used to undertake this quarrying work and how the use of explosives will be controlled to prevent harm to people and the environment. It is anticipated that in addition to quarry blasting, other minor blasting works may be required outside the quarry area, and that these works will follow the same rules and controls contained within this plan.

Figure 1 – Rothera Research Station showing the proposed blasting area.

2 Project Rock Requirements

It is anticipated that approximately 26,000m^3, 52,000t of rock backfill will be required for the proposed wharf construction design – option H. In addition to this backfill, top surface course material of 30-80mm is required to be placed on top of the backfill at a thickness of 0.5m.

Further quarried rock products may be required for the coastal stabilisation works in the cove adjacent to Biscoe Wharf, southern runway embankment, northern runway embankment, Rothera Wharf, or later redevelopment works.

The total anticipated requirements are shown in the table below.

Item	Project Requirement	Type	Grading	Net Quantity (tonnes)	Comments
1	Wharf	Rock Backfill	5-40kg	52,000	Grading tbc
2	Wharf	Surface material	30-80mm	9,000	Quantity tbc
3	Coastal stabilization in the cove adjacent to Biscoe Wharf	Rock Backfill	5-40kg	2,700	Grading tbc
4	Southern Runway Embankment (excluding item 3 above)	Rock Backfill	5-40kg	12,150	Grading tbc
5	Northern Runway Embankment	Rock Backfill	5-40kg	2,700	Grading tbc
6	Runway	Base course	<25mm	1,620	Grading tbc
7	Runway	Sub-base	25-100mm	1,620	Grading tbc
8	Aggregates		tbc	tbc	Size and quantity tbc
9	Under layer for X blocks		335-670kg	N/a	It is not anticipated that this large size grading will be available at Rothera due to the close fracture spacing of the in-situ rock.

Recycling / re-processing of fill materials recovered from the existing wharf can be undertaken to reduce the volume of rock extracted from the quarry. Although the extent of this recycling will be dependent on the grading of the existing rock backfill material available, an outline estimate indicates that:

- c.2,000m^3 or 4,000t of existing fill can be left in-situ. This will directly reduce the production requirement by 4,000t.
- A further c.15,000m^3, or 30,000t of recovered material can be reprocessed through the quarry plant along with quarried materials. The estimated yield from this process is 10,000t of rock-backfill. This quantity can be removed from the quarrying requirement, both reducing the size of the excavation and use of explosives.

For the products and quantities detailed above, the total extraction from the quarry will be controlled by the need to produce rock-fill material, with all other smaller material being produced from the by-product of this primary production. As some rock-fill is expected to be recoverable from recycled backfill materials from the existing wharf, the total quarry extraction is as follows:

Total from above		*69,550t*
Less material left in-situ	*4,000t*	
Less material re-cycled material re-processed	*10,000*	
Net quantity required from quarrying of		***55,550t***

The specifications for backfill and surface dressing material are contained in document s BAA.4001-DMC-ZZ-ROT-DS-S-1002 – see figure 2 and 3 for details – though these may be subject to later design changes.

No.	Grading(2) (kg)	ELL <2% passing (kg)	NLL <10% passing (kg)	NUL >70% passing (kg)	EUL >97% passing (kg)	Effective mean mass (M_{em}) (kg)
1	5 - 40	1.5	5	40	80	10 - 20

Figure 2 - Backfill specification.

No.	Grading (mm)	D_{50} (m)	M_{50} (kg)	D_n (m)	D_{85} (m)	D_{15} (m)	D_{85}/D_{15} (-)
2	30 - 80	0.045 – 0.065	0.15 – 0.45	0.038 – 0.055	0.085 – 0.064	0.048 – 0.024	2.22

Figure 3 - Surface material specification.

3 Quarry Design

In order to produce the required quarried rock products shown in section 2, it is anticipated that a gross quantity of approximately 140,000 to 155,000 tonnes of in-situ rock will be required from the quarry, though as this quantity is based on estimated yields of rock products from the blasted rock-pile, it may be necessary for rock extraction to be extended up to the quarry boundary shown in this document, or reduced in extent. Detailed processing is shown in section 5 of this document.

The choice of the quarry location has been made to minimise the environmental impact of the excavation by keeping it within the existing developed Rothera base area, and also to maximise the utility of the extra level ground created by the rock extraction by locating it close to the wharf area. Locating the quarry close to the wharf area will also minimise haulage distances and keep potential dust creating activities at the maximum possible distance from the glacier and residential buildings.

The extraction area is limited to the west by the existing face and the east by a valley between the extraction outcrop and the higher outcrop to the east – see figure 4. To the north the area is limited by a valley just north of the DME/NDB location. Extraction will be in two benches (split approximately 10m above the existing working level) working north as far as required within the area defined to extract the required quantity. The top bench would advance ahead of the bottom allowing sufficient space for excavation and loading.

Figure 4 – Plan view of quarry extraction area.

Figure 5 – Quarry extraction area from the south – the red line shows the approximate quarry boundary.

3.1 Quarry Development Plan

The quarry will be developed in the following stages as outlined below:

Stage 1 - The lower area close to the wharf will be removed in one bench to create working space near the wharf and to allow a ramp to be created up to the upper quarry bench level. The blue line in figure 6 represents the face position after a few blasts and this face will be at approximately 80 degrees from horizontal.

Figure 6 – Quarry stage one image from the west, showing the rock to be removed in purple hatching.

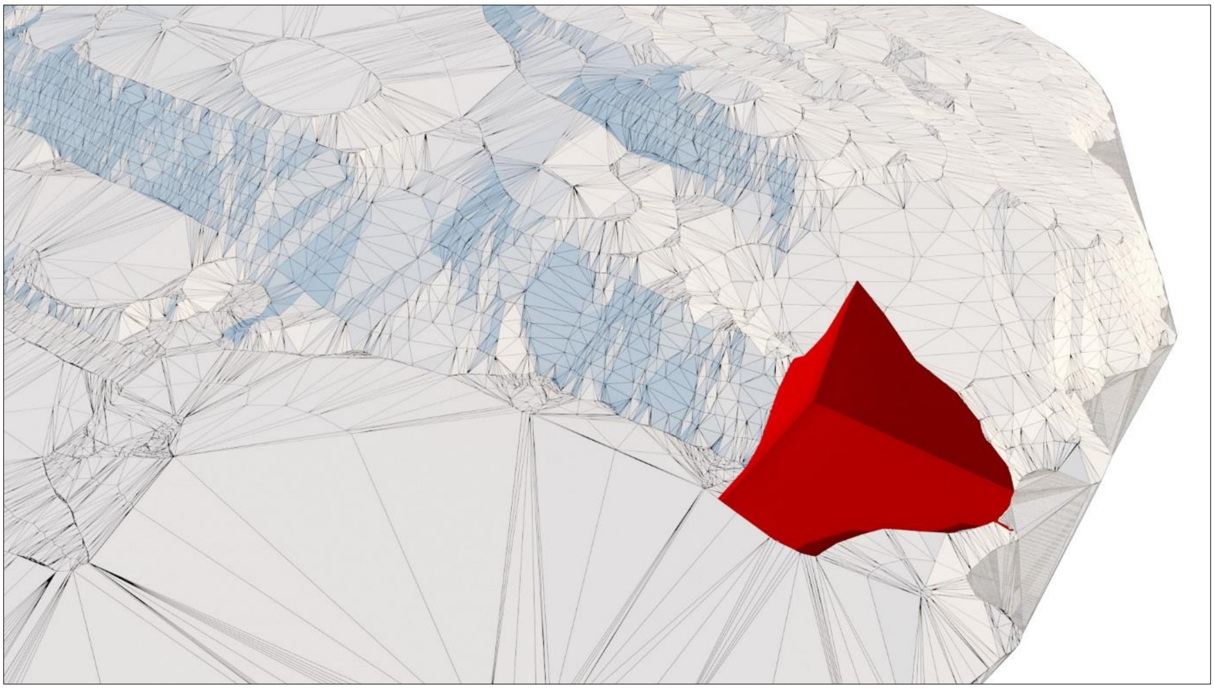


Figure 7 – Quarry stage one isometric view.

Stage 2 - Production continues on the upper bench with the working floor at +10m above the wharf level. This is worked north blast by blast. A ramp will be created to access the upper bench from the wharf level using blasted material.

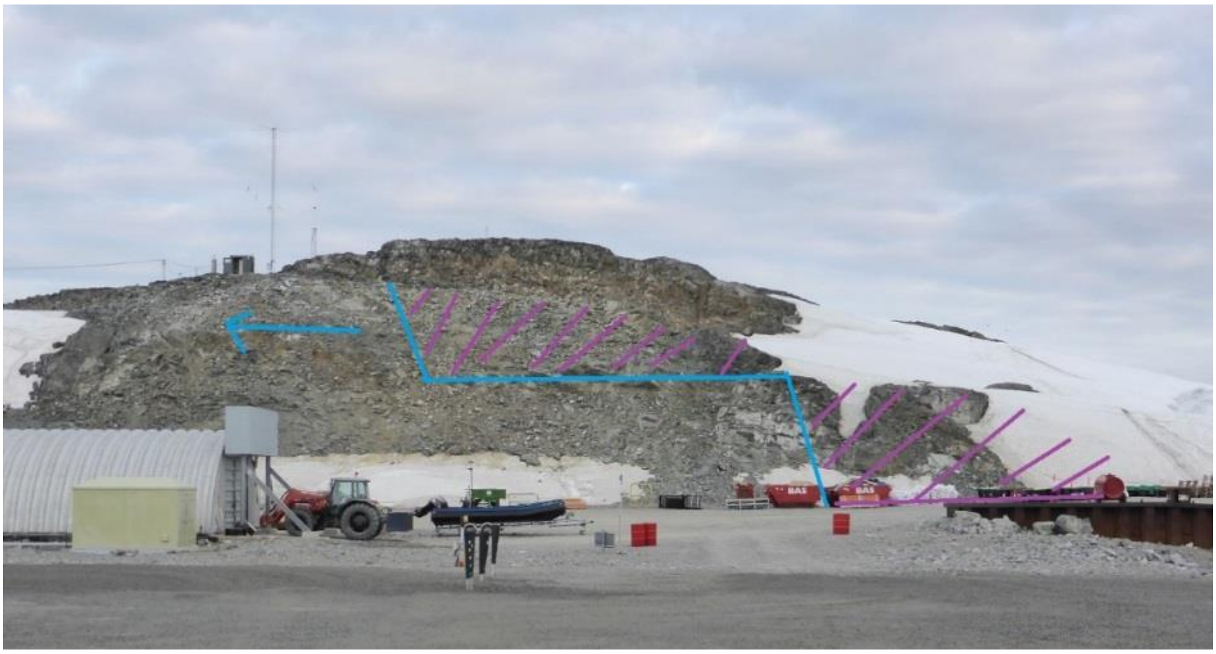


Figure 8 – Quarry stage 2 showing the upper face progression towards the north.

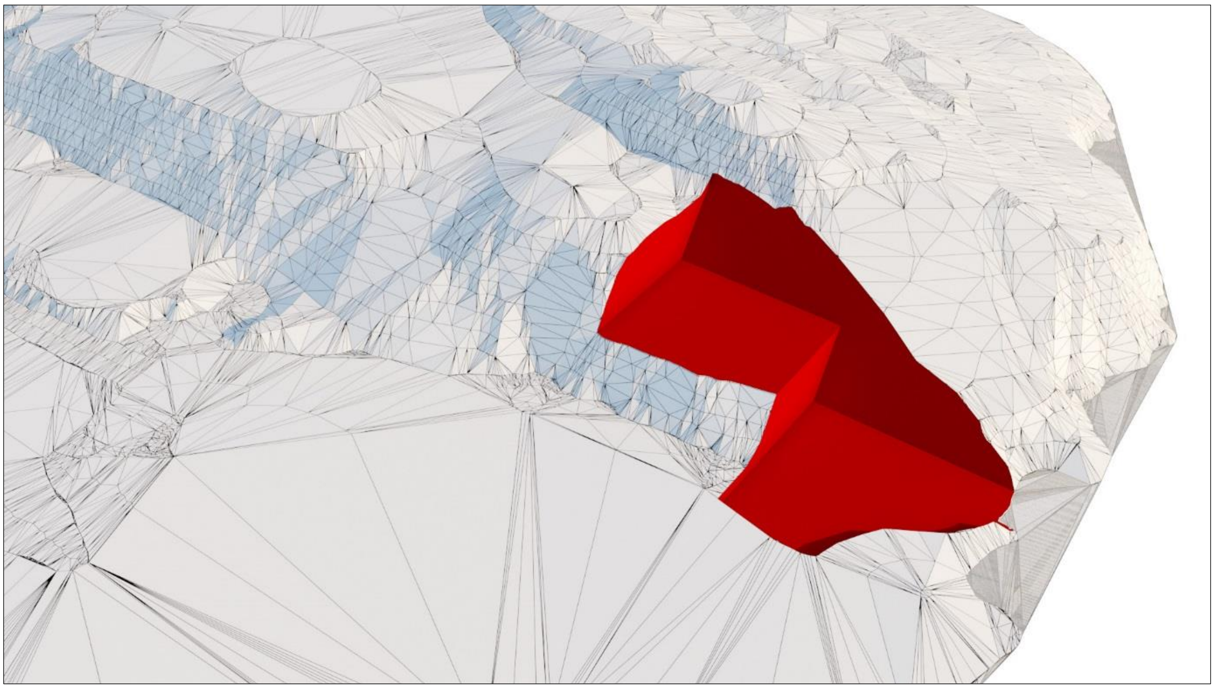


Figure 9 – Quarry stage two isometric view.

Stage 3 – Once the upper bench has been fully worked out the final face is dressed to a more natural angle of approximately 50 degrees from horizontal. Rock extraction continues on the lower bench. Access for drilling and blasting will be made to the upper bench level from above, whilst the lower ramp is removed during processing.

Figure 10 – Quarry stage 3 showing the upper bench worked out and production continuing on the lower bench.

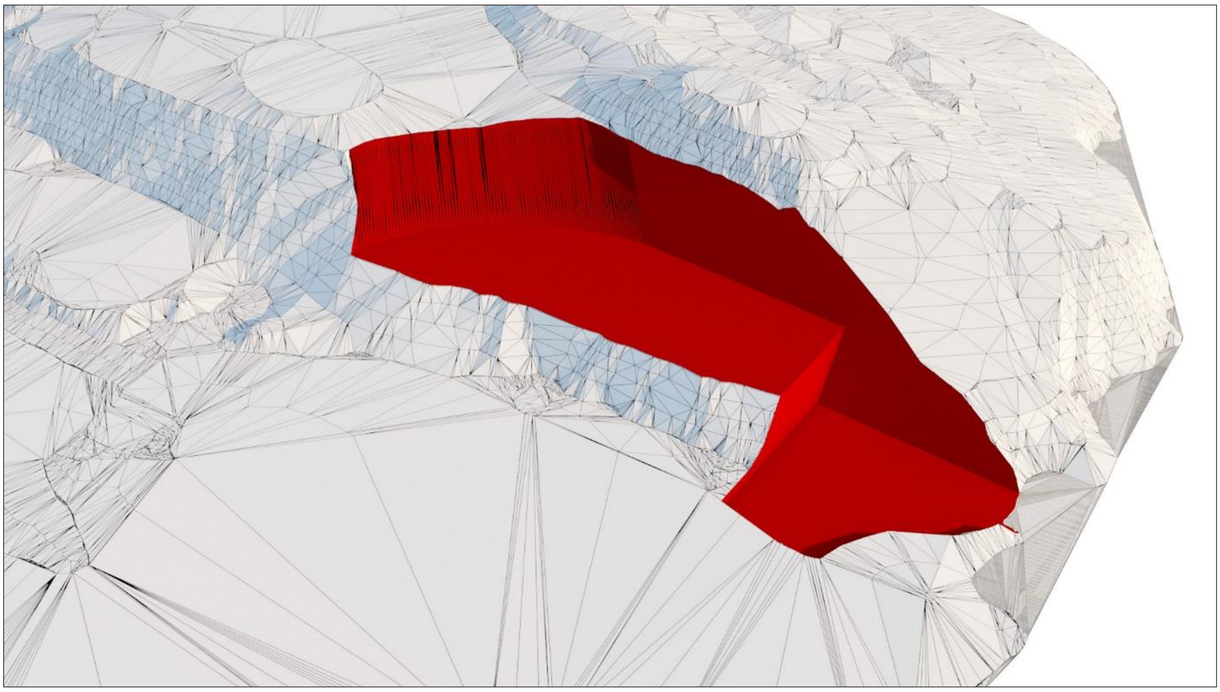


Figure 11 – Quarry stage three isometric view.

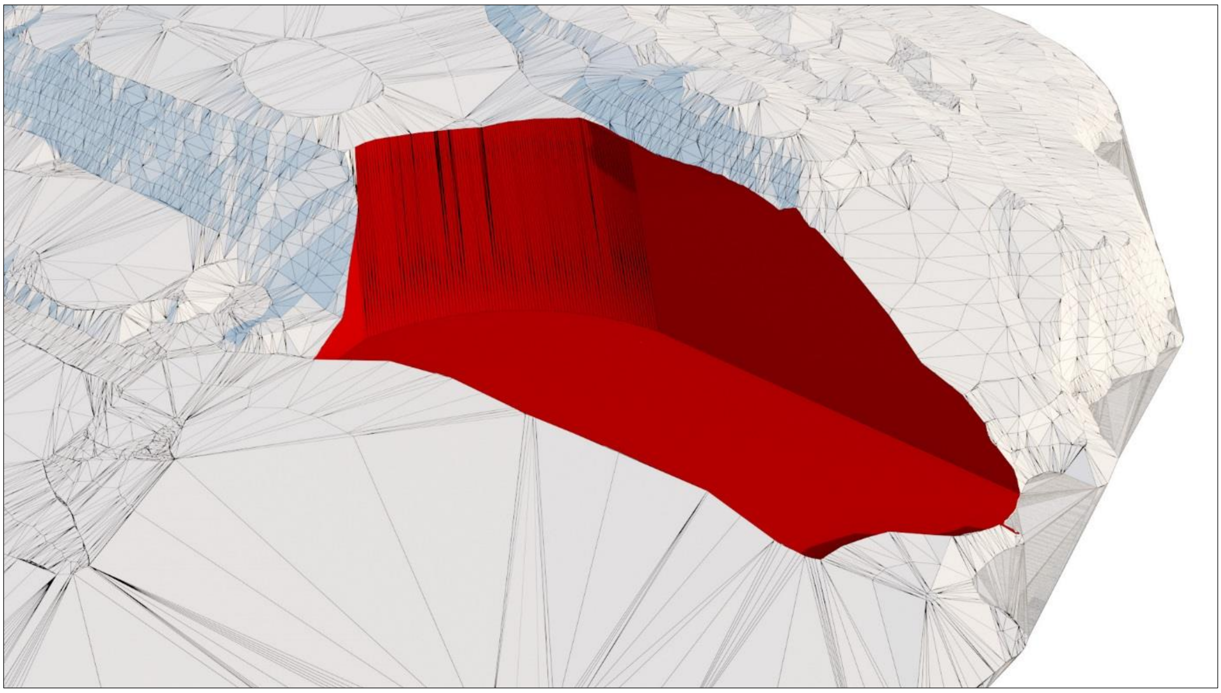


Figure 12 - Final extraction outline – isometric view. The final back-wall has been dressed to 50 degrees from horizontal, though it appears steeper in the image.

Working production faces will be inclined at approximately 10 degrees from the vertical. Final faces will be dressed back to around 50 degrees from horizontal to create stable and more natural looking slopes similar to existing slopes adjacent to the Gerritsz laboratory. It is suggested that snow accumulation modelling be undertaken to determine if it is possible to further optimise the final profile to minimise future snow accumulation.

Face heights will be approximately 10m high, though will vary with the variable surface topography. During rock extraction, the ice cliff adjacent to the quarry will be removed by mechanical excavation from the land, or if necessary with the minimal use of explosive charges. Care will be taken to minimise disturbance to the ice cliff beyond the extraction area. Any other snow will be removed prior to drilling.

The west facing open face is currently inclined at approximately 50 degrees from horizontal, so splitting the outcrop into two benches will allow access to the lower slope areas from above sufficient to obtain reasonable burdens during blasting. To the north and east the area is bounded by snow gullies, except at the NE corner where access for the drill rig would be made.

Quarry processing will be undertaken on the flat ground adjacent to the quarry extraction area as shown in the schematic processing diagram figure 13.

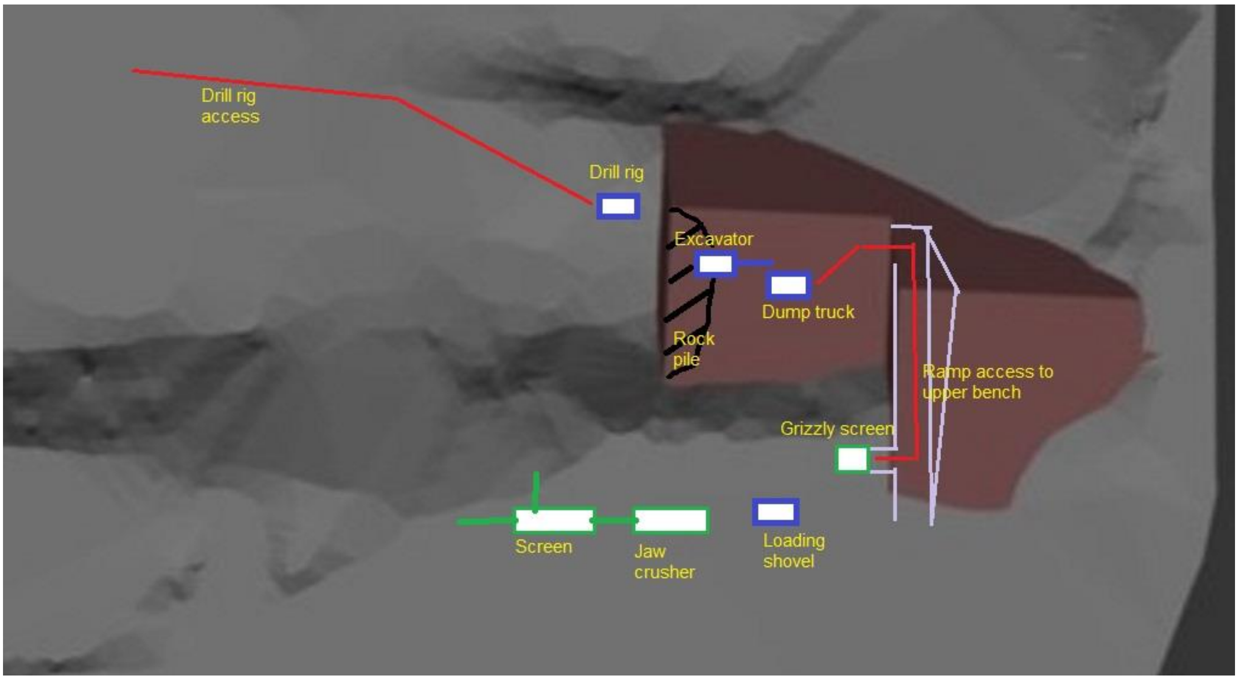


Figure 13 Schematic Quarry processing diagram – set up for backfill production.

3.2 Access and Egress to the Drill and Blast Area

Access to the quarry will be extended from the existing access route to the explosives storage location and other installations, and additionally directly from the floor adjacent to the wharf by constructing a ramp. These routes minimise the need for additional disruption to the environment for access and egress purposes as they are contained in the existing disturbed area.

Access for the drill rig onto the area will be created using an excavator, either to clear snow or loose rocks, and to make access ramps to drilling areas. Loose rocks will be used initially for the construction of these access ramps and later for processing as there is very little overburden material. Clean snow will be pushed into the sea.

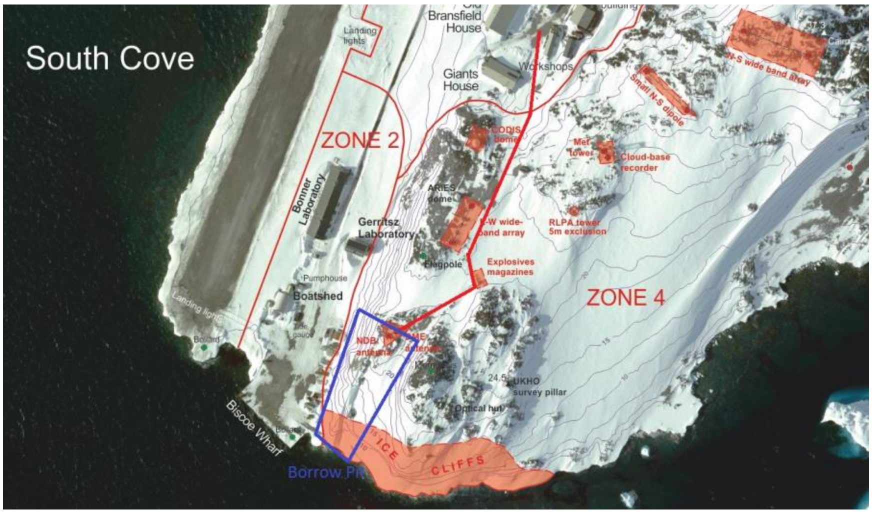


Figure 14 Access route to the quarry from above shown in red.

4 Drilling and Blasting

Primary rock extraction from the quarry will be undertaken using drilling and blasting with explosives. This will involve the drilling of vertical, or near vertical holes, in the range of 64mm to 102mm diameter, with a tracked drill rig. These holes will be drilled in rows parallel and adjacent to an open face, or in a pattern to develop an open face. These holes will then be charged with explosives and stemmed with angular aggregates (see images and sketch below).

It is anticipated that the majority of blasting will be undertaken during the 2018-2019 austral summer, with approximately 20 – 25 individual blasts. The duration of each blast will typically be less than 0.5 seconds. Drilling will continue during working hours on most of the working days during this period.

This drilling and blasting process will be strictly controlled following BAM Ritchies blasting procedures and following the requirements of the UK Quarries Regulations 1999. The Quarries Regulations 1999 provide the strictest requirements currently in place and also ensure compliance with BS5607:1998 Code of practice for the safe use of explosives in the construction industry. In addition the use of explosives will comply with British Antarctic Survey Code of Practice: Explosives, 3rd edition, 2007. This management plan also forms the shotfiring rules as described in the legislation.

Figure 15 Example of tracked drilling rig suitable for uneven ground conditions.

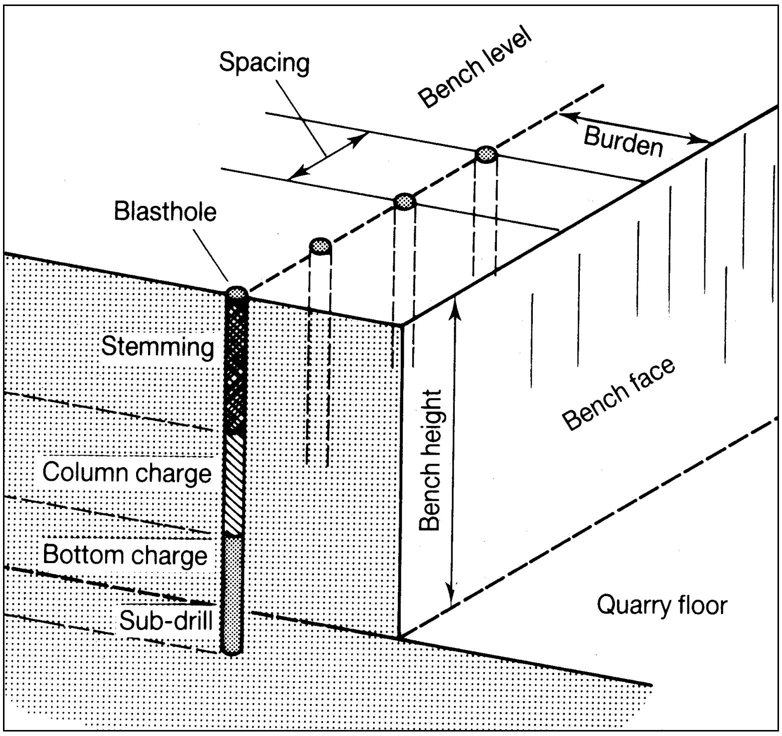


Figure 16 Drilling and blasting terminology

Term	Definition
Burden	The rock thickness between a hole and the rock face, or hole in front (metres).
Spacing	The distance between holes within the same row (metres)
Sub-grade drilling	The distance shot-holes are drilled below the design floor level to ensure the floor breaks to design (metres)
Stemming	Non-explosive material placed in the top of the hole to confine the explosive and prevent ejection. For surface blasting this is normally aggregate chippings of approx 0.1 to 0.15x the hole diameter
Powder factor or blast ratio	The quantity of explosive used to blast a unit volume of rock kg/m^3 (sometimes expressed as a ratio - tonnes of rock per kg of explosive)
MIC	Maximum Instantaneous Charge – the charge weight fired in any one delay period, separated from other charges typically by a minimum of 8 milliseconds (ms)

4.1 Drilling and Blasting Management

Within the drill and blast department, BAM Ritchies control blasting activities at a number of levels, as follows:

- At an overall company level, operations are controlled by the Manager, Drill & Blast, supported by Contracts Managers, Project Managers and Engineers. The main documents detailing this are the ‘Operational Management Plan’, ‘Drill and Blast Procedures’ and ‘Drill and Blast Guidance’.

- At a quarry / site / project level, operations are controlled by the Site Supervisor, Explosives Supervisor and site management following this ‘Operational Management Plan’, ‘Drill and Blast Procedures’ and ‘Drill and Blast Guidance’, along with site documents – Site Rules, this Drill and Blast Management Plan and ‘Risk Assessments’.

- At an individual blast level, controlled by the Explosives Supervisor and Shotfirer, using the ‘Blasting Specification’ and any blast specific risk assessments.

Above all, by following this system of control meets the requirements of legislation, in particular the Quarries Regulations 1999.

The following sections provide more detail of the overall system of control and the role of this document.

4.1.1 Control at the Company level - BAM Ritchies

The 'Drilling and Blasting Operational Management Plan' describes how the company manages health & safety and environment activities within the drill and blast department. This overriding management plan can used at site level in conjunction with site specific documents to form a complete site drilling and blasting management folder.

In addition, a number of other company standard documents provide instruction, or guidance, on more specific tasks. These are BAM Nuttall procedures and guidance, and BAM Ritchies procedures and guidance.

4.1.2 Control at a Quarry / Project level.

At each site, quarry or project, the supervisor in charge will prepare and maintain a 'Site Drilling and Blasting Management Folder' which should detail how drilling and blasting operations are managed at that site. A minimum contents is set out below, but additional information relevant to drilling and blasting operations should be included where relevant.

'Drilling and Blasting Management Folder' Contents:

1. Site emergency procedures.
2. Site drill and blast organisation chart and contact details.
3. Drilling and Blasting Operational Management Plan.
4. This Drill and Blast Management Plan.
5. Other site rules.
6. Site specific environmental requirements if not included in this plan.
7. Departmental and Operational Procedures (BAM Ritchies).
8. Site Specific Risk Assessment.
9. Copy of appointments (including Explosive Supervisor Register if not displayed elsewhere).
10. COSHH assessments.
11. Guidance:
    - BAM Ritchies Drill & Blast Guidance Series.
    - Other legislation and guidance eg Quarries Regulations 1999, British Standards, BAS Explosives ACOP.
    - Product information - Material Safety Data Sheets, Technical Data Sheets.

Site drilling and blasting activities will be carried out following the 'Drill and Blast Management Plan, 'Risk Assessment', 'Drill and Blast Procedures' and 'Drill and Blast Guidance'.

Generally, one site specific risk assessment will be prepared to assess the risks involved when undertaking work following the 'Drill and Blast Management Plan, the 'Operational Management Plan' and BAM Ritchies standard procedures. This should be prepared by the Supervisor, in conjunction with other members of the team, but always including the Explosives Supervisor and Shotfirer. It should be reviewed at a minimum every six months, or sooner if conditions change. Other additional task specific risk assessments may be required.

4.1.3 Control at the blast level

This is principally controlled by the 'Blasting Specification' as defined in the Quarries Regulations 1999. Further documents may be required eg. additional risk assessments for blast specific conditions - for weather conditions, or working under faces.

4.2 Appointments and Responsibilities

Quarrying operations including drilling and blasting operations are carried out by BAM Ritchies a division of BAM Nuttall for The British Antarctic Survey (BAS) as part of a construction partnership between BAM and BAS. In order to safely control blasting operations a number key appointments are required as a minimum. Full duties of each role are described below and in individual appointments.

The person appointed to organise and supervise all work at the quarry involving the use of explosives is the Explosives Supervisor. The Explosive Supervisor will be appointed in writing by the Project Manager.

All other appointments listed below will be appointed in writing by the Explosives Supervisor:
- Shotfirer
- Explosives Storekeeper
- Blast Controller
- Sentries
- Laser Surveyor
- Driller

Written appointment records will be kept during the term of the appointment and for 3 years after completion of the project.

It is the responsibility of the appointor to ensure that the appointees have suitable training, qualifications and experience to competently undertake that role and check that they are not a prohibited person. Records of these checks must be kept with the appointment – these may be in the form of training records, competency assessment forms, or copies of a CV and certificates.

The duties and responsibilities of each role must be included in the written appointment. Individuals may be appointed to several roles, but must follow the rules relating to the role they are undertaking irrespective of their employment job title.

4.2.1 Explosives Supervisor (ES)

The person appointed to organise and supervise all work at the quarry involving the use of explosives.

Although more than one person may be appointed as Explosives Supervisor, only one may act in this role at any time. This is controlled by completion of the 'Explosives Supervisor Register' which will be on display in the project office. This must be completed and then signed by the acting Explosives Supervisor and Project Manager. On transfer to another Explosive Supervisor the end date must be completed for the outgoing ES and a new line completed for the incoming ES. The Explosives Supervisor should ensure that a handover is undertaken to pass any new relevant information or changes.

Key Responsibilities:

- To ensure that explosives are handled and used in a manner that is without risk to the health and safety of personnel in the vicinity, and bring anything which may adversely affect this to the Project Manager's attention immediately.
- The Quarries Regulations 1999, Part V Explosives are complied with.
- An adequate written blast specification is produced for each blast - prepared by themselves or the Shotfirer. This is evidenced by the Explosive Supervisor signing at least the cover sheet and proposed explosives loading sheets prior to charging operations commencing.
- Making all explosives appointments on site (except Explosives Supervisors).
- Equipment used for shotfiring is suitable and safe.
- Site conditions are in line with the blast specification before work with explosives begins.
- Explosives are only kept in the approved storage areas unless they are being transported or are being used and accurate records are maintained.
- Implementation of the misfire procedure in conjunction with the Shotfirer.
- Defining the danger zone required. This may be a standard danger zone for blasting, but must be reconsidered for every blast when approving the blasting specification, or if notified of any change during charging notified by the Shotfirer. The extent of the danger zone and position of any safe areas must be notified to the Blast Controller before charging commences and prior to clearing the danger zone in the event of changes in conditions as a result of actual charging.
- Ensuring that all personnel upon which this 'Drilling and Blasting Management Plan' imposes duties have received the latest copy and have understood, accepted and signed their copy. A copy of the signed acceptance should be kept.
- Ensuring that risk assessments are in place for all blasting activities, even though they may be assessed by others.

4.2.2 Shotfirers

Key Responsibilities:

- Marking out shots prior to drilling.
- Surveying shots, or ensuring information provided by a separate surveyor is adequate for use preparing the blasting specification.
- Preparing an adequate blast specification as defined in the Quarries Regulations 1999.
- To prepare, or mix explosives for immediate use.
- Supervising transport of explosives on-site.
- Prepare primers with detonators.
- Charge and stem holes as per the blasting specification, or within the allowable variation shown on the specification. They must notify the Explosives Supervisor of any changes outside the allowable variation, or changes to any conditions since the approval of the specification.
- Link, connect or otherwise prepare the initiation system ready for firing.
- Inspect and test the initiation system as appropriate for the type being used.
- Liaise with the Blast Controller to ensure that the danger zone is clear before testing any live initiation system.
- Fire the shot from a safe designated location.
- Carryout post-blast inspections to check for misfires.

- Comply with The Quarries Regulations 1999, Part V Explosives, and this management plan relating to the storage, handling & use of explosives and instructions from the Explosives Supervisor.
- Check that equipment used for shotfiring is suitable and safe and site conditions are in line with the blasting specification before work with explosives begin.
- Maintaining security of explosives and control of the blast site as a restricted area.

4.2.3 Explosives Storekeeper

The Shotfirer will act in this role. Key responsibilities:

- The security and safe storage of explosives, including detonators.
- Keys to the store are kept in a secure location at all times.
- Check and maintain the field storage location and ensure that the explosives are not exposed to weather and deterioration.
- Keeping accurate records.
- The issue and receipt of explosives only to authorised persons.
- Immediately reporting any loss or theft of explosives to the Project Manager.
- Exercise good stock rotation practice. Conduct regular checks of the condition of explosives being stored.
- Ensuring that the inside of the store is kept clean and free from grit at all times and nothing but explosives shall be stored in the magazine, except essential non-ferrous items eg. a broom.
- Keeping the area surrounding the explosives store clear of grass, shrubbery, spilled fuel oil, or other organic material in order to minimise the risk of fire.
- Stock is checked to ensure that the totals of items that have been used on that day are correct. Total stock checks are done and recorded in the book on a regular basis.

4.2.4 Blast Controller

The Blast Controller's primary role is to ensure that the blasting danger zone is clear of personnel, secured against entry from outside, and to communicate directly with the Shotfirer as per the blasting procedure to allow the safe firing of shots without risk to personnel. It is not the role of the Blast Controller to determine the extent of the danger zone. The Blast Controller does not need blasting experience and could be for instance a construction supervisor.

Blast Controller key responsibilities**:**

- To make any ‘public - BAS’ notifications, internal quarry notifications and to place any signs as required in this document. If this is delegated, they must ensure that it has been done.
- For each blast, to select sentries (previously appointed) and brief them of their location and specific duties for that blast. Ensure that they have a radio, and understand their specific duties. At this point ensure that the sentries understand who is acting as Blast Controller.
- Ensure that they are able to communicate with all the sentries and the shotfirer.
- To ensure that no person is left in the danger zone once sentries are in position. Only the shotfirer and those personnel with specific duties in the clearance procedure enter the danger zone at this time.
- To only give the instruction to the Shotfirer that they may fire the shot when the danger zone is secure and clear as per the procedure in these rules. The acting shotfirer and trainee shotfirers under their control are the only people allowed to enter the danger zone from this instruction until the 'all clear' is given by the shotfirer.
- Only communicate to the shotfirer when he may fire the blast, when there is no doubt in communications, or interference in communications of any sort.
- If anyone gives the STOP, STOP, STOP notice, ensure that the Shotfirer confirms this. If not, repeat the notice until the Shotfirer confirms. Once confirmed, investigate the cause and only recommence the procedure once safe.

4.2.5 Sentries

The primary role of sentries is to guard a position so as to prevent access to the blasting danger zone from the time they are positioned until relieved by the ‘all clear’. Sentries may have additional roles prior to taking up their position eg. checking an area is clear of personnel then working outwards to the entrance before blocking access to it.

Sentries will be instructed by the Blast Controller and must only follow instructions from the Blast Controller, or the Shotfirer directly.

Sentries will be briefed on their specific role for each blast by the Blast Controller. They will be given clear instructions, informing them of their duties and responsibilities and where they must position themselves for the blast.

- They must ensure that they are in position in sufficient time to clear their area of responsibility, take up position and bar entry to the danger zone.
- They must ensure that they understand the method of communication.
- They must be in contact with the Blast Controller and Shotfirer and when asked to do so, report that they are in position and that there area of responsibility is secure, or not.
- Immediately report to the shotfirer, if at any stage the danger zone is breached, or there is some other matter affecting the safety of the blast. Call **STOP, STOP, STOP** at any time to postpone firing - explanation can be made after.
- Stay in position when the shot is fired and bar all entry to the danger zone until the ‘all clear’ signal is sounded and you are relieved by the Blast Controller by radio. If in doubt **stay in position** and contact the Blast Controller.

4.2.6 Laser Surveyor

The laser surveyor is responsible for carrying out face profiling using laser profiling equipment, and hole surveying using either a manual method or an electronic probe. In addition the surveyor is responsible for preparing face profiles, sections, plans and elevations as required by the Shotfirer or Explosives Supervisor.

They must only use equipment that is within calibration and when conditions are suitable to allow a survey to be carried out and used as part of a compliant blast specification as required by the Quarries Regulations 1999.

4.2.7 Drillers

Drillers are responsible for drilling holes as per the driller’s log instruction and within limits of allowable variations. They must:

- Report to the Explosive Supervisor should they be unable to drill any shot hole as indicated on the drill log, or within the allowable variation allowable.
- Ensure that all cavities, obstructions, clay bands, basalt and other geological features that may affect the shot encountered during drilling are recorded on the drill log.
- Securely anchor the drill rig if drilling on steeply inclined ground.
- Do not leave the rig unattended during drilling operations. Lock and isolate the rig when it is unattended.
- If there is not adequate lighting then all operations will cease during poor visibility and darkness.

4.3 General Rules

No person shall carry out any operation unless they are qualified and appointed to do so.

Everyone must report to their supervisor any accident or injury, defects in plant or equipment, hazards in their workplace.

All personnel will undergo a site induction as required by that individual site and sign-in / clock-in and out at the appropriate place at all times.

All personnel must follow site rules and wear appropriate PPE at all times.

All personnel should ensure that they are aware of the contents of the site specific risk assessment for drill and blast operations - maintained by the Explosives Supervisor.

4.4 Restricted Working Area

The area where explosives are being used will be controlled as a restricted area and be under the constant supervision of either the Shotfirer, or another appropriate person if no charging is being undertaken. Access to this area should be restricted to those personnel directly involved in the operations and with the permission of the Shotfirer (verbal permission is adequate). The Shotfirer may prohibit anyone from accessing the charging area.

Signs and / or cones must be placed at the entrance to the top of the shot and on the quarry bench below to warn people and prevent access to the blast site by unauthorised personnel and general quarry traffic.

4.5 Working under faces

Extra caution is required when work needs to be undertaken below a quarry face. This includes toe holes and production holes which might be at risk from material falling from above. The procedure for this will involve the Driller and the Shotfirer assessing each individual blast with the Quarry Supervisor and completing a risk assessment that will form part of the documentation for that blast (eg. BAM Ritchies DB RA03 Risk Assessment for drilling below faces).

The conditions must be re-assessed each day and any changes reported to the Quarry Supervisor. Any instructions arising from the risk assessment must be adhered to before work continues.

4.6 Edge Protection

On commencing works, the Explosives Supervisor will undertake a risk assessment to determine the most suitable form of edge protection following the hierarchal approach and risk assessment as per drill and blast guidance DB G12 Selection of Edge Protection.

4.7 Explosives Custody

Explosives will be either in the locked explosives magazine, designated field storage location, or under the constant supervision of an appointed person. Supervision does not imply use and the explosives may be supervised by any of the persons with explosives appointments when verbally instructed by the Shotfirer.

Explosives deliveries will only be received by the Explosives Storekeeper or Shotfirer.

Explosives types and quantities supplied must be checked against the order and delivery note by the appointed person, before taking control of the delivery. This should include a check that the boxes are sealed and labelled.

Explosives and detonators must be transferred as soon as practical to the approved magazines or designated storage area.

The delivery shall be recorded in the Explosives Record book as soon as practicable. This must be done at the latest by the end of the shift

Explosives being transported will be transferred to a suitable vehicle and remain under constant supervision of at all times.

The shotfirer will ensure that:

- Manufacturers’ containers or other suitable robust containers are used for transportation.

- Detonators will be carried within the manufacturers’ containers **or** a lockable container lined with shock absorbing, antistatic material, kept clean and used only for detonators.

Detonators and explosives materials will only be removed from the manufacturers’ container immediately before use.

Unused detonators, primers or explosives will remain within a manufacturer’s containers and under the constant supervision of the shotfirer at all times until returned to the magazine or storage area.

Detonators, primers and explosives cartridges can be laid out at each blast hole as per the blast specification, with no more laid out that would compromise the requirement for **constant supervision.** Excess cartridges from a previous hole may be moved onto the next hole to avoid being used by mistake. The loose cartridges must remain in the box at the next hole until used.

All boxes will be checked to ensure they contain no explosives residue and stored of the immediate blast area before disposal.

4.8 Explosive Deliveries, transport and storage at BAS Rothera

Explosives for will arrive at Rothera by sea on a chartered vessel and be off-loaded at the existing Briscoe wharf. These explosives will be carried in 20ft shipping containers and will have mixed loads of class 1.1D packaged explosives and 1.4S packaged detonators. These containers will be unloaded from the vessel in their containers and taken to a temporary location for transfer to other vehicles and transfer to the project storage areas.

4.8.1 Receipt of Explosives at Rothera

Coordination between ship and shore is of the utmost importance when discharging explosives at BAS Rothera. It is essential that the Shotfirer is on site and in charge on the shore side during the operation and has good communication between ship and shore as to when in the sequence of the unloading the explosives will be discharged, so that the necessary people can be on site with suitable vehicles to remove the explosives to the magazines or field dumps with the minimum of delay.

- All personnel involved in the transfer must be briefed by the shotfirer and understand their duties in the operation. There should be sufficient personnel to ensure that custody of the explosives is preserved.
- Due to the size of the delivery, the explosives containers should be transferred to the north-west side of the runway temporarily for transfer to air-transport, or on-site transport vehicles. A designated area shall be cordoned off for this purpose and no fuel shall be stored within 25m of this location.
- The explosives storage area on the glacier must have been pre-prepared prior to the delivery to avoid delay.
- The air-craft or vehicles required for the safe and prompt transfer of explosives shall be pre-arranged for the transport operation.
- The detonator magazine will arrive on the same ship as the explosives, so this must be identified as soon as possible and made ready for use.

Once the containers are in the temporary storage location, the detonators should be removed first and taken the short transfer to the BAS Rothera storage location. The main explosives should be supervised by the Shotfirer, or appointed person until all loads have been transferred to the field storage location. This activity is likely to take some time.

4.8.2 Transport of Explosives at Rothera

Transport at Rothera is split between transport on station and to and from the glacier storage depot, with a transfer location to the NW of the Rothera station runway.

The transport routes to be used are shown on figures 17 and 18.

Transport between Rothera station and the Rothera ice-runway storage depot:

- The BAS preferred method of transport between the Rothera station transfer point and the ice-runway storage location is by air using Twin Otter aircraft. Each aircraft has a 3000lb (1363kg) payload. Loading of aircraft will be undertaken as per s5.4.3 BAS Explosives COP 2007.
- Blast planning will aim to minimise the number of journeys by planning explosive usage to match full loads.
- As a back-up, and subject to approval by BAS station management, transport may be undertaken using the BAS owned Tucker snow-cat and a sledge trailer, or skidoo and trailer. These can carry up to 1250kg and 200kg respectively.

Transport on the base:

- This should be undertaken as per BAS Explosives COP 2007.
- This should preferably be undertaken using a tractor and trailer, with a net or tarpaulin used to secure the explosives.
- **NEVER** load explosives and detonators on the same vehicle or trailer.
- No spark producing metal, spark producing tools, oils, matches, firearms, electric storage batteries, flammable substances, acid, oxidising materials or corrosive compounds may be carried in the body of a vehicle transporting explosive materials. The vehicle should not be used to carry other equipment except essential shotfiring equipment and fire-fighting equipment.
- Display warning signs front, back and sides either saying “EXPLOSIVES”, or an explosives hazard diamond.
- Carry a minimum of two dry powder fire extinguishers of 3kg or more.
- Be kept clean and free of grit.
- In the event of fire the trailer should be separated if possible. Only fires on the tractor itself should be fought.
- As a back-up explosives may be transferred by BAS John Deere Gators that can carry approximately 200kg each per journey. The route and transfer location is shown in red on Figure 10.
- Once loaded the transport should go directly from the loading location to the destination location. The transport journey should not commence if it cannot be completed e.g. due to aircraft operations.
- Vehicles carrying explosives must not enter, pass closely or wait next to offices, workshops or fuel storage areas.

Transfer at the foot of the ramp:

- Where explosives are going to, or from the runway to the blast site, it is necessary to transfer them from the tractor and trailer to the Twin Otter, or vice versa. This should be undertaken at a designated location well clear of the fuel storage facility. The exact location may vary due to snow conditions, but should be as flat as possible to avoid slips, trips and falls during manual handling.
- No explosives shall be stored at this location.

Transport general:

- Where it is possible to transport explosives in full pallets of 1250kg, these should be loaded using equipment fitted with a fork-lift in preference to manual handling.

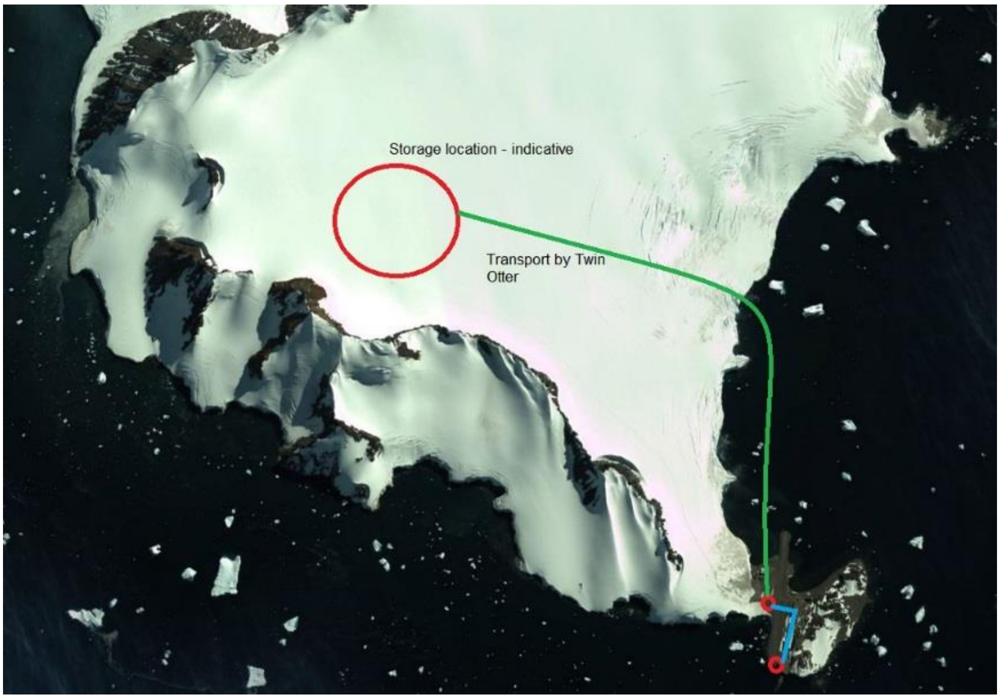


Figure 17 – Explosives transport route to storage location on the glacier - indicative.

Figure 18 – Explosive transport routes and transfer areas.

4.8.3 Explosives Storage

Detonators will be stored in a new magazine located at the existing Rothera explosive storage site. This magazine will be constructed to UK requirements. The location of an additional detonator store adjacent to the existing area will not adversely affect the current separation distances provided the total 700kg is not exceeded.

Due to the large explosives requirement for the quarry operation it will not be possible to store the project explosives at the current storage location and instead these explosives will be stored on the glacier as shown in figure 12. Note: For 10,000 – 20,000kg of explosives, the Explosives Regulations 2014, do not suggest separation distances for exposed explosives, however they do suggest 554 – 606m for metal or brick unmounded stores. Further to this, document 'CFRA Fire and rescue service operational guidance: incidents involving hazardous materials' suggests an exclusion zone of 1000m for in excess of 2000kg of explosives. The BAS Explosives ACOP suggests 500m for 5000kg of field storage.

Explosives will be stored adjacent to the ice runway at a place designated by BAS station management, close enough to allow Twin Otters to taxi for loading and unloading. This area should have a marked exclusion zone, and personnel will be briefed not to approach the store area.

Storage will be as per current BAS best practice as detailed in the BAS Explosives Code of Practice. A BAS Field Guide will supervise the location and construction of the store. Explosives stored at this location will be wrapped in plastic film and covered with a tarpaulin to protect packaging from deterioration.

If necessary, small quantities of packaged explosives may be stored temporarily in the existing BAS explosive store subject to space being available.

Once explosives and detonators are removed from the storage areas they will remain under the close control of the Shotfirer in a restricted working area. No smoking or hot works will be permitted in the vicinity of explosives.

Records of explosives stored and used will be kept by the Explosives Storekeeper.

4.8.4 Control of keys

The keys to the explosives stores will be kept by the Station Leader in a secure place. The keys must only be released to a recognised Explosives Storekeeper or Shotfirer. During the day the keys must be held kept on the person of the Explosives Storekeeper and be returned to the secure place at the end of the day.

Keys may not be passed from BAM personnel directly to other BAS staff without the explicit approval of the Station Leader.

4.8.5 Explosives stock records

A permanent record must be kept of the contents of all explosives stores. All movements of materials in and out of the stores must be recorded. The primary record will reside with the station leader unless otherwise agreed on site.

4.8.6 Storage procedure

Care must be taken to ensure that, during delivery of explosives to a storage place or during the removal of material from it, no grit is allowed to contaminate the cases or the store and the floor of the magazine must be thoroughly swept after any delivery or withdrawal of explosives.

All cases of explosives should be stored flat with their top sides uppermost and in such a way as to allow the name of the explosive and of its manufacturer and the date of manufacture to be clearly visible. If this is not possible in the confines of the small storage space available, then the boxes must be marked up with the relevant information on the face which is visible on entry to the store. Cases of explosive must be so stacked that any pile is stable and so as to allow all-round ventilation.

Only persons who are appointed may enter the explosives store / storage area (Explosives Supervisor, Shotfirer, and Explosives Storekeeper). Before entering the explosives store, personnel must ensure footwear is clean and free from grit.

Footwear with exposed metal parts (exposed steel toe-caps, steel tips or studs) must not be worn in the explosives store.

The Shotfirer must ensure that any surplus explosives are returned to the explosives store / storage area at the earliest opportunity and the records amended accordingly; no attempt to fire the shot takes place until surplus explosives (including detonators) have been removed from the blast area.

Stock record books must be completed at the time of adding or removing stock from the magazine. Copies of material safety data sheets and technical data sheets should also be available for every product held – these records may be kept electronically or as hard copies in the office. When explosives are added or removed, the storekeeper must check that the resulting stock matches the record book for that type of explosive.

A total stock check must be undertaken at least once per week and the magazine book signed as a full check. Ideally this should be undertaken by a separate authorised person eg. Shotfirer or Explosives Supervisor.

Any discrepancy must be immediately investigated eg. re-check the quantities written down in the record book against the delivery note, specification or other document. If the difference is not immediately found, or does not relate to the current entry for that day, it must be reported to the Project Manager and Explosives Supervisor. The Explosives Supervisor must then ensure that the difference is investigated by checking the record book against delivery notes and blasting specifications and either rectify the error in the record book, or when there is any evidence of theft, or when missing explosives cannot be accounted for, this must be reported to the Station Leader.

Other requirements:

- Stacks should not exceed a height of 1.5m and a 10cm ventilation gap should be maintained between the explosives and the wall and between stacks.
- All excess packaging shall be removed.
- Only one box shall be opened of each type at a time. Any part boxes shall be labelled with the actual contents.
- The magazine must be earthed.
- No dragging boxes across the floor of the store.
- No tools or equipment should be kept in an explosives store except such as are required for keeping the store clean. Cleaning equipment must not incorporate parts made of iron or steel.

4.8.7 Fire Prevention

It is essential that smoking materials, matches, lighters or any other sources of ignition are not taken in to an explosives storage area. Fires, naked lights or lighted cigarettes are not permitted within 25m of any explosives store. No petrol, oil, flammable solvents, wastepaper or similar material whose ignition might imperil the explosives store is permitted within 25m of any place where explosives are stored.

4.9 Shotfiring Equipment

The Explosives Supervisor is responsible for ensuring that equipment provided is suitable and safe and to take out of use anything that is not. Equipment must be tested / checked and assessed as outlined below.

1. Exploders for non-electric exploders will be tested every 6 months by BAM Ritchies on-site.

2. Equipment used with electronic detonation systems, however named eg. loggers, blasters, will be tested by an external tester approved by the supplier. This will be undertaken prior to the project and then as advised by the supplier during the project. If necessary these small items can be taken back to the UK between seasons for this purpose.

3. Laser profiling equipment and electronic hole probes, will be tested every 12 months as advised by the supplier. If necessary these small items can be taken back to the UK between seasons for this purpose.

4. Other equipment – including measuring tapes, prickers, stemming rods, shovels, torches, inclinometers – will be field checked by the user prior to use and checked monthly by the Explosives Supervisor. This will be evidenced by completion of BAM Ritchies checklist DB PPEa or b and will be kept on-site and available for inspection.

All equipment will be tested following any major repair or failure, or for exploders, following an unexplained misfire.

Any equipment not safe or suitable will be removed from site, or labelled ‘out of service’.

Exploders will either have a removable key (or other devise that renders it inactive), or be small enough that they can be kept on the shotfirers person (some types of non-electric starters have no key, but are small enough to keep in a pocket – removal of key below means removal of the entire exploder for these types).

The Shotfirer will only fit the key once he is ready to fire the shot and will immediately remove the key after firing. The Shotfirer will keep the removable key in a safe place during the charging of the shot. Any duplicate keys must to be kept in a secure place.

4.10 Explosive Products

Although explosives are only used by trained and competent users, there are a great number of alternative explosive products available from different manufacturers and suppliers, and whether they are packaged explosives, boosters or initiation products, Explosives Supervisors and Shotfirers must ensure that they understand the nature and safe use of each product prior to its use.

As a minimum users should have read the product information provided eg Technical Data Sheets and Material Safety Data Sheets from the supplier. Some products may require more specific training eg electronic initiation systems. If in doubt contact the Explosives Supervisor. The Explosive Supervisor may contact the manufacturer, or the BAM Ritchies Manager, Drill and Blast for additional information.

The following explosives types will be used:

- Packaged emulsion explosives (eg. EPC's EXEM 100, or similar) will form the main explosive charge.
- Cast boosters (primers) will be used to initiate/boost the packaged emulsion explosives.

Figure 19 - A packaged emulsion explosive and cast boosters.

These explosives have been selected for a number of reasons to minimise impact to the environment:

1. The explosives have been manufactured to a high standard of quality control in an explosives factory to have a good oxygen balance, minimising the production of harmful toxic emissions of NOx and excessive CO, CO_2. Some emissions will be released to the atmosphere as indicated in product 'material safety data sheets'.
2. These explosives contain no nitro-glycerine and deteriorate to a greater state of safety in the unlikely event of a misfire.
3. They are relatively insensitive during handling in relation to other explosives types, and are suitable for cold conditions.
4. They are waterproof.

Although most packaged emulsion explosives are detonator sensitive, cast boosters can be used to avoid desensitisation in difficult conditions.

Non-electric, or electronic detonators have been selected to initiate the explosives and to control the initiation sequence. These detonators are not affected by radio frequency hazards and are sufficiently robust for use in the process described below.

Figure 20 - Examples of non-electric detonators

Waste packaging from explosives must be burned on site in a controlled manner as this is the best means of disposal of potentially contaminated packaging in a safe manner. This is as per the HSE / CBI Guidance for the Safe Management of the Disposal of Explosives 2007 s11.2.3.5, as referenced in the UK Explosives Regulations 2014. This process is anticipated to have a minimal impact with the small size of the blasting operations. No other waste will be burnt during this process.

4.11 Blasting Times

Blasting will be permitted 6 days per week Mon - Sat during daylight hours.

The Explosives Supervisor will check the local weather condition and weather forecast with the Station Leader prior to commencing charging to identify any adverse weather conditions that may either affect safety in, as follows:

- Conditions that may restrict visibility eg. snow, fog, low cloud.
- Risk of electrical storms.
- High winds.
- Any other adverse weather.

Conditions will be discussed with the Project Manager, or his deputy, to determine if charging should commence. Both must agree if the decision is to start charging, though either one alone may postpone the shot.

Prior to commencing the blasting procedure (including clearance and securing of the danger zone), the Shotfirer and Blast Controller will assess the conditions once again to ensure that there is sufficient visibility to safely clear and secure the danger zone and fire the shot, including allowing time to carry out the post-blast inspection. Both must agree if the decision is to fire the shot, though either one alone may postpone the shot. In the event of doubt (marginal conditions) the Explosives Supervisor should be consulted for advice. The Shotfirer and Blast Controller still retain the right to postpone.

4.12 Blasting Constraints

The following are not permitted:

- Blasting methods prohibited in the Quarries Regulations 1999 Reg.29 4(b) and (c)
- Initiating explosives except those confined in a shot-hole, or as part of an initiation system, or when destroying detonators unless approved in writing and an additional activity plan and risk assessment carried out (eg. blasting snow).
- Use of Safety fuse unless approved in writing by the Explosives Supervisor and additional misfire provisions made.

The table below details the required blast parameters for each given hole diameter and should form the basis of all design. This will be completed on-site by the Explosives Supervisor after inspection of the blast site but prior to the blasting works. Shotfirers **must** work within these constraints, or refer to the Explosives Supervisor if they consider it necessary to work outside these limits.

Should the Explosives Supervisor have to either design a blast, or approve a specification where the values are below the required minimum shown below in 3 and 5 and, or outside the allowable variation, then the reasons must be annotated on the given blast specification and the Project Manager notified.

If the Explosives Supervisor wishes to impose greater restrictions for a specific blast then these should be communicated directly to the Shotfirer ideally before the shot is marked, but at least prior to approval of the blast specification. In addition restrictions should be written on the specification.

No	Item	Hole Diameter	
		64/66mm	89mm
1	*Maximum allowable variance from the design charge before discussing with Explosives Supervisor. Per hole.*	*+ 10% -100%*	*+ 10% -100%*
2	*Design Stemming Depths*	*tba*	*tba*
3	*Absolute Minimum Stemming Depths*	*tba*	*tba*
4	*Design Burden based on desired pattern*	*tba*	*tba*
5	*Minimum burden to be charged*	*tba*	*tba*
6	*Minimum spacing to be charged*	*tba*	*tba*
7	*Design Sub Drill*	*tba*	*tba*
8	*Required Burden to be Reported by Burden Master*	*tba*	*tba*

The Explosives Supervisor must be notified if two adjacent holes (in any direction) cannot be charged, to allow them to determine the best course of action (eg re-drill at a different location).

4.13 Environmental

There are a number of potential environmental effects that blasting at Rothera may have on receptors.

1. Removal of ground currently occupied by structures, science or communications equipment.
2. Permanent ground displacement in the immediate vicinity of the blasting that may affect the integrity of a structure or its foundations.
3. Rock projection from the blast site, or displacement from adjacent faces may affect anything within this region.
4. Ground vibrations from the blasting affecting structures, fauna or science adjacent to the blast area.
5. Sound pressure waves in the water from transmission from blasting on adjacent land may cause disturbance to marine fauna.
6. Air-overpressure (noise) affecting fauna in the vicinity.

These aspects and mitigation measures are discussed in the following sections.

4.13.1 Removal of ground currently occupied.

There are currently three pieces of equipment occupying the land where blasting is proposed, as follows:

- NDB antenna
- DME antenna
- DORIS beacon

For blasting is to be undertaken at this location, this equipment will need to be removed. Any blasting in the quarry area, prior to this relocation must consider the effects of blasting on these sensitive receptors and may be restricted and limited in scope prior to their removal.

Figure 21 DME, NDB and DORIS

4.13.2 Permanent ground displacement

Disturbance due to permanent ground displacement beyond the blast area will only affect a very small distance of a few meters beyond the extraction area. This will be controlled through the blast design process to minimise back-break. With current rock extraction requirements it is not anticipated that this will affect any activities in any way. Geological and geotechnical conditions will be taken into consideration to avoid ground failure that might extend beyond the blast area.

4.13.3 Rock throw and rock fall from adjacent faces

Rock throw is strictly controlled through the blast design process, which involves laser surveys of the face, hole surveys and the production of a 3D model of the blast to allow carefully considered explosive placement. Rock throw is therefore contained in the working area in front of the face, with minimal ejection behind the blast beyond a few meters. The size of the exclusion zone beyond the blast area is a safety measure and does not represent the extent of expected rock projection.

Rock throw will be contained within the quarry footprint and directly in front e.g. within lay down area 3 and the adjacent access road. Rock throw or roll on the access road will be cleaned up using a loading shovel immediately after the blast.

To prevent damage to the Gerritsz Laboratory from rock fall/roll from the adjacent un-blasted face a rock bund can be created between the building and face.

4.13.4 Vibration

For any specific site, the intensity of blast vibrations are related to the size of the charge fired, the distance from the blast site to the receiver, and the geological and topographical conditions at that location. Although the effect that specific geological and topographical conditions at Rothera will have on vibration attenuation is not known, it is possible to make outline predictions of the intensity of vibration levels at different distances for a given charge weight and use these predictions to guide the decision process.

At very close proximity to the blast - a few metres - it is permanent displacement rather than ground vibration that will have the controlling influence on structures. Beyond a few metres of the blast site the vibrations are transient with a small proportion of the explosive energy is transmitted into the rock mass as seismic waves.

It is possible to make prediction of the likely intensity of the vibrations at each location based on an empirical relationship derived by the US Bureau of Mines relating ground vibration to distance and charge weight, taking into account local geological factors, as follows:

$PPV = a\,(SD)^{b}$

Where:
PPV = peak particle velocity (mm/s)

SD = scaled distance = Distance (D in meters) **/** maximum instantaneous charge (MIC in kg)$^{1/2}$

a and **b** are dimensionless site factors,

Appendix B lists the sensitive receptors identified at Rothera, their distance from the quarry area and predicted peak particle velocity values for each. The predictions shown use site factors from the ISEE Blaster's Handbook 18th Edition for predicting upper boundary limits for construction blasting. Values are given for various maximum instantaneous charge weights (MIC) at various distances – the actual charge weights will be determined by the Explosives Supervisor and Shotfirer during the blast design process.

The relative sensitivity of structures and instrumentation has been discussed with the owners / managers of the sensitive receptors.

The specific requirements relating to each sensitive receptor are shown in appendix B and are discussed briefly below:

- POM Sun Photometer – this can easily be removed and must be removed during blasting.
- Newcastle University GPS receiver – this has been reported as not adversely affected, however notification of blast times required to remove anomalies from results.
- The search coil magnetometer has been reported as not adversely affected due to its location more than 800m from the blast site, however notification of blast times is required to remove anomalies from results.
- Other meteorological, science and communications equipment has been reported as unaffected by blasting vibration.
- It has been reported that no science being undertaken in the Bonner and Gerritsz laboratories will be affected by blasting vibration.
- No buildings have any specific sensitivity to blasting vibration. Vibration will therefore be controlled as per the requirements of BS7385-2:1993 Evaluation and measurement for vibration in buildings.
- There are five memorials in close proximity to the quarry location and vibration levels cannot practically be controlled to the levels for structures in BS7385-2 without excessive cost, however the bases to these memorials are simple structures that can easily be repaired in the event of damage by cracking, whilst the plaques themselves are robust.
- A survey cairn in the ASPA area is not considered to be at risk due to the considerable separation from the blast area.
- Briscoe wharf is shown in close proximity to the quarry area and despite being demolished, vibration levels should be monitored and charge weights limited at the closest proximity.

4.13.5 Blasting adjacent to the marine environment

Where land blasting is undertaken in close proximity to a water body, some of the ground vibration will be transmitted across the land / water boundary into the water. Within the water this energy is transmitted as a pressure pulse similar to noise in the air and may cause harm or disturbance to marine fauna at very close proximities.

The following calculation has been made to predict the level of transmission into the water body based in part on Guidelines for the use of explosives in, or near Canadian Fisheries Waters – Wright and Hopky 1998 and the ISEE Blaster's Handbook 18th Edition. These assume a perpendicular single boundary between the rock and water with no intermediate broken or weathered layers and as such can be considered conservative.

It is not anticipated that the level of blast vibration transmitted to the water will be sufficiently high to cause harm to the marine environment, however predictions will be made during the project using this method where blasting is in close proximity to the marine environment (less than 20m), and discussed with the BAM Environmental Manager. Where these predictions are sufficiently high that the possibility of harm or disturbance to marine fauna may be caused, then action must be taken, which may include the following:

- Monitor actual peak pressure in the water with a hydrophone when blasting at greater distances (before reaching the potentially harmful locations) to obtain real values of peak pressure levels to inform predictions. It is anticipated that they will be lower than those calculated above.
- Reduce explosive charge weights, or otherwise alter the blast design to reduce intensity.
- Implement a marine fauna watch to ensure that no marine mammals are in the vicinity at the time of blasting.

Equations from: Guidelines for the Use of Explosives In or Near Canadian Fisheries Waters - Wright and Hopky 1998

Step 1 Zw=DwCw Zr=DrCr
Equation B

Dw=	Density of water	1.0	gcm^{-3}	
Dr=	Density of rock#	2.70	gcm^{-3}	assumed
Cw=	Compressional wave vel in water	146300	cms^{-1}	
Cr=	Compressional wave vel in rock#	457200	cms^{-1}	assumed for granite

Zw=	146300
Zr=	1234440
Zw/Zr=	0.1185

estimate from Wright and Hopky

Step 2 Pw = 2(Zw/Zr)Pr/(1+(Zw/Zr))
Equation A

Pw=	Pressure in water kPa	
Zw=DwCw		0.1185
Zw=	Accoustic impedance water	146300
Zr=	Accoustic impedance rock	1234440

Pw= 0.212 *Pr

Step 3 Indicative Blast Vibration Prediction
ISEE Blasters PPV = a(D/MIC^0.5)^b
where
PPV = Peak Particle Velocity (mm/s)
D = Distance from blast to sensitive location (m)
MIC = Maximum instantaneous charge (kg)
a and b = Site factors
ISEE Blaster's Handbook values

	Construction Upper Boundary
a	1730
b	-1.6

M.I.C (kg)	20	35	50
Distance (m)	PPV (mm/s)		
10	477.4		
20		246.4	
convert to cm/s	47.74	24.64	

Step 4 Vr=2Pr/DrCr
therefore Pr=VrDrCr/2

10m 20kg	Pressure rock=	29466083	gcms2	2947	kpa
20m 35kg	Pressure rock=	15208301	gcms2	1521	kpa

Pw= 0.216 *Pr

10m 20kg	Pressure water=	636	kpa
20m 35kg	Pressure water=	328	kpa

Step 5
Peak Pressure (dB)= 20 x log(P/P_0)
P_0 reference level 0.000001 Pa or 1µPa

For	10m 20kg	176	dB
For	20m 35kg	170	dB

Figure 22 Calculations relating to blasting adjacent to water

4.13.6 Air Overpressure and noise from blasting

When an explosive is detonated, transient airborne pressure waves are generated. As these pressure waves pass a given position, the pressure of the air rises very rapidly to a value above the ambient pressure, then falls more slowly to a value below atmospheric pressure, before returning to the ambient value after a series of oscillations. The maximum pressure reached is the peak air overpressure.

These pressure waves comprise of energy over a wide frequency range, with above 20 Hz audible to the human ear as sound, whilst that below 20 Hz is in the form of concussion. The sound and concussion together is known as air overpressure and is usually measured in decibels (dB) with no frequency filtering applied.

In a blast, these airborne pressure waves are produced from five main sources:

- Rock displacement from the face.
- Ground induced airborne vibration.
- Release of gases through natural fissures.
- Release of gases through stemming.
- Insufficiently confined explosive charges.

Although it is possible to make predictions of the attenuation of air-overpressure, it is considered unrealistic to do so due to the affect that meteorological factors and surface topography have on the transmission of this energy. UK guidance contained within mineral planning guidance MPG 9:1992 and MPG 14:1995, MTAN1 (Wales) and the DETR report: The environmental effects of production blasting from surface mineral workings 1998 recommend that air-overpressure should be controlled at source rather than setting a specific limit. These control measures are discussed below in s4.13.7.

It is not anticipated that any structural damage, even cosmetic damage, will be caused by air-overpressure due to the nature of the controlled blasting that will be undertaken for these works.

The only terrestrial fauna identified in close proximity to the blasting location are nesting Skuas as shown in figure 23 below. This plan shows the location of one nest site to the north-west of the blast site, though BAS staff at Rothera have confirmed that this location has not been occupied for two years. Further nesting sites are located at a considerable distance to the proposed quarry location. BAS staff have confirmed that in their opinion blasting air-overpressure should not adversely affect terrestrial fauna. Prior to blasting the Shotfirer will check the blast site to ensure that it is clear of any birds and will report any disturbance.

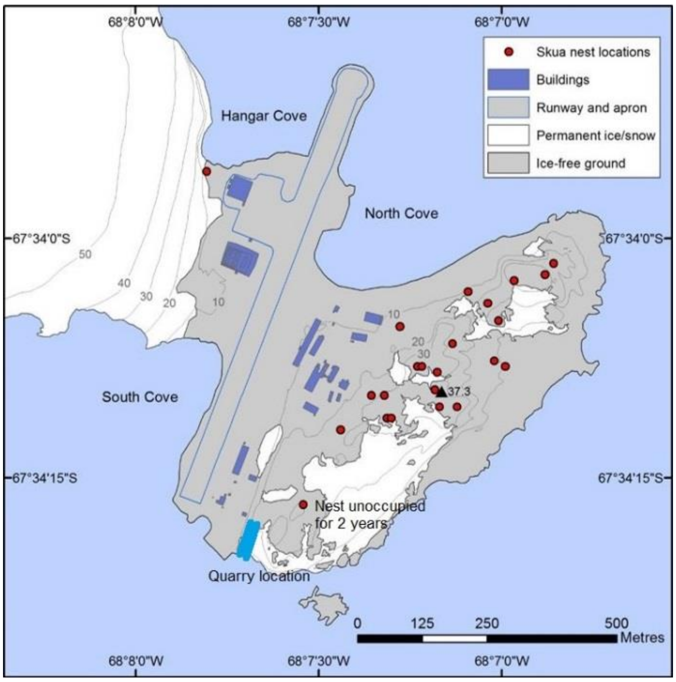


Figure 23 Potential Skua nesting sites

4.13.7 Blast Design Control Measures

The following measures will be considered during the blast design process to minimise the effects of blasting vibration, air-overpressure and rock projection.

Blast design measures to reduce blast vibration:

- Reduce the maximum instantaneous charge by reducing the face height, reducing the hole diameter, or introducing decks of explosives in the hole. The ratio of explosives to rock must be maintained to avoid increased vibration.
- Strict control of drilling deviation, burdens and spacings to ensure even and appropriate distribution of explosives. Survey techniques and modelling will verify these parameters.
- Maximise the use of free faces to allow the rock to expand and avoid transmission of vibration.
- Use appropriate initiation sequences to ensure the rock moves in a controlled manner and new free faces are created.
- Control sub-grade drilling levels.
- Control the powder factor / blast ratio as reducing the explosive quantity may increase vibration if there is an insufficient quantity to break the rock. This is not just the ratio for the entire blast, individual heavy burdens may create high local blast ratios which will cause higher vibration.

Measures to reduce air-overpressure at source:

- Reducing the maximum instantaneous charge fired in any one delay period.
- Record geological conditions during drilling to ensure that weak areas are decked in the hole with aggregates to avoid energy escape.
- Correct confinement of explosives through use of correct burden and stemming.
- Utilise laser surveying of open faces and shot-holes to allow correct explosive placement and to avoid low burdens that allow energy to escape to the atmosphere.
- Ensure quality stemming is used in the top of the holes to prevent energy release through the hole collar.
- Use in-hole initiation systems.
- Avoiding un-confined explosives, including detonating cord, by using non-electric surface initiation systems.
- Avoid blasting when weather conditions may lead to increased propagation of air overpressure to the sensitive receptors; such as downwind conditions from the blasting site to the receptor(s) and when there is low cloud or an atmospheric temperature inversion.
- Controlling the direction of firing shots to help limit sound travelling in unfavourable directions.
- No secondary blasting of boulders.
- Careful selection of the location of the quarried rock source in conjunction with BAS management to minimise the impact through distance and orientation in respect to sensitive receptors.

4.13.8 Blast Vibration Monitoring and Analysis

During operations, blasting vibration levels will be monitored using blasting seismographs to measure levels of peak particle velocity and air-overpressure at selected site sensitive locations. This monitoring will be both to ensure compliance with site threshold limits and to further increase the number and distribution of results, to allow continuous improvement of vibration prediction models and increasing confidence in MIC predictions.

Monitoring should initially be undertaken at the closest sensitive receptors of each type, or agreed on site with project and station management. Once confidence is gained that vibration limits will not be exceeded at these receptors, monitoring should continue at varied distances to obtain data for prediction models.

Figure 24 – Example blasting Seismograph for monitoring PPV and air-overpressure

4.13.9 Monitoring the Condition of Memorials

There are five memorials located at Rothera Point which are considered of high value to current and past staff members, visitors and other interested parties. In general, it is the plaques that are considered of high importance, whilst the base structures should be maintained in good condition. Whilst the plaques are considered to be robust in relation to damage potential from blast vibration, the base structures may be subject to minor cracking damage.

In order to correctly monitor the condition of the memorials, pre-blast photographs will be taken of each one from all sides to form a baseline from which to compare and deterioration. During blasting operations, regular inspections will be made of the condition of each memorial, and repairs implemented to maintain the original condition after discussion with the Station Leader.

Should there be any risk of damage from rock projection to the actual plaques, then additional mitigation measures should be implemented, such as providing a protective covering, or temporarily removing the plaques to a safe location.

Details of the memorials are contained in appendix B.

4.14 Accidental Initiation

There are a number of sources of RF transmissions and therefore a risk of potential accidental initiation of electric detonators. Therefore only non-electric and electronic detonators will be used for this project. This complies with BAS Explosives COP s6.3.2.

4.15 Electrical storms

There have been no electrical storms reported at Rothera during the last 40 years, however the potential consequence of an electrical storm is considered high and is therefore still considered. The first warning of electrical storms may come from the weather forecast. This will be checked on the morning of the blast by the Explosives Supervisor prior to commencing charging – see above.

Actions during the electrical storm

As soon as you hear thunder or see lightning operations should be suspended and you should take precautionary measures.

- Shotfirer to inform the Station Leader, Project Manager and Blast Controller of the need to evacuate the danger zone. Warning to be given over the designated radio channel.

- Blast Controller to implement the blasting danger zone as if the shot was to be fired. Care should be taken to avoid positioning sentries where they are at a danger from direct strikes.

- Other personnel evacuated from the area to retire to the safe designated place at New Bransfield House.

- Where a storm approaches during the blasting procedure and the danger zone is clear and secure, the Shotfirer and Blast Controller may agree to fire the blast if this can be done immediately.

Recommencement of Operations

After the electrical storm has passed, do not return to the site until the Shotfirer and Explosives Supervisor agree that it is safe to do so. As a minimum, this should be after a period of 30 minutes have passed since the last sighted lightning strike or thunder. A heightened level of vigilance should be maintained in case of a second storm approaching.

4.16 Indicative Blast Designs

The following blast designs are indicative and for information only. Actual blast designs will be made to suit site conditions and restraints and will be approved by the Explosives Supervisor.

Blast design parameter	Unit	Typical quarry production blast
Face height / cut depth	m	c.10.0
Drill diameter	mm	89
Burden	m	2.5
Spacing	m	3.0
Sub-drill	m	0.5 - 1.0
Stemming length	m	3.0
Explosive diameter	mm	70
Explosive type		Packaged emulsion
Primer type		Cast booster
Initiation type		Electronic and/or non-electric
Powder factor	kg/m3	c.0.50
Hole angle (from vertical)	degrees	Vertical to 10

The quarry production design shown above is indicative of the level of controlled blasting required to blast safely without adverse effects to the surrounding sensitive receptors eg Gerritsz laboratory, optical hut etc. Additional controls (as shown in s4.13.7) may be required where blasting is undertaken closer to the wharf structure or prior to the removal of close proximity equipment eg. DORIS equipment.

4.17 Drilling Operations

The area where the shot will be marked out will be communicated by the Quarry Supervisor, to the Shotfirer on-site.

The Quarry Supervisor will ensure that:

- The area has been checked as required to ensure that it is safe from face collapse, either on the bench, or from an adjacent bench.
- That the access route to the location is safe and sufficient for drilling equipment and shotfiring / charging vehicles.
- That the ground is sufficiently cleaned off to allow drilling.

The Shotfirer will also check that the proposed blast location, and access to it, is suitable, prior to the shot being marked.

The shot will be marked out by the Shotfirer and a ‘Driller’s log’ instruction prepared. The minimum to be marked on the ground will be the hole positions, hole numbers and azimuth markers for front row holes. For holes marked on a square/rectangular pattern, the azimuth marker for all other rows will be the hole in front. Where this differs an azimuth marker must be provided on the ground and on the driller’s log. Every effort will be made to avoid geological anomalies, which may give rise to fly rock.

The Driller’s log shall instruct the driller on hole location, diameter, depth and inclination and azimuth.

The driller shall carry out the drilling instructions. He will record on the driller's log any variations from the intended hole locations and the position and extent of any voids, clay, broken ground, or zones of poorer quality rock identified during the drilling operation. Where there is a need for a substantial departure* from the instructions given, the driller must refer the matter to the Shotfirer or Explosives Supervisor. (*If the driller needs to move a hole more than 1m from its original position, or closer to the next hole than the minimums shown in section Blasting Constraints, or where there is any doubt.)

At each blast hole location, the driller will position the drill rig and set the drill mast at the angle specified in the Driller's Log Instruction and in the direction of the hole indicator marked on the ground. The mast angle will be re-checked after approximately 2.0 meters of drilling and adjusted as necessary. Blast holes will be numbered sequentially, usually from right to left as the driller approaches the blast pattern from the top.

The rig must be positioned with the tracks perpendicular to the face to keep the rig's centre of gravity as far away from the face as possible. If it is necessary to drill with the rig's tracks parallel to the face a risk assessment will be completed prior to commencement.

As far as is reasonably practical, the front row will be drilled first, starting from any open end, working back through the blast hole pattern. The driller's log will be completed continuously with information recorded during drilling or immediately after each hole is completed.

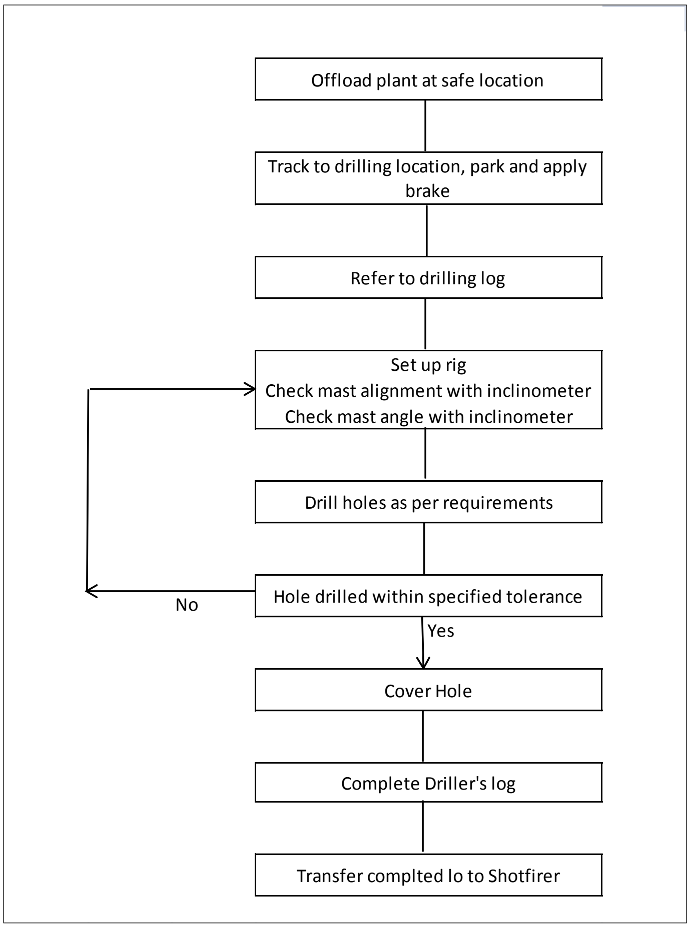


Figure 25 – Drilling Process Flowchart

On completion of drilling, the driller's log will be submitted to the Shotfirer or Explosives Supervisor to enable the blast specification to be produced - a copy of which will later be attached to the blast specification

Cones must be placed at the entrance to the top of the shot and on the quarry bench below to warn people and prevent access to the blast site by unauthorised personnel and general quarry traffic.

The driller shall:

- Report to the Shotfirer or Explosive Supervisor should they be unable to drill any shot hole as per the driller's log, or within the allowable variation.
- Report to the Shotfirer or Explosive Supervisor if cavities, caves, holes, whether in-filled by clay or empty, are seen in the face or as a surface expression on the quarry top.
- Ensure that all cavities, obstructions, clay bands, faults and other geological features, which may affect the shot encountered during drilling are recorded on the drill log.
- Ensure that if the shot hole is not to be used for the purpose of the blast, it is in filled with inert incombustible material before any shot is charged.
- Check the hole depth with a tape measure to check the depth is correct and cover if required.

No drilling is permitted adjacent to charged holes where any part of the hole is within 10m of a charged hole without the completion of a specific activity plan and risk assessment for the activity (approved by the Explosive Supervisor). Although permitted, drilling adjacent to charged holes should be avoided wherever possible. Even with the appropriate control measures in place this should normally only be considered during the treatment of misfires.

4.18 Blasting Specifications

4.18.1 Surveying

To enable complete and accurate face surveys to be carried out the face must be cleared of all loose blasted material in the intended blast area. If any material is removed, or falls out of the face, after the survey then the survey should be repeated. Face surveys will be carried out using approved laser equipment (buffer blasts excepted).

All holes will be marked to identify hole numbers, going from left to right when looking at the face.

The Shotfirer will provide the Surveyor with details of the shot - number of holes, rows and provide the hole angles, unless the holes are to be probed. If the Surveyor is measuring the hole angles with a torch and inclinometer on the behalf of the Shotfirer, the Shotfirer must communicate any rules relating to the minimum length of holes that must be visible for a measurement to be valid, and details of any other information required. The responsibility remains with the Shotfirer and Explosives Supervisor.

Profiling will be carried out by an experienced surveyor, using laser profiling equipment within current calibration. The profiler will submit the completed survey to the Shotfirer or the Explosives Supervisor. New or irregular faces may require to be surveyed before drilling.

The laser operator will survey the face as required by the shotfirer taking care to ensure that any open ends are included and that a sufficient density of measurements are taken to ensure the accuracy of the survey. It may be necessary to survey the face from more than one location to ensure that a suitable density of measurements are obtained and there are no areas missed.

Figure 26 – Surveyor using electronic probe to survey holes

The collar of all holes will be surveyed using the laser profiling equipment.

The angle of all holes will be measured and recorded. This can be done manually using a torch and inclinometer, recording the values in a Blasting Record Book, or using an electronic probe.

The azimuth of all holes will be measured and recorded, either manually, or using an electronic probe. Where azimuths are checked manually, the following applies:

- For front row holes, and those adjacent to a face, an azimuth mark must be made on the ground and surveyed.
- For all other holes, standard practice is to use the hole in front as the azimuth marker. Where the actual azimuth differs an azimuth marker must be marked on the ground and surveyed.

Survey staffs should be in good condition and fitted with a levelling bubble to reduce errors. The surveyors acting assistant must ensure the staff is vertical. The staff should be held over the centre of the hole collar.

Avoid having the survey staff extended to great length as this increases the chance of positioning errors. If this is necessary for back-row holes, reduce the error on the front holes by having the staff in a low position for the front row and only extending it for the back row holes. Alternatively transfer a station by bearing and distance to the quarry top for the purpose of surveying back-row holes.

The surface position and direction of all holes will be recorded and part of the printout will include a table showing the surface position of all the holes.

Wet or deviated holes will be surveyed by electronic probe. This information will be downloaded directly to the survey program. When using a probe ensure that the magnetic declination is taken into account.

Figure 27 – Undertaking a laser profiling survey of the face

The surveyor will complete the survey and transfer the information to the Shotfirer / Explosives Supervisor who is responsible for confirming the validity of the information.

The surveyor will provide the following as a minimum:

- Profiles landscape with burden master matrix – all holes adjacent to a face.
- Front elevation view for all rows (showing hole to hole distances).
- Side view elevation between holes in different rows (one in front of the other).
- Plan (ideally to scale and showing the burdens and spacings).
- Survey assessment.
- Resection print out confirming the accuracy of the surveyor's position.
- 3D View.
- Hole Report – this provides co-ordinates of all holes.

4.18.2 Blast Specification Documentation

The specification will be prepared by the Explosives Supervisor or Shotfirer.

The Shotfirer will design each blast and prepare the blasting specification taking into account the survey information, site conditions and using experience gained from previous blasts in the locality to produce the desired outcome in a safe and controlled manner.

In preparing the specification the Shotfirer will consider the information from, driller's logs, specified vibration constrains and other information including that gained from previous blasts in determining the hole charging plan and initiation sequence.

The initiation of individual explosive charges, either on a hole by hole basis or within an individual blast hole, will be designed to minimise environmental impact from ground vibration and air-blast whilst optimising the result of the blast.

The blasting specification will include the following:

- The angle of inclination, depth and diameter of each shot-hole and the length of sub-grade drilling.
- The face angle in-front of each hole.
- The level of any water in the holes.
- Details of any face inspection, especially where weak layers or cavities are identified.
- The burden in front of each hole to the face or the hole in front.
- The spacing between each hole.
- The completed driller’s log.
- Type and quantity of explosive for each hole including stemming required.
- Position and number of primers and in-hole detonators.
- Surface initiation plan.
- Danger zone, sentry positions and firing position (this could be one plan used for all blasts within a specified area).

The blast design must ALSO CONSIDER:

- Any geo-technical information available.
- Any adjacent ice cliffs.
- Any ongoing construction activities.
- Previous blasting experience.
- Any sensitive receptors – structures, land & marine fauna and science.
- Air, marine or dive operations.

Prior to commencing charging the Shotfirer must sign the blasting specification and transfer it to the Explosives Supervisor. The Explosives Supervisor then checks the blasting specification is complete and adequate and then signs to approve it. The Explosives Supervisor should only sign the specification once they have checked that actual conditions are in line with the blasting specification.

Shotfiring operations must only commence when the blast specification is complete and signed. It is preferable that the Shotfirer and Explosives Supervisor roles are carried out by different people, though it is acceptable for the same person to undertake both roles.

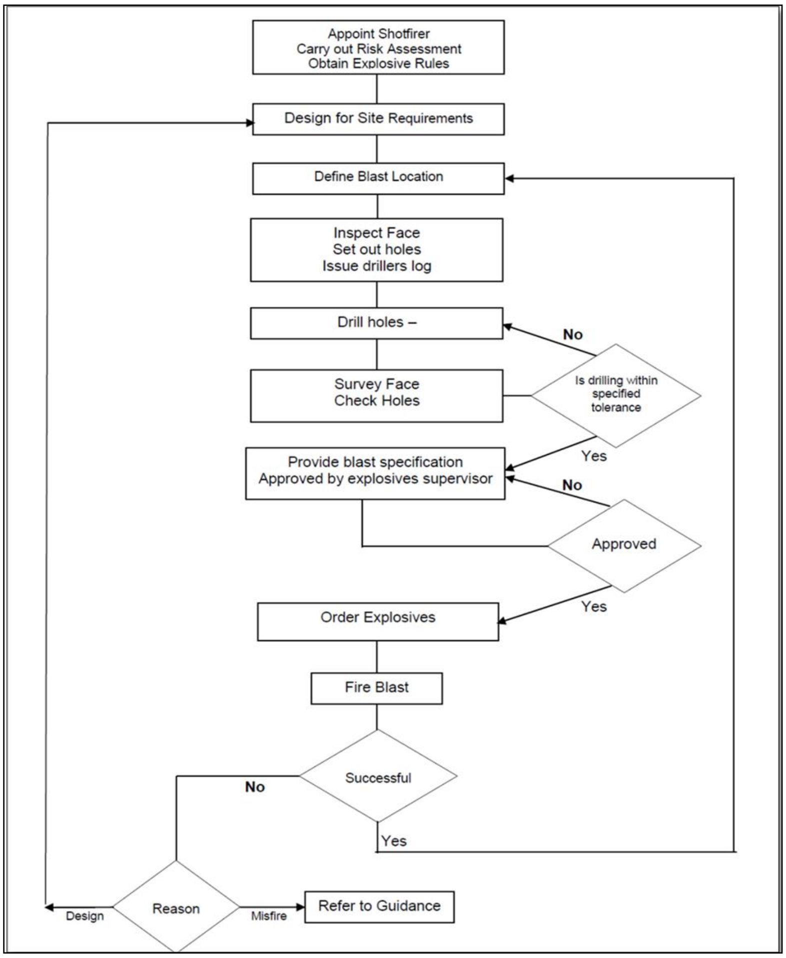


Figure 28 – Shotfiring Process Flowchart

Only one copy of the entire Blasting Specification will be produced. This will be held by the persons upon whom it imposes duties at that time. This is as follows:

Document	From	To
Drill log instruction	Shotfirer or Explosives Supervisor	Driller to complete
Completed drill log	Driller	Shotfirer or Explosives Supervisor
Survey profiles, plans and other data	Laser Surveyor	Shotfirer, or Explosives Supervisor
Complete proposed blasting specification	Shotfirer after completion and signing	Explosives Supervisor for approval
Complete proposed blasting specification	Explosives Supervisor	Shotfirer for charging
Completed actual Blasting Specification	Shotfirer after firing and completing post blast information.	Explosives Supervisor for review for future blasts
Completed actual Blasting Specification	Explosives Supervisor	Quarry Supervisor for filing
The danger zone plan, including sentry positions, should be copied as necessary and given to the acting Blast Controller, Sentries and publicised as described in section 4.21.		

4.19 Shotfiring Operations

4.19.1 Charging

The Shotfirer must be present at all times when holes are being charged. The shot / explosives may be guarded by a suitable person – but charging must be suspended until the Shotfirer returns. Where several Shotfirers are working together, the Shotfirer who has signed the blast specification is the acting Shotfirer for that blast and other shotfirers are acting under their instruction.

For packaged explosives the rise will be checked at regular intervals of not less than every 25kg. Any tape used must be of the correct length and have a non-ferrous weight.

Stemming material must be granular and loaded in such a way to avoid bridging – angular aggregate of approximately 0.1 to 0.15 times the shot-hole diameter.

The Shotfirer is allowed to increase or decrease any charge by the amount indicated in the section blasting constraints within this document. The Shotfirer must record these changes on the blast specification sheet, and if at any time substantial changes are required, or if there is an increased risk resulting from shotfiring operations then the Explosives Supervisor must be informed.

If it is not possible to stem holes as per the specification, or within allowable variations, the Explosives Supervisor must be notified immediately.

The Shotfirer will ensure:

- Explosives are not removed from boxes or containers until required for immediate use and that, where practicable, only one container of explosives is open at a shot-hole at any one time.
- No detonators or shock tube connectors are used unless they are clearly marked and identifiable.
- Primers are assembled in the approved manner and in accordance with the specification for each shot-hole.
- Particular care must be taken when lowering electronic detonators with primers on plastic reels. Care must be taken that the clip end is not damaged as the reel spins. The reel should be placed on the non-ferrous rod to unravel the reel, using a gloved hand to brake the reel as it spins.
- Under no circumstances are two detonators attached to, or inserted into, a cast primer that is designed to receive only one detonator.
- Only approved non-ferrous tools in good order and free from grit are used when it is necessary to pierce a cartridge.
- Primer cartridges must be carefully lowered and the position checked against the specification.
- No person forcibly removes any detonator lead, or other system for initiating shots from a shot-hole after the shot has been charged and primed.
- Great care is taken to ensure that all down hole initiating lines are neatly coiled and secured near to the shot-hole collars.
- Detonating cord is only cut with a sharp knife in free air, or on a wooden anvil, or using specialist cutting equipment designed for this purpose.
- The Shotfirer must be fully satisfied that each shot-hole has been charged in accordance with the blasting specification and that the loading horizons and charge weights for each shot-hole have been accurately recorded.
- Detonators, other explosives or charged holes are not left unattended.
- The shotfirer will ensure that there is no naked flame within 10 metres of any explosives or detonators.
- Surplus explosives must be removed from the blast area before firing, not left unattended and returned to store as soon as possible.
- The shotfirer must ensure that no explosives remain in discarded containers by inspecting them prior to placing them at the burning location. These waste containers, and only this type of waste must be burnt after the shot, or at a designated place at least 100m from the shot.
- Before any shot-hole is fired for the purpose of a primary blast, the Shotfirer shall ensure that it has been charged in accordance with the blast specification. In the event that the Shotfirer finds that a shot-hole has not been charged in accordance with the blast specification he shall report that discrepancy immediately to the Explosive Supervisor.

Where practicable, all chippings for stemming and cover material for the shock tube connectors is placed near each shot-hole prior to charging taking place and the Shotfirer personally checks that all stemming material complies with the blasting specification.

4.19.2 Connecting the initiation system

The Shotfirer must ensure that:

- All charged shot-holes are connected up in accordance with the initiation plan in the specification.
- All detonators are connected to the harness wire or other nonel detonator tube as per the manufacturer’s recommendations.
- Electronic detonators logged to a computer design are connected to the harness wire in the correct sequence as per the design and each detonator is checked with the logger to ensure that

it is the correct hole, the detonator has logged and there are no errors. Every effort must be made to ensure that the connectors are not sitting in pools of water.

- Nonel connector blocks are not overloaded with more nonel tubes than they are designed for.
- Nonel connectors are at least 1.2 metres apart and the initiating detonator is at least 1.0m from the connector being fired.
- Kinks in shock tubes, tubes crossing back over the connector block are avoided.
- Before the connector blocks are covered, the Shotfirer personally carries out a thorough check to confirm that all down-lines are connected into the connector blocks and that all connector blocks are connected into the circuit.
- All connector blocks are covered with a minimum of 200mm of damp dust or chippings to prevent damage to surface lines by shrapnel.
- Great care is taken to avoid contact between shovel and initiation lines during covering operations.

4.19.3 Testing the initiation system

The Shotfirer must ensure that:

- The connecting, testing and firing of initiation systems must only be carried out by themselves, or another Shotfirer.
- Only currently certificated testers and exploders must be used.
- When using electronic detonators, once all detonators are logged, the circuit must be tested for leakage and also tested for errors that must be rectified prior to blasting. Only those tests that do not require the detonators to be ‘charged’, or in any risk of being initiated, may be carried out prior to the danger zone being cleared.
- Tests to live circuits are made from the blast shelter, or from outside the danger zone once the danger zone has been cleared of personnel.
- The testing of the non-electric exploder will be carried out using an off cut length of lead in line to ensure that it operates correctly.

When in charge of an exploder, the Shotfirer:

- Retains any removable handle or key in their possession throughout the period of duty.
- Does not place any removable handle or key in position in the apparatus until they are about to fire a shot.
- Where a shock tube-initiating device is used, this is classed as a key and is retained in their possession throughout the period of duty.

If the circuit tester indicates discontinuity, first disconnect the cable and retest it. If the fault remains then further examinations must be carried out. The removable handle or key will not be placed in the exploder until the exploder is about to be used by the Shotfirer and it will be removed immediately after firing.

4.20 Blasting Danger Zone

This Danger Zone is that described in the Quarries Regulations 1999. No personnel are allowed to be in areas demarcated as the danger at the time of firing the shot, except within a suitably located and constructed blasting shelter capable of offering protection from projected rock.

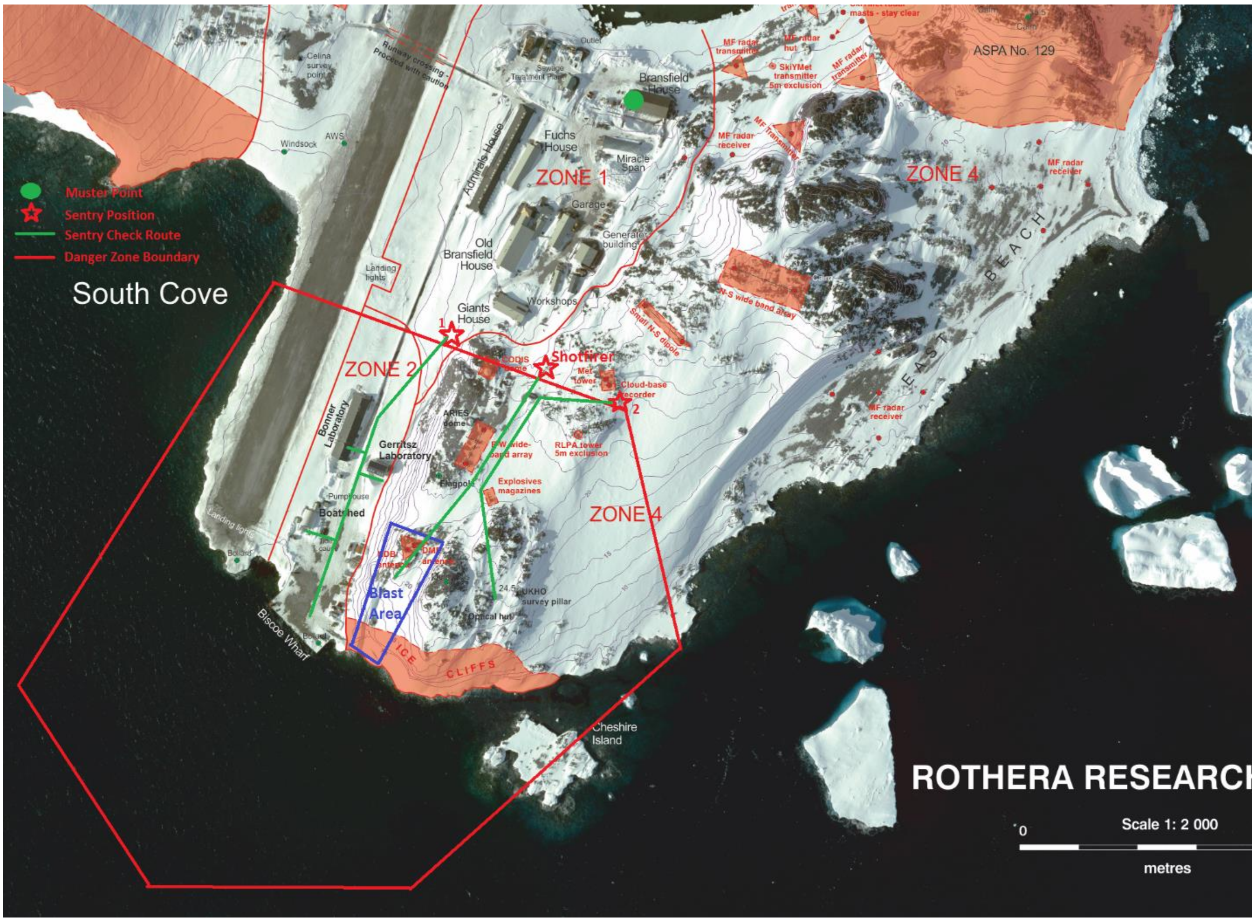


Figure 29 – Blasting Danger Zone

Specific sentry duties:

- **Sentry 1** – This sentry walks from the Briscoe wharf and makes a final visual check of the Boat shed, Bonner laboratory and Gerritsz laboratory for personnel. They then take up position near the foot of the ramp below Giant's house preventing access from the direction of Giant's or Admiral's house.
- ***Sentry 2*** – This sentry walks from the Optical hut and checks that the areas are clear of personnel. They then walk to the MET tower from where they can observe the slopes down to East Beach.
- ***Shotfirer*** – The Shotfirer makes a final check of the blast area and sea in front of the wharf before walking to the firing position. The Blast Controller will normally occupy this same location.

Sentry Rules:

Shotfiring operations are subject to the Quarries Regulations 1999.

If you are asked to act as a sentry, you must be appointed and have been briefed of your duties:

1. You will be given clear instructions, issued by the Blast Controller or Shotfirer, informing you of your duties and responsibilities and where you must position yourself for the blast.
2. You must ensure that you are in position in sufficient time to clear your area of responsibility and bar all entry to the danger zone.
3. You must ensure that you understand the method of communication.
4. You must stop traffic, personnel movements as directed.
5. You must be in contact with the Blast Controller and Shotfirer and when asked to do so, report that you are in position and that your area of responsibility is secure. As per the instructions below.
6. You will immediately report to the Blast Controller and Shotfirer if at any stage the danger zone is breached, or there is some other matter affecting the safety of the blast.
7. You must ensure that you fully understand the audible warning procedure as detailed below.
8. You must stay in position when the shot is fired and bar all entry to the danger zone until the 'all clear' signal is sounded and the shotfirer gives the 'all clear by radio. If in doubt **stay in position** and contact the shotfirer.

9. In the event of a misfire, you must stay in position and bar all entry to the danger zone until instructed to do otherwise by the shotfirer.

IMPORTANT If someone is determined to pass, do not attempt to restrain them by any means other than gentle persuasion.

If at any time you are unable to properly discharge your responsibilities, you are required, without delay, to bring the matter to the notice of the explosives supervisor.

The Explosives Supervisor may re-determine the danger zone and muster points at any time either routinely, during the preparation of the blasting specification or due to changes during charging. Any changes must be notified / publicised as described below.

The Danger zone plan for any blast must show the following items:

- The Danger zone boundary.
- The firing position. If this is within the danger zone it must be a suitable blasting shelter.
- Sentry positions with sentry names or numbers clearly marked.
- The blast location

The plan in use on the day must be publicised as follows:

- Personally to the Blast Controller from the Explosives Supervisor.
- Personally to all sentries by the Blast Controller.
- Posted on the notice board in New Bransfield House.
- Posted on the notice board in the site office.

The Explosives Supervisor and Shotfirer will reassess the suitability of the extent of the danger zone during preparation of the blast specification and again after charging if conditions change, or if charging was different to that proposed. Any changes will be notified to the Quarry Supervisor and Blast Controller as soon as possible, though this must be before the commencement of the firing procedure. Any changes after commencement of the firing procedure will result in a postponement and re-start – with sentries re-briefed as required.

During re-assessed of the extent of the danger zone the Explosives Supervisor will consider the following factors:

- prevailing face condition
- past experience in the behaviour of similar blast patterns and blast ratios at the location
- relevant information included in the geotechnical assessments
- orientation of the face
- type of blasting being carried out
- geological anomalies and other information revealed during drilling and loading of the shot holes
- feedback from the Station Leader and Construction Manager
- the proximity to access routes
- the degree of throw expected
- any other factors considered to be relevant on the day.

4.21 Communication of Blast Times

The following notifications will take place 24 hours prior to blasting:

The Blast Controller should communicate the blast time as follows.

- BAM Construction Manager – to discuss any issues that might affect, or be affected by blasting, including the need to remove equipment (in addition to personnel) or carry out any temporary works to prepare construction works prior to blasting.
- Station Leader – to discuss any issues that might affect, or be affected by blasting.
- Communications Tower for flight co-ordination – the communications tower should advise of any anticipated ‘point of no return’ flight plans that will block blasting. They may discuss flight plans with the Chief Pilot to avoid the blasting time for less urgent flight arrangements.
- Meteorologist and Science Co-ordinator - notification only, though check for feedback. Arrange to remove the Sun Photometer if required.
- Science and Bonner Laboratory Leader - notification only, though check for feedback.

- Communications Manager - notification only, though check for feedback.
- Electrical Engineer - notification only, though check for feedback.
- Boat and Dive co-ordinator - notification only, though check for feedback.
- Sentries.

In addition the Blast Controller places a notice giving the time of the blast and the nature of the danger zone on a plan at the following locations:

- *Project office notice board*
- *Bransfield House canteen notice board*

The Blast Controller prepares a blast protocol checklist (see appendix A) and notes all communications and checks and the date and time that they are made.

On the morning of the blast the Blast Controller will place a 'Danger Blasting' sign with the time at the following locations:

- On the access road approaching the Bonner laboratory from the main station at the boundary of zone 1 and zone 2.
- On the access road to the zone 4 close to Giant's house on route to the explosives magazine.
- On the access from the runway to zone 2.

4.22 Firing Procedure

When the shot is ready to be fired, except for the connection of the exploder, the Blast Controller will be informed by the Shotfirer. The following procedure will be carried out by the Blast Controller:

NOTE: All communication will from this point on be by site radio on the designated channel**,** or direct verbal communication.

All communications must be clear.

When any message is not clearly understood the safest situation must be maintained – the shot is not fired, or the danger zone is maintained.

Other radio communication on this channel must cease until after the 'all clear' – any interference may cause a postponement.

The following main communications will be used:

- From the Blast Controller to a Sentry 'Sentry (name or number) are you in position and your area secured?'
- Response from Sentry – for area secure 'Sentry (name or number) in position and area secure). If not secure 'Sentry (name or number) not secure' then explain.
- From Blast Controller to Shotfirer to give permission to fire 'Blast Controller to Shotfirer you are authorised to fire when ready'
- From Shotfirer to Blast Controller 'Firing in 'x' seconds unless anybody calls STOP' (x = approximate time to firing)
- From Shotfirer to Blast Controller after firing 'All Clear', or explain otherwise.
- By anyone to stop the blast 'STOP, STOP, STOP'.
- Other communications between the parties involved are allowed by way of explanation, but the above communication is required to allow the firing to proceed and the phrases should not be used in other contexts (eg. a sentry should not say 'in position and all clear').

The Sentries will be placed where deemed necessary at strategic positions around the quarry and as shown on the Danger Zone plan prepared prior to each specific blast. Any person who is appointed as a Sentry must have full knowledge of the siren procedures and the method for indicating the "all clear". No Sentry shall leave his position until the 'all clear' is sounded or otherwise authorised by the Blast Controller. If someone is determined to enter the danger zone no attempt must be made to restrain him or her by physical means, but the sentry must call 'STOP, STOP, STOP' over the radio.

15 Minutes prior to blasting

The Blast Controller:

1. Gives ‘all station warning’ on the designated channel ‘All station warning, all station warning, blasting will be taking place in the quarry area in 15 minutes time, please keep clear of the area’.
2. Obtains positive confirmation from the dive and boat controller that all divers are clear of the water in the area of the wharf – minimum 500m for land blasting – and that boats are in a safe location.
3. Obtains confirmation from the Construction Manager that the construction team is clear of the area, plant in a safe place and the construction site is prepared for blasting.
4. Obtains confirmation from the Bonner Lab Manager that the Bonner and Gerritsz laboratories have been cleared of personnel.
5. Obtains confirmation from the Quarry Manager that the quarry team is clear of the area and all quarry equipment is in a safe place.
6. Instructs sentries to undertake their checks to ensure the danger zone is clear and then take up their position to secure their boundary. The sentries should notify the Blast Controller once in position and secure.

Personnel are notified of the blast time by their immediate supervisor and will stop work and leave the danger zone, by *15* minutes before the blasting time. All mobile plant will be parked in a safe place.

At 3 minutes prior to firing

The Blast Controller:

1. Confirms with the Shotfirer that he is ready to fire.
2. Checks with all the sentries that they are in position and their area is secure.
3. Give ‘all station warning’ on the designated channel.
4. Once the Blast Controller has satisfied that danger zone is clear he will sound the audible siren. Sound the siren for 2 * 15 seconds

The Shotfirer may now carry out any tests/checks requiring the danger zone to be cleared, including charging-up electronic detonators.

Firing the shot and post blast

1. The Blast Controller sounds the siren for 30 seconds continuously
2. After the 30 second siren the Blast Controller gives the Shotfirer authorisation to fire.
3. The Shotfirer fires the shot and then carries out the post-blast inspection. He then gives the ‘all clear’ or informs the Blast Controller in the event of a misfire – the misfire procedure would then be followed.
4. The Blast Controller, repeats the ‘All Clear’ over the radio on the designated channel, and 3 short blasts of the siren are sounded. The sentries can stand down.

Until the ALL CLEAR has been given **NO** person or vehicle traffic may return into the danger zone except:

- The Shotfirer
- Those specifically authorised on that occasion by the Quarry Manager and Explosives Supervisor during treatment of a misfire.

To stop the procedure at any time, anyone may call ‘STOP, STOP, STOP’. The shotfirer will confirm by saying ‘Blast Postponed’ and will not fire the shot until the Blast Controller has determined the reason and re-established control of the danger zone. In this instance the Shotfirer should explain to the Blast Controller the state of safety of the initiation system (eg. are the detonators charged) and advise the Blast Controller accordingly.

4.23 General

The Shotfirer must:

- Not fire a shot unless there is sufficient visibility to ensure that the shotfiring operation and any site inspection after the shot is fired can be carried out safely.

- When using electronic detonators sufficient time must be allowed to programme the detonators, a rule of 2 seconds per detonator will allow sufficient time for programming to take place. (NB – If it is likely that the number of detonators in the circuit will take longer than 3 minutes to programme the blast controller must be notified and delay sounding the siren if necessary. Once all detonators have been programmed the shotfirer generally has 10 minutes to fire the shot before it is necessary to re-programme the entire shot.)

- Fire the shot from a safe place – outside the danger zone or in a suitable shelter positioned in a safe location. (NB – In selecting a safe place for the firing shelter, due consideration must be given to the direction of possible rock projection and to avoid being downwind of post blast fumes and falling rock from higher benches.)

- At the allotted time:
  a) Connect the circuit to the exploder.
  b) Fire the shot at the appropriate time.

- Be certain that all explosives cases have been checked to ensure that no explosive remains hidden or lodged inside any of them before arranging disposal.

- Ensure that all empty explosives cases are disposed of by burning as soon as practicable after the shot has been fired - this must be carried out at a suitable burning station used solely for burning of explosives packaging.

4.24 Post Blast Inspections

After the shot is fired:

1. Remove the key from the exploder or personally retain the shock tube initiating device.
2. Disconnect the shotfiring cable from the exploder as appropriate.
3. Wait for the dust and fumes to disperse.
4. The shotfirer will inspect the blast site to check for misfires and the state of the face for overhangs and loose boulders. He will ensure that all precautions are taken during this exercise to avoid harm to himself.
5. Only when he has satisfied himself that it is safe should he give the “ALL CLEAR”.

In the event of a misfire, follow the misfire rules.

The ‘all clear’ signifies that the blast has fired and that the danger zone is no longer required. Immediately following this the Shotfirer should notify the Quarry Supervisor if any remedial work is required to make the face safe.

4.25 Safeguarding shots overnight

The Shotfirer must ensure that the Explosives Supervisor and Quarry Supervisor are informed as soon as it becomes apparent that the shot cannot be fired within permitted times.

The Quarry Supervisor must ensure that when a shot is being left overnight it must be guarded by a suitable person (appointed as Explosives Supervisor, Shotfirer, or Sentry), or made secure with barriers and warnings. Due to the nature of the remote location and the weather conditions, guarding may not be required, though suitable measures must be put in place and station staff notified to keep clear.

General:

- All charged shot holes will be completed and stemmed to prevent any off the detonators / explosives being removed from the column.
- No surface connector detonators are left attached. If already in place these should be removed and returned to the store.

- All in-hole detonator tubes/wires will be suitably anchored. This would normally be done by wrapping the loose ends around a large rock to ensure that they are not pulled into the stemming in the event that the column settles whilst being slept.
- The blasting record is completed, and all unused explosives, detonators and accessories are returned to the explosives store. In other words the paperwork reflects the current situation on site.
- All blasting keys are kept locked secure.
- Notices / barriers are erected to inform personnel that a danger exists. All entry points onto the bench containing the charged holes are coned off to restrict access and to demark the area that is being left charged; only authorised personnel are allowed to enter the coned area.

Charged holes should not be left unfired for a period exceeding 72 hours; this is to reduce the effects of water on the column of explosives.

4.26 Destruction of surplus explosives

Specific guidance is available on the disposal of surplus explosives in guidance ‘BAM Ritchies DB G27 Disposal of Explosives during Blasting Activities’ and from explosives suppliers. If you are not familiar with safe methods of disposal discuss with the Explosives Supervisor.

4.27 Misfires

The following procedure should be followed in the event of any type of misfire occurring or being discovered whilst shotfiring operations, inspecting the face or loading the rock-pile:

A misfire is described as:

Type A: Where testing before firing reveals broken continuity which cannot be rectified.

Type B: Where a shot or any part of a shot fails to initiate when an attempt is made to fire it.

- The Shotfirer shall remove the key from the exploder and disconnect the shotfiring cable or the shock tube from the starter. The Shotfirer must stay in the shotfiring shelter for a period of at least 5 minutes after the misfire has occurred.

- The Explosive Supervisor and Quarry Manager must be informed by the quickest possible means of the type and nature of the misfire.

- The ‘all clear’ should not be given and all personnel must remain out of the danger zone.

- The Quarry Manager and Explosive Supervisor must attend the scene with the Shotfirer as soon as possible, being in possession of:

  - The blast specification
  - These rules
  - The MPQC, Explosives at Quarries, Guidance Note 1 – Misfires
  - Camera

- The course of action to be taken to deal with the misfire will be agreed between the Explosive Supervisor, Quarry Manager and Shotfirer with reference to the MPQC Misfires - Guidance Note
- These parties will assess the risks associated with any remedial actions. Where deemed necessary by these parties a written risk assessment and method statement should be prepared.

- Any misfired material found must be packaged, labelled ‘MISFIRED MATERIAL’ and removed to the explosive store. Explosives and detonators must be packaged separately.

- The misfired material must be made available for further investigation.

- Every effort shall be made to discover the cause of the misfire and the following should be recorded on BAM Ritchies misfire report DB MSF 01 and placed with the blast specification.
  - Who discovered the misfire

  - Date and time of discovery
  - Procedure adopted to deal with the misfire
  - The cause of the misfire (if known)
  - Date when he misfire was satisfactorily dealt with
  - Modifications necessary to existing procedures as a result of the investigation.

- The process of searching for explosive material in the heap with heavy loading equipment must be agreed by the Quarry Manager to include measures to minimise the risk of the bucket or falling rock causing detonation, banksman to work with the loading operator and for the material taken to level area to be carefully deposited and searched.

- Using available information the possible quantities and types of explosives involved should be determined.

- When the Quarry Manager has completed a risk assessment of the heap normal working may be resumed.

- If the misfire contains accessible explosives and / or detonators an authorised guard must be posted to ensure there is no unauthorised access and to ensure the security of the explosives.

- It may be possible to remove stemming in order to gain access and to re-prime the charge but this should only be attempted after detailed consideration due to the hazards involved.

- Any attempt to re-fire part or all of the shot should take into account that much of the surrounding rock will have been loosened. It may therefore be necessary to build up a burden of inert material to achieve the confining of effect the solid burden and stemming. It is highly likely that the danger zone will have to be considerably extended.

- If there has been no prior indication of a misfire and explosives and / or detonators are discovered during loading operations, work will cease at once and the Quarry Manager informed immediately – he will in turn inform the Explosives Supervisors. All loaded dumpers running from the blast pile where the explosives were found must will be tipped off in a designated area to inspect the loads. Guidance can be found in BAM Ritchies Guidance 'DB G25 Recognising Uninitiated Explosives'.

- A Misfire is classed as a dangerous occurrence under the UK regulations 'Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 2013' (RIDDOR). Although not strictly applicable at this location, any misfire should be reported to the Manager Drill and Blast in the UK for reporting to the Health and Safety Executive (HSE).

4.28 Compliance and Auditing

4.28.1 Understanding of the rules

The first stage of ensuring compliance with these rules, is to ensure that they are fully understood by those persons upon whom they impose duties. This is done by the Quarry Supervisor or Explosives Supervisor directly issuing the rules to each person or group of persons and briefing them on the contents and checking their understanding. The individual must sign their copy once they have read, understood and are able to act following the rules. A record of the briefing, the receipt or alternative briefing record by the Quarry Supervisor.

4.28.2 Monitoring & Review

An audit of the blasting operations will be carried out at intervals not greater than once every construction season by the Overseas Projects Manager. The findings of the audit will be the subject of a separate report prepared by the auditor.

The Explosives Supervisor or Quarry Supervisor will carry out an internal audit periodically, with not less than two audits per construction season.

The audits and spot checks are designed to confirm that:

- Those involved in the operation understand the requirements of the quarry's Shotfiring rules and are complying with them.
- They continue to be practical and workable.
- Changes necessary to accommodate altering circumstances and statutory requirements are introduced.

4.29 Record Keeping

Records of all appointments shall be kept at a suitable place for at least 3 years following the end of each individual's employment at the quarry, or if they cease to undertake that role. They should be marked cancelled and the date of cancellation noted.

Blast specifications and reports of misfires shall be kept for at least 3 years from the date on which it was made.

Retain exploder and circuit tester repair records for 3 years.

A copy of the written statement of duties of all persons appointed at the quarry under Part V of the Quarries Regulations 1999 shall be kept at a suitable place for at least 12 months after the date on which the appointment ceased to have effect.

5 Load, Haul and Rock Processing

As shown in section 2, a number of quarried rock products are required – backfill and surface materials. The production processes described below involve the use of the same items of plant in different configurations to minimise overall plant requirements, and as such it is only possible to produce one product at any time. Approximately two days is required to change between any one production process and another.

Type	Tonnage	Comments
5-40kg backfill	Circa 65,550	10,000t from recycled back-fill material. 58,550t from blasted rock.
30-80mm surface course material	Circa 9,000	
Sub-base	1,620	
Base course	1,620	
Aggregates	tbc	

It has been estimated that c.140,000t to 155,000t of blasted rock is required for processing feed to produce the c58,550t of 5-40kg backfill, though this is subject to the yields obtained during production. Sufficient <5kg undersize material from this production is then available for 30-80mm, sub-base, base course and small quantities of aggregates.

The flow diagrams and descriptions below outline the production processes required for each of these products. As the production process has not been tested, the quantities are indicative only and some contingency will be allowed for. The results of actual processing will dictate the overall extraction volume and final face positions.

5.1 Crushing and Screening Location

In the initial stages of the project there will not be sufficient space for crushing plant in the quarry extraction area, so rock will be loaded and taken to the crushing area located in laydown area 3 as shown on figure 30.

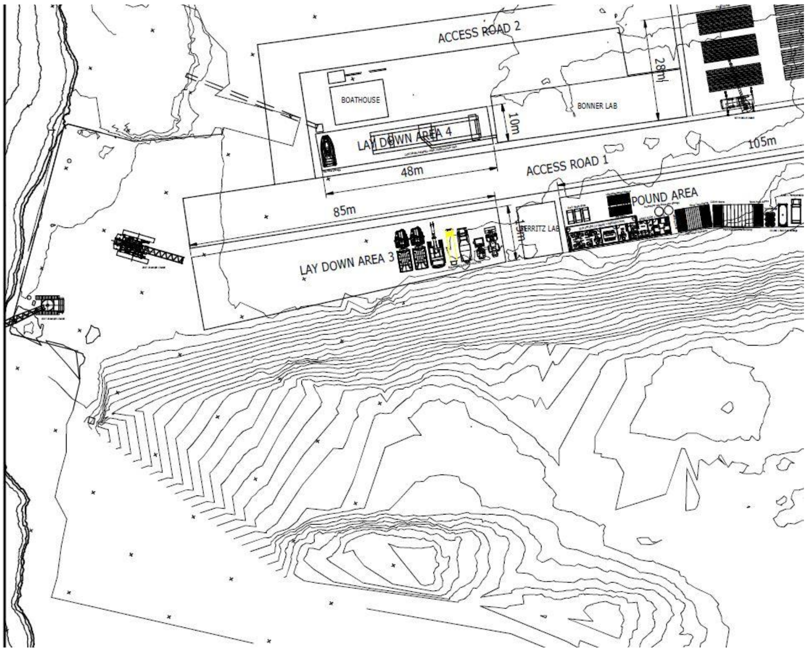


Figure 30 – Laydown area 3 is designated for quarry processing plant.

At a later date, and if space allows, the crushing and screening plant may more conveniently located at the face in the extraction area.

5.2 Production of Backfill Material from Blasted or Recycled Material

The production process is shown in figure 31 below. The first stage is to pass the as-blasted / recovered material over a simple grizzly screen to separate <250mm from >250mm – see figure 32. This ensures that as much as possible of the rock naturally falling in the 5-40kg range is retained. The <250mm material passing the screen is then taken to a second mobile double-decked screen where >125mm material passes and the 5-40kg product retained – see figure 33. It is not possible to pass the as-blasted material direct to this second screen as damage may be caused by larger sized material.

At this stage only as-blasted material already in the 5-40kg range has been separated. To improve the yield, the >250mm material is fed to a mobile jaw crusher – see figure 34. To ensure that >250mm material is crushed, but to avoid over-crushing the 125-250mm material, the crusher will be trickle fed on its widest setting, though even doing this will create most material in the 125-200mm range. This material is then also passed over the 125mm screen to remove fines and the 5-40kg product passes to the stockpile. If the crushed material results in a too small median size for the specification, it can be augmented with rock broken using a hydraulic breaker fitted to the excavator.

All waste material from this process becomes feed for smaller rock products, or stockpiled for future use.

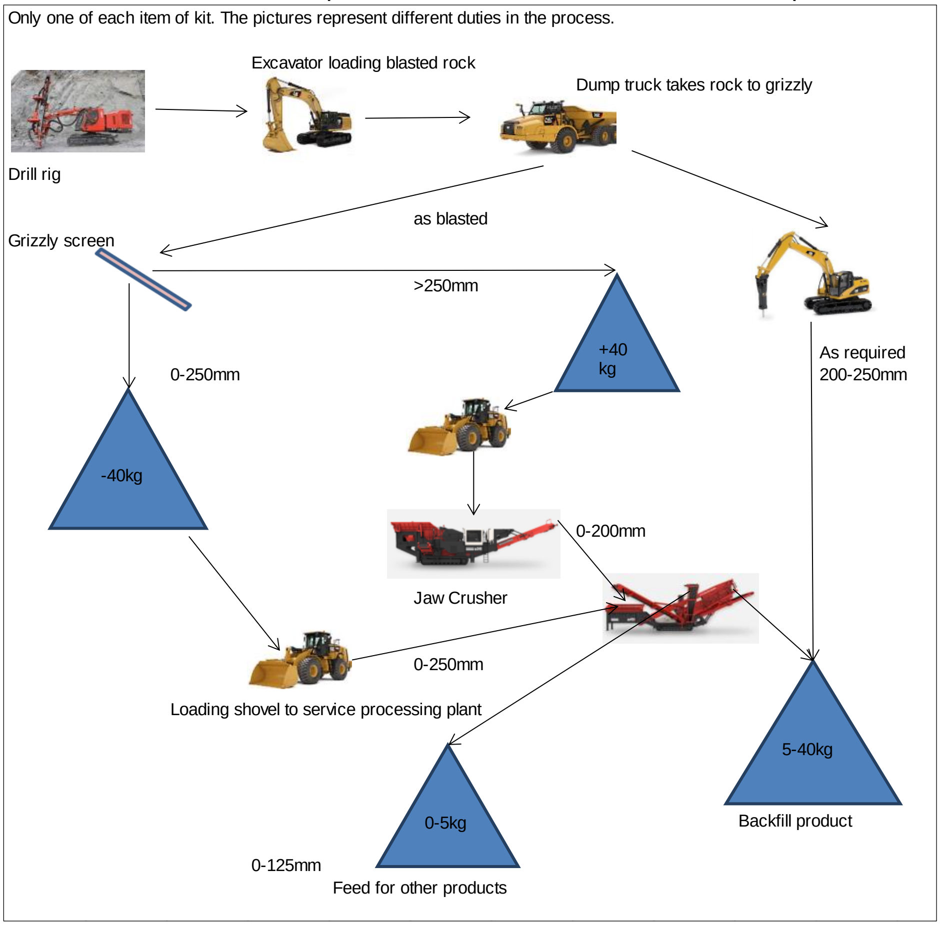


Figure 31 – Schematic process diagram for backfill production

Figure 32 Example of a grizzly screen

Figure 33 Example of a mobile screen

Figure 34 Example of mobile jaw crusher

5.3 Surface material and sub-base production

0-125mm feed material from the backfill process is passed over a two-deck screen to separate undersize (either <25 or <30mm), 30-80mm (or 25-100mm) products and oversize. Oversize can be fed to the jaw crusher and then returned to the screen. This simple screening process does not impart any shape to the product. Both products are then loaded to stock, or direct to the project.

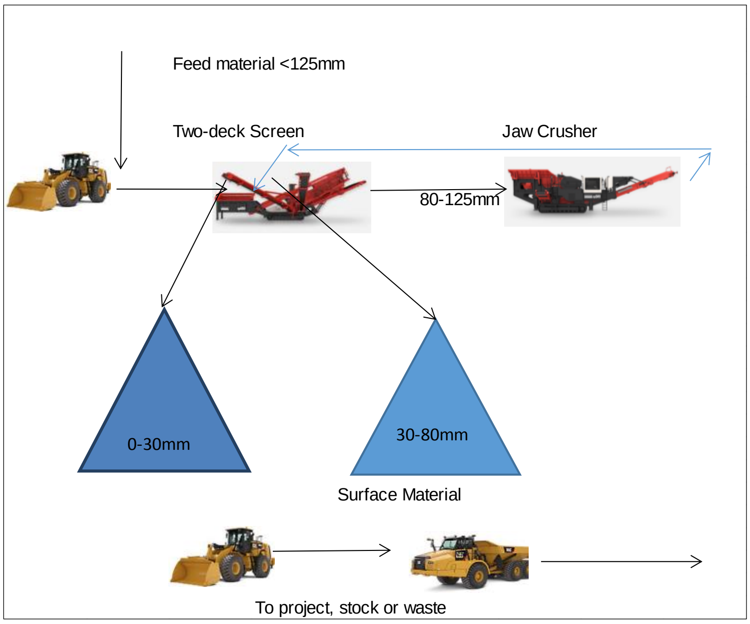


Figure 35 Schematic process diagram for surface material production (30-80mm shown).

5.4 Base course production

Feed material 0-125mm from previous production is fed by loading shovel to the jaw crusher, from where it passes directly by conveyor to feed the secondary cone-crusher. The finished product is discharged from the cone crusher. If oversized product is included in the material, the screen can be used to remove this – see figure 36.

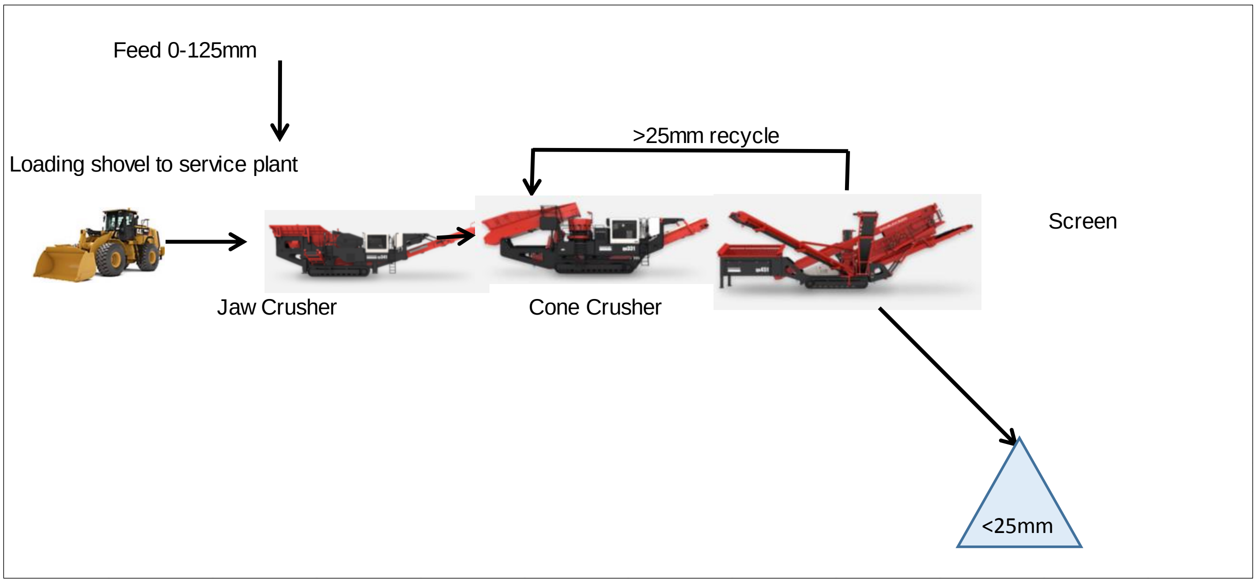


Figure 36 Schematic process diagram for base course production

5.5 Aggregate production

Feed material 0-125mm from previous production is fed by loading shovel to the jaw crusher, from where it passes directly by conveyor to feed the secondary cone-crusher, which in turn discharges by conveyor directly to the two deck screen. The two deck screen is capable of separating a fine aggregate product (sand), aggregates, and oversize which can re-feed to the cone-crusher.

Note: If more product sizes are required the two-deck screen can be replaced by a three-deck screen for this and the previous processes. Product sizes shown in figure 37 are indicative only. The secondary cone-crusher is an additional item of plant not used in the previous processes.

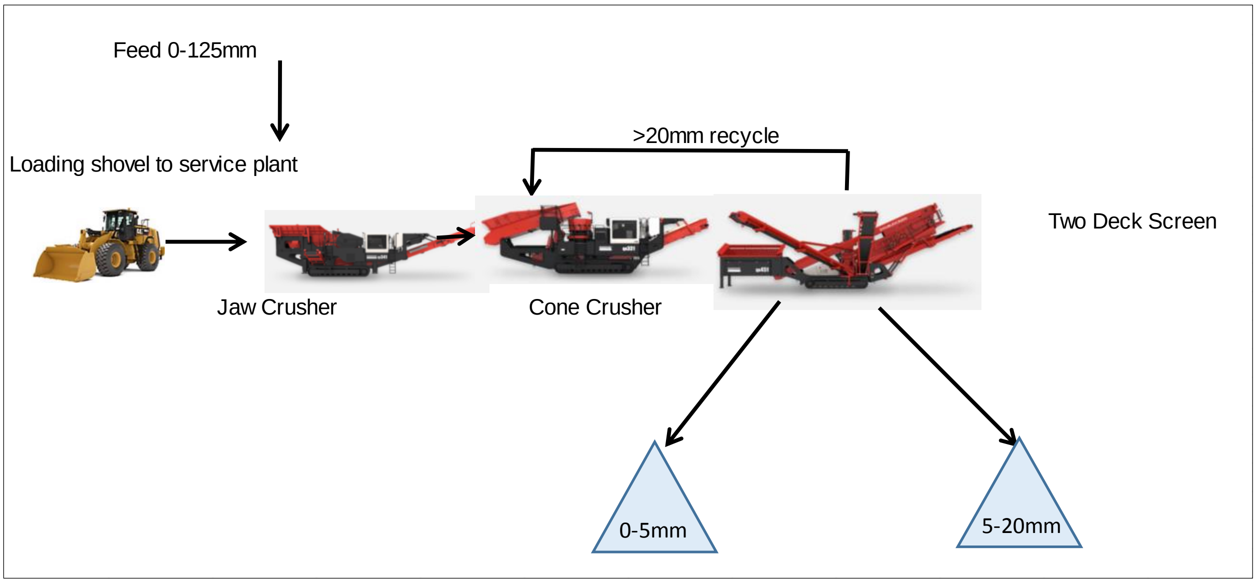


Figure 37 Schematic process diagram for aggregate production

5.6 Production rates

The following production rates are anticipated for the processing described above. These rates are based on six working days per week, and eight operational hours per day excluding rest breaks. The process below describes one blast per week, with the blast size tailored to match a single load of explosives carried in a Twin Otter aircraft.

1. *Pre-production development.*

   Prior to drilling and blasting commencing it is anticipated that one week will be required to remove snow cover and create access for drilling equipment and prepare the processing area. No production will be undertaken during this week. Standard quarry equipment will be used for this process. Once drilling commences there will be approximately one further week prior to the start of processing.

2. *Drilling and Blasting*

   It is anticipated that one blast will be fired per week, yielding around 7,000 tonnes or rock. The blast size chosen to match one load of explosives transported from the storage area.

   A typical drill and blast cycle is as follows:
   Day 1 and 2 - drilling. This can continue into days 3 to 5 if problems are encountered.
   Day 3 to 5 - waiting for excavation of previous shot.
   Day 5 pm - surveying and preparation of blasting specification.
   Day 6 - fire blast.

   The first blast would be fired as soon as the shot is drilled and the specification completed. During the first one or two weeks it may be necessary to fire smaller blasts during development. Production can commence as soon as the first blast is fired and the processing plant set-up.

3. *Excavation, load and haul*

   Excavation, load and haul can only take place for five of the six day cycle, as no excavation can be undertaken from the time of the face survey until after the shot is fired. The equipment will work on other quarry duties on the sixth day.

   The excavator loads the 30t ADT which transports the blasted rock to the grizzly screen.
   - 7000t / 5 days = **1400t/day**
   - 25t per dumper load = 56 loads per day.

4. *Processing rock backfill*

The entire 1400t/day passes over the grizzly screen.

The loading shovel loads the entire 1400t, either oversize to the crusher, <250mm to the screen, or to a temporary stockpile for processing on day 6. Further processing is undertaken over 6 days at 7000/6 = 1167t/day. The loading shovel also loads product and waste from the process.

Total loading shovel output per day is 1400+1167 = 2567t.

For the anticipated gross quantity to be processed from quarrying of 140,000t to 155,000t, a total of 20 to 22 weeks are anticipated. Weekly production c.2,700 tonnes of backfill.

For recycled materials, production rates will be dependent on the grading of the feed, but any quantity produced from recycling will reduce the quantity and duration of production using blasted rock feed. Processing at the same feed rate of 7000t per week, for a total of 30,000t of feed material gives an anticipated duration of 4 to 5 weeks. Weekly production c.2,300 tonnes of backfill.

5. *Loading out backfill.*

An anticipated 1167t of backfill and ‘waste’ will be produced per day. If this is loaded to 25t articulated dump trucks, with 20t per load, a total of 58 loads per day are required. The number of dump trucks required will be dependent on the timing of the production in relation to use at the wharf site and/or location of the stockpiles.

6. *Change over time between different types of production.*

As described earlier the different rock products will be produced with the same equipment as far as possible, therefore one or two days of non-production will be required to reconfigure the equipment.

7. *Production of sub-base, base course and 30-80mm products.*

A production rate 100 t/hr, 800t/day is anticipated for these products. For a total of 11,240 tonnes, 14 days or 2 weeks and 2 days.

8. *Production of aggregates.*

A production rate 80 t/hr, 640t/day is anticipated for these products. The quantity and duration are yet to be determined.

All equipment, with the exception of the drill rig will be fully utilised during working hours. The drill rig is anticipated to be operational 2 to 3 days per week.

5.7 Loading at the face

Blasted rock will be loaded using a hydraulic excavator into an articulated dump truck - as shown in the example below.

Figure 38 Example of loading at the face

Excavators working at the face will create a rock platform and rock trap between the rock-pile and the platform to prevent the rock being worked collapsing on the excavator or dump trucks. This platform is constructed with material from the rock-pile compacted by the excavator tracking back and forward. As the rock-pile continues to be worked, the platform is extended as the excavator works along the rock-pile starting at one end, removing the platform from the worked out area in a progressive sequence. The slopes of the platform must not be undercut, but follow the natural angle of repose of the material. The height of the platform shall be such that it enables the excavator to load safely into the rear of the dump trucks or mobile crusher being loaded. Figure 39 shows the geometry of the rock platform and rock trap.

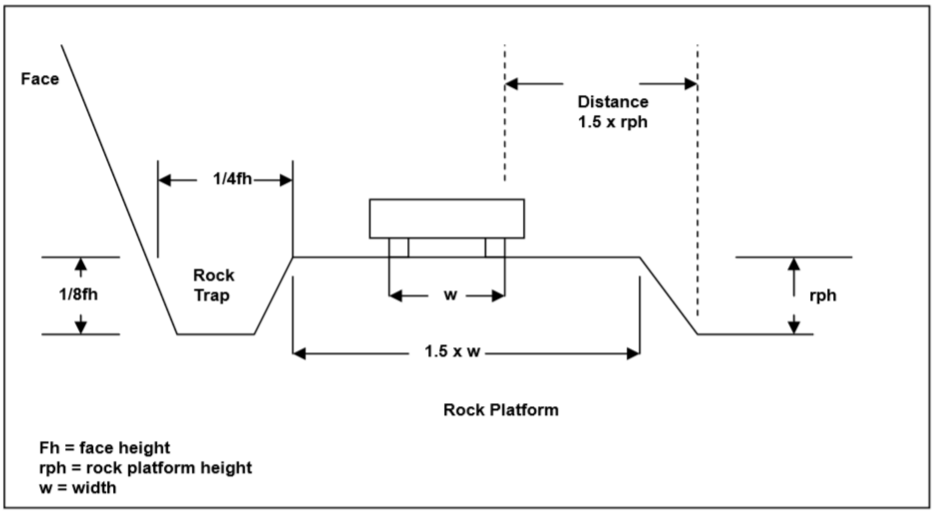


Figure 39 - Cross-sectional view of rock platform and rock trap.

The area where dump trucks are being loaded is a restricted loading zone - see figure 40. This loading zone is defined by the manoeuvring zone of the excavator or loading shovel and the manoeuvring zone of the trucks being loaded.

Within this restricted zone only the excavator and dump trucks being loaded may enter.

Access to the restricted zone for other vehicles will be controlled by the supervisor or designated banksman and will only be permitted when loading has been stopped and the equipment is in its safe position and will not recommence until the other vehicles have left the area and permission is given by the supervisor. Other vehicles will wait as directed by the supervisor and in an area separate to waiting dump trucks.

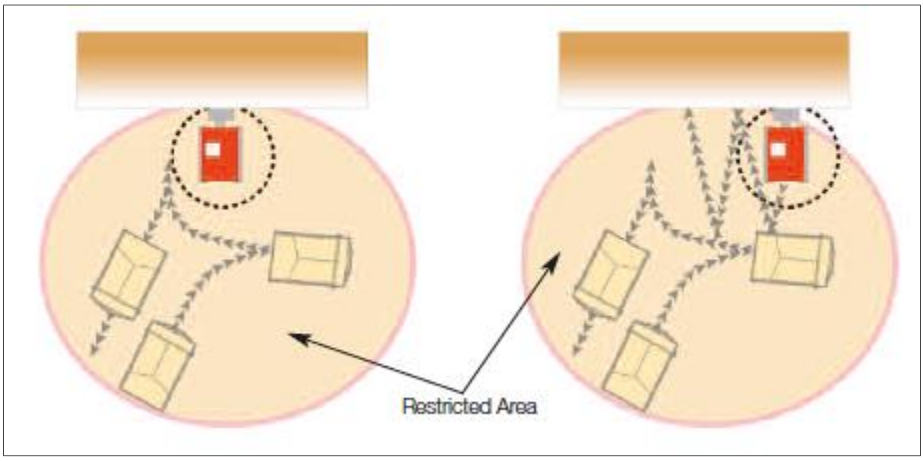


Figure 40 - Restricted area for loading operations

During normal loading operations, when the excavator operator is satisfied that a truck is positioned safely to receive a load he will discharge the load from the bucket. On completion of the load and when the excavator operator is satisfied the truck is safely loaded the excavator horn to inform the truck driver to move off. When a dump truck has been loaded it must leave the loading zone and proceed to the tipping area without delay.

5.8 Tipping Areas

The areas where dump trucks tip to feed processing plant, stocking areas, or directly in the construction area will be restricted areas in a similar way to the loading area describes above. Dump trucks coming from the face to areas where other personnel are present will be controlled by a designated banksman who will control when the truck can off-load. Where necessary trucks will wait in a designated area prior to tipping and will leave the tipping area as soon as possible.

Where tipping over an edge, a protection barrier will constructed using an excavator to prevent trucks being able to reverse too far. No ancillary plant or vehicle may enter the restricted area until allowed by the banksman or supervisor and only when tipping operations are stopped.

Figure 41 Example edge protection for tipping operations

5.9 Control of dust from operations

As far as possible the production of dust will be avoided, but the process of drilling, fragmenting, loading, transporting and crushing rock produces dust. The following measures outline how this will be controlled to minimise the dust becoming airborne and a hazard to personnel and the environment.

1. Position the dust creating activities as far as practical from sensitive receptors and where possible downwind of the glacier.

2. Reduction of dust from drilling operations. The drill rig will be fitted with dust suppression equipment. This will normally consist of a dust hood at the foot of the mast, which makes a seal with the ground, a dust ring, which seals around the drill string, and a dust collection system

which extracts the dust directly away from the hole and places it onto the ground. Although the dust is still susceptible to being picked up by wind, the effects are significantly reduced.

3. Reduction of dust from blasting**.** Careful blast design will prevent excessive ejection of material into the air, however in dry conditions, some dust cannot be avoided. The direction of firing may reduce the pick-up of dust into the air by using natural topography to create shelter. On very windy days, when the wind is blowing directly towards a close sensitive receptor, blasting may need to be suspended. For this to occur safely however the decision to suspend blasting operations should be taken before charging commences.

4. Control of dust from plant. The following measures may help to reduce the source of dust from activities, by preventing their escape to the atmosphere:
   - After the blast has been fired and before any crushing takes place the rock pile area that crushing/loading is to take place will be watered with seawater using a tractor and bowser. It should be possible after the first few blasts to feed the primary crusher directly with the excavator from the face, the primary will have a covered conveyor as well as hanging skirts from the discharge belt to help curtail air-borne dust. Again consideration will be given to the weather conditions particularly wind direction.
   - The haul roads can also be sprayed with the seawater should the need arise.
   - Screens will be fitted with seawater spray bars at the end of the dust belt conveyor plus skirts, all conveyors will be covered, as with all activities special attention will be given to the weather conditions.
   - Crushers will be fitted with seawater pumps which can be fed with the water bowser.
   - All water lines will be cleared at the end of each day's production to prevent water lines from freezing.
   - Use of crushing and screening plant within its design capacity prevents excess dust.
   - Ensuring haul roads have a firm compact surface and are well maintained.
   - Good maintenance of all plant and equipment
   - Limiting drop heights during stockpiling, processing and loading operations.
   - Maintain and enforce low speed limitations on site.
   - Minimise double handling as far as practical to reduce the overall number of tipping actions.

5. Temporary suspension of operations during high winds. As with blasting, during excessively dry, windy conditions, especially where the wind direction will blow dust towards sensitive receptors, it may be necessary to suspend other operations if it is not possible to control dust by other means.

5.10 Traffic Management in the Quarries

Traffic will be managed within the quarries to prevent accidents both involving individual vehicles and from accidents arising from the interaction between vehicles, especially between heavy and light vehicles, or pedestrians. This is achieved by a number methods outlined as follows and discussed below:

- Ensuring that the design of the quarry layout minimises the interactions between vehicles, especially different types of vehicles or pedestrians.
- Design of haul roads with gentle gradients, safety bunds and avoiding blind spots.
- Ensuring communication of rules and best practice through training, inductions, signs and traffic controllers/banksmen.
- Ensuring adequate maintenance of plant and haul roads.
- Ensuring adequate site visibility.
- Planning and maintaining pedestrian walkways.

5.11 Plant Controllers / Banksmen

At key areas such as restricted tipping areas, plant controllers / banksmen will direct plant/vehicle movements. These will be specifically trained in their duties by the supervisor for that area. They will be competent in methods used to ensure their own and other people's safety.

5.12 General Rules

When driving a vehicle on the site the following rules apply:

- Ensure that the area around the vehicle is clear before moving away or altering direction.
- Drive with due care and attention and at a speed that is appropriate to the prevailing ground, weather and visibility conditions, but not exceeding the appropriate speed limits - maximum 20kph.
- A safe distance must be maintained from the vehicle in front so that emergency action can be taken - minimum of 3 large truck lengths.
- Loaded vehicles always have priority over empty vehicles.
- Seat-belts should be worn at all times when the plant is running.
- Light vehicles must always give way to heavy vehicles and not enter heavy vehicle restricted areas without permission from traffic controllers.
- When vehicles of similar size and capacity are sharing a haul road and there is a need to give way, the vehicle travelling uphill has priority.
- Only trucks for loading or tipping purposes may enter the swing radius of an excavator or manoeuvring zone of a dozer or loading shovel.
- On no account should a vehicle be driven within any cordoned off areas.
- Vehicle operators must keep their cabs clean and tidy, store loose and personal items securely and ensure there are no obstructions to visibility aids, windows, controls, gauges, warning lights etc. Vehicles will be driven with the doors closed at all times.
- Plant operators must immediately contact a site supervisor in the event of any breakdowns, emergencies or any other unplanned event.
- The use of mobile phones when driving is strictly prohibited.
- Vehicles should be parked on level ground in an authorised parking/waiting wherever possible to minimise the possibility of them being set in motion.
- When leaving a vehicle unattended the engine should be switched off, ignition key removed, all brakes applied and the appropriate gear selected to suit any gradient.
- Ground engaging equipment i.e. excavator buckets, dozer blades, ripper teeth and scraper bowls should be lowered to the ground when parking and if stopping to be serviced or fuelled.
- Vehicles must always be reversed parked.
- Dump truck drivers shall stay in their cabs whilst loading is taking place.
- Tipping shall only take place on level ground to prevent overturning. After tipping, dump truck bodies shall be lowered before moving off.
- Plant operators shall not allow the bucket of any vehicle to pass over the cab of any dump truck or haulage vehicle.
- It is strictly forbidden for anyone to travel in a loading shovel/excavator bucket or to use it as a work platform.
- Where haul roads transit close to the bottom of a face, rock traps will be constructed to catch material and keep traffic clear of the face.
- Edge protection bunds will be provided to prevent mobile plant and ancillary vehicles from being driven over an unprotected edge. This will be a minimum of 1m, or the radius of the largest vehicles wheel, whichever is greater.
- Roads will be regularly maintained so that they do not develop bumps, ruts or potholes which may make control of vehicles difficult. Roads will be designed to drain naturally.
- Operational areas will be lit with mobile lighting towers during reduced visibility should it be necessary to work in these conditions.

5.13 Plant Maintenance

- Prior to use all plant and haulage equipment will be inspected to ensure it is suitable for use, including checks of brakes, lights and visibility aids.
- At the start of each shift plant operators will carry out a designated pre-start/start-up inspection of their vehicle.
- Plant will receive regular routine maintenance.
- Lights and windows must be kept clean at all times.
- Regular break testing will be undertaken in the designated area.

6 Resources - Personnel, equipment

6.1 Personnel

- 1 Quarry Manager / Blasting Engineer
- 1 Shotfirer
- 1 Driller (possibly one person acting as Shotfirer/Driller)
- 1 Excavator / Crusher Operator
- 1 Loading Shovel Operator
- 1 Dumper Operator

Notes:

- The role of Explosives Supervisor will be held by the Quarry Manager.
- The roles of Laser Surveyor, Explosives Storekeeper will be held by the Shotfirer and / or Explosives Supervisor.
- An appropriate person will be instructed and appointed Blast Controller and may be part of the BAM or BAS teams.
- Sentries will be trained and appointed from the quarrying or construction personnel.

6.2 Equipment

The following main quarry equipment will be used for excavation, load, haul, production and loading out of the quarry area. This does not include equipment for transport to the work area, to/from stockpiles, or for stockpile management.

Item	No.	Comments
Excavator for rock excavation	1	45t (Minimum size 35t) ROPS and FOPS cab, window screen protection (for use with rock hammer). Standard track widths would be acceptable but narrow rock tracks would be preferred. Including hydraulics for rock hammer. Camera and mirrors
Hydraulic rock breaker	1	To match above
Wheel loader	1	Cat 966 or equivalent with ROPS and FOPS cab, rock tyres, rock bucket with suitable teeth ware plates etc Reversing cameras and mirrors plus flashing lights etc.
Articulated dump truck (ADT)	1	30t ADT with ROPS and FOPS cab, rock tyres, camera and mirrors
Drill rig – Eg. Atlas Copco FlexiROC T35	1	
Grizzly screen	1	
Mobile Jaw Crusher	1	
Mobile cone crusher	1	Optional if aggregates are required
Mobile Double deck screen	1	

Additional ancillary equipment may be required, or be shared with construction activities. Eg. Water bowsers, fuel bowsers, maintenance equipment, tractors and trailers, and aircraft.

APPENDIX A

BLAST CHECKLIST TO BE COMPLETED FOR EACH BLAST PERFORMED - DRAFT

Programmed Time of Shot	
Date Fired:	
Time Fired:	
Blast Number:	
Location	
Number of Blast Holes:	
Total charge in kg :	
Maximum instantaneous charge kg	

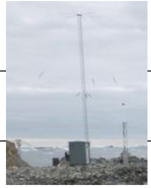
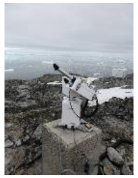
Wind Speed	
Wind direction	
Cloud cover 8th	
Precipitation	
Visibility	
Sea State	

	Time	Clear	Name
24 Hours prior to blasting			
Notify BAS station leader			
Notify BAM Construction Manager			
Notify Communications tower for flight operations and shipping			
Notify Meteorologist and Science co-ordinator			
Notify Science and Bonner Laboratory Manager			
Notify Communications Manager			
Notify Electrical Engineer			
Notify boat and dive co-ordinator			
Place notices in Project Office and Bransfield House			
On the morning of the blast			
Notify sentries			
Place warning 'Danger Blasting (with time)' signs at the two access roads			
60 minutes prior to blasting			
Notify BAS station leader			
Notify BAM Construction Manager to clear all personnel by 15 minutes prior to blasting			
Notify Communications tower for flight operations and shipping			
Notify Bonner lab manager to clear personnel by 15 minutes prior to blasting			
Notify boat and dive co-ordinator			
Notify BAM construction Manager			
Radio check with sentries			
15 minutes prior to blasting			
Give 'all station warning' on channel 1			
Positive confirmation from dive master that all divers are clear of the water in the vicinity			
Construction Manager ensures that all project personnel are clear of construction area			
Bonner and Gerritsz lab manager to ensure all personnel are clear of the laboratory area			
Sentries start their designated checks and move to position and secure the area			
Shotfirer makes final check of blast area and checks for shipping and fauna			
3 minutes prior to blasting			
Confirmation from shotfirer - ready to fire			
Check that land side sentries are in position and area secure			
Give 'all station warning' Firing in 3 minutes' on VHF CH 1			
Sound horn - 2 x 15 seconds			
Blasting and post blast			
Sound horn 30 seconds then fire			
Shotfirer checks that the shot has fired and radios the 'all-clear'			
Give 'all clear' to on VHF Ch 1			
Notifys the Quarry Manager and Construction Manager of any remedial or safety measures required			

Comments

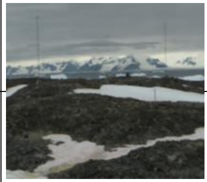
Checklist completed by: Blast controller	

APPENDIX B

Sensitive Receptor	Description	Responsible Person	Limits	Limit Source	Comments	M.I.C (kg)	10	20	30	40
						Distance (m)	PPV (mm/s)	PPV (mm/s)	PPV (mm/s)	PPV (mm/s)
General MET instruments	Various	Rosey Grant MET and Science Co-ordinator	Dust is considered an issue for MET instruments, in particular the Sun Photometer. BAS understand that blasting creates dust that is difficult to limit. Blasting will be avoided when the wind is blowing S-N.	Meteorologist and Science Co-ordinator - Rosey Grant	Drill and blast management plan to include avoidance of blasting when the wind blows N to S.	na				
NDB antenna	Antenna 	Ben Keitch - Electrical Engineer	?	?	This antenna is located directly in the proposed blasting area and therefore must be moved under these circumstances.					
DME antenna (to be moved)	Antenna	Ben Keitch - Electrical Engineer	?	?	This antenna is located directly in the proposed blasting area and therefore must be moved under these circumstances.					
DORIS	Beacon on concrete plinth.	Ben Keitch - Electrical Engineer	?	?	This antenna is located directly in the proposed blasting area and therefore must be moved under these circumstances.					
POM Sun Photometer	Instrument bolted on concrete pillar 	Rosey Grant MET and Science Co-ordinator	Unknown impact from blasting vibration, but impact from dust expected to be considerable. It has been agreed that this instrument will be removed during blasting, for short duration (eg 1 hour), or for the entire blasting programme. The MET and Science co-ordinator will be included on the blast protocol to allow this to be carried out.	Meteorologist and Science Co-ordinator - Rosey Grant	Sensitive to dust, so to be removed during blasting. Easily removed	50	20.9	36.4	50.3	63.3
GPS receiver	GPS receiver for long term movements 	Peter.clarke@newcastle.ac.uk	Not considered to be adversely affected by vibration - email 22.02.17 Peter Clarke of Newcastle University.	Peter Clarke	Peter Clarke at Newcastle University to be notified post-blast of the blasting time to allow checks on data anomolies. Add this to the drilling and blasting management plan, blast protocol.	50	20.9	36.4	50.3	63.3
Optical Hut - SAOZ	The optical hut houses a number of instruments listed left	Rosey Grant MET and Science Co-ordinator	Not adversely affected by vibration	Meteorologist and Science Co-ordinator - Rosey Grant		60	15.6	27.2	37.6	47.3
Optical Hut - Sun Photometer logger		Rosey Grant MET and Science Co-ordinator	Not adversely affected by vibration	Meteorologist and Science Co-ordinator - Rosey Grant		60	15.6	27.2	37.6	47.3
Optical Hut - AG Spectrometer		Ben Keitch - Electrical Engineer	Winter operation only. Not adversely affected by	Ben Keitch - Electrical Engineer		60	15.6	27.2	37.6	47.3
Optical Hut - OH Imager		Ben Keitch - Electrical Engineer	Winter operation only. Not adversely affected by	Ben Keitch - Electrical Engineer		60	15.6	27.2	37.6	47.3
Optical Hut - All Sky Cam		Ben Keitch - Electrical Engineer	Winter operation only. Not adversely affected by	Ben Keitch - Electrical Engineer		60	15.6	27.2	37.6	47.3
Optical Hut - IR All Sky Cam		Ben Keitch - Electrical Engineer	Winter operation only. Not adversely affected by	Ben Keitch - Electrical Engineer		60	15.6	27.2	37.6	47.3

Sensitive Receptor	Description	Responsible Person	Limits	Limit Source	Comments	M.I.C (kg)	10	20	30	40
						Distance (m)	PPV (mm/s)	PPV (mm/s)	PPV (mm/s)	PPV (mm/s)
Memorial plaque for Stanley E Black, David Statham and Geoffrey Stride, died 27 May 1958.		Mike Brian - Station Leader	No limit can be practically applied at this close proximity. Make photographic record of the memorial pre-blast and monitor throughout workes. It was considered acceptable to repair minor damage to the structure should this occur. Monitor risk throughout the project and consider further controlles as required.	na	Distance approximate for closest works	30	47.3	82.3	113.9	143.3
Memorial cross, with plaque, for John H M Anderson and Robert Atkinson, died 16 May 1981		Mike Brian - Station Leader	No limit can be practically applied at this close proximity. Make photographic record of the memorial pre-blast and monitor throughout workes. It was considered acceptable to repair minor damage to the structure should this occur. Monitor risk throughout the project and consider further controlles as required.	na	Distance approximate for closest works	30	47.3	82.3	113.9	143.3
Memorial cairn, with plaque, for Kirsty M Brown, died 22 July 2003		Mike Brian - Station Leader	No limit can be practically applied at this close proximity. Make photographic record of the memorial pre-blast and monitor throughout workes. It was considered acceptable to repair minor damage to the structure should this occur. Monitor risk throughout the project and consider further controlles as required.	na	Distance approximate for closest works	30	47.3	82.3	113.9	143.3
Memorial plaque for N J Armstrong (Canada), D N Fredlund (Canada), J C Armstrong (Canada) and E P Odegard (Norway), died 23 Nov 1994)		Mike Brian - Station Leader. This may have other non-BAS Canadian owners, though liaison should be made through BAS.	No limit can be practically applied at this close proximity. Make photographic record of the memorial pre-blast and monitor throughout workes. It was considered acceptable to repair minor damage to the structure should this occur. Monitor risk throughout the project and consider further controlles as required.	na	Distance approximate for closest works	30	47.3	82.3	113.9	143.3
The British Antarctic Sledge Dog plaque.		Mike Brian - Station Leader	No limit can be practically applied at this close proximity. Make photographic record of the memorial pre-blast and monitor throughout workes. It was considered acceptable to repair minor damage to the structure should this occur. Monitor risk throughout the project and consider further controlles as required.	na	Distance approximate for closest works	30	47.3	82.3	113.9	143.3
Cairn, built from rocks. Erected Sept. 1957 by Nigel Procter, and used in Oct. 1957 by John Rothera as a survey station during the first mapping of the area, referred to as Adelaide Island Trig Point (see relevant reports in BAS Archives, refs. AD6/2Y/1957/K13 and 14).	No image	Mike Brian - Station Leader	Not considered to be adversely affected by vibration due to distance.	Jan Cordon	No access easily available	640	0.4	0.6	0.9	1.1

Sensitive Receptor	Description	Responsible Person	Limits	Limit Source	Comments	M.I.C (kg)	10	20	30	40
						Distance (m)	PPV (mm/s)	PPV (mm/s)	PPV (mm/s)	PPV (mm/s)
UKHO survey pillar	Concrete pillar 	Unknown	Not considered to be adversely affected by vibra	Jan Cordon	Predicted vibration is below BS7385-2:1993 for cosmetic damage to buildings	90	8.2	14.2	19.6	24.7
Flagpole	Steel pole on concrete base 	Mike Brian - Station Leader	Not considered to be adversely affected by vibra	Jan Cordon	Inspect on a regular basis.	40	29.8	51.9	71.9	90.4
Explosives Magazines / Stores	Steel storage boxes to UK spec 	Ed King	Not considered to be adversely affected by vibra	Jan Cordon		60	15.6	27.2	37.6	47.3
E-W wide band array	Two connected antennae 	Alan Messenger - Communications Manager	Not considered to be adversely affected by vibra	Alan Messenger - Communications Manager		70	12.2	21.2	29.3	36.9
ARIES DOME	Dome structure with satelitte antenna inside 	Rosey Grant MET and Science Co-ordinator	Not considered to be adversely affected by vibra	Meteorologist and Science Co-ordinator - Rosey Grant		100	6.9	12.0	16.6	20.9
RLPA tower	Steel tower with ariel like structure 	Alan Messenger - Communications Manager	Not considered to be adversely affected by vibra	Alan Messenger - Communications Manager		150	3.6	6.3	8.7	10.9

Sensitive Receptor	Description	Responsible Person	Limits	Limit Source	Comments	M.I.C (kg)	10	20	30	40
						Distance (m)	PPV (mm/s)	PPV (mm/s)	PPV (mm/s)	PPV (mm/s)
CODIS dome	Dome structure with unknown contents 	Alan Messenger - Communications Manager	Not considered to be adversely affected by vibra	Alan Messenger - Communications Manager		145	3.8	6.6	9.2	11.5
MET tower - sonic anemometer, sun duration sensor, 3x present weather sensors, cloud vase recorder, sun radiation sensor	Steel tower with MET instruments 	Rosey Grant MET and Science Co-ordinator	Not considered to be adversely affected by vibra	Meteorologist and Science Co-ordinator - Rosey Grant		195	2.4	4.1	5.7	7.2
Snow Gauge (tipping cup)	Close to Giant's House 	Rosey Grant MET and Science Co-ordinator	Not considered to be adversely affected by vibra	Meteorologist and Science Co-ordinator - Rosey Grant		180	2.7	4.7	6.5	8.2
AWS air wind speed	Opposite side of runway 	Rosey Grant MET and Science Co-ordinator	Not considered to be adversely affected by vibra	Meteorologist and Science Co-ordinator - Rosey Grant		315	1.1	1.9	2.6	3.3
Ozone detector	East Beach - not seen	Rosey Grant MET and Science Co-ordinator	Not considered to be adversely affected by vibra	Meteorologist and Science Co-ordinator - Rosey Grant	Location not confirmed - assumed as equal to closest East Beach MF Radar. Very distant to blast location.	550	0.5	0.8	1.1	1.4
Bentham Container - MET tower comms		Rosey Grant MET and Science Co-ordinator	Not considered to be adversely affected by vibra	Meteorologist and Science Co-ordinator - Rosey Grant		150	3.6	6.3	8.7	10.9
Small N-S dipole	Two connected antennae 	Alan Messenger - Communications Manager	Not considered to be adversely affected by vibra	Alan Messenger - Communications Manager	Distant to blasting operations	265	1.4	2.5	3.5	4.4
N-S wide band array	Two connected antennae	Alan Messenger - Communications Manager	Not considered to be adversely affected by vibra	Alan Messenger - Communications Manager	Distant to blasting operations	340	1.0	1.7	2.3	2.9

Sensitive Receptor	Description	Responsible Person	Limits	Limit Source	Comments	M.I.C (kg)	10	20	30	40
						Distance (m)	PPV (mm/s)	PPV (mm/s)	PPV (mm/s)	PPV (mm/s)
MF radar receiver (east beach)		Ben Keitch - Electrical Engineer	Not considered to be adversely affected by vibra	Ben Keitch - Electrical Engineer	Distant to blasting operations	550	0.5	0.8	1.1	1.4
MF radar receiver (Bransfield Hse)		Ben Keitch - Electrical Engineer	Not considered to be adversely affected by vibra	Ben Keitch - Electrical Engineer	Distant to blasting operations	410	0.7	1.3	1.7	2.2
MF radar transmitter (closest)		Ben Keitch - Electrical Engineer	Not considered to be adversely affected by vibra	Ben Keitch - Electrical Engineer	Distant to blasting operations	450	0.6	1.1	1.5	1.9
SkiYMet transmitter		Ben Keitch - Electrical Engineer	Not considered to be adversely affected by vibra	Ben Keitch - Electrical Engineer	Distant to blasting operations	485	0.6	1.0	1.3	1.7
SkiYMet radar masts		Ben Keitch - Electrical Engineer	Not considered to be adversely affected by vibra	Ben Keitch - Electrical Engineer	Distant to blasting operations	540	0.5	0.8	1.1	1.4
Search Coil Magnetometer	Ben Kietch reports in email dated 04/05/17 that the instrument is located in excess of 800m from the blasting	Richard Horne rh@bas.ac.uk	No specific limit due to location. Results will be a	Richard Horne, David Maxfield and Ben Kietch	Notify blast times to Richard Horne rh@bas.ac.uk and David Maxfield djmax@bas.ac.uk	800	0.2	0.4	0.6	0.7
ASPA No.129	Designated control area with natural lan	n/a	Not considered to be adversely affected by vibra	Jan Cordon	Land set aside for control purposes and of no concern due to distance	550	0.5	0.8	1.1	1.4
Tide gauge	Suspended in water in shaft near boathouse 	Rosey Grant MET and Science Co-ordinator	Not considered to be adversely affected by vibra	Meteorologist and Science Co-ordinator - Rosey Grant		50	20.9	36.4	50.3	63.3
Boatshed	Anderson shelter design to be replaced	General station building	PPV 50 mm/s	BS7385:2-1993	Monitor and check blast design due to proximity	50	20.9	36.4	50.3	63.3
Bonnar Laboratory	Science Building 	General station building	PPV 50 mm/s	BS7385:2-1993	Monitor and check blast design due to proximity	55	17.9	31.2	43.2	54.3
Bonnar Laboratory Science	Science Projects	Ali Massey - Science leader	Not considered to be adversely affected by vibra	Ali Massey - Science leader	Science leader to be added to blast protocol	55	17.9	31.2	43.2	54.3
Briscoe Wharf			PPV 100mm/s	DMC	Email sent to Koen 21.02.17. Monitor and check blast design due to close proximity	30	47.3	82.3	113.9	143.3

Sensitive Receptor	Description	Responsible Person	Limits	Limit Source	Comments	M.I.C (kg)	10	20	30	40
						Distance (m)	PPV (mm/s)	PPV (mm/s)	PPV (mm/s)	PPV (mm/s)
Gerritsz Laboratory	Steel Frame Construction 	Dutch Antarctic Survey	PPV 50 mm/s	BS7385:2-1993	Monitor and check blast design due to proximity	35	36.9	64.3	89.0	112.0
Gerritsz Laboratory Science	Science Projects	Dutch Antarctic Survey / Ali Massey	Not adversely affected by vibration. No science operations are planned until 2019.	Ali Massey - Science leader	No operations planned until 2019	35				
Giants House	Accommodation 	BAS - Station Leader	15-50 mm/s	BS7385:2-1993	Distant to blasting operations	190	2.5	4.3	5.9	7.5
Old Bransfield House and other static	Offices, workshops 	BAS - Station Leader	15-50 mm/s	BS7385:2-1993	Distant to blasting operations	230	1.8	3.2	4.4	5.5
Admirals House	Accommodation 	BAS - Station Leader	15-50 mm/s	BS7385:2-1993	Distant to blasting operations	265	1.4	2.5	3.5	4.4
Bransfield House	Canteen and other facilities 	BAS - Station Leader	15-50 mm/s	BS7385:2-1993	Distant to blasting operations	395	0.8	1.3	1.8	2.3
Fuel Tanks		BAS - Station Leader	na due to distance	Jan Cordon	Distant to blasting operations	450	0.6	1.1	1.5	1.9
Marine Fauna due to transmission to water	Transmission of shock waves to water from land blasting adjacent to water.		No limit as such, though consider marine fauna watch if calculated values are an issue.	Ali Massey - Science leader	Calculation made as per Canadian Guidance and will be included in D&B Mgt Plan					
Land based fauna		Richard Philips raphil@bas.ac.uk	Not considered an issue - email 22.02.17, though any adverse effects should be monitored. This should include a check for Fauna immediately prior to blasting, including in the sea in the immediate vicinity of the blast area. Any disturbance to be reported immediatley. Include this check in the blasting protoo.	Richard Philips	Email sent to Richard Philips 21.02.17					

APPENDIX C:

EQUIPMENT LIST: ROTHERA WHARF

Antarctic Construction Partnership
EQUIPMENT LIST - Rothera Wharf
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Item No.	Plant Type	Project	Equipment
1	10	Rothera Wharf	Mobile RT Crane 45t Terex RT45
3	15	Rothera Wharf	Crawler Crane 250t Liebherr LR1250
4	15	Rothera Wharf	Crawler Crane 250t Liebherr LR1250
5	16	Rothera Wharf	Telescopic Handler 12m 4t
6	17	Rothera Wharf	MEWP Knuckleboom 18-20m
7	17	Rothera Wharf	EWP Knuckleboom 18-20m
10	19	Rothera Wharf	Rigging
11	19	Rothera Wharf	Timber Crane Mats 60nos, 5m x 1m x 150mm
31	22	Rothera Wharf	Flatbed articulated 40'
16	25	Rothera Wharf	Flatbed Trailer 20ft.
17	25	Rothera Wharf	Fuel Bowser With Pump 5000L
18	25	Rothera Wharf	Water Bowser 5000L
19	26	Rothera Wharf	Agricultural Tractor 4x4 73kW
22	27	Rothera Wharf	Gator, 4 nos. 4x6
23	31	Rothera Wharf	RIB Rescue Boat Spec. TBC
256	31	Rothera Wharf	Dory Workboat 20ft.
25	33	Rothera Wharf	Unifloat Pontoon (8Nos) 6.1x2.5x1.5m
27	40	Rothera Wharf	Cement Silos, drymix 30m3
28	40	Rothera Wharf	Concrete Silt Buster/ Settlement Tanks Spec. TBC
32	41	Rothera Wharf	Grout Mixing Plant Spec. TBC 410
39	41	Rothera Wharf	Batching Plant, dry mix 30m3/hr SAMI model Tecno 3-100
40	42	Rothera Wharf	ROV Spec. TBC
43	43	Rothera Wharf	Static Grizzly Screen 250mm
71	43	Rothera Wharf	Mobile Jaw Crusher - Sandvik QJ341
72	43	Rothera Wharf	Mobile Cone Crusher - Sandvik QH331
81	51	Rothera Wharf	Wheel Loader 3500L CAT 966
98	53	Rothera Wharf	Crawler Excavator 90t Caterpillar 390 OLR
107	53	Rothera Wharf	Crawler Excavator, 2 nos., 40t Caterpillar 345
108	53	Rothera Wharf	Crawler Excavator 20t Caterpillar
109	53	Rothera Wharf	Crawler Excavator 8t
103	55	Rothera Wharf	Smooth Roller? Bomag AD200
42	56	Rothera Wharf	Articulated Dump Truck 25t CAT 730
58	61	Rothera Wharf	Water Pump 75mm
142	61	Rothera Wharf	Water Pump 150mm
34	67	Rothera Wharf	Powerpack, for vibro hammer
148	68	Rothera Wharf	Hydraulic Hammer CAT390
149	68	Rothera Wharf	Hydraulic Hammer CAT345
151	70	Rothera Wharf	Generator 60kVA

Antarctic Construction Partnership
EQUIPMENT LIST - Rothera Wharf
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Item No.	Plant Type	Project	Equipment
153	70	Rothera Wharf	Generator 30kVA
154	70	Rothera Wharf	Generator 30kVA
155	70	Rothera Wharf	Generator 30kVA
158	71	Rothera Wharf	Diesel Lighting Units/ Light Towers 4kW
159	71	Rothera Wharf	Diesel Lighting Units/ Light Towers 4kW
160	71	Rothera Wharf	Diesel Lighting Units/ Light Towers 4kW
161	71	Rothera Wharf	Diesel Lighting Units/ Light Towers 4kW
162	71	Rothera Wharf	Diesel Lighting Units/ Light Towers 4kW
163	71	Rothera Wharf	Diesel Lighting Units/ Light Towers 4kW
164	72	Rothera Wharf	Diesel Welder 580A
165	72	Rothera Wharf	Diesel Welder 580A
166	72	Rothera Wharf	Inverter 350V
167	72	Rothera Wharf	Inverter 350V
168	72	Rothera Wharf	Inverter 350V
169	72	Rothera Wharf	Inverter 350V
170	72	Rothera Wharf	Wire Feeder/ or stick welding; tbc 400A
171	72	Rothera Wharf	Wire Feeder/ or stick welding; tbc 400A
172	72	Rothera Wharf	Wire Feeder/ or stick welding; tbc 400A
173	72	Rothera Wharf	Wire Feeder/ or stick welding; tbc 400A
175	72	Rothera Wharf	Wire Feeder/ or stick welding; tbc 400A
180	79	Rothera Wharf	Preheat Mats/ Electric Blankets
181	81	Rothera Wharf	Vibrating Hammer 40kgm PVE 40VM
183	86	Rothera Wharf	Drilling - Break Out Jaws 406mm Ritchies
184	86	Rothera Wharf	Drilling - Rotary head KH32 c/w mast slide
185	86	Rothera Wharf	Drilling - control panels
186	86	Rothera Wharf	Drilling - Scorpion
187	86	Rothera Wharf	Drilling - Oil Pump
188	86	Rothera Wharf	Drilling - Cube Moulds
189	86	Rothera Wharf	Drilling - Compressor
190	86	Rothera Wharf	Drilling - Air Receiver
191	86	Rothera Wharf	Drilling - Ringbit Consumables
192	86	Rothera Wharf	Drilling - casing Consumables
193	86	Rothera Wharf	Drilling - pilot Consumables
194	86	Rothera Wharf	Drilling - hammer Consumables
195	86	Rothera Wharf	Drilling - shock Abs Consumables
196	86	Rothera Wharf	Drilling - Drill rod Consumables
197	86	Rothera Wharf	Drilling - Cross over Consumables
198	86	Rothera Wharf	Drilling - adapter Consumables

British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

SWECO

bam

Antarctic Construction Partnership
EQUIPMENT LIST - Rothera Wharf
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Item No.	Plant Type	Project	Equipment
199	86	Rothera Wharf	Drilling - sava sub Consumables
200	86	Rothera Wharf	Drilling - lifting swivel Consumables
201	86	Rothera Wharf	Drilling - spanners Consumables
202	86	Rothera Wharf	Drilling - Inlet swivels Consumables
203	86	Rothera Wharf	Drilling - Blow down/back subs Consumables
204	86	Rothera Wharf	Drilling - Hammer Oil. Consumables
205	86	Rothera Wharf	Drilling - Thread Compound Consumables
206	86	Rothera Wharf	Drilling - Site Consumables Consumables
207	86	Rothera Wharf	Drilling - Grout Hose Consumables
208	86	Rothera Wharf	Drilling - Lifting Equipment Consumables
227	86	Rothera Wharf	Drill Rig 64-89mm Atlas Copco FlexiROC T35
231	90	Rothera Wharf	Workshop Container 20ft.
232	90	Rothera Wharf	Satellite Office 20ft.
233	90	Rothera Wharf	Satellite Office 20ft.
234	90	Rothera Wharf	Satellite Office 20ft.
101	91	Rothera Wharf	Fuel Tank, 4nos. 2250L
120	91	Rothera Wharf	8Yrd Skips
239	91	Rothera Wharf	Diving Equipment 20ft.
240	91	Rothera Wharf	Ablution Unit 10ft.
250	91	Rothera Wharf	Explosive Storage Container 20ft.
251	91	Rothera Wharf	Container Dome Shelter Workshop 20ft.
260	93	Rothera Wharf	Airshelter Heaters 5.5kW
261	93	Rothera Wharf	Airshelter Heaters 5.5kW
262	93	Rothera Wharf	Airshelter Heaters 5.5kW
266	93	Rothera Wharf	High Pressure Wash Spec. TBC
267	93	Rothera Wharf	High Pressure Wash Spec. TBC
268	93	Rothera Wharf	High Pressure Wash Spec. TBC
272	96	Rothera Wharf	Survey Equipment Leica T802 Total Station Spec. TBC
273	96	Rothera Wharf	Survey Equipment Total Station Spec. TBC
274	96	Rothera Wharf	Survey Equipment Theodolite Spec. TBC
275	96	Rothera Wharf	Survey Equipment Landmeter Spec. TBC
276	96	Rothera Wharf	Survey Equipment GPS Beacons Spec. TBC
288	99	Rothera Wharf	Diving Cage Spec. TBC
289	99	Rothera Wharf	Diving Cage Spec. TBC
Total	110		

APPENDIX D:

SITE WASTE MANAGEMENT PLAN: ROTHERA WHARF

Schedule C1 **Site Waste Management Plan**

NOTE: This model SWMP will be finalised prior to mobilisation to site.

This declaration is to be used in conjunction with and uploaded into BAM Smart – the web-based sustainability monitoring and reporting tool

Project reference	BAA.4001
Project title	Rothera Wharf
Client	Natural Environmental Research Council / British Antarctic Survey
Principal contractor	BAM
Site waste coordinator / Environment engineer	Neil Goulding
Contract value	
Address/location	Rothera Research Station, Rothera Point, Adelaide Island, Antarctic Peninsula.
Project description	Design and Build contract to extend the existing wharf at Rothera to accommodate the new research ship, the RRS Sir David Attenborough. The wharf wall is to be constructed using steel sheet piles which will be filled with locally quarried rock.
Document prepared by	Neil Goulding

Declaration:

We the client and principal contractor confirm that all reasonable steps will be taken to ensure that:

a) all waste from the site is dealt with in accordance with the duty of care in section 34 of the Environmental Protection Act and the Protocol on Environmental Protection to the Antarctic Treaty

b) materials will be handled efficiently and waste managed appropriately as per the BAS Waste Management Handbook (10th Edition)

Client:	Signed:
Principal contractor:	Signed:
Key subcontractor(s):	Signed:

This plan is reviewed at least every three months by the site waste coordinator and updated as necessary to ensure that waste management practices are in accordance with this plan.

Reviewed by	Date	Rev no.	Revision details (where applicable)

Introduction

This site waste management plan identifies and monitors:

- Legislative requirements for waste management
- Types and quantities of waste expected to be generated during the construction of Rothera Wharf.
- Reuse of materials on the project e.g. cut and fill, site won materials
- Waste minimisation methods to be implemented on the project
- Waste management options for waste generated during the works including waste generated by subcontractors
- Storage and disposal options for each waste stream
- Any cost savings achieved through waste minimisation

Materials identified within this SWMP are not necessarily statutory waste as they do not fall within the legal definition of waste i.e. 'any substance or object which the holder discards intends to discard or is required to discard.' There is no intention to discard materials such as:

- Site won excavated materials
- Pre-planned use of materials

All materials whether they are imported, reused 'as is' on site, recycled (on or off site) or sent off site for disposal are identified within the plan.

(See Appendix 1 for roles and responsibilities.)

Legislation

Antarctic Environmental Legislation

To ensure the protection of the Antarctic environment, the Antarctic Treaty nations adopted the Protocol on Environmental Protection to the Antarctic Treaty in 1991. The UK enforces the provisions of the Protocol through the Antarctic Act, 1994, the Antarctic Act 2013, and the Antarctic Regulations, 1995/490 (as amended).

Annex III: Waste Disposal and Waste Management

Annex III of the Environmental Protocol sets out regulations both for waste management planning and disposal of wastes (see Appendix 1). The Annex obliges all operators to reduce the quantity of waste produced and or disposed of in Antarctica in order to minimise any impact on the environment. Emphasis is placed on the storage, disposal and removal of waste from the Antarctic Treaty area, as well as recycling and source reduction.

As a contractor to BAS operating in Antarctica, BAM will comply with the requirements of Annex III by means of conditions attached to the BAS Operating Permit granted by the Foreign and Commonwealth Office.

Annex IV: Prevention of Marine Pollution

Within the Antarctic Treaty Area (south of 60° latitude) the discharge of all toxic and noxious chemicals, oil and oily wastes, plastics and other forms of non-biodegradable rubbish into the sea is prohibited. Annex IV largely parallels the international regulations controlling ship-generated pollution under MARPOL 73/78.

MARPOL 73/78

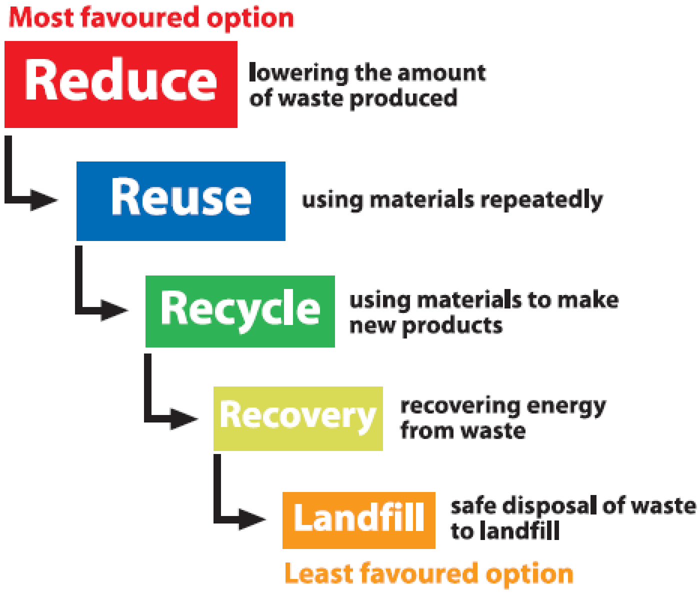
Since 1992, the Antarctic Treaty Area has been designated by the International Maritime Organisation (IMO) as a Special Area under Annex I (Oil) and Annex V (Garbage) of MARPOL 73/78 (Revised 2013). This means that the discharge of any oil or oily mixture, bulk chemicals or garbage from a ship is prohibited in Antarctica. Most waste, other than food and sewage, is discharged at port reception facilities outside the Special Area.

Whilst working in Antarctica, BAM will ensure that they or any of their subcontractors will meet the requirements of MARPOL 73/78.

UK Environmental Legislation

The Waste (England and Wales) (Amendment) Regulations, 2014

The Waste Framework Directive, which is the primary European legislation for the management of waste, is implemented through the Waste (England and Wales) (Amendment) Regulations 2014. It places great emphasis on the waste hierarchy to ensure that organisations deal with waste in the priority order of:



The waste hierarchy is partly implemented through the amended Duty of Care regulations.

The Duty of Care Regulations, 1991

Under the Environmental Protection (Duty of Care) Regulations, 1991, BAM is required to take all reasonable steps to keep its waste safe and secure so that it does not cause pollution or injury.

In particular, BAM must:

- Fulfil the legal requirement to apply the waste hierarchy.
- Ensure safe and correct packing and containment. This is of particular importance while the waste is in transit.
- Check that waste contractors are appropriately registered with the Environment Agency.
- Describe the waste on a Duty of Care transfer note so that the waste carrier can avoid committing an offence under the Regulations.

Failure to comply with the Duty of Care Regulations is a criminal offence, and could result in a fine of an unlimited amount. The Environment Manager is responsible for compliance with the Environmental Protection (Duty of Care) Regulations, 1991 with regard to wastes returned by BAM from Antarctica for disposal in the UK.

The Hazardous Waste Regulations, 2005

Hazardous wastes are amongst the most harmful and difficult wastes to deal with. The Hazardous Waste Regulations 2005 control the licensing, transfer and disposal of such waste in the UK.

Classification of our wastes as hazardous

- Correct separation and storage of hazardous waste
- Use of authorised businesses to collect, recycle or dispose of our hazardous waste
- Preparation of consignment notes for every movement of hazardous waste in the UK.
- Keep records for 3 years of all produced and stored waste

Materials resource efficiency

The following waste reduction and reuse measures have been included in the design and/or specification for this project and will be further developed as the design progresses:

Design specifications	The specification for the fill material of the new wharf has been designed to meet likely materials sizes from quarry works and existing wharf fill. This has enabled a larger proportion of the existing wharf fill to be recycled and will reduce the amount of waste material produced from quarrying. It is proposed to dry and grade the existing fill material to obtain maximum quantities that will meet the specification for re-use.
Choice of materials	The use of concrete in the structure has been actively designed out as much as possible. This was driven by the desire to reduce the risk of pollution from placing concrete in the marine environment, but will also reduce waste produced by mixing and pumping concrete on site. Concrete also has larger embodied carbon than the steel alternative.
Methods of construction	75% of existing fill material to be re-used in new wharf. This will reduce waste from the deconstruction of the existing wharf and reduce the requirement for quarried raw material in the construction of the new wharf. The design has sought to reduce the amount of preparation of the sea bed required for construction and has eliminated the original proposal for milling a trench underwater to fix the toe of the sheet pile wall in position. This has reduced the quantity of both recoverable waste and unrecoverable waste in the form of sediments. The method of constructing the new wharf with piles fixed to frames will allow for simple decommissioning and all materials used in the construction will be readily recyclable.
Pre-fabrication off site	Steel frames pre-fabricated and pre-assembled as much as possible off site Mooring points - concrete precast off site

THIS SECTION TO BE UPDATED AFTER FURTHER DESIGN WORK

Forecast of the types and quantities of waste

It is estimated that this site will produce the following types and quantities of waste: Tbc following development of design.

Excavation Waste

Type of Waste	EWC Code	Estimated Quantity Tonnes/(m^3)				Waste Management Action in Detail	Storage Arrangements
		Total	Re-Use	Recycle	Dispose		
Crushed Stone	17 05 04	27,750 (1,500)	27,750 (1,500)			75% to be re-used within the new wharf, remainder to be retained at Rothera and used within future projects	Stockpile

Construction Waste

Type of Waste	EWC Code	Estimated Quantity kg/(m^3)				Waste Management Action in Detail	Storage Arrangements
		Total	Re-Use	Recycle	Dispose		
Steel	17 04 05	20,000 (2.6)		20,000 (2.6)		Cut into manageable pieces. Returned to the UK for recycling	Skip or ISO Container
Concrete / Grout	17 01 01	12,000 (5.2)		12,000 (5.2)		Excess concrete will be crushed and re-used within the wharf or other Rothera projects	Stockpile
Cementitious Wash Water		20,000 (20)			20,000 (20)	Cementitious wash waters to be neutralised using carbon dioxide and solids filtered out before being discharged to the sea.	Skip or Siltbuster

Alkaline Batteries	20 01 33	2 (0.01)		2 (0.01)		Tape up terminals. Separate into the different types where practicable. Bag and labelled accordingly. Pack bags into separate sections of a plastic-lined UN nefab box filled with vermiculite. Paint the case yellow, stencil with green recycling triangle and mark the top and sides with the case number and "ASSORTED WASTE BATTERIES,	UN boxes 4GV or 4DV with tops and upper parts of the sides painted yellow
Clothing / Textiles	20 01 10	50 (≈1)		50 (≈1)		Stored in green FIBC marked "WASTE TEXTILES FOR RECYCLING" and returned to the UK	Green FIBC marked "WASTE TEXTILES FOR RECYCLING"
Cardboard	20 01 01	200 (0.3)		200 (0.3)		Broken down, baled and stored in green FIBC or palletised. Returned to the UK for recycling	Green FIBC or Pallet
Paper	20 01 01	50 (0.3)		50 (0.3)		Re-use on site for packaging where suitable. Placed in BAS recycling bins	BAS recycling bins
Timber	17 02 01	1000 (2)	500 (1)	500 (1)		Wood that can be used on station should be given to the Station Manager. Other wood is stored in wooden crates and marked "WASTE WOOD". Returned to the UK for recycling	Wooden crates and marked "WASTE WOOD"
Plastic	20 01 39	50 (0.05)		50 (0.05)		Compacted and stored in 205ltr drum marked with recycling logo and the word "PLASTICS". Returned to the UK for recycling.	205 ltr Drum marked with green recycling logo and "PLASTICS"
Oil	13 02 07	5000 (5)			5000 (5)	Store in 205 ltr drums painted yellow and marked "WASTE LUBRICANT" and with the recycling triangle. Returned to the UK for recycling.	205 ltr drums painted yellow and marked "WASTE LUBRICANT" and with the recycling triangle
Oil Filters	16 01 07	50 (0.1)			50 (0.1)	Empty oil filter and store in yellow 205 ltr drum marked "OIL FILTERS" and "UN 3077 Class 9 Environmentally Hazardous Substance, solid, n.o.s (oil filters)". Return to the UK for disposal.	Yellow 205 ltr drum marked "OIL FILTERS" and "UN 3077 Class 9 Environmentally Hazardous Substance, solid, n.o.s (oil filters)"

Oil Contaminated Rags	15 02 02	50 (0.2)			50 (0.2)	Store in 205 ltr drum painted yellow and labelled "WASTE RAGS, OILY". Allocate hazard class 4.2, UN no. 1856. Return to the UK for disposal	205 ltr drum painted yellow and labelled "WASTE RAGS, OILY"
Aerosols	16 05 04 16 05 05	10 (0.1)			10 (0.1)	Seal tops of aerosols with packing tape and place in a plastic lined UN approved case filled with vermiculite and painted yellow with the words "WASTE AEROSOLS" on the top and sides. Affix appropriate hazard labels and label the case UN no. 1950. Where possible aerosols with different hazard classes should be packed separately. If a case contains a mixture of aerosols with different hazard classes, then label with all relevant hazard	Yellow plastic lined UN approved case marked "AEROSOLS" with appropriate hazard class and UN no. 1950

All hazardous material will be stored in containers with suitable bunding to contain 110% of any liquids stored.

Domestic waste produced by BAM staff will be managed and disposed of by BAS

Demolition Waste

Type of Waste	EWC Code	Estimated Quantity Tonnes/(m^3)				Waste Management Action in Detail	Storage Arrangements
		Total	Re-Use	Recycle	Dispose		
Concrete	17 01 01	61 (26.5)	61 (26.5)			Crush and retain at Rothera for future re-use during modernisation works	Stockpile
Steel	17 04 05	550 (71)		550 (71)		Cut into manageable pieces. Return to the UK for recycling	Skip or ISO container

Management of waste

The production of waste material on this site during the construction phase is avoided wherever possible by following the '*reduce, reuse, recycle, recover*' measures outlined below. Only where these options have been exhausted is waste sent for disposal.

Reduction and reuse measures

BAM's target is to divert from landfill 90% of all waste and 80% of construction waste.

The following measures will be employed to reduce and reuse waste on this site:

General	
Reduction measures	**Reuse measures**
• Accurate measurement, and minimal wastage will be allowed when using materials	• All waste materials to be offered to the Research Station Manager for re-use within the station
• Materials are to be stored and transported correctly so as to avoid damage	
• All operatives are to receive training on the agreed reduction measures	
Concrete and hardcore	
Reduction measures	**Reuse measures**
• Accurate measurement, and minimal wastage will be allowed when batching cementitious materials	• Re-use of suitable fill material from existing wharf
• Cementitious materials are to be kept off the ground by the use of pallets or timber bites	•

Excavated material (soil & stones)	
Reduction measures	**Reuse measures**
• Trenches to be sheeted rather than battered to reduce excavated material	• Excavated soil and stone to stockpiled for future use on site
Timber	
Reduction measures	**Reuse measures**
THIS SECTION TO BE COMPLETED AFTER FURTHER PLANNING WORK	***THIS SECTION TO BE COMPLETED AFTER FURTHER PLANNING WORK***

Metals	
Reduction measures	**Reuse measures**
• Accurate seabed survey to be carried out to enable piles to be pre-cut to correct length.	• Re-use of steel elements from existing wharf for temporary elements of new construction
•	• All waste materials to be offered to the Research Station Manager for re-use within the station

Recycle and recovery measures

The following waste streams are to be segregated for recycling/ recovery off site:

Waste stream	EWC code	Storage option	Management option
Ferrous Metal	17 04 05	Orange Pallet or 205 ltr drum	Secured to pallet painted orange or in orange 205 ltr drum and returned to the UK for recycling
Timber	17 02 01	Wooden crates and marked "WASTE WOOD"	Wood that can be used on station should be given to the Station Manager. Other wood is stored in wooden crates and marked "WASTE WOOD". Returned to the UK for disposal
Paper	20 01 01	FIBC marked "PAPER" and with the recycling triangle.	Re-use on site for packaging where suitable. Store in FIBC marked "PAPER" and with the recycling triangle. Return to the UK for recycling
Cardboard	20 01 01	Green FIBC or Pallet	Broken down, baled and stored in green FIBC or palletised. Returned to the UK for recycling
Alkaline Batteries	20 01 33	Yellow UN nefab box	Tape up terminals. Separate into the different types where practicable. Bag and labelled accordingly. Pack bags into separate sections of a plastic-lined UN nefab box filled with vermiculite. Paint the case yellow, stencil with green recycling triangle and mark the top and sides with the case number and "ASSORTED WASTE BATTERIES, NON REGULATED". They do not require hazard labels under the IMDG code for shipping. Consign to the Environmental Manager in the UK.
Clothing / Textiles	20 01 10	Green FIBC marked "WASTE TEXTILES FOR RECYCLING"	Stored in green FIBC marked "WASTE TEXTILES FOR RECYCLING" and returned to the UK
Plastic	20 01 39	205 ltr Drum marked with recycling logo and "PLASTICS"	Compacted and stored in 205ltr drum marked with recycling logo and the word "PLASTICS". Returned to the UK for recycling.

Oil	13 02 07	Orange 25 ltr plastic container marked “WASTE LUBRICANTS” and with the recycling triangle.	Store in 25 ltr plastic containers painted orange and marked “WASTE LUBRICANT” and with the recycling triangle. Return to the UK for disposal.
Oil Filters	16 01 07	Yellow 205 ltr drum marked “OIL FILTERS” and “UN 3077 Class 9 Environmentally Hazardous Substance, solid, n.o.s.”	Empty oil filter and store in yellow 205 ltr drum marked “OIL FILTERS” and “UN 3077 Class 9 Environmentally Hazardous Substance, solid, n.o.s.”. Return to the UK for disposal.
Oil Contaminated Rags	15 02 02	205 ltr drum painted yellow and labelled “WASTE OILY RAGS”	Store in 205 ltr drum painted yellow and labelled “WASTE OILY RAGS”. Allocate hazard class 4.2, UN no. 1856. Return to the UK for disposal
Aerosols	16 05 04 16 05 05	Yellow plastic lined UN approved case marked “AEROSOLS”	Seal tops of aerosols with packing tape and place in a plastic lined UN approved case filled with vermiculite and painted yellow with the words “WASTE AEROSOLS” on the top and sides. Affix appropriate hazard labels and label the case UN no. 1950. If a case contains a mixture of aerosols with different hazard classes, then label with all relevant hazard classes. Return to the UK for disposal
Detergents and Disinfectants	20 01 30	In original bottles within a yellow UN approved case marked WASTE “DETERGENTS AND DISINFECTANTS”	Offer to Rothera Station Manager. If not required keep in original bottles within a yellow UN approved case marked WASTE “DETERGENTS AND DISINFECTANTS”. Return to the UK for disposal
Fluorescent Tubes	20 01 21	Store in original cardboard box within a polythene lined wooden box labelled “WASTE / FLUORESCENT TUBES”	Store in original cardboard box within a polythene lined wooden box labelled “WASTE / FLUORESCENT TUBES” and returned to the UK for disposal.

Packaging, Labelling, Transfer and Shipping Documentation

It is currently envisaged that BAM will charter ships for the disposal of waste arising from the wharf construction and deconstruction works. Should it be agreed that BAS ships are to be used for the removal of this waste, the packaging requirements set out in the BAS Waste Management Handbook will be adhered to.

It is essential that waste materials are securely packaged, are clearly marked and have the appropriate documentation attached. The following procedures should be followed to ensure consignments are safe for handling and are transported according to legal requirements.

Packing

<u>Containers</u>

A variety of containers are available for packing waste as listed in the table below.

Type of Waste	Container	Waste
Non-Hazardous Inert	Flexible intermediate bulk bags, (FIBCs) – with green recycling logo	Segregated dry recyclable waste (e.g. card, plastics, textiles etc.)
	NB FIBCs should not be used for general cargo	
	Clean 205 ltr drums	Plastic
	Pallets	Wood waste
	Skips	Scrap metal
Hazardous	Old 205 ltr AVTUR drums	Waste fuel (not petrol), lubes, oil and oily rags
	Old petrol drums	Only for waste petrol
	Wooden containers and crates (lined with plastic)	Fluorescent light bulbs and WEEE waste
	UN approved boxes	Batteries, aerosols and empty paint containers
	UN approved 25l, 30l or 60l metal and plastic drums	Waste chemicals

<u>Packaging Materials</u>

Packaging materials that have been sent in containers carrying items to bases should be reused as much as possible. For example:

- Vermiculite (for all liquids);
- Shredded paper;
- Bubble wrap; and
- Cardboard.

Packing Groups and UN Approved Packaging

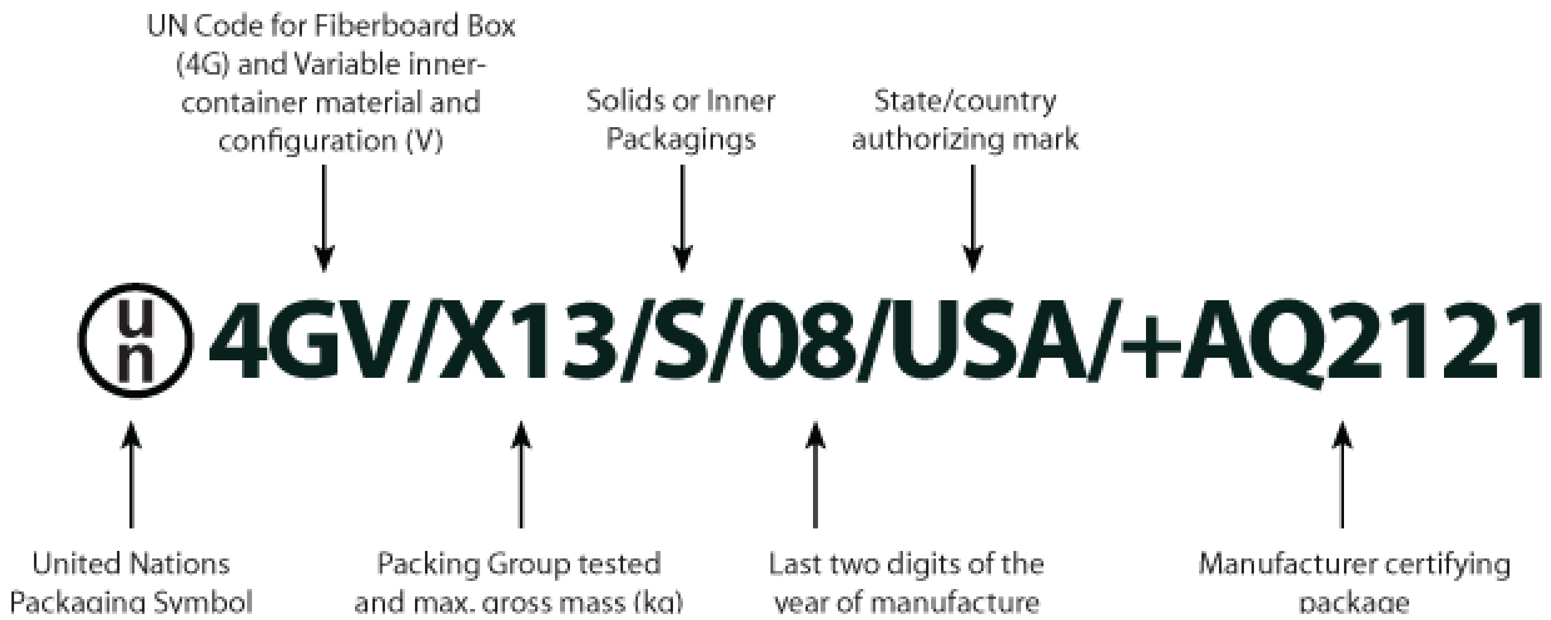
All hazardous waste must be packed in correct Group I, II or III packing containers (see Appendix 3). The packing groups are based on the degree of danger associated with the material.

- Packing Group I — Materials are highly dangerous
- Packing Group II — Materials are of medium danger
- Packing Group III — Materials are of low danger

All enquiries for general hazardous materials packaging and transportation should be directed Neil Goulding neil.goulding@bamnuttall.co.uk.

Packaging has to be designed and constructed to UN specification standards and must pass practical transport related tests such as being dropped, held in a stack and subjected to pressure demands. It must also meet the needs of the substance it is to contain. Packaging must be certified by a national competent authority. UN approved packaging is marked with the prefix 'UN' and followed by a series of codes representing; type of container, packing group, quantity of contents, year of manufacture, country of origin and certification of the package.

An example is shown below.



Packing Hazardous Waste

Liquids
Hazardous liquid wastes are generally transported in UN approved 25, 30 or 60 litre chemical drums. Check the drums for leaks and that the seals on caps are intact. Be particularly vigilant when using dented or rust-marked drums.

Solids
UN approved cartons or crates should be used to return solid hazardous waste or small bottles containing hazardous liquids.
All contents must be sealed in a heavy gauge plastic liners and sufficient vermiculite to protect the contents and absorb any spillage. Do not overload boxes or cases.

A copy of the Bill of Lading (BOL) *see shipping documentation*, sealed in a plastic wallet must be securely taped to the outside of any container containing hazardous wastes. The following should be considered when packing hazardous waste:
• previous hazardous cargo labels and markings must be removed or painted over (not just crossed out);
• do not paint over container dimensions or UN marking (shown above);
• all sides (except the bottom) of the package must be labelled;
• all sides (except the bottom) must have the appropriate hazard class labels; and
• top and upper part of containers should be painted yellow.

Manual handling

All waste is man-handled several times over, from when it is first disposed of and packaged on base, to being loaded onto chartered vessels in the Antarctic, offloaded in the UK, loaded onto waste contractor lorries and then offloaded at its final disposal point.

It is essential therefore to pack waste appropriately to avoid injury to those handling it. The following points should be considered by anyone involved in packing waste:

- FIBC's should be checked prior to being hoisted by crane onto chartered vessels to ensure that they do not contain sharp objects which may injure handlers or tear bags;
- Boxes and crates must be in good condition and not overloaded;
- Waste loaded onto pallets should be carefully packed to ensure there are no sharp edges and that protruding nails or screws are removed;
- Old fuel drums should be fully drained and wiped with absorbents to ensure no vapours or liquid remains;
- Drums should not be over-filled as they become too heavy for people to easily handle;
- When storing liquids in drums, space should be allowed for expansion at warmer temperatures; and
- Drums that have been fitted with a lid and ring clamp must not be lifted using drum lifting clamps; instead they should be netted when loaded by crane.

Storage

It is extremely important that waste ready for shipment is stored appropriately i.e. according to the hazard it may create. This could be inside the designated waste store, in an ISO container, or outside on the dockside. If waste is stored outside it must be secured in case of strong winds (in particular empty drums), and properly sealed to prevent ingress of water. Hazardous wastes must be kept in the designated storage facilities within the construction compounds. Drums should always be stored upright in designated waste stores on the stations and ships.

N.B. Lithium Batteries are a FIRE HAZARD when wet and must be kept dry at all times!

Labelling

Each consignment of waste must be appropriately colour coded and clearly marked with the type of waste it contains. In addition each consignment must have a BAS case number. See Section 4.3 Shipping Documentation for further details.
For hazardous waste the cases must also be marked on the outside with the following information:

- Proper shipping name (PSN)
- UN hazard class label(s)
- Flashpoint (if applicable)
- UN number

This information can be found listed in the 'Hazcheck' software tools used on BAS stations or from Neil Goulding neil.goulding@bamnuttall.co.uk.
As an example, a drum containing waste methanol/water mixture would be recorded as:
• ***waste methanol mixture (methyl alcohol) / water >70%***
• ***hazard class 3***
• ***flashpoint 20°C***
• ***UN No 1230***
If the waste has a primary hazard and a subsidiary risk then both hazard labels must be stuck onto the package.
The *Approved Carriage List* (Health and Safety Executive, 1994), available on stations and ships, contains a comprehensive listing of chemicals and hazardous substances.

Colour Coding

All containers carrying waste should be colour coded to reflect the final disposal location and waste contractor. For solid containers this will involve painting the tops and upper part of the sides of the unit. FIBC's are generally ready supplied with a colour code in the form of a green recycling logo on the side. **All old labels and hazard markings for any previous contents must be removed or painted over.**

Type of Waste	Colour Coding	Disposal Locations
Non-hazardous landfill	Blue	UK
Fuels and oils	Yellow with recycling logo	UK
Resale items	No colour	Locally or UK
Recyclables	Green plus recycling logo	UK
Hazardous waste, radioactive materials and other chemicals	Yellow	UK

Hazardous Wastes Classification

Hazardous wastes must be carried in accordance with the *International Marine Dangerous Goods (IMDG) Code*. This covers the carriage of dangerous goods at sea. It is the Chief Officer's responsibility to ensure that the regulations are followed on-board ship. Hazardous materials must be separated into nine different general classes based on the United Nations (UN) hazard classification.
The general classes and subclasses are as follows:

Hazard Class	**Class Description**
Class 1	Explosive
Class 2.1	Flammable gas
Class 2.2	Compressed gas (non-flammable, non-toxic)
Class 2.3	Toxic gas
Class 3	Flammable liquid *
Class 4.1	Flammable solid
Class 4.2	Spontaneously combustible
Class 4.3	Dangerous when wet
Class 5.1	Oxidising agent
Class 5.2	Organic peroxide
Class 6.1	Toxic
Class 6.2	Infectious substance
Class 7	Radioactive material
Class 8	Corrosive
Class 9	Miscellaneous substance
*** Packing Groups for flammable liquids:**	
I	Flammable liquids - flash point below -18°C
II	Flammable liquids - flash point -18°C up to +22°C
III	Flammable liquids - flash point +23°C up to +61°C

If chemicals of the same class are mixed a list should be attached to the container identifying the approximate volumes of each different chemical it contains.
NEVER mix substances with different UN hazard classes. This is highly dangerous.

Special attention must be given to ensure that oxidising agents (Hazard Class 5.1) are kept separate from other chemicals
Acids and alkalis (hazard class 8) are not to be packed in the same container. They must be clearly labelled in separate containers.

Shipping Documentation

What is a Bill of Lading (BOL)?

All waste sent out from BAS research stations and ships must be accompanied by an accurate Bill of Lading (BOL). BOLs are the principal documentation for waste removed from Antarctica. They are primarily used to ensure goods are loaded and transported appropriately and discharged in the correct location.
In addition the BOL's for waste are used to agree waste disposal contracts, verifying disposal invoices, auditing the waste management system and monitoring the quantity of waste that is produced in Antarctica. **Waste data has to be reported to the Antarctic Treaty Parties, HM Treasury, BAM Nuttall, NERC and the BAS Board.** It is therefore essential that the information provided on the BOL is complete, accurate and dated.

BOL's must be prepared by the person who is responsible for the waste, in conjunction with the Station Leader.

BOLs for major construction activity need to specify which project the waste originated from so that these records can be attributed to the correct project.

Each base has been provided with a pallet truck which has built in scales. Standard weights and volumes for use on BOL's are shown below. These should be used **only** in the absence of weighing or measuring facilities. **It is important that the weights and volumes are as accurate as possible.**

Waste	Volume (m^3)	Weight (kg)
205 litre drum – Empty	0.3	20
205 litre drum - Filled e.g. fuel, seawater (do not fill to the top - part fill only)	0.3	185
205 litre drum - Crushed	0.065	20
25 litre drum – Filled e.g. chemicals (do not fill to the top - part fill only)	0.04	30
ISO-container empty	25.0	As per tare plate on container
ISO-container full (crushed drums)	25.0	14,500
Skips	6	Dependent on contents
Small FIBC	0.5(max)	Dependent on contents
Large FIBC	0.75(max)	Dependent on contents

Completing a BOL
Examples of completed BOLs for both non-hazardous waste and hazardous wastes are shown at the end of this section.
The following information is required on all waste BOLs:
- Date
- Consignor
- Consignee
- Station/vessel generating waste
- Vessel used for transportation of waste
- Special stowage instructions (if applicable)
- BOL number

- Quantity and type of package
- Full description of contents
- Case/drum number (new number for each individual item)
- Case dimensions (cm)
- Weight (kg)
- Volume (m3) per item
- Estimated value (if applicable)

Submitting a BOL

Before loading waste onto a ship, the Station Leader must e-mail copies of the relevant BOLs to the Senior Shipping Officer at BAS, Cambridge and to the Chief Officer of the vessel taking the waste.

The Chief Officer must notify the BAS Logistics Co-ordinator of details of the incoming waste shipment.

The Senior Shipping Officer ensures that copies of the waste BOLs being consigned to the UK are provided to the Environmental Manager. The Environmental Manager then informs the contractor of the waste to be offloaded in the UK.

BOLs for hazardous wastes

A BOL must be prepared for each individual case/drum of hazardous waste. However, there may be times when large numbers of drums of identical size and content may be included together on one single BOL. Contact the Senior Shipping Officer in advance if you plan to include more than one drum on a BOL. The information listed in Section 4.2 must be included on a hazardous waste BOL. Please see the example BOL for hazardous waste Section 4.3.6.
All enquiries for general hazardous materials packaging and transportation should be directed to neil.goulding@bamnuttall.co.uk.

Project close-out review

This section of the plan is completed prior to the project close-out review, and discussed as part of the review meeting. The estimated quantities are drawn from the table in section 2, and reconciled against the actual quantities removed from site as detailed in BAM SMaRT.

Comparison of estimated and actual quantities

Actual waste quantities from BAM SMaRT. Will be issued upon completion

Source and type of waste	EWC Code	Estimated quantity of waste (tonnes)	Actual quantity of waste (tonnes)
Excavation waste			
Hazardous excavated material	17 05 03*		
Non-hazardous soil and stones	17 05 04		
Inert soil and stones	17 05 04		
Construction (skip) waste			
Concrete	17 01 01		
Mixed hardcore	17 01 07		
Timber	17 02 01		
Glass	17 02 02		
Plastic	17 02 03		
Mixed metals	17 04 07		
Other mixed construction waste	17 09 04		
Hazardous construction waste	Various		
Mixed municipal waste	20 03 01		
Demolition waste			
Concrete	17 01 01		
Bricks	17 01 02		
Mixed hardcore	17 01 07		
Timber	17 02 01		
Glass	17 02 02		
Plastic	17 02 03		
Mixed metals	17 04 07		
Other mixed demolition waste	17 09 04		
	Totals	0	0
		Difference	0

Delete / add waste streams as appropriate by double clicking on this table.

Explanation of any deviation from the original plan

N/A

Appendix 1 Roles and responsibilities

The Employer's Representative will:

- Appoint a Principal Contractor
- Provide the Principal Contractor with details of all decisions taken before the site waste management plan was drafted on the nature of the project, its design, construction method or materials employed in order to minimise the quantity of waste produced on site
- Ensure a construction phase SWMP is produced

The agent for the Principal Contractor will:

- Ensure the SWMP for the construction phase is produced, and distributed to all staff and subcontractors
- Ensure that within three months of project completion:
  - that the plan has been monitored on a regular basis
  - section 5.1 is completed comparing estimated quantities with actual
  - section 5.2 is completed to explain any deviation from the plan
  - section 5.3 is completed to estimate the cost saving that have been achieved
- Keep a copy of the SWMP for a minimum of two years after project completion

The site waste co-ordinator / environmental engineer for the Principal Contractor will:

- Produce the construction phase SWMP prior to works starting on site in conjunction and agreement with the client
- Obtain from the client details of all decisions taken before the site waste management plan was drafted on the nature of the project, its design, construction method or materials employed in order to minimise the quantity of waste produced on site, for inclusion in the construction phase SWMP
- Keep a copy of the SWMP on site and display in suitable locations for information
- Review the plan monthly and update where necessary to accurately reflect progress
- Ensure the following waste data is recorded within BAM SMaRT when any waste is removed from site:
  - a description of the waste, including the 6 figure EWC code
  - the name of the company collecting the waste (waste carrier)
  - the site where the waste is being taken to (waste destination)
  - the quantity of the waste and whether it was;
  - reused on site
  - taken for reuse at an exempt or standard permit site

- taken to a transfer station for segregation and onward recycling
- taken to a dedicated recycling facility
- sent to landfill (only if all other options have been discounted)

- Ensure details of recycling figures for the transfer stations used within the region are obtained and entered onto BAM SMaRT on a quarterly basis
- Ensure details of all waste carrier registration numbers, environmental permit numbers and exemption references for the carriers and disposal sites used within the region are checked and sent to the area environment advisor for input onto BAM SMaRT

APPENDIX E:

BIOSECURITY PLAN: ROTHERA WHARF

Antarctic Construction Partnership – Rothera Wharf			
Employer	NERC/British Antarctic Survey	Project Number	BAA4001
Tech Adv	Ramboll	Document Number	BAA4001-BAM-ZZ-YYY-RC-YE-0002
Contractor	BAM Nuttall	Revision	P-05

Rothera Wharf Biosecurity Plan

Reference Sheet

Document Number	Description
BAS	Biosecurity Handbook

Revision History

Revision	Date	Revision Description
P-05	10-01-18	Addition of signature box on checklists and break bulk checklist
P-04	13-12-17	Incorporating Further BAS comments
P-03	17-11-17	Incorporating BAS comments at CEE review
P-02	06-06-17	Incorporating BAS comments
P-01	10-03-17	First Draft

Prepared by	Checked by		Approved by
NDG			
Author	Project	Corporate / Area Process Owner	Project Manager

Status Definition (latest revision)	Total number of pages (including attachments)
For Issue	19
	0.17

Uncontrolled when printed, unless stamped in RED to the contrary.

Table of contents

1. Introduction

Many plant and animal species have been moved around the world through human activities to areas they would not reach naturally. Once in a new location, these 'non-native' species may establish, with potentially severe impacts on local species and ecosystems. The Antarctic continent currently has few confirmed non-native species, but numbers are increasing. Future increases in human presence in the Antarctic region, either through tourism, governmental operators or other commercial activities, will increase the risk of further non-native species introductions. At the same time, climate change may increase the chances of non-native species establishment and range expansion.

The Antarctic Act (1994, amended 2013) legislates to minimise the risk of non-native species introductions in the Antarctic, and BAM is obliged to conform to this legislation.

BAMs projects in the Antarctic cover several locations of distinct biological diversity. It is essential that all necessary precautions are taken to prevent the introduction of non-native species to Rothera Point and the surrounding area from other locations, including Europe, South America or any of the other BAS Research Stations or logistics hubs.

This document provides guidance to BAM personnel on the measures to be taken when moving plant, materials or personnel to Rothera Research Station.

1.1. Prohibited Items

No BAM personnel or their subcontractors will be permitted to take any of the items below to the Antarctic:

- Any living plant, animal or microorganism.
- Non-sterile soil or compost.
- Any plant propagules (e.g. seeds, bulbs, cuttings) or invertebrate eggs (e.g. brine shrimp or sea monkey eggs).
- Untreated wood where bark remains attached.
- Any perishable foods including fruit, vegetables, cheese, fish or meat in personal cargo (no personal foods are allowed but fresh foods as part of the construction team food supply will be arranged).
- Packing materials of polystyrene beads or chips, used sacking, hay, straw, chaff or wood shavings.

1.2. Roles & Responsibilities

- Environmental Lead – Neil Goulding, neil.goulding@bamnuttall.co.uk - 07770 223441
    - Overall responsibility for environmental management of the project.
    - Ensuring that the designers, buyers and construction team are aware of the biosecurity issues covered in this document.
    - Nominating and training of biosecurity inspectors.
    - Training of the Environmental Engineer
    - Answer any queries or questions from BAM staff on environmental or biosecurity issues.

- Project Manager – Martha McGowan, Martha.mcgowan@bamnuttall.co.uk – 07557 633546
    - Responsible for all construction works including mobilisation and demobilisation
    - Appointing an Environmental Engineer from within the site team.

- Ensuring cargo is biosecure before off loading at Rothera

- BAM Environmental Engineer: TBC (appointed from within the Rothera construction team on site)
    - Responsible for managing and monitoring the environmental performance and biosecurity measures on site.
    - Responsible for managing the Biosecurity Inspectors on site.
    - Carries out all final biosecurity inspections before cargo is offloaded from the ship to Rothera
    - Completes the relevant biosecurity checklists (Checklists 2, 3, 4, 5 and Form 1)
    - Reports to the BAM Environmental Lead

    - BAM Biosecurity Inspectors: TBC (at least one member of the Rothera construction team and at least one BAM staff member responsible for checking cargo at packing and loading stages in the UK and other gateways)
    - Responsible for ensuring that all plant and materials are thoroughly inspected and pose no biosecurity risk.
    - Responsible for completing the relevant biosecurity checklists (Checklists 2, 3, 4, 5)
    - Inspections will be required at all port where materials are loaded
    - Report to the BAM Environmental Lead unless at BI in which case reports to the Environmental Engineer

- All BAM Personnel
    - Personnel will be responsible for ensuring that there personal belongings are biosecure and do not contain any prohibited items.

2. Pre-departure Biosecurity

2.1. Personal Biosecurity

- Immediately before leaving home for Rothera, BAM personnel should ensure that all outer clothing has been washed, at the hottest temperature suitable for the garment, to remove seeds, soil and other propagules. Particular attention should be paid to Velcro, gaiters, pockets, turn-ups in trousers and hoods of jackets. (Please see Appendix A. Checklist 1).
- Footwear should be cleaned (inside and out) to remove soil, seeds or any other plant material.
- Personal clothing and equipment shall also be checked on the ship prior to arrival in Antarctica (see section 3.2 and 6.1.1).
- Avoid picking up soil, seeds and other propagules on your clothing during travel to Antarctica (i.e. be careful to ensure clothing is clean after walking in the countryside in any South American countries or South Atlantic gateways prior to departure)
- If possible, before entering Antarctica wear new items of outer clothing which will be free of non-native species and propagules.
- If moving between BAS stations please check clothing and personal belongings to prevent transport of biological material between sites (especially from South Georgia station to Antarctic locations).
- Ensure all clothing and personal effects are packed indoors in a clean environment.
- Before handing in any personal items to the BAM Logistics Stores in the UK, Netherlands or Chile for transportation to Antarctica, ensure that they are clean and free of soil and propagules.

2.2. Cargo Packing Areas

Plant and materials bound for the Rothera Wharf project will be loaded onto ships at Rotterdam, Southampton or Punta Arenas. Logistic centres will be established close to the ports for storing plant and material before loading onto vessels. The following biosecurity measures will be adopted for cargo packing areas (Please see Appendix A. Checklist 2).

- Cargo packing and storage areas shall be deep cleaned prior to the commencement of use by BAM and, thereafter, at least once per year or as deemed necessary.
- Internal and external cargo storage and packing areas shall be free of weeds, plants and invertebrate infestations. (i.e. regular spraying of weeds that emerge on hard standing).
- Any pallets stored outside shall be checked for bird nests before use, and if found should be removed and the pallet cleaned.
- Rodent and insect pest control measures will be in place in cargo packing and storage areas (i.e. regularly inspected sticky traps for insects and bait boxes for rodents).
- Store doors are to be kept closed, whenever possible.
- Cargo will be stored inside, where possible.
- Shipping containers should be stored on concrete surfaces (as opposed to bare earth). If containers are not stored on hard surfaces, additional checks shall be made to ensure they are free from soil and biological material prior to on-ward transportation.

2.3. Packaging

The following packaging materials are prohibited:

- No used meat, fruit or plant product cartons will be reused.

- No polystyrene beads or chips, soil, moss, used sacking, hay, straw, chaff or wood shavings will be used.

The following packaging types are acceptable:

- Reusable packaging (e.g. reusable Nefab boxes or aluminium or plastic trunks) as long as it is new or has been inspected and thoroughly cleaned (preferably with disinfectant) prior to repacking.
- All packaging containers (boxes, Nefab, trunks etc.) shall contain an internal sealed plastic liner and all containers shall be taped and sealed shut on all sides.
- Packaging and filling materials may include shredded paper, vermiculite, bubble wrap and other air-filled cushioning materials.
- Wood packaging (such as cases, crates, dunnage, pallets and timbers for the purpose of bracing, separating, protecting or securing cargo) as long as it is new and complies with the International Standards for Phytosanitary Measures No. 15 (ISPM 15).
- Where other cost-effective options exist, use of corrugated card board boxes should be minimized, as they may carry non-native invertebrates within the corrugations.

2.4. Break Bulk Cargo

Break bulk cargo may present a more substantial biosecurity risk than containerised cargo, therefore, it is important that the amount of break bulk cargo generated is kept to a minimum. Break bulk cargo can vary greatly in shape, size and type (e.g. construction materials, timber, scaffolding poles, etc.). All break bulk cargo must be clean and free of soil and biological material before loading on the ship. Therefore, all items of break bulk cargo, including packaging, shall be visually inspected for signs of rodent gnawing or rodent ingress. Cargo shall also be checked for any soil or biological material and if found the item shall be cleaned. During off loading, a nominated BAM staff member will check the item against the manifest and then allow it to be transported to the station. If a biosecurity issue is noted, the cargo shall not be off-loaded until this issue is resolved.

2.5. Small Plant & Tools

Prior to packing any previously used small tools or small plant items for transport to, or between, Antarctic Research Stations, the following procedure is to be followed. The high levels of cleanliness apply to all mechanical plant and tools, irrespective of size; however, individual hand tools do not need to be listed separately in the Appendix A. Biosecurity Checklist 3 Small Plant and Tools.

- Plant items are to be placed on a clean concrete or asphalt hard standing.
- Plant is to be cleaned externally using high pressure steam or hot water to ensure that no soil, mud or biological material is left on the items. Where the use of water is not possible, the item will be cleaned using a combination of hard and soft brushes and/or a damp cloth.
- Following cleaning, small tools and plant are to be inspected by a nominated Biosecurity Inspector to ensure that they are free of visible soil and biological material (e.g. plant fragments, seeds and insects) This information is to be recorded for auditing purposes (Please see section Appendix A. Checklist 3)
- Care should be taken not to contaminate the small tools and plant prior to loading onto the ship or aircraft. Plant storage facilities should minimise the potential for recontamination of cleaned small plant and tools to transport and, if necessary, arrangements should be made to thoroughly clean the small plant and tools at the ship or aircraft loading site.
- Immediately before being loaded onto the ship or aircraft for transportation, all small tools and plant should be checked by a nominated Environmental Engineer to ensure they are free of soil and biological

material. If any soil or biological material is found, the contaminated item should be cleaned and re-inspected before being transported.

2.6. Vehicles & Large Mechanical Plant

Mechanical plant (particularly tracked vehicles) pose a high risk to biosecurity. The undercarriage of wheeled or tracked plant can pick up soil which could contain plant fragments, seeds, invertebrates or invertebrate eggs.

Prior to loading any item of large mechanical plant for transport to or between Antarctic Research Stations, the following procedure is to be followed (Please see Appendix A. Checklist 4):

- Plant items are to be placed on a clean concrete or asphalt hard standing.
- Plant is to be cleaned externally using high pressure steam or hot water to ensure that no soil, mud or biological material is left on the vehicle, including the wheels, wheel arches, tracks and areas underneath the vehicle. Plant accessories, such as forks and buckets, should be cleaned in a similar manner.
- Where the plant has a cab, upholstery and mats should be brushed and/or vacuum cleaned to remove any soil or biological material.
- Following cleaning, plant is to be inspected by a nominated Biosecurity Inspector to ensure that they are free of visible soil and biological material (e.g. plant fragments, seeds and insects).
- Care should be taken not to contaminate the plant prior to loading onto the ship or aircraft. Plant storage facilities should minimise the potential for recontamination of cleaned vehicles prior to transport and, if necessary, arrangements should be made to thoroughly clean the vehicles at the ship or aircraft loading site.
- Immediately before being loaded onto the ship or aircraft for transportation, all vehicles should be checked by a nominated Biosecurity Inspector to ensure they are free of soil and biological material. If any soil or biological material is found, the contaminated vehicle should be cleaned and re-inspected before being transported.
- Motorised plant is to have its engines started before loading, to ensure rats and mice are not living in the engine compartments.

2.7. Construction Materials

The following section does not constitute a complete list of the construction materials but simply identifies the materials considered to pose the highest biosecurity risk and details the specific measures to be taken.

2.7.1. Aggregates

Aggregate is defined as any course particulate material used in construction, including sand, gravel, crushed stone, boulders, pebbles or slag. It presents a biosecurity risk because biological material such as seeds, soil and invertebrates can easily become entrained during production and transport.

- Aggregate to be obtained from marine sources.
- To prevent seed contamination during storage and transport aggregate must be contained in clean sealed packaging (such as FIBCs).
- Packaged aggregate will be transported in clean ISO containers.
- Aggregate must be carefully handled to prevent damage to the packaging.
- Only the minimum amount of aggregate needed for the project will be sent to the site.

- All aggregate will be used as quickly as possible after delivery to the site to reduce the risk of establishment of any non-native species present in the aggregate.
- Aggregate must be stored in a defined area at the construction site. Any spilled aggregate must be cleaned up immediately and contained within packaging, until used.
- Aggregate will be stored in its sealed packaging at the site and will not be left open to the environment.
- When aggregate is removed from its packaging for use, it must be used as soon as possible.
- Aggregate must be encapsulated as a component of concrete, or buried so that propagule release is not possible.

In the event that one or more of these management steps are not possible, further consultation with the BAS Environment Office must take place. Consultation with the BAS Environment Office must occur prior to any aggregate being purchased from suppliers.

2.7.2. Timber

Timber will be required as a construction material and required for packaging materials. Due to the risk of infestation by pests the following precautions must be observed before timber can be imported to Antarctica:

- Timber materials must be heated in accordance with a specific time–temperature schedule that achieves a minimum temperature of 56 °C for a minimum duration of 30 continuous minutes throughout the entire profile of the wood (including at its core).
- All timber products are to be inspected for signs of wood borrowing animals such as wood boring beetles and woodworm (a beetle larvae) before being shipped.
- If any evidence wood burrowing animals is discovered the timber must be treated with a pesticide or fumigated in a sealed container.
- All packaging timber should conform to the requirements of International Standards for Phytosanitary Measures No. 15 (ISPM 15) and be stamped with IPPC logo, country of origin and method of treatment.

2.7.3. Sheet Piles

Whilst sheet piles have relatively smooth faces, when stacked large voids are produced which are hard to inspect, particularly when using long piles. Checks shall be made by a BAM staff member when packing and shipping these materials to ensure that no invertebrates or their eggs are hidden between the sheets.

2.7.4. Scaffold Tubes

Scaffold tubes will be used for temporary works such as handrails to the wharf. The hollow section forms an ideal place for invertebrates to hide from predation. Scaffold tubes shall be cleaned using a pressure washer, taking care to clean any invertebrates or their eggs from the inside of the tubes.

2.8. ISO Containers

Prior to loading any ISO or other sealed container for transport to or between Antarctic Research Stations, the following procedure is to be followed.

- Shipping containers are to be stored on concrete surfaces (as opposed to bare earth).
- Shipping containers are to be kept clean and free of soil, mud, spiders' webs, invertebrates, debris, wood fragments (e.g. from pallets) and plant material. A record shall be kept of this inspection for auditing

purposes (Please see Appendix A. Checklist 5). If deemed necessary by the nominated Environmental Engineer, containers shall be washed inside and out before being sent to Antarctica.

- Prior to being sealed for the last time before being sent to Antarctica, containers (except those containing fresh foods) shall be fumigated using a single-use pyrethrum fogger, to eradicate any invertebrates within.

2.9. Fresh foods

Provisions for biosecurity measures associated with fresh foods have not be detailed in this document, as all fresh foods for BAM personnel will be supplied by BAS

3. In-transit Biosecurity

3.1. Ships

Any ship chartered by BAM for the transport of cargo and personnel must meet the following biosecurity measures and evidence needs to be provided to BAS that the following biosecurity requirements are included in the contract:

- All ships must have a Ship Sanitation Certificate (SSC).
- All ships must conform with Resolution MEPC.163(56) Guidelines For Ballast Water Exchange In The Antarctic Treaty Area.
- All ships shall have rodent boxes with poison bait that are inspected before, during and after each port visit.
- Insect sticky traps should be placed in food storage areas, and replaced when necessary.
- Electric UV insect killers shall be used in food storage areas.
- Biosecurity inspections of all ship and Antarctic station cargo shall be undertaken prior to loading and off-loading. (Please see checklists 3, 4, and 5)

3.1.1. When in Port

- Ships must have rat guards on the mooring lines.
- The gangway shall be lifted at night, or if lowered, lit with flood lights. An ultrasonic rat deterrent must be available and switched on.
- External doors and windows should be closed, wherever possible, to minimise the attraction of insects onto the ship.
- Boot/shoe washing facilities must be made available at the gangway to allow boot/shoe washing ON and OFF the ship.
- The inside of the tenders shall be cleaned between each landing to remove soil and other biological material knocked off passengers' boots.
- It is important that the boots and clothing of those arriving in Antarctica by ship is adequately cleaned before disembarkation. At a suitable interval before the arrival date, BAM should inform landing personnel and crew that clothing must be cleaned to remove soil, seed and other propagules. Spot check shall be undertaken to ensure compliance.
- Just prior to disembarkation at locations in Antarctica, all footwear must be cleaned in disinfectant (e.g. Virkon S).
- Disinfectants can become ineffective over time, or if contaminated excessively with soil or organic material. Therefore, disinfectant solutions provided for footwear cleaning shall be changed regularly (at least once per week), and a specific individual assigned this task as part of their duties.

3.2. Cargo Inspection Pre-offload

3.2.1. Cargo Boxes and Break Bulk

All items of break bulk cargo, including packaging, shall be visually inspected by the Biosecurity Inspector for signs of rodent gnawing or rodent ingress. They shall also be checked for any soil or biological material and if found the item shall be cleaned. Once these checks are complete and the item is biosecure, a nominate BAM staff member will check the item against the manifest and then allow it to be transported to the station. If a biosecurity issue is noted, the cargo shall not be off-loaded until this issue is resolved.

3.2.2. Vehicles and Large Mechanical Plant

All vehicles must be inspected before off-loading and a record of this made (Please see Appendix A. Checklist 4). If contamination is found, further cleaning must be done before off-loading.

3.2.1. ISO Containers

ISO containers shall be inspected externally for soil, plant material and invertebrates prior to off-loading. Details of the check shall be kept for auditing purposes (Please see Appendix A. Checklist 5)

4. Biosecurity on Arrival at Rothera

4.1. Personnel Disembarkation

- Personnel disembarking at Rothera Point or elsewhere in Antarctica or South Georgia must adequately clean their clothing, personal belongings and boots before they leave the ship and upon returning to the ship (see Appendix A: Biosecurity Checklist 1. Personal Biosecurity).
- Clothing and personal belongings (such as bags, camera cases etc.) must be checked for biological material at a suitable time before arrival - remove any seeds, soil and other propagules found whilst still on the ship. Check Velcro, gaiters, pockets, turn-ups in trousers and hoods of jackets.
- Boots must be inspected and cleaned and any soil or seeds removed before arrival at Rothera Point.
- All personnel must use the boot washing facilities (provided by the vessel) at the gangway to disinfect their footwear before disembarkation.

4.2. Inspection of Cargo

External surfaces shall be checked to ensure cargo items are free of soil, biological material and signs of gnawing, or other routes of rat ingress. Those opening ISO containers upon arrival, should stay vigilant for signs of live invertebrates. If found, these invertebrates should be eradicated immediately.
When opening cargo boxes, remain vigilant for imported soil or biological material.

4.3. Aggregate

- On arrival at Rothera Point, aggregate should be contained in sealed packaging and stored in a demarked area (preferably hard standing/concrete or on a tarpaulin.
- If aggregate is to be used in concrete, this should be done at a designated concrete batching area and then the concrete moved out to the site where it is to be used

4.4. General Awareness

When on station all personnel shall remain vigilant for any indications of:

- biosecurity breaches
- evidence of non-Antarctic soil importation
- non-native species colonisation, including within buildings
- rats or rodents

If in doubt, personnel should report any potential issues to the BAM Environmental Lead, who will assess the situation and, as appropriate, take any immediate action and complete and submit an AINME report.

5. Non-conformances

- All biosecurity breaches and near misses should be reported to the BAM Environmental Lead, the BAM Project Manager, the BAS Station Leader and the BAS Environment Office at the time of the incident.

- A near miss/environmental incident report must be produced and provided to the BAS Station Leader for inclusion in the Accident, Incident, Near-Miss and Environment (AINME) Reporting System as soon as relevant information is available and at most within 48 hours.

- Examples of biosecurity breaches may include, but are not limited to, the following:
    - Non-Antarctic soil or biological material (e.g. weeds) found on vehicles or other plant after unloading at Rothera
    - Live insects within cargo
    - ISO containers with soil or biological material on the interior and exterior surfaces
    - Any rodent sighting or any evidence of rodents (gnawing, etc.)
    - Failure to clean items delivered to station
    - Failure for biosecurity measures to be performed at appropriate stage of the supply chain
    - Failure for personnel to adequately clean their clothing or personal equipment.
    - Unintentional or deliberate importation of soil or biological material by BAM staff.
    - Importation of wood with bark still attached.
    - Failure for appropriate biosecurity checks of cargo packing areas to be performed.

Appendix A: Biosecurity Checklists

Biosecurity Checklist 1. Personal Biosecurity

(Pre-departure and pre-arrival for individuals going to Antarctica)

This checklist will be circulated to all BAM personnel prior to their deployment to Antarctica and is intended as a guide to assist individuals in undertaking their own biosecurity checks before travelling south.

Non-native species are those species that do not occur naturally in an area, but have been introduced by human activities, either intentionally or unintentionally. Unpermitted importation of non-native species is a breach of UK legislation and is in contravention of the Environmental Protocol and could lead to serious consequences for the responsible individual and BAM, including up to two years imprisonment and/or an unlimited fine.

Use the following checklist to reduce your risk of importing non-native species:

Personal Biosecurity Checklist	✓
All clothing is either new (i.e. straight out of the packet) or has been washed to remove plant seeds, invertebrates and soil (*Tip: check any Velcro® is clean and pay particular attention to pockets!*)	
All footwear has been scrubbed free of all plant seeds, invertebrates and soil (*Tip: check under the insole and tongue too!*)	
All bags and personal equipment have been cleaned, washed and/or vacuumed and are free of plant seeds, invertebrates and soil.	
All personal recreational equipment (including climbing gear, walking poles, ski and snow board equipment, kiting equipment and bicycles) has been cleaned and is free of soil and biological material.	
The following items have NOT been packed:	
• Any living plant, animal or microorganism - unless in possession of an appropriate permit	
• Non-sterile soil or compost	
• Any plant propagules (e.g. seeds, bulbs, cuttings) or invertebrate eggs (e.g. brine shrimp or sea monkey eggs) - growing plants and animals in Antarctica and South Georgia is NOT permitted	
• Untreated wood where bark remains attached	
• Any perishable foods including fruit, vegetables, cheese, fish or meat.	
You have explained the above restrictions to any person that is likely to send gifts or packages to you while in South Georgia or Antarctica.	

Biosecurity Checklist 2. Cargo Packing Areas

For each Cargo Packing Area that BAM utilises, a weekly checklist will be completed (for the duration of the packing period). The checklists will be stored on file and made available for auditing purposes either by BAM or by BAS personnel.

Weekly Cargo Packing Area Biosecurity Checklist	**Yes/No**	**Date checked**	**Any subsequent action or other notes**
Site is free of weeds and vegetation[1]			
Site is free of wind-blown seeds (e.g. from dandelions)			
Site is free of invertebrate infestation			
Site is free of rodents			
Rodent bait boxes are charged with poison bait[2]			
Insect sticky traps are present and still effective[3]			
Storage area doors are kept closed as much as possible			
Pallets and packing materials are kept inside in a clean area			
ISO containers are stored on hard standing			

[1]Regular use of herbicides may be required
[2]Using the AINME system, provide details of any rodents caught in bait stations.
[3]State the date when the insect sticky traps are replaced (typically every 2 months)

Biosecurity Checklist 3. Small Plant & Tools

All small plant and tools that have been used on jobs in other parts of the world shall be cleaned and checked prior to being sent to Antarctica.

Checks prior to off-loading shall be simple visual checks as described for all general cargo. If for some reason any checks are not possible at any stage of the supply chain, please note details of the circumstances here and report using the AINME system. Individual hand tools do not need to be listed separately using this checklist, but do need to be free of soil and biological material before transfer to Rothera. The checklists will be stored on file and made available for auditing purposes either by BAM or BAS personnel.

Small plant/tools identification details:		
Details of journey initial and final destinations (e.g. UK to Rothera, or Rothera to KEP):		
Transporting vessel (e.g. RRS Shackleton):		
Name (print) and Signature of Inspector		
Post-cleaning check	**Date completed**	**Notes (including details of any associated AINME reporting)**
Exterior surfaces (top and side)		
Exterior underneath surfaces		
Interior surfaces (as possible)		
Insect spray in crevices (as possible)		

Small plant/tools identification details:		
Details of journey initial and final destinations (e.g. UK to Rothera, or Rothera to KEP):		
Transporting vessel (e.g. RRS Shackleton):		
Name (print) and Signature of Inspector		
Post-cleaning check	**Date completed**	**Notes (including details of any associated AINME reporting)**
Exterior surfaces (top and side)		
Exterior underneath surfaces		
Interior surfaces (as possible)		

Small plant/tools identification details:		
Details of journey initial and final destinations (e.g. UK to Rothera, or Rothera to KEP):		
Transporting vessel (e.g. RRS Shackleton):		
Name (print) and Signature of Inspector		
Post-cleaning check	**Date completed**	**Notes (including details of any associated AINME reporting)**
Exterior surfaces (top and side)		
Exterior underneath surfaces		
Interior surfaces (as possible)		

Biosecurity Checklist 4. Vehicle & Large Mechanical Plant

Mechanical plant (particularly tracked vehicles) pose a high risk to biosecurity. The undercarriage of wheeled or tracked plant can pick up soil which could contain plant fragments, seeds, invertebrates or invertebrate eggs.

The following checklist and the procedures listed in Section 2.6 of this document will be followed to ensure vehicles and large mechanical plant arrive in Antarctica and/or the sub-Antarctic free of soil and biological material. If these checks are not completed at any stage of the supply chain, please note details of the circumstances here and report using the BAS AINME system

A checklist for each vehicle or plant consigned to Rothera will be stored on file and made available for auditing purposes either by BAM or by BAS personnel.

Vehicle model and identification details:		
Details of journey initial and final destinations (e.g. UK to Rothera, or Rothera to KEP):		
Transporting vessel (e.g. RRS Shackleton):		
Name (print) and Signature of Inspector		
Post-cleaning check: remain vigilant for mud, soil, debris, plant material, webbing or live spiders, other invertebrates or signs of rodents	**Date completed**	**Notes (including details of any associated AINME reporting)**
Vehicle exterior (top and sides)		
Vehicle wing mirrors and windscreen		
Vehicle exterior (underneath)		
Wheels and wheel arches		
Vehicle interior (including under floor mats, door pockets, down the sides and below the front seats, the boot/trunk, and under the spare tyre).		
Vehicle accessories (forks, buckets, etc.)		
Engine started to ensure no rodents/birds in vehicle interior		

Use insecticide spray in crevices where possible		
Name (print) and Signature of Inspector		
Check prior to loading onto vessel remain vigilant for mud, soil, debris, plant material, webbing or live spiders, other invertebrates or signs of rodents	**Date completed**	**Notes (including details of any associated AINME reporting)**
Vehicle exterior (top and sides)		
Vehicle wing mirrors and windscreen		
Vehicle exterior (underneath)		
Wheels and wheel arches		
Vehicle interior (including under floor mats, door pockets, down the sides and below the front seats, the boot/trunk, and under the spare tyre).		
Vehicle accessories (forks, buckets, etc.)		
Engine started to ensure no rodents/birds in vehicle interior		
Use insecticide spray in crevices where possible		
Name (print) and Signature of Inspector		
Check prior to off-loading at BAS station	**Date completed**	**Notes (including details of any associated AINME reporting)**
Vehicle exterior (top and sides)		
Vehicle wing mirrors and windscreen		
Vehicle exterior (underneath)		
Wheels and wheel arches		

Vehicle interior (including under floor mats, door pockets, down the sides and below the front seats, the boot/trunk, and under the spare tyre).		
Vehicle accessories (forks, buckets, etc.)		
Use insecticide spray in crevices where possible		

Biosecurity Checklist 5. ISO Containers

All ISO containers must be checked prior to loading on the ship and prior to off-loading at the stations. Appropriate cleaning equipment must be made available during checks. For each ISO container consigned to Rothera a checklist will be completed and stored on file. The checklist will be made available for auditing purposes either by BAM or by BAS personnel. If these checks are not completed at any stage of the supply chain, please note details of the circumstances here and report using the BAS AINME system.

ISO container or Bunk-a-bin identification details:		
Details of journey initial and final destinations (e.g. UK to Bird Island):		
Transporting vessel (e.g. RRS Shackleton):		
Name (print) and Signature of Inspector		
Check prior to packing container*	**Date completed**	**Notes (including details of any associated AINME reporting)**
Container exterior surfaces (top and sides)		
Container exterior doors and hinges		
Container exterior underneath surfaces (as possible)		
Container interior surfaces		
Container interior high and low level corners and door hinges		
Container fumigated prior to locking doors		
Name (print) and Signature of Inspector		
Check prior to loading onto vessel*	**Date completed**	**Notes (including details of any associated AINME reporting)**
Container exterior surfaces (top and sides)		
Container exterior doors and hinges		

Container exterior underneath surfaces (as possible)		
Name (print) and Signature of Inspector		
Check prior to off-loading at BAS station*	**Date completed**	**Notes (including details of any associated AINME reporting)**
Container exterior surfaces (top and sides)		
Container exterior doors and hinges		
Container exterior underneath surfaces (as possible)		

Biosecurity Checklist 6. All break-bulk items (any item which is not containerised and not covered by a specific checklist)

All breakbulk (individual boxes/crates, timber, cladding and other cargo which is not containerised) must be checked prior to loading on the ship and prior to off-loading at the stations. Appropriate cleaning equipment must be made available during checks. If these checks are not completed at any stage, please note details of the circumstances here and report using the BAS AINME system. For each break-bulk inspection a checklist will be completed and stored on file detailing the items inspected and any outcomes. The checklist will be made available for auditing purposes either by BAM or by BAS personnel.

Description of all break-bulk inspected (e.g. 10 x wooden crates, 10 x zarges boxes, 20 x bundles of timber, 15 x bundles of cladding)		
Details of journey initial and final destinations (e.g. UK to Bird Island):		
Transporting vessel (e.g. RRS Shackleton):		
Name (print) and Signature of Inspector		
Check break bulk items prior to loading onto vessel	**Date completed**	**Notes (including details of any associated AINME reporting)**
Items exterior surfaces (top and sides)		
Items exterior underneath surfaces (where possible)		
Items clean and free of soil, biological material and any signs of rodent gnawing or ingress, invertebrates such as spider webbing or cocoons.		
Name (print) and Signature of Inspector		
Check break bulk items prior to off-loading at BAS station	**Date completed**	**Notes (including details of any associated AINME reporting)**
Items exterior surfaces (top and sides)		
Items exterior underneath surfaces (where possible)		
Items clean and free of soil, biological material and any signs of rodent gnawing or ingress, invertebrates such as spider webbing or cocoons.		

APPENDIX F:

MONITORING PLAN: ROTHERA WHARF

Appendix F

Monitoring Plan: Rothera Wharf Reconstruction and Coastal Stabilisation Works

Introduction

The monitoring activities at Rothera Research Station detailed in this section are those that will require the collection of information or data to verify the effectiveness of the impact prediction and proposed monitoring described in the Rothera Wharf Reconstruction and Coastal Stabilisation CEE.

The monitoring tasks are divided into two groups.

- Monitoring of activities which could result in an immediate impact on the environment and can be modified during the construction programme to avoid adverse effects.
- Monitoring of activities which could result in impacts that can only be measured in the long term (i.e. over several Antarctic season) and subsequently are unlikely to be modified beyond the original mitigation identified in the CEE.

Any changes to activities proposed as a result of the monitoring data, will be made by the BAM Construction Manager in conjunction with the BAS Environment Office. All monitoring data will be communicated to the BAS Environment Office and be available on request for auditing purposes.

In addition to the monitoring activities included in this document the construction team will follow other environmental management procedures included in the CEE and the Project Execution Plan including those outlined in the Rothera Wharf specific Biosecurity Plan, Site Waste Management Plan and Oil Spill Contingency plan.

Monitoring activities:

Short-term monitoring

a) Neutralisation of cement contaminated water
b) Wet well seawater turbidity
c) Wildlife displacement
d) Noise from quarrying and construction activities
e) Vibration from quarrying and construction activities
f) Marine noise from construction activities
g) Airborne dust

Longer-term monitoring

h) Skua breeding success on Rothera Point
i) Marine benthic invertebrate communities

A. Neutralisation of cement-contaminated water

1	**Monitoring type and purpose**:
	Measurement of the pH of cement contaminated water, to ensure only pH neutral water is discharged into the environment NB: Neutralised water must be discharged below the low water mark in North Cove.
2	**Description of the monitoring activity**:
	Use of cement may produce waste water that is strongly alkali. Before release into the local marine environment, the waste water should be neutralised using CO_2 deployed though Siltbuster equipment (see: http://www.siltbuster.co.uk/siltbuster-products/concrete-washwater/).
3	**Methodology used** (equipment, thresholds)
	A pH meter incorporated into the Siltbuster Roadside Concrete Washout (RCW) will be used to ensure waste water has a neutral pH (7.0) before release into the marine environment.
4	**Designated person undertaking the monitoring**
	BAM Site Environmental Engineer
5	**Period over which monitoring will occur**
	Monitoring only needs to occur during the period of cement use and when waste water is generated. Estimated volumes of wash waters would be c. 20 m^3.
6	**Frequency of monitoring**
	During period of neutralisation of cement contaminated waste water, and immediately prior to subsequent disposal.
7	**Action(s) should any thresholds be exceeded**
	Should the pH not be reduce to pH 7.0, the waste water shall not be released, but more CO_2 bubbled thought the waste water until the desired pH is achieved.
8	**Recording and management of monitoring data**
	For each water release event, the following information shall be recorded and reported to the Environment Office. • The volume of neutralised water released to the environment • The pH of the water
9	**Method of results communication to the Environment Office**
	• The monitoring data must be presented to the Environment Office every two weeks, and in a final report submitted five months after the commencement of the construction work at Rothera Research Station. • Should any waste water be released to the environment that has not been adequately neutralised (pH 7.0) then the Environment Office shall be informed immediately and an AINME report describing the circumstances completed.

B. Wet well seawater turbidity

1	**Monitoring type and purpose**:
	Measurement of turbidity in the salt water wet well (suspended sediment in water) as high levels of turbidity may have detrimental impact upon station system.
2	**Description of the monitoring activity**:
	The wet well is the source of seawater that supplies the Bonner Laboratory aquarium and the station reverse osmosis plant. Although no turbidity thresholds have been identified by the Aquarium or Estates teams, monitoring of seawater turbidity may provide useful information should problems arise, such as blockage of water filters or excessive sediment deposition in aquarium tanks.
3	**Methodology used** (equipment, thresholds)
	A turbidity meter (HACH 2100Q Portable Turbidimeter) will be used to measure seawater turbidity. At each time point, turbidity shall be measured in three separate batch taken from the wet well.
4	**Designated person undertaking the monitoring**
	BAM Site Environmental Engineer
5	**Period over which monitoring will occur**
	Throughout the period of the wharf project
6	**Frequency of monitoring**
	Twice per day, during periods where work within the marine environment in the vicinity of the water intake is underway (i.e. wharf construction and coastal stabilisation).
7	**Action(s) should any thresholds be exceeded**
	A reading over 5mg/l Formazin will trigger an investigation to understand the reason for the high values (e.g. increased suspended sediment due to wharf activities, marine algal bloom, etc.) and to determine if there are any adverse impacts upon the station reverse osmosis plant or Bonner Laboratory aquarium. If high values are resulting in adverse impacts, then additional filtration systems will be introduced. In addition if BAS Estates or the Aquarium Teams see changes in water quality that lead to problems, then this will trigger an investigation and a change in activities.
8	**Recording and management of monitoring data**
	Data shall be collected and recorded on a spreadsheet. The data shall be made available to station management upon request.
9	**Method of results communication to the Environment Office**
	The monitoring data must be presented to the Environment Office every two weeks, and in a final report submitted five months after the commencement of the construction work at Rothera Research Station. The raw data files must also be made available.

C. Wildlife displacement

NB: Displacement of flying birds not associated with nests are not included in this monitoring, as numbers in the vicinity of the wharf and station are typically low and these birds are will readily fly away if approached.

1	**Monitoring type and purpose:**
	Recording of wildlife displacement, i.e. herding of seals and penguins located on land to remove them from areas where work is being undertaken or vehicle access routes. • All those moving or herding wildlife must have undergone training on station by BAS management. • No bird nest sites are to be moved or physically disturbed by individuals or machinery, without prior consultation with the BAS Environment Office
2	**Description of the monitoring activity**
	Records must be kept of all wildlife displacement events involving seals and penguins. Such events may include the movement or herding of seals or penguins to allow the site to be secured (to enable, for example, building work to commence) or for vehicle movement around Rothera Point.
3	**Methodology used (equipment, thresholds)**
	Visual observations and recording of the species displaced. Thresholds: • more than two seal displacement events per day, or • more than five penguin displacement events per day, averaged over a one week period
4	**Designated person undertaking the monitoring**
	BAM Site Environmental Engineer
5	**Period over which monitoring will occur**
	Recording shall be undertaken during the period when BAM is present on site
6	**Frequency of monitoring**
	Displacement events must be recorded following every occurrence.
7	**Action(s) should any thresholds be exceeded**
	Should the thresholds be exceeded, then BAM shall contact the Environment Office within 24 h to discuss the feasibility of mitigation measures.
8	**Recording and management of monitoring data**
	For each displacement event record the following information: • Number, type, and maturity of displaced seals or penguins (where known) • Reason for displacement (e.g. vehicle movements) • Location where wildlife was moved from and where it was moved to
9	**Method of results communication to the Environment Office**
	• The monitoring data must be presented to the Environment Office every two weeks, and in a final report submitted five months after the commencement of the construction work at Rothera Research Station. • Any wildlife injury or fatality associated with the work should be reported immediately to the Environment Office and an AINME report submitted within 24 h.

D. Noise from quarrying and construction activities

1	**Monitoring type and purpose:**
	Air overpressure and noise from quarrying and construction activities. Excessive noise may cause disturbance to local wildlife and needs to be monitored to ensure thresholds are not exceeded. Before commencing use of particularly noisy equipment (e.g. hydraulic breaker or impact driver) consideration should be given to the impact upon wildlife. Animals on land are likely to move away from the noise source at the commencement of the activity. To allow this to occur, if wildlife are in the vicinity of the work, the noise source should be operated for 30 seconds then switched off, to allow animals the opportunity to move away. Once any disturbed animals have stopped moving, operate the equipment for another 30 seconds and then observe the response of the animals. Continue this cycle until wildlife has moved away to a distance where the noise no longer causes further movement away. Only then should the equipment be used more continuously.
2	**Description of the monitoring activity**
	Air overpressure from quarry blasting Although it is possible to make predictions of the attenuation of air-overpressure, it is considered unrealistic to do so due to the affect that meteorological factors and surface topography have on the transmission of this energy. UK guidance contained within mineral planning guidance MPG 9:1992 and MPG 14:1995, MTAN1 (Wales) and the UK Department of the Environment, Transport and the Regions report 'The environmental effect of production blasting from surface mineral workings 1998' recommend that air overpressure should be controlled at source rather than setting a specific limit. Control measures will therefore be used as detailed in (Section 11.3.2) *Noise from construction activities* Monitoring will occur at sites around Rothera Point to estimate the noise generated by de-construction/construction activities, rock crushing and grading, and plant operation and movement.
3	**Methodology used (equipment, thresholds)**
	Noise shall be monitored using a Norsonic Nor140 Sound Analyser. One monitor shall be positioned at each of the following sites: 1. In the proximity of the nesting skuas midway along the roughly N-S 'ridge' of Rothera Point 2. Within the ASPA. 3. Admirals House 4. Bonner Laboratory In the absence of established Antarctic limits, noise thresholds will be monitored in accordance with British Standard 5228 Part 1, i.e. 'noise levels… …should not exceed: 75 decibels (dBA) in urban areas near main roads in heavy industrial areas'.
4	**Designated person undertaking the monitoring**
	BAM Site Environmental Engineer
5	**Period over which monitoring will occur**
	During entire build period

6	**Frequency of monitoring**
	Continuous
7	**Action(s) should any thresholds be exceeded**
	Activities related to vehicle movement and de-construction/construction must cease and noise management be reassessed. If thresholds are exceeded, noisy activities should not be undertaken simultaneously, but rather rescheduled to occur sequentially and thereby reduce the noise. Acoustic screens may be used to further reduce noise levels.
8	**Recording and management of monitoring data**
	1. Noise data must be backed up once downloaded from measuring equipment to ensure data is not lost 2. Noise thresholds must be programmed into the noise recorder, so that the designated person on site is alerted should thresholds be exceeded.
9	**Method of results communication to the Environment Office**
	• The monitoring data must be presented to the Environment Office every two weeks. A summary of the monitoring data must be presented to the Environment Office in a report submitted five months after the commencement of the construction work. The raw data files must also be made available. • Should mitigation measures and practices be insufficient to keep noise levels below the threshold, contact must be made with the Environment Office at the earliest opportunity to discuss further options.

E. Vibration from quarrying and construction activities

1	**Monitoring type and purpose:**
	Vibration from quarrying and construction activities. Vibration will be monitored to ensure levels do not significantly impact upon local wildlife. Before commencing use of particularly noisy equipment (e.g. hydraulic breaker or impact driver) consideration should be given to the impact upon wildlife. Animals on land are likely to move away from the noise/vibration source at the commencement of the activity. To allow this to occur, the noise/vibration source should be operated for 30 seconds then switched off, to allow animals the opportunity to move away. Once any disturbed animals have stopped moving, operate the equipment for another 30 seconds and then observer the response of the animals. Continue this cycle until wildlife has moved away to a distance where the noise/vibration no longer causes further movement away. Only then should the equipment be used more continuously.
2	**Description of the monitoring activity**
	Vibration from quarrying activities Where land blasting is undertaken in close proximity to a water body, some of the ground vibration will be transmitted across the land/water boundary into the water. Within the water this energy is transmitted as a pressure pulse similar to noise in the air and may cause harm or disturbance to marine fauna at very close proximities. Calculation have been made to predict the level of transmission into the water body based, in part, on Guidelines for the use of explosives in, or near Canadian Fisheries Waters – Wright and Hopky 1998 and the ISEE Blaster's Handbook 18th Edition. These assume a perpendicular single boundary between the rock and water with no intermediate broken or weathered layers and as such can be considered conservative. It is not anticipated that the level of blast vibration transmitted to the water will be sufficiently high to cause harm to the marine environment. Nevertheless, predictions will be made during the project where blasting is in close proximity to the marine environment (less than 20 m). Initial calculations show that a 10 kg charge at 20 m from the land/water interface would produce a Peak Sound Pressure Level (SPL) of 161 dB re 1µPa. This level would be below the level for onset of Temporary Threshold Shift in pinipeds (212 dB re: 1 µPa peak) and cetaceans (224 dB re: 1 µPa peak) as stated in Southall et al 2007. Should further calculations show the possibility of harm or disturbance to marine fauna, then action must be taken, which may include the following: • Monitor actual peak pressure in the water with a hydrophone when blasting at greater distances (before reaching the potentially harmful locations) to obtain real values of peak pressure levels to inform predictions. It is anticipated that they will be lower than those calculated above. • Reduce explosive charge weights, or otherwise alter the blast design to reduce intensity. • Implement a marine fauna watch to ensure that no marine mammals are in the vicinity at the time of blasting. *Vibration from construction activities* Monitoring of vibration from construction activities (vehicle movement, etc.) shall be done to ensure local receptors are not impacted above threshold levels (see below).

3	**Methodology used (equipment, thresholds)**
	Vibration shall be monitored using Instantel® Minimate Pro6™ vibration and overpressure monitors. *Vibration from quarrying* During operations, blasting vibration levels will be monitored using blasting seismographs to measure levels of peak particle velocity and air-overpressure at selected sensitive locations. This monitoring will be both to ensure compliance with site threshold limits and to further increase the number and distribution of results, to allow continuous improvement of vibration prediction models and increasing confidence in MIC predictions. Monitoring should initially be undertaken at the closest sensitive receptors of each type. Once confidence is gained that vibration limits will not be exceeded at these receptors, monitoring should continue at varied distances to obtain data for prediction models. *Vibration form construction activities* In the absence of established Antarctic limits, vibration thresholds will be monitored in accordance with British Standard 5228 Part 2, i.e. 3.0 ms^{-1}. Monitors shall be positioned: 1. In the proximity of the nesting skuas midway along the roughly N-S 'ridge' of Rothera Point 2. Within the ASPA. 3. Admirals House 4. The Bonner Laboratory
4	**Designated person undertaking the monitoring**
	BAM Site Environmental Engineer
5	**Period over which monitoring will occur**
	During entire build period
6	**Frequency of monitoring**
	Continuous
7	**Action(s) should any thresholds be exceeded**
	Activities must cease and noise/vibration management reassessed. If thresholds are exceeded, activities likely to produce substantial vibration should not be undertaken simultaneously, but rather rescheduled to occur sequentially and thereby reduce the total level. Acoustic screens may be used to further reduce noise levels.
8	**Recording and management of monitoring data**
	Noise data must be backed up once downloaded from measuring equipment to ensure data is not lost. Noise thresholds must be programmed into the noise recorder, so that the designated person on site is alerted should thresholds be exceeded.
9	**Method of results communication to the Environment Office**
	• The monitoring data must be presented to the Environment Office every two weeks. A summary of the monitoring data must be presented to the Environment Office in a report five months after the commencement of the construction work. The raw data files must also be made available. • Should mitigation measures and practices be insufficient to keep vibration levels below the threshold, contact must be made with the Environment Office at the earliest opportunity to discuss further options.

F. Marine noise from construction activities

N.B. Marine activities likely to generate substantial levels of noise (drilling, driving, piling or blasting) shall not occur concurrently.

<table>
<tr><td>1</td><td>Monitoring type and purpose:</td></tr>
<tr><td></td><td>Marine noise from marine rock removal (blasting) and construction activities (e.g. pile driving, drilling, etc.). Marine noise has the potential to cause disturbance to marine wildlife and noise levels need to be monitored to ensure thresholds are not exceeded, or wildlife is not in the vicinity of the activity upon commencement.</td></tr>
<tr><td>2</td><td>Description of the monitoring activity</td></tr>
<tr><td></td><td>Marine Mammal Observers (MMOs) will be deployed to watch for the presence of marine mammals in the vicinity of the wharf activities prior to the commencement of and during the activity</td></tr>
<tr><td>3</td><td>Methodology used (equipment, thresholds)</td></tr>
<tr><td></td><td>Trained Marine Mammal Observers (MMOs) should be deployed prior to and during (1) submerged underwater rock breaking operations and (2) underwater rock blasting.
The MMOs shall be properly equipped for this purpose and possess means of communication with those responsible on site for the operations generating the noise.
MMOs should be satisfied that they have visibility of at least to 1000, and should be in place 30 minutes before operations begin. The extent of the zone of observation shall be mapped in advance by the contractor. Where available, key landmarks will be identified to help demarcate the 1000 m visible area and the 500 m exclusion boundary. Binoculars will be used to aid observations. At least one observer will be positioned on high ground to ensure good visual coverage of the exclusion zone.
<u>Marine blasting</u>
Marine Mammal Observers (MMO) will survey the area for the presence of marine mammals 30 minutes before the start of each blast.
The 500 m exclusion zone must have been free of visible marine mammals for 30 minutes, before blasting activities are permitted to commence.
Underwater blasting shall not proceed if marine mammals are observed within 500 m of the blast location
<u>Marine drilling, pecking or driving</u>
Marine Mammal Observers (MMO) will survey the area for presence of marine mammals 30 minutes before the onset of the ‘soft start’.
If marine mammals are sighted within the 500 m exclusion area then works cannot commence.
Soft starts of machinery will follow JNCC guidelines with maximum sound output or sound duration being achieved 20 minutes after soft start has commenced in waters less than 200 m depth. For activities such as pecking, drilling or driving, the closest approach to a ‘soft start’ is the gradual increase from short bursts of activity of a few seconds to continuous operations. Therefore, the activity shall:
- proceed for 15 seconds, then
- stop for 1 min 45 seconds.
This cycle should be repeated 10 times before continuous commencement of the activity.</td></tr>
</table>

	• Once activities have commenced, the presence of marine mammals in, or approaching towards, the observation zone shall not cause the activity to cease. • Special care is required where there have been extended periods (greater than 10 minutes) where operations may have temporarily ceased, to ensure that animals have not entered this zone during such periods. Should activities stop for more than 10 minutes, the 'soft start' procedure shall be carried out again.
4	**Designated person undertaking the monitoring**
	BAM Site Environmental Engineer and designated MMOs
5	**Period over which monitoring will occur**
	During periods of marine blasting or marine construction work in the vicinity of the wharf and the coastal stabilisation works, which are likely to include most of the summer season during 2018/19 and 2019/20.
6	**Frequency of monitoring**
	Prior to the commencement of marine activities involving blasting, pecking, drilling or pile driving
7	**Action(s) should any thresholds be exceeded**
	Underwater blasting shall not proceed if marine mammals are observed within 500 m of the blast location
8	**Recording and management of monitoring data**
	A log of marine mammal activity, by species where possible, and any consequent actions shall be maintained by each MMO throughout periods in which operations are taking place
9	**Method of results communication to the Environment Office**
	• The monitoring data must be presented to the Environment Office every two weeks. A summary of the monitoring data must be presented to the Environment Office in a report submitted five months after the commencement of the construction work. The raw data files must also be made available. • Should mitigation measures and practices be insufficient to keep noise levels below the threshold, contact must be made with the Environment Office at the earliest opportunity to discuss further options. • Any wildlife injury or fatality associated with the work should be reported immediately to the Environment Office and an AINME report submitted within 24 h.

G. Airborne dust

1	**Monitoring type and purpose:**
	Dust and particulate deposition may have adverse impacts upon the melting rate of the ice ramp, the small areas of vegetation present on Rothera Point and the breathing of personnel.
2	**Description of the monitoring activity**
	Monitoring of dust will be undertaken to ensure excessive generation is avoided for the duration of the quarrying and construction process.
3	**Methodology used (equipment, thresholds)**
	Particulate monitoring will be undertaken using an Aeroqual Dust Sentry with a threshold of >250 µg particulates m^{-3} 15 min^{-1}. Monitoring equipment shall be positioned: 1. At the bottom of the ice ramp (i.e. on the opposite side of the runway relative to the station buildings). 2. Within the ASPA. 3. Beside the area of green vegetation located behind the miracle span
4	**Designated person undertaking the monitoring**
	BAM Site Environmental Engineer
5	**Period over which monitoring will occur**
	During entire build period
6	**Frequency of monitoring**
	Continuous
7	**Action(s) should any thresholds be exceeded**
	Dust suppression strategies will be investigated to reduce dust levels associated with quarrying and deconstruction/construction activities.
8	**Recording and management of monitoring data**
	Particulate data must be backed up once downloaded from measuring equipment to ensure data is not lost. Particulate thresholds must be programmed into the particulate recorder, so that the designated person on site is alerted should thresholds be exceeded.
9	**Method of results communication to the Environment Office**
	• The monitoring data must be presented to the Environment Office every two weeks. A summary of the monitoring data must be presented to the Environment Office in a report five months after the commencement of the construction work. The raw data files must also be made available. • Should mitigation measures and practices be insufficient to keep dust levels below the threshold, contact must be made with the Environment Office at the earliest opportunity to discuss further options.

H. Skua breeding success on Rothera Point

1	**Monitoring type and purpose:**
	Skua breeding success on Rothera Point. Nesting skua populations on Rothera Point may be vulnerable to disturbance associated with the proposed works. This monitoring work will proceed to assess the impact of the quarrying and construction activities on skua breeding success.
2	**Description of the monitoring activity**
	BAS routinely undertake monitoring of skua breeding success as part of its long-term monitoring commitments.
3	**Methodology used (equipment, thresholds)**
	The breeding parameters that will be recorded include laying dates, clutch size, egg dimensions, hatching success, fledging success, chick condition and adult attendance (which provides an index of foraging effort). In addition, monitoring includes re-sighting of colour-ringed adults, which can be used to estimate adult survival, breeding frequency and divorce rates, and to determine the breeding histories of individuals and the effects of mate change. In addition, there will be monitoring of birds on Anchorage Island, which will act as controls.
4	**Designated person undertaking the monitoring**
	BAS: Bonner Lab Manager
5	**Period over which monitoring will occur**
	November 2018 to March 2019 and November 2019 to March 2020
6	**Frequency of monitoring**
	Weekly
7	**Action(s) should any thresholds be exceeded**
	Should any direct physical damage to birds or nests be noted, this will be communicated to the Environment Office immediately and an AINME report completed within 24 hours.
8	**Recording and management of monitoring data**
	Data is routinely recorded by the Bonner Lab Manager and submitted to the BAS Data Centre
9	**Method of results communication to the Environment Office**
	• A summary of the monitoring data must be presented to the Environment Office at the end of each breeding season. • Should any direct physical damage to birds or nests be noted, this will be communicated to the Environment Office immediately and an AINME report completed within 24 hours.

I. Marine benthic invertebrate communities

1	**Monitoring type and purpose:**
	Marine benthic invertebrate communities. Marine invertebrate communities on the sea floor may be vulnerable to disturbance from construction activities, making monitoring essential to determine the extent and severity of impact.
2	**Description of the monitoring activity**
	Monitoring to determine the impacts of wharf construction activities on the benthic marine communities in the vicinity of the wharf and south end of the runway
3	**Methodology used (equipment, thresholds)**
	ROVs and dive surveys will be used to determine the degree of change in benthic community, relative to control sites, occurring on the slope beneath the wharf down to a depth of c. 100 m.
4	**Designated person undertaking the monitoring**
	Ben Robinson (NERC PhD student with Southampton University)
5	**Period over which monitoring will occur**
	March 2017 to April 2020. Further surveys may be undertaken to assess on-going benthic community recovery rates.
6	**Frequency of monitoring**
	Before construction programme commences and after the construction programme has been completed
7	**Action(s) should any thresholds be exceeded**
	N/A
8	**Recording and management of monitoring data**
	Research is being undertaken as part of a PhD on human and natural impacts upon near-shore benthic communities with BAS and University of Southampton co-supervision. All data will be managed in accordance with existing BAS standards and curation protocols.
9	**Method of results communication to the Environment Office**
	Summary reports will be delivered to the Environment Office, as data is analysed. Ultimately academic papers will provide more detail and form the basis of the report at the end of the benthic monitoring.

APPENDIX G:

NOISE ASSESSMENT

aquatera
environmental services and products

Evaluation of the Environmental Impact on Marine Fauna of Underwater Noise Generated During Wharf Redevelopment and Extension Works at Rothera Research Station, Antarctica

Version 2

Report to BAM Nuttall

Issued by Aquatera Ltd

P818 – January 2018

This study was completed for:

BAM Nuttall
St James House
Knoll Road
Camberley
Surrey
GU15 3XW

Contact: Neil Goulding
Tel: 01276 63484
Email: Neil.Goulding@BAMNuttall.co.uk

This study was completed by:

Aquatera Ltd
Old Academy Business Centre
Stromness
Orkney
KW16 3AW

Contact: Gareth Davies
Tel: 01856 850 088
Email: office@aquatera.co.uk

Issue record

The version number is indicated on the front cover.

Version	Date	Details
V1	09/01/2018	Draft report issued to client for review
V2	10/01/2018	Final report

Executive summary

The refurbishment and expansion of the wharf at the Rothera Research Base which is situated on the west of the Antarctic Peninsular is planned to take place between late 2018 and 2020. As part of the environmental stewardship process the British Antarctic Survey (BAS) and their construction works contractor BAM Nuttall have commissioned a detailed assessment of possible noise impacts associated with the planned works. This assessment has been completed by environmental consultants Aquatera, supported by noise modelling specialists Subacoustech.

The assessment has considered the work programme comprising the removal of the existing wharf, removal of specific bedrock areas that impinge on the new wharf design and installation of the new wharf structure. These activities will give rise to underwater noise arising from vibro pile removal, drilling, blasting and rock breaking with mechanical pecker. This study has not included shipping related noise or transmitted noise from any onshore works as these were considered to be low intensity and or short term sources outside the scope of work for this study.

Sound source levels for the various activities and patterns of noise generation were determined. These showed that blasting would give rise to the largest noise levels but for very short time periods over between 4 and 6 blasting sequences. Rock breaking and vibro piling were the next noisiest activities but there source levels are expected to be much lower, although the duration of noisy activities will be greater. Drilling was found to give rise to rather lower noise levels.

The marine environment around the wharf at the Rothera Research Base comprises a semi enclosed embayment Ryder Bay. The seabed drops off sharply at the coast at an angle of around 45° to a depth of around 500 m. At a range of 2 to 5 km or so the coastlines of the bay to the west, islands and small islets to the south and a shallower rock ridge to the east act to enclose Ryder Bay to some extent. Beyond the Ryder Bay to sea opens into a wider and deeper embayment known as Marguerite Bay.

The environs of the base and wider Ryder and Marguerite Bay's hold a number of wildlife populations that are of relevance to possible noise impacts. These include Cetaceans (minke, humpback, whales and orca); seals (Weddell, crabeater, elephant, leopard, fur); a number of fish species and diving birds (adele, emperor, Gentoo and chinstrap penguins and imperial shag). Most of these species were considered to be of low sensitivity based upon ICUN population status, with a few species being considered on medium sensitivity (minke whale, orca and emperor penguin).

Where available sound level thresholds at which temporary and permanent impairment of hearing may occur have been established for each major species group. The cetaceans were divided into high, medium and low frequency adapted groups and the seals between eared and non-eared groups. Fish were considered as one group, similar to medium frequency cetaceans, but no such criteria are available for diving birds.

Based upon the source sound levels, proposed operational approaches and local conditions sound propagation models were established for blasting, rock breaking, vibro piling and drilling activities. This modelling indicated the following key ranges for temporary and permanent effects on the different groups (excluding high frequency adapted cetaceans which are not found in the operational area):

Temporary hearing effects (modelled range in metres)

Group	Blasting		Rock breaking	Vibro piling	Drilling
	SPL	SEL			
LF cetaceans	1000	4700	520	400	80
MF cetaceans/fish	150	29	41	70	6
PW Pinnipeds	1200	870	150	200	10
OW Pinnipeds	110	42	10	20	1

SPL = sound pressure level; SEL = sound exposure level

Permanent hearing effects (modelled range in metres)

Group	Blasting		Rock breaking	Vibro piling	Drilling
	SPL	SEL			
LF cetaceans	370	350	23	30	5
MF cetaceans/fish	56	2	1	5	1
PW Pinnipeds	440	66	7	100	1
OW Pinnipeds	39	3	<1	1	<1

SPL = sound pressure level; SEL = sound exposure level

Taking into account all of the information gathered in this study and also considering established guidance for environmental management of noise generating activities an impact mitigation scheme has been proposed by the project which combines establishing appropriate faunal observation zones as well as using passive acoustic monitoring buoys to detect the presence of any noise emitting animals.

The zones have been established to primarily seek to avoid any permanent hearing effects and to minimise temporary hearing effects, whilst also taking into account practical limits for observations of this type.

Observation zones of 1200 m for cetaceans, 600 m for seals and 300 m for birds will be applied for blasting and a reduced zone of 200 m for all faunal groups for rock breaking and vibro piling.

On the basis of this analysis and the approach to the works it is predicted that any arising impacts will be temporary and negligible in terms of the numbers of animals involved for marine mammals and birds. There may be some very localised mortality to fish closely associated with the wharf location due to blasting and rock breaking but again such impacts are not considered significant. The observations and measurements taking place around the activities will enable these predictions to be verified and in the unlikely event that outcomes differ from those predicted adaptive measures can be implemented if necessary.

There are not considered to be any cumulative impact mechanisms that will alter or add to the outcomes outlined above.

Overall therefore it is concluded that the management plan that is suggested for the planned operations will allow them to be completed without any significant environmental effects arising

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1 INTRODUCTION

This study has been carried out to evaluate the environmental impact on marine fauna of underwater noise generated during the redevelopment and extension of Biscoe Wharf at Rothera Research Station, Adelaide Island, Antarctic Peninsula. Rothera is part of the UK's Antarctic research station network operated by the British Antarctic Survey (BAS). As part of the ongoing maintenance and development of the base it is planned to expand the wharf facilities to enable larger vessels to service the base. These construction works are being managed by BAM Nuttall on behalf of BAS. Within the overall environmental stewardship process for the wharf redevelopment works it has become apparent that the possible environmental impacts associated with underwater noise need specific attention. Consequently, an environmental impact assessment and associated noise propagation modelling study have been commissioned by BAM Nuttall on behalf of BAS.

The impact assessment presented in this report has been undertaken by environmental consultancy Aquatera Ltd and is informed by noise modelling undertaken by underwater acoustic specialist Subacoustech Environmental Ltd. Refer to Appendix A for the full noise modelling report.

This assessment will feed into a wider Comprehensive Environmental Evaluation (CEE) for the Rothera Wharf redevelopment and extension proposals.

The main underwater noise generating activities associated with the wharf redevelopment, which have been assessed for their impact on marine fauna, include:

- Underwater drilling and rock blasting;
- Underwater rock breaking using a hydraulic hammer;
- Underwater vibratory pile hammering for extraction and installation of sheet piles; and
- Underwater drilling works to fix frames during installation of new wharf walls.

Wharf redevelopment and extension is planned to be carried out over two summer seasons, beginning in December 2018 and finishing 16 months later in April 2020. Within that timeframe underwater noise generating activities are planned to commence in February 2019 and end a year later in February 2020.

The assessment includes the following sections:

- Section **Error! Reference source not found.**: Relevant project parameters, including project design elements nd construction methods;
- Section 2: Legislative framework and policy considerations which are relevant to the assessment;
- Section 3: Assessment methodology, including assessment criteria, supporting surveys and studies, and consideration of data gaps and uncertainties;
- Section 4: Baseline description which characterises the local environment and population status for relevant species including cetaceans, pinnipeds, birds and fish; and
- Section 5: Impact assessment which considers potential impacts during the construction phase taking into account agreed mitigation measures, with a brief consideration of any need for additional mitigation measures and associated residual effects.

1.1 STUDY AREA

Rothera Research Station is a major logistical hub for BAS operations in Antarctica. The Rothera area has been subject to human activity for over 40 years, and in that time some parts have been dramatically modified from their original state, while others remain relatively free of impacts (Hughes et al, 2016[1]). The area of direct physical transformation from base construction is however relatively limited, covering some 0.16 square kilometres (km^2) at Rothera Point.

Rothera Point is on the southeast of Adelaide Island, which lies just off the western ridge of the Antarctic Peninsula. The station is accessed by boat through an existing wharf which is located at the southeast of the site within Ryder Bay. Ryder Bay is contained within the much larger area of Marguerite Bay which tracks approximately 344 km along the western ridge of the Antarctic Peninsula from the southeast of Adelaide Island to the northeast of Alexander Island (Figure 1.1).

Ships come to the base to deliver supplies and remove waste and surplus equipment in the summer months. Aircraft are also used to transport people and light goods through the summer period. There are also vessel, aircraft and overland vehicle movements associated with the research and monitoring programmes of the base.

The study is especially focussed upon underwater noise impacts. As will be seen later, the extent of possible impact thresholds are all less than 20 km. Consequently, a study area of 50 km radius from the location of the proposed works has been used as the extent of the core study area. The presence of sensitive species or designated sites outside this area has also been considered where those populations may have some connectivity with the core study area during foraging, migration or other behavioural activities.

Figure 1.1 shows Rothera Research Station and the location of the proposed underwater noise generating activities in the context of Ryder Bay and in the wider context of the Marguerite Bay area.

Figure 1.2 is an aerial photograph, taken in 2013, of Rothera Research station. Of note is the runway, the existing wharf at the southeast of the station, BAS buildings and facilities and the ice shelf which connects Rothera Point to Adelaide Island which is visible to the west.

1.2 PROJECT DESIGN CONSIDERATIONS

The Rothera Research Station is a permanently manned base accommodating between 20 and 120 people in winter and summer, respectively. It is serviced by air and sea, with the sea access being restricted to the ice-free months from October to March. As part of the ongoing development of Antarctic capacity, the UK has recently invested in new vessels for its Antarctic activities. In order to facilitate the access of larger vessels into Rothera Research Station, BAS require to redevelop and extend the existing wharf. The following sections provide a brief description of the relevant underwater noise generating construction and operational activities planned for the Rothera base.

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[1] Hughes, K.A. (Lead Author). *Environmental Baseline Information for Rothera Point, Adelaide Island, Antarctica*. Draft Publication. BAS Environment Office, December 2016.

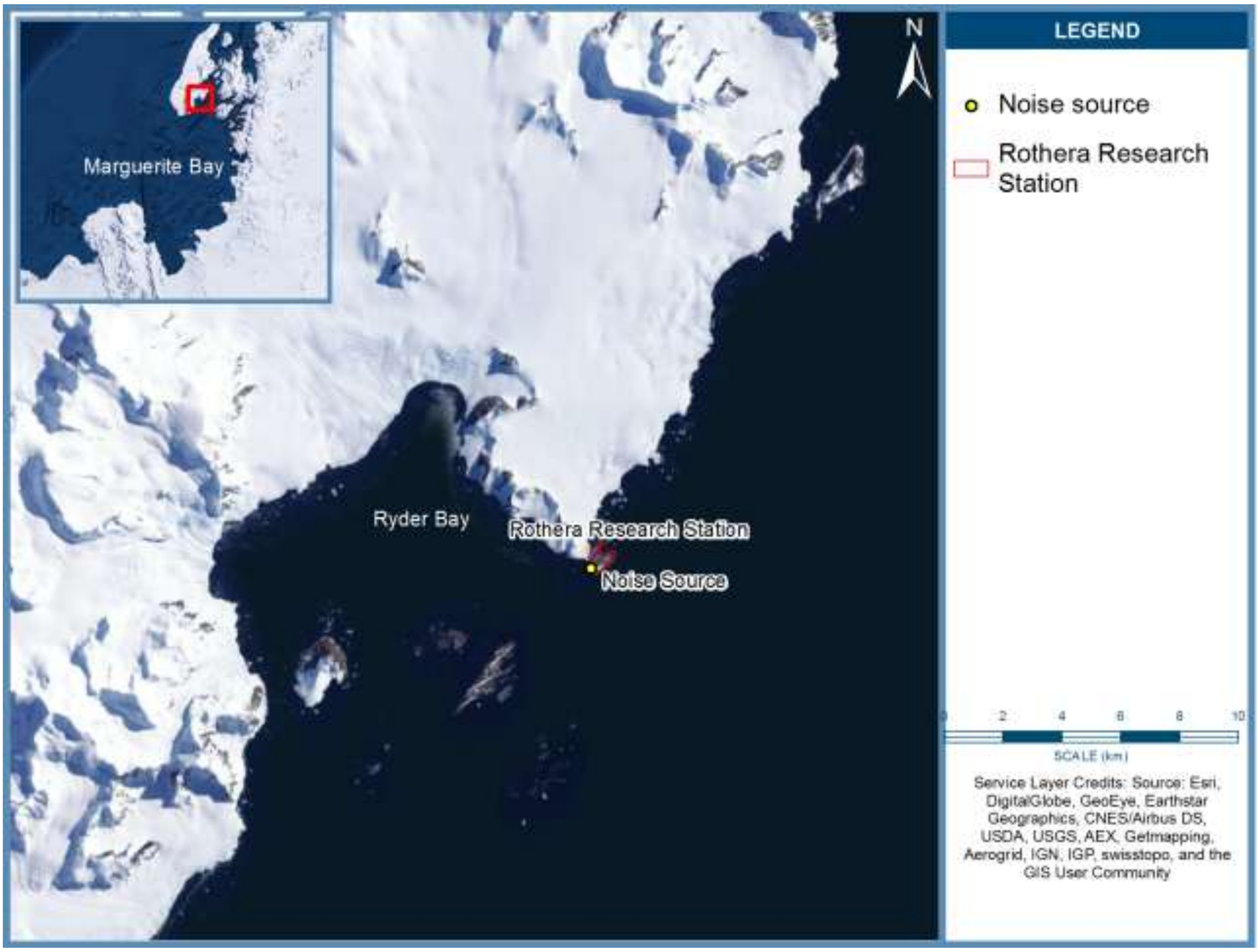

Figure 1.1 Map of study area

Figure 1.2 Map showing existing wharf and expanded construction area

1.2.1 Discussion of potential noise sources

The wharf redevelopment and extension programme will involve works along a 200 m section of coastline on the southern flanks of the research station. The works will entail the partial demolition of the existing wharf facilities, the removal of certain bedrock features, which the proposed wharf design requires, and the installation of the new steel wharf structures.

No operational vessels will be alongside the wharf during construction, and there will only be limited shipping activities associated with the delivery and removal of equipment at the start and end of the project. Therefore the impacts of vessel engine noise on marine fauna have not been included in the assessment as this level of activity is not considered to pose any threat to local species either as an isolated operation or in combination with the construction operations.

Underwater noise sources associated with the construction of a new wharf at Rothera are:

- Drilling of boreholes for insertion of 10 kg charges;
- Underwater blasting from detonation of charges;
- Rock breaking with a pneumatic rock chisel;
- Use of a vibratory pile hammer (vibropiling) for extraction and installation of sheet piles; and
- Drilling associated with wharf dismantling and installation works.

Based upon these types of activity Table 1.1 lists the typical noise sources that may be associated with them and the timing and duration of each activity being considered. For a description of the potential underwater noise levels produced by these sources see Section 5.4.

Further details of each of the above-mentioned noise sources are presented in the following sections.

Table 1.1 Construction activities, their relevant noise source, machine time on activity and probable total duration of each activity

Activity	Noise Source	Start Date	End Date	% of Time on Activity	Probable Duration of Activity
Pile Extraction	Vibropiling Hammer	01/02/19	11/02/19	25%	10 hours
Sea Bed Preparation	Breaker	09/03/19	20/04/19	5%	10 hours
Sea Bed Preparation	Breaker	05/12/19	20/12/19	5%	10 hours
Sea Bed Preparation	Marine Drill & Blast	01/03/19	18/03/19	See Section 1.2.1.1 – blasting itself will take less than 1 second and 5-6 blasting events are planned	
Fixing Frames	150Ø Drill	09/03/19	10/04/19	10%	5 hours
Fixing Frames	150Ø Drill	03/12/19	10/02/20	5%	5 hours
Side Walls	Vibropiling Hammer	06/04/19	17/04/19	10%	30 mins several times per day
Front Wall	Vibropiling Hammer	03/12/19	10/02/20	10%	30 mins several times per day

1.2.1.1 Drilling and blasting

All drilling and blasting will be undertaken at the eastern end of the wharf and will break up the rock to make space for the new wharf walls.

Firstly, a detailed plan for drill holes will be prepared with each hole being assigned x and y coordinates and a target hole bottom position. The drilled holes will be 89 mm in diameter and will have a minimum length of 0.3 m which will greatly reduce the pressure pulse released into the water. When holes are ready to be drilled, the drill casing will be lowered onto the rock and then the drill string lowered down the casing and the hole drilled to the required level. Once completed, the drill string is removed and the shot-hole depth is confirmed using calibrated stemming rods or tape measure. Up to twenty holes to be drilled for each blasting event, of which there will be five or six.

A 10 kg charge will then be placed in each drilled hole with a fuse wire attached and the top of the hole is then filled with a packing material to help concentrate the eventual blast in the target layers of the rock. The charging process does not itself result in any underwater noise. Drilling and charging are undertaken as a continuous process where each hole is drilled and then immediately charged before the drill rig repositions on the next hole.

A system of advanced initiation will be used, where in-hole detonators have the same delay (300 milliseconds). The detonator tubes are then connected in sequence onshore using connector detonator assemblies to control the initiation timing and ensure each hole is fired on a separate delay. This system ensures that all in-hole detonators are 'burning' through their delay element prior to the detonation of the first detonator in the sequence, preventing premature ground movement and misfire due to cut-offs. This control of the initiation timing ensures that the maximum instantaneous charge weight fired in any delay, and consequently the underwater noise generated, is kept to the minimum.

A 'blasting protocol' will be followed for each of the actions undertaken to allow the shot to be charged and fired in such a way as not to harm personnel, marine fauna, equipment, air traffic, marine vessels and infrastructure. This protocol will be developed between BAM and BAS on-site to ensure all the necessary control measures and communications are in place to allow the blast to be charged and initiated safely.

The 'blasting protocol' consists of a number of checks, actions and warnings to be undertaken at various times, for example, prior notification of blasting activities to the relevant personnel and the logging of commencement of marine fauna observation.

Once confirmation has been received from the shotfirer that final checks of the charges, initiation system and blast area have been made and that the area is safe and clear of sensitive species, detonation of charges can commence.

Blasting has been selected as the most effective and appropriate method of rock removal given the logistical limits of the site and the nature and location of the rock material to be removed. The rock that will be removed by the blasting operation can be considered as three distinct areas:

- Rock that can be drilled and charged from above water, with a design level above the low water level. This is equivalent to land blasting but is in close proximity to the marine environment so still has a potential impact (see Section 5.5.5) (this is shown as orange in Figure 1.3 and consists of approximately 300m^2, 1300m^3 of rock between +5 to +1 m to Chart Datum (CD);
- Rock that can be drilled and charged from above water, but which has a free face in the water and a design level below the water level. This is shown as the lower slopes in red and the upper slopes in beige on Figure 1.3 and consists of 200m^2, 300m^3 of rock between +1.0 to approximately -3.0m CD); and

- Rock that is entirely below water. Shown as green in Figure 1.3 although also includes the lower slopes shown in beige. This consists of approximately 180m^2, 100m^3 of the lower slopes in beige

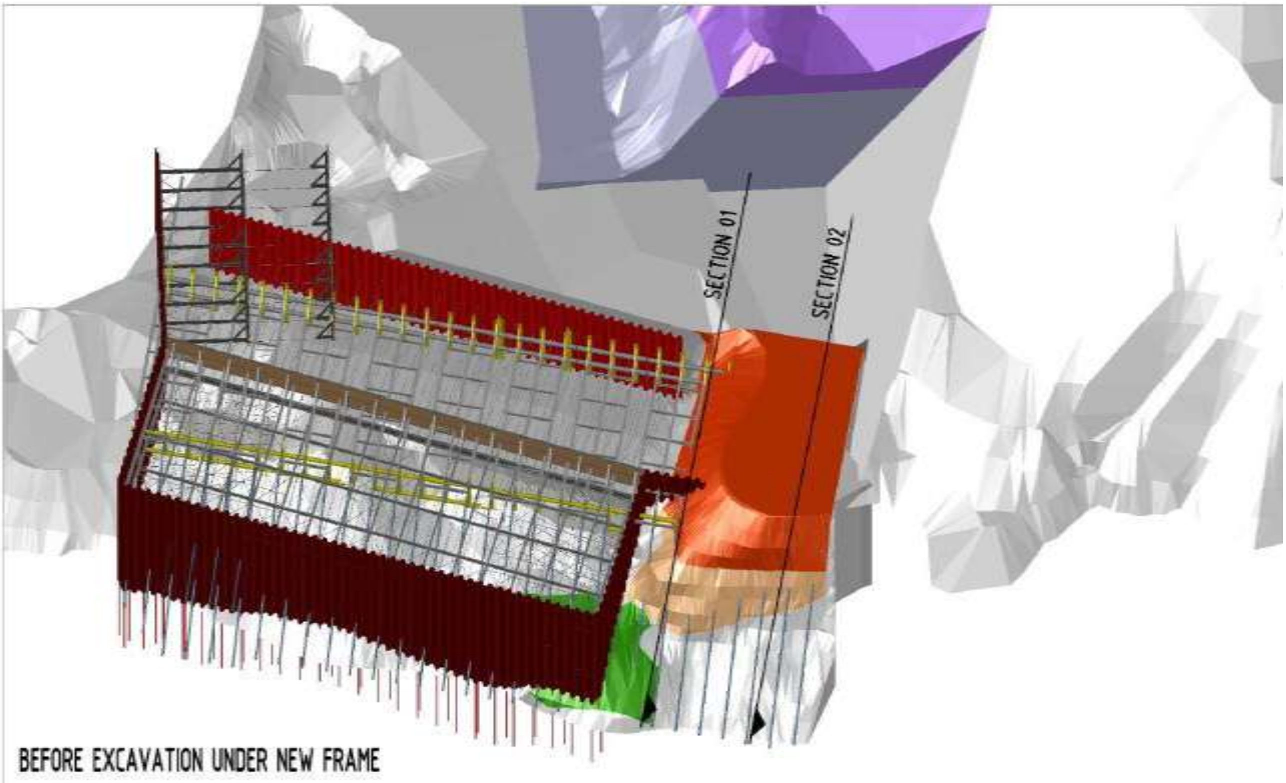

Figure 1.3 Image showing the areas to be blasted underwater and above water. Lower slopes of red and upper of beige are above water and lower slopes of beige and green are below water

It is anticipated that the total area of the seabed to be blasted of 240m^2 will result in approximately 5-6 blasting events taking place over a 17-day period (subject to weather and sea ice conditions). Each blasting event will require up to 20 holes to be drilled, into which the individual 10 kg charges will be placed.

Some blasting associated with wharf redevelopment will take place onshore including quarrying works. This is likely to include some controlled explosions that are sufficiently close to the shore that some of the ground vibration will be transmitted across the land / water boundary into the water. Associated effects on marine fauna have not been the subject of detailed assessment as the zones and magnitude of impact will be small in comparison with those arising from underwater blasting. However, potential impacts and planned mitigation for this activity are considered briefly in Section 5.5.5.

1.2.1.2 Rock breaking/hammering

During preliminary works for the mid and rear walls of the new wharf a trench needs be dug; to the western end of this trench, rock will be broken using a Prodem PRD500 hydraulic breaker attached to an excavator. It is anticipated that rock breaking will be carried out during March or April 2019 and in December 2019. In each of these periods the total duration of the activity will be ten hours with a machine time on activity of 5%, i.e. 30 minutes.

1.2.1.3 Vibratory piling

Deconstruction of the existing wharf will require a vibratory pile extraction hammer to be used. Additionally, construction of the mid, front and side walls of the new wharf will require sheet piles to be installed. Where possible, piles will be lowered into the existing clutches – the hollowed-out grooves which will have been left over from removal of the old wharf – using a crawler crane until fully engaged and resting on the rock bed. If the pile is unable to be lowered under gravity, the crane will be disconnected and a vibratory piling hammer will be used to drive the pile to the correct level. The following assessment has assumed, as a worst case, that vibratory piling will be required to drive the sheet piles into the rock.

1.2.1.4 Drilling for installation of frames supporting new wharf walls

The drilling works for the construction frames will be as follows. In Construction Season 1, as part of Rear Wall to Mid Wall Construction, the rig will drill a 150 mm diameter hole centrally to the pile through the thick walled supporting tube at the toe of mid wall pile and into rock. Once the hole has been drilled the drill string will be retracted and the rig repositioned on the frame to drill the next pile in the same manner. Once both of the mid wall piles in the frame have been drilled the drill rig will be removed from the frame. In Construction Season 2, as part of Mid Wall to Front Wall Construction, the rig will drill a 150 mm diameter hole centrally to the pile into the rock. Once the hole has been drilled the drill string will be retracted and the rig repositioned on the frame to drill the next pile in the same manner. Once both piles have been drilled the drill rig will be removed from the frame using the crane.

2 LEGISLATIVE FRAMEWORK AND POLICY CONTEXT

The legislative framework that influences the assessment process is the Protocol on Environmental Protection to the Antarctic Treaty 1998 and associated annex, Annex I of the Environmental Protection to the Antarctic Treaty: Environmental Impact Assessment (ATS, 2016)[2].

The protocol was established by the Consultative Parties in order to commit themselves to the comprehensive protection of the Antarctic environment and dependent and associated ecosystems. The protocol sets principles applicable to human activities in Antarctica and establishes a number of environmental principles which can be considered a guide to environmental protection in Antarctica.

Activities in the Antarctic Treaty area must be planned and conducted on the basis of information sufficient to allow prior assessments of, and informed judgements about, their possible impacts on the Antarctic environment and dependent and associated ecosystems[3]. The proposed wharf redevelopment is therefore a relevant activity to these requirements and requires approval under the Treaty Protocol.

Annex I outlines the procedures for EIA for planned activities in Antarctica and provides basic principles which Consultative Parties should follow when undertaking such an assessment. These procedures ensure that the EIA process is transparent and there is a consistent approach to fulfilling the obligations of the Protocol. The assessment is therefore conducted in line with these principles.

[2] Antarctic Treaty Secretariat. Annex I to the Protocol on Environmental Protection to the Antarctic Treaty: Environmental Impact Assessment. Available at: https://www.ats.aq/documents/recatt/Att008_e.pdf

[3] Antarctic Treaty Secretariat. 2016. Guidelines for EIA in Antarctica. Available at: http://www.ats.aq/documents/recatt/Att605_e.pdf

3 ASSESSMENT METHODOLOGY

The impact assessment methodology has been established in accordance with Article 8 and Annex I of the Protocol, which set out the requirements for EIA in Antarctica. The methodology also gives consideration to the Antarctic Treaty Guidelines for Environmental Impact Assessment in Antarctica (ATS, 2016)[4] and the Chartered Institute of Ecology and Environmental Management (CIEEM) Guidelines for Ecological Impact Assessment in The UK and Ireland, Terrestrial, Freshwater and Coastal (CIEEM, 2016)[5]. While the latter has been commissioned for the UK and Ireland, the principles promote good practice, a common framework, and a rigorous and transparent approach to EIA.

The principal interactions with receptors arising from project activities (equivalent to 'environmental aspects' per ATCM guidance) that are considered in this assessment relate to the emission of different types of underwater sound. Current guidelines on thresholds of effect for marine mammals (NMFS, 2016)[6] and fish (Popper et al, 2014)[7] exposed to man-made underwater sound have been used to underpin the assessment.

Aquatera uses a 'matrix' approach only as a guide to determine impact significance; this is supported by expert judgement and a transparent differentiation in the assessment between evidence-based and value-based judgements so that decision-makers and other stakeholders are aware of the level of subjective evaluation that has been used. Spurious quantification is avoided by ensuring that where impact rankings are used, clear definitions of the criteria and thresholds that underpin them are provided.

3.1 ASSESSMENT CRITERIA

3.1.1 Exposure risk

The first criteria to consider is whether the species is likely to be present in the area or not. This has been termed exposure risk. The likely exposure risk is related to: the normal distribution of a species; to any strong seasonal changes in distribution; and to any seasonal behavioural traits such as species which exhibit seasonal haul out behaviours. The outcome of the exposure risk assessment is that species are either considered to be at risk of exposure due to their possible or likely presence or they are considered to be absent from the area on a seasonal or permanent basis.

3.1.2 Sensitivity of receptor

Since the underwater noise generating activities in this assessment will result in minimal change to habitat, the assessment of receptor sensitivity relates to species, populations, communities and assemblages, rather than habitat. When determining the sensitivity of each receptor, the following criteria are important to understand the status of the

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[4] Antarctic Treaty Secretariat. 2016. Guidelines for EIA in Antarctica. Available at: http://www.ats.aq/documents/recatt/Att605_e.pdf

[5] CIEEM. (2016). *Guidelines for Ecological Impact Assessment in the UK and Ireland: Terrestrial, Freshwater and Coastal, 2nd edition.* Winchester: Chartered Institute of Ecology and Environmental Management.

[6] National Marine Fisheries Service. 2016. Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing: Underwater Acoustic Thresholds for Onset of Permanent and Temporary Threshold Shifts. U.S. Dept. of Commer., NOAA. Available at: http://bit.ly/2j0qcOh

[7] [7]Popper, A. N., Hawkins, A. D., Fay, R. R., Mann, D., Bartol, S., Carlson, T., Coombs, S., Ellison, W. T., Gentry, R., Halvorsen, M. B., Lokkeborg, S., Rogers, P., Southall, B. L., Zeddies, D., and Tavolga, W. N. (2014). "Sound Exposure Guidelines for Fishes and Sea Turtles: A Technical Report," ASA S3/SC1.4 TR-2014 prepared by ANSI-Accredited Standards Committee S3/SC1 and registered with ANSI. Springer and ASA Press, Cham, Switzerland.

species population, whether the species has protection status or is linked to designated habitats and potential response to particular impacts.

Criteria include:

- Vulnerability;
- Value/importance; and
- Recoverability.

Table 3.1 Criteria for sensitivity of receptor

Sensitivity	Criteria
High	• Species included on the IUCN Red List of Threatened Species as Critically Endangered (CR) or Endangered (EN). Species having a globally Restricted Range (i.e. plants endemic to a site or found globally at fewer than 10 sites, fauna having a distribution range (or globally breeding range for bird species) less than 50,000 km^2. • Internationally important numbers of migratory species • Key evolutionary species • Rare species of international or national importance with very restricted distribution, limited range or threatened populations
Medium	• Species included on the IUCN Red List of Threatened Species as Vulnerable (VU), Near Threatened (NT) or Data Deficient (DD) (IUCN 2011). Species protected under national legislation. • Regionally restricted range species • Regionally important number of migratory or congregatory species • Species is listed in regional legislation as requiring protection
Low	• Species which are included on the IUCN Red List of Threatened Species as Least Concern (LC) • Species of local importance

3.1.3 Magnitude of impact

The potential impacts in terms of physical environmental change are identified and characterised based on the nature of the impact (including direct/indirect) and a number of criteria including:

- extent;
- intensity;
- duration;
- frequency and timing; and
- reversibility.

These factors are characterised as high to negligible magnitude within Table 3.2 and inform the assessment of impacts to reach an overall impact magnitude using expert judgement.

Table 3.2 Criteria for magnitude of impact

Magnitude	Criteria
High	• An irreversible (permanent) impact/mortality on an entire population or species at sufficient scale to cause a substantial decline in abundance and/or change in distribution as a result of which natural recruitment (reproduction, immigration from unaffected areas) may not return that population or species, or any population or species dependent upon it, to its former level within several generations, or when there is no possibility of recovery. • Major loss or major alteration to key elements of the baseline (pre-development) conditions such that the post-development character / composition / attributes will be fundamentally changed.
Medium	• A reversible (temporary) impact on a sufficient proportion of a species population that it may bring about a substantial change in abundance and /or reduction in distribution over one or more generations, but does not threaten the long-term viability of that population or any population dependent on it
Low	• A reversible (temporary) impact on a small proportion of the population from which spontaneous recovery is possible or that is within the range of variation normally experienced between years. • Impact confined to disturbance to individuals within the site of activity • Minor shift away from baseline conditions; change arising from the loss / alteration will be discernible but underlying character / composition / attributes of the baseline condition will be similar to the pre-development situation.
Negligible	• Very slight change to the baseline condition; change barely distinguishable, approximating the 'no change' situation.

3.1.4 Significance of effects

In order to determine the overall significance of effects on a given receptor, the magnitude of impact is evaluated against the sensitivity of the receptor. Effects are categorised by their significance and are in line with the ATCM (2016) definitions:

- Less than a minor or transitory impact (negligible)
- A minor or transitory impact (minor)
- More than a minor or transitory impact (moderate to major)

The following matrix approach (Table 3.3) is used as a guide to inform the assignment of significance. Significance is determined with consideration of all elements that define receptor sensitivity and impact magnitude and is supported with evidence and expert judgement in the discussion of residual effects for each impact in Section 5.7.

Table 3.3 Impact significance

Sensitivity of Receptor	Magnitude of effect			
	High	Medium	Low	Negligible
High	MAJOR	MAJOR	MODERATE	MINOR
Medium	MAJOR	MODERATE	MINOR	NEGLIGIBLE
Low	MODERATE	MINOR	NEGLIGIBLE	NEGLIGIBLE

4 BASELINE DESCRIPTION

4.1 INTRODUCTION

The Rothera base is located on Adelaide Island adjacent to the Antarctic continental landmass and is therefore part of the overall Antarctic ecosystem. The physical and ecological environments are dominated by the effects of cold, snow and ice in combination with the underlying geology, hydrography and weather patterns.

This section pulls together the available baseline information and endeavours to use this, along with wider principles of species behaviour and ecosystem dynamics to build a comprehensive picture of how the ecosystem may function and the traits and sensitivities of the species that may be found there. All of the information presented is focussed upon the topic of noise propagation and effects in water, other baseline characteristics which are not relevant to this topic are not covered.

Sources that have been used to compile this baseline section include:

- Environmental baseline information for Rothera Point, Adelaide Island, Antarctica (Hughes et al, 2016);
- Benthic survey conducted in January 2016 off the south coast of Rothera Point (Hughes et al, 2016);
- Rothera Research Station Survey Data: Ad-hoc sightings of cetaceans, pinnipeds and birds recorded over the last 10 years for the summer period (November – April) have been analysed to understand the range of species present, the most commonly sighted and in broad terms the seasonal/inter-annual variation. The focus of the data for this assessment has been on the summer season because this is when construction activity will occur and when species will be exposed to impacts and also because sightings are less frequent in the winter months due to weather conditions, reduced staffing and suitable conditions to record species, particularly marine mammals. As there has been no dedicated survey effort these results have been used with caution, as discussed in Section 4.2.1. The data were analysed primarily in the following ways:
    - Presence/absence of species has been analysed for the last ten years to indicate patterns of presence during the summer period of November to April, when construction activities will occur; and
    - Maximum count observed in a single day has been analysed for the last three years of the summer season (November to April, 2014-2017) to indicate numbers of species that could be present at any one time during construction activities.

4.2 DATA GAPS AND UNCERTAINTIES

There are a number of data gaps and uncertainties associated with the information that was used to compile this baseline description. These are outlined in the following sections.

4.2.1 Rothera Station Survey Data

Three datasets of wildlife sightings have been recorded by staff which were collated at buildings based at Rothera Research Station including the station hangar, New Bransfield House and Bonner Laboratory. Sightings are generally incidental and recorded on an ad hoc basis by members of staff when out boating or walking around Rothera Point. Records from New Bransfield House and Bonner Laboratory have been collated since 1998, while data from the hangar have been collated since 2014. The latter is likely to be more accurate as these have been recorded by a single dedicated observer and reduce potential for duplication.

Various recording methods have been employed over the extensive years of data collation including number of sightings per day, maximum sightings in any week and sightings without numbers of individuals recorded. As there is no prescribed methodology or consistent approach in terms of dedicated effort, frequency or recording numbers the data cannot be analysed to provide accurate population estimates in order to characterise the baseline. However, they do provide an indication of the type of species present, the general seasonality of species presence and the most commonly sighted species within the vicinity of Rothera Point, over numerous years. This allows a reasonable insight into the species likely to be present during the proposed construction period and potential peak numbers in any single day.

4.3 LOCAL ENVIRONMENT/HABITAT

4.3.1 Bathymetry

The seabed around Rothera Point shelves steeply with depths in excess of 500 m found within 5 km of the station. Waters less than 50 m deep are restricted to the immediate fringes of the coastline (Hughes et al*,* 2016). Currents along the coastline are minimal; however, the channel between Rothera Point and Killingbeck Island (approximately 2 km northeast) experiences current speeds in excess of 0.5 knots.

Bathymetry data was provided by BAS and has a data resolution of 50 m (see Figure 4.2). Figure 4.2 shows that the seabed to the south and west of the existing wharf steeply drops to depths of around 400 m at approximately 0.8 km from Rothera Point. The seabed to the east and north is characterised by shallower depths closer to shore and a more gradual descent into deeper waters.

A bathymetric survey was conducted at the existing wharf during February 2016 (Figure 4.1). As described above the seabed is steeply sloping (majority steeper than 25° angle) and consists primarily of rock (Hughes et al*,* 2016). Seawater depths reach 40 m within close proximity of the shoreline.

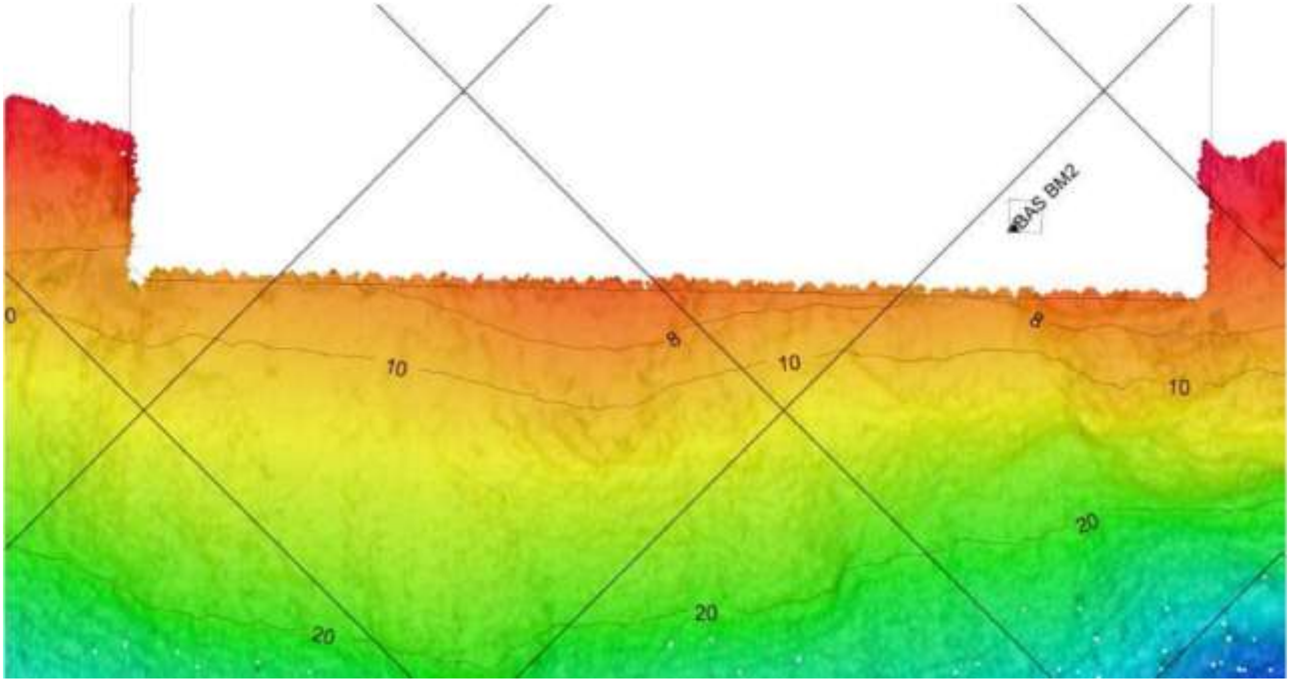

Figure 4.1 Figure showing the bathymetry at the existing wharf

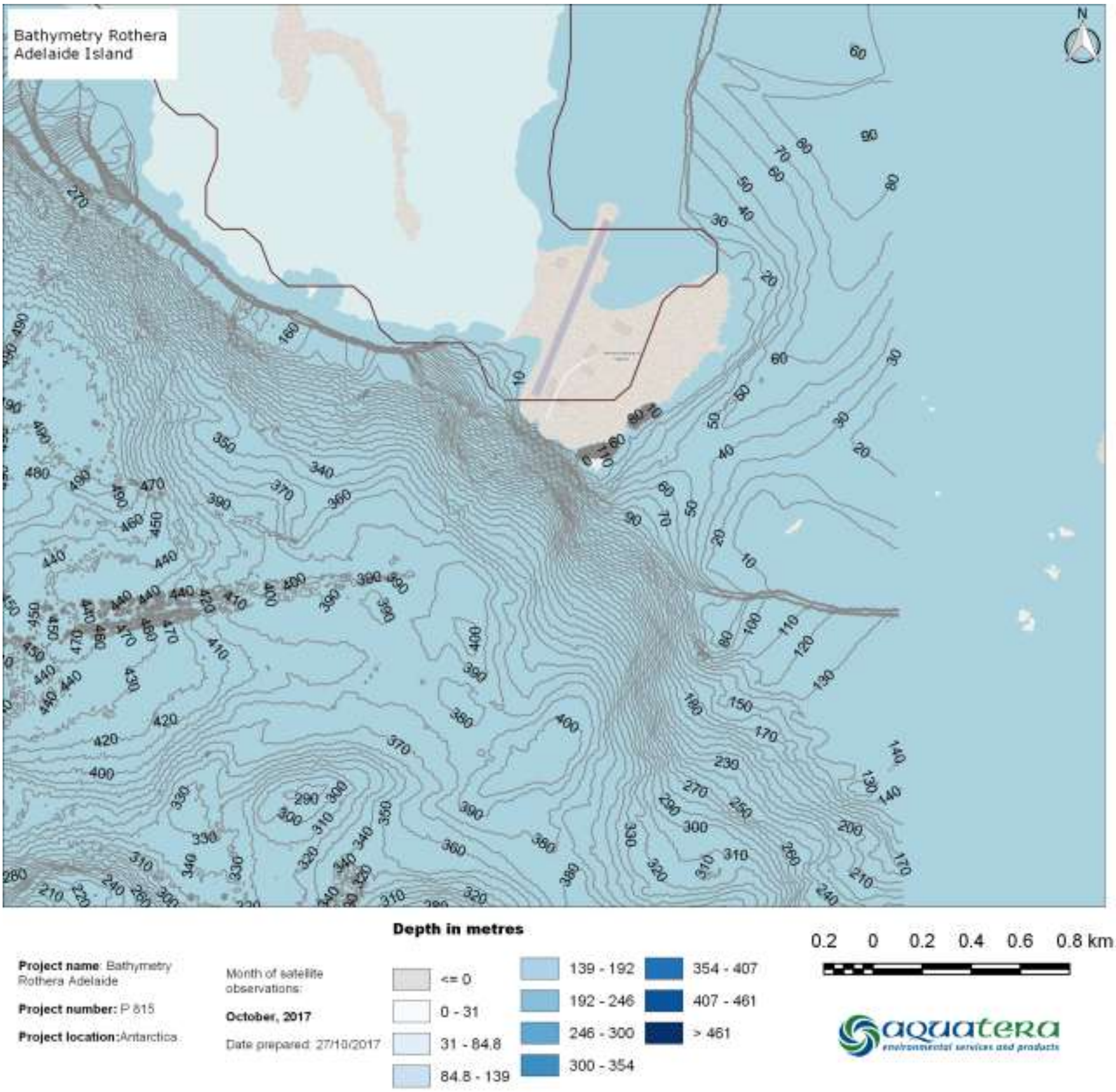

Figure 4.2 Bathymetry of the area around Rothera Point

4.3.2 Tidal range

The tides at Rothera are diurnal (i.e. one high tide and one low tide each day). On some neap tides the difference between high and low water can be very small.

Astronomical tides for Rothera Point are given on Admiralty Chart 3462 as follows:

- Mean High High Water (MHHW) - +1.3 m CD
- Mean Low Low Water (MLLW) - +0.4 m CD
- Mean Sea Level (taken as mean of MHHW & MLLW) - +0.85 m CD

4.3.3 Bedrock geology and sedimentology

Existing models showing the growth of the Antarctic Peninsula through the collision of the Continent with an offshore volcanic island chain were recently reinterpreted by Johnson and Riley (2015)[8] as having evolved through a series of distinct events which emplaced new magmatic rocks and deposited new sedimentary rocks directly on to and from within the Peninsula.

The stratified rocks of central Adelaide Island are probably of Late Jurassic age, based on similarities to rocks from elsewhere on the west coast of the Antarctic Peninsula (Hughes et al*,* 2016). The lithological unit that is directly relevant to Rothera Point and the surrounding area is the 'Adelaide Island intrusive suite' which is a series of isolated and composite granitoid plutons. A large part of the exposed geology on Adelaide Island consists of these plutonic rocks. Many of the plutons on Adelaide Island are heterogeneous and are characterised by concentrations of well-rounded xenoliths, which are typically more mafic than the host rock. The plutons can be seen to intrude the volcano-sedimentary sequences at several localities, including Reptile Ridge which lies at the top of the Rothera ice ramp.

The geology around Rothera Point is dominated by granodiorite, with minor amounts of quartz diorite and diorite. The geology of Rothera Point is interpreted to be consistent with the rest of the Adelaide Island intrusive suite and is therefore thought to be approximately 48 Ma (Eocene age). The mineralogy of the Rothera Point granodiorite consists of plagioclase, quartz, amphibole, biotite and variable amounts of chlorite and epidote, which has formed along cracks and joints in the rock, as a result of hydrothermal alteration. Malachite (copper) mineralisation is also a characteristic of the granodiorites of the Wright Peninsula and Rothera Point.

Generally, given steep subsea slopes and surrounding terrain with limited catchment areas at Rothera, there is likely to be limited sediment accumulations.

4.3.4 Weather features

Prevailing winds at Rothera come from the south and can reach gale force around 70 days a year (BAS, 2017)[9]. Sea ice forms during late May to late November with sustained periods of calm conditions required for ice to form and become fast[9].

Visibility observations at Rothera during the summer months (Oct 1st to March 31st) indicate that since 2008/2009 there have been relatively few days where visibility was less than 1 km with only 12% of daily recordings (taken at 0900, 1200, 1500 and 2100 hours) falling into this category.

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[8] Johnson, B. A. and Riley, T. R. 2015. Autochthonous v. accreted terrane development of continental margins: a revised in situ tectonic history of the Antarctic Peninsula http://jgs.lyellcollection.org/content/jgs/172/6/822.full.pdf

[9] BAS (2017) https://www.bas.ac.uk/polar-operations/sites-and-facilities/facility/rothera/

4.3.5 Ambient underwater noise

Antarctica's isolation and rough conditions mean its waters do not experience as much anthropogenic noise pollution as other areas of the planet. Shipping traffic in the southern hemisphere is 20 dB lighter than elsewhere in the world, there is no mineral exploration/exploitation or construction of offshore renewable energy installations in the Antarctic and the hardy conditions mean only highly equipped vessels are suitable for travel there (Umwelt Bundesamt, 2016) [10]. However, in recent years the Antarctic Peninsula area has increasingly experienced higher concentrations of shipping traffic during the summer months, as tourists, research and fishing vessels enter the area[10].

Existing anthropogenic underwater noise sources in the area around Ryder Bay are low and take the form of vessel traffic, consisting mainly of supply and personnel drop-offs to Rothera Research Station. This is sporadic and only occurs in the ice-free summer months.

Another potential source of underwater noise is naturally occurring and is formed by icebergs. Much research is still needed on this to be able to quantify and understand iceberg generated noise; however, the types of sounds generated by icebergs are two-fold: one is a long-duration harmonic tremor and the other is a broadband burst (Matsumoto et al*,* 2014)[11]. Harmonics tremors are generated when icebergs shoal together or collide with one another, while the more common short-duration bursts are generally associated with iceberg breakup (ice-quakes) in the open sea and are probably caused by edge wasting and rapid disintegration processes (Scambos et al*,* 2006)[12].

The area in the vicinity of the new wharf could not be classed as open sea and so it is reasonable to assume that the majority of naturally introduced noise from icebergs in the Rothera area will take the form of long-duration harmonic tremors as the ice collides and shoals together as it melts and breaks up in the summer months (late October to March). These noise levels are not as loud or impulsive as the short-duration broadband signals measured from large melting icebergs in warm, open sea waters and so the underwater noise levels produced from these would be less. Furthermore, there is potential that marine mammals in the area are habituated to these sorts of noise sources and it can be expected that they will either move away from, or are able to tolerate them, although the potential impact of noise generated by the collision and shoaling together of icebergs is not an area that has been the subject of detailed study.

[10] The Umwelt Bundesamt. 2016. Underwater noise. Available at: https://www.umweltbundesamt.de/en/underwater-noise#textpart-1

[11] Matsumoto, H., Bohnenstiehl, R. D., Tournadre, J., Dziak, P., Haxel, J. H., Lau, T. k. A., Fowler, M. and Salo, S. 2014. Antarctic icebergs: A significant natural ocean sound source in the Southern Hemisphere. *Geochemistry, Geophysics, Geosystems.* 15, 3448–3458, doi:10.1002/2014GC005454. Available at: http://onlinelibrary.wiley.com/doi/10.1002/2014GC005454/pdf Accessed 29 December 2017

[12] Scambos, T., R. Bauer, Y. Yermolin, P. Skvarca, D. Long, J. Bohlander, and T, Haran (2008), Calving and ice-shelf break-up processes investigated by proxy: Antarctic tabular iceberg evolution during northward drift, J. Glaciol., 54, 579–591, doi:10.3189/002214308786570836

4.4 ECOLOGICAL ENVIRONMENT

This section provides discussion around the protected areas, cetaceans, pinnipeds, fish and birds known to occur at or in the vicinity of the study area (Figure 1.1). These are the features that are considered to be possibly sensitive to underwater noise.

4.4.1 Protected areas

4.4.1.1 Antarctic Specially Protected Area (ASPA) 117 Avian Island

This site, located 0.25 km off the southwest tip of Adelaide Island and is approximately 40 km to the southwest of the underwater noise generating activities. The island is approximately 0.8 km^2 and, along with its littoral zone, has been designated an ASPA because of its abundance and diversity of breeding seabirds, particularly, Adélie penguins, blue-eyed shags, southern giant petrels, Dominican gulls, skuas, and Wilson's storm petrels (BAS, 2017)[13]. The site is also used by breeding Weddell seals and by fur seals hauling out.

This site is located off the southwestern tip of Adelaide Island and as a result would not be directly impacted by the underwater noise generating activities while birds or seals were in its immediate vicinity. This is because Adelaide Island prevents direct propagation of the underwater noise, from Rothera to Avian Island (see Figure 1.1). However, if birds and seals were to be feeding to the south and east of Avian Island there is potential that they could be in the path of the underwater noise. The potential impact of the underwater noise generating activities on these species is considered in Section 5.5.

4.4.1.2 Site of Special Scientific Interest (SSSI) 129 Rothera Point, Adelaide Island

This site, located on the northwest of Rothera Point, is approximately 0.1 km^2. It was designated on the grounds that the site serves to monitor the impact of the nearby station on an Antarctic fellfield ecosystem (Hughes et al*,* 2016). The site was not designated for its biodiversity value and so is not overly productive, with some polar skua and Dominican gulls known to nest there. This site will not be impacted by the underwater noise generating activities and so is not considered further in this assessment.

4.4.2 Cetaceans

4.4.2.1 Mysticetes

Mysticetes, also known as baleen whales, rely on their baleen plates to sieve plankton and other small organisms including krill and small fish from the water. They use low frequency sound to communicate and navigate over long distances. Species known to be present in waters in the Study Area include minke whale, humpback whale, blue whale and fin whale.

Minke whale

The Antarctic minke whale (*Balaenoptera bonaerensis*) is abundant in Antarctica throughout the summer months and is present in greatest densities near to the ice edge and to some extent within the pack ice and polynyas (Reilly et al, 2008[14]). The species is classified as being Data Deficient (DD) on the IUCN's Red List of Threatened Species and is

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[13] British Antarctic Survey. 2017. Antarctic Protected Areas Proposed by the UK. https://www.bas.ac.uk/about/antarctica/environmental-protection/special-areas-and-historic-sites-of-antarctica/antarctic-protected-areas-proposed-by-the-uk/

[14] Reilly, S.B., Bannister, J.L., Best, P.B., Brown, M., Brownell Jr., R.L., Butterworth, D.S., Clapham, P.J., Cooke, J., Donovan, G.P., Urbán, J. & Zerbini, A.N. 2008a. *Balaenoptera bonaerensis*. The IUCN Red List of Threatened Species

listed in Appendix II of the Conservation of Migratory Species of Wild Animals (CMS) or the Bonn Convention. Appendix II covers migratory species that have an unfavourable conservation status and that require international agreements for their conservation and management, as well as those that have a conservation status which would significantly benefit from the international cooperation that could be achieved by an international agreement (CMS, 2015[15]). Despite being classed as DD numbers are thought to be high, in the hundreds of thousands. Particularly high densities of minke whale have been observed in some years in high Antarctic areas such as Prydz Bay (located over 4000 km east on the south Indian Ocean side of Antarctica), the Weddell Sea (located approximately 400 km away on the eastern side of the Antarctic Peninsula) and the Ross Sea (over 3000 km south west in the South Pacific region of Antarctica (Kasamatsu et al, 1997[16]).

Antarctic minke whales can be solitary or form small groups, but they are generally seen in groups of two to four individuals. Individuals are known to form clusters in relatively enclosed areas (e.g. bays) as opposed to open water habitats (Ainley et al, 2007[17]). The species is known to actively avoid moving ships and uses 'porpoising' (swimming close to the surface at high speed) behaviour in doing so. Conversely, the species is known to be one of the most inquisitive and as a result they are one of the most frequently observed baleen whales because of their habit of approaching stationary boats (Ainley et al., 2007). Niche partitioning is thought to occur at Rothera Point with minke whale feeding near to the surface and humpback whales feeding in deeper waters (Hughes et al, 2016).

Observational records indicate that minke whales are present in the waters around Rothera throughout the summer season with more frequent sightings in January and February. Within the last three years, a maximum summer count of four minke whales was observed in a single day in March of 2017 (2014-2017). Overall, these sightings account for a very limited proportion of the total Antarctic minke whale population which is thought to be in the hundreds of thousands[14].

Despite its known abundance throughout the Antarctic the minke whale's DD status on the IUCN Red List of Threatened Species means it is considered to be of medium sensitivity for the purposes of this assessment.

Humpback whale

The humpback whale (*Megaptera novaeangliae*) is abundant throughout the Antarctic during summer where they predominantly feed on krill. The species is listed as Least Concern (LC) on the IUCN's Red List of Threatened Species (Reilly et al, 2008a[18]) and is on Appendix I of the CMS. Appendix I of the CMS comprises migratory species that have been assessed as being in danger of extinction throughout all or a significant portion of their range (CMS, 2015). They

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2008: e.T2480A9449324. http://dx.doi.org/10.2305/IUCN.UK.2008.RLTS.T2480A9449324.en. Downloaded on 27 November 2017

[15] Convention on the Conservation of Migratory Species of Wild Animals. 2015. Appendix I and II of CMS. Available at: http://www.cms.int/en/page/appendix-i-ii-cms

[16] Kasamatsu, F., Ensor, P. and Joyce, G. G. 1997. Preliminary investigation on aggregations of minke whales in Ross Sea, Weddel Sea and Prydz Bay. *International Whaling Comimission Scientific Committee*.

[17] Ainley, D., K. Dugger, V. Toniolo, I. Gaffney. 2007. Cetacean occurrences patterns in the Amundsen and southern Bellingshausen sea sector, Soutern Ocean. *Marine Mammal Science*, 23(2): 287-305.

[18] Reilly, S.B., Bannister, J.L., Best, P.B., Brown, M., Brownell Jr., R.L., Butterworth, D.S., Clapham, P.J., Cooke, J., Donovan, G.P., Urbán, J. & Zerbini, A.N. 2008. *Megaptera novaeangliae*. The IUCN Red List of Threatened Species 2008a: e.T13006A3405371. http://dx.doi.org/10.2305/IUCN.UK.2008.RLTS.T13006A3405371.en. Downloaded on 27 November 2017.

are usually seen alone or with one other whale, but they may form small groups of four or five individuals. They are present up to the ice edge, but not within the pack ice zone (Reilly et al, 2008a). The species was significantly reduced due to commercial whaling, but is now believed to be recovering (Johnston et al, 2012[19]). Humpbacks make long migrations north to breed during winter; however a recent study has found an increasing reluctance of the species to leave these summer feeding grounds, and has revealed that Antarctica's bays are a more important food source than scientists had expected (Johnston et al, 2012).

The Antarctic population of humpback whales is divided into seven major breeding stocks (A through G), based on their wintering breeding grounds (Reilly et al, 2008b). The wintering grounds of these are:

A. Southwest Atlantic: coast of Brazil
B. Southeast Atlantic: the coast of West Africa from the Gulf of Guinea down to South Africa
C. Southwestern Indian Ocean: coasts of eastern South Africa, Mozambique, Madagascar (southern, western and eastern coasts), Mayotte, the Comoros and other western Indian Ocean island groups;
D. Southeastern Indian Ocean: northwestern Australia
E. Southwest Pacific: northeastern Australia, New Caledonia, Tonga and Fiji.
F. Central South Pacific: Cook Islands and French Polynesia
G. Southeast Pacific: Ecuador, Galápagos, Colombia, Panama and Costa Rica

The abundance of humpback whales during summer in the Antarctic, south of 60°S, has been estimated from data from the International Decade of Cetacean Research (IDCR) (later the Southern Ocean Whale and Ecosystem Research, SOWER) programme surveys. Areas of the Antarctic have been surveyed each year since 1978/79, yielding three sets of circumpolar surveys. The results of each circumpolar survey are listed in Table 4.1. It should be noted that all three circumpolar estimates are probably underestimates of the hemispheric population, because not all humpback whales will have been south of 60°S during the surveys, and major summer concentration areas north of 60°S in the South Atlantic (to the east of South Georgia and in the vicinity of the South Sandwich Islands and around Bouvet Island) were not included.

Table 4.1 Circumpolar abundance estimates for humpback whales in their summer feeding range south of 60° S (Reilly et al, 2008a)

Period	Estimate	Confidence Value
1978-84	7,100	0.36
1985-91	10,200	0.30
1992-2004	41,800	0.11

At Rothera Point, in keeping with occurrences throughout Antarctica, humpback whales are more generally observed at the pack edge which shifts position as the season progresses. Antarctic krill are broadly distributed along the continental shelf and nearshore waters during the spring and early summer, and move closer to land during summer and autumn. More specifically, there are areas within Marguerite Bay which have been predicted (based on habitat

[19] Johnston, D., Friedlaender, A. S., Read, A. J. and Nowacek, D. P. 2012. Initial density estimates of humpback whales Megaptera novaeangliae in the inshore waters of the western Antarctic Peninsula during the late autumn. *Endangered Species Research*. Vol 18 pp 63-71. Available at http://www.int-res.com/articles/esr_oa/n018p063.pdf Accessed 27 November 2017.

modelling) to have high humpback whale occurrence rates due to the presence of krill, including the area around Rothera Point and the northern extent of Marguerite Bay near the southeastern end of Adelaide Island (Figure 4.3).

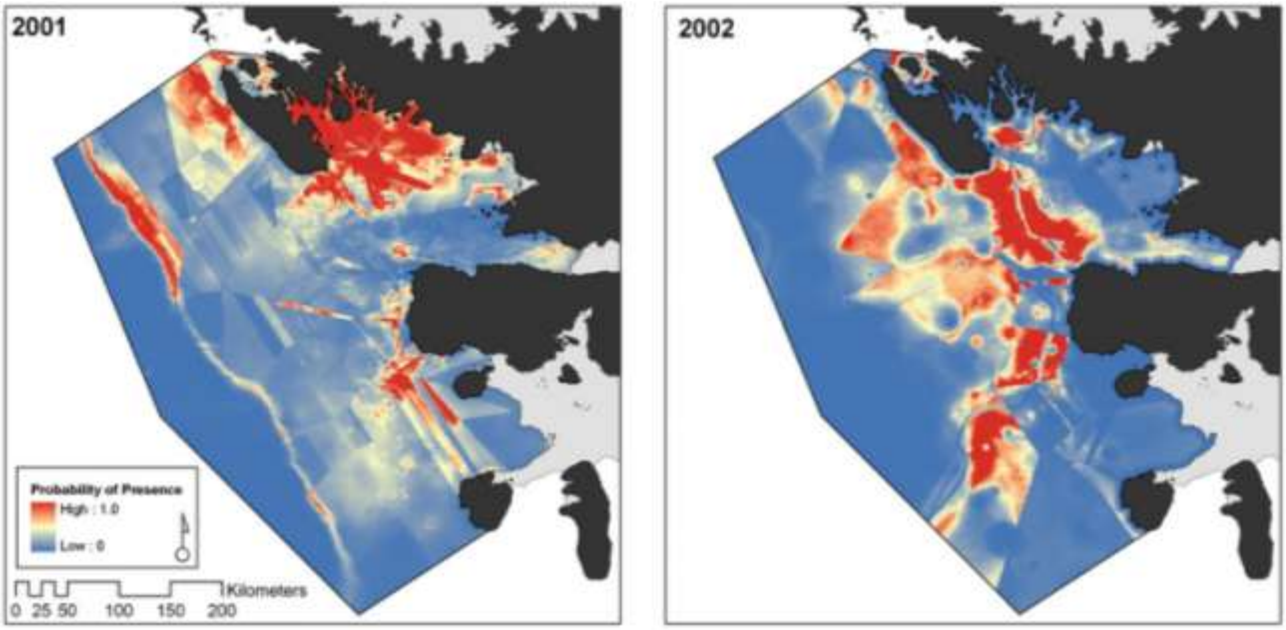

Figure 4.3 Predictions of suitable habitat for humpback whales in 2001 and 2002 based on prey distribution (Friedlaender et al, 2011[20])

Niche partitioning has been observed between humpback and minke whales in this area, suggesting minke whales feed closer to the surface and humpbacks feed in deeper waters (Friedlaender et al, 2011). Consequently, humpback whale occurrences are linked with prey availability, and numbers may increase as the summer season proceeds, with the peak period between December and April. These studies are further corroborated by observational data collected from Rothera Point which indicate regular sightings throughout the summer season, though most frequently from December to January, suggesting that local waters around Rothera Point are summertime foraging habitat for humpback whales, but that visitors make up a relatively small proportion of the total Antarctic population south of 60° S which is greater than 40,000 individuals (Reilly et al, 2008a). Within the last three years, a maximum summer count of eight humpback whales was observed in a single day in April of 2015 (2014-2017).

Thus, Antarctica's bays are important feeding grounds for humpback whale and the species is relatively regularly occurring in the vicinity of Rothera, though not in significant numbers and with no correlating data to suggest high abundance in the wider Study Area. In view of the LC status of this species on the IUCN's Red List of Threatened Species, it is considered to be of low sensitivity to the underwater noise generating activities (see Section **Error! eference source not found.**).

[20] Friedlaender, A. S., Johnston, D. W., Fraser, W. R., Burns, J., Halpin, P. N., & Costa, D. P. (2011). Ecological niche modeling of sympatric krill predators around Marguerite Bay, Western Antarctic Peninsula. *Deep-Sea Research II*(58), 1729-1740.

Blue whale

Sometimes called the 'true' blue whale (*B. musculus ssp. intermedia*) the Antarctic blue whale is distinguished by its larger size and its Antarctic distribution in summer. The Antarctic population, which once provided the greatest contribution to the global blue whale population (estimated at 239,000 before exploitation), was severely impacted by commercial whaling (Branch et al, 2004[21]). The subspecies experienced a depletion of over 98% and as a result is classified as Critically Endangered (CR) on the IUCN's Red list of Threatened Species while other subspecies are classed as Endangered (E) (Reilly et al, 2008b[22]). The species is also listed on Appendix I of the CMS.

The Antarctic blue whale is a summer resident in Antarctica, from the Antarctic Polar Front up to and into the ice. Its winter distribution is not well understood, although it is presumed that animals migrate to lower latitudes, mainly because, throughout the commercial whaling period, they were caught off Namibia, South Africa and Chile during winter (Reilly et al, 2008b). The Southern Hemisphere (excluding pygmy blue) approximate population estimate in 1997/98, based on data from the IWC was 2,300 and is estimated to have been increasing at a rate of 8.2% per year between 1978/79 and 2003/04 (Reilly et al, 2008b).

A survey undertaken in 2001 and 2002 by Sirovic and Hildebrand (2011)[23], which utilised passive acoustic monitoring equipment to monitor blue whale vocalisations, provided a rare opportunity to investigate distribution patterns by calling blue whales in the Ryder Bay region. The study found blue whales are more likely to be located west of Adelaide Island with little evidence for blue whale activity in Marguerite Bay.

There were no recorded sightings of blue whale within the vicinity of Rothera Point from the observational data since records began in 1998. Although it is recognised that absence of incidental sightings does not necessarily negate their presence, it is considered to be a reasonable indication, when considered in combination with the results of the Sirovic and Hildebrand study.

In summary, the Antarctic blue whale is considered to be of high sensitivity to underwater noise generating activities due to its IUCN Red List status of CR. However, the species is not anticipated to use the waters around the Rothera base and is therefore considered not to have any exposure risk to possible PTS or TTS noise impacts.

Fin whale

While some fin whales (*B. physalus*) do penetrate into the high Antarctic, the majority of fin whale summer distribution is in the middle latitudes of the southern hemisphere (Reilly et al, 2013[24]). The species is classed as Endangered (EN)

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[21] Branch, T. A. and Butterworth, D., S. 2001. Estimates of abundance south of 60°S for cetacean species sighted frequently on the 1978/79 to 1997/98 IWC/IDCR-SOWER sighting surveys. Available at: http://bit.ly/2iN9GOz Accessed 24 November 2017.

[22] Reilly, S.B., Bannister, J.L., Best, P.B., Brown, M., Brownell Jr., R.L., Butterworth, D.S., Clapham, P.J., Cooke, J., Donovan, G.P., Urbán, J. & Zerbini, A.N. 2008. *Balaenoptera musculus*. The IUCN Red List of Threatened Species 2008b: e.T2477A9447146. http://dx.doi.org/10.2305/IUCN.UK.2008.RLTS.T2477A9447146.en. Downloaded on 24 November 2017.

[23] Sirovic, A, Hildebrand JA. 2011. Using passive acoustics to model blue whale habitat off the Western Antarctic Peninsula. Deep-Sea Research Part Ii-Topical Studies in Oceanography. 58:1719-1728.

[24] Reilly, S.B., Bannister, J.L., Best, P.B., Brown, M., Brownell Jr., R.L., Butterworth, D.S., Clapham, P.J., Cooke, J., Donovan, G.P., Urbán, J. & Zerbini, A.N. 2013. *Balaenoptera physalus*. The IUCN Red List of Threatened Species 2013: e.T2478A44210520. http://dx.doi.org/10.2305/IUCN.UK.2013-1.RLTS.T2478A44210520.en. Downloaded on 27 November 2017.

on the IUCN Red List of Threatened Species, mainly due to a global population decline of more than 70% over the last three generations (1929-2007), of which major reductions are attributed to a loss of animals in the southern hemisphere.

The EN status of fin whale means it is considered to be of high sensitivity to underwater noise generating activities. Studies in and around Marguerite Bay have provided little evidence for substantial fin whale activity (Hughes et al, 2016). There were no recorded sightings of fin whale within the vicinity of Rothera Point from the observational data since records began in 1998. Although, it is recognised that absence of incidental sightings does not necessarily negate their presence, it is considered a reasonable indication that the species does not use the waters around the Rothera base and is therefore, like the blue whale, considered not to have any exposure risk to possible PTS or TTS noise impacts.

4.4.2.2 Odontocetes

Odontocetes, often referred to as the toothed whales, include, for example, dolphin, porpoise and sperm whale. Odontotocetes use high frequency vocalisations for echolocation or biosonar. The only species of toothed whale known to be present in the Study Area is orca (*Orcinus orca*). However, there is a very slight potential for the occurrence of spectacled porpoise (*Phocoena dioptrica*) at the site and so it has been included in this assessment.

Orca

Orca, or killer whales, are currently considered to be monotypic (belonging to one species). However, as research has expanded researchers have described different ecotypes of the species, of which variations in appearance and prey, have been described. They are classified as DD (with some populations greatly reduced) on the IUCN's Red List of Threatened Species and are listed on Appendix II of the CMS.

Several analyses of line-transect surveys have provided abundance estimates for orca around Antarctica (Hammond 1984[25]; Kasamatsu and Joyce 1995[26]), although some of these have been considered biased because of their methodology and the survey coverage (Branch and Butterworth, 2001). More recent analyses that account for some of these biases resulted in an estimate of 25,000 for waters south of 60°S (Branch and Butterworth, 2001); however due to a lack of certainty related to coverage of areas in the pack ice, this abundance estimate could be higher. Densities of orcas in Antarctic waters vary locally, with densities understood to be higher closer to the ice edge where smaller ecotypes can occur in large aggregations of tens to hundreds of animals (Pitman and Ensor, 2003[27]).

A photo-identification study by Reisinger et al (2011)[28] of the three different ecotypes that occur in the Antarctic Peninsula area identified at least 372 type A Killer Whales (specialist predators of minke whales). In the Prince Edward Island Archipelago (mainly around Marion Island) from 2006-2009 the local population was estimated at around 42 individuals (95% CI=35-50) that are known to prey seasonally on penguins and elephant seals.

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[25] Hammond, P. S. 1984. Abundance of killer whales in Antarctic areas II, III, IV and V. *Reports of the International Whaling Commission* 34: 543-548.

[26] Kasamatsu, F. and Joyce, G. G. 1995. Current status of odontocetes in the Antarctic. *Antarctic Science* 7: 365-379.

[27] Pitman, R. L. and Ensor, P. 2003. Three forms of killer whales (*Orcinus orca*) in Antarctic waters. *Journal of Cetacean Research and Management* 5: 131-139.

[28] Reisinger, R.R., de Bruyn, P.J.N., and Bester, M.N. 2011. Abundance estimates of killer whales at subantarctic Marion Island. *Aquatic Biology* 12: 177–185. DOI: 10.3354/ab00340.

Orcas are known to inhabit Marguerite Bay. This is evidenced by the relatively large number of sightings each summer (Hughes et al, 2016) with observational data indicating sightings most frequently around December to March around Rothera Point and the nearby bays. Within the last three years, a maximum summer count of eighteen orcas was observed in a single day in February of 2017 (2014-2017). Anecdotal records indicate that orca enter Ryder Bay and navigate through South Cove and along the front of the wharf. Although orcas are regularly sighted in relatively large numbers in the waters around Rothera, these numbers do not represent a significant proportion of the population south of 60°S which, in 2001 was estimated to be 25,000 (Branch and Butterworth, 2001).

For the purposes of this assessment orca are considered to be of medium sensitivity because of their observed frequency of occurrence in the Ryder Bay area and their listing as DD on the IUCN's Red List of Threatened Species.

Spectacled porpoise

The spectacled porpoise is an elusive species with its range thought to be circumpolar in the sub-Antarctic zone, inhabiting water with temperatures of at least 1-10° (Sekiguchi et al*,* 2006[29]). The species is thought to be oceanic in nature, but sightings at sea are rare with only a few dozen live sightings often of low numbers of individuals (up to 3). Despite the lack of live sightings stranding records indicate that spectacled porpoise has a widespread distribution in the Southern Ocean and may be more regularly occurring in some regions than previously thought. Bone remains or strandings have been recorded from the coasts of Uruguay, Argentina and South Georgia in the Atlantic Ocean, and sightings records also show a concentration in the Pacific Ocean sector of the Antarctic (Sekiguchi et al*,* 2006). The southernmost sighting of the species was at 64° 34°S which is over 4000 km to the northeast (Hammond et al*,* 2008[30]) of the study area. While it is highly unlikely that this species would be present in the study area, it has been scoped into the assessment as a precautionary measure.

In summary, the species has DD status on the IUCN's Red List of Threatened Species meaning that it is classed as being of medium sensitivity to the underwater noise generating activities. However, the spectacled porpoise's oceanic nature and apparent occurrence in the more temperate waters of the sub-Antarctic, particularly in the Pacific region, means its potential for occurrence at the site is highly unlikely, and the species is therefore considered not to have an exposure risk from the proposed activities.

4.4.3 Pinnipeds

Pinnipeds found in the Study Area include Weddell seal (*Leptonychotes Weddellii*), fur seal (*Arctocephalus gazella*), crabeater seal (*Lobodon carcinophaga*), elephant seal (*Mirounga leonina*) and to a lesser extent leopard seal (*Hydrurga leptonyx).*

The following sections describe the species, known to occur at the site, which belong to two separate families of the pinnipedia; the true (earless) seals, also referred to as Phocidae, and the eared seals also referred to as Otariidae.

[29] Sekiguchi, K., Olavvarria, C., Morse, L., Olson, P., Ensor, P., Matsuoka, K., Pitman, R., Findlay, K. and Gorter, U. 2006. The spectacled porpoise (Phocoena dioptrica) in Antarctic waters. *Cetacean Resource Management*. Available at: https://www.researchgate.net/publication/288842846_The_spectacled_porpoise_Phocoena_dioptrica_in_Antarctic_waters

[30] Hammond, P.S., Bearzi, G., Bjørge, A., Forney, K., Karczmarski, L., Kasuya, T., Perrin, W.F., Scott, M.D., Wang, J.Y., Wells, R.S. & Wilson, B. 2008. *Phocoena dioptrica*. The IUCN Red List of Threatened Species 2008: e.T41715A10545460. http://dx.doi.org/10.2305/IUCN.UK.2008.RLTS.T41715A10545460.en. Downloaded on 06 Jan 2018.

The earless seals have been found to hear over a wider range of frequencies than eared seals (NMFS, 2016[31]) which is why they have been considered separately.

All seal species known to occur at the site are classed as LC on the IUCN's Red List of Threatened Species and are all, therefore, based on the criteria set out in Table 3.1, considered to be of low sensitivity to the proposed underwater noise generating activities.

4.4.3.1 True (earless) seals

Weddell seal

The Weddell seal is the world's southern-most breeding mammal and is widespread throughout the Southern Ocean (Hückstädt, 2015[32]). Abundance estimates are difficult and expensive to make with estimations varying from 200,000 to 1,000,000 million individuals (Hückstädt, 2015). Weddell seals are present at many islands along the Antarctic Peninsula that are seasonally ice free.

Weddell seal habitat usage and patterns vary largely at a regional scale with large differences in the scale of their movements (tens to hundreds of kilometres) depending on the area they inhabit (Hückstädt, 2015). Additionally, there also appears to be individual variability in their patterns of habitat usage with some individuals staying near to their breeding colonies while others venture into the pack ice and are thought to be exploiting polynyas and areas of thinner sea ice (Hückstädt, 2015).

Weddell seals can reach depths of up to 600m and can undertake dives of at least 82 minutes. Their diet varies at a regional scale with seals around Rothera Point likely feeding on a mixture of Antarctic silverfish, Antarctic toothfish and cephalopods. They are known to feed with a diurnal pattern and at depths of 100-350m (Testa, 1994[33]).

Weddell seals are not known to use Rothera Point as a breeding site but are present in the area around Rothera Point all year round with pups being born out on the sea ice in late September (Hughes et al, 2016). They mainly appear to the north of the point and East Beach and have been recorded on Lagoon Island south-southeast of Rothera Research Station with regular observational sightings recorded throughout the summer season. Within the last three years, a maximum summer count of 28 seals was observed in a single day in February of 2016 (2014-2017). Despite these sightings the Weddell seal population at Rothera is not considered to represent a significant proportion of the wider Antarctic population.

Crabeater seal

Crabeater seals are found right up to the coast and ice shelves of Antarctica and as far south as the Bay of Whales during late summer ice breakup (Hückstädt, 2015a[34]). Crabeater seals are abundant year-round residents of the

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[31] National Marine Fisheries Service. 2016. Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing: Underwater Acoustic Thresholds for Onset of Permanent and Temporary Threshold Shifts. U.S. Dept. of Commer., NOAA. Available at: http://bit.ly/2j0qcOh

[32] Hückstädt, L. 2015. *Leptonychotes weddellii*. The IUCN Red List of Threatened Species 2015: e.T11696A45226713. http://dx.doi.org/10.2305/IUCN.UK.2015-4.RLTS.T11696A45226713.en. Downloaded on 27 Nov 2017.

[33] Testa, J.W. 1994. Over-winter movements and diving behavior of female Weddell seals (*Leptonychotes weddellii*) in the southwestern Ross Sea, Antarctica. *Canadian Journal of Zoology* 72(10): 1700-1710.

Antarctic pack ice (Hückstädt, 2015a). They occur in greatest numbers in the shifting pack ice surrounding Antarctica. Pups are born from September to December with a high rate of first-year mortality, possibly up to 80%, much of which is attributed to leopard seal predation (Siniff and Bengtson, 1977[35]).

Crabeater seals are the most abundant seal in the world, with estimations of their abundance ranging from seven million up to 75 million seals living in Antarctica[36]. This huge abundance is linked to the decline in the number of baleen whales as a result of commercial whaling throughout the nineteenth and twentieth centuries which meant less competition for the crabeater's main source of food, krill.

Research has revealed that crabeater seals can dive up to 600 m and remain underwater for 24 minutes, however, most feeding dives occur within the top 50 m and are shorter in duration (Burns et al, 2004[37]). Foraging occurs principally at night, with records of seals diving continuously for up to sixteen hours (Hückstädt, 2015a). Research shows that dives are deeper at dawn and dusk which indicates that feeding activity is tied to the daily vertical migrations of krill (not crabs as their name would suggest) (Hückstädt, 2015a). There is a general pattern of feeding from dusk until dawn, and hauling out in the middle of the day.

The patchy distribution of krill which varies seasonally and because of environmental conditions means crabeater seal behavioural strategies are likely to change seasonally in response to factors that influence krill populations (Burns et al, 2004).

During summer, crabeater seals are likely to conduct shorter and shallower dives because of increased abundance of adult krill in the upper 50 m of the water column, at these times (Burns et al, 2004). Burns et al (2004) also indicates that deeper and longer dives throughout the winter are likely linked to an increased take of fish species (which are more prevalent in deeper water) and which crabeater seals rely on because of the decreased biomass of krill and large zooplankton throughout winter.

Observational records of crabeater seals indicate that they are present throughout the summer season. Within the last three years a maximum summer count of 40 seals was observed in a single day in February of 2017 (2014-2017).

Elephant seal

The southern elephant seal population is thought to be concentrated around South Georgia. There are no recent comprehensive estimates of abundance throughout the entire distribution range, although the global population was

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[34] Hückstädt, L. 2015a. *Lobodon carcinophaga*. The IUCN Red List of Threatened Species 2015: e.T12246A45226918. http://dx.doi.org/10.2305/IUCN.UK.2015-4.RLTS.T12246A45226918.en. Downloaded on 28 Nov 2017.

[35] Siniff, D.B. and Bengtson, J.L. 1977. Observations and hypotheses concerning the interactions among crabeater seals, leopard seals and killer whales. *Journal of Mammalogy* 58: 414-416.

[36] Bishop, C. 2017. The crabeater seals of Antarctica. Available at: https://oceanwide-expeditions.com/blog/the-crabeater-seals-of-antarctica

[37] Burns, J. M., Costa, D. P., Fedak, M. A., Hindell, M. A., Bradshaw, C., Gales, N. J., McDonald, B., Trumble, S. J. and Crocker, D. E. 2004. Winter habitat use and foraging behaviour of crabeater seals along the Western Antarctic Peninsula. *Deep Sea Research*. pp 2279-2303.

estimated to be 650,000 in the mid-1990s (SCAR EGS 2008[38]). Four distinct populations have been identified in the Southern Ocean. The Atlantic sector subpopulations which are nearest to the Antarctic Peninsula include colonies at:

- South Georgia
- South Orkney Islands
- South Shetland Islands

These colonies are known to be growing or stable (Hofmeyr, 2015) [39].

Southern elephant seals undertake an annual double migration between foraging grounds and isolated haul-out sites, at which they are born and where they breed in spring, moult in summer and, as infants, haul-out in winter (Hofmeyr, 2015). The species spends the majority of its time at sea, with adult females spending more than 85% of each year at sea, while adult males spend less than 80%. Foraging grounds may be located over 5,000 km from their terrestrial haul-out sites (Bailleul et al, 2007[40]).

Southern elephant seals spend most of their at-sea time foraging in association with frontal systems, currents and shifting ice edge zones. Studies of these foraging zones suggest that they are sensitive to fine-scale variation in bathymetry and ocean properties (sea-ice concentration and sea temperature profiles) which affect the distribution of their prey (Hofmeyr, 2015).

Elephant seals are accomplished divers, with depth and length varying between seasons and sexes, but mostly ranging from 200 m to 700 m deep and from 20 to 30 minutes in length (McIntyre et al, 2010[41]). Both sexes are thought to spend over 65% of their lives below 100 m (Hofmeyr, 2015).

Elephant seals appear in the Study Area in November and mainly congregate around North Cove and the northern end of the point, coming on to beaches and the base as the sea ice melts. Observational records indicate that they are present throughout the summer season. Within the last three years, a maximum summer count of 100 seals was observed in a single day in December of 2014 (2014-2017) which does not represent a significant proportion of the species population which is concentrated in the hundreds of thousands, around South Georgia.

Leopard seal

The Leopard seal (*Hydrurga leptonyx*) is widely distributed throughout Antarctic and sub-Antarctic waters being present from the coast of the Antarctic continent throughout the pack-ice and at most sub-Antarctic islands. Understanding of leopard seal habitat use and abundance is still limited and further study is required (Southwell et al,

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[38] SCAR-EGS. 2008. Scientific Committee for Antarctic Research – Expert Group on Seals Report. Available at: http://www.seals.scar.org/pdf/statusofstocs.pdf.

[39] Hofmeyr, G.J.G. 2015. *Mirounga leonina*. The IUCN Red List of Threatened Species 2015: e.T13583A45227247. http://dx.doi.org/10.2305/IUCN.UK.2015-4.RLTS.T13583A45227247.en. Downloaded on 28 November 2017.

[40] Bailleul, F., Charrassin, J. B., Monestiez, P., Roquet, F., Biuw, M. and Guinet, C. 2007. Successful foraging zones of southern elephant seals from the Kerguelen Islands in relation to oceanographic conditions. *Philosophical Transactions of the Royal Society B, Biological Sciences* 362: 2169-2181.

[41] McIntyre, T., deBruyn, P.J.N., Ansorge, I.J., Bester, M.N., Bornemann, H., Plötz, J. and Tosh, C.A. 2010. A lifetime at depth: vertical distribution of southern elephant seals in the water column. *Polar Biology* 33: 1037-1048.

2012[42]). An analysis of ship and aerial sighting surveys undertaken in Antarctica as part of the Antarctic Pack-Ice Seal (APIS) project which also included deployment of satellite-linked dive recorders to investigate haul-out behaviour, resulted in an estimated 35,500 leopard seals in the surveyed areas (Southwell et al, 2012). However, it should be noted that very few sightings of leopard seals have ever been obtained from sighting surveys and as a result these estimates have considerable uncertainty.

Both at sea and on ice, leopard seals tend to be solitary. Pups are born on sea ice from early November until late December, although the period may be as long as early October to early January (Southwell et al, 2003[43]).

Leopard seal diet is highly varied and changes with seasonal and local abundance. It includes, krill, fish, squid, penguins, a variety of other types of seabirds and juvenile seals, including crabeater, southern elephant and fur seals (Southwell et al, 2012). Leopard seals are known to regularly patrol penguin colonies and wait to ambush animals transiting to and from them (Hückstädt, 2015b [44]). Krill are also understood to be an important prey species (Lowry et al, 1988[45]).

Leopard seals are known to inhabit the waters around Rothera Point all year round (Hughes et al, 2016). Observational records indicate that they may be present throughout the summer season in low numbers. Within the last three years, a maximum summer count of six seals was observed in a single day in February of 2017 (2014-2017). This represents a very small proportion of the Antarctic population which is thought to be around 35,000.

4.4.3.2 Eared seals

Fur seal

Antarctic fur seals are the most abundant species of fur seal (Hofmeyr, 2016[46]). The majority (approximately 95%/550,000) of the population of this species are known to haul-out and breed on South Georgia, while the remaining population are known to use eleven other sites including numerous islands and the coast of Antarctica (Hofmeyr, 2016). Antarctic fur seals are thought to have a continuous circumpolar range with no distinct subpopulations. They are able to travel great distances having been recorded to move between island groups and as vagrants to distant localities (Boyd et al, 1998[47]; Shaughnessy et al, 2014[48]).

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[42] Southwell, C., Bengtson, J. Bester, M., Blix, A.S., Bornemann, H., Boveng, P., Cameron, M., Forcada, J., Laake, J., Nordøy, E., Plötz, J., Rogers, T., Southwell, D., Steinhage, D., Stewart, B.S. and Trathan, P. 2012. A review of data on abundance, trends in abundance, habitat use and diet of ice-breeding seals in the Southern Ocean. *CCAMLR Science* 19: 49-74.

[43] Southwell, C., Kerry, K., Ensor, P., Woehler, E.J. and Rogers, T. 2003. The timing of pupping by pack-ice seals in East Antarctica. *Polar Biology* 26: 648-652.

[44] Hückstädt, L. 2015b. *Hydrurga leptonyx*. The IUCN Red List of Threatened Species 2015: e.T10340A45226422. http://dx.doi.org/10.2305/IUCN.UK.2015-4.RLTS.T10340A45226422.en. Downloaded on 28 November 2017.

[45] Lowry, L.F., Testa, J.W. and Calvert, W. 1988. Notes on winter feeding of crabeater and leopard seals near the Antarctic Peninsula. *Polar Biology* 8: 475-478.

[46] Hofmeyr, G.J.G. 2016. *Arctocephalus gazella*. The IUCN Red List of Threatened Species 2016: e.T2058A66993062. http://dx.doi.org/10.2305/IUCN.UK.2016-1.RLTS.T2058A66993062.en. Downloaded on 28 November 2017.

[47] Boyd, I., McCafferty, D. J., Reid, K., Taylor, R. and Walker, T. R. 1998. Dispersal of male and female Antarctic fur seals. *Canadian Journal of Fisheries and Aquatic Sciences* 55: 845-852.

Fur seals are known to arrive to Rothera Point in varying numbers at the end of each summer (Hughes et al, 2016). Observational records indicate that they appear later in the season from January and can stay long into winter. They are also known to favour the northern end of the point and East Beach areas (i.e. the opposite end of the point to where the wharf is), but also often haul out in South Cove or venture along the southern end of the runway. Within the last three years, a maximum summer count of 240 seals was observed in a single day in March of 2017 (2014-2017). These observational records do not indicate a significant proportion of the total Antarctic fur seal population.

4.4.4 Fish

At a regional level, Donnelly and Torres (2007)[49] surveyed pelagic fishes in Marguerite Bay, an extensive area at the northern extremity of which Rothera is situated (see Figure 1.1). This research was part of the Southern Ocean Global Ocean Ecosystems Dynamics (SO GLOBEC) programme and took place during the Antarctic autumn and winter using a MOCNESS sampling net. Pelagic fishes are an important component of Antarctic ecosystems making up a major constituent of water column biomass in both oceanic and coastal areas. Six thousand and sixty individuals of 34 species, representing 13 families, were collected in autumn while 672 individuals of 22 species from 10 families were collected in the winter. Nearly all of the notothenioid specimens collected were either larvae or young juveniles (0-2 years), while the majority of the non-notothenioid specimens collected were predominantly adults. Notothenioids, sometimes referred to as icefishes or cod icefishes, are prevalent in the fish fauna of the Southern Ocean. They have evolved with various physiological and biochemical traits to adapt to cold water conditions. Many, though not all, of the Antarctic species of notothenioid have antifreeze glycoproteins in their body fluids that enable them to survive at water temperatures close to freezing point.

The study found that, generally, the pelagic fish community within Marguerite Bay is a variable mixture of mesopelagic and shallow water fauna. At one end of the spectrum is an oceanic assemblage displaying high-diversity indices and characterised by genera such as *Electrona, Gymnoscopelus*, *Protomyctophum*, *Bathylagus*, *Cyclothone*, and *Notolepis*. At the other end of the spectrum is a coastal assemblage with low diversity indices dominated by larval and juvenile notothenioids, particularly Antarctic silverfish (*Pleuragramma antarctica*).

Recent reductions in Antarctic silverfish have been observed along the west coast of the Antarctic Peninsula and are thought to be linked to a reduction in sea ice as a result of global warming[50]. The species is currently classed as Least Concern on the IUCN Red List of Threatened Species, which notes that it has been reported to be the most dominant pelagic fish species in areas of its broad distribution, but because this species plays an important role in the Antarctic ecosystem food web, continued monitoring of the population numbers is needed[51].

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[48] Shaughnessy P.D., Kemper, C.M., Stemmer, D. and McKenzie, J. 2014. Records of vagrant fur seals (family Otariidae) in South Australia. *Australian Mammalogy* 36: 154-168.

[49] Donnelly, J., Torres, J.J. Pelagic fishes in the Marguerite Bay region of the West Antarctic Peninsula continental shelf. In Deep Sea Research Part II: Topical Studies in Oceanography. Volume 55, Issues 3-4, February 2008, Pages 523-539. Available online 27 December 2007: https://doi.org/10.1016/j.dsr2.2007.11.015

[50] https://antarcticsun.usap.gov/science/contenthandler.cfm?id=2192

[51] Gon, O. & Vacchi, M. 2010. *Pleuragramma antarctica*. The IUCN Red List of Threatened Species 2010: e.T154785A4633007. http://dx.doi.org/10.2305/IUCN.UK.2010-4.RLTS.T154785A4633007.en. Downloaded on 03 January 2018.

At a more local level, there is limited information on fish found in the waters close to Rothera Wharf and in Ryder Bay. Hughes et al (2016)[52] describes marine benthic surveys that were carried out on three sites off the south coast of Rothera Point in depths of 9-10 m, in January 2016. The sites were: below the front of the current wharf (67.5723 S, 68.1296 W); at the end of the runway (67.5717 S, 68.1312 W); and inside of South Cove (67.5697 S, 68.1319 W).

The study found the benthic environment was made up of a mixture of bed rock and loose cobbles with occasional pockets of mixed cobbles and sediment with the area around the existing wharf largely consisting of loose cobles. Fish numbers were found to be very low, with only five individuals counted during the three surveys: 2 x *Notothenia coriiceps* (black rockcod); 1 x *Trematomus newnesi* (dusky rockcod); 1 x *Trematomus hansoni* (striped rockcod); and 1 x *Harpagifer antarcticus* (Antarctic spiny plunderfish). All of these species apart from *Harpagifer antarcticus* are notothenioids. None are evaluated on the IUCN Red List of Threatened Species.

In an appendix to Hughes et al (2016) a Marine Species List for Rothera (Biscoe) Wharf is provided based on review of 25 photos of the benthic environment at 100 m water depth during the Antarctic summer, coinciding with the plankton bloom. Notothenioids (Notothenia sp. and "pink icefish") are the only fish referred to in this list.

Campbell et al (2011) refer to the capture of 166 *Notothenia coriiceps* (black rockcod) in a 1 km^2 inshore area off Rothera Research Station between January 2004 and March 2005 as part of an experimental study to understand fish hibernation[53].

Thus, based on the available data it seems reasonable to assume that the fish fauna in the Rothera area will be similar to the coastal assemblage referred to by Donnelly and Torres (2007) in their wider regional study referred to above, i.e. dominated by notothenioids. The limited evidence available suggests that fish are not abundant in the immediate vicinity of the Rothera Wharf.

4.4.5 Birds

Species which are known to regularly occur at the site, but which are not considered to be sensitive to the underwater noise generating activities, due to foraging habits have been scoped out of the assessment. These include Antarctic petrel (*Thalassoica Antarctica*), snow petrel (*Pagodroma nivea*), Wilson's storm petrel (*Oceanites oceanicus*), south polar skua (*Stercorarius maccormicki*), kelp gull (*Larus dominicanus*), Antarctic (southern) fulmar (*Fulmarus glacialoides*) and southern giant petrel (*Macronectes giganteus*).

Additionally, species that have been observed around Rothera Point but of which sightings are less common or rare during the summer season, and which are also not considered to be especially sensitive to the underwater noise generating activities based on foraging habits, have also been scoped out of the assessment: Arctic tern (*Sterna paradisaea*), Cape petrel (*Daption capense*), snowy sheathbill (*Chionis albus*) and Brown skua (*Stercorarius antarcticus*).

4.4.5.1 Adélie penguin

The Adélie penguin (*Pygoscelis adeliae*) is common along the entire Antarctic coast, the only habitat in which it is resident. The species is listed as LC on the IUCN's Red List of Threatened Species. These inquisitive creatures feed

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[52] Hughes, K.A. (Lead Author). *Environmental Baseline Information for Rothera Point, Adelaide Island, Antarctica*. Draft Publication. BAS Environment Office, December 2016.

[53] Campbell, H.A., Fraser, K.P.P., Bishop, C.M., Peck, L.S. and Egginton, S. *Hibernation in an Antarctic Fish: On Ice for Winter*. In Research Progress in Fisheries Science edited by William Hunter, III. 2011. Pages 148-163.

mainly on a diet of krill, with Antarctic silverfish and glacial squid contributing to their food intake during the chick-rearing season.

At Rothera Point, Adélie penguins are seen almost daily during the summer months (late October to March) and less frequently, but still regularly, throughout the remainder of the year (Hughes et al, 2016). In summer, there is a large variation in counts with up to 120 birds observed on East Beach, 0.68 km to the northeast of the noise generating activities (Hughes et al, 2016). Winter occurrence is understood to be largely dependent on sea ice coverage with available records suggesting that they become quite scarce when the sea ice is at its most extensive. During February and March, many of the birds present come ashore to moult. From late February to April, a small number of first-year birds are often recorded, although during the winter almost all birds are adults.

Adélie penguins can be seen from November onwards at the northern end of the point, East Beach and Cheshire Island. During late December to February many will come ashore to moult during which time they are not able to return to the water to feed. Observational records over the last 10 years indicate regular presence throughout the summer season. Within the last three years, maximum summer counts in a single day average 30 individuals, with a peak count of 70 in April of 2016 (2014-2017).

4.4.5.2 Emperor penguin

The emperor penguin (*Aptenodytes forsteri*) breeds the farthest south of any penguin species, forming large colonies on the sea-ice surrounding the Antarctic continent. It is classified as Near Threatened (NT) on the IUCN's Red List of Threatened Species. Emperor penguins have the deepest and longest dives of any bird, being able to reach depths of 700 feet, and can stay submerged for up to 18 minutes (BAS, 2017[54]).

At Rothera Point emperor penguins are rare but sighted in most years, normally between August and November, but they can sometimes be seen towards the turn of the year. Within the last three years (2014-2017), the maximum summer count in a single day was three individuals in January of 2016. Recently it is generally single birds that have been seen, although a group of 19 was recorded once on 7 November 1977 (Hughes et al, 2016). Although the presence of this species around the base cannot be discounted the numbers are clearly very small.

4.4.5.3 Gentoo penguin

The Gentoo penguin (*Pygoscelis papua*) has a circumpolar breeding distribution and is found throughout Antarctica (BirdLife International, 2016[55]). The Antarctic Peninsula is one of the three most important breeding locations in its range with 94,751 pairs. The species is classed as LC on the IUCN's Red List of Threatened Species with global populations estimated to be growing, particularly in the southern extent of its range, with an increase from 314,000 to 387,000 pairs (Woehler 1993; Lynch 2013 in Birdlife International, 2016).

On the Antarctic Peninsula the species typically nests on low lying gravel beaches and dry moraines and forages close to breeding colony sites.

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[54] BAS. 2017. Emperor penguin. Available at: https://www.bas.ac.uk/about/antarctica/wildlife/penguins/emperor-penguin/

[55] BirdLife International. 2016. Pygoscelis papua. The IUCN Red List of Threatened Species 2016: e.T22697755A93637402. http://dx.doi.org/10.2305/IUCN.UK.2016-3.RLTS.T22697755A93637402.en. Downloaded on 05 January 2018

Sightings of the Gentoo penguin around Rothera have been very rare over the last ten years, most recorded around January during the summer season with only individual sightings. Within the last three years, individuals have been recorded in January 2016 and January 2017.

4.4.5.4 Chinstrap penguin

The chinstrap penguin (*Pygoscelis antarctica*) has a circumpolar distribution and is found throughout Antarctica. The global population is estimated at eight million and the species is classified as LC on the IUCN's Red List of Threatened Species (BirdLife International, 2012).

The birds are rare summer visitors to Rothera Point with records usually involving single birds between January and March (Hughes et al, 2016). The observational records indicate rare presence during the summer season and within the last three years, only individual sightings have been recorded in December 2014, January 2016 and February 2017.

4.4.5.5 Imperial shag/blue-eyed shag

The imperial shag or blue-eyed shag (*Phalacrocorax [atriceps] bransfieldensis*) is placed in the genus *Leucocarbo* by some taxonomic authorities and is listed as LC on the IUCN's Red List of Threatened Species. The species breeds in colonies up to hundreds of pairs, but often smaller.

Imperial shags feed on small benthic fish, crustaceans, polychaetes, gastropods and octopuses diving to, on average, 25 m. Most feeding takes place in inshore regions, however some populations will travel some distance from the shore for fish (Shirihai, 2002[56]).

Hughes et al (2016) describes the imperial shag population at Rothera Point. Up to 24 pairs are known to breed on a small rock just to the north of Killingbeck Island (1.6 km east of Rothera Point), approximately six pairs on the north end of Killingbeck Island and around 50 pairs on another small rock close to Lagoon Island (5 km to the southwest of the underwater noise source), although the exact numbers may vary considerably between years. Imperial shags are known to be present at all times of the year, with their presence in winter dependent on sea-ice conditions. Between late March and late June 1996, large flocks containing 300–400 adult and juvenile birds were seen, with over 1000 recorded on 22 June 1996, indicating that more than just the local breeding population was present. The observational records indicate presence throughout the summer season. Within the last three years maximum summer counts observed in a single day are generally around 50 to 60 individuals, however a peak of 200 birds was observed in a single day in April 2016 (2014-2017).

4.4.5.6 Antarctic tern

The Antarctic tern (*Sterna vittata*) has a very large range and population and is classified as LC on the IUCN's Red List of Threatened Species. The species is found along Antarctic coastlines and in a number of islands in the Southern Ocean. It breeds on rocky areas very near to the coast or a short distance inland, between November and December and generally nests in small colonies of 5-20 pairs (Birdlife International, 2016[57]). Outside of the breeding season the species moves to open water areas where they form communal roosts on ice floes and icebergs. Its diet consists mainly of small fish, however the species does take polychaetes, crustaceans, insects and algae[57].

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[56] Shirihai, H. (2002). *The Complete Guide to Antarctic Wildlife*. Princeton & Oxford: Princeton University Press

[57] BirdLife International. 2016. Sterna vittata. The IUCN Red List of Threatened Species 2016: e.T22694635A93460313. http://dx.doi.org/10.2305/IUCN.UK.2016-3.RLTS.T22694635A93460313.en. Downloaded on 06 January 2018.

Hughes et al, (2016) notes the presence of Antarctic tern in the vicinity of Rothera Point. The species breeds locally on Killingbeck Island, Reptile Ridge (approximately 100 pairs) and on Lagoon Island and possibly Anchorage Island. Birds are seen commonly around Rothera Point between late September/early October and March and far more rarely in winter. The observational records indicate variable presence throughout the summer period in the last ten years. Within the last three years, maximum summer counts in a single day vary from 10-40 with a peak count of 120 individuals in January of 2016 (2014-2017). Antarctic terns are plunge divers – quickly diving under the water to catch fish near the surface – and do not spend a lot of time underwater. They are not considered as sensitive to the underwater noise generating activities as penguins and shags which have longer duration dives to greater depths and are, therefore, not considered further within this assessment.

4.5 BASELINE SUMMARY

Table 4.2 summarises the species that will be considered in the impact assessment, their IUCN status, their likely presence and abundance (exposure risk), based on incidental observation data, and their sensitivity for the purposes of this impact assessment.

Table 4.2 Species that will be considered in the impact assessment and their exposure risk and sensitivity to the proposed activities

Species	IUCN Status	Likely presence and abundance based on incidental observational data gathered at Rothera Point (Exposure risk)	Sensitivity for assessment (based on criteria in Table 3.1)
Antarctic minke whale	DD	Regular sightings around Rothera throughout summer season in relatively low numbers compared to wider waters. Most frequent sightings in January and February.	Medium
Humpback whale	LC	Regular sightings around Rothera throughout the summer season, most frequently from December to January. Species likely to be abundant throughout northern Marguerite Bay.	Low
Antarctic blue whale	CR	No sightings around Rothera, likely to be infrequent visitor to local waters. **Therefore not considered to be at risk of impact exposure.**	High
Fin whale	EN	No sightings around Rothera, likely to be infrequent visitor to local waters. **Therefore not considered to be at risk of impact exposure.**	High
Orca	DD	Regular sightings of species around Rothera throughout the summer season, most frequently from December. Pod sightings vary between 3-10 individuals in Ryder Bay and have been as high as 18 in 2017.	Medium
Spectacled porpoise	DD	No sightings around Rothera. Species very unlikely to occur in the study area. **Therefore not considered to be at risk of impact exposure.**	Medium
Weddell seal	LC	Regular sightings around Rothera and wider area. Species is present year-round. Rothera Point not known to be used as a breeding colony site.	Low
Crabeater seal	LC	Regular sightings around Rothera throughout the summer season. Species is widely abundant in region. Rothera Point not known to be used as a breeding colony site.	Low

Species	IUCN Status	Likely presence and abundance based on incidental observational data gathered at Rothera Point (Exposure risk)	Sensitivity for assessment (based on criteria in Table 3.1)
Elephant seal	LC	Regular sightings around Rothera throughout the summer season, most commonly to the north of Rothera Point. Rothera Point not known to be used as a breeding colony site.	Low
Leopard seal	LC	Sightings throughout the summer season in low numbers, generally a solitary species. Species is present year-round.	Low
Fur seal	LC	Regular sightings generally later in the summer season and most commonly found hauling out towards the north of Rothera Point. Species is highly abundant in region.	Low
Fish spp.	LC or not evaluated	No evidence of fish abundance in area close to Rothera Wharf (based on very limited survey work). Fish fauna likely to be dominated by notothenioid species.	Low
Adélie penguin	LC	Regular sightings of species around Rothera in the summer season and most commonly to the north of Rothera Point and at East Beach. Average maximum count of 30 individuals.	Low
Emperor penguin	NT	Very rare sightings of species around Rothera in the summer season, generally around November averaging at a maximum count of three individuals.	Medium
Gentoo penguin	LC	Very rare sightings of species around Rothera and in single individuals	Low
Chinstrap penguin	LC	Very rare sightings of species around Rothera and in single individuals.	Low
Imperial shag	LC	Regular sightings of species throughout summer season, although generally in wider area of Lagoon Island and Killingbeck Island. Average maximum counts of 50-60 individuals, however up to 200 have been sighted.	Low

It can be seen from this assessment that three species have been considered to have no significant exposure risk, these are three cetaceans that have never been observed in the area (blue whale, fin whale and spectacled porpoise).

The species known to regularly occur at the site and which have been scoped out of the assessment because they are not deemed to be at significant risk of adverse impact as a result of the proposed underwater noise generating activities are as follows:

- Antarctic tern;
- Snow petrel;
- Wilson's storm petrel;
- South polar skua;
- Kelp gull;
- Antarctic (Southern) fulmar; and
- Southern giant petrel.

5 IMPACT ASSESSMENT

The assessment of impacts of anthropogenic noise upon species in the environment is a notoriously challenging task due to the need for quantitative analysis and modelling to predict any kind of impact ranges, with the associated limitation of available data about the environment and about the reactions and the responses of specific species to particular noise level and types over time. As an introduction to this section therefore some of the basic principles and assumptions that have been made for this assessment are outlined, followed by a modelled quantitative, but indicative, analysis of possible site and species-specific impact ranges. This section therefore includes the following sub-headings before entering into the impact assessment discussion:

- Overview of sound and its propagation through water
- Overview of hearing sensitivity in marine animals
- Response levels of receptors to noise
- Analysis of potential noise levels produced

5.1 OVERVIEW OF SOUND AND ITS PROPAGATION THROUGH WATER

Sound travels in waves of pressure through water and the level of sound can therefore be measured in terms of the change of pressure created by the 'noise'. The unit for pressure is Pascal (Newton per square metre). Sounds occur over a wide range of pressures and it is standard practice to describe sound level by use of the decibel scale. The specific sound pressure level (SPL) of a sound of pressure P is given in decibels (dB) by:

SPL (in dB) = 10 log10 ($P^2/P0^2$)

In the above equation P is the measured pressure level and P0 is the reference pressure. The reference pressure in underwater acoustics is defined as one microPascal (1µPa).

The dB value is given on a logarithmic scale, so doubling the pressure of a sound leads to a 6 dB increase in sound pressure level.

It is noteworthy that the reference pressure for measurements in water and air differ acoustically. In water the reference pressure is 1 µPa in air is 20 µPa. This means that the dB levels for sound in water and in air cannot be compared without first applying conversion factors. This is achieved by subtracting 26 dB from the underwater dB due to the difference in reference units and then subtracting another 36 dB to account for the difference in acoustic impedance between air and water. An underwater sound pressure level of 200 dB re 1 µPa would therefore correspond to 138 dB re 20 µPa in air[58].

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[58] Thomsen, F., McCully, S.R., Wood, D., White, P. and Page, F., 2009. A generic investigation into noise profiles of marine dredging in relation to the acoustic sensitivity of the marine fauna in UK waters: PHASE 1 Scoping and review of key issues, Aggregates Levy Sustainability Fund / Marine Environmental Protection Fund (ALSF/MEPF), Lowestoft, UK.

The acoustic pressure referred to above can be expressed as either the peak (peak) or root mean square (rms).

- The peak pressure is the maximum absolute pressure for a signal;
- The rms is the square root of the mean of the instantaneous pressures squared over one pulse and has the units dB re 1 μPa2s.

Sound waves dissipate as they travel from their source, so the characteristics of the received sounds depend not only on the source level but also on the distance between source and receiver and the nature of the environment between them. The level of sound at any location is therefore dependant on a large number of variables including topography, seabed or ground properties, temperature gradients, water depth, source and receiver depths, sea surface properties and salinity[59]. For example, underwater sounds are, depending on individual site characteristics, known to generally attenuate more rapidly in shallow water as compared to deeper water [60].

Sounds occur over a wide range of frequencies (measured in Hertz (Hz)) and receptors to sounds have different sensitivities to sounds at different frequencies. The frequency of the sound itself also affects propagation with high frequencies attenuating more rapidly than low frequencies.

Source sound levels are normally quoted as if measured at one metre from the source. In most cases this is a theoretical point and a real measurement of sound at this distance cannot be made in practice. Source noise levels are therefore estimated by using modelled approximations of sound propagation, working backwards towards the source from a more practical measuring distance. Such modelling can, however, be complex due to the fact that sound will attenuate at different rates depending on the environment it is produced in.

5.1.1 Noise attenuation with distance from source in water

Numerous models with differing levels of complexity exist for propagation of sound under water. Selection of the most relevant model depends on several factors including the individual characteristics of the location in question, the information available for input, and the granularity required in output. Application of complex models requires significant resource but can provide a high level of detail which is particularly useful when potentially significant impacts are estimated. Simple models are easier to apply and also provide practical and useful analysis, albeit at a lower level of detail, where less significant noise scenarios are being examined.

For this study, complex modelling was carried out for blasting and rock breaking while simpler modelling was carried out for vibropiling and rock drilling. The simple modelling is based on a simple geometric spreading model of the form $N\log10R-\alpha R$ where R is the range and values for N and α are based on approximations from field measurements.

In contrast, the complex modelling is based on physical approximations of underwater wave propagation and considers variations in bathymetry, seabed type and sound speed profile for multiple depths and for each frequency band. With the simple methodology these factors are intrinsic to the conditions of the measurements. For blasting and vibropiling modelling methodology see Section 5.5.2.1 and 5.5.4.1 respectively.

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[59] Seiche Measurements Limited., 2008. Joint Industry Programme on Sound and Marine Life: Review of Existing Data on Underwater Sounds Produced by the Oil and Gas Industry Issue 1. Seiche Measurements Limited

[60] Thomsen, F., Lüdemann, K., Kafemann, R., Piper, W., 2006. *Effects of offshore wind farm noise on marine mammals and fish.* Biola, Hamburg, Germany on behalf of COWRIE Ltd, Newbury, UK. 62 pp.

5.1.2 Ambient marine sound levels from various sources

Noise is ubiquitous in the sea from a vast array of natural sources and, since mechanisation of maritime activities has occurred, there has been an increasing number of anthropogenic sources as well. In the natural world weather, water movement and geologically derived noise are all significant as are a huge range of sounds used by animals for communication, echolocation etc. Anthropogenic noise arises from shipping activity, maritime industrial activities, maritime construction activities and from underwater monitoring, research and communications.

Each of these sources has its own characterising levels, frequencies and patterns/trends over time.

Some examples of the levels of marine sound produced by various activities/events including a variety of sources in the natural environment are given in Table 5.1 as a point of reference.

Table 5.1 Marine Sound Levels

Source	Noise level[(a)]	Reference
Waves	45-80 dB	Richardson et al (1995)[61]
Rain	80 dB	Richardson et al (1995)
Lightning strike on sea surface	250 dB	Heathershaw, Ward et al (2001)[62]
Undersea earthquake (magnitude 4.0)	272 dB	Heathershaw, Ward et al (2001)
Bottlenose dolphin echolocation clicks	226 dB	Heathershaw, Ward et al (2001)
Whale vocalisations (various species)	185-200 dB	Heathershaw, Ward et al (2001)
Open ocean ambient noise (sea state 3-5)	74-100 dB	Heathershaw, Ward et al (2001)
Ambient noise due to normal vessel traffic	80 dB	Richardson et al (1995)
Ambient noise in exploited, industrialised seas	120 dB	Nedwell et al (2007)[63]
Note: (a) SPL – where specified in the literature it is generally expressed as dB re 1 μPa @ 1 m		

It can be seen that some of these natural sources of sound can be very loud, but locally specific whilst other sounds may be lower but more widespread. The key factor here is that the sea is already filled with different types of sound and that sound may therefore be very important to certain species that use it or seek to avoid it.

[61] Richardson, W J, Greene, Jr C R, Malme, C I, Thomson, D H, 1995. Marine Mammals and Noise. Academic Press, San Diego

[62] Heathershaw, A D, P D Ward, et al, 2001. The Environmental Impact of Underwater Sound. Proceedings of the Institute of acoustics 23(part 4): 12. Cited in Seiche (2008). Joint Industry Programme on Sound and Marine Life: *Review of Existing Data on Underwater Sounds Produced by the Oil and Gas Industry Issue 1.* Seiche Measurements Limited. 2008.

[63] Nedwell, J R, Parvin, S J, Edwards, B, Workman, R, Brooker, A G, Kynoch, J E, 2007. Measurement and interpretation of underwater noise during construction and operation of offshore windfarms in UK waters. Subacoustech Report No. 544R0738 to COWRIE Ltd. ISBN: 978-0-9554279-5-4. December, 2007.

5.2 RESPONSE LEVELS OF RECEPTORS TO NOISE

This section considers the factors influencing response to noise by marine mammals, diving birds and fish, the main types of response and the methods used for estimating different response levels.

5.2.1 Factors influencing the level of response to noise

The potential impact on a given individual or group of animals depends on a range of factors including:

- hearing sensitivity of the species;
- intensity, frequency and duration of the sound generated;
- extent of sound propagation;
- background noise levels;
- likelihood of animals being within a range at which an impact could occur;
- age, sex, condition of the animal(s);
- presence of offspring;
- animal activity when sound exposure occurs (e.g. foraging, feeding, mating, socialising, resting, migrating); and
- degree of habituation/sensitisation through previous exposure to similar sounds.

Each species has a different hearing sensitivity which is commonly expressed by means of an audiogram which plots the species threshold hearing level at different frequencies. This indicates the range of frequencies at which the species has the ability to hear and also the frequency range at which its hearing is most acute.

5.2.2 Classification of response levels to noise

Anthropogenic sound emitted to the marine environment can potentially affect marine organisms in various ways. It can mask biologically relevant signals, it can lead to a variety of behavioural reactions, hearing organs can be affected in the form of hearing loss, and at very high received levels sound has the potential to injure or even kill marine life[64]. There are five main levels of potential response by marine animals to noise[65]:

- detection level – the noise level that the animal would normally be able to detect in a quiet sea state;
- avoidance level – the noise level at which the animal would start to exhibit active avoidance behaviour, such as swimming away, to avoid the noise level that it was experiencing;
- temporary hearing shift level – the noise level that would cause a temporary but reversible shift in the individual's hearing sensitivity, also known as a temporary threshold shift (TTS);
- permanent hearing shift level – the noise level that would cause a permanent shift in the individual's hearing sensitivity, also known as a permanent threshold shift (PTS); and
- physical damage level – the noise level or pressure level that would result in gross physical damage to the organism's auditory system, other organs or tissue.

In this assessment particular use has been made of the permanent and temporary hearing threshold shift levels.

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[64] OSPAR, 2009. *Overview of the impacts of anthropogenic underwater sound in the marine environment*. OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic. Available at : <www.ospar.org>.
[65] Vella, G, Rushforth, I, Mason, E, Hough, A, England, R, Styles, P, Holt, T, Thorne, P, 2001. *Assessment of the effects of noise and vibration from offshore windfarms on marine wildlife.* A report for the UK DTI by ETSU, reference W/13/00566/REP: DTI/Pub URN 01/1341.

5.3 ESTIMATION OF RESPONSE LEVELS TO NOISE

There are a wide range of responses that species may make to ambient and anthropogenic noise levels and patterns. They may use sound directly for hunting prey or warning of predator approaches.

5.3.1 Uncertainties and assumptions

There is a relatively high uncertainty in relation to the criteria for onset of both physiological and behavioural effects. Physiological and injury response thresholds have been recently published for marine mammals and fish (NMFS, (2016)[66] and Popper et. al, (2014)[67] respectively) which provide guidance for assessing the potential for mortality, injury and temporary hearing impairment. No direct measurements of marine mammal PTS have been published, with PTS onset acoustic thresholds having been extrapolated from marine mammal TTS measurements (NMFS, 2016). This presents uncertainty of PTS thresholds.

In recommending criteria for impact thresholds data is only available for a limited number of species, a limited number of individuals within a species and/or a limited number of sound sources (Southall et al, 2007[68]; NMFS, 2016). NMFS apply the assumption of a "representative or surrogate individual/species for establishing PTS onset acoustic thresholds for species where little or no data exists." Other uncertainties and variability in impact thresholds include, dose dependency in PTS/TTS onset, variations for individuals and uncertainties regarding behavioural response, swim speed and direction.

For the purpose of this assessment, NMFS (2016) PTS and TTS thresholds for marine mammals have been used. The assumptions made in the development of the NMFS 2016 guidelines are such that the resulting criteria may be considered conservative, especially when compared to the previously accepted criteria. Section 5.4.5 provides further explanation of these assumptions and their potential effect on the results of the modelling.

In respect of fish the Popper et al (2014) mortality/PTS thresholds for explosions have been used in assessing the impact of the planned blasting operations. No quantitative TTS thresholds for blasting works are available, but the Popper et al (2014) qualitative guidance for impairment and behavioural effects at different distances to the source of an explosion and in response to continuous sounds such as those arising from other planned works at Rothera have been taken into account. As the authors of this guidance observe, there are more than 32,000 species of fish compared to about 130 species of marine mammals and there is much more anatomical, physiological, ecological and behavioural diversity among fishes than with marine mammals. Since data on fish hearing capabilities may only exist for around 100 fish species[69] and experimental research in relation to the effects of underwater sound on fishes has

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[66] National Marine Fisheries Service. 2016. Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing: Underwater Acoustic Thresholds for Onset of Permanent and Temporary Threshold Shifts. U.S. Dept. of Commer., NOAA. Available at: http://bit.ly/2j0qcOh

[67] Popper, A. N., Hawkins, A. D., Fay, R. R., Mann, D., Bartol, S., Carlson, T., Coombs, S., Ellison, W. T., Gentry, R., Halvorsen, M. B., Lokkeborg, S., Rogers, P., Southall, B. L., Zeddies, D., and Tavolga, W. N. (2014). "Sound Exposure Guidelines for Fishes and Sea Turtles: A Technical Report," ASA S3/SC1.4 TR-2014 prepared by ANSI-Accredited Standards Committee S3/SC1 and registered with ANSI. Springer and ASA Press, Cham, Switzerland.

[68] Southall, B L, Bowles, A E, Ellison, W T, Finneran, J J, Gentry, R L, Greene, C R J, Kastak, D, Ketten, D R, Miller, J H, Nachtigall, P E, Richardson, W J, Thomas, J A, Tyack, P, 2007. Marine mammal noise exposure criteria: initial scientific recommendations. Aquatic Mammals 33:411-521.

[69] Hastings, M. C. and Popper, A. N. 2005. *Effects of Sound on Fish*. Prepared for Jones & Stokes and the California Department of Transportation. Sacramento, CA.

been largely carried out on captive, enclosed animals whose behavioural responses to sound may not reflect those of fish in a natural setting, there are evident gaps in knowledge regarding the impact of sound on fish and caution is required in interpreting and extrapolating the existing data.

The only published impact threshold for diving birds is US guidance[70] regarding potential injury to foraging marbled murrelet (*Brachyramphus marmoratus*), a species of auk, from underwater sound resulting from the impact pile driving of steel piles. This guidance is referred to in the assessment, although it relates to an activity not planned at Rothera. In general there is limited understanding of the effects of underwater sound on birds, therefore this assessment is essentially qualitative.

5.3.2 Marine mammals

A technical report produced by Subacoustech describing the underwater noise propagation modelling is available in Appendix A. The modelling was carried out to estimate the received sound pressure levels in the region, with a focus on the impact on marine mammals, which are the receptors most vulnerable to underwater noise impacts. To assess the impact on key marine species the modelling uses criteria set out in the NMFS (2016) guidance[71].

The NMFS guidance groups marine mammals into functional hearing groups and applies filters to the unweighted noise to approximate the hearing response of the receptor. The hearing groups given in the NMFS (2016) are summarised in Table 5.2.

Table 5.2 Marine mammal hearing groups (NMFS, 2016)

Hearing group	Example species	Generalised hearing range
Low Frequency (LF) Cetaceans	Baleen Whales	7 Hz to 35 kHz
Mid Frequency (MF) Cetaceans	Dolphins, Toothed Whales (including Orca), Beaked Whales, Bottlenose Whales	150 Hz to 160 kHz
High Frequency (HF) Cetaceans	True Porpoises	275 Hz to 160 kHz
Phocid Pinnipeds (PW) (underwater)	True Seals	50 Hz to 86 kHz
Otariid Pinnipeds (OW) (underwater)	Sea lions, Fur seals	60 Hz to 39 kHz

There are four species of LF cetacean known to occur in the waters off Adelaide Island or in the wider Marguerite Bay area during the summer months. These are minke, humpback, Antarctic blue and fin whale, although the last two have not been observed close to Rothera and are therefore not considered to be at risk of exposure (see Section 4.4.2). There is one MF species, orca, known to occur relatively regularly near Rothera during the summer months. There there are no recorded sightings, for any HF species, such as the spectacled porpoise at the site and they are therefore also considered not to be at risk of exposure to this project. Nevertheless the modelling results for HF species are still presented.

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[70] https://www.wsdot.wa.gov/NR/rdonlyres/B08285E3-9E90-4615-891E-0ABB971F623D/0/MarbledMurrelet.pdf

[71] National Marine Fisheries Service. 2016. Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing: Underwater Acoustic Thresholds for Onset of Permanent and Temporary Threshold Shifts. U.S. Dept. of Commer., NOAA. Available at: http://bit.ly/2j0qcOh

The impact ranges (i.e. the range within which the received sound levels will likely exceed the NMFS (2016) criteria for PTS and TTS in marine mammals) vary significantly depending on the functional hearing group.

NMFS (2016) presents unweighted peak criteria (SPL_{peak}) and cumulative, weighted sound exposure criteria (SEL_{cum}) for both PTS and TTS. Table 5.3 and Table 5.4 summarise these criteria for each of the key marine mammal hearing groups for impulsive and non-impulsive sounds respectively. Of the proposed project activities, blasting will generate impulsive sounds while rockbreaking, vibropiling and drilling will create non-impulsive, continuous sounds.

Table 5.3 Assessment criteria for marine mammals from NMFS (2016) for impulsive noise (e.g. blasting)

Impulsive Noise	TTS Criteria		PTS Criteria	
Functional Group	SEL_{cum} (weighted) dB re 1 μPa2s	SPL_{peak} (unweighted) dB re 1 μPa	SEL_{cum} (weighted) dB re 1 μPa2s	SPL_{peak} (unweighted) dB re 1 μPa
LF Cetaceans	168	213	183	219
MF Cetaceans	170	224	185	230
HF Cetaceans	140	196	155	202
PW Pinnipeds	170	212	185	218
OW Pinnipeds	188	226	203	232

Table 5.4 Assessment criteria for marine mammals from NMFS (2016) for non-impulsive noise (e.g. rock breaking, vibropiling and rock drilling)

Non-impulsive Noise	TTS Criteria	PTS Criteria
Functional Group	SEL_{cum} (weighted) dB re 1 μPa2s	SEL_{cum} (weighted) dB re 1 μPa2s
LF Cetaceans	179	199
MF Cetaceans	178	198
HF Cetaceans	153	173
PW Pinnipeds	181	201
OW Pinnipeds	199	219

These criteria have limitations but are generally recognised as the most current for evaluating the potential for noise induced injury in marine mammals. As such, they are used in this document as a basis for impact assessment.

It is difficult to determine thresholds for a behavioural response in marine mammals as this is influenced not only by simple acoustic metrics, such as received level of sound, but also by contextual variables (e.g. laboratory versus field conditions, animal activity at the time of exposure, habituation/sensitisation to the sound and other factors). Under certain conditions there appears to be some relationship between the exposure and the magnitude of behavioural response, but in many cases there is no such correlation (Southall et al*,* 2007).

5.3.3 Fish

There are two general anatomical structures which fish can use to detect sound; these are the inner ear and the lateral line. Morphological variations of these two structures result in some fish being more sensitive to sound than others. One factor that potentially affects the sensitivity of a fish to sound is the proximity of the swim bladder (or other gas chamber) to the inner ear. The gas inside the swim bladder reacts to sound pressure more efficiently than the tissue making up the body of the fish, and in some cases, is able to stimulate movement of the sensory hairs of the inner ear used to detect sound. The transfer of sound in this way is only possible if the swim bladder is in close proximity or connected to the inner ear[72].

Most fishes respond to the particle motion component of sound waves. However, species with a swim bladder or other gas chamber have a greater susceptibility to physiological trauma (barotrauma), and those species with a functional physical connection between the swim bladder or other gas chamber and the inner ear are the most vulnerable to tissue/organ injury resulting from rapid pressure changes since the hearing abilities of these animals depend much more upon sound pressure. Fish species that lack a swim bladder/gas chamber are not as vulnerable to trauma from extreme sound pressure changes.

The presence of a swim bladder/gas chamber is also likely to increase the ability of many species of fish to detect sounds over a broader frequency range and at greater distances from the sound source than fishes without such structures.

Thus, in determining sound exposure guidelines for fishes, Popper at al (2014) firstly divide fishes into three categories based on the presence or absence of a swim bladder and on the potential for the swim bladder to improve hearing sensitivity and range of hearing:

- *Fishes with no swim bladder or other gas chamber* (e.g., dab and other flatfish). These species are less susceptible to barotrauma and only detect particle motion, not sound pressure. However, some barotrauma may result from exposure to sound pressure.
- *Fishes with swim bladders in which hearing does not involve the swim bladder or other gas volume* (e.g., Atlantic salmon). These species are susceptible to barotrauma although hearing only involves particle motion, not sound pressure.
- *Fishes in which hearing involves a swim bladder or other gas volume* (e.g., Atlantic cod, herring and relatives, Otophysi). These species are susceptible to barotrauma and detect sound pressure as well as particle motion.

Popper at al (2014) also consider thresholds of effect on fish eggs and larvae, recognising the lack of supporting data and that current concerns regarding underwater sound effects on eggs and larvae relate mainly to barotrauma rather than hearing.

For all receptors (3 categories of fish, fish eggs/larvae) Popper et al consider the following effects:

- *Mortality and mortal injury* – immediate or delayed death.
- *Recoverable injury* – injuries, including hair cell damage, minor internal or external hematoma, etc. None of these injuries are likely to result in mortality.

[72] Popper, A N, and Fay, R R. 1993. Sound detection and processing by fish: Critical review and major research questions. Brain, Behaviour and Evolution 41:14-38.

- *TTS* – short or long term changes in hearing sensitivity that may or may not reduce fitness. TTS, for these guidelines, is defined as any change in hearing of 6 dB or greater that persists. This level is selected since levels less than 6 dB are generally difficult to differentiate. It is also the view of the Working Group which produced the guidelines that anything less than 6 dB will not be a significant effect from the standpoint of hearing.
- *Masking* – impairment of hearing sensitivity by greater than 6 dB, including all components of the auditory scene, in the presence of noise.
- *Behavioural effects* – substantial change in behaviour for the animals exposed to a sound. This may include long-term changes in behaviour and distribution, such as moving from preferred sites for feeding and reproduction, or alteration of migration patterns. This behavioural criterion does not include effects on single animals, or where animals become habituated to the stimulus, or small changes in behaviour such as a startle response or small movements.

Where insufficient data exist to make a recommendation for guidelines a subjective approach is adopted in which the relative risk of an effect is placed in order of rank at three distances from the sound source – near, intermediate and far. No precise distances are ascribed to these terms due to the many variables that will apply on a case by case basis, but the authors suggest that "near" might be considered to be in the tens of metres from the source, "intermediate" in the hundreds of metres, and "far" in the thousands of metres. The relative risk of an effect taking place at different distances from the source is then indicated as being "high", "moderate" or "low"; these terms are broad indications that are not further defined.

The sound exposure guidelines for explosions are shown in In addition, Popper et al (2014) present a combination of quantitative thresholds and qualitative rankings relating to the effects on fish from other activities generating transient, impulsive sounds: pile driving (impact piling); seismic airguns; and low and mid frequency sonar.

Of more relevance to this assessment, they also consider the effects of continuous sounds from shipping and other sources including vibratory pile driving. The only quantitative thresholds they cite in respect of continuous sounds relate to impairment in fish with a swim bladder which is involved in hearing via sound pressure detection: 170 dB rms for 48 hours with regard to recoverable injury; 158 dB rms for 12 hours with regard to TTS. For all fish (with or without swim bladders) they classify the risk of mortality or potential mortal injury as "Low" at near, intermediate and far distances to the source of continuous sound.

Caltrans (2015) provides guidance on the hydroacoustic effects of pile driving on fish. Like the Popper et al (2014) guidance specific to pile driving, this relates to the use of an impact hammer for pile installation.

Table 5.5 below. These have been taken into account in assessing the effects of the potential blasting works at Rothera. It should be noted that these guidelines relate to "a single explosion from dynamite or another relatively small charge used to dismantle in-water structures" and not to larger or multiple explosions.

Among the impairment effects considered in this guidance, masking is not considered by the authors to be of any consequence as a result of explosives. While the detection of biologically relevant sounds may be masked during an explosion, this effect would only occur during the brief duration of the sound.

In addition, Popper et al (2014) present a combination of quantitative thresholds and qualitative rankings relating to the effects on fish from other activities generating transient, impulsive sounds: pile driving (impact piling); seismic airguns; and low and mid frequency sonar.

Of more relevance to this assessment, they also consider the effects of continuous sounds from shipping and other sources including vibratory pile driving. The only quantitative thresholds they cite in respect of continuous sounds relate to impairment in fish with a swim bladder which is involved in hearing via sound pressure detection: 170 dB rms for 48 hours with regard to recoverable injury; 158 dB rms for 12 hours with regard to TTS. For all fish (with or without swim bladders) they classify the risk of mortality or potential mortal injury as "Low" at near, intermediate and far distances to the source of continuous sound.

Caltrans (2015)[73] provides guidance on the hydroacoustic effects of pile driving on fish. Like the Popper et al (2014) guidance specific to pile driving, this relates to the use of an impact hammer for pile installation.

Table 5.5 Sound Exposure Guidelines for Explosions (from Popper et al, 2014[74])

Receptor	Mortality and Potential Mortal Injury	Impairment			Behaviour
		Recoverable Injury	TTS	Masking	
Fish: no swim bladder (particle motion detection)	229 - 234 dB re 1 µPa peak	(N) High (I) Low (F) Low	(N) High (I) Moderate (F) Low	N/A	(N) High (I) Moderate (F) Low
Fish where swim bladder is not involved in hearing (particle motion detection)	229 - 234 dB re 1 µPa peak	(N) High (I) High (F) Low	(N) High (I) Moderate (F) Low	N/A	(N) High (I) High (F) Low
Fish where swim bladder is involved in hearing (primarily pressure detection)	229 - 234 dB re 1 µPa peak	(N) High (I) High (F) Low	(N) High (I) High (F) Low	N/A	(N) High (I) High (F) Low
Fish eggs and larvae	>13 mm s^{-1} peak velocity	(N) High (I) Low (F) Low	(N) High (I) Low (F) Low	N/A	(N) High (I) Low (F) Low
Footnote: (N) = Near, (I) = Intermediate and (F) = Far. These relate to distance from sound source.					

The Caltrans guidelines point out that there are no established injury criteria for vibro-piling and US resource agencies in general are not concerned that vibratory pile driving will result in adverse effects on fish. This document also mentions that to some extent the use of vibro-piling in preference to an impact hammer, where this is technically feasible, can be viewed as mitigation.

Both Caltrans (2015) and Popper et al (2014) refer to a criterion for behavioural response in fish to impulsive sounds such as pile driving of 150 dB re 1 µPa currently adopted by the US NMFS but also point out that this threshold appears somewhat questionable since its origin and scientific validity are uncertain, no supporting data has been

[73] California Department of Transportation (Caltrans). *Technical Guidance for Assessment and Mitigation of the Hydroacoustic Effects of Pile Driving on Fish*. November 2015.

[74] Popper, A. N., Hawkins, A. D., Fay, R. R., Mann, D., Bartol, S., Carlson, T., Coombs, S., Ellison, W. T., Gentry, R., Halvorsen, M. B., Lokkeborg, S., Rogers, P., Southall, B. L., Zeddies, D., and Tavolga, W. N. (2014). "Sound Exposure Guidelines for Fishes and Sea Turtles: A Technical Report," ASA S3/SC1.4 TR-2014 prepared by ANSI-Accredited Standards Committee S3/SC1 and registered with ANSI. Springer and ASA Press, Cham, Switzerland.

provided and exceedance of the threshold does not trigger any mitigation requirement. Caltrans consider that the agencies view this as a rms (rather than peak) sound level and a threshold that relates to temporary behavioural changes (startle and stress) that could decrease a fish's ability to avoid predators.

5.3.4 Birds

The effects of underwater noise on birds has not been the subject of detailed research to date. A study by Dooling and Therrien (2012)[75] suggests that for birds in air, continuous noise exposure at levels above 110 dB(A) SPL or blast noise over 140 dB SPL can result in physical damage of the auditory system and PTS, but that birds are generally more resistant to auditory system damage and PTS from noise exposure, than mammals. The authors consider that trapped air may allow the middle air cavity of birds to function much like a swim bladder functions in fish. It is this physiological feature which makes diving birds sensitive to underwater noise, particularly impulsive noise generated by blasting.

In the US the Federal Highway Administration (FHWA), the US Fisheries and Wildlife Service (USFWS) and the Washington State Department of Transportation (WSDOT) recognised via a joint memorandum issued in February 2012[76] the following criteria for exposure of foraging marbled murrelets, a small seabird and member of the auk family, to underwater sound from the impact pile driving of steel piles, i.e. repetitive underwater impulsive sounds:

- Auditory injury threshold: 202 dB SEL
- Non-auditory injury threshold: 208 dB SEL
- Non-injurious hearing threshold shift zone out to 183 dB SEL
- Potential behavioural effects out to 150 dBrms

USFWS considers the non-injurious and behavioural effects thresholds to be effects analysis guidelines, not threshold criteria for marbled murrelets. They state that other factors (e.g. duration) are important to consider when determining whether exposure in these zones will result in adverse effects.

Audiograms (a graph that shows the audible threshold for various frequencies) are available for over 50 species of birds, showing, on average, that they hear best between 2 and 5 kHz, with absolute thresholds approaching 0 dB SPL in air (Dooling and Therrien, 2012). This has been shown to be the case for diving birds with an audiogram for black-footed penguin (*Spheniscus demersus*) delivering similar results.

A study by Pichegru et al., (2017)[77] examined the behavioural response of breeding black-footed penguin in waters off South Africa, to seismic surveys (the most intense anthropogenic noise source), by using a multi-year GPS tracking dataset. Although sound source levels from blasting are not directly comparable to noise from seismic surveys as the underwater blasting described in Section 1.2.1.1 is likely to be less intrusive than seismic surveys because of its short duration, the behavioural response of black-footed penguins can, for the purposes of this assessment, be considered to be broadly indicative of potential behavioural responses by penguin species present in the waters around Rothera to impulsive sounds (see Section 4.4.4).

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[75] Dooling, R. J. and Therrien, S., C. 2012. Hearing in Birds: What Changes from Air to Water. Published in Popper and Hawkins (eds.) *The Effects of Noise on Aquatic Life*. pp78-82.

[76] https://www.wsdot.wa.gov/NR/rdonlyres/B08285E3-9E90-4615-891E-0ABB971F623D/0/MarbledMurrelet.pdf

[77] Pichegru, L., Nyengera, R., McInnes, A. and Pistorious, P. 2017. Avoidance of seismic survey activities by penguins. *Nature*. Available at: https://www.nature.com/articles/s41598-017-16569-x Accessed 14 December 2017.

The results found that penguins exhibited a clear change of foraging direction, increasing their distance between their feeding area and the location of the seismic vessel. It could not be ascertained whether the avoidance behaviour exhibited by the penguins was a result of direct disturbance from the noise generated or was as a result of a change in fish distribution (which may have occurred as a result of seismic activities) during that period. The penguins in the study were found to quickly revert to normal foraging behaviour following cessation of seismic activities, therefore suggesting a relatively short-term influence of the activity on their behaviour/or that of their prey. Overall, there are still significant research gaps in our understanding of the physiology of penguin and other diving birds' hearing and how anthropogenic noise affects long-term impacts on hearing ability, disruption to communication between individuals and groups, foraging performance and ability to detect predators (Pichegru et al., 2017). However, it can be assumed from the aforementioned studies, that in response to impulsive noise sources such as underwater blasting, penguins (and potentially other diving birds) are likely to exhibit direct avoidance behaviour that is dependent upon the incident sound level, sound frequency, duration of exposure, and/or repetition rate of the sound wave.

5.4 POTENTIAL UNDERWATER NOISE LEVELS PRODUCED

Sources of marine noise from the project (see Section 0) considered in this assessment are derived from four basic activities:

- Rock blasting;
- Vibropiling;
- Rock breaking; and
- Rock drilling.

The relative sound levels which can potentially be expected from each of the activities is considered here with reference to relevant literature.

5.4.1 Rock blasting

The proposed blasting at the Rothera site consists of several blasting events involving detonation at 20 borehole locations each with a delay of approximately 0.3 seconds using a maximum instantaneous charge weight (MIC) of 10 kg. Based on the area where blasting is required, approximately 5-6 blasting events will take place over a 17-day period. It is not expected that multiple blasting events will happen on the same day.

When high explosives are confined to boreholes, the pressure wave is significantly reduced in level over that which would result from a charge detonated in the water without confinement. It has been reported as a result of numerous measurements of blast by Nedwell and Thandavamoorthy (1989), both in the laboratory and by monitoring during various consultancy projects, that the peak pressure from an embedded charge is reduced substantially to approximately 5% of that for a freely suspended charge.

The calculation that has been used to calculate peak pressure for waterborne borehole blasting, when conducted with no mitigation, are based on equations from Barrett (1996) and Arons (1954), modified using information from Nedwell and Thandavamoorthy (1989), and are as follows:

$$Peak\ Pressure\ (Pa) = 2.5 \times 106W0.27R-1.13$$

For this formula, W is the charge weight (in kilograms) and R is the range (in metres) from the source. The estimates given using this equation have been found by Subacoustech Environmental to give reasonable agreement with typical values recorded during actual blasting operations, although there will always be natural variability due to precise site conditions, which is why this equation has only been used to calculate the source level at 1 m for borehole blasting.

Using the equation to calculate the SPL_{peak} source level for a 10 kg charge weight gives a source level of 253.4 dB re 1 μPa (SPL_{peak}) @ 1 m.

In order to carry out the detailed noise modelling of borehole blasting a source spectrum needs to be used. Figure 3-2 presents the third-octave levels from a blasting shifted to achieve the required SPLpeak source level of 253.4 dB re 1 μPa for a 10 kg charge weight. This source level equates to a SEL source level of 218.5 dB re 1 μPa2s for the MIC based on the 0.3s duration of all the proposed delays. The original source spectrum is based on measured data from borehole blasting in Singapore harbour taken by Subacoustech.

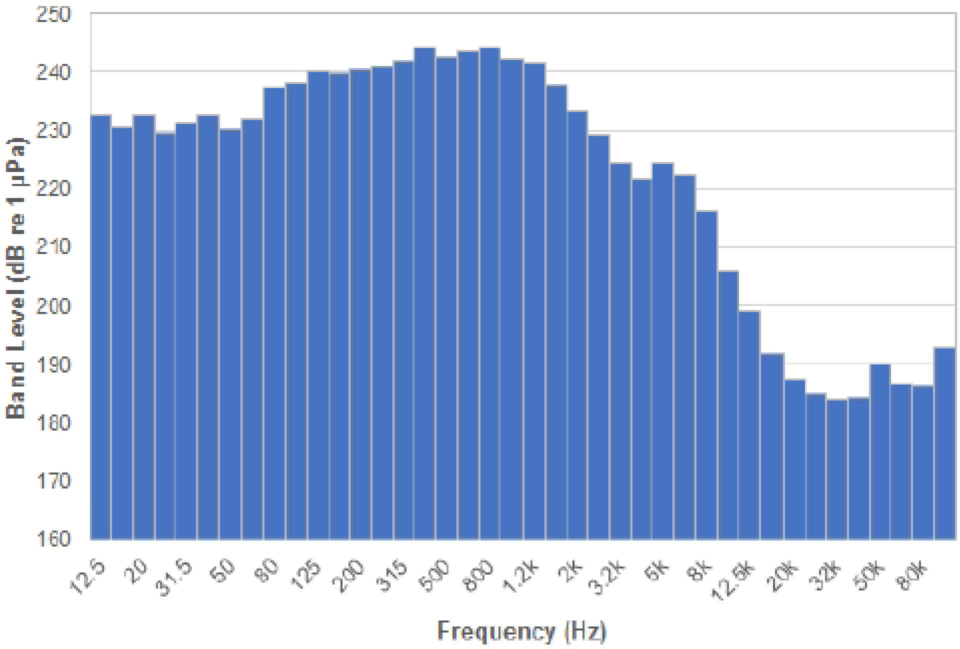

Figure 5.1 Source third octave band levels used to model borehole blasting (SPL_{peak})

5.4.2 Rock breaking

It is proposed that a Doosan PRODEM PRB500 hammer will be used for rock breaking activities, the hammer operates at a pressure of between 165 and 185 bar, resulting in an output energy of between 7.9 and 10.4 kJ depending on its speed; the hammer can operate at rates of between 250 and 500 strikes per minute.

An extract from one study which cited the actual underwater measurements of sound generated by rock breaking near a port in New Zealand (Marshall Day Acoustics, 2016)[78] is provided below:

[78] Marshall Day Acoustics for Port Otago Ltd. Underwater Noise Measurements – Rock Breaking at Acheron Head. August 2016.

"The hammer used was an Xcentric Ripper XR60 unit, which is somewhat different in mechanical operation to the Doosan PRODEM PRB500 hammer, with the Ripper penetrating the rock and pulling it up, whereas the hammer breaks up rocks by purely peckering into the rock. Based on the manufacturer's data the XR range, which includes smaller units than the XR60, has a stated and measured sound power level of 120dB (Lwa dB). The underwater measurements resulted in a predicted sound source level for the Xcentric Ripper XR60 of approximately 162 dB re 1 µPa RMS@ 10m. The noise level at 100m was predicted to be 147 dB re 1 µPa RMS, which was comparable to typical vessel movements measured at a similar receiver distance. Underwater sound propagation was modelled and sound exposure levels for marine mammals were assessed with reference to the US National Marine Fisheries Service (NMFS) criteria for Permanent Threshold Shift (PTS) and behavioural disruption. The potential PTS zone for the Xcentric Ripper was predicted to be around 2 – 3 m and therefore was considered to be a negligible risk. The zone of behavioural disruption was predicted to be 15 metres from the sound source."

In the detailed modelling Subacoustech, through analysis of the Marshall Day Acoustics (2016) report estimates the RMS source level of the Xcentric Ripper at 1 m as being 177.2 dB re 1 µPa, with the equivalent SEL and SPL_{peak} source levels are estimated to be 205 dB re 1 µPa2s @ 1 m and 212 dB re 1 µPa @ 1 m respectively. However, there are other differences between the two hammers which needs to be taken into account. The XR60 Ripper has a hydraulic working pressure of 26 to 28 MPa operating at a speed of 1000 strike per minute. The Doosan hammer has an operating pressure of between 165 and 185 bar (16.5 to 18.5 MPa), resulting in an output energy of between 7.9 and 10.4 kJ depending on its speed, which can be between 250 and 500 strikes per minute.

Based on these figures, the source level can be reduced using a simple formula method based on the differences between operating pressures.

$Scaling\ Factor\ (dB) = 10\ \log10\ (P1\ P2)$

This process essentially assumes that the energy conversion efficiency, in terms of the acoustic energy radiated versus the operating pressure is the same for the two devices. Using the largest of both estimates (28 MPa for the XR60 and 18.5 MPa for the Doosan hammer) the calculated source level for the Doosan hammer is 1.8 dB lower than the XR60 Ripper presented above. A summary of the source levels used for modelling is given below in

Table 5.6 Summary of rock breaking source levels used in underwater noise propagation modelling

	RMS (1s SEL)	SEL	SPL_{peak}
Source level @ 1 m	175.4 dB re 1 µPa	203.2 dB re 1 µPa^{2}s	210.2 dB re 1 µPa

In order to assess the potential worst-case it was assumed that rock breaking will occur for approximately 8 hours in any one 24-hour period. Due to this, continuous rock breaking noise for a period of 8 hours was assumed for cumulative SEL modelling. This is a highly conservative approach as it is anticipated that rock breaking will only be undertaken for two 10-hour periods in which the percentage of 'time on' activity will be 5%, i.e. half an hour of rock breaking over each 10-hour period.

5.4.3 Vibratory piling

Vibratory pile drivers apply vibrations to piles to reduce the friction between the pile and the soil causing minor liquefaction which enables piles to be driven into the ground with very little added weight. Vibratory piling (vibropiling) is best suited to round grain sand or gravel soil types which are moist, submerged or fully saturated (Tespa, 1998)[79].

Vibratory piling generally produces lower levels of sound than impact piling. Indeed vibratory piling is noted in the UK Joint Nature Conservation Committee (JNCC) guidance on piling mitigation for the protection of marine mammals as a technique which may reduce noise levels in comparison to hammer (impact) piling (JNCC, 2009)[80].

Nedwell et al (2002) measured noise from both impact and vibration piling of tubular piles (diameter not stated) undertaken along the margin (in water with onshore equipment) of the River Arun (Nedwell and Edwards, 2002)[81]. Vibropiling produced noise levels of 132 to 152 dB re 1 μPa (compared to a source level of about 192 dB re 1 μPa for impact piling). Using this study as a reference it is assumed that vibropiling may create maximum noise levels of 152 dB re 1 μPa during removal of the existing wharf walls and construction of the rear and side walls. It should be noted that this is a worst case scenario as the clutches left during removal of the existing wharf walls will be re-used in the installation of the new walls which may negate the need for vibropiling during installation.

5.4.4 Rock drilling

Source levels used for drilling are based on third octave band measurements undertaken by Subacoustech of drilling. The project was drilling anchor sockets in rock for a tidal turbine.

5.4.5 Noise modelling uncertainties and assumptions

To estimate the likely noise levels from blasting and rock breaking operations, modelling was carried out using an approach that is widely used and accepted by the acoustics community, however, there are a number of uncertainties and assumptions associated with this, that need to be discussed.

Underwater noise modelling is based on numerical approximations of various environmental parameters as well as the physical process of noise propagation. Parameters such as temperature and salinity (used to determine the sound speed profile) exhibit a high degree of temporal variability which cannot be easily accounted for within the scope of this work. Further parameters such as the sound speed in the substrate are based on assumptions about the type of rock and material properties found in the literature rather than measurements made on site. It is impossible to know with certainty what the exact values of these environmental parameters are in advance of the works and in the absence of detailed geotechnical and oceanographic data from the site.

In addition to environmental parameters, the sound source level is a significant input to the model and this is based on previous measurements of similar activities according to the likely engineering parameters. Whilst every effort has been made to ensure that the source level is a reasonable estimation, some variation is to be expected. For this reason, underwater acoustic modelling is considered indicative although a conservative approach has been taken in determining values for these parameters and the outputs from the model such that impact ranges in practice are expected to be less than predicted by the modelling.

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[79] TESPA, 1998. *Installation of Steel Sheet Piles*, Technical European Steel Sheet Pile Association, Arcelor Mittal, Luxembourg

[80] JNCC, 2009. Annex B- Statutory Nature Conservation Agency Protocol for Minimising the Risk of Disturbance and Injury to Marine Mammals from Piling Noise. Joint Nature Conservation Committee, Peterborough, UK.

[81] Nedwell J R, Edwards, B, 2002. Measurements of Underwater Noise in the Arun River during Piling at County Wharf, Littlehampton. Subacoustech Report Reference: 513R0108, August 2002

Underwater noise levels have been assessed in accordance with the NMFS 2016 guidelines which are based on a large number of different academic studies. There are a number of knowledge gaps and assumptions made in the development of the NMFS 2016 guidelines such that the resulting criteria may be considered conservative, especially when compared to the previously accepted criteria. The studies used to inform the NMFS 2016 criteria were based on small samples of animal (typically 1 to 3 individuals) in a controlled environment, only consider TTS and only in MF and HF species groups. The LF criteria is based on bioacoustic modelling rather than live studies. Further, all PTS criteria are based on inferences from studies of other (non-marine) species to determine the increase in noise level required to move from the onset of TTS to PTS. These assumptions and knowledge gaps are widely acknowledged within the scientific community, but such nuances are lost once fixed criteria have been defined. However, the NMFS 2016 guidelines have tended to use the most conservative findings to inform the criteria for each functional group, such that the criteria likely overestimate the impact.

5.5 POTENTIAL IMPACTS AND IMPACT ASSESSMENT

The following assessment of impacts takes account of embedded mitigation measures within the project and makes reference to specific embedded mitigation measures where appropriate. A full list of the embedded mitigation measures relevant to the proposed activities is provided in the following sections. It should be noted that no mitigation is considered necessary for drilling operations given the low levels of emitted noise.

A key part of these mitigation plans is the establishment of a monitored mitigation zone at times of certain activities. The use of and extent of these zones has been informed by the levels of noise related impact risk associated with the specific operations, the audio sensitivity of certain species groups and the practicality of monitoring such zones in local conditions for the different groups involved. Regards the impact risks considered within the mitigation plan, the proposed mitigation zones cover all of the predicted permanent impairment zones and should therefore help to avoid any permanent and therefore significant impacts. There are predicted temporary effects outside the nominated zones but these are considered to pose a tolerable risk and may not arise due to the conservatism in the modelling process and the actual likelihood of species being present in the affected area at the time of blasting or other activities.

5.5.1 Embedded Mitigation measures

5.5.1.1 Underwater blasting

Underwater Blasting Embedded Mitigation Measures		
Ref	**Title**	**Description**
BE01	Shot-holes	All explosives will be placed in shot-holes drilled in the seabed and confined in the holes with angular aggregate of approximately 1/12th hole diameter. A minimum of 0.3m length will be used, greatly reducing the pressure pulse released to the water.
BE02	Short delay detonators	Short delay detonators will be used between holes to reduce the maximum charge weight fired and therefore the peak pressure pulse. The maximum instantaneous charge will therefore be that quantity fired in one hole, or deck within a hole, rather than the overall quantity in the blast.
BE03	Detonation conditions	Detonations will only be commenced during the hours of daylight and in good visibility (MFOs should be able to monitor the full extent of the marine fauna mitigation zone).
BE04	Mitigation zone	Implementation of a marine fauna mitigation zone and clearance protocol. This is defined as the area where a Marine Fauna Observer (MFO) keeps watch and delays the start of activity should any sensitive species be detected. This zone is considered to be a 1200 m radial zone for cetaceans; 500 m for seals and 300 m for birds measured from the explosive source. These ranges take account of the practical feasibility of undertaking the observations. The observer(s) will observe from strategic viewpoints to ensure no marine fauna are present

Underwater Blasting Embedded Mitigation Measures		
Ref	**Title**	**Description**
		from 30 minutes before the blasting, until 10 minutes after the blasting. Any sightings of marine fauna will reset a 30 minute countdown. Works shouldn't take place in weather conditions where such observations are impractical.
BE05	Passive Acoustic Monitoring (PAM)	A hydrophone will be used to identify the presence of marine mammals in the area. Should cetaceans be identified in the area, close to the area, or getting closer (louder) then blasting would be postponed. If a marine mammal has been detected acoustically the PAM operative should use a range indication and their professional judgement to determine whether the marine mammal is within the mitigation zone.
BE06	PAM	Where feasible PAM will be used to monitor peak pressure pulse levels during blasting operations and to verify predictions.
BE07	Use of trained MFOs and PAM operatives	Trained MFOs and Passive Acoustic Monitoring (PAM) operatives will implement best practice procedures within the mitigation zone, as follows: • Detonations will be delayed if marine mammals or diving birds are detected within the mitigation zone; • It is vital that clear communication channels exist between MFOs/PAM operators and those carrying out the underwater blasting. A strict blasting protocol will be developed with communications between the marine fauna observer, the shotfirer and dive controllers to ensure the exclusion zone is clear.

5.5.1.2 Rock breaking and vibro pile hammering

Rock Breaking and Vibro pile Hammering Embedded Mitigation Measures		
Ref	**Title**	**Description**
B01	Mitigation zone	Implementation of a marine fauna mitigation zone and clearance protocol. This is defined as the area where a Marine Fauna Observer (MFO) keeps watch and delays the start of activity should any marine mammals/fauna be detected. An observation zone of 200 m radially measured from the noise source is considered appropriate for all faunal groups given the relatively low noise levels. The observer(s) will observe from strategic viewpoints to ensure no marine fauna are present from 30 minutes before the activity, until 10 minutes after. Any sightings of marine fauna will reset a 30 minute countdown. Works shouldn't take place in weather conditions where such observations are impractical.
B03	Passive Acoustic Monitoring (PAM)	A hydrophone will be used to identify the presence of marine mammals in the area. Should cetaceans be identified in the area, close to the area, or getting closer (louder) then blasting would be postponed. If a marine mammal has been detected acoustically the PAM operative should use a range indication and their professional judgement to determine whether the marine mammal is within the mitigation zone.
B04	Use of trained MFOs and PAM operatives	Trained MFOs and Passive Acoustic Monitoring (PAM) operatives will implement best practice procedures within the mitigation zone, as follows: • Activity will be delayed if marine mammals or diving birds are detected within the mitigation zone; • It is vital that clear communication channels exist between MFOs/PAM operators and those carrying out the noise generating activity. A strict protocol will be developed with communications between the marine fauna observer and the person responsible for managing the rock breaking, vibro piling and rock drilling activities, to ensure the exclusion zone is clear.

5.5.2 Potential impact of underwater noise produced by rock blasting on marine mammals, fish and birds, during construction of a new wharf at Rothera

5.5.2.1 Noise modelling methodology

Underwater acoustic propagation modelling was conducted by Subacoustech (see Appendix A) to evaluate the potential propagation of noise associated with rock blasting. The purpose of the modelling was to estimate the received sound pressure levels in the region, with particular concern for the impact on marine mammals.

Modelling was undertaken at one representative location to predict the levels of underwater noise from both the proposed blasting and rock breaking activities (for rock breaking impact assessment see Section 5.5.1). The source from which the underwater noise propagation was modelled is to the east of the existing wharf at the south of the research station, where blasting is to be carried out (Figure 1.3).

Modelling of underwater noise is complex and can be approached in several different ways. Subacoustech used a numerical approach that is based on two different solvers:

- A parabolic equation (PE) method) for lower frequencies (12.5 Hz to 250 Hz); and
- A ray tracing method for higher frequencies (315 Hz to 100 kHz).

The PE method is widely used within the underwater acoustics community but has computational limitations at high frequencies. Ray tracing is more computationally efficient at higher frequencies but is not suited to low frequencies (Etter, 1991). The modelling carried out by Subacoustech utilises the dBSea implementation of these numerical solutions.

These solvers account for a wide array of input parameters, including bathymetry, sediment data, sound speed and source frequency content to ensure as detailed results as possible. A summary of the input parameters is provided in the following, for detailed information on these refer to Appendix A:

- Bathymetry
- Sound speed profile
- Seabed properties
- Blasting source levels (see Section 5.4.1)
- Rock breaking source levels (see Section 5.4.2)

For blasting, distances have been calculated over which noise might cause TTS or PTS using the following criteria established by NMFS (2016) for marine mammals.

Table 5.7 Assessment criteria for marine mammals from NMFS (2016) for impulsive noise (blasting)

Impulsive Noise	TTS Criteria		PTS Criteria	
Functional Group	SEL_{cum} (weighted) dB re 1 μPa2s	SPL_{peak} (unweighted) dB re 1 μPa	SEL_{cum} (weighted) dB re 1 μPa2s	SPL_{peak} (unweighted) dB re 1 μPa2s
LF Cetaceans	168	213	183	219
MF Cetaceans	170	224	185	230
HF Cetaceans	140	196	155	202
PW Pinnipeds	170	212	185	218
OW Pinnipeds	188	226	203	232

Noise from blasting is predominantly low frequency in nature and reduces significantly at frequencies above 1 kHz. A summary of the weighted single pulse source levels for blasting are given in Table 5.8.

Table 5.8 Summary of the NMFS (2016) weighted source levels at 1 metre used for detailed modelling

Functional group	Blasting source level (single pulse SEL) (0.3s)
Unweighted	218.5 dB re 1 μPa2s
LF Cetaceans	217.1 dB re 1 μPa2s
MF Cetaceans	189.6 dB re 1 μPa2s
HF Cetaceans	183.5 dB re 1 μPa2s
Phocid Pinnipeds	209.3 dB re 1 μPa2s
Otariid Pinnipeds	209.8 dB re 1 μPa2s

5.5.2.2 Modelling results

The SPLpeak noise level from borehole blasting using a 10 kg charge weight is presented in Figure 5.2 for the maximum level in the water column. These results are analysed in terms of TTS and PTS ranges for species of marine mammal using the NMFS (2016) SPLpeak criteria in Table 5.9.
Table 5.9 also provides a summary of the PTS and TTS ranges for all the modelling scenarios and shows the spread of impact ranges for underwater blasting. The greatest impact ranges were seen for HF cetaceans. This is not unexpected given the particularly strict SPL_{peak} criteria specified by NMFS (2016).

As each blasting event can be defined as a single noise event (with multiple blasts happening over a period of approximately 0.3 s) it is unnecessary to calculate cumulative SEL values. A single pulse SEL source level has been derived using the SPL_{peak} data for the period of the blast, and from this, weightings have been applied in order to assess the noise using the NMFS (2016) criteria

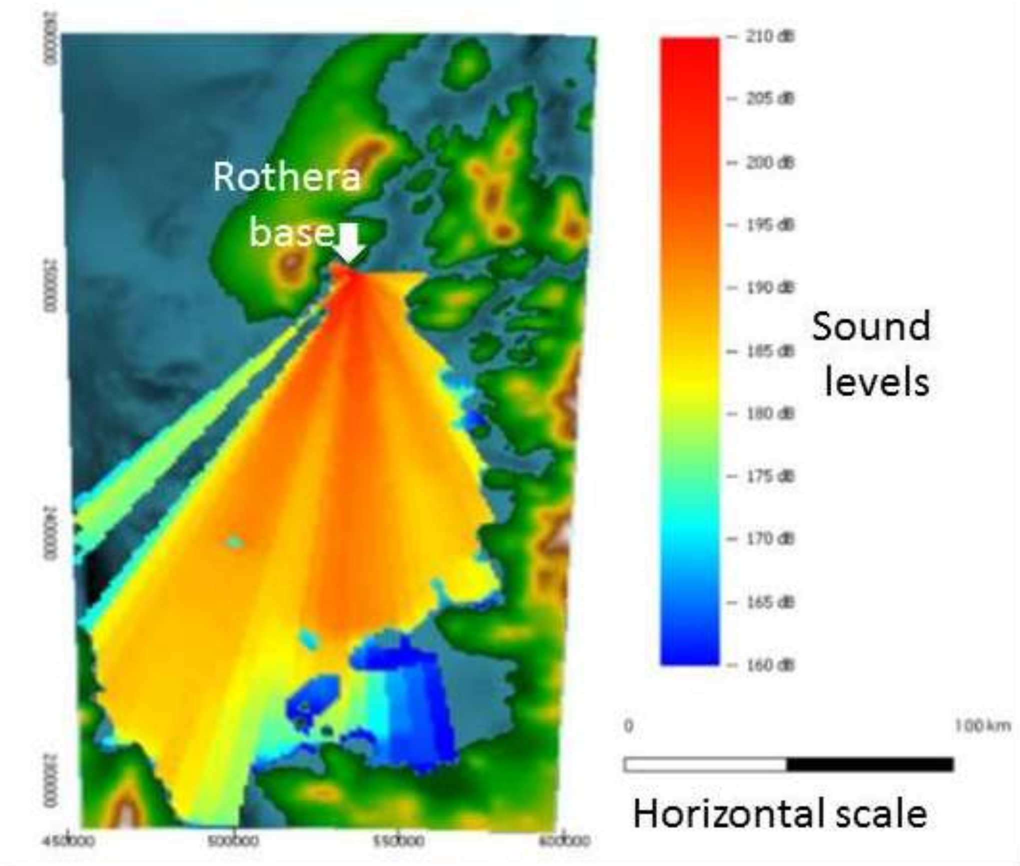

Figure 5.2 Distribution of noise arising from blasting operations expressed as SPL (peak) (From Subacoustech report)

.

Table 5.9 Ranges to NMFS (2016) PTS and TTS auditory injury criteria for underwater blasting

Threshold	Criteria SPL_{peak} (unweighted) dB re 1 $\mu Pa^2 s$	SPL_{peak} Maximum range	Criteria SEL (weighted) dB re 1 $\mu Pa^2 s$	SEL_{ss} (0.3s) Maximum range
		PTS		
LF Cetaceans	199 dB	370 m	183 dB	350 m
MF Cetaceans	198 dB	56 m	185 dB	2 m
HF Cetaceans	173 dB	6.7 km	155 dB	130 m
PW Pinnipeds	201 dB	440 m	185 dB	66 m
OW Pinnipeds	219 dB	39 m	203 dB	3 m
		TTS		
LF Cetaceans	213 dB	1.0 km	168 dB	4.7 km
MF Cetaceans	224 dB	150 m	170 dB	29 m
HF Cetaceans	196 dB	19 km	140 dB	1.7 km
PW Pinnipeds	212 dB	1.2 km	170 dB	870 km
OW Pinnipeds	226 dB	110 m	188 dB	42 m

The results are based on the maximum predicted noise level in the water column and this approach has been used as it is not possible to predict the depth of a marine mammal at the time of a single impulsive event. The Subacoustech report indicates an even distribution of noise through the water column with the maximum generally occurring in the mid-water region indicating that the use of maximum noise level is a reasonable approach.

Given the proximity to the coast, only the maximum ranges have been presented above as any attempt to present a mean range would be subject to considerable bias from many very short transects and would therefore be misleading. In practice only a very small number of transects will be subject to the maximum range. Figure 4-4 in the Subacoustech report shows the HF TTS ranges (which includes the greatest range) along each transect and only 8 transects exceed 15 km and 19 out of 180 transects exceed 10 km.

NMFS (2016) requires that where an assessment includes both SPL_{peak} and cSEL then the greater of the two (i.e. the most conservative) impact ranges should be used. For blasting, the SPL_{peak} criteria gave rise to the greatest ranges across all functional groups.

It should be noted that these modelling results do build in the preparatory planning and engineering mitigation but do not explicitly deal with the mitigation provided by MMO observations and other operational safeguards which should ensure that no vulnerable mammals or birds are present within the hazardous range of any particular noise generating activity. In addition the noise modelling outputs can be considered as being conservative due to the nature of the criteria set out in NMFS (2016).

5.5.2.3 Potential impact on marine mammals

Of the marine mammal species present in the general area, Antarctic blue whale and fin whale are classed as being of high sensitivity because they are listed as Critically Endangered and Endangered on the IUCN Red List of Threatened Species, respectively. However, neither species has ever been observed in the vicinity of Rothera and consequently they are not considered to be at risk of impactful exposure to the noise generated from construction activities. Minke whale and humpback whale, the other LF cetaceans which are known to be present at the site, are classed as being of medium and low sensitivity respectively. The minke whale, despite being thought to be abundant in Antarctica (numbers in the hundreds of thousands) is listed as DD on the IUCN Red list while the humpback whale is listed as LC.

Taking account of the use of the area by these species throughout the summer season, the relatively small number of blasting events (five or six events over a 17 day period) and the results of the numerical modelling, which suggest that these LF cetaceans would have to be within 430 m of the blasting activity for PTS to potentially occur, the potential magnitude of impact is considered to be negligible, as only a very slight change in the baseline condition is expected. The significance of the potential impact on minke whale and humpback whale (based on sensitivity and magnitude) is therefore evaluated as **Negligible.**

Orca, a medium frequency species is considered to be of medium sensitivity to the proposed blasting activities. They are known to regularly occur in the waters around Rothera, with anecdotal observations stating occurrence at the existing wharf, and are listed as Data Deficient on the IUCN Red List. Taking account of the relative infrequency of the blasting activity, the embedded mitigation measures which includes, short delay detonators and confined shot holes, and the modelling results which suggest that for MF cetaceans such as orca they would have to be within 61m of the blasting activity in order for PTS to potentially occur, the potential magnitude of impact is considered to be negligible, as only a slight change in baseline conditions is expected. The significance of potential impact on orca (based on sensitivity and magnitude) is therefore evaluated as **Negligible**.

The spectacled porpoise is also considered to be of medium sensitivity due to its IUCN Red List status of DD. The spectacled porpoise is a HF cetacean. However this species is primarily an oceanic and is distributed in more temperate waters of the sub-Antarctic (see Section 4.4.2.2). Therefore this species was considered to have no noise exposure risk from the proposed construction activities.

All seal species known to occur at the site are classed as LC on the IUCN Red List of Threatened Species and are all, therefore, considered to be of low sensitivity to the proposed blasting activities. The modelling results suggest that for phocid species there is potential for PTS to occur within 440 m while for otariid species the potential distance is 39m. Taking account of the use of the area by seals (see Section 4.4.3), the embedded mitigation zone which includes a marine mammal mitigation zones of 1200m for cetaceans, 500m for seals and short-delay detonators couple with the relatively small number of blasting events, the potential magnitude of impact is considered to be negligible because only a slight change in the baseline conditions for a very short period of time is expected. The significance of potential impact (based on sensitivity and magnitude) is therefore evaluated as **Negligible**.

5.5.2.4 Potential impact on fish

As noted in the Marine Drilling and Blasting Management Plan for Rothera Wharf, some minor fish kill is possible as a result of blasting. This would most likely occur as a result of physical trauma due to sound pressure changes in the water column. Fishes with a swim bladder would be the most vulnerable.

The Popper et al (2014) sound exposure guidelines for fish in relation to explosions cite a mortality/mortal injury threshold of 229 - 234 dB re 1 µPa SPL_{peak}. This is similar to the NMFS (2016) recommended PTS SPL_{peak} thresholds for impulsive sounds (such as blasting) in respect of MF cetaceans (224 dB re 1 µPa) and otariid pinnipeds (226 dB re 1 µPa). The Subacoustech modelling of sound propagation from potential blasting works at Rothera suggests that PTS thresholds for MF cetaceans and otariid pinnipeds would be reached at 61 m and 43 m respectively from the sound source. It is therefore reasonable to assume that any direct fish mortality would also occur within a few tens of metres of the blasting source.

The probability of TTS or other temporary impairment to fish or of notable behavioural responses by fish as a result of blasting is classed in the Popper et al (2014) guidance (In addition, Popper et al (2014) present a combination of quantitative thresholds and qualitative rankings relating to the effects on fish from other activities generating transient, impulsive sounds: pile driving (impact piling); seismic airguns; and low and mid frequency sonar.

Of more relevance to this assessment, they also consider the effects of continuous sounds from shipping and other sources including vibratory pile driving. The only quantitative thresholds they cite in respect of continuous sounds relate to impairment in fish with a swim bladder which is involved in hearing via sound pressure detection: 170 dB rms for 48 hours with regard to recoverable injury; 158 dB rms for 12 hours with regard to TTS. For all fish (with or without swim bladders) they classify the risk of mortality or potential mortal injury as “Low” at near, intermediate and far distances to the source of continuous sound.

Caltrans (2015) provides guidance on the hydroacoustic effects of pile driving on fish. Like the Popper et al (2014) guidance specific to pile driving, this relates to the use of an impact hammer for pile installation.

Table 5.5) as high near to the source (roughly within tens of metres), moderate to high at intermediate distances (within hundreds of metres) and low at far distances (within thousands of metres). Such effects on fish eggs and larvae are viewed as being of high probability near to the source and low probability beyond that.

Given that few fish have been recorded in the immediate vicinity of Rothera Wharf and the dominant species in this coastal area are nothenioids, which do not have a swim bladder (MacDonald and Montgomery, 1991)[82] and are therefore less susceptible to barotrauma and hearing impairment, and considering the small number of blasting events (5-6), their short duration (less than a second) and their distribution over ~17 days, the magnitude of the impact of blasting on fish is assessed as low since no impacts at community or population level are envisaged. As the sensitivity of fish species in the region is also low, the significance of blasting impacts on fish is evaluated as **Negligible**.

5.5.2.5 Potential impact on diving birds

There are four penguin species and a species of shag, which have potential to occur at the site (see Section 4.4.4) and which could potentially be adversely impacted as a result of underwater noise from the proposed underwater rock blasting activities. Penguins are proficient divers, the most extreme being the emperor penguin which is capable of diving to depths of 500 m and remaining submerged for over twenty minutes (Meir et al., 2008). It is clear then that at depths where light is limited, birds may potentially rely on senses other than sight, however, the extent of the importance of underwater hearing for diving birds remains unclear (Dooling and Therrien, 2012) [83].

The diving bird species which are considered in the assessment are:

- Emperor penguin;
- Adelie penguin;
- Gentoo penguin;
- Chinstrap penguin; and
- Imperial shag.

All of these species are listed as LC on the IUCN's Red List of Threatened Species with the exception of emperor penguin which is listed as NT. Therefore, emperor penguin is considered to be of medium sensitivity to the proposed blasting activities, while the other diving bird species are considered to be of low sensitivity.

As noted above and in Section 5.3 our understanding of underwater hearing in diving birds is limited and while it has potential to be important for underwater foraging, diving birds can be considered to be less vulnerable to underwater noise than marine mammals (Dooling and Therrien, 2012)[84]. There is still potential for behavioural responses and the masking of vocal signals (Pichegru et al., 2017)[85], however the short-term duration of the blasting and the relatively few blasting events would mean this would we highly unlikely to result in long term negative effects.

Emperor penguin is a rare visitor in spring time to Rothera and only very occasionally can be seen during the summer months. Consequently although present this species is very unlikely to be impacted by the proposed blasting activities.

[82] MacDonald, J.A. and Montogomery, J.C. The Sensory Biology of Notothenioid Fish. In Biology of Antarctic Fish (di Prisco, G., Maresco, B. and Tota, B. eds). Springer Verlag. 1991. Pp. 145-162.

[83] Dooling, R. J. and Therrien, S., C. 2012. Hearing in Birds: What Changes from Air to Water. Published in Popper and Hawkins (eds.) *The Effects of Noise on Aquatic Life*. pp78-82.

[84] Dooling, R. J. and Therrien, S., C. 2012. Hearing in Birds: What Changes from Air to Water. Published in Popper and Hawkins (eds.) *The Effects of Noise on Aquatic Life*. pp78-82.

[85] Pichegru, L., Nyengera, R., McInnes, A. and Pistorious, P. 2017. Avoidance of seismic survey activities by penguins. *Nature*. Available at: https://www.nature.com/articles/s41598-017-16569-x Accessed 14 December 2017.

Taking account of the embedded mitigation measures, which includes the placement of charges in confined shot-holes and the use of the short delay detonation system, and the relatively few number of blasting events, the potential magnitude of impact on the remaining diving birds is considered to be negligible because only a slight change in baseline conditions over a very short period of time is expected. As a result, the significance of potential impact is evaluated as **Negligible**.

5.5.3 Potential impact of underwater noise produced by rock breaking on marine mammals, fish and birds during construction of a new wharf at Rothera

5.5.3.1 Noise modelling methodology

The modelling methodology carried out for rock breaking was the same as for blasting (see Section 5.5.2.1).

5.5.3.2 Modelling results

5.5.3.2.1 Unweighted RMS

The one second RMS noise levels from rock breaking noise, using the methodology described in Section 5.5.2.1 are presented as SPL_{RMS} noise plots at both near- and far-field in Figure 5.3.

It can be seen that the spreading levels of noise arising from rock breaking are much lower than was indicated for rock blasting. This reflects the lower source level and also some of the frequency spectrum differences that will arise. The masking of noise by intermediate shallows and islands can be clearly seen once again. The vertical distribution of noise is expected to be rather linear, as for blasting, but with reduced sound levels in bathymetric low points.

5.5.3.2.2 Cumulative SEL (SELcum)

The noise from rock breaking has been considered a continuous noise due to the rapid rate of peckering from the equipment. As such the 1 second RMS value has been used as a basis for estimating the cumulative SEL value assuming a rock breaking operation lasting 8 hours. Table 5.10 presents impact ranges for species of marine mammal using the NMFS (2016) SELcum criteria for PTS and TTS assuming a stationary receptor. If a fleeing receptor were assumed for these results, the predicted impact ranges would be reduced.

It should be noted that these modelling results do not take account of the proposed soft start mitigation procedure which allows animals to move away from the noise source before it reaches its maximum. Even excluding mitigation, they can be viewed as being conservative due to the nature of the criteria set out in NMFS (2016) (see Section 5.5.2.1).

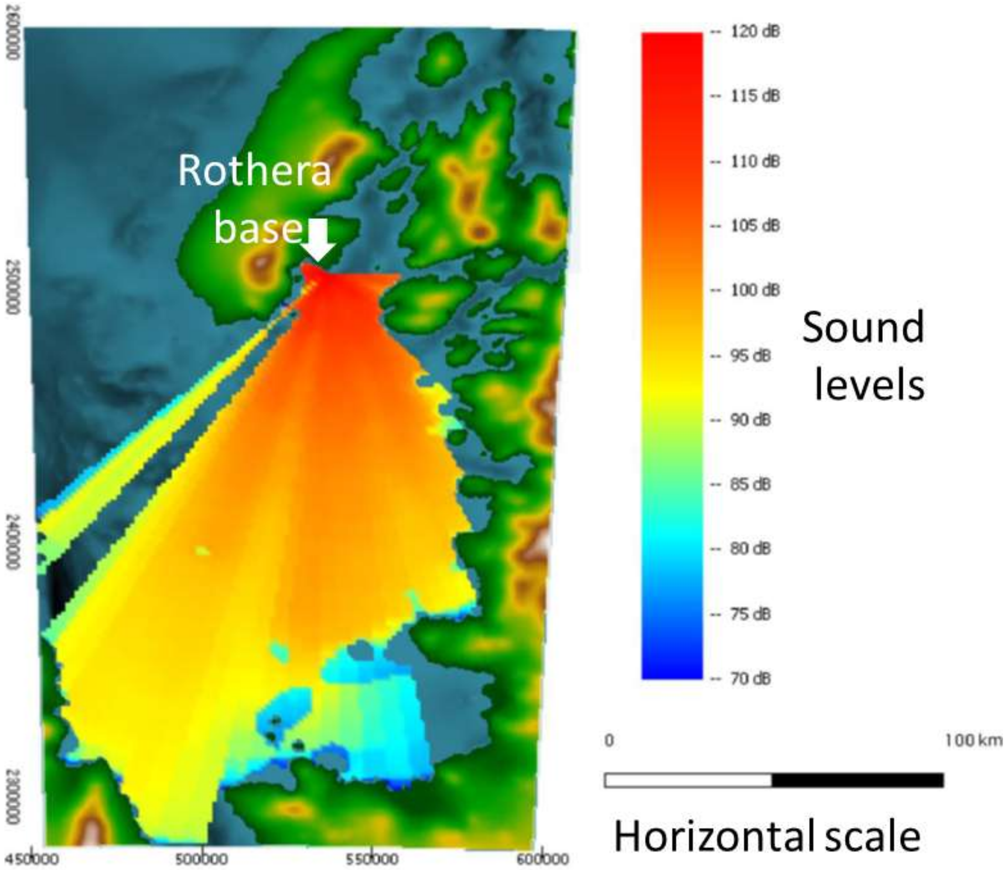

Figure 5.3 Noise propagation from rock breaking activity expressed as unweighted SPL 1 second RMS

Table 5.10 Ranges to NMFS (2016) SEL_{cum} PTS and TTS criteria for rock breaking based on the maximum level in the water column assuming a stationary receptor over a period of 8 hours

Threshold	Criteria SEL_{cum} (weighted)	Rock Breaking SEL_{cum} (8 hours) Maximum range
	PTS	
LF Cetaceans	199 dB re 1 μPa^{2}s	23 m
MF Cetaceans	198 dB re 1 μPa^{2}s	1 m
HF Cetaceans	173 dB re 1 μPa^{2}s	60 m
PW Pinnipeds	201 dB re 1 μPa^{2}s	7 m
OW Pinnipeds	219 dB re 1 μPa^{2}s	< 1 m
	TTS	
LF Cetaceans	179 dB re 1 μPa^{2}s	520 m
MF Cetaceans	178 dB re 1 μPa^{2}s	41 m
HF Cetaceans	153 dB re 1 μPa^{2}s	1.3 km
PW Pinnipeds	181 dB re 1 μPa^{2}s	150 m
OW Pinnipeds	199 dB re 1 μPa^{2}s	10 m

5.5.3.3 Potential impact on marine mammals

Chronic noise exposure is unlikely to be an issue as a result of rock breaking works, as it will be confined to a relatively small area of seabed for a relatively short period (a total period of twenty hours with only 5% time on activity, i.e. one hour of underwater rock breaking) and avoidance behaviour on the part of marine mammals is likely. Therefore, any auditory injury, even TTS, is unlikely and behavioural changes will be the main potential effect of underwater noise from rock breaking on marine mammals.

Minke whale and humpback whale are known to occur in Marguerite and Ryder Bays throughout the summer months. Minke whale is listed as DD on the IUCN's Red List and so is considered to be of medium sensitivity, while humpback whales are listed as LC and therefore considered to be of low sensitivity. Antarctic blue whale and fin whale are listed as being CR and E respectively, on the IUCN's Red List of Threatened Species and are therefore considered to be of high sensitivity however as before these species have never been observed in the area and therefore are not considered to be at exposure risk to impactful noise levels.

The modelling results show that for LF cetaceans they would have to be within 26 m of the rock breaking activity in order for PTS to potentially occur and within 670 m for TTS to potentially occur, however it should be noted that the results consider a stationary animal with these ranges being reduced were a fleeing animal to be assumed.

Taking account of the relatively short duration of the rock breaking activity, the modelling results, which are conservative in nature (see Section 5.5.2.1) the magnitude of potential impact is considered to be negligible, because only a very slight change to the baseline condition can be expected as the embedded mitigation measures would ensure that no animal was within 600 m of the rock breaking activity. Therefore, the significance of potential impact on minke whales is evaluated as **Negligible** and on humpback whales also as **Negligible**.

Orca are classed as DD on the IUCN Red List and are, therefore, categorised as being of medium sensitivity to the proposed activities. Orca are known to be present in Ryder Bay during the summer months. The modelling results show that there is potential for TTS to be exhibited within 7 m of the rock breaking and within 48 m for PTS.

The embedded mitigation measures indicate that a mitigation zone of 200 m radius from the noise source will be implemented and therefore it is highly unlikely that any orca would be within the area when rock breaking was being carried out. Taking account of this, the relative infrequency of rock breaking activities and the results of the numerical modelling, the potential magnitude of impact is considered to be negligible as these MF hearing cetaceans would need to be within 1 m of the rock breaking activities in order for PTS to have the potential to occur which, even for an individual animal, is highly unlikely to occur. Additionally, the short duration of the rock breaking activity (one hour in total) would result in only a very slight change to the baseline condition. Therefore, the significance of potential impact on orca is evaluated (based on sensitivity and magnitude) as **Negligible**.

The spectacled porpoise is classed as DD on the IUCN Red List and is therefore considered to be of medium sensitivity. However, as before its distribution lies to the north of Antarctica and the species is considered to have no exposure risk.

All seal species known to occur at the site are classed as LC on the IUCN's Red List of Threatened Species and are all, therefore, considered to be of low sensitivity to the proposed rock breaking activities. Seal species are known to be present at the site to varying degrees at different times of the year (see Section 4.4.3), however, taking account of the short duration of the rock breaking activities and the modelling results which suggest that for phocid species PTS only has the potential to occur within 7 m and for otariid species within less than 1 m, for TTS the ranges are slightly larger but still relatively small at 150 m and 10 m respectively for phocids and otariid species. the magnitude of potential impact is considered to be negligible because the short duration over which rock breaking is anticipated and the relatively low levels of noise produced would only result in a slight change to the baseline conditions. Therefore, the significance of potential impact on seals is evaluated as **Negligible**.

5.5.3.4 Potential impact on fish

The Popper et al (2014) sound exposure guidelines for fish suggest there is a low probability of mortality of fish (all groups) and fish eggs/larvae as a result of exposure to continuous sounds. Temporary effects on fish can be anticipated, with a generally low to moderate probability of recoverable injury/TTS and moderate to high probability of masking and/or behavioural effects, depending of course on the sound levels, exposure duration and distance of receptor to source.

Given that few fish have been recorded in the immediate vicinity of Rothera Wharf and the dominant species are nothenioids, which do not have a swim bladder and are therefore less susceptible to barotrauma and hearing impairment, and considering the short duration of rock breaking works, the magnitude of the impact of rock breaking on fish is assessed as low since no impacts at community or population level are envisaged. As the sensitivity of fish species in the region is also low, the significance of rock breaking impacts on fish is evaluated as **Negligible**.

5.5.3.5 Potential impact on diving birds

As noted previously there are no sound exposure guidelines for birds and continuous noise sources. In keeping with the impact on marine mammals, chronic noise exposure in diving birds is unlikely to be an issue as a result of rock breaking works, as it will be confined to a relatively small area of seabed for a relatively short period (total of one hour) with avoidance behaviour, being the most likely outcome.

Again as noted above and in Section 5.3 the understanding of underwater hearing in diving birds is limited and while it has potential to be important for underwater foraging, diving birds can be considered to be less vulnerable to underwater noise than marine mammals (Dooling and Therrien, 2012)[86].

As before, the emperor penguin may not be present during the construction activity period and if present will be there in very small numbers. The species is therefore considered to have a very low exposure risk to the possible impacts, although the sensitivity of the species is classed as medium. All other diving birds which are found in the area during the planned construction period are categorised as being of low sensitivity to the underwater rock breaking activities. The results of the modelling show that underwater noise from rock breaking will dissipate rapidly from source. Taking account of this, the embedded mitigation measures and the short duration of the activity, the magnitude of potential impact is would be negligible, as only a very slight change in baseline conditions is expected. Therefore, the significance of potential impact is evaluated as **Negligible** for adelie, gentoo and chinstrap penguin and imperial shag.

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[86] Dooling, R. J. and Therrien, S., C. 2012. Hearing in Birds: What Changes from Air to Water. Published in Popper and Hawkins (eds.) *The Effects of Noise on Aquatic Life*. pp78-82.

5.5.4 Potential impact of underwater noise produced by vibro piling and rock drilling on marine mammals, fish and birds during construction of a new wharf at Rothera

5.5.4.1 Noise modelling methodology

Modelling of noise from drilling and vibro extraction have been undertaken using a simple modelling approach. This methodology has been chosen due to either low levels of noise or limited data availability. It involves using existing measurement data from similar activities taken by Subacoustech and modifying the source level to best match the scenario being modelled.

Source levels used for drilling are based on third octave band measurements undertaken by Subacoustech of drilling. The project was drilling anchor sockets in rock for a tidal turbine. Vibro extraction of old sheet piles uses the same tool as for driving sheet piles. Noise is generated in the sheet piles through the coupling to the piling hammer. Third octave band source levels are based on measurements taken by Subacoustech of the vibro piling of sheet piles.

The simple modelling is based on a simple geometric spreading model of the form $N\log10R-\alpha R$ where R is the range and values for N and α are based on approximations from field measurements taken by Subacoustech.

The ranges for drilling assumed a stationary animal and drilling being undertaken for up to 8 hours in a given 24-hour period. For vibro extraction, ranges were calculated for both stationary and fleeing animals and are based on 2 hours of operation in a given 24-hour period.

5.5.4.2 Modelling results

Table 5.11 Ranges to NMFS (2016) SELcum injury criteria for vibro extraction and drilling operation using a qualitative modelling approach assuming a stationary receptor over a period of 8 hours

Threshold	Criteria SPL_{cum} (weighted)	Vibro-Piling Extraction (2 hours)		Drilling (8 Hours)
		Stationary Animal	Fleeing Animal (1.5m/s)	
PTS				
LF Cetaceans PTS	199 dB re 1 µPa²s	30 m	-	5 m
MF Cetaceans PTS	198 dB re 1 µPa²s	5 m	-	< 1 m
HF Cetaceans PTS	173 dB re 1 µPa²s	80 m	-	9 m
PW Pinnipeds PTS	201 dB re 1 µPa²s	10 m	-	1 m
OW Pinnipeds PTS	219 dB re 1 µPa²s	1 m	-	< 1 m
TTS				
LF Cetaceans TTS	179 dB re 1 µPa²s	400 m	7 m	80 m
MF Cetaceans TTS	178 dB re 1 µPa²s	70 m	-	6 m
HF Cetaceans TTS	153 dB re 1 µPa²s	1000 m	60 m	100 m
PW Pinnipeds TTS	181 dB re 1 µPa²s	200 m	2 m	10 m
OW Pinnipeds TTS	199 dB re 1 µPa²s	20 m	-	1 m

5.5.4.3 Potential impact on marine mammals

Chronic noise exposure is unlikely to be an issue as a result of the vibro piling or rock drilling works, as it will be confined to a relatively small area of seabed for a relatively short period of time and avoidance behaviour on the part of marine mammals is likely. Therefore, any auditory injury, even TTS, is unlikely and behavioural changes will be the main potential effect of underwater noise from rock breaking on marine mammals.

The modelling results for vibropiling show that even for a stationary animal which is a conservative approach when considering that it is likely marine mammals would move away from the area if disturbed by underwater noise, the ranges for PTS are low – up to 80 m for HF cetaceans. The ranges for TTS for all threshold categories are within 1000 m with those for LF, MF, PW and OW species being below 400 m. For drilling which has again taken a very conservative approach by assuming 8 hours of drilling activity, the ranges for PTS and TTS can all be seen to be within 100 m of the activity, this is much less than for vibropiling and the short duration of the drilling activity would result in, at most, a temporary behavioural reaction or masking of vocalisations which would be highly unlikely to result in long-term adverse effects.

Considering embedded mitigation measures which include a marine fauna mitigation zone of 200 m, the fact that it is presumed that no high frequency species will be present in the study area and the conservative nature of the modelling, means the magnitude of impacts on marine mammals are considered to be negligible. With Orca and Minke whales being considered of medium sensitivity and humpback and seals considered of low sensitivity, the overall potential significance of effect is evaluated as **Negligible** for minke whale, orca, humpback whale and seals.

5.5.4.4 Potential impact on fish

As noted above in relation to rock breaking impacts, the Popper et al (2014) sound exposure guidelines for fish suggest there is a low probability of mortality of fish (all groups) and fish eggs/larvae as a result of exposure to continuous sounds. Temporary effects on fish can be anticipated, with a generally low to moderate probability of recoverable injury/TTS and moderate to high probability of masking and/or behavioural effects, depending of course on the sound levels, exposure duration and distance of receptor to source.

Given that few fish have been recorded in the immediate vicinity of Rothera Wharf and the dominant species are nothenioids, which do not have a swim bladder and are therefore less susceptible to barotrauma and hearing impairment, and considering the very short duration of the proposed vibro-piling and drilling works, the magnitude of their impact on fish is assessed as negligible to low. As the sensitivity of fish species in the region is also low, the significance of vibro-piling and rock drilling impacts on fish is evaluated as **Negligible**.

5.5.4.5 Potential impact on birds

There are no underwater noise exposure guidelines for birds and continuous noise sources.

Chronic noise exposure in diving birds is unlikely to be an issue as a result of vibropiling or rock drilling works, as they will be confined to a relatively small area of seabed for a short period, with avoidance behaviour being the most likely outcome. Vibropiling may only be required to remove the existing wharf walls with the left over clutches from this being utilised for installation of the new wharf walls, which may negate the need for vibropiling during their installation.

As noted above and in Section 5.3 understanding of underwater hearing in diving birds is limited and while it has potential to be important for underwater foraging, diving birds can be considered to be less vulnerable to underwater noise than marine mammals (Dooling and Therrien, 2012)[87].

The emperor penguin is considered to be of medium sensitivity but has a low exposure risk due to its low numbers. All other locally present diving birds are categorised as being of low sensitivity to the underwater rock breaking activities. The results of the modelling show that underwater noise from vibropiling and rock drilling will dissipate rapidly from source (see Appendix). Taking account of this, the embedded mitigation measures and the short duration of the activity, the magnitude of potential impact is considered to be negligible, as only a very slight change in baseline conditions is expected. Therefore, the significance of potential impact (based on sensitivity and magnitude) is evaluated as **Negligible** for adelie, gentoo and chinstrap penguin and imperial shag.

5.5.5 Underwater noise impact from onshore quarrying and blasting

To facilitate the development of the wharf there will be a requirement for onshore quarrying and blasting which will be undertaken in close proximity to the marine environment (the red area in Figure 1.3). It is anticipated that there will be 20-25 onshore blasting events for quarrying. These blasting events would be near to, but above the waterline with the majority of sound pressure travelling through air, and therefore, the potential for underwater noise propagation to the marine environment is limited. There is however some potential for underwater noise through the transmission of ground vibration across the land/water boundary. Within the water this energy is transmitted as a pressure pulse similar to noise in the air and if sufficiently strong could cause harm or disturbance to marine fauna at very close proximities.

Mitigation measures outlined in the Quarrying, Drilling and Blasting Management Plan will ensure that the potential transmission of noise from land to water is calculated if blasting is carried out less than 20 m from the marine environment and, if there is potential for this noise level to be at or above that which is potentially harmful to marine fauna then additional measures will be implemented. These include, actual monitoring of peak pressure levels in the water, reduction of explosive charge weights. Since the zones and magnitude of impact will be small in comparison with those arising from underwater blasting and taking into account the planned mitigation, the impact of onshore quarrying and blasting would be negligible and considered highly unlikely to result in significant adverse underwater noise impacts on the species outlined in Section 4.

5.6 PROJECT SPECIFIC MITIGATION MEASURES

The comprehensive mitigation plan built into the planned operations should lead to no or negligible impacts arising on marine mammals, fish and seabirds as a result of exposure to underwater sound, with no population level effects predicted. Given these low levels of impact no additional mitigation measures are needed to further control these impacts. It will however be prudent to verify that all of the assumed circumstances for the operations arise in reality. Should alterations to the planned works take place then these changes should be considered in relation to the potential for unplanned impacts to arise. The impact assessment has also been made on the basis of modelled analysis and available baseline data to give what is believed to be a conservative prediction of possible impacts. The expectation is that the actual zones of effect will be less than predicted. If however any unforeseen impacts were to occur and some mammal or birds were seen to be impacted by underwater noise, or the fish related impacts were much greater than

[87] Dooling, R. J. and Therrien, S., C. 2012. Hearing in Birds: What Changes from Air to Water. Published in Popper and Hawkins (eds.) *The Effects of Noise on Aquatic Life*. pp78-82.

predicted, then additional mitigation should be considered. In the case of rock blasting this may include the covering of the blasting area with additional aggregate once the charges are set, or building an aggregate/rock barrier seaward of the blast area to help reduce the spread of noise from the blasting zone. It is however considered highly unlikely that such measures will be needed.

5.7 RESIDUAL EFFECTS

Since in this project the planned approach to works and the associated mitigation plan have been deemed sufficient to avoid harmful impacts or at least maintain them at negligible levels no additional mitigation has been recommended as a result of this assessment process. Consequently the residual effects are considered to be the same as the initial predicted effects for this project.

On this basis it is predicted that the project can be completed without harm arising to sea mammals and seabirds in the area of the works and with only limited and negligible impacts on fish due to potential localised mortality as a result of blasting.

5.8 CUMULATIVE EFFECTS

Cumulative impacts may arise through a sequence of concurrent or sequential tasks within the project or through the presence of additional, non-project activities in the vicinity of the works and associated impact zone. In the case of this project there are a sequence of activities taking place over two summer seasons and some consideration of any possible effects associated with the sequence of activity needs to be made. In terms of the potential for other projects or noise related activities to be taking place in the area, this is expected to be solely limited to the ongoing research activities being undertaken at or near to the Rothera base. There are no other bases near to Rothera and there are not expected to be any other research or tourism activities in the vicinity. Cumulative underwater noise effects with other activities, beyond those of the base itself can therefore be discounted.

In terms of the sequence of work activities the planned schedule shows them extending over two summer seasons. The types of activity alter week by week and month by month and there are periods in the schedule where activities overlap. Although each of the planned activities have some noise emanating tasks within them, none of the tasks are continuous in terms of noise generation. It is likely therefore that the works will give rise to a series of changing levels of noise for discrete and short time periods throughout the construction programme. The temporal patterns of noise outputs over the construction period are indicated in Table 6-13.

Table 5.12 Indication of the temporal pattern of noise generating activity arising from jetty refurbishment

Factor	2018 late summer season				2019 early summer season																2019 later summer season				2020 early summer season											
Project months	12				1				2				3				4				12				1				2				3			
Project weeks	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Percentage noise generating activity per working day	0	0	0	0	0	0	0	0	25	25	0	0	10	20	20	15	15	25	15	0	20	20	20	15	15	15	15	15	15	15	0	0	0	0	0	0

The cumulative nature of noise outputs from different sources is not an easy matter to analyse. Since noise is reported through a logarithmic scale, the combined scale of two sources is not a simple mathematical addition of the quoted sound sources. In order of noise levels, blasting activities are clearly the loudest, but the noise sources may only last for less than 0.3 seconds across 5-6 blasting sequences.

What can be more easily assessed is the duration of noise emitting activities. As outlined above none of the proposed activities create continuous underwater noise. The anticipated periods of noisy activities during a week may alter from 25% of the working day or 10% of the full day from vibro-hammer pile removal, down to between 10 and 5% of the working day for drilling, breaking and hammer driving activity and as little as 0.01% of the time in a week, over a period of a few weeks, taken up by specific blasting events.

From the modelling activity undertaken it has been shown that for all the target species the extent of any significant, permanent impact mechanisms would be limited to within 440 m (for blasting and seals) of the planned works and that for most periods and types of activity the range will be even less, often a few tens to a few hundreds of metres. Temporary impacts may extend to some 4.7 km (for blasting and LF cetaceans). The intermittent nature of the noise and the use of MFOs and other mitigation procedures should ensure that no target species are present in these areas whilst noise generating activities are taking place. The assurance of this case is helped by the relatively short range over which any impacts will manifest themselves. Coupled with this potential for robust avoidance or mitigation of impacts is the pattern of behaviour in target species. None of them are expected to be or have been observed to be permanently resident in the waters in the immediate vicinity and to the south of the base. Rather the species of interest may occasionally transit through the area en route between foraging areas or between foraging and roosting/haul out areas. These behavioural traits mean that no individual mammals or birds are likely to ever be exposed to multiple noise events over a period of time, rather they may experience occasional low level noise regimes as they roam around the area south of the Rothera base.

Given all of these factors it is considered very unlikely that any mechanisms for cumulative impacts exist for this project given the nature of the proposed operations and the site specific sensitivities and species present.

6 APPENDICES – SUBACOUSTEC NOISE MODELLING REPORT

The noise modelling undertaken by sub acoustic has been reported in a stand along document appended to this report when provided in paper format and provided as a separate electronic file if transmitted digitally.

Submitted to:

Carla Houghton
Aquatera Ltd
Old Academy Business Centre
Stromness
Orkney
KW16 3AW

Tel: +44 (0)1856 850 088

E-mail: carla.houghton@aquatera.co.uk
Website: www.aquatera.co.uk

Submitted by:

Sam East
Subacoustech Environmental Ltd
Chase Mill
Winchester Road
Bishop's Waltham
Hampshire
SO32 1AH

Tel: +44 (0)1489 892 881

E-mail: sam.east @subacoustech.com
Website: www.subacoustech.com

Underwater noise propagation modelling of construction activity at Rothera Research Station, Antarctica

Richard Barham and Sam East

10 January 2018

Subacoustech Environmental Report No. P218R0105

Document No.	*Date*	*Written*	*Approved*	*Distribution*
P218R0101	*15/12/2017*	*R Barham*	*S East*	*Carla Houghton (Aquatera)*
P218R0102	*02/01/2018*	*R Barham*	*S East*	*Carla Houghton (Aquatera)*
P218R0103	*05/01/2018*	*R Barham*	*S East*	*Carla Houghton, Gareth Davies (Aquatera)*
P218R0104	*08/01/2018*	*R Barham*	*S East*	*Carla Houghton, Gareth Davies (Aquatera)*
P218R0105	*10/01/2018*	*R Barham*	*S East*	*Carla Houghton, Gareth Davies (Aquatera)*

This report is a controlled document. The report documentation page lists the version number, record of changes, referencing information, abstract and other documentation details.

List of contents

1 Introduction

Subacoustech Environmental have been instructed by Aquatera to undertake acoustic propagation modelling for proposed blasting, rock breaking and other noise-making operations near the Rothera Research Station, Antarctica.

The purpose of the modelling is to estimate the received sound pressure levels in the region, with particular concern for the impact on marine mammals. This report has been prepared by Subacoustech Environmental Ltd for Aquatera and presents the results and findings of the modelling assessment.

1.1 Survey area

The area of operational activity for the works at the Rothera Research Station is relatively small, and as such only a single representative modelling location has been selected. The location of the research station and the representative modelling location (shown by the red marker) and the works area (approximated by the yellow box) is detailed in Figure 1-1.

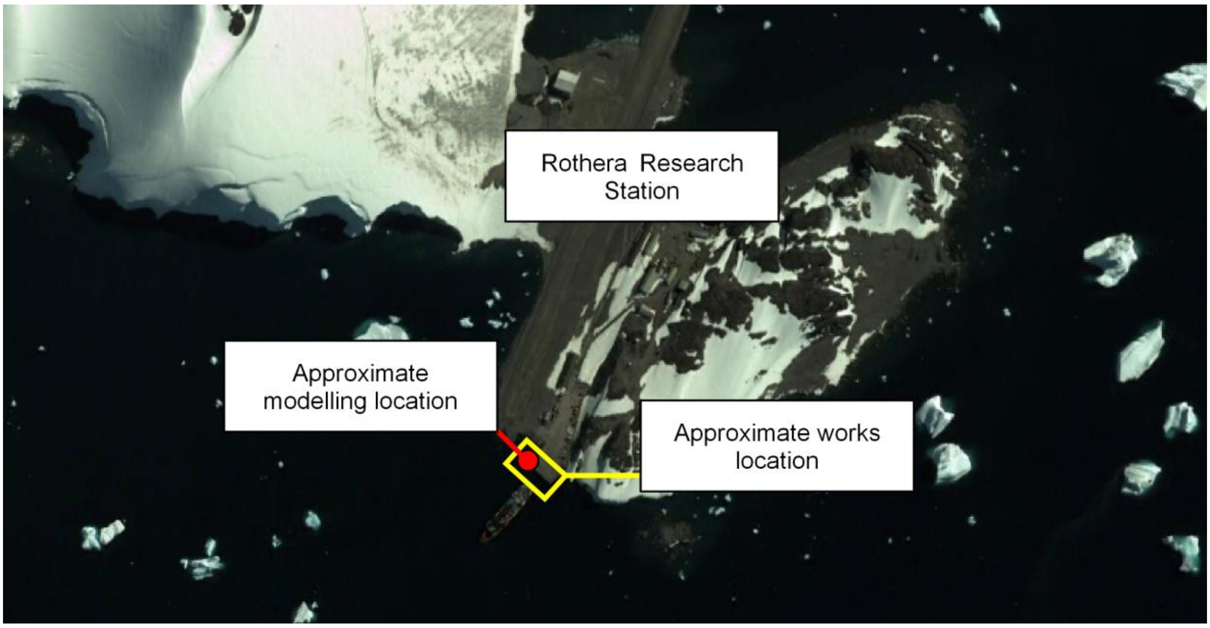

Figure 1-1 Satellite image showing the Rothera Research Station and the approximate modelling and works locations (image from Google Earth ©2017 DigitalGlobe)

1.2 Blasting

The proposed blasting activity comprises of 20 charges in boreholes being detonated in sequence with a few milliseconds delay. A maximum instantaneous charge weight (MIC) of 10 kg has been modelled. It is expected that a total of 5-6 blasting events will take place.

1.3 Rock breaking

It is proposed that a Doosan PRODEM PRB500 hammer will be used for rock breaking activities, the hammer operates at a pressure of between 165 and 185 bar, resulting in an output energy of between 7.9 and 10.4 kJ depending on its speed; the hammer can operate at rates of between 250 and 500 strikes per minute.

1.4 Other noise sources

In addition to blasting and rock breaking, use of a vibro pile driver for the extraction of sheet piles along with drilling to create the boreholes will also be required. These activities have been considered using a high-level, simple modelling approach.

1.5 Assessment overview

This report presents a detailed assessment of the potential underwater noise at the Rothera Research Station and covers the following:

- Review of background information on the units for measuring and assessing underwater noise
- Discussion of the approach, input parameters and assumptions for the noise modelling undertaken;
- Presentation of detailed subsea noise modelling using unweighted metrics and interpretation of the results using suitable noise metrics and criteria; and
- Summary and conclusions.

2 Measurement of underwater noise

Sound travels much faster in water (approximately 1,500 ms^{-1}) than in air (340 ms^{-1}). Since water is a relatively incompressible, dense medium, the pressures associated with underwater sound tend to be much higher than in air. As an example, background levels of sea noise of approximately 130 dB re 1 µPa for UK coastal waters are not uncommon (Nedwell *et al*, 2003 and 2007). This level equates to about 100 dB re 20 µPa in the units that would be used to describe a sound level in air.

2.1 Units of measurement

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

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

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

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

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

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

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

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

2.2 Quantities of measurement

Sound may be expressed in many ways depending upon the type of noise, and the parameters of the noise that allow it to be evaluated in terms of a biological effect. These are described in more detail below.

2.2.1 Sound Pressure Level (SPL)

The Sound Pressure Level is normally used to characterise noise and vibration of a continuous nature such as drilling, boring, continuous wave sonar, or background sea and river noise levels. To calculate the SPL, the variation in sound pressure is measured over a specific time period to determine the Root

Mean Square (RMS) level of the time varying sound. The SPL can therefore be considered a measure of the average unweighted level of sound over the measurement period.

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

2.2.2 Peak Sound Pressure Level (SPL_{peak})

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

A further variation of this is the peak-to-peak SPL where the maximum variation of the pressure from positive to negative within the wave is considered. Where the wave is symmetrically distributed in positive and negative pressure, the peak-to-peak level will be twice the peak level, or 6 dB higher.

2.2.3 Sound Exposure Level (SEL)

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

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

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

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

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

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

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

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

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

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

Weighted metrics for marine mammals have been proposed by the National Marine Fisheries Service (NMFS) (2016), these assign a frequency response to groups of marine mammals, and are discussed in detail.

3 Modelling Methodology

To estimate the likely noise levels from blasting and rock breaking operations, modelling has been carried out using an approach that is widely used and accepted by the acoustics community, in combination with publicly available environmental data and information provided by Aquatera. The approach is described in more detail below.

Modelling has been undertaken at one representative location to predict the levels of underwater noise from both the proposed blasting and rock breaking activities. The modelling location is to the east of the existing wharf at the south of the research station, as shown in Figure 1-1.

Modelling of underwater noise is complex and can be approached in several different ways. Subacoustech have chosen to use a numerical approach that is based on two different solvers:

- A parabolic equation (PE) method) for lower frequencies (12.5 Hz to 250 Hz); and
- A ray tracing method for higher frequencies (315 Hz to 100 kHz).

The PE method is widely used within the underwater acoustics community but has computational limitations at high frequencies. Ray tracing is more computationally efficient at higher frequencies but is not suited to low frequencies (Etter, 1991). This study utilises the dBSea implementation of these numerical solutions.

These solvers account for a wide array of input parameters, including bathymetry, sediment data, sound speed and source frequency content to ensure as detailed results as possible. These input parameters are described in the following section.

3.1 Input parameters

The modelling takes full account of the environmental parameters within the study area and the characteristics of the noise source. The following parameters have been assumed for modelling.

3.1.1 Bathymetry

The bathymetry data used in the modelling was supplied by Aquatera direct from data gathered by the Rothera Research Station, this data has a resolution of 50 m. Where data is not available using this set, information from GEBCO (General Bathymetric Chart of the Oceans) was used; this data has a resolution of 30 arc-seconds (approximately 500 metres square). The extent of the bathymetry used, along with the modelling location shown in red, is given in Figure 3-1.

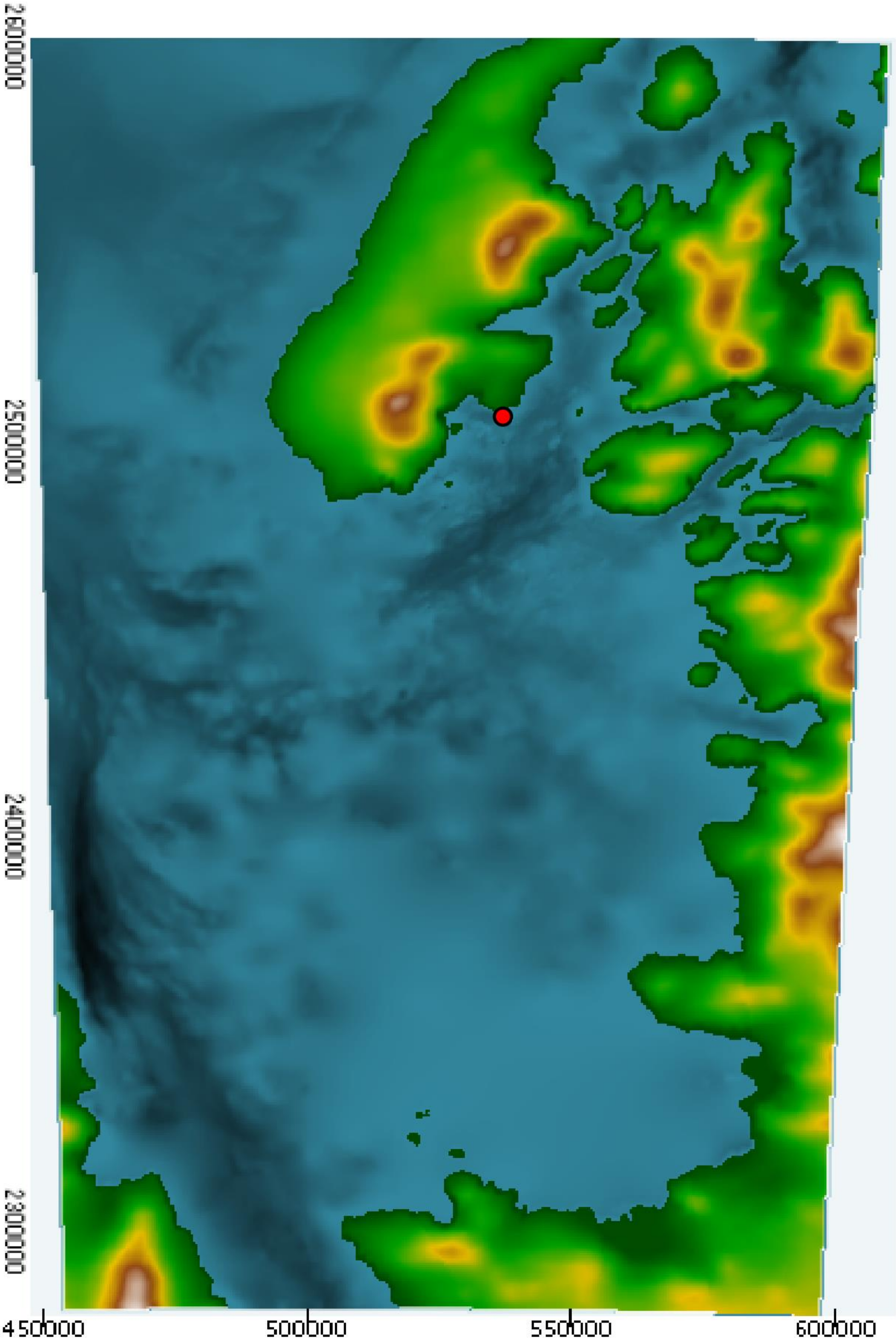

Figure 3-1 Overview of the bathymetry used for the detailed modelling

3.1.2 Sound speed profile

The speed of sound in the water has been calculated using data supplied by Aquatera cross-referenced with generic Antarctic data from Gotoh *et al*. (2015) for very deep water and data specific to the areas around the research station from Chu and Wiebe (2005). The resulting profile is shown in Figure 3-2.

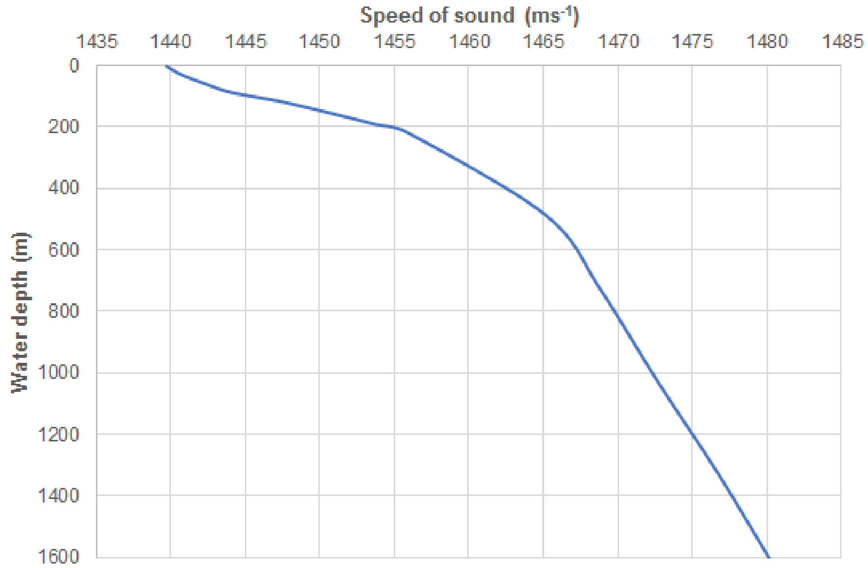

Figure 3-2 Sound speed profile used for modelling

3.1.3 Seabed properties

Minimal information was available regarding the characteristics of the seabed, based on data from Ó Cofaigh *et al.* (2002), the seabed in the vicinity was assumed to be a thin sediment layer covering bedrock with several bedrock outcrops. Geo-acoustic properties for the seabed were based on available data from Jensen *et al*. (2011) for Moraine, which is the closest available dataset for solid bedrock, and are provided in Table 3-1.

Compressive sound speed profile in substrate (m/s)	Density profile in substrate (kg/m³)	Attenuation profile in substrate (dB/wavelength)
1950	2100	0.4

Table 3-1 Seabed geo-acoustic properties

3.1.4 Blasting source levels

The proposed blasting at the Rothera site consists of several blasting events involving detonating at 20 borehole locations all within a period of approximately 0.3 seconds using a maximum instantaneous charge weight (MIC) of 10 kg. Based on the area where blasting is required, approximately 5-6 blasting events will take place over a 1-2 week period. It is not expected that multiple blasting events will happen on the same day.

When high explosives are confined to boreholes, the pressure wave is significantly reduced in level over that which would result from a charge detonated in the water without confinement. It has been reported as a result of numerous measurements of blast by Nedwell and Thandavamoorthy (1989), both in the laboratory and by monitoring during various consultancy projects, that the peak pressure from an embedded charge is reduced substantially to approximately 5% of that for a freely suspended charge.

The calculation that have been used to calculate peak pressure for waterborne borehole blasting, when conducted with no mitigation, are based on equations from Barrett (1996) and Arons (1954), modified using information from Nedwell and Thandavamoorthy (1989), and are as follows:

$$Peak\ Pressure\ (Pa) = 2.5 \times 10^{6} W^{0.27} R^{-1.13}$$

For this formula, W is the charge weight (in kilograms) and R is the range (in metres) from the source. The estimates given using this equation have been found by Subacoustech Environmental to give reasonable agreement with typical values recorded during actual blasting operations, although there will always be natural variability due to precise site conditions, which is why this equation has only been used to calculate the source level at 1 m for borehole blasting.

Using the equation to calculate the SPL_{peak} source level for a 10 kg charge weight gives a source level of 253.4 dB re 1 µPa (SPL_{peak}) @ 1 m.

In order to carry out the detailed noise modelling of borehole blasting a source spectrum needs to be used. Figure 3-3 presents the third-octave levels from a blasting shifted to achieve the required SPL_{peak} source level of 253.4 dB re 1 µPa for a 10 kg charge weight. This source level equates to a SEL source level of 218.5 dB re 1 µPa²s for the MIC based on the 0.3s duration of all the proposed delays. The original source spectrum is based on measured data from borehole blasting in Singapore harbour taken by Subacoustech.

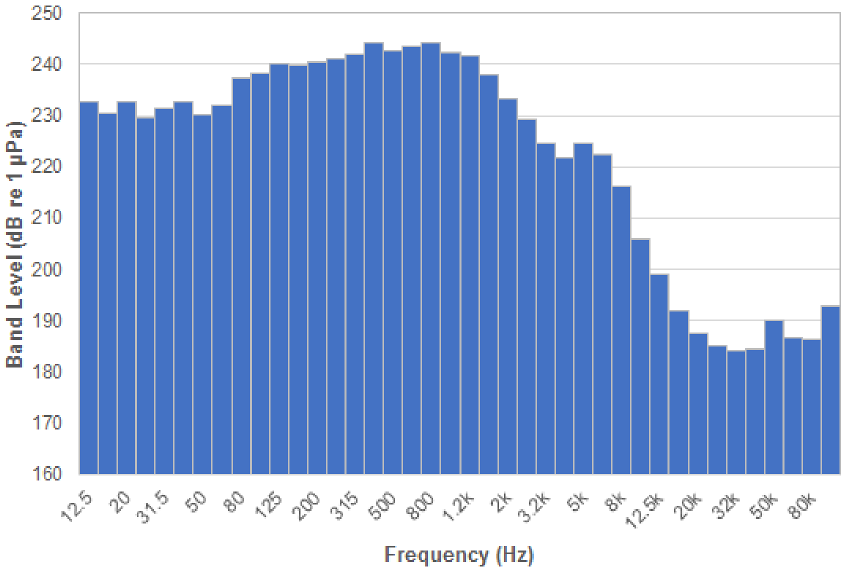

Figure 3-3 Source third octave band levels to be used to model borehole blasting (SPL_{peak})

3.1.5 Rock breaking source levels

Measured data of rock breaking has been sourced from a report by Marshall Day Acoustics (Lawrence, 2016) and is, at the time of writing, the best available information on underwater noise levels from rock breaking activities. The methodology used in these measurements differs from the proposed rock breaking at Rothera Wharf in that the measurements use a Xcentric XR60 Ripper device, whereas the works at Rothera Wharf are expected to use a Doosan PRODEM PRB500 hammer. These devices perform slightly differently to each other with the Ripper penetrating the rock and pulling it up, whereas the hammer breaks up rocks by purely peckering into the rock.

Figure 3-4 presents the noise levels in the Marshall Day report and assumes an $L_r = N \log_{10} r - \alpha r$ fit to the data to estimate a source level. This gives an estimated RMS source level at 1 m of 177.2 dB re

1 µPa. The equivalent SEL and SPL_{peak} source levels are estimated to be 205 dB re 1 µPa²s @ 1 m and 212 dB re 1 µPa @ 1 m respectively.

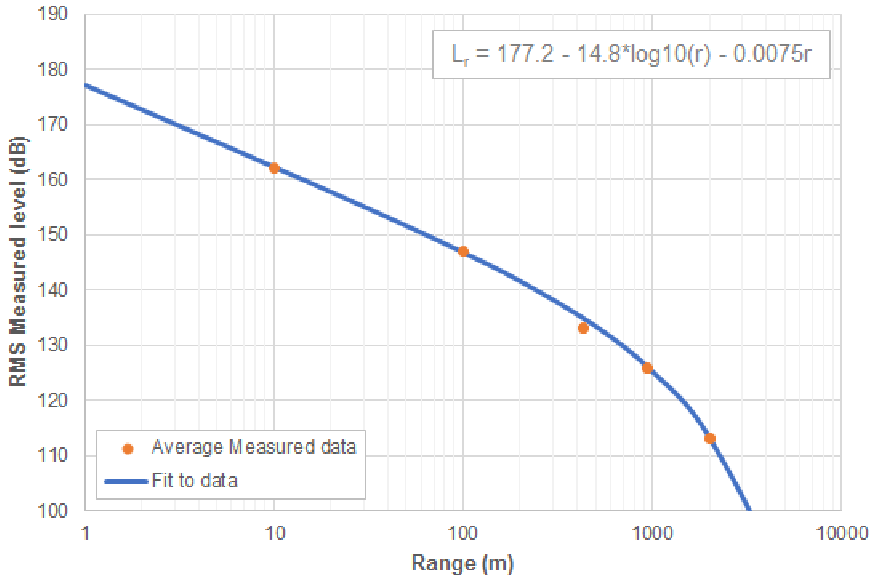

Figure 3-4 Rock breaking fit to measured data (RMS)

The other main difference between the two devices is their power outputs. The XR60 Ripper has a hydraulic working pressure of 26 to 28 MPa operating at a speed of 1000 strike per minute. The Doosan hammer has an operating pressure of between 165 and 185 bar (16.5 to 18.5 MPa), resulting in an output energy of between 7.9 and 10.4 kJ depending on its speed, which can be between 250 and 500 strikes per minute.

Based on these figures, the source level can be reduced using a simple formula method based on the differences between operating pressures.

$$Scaling\ Factor\ (dB) = 10\log_{10}\left(\frac{P_1}{P_2}\right)$$

This process essentially assumes that the energy conversion efficiency, in terms of the acoustic energy radiated versus the operating pressure is the same for the two devices. Using the largest of both estimates (28 MPa for the XR60 and 18.5 MPa for the Doosan hammer) the calculated source level for the Doosan hammer is 1.8 dB lower than the XR60 Ripper presented above. A summary of the source levels to be used for modelling is given below in Table 3-2.

	RMS (1s SEL)	SEL	SPL_{peak}
Source level @ 1 m	175.4 dB re 1 µPa	203.2 dB re 1 µPa²s	210.2 dB re 1 µPa

Table 3-2 Summary of rock breaking source levels to be used for modelling

The modelling of rock breaking requires that a third-octave spectrum of the noise is used as an input. As no detailed noise data for rock breaking is available, a proxy spectrum must be used.

Due to the physical process of the rock breaking equipment, a 180 mm diameter tool striking the rock, a small-scale impact piling event has been chosen to give an approximate noise signature for rock breaking. The strike rate of rock breaking is far in excess of that used for impact piling, however this will not affect the source spectrum. The spectrum is from impact piling to install a 508 mm diameter pile at a range of 53 m from the source, which has been scaled linearly to achieve the source level for modelling.

Figure 3-5 presents the third-octave levels from a small-scale impact piling event shifted to achieve the required RMS source level of 175.4 dB re 1 µPa.

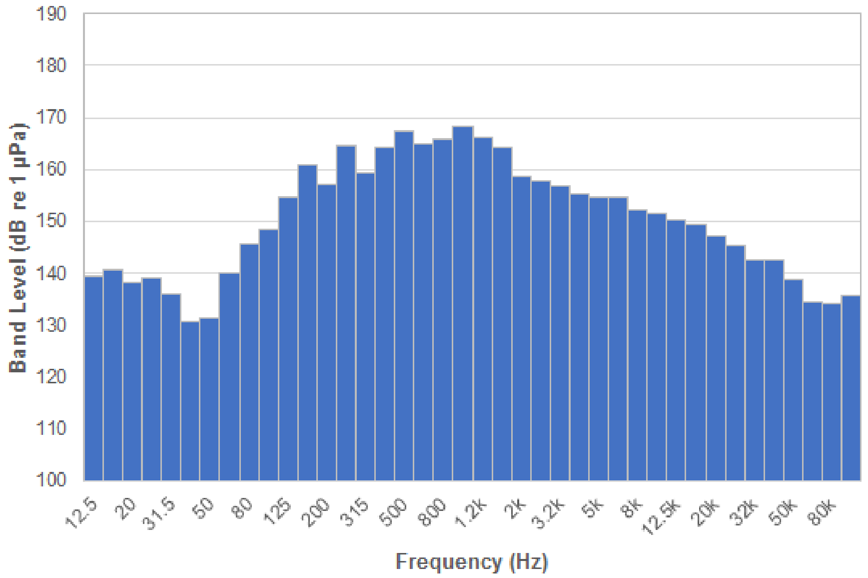

Figure 3-5 Source third octave band levels to be used to model rock breaking (RMS)

It is assumed that rock breaking will occur for approximately 8 hours in any one 24-hour period. Due to this, continuous rock breaking noise for a period of 8 hours has been assumed for cumulative SEL modelling.

3.1.6 Simple modelling – Drilling and vibro extraction source levels

Modelling of noise from drilling and vibro extraction have been undertaken using a simple modelling approach. This methodology has been chosen due to either low levels of noise or limited data availability. The simple modelling methodology comprises of using existing measurement data from similar activities taken by Subacoustech and modifying the source level to best match the scenario being modelled.

Source levels used for drilling have been are based on third octave band measurements undertaken by Subacoustech of drilling. The project was drilling anchor sockets in rock for a tidal turbine.

Vibro extraction of old sheet piles uses the same tool as for driving sheet piles. Noise is generated in the sheet piles through the coupling to the piling hammer. Third octave band Source levels are based on measurements taken by Subacoustech of the vibro piling of sheet piles.

The simple modelling is based on a simple geometric spreading model of the form $N \log_{10} R - \alpha R$ where R is the range and values for N and α are based on approximations from field measurements taken by Subacoustech. In contrast, the PE / Ray tracing solution is based on a physical approximations of underwater wave propagation and considers variations in bathymetry, seabed type and sound speed profile for multiple depths and for each frequency band. With the simple methodology these factors are intrinsic to the conditions of the measurements. In practice, the complex numerical modelling is extremely resource intensive and a single scenario can take over 48 hours to complete and it is common practice to use different modelling techniques according to the source being modelled and the anticipated impact range.

3.2 Assessment criteria

3.2.1 Background

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

The impacts of underwater sound can be broadly summarised into three categories:

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

The following sections discussed the agreed upon criteria for assessing these impacts in key marine species. The metrics and criteria that have been used in this study to assess environmental effect come from the latest NOAA report concerning underwater noise and its effects on marine mammals; the National Marine Fisheries Service Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (NMFS, 2016).

3.2.2 Marine mammals

Since it was published, Southall *et al* (2007) has been the source of the most widely used criteria to assess the effects of noise on marine mammals. NMFS (2016) was co-authored by many of the same academics from the Southall *et al* (2007) paper, and effectively updates it. In the updated guidelines, the frequency weightings have changed along with the criteria. As a result, the criteria have generally become more strict and potential impact ranges may increase substantially in some cases.

The NMFS (2016) guidance groups marine mammals into functional hearing groups and applies filters to the unweighted noise to approximate the hearing response of the receptor. The hearing groups given in the NMFS (2016) are summarised in Table 3-3.

The auditory weighting functions for each hearing group are provided in Figure 3-6.

Hearing group	Example species	Generalised hearing range
Low Frequency (LF) Cetaceans	Baleen Whales	7 Hz to 35 kHz
Mid Frequency (MF) Cetaceans	Dolphins, Toothed Whales, Beaked Whales, Bottlenose Whales (including Bottlenose Dolphin)	150 Hz to 160 kHz
High Frequency (HF) Cetaceans	True Porpoises (including Harbour Porpoise)	275 Hz to 160 kHz
Phocid Pinnipeds (PW) (underwater)	True Seals (including Harbour Seal)	50 Hz to 86 kHz
Otariid Pinnipeds (OW) (underwater)	Sea lions, Fur seals	60 Hz to 39 kHz

Table 3-3 Marine mammal hearing groups (from NMFS, 2016)

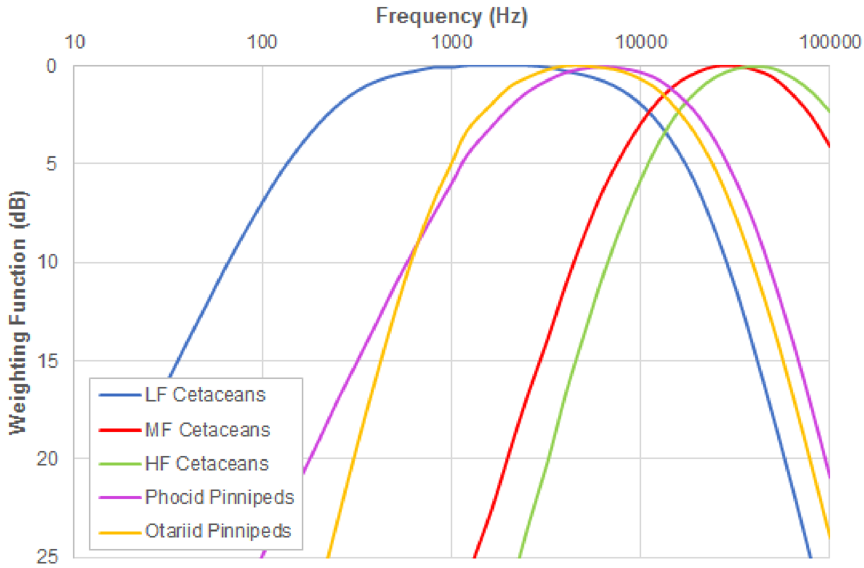

Figure 3-6 Auditory weighting functions for low frequency (LF) cetaceans, mid frequency (MF) cetaceans, high frequency (HF) cetaceans, phocid pinnipeds (PW) (underwater), and otariid pinnipeds (OW) (underwater) (from NMFS, 2016)

NMFS (2016) presents unweighted peak criteria (SPL_{peak}) and cumulative, weighted sound exposure criteria (SEL_{cum}) for both permanent threshold shift (PTS) where unrecoverable hearing damage may occur and temporary threshold shift (TTS) where a temporary reduction in hearing sensitivity may occur in individual receptors. Table 3-4 and Table 3-5 summarise the NMFS (2016) criteria for onset of risk of PTS and TTS for each of the key marine mammal hearing groups for impulse and non-impulsive noise.

In the assessment of cumulative SEL values, a stationary animal model has been used assuming as a worst case, assuming the receptor stays at the same range from a noise source for its entire duration.

Impulsive noise	**TTS criteria**		**PTS criteria**	
Functional Group	**SEL_{cum} (weighted) dB re 1 µPa^{2}s**	**SPL_{peak} (unweighted) dB re 1 µPa**	**SEL_{cum} (weighted) dB re 1 µPa^{2}s**	**SPL_{peak} (unweighted) dB re 1 µPa^{2}s**
LF Cetaceans	168	213	183	219
MF Cetaceans	170	224	185	230
HF Cetaceans	140	196	155	202
PW Pinnipeds	170	212	185	218
OW Pinnipeds	188	226	203	232

Table 3-4 Assessment criteria for marine mammals from NMFS (2016) for impulsive noise (blasting)

Non-impulsive noise	TTS criteria	PTS criteria
Functional Group	**SEL_{cum} (weighted) dB re 1 μPa²s**	**SEL_{cum} (weighted) dB re 1 μPa²s**
LF Cetaceans	179	199
MF Cetaceans	178	198
HF Cetaceans	153	173
PW Pinnipeds	181	201
OW Pinnipeds	199	219

Table 3-5 Assessment criteria for marine mammals from NMFS (2016) for non-impulsive noise (rock breaking, vibro-piling and drilling)

3.2.3 <u>Weighted source levels</u>

To undertake the modelling with regards to the weighted criteria, the source levels were first adjusted using the auditory weighting functions shown in Figure 3-6. This significantly alters the source level for each functional group as shown in Figure 3-7 to Figure 3-9.

Noise from blasting and rock breaking is predominantly low frequency in nature and reduces significantly at frequencies above 1 kHz. The blasting source levels given in Figure 3-7 to Figure 3-9 show that the weighting makes only a modest difference to source levels for LF cetaceans when frequency weightings are applied and a significant reduction for other functional groups. The source levels for rock breaking show a similar pattern, a summary of the weighted single pulse source levels for blasting and 1 s RMS source levels for rock breaking are given in Table 3-6.

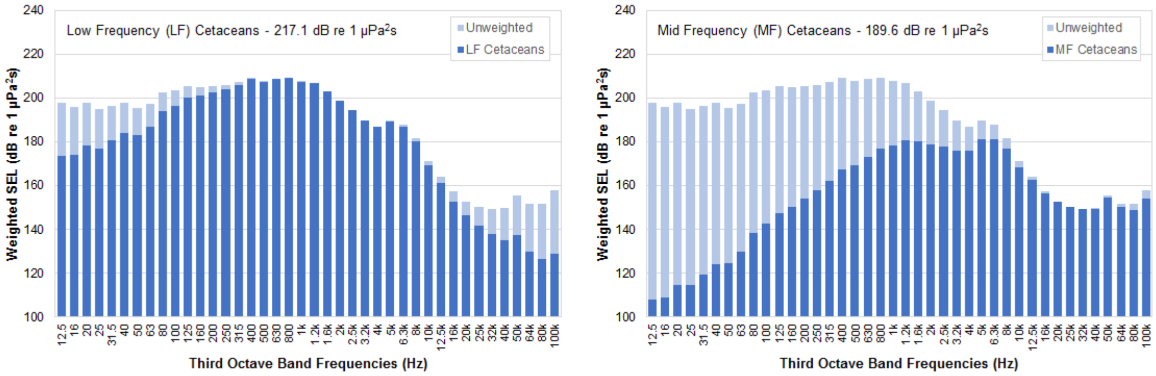

Figure 3-7 Unweighted and NMFS (2016) weighted SEL source level third octave values for LF and MF cetaceans (blasting)

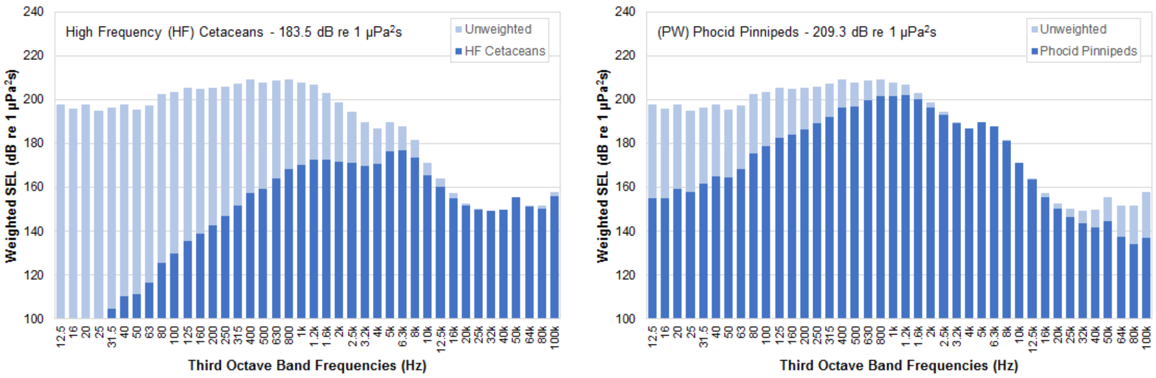

Figure 3-8 Unweighted and NMFS (2016) weighted SEL source level third octave values for HF cetaceans and phocid pinnipeds (blasting)

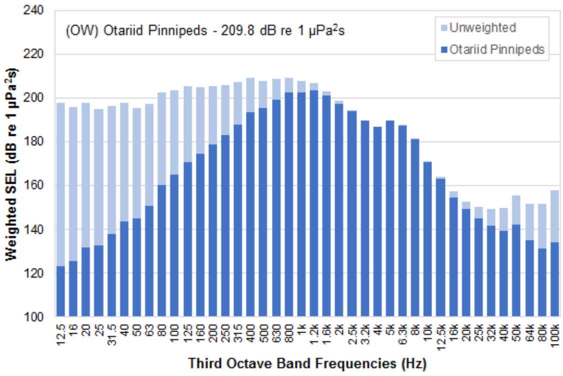

Figure 3-9 Unweighted and NMFS (2016) weighted SEL source third octave values spectra for otariid pinnipeds (blasting)

	Blasting source level (single pulse SEL) (0.3s)	Rock breaking source level (1 second RMS)
Unweighted	218.5 dB re 1 µPa²s	175.4 dB re 1 µPa
LF Cetaceans	217.1 dB re 1 µPa²s	174.8 dB re 1 µPa
MF Cetaceans	189.6 dB re 1 µPa²s	157.5 dB re 1 µPa
HF Cetaceans	183.5 dB re 1 µPa²s	154.9 dB re 1 µPa
Phocid Pinnipeds	209.3 dB re 1 µPa²s	169.1 dB re 1 µPa
Otariid Pinnipeds	209.8 dB re 1 µPa²s	169.7 dB re 1 µPa

Table 3-6 Summary of the NMFS (2016) weighted source levels at 1 metre used for detailed modelling

Source levels used for vibro-extraction and drilling have been weighted in the same way and are provided in Table 3-7.

	Vibro-piling source level (1 second RMS)	Drilling source level (1 second RMS)
Unweighted	188.0 dB re 1 µPa²s	168.0 dB re 1 µPa
LF Cetaceans	187.8 dB re 1 µPa²s	163.8 dB re 1 µPa
MF Cetaceans	173.3 dB re 1 µPa²s	143.9 dB re 1 µPa
HF Cetaceans	169.0 dB re 1 µPa²s	142.1 dB re 1 µPa
Phocid Pinnipeds	184.6 dB re 1 µPa²s	155.5 dB re 1 µPa
Otariid Pinnipeds	185.3 dB re 1 µPa²s	155.7 dB re 1 µPa

Table 3-7 Summary of the NMFS (2016) weighted source levels at 1 metre used for simple modelling

4 Modelling results

4.1 Blasting

4.1.1 Unweighted SPL_{peak}

The SPL_{peak} noise level from borehole blasting using a 10 kg charge weight is presented in Figure 4-1 for the maximum level in the water column. Cross sections of the southern transect (182°) are presented in Figure 4-2 and Figure 4-3 to show the distribution of noise through the water column along with the water depth profile. These results are analysed in terms of TTS and PTS ranges for species of marine mammal using the NMFS (2016) SPL_{peak} criteria in Table 4-1.

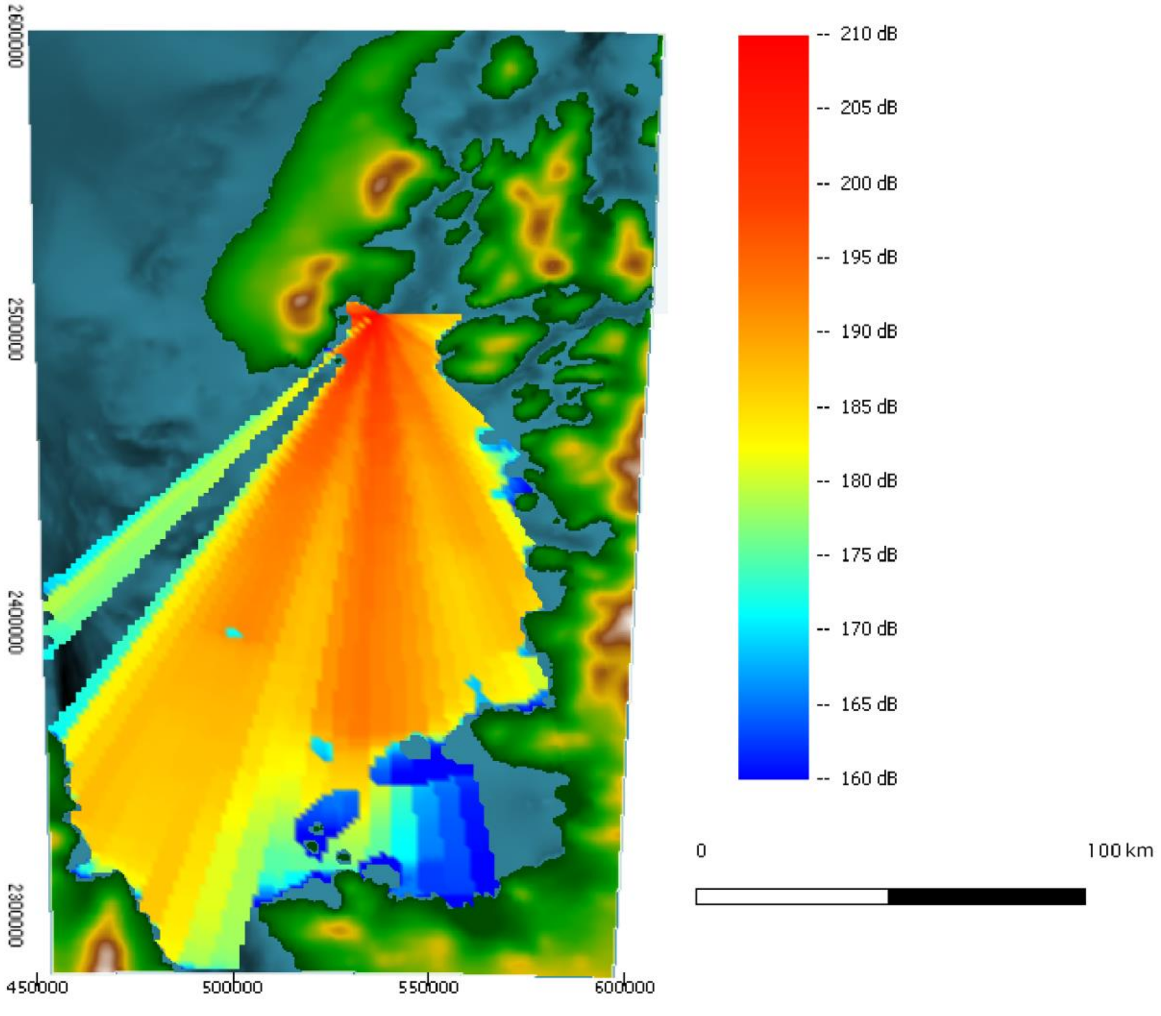

Figure 4-1 Blasting (10 kg charge weight), unweighted SPL_{peak}

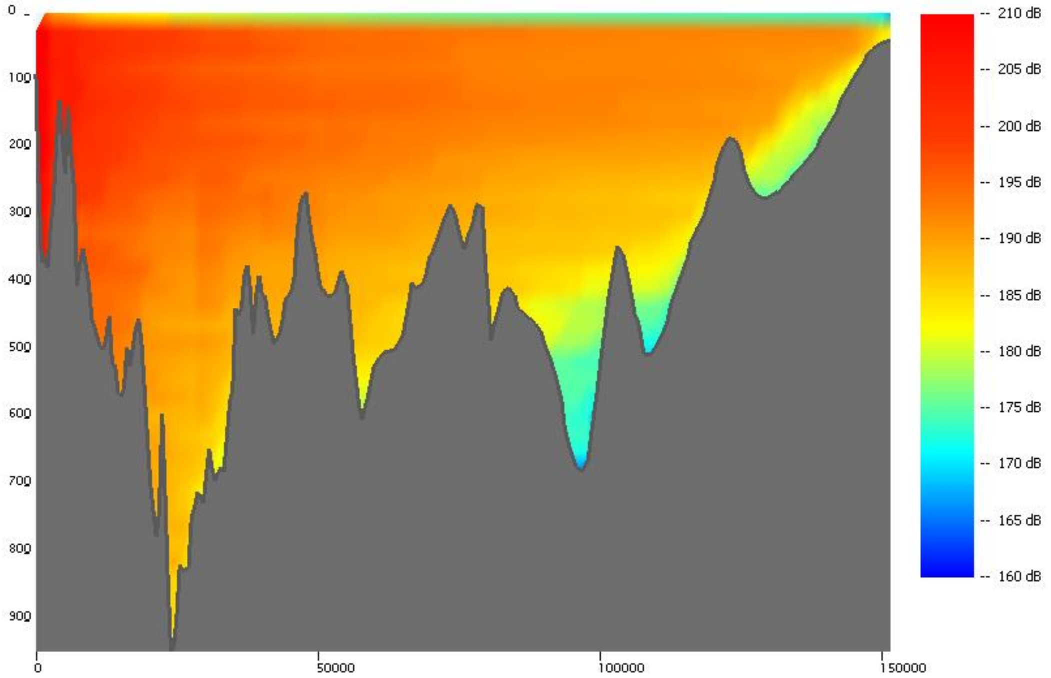

Figure 4-2 Cross section of 182° transect from blasting (10 kg charge weight), unweighted SPL_{peak}

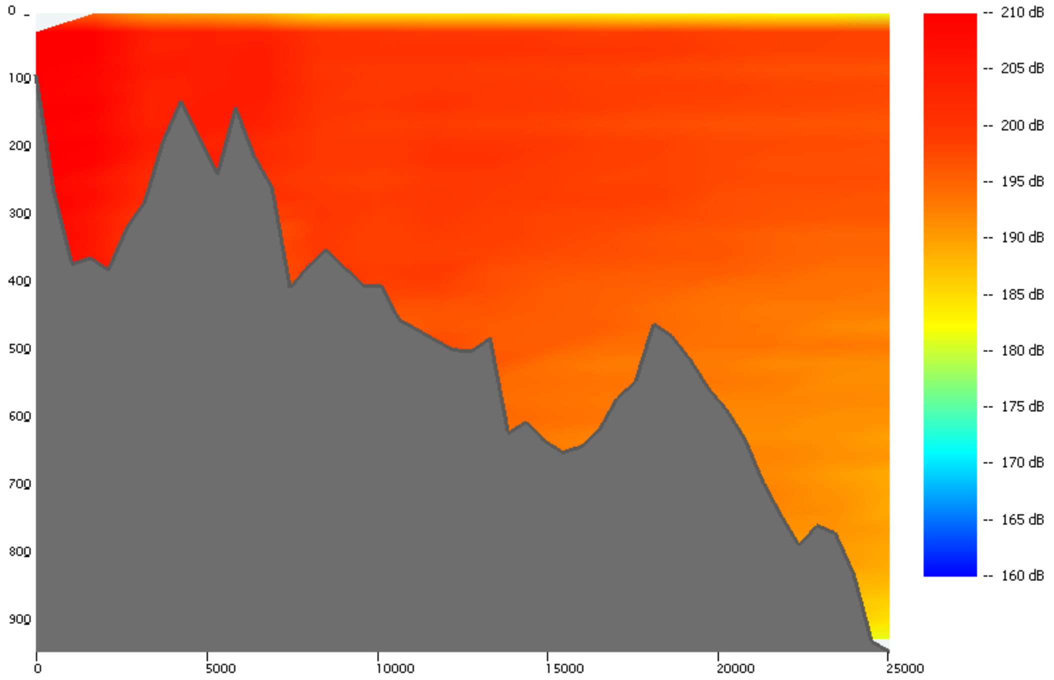

Figure 4-3 Truncated (25 km) cross section of 182° transect from blasting (10 kg charge weight), unweighted SPL_{peak}

Threshold	Criteria SPL_{peak} (unweighted)	Blasting (10kg) SPL_{peak} Maximum range
LF Cetaceans TTS	213 dB re 1 µPa	1.0 km
MF Cetaceans TTS	224 dB re 1 µPa	150 m
HF Cetaceans TTS	196 dB re 1 µPa	19 km
PW Pinnipeds TTS	212 dB re 1 µPa	1.2 km
OW Pinnipeds TTS	226 dB re 1 µPa	110 m
LF Cetaceans PTS	219 dB re 1 µPa	370 m
MF Cetaceans PTS	230 dB re 1 µPa	56 m
HF Cetaceans PTS	202 dB re 1 µPa	6.7 km
PW Pinnipeds PTS	218 dB re 1 µPa	440 m
OW Pinnipeds PTS	232 dB re 1 µPa	39 m

Table 4-1 Ranges to NMFS (2016) SPL_{peak} injury criteria for blasting based on the maximum level in the water column

The results are based on the maximum predicted noise level in the water column and this approach has been used as it is not possible to predict the depth of a marine mammal at the time of a single impulsive event. Figure 4-2 and Figure 4-3 indicate an even distribution of noise through the water column with the maximum generally occurring in the mid-water region indicating that the use of maximum noise level is a reasonable approach.

Given the proximity to the coast, only the maximum ranges have been presented above as any attempt to present a mean range would be subject to considerable bias from many very short transects and would therefore be misleading. In practice only a very small number of transects will be subject to the maximum range. Figure 4-4 and Figure 4-5 show the distribution of the impact ranges for each transect (MF Cetaceans and Otariid Pinnipeds have not been included due to size of the predicted impact ranges). For example, the HF TTS ranges (which includes the greatest range) along each transect and only 8 transects exceed 15 km and 19 out of 180 transects exceed 10 km.

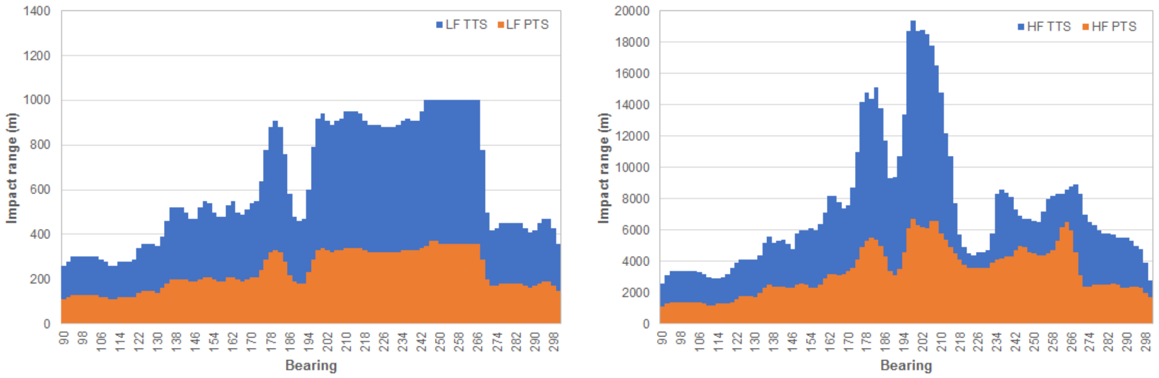

Figure 4-4 Blasting impact ranges for each transect for LF and HF cetaceans (SPL_{peak})

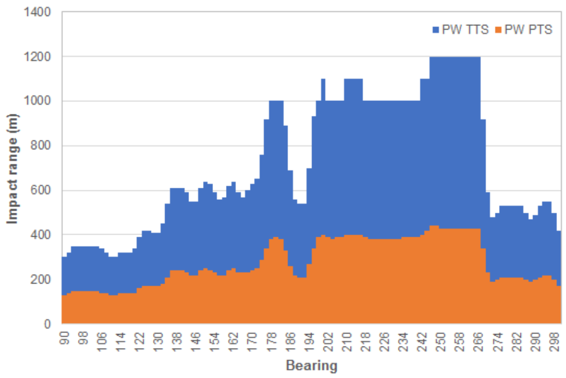

Figure 4-5 Blasting impact ranges for each transect for Phocid Pinnipeds (SPL_{peak})

4.1.2 SEL

As each blasting event can be defined as a single noise event (with multiple blasts happening over a period of approximately 0.3 s) it is unnecessary to calculate cumulative SEL values. A single pulse SEL source level has been derived using the SPL_{peak} data for the period of the blast, and from this, weightings have been applied in order to assess the noise using the NMFS (2016) criteria, as discussed in section 3.2.3.

Table 4-2 presents the modelling impact ranges for blasting using the NMFS (2016) SEL criteria for TTS and PTS on species of marine mammal. The distribution of the impact ranges for each transect are shown in Figure 4-6 to Figure 4-7 (MF Cetaceans and Otariid Pinnipeds are not included due to size of the predicted impact ranges).

Threshold	Criteria SEL (weighted)	Blasting (10kg) SEL_{ss} (0.3s) Maximum range
LF Cetaceans TTS	168 dB re 1 $\mu Pa^2 s$	4.7 km
MF Cetaceans TTS	170 dB re 1 $\mu Pa^2 s$	29 m
HF Cetaceans TTS	140 dB re 1 $\mu Pa^2 s$	1.7 km
PW Pinnipeds TTS	170 dB re 1 $\mu Pa^2 s$	870 m
OW Pinnipeds TTS	188 dB re 1 $\mu Pa^2 s$	42 m
LF Cetaceans PTS	183 dB re 1 $\mu Pa^2 s$	350 m
MF Cetaceans PTS	185 dB re 1 $\mu Pa^2 s$	2 m
HF Cetaceans PTS	155 dB re 1 $\mu Pa^2 s$	130 m
PW Pinnipeds PTS	185 dB re 1 $\mu Pa^2 s$	66 m
OW Pinnipeds PTS	203 dB re 1 $\mu Pa^2 s$	3 m

Table 4-2 Ranges to NMFS (2016) SEL injury criteria for blasting based on the maximum level in the water column

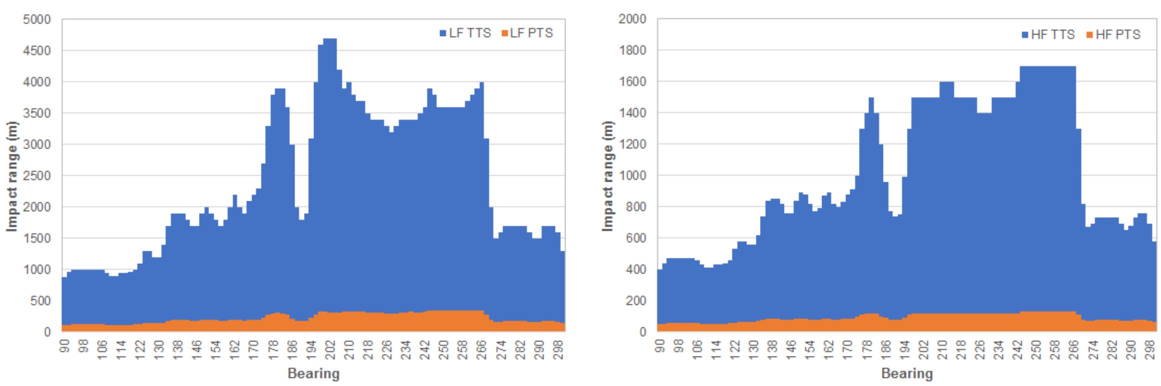

Figure 4-6 Blasting impact ranges for each transect for LF and HF cetaceans (SEL_{ss})

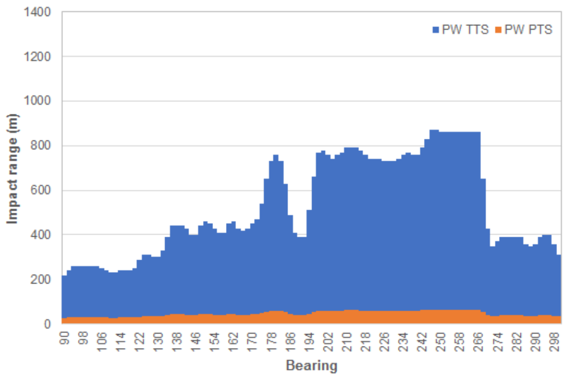

Figure 4-7 Blasting impact ranges for each transect for Phocid Pinnipeds (SEL_{SS})

4.2 Rock breaking

4.2.1 Unweighted RMS

The one second RMS noise levels from rock breaking noise, using the methodology described in section 3.1.5, are presented as SPL_{RMS} noise plots in Figure 4-8. There are no criteria given for RMS values in NMFS (2016). Cumulative SEL results are presented in the following section (4.2.2).

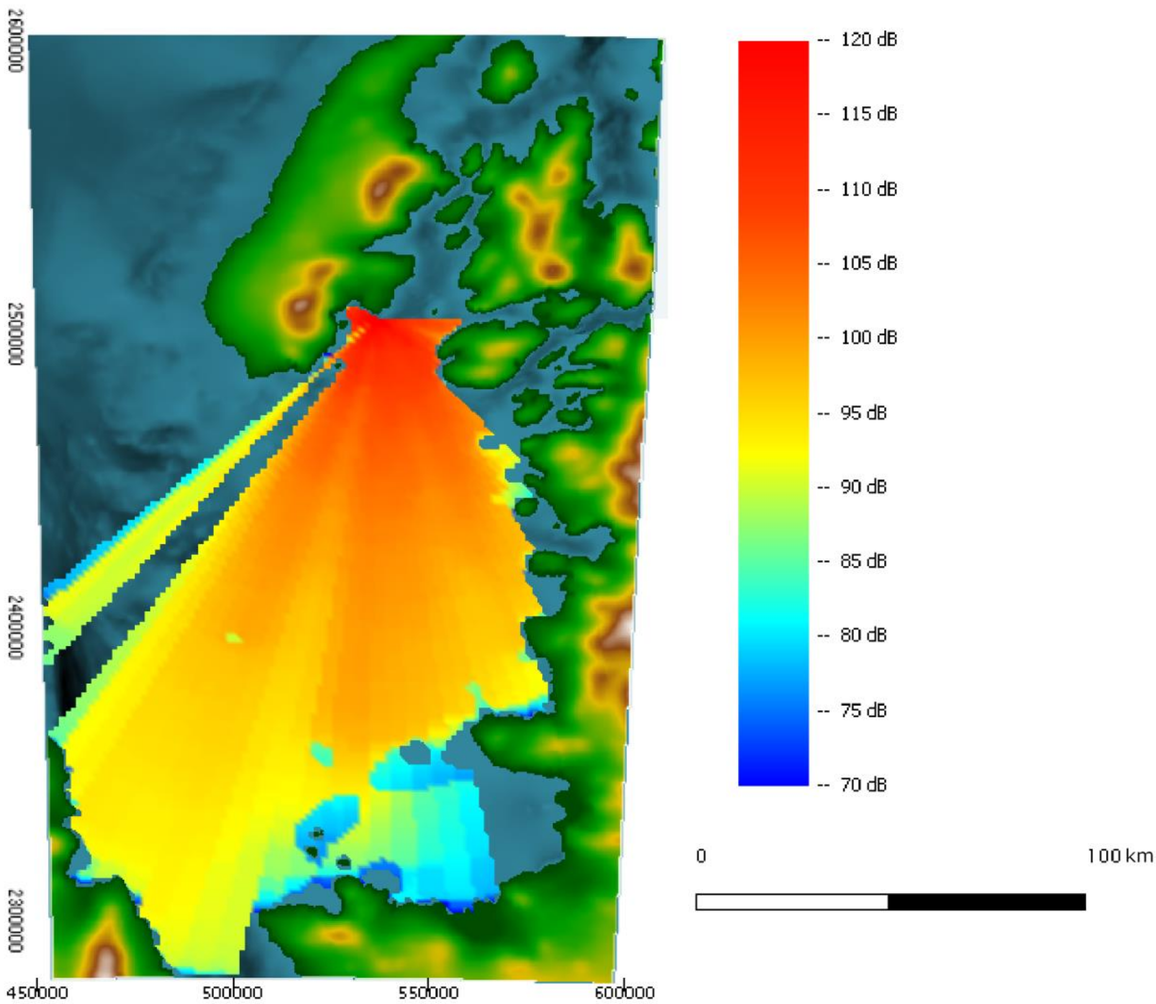

Figure 4-8 Rock breaking, unweighted SPL 1 second RMS

4.2.2 Cumulative SEL (SEL_{cum})

The noise from rock breaking has been considered a continuous noise due to the rapid rate of peckering from the equipment. As such the 1 second RMS value has been used as a basis for estimating the cumulative SEL value assuming a rock breaking operation lasting 8 hours. Table 4-3 presents impact ranges for species of marine mammal using the NMFS (2016) SEL_{cum} criteria for TTS and PTS assuming a stationary receptor. If a fleeing receptor were assumed for these results, the predicted impact ranges would be reduced.

Figure 4-9 shows the distribution of the impact ranges for each transect (MF Cetaceans, Phocid Pinnipeds and Otariid Pinnipeds are not included due to size of the predicted impact ranges).

Threshold	Criteria SEL_{cum} (weighted)	Rock Breaking SEL_{cum} (8 hours) Maximum range
LF Cetaceans TTS	179 dB re 1 μPa^2s	520 m
MF Cetaceans TTS	178 dB re 1 μPa^2s	41 m
HF Cetaceans TTS	153 dB re 1 μPa^2s	1.3 km
PW Pinnipeds TTS	181 dB re 1 μPa^2s	150 m
OW Pinnipeds TTS	199 dB re 1 μPa^2s	10 m
LF Cetaceans PTS	199 dB re 1 μPa^2s	23 m
MF Cetaceans PTS	198 dB re 1 μPa^2s	1 m
HF Cetaceans PTS	173 dB re 1 μPa^2s	60 m
PW Pinnipeds PTS	201 dB re 1 μPa^2s	7 m
OW Pinnipeds PTS	219 dB re 1 μPa^2s	< 1 m

Table 4-3 Ranges to NMFS (2016) SEL_{cum} injury criteria for rock breaking based on the maximum level in the water column assuming a stationary receptor over a period of 8 hours

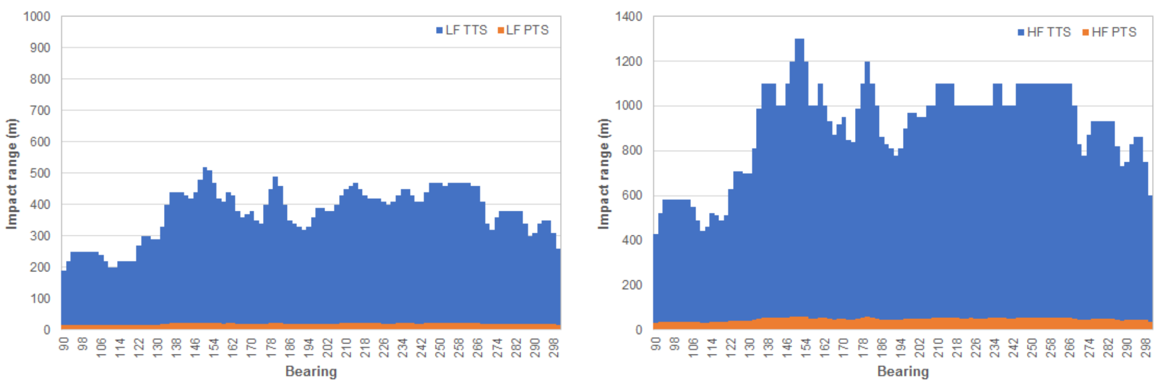

Figure 4-9 Rock breaking impact ranges for each transect for LF and HF cetaceans (SEL_{cum} 8 hours)

4.3 Drilling and vibro-piling (simple modelling)

Underwater noise from the extraction of piles using a vibro pile driver along with drilling into rock have been modelled using Subacoustech's SPEAR model. This is a simple model which uses a large amount of measurement data to estimate noise levels with range.

The ranges for drilling have assumed a stationary animal and drilling being undertaken for up to 8 hours in a given 24-hour period. For vibro extraction, ranges have been calculated for both a stationary and fleeing animals and are based on 2 hours of operation in a given 24 hour period.

Threshold	Criteria SEL_{cum} (weighted)	Vibro extraction (2 hours)		Drilling (8 hours)
		Stationary animal	Fleeing animal (1.5m/s)	
LF Cetaceans TTS	179 dB re 1 µPa²s	400 m	7 m	80 m
MF Cetaceans TTS	178 dB re 1 µPa²s	70 m	-	6 m
HF Cetaceans TTS	153 dB re 1 µPa²s	1000 m	60 m	100 m
PW Pinnipeds TTS	181 dB re 1 µPa²s	200 m	2 m	10 m
OW Pinnipeds TTS	199 dB re 1 µPa²s	20 m	-	1 m
LF Cetaceans PTS	199 dB re 1 µPa²s	30 m	-	5 m
MF Cetaceans PTS	198 dB re 1 µPa²s	5 m	-	< 1 m
HF Cetaceans PTS	173 dB re 1 µPa²s	80 m	-	9 m
PW Pinnipeds PTS	201 dB re 1 µPa²s	10 m	-	1 m
OW Pinnipeds PTS	219 dB re 1 µPa²s	1 m	-	< 1 m

Table 4-4 Ranges to NMFS (2016) SEL_{cum} injury criteria for vibro extraction and drilling operations using a qualitative modelling approach assuming a stationary receptor over a period of 8 hours

4.4 Discussion

The impact ranges seen in the preceding sections vary significantly depending on the functional hearing (species) group and the NMFS (2016) criteria that defines the onset of PTS and TTS.

Summarising the PTS ranges for all scenarios modelled above, Table 4-5 and Table 4-6 show the spread of the PTS impact ranges between different functional groups and criterion.

NMFS (2016) requires that where an assessment includes both SPL_{peak} and cSEL then the greater of the two impact ranges should be used in the assessment. For blasting, the SPL_{peak} criteria gave rise to the greatest ranges across all functional groups.

The greatest impact ranges were seen for HF cetaceans with blasting. This is not unexpected given the particularly strict SPL_{peak} criteria specified by NMFS (2016).

Despite this, the SPL_{peak} ranges should still be considered conservative as physical processes in propagation alter the shape of the waveform and reduce the peaks with increasing range. NMFS (2016) refers to this effect (p27, paragraph 2) but it is not easily quantified or accounted for in the modelling.

Threshold	Criteria SPL_{peak} (unweighted) dB re 1 µPa²s	SPL_{peak} Maximum range	Criteria SEL (weighted) dB re 1 µPa²s	SEL_{ss} (0.3s) Maximum range
LF Cetaceans PTS	219 dB	370 m	183 dB	350 m
MF Cetaceans PTS	230 dB	56 m	185 dB	2 m
HF Cetaceans PTS	202 dB	6.7 km	155 dB	130 m
PW Pinnipeds PTS	218 dB	440 m	185 dB	66 m
OW Pinnipeds PTS	232 dB	39 m	203 dB	3 m

Table 4-5 Ranges to NMFS (2016) PTS auditory injury criteria for blasting.

Threshold	Criteria SEL_{cum} (weighted)	Rock Breaking (8 hours)	Vibro-extraction (2 hours)	Drilling (8 hours)
LF Cetaceans PTS	199 dB re 1 µPa²s	26 m	30 m	5 m
MF Cetaceans PTS	198 dB re 1 µPa²s	1 m	5 m	< 1 m
HF Cetaceans PTS	173 dB re 1 µPa²s	71 m	80 m	9 m
PW Pinnipeds PTS	201 dB re 1 µPa²s	7 m	10 m	1 m
OW Pinnipeds PTS	219 dB re 1 µPa²s	< 1 m	1 m	< 1 m

Table 4-6 Ranges to NMFS (2016) PTS auditory injury criteria for continuous sources, assuming a stationary receptor.

5 Summary and conclusions

Subacoustech Environmental has undertaken a study of noise propagation for Aquatera near the Rothera Research Station, Antarctica, for blasting and rock breaking activities.

The level of underwater noise from blasting and rock breaking has been estimated using a parabolic equation (PE) method for lower frequencies and a ray tracing solution at higher frequencies. The modelling considers a wide variety of input parameters including source noise levels, frequency content, duty cycle, seabed properties and the sound speed profile in the water column. Full account is taken of the complex bathymetry in the area.

A representative location to the east of the existing wharf at the south of the research station has been modelled to give worst case ranges into the open water.

Further simple modelling has been carried out to assess the effects of vibro extraction and drilling noise in the area.

Noise levels have been assessed in terms of the criteria provided by NMFS (2016) for SPL_{peak} and SEL_{cum}. In each case, the 1/3 octave band spectrum of the source level has been weighted according the LF, MF, HF, PW, and OW frequency weightings stipulated in the guidelines.

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P218R0100	02	05/12/2017	Initial writing and internal review
P218R0101	02	15/12/2017	Initial issue to client, minor amendments following review
P218R0102	01	02/01/2018	Further amendments
P218R0103	01	05/01/2018	Further minor amendments
P218R0104	01	08/01/2018	Updated Table 4-5
P218R0105	-	10/10/2018	Reissue to client

Originator's current report number	P218R0105
Originator's name and location	S East; Subacoustech Environmental Ltd.
Contract number and period covered	P218; November 2017 – December 2017
Sponsor's name and location	Carla Houghton; Aquatera
Report classification and caveats in use	COMMERCIAL IN CONFIDENCE
Date written	December 2017
Pagination	Cover + i + 26
References	20
Report title	Underwater noise propagation modelling of construction activity at Rothera Research Station, Antarctica
Translation/Conference details (if translation, give foreign title/if part of a conference, give conference particulars)	
Title classification	Unclassified
Author(s)	Richard Barham and Sam East
Descriptors/keywords	
Abstract	
Abstract classification	Unclassified; Unlimited distribution

APPENDIX H:

ECOLOGICAL SPECIES LIST

APPENDIX H

ANNEX 1- TERRESTRIAL AND FRESHWATER SPECIES LISTS FOR ROTHERA POINT

Terrestrial invertebrate fauna

Group	**No.**	**Species**
Collembola	1	*Cryptopygus antarcticus*
	2	*Friesea grisea*
Acari	1	*Alaskozetes antarcticus*
	2	*Apotriophtydeus spp.*
	3	*Gamasellus racovitzai*
	4	*Halozetes begicae*
	5	*Magellozetes antarcticus*
	6	*Oppia loxolineata*
	7	*Paratydaeolus enigmaticus*
	8	*Pretriophtydeus tilbrooki*
	9	*Stereotydeus villosus*
Tardigrada	1	*Echiniscus jenningsi*
	2	*Hypsibius alpinus*
	3	*Hypsibius pinguis*
	4	*Macrobiotus furciger*
Protozoa	1	*Assulina muscorum*
	2	*Centropyxis aerophila*
	3	*Corythion dubium*
	4	*Difflugia lucida*
	5	*Difflugia mica*
	6	*Nebela lageniformis*
	7	*Nebela wailesi*
	8	*Phryganella acropodia*
	9	*Trigonopyxis arcula*

Freshwater biota

Group	**No.**	**Species**
Nematoda	1	*Monhystera* sp.
Rotifera	1	*Colurella colurus compressa*
	2	*Encentrum* cf. *gulo*
	3	*Philodina* sp.
	4	*Resticula gelida*
Flora		
Cyanophyta	1	*Chroococcus* sp.
	2	*Lyngbya* spp.

	3	*Microcystis* sp.
	4	*Oscillatoria* spp.
	5	*Phormidium* spp.
Chlorophyta	1	*Oedogonium* sp.
Bacillariophyta	1	*Acnanthes brevipes*
	2	*Acnanthes germanii*
	3	*Acnanthes ninckeri*
	4	*Acnanthes* spp.
	5	*Amphora* sp.
	6	*Cocconeis costata* (marine source)
	7	*Fragilaria* sp.
	8	*Navicula cryptocephala* var. *intermedia*
	9	*Navicula muticopsis*
	10	*Nitzschia curta*
	11	*Nitzschia cylindrus*
	12	*Pinnularia borealis*
	13	*Pinnularia krookei*
	14	*Thalassiosira gracilis*
	15	*Tropidoneis leavissima*

Algae

1	*Prasiola crispa*

Liverworts

1	*Cephaloziella exiliflora* (Tayl.) Steph
2	*Cephaloziella varians* (Gott.) Steph
3	*Lophozia excisa* (Dicks.) Dum.

Lichens

1	*Acarospora macrocyclos* Vain.
2	*Amandinea petermannii* (Hue) Matzer, Mayrh. & Scheidegger
3	*Buellia anisomera* Vain.
4	*Caloplaca ammiospila* (Ach.) Oliv.
5	*Caloplaca cirrochrooides* (Vain.) Zahlbr.
6	*Caloplaca isidioclada* Zahlbr.
7	*Caloplaca regalis* (Vain.) Zahlbr.
8	*Candelariella vitellina* (Hoffm.) Mull. Arg.
9	*Cladonia chlorophaea* (Florke ex Sommerf.) Sprengel
10	*Cladonia fimbriata* (L.) Th.Fr.
11	*Lecania brialmontii* (Vain.) Zahlbr.
12	*Lecidea placodiiformis* Hue
13	*Leproloma cacuminum* (Massal.) Laundon
14	*Leptogium puberulum* Hue
15	*Massalongia carnosa* (Dicks.) Koerb.
16	*Mastodia tessellata* (Hook. f. & Harv.) Hook. f. & Harv.
17	*Ochrolechia frigida* (Sw.) Lynge
18	*Parmelia saxatilis* (L.) Ach.
19	*Physcia caesia* (Hoffm.) Furnr.
20	*Physconia muscigena* (Ach.) Poelt
21	*Pleopsidium chlorophanum* (Wahlenb.) Zopf
22	*Pseudephebe minuscula* (Nyl. ex Arnold) Brodo & Hawksw.
23	*Pseudephebe pubescens* (L.) Choisy
24	*Psoroma cinnamomeum* Malme
25	*Rhizocarpon geographicum* (L.) DC.
26	*Rhizoplaca aspidophora* (Vain.) Redon
27	*Rhizoplaca melanophthalma* (Ram.) Leuck. & Poelt
28	*Stereocaulon antarcticum* Vain.
29	*Stereocaulon glabrum* (Mull. Arg.) Vain.
30	*Stereocaulon vesuvianum* Pers.
31	*Umbilicaria antarctica* Frey & Lamb
32	*Umbilicaria decussata* (Vill.) Zahlbr.
33	*Umbilicaria kappeni* Sancho, Schroeter & Valladares
34	*Umbilicaria nylanderiana* (Zahlbr.) H. Magn.
35	*Usnea antarctica* Du Rietz
36	*Usnea aurantiaco-atra* (Jacq.) Bory
37	*Usnea sphacelata* R. Br.
38	*Usnea subantarctica* F.J. Walker
39	*Usnea trachycarpa* (Stirt.) Mull. Arg.
40	*Xanthoria candelaria* (L.) Th. Fr.
41	*Xanthoria elegans* (Link.) Th. Fr.

Mosses

1	*Andreaea depressinervis* Card.
2	*Andreaea gainii* Card.
3	*Andreaea gainii var. gainii* Card.
4	*Andreaea regularis* C. Muell.
5	*Bartramia patens* Brid.
6	*Bryum archangelicum* Bruch & Schimp.
7	*Bryum argenteum var. muticum* Hedw.; Brid.
8	*Bryum pseudotriquetrum* (Hedw.) Gaertn.
9	*Ceratodon purpureus* (Hedw.) Brid.
10	*Coscinodon reflexidens* Mull. Hal.
11	*Didymodon brachyphyllus* (Sull.) Zander
12	*Ditrichum hyalinocuspidatum* Card.
13	*Hennediella antarctica* (aengstr.) Ochyra & Matteri
14	*Hypnum revolutum* (Mitt.) Lindb.
15	*Pohlia cruda* (Hedw.) Lindb.
16	*Pohlia nutans* (Hedw.) Lindb.
17	*Polytrichastrum alpinum* (Hedw.) G.L. Smith
18	*Sanionia uncinata* (Hedw.) Loesk
19	*Schistidium antarctici* (Card.) L. Savic. & Smirn.
20	*Syntrichia magellanica* (Mont.) R.H. Zander
21	*Tortella alpicola* Dixon

Vascular plants

1	*Colobanthus quitensis* (Kunth) Bartl. (Caryophyllacaea) ?
2	*Deschampsia antarctica* (Desv.) (Poaceae) ?

ANNEX 2

MARINE SPECIES LIST FOR BISCOE WHARF AT 100 M DEPTH

Species from the shallow depths around the Biscoe Wharf (South Cove and Cheshire Island) are described in various publications such as Barnes & Brockington (2003) and Bowden (2005). The species list presented here is from the deepest depths available (100 m) as this is where there is less information in the literature. The species were identified from 25 photos taken from 100 m depth, approximate position Latitude 67° 34.315'S, Longitude 068° 07. 953'W. The images were taken during polar summer, coinciding with the plankton bloom, so that the majority of epi-macrofauna (animals greater than >5 mm living on top of the seafloor) would be actively out and feeding on marine snow (falling organic matter from the bloom). It is also worth noting that this is a preliminary species list taken from images, many of the species require collection and close examination with the correct literature and expertise to be confident. The taxa can be divided into morphotypes (organisms with clear difference in their morphology), a useful taxonomic unit but should not be considered a species. Where possible a species name has been provided and where the species is conspicuous, such as *Flabelligera mundata*, *Nuttallochiton mirandus* or *Primnolla* sp., this can be given with confidence. However other species, most notably all nine morphothypes of Porifera (sponges), are difficult to classify from images as different species as identification relies on spicules (sponges skeletal structures).

To summarise, this list is an underestimation of the diversity that exists at this depth, it ignores all organisms <5mm and it is difficult to separate many of taxa such as the bryozoans which probably have a higher diversity than described here. However, it is a useful to provide an indication of the community present at these depths as well as how potentially diverse they have been.

Phylum	**Species name** / Description
Porifera	Large, Yellow, Encrusting sponge
Echinodermata	Pink sea cucumber
Echinodermata	***Sterechinus agassizi***
Echinodermata	***Ophionotus victoriae***
Bryozoa	broad, heavily silted, foilose Cheilostome bryozoan
Chordata	Pale, blotchy, visible siphones, clonial ascidian
Cnidaria	***Primnoella* sp.**
Chordata	***Pareugyrioides arnbackae***
Bryozoa	Thin, branched foilose bryozoans
Porifera	Globular, yellow, lobate, multiple operculum, sponge
Cnidaria	***Thourella* sp.**
Bryozoa	Bush-like resembles hydroids, Chelistome bryozoan
Porifera	Small tubular sponge
Bryozoa	Encursting bryozoan
Annelida	***Flabelligera mundata***
Cnidaria	***Hormanthia lacunifera***
Annelida	***Perkinsiana littoralis***
Brachiopoda	White, superficially bivalve-looking brachiopod
Cnidaria	Seawhip, branched into two, Octocoral
Cnidaria	***Oswaldella incognita***
Chordata	***Pyura setosa***
Chordata	***Mogula pedunculata***
Echinodermata	***Amphioplus peregrinator***
Annelida	***Serpula narconensis***
Mollusca	Transulcent, gills visible, nudibranch
Chordata	***Sycozoa sigillinoides***
Echinodermata	***Ophiosparte gigas***
Echinodermata	***Odontaster validus***
Cnidaria/Bryozoan	Brown with yellow growing edge, stylasterid hydrocoral or Bryozoan??
Porifera	Encursting yellow sponge attached to feather worm tube
Cnidaria	Hydroids growing on feather worm tube
Chordata	***Pyura obesa***
Echinodermata	***Cryptasterias turqueti***
Echinodermata	***Cuenotaster involutus* Juv.**
Arthropoda	Mantis shaped, yellow isopoda
Cnidaria	***Dactylanthus*sp.**
Bryozoa	***Cellarinella* sp.**
Echinodermata	***Psolus charcotii***
Porifera	Red/orange encrusting spots of sponges
Echinodermata	***Echinopsolus acanthocola***
Arthropoda	Semi-transulcent, red shrimp with green spot on head
Chordata	***Notothenia* sp.**
Porifera	Pale orange sponge or colonial sea squirt
Porifera	Burrowing sponge, two possible colour morphs?
Chordata	pink icefish
Chordata	Yellow pale clonial sea squirt
Mollusca	***Nuttallochiton mirandus***
Porifera	Tubular yellow sponge
Arthropoda	Yellow, squat, Sea spider

Echinodermata	***Diplasterias brucei***
Bryozoa	Small, delicate, branching, foliose bryozoans
Arthropoda	***Callochiton* sp.**
Chordata	***Ascidia* sp.**
Mollusca	**Austrodoris kerguelensis**
Porifera	***Sphaerotylus antarcticus***
Bryozoa	***Isosecuriflustra angusta***
Bryozoa	**Reteporella**
Echinodermata	***Odontaster meridionalis***
Echinodermata	***Porania antarctica***

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APPENDIX I:

GEOTECHNICAL INTERPRETATIVE REPORT

British Antarctic Survey

Rothera Wharf Design

Geotechnical Design – Geotechnical Interpretative Report

9 October 2017
BAA.4001-DMC-GT-R-0014

003888 British Antarctic Survey

Rothera Wharf Design – Geotechnical Design – Geotechnical Interpretative Report

Report number: BAA.4001-DCM-GT-R-0014

Client

BAM Nuttall - BAM International Joint Venture

BAM Nuttall
St. James House
Knoll Road, Camberley, GU15 3XW
United Kingdom

BAM International
Prinses Beatrixlaan 5
2595 AK The Hague
The Netherlands

Author
Name: Johan van Staveren
E-mail: Johan.van.Staveren@bam.com
Address: H.J. Nederhorststraat 1, 2801 SC Gouda, The Netherlands
P.O. Box 268, 2800 AG Gouda, The Netherlands
Telephone +31182590610 / www.dmc.nl / dmc@dmc.nl

P03	For Approval	JST	19/10/2017	MHG	19/10/2017	MEIJ	19/10/2017
P02	For Review	JST	06/09/2017	MHG	06/09/2017	MEIJ	06/09/2017
P01	For Review	JST	17/08/17	MHG	17/08/17	MEIJ	17/08/17
Revision	Status / Suitability	Author	Date	Verified	Date	Released	Date

Index

1 Introduction

1.1 General Introduction

This report encompasses the assessment of the obtained geotechnical information relevant to the design of the foundations for the wharf structure.

This report is to be viewed as an addendum report to the Geotechnical Design – Foundations report, Document No. BAA.4001-DMC-GT-R-0006, Ref. [1]. This report reviews the field and laboratory testing results of the site investigation carried out for BAM during March and April 2017, by Fugro Chile. An interpretation of the new factual geotechnical information is carried out to establish a representative set of characteristic geotechnical parameters relevant to the design of the Wharf structure.

The updated characteristic geotechnical parameters determined in this report are compared to the initial characteristic design parameters, derived from previously available geotechnical information, used for the initial 65% Design Stage. This comparison will serve to confirm if the parameters used previously have been sufficiently representative of the encountered geotechnical conditions, and what impact, if any, the updated parameters may have on the 65% Design stage.

The updated characteristic rock mass parameters determined herein will be used to determine characteristic geotechnical parameters for all wharf-related geotechnical designs going forward.

These characteristic parameters may be used as a baseline for other design purposes at the Rothera Station, provided that a similar assessment of the relevant, nearby, geotechnical investigation locations is included in the particular geotechnical assessments for those designs.

1.2 Scope of the Report

This report reviews the factual geotechnical information obtained during the site investigation works carried out on behalf of BAM Nuttal / BAM International JV by Fugro Chile. The factual geotechnical information obtained is assessed and interpreted to derive a set of characteristic geotechnical parameters for use in the design of the foundations necessary to support the reconstruction of the Biscoe Wharf at Rothera Station.

1.3 Structure of the Report

The structure of the report is shown in the Table of Contents. Section 2 covers safety items with regard to the design, construction and operation of the wharf. Section 3 details the Codes, Standards and other reference documents that are relevant to the geotechnical design portion contained within this report. The geotechnical data available from the recent site investigation works are discussed in Section 4 and the assessment of the data and the geotechnical design parameters are included in Section 5. Section 6 sets out the kinematic analysis of the geological structures and the interaction thereof with the proposed works. The conclusions and recommendations arising from this assessment of the geotechnical information are set out and discussed in Section 7. An updated geotechnical risk assessment is included in Section 8.

1.4 Report Revisions

A vertical line along the left hand side margin of the relevant section shall indicate revisions made to this report. Where tables are revised, the title of the table contains a vertical line in the LHS margin.

Where tabulated references have been updated due to inclusion of additional references, these have not been marked in the text.

This report has been reviewed internally by BAM and externally by RAMBOLL. The comments arising and responses thereto are included as Attachment D.

2 Safety by Design

2.1 General

This report is an assessment of the results of the recent ground investigation carried out at Rothera Station, and as such serves as an ancillary report to the Geotechnical Design report(s). Aspects of the safety philosophy are included below for completeness.

All proposed designs and construction methods are based on proven concepts and methods that are known to DMC and our designers.

For further details of the Safety by Design, please see the Geotechnical Design – Foundations report, report number BAA.4001-DMC-GT-R-0006, Ref. [1].

2.2 Geotechnical Safety Philosophy

Design is to Eurocode with appropriate Design Approach and associated partial factors.

The assessment of the required parameters has been carried out by the determination of confirmatory characteristic rock strength parameters on the basis of the DNV Recommended Practice, Ref. [3], as previously described. By determining characteristic parameters as set out in the DNV Recommended Practice, the probability that a worse parameter can occur is significantly low, i.e. there is only a 5% probability that worse parameters can occur. Furthermore, as characteristic parameters are used as inputs into the Hoek-Brown failure criterion, all derived parameters can also be viewed as characteristic.

The methods used in the derivation of the characteristic rock strength parameters and the kinematic analysis contained herein are based on proven concepts and knowledge that have been peer-reviewed and published for wider application.

Additionally, by applying the Eurocode to the design whereby partial factors are applied to characteristic loads, material properties and determined resistances, the inherent uncertainties are suitably encompassed.

A geotechnical risk register is included in Section 8 of this report.

2.3 Additional Safety Considerations

This assessment of the geotechnical ground parameters is not meant to address risks originating from other points of contact of the construction. However, the following additional safety considerations must be included in the Project Risk Assessment and Risk Register:

- No consideration to required temporary works is made in this document. Necessary temporary works will need to be assessed separately;
- The proposed new wharf will replace the existing wharf with the necessary demolition thereof, all demolition works must be properly risk assessed and appropriate mitigation measures applied to risks that cannot be eliminated;
- Works will be carried out adjacent to / over water with potential for hypothermic conditions;
- Diving operations will be carried out in close proximity to moving plant and materials and in proximity to potentially dangerous, predatory wildlife;
- Sub-zero working conditions may be experienced;
- Stricter than normal environmental controls may be required;
- Blasting works will be carried out in close proximity to construction works –these must be controlled by a Quarry Management or Blast Management Plan and sufficient co-ordination between works activities.

3 Reference Documents

3.1 Design starting points

The following Delta Marine Consultants and Fugro documents form the basis for this report:

[1] BAA.4001-DMC-GT-R-0006 Geotechnical Design - Foundations;
[2] Rothera Station Site Investigation – Antarctic Peninsula: Factual Report – Fugro Chile, Document No.: 8144-RPT-FCT-001, dated 13 July 2017;

3.2 Codes and Standards

3.2.1 Main codes and standards

For the design of the quay wall, Eurocode and British Standards with UK National Annexes are used, for which the main applicable codes and standards are summarized below:

Table 1: Main Codes and standards

Code	Title
BS 6349-1-1:2013	Maritime works. General. Code of practice for planning and design for operations
BS 6349-1-3:2012	Maritime works. General. Code of practice for geotechnical design
BS 6349-1-4:2013	Maritime works. General. Code of practice for materials
BS 6349:1:2000	Maritime Structures. Part 1: Code of practice for general criteria (Partially superseeded by the above standards)
BS 6349-2:2010	Code of practice for the design of quay walls, jetties and dolphins
BS EN 1992-1-1:2004	Design of concrete structures. General rules and rules for buildings
BS EN 1993-1-1:2005	Design of steel structures. General rules and rules for buildings
BS EN 1993-5:2007	Design of steel structures - Piling
BS EN 1997-1:2004 +A1 2013	Geotechnical design - Part 1: General rules with UK National Annexes
BS EN 1998-1:2004	Design of structures for earthquake resistance;
BS 8002:2015	Code of practice for Earth Retaining Structures
BS EN 1537:2013	Execution of Special Geotechnical Works – Ground Anchors
BS EN 14199:2005	Execution of Special Geotechnical Works – Micropiles
BS EN ISO 14689-1	Geotechnical investigation and testing — Identification and classification of rock — Part 1: Identification and description

3.2.2 Other codes and standards

Other international codes and guidelines used:

[3] Statistical Representation of Soil Data, Det Norske Veritas AS, Recommended Practice, Document No. DNV-RP-C207, January 2012

3.3 Literature

[4] Practical Estimates of Rock Mass Strength, Hoek, E., and Brown, E.T., International Journal of Rock Mechanics and Mining Sciences, Vol 34, No. 8, 1997;

[5] The Hoek-Brown Failure Criterion – 2002 Edition, Hoek, E., Carranza-Torres, C., and Corkum, B., Proceedings of the 5th North American Rock Mechanics Symposium, 1: 267–273, 2002;

[6] The geological strength index: applications and limitations, Marinos, V., Marinos, P. and Hoek, E., Bulletin of Engineering Geology and the Environment 64: 55-65, 2005;

[7] Rock Slope Engineering: Civil and Mining, Wylie, D.C. and Mah, C.W., 4th Edition, Taylor & Francis, 2005;

[8] Engineering Classification and Index Properties for Intact Rock, Deere, D.U. & Miller, R.P, Technical Report No. AFWL-TR-65-116, December 1966;

[9] The Point-Load Strength Test, Broch, E. & Franklin, J.A., Int. J. Rock. Mech. Min. Sci. Vol 9, 1972;

[10] Determination of Rock Strength and Deformability of Intact Rocks, Tziallas, G.P., Tsiambaos, G., and Saroglou, H., EJGE Volume 14, Bundle G, 2009;

[11] The effect of rock classes on the relation between uniaxial compressive strength and point load index, Kahraman, S. and Gunaydin, O., Bulletin of Engineering Geology and the Environment, August 2009;

[12] The determination of uniaxial compressive strength from point load strength for pyroclastic rocks, Kahraman, S., Engineering Geology, February 2014;

[13] Use of the block punch test to predict the compressive and tensile strengths of rocks, Mishra, D.A., & Basu, A., Int. J. Rock. Mech. Min. Sci.Vol. 51, 2012;

[14] Rockmass.net (http://www.rockmass.net/files/compr_strength_table.pdf) Palmström, A., recovered 1/08/2017.

3.4 Reports

The following DMC design reports, additional to Ref. [1], above, have been used as a starting point for the geotechnical interpretation:

None

3.5 Drawings

The following drawings have been created or used in the preparation of this report:

[15] BAA.4001-DMC-D-1001-003, General arrangement- Layout boreholes

3.6 Other Information

The following documents have been used to provide additional information relevant to the design or background information to aid in the development of the characteristic geotechnical parameters:

None

4 Geotechnical Data

4.1 Recent Additional Site Investigation

A recent site investigation comprising 7 No. rotary cored boreholes has been carried out at the BAS Rothera Station. The purpose of this site investigation is to provide geotechnical design information to confirm the design parameters used for the 65% design stage of the proposed new wharf. Additionally, the investigation was to provide information for the assessment of the proposed quarry location immediately to the east of the wharf location. The investigation comprised the following:

- 4 No. nearshore boreholes advanced in the sea bed immediately in front of the existing wharf (BH01 to BH04);
- 2 No. boreholes near the bollard at the end of the runway (BH-OS-05 and BH-OS-06);
- 2 No. boreholes in the quarry locations (BH06 and BH07);
- 1 No. borehole adjacent to the hanger building to the northwest of the airstrip (BH-OS-07).

The borehole co-ordinates, natural ground or seabed elevation at location, total depth and general location of the boreholes are included in Table 2 below.

The borehole carried out at the hanger location is not particularly relevant to the design of the new quay wall, and is, for the most part, not included in this assessment. It has been used in the determination of the rock strength parameters so as to make use of the entirety of the data obtained.

The locations of the nearshore, quarry and runway boreholes are included in the borehole location drawing, Ref. [15], and included as Attachment A.

The boreholes at the quarry location, due to the proximity of the wharf, are more applicable to the determination of the design rock strength and rock mass strength parameters. These boreholes are not used in the kinematic analysis of the slopes, however, due to their location being above ground level with respect to the submarine slope at the base of the wharf.

The boreholes comprised rotary core drilling utilising wireline methods and PQ-sized core barrels. Recovered cores were approximately 82mm in diameter.

Table 2: Borehole Data Summary

Borehole ID	Easting*1 [m]	Northing*1 [m]	Natural Ground / Sea Bed Level*2 [m CD]	Total Depth [m]	Location [-]
BH01	537035	2504612	-4.90	18.55	Nearshore wharf
BH02	537042	2504595	-5.48	15.80	Nearshore wharf
BH03	537058	2504576	-8.19	16.20	Nearshore wharf
BH04	537076	2504569	-2.93	15.80	Nearshore wharf
BH06	537170	2504567	+25.80	25.00	Quarry
BH07	537198	2504665	+26.40	25.10	Quarry
BH-OS-05	537007	2504642	+2.50	10.00	Runway wharf
BH-OS-06	536993	2504666	+4.00	14.30	Runway wharf
BH-OS-07	537103	2505251	+4.00	6.00	Hangar

Notes:
*1 Co-ordinates in WGS84 projection
*2 Natural Ground / Sea Bed Level has been inferred after the locations of the boreholes had been set out on the topographic and bathymetric plots.

The natural ground level or sea bed level at each borehole location has been determined separately from the values reported by Fugro. For the determination of these values, the following information has been used:

- Reference Level Wharf: +4.7m CD
- Mean Sea Level: +1.19m CD

The reduced level for the wharf boreholes (BH01 to BH04) is therefore Ref Level + Clamp Level − Distance Clamp to seabed. The Clamp level and measured distance between clamp and sea bed have been provided separately by Fugro. This information is included below in Figure 1.

Designation	Location	Total Depth (m)	Date Performed	As Built Coordinates [(1)]		Elevation Reference Biscoe Wharf [(2)]	Top of Clamp to Platform	Top pf Clamp to Seawater	Top of Clamp to Seabed	Water Depth	Seabed Elevation
				East	South	MSL	(m)	(m)	(m)	(m)	(m)
BH-01	Biscoe Wharf West	18.55	22-mar-17	537,035.00	2,504,612.00	4.00	0.72	4.75	10.32	5.57	-5.6
BH-02	Biscoe Wharf Southwest	15.80	18-mar-17	537,042.00	2,504,595.00	4.00	0.72	5.10	9.34	4.24	-4.6
BH-03B	Biscoe Wharf Southeast	16.20	14-mar-17	537,058.00	2,504,576.00	4.00	0.93	5.35	13.82	8.47	-8.9
BH-04	Biscoe Wharf Southeast	15.80	12-mar-17	537,076.00	2,504,569.00	4.00	0.72	5.35	8.35	3.00	-3.6

Notes:
(1) WGS84 UTM Zone 19D, in meters (measured with Garmin Dakota 20)
(2) Reference Elevation Top of Wharf +/- 4.0 m MSL

Figure 1: Borehole Elevation data for Wharf boreholes supplied by Fugro separate to Factual GI report

For the remaining boreholes in the vicinity of the runway and the quarry, these have been set out in the combined bathymetry and ground survey plot, and the elevation inferred from the contour data. All inferred elevations are in metres Chart Datum.

Down-the-hole (DTH) geophysical methods, comprising Acoustic Borehole Imaging (ABI) or Optical Borehole Imaging (OBI) techniques coupled with Natural Gamma logging (GR), were carried out in 8 of the boreholes, all located in the vicinity of the wharf and quarry areas, i.e. boreholes BH01 through BH04, BH06 and BH07, and boreholes BH-OS-05 and BH-OS-06. An overview of the DTH logging is contained in Table 3.

Table 3: DTH Geophysical Surveys summary

Borehole ID	Acoustic Imaging	Optical Imaging	Natural Gamma	Derived Data provided for analysis	Remarks
BH01	✓	✓	✓	OBI orientation only	
BH02	✓	✓	✓	ABI & OBI orientation and GR	
BH03	✓	✓	✓	OBI orientation and GR	
BH04	✓	✓	✓	OBI orientation and GR	
BH06	✓	✓	✓	ABI & OBI orientation and GR	OBI data missing between 1.17m and 15.34m
BH07	✓	✓	✓	ABI & OBI Orientation and GR	OBI data missing between 2.17m and 8.25m
BH-OS-05	✓	✓	✓	ABI & OBI Orientation and GR	
BH-OS-06	✓	✓	✓	ABI & OBI Orientation and GR	
BH-OS-07	×	×	×		No DTH surveys

The DTH methods provide oriented discontinuity data that may be used for Joint / Discontinuity Pattern Analysis and Kinematic Slope Stability Analyses. In the resulting data sets, the following feature types have been identified:

- Fractures;
- Veins;

- Unidentified features (features insufficiently distinct to identify).

In assessing the data, it is evident that many of the veins follow the same orientations as the fractures, particularly the lower angle fractures. DMC therefore consider that the entire data set may represent fractures and fractures infilled by secondary mineralisation. As such, the entire data set from each televiewer analysis is used in subsequent analyses, however only the data from the boreholes in the immediate vicinity of the wharf and runway have been used for the assessment of the submarine rock slope that will form the foundation of the quay wall.

Laboratory testing carried out on recovered cores comprised the following:

- 34 No. unconfined compressive strength tests (UCS) according to ASTM D7012;
- 71 No. Point Load Strength Index determinations according to ASTM D5731;
- 10 No. Aggregate Soundness Test using Sodium Sulphate or Magnesium Sulphate according to ASTM C88.

4.2 Quality of Additional Information

Due to the intensely fractured nature of the bedrock, and the relatively large diameter of the returned core samples, obtaining intact samples for UCS testing has been difficult. Of the 34 samples tested, 10 samples were not compliant with the ASTM, due to the length to diameter ratio (L/D ratio) being less than the required value of 2.0 to 2.5. The test results thereof have been ignored in the assessment of the data available.

The average Point Load Strength Index values that have been determined by Fugro have not been determined strictly in accordance with the published standard. As the test results included all the specimen data for each test sample, this has been corrected in this assessment. The effect of this is not significant, but it does mean that the average PLI value determined by DMC is slightly higher than that of Fugro.

5 Geotechnical Parameter Assessment

5.1 Assessment of Rock Quality Designation (RQD) and Joint Spacing

5.1.1 Rock Quality Designation Assessment

Based on the borehole logs, and the tables presented in the Fugro factual report, Ref. [2], an apparent Rock Quality Designation (RQD) for the boreholes has been determined for each of the boreholes as follows:

- The RQD categories are set based on the RMR categories, i.e. 0 – 25, 25 – 50, 50 – 75, 75 – 90 and 90 – 100;
- The linear length of borehole corresponding to each of the categories is summed;
- The weighted RQD is determined from the length of each category multiplied by the maximum RQD for the category and then divided by the length of borehole drilled.

The weighted value of apparent RQD and the linear length of core run corresponding to each RQD category are summarised in Table 4 for each borehole. This is an apparent RQD due to the weighted RQD being calculated. Furthermore, due to the low total core recovery (TCR) in some portions of the boreholes, any calculated RQD is likely only to be an indication of the quality of the recovered rock.

Table 4: Weighted Apparent RQD

	Linear BH Length of RQD category [m]					Weighted Apparent
Borehole	0 - 25	25- 50	50 - 75	75 -90	90 - 100	RQD [%]
BH01	11.65	4.25	2.5	0.0	0.15	38.1
BH02	8.3	7.5	0.0	0.0	0.0	36.9
BH03	4.5	2.5	7.8	1.5	0.0	58.8
BH04	2.85	1.35	4.5	4.1	3.0	72.5
BH06	4.05	5.75	3.8	10.8	0.6	68.2
BH07	6.4	3.05	11.3	4.0	0.35	62.0
BH-OS-05	4.8	0.8	4.2	0.0	0.2	49.5
BH-OS-06	10.8	3.4	0.0	0.0	0.1	31.5

For the Wharf area, the Televiewer data has also been used to determine an apparent RQD for the boreholes. To determine the RQD from the televiewer profile, the following procedure has been used:

- Divide the profile into approximate 1m sections, using the SBL as the reference level;
- Sum the length of core greater than 100mm, based on the spacing of the fractures;
- Divide by the “core run” length between the top and bottom of the 1m section;
- Apply the RQD to the entire interval for which it is calculated.

An example of this method is shown in Figure 2 below. The resulting minima, maxima, mean and standard deviations for the apparent RQD are tabulated in Table 5. In Figure 2, the green triangles represent the RQD value for the interval, and the orange circles represent the change in core length greater than 100mm. As is evident from the figure, the majority of the core does not form intact pieces greater than 100mm. These values are based solely on the spacing of fractures (discontinuities and joints) identified in the provided analysis of the televiewer data. Therefore it has been termed an apparent RQD.

A second method using the software DIPS by Rocscience has also been used to determine the apparent RQD. DIPS can calculate the RQD if the data from the televiewer is entered as a traverse”, i.e. the data is provided with a trend and plunge of the “scanline”. In this case the scanline is the borehole axis, the trend of which is 000°N, as the televiewer data is oriented, and the plunge of which is 90°, i.e. a vertical downward borehole. The distance value for the calculation of the RQD is equal to the depth of the fracture detected by the televiewer measured from a datum – in this case the top of the seabed. For this method, all of the data from the televiewer logs is assessed as a single data set, but with separate traverses per borehole.

The apparent RQD resulting from the DIPS RQD analysis is depicted in Figure 3, below. For this purpose, in order to plot each of the borehole relative to one another, a fictive reference level of +100m CD has been used. A level of 100m in the plot is equal to MSL / Chart Datum.

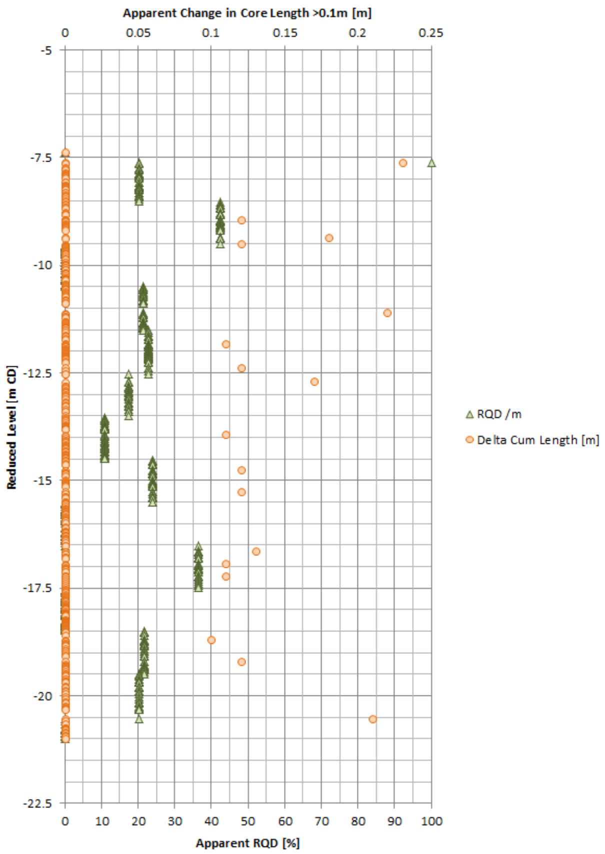


Figure 2: Apparent RQD from Televiewer data BH02

Table 5: BH Televiewer and DIPS RQD analysis

Borehole No.	Apparent RQD (Televiewer)				Apparent RQD (DIPS)			
	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev
BH01	0	87	37	23	9	100	44.5	25.76
BH02	0	100	16	13	0	35	17.1	10.25
BH03	0	96	49	19	0	97	49.9	24.68
BH04	35	100	66	16	36	100	71.1	16.97
BH-OS-05	0	67	40	20	4	100	51.1	25.61
BH-OS-06	0	85	19	18	0	82	22.4	23.61

From the above tables, Table 4 and Table 5, it is evident that the RQD is generally less than 75% for all boreholes, with boreholes BH02 and BH-OS-06 being less than 25%. Boreholes BH03 and BH04 display higher RQD values, in the range 50% to 74%.

Evident from Figure 3, below, boreholes BH01 and BH03 show an increase in RQD below a level of approximately -14m CD (distance 114m in the figure). Below this level boreholes BH01, BH03 and BH04 display an average RQD of about 60% to 70%. Above this level, the average RQD for boreholes BH01 and BH03 falls in the range 10% to 20%, that of BH04 in the range of 40% to 90%.

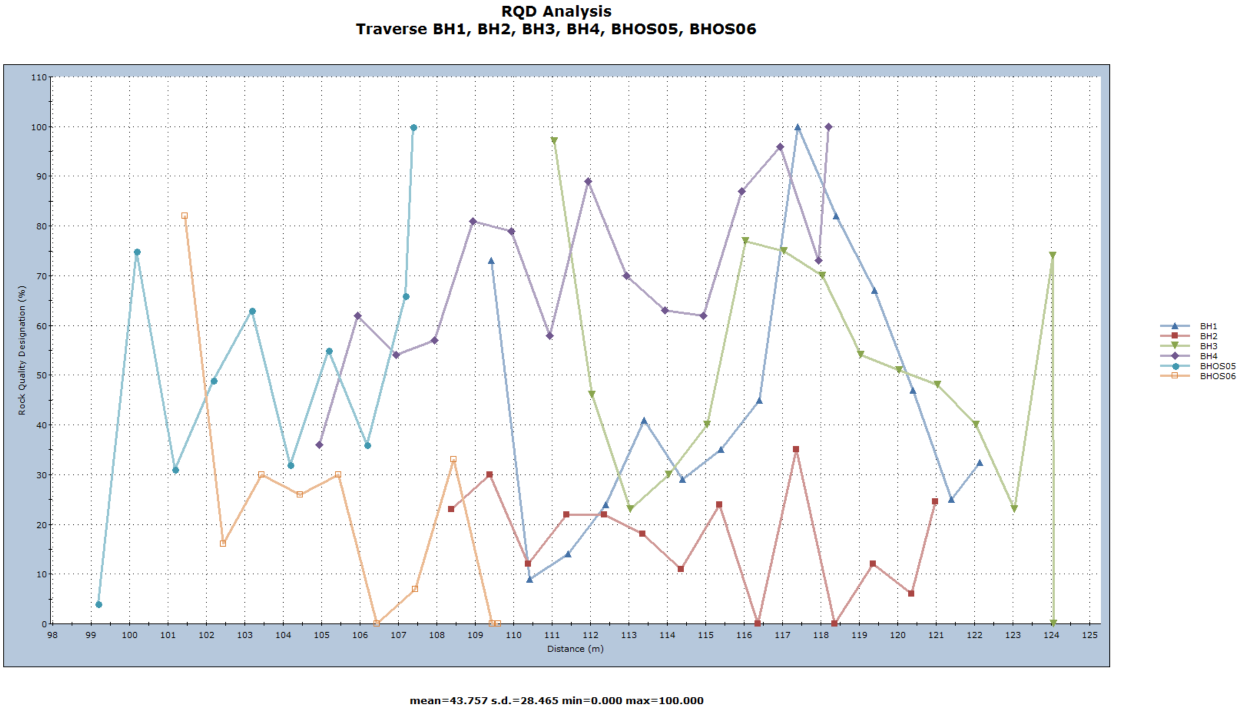


Figure 3: DIPS RQD Analysis

Based on the above information, for the purposes of RMR determinations, an overall average RQD of between 40% and 45% should be used. Based on this, the RMR Drill core quality rating could be increased to 8.

5.1.2 Joint Spacing Analysis

A Joint Spacing analysis has been carried out on the Televiewer data, using the complete data set, as outlined in Section 4. The distance between fractures is taken as the distance between successive fractures or veins in the Televiewer data. The analysis thereof is based on the Joint Spacing for RMR classification:

- 0 – 60mm;
- 60 – 200mm;
- 200 – 600mm;
- 600 – 2000mm;
- 2000+mm.

For each borehole the percentage falling into each spacing category is calculated and tabulated below.

Table 6: Joint Spacing Analysis – Televiewer data

Bin	BH01 % Frequency	BH02 % Frequency	BH03 % Frequency	BH04 % Frequency	BHOS05 % Frequency	BHOS06 % Frequency	Average % Frequency
0	7.1	17.9	5.7	2.1	16.1	18.1	**11.2**
60	54.9	72.1	50.8	36.6	56.5	64.8	**55.9**
200	35.3	9.5	37.3	50.0	25.4	16.4	**29.0**
600	2.7	0.6	5.7	11.3	2.1	0.7	**3.8**
2000	0.0	0.0	0.5	0.0	0.0	0.0	**0.1**
More	0	0	0	0	0	0	**0**

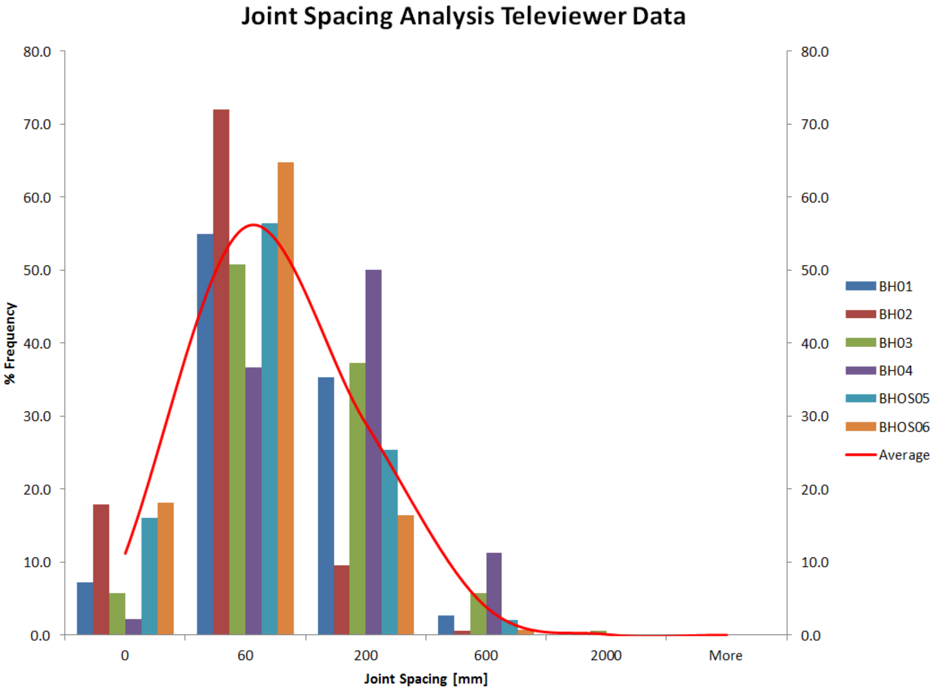


Figure 4: Joint Spacing Histogram - Televiewer Data

As can be seen from both Table 6 and Figure 4, the majority of the joint spacing falls in the range 0 to 60mm (67% of the data) with a significant portion also falling in the range 60mm to 200mm (29%). Joints spaced wider than 600mm are rare.

Using DIPS, a true joint spacing per identified Joint Set can be carried out. An example of this is shown in Figure 5 below. The identified joint sets will be discussed in Section 6.2, below. For these identified sets, the minima, maxima, mean and standard deviations are included in Table 7.

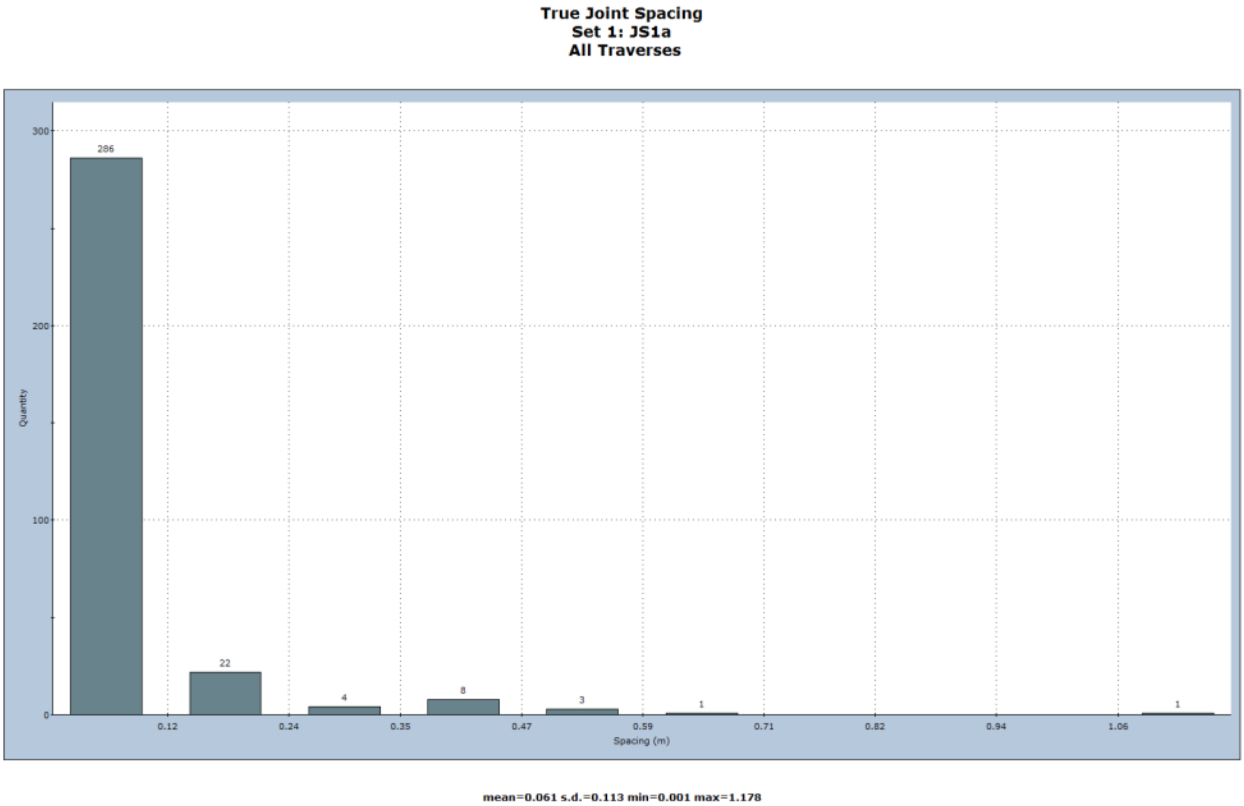


Figure 5: True Joint Spacing Analysis, JS1a, all wharf boreholes

Table 7: Joint Spacing Analysis - DIPS analysis

Borehole No.	True Joint Spacing (DIPS) [m]				
	Min	Max	Mean	St. Dev	Count
JS1a	0.001	1.178	0.061	0.113	325
JS1b	0.001	2.409	0.342	0.457	79
JS2a	0.003	1.871	0.230	0.364	67
JS2b	0.001	1.687	0.254	0.384	48
JS3	0.001	3.032	0.284	0.554	61
JS4	0.004	3.656	0.508	0.747	47
JS5	0.002	3.962	0.519	0.722	80

Unfortunately, DIPS does not allow the bin size for the analysis to be set, the programme uses 10 bins spread across the range of the data for each set. This gives the data a distinct log-normal appearance to the distribution. As can be seen from Table 7, above, Joint Set 1a (JS1a) is the most prominent joint set, with a low mean spacing of 61mm.

For the purposes of RMR determinations and the geotechnical design, a joint spacing category of 60 to 200mm should be used. For design purposes for anchors etc., a minimum joint spacing of 60mm, as used previously in the 65% Design, appears to be reasonable.

5.2 Unconfined Compressive Strength (UCS)

A total of 34 No. UCS tests were carried out on samples recovered from the borehole cores. As mentioned previously, a number of tested UCS samples (10 No.) did not comply with the ASTM for sample preparation, ASTM D4543, where the length to diameter (L/D) ratio of the tested samples fell outside of the prescribed range of 2.0 to 2.5 (Clause 5.2 of ASTM D4543).

Additionally, Delta Marine Consultants (DMC) has assessed the predominant failure mode for each UCS test. This has been done by assessing the available core photos from before and after testing, and visually assessing the stress-strain plots for the tests. Where failure of the samples has clearly been governed by the presence of (healed) fractures or joints, these samples have been described as being fractured. Where fracturing is not clear, the sample has tentatively been described as “intact”. Additionally, the UCS sample test depths have been compared to the data arising from the down-the-hole Televiewer scans. Where the Televiewer scanning and analysis has detected and identified obvious discontinuities in the sample depth of the UCS test sample, this has also been used to determine if the test sample is intact or not.

The relevant data available from the UCS testing is summarised in Table 8 for the entire data set.

Table 8: Summary UCS tests all samples

Parameter	Unit	All data				
		Min	Max	Ave	St.Dev	Count
Specific Gravity	[g/cm^3]	2.67	2.79	2.75	0.03	34
Unit Weight	[kN/m^3]	26.21	27.39	26.95	0.30	34
Moisture Absorption	[%]	0.21	1.17	0.45	0.20	34
UCS	[MPa]	19.20	133.99	72.42	29.34	34
Young’s Modulus (E')	[MPa]	1923.00	25000.00	15291.85	5379.42	34
Poisson's Ratio (v)	[-]	0.12	0.63	0.26	0.14	34

Table 9 summarises the data for the data set corresponding to the compliant samples, i.e. where 2.0 < L/D < 2.5.

Table 9: Summary UCS tests compliant samples

Parameter	Unit	Compliant data				
		Min	Max	Ave	St.Dev	Count
Specific Gravity	[g/cm^3]	2.70	2.79	2.76	0.03	24
Unit Weight	[kN/m^3]	26.45	27.39	27.03	0.27	24
Moisture Absorption	[%]	0.21	0.59	0.38	0.12	24
UCS	[MPa]	29.33	133.99	77.61	25.90	24
Young's Modulus (E')	[MPa]	1923.00	23214.00	16590.00	4364.69	24
Poisson's Ratio (v)	[-]	0.12	0.63	0.26	0.13	24

Compliant sample data for samples that do not display obvious discontinuities or joints that govern the failure mechanism are summarised in Table 10.

Table 10: Summary UCS Tests compliant & "intact" samples

Parameter	Unit	Compliant & "Intact" data				
		Min	Max	Ave	St.Dev	Count
Specific Gravity	[g/cm^3]	2.70	2.78	2.75	0.02	9
Unit Weight	[kN/m^3]	26.52	27.31	27.02	0.23	9
Moisture Absorption	[%]	0.21	0.57	0.36	0.10	9
UCS	[MPa]	45.18	113.58	83.16	23.57	9
Young's Modulus (E')	[MPa]	16176.00	23214.00	18558.89	2267.97	9
Poisson's Ratio (v)	[-]	0.12	0.32	0.22	0.07	9

Table 11 summarises the data for samples where the failure of the sample has clearly been governed by the presence of discontinuities or joints within the tested sample.

Table 11: Summary UCS Tests compliant & fractured samples

Parameter	Unit	Compliant & Fractured data				
		Min	Max	Ave	St.Dev	Count
Specific Gravity	[g/cm^3]	2.70	2.79	2.75	0.03	14
Unit Weight	[kN/m^3]	26.45	27.39	27.01	0.29	14
Moisture Absorption	[%]	0.21	0.59	0.39	0.13	14
UCS	[MPa]	29.33	133.99	72.36	26.57	14
Young's Modulus (E')	[MPa]	1923.00	22222.00	15319.71	5024.47	14
Poisson's Ratio (v)	[-]	0.12	0.63	0.29	0.16	14

The data from the previous geotechnical investigation carried out at Rothera Station for the airfield expansion programme is included in Table 12.

Table 12: Previous Data Airfield Expansion

Parameter	Unit	All data				
		Min	Max	Ave	St.Dev	Count
Dry Specific Gravity	[g/cm^3]	2.69	2.77	2.72	0.03	10
Dry Unit Weight	[kN/m^3]	26.34	27.13	26.73	0.31	10
Saturated Specific Gravity	[g/cm^3]	2.69	2.77	2.73	0.03	10
Sat Unit Weight	[kN/m^3]	26.39	27.19	26.78	0.30	10
Moisture Absorption	[%]	0.14	0.29	0.20	0.04	10
UCS	[MPa]	113.50	260.10	176.42	42.65	10

The previous investigation included UCS testing carried out on 26.7mm diameter core samples, with an L/D ratio of at least 2.0. In terms of compliance with the current standards, these would no longer be considered compliant as the minimum core diameter applicable for testing under the ASTM is 47mm – equivalent to a DCDMA N-size core barrel.

The Coefficients of Variance (the ratio of the sample Standard Deviation to the sample Mean value) of the UCS values for the various test programmes are tabulated below:

Table 13: Coefficients of Variance UCS testing

Sample Set	Coefficient of Variance
Current All data	0.41
Current Compliant Data	0.33
Current Compliant & “intact” data	0.28
Current Compliant & fractured data	0.37
Previous Airfield Expansion	0.24

As is evident from the Table 8 through Table 12, the UCS data presented for the current investigation is significantly lower than that determined previously during the airfield expansion programme, i.e. a mean value of 72 – 83MPa vs 176MPa.

The previous investigation indicates that the intact rock falls into the categories of “very strong” to “extremely strong” according to Table 5 of BS EN ISO 14689-1. The current investigation appears to indicate that the rock strength falls into the categories “weak” to “very strong” if all the data is considered and “medium strong” to “very strong”, with an average strength of “strong” if only the compliant and intact data is considered. This appears to show a considerable decrease in the intact strength of the diorite / granodiorite bedrock. It is unlikely that this is the case.

This can partly be explained by the following:

a. The core drilling carried out previously recovered 26.7mm diameter cores compared to the 82mm diameter cores recovered during the current investigation;
b. The average joint spacing is approximately 60mm;
c. The sample length for the previous investigation varies from 63mm to 67mm;
d. The sample length for the current investigation varies between 116mm and 205mm.

Therefore it is possible that the previous investigation has managed to obtain intact samples of the rock mass, whereas the current investigation, due to the significantly increased core diameter, has not been able to achieve this. Drilling rock sample cores at the previous diameter of 26.7mm would not be compliant with the current testing standards for intact rock strength either, where the standard requires a minimum core diameter of 47mm (Clause 5.2 of ASTM D4543). As such, with an average joint spacing of 61mm, as determined above, any core drilling carried out is unlikely to recover completely intact samples.

The Coefficients of Variance indicate that there is a greater variance in the data from the current investigation, though this variance decreases to a similar order of magnitude of that for the previous investigation if only the compliant and “intact” samples are selected.

Comparing the UCS sample depths to the Televiewer logs reveals that, in almost all cases, multiple discontinuities or joints are present within the UCS sampling interval, and given the spacing of these discontinuities an intact sample, free from joints or discontinuities, cannot be obtained.

Taking the above into account, Delta Marine Consultants considers that the results of the UCS testing do not represent the intact strength of the rock, but rather the fractured strength of the rock mass. Please note that some of the samples have included remineralised or “healed” joints and this could explain some of the higher rock strengths determined by the UCS testing.

If this is the case, the results obtained from the UCS testing could be analogous to the σ'_{cm} of the Hoek-Brown Failure Criterion – the rock mass compressive strength. In this situation, the intact rock strength could be derived from a back calculation of the following equation, (Hoek et al., 2002 Ref [5] Equation (17)):

$$\sigma'_{cm} = \sigma_{ci} \cdot \frac{\left(m_b + 4 \cdot s - a(m_b - 8 \cdot s)\right)(m_b/4 + s)^{a-1}}{2 \cdot (1+a)(2+a)}$$

Where:

σ'_{cm} is the Hoek-Brown rock mass compressive strength;
σ'_{ci} is the intact rock compressive strength
m_b, a and s are the Hoek-Brown failure criterion parameters.

Equation (17) of Ref [5] is used, rather than Equation (6), as the value determined from these UCS tests is likely to be analogous to a rock mass strength rather than a rock mass compressive strength. Should Equation (6) be used, unrealistically high UCS values result.

The above equation can be rearranged to provide the intact rock compressive strength. In this case, using the Hoek-Brown parameters determined previously for the 65% Design Stage, see Table 11 of Ref [1], an intact rock strength value of approximately 294MPa is determined, see Table 14 below.

This value would be considered to be on the high end of the scale for a granodiorite type rock, which shows a typical mean unconfined strength of around 105MPa according to published data, Ref. [13]. Figure 6 below, compiled by Palmström, Ref. [13], provides a range of low, average and high compressive strength values for various rock types. Please note that the values in Figure 6 appear to be offset one line in most areas. The value of 294MPa does fall close to the high value for a Gabbro, i.e. 285MPa, given in Figure 6, but is significantly greater than the high UCS values of both a diorite (190MPa) and a granodiorite (135MPa).

Based on Figure 6, an average intact compressive strength for the rock of between 100MPa and 200MPa is not unrealistic given the rock type present at Rothera.

Table 14: Determination of UCS from rock mass strength

Parameter	Value	Unit
GSI	53	[-]
mb	4.067	[-]
s	0.0022	[-]
a	0.508	[-]
σ'_{cm}	77.61	[MPa]
σ'_{ci}	**293.5**	**[MPa]**

Normal variation of *compressive strength* and the *factor m* in Hoek-Brown failure criterion for some rocks (data from Hanssen, 1988; Hoek and Brown, 1980 and Hoek et al., 1992).

Rock name	Uniaxial compressive strength σ_c			Rating of the factor	Rock name	Uniaxial compressive strength σ_c			Rating of the factor
	low	average	high	m_i [1)]		low	average	high	m_i [1)]
Sedimentary					**Metamorphic**				
rocks		120"?		13	**rocks**	75	125	250	25 - 31
Anhydrite	16"	21"	26"	(8 - 21)	Amphibolite	95	160	230	31 ?
Coal	2'	5'	10'	4	Amphibolitic	95	160	230	33 ?
Claystone	70	85	100	(22)	gneiss	35	70	105	
Conglomerate	3	10	18	7	Augen gneiss	75	105	130	
Chalk	60'	100'	300'	10	Black shale	80	120	155	(19)
Dolomite					Garnet mica schist				
	100	120	145	(18)	Granite gneiss	80'	150	280	
Greywacke	50*	100'	180*	9		80	130	185	33
Limestone	45	95	145		Granulite	65	105	140	30 ?
Mudstone	36"	95"	172"		Gneiss	65	75	85	(4 - 8)
Shale	75	120	160	19	Gneiss granite	120'	170*	280*	25 ?
Sandstone	10'	80'	180'	9	Greenschist				
Siltstone	3'	25'	150'	(15)	Greenstone				(19)
Tuff						60'	130'	230'	9
Igneous rocks	75'	140'	300'	19	Hornfels	55	80	100	30 ?
Andesite	40	125	210		Marble	45	85	125	25 ?
Anorthosite	100	165	355"	(17)	Mica gneiss	20	80*	170*	4 - 8
Basalt	227"	280"	319"	(19)	Mica quartzite				
Diabase (dolerite)	100	140	190	(28)	Mica schist				(30)
Diorite	190	240	285	27		65	90	120	(6)
Gabbro					Migmatite	21	50	80	(10)
	95	160	230	33	Mylonite	70	120	175	
Granite	75	105	135	(30)	Phyllite	75	145	245	24
Granodiorite	85	145	230	30 ?	Quartz sandstone				
Monzonite	125	165	200		Quartzite	45	100	155	
Nepheline syenite	290"	298"	326"	22		65	135	200	
Norite					Quartzitic phyllite	120'	190'	300'	9
	39	50	62		Serpentinite	45	65	90	(4 - 8)
Pegmatite			85"?	(16)	Slate				
Rhyolite	75	150	230	30 ?	Talc schist				
Syenite	80'	160	360						
Ultra basic rock									

Soil materials[2)]:
Very soft clay $\sigma_c = 0.025$MPa Soft clay $\sigma_c = 0.025 - 0.05$MPa Firm clay $\sigma_c = 0.05\text{-}0.1$MPa
Stiff clay $\sigma_c = 0.1 - 0.25$MPa Very stiff clay $\sigma_c = 0.25 - 0.5$MPa Hard clay $\sigma_c > 0.5$MPa
Silt, sand $\sigma_c = 0.0001 - 0.001$MPa (assumed)

* Values found by the Technical University of Norway, (NTH) Inst. for rock mechanics.
' Values given in Lama and Vutukuri (1978).
" Values given by Bieniawski (1984).
1) m_i is the parameter for intact rock in the Hoek-Brown failure criterion for rock masses by Hoek et al. (1998). Values in parenthesis have been estimated by Hoek et al (1992); values with question mark have been assumed
2) For clays the values of the uniaxial compressive strength is based on ISRM (1978), refer to Table 2.7.

Figure 6: Compressive Strength of various rock types (Palmström, Rockmass.net)

The above analysis of the UCS test data indicates that these tests results do not provide an explicit value for the intact rock strength. As a result of this, the assessment of the intact rock strength will require an assessment of the point load strength index (PLI) test data, and the determination of a relationship between the PLI values and the intact rock strength.

5.3 Point Load Strength Index (PLI)

Seventy one (71) Point Load Strength Index (PLI) tests have been carried out on samples obtained from the borehole cores. These samples appear to generally comprise irregular lump samples with some axial and diametral samples.

As noted in Section 4.2, above, Fugro have not consistently applied Clause 10.3 of the ASTM for this test when determining the Mean $Is_{(50)}$ or PLI value. Clause 10.3.2 states that where a test sample comprises 10 or more specimens, the mean value shall be determined by discarding the top and bottom 2 values, and the PLI is then the average of the remaining values. Where the sample comprises less than 10 specimens, only the top and bottom values are discarded and the PLI is then the average of the remaining values. DMC has corrected this by re-determining the PLI values for each sample.

The samples have been grouped by their location to provide minima, maxima, mean and standard deviations for all the data, the wharf location and the quarry location. These data are presented below:

Table 15: PLI ($Is_{(50)}$) values

Location	$Is_{(50)}$ [MPa]					
	Min	Max	Ave	St.Dev	Count	CoV
All Data	2.25	16.14	9.06	2.59	71	0.29
Wharf & Runway	2.88	16.14	9.48	2.38	45	0.25
Quarry	4.2	13.18	9.08	2.19	21	0.24

The distribution of the $Is_{(50)}$ values with depth is given in Figure 7 below. This figure includes two plots, one for the Wharf and Runway location and one for the Quarry location. In both plots, the $Is_{(50)}$ values are plotted against the reduced level.

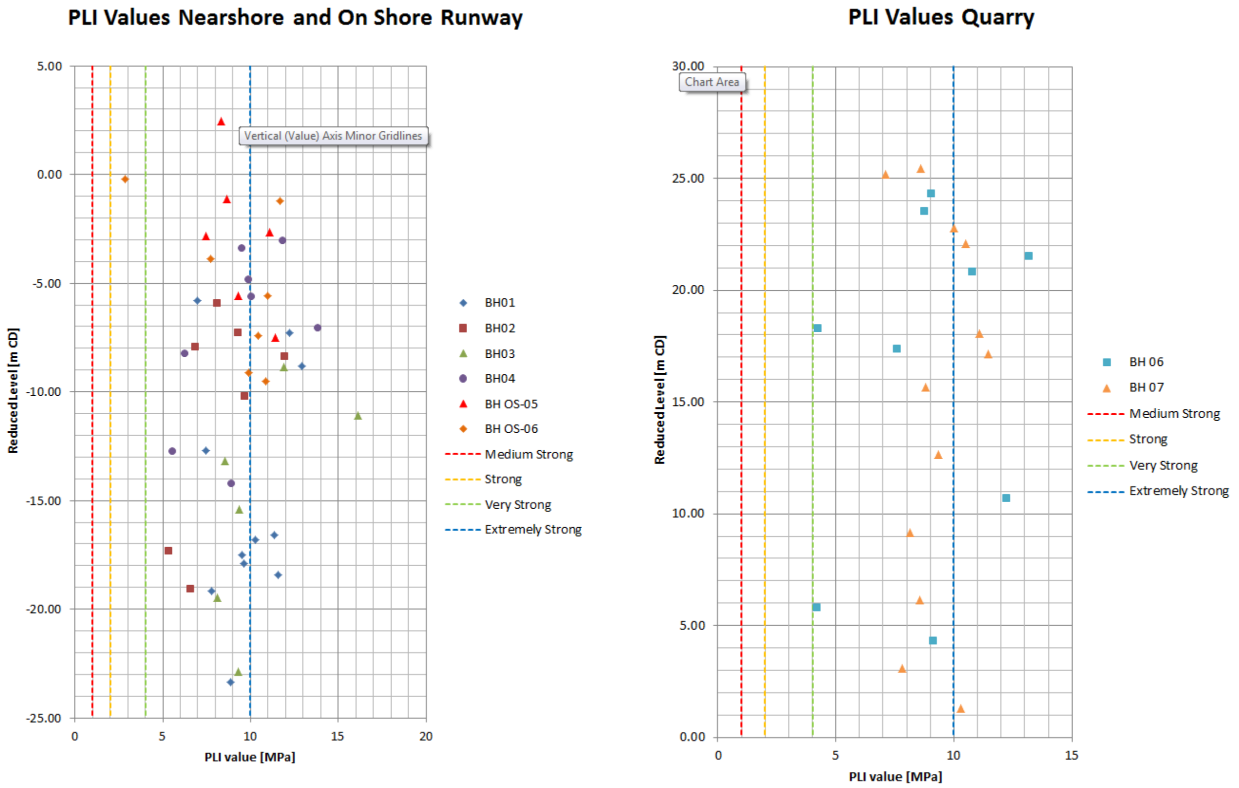


Figure 7: $Is_{(50)}$ values vs Reduced Level

The rock strength boundaries, medium strong, strong, etc., included in the above Figure are based on the boundaries used in the Rock Mass Rating (RMR^*_{89}) scheme of Bieniawski. As can be seen, for both locations, the $Is_{(50)}$ values are clustered around the PLI value of 10, with a range between 2.9 and 16.1 for the Wharf and Runway area and 4.2 and 13.2 for the Quarry area. This would appear to indicate that the rock strength falls within the strong, very strong and extremely strong categories.

5.4 Relationship between UCS and PLI

In order to be able to use the Point Load Index data to determine the intact rock strength (UCS – σ_{ci}), a relationship between the UCS and PLI is needed. Deere & Miller (1966), Ref. [8], and Broch & Franklin (1972), Ref. [9], have developed some of the early correlations between UCS and PLI. Since then a significant number of published relationships of PLI to UCS have appeared in the geotechnical literature. Table 1 of Kahraman, S. (2014), Ref. [12], lists a number of these relationships. Many of these relationships have been established for specific rock types (e.g. sedimentary rocks, sandstones, etc.), whereas some of them are generalised, all rock-types, relationships. Mishra and Basu (2012), Ref. [13] investigated the use of block punch tests to determine UCS values, and correlated this with Point Load test results on the same samples. Tziallas, G.P. et al (2009), Ref. [10], have reviewed a number of the published relationships and proposed five (5) sets of relationships (both linear and exponential for each relationship) for various rock types based on existing databases of rock strength parameters and additional laboratory testing carried out as part of their particular study. Their proposed Set 5 contains two relationships for igneous rock types, namely; a linear relationship and an exponential relationship.

These published relationships can be used as a starting point for the determination of the relationship between PLI and UCS; however it is better to establish this relationship for each site based on the available laboratory testing data. A significant requirement of this procedure, however, is that the results used to establish the relationship are unambiguous, are of good quality, and that the UCS results properly indicate the intact strength of the rock.

Fugro, in the Factual Report, Ref. [2], establishes a relationship of:

$$\sigma_{ci} = 7.7 \cdot Is_{(50)}$$

Where:

σ_{ci} is the UCS value;
$Is_{(50)}$ is the PLI value

Unfortunately, Fugro does not include the regression co-efficient (R^2 value) in their analysis. This regression coefficient would provide an indication of how well the established (linear) relationship fits with the data set. The associated Figure 4.1, Ref. [2] pg. 15 and Figure 8 below, shows a significant scatter to the data, using 25 data points, i.e. the entire compliant UCS test data set. The regression coefficient is therefore likely to be very low, i.e. a very poor fit to the data. This established relationship is also on the low side for an igneous rock, and is to be expected if the UCS values used do not reflect the true intact strength of the rock. In developing their proposed relationship, Fugro have not discounted any of the non-intact UCS samples. This effectively skews the relationship towards a lower strength index.

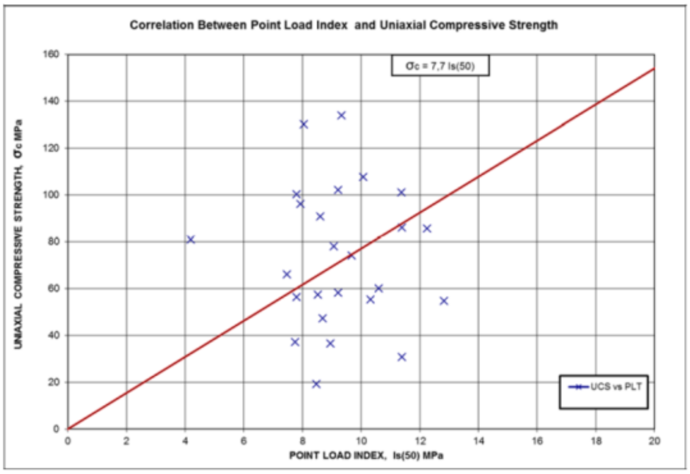


Figure 4.1: Correlation between PLT and UCS

Figure 8: Fugro Figure 4.1 Correlation between PLI value and UCS

DMC has attempted to establish the relationship using data where the UCS tests may be considered as “intact”, and matching these to available PLI test results at the same or similar depth as the UCS sample. In this case, only 9 data points are available to determine the relationship (compliant and “intact”). Regression analyses have been performed using the following methods:

- Linear;
- Linear with a zero intercept;
- Logarithmic; and,
- Exponential.

The method providing the best fit to the data is the linear with a zero intercept method, which provides a regression coefficient (R^2) of 0.31, and is illustrated in Figure 9, below. As the regression co-efficient is significantly below a value of 0.5, a value which would indicate a minimum acceptable fit to the data, this fit is considered to be very poor to poor. Furthermore, as noted, the data set available for the regression analysis is quite small (9 samples). The PLI data range is limited, whereas that of the UCS data is quite spread. Taken together, these limitations reduce the suitability of the site-data determined fit.

The site-data based linear best-fit method provides the following linear (with a zero intercept) relationship for UCS vs PLI:

$$\sigma_{ci} = 8.153 \cdot Is_{(50)}$$

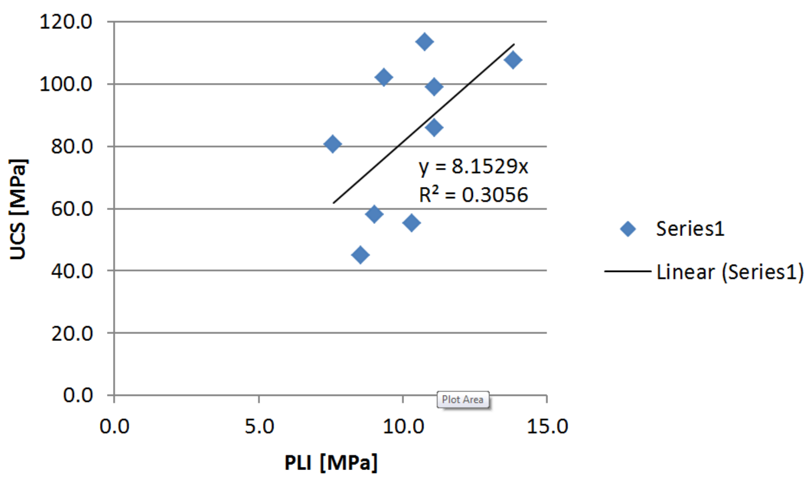


Figure 9: UCS vs PLI for Compliant & "intact" samples

Again, this relationship is on the low side for an igneous rock, particularly given the data from the previous investigation in which an average intact rock strength of 176.4MPa was determined.

As noted in Section 5.2, above, DMC does not consider that any UCS tests from this GI campaign were successfully carried out on intact rock samples. Therefore, the k-value determined above is not considered to be representative of the diorite / granodiorite bedrock encountered at Rothera Station.

If this is the case, another relationship needs to be established for the materials, in order to accurately determine the intact strength of the rock from the available laboratory test data. Looking at the literature mentioned above, a number of relationships have been presented for igneous type rocks. These, along with the generalised accepted relationships, are summarised in the table below.

Table 16: Published Relationships between PLI and UCS

Reference	Relationship PLI to UCS	R^2
Broch & Franklin (1972)	$\sigma_{ci} = 24 \cdot Is_{(50)}$	0.88
Mishra & Basu (2013) [Granite]	$\sigma_{ci} = 10.9 \cdot Is_{(50)} + 49.03$	0.8
Tziallas et al (2009) [Linear]	$\sigma_{ci} = 14.4 \cdot Is_{(50)}$	0.88
Tziallas et al (2009) [Exponential]	$\sigma_{ci} = 6.65 \cdot Is_{(50)}^{1.34}$	0.91
Deere & Miller (1966)	$\sigma_{ci} = 20.7 \cdot Is_{(50)} + 29.6$	0.84

Of the above relationships, the ones by Mishra & Basu and Tziallas et al are the only ones specifically established for granitic or igneous rock types. The relationships developed by Broch & Franklin and Deere & Miller are generalised relationships determined on results from a number of rock types. As can be seen from the above relationships, the relationship between $Is_{(50)}$ and intact strength of rock appears to be slightly lower for igneous rocks than for sedimentary rocks. Furthermore, in the literature, the relationship between PLI and UCS is higher (sometimes significantly so) than the relationship proposed by Fugro; and also higher than that determined from the compliant and “intact” test data by DMC.

The relationships tabulated above have all been used to determine the equivalent intact rock strength from the point load strength index test results. These determinations are set out in Figure 10 below. As is evident from this figure, Broch & Franklin and Deere & Miller provide the highest intact strength values, whereas the DMC-determined relationships provide the lowest. The Mishra & Basu and the Tziallas et al relationships fall in between.

Therefore, DMC proposes that the relationship of Mishra & Basu is used for the determination of the unconfined compressive strength of the intact rock. Using all of the relationships mentioned above, the minima, maxima, mean and standard deviation for the equivalent intact rock strength for all of the PLI test data as well as the subset of the Wharf location are given in Table 17.

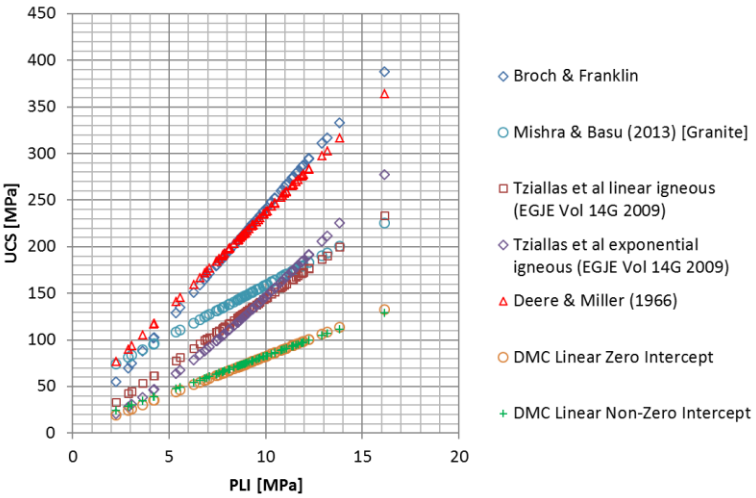


Figure 10: UCS from PLI value for various relationships

Table 17: Mean $Is_{(50)}$ and Equivalent UCS value based on PLI relationships – All Data and Wharf Area

Relationship / Method	Mean $Is_{(50)}$ and Equivalent UCS – All Data					Mean $Is_{(50)}$ and Equivalent UCS – Wharf				
	Min	Max	Ave	Std. Dev	Count	Min	Max	Ave	Std. Dev	Count
Mean $Is_{(50)}$	**2.25**	**16.14**	**9.06**	**2.59**	**71**	**2.88**	**16.14**	**9.48**	**2.38**	**45**
Broch & Franklin	54.00	387.36	217.32	62.19	71	69.12	387.36	227.41	57.16	45
Deere & Miller	76.18	393.70	217.04	53.63	71	89.22	363.70	225.74	49.3	45
Mishra & Basu	73.56	224.96	147.73	28.24	71	80.42	224.96	152.31	25.96	45
Tziallas et al (linear)	32.40	232.42	130.39	37.31	71	41.47	232.42	136.45	34.30	45
Tziallas et al (exp.)	19.71	276.32	129.88	47.42	71	27.44	276.32	137.35	45.25	45
DMC Linear Zero Int.	18.34	131.59	73.83	21.12	71	23.48	131.59	77.25	19.42	45

The data corresponding to the subset of the Quarry area are included in Table 18 below.

Table 18: Mean $Is_{(50)}$ and Equivalent UCS value based on PLI relationships – Quarry Area

Relationship / Method	Mean $Is_{(50)}$ and Equivalent UCS – Quarry				
	Min	Max	Ave	Std. Dev	Count
Mean $Is_{(50)}$	4.2	13.18	9.08	2.19	21
Broch & Franklin	100.80	316.32	218.03	52.50	21
Deere & Miller	116.54	302.43	217.65	45.28	21
Mishra & Basu	94.81	192.69	148.05	23.84	21
Tziallas et al (linear)	60.48	189.79	130.82	31.50	21
Tziallas et al (exp.)	45.50	210.62	129.70	40.13	21
DMC Linear Zero Int.	34.24	107.46	74.07	17.83	21

Based on the above tables, the mean intact rock strength (UCS) based on the Mishra and Basu relationship varies between approximately 148MPa for all the PLI data from all of the boreholes, to 152MPa for the Wharf boreholes only. These values fall within the expected UCS range for the rock types present at Rothera Station, as noted in Section 5.2 above.

5.5 Determination of Geotechnical Design Parameters

5.5.1 Intact Rock Strength

Using the data from Table 17 and Table 18, and the methods used previously for the determination of a characteristic value with a 95% confidence limit, as given in Section 6.1.5 of the 65% Design Stage Geotechnical Design report, Ref. [1], the characteristic intact rock strength is as follows:

- $\sigma_{ci;k}$ = 147.73 – 2.22 * 28.24 = 85.0 MPa – (Mishra & Basu all data);
- $\sigma_{ci;k}$ = 152.31 – 2.22 * 25.96 = 94.7 MPa – (Mishra & Basu Wharf data)
- $\sigma_{ci;k}$ = 148.05 – 2.40 * 23.84 = 90.8 MPa – (Mishra & Basu Quarry data)

A $c_{1\text{-}\alpha}(n)$ value of 2.22 has been chosen for the complete data set as well as the wharf data as we do not have an infinite sample set. While this value corresponds to an n=30 sample set, it is considered appropriate in this case, given the relatively extensive data set of point load index tests available.

For the Quarry data, a $c_{1\text{-}\alpha}(n)$ value of 2.40 is appropriate due to the more limited data set available for this area. The above value for equivalent intact rock strength may be used as a baseline value for the intact rock strength of the quarry area.

For the purposes of determining the equivalent Hoek-Brown failure criterion rock mass strength parameters, a characteristic intact rock strength of 85MPa is recommended. Using the above mentioned procedures to determine the characteristic value ensures that there is only a 5% probability that any encountered rock material will have an intact strength less than this value.

5.5.2 Rock Mass Strength

As previously shown in the Geotechnical Design – Foundations report for the 65% Design, Ref. [1], the rock mass strength can be determined using the Hoek –Brown failure criterion coupled with the Geological Strength Index value, as shown in Hoek, E. et al (2002), Ref. [5].

Based on the geological descriptions of the rock mass contained in the borehole logs produced by Fugro, and the fact that at least 5 major joint sets have been identified, the GSI value for the rock mass will fall into the zone described by very blocky structure and very good to good surface conditions, see Figure 11, below. The GSI value for the rock mass is likely to fall in the range 45 to 75, with an average in the range 55 to 65.

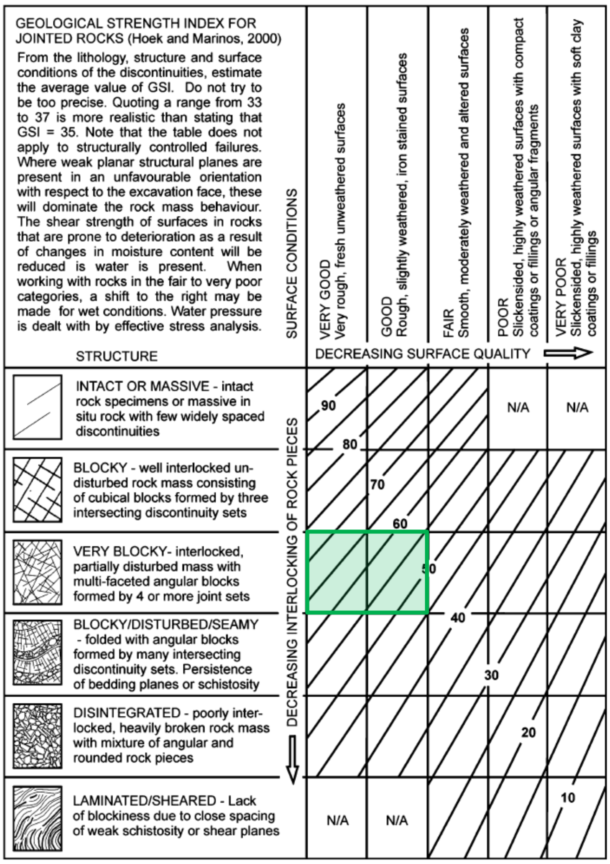


Figure 11: GSI for Rothera Wharf rock mass with GSI zone highlighted

Table 19 shows the determination of the revised RMR*$_{89}$ values based on the revised rock strength, RQD and discontinuity spacing values outlined in the previous sections.

Table 19: Revised RMR*$_{89}$ for Rothera Station

A	Classification Parameters and their Ratings							Rating
Parameter			**Range of Values and Ratings**					
1	Strength of intact rock material	Point Load strength index	>10 MPa	4-10 MPa	2-4 MPa	1-2 MPa	For this low range UCS is preferred	**7 – 12**[*2]
		Uniaxial Compressive Strength	>250 MPa	100-250 MPa	50-100 MPa	25-50 MPa	5-25 MPa / 1-5 MPa / <1 MPa	
		Rating	15	12	7	4	2 / 1 / 0	
2	Drill core quality	RQD	90% - 100%	75% - 90%	50% - 75%	25% - 50%	<25%	**8**
	Rating	Rating	20	17	13	8	3	
3	Discontinuity Spacing		>2.0m	0.6 – 2.0m	200 – 600mm	60 – 200mm	<60mm	**8**
	Rating		20	15	10	8	5	
4	Condition of Discontinuities (See E)		Very rough surfaces Not continuous No separation Unweathered wall rock	Slightly rough surfaces Separation < 1mm Slightly weathered walls	Slightly rough surfaces Separation < 1 mm Highly weathered walls	Slickensided surfaces **or** Gouge < 5mm thick **or** Separation 1-5mm Continuous	Soft gouge >5mm thick **or** Separations > 5mm Continuous	**25 - 30**
	Rating		30	25	20	10	0	
5	Groundwater	Inflow per 10m length tunnel (ltr/min)	None	< 10	10 - 25	25 – 125	>125	**15**[*1]
		(Joint water pressure) / (Major principal stress σ)	0	<0.1	0.1 – 0.2	0.2 – 0.5	>0.5	
		General Conditions	Completely Dry	Damp	Wet	Dripping	Flowing	
	Rating		15	10	7	4	0	
							RMR*$_{89}$	**63 - 73**

Notes:
*1 For GSI determinations, the groundwater condition is taken as Dry as all subsequent calculations are carried out using effective stresses, thereby taking the submerged condition and groundwater conditions into account
*2 The average PLI value is 9.1, giving a rating of 12

Based on the above figure and table, the minimum revised GSI value should be 58.

Using the parameters determined here, the input parameters for RocLab are as follows:

Table 20: RocLab Input Parameters

Parameter	Value	Unit
Intact rock strength (σ_{ci})	85	MPa
Unit weight rock (γ')	0.0169*1	MN/m^3
GSI	58	
m_i	29*2	-
D	0	-
E_i	36125*3	MPa
MR	425*2	-

Notes:

*1 Submerged unit weight is used as the slope is a submarine slope. Value adjusted to include data from recent UCS testing. Mean value has been used
*2 RocLab values for granodiorite rock type
*3 Derived by RocLab from MR and σ_{ci}

Based on the above input parameters, RocLab produces the Rock Mass strength values and the equivalent Mohr-Coulomb parameters shown in Table 21, below. As characteristic input parameters are used, the outcome parameters are similarly defined as being characteristic. The characteristic rock mass parameters used in the (previous) 65% Design are included in Table 21 for comparison.

Table 21: Rock Mass and Mohr Coulomb Parameters with comparison to 65% Design values

Parameter	Current Value	65% Design Value	Units
Hoek-Brown Criterion			
mb	6.471	5.413	-
s	0.0094	0.005	-
a	0.503	0.505	-
Failure Envelope Range			
$\sigma_{3;max}$	0.837	0.746	MPa
Unit weight*1	0.0169	0.0166	MN/m^3
Slope height*2	50	50	m
Mohr-Coulomb Fit			
c'	0.935	0.551	MPa
ϕ'	64.82	61.1	°
Rock Mass Parameters			
σ_t	-0.124	-0.05	MPa
σ_c	8.12	3.27	MPa
σ_{cm}	29.17	14.16	MPa
E_{rm}	17150	7094	MPa

Notes:

*1 The submerged unit weight is used
*2 The slope height is measured to the top of the hill near to the wharf

As can be seen from the above table, the parameters used during the previous 65% Design stage are lower than the updated characteristic rock mass parameters determined from the recent geotechnical investigation. As such the results of the recent ground investigation serve to confirm that a moderately conservative parameter set has been chosen initially, based on the limited geotechnical information previously available.

However, as developments in the project have resulted in a re-set of the 65% Design to a different structural conformation, the characteristic rock mass strength parameters determined herein, and reported in Table 21, may be used to define an updated geotechnical parameter set for the new design. All necessary geotechnical parameters for other design conformations will be contained within the specific geotechnical design reports for those designs.

6 Geological Structural and Kinematic Analyses

6.1 Introduction

The down-the-hole Televiewer surveys carried out in the boreholes provides corrected orientation data for any structural features detected during the survey. These structural features include joints or discontinuities, veins, lithological contacts, stratification, and shistosity or foliation. The corrected orientation is obtained from the internal 3-axis magnetometer and accelerometer included in the probe, and includes the azimuth and dip of the feature (dip direction and dip, in geological terms).

The data includes the depth below a known reference level at which the detected feature occurs. This depth data may be used to perform a number of geological structural analyses such as joint spacing analysis and RQD analysis.

The orientation data of the features, coupled with either slope orientation data or cavern / tunnel orientations, can be used to perform kinematic analyses of slope stability. This type of analysis does not provide a quantitative analysis of slope stability, e.g. a factor of safety against sliding, but rather provides an assessment of the modes of a failure that can occur, given the geometrical interaction of the geological features with the natural rock slope occurring at the wharf location.

For these purposes, the geological software DIPS published by Rocscience is used. DIPS enables geological and statistical analyses to be made of geological orientation data by the plotting of the orientation data on a stereographic projection (stereonet). All analyses used here are based on a Lower Hemisphere, Equal Angle, Equatorial stereonet. Orientation data is generally plotted on stereonets as poles to the plane of the structure, i.e. a flat planar structure can be plotted as a single point on a stereonet using the normal to the plane – i.e. a single line perpendicular to the flat plane.

The DIPS report containing all of the results of the various analyses carried out in DIPS is included in Attachment B of this report.

6.2 Geological Structural Analysis

6.2.1 Oriented Data and Dips Input

The orientation data originating from the televiewer analyses has been put in to DIPS with the boreholes defined as Traverses so as to enable the assessment of the joint spacing and the RQD as mentioned above.

The following traverses have been defined in DIPS from the boreholes:

ID	Data Format	Type	Orient1	Orient2	Orient3	Label
BH1	Dip / Dip Direction	Linear	0	90		BH01
BH2	Dip / Dip Direction	Linear	0	90		NH02
BH3	Dip / Dip Direction	Linear	0	90		BH03
BH4	Dip / Dip Direction	Linear	0	90		BH04
BHOS05	Dip / Dip Direction	Linear	0	90		BHOS-05
BHOS06	Dip / Dip Direction	Linear	0	90		BHOS-06

Figure 12: Traverses defined in DIPS

As the boreholes are all vertical bores, the traverses have a trend (orient 1) of 000° and plunge (orient 2) of 90° (vertically downward).

As can be seen from the above table, the information from boreholes BH06 and BH07 have not been included in this analysis. The reason for this is that this data corresponds to above ground areas of the quarry, and the inclusion thereof in the analysis of the submarine slope may skew the results somewhat. As such, only the nearshore / submarine data has been used for the analysis of the Biscoe Wharf location.

All of the orientation data has been input into DIPS in the formats defined in Table 22 below.

Table 22: DIPS input data from Televiewer output information

DIPS Input	Televiewer Data
Dip	Dip
Dip Direction	Azimuth
Traverse	Borehole number – see Figure 12
Distance	Depth relative to a defined reference level, in this case +100m CD to allow plotting of data to a common reference
Type	Description

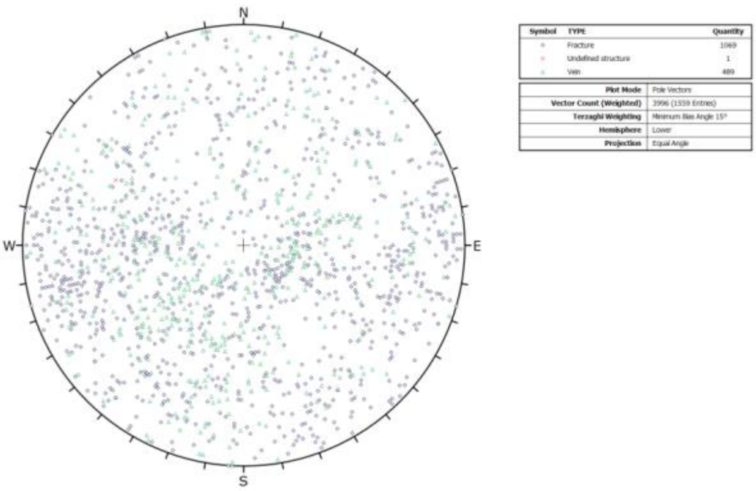


Figure 13: Pole Locations for All Data BH01 to BH-OS-06

As can be seen in the above plot, Figure 13, there is a relatively wide scatter to the data, with the orientations of the "Vein" data roughly shadowing that of the "Fracture" data. Generally, the vein data appears to have a greater concentration at similar orientations to the lower angle fracture sets, however the orientations do shadow all of the fracture orientations.

As the data is oriented, and the boreholes are vertical, these can be interpreted as vertical scan lines. Due to the significant majority of the jointing being high angle jointing, vertical boreholes will intersect fewer high angle joints than low angle joints, see Figure 14. This introduces a bias into the data, due to the greater density of the low angle features intersected. In an attempt to minimise the inherent bias, a Terzaghi weighting has been applied to the data. DIPS uses a minimum bias angle to limit the weighting factor because as the angle between the structural feature and scanline tends towards zero, the weighting factor tends towards infinity. In this case, a minimum bias angle of 15° has been applied as recommended by DIPS. The net result of this Terzaghi weighting is that slightly more weighting is given to joints that plot around the outside of the stereonet for the GI data set.

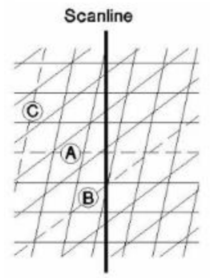


Figure 14: Bias due to scanline orientation[1] (source DIPS online help)

Unweighted and weighted plots of the borehole televiewer data are given in Figure 15.

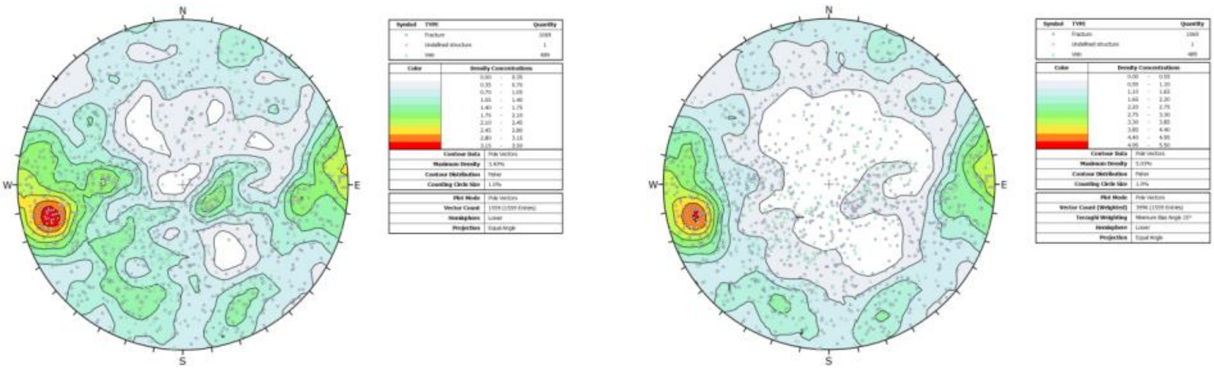


Figure 15: Unweighted (left) and Weighted (right) Contour Plots of the Televiewer Data

As is evident from the weighted plot on the right, the low angle joint sets plotting near the centre of the stereonet have a slightly lower concentration in the contours, whereas the high angle set plotting to the middle left margin of the stereonet has an increased concentration in relation to the unweighted plot. Utilising the Terzaghi weighting serves to clarify the seeming randomness of the orientation data somewhat.

6.2.2 Orientation Data, Data Contouring and Identification of Major Planes

The joint and vein orientation data is presented in Figure 16 below as a scatter plot. This plot shows that there are 3 main concentrations of joint plane data identified by the larger and darker coloured circles in the figure. This figure also shows the contoured density concentration of the data. A standard Fisher distribution with a 1.0% counting circle has been used for the contouring of the data.

[1] Based on the orientation of the scanline, fewer joints of joint set C (near vertical set) will be encountered than those of Joint set A (horizontal set) or Joint set B (low angle inclined) even though the joint spacing of the 3 sets appears to be similar. Terzaghi weighting attempts to correct this bias by weighting joints close to the scanline trend and plunge higher than those perpendicular to it

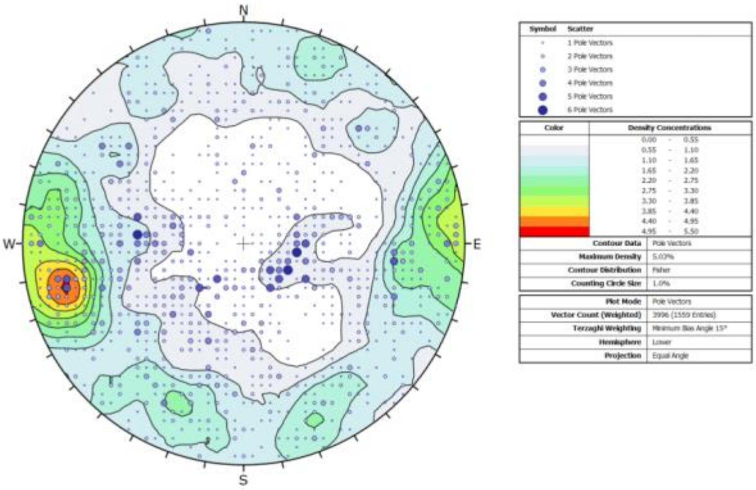


Figure 16: Contoured Orientation Data - All boreholes showing density contours and data density scatter

Based on the above, a number of joint sets have been identified as shown in Figure 17. In some cases the selection of joint sets has been done by defining a window around the data. In other cases, the built-in cluster analysis method has been used with a cluster cone limit of 15°. On the basis of these identified joint set windows, major joint set planes have been defined. The major planes are shown in Figure 18, and the corresponding joint sets are shown in Figure 18 and tabulated in Table 23.

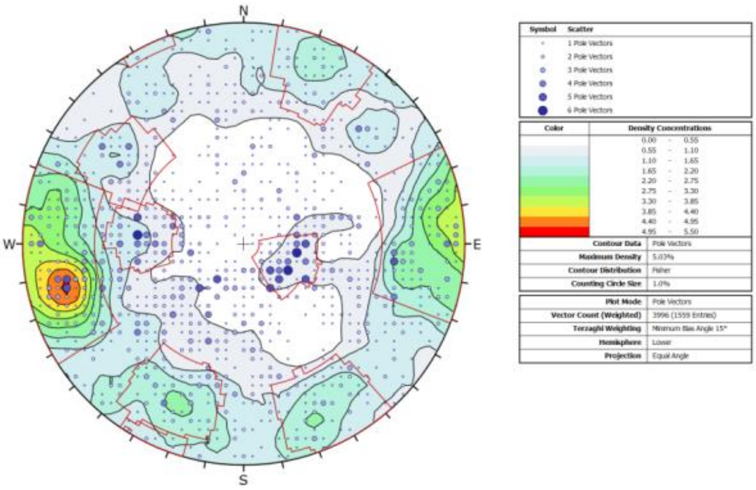


Figure 17: Selection windows for identification of Joint Sets

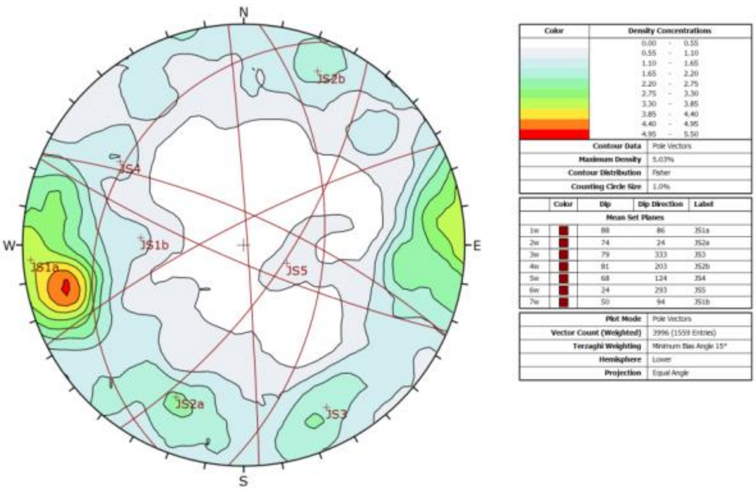


Figure 18: Major Joint Set Orientations

The identified major joint sets are set out in Table 23 below, along with the number of pole orientations that define the joint set.

Table 23: Identified Major Planes

Joint Set	Dip	Dip Direction	Number of Poles	Weighted No. of Poles
JS1a	88	086	331	1201
JS1b	50	094	85	135
JS2a	74	024	73	238
JS2b	81	203	54	196
JS3	79	333	67	243
JS4	68	124	53	140
JS5	24	293	86	96

As can be seen from Table 23, Joint Sets 1a and 1b represent a significant majority of the orientations, approximately 27% of the total oriented data set (1559 No.). Joint set 2 forms the next highest majority with approximately 8%. As is evident from both Figure 18 and Table 23, Joint set 2 comprises 2 planes (2a and 2b)that dip between 70 and 80 degrees either to the north east or south west, but have similar trends; 024° and 203° are approximately 180° degrees apart, and therefore have the same trend. Joint Set 5 represents a low angle joint set dipping to the north west, i.e. obliquely into the slopes.

Figure 19 compares the previous historical joint orientation data with that determined from the current ground investigation. Important to note is that the historical information is plotted to Magnetic North while the current data is plotted against True North. Magnetic declination at Rothera Station is currently approximately 20°E, with an annual change of approximately -0.05° / annum.

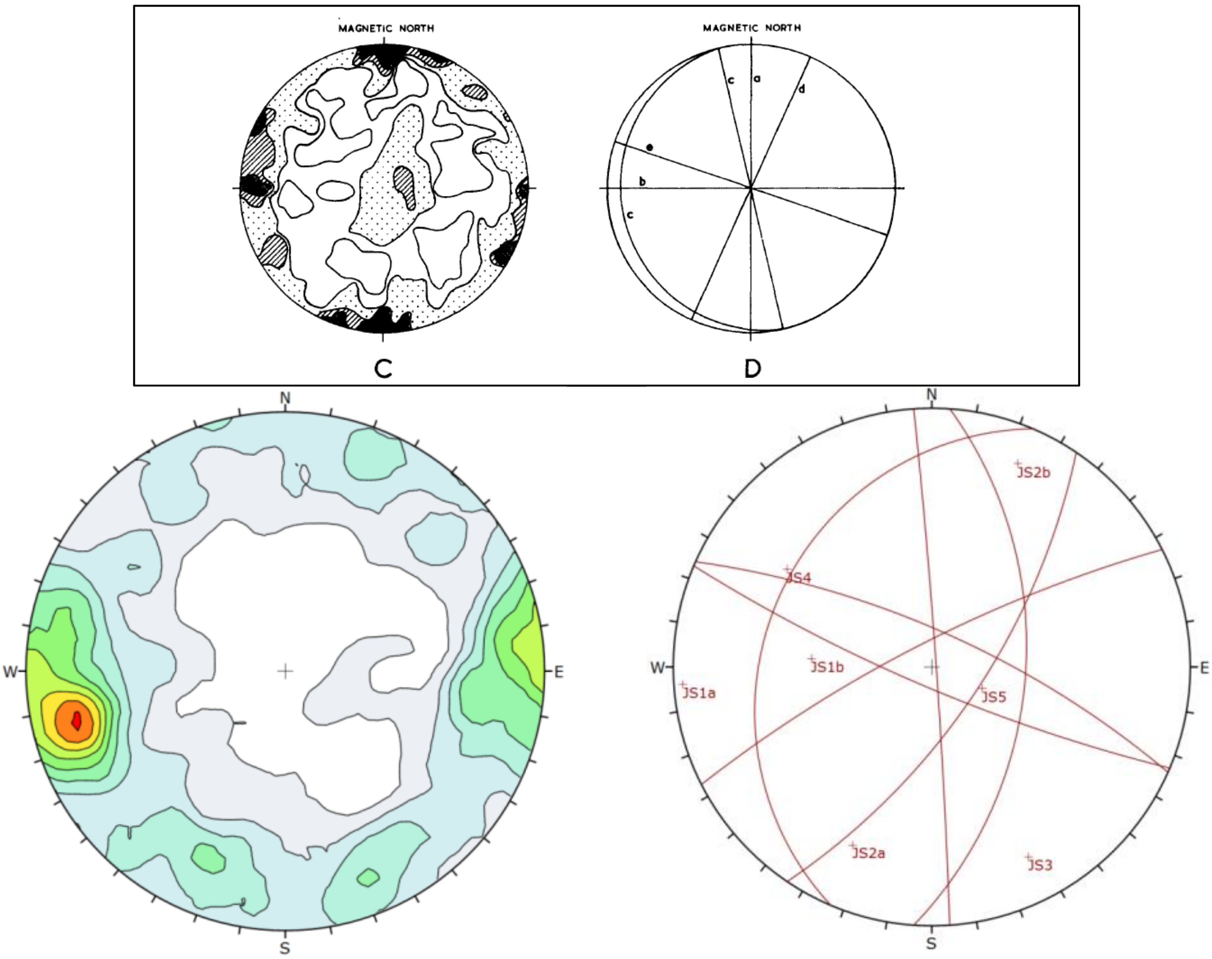


Figure 19: Comparison of Joint Orientations to previous information

The current data would need to be rotated approximately 20° - 22° to the right to reflect the Magnetic North orientation of the 1970's. If this is done, the joint sets determined from the current data match reasonably well with those determined by Dewar, 1970. The only joint set not clearly visible in the current data set is that of the previous joint set "c", the very low angle to near horizontal joint dipping to the west.

6.3 Kinematic Analysis

With the joint sets identified above, a kinematic analysis can be carried out based on the orientation and dip of the submarine seabed slopes in the vicinity of the proposed quay wall. A kinematic analysis of the slope stability is an assessment of the likelihood that the interaction of the orientation of the joint or discontinuity planes and the slope will form blocks that could move or come loose in the slope. This movement could result due to joint planes, or the intersection plane between two joints, "daylighting" into free space, i.e. inclined out of the slope in the case of planar or wedge failures, with no intact rock forming an obstruction to movement.

Table 24 sets out the slope orientations and angles/ dip approximately at the locations of the boreholes.

Table 24: Slope Directions and Dip Angles near Wharf

Slope ID	Location	Closest Borehole	Dip of Slope	Slope Dip Direction
S1	Sidewall West	BH01	26 - 39	210
S2	Main Wall Deep -West	BH02	45	240
S3	Main Wall Typical - East	BH03	48	220
S4	Sidewall East	BH04	32 - 63	215
S5	Honey Bucket Island	BH-OS-05	50	215
S6	End Runway	BH-OS-06	41	230

For the purposes of the kinematic analyses, the steepest slope face of the particular locations has been used at each location.

The approximate locations at which the slope orientation and slope angle have been determined are given in the figure below.

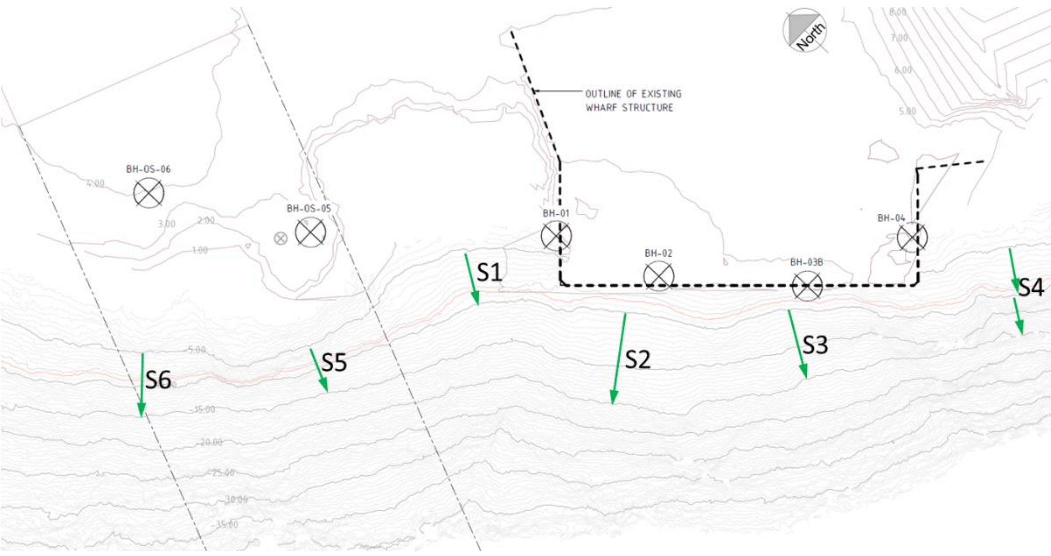


Figure 20: Locations of slope orientation determinations

6.3.1 Failure modes of slopes

The failure of rock slopes can occur in a number of modes, namely:

- Planar failure / sliding;
- Wedge failure / sliding;
- Toppling failure;
- Circular failure.

The modes of failure and how they appear on stereonets is given in Figure 21, taken from Figure 2.16 of Wylie and Mah, Ref. [7].

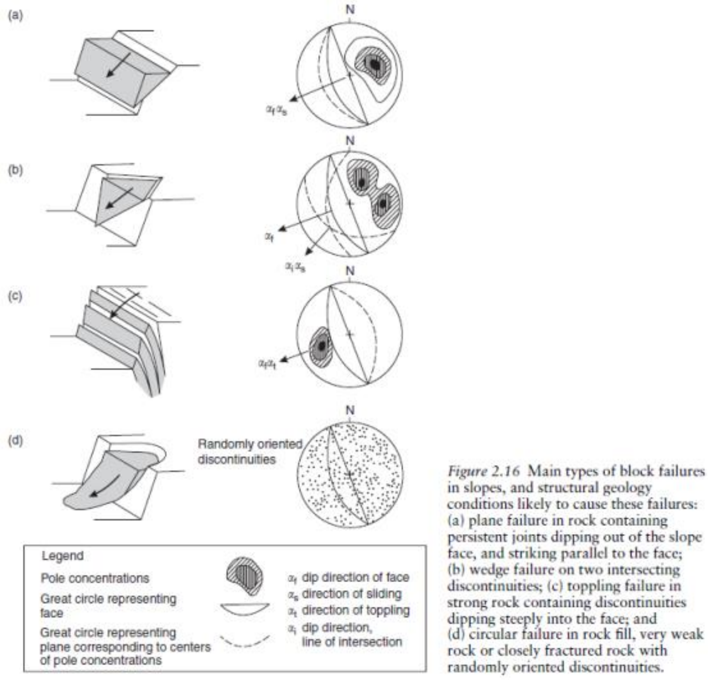


Figure 21: Modes of Slope Failure – Figure 2.16 Wylie & Mah, Ref.[7]

Planar failure is shown in (a) above, wedge failure in (b) and toppling failure in (c).

Two toppling failure modes can occur. The first is flexural toppling, where the slab or rock "bends" before toppling and falling, and the second is direct toppling where the slab overturns as a rigid body. Direct toppling often requires a bottom release plane to allow the slab to overturn as a rigid body. Should this not be present, the block may still topple, but the failure mechanism will be flexural until the tensile strength of the rock slab is reached at which point brittle rupture will occur, resulting in overturning.

Circular failure rarely occurs in jointed, hard rock masses, unless the jointing is to such an extent that the rock displays soil-like behaviour. Despite the distribution of the joint planes and veins, circular failure is not considered to be a significant risk, due to the high equivalent Mohr-Coulomb parameters of the rock mass, coupled with the orientation of the joint sets. The low angle joint set, JS5, dips, for the most part, obliquely into the slope.

For the purposes of assessing the likely modes of failure, a base rock friction angle, equivalent to Barton's φ'_b, of 30° has been used. In reality, the friction angle of the rock mass has been estimated as higher than this at 61° to 64°, by the Hoek-Brown failure criterion. The lower friction angle is used only in order to gauge the magnitude of the risks, for any quantified determinations of stability, the determined rock mass friction should be used to calculate resistances or factors of safety. Kinematic analysis also does not take any of the apparent cohesion into account.

In DIPS, the kinematic analyses can be carried out with or without lateral limits. Generally, slopes will only fail (generally under planar sliding conditions) if joint planes intersect the slope within a certain angular limit of the slope face dip direction. General experience shows that this limit lies between 20°and 30° of the slope face dip direction. In this case, analyses have been carried out with a lateral limit of 25°.

6.3.2 Results of Kinematic Analyses

The results for the kinematic analyses for each of the slopes, and each of the modes of failure are tabulated below. The data tabulated shows the number of intersections between the joint plane orientations, or joint plane intersections, and the slope orientation, expressed as a percent of the total number of joint planes or joint plane intersections in the data set. Where identified joint sets have an orientation such that movement could occur, these are also individually listed as a percentage of the orientations that form the particular joint set.

Table 25: Results of Kinematic Analysis

Slope ID	Percent of Critical Intersections*1,2				
	Planar (Limits)	Planar (No Limits)	Wedge	Flexural Toppling	Direct Toppling
S1	0.21	All: 0.39	1.23	All JS: 3.00 JS2a: 8.13 JS2b: 13.80	Direct: 9.29 Oblique: 14.29 Base All JS: 2.48 Base JS5: 44.38
S2	0.95	All JS: 1.43 JS6: 12.41	2.57	All JS: 9.38 JS1a: 24.13 JS2a: 1.63	Direct: 8.99 Oblique: 15.93 Base All JS: 3.83 Base JS5: 75.96
S3	0.61	All JS: 1.50 JS5: 6.17	3.36	All JS: 7.53 JS1a: 5.41 JS2a: 52.22 JS2b: 13.80	Direct: 10.42 Oblique: 15.05 Base All JS: 3.00 Base JS5: 52.30
S4	1.57	All JS: 3.91 JS5: 8.67	9.34	All JS: 12.08 JS1a: 3.16 JS2a: 96.57 JS2b: 13.80	Direct: 12.99 Oblique: 14.61 Base All JS: 3.84 Base JS5: 46.66
S5	0.66	All JS:1.65 JS5: 4.92	4.03	All JS: 8.74 JS1a: 3.16 JS2a: 73.45 JS2b: 13.80	Direct: 11.01 Oblique: 14.61 Base All JS: 2.93 Base JS5: 46.66
S6	0.46	All JS: 0.76 JS5: 4.92	1.56	All JS: 5.51 JS1a: 9.65 JS2a: 6.51 JS2b: 9.86	Direct: 8.59 Oblique: 15.86 Base All JS: 3.17 Base JS5: 69.18

Notes :

*1 The percentage of critical intersections is expressed in terms of the total number of intersections or number of planes identified as part of the particular joint set

*2 Where a particular joint set is identified as part of the kinematic analysis, this is listed in the results as JSx where "x" corresponds to the identified joint set number in Table 23

As is evident from the above table planar sliding of blocks on the slope is not a significant concern; less than 2% to 4%. Where the rock mass shear strength is determined using the Hoek-Brown rock mass friction angle and cohesion, it is likely that the chance of planar sliding is negligible, due to the high rock mass friction and apparent cohesion.

Similarly, wedge failure is an unlikely failure mechanism to occur in the slope; less than 10%. Very few critical intersections dipping out of the slopes occur.

Toppling failure, both Flexural and Direct, however presents the most likely mechanism or mode of failure of the slope. Joint Sets 1a, 2a and 2b all form sub-vertical planes in the rock mass that can interact with the slope face orientations. Joint Set 1a forms an oblique intersection with the slope, whereas for most of the slope orientations Joint Set 2a (and 2b) are sub-parallel to the slopes. For direct toppling (overturning), Joint Set 5 forms a low angle release plane that could allow blocks to overturn. For flexural topping, the percentage of critical intersections is generally less than 13%, whereas for direct toppling this can be as high as 13% and for oblique toppling 16%.

Joint sets 2a and 2b are oriented roughly parallel to the slope face and therefore form the vertical release plane to blocks that may be subject to displacement.

Taking the Main Wall slope at BH03 location, i.e. S3, and using the rock mass friction angle of 61°, the likelihood of the planar and wedge failure mechanisms have been reassessed. This slope has been selected as it forms the majority of the main wall of the proposed quay. The results are included in Table 26.

Table 26: Results of Kinematic Analysis S3 with φ = 61°

Slope ID	Percent of Critical Intersections			
	Planar (Limits)	Planar (No Limits)	Wedge	Flexural Toppling
S3	0.00	0.00	0.00	0.00

As can be seen from the above table, the likelihood for the planar, wedge and flexural toppling failure mechanisms decreases to 0%, as the high rock mass friction value makes these mechanisms physically unlikely due to the high shear stress that would occur along the plane of movement.

Toppling failure of blocks in a slope requires interface layer slip to occur between the blocks defined by the joint planes. Similarly to planar and wedge failure, this interlayer slip is governed by the shear strength of these planes. Due to the high equivalent Mohr-Coulomb parameters of the rock mass (cohesion and friction angle), this mechanism is also not likely to occur, due to the significantly high shear stress that would be required, event at shallow depth in the slope.

Examples of the resulting kinematic plots from the DIPS analysis of Slope S3 are included in Attachment C of this report.

6.4 Conclusions of the Kinematic Analysis

In itself and in the natural condition, the slope is considered stable. This is shown by the reduction in critical intersections to 0% when the rock mass friction angle is used. This is further reinforced by the fact that the slope is standing at a naturally steep angle as indicated by the bathymetric survey carried out previously.

Toppling failure mechanisms could occur in the natural condition of the slope; however this is only likely to occur under the action of significant outside forces to overcome the shear resistance between the rock joints and any secondary mineralisation that is present along the joint planes.

As the current wharf has not shown signs of global stability distress over the previous design life, it is considered highly unlikely that the re-constructed wharf will destabilise the current stable situation of the slope.

The current proposal that includes the dismantling and reconstruction of the quay wall removes the need for lateral restraint mechanisms to be installed in the sea bed rock slope to counteract the lateral load imposed by the back fill at the toe of the structure. The proposed current design is a structural form similar to that of the existing wharf whereby lateral wall loads are transferred internally by the braced framework to an anchor wall located behind the quay wall structure. Lateral loads therefore are transferred away from the front wall and are no longer imposed into the rock substrate underlying the wharf.

7 Conclusions and Recommendations

7.1 Rock Mass Strength Parameters

7.1.1 Previous 65% Design Stage

The analysis of the results of the current geotechnical investigation carried out by Delta Marine Consultants included in Section 5 indicates that the rock mass strength parameters determined previously by DMC as part of the 65% Design stage for a quay wall founded on an anchored spigot bottom connection are moderately conservative values. These 65% Design stage parameters are slightly lower than those determined from the detailed analysis contained herein, such that the difference between the two parameter sets is insignificant.

Therefore, the rock mass strength parameters and the geotechnical data set determined on the basis of the previous geotechnical information available for the Rothera Station is confirmed by the recent ground investigation carried out by Fugro Chile on behalf of BAM Nuttal / BAM International JV.

For the previous anchored spigot foundations design, the difference between the 65% Design Stage geotechnical parameters and the characteristic geotechnical parameters determined herein is unlikely to produce significant improvements in the required design for the foundation elements. Therefore, DMC consider that the 65% Design Stage parameter set is a suitable parameter set for use through to the 95% Design Stage, and the parameters do not require adjustment when used for the further development of the previous anchored spigot foundation design concept.

7.1.2 Current 65% Design Stage and Further Design Development

Arising from “optioneering” discussions, additional options for the re-development of the Biscoe Wharf have been explored in consultation with the Client and the Client’s Engineer. The outcome of these “optioneering” assessments is that the re-development of the Biscoe Wharf should comprise a dismantling of the existing structure and the re-construction of the wharf.

The reconstruction of the wharf will utilise construction methods and designs that remove the need for a rock dowel (anchor) to provide the lateral restraint at the toe of the wall. An internally braced frame or tie-rod back to an anchor wall located behind the wharf will provide the lateral restraint to the front wall of the wharf. This solution reduces, and simplifies, the connection between the bottom of the quay wall and the rock slope to a tension rock dowel connection whereby the toe connection is only required to resist a reduced uplift reaction force at the toe of the wall.

This tension rock dowel solution can be suitably and economically designed based on the updated geotechnical parameters derived from the characteristic rock mass strength properties determined as part of this Geotechnical Interpretative Report.

The characteristic rock mass strength properties from which the necessary geotechnical parameters should be derived are given in Table 27 below.

Table 27: Characteristic Rock Mass Strength Parameters

Parameter	Characteristic Value	Units
Hoek-Brown Criterion		
mb	6.471	-
s	0.0094	-
a	0.503	-
Failure Envelope Range		
$\sigma_{3;max}$	0.837	MPa
Unit weight*1	0.0169	MN/m^3
Slope height*2	50	m
Mohr-Coulomb Fit		
c'	0.935	MPa
ϕ'	64.82	°
Rock Mass Parameters		
σ_t	-0.124	MPa
σ_c	8.12	MPa
σ_{cm}	29.17	MPa
E_{rm}	17150	MPa

Notes:

*1 The submerged unit weight is used

*2 The slope height is measured to the top of the hill near to the wharf

7.2 Kinematic Analysis

In its natural state, and with the current development of the Biscoe Wharf, the submarine slope at Rothera Station is stable.

The current proposal that includes the dismantling and reconstruction of the quay wall removes the need for lateral restraint mechanisms to be installed in the sea bed rock slope to counteract the lateral load imposed by the back fill at the toe of the structure. The proposed current design is a structural form similar to that of the existing wharf whereby lateral wall loads are transferred internally by the braced framework to an anchor wall located behind the quay wall structure. Lateral loads therefore are transferred away from the front wall and are no longer imposed into the rock substrate underlying the wharf.

The results of the kinematic analysis indicate that the predominant slope failure mechanisms that may result due to changes in the insitu stress field as a result of the construction of the new quay wall are toppling failure mechanisms.

These toppling failure mechanisms will only occur where the foundations transfer lateral loads to the underlying rock mass without significant embedment / anchoring back into the jointed rock mass. These failure mechanisms occur due to the presence of closely spaced, near vertical joint sets in the rock mass at trending roughly parallel to the slope face.

However the high equivalent Mohr-Coulomb apparent cohesion and friction angle for the rock mass determined from the Hoek-Brown Failure Criterion indicate that significant loads will be required to overcome the shear strength of the rock mass. Furthermore, low angle joint sets dip obliquely into the slope, effectively providing additional resistance to overturning of the rock slabs. Interface slip between the rock slabs, required for toppling failure to occur, is resisted by the high rock mass shear strength.

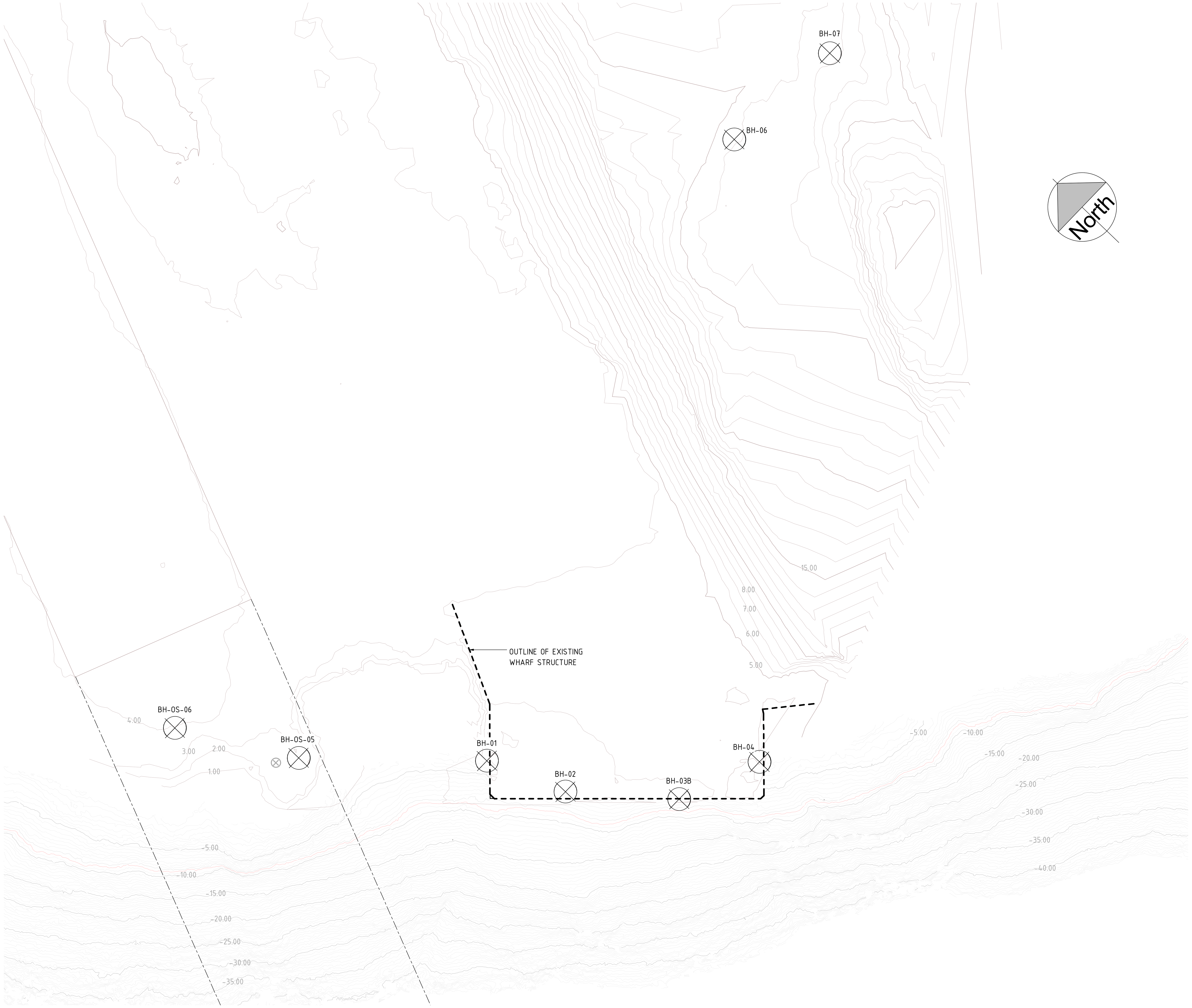
8 Geotechnical Risk Assessment

Based on the information available to DMC previously, a risk register was established wherein a number of items constituting a geotechnical risk to the project were identified. The identified hazards, causes, likelihood and potential mitigation measures are tabulated below, along with the updates to these geotechnical risks based on the current geotechnical investigation. Where risks have been mitigated, these have been struck out in the register, but are included to show that they have been previously considered and mitigated.

Hazard	Potential Cause	Risk / Impact	Likelihood	Mitigation Measure	Mitigation Results
~~Insufficient geotechnical data~~	~~Insufficient ground investigation~~ ~~No ground investigation at wharf location~~ ~~Limited samples previously tested~~	~~Low characteristic strength parameters for geotechnical materials~~	~~High~~	~~Additional ground investigation works planned and being carried out~~	~~Potentially increased characteristic ground parameters~~ ~~Potential for design optimisation~~
~~Insufficient data of geological structure of rock mass~~	~~Insufficient ground investigation~~ ~~Limited surveys of structural geology~~	~~Potential Slope stability risk due to intersection of joints and slope orientations~~ ~~High: Failure could lead to structural collapse~~	~~Medium to High~~	~~Geological survey including discontinuity survey of joints~~	~~Detailed assessment of slope stability issues possible~~
Significant drainage lag of backfill	Fines percentage too high Presence of existing quay wall preventing free drainage Drainage system not maintained / frozen	Hydraulic head becomes larger than 0.5m design value	Low to Medium	Design for hydraulic head > 0.5m Design backfill as free draining Provide no-fines rockfill	Heavier wall
~~Pin failure – no redistribution to other pins possible in current design~~	~~Unforeseen loads in pin~~	~~High - cascading failure as neighbouring pins fail~~	~~Low~~	~~Investigate installation of waler beam~~ ~~Robust design~~ ~~Build in sufficient redundancy in the design~~	~~Heavier pin design due to increased safety requirement~~
~~Anchor (rock dowel) failure~~	~~Rock parameters worse than assumed~~ ~~Accelerated corrosion of anchor components leading to failure~~	~~High – cascading failure as no facility for load re-distribution~~	~~Low~~	~~Robust design~~ ~~Test all and/or pre-stress the anchors~~ ~~Appropriate corrosion protection for all~~	~~Heavier vertical pin design~~ ~~Vertical pin embedment depth determined to accommodate accidental load due to anchor~~

Hazard	Potential Cause	Risk / Impact	Likelihood	Mitigation Measure	Mitigation Results
				~~anchor components~~ ~~Vertical pin could be designed to accommodate a portion of the horizontal load~~ ~~Install a waler beam to accommodate spreading of loads~~	~~failure~~ ~~Additional design to accommodate waler~~
Tension rock dowel	Accelerated corrosion of anchor components leading to failure	Low – tension anchor serves only to resist the uplift actions on the wall due to tie-rod anchors	Low	Appropriate corrosion protection or corrosion allowance to be included in the structural design of the tension element	Most economical, minimum dowel diameter to be used

Attachment A: Borehole Location Drawing BAA.4001-DMC-D-1001-003



LAYOUT - BOREHOLES

SCALE 1 : 500

BOREHOLES			
Mark	EAST (m)	NORTH (m)	ELEVATION (m)
BH-01	537035	2504612	3.0
BH-02	537042	2504595	4.0
BH-03B	537058	2504576	4.0
BH-04	537076	2504569	4.0
BH-06	537170	2504667	26
BH-07	537198	2504665	27
BH-OS-05	537007	2504642	2.0
BH-OS-06	536993	2504666	4.0

NOTE:
BOREHOLE LOCATION PROVIDED BY FUGRO, ELEVATION ESTIMATED BASE ON BATHYMETRY.

Client: BRITISH ANTARCTIC SURVEY

Project: ROTHERA POINT
WHARF UPGRADE

Description: GENERAL ARRANGEMENT
LAYOUT BOREHOLES

Delta Marine Consultants

Office: H.J. Nederhorststraat 1
2801 SC Gouda
The Netherlands
Postal address: P.O. Box 268
2800 AG Gouda
Phone: +31 182 590 610
Internet: www.dmc.nl / dmc@dmc.nl

Scale: 1:500
Author: MSG Signature: Date:
Checker: Checker Signature: Date:
Paper size: A1
Released: Approver Signature: Date:
Drawing number: BAA.4001-DMC-D-1001-003
BAM Drawing number:

Status: WORK IN PROGRESS
Revision: P01.01
Suitability: S0
Date: 17/08/17

E:\Revit Project Data 2016\BAA4001-DMC-ZZ-ROTH-M3-C-0001 - New Proposal_Central_MarianoGonzales.rvt

Attachment B: DIPS BH Televiewer Analysis – DIPS Info View

Dips Analysis Information

BAS Rothera Station Wharf

Project Summary

File Name: Televiewer All Data 2.dips7
Last saved with Dips version: 7.01
Project Title: BAS Rothera Station Wharf
Analysis: Joint Analysis All BHs Televiewer Data
Author: JST
Company: DMC
Date Created: 28-7-2017, 11:51:08
Comments:
All Borehole Televiewer Data

General Settings

Data Format: Dip / Dip Direction
Magnetic Declination (E pos): 0°
Multiple Data Flag (Quantity): OFF
Distance Column: ON
Extra Data Columns: 1
Units: Metric
Poles: 1559
Entries: 1559

Traverses

ID	Data Format	Type	Orient1	Orient2	Orient3	Label
BH1	Dip / Dip Direction	Linear	0	90		BH01
BH2	Dip / Dip Direction	Linear	0	90		NH02
BH3	Dip / Dip Direction	Linear	0	90		BH03
BH4	Dip / Dip Direction	Linear	0	90		BH04
BHOS05	Dip / Dip Direction	Linear	0	90		BHOS-05
BHOS06	Dip / Dip Direction	Linear	0	90		BHOS-06

Global Mean

	Dip	Dip Direction
Unweighted	14.32	39.87
Weighted	19.29	41.92

Global Best Fit

Unweighted			
	Dip	Dip Direction	Eigenvalue
S1	75.60	76.07	0.425758
S2	57.95	336.82	0.324557
S3	35.87	186.87	0.249685

Woodcock S1 / S3 = 1.312
Woodcock K = 1.035
Woodcock C = 0.271

Weighted			
	Dip	Dip Direction	Eigenvalue
S1	84.28	79.90	0.486337
S2	82.17	349.11	0.351003
S3	9.72	205.68	0.162660

Woodcock S1 / S3 = 1.386
Woodcock K = 0.424
Woodcock C = 0.326

Mean Set Planes

ID	Dip	Dip Direction	Label
1m	88.50	85.92	JS1a
1w	88.23	85.74	JS1a
2m	72.75	23.49	JS2a
2w	73.80	23.72	JS2a
3m	78.41	333.28	JS3
3w	78.96	333.32	JS3
4m	80.09	203.25	JS2b
4w	80.87	203.17	JS2b
5m	65.92	123.54	JS4
5w	67.66	123.72	JS4
6m	23.80	293.28	JS5
6w	24.18	293.12	JS5
7m	49.11	94.34	JS1b
7w	50.19	94.28	JS1b

Set Statistics

Set: 1m: JS1a (UNWEIGHTED)

Poles: 331
Entries: 331
Fisher's K: 18.6101

	68.26%	95.44%	99.74%	50%
Variability Limit	20.2262°	33.4802°	47.1438°	15.6868°
Confidence Limit	1.13686°	1.86489°	2.5893°	0.883532°

Set: 1w: JS1a (WEIGHTED)

Poles (weighted): 1201
Entries: 331
Fisher's Kw: 19.5644

	68.26%	95.44%	99.74%	50%
Variability Limit	19.7217°	32.6301°	45.9121°	15.2971°
Confidence Limit	1.10726°	1.81633°	2.52188°	0.860528°

Set: 2m: JS2a (UNWEIGHTED)

Poles: 73
Entries: 73
Fisher's K: 64.254

	68.26%	95.44%	99.74%	50%
Variability Limit	10.845°	17.8349°	24.8564°	8.42348°
Confidence Limit	1.27729°	2.09526°	2.90919°	0.992667°

Set: 2w: JS2a (WEIGHTED)

Poles (weighted): 238
Entries: 73
Fisher's Kw: 66.363

	68.26%	95.44%	99.74%	50%
Variability Limit	10.6708°	17.5469°	24.4521°	8.28831°
Confidence Limit	1.25651°	2.06118°	2.86187°	0.976523°

Set: 3m: JS3 (UNWEIGHTED)

Poles: 67
Entries: 67
Fisher's K: 62.959

	68.26%	95.44%	99.74%	50%
Variability Limit	10.9563°	18.0189°	25.1149°	8.50983°
Confidence Limit	1.3471°	2.20979°	3.06823°	1.04692°

Set: 3w: JS3 (WEIGHTED)

Poles (weighted): 243
Entries: 67
Fisher's Kw: 64.1887

	68.26%	95.44%	99.74%	50%
Variability Limit	10.8505°	17.844°	24.8693°	8.42777°
Confidence Limit	1.33393°	2.18818°	3.03823°	1.03669°

Set: 4m: JS2b (UNWEIGHTED)

Poles: 54
Entries: 54
Fisher's K: 63.1123

	68.26%	95.44%	99.74%	50%
Variability Limit	10.943°	17.9968°	25.0839°	8.49946°
Confidence Limit	1.49863°	2.45838°	3.41344°	1.16468°

Set: 4w: JS2b (WEIGHTED)

Poles (weighted): 196
Entries: 54
Fisher's Kw: 66.59

	68.26%	95.44%	99.74%	50%
Variability Limit	10.6525°	17.5168°	24.4097°	8.27415°
Confidence Limit	1.45837°	2.39232°	3.32171°	1.13339°

Set: 5m: JS4 (UNWEIGHTED)

Poles: 53
Entries: 53
Fisher's K: 74.5133

	68.26%	95.44%	99.74%	50%
Variability Limit	10.0687°	16.5524°	23.0566°	7.82115°
Confidence Limit	1.39048°	2.28096°	3.16706°	1.08064°

Set: 5w: JS4 (WEIGHTED)

Poles (weighted): 140
Entries: 53
Fisher's Kw: 77.1257

	68.26%	95.44%	99.74%	50%
Variability Limit	9.89628°	16.2677°	22.6575°	7.68735°
Confidence Limit	1.36642°	2.24148°	3.11225°	1.06194°

Set: 6m: JS5 (UNWEIGHTED)

Poles: 86
Entries: 86
Fisher's K: 65.2686

	68.26%	95.44%	99.74%	50%
Variability Limit	10.7601°	17.6946°	24.6594°	8.35764°
Confidence Limit	1.16748°	1.91513°	2.65907°	0.907334°

Set: 6w: JS5 (WEIGHTED)

Poles (weighted): 96
Entries: 86
Fisher's Kw: 64.8263

	68.26%	95.44%	99.74%	50%
Variability Limit	10.7969°	17.7553°	24.7447°	8.38615°
Confidence Limit	1.17152°	1.92175°	2.66826°	0.910471°

Set: 7m: JS1b (UNWEIGHTED)

Poles: 85
Entries: 85
Fisher's K: 68.5623

	68.26%	95.44%	99.74%	50%
Variability Limit	10.4978°	17.261°	24.0507°	8.15406°
Confidence Limit	1.14535°	1.87882°	2.60865°	0.890134°

Set: 7w: JS1b (WEIGHTED)

Poles (weighted): 135
Entries: 85
Fisher's Kw: 69.2257

	68.26%	95.44%	99.74%	50%
Variability Limit	10.4472°	17.1775°	23.9335°	8.11484°
Confidence Limit	1.13977°	1.86967°	2.59594°	0.885796°

Set Windows

Set ID	Window	Type	Wrapped
1	1a	Curved	No
1	1b	Curved	Yes
2	2a	Cluster Analysis	No
3	3a	Cluster Analysis	No
3	3b	Cluster Analysis	Yes
4	4a	Cluster Analysis	No
4	4b	Cluster Analysis	Yes
5	5a	Cluster Analysis	No
6	6a	Cluster Analysis	No
7	7a	Cluster Analysis	No

Intersections

Intersection Type	Number
Grid Data Planes	1214403
All Set Planes	210638
Set 1: JS1a vs Set 2: JS2a Planes	24163
Set 1: JS1a vs Set 3: JS3 Planes	22177
Set 1: JS1a vs Set 4: JS2b Planes	17874
Set 1: JS1a vs Set 5: JS4 Planes	17543
Set 1: JS1a vs Set 6: JS5 Planes	28466
Set 1: JS1a vs Set 7: JS1b Planes	28135
Set 2: JS2a vs Set 3: JS3 Planes	4891
Set 2: JS2a vs Set 4: JS2b Planes	3942
Set 2: JS2a vs Set 5: JS4 Planes	3869
Set 2: JS2a vs Set 6: JS5 Planes	6278
Set 2: JS2a vs Set 7: JS1b Planes	6205
Set 3: JS3 vs Set 4: JS2b Planes	3618
Set 3: JS3 vs Set 5: JS4 Planes	3551
Set 3: JS3 vs Set 6: JS5 Planes	5762
Set 3: JS3 vs Set 7: JS1b Planes	5695
Set 4: JS2b vs Set 5: JS4 Planes	2862
Set 4: JS2b vs Set 6: JS5 Planes	4644
Set 4: JS2b vs Set 7: JS1b Planes	4590
Set 5: JS4 vs Set 6: JS5 Planes	4558

Set 5: JS4 vs Set 6: JS5 Planes	4558
Set 5: JS4 vs Set 7: JS1b Planes	4505
Set 6: JS5 vs Set 7: JS1b Planes	7310
Grid Data Planes (Weighted)	7975624
All Set Planes (Weighted)	1705847
Set 1: JS1a vs Set 2: JS2a Planes	285335
Set 1: JS1a vs Set 3: JS3 Planes	292455
Set 1: JS1a vs Set 4: JS2b Planes	235343
Set 1: JS1a vs Set 5: JS4 Planes	167887
Set 1: JS1a vs Set 6: JS5 Planes	115038
Set 1: JS1a vs Set 7: JS1b Planes	161861
Set 2: JS2a vs Set 3: JS3 Planes	57843
Set 2: JS2a vs Set 4: JS2b Planes	46547
Set 2: JS2a vs Set 5: JS4 Planes	33206
Set 2: JS2a vs Set 6: JS5 Planes	22753
Set 2: JS2a vs Set 7: JS1b Planes	32014
Set 3: JS3 vs Set 4: JS2b Planes	47709
Set 3: JS3 vs Set 5: JS4 Planes	34034
Set 3: JS3 vs Set 6: JS5 Planes	23321
Set 3: JS3 vs Set 7: JS1b Planes	32813
Set 4: JS2b vs Set 5: JS4 Planes	27388
Set 4: JS2b vs Set 6: JS5 Planes	18766
Set 4: JS2b vs Set 7: JS1b Planes	26405
Set 5: JS4 vs Set 6: JS5 Planes	13387
Set 5: JS4 vs Set 7: JS1b Planes	18836
Set 6: JS5 vs Set 7: JS1b Planes	12907
User and Mean Set (Unweighted) Planes	21
User and Mean Set (Weighted) Planes	21
User Planes	0
Mean Set (Unweighted) Planes	21
Mean Set (Weighted) Planes	21

Kinematic Analysis

Slope Dip: 48
Slope Dip Direction: 220
Friction Angle: 30°
Lateral Limit Angle: 25°

Planar Sliding

Planar Sliding	Critical	%	Total
All Vectors	19	1.22%	1559
All Vectors (Weighted)	24	0.61%	3996

Planar Sliding (No Limits)

Planar Sliding	Critical	%	Total
All Vectors	48	3.08%	1559
All Vectors (Weighted)	60	1.50%	3996
Set 6: JS5	5	5.81%	86
Set 6: JS5 (Weighted)	6	6.17%	96

Wedge Sliding

Critical 1 = Wedge Sliding (Both Planes)
Critical 2 = Wedge Sliding (One Plane)

Intersection Type	Critical 1	%	Critical 2	%	Total
Grid Data Plane Intersections	36624	3.02%	14268	1.17%	1214403
Grid Data Plane Intersections (Weighted)	218388	2.74%	49373	0.62%	7975624
All Set Planes	3429	1.63%	116	0.06%	210638
Set 1: JS1a vs Set 2: JS2a Planes	0	0.00%	0	0.00%	24163
Set 1: JS1a vs Set 3: JS3 Planes	0	0.00%	0	0.00%	22177
Set 1: JS1a vs Set 4: JS2b Planes	0	0.00%	0	0.00%	17874
Set 1: JS1a vs Set 5: JS4 Planes	2708	15.44%	0	0.00%	17543
Set 1: JS1a vs Set 6: JS5 Planes	0	0.00%	0	0.00%	28466
Set 1: JS1a vs Set 7: JS1b Planes	294	1.04%	0	0.00%	28135
Set 2: JS2a vs Set 3: JS3 Planes	0	0.00%	0	0.00%	4891
Set 2: JS2a vs Set 4: JS2b Planes	0	0.00%	0	0.00%	3942
Set 2: JS2a vs Set 5: JS4 Planes	0	0.00%	0	0.00%	3869
Set 2: JS2a vs Set 6: JS5 Planes	0	0.00%	0	0.00%	6278
Set 2: JS2a vs Set 7: JS1b Planes	0	0.00%	0	0.00%	6205
Set 3: JS3 vs Set 4: JS2b Planes	1	0.03%	0	0.00%	3618
Set 3: JS3 vs Set 5: JS4 Planes	0	0.00%	0	0.00%	3551
Set 3: JS3 vs Set 6: JS5 Planes	369	6.40%	97	1.68%	5762
Set 3: JS3 vs Set 7: JS1b Planes	0	0.00%	0	0.00%	5695
Set 4: JS2b vs Set 5: JS4 Planes	0	0.00%	0	0.00%	2862
Set 4: JS2b vs Set 6: JS5 Planes	57	1.23%	19	0.41%	4644
Set 4: JS2b vs Set 7: JS1b Planes	0	0.00%	0	0.00%	4590
Set 5: JS4 vs Set 6: JS5 Planes	0	0.00%	0	0.00%	4558
Set 5: JS4 vs Set 7: JS1b Planes	0	0.00%	0	0.00%	4505
Set 6: JS5 vs Set 7: JS1b Planes	0	0.00%	0	0.00%	7310
All Set Planes (Weighted)	27932	1.64%	485	0.03%	1705847
Set 1: JS1a vs Set 2: JS2a Planes (Weighted)	0	0.00%	0	0.00%	285335
Set 1: JS1a vs Set 3: JS3 Planes (Weighted)	0	0.00%	0	0.00%	292455
Set 1: JS1a vs Set 4: JS2b Planes (Weighted)	0	0.00%	0	0.00%	235343
Set 1: JS1a vs Set 5: JS4 Planes (Weighted)	24165	14.39%	0	0.00%	167887
Set 1: JS1a vs Set 6: JS5 Planes (Weighted)	0	0.00%	0	0.00%	115038
Set 1: JS1a vs Set 7: JS1b Planes (Weighted)	1960	1.21%	0	0.00%	161861
Set 2: JS2a vs Set 3: JS3 Planes (Weighted)	0	0.00%	0	0.00%	57843
Set 2: JS2a vs Set 4: JS2b Planes (Weighted)	0	0.00%	0	0.00%	46547
Set 2: JS2a vs Set 5: JS4 Planes (Weighted)	0	0.00%	0	0.00%	33206
Set 2: JS2a vs Set 6: JS5 Planes (Weighted)	0	0.00%	0	0.00%	22753
Set 2: JS2a vs Set 7: JS1b Planes (Weighted)	0	0.00%	0	0.00%	32014
Set 3: JS3 vs Set 4: JS2b Planes (Weighted)	8	0.02%	0	0.00%	47709
Set 3: JS3 vs Set 5: JS4 Planes (Weighted)	0	0.00%	0	0.00%	34034

Set 3: JS3 vs Set 6: JS5 Planes (Weighted)	1589	6.81%	416	1.78%	23321
Set 3: JS3 vs Set 7: JS1b Planes (Weighted)	0	0.00%	0	0.00%	32813
Set 4: JS2b vs Set 5: JS4 Planes (Weighted)	0	0.00%	0	0.00%	27388
Set 4: JS2b vs Set 6: JS5 Planes (Weighted)	211	1.12%	69	0.37%	18766
Set 4: JS2b vs Set 7: JS1b Planes (Weighted)	0	0.00%	0	0.00%	26405
Set 5: JS4 vs Set 6: JS5 Planes (Weighted)	0	0.00%	0	0.00%	13387
Set 5: JS4 vs Set 7: JS1b Planes (Weighted)	0	0.00%	0	0.00%	18836
Set 6: JS5 vs Set 7: JS1b Planes (Weighted)	0	0.00%	0	0.00%	12907
User and Mean Set (Unweighted) Plane Intersections	0	0.00%	0	0.00%	21
User and Mean Set (Weighted) Plane Intersections	0	0.00%	0	0.00%	21
User Plane Intersections	No results				
Mean Set Plane (Unweighted) Intersections	0	0.00%	0	0.00%	21
Mean Set Plane (Weighted) Intersections	0	0.00%	0	0.00%	21

Flexural Toppling

Flexural Toppling	Critical	%	Total
All Vectors	79	5.07%	1559
All Vectors (Weighted)	301	7.53%	3996
Set 1: JS1a	17	5.14%	331
Set 1: JS1a (Weighted)	65	5.41%	1201
Set 2: JS2a	33	45.21%	73
Set 2: JS2a (Weighted)	124	52.22%	238
Set 4: JS2b	7	12.96%	54
Set 4: JS2b (Weighted)	27	13.80%	196

Direct Toppling

Base Plane	Critical	%	Total
All Vectors	106	6.80%	1559
All Vectors (Weighted)	120	3.00%	3996
Set 6: JS5	46	53.49%	86
Set 6: JS5 (Weighted)	50	52.30%	96

Critical 1 = Direct Toppling (Intersection)
Critical 2 = Oblique Toppling (Intersection)

Intersection Type	Critical 1	%	Critical 2	%	Total
Grid Data Plane Intersections	89617	7.38%	97918	8.06%	1214403
Grid Data Plane Intersections (Weighted)	830790	10.42%	1200027	15.05%	7975624
All Set Planes	23714	11.26%	30920	14.68%	210638
Set 1: JS1a vs Set 2: JS2a Planes	7723	31.96%	12460	51.57%	24163
Set 1: JS1a vs Set 3: JS3 Planes	8978	40.48%	7810	35.22%	22177
Set 1: JS1a vs Set 4: JS2b Planes	72	0.40%	3168	17.72%	17874
Set 1: JS1a vs Set 5: JS4 Planes	67	0.38%	2473	14.10%	17543
Set 1: JS1a vs Set 6: JS5 Planes	0	0.00%	0	0.00%	28466
Set 1: JS1a vs Set 7: JS1b Planes	63	0.22%	16	0.06%	28135
Set 2: JS2a vs Set 3: JS3 Planes	2446	50.01%	2238	45.76%	4891
Set 2: JS2a vs Set 4: JS2b Planes	0	0.00%	10	0.25%	3942
Set 2: JS2a vs Set 5: JS4 Planes	368	9.51%	1396	36.08%	3869
Set 2: JS2a vs Set 6: JS5 Planes	0	0.00%	0	0.00%	6278

Set 2: JS2a vs Set 7: JS1b Planes	180	2.90%	198	3.19%	6205
Set 3: JS3 vs Set 4: JS2b Planes	7	0.19%	109	3.01%	3618
Set 3: JS3 vs Set 5: JS4 Planes	968	27.26%	42	1.18%	3551
Set 3: JS3 vs Set 6: JS5 Planes	0	0.00%	0	0.00%	5762
Set 3: JS3 vs Set 7: JS1b Planes	2001	35.14%	5	0.09%	5695
Set 4: JS2b vs Set 5: JS4 Planes	0	0.00%	852	29.77%	2862
Set 4: JS2b vs Set 6: JS5 Planes	0	0.00%	0	0.00%	4644
Set 4: JS2b vs Set 7: JS1b Planes	0	0.00%	40	0.87%	4590
Set 5: JS4 vs Set 6: JS5 Planes	0	0.00%	0	0.00%	4558
Set 5: JS4 vs Set 7: JS1b Planes	841	18.67%	103	2.29%	4505
Set 6: JS5 vs Set 7: JS1b Planes	0	0.00%	0	0.00%	7310
All Set Planes (Weighted)	277277	16.25%	386303	22.65%	1705847
Set 1: JS1a vs Set 2: JS2a Planes (Weighted)	92970	32.58%	154052	53.99%	285335
Set 1: JS1a vs Set 3: JS3 Planes (Weighted)	120262	41.12%	104137	35.61%	292455
Set 1: JS1a vs Set 4: JS2b Planes (Weighted)	1075	0.46%	44438	18.88%	235343
Set 1: JS1a vs Set 5: JS4 Planes (Weighted)	744	0.44%	27185	16.19%	167887
Set 1: JS1a vs Set 6: JS5 Planes (Weighted)	0	0.00%	0	0.00%	115038
Set 1: JS1a vs Set 7: JS1b Planes (Weighted)	397	0.25%	105	0.06%	161861
Set 2: JS2a vs Set 3: JS3 Planes (Weighted)	28756	49.71%	27011	46.70%	57843
Set 2: JS2a vs Set 4: JS2b Planes (Weighted)	0	0.00%	149	0.32%	46547
Set 2: JS2a vs Set 5: JS4 Planes (Weighted)	3377	10.17%	15633	47.08%	33206
Set 2: JS2a vs Set 6: JS5 Planes (Weighted)	0	0.00%	0	0.00%	22753
Set 2: JS2a vs Set 7: JS1b Planes (Weighted)	812	2.54%	1512	4.72%	32014
Set 3: JS3 vs Set 4: JS2b Planes (Weighted)	104	0.22%	1627	3.41%	47709
Set 3: JS3 vs Set 5: JS4 Planes (Weighted)	11267	33.10%	615	1.81%	34034
Set 3: JS3 vs Set 6: JS5 Planes (Weighted)	0	0.00%	0	0.00%	23321
Set 3: JS3 vs Set 7: JS1b Planes (Weighted)	13040	39.74%	42	0.13%	32813
Set 4: JS2b vs Set 5: JS4 Planes (Weighted)	0	0.00%	8915	32.55%	27388
Set 4: JS2b vs Set 6: JS5 Planes (Weighted)	0	0.00%	0	0.00%	18766
Set 4: JS2b vs Set 7: JS1b Planes (Weighted)	0	0.00%	331	1.25%	26405
Set 5: JS4 vs Set 6: JS5 Planes (Weighted)	0	0.00%	0	0.00%	13387
Set 5: JS4 vs Set 7: JS1b Planes (Weighted)	4472	23.74%	550	2.92%	18836
Set 6: JS5 vs Set 7: JS1b Planes (Weighted)	0	0.00%	0	0.00%	12907
User and Mean Set (Unweighted) Plane Intersections	2	9.52%	2	9.52%	21
User and Mean Set (Weighted) Plane Intersections	2	9.52%	3	14.29%	21
User Plane Intersections	No results				
Mean Set Plane (Unweighted) Intersections	2	9.52%	2	9.52%	21
Mean Set Plane (Weighted) Intersections	2	9.52%	3	14.29%	21

Jointing Analysis

Spacing

Spacing		True		Apparent		Number of Spacings
Set	Traverse	Mean	Std-Dev	Mean	Std-Dev	
1	BH1	0.06	0.07	0.22	0.27	61
1	BH2	0.02	0.04	0.08	0.17	148
1	BH3	0.08	0.16	0.30	0.63	39
1	BH4	0.17	0.14	0.67	0.55	19

1	BHOS05	0.11	0.16	0.42	0.63	21
1	BHOS06	0.06	0.07	0.23	0.26	37
1	All	0.05	0.10	0.21	0.39	325
2	BH1	0.41	0.50	1.37	1.68	5
2	BH2	0.12	0.26	0.40	0.86	32
2	BH3	0.20	0.20	0.69	0.68	11
2	BH4	0.34	0.37	1.14	1.26	11
2	BHOS05	1.87	0.00	6.31	0.00	1
2	BHOS06	0.25	0.15	0.85	0.51	7
2	All	0.23	0.36	0.77	1.23	67
3	BH1	0.57	0.66	2.20	2.54	6
3	BH2	0.42	0.52	1.63	2.00	8
3	BH3	1.00	0.45	3.85	1.72	2
3	BH4	2.68	0.00	10.37	0.00	1
3	BHOS05	0.13	0.14	0.51	0.54	13
3	BHOS06	0.07	0.07	0.27	0.29	31
3	All	0.25	0.49	0.97	1.89	61
4	BH1	0.00	0.00	0.00	0.00	0
4	BH2	0.10	0.24	0.39	0.92	26
4	BH3	0.52	0.39	2.02	1.52	6
4	BH4	0.48	0.46	1.84	1.77	7
4	BHOS05	0.00	0.00	0.00	0.00	1
4	BHOS06	0.21	0.17	0.81	0.64	8
4	All	0.22	0.34	0.87	1.31	48
5	BH1	0.26	0.39	0.63	0.96	21
5	BH2	1.00	0.97	2.46	2.37	5
5	BH3	0.51	0.58	1.26	1.43	9
5	BH4	1.34	1.48	3.29	3.62	4
5	BHOS05	0.45	0.43	1.10	1.06	6
5	BHOS06	0.39	0.14	0.96	0.35	2
5	All	0.51	0.75	1.25	1.83	47
6	BH1	0.34	0.38	0.38	0.41	30
6	BH2	1.09	1.18	1.19	1.29	7
6	BH3	1.97	1.41	2.15	1.54	3
6	BH4	1.79	1.00	1.95	1.09	2
6	BHOS05	0.46	0.33	0.50	0.36	15
6	BHOS06	0.32	0.44	0.35	0.48	23
6	All	0.52	0.72	0.57	0.79	80
7	BH1	0.13	0.08	0.20	0.13	2
7	BH2	0.36	0.40	0.55	0.62	23
7	BH3	0.38	0.51	0.58	0.78	22
7	BH4	0.63	0.90	0.96	1.38	5
7	BHOS05	0.27	0.33	0.41	0.50	19
7	BHOS06	0.23	0.17	0.35	0.27	8
7	All	0.34	0.46	0.52	0.70	79

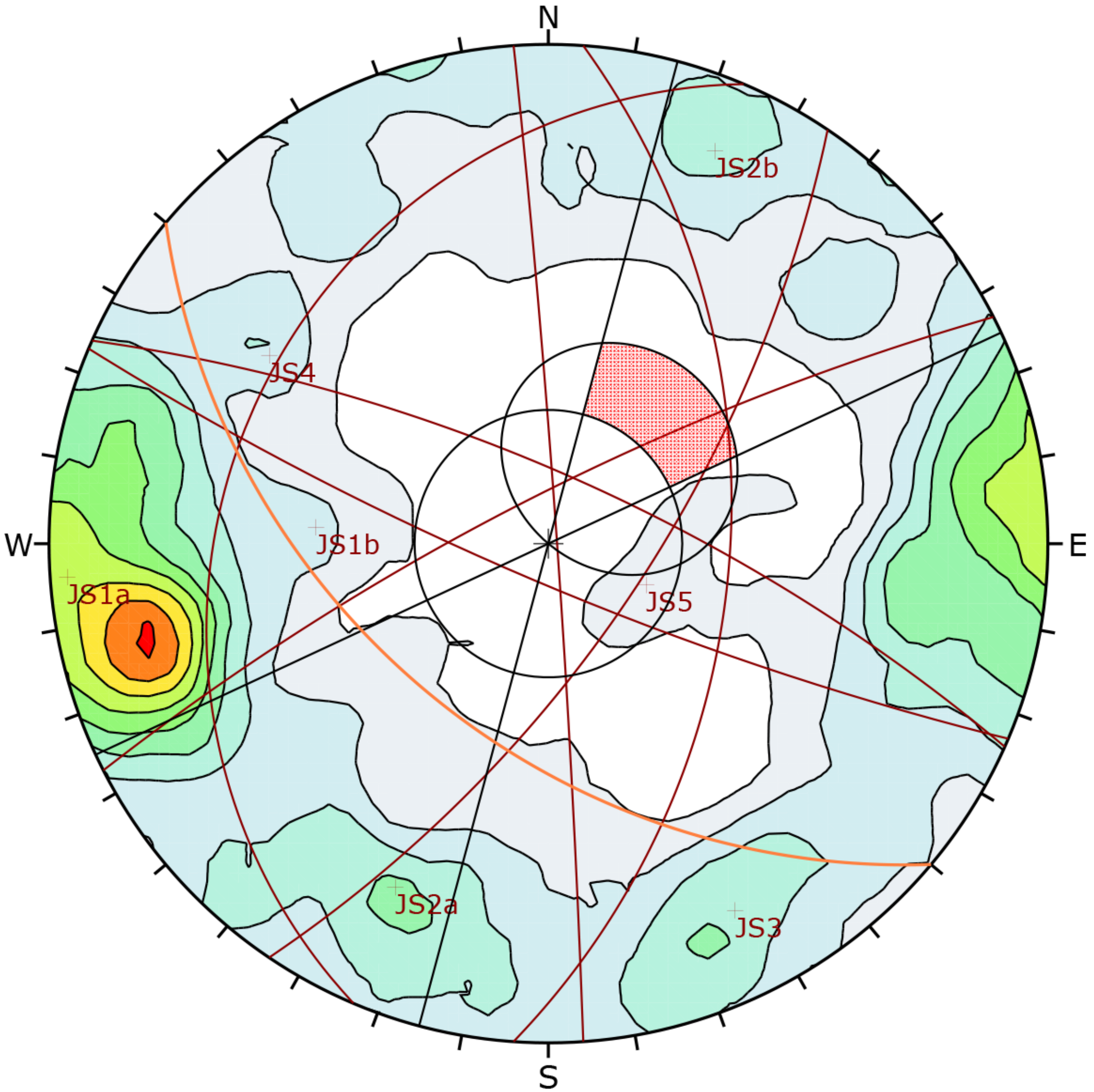
RQD

Traverse	RQD (%)
BH1	44.76
BH2	16.90
BH3	53.39
BH4	69.64
BHOS05	46.79
BHOS06	24.43

Frequency

Traverse	Frequency	Weighted Frequency
BH1	16.30	42.63
BH2	38.65	102.69
BH3	13.78	33.52
BH4	9.96	26.32
BHOS05	21.00	48.51
BHOS06	30.64	78.67

Attachment C: Slope #3 Kinematic Analysis – DIPS Plots



Color	Density Concentrations
	0.00 - 0.55
	0.55 - 1.10
	1.10 - 1.65
	1.65 - 2.20
	2.20 - 2.75
	2.75 - 3.30
	3.30 - 3.85
	3.85 - 4.40
	4.40 - 4.95
	4.95 - 5.50

Contour Data	Pole Vectors
Maximum Density	5.03%
Contour Distribution	Fisher
Counting Circle Size	1.0%

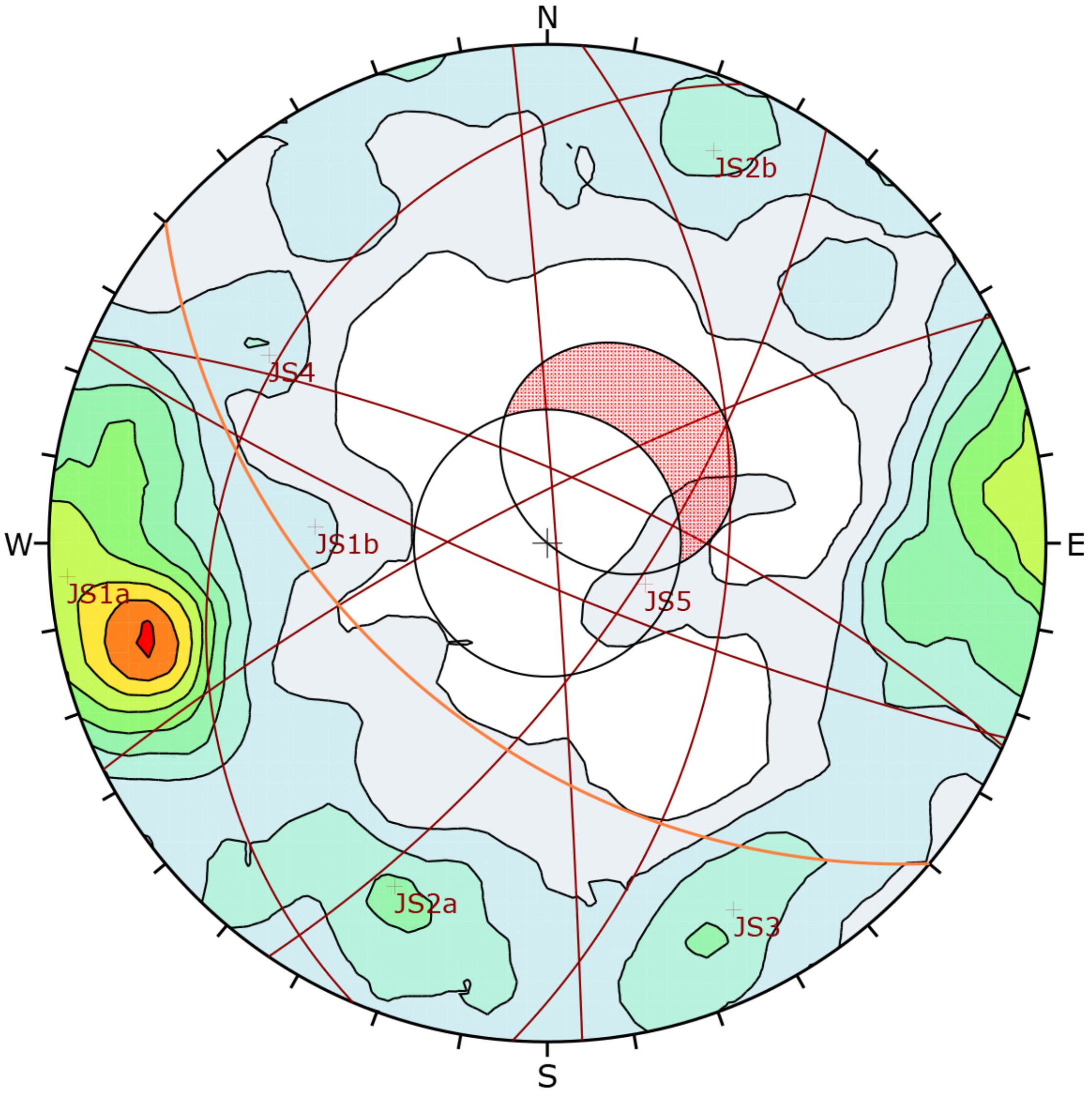
Kinematic Analysis	Planar Sliding		
Slope Dip	48		
Slope Dip Direction	220		
Friction Angle	30°		
Lateral Limits	25°		
Weighted Results	Critical	Total	%
Planar Sliding (All)	24	3996	0.61%

Plot Mode	Pole Vectors
Vector Count (Weighted)	3996 (1559 Entries)
Terzaghi Weighting	Minimum Bias Angle 15°
Hemisphere	Lower
Projection	Equal Angle

Delta Marine Consultants

DIPS 7.010

Project	BAS Rothera Station Wharf		
Analysis Description	Joint Analysis All BHs Televiewer Data		
Drawn By	JST	*Company*	DMC
Date	28-7-2017, 11:51:08	*File Name*	Televiewer All Data 2.dips7



Color	Density Concentrations
	0.00 - 0.55
	0.55 - 1.10
	1.10 - 1.65
	1.65 - 2.20
	2.20 - 2.75
	2.75 - 3.30
	3.30 - 3.85
	3.85 - 4.40
	4.40 - 4.95
	4.95 - 5.50

Contour Data	Pole Vectors
Maximum Density	5.03%
Contour Distribution	Fisher
Counting Circle Size	1.0%

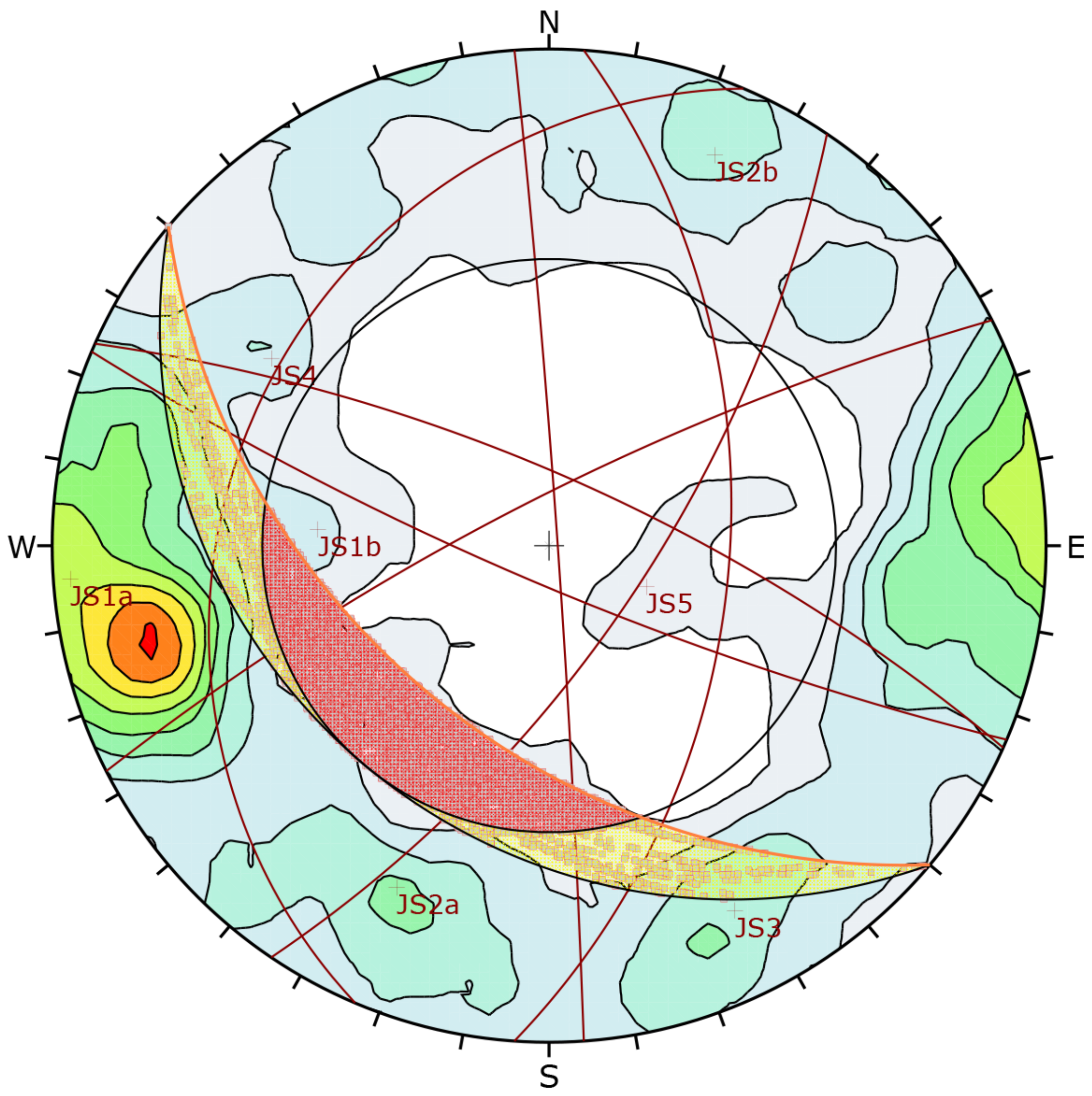
Kinematic Analysis	Planar Sliding		
Slope Dip	48		
Slope Dip Direction	220		
Friction Angle	30°		
Weighted Results	Critical	Total	%
Planar Sliding (All)	60	3996	1.50%
Planar Sliding (Set 6: JS5)	6	96	6.17%

Plot Mode	Pole Vectors
Vector Count (Weighted)	3996 (1559 Entries)
Terzaghi Weighting	Minimum Bias Angle 15°
Hemisphere	Lower
Projection	Equal Angle

Delta Marine Consultants

DIPS 7.010

Project	BAS Rothera Station Wharf		
Analysis Description	Joint Analysis All BHs Televiewer Data		
Drawn By	JST	*Company*	DMC
Date	28-7-2017, 11:51:08	*File Name*	Televiewer All Data 2.dips7



Symbol	Feature
■	Critical Intersection

Color	Density Concentrations
	0.00 - 0.55
	0.55 - 1.10
	1.10 - 1.65
	1.65 - 2.20
	2.20 - 2.75
	2.75 - 3.30
	3.30 - 3.85
	3.85 - 4.40
	4.40 - 4.95
	4.95 - 5.50

Contour Data	Pole Vectors
Maximum Density	5.03%
Contour Distribution	Fisher
Counting Circle Size	1.0%

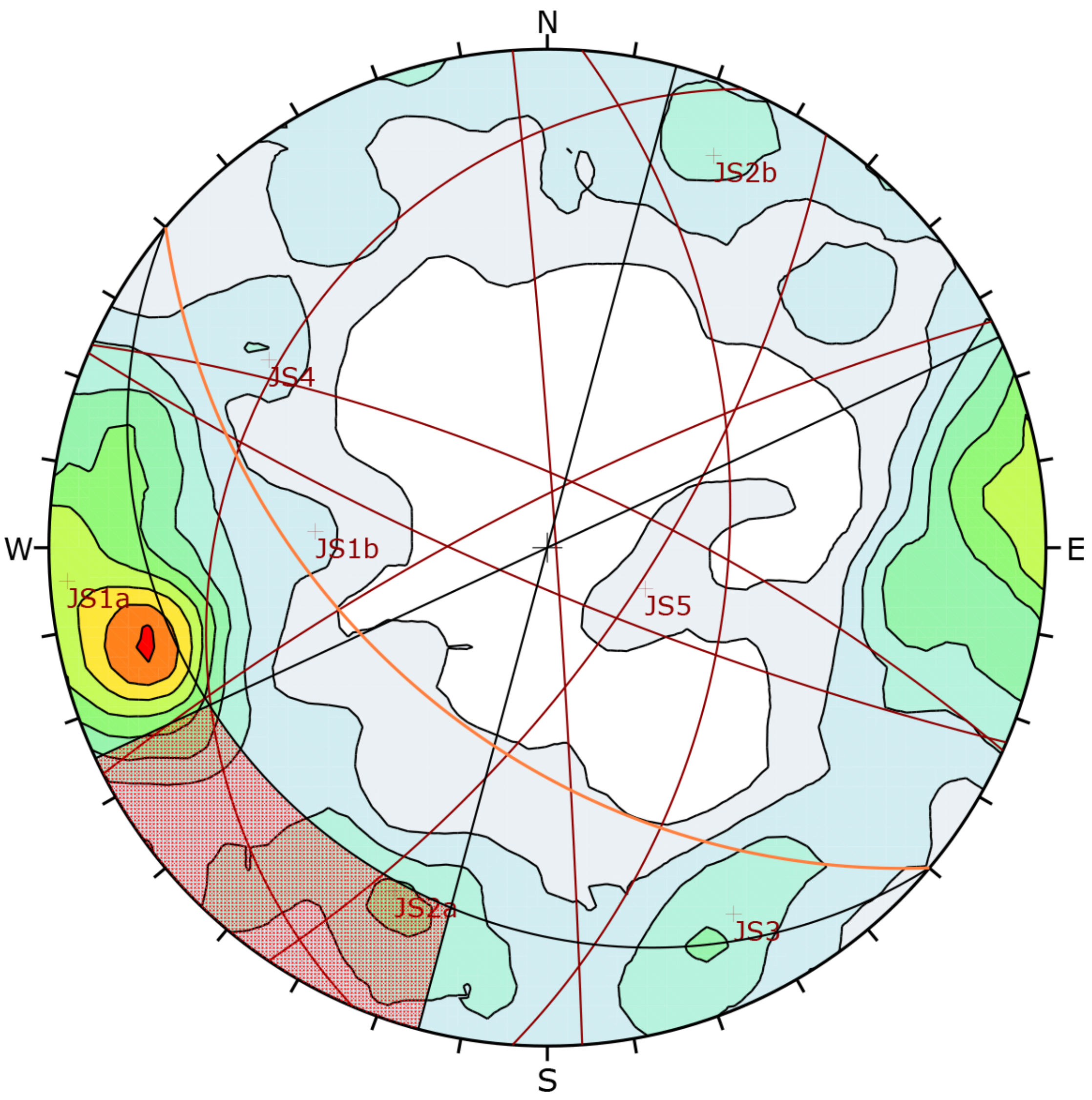
Kinematic Analysis	Wedge Sliding		
Slope Dip	48		
Slope Dip Direction	220		
Friction Angle	30°		
Weighted Results	**Critical**	**Total**	**%**
Wedge Sliding	267761	7975624	3.36%

Plot Mode	Pole Vectors
Vector Count (Weighted)	3996 (1559 Entries)
Terzaghi Weighting	Minimum Bias Angle 15°
Intersection Mode	Grid Data Planes
Intersections Count (Weighted)	7975624
Hemisphere	Lower
Projection	Equal Angle

Delta Marine Consultants

DIPS 7.010

Project	BAS Rothera Station Wharf		
Analysis Description	Joint Analysis All BHs Televiewer Data		
Drawn By	JST	*Company*	DMC
Date	28-7-2017, 11:51:08	*File Name*	Televiewer All Data 2.dips7



Color	Density Concentrations		
	0.00	-	0.55
	0.55	-	1.10
	1.10	-	1.65
	1.65	-	2.20
	2.20	-	2.75
	2.75	-	3.30
	3.30	-	3.85
	3.85	-	4.40
	4.40	-	4.95
	4.95	-	5.50

Contour Data	Pole Vectors
Maximum Density	5.03%
Contour Distribution	Fisher
Counting Circle Size	1.0%

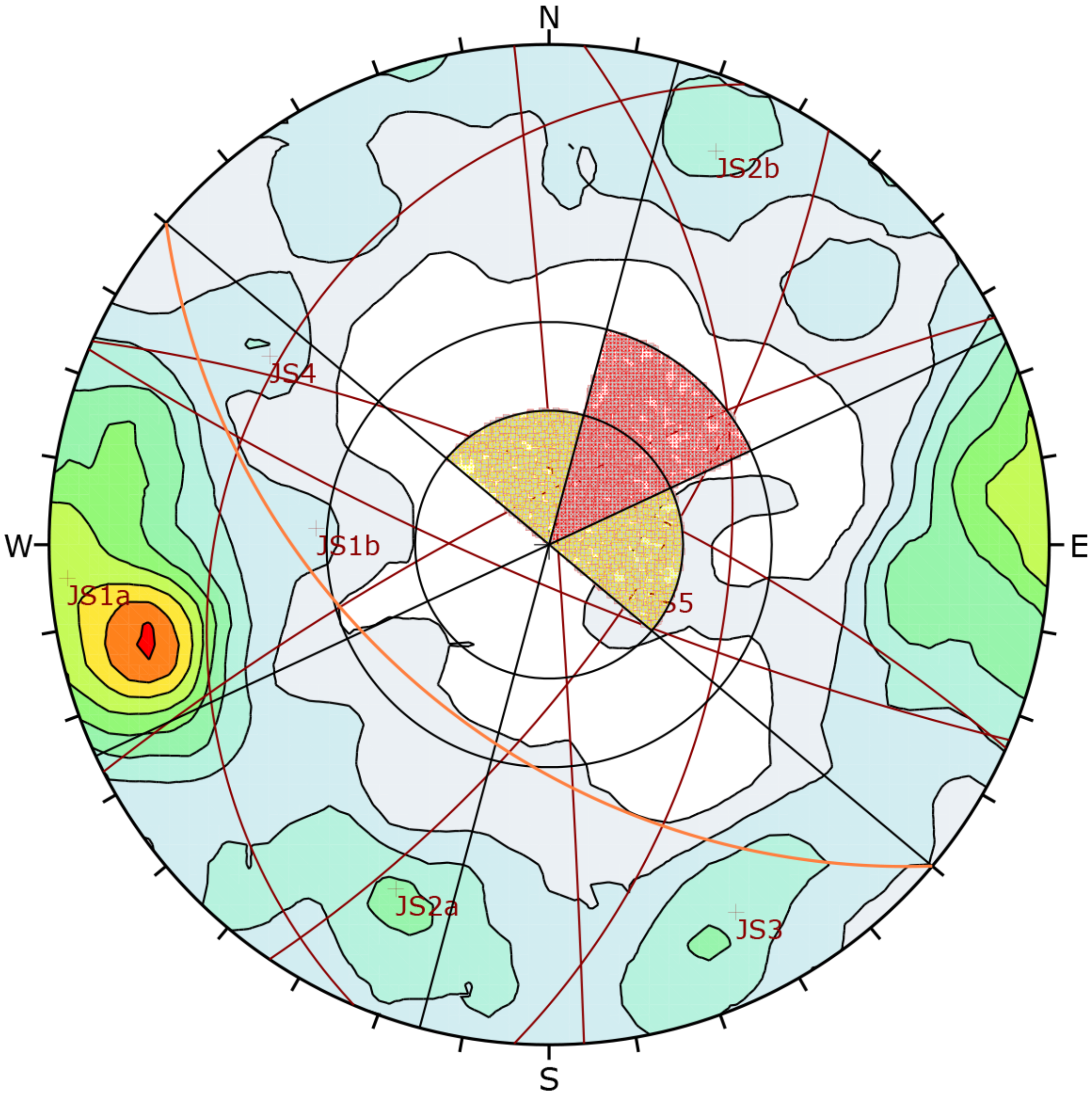
Kinematic Analysis	Flexural Toppling		
Slope Dip	48		
Slope Dip Direction	220		
Friction Angle	30°		
Lateral Limits	25°		
Weighted Results	**Critical**	**Total**	**%**
Flexural Toppling (All)	301	3996	7.53%
Flexural Toppling (Set 1: JS1a)	65	1201	5.41%
Flexural Toppling (Set 2: JS2a)	124	238	52.22%
Flexural Toppling (Set 4: JS2b)	27	196	13.80%

Plot Mode	Pole Vectors
Vector Count (Weighted)	3996 (1559 Entries)
Terzaghi Weighting	Minimum Bias Angle 15°
Hemisphere	Lower
Projection	Equal Angle

Delta Marine Consultants

DIPS 7.010

Project	BAS Rothera Station Wharf		
Analysis Description	Joint Analysis All BHs Televiewer Data		
Drawn By	JST	*Company*	DMC
Date	28-7-2017, 11:51:08	*File Name*	Televiewer All Data 2.dips7



Symbol	Feature
▪	Critical Intersection

Color	Density Concentrations
	0.00 - 0.55
	0.55 - 1.10
	1.10 - 1.65
	1.65 - 2.20
	2.20 - 2.75
	2.75 - 3.30
	3.30 - 3.85
	3.85 - 4.40
	4.40 - 4.95
	4.95 - 5.50
Contour Data	Pole Vectors
Maximum Density	5.03%
Contour Distribution	Fisher
Counting Circle Size	1.0%

Kinematic Analysis	Direct Toppling
Slope Dip	48
Slope Dip Direction	220
Friction Angle	30°
Lateral Limits	25°

Weighted Results	Critical	Total	%
Direct Toppling (Intersection)	830790	7975624	10.42%
Oblique Toppling (Intersection)	1200027	7975624	15.05%
Base Plane (All)	120	3996	3.00%
Base Plane (Set 6: JS5)	50	96	52.30%

Plot Mode	Pole Vectors
Vector Count (Weighted)	3996 (1559 Entries)
Terzaghi Weighting	Minimum Bias Angle 15°
Intersection Mode	Grid Data Planes
Intersections Count (Weighted)	7975624
Hemisphere	Lower
Projection	Equal Angle

Delta Marine Consultants

DIPS 7.010

Project	BAS Rothera Station Wharf		
Analysis Description	Joint Analysis All BHs Televiewer Data		
Drawn By	JST	*Company*	DMC
Date	28-7-2017, 11:51:08	*File Name*	Televiewer All Data 2.dips7

Attachment D: Client Comments and Responses

REVIEW RECORD

Project Name: BAS SD3 Rothera Wharf Redevelopment **Job No: 1620001748**

Structure: Rothera Wharf – Geotechnical Design – Geotechnical Interpretative Report

Checker: Jenny Symons, Beccy Cusworth (Ramboll) Signature:

Review Category: Date: 03 October 2017

REF.	**REVIEWING ENGINEER'S COMMENTS**	**DESIGNER'S ACTION**	**Initials/ Date**	**Status** 1.Action Complete 2.Action Outstanding 3.Disputed Item 4. Address at 95% Design Stage
1	Section 1.1 (General Introduction). Are the parameters also considered appropriate to support the design of the runway stabilisation and modernisation buildings?	This report pertains to the derivation of geotechnical design parameters for the Wharf Design only as noted in the title of the report. This report may be used as the basis for the determination of parameters for the runway stabilisation works and for the modernisation of buildings such as the hanger.	JST / 13-10-2017	2
2	Section 1.2 (Scope of the Report). The wording seems slightly odd. Was the factual geotechnical information assessed, interpreted and used to derive parameters, which happen to confirm those used in the 65% design, or was the intent to confirm the 65% design parameters?	The initial aim of the report was to confirm the design parameters of the 65% Design Stage. Where this confirmation showed the previously determine parameters were not sufficiently characteristic, the design would be updated by revised parameters determined in this report. This report therefore confirms that the initial parameter set derived as part of the previous 65% design stage were characteristic of the materials present at site.	JST / 13-10-2017	2

REVIEW RECORD

Project Name: BAS SD3 Rothera Wharf Redevelopment **Job No: 1620001748**

REF.	REVIEWING ENGINEER'S COMMENTS	DESIGNER'S ACTION	Initials/ Date	Status 1.Action Complete 2.Action Outstanding 3.Disputed Item 4. Address at 95% Design Stage
		However, the initial starting points for the design of the wharf have changed sufficiently that the revised parameter set determined in this report may be used for the current design proposal. To ignore these slightly improved parameters is not in the best interests of the project. Clarification will be included in the paragraph.		
3	Section 3.4 (Reports). It is stated there are no DMC design reports which have been used as a starting point for the geotechnical design in this section. Should the Geotechnical Design – Foundations Report be listed here also so that it is in continuity with Section 3.1 (Design Starting Points)?	Reference to previous report to be included.	JST / 13-10-2017	2
4	Section 4.1, para 1. As per comment 2, was the intent to derive or confirm the parameters? The investigation was also providing information for the design of the runway south stabilisation and the hangar. Whilst this wasn't the original intent of the investigation, the information will be/ has been used to support the design of these elements.	The intent of the report was confirmation of the 65% design parameters chosen for the initial design including a bottom connection with rock dowel anchors to counteract the lateral forces. Since the submission of the initial 65% design, evolution of the design, to a dismantle-and-reconstruct option, has occurred. In this case, the parameters contained in this report may be used as the basis of the geotechnical design.	JST / 13-10-2017	2

REVIEW RECORD

Project Name: BAS SD3 Rothera Wharf Redevelopment **Job No: 1620001748**

REF.	REVIEWING ENGINEER'S COMMENTS	DESIGNER'S ACTION	Initials/ Date	Status 1.Action Complete 2.Action Outstanding 3.Disputed Item 4. Address at 95% Design Stage
		The scope of work of this design team is the design of the wharf only. This report has been prepared in support of that scope. The geotechnical interpretative report presented may be used as a basis for other designs; however these designs should also take into account any particulars of parameters pertinent to any nearby GI locations.		
5	Section 4.1, table. Please confirm in the text how the elevations in the table have been derived/ obtained.	To be included.	JST / 13-10-2017	2
6	Section 5.1.2 (Joint Spacing Analysis). In some boreholes, both the optical and acoustic televiewer methods were used, with a different number of features (i.e. fractures/veins) picked up for each method. For example in BH06 (Quarry) the optical televiewer did not identify any features between 1.17m and 15.34m depth, however features were picked up over this depth in the acoustic televiewer. Also, in BH-OS-05 (Runway South) the acoustic televiewer picked up 63 features whereas the optical televiewer picked up 130 over the same length of borehole. The different number of features identified by the different down hole logging methods would affect the calculated spacing between adjacent features and the data gaps could skew the result for fracture spacing. Have these discrepancies between	Firstly, neither method identifies 100% of the structures. Some structures are not optically visible, whereas they are acoustically detectable, and vice versa may also be true. Some structures are both optically and acoustically visible and identified. Secondly, structures identified are dependent on the operator picking the structures. In general, the significant majority of structures have been identified. To answer the question regarding skewing of results due to some data not being present and some data containing more sampling points than others, this is	JST / 13-10-2017	2

REVIEW RECORD

Project Name: BAS SD3 Rothera Wharf Redevelopment **Job No: 1620001748**

REF.	REVIEWING ENGINEER'S COMMENTS	DESIGNER'S ACTION	Initials/ Date	Status 1.Action Complete 2.Action Outstanding 3.Disputed Item 4. Address at 95% Design Stage
	the optical and acoustic methods been accounted for in the joint spacing analysis? Has the televiewer data from the quarry boreholes (BH06 and BH07) been used in the joint spacing analysis?	why statistical analysis methods have been used. These account for the data set not being 100% complete and provide a measure of the spread of the data within the returned results. The Mean and Standard deviations of the joint sets are reported. Additionally, the data has been contoured on a stereonet to identify the prominent joint sets. Multiple recordings of the same joint set often occur in scanline / traverses of slopes and this aids in identification of the most prominent joint sets. Addressing the issue regarding skewing of the JSA due to multiple features being included in the data, i.e. the same joint being identified in both the ABI and OBI logs, this is addressed during the contouring of the data in DIPS to identify the joint sets. Yes, multiple features identified at the same depth will result in a spacing of 0m for those particular features, however if they occur in different joint sets this will not affect the results of either joint set, when analysed, as this is done separately for each joint set. Joint spacing analysis, using DIPS, has been done		

REF.	REVIEWING ENGINEER'S COMMENTS	DESIGNER'S ACTION	Initials/ Date	Status 1.Action Complete 2.Action Outstanding 3.Disputed Item 4. Address at 95% Design Stage
		looking at individual identified joint sets, i.e. where DIPS has labelled a fracture as a particular joint set (after it has been identified by the user/analyst) and then taking the spacing of these into account using the distance column of the data. To ensure that there was a common datum the depth data were converted to a reduced level using the elevation of the seabed at the top of borehole and the depth below top of borehole recorded by the DTH probes. A common datum of +100m CD was used to convert the reduced level to a positive integer. A statistical assessment of the joint spacing has been done as noted in the report. Using these methods, skewing of the results is avoided as much as possible. No, the information from BH06 and BH07 has not been used in the analysis. The reason for this is that these boreholes have been carried out at a significantly higher elevation than those in the vicinity of the wharf. The boreholes barely penetrate below the commencement level of the boreholes in the vicinity of the wharf. Therefore use of these		

REVIEW RECORD

RAMBOLL

Project Name: BAS SD3 Rothera Wharf Redevelopment **Job No: 1620001748**

REF.	REVIEWING ENGINEER'S COMMENTS	DESIGNER'S ACTION	Initials/ Date	Status 1.Action Complete 2.Action Outstanding 3.Disputed Item 4. Address at 95% Design Stage
		boreholes in the kinematic analysis of submarine slope is not advised. Furthermore, as the data from BH06 and BH07 is not used in the kinematic analysis, skewing of the data due to missing data from these boreholes is therefore avoided.		
7	Section 5.1.2 (Joint Spacing Analysis), page 15. The report says "for the purposes of RMR determinations and the geotechnical design, a joint spacing category of 0 to 60mm should be used". However in Table 16 (Revised RMR*$_{89}$ for Rothera Station), the RMR*$_{89}$ has been derived based on category of 60-200mm (score of 8).	That is a typographical error; the spacing 60mm to 200mm should be used. This has been corrected in the report.	JST / 13-10-2017	2
8	Table 7. Typo in title of table – complaint sample rather than compliant sample	Corrected.	JST / 13-10-2017	2
9	Section 5.2 (UCS), paragraph immediately above Table 12, page 18. The report says "*The value of 295 MPa does fall close to the maximum value for a Diorite i.e. 285 MPa, given in Figure 5".* The values of the UCS for different types of rock are given in Figure 5, but it appears the values printed in the table are offset from the rock type listed. The 285 MPa value is actually for a gabbro. The min-max and average	Paragraph has been corrected and additional comment made.	JST / 13-10-2017	2

REVIEW RECORD

Project Name: BAS SD3 Rothera Wharf Redevelopment **Job No: 1620001748**

REF.	REVIEWING ENGINEER'S COMMENTS	DESIGNER'S ACTION	Initials/ Date	Status 1.Action Complete 2.Action Outstanding 3.Disputed Item 4. Address at 95% Design Stage
	values of UCS presented in the table for both granodiorite (75-135 MPa, average 105MPa) and diorite (100-190 MPa, average 140MPa) are still in excess of values derived based on the March 2017 UCS testing.			
10	Section 6.3.2 (Results of Kinematic Analysis), page 34, 5th paragraph – unfinished sentence	Corrected. Missing was the reference to the table immediately below.	JST / 13-10-2017	2
11	Section 6.3.2 (Results of Kinematic Analysis), toppling failure has been highlighted as presenting a significant risk to the slope. How will this risk be mitigated in the design? Will any additional stability assessment be carried out to check that outside forces do not cause toppling failure?	Please note that the Kinematic analysis only serves to highlight possible modes of failure that may occur purely from the viewpoint of geometrical interaction between the orientation of fractures and the slope directions. It does not provide a Factor of Safety against the mechanism occurring. The stated percentages of critical intersections, i.e. the number of joint intersections / poles that fall in the zones that define the failure mechanisms, in the report are as a measure of either the entire data set, or individual joint sets. For all of the data, the maximum number of critical orientations does not exceed 15% (highest is ~13% for S4 – Direct topple). Where percentages are listed for individual joint sets,	JST / 13-10-2017	2

REVIEW RECORD

Project Name: BAS SD3 Rothera Wharf Redevelopment **Job No: 1620001748**

REF.	REVIEWING ENGINEER'S COMMENTS	DESIGNER'S ACTION	Initials/ Date	Status 1.Action Complete 2.Action Outstanding 3.Disputed Item 4. Address at 95% Design Stage
		this is the percent of that joint set that falls within the critical zone. JS2 has the highest percentage of critical orientations, purely because this joint set is oriented roughly parallel to the slope orientations. This does not mean that slope failure by toppling is ongoing or a significant future risk. The design of the wharf structure using braced frames ensures that the transfer of forces is rearward to the anchor wall located at the rear of the structure. This anchor wall and internal structural interaction ensure that no lateral loads are imparted into the rock mass due to the foundations of the structure.		
12	Section 7.1. Why are the 65% Design Stage parameters proposed for use at the 95% Design Stage, when the detailed analysis in this report results in slightly different (and improved) parameters? This appears to be contradicted in Section 7.3, in which the revised characteristic rock mass properties are proposed for the design of tension dowels.	See answer given in comment 1 above. As the design concept has changed, the updated parameter set has been used for subsequent designs, but the previous 65% Stage design has not been adjusted. The paragraphs in the conclusions have been re-ordered to clear up misunderstanding.	JST / 13-10-2017	2